An ESSC-ESF position paper

Recommendations for ESA's Future Programme in Life and Physical Sciences in Space

Results of an ESF-ESSC study

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European Space Science Committee (ESSC)

The European Space Science Committee is an ESF Expert Committee. Established in 1975, it covers life and physical sciences in space, Earth observation and space physical science. It considers issues of space research activities in Europe, with particular emphasis on the definition and organisation, collaboration and exploitation, and assessment of such research endeavours.
The Committee investigates and presents the view of the scientific community in Europe and provides an independent voice on European space science policy.

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Background to the study

The ESA Directorate for Manned Space Flight and Microgravity (D-MSM) and the Microgravity Programme Board (PB-MG) are defining a "Research Plan / Programme Proposal for Future Life and Physical Sciences in Space". This Research Plan, along with the ESA Executive input to the overall "European Strategy for Space", prepares the ground for the ESA Programme Proposal to be submitted in November 2001 to the Ministerial Council. The present status of this Research Plan is described in the document ESA/PB-MG(2000)41.

The Research Plan is in the form of four pyramids (Appendix 4) which are based on the requirements expressed by the users in proposals for space experiments submitted to ESA in response to European and international Announcements of Opportunities (AOs). Specific research topics (e.g. measurements to be made, experiments to be performed) taken from the proposals are the foundations of the pyramids. They are then grouped into research priorities, which are the second level of the pyramids. At the top level, there are four objectives (*Exploring Nature, Improving Health, Innovating Technologies and Processes, Energy and Environment*), which embrace both basic and applied research topics.

The purpose to define and implement this plan comes from the recognition by the ESA Executive of the importance of an overall European Research Strategy in space in which ESA and national activities would be represented. Recent events, such as the relatively low European success rate in the latest International Life Sciences Research Announcement, indicate that Europe is slowly losing its traditional position of excellence. The ESA Executive believes that this is primarily caused by the present difficulty in bringing together substantial European efforts in areas where international competition is growing, as well as a weak ground-based research programme. Indeed, and in contrast to the USA, ground-based research is not funded by ESA but supported by the individual European national funding agencies.

ESA will interact with external bodies, e.g. national research councils, EMBL[1], CERN[2], ESRF[3], EC[4], on the basis of this document, which will be a platform for discussions with the scientific community. On-going discussions proceed along two lines: (i) political discussions at the PB-MG level and; (ii) scientific discussions, for which it is necessary to define a Research Plan to form the backbone of the future programme proposal.

ESA wishes to integrate this future programme within a larger European scheme to achieve a "Union of Programmes" in which a common strategy is agreed and implemented. Coherence between ESA and national programmes is therefore essential. It was recognised by the ESA executive bodies that the European Science Foundation (ESF) should undertake an independent scientific assessment of this research plan, acting as a liaison with the main scientific disciplines. D-MSM therefore asked the European Space Science Committee (ESSC, the ESF expert committee on space science) and the ESF to conduct an

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[1] European Molecular Biology Laboratory
[2] Organisation Européenne pour la Recherche Nucléaire – European Organisation for Nuclear Research
[3] European Synchrotron Radiation Facility
[4] European Commission

independent assessment of the scientific relevance of their Research Plan.

ESA asked ESF specifically to consider and answer the following questions:

- is the draft research plan / strategy effectively based on user demand as defined by:
  - (i) scientific priorities assessed by the scientific community, scientific advisory boards and the relevant scientific bodies?
  - (ii) responses to existing and future AOs?
  - (iii) scientific priorities, as identified by national space agencies and bodies managing space research at the national level?
- can the scope of this future Programme Proposal be broadened to:
  - (i) demonstrate its scientific and potential economic value?
  - (ii) take into account the increased dimension arising from the involvement of the European Union in space activities?
- what steps should be taken by the scientific community and ESA to efficiently incorporate new ideas and themes in the research plan in a flexible way?
- from a budgetary viewpoint, is this future strategy compatible with the presently predicted decrease of involvement of the Member States in this area of research?

Given the broad scope and interdisciplinary nature of the activities covered by this plan, the ESSC suggested that several ESF standing committees be involved in this assessment. First contacts were made in March 2000, and an official invitation to participate in a dialogue was sent by the ESA Executive to the ESSC and to the three standing committees of ESF, the Standing Committee for Life and Environmental Sciences (LESC), the Standing Committee for Physical and Engineering Sciences (PESC) and the European Medical Research Councils (EMRC). A planning group was set up, comprising delegates of these three ESF standing committees and of ESSC, as well as members of the ESA Executive. This planning group met twice, and an ESSC representative attended the PB-MG open meeting on 8 May 2000.

At its first meeting held on 5 July 2000 in Noordwijk, The Netherlands, the group decided that this evaluation exercise would best be carried out by gathering knowledgeable scientists from the thematic areas covered by ESA's Research Plan, with an adequate mix of people with "space" and "non-space" experience.

Six main disciplines were identified:

- biology
- physiology
- exobiology
- material sciences
- fluid sciences
- fundamental physics

Scientists in each of these disciplines were therefore invited to a workshop to discuss and assess ESA's plan in their respective areas. This workshop was held near Strasbourg, France, on 28-30 November 2000 with some 50 participants from various disciplines, including space and non-space experts, as well as observers from the PB-MG and from the European Low-Gravity Research Association

(ELGRA) and auditors from ESSC, LESC, PESC and EMRC. The list of these participants appears in Appendix 1.

Workshop structure

At the beginning of the workshop the ESA Executive presented the status of their research plan to the participants. After a general discussion disciplinary groups were formed and chairpersons were nominated in each group. The groups met during splinter sessions where the discussions were introduced by overviews of the discipline area, i.e. status of the research, pending scientific questions, role of research in space and on the ground, etc.

A set of questions and criteria were defined and agreed during the workshop in order to carry out comparable assessments in all disciplines:

General criteria

1. Scientific excellence
- are the objectives well defined and do they represent the scientific needs?
- is the programme proposal effectively based on user/science demands?
- are the standard criteria for scientific excellence applied?
- is the programme specific for space?

2. Structure, pyramids, process
- flexibility: what steps should be taken to efficiently incorporate new ideas and themes?
- are there any missing items?

3. European dimension
- how well is the programme proposal connected with general research priorities and programmes in Europe?
- European competitiveness: how well does the programme proposal strengthen/support European excellence?
- in what areas is there a potential for European leadership?
- international cooperation: to what extent and in what fields can we benefit from, and contribute to, cooperative programmes/projects with non-European organisations?
- multidisciplinary cooperation: in what fields is multidisciplinary cooperation wanted/mandatory?

