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Extract of Cross-Scale section

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5.2 Cross-Scale

Introduction

Most of the visible Universe is in the highly-ionised plasma state. Plasma processes are at work everywhere, from radio galaxy jets and supernova explosions to solar flares and planetary magnetospheres. Cross-Scale is an M-class mission dedicated to quantifying the coupling in plasmas between different physical scales. This cross-scale coupling, being highly variable and structured, is critical in underpinning and quantifying the physical mechanisms inferred in plasmas that are difficult to observe. As plasma regimes encounter each other, the absence of collisions raises fundamental questions about how energy is shared amongst the three main elements: electrons, ions, and overall bulk flows. These constituents, each of which operates on its own physical scale, are coupled through electromagnetic fields.

Three fundamental physical processes operate to bring about the universal collisionless plasma coupling in physical environments where momentum and energy transfer is important:

— Shock waves guide strong flows around obstacles or at interfaces between two flow regimes. They are important locations for the transfer of directed bulk flow energy into heat, with an attendant acceleration of energetic particles.

— Magnetic reconnection releases stored magnetic energy to the plasma, and allows for exchange of material between previously isolated regions. Moreover, the consequent change in magnetic topologies provides a coupling between plasma regions, which often drives the global scale dynamics of the system.

— Turbulence transports energy from large scales at which it is input to small scales where it is dissipated. In the process, it interacts strongly, and often selectively, with plasma particle populations as either a source or sink (or both) of energy.

Cross-Scale will target compelling and fundamental questions, such as:

— How do shocks accelerate and heat particles?

— How does reconnection convert magnetic energy?

— How does turbulence control transport in plasmas?

These address directly the Cosmic Vision question ‘How does the Solar System work?’ by studying basic processes occurring ‘From the Sun to the edge of the Solar System.’ Moreover, by quantifying the fundamental plasma processes involved, the advances made by the mission will extend beyond the Solar System to plasmas elsewhere in the Universe.

Mission profile

Cross-Scale will employ 10 spacecraft which will fly with two highly complementary spacecraft from its sister mission SCOPE provided by JAXA. Together, they will form three nested tetrahedra to separate spatial and temporal variations simultaneously on the three key scales for the first time. This optimum configuration ensures that the measurements at each smaller scale are centred within their larger context. Soyuz-Fregat launch capabilities would deliver 10 suitably instrumented spacecraft into an Earth orbit where they can address the science objectives posed in the introduction above; this forms the Cross-Scale ESA mission. Cross-Scale’s partner, the SCOPE mission to be provided by JAXA, complements the minimal configuration with (at least) two additional spacecraft, one with a comprehensive suite of high resolution instruments that enhances the finely targeted Cross-Scale capabilities at the smallest

For further information, see http://sci.esa.int/crossscale scales. The combination thus meets the optimal 12 spacecraft configuration (Fig. 5.2.1) with an optimal payload. The final apogee is of order 25 Re (Earth Radii) with a low perigee (1.4 Re geocentric). This roughly equatorial (14 degree inclination) orbit enables Cross-Scale to reach the regions where the targeted physics is occurring, including the dayside bowshock (12–20 Re), reconnection at the magnetopause (8–12R e), the 'tailbox' region of the geomagnetic tail (10–20 Re), and turbulence in the solar wind (12–25 Re), magnetosheath, and geomagnetic tail/plasma sheet. Final orbit selection will be agreed between the Cross-Scale and SCOPE elements. Commissioning and interspacecraft calibration will require 6 months followed by a nominal mission of 2 years. This will allow each of the relevant regions to be visited twice, permitting alternative spacecraft separation strategies/scales to be explored based on the science objectives and experience gained during the first year.

Mission payload

The payload consists almost entirely of proven technology, with heritage from recent missions (e.g. Cluster, Polar, THEMIS, STEREO) and well-advanced concepts (e.g. MMS). Although the spacecraft bus and subsystems are identical, spacecraft devoted to different scales need different payload in terms of e.g. time resolution, particle distributions vs. gross characteristics, and DC/AC fields. The largest demands come from the smallest scale (electron) spacecraft, with those at the fluid scale more modest. The instrument complement on each spacecraft is targeted in terms of type of measurement, time resolution, and level of detail to examine the science goals of the mission. Instrumentation will consist of DC and AC magnetometers, electric field antennae, electron density sounders, electrostatic particle detectors, energetic ion and electron detectors and active spacecraft control. All instruments have recent flight heritage. The basic characteristics and technology reference level (TRL) of the instruments are described in Table 5.2.1. Ongoing developments in mass, power, and science performance will be utilised to optimise the actual mission hardware.

