The Caroline Mission Concept: Exploring the diversity of primitive bodies

Geraint H. Jones

Mullard Space Science Laboratory, University College London
The Centre for Planetary Sciences at UCL/Birkbeck

Material that has evolved little since the formation of the solar system is key to understanding the conditions under which Earth and the other planets formed. Such material is believed to be present in cometary nuclei and in primitive asteroids. The four cometary nuclei imaged to date at close range by spacecraft show significant differences, indicating a broad diversity in the nature of these objects. The discovery in recent years of the presence of outgassing objects – main belt comets – within the asteroid belt, suggests that many bodies within that region of the solar system still contain volatiles near their surfaces, and that there exists a continuum of object types from those with few volatiles present to some largely composed of ices.

The Caroline mission concept, outlined here, would involve a single spacecraft's encounters with several primitive bodies to characterize their surface composition, the makeup of evolved gases in their vicinity, both neutral and ionized, the nature of their comae and plasma tails, and their dust environments. With an instrument suite dedicated to the detailed analysis of these bodies' composition, a better understanding is anticipated of conditions at the time of the solar system's birth. In the style of NASA's lost Contour mission, several bodies would be targeted. Power and mass constraints favour a mission to bodies when at similar distances from the Sun as that of the Earth. However, the potential scientific bounty of an encounter with a main belt comet, at heliocentric distances of ~2.5 AU, strongly favours a consideration of a spacecraft aphelion excursion to the asteroid belt itself, that would benefit from the application of ion drive technology to control the spacecraft's trajectory.

The use of penetrators for delivering instrumentation to the bodies' subsurface strongly deserves to be explored: such instrumentation could allow the invaluable in situ determination of the D/H ratio on such bodies, and the prevalence of trapped noble gases that cannot the detected remotely. However, as encounter velocities are likely to be at least several kilometres per second, the operation and targeting of such high kinetic energy packages would be extremely challenging. An overview will be given of the science goals of this mission concept, the means to achieve those goals, and the challenges facing the execution of such a mission.

Mission opportunities with China.

Alan Smith, Malcolm Dunlop, Dhiren Kataria and others

Various future Chinese space missions have been identified as potential for UK collaboration in space science instrumentation. These follow a long heritage of cooperation, beginning with Double Star and explored further during the Kuafu pre-study. Apart from an ongoing review of mission options for Kuafu, currently there are a number of other options for both immediate and longer term involvement, such as:
Multi-spacecraft microsat mission comprising three spacecraft in a 'string of pearls' configuration with launch in 2015+_. Potential collaborations include:
Micro satellite (possibly 3U cubesat) comprising plasma package of at least magnetometer, electron and ion analysers. It was noted that this would allow a 'Cluster' like configuration of 4 satellites with spacings appropriate to the ion gyro-radius

Plasma instrumentation (to be discussed but including energetic particle detector, electron analyser, and possibly magnetometer and auroral imager)

Mars Mission in 2013. The timescales for this mission are very short and so only highly developed hardware would be possible. Such hardware might include:
Imperial College magnetometer and/or and MSSL electron/ion micro analyser.

A 3U cubesat comprising magnetometer, electron and ion analysers currently under development for a UK cubesat mission.

Feng Yun solar wind / space weather monitor. Launch late 2014 to include: RAL Energetic particle analyser and possibly magnetometer.

A strategic collaboration between China and the UK in the development of instrumentation for space science would therefore be valuable, with the purpose to develop a 'plasma package' comprising for instance of magnetometer, electron and ion analysers and energetic particle detectors.

Plasma coupling and energetics in the solar atmosphere

Sarah Matthews

Observations from SOHO, TRACE, RHESSI, Hinode have produced great advances in our understanding of the origins and dynamics of thermal and non-thermal plasma distributions in the solar atmosphere, but have also raised many new questions about the relationship between the processes that produce these distributions and their relative energetics. We propose a mission to investigate the coupling and dynamics of thermal and non-thermal distributions in the solar atmosphere to address fundamental questions related to how non-thermal distributions are created, whether they constitute a natural extension of thermal populations, and how they evolve, i.e. what is the feedback between non-thermal particles, magnetic fluctuations and structures, and the dynamics of the bulk plasma. These are fundamental questions relating to the processes that transport, convert and release energy in astrophysical plasmas of all kinds, and are crucial for understanding how energy is transported from the Sun out into the heliosphere and the near Earth space environment.

