

# Draft NUAP report: Space Physics

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## 1. Executive Summary

The Near Universe Advisory Panel (NUAP) covers those parts of the astronomy and space science programmes concerned with the Sun, the solar system, and the properties of objects within our galaxy. The aim of the NUAP is to draft and maintain a roadmap which describes current and future research opportunities, for presentation and approval by PPAN. The initial step in this process is to consult widely and carefully with the community, to ensure a transparent and representative approach is adopted. This document aims to provide the first *draft* of a summary of the Space Physics community's science priorities, technology requirements, and opinions on approaches to the inevitable prioritisation process which we must now undergo. The information contained here has been collated from an initial consultation with a cross-section of renowned experts in the field of Space Physics. Their excellent input has inevitably been distilled, and reduced for the purposes of this draft. It is imperative that the community appreciates that this document serves as a starting point to which reactions are *required*, and that the purpose of the next stage of the NUAP process (i.e. full consultation with the community) will rely on the input of the community to devise a complete strategy, which *must be* prioritised. Clearly, the field of Space Physics is one of a number of areas undergoing a similar process within the NUAP, and the eventual strategy will emerge through a prioritisation process across the entire remit of the panel.

## 2. Introduction

The field of Space Physics is large, and contains many sub-strands. Other panel members will be looking at other (potentially related) NUAP areas, such as Solar Physics, Planetary Geology, Exoplanets, Stellar Astronomy, and the Diffuse Matter and Star/Planet Formation. Of course there will be some cross-over between these broad topics, and part of the aim will be to highlight such cross-over topics in the final documentation. Within the broad topic of Space Physics are sub-topics including the space environments of magnetised and non-magnetised bodies (e.g. Mars, Venus, planetary moons, comets) throughout the solar system. The field of solar terrestrial physics (both ground- and space-based aspects) is covered within this description, as are non-terrestrial magnetospheres, ionospheres, and atmospheres. Investigations of basic plasma processes which are relevant to a wide range of astrophysical phenomena are at the root of what the Space Physics community currently achieves through a broad and internationally recognised programme of scientific data analysis, theoretical and numerical modelling, and technology development (particularly for space hardware projects). The emerging consensus from the cross-section input consistently calls for two important steps for the STFC to recognise: 1) to secure the present and near-future as a critical path to both defining and reaching longer-term (10-15 years) goals through continued support for both current missions and critically for post-doctoral researchers, 2) to properly fund (starting now) the science teams and technology developments required to take part in those longer-term goals (e.g. the Cosmic Vision missions). The rest of this document aims to provide an example set of responses to some of the questions in the accompanying questionnaire.

## 3. World-wide scientific challenges for the next 10-15 years (in no particular order)

- Investigate the nature of plasma processes across multiple scales, e.g. magnetic reconnection, collisionless shock waves, turbulence, and dusty plasma processes. Thus pose testable quantitative questions within the Near Universe environment.
- Determine the physics involved in the formation and dissipation of the terrestrial radiation belts, before and after geomagnetic storms and the impact on space technology.
- Determine how energy flows from the solar wind, through the magnetosphere and into the auroral zones in the terrestrial system.

- Understand the fundamental process of magnetic reconnection at the dayside terrestrial magnetosphere, its location and rate as a function of solar wind and interplanetary magnetic field orientation. Understand the episodic nature of magnetopause reconnection.
- Investigate large-scale instabilities in the terrestrial magnetotail, including unravelling the complexities of e.g. substorm onset mechanisms and substorm triggering by the solar wind.
- Understand the details of the Earth's auroral acceleration processes, from the ground and from orbiting spacecraft. For example, determine the relationship between aurora and field-aligned current systems.
- In situ monitoring of the Earth's ionosphere: e.g. ionospheric convection, structuring of the ionosphere, influence of this structuring on satellite communications and radio systems (GPS), coupling between the ionosphere-thermosphere-lower atmosphere, and active experiments (e.g. heating the ionosphere).
- Determine the links between the activity observed on the Sun, and the nature of the resulting solar wind emitted into the inner heliosphere.
- Develop a system-level understanding of the outer plasma environments at Jupiter and Saturn as magnetic-aligned rotators dominated by internal moon sources of gas and plasma. For example, radial transport and loss of plasma; influence of solar wind interactions on outer magnetospheric structure; particle acceleration processes related to magnetosphere-ionosphere coupling; radio and auroral emissions as remote diagnostics of magnetosphere dynamics; and mutual influence of magnetosphere-ionosphere coupling on the thermosphere.
- Develop system-level understanding of the plasma environment at Mercury as a non-rotating system dominated by the solar wind interaction. Specifically, the nature of solar-wind magnetosphere interactions under extreme solar wind conditions; related tail dynamics and acceleration processes; and the consequences of a lack of conducting ionosphere for magnetospheric dynamics.
- Develop system-level understanding of the plasma environments of Uranus and Neptune resulting from large magnetic inclinations to the spin axis, and of the spin equator to the orbit plane in the case of Uranus. Including, the nature of the solar wind interaction in these systems; the role of planetary rotation; and the nature of magnetosphere-ionosphere interactions.
- Understand the physical processes in non-terrestrial magnetospheres that underlie and influence the structure and dynamics of these environments, and how their relative significance and interplay depends upon system properties. Note that these challenges link directly to the study and understanding of exoplanets, whose electromagnetic outputs (yet to be detected) will be determined by directly-related properties and physical processes.
- Comparison of solar system activity (e.g. solar flares, planetary AKR) with that in other solar systems with Sun-like stars.
- Develop an understanding of the solar-wind comet interaction. For example, how ion pick-up varies in cometary environments as the strength of the ion source changes, and how the solar wind affects cometary dust and vice versa.
- Determine the details of the processes by which planetary moons are coupled to the parent planet magnetosphere. Investigate the general effects of plasma impact onto moon surfaces, and the reciprocal effects on the impinging medium. Study the nature of e.g. Ganymede's internal magnetic field, and how does it couple to the surrounding field and plasma? Do other planetary satellites possess internal magnetic fields?

- Compare the Titan space environment with that of Mars and Venus, and consider the interaction of the Titan ionosphere with Saturn's magnetosphere and the variations as a function of time.
- Compare the differences and similarities in the solar-planetary interactions at Venus, Earth, and Mars. For example, how does the highly localised crustal magnetic field structure at Mars interact with other localised phenomena (e.g. dust storms)?
- Quantify the risks posed to society from space weather and strategies for mitigating these risks where necessary. What are the impacts of "space weather" elsewhere, e.g. at the Martian surface? What is the impact on technology and organic material?
- What can we learn about the Earth's atmosphere in general and about forecasting weather and climate change through the study of other terrestrial atmospheres as "planetary laboratories"? How have the atmospheres of Earth, Venus, and Mars evolved to their present state? How stable is this present day climate and what is the magnitude of climate change on various timescales? Can models of terrestrial planet atmospheres be used to improve quantitative predictions to aid in future mission design?
- Understand the reason why exospheric temperatures at the giant planets are significantly higher than can be maintained by solar heating alone. Understand the role of electrical circuits in the dynamics of planetary atmospheres.
- Determine how energy is transferred from auroral precipitating particles to planetary ionospheres, via the formation of turbulent structures at different length-scales in the ionosphere. Study the effect of magnetospheric forcing on the thermosphere, and vice versa.
- Characterise the present day habitability of Mars by e.g. the investigation of the sources of methane plumes. Are there potential habitats elsewhere in the solar system, e.g. Europa? Characterise the meteorology and methane hydrological cycle of Titan and identify the sources and sinks of methane in Titan's atmosphere.

#### **4. Highlight the UK involvement in above research including the UK reputation**

The UK Space Physics community has an excellent world-wide reputation and productivity in all of the scientific areas covered above. The UK boasts a strong instrumentation programme in Space Physics, coupled with data analysis and theoretical modelling. Overall, the UK Space Physics community is well-placed to make substantial future impacts in all of the above areas given the appropriate opportunities. More specific details are given below:

- The UK provided the back-bone to the ESA Cluster mission, with major hardware provision and science exploitation occurring at Imperial College, UCL/MSSL, RAL, Sheffield, Leicester, QMUL, Lancaster, St. Andrews, Aberystwyth, Southampton and BAS. The UK has lead or participated in many of the stand-out results.
- Ground-based solar terrestrial physics expertise including the build, operation, acquisition and analysis of data from of radars, radio instruments, and cameras led by Leicester, Lancaster, BAS, Aberystwyth, Bath UCL and Southampton.
- The UK has significant involvement in solar system missions Mars and Venus Express, Mars Reconnaissance Orbiter, Cassini-Huygens, Rosetta, and BepiColombo (including PI and Co-I roles at Imperial, MSSL, Oxford, Leicester, QMUL).
- There is a vibrant theory (e.g. St. Andrews), modelling (e.g. Leicester, Oxford, OU, Sheffield UCL) and simulation (e.g. QMUL, Warwick) activity that supports the main science questions raised above, and these are well connected into larger international networks.

- Groups such as Imperial, Leicester, and UCL have excelled at exploiting US-based outer planet auroral datasets and/or acquiring their own ground-based infrared observations.
- Lead roles in future missions (StormDARN, KuaFu, Solar Orbiter, Cross-Scale, Exomars, Europa-Jupiter System Mission) will enable UK scientists to maintain and enhance their world-leading reputation, and make significant contributions to the broad questions above into the next 10-15 years.

## **5. Identify what facilities and human resources will be need for the UK to make significant contributions to these areas (no particular order)**

- Provide proper post-doctoral support in order to support all science areas identified.
- Continued funding of operations and science exploitation for existing major facilities (e.g. Mars Express, Cluster, Cassini, and SuperDARN) allowing the UK to continue to harvest the return on its investment in international projects.
- STFC should give proper consideration to funding proposals exploiting data from Themis, Radiation Belt Storm Probes (RBSP), the Magnetospheric Multi-Scale (MMS), the NASA Juno mission to Jupiter, Mercury analysis (both Messenger and BepiColombo), and Rosetta.
- Provide funding for synoptic, long-term measurements (e.g. radars, magnetometers, cameras, riometers) which are the key to understanding the terrestrial magnetosphere.
- Provide funding for the Chinese KuaFu mission in order to secure the UK roles which have been identified.
- Continued support for both ground-based infrared and Hubble Space telescope observations of the outer planetary aurora.
- Provide a rigorous data archiving policy.
- Form centres of excellence, where scientists can interact, specialised training can take place, and science workshops can be provided. This would encourage cross-discipline projects e.g. between solar physics and solar terrestrial physics communities, and between exoplanetary systems and planetary magnetosphere communities.
- Increase long-term support for modelling activities, including provision of established posts allowing larger technical teams to be built up and maintained.
- In order to maximise the science return from the investment in the ESA subscription, STFC needs to undertake to properly fund the study, design, build, operation and analysis of data from Solar Orbiter, Cross-Scale, and the Europa-Jupiter System Mission.

## **6. What are the priorities (not in order)?**

- Continued support for existing missions (as stated above).
- Provide proper post-doctoral support in order to support science areas identified.
- Support and commitment for future ESA missions to ensure that the UK science priorities are reflected in both the ESA decision-making process and subsequently exploited through major stakes in the mission design, build, operations, and analysis.

## **7. What criteria should be used to prioritise?**

Key criteria are:

- Involvement in ESA missions, as long as this strategy is actually put into practise.
- Likely prospects for new high-impact scientific research
- Strength and vitality of the UK community in taking up opportunities and challenges
- Support for a broad cross-group UK scientific community
- Research excellence as a function of cost

## **8. What are the technological needs in both academia and industry?**

The technological needs of the Space Physics community are relatively modest, given their current capability. However, some specific areas have been highlighted:

- The technological needs are for the current base of instrument-building knowledge to be maintained and expanded through training of younger scientists and technicians.
- Specifically we require the ability to sample electron scale physics, e.g. fast high-voltage sweep units for electron detectors (e.g. for Cross-Scale).
- Provision of radiation-hardened components and the applications of shielding techniques to ensure reliable operations in the harsh Jovian environment (e.g. for EJSM).
- Miniaturisation of existing designs (to remain competitive for e.g. constellation class missions).
- Onboard data handling or compression techniques (all).
- Maintain good links with industrial partners at both instrument and component level, and through generic mission design studies.

## **9. What are the broader benefits of the research area to the UK?**

- Enthusing and training a numerate future generation for deployment throughout the financial, educational, and industrial sector.
- Raising interest in science of school pupils and the public in general.
- Hardware programmes provide numerous opportunities for knowledge exchange, e.g. miniaturisation.
- Knowledge transfer with other disciplines. For example, the science of other low-frequency high-impact events (earthquakes/volcanoes/tsunamis) informs the study of space weather events and impact on society.
- Solar terrestrial physics provides an understanding of space weather which will have an impact on satellite communications, GPS systems etc. In this technological age, this becomes increasingly important.
- Improved understanding of planetary atmosphere inevitable impacts on improvements to terrestrial weather forecasting, data analysis, and climate change prediction.
- Improved satellite / space mission test beds through the incorporation of better planetary atmosphere simulators.