Contract Number 14069/99/NL/SB

Space Weather Space Segment Options

Technical Note for WP420
DRAFT 08

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1. INTRODUCTION

The aim of this Work package 420 series is to outline the space segment options for a Space Weather service based on the study requirements, which call for consideration of at least three space segment options which have different levels of programme cost and complexity:

- A 'full scale' space segment requiring development of new instruments and spacecraft platforms.
- A concept based on the addition of 'hitchhiker' space weather payloads (standard plasma, field or radiation environment monitors) to planned European spacecraft.
- Use of existing and planned space assets developed under the space programmes of ESA member states, with no supplementary hardware development.

Each of the space segment options addresses the system measurement requirements that are defined in WP410 to varying levels

Although emphasis is placed upon ESA autonomy, it is realised that the cost of such may be unrealistic. Therefore, each of the three options also considers potential collaboration with National European Agencies such as CNES or DLR, and National Non-European Agencies such as NASA, NOAA and NASDA.

2. SCOPE

This document considers only ESWS space segment options to meet the system requirements derived in WP410. ESWS ground based and ground segment options are covered in WP430, although issues such as data rate, data links/coverage and Ground station availability are considered.

3. REFERENCE DOCUMENTS

The following is a set of references used for this section of the study. However many other references not listed here are given in the final column of the existing and planned mission review in section 6.1.1.

(RD/1) Analysis of Candidate Missions for Remote Sensing from Geostationary Orbit (MMS Proposal to ESA for AO/1-3632/99/NL:/DC) Feb 2000

(RD/2) TNO/GEO-EO/0001 and TNO/GEO-EO/0004 part of the Analysis of Candidate Missions for Remote Sensing from Geostationary Orbit (Astrium Study for ESA) Oct 2000

(RD/3) American National Standard for Telecommunications Glossary 2000 http://www.its.bldrdoc.gov/projects/t1glossary2000/

(RD/4) WP410 ESA Space Weather Study (DERA)

(RD/5) MUNIN Nanosatellite http://munin.irf.se/frames/index.html

(RD/6) CubeSat Home Page: http://ssdl.stanford.edu/cubesat/
(RD/7) ASTRID-2 http://www.ssc.se/ssd/msat/astrid2.html

(RD/8) OERSTED http://web.dmi.dk/projects/oersted/homepage.html

(RD/9) PICARD http://www-projet.cst.cnes.fr:8060/PICARD/Fr/index.html

(RD/10) M2 http://m-2.ryp.umu.se/the%20project/the%20project.html

(RD/11) EUROSPACE Platform database http://www.eurospace.org/astrid.html

(RD/12) PROTEUS http://www.alcatel.com/space/activities/platforms.htm

(RD/13) ROEMER http://www.dsri.dk/roemer/pub/Presentations/

(RD/14) ROEMER http://astro.ifa.au.dk/~jcd/MONS/english/Roemer/

(RD/15) STRV http://www.dera.gov.uk/html/space/strv/home.htm

(RD/16) SSTL http://www.sstl.co.uk/services/subpage_services.html

(RD/17) STORMS http://spdext.estec.esa.nl/content/doc/43/24387_.htm#top

(RD/18) CCSDS Radio frequency and modulation systems report CCSDS 411.0-G-3 – May 1997

(RD/19) ESA ESTRACK network http://www.esoc.esa.de/pr/facilities/estrack.php3

(RD/20) A Definition of instruments needed for Space Weather measurements - ESWS-RAL-TN-0001

(RD/21) Space mission analysis and design – Wertz and Larson Edition 3

4. METHODOLOGY

4.1 Timing

The space segment of a space weather programme should be continuous, unlike most space science missions, which have a finite mission lifetime. When one mission fails, it must be replaced so that measurements can be continuous, without breaks in the service provided. It is therefore necessary to assume that our space segments should be studied up to 2015 to clearly show the programmatic and cost effects of a rolling space weather programme. This timescale is also useful in that it includes important periods such as the next Solar Maximum (2011) and the end of low-cost Russian Launches (described in more detail later).

Programmatically, there would be a time-lapse between the present time, and when we could reasonably expect hitch-hiking and dedicated spacecraft to be added to a space segment. By taking an optimistic viewpoint we should assume that hitch-hikers could be used from 2004, whilst dedicated spacecraft would be a little longer at around 2005.

The lifetime of each hitch-hiker/dedicated component is also a very important factor, as it defines how often they should be replaced. A long lifetime is desired, as it reduces the amount of replacements, although it may increase costs due to increased reliability. By assuming a lifetime of 5 years, we arrive at a reasonable trade-off between replacement cost and complexity.

4.2 Collaboration

Collaboration could play a powerful role in a future ESA Space Weather Service. Three levels of collaboration have been identified and closely examined throughout this part of the study. The first option considers using all present and planned spacecraft in a future ESA Space Weather Service. This would include even pure national agency missions such as GOES and GENESIS, that may have no clear link to ESA or any European National Agency. The problem with this option is that European autonomy is not fostered, and reliance on programmes with no ESA involvement results.

The second option, and perhaps the most attractive includes non-European missions that have some involvement from European Scientists, ranging from Co-Pi-ship to instrument or even spacecraft design and responsibility. This would include missions, such as SOLAR-B and STEREO. This option potentially offers more missions to have access to, without the added cost of complete autonomy.

The final option is complete European autonomy and includes only missions that are European-led, such as PICARD, METOP and SOHO. Although this option would be the most preferred in terms of complexity, it is also much more expensive than collaborative options.

4.3 Space segment study flow

Each of the space segment options varies in cost and complexity. As the simplest and least expensive space segment option is to use only existing and planned space assets, then it follows that these missions should be the bedrock of any future space segment. By defining an existing and planned space segment, extended space segments such as those including hitch-hiker instruments and/or dedicated spacecraft can be developed. The methodology in Figure 1 can be applied in designing each space segment option.

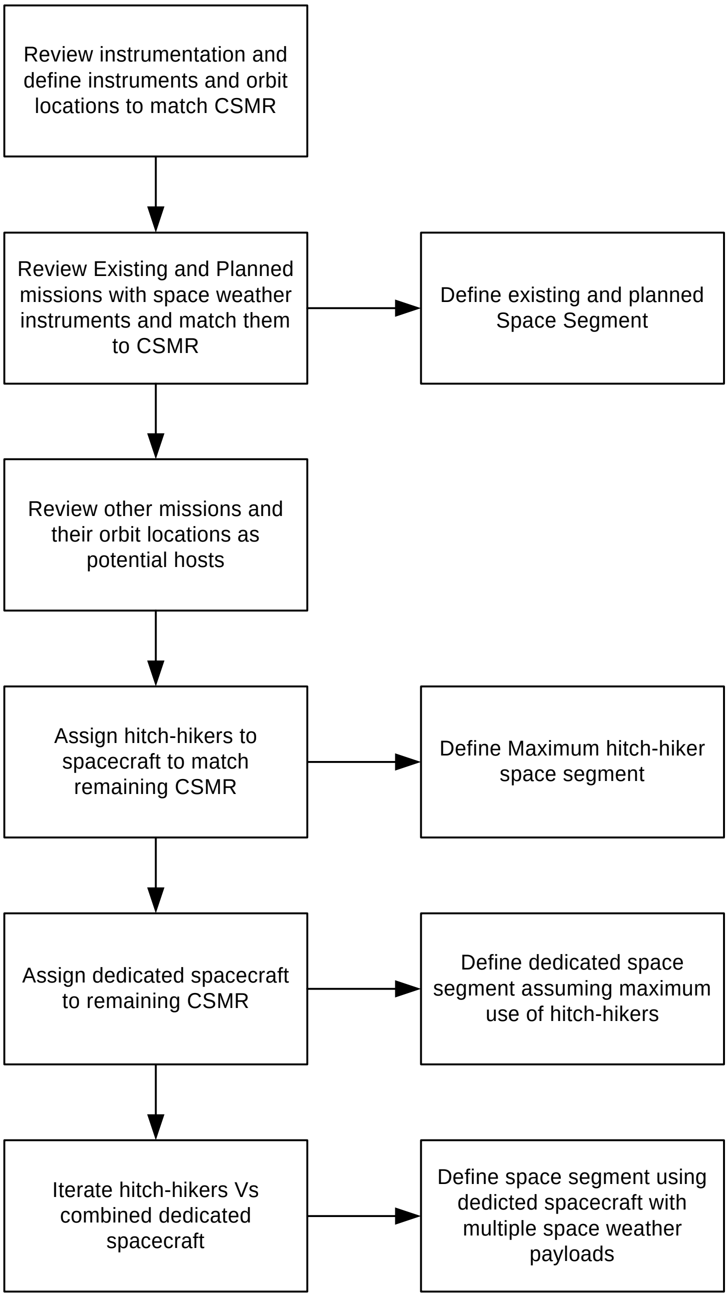


Figure 1 Space Segment Study Flow

4.4 Space segment philosophy and service

The philosophy behind each space segment option is to provide a space segment contribution to the space weather service at maximum speed and minimum cost and risk, whilst still meeting every possible requirement.

It is expected that each option will differ in terms of service provision. For instance, one would expect a dedicated Space Weather Service to provide a much better and more efficient service than one just using Current and Planned missions, even for those CSMR that are met by the Current and Planned missions. One major reason behind this is because the data products from a dedicated spacecraft are prioritised as inputs to a Space Weather Service (as is the mission itself). For a service using Current and Planned missions and even hitch-hikers, the data products will have to be retrieved via the Current and Planned mission or Host Operations centre before it reaches the eventual service provider.

5. WP421 (RAL) – PAYLOAD DEFINITION

See RD/20

6. PAYLOAD REQUIREMENTS ANALYSIS FOR PAYLOADS THAT COULD MEET OUTSTANDING SYSTEM REQUIREMENTS

The instrument requirements from page 21 of WP421 report provide input to the type of mission/platform that may be suitable as to meet the CSMR either a current and planned mission, hitch-hiker element or as a dedicated spacecraft. The following table is a summary of the requirements from WP421.

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Max Gap in G.S. coverage	No. of instances	Mass (kg)	Power (W)	Dimensions (cm)	Pointing req	Sampling direction req	Data Rate (Raw) kbit/s	Data Rate (Reduced) kbit/s
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	Single point measurement in space	1 hr	20 min	1	10	3	200x25x40	several arcsec		5	0.5
2	Solar coronagraph images	Coronagraph	L1 / L4 / L5 / SS/ GEO	Single point measurement in space	1 hr	20 min	1	17	25	80x30x30	several arcsec		5	
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	L4+L5	2 points well separated from Earth e.g. L4 & L5	1 hr	20 min	2	10	3	200x25x40	several arcsec		5	0.5
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	From polar elliptical orbit, Single point measurement	1 hr	20 min	2	29	30	60x70x25			11	
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	Single point measurement in space	1 min	20s	1	27	27	26x14x11				
12	UV flux	UV photometer	L1 / SS / GEO	Single point measurement in space	1 day	8 hours	1	27	27	26x14x11			0.25	
13	EUV flux	EUV photometer	L1 / SS / GEO	Single point measurement in space	1 day	8 hours	1	27	27	26x14x11			0.25	
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Single point measurement at L1	1 min	3 min	1	5	4	25x20x20		sample all 4PI solid angle	6	0.1

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Max Gap in G.S. coverage	No. of instances	Mass (kg)	Power (W)	Dimensions (cm)	Pointing req	Sampling direction req	Data Rate (Raw) kbit/s	Data Rate (Reduced) kbit/s
36 to 38	IMF (B-field)	Magnetometer	L1	Single point measurement at L1	1 min	3 min	1	3	3	20x10x16			0.2	
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO/ SS		1 hour	3 min	1		25	110x40x30			0.2	
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Throughout magnetosphere (constellation type such as SWARMS)	1 hour	20s	4 to 100	3	3	20x10x16			6	0.1
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	PEO	seconds	1s	5 to 10	10 (E field) and 5 (ion spec)	4	25x20x20			6	0.1
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical e.g. GTO	L=7 and below	1 min	20s	4 with ion, 2 with UV imager/ ionosonde	5 (ion spec), 50 (ionosonde), 16 (UV imager)	4	25x20x20		sample all 4PI solid angle	0.2	
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	L=3 to 9, GEO. Want several (e.g. 3) equi-spaced in longitude	1 min	20s	4 or more	6	4	17x8x7		sample all 4PI solid angle	6	0.1
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	Single point measurement in interplanetary space	<30 min	10 min	1	5	4	25x20x20		sample all 4PI solid angle	6	0.1

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Max Gap in G.S. coverage	No. of instances	Mass (kg)	Power (W)	Dimensions (cm)	Pointing req	Sampling direction req	Data Rate (Raw) kbit/s	Data Rate (Reduced) kbit/s
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO / mid-EO	Throughout inner radiation belt	<30 min	10 min	3 or more	5	4	25x20x20		sample all 4PI solid angle	2	
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	Single point measurement in space	1 hr	20 min	1	8	6	20x20x10		sample all 4PI solid angle	2	
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO, GTO	<30min	10 min	3 or more	8	6	20x20x10		sample all 4PI solid angle	0.03	
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO	6 months for debris, 1 day for meteoroids	8 hours	1			3x20x20			2	
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s / craft	Onboard spacecraft	5 min	100s	1	8	6	20x20x10		sample all 4PI solid angle		
73	Total Dose		Sensor worn by astronaut		mission integrated									
74	Satellite position				30 minutes								20	
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	Single point measurement in space	1 hour	20 min	1		6				0.5	

Table 1 Summary of instrument requirements to meet the CSMR

The following platform issues are discussed with reference to meeting the needs of the instrument requirements.

6.1 AOCS and Pointing

The pointing requirements for CSMR needing Sun pointed instruments (e.g. Whole disk imager, and Photometers) are quite stringent with a value of the order of arcseconds. These requirements on the platform may be overcome by using the instrument itself to correct for platform-induced errors. This is exactly how SODISM on the CNES microsatellite, PICARD will operate and could be a possible method to overcome the tight pointing requirements without needing an ultra-stable platform. For other CSMR the pointing requirements are less stringent, as long as we can reconstruct the attitude.

It should be noted that the spacecraft stabilisation is important in choosing a platform for space weather instruments. For instance, certain instruments such as ion and electron spectrometers/detectors require 4π Steradians coverage that is best met by a spin-stabilised spacecraft. This does not mean that 3-axis platforms are unsuitable. It merely means that they require at least two instruments, each covering almost 2π Steradians. This however, adds mass and cost.

Eclipses can also be problem for spinning platforms where instruments need to know spacecraft spin phase as a function of time. This is needed for some particle instruments to determine particle direction and, often, is also used to phase lock internal energy scans with the spin. Spin phase is usually determined by a sun sensor that produces a "sun reference pulse" once per spin. Since we know the direction of the Sun from astronomical data and construction data gives us the orientation of the instrument on the spacecraft, it's straightforward to work out where the instrument was pointing at any time. This fails during eclipses. It might be worked round by an internal clock - but that adds complexity that we want to avoid. It may be better just to say no data during eclipses.

6.2 Size, mass and Power

Size, mass and power are very important and may be crucial in determining whether an instrument can be used as a hitch-hiker or not. Free space on satellites can be extremely limited so small, compact instruments with little impact on the host have a much better chance of finding a host, than large instruments with complex interfaces.

As with the pointing, the sun-pointed instruments have the larger mass, size and power requirements. This may reduce the probability of finding a suitable host satellite to the point where it is more sensible to think about using a dedicated satellite.

6.3 Data handling, retrieval and downlink

6.3.1 Data Handling

Data Handling might be a problem for hitch-hiking if the host spacecraft's on-board processor is limited (if not using a dedicated processor). This may limit the maximum data rate that can be downlinked.

6.3.2 Data Retrieval

A spacecraft's ground segment could also present a problem in terms of data retrieval speed. This would be relevant to current/planned missions and hitch-hiking (if not using a dedicated antenna), as speed of data retrieval may not be of the essence for non-dedicated space weather missions, and this needs consideration when planning the use of hitch-hikers in a space segment.

6.3.3 Data Downlink and Link Budgets

Link budget calculations are important in assessing data rate feasibilities and sizing antennas. A wide range of orbit possibilities is given in Table 1 and a preliminary parametric analysis has been carried out to assess the antenna sizing requirements for each of the proposed orbit locations.

Assumptions in Link Budget calculations:

- Transmit powers of 10W are used for all calculations (although higher powers of 20W and 50W are also investigated for heliocentric orbits to meet CSMR 3)
- Receive Antenna diameters are assumed to be 10m and the transmit frequency is X-band. This is consistent with NASA and ESA ground stations at Perth, Svalbard, Kourou, Maspalomas and McMurdo (In fact Perth, Kourou and Maspalomas have 15m diameters, so this is a conservative assumption if these ground stations are utilised)
- Reed-Soloman (255,233), R=1/2, K=7 Viterbi encoding is assumed. Therefore the useful data rate is half of the actual data rate (i.e. 500bps of data would require an actual data rate of 1000kbps, as 2 bits are required per every 1 bit of data)
- For L1 halo orbits, 2 different halo orbit radii where considered, 750 000km as proposed for SMART2, and 400 000km. This leads to a minimum beamwidth requirement of 53.1degrees for a halo orbit radius of 750 000km (see Figure 2), and 29.9 degrees for a halo orbit radius of 400 000km, otherwise antenna steering is required. A larger halo radius also results in a longer link distance.

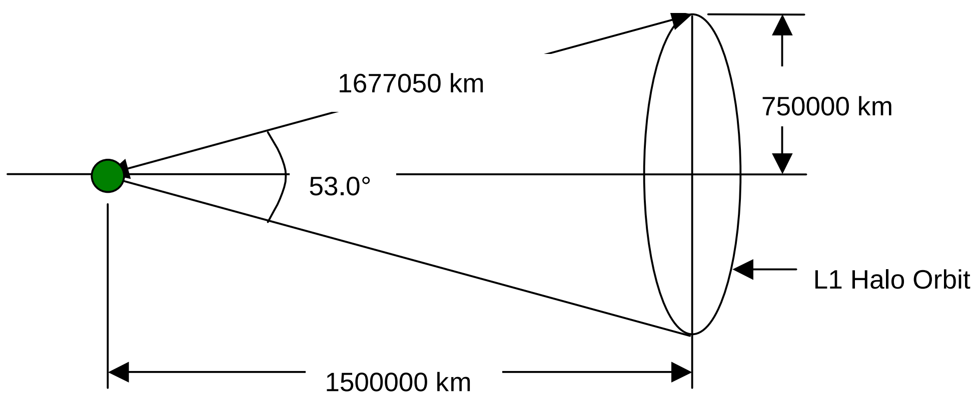


Figure 2 Geometry for an L1 Halo orbit of radius 750 000km

Table 2 is an example of a link budget for a 3dB Link margin at L1 for an actual data rate of 1000kbps (useful data rate 500kbps)

Telemetry Link Budget		
Link Parameter	**Units**	**X-Band**
Antenna Diameter	m	0.4470
Tx O/P power	W	10.00
Tx O/P power	dBW	10.00
D/L Frequency	MHz	8420.00
On Board Losses	dB	-1.00
Antenna Gain	dBi	29.4
Depointing Loss	dB	-0.50
Polarisation Loss	dB	-0.50
Spacecraft EIRP	dBW	37.37
Antenna Beam Width (3dB)	Degrees	5.579598
Spacecraft Range	km	1.68E+06
Space Loss	dB	-235.47
Ground Station G/T (11m)	dB/K	35.30
k	dBW/Hz/K	228.60
C/No	dBW/Hz/K	65.80
Data Rate	kBits/s	1000.00
Data Rate	dBbps	-60.00
Eb/No	dB	5.80
Required BER	1 in 10(X)	6.00
Required Eb/No	dB	2.80
Link Margin	**dB**	**3.00**

Table 2 Typical Link budget Calculation table for a 3dB Link margin at L1

Table 3 illustrates Antenna diameter requirements for various orbits. Link budget calculations for orbits closer to Earth (e.g. GEO, Molniya, LEO and GTO) are omitted as the antenna requirements are only very small and no problems in size are predicted. This can be attributed to the fact that the instrument data rates are fairly low, even for the imaging instruments.

Data Rate (kbps)	**Orbit**			
	L4 (1.496E+08 km link distance)	**L1 750 000km halo radius (1677050km link distance)**	**L1 400 000km halo radius (1552417km link distance)**	**Magnetospheric (20RE/127400km link distance)**
0.05	0.399m	0.0069m (isotropic - 6.81db margin)	0.0069m (isotropic - 7.48db margin)	0.0069m
0.5	1.261m	0.0141m (176.4377 deg beamwidth)	0.0131m (190.6078 deg beamwidth)	0.0069m
5	3.988m (0.63 deg beamwidth)	0.0447m (55.794 deg beamwidth)	0.0414m (60.275 deg beamwidth)	0.0069m
50	12.61m	0.1414m (17.644 deg beamwidth) – Either steerable antenna or more power required	0.1308m (19.0654deg beamwidth) – Either steerable antenna or more power required	0.0107m
500	39.874m	0.447m (5.579 deg beamwidth) – Either steerable antenna or more power required	0.4138m (6.027 deg beamwidth) – Either steerable antenna or more power required	0.034m

Table 3 Antenna diameters for a Link Margin of 3dB (m) and Tx output power of 10W

From Table 3 it is evident that the L1 and magnetospheric orbit locations present no problems in terms of antenna size, even if the data rate is high (it is unlikely that data rates will be much more than 100kbps even for dedicated satellites carrying multiple space weather payloads). This means that such antennas on microsatellites would be compatible for launches in ASAP5 on ARIANE 5 (discussed in more detail later in the report). The L1 halo radius determines the minimum antenna beamwidth that is required in order for a fixed antenna to provide coverage at all points on the halo orbit, assuming that the spacecraft is nominally Sun-pointing (see Figure 3). As the antenna beamwidth decreases with increasing data rate (see Figure 4), there is a limit on the data rate that can be transmitted by a fixed antenna in a given L1 halo orbit. A 750 000km halo orbit requires a minimum 53.1deg beamwidth and thus the data rate is limited to about 8kbps, whilst at 400 000km, the minimum beamwidth drops to 29.9deg, and the data rate increase to about 30kbps.

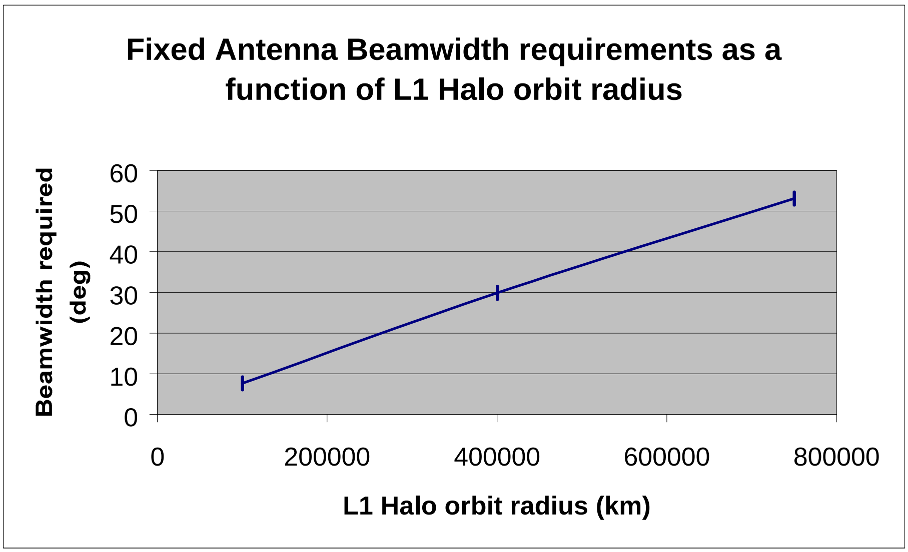


Figure 3 Minimum Beamwidth Requirements for a Fixed Antenna as a function of L1 Halo orbit radius

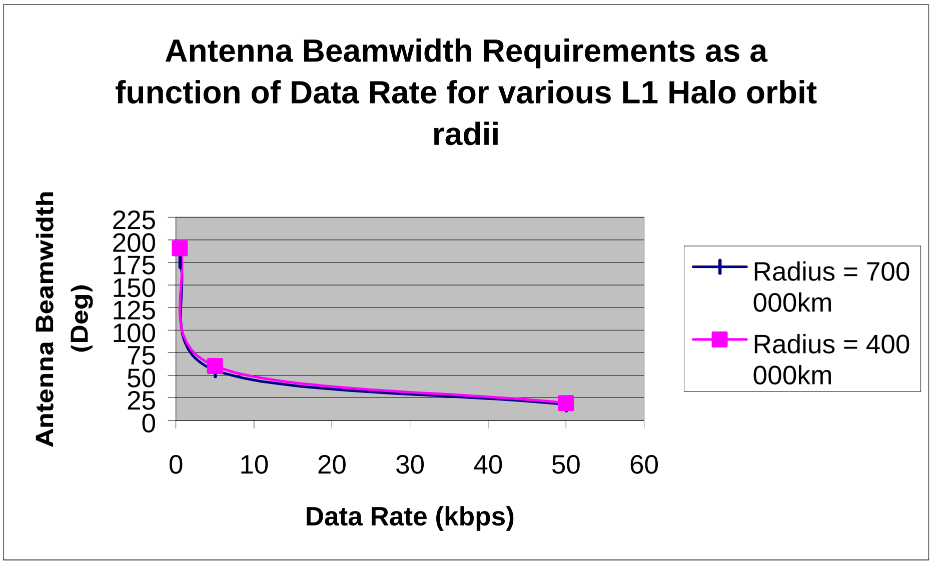


Figure 4 Antenna Beamwidth Requirements as a function of Data Rate for L1 Halo orbits

Table 3 also indicates that positioning a spacecraft at L4 is unfeasible for a 10W transmitter unless a 4m transmit antenna is used, as expected data rates for CSMR 3 are >5Mbps. Further investigation looked at reducing the angle between the Earth-Sun line and the spacecraft to reduce the antenna diameter, or increasing the transmit power to 20W or 50W (which would increase solar array size and heat dissipation requirements). As L4 is at 60 degrees, smaller angles are required. Table 4 to Table 6 display how the antenna size requirements vary with decreasing heliocentric angle from the Earth-sun line, for transmit powers of 10W (Table 4), 20W (Table 5) and 50W (Table 6).

Data Rate (kbps)	Orbit				
	L4 (1.496E+08 km)	40 deg (1.023E+08km)	30deg (7.744E+07km)	20deg (5.196E+07km)	10deg (2.608E+07km)
0.05	0.399m	0.273m	0.206m	0.138m	0.07m
0.5	1.261m	0.863m	0.652m	0.438m	0.22m
5	3.988m	2.727m	2.063m	1.385m	0.695m
50	12.61m	8.623m	6.524m	4.38m	2.198m

Table 4 Antenna diameters for a Link Margin of 3dB (m) and output power of 10W

Data Rate (kbps)	Orbit				
	L4 (1.496E+08 km)	40 deg (1.023E+08km)	30deg (7.744E+07km)	20deg (5.196E+07km)	10deg (2.608E+07km)
0.05	0.282m	0.193m	0.146m	0.098m	0.049m
0.5	0.892m	0.61m	0.461m	0.31m	0.155m
5	2.82m	1.928m	1.459m	0.979m	0.492m
50	8.916m	6.097m	4.613m	3.097m	1.554m

Table 5 Antenna diameters for a Link Margin of 3dB (m) and output power of 20W

Data Rate (kbps)	Orbit				
	L4 (1.496E+08 km)	40 deg (1.023E+08km)	30deg (7.744E+07km)	20deg (5.196E+07km)	10deg (2.608E+07km)
0.05	0.178m	0.122m	0.092m	0.062m	0.031m
0.5	0.564m	0.386m	0.292m	0.196m	0.098m
5	1.783m	1.219m	0.923m	0.619m	0.311m
50	5.639m	3.856m	2.918m	1.959m	0.983m

Table 6 Antenna diameters for a Link Margin of 3dB (m) and output power of 50W

As a target antenna size would be <0.6m to be compliant with ASAP5 dimensions, these tables show that for data rates of >5kbps, transmit powers of >10W are required just to meet the required link margin at 10 degrees separation. With a transmit power of 50W, separations of approaching 20 degrees are possible, however extra solar array mass would be required to provide input powers of around 112W to the transmitter. Figure 5 illustrates Antenna Diameter Requirements as a function of data rate for various heliocentric drift orbits assuming a 50W transmitter.

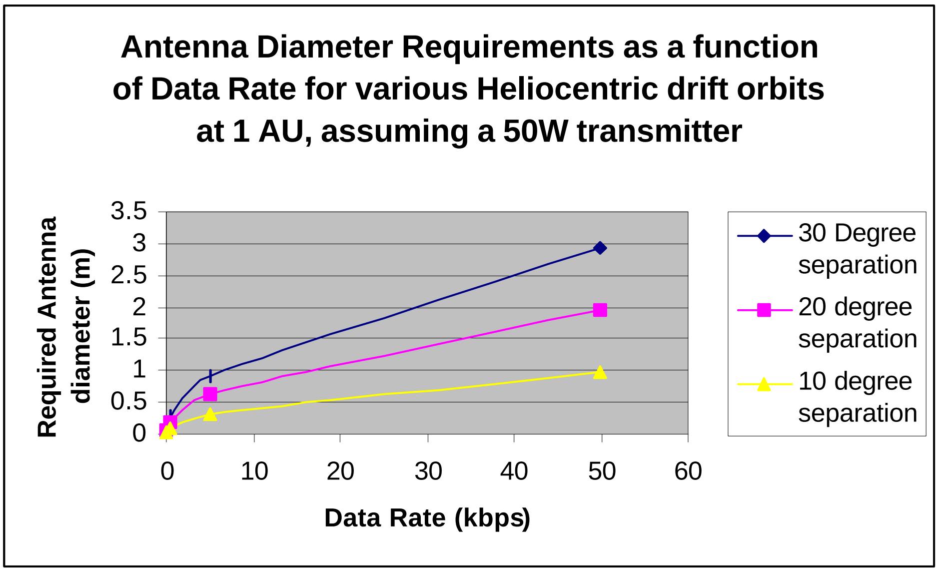


Figure 5 Antenna Diameter Requirements as a function of data rate for various heliocentric drift orbits assuming a 50W transmitter

6.3.4 Methods for reducing the data downlink requirements

One way to possibly reduce the data rate requirements would be for instruments to either employ advanced compression techniques, or operate in beacon mode, as with STEREO. This means that the instrument only operates with low data rates in less active periods of solar activity, but when activity increases the instrument could temporarily go into high real-time data rate mode.

6.4 Ground station coverage and Gap limitation

Ground station coverage can be a problem for some CSMR if the re-visit time is slow for that particular orbit configuration. Certain CSMR have requirements that the gaps between ground station coverage are very small. This may mean that more than one spacecraft and/or ground station would be required, which would increase mission cost and complexity.

Inter-satellite links using RF or Optical technologies, may be a way of removing the need for multiple satellites and/or ground stations for CSMR that require regular ground station visibility. Various routing architectures are possible, such as a LEO to GEO to ground link as with the experimental Ka band link which will be used from ENVISAT in LEO, to ARTEMIS in GEO. This, however requires a steerable antenna. In addition, at least three satellites in GEO would be required to provide a continuous link because of Earth obscuration. ARTEMIS will also have an experimental optical link with SPOT4 (SILEX optical terminal), however these terminals have substantial mass at present, and have tight pointing constraints. There is also the possibility of using the NASA TDRS satellites in GEO. The NASA TDRS system is a long-term system to provide geostationary communications relays to be used by other satellites, in order to reduce communications outages below what they would otherwise be. For example the Space Shuttle orbiters, the International Space Station, and the Global Rainfall Monitoring Mission use the TDRS system. The main problems with the TDRS satellites are that they have no European involvement and their availability and data rate limits are unknown at this stage.

Intersatellite links are therefore not considered within the context of this study due to the lack of maturity for European systems and the uncertainty/lack of European autonomy with the TDRS system. However, they may be a useful component to a future space weather service if either: use of the NASA TDRS satellites is possible, or when European systems reach full maturity. Analysis of ground station coverage by standard spacecraft to ground links provides a worst-case scenario of the space segment architecture in terms of numbers of spacecraft and ground stations required.

It is noted from Table 1 that several CSMR that could be met from sun-synchronous orbits can have a problem with re-visit time if the maximum limit on outage time is small (e.g. 20 minutes for CSMR 1,2 4/6). This means that 1 satellite and 1 ground station is not enough to meet this requirement (in fact CSMR 8-11 would require almost continuous coverage, i.e. a ground station always in contact with a spacecraft).

A preliminary analysis of Ground station coverage has been carried out to assess the effect of maximum allowed gap requirements in ground station coverage.

6.4.1 Heliocentric/L4/L5/L1/L2 orbits

Three ground stations are required if the outage time limitation is of the order of few minutes. These ground stations must be of sufficiently low latitude and have a wide enough longitude spacing from each other to allow continuous coverage (120 degree separation would be ideal) A suggested ESA ground station architecture could comprise of Perth, Maspalomas and Kourou (see Table 7), although it would be better in terms of longitude coverage, to replace Kourou with say, Goldstone (35°N, 117°W), which is a NASA ground station.

Ground Station	Latitude (deg)	Longitude (deg)	Antenna diameter (m)
Maspalomas	27.76289200°N	15.63380717°W	15m
Kourou	5.25143694°N	52.80466242°W	15m
Perth	31.80252491°S	115.88515564°E	15m

Table 7 Perth, Maspalomas and Kourou ground station characteristics

6.4.2 Geostationary Transfer Orbits (GTO)

Several CSMR that can be satisfied at GTO (e.g. CSMR 52), have a max gap in ground station coverage of only 20s. Four satellites, equally spaced in longitude are also required to meet CSMR 52. However employing an orbit configuration in this way requires more ground stations than just Kourou and Perth (which are almost 170 degrees in longitude apart), as there will be outages exceeding the 20s limitation. Therefore a combination of three fairly equally spaced, low latitude ground stations would be required, unless more satellites were to be added as part of the constellation.

6.4.3 Sun-synchronous orbits

The aim is to satisfy the CSMR requirements for CSMR 1,2 4/6, and 18 (max gap in ground station coverage 20 minutes) and secondly CSMR 8-11 and 50-51 (max gap in ground station coverage 20 seconds) by minimum use of spacecraft and/or ground station coverage.

It is widely known that for sun-synchronous satellites, coverage of once per orbit can only be achieved by very high latitude ground stations. Only Svalbard (also called Longyearbyen or Mine 7) and McMurdo (see Table 8) can meet these requirements, although the coverage varies on each pass and can be quite short (see Figure 6). Use of other ground stations may result in outages over several orbits, and this gets worse as the latitude of the ground station decreases. Therefore lower latitude ground stations are not considered as many would be required in order to meet such short re-visit times.

Ground Station	Latitude (deg)	Longitude (deg)	Antenna diameter (m)	Minimum receive elevation (Deg)
Svalbard	78.1583	16.03333	11.3	3
McMurdo	-77.5021	193.1959	10	1

Table 8 Svalbard and McMurdo ground station characteristics

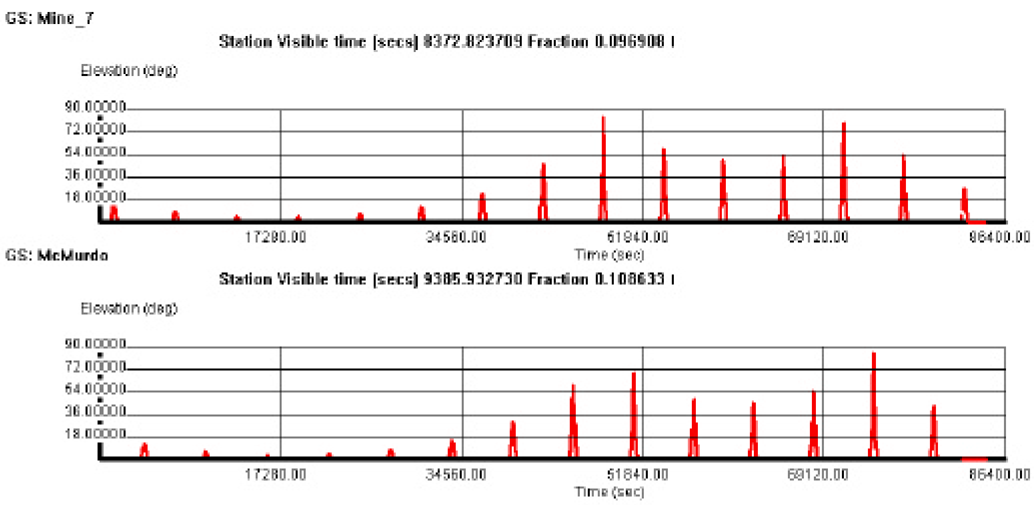


Figure 6 Coverage plots over 1 day for a satellite in a 600km Sun-synchronous orbit using Svalbard (top) or McMurdo (bottom) as a ground station

If only Svalbard is used as a ground station, then it is possible to show that the minimum no. of spacecraft required to meet CSMR 1,2 4/6 and 18 is a 4 satellite constellation in identical orbits, apart from a 90 degree separation in true anomaly and a difference (6.3deg) in RAAN (Right ascension of the ascending node) to ensure a follow-the-leader configuration. Table 9 shows the maximum gaps in ground station coverage for various altitudes of sun-synchronous orbits. As the maximum gap requirement for CSMR 1,2 4/6 and 18 is 20 minutes, orbits > 600km can meet this criterion. The gap in coverage reduces with increasing altitude, but orbits just under 600km altitude would not meet the gap requirement.

Orbit Altitude	Orbit Period	Time Lag in successive satellites (1/4 orbit period)	Min coverage in one pass	Gap in Ground station coverage
600km	96.687min	1450.305s	264.5393s	19.76min
700km	98.773min	1481.595s	383.64s	18.30min
800km	100.874min	1513.11s	479.2152s	17.23min

Table 9 Gaps in ground station coverage for various Sun-synchronous altitudes for a 4-satellite constellation

For CSMR 8-11 and 50-51, again using only Svalbard as a ground station, then it is also possible to show the minimum no. of spacecraft required such that the maximum gap in ground coverage is 20s (1s for CSMR 8-11). We can assume that to meet this requirement, a spacecraft must be in view of a ground station all the time. The number of spacecraft is thus the orbit period divided by the minimum coverage time (in a similar constellation arrangement for CSMR 1,2,4-6,18).

Orbit Altitude	Orbit Period	Min coverage in one pass	No of satellites required
600km	96.687min	264.5393s	22
700km	98.773min	383.64s	16
800km	100.874min	479.2152s	13

Table 10 No. of satellites required to meet CSMR 8-11, 50-51 using Svalbard as a ground station

If both Svalbard and McMurdo are used as a ground stations, then it is possible to show that the minimum no. of spacecraft required to meet CSMR 1,2 4/6 and 18 is a 2 satellites in identical orbits, apart from a 90 degree separation in true anomaly and a difference (6.3deg) in RAAN (Right ascension of the ascending node) to ensure a follow-the-leader configuration. Table 11 shows the maximum gaps in ground station coverage for various altitudes of sun-synchronous orbits. Although Svalbard and McMurdo are almost at opposite sides of the Earth, they are not completely and one flight time between ground stations is slightly longer than the other. Therefore the situation is a little worse now than with 4 satellites and Svalbard only. Table 11 shows the maximum gaps in ground station coverage for various altitudes of sun-synchronous orbits. As the maximum gap requirement for CSMR 1,2 4/6 and 18 is 20 minutes, orbits > 600km can still meet this criterion. Again, the gap in coverage reduces with increasing altitude, but orbits just under 600km altitude would not meet the gap requirement.

