# Final Review – 6th Dec 2001

# ESA Space Weather Study, Space Segment Options

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## Aim of the space segment study

The aim of this Workpackage 420 series is to consider at least three space segment options which have different levels of programme cost and complexity:

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

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

# Methodology - Timing

- Must be a continuous programme, with replacements
- Necessary to study up to 2015 to see effects of such a programme
- This timescale includes next Solar Maximum and end of ICBM's (2007)
- Assume hitch-hikers start 2004, dedicated spacecraft 2005
- Assume lifetime of 5 years

# Methodology - Collaboration

Three levels of collaboration have been identified and closely examined throughout this part of the study**:**

- All missions including pure national agency missions such as GOES and GENESIS, that may have no clear link to ESA or any European National Agency.
  - Problem is that European autonomy is not fostered.
  - Reliant on other programmes.
- European missions that have some involvement from European Scientists, ranging from Co-Pi-ship to instrument or even spacecraft design and responsibilty. This would include missions, such as SOLAR-B and STEREO.
  - This option potentially offers access to more missions, without the added cost of complete autonomy.
- European autonomy and includes only missions that are European-led, such as PICARD, METOP and SOHO. Although this option would be preferred in terms of political complexity, it is more expensive than collaborative options.

# Payload Requirements

| 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 | 26x1 4x11 | | | 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 |

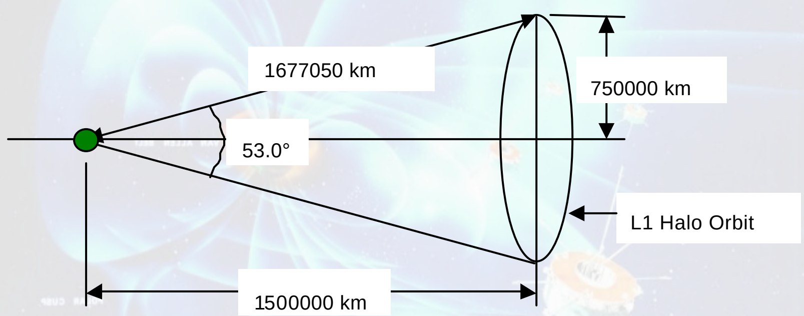
# Payload Requirements and key system issues

- AOCS and pointing
  - The pointing requirements for CSMR needing Sun pointed instruments (e.g. Whole disk imager, and Photometers) are stringent with a value of the order of arcseconds.
  - Spacecraft stabilisation is important as certain instruments such as ion and electron spectrometers/detectors require $4\pi$ Steradians coverage which is best met by a spin-stabilised spacecraft.
- Size, mass and power
  - 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.
  - The imagers and the coronagraph generally 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.
- Data rates and downlink
- Ground Station coverage

# Data rates and downlink

- Data rates, although not high are critical for orbits where either the minimum beamwidth constrains the data rate (e.g. L1 halo orbits) or the link distance is large (e.g Heliocentric orbits)
- 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 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.
- Several Heliocentric orbits at varying angular separations from Earth were considered for a potential stereo mission
  - A larger angle results in a longer link distance and therefore a larger antenna

# Data Downlink (1) – Geometry at L1



# Data Downlink (2) – Typical Link budget for a 3db margin and a 10W transmitter output power

| 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 |

# 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.
- Intersatellite links may be possible, but are 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.

# Existing and Planned missions

- The objective is to comprehensively review existing and planned missions out to 2015 that may be able to meet the CSMR's.
  - Not all STP missions meet CSMR, e.g. CLUSTER
- 58 missions reviewed
- 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.
- Level of collaboration determines which missions are applicable.
- 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.

# Existing and planned missions - Conclusion

- 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.
- Some individual missions may not exactly meet the CSMR ALL THE TIME.
  - Some are in the wrong orbit, e.g. IRIDIUM, or occasionally the right orbit, e.g SOLO
  - Eclipses which would cause outages in science return for solar observations.
  - Another problem would be 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 allowed gap in data downlink.

## Hitch-hikers – Rationale and options

- 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.
- Employing a Space Weather 'guest payload' on a host spacecraft can save on standard costs associated with a dedicated mission.
- Two space segment options are covered, although in theory, many configurations are possible. The two options are:
  - Maximum hitch-hikers and existing/planned infrastructure only. The aim here being to meet as many outstanding system requirements with purely hitch-hiker instrumentation. A dedicated space segment would be required to meet the remaining CSMR .
  - The second option assumes that large instruments cannot be met by hitch-hiking, and must therefore require a dedicated spacecraft.

## Hitch-hikers – General Mission review

- Over 300 future missions reviewed up to 2015 (not commercial comms due to quick turnaround).
- Historical launch record illustrates frequency of launches to GTO, LEO and Sun-synchronous orbits.
- Majority of missions scheduled for launch to GTO and LEO (both about 40/yr) with some to SS (15/yr).
- Missions to other orbits few and far between
  - Access to these orbits would therefore require dedicated spacecraft as there is no confirmed regularity.
- Large Instrument mass/size may also make hitch-hiking impossible
  - Therefore a dedicated mission would be required.
  - However, the GOES-NEXT series of spacecraft will have an X-ray imager as part of it's instrument complement., located on the SADM of the spacecraft – so it can be done.

