Unveiling plasma energization and energy transport in the Earth's Magnetospheric System: the multi-scale Plasma Observatory ESA M7 mission candidate.

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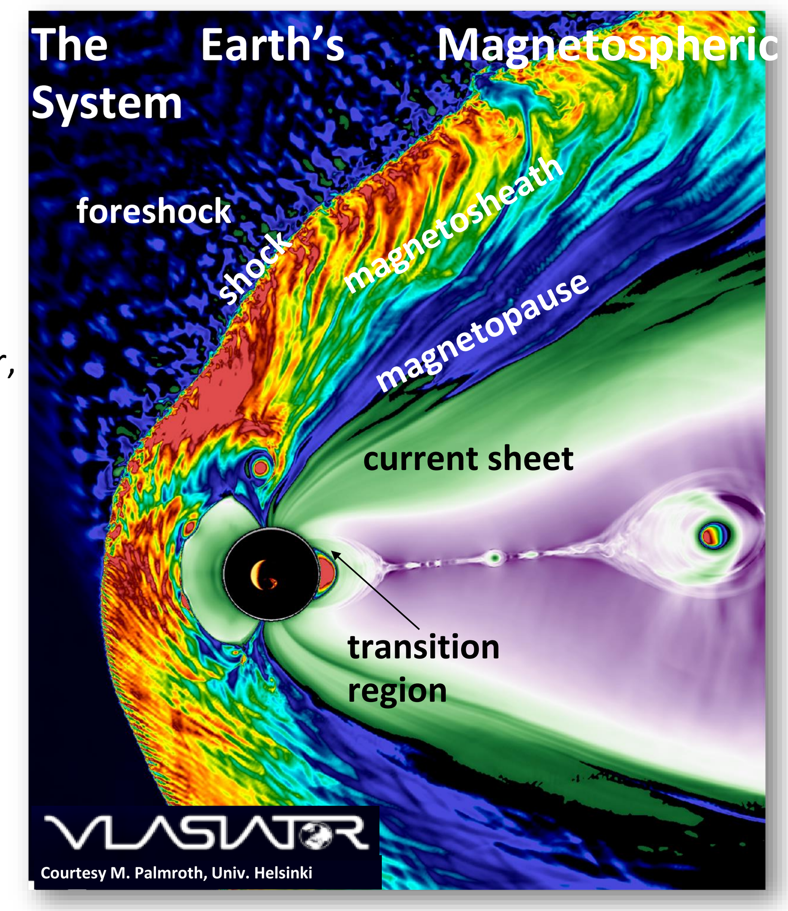
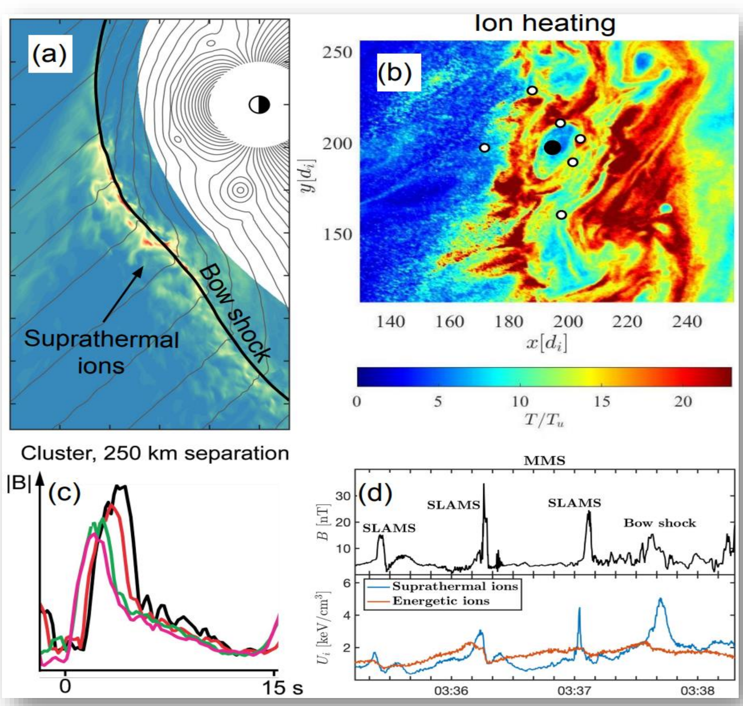
and the PO Science Team



In the **Earth's Magnetospheric System** the largest amount of energy transport and particle energization occur between **ion and fluid scales** through **multi-scale processes** within **non-planar and non-stationary plasma structures.** Understanding these processes allow us to eventually understand ***how our planet works*** with impact for **Space Weather science** and **solar, planetary and astrophysical plasma physics.**

