Space instrumentation and system requirements

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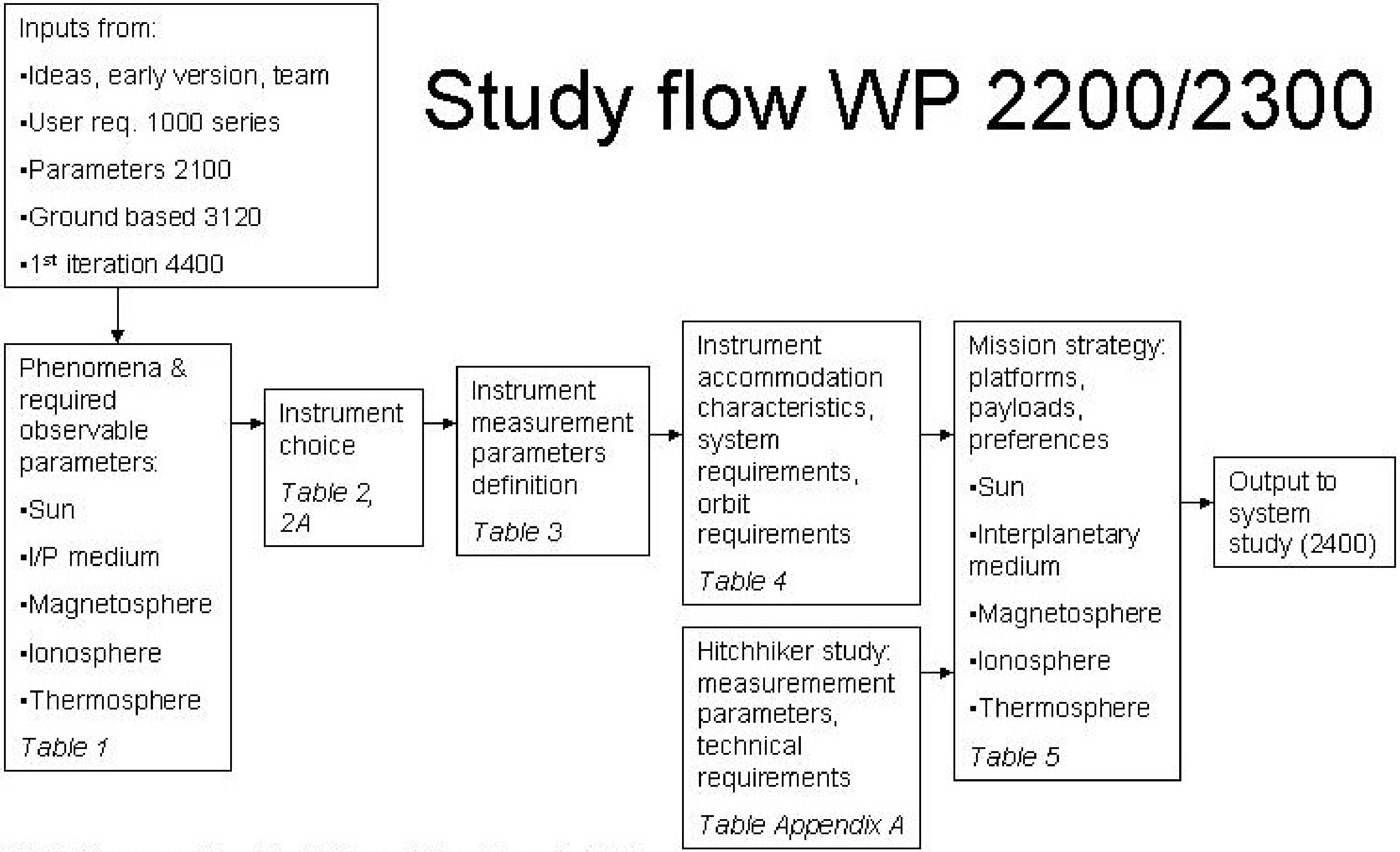

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Table 1: Physical Phenomena, Required Observations and Users

