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STUDY ON SPACE SCIENCES IN BRAZIL

Roger-Maurice Bonnet[*]

Valer a pena, tudo vale a pena se a alma não è pequena (F. Pessoa)

FOREWORD

The author wants to commend INPE and the Brazilian space community for having invited international experts to analyze their accomplishments in space and help them do better. This is a great sign that ***matters are taken seriously in the country***. The tone of this report may in some places sound over-critical, but none of these "critics" is formulated in a negative spirit. Just there to help a country that has so much to offer to the world.

The excellent web page of INPE has been an important tool in trying to understand the present situation of Brazil. Unfortunately, the author regrets that it has not been possible to interview directly on the spot a large number of representatives of the scientific community and of industry as well as of INPE and the Brazilian Space Agency. In that context, he would like to thank in particular Drs Odim Mendes Jr., Inez Staciarini Batista and all those who at INPE or in the Brazilian and international scientific community have provided elements and information not usually available on the web.

The report ends with a set of 22 recommendations. Some of them may look trivial or are already taken into account, and in that case we apologize if we unlock doors already opened. However, the main remark to make at the onset is the ***very modest involvement of INPE in space sciences*** (only 2% of the budget) as well as the small number of space scientists, even though their quality is world class. ***A special effort therefore ought to be made*** by the Brazilian authorities ***to redress such a situation,*** faulty of which Brazil will remain in a marginal position on this essential activity of science and knowledge which makes great nations worth being respected.

1. INTRODUCTION

Space Research was initiated at the occasion of the International Geophysical Year with the launch by the Soviets of Sputnik-1, the first artificial satellite of the Earth on 4 October 1957. This historical event marked the beginning of a genuine revolution in science and technology. It rapidly opened the possibility of managing

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the planet on a global scale, through observation satellites, yielding spectacular progress in weather forecasting and in the understanding of the Earth system. It was born during the most intense moments of the cold war between the Soviet Union and the United States. The following 35 years were marked by the competition between these two super powers and at the same time by cooperation between them and the rest of the world until the fall of the Berlin wall in November 1989. That event let the United States alone as undisputable leaders in space, far above all other countries in terms of space expenditures in all sectors of civilian and military activities.

In that same period, other countries soon realized the potential assets of space activities. That was the case of Japan and of individual European nations, which pursued in parallel to their own domestic space program a common European program, first through the ESRO/ELDO organizations and then through the European Space Agency (ESA) which also includes Canada and the former East European countries. The next 50 years will witness an increased role of space in the fields of science and exploration, Earth management, navigation, and applications in general. They will also be marked by the increasing role of countries with potentially strong expanding economies already involved in space which include primarily Russia, China, India and Brazil. These countries will modify the present balance of roles and they will have an increasing contribution to major international projects. Given their enormous human potential, they have the capability of becoming leaders in their full right. Brazil in this context, as the biggest space nation of South America, if it so wishes, could play the leadership role that its history and culture justify it embraces seriously. The author of this report would be happy if he can contribute to this justified ambition.

In the limited set of presently existing space faring nations we can distinguish two main groups. The first, called ***Group-1*** in the report is constituted of the USA, Europe, Canada and Japan. The second, called ***Group-2*** regroups countries with potentially strong expanding economies and large territories: China, India and Brazil, Russia staying between these two categories. It can easily be verified that countries with a high scientific level (the G-8 countries) have developed a broad spectrum of activities in all branches of space science, while countries with a less visible scientific capacity seem to have restricted themselves to more applied activities, directly responding to their respective government's concerns.

For countries in Group-1, Space is part of their foreign, national and industrial policy, it is also considered as a scientific as well as a cultural and strategic asset. The same can characterize the countries of Group-2; however, their priority has been logically given to the management of their large territory, of their resources and of the natural as well as of the man-induced phenomena and disasters. It appears as if involvement in space activities in countries of Group-2 can be more easily justified on the basis of immediate and visible domestic benefits than on considerations of prestige or of international dominance. The costs of space science missions, usually higher than other types, might have been a dissuasive element for these countries.

The situation is changing in China and India whose space programs now incorporate ambitious astronomy and planetary missions, including missions to the Moon and Mars. As far as we can judge, Brazil is not involved in such missions.

This report analyzes first the situation of space science in the world, its achievements in the past 50 years and its prospects for the next 50 years. It also discusses the role of space science with respect to national strategies and policies, and its relations to other branches of space activities. It discusses also the role and place of emerging nations such as China, India and Brazil, and makes an attempt to outline a possible strategy for Brazil.

2. ANALYSIS OF THE EVOLUTION OF SPACE SCIENCE

2.1 The past 50 years

The use of artificial satellites, space probes as well as rockets and balloons have led to a genuine revolution in science and in knowledge. The main reasons are directly connected to the capability of:

- observing above the Earth's atmosphere through the whole electromagnetic spectrum, unaffected by atmospheric turbulence,
- exploring in situ the planets and the smaller bodies of the solar system sometimes landing on some of them (Figure1),
- using the same set of instruments to observe the whole sky as opposed to different instruments used on different parts of the Earth (Figure2),
- observing the Earth from above, simultaneously over different parts of its surface (Figure3),
- conducting experiments in a reduced gravity environment in particular on living organisms, including Man.

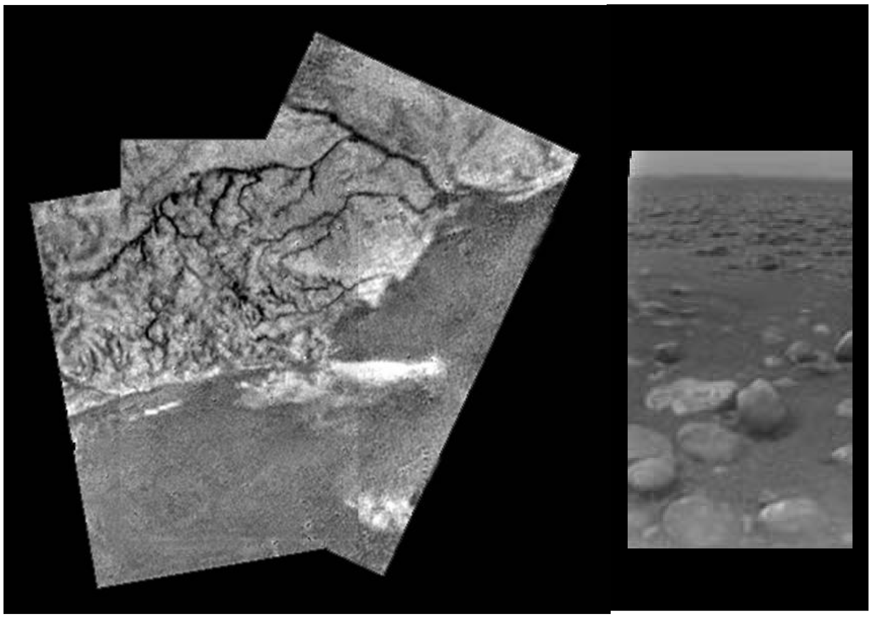

Figure 1: First images of the surface of Titan made by the European Huygens probe on board NASA Cassini mission. Credit ESA.

The achievements of this activity are spectacular. They extend to the discovery of X-ray emission by neutron stars and black holes, the observation of the characteristics of the cosmic background radiation 300,000 years after the Big Bang, the precise determination of the age of the Universe and the evolution of its structures, dark matter and dark energy, galaxies and stars, from their birth to their deaths, and planets. They reveal the diversity of the objects of the solar system, evidencing the commonality of several phenomena such as craterization, volcanism, fluvial circulation, magnetospheric envelope, leading to an improved scenario for its formation. They refer to our understanding of the solar interior, of its eleven years activity cycle, and how its radiation and its magnetic field vary in time and influence the Earth and the whole solar system. They offered an unprecedented view of our planet and of its evolution in the context of global warming and other natural or anthropogenic induced phenomena and disasters. These results have been acknowledged by prestigious awards such as among others the Crafoord Prize in 1985, 1986 1989 and the Nobel Prize in Chemistry in 1995 and Physics in 2002 and 2006, (Table 1).

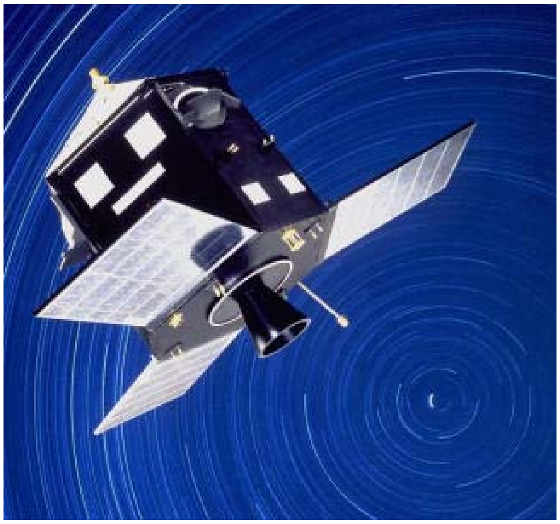

Figure 2: The Hipparcos astrometry mission has led to a quantum jump in precision by observing the whole celestial sphere from above the Earth's atmosphere using a single telescope.