4. Public outreach and education

5. Application-oriented aspects: what is good for solving terrestrial problems?

6. Implementation: what steps should be taken to realise the programme?

Thematic criteria

- completeness: are the essential elements reflected in the programme proposal?
- maturity: what is the state of development of this field; what is its potential to grow?
- cross-fertilisation: what relations should be established with other disciplines in space research and non-space research?
- applications: what is the application potential?
- approach: how can the objectives best be reached?

The groups met several times in splinter sessions interspersed with plenary sessions, during which thematic findings were discussed and general conclusions reached.

On the basis of these discussions a draft report was established which was discussed by the participants through their session chairs and by the auditors. This draft report was discussed by the ESSC and the ESF standing committees at their January and February 2001 meetings.

These conclusions and recommendations, both general and disciplinary, are laid out in this document; the thematic findings generally follow the order of the criteria presented above. When remarks concerning the specific contents of the programme proposal or the pyramids were made they appear in the sections presenting the findings by discipline. A preliminary presentation of the most general findings was made at the meeting of the PB-MG on 5 December 2000.

General recommendations

Nature of the research plan: programme proposal or strategy?

There was a general recognition by the workshop participants that the request by ESA for an independent scientific assessment of its programme/strategy was courageous and that it would be beneficial to repeat such an exercise regularly. The participants concluded, however, that the ESA document is currently more a description of programme than a true strategy. Both documents are nevertheless complementary. A top-level strategy is needed first, preceding the programme. This strategy paper should be shorter (about two pages), more focused, and state objectives; furthermore, it should identify rationale(s) for undertaking specific programmes. The strategy should stress what has been done in the past and the future direction that it is taking, in order to demonstrate its continuity. Concerning the exploration of new scientific ideas the concept of Topical Teams was supported and adapted.

ESA's new bottom-up approach, i.e. basing the programme on the inputs from the scientific community, was welcomed by the participants. Some splinter groups also recommended that, in addition, the overall strategy should continue to receive some guidance from the Directorates of ESA, i.e. incorporating a top-down element.

Structure of the research plan; relevance of the pyramidal presentation

The pyramid structure was discussed during the workshop. Participants thought that it was not ideal, but no better presentation could be identified. The third level of these pyramids, i.e. the experiments, was considered too detailed to be in a general strategic document; conversely, the second level lacked precision in certain disciplines (e.g. biology). As originally described the first objective (*Exploring Nature*) was seen by members of the Fundamental Physics splinter group as confusing, since it mixes basic science and applications. For example, people belonging in columns 1-3 of that pyramid publish mainly in scientific journals, while those involved in column 4 activities work through patents and set up SMEs. Therefore, the original fourth column (Develop advanced capabilities for human space exploration) would be better placed as part of the third objective (*Innovating*

Technologies and Processes). Concerning the general structure and contents of the programme proposal itself it was felt that the space specificity was not always obvious.

The peer review procedure should be presented in the programme and be made more transparent. An important comment was that two main disciplinary areas, namely Fundamental Physics and Exobiology, are currently managed in two ESA Directorates (D-SCI and D-MSM), thereby calling for increased coordination within ESA. In those areas a global strategic view requires the existence of a science advisory committee that can advise across Directorates and relate the space programmes to ground-based programmes of other agencies.

Public outreach and education issues

This aspect was considered important by all the workshop participants and essential to incorporate in any future strategy for space. It was deemed essential to dedicate a few percent of ESA D-MSM's (and more generally of ESA's) budget to increase public awareness and change the present situation in which ESA clearly lacks visibility, even in Europe, compared to NASA. To achieve this change a strategy is needed to translate science results into public relations with the help of scientists. With regard to NASA, there is a correlation between the increase in recent years of their public relations budget, the subsequent public interest in their activities and an enhancement in the science budget of the Agency. The ESA Directorate of Science has recently increased its efforts in that direction and D-MSM is encouraged to undertake similar efforts. This must be complemented by efforts in the education area, where initiatives should start at the elementary school level.

The issue of grants and fellowships was discussed. It was recommended that ESA identifies funds to provide such grants and fellowships to post-graduate students. The case of CERN was considered to be a good example, as there is an obvious added-value for a post-graduate grant/fellowship delivered by such a supranational body, as compared with a national award.

European competitiveness

All disciplinary groups identified many areas of potential European leadership, e.g. near & supercritical fluids, plant gravity response, cold atoms, complex plasmas, quantum fluids, cosmic dust, cell biology, basic integrated physiology, muscle physiology, etc. However, a major problem was identified. Given that ground-based work is being funded nationally while space research is funded through ESA, it is essential to ensure better coordination between space- and ground-based research, i.e. between ESA and national agencies.

AOs. Scientific community outreach

Several splinter groups advised that some of the best science groups in Europe were not aware of ESA's programmes and do not therefore respond to AOs and compete with other groups. One recommended improvement was that ESA should reach out more towards science communities that have not traditionally taken part in their space programmes.

Specific recommendations for the different disciplines

Biology

Life on Earth has evolved in the presence of a persistent gravitational field. Scientists in space and gravitation biology are investigating the influence of different g-levels and radiation on life systems, ranging from unicellular to the most complex life forms, including ourselves. Many experiments demonstrate that gravity directly influences fundamental aspects of biological processes at the molecular and cellular level in all organisms.

In space biology, the following recommendations were made:

- ESA does not seem to be reaching the best groups working in the biology field, who are therefore not responding to AOs; the fact that ground-based research is not supported by ESA, but only at the national level, increases the difficulty to get some of these groups involved in space-related research. Consequently ESA's approach in basing the new programme on the inputs from the scientific community (bottom-up approach) should be complemented by an active top-down approach:
  - ⇒ ESA should directly talk to scientific groups in certain areas of expertise in Europe, especially those not involved in space research
  - ⇒ ESA should be better represented in non-space meetings
  - ⇒ ESA should foster new groups to come up with their proposals to increase competition
  - ⇒ ESA should make the peer-review process more transparent and possibly improve it
  - ⇒ ESA has the leadership in the development of hardware, but the use of ground-based hardware is so far not included. Ways to coordinate ESA and national funding for ground-based research should thus be implemented.
- ESA should pay attention to the fact that any experimentation in space must be justified: what can be done on Earth should be tested on Earth.
- Several items in the pyramid structure need to be amended:
  - ⇒ In addition to the four top objectives listed in the programme, a fifth objective "*Education*" should be added
  - ⇒ Research priorities in the second level of the pyramids should be more precise, e.g. under the top objective "*Exploring Nature*" the second level should read "*Understand the mechanisms of gravity perception, transduction and responses in organisms*"
  - ⇒ The programme should be kept open for Topical Team proposals and for new themes.
- Europe has a potential for leadership in plant gravity responses. To increase European competitiveness it is recommended that ESA:
  - ⇒ convinces the governments to provide individual grants to young scientists and to give them access to laboratory space, not limited to space experiments
  - ⇒ introduces a PhD-programme dedicated to space biology
  - ⇒ quickly disseminates the results of experiments performed in space biology to the public

- There probably exist many examples where benefits for solving terrestrial problems have arisen from space experiments; an example is tissue architecture. Such application-oriented aspects should be fostered.

