Executive Summary

Ten to twenty years from now, a succession of clever new spacecraft will need to be ready to fly in ESA's continuing Science Programme, now called Cosmic Vision. They will tackle some of the big scientific questions that are posed in this document. Such long-term planning has already proved its worth in the Horizon 2000 (1984) and Horizon 2000 Plus (1994-1995) plans. They enabled Europe's scientific, technological and industrial teams to commit themselves with confidence to the many years of hard work that it takes to conceive and execute space projects of world-beating quality.

In that highly successful tradition, Cosmic Vision 2015-2025 aims at furthering Europe's achievements in space science for the benefit of all mankind. The plan is based on a massive response by the scientific community to ESA's call for themes, issued in April 2004. A total of 151 novel ideas (listed in Annex 2) were submitted, more than twice as many as for the equivalent exercise in 1984.

ESA's scientific advisory committees and working groups then made a preliminary selection of themes, which were discussed in a workshop in Paris in September 2004, attended by nearly 400 members of the scientific community. After an iteration with the Science Programme Committee (SPC) and its national delegations, ESA's Space Science Advisory Committee (SSAC) prepared the present plan with the keen assistance of ESA's Directorate of Science. The SSAC is made up of scientists chosen for their scientific standing and who are expected to represent the views of the European science community as a whole rather than any particular national interest. A further encounter with the wider space science community occurred at a symposium in Noordwijk in April 2005. On 5 May 2005, in Helsinki, the SPC saw a draft of the report and endorsed the approach.

Science in the 21st Century is seeking answers to profound questions about our existence, and our survival in a tumultuous cosmos. What is even more important is the rate of increase of our knowledge. We can now pose questions that seemed beyond our reach less that a generation ago. Many of the answers can be sought and found only with space projects of ever-increasing ingenuity. ESA is not alone in recognising the scientific challenges, and it embraces collaboration with other agencies whenever that is opportune. However, Europe has made its most distinctive contributions to space science by giving its own scientists every opportunity to prioritise their goals.

Cosmic Vision 2015-2025 addresses four main questions that are high on the agenda of research across Europe (and, indeed, worldwide) concerning the Universe and our place in it:

— what are the conditions for planet formation and the emergence of life?
— how does the Solar System work?
— what are the fundamental physical laws of the Universe?
— how did the Universe originate and what is it made of?

Chapters 1 to 4 spell out the opportunities under these headings, and identify specific aspects of each general theme that are judged to be especially ripe for investigation by new space tools in the period 2015-2025. Chapter 5 reviews the technology that will have to be developed. Finally, this planning on behalf of the scientific community and aerospace industry takes into account the Science Directorate's preliminary reckoning of the practical constraints of technology. In *Proposed Strategies and Their Implementation* (Chapter 6), the outcome of these deliberations is summarised in four tables that correspond to our four key questions. A compacted version of those tables is shown overpage.

The team preparing Cosmic Vision 2015-2025 has subdivided the four main questions by selecting areas where major progress can be expected in the next two decades. Under each of the resulting sub-headings, one, two or three appropriate space techniques (or tools) are nominated. It is here that technical progress in the next 10 years is required, and the targets finally chosen and the progress made will determine what we can confidently do scientifically maybe 20 years from now. In some cases, the same technique or tool appears in more than one context, thanks to its cross-disciplinary character.

The breadth of the investigations represented in the table is enormous. They range from the poles of the Sun to the birth of the Universe, from gigantic cosmic structures to sub-atomic particles. Also remarkable is the way that very different techniques converge on the same question, whether it is the origin of life or the fundamental physics of the cosmos that make our existence possible.

The space tools in the table should be seen as candidate concepts for missions, rather than as cut-and-dried requests for individual funding. Still less are they firm promises to the scientific community. Too many projects have been proposed for them all to be affordable in the 2015-2025 timeframe. Exactly how much can be accomplished will depend on the Level of Resources of the Science programme, but also, in part, on what international collaborations can be arranged. Competition between the candidate concepts will be unavoidable.

In any case, some flexibility must remain in the space science programme, to allow for unforeseen opportunities or difficulties, whether in the science or in the technology. The readiness of the technology – often highly innovative – will be a factor in the selection and sequencing of the eventual missions.