Prize	*Year*	*Discipline*	*Laureates*
Crafoord	**1985**	**Astronomy**	**L. Spitzer**
Crafoord	**1986**	**Geosciences**	**C.J. Allègre, G.J. Wasserburg**
Crafoord	**1989**	**Astronomy**	**J. Van Allen**
Nobel	**1995**	**Chemistry (Earth sciences)**	**P. Crutzen, M.J. Molina, F. Sherwood-Rowland**
Nobel	**2002**	**Physics**	**R. Giaconi**
Nobel	**2006**	**Physics**	**J.C. Mather, G.F. Smoot**

Table 1: List of the most prestigious awards in physics, chemistry, astronomy and geosciences in connection with the space involvement of the respective laureates

Most of these prizes have been obtained in the framework of international cooperation between the various space faring nations but not only. Indeed, international cooperation has been a powerful motor for space science and still today is a sign of world wide recognition, of scientific value and of merit. Many of the most prestigious space projects have been conducted in the framework of international cooperation. This is the case for example of all ESA missions, and also of the Hubble Space Telescope (NASA-ESA), Comet Haley missions (ESA- ISAS-IKI-NASA), Cassini-Huygens (ESA-NASA), SOHO (ESA-NASA), Topex-Poseidon (NASA-CNES) and Jason (NASA-CNES), and many others.

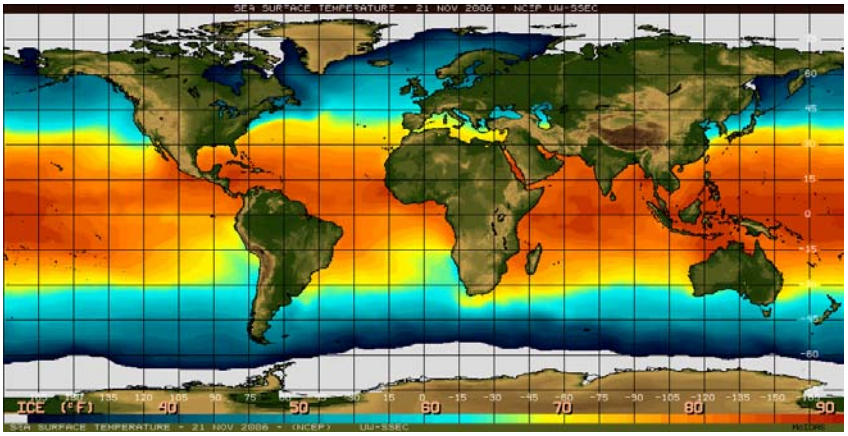

Figure 3: Global map of the Sea Surface temperature of 21 November 2006, ranging from 0°C to 32°C. These maps are established on a daily basis. (Credit: Space Science and Engineering Center, University of Wisconsin,-Madison).

The synergy between space and ground-based observations has been and still is an essential element of space science programs. In the case of astronomy their complementarity ensures access to larger and more powerful facilities, while for Earth observations it offers the possibility of conducting in situ measurements as well as of calibrating space borne instruments through precise data points in different local spots. If balloons and rockets have played a major role in the early days of space research, they tend to be more and more used as complements to satellite borne measurements, also for in situ measurements, calibration, testing or qualifying new instrumentation/technologies, or as part of observation campaigns. This role should not be undermined, even though the source of the main discoveries or of surveys is clearly falling in the camp of artificial satellites, space probes or planetary landers.

2.2 The next 50 years

The next 50 years will be marked by major progress due to the use of bigger facilities or of systems of satellites flying in formation, of tightly coordinated missions integrated into systems addressing scientific problems requiring different technologies or different observing sites. In that context, international cooperation will play an essential role especially in view of the emergence of new and powerful partners such as the countries of Group-2.

2.2.1 Astronomy.

The main space agencies in Group-1 regularly conduct in-depth reviews of the status of space science for the purpose of establishing their medium and long-term plans. One of the most recent of those has been prepared by the European Space Agency. Called ***Cosmic Vision,*** it offers an up to date view of the situation of space science and of the tendencies for future strategies in the field[*]. What follows is largely inspired by this recent reflection. The US Academy of Sciences is also conducting decadal surveys for both ground based and space astronomy.

For the sake of concision, four main themes of interest can be identified which will frame the choice and definition of future space programs. We review them now. The first two are very similar in scope. However, they require fairly different instrument or tools to be implemented. This is the reason why they have been separated into two different categories.

Theme A1: Cosmology, the origin and evolution of the Universe.

One great question concerns the existence and nature of ***dark matter and dark energy*** as a possible explanation to the apparent irregular expansion of the Universe, starting with ***inflation***, then ***deceleration*** until 4 to 5 billion years and then ***acceleration*** again. Finding the origin of dark matter and of its distribution requires large facilities operating in the visible and in the infrared as well as in X-rays. They will exploit the technique of ***gravitational lensing***, the establishment of a precise luminosity to red shift relation of distant supernovae, the measurement of polarization of the cosmic microwave background yielding presently missing data on the physical conditions of the ***Big Bang.*** Hopefully ESA's ***Planck*** mission to be launched in 2008 will add more data to the already rich harvest obtained with NASA's ***COBE*** and ***WMAP*** missions. It is very likely that they will require follow-on observations due to the complexity and evolving character of the Big Bang scenario. Some of them might be conducted with ***balloons from the South Pole.***

Another great question concerns the birth and development of the first structures of the Universe: have stars formed first and how, or have galaxies developed first becoming then the cradle of stars? What has been the role of ***black holes*** in the whole process? Were they precursors to galaxies or the result of early galaxies merging into each others trough gigantic collisions? Since these objects are far away, because of their red-shifted light they can be observed only with large telescopes operating in the far infrared, in the millimetric or sub-millimetric range such as the 3,5 m ***Herschel telescope*** of ESA. The detection of super-massive black holes can be done through the measurement of the velocity and temperature of matter as it is accreted in their vicinity and through the transient emission of high energy radiation. In that respect, ***X and gamma ray instruments*** will play an essential role as

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[*] Cosmic Vision is the follow-on of the Horizon 2000 and Horizon 2000-plus long-term programs which the author has conducted while at ESA as Director of the Science Program.

well as high resolution infrared spectrometers able to pierce the blocking effect of the dust which masks the centers of galaxies, where these massive black holes reside.

The tools required to cope with Theme A1 *include as examples:* ***large-aperture far infrared, X-ray and gamma-ray imaging observatories****. In addition, following the forthcoming* ***JWST****, wide-field* ***optical imagery*** *and* ***polarization measurements*** *as well as infrared* ***Gravitational wave*** *detectors will offer the possibility of understanding the physical conditions which characterize the Big Bang.*

Theme A2: revisiting the fundamental physical laws of the Universe

Space astronomy offers unique possibilities to explore the ***limits of physics***: limits of ***gravity***, of ***time***, of distances, of temperatures, of densities and velocities. As of now, space techniques have not yet been fully exploited. Nevertheless, there is a growing interest to use the Universe and the space environment as a ***scientific laboratory*** to test the fundamental laws of physics and verify their validity in various and extreme conditions. This is the case of ***general relativity***, symmetry violations, fundamental constants, short-range forces, quantum physics of Bose-Einstein condensates, ***ultra-high-energy cosmic rays***, looking for clues to unified theories.

The stable and gravity-free environment of space offers unique conditions to implement high-precision experiments, searching for tiny deviations from the standard model of fundamental interactions, testing the ***validity of Newtonian g*****ravity** using a trans-Saturn drag free mission. From orbit it is also possible to observe the patterns of light emitted from the Earth’s atmosphere by the showers of particles produced by the impacts of sub-atomic particles of ultra-high-energy.

Primordial ***gravitational waves***, unaffected by ionized matter, are ideal probes for checking the validity of the laws of physics at the extreme energies and temperatures of the Big Bang. They open an ideal window to probe the ***Universe*** and ***dark energy at very early times.***

The study of the spectrum and time variability of radiation from matter near black holes shows the imprint of the ***curvature of space-time*** as predicted by general relativity. This has strong implications for astrophysics and cosmology in general.

__The tools for Theme A2__ include a broad spectrum of very diverse missions highly demanding in terms of technologies and of systems. They should be defined by the physicists themselves after consultation and competitive selection. This consultation should proceed at the same time as the ongoing __Gravity Probe-B__ mission and the studies of the Laser Interferometer for Space Astronomy (__LISA__) proceed. In the latter case however, there are doubts that the mission might start in the immediate future due to the re-organization of NASA's programme to cope with the Exploration initiative (see section 2.3).

Such a fundamental physics programme should include in particular for example, a __Deep Space Gravity Probe__, a Space detector for __ultrahigh-energy cosmic rays__, a __Gravitational Wave Surveyor__ and __Large-aperture X-ray telescopes__.

Theme A3: Life in the Universe and the formation of stars and planets

The next 50 years will most probably witness the ***discoveries of other Earth's*** in our galaxy, and hopefully the discovery of extra-terrestrial ***forms of life***. The habitability of extra-solar planets is indeed one of the most fast-growing emerging fields in astronomy these days after the first discoveries (from the ground) of non-solar planets. The ***Hubble Space Telescope*** has cast light on the scenario of star and planet formation. This scenario however is still sketchy and requires more detailed and more numerous observations to be better ascertained. Improvements will come from the systematic investigation of star-formation areas, proto-stars and proto-planetary discs, and from finding out what kinds of host stars are the most favorable for the formation of planets and in which locations in the Galaxy.