## Hitch-hikers – Other Trade-off Considerations

- Nature of satellites planned to inhabit orbits
- View requirement and eclipse duration/regularity
- Pointing requirements
- Data rates and downlink requirements
- Ground Stations and coverage
- Cost (Instrument and payment to host)
- Lifetime
- Politics/Programmatics
- Power/Thermal Interface

## Hitch-hikers - Example of preferred orbit locations

- 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 SS (Sun-synchronous), as payload displacement charge is same

| 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 | Aurora l 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 |

## Hitch-hikers – Rank and Costs for Euro + Collaboration

- Hitch-hikers ranked according to need (described later in cost analysis).
- Costs are space segment programme costs (up to 2015) for each hitch-hiker type

| Option | CSMR | Description | Rank | Rationale | Cost without Ground interface (MEuro) |
|---|---|---|---|---|---|
| 14 | 72 | Dose monitor | 1 | Human safety | 31 |
| 11 | 63 to 65 | High energy ion detector | 2 | GCR's, SEPE's | 23 |
| 12 | 66 to 67 | High energy electron spectrometer | 3 | Killer electrons | 90 |
| 13 | 69 to 71 | Debris monitor | 4 | | 20 |
| 8 | 53 to 55 | Medium energy electron spectrometer | 5 | | 69 |
| 9 | 56 to 58, 62 | High energy ion detector/GEO | 6 | | 20 |
| 10 | 59 to 61 | High energy ion detector/GTO | 7 | | 59 |
| 6 | 13 | EUV photometer | 8 | | 19 |
| 5 | 12 | UV photometer | 9 | | 16 |
| 4 | 8 to 11 | X-ray photometer / spectrometer | 10 | | 66 |
| 3 | 4,6 | Auroral imager | 11 | | 104 |
| 2 | 2 | Coronagraph | 12 | | 59 |
| 1 | 1 | Whole disk imager | 13 | | 48 |
| 7 | 36 to 38 | Magnetograph | 14 | | 134 |
| | | ***Total Cost of All Hitch-Hikers*** | | | **758** |

# Hitch-hikers - Conclusions

- 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 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.

# Dedicated Options

- The most ambitious and possibly the most expensive space segment option is a dedicated option.
- There are several dedicated space segment options that could employ dedicated spacecraft.
  - Maximum Hitch-hikers (i.e. just use dedicated spacecraft to fill in remaining gaps)
  - Large Instruments Dedicated (i.e. recognise difficulty in obtaining Hitch-hikers for large instruments)
  - Full dedicated (i.e. No Hitch-hikers; Dedicated space weather spacecraft meet all the remaining CSMR)

# Dedicated using Maximum Hitch-hikers

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

| 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 |

## Large instruments requiring dedicated spacecraft

- CSMR that are assumed not met by Hitch-hiking due to instrument size

| 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 |

## Launch 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.
- It is notable that many of the Russian launchers, such as START, EUROCKOT and DNEPR off 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.

# Orbit architecture options

- WP421 - instrument definition, derived orbit locations for each CSMR
- The orbit locations for CSMR are viewed as either core or optional.
- Definition depends on whether an orbit location is usually an option for each CSMR (e.g. L1 is usually an option, GTO is usually a core requirement)
- Core orbit locations are defined for orbits which are generally the only orbit location when globally analysing all CSMR (e.g. L4, Magnetospheric or GTO only),
  - These form part of the core architecture if considered as one of the dedicated options.
  - Spacecraft must reside at that orbit.
- Optional orbit locations (e.g. L1/SS/GEO),
  - These form part of the optional architecture if considered as one of the dedicated options.
  - Three main option permutations considered are grouped as L1, SS or GEO biased,
  - This indicates which orbit is the preference for designating majority of instruments to one or more potential spacecraft.
  - May still be residual spacecraft element at another orbit location
  - Many other permutations are possible which are hybrids of the three permutations described.

