ESA SSA Space Weather Network

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ESA SSA Programme Office

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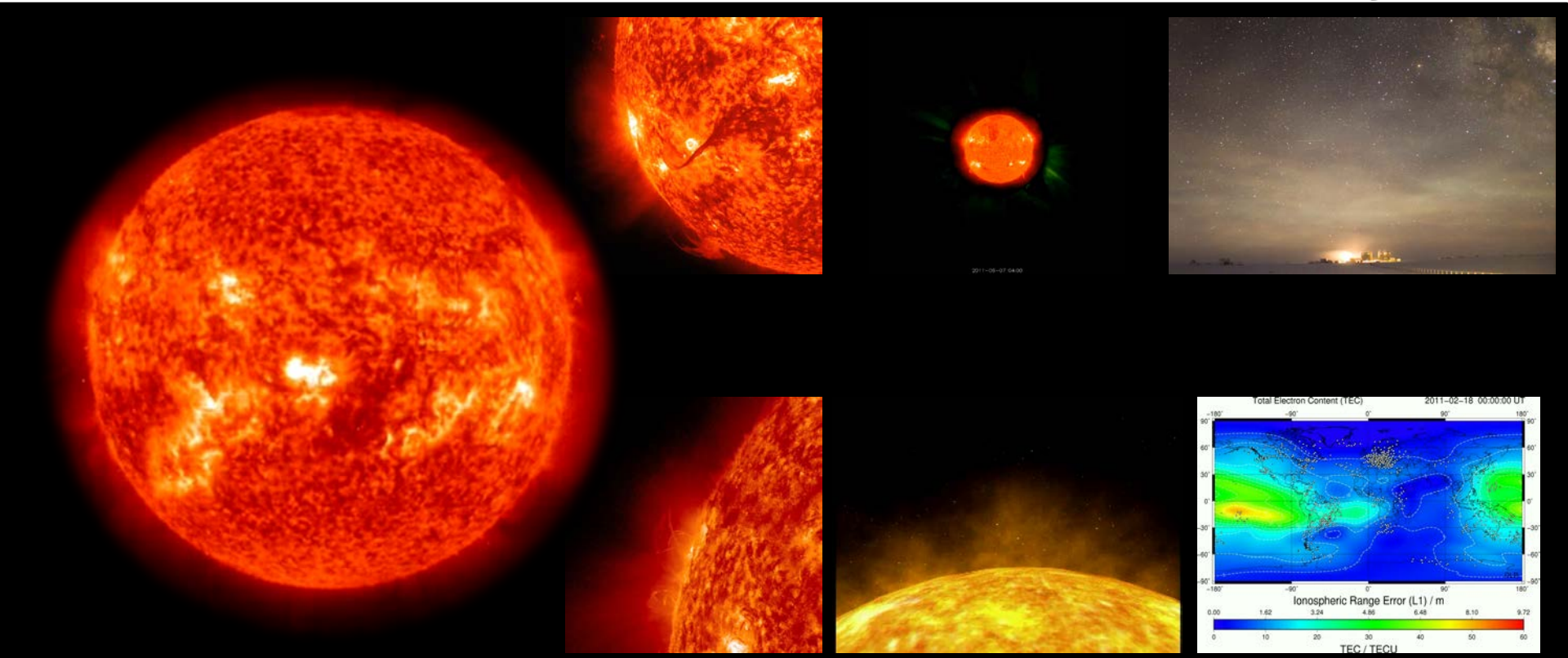
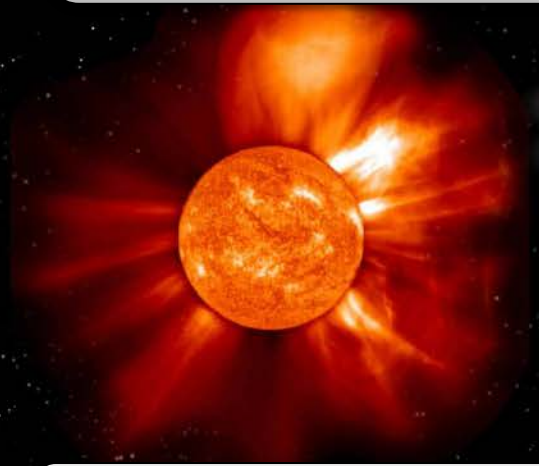
What is ”Space Weather”?



Solar Wind

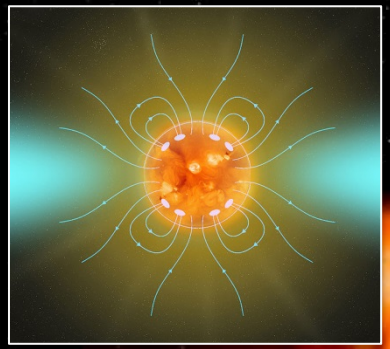
Solar Wind: constant emission of charged particles from the upper atmosphere of the Sun

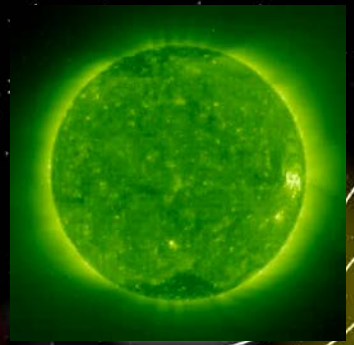
Solar wind pressure shapes the magnetic field of the Earth: compressed day-side and tailed in the night side

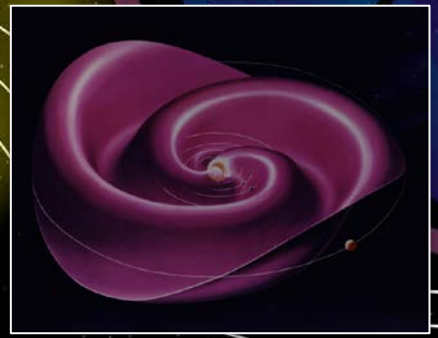


Velocity of ambient, slow solar wind is around 400 km/s

Interplanetary Magnetic Field (IMF)

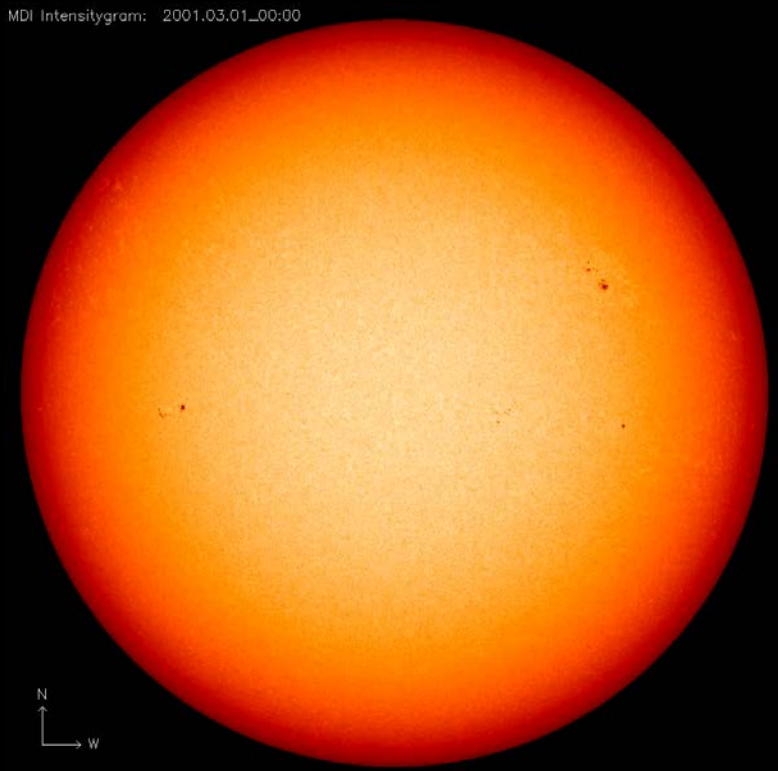


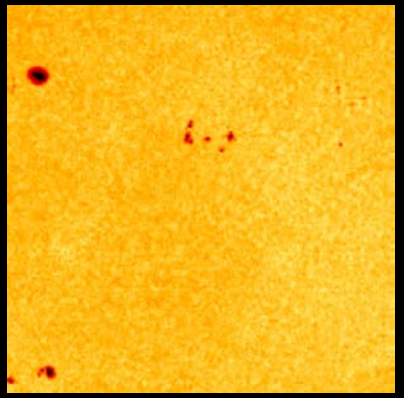




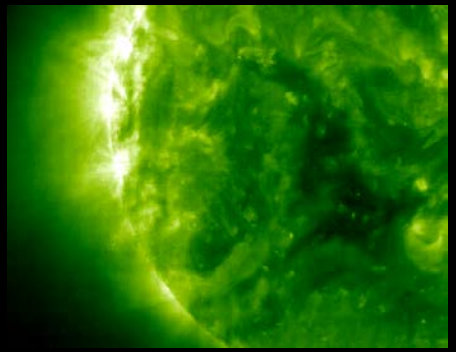
Fast solar wind from coronal holes can reach speeds over 800 km/s

Active Regions (Sunspots)



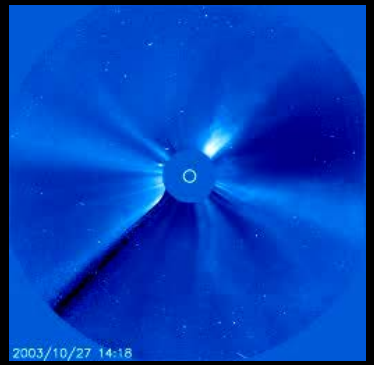


Solar activity from Active Regions



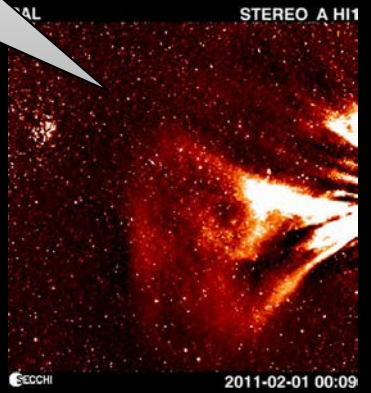
Solar flares: bursts of electromagnetic radiation