We propose a payload including a high spatial resolution and temporal resolution X-ray telescope (0.1 arcsec, ~3-20 keV); direct HXR imaging and spectroscopy up to ~ 70 keV and a sub-mm/FIR imager that would probe the largely unexplored regions around 30 - 100 microns. Other possibilities include an optical telescope providing chromospheric magnetic field measurements and a Fabry-Perot instrument for photospheric/chromospheric imaging/intensity, magnetic field strength and direction and vertical and horizontal velocities.

New Questions in the Science of airless bodies – What next for the Moon and asteroids?

Neil Bowles, Karen Aplin, Ian Thomas,

Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford

Nick Teanby,

Department of Earth Sciences, University of Bristol.

This presentation will discuss how the results from recent missions to the Moon and objects such as asteroids are changing our views of their current and past state and the new types of mission that are required to answer the new, and not so new, questions they have revealed. For example, recent discoveries of water ice spectral signatures in the Lunar regolith show that volatiles previously thought to be absent from the lunar environment may be present in far greater quantities. What is the origin of this water, how does it transport around and trap during the lunar day? Can we detect it by in-situ measurements from orbit? For both the Moon and asteroids, what role does charging of the surface play in the transport of dust? What can we learn about the interiors of these objects with, for example, in-situ seismic and heat flow measurements? What do samples tell us about the history of the object, and the evolution of the Solar system?

The data to answer these and numerous other questions cross many disciplines in planetary science and can only be acquired from new space based missions, both remotely, in-situ, by landers and sample return.

HiRISE: a Dedicated High Resolution Mission for the Dynamical Chromosphere-Corona Interface

Luc Damé (1), Robert Erdélyi (2), Philippe Lamy (3) and the HiRISE Team
1) LATMOS/IPSL/CNRS/UVSQ, Guyancourt, France
e-mail: luc.dame@latmos.ipsl.fr
2) SP2RC, Dept. of Applied Mathematics, University of Sheffield, UK
3) Laboratoire d'Astrophysique de Marseille, Marseille, France

Several ground facilities and space missions are currently dedicated to the study of the Sun at high resolution and of the solar corona in particular. However, and despite significant progress with the advent of space missions and UV, EUV and XUV direct observations of the hot chromosphere and million degrees coronal plasma, much is yet to be achieved in the understanding of these high temperatures, fine dissipative structures and of the coronal heating in general. Recent missions have shown the definite role of waves and of the magnetic field deep in the inner corona, at the chromosphere-corona interface, where dramatic changes occur.
The dynamics of the chromosphere and corona is controlled by the emerging magnetic field, guided by the coronal magnetic field. Accordingly, the direct measurement of the chromospheric and coronal magnetic fields is of prime importance. The solar corona consists of many thin loops or threads with the plasmas brightening and fading independently. The dynamics in each thread is believed to be related to the formation of filaments, each one being dynamic, in a non-equilibrium state. The mechanism sustaining that dynamics, oscillations or
waves (Alfvén or MHD?), require both very high-cadence, multi-spectral observations, and high resolution. This is foreseen in the future Space Mission HiRISE (High Resolution Imaging and Spectroscopy Explorer), the ultimate new generation ultrahigh resolution, interferometric and coronagraphic, Solar Physics Mission, proposed for ESA Cosmic Vision (pre-selected in 2007, and under consideration for the second call).

HiRISE, at the L1 Lagrangian point, provides meter class FUV imaging and spectro-imaging, EUV and XUV imaging and spectroscopy, and ultimate coronagraphy by a remote external occulter (satellites in formation flying 280 m apart) allowing to characterize temperature, densities and velocities in the solar upper chromosphere, transition zone and inner corona with, in particular, 2D very high resolution multi-spectral imaging-spectroscopy, direct coronal magnetic field measurement: a unique set of tools to understand the structuration and onset of coronal heating. We give a detail account of the proposed mission profile, major scientific objectives and model payload of HiRISE, a natural complement to the Solar Probe type missions lacking duty cycle, high resolution, spatial, spectral and temporal multitemperature diagnostics and full coronal magnetometry.