Physiology/Medical research

Space physiology and medicine include the study of the influences of gravity and weightlessness on the body and its subsystems. There are many parallels between these influences and the effects of disease, ageing, and a sedentary life-style on Earth. Recent space experiments have led to unexpected discoveries, emphasizing that our present knowledge of the physiological effects of gravity is incomplete. Further studies of the physiology of, for instance, the nervous system, lung, kidney, heart, muscle and bone will therefore result in new knowledge that will have potential for improving treatment and rehabilitation, and lead to improved health for the general public.

In the area of space physiology and medicine the following recommendations were made:

- The programme is well connected with general ("non-space") research priorities/programmes in Europe, because almost all groups are also involved in non-space research and they use microgravity as a tool for part of their work. However, some steps should be taken to increase the number of active scientists involved in human space research:
  - ⇒ This new user-driven approach will probably require important organisational changes at top-management level and throughout the technical and managerial structure of ESA. Attracting more resources will be a major task of this management, which highlights the crucial importance of public relations
  - ⇒ The new structure as foreseen by ESA is mainly based on the inputs from responses to AOs. Therefore it should be ensured that a larger part of the scientific community is acquainted with these AOs. In addition, more frequent AOs are required, with an increased number of flight opportunities, e.g. twice a year
  - ⇒ These AOs should include thematic subjects, which should be regularly reviewed and updated
  - ⇒ There should be a quicker turn-around time for flight opportunities
  - ⇒ A streamlining of the process for the submission and evaluation of proposals would be reached if scientists are invited initially to submit an outline proposal that is peer-reviewed and which may then be selected for a more detailed proposal
  - ⇒ ESA should evaluate the scientific results of the space experiments more carefully so that the programme can be adjusted accordingly
  - ⇒ More emphasis should be laid on injection of scientific results into the non-space scientific community, e.g. by publishing in non-space scientific journals and participating in regular scientific meetings within the discipline.

- Several items in the pyramid structure should be amended:
  - ⇒ It should be indicated that in the third level of the pyramids, which is based on the inputs (proposals) from the scientific community, the systems mentioned are only examples. Therefore, this level should be headed: "*any system sensitive to space, such as microgravity, should be included*"
  - ⇒ In the pyramid with the top level objective "*Improving Health*" the following research priority topic should be added: "*Understand the effect of environmental conditions, airborne contamination, sterilisation, vestibular disturbances, clinical countermeasures, and ageing*"
  - ⇒ In the pyramid with the top level objective "*Exploring Nature*" the left column "*Understand the effects of gravity and basic biological phenomena*" should be changed to "*Biological phenomena and integrated physiology*"
  - ⇒ Some technological items, such as rotating chair, short-arm centrifuge, etc. which are used in "*neurophysiology*", should be added
  - ⇒ Concerning the programme document itself : "*Gravity effect on the lungs*" should be added under "*Improving Health*"; in that section, "*airborne contamination and sterilisation*" should be added under "*Understanding the effects of environmental conditions...*"; "*Beneficial effects for the ageing community on the ground*" should be added under "*Developing clinical countermeasures for rehabilitation*"; "*Applications for telemedicine*" should be added under "*Developing advanced instrumentation for monitoring diagnostics*"
  - ⇒ If at all possible a 3D presentation should be used for PR purposes and to make apparent the links between the programmes

- Europe has a leading position in the following areas: cell biology, basic integrated physiology, and muscle physiology, which should be further fostered.
  - ⇒ International cooperation is especially important for integrated human physiology, which should be combined with operational space medicine in the USA for the benefit of the astronauts
  - ⇒ Multidisciplinary cooperation is especially required in the field of biomedical instrumentation (physicists, engineers), biotechnology, mathematical modelling of integrated physiology, artificial intelligence, robotics, and statistics

- Several space-based developments have the potential to contribute to the solution of terrestrial problems, such as:
  - ⇒ New knowledge obtained from space experiments on basic physiology may lead to better medical treatments and procedures
  - ⇒ Space-based development of instruments may lead to terrestrial applications. In this field, the industrial development should be managed in connection with selected scientists
  - ⇒ The International Space Station, ISS, may serve as a testbed for studying diseases

- ESA should initiate interdisciplinary linking of projects, such as projects between human physiology, exobiology (for the exploration of Mars), hospital medicine, operational medicine, fluid science physicians (peripheral blood flow), and technology programmes.

Exobiology

Exobiology (sometimes called astrobiology) attempts to reveal the origin, evolution and distribution of life on Earth and throughout the Universe. Exobiology is a multidisciplinary research field, combining astronomy, astrophysics, biology, biochemistry, chemistry, geology, and specific fields such as palaeobiology, organic chemistry, geomicrobiology, ecogenomics (genome evolution) and others. To understand the origins of life in the context of planetary environments, numerous space missions and space- and Earth-based experiments are either currently being carried out, or are planned for the near future. Research goals and questions to be addressed within the field of exobiology can be divided into three topics, the subject matters of which are interlinked, and can be seen as a progression in space and through time:

1. Exobiology packages for exploration science missions
2. Chemistry of the origin of life
3. Biological evolution of life

To maintain European competitiveness in this rapidly evolving, multidisciplinary field of exobiology, ESA's role is essential as a cooperator (to be on equal footing with NASA) and the following actions are recommended:

- ESA must step up its involvement in Mars missions, building on the experience gained from Mars Express
- Europa is a primary target for future exploration; mission studies need to start now, and would require inter-directorate co-operation
- Ground-based work must be done in the fields of mission preparation, simulated surfaces, instrumental testing and development, terrestrial analogues, site selection
- ESA's technology research programme needs to be involved
- The vast potential for applications in, e.g. genomics and biotechnology should be exploited
- Outreach and education: needs a structure and a budget, and must be effective
- There must be an ESA involvement in exobiological international collaboration

In the new programme of ESA, the scientific objectives should be in the first part of the document. For exobiology they should include the following topics:

Exobiology packages for exploration science missions

The search for life beyond the Earth is a topic that has fascinated mankind for generations, but it is only recently that realistic attempts to undertake that search have gained a good chance of success. ESA recently coordinated an exobiological study in order to propose a suitable lander/rover package to search for life on Mars (ESA SP 1231). Several space missions are in progress, or well into the planning stage, that have key objectives concerning the nature of extraterrestrial organic chemistry and the search for traces of past or present life. These include Mars Express (to Mars), Cassini-Huygens (to

Saturn and Titan), Rosetta (to comet Wirtanen). Future space missions, either already accepted for development (e.g. Darwin, Bepi-Colombo, Herschel) or at the proposal stage, can build on and extend current mission objectives for life-searching strategies. For such missions to be successful, there must be full inter-Directorate co-operation and collaboration. It is also imperative that ESA takes a lead in proposing new missions in which astrobiology packages play a major role (such as the Mars lander/rover). The primary target in this category, for which no mission is currently planned, is the jovian satellite Europa.

Specific questions that need to be tackled, and in which European scientists are well-placed to take a leading role, are:

- ***Mars**:* Subsequent to the Mars Express and Beagle 2 lander mission the next stages in the search for martian life need to address:
  - ⇒ what specific organic compounds are present in the martian soil ? What are their isotopic signatures? What are their structural characteristics (i.e. branched or straight hydrocarbon chain, chirality)?
  - ⇒ how widely distributed are the organics (by area, and by depth)? What is the oxidation profile of the soil?
  - ⇒ at what depth is a permafrost layer encountered? What is the ice composition and temperature? What are its dissolved gas and organics contents?
  - ⇒ how abundant are carbonates and other salts within the soil layer?

  Furthermore, many important studies cannot be done *in situ*, such as the detection of signatures of microbial life, as well as many detailed geochemical analyses. Thus, these lander-based missions should be followed as soon as possible by sample return missions and, eventually, by human exploration, for which no robotic mission can substitute.

- ***Europa**:* Results from the magnetometer on the Galileo probe have been interpreted as indicating that below the surface ice crust on Europa is a liquid, or semi-liquid layer, possibly of salty water or water/ice slush. On this basis, a mission, complete with ice-penetrator, is required to assess:
  - ⇒ is a sub-surface ocean present? What is its depth and composition? What are its temperature, salinity and density gradients? What are its dissolved gas and organics contents? What is the heat source that keeps it liquid?
  - ⇒ what is at the liquid/ocean floor interface? Are Europan analogues of hydrothermal vents present? If so, do they have an associated fauna?

- ***Comets**:* ESA's Rosetta mission to comet P/Wirtanen is currently well into the building stage, with a launch due in 2003. Although this mission is designed to answer many questions concerning the origin and composition of primitive solar system materials, future cometary missions will be required to build on knowledge resulting from Rosetta. Specific questions that will still be outstanding include:

- ⇒ what sort of compositional variations (abundance, elemental and isotopic, in ice, dust and gas) are exhibited by different comets, and how are these related to cometary evolution?
- ⇒ what is the mineralogy of cometary dust? How does this relate to the mineralogy of primitive chondritic meteorites, and to the mineralogy of dust in protoplanetary disks and the interstellar medium?

- ***Other solar system bodies, e.g. Io, Callisto, Kuiper Belt Objects (KBOs):*** The realisation that life can survive and flourish in a range of hostile environments on Earth has opened up the possibilities that primitive life-forms, or their prebiotic precursors, might have been more widespread than previously believed. This observation, coupled with results from the Galileo probe (for the jovian satellites) and ground-based telescopes (for KBOs) suggests that, at the least, additional laboratory studies are necessary to investigate the prospects for extraterrestrial life in a wide range of environments. Moreover, experimental studies concerning the survivability of microbial spores in the space environment have underlined the potentiality of finding live spores in extraterrestrial materials.

- ***Extra-solar planets, and their spectral signatures:*** Current searches for extra-solar planets have succeeded in identifying larger than Jupiter-sized objects orbiting close to their central star (although an alternative hypothesis postulates that they are brown dwarves). Whatever the real nature of these large objects, their identification is an important step in the search for Earth-like planets. ESA's Darwin telescope, scheduled for launch around 2013, will search for Earth-like planets orbiting Sun-type stars and determine their spectral signatures.

Chemistry of the origin of life

There is a broad understanding that life originated from simple precursor molecules and proceeded via more complex molecules to self-replicating, metabolising entities capable of independent existence and subsequent evolution. However, the stages and mechanisms that comprise these processes are still poorly-understood. Topics within this field include the origin and identification of prebiotic molecules and the reactions that they undergo; specific questions still outstanding include:

- What are the chemical pathways by which organic molecules form in space?
- What is the inventory of precursor molecules in space, and their possible role in prebiotic chemistry?
- How are prebiotic molecules affected by thermal processing upon impact or radiation?
- To what extent did the geological environment of the early Earth control the appearance of life?
- How did complex prebiotic molecules progress to self-replication and metabolic activities?
- Did the metabolic function develop in parallel with the ability to self-replicate?
- Is the presence of a gravitational field important for the prebiotic-biotic transition?

Biological evolution of life

Following on closely from the previous topic are studies concerning the biological evolution of life. In order to trace the possible evolution of life in extraterrestrial habitats it is essential that the full range of possible habitats and the environmental envelope in which organisms can survive and flourish on Earth is appreciated and understood. To this end, outstanding questions include:

- What are the limits of life?
- Can a common ancestor be traced back from modern extremophilic microorganisms?
- Were the earliest organisms photosynthetic or chemosynthetic?
- How far did the geochemical evolution of the Earth influence the early evolution of life?
- How far did the early geological evolution of the Earth influence the subsequent evolution of life?
- How relevant is the geological environment to the appearance and evolution of life on other terrestrial bodies?

Fluid physics

Fluid physics involves the study of physical phenomena that develop in fluid phases and at their interfaces with other fluid or solid phases (heat and mass transfer, radiation, phase changes, complex fluids, combustion, etc.).