Coronal Mass Ejections: Ejection of solar plasma into space

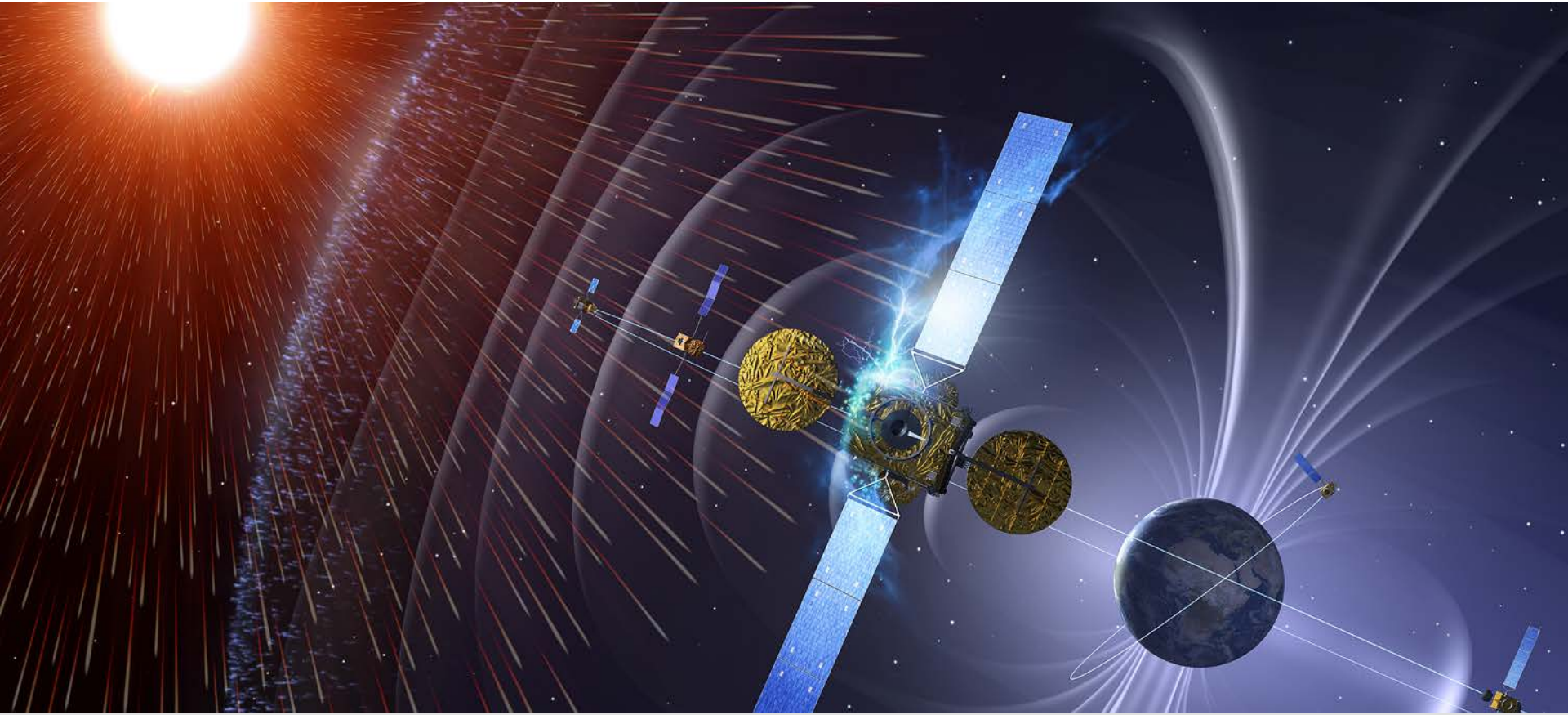


Solar Energetic Particles: protons and electrons accelerated to relativistic speeds

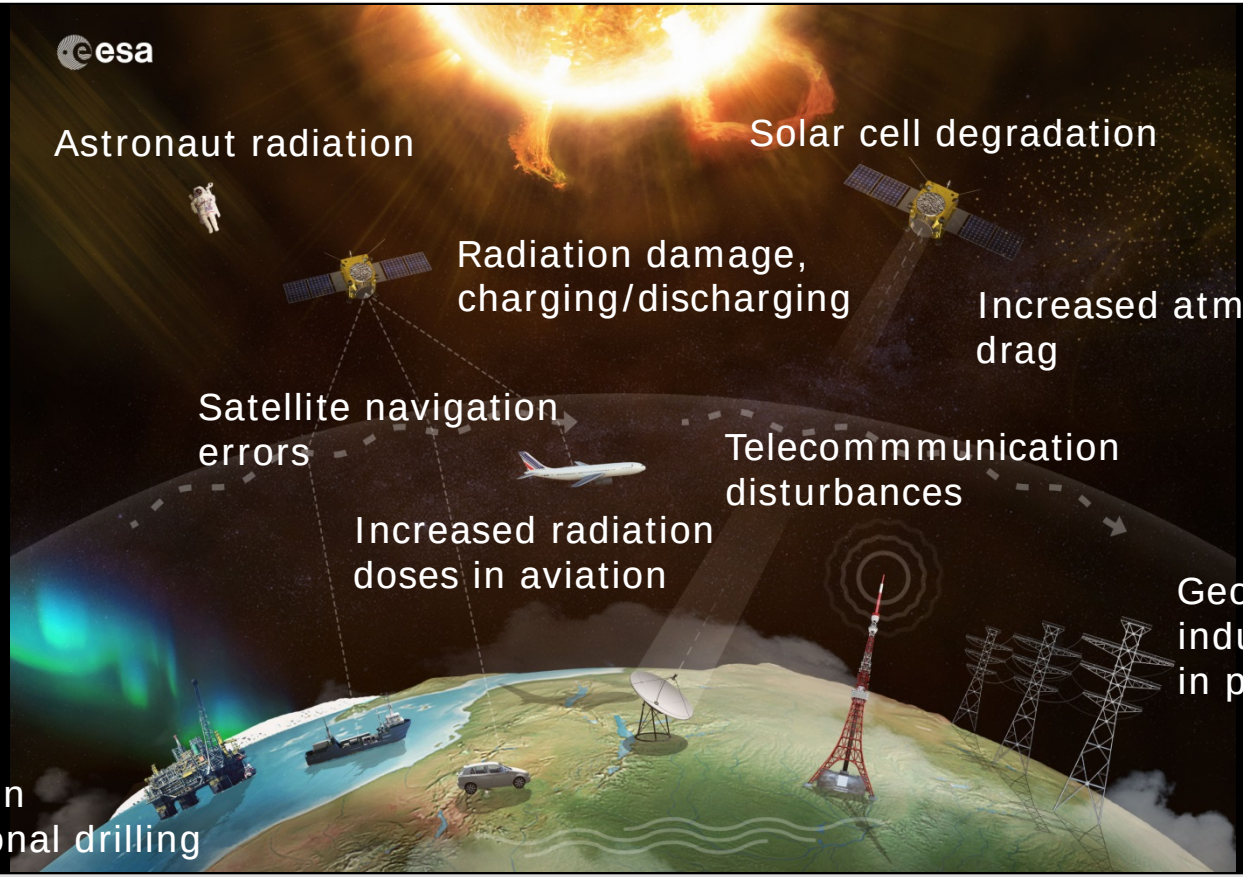
2003/05/26 00:00



Why do we worry about space weather

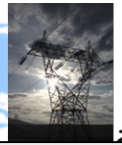


Space Weather Hazards for Infrastructure



Ground Effects of Space Weather during Halloween storm (Oct – Nov 2003)

NOTAM: Polar flight route restrictions due to geomagnetic storm impacts on radio communications



Power blackout in Malmö

Failures in GPS based positioning

SatComm and HF outages in Asia and Australia

Nuclear power plants reduced power due to electromagnetic storm

Widespread HF radio outage over African continent

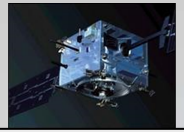
Survey instrument impacts globally

Transformer damage in South Africa

Effects on Space Missions during the Halloween storm

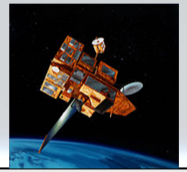
Mars Odyssey mission:
Safe mode during radiation storm.
Memory error and loss of MARIE instrument

Mars Express star trackers blinded by particle radiation



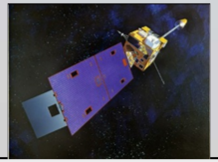
Smart-1 spacecraft solar panels damaged

DMSP F16: SSIES sensor lost data twice, microware sounder damaged



ADEOS-2
Spacecraft lost

ACE: EPAM instrument permanently damaged



GOES-9, 10 and 12:
High bit error rates (9,10), magnetic torguers disabled (12)

Multiple anomalies in GEO TV and Pay Radio satellites: Momentum wheels, CPU, service outages, …

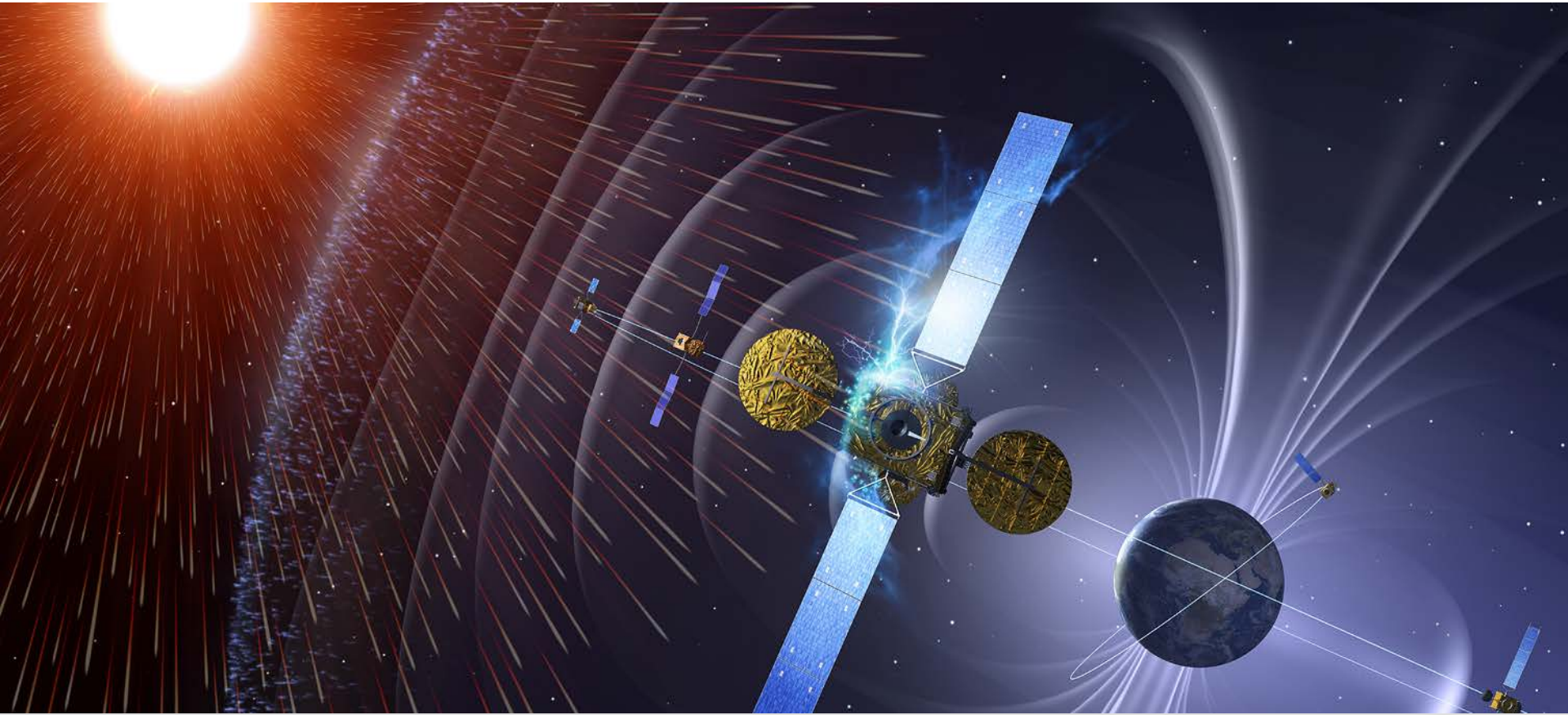
Results of the CBA for the SWE segment

Cost/Benefit	Do nothing scenario	Do ESA scenario	Value added of ESA services
User domain benefits			
Satellite operations	- €293 M	- €267 M	€26 M
Launch operations	- €0.3 M	- €0.1 M	€0.2 M
Resource exploitation	- €327 M	- €135 M	€192 M
Power grids operations	- €5,771 M	- €4,546 M	€1,225 M
Aviation	- €3,312 M	- €3,066 M	€246 M
Logistic/Road transport	- €3,432 M	- €2,888 M	€544 M
Investment benefits			
GDP impact	None	€952 M	€952 M
Total Benefits (b)	- €13,135 M	-€9,950 M	**€3,185 M**
Programme Costs (c)	None	- €529 M	**- €529 M**
Total Net Benefits	- €13,135 M	- €10,479 M	**€ 2,656 M**
		Benefit / Cost ratio (b/c)	**6**