Orbit Altitude	Orbit Period	Time Lag in successive satellites (1/4 orbit period)	Maximum outage	Min coverage in one pass	Gap in Ground station coverage
600km	96.687min	1450.305s	2643.352s	264.539s	19.88min
700km	98.773min	1481.595s	2596.568s	383.64s	18.58min
800km	100.874min	1513.11s	2570.687s	479.215s	17.63min

Table 11 Gaps in ground station coverage for various Sun-synchronous altitudes for a 2 satellites and using both Svalbard and McMurdo as ground stations

If both Svalbard and McMurdo are used as a ground stations for CSMR 8-11 and 50-51, then the minimum no. of spacecraft required to meet maximum gap in ground coverage of 20s is shown in Table 12. This time half of the constellation described when using Svalbard only is removed. The remaining spacecraft still follow each other closely enough to be in successive contact with one ground station before swapping to the next with the leading spacecraft.

Orbit Altitude	Orbit Period	Min coverage in one pass	No of satellites required
600km	96.687min	264.539s	11
700km	98.773min	383.64s	8
800km	100.874min	479.215s	7

Table 12 No. of satellites required to meet CSMR 8-11 using both Svalbard and McMurdo as ground stations

The conclusions from this ground station analysis are that CSMR 1,2, 4-6, and 18 could reasonably be met by using 2 satellites and 2 Ground stations. It is unlikely that use of 4 satellites and one ground station would be considered on the grounds of cost.
With much shorter re-visit times, the number of satellites becomes totally unfeasible, even if 2 ground stations are used. Therefore CSMR 8-11, 36-38 (magnetograph - revisit time actually 3min which is not quite as bad as 20s), and 50-51 cannot be met from sun-synchronous orbit due to the high number of satellites that would be required. This may not be a problem for CSMR 36-38 and 50-51 as they can actually be met by ground observations. CSMR 36-38 can also be met by a magnetometer at L1.

7. WP 422 – IDENTIFICATION OF SPACE SEGMENT OPTIONS

The system measurement requirements that are defined in WP410 are the baseline for the development of space segment options. They describe the spatial and temporal resolution of parameters that are required to be measured in order to meet each particular requirement. This section describes the assignment of instrumentation to meet the system requirements and the extent to which the system requirements are met by the three space segment options; instrumentation on existing and planned missions, hitch-hiker instrumentation and instrumentation that can only be met by mounting onto dedicated space weather spacecraft.

7.1 Existing and Planned missions/instruments

The objective of this section is to comprehensively review existing and planned missions out to 2015 that may be able to meet the CSMR's. The review consists of three types of existing and planned space segments;

- All missions including missions without European involvement
- Missions with European involvement
- Only European-led missions

The idea is that each CSMR is mapped out to 2015. Missions that meet some of CSMR's, can then be assigned to each CSMR timeline for the duration of the mission. Gaps in the CSMR timelines illustrate the level at which current and planned missions go to providing a space segment for a potential space weather service. Any gaps then lead to the second and third space segment options of using hitch-hiker instruments or even dedicated spacecraft.

7.1.1 Existing and Planned Mission Review

The following table is a comprehensive review of existing and planned missions that have instruments as part of their payload complement that may contribute to a future ESA space weather service. Missions with a blue band are only proposed missions at this stage and may or will not become actual missions. Missions in yellow bands are missions that have only recently ceased to be operational.

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
ACE Advanced Composition Explorer	NASA	August 25,1997 operational	Two years with a five-year goal	Solar wind composition, density and velocity. Magnetometer. (CRIS Cosmic Ray Isotope Spectrometer ;EPAM Electon, Proton, and Alpha Monitor ; MAG Magnetometer ; SEPICA Solar Energetic Particle Ionic Charge Analyzer; SIS Solar Isotope Spectrometer; SWEPAM Solar Wind Electron, Proton, and Alpha Monitor; SWICS Solar Wind Ionic Charge Spectrometer ; SWIMS Solar Wind Ion Mass Spectrometer; ULEIS Ultra Low Energy Isotope Spectrometer)	Space Weather early warning system, looks at CME's and solar wind	L1	1m high, 1.6m across	785kg at launch	464 W (443 W end-of-life @ 5 years)	Spins at 5 rpm, Attitude Subsystem: Spinning spacecraft, Star Sensor and Sun Sensors	http://www.srl.caltech.edu/ACE/ace_mission.html
ARGOS	USAF	Feb-99	3 years	SPADUS will provide definitive measurements of orbital debris in a highly populated DoD orbit		450 nautical mile circular sun synchronous orbit, with a 98.7 degree inc					http://www.laafb.af.mil/SMC/PA/Fact_Sheets/Argos.htm
BEEquator (Mosaic proposal)	UK	mid 2004? Consistent with CLUSTER extended mission	2 years	Triaxial fluxgate magnetometer, 2 electrostatic analysers, one for electrons one for ions	Study substorm physics in the mid distance range of the Earth's geomagnetic tail in addition to dayside monitoring and study of the interplanetary medium, bowshock and dayside connection. Also enhances CLUSTER data	Transfer from GTO. 15Re semi major axis, perigee could be as low as 2000km alt making Ra at or beyond 28.5 Re. Phased with respect to CLUSTER to allow study of near and mid tail phenomena at one apogee and simultaneous cusp/tail studies during		50kg			

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
						the next orbit.					
CLUSTER	ESA	launched 9 Aug/16 Jul Operational, 2000	2 years	Various field and particle experiments	Plasma physics in solar wind & magnetosphere	4 s/c, 19.6 by 4 Re. Tetrahedral formation in regions of interest	2.9 m x 1.3 m	1 200 kg wet	Array power 224 W	Spinners 15rpm	http://sci.esa.int/cluster/
CORIOLIS (SMEI)	US (UK involvement with Birmingham University)	Future, NET 18 February 2002	One-year goal for experiment operations; develop forecasting capabilities, Two additional years of expected experiment lifetime; demonstrate forecasting capabilities	SMEI Solar mass ejection Imager	Images CME's	830km sun-synchronous					http://www-vsbs.plh.af.mil/projects/smei/smei.html; http://www.te.plk.af.mil/teo/missions/coriolis/coriolis.html
CORONAS-F	Russia	? Dec 2000	More than 1 year	DIFOS Solar interior structure; SORS Solar radio bursts of types II,III,IV.; ZENIT Study of Solar corona.; SUFR Total Solar UV radiation flux variations.; VUSS Solar UV radiation near the Íl resonance line. ; DIAGENESS X-ray radiation of Solar active regions and flares. ;RESIK Solar X-ray radiation in the lines of ionized Ar,Mg,Si,S,Ca,Fe,K,Ni and in continuum. ; IRIS Solar flares in X-rays. ; HELIKON Solar flares in X-ray and gamma rays.; SKL Solar cosmic rays. ;RES-K Study of the X-ray spectrum of the radiation from Solar active regions and flares	The scientific goal of the project is to conduct complex research of the powerful dynamic processes of the solar activity (active regions, flares, mass ejections) in the broad range of spectrum from radio to gamma rays, study solar cosmic rays accelerated in the solar active phenomena as well as conditions for their release, propagation into the IMF and influence on the Earth's magnetosphere	circular orbit with ~500 km; altitude 82.5°		2260 kg			http://www.izmiran.rssi.ru/projects/CORONAS/F/index
DEMETER	France - CNES	End 2002	2 yrs	4 electric antennas; 1 search-coil magnetometer 3 components; 1 Langmuir probe ;- total plasma density (electrons and ions), - electronic temperature, - measure of the satellite potential, - direction of ions flow; 1 plasma analyzer measuring :- total plasma	Study of ionospheric disturbances associated with natural geophysical phenomena such as earthquakes, volcanic eruptions, or tsunamis. A secondary objective is to study the electromagnetic disturbances of the	Circular 800km Sun-synchronous	600x750x800mm	110kg	78W	3-axis, 0.1deg accuracy	http://www-projet.cst.cnes.fr:8060/DEMETER/Fr/index.html

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
				density and ionic composition, - ionic temperature,- plasma global speed ; 1 particle detector measuring precipitation of energetic electrons (30keV – 1MeV)	planet linked with human activity.						
DMSP (USAF weather satellite series)	USAF/ NOAA	Rolling program	Rolling program	SSJ/4- Preipitating Electron and Ion Spectrometer (electron and ion particle fluxes between 30 eV and 30 KeV recorded every second,) ; SSIES- Ion Scintillation Monitor (The SSI/E instruments measured the ambient electron density and temperatures, the ambient ion density and the average ion temperature and molecular weight) ; SSM - Magnetometer		DMSP satellites are in a near polar orbiting, sun synchronous orbit at an altitude of approximately 830 Km above the earth					http://web.ngdc.noaa.gov/dmsp/dmsp.html http://www-vsbp.plh.af.mil/projects/
DOUBLE STAR	CHINA/ ESA	December 2002 and April 2003		The proposed European contribution includes: FGM - the fluxgate magnetometer (Imperial College, London and IWF, Graz); EPS - the energetic particle spectrometer (IDA, Braunschweig) ; CIS - the Cluster ion spectrometer (CESR, Toulouse); ASPOC - active spacecraft potential control (IWF, Graz); PEACE - plasma electron and current experiment (MSSL-University College London); STAFF / DWP - spatio-temporal analysis of field fluctuation experiment / digital wave processing experiment (CETP Vélizy / Sheffield University); NIA - natural atom imager (National University of Ireland, Maynooth)	This will enable scientists to obtain simultaneous data about the changing magnetic field and population of electrified particles in different regions of the magnetosphere	Polar satellite - 350 x 25 000 km orbit; equatorial satellite - 550 x 60 000 km, inclined at 28.5deg		270 kg			http://sci.esa.int/content/news/index.cfm?aid=8&cid=31&oid=26818
EARTH-SHINE	UK		5yrs	Heliospheric flux monitor (magnetometer and 3axis, Interplanetary strahl instrument (ISIS)	Earth Albedo	L1					

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
FAST	NASA	launched on August 21, 1996; operational	1 year	E-field expt, B-field expt, Time of flight energy angle mass spectrograph, Electrostatic analysers	Investigates the plasma physics of the auroral phenomena which occur round both poles	350 x 4200km at inc of 83Deg	Total Length: 1.8 m. Maximum Diameter: 1.2 m.	191kg	52 W from array	12 rpm spinner,	http://sprg.ssl.berkeley.edu/fast/; **http://sunland.gsfc.nasa.gov/smex/fast/mission/; http://sunland.gsfc.nasa.gov/smex/fast/**
FBM (French Brazilian Micro-satellite)	CNES and INPE	End 2002	13 months	FIRE (Flare IR expt observing flares from 25 to 35microns, and 100-200 micron; Plasma diagnostic package measuring temp,dens, structure of ionospheric plasma at low alt near equator; DEBRIS : Debris in orbit evaluator : measurement of the dust environment distribution in the low earth equatorial orbit.; RADIOMETER/FLUXIMETER - FLUXRAD : This experiment consist to measure the net flux radiated by the Sun and by space collected by the satellite	Study of the Sun	750km circular, inc 6deg	0.6*0.6*0.8 m3	100 kg (allowable 110 kg for VLS and ASAP-5)	36W	3-axis, 0.5deg accuracy	http://www-projet.cst.cnes.fr:8060/FBM/index.html
GEC Geospace Electrodynamics Connections	NASA	Future Sept 2008	2 years	Energetic particle sensor, neutral wind meter, Ion and neutral mass spectrometers, Langmuir probe + others	Magnetosphere-atmosphere physics	4 satellites in initially ellipical parking orbits 200 by 2000km, high inc orbits				3 axis (pitch momentum biased)	http://sec.gsfc.nasa.gov/gec.htm http://gec.gsfc.nasa.gov/default.htm
GENESIS	NASA	Future Jun 2001	sample return on Sept 2004; 2 yr mission	Electron and Ion analysers	Solar wind collector	L1 sample return					http://genesismission.jpl.nasa.gov/
GEOTAIL	ISAS	Jul-92	design lifetime of about four years.	Plasma investigation, Plus particle and field and wave expts	Explores the tail of the magnetosphere	8-220Re orbit; 22.4 deg. Inc.	Cylindrical- approx 2.2 m in diameter and 1.6 m high	Mass: 1,008 kg		The nominal spin rate of the spacecraft is about 20 rpm around a spin axis	http://www-spof.gsfc.nasa.gov/istp/geotail/

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
										maintained between 85 and 89 deg to the ecliptic plane.	
GOES (e.g. GOES 10)	NASA	Apr 25 1997	7 year mission	space environment monitor. The latter consists of a magnetometer, an X-ray sensor, a high energy proton and alpha detector, and an energetic particles sensor. All are used for monitoring the near-Earth space environment or solar "weather."		GEO	2.0m (6.6 ft) by 2.1m (6.9 ft) by 2.3m (7.5 ft)	2105 kg		3 axis	http://www.earth.nasa.gov/history/goes/goes.html http://www.sel.noaa.gov/sxi/sxi_doc/SXI_SPIE.html
GOES NEXT	NASA	Apr 2002 (GOES N); Apr 2005 (GOES O)	3 year design life requirement with a goal of 5 years (7 year mission)	SXI (Solar X-ray Imager) + previous GOES space envrionment monitors	Proton event warnings from flare detection and location ; Prediction of geomagnetic activity from coronal hole boundaries and coronal mass ejection signatures; Flare probability forecasts from active region complexity; 3-day advance 10.7cm forecasts based on east-limb activity	GEO				3 axis	http://rsd.gsfc.nasa.gov/goes/text/goesnopq.status.9701.html; http://www.hughespace.com/factsheets/601/goes_nopq/goes_nopq.html http://www.sel.noaa.gov/sxi/sxi_doc/SXI_SPIE.html
HESSI - High energy solar spectroscopic imager	NASA, U of Berkeley	Late Spring, 2001	Operations Lifetime: 2 years (3 years desirable)	HEISPEC	X-ray/Gamma ray imaging for high energy aspects of Solar flares; high resolution imaging and spectroscopy of solar flares from 3 keV X-rays to 20 MeV gamma rays with high time resolution	Circular at 600km, 38 deg inc.	Small Explorer (SMEX)	290kgNASA (s/c)	110 watts	Spin-stabilized at 15rpm	http://hessi.ssl.berkeley.edu/; http://hesperia.gsfc.nasa.gov/hessi/sheet.htm
IHC (Inner Heliospheric Sentinels)	NASA	Dec-08	3 year mission life, 5 year goal	4 in-situ instruments per spacecraft selected through the AO process	Living with a star core missions	4 identical spacecraft in elliptical heliocentric orbits at various distance from the sun (0.5 to 0.95 AU)				Spin-stabilized	http://lws.gsfc.nasa.gov/lws.htm http://rsdo.gsfc.nasa.gov/Presentations/Robinson_LWS.pdf

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
IMAGE	NASA	March 25, 2000, operational	2 years	Neutral Atom Imager, Extreme UV Imager, Far UV Imager, Radio Plasma Imager	Global response of magnetosphere to changes in the solar wind	1000km perigee, 7Re apogee polar orbit. (varying in inclination (40-90) and local time	2.25 meters (7.4 feet) in diameter and 1.52 meters (4.99 feet) in height	and weighs 494 kg	250 Watts required	spin-stabilized spacecraft	http://pluto.space.swri.edu/IMAGE/
IMEX (Inner magnetosphere explorer)	NASA	Was planned as 2003, but now defunct due to lack of funds			study the electromagnetic fields and energetic particles that episodically appear inside the Earth's magnetosphere.	350-kilometer by 35,000-kilometer					http://ham.space.umn.edu/spacephys/imex.html http://lasp.colorado.edu/programs_missions/present/imex/ http://lasp.colorado.edu/stp/imex/imex_main.html
IMP-8	NASA	Operating since 1973		Various energetic particle/plasma/field and wave expts	Detail of solar wind(7 days) and magnetosphere/magnetosheath (5 days)	35Re near circular 12 day period Earth orbiter	drum-shaped spacecraft, 135.6 cm across and 157.4 cm high	On-orbit dry mass: 371 kg	Nominal Power Output: 150 W	spin rate was 23 rpm	http://nssdc.gsfc.nasa.gov/space/imp-8.html
INTERBALL	Russia	Two s/c pairs Tail probe Aug 1995 & Auroral probe Aug 1996, non-operational		Plasma investigation, Plus particle and field and wave expts	Cusp, magnetopause and neutral sheet. Auroral acceleration	1 at 1.1 x 31 Re & 1 at 1.1 x 4 Re. Both with 63Deg inclination.					http://www.iki.rssi.ru/interball.html
IRIDIUM	US	from 1997 to 1999?	8 years	Comsats with magnetometers	Global measurements of magnetic field at LEO	66 satellites in 780km polar constellation					http://www.spacedaily.com/news/iridium-01a.html http://www.ithaco.com/Magnetometers.html http://www.iridium.com/ http://www.friends-

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
											partners.org/mwade/craft/lm700.htm
ISS (International Space Station)		Feb-01	6 months	Bonner Ball Neutron Detector		51 deg, Circular 250-450km orbit					http://spaceflight.nasa.gov/station/science/experiments/bball.html http://www.nsbri.org/Radiation/ http://jem.tksc.nasda.go.jp/iss/exp/bbnd_e.html
MC/DRACO Magnetotail Constellation 2008 to 2010/11	NASA	2010	2 years	Particles & fields instruments (inc. magnetometer and Ion detector)	Magnetotail physics	100 satellites in Nested, near equatorial orbits with Rp = 3Re, Ra =7-40 Re	Diameter = 30 cm. (12 in.) Height=10cm.(4in.)	Mass = 10 kg. total (includes propellant)	Power = 3 - 5 w.	Spin stabilized	http://sec.gsfc.nasa.gov/magcon.htm http://magcon.gsfc.nasa.gov/
METOP 1,2,3	ESA	2003	5 years, but rolling program of >14 yrs	Space Environment monitor. (NOAA instrument)	Earth Observation	835km circular sun-synchronous		4.5Tonnes		3 axis	http://www.esa.int/esa/progs/METOP.html
MMS Magnetospheric Multiscale	U.S	Jun-07	2 years	Magnetic and electric fields (100-m wire booms); Electron and ion plasma spectrometers, 3D distribution in 1/2 spin; Energetic particles; Plasma waves; High temporal, spatial resolution; Burst event recording	Magnetospheric physics	4 identical spacecraft in a variably spaced tetrahedron (1 km to several RE) in magnetospheric orbits				spin rate 20 rpm	http://mms.gsfc.nasa.gov/ ; http://sec.gsfc.nasa.gov/magmulti.htm
MTI (Multi-spectral Thermal Imager)	U.S./Czech	Mar 12 2000	3 years	Hard X-ray Spectrometer	The mission has three primary objectives: a) to collect high time resolution solar hard X-ray data for flare research; b) to evaluate the efficacy of this type of instrument to predict interplanetary proton events and, c) to test the effectiveness of new shielding methods applied to	555 km circular, sun-synchronous orbit.		610 kg total spacecraft mass	575 Watts maximum power consumption		http://www.asu.cas.cz/english/new/HXRS_descr.htm http://nis-www.lanl.gov/nis-projects/mti/

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
					this instrument to mitigate the effects of ambient high energy electrons – a combination of magnetic deflection shielding and organic plastic moderators which will enable this type of instrument to make long term solar hard X-ray observations at geostationary orbit.						
MUNIN	Sweden	2000 Nov 21	The Last contact with Munin was 2001-02-12.After a manual CPU reset Munin has been quiet.Probably due to boot PROM failure.	Electron/ion spectrometer, high energy particles, auroral imager	Auroral research	elliptical orbit, 698 x 1810 km (377 x 977 nmi), at 95.4 deg inc.	20 x 20 x 25 cm stowed				http://munin.irf.se/
ORSTED	Denmark	ØRSTED has been successfully launched on the 23rd of february, 1999. The satellite is still flying and acquiring measurements of the Earth's magnetic field	14 months	CSC flux-gate magnetometer, Star-imager , Overhauser magnetometer, Particle detectors to measure the flux of fast electrons (0.03-1 MeV), protons (0.2-30 MeV), and alpha-particles (1-100 MeV)	precise global mapping of the Earth's magnetic field	An elliptic orbit of heights between 500 and 850 km	34x45x72 cm	62kg	5 GaAs solar-panels yield approximately 37 W in average during an orbit		http://www-projet.cst.cnes.fr:8060/OVH/index.html http://web.dmi.dk/fsweb/projects/oersted/

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
PICARD	France	Future, 2002-2003 2-6yrs mission	2-6years	Whole sun imager (SODISM), SOVAP(radiometer), PREMOS(UV/VIS Photometers), 45kg total	Solar diameter variation	Sun-synch	60x75x80cm	120kg (10kg margin)	78w	3 axis, 0.1 deg accuracy, 0.01deg stability	http://www-projet.cst.cnes.fr:8060/PICARD/Fr/index.html
POES (NOAH L,M,N,N)	NOAA	L launched Sept 21 2000, M launched Mar 2002, N launched Dec 2003, N' Launched Mar 2008	2 years (3 yrs instrument life) Rolling program with gaps?	Space Environment monitor. (NOAA instrument)	Earth Observation	833 km polar sun-synchronous		2231.7 kg (4920 lbs.) at launch			http://www.earth.nasa.gov/missions/ref_web/mnoaa.htm http://poes2.gsfc.nasa.gov/
POLAR	NASA	1996 operational	3 yr life,	11 (including particle and field exps, and a U.V imager and Visible Imaging system	Entry, energization, and transport of plasma into the magnetosphere	1.8-9 Earth radii polar orbit (86deg) Initially apogee was over the northern polar region, but apogee has been moving towards the equator at about 16° per year	2m length, 2.4m diameter	1230 kg		Spin-stabilised,	http://www-spof.gsfc.nasa.gov/istp/polar/
Radiation Belt Mappers (RBM)	NASA	Apr-08	2 year mission design life with 5 year goal	7 in-situ instruments per spacecraft through AO process	Living with a star core missions	Three satellites in 500km x 6.5Re petal orbits		small		Spin-stabilised,	http://lws.gsfc.nasa.gov/lws.htm http://rsdo.gsfc.nasa.gov/Presentations/Robinson_LWS.pdf
Reconnection and Collisionless Shock Explorer	UK		2 years	dual sensor magnetometer with boom, e-field measurements and a suite of body mounted plasma analysers	Understanding the process of magnetic reconnection	(similar to AMPTE-UKS) apogee 17Re transfer from GTO, near equatorial plane orbit				Spin stabilised (1 rps)	

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
(Mosaic proposal)											
SACI-1	Brazil	Oct-99	2 years	The payload of SACI-1 is composed of four scientific experiments namely: ORCAS, an investigation of the anomalous cosmic radiation fluxes; FOTSAT, an airglow photometer to measure the terrestrial airglow emissions; PLASMEX, a study of the plasma bubbles evolution and MAGNEX, a research of the geomagnetic field effect on charged particles.	The satellite includes experiments to study the Earth's magnetic field and its interaction with the Sun.	sun-synchronrous orbit at an altitude of approximately 760 km	The overall dimensions are 600 x 400 x 400 mm;	60-kg		Spin-stabilized	http://www.dea.inpe.br/papers/asainta.html http://www.spaceviews.com/1999/10/14a.html http://denali.gsfc.nasa.gov/research/mag_field/purucker/mag_missions.html#SACI http://ipe.nma.embrapa.br/sat_us/saci.html
SAC-C	Argentina. International participation includes NASA (launch, magnetometer) and Denmark (Magnetic mapping package).	: Nov. 18, 2000	4 years	Magnetic instrumentation: 8 m boom w. triaxial fluxgate, helium scalar		702 km circular, sun synchronous	370W	425 Kg			http://www.invap.com.ar/sacc.html http://denali.gsfc.nasa.gov/research/mag_field/purucker/mag_missions.html#SACI
SAMPEX	NASA/ Germany	1992, TBD	One year, three year goal (still in operation)	Energetic particles	Energetic particles from Sun & magnetosphere	550 x 675km LEO, 82Deg inclination		157 kg	82W	3axis	http://sunland.gsfc.nasa.gov/smex/sampex/index.html

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
SDO (Solar Dynamics Observatory)	NASA	Dec-06	5 years	4 solar pointed instrument packages through AO process	Living with a star core missions	Geosynchronous, 28.5 deg inclination				3axis	http://lws.gsfc.nasa.gov/lws.htm http://rsdo.gsfc.nasa.gov/Presentations/Robinson_LWS.pdf
SMART-1	ESA	Oct-02	15-17 months cruise to MOON, then orbit Moon for F36 months	debris monitor DEBIE		Lunar					http://sci.esa.int/home/smart-1/index.cfm
SOHO	ESA/ NASA	1995, operational	ESA and NASA have decided to prolong its life until 2003; fuel reserves will last for 25 yrs	Coronagraphs, EUV imagers, Solar wind	Solar interior, surface,corona, solar wind	L1	3.65 x 3.65 m x 9.5 m	1850 kg at launch			http://sohowww.nascom.nasa.gov/ http://sci.esa.int/home/soho/index.cfm
SOLAR ORBITER	ESA	Jan-09	1.86 cruise + 2.88 nominal+ 2.28 ext	solar wind analyser, plasma wave analyser, particle detector, dust detector, EUV/X-ray imager, EUV spectrometer,, magnetograph,, coronagraph	view sun from out-of-ecliptic, near sun, heliocentic orbit (spectroscopy and imaging at high spatial and temporal resolution, in-situ sampling of particles and fields from a quas-corotational perspective, remote-sensing of the polar regions of the sun	initial perihelion 0.21AU aphelion 0.9AU, inc 6.7deg, final perihelion 0.3AU aphelion 0.8AU, inc 23.4deg, ext mission final orbit peri 0.3AU aphelion 0.7AU, inc 31.7deg	3000x1200x1600mm	1510		3-axis, stability better than 3arcsec/15min	
SOLAR PROBE	NASA	launch 2008 or later, arrive 2011+		TBD	Solar corona	Probe travelling out to Jupiter and then propelled close flyby of Sun (3 Rs).					http://www.jpl.nasa.gov/ice_fire//sprobe.htm
SOLAR-B	Japan/US/UK	Future September 2005	Solar-B is to operate for at least 3 years.	Optical telescope, EUV telescope, X-ray telescope,	Solar magnetic variability as space weather driving force	600km 97.9 deg Polar Sun-synchronous		875kg	500W (two 1-axis solar arrays)		http://sec.gsfc.nasa.gov/solar-b.htm http://science.msfc.nasa.gov/ssl/pad/solar/solar-

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
											b.htm
SOLAR SPACE TELESCOPE (SST)	China/ Germany	2003???									http://www.sciam.com/specialissues/0398cosmos/0398beardsley.html http://optics.org/article/news/02/3/11 http://dawning.iist.unu.edu/china/bjreview/98Nov/bjr98-45-36.html
SORCE - SOlar Radiation and Climate Experiment	NASA	Future 2002	5 years (6 year goal),	Total Irradiance Monitor (TIM), Solar Stellar Irradiance Comparison Experiment(SOLSTICE), Spectral Irradiance Monitor (SIM), and the XUV Photometer System (XPS).	It will continue the precise measurements of total solar irradiance (TSI) and will also provide measurements of the solar spectral irradiance from 1 nm to 2000 nm, accounting for 95% of the spectral contribution to TSI.	645 km, 40° inclination	58.5" height 44" diameter	268 kg	730 watts orbit average at EOL	3 axis, solar pointed	http://lasp.colorado.edu/sorce/
STEREO	NASA	Future 2003	5 yrs	Solar coronal imager, Coronagraph, Radio burst tracker, heliospheric imager, Solar wind plasma analyser, magnetometer, energetic particle detector	Solar terrestrial (CME origin and consequences, evolution in heliosphere, 3D structure etc)	2 spacecraft at 1 AU orbit but away from Sun-Earth line					http://sd-www.jhuapl.edu/STEREO/ http://stp.gsfc.nasa.gov/missions/stereo/stereo.htm
STRV 1	UK		1 year planned, but longer may be required		To map the radiation environment of GTO with high temporal and spatial resolution at post-solar minimum conditions.	GTO					http://www.dera.gov.uk/html/space/strv/home.htm

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
ST5	NASA	2003	? Prob 1 year	energetic particle detector and a magnetometer	measure the effect of solar activity on the Earth's magnetosphere (Magnetospheric Constellation Technology demonstrator)	3 spacecraft in GTO, 200 by 35,790 km	42 centimeters (17 inches) across and 20 centimeters (8 inches) high	weighs about 21.5 kilograms (47 pounds)			http://nmp.jpl.nasa.gov/st5/
swarm: a Danish Small-Satellite Mission to Observe the Dynamics of the Earth's Magnetic Field	ESA/Denmark	2003 (Solar Minimum)	3 years			Circular, preferably below 500 km; Multiple satellites in near-polar orbits and a single satellite in a near-equatorial orbit. The satellites in near-polar oribts have slightly different inclinations.					http://www.dsri.dk/smaasatellit/swarm.html
SWARMS (UK) - Mosaic proposal	UK			Magnetometer, combined ion/electron e/q analyser	3d time dependant measurements of the magnetosphere	30 satellites in vaious magnetospheric orbits		30kg			
TIMED	NASA	Aug 10 2001	2 years	Global Ultraviolet Imager (GUVI), Sounding of the Atmosphere using Broadband Emission Radiometry (SABER), Solar Extreme Ultraviolet Experiment (SEE), TIMED Doppler Interferometer (TIDI). SEE is comprised of a spectrometer and a suite of photometers designed to measure solar ultraviolet radiation Ð the primary energy that's deposited into the MLTI atmospheric region.	understand the energy transfer into and out of the Mesosphere and Lower Thermosphere/Ionosphere (MLTI) region of the Earth's atmosphere (energetics), as well as the basic structure (i.e., pressure, temperature, and winds) that results from the energy transfer into the region (dynamics).	625-km, circular orbit, inclined 74.1 degrees		587-kilogram			http://sec.gsfc.nasa.gov/timed.htm http://www.timed.jhuapl.edu/

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
TRACE	NASA	1997, operational	1 year baseline	Imager	Solar surface	600x650km sun-synch		SMEX			http://vestige.lmsal.com/TRACE/
TRIANA	NASA	May 2004 launch; 3.5 yrs transit phase and 6 months to L1	2-5 yrs	Plasma-Mag: a package consisting of a magnetometer and Faraday cup to measure properties of the solar wind and to detect the onset of extreme solar events that are likely to affect Earth orbiting satellites and electrical equipment on the ground. The instruments will provide rapid warning (within about 5 minutes) of events that will reach the Earth about 1 hour later. Has a time resolution of 0.1 seconds	Primarily an Earth radiation emission mission	L1		SMEX Lite 4239.74kg (inc star 48 booster and Gyroscopic upper stage))		3-axis	http://cloud.ucsd.edu/missions/triana/abstract.html http://www.cslp.net/triana/ http://triana.gsfc.nasa.gov/home/
TWINS	NASA	Depending on the exact TWINS timing and the duration of the IMAGE science phase, the first TWINS spacecraft may overlap with the IMAGE mission, providing an even earlier oppurtunity for	TWINS will provide a two year stereo imaging mission.	The TWINS instrumentation is essentially the same as the MENA instrument on the IMAGE mission. This instrumentation consists of a neutral atom imager covering the ~1-100 keV energy range with 4x4o angular resolution and 1-minute time resolution, and a simple Lyman-alpha imager to monitor the geocorona.	The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) mission provides a new capability for stereoscopically imaging the magnetosphere	Each spacecraft in a Molniya orbit with 63.4o inclination and 7.2 RE apogee, 1000km perigee an ideal orbit for magnetospheric imaging. Ascending nodes separated by 180deg				3-axis Nadir pointing	http://nis-www.lanl.gov/nis-projects/twins/

MISSION	ORG	LAUNCH & STATUS	LIFETIME	SW INSTRUMENTS	SCIENCE COVERED	ORBIT AND OTHER REQUIREMENTS	S/C SIZE	S/C MASS	S/C POWER	AOCS	contact
		magnetospheric stereo imaging.									
ULYSSES	ESA	1990, operational	at the present time, the Ulysses Mission has been funded until December 2001. At its meeting in Paris on 5-6 June 2000, ESA's Science Programme Committee approved the continuation of orbital operations from the end of 2001 to 30 September 2004. If NASA follows ESA's lead, the extension will allow Ulysses to observe the Sun's environment as sunspot activity gradually declines after sunspot maximum in 2000. Milestones up to Nov 2007 are envisioned	Magnetometer, plasma and energetic particles	3-D structure of heliosphere	1.4 by 5 AU, at 82 degrees to ecliptic				Ulysses spins at 5 rpm. The critical attitude,control requirement for Ulysses is to keep the HGA boresight pointed at the Earth to within about 0.5°	http://helio.estec.esa.nl/ulysses/
WIND	NASA	1994, operational		Array of Charged particle and field expts	Solar Wind	Complex earth orbit with apogee up to 200 Re., 4.5-250Re, then L1					http://www-spof.gsfc.nasa.gov/istp/wind/
YOHKOH	Japan/US/UK	1991, operational	will re-enter in 2002	the Bragg Crystal Spectrometer (BCS), the Wide Band Spectrometer (WBS a soft x-ray, a hard x-ray, and a gamma-ray spectrometer), the Soft X-Ray Telescope (SXT), the Hard X-Ray Telescope (HXT).	Solar Corona	570 km to 730 km elliptical					http://www.lmsal.com/SXT/

Table 13 Existing and Planned Mission Review

7.1.2 Existing and Planned Mission timeline

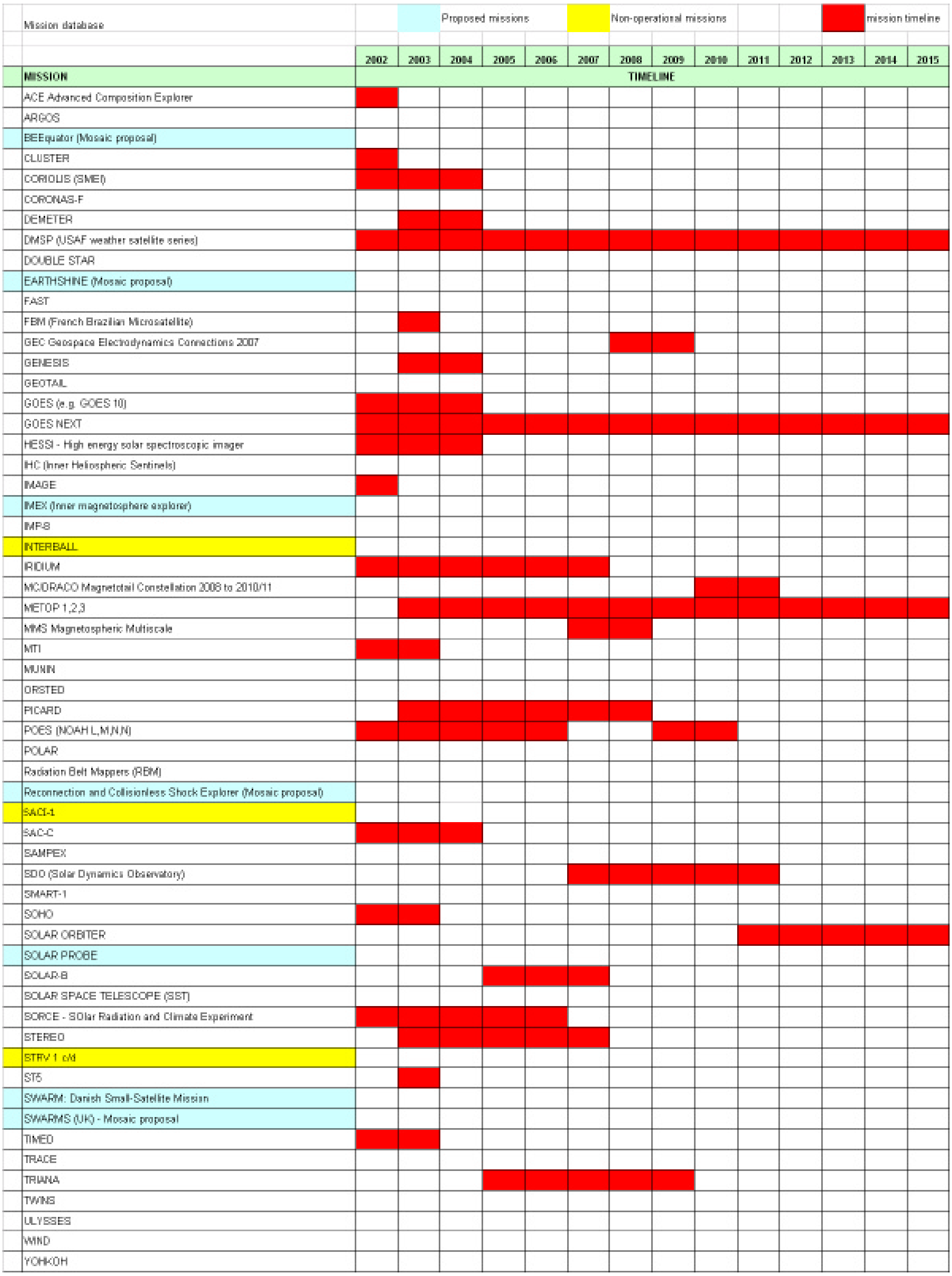


Figure 7 Existing and Planned Mission Timeline

7.1.3 CSMR Timeline with Existing and Planned missions that meet CSMR

CSMR timelines show how various missions meet each CSMR from the instruments onboard their spacecraft. The CSMR timeline is, in some cases severely constrained by space weather service requirements such as temporal sampling, continuous viewing, and limits on the gaps in ground station coverage. SOLO (Solar Orbiter) is an example of a mission that only fully meets the requirements SOMETIMES, i.e. when it passes close to the Earth-Sun line. The CNES missions, DEMETER and PICARD, are missions whose instrument would meet certain CSMR, however they suffer from the gaps between ground station coverage being too large. Therefore they only meet the requirement when gap duration limit is not exceeded.

The orbit of METOP means that CSMR 53 to 55 are only met at middle to high latitudes. As a rough guide the "L value" (McIlwain parameter) quoted in the CSMR's translates to a magnetic latitude as:

Arccos $\sqrt{(1/L)}$ - This would be exact if the geomagnetic field were a pure magnetic dipole at the centre of the Earth.

The magnetometers on IRIDIUM only meet parts of the regions for CSMR 39 to 43, so again only partial coverage of the requirements is fulfilled.

CSMR 36-38 can be met either by a Magnetometer at L1 or a Magnetograph. The Magnetometer is preferred as it gives direct measurement of the Magnetic field at L1, whilst a magnetograph provides indirect measurement of the interplanetary magnetic field. Both options are investigated for completeness. The Magnetograph measurements can alternatively be performed by ground-based instruments, however space based is preferred.