The following findings and specific recommendations were made for the fluid physics field:

- The new programme of ESA reflects a large number of space peer-reviewed proposals (135 in life sciences, 80 for fluid sciences). Consequently we consider it as representative of user/scientist demand. The chosen major topics are important for mankind (increase of knowledge, health improvement, development of new useful technologies, environment protection). This new bottom-up strategy has to be encouraged, even though the previous constraints are considered “not so bad”.
- The standard criteria for scientific excellence have been applied, as shown by the following facts: (i) evaluation of the results obtained during the last five years has led to high quality publications; (ii) the strict and international peer-review procedure put in place by ESA has improved the quality of the experiments; (iii) the involvement of Topical Teams, advisory panels, and working groups at European level has brought up new and interesting themes. Therefore in the area of fluid physics the needs are corresponding to the requests of a large fraction of the relevant teams. To improve the programme further, it is recommended that:

  ⇒ the criteria used by the peer reviewers during the evaluation phase have to be formalised, as well as the rules for the selection of the peer reviewers

  ⇒ the cross-fertilisation in the work of the Topical Teams has to be made more visible; their coordination will emphasize European excellence

  ⇒ the development of quick turnaround experiments should be fostered as long delays are detrimental

- The importance of the facilities under development must not be overlooked; they will be responsible for some inertia in the evolution of the programme. But the modularity of the new instrument suites is increased substantially; the importance of the EDR[5] concept is underlined.
- The structure of the pyramids reflects the essential elements in fluid physics; however some points should be added in the document under the top objective "*Exploring Nature*", namely "*Vibration and interfaces*".
- Fluid physics is a basic discipline used in many fields of science; the rigidity of the proposed structure often masks existing interdisciplinarity; the document should address how to remedy this problem.
- Europe has a leading position in the following areas: near and supercritical fluids, interface physics, Marangoni convection, granular material and, in general, all fluid physics. The USA has performed only a limited number of experiments in that field.
- There are numerous application-oriented aspects where benefits have been obtained for solving terrestrial problems, such as decontamination by supercritical solvents, improved oil recovery, clean combustion, cold oxidation, improved industrial evaporators, and improved crystal quality. Further emphasis should be laid on these application-oriented aspects.
- Fluid Physics is a fundamental field in many disciplines, including those that are not space specific. Therefore further interdisciplinary cooperation should be fostered. Already major results (e.g. capillary flows, near & supercritical behaviour of fluids) have been obtained thanks to gravity-free experiments. New projects, often multidisciplinary, are developing, such as granular material, biological flow, fluid handling.

Material sciences

The field of Material science deals with research on the relationship between the "structure" and the "properties" of materials. It also includes the design and fabrication of new materials with pre-determined properties. The term "structure" relates both to the microscopic scale, which implies the organisation of the component atoms, molecules or even electrons inside the material, and the macroscopic scale. Material properties are usually described in terms of mechanical, electrical, thermal, magnetic, optical and chemical properties.

This is an interdisciplinary field. Problems related to the behaviour of the chosen materials are almost always encountered in any scientific, technical or engineering activity. The degradation of materials under service ("ageing") is also an important area of research. In spite of the enormous advances in the knowledge and development of materials, securing of continued technological progress requires new, more specialised and reliable materials. This challenge and the economic implications make the field one of the most active areas of research.

The following recommendations are made for Material sciences:

- The new approach of ESA is generally good, but some changes should be

[5] European Drawer Rack; a multi-experiment facility on the International Space Station

made in the strategy for programme selection:

⇒ Improvement of peer reviews: the peer-review process should be based on two "legs", consisting of two different mixed advisory committees: (i) LPSAC (by ESA, ESF and others) to which input programmes come, in which comments are received from outside referees; the selection of proposals should be guided by excellence or innovation potential, by the feasibility of the experiment and the competence or experience of the group; there should be complementarity between space and ground experiments to support the proposals. (ii) Technical committees (ESA and others) should take into account facilities and infrastructure constraints (what is available, what new facilities are required) and manage the development of new instrumentation or facilities through open programmes).

⇒ The timetable for new facilities and for flights should be known well in advance.

⇒ Some top-down approach is also required to encourage cooperation, instrument development, etc.: the committees mentioned above should manage this in addition to the bottom-up approach.

⇒ Multidisciplinary cooperation is important and should be promoted top-down in any field.

- The relevance to space is important for this discipline and must be emphasized in proposal requirements.

- It is important to include new topics and ideas in the programme. Therefore there is a need for more frequent and open topical groups to promote scientific excellence ("fresh blood"); these activities can also come from the recommendations of the above mentioned committees.

- Concerning the pyramid structure, the following amendments are recommended:
  ⇒ under the top objective "*Exploring Nature*", the second level research priority "*Understanding physics*" is not a good title.
  ⇒ instead of "*Develop innovative......*" we propose "*Innovating technological processes.....*" (third pyramid)
  ⇒ "*polymers and polymorphism research*" should be included (third pyramid)
  ⇒ under the top objective "*Energy and Environment*" the topic "*Remote monitoring*" should be included
  ⇒ a programme for development of *in situ* characterisation facilities (such as spectroscopy, X-ray, etc.) is lacking and should be implemented.

- It is difficult to identify the potential for European leadership, compared with NASA. European excellence exists in the development of high-tech instrumentation. Furthermore, Europeans are more concerned about environmental protection and energy savings. There is a also great future for growth of materials from low viscosity fluids in microgravity environments, e.g. metallic foams, molecular crystals.

- International cooperation is important in this discipline: it affects all fields and, more importantly, the field of new instrumentation. It is recommended that special attention should be paid to cooperation with Latin-American countries.

- Examples of application-oriented research are: (i) measurements in a low-gravity environment permit the determination of material parameters that are important for developing casting technologies, new industrial solidification processes, etc., which is important in the case of the metallurgical industry; (ii) the development of novel sensors and remote control monitors; (iii) growth of high-purity crystals and detection of free crystals for micro-probe standards. Such activities should be further fostered.

Fundamental physics

D-MSM supports research in fundamental physics which seeks to understand the laws that determine:

- the fundamental nature of space and time
- fundamental interactions and symmetries
- quantum phenomena
- complexity (e.g. aerosols, colloids, etc.) and non-linear phenomena

Yet research in fundamental physics is also in the remit of other Directorates, most significantly in D-SCI, and a general finding of this workshop is that there is a need for improved coordination between these Directorates so as to integrate their research programmes more effectively.

- The workshop recognised and welcomes the fact that the programme planned by D-MSM is now primarily user-driven and is mainly based on proposals made by the scientific community. However, it felt that ESA must also have an overall strategic view of what it hopes to achieve in the area of fundamental physics and this will require coordination and cross-Directorate planning. To help to develop such a strategic view the existence of an independent permanent science advisory committee is important, one that can advise across Directorates and relate the space programme in fundamental physics to ground-based programmes of other agencies.