Extreme SWE event impact estimates

Domain	2016 (year 1)	2024 (year 9)	2032 (year 17)
Spacecraft design and operations	- €912.9 M	- €1,123.2 M	- €1,389.4 M
Launch operations	- €0.008 M	- €0.037 M	- €0.051 M
Aviation	- €6,635.6 M	- €11,139.8 M	- €18,701.5 M
Resource exploitation	- €197.5 M	- €234.9 M	- €279.5 M
Power system operators	- €5,630.5 M	- €6,364 M	- €7,195.2 M
Road & Transportation	- €1,595.4 M	- €1,783 M	- €1,992.8 M
TOTAL	- €14,971.9 M	- €20,644.9 M	- €29,558.4 M
Estimated savings with ESA SSA SWE	2,500 M	3,500 M	5,000 M

Protecting our Infrastructure



ESA Space Situational Awareness Programme

Objective:

- Protection of space and ground assets against adverse effects from space

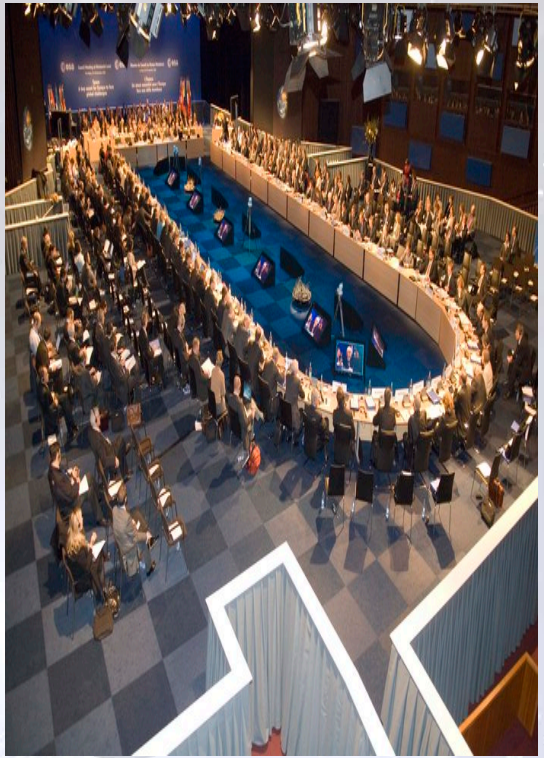
Three main areas or segments:

- Space Weather (SWE)
- Near Earth Objects (NEO)
- Technology R&D for Space Surveillance and Tracking (SST)

SSA Programme initiated in April 2008 (ESA Council, SSA Enabling Resolution)

SSA Programme executed in Periods

- Period 1 decided at MC in November 2008 (Prep. Programme)
- Period 2 decided at MC12 in November 2012
- Period 3 decided in MC16 in December 2016



Networking European Space Weather Expertise

Data archives

- SSA SWE Data Centre (Redu)
- Federated data repositories

SSA SWE Coordination Centre

- User Helpdesk
- Space Pole, Belgium

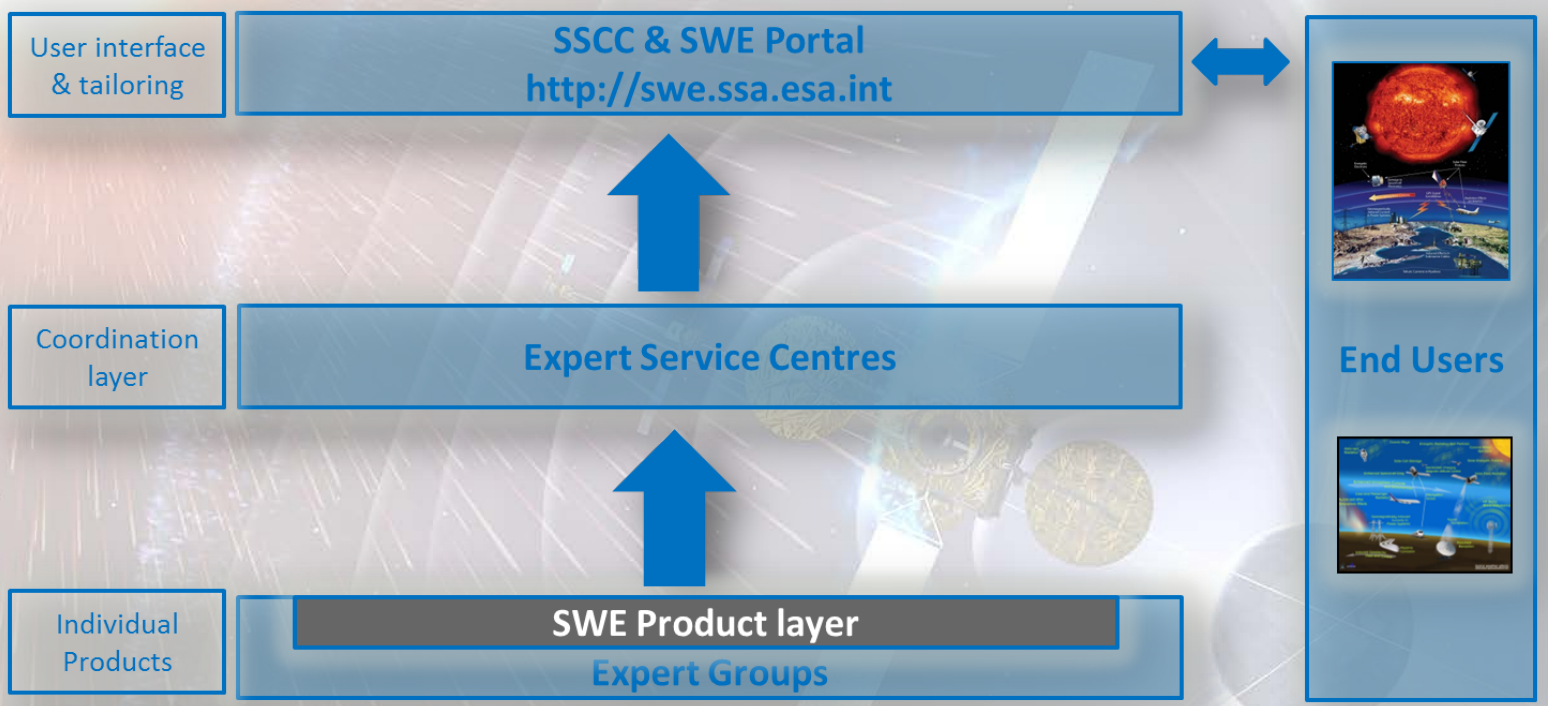
SWE Expert Service Centres (ESCs)

Solar Weather | Ionospheric Weather | Space Radiation | Geomagnetic Conditions | Heliospheric Weather

European expert groups and centres of excellence

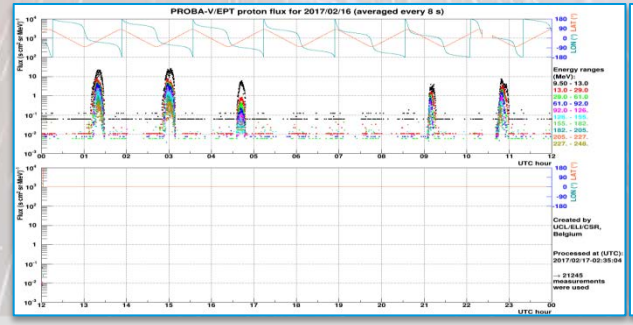
Sensor systems

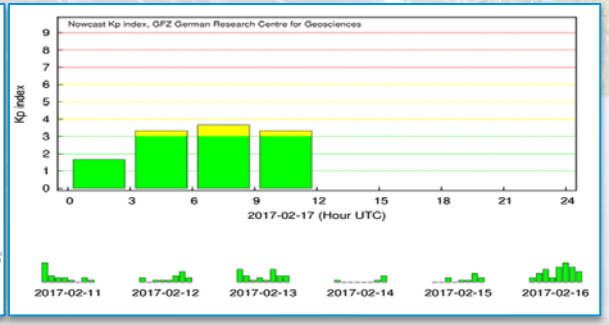
SWE Services Business Logic

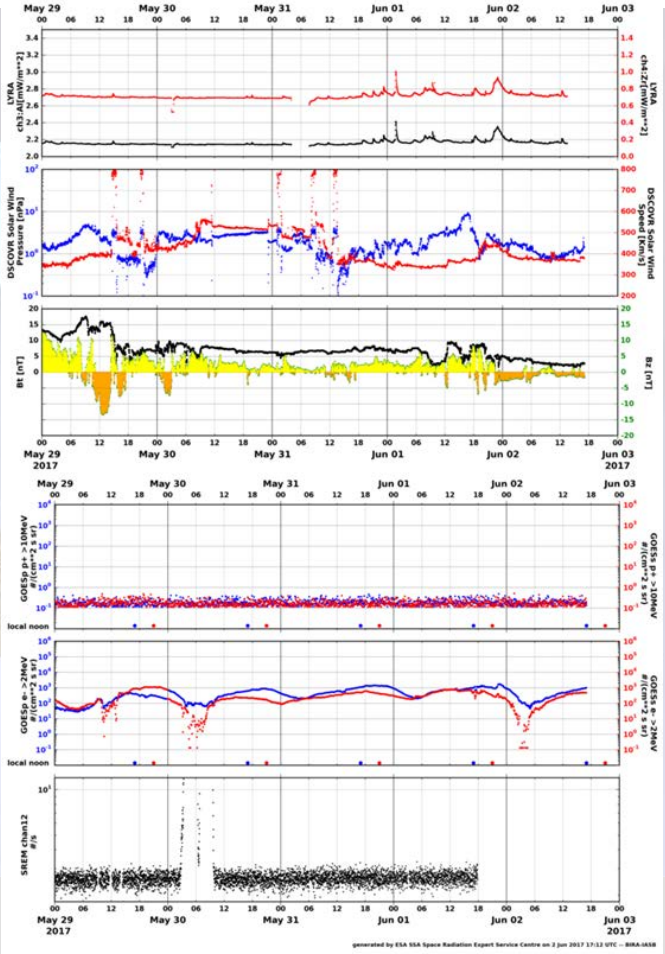


SWE Service For Spacecraft Operators: In-orbit Environment and Effects Monitoring

