Status update on ESA's Cross-scale Technology Reference Study

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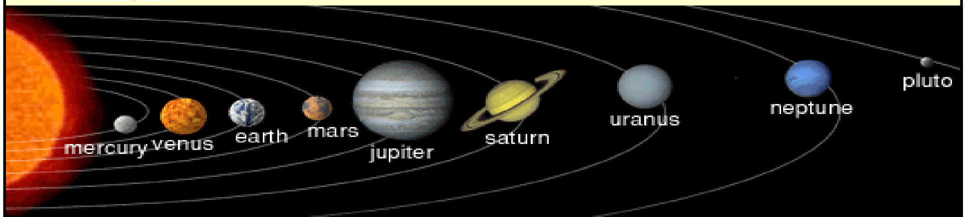
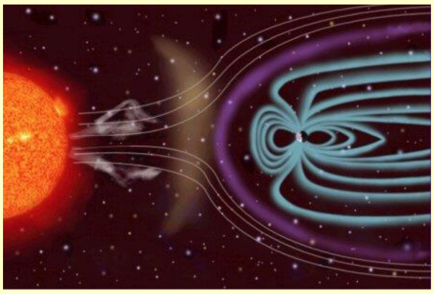


Outline

- Objective of the Cross-scale Technology Reference Study
- Study approach
- Study status
- Key mission requirements
- Mission architecture trade
- Baseline mission concept
- Identified mission drivers
- Conclusions and future work
- Summary



Objective of Cross-scale TRS

Study a possible plasma physics mission concept

- Scientifically meaningful
- Technically feasible
- Cost-efficient

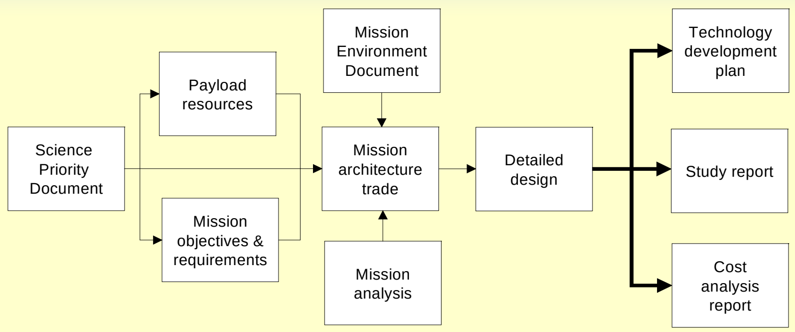
Through a detailed industrial system design study

Study documentation is a <u>reference</u> for

- Technology development roadmap
  - ✓ critical technologies
  - ✓ cost-reducing technologies
- Other mission concepts and proposal assessment

Technology Reference Studies help support longer term programme

TRS study outline



Sci-A & Sci-S (if possible with help from community)

Sci-A

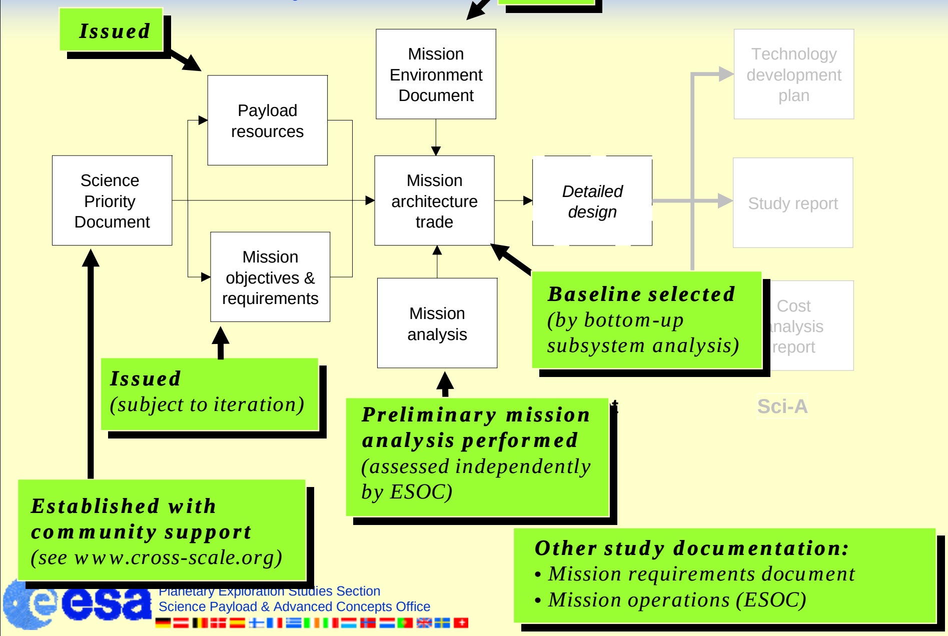
Industrial Assessment

Sci-A

Technology Reference Studies focus on:

- ***Technological feasibility***
- ***Fulfilment of science requirements***
- ***Cost-efficiency***

Cross-scale study status



Mission objectives

Investigation of ***fundamental space plasma*** processes
that involve ***non-linear coupling***
across ***multiple length scales***

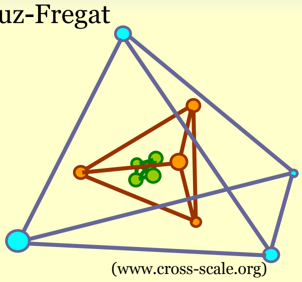
The key universal space plasma processes are:

All three processes:

- ✓ Are dynamical
- ✓ Involve complex 3-D structured interaction between different length scales (electrons, ions, MHD fluid)
- ✓ Can be investigated in near-Earth space (bowshock, current sheet, magnetosheath)

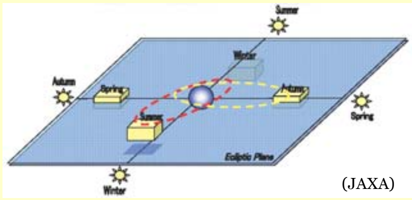
Cross-scale TRS mission requirements (I)

- 8 – 12 spacecraft to be launched with a single Soyuz-Fregat
  - 1 – 4 on electron scale: 2 – 100 km
  - 4 on ion scale: 50 – 2,000 km
  - 3 – 4 on large scale: 3,000 – 15,000 km



(www.cross-scale.org)

- Spacecraft constellation scales are concentric
- Constellation passes through bowshock, magnetopause and magnetotail
  - Visit 'tail box' region at least once a year
- Constellations optimized at apogee and *possibly* perigee (for 10 Re)



(JAXA)

- Range of constellation length scales is sampled at least once

Cross-scale TRS mission requirements (II)

Programmatics:

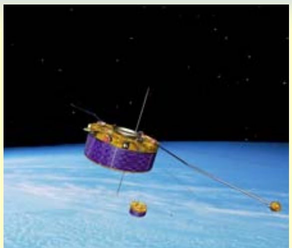
- ✓ Mission lifetime 3 – 5 years
- ✓ Technology development and demonstration horizon less than 5 years (TRL 5 in 2011)

Science data-rates (for complete constellation):

- ✓ On-board storage: > 1.5 Mbps × 2 orbital periods
  - Use of Hard-Disk Drive or SSMM (~100 Gbit per S/C)
- ✓ Downlink: 800 kbps (i.e. 65 - 100 kbps per S/C)

Inter spacecraft localization/synchronization:

E-scale	0.25 ms	125 m
Ion-scale	0.25 – 2 ms	1% of distance
Large scale	2 ms	1% of distance



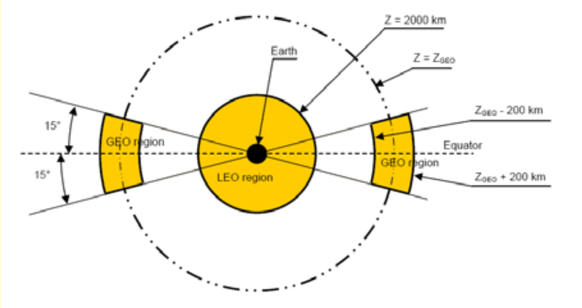
Cluster II

Cross-scale TRS mission requirements (III)

"European Code of Conduct for Space Debris Mitigation:"

No space segment shall enter the protected regions after mission completion, by taking one of the following precautions:

- Direct re-entry
- Limit orbital lifetime to less than 25 years
- Higher parking orbit