7.1.3.1 All missions[1]

Temporal sampling requirement and Max Gap requirement in Ground station contact chosen is the shortest so that all CSMR's for a particular instrument and orbit are met

= data rate problem

* = international collaboration

(solid red) represents period where CSMR requirements are covered

(hatched red) represents period where CSMR requirements are partially covered

CSMR 36 to 38 can be met by either Magnetometer at L1 or a Magnetograph

CSMR	Measure what ?	Instrument ?	Where	Spatial sampling require-ment	Temporal sampling require-ment	Max Gap in coverage	No. of instances	2002 – 2015
1	Solar EUV/ X-ray images	Whole disk imager	L1/SS/GEO	Single point measurement in space	1hr	20 min	1	SOHO (2002-2003) ESA*, SDO (2007-2011) NASA*, GOES-NEXT (2002-2015) NOAA, HESSI, (2002-2004) NASA, PICARD (2003-2008) CNES, SOLAR B (2005-2007) ISAS*, STEREO (2003-2007) NASA*, YOHKOH (2002?) ISAS*
2	Solar coronograph images	Coronograph	L1/L4/L5 /SS/ GEO	Single point measurement in space	1hr	20 min	1	SOHO (2002-2003) ESA*, SDO (2007-2011) NASA*, CORIOLIS (2002-2004) AFRL*, SOLAR ORBITER (2011-2015) ESA, STEREO (2003-2007) NASA*
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4+L5	2 points well separated from Earth eg L4 & L5	1hr	20 min	2	SOLAR ORBITER (2011-2015) ESA, STEREO (2003-2007) NASA*
4,5	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO/Molniya	From polar elliptical orbit, Single point measurement	1hr	20 min	2	POLAR (???) NASA*
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1/SS/GEO	Single point measurement in space	1 min	20s	1	Weakly HESSI (2002-2004) NASA, GOES NEXT (2002-2015) NOAA, SOLAR B (2005-2007) ISAS*, YOHKOH (2002?) ISAS*
12	UV flux	UV photometer	L1/SS/GEO	Single point measurement in space	1day	8 hours	1	PICARD (2003-2008) CNES, SORCE (2002-2006) NASA*?(couple of Euro CO-P.I.s), TIMED (2002-2003) NASA*
13	EUV flux	EUV photometer	L1/SS/GEO	Single point measurement in space	1day	8 hours	1	SORCE (2002-2006) NASA*?(couple of Euro CO-P.I.s) TIMED (2002-2003) NASA*
23 to 27	Flux and flow	Thermal energy ion spectrometer	L1	Single point measurement at L1	1 min	3 min	1	ACE (-2002) NASA*, SOHO (2002-2003) ESA*, GENESIS#(2003-2004) NASA, TRIANA (2006-2009) NASA
28 to 30	IMF (B-field)	Magnetometer	L1	Single point measurement at L1	1 min	3 min	1	ACE (-2002) NASA*, TRIANA (2006-2009) NASA, IMP-8 (?) NASA
36 to 38	IMF (B-field)	Magnetograph	L1/L4/L5 /SS/ GEO		1 hour	3 min	1	SDO (2007-2011) NASA*, SOLAR ORBITER (2011-2015) ESA
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	Throughout magnetosphere (constellation type such as SWARMS)	1 hour	20s	4 to 100	IMP-8 (?) NASA, ST5 (2003-?) NASA, MAG CON/DRACO (2010-2011) NASA*, SWARMS ?? UK, Weakly IRIDIUM (1997/99-2005/2007) NASA
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO/LEO	PEO	seconds	1s	5 to 10	DEMETER (2003-2004) CNES
52	Cold ions: Total density only	Thermal energy ion spectrometer, Ionosonde, UV Imager	Elliptical eg GTO	L>1 and below	1 min	20s	4 with ion, 2 with UV imager/ ionosonde	IMAGE (U.V. IMAGER AND POSS IONOSONDE) (2002 BUT COULD GO TO 5 YEARS) NASA
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO/GTO	L=1 to 8, GEO "Want several (eg 3) equi-spaced in longitude	1 min	20s	4 or more	METOP/POES (2002-2015) ESA/NOAA , STORMS (not selected) ESA
56 to 58, 62	>10MeV ions (SPE) (MPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1/GEO	Single point measurement in interplanetary space	<30 min	10 min	1	ACE (-2002) NASA*, SOHO (2002-2003) ESA*, IMP-8 (?) NASA*?,
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO/GTO/ LEO/mid-EO	Throughout inner radiation belt	<30 min	10 min	3 or more	SAMPEX (2002-?) NASA*, ST5 (2003-?) NASA
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO/L1/L2	Single point measurement in space	1hr	20 min	1	ACE (-2002) NASA* GOES NEXT (2002-2015) NOAA, SOHO (2002-2003) ESA*, STEREO (2003-2007) NASA*
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO, GTO	<30min	10 min	2 or more	GOES NEXT (2002-2015) NOAA
68 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO	6 months for debris, 1day for meteoroids	8 hours	1	FBM (2003) CNES/INPE*
72	Dose-rate & LET spectrum	High energy electron spectrometer	Onboard s/craft	Onboard spacecraft	5 min	180s	1	INTERNATIONAL SPACE STATION (?)*
73	Total Dose		Sensor worn by astronaut		mission integrated			
74	Satellite position				30 minutes			GPS/GALILEO/GLONASS/Ground based
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	Single point measurement in space	1 hour	20 min	1	STEREO (2003-2007) NASA*

Figure 8 Timeline of CSMR, which are met by instruments on All Missions

1 The gap in timeline for CSMR 36 to 38 during the period 2003/4 is an important result

7.1.3.2 European and International collaboration[2]

Temporal sampling requirement and Max Gap requirement in Ground station contact chosen is the shortest so that all CSMR's for a particular instrument and orbit are met

= data rate problem

* = international collaboration

represents period where CSMR requirements are covered

represents period where CSMR requirements are partially covered

CSMR 36 to 38 can be met by either Magnetometer at L1 or a Magnetograph

CSMR	Measure what ?	Instrument ?	Where	Spatial sampling require-ment	Temporal sampling require-ment	Max Gap in coverage	No. of instances	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	Single point measurement in space	1hr	28 min	1	SOHO (2002-2003) ESA*, SDO (2007-2011) NASA*, PICARD (2003-2008) CNES, SOLAR B (2005-2007) ISAS*, STEREO (2003-2007) NASA*, YOHKOH (2002?) ISAS*													
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / SS / GEO	Single point measurement in space	1hr	28 min	1	SOHO (2002-2003) ESA*, SDO (2007-2011) NASA*, CORIOLIS (2002-2004) AFRL*, SOLAR ORBITER (2011-2015) ESA, STEREO (2003-2007) NASA*													
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4+L5	2 points well separated from Earth eg L4 & L5	1hr	28 min	2	SOLAR ORBITER (2011-2015) ESA, STEREO (2003-2007) NASA*													
4,5	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	From polar elliptical orbit, Single point measurement	1hr	28 min	2	POLAR (???) NASA*													
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	Single point measurement in space	1min	28s	1	SOLAR B (2005-2007) ISAS*, YOHKOH (2002?) ISAS*													
12	UV flux	UV photometer	L1 / SS / GEO	Single point measurement in space	1day	9 hours	1	PICARD (2003-2008) CNES, SORCE (2002-2008) NASA*?(couple of Euro CO-P.I.s), TIMED (2002-2003) NASA*													
13	EUV flux	EUV photometer	L1 / SS / GEO	Single point measurement in space	1day	9 hours	1	SORCE (2002-2008) NASA*?(couple of Euro CO-P.I.s), TIMED (2002-2003) NASA*													
22 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Single point measurement at L1	1min	3 min	1	ACE (-2002) NASA*, SOHO (2002-2003) ESA*													
36 to 38	IMF (B-field)	Magnetometer	L1	Single point measurement at L1	1min	3 min	1	ACE (-2002) NASA*													
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / SS / GEO		1 hour	3 min	1	SDO (2007-2011) NASA*, SOLAR ORBITER (2011-2015) ESA													
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	Throughout magnetosphere (constellation type such as SWARMS)	1hour	28s	4 to 100	MAG CON/DRACO (2010-2011) NASA*, SWARMS ?? UK													
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	PEO	seconds	1s	5 to 10	DEMETER (2003-2004) CNES													
52	Cold ions. Total density only	Thermal energy ion spectrometer, Ionosonde, UV imager	Elliptical eg GTO	L<7 and below	1min	28s	4 with ion, 2 with UV imager/ ionosonde														
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	L=3 to 8, GEO. Want several (eg 3) equi-spaced in longitude	1min	28s	4 or more	METOP/POES (2002-2015) ESA/NOAA, STORMS (not selected) ESA													
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	Single point measurement in interplanetary space	<30 min	10 min	1	ACE (-2002) NASA*, SOHO (2002-2003) ESA*													
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	Throughout inner radiation belt	<30 min	10 min	2 or more	SAMPEX (2002-?) NASA*													
63 to 65	>100MeV ions (CSR)	High energy ion detector	GEO / L1 / L2	Single point measurement in space	1hr	28 min	1	ACE (-2002) NASA*, SOHO (2002-2003) ESA*, STEREO (2003-2007) NASA*													
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO, GTO	<30min	10 min	2 or more														
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO	6 months for debris, 1 day for meteoroids	9 hours	1	FBM (2003) CNES/INPE*													
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s / craft	Onboard spacecraft	5 min	10s	1	INTERNATIONAL SPACE STATION (?)*													
73	Total Dose		Sensor worn by astronaut		mission integrated																
74	Satellite position				30 minutes			GPS/GALILEO/GLONASS/Ground based													
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	Single point measurement in space	1 hour	20 min	1	STEREO (2003-2007) NASA*													

Figure 9 Timeline of CSMR, which are met by instruments on Missions with European involvement

2 The gap in timeline for CSMR 36 to 38 during the period 2003/6 is an important result

7.1.3.3 European only[3]

Temporal sampling requirement and Max Gap requirement in Ground station contact chosen is the shortest so that all CSMR's for a particular instrument and orbit are met

= data rate problem

* = international collaboration

(solid red) represents period where CSMR requirements are covered

(hatched red) represents period where CSMR requirements are partially covered

CSMR 36 to 38 can be met by either Magnetometer at L1 or a Magnetograph

CSMR	Measure what ?	Instrument ?	Where	Spatial sampling require-ment	Temporal sampling require-ment	Max Gap in coverage	No. of instances	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Solar EUV / X-ray images	Whole disk image	L1 / SS / GEO	Single point measurement in space	1hr	28 min	1	SOHO (2002-2003) ESA*, PICARD (2003-2008) CNES,													
2	Solar coronagraph images	Coronagraph	L1 / L4 / L5 / SS / GEO	Single point measurement in space	1hr	28 min	1	SOHO (2002-2003) ESA*, SOLAR ORBITER (2011-2015) ESA,													
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	L4-L5	2 points well separated from Earth eg L4 & L5	1hr	28 min	2	SOLAR ORBITER (2011-2015) ESA													
4,5	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	From polar elliptical orbit, Single point measurement	1hr	28 min	2	POLAR (???) NASA*													
8 to 11	X-ray flux & spectrum(CSMR11)	X-ray photometer / spectrometer	L1 / SS / GEO	Single point measurement in space	1min	28s	1														
12	UV flux	UV photometer	L1 / SS / GEO	Single point measurement in space	1day	8 hours	1	PICARD (2003-2008) CNES													
13	EUV flux	EUV photometer	L1 / SS / GEO	Single point measurement in space	1day	8 hours	1														
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Single point measurement at L1	1min	3 min	1	SOHO (2002-2003) ESA*													
36 to 38	IMF (B-field)	Magnetometer	L1	Single point measurement at L1	1min	3 min	1														
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / SS / GEO		1 hour	3 min	1	SOLAR ORBITER (2011-2015) ESA													
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Throughout magnetosphere (constellation type such as SWARMS)	1 hour	28s	4 to 100	SWARMS ?? UK													
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	PEO	seconds	1s	5 to 10	DEMETER (2003-2004) CNES													
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical eg GTO	L<7 and below	1min	28s	4 with ion, 2 with UV imager/ ionosonde														
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	L=3 to 8, GEO. Want several (eg 3) equi-spaced in longitude	1min	28s	4 or more	METOP/POES (2002-2015) ESA/NOAA, STORMS (not selected) ESA													
56 to 59, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	Single point measurement in interplanetary space	<30 min	10 min	1	SOHO (2002-2003) ESA*													
58 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	Throughout inner radiation belt	<30 min	10 min	3 or more														
63 to 65	>100MeV ions (CSR)	High energy ion detector	GEO / L1 / L2	Single point measurement in space	1hr	28 min	1	SOHO (2002-2003) ESA*													
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO, GTO	<30min	10 min	3 or more														
68 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO	6 months for debris, 1 day for meteoroids	8 hours	1	FBM (2003) CNES/INPE*													
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/craft	Onboard spacecraft	5 min	10s	1	INTERNATIONAL SPACE STATION (?)*													
73	Total Dose		Sensor worn by astronaut		mission integrated																
74	Satellite position				30 minutes			GPS/GALILEO/GLONASS/Ground based													
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	Single point measurement in space	1 hour	20 min	1														

Figure 10 Timeline of CSMR, which are met by instruments on European-led missions

3 The gap in timeline for CSMR 36 to 38 during the whole timeline is an important result

7.1.4 Conclusion of ‘Existing and Planned only’ Space Segment

Existing and planned missions do go some way to meeting some of the CSMR, however the extent to which they do so is limited and generally sporadic, even if all missions are included. Many CSMR are not met or are only poorly met by existing and planned missions.

It must also be said that some individual missions may not exactly meet the CSMR all the time. The main problem would be from ground station coverage. As many of these missions will be served by only one ground station, the gap duration in ground station view may exceed the gap in data downlink. For Space Weather predictive requirements, this would be prohibitive unless either multiple ground stations or multiple spacecraft are used. A primary example of a mission that suffers from ground station coverage is SOLAR B, which only meets CSMR 1 and 8-11, when close enough to the ground station to meet the ground station gap requirements, i.e. 20 minutes for CSMR 1 and 20 seconds for CSMR 8-11.

Another problem would be eclipses, which can cause outages in science return for solar observations (CSMR 1, 2, 8-11, 12, 13 and 36-38(magnetograph)). This is only a problem, though, if both the spacecraft is in eclipse when downlinking data and the eclipse duration is greater than the ground station gap requirement. The orbit and ground station configuration must be carefully selected such that this does not happen.

An important result is that of CSMR 36 to 38 which has a gap in timelines for all three collaborative programmes. For missions with European involvement there is a clear gap between 2003 and end of 2006 before Solar Dynamics Observatory is launched.

7.2 Hitch-Hiker Options

7.2.1 Introduction

This section discusses possibility of using host satellites to carry ‘hitch-hiker’ Space Weather payloads in order to meet the system requirements. Employing a Space Weather ‘guest payload’ on a host spacecraft can save on standard costs associated with a dedicated mission. The high number of spacecraft being launched into certain orbits such as LEO and GEO, combined with the industrial nature of production of many of these platforms, could offer significant cost advantages. We have basically covered two space segment options that could employ hitch-hikers in some form or other, although in theory, many configurations are possible.

The baseline option considers a space segment made up of hitch-hikers and existing/planned infrastructure only and no dedicated spacecraft. The aim here being to meet as many outstanding system requirements with purely hitch-hiker instrumentation. For this option a trade-off is required between implementation of Space Weather payloads on host spacecraft in optional orbit locations (if options exist) for each particular system requirement. This option is complicated in that some instruments are fairly large, and it is uncertain as to whether they could be classified as possible hitch-hikers. Therefore two scenarios were investigated; one where the larger instruments (Whole disk and Auroral Imagers) could be classed as hitch-hikers, and one where the larger instruments would have to be part of a dedicated space segment.

A secondary option – Full Dedicated, consists of both hitch-hikers and dedicated spacecraft. This option is actually part of the dedicated options as it contains only dedicated spacecraft and no hitch-hikers on ‘non-space-weather’ hosts, but must be considered here as it does involve a hitch-hiker element. This may be an attractive option as a group of hitch-hiker elements could be instead be brought together to form a dedicated spacecraft or more appropriately, a combined dedicated satellite, where the overall cost might be cheaper than the sum cost of the individual hitch-hikers. For this option there is a trade-off between implementation of Space Weather payloads on dedicated spacecraft in optional orbit locations (if options exist) for each particular system requirement. Singular hitch-hikers are not considered within this option, although it is possible that in some cases, hitch-hiking may actually be preferred over being part of a dedicated spacecraft. This may be true of small hitch-hikers

7.2.2 Definition of Terminology

For clarity, it is useful to summarise exactly what is meant here by the terms ‘host’, ‘guest’, and ‘dedicated’.

Host satellite: A satellite class or type, or even a specific example (although this is less likely due to the long timescale of mission planning), with its own primary mission objective that is unrelated to that of the space weather payload, and which is suitable to act as a host to at least one **guest** space weather payload concept, supplying power and accommodation, without compromising its own mission objectives or causing significant system re-sizing. The host may or may not provide shared communications, thermal control, computing and other services. Thus the host possibilities include a fully integrated approach, where all services to the guest are somehow provided by or shared with the host satellite, or a clean mechanical and electrical interface only, with the guest effectively having its own ‘payload module’ with dedicated thermal control, communications, computing subsystems etc.

Guest payload: A space weather payload installed on a host satellite. As described above, the guest could consist of an instrument only with all support services provided by the host, or a complete guest payload module with minimised interfaces with the host.

Dedicated satellite: This term is taken to mean two types of implementation of a space weather payload on a satellite

True Dedicated: The complete satellite exists to serve the one space weather payload identified as its primary mission, and carries no other payload

Combined Satellite: The complete satellite serves an identified space weather payload as its primary mission, but also in addition can serve one or more other payloads that may or may not be related to space weather or to the first payload. This approach could offer better value for money (compared to a true dedicated) for implementing space weather payloads that are not considered suitable to be a guest on a host satellite. Examples are where the technical requirements of the space weather payload would cause significant re-sizing of the system on a host satellite, but when solved on a dedicated solution, the step change required is already sufficiently large that resources can be made available to other payloads much more cost effectively than would otherwise be the case. Taken to one extreme, this approach could mean multiple space weather monitoring payloads on one combined satellite.

7.2.3 Summary characteristics of potential orbit locations and their scheduled existing and planned non-space weather missions

Before we can trade-off potential orbit locations for each hitch-hiker instrument to match the outstanding CSMR's, it is necessary to review the characteristics of planned non-space weather missions and their planned orbit locations. From this we can assess each orbit by:

- The number of planned missions that occupy each location, including EU only missions and international programmes
- The nature of the satellite carrying out the mission and the respective owners/authorities (are they small satellites with little or no available volume, or are they receptive, e.g. Russians who are notably open to offers regarding cost-cutting)

This will help to eliminate certain orbit locations that may be inaccessible by hitch-hiker payloads either because

- There aren't any or enough prospective 'host's at that location.
- The 'host's are unacceptable as permission to hitch-hike is denied by customer as too great a risk either financially or for security reasons
- The instrument is too big to be accommodated.

A more detailed trade-off of 'orbit 1 versus orbit 2' is addressed later.

7.2.3.1 Mission review (taken from Propulsion 2000 study)

The following table, based on an input for the Propulsion 2000 study describes a range of future science missions, including data on application, expected launch dates, client and orbit location. The missions considered are scheduled to be launched in the time frame of 2000 to 2010, with some exceptions even at a later date. While those missions slated for launch within the next three years can be considered as certain, those missions scheduled in the long range (in five years or even later) are mostly speculative and their funding is not secured at this time. Nevertheless the table shows the expected percentage of missions to a specific orbit, which is assumed to be representative. The table shows that by far the most missions are planned for a low Earth orbit, with those missions to geostationary (transfer) orbit and deep space missions essentially making up for the rest. Only very few scientific spacecraft are to be launched to a medium Earth orbit or to the moon, with the number of missions to heliocentric orbits or a Lagrange Point being almost negligible.

In addition to the scientific missions considered in the table below, a large number of commercial satellites are to be placed primarily into the geostationary transfer orbit or into a low Earth orbit. They are not represented here, as the duration between contractor selection and launch is only 2/3 years.

Military satellites play a major role in the USA, and to a certain extent in Russia, but in Europe no market for military satellite applications is existent (apart from few exceptions). As these non-European military satellites are not available for the free market, it is difficult to see how they could be used as host spacecraft for space weather instruments. Therefore military spacecraft and their respective launch vehicles are not considered in the present mission categorisation.

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2000	Govt	LEO	1	650	Ariane	Amsat- DL phase 3	Amsat (France)	Contracted		
2000	Govt	MEO	1	650	Ariane 5	Amsat Phase 3D	Amsat Germany	Contracted		Communications
2000	Govt	LEO	1	1680	MV-4	Astro-E	NASDA	Launched		X-ray observation
2000	Govt	LEO	1	297	Tsyklon	Cesar	ASI/Czech Republic/Poland	Contracted	Alenia Spazio SpA	Space science
2000	Govt	LEO	1	400	Cosmos	Champ	DLR	Contracted	GFZ	study magnetic fields
2000	Govt	HEO	2	1200	Soyouz	Cluster 2	European Space Agency	Contracted	Astrium	Space science
2000	Govt	HEO	2	1200	Soyouz	Cluster 2	European Space Agency	Contracted	Astrium	Space science
2000	Govt	LEO	1	425	Delta	EO 1/NMP	NASA	Contracted	Swales Aerospace	RS technology
2000	Govt	LEO	1	3000	Delta 2	EOS-PM-1	NASA	Contracted	TRW	Observation
2000	Govt	GEO	1	880	CZ 3A	FY-2C (Feng Yun 2C)	State Bureau for Meteorology (China)	Contracted		
2000	Govt	GEO	1	2105	Atlas 2A	GOES L	NOAA	Contracted	SS/L	Meteorology
2000	Govt	GEO	1	2000	Atlas	GOES-M	NOAA	Contracted	Hughes Space and Communications	
2000	Govt	GEO	1	1500	PSLV	Gramsat 1A	Indian Space Research Organization	Contracted		
2000	Govt	GEO	1	1500	PSLV	Gramsat 1B		Contracted		

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2000	Govt	LEO	1	130	Pegasus XL	HETE-2	NASA	Contracted	MIT/AeroAstro	Astronomy
2000	Govt	LEO	1	350	CZ 4B	HY-1	CAST	Contracted	CAST	ocean monitoring
2000	Govt	GEO	1	2200	Ariane	Insat 3A/DTH	Indian Space Research Organization	Contracted	Indian Space Research Organization	Communications
2000	Govt	GEO	1	2700	GSLV	Insat 3B	Insat	Contracted	Indian Space Research Organization	Communications
2000	Govt	LEO	1	1350	PSLV	IRS-P5 (Cartosat)	Indian Space Research Organization	Contracted		
2000	Govt	LEO	1	1000	Delta 2	MIDEX-01 (Image)	NASA	Contracted	Lockheed Martin	Space science
2000	Govt	LEO	1	153	Cosmos	MITA mission (NINA)	ASI/INIFN	Contracted	Carlo Gavazzi Space SpA	Scientific
2000	Govt	GEO	1	1800	Ariane 5	MSG-1 Meteosat 8	Eumetsat	Contracted	Aerospatiale	Meteorology
2000	Govt	LEO	1	450	Taurus	MTI - Multispectral Thermal Imaging	LANL / Sandia National Lab	Launched	Ball Aerospace	Technology
2000	Govt	LEO	1	500	Rockot	Navy Earth Map Observer (NEMO)	US Navy / EarthMap Inc.	Contracted	Space Technology Development Corp.	
2000	Govt	LEO	1	289	Athena	NEW MIL-03 (ESSP1 Veg. Canopy Lidar-VCL)	NASA/Univ. of Maryland	Contracted		Earth Observation
2000	Govt	LEO	1	2234	Titan	NOAA-L	NASA/NOAA	Contracted	Lockeed Martin Missiles & Space	
2000	Govt	LEO	1	250	Start 1	Odin	Swedish Space Corp.	Contracted	Swedish Space Corp.	Space science
2000	Govt	LEO	1	270	*Shavit*	Ofeq-5	Israel Space Agency	Contracted	Israel Aircraft Industries Ltd.	
2000	Govt	LEO	1	550	J-1	OICETS	NASDA	Contracted	Japanese	Technology
2000	Govt	MEO	1	5220	Proton	Radioastron	RKA	Contracted	NPO Lavochkin	Radio astronomy
2000	Govt	LEO	1	425	Delta-7320	SAC-C	CONAE (Argentina)	Contracted	Investigationes Aplicada (Argentina)	Remote Sensing
2000	Govt	LEO	1	115	Shuttle	Sloshsat	NIVR	Contracted	NLR	Technology (fluid dynamics)
2000	Govt	LEO	1	250	Pegasus	SMEX-06 (HESSI)	NASA	Contracted		
2000	Govt	MEO	1	6000	Proton	Spektrum-X	RKA/IKI	Contracted	NPO Lavochkin	Astronomy
2000	Govt	GEO	1	2000	Ariane	Stentor	CNES/DGA/France Télécom	Contracted	Matra Marconi Space NV	Exp. Telecom.
2000	Govt	GEO	1	3000	Atlas	TDRSS 2F1 (H)	NASA	Contracted	Hughes	Data relay
2000	Govt	LEO	1	1000	Delta 2	TIMED Dynamics (TIMED-D)	NASA	Contracted		Space science
2001	Govt	GEO	1	2600	H-2 A	Artemis	European Space Agency	Contracted	Alenia Spazio SpA	Data Relay
2001	Govt	LEO	1	8000	Ariane 5	Envisat	European Space Agency	Contracted		
2001	Govt	LEO	1	449	Delta	Jason-1	CNES/NASA	Contracted	Aerospatiale	Scientific

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2001	Govt	L2	1	1000	Delta 2	MAP - Microwave Anisotropy Probe	NASA	Contracted		Scientific
2001	Govt	LEO	1	100	PSLV	PROBA	European Space Agency	Contracted	Verhaert Design & Development	Technology
2001	Govt	LEO	1	3600	H-2A	ADEOS-2 (Advanced Earth Observation Satellite)	NASDA	Contracted		
2001	Govt	LEO	1	118	Delta 2	CATSAT	Weber State/New Hampshire U.	Contracted	Weber State/New Hampshire U.	
2001	Govt	LEO	1	1460	CZ 4A	CBERS-2/ZY-2	INPE/CAST	Contracted		
2001	Govt	LEO	1	*150*	Cosmos	CHIPS	NASA/Univ. of California	Contracted	Univ. of california	ultraviolet spectrograph
2001	Govt	L1	1	300		DISCOVER-06 (Genesis)	NASA Ames Research Center	Captive		Planetary
2001	Govt		1	130		Earthquake precursor	RSA	Captive	Arsenal Design Bureau	Seismology
2001	Govt	LEO	2	381	Rockot	ESSP 2 (Gravity Recovery & Climate Exp-GRACE)	JPL/NASA/DLR	Contracted	Dornier	
2001	Govt	LEO	1	950	CZ	FY 1D	State Bureau for Meteorology	Contracted	Shangai Institute of Sat. Engineering	Remote sensing
2001	Govt	GEO	1	2500	Proton	GOMS-2/Elektro-2	Rosghydromet	Contracted		
2001	Govt	LEO	1	2500	Delta 2	Gravity Probe-B	NASA	Contracted		
2001	Govt	LEO	1	350	CZ	HY 1 (Marine 1)	CAST	Contracted	CAST	Remote sensing
2001	Govt	LEO	1	700		ICESAT	NASA	Captive	Ball Aerospace Corp.	oceanography
2001	Govt	GEO	1	2700	GSLV	Indian DBS-1	Indian Space Research Organization	Contracted	Indian Space Research Organization	Communications
2001	Govt	LEO	1	1350	PSLV	IRS-P6 (ResourceSat)	ISRO (India)	Contracted		
2001	Govt	Mars	1	*150*	Delta	Mars 2001 lander	NASA	Contracted		
2001	Govt	Mars	1	*500*	Delta	Mars 2001 orbiter	NASA	Contracted		
2001	Govt	LEO	1	450	H-2A	MDS 1	NASDA (Japan)	Contracted		
2001	Govt	LEO	1	110	PSLV	Micro-sat (Demeter)	CNES	Captive		seismology
2001	Govt	LEO	1	550	Pegasus	Minisat 1	INTA (Spain)	Contracted	CASA (Spain)	Remote Sensing
2001	Govt	LEO	1	1416	Titan	NOAA-M	NOAA	Contracted	Lockheed Martin	Meteorology
2001	Govt	LEO	1	500		SAOCOM-1	CONAE (Argentina)	Open Market Max		Remote Sensing
2001	Govt	heliocentric	1	930	Delta 2	SIRTF	NASA	Contracted	Lockheed Martin	Astronomy
2001	Govt	LEO	1	250	Pegasus	SMEX-07 (GALEX)	NASA	Contracted	OSC	Astronomy
2001	Govt	LEO	1	400	CZ 2 ?	SMMS	CNSA/KARI/Suparco…	Captive	CAST	Remote sensing
2001	Govt	GEO	1	3000	Atlas	TDRSS 2F2 (I)	NASA	Contracted	Hughes	
2002	Govt	MEO	1	3900	Proton	Integral	ESA	Contracted	Alenia Spazio SpA	Astronomy
2002	Govt	L1	1	150	Shuttle	Triana	NASA	Contracted	Scripps	Imaging, atmosphere

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
									Institution	
2002	Govt	LEO	1		PSLV	Aero/Astro	ISRO	Captive	ISRO	astronomy
2002	Govt	LEO	1	180-200		AGILE (MITA mission)	ASI	Open market	Carlo Gavazzi	Astronomy
2002	Govt	LEO	1	4000	H-2 A	ALOS-1 (Advanced Land Observation Satellite)	NASDA	Contracted		
2002	Govt	LEO	1	136	VLS	FBM	CNES/INPE	Contracted		Science/Techno.
2002	Govt	LEO	1	*500*		Cryosat	ESA	Captive		Remote sensing
2002	Govt	Cometary (0.75-1.5AU)	1	775	Delta	DISCOVER-07 (Contour)	NASA Ames Research Center	Contracted		Cometary
2002	Govt	GEO	1	2650	H-2 A	DRTS-E (Data Relay Telecommunications Satellite)	NASDA	Contracted		Data relay
2002	Govt	GEO	1	2650	H-2 A	DRTS-W (Data Relay Telecommunications Satellite)	NASDA	Contracted		Data Relay
2002	Govt	LEO	1	3000	Delta 2	EOS CHEM-1	NASA	Contracted	TRW	
2002	Govt	LEO	1	325	EELV	Geosat Follow-On (GFO-2)	U.S. Navy	Captive	Ball Aerospace	Geodesy
2002	Govt	GEO	1	2100	Delta 3	GOES-N	NOAA	Contracted		Meteorology
2002	Govt	GEO	1	2200	PSLV	Insat 3E	Insat	Contracted	Indian Space Research Organization	
2002	Govt	LEO	1	1500	PSLV	IRS-2A	Indian Space Research Organization	Contracted		
2002	Govt	LEO	1	*100*		Kitsat 4	Sat Tech. Research Center	Open market	KAIST	Communications
2002	Govt	LEO	1	750		Kompsat 2	Korea Aerospace Research Institute	Captive	Local	Sciences
2002	Govt	Lunar	1	520	M5	Lunar A	ISAS	Contracted	NEC	Study of moonquakes
2002	Govt	LEO	1	100-500	Russian?	Mesbah	Org. For Scientific & Ind. Research	Captive		educational
2002	Govt	LEO/SS	1	100	Ariane 5	Micro-sat (Picard))	CNES	Contracted		solar science
2002	Govt	GEO	1	1800	Ariane	MSG-2 Meteosat 9	Eumetsat	Contracted	Aérospatiale	Meteorology
2002	Govt	GEO	1	2900	H-2 A	MTSAT-2	Ministry of Transportation (Japan)	Contracted		Navigation/meteo
2002	Govt	LEO	1	365	M5	MUSES-C	ISAS	Contracted	NEC	Scientific
2002	Govt	LEO	1	2200	Titan	NOAA N	NASA/NOAA	Contracted	Lockheed Martin	
2002	Govt	LEO	1	300	Shavit	Ofeq-6	Israel Space Agency	Captive	IAI	Remote sensing
2002	Govt	LEO	1	400		Rocsat-2	NSPO	Open Market	MMS	Remote sensing
2002	Govt	LEO	1	*400*		Rocsat-3	NSPO	Open Market		Meteo/atmos. Research
2002	Govt	LEO	1	<500		SAC D	CONAE	Open market		Scientific

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2002	Govt	LEO	1	280	VLS	Satelite de Sensorimiento Remoto (SSR-1)	INPE (Brazil)	Contracted	INPE/Embraer (Brazil)	Remote Sensing
2002	Govt	LEO	1	140	Pegasus	SciSat-1	Canadian Space Agency	Contracted	Bristol Aerospace	Space science
2002	Govt	LEO	1	268	Pegasus	SORCE	NASA	Contracted	OSC	study of solar radiation
2002	Govt	GEO	1	3000	Atlas	TDRS 2F3 (J)	NASA	Contracted	Hughes	Data relay
2002	Govt	LEO	1	300	Pegasus XL	TOMLS (FM-5) Total Ozon	NASA	Contracted	OSC	Scientific
2002	Govt	Molniya	1	*200*	Ariane	TWINS-1	NASA/CNES	Contracted		Image of Earth's magnetosphere
2002	Govt	LEO	1	382	Shavit	Unex	CNES/Israel	Captive	Aerospatiale	Astronomy
2002	Govt	Lunar	1	350	Ariane	SMART 1	European Space Agency	Contracted	SSC	Technology (solar propulsion)
2003	Govt	GTO	1	*150*	Titan	IMEX	NASA/Univ. of Minnesota	Contracted	Univ. of Minnesota	study of the Earth's magnetosphere
2003	Govt	LEO	1	500	Vega ?	3S (Spot Follow on)	CNES/Spot Image	Captive		Earth Observation
2003	Govt	LEO	1	3500	H-2	ADEOS-3	NASDA	Contracted		
2003	Govt	LEO	1	960	M-5	Astro F (Iris)	ISAS	Contracted		Astronomy
2003	Govt	LEO	1	*1450*	CZ	CBERS 3	INPE/CAST	Captive		Earth Observation
2003	Govt	LEO	1	*500*		CESAR	CONAE/INTA	Open Market		Earth Observation
2003	Govt	GEO	1	6000	H-2 A	ETS-8 (Engineering Technology Satellite)	NASDA	Contracted	Melco	Technology
2003	Govt	Europa	1	950	Shuttle	Europa Orbiter	NASA	Captive		Jupiter's Satellite exploration
2003	Govt	GEO	1			Gigabit satellite	MPT	Captive		Technology
2003	Govt	LEO	1	*1000*	EuRockot?	GOCE	ESA	Captive		Earth Observation
2003	Govt	GEO	1	2200	PSLV	Insat 3C	Indian Space Research Organization	Contracted	Indian Space Research Organization	Communications
2003	Govt	LEO	1	1500	PSLV	IRS-2B (Cartosat-2)	Indian Space Research Organization	Contracted		
2003	Govt	Deep Space	1	1100	Soyuz-Fregat	Mars Express (Flexi-1)	ESA	Contracted		Mars Orbiter
2003	Govt	Deep Space	1	2200	Delta 3	Mars Surveyor 03	NASA	Contracted		Space science
2003	Govt	LEO	1	650	J1U ?	MDS 2	NASDA (Japan)	Captive	NEC	Technology
2003	Govt	LEO	1	4500	Ariane 5	Metop-1	European Space Agency	Contracted		
2003	Govt	LEO	1	100		Micro-sat	CNES	Open market		Scientific/Technology
2003	Govt	LEO	1	100		Micro-sat	CNES	Open market		Scientific/Technology
2003	Govt	LEO	1	2200	Titan	NOAA N'	NASA/NOAA	Contracted	Lockheed Martin	
2003	Govt	LEO	1	476	Taurus	Picasso Cena (ESSP-3)	NASA/Cnes	Contracted	Ball/Aerospatiale	Earth Observation

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2003	Govt	Cometary	1	2300	Ariane 5	Rosetta	European Space Agency	Contracted		
2003	Govt	LEO	1	350		Sabia 3	INPE/SAC	Open Market	INVAP S.E.	Earth Observation
2003	Govt	LEO	1	285	VLS	Satelite de Coleta de Dados (SCD-3)	INPE (Brazil)	Contracted	INPE/Embraer (Brazil)	Data collection
2003	Govt	LEO	1	1000		SERVIS-1	MITI	Captive		Technology
2003	Govt	LEO	3	600		SkyMed/COSMO	ASI	Captive	Alenia	Earth Observation
2003	Govt	LEO	3	350	CZ	Small Multi-Mission Sat. (optical)	CASC	Captive	CAST	Earth Observation
2003	Govt	LEO	2	500	CZ	Small Multi-Mission Sat. (radar)	CASC	Captive	CAST	Earth Observation
2003	Govt		1	2500	CZ	Solar Space Telescope	CAS/DLR	Captive		solar physics
2003	Govt	MEO	1	*>5000*	Proton	Spektr-UFT	RSA	Contracted	NPO Lavochkin	Space science
2003	Govt	LEO	1	800	Medlite	SWIFT (MIDEX 3)	NASA	Contracted		Space science
2003	Govt	LEO	1			TRMM-2	NASA/autre ?	Captive		
2003	Govt	Deep space	1	220	Ariane	Twin (Mars micromission)	NASA	Contracted	Ball	data relay
2004	Govt	LEO	1	*3500*		China radar	CAST	Captive		Remote Sensing
2004	Govt	LEO?	1	280-300		DAVID (Prima 1)	ASI	Open market		Technology
2004	Govt	Deep space	1	500	Delta 2	Deep Impact (Discovery 8)	NASA	Captive	Ball	Scientific
2004	Govt	LEO	1			Earth Probe-1		Captive		
2004	Govt	LEO	1	*2000*	Ariane 5 ?	Earth Watch-1	ESA/partners	Captive		Remote sensing
2004	Govt	GEO	1	*1000*	Delta-2 class	FAME	NASA	Captive		Astronomy
2004	Govt	GEO	1	2500	Proton	GOMS-3/Elektro-3	Rosghydromet	Contracted		
2004	Govt	GEO	1	2200	GSLV	Insat 3D	Indian Space Research Organization	Contracted	Indian Space Research Organization	Communications
2004	Govt	LEO	1	1500	PSLV	IRS-2C (Resourcesat-2)	ISRO	Contracted		Earth Observation
2004	Govt	LEO	1	500	Medlite	Jason 2	NASA/CNES	Contracted		Atmospheric
2004	Govt	LEO	1	*100*		Kitsat 5	Sat Tech. Research Center	Open market		TBD
2004	Govt	magnetospheric	5	213	Delta 2	Magnetospheric Multiscale	NASA	Contracted		Study of the magnetosphere
2004	Govt	LEO	1	500-800	J1U ?	MDS 3	NASDA (Japan)	Captive		Technology
2004	Govt	Mercury	1	1066	Delta 2	Messenger	NASA	Captive	APL	Scientific
2004	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientific/Technology
2004	Govt	LEO	2	100		Micro-sat	CNES	Captive		Scientific/Technology
2004	Govt	LEO	1	500		Minisat 2	INTA (Spain)	Captive	CASA (Spain)	Communications

