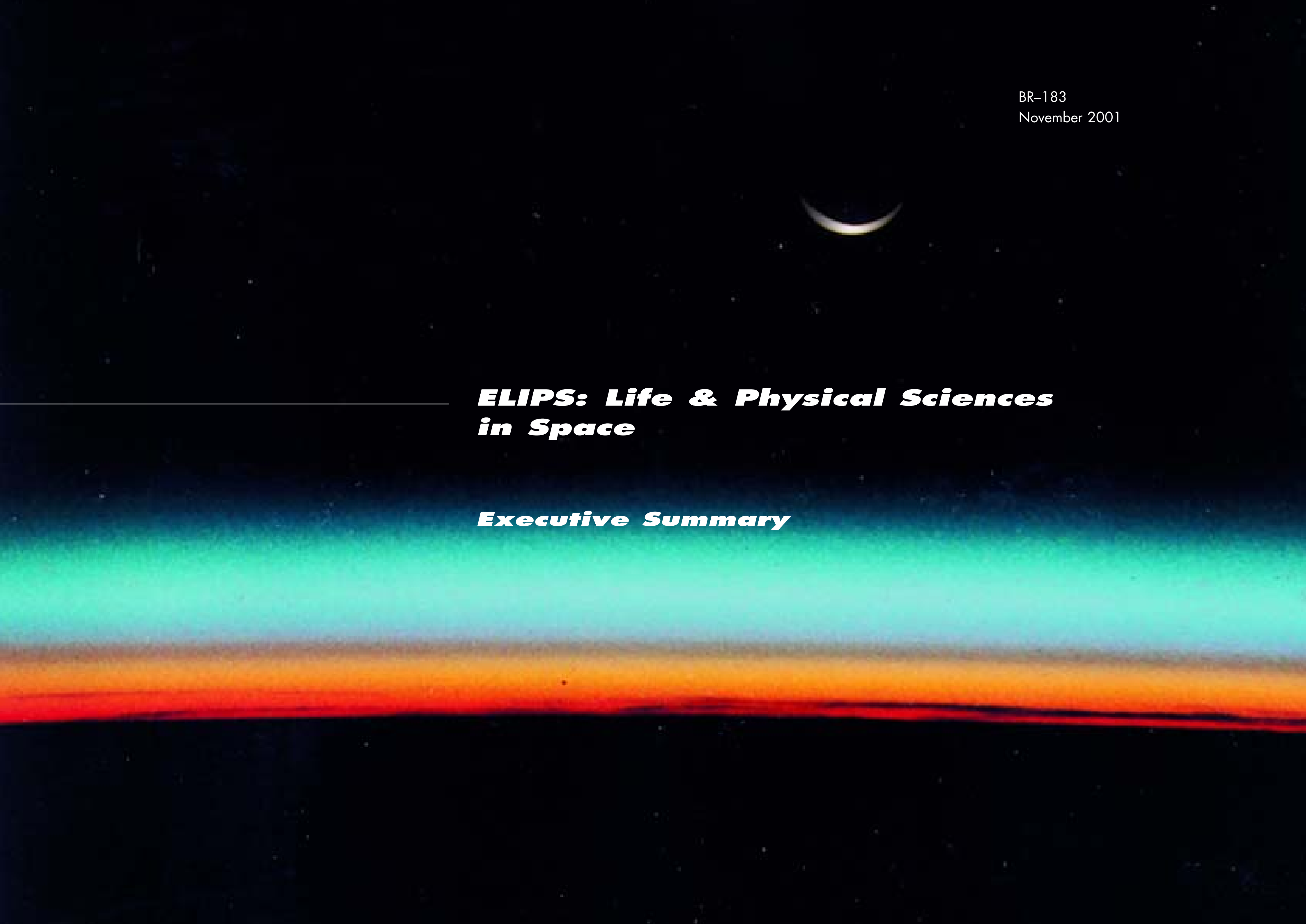
BR–183
November 2001

ELIPS: Life & Physical Sciences in Space

Executive Summary



1

Context and Overall Goals

Access to space opens up new frontiers for scientific research and human exploration endeavours. In space laboratories like the International Space Station (ISS), unique research has become possible in a variety of disciplines, making use of the special conditions of the space environment such as weightlessness, radiation and extreme vacuum. Top-level research into fundamental questions in biology, physics and chemistry will be conducted through the collaboration of scientists from all over the world. At the same time, applications of the research in space will find its way into new medical techniques, industrial innovations and environmental technologies, to the general benefit of Earth's population.