The science case and challenges for L class missions to Uranus or Neptune

C.S. Arridge1,2, N. Achilleos3,2, C. Agnor4, A.J. Coates1,2, M.K. Dougherty5, A.N. Fazakerley1,2, L. Fletcher6, C. Forsyth1, A.D. Fortes2, M. Galand5, R. Holme7, P Irwin6, C.M. Jackman5, G.H. Jones1,2, A. Masters1,2, H. Melin8, S. Miller3,2, C.D. Murray4, C.J. Owen1, A. Smith1, T. Stallard8, N. Teanby6, A.P. Walsh1

1. Mullard Space Science Laboratory, University College London, UK.
2. The Centre for Planetary Sciences at UCL/Birkbeck, London, UK.
3. Department of Physics and Astronomy, University College London, UK.
4. Astronomy Unit, Queen Mary University of London, UK.
5. Department of Physics, Imperial College London, UK.
6. Department of Physics, Oxford University, UK.
7. Department of Earth and Ocean Sciences, University of Liverpool, UK.
8. Department of Physics and Astronomy, University of Leicester, UK.

The ice giants Uranus and Neptune are now the only planets in the solar system that have not been studied in detail by an orbiting spacecraft, both having only been briefly surveyed by Voyager 2. These giant planets are fundamentally different to their gaseous siblings and reflect their very different formation environment beyond the solar system snow line. Consequently their interiors are very different to the other planets and their location in the solar system produces very cold atmospheres, however interestingly Neptune's atmosphere is highly dynamic and possibly driven by heat from Neptune's interior. Uranus's atmosphere has displayed a range of activity levels, possibly seasonal in nature, and was much more dynamic during its recent equinox than when encountered by Voyager 2. Both planets have large obliquities (very large in the case of Uranus) and have intrinsic magnetic fields that are highly asymmetric, consequently producing highly time-variable magnetospheres. Dynamo simulations suggest that these asymmetric intrinsic fields should display a high level of secular variation and new spacecraft observations will have fundamental implications for our understanding of dynamo theory.

Both planets have ring systems consisting of narrow discrete rings and Neptune's rings contain prominent arcs, probably due to gravitational interactions with Neptune's moons. Finally, both planets have an extensive system of natural satellites. Neptune's moon Triton is thought to be a captured Kuiper belt object and so represents an important solar system target in its own right, but also liquid nitrogen cryovolcanism was observed by Voyager 2 thus driving speculation that Triton may represent the Enceladus of the neptunian system. The present focus on gas giants excludes the valuable lessons that ice giants have to tell us about planetary structure, formation, dynamics and evolution, and this knowledge will be key in better understanding other planetary systems in the future.

A mission to Neptune or Uranus represents the quintessential aspects of the Cosmic Vision programme and addresses all four of the Cosmic Vision overarching science questions. Such a mission also naturally fits in the NUAP science priorities identified by the UK solar system community. However, despite strong science drivers for a mission to either Uranus or Neptune there are considerable technological challenges (principally in telemetry bandwidth, electrical power and delta-V) to overcome in launching and operating a spacecraft out to 20-30 AU. In this talk we address the science case for such a mission and discuss the challenges involved.

Towards Interplanetary Space Weather: Strategies for Manned Missions to Mars

Claire Foullon, CFSA,

University of Warwick

By 2030 an international human mission to Mars (or nearby asteroids and moons) may be a reality, with the Moon as a likely intermediate step. The desire to explore and send humans into interplanetary space is currently confronted with many uncertainties for assuring the crew's safety from radiation. One option to reduce these uncertainties and mitigate the potential radiation induced health risks is to consider operational approaches. Future interplanetary manned missions will require global monitoring and warning systems capable of providing space weather forecasts and alerts and assuring adequate warning and protection from solar proton events (SPEs) during extra-vehicular activities. To ensure adequate warnings of potentially large SPE fluxes, the forecasting strategy is to provide continuous observations of the solar regions generating solar disturbances and to provide a global picture of the interplanetary medium, where solar wind disturbances propagate. Multi-spacecraft systems require a separation angle between the spacecrafts that allows stereoscopic imaging and reconstructions of spatial characteristics in the solar wind. These systems _ and occasional monitors _ may combine several individual spacecraft missions observing at the same time. They include not only interplanetary solar satellites but also Earth-based platforms.