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2004	Govt	Deep space	1	100	Delta 2 or Molnya	Pluto/Kuiper Express		Captive		Pluto flyby
2004	Govt	LEO	1	<500		SAC E	CONAE	Open market		Remote sensing
2004	Govt	LEO	1	500		SAOCOM-2	CONAE (Argentina)	Open Market Max		Communications
2004	Govt	LEO	1	280	VLS	Satelite de Sensorimiento Remoto (SSR-2)	INPE (Brazil)	Contracted	INPE (Brazil)	Remote Sensing
2004	Govt	LEO	1	*200*	SLV	SciSat-2	Canadian Space Agency	Captive	Bristol Aerospace	Space science
2004	Govt	Moon	1	2100	H2A	Selene 1	NASDA/ISAS	Contracted	NEC	Lunar mapping
2004	Govt	LEO	1	600	Vega ?	SkyMed/COSMO	ASI	Captive	Alenia	Earth Observation
2004	Govt	LEO	1	600	Vega ?	SkyMed/COSMO	ASI	Captive	Alenia	Earth Observation
2004	Govt	LEO	1	600	Vega ?	SkyMed/COSMO	ASI	Captive	Alenia	Earth Observation
2004	Govt	LEO	1	600	Vega ?	SkyMed/COSMO	ASI	Captive	Alenia	Earth Observation
2004	Govt	LEO	1	*250*		SMEX mission	NASA	Captive		Scientific
2004	Govt	LEO	1	475		SMOS	ESA	Captive		Earth Observation
2004	Govt	Molniya			Soyuz-Fregat shared with molniya sat	Roemer	Danish Space research institute			Astrophysics
2004	Govt	LEO	2	300		Telecom Latin America	Telecom Brazil - INPE	Captive		Telecommunications
2004	Govt	Moniya	1	*200*	Ariane	TWINS-2	NASA/CNES	Contracted		Image of Earth's magnetosphere
2005	Govt	LEO	1	900	M-5	Solar B	ISAS	Contracted	Japan	Astrophysics
2005	Govt	LEO	1	500		3S (Spot Follow-on)	SPOT Image	Captive		Remote sensing
2005	Govt	LEO	1	*1000*	EuRokot ?	ADM	ESA	Captive		Atmospheric Dynamics Mission
2005	Govt				EELV	C1	US DoD	Contracted		Classified
2005	Govt	LEO	1	*1450*	CZ	CBERS 4	INPE/CAST	Captive		Earth Observation
2005	Govt	LEO	1			Earth Probe-2		Captive		
2005	Govt	LEO	1			EOS FO-1	NASA	Captive		Land cover/use Inventory Program
2005	Govt	LEO	1			EOS FO-2	NASA	Captive		Global Terrestrial and Oceanic Productivity Mission
2005	Govt	LEO	6			GalileoSat (1-6)	ESA	Captive		Navigation
2005	Govt	LEO	1			GCOM-A1	NASDA	Captive		atmospheric monitoring
2005	Govt	LEO	1			GCOM-B1	NASDA	Captive		Remote sensing
2005	Govt		1			GLAST	NASA	Captive		Astronomy
2005	Govt	GEO	1	2000	Delta	GOES-O	NOAA	Contracted	Hughes	Remote sensing
2005	Govt	LEO	1			IRS-3A	Indian Space Research Organization	Captive		Remote sensing
2005	Govt	LEO	1			Kompsat-3	KARI	Open		Stereoscopic optical

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
								market		R.S.
2005	Govt	Mars	1		Ariane 5	Mars micromission	NASA	Contracted		Scientific
2005	Govt	Mars	1			Mars probe	RSA	Captive		Scientific
2005	Govt	Mars	2		Ariane 5	Mars Surveyor 05	NASA/CNES	Contracted		Mars Lander and Orbiter
2005	Govt	LEO	1	500	PSLV	Megha-Tropiques	CNES/ISRO	Captive		Atmosphere
2005	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientific/Technology
2005	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientific/Technology
2005	Govt	LEO	1	*1000*		MIDEX-Mission	NASA	Captive		
2005	Govt	Deep space	1	370		Muses-D	ISAS	Captive		Mercury probe
2005	Govt	LEO	2	332		proteus mission (COROT-Convection et Rotation)	CNES	Open Market	Aerospatiale	Remote sensing
2005	Govt	LEO	1	*300*	VLS	Satelite de Coleta de Dados (SCD-4)	INPE (Brazil)	Captive	INPE/Embraer (Brazil)	Data collection
2005	Govt	LEO	1	1000		SERVIS-2	MITI	Captive		Technology
2005	Govt	LEO	1			SIM	NASA	Captive	TRW	Interferometry
2005	Govt	LEO	1	*250*		SMEX-Mission	NASA	Captive		Scientific
2005	Govt	1 AU heliocentric (17Mkm trailing)	2		Delta 2	Space Technology-3/ STARLIGHT	NASA	Contracted	Ball Aerospace Corp.	Interferometry
2005	Govt	heliocentric	2			Stereo	NASA	Captive		Images of solar coronal mass ejections
2006	Govt	L1 or L2	1	*300*	Ariane 5	SMART 2 /Ministep	European Space Agency	Contracted		Optical Interferometry
2006	Govt	LEO	1		H2	Alos 2	NASDA	Captive		Remote sensing
2006	Govt				EELV	C2 ?	US DoD	Contracted		Classified
2006	Govt	Deep space	1			Discovery mission	NASA	Captive		Scientific
2006	Govt	LEO	1	*500*	Ariane 5	Earth Explorer (opportunity)	European Space Agency	Captive		Remote sensing
2006	Govt	LEO	1			Earth Probe-3		Captive		
2006	Govt	LEO	1			EOS FO-3		Captive		Climate Variabillity and Trend Mission
2006	Govt	LEO	6			GalileoSat (7-12)	ESA	Captive		Navigation
2006	Govt	GEO	1			GalileoSat GEO-1	ESA			
2006	Govt	LEO	1			IRS-3B	Indian Space Research Organization	Captive		Remote sensing
2006	Govt	LEO	1	*100*		Kitsat 6	Sat Tech. Research Center	Open market		TBD
2006	Govt	Lunar	1	520	M5	Lunar E	ISAS	Contracted	NEC	Study of moonquakes
2006	Govt	LEO	1	500-800	J1U ?	MDS 4	NASDA (Japan)	Captive		Technology

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2006	Govt	LEO	1	100		Micro-sat	CNES	Open Market Max		Scientific/Technology
2006	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientific/Technology
2006	Govt	LEO	1	*1000*		MIDEX mission	NASA	Captive		Space Science
2006	Govt	LEO	1			Mita mission	ASI	Open Market Max	Carlo Gavazzi Space spa	Scientific
2006	Govt	LEO	1			NPP	NASA/NPOESS IPO	Captive		
2006	Govt	LEO	1	*300*	VLS	Satelite de Sensorimiento Remoto (SSR-3)	INPE (Brazil)	Captive	INPE (Brazil)	Remote Sensing
2006	Govt	Moon	1	2100	H2A	Selene 2	NASDA/ISAS	Captive	NEC	landing lunar rover
2006	Govt	LEO	1	*300*	Ariane 5	SMART 3	ESA	Captive		IR Interferometry
2006	Govt	LEO	1	*250*		SMEX-Mission	NASA	Captive		Space Science
2007	Govt	LEO	1	500		3S (Spot Follow-on)	SPOT Image	Captive		Remote sensing
2007	Govt				EELV	D2 ?	US DoD	Contracted		Classified
2007	Govt	LEO	1	*1000*		Earth Explorer (core)	ESA	Captive		Earth Observation
2007	Govt	LEO	1			Earth Probe-4		Captive		
2007	Govt		1			Eavesdropping satellite	DGA	Captive		
2007	Govt	LEO	1			EOS FO-4		Captive		Global Precipitation Mission
2007	Govt	LEO	1	*3000*	Medlite ?	EOS-ALT 2 Radar	NASA	Open Market		Observation
2007	Govt	L2	1	2500	Ariane	Far Infrared Space Telescope (FIRST/Cornerstone-4)	European Space Agency	Captive		
2007	Govt	L2	2		Ariane 5	First/Planck Surveyor	ESA	captive		Astronomy
2007	Govt	LEO	6			GalileoSat (13-18)	ESA	Captive		Navigation
2007	Govt	GEO	1			GalileoSat GEO-2	ESA			
2007	Govt	GEO	1	2000		GOES-P	NOAA	Captive	Hughes	Meteorology
2007	Govt	GEO	1	2500	Proton	GOMS-4/Elektro-4	Rosghydromet	Contracted		
2007	Govt		1		Delta-class	HTSX-1	NASA	Captive		X-ray interferometry
2007	Govt		1		Delta-class	HTSX-2	NASA	Captive		X-ray interferometry
2007	Govt		1		Delta-class	HTSX-3	NASA	Captive		X-ray interferometry
2007	Govt	LEO	1			IRS-3C	Indian Space Research Organization	Captive		Remote sensing
2007	Govt	LEO	1			Kompsat-4	KARI	Open market		High resolution EO
2007	Govt	Deep space	1		Ariane 5	Mars micromission	NASA	Contracted		Scientific
2007	Govt	Deep Space	1	*2000*	Delta 3	Mars Surveyor 07	NASA	Captive		Mars Lander
2007	Govt	LEO	1	100		Micro-sat	CNES	Open Market Max		Scientic/Technology
2007	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientic/Technology
2007	Govt	LEO	1	*1000*		MIDEX-Mission	NASA	Captive		Space Science
2007	Govt	LEO	1	*500*		Proteus mission	CNES and others	Captive	Europe	Remote sensing

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2007	Govt	LEO	1	*200*	SLV	SciSat-3	Canadian Space Agency	captive	Bristol Aerospace	Space science
2007	Govt	LEO	1	*250*		SMEX-Mission	NASA	Captive		Scientific
2007	Govt	heliocentric	1		EELV	Solar Probe	NASA	Captive		Space science
2008	Govt	LEO	4	*700*		Discoverer 1 to 4	USAF/NRO/DARPA	Captive		Earth Observation
2008	Govt	Deep space	1			DISCOVERY-Mission	NASA	Captive		Planetary
2008	Govt	LEO/ GEO?	1	*500*	Ariane 5	Earth Explorer (opportunity)	European Space Agency	Captive		Remote sensing
2008	Govt	LEO	1			Earth Probe-5		Captive		
2008	Govt	LEO	1	3000		EOS CHEM-2	NASA	Open market	TRW	Earth Observation
2008	Govt	LEO	1	2500		EOS CHEM-2B	NASA	Open market	TRW	Earth Observation
2008	Govt	Deep Space	1			F2 (Flexi-mission)	ESA	Open Market		
2008	Govt		1			F3 (3rd Flexible mission)	ESA	Captive		Scientific
2008	Govt	LEO	6			GalileoSat (19-24)	ESA	Captive		Navigation
2008	Govt	GEO	1			GalileoSat GEO-3	ESA			
2008	Govt	200 by 2000km, high inc orbits	5			Global Electrodynamics (GEC)	NASA	Captive		coupling solar wind/upper atmosphere
2008	Govt	GEO	1	2000		GOES-R	NOAA	Captive	Hughes	Meteorology
2008	Govt		1		Delta-class	HTSX-4	NASA	Captive		X-ray interferometry
2008	Govt	LEO	1	*100*		Kitsat 7	Sat Tech. Research Center	Open market		TBD
2008	Govt	Lunar	1		PSLV	Lunar mission	ISRO	Captive		Scientific
2008	Govt	LEO	1	5000	Ariane 5	Metop-2	European Space Agency	Contracted		Meteorology
2008	Govt	LEO	1	100		Micro-sat	CNES	Open Market Max		Scientic/Technology
2008	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientic/Technology
2008	Govt	LEO	1	*1000*		MIDEX-Mission	NASA	Captive		Space Science
2008	Govt	GEO	1	1700	Ariane	MSG-3 (Météosat)	Eumetsat	Contracted		Meteorology
2008	Govt	Deep Space	1	2700	Delta 4 or Atlas 5	NGST	NASA	Captive		Telescope
2008	Govt	LEO	1	3000		NPOESS 1	NASA/DoD	Captive		Meteorology
2008	Govt	LEO	1	*1500*	Medlite	NPOESS-1	NOAA/DOD	Contracted		Meteorology
2008	Govt		1	*300*		Prima 2	ASI	Open market		Technology
2008	Govt	LEO	3	600		SkyMed/COSMO replenishment	ASI	Captive	Alenia	Earth Observation
2008	Govt	LEO	1	*250*		SMEX-Mission	NASA	Captive		Scientific
2008	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2008	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications
2008	Govt	LEO	1	*130*	Pegasus	UNEX-Mission	NASA/Universities	Contracted		Scientific
2009	Govt	Mercury	1		Ariane 5	BepiColombo	ESA	Contracted		Mercury probe
2009	Govt	LEO	4	*700*		Discoverer 5 to 8	USAF/NRO/DARPA	Captive		Earth Observation
2009	Govt	LEO?	1	*1000*		Earth Explorer (core)	ESA	Captive		Earth Observation
2009	Govt	LEO	1			Earth Probe-6		Captive		
2009	Govt	LEO	1	*2000*	Ariane 5 ?	Earth Watch-2	ESA/partners	Captive		Remote sensing
2009	Govt	LEO	1			EO India	ISRO	Captive		Remote sensing
2009	Govt	Deep Space	1			F3 (Flexi-mission)	ESA	Open Market		
2009	Govt	Deep space	1		Ariane 5	Mars micromission		Contracted		Scientific
2009	Govt	Deep Space	1		Delta 3	Mars Surveyor 09 (Lander))	NASA	Contracted		Mars Lander
2009	Govt	Deep Space	1		Delta 3	Mars Surveyor 09 (Orbiter)	NASA	Contracted		Mars orbiter
2009	Govt	Deep Space	1	1617	Ariane	Mercury Orbiter	ESA	Captive		Communications
2009	Govt	LEO	1	4500	Ariane 5	Metop-3	European Space Agency	Contracted		Meteorology
2009	Govt	LEO	1	100		Micro-sat	CNES	Open Market Max		Scientic/Technology
2009	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientic/Technology
2009	Govt	LEO	1	*1000*		MIDEX-Mission	NASA	Captive		Space Science
2009	Govt	GEO	1	2900	H2	MTSAT-3	Ministry of Transportation (Japan)	Captive		Navigation/Meteo
2009	Govt	L2?	1	*3000*	EELV ?	Next Generation Space Telescope (NGST)	NASA	Captive		Astronomy
2009	Govt	LEO	1	2200	Medlite ?	NOAA O	NASA/NOAA	Open Market	Lockheed Martin	
2009	Govt	LEO	1	2200	Medlite ?	NOAA P/NPOESS-2	NASA/NOAA	Open Market	Lockheed Martin	
2009	Govt	LEO	1	*500*		Proteus mission	CNES and others	Captive	Europe	Remote sensing
2009	Govt	LEO	3	600		SkyMed/COSMO replenishment	ASI	Captive	Alenia	Earth Observation
2009	Govt	LEO?	1	*300*	Ariane 5	SMART 4	ESA	Captive		TBD
2009	Govt	LEO	1	*250*		SMEX-Mission	NASA	Captive		Scientific
2009	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications
2009	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications
2010	Govt	LEO	4	*700*		Discoverer 9 to 12	USAF/NRO/DARPA	Captive		Earth Observation
2010	Govt	Deep space	1			Discovery mission	NASA	Captive		Scientific
2010	Govt	LEO?	1	*500*	Ariane 5	Earth Explorer (opportunity)	European Space Agency	Captive		Remote sensing
2010	Govt	LEO	1			Earth Probe-7		Captive		
2010	Govt	LEO	1			EO France	CNES	Captive		Earth Observation

Year	Client	Orbit	No.	kg	Launcher	Payload	Operator	Contracted/ Open Launch market	Prime contractor	Application
2010	Govt	LEO	1			EO India	ISRO	Captive		Remote sensing
2010	Govt	LEO	1			EOS FO-5	NASA	Captive		Polar Altimetry mission
2010	Govt	LEO	1	3000		EOS-ALT 3 Radar	NASA	Open Market		Observation
2010	Govt	LEO	1	5186	Taurus ?	EOS-AM-3	NASA	Open Market		
2010	Govt		1			F4 (4th Flexible mission)	ESA	Captive		Scientific
2010	Govt	LEO	1		H-2?	GCOM-A2	NASDA	Captive		atmospheric monitoring
2010	Govt	LEO	1		H-2?	GCOM-B2	NASDA	Captive		Remote sensing
2010	Govt	GEO	1	2000		GOES-Q	NOAA	Captive	Hughes	Meteorology
2010	Govt	LEO	1	100		Kitsat 8	Sat Tech. Research Center	Open market		TBD
2010	Govt	LEO	1			Kompsat-5	KARI	Open market		Meteorology
2010	Govt	LEO	1	100		Micro-sat	CNES	Open Market Max		Scientic/Technology
2010	Govt	LEO	1	100		Micro-sat	CNES	Captive		Scientic/Technology
2010	Govt	LEO	1	1000		MIDEX-Mission	NASA	Captive		Space Science
2010	Govt	LEO	1	150		Mita mission	ASI/INIFN	Captive	Carlo Gavazzi Space Spa.	Scientific
2010	Govt	LEO	1	200	SLV	SciSat-4	Canadian Space Agency	Captive	Bristol Aerospace	Space science
2010	Govt	Moon	1	2000	H2A	Selene 3	NASDA/ISAS	Captive	NEC	lunar-surface telescope
2010	Govt	LEO	1	250		SMEX-Mission	NASA	Captive		Scientific
2010	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications
2010	Govt	GEO	1		EELV	UFO Follow on	US Navy	EELV		Communications
2011	Govt	LEO	1	3000	Medlite ?	EOS-ALT 3 Laser	NASA	Open Market		Observation
2011	Govt	LEO	1	2200	Medlite ?	NOAA Q	NASA/NOAA	Open Market	Lockheed Martin	
2012	Govt	LEO	1	3000		EOS-PM-3	NASA	Open Market	TRW	Observation
2012	Govt	LEO	1	100		Kitsat 9	Sat Tech. Research Center	Open market		TBD
2012	Govt	LEO	1			Kompsat-6	KARI	Open market		Meteorology
2012	Govt	LEO	1			Kompsat-7	KARI	Open market		Meteorology
2014	Govt	LEO	1	2500		EOS CHEM-3	NASA	Open market	TRW	Earth Observation

Table 14 Future Mission Review

7.2.3.2 Review of launch frequency to various orbits

The attached figures are the historical record of launches with different lower mass cut-offs. Further divisions such as node time (SS) or longitude (GTO/GEO) are not included. LEO is everything else so various inclined orbits are included. Manned missions and ISS are not included.

These graphs give an indication to the prospect of finding a host satellite based purely on the frequency of launch to various orbits.

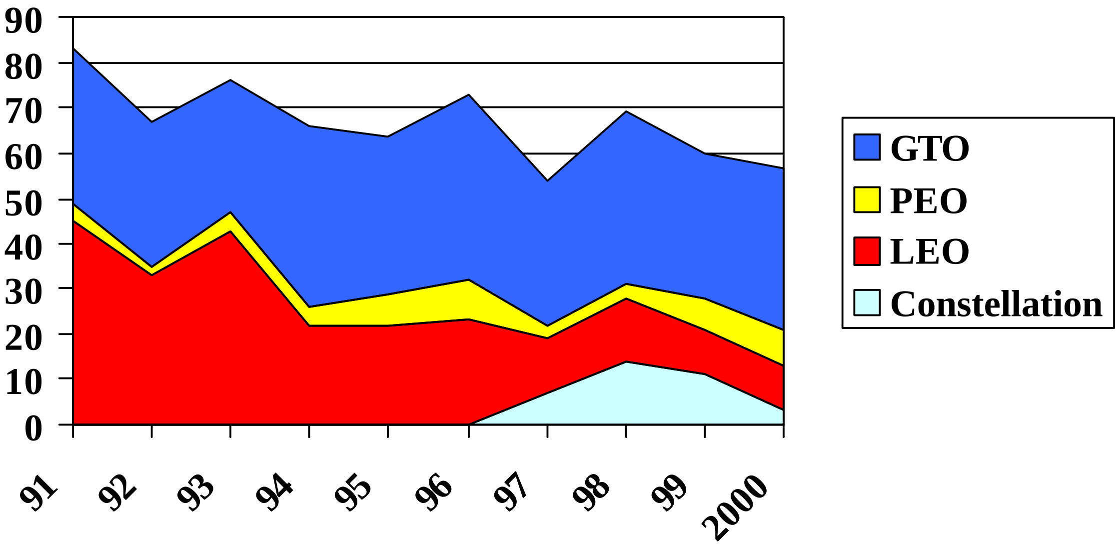


Figure 11 Values for Payloads > 700kg

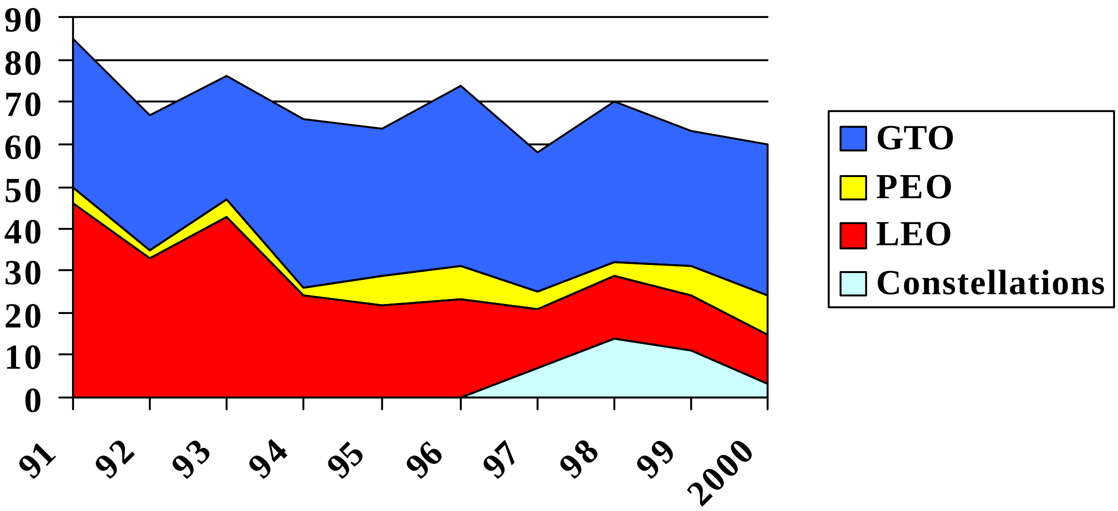


Figure 12 Values for Payloads > 500kg

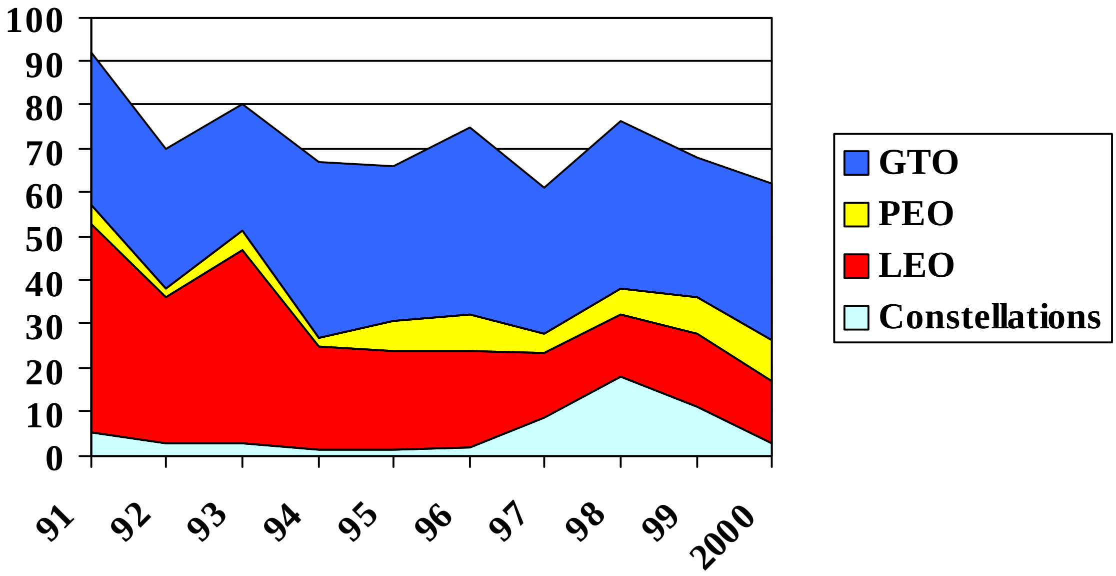


Figure 13 Values for Payloads > 30kg

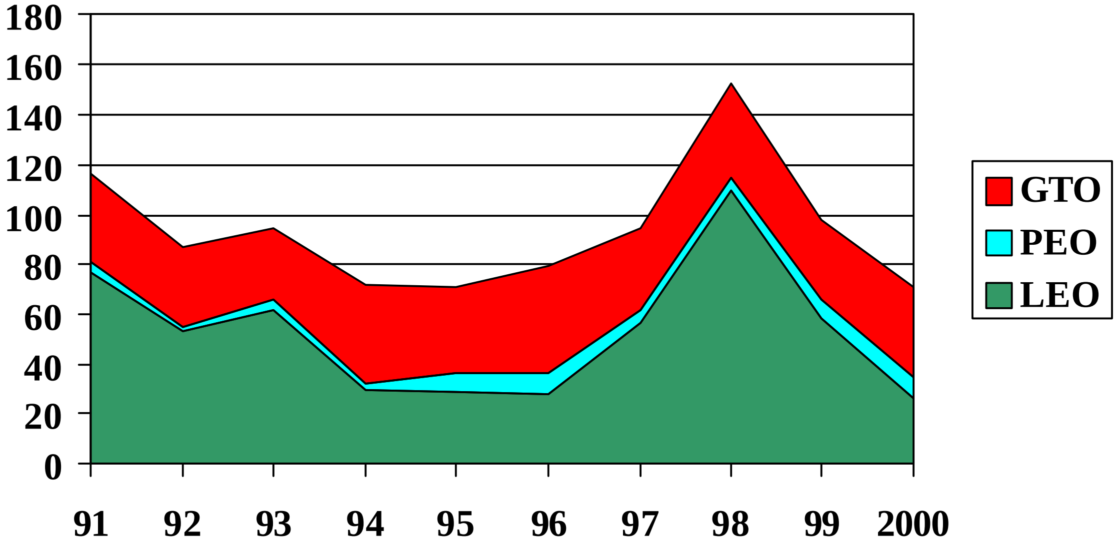


Figure 14 Values for Payloads > 300kg with Constellation Payloads included Individually

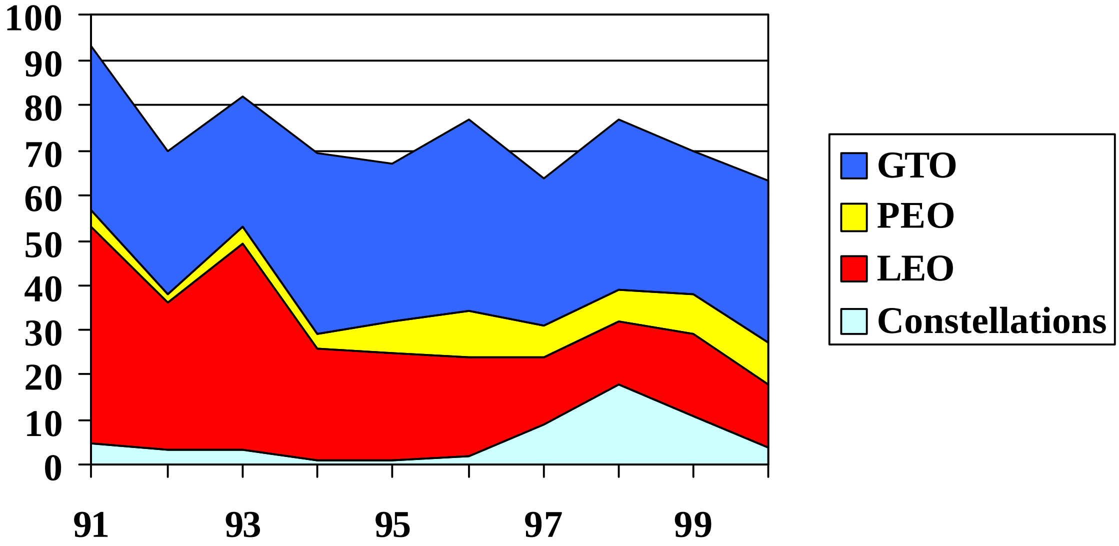


Figure 15 Values for Payloads > 200kg

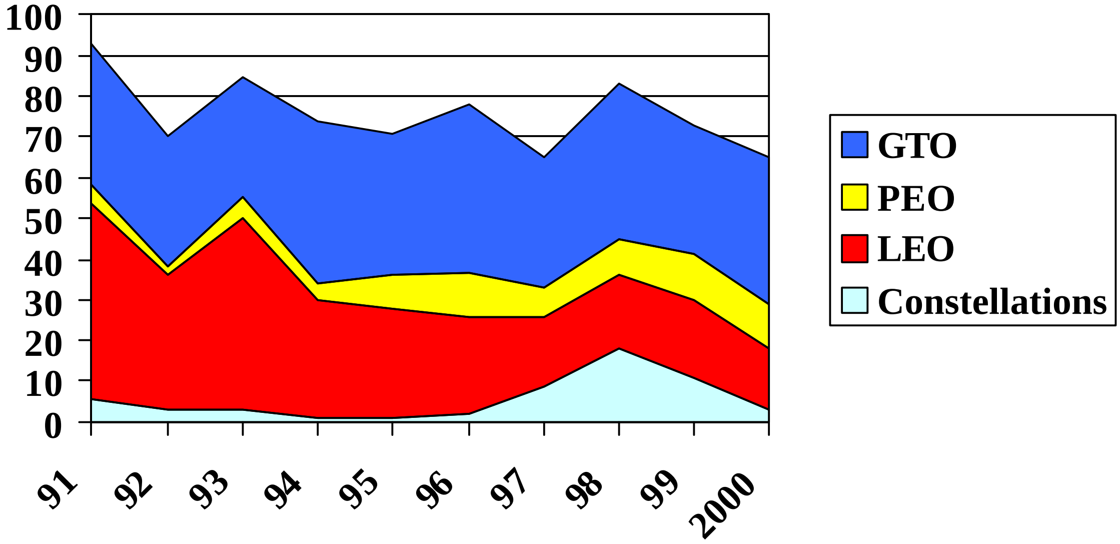


Figure 16 Values for Payloads > 100kg

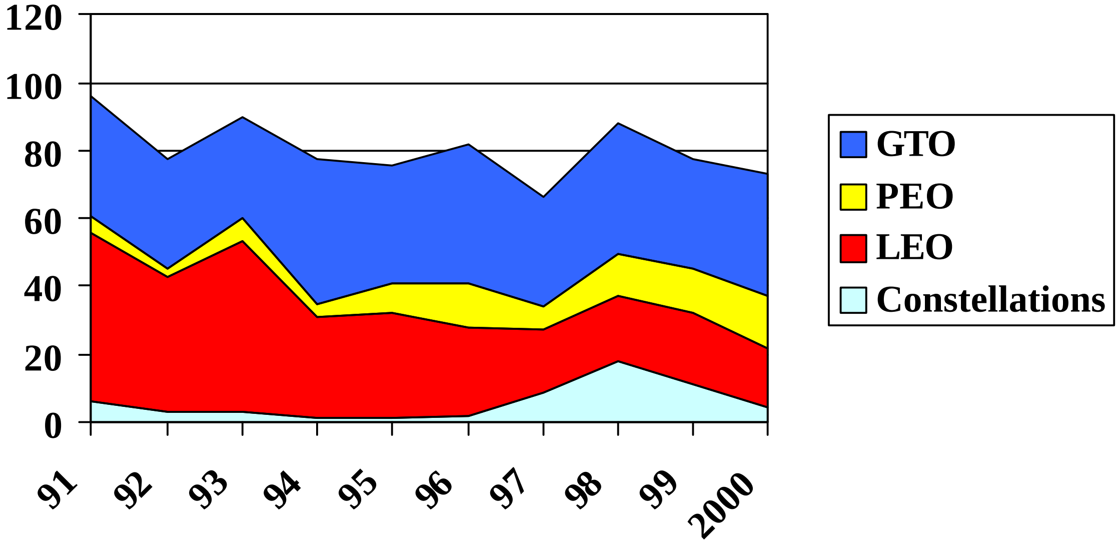


Figure 17 Values for Payloads > 50kg

7.2.3.3 Review of L4/5 or separated 1AU orbits and the existing and planned non-space weather missions scheduled to go there

Heliocentric orbits at 1AU orbit the sun in the same period as the Earth, i.e. 1 year. They are ultimately unstable if left uncontrolled, unless they occupy special orbits at the L4 or L5 Lagrange points. A heliocentric orbit can either be at a fixed angle from the Earth with respect to the sun, or can be left to slowly drift away from the Earth (c.f. STEREO). A hyperbolic escape velocity of 1km/s is required to reach adrift orbit, whereas an extra 1km/s is required to fix the angle with respect to the sun. A moderate Delta V of roughly 700m/s is enough to place a satellite into a heliocentric drift orbit from GTO. Therefore a drift orbit is preferred if the science allows it. As STEREO utilises a drift orbit we assume that a drift orbit is okay for space weather monitoring purposes.

A major drawback with heliocentric orbits is the very large communications link distance to Earth. This results in a need for large transmit antennas and/or powers, even at moderate data rates.

In terms of missions planned, there are only a few, including SIRTF, STEREO, LISA and ST3/STARLIGHT and opportunities for hitch-hiking will be very scarce if any.

7.2.3.4 Review of L1 orbit and the existing and planned non-space weather missions scheduled to go there

The L1 orbit is a ‘halo’ orbit around the L1 Lagrange point between the Earth and the Sun of radius depending on the mission application. The reason for not going directly to the L1 point are that communications with spacecraft located at L1 are nearly impossible due to the interference from the Sun. The Sun also emits radio waves, and against its blaring output, the tiny signal from a spacecraft would be almost indistinguishable. Therefore, the most efficient way to take advantage of the L1 point's location and relative stability is to move the spacecraft into an ‘halo’ orbit about the L1 point. This though, places increased complexity on the communications system as a steerable antenna may required to point exactly Earthward if the data rate is too high. The radius of the Halo orbit is also important as increasing the halo orbit radius requires a larger the antenna beamwidth, which in turn results in a lower transmittable data rate.

L1 is located at a distance of roughly 0.99AU from the Sun (1.49 x 10^6km) or 0.01AU from the Earth (233.6R_E). The plasma environment at L1 is the same as the interplanetary environment at 0.99AU as it is upstream of the Earths magnetosphere. This is advantageous in that it is relatively stable.

A drawback with L1 orbits is the fairy large communications link distance to Earth. This results in a need for reasonably large transmit antennas and/or powers, if the data rates are very high. This is made slightly worse by the halo orbit requirement as described above, as the link distance further increases.

Compared to Highly Elliptical Orbits (HEO's), the L1/L2 orbits have the advantage of a more stable plasma environment. However an orbit about L1 is more desirable than L2 as are no solar eclipses that would make additional manoeuvring necessary, and the magnetic environment is more stable than it is at L2, as a halo orbit about L2 would periodically drift in and out of the Earth's Magnetotail.

L1/L2 orbits are optimal in the sense that they provide a maximal distance from Earth with a total delta v requirement of about 1km/s from a geosynchronous transfer orbit (GTO). In comparison, the delta v required to get from GTO into a geosynchronous orbit (GEO) is about 1.6 km/s.

In terms of missions planned to go to L1, there are few. In fact there are no missions planned to go to L1 that have not already been reviewed for the existing and planned space weather option. This means that a continuous hitch-hiker programme using L1 as a chosen orbit location would be unlikely due to the lack of regular missions.

7.2.3.5 Review of L2 orbit and the existing and planned non-space weather missions scheduled to go to there

The L2 orbit is an orbit about a virtual point in space known as the 2nd Lagrange point. Like the L1 point, the L2 point is located about 1.5 million km from the Earth in the anti-Sun direction. It is soon set to become quite a popular destination for astronomical missions. One of the many advantages of this orbit is that it offers the possibility of long uninterrupted observations, since the Earth, Moon and Sun remain behind the spacecraft viewing direction. The entire celestial sphere can be observed in the course of a year, avoiding "observation holes". The L2 orbit is also a very stable thermal and radiation environment. These advantages have led to this orbit becoming the "orbit of choice" for many ESA astronomy missions. Eddington, Herschel-Planck, NGST and GAIA will all make their way to this observation point in the coming years.

However, apart from the occasional astronomy mission there are no missions planned to go to L2, meaning that a continuous hitch-hiker programme using L2 as a chosen orbit location would be unlikely due to the lack of missions to L2.

7.2.3.6 Review of Magnetospheric orbits and the existing and planned non-space weather missions scheduled to go to there

Magnetospheric orbits are orbits whose paths cross the Earth's magnetosphere. An example mission with spacecraft in magnetospheric orbits would be CLUSTER. These orbits are seldom used for missions other than solar-terrestrial missions, in fact no missions planned to have magnetospheric orbits that have not already been reviewed for the existing and planned space weather option. These orbit locations are therefore unsuitable for a continuous hitch-hiker programme.

7.2.3.7 Review of Geostationary orbits (GEO) and the existing and planned non-space weather missions scheduled to go to there

The definition of a Geostationary orbit is a circular orbit in the equatorial plane, any point on which revolves about the Earth in the same direction and with the same period as the Earth's rotation. An object in a geostationary orbit will remain directly above a fixed point on the equator at a distance of approximately 42,164 km from the centre of the Earth, i.e., approximately 35,786 km above mean sea level. This makes the GEO orbit popular for communication satellites in particular, where continuous coverage of the Earth can be carried out up for latitudes up to approximately 60°.

One problem for satellites in geostationary orbit with solar observation instruments onboard is eclipses. Satellites in geostationary orbit will experience eclipses twice a year at the equinoxes. The equinox seasons contain eclipse periods, where the spacecraft will move into the Earth's shadow for a period. Thus we have two eclipse seasons per year, of 46 days duration each. The maximum eclipse duration is 72 minutes at the two equinoxes – see Figure 18. This means an outage of certain science data, such as solar imaging in these periods of 72 minutes. This would mean that two spacecraft, with sufficient longitude spacing would be needed to guarantee continuous observation. Occasional eclipses of the Sun by the Moon can also occur, and will be predicted well in advance.

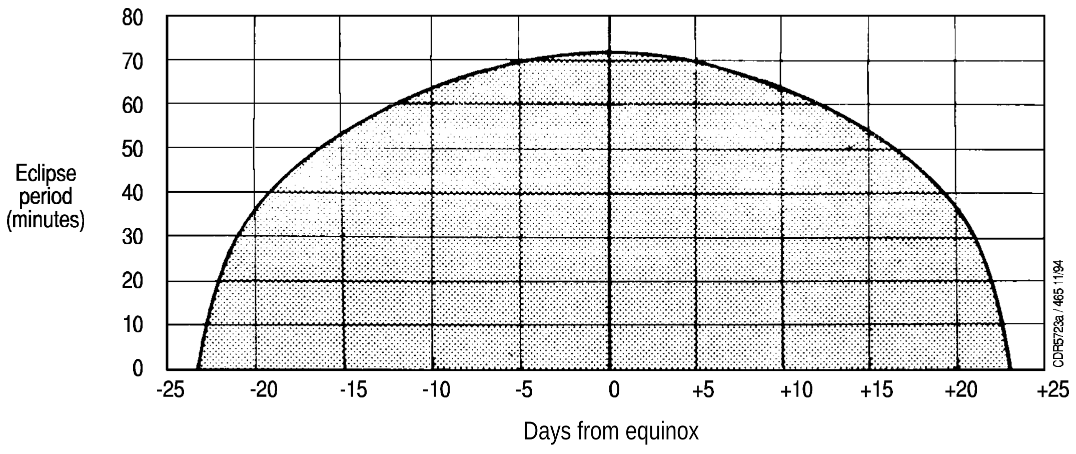


Figure 18 Duration of eclipse periods before and after Equinox

GTO is the standard intermediate orbit for satellites whose final destination is GEO. It is the most popular destination for launchers and numbers about 40 per year, of which almost all are above 700kg payloads. This would suggest that there are potentially many opportunities for instruments to fly as hitch-hiker payloads. Most existing and planned GEO satellites fall into the following categories of mission application:

Civil Comsats: This is the biggest single user of the GEO orbit, and also the fastest growing. Thus the number of potential hosts is greatest. This application has grown out of international institutions such as Intelsat and Eutelsat to become truly commercially driven, with commercial profit being the motivating factor for almost all operators. The possibility for altruistic motives is thus reduced. INTELSAT will be privatised into a commercial corporation New Intelsat by March 2001. By July 2001 Eutelsat SA will be a limited company, supervised by a small inter-governmental organisation with very limited tasks. Thus Eutelsat, in common with almost all operators, would approach a ‘guest’ payload on commercial terms.