	Phenomenon	Observable	Users
Sun	CME (prediction)	Solar magnetic fields Soft X-ray and H-á imaging	Satellite operators
	CME (onset and velocity)	EUV, soft X-ray and H-á imaging Visible light coronal imaging Radio (MHz-GHz imaging, ground-based) Particle and solar-wind parameters	Satellite operators
	Proton Flares	Soft X-ray flux and radio fluxes Particle fluxes Soft X-ray and EUV images Magnetic fields	Satellite operators, launchers humans in space, research
	Coronal Holes	X-ray and EUV images, radio	Spacecraft operators
	Solar constant	Flux intensity over wide-band	Climate - Humans on Earth
	CME with no coronal proxies	Radio (IPS and radio bursts) Particle and solar-wind parameters Hα, EUV	Satellite operators
Inter-planetary Medium	Solar wind parameters and disturbances	Solar wind particles (pressure, velocity) and magnetic field (mainly N-S component)s	Satellite operators, defence, power grids and pipelines
	Galactic and solar cosmic rays	Energetic particle spectrum	Civil aviation, human is space, research
	Irregularities in the electron density	In-situ electron measurements Thomson diffusion in white light	Storm predictions – Satellite operators
	Suprathermal electron beams and shock waves	In-situ electron measurements Radio emission (ground based)	Storm predictions – Satellite operators
	Large scale structure	Velocity and density projected on the sky (interplanetary scintillation, ground-based)	Satellite operators (GPS)
	Primary and secondary galactic cosmic rays	Flux and energy spectrum (Satellite, neutron monitor, air shower)	Aviation

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Table 1: Physical Phenomena, Required Observations and Users Cont.

	Phenomena		Observable	Users
Magneto-sphere	Particle and field conditions within the magnetosphere including configuration, substorms, particle acceleration		Particle flux (E 100 MeV) Spectra of magnetospheric plasma (e$^-$, H$^+$; E 100 keV) VLF waves Electric field Remote sensing (UV and ENA) Magnetic field and indices (ground based)	Satellite operators, defence, research and launch operators, power grids, pipelines
	Radiation belt conditions		Energetic particles	Satellite operators, defence, research and launch operators
Ionosphere	Auroral particle precipitation		Spectra of auroral precipitations (e$^-$, H$^+$; E 100 keV)	Satellite operators, defence, research
	Images of auroral ovals		UV, visible	Research, outreach
	Convection electric field		Electric field (from in-situ and ground based techniques)	Defence, research, telecommunications, power grids, pipelines
	Electron density	Variation with altitude	Electron density (in-situ a ground-based radars)	Defence, research, civil aviation
		TEC, foF2 and hmF2	TEC (GPS, ionosondes))	Defence, research, civil avaiation
Thermo-sphere	Neutral wind		Wind speed, density, temperature (interferometry, accelerometry)	Satellite operators, launch, defence
	Neutral density		Spectrometry	Satellite operators, research
	Neutral temperature		Interferometry	Satellite operators, research
Debris	Location of debris, interplanetary dust		In situ (hitchhikers) and ground based radars	Satellite operators, research

Table 1: Physical Phenomena and Required Observations

2.1.1 Key phenomena, parameters and research issues - Sun

Key space weather related phenomena may be summarised as follows :

- CME onset
- CME propagation
- CME (few coronal proxies)
- Flares
- Flares with protons
- Coronal holes

Key parameters on the Sun for space weather are:

- Solar magnetic field as a proxy for solar activity (onset of flares and CMEs, quiet periods)
- EUV/UV spectral flux
- CME lift-off time and velocity to determine their arrival time at Earth
- Solar energetic particle flux
- H-α, EUV/UV and X-ray imaging (for forecasting CMEs, flares, proton events)
- Radio signatures of shocks in the corona and interplanetary medium

Major research issues are:

- Understand the initiation process of CMEs
- Predict CME lift-off time, speed and orientation
- Predict CME geoeffectiveness using CME initial conditions and ambient solar wind conditions
- Understand the initiation process of solar flares
- Predict solar flare onset time
- Predict geoeffectiveness of high speed solar wind streams