- In any particular area of fundamental science, progress will almost certainly require contributions from both space and ground-based programmes, and it is a problem that the former will primarily take place in ESA programmes and the latter in national programmes. Much improved collaboration between these programmes is essential. We observed that there is a better integration of ground-based and space-based science in the USA and, unless this problem is addressed in Europe, its competitiveness in this area will be badly affected. It also seems to be the case that the best groups in Europe are not necessarily applying for support for space-based proposals, preferring to concentrate on ground-based experiments. The reason may be the extreme complexity of approaching and convincing both national bodies and ESA. Approval mechanisms must therefore be made easier.

- In any strategy document produced by D-MSM it would be desirable to record what has been done in the past. However, more importantly, many areas of fundamental physics necessarily involve long-term planning and the workshop felt there was a need for more long-term exploratory workshops to supplement the successful development of Topical Teams.

- There are a number of areas in fundamental physics where Europe is particularly strong or playing a leading role. Some of these obviously require space-based programmes and therefore have a potential for European leadership in these areas of space-based research. Examples are:
  - ⇒ cold atoms (very precise clocks)
  - ⇒ complex plasmas
  - ⇒ quantum fluids
  - ⇒ cosmic and atmospheric dust
  - ⇒ superfluids

- The USA is catching up fast in these areas. Our American colleagues tend to move faster than in Europe, and those involved in planning must also move quickly if we are not to lose these opportunities.

- Though it is the hope of the workshop that Europe can play a leading role in some areas of space-science, it must be remembered that in the areas of fundamental science international collaboration is likely to be good for all the participants provided that they come together as equal partners.

- There are probably fewer opportunities for genuine multidisciplinary cooperation in the area of fundamental physics than in other areas of the D-MSM programme, but possibilities exist in the emerging field of complex and non-linear systems. On the other hand, the general public tends to be more positive about basic science than about certain applications of science and technology and the fundamental science programme provides opportunities for ESA's work to be better known. As has been said elsewhere ESA is not as well known as NASA and a bigger effort in public outreach is therefore needed.

- The workshop addressed the issue of education and felt that it did not wish to recommend that ESA fund PhD programmes which are best left to national authorities. However, fellowships at the post-doctorate level could be managed by ESA, even at the cost of some reduction of national fellowships. The example that could be followed is that of the CERN fellowships, which have achieved a very high status.

Appendix I
Participants to the Workshop – Planning Group members

Experts

Biology

• Kiefer, Jürgen	Universität Giessen, DE	*Physicist & biologist*	Overview
• Pages, Montserrat	CSIC, ES	*Molecular genetics*	
• Stackebrandt, Erko	DSMZ GmbH, Braunschweig, DE	Microbial taxonomy	Chair
• Trewavas, Tony	Inst. Cell & Molecular Biology Edinburgh, UK	*Molecular, plant, microbiology*	Overview

Physiology/Medical research

• Clément, Gilles	CRCC Toulouse, FR	*Neurosensory*	
• Di Prampero, Pietro E.	School of Medecine Udine, IT	*Muscle*	
• Linnarsson, Dag	Karolinska Inst., Stockholm, SE	*Pulmonary*	Overview
• Norsk, Peter	DAMEC Res. Copenhagen, DK	*Cardiovascular*	Chair
• Fong, Kevin	Pinner, Middlesex, UK	*Emergency medecine*	
• Sutherland, Ian	Brunel Inst. Bioengineer., UK	–	
• Thompson, Richard P.H.	EMRC-ESF	*Gastroenterology*	*Auditor*

Exobiology

• Brack, André	CNRS Orléans, FR	*Organics*	Overview
• Ehrenfreund, Pascale	Leiden Observatory, NL	*Cosmic chemistry*	
• Perez-Mercader, Juan	LAEFF-INTA, Torrejon, ES	*General exobiology*	
• Prieur, Daniel	UBO/IUEM, Brest, FR	*Marine biology*	
• Westall, Frances	Lunar & Plan. Inst., Houston, USA	*General exobiology*	Chair
• Wynn-Williams, David	BAS - NERC, UK	*Extremophiles*	Overview
• Grady, Monica	Natural History Mus., London, UK	*General exobiology*	Overview
• Konhauser, Kurt	University of Leeds, UK	*Environmentgeochemistry*	

Fluid sciences

• Beysens, Daniel	CEA Pessac, FR	*Critical point*	
• Joulain, Pierre	ENSMA Poitiers, FR	*Combustion*	
• Legros, Jean-Claude	ULB Bruxelles, BE	*Fluids, thermodynamics*	Chair
• Passerone, Alberto	CNR/ICFAM Genoa, IT	*Emulsions*	Overview
• Amberg, Gustav	KTH Stockholm, SE	*Marangoni, 2-phase fluids*	Overview
• Giglio, Marzio	Università di Milano, IT	*Properties of fluid systems*	

Material sciences

• Fecht, Hans J.	Universität Ulm, DE	*Thermophysical properties*	Overview
• Garcia-Ruiz, Juan M.	CSIC Granada, ES	*Crystals*	
• Da Silva, Maria Fernanda	ISP, Lisboa, PT	*Material sciences*	
• Orera, Victor M.	Faculdad de Ciencia, Zaragoza, ES	*Material sciences*	Chair
• Ott, Hans Rudolf	ETH – HPF, Zürich, CH	*Material sciences*	
• Omling, Pär	PESC-ESF	*Solid state physics*	Auditor

Fundamental physics

• Prodi, Franco	ISAO-CNR Bologna, IT	*Atmospheric particles*	
• Salomon, Christophe	ENS-CNRS, Paris, FR	*Cold atoms, relativity*	Overview
• Butterworth, Ian	Imperial College, London, UK	*Fundamental physics*	Chair
• Galazka, Robert R.	Inst. Physics, PAS, Warsaw, PL	*Solid state physics*	Overview
• Guet, Claude	CEA Grenoble, FR	*Fundamental physics*	

Guest observers

• Cogoli, Marianne	ELGRA	President ELGRA
• de Groot, Rolf P.	ESA PB-MG	Netherlands delegate
• Léon-Hirtz, Sylvie	ESA PB-MG	France delegate
• Magnusson, Per	ESA PB-MG	Sweden delegate
• Ruyters, Günther	ESA PB-MG	Germany delegate

Auditors

• Amhrein, Nikolaus	LESC-ESF
• Horneck, Gerda	ESSC-ESF
• Omling, Pär	PESC-ESF
• Thompson, Richard P.H.	EMRC-ESF