- NRT estimate of space environment
- Effects experienced in spacecraft operations
- Geomagnetic storms, substorms, high-speed streams, solar energetic particle events & Earth-directed CMEs
- Training of mission operators
- New radiation environment forecast services under development => ESOC WS 14th June







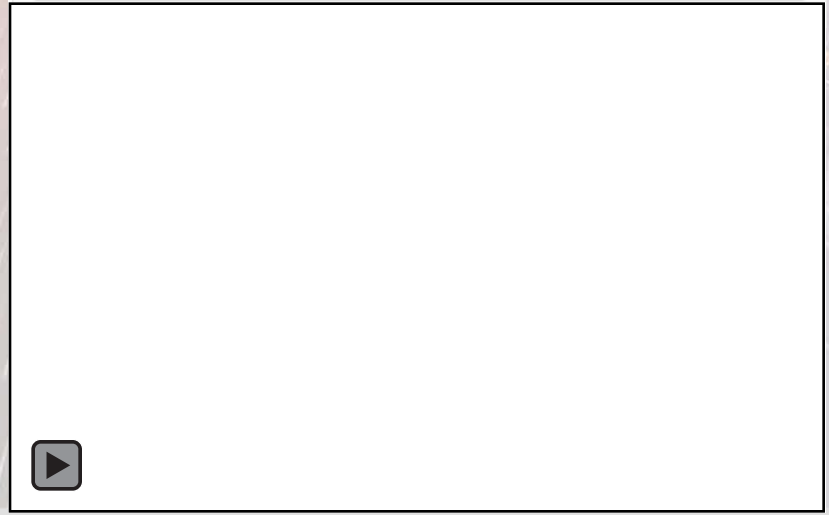
SWE Service For Spacecraft Operators: In-orbit Environment and Effects Monitoring

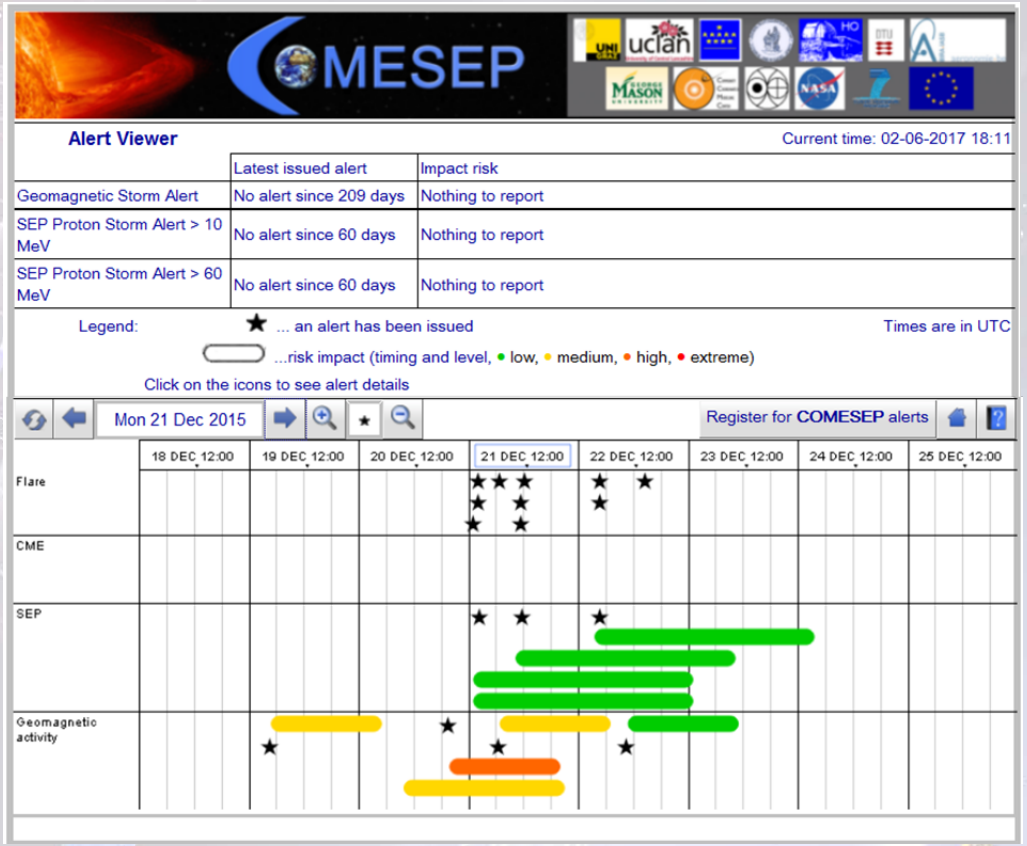
Met Office — Heliospheric Weather Expert Service Centre

Mercury | Venus | Earth | Mars

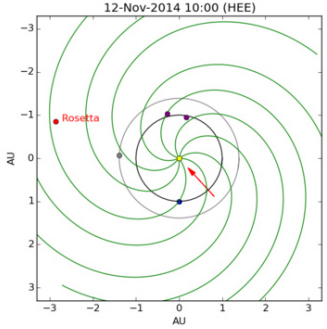
GEOMAGNETIC STORMS

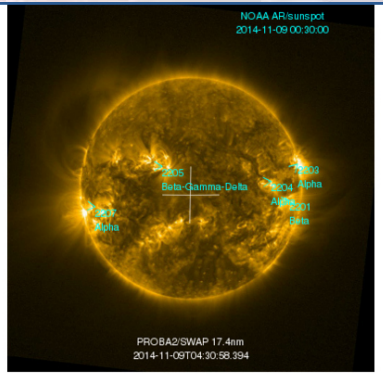
Exceedance	Level	Past 24 h.	Day 1	Day 2	Day 3	Day 4
Minor or moderate	G1 to G2	No	10%	10%	5%	5%
Strong	G3	No	1%	1%	1%	1%
Severe	G4	No	1%	1%	1%	1%
Extreme	G5	No	1%	1%	1%	1%

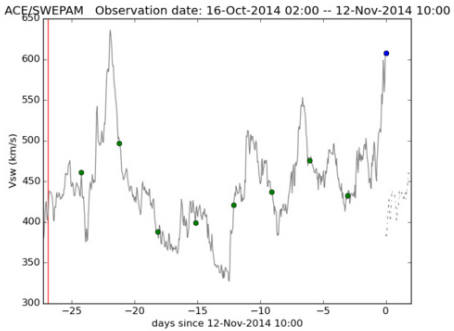


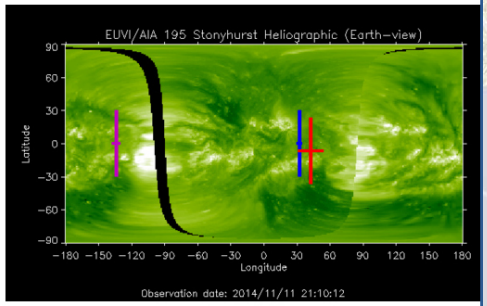


Tailored SWE Bulletins: Rosetta





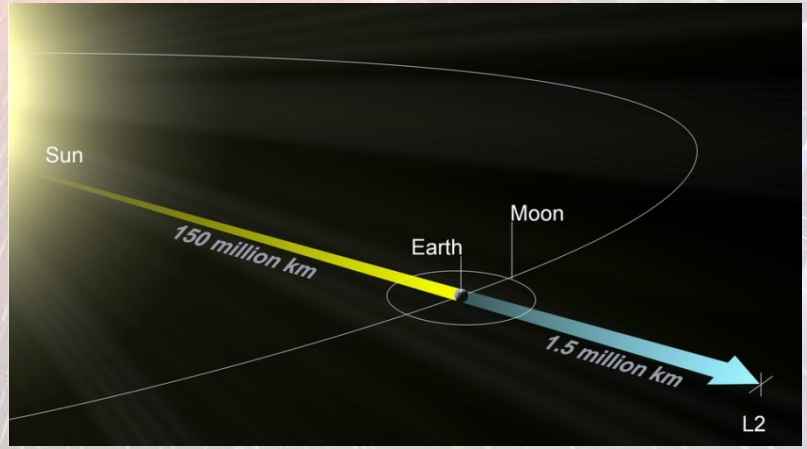


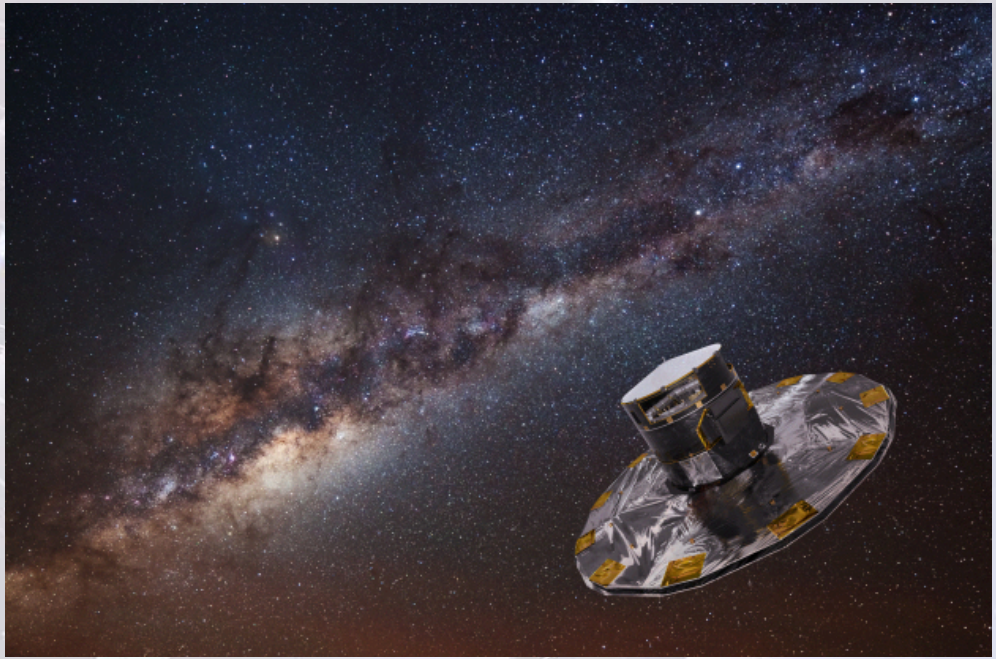


Solar-Terrestrial Centre of Excellence

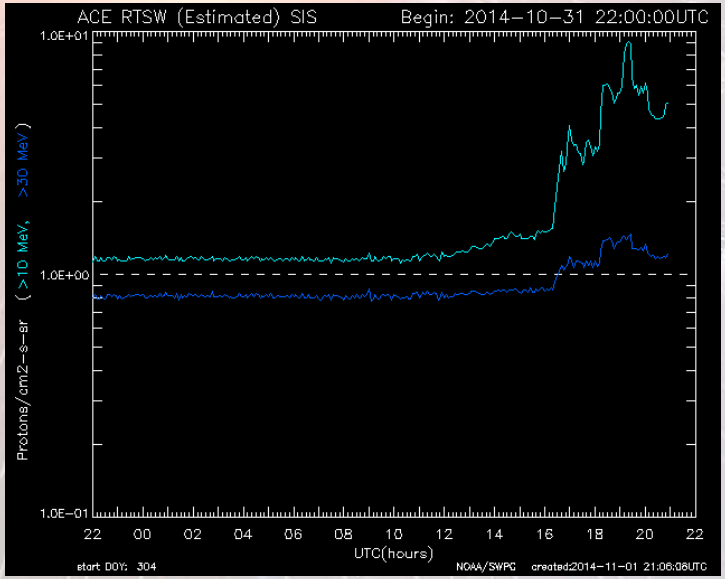
Graphical overview of the solar and interplanetary conditions supporting the risk evaluation of high-energy proton events for the Rosetta mission, part of the tailored space weather bulletin provided by the SSA space weather service network.