2.2.1 Key phenomena, parameters and research issues – Interplanetary medium

Key space weather related phenomena may be summarised as follows :

- Corotating Interacting Regions (CIRs)
- Shocks
- Magnetic clouds
- Upstream plasma conditions
- Cosmic Ray Particles

Key parameters on the interplanetary medium for space weather are:

- Topology of the interplanetary magnetic field, in particular its north-south component, which controls the energy input of the solar wind into the magnetosphere
- Solar wind velocity which drives instabilities, and therefore particle acceleration, in the magnetosphere
- Solar wind dynamic pressure, which determines the pressure on the magnetospheric system and therefore the magnetopause position
- Solar and galactic energetic particle flux prior to interaction with magnetosphere
- Radio signatures of shocks in the corona and in the interplanetary medium

Major research issues are:

- Understanding the solar wind acceleration and heating process
- Predicting the solar wind conditions at Earth (north-south component of field, pressure)
- Relationship between CMEs and interplanetary CMEs (ICMEs).
- Understanding the evolution of plasma structures through the interplanetary medium

2.3.1 Key phenomena, parameters and research issues - Magnetosphere

Key space weather related phenomena may be summarised as follows :

- Geomagnetic storms
- Substorms
- Radiation belt enhancements
- Enhanced low energy plasma
- Ring current changes

Key parameters on the magnetosphere for space weather are:

- Low energy (eV-keV) particle fluxes which determine spacecraft charging
- High energy (keV-MeV) particle fluxes (vs time and space) which may cause deep dielectric charging
- Magnetic field which determines particle trajectories
- Electromagnetic wave spectrum, which affects velocity space diffusion of the radiation belt particles
- Boundaries

Major research issues are:

- Understand coupling of the solar wind with the magnetosphere and the transport of particles
- Predict onset of substorms
- Understand the dynamics, acceleration and loss processes for radiation belt particles
- Predict radiation belt fluxes during storm and quiet times
- Understand coupling to the ionosphere

2.4.1 Key phenomena, parameters and research issues - Ionosphere

Key space weather related phenomena may be summarised as follows:

- Ionospheric density changes
- Auroral oval shape & dynamics
- Convection electric field pattern
- Auroral precipitation

Key parameters for space weather are:

- Electron density variation with time, altitude, longitude and latitude
- Electric field

Major research issues are:

- Understand ionospheric response to geomagnetic storma and substorms
- Forecast the variability

2.5.1 Key phenomena, parameters and research issues - Thermosphere

Key space weather related phenomena may be summarised as follows :

- Neutral atmosphere density changes (drag)

Key parameters for space weather are:

- Neutral gas density profile with altitude
- Neutral wind velocities

Major research issues are:

- Understand changes in neutral parameters, and effects of solar and magnetic activity
- Improve empirical models used in orbit analysis
- Forecast neutral density profiles

Table 2A: Required space based instruments for monitoring key parameters

	Key parameters	Instruments (see Table 3)
Solar	Solar magnetic field	3
	EUV/UV spectral flux	1,2,6,8
	CME lift-off time and velocity	1,2,4,5
	Solar energetic particle flux	9
	X-ray, Hα, EUV, UV imaging	1,2,5
	Radio signatures of shocks	7
Interplanetary	IMF topology	13
	Solar wind velocity	10 or 11
	Solar wind dynamic pressure	10 or 11
	Energetic particle flux	9
	Radio signatures of shocks	7
Magnetosphere	eV-keV particles	11
	keV-MeV particles	12
	Magnetic field	13
	Electromagnetic wave spectrum	15
	Boundaries	11,13,14,15
Thermosphere	Neutral gas density profile with altitude	20,21
	Neutral wind velocities	19
Ionosphere	Electron density	18,17,25,24
	Electric field	16
	Convection electric field	16
	Auroral precipitation	18,22,23

Table 2: Required space-based instruments necessary to observe a given space weather inducing phenomenon