The past, present, and future missions into interplanetary space open the challenging opportunity to reach a comprehensive understanding of the processes at work in CME initiation, shock propagation, and particle acceleration. Our ability to protect the crew of interplanetary missions from SPEs depends on the future of these missions and the know-how they will bring. With the associated development of real-time models and forecasts, it becomes possible to decide on the choice of multi-spacecraft missions and minimum instrument packages necessary to assure a continuous monitoring of the Sun and outer space. In general, we may safely say that aside from traditional in-situ instruments (solar wind analyzer, magnetometer and energetic particle detector), remote sensing instruments _ including a full disk imager, a Doppler magnetograph, and a coronagraph _ are essential as well. In particular, we need to make sure that future Earth-based platforms provide all necessary instruments, not only for terrestrial space weather and missions to the Moon, but also for the development of our interplanetary space weather expertise.

Reference: Foullon, C., Crosby, N.B. and Heynderickx, D., 2005, Space Weather 3, S07004, doi: 10.1029/2004SW000134.

An M-Class Mission Concept: Investigation of MagnetoPause Activity using Longitudinally-Aligned Satellites (IMPALAS).

Christopher J. Owen,

UCL/Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, RH5 6NT.

The NASA/THEMIS mission shows that significant progress on some of the major unanswered questions in magnetospheric physics can be made by tailoring a multi-spacecraft mission to make measurements in specific locations in the magnetosphere, and that this progress will be augmented if ground-based capability can be included as an extra measurement point. Moreover, lessons from the recent Cross-Scale experience include, perhaps, the understanding that the ESA M-Class budget is sufficient for only 2 or 3 ESA-sponsored spacecraft, although clearly this is a function of orbit, payload mass, etc. Under this philosophy, we have given some preliminary thought to mission possibilities, and broadly describe here a mission aimed at the Investigation of MagnetoPause Activity using Longitudinally-Aligned Satellites (IMPALAS).

The dayside magnetopause is the primary site of energy transfer from the solar wind into the magnetosphere, and activity on this boundary modulates much of the activity observed within the magnetosphere itself (including 'Space Weather'), and indeed that propagating down into the ionosphere. Some specific plasma physical processes are already known to operate on the magnetopause, such as the occurrence of magnetic reconnection, the generation of boundary waves, the propagation of pressure-pulse induced deformations of the boundary, the formation of boundary layers and the generation of Alfven waves and field-aligned current systems that connect the boundary to the inner magnetosphere and ionosphere. However, many of the details of these processes, how they operate on the magnetopause and how they evolve are not fully understood. For example, magnetic reconnection is known to occur sporadically to produce flux transfer events, but how and where these arise, and their importance to the global dynamics of the magnetospheric system is still unresolved.

Many of the phenomena described above involve propagation across the magnetopause surface, in some cases (e.g. magnetic reconnection, boundary waves), are influenced by the northward pointing direction of the terrestrial magnetic field. Understanding of these phenomena would be enhanced by measurements made at widely-spaced ($\Delta \sim 5$ RE) intervals along the direction of dayside terrestrial field lines at the magnetopause. We propose a mission involving deployment of a fairly standard fields and plasmas payload package (including magnetometer, ion and electron spectrometer and energetic particle telescopes, all of which are of interest to UK hardware groups) on 3 identical spacecraft. IMPALA 1 would be in a circular equatorial orbit of radius ~10.48 RE, which has a period of exactly 2 days. Moreover, this orbit radius is also very close to the average location of the dayside magnetopause, such that the spacecraft would be expected to 'skim' along (and thus sample) this boundary over many hours during its dayside passage. The orbit should also be phased such that when the spacecraft was at local midday, northern European ground-based facilities were also at, or very near, local midday. IMPALA 2 and IMPALA 3 would be placed in orbits of +30 degrees and -30 degrees inclination, with slight eccentricity to increase their apogee to ~11 RE, the typical position of the noon magnetopause at these inclinations, while maintaining the 2 day period and phase with respect to IMPALA 1. These spacecraft would thus skim the magnetopause about 5 RE above and below IMPALA1 while all 3 spacecraft maintain common longitude and thus sample along the same field line. Moreover, when the spacecraft are at local noon European ground based facilities would sample at or near the foot of that field line.

The baseline mission described above could support many options, depending on available resources. For example, nadir pointing cameras on IMPALA 2 and IMPALA 3 would allow remote sensing of the auroral zone when the spacecraft are near local noon (and indeed local midnight). It may be possible to plan for a later phase of the mission in which the apogee of all 3 spacecraft is boosted to bow shock altitudes, such that cross-surface studies of the shock dynamics could be undertaken. If resources allow, further spacecraft could be deployed to increase longitudinal, latitudinal and/or radial coverage. The feasibility of the baseline mission, together with these and other options, need to be the subject of a more comprehensive assessment study, and we suggest that the Cosmic Vision M3 opportunity may well be appropriate for that study.