Tailored SWE Bulletins: GAIA





Tailored SWE Bulletins: GAIA



GAIA Flight Control Team,

An operator has replied to your support request, #605830 with the following response:

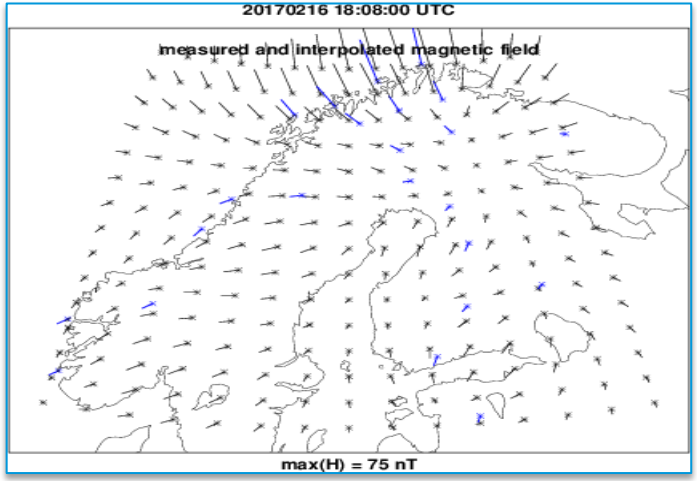
== Space Weather bulletin for GAIA spacecraft ==
Extra bulletin prepared by Andy Devos (SSCC, SIDC forecaster) on November 1, 2014 at 21:30 UTC
Valid until November 3, 2014 at 21:30 UTC

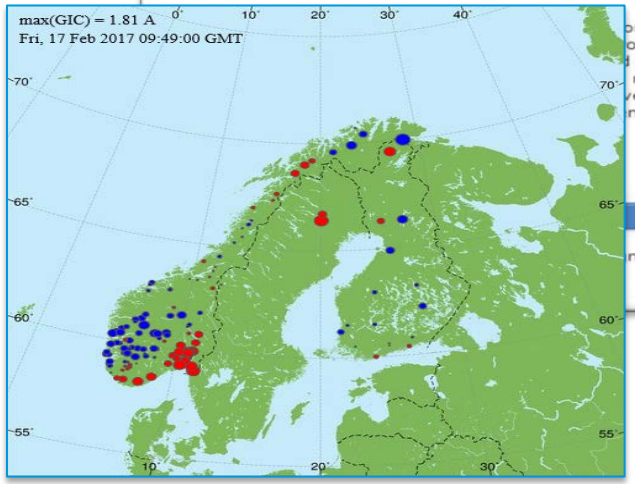
== Past hours ==
Earth and GAIA viewpoint:
A PRESTO message was sent on 21:19 UTC on a significant rise in the proton flux, reaching almost the event threshold (as seen in the attached figure). This rise is possibly related to flaring activity in the NOAA active region 2192.

== Next hours to days ==
The proton flux has chances to rise again in case of an additional strong flares or a CME-driven shock.

SWE Service For Power System Operators

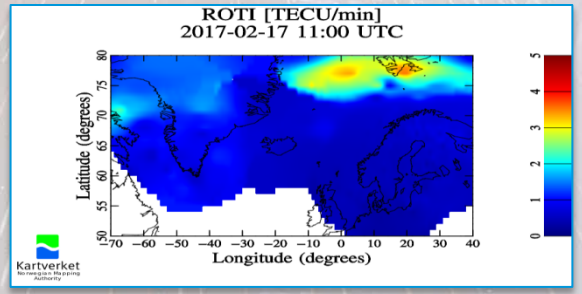
Monitoring potential GIC levels in power systems using state of the art models and near real-time ground magnetic field recordings

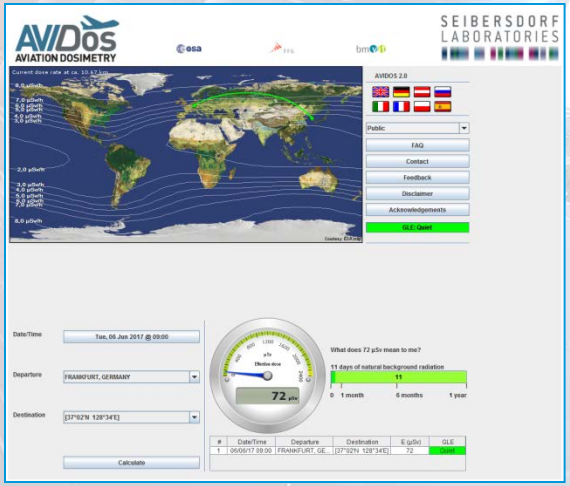


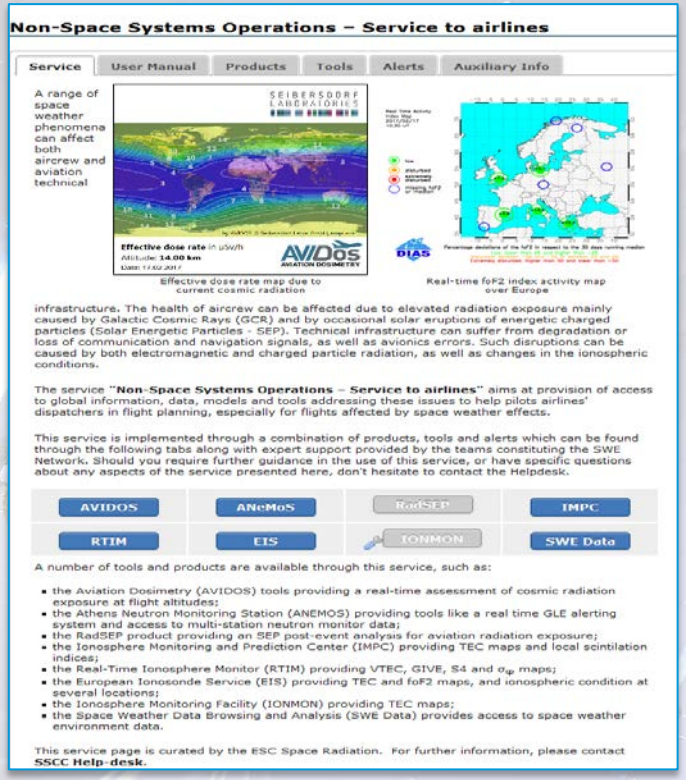


SWE Service For Aviation

Near real-time assessment of cosmic radiation exposure at flight altitudes and timely information about potential space weather induced communication/ navigation disturbances







Next Steps in SSA Period 3

SSA SWE System Objectives in P3

- Mature elements of the SSA SWE system
- Develop and validate improved services for key users
- Establish robust R2O process for models and tools
- Continue development of the SWE mission to L1/L5
- Develop Distributed SWE Sensor System (D3S)
- Develop SWE instruments for L5 mission and D3S

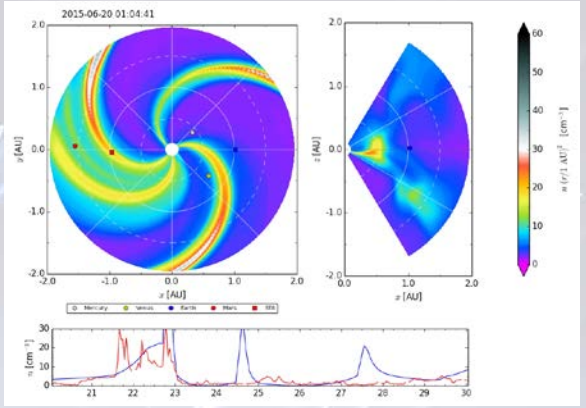
- Reinforce and mature SWE system
- Reduce dependence on non-European systems
- Begin transition towards operational system

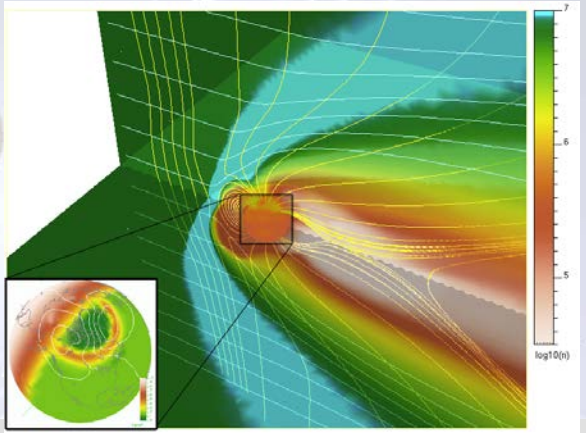
Capability Assessment

- Measure maturity of services and constituent elements
- Provide accuracy and reliability information to SWE users
- Product maturity
  - How well does the product match the target requirement? Scope… accuracy…timeliness
- Service maturity
  - Combination of available product maturity + operational implementation
- Collaboration with international partners
  - Formats, metrics, validation, …

SWE Service Enhancements

- Target: protection of sensitive infrastructure and human life
- Improved SWE forecasting capability:
  - Physics based models
  - Utilisation of new data: L1 + L5, D3S
- Focussed target domains including e.g.
  - Power grid operation
  - Aviation
  - Satellite operation
  - Arctic region
- Enhancement of SWE monitoring capability