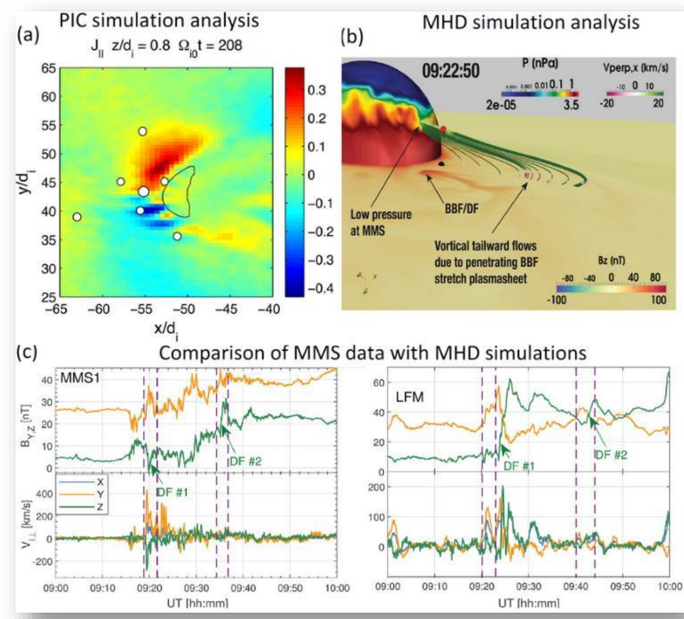
SQ1. *How are particles energized in space plasmas ?*



How are particles energized: at shocks; during magnetic reconnection; by waves and turbulent fluctuations; in plasma jets; during combination of different processes ?

Example: non-planar and non-stationary ion-scale fluctuations (e.g. SLAMS) embedded in fluid-scale shock dynamics (Trotta+, PNAS, 2021; Johlander+, ApJ, 2021; Lucek+, JGR, 2008). See also ESA Voyage 2050 White Paper by Retinò et al., Experimental Astronomy, 2021.

SQ2. *Which processes dominate energy transport and drive coupling between the different regions of the Earth's Magnetospheric System?*



How do plasma jets interact with Earth's dipole field?
How do field-aligned currents connect different regions of the magnetospheric system?
Which are the key plasma instabilities involved in energy transport?
How is energy flux partitioned in different energy transport processes?

Example: plasma jet interaction with the Earth's dipolar field in the transition region (Pritchett+, JGR, 2017; Merkin+ JGR, 2019)

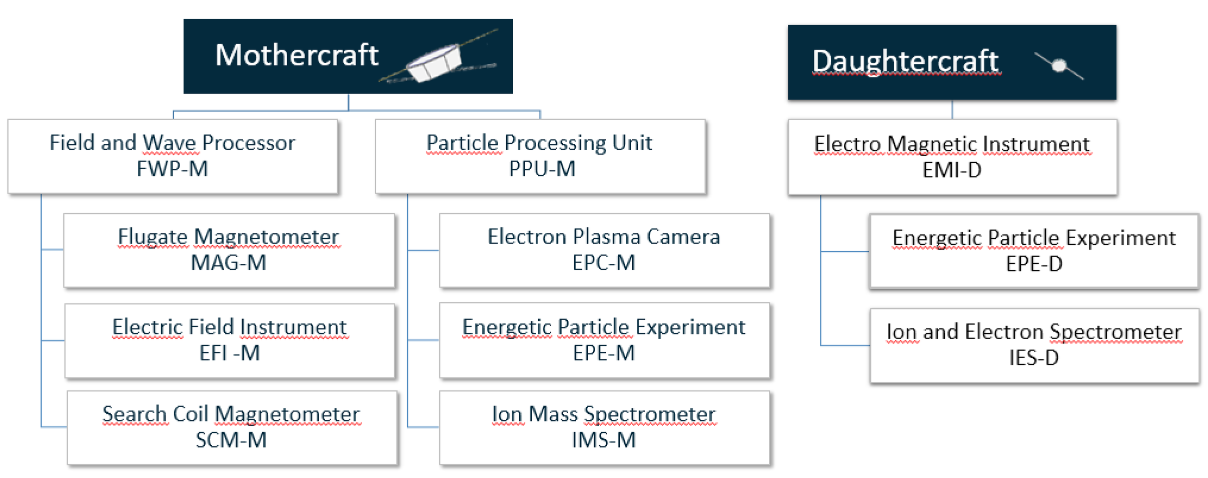
Scientific Requirements

- Observations of basic particle and field quantities simultaneously at seven points, to spatially resolve ion and fluid scales.
- Observations of advanced particle and field quantities at one single point, to temporally resolve sub-ion scales.