Waves and Acceleration of Relativistic Particles (WARP)

Richard Horne (BAS), Mick Denton (Lancaster), Misha Balikhin (Sheffield)

Particle acceleration to extremely high energies is one of the unresolved fundamental problems in space plasmas. The Earth's magnetosphere acts as a giant particle accelerator energizing electrons and ions from a few eV up to hundreds of MeV in the radiation belts through multi-step processes. Kinetic micro-scale processes involving electromagnetic fields and waves play an essential role in particle acceleration, transport and loss processes and in coupling different plasma populations together. Over the last 5 years it has been shown that there must be a local acceleration process operating inside the heart of the radiation belts, together with other transport and loss processes, which has changed scientific direction. Here we discuss some of the most important physical processes that could contribute to electron acceleration, transport and loss. We discuss the ideas of radial diffusion, magnetic pumping, recirculation, and highlight the emerging importance of resonant wave-particle interactions with ULF, EFL and VLF waves and particularly nonlinear wave-particle interactions. We discuss the role of substorms, the ring current, the structure of large scale electric and magnetic fields, and the motion of plasma boundaries on acceleration and loss processes. We suggest a satellite mission similar to WARP that was submitted to the ESA Cosmic Visions that could test these theoretical ideas, which has a focus on high time resolution measurements for kinetic micro-scale processes, and which has an orbit to maximise radiation belt coverage. We discuss how such a mission would compliment CLUSTER, the NASA RBSP, and Japanese ERG missions, and how ground based radars such as SuperDARN, and magnetometer chains, could contribute essential scientific input.

NanoSats as Space Weather “balloons” for in-situ monitoring of the Earth’s ionosphere and thermosphere.

Dhiren Kataria1, Anasuya Aruliah2
1Mullard Space Science Laboratory, Department of Space and Climate Physics, University College London, Holmbury St. Mary, Dorking Surrey RH5 6NT
2Atmospheric Physics Laboratory, University College London, Holmbury St. Mary, Dorking Surrey RH5 6NT

New space missions do not have to be confined to expensive large spacecraft, which require decades of preparation. The UK has an impressive satellite industry and a new era of building smaller satellites has created new opportunities for science and technology. In addition, advancements in micro fabrication techniques and micro-electronics are enabling powerful low mass sensor systems. The combination of the two is set to revolutionise Space Weather research and monitoring. The proposal is to send up bunches of lightweight nano-satellites, 2-3 at a time, piggy-backing on rockets at a cheap cost. Similar to the weather balloons used to monitor tropospheric weather conditions, these satellites will be Space Weather “Balloons” providing constraints on climate models as well as providing continuous monitoring of space weather conditions. Miniaturised sensor systems are already under development in the UK. For example, MSSL is in the process of testing a plasma analyser that weighs 200g, and Imperial College has built a miniaturised magnetometer to launch on a CubeSat that will weigh 1-2 kg. The satellites would be launched opportunistically on available rockets, and released at whatever altitude is required by the main payload. They are then tracked carefully as they descend until they burn up at around 90 km altitude. With multiple launches over time, an array of randomly distributed satellites will be available and with 2-3 launched together, it will be possible to study the meso-scale structure of the ionosphere and thermosphere by comparing observations from the closely spaced satellites along with others launched earlier. Measurements from a single satellite contains an ambiguity of whether a variation is temporal or spatial, while multiple satellites can minimise this problem as has been demonstrated by the CLUSTER spacecraft in studies of the magnetopause, for example. There are many meso-scale science objectives to study, such as the considerable energy dissipation of meso-scale variations. The descent of the satellites below 300km will chart a very poorly observed region of the atmosphere. The multiple data points will provide calibration for atmospheric models with a view to Space Weather prediction capabilities. This is extremely valuable for the communications industry as well as being of intrinsic interest to the Space Science community. The insights that will arise from these meso-scale measurements applied to models will be used to inform Planetary Atmospheres models.