	Instrument	CME onset	CME propagation	CME (few coronal proxies)	Flares	Flares with protons	Coronal holes	Corotating Interacting Regions (CIRs)	Shocks	Magnetic clouds	Upstream plasma conditions	Geomagnetic storms	Substorms	Cosmic Ray Particles	Radiation belt enhancements	Enhanced low energy plasma	Ring current changes	Ionospheric density changes	Neutral atmosphere density changes (drag)	Auroral oval shape & dynamics	Convection pattern
1	Soft X-ray imager *	X	X		X	X	X			X											
2	EUV imager *	X	X		X	X	X			X											
3	Magnetograph *	X	X		X	X	X				X										
4	Coronagraph *		X							X											
5	H-α imager	X		X	X	X															
6	Soft X-ray & UV flux monitor *				X	X												X	X		
7	Radio spectrograph – a. High freq.		X	X	X	X		X	X	X											
	b. Low freq		X	X					X												
8	EUV spectrograph																	X	X		
9	Solar & galactic radiation monitor *					X								X							
10	Solar Wind monitor *		X	X			X	X	X	X	X	X	X		X						
11	Thermal plasma monitor *		X	X			X	X		X	X	X	X		X	X	X				
12	Mid energy particle monitor *		X	X						X		X	X		X		X				
13	Magnetometer *		X	X			X			X	X	X	X				X				
14	Waves – a. Magnetic								X			X	X		X						
	b. Electric								X												
15	Neutral particle imager												X				X				
16	E field antennae																	X			X
17	Sounder																	X			
18	Low energy plasma monitor															X		X			
19	Interferometer																		X		
20	Spectrometer																	X	X		
21	Accelerometer																		X		
22	UV imager																			X	
23	Visible imager																			X	
24	GPS receiver																		X		
25	Topside sounder																	X			

N.B.: The instruments marked with a (*) provide fundamental parameters which are used in space weather forecasting or monitoring at present. The other instruments are at present used for research but may ultimately be used operationally.

Table 3: Required instruments and their corresponding technical characteristics

	Instrument	Platform	Description
1	Soft X-ray imager *	Solar	Broad band, full Sun, 5" pixels, 1 minute, pair of filters
2	EUV imager *	Solar	Narrow band EUV (195 and 304 Å) , full Sun, 5" pixels, 2.5 min.
3	Magnetograph *	Solar	Full Sun, 2" pixels, 15 min. (average several images onboard)
4	Coronagraph *	Solar	1.5-30 Solar radii, 1024x1024 pixel CCD, 10 min. Two coronagraphs (inner and outer)
5	H-α imager	Solar	Selectable narrow bands around H-α line +/- 2 Å centre, full Sun, 2" pixels, 30 second
6	Soft X-ray & UV flux monitor *	Solar	Wide band flux monitors (SXR GOES-like), 1 minute
7	Radio spectrograph	Solar	a. 10 MHz-400 MHz (new development) b: 30 kHz-10 MHz (Wind heritage)
8	EUV spectrograph	Solar	Absolute EUV flux (full disc)
9	Solar and galactic radiation monitor *	Upstream	2-100 MeV ions, 2-20 MeV electrons, ≥500 MeV particles, 1 minute
10	Solar Wind monitor*	Upstream	Solar wind velocity and density, 1 minute
11	Thermal plasma monitor *	Upstream Magnetospheric	0-40 keV ions and electrons, 45° cone in solar wind, 4π in magnetosphere, 5° resolution upstream (ions), 45° elsewhere, 1 minute
12	Mid energy particle monitor *	Upstream Magnetospheric	40keV-2MeV ions and electrons, 4π, 45° resolution, 1 minute
13	Magnetometer *	Upstream, Magnetospheric, Ionospheric	0-±64, 0-±256 nT, 0-±65536 nT, 1 minute
14	Waves	Magnetospheric	a. 1 Hz-10 kHz, 3 magnetic antennae b. 1 Hz-100 kHz 1 electric antenna
15	Neutral particle imager	Magnetospheric	ENA
16	E field antennae	Ionospheric	3 orthogonal pairs if possible
17	Sounder	Ionospheric Magnetospheric	Excitation of plasma frequency
18	Low energy plasma monitor	Ionospheric	0-40 keV ions and electrons Langmuir probe and drift meter
19	Interferometer	Ionospheric	Fabry Perot
20	Mass spectrometer	Ionospheric	Ion mass and neutral atom
21	Accelerometer	Ionospheric	Drag and solar radiation pressure
22	UV imager	Magnetospheric Ionospheric	130-190 nm
23	Visible imager	Magnetospheric Ionospheric	Visible
24	GPS receiver	Ionosphere/thermosphere	Orbit position, TEC, tomography
25	Topside sounder	Ionosphere	Ionospheric density profile