A first-order approach will be done by the NASA/ESA James Web Space Telescope ***(JWST).*** However, JWST does not possess any ***ultraviolet capability*** which is essential for the characterization of stellar activity and early stellar winds as well as of the atmospheres of stars. Such a facility is eagerly required. These observations will be on going in parallel with the direct detection of ***Earth-like planets***, the physical and chemical characterization of their atmospheres and the identification of unique biomarkers. Both ESA and NASA have plans with missions like ***Darwin*** (ESA) and the ***Terrestrial Planet Finder*** (NASA). However, the latter may be postponed indefinitely (see Section 2.3). The ultimate goal will be to image terrestrial planets with large optical interferometers or the newly proposed ***hypertelescopes.***

Our solar system is the only one of which, as of today, we know all the planets! It is a unique set but we still do not understand properly why these planets are where they are, and how they have migrated in the plane of the ecliptic. The terrestrial planets (Mercury, Venus, the Earth and Mars) have followed a different evolution, with only one having developed the right conditions for the emergence of an evolved form of life. The climates of Mars and of the Earth have followed different paths, not only because of the planets physical or astronomic properties but also because ***the Moon*** has had a stabilizing effect on the obliquity of the Earth's rotation axis. The understanding of how the Earth-Moon system came into being is relevant to the search for the universality of life on Earth-like planets. ***This requires a more detailed investigation of the history of the formation of the Moon itself.***

Giant planets seem to be plentiful around other stars and it is still to be understood why and if they represent an ordinary step in the evolution of stellar planetary systems. Our present set of observations is strongly biased toward big objects because of instrumental and observational limitations, and may not be representative of a more universal scenario. Studying the giant planets of our solar system with their ***rings,*** their diverse satellites and their complex environments constitute a priority to understand this scenario and what role do they play in the evolution of planetary systems.

Environmental conditions for the appearance and evolution of life include not only geological processes, the presence of water and favorable climatic and atmospheric conditions, but also the protections against the effects of the mother star's magnetic field: a magnetosphere and an atmosphere. Logically of course, the planets of our own solar system will be thoroughly investigated for the possible existence of life thereon.

Mars in particular is ideally suited to address key scientific questions of habitability. Mars however presents ***a genuine challenge*** because if life may exist thereon it is not necessarily spread evenly and may exist here and there. The fact that life is not found at a given spot may not imply that it does not exist a few km away. What would be needed here is a technique for ***life-detection on the global planetary scale***, using bio-signatures detectable from orbit. Methane emission might be such a signature if it is confirmed that methane is indeed outgassing from the Martian surface.

Europa is another interesting candidate because it is assumed to possess an ocean underneath its icy crust. Furthermore, the recent observations of ***Titan*** with the ***Cassini-Huygens*** NASA-ESA mission have given some clues on the prebiotic conditions of the early Earth and should be complemented by new *in situ* observations.

Finally, as building blocks of the Solar System, the primitive ***small bodies*** (comets and asteroids) give clues to the chemical mixture and initial conditions from which the planets were formed in the early solar nebula. Some do contain organic matter and they may well be part of the scenario of life-emergence. In general however, their chemical composition is poorly known leading to possibly wrong interpretations of solar system formation. They may also represent an ultimate source of rare minerals that are being presently rapidly exhausted on Earth, and a more systematic investigation of their chemical compositions and structures is of great importance.

The tools required for Theme A3, *include* ***far infrared observations,*** *with high spatial and low-to-high spectral resolution. An* ***ultraviolet capability*** *is missing and is an essential tool for the characterization of stellar atmospheres and envelopes, as well as of the* ***Interstellar Medium.***

*A****strometric telescopes*** *such as ESA's* ***Gaia*** *mission will contribute enormously to the identification of non-solar planets. Near-infrared* ***nulling interferometers*** *with high spatial resolution and spectroscopy capabilities will help characterizing the atmospheres of these planets in search for life-specific molecular compounds such as molecular oxygen and ozone.*

Mars *observers properly equipped to detect* ***life-signature on the global planetary scale****, complemented with a series of* ***landers*** *and* ***sample return missions*** *will hopefully confirm or not the presence of living organisms or of fossils prior to deciding to send human beings on the surface of the red planet (see section 2.2.3).*

Missions to the Moon *would provide the necessary data to better reconstruct the scenario of the formation of the Earth-Moon system. Several missions are planned world wide in the context of the* ***Exploration programs*** *of the diverse agencies, but it is not clear at this stage, because of their mixed blend of scientific and industrial-type objectives, whether these initiatives will be compatible mutually.*

Jupiter and Saturn probes *will continue the very successful work of both the Galileo and Cassini-Huygens missions. A* ***Europa*** *orbiter and/or a lander should also be envisaged in the framework of this theme. A* ***return to Titan*** *seems to be a must after the successful landing of Huygens on Saturn's largest moon.*

Near-Earth object sample return missions *should be part of any future exploration scenarios.*

Theme A4: Understanding the Sun's influence on the Solar System

All planets of the solar system "live" in the magnetic environment of the Sun. The Sun is a magnetic star which is characterized by its eleven years activity cycle which modulates the emergence of magnetic spots, active regions, Coronal Mass Ejections, (CME's), the solar wind, the total and spectral irradiance, the penetration of cosmic rays. Our own planet feels the direct and indirect effects of these influences and it is essential to properly assess this influence for better appreciating and further correcting, the anthropogenic effects on our atmosphere and our climate. The study of ***Sun-Earth relations*** is one of the most prioritary issues in modern space science. Forecasting solar activity is not yet proven. It requires a proper understanding of the origin of the Sun's magnetic field and observations of the visible surface field around and above the poles.

The solar system, pervaded by the solar plasma and magnetic field, offers unique possibilities to study the interactions of the solar wind with other planets. *In* *situ* observation of the heliopause would also provide ‘ground truth’ measurements of the interstellar medium.

The tools for Theme A4 *are plenty. They range from* ***solar observatories*** *fully exploiting the* ***helioseismology technique*** *so successfully used on board the ESA-NASA* ***SOHO*** *mission and soon to be pursued with the* ***Solar Dynamic Observatory,*** *through to all the missions of the* ***International Living With a Star Program*** *led by NASA. ESA’s* ***Solar Orbiter*** *is the only mission presently planned to observe the poles of the Sun some 30° above the ecliptic plane. Its capabilities may not be enough however to study the interior of the Sun along the magnetic polar axis, an observation which is crucial for a proper investigation of the* ***solar dynamo*** *and of the solar cycle and for its forecasting. Hence, a* ***Solar Polar Orbiter*** *to chart the Sun’s magnetic field in three dimensions is a key instrument for future progress in this area.*

*Close to the Earth****, magnetospheric*** *missions or* ***swarms*** *of satellites, would continue and refine the progress already accomplished by the satellites like ESA-NASA* ***Cluster*** *mission. Further away from the Sun, an Interstellar Heliopause Probe would explore with more modern means, the interaction between our* ***local bubble*** *and the Interstellar Medium.*

Monitoring the ***Total Solar Irradiance*** *(TSI) as well as the* ***spectral irradiance*** *is of importance for both the understanding of the Sun’s atmosphere, and the effect of solar forcing on the Earth itself (see Theme 3 of the Geosciences section). Because of the tiny amplitude of these variations (a few parts per thousand for the TSI), such measurements require* ***continuity for ensuring the best precision. Radiometers and spectrometers*** *are required for such measurements.*

2.2.2 Geosciences

At INPE, this term is divided into two main sub-disciplines: ***Space geophysics*** and ***Aeronomy***. We will not necessarily follow that division mostly because the Earth is a very complex system. All its components interact. All are in a state of evolution: the solid Earth, the hydrosphere which includes the oceans, the aquifers and the dams, the cryosphere which includes all the ice cover found in the polar caps and in glaciers, the atmosphere which includes the troposphere, the stratosphere, the ionosphere and the magnetosphere, and of course the biosphere.

The accuracies required and the spatial and time resolution are usually very high, putting severe constraints on the instruments. For example, the motion of plate tectonics is measured in centimeters per year and the rise of the sea level in millimeters per year. These precisions are now easily within the reach of present space borne sensors and will obviously be increasing in the future. As in the previous section, we find in the ESA ***Living Planet Program***[*] a very complete and useful set of studies and analyses which have inspired us in establishing this view of the future.

The tools for Geosciences *include methods and techniques which cross through the respective themes. They permit the* ***monitoring of the Earth's surface****, be it solid or liquid, of its shape, its motions, and its precise altitude and topography variations, of its temperature and of its vegetation cover. They should allow* ***measuring the composition of gases****, the* ***concentration and circulation of aerosols*** *and their temperature as well. In the future, they should support* ***studying the climate****, if possible at a similar degree of reliability as we manage today for the weather. They should allow the forecasting of natural as well as of* ***anthropogenic hazards****. They must offer the capabilities of continuously observing and measuring* ***solar radiation****, and the ultra-violet flux in particular.*

*Satellites have the capabilities of making global measurements. They should be complemented by in situ measurements by means of local probes, in oceans (buoys), on the surface (stations), or in the atmosphere with airplanes but also balloons and sounding rockets. The large number of instruments and sensors requires that they should be coordinated and integrated into an international system such as the Committee on Earth Observation Satellites (****CEOS****) and the Group for Earth Observation program (****GEO****).*

The following, copied from the CEOS list illustrates the set of instruments found usually on board Earth observation and satellites:

Atmospheric chemistry instruments
Atmospheric temperature and humidity sounders
Cloud profile and rain radars
Earth radiation budget radiometers
High resolution optical imagers
Imaging multi-spectral radiometers (visible/infrared)
Imaging multi-spectral radiometers (passive microwave)
Imaging microwave radars
Lidars
Multiple direction/polarization instruments
Ocean color instruments
Radar altimeters
Radiometers
Scatterometers
Gravity, magnetic field, and geodynamic instruments

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[*] The author also contributed to establish this plan.

