Cross-Scale: Multi-scale Coupling in Space Plasmas
Letter of Intent: ESA Cosmic Vision 2015-2025 Call for Proposals

The Cross-Scale Team

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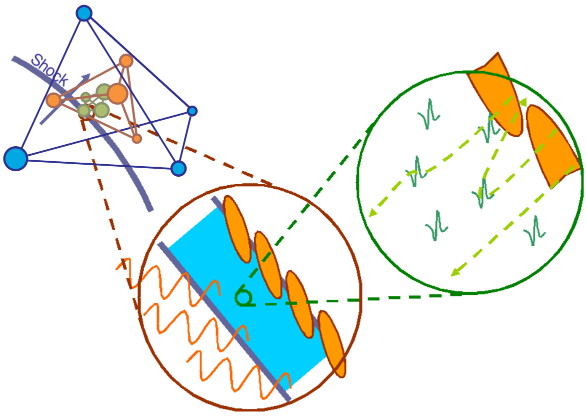

Introduction and Scientific Objectives

A small number of phenomena dominate the behaviour and effects of plasmas throughout the Universe: collisionless shocks, magnetic reconnection and plasma turbulence. All of these phenomena are controlled by dynamics which are coupled on at least 3 scales simultaneously: electron kinetic, ion kinetic, and fluid. It is the non-linear interaction of 3D, time-varying structures on these 3 scales which produces the complex behaviour and consequences of these processes. To make quantitative progress, therefore, particles and fields must be measured within and around them, simultaneously, at a sufficiently large number of locations to discover the time-varying 3D structure on electron, ion and fluid scales and how these interact with each other. This can only be achieved by flying a large number (of order 12) spacecraft in formation through regions in which these processes are operative, equipped with state of the art in situ instrumentation. Near-Earth space, which is relatively accessible and contains examples of all the phenomena of interest, is the obvious target for such a mission, which we call Cross-Scale.

Mission Profile

The ESA mission consists of 10 spacecraft utilising a common spacecraft design but instrumented and operated to optimise the available resources. Cross-Scale's partner, the SCOPE mission to be provided by JAXA, complements the minimal configuration by two additional spacecraft, one with a comprehensive suite of high-resolution instruments, to enhance the finely-targetted constrained Cross-Scale capabilities at the smallest scales.

Launch and Orbit

The 10 ESA spacecraft will be accommodated on a single deployment module, with the entire assembly launched using a Soyuz-Fregat 2 from Kourou. JAXA will provide a separate launch for SCOPE. The final apogee is of order $25R_e$ with a low perigee (500 – 2500 km altitude). This roughly equatorial orbit enables Cross-Scale to reach the regions where the targetted physics is occurring (the bow shock, reconnection at the magnetopause and in the geomagnetic tail, and turbulence in the solar wind, magnetosheath, and plasma sheet). An alternative $10 \times 25\, R_e$ orbit is also practical in terms of science goals and space debris control.

Ground segment

The data acquisition rate for the entire constellation is large even allowing for significant data compression. A realistic downlink capability of $\sim$ 800 kbps *in total* would return $\sim$ 10% of the data. Each spacecraft will communicate directly with the ground station. Payload and spacecraft operations, and downlinks, need a high degree of autonomy to minimise the required ground segment resources.

Other Requirements and Issues

Final orbit selection will be agreed between Cross-Scale and SCOPE elements.

Payload

Overview

The payload consists of entirely proven technology, with heritage in recent missions (e.g., Cluster) and others (e.g, Polar, Themis, STEREO). 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.

Instruments

The following instruments are envisaged for deployment on some, but not necessarily all, of the 10 ESA spacecraft: magnetometers (DC fluxgate and AC search coil), 2D wire double probe electric antennae, dual axial electric antennae, electron sounder, electrostatic particle analysers (electron, ion, and/or combined, with possible steerable aperture beam), time-of-flight analysers (ion composition, energetic ions/electrons), solid state high-energy particle detectors. Additionally, dedicated and centralised processing units will be provided.

Spacecraft Considerations

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 key measurements at the appropriate physical scale (electron, ion, or fluid), with some limited redundancy between scales. Each spacecraft will require a storage device of ~ 100 Gbits to hold two full orbits of data.

Science Operations and Archiving

Operations will be centralised and, where possible, autonomous, e.g., in terms of instrument modes and data taking. The full dataset will be far too large to transmit to ground, so data selection will be performed by the SOC based on a sub-sample (summary, coarse resolution, etc.) of the full set. Onboard event selection based on suitable triggers provides an alternative if practical. The selected dataset will then be retrieved during the following contact period(s).

The mission will adopt a modern approach to data access, with the full dataset available to the Cross-Scale community, and open to the wider scientific community after a suitable delay (e.g., 6 months) to ensure adequate calibration and quality control. The Cluster experience of distributed data centres and an Active Archive will serve as a guide, but will form part of the mission concept from the outset.

Technology

The mission has no obvious technological obstacles. An ongoing ESA TRS has confirmed its overall feasibility at mission, spacecraft, subsystem, payload, and operations levels.

Payload Readiness

Most, if not all, the instrumentation has sufficient heritage that it could be built and flown immediately. Improvements in mass and power requirements, increased autonomy, rapidity of data cycle, and demonstrable multi-functionality (e.g., combined ion/electron detectors, capability for both hot and cold/solar wind ion distributions, etc.) will help to increase both the margins and the science return. Data compression, calibration and data processing are areas where efficiency will be paramount.

Mission and Spacecraft

No novel spacecraft engineering is required. Ongoing studies will focus on the control and reconstruction of the interspacecraft positioning and synchronisation. This requires good use of existing technology. The operation of 10 spacecraft, and the joint operations with JAXA, to appropriately position the spacecraft in the nested, multi-scale configuration, within limited M-class resources, is a challenge. However, ESA has ample experience in multi-spacecraft operations from which to evolve an effective strategy.

Programmatics and Costs

SCOPE

The minimum configuration that can address multi-scale coupling is 10 spacecraft, with all three scales sharing a common corner. Twelve spacecraft would provide 3 independent tetrahedra, one on each scale, with successively smaller scales centred in their larger contexts. The Cross-Scale/SCOPE combination not only meets this optimal configuration to fulfill the mission objectives but also provides comprehensive high-resolution capability at the electron scale.

Payload Provision

The number of spacecraft in Cross-Scale demands a large number of instruments, which under normal practice would be provided by the national agencies. This is feasible provided economies of mass production are fully exploited. A programme of streamlined ground calibration (plus in-flight inter-calibration) will enable instruments to be delivered in a timely fashion. Instrument costs will be addressed in the full proposal.

Communications and Outreach

Cross-Scale is an ambitious undertaking targetted at quantifying fundamental, complex processes. While traditional Space Weather arguments provide a natural focus for Outreach programmes, the heart of the mission lies in laying bare fundamental processes, and the actual Outreach programme will thus depend critically on a clear exposition of the excitement embodied by such a breakthrough. A familiar blend of web resources and media coverage will be employed.

Cross-Scale Community

The Cross-Scale Community includes over 100 scientists from 18 countries who have the courage to take the step from initial exploration and phenomenology to a quantitative understanding of dynamic, multi-scale physics in which the feedback between widely disparate scales is fuelled by the complexity and collisionless nature of plasmas in space.

References

Cross-Scale Science Priority Document, http://www.cross-scale.org/ Documents/ CrossScaleSciPriorityDocV1.3a.pdf

The Cross-Scale Technology Reference Study Documentation at http://sci.esa.int/ science-e/www/ object/ index.cfm?fobjectid=38982

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