Table 3A: Comparison of proposed solar instruments with SOHO

Instrument	Comments
SXR Imager	No X-ray instruments on SOHO; Similar to design of GOES-SXI
EUV Imager	Similar design to SOHO-EIT; half spatial resolution, higher cadence, fewer channels
Coronagraph	Similar to SOHO-LASCO; comparable spatial and temporal resolutions
Magnetograph	Line-of-sight magnetograph: very similar to SOHO-MDI; higher cadence Vector magnetograph: never flown before, similar to one planned for the LWS SDO mission
H-Alpha Imager	Not flown previously

Instruments	Comments
X-ray and EUV imager	Require space-based platform, atmosphere absorbs these wavelengths.
Coronagraph	Some measurements possible from the ground, but atmospheric scattering limits radial distance from solar disk that can be observed.
Magnetograph and H-alpha imager	Could be made from the ground, but continuous, reliable coverage would require an extensive network of ground-based observatories. Better coverage from space.

	Instrument	Mass (kg)	Power (W)	Telemetry (kbps)	Cost (MEuro)	Status	Main references	Size (cm)	3 axis/Spin
1	Soft X-ray imager	25	20	70	15	1	Yohkoh, GOES SXI	30x15x140	3
2	EUV imager	28	20	28	15	2	SOHO, TRACE, SO	30x15x140	3
3	Magnetograph	26	25	9.5*	15	2	Solar B, SDO, SO	30x40x120	3
4	Coronagraph	18 – 25	25	50	15	2	SOHO, STEREO	20x20x50	3
5	H-α imager	18	20	120	15	4	Similar instruments	20x20x50	3
6	Soft X-ray & UV flux monitor	5	5	0.2	7	1	GOES, UARS	11x11x22	3
7	Radio spectrograph A high freq.	12	6	0.5	15	4	None	Antenna 3.5x2.5m+elec	3
	Radio spectrograph B low freq.	2	0.8	0.8	3	1	Wind, SO	5m boom+10x10x10	3/S
8	EUV spectrograph	5	5	1	5	3	UARS, TIMED	11x11x22	3
9	Solar and galactic radiation monitor	6	8	0.1	10	2	GOES, Ulysses	20x20x20	3/S
10	Solar Wind monitor	6	5	2	5	2	ACE, AMPTE, Giotto, Cassini, Cluster	20x20x20	S/3
11	Thermal plasma monitor	6	8	2	5	2	AMPTE, CRRES, Cluster, Cassini	20x20x20	S/3
12	Mid energy particle monitor	2	4	2	5	2	CRRES, Polar, Cluster, GOES, Hitchhikers	15x15x15	S/3
13	Magnetometer	1	2	0.2	3	1	Cluster, Rosetta	20x10x5 (elec) 4x4x4 (2 sensors on boom)	S/3
14	Waves A magnetic	1.3	1.2	2	2	1	Cluster, SO	20x10x5 (elec) + booms	S/3
	Waves B electric	8	0.6	2	5	1	Demeter	TBD	
15	Neutral particle imager	3	3	2	3	2	Mars Express, STORMS, IMAGE	15x15x15	3
16	E field antennae	17.5	3.1	1.5	6	1	Cluster	20x10x5 (electronics) plus booms	S/3
17	Sounder	1.2	2	0.3	2	1	Rosetta	TBD	S/3
18	Low energy plasma monitor	2	4	1	5	2	UARS, Cluster, Rosetta	15x15x15	S/3
19	Interferometer	42	19	1	10	3	UARS, TIMED	4 tel. 20x12x12, int. 40x15x15 + elec	3
20	Mass spectrometer	2.7	7.4	1	10	3	Cluster, UARS	15x15x15	S/3
21	Accelerometer	0.5	1	1	0.5	2	CHAMP, Huygens	5x5x5	3
22	UV imager	20	10	10	10	2	Polar, IMAGE	80x50x30	3
23	Visible imager	29	10	10	10	2	Polar, IMAGE	60x60x25	3
24	GPS receiver	8.5	12	0.1	1	2	SAC-C, CHAMP,JASON-1	20x20x10 + antennae	3/S
25	Topside sounder	10	10	1	5	3	ISIS, Alouette, SSTL	15m boom + elec	3/S