Theme G1: the solid Earth

The characteristics and properties of the solid Earth are fixing limits to the whole Earth system. Their variations and long-term evolution do influence this system. This is why the study of the Earth's interior as well as the surveillance of its phenomena are proving every day to be more indispensable for the understanding of the natural forcing on this system. Among them are the magnetic field, plate tectonics and volcanism. The last two are the cause of some of the most harmful natural hazards. Any information that may be used to forecast them is essential.

Magnetic measurements offer powerful means for understanding the mechanisms which are driving the dynamics of the Earth's interior. Because these phenomena are essentially global or at least do cover a substantial area and volume of the planet, satellite-based measurements are adding their accurate power to those performed from the ground. A tight correlation between these respective data is the source of important progress. One of the poorly known phenomena is the generation and ***the evolution of the magnetic field.*** The existence of the ***South Atlantic Anomaly*** is also not fully explained. In view of its effects on the Earth's radiation belts and on the satellites, it is certainly an area of research which needs to be pursued. Because these phenomena have usually long time constants, ***the need for continuity is essential***.

The Earth's field is the superposition of the intrinsic field generated by the Earth's dynamo and of the fields generated in the ***ionosphere,*** and in the ***magnetosphere***. Even though the intensity of that second component is negligible, its effects are important. In particularly it modulates the flux of cosmic particles that penetrate the atmosphere, and might indirectly modify the climate through the ***formation of clouds.*** Such effects need precise monitoring.

Tracking the ***motions of tectonic plates*** and understanding how they relate to ***earthquakes*** and ***volcanic eruptions*** allows reconstructing the seismic history of a given area, a first step toward forecasting. Space techniques allow a better surveillance and lessen the dependence on ground-based instruments. ***Space borne radars*** can peer through vegetation and follow with a precision of millimeters how plates are moving and how the strain is building up before earthquakes and eruptions. With the growth of the population, new centers of habitation are occupying areas of greater risk and there is a clear need to systematically monitor the motions and displacement of the ground in view of mitigating the consequences of the related hazards. The deformations of the solid Earth also induce changes in the global sea-level, modifying the boundaries between land and water.

Tools for Theme G1

The changes in the Earth's gravity field and of its shape are influenced by the motions of tectonic plates, by the level of the oceans, of the ice cover, and by the distribution of water in general, including lakes and rivers. They are detectable with ***geodetic*** *and* ***altimetry satellites****. Measurements with one millimeter accuracy are now achieved with the German American* ***GRACE*** *mission, launched in 2002, made of two satellites co-orbiting at near polar inclinations at 300-500 km altitude and separated by about 220km. ESA is also preparing the* ***GOCE*** *mission to be launched in 2008 which will provide global and regional models of the Earth's gravity field and establish a geoid with 1 cm accuracy over about 100 km spatial resolution, and a gravity field model.*

Radar altimeters *have been in operation since the mid 1970s on board US as well as Canadian and European satellites, in particular the couple* ***ERS-1, 2****, and* ***ENVISAT*** *from ESA, and the US-French* ***Topex-Poseidon*** *and its successor* ***Jason-1****. When combined with the* ***GPS*** *or other altimetry systems, they have achieved the most accurate measurements of the dynamics of the oceans and how they influence climate evolution. Satellite altimetry has also for the first time provided unambiguous evidence of* ***regional variability of sea level change****, with some regions exhibiting trends about 10 times the global mean, with the highest magnitudes encountered in the Pacific and eastern Indian oceans. Radar altimetry proves also to be an invaluable tool for the observation of the polar ice caps.*

Differential interferometry *using* ***Synthetic Aperture Radars*** *(SARs) allows the quantification of small topographic changes and the assessment of surface* ***dislocation and subsidence*** *due to* ***earthquakes*** *and other natural or anthropogenic activities with millimeter accuracy over areas at the km^2 scale. The applications of that technique are numerous, varying from the determination of relief, humidity, vegetation cover, and of the deformations induced by* ***tectonic activity****.*

Optical imaging *instruments allow for the monitoring of* ***natural hazards****,* ***volcanoes and earthquakes*** *as well as those induced by Man. Their power is considerably increased by combining their data with those of SAR's.* ***Imaging multispectral radiometers*** *prove to be ideal tools for monitoring the thermal status of the Earth's surface during night, and in getting an early warning of any imminent eruptive activity.*

Magnetic field *satellites provide a unique tool for the* ***monitoring of the Earth's dipole*** *and of the behavior of the* ***magnetosphere,*** *and how it reacts to the* ***solar wind.*** *Monitoring satellites like the Danish* ***Oersted*** *mission prove to be crucial in that respect. Ideally, they must be combined with magnetospheric and solar wind instruments. An excellent example is ESA's* ***SWARM*** *project to be launched in 2009.*

Theme G2: the water cycle

The global water cycle – the transport and distribution of large amounts of water, associated with its constant phase changes between the solid, liquid and gaseous states – is one of the most important features of the Earth system. Oceans absorb at least half of the excess heat energy received by the Earth and then transfer this energy from the tropics to the poles. Their enormous thermal inertia helps regulating and balancing the temperature of the whole planet as they smooth out all brusque local or temporary temperature variations. Oceanic circulation plays a crucial role in the recycling of carbon dioxide and may induce cooler or warmer climates in a way which is not yet fully understood and could surpass all other reasons of climate forcing, in particular through the ***El Niño*** effect. The distribution of fresh water over continents is a vital parameter for populations especially in desertic or semi-desertic areas. The salinity of water is modifying oceanic circulation and changing the currents, and it must be monitored. In addition, the total volume of liquid water is strongly temperature dependent through two additive effects: melting of ice and thermal expansion.

Sea-level rise is one of the most concerning problem for populations living along the coastal areas. It involves interactions between the atmosphere, the hydrosphere the cryosphere and the biosphere and requires a complete system approach. Furthermore, mass exchanges between these components and changes in the mass distribution in the Earth's interior must be known precisely in order to quantify their relative contributions. Another typical effect of water is its contribution to the ***Earth's albedo***, as clouds, snow, and ice have reflective broad band albedos varying between 60 and 90%. Continuous spatially resolved observations of ground water and in particular of the cryosphere are therefore essential.

In its 2001 assessment of global warming the ***International Program on Climate Change*** (IPCC) projected that the global mean sea level is expected to rise between 10 and 90 centimeters by 2100, with a 'best estimate' of 50 centimeters, as a result of ***thermal expansion*** and of the rise in temperature. Thermal expansion is the main component of expected sea-level rises over the 21st century. Such a rise would make entire beaches being washed away, together with a significant chunk of the coastline.

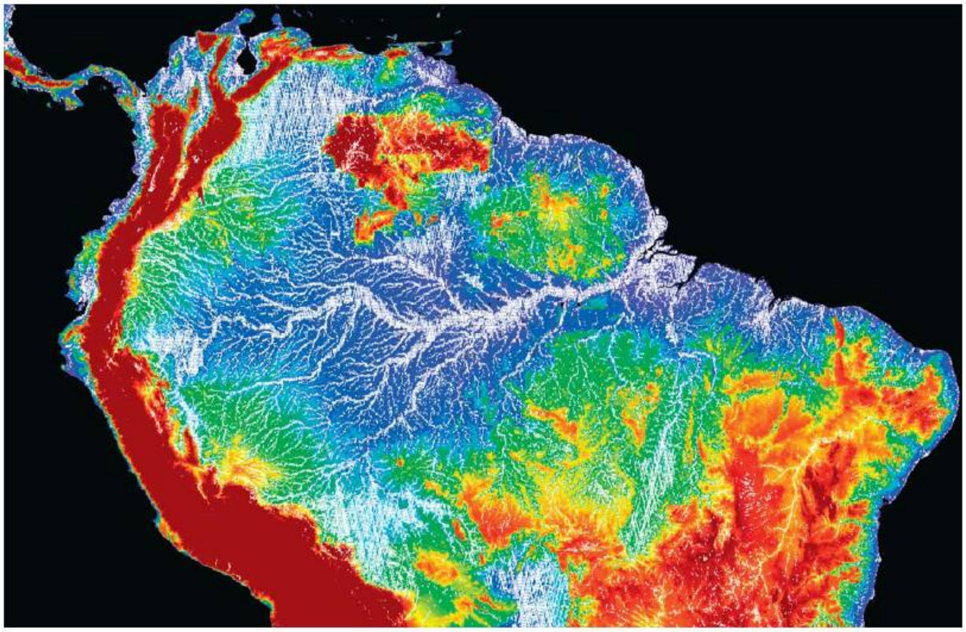

Figure 4: The Amazon River Basin observed with ERS-1 Radar Altimeter. Linear structures on the pictures are artefacts produced by the radar imaging technique. (Credit: ESA)

Tools for Theme G2

Geodesy satellites *like* ***GRACE*** *are now able to monitor in detail the distribution of water between rivers, lakes, the ice caps and glaciers and the oceans.* ***SARs*** *and* ***optical instruments*** *allow observations of the oceans, of the soil moisture, the rivers, the cryosphere and also the* ***clouds.*** *In combination, they allow the monitoring of global climatological and environmental evolution.*

Radar altimetry *represents one of the most precious tools for measuring sea-level rise as well as fluvial circulation (Figure X).*

ESA's ***Cryosat*** *radar altimetry mission which was lost during its first launch attempt is now being replaced for a launch in 2009. This three-year mission will determine variations in the thickness of the Earth's continental ice sheets and marine ice cover, and test the prediction of thinning arctic ice due to global warming, with an accuracy of about 0.12 cm/year over areas of more than* 10^7 *km*^{2}*.*