The history of civil telecommunications missions is one of rapid growth of technical requirements, resulting in larger and larger missions carrying bigger and more powerful (and more complex) payloads. A good rule-of-thumb of the worth to commercial operators of a single transponder is US $1.5 Million per year. Therefore should a ‘guest’ payload displace even one transponder over the course of a typical lifetime of up to 15 years, the cost to the operator could exceed US $20 Million.

The capacity of commercial buses has been led by the market demand and it is has been relatively rare, though not unknown, for there to be spare capacity for extra payload in particular satellites. However a number of high power satellite classes have entered the market recently, including HS702 and Eurostar 3000. These are available in modular sizings, and it is possible that a small number of missions at the lower end of the range may have some significant room for manoeuvre to accommodate a guest payload.

Typical schedules have reduced over the past years to 24-months and below. Due to the nature of the business, late start-up can cost an operator severely. Thus confidence in the schedule of the science payload and in interface control must be high in order not to lose the host due to science payload delays. Identification of a back up could be difficult, and choosing to work with a series of near-identical Comsats from the same organisation could be attractive in this respect.

The vast majority of new civil Comsats will be three-axis stabilised commercial platforms.

Military Comsats: The UK and USA have dedicated military Comsats in GEO orbit, with other European nations flying combined civil and military payloads. Although the operators of such spacecraft are motivated by security, the paymasters (i.e. governments) are open to political and financial considerations. Flying a European science mission on a non-European military satellite does not appear viable for security reasons, but utilisation of a European mission may be possible. Military missions traditionally have longer schedules and have been more ready to accept bespoke tailoring to match unique military requirements. As ultimately the same organisations (governments) pay for both military and science missions, it is conceivable that a combination of effort could prove financially attractive. One counter against this is the trend, especially in the UK, towards procurement of secure service rather than procurement of secure systems. The next UK system is likely to be privately owned, providing secure communications to military and private users. This would reduce the direct influence government could have on the nature of the system, and the private owners become motivated in the same way as in the civil sector. The technical interface characteristics of military Comsats would be similar to those of civil Comsats.

Meteorological: The US (GOES), Europe (Meteosat), Japan (GMS), India (multi-purpose Insat), Russia (GOMS) and China (Feng-Yun) currently fly weather satellites in GEO orbit. The US is the only country to fly dedicated military weather satellites in GEO (DMSP). The latest satellites are a mixture of spin-stabilised (e.g. Meteosat Second Generation) and three-axis stabilised (e.g. GOES I-M) designs. Insat is an interesting case study as it provides a concrete example of a multi-purpose satellite, carrying TV and telephone transponders in addition to weather sensors. Similarly the GOES I-M and GOES-NEXT range includes a Space Environment Monitor with multiple detectors, with GOES-NEXT also having an x-ray imager (see Figure 19), which can clearly be seen on the solar array. The relatively low overheads of weather payloads and existing examples of multi-purpose use make this type of satellite a promising field for identifying candidate hosts.

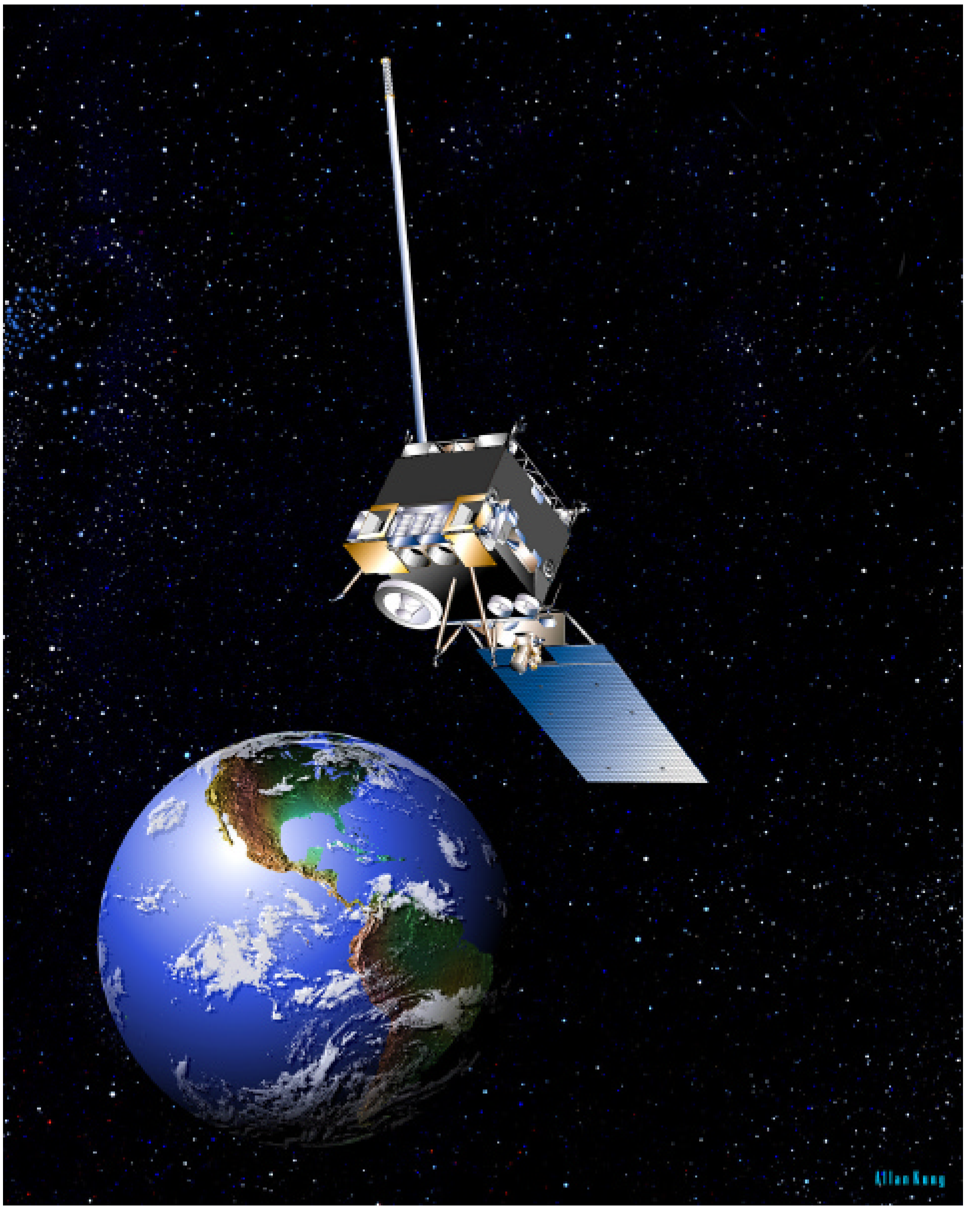


Figure 19 GOES-NEXT satellite

Missile Early Warning: Highly classified US military satellites are not viable prospects for accommodating a non-US science guest payload.

Summary Opportunities for Guest Space Weather instruments:
There is a clear difference between the following types of users of the geostationary orbit:-

Purely Commercial private organisations

- Communications, motivated to reduce cost per transponder, implies more transponders, frequency re-use, more complicated satellites with less margin to accommodate a guest. Also need for on-board flexibility to match changing market in-life, this also adds to complexity. Therefore tends towards technical limits of available buses. Would need to be compensated for the market worth of the comms payload displaced by a space weather package. However, certain space weather instruments (e.g. energetic particle detectors) can be used by commercial operators as diagnostic tools for spacecraft anomalies. For such hitch-hiker instruments, the prospect of a cheap, or even free ride is a possibility.

National, Governmental, Quasi-governmental, Intergovernmental organisations

- meteorological, national first generation satellite telecomms or educational / health / public service comms, military telecomms, technology development. Motivated to reduce the capital cost of the system rather than the 'cost per transponder'.

It is clear that the second category offers an easier route to mesh interests and negotiate a guest SW package. This is because, for a large comsat operator, any potential technical margin is attractive to use for more payload, to obtain more earning power. Therefore margin will only be available if the system is badly oversized technically in the first place. However, the second group of users have a set limit of payload ambition and wish to minimise capital cost. Inviting a partner to share on-board (and possibly ground) resources is one way to do this. In addition, these users are increasingly making use of small minisatellite approaches in GEO that can reduce launch cost dramatically by offering the possibility of being a secondary payload on a direct injection to GEO. The technical performances of such buses will not be suitable for every Space Weather mission (particularly those requiring large instruments or stringent pointing), but could be a very cost effective way of flying more than one simple Space Weather instrument, say three to four at various longitudes in order to achieve global longitude coverage.

7.2.3.8 Review of Low Earth orbits (LEO) and the existing and planned non-space weather missions scheduled to go to there

A Low Earth Orbit (LEO) generally describes satellites in the orbital altitude range (500 to 2000 km above the surface of the Earth). This is the most popular and usually the least expensive orbit to send a spacecraft into and is used for many different mission applications, including Science, Earth Observation, Military Surveillance, Military Communications, Civil Communications (including large constellations) and Manned Flight.

Launches to LEO are frequent and number almost the same as for GEO (around 40/year), and this would suggest that there are potentially many opportunities for instruments to fly as hitch-hiker payloads. However, almost half of these of these launches carry payloads of less than 700kg, which may reduce the possibility of finding room on these smaller satellites. As with GEO, LEO is served by both Commercial private organisations and National Agency type organisations. A similar methodology can be applied to LEO, in the way the prospect hitch-hiking can be approached.

Ground station coverage can vary depending on the inclination of the orbit and the latitude of the ground station. Low inclination orbits will require a low latitude ground station (at ~ inclination = latitude), however this does not mean that coverage occurs every orbit. In fact it only occurs roughly twice a day on average. This is untrue though for very low inclination orbits such as equatorial orbits, which would have coverage once per orbit. High inclination orbits, may have much better coverage if a high latitude ground station is chosen, and may be almost on average once per orbit if Svalbard is used.

Regular Ground Station view is required for many CSMR (especially those associated with forecasting). As the orbit period is around 90-100 minutes, and the ground station view is for around 10 minutes, there will be a gap of at least 80 minutes (could be much longer) before the ground station is in view again. For regular contact, at least two ground stations or spacecraft would be needed to guarantee that ground station contact outages are kept within acceptable levels,

As with satellites at GEO, a problem for satellites in Low Earth Orbits is eclipses. This causes outages in data from solar observation instruments onboard the satellite. The main factors that can be a problem are eclipse frequency and duration. As the orbit altitude is increased, the orbital velocity decreases and the orbit circumference increases, which results in the eclipse frequency decreasing. However, the eclipse duration increases with increasing altitude. Table 15 describes how eclipse duration varies for different Low Earth Orbits

Inclination	Altitude (km)	Minimum Eclipse time (min)	Maximum eclipse time (min)
Sun Synchronous (Dawn-Dusk)	500	0	22.7
	800	0	16.9
Sun Synchronous (10am-10pm))	500	33.7	34.6
	800	32.3	33.7
60deg	500	32.7	35.8
	800	30.9	35.1
30deg	500	32.7	35.8
	800	35.0	35.1
0deg	500	34.7	35.8
	800	33.6	35.1

Table 15 Example eclipse durations for Low Earth Orbits

To guarantee continuous observation of the sun, at least two spacecraft would be needed (unless above 1395km for dawn-dusk sun-synchronous orbits). It is possible that for some LEO orbits to meet certain CSMR (e.g. solar forecasting observations with very frequent contact with ground station), more than 1 spacecraft AND ground station would be required.

7.2.3.9 Review of Polar Earth orbits (PEO) and the existing and planned non-space weather missions scheduled to go to there

A Polar Earth orbit is a generic term applied to high inclination orbits whose orbit crosses over or in the vicinity of the poles. They are a subset of LEO.

Launches to Polar orbits are less frequent than to GTO, however there are still around 15 launches per year, of which around half are payloads less than 700kg. This would suggest that there are potentially a fair number of opportunities for instruments to fly as hitch-hiker payloads to PEO. Most of these launches will be to Sun-synchronous orbit, so the same applies to such orbits.

At least two spacecraft must be used if hourly coverage of the Auroral regions is to be met.

Greater detail on eclipses and Ground station coverage is described in the section on Low Earth Orbits

7.2.3.10 Review of Sun-Synchronous orbits and the existing and planned non-space weather missions scheduled to go to there

Sun-synchronous orbits are a subset of Polar Earth orbits (PEO) and Low Earth orbits (LEO), and their inclination is chosen such that the orbit plane regresses at the same rate as the Earth revolves around the sun. This means that the satellite passes over the same part of the Earth at roughly the same local time each day. This can make communication and various forms of data collection very convenient. The local time can be chosen to suit the mission requirements and an example is called a dawn-to-dusk orbit, where, the satellite is always above the Earth's terminator.). An example of such as spacecraft is RADARSAT, which has an altitude of 798km. The orbit allows the satellite to always have its solar panels facing the sun, without the use of a Solar Array Drive Mechanism (SADM), and therefore can rely mostly on solar power and not batteries.

Spacecraft in dawn-dusk Sun-synchronous orbits will experience eclipses in Northern Hemisphere Summer for a 6pm ascending node, or Northern Hemisphere Winter for a 6am ascending node, unless the altitude is greater than 1395km whereby no eclipses occur. Therefore, for instruments that require continuous solar observations, a high altitude dawn-dusk, sun-synchronous orbit would be desirable as the eclipse duration is low/zero.

To guarantee continuous observation of the sun, at least two spacecraft would be needed (unless above 1395km for dawn-dusk sun-synchronous orbits). If regular ground station coverage is also required then more than one satellite and/or ground station may also be required depending on exactly what the maximum outage requirement is. It is also important to ensure that eclipses do not occur when in view of a ground station, otherwise the eclipse duration may exceed the outage limit. This can be avoided by careful choice of the number of spacecraft/ground stations, orbit altitude and ascending node, and ground station latitude.

7.2.3.11 Review of Medium Earth orbits (MEO) orbits and the existing and planned non-space weather missions scheduled to go to there

Medium Earth Orbits (MEO) generally have orbital altitudes between 8,000 and 20,000 km. Such orbits are mainly used by communication satellites that provide communications capabilities for such services as cellular telephone communications and GPS (global positioning system) signals. The GPS satellites are US Military and are very unlikely act as hosts for ESA space weather instruments.

One possible future avenue for hitch-hiking may be the forthcoming GALILEO satellites , although it is unknown as to whether they would be receptive to act as host satellites for space weather instrumentation.

Maximum Eclipse times are generally 55 minutes for MEO's. As the orbit period is around 11.7 hours, large gaps in ground station coverage (7 hours) will occur if only one spacecraft and ground station is used.

7.2.3.12 Review of Molniya orbits and the existing and planned non-space weather missions scheduled to go to there

The Molniya orbit is a specialized orbit developed by the former Soviet Union in the early 1960s to meet their communication needs as it spends most of its time over high Northern latitudes. However, interest is no longer confined to Russia - the Danish small scientific satellite, Roemer (mass 84kg) is due to piggyback on a Soyuz-Fregat in 2004.

Spacecraft in Molniya orbits have a 12-hour period, with an eccentricity of about 0.7, and a critical inclination near 63.4 degrees so that the argument of perigee remains nearly fixed over the southern hemisphere. The apogee is thus fixed high over northern latitudes and has an altitude of around 39-40000km. Maximum Eclipse times for Molniya orbits are generally 55 minutes. At least two spacecraft must be used if continuous ground station coverage or hourly coverage of the Auroral regions is required.

The extent of the Russian Molniya communication satellite programme is unknown at present, so it is difficult to predict the regularity of launch of such spacecraft.

7.2.3.13 Review of Geostationary Transfer orbits (GTO) orbits and the existing and planned non-space weather missions scheduled to go to there

Geostationary Transfer orbits (GTO) orbits are generally intermediate orbits for Communications satellites whose final destination is GEO. This is the orbit that the launch vehicle delivers the satellites to before their on-board propulsion boosts them to GEO. GTO's have perigees of typically 200-500km and apogees of ~35787km (GEO altitude).

GTO is the most popular destination for launches and numbers about 40 per year, of which almost all are above 700kg payloads. The problem, in terms of hitch-hiking is that the orbit is seldom used, and has very few planned visitors. However, GTO is very inexpensive to reach if satellites are small enough, as they can be secondary payloads on the ASAP-5 adaptor on ARIANE 5. This makes GTO an attractive orbit option for dedicated space weather spacecraft.

Maximum Eclipse times are generally 53 minutes. Large gaps in ground station coverage (7hours) will occur will if only one spacecraft and ground station is used.

7.2.4 Trade-off discussion of orbit locations (e.g. L1 versus Sun-synchronous) and Host versus Dedicated for each remaining system requirement

This section discusses the trade-off between implementation of Space Weather payloads on a host spacecraft in optional orbit locations.

If a space segment of hitch-hikers only, is to be considered, then the orbit trade-off decides where a fleet of hitch-hikers will inhabit for each CSMR. This fleet of hitch-hikers along with the present and planned space infrastructure then forms the space segment for option 2 (Hitch-hikers). However, if a space segment is to include hitch-hikers on a Full dedicated spacecraft, a different approach is required. This means that each CSMR can no longer be treated individually, and the whole picture must be investigated simultaneously. This iteration between hitch-hiker and dedicated is addressed in the section on Dedicated options.

Both 'hitch-hiker' space segment options compare the characteristics of planned missions from the earlier review against the trade-off criteria identified for implementation on a host spacecraft in optional orbit locations and/or host or dedicated spacecraft. A trade-off is performed for each CSMR and a recommended implementation concept arrived at.

7.2.4.1 Trade-off Criteria

The following criteria are key for determining whether hitch-hiking is possible, and what the most appropriate orbit for hitch-hiking is:

- Orbits (location and frequency of satellites inhabiting certain orbits)
- Interface requirements
- Payment to host for accommodation
- Nature of satellites planned to inhabit orbits
- Mass of instrument
- Volume of instrument
- Power requirement of instrument
- Thermal requirement (e.g. special cooling considerations)
- View requirement and eclipse duration/regularity
- Science lifetime
- Pointing requirements
- Agility requirements
- Data downlink requirements
- Programmatics
- Politics
- Data rates and telemetry
- Ground Stations and coverage
- On-station longitude (as for example, hosts may not exist at a required longitude which is not used for other purposes)

However, we have only focussed on those criteria that drive the space segment architecture, such as orbit location, frequency and nature of satellites inhabiting certain orbits, instrument size/mass/pointing/data rates, view and ground station coverage. Other criteria are added for completeness, but are a matter for detailed design that is beyond the scope of this study.

The most important criterion is the orbit location and the ease of finding a suitable host. If there are few or no potential host spacecraft for a given orbit location (e.g. Heliocentric at 1 AU), then the other trade-off areas are meaningless.

A hierarchy of orbit locations can be constructed based upon the frequency of launches to a particular orbit location. This is described roughly in Table 16.

Hierarchy	Orbit	Comments
1	GEO	Wide range of opportunities expected
	LEO	Wide range of opportunities expected
2	PEO	Several opportunities expected
3	SS	Several opportunities expected
5	Molniya	Some opportunities via Russian Molniya comsats programme, however schedule of this is unknown
6	Mid-EO	Possible opportunities via regular future GALILEO programme. However, SW instruments could be seen in an unfavourable light due to high mission costs. US GPS satellites are military and would be unlikely hosts. Future status of GLONASS satellites unknown at this stage
7	GTO	Unlikely as few opportunities
8	L2	Unlikely as few opportunities
9	L1	Unlikely as few opportunities
10	Magnetosphere	Unlikely as very few opportunities
11	1 AU Heliocentric/ L4or5	Unlikely as very few opportunities

Table 16 Hierarchy of preferred orbit locations based upon launch frequency

The approach is then to determine whether the Space Weather concept is suitable to act as a guest on a host satellite. In the interests of ensuring a wide range of possible hosts are considered, this is done in a general sense and not compared against a specific potential host. The trade is made by reference to common engineering principles, applied to current and existing planned missions detailed earlier in this section.

Finally we can compare orbit options, the host satellites that they offer and the cost and complexity that is required to meet each CSMR. This enables us to select the most appropriate orbit/host combination to meet a particular CSMR.

7.2.4.2 Discussion of matching CSMR with Hitch-hiker instruments and their ‘hosts’ orbit locations

In order to best understand the factors that influence the suitability of orbit locations and ‘host versus dedicated’ (if dedicated option is considered) for a hitch-hiker to match a particular CSMR, it is necessary to review each of the outstanding CSMR and the characteristics of their potential orbit locations. Each orbit location is then assessed on the trade-off areas described earlier. Some of the system requirements can be met by more than one orbit location, and this leads to a multiple trade-off in terms of preferred orbit location. If a CSMR has no orbit locations that are suitable in terms of hitch-hiking, then a dedicated spacecraft is required.

An example trade-off of orbit locations for sun-pointed instruments based upon the trade-off criteria described earlier is shown in Figure 20.

Trade-off area	L1	LEO (Non SS)	SS	GEO
Ease of finding host to that orbit based on launch frequency	Very difficult	Very good	Quite good	Very good
Spacecraft Pointing	Variable	Variable on mission	Generally good	Poor for Comsats, good for Met sats, e.g. Goes-Next
View requirement (of sun)	Very good – no eclipses	Variable eclipses depending on inclination and position of ascending node relative to sun	Eclipses in one of solstices if dawn-dusk and < 1395km; every orbit if otherwise	Eclipses at equinoxes, need 2 hitch-hikers with sufficient longitude spacing
Data rates and telemetry	Poor	Very good	Very good	Good
Ground Stations and coverage	Need several (3) Ground stations for continuous contact. Must also be low latitude.	Problems with downlink. Require multiple Ground stations and/or hitch-hikers	Need 4 hitch-hikers + Very high latitude ground station	Very good – Continuous coverage

Figure 20 Example trade-off for sun-pointed instruments

7.2.4.3 Discussion of size implications for certain Hitch-hiker instruments

Some instruments matching CSMR 1, 2, 3, 4, 6 , 36-38 (magnetograph) are quite large in comparison with other instruments terms of volume. This may pose a problem in terms of finding accommodation on some if not most host spacecraft. However, the GOES-NEXT series of spacecraft will have an x-ray imager as part of its instrument complement, located on the SADM of the spacecraft. This indicates that hitch-hiking may be possible in most, if not all cases as long as the host is willing and adequate planning is undertaken. As there are always 2 GOES spacecraft 75deg in longitude apart, continuous solar observation is possible.

7.2.5 No. of hitch-hikers and/or Ground stations required to meet each CSMR (preferred orbit for each CSMR in bold)

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Hitch-hiker	Probable orbit for hitch-hiker	Issues	Max Gap in coverage	No. of instances	SS	GEO	LEO	Mid-EO	PEO	Molniya	Final comments
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	Single point measurement in space	1 hr	No	N/A	problem with size	20 min	1	2 hitch-hikers required + 2 high latitude ground stations	**2 hitch-hikers required**					GEO preferred
2	Solar coronagraph images	Coronagraph	L1 / L4 / L5 / SS/ GEO	Single point measurement in space	1 hr	Yes	GEO or SS	problem with size	20 min	1	2 hitch-hikers required + 2 high latitude ground stations	**2 hitch-hikers required**					GEO preferred
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	L4+L5	2 points well separated from Earth eg L4 & L5	1 hr	No	N/A	problem with size	20 min	2							
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	From polar elliptical orbit, Single point measurement	1 hr	Yes	PEO / Molniya	screen straylight from sun	20 min	2					2 hitch-hikers required + 2 high latitude ground stations	2 hitch-hikers required	PEO preferred

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Hitch-hiker	Probable orbit for hitch-hiker	Issues	Max Gap in coverage	No. of instances	SS	GEO	LEO	Mid-EO	PEO	Molniya	Final comments
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	Single point measurement in space	1 min	No	N/A		20s	1	11 hitch-hikers for continuous ground station coverage	**2 hitch-hikers required**					GEO preferred
12	UV flux	UV photometer	L1 / SS / GEO	Single point measurement in space	1 day	Yes	GEO or SS but could be problem with size	problem with size???	8 hours	1	**one hitch-hiker**	**one hitch-hiker**					Either SS or GEO
13	EUV flux	EUV photometer	L1 / SS / GEO	Single point measurement in space	1 day	Yes	GEO or SS but could be problem with size	problem with size???	8 hours	1	**one hitch-hiker**	**one hitch-hiker**					Either SS or GEO
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Single point measurement at L1	1 min	No	N/A	sample all 4PI solid angle	3 min	1							
36 to 38	IMF (B-field)	Magnetometer	L1	Single point measurement at L1	1 min	No	N/A	boom reqd to reduce interference	3 min	1							
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO/ SS		1 hour	Yes	GEO or SS		3 min	1	>2 hitch-hikers for continuous coverage	**2 hitch-hikers required**					GEO preferred

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Hitch-hiker	Probable orbit for hitch-hiker	Issues	Max Gap in coverage	No. of instances	SS	GEO	LEO	Mid-EO	PEO	Molniya	Final comments
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Throughout magnetosphere (constellation type such as SWARMS)	1 hour	No	N/A	boom reqd to reduce interference	20s	4 to 100							
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	PEO	seconds	Yes	LEO	large booms for e-field; sample all 4PI solid angle for spectrometer	1s	5 to 10			>10 hitch-hikers		**11 hitch-hikers**		Ground-based preferred.
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical eg GTO	L=7 and below	1 min	No	N/A	sample all 4PI solid angle	20s	4 with ion, 2 with UV imager/ ionosonde							
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	L=3 to 9, GEO Want several (eg 3) equi-spaced in longitude	1 min	Yes	GEO x 3	sample all 4PI solid angle	20s	4 or more		**4 or more hitch-hikers; 3 ground stations**					GEO preferred
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	Single point measurement in interplanetary space	<30 min	Yes	GEO	sample all 4PI solid angle	10 min	1		**1 hitch-hiker**					GEO preferred

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Hitch-hiker	Probable orbit for hitch-hiker	Issues	Max Gap in coverage	No. of instances	SS	GEO	LEO	Mid-EO	PEO	Molniya	Final comments
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO / mid-EO	Throughout inner radiation belt	<30 min	Yes	GEO or LEO	sample all 4PI solid angle	10 min	3 or more		**3 or more hitch-hikers; 3 ground stations**	>2 S.S. hitch-hikers + SVALBARD	at least 3 or more hitch-hikers and/or ground stations			GEO preferred
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	Single point measurement in space	1 hr	No	N/A	sample all 4PI solid angle	20 min	1		**1 hitch-hiker**					GEO preferred
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO, GTO	<30min	No	N/A	sample all 4PI solid angle	10 min	3 or more		**3 or more hitch-hikers; 3 ground stations**					GEO preferred
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO	6 months for debris, 1 day for meteoroids	Yes	LEO		8 hours	1			**1 hitch-hiker**				LEO preferred
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s / craft	Onboard spacecraft	5 min	Yes	Onboard spacecraft	sample all 4PI solid	100s	1							

CSMR	Measure what ?	What instrument ?	Where	Spatial sampling requirement	Temporal sampling requirement	Hitch-hiker	Probable orbit for hitch-hiker	Issues	Max Gap in coverage	No. of instances	SS	GEO	LEO	Mid-EO	PEO	Molniya	Final comments
								angle									
73	Total Dose		Sensor worn by astronaut		mission integrated	Yes											
74	Satellite position				30 minutes	No	N/A										
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	Single point measurement in space	1 hour				20 min	1							

Table 17 No. of Hitch-hikers and/or Ground stations required to meet each CSMR

7.2.6 Cost

Costing for Hitch-hikers is a very difficult task and is related to many factors, such as instrument costs, instrument mass and volume, host acceptability and risk. A preliminary rough-order-of-magnitude cost estimate comparison has been made based on data from recent instrument studies, combined with experience of both commercial GEO and science programme mission costs.

7.2.7 Hitch-hiker cost methodology

The idea behind the hitch-hiker costing was to set up a spreadsheet with an algorithm to quickly calculate associated costs behind hitch-hiking for a range of different CSMR. The algorithm calculated these associated costs by inputting known cost and mass values of the instrument and known wet mass of the spacecraft.

7.2.7.1 Programme Management Costs

This is the cost of keeping people working on the project including interface engineering. This cost is quasi-scalable with instrument cost. For the purposes of this study, a linear fit was applied to two example instruments with different costs. The cost is independent of instrument or spacecraft mass

The first instrument example is large with a cost of 26MEuro. An instrument such as this would require roughly 16.67 people full-time, for 3 years, i.e. 50 man years. At a commercial manpower cost of 160KEuro/person/year, the total programme management cost would be 8MEuro.

The second instrument example is a small 1MEuro instrument. This would require approximately three people full-time for three years, which would result in a total programme management cost of 1.44 MEuro.

By applying the following linear fit to these two costs we can quickly calculate the programme management costs for any instrument cost:

$$y = ax + b$$

where y is the programme management cost
x is the instrument cost
and a and b are constants, where a is 1.1776 and b is 0.2624

7.2.7.2 Charge payable to Host for Accommodation, Integration, Integrated Test

This is the cost of people working on the project who are involved in the AIT of the instrument with the main spacecraft. This cost is also quasi-scalable with instrument cost. Again, for the purposes of this study, a linear fit was applied to the same two example instruments as with programme management costs. The cost is independent of instrument or spacecraft mass

The first instrument example is large with a cost of 26MEuro and would require roughly 12.5 people full-time for three years, i.e. 37.5 man years. At a commercial manpower cost of 160KEuro/person/year, the total programme management cost would be 6MEuro.

The second instrument example is a small 1MEuro instrument and would require roughly 1 person for 3 years people full-time, and a further two people for 1 year full time, i.e. 5 man years. At a commercial manpower cost of 160KEuro/person/year, the total programme management cost would be 0.8MEuro

By applying the following linear fit to these two costs we can quickly calculate the programme management costs for any instrument cost:

$$y = ax + b$$

where y is the programme management cost
x is the instrument cost
and a and b are constants, where a is 0.592 and b is 0.208

7.2.7.3 Charge payable to Host for Launch Services

This is the charge payable to the host as compensation for taking up payload mass and volume available to the host spacecraft. This is based on the mass ratio of available payload to hitch-hiker payload, and is scalable with instrument mass, total available payload mass and launch cost. The available payload mass is assumed to be 1/6 of the launch mass. The charge payable to host for launch services is thus:

Charge payable to host = Total launch cost x (Hitchhiker mass)/(Available payload mass)

The cost is therefore independent of instrument cost.

7.2.7.4 Cost Example - 10kg Space Weather Payload on Host 500kg Sun-synchronous (SS) satellite and a 3000kg (launch mass) class GEO satellite:

The 10kg payload includes all dedicated support to the instrument, e.g. necessary thermal control enhancements and electronic interfaces. No impact on power sizing is assumed – this is achievable for a space weather mission flown for life duration less than the host satellite, making use of excess margins in early to mid-life. The charges payable to the host have been estimated on the basis of maximum displaced host payload The bigger the host, the bigger the available payload, the larger the fraction of main payload to hitch-hiker and hence the share of the cost reduces in terms of hitch-hiking. The assumed launch cost to GEO is assumed to be 75MEuro, whilst 15.4MEuro to Suns-synchronous. So although it is more expensive to go to GEO than to SS, the share of the launch cost will be very small, as the hitch-hiker will be much less massive than the main payload. A sun-synchronous is more likely to be much smaller than a GEO satellite, and therefore the mass ratio of main payload to hitch-hiker will be less, and the share of the launch cost with the host will be more even, (unless one could find regular ENVISAT type hosts!)

ROM Cost Breakdown for Hitch-hiking	**Orbit**	
	SS	**GEO**
Instrument	5 MEuro	5 MEuro
Programme Management (including Interfaces Engineering)	2.5 MEuro	2.5 MEuro
Charge payable to Host for Accommodation, Integration, Integrated Test	1.6 MEuro	1.6 MEuro
Charge payable to Host for Launch Services	1.8 MEuro	1.5 MEuro
Insurance at 15% of Total Value	1.6 MEuro	1.6 MEuro
Contingency 10%	1.3 MEuro	1.3 MEuro
TOTAL COST	**13.8 MEuro**	**13.5 MEuro**

Table 18 Example cost of Hitch-Hiking on a GEO and Sun-synchronous satellites

Therefore the cost of hitch-hiking is likely to be similar whether the host is SS or GEO based.

Note that this is the cost for a 5 year programme. A 15-year programme would therefore be three times this value at around 41.4 MEuro.

7.2.8 Hitch-hiker timelines and associated cost

The following timelines describe two space segment scenarios: maximum hitch-hikers (only sparse orbit locations ignored as hitch-hiker locations) and Large instrument dedicated (similar to maximum dedicated, except that large instruments such as whole disk imagers and auroral imagers are deemed to be dedicated possibilities only). It should be noted that for Full dedicated space segments, all hitch-hikers would be replaced by dedicated spacecraft and would have the same key on the timelines, i.e. purple. These would then be grouped together to form multiple instrument, dedicated spacecraft.
Many of the CSMR must be met by several instruments simultaneously, i.e. at different longitudes. It is assumed that if hitch-hiking is possible, then it is also possible to meet these CSMR by multiple hitch-hikers. In reality, this may be difficult. For example it might not be easy to find 4 host satellites, with dawn-dusk sun-synchronous orbits, altitudes >600km and all separated by 90 degrees to each other in their respective orbits, with Svalbard as their common ground station.

A preliminary costing has also been carried out, which defines hitch-hiker costs for each mission element. A cost model has been used to do this and takes into account initial instrument costs (including non-recurring costs) as well as subsequent instrument costs, which are cheaper as they do not include non-recurring elements. Learning factors and batch costings are not included as they are beyond the scope of this study, but would result in lower costs for later elements in a continuous programme.

Operations processing/archive/dissemination/space weather service costs, are not within the scope of the space segment study as they are covered in WP431 and WP432.

Each hitch-hiker instrument is costed for both an initial instrument and as a follow-on instrument.. Both of these costs are divided by 5 to arrive at a figure in cost/year. If for example 9 years were required to hitch-hike, i.e. between 2007-2015, then 5 years would be using the initial instrument (and initial instrument costs), and 4 years would be using the follow-on instrument. The cost is calculated from the number of years for which each instrument is used.

7.2.8.1 All missions – Maximum Hitch-hiker

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															0.00	0.00	12.87	6.28	0.00
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / SS/ GEO	GEO															4.00	0.00	14.83	7.88	69.34
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4+L5	Dedicated																	0.00	0.00	0.00
4,5	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															5.00	7.00	11.09	6.91	103.62
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	GEO															0.00	0.00	6.86	4.68	0.00
12	UV flux	UV photometer	L1 / SS / GEO	GEO															5.00	2.00	2.40	1.89	15.78
13	EUV flux	EUV photometer	L1 / SS / GEO	GEO															5.00	4.00	2.40	1.89	19.55
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO/ SS	GEO															5.00	2.00	22.21	8.46	133.99
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															0.00	0.00	0.00	0.00	0.00
52	Cold ions: Total density only	Thermal energy ion spectrometer; Ionosonde, UV imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.68	68.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	GEO															5.00	7.00	2.13	1.30	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO (mid-EO	GEO															5.00	7.00	6.38	3.98	69.15
63 to 65	>100MeV ions (COR)	High energy ion detector	GEO / L1 / L2	GEO															0.00	0.00	3.36	1.91	0.00
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															0.00	0.00	10.87	5.72	0.00
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	20.24
72	Dose rate & LET spectrum	Hight energy electron spectrometer	Onboard s / craft	Onboard s/c															5.00	7.00	3.43	1.98	30.98
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4-L5/separated heliocentric at 1AU	Dedicated																	0.00	0.00	0.00

Total 530.386 with magnetograph)
396.398 thout magnetograph)

Figure 21 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

7.2.8.2 European and International Collaboration – Maximum Hitch-hiker

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by currently planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1/SS/GEO	GEO															4.00	0.00	12.07	6.29	41.29
2	Solar coronograph images	Coronograph	L1/L4 / L5 / GEO/ SS	GEO															4.00	0.00	14.83	7.80	51.34
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4+L5	Dedicated																	0.00	0.00	0.00
4,5	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															5.00	7.00	11.09	6.51	103.62
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1/SS/GEO	GEO															5.00	7.00	6.66	4.60	65.50
12	UV flux	UV photometer	L1/SS/GEO	GEO															5.00	2.00	2.40	1.85	15.78
13	EUV flux	EUV photometer	L1/SS/GEO	GEO															5.00	4.00	2.40	1.93	19.85
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
30 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetograph	L1/L4 / L5 / GEO/ SS	GEO															5.00	2.00	22.21	11.46	133.93
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															5.00	7.00	0.00	0.00	0.00
52	Cold ions. Total density only	Thermal energy ion spectrometer, Ionosonde, UV Imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.63	61.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1/ GEO	GEO															5.00	7.00	2.13	1.31	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO / mid-EO	GEO															5.00	7.00	6.38	3.30	53.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	GEO															5.00	3.00	3.36	1.81	22.50
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															5.00	7.00	10.07	5.72	51.40
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	21.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/craft	Onboard s/c															5.00	7.00	3.42	1.91	31.98
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5/seperated heliocentric at 1 AU																		0.00	0.00	0.00
																	Total	757.67	Meuro (with magnetograph)				
																		623.68	Meuro (without magnetograph)				

Figure 22 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

7.2.8.3 European only – Maximum Hitch-hiker

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															5.00	7.00	12.07	6.29	104.32
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / GEO/SS	GEO															5.00	7.00	14.83	7.80	128.79
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4/L5	Dedicated																	0.00	0.00	0.00
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															5.00	7.00	11.05	6.91	103.62
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	GEO															5.00	7.00	6.66	4.60	65.50
12	UV flux	UV photometer	L1 / SS / GEO	GEO															5.00	2.00	2.40	1.89	15.78
13	EUV flux	EUV photometer	L1 / SS / GEO	GEO															5.00	7.00	2.40	1.89	25.21
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO/SS	GEO															5.00	7.00	22.21	11.46	191.29
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															5.00	7.00	0.00	0.00	0.00
52	Cold ions: Total density only	Thermal energy ion spectrometer, Ionosonde, UV Imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.68	68.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1/GEO	GEO															5.00	7.00	2.13	1.30	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	GEO															5.00	7.00	6.38	3.90	59.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	GEO															5.00	7.00	3.36	1.91	30.18
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															5.00	7.00	10.07	5.72	90.40
68 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	20.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/craft	Onboard s/c															5.00	7.00	3.43	1.98	30.58
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5 seperated heliocentric at 1AU	Dedicated																	0.00	0.00	0.00
																		Total	953.75	n (with magnetograph)			
																			782.46	(without magnetograph)			

Figure 23 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

7.2.8.4 All missions – Large instruments dedicated

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partialy covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First Instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															0.00	0.00	12.07	6.28	0.00
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / SS / GEO	GEO															0.00	0.00	14.92	7.08	0.00
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4-L5	Dedicated																	0.00	0.00	0.00
4-6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															0.00	0.00	11.15	6.31	0.00
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	GEO															0.00	0.00	6.66	4.58	0.00
12	UV flux	UV photometer	L1 / SS / GEO	GEO															5.00	2.00	2.40	1.89	15.78
13	EUV flux	EUV photometer	L1 / SS / GEO	GEO															5.00	4.00	2.40	1.89	19.55
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
35 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
35 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO / SS	GEO															5.00	2.00	22.21	11.46	133.99
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															5.00	7.00	0.00	0.00	0.00
52	Cold ions. Total density only	Thermal energy ion spectrometer, Ion sonde, UV Imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.60	68.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	GEO															5.00	7.00	2.13	1.30	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	GEO															5.00	7.00	6.38	3.80	53.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	GEO															0.00	0.00	3.36	1.51	0.00
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															0.00	0.00	10.07	5.72	0.00
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	20.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s / craft	Onboard s/c															5.00	7.00	3.43	1.90	30.50
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5 or separated heliocentric at 1AU	Dedicated																	0.00	0.00	0.00

Total 368 Meuro (with magnetograph)
234.04 Meuro (without magnetograph)

Figure 24 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a large instruments dedicated scenario

7.2.8.5 European and International Collaboration – Large instruments dedicated

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are prefered
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partialy covered by current and planned missions, but dedicated is prefered

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First Instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															0.00	0.00	12.07	6.28	0.00
2	Solar coronograph images	Coronograph	L1/L4/L5/GEO/SS	GEO															0.00	0.00	14.83	7.80	0.00
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4-L5	Dedicated																	0.00	0.00	0.00
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															0.00	0.00	11.05	6.91	0.00
9 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	GEO															5.00	7.00	6.66	4.60	65.80
12	UV flux	UV photometer	L1 / SS / GEO	GEO															5.00	2.00	2.41	1.89	15.78
12	EUV flux	EUV photometer	L1 / SS / GEO	GEO															5.00	4.00	2.41	1.89	19.55
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetograph	L1/L4/L5/GEO/SS	GEO															5.00	2.00	22.21	11.48	133.19
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															5.00	7.00	0.00	0.00	0.00
52	Cold ions: Total density only	Thermal energy ion spectrometer: Ionosonde, UV imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.68	68.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	GEO															5.00	7.00	2.13	1.30	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	GEO															5.00	7.00	6.31	3.80	58.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	GEO															5.00	3.00	3.36	1.91	22.80
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															5.00	7.00	10.07	5.72	90.40
68 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	20.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s / craft	Onboard s/c															5.00	7.00	3.43	1.98	30.98
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4-L5/separated heliocentric at 1AU	Dedicated																	0.00	0.00	0.00
																	Total		546.42	(with magnetograph)			
																			412.44	ithout magnetograph)			

Figure 25 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Large instruments dedicated scenario

7.2.8.6 European only - Large instruments dedicated

Legend:
- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	Cost/yr First Instrument	Cost/yr next instruments	Total cost
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															1.00	0.00	12.07	6.29	0.00
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / SS	GEO															1.00	0.00	14.83	7.80	0.00
3	Stereo visible or UV images of Sun-Earth space	Coronograph	L4+L5	Dedicated																	0.00	0.00	0.00
4,6	Auroral Imaging. Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	PEO															1.00	0.00	11.05	6.91	0.00
9 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	GEO															5.00	7.00	6.66	4.60	65.50
12	UV flux	UV photometer	L1 / SS / GEO	GEO															5.00	2.00	2.40	1.89	15.78
13	EUV flux	EUV photometer	L1 / SS / GEO	GEO															5.00	7.00	2.40	1.89	25.21
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetometer	L1	Dedicated																	0.00	0.00	0.00
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO / SS	GEO															5.00	7.00	22.21	11.46	191.29
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	Dedicated																	0.00	0.00	0.00
50 and 51	Cross-tail electric field and ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	Ground															5.00	7.00	0.00	0.00	0.00
52	Cold ions. Total density only	Thermal energy ion spectrometer, Ionosonde, UV imager	Elliptical eg GTO	Dedicated																	0.00	0.00	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GEO															5.00	7.00	7.17	4.88	68.82
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	GEO															5.00	7.00	2.13	1.30	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO	GEO															5.00	7.00	6.39	2.90	53.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	GEO															5.00	7.00	3.36	1.81	31.13
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	GEO															5.00	7.00	10.07	5.72	90.40
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	LEO															5.00	7.00	2.17	1.34	20.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/craft	Onboard s/c															5.00	7.00	3.43	1.98	30.98
73	Total Dose		Sensor worn by astronaut	?															5.00	7.00	0.00	0.00	0.00
74	Satellite position			Ground																	0.00	0.00	0.00
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5 separated heliocentric at 1 AU	Dedicated																	0.00	0.00	0.00
																	Total	617.02	Meuro (with magnetograph)				
																		425.73	Meuro (without magnetograph)				

Figure 26 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Large instruments dedicated scenario

7.2.9 Hitch-Hiker overall cost results

Table 19 summarises the total cost results for each Hitch-hiker and programme type, which are derived from summing each individual Hitch-hiker cost. A total cost per year can be calculated from these results, but would depend on when funding would start, i.e. if funding began in 2004 at 50Meuro/year, then a total of 12 years funding would be available up to and including the period studied of 2015, i.e. 600Meuro (Note that this amount is the total funding, and includes funding for ground segment costs). It can be seen that if this were the case, then the budget would already be exceeded, even if including all missions for a maximum hitch-hiker space segment. This would indicate that some form of prioritisation of CSMR would be necessary in order to keep within the allocated budget.