The ELIPS programme is intended to prepare and perform research on the International Space Station and other carriers such as sounding rockets and unmanned orbital vehicles, in fundamental and applied Life and Physical sciences. ELIPS will be the indispensable programme to ensure that Europe's investment in the development and exploitation of the ISS produces the best scientific results. To this end, ELIPS promotes global cooperation, international peer review of research proposals and European coordination in facility development and resource utilisation.

The overall goal of the ELIPS programme is to

pursue excellent fundamental and applied research in Life and Physical sciences using the extraordinary conditions in space, in particular by utilising the ISS

In order to reach this overall goal, the following key objectives are identified for ELIPS:

- maximise the benefits for society from the utilisation of the ISS
- strengthen and further develop the scientific and industrial user community in Life and Physical sciences in Space
- vigorously pursue the principle of best science at a transnational and global level by coordination with the ISS Partners and competition among scientists
- promote applications by teaming researchers from academia and industry and achieving increased industrial engagement and benefits
- provide European programmatic coherence in this area
- promote scientific research in space to the general public and in particular the younger generations by education and outreach activities
- engage small- and medium-sized European companies, as developers of advanced equipment and users of the ISS capabilities.

Without ELIPS, the European investments in ISS Development and Exploitation will not produce benefits for science and society.

ELIPS: European programme for LIfe and Physical sciences and applications utilising the international space Station

Columbus: Europe's prime Space Station location for research into fluids, materials, biology and physiology

Over the past 15 years, the use of space conditions for research in Life and Physical sciences has matured considerably in Europe. This is demonstrated by several favourable recent evaluations of the field in different participating states, such as that by the Fraunhofer Institute in Germany, and the endorsement of this ELIPS Proposal by the European Science Foundation (ESF).

In particular, the following positive trends can be clearly recognised:

- a very significant increase in the quantity and quality of scientific publications in international, peer-reviewed journals
- a growing interest from scientists new to space representing the mainstream of the mother disciplines
- strongly increasing transnational cooperation between scientific teams, leading to coherent and focused research efforts and competition on a global scale
- growing interest from industrial and societal research entities, building on the convincing applications value of some of the research themes.

This growing quantitative and qualitative interest from the scientific and industrial user communities has developed in parallel with the strengthening of the peer-review procedures at ESA. Since the beginning of the 1990s, all proposals have been reviewed by independent experts according to predefined criteria. For proposals aimed at utilising the International Space Station, soliciting and reviewing proposals is now fully internationalised in both the Life and the Physical sciences.

More than 600 proposals have already been forwarded to ESA, of which 229 accepted experiments were rated as 'Outstanding' or '(Highly) Recommended' in international peer reviews. Almost 1000 European scientists and some 125 European industries are directly involved in these proposals. The ELIPS programme will ensure continuity and perspective for this impressive and still growing user community interested in utilising the ISS, strengthen the connection with the mother disciplines and provide suitable experiment opportunities for Life and Physical sciences in Space.

Most of the currently selected research projects are transnational. By pursuing this, the ELIPS programme will be ESA's contribution towards strengthening the foundation of a European Research Area in the Life and Physical science disciplines, leading to a greater synergy with the New Framework Programme of the European Community. In addition, ELIPS will form the framework for intensifying strategic and scientific links with entities like the European Science Foundation, the European Commission, the European Molecular Biology Laboratory (EMBL), the Organisation for Economic Cooperation and Development (OECD), the World Health Organisation (WHO) and others with the aim of developing complementary objectives and fully exploiting the potential of research in Life and Physical sciences in Space.

In terms of international cooperation, ELIPS will enable Europe to exploit the ISS as a global research laboratory. The facilities under development or study at ESA are of clear interest to other ISS Partners, and the same is true reciprocally for facilities that are available or under consideration outside of Europe. By investigating further collaboration possibilities with its US and Russian counterparts, ESA will obtain appropriate flight opportunities and resources for European facilities and research projects.