It is foreseen that ESA's Directorate of Science will issue a succession of Calls for Mission Proposals to implement the plan. Following a successful tradition, international collaboration with non-European space agencies, including NASA, will be a key ingredient in the implementation of this programme. Within Europe, interactions with national space programmes, and also with the European Southern Observatory (ESO) and the European Organisation for Nuclear Research (CERN), will be explored in full. Within ESA itself, strong coordination with the Earth Observation Programme, the Aurora Exploration Programme and other programmes will give an overall boost to the scientific and technological activities proposed here.

Thanks to the blend of ambition and realism in our plan, Europe's aerospace industry has not only expressed a strong interest in the ideas, but also pledged its support for the future of science in space. With every new space technique or tool envisaged here, Europe's technological competence will grow.

Above all, Cosmic Vision 2015-2025 should appeal to the new European Space Council, because it fosters the European Union's visible presence in space activities from which many strategic, industrial, cultural and educational benefits will flow. The plan is an expression of trust in Europe's political will, from the large and multi-faceted space science community in universities and institutes throughout the continent. The scientists who gladly contributed their best ideas and expertise to our study now confidently expect support for the timely implementation of this exciting programme.

Prof. Giovanni F. Bignami,
Chair, Space Science Advisory Committee

Prof. Peter J. Cargill,
Chair, Solar System Working Group

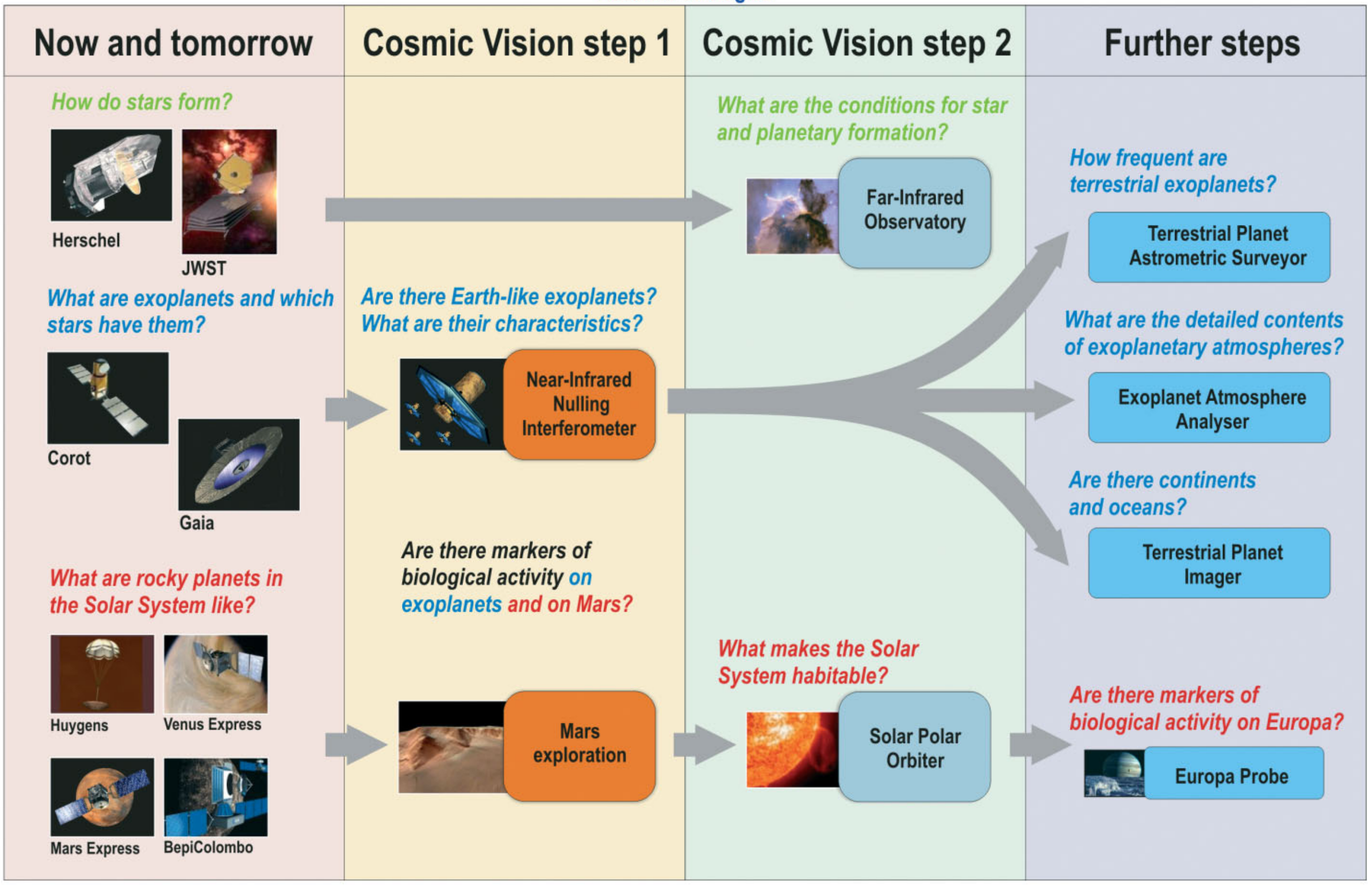
Prof. Bernard Schutz,
Chair, Fundamental Physics Advisory Group