Hard requirement

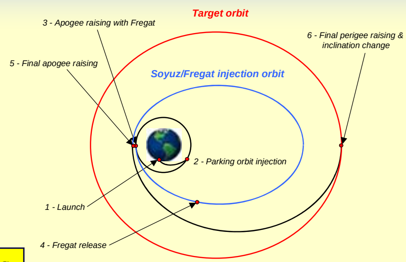
Impacts all Cross-scale S/C:

- Dispenser/transfer vehicle
- Constellation S/C

Unless perigee above 6.7 Re

Mass analysis: Launch and transfer

- Launch by Soyuz-Fregat 2 (1b) from Kourou:
  - Mass into GTO: 3026 kg (TBC)
  - Effective mass into GTO: 2430 kg (20% system margin, 110 kg adapter)
- Operational orbits of interest:
  - Perigee: 1 Re + 500 km – 15 Re
  - Apogee: 25 Re (25 Re – 50 Re)
  - 'Near equatorial'



Approximate dry mass in orbit (Isp = 325 s)

Orbit	Transfer ΔV (m/s)	Space debris ΔV (m/s)	Mass (kg)
$10\ R_E \times 25\ R_E \times 14°$	1390	0	1570
$10\ R_E \times 25\ R_E \times 14°$ (lunar resonances)	1115	0	**1713**
$4\ R_E \times 25\ R_E \times 14°$	1005	185	1673
$2\ R_E \times 25\ R_E \times 14°$	775	200	1790
$1.4\ R_E \times 25\ R_E \times 14°$ (2500 km)	675	110	**1900**

- Masses quoted are inclusive possible transfer vehicle, propellant tanks and propulsion system
- Deployment and reconfiguration ΔV not included in this table

Clearly, if mass-constrained $10 \times 25\ R_E$ and $1.4 \times 25\ R_E$ are the most attractive

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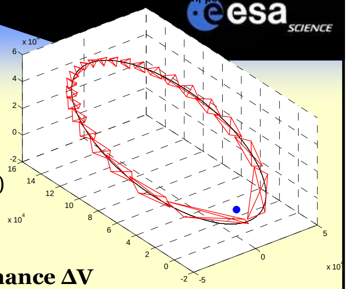
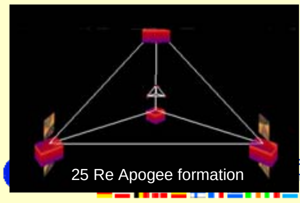
Mass Analysis: Constellation design



During operational phase propellant required for
- Deployment
- Spin-up and spin maintenance
- Constellation reconfiguration (medium+large: limited)
- Constellation maintenance (perturbations and drift)

Deployment/reconfiguration/maintenance ΔV

Orbit	Small scale ΔV (m/s)	Medium scale ΔV (m/s)	Large scale ΔV (m/s)	% Mass (large) (Isp = 308 s)
10 R_E × 25 R_E	5 m/s	50 m/s	200 m/s	~7%
4 R_E × 25 R_E	5 m/s	90 m/s	350 m/s	~11%
2 R_E × 25 R_E	10 m/s	115 m/s	450 m/s	~14%
1.4 R_E × 25 R_E	10 m/s	125 m/s	475 m/s	~15%



25 Re Apogee formation

- If tetrahedron @ perigee is required, numbers becomes substantially higher
- Lower perigee:
  - Higher ΔV during mission
  - More frequent control manoeuvres (still only ~1 x per year)

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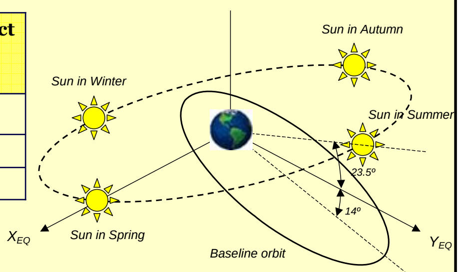
Orbital analysis

Characteristics of orbits selected for preliminary mission analysis:

Orbit parameters	Period (days)	Time per orbit between 9 - 11 R_E	Time in tailbox per year	Average tailbox time (h)	Remarks
10 R_E × 25 R_E × 14 ° (max ΔV: 1315 m/s)	4.3	9.8% (2.9 km/s)	8.0% (> 1.2 km/s)	9 (0.6 - 16)	Most encounters (many away from apogee), at relatively high speeds
4 R_E × 25 R_E × 14° (max ΔV: 1540 m/s)	3.2	4.6% (2.1 km/s)	6.4% (~0.8 km/s)	11 (0.13 – 23)	
~1 R_E × 25 R_E × 14° (max ΔV: 1260 m/s)	2.8	4.2% (1.2 km/s)	3.5% (~0.5 km/s)	14 (1.1 - 33)	Fewest encounters, at relatively low speeds