2

Research Objectives and Priorities

A Research Plan in Life and Physical sciences and Applications in Space was developed during 2000 and 2001 in discussion with the user community. Four top-level science and applications objectives of the ELIPS programme were defined, based on the existing set of recommended proposals as the starting point:

Exploring Nature

Using the conditions of weightlessness and radiation in space will generate findings in fundamental Life and Physical sciences that can change our understanding of Nature. In addition, research will prepare for human planetary exploration missions, which are expected to be one of the major endeavours of the 21st century.

Improving Health

Performing human physiology experiments using astronauts on the ISS will contribute to solving the health problems on Earth created by ageing, disease and disability, such as osteoporosis and cardiovascular problems. The focus will be on understanding the underlying physiological processes, testing drugs and countermeasures and developing advanced, tele-operated, diagnostic techniques.

Innovating Technologies and Processes

Studies in materials sciences and fluid physics deal mostly with the liquid state of matter, the properties of which can be masked by gravity-induced effects. Results of these studies are often important for modelling and understanding processes in the (petro) chemical, biotechnology and metallurgical industries, as well as for developing new technologies and materials.

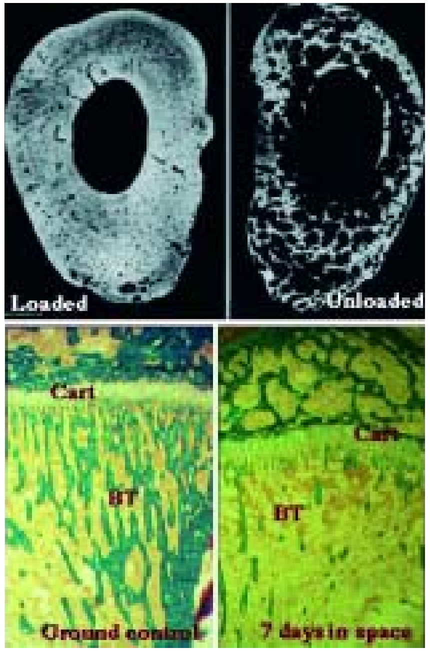
Caring for the Environment

Combustion experiments in space reveal details of the burning process that cannot be obtained on Earth and which are important for improving the efficiency and environmental load of engines and power plants. The development of Life Support Systems for use in spacecraft will lead to technologies for waste treatment, rapid detection of microorganisms, and food production.

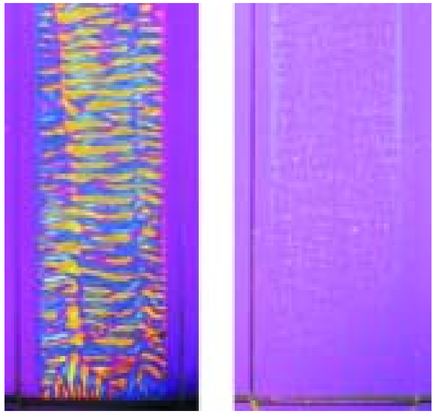
ESA asked the European Science Foundation to identify the specific European fields of excellence that can contribute to reaching these objectives. Following the ESF recommendations, the identified fields of Excellence have been concentrated into 14 Research Cornerstones. These 14 Cornerstones within the six disciplines covered by the ELIPS programme are described in the Tables, which provide details on the specific science targets and potential applications. The correlation between these 14 Cornerstones within the six disciplines and the above four overall science and applications objectives is given in the matrix of Table 2.

Examples of results from each of the four Research Objectives

IMPROVING HEALTH. *Space research can improve our understanding of physiological changes such as bone loss. This research may lead to better medications and countermeasures against diseases such as osteoporosis. The images compare loaded and unloaded bones and the changes in the bones of rats after a week in space. (Courtesy A. Zallone & L. Vico)*