Dr. Catherine Turon,
Chair, Astronomy Working Group

Scientific Questions ***subdivided into topics where important progress can be expected in the Cosmic Vision 2015-2025 timeframe***	**Candidate Projects** ***in strategic sequences (question by question)***
1. What are the conditions for planet formation and the emergence of life? **1.1 From gas and dust to stars and planets** Map the birth of stars and planets by peering into the highly obscured cocoons where they form **1.2 From exo-planets to biomarkers** Search for planets around stars other than the Sun, looking for biomarkers in their atmospheres, and image them **1.3 Life and habitability in the Solar System** Explore *in situ* the surface and subsurface of the solid bodies in the Solar System most likely to host – or have hosted – life Explore the environmental conditions that makes life possible	**Near-Infrared Nulling Interferometer** **Mars Landers + Mars Sample Return (*with Aurora Programme*)** **Far-Infrared Observatory** **Solar Polar Orbiter** **Terrestrial Planet Astrometric Surveyor** **Europa Landers**
2. How does the Solar System work? **2.1 From the Sun to the edge of the Solar System** Study the plasma and magnetic field environment around the Earth and around Jupiter, over the Sun's poles, and out to the heliopause where the solar wind meets the interstellar medium **2.2 The giant planets and their environments** *In situ* studies of Jupiter, its atmosphere, internal structure and satellites **2.3 Asteroids and other small bodies** Obtain direct laboratory information by analysing samples from a Near-Earth Object	**Earth Magnetospheric Swarm** **Solar Polar Orbiter** **Jupiter Exploration Programme *including* Europa Orbiter and Jupiter probes** **Near-Earth Object Sample Return** **Interstellar Heliopause Probe**
3. What are the fundamental physical laws of the Universe? **3.1 Explore the limits of contemporary physics** Use stable and weightless environment of space to search for tiny deviations from the standard model of fundamental interactions **3.2 The gravitational wave Universe** Make a key step toward detecting the gravitational radiation background generated at the Big Bang **3.3 Matter under extreme conditions** Probe gravity theory in the very strong field environment of black holes and other compact objects, and the state of matter at supra-nuclear energies in neutron stars	**Fundamental Physics Explorer Programme** **Large-Aperture X-ray Observatory** **Deep Space Gravity Probe** **Gravitational Wave Cosmic Surveyor** **Space Detector for Ultra-High-Energy Cosmic Rays**
4. How did the Universe originate and what is it made of? **4.1 The early Universe** Define the physical processes that led to the inflationary phase in the early Universe, during which a drastic expansion supposedly took place. Investigate the nature and origin of the Dark Energy that is accelerating the expansion of the Universe **4.2 The Universe taking shape** Find the very first gravitationally-bound structures that were assembled in the Universe – precursors to today's galaxies, groups and clusters of galaxies – and trace their evolution to the current epoch **4.3 The evolving violent Universe** Trace the formation and evolution of the supermassive black holes at galaxy centres – in relation to galaxy and star formation – and trace the life cycles of matter in the Universe along its history	**Large-Aperture X-ray Observatory** **Wide-Field Optical-Infrared Imager** **All-sky Cosmic Microwave Background Polarisation Mapper** **Far-Infrared Observatory** **Gravitational Wave Cosmic Surveyor** **Gamma-Ray Imager**