Perigee	krad (5 y and 4 mm Al)	Max. eclipse time	Av. GS contact time	Contact %
10 R_E	6	3.3 h	14.5 h	47
4 R_E	70-90	5 h	13.6 h	48
~1 R_E	60	8 h	11.7 h	49



Science return optimization criteria

Science priorities:

1. Visit regions of interest
2. Maximization of number of S/C
3. Maximization of payload resources
4. Optimization of orbit

Note: Within financial envelope

Optimization of science products:

Typically, plasma science investigations are performed on:

1. Detailed analysis of events that are constrained in time (<~2 hr)
2. General space plasma characteristics along the orbit

Science return optimization:

1. Allow different P/L configurations on identical S/C
   - Use standard slots and interfaces for e.g. particle instruments
   - Design all S/C for a standard 'maximum' P/L configuration
2. Only downlink 'useful' science data:
   - Nominal data over complete orbit
   - High-data rate products for selected time slots:
     - On-board triggering (difficult for constellation 'events')
     - On-ground selection based on nominal data (requires on-board memory and streamlined Mission Ops/Science Ops)

Mission architecture trade

Launch with SF 2-1b from CSG.
- Initial orbit lower than GTO (20,000 km)

Transfer to operational orbit by dispenser-like transfer vehicle
- Reduction of mission operations complexity
- Mass optimization (propulsion staging, constellation S/C design)
- Scaleable design (operational orbit vs number or mass of S/C)
- Payload accommodation (axial antenna)

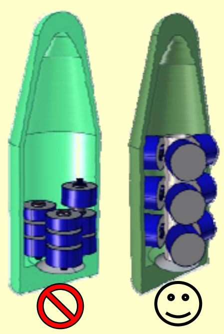
Operational orbit **1.4 ×25 R_E**
- Maximization of number of S/C (10 S/C in baseline orbit)
- Space Debris policy

Identical spacecraft
- Cost optimization (design, AIV and Ops)

Nearly identical payload
- Identical P/L interfaces to S/C for a set of possible P/L configurations
- Requirements on P/L autonomy and reliability

Communication architecture
- Direct link of individual S/C to G/S

Operations
- Cost optimization (see also above)
- Automated downlink
- S/C autonomy/reliability vs operational complexity
- S/C memory vs operational complexity ('data'-selection)

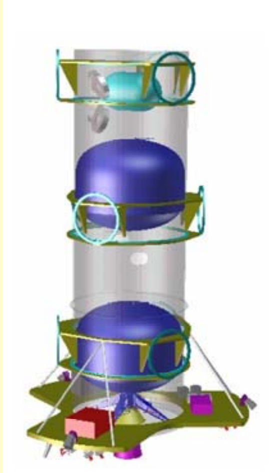


Dispenser preliminary design

- Structure based on SpaceBus 4000
  - ✓ Existing design (cost-efficient)
  - ✓ Qualified up to 5,000 kg
  - ✓ Low weight CFRP
  - ✓ Use of existing propellant tank configurations

Dispenser characteristics:

- Transfer to operational orbit, deployment, de-orbit
- Independent operation:
  - ✓ AOCS (3-axis)
  - ✓ Comms (S-band)
  - ✓ CDMU
  - ✓ Power (3.5 hr eclipse)
- Safe mode: slowly spinning



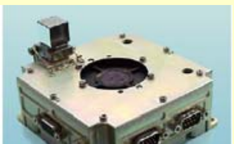
Scaleable design

S/C preliminary design

Key characteristics of preliminary baseline:

Number of S/C	10 (4 large, 4 medium, 2 small scale)
Dimension	~1.5 m (Ø) × ~1 m (height)
Spinning rate	20 – 40 rpm
Total mass	145 – 160 kg (depending on scale)
Dry mass (excl. P/L)	106 kg
Power	160 W
Communication	X-band, 10 W (RF) , omnidirectional, variable data-rate (up to 3 Mbps)
On-board memory	256 Gbits SDRAM/DDRAM
AOCS	Star mapper, sun sensors, bipropellant thrusters
Max. P/L mass	42 kg (excl. S/C ranging)
Max. P/L power	30 W (exc. S/C ranging)
P/L / total dry S/C	10 - 30%(incl. S/C ranging)