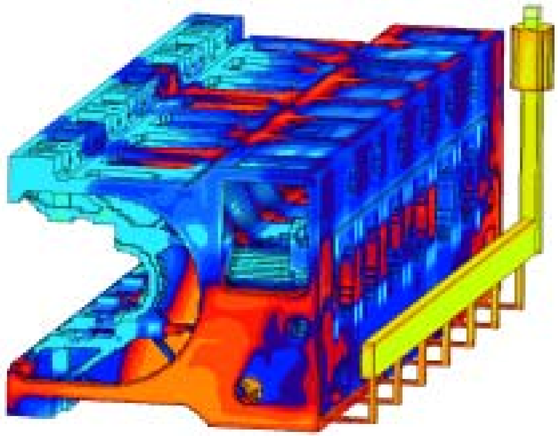


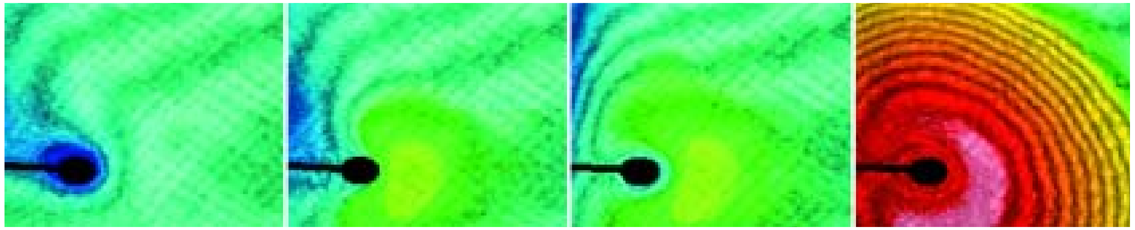
EXPLORING NATURE. *Microtubules are important building blocks of biological cells. A recent experiment in space has shown that the self-organisation of these microtubules depends on gravity. This important finding has implications for understanding the biological functioning of cells. (Courtesy J. Tabony)*



1g 0g

INNOVATING TECHNOLOGIES & PROCESSES. *Studies in materials science are often relevant for modelling and understanding processes in, among others, the metallurgical industry. Space research can improve the casting process used, for example, to produce car-engine blocks. Shown is the temperature distribution of a block-casting simulation. The accuracy of the simulation depends strongly on the parameters measured in the microgravity environment*





CARING FOR THE ENVIRONMENT. *More efficient combustion of fuels on Earth would reduce atmospheric pollution. Research in microgravity without convection can lead to improved combustion. The inherent transport phenomena needed for modelling and optimising the process are best studied in weightlessness. The illustration shows false-colour interferograms of a self-igniting suspended n-heptane droplet in microgravity. From left to right: cool vapour around the droplet; bright green cool flame; cool flame expanding; hot ignition*

3

Implementation

In terms of implementation, the ELIPS programme is characterised by the following principles.

ELIPS is proposed as an Envelope Programme of the Agency, thus allowing for a science- and applications-driven programme with a long-term strategic horizon and complete decision synchronism with the ISS Exploitation programme. The Microgravity Programme Board will endorse a 3-year prospective Implementation Plan on an annual basis, indicating for each of the Research Cornerstones the specific implementation steps foreseen. Budget approvals are for 5-year periods, of which 3 years are fixed and 2 years are provisional.

Strategic planning and actual content and implementation of the ELIPS programme will be driven primarily by the requirements of the scientific and industrial user communities. The soliciting and selecting of research proposals will be coordinated at European and International level, thus ensuring that absolute top-class science will be performed on the ISS.

Regular European coordination meetings will be organised with the aim of avoiding duplication, Europeanising fields and activities of general European interest, and producing an efficient scheme of facility development and procurement of mission opportunities. Such a scheme will build upon and reflect the existing National expertise and priorities and will lead to a strong and common European position vis-à-vis the other ISS Partners. The coordination meetings will contribute significantly to strengthening the network between cooperating Agencies and centres. Such coordination meetings will also address related activities in other Agency programmes such as the General Support Technology Programme (GSTP) and PRODEX.

ESA Astronaut Claudie Haigneré inspects Biolab's centrifuge rotor

Efficient coordination is taking place within the Directorate of Manned Spaceflight and Microgravity to link the ISS Exploitation Programme with the ELIPS Programme and with other Directorates in the Agency concerned with Fundamental Physics, Astro/Exobiology and Planetary Exploration. Within the framework of the ELIPS Programme, similar coordination will be set up with the Directorates responsible for technology development, GSTP and the Technology Research Programme (TRP), with the aim of optimising ISS utilisation.