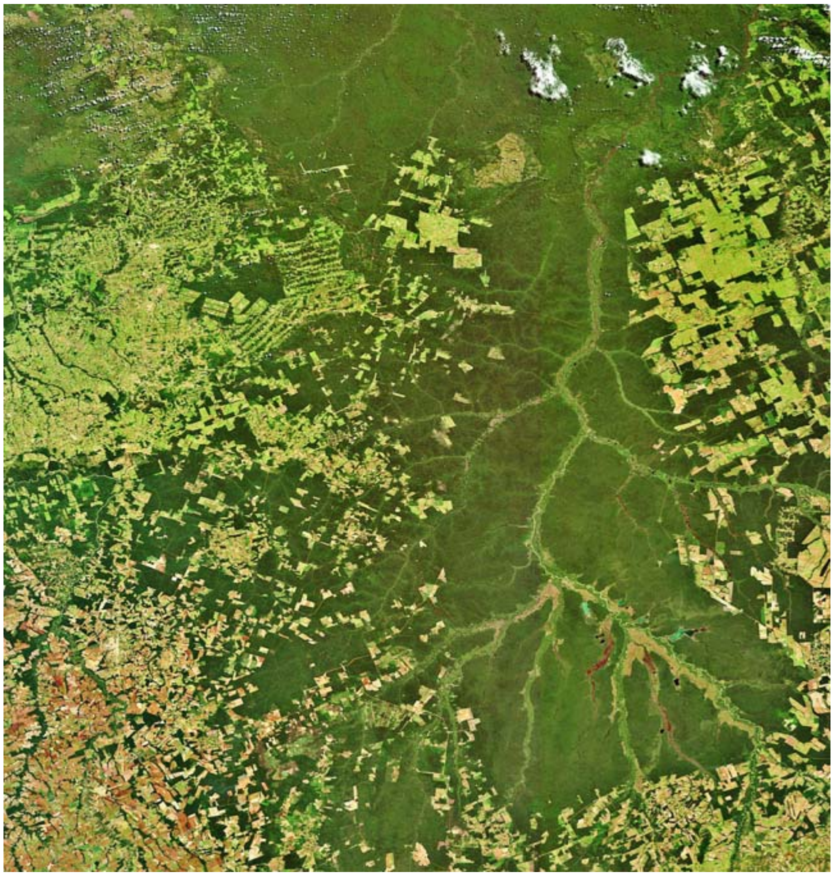

Figure 5: Image of the Xingu River in Brazil acquired by ENVISAT MERIS instrument on 30 May 2006, clearly highlighting the contrast between the rainforest and the nearby sprawling urbanization. (Credit ESA).

Theme G3: the atmosphere

The atmosphere of the Earth is probably the most fragile part of the Earth system. All gas emissions have no other alternative than going first into the atmosphere which is extremely sensitive to any changes in chemical composition. It is a thermodynamical as well as a dynamical system, being pervaded by winds, vertical currents and hurricanes. Its physical properties are strongly influenced by the presence of water, clouds and aerosols which have the ability to change the albedo and influence the proportion of s***olar radiation*** absorbed in its various layers and that which reaches the ground. Understanding the various mechanisms at play and the way the atmosphere reacts to natural and to anthropogenic perturbations is indispensable for understanding the Earth system.

The composition of the atmosphere can be modified naturally through outgassing and volcanism, or as a result of anthropogenic activities, by living organisms, and to a lesser extent by meteoritic bombardment. Any modification in the chemical content of ***Green House Gases*** (GHG) in the atmosphere may have important consequences on the ***climate*** and, as already mentioned, with rising temperatures, on the height of the oceans. Monitoring continuously the chemical composition and its modifications is therefore an absolute requirement.

The most important element to monitor is probably ***carbon dioxide***. The total number of carbon atoms on the Earth is more or less fixed, if we exclude the contribution from meteoritic bombardment. Carbon is recycled through the ocean, the atmosphere and the biosphere and its concentration in the various parts of the Earth's system varies. In particular, human activities have definitely changed the balance, with levels now exceeding those resulting from regular cyclic variations over the last 400 000 years. Only about half of the anthropogenic emissions sent into the atmosphere stay there. The rest is probably absorbed in the oceans and in the land, with around 14% of worldwide carbon stored in permafrost, soils and sediments. ***Tundra wetlands*** are considered major contributors to the global carbon balance, and anticipated to be highly sensitive to climate change: if they were to suddenly outgas, the resulting global warming effects would be much more dramatic than what it is presently. This is why it is a necessity to ***follow the carbon cycle*** and observe the exchange or the flux between the land and ocean surface and the atmosphere. The observations must not only address monitoring atmospheric but also surface monitoring, including ***forest and vegetation cover***, tundra, fires, humidity and sea and land photosynthesis and biomass in general.

Another most important life-protecting atmospheric constituent is ***ozone***. Because organic components of life are strong absorbers of lethal UV radiation, ozone plays a unique role in the preservation of life. Ozone however is very sensitive to anthropogenic pollutants like ***"Chloro-Fluoro-Carbons"*** (CFCs) which destroy the molecule. Permanent monitoring of CFCs and of ozone concentration is therefore essential.

Aerosols counteract the warming effect of the GHGs because they intercept sunlight, resulting in less energy reaching the Earth's surface, hence cooling! However, their contribution is uncertain. Some also absorb light, resulting in warming of the atmosphere and potentially reducing cloudiness. Several millions of tons of aerosols are emitted daily coming from a large variety of sources both natural (volcanic, biologic, desertic, marine) and anthropogenic (burning, industrial dusts, agriculture). They are mostly found in the ***troposphere*** where their time of residence can reach several days. Being strongly influenced by rain precipitation their concentration is fairly inhomogeneous at the regional scale as opposed to the GHGs whose distribution tends to be more global. They do play a fundamental role in influencing the air quality and the climate.

Their interaction with clouds is important but yet poorly understood because of the complexity of such interactions and of their transport. They are made of liquid or solid particles in suspension in the atmosphere. Their small droplets may increase the lifetime of clouds and thereby the Earth's albedo, amplifying their cooling effect. The knowledge of these complex and indirect effects is essential to properly assess the opposing consequences on global warming of GHGs and aerosols. Future progress will come from both space-based observations and *in situ* local measurements by means of ***balloons*** in particular.

The Earth's atmosphere is also subject to ***powerful electrical phenomena*** such as ***thunderstorms*** and is also strongly influenced by ***cosmic and solar radiation***. Together with the ***magnetosphere*** it acts as a protective shield against these radiations, in particular solar ultraviolet.

Tools for Theme G3

Spectroscopy *and* ***atmospheric chemistry instruments*** *are powerful tools for analyzing the present* ***chemical state of the atmosphere*** *and its evolution. Operating in many different spectral bands, they provide global data on a large variety of parameters and* ***trace gases*** *that play a key role in the atmosphere's chemistry and physics. It allows the monitoring of changes in atmospheric composition, particularly over industrial regions and biomass burning areas.* ***Ozone*** *measurements, in particular over the Antarctic and the Artic, are part of nearly all atmospheric sounders, like the* ***Global Ozone Monitoring Experiment*** *(GOME) on board ESA's ERS-2 mission.*

Limb occultation *and* ***limb atmospheric emissions ranging*** *are also commonly used on board atmospheric sounding missions. They allow the analysis of numerous race gases including stratospheric ozone,* NO_y ***compounds*** *and greenhouse gases.* ***Lidars,*** *back-scattering and reflection of radiation from the atmosphere is also used on remote-sensing instruments, such as* ***SCIAMACHY*** *on board ENVISAT, for measuring atmospheric constituents and parameters of importance in the* ***stratosphere*** *and* ***troposphere****. These techniques are very well suited for the determination of* ***aerosols*** *and* ***clouds*** *in particular.*

Imaging multispectral radiometers *operating in the infrared allow high accuracy radiometry measurements of the temperature of land and sea surface, reaching a few tenths of a degree in precision (0.3° with the AATSR on ENVISAT). They also provide surface monitoring of the* ***vegetation cover****, tundra, fires, biomass, humidity and sea and land photosynthesis.*

Scatterometers *using* ***radar imagery*** *allow the measurements of* ***winds*** *through the measurements of the waves in the oceans.*

Theme 3 is particularly well suited to using ***in situ*** *measurement, and future progress will come from both satellite-based observations and local measurements by means of* ***balloons*** *in particular.*

Theme G4: the biosphere

The biosphere, or ecosphere, ranges from about 10 kilometers above ground into the atmosphere to the deepest ocean floor including most of the lower atmosphere, the hydrosphere and the upper lithosphere. In this area all living organisms are found interacting with one another and with their non-living environment. The estimated number of identified living species is about ~1.75 millions, but it is likely that the total number is above 30 millions and may be as high as 100 millions, to be found mostly in yet unexplored zones of ***tropical forests and jungles***.

Biodiversity is currently being lost across the globe at a rate unprecedented in human times, due to the disappearance of many species victims of anthropogenic activities. The growing world population is rapidly transforming the ecosphere, putting increasing pressure on biodiversity. Growing cities are definitely eliminating large parts of fertile lands which cannot be used anymore for providing the necessary food (Figure 5). It is therefore understandable that the mass of the biosphere cannot be estimated very accurately. For answering key environmental, agricultural and health questions, biodiversity scientists are obliged to base their predictive models on incomplete data. Our food, part of our energy, fibers, the control of pests and diseases and the discovery of novel natural products, such as Pharmaceuticals, all rely on biodiversity.

