University of Glasgow

Space Glasgow

Executive Summary

The University of Glasgow has been active in space research over many years. The present research activities within the University are wide ranging and incorporate many different disciplines, primarily across the College of Science and Engineering.

The Space Glasgow research activities fall within five key themes:

- Enabling technologies for space - hardware
- Enabling technologies for space - software
- Future mission concepts
- Mission and risk analysis
- Exploring and Understanding the Solar System

This brochure highlights individual research activities presently being undertaken within the University ranging from planetary sample gathering and analysis through to the engineering management and challenges in space mission planning and execution.

Foreword

The University of Glasgow ranks in the top 1% of the world's higher education institutions due to its ongoing focus on research excellence. Within this framework, the College of Science and Engineering is home to wide-ranging and high quality space research, and the Space Glasgow Research Cluster has been established both to increase cooperation within the University and to promote our shared expertise to potential external partners.

Officially launched in 2012 by the Rt. Hon. David Willetts MP, Minister of State for Universities and Science, Space Glasgow currently brings together scientists and researchers from disciplines including Chemistry, Computing Science, Engineering, Geography & Earth Sciences, Mathematics, and Physics & Astronomy.

Academics from the School of Physics & Astronomy are involved in the construction of critical hardware for the LISA pathfinder mission, while researchers in the School of Geography and Environmental Science study the ancient Martian hydrosphere. The School of Computing Science regularly contributes expertise to the EU and NASA on mission-specific risk and considers the cyber security of space critical infrastructures. The School of Engineering is involved in numerous sounding rocket payloads and small satellite systems.

This activity is supported by an array of UK, European and international funding sources, both public and private, amounting to a current portfolio of around £14 million.

Working together, we believe we can do more. Engineering activities can deliver scientific payloads to new locations and new worlds. Chemical research can identify new mechanisms to explain findings made by planetary scientists. Interdisciplinary activities fostered by Space Glasgow will thus provide us with a mechanism to propose new ideas, increase the impact of our space research, and improve the capabilities of the missions on which we work.

We trust that this brochure will provide a clear view of our activities and the synergies between them. As our activities become more interconnected we will be looking outward to new partnerships and hope that you will be able to engage with us in the future.

Prof John Chapman

Head of College of Science and Engineering

University of Glasgow

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Space communications

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Tarantula Nebula. Image courtesy of NASA/ESA

The challenge

Satellite communications is no longer limited to a large satellite communicating with a ground station. Now there are future challenges associated with the ever smaller size of satellites and the possibilities of large swarms of satellites all needing to communicate amongst themselves. This is not unlike the explosion of wireless communication requirements in ground based applications, although the constraints of space based operation require new solutions.

How it is solved

Key requirements for communications include energy efficiency (especially in smaller satellites where battery capacity and solar panel carrying capacity is limited), directivity of radiated radio beams (to avoid both wasting transmitted power and swamping nearby satellites in a swarm with unwanted signals) and compact antenna design so that maximum flexibility is retained in the payload.

Why it is important

Effective communications will underpin the successful operation of satellite swarms, enabling the advantages of this type of mission to be fully realised. These include cost reduction, better survivability (failures are limited to a single swarm element), and better quality data due to larger effective aperture of the collection system.

3D Printing of chemical nanofactories for space and extra-terrestrial manufacturing

Prof L. Cronin

The challenge

To venture into space, via humans or robots, access to the universal chemistry-set available on earth is going to be essential to conduct new science, for repair, and even production of drugs, sensors, fuel, and feedstocks.

How it is solved

The only way to do this effectively is to bring a minimal chemistry set into space that can then be built into more complex molecules, materials, and polymers. The Chemospace project aims to do this in two ways (1) by using a small 3D printer to print the reaction networks and then (2) to print the chemical building blocks into the matrix which can then be reacted in a cascade to give the compound in a pure form on the micro-chemistry-lab.

Why it is important

NASA and ESA have both stated that it is essential to access 'terrestrial' chemistries in space if advanced science / human exploration beyond LEO is going to be possible. This is because drugs, chemicals etc suffer badly in space from radiation damage, high CO2 etc. Also, it may be possible to use a chemical platform to use raw materials on Mars and Moon for fuel, water and/or basic chemical transformations.

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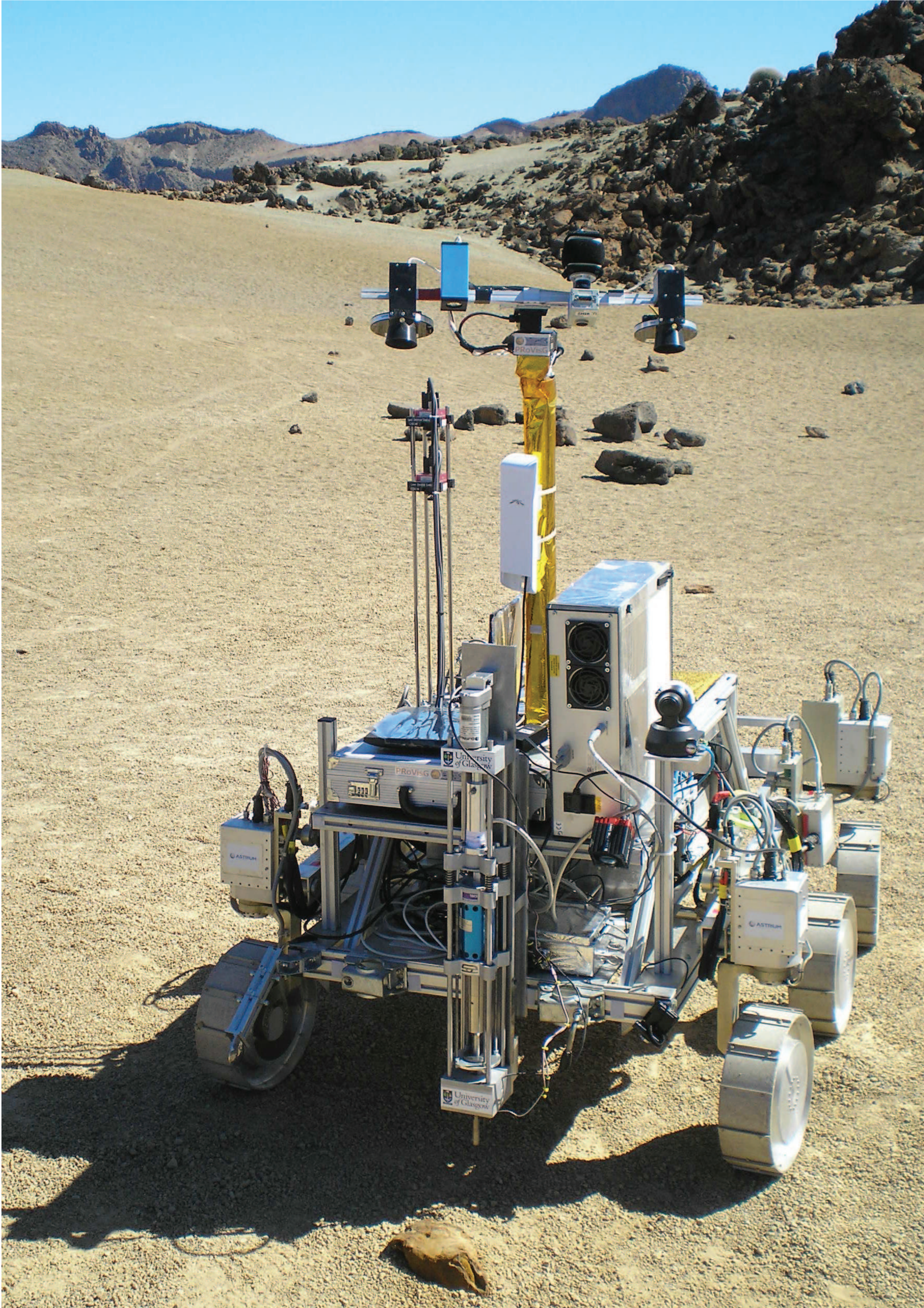
Image courtesy of NASA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Ultrasonic drill tools for planetary exploration

Dr P. Harkness and Prof M. Lucas

The challenge

Drilling on the surface of extraterrestrial planets such as Mars is difficult. The low gravity means that the rover on which the drill could be mounted will appear to have very little weight, which makes it difficult to press the drill firmly against the rock. The next generation of Mars landers will therefore require a new system for drilling into the surface soil, rock and ice.

How it is solved

A Mars drill should have three main characteristics: it should be able to achieve penetration with a low drilling force, it should have low electrical power consumption, and it should have a simple deployment process. To achieve these aims, we use high-frequency ultrasonic vibrations to excite a hammering action in a drillbit rather than pressing the drillbit down from above as in a traditional household drill. This means that the applied forces are lower, less power is required, and the support architecture can be scaled back to simplify the system.

Why it is important

It is thought that in the past Mars was much warmer and wetter than it appears to be today. This means that there could be important evidence of flowing water, or even life, just below the surface. To learn about the planet and solar system's past, future spacecraft will have to use drill tools such as the ultrasonic device we developed to obtain access to these underground areas.

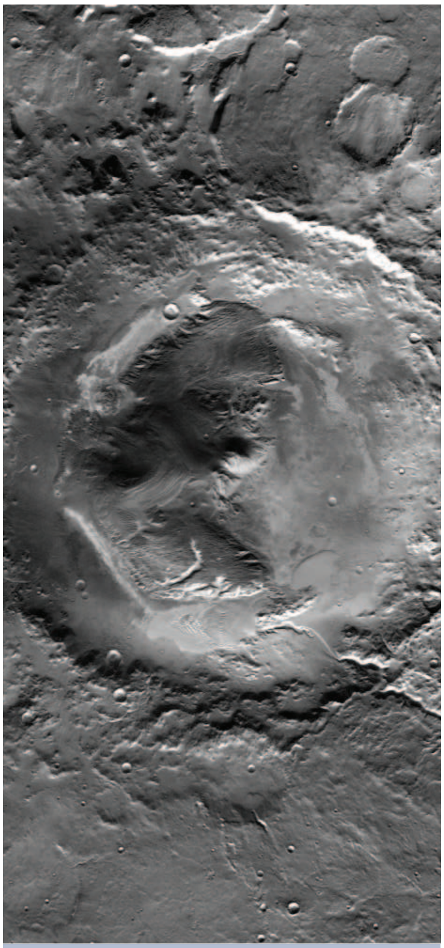

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Image courtesy of NASA/JPL-Caltech/ASU

Aerobrakes for space debris mitigation

Dr P. Harkness

The challenge

Old spacecraft continue to travel at many miles per second, posing a collision risk to active and manned vehicles. Fortunately in low Earth orbit the upper atmosphere is still thick enough to exert a drag force which eventually causes spacecrafts to re-enter and burn up. Providing each spacecraft with a deployable aerobrake to be used at the end of their missions could reduce the duration of this dangerous period.

How it is solved

The aerobrake must be extended from a folded configuration and supported in place by a deployed rigid structure. This is necessary because the thin atmosphere in low Earth orbit cannot support an inflated membrane in the manner of a more familiar parachute system. As the spacecraft starts to burn up, the sprung elements must collapse and allow the aerobrake to fold again. This is essential because the aerobrake would otherwise serve to slow the re-entry process and reduce the thermal loading on the spacecraft. This could result in dangerous debris surviving the fall and reaching the ground.

Why it is important

Space debris in low Earth orbit has the potential to completely close down access to space, because every collision with a debris object produces yet more fragments. If current trends continue, near-Earth space will become too dangerous to cross, so devices such as this aerobrake are needed to remove old spacecraft before they have a chance to fragment due to collisions with existing debris.

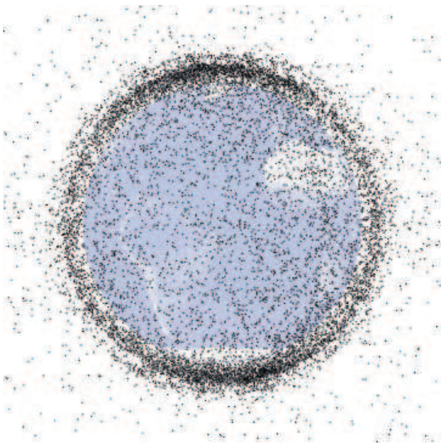

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Image courtesy of the NASA/Orbital Debris Program Office

Diamond electronics for space-based operation and exploration

Dr D. A. J. Moran, Dr S. Russell

The challenge

Research into solid-state based electronics solutions continues to gain momentum as demand for such technology increases. The main challenge is to deliver the next generation of satellite based communications and to address the requirements of future electronic component operation within the harsh environmental conditions of space. Meeting the performance and operation criteria for this technology however requires a unique material system that itself possesses a range of extreme physical properties.

How it is solved

A solid-state based electronics solution able to perform in the specified conditions must be established using a material that will satisfy both the current and foreseeable future performance requirement in terms of high frequency and high power operation. This requirment must be combined with guaranteed long term reliable operation across the large temperature range and radiation intensive environments such components will be exposed to. Of all the currently manufacturable semiconductor material systems available today, diamond remains a unique potential solution to this growing issue due to its unrivalled thermal conductivity, radiation hardness and high frequency/power performance potential.

Why it is important

The European Space Agency has indentified the incorporation of solid-state based electronics as critical for future space based missions and satellite communications. The impact of the development of a suitable technology such as diamond would therefore result in a crucial enabling capability for future explorative space missions but also "next generation" consumer services via advanced telecommunication capabilities in satellites.

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Planck's Space Detectors. Courtesy of ESA (Image by AOES Medialab)

High precision laser interferometry for spaceborne applications

Dr E. Fitzsimons, Prof J. Hough, Dr C. Killow, Mr M. Perreur-Lloyd, Dr D. Robertson, Prof. S. Rowan, Mr A. Taylor and Dr H. Ward

The challenge

Spaceborne experiments that probe subtle gravitational effects often involve picometre-scale measurements over timescales of minutes to hours and over long baselines. Current examples include: 1) LISA, a spaceborne gravitational waves mission which involves inter-spacecraft ranging over millions of kilometres; 2) LISA's precursor technology demonstrator mission (LISA Pathfinder) which requires distance monitoring over tens of centimetres within a single spacecraft, and 3) GRACE II, a proposed follow-on to the GRACE gravity and climate explorer mission, which features inter-spacecraft distance monitoring over hundreds of kilometres.

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Only laser interferometry offers the required precision of measurement required over such baselines.

How it is solved

As part of our longer term scientific goal of playing a lead role in a future LISA mission, our recent work has focused on LISA Pathfinder, for which Glasgow University developed and prototyped the optical bench, the measurement "heart" of the spacecraft. The optical bench is a 20cm square block of low expansion material to which are attached multiple silica mirrors and beamsplitters.

For the component mounting we developed a technique, hydroxy-catalysis bonding, that forms an ultra–strong and dimensionally stable bond but which allows a period of adjustment of component alignment prior to a bond forming.

We also developed component manipulation and beam measurement techniques that allow absolute location of interferometer beams at the 10 micron level, and pointing with better than a few tens of microradian accuracy.

With our custom designed and developed optical fibre systems we have demonstrated excellent interferometer alignment stability over the often harsh temperature, radiation and vibration conditions involved in spaceflight.

As the culmination of this work we have essentially completed the build of the flight optical benches for LISA Pathfinder and we have now embarked on development of the much more complex optical systems that will be required for the LISA mission.

Why it is important

The advent of a spaceborne gravitational wave detector will reveal directly for the first time extreme astrophysical events such as supermassive black hole collisions, enhancing greatly our understanding of the Universe.

Undertaking such technologically challenging projects necessarily requires invention of novel assembly methods and innovative hardware solutions, and applications of our spaceborne interferometry capabilities are expected to grow significantly.

Furthermore we have already seen industrial interest beyond the space sector – e.g. in areas such as high power lasers. Such lasers are of great interest for manufacturing, in defence and for communications.

Suaineadh – Deployment of a spinning space web in a microgravity environment

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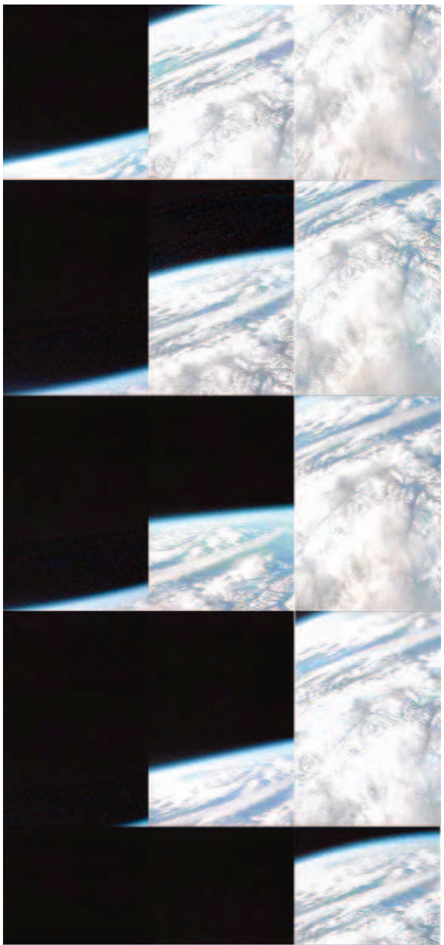

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The challenge

The experiment objectives were to deploy a space web in March 2012 from a spinning central assembly by exploiting centrifugal forces and to stabilise the structure by an active control method. This is achieved using an on-board reaction wheel that transfers angular momentum from the reaction wheel to the central assembly, thus initiating spinning motion. Operational data of the mission is accumulated visually by cameras and by on-board sensors.

How it is solved

In Dec 2010 , the Suaineadh team participated in the REXUS 11/12 selection workshop at the European Space Research and Technology Centre (ESTEC) to compete for a place onboard a REXUS sounding rocket. "The REXUS (Rocket-borne Experiments for University Students) programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA)". The Suaineadh team was successful in winning a place to launch the experiment into a micro-gravity environment in March 2012 from ESRANGE, Kiruna, Sweden.

Why it is important

The technology was developed on a budget of only £30k and is scalable in its design meaning that the same principle could be used to develop much larger structures, whilst reducing the mass/volume normally needed for such projects with obvious benefits. Space webs present a vast range of exciting opportunities including:

- Solar propulsion in the form of solar sails
- Solar energy harvesting with microwave power transmission
- Large scale antennas for delving deeper into the universe
- Scaffolding platforms from which to build larger space structures

Following the successful launch, small packets of data that include images taken from space were retrieved via the wireless link between the ejected experiment and the REXUS 12 rocket. The team will return to the impact site to retrieve the ejected section to carried out more thorough analysis.

Images captured by the Suaineadh experiment from space showing the curvature of the Earth as the module begins to spin up for deployment

New materials for autonomous power systems

Prof D. Gregory

The challenge

Launchers use MEMs based microsensor packs extensively to monitor numerous parameters from launch preparation through launch to flight. Typically these require powers up to 100 mW. Limited cycle life and power densities (<0.1 kW/kg) however restricts existing batteries as a solution. Similarly, satellites require power sources able to operate under extreme conditions (e.g. low temperature). Solutions that provide lightweight and autonomous power for such applications are essential to further technological development.

How it is solved

Either new batteries or alternative power sources are needed if the challenges of the extreme and demanding environments of space applications are to be addressed. Launchers (such as Ariane) require lightweight sensors that can operate at high temperatures whereas satellites demand power sources for usage at the opposite extremes. Our research embraces 3 relevant and complementary technologies; hydrogen storage for micro fuel cells, nanoscale thermoelectrics and new Li-ion batteries. We thus have the means of both harvesting (converting) and storing energy in extreme conditions allowing (a) development of sensors for next generation launchers; (b) prolonged and efficient operation of satellites and deep space probes.

Why it is important

We have the capability, with industrial partners, to provide novel power supplies and devices. Power–hungry systems demand more from materials with reduced weight, volume and increased lifetime. Rates of supply, charge and discharge are crucial and can be revolutionised via nano-materials and device approaches. A step change in thermoelectric efficiency would provide power from heat previously inaccessible. New hydrogen stores provide the means for high-efficiency fuel cells to be exploited in space for the first time.

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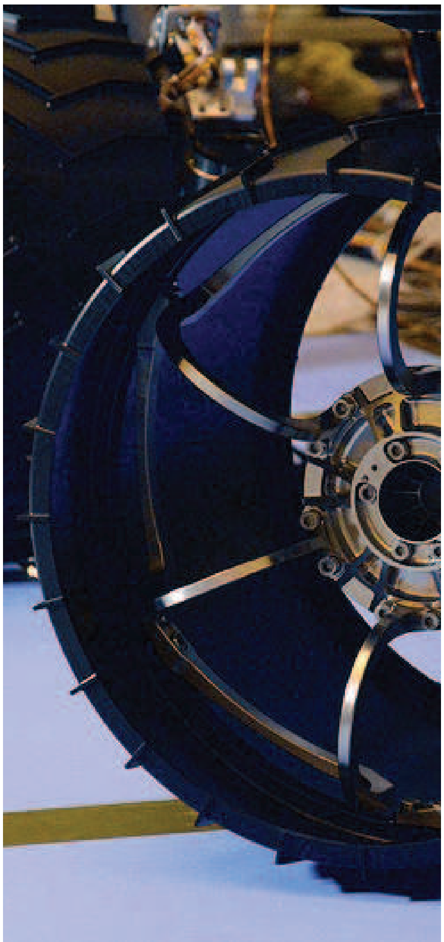
Image Courtesy of NASA

Cognitive binocular vision for space robotics

Dr J. P. Siebert, Dr W. P. Cockshott, Mr G. A. Camarasa, Mr M. Dooner



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The challenge

The expense and hazards of space travel and sheer distances involved (with associated communications lags to Earth) have driven the need for launching wholly autonomous robot controlled missions.

Real-time visual perception by machine is a key ingredient required to control planetary rovers or other time-critical operations such as spacecraft docking spacecraft to allow these autonomous systems to "see what they are doing".

How it is solved

Our current work in the School of Computing Science exploits a combination of algorithms that mimic aspects of human visual perception, including space-variant visual sensing (foveation), to model feature extraction and construct visual representations that drive visual search behaviours based on both reactive and deliberative (cognitive) control mechanisms.

Why it is important

Reliable and sophisticated cognitive vision systems will underpin advanced robotics systems capable of undertaking complex mission that require flexible responses to unpredictable circumstances. Examples are how to learn the appearance of a landing site to allow this to be reliably navigated by a rover or how to control the operation of a manipulator to allow visual interaction with samples identified and collected during a mission. Similarly in-transit missions such as robotic inspection of spacecraft exteriors and subsequent repair or adjustment becomes possible only when supported by advanced visual sensing.

Curiosity's Rover Wheels. Image courtesy of Robert Z. Pearlman/SPACE.com

Spacecraft attitude estimation and control

Dr J. Kim, Dr Y.-B. Zhao, Mr A. Pollock

The challenge

Almost all existing spacecraft attitude estimation and control algorithms are based on linear dynamics. The algorithms introduces the practical hard limitations in the spacecraft attitude manoeuvre and thereby the nature of missions to be accomplished. Unified framework for designing robust and yet optimal algorithms for fast attitude reorientation or tracking manoeuvre is still an important open problem.

How it is solved

Our approaches are inspired by biological systems, which are processing massive measurements in real-time. Many researchers have suggested non-linear control and estimation algorithms. Because of the large amount of data to be processed and the computational high demand, however, the real-time applications were not very successful and most previous work has been focused on how to reduce the required calculations. In our approach, we take a rather different direction, by maximising the amount of data to be fused by using the parallel processing capability.

Why it is important

It is quite noticeable that whenever we watch space mission, all movements are extremely slow unlike the ones in scientific fiction movies. Unless we solve these issues from the inherent non-linearities in spacecraft dynamics, all future space mission would be stuck in the current limitation. We are at the right time to almost solve these problems using the computational power, which has been increasing exponentially fast for the last decades.

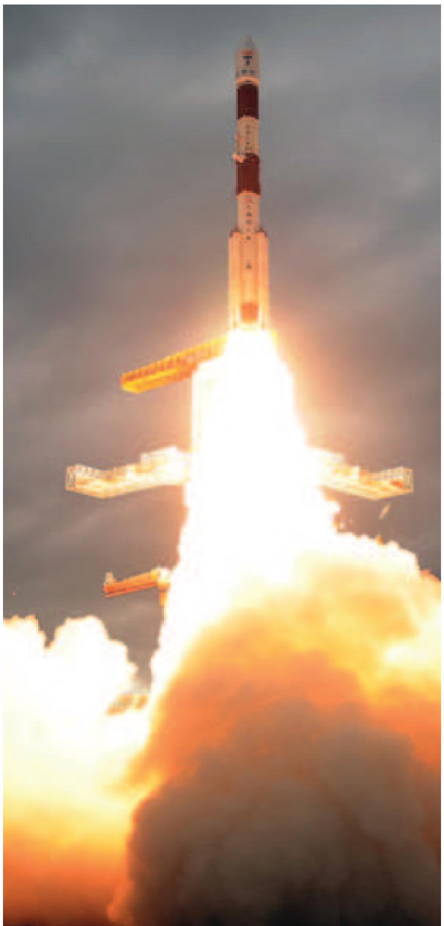

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Image courtesy of India Space Research Organization

Asteroid deflection and exploitation

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Image Courtesy of NASA

The challenge

In the last 50 years astronomers have discovered a vast number of small asteroids orbiting the Sun. A tiny fraction of these objects follow trajectories, which bring them near to the Earth. These Near Earth Objects, which travel at very high speeds relative to Earth, range in size from pebbles to kilometre-sized objects. Such objects have collided with our planet since its formation and have contributed to shaping life on Earth. Near Earth Objects represent a huge risk to human kind, but no near term means to mitigate the consequences of such impacts currently exists. This threat raises major issues: among them the inadequacy of our current knowledge of the orbits of such bodies, confirmation of hazard after initial observation, disaster management and communication with the public.

How it is solved

For the first time in the history there are possibilities for mitigating or removing the risks of Near Earth Objects impacting the Earth. This depends on first improving our ability to detect such objects well in advance and to accurately measure their orbital parameters and physical properties. There is however very little work being carried out both at national and international levels on the techniques and technologies necessary to investigate mitigation and threat removal possibilities. The only realistic course of action to avoid the devastating consequences of a large object impacting the Earth is to avert the predicted collision. A number of possible mechanisms have been proposed for deflecting or breaking up potentially hazardous Near Earth Objects; some require the use of a spacecraft with some means of transferring energy and momentum to the object while other methods would be to fly, for months or even years, a large spacecraft alongside the object, nudging it slightly off its collision course. We are also investigating the use of lasers to create mass ejecta and a change in the asteroid's trajectory.

Why it is important

Near Earth Objects interception and hazard mitigation has been recognised as a key issue for the safety of life on Earth. This research will respond to this requirement and, by exploring new ideas and concepts, and develop methodologies which will allow the interception and deviation of potentially hazardous NEOs by future spacecraft.

Solar power satellites

Dr G. Radice

The challenge

Reliable energy supply, capable to meet ever increasing demands, is of fundamental importance for prosperous and peaceful worldwide development. United Nations figures, suggest that the current world population of nearly six billions will approach ten billion by 2050, with the bulk living in developing and transitional economies. In this context, even the most constrained economic growth scenarios project an increase of at least 50% in the energy consumption by 2050, over 1990 values.

How it is solved

The solar power satellite (SPS) is conceptually very simple: a large satellite designed to act as an electric power plant in orbit. It consists of three main segments: a solar energy collector to convert the solar energy into direct current (DC) electricity, a DC-to-microwave converter, and a large antenna which beams the microwave power to the ground. The solar collector can be either photovoltaic cells or solar thermal power generation. The DC-to-microwave converter can be either a microwave tube system and/or a semiconductor system, or their combination. The third segment is a gigantic antenna array. The overall SPS system includes, other than the spacecraft, a ground power receiving station. The latter, which uses a rectenna (rectifying antenna) to receive and rectify the microwave power beam and convert it back to DC power, is connected to existing electric power networks.

Why it is important

Renewable and alternative sources of energy, such as wind and wave turbines yield relatively low power return, nuclear power is fraught with political issues, and solar energy is limited by cell efficiency, the natural day/night cycle and the Earth's atmosphere. In contrast to existing renewable power sources, solar power from space is highly promising in its 24 hours power supply capability and CO2 clean nature as a new energy system that can guarantee sustainable development of our planet. In space, collection of the Sun's energy is unaffected by the various obstructions which reduce efficiency or capacities of Earth surface solar power collection. Extraterrestrial solar irradiance is thus 144% of the maximum terrestrial irradiance, and the solar collection panels can be exposed to a consistently high amount of solar radiation.

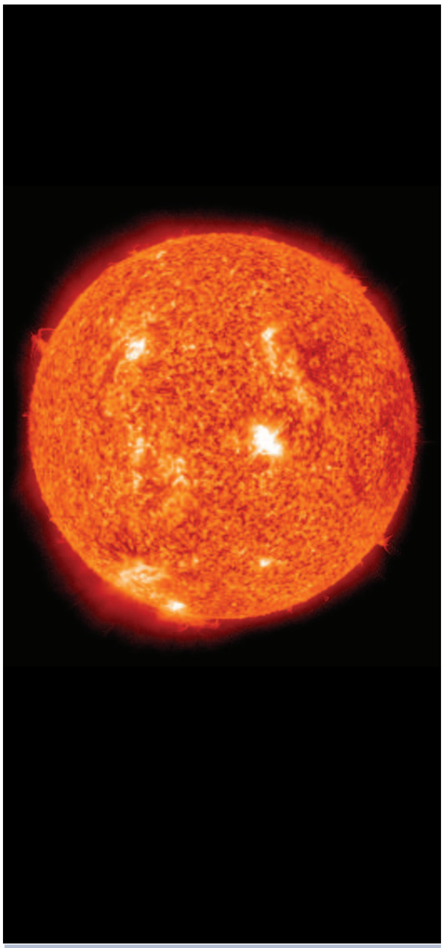

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Image Courtesy of NASA

Dynamics and control of formations of large, lightweight spacecraft

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The challenge

Spacecraft formations need the correct positioning of each spacecraft with respect to the others, in terms of orbit and attitude. This requirement leads to challenging control and station-keeping problems. When large, lightweight spacecraft are employed, the effect of solar radiation pressure (SRP) becomes comparable to the gravity, increasing the complexity of the orbital and attitude dynamics of the formation. Therefore, design of such constellations requires consideration of these effects.

How it is solved

This study investigates the dynamics and control of large, high area-to-mass ratio spacecraft formations with SRP. Our research explores novel constellations that are enabled by the presence of SRP. This includes formation flying on large-amplitude, libration-point orbits in the Sun-Earth and Earth-Moon systems and displaced orbits around small bodies (asteroids and comets). It also investigates the attitude and orbital control of such formations, by exploiting the pressure of the photons impinging on large surfaces covered with photo-chromic materials. Since no propellant is required, as opposed to traditional thrusters, the mission lifetime is extended. Smart and autonomous reconfiguration of the formation is also investigated, in order to accomplish different mission goals, and cope with contingencies.

Why it is important

The full understanding of the dynamics is essential for the design of future missions. Several scenarios for asteroid deviation and exploitation require a number of large solar reflectors orbiting around the asteroid itself. Some of the solar power satellite designs involve the use of multiple large mirrors, concentrators and collectors, whose positioning needs to be accurately controlled. Finally, the constellations can serve for space weather monitoring and global Earth observation.

The Progress 42 Vehicle Departs the International Space Station. Image courtesy of NASA

Optimisation of hybrid high/low thrust trajectories

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The challenge

Solar electric propulsion (SEP) is a modern technology that provides a relatively low thrust to a spacecraft with high specific impulse. Conventional chemical propulsion, instead, is less efficient, but can achieve higher thrust levels, therefore offering impulsive velocity changes and fast orbital transfers. The combination of the two systems on the same spacecraft could potentially offer the advantages of both, with the capability to use the appropriate thruster in each mission phase.

How it is solved

The research studies techniques for optimal design of hybrid high/low thrust trajectories. In conventional spacecraft, where a single propulsion system is used, the standard approach to trajectory optimisation usually involves the simultaneous minimisation of the total velocity change, the transfer time and some other constraints. However, the problem is more complicated when different technologies are used. An additional task is to select which propulsion system to use in each mission phase. Furthermore, the optimisation problem becomes multidisciplinary, as it involves the simultaneous design of the trajectory and the sizing of the two propulsion systems, with the overall aim of minimising the launch mass and transfer time.

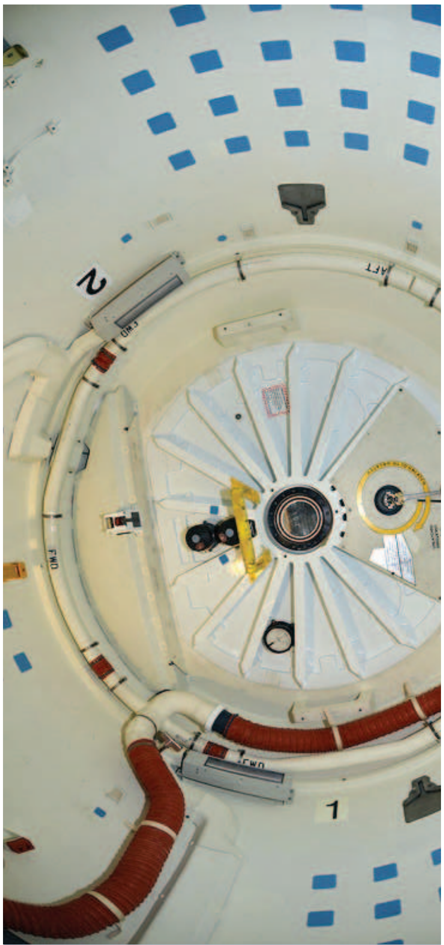
Why it is important

This novel type of hybrid propulsion technology opens the way to new mission scenarios. For example, low-thrust propulsion can be used for long, interplanetary transfer phases, with significant propellant saving. Injection into target orbit and subsequent orbit transfers are then performed with high-thrust chemical engine, when a single impulse is necessary. An automated tool can identify optimal hybrid trajectories in more complex mission scenarios, for example in multi-body problems.

Image courtesy of NASA

National and international resilience to the failure of space infrastructures

Prof C. Johnson



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The challenge

Space based systems now form a core component for national critical infrastructures. GPS and GLONAS provide location and timing information for a variety of uses from Unmanned Airborne Vehicles, to electricity distribution and road traffic management systems. However, these systems are very vulnerable to physical and cyber attacks as well as to accidental faults. End users are typically unaware of the threats identified to satellite based infrastructures and this creates enormous vulnerabilities.

How it is solved

Together with NASA, the European Space Agency and the United States Air Force Space Command, we have developed tools that help the end users of space based systems to assess the likelihood and consequences of failure to their operations (military or civil). This is a unique initiative and Scotland is 'world leading' in this area. For example, we have been working with the safety teams using satellite location and timing information to assist precision approaches to European airports to identify a range of potential vulnerabilities.

Why it is important

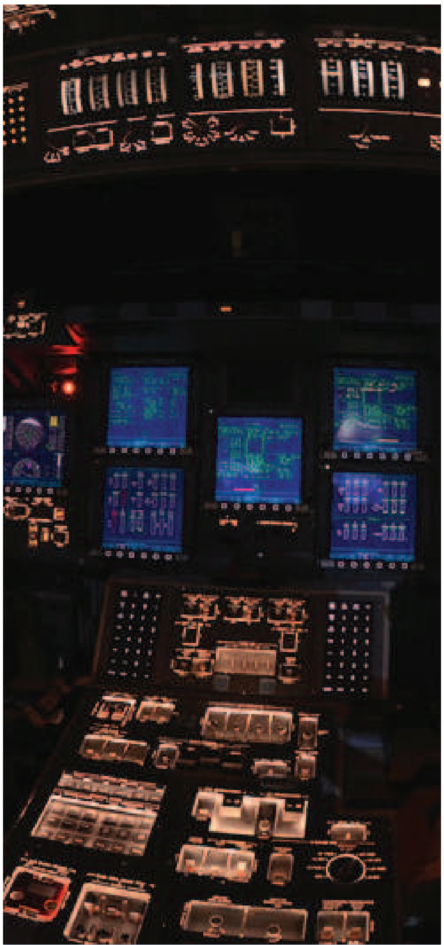
National critical infrastructures depend on space based systems. The European Commission recently certified EGNOS extensions to GPS for Safety of Life services. For example, EGNOS can increase the capacity of rail networks by using the exact location of trains to control signals rather than closing off large sections of track every time a train passes. The consequences of failure in this and the aviation examples, cited above, are obvious.

Last Look Inside Space Shuttle Atlantis. Image courtesy of © collectSPACE/Robert Z. Pearlman

Russian Cosmonaut Anton Shkaplerov outfitting the International Space Station. Image courtesy of NASA.

Accident and incident investigation for space-based systems

Prof C. Johnson



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The challenge

Space is a 'high-risk' business. However, many missions fail to learn from previous failures. This can be illustrated by the common causes between the Mars Polar Lander and Beagle 2 missions.

It is very difficult to identify these common causes and to anticipate that they might affect a future mission. Space systems often fail from complex interactions between software issues, hardware faults, navigation and environmental constraints.

How it is solved

Together with teams from NASA, the European Space Agency and the US Air Force we have worked for 20 years to identify techniques that assist in mishap investigations for space based systems.

The intention is to identify a wide range of root causes and contributory factors so that engineers can learn lessons from previous failures. Much of this research was motivated by the Columbia and Challenger tragedies.

A key requirement has been to develop analytical tools that can trace how faults develop between multiple private companies who increasingly must work together on complex space missions, following the Obama funding reforms.

Why it is important

We have worked with the NASA Shuttle and International Space Station teams and the ESA human space flight groups.

An innovative feature of our work is that we are using information about previous failures to assess risks for future missions.

For Mars missions, we built software to help the crew cope with on-board systems faults during the 90 minutes that it would take radio communication to reach ground control. These techniques can also be used to identify failure modes for conventional satellite operations.

Last Look Inside Space Shuttle Atlantis. Image courtesy of © collectSPACE/Robert Z. Pearlman

Cyber-security for space based systems

Prof C. Johnson

The challenge

Space-based systems are a core component of national critical infrastructures. This is illustrated by the increasing use of satellite communications systems and by the range of industries that now rely on location and timing services from GPS etc.

Software is at the heart of all complex, space-based systems. Both the space based and ground based components are vulnerable to cyber attacks.

How it is solved

Our work focuses on the development of protection and mitigation techniques against cyber attacks on space based systems. Some of the techniques are relatively simple, for instance through the application of conventional security management techniques. Others are more complex, focusing on intrusion detection and pattern identification for a range of security threats. This work is informed by involvement in the analysis of previous attacks against both civil and military applications. A unifying feature of our work is the need to coordinate, document and critically assess security concerns across the development and operational lifecycle of space systems.

Why it is important

Both the UK and US military have suffered recent attacks on their space-based infrastructures. Most incidents have involved the transfer of 'conventional' viruses typically from USB sticks to mass-market operating systems (eg Linux) during periodic updates. However, the STUXNET attacks and the coordinated denial of service on Georgian infrastructures justifies greater focus on this area, which is very much in its infancy and is currently addressed by only a handful of research teams in the world.

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Last Look Inside Space Shuttle Atlantis. Image courtesy of © collectSPACE/Robert Z. Pearlman

Space geodesy for land subsidence hazards

Dr Z. Li

The challenge

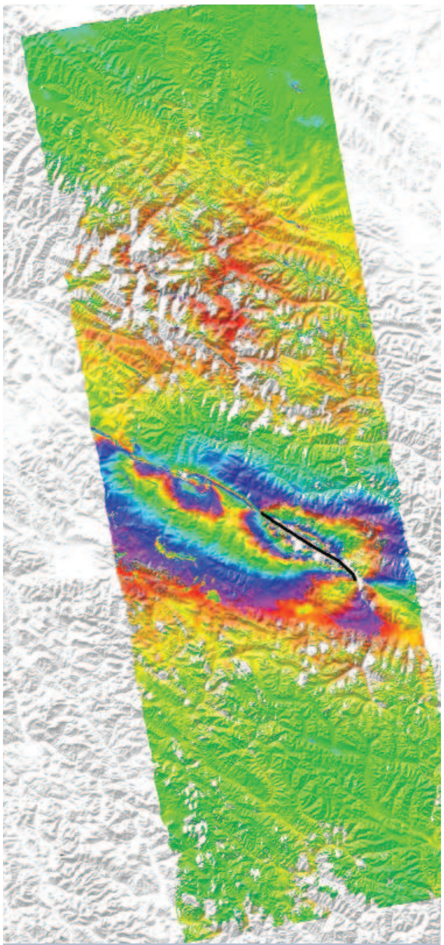
Land subsidence is a major worldwide hazard that can result from natural processes such as landslides, earthquakes, and volcanoes, or from anthropogenic processes including extraction of groundwater, oil and coal.

How it is solved

Interferometric Synthetic Aperture Radar (InSAR) uses phase changes between two complex (magnitude and phase) radar images over a given area taken at different times to make an interferogram that measures the component of the surface displacement in the radar line of sight with millimeter precision over a wide area (e.g. 100km x 100km). We are developing advanced InSAR techniques (e.g. atmospheric correction models and time series algorithms) to improve the accuracy and reliability of InSAR for deformation mapping.

Why it is important

Space geodesy provides accurate data in support of basic research in the monitoring of land subsidence hazards, and leads to a better understanding of them. In the long term, this research not only benefits the safety of the general public but also sustainable economic development.



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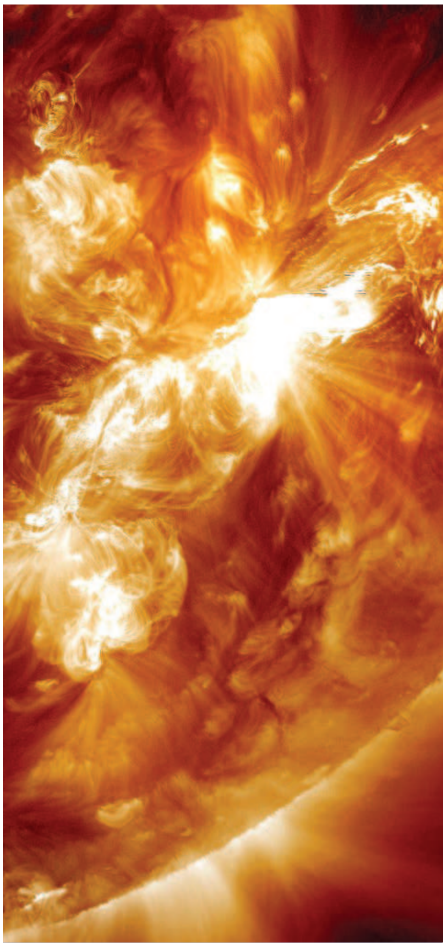
Solar-flare forecasting with multi-wavelength data

Dr L. Fletcher, Dr N. Labrosse



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The challenge

Major space weather events have their origin in activity on the Sun. Solar flares and coronal mass ejections can cause damage to space hardware, and also to terrestrial systems such as power distribution. Can we learn to predict flares and ejections well enough to give useful warning?

How it is solved

Understanding and predicting solar activity involves a combination of mathematical modelling and analysis of data taken in many wavelengths of radiation: both present huge computational challenges. Focusing on observations, the task is to automatically detect, measure and characterise features such as sunspots, prominences, and coronal loops in multi-wavelength images of solar active regions (digital image processing); to analyse the relationships between features, their evolution, and the occurrence of activity (synthesis); and finally to interpret these in terms of robust physical rules which have predictive power (theory).

Why it is important

Forecasting the space weather is as important to satellite operators as forecasting the terrestrial weather is to airlines or shipping companies. The ability to identify the early signs that a flare or ejection will happen, or being able to give a robust likelihood that a given region on the Sun will produce a flare, gives additional warning time of major events, and can inform operational strategies for space hardware.

M9 Solar Flare, January 23, 2012. Courtesy of NASA/SDO and the AIA Consortium/Edited by J. Major

Numerical models of stellar and planetary dynamos

Dr R. D. Simitev

The challenge

Stellar and planetary magnetic fields, including the best known geomagnetic field, are among the most notable properties of stars and planets and play a crucial part in a variety of cosmic processes. The established theory of the nature of these magnetic fields is that they are generated by a dynamo process driven by convection in the fluid regions of planets and stars. These regions are inaccessible for direct observations, e.g. the Earth's fluid outer core where the geomagnetic field is generated is located at some 2800km below the surface of the planet. Self-consistent numerical models are thus one of the very few methods available to obtain key insights into the convection-driven dynamo process as well as into a myriad of other aspects of stellar and planetary structure and dynamics where many questions still remain open.

How it is solved

In the last 10 years, we have developed cutting-edge numerical models and expertise in simulation of geo- and planetary magnetic fields. We solve the fully nonlinear magnetohydrodynamic equations, derived from first-principles without ad-hoc turbulent and transport models. Although restricted to moderately turbulent regimes by the computing power available at present, this approach is desirable for its self-consistency. By studying the parameter dependences and the basic physical mechanisms of the convection and the dynamo processes, we hope to achieve a meaningful extrapolation towards the turbulent regimes of actual stellar and planetary magnetic fields.

Why it is important

While the state-of-the-art models still fall short of resolving the full details of the geo-, planetary and stellar magnetic fields, it is essential to keep building up capability in this area. For instance, the presence of the geomagnetic field has broad implications for life on our planet. It shields Earth's surface from harmful incoming radiation and protects the many man-made satellites orbiting the planet. Geomagnetism has been long used as a navigational aid by humans and animals and has fascinated people since antiquity. Similarly important are the studies of solar magnetism, which is so strong that it controls much of the visible solar activity, and of planetary magnetism, which can tell us much about the geology and the formation of planets.

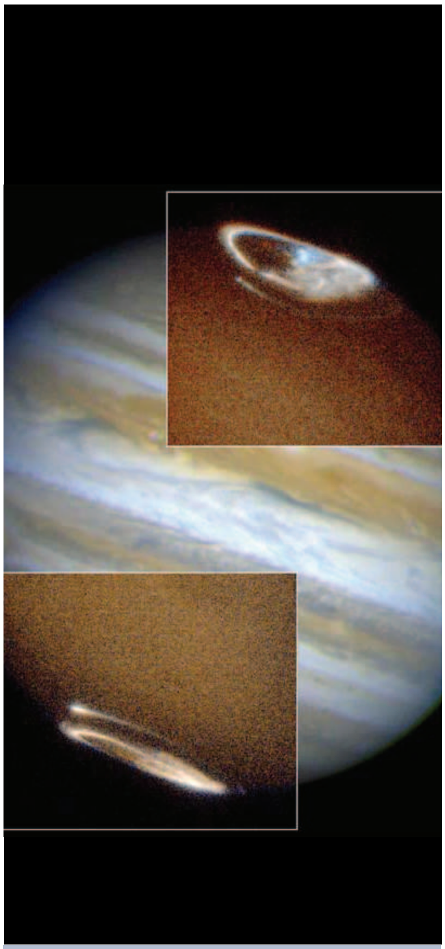

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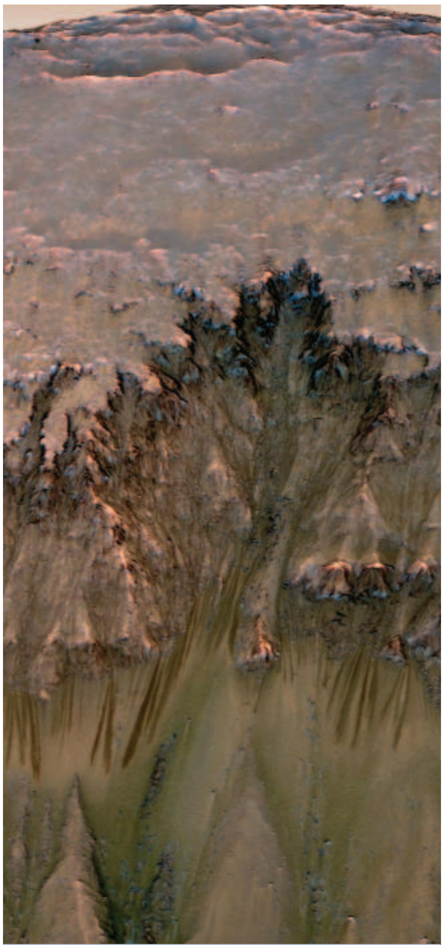
Image courtesy of NASA

Extraterrestrial hydrology: the history of water on Mars

Dr F. Stuart, Dr D. Mark, Dr T. Tomkinson



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The challenge

There is now abundant evidence that free water once flowed across the surface of Mars. The origin and nature of this water remains obscure. When was free water present? Where did it come from? What caused hydrological systems to be established and how long did they exist for?

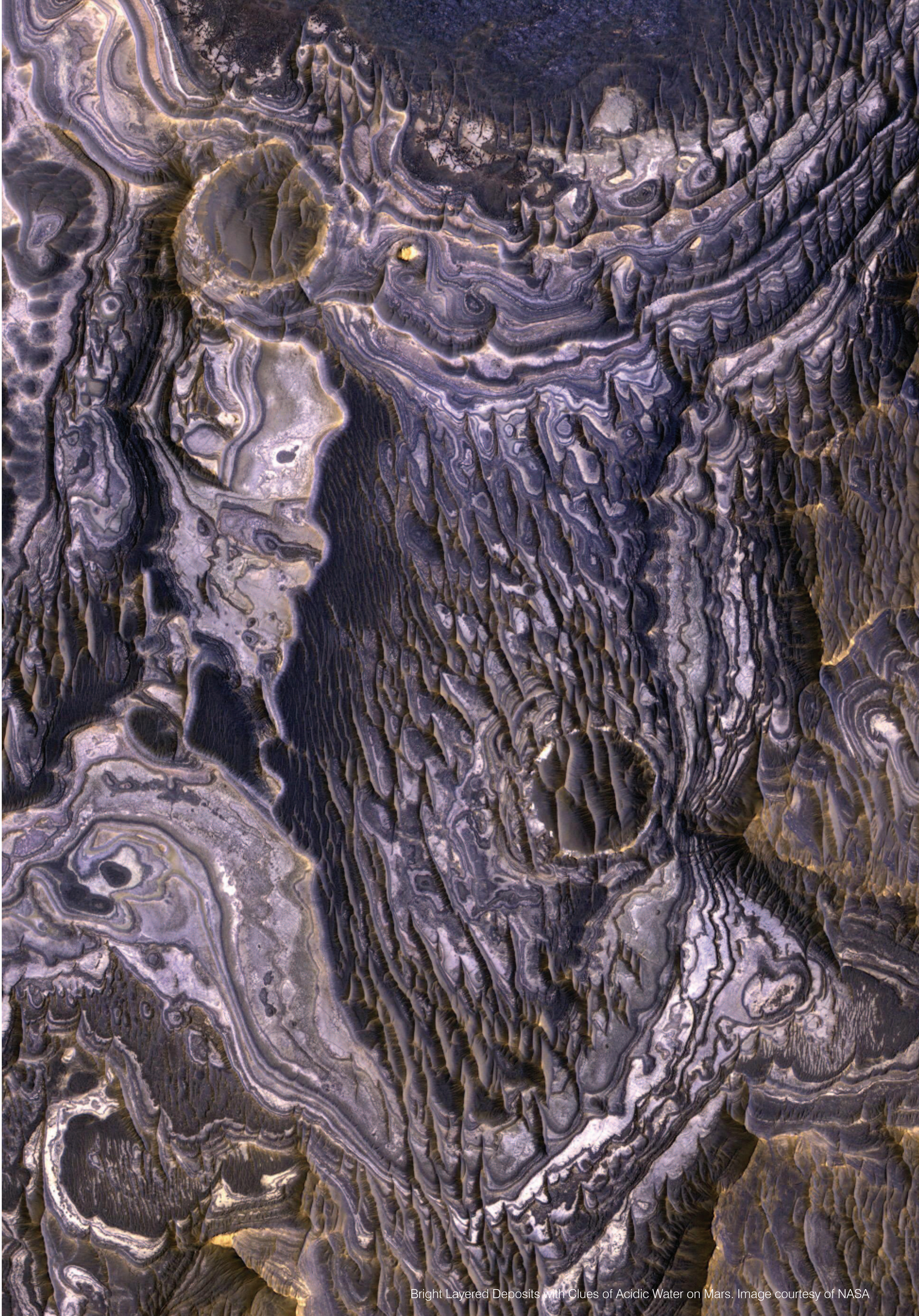
How it is solved

Fragments of rocks from Mars have been delivered to Earth in the form of meteorites called nakhlites. These contain microscopic evidence that hot water once flowed within, as well as on, the Martian rock surface. We aim to study the history of hydrothermal systems on Mars by analysing the fluid bubbles trapped in minerals and the clays produced as the rocks reacted with the high temperature water. We are using atomic-scale high-resolution microscope techniques and high precision isotope techniques to trace the source of the water and determine when, and for how long, it flowed.

Why it is important

Whether life exists beyond Earth remains an enduring question. Water is essential to the development and maintenance of life, and understanding the history of water reservoirs on solar system bodies such as Mars, and their satellites, is a first step is to identifying suitable extraterrestrial habitats.

Oblique View of Warm Season Flows in Newton Crater, Mars. Image courtesy of NASA.



Bright Layered Deposits with Clues of Acidic Water on Mars. Image courtesy of NASA

Solar and heliospheric physics: energetic particles from the Sun to the Earth

Dr N. H. Bian, Dr I. G. Hannah, Dr E. P. Kontar, Dr A. L. MacKinnon

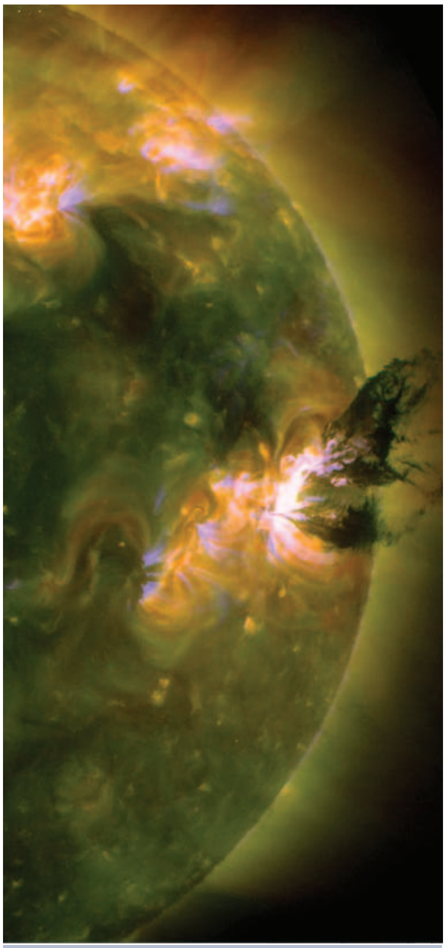


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Image courtesy of NASA/GSFC, LMSAL and SDO/AIA

The challenge

Our current understanding of the Universe owes much to observations of energetic particles and their emission signatures. Solar activity is one of the natural phenomena producing these energetic particles. However, it is still not clear how these particles energise, how they escape the solar atmosphere and how they travel from the Sun to the Earth and beyond.

How it is solved

Over the last decade or so, a fleet of Sun-observing satellites has provided us with unprecedented data, bringing invaluable observations but also posing new questions. Our group, in collaboration with colleagues from the US, Italy, France and Switzerland is conducting an integrated research programme in solar flare energetic particles. Using X-ray, radio and in-situ data strengthened by numerical modelling we investigate the physical processes related to energetic electrons in a quantitative manner. We utilise space-based remote sensing solar observations, in-situ particle observations and ground-based radio data to better understand the fundamental physics of collective energetic particle-plasma interactions in the heliosphere and to build a unified scenario for energetic particles.

Why it is important

The Sun is the main source of energy in our planetary system and is the major driver of heliospheric and geophysical processes. These processes affect ground-based and space-based human activities. We are trying to understand how solar flares work and how our star affects our civilisation's activities.

The Sun: our astrophysical accelerator laboratory

Dr N. H. Bian, Dr L. Fletcher, Dr I. G. Hannah, Dr E. P. Kontar, Dr A. L. MacKinnon

The challenge

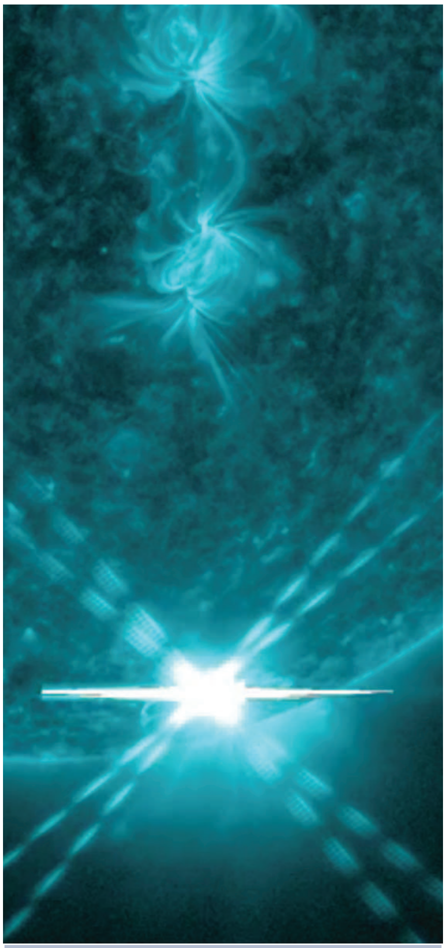
The Sun is the most prolific accelerator of particles in the solar system, able to rapidly increase a particle's energy by many orders of magnitude. Such impulsive bursts of energy (solar flares) produce intense radiation and power space weather. Yet we do not understand many basic properties of the physical processes involved or the specific conditions that trigger the onset and control the evolution of the acceleration.

How it is solved

As the Sun is our closest star we are able to carefully study particle acceleration in solar flares using both ground and space-based telescopes with unprecedented spatial and temporal resolutions. The rapid energy release in flares results in emission that covers a wide spectral range from radio, through optical, to X-rays and gamma-rays, and reveals the accelerated particle spectrum. Using detailed observations, the latest data analysis techniques and advanced computational simulations Glasgow researchers are leading international collaborations to deduce the underlying energy release and acceleration processes.

Why it is important

Understanding how energy is released and particles accelerated in the Sun informs us not only about the mechanisms behind solar flares but also fundamental plasma and high energy processes throughout the universe. These processes are ubiquitous, from black holes in distant galaxies to fusion laboratories on Earth, which are trying to recreate the power source of the Sun and stars to provide a future renewable energy resource.



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UV View of the Aug. 9, 2011 Solar Flare. Courtesy of NASA/SDO/GSFC

Water and life in the solar system

Prof M. Lee, Dr P. Lindgren, Dr V. Phoenix, Dr J. Bendle

The challenge

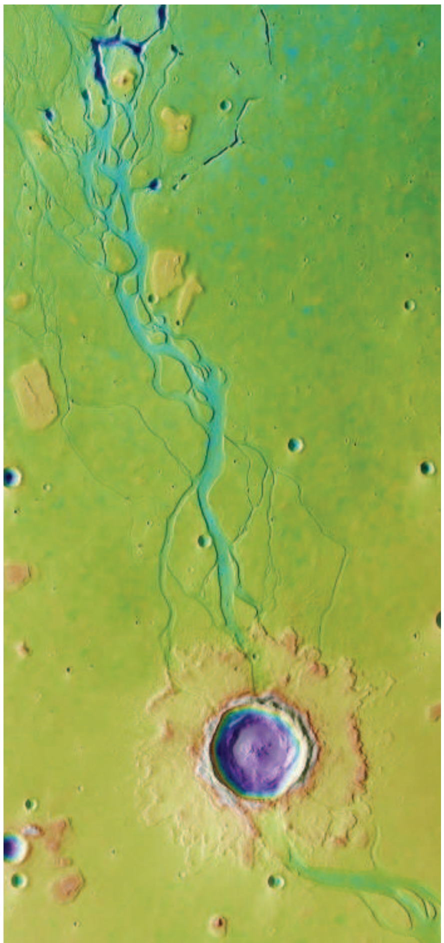
Research in Geographical and Earth Sciences focuses on two related questions: (i) Where and when was liquid water present in the Solar System? (ii) Were these aqueous environments suitable for the evolution and subsequent survival of life? This work currently focuses on primitive asteroids, Mars and martian analogue sites on Earth.

How it is solved

Evidence for the former presence of liquid water within asteroids and the crust of Mars comes from the identification of hydrous minerals within meteorites, and their crystallisation ages are then determined by isotopic analysis. Whilst water is a prerequisite for life, our assessment of its potential presence beyond Earth is informed by analysing samples from analogous terrestrial environments (e.g. low temperature and high altitude sites in the Chilean Andes) for microbial life and preserved organic molecules (biomarkers).

Why it is important

An understanding of the history of liquid water and the conditions under which microbial life is viable is a critical input for models of the early history of the solar system and the evolution of life on Earth. Results of this work are also highly relevant to interpretation of results from recent commetary, asteroidal and planetary orbiters and sampling missions in addition to the planning of future planetary exploration.



Hephaestus Fossae ortho-image. Image courtesy of ESA/ DLR/ FU Berlin (G. Neukum)

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