The ELIPS Programme will be especially attractive for companies other than major system integrators: small system integrators, equipment suppliers and Small- and Medium-sized Enterprises (SMEs), with open competition for prime responsibility and an overall industrial return target of 50% for these types of companies. This will constitute an important contribution to the ESA Industry Policy, now under development, for non-primes, SMEs and R&D entities involved in ESA programmes.

4

Contents of Programme

A full analysis of the 229 proposals approved so far has shown that a comprehensive programme will require funding of five broad categories of activity. These are grouped in the following programme elements:

General Activities
Experts, Advisory Groups, User Information and Purchase Order, Future Studies, Topical Teams and Virtual Institutes, and Education and Outreach.

Preparatory and Supporting Activities
Access to Ground-based Facilities in Europe, Baseline Data Collection, Bed Rest Studies, Droptowers and Parabolic Flights, Preparation of Planetary Exploration, Experiment Preparation at User Support and Operations Centres (USOCs).

Support for Application-Oriented Projects
Initiation of applied research projects in Life and Physical sciences in Public-Private Partnership with industry and institutes.

Hardware Development
Sounding Rocket Research Modules, Evolution and Refurbishment of Existing Facilities, Inserts for Microgravity Facilities for Columbus (MFC), Development of New Facilities and Equipment for Russian ISS Flights.

Flight Costs
Sounding Rocket Flights, Manned and Unmanned Flight Opportunities.

The total envelope of the ELIPS programme as proposed here is 320 MEuro, including ESA internal costs. Details can be found in Table 3. This budget is in line with the present annual spending of approved Microgravity Programmes of the Agency. For the following phases of the programme, it is foreseen to have a flat funding profile at the approximate level indicated for the last 2 years of this phase.

Launch of a Maxus sounding rocket from Esrange, in Sweden

Table 1.1. The Research Cornerstones: Fundamental Physics; Fluid and Combustion Physics

	Research Cornerstone	Description	Science Targets	Potential Applications
Fundamental Physics	Complex Plasmas and Dust Particle Physics	Understand the three-dimensional behaviour of particles in Complex Plasmas, and aggregation processes that require weightlessness	Enhance theoretical decription of complex plasmas, including self-ordering and phase-transition phenomena. Improve modelling of the interaction of proto-planetesimals, their optical properties, and of the behaviour of atmospheric pollutants.	Develop novel plasma coating techniques. Nucelation and growth of novel substances for solar cells and plasma screens. Improved modelling of Earth climate and environment
	Cold Atoms and Quantum Fluids	Study properties and applications of cold atoms, including Bose-Einstein condensates	Develop and operate a cold-atom clock in space. Check limits of validity of theories of relativity and quantum electrodynamics.	Improved accuracy of absolute time measurements. Increased accuracy for navigation and geodetic systems.
Fluid and Combustion Physics	Structure and Dynamics of Fluids and Multiphase Systems	Study of multiphase systems, their phase transitions and related dynamics, critical and supercritical fluids, granular materials. Geophysical fluid flows.	Quantify heat transfer, mass exchange and chemicalprocesses in multiphase systems and supercritical fluids. Measure diffusive processes in mixtures. Study the stability of foams and emulsions. Describe dynamic coupling in granular materials under vibration.	Develop reactors for supercritical oxidation of industrial contaminants. Develop high-efficiency heat exchangers. Improve reactor design in industrial plants. Design improved oil-recovery techniques.
	Combustion	Study combustion phenomena that are dominated on the ground by buoyancy convection.	Quantify fuel droplet and spray evaporation, auto-ignition and combustion processes. Detail the process of soot formation in flames and the conditions for flammability of solid fuels.	Improve efficiency of electrical power plants. Reduce emissions of engines. Improved flammability test procedures.