Concept spacecraft design

For reasons of economy, all 10 spacecraft will share a common bus with instrument 'bays' capable of accommodating different instruments. The instrument suite on an individual spacecraft will target the appropriate key measurements for one physical scale (electron, ion, or fluid), with some limited redundancy between scales. The spacecraft design is 1.5 m in diameter with a total dry mass (excluding payload) of 110 kg. The Attitude and Orbit Control Subsystem (AOCS) consists of combined Sun and star sensors together with mono- or bipropellant thrusters. The spacecraft are spin-stabilised at 20–40 rpm. Faster spin-rates improve data resolution at the fluid scales, but at the electron scales stability of the spin-axis electric antennas limits the spin-rate to these values. Intersatellite ranging is required on at least the electron-scale spacecraft, and will be carried on the ion-scale spacecraft to guarantee the accuracy demanded by the mission and to provide redundancy. This would utilise the X-band transponders, although a separate S-band system could be employed. This area will require close coordination with the SCOPE to ensure that compatible systems are flown on both missions. The maximum science payload, excluding margins that can be accommodated by the bus design, is 40 kg consuming 40 W. Less mass is available on the ion and fluid spacecraft due to the additional fuel requirements. Each spacecraft will require a storage device of 256 Gbits to hold two full orbits of data. Communications will be direct to ground stations using an X-band transponder such as that baselined for GAIA. This provides variable data rates up to 6.5 Mbps.

Figure 5.2.1 The Cross-Scale concept of the three nested tetrahedra will separate spatial and temporal variations simultaneously on the three key scales for the first time.

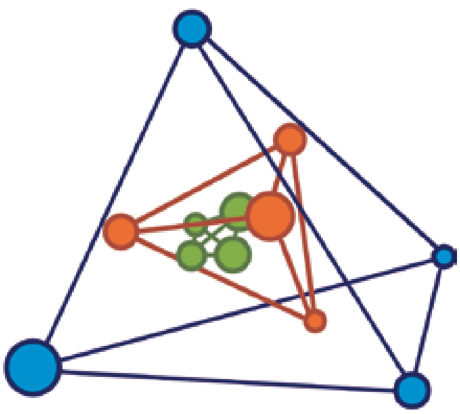

Table 5.2.1. The basic characteristics of the Cross-Scale instruments

Instrument	*Mass* (kg)*	*Power* (W)*	*Volume** (cm³)*	*Measurement*	*Recent Heritage*	*TRL*
MAG	1.5	0.5	11 x 5 x 5 (x 2 units)	Boom-mounted DC vector magnetic field	VEX, Double Star	9
ACB	1.75	0.1	10 x 10 x 10	Boom-mounted AC vector magnetic field 1Hz–2kHz (spectra +waveform)	THEMIS, Demeter	9
E2D	8.0	3.0	20 x 30 x 15 (x 4 units)	30–50m wire double probe 2D electric field (DC + spectra) 0–100kHz (DC + spectra)	THEMIS, MMS, Demeter	8
E3D	4.0	2.0	10 cm diameter	Dual axial 5m antennae; (DC + spectra)	Polar, THEMIS	7
EDEN	0.2	0.25	-	Electron density sounder	Cluster	7
ACDPU	1.5	2.0	23 x 19 x 6	Common processor & electronics for ACB, E2D, E3D, EDEN	Cluster	7
EESA	2.0	3.0	26 x 15 x 26	Dual-head thermal 3D electron electrostatic analyser 3eV–30keV	MMS	6
CESA	2.5	2.0	15 x 20 x 15	Combined 3D ion/electron electrostatic analyser 3eV–30keV ions, electrons	Medusa/Astrid	6
ICA	5	6	25 x 45 x 25	3D ion composition <40 keV	Cluster	8
ECA	1	0.5	10 x 15 x 15	3D energetic multi-species ion analyser 100 keV–1MeV	STEREO	8
HEP	1.2	1	15 x 5 x 15	Solid-state high energy particle detector >30 keV	THEMIS, Demeter	9
CPP	3.0	2.0	10 x 20 x 5	Centralised payload processor	THEMIS, SpaceWire	5
ASP	1.9	2.7	19 x 16 x 17	Active potential control	Cluster, MMS	8

*Total (all units); excluding most margins; excludes booms

**Sensor volume only for MAG, ACB; MAG electronics 19x16x10

Operation

Operations will be centralised and, where possible, autonomous, e.g. in terms of instrument modes and data taking. The full dataset will be too large to transmit to ground. Data will be stored onboard during each orbit, with a representative subset (i.e. everything except the highest resolution data from the electron scale spacecraft) telemetred to the Mission Operations Centre. The Science Operations Centre will use that data to select periods of interest with regard to the science objectives and of sufficient duration to fill the downlink budget. Data from those intervals, from all spacecraft, will be telemetred during the next contact period(s). A fallback automatic selection based on average locations of the boundaries and processes and the orbital position will be in place. Onboard event selection based on suitable triggers provides an alternative and reduces the onboard storage requirements.

International cooperation

As noted above, Cross-Scale will work in partnership with its JAXA sister mission, SCOPE. In addition there is already considerable international interest in the mission, including participation in the flight hardware and science objectives, which are well-aligned with those of many international space agencies. NASA is also involved in the assessment study and may provide a contribution on the payload or spacecraft level. Other agencies, such as the Canadian Space Agency, China National Space Administration, Roscosmos and Indian Space Agency have indicated great interest in collaborating on the mission. These could either be independently launched or possibly integrated into the SCOPE mission as daughter spacecraft.