Unveiling plasma energization and energy transport in the Earth's Magnetospheric System: the Plasma Observatory mission.

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Particle energization and transport of energy are key open problems of space plasma physics. Their comprehension has major implications on research fields that span from space weather to the understanding of distant astrophysical plasmas.
Plasma energization is driven by fundamental processes such as shocks, magnetic reconnection, turbulence and waves, plasma jets, and their combination. Key aspects of energy transport are field-aligned currents, instabilities and partition of energy flux. All these processes are at the core of current space plasma physics research.
The Magnetospheric System is the complex and highly dynamic plasma environment where the strongest energization and energy transport occurs within near-Earth space. Previous multi-point observations from missions such as ESA/Cluster and NASA/MMS have greatly improved our understanding of plasma processes at a given scale. However, simultaneous measurements at both large, fluid and small, kinetic scales are required to resolve scale coupling and to ultimately fully understand plasma

energization and energy transport processes. Such measurements are currently not available.

Here we present the Plasma Observatory (PO) multi-scale mission concept tailored to study plasma energization and energy transport in the Earth's Magnetospheric System through simultaneous measurements at both fluid and ion scales. These are the scales at which the largest amount of electromagnetic energy is converted into energized particles and energy is transported. PO baseline mission includes one mothercraft and six identical smallsat daughtercraft, covering all the key regions of the Magnetospheric System including the foreshock, the bow shock, the magnetosheath, the magnetopause, the magnetotail current sheet, and the transition region. Along the orbit, the separations between the spacecraft range from fluid (5000 km) to ion (30 km) scales. MSC payload provides a complete characterization of electromagnetic fields and particles in a single point with time resolution sufficient to resolve kinetic physics at sub-ion scales (for both protons and heavy ions). The DSCs have identical payload, simpler than the MSC payload, yet giving a full characterization of the plasma at the ion and fluid scales. Moreover, PO will take advantage of the massive progresses made in supercomputer simulations during the last decades. The simulations will support PO mission design and provide theoretical predictions on particle energization and energy transport which will help interpretation of PO data.

PO will be the next logical step after Cluster and MMS. It targets the two ESA Voyage 2050 themes “Magnetospheric Systems” and “Plasma Cross-scale Coupling” and will allow us to resolve for the first time scale coupling in the Earth's Magnetospheric System, leading to transformative advances in the field of space plasma physics.

PO is one of the three ESA M7 candidates, which have been selected in November 2023 for a competitive Phase A with a mission selection planned in 2026 and launch in 2037.