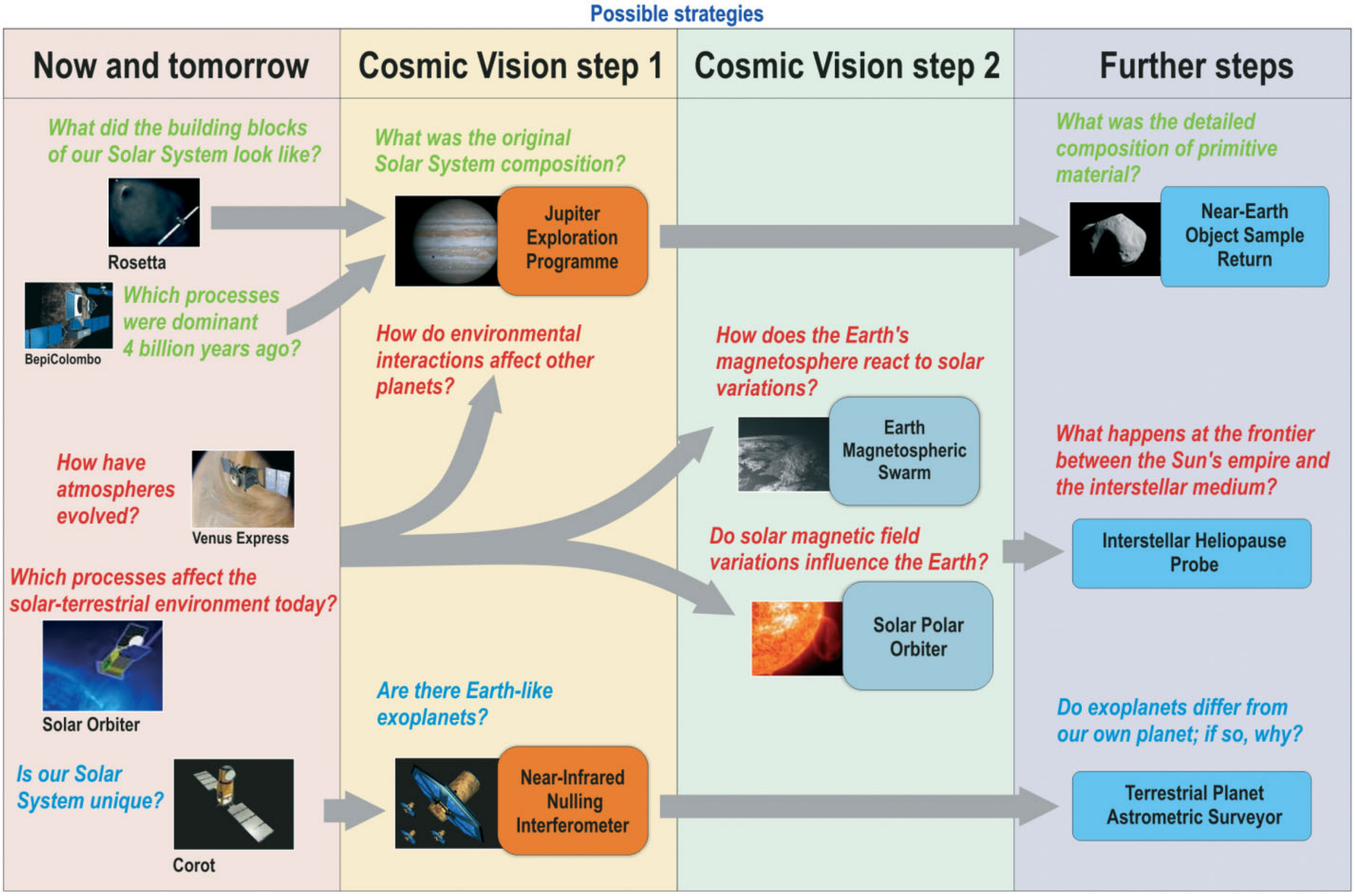
1. What are the conditions for planetary formation and the emergence of life?