Hitch-hiker type	Programme type	Total cost (MEuro)	Total cost without magnetograph (MEuro)
Max hitch-hikers	All missions	530.99	397.00
Max hitch-hikers	Euro + International collaboration	757.67	623.68
Max hitch-hikers	European led only	953.76	762.46
Large instrument dedicated	All missions	368.03	234.04
Large instrument dedicated	Euro + International collaboration	546.43	412.44
Large instrument dedicated	European led only	617.02	425.73

Table 19 Hitch-hiker overall cost results

7.2.10 Conclusion

It appears that many CSMR may be filled by the implementation of Hitch-hiker payloads. However, one note of caution is that the prospect of hitch-hiking cannot be guaranteed, and much negotiation will be required, either with potential commercial customers, other National Agencies, or even within other ESA directorates (e.g. Earth Observation/Manned Spaceflight).

It is apparent though, from the timeline tables that some CSMR cannot or are very unlikely to be regularly met by hitch-hikers. This then will define the limit of a Space Weather Service based purely upon hitch-hikers and Current/Planned missions.

Table 20 illustrates the preferred orbit selections for a space segment composed of maximum hitch-hikers based upon the major trade-off areas described earlier. We can conclude that GEO is generally the preferred option as it is a popular orbit location for many missions, has good communications links and has a hitch-hiking cost comparable with its rival - SS (Sun-synchronous).

CSMR	Measure what ?	What instrument ?	Orbit selected for hitch-hiking
1	Solar EUV / X-ray images	Whole disk imager	GEO
2	Solar coronagraph images	Coronagraph	GEO
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	Must be Dedicated
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	SS
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	GEO
12	UV flux	UV photometer	GEO
13	EUV flux	EUV photometer	GEO
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	Must be Dedicated
36 to 38	IMF (B-field)	Magnetometer	Must be Dedicated
36 to 38	IMF (B-field)	Magnetograph	GEO
39 to 43	Magnetospheric B-field	Magnetometer	Must be Dedicated
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	Ground
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Must be Dedicated
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	GEO
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	SS
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/c
73	Total Dose		?
74	Satellite position		Ground
75	Interplanetary radio bursts	Radio Wave Detector	Must be Dedicated

Table 20 Orbits selected for Maximum Hitch-hiker space segment

8. WP423 – SPACE SEGMENT SYSTEM ARCHITECTURE – DEDICATED OPTIONS

8.1 Introduction

The most ambitious but also the most expensive space segment option is a full-blown dedicated option. There are several dedicated space segment options that could employ dedicated spacecraft.

The baseline option considers a dedicated space segment, maximising use of hitch-hikers (as with the baseline hitch-hiker option), existing/planned infrastructure only and dedicated spacecraft that fill in the outstanding system requirements. This results in standard system trades (e.g. large single satellite versus several microsatellites)

A secondary option is a refinement of the baseline option and also consists of both hitch-hikers and dedicated spacecraft, but seeks to optimise the use of hitch-hikers and dedicated spacecraft. This is an attractive option because a group of hitch-hiker elements could be brought together to form a dedicated spacecraft, where the overall cost might be cheaper than the sum cost of the individual hitch-hikers. For this option there are trade-offs in two main areas, i.e. between implementation of Space Weather payloads on a host spacecraft in optional orbit locations (if options exist) for each particular system requirement. and between implementation of Space Weather payloads on a host spacecraft or a dedicated spacecraft for each particular system requirement.

A dedicated spacecraft allows maximum potential to satisfy the technical requirements of the payload without consideration to the host. It also allows the programmatics to be geared towards the success of the science mission, such that problems in payload development or test can be mitigated by schedule rearrangement and/or redirection of resources from less problematic areas. However, the full cost of spacecraft build, test, launch and operation needs to be borne by the science mission. By employing a science ‘guest payload’ on a host spacecraft, these costs can be shared. The high number of spacecraft being launched into certain orbits such as LEO and GEO, combined with the industrial nature of production of many of these platforms, could offer significant cost advantages.

8.2 Launcher Options

A launcher survey has been carried out in order to assist in the trade-off of potential orbits for dedicated platforms. The survey is aimed at satellites in the micro to small/medium size range as this is the range that dedicated space weather satellites are expected to fall within, as WP421 showed that most instruments were fairly small and lightweight.

Future launch Costs are difficult to predict. Costs can vary from launch to launch and also many options are partner-dependant. The table below is intended as a guideline only, and should not be taken as a definitive list of firm prices.

It is notable that many of the Russian launchers, such as START, EUROCKOT and DNEPR offer low-cost access to space, however, it is essential to note that many of the Russian launchers are ICBM's (Intercontinental Ballistic Missiles) which are to be phased out after 2007 following the ABM (Anti-ballistic missile) Treaty. (The following Russian launchers are not ICBM's : SOYUZ, PROTON, SEALAUNCH-ZENIT.). The result of this treaty means that smaller US launchers such as KISTLER, PEGASUS, TAURUS and DELTA II will become the most attractive launch options in terms of low-cost missions.

8.2.1 Launcher dimension limitations

Some of the smaller launch options, such as ASAP 5, are dimension limited. A couple of the most promising are described below in more detail

ASAP5
ASAP-5 satellites must fit between the main satellite adapter (diameter 2624 mm) and the SYLDA fairing structure (diameter 4000 mm). They sit on a 91 mm high, 300 mm diameter adapter, and can be up to 800 mm above this plane. Each adapter is currently qualified to 120 kg. In normal microsat configuration, the volume constraint per microsat is limited to 800mm x 600mm x 600mm.

The Bananasat configuration is an alternative to using the standard microsat configuration. For Bananasat, it has basically been proposed to use two adjacent adapters, which are nominally positioned at roughly 45-degree intervals. However, there is nothing sacrosanct about the 45 degrees and it is certain that we could position them closer together if needed. The mass limit in the Bananasat configuration is just under twice that of a single adapter, at around 220kg, although the shape is constrained to that resembling a 'Banana' in a 90-degree sector of the ASAP5 microsatellite ring.

ROCKOT to L1
Rockot to L1 involves placing the spacecraft on top of a Star 37 stage on top of Rockot. The Rockot fairing is an elliptical cylinder with a cone on top. There are internal protrusions, but these probably don't concern us at this point. The internal diameter of the fairing cylinder is 2100 mm x 2380 mm with a height of 3481 mm above the mounting interface. The cone then goes up a further 2554 mm, with a flat tip not dimensioned. The Star 37 has an overall length of 1684 mm (and a diameter of 1095 mm), but we can assume that there will be extra height required for adapters fore and aft.

8.2.2 Launcher Survey

Orbit	Launcher	Mass limit	Cost
1AU separated Heliocentric	ASAP5 to GTO (8 microsats), then translunar flyby. DV from GTO is 700m/s (cannot launch into Earth trailing orbit)	<120kg (700m/s Delta V or DV)	$3M per satellite
	ASAP5 to GTO (4 minisats in bananasat configuration). DV from GTO is 700m/s (cannot launch into Earth trailing orbit)	<220kg (DV 700m/s)	$6M
	ARIANE 5 to GTO (4 minisats in SPELTRA) Must find 4 similar partners otherwise pay ¼of launch cost of $130M or $32.5 M	<300kg but could be as high as 800kg (700m/s DV)	$6-8M per satellite if all minisat ring filled
	Eurockot/Star37 Direct	<317kg	$18M
	TAURUS direct to orbit	350kg	$28M each
L1/L2	ASAP5 to GTO (8 microsats)	<120kg (1km/s DV))	$3M per satellite
	ASAP5 to GTO (4 minisats in bananasat configuration)	<220kg wet	$6M
	ARIANE 5 to GTO (4 minisats in SPELTRA) Must find 4 similar partners otherwise pay ¼of launch cost of $130M or $32.5 M	<300kg but could be as high as 800kg	$6-8M per satellite if all minisat ring filled
	Eurockot/Star37 Direct to L1	<317kg	$18M
	Soyuz/Fregat	<1620kg	$45M but could be $22.5M shared??
LEO/PEO/ SS	START	<300-600kg depending upon altitude	~$10M
	EUROCKOT	<1750Kg (500km/63°) <1600kg (Sun-synch)	$12-13M
	EUROCKOT piggyback/dual launch		$10-15K/kg to SS depending upon interface reqs
	PEGASUS	Usually 500kg (210kg to 1000km SS))	$15M
	DELTA II	Up to 1500kg for secondary in DPAF under primary	$40M dedicated, but sliding scale share negotiable NB/ DPAF alone costs at least $4M
	DELTA II microsat (2 available)	<60-70kg	$3M each
	KISTLER (Delta II class) after 2007	Multiple launches envisaged on a sliding scale. Microsat 'Bus' launch expected once per year	$17M dedicated $7/8 K/kg
	TAURUS	950kg to 400km	$15-25M
	HII	~Up to 4 x 50kg	Cost Unknown

Orbit	Launcher	Mass limit	Cost
	DNEPR	No primary payload in secondary payload config. Capability for 5 microsats	$6-8M for small sats ; $10-15K/kg
	SOYUZ	4 x 125kg	$1M envisaged but prob similar to ASAP, i.e. $3M
GEO	DELTA II	1869kg dedicated	$40M dedicated, but sliding scale share negotiable NB/ DPAF alone costs at least $4M
	DELTA II microsat (2 available)	<60-70kg	$3M each
	Dual launch to GTO on DELTA IV or ATLAS V (EELV)	6 x 180kg microsats (must buy all ring)	$1-2M (first flight trailblazer GTO – ST5???) ~$6M total
	ASAP5 to GTO (8 microsats)	<120kg ~1475ms DV)	$3M per satellite
	ASAP5 to GTO (4 minisats in bananasat configuration). DV from GTO is 1475m/s	<220kg (DV 1475m/s)	$6M
	ASAP5 to GTO (4 minisats) Must find 4 similar partners otherwise pay ¼of launch cost of $130M or $32.5 M	<300kg but could be as high as 800kg (~1475ms DV)	$6M per satellite if all minisat ring filled
	Dual launch to GTO on ARIANE 5	<1550kg	¼of launch cost of $130M or $32.5 M
	PSLV	<850kg to 18°GTO	$25M
	PROTON piggyback	<500kg	? At this stage
	VEGA + STAR37		$20M + $5M (Star37)
	EP Transfer from GTO or LEO		?
	HII piggyback	~50kg	?
Molniya	Soyuz-Fregat piggyback	At least 81kg	?
GTO	ASAP5 to GTO (8 microsats)	<120kg	$3M
	ASAP5 to GTO (4 minisats in bananasat configuration).	<220kg	$6M
	ARIANE 5 to GTO (4 minisats in SPELTRA) Must find 4 similar partners otherwise pay ¼of launch cost of $130M or $32.5 M	<300kg	$6-8M per satellite if all minisat ring filled
MEO	Delta II (GPS)		$40
Magneto-sphere	Microsat configuration on ASAP5 to GTO	<120kg for each microsat location	$3M for each microsat location

Table 21 Launcher Survey

8.3 Trade-off criteria

The following criteria are key for determining whether a dedicated spacecraft design could be suitable for one or more CSMR, and what the choice of dedicated spacecraft architecture could be.

- Mass
- Volume
- AOCS (e.g. 3-axis or Spin-stabilised)
- Power requirement
- Thermal requirement (e.g. special cooling considerations)
- Science lifetime
- Pointing requirements
- Data downlink requirements
- On-station longitude
- Programmatics
- Interfaces
- Orbit
- Nature of satellites planned to inhabit orbits
- View and eclipses (e.g. Whole disk imager)
- Launcher
- Data rates and telemetry
- Ground Stations and coverage
- Risk
- Cost

Although, as with the trade-off section in the hitch-hiker options, we have only focussed on generic issues, which drive the space segment architecture, such orbit location, launch options, instrument size/mass/pointing/data rates, view and ground station coverage. Other criteria are added for completeness, but are a matter for detailed design that is beyond the scope of this study.

The choice of orbit location is a good example of one of the primary drivers behind the architecture of a dedicated space segment, as it incorporates other trade-off areas, such as view, thermal and data rates.

Trade-off area	L1	Dawn-Dusk SS	GEO
Launch cost	Good if can fit on ASAP. Otherwise poor	Good	Good if can fit on ASAP. Otherwise very poor
Thermal requirement (e.g. special cooling considerations)	V.good	Good	Good
View requirement (of sun)	V.good as no eclipses	Short Eclipses in one of solstices, but only one spacecraft required	Eclipses at equinoxes – need two spacecraft with sufficient longitude spacing
Data rates and telemetry	Poor	V.good	Good
Ground Stations and coverage	Need three Ground stations for continuous contact	Need four spacecraft due to gap in ground station coverage limitation. Need V. high latitude Ground station such as Svalbard	V.good. Require only one ground station

Table 22 Example trade-off - Orbit location of dedicated spacecraft

8.4 No. of Spacecraft and/or Ground stations required to meet each CSMR

CSMR	Measure what ?	What instrument ?	Where	Temporal sampling requirement	Max Gap in coverage	No. of instances	L4/5	L1	L2	Magneto-sphere	SS	GEO	LEO	Mid-EO	PEO	Molniya	GTO
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	1 hr	20 min	1		Three ground stations required			2 spacecraft required + 2 high latitude ground stations	2 spacecraft required					
2	Solar coronagraph images	Coronagraph	L1 / L4 / L5 / SS/ GEO	1 hr	20 min	1	Three ground stations required	Three ground stations required			2 spacecraft required + 2 high latitude ground stations	2 spacecraft required					
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	L4+L5	1 hr	20 min	2	Three ground stations required										
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	1 hr	20 min	2									4 spacecraft required	2 spacecraft required	
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO	1 min	20s	1		Three ground stations required			11 for continuous ground station coverage	2 spacecraft required					

CSMR	Measure what ?	What instrument ?	Where	Temporal sampling requirement	Max Gap in coverage	No. of instances	L4/5	L1	L2	Magneto-sphere	SS	GEO	LEO	Mid-EO	PEO	Molniya	GTO
12	UV flux	UV photometer	L1 / SS / GEO	1 day	8 hours	1		Two ground stations required			one spacecraft	one spacecraft					
13	EUV flux	EUV photometer	L1 / SS / GEO	1 day	8 hours	1		Two ground stations required			one spacecraft	one spacecraft					
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	1 min	3 min	1		Three ground stations required									
36 to 38	IMF (B-field)	Magnetometer	L1	1 min	3 min	1		Three ground stations required									
36 to 38	IMF (B-field)	Magnetograph	L1 / L4 / L5 / GEO/ SS	1 hour	3 min	1	Three ground stations required	Three ground stations required			>2 spacecraft for continuous coverage + 2 ground stations	2 spacecraft required					
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	1 hour	20s	4 to 100				4 to 100 sats							
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	PEO / LEO	seconds	1s	5 to 10							>11		11		

CSMR	Measure what ?	What instrument ?	Where	Temporal sampling requirement	Max Gap in coverage	No. of instances	L4/5	L1	L2	Magneto-sphere	SS	GEO	LEO	Mid-EO	PEO	Molniya	GTO
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical eg GTO	1 min	20s	4 with ion, 2 with UV imager/ ionosonde											4 with ion, 2 with UV imager/ ionosonde
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	1 min	20s	4 or more						4 or more					4 or more
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	<30 min	10 min	1		Three ground stations required				1 satellite					
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO / mid-EO	<30 min	10 min	3 or more						3 or more spacecraft; 3 ground stations	>2 for SS spacecraft + 2 polar ground stations	at least 3 or more spacecraft and/or ground stations			3 or more
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2	1 hr	20 min	1		Three ground stations required	Three ground stations required			1 satellite					
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO	<30min	10 min	3 or more						3 or more spacecraft; 3 ground stations					3 or more spacecraft; 3 ground stations
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	6 months for debris, 1 day for meteoroids	8 hours	1							1 satellite				

CSMR	Measure what ?	What instrument ?	Where	Temporal sampling requirement	Max Gap in coverage	No. of instances	L4/5	L1	L2	Magneto-sphere	SS	GEO	LEO	Mid-EO	PEO	Molniya	GTO
72	Dose rate & LET spectrum	Hight energy electron spectrometer	Onboard s / craft	5 min	100s	1											
73	Total Dose		Sensor worn by astronaut	mission integrated													
74	Satellite position			30 minutes													
75	Interplanetary radio bursts	Radio Wave Detector	Single point measurement in space	1 hour	20 min	1	Three ground stations required										

Figure 27 No. of Spacecraft and/or Ground stations required to meet each CSMR

8.5 Baseline Dedicated Option – Maximum Hitch-hikers (with and without the larger instruments)

8.5.1 CSMR not met by Hitch-hiking due to lack of hosts

The analysis of hitch-hiker options and the extent to which they could meet CSMR, showed that there were several CSMR that almost certainly could not be met on a regular basis by hitch-hiker payloads, due to lack of launch options. These CSMR are as follows:

CSMR not met by Hitch-hiking due to lack of hosts	Instrument	Orbit
CSMR 3	17kg Coronagraph	At 1AU separated heliocentric/ L4/ L5
CSMR 75	11kg Radio Wave Detector	
CSMR 23-27	5kg Thermal energy ion spectrometer	L1
CSMR 36-38	3kg Magnetometer	
CSMR 39-43	3kg Magnetometer	Magnetosphere
CSMR 52	3kg Thermal energy ion spectrometer or Ionosonde or UV Imager, but Thermal energy ion spectrometer preferred due to it having the least mass	Elliptical e.g. GTO

Table 23 CSMR not met by Hitch-hiking due to lack of hosts

8.5.2 CSMR possibly not met by Hitch-hiking due to instrument size

There are several other CSMR, whose instrumentation may have difficulty in finding a host because of their size. These CSMR are as follows

CSMR possibly not met by Hitch-hiking due to instrument size	Instrument	Orbit
CSMR 1	10kg, 200x25x40cm Whole disk Imager	L1/GEO/SS
CSMR 2	17kg 80x30x30cm Coronagraph	1AU helio/L1/GEO/SS
CSMR 4, 6	29kg, 60x70x25cm Auroral Imager	PEO/Molniya

Table 24 CSMR possibly not met by Hitch-hiking due to instrument size

There is some infilling of these CSMR by current and planned missions, and the extent of this varies depending on the amount of collaboration, however, to be fully compliant with all of the CSMR, several dedicated spacecraft are required as platforms for the instruments.

8.5.3 Architecture trade-offs

8.5.3.1 Maximum hitch-hikers (minimum dedicated space segment)

The minimum amount of dedicated spacecraft required is the number of CSMR whose orbit locations have a lack of host spacecraft option. This minimum dedicated space-segment is as follows, including suggested launch scenarios

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 3 (17kg Coronagraph 1)	Leading heliocentric orbit at 1AU	1 micro-spacecraft (700m/s DV)	Microsat configuration on ASAP5 to GTO	$3M
CSMR 3 (17kg Coronagraph 2), CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	1 micro-spacecraft <120kg (1km/s DV)	ASAP5 to GTO (8 microsats)	$3M each
CSMR 39-43 (3kg Magnetometer)	Magneto-spheric orbit	Constellation like UK Swarms throughout magnetosphere	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack
CSMR 52 (3kg Thermal energy ion spectrometer)	GTO	4 micro-spacecraft constellation equally separated in longitude	ASAP5 to GTO	$3M each

Table 25 CSMR met by Minimum dedicated spacecraft using maximum hitch-hikers

8.5.3.2 Maximum hitch-hikers with larger instruments dedicated

If large enough host spacecraft cannot be found for CSMR 1,2, 4/6, 12 and 13, then the dedicated space segment above must be extended. This extended space segment could take the form of several main permutations, which would have the following missions as core elements:

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 3 (17kg Coronagraph)	Leading heliocentric orbit at 1AU	1 micro-spacecraft <120kg (700m/s DV)	Microsat configuration on ASAP5 to GTO	$3M
CSMR 2/3 (17kg Coronagraph); CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M
CSMR 39-43 (3kg Magnetometer)	Magneto-spheric orbit	Constellation like UK Swarms throughout magnetosphere	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack
CSMR 52 (3kg Thermal energy ion spectrometer)	GTO	4 micro-spacecraft equally separated in argument of perigee	ASAP5 to GTO	$3M each

Table 26 Core dedicated spacecraft to meet CSMR

Three main permutations are grouped as L1, SS or GEO biased, which indicates how the configuration of dedicated space segments varies depending on which of the three orbit locations is the preferred choice for carrying instruments with the three orbits as optional locations. It should be noted that many other permutations are possible which are hybrids of the three permutations described, and the permutations below are intended as a guide only to give a feel for the kinds of space segment architectures that would be required.

Permutation 1 – L1 biased option

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 1 (10kg) Whole disk Imager, CSMR 23-27 (5kg Thermal energy ion spectrometer) and CSMR 36-38 (3kg Magnetometer)	L1	Either several microspacecraft <120kg each (1km/s DV)	ASAP5 to GTO (8 microsats)	$3M per satellite
		Or several microspacecraft <220kg wet,	ASAP5 to GTO (carries 4 minisats in bananasat configuration)	$6M
		Or 1-2 mini-spacecraft <300kg but could be as high as 800kg	ARIANE 5 to GTO (4 minisats in SPELTRA)	$6-8M each
		Or 1 minispacecraft <317kg	Eurockot/Star37 Direct to L1	$18M
CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude	2 micro-spacecraft separated in true anomaly by 90deg	Direct (START)	$10M
			Dual/Multi- (DNEPR/ EUROCKOT/ DELTA II)	$2-3M

Table 27 L1 biased baseline option

Permutation 2 – SS biased

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	One micro-spacecraft <120kg each (1km/s DV)	ASAP5 to GTO (8 microsats)	$3M per satellite
CSMR 1 (10kg) Whole disk Imager, CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg.	Single (START)	$10M
			Dual (micro)/Multi- (DNEPR/ EUROCKOT/ DELTA II)	$2-3M
			Single (DNEPR, EUROCKOT, TAURUS, KISTLER	$12-20M?
			Dual (DELTA II)	$8-10M

Table 28 SS biased baseline option

Permutation 3 – GEO biased

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	One micro-spacecraft <120kg each	ASAP5 to GTO (8 microsats)	$3M per satellite
CSMR 1 (10kg) Whole disk Imager	GEO	Need two spacecraft each with a whole disk imager.	2 separate micro-satellites on ASAP5 to GTO <120kg	$3M per satellite
			Several microsatellites on ASAP5 to GTO (4 minisats in bananasat configuration). <220kg	$6M
			1 or 2 minisats on ASAP5 to GTO (4 minisats) Must find 4 similar partners otherwise pay ¼ of launch cost of $130M or $32.5 M <300kg but could be as high as 800kg	$6M each
			1 smallsat in Dual launch scenario to GTO on ARIANE 5	¼ of launch cost of $130M or $32.5 M
			PSLV To GTO dedicated <1550kg	$25M
CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg.	Direct (START)	$10M
			Dual/Multi- (DNEPR/ EUROCKOT/ DELTA II)	$2-3M

Table 29 GEO biased baseline option

8.6 Secondary Dedicated Option – Optimum use of hitch-hikers and dedicated spacecraft

8.6.1 Architecture trade-offs

This section discusses the extension of previously defined dedicated space weather spacecraft as hosts for the space weather instruments that met the CSMR as hitch-hikers.

Previously a space segment of hitch-hikers only, was considered, and an orbit trade-off decided where a fleet of hitch-hikers should inhabit, if possible, for each CSMR. This fleet of hitch-hikers along with the present and planned space infrastructure formed the space segment for option 2. However, if a space segment is to include hitch-hikers and dedicated spacecraft, a different approach is required. This means that each CSMR can no longer be treated individually, and the whole picture must be investigated simultaneously.

A classic example would be the trade-off between L1 and Sun-synchronous orbit. Previously, when considering only hitch-hiker additions to a space segment, a sun-synchronous orbit would have been preferred on the basis that there are far more opportunities for hitch-hikers to go to SS. However, if several CSMR's are grouped together, then it may be more cost-effective to have a dedicated spacecraft at L1, than have several hitch-hikers at SS.

As with the baseline dedicated option, an extended space segment could take the form of several main permutations, which would now have the following missions as core elements:

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 3 (17kg Coronagraph)	Leading heliocentric orbit at 1AU	1 micro-spacecraft <120kg	Microsat configuration on ASAP5 to GTO	$3M
CSMR 2/3 (17kg Coronagraph), CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M
CSMR 39-43 (3kg Magnetometer)	Magnetospheric orbit	SWARM-type constellation	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack
CSMR 52 (3kg Thermal energy ion spectrometer), CSMR 53 to 55 (6kg Medium energy electron spectrometer, CSMR 59 to 61 (5kg Thermal energy ion spectrometer), CSMR 66 to 67 (8kg High energy electron spectrometer)	GTO	4 micro-satellites equally separated in argument of perigee	ASAP5 to GTO	$3M

Table 30 Core dedicated spacecraft to meet CSMR in optimum dedicated option

As with the baseline dedicated option, three main permutations are grouped as L1, SS or GEO biased, which indicates how the configuration of dedicated space segments varies depending on which of the three orbit locations is the preferred choice for carrying instruments with the three orbits as optional locations. Again, many other permutations are possible, which are hybrids of the three permutations described, and the permutations below are intended as a guide only to give a feel for the kinds of space segment architectures that would be required.

Permutation 1 – L1 biased (GTO given priority over GEO as cheaper launch costs)

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 1 (10kg) Whole disk Imager, CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer), CSMR 23-27 (5kg Thermal energy ion spectrometer) and CSMR 36-38 (3kg Magnetometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector)	L1	Either several microspacecraft <	ASAP5 to GTO (8 microsats)	$3M per satellite
		Or several microspacecraft <220kg wet,	ASAP5 to GTO (4 minisats in bananasat configuration)	$6M each
		Or 1-2 minispacecraft	ARIANE 5 to GTO (4 minisats in SPELTRA) Must find 4 similar partners otherwise pay ¼ of launch cost of $130M or $32.5 M	$6-8M per satellite if all minisat ring filled
		Or 1 minispacecraft <317kg	Eurockot/Star37 Direct to L1	$18M
CSMR 4, 6 (29kg) Auroral Imager, CSMR 69 to 71 (Debris monitor)	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg.	Direct (START)	$10M
			Dual/Multi-(DNEPR/ EUROCKOT	$2-3M each

Table 31 L1 biased extended option

Permutation 2 – SS biased (L1 priority over GEO)

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector)	L1	1 or 2 microsatellites	ASAP5 to GTO (8 microsats)	$3M per satellite
CSMR 1 (10kg) Whole disk Imager, CSMR 4, 6 (29kg) Auroral Imager, CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer), CSMR 69 to 71 (Debris monitor)	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg. 1 spacecraft has only Whole disk imager and Auroral imager	Single (START)	$10M
			Dual(micro)/Multi-(DNEPR/ EUROCKOT/ DELTA II)	$2-3M
			Single (DNEPR, EUROCKOT, TAURUS, KISTLER	$12-20M?
			Dual (DELTA II)	$8-10M

Table 32 SS biased baseline option

Permutation 3 – GEO biased (GTO priority over GEO)

CSMR	Orbit	Spacecraft	Launcher	Launch cost
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	<120kg	ASAP5 to GTO (8 microsats)	$3M per satellite
CSMR 1 (10kg) Whole disk Imager, CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector),	GEO	Need two spacecraft - each with a whole disk imager. Need only one spacecraft each for other instruments	Separate micro-satellites on ASAP5 to GTO <120kg	$3M per satellite
			Several microsatellites on ASAP5 to GTO (4 minisats in bananasat configuration). <220kg	$6M
			1 or 2 minisats on ASAP5 to GTO (4 minisats) Must find 4 similar partners otherwise pay ¼ of launch cost of $130M or $32.5 M <300kg but could be as high as 800kg	$6M per satellite if all minisat ring filled
			1 smallsat in Dual launch scenario to GTO on ARIANE 5	¼ of launch cost of $130M or $32.5 M
			PSLV To GTO dedicated <1550kg	$25M
CSMR 4,6 (29kg) Auroral Imager, CSMR 69 to 71 (Debris monitor)	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg. 1 spacecraft has only Whole disk imager and Auroral imager	Direct (START)	$10M
			Dual/Multi-(DNEPR/ EUROCKOT	$2-3M each

Table 33 GEO biased baseline option

9. WP424 – PLATFORM DEFINITION

9.1 Current/available and planned platform survey

The following table describes many current and planned European platforms. Some have been used (or were intended to be used) for solar-terrestrial mission (e.g. Astrid, Cluster, Munin, SOHO and Storms), and re-using such platforms for similar purposes may be attractive. The costs are very rough, and were extrapolated from known missions using a mass/cost relationship (i.e. cost scaling with mass). This is not always the case and therefore the estimation is only useful as a first cut.

	ASTRID/ FREJA	CLUSTER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Class	Micro (10-100kg)		Micro (10-100kg)	Mini (100-500kg)	Mini (100-500kg)	Small (500-1000kg)		Mini (100-500kg)	Nanosat	Micro (10-100 kg)	Small (500-1000kg) and Large (>1000 Kg)	Mini (100-500kg)	Mini (100-500kg)	Micro (10-100kg)		Mini (100-500kg)	Micro (10-100kg)	Micro (10-100kg)	Mini (100-500kg)	
Dimensions	95*45*40 cm(stowed solar panels)	d 2.9m x h 1.3m	60x75x80 cm (PICARD)	65*65*75 cm	95*95*95 cm	1.5m high	1.5x1.5x1.7m	255,7*283,9*122,6 cm	21 x 21 x 21 cm	72*45*34 cm	Platform module: diam. < 2m ; h: 1m	80,5*60*60 cm	100*100*100 cm	60 x 60 x 71 cm			680x580x525mm	69*36*36 cm (84,3*58,2*58,2 cm antennas fully ext)	120 cm diameter, 100 cm Height	1.5m x phi2.6m
Bus dry Mass	21 kg	550kg	Approx. 70 kg	150-200 kg	250 to 300 kg	500kg	500kg	200 kg	5kg	50 kg?	300-1000 kg (350kg)		270 kg				90-100 kg	50 kg	400 kg	552kg inc 58kg payload and 139kg prop system
Mass at Launch	30 kg	1200kg	Approx. 120 kg	250 to 600 kg	500 to 1300 kg	1000kg?	1470kg	600 kg	6kg	60 kg	up to 2000 kg	about 100 kg	400 to 600 kg	84kg		200kg	110 - 130 kg	50-90 kg	550 kg	1873kg

	ASTRID/ FREJA	CLUS TER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Payload available mass	9kg for ASTRID2	72kg	up to 50 kg	100 to 400 kg	200 to 1000 kg	600kg	370kg	300 kg			up to 1000 kg for SAR		100-300 kg				25 kg	15-35 kg	150 kg	>58kg
Payload available volume			Depends on the launcher								Payload module: diam. < 2m ; h up to 2m							Up to three standard modules with a total volume 35*35*76cm		
Payload available power	16w continiou sly	47W	75 W	Typ 250 W (up to 600 W)	Typ 450 W (up to 1000 w)	650W		360 W		30 W	up to several KW depending on specific mission characteristics	30 W average in eclipse	200 up to 300 W				60 W (BOL)	15 W	300 W	
Stabilisat ion type	spin	spin	3 Axis	3 Axis	3 Axis	3 Axis	3 Axis	3 Axis	Passive magnetic (spin once per orbit relative to Earth)	Gravity gradient	3 Axis	3 Axis	3 Axis	3 Axis			Spin	Gravity gradient/3A xis	Gravity gradient/3A xis	spin
Pointing accuracy	Solar aspect angle - Accuracy : ± 0.15deg in solar angle 4-30deg		0.1deg (PICARD)		<10^-4deg/s stability	RPE 10"	RPE 30"	Custom			RPE 30"		0.05deg; RPE 150"	Pitch/Yaw : 2 arcmin absolute; Roll 60 arcmin absolute			Spin stabilised control to ± 3°. ; knowledge - Sun & Earth aspect angle to	1 arc minute	0.1 degree attitude control	0.5deg

	ASTRID/ FREJA	CLUSTER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
																	± 2°			
Pointing Stability			0.01deg (PICARD)											Pitch/Yaw :0.8 arcmin over 1 sec. , 0.35 arcmin over 0.1 sec. ; Roll : 2 arcmin over 60 sec.						0.2deg
Navigation			Doppler, Doris or GPS		GPS			n/a	No GPS	GPS	GPS	Norad/GPS	GPS					NORAD (+/- 1 km)	GPS autonomous orbit	
Data rate	128Kbps (S-band)	262kbps	613kbps (S-band)		10-100kbps	X band	X-band	S-band		256 kbits/s	X-band		613kbps (S-band)	64kbit/s			10kbps	S-band	L/S-band 1Mbps	2Mbps
Mass memory			1Gbits			160Gbits	12Gbits	0.3Gbits	2Mbytes RAM		300Gbits		2Gbits					1.5Gbits		
Propulsion type	Solid propellant		Hydrazine	Hydrazine	Hydrazine	Hydrazine	Biprop	Hydrazine		n/a	Hydrazine	n/a	Hydrazine				Cold gas (Xe)	Cold gas or electric	Cold gas or electric	

	ASTRID/ FREJA	CLUSTER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Mission lifetime			3 years	up to 5 years	up to 5 years	up to 5 years	>6years	2 to 3 years		14 months	up to 7 years	2 years	3 to 5 years				4 years	1 to 3 years		2yrs+4yrs extended
Propellant Mass		650kg	2,5 kg				600kg	100 kg		n/a	up to 135 kg	n/a	28 kg							
Orbit type	LEO		LEO or GTO	LEO	LEO			LEO	LEO	LEO	any LEO	LEO	LEO				Exotic	LEO	LEO	709x44647km, +/-15deg inc
Orbit intended	Circular (1000km altitude)		altitude: 400 to 1200 km	450 to 1500 km altitude	450 to 1500 km altitude			Circular (600 km)		Elliptical orbit (apogee 857 km, perigee 655 km)	Sun Synchronous Orbits	Circular (817 km)	Various orbits (phased, sun synchronous, frozen and inertial orbits)				GTO (300*36 000 km)	Sun synchronous (400 to 1400 km)		
Orbit inclination	83°		Any inclination	Any inclination	Any inclination			28,5°		96,47°	any Sun Synchronous Orbits	98,7°	From 15° to 145°				4° to 7°	Around 98°		
Mission type	Science		Science or Technology	Multipurpose	Multipurpose			Science		Science	Multipurpose	Earth Observation/Science	Multipurpose				Science	Multipurpose	Multipurpose	

	ASTRID/ FREJA	CLUSTER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Programs	Astrid-2		DEMETER, PICARD, FRANCO BRESILIEN, PARASOLE, MICROSCOPE		Rocsat 2			Minisat		Danish Orsted Satellite	RADARSAT 2, Cosmo/Skymed (ASI), David (ASI)	PROBA: Project for on board autonomy	JASON, Corot, PICASSO-CENA				STRV (Space Technology Research Vehicle)	UOSAT-3, UOSAT-5, KITSAT-1, S-80/T, KITSAT-2, HealthSat II, PoSAT-1, CERISE, FASat-Alfa	UOSAT-12	
Prime contractor	Swedish Space Corporation	Dornier (now Astrium)	CNES	MATRA MARCONI SPACE (now Astrium)	MATRA MARCONI SPACE (now Astrium)	MATRA MARCONI SPACE (now Astrium)	Astrium	INTA		TERMA Elektronik AS (click)	Alenia Aerospazio Space Division	VERHAERT	Alcatel Space Industries CNES		MATRA MARCONI SPACE (now Astrium)	Astrium	Quinetic	Surrey Satellite Technology Ltd (SSTL)Guildford, Surrey GU2 5XH, UK	Surrey Satellite Technology Ltd (SSTL)Guildford, Surrey GU2 5XH, UK	
Prime contractor	http://www.ssc.se/	http://www.astrium-space.com	http://www.cnes.fr/	http://www.astrium-space.com	http://www.astrium-space.com	http://www.astrium-space.com	http://www.astrium-space.com	http://www.inta.es/		http://www.terma.com/	Alenia Aerospazio Space Division	http://www.verhaert.com/	http://www.alcatel.com/		http://www.astrium-space.com	http://www.astrium-space.com	http://www.dera.gov.uk/	http://www.sstl.co.uk/	http://www.sstl.co.uk/	

	ASTRID/ FREJA	CLUS TER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Country of the prime	Sweden	Germany	France	UK/France	UK/France	UK/France	UK/France	Spain	Sweden	Denmark	Italy	Belgium	CNES (click)			UK	UK	UK	UK	
Production site/integration	Swedish Space Corporation PO Box 4207 S-17104 SOLNA, SWEDEN		CNES 18 Avenue Edouard Belin F-31401 TOULOUSE	MMS Toulouse				INTA Carretera de Ajalvir, km.4 Torrejon de Ardoz E-28850 Madrid		TERMA Elektronik AS - Bregnerodveg 144- DK-3460 Birkerod	Alenia Aerospazio - Via Saccomuro 24 Space Division I-00131 Roma	Verhaert Design & Development	France				DERA Farnborough, Hampshire GUI4 OLX United Kingdom	Surrey Space Centre - University of Surrey Guildford, Surrey GU25XH, UK	Surrey Space Centre - University of Surrey Guildford, Surrey GU25XH, UK	
Launchers	Cosmos-3M		PSLV, Ariane, PLS	Pegasus XL, Leolink 1, Start.	Eurockot, Athena 2, Leolink 2, Cosmos, Taurus.		Soyuz-Fregat	Pegasus XL	Delta II (third passenger with EO-1)	Delta II	small: Vega, Rockot, Taurus, Athena; large: Delta II, PSLV, Soyuz 2	PSLV(Polar satellite launch vehicle) from Antrix/ISRO India	Alcatel Space Industries - BP 99-				Ariane 5	Ariane, Long March, Delta, Zenit, SS18/Dnepr	Ariane, Long March, Delta, Pegasus, CIS	
First launch	1998		2001		1 Planned		2003	1997		1999	2002	2000	Compatible with all launch vehicles (Fairing>1,9m)				2000 planned	1990	1999	

	ASTRID/ FREJA	CLUS TER	CNES MICRO	LEOSTAR 200	LEOSTAR 500	LEOSTAR 500X0	MARS EXPRESS	MINISAT 01	MUNIN	OERSTED	PRIMA	PROBA	PROTEUS	ROEMER	SOHO	SPECTRE /AMM	STRV-1 c,d	SSTL micro	SSTL mini	STORMS
Number of flights	3		5 Planned (2001 to 2004)		1 Planned			1		1	9 planned	1 (scheduled 3rd Quarter 2000)	2000				2 planned	11?	1	
Units Produced	3		5 planned		1 Planned			1		1	9 planned	1	5 planned (2000, 2002,…)				2	11	1	
Website	http://www.ssc.se/ssd/msat/astrid2.html								http://munin.irf.se/frames/index.html				5 planned (2000, 2002,…)							

9.2 Potential space weather applications of selected current/available and planned platforms

This section contains illustrations of several potential European platforms surveyed, to give an indication of the type of configuration the spacecraft would have, along with a description of the type of space weather application, that the platform might be suitable for.