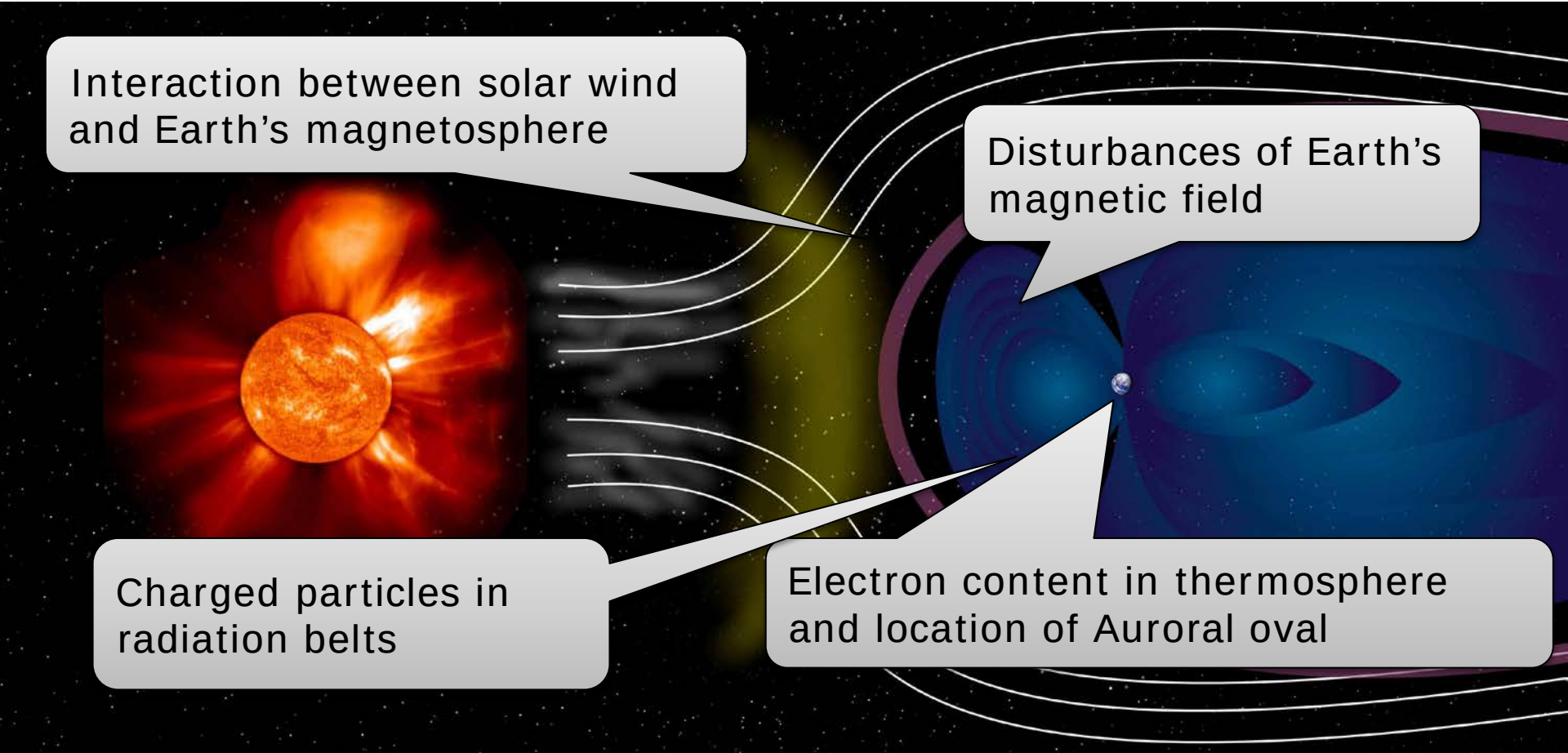




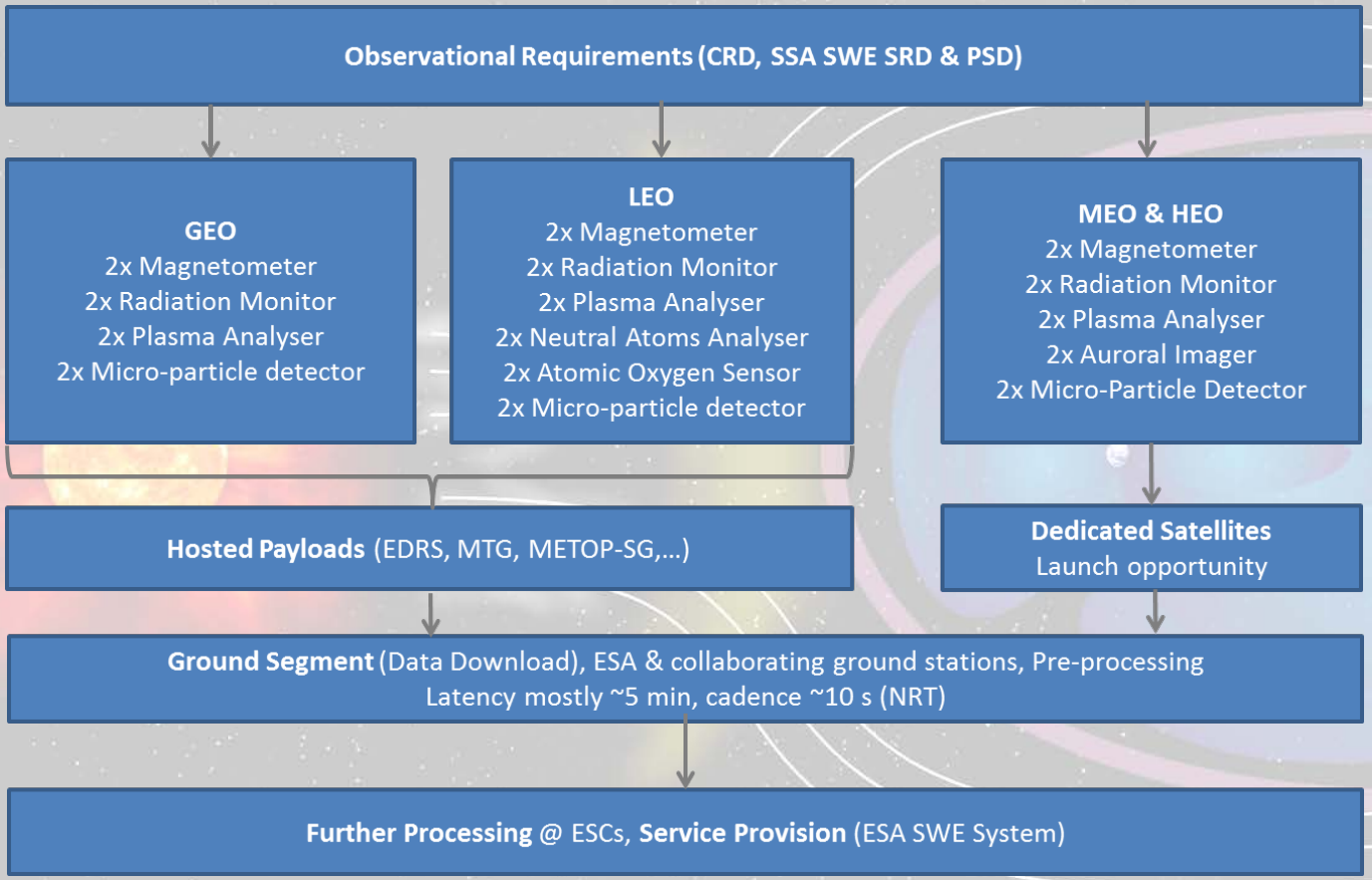
Ground based Space Weather Measurements

Measurement	Existing Assets
Solar images: H-alpha, white-light	Solar telescopes (e.g. Kanzelhoehe Solar Observatory)
Solar Magnetogram images	Solar telescopes (e.g. IAC contribution to GONG network)
Solar indices: F10.7	Solar radiometer. Currently only DRAO Penticton (Canada)
Solar Radio Bursts	Solar radio spectrograph network (e.g. eCALLISTO network)
Cosmic Ray Neutron Flux	Existing neutron monitor network (e.g. http://www.nmdb.eu/)
Earth surface vector magnetic field	Vector magnetometers in existing networks (additional stations particular in arctic region would be needed). Global coverage through agreement (e.g. INTERMAGNET).
TEC maps	Existing GNSS receiver networks (e.g. IGS, EUREF)
Auroral visible imaging	All-sky imagers (e.g. FMI real-time auroral cameras)
Ionosphere: URSI parameters	Ionospheric sounders: Digisonde/ionosonde networks (e.g. DIAS network). Completion of global coverage through international cooperation agreements.
Ionospheric Scintillation: S4 and Sigma_Phi	Dedicated GNSS receivers for scintillation monitoring (e.g. ESA Monitor network). Deployment of further sensors should be considered.
Ionospheric Electric Field	Incoherent/coherent radar network (e.g. SuperDARN and EISCAT). Current assets not suitable for continuous monitoring => EISCAT_3D
Ionospheric Radio Absorption	Riometer network (e.g. AAR/AIRS (Nor), IRIS (Fin), Svalbard (Nor), NORSTAR (Can)).
CME detection through cosmic ray anisotropy	Muon telescope network (e.g. MuSTAnG). European element of the network in prototype status and would require upgrade.

Monitoring Space Weather Impacts

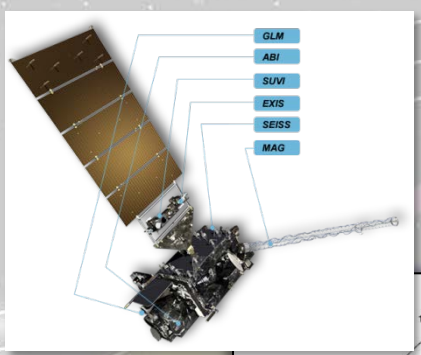


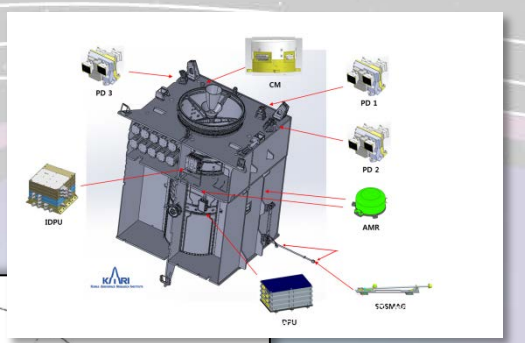
Distributed SWE Sensor System (D3S)

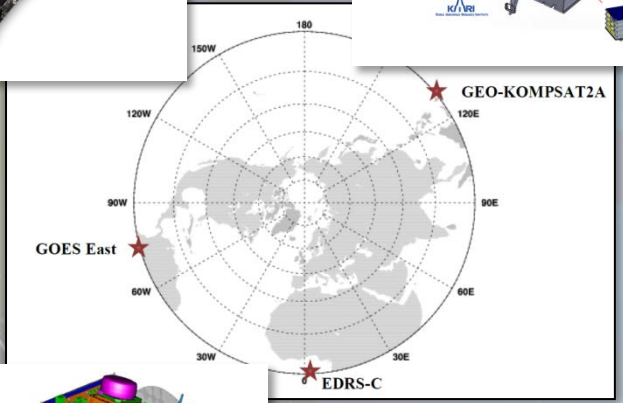


ESA SSA D3S Precursor Missions

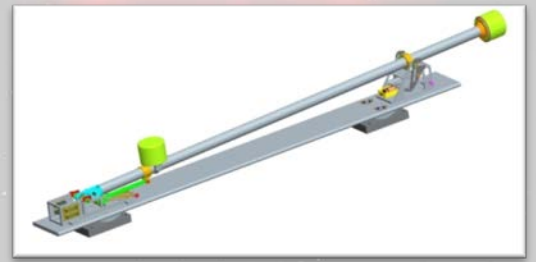
Next Generation Radiation Monitor (NGRM)
→ ARTES 7, EDRS-C (2018)