## Full Dedicated Spacecraft at core orbit locations (GTO/GEO options assumed as core GTO,as launch costs to GTO cheap)

| 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 |

Full Dedicated Spacecraft with L1 as the prime optional orbit location

| 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 <120kg | 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 |
| | | | Direct (START) | $10M |
| 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. | Dual/Multi (DNEPR/ EUROCKOT | $2-3M each |

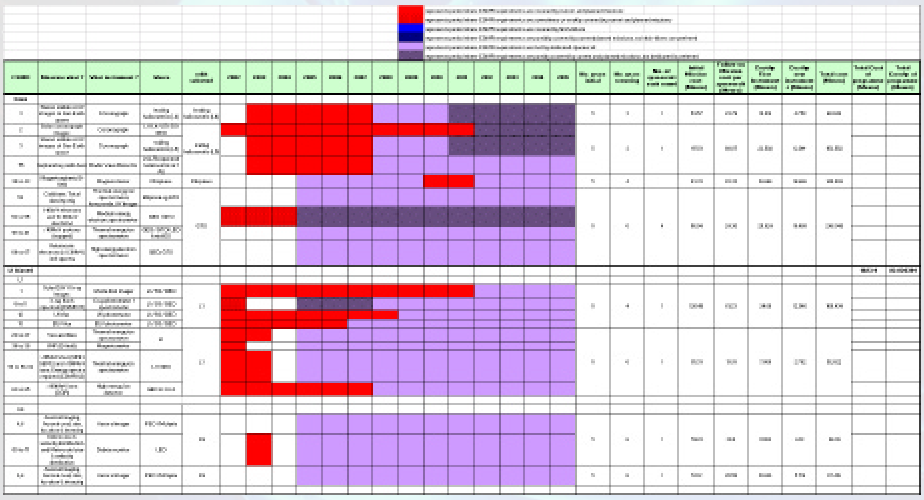
# Platform Definition and costing

- Study reviewed 20 European platforms
- Several 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 DeltaV capability, pointing, stability, cost and thermal as described earlier. These factors must be taken into account before selecting one of the platforms.
- More detailed study may show 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.

## Platforms used as dedicated space weather spacecraft

| 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 |

## Dedicated timelines and associated cost – L1 preferred, Full dedicated, Euro + collaboration



## Dedicated rank and cost – L1 preferred, Full dedicated, Euro + collaboration

- Dedicated spacecraft ranked according to need (described later in cost analysis).
- Costs are space segment programme costs (up to 2015) for each spacecraft type

| *Option* | *CSMR* | *Description* | *Rank* | *Rationale* | *Cost without Ground interface (MEuro)* |
|---|---|---|---|---|---|
| 6 | 23 to 27, 36 to 38, 56 to 58, 62, 63 to 65 | Thermal energy ion spectrometer, Magnetometer, Thermal energy ion spectrometer, High energy ion detector | 1 | Upstream solar wind monitoring | 52 |
| 5 | 1, 8 to 11, 12, 13 | Whole disk imager, X-ray photometer / spectrometer, UV photometer, EUV photometer | 2 | Solar monitoring | 169 |
| 4 | 52, 53 to 55, 59 to 61, 66 to 67 | Thermal energy ion spectrometer;/Ionosonde,/UV Imager, Medium energy electron spectrometer, Thermal energy ion spectrometer, High energy electron spectrometer | 3 | Radiation belt monitoring | 246 |
| 1 | 3 | Coronagraph | 4 | Viewing Earth-directed CME's | 69 |
| 2 | 2, 3, 75 | Coronagraph, Radio Wave Detector | 5 | Viewing Earth-directed CME's | 154 |
| 7 | 4,6, 69 to 71 | Auroral imager, Debris monitor | 6 | Auroral monitoring | 96 |
| 8 | 4,6 | Auroral imager | 7 | Auroral monitoring | 87 |
| 3 | 39 to 43 | Magnetometer | 8 | Magneto-spheric dynamics | 150 |
| | | ***Total Cost of All Hitch-Hikers*** | | | **1023** |

## L1 Data Downlink problems/solutions

- L1 halo orbit (data rate problem due to high beam width requirement)
  - Aim is to downlink measurements with a fixed antenna from a spinning ASTRID-2 type spacecraft 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 the antenna is fixed. 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 insertion DeltaV.
  - If reduced data rates are acceptable, then a 10W fixed antenna meets all of the data rate requirements at L1

## Heliocentric Data Downlink problems/solutions

- Heliocentric orbits (data rate/antenna size problem due to link distance)
  - Aim is to downlink stereo measurements with antenna compatible with ASAP (0.6m) for one of the spacecraft contributing to CSMR 3 (3-axis PICARD)
  - This instrument requires a total raw data rate of 5kbps.
  - This could be achieved with a separated angle of just under 10deg for a 10W transmitter output, 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 0.5kbps are acceptable, then a transmitter output power of 43W and an antenna 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
  - The other spacecraft contributing to CSMR 3 is not constrained to keep antenna under 0.6m, so greater separation angles are feasible

# Cost Conclusions

- Full dedicated space segment, is generally cheaper than using individual hitch-hikers and a few dedicated spacecraft to meet the remaining CSMR.
- L1 would be the least expensive orbit option for space segments with either Euro + International collaboration and Euro only programmes.
- 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.

# Final Conclusions (1)

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), 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

# Final Conclusions (2)

- 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 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.

# Final Conclusions (3)

- 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 proposed 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.
- Cost can be reduced by:
  - Reducing instrument and platform sizes
  - Increasing the mission lifetime
  - More efficient data downlink (e.g. data relay/small communications constellation)