9.2.1 CNES Microsatellite – PICARD

PICARD is one of a number of CNES microsatellites, which have the same generic platform. As PICARD observes the Sun, the CNES Microsatellite bus might be a potential platform for instruments, such as Whole Disk Imagers and Coronagraphs, which also observe the sun. It is 3-axis stabilised and has a mass of less than 120kg.

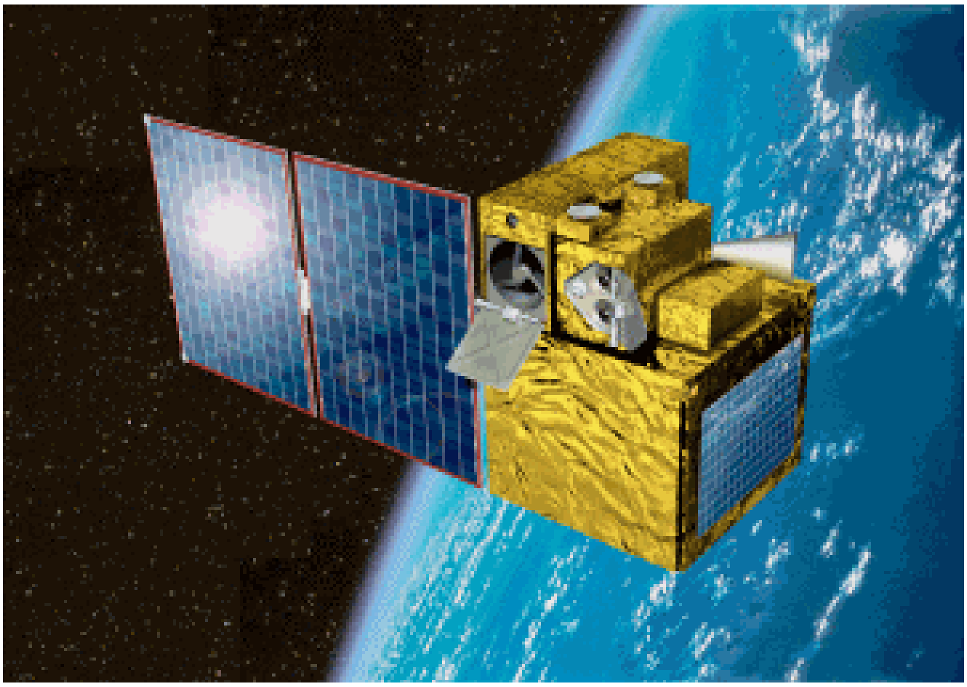


Figure 28 CNES Microsatellite – PICARD

9.2.2 CLUSTER

The CLUSTER satellites are multi-payload Solar-Terrestrial Physics mission. Although, not exactly a small satellite, it may be a potential platform for carrying out multi-payload space weather measurements at L1 or possibly even GEO

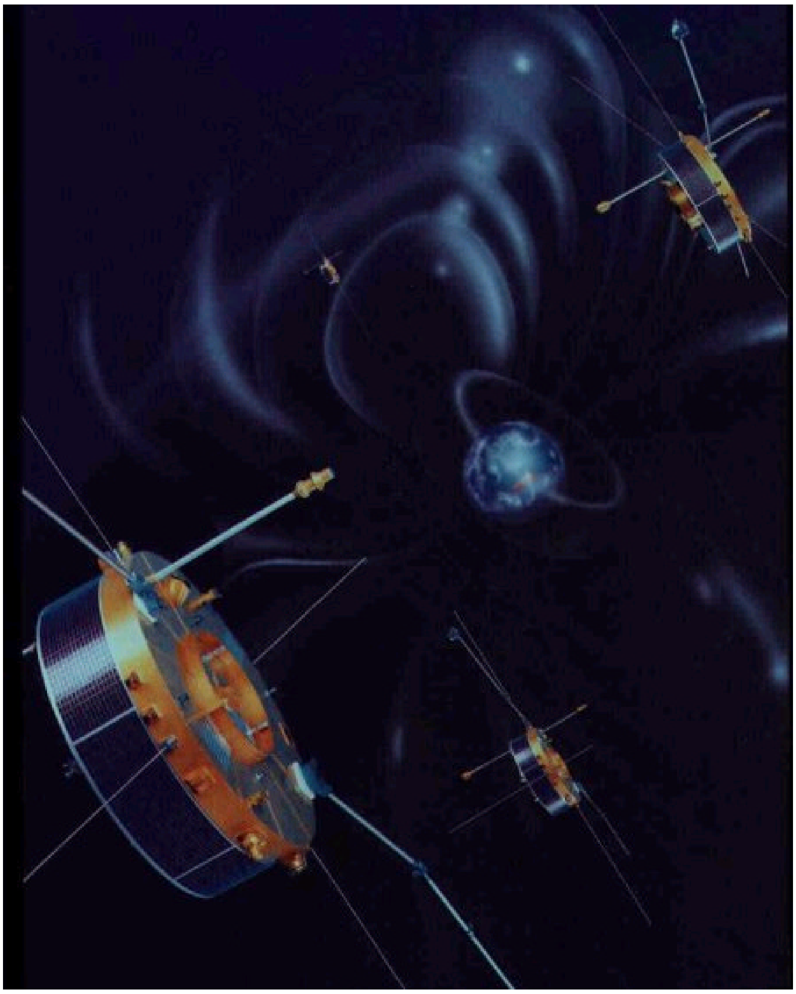


Figure 29 CLUSTER

9.2.3 STRV c/d satellites

STRV c/d are micro-satellites, which are specifically designed for GTO. Therefore, it may be a potential platform for carrying out space weather measurements at GTO.

Figure 30 STRV c/d satellites

9.2.4 ASTRID 2

ASTRID-2 is a spin-stabilised micro-spacecraft platform, and may be a potential platform for carrying out space weather measurements with smaller instruments that better suited by a spinning platform. Potential orbit locations could be L1 or Sun-synchronous.

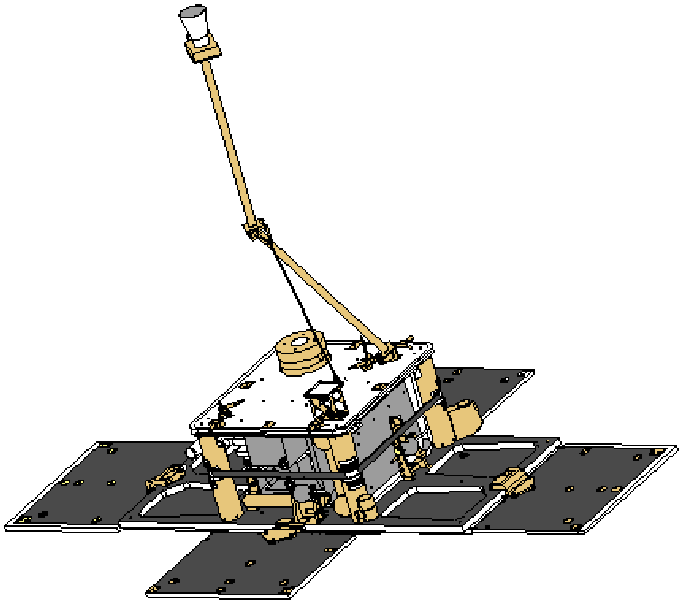


Figure 31 ASTRID 2

9.2.5 MUNIN Nanosatellite

The MUNIN nano-satellite had a mass of less than 10kg, and carried out Auroral measurements during its mission. It might therefore be useful to carry out similar measurements for a future space weather service.

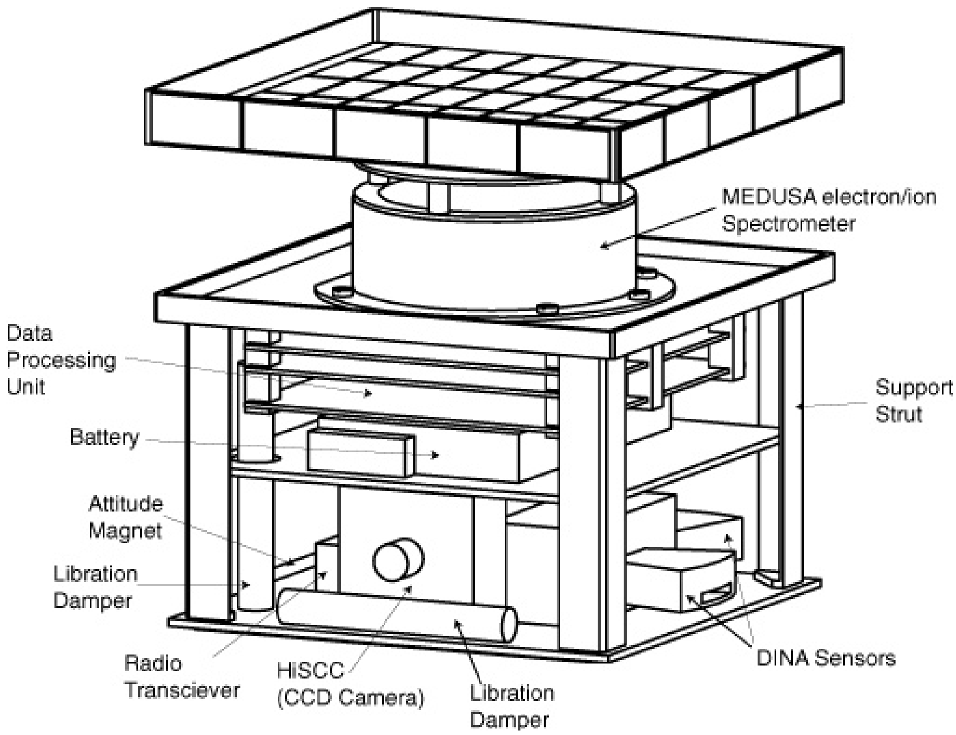
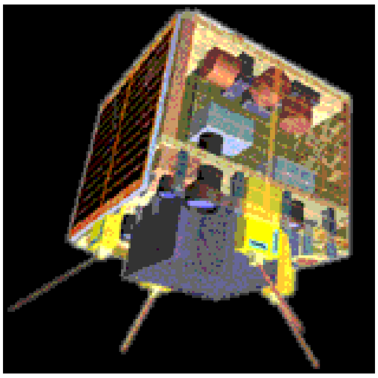


Figure 32 MUNIN Nanosatellite

9.2.6 SSTL enhanced microsat and SSTL Minisat

SSTL have developed both Microsats and Minisats in recent years. These might be potential platforms for a range of orbits depending on the application.



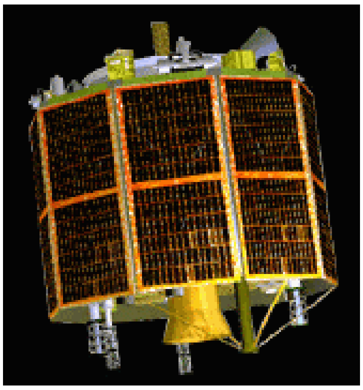


Figure 33 SSTL enhanced microsat (left) and SSTL Minisat (right)

9.2.7 LEOSTAR 200

The LEOSTAR 200 is the smallest of the 3-axis LEOSTAR platforms. It may be a suitable platform for carrying several space weather payloads as it is larger than the CNES microsatellite bus, and also small enough to be compatible with Rockot to L1 and START or PEGASUS to LEO deliveries.

Figure 34 LEOSTAR platform

9.2.8 STORMS spacecraft

The STORMS spacecraft, like CLUSTER were intended to be multi-payload Solar-Terrestrial Physics spacecraft. As with CLUSTER, STORMS satellites are not exactly small, however it may be a potential platform for carrying out multi-payload space weather measurements at L1 or possibly even GEO

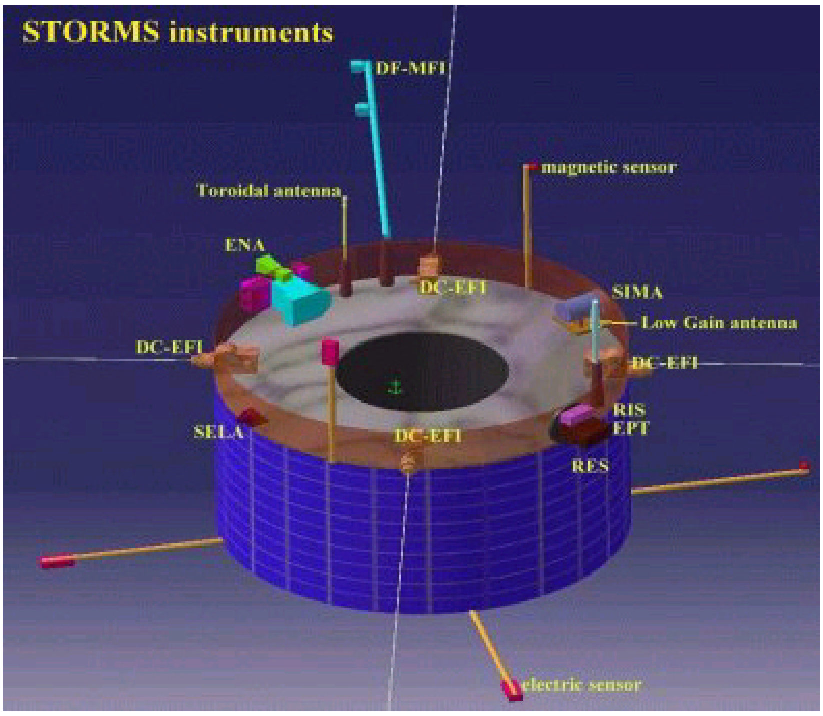


Figure 35 STORMS spacecraft

9.3 Platform Definition and costing

A wide choice of potential European platforms could be available to meet the requirements of a dedicated element of a space weather service. Defining applicable platforms to meet the CSMR depends on many factors such as pointing, stability, cost and thermal as described earlier. These factors must be taken into account before selecting one of the platforms. It is entirely possible that none of the platforms described would be applicable to meet a particular CSMR. In this situation, either a complete re-design of an available platform, or even bespoke platform concept would be required. However, for the purpose of this study we have assumed that CSMR requiring dedicated spacecraft can be met by existing European platforms. The list of platforms used in defining the dedicated space segments is shown in Table 34.

Platform	Stabilisation	Launch Mass assumed
CNES microsatellite (e.g. PICARD	3 axis	120kg
ASTRID	Spin Stabilised	30kg
LEOSTAR 200	3 axis	250kg
STRV c/d	Spin Stabilised	120kg
SWARM	Spin Stabilised	30kg

Table 34 Platforms used in dedicated space segments

A preliminary costing has also been carried out, which defines costs for each mission element. A cost model (based on RD/21, table 20-9, page 799) has been used to do this and takes into account initial spacecraft/instrument costs (including non-recurring costs) as well as subsequent spacecraft /instrument costs, which are cheaper as they do not include non-recurring elements. Learning factors and batch costings are not included as they are beyond the scope of this study, but would result in lower costs for later elements in a continuous programme. Table 35 shows an example cost breakdown, which could meet CSMR 3 for a PICARD type spacecraft carrying a 14Meuro Whole disk imager. All costs apart from the instrument cost, are parametrically related to the launch mass. The instrument costs are not parametrically related, and are actual costs that originate from the WP421 report.

As the instrument cost is not accounted for in the estimate of AIT and Programme level costs), the model may become slightly less accurate if the instrument costs are high in ratio to the spacecraft/bus costs. This is because the original model in RD/21 assumed a parametric payload cost fraction of 40% of the bus cost, which was replaced by actual space weather instrument costs for the purpose of this study. Therefore a high instrument cost on a microsatellite would slightly under-predict Programme level and AIT costs.

As with hitch-hiking, operations processing/archive/dissemination/space weather service costs, are not within the scope of the space segment study as they are covered in WP431 and WP432.

Subsystem	Fraction of Bus cost (%)	First spacecraft costs (MEuro)	Second spacecraft costs MEuro)
Payload	120 @ 14MEuro	14.00	
Spacecraft Bus Total	**100.0**	**11.71**	
Structure	18.3	2.14	
Thermal	2.0	0.23	
Power	23.3	2.73	
TT&C	12.6	1.46	
C&DH	17.1	2.00	
ADCS	18.4	2.15	
Propulsion	8.4	0.98	
Integration, Assembly and Test	13.9	1.63	
Program Level	22.9	2.68	
Ground Support Equipment	6.6	0.77	
Launch & Ops support	6.1	0.71	
Total Spacecraft	**189.5**	**31.50**	**12.40**
Launch		3	3
ESA/Other costs (10% of Total spacecraft costs)		3.15	1.24
TOTAL		**37.65**	**16.64**
Insurance (15%)		5.65	2.50
Contingency (10%)		4.33	1.91
Mark-up (8%)		2.52	0.99
GRAND TOTAL		**50.15**	**22.04**

Table 35 Cost breakdowns for a 120kg mass spacecraft, 14Meuro instrument and 3Meuro launch

Each dedicated spacecraft is costed for both an initial spacecraft and as a follow-on spacecraft. Both of these costs are divided by 5 to arrive at a figure in cost/year. If for example 9 years were required to hitch-hike, i.e. between 2007-2015, then 5 years would be using the initial spacecraft (and initial instrument costs), and 4 years would be using the follow-on spacecraft (and instrument). The cost is calculated from the number of years for which each instrument is used.

The following tables contain information regarding each dedicated space segment option, including suggested platform, instrument cost on a particular platform, initial programme costs and subsequent programme costs. This information is key in determining an estimated cost for each dedicated space segment option.

In order to reduce costs the aim is to try and find the most cost efficient solutions for each CSMR. Examples would be taking advantage of the extremely cheap launches as an ASAP 5 microsatellite, or using a spin-stabilised satellite as platform for instruments best suited as a spinner.

9.3.1 Platforms to meet CSMR using Minimum dedicated space craft and maximum hitch-hikers

The minimum amount of dedicated spacecraft required is the number of CSMR whose orbit locations have a lack of host spacecraft option. This minimum dedicated space-segment is as follows, including suggested launch scenarios.

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 3 (17kg Coronagraph 1)	Leading heliocentric orbit at 1AU	1 micro-spacecraft <120kg	Microsat configuration on ASAP5 to GTO	$3M	CNES microsatellite (e.g. PICARD)	3 Ground Stations required. Re-fit required for propulsion?	17	54.57	23.79
CSMR 2/3 (17kg Coronagraph 2), CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M	LEOSTAR 200	3 Ground Stations required.	22	117.51	60.07
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	1 micro-spacecraft <120kg	ASAP5 to GTO	$3M per satellite	STRV C/D	3 Ground Stations required. Re-fit required for propulsion?	9	42.79	19.15
CSMR 39-43 (3kg Magnetometer)	Magneto-spheric orbit	Constellation like UK Swarms throughout magnetosphere	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack	SWARM	Require mobile constellation for downlink?	5	83.33 (£50M)	83.33 (£50M)
CSMR 52 (3kg Thermal energy ion spectrometer)	GTO	4 micro-spacecraft < 120kg, in a constellation equally separated in longitude	Microsat configuration on ASAP5 to GTO	$3M	STRV c/d	3 well separated, low latitude ground stations required	4	35.44	16.25

Table 36 Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers

9.3.2 Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

9.3.2.1 Core Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

If large enough host spacecraft cannot be found for CSMR 1,2, 4/6, then the dedicated space segment above must be extended. This extended space segment could take the form of several main permutations, which would have the following missions as core elements:

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 3 (17kg Coronagraph)	Leading heliocentric orbit at 1AU	1 micro-spacecraft <120kg	Microsat configuration on ASAP5 to GTO	$3M	CNES microsatellite (e.g. PICARD)	3 Ground Stations required. Re-fit required for propulsion?	17	54.57	23.79
CSMR 2/3 (17kg Coronagraph), CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M	LEOSTAR 200	3 Ground Stations required.	22	117.51	60.07
CSMR 39-43 (3kg Magnetometer)	Magneto-spheric orbit	Constellation like UK Swarms throughout magnetosphere	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack	SWARM	Require mobile constellation for downlink?	5	83.33 (£50M)	83.33 (£50M)
CSMR 52 (3kg Thermal energy ion spectrometer)	GTO	4 micro-spacecraft constellation equally separated in longitude	<120kg per satellite	$3M	STRV c/d	3 Ground Stations required	4	35.44	16.25

Table 37 Core Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

Three main permutations are grouped as L1, SS or GEO biased, which indicates how the configuration of dedicated space segments varies depending on which of the three orbit locations is the preferred choice for carrying instruments with the three orbits as optional locations. It should be noted that many other permutations are possible which are hybrids of the three permutations described, and the permutations below are intended as a guide only to give a feel for the kinds of space segment architectures that would be required.

9.3.2.2 L1 biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 1 (10kg) Whole disk Imager,	L1	Minispacecraft	Eurockot/Star37 Direct to L1 to carry both Mass limit is <317KG	$18M (free launch assumed for ASTRID)	PICARD (3 axis--stabilised)	3 Ground Stations required.	14	69.13	41.02
CSMR 23-27 (5kg Thermal energy ion spectrometer) and CSMR 36-38 (3kg Magnetometer)	L1	Micro-spacecraft			ASTRID (spin-stabilised)	3 Ground Stations required.	9	19.15	7.54
CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude)	2 micro-spacecraft separated in true anomaly by 90deg	Direct (START)	$10M	PICARD	2 Polar Ground Stations required	10	53.12	28.58

Table 38 L1 biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

9.3.2.3 SS biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 23-27 (Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	One micro-spacecraft <120kg	ASAP5 to GTO	$3M per satellite	STRV	3 Ground Stations required.	9	42.79	19.15
CSMR 1 (10kg) Whole disk Imager, CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg	Single (START)	$10M	PICARD	2 Polar Ground Stations required	24	73.72	36.69

Table 39 SS biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

9.3.2.4 GEO biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	One micro-spacecraft <120kg	ASAP5 to GTO (8 microsats)	$3M per satellite	STRV	3 Ground Stations required	9	42.79	19.15
CSMR 1 (10kg) Whole disk Imager	GEO	Need two micro-spacecraft	2 separate micro-satellites on ASAP5 to GTO <120kg	$3M per satellite	PICARD	2 Ground Stations required	14	50.15	22.05
CSMR 4, 6 (29kg) Auroral Imager	SS (Dawn-dusk >600km altitude)	2 spacecraft separated in true anomaly by 90deg	Direct (START)	$10M each	SSTL micro/MUNIN	2 Polar Ground Stations required	10	53.12	28.58

Table 40 GEO biased Platforms to meet CSMR using Minimum dedicated spacecraft and maximum hitch-hikers (larger instruments dedicated)

9.3.3 Platforms to meet CSMR using Full dedicated space segment

9.3.3.1 Core Platforms to meet CSMR using Full dedicated space segment

This section discusses the extension of matching platforms to previously defined dedicated space weather spacecraft as hosts for the space weather instruments that met the CSMR as hitch-hikers. As with the baseline dedicated option, platforms included in an extended space segment could take the form of several main permutations, which would now have the following missions as core elements:

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 3 (17kg Coronagraph)	Leading heliocentric orbit at 1AU	1 micro-spacecraft <120kg	Microsat configuration on ASAP5 to GTO	$3M	PICARD	3 ground stations required	17	54.57	23.79
CSMR 2/3 (17kg Coronagraph), CSMR 75 (11kg Radio Wave Detector)	Trailing heliocentric orbit at 1AU	Mini-spacecraft, <317kg	Eurockot/Star37 Direct	$18M	LEOSTAR 200	3 ground stations required	22	117.51	60.07
CSMR 39-43 (3kg Magnetometer)	Magnetospheric orbit	SWARM-type constellation	Possibly Stacks of 6 in Microsat configuration on ASAP5 to GTO	$3M per stack	SWARM	Require mobile constellation for downlink?	5	83.33 (£50M)	83.33 (£50M)
CSMR 52 (3kg Thermal energy ion spectrometer), CSMR 53 to 55 (6kg Medium energy electron spectrometer, CSMR 59 to 61 (5kg Thermal energy ion spectrometer), CSMR 66 to 67 (8kg High energy electron spectrometer)	GTO	Need 4 equally separated, identical micro-spacecraft	<120kg per satellite	$3M	STRV c/d	3 well separated, low latitude ground stations required	18	56.04	24.36

Table 41 Core Platforms to meet CSMR using Full dedicated space segment

As with the baseline dedicated option, three main permutations are grouped as L1, SS or GEO biased, which indicates how the configuration of dedicated space segments varies depending on which of the three orbit locations is the preferred choice for carrying instruments with the three orbits as optional locations. Again, many other permutations are possible, which are hybrids of the three permutations described, and the permutations below are intended as a guide only to give a feel for the kinds of space segment architectures that would be required.

9.3.3.2 L1 biased Platforms to meet CSMR using Full dedicated space segment (GTO given priority over GEO as cheaper launch costs)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 1 (10kg) Whole disk Imager, CSMR 8-11 (27kg) X-ray Photometer, CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer)	L1	Minispacecraft	Eurockot/Star37 Direct to L1 to carry both Mass limit is <317KG	$18M (free launch assumed for ASTRID)	LEOSTAR 200 (3 axis--stabilised)	3 Ground Stations required.	24	120.45	61.23
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector)		Micro-spacecraft spacecraft			ASTRID (spin-stabilised)	3 Ground Stations required.	20	35.33	13.91
CSMR 4, 6 (29kg) Auroral Imager, CSMR 69 to 71 (Debris monitor)	SS (Dawn-dusk >600km altitude)	2 micro-spacecraft spacecraft separated in true anomaly by 90deg	Direct (START)	$10M	PICARD	2 polar ground stations required	14	59.01	30.9
CSMR 4, 6 (29kg) Auroral Imager,			Direct (START)	$10M	PICARD	2 polar ground stations required	10	53.12	28.58

Table 42 L1 biased Platforms to meet CSMR using Full dedicated space segment (GTO given priority over GEO as cheaper launch costs)

9.3.3.3 SS biased Platforms to meet CSMR using Full dedicated space segment (L1 given priority over GEO as already going there)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 8-11 (27kg) X-ray Photometer,	L1	Minisat	Eurockot/Star37 Direct to L1 to carry both Mass limit is <317KG	$18M (free launch assumed for ASTRID)	PICARD	3 Ground Stations required.	5	55.88	35.8
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector)		Microsat			ASTRID	3 Ground Stations required.	20	35.33	13.91
CSMR 1 (10kg) Whole disk Imager, CSMR 4, 6 (29kg) Auroral Imager,	SS (Dawn-dusk >600km altitude), 2 spacecraft separated by 90 deg in true anomaly	Microsat	Single (START)	$10M	PICARD	2 polar ground stations required	24	73.72	36.69
CSMR 1 (10kg) Whole disk Imager, CSMR 4, 6 (29kg) Auroral Imager, CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer), CSMR 18 (1kg Neutron monitor), CSMR 50-51 (5kg Thermal energy ion spectrometer), CSMR 69 to 71 (Debris monitor)		Minisat	Single (START)	$10M	LEOSTAR 200	2 polar ground stations required	33	123.58	56.33

Table 43 SS biased Platforms to meet CSMR using Full dedicated space segment (L1 given priority over GEO as already going there)

9.3.3.4 GEO biased Platforms to meet CSMR using Full dedicated space segment (GTO given priority over GEO as already going there)

CSMR	Orbit	Suggested Spacecraft	Suggested Launcher	Launch cost	Possible Platform	Notes	Total Instrument cost (MEuro)	Mission costs for first spacecraft (MEuro)	Subsequent mission costs (MEuro)
CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer)	L1	<120kg (37.9% fuel required for 1km/s DV so 74.5kg)	Microsat on ASAP5 to GTO	$3M	STRV	3 Ground Stations required	9	42.79	19.15
CSMR 1 (10kg) Whole disk Imager, CSMR 8-11 (27kg) X-ray Photometer	GEO	Need two mini-spacecraft - each with a whole disk imager and X-ray Photometer	All 3 minisats sharing in ASAP5 to GTO (capable of up to 4 minisats) Hence, pay ¼of launch cost of $130M or $32.5 M, i.e. ~ $11M each Limit <300kg but could be as high as 800kg	$11M	LEOSTAR 200	2 Ground Stations required	19	94.12	39.36
CSMR 12 (27kg UV Photometer), CSMR 13 (27kg EUV Photometer),		1 minispacecraft		$11M	LEOSTAR 200	1 Ground Station required	5	73.52	31.25
CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector),		1 microsat	Microsat on ASAP5 to GTO	$3M	STRV	1 Ground Station required	11	45.74	20.31
CSMR 4,6 (29kg) Auroral Imager, CSMR 69 to 71 (Debris monitor)	SS (Dawn-dusk >600km altitude),	2 microsats separated by 90 deg in true anomaly PEO >600km	Direct (START)	$10M	PICARD	2 polar ground stations required	14	59.01	30.9
CSMR 4,6 (29kg) Auroral Imager			Direct (START)	$10M	PICARD	2 polar ground stations required	10	53.12	28.58

Table 44 GEO biased Platforms to meet CSMR using Full dedicated space segment (GTO given priority over GEO as already going there)

9.3.4 Data Downlink Discussion

Few data downlink problems result from the dedicated space segment definition, however a couple of orbit location/spacecraft combinations are discussed in more detail as their raw data rate requirements fail to be met by a simple fixed 10W transmitter. It should be noted that if reduced data rates are acceptable then these problems either disappear or are greatly reduced.

9.3.4.1 Full dedicated spacecraft at L1

A spinning ASTRID-2 type spacecraft was defined to meet the following CSMR/instruments for both the L1 and SS architecture options - CSMR 23-27(Thermal energy ion spectrometer), 36-38 (magnetometer), CSMR 56 to 58, 62 (5kg Thermal energy ion spectrometer >10MeV ions, CSMR 63 to 65 (8kg High energy ion detector). These instruments require a total raw data rate of 14.2kbps, which the highest data rate for any of the proposed L1 spacecraft. As a halo radius of 750 000km requires a minimum beamwidth of 53.1 degrees, a high gain antenna cannot be used if a fixed antenna is used. To meet the data rate requirements a minimum transmitter output power of 26W is required. A 10W transmitter is fine if the halo radius is reduced to 400000km however this requires a higher DeltaV.
If reduced data rates are acceptable, then a 10W fixed antenna meets all of the data rate requirements at L1

9.3.4.2 Heliocentric orbits (data rate/antenna size problem due to link distance)

A 3-axis PICARD type spacecraft was defined as one of two spacecraft to meet the following CSMR/instrument for all of the Core architectures - CSMR 3 (17kg Coronagraph). This instrument requires a total raw data rate of 5kbps. The aim is to downlink stereo measurements with an antenna compatible with ASAP (0.6m). This could be achieved with a separated angle of just under 10deg for a 10W transmitter, or a separated angle of just under 20deg for a 50W transmitter. A transmitter of around 450W would be required at L5/L4 , which would probably be unfeasible with a such a microsat.
If reduced data rates of 0.5W are acceptable, then a transmitter output power of 43W and a transmitter diameter of 0.6m can meet the data rate requirements at L4/5. This transmitter power requirement drops to just 12W for an orbital separation of 30 degrees
Other spacecraft contributing to CSMR 3 is not constrained to keep antenna under 0.6m, so greater separation angles are feasible

9.4 Budgets

Mass budgets are important in further confirming the feasibility of certain platforms to meet CSMR as dedicated platforms. Power budgets, although important, are not seen as significant a driver as the mass budgets. This is because the instrument power requirements are fairly low, and as solar array power density is around 50W/kg, no problems are foreseen unless the antenna input power requirement becomes too high (it is worth noting that 120W of antenna input power would only result in a required array mass of 2.4kg at 50W/kg). Power budgets, therefore are taken no further within the context of this study.

TABLE 45 shows a mass budget for a PICARD type microsatellite (wet mass 120kg) carrying a 10kg payload to various orbits from GTO. This is to analyse the feasibility of such transfers from GTO in a cheap ASAP 5 delivery scenario. A liquid bipropellant propulsion system (Specific Impulse of 320s) is assumed. For a delta V of 1000m/s and 1500m/s, the dry mass would have to be reduced as the required propellant takes the total mass over the 120kg limit on ASAP 5, and this may either mean a redesign of the platform, or that a bespoke platform would be required. The conclusion from these results, however is that transfers from GTO should be feasible for all three Delta V’s.

Any redesign would be accounted for in the costing process as the cost of the initial spacecraft in any sequence includes non-recurring costs such as design and development.

	Delta V required to reach various orbits from GTO		
Item	**700m/s (Drifting Heliocentric)**	**1000m/s (L1)**	**1500m/s (GEO)**
Platform	65kg	65kg	65kg
Payload (CSMR 1 - Whole disk imager)	10kg	10kg	10kg
Propellant required for a wet mass of 120kg	23.99kg	45.49kg	59.87kg
Total	**98.99kg**	**120.49kg**	**134.87kg**
Difference	+21.01kg	-0.49kg	-14.87kg

Table 45 Mass budget assuming a Liquid Bipropellant propulsion system for PICARD platform

9.5 Dedicated timelines and associated cost

The following timelines describe three dedicated space segment scenarios: maximum hitch-hikers (only sparse orbit locations ignored as hitch-hiker locations) and Large instrument dedicated (similar to maximum dedicated, except that large instruments such as whole disk imagers and auroral imagers are deemed to be dedicated possibilities only) and Full dedicated.