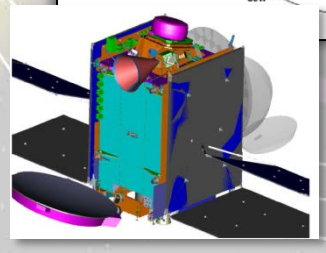




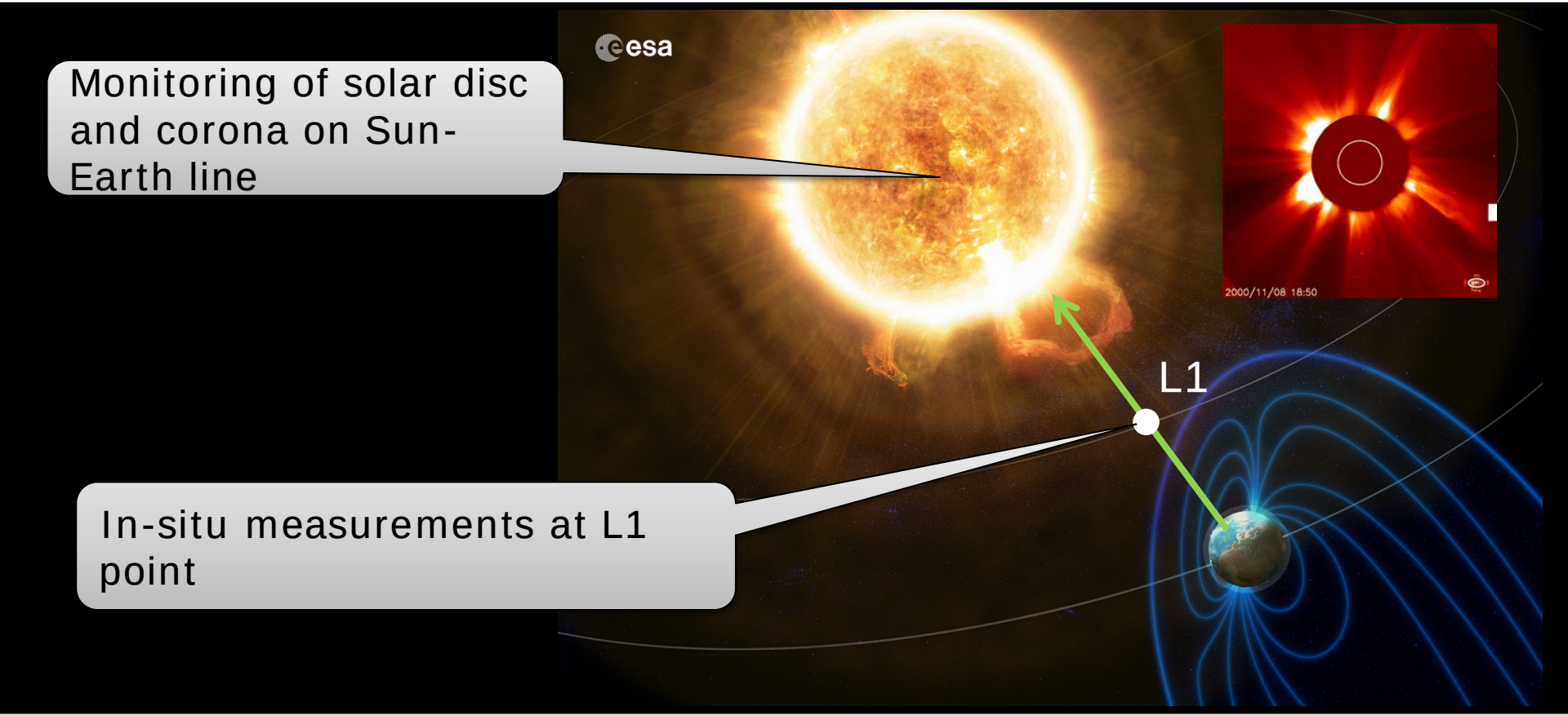


Service Oriented Spacecraft Magnetometer (SOSMAG)
→ Korean GEO-KOMPSAT-2A (2018)

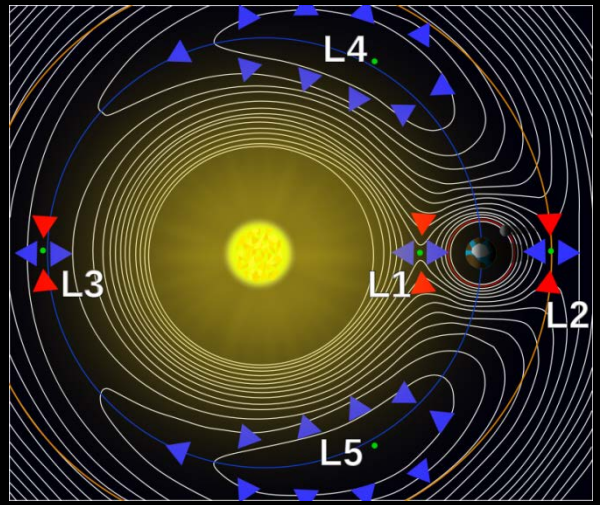


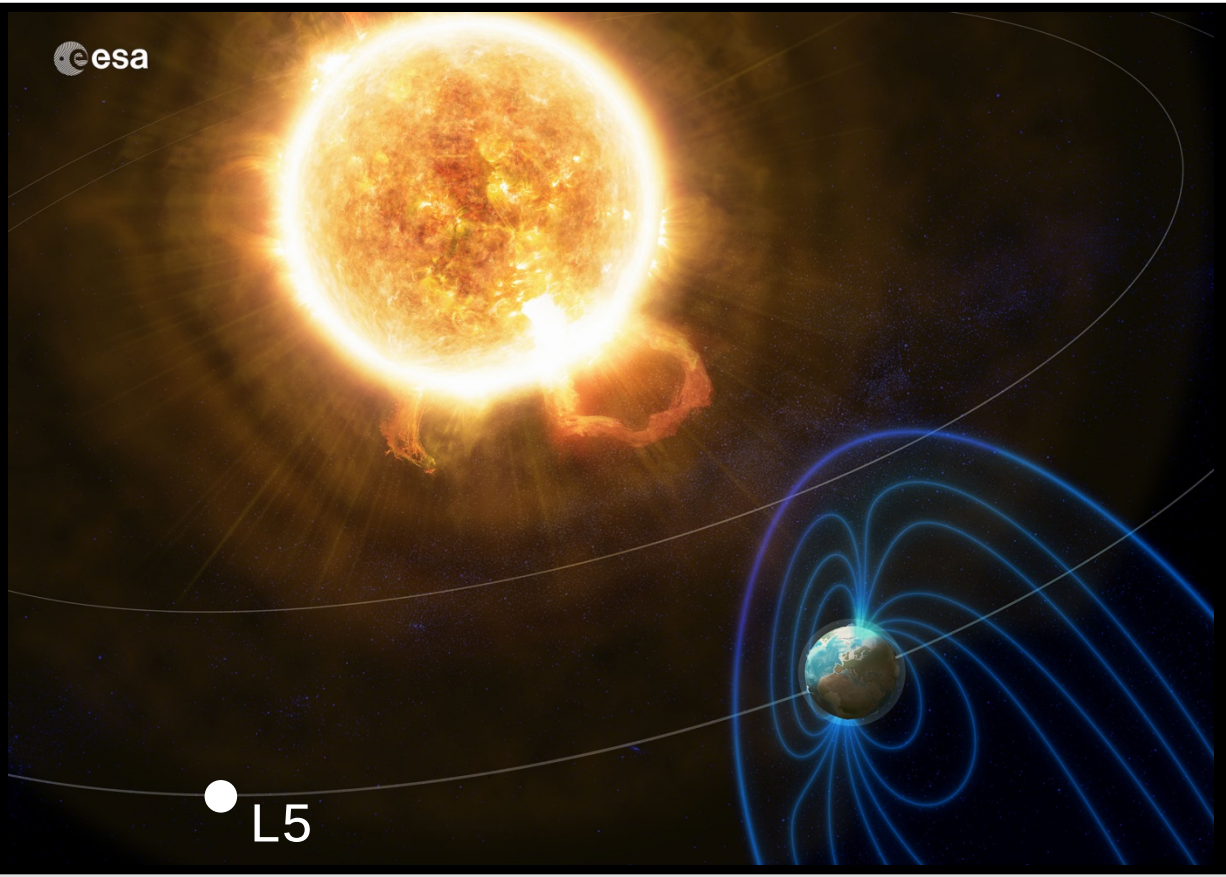


Monitoring the Sun-Earth line



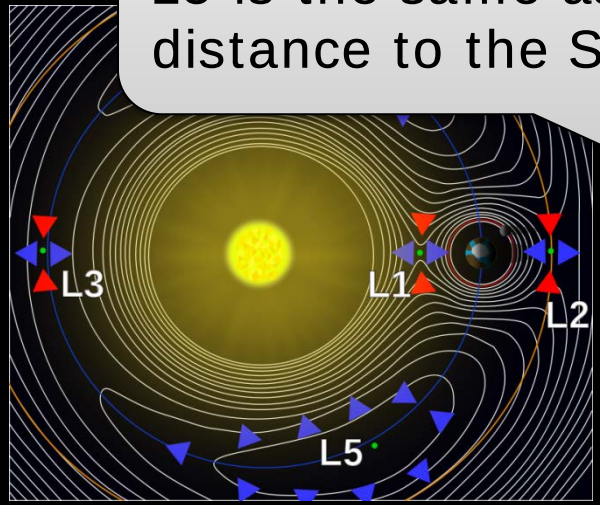
Measurements from L5 point





Measurements from L5 point

Distance from Earth to L5 is the same as the distance to the Sun

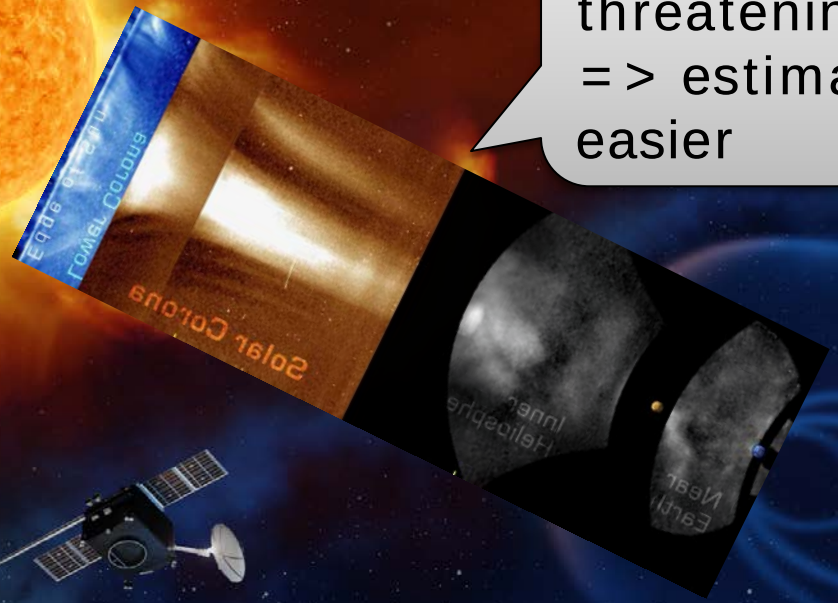


1 Au = 150 000 000km

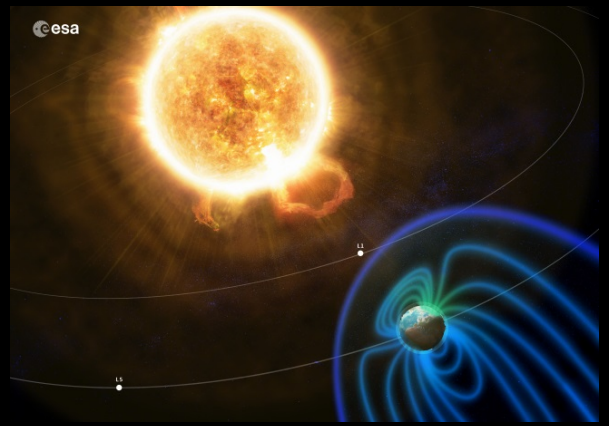
L5

Benefits of L5 Measurements

Spacecraft in L5 can see Earth threatening CMEs from the side
=> estimation of speed and direction easier