Possible strategies



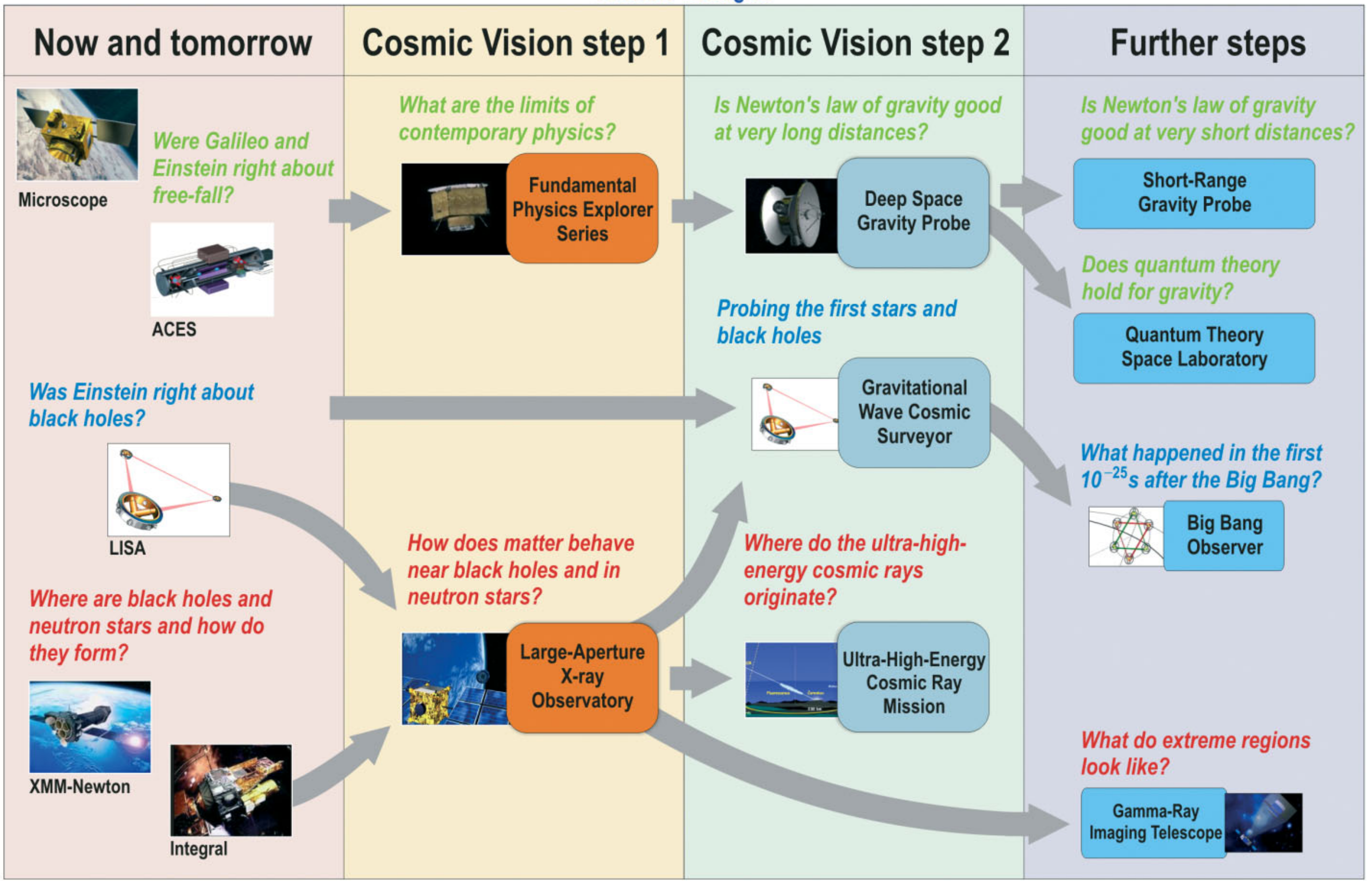
2. How does the Solar System work?

Possible strategies



3. What are the fundamental physical laws of the Universe?

Possible strategies



4. How did the Universe originate and what is it made of?

Possible strategies