Science Measurements

Single point. 3D electric and magnetic fields and 3D particle distributions measured with cadence to resolve sub-ion.

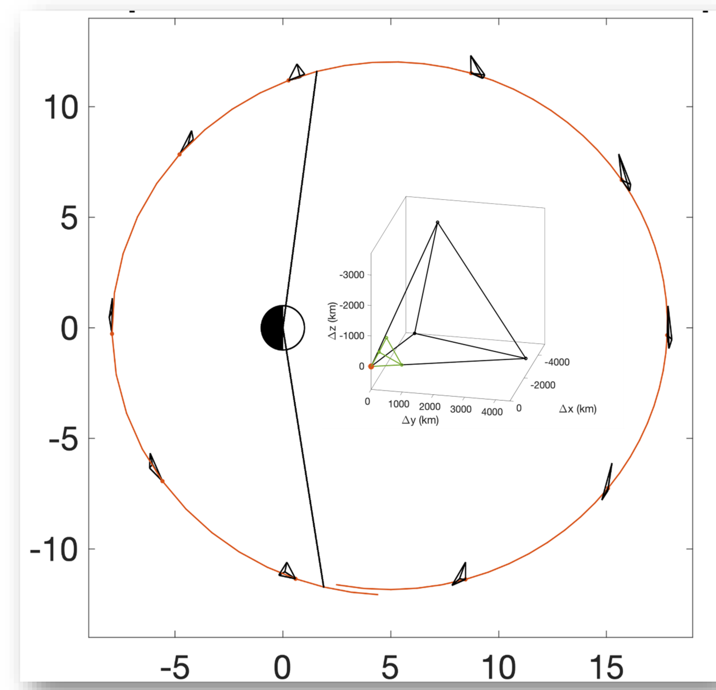
Multipoint. 3D electric and magnetic fields and 3D particle distributions measured with cadence to resolve ion and fluid scales in 7 points.



Instrument	PI	Co-PIs	Lead-CoIs
Mothercraft			
FWP-M	A. Dimmock IRF (Sweden)	J. Soucek, IAP (Czech Republic); M. Morawski CBK PAN (Poland); K. Issautier, LESIA (France)	
FGM-M	L. Matteini - ICL (UK)	E. Panov, IWF (Austria); F. Plaschke, TUB (Germany)	
SCM-M	O. Le Contel - LPP (France)	M Kretzschmar, LPC2E (France)	
EFI-M	Y. Khotyaintsev- IRF (Sweden)	S. Bale, UC Berkeley (US); H. Rothkaehl, CBK (Poland)	N. Ivchenko, KTH (Sweden)
PPU-M	R. D'Amicis - INAF- IAPS (Italy)		
IMS-M	M.F. Marcucci INAF-IAPS (Italy)	B. Lavraud, IRAP & LAB (France); L. Kistler UNH (US)	J. De Keyser, BIRA(Belgium); A. Retinò, LPP (France); A. Galli, UniBern (CH); V. Genot, IRAP (France)
EPC-M	M. Berthomier - LPP (France)	C. Forsyth, MSSL (UK)	
EPE-M	R. F. Wimmer-Schweingruber - UnKiel, (Germany)	M. Dunlop, RAL(UK)	R. Vainio, UTU (Finland)
Daughtercraft			
EMI-D	H. Rothkaehl, CBK (Poland)	J. Soucek, IAP (Czech Republic); M. Steller, IWF (Austria); M. Kretzschmar, LPC2E (France); M. Maksimovic, LESIA (France)	
FGM-D		E. Panov, IWF (Austria); F. Plaschke, TUB (Germany)	L. Matteini, ICL (UK)
EFI-D		H. Rothkaehl, CBK (Poland)	
IES-D		Y. Saito, ISAS (Japan); M. Fränz, MPS (Germany)	E. Roussos, MPS (Germany)
EPE-D		M. Dunlop, RAL (UK)	V. Angelopoulos, UCLA(US); R. Vainio, UTU (Finland)

Orbit

HEO $8R_E \times 18R_E$ (15° inclination) covering the **Key Science Regions** (KSR): foreshock, bow shock, magnetosheath, magnetopause, magnetotail current sheet, and transition region.