Vegetation is the key component of the biosphere. ***Phytoplankton*** in particular accounts for the majority of the biomass in the oceans, and has a bigger effect on the climate through the recycling of carbon than any other living species - including all the world's forests. Vegetation represents the ultimate source of our subsistence. It is the source of the oxygen we breathe and of the amino acids from which all animals, in particular humans, build up their own proteins. ***Monitoring the evolution of the biomass*** and more specifically of the global vegetation and phytoplankton appears as a vital activity.

The biosphere interacts with the water cycle, the carbon cycle, the energy cycle and the climate among many other things. Humans and animals need a proper climate to survive and at the same time they have a strong influence on the climate! The interactions between these different components are very dynamic and, as we have seen many times, very complex and not well understood today because this requires a large variety of data and scientific analysis that do not exist today at least with the proper degree of accuracy. The problem is both global and local. It involves space-based as well as *in situ* and local measurements.

Tools for Theme G4

If we want to understand and evaluate ***biodiversity*** *and accurately predict the consequences of further loss, many sources of observations must ideally be pooled together. Most of them are, and will continue to be, made in situ, while satellite data will provide a global and macroscopic view of the ecosphere status. Of great importance is the monitoring of the amount of* ***phytoplankton*** *and of the* ***land vegetation covers*** *around the World.*

The tools used for theme G2 are here also very powerful in fulfilling this goal. We refer to the description given for G2 and also G3.

2.2.3: New emphasis on Lunar and Martian exploration

The international space science context has recently been submitted to strong changes following the announcement by President George-W Bush in 2004 of the American Exploration initiative which foresees a permanent settlement of astronauts on the Moon as of 2024, and later also on Mars. All programs at NASA have been affected by that decision which has to be started with no additional money for the Agency. This means that all other ongoing or future NASA programs will have to be postponed or cancelled in order to leave way to the various elements of this new vision. This is the case in particular of the ***LISA*** and of the ***TPF*** missions which have been postponed indefinitely for the time being.

NASA has been re-organized in order to better implement the new policy which will see the development of a new lunar vehicle called ***Orion*** and a new launcher called ***Ares-1*** with the capability of launching 25 tons in low Earth orbit with a crew of 4 to 6 astronauts in ~ 2014. A heavy version of the launcher called **Ares-5** will carry 140 tons of equipment and the lunar landing module to which Orion will dock in Low Earth Orbit. At a recent meeting in Houston, NASA announced that it will send the first astronauts to the Moon by 2020. As of 2024, NASA plans a permanent outpost at one of the Moon's poles.

The aim of this program is not necessarily scientific but involves also industrial activities and the search for lunar resources of potential commercial interest. Figure 6 gives an indication of the NASA road map to implement the initiative. The space literature also abounds of detailed descriptions of this program such as the 11 December issue of Aviation Week and Space Technology. All these descriptions must be taken with great care due to the rapidly evolving state of the program.

Amazingly, the US Exploration initiative is paralleled in several space agencies which indicate also plans to go to the Moon and to Mars. ESA had launched a small lunar mission, ***Smart-1***, which reached the Moon using solar-electric propulsion and crash-landed on the lunar surface at the end of its mission on September 3, 2006. It is elaborating also a lunar and Mars program called ***Aurora*** which plans to send Humans to Mars in 2035. Figure 7 is an early version of the ESA road map. At this moment, the priority has been given to un-manned missions to

Mars with a mission to search for life called ***ExoMars,*** now in development and to be launched in 2013, which may be followed by a ***Mars Sample Return mission*** sometime before 2020. Aurora also includes manned missions to the Moon by 2024 at the earliest. No budget however has been attributed to this phase.

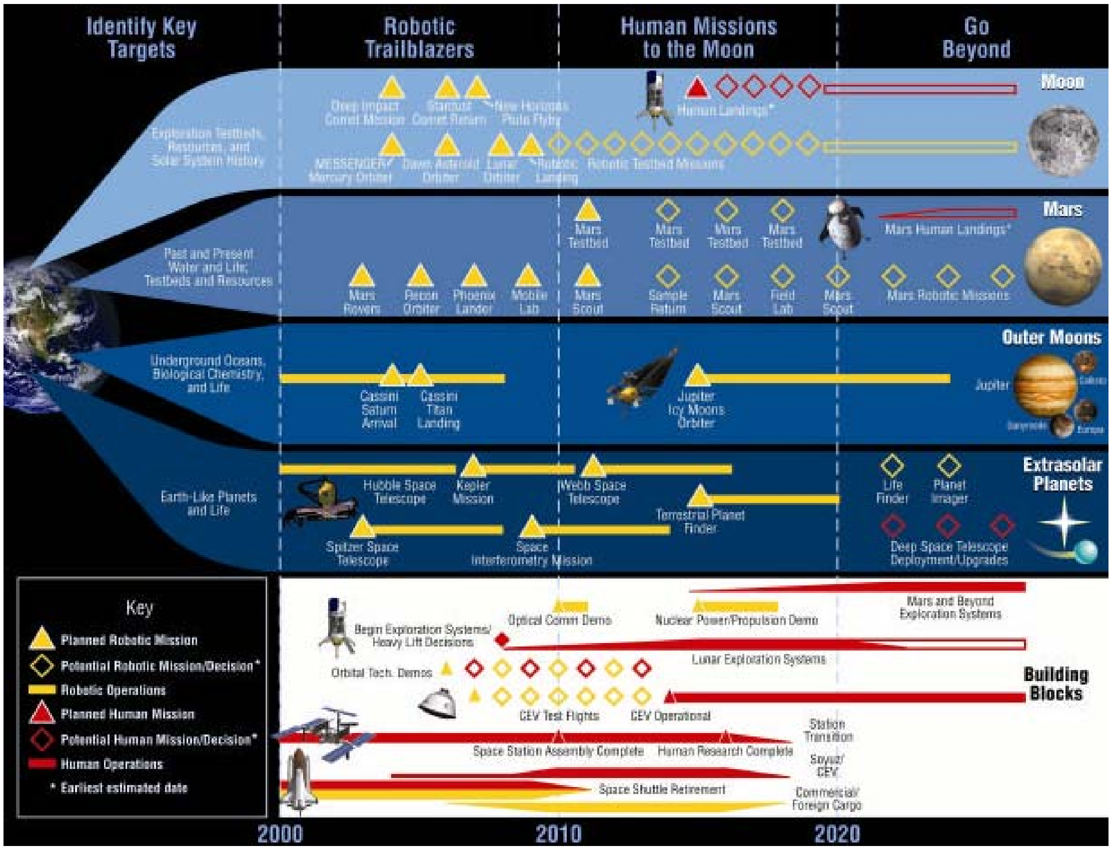

Figure 6: A preliminary version of NASA's road map to implement the Moon and Mars Exploration initiative. Due to the fluctuations of the scenarios, this figure is to be read with some care.

Russia for its own sake is envisioning a fairly ambitious lunar program with the ***Luna-Globe*** lander in 2012, followed by a lander and a rover (***Luna-Rover***), a sample return mission (***Luna-Grunt***) and a surface laboratory (***Luna-Polygone***) by 2020. A manned mission to the Moon could occur as early as 2020, and an orbiting lunar station should be in operation in 2025 preceding the deployment of a lunar base in 2030. The Russian ambitions are also fairly high on Mars, with a return mission to Phobos (***Phobos-Grunt***) in 2009, a Mars sample return mission between 2020 and 2025. Manned missions could occur in 2033.

Table 2 summarizes the set of lunar missions presently approved or to be confirmed in the various agencies between now and ~ 2020 when the first manned missions are planned. As far as Mars is concerned, it is worth noting that India is planning a mission for 2019. It plans also missions to an asteroid or a comet for 2015 and, later, missions toward Venus and possibly Mercury.

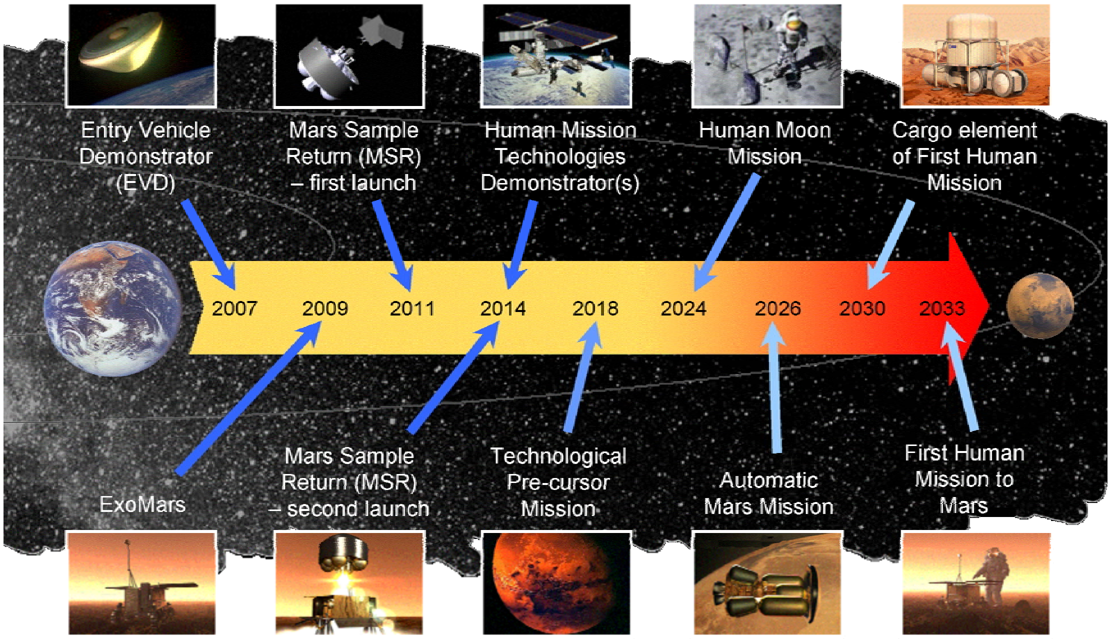

Figure 7: The original ESA Aurora Program road map. The content of the map is more or less valid even though the dates have slipped already by several years. ExoMars is now scheduled for 2013 and the Mars Sample Return mission for 2020.