Table 1.2. The Research Cornerstones: Materials Sciences; Biology

	Research Cornerstone	Description	Science Targets	Potential Applications
Materials Sciences	*Thermophysical Properties*	*Use the extended possibilities of containerless processing in space to measure critical properties of highly reactive liquid metals.*	*High-accuracy measurements of the properties of stable and metastable (undercooled) liquid metals.*	*Improve the reliability of numerical simulation and control of casting facilities in the metallurgical industry.*
	New Materials, Products and Processes	*Understand the physics of solidification and crystal growth of metals, organic and inorganic materials and biological macromolecules.*	*Quantify the influence of the growth conditions on the homogeneity and defects in crystals, including protein crystals.* *Improve numerical models of the microstructure formation in metals and alloys.*	*Improve and validate models for predicting grain structures in industrial castings.* *Develop processes towards new metallurgical products.* *Improve efficiency of production of industrial crystals.* *Contribute to tailored drug design.*
Biology	*Biotechnology*	*Investigate in weightlessness transmembrane and intracellular flux of mediators that control cell differentiation.*	*Improve knowledge of the relation between material flux at the cell-medium interface and gene expression.* *Improve the properties of recombinant products.* *Quantify interfacial transfer and especially interfacial turbulence and control of the membrane porosity.*	*Develop artifical functional tissues and targets for drug screening.* *Develop a bioreactor for tissue engineering, e.g. cartilage for implantation.* *Develop novel micro-encapsulated drugs and cells.*
	Plant Physiology	*Study mechanosensory elements involved in gravitropism.*	*Identify mechanosensory and signalling elements determining gravitropism.* *Identify gene interactions important in the gravistimulus response chain.*	*Improvement of plant growth and mechanical properties of plants.* *Develop techniques for plant survival and growth in space.*
	Cell and Developmental Biology	*Study the effect of gravity on cell. and whole-body development and reproduction.*	*Study altered gene expression in altered gravitational environment, e.g. micro-arrays.* *Improve understanding of the impact of the cytoskeleton architecture on signal transduction, e.g. functional genomics.* *Understand the effect of gravity on the development of the vestibular and sensori-motor systems in vertebrates.*	*Design pharmacological relevant substances for animal and human applications relevant to human development.* *Develop techniques and pharmacological substances for cell and tissue regeneration, e.g. neuronal repair.*

Table 1.3. The Research Cornerstones: Physiology

Physiology

Research Cornerstone	Description	Science Targets	Potential Applications
Integrated Physiology	Use the extreme conditions of space to study the impact of gravity and stress on vegetative regulations.	Study cardiovascular control, e.g. blood pressure regulation, under microgravity. Investigate the influence of sensori-motor and. proprioceptive inputs on cardiovascular control Study the dependence of energy uptake on exercise and load	Develop miniaturised, automated devices for medical diagnostics. Improve techniques and devices for medical applications, e.g. sports medicine. Improve protocols for post-traumatic rehabilation. Improve treatment of stress-related disease.
Muscle and Bone Physiology	Use absence of or reduced gravity to study the effects of load on the human musculo-skeleton.	Study effects of changes in load on muscle atrophy and plasticity. Understand and quantify bone mass turnover as a function of, e.g., local blood perfusion and mechanical stress.	Develop devices and protocols for medicine. Improve means for diagnostics, prevention and treatment of osteoporesis. Improve rehabilitation after long-term incapacitation, particularly involving bed rest.
Neuroscience	Understand the effects of gravity on control of posture, locomotion and cognition.	Investigate the interaction of the vestibular system with other inputs relevant to locomotion and posture (e.g. vision, proprioception). Understand cognitive strategies in the absence of gravity.	Develop improved approaches for the treatment of neurological diseases involving impaired cognition, control of posture and locomotion (e.g. cerebellar impairment).

Table 1.4. The Research Cornerstones: Astro/Exobiology, Planetary Exploration

Research Cornerstone	Description	Science Targets	Potential Applications
Origin, Evolution and Distribution of Life	*Study the survivability of organisms under extreme conditions on Earth (extremophiles) and in space.*	*Investigate the contribution of space conditions, including radiation, to the formation of prebiotic molecules.* *Identify the conditions for survivability of microorganisms from and in space, including planetary surfaces.* *Identify markers and tools to search for extinct and extant life.*	*Identify novel enzymes and bacteria from extreme physical and chemical environments with industrial application, e.g. biocatalysis.*
Preparation of Human Planetary Exploration	*Study novel aspect of human planetary expeditions.*	*Quantify radiation risk for humans and understand the specific biological action of space radiation.* *Study effects of isolation in high-stress environments.* *Quantify needs for consumables during mission.* *Perform simulation tests on in-situ resource utilisation potential.*	*Develop advanced radiation sensors and countermeasure devices.* *Develop technology for telemedicine/telesurgery in remote areas.* *Develop protocols for handling stress effects.* *Develop methods for in-situ resource utilisation.* *Develop life-support systems for use in space and other isolated environments.* *Develop the technologies for identification and utilisation of in-situ resources.*