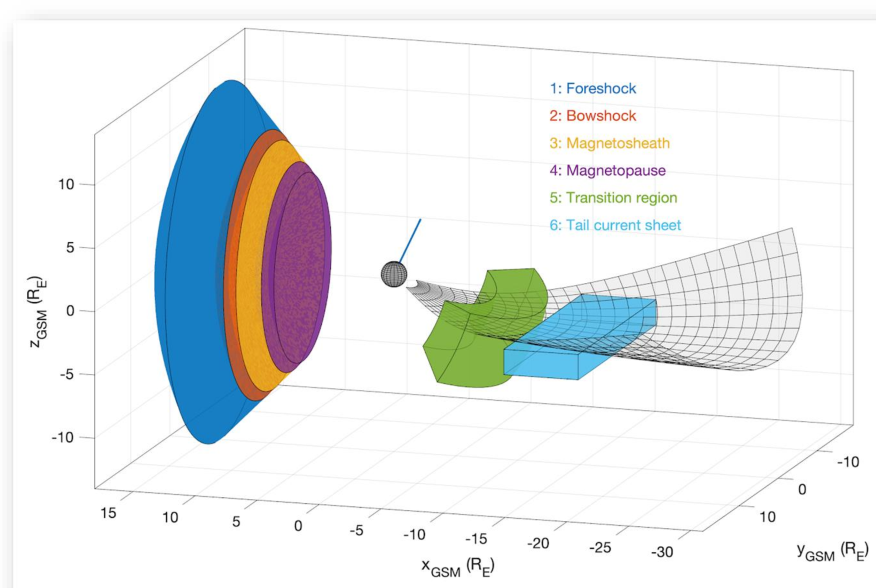
Constellation

1 mothercraft (MSC) and 6 smallsat daugthercraft (DSCs) in two nested tetrahedra formation with MSC at the common vertex for both tetrahedra

Spacecraft separation for the three Nominal Science Phases will permit resolving scales from fluid to sub-ion.

NSP	Inner (km)	Outer (km)
1	30	150
2	150	750
3	1000	5000

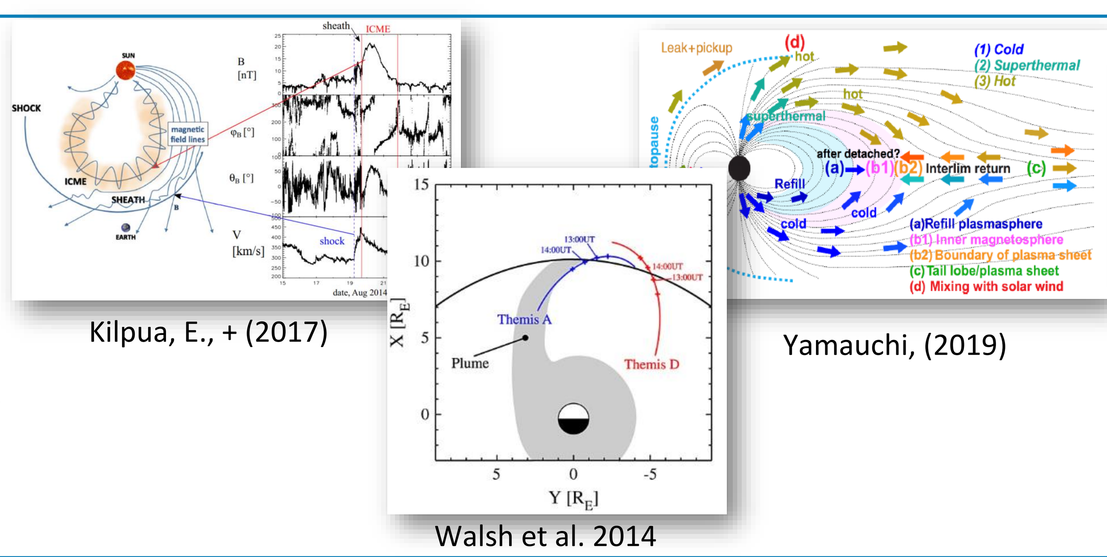
KSR definition



KSR	Definition	
	Cone angle around Sun-Earth line	Range of radial distances (RE)
Foreshock	45°	13.5 -18
Bow shock	45°	12.5 -13.5
Magnetosheath	45°	10.5 -12.5
Magnetopause	45°	9.5 -10.5
Transition region	In Solar Magnetic (SM) system. Range of radial distances: 8 - 12 RE. -15° < lat <15° (SM equator +- 15°). 135° < long < 225° (SM midnight +- 45°).	
Magnetotail current sheet	-18 <X_GSM <-12; -10 <Y_GSM <10; Z0_GSM(t)-1R$_E$ < Z_GSM <Z0_GSM(t)+1R$_E$ with Z0_GSM (t) function of time and defined by Tsyganenko model as location of the current sheet at X_GSM=-16 RE, Y_GSM=0	

Additional Science

Ionosphere/magnetosphere coupling (e.g. O+ outflow extent); outer radiation belts/inner magnetosphere dynamic (e.g. multi-point/multi-scale measurements of plasma plumes); pristine solar wind (e.g. study of solar wind transients); Space Weather science.