Planning Group members

• Amhrein, Nikolaus	LESC-ESF	
• Clancy, Paul	ESA D-MSM	
• Culhane, J. Leonard	ESSC-ESF	Chairman ESSC
• Heppener, Marc	ESA D-MSM	
• Horneck, Gerda	ESSC-ESF	Chair ELIPS-ESSC
• Mehlert, Svenje	ESF	Scientific Secretary ESF (PESC, LESC)
• Omling, Pär	PESC-ESF	
• Thompson, Richard P.H.	EMRC-ESF	
• Worms, Jean-Claude	ESSC-ESF	Executive Secretary ESSC

Appendix 2
ESSC members in 2000

Chairman:

John Leonard Culhane	Mullard Space Science Laboratory, University College London, UK

Daniel Beysens	Commissariat à l'Energie Atomique, Pessac, France
Johan A.M. Bleeker	Space Research Laboratory, SRON, Utrecht, Netherlands
Anny Cazenave	LEGOS, GRGS-CNES, Toulouse, France
Marie-Lise Chanin	SPARC Office, Verrières-le-Buisson, France
Augusto Cogoli	Space Biology Group, ETH Zürich, Switzerland
Hasse Fredriksson	Dpt. of Materials Processing, KTH, Stockholm, Sweden
Gerda Horneck	DLR – Institut für Luft und Raumfahrtmedizin, Köln, Germany
Hannu Koskinen	Dpt. of Physics, University of Helsinki, Helsinki, Finland
Niels Lund	Danish Space Research Institute, Copenhagen, Denmark
Philippe Masson	University Paris-Sud, Orsay, France
Ian S. Robinson	Southampton Oceanography Centre, Southampton, UK
Rafael Rodrigo	Instituto de Astrofisica de Andalucia, Granada, Spain
Paul C. Simon	Institut d'Aéronomie Spatiale de Belgique, Bruxelles, Belgium
Gianni Tofani	Osservatorio Astrofisico Arcetri, Firenze, Italy
Martin J.L. Turner	University of Leicester, Leicester, UK
Stefano Vitale	Dipartimento di Fisica, Università di Trento, Italy
John C. Zarnecki	The Open University, Milton Keynes, UK

ESSC Executive Secretary:

Jean-Claude Worms	Illkirch, France

ESF Scientific Secretary:

Svenje Mehlert	Strasbourg, France

Ex Officio (COSPAR):

Gerhard Haerendel	International University, Bremen, Germany

Appendix 3
Reference documents

1. Roadmap for the Future Programme in Life and Physical Sciences and Applications, Microgravity Programme Board, ESA/PB-MG(2000)13, Paris, 14 March 2000.

2. Letter from D-MSM to ESSC, MSM-GA/099-00/MH, Noordwijk, 4 April 2000.

3. Preparation of the Physical and Life Sciences Research and Applications Programme, Presentation to the ESA-ESSC-ESF brainstorming meeting, ESTEC, 8 May 2000.

4. Towards a European Strategy in Life and Physical Sciences in Space, Presentation to the ESA-ESSC-ESF brainstorming meeting, ESTEC, 8 May 2000.

5. Topics in Physical Sciences, Presentation to the ESA-ESSC-ESF brainstorming meeting, ESTEC, 8 May 2000.

6. Towards a Harmonized Peer-review Procedure for Life and Physical Sciences in Space, Presentation to the ESA-ESSC-ESF brainstorming meeting, ESTEC, 8 May 2000.

7. ISLSWG Principle: Pooling of Life Sciences ISS Resources, Presentation to the ESA-ESSC-ESF brainstorming meeting, ESTEC, 8 May 2000.

8. Assessment of ESA's Roadmap for a Future Programme in Life and Physical Sciences and Applications, ESSC Terms of Reference for a European Workshop, DOC(00)3, ESSC-ESF, Strasbourg, 15 May 2000.

9. Letter from ESSC to D-MSM, LET(00)43, Strasbourg, 15 May 2000.

10. European Research Plan for Life and Physical Sciences in Space, Microgravity Programme Board, ESA/PB-MG(2000)24 and 3 annexes, Paris.

11. Status of MAPs, Topical Teams and Experiment Selection, Microgravity Programme Board, ESA/PB-MG(2000)27 and 2 annexes, Paris, 16 June 2000.

12. ESA D-MSM briefing to the planning group meeting, ESTEC, 5 July 2000.

13. Letter from D-MSM to ESSC, MSM-GA/212-00, Noordwijk, 17 July 2000.

14. Status of MAPs, Topical Teams and Experiment Selection, Microgravity Programme Board, ESA/PB-MG(2000)27, rev. 1 and 2 annexes, Paris, 23 November 2000.

15. A European Research Strategy for Life and Physical Sciences and Applications in Space, ESA D-MSM, ESTEC, 23 November 2000.

16. ESA Experiment Facilities for Life and Physical Sciences in Space, Information note to the workshop participants, Le Bischenberg, 28 November 2000.

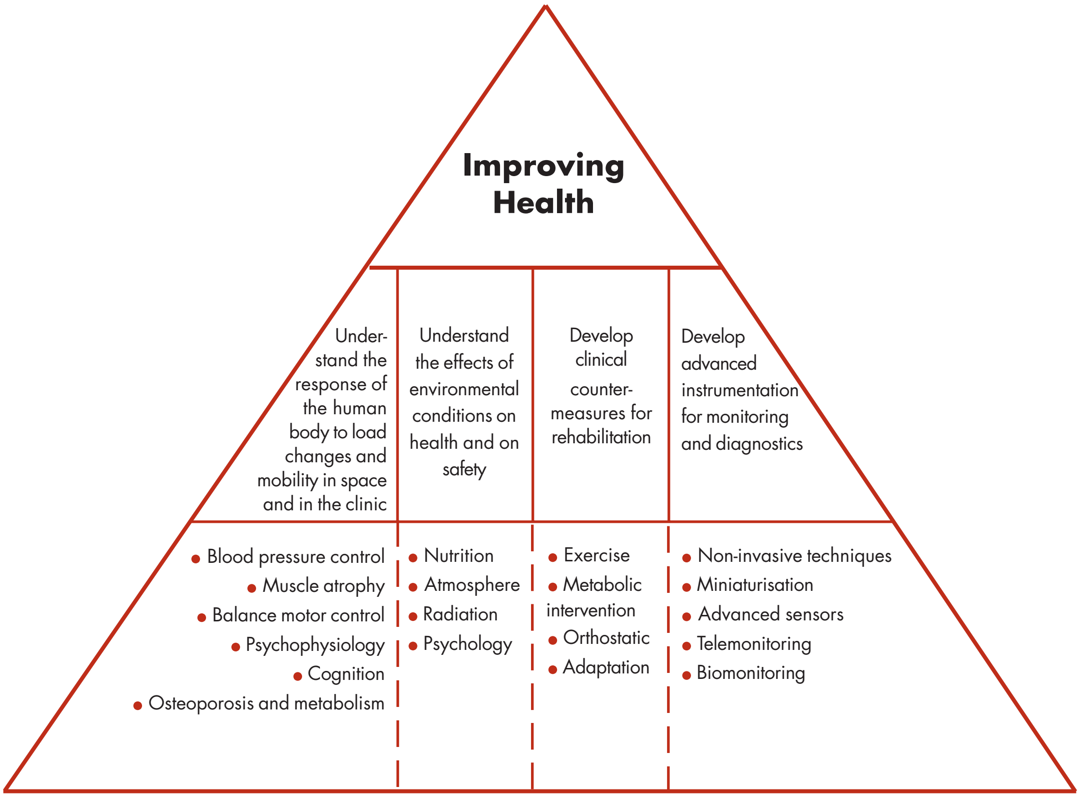
17. Information on Requirements and Selection Criteria in ESA Announcements of Opportunity, Information note to the workshop participants, Le Bischenberg, 28 November 2000.