Table 4: System requirements for the various instruments (preliminary)

In the Table, under status, we indicate the maturity of instruments' 'industrial maturity'. The codes are: 1=off the shelf, 2=to be adapted from existing designs, 3=need further development, but technology exists, 4=need for technological development, 5=feasibility to be proven. Cost column includes manpower and development where required. * assumes data compression; raw rate up to 200 kbps

Table 5A: Suggested mission strategy (possible payload)

	Option	Strategy	No. of Space-craft	Orbit	Possible payload
Solar and Upstream Measurements	1A	SOLAR MONITORING	1	L1	1. Soft X-ray imager 2. EUV imager 3. Magnetograph 4. Coronograph 5. H-á imager 6. Soft X-ray & UV flux monitor 7. Radio spectrograph A 8. EUV spectrograph
	1B	UPSTREAM MONITORING	1	L1	9. Solar and galactic radiation monitor 10. Solar wind monitor 11.Thermal plasma monitor 12. Mid-energy particle monitor 13. Magnetometer
	2	A - SOLAR MONITORING	2	2 in Near-Earth Sun-synchronous orbit OR 2 in Geo-synchronous orbit	1. Soft X-ray imager 2. EUV imager 3. Magnetograph 4. Coronograph 5. H-á imager 6. Soft X-ray & UV flux monitor 8. EUV spectrograph
		B - PLASMA MONITORING	1	1 spacecraft at L1	9. Solar and galactic radiation monitor 10. Solar wind monitor 11.Thermal plasma monitor 12. Mid-energy particle monitor 13. Magnetometer 7. Radiospectrograph (B only if resources limited)
			3	3 spacecraft in High Circular Orbit (may replace 1 spacecraft downstream of L1)	
			1	1 spacecraft upstream of L1	10. Solar wind monitor 13. Magnetometer
			1	1 spacecraft downstream of L1	

Table 5B: Suggested mission strategy (possible payloads)

	Option	Strategy	No. of spacecraft	Orbit	Possible payload
Magnetospheric Measurements	1	RADIATION BELT MONITORING	1-3	1-3 equatorial spacecraft in GTO (At least 1, 3 preferable)	11.Thermal plasma monitor 12. Mid-energy particle monitor 13. Magnetometer 14. Waves (A only if resources limited)
	2	OUTER RADIATION BELT MONITORING NEAR EUROPEAN ASSETS	1	1 geo-synchronous spacecraft over Europe	11.Thermal plasma monitor 12. Mid-energy particle monitor
	3	PLASMA MONITORING	30-50	Multi-satellite constellation of small satelittes (SWARM)	11. Thermal plasma monitor 12. Mid-energy particle monitor 13. Magnetometer
	4	PIGGY-BACK INSTRUMENTS	As many as possible	Geo-synchronous, Medium Earth Orbit, and Low Earth Orbit	[11. Thermal plasma monitor] 12. Mid-energy particle monitor [9. Solar and galactic radiation monitor]

Table 5C: Suggested mission strategy (possible payloads)