Planet-X: A novel view of the solar system

G. Branduardi-Raymont, A. J. Coates, G. H. Jones, C. Forsyth, D. Kataria
University College London
Mullard Space Science Laboratory
Holmbury St Mary
Dorking, Surrey

Abstract

X-ray studies of solar system bodies are now a hot topic, thanks to spectroscopy by XMM-Newton and sharp imaging with Chandra. Some of the processes taking place in planetary magnetospheres, e.g. those of Jupiter and Earth, and in particular processes generating planetary aurorae, involve highly energetic plasmas and powerful magnetic fields. X-ray observations provide unique remote sensing data with which we can explore globally, and in detail, particle populations, their acceleration and their response to solar activity.
Ubiquitous in the solar system is the process of charge exchange, by which highly stripped, energetic ions of the solar wind collide with atmospheric atoms and molecules, acquire an electron, and are left in an excited state; the ions then decay with the emission of characteristic soft X-ray lines, the brightest of which are normally from Helium-like and Hydrogen-like oxygen (i.e. ions with only 2 or 1 electrons left). In addition to playing an important role in Jupiter's X-ray aurorae, charge exchange is responsible for X-ray emission at the un-magnetised planets, Mars and Venus, and for the bright X-ray emission of comets, when solar wind ions interact with their extended, low density comae. Recently XMM-Newton has shown that X-rays from charge exchange of the solar wind with particles in the Earth's magnetosphere can be directly associated with enhancements in solar activity, thus offering a powerful new tool for global magnetospheric monitoring and investigating space weather processes.
X-ray observations make a very novel approach to solar-terrestrial, planetary and heliospheric science; they provide an unparalleled global view, complementary with the spot-checks carried out with in-situ observations. We suggest that such a novel approach is important to consider in the near future, and especially in the context of the forthcoming ESA Cosmic Vision mission opportunities, be it in the form of a terrestrial space weather monitoring probe (e.g. orbiting the Moon), of nano-satellites to study the Earth's aurorae, or of X-ray instrumentation, perhaps combined with UV and optical imaging, for remote planetary and cometary observations. We will discuss a range of mission ideas including the Planet-X M-type mission.

A 24/7 and interhemispheric global auroral imaging mission

Steve Milan and Mark Lester
University of Leicester

Since its inception in the 1980s FUV global auroral imaging from space has become a proven method of remote-sensing the large and meso-scale structure and dynamics of the magnetosphere under the influence of its interaction with the solar wind. As well as being a research tool in itself, global auroral imaging provides supporting context to almost all other measurements, ground- or space-based, of the magnetospheric system.

As well as outlining the science case, this talk will describe a global auroral imaging mission comprising two spacecraft in identical polar orbits, phased such that at least one spacecraft is always imaging the northern or southern hemisphere, providing 24/7 coverage. There will be two periods each orbit when one spacecraft will be able to image the opposite hemisphere, providing regular conjugate imaging. Opportunities for the addition of other remote-sensing or in-situ instrument packages will also be discussed.

Multi-spacecraft mission to the aurora

A.N. Fazakerley, M. Lester, S. Milan

Mullard Space Science Laboratory, University College London, U.K.
Dept. Physics & Astronomy, University of Leicester UK

The aurora are the one manifestation of space plasma physics effects which the general public are usually aware of and able to experience personally. Visible light emission are accompanied by UV and X-ray emission, as well as strong AKR radio emissions. Aurorae are also observed at other solar system planets including Jupiter, Saturn and Mars, and it is highly likely that they occur at exoplanets. Aurorae can be divided into several types based on observational differences; arcs related to upward and downward field aligned- current systems; alfvenic aurorae, pulsating aurora, and the diffuse aurora. Auroral structures exhibit a range of natural scale sizes, from 100's kms to kms and even smaller, and show dynamic behaviour.

The FAST mission demonstrated convincingly that particles and fields data must be collected at a high cadence (0.1 sec or better) in order to properly measure particle distributions and their interaction with electric and magnetic field disturbances.

Cluster remote sensing of the AKR has led to a new understanding of the directional characteristics of AKR emission (with implications for interpretation of AKR from other planets). Now Cluster is serendipitously making the first multi-point measurements in the auroral acceleration region although its science potential is limited by particle instrument cadences and a limited number of passes.

The aurorae cannot be understood in terms of simple MHD models. For example, field-aligned current closure is thought to be achieved through parallel electric fields which decouple the ionosphere and magnetosphere. The aurora offer the possibility to study cross-scale coupling at the nearby magnetosphere-ionosphere boundary.