Saab-Ericsson antenna (Herschel/Planck)



Galileo Avionica Sun sensor (Cluster-II)

TNO-TPD Star Mapper (Cluster-II)

Key spacecraft mass drivers

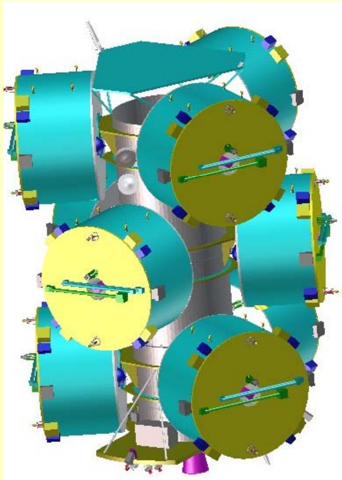
- Identical S/C
- Power (downlink requirements, maximum P/L power)
- Accommodation of maximum P/L mass (42 kg)

Launch stack

Projected mass budget:

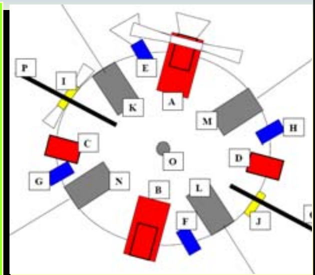
Item	Number	Mass each (kg)	Remarks
Large scale S/C	4	144	13 kg P/L
Medium scale S/C	4	158	34 kg P/L + S/C ranging
Small scale S/C	2	162	42 kg P/L + S/C ranging
S/C total	**10**	**1532**	
Dispenser	1	515	Dry mass
Propellant	1	1157	Only for transfer
TOTAL		**3204**	
Launch capacity		3885	Into 20,000 km, adapter subtracted
MARGIN		681	21% system level margin (**20% required**)

Preliminary design



Possible payload distribution

Instrument	Location of instruments				
	e - scale #1	e - scale #2	ion scale #1	ion scale #2-4	Large scale
DC Magnetometer	P	P	P	P	P
AC Magnetometer	Q	Q	Q	Q	Q
Wire boom antenna	KLMN	KLMN	KLMN	KLMN	-
Axial antenna	O	O	-	-	-
Electron ESA	EFGH	-	-	-	-
Ion ESA	-	EFGH	-	-	-
Electron/Ion ESA	ABCD	ABCD	CD	ABCD	A
Ion composition	-	-	AB	-	-
Hot plasma particle composition	-	-	-	EF	-
Solid State Telescope	-	IJ	-	IJ	I



Key requirements (feasibility TBC):

- Limitation of payload instrument modes
- Autonomous instrument operation (also during eclipses, radiation belt, solar flare)
- Speedy initialization/recovery procedures (maximum 1 day)

Identified mission drivers

Driver	Impacts
Operational orbit	Launch mass
Space debris mitigation	Launch mass, S/C design, mission lifetime
Large scale constellation (re)configuration	Propellant, S/C design, mission operations
Number of satellites	Launch mass, AIV, mission operations
Number of different satellites	AIV, mission operations
Payload mass + power	Launch mass
Instrument modes	Operations
On-board data storage	Launch mass, mission operations
Downlink rate	Communication system, power system, ground system

Identified technology requirements

Technologies	Remarks
Small/medium scale synchronization	Real-time inter-S/C system for spinning satellite
On-board memory	Hard-Disk-Drive would allow large amount of on-board data storage
Low-resource X-band transponder and amplifier	Applicable for most of future (science) mission concepts
TO BE CONTINUED	

Conclusions

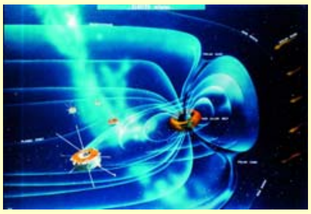
Cross-scale Technology Reference Study is work in progress

- ✓ Mission analysis has been performed
- ✓ Mission architecture trade concluded
- ✓ Mission architecture baseline selected

Next steps

- ✓ Refined spacecraft design
- ✓ Mission operations
- ✓ Programmatics

➢ ***Technology development plan***



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