	Robotic	*Manned*	*Date*	*Status*
NASA	Lunar Reconnaissance Orbiter		2008	**A**
	Lunar CRater Obs. & Sampling S/C		2008	**A**
	Landing site recognition		2011	**TBC**
		Orion	2014	**A**
		Manned lunar Landing	2020	**TBC**
		Permanent Settlement	2024	
ESA	?			
		Human Mission	2024	**TBC**
JAXA	Selene-1 Lander		2007	**A**
	Selene-2 Rover		2010	**TBC**
	Selene-3 Lander		2015	**TBC**
		Manned Mission	2020	**TBC**
China	Chang'e-1 Orbiter		2007	**A**
	Chang'e-2 Rover		2012	**TBC**
	Chang'e-3 Sample Return		2020	**TBC**
		Manned Mission		**TBC**
			2020	
India	Chandrayaan-1 Orbiter		2008	**A**
	Chandrayaan-2		2011	**TBC**
		Manned Mission	2020	
Russia	Luna-Glob Lander		2012	**TBC**
		Manned Missions	2020	**TBC**

Table 2: Planned robotic an manned lunar missions in the various space organizations. The status refers to A: Approved, and TBC: To Be Confirmed. This list is very tentative and needs to be read with caution given the status of all non-approved missions.

All this clearly indicates that a new phase of space research has started which involves not only the Group-1 countries but also China and India from the Group-2 countries. ***The firmness of these plans is far from being assured***. However, it can easily be understood that a new race is ongoing which may affect the agencies' budgets as it has already influenced NASA's and that, unless fresh money is added to the respective programs, a substantial reshuffling of planned missions is inevitable.

2.3: The main technological challenges

To be implemented, the future program outlined above will require ***major breakthroughs in technology*** and ***management*** procedures. If the first phase of space research was conducted on the basis of individual and specific missions, the next phase will see the uprising of ***systems*** of missions or even ***systems of systems***. In astronomy and solar system sciences, the needs are clearly technical and operational. In particular, we see that several missions will require several ***satellites flying in formation***, a new requirement clearly impacting also ***mission operations.*** In geosciences, there are in addition stringent requirements in the areas of coordination and in the implementation of different missions and systems of missions. Geosciences are also particularly demanding in terms of ***data transmission and storage*** and in ***modelization***. The development of high capacity ***mass memories*** applies to all domains. ***Planetary protection*** rules will impose a severe discipline and a set of integration procedures which will probably heavily impact the costs of these missions. We review the specific needs below, separating between these various domains.

2.3.1: Astronomy

The general trend and challenge in astronomy will be ***formation flying*** between several satellites. This is the case for example of ***interferometers*** using several identical satellites precisely positioned (***Darwin***, LISA, TPF) or for observatories made of different satellites such as the ***XEUS*** concept of ESA (Figure 8), a large X-ray facility in which the telescope mirrors and the detectors are placed on two different satellites separated by tens of meters (50 m for XEUS) in order to increase the focal length and therefore the spatial resolution. This constellation's control system will require high precision metrology and the development of micro-propulsion thrusters, using for example, ionic propulsion.

The need for ***larger aperture telescopes*** implies that we dispose of deployable mirror systems or/and of ***light weight mirrors*** (membrane reflectors of a few kg /m2 or less), and more generally of lighter platforms, structures and subsystems, hence, ***miniaturization***. The use of ***adaptive optics*** and ***active optics*** which is now fairly common for ground-based telescopes will be generalized also in the case of space observatories, correcting for thermal or mechanical deformations of membrane reflectors.

Infrared astronomy will probably be privileged, because of the need to look at distant objects whose light is red-shifted, or because infrared photons offers the powerful advantage of passing through the dust thereby allowing the observation of star and planet formation as well as galaxy centers. Because of its longer wavelengths, the infrared is particularly well suited for interferometry which will certainly see major developments in the future, requiring, again, precision-positioning, high-stability optical benches and the use of fiber optics or integrated optics, as well as of optical delay line and phase shifters. Telescopes and focal plane instruments must be kept at very low temperatures (near absolute zero) and require cryogenic systems such as ***cryocoolers*** and long-life ***closed-cycled coolers.*** Detectors are particularly demanding here, requiring the development of ***bolometers*** and high-sensitivity, ***large-area arrays*** of ***semiconductors*** or ***photo-conductors***. In the case of an all-sky cosmic microwave background telescope (the successor of Planck), future progress will come from polarization mapping, and will require ***polarization-sensitive sensors.***

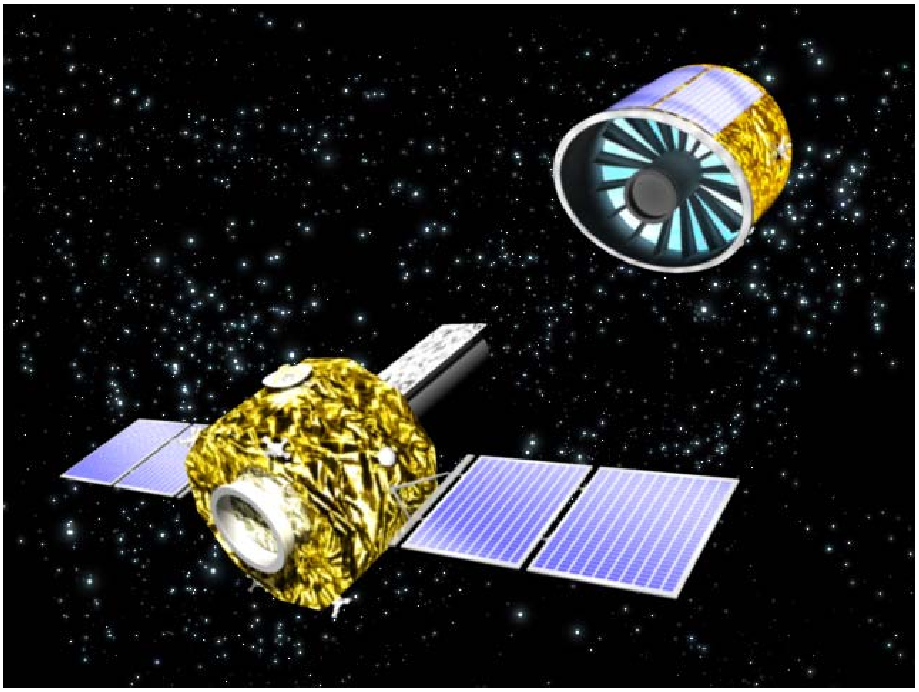

Figure 8: The concept of ESA's XEUS mission made of two different spacecraft flying in formation and very accurately positioned to maintain perfect optical alignment.

High energy astronomy will require higher spatial resolution because the state of the art for X-ray and gamma-ray telescopes is not very performing as compared to UV or visible and infrared astronomy. This is because normal incidence telescopes are not usable in the X-ray domain and require grazing incidence optics, while for gamma rays only the coded mask technique is able to make images but with a rather poor angular resolution of a few arcmin. Large aperture X-ray observatories will require deployable grazing incidence mirrors of low mass, large aperture, special coatings for optimized reflectivity. Formation-flying will be required for two-satellites systems like the XEUS concept mentioned above. Whenever bolometers will be required as detectors, closed-cycled low-temperature long-life and low-temperature coolers will be necessary as well as wide-field semiconductor sensors and large-format arrays. For the detection of rapid transient sources, high time-resolution sensors with rates > 1 MHz and resolution ~1 μsec are necessary as well as precision clocks giving an absolute local time to a precision of 100 ns.

For ***higher energy systems***, layered synthetic microstructures will be required for the mirrors, while ***gamma-ray imaging telescopes***, will rest on the availability of high-energy large-aperture deployable and focusing optics. It is also envisaged to deploy interferometers which will require long-baseline formation-flying over ~1 km baseline.

2.3.2: Fundamental physics

This theme is one of the most demanding in technology. For gravitational wave detectors, interferometers with baselines of several hundred thousands km are considered that will rest on the utilization of phase-locked ***high power lasers*** (100 W at 1 μm), **h*igh-sensitivity drag-free control*** (noise < 10–16 m s^{-2} $Hz^{-1/2}$), using new generation inertial sensors and high-precision pointing system (10^{-6} over 10^{5} km), ***FEEP thrusters*** and control systems. Each type of experiment will have its own requirement and it is impossible to give the complete list here. This can be found partly in ESA's Cosmic Vision.

Ultra-stable lasers with low-amplitude and low frequency noise, and accurate beam-shaping are the generic systems that will form the basis of any such experiments. These lasers require ***ultra-stable microwave source*** for laser control as well as ***frequency comb***. The same can be said of ***cryogenic accelerometers***, Superconducting test masses and readout systems (***SQUIDs***) requiring magnetic shielding and therefore extremely low stray fields. These are just a few examples.