Kilpua, E., + (2017)

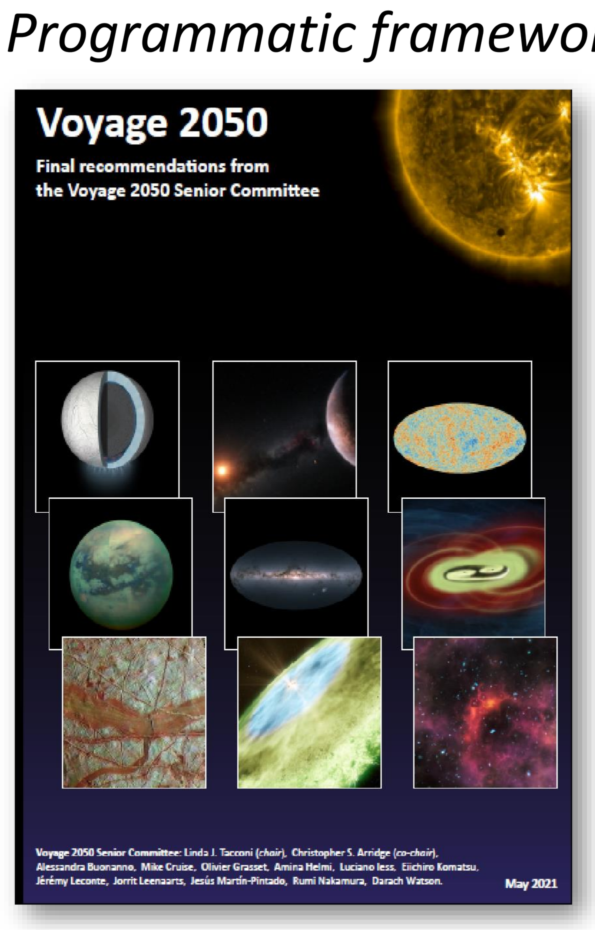
Yamauchi, (2019)

Walsh et al. 2014

French contribution

- **Co-Lead Scientist of the mission**
- **Largest contribution to PO payload** (5 instruments):
  - PI (LPP) / coPI(LPC2E) of SCM-M
  - coPI (LESIA) of FWP-M
  - PI (LPP) of EPC-M
  - coPI (IRAP&LAB) / Lead CoI (LPP) of IMS-M
  - coPI (LPC2E) of EMI-D
- **40+ members from 9 French labs** incluing many young scientists
- **Important upcoming contributions to PO WGs:** Numerical Simulation WG, Ground-based Coordination WG, Multi-point Data Analysis WG

Programmatic framework



From ESA Voyage 2050 report: *The importance of understanding the multi-scale processes of plasma is expected to become a coherent theme of the plasma Universe in the Voyage 2050 era.*

Plasma Observatory targets the two Voyage M-class themes :"*Magnetospheric Systems*" and "*Plasma Cross-scale Coupling*".

Plasma Observatory targets top priority of CNES SHM in SPS report 2019-2024:

Thème scientifique	Type de mesure/ d'observables	Cadre de réalisation(1)	R&T associée
Résoudre la dissipation aux plus petites échelles turbulentes dans le vent solaire proche, l'accélération des particules dans la magnétosphère terrestre, la reconnexion magnétique et la physique du choc magnétosphérique	Observations simultanées des échelles fluide, ionique et électronique	ESA, NASA, JAXA	

Need for new multi-scale constellations to study space plasmas recognized by international space agencies (e.g. NASA Heliophysics 2024 Decadal Survey, JAXA roadmap)

Towards a new era for magnetospheric physics in mid/late 2030s ? ESA Plasma Observatory (late 2030s); NASA MagCon (mid-late 2030s); JAXA NEO-SCOPE (mid 2030s)

Plasma Observatory assets

First multi-scale measurements tailored to study the Magnetospheric System. Next quantitative leap after Cluster and MMS 4-point measurements.

Will lead to transformative advances in magnetosheric physics. Important also for Space Weather science as well as solar, planetary and astrophysical plasmas.

Very large scientific community: 350+ researchers from 25 countries (17 in Europe). Strong international support (US, Japan, China).

Fits current programmatic framework. Targets the two ESA Voyage 2050 M-class themes :"Magnetospheric Systems" and "Plasma Cross-scale Coupling"

For joining the PO Team please contact:
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