Table 2. Correlation Between the 14 Cornerstones and Four Overall Science and Applications Objectives, and the Number of Selected Experiments

	Complex Plasmas and Dust Particle Physics	Cold Atoms and Quantum Fluids	Fluids and Multi-phase Systems	Combustion	Thermophysical Properties	New Materials and Processes	Plant Physiology	Cell and Developmental Biology	Biotechnology	Integrated Physiology	Bone and Muscle Physiology	Neurosciences	Origin, Evolution and Distribution of Life	Preparation of Human Planetary Exploration	NUMBER OF EXPERIMENTS
Exploring Nature	XX	XX	X	X	X	X	XX	X	X	X	X	XX	XX	X	103
Improving Health			X			X		XX	X	XX	XX	X		X	60
Innovating Technologies and Processes	X	X	XX	X	XX	XX			XX					X	44
Caring for the Environment	X		X	XX		X	X		X					X	22
NUMBER OF EXPRIMENTS	**11**	**5**	**30**	**8**	**8**	**46**	**6**	**16**	**15**	**27**	**18**	**11**	**14**	**14**	**229**

X: contribution *XX: essential contribution*

Table 3. ELIPS Programme Budget (MEuro)

Budget Line	Projected Contribution	Total	2002	2003	2004	2005	2006
General Activities							
Experts, Advisory Groups, User Information and Purchase Orders	*1.5 MEuro/year*						
Future Studies	*Pre-Phase-A and Phase-A: 1 MEuro ; Phase-B: 3.5 MEuro*	19	3	4	4	4	4
Topical Teams and Virtual Institutes	*0.6 MEuro/year*						
Education and Outreach	*0.8 MEuro/year*						
Preparatory and Supporting Activities							
Access to Facilities in Europe	*1.2 MEuro/year*						
Baseline Data Collection	*0.8 MEuro/year*						
Bed Rest Studies	*0.6 MEuro/year*	46	6	7	11	11	11
Droptowers and Parabolic Flights	*1.8 MEuro/year*						
Preparation of Planetary Exploration	*1.0 MEuro/year*						
Experiment Preparation at USOCs	*3.8 MEuro/year*						
Support to Application-Oriented Projects							
Life and Physical Sciences	*16 MEuro*	16	2	3	3	4	4
Hardware Development							
Sounding Rocket Research Modules	*6.0 MEuro/year*						
Evolution/Refurbishment of Existing Facilities	*2.5 MEuro/year*						
Inserts for MFC	*4.5 MEuro/year*						
Development of New Facilities	*2 major facilities @ 25 MEuro*	140	13	24	31	36	36
	+ 2 EDR-type facilities @ 10 MEuro = 70 MEuro						
Equipment for Russian ISS Flights	*1 Russian ISS Flight = 1 MEuro/year*						
Flight Costs							
Sounding Rockets	*Maser/Texus-type 1/year*						
	+ Maxus-type 1/2 years = 25 MEuro	45	7	8	8	11	11
Manned and Unmanned Flights	*Foton and/or Spacehab Flights: 20 MEuro*						
Subtotals		266	31	46	57	66	66
ESA Internal Cost (17%)		54	1	10	13	15	15
TOTAL PROGRAMME		**320**	**32**	**56**	**70**	**81**	**81**

BR-183, November 2001 based on ESA/PB-MG(2001)11, rev 3

Prepared by: ESA Directorate of Manned Spaceflight and Microgravity

Published by: ESA Publications Division
ESTEC, PO Box 299
2200 AG Noordwijk
The Netherlands

Editor: Andrew Wilson
Design: Leigh Edwards

ISSN: 0250-1589
ISBN: 92-9092-718-6
Price: 15 Dfl/7 Euros
Printed in The Netherlands