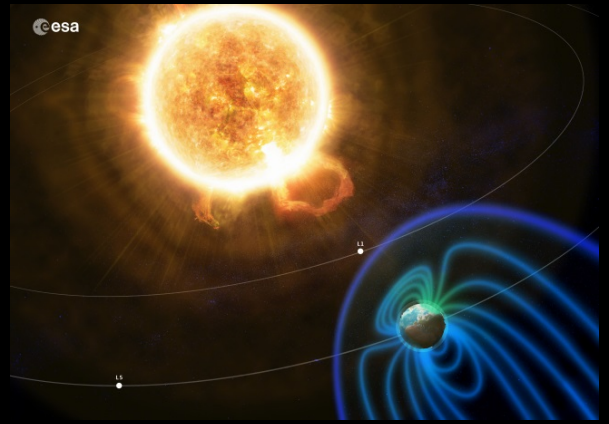


Video: NASA



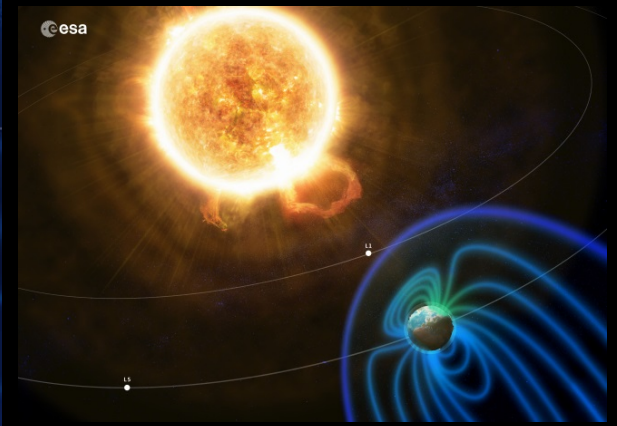
Benefits of L5 Measurements

Active regions are visible 4-5 days before they are visible to the earth => better forecasts



Benefits of L5 Measurements

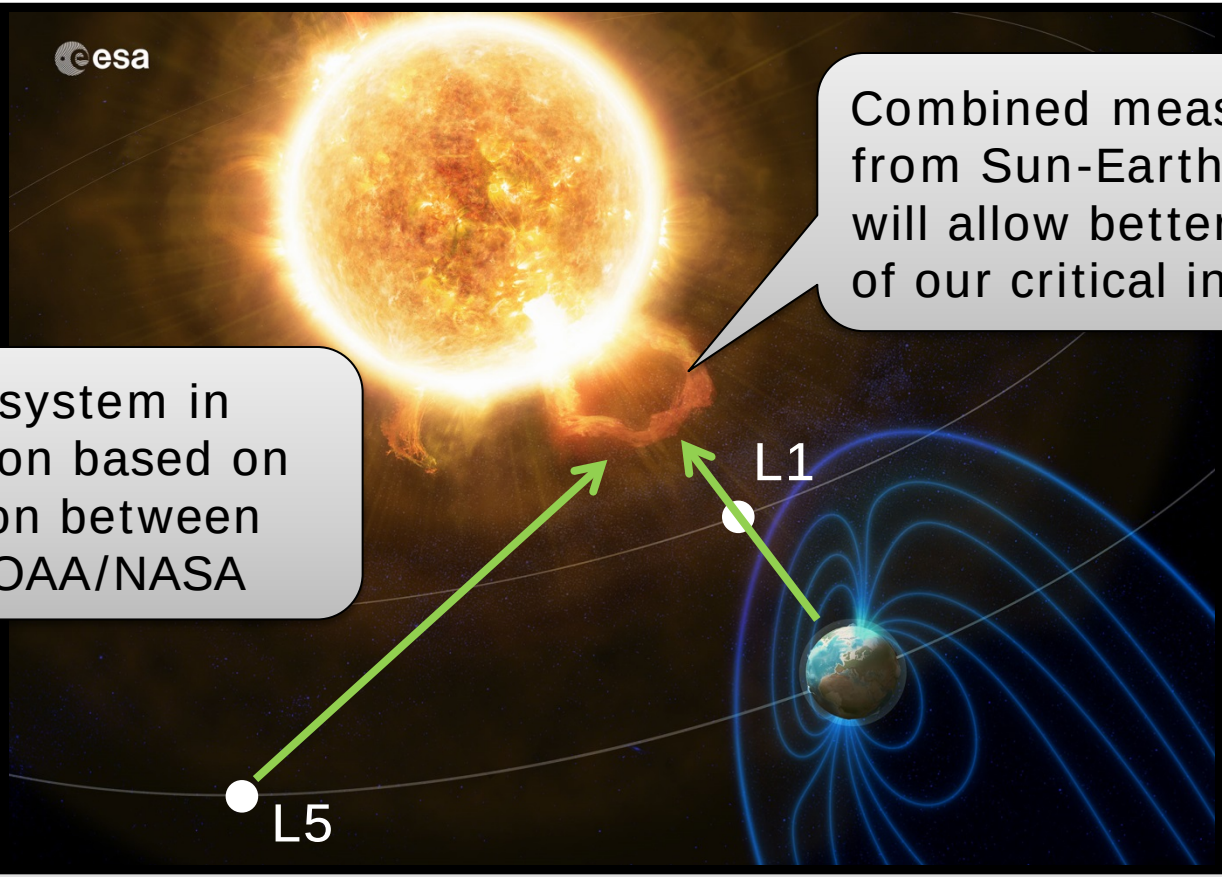
Coronal holes are visible 4-5 days before they are geoeffective => advance warnings for spacecraft charging conditions and geomagnetic storms



ESA L1/L5 Observations and Instruments

#	Product Name	Observation / measurement	Classification	Instrument
1	Interplanetary Magnetic-Field (IMF)	IMF properties and dynamics	High priority	**Magnetometer**
2	Solar-Wind Properties	Solar-wind velocity, bulk-density and temperature	High priority	**Plasma Analyser**
3	Photospheric Solar Disk Magnetic Field	Magnetic-field mapping of the photosphere	High priority	**Magnetograph**
4	White-light wide-angle Coronagraph Images	Intensity Mapping of outer corona	High priority	**Coronagraph**
5	Coronal EUV Images of the Sun	Intensity mapping of the low Corona	High priority	***EUV imager***
6	Heliospheric Images	Intensity Mapping of Heliosphere	High priority	**Heliospheric Imager**
7	Solar X-ray flux	X-ray flux monitoring	High priority	**X-ray monitor**
8	High Energy Protons	Energy distribution and flux dynamics with E>10 MeV	High priority (L1) Enhancing (L5)	**Radiation monitor**
9	Medium-Energy ions	Detection of Solar-Wind Ions with E = 30keV/nuc to 1 MeV/nuc	High priority (L1) Enhancing (L5)	***Medium Energy Particle Spectrometer***
10	Medium-Energy electrons	Solar-Wind Electron flux and energy distribution with E = 30 keV to 8 MeV	High priority (L1) Enhancing (L5)	***Medium Energy Particle Spectrometer***
11	Solar radio-spectrographic emissions	Detection of radio burst/flare signatures and associated outward expanding shocks	Enhancing	**Radio burst spectrograph**
12	Medium-Energy Ions	Solar-Wind Ion flux and energy distribution with E = 1 to 10 MeV/nuc	Enhancing	***Medium Energy Particle Spectrometer***
13	High-Energy Ions	Solar-Wind Ion flux and energy distribution with E >10 MeV/nuc	Enhancing	**Radiation monitor**

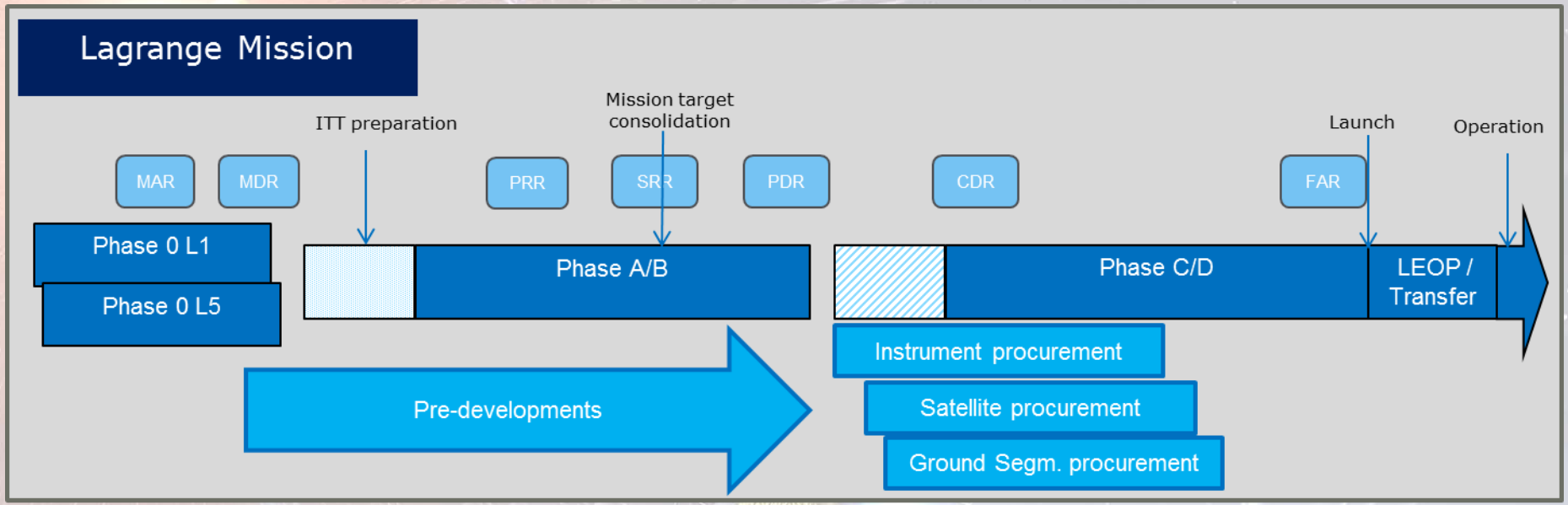
Joint L5 and L1 measurement system



Combined measurements from Sun-Earth line and L5 will allow better protection of our critical infrastructure

Join L5/L1 system in consideration based on collaboration between ESA and NOAA/NASA

SSA SWE Lagrange Mission Roadmap




For more information:
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