18. Status of Research Plan/Programme Proposal for Future Life and Physical Sciences Programme, ESA/PB-MG(2000)41 and addendum 1, Paris, 29 November 2000.

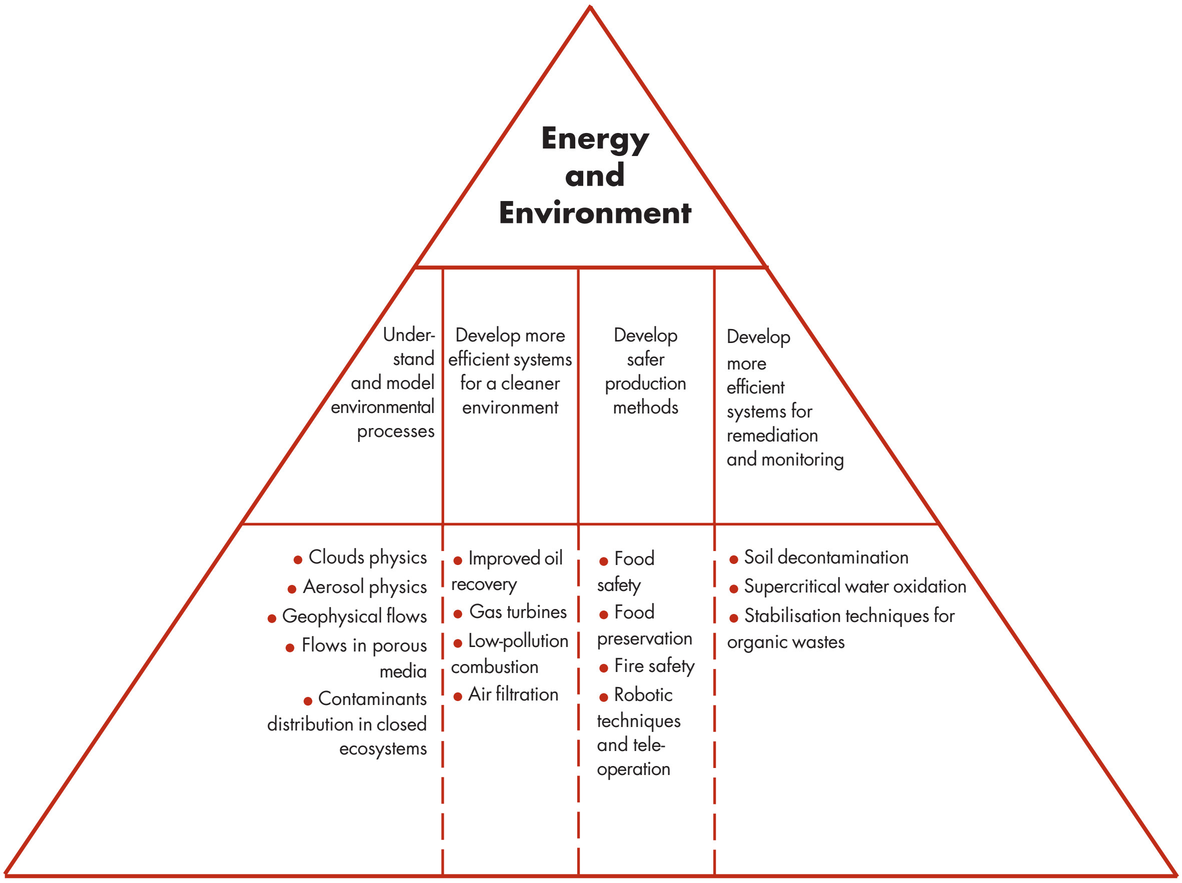
Appendix 4 – Pyramids

Remarks concerning the specific contents of the programme proposal or the pyramids appear in the sections presenting the findings by discipline. The pyramids proposed by ESA and PB-MG are the following:

- Pyramid 1: Exploring Nature
- Pyramid 2: Improving Health
- Pyramid 3: Innovating Technologies and Processes
- Pyramid 4: Energy and Environment


Improving Health
Understand the response of the human body to load changes and mobility in space and in the clinic
Understand the effects of environmental conditions on health and on safety
Develop clinical counter-measures for rehabilitation
Develop advanced instrumentation for monitoring and diagnostics
Blood pressure control
Muscle atrophy
Balance motor control
Psychophysiology
Cognition
Osteoporosis and metabolism
Nutrition
Atmosphere
Radiation
Psychology
Exercise
Metabolic intervention
Orthostatic
Adaptation
Non-invasive techniques
Miniaturisation
Advanced sensors
Telemonitoring
Biomonitoring


Innovating Technologies and Processes
Understand the role of gravity in agriculture and bioengineering
Understand the role of gravity-influenced flows in processes
Support the development of models for process prediction and optimisation
Develop innovative processes and materials
Genetic improvement of plant g-sensitivity
Micro-encapsulation for controlled drug release, and for cell protection
Transport mechanisms
Microstructure formation in metals and alloys
Defect formation in crystal growth
Interfacial phenomena
Foams and emulsions
Flows in bioprocesses
Thermo-physical properties measurements (high-T melts, crude oils etc.)
Validate models with experiments performed under well defined conditions
Artificial functional tissues for parallel drugs screening
Alternatives for animal models
Combustion
Casting
Crystallisation
Advanced heat exchangers
Advanced plasma-based technologies
Magnetic fluids
Metallic foams
Functional & structural materials
Nano-materials
Advanced sensing systems
Analytical bioreactors for artificial organs



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