2.3.3: Solar system science

Wherever ***Mars landers*** will be considered, ***Entry, Descent and Landing System (EDLS)*** will be required for a safe and secure landing on Mars. This will lead to the optimization of spin-up & eject mechanism with improved accuracy for ***parachutes*** and ***thrusters***, for velocity control during descent, guidance, navigation & descent control by means of ***radars or lidars*** and optical cameras. Airbags optimization will also help, using in particular the most realistic ground testing procedures. Instrumentation for ***surface and subsurface science*** in geophysics and biology will require ***miniaturization and compactness*** of optical imaging systems (***microscopes***), ***advanced robotics*** and ***rovers*** with mini manipulator arms and drilling devices able to go at depths of several meters. All system and subsystems on such missions will be submitted to ***Planetary Protection requirements*** which might ***impose severe (and expensive) constraints*** on the development and integration of the spacecraft.

Future missions to Saturn and Jupiter will require both ***high efficiency solar cells*** up to the orbit of Jupiter and a new generation of power sources or of ***RTGs*** - which are presently under strict US control- beyond Jupiter's orbit where solar panels cannot operate due to the distance to the Sun. They will also require efficient high energy particle ***shielding*** for payloads and subsystems. A Jupiter probe will be very demanding because any type of Jupiter atmospheric entry is extremely challenging, both thermally and because of the high pressures deep in the atmosphere. ***Autonomy*** and ***low-resource communication systems*** will bring this type of mission within reach of the capabilities of more modest agencies than NASA.

The very essential ***Solar Polar Orbiter*** will be based on a ***solar sail*** propulsion system or on ***nuclear reactors***. Clearly, the development of solar sailing will be easier to undertake. Since it is essential for all kind of missions, be they solar or for asteroids and comets encounters, the development of large sails (several tens of m^2) is an obvious option. It will require the best choice of low-weight material and coatings, withstanding long-term degradation in orbit, the adjustment of a reliable deployment strategy, including the critical sail jettison system.

An ***Interstellar Heliopause Probe*** will also be based on solar sailing (alternatively on nuclear power), and consequently on the mandatory use of ***light-weight and high-efficiency RTGs*** (~8 W/kg), on autonomy and Deep-space communications. Because of the duration of such missions, autonomous navigation and long-life components applies to all.

Near-Earth object missions will concentrate on ***sample return scenarios.*** These missions will be fairly straightforward for rendezvous and landing but very demanding in terms of ***robotics***, energy and communication. They will require mechanisms such as touch-and-go multi-site sampler mechanisms, ***anchoring devices***, site recognition and course correction during sampling, in situ analysis, transfers of samples from the sampling device to the Earth entry vehicle, guidance and navigation systems and high levels of autonomy. As all extraterrestrial missions to solar system objects they will be submitted to ***Planetary Protection*** requirements.

2.3.4 Geosciences

The challenges in this area are plentiful and of a more complex nature than in the previous fields. This comes essentially from the fact that Geosciences are studying a single object, the Earth, which is, as said many times, a very complex system where all components interact and interfere. Scientific investigations (and their applications) are indeed wide ranging from studies of the Earth's mantle, atmosphere, oceans, ice and land formations, to vegetation, agriculture and cartography. ***Single missions*** can make a substantial impact on a specific scientific problem over a limited amount of time. However, ***long-term measurements*** are more necessary in order to follow phenomena over the often long time constants of natural or anthropogenic phenomena. In that case, a multiple of instruments both from space and from the ground, that have to operate simultaneously and whose data must be analyzed coherently, and where ***continuity*** is crucial, is therefore obligatory. This has many implications.

The first obvious one is the necessity of ***coordinating several missions*** addressing several different issues: a single mission can barely stand by itself in the forthcoming future. In this context, the ***utilization of constellations*** of several satellites for a common objective naturally becomes more common. This opens the possibility of developing ***mini or micro satellites***, allowing the ***Group-2 nations*** to participate more easily.

The second one is a direct consequence of the first: since over time, more and more Earth sciences missions and instruments are becoming necessary they will progressively provide a wider range of sensed data types at ***increasing data rates and volumes.*** Satellite-borne sensors are capable of collecting information globally and over extended areas and time periods, generating a huge volume of data to be catalogued, archived and processed. This implies large amounts of computing time, network bandwidth and storage space, requiring that the supporting Information Technology infrastructures be dimensioned accordingly. ESA's ENVISAT mission, for example, generates some ***400 terabytes of data products per year***, which have to be handled by the dedicated ground infrastructure distributed across various countries. The next generation of missions will generate even more data because of increasing angular resolution, spectral bands and resolution. Many of these investigations make use of large-scale, high-capacity distributed processing facilities and also involve considerable coordination and interaction between a large number of players in the scientific, operational and commercial sectors, requesting simpler and faster access to data and related products. This raises engineering issues in areas like data acquisition, processing, archiving, cataloguing, searching, retrieval, distribution, etc.

A ***Grid network*** would facilitate these interactions by providing a standard infrastructure and a collaborative framework within which to share data, storage and processing resources, algorithms and data products in a coordinated way. Where it is preferable to maintain downsized local facilities, the Grid can provide the extra resources needed during times of peak load. Several countries have already embarked on Grid development. This is the case of the United States where several programs are underway[*]. In Europe, the main initiatives are DataGrid[**] and EuroGrid (both funded by the European Commission), the Nordugrid test bed formed mainly by the Scandinavian countries, and the German UNICORE science and engineering Grid. In the United Kingdom, Grid development is the centerpiece of a major national drive consisting of hundreds of projects and initiatives to develop the new 'e-science' infrastructures. All of these infrastructures include widely distributed resources and sites.

As in the case of the previous disciplines, future progress will also rest on extensive research in order to explore new technologies offering continuous improvements at declining operational cost. The main areas for instrumental progress can be summarized in the following list:

- Microwave Equipment and Antennas

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[*] Most notably the NASA Information Power Grid, the Department of Energy (DOE) Science Grid, the National Science Foundation TeraGrid, and the Alliance National Technology Grid.

[**] The DataGrid, of which ESA is a member, is made up of 21partners in 11 different countries and is currently running across many of Europe's main computing centers, e.g. CERN (F/CH), Lyon (F), AL (UK), CNAF (I) and NIKHEF (NL), all of which are sharing their resources. DataGrid is a major EC-funded Grid project which began in 2001. It is worth mentioning that the collaboration started within the ***CEOS*** (Committee on Earth Information Systems and Services) for demonstrating the potential interaction of European and US-based Grid systems.

- Electromagnetic techniques
- Optics
- Electro-Optical techniques
- Lidars
- On-Board Payload Data Processing

For Geosciences missions, the ***Ground Segment*** is a critical element because of the large volumes of data and of the many different user categories involved. Most important is the ***payload/data Ground Segment***. New techniques are needed in the data handling area, including cheap, simple, automatic data acquisition, processing (fast, data fusion, high-level products, new formats, data access support), archiving (high volumes, fast access, on-line archiving), cataloguing, compression, encryption, etc. These elements are essential for future missions and their development, contrary to flight hardware, does not require the same level of space qualification. Hence, they are well within the capabilities of new and young generation of engineers. ***Their development is an excellent school of formation offering excellent training possibilities.***

3. THE ROLE OF SPACE SCIENCES

For space fairing nations, space sciences do offer many important assets. Not only can their success yield very spectacular results, justifying the financial investment by the governments, but they also generate national pride and prestige on top of their prime scientific achievements. They are synonymous of leadership, of culture and of scientific excellence.

3.1 Importance of international cooperation in space research; Importance of space research to foster international cooperation

By its very nature, and as proven by the history of the first 50 years of the space era, space research is intrinsically international. There are very few domains of space sciences, if any, which do not require international partnership and many national instances have naturally developed cooperative programs. However, the term “cooperation” has different meanings in different parts of the world. Also, there is a slight difference between space sciences (astronomy and extraterrestrial solar system science) and the geosciences. For the former, there is no barrier to cooperate (with the exception sometimes of hardware development and the fear by some agencies of technology transfers), while in the latter case, the commercial or strategic nature of the dada may make it more difficult.

In the ***US***, international cooperation is part of the ***space act*** of 1958 and considered as a tool for fostering scientific and international dialogue. At the same time, it is also a means of controlling the potential partners, preventing them from developing programs which might compete with the US program. This was the case for the development of ***Spacelab*** with Europe, even more so of the ***International Space Station*** and now with the ***Exploration initiative***. This US policy is open and clear! In fact, it has not prevented (it has even allowed) the partners to develop and expand their national capabilities.

In ***Europe***, international cooperation has led to the creation of the European Space Agency, the only truly international space research organization, which can be considered as a success and a possible model for other parts of the world such as ***Asia*** and **South America.** The cement which has maintained ESA at its present level is not only political but also linked to the necessary scientific cooperation among formally warring nations and (certainly not the least of arguments), to the support of an industrial policy through the rule of "***juste retour*** "which has contributed in an important way to make Europe a very serious competitor on the international space markets.

Today, all space agencies do cooperate and there are no exceptions. The ***COSPAR*** Scientific Assemblies do offer mechanisms to foster international cooperation through meetings and establishing partnership for the development of payloads or for data analysis and scientific research in general. However, only space agencies can establish the formal treaties or Memorandums of Understanding that frame –and finance- these cooperative agreements. ***Brazil*** for its own sake, has established cooperative agreements with a substantial number of countries: Argentina, Canada, China, France, Germany, India, Italy, Japan, Mexico, Mozambique, Portugal, Russia, Spain, the United States of America, and the United Kingdom. It also cooperates with the United Nations and is a member of COSPAR.

As explained in Section 2.2.3, the context of international cooperation is presently changing and will change even more so in the future due to three important elements. First, are the increasing difficulties of cooperating with ***the United States*** after the 11 of September 2001, and the strict application of the ***ITAR rules*** which prevent non US scientists and engineers to participate as full partners in technical discussions, in parