Protection of Telecommunications and Navigational Satellite Operations (SATPRO)

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FP6 Thematic Priority: 1.1.4 Aeronautics and Space
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1. Vision

Our goal is to build a world leading European integrated project that will mitigate the effects of space environment on the design and operation of spacecraft used for telecommunications and navigation through scientific research, analysis, modelling, and real-time risk prediction.

2. Background

During 2000-2001 the European Space Agency commissioned a European Space Weather Programme Study. Our consortium, led by Alcatel Space, conducted a user survey to identify problems associated with Space Weather originating from the Sun, interplanetary medium and the Earth's space environment. We identified several key industries that are affected, including the design, launch and operation of spacecraft, and proposed a programme of research, analysis, modelling and prediction that could help these industries. The proposals were accepted by ESA in 2001. The results were also presented to the EU (January 2002) who encouraged us to apply for FP6 funding.

3. Need and Relevance for Europe

The design, construction and operation of geostationary telecommunication spacecraft are major industries in Europe. For example, in telecommunications the total annual market is expected to grow from US$20B to US$100B over the next ten years [UK House of Commons Select Committee Report, 2000]. In addition, the EU recently announced the funding of the Galileo global navigation system consisting of 30 spacecraft. This will provide opportunities to develop new space based services and will stimulate European expertise in satellite design, construction and operations.

The European space industry face considerable challenges to design and operate spacecraft that can withstand the adverse effects of the Sun-Earth system. There are five main areas of need

- All geostationary telecommunications spacecraft must be designed to withstand the harsh radiation environment in the Earth's outer radiation belts. In addition, the Galileo spacecraft will pass through the heart of the radiation belts at an altitude of approximately 23,000 km. These are very hazardous regions. US prime contractors have an advantage of designing a large number of military and GPS spacecraft for these regions and therefore have more experience than European prime contractors. The key is to provide enough protection from the radiation environment without a costly over-design. Our proposed research to understand and model the radiation environment will help improve the competitiveness of European design teams.

- All spacecraft are subject to problems that affect operations, known as satellite anomalies, due to the radiation environment. In many cases their effects are small, but in a few cases they can cause catastrophic failure. The radiation environment is highly variable and this variability is a major risk factor. Research assessment of past events, and real-time prediction and warning can be used to help operators take action to mitigate the effects and improve operational reliability.
- The reliability of satellite navigation signals is of the utmost importance for safety critical systems such as aviation (aircraft landing) and search and rescue. All satellite navigational signals pass through the ionosphere, which can cause an error in position and loss of signal through phase and amplitude scintillation. Ionospheric effects are an important problem at high latitudes (e.g., latitudes north of London) and particularly in the equatorial region where they can affect signals from low elevation spacecraft across Europe. Existing single frequency systems such as the European EGNOS require better models of the ionosphere. Dual frequency systems such as Galileo will still be subject to amplitude and phase scintillations that may affect system integrity. Our research, to measure and quantify these effects, can also provide real-time prediction and complementary warning information for safety critical users so that alternative systems can be used.
- The proposed project would allow a better definition of the Galileo working environments. This would consolidate the service performances in view of certification of navigation services for safety-of-life users. In addition, a direct interface with Galileo would complement and improve the Galileo user ionospheric environment models assumed in the system definition and used during validation. Satellite environment models are still not frozen in Galileo and need a careful consideration due to their impact on performance.
- Current developments, such as Galileo, provide a unique opportunity to:
  - embark simple equipment that can further extend the sources of data on the radiation environment in the Earth's radiation belts.
  - Obtain very accurate satellite ephemeris and understand the effect of radiation environment on satellite orbits.
  - Develop better orbit determination algorithms, capable of coping with anomalous radiation environments. This is a first step for Galileo orbit determination improvements in future upgrades. Other system such as IGS could benefit from it.

4. Objectives

We have built a European team that will focus on the following objectives:

- To identify the most important risk factors on the design and operation of spacecraft due to
  - The sun
  - The Earth's trapped radiation
  - The ionosphere
- To predict periods of enhanced risk for satellite operators and safety critical users
- To develop new research models, understand physics, and test new theories
- To assess the way to measure the radiation environment through Galileo
- To provide a source of expert information

5. Integration of Research and European Business

In order to enable best satellite design and best operations it is essential to identify the problems correctly. Although research scientists have considerable expertise, our knowledge does not extend to the needs of the commercial world. Our proposal will bring together a major European satellite prime contractor (Alcatel Space), associated with the largest satellite operators world-wide (SES Global, EUTELSAT, HISPASAT, …), the designers of the Galileo system (Galileo Industries), small and medium size enterprise in market research (ESYS), and key European research Groups. The companies will help define the problems, help focus research, provide data, and help evaluate the usefulness of research products. In return they will receive expert information, training, understanding and products useful to their operations.

6. Research Elements

For satellite design we propose analysing databases of satellite anomalies from commercial companies within the consortium (and others from Europe and the USA) in relation to variability on the sun and the Earth's radiation environment. This will enable us to determine the major risk factors. We will also apply the mathematics of extreme events to determine the worst-case scenarios.

For satellite operators we propose developing real-time prediction models to predict periods of enhanced risk for satellite operations, due to the sun, interplanetary space, and the Earth's trapped radiation. Predictions will be given direct to the operations rooms via the web for immediate action. Given warning of hazardous events, satellite operators can take a series of measures. For example, they can have more staff available to deal with problems, curtail non-routine operations, make back-up systems immediately available, shut down non-essential systems, or use alternative systems.

For safety critical users of global navigation systems, we propose measuring the disruption of global navigational signals at different locations within Europe to determine the intensities, duration, and day-to-day variability of signal disruption due to ionospheric effects. We propose developing models to predict periods and locations at risk using existing scientific radars and satellite observations. These results will be provided to the operators of global navigational signals to assess the system integrity.

Our prediction models and analysis tools will be research products for the end user.

Our existing capability only enables prediction for one hour ahead or so. To achieve longer prediction times would be a major break-through. To achieve this we propose research to understand the pre-cursors of events at the sun and the Earth. The objectives of our basic research are:

- To determine the pre-cursors for major solar transient events that cause solar energetic particle acceleration at the sun, and in the solar wind
- To understand and model the propagation processes of energetic particles and ejecta from solar transients towards the Earth
- To understand how are particles accelerated to very high energies in the Earth's radiation belts
- To determine why only 50% of magnetic storms result in particle acceleration inside the Earth's magnetic field
- To understand what determines the day-to-day variability of ionospheric scintillations?

7. Integrating the Research Effort Across Europe

To achieve the objectives we will access the following:

- Data from European, US and Japanese satellites
- Data from 9 multi-€M radars in the Arctic
- Data from 6 multi-€M radars in the Antarctic
- Modelling codes in several European Groups, and Russia
- Measurements of the Earth's magnetic field in Scandinavia, Greenland, UK, Canada, Alaska, and the Antarctic
- Databases in Europe, USA and Japan
- Research expertise across Europe
- Efficient data access and analysis facilities within Europe, such as SPACE GRID, and outside via the web and internet.
- Efficient management

These requirements are too large for any one country and require integration of effort across Europe. We have identified the key European Groups who already have access to the relevant datasets, and have the expertise necessary for this project. They have all agreed to participate. They are listed in Table 1.

The core group of the consortium was established during work for an ESA contract on space weather in 2000. This was delivered on time and within budget; we have a successful track record of management.

8. New Measurements in Space

To test the quality of the prediction codes, and to develop better models, it is essential to measure the radiation environment at the orbits of telecommunications and Galileo spacecraft. We will identify detectors to be flown on Galileo and other spacecraft in a unique collaboration between European industry and research.

9. Benefits for Europe

The results of our research will help all European satellite prime contractors and operators of telecommunications and global navigation satellites. It will be particularly important for first EGNOS and then Galileo. Space business is a growth area and Europe has substantial investment. For example, Europe has two of the five major satellite prime contractors world-wide, Alcatel Space of Paris and Astrium; the largest satellite operator world-wide, SES Global of Luxembourg; a major launch operator, Arianespace of Evry; and many more smaller operators and sub-contractors. In addition, 60% of the world's space insurance is conducted through the London market. There are approximately 600 satellites in orbit (250 in geostationary orbit) valued between US$50-100B. In the year 2000 European prime contractors won more orders for telecommunications spacecraft than the US. Our research will help protect this investment and the competitiveness of the European space industry.

Our research will provide and independent European capability in terms of modelling, although it will still require data from the USA and Japan for predictions. However, it will exploit and pull together European expertise to provide an expert Group for advice and help. The research effort will benefit from cross fertilization between different science areas, and between science and business.

European satellite operators and safety critical users will benefit from real-time predictions that will help them take operational decisions. Our prediction models will provide data via the web direct to operations rooms. There will be a continuing need for this service well beyond the lifetime of the project, and hence long-term benefits.

Research Organisation	**Contact**	**Country**	**Relevant Expertise**
British Antarctic Survey	Dr Richard Horne	UK	Electron acceleration and loss in the radiation belts Magnetic storm prediction Analysis of satellite anomalies and extreme events Antarctic SuperDARN data Ionospheric scintillations Satellite data: CLUSTER
University of Bath	Dr Cathryn Mitchell	UK	Ionospheric scintillations Ionospheric corrections to navigational signals
Rutherford Appleton Laboratory	Prof Richard Harrison	UK	Coronal mass ejections Solar energetic particles, Solar flares, coronal holes Satellite data: SOHO, TRACE, CLUSTER, Stereo, Solar B
University of Cambridge	Dr Helen Mason	UK	Coronal mass ejections Training and public outreach
Univeristy of York	Dr Ian Mann	UK	Magnetometer data ULF waves Electron acceleration in the radiation belts
University of Leicester	Prof Mark Lester	UK	Arctic SuperDARN data ULF waves Plasma convection
Mullard Space Science Laboratory	Dr Andrew Coates	UK	Coronal mass ejections Solar energetic particle events Satellite data: CLUSTER, Yohkoh, CRRES, STRV Satellite particle detectors
Laboratoire de Physique et Chimie de l'Environment	Prof Francois Lefeuvre	France	VLF waves VLF wave model Antarctic SuperDARN radar data
Onera	Dr Daniel Boscher	France	Radiation belt transport code Radiation belt data
Observatoire de Paris	Prof Monique Pick	France	Coronal mass ejections Solar energetic particle events
Max Planck Institut	Prof Rainer Schwenn	Germany	Coronal mass ejections Solar energetic particle events Satellite data from SOHO, TRACE, ACE, WIND, and RHESSI
Belgian Institute for Space Aeronomy	Dr Daniel Heynderickx	Belgium	Radiation belt models Satellite data on radiation belts Satellite design tools
Swedish Space Research Institute	Prof Henrik Lundsted	Sweden	Neural network methods Radiation belt predictions Satellite anomalies
Moscow State University	Prof Igor Alexeev	Russia	Magnetic field models
IFAC	Dr Paolo Spalla	Italy	Ionospheric corrections to navigational signals Ionospheric scintillations
Company	**Contact**	**Country**	**Relevant Expertise**
Alcatel Space	Mr Bertrand Huet	France	Satellite prime contractor Project management Problem definition Satellite anomaly data
ESYS	Mr Andrew Shaw	UK	Market research
Companies to be associated	**Contact**	**Country**	**Relevant Eexpertise**
Galileo Industries		Italy	Global satellite navigation
SES Global		Luxembourg	Satellite operator
EUTELSAT		France	Satellite operator
HISPASAT		Spain	Satellite operator

Table 1. Consortium members and areas of expertise.