Top level open questions include what exactly are the energy sources for maintaining long-lived aurorae and transient aurorae? How are narrow auroral arcs created and what controls how they evolve? how is energy is coupled from large to small scales? what causes diffuse aurora? What causes pulsating aurora?

Progress on auroral physics requires new observations; specifically simultaneous multipoint measurements from space and the ground at different scales. Multi-point measurements are essential in order to test models of auroral particle acceleration (measurements at different points on a field line are needed) and models of the development and motion of auroral structures (measurements transverse the field lines are needed). A number of multi-point auroral missions have been studied and/or proposed to space agencies over time with these aims in mind, including; Auroral Multi-scale Mission; IBIZA/IMPACT; Auroral Lites, Global Electrodynamics Mission, APEX. We discuss the science potential and prospects of such a mission within the resource envelope associated with an ESA M-Class mission.

Fast Auroral Mars Explorer (FAME)

A.J. Coates[1,2], G.H. Jones[1,2], C.S. Arridge[1,2], A. Masters[1,2], G. Branduardi-Raymont[1], D.O. Kataria[1], A.Smith[1], A.D.Aylward[3,2], M.K. Dougherty[4], M. Lester[5], S.Milan[5], N.Bannister[5], P.Irwin[6], P.Read[6], S.Lewis[7], F.Leblanc[8]

1. Mullard Space Science Laboratory, UCL, 2. Centre for Planetary Sciences at UCL/Birkbeck, 3. Atmospheric Physics Laboratory, UCL, 4. Imperial College London, 5. University of Leicester, 6. University of Oxford, 7. Open University, 8. LATMOS/IPSL, France

Atmospheric escape at Mars has played a key role in the evolution of the Martian atmosphere. Mars lost its magnetic field some 3.8 billion years ago, leaving only crustal magnetic fields mainly in the Southern hemisphere. Since that time, the Martian atmosphere has been exposed to the solar wind more directly, since the Martian exobase is above the ionosphere. Recently, evidence for aurora on Mars associated with the crustal magnetic fields has been found by Mars Express. The extent of solar wind control of the aurora, the global morphology of the auroral emissions and of their generation processes, and the process of large scale morphology of plasma escape, are as yet unknown. FAME will provide the required measurements.

Also, 4D infrared measurements on the Martian atmosphere are planned for FAME, to provide tomography of the atmosphere down to the surface. In addition, a microwave limb-sounder will map and measure Doppler winds as well as temperatures, complementing previous missions especially for low-latitude circulation and meteorology. It will also facilitate measurements even in the presence of thick dust.

Missions to Mars have in the past involved non-simultaneous plasma measurements, e.g. the magnetometer - electron reflectometer on Mars Global Surveyor, and ASPERA-3 (ions, electrons and ENAs) on Mars Express. The MAVEN mission will address this aspect, with simultaneous plasma measurements including magnetic fields, ions and electrons. This will allow progress on atmospheric escape. However, several key measurements are missing from MAVEN, including fast ion data at speeds near the ion gyrofrequency, global auroral measurements, photoelectrons with good resolution, and multipoint plasma measurements.

Mars Express has shown that escape is mainly via the tail, though pickup can and does also occur at any local time, and that low energy ions are an important component of the escaping plasma (Lundin et al., 2009). Recently, it has been shown that ambipolar electric fields may be an important part of the escape process at Mars, as well as at Venus, Titan and Earth (Coates et al., 2010).

We therefore propose the FAME mission to provide more detailed understanding of the Mars environment post-MAVEN. This will include a spacecraft in elliptical, inclined orbit around Mars, which on the night side will be the ideal platform for observations of the aurora. A multi-wavelength imaging suite will measure the global Martian aurora for the first time. In addition, the payload will include a fast ion instrument with mass resolution, to measure 3D ion distributions at speeds approaching the ion gyrofrequency, allowing the investigation of non-gyrotropic processes. An electron sensor with excellent energy resolution will make the best measurements of ionospheric photoelectrons yet. Such electrons may play a key role in the escape process. A magnetometer will provide context and in-depth measurements of the crustal magnetic fields.

As well as the main spacecraft, FAME will include 3 co-orbiting nanosatellites spaced around the orbit, to provide the large scale morphology of the escape process, together with an upstream solar wind monitor at the Martian L1 point. Here we provide a summary of the science of the proposed mission.