9.5.1 All missions – Maximum Hitch-hikers

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of space-craft per round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/yr First Instrument (Meuro)	Cost/yr next instruments (Meuro)	Total cost (Meuro)
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	3	1	54.57	22.79	10.914	4.758	68.944
3 and 76	Stereo visible or UV images of Sun-Earth space, and Interplanetary radio bursts	Coronagraph and Radio Wave Detector	trailing heliocentric (L5)	trailing heliocentric (L5)															5	3	1	117.51	60.87	23.502	12.014	153.552
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	1	1	42.73	19.85	8.559	3.92	46.62
36 to 38	IMF (B-field)	Magnetometer																								
39 to 42	Magnetospheric B-field	Magnetometer	M/sphere	M/sphere															5	4		83.33	93.33	16.666	16.666	149.994
62	Cold ions. Total density only	Thermal energy ion spectrometer; ionosonde, UV imager	Elliptical eg GTO	GTO															5	6	4	75.44	16.25	15.838	13	162.18
																								Total	581.2	Meuro

Figure 36 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

9.5.2 European and International Collaboration – Maximum Hitch-hikers

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partialy covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of space-craft per round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/yr First Instrument (Meuro)	Cost/yr next instruments (Meuro)	Total cost (Meuro)
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	3	1	54.57	23.79	10.914	4.758	68.844
3 and 78	Stereo visible or UV images of Sun-Earth space, and Interplanetary radio bursts	Coronagraph and Radio Wave Detector	trailing heliocentric (L5)	trailing heliocentric (L5)															5	3	1	117.51	68.07	23.502	12.014	153.552
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															6	6	1	42.79	18.18	8.558	3.83	65.77
26 to 28	IMF (B-field)	Magnetometer																								
38 to 43	Magnetospheric B-field	Magnetometer	M/sphere	M/sphere															5	4		83.33	83.33	16.666	16.666	149.994
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical eg GTO	GTO															5	6	4	35.44	16.25	16.838	13	162.19
																									Total	600.35 Meuro

Figure 37 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

9.5.3 European only – Maximum Hitch-hikers

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft per round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/yr First Instrument (Meuro)	Cost/yr next instruments (Meuro)	Total cost (Meuro)
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	6	1	54.57	23.73	18.514	4.758	83.185
3 and 75	Stereo visible or UV images of Sun-Earth space, and interplanetary radio bursts	Coronagraph and Radio Wave Detector	trailing heliocentric (L5)	trailing heliocentric (L5)															5	6	1	117.51	60.07	23.502	12.814	189.594
23 to 27 and 35 to 38	Vsw and Nsw, and IMF (B-field)	Thermal energy ion spectrometer and Magnetometer	L1	L1															5	6	1	42.75	15.15	8.958	3.83	68.77
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	M'sphere															5	6		83.33	83.33	16.666	16.666	183.326
52	Cold ions: Total density only	Thermal energy ion spectrometer, ionosonde, UV Imager	Elliptical eg GTO	GTO															5	6	4	35.44	15.25	16.939	13	162.19
																									Total	683.998 Meuro

Figure 38 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a maximum hitch-hiker scenario

9.5.4 All missions – Large instruments dedicated

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/p First instrument (Meuro)	Cost/p next instruments (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Cost/p of programme (Meuro)
Core																												
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	3	1	54.57	22.73	18.914	4.759	68.944		
2	Solar coronograph images	Coronagraph	L1 / L4 / L5 / SS / GEO																									
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)	trailing heliocentric (L5)															5	3	1	117.51	60.87	23.502	12.114	153.552		
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5/separated heliocentric at 1AU																									
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	M'sphere															5	4		93.33	83.33	16.666	16.666	149.994		
52	Cold ions. Total density only	Thermal energy ion spectrometer, Ionosonde, UV imager	Elliptical eg GTO	GTO															5	6	4	35.44	16.25	10.830	13	162.15		
L1 biased																											705.53	64.139091
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	L1															0	0	1	69.13	41.02	13.828	8.204	0		
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	1	1	18.95	7.54	3.83	1.508	28.658		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
4,8	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	2	53.12	28.58	10.24	11.432	158.292		
SS biased																											779.695	70.879727
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	1	1	42.79	19.85	9.559	3.83	49.62		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	SS															5	6	2	73.72	36.69	22.082	14.676	198.468		
4,8	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS																								
GEO biased																											731.452	66.495273
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	1	1	42.79	19.85	9.559	3.83	49.62		
36 to 38	IMF (B-field)	Magnetometer																										
GEO																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															0	0	2	50.15	22.85	14.44	6.82	0		
SS																												
4,8	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	2	53.12	28.58	10.24	11.432	158.292		

Figure 39 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a large instruments dedicated scenario

9.5.5 European and International Collaboration – Large instruments dedicated

- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost for First instrument (Meuro)	Cost for next instrument s (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Cost/yr of programme (Meuro)
Core																												
2	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	3	1	54.57	23.79	18.914	4.758	68.844		
2	Solar coronagraph images	Coronagraph	L1/L4/L5/SSI GEO	trailing heliocentric (L5)																								
2	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)																5	3	1	117.51	60.07	23.502	12.114	153.552		
15	Interplanetary radio bursts	Radio Wave Detector	L4+L5 (separated) heliocentric at 1AU																									
35 to 43	Magnetospheric B-field	Magnetometer	M/sphere	M/sphere															5	4		83.33	83.33	16.666	16.666	149.994		
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV imager	Elliptical eg GTO	GTO															5	6	4	35.44	16.29	16.838	13	162.19		
L1 biased																											**768.374**	**69.852182**
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	L1															4	8	1	63.13	41.82	13.626	8.204	55.304		
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	15.78	7.94	3.03	1.588	28.188		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	SS															5	6	2	53.12	28.58	16.34	11.432	150.292		
SS biased																											**798.886**	**72.626636**
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	42.79	19.15	8.558	3.83	65.77		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	SS															5	6	2	73.72	36.63	22.892	14.676	198.466		
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	SS																								
GEO biased																											**808.402**	**73.491856**
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	42.79	15.78	8.558	3.03	65.17		
36 to 38	IMF (B-field)	Magnetometer																										
GEO																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															4	8	2	58.15	22.05	14.44	8.82	57.78		
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	SS															5	6	2	53.12	28.58	16.34	11.432	150.292		

Figure 40 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Large instruments dedicated scenario

9.5.6 European only - Large instruments dedicated

- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/yr First Instrument (Meuro)	Cost/yr next instruments (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Cost/yr of programme (Meuro)
Core																												
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	6	1	54.57	22.79	10.914	4.558	113.89		
2	Solar coronagraph images	Coronagraph	L1/L4/L5/SS/GEO	trailing heliocentric (L5)																								
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)																5	6	1	117.51	60.17	23.502	12.034	188.594		
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5 separated heliocentric at 1 AU																									
33 to 43	Magnetospheric B-field	Magnetometer	M'sphere	M'sphere															5	6		83.33	83.33	16.666	16.666	183.326		
52	Cold ions: Total density only	Thermal energy ion spectrometer, ionosonde, UV imager	Elliptical eg GTO	GTO															5	6	4	35.44	16.25	16.838	13	162.19		
L1 based																											915.072	93.188364
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	L1															5	6	1	69.13	41.02	13.826	8.204	110.354		
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	19.65	7.54	3.93	1.508	29.198		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	2	53.12	28.58	16.34	11.432	158.292		
SS based																											892.464	89.224
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	42.79	19.65	8.558	3.93	65.77		
36 to 38	IMF (B-field)	Magnetometer																										
SS																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	SS															5	6	2	73.72	26.89	22.082	14.878	158.466		
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS																								
GEO based																											959.41	87.219091
L1																												
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	42.79	19.65	8.558	3.93	65.77		
36 to 38	IMF (B-field)	Magnetometer																										
GEO																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	GEO															5	6	2	50.78	22.85	14.44	8.82	125.12		
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	2	53.12	28.58	16.34	11.432	158.292		

Figure 41 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Large instruments dedicated scenario

9.5.7 All missions – Full Dedicated (1)

- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Costfor First Instrument (Meuro)	Costfor next instruments (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Costfor of programme (Meuro)
Core																												
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	2	1	54.57	23.79	11.114	4.759	69.044		
2	Solar coronograph images	Coronograph	L1 / L4 / L5 / SS / GEO	trailing heliocentric (L5)															5	3	1	117.51	60.07	23.502	12.014	158.552		
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)																									
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5/separated heliocentric at 1AU																									
39 to 43	Magnetospheric B-field	Magnetometer	M'sphere	M'sphere															5	4		83.33	83.33	16.666	16.666	149.994		
52	Cold ions. Total density only	Thermal energy ion spectrometer; ionosonde, UV imager	Elliptical eg GTO	GTO															5	6	4	56.04	24.36	25.824	19.408	246.048		
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO																									
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO																									
66 to 67	Relativistic electrons (>0.3MeV) and spectra	High energy electron spectrometer	GEO, GTO																									
L1 biased																											1023.4	93.03636364
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	L1															5	4	1	120.45	61.23	24.09	12.246	166.434		
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO																									
12	UV flux	UV photometer	L1 / SS / GEO																									
13	EUV flux	EUV photometer	L1 / SS / GEO																									
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	35.22	13.91	7.066	2.792	52.822		
36 to 39	IMF (B-field)	Magnetometer																										
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO																									
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2																									
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	1	58.81	31.9	11.802	6.16	96.09		
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO																									
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	1	53.12	28.58	10.624	5.116	87.416		

Figure 42 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (1)

9.5.8 All missions – Full Dedicated (2)

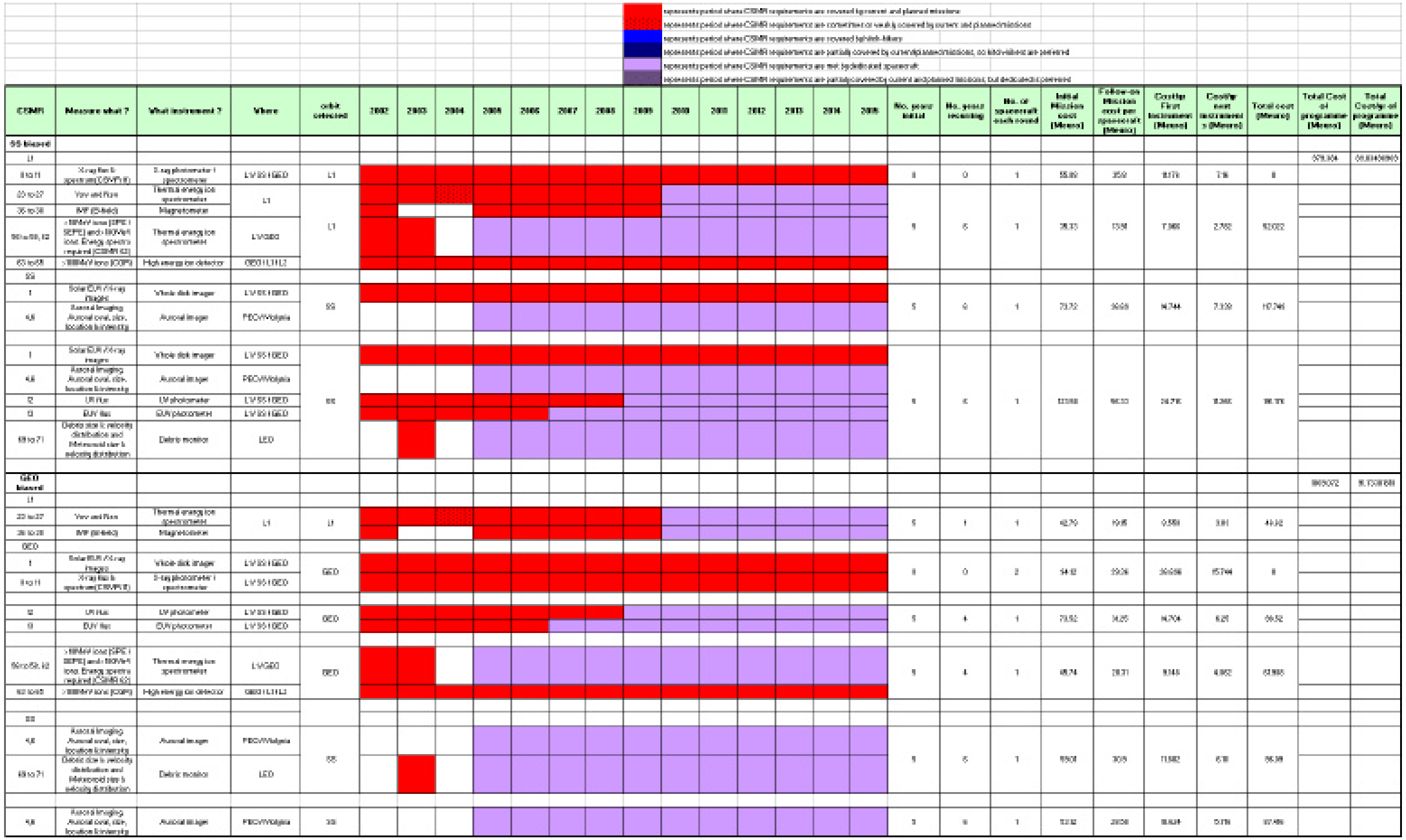


Figure 43 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (2)

9.5.9 European and International Collaboration – Full Dedicated (1)

- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost/p First Instrument (Meuro)	Cost/p next instruments (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Cost/p of programme (Meuro)
Core																												
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	3	1	54.57	23.79	10.914	4.758	68.844		
2	Solar coronagraph images	Coronagraph	L1/ L4 / L5/ SSI GEO																									
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)	trailing heliocentric (L5)															5	3	1	117.51	60.87	23.502	12.174	153.552		
71	Interplanetary radio bursts	Radio Wave Detector	L4+L5 separated heliocentric at 1 AU																									
39 to 42	Magnetospheric B-field	Magnetometer	Multiple	Multiple															5	4		82.33	82.33	16.466	16.466	148.194		
52	Cold ions: Total density only	Thermal energy ion spectrometer, Ionosonde, UV imager	Elliptical eg GTO																									
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO	GTO															5	6	4	96.84	24.36	25.824	19.488	246.848		
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO/ LEO / midEO																									
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO, GTO																									
L1 based																											1023.4	93.036364
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SSI GEO																									
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1 / SSI GEO	L1															5	4	1	128.45	61.23	24.09	12.246	169.434		
12	UV flux	UV photometer	L1 / SSI GEO																									
13	EUV flux	EUV photometer	L1 / SSI GEO																									
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1																									
28 to 30	IMF (B-field)	Magnetometer																										
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	L1															5	6	1	35.33	12.81	7.066	2.792	52.022		
63 to 65	>100MeV ions (CSP)	High energy ion detector	GEO / L1 / L2																									
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya																									
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO	SS															5	6	1	59.01	30.9	11.802	6.18	96.89		
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molniya	SS															5	6	1	53.12	28.88	10.624	5.776	87.416		

Figure 44 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (1)

9.5.10 European and International Collaboration – Full Dedicated (2)

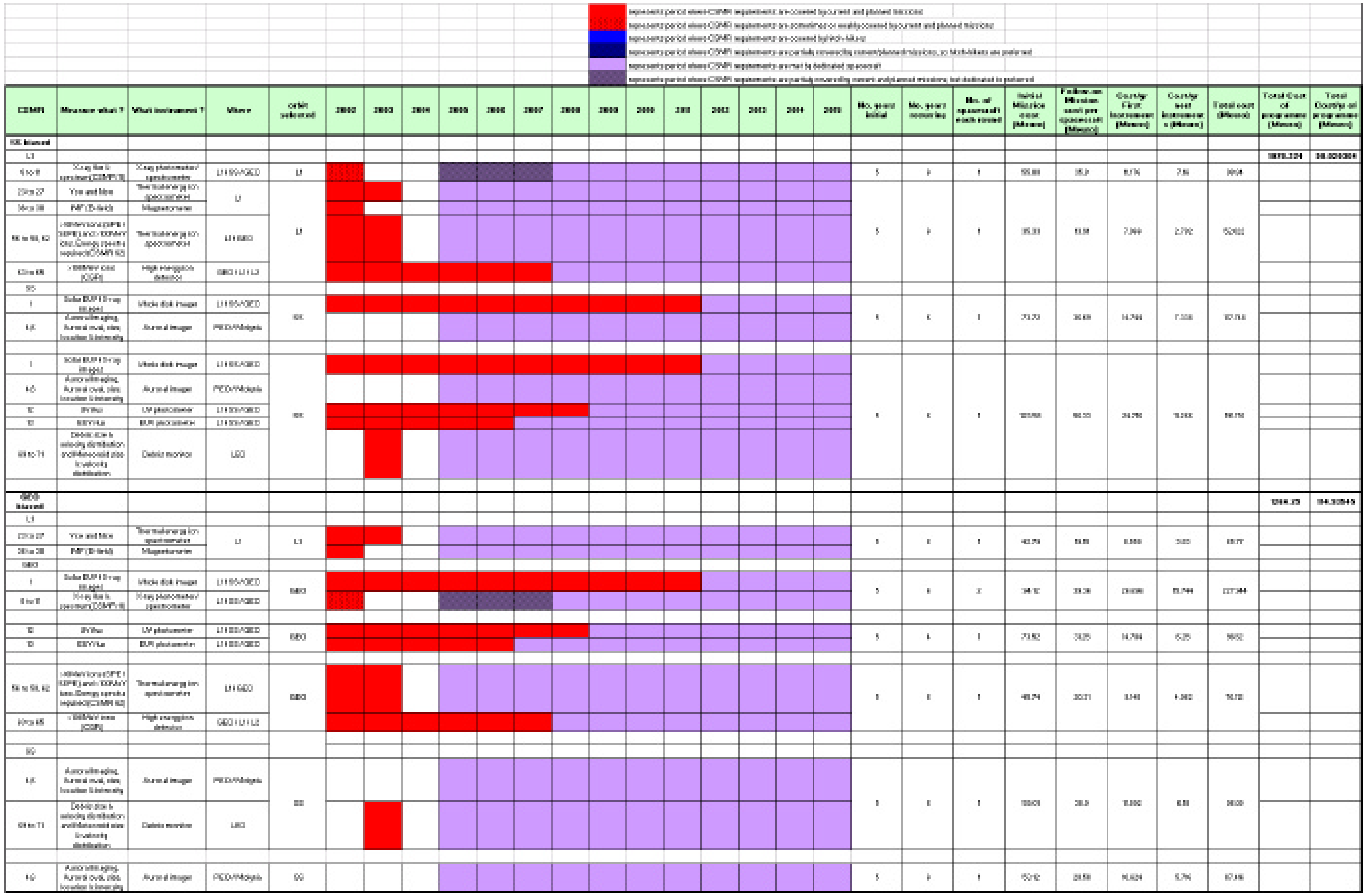


Figure 45 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (2)

9.5.11 European only - Full Dedicated (1)

- represents period where CSMR requirements are covered by current and planned missions
- represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
- represents period where CSMR requirements are covered by hitch-hikers
- represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
- represents period where CSMR requirements are met by dedicated spacecraft
- represents period where CSMR requirements are partially covered by current and planned missions, but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years recurring	No. of spacecraft each round	Initial Mission cost (Meuro)	Follow-on Mission cost per spacecraft (Meuro)	Cost for First instrument (Meuro)	Cost for next instruments (Meuro)	Total cost (Meuro)	Total Cost of programme (Meuro)	Total Cost for programme (Meuro)
Core																												
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	leading heliocentric (L4)	leading heliocentric (L4)															5	6	1	54.57	23.79	10.394	4.758	83.118		
2	Solar coronagraph images	Coronagraph	L1 / L4 / L5 / SS / GEO	trailing heliocentric (L5)															5	6	1	117.51	60.87	23.502	12.014	183.594		
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	trailing heliocentric (L5)																									
75	Interplanetary radio bursts	Radio Wave Detector	L4+L5/separated heliocentric at 1AU																									
39 to 43	Magnetospheric B-field	Magnetometer	M/sphere	M/sphere															5	6		83.33	83.33	16.666	16.666	192.326		
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Elliptical eg GTO	GTO															5	6	4	96.04	24.36	25.824	19.458	246.048		
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO / GTO																									
58 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO / GTO / LEO / mid-EO																									
66 to 67	Relativistic electrons (>0.3MeV) incl. spectra	High energy electron spectrometer	GEO, GTO																									
L1 biased																											1031.54	192.96727
L1																												
1	Solar EUV / X-ray images	Whole disk imager	L1 / SS / GEO	L1															5	6	1	120.45	61.23	24.85	12.246	193.526		
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1 / SS / GEO																									
12	UV flux	UV photometer	L1 / SS / GEO																									
13	EUV flux	EUV photometer	L1 / SS / GEO																									
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	35.33	13.91	7.066	2.782	52.822		
36 to 38	IMF (B-field)	Magnetometer																										
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO																									
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO / L1 / L2																									
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	1	59.01	30.9	11.802	6.18	96.09		
68 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO																									
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molynia	SS															5	6	1	53.12	28.58	10.624	5.716	87.446		

Figure 46 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (1)

9.5.12 European only - Full Dedicated (2)

represents period where CSMR requirements are covered by current and planned missions
represents period where CSMR requirements are sometimes or weakly covered by current and planned missions
represents period where CSMR requirements are covered by hitch-hikers
represents period where CSMR requirements are partially covered by current/planned missions, so hitch-hikers are preferred
represents period where CSMR requirements are met by dedicated spacecraft
represents period where CSMR requirements are partially covered by current and planned missions but dedicated is preferred

CSMR	Measure what ?	What instrument ?	Where	orbit selected	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	No. years initial	No. years remaining	No. of spacecraft each round	Initial Mission cost [Meuro]	Follow-on Mission cost per spacecraft [Meuro]	Costs for First Instrument [Meuro]	Costs for next Instruments [Meuro]	Total cost [Meuro]	Total Cost of programme [Meuro]	Total Costs of programme [Meuro]
SS based																												
L1																											1181.832	1108.62472
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1/ SS / GEO	L1															5	6	1	55.08	20.8	8.170	7.18	38.84		
21 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	38.33	11.81	7.366	2.742	52.022		
30 to 31	IMF (B-field)	Magnetometer																										
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO																									
61 to 65	>100MeV ions (CSR)	High energy ion detector	GEO / L1 / L2																									
SS																												
1	Solar EUV / X-ray images	Whole disk imager	L1/ SS / GEO	SS															5	6	1	79.72	36.49	14.744	7.310	97.746		
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molnyia																									
1	Solar EUV / X-ray images	Whole disk imager	L1/ SS / GEO	SS															5	6	1	123.56	56.40	24.796	8.206	151.676		
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molnyia																									
12	UV flux	UV photometer	L1/ SS / GEO																									
13	EUV flux	EUV photometer	L1/ SS / GEO																									
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO																									
GEO based																											1160.168	823.67598
L1																												
21 to 27	Vsw and Nsw	Thermal energy ion spectrometer	L1	L1															5	6	1	40.79	13.15	8.208	3.83	60.77		
30 to 31	IMF (B-field)	Magnetometer																										
GEO																												
1	Solar EUV / X-ray images	Whole disk imager	L1/ SS / GEO	GEO															5	6	2	98.12	31.36	20.036	10.714	207.880		
8 to 11	X-ray flux & spectrum (CSMR 11)	X-ray photometer / spectrometer	L1/ SS / GEO																									
12	UV flux	UV photometer	L1/ SS / GEO	GEO															5	6	1	73.82	33.28	14.764	6.28	81.00		
13	EUV flux	EUV photometer	L1/ SS / GEO																									
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	L1 / GEO	GEO															5	6	1	45.74	20.21	9.145	4.062	70.12		
61 to 65	>100MeV ions (CSR)	High energy ion detector	GEO / L1 / L2																									
SS																												
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molnyia	SS															5	6	1	50.01	30.8	10.002	6.9	86.85		
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	LEO																									
4,6	Auroral imaging, Auroral oval, size, location & intensity	Auroral imager	PEO / Molnyia	SS															5	6	1	83.12	30.80	16.624	8.770	87.486		

Figure 47 Timeline of potential Hitch-hiker and dedicated solutions in order of CSMR for a Full Dedicated scenario (2)

9.6 Dedicated spacecraft overall cost results and conclusions

Table 46 and Table 47 summarise the total cost results for each dedicated space segment type, which are derived from summing each individual dedicated spacecraft cost. These costs are for dedicated spacecraft only, and do not include hitch-hiker costs (note that a Full dedicated space segment has no hitch-hikers anyway). The space segments are generic in terms of programme type, and therefore several instruments on certain dedicated spacecraft can be redundant for a period of time, i.e. the whole disk imager (CSMR 1) and the X-Ray Photometer (CSMR 8-11) on the L1 element of the Full dedicated space segment including all missions (these instruments are actually redundant up to2015). This may give these dedicated spacecraft an artificially higher cost than would be required, as they include instruments that may not be needed. These instruments are included in the costing though, as most CSMR timelines are not fully covered by Current and Planned missions up until 2015, and therefore the instruments will be required at some stage. The example given is the exception rather than the rule.

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	581.20
Max hitch-hikers	Euro + International collaboration	600.35
Max hitch-hikers	European led only	684.00

Table 46 Dedicated space segments with maximum hitch-hikers - Overall cost results

Table 47 shows cost for three different orbit options, L1, Sun-Synchronous and Geostationary orbit (GEO). These orbit options are the result of where emphasis was placed in deciding the location of dedicated spacecraft where options where possible. The cost of these options includes the cost of core spacecraft, which are common to a particular implementation type. The costs in Table 46 for a maximum hitch-hiker space segment contain no orbit options, as the orbit locations for the CSMR are compulsory.

		Total Costs (MEuro) for each Orbit preference for CSMR with optional orbits		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Large instrument dedicated	All missions	705.53	779.67	731.49
Large instrument dedicated	Euro + International collaboration	768.37	798.82	808.40
Large instrument dedicated	European led only	915.07	882.46	959.41
Full dedicated	All missions	1023.4	979.38	1009.07
Full dedicated	Euro + International collaboration	1023.4	1078.22	1264.29
Full dedicated	European led only	1131.54	1161.87	1360.44

Table 47 Dedicated space segment with large instruments dedicated and Full dedicated overall cost results

The cost of each space segment increases from Maximum hitch-hiker, which is cheapest to Full dedicated which is most expensive. However, these costs do not include the cost of hitch-hikers. If we then add the cost of hitch-hiker instruments (without the magnetograph as it is covered by the magnetometer at L1) from Table 19 to these dedicated spacecraft costs, then we can compare the costs of the three different dedicated space segment options, i.e.

Maximum Hitch-hiker, Large Instruments dedicated and Full dedicated. Table 48 to Table 54 show the total space segment cost of hitch-hiking and dedicated spacecraft.

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	978.20
Max hitch-hikers	Euro + International collaboration	1224.03
Max hitch-hikers	European led only	1446.46

Table 48 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of Maximum hitch-hikers

		Total Cost (MEuro)		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Large instrument dedicated	All missions	939.57	1013.71	965.53
Large instrument dedicated	Euro + International collaboration	1180.82	1211.26	1220.85
Large instrument dedicated	European led only	1340.80	1308.20	1385.14

Table 49 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of with large instruments dedicated

		Total Cost (MEuro)		
Implementation type	**Programme type**	**L1**	**SS**	**GEO**
Full dedicated	All missions	1023.4	979.38	1009.07
Full dedicated	Euro + International collaboration	1023.4	1078.22	1264.29
Full dedicated	European led only	1131.54	1161.87	1360.44

Table 50 Total Cost of space segment of Full Dedicated spacecraft

These results are interesting as they show that grouping instruments together onto multi-payload dedicated spacecraft to form a Full dedicated space segment, is generally cheaper than using individual hitch-hikers and a few dedicated spacecraft to meet the remaining CSMR (though, this is not the case if all missions are included, in which case large instruments dedicated is the cheapest option). It also shows that L1 would be the least expensive orbit option for all three collaborative space segments. GEO performs poorly as an orbit option in comparison to L1 and SS. This can be attributed to the higher spacecraft and launch costs that GEO demands.

We can interpret the higher cost of a space segment involving hitch-hikers to the fact that they require higher integration, programme management and launch costs per instrument than an instrument on a cheap-launch, multi-payload, dedicated spacecraft.

At a cost of 1023.40 MEuro for the best option in terms of politics and cost, i.e. L1 preferred orbit option of a Full dedicated space segment comprising spacecraft with European and International collaboration, we would still be over the total ESWS allocated budget of 50MEuro/year over 11 years at 550MEuro, or 12 years at 600MEuro. We can therefore conclude that to meet all of the CSMR for the optimum space segment configuration, then the budget must be increased over 12 years to be compliant up to and including the year 2015. If this is not possible then some form of CSMR prioritisation must be implemented to ensure that the highest priority CSMR are met within the allocated budget.

9.7 Future Platform technologies

Future platform concepts that may be of interest for space weather purposes are likely to be small and may even be in the Nanosat (defined as satellite mass between 10kg and 1kg) or Picosat (defined as satellite mass less than 1kg) range if instrument size can be driven down. The following platform concepts have been identified as potential platforms components for a future space weather service:

CUBESAT

The CubeSat concept has been developed at Space Systems Development Laboratory, Stanford University by Prof. Bob Twiggs and his colleagues and students in conjunction with California Polytechnic State University. The basic idea is to build a picosat 100 x 100 x 100 mm, mass below 1 kg and power consumption below 1 W, and deploy it together with a number of CubeSats from a dedicated dispenser for less than $50000 total.A 10-centimeter cube will have a large empty volume inside. The current CubeSat design has a mass of about 800 grams leaving 200 grams for the payload. The payload also has access to the transmitter modulation signal.

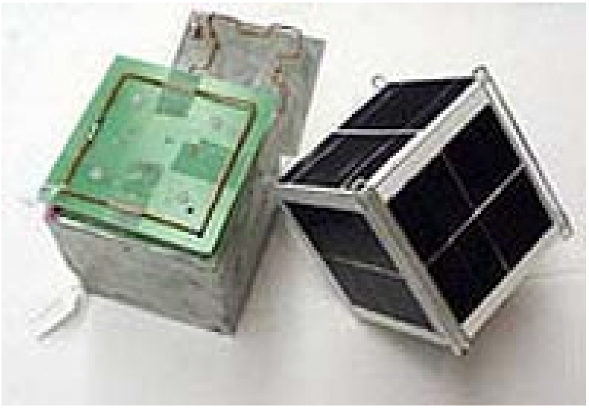


Figure 48 CUBESAT Picosatellite concept

M2

The first and present step in the M-2 project is to design a new platform for nano-satellites. The platform is to be developed in cooperation with the Swedish Institute of Space Physics in Kiruna and Uppsala. Initially the task is to develop satellite subsystems, which can be used on board satellites or even used as on board systems for sounding rockets and balloon experiments. These subsystems should be constructed as generic as possible, so that they could be used as commercial of the shelf (COTS) components for different satellite applications.

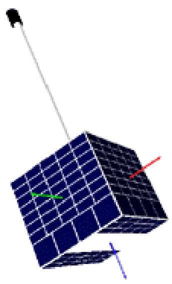


Figure 49 M2 Nanosatellite platform concept

The next step is to design actual satellites for LEO operations, which initially will have passive attitude control and stabilization systems. The two passive techniques possible are the gravity gradient, where the satellite always has one axis pointing toward Earth, and the "follow the field" (FTF) model, where one of the satellite axis is pointing along the Earths magnetic field lines, as in the case of the Munin satellite. The FTF model has proven to be very well suited for plasma measurements in low Earth orbits. Later generations of satellites (M-3 and M-4) will be more complex and use other types of attitude stabilization.

Launch of the first satellite is planned to late 2002, as piggyback on a Delta II rocket.

9.8 Identification of areas for technology development

The following areas have been identified as critical to driving down the cost of a potential ESA Space Weather service:

- Reduction of instrument size to fit on smaller platforms, e.g. SODISM on PICARD
- Development of smaller platforms
- Increased lifetimes
- Efficient data downlink capabilities (e.g. small communications constellation)

10. OVERALL SPACE SEGMENT SUMMARY AND CONCLUSIONS

10.1 Cost Summary

The following tables are a summary of the total cost of all the possible space segment architectures. It is assumed that a space segment comprised of Current and Planned missions only, will cost 0MEuro from a space segment point of view.

Hitch-hiker type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	530.99
Max hitch-hikers	Euro + International collaboration	757.67
Max hitch-hikers	European led only	953.76
Large instrument dedicated	All missions	368.03
Large instrument dedicated	Euro + International collaboration	546.43
Large instrument dedicated	European led only	617.02

Table 51 Hitch-hiker only preferred orbit solutions

Implementation type	Programme type	Total cost (MEuro)
Max hitch-hikers	All missions	978.20
Max hitch-hikers	Euro + International collaboration	1224.03
Max hitch-hikers	European led only	1446.46

Table 52 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of Maximum hitch-hikers

		Total Cost (MEuro)		
Implementation type	Programme type	L1	SS	GEO
Large instrument dedicated	All missions	939.57	1013.71	965.53
Large instrument dedicated	Euro + International collaboration	1180.82	1211.26	1220.85
Large instrument dedicated	European led only	1340.80	1308.20	1385.14

Table 53 Total Cost of space segment including Hitch-hikers and Dedicated spacecraft for space segment of with large instruments dedicated

		Total Cost (MEuro)		
Implementation type	Programme type	L1	SS	GEO
Full dedicated	All missions	1023.4	979.38	1009.07
Full dedicated	Euro + International collaboration	1023.4	1078.22	1264.29
Full dedicated	European led only	1131.54	1161.87	1360.44

Table 54 Total Cost of space segment of Full Dedicated spacecraft

Table 55 summarises the results to show what the cheapest implementation solution is for each programme type.

Programme type	Cheapest Implementation type	Orbit location	Total cost (MEuro)
All missions	Large instrument dedicated	L1	939.57
Euro + International collaboration	Full dedicated	L1	1023.4
European led only	Full dedicated	L1	1131.54

Table 55 Summary of cheapest implementation solutions to each programme type

10.2 Summary of CSMR solutions for Hitch-hiker only and Dedicated space segments

Throughout this study, many options for hitch-hiking and dedicated spacecraft have been reviewed. However certain solutions to meet the CSMR are better in terms of cost and/or complexity than others. Presented are tables showing the preferred orbit options for both hitch-hiker only space segments and dedicated space segments

10.2.1 Hitch-hiker only space segment - preferred solution

Table 56 shows a summary of the preferred orbit selections for a space segment composed of maximum hitch-hikers only, with no dedicated spacecraft. GEO is generally the preferred option as it is a popular orbit location for many missions, has good communications links and has a hitch-hiking cost comparable with its rival - SS (Sun-synchronous). A space segment of current and planned missions with European involvement and International collaboration is selected, as it is a happy medium between autonomy and cost.

CSMR	Measure what?	What instrument?	Orbit selected for hitch-hiking	Total cost (MEuro)
1	Solar EUV / X-ray images	Whole disk imager	GEO	48.28
2	Solar coronagraph images	Coronagraph	GEO	59.34
3	Stereo visible or UV images of Sun-Earth space	Coronagraph	Must be Dedicated	0.00
4,6	Auroral Imaging, Auroral oval, size, location & intensity	Auroral imager	SS	103.62
8 to 11	X-ray flux & spectrum(CSMR 11)	X-ray photometer / spectrometer	GEO	65.50
12	UV flux	UV photometer	GEO	15.78
13	EUV flux	EUV photometer	GEO	19.55
23 to 27	Vsw and Nsw	Thermal energy ion spectrometer	Must be Dedicated	0.00
36 to 38	IMF (B-field)	Magnetometer	Must be Dedicated	0.00
36 to 38	IMF (B-field)	Magnetograph	GEO	133.99
39 to 43	Magnetospheric B-field	Magnetometer	Must be Dedicated	0.00
50 and 51	Cross-tail electric field and Ionospheric ion drift velocity	Electric field and Thermal energy ion spectrometer	Ground	0.00
52	Cold ions. Total density only	Thermal energy ion spectrometer; Ionosonde, UV Imager	Must be Dedicated	0.00
53 to 55	1-10keV electrons and 10-100keV electrons	Medium energy electron spectrometer	GEO	68.62
56 to 58, 62	>10MeV ions (SPE / SEPE) and >100MeV ions. Energy spectra required (CSMR 62)	Thermal energy ion spectrometer	GEO	19.72
59 to 61	>10MeV protons (trapped)	Thermal energy ion spectrometer	GEO	59.15
63 to 65	>100MeV ions (CGR)	High energy ion detector	GEO	22.50
66 to 67	Relativistic electrons (>0.3MeV) incl spectra	High energy electron spectrometer	GEO	90.40
69 to 71	Debris size & velocity distribution and Meteoroid size & velocity distribution	Debris monitor	SS	20.24
72	Dose rate & LET spectrum	High energy electron spectrometer	Onboard s/c	30.98
73	Total Dose		?	0.00
74	Satellite position		Ground	0.00
75	Interplanetary radio bursts	Radio Wave Detector	Must be Dedicated	0.00
			Total cost of all hitch-hikers	**757.67**

Table 56 Hitch-hiker only preferred orbit solution – Maximum Hitch-hikers with European involvement and International Collaboration

10.2.2 Dedicated space segment - preferred solution

Table 57 shows a summary of the preferred orbit and platform solutions for a dedicated space segment. This is composed entirely of dedicated spacecraft, with L1 as the preferred orbit for CSMR with orbit options. Note how instruments are grouped together onto platforms that suit the instrument requirements. This helps to bring down the mission costs. L1 is useful in that only one spacecraft is required to meet CSMR, such as Whole disk imaging. This space segment includes current and planned missions with European involvement and International collaboration, as it is a happy medium between autonomy and cost.

CSMR	What instrument ?	orbit selected	Platform selected	No. of spacecraft each round	Initial Mission cost per spacecraft (MEuro)	Follow-on Mission cost per spacecraft (MEuro)	Total cost (MEuro)
3	Coronagraph	leading heliocentric (L4)	PICARD	1	54.57	23.79	68.844
2	Coronagraph	trailing heliocentric (L5)	LEOSTAR 200	1	117.51	60.07	153.552
3	Coronagraph						
75	Radio Wave Detector						
39 to 43	Magnetometer	M/sphere	SWARM	30	83.33	83.33	149.994
52	Thermal energy ion spectrometer; Ionosonde, UV Imager	GTO	STRV c/d	4	56.04	24.36	246.048
53 to 55	Medium energy electron spectrometer						
59 to 61	Thermal energy ion spectrometer						
66 to 67	High energy electron spectrometer						
1	Whole disk imager	L1	LEOSTAR 200	1	120.45	61.23	169.434
8 to 11	X-ray photometer / spectrometer						
12	UV photometer						
13	EUV photometer						
23 to 27	Thermal energy ion spectrometer	L1	ASTRID	1	35.33	13.91	52.022
36 to 38	Magnetometer						
56 to 58, 62	Thermal energy ion spectrometer						
63 to 65	High energy ion detector						
4,6	Auroral imager	SS	PICARD	1	59.01	30.9	96.09
69 to 71	Debris monitor						
4,6	Auroral imager	SS	PICARD	1	53.12	28.58	87.146
						Total Cost of programme (MEuro)	**1023.40**

Table 57 Preferred Dedicated Space Segment – Full Dedicated with L1 preference using missions with European involvement and International Collaboration

10.3 Key points

Several key points have arisen during this space segment section of the space weather study. These can be summarised as:

- CSMR 36 to 38 has a gap in timelines for all three collaborative programmes. For missions with European involvement there is a clear gap between 2003 and end of 2006 before Solar Dynamics Observatory is launched.
- Many Current and Planned missions only partially meet the CSMR and it is assumed that either hitch-hikers or dedicated missions are required to meet these CSMR.
- CSMR with short re-visit time requirements, i.e. CSMR 8-11, 36-38 (magnetograph - revisit time 3min so not quite as bad as 20s), and 50-51 cannot be met from sun-synchronous orbit due to the high number of satellites that would be required. This may not be a problem for CSMR 36-38 and 50-51 as they can actually be met by ground observations.
- CSMR 50-51 should be met by ground observations
- Many CSMR may be filled by the implementation of Hitch-hiker payloads. However, one note of caution is that the prospect of hitch-hiking cannot be guaranteed.
- Some CSMR cannot or are very unlikely to be regularly met by hitch-hikers, generally because their required orbit location is not very well populated. This then will define the limit of a Space Weather Service based purely upon hitch-hikers and Current/Planned missions.
- GEO is generally the preferred option for hitch-hiking as it is a popular orbit location for many missions, has good communications links and has a hitch-hiking cost comparable with is rival SS (Sun-synchronous).
- Many of the Russian launchers are ICBM’s (Intercontinental Ballistic Missiles), which are to be phased out after 2007 following the START/ABM (Anti-ballistic missile) Treaty.
- Transfers from GTO are be feasible for microsatellites on ASAP 5, however, Delta V’s of over 1000 m/s may require either a redesign of the platform to reduce mass, or a bespoke platform.
- Grouping instruments together onto multi-payload dedicated spacecraft to form a Full dedicated space segment is generally cheaper than using individual hitch-hikers and a few dedicated spacecraft to meet the remaining CSMR.
- At a cost of 1023.4 MEuro, L1 would be the least expensive orbit option for a Full dedicated space segment with European and International collaboration. This is therefore the preferred option for a dedicated space segment
- The ESA budget of 50MEuro/year is clearly not enough to meet all of the CSMR in a future ESA Space Weather Service
- CSMR prioritisation must be implemented to ensure that the highest priority CSMR's are met within the allocated budget, unless space segment costs can be reduced by use of smaller/cheaper instruments and platforms.

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