	Option	Strategy	No. of spacecraft	Orbit	Possible payload
Ionospheric Measurements	1	DAYSIDE/ NIGHTSIDE MONITORING	2	Sun-synchronous orbit (SSO), 97.8 inclination, 600 km altitude 3-15h and 9-21h	16. E-field antennae 18. Low energy plasma monitor 20. Neutral mass spectrometer 24. GPS receiver 25. Topside sounder 9. Solar and galactic radiation monitor
		DAYSIDE/ NIGHTSIDE MONITORING	2	Equatorial Orbit, 600 km altitude	19. Interferometer 20. Neutral mass spectrometer 24. GPS receiver 25. Topside sounder
		DAYSIDE/ NIGHTSIDE MONITORING	2	75 inclination 600 km altitude	18. Low energy plasma monitor 19. Interferometer 20. Neutral mass spectrometer 24. GPS receiver 25. Topside sounder 9. Solar and galactic radiation monitor
		NORTHERN AURORAL & POLAR CAP MONITORING	1	Highly Eccentric Orbit, perigee around 600 km, apogee around 3 Earth radii	22. UV imager 23. Visible imager

Table – piggy back monitors

TABLE
PIGGY-BACK MONITORS 1

INSTRUMENT	MEASURED PARAMETER	ENERGY RANGE	MASS	POWER	TELEMETRY
REM	- Electrons - Protons	- 1 MeV - 25 MeV	1.8 kg	< 5 W	
SREM	- Electrons - Protons	- 0.3 to 6 MeV - 8 to 300 MeV	< 2.5 kg	< 2 W	
CEASE I	Radiation dose Radiation dose rate Electron flux	50 < E < 250 keV E > 250 keV	1.0 kg	1.5 W*	10 bytes/60 s
CEASE II	Radiation dose Radiation dose rate Electron flux	50 < E < 250 keV E > 250 keV	1.3 kg	1.7 W*	10 bytes per 60 s
DIDM	Ions	Velocity vector Density Temperature	5 lbs (2.3 kg)	5 W from a 28 V supply	
ESA-200	Electrons Ions (angular distribution) 8° x 2° viewing angle	30 eV to 30 KeV	6 lbs. (2.7 kg)	0.5 W from a 28 VDC supply	
ESA-500	Electrons Ions (angular distribution) 8° x 90° viewing angle	30 eV to 30 KeV	7 lbs. (3.2 kg)	1.5 Watts from a 28 VDC supply	

(*) Power requirements can vary for non-standard interfaces.

TABLE
PIGGY-BACK MONITORS 2

INSTRUMENT	MEASURED PARAMETER	ENERGY RANGE	MASS	POWER	TELEMETRY
CPA	- Electrons - Protons	- 30 keV to 2 MeV - 75 keV to 200 MeV			
SOPA	- Electrons - Protons - Heavier Ions	- 50 keV to 26 MeV - 50 keV to >50 MeV - >0.5 MeV			
MPA	Plasma Electron and Ion Distributions	E/q ~ 1 eV/q to 40 keV/q	3.6 kg	3.5 W	
MSSL HE	electrons	300 keV-3 MeV	0.5 kg	2 W	100 bits/s
MSSL LE	electrons	0-30 keV	0.8 kg	2 W	100 bits/s
ICARE/COMRAD	Electrons, protons, heavy ions	50keV-6MeV (e), 8-30 MeV (i), 1-100 MeV (heavy)	2.4	7	
Iridium Magnetometer IM-102	Earth's Magnetic field	+/- 600 mG	< 220 g	<50 mW (0 mG) <100 mW (600 mG)	
Iridium Magnetometer IN-103	Earth's Magnetic field	+/- 600 mG	< 227 g	<0.8 mW (0 mG) <1.0 mW (600 mG)	
Iridium Magnetometer IM-203	Earth's Magnetic field	+/- 1000 mG	< 635 g	<1.4 mW (0 mG) < 1.7 mW (600 mG)	
Gorizont 91/2 (ADIPE)					
SXI	X-ray	0.6-6 nm (0.2-2 keV)	14.76 kg telescope 7.9 kg electronics	57 W	

TABLE
PIGGY-BACK MONITORS 3

INSTRUMENT	MEASURED PARAMETER	ENERGY RANGE	MASS	POWER	TELEMETRY
DEBIE	small-size (sub-millimeter) meteoroid & space debris		3.0 kg with four Sensor Units	less than 4.0 W with four Sensor Units	
GORID	submicron to millimetre size meteoroid & space debris		3.8 kg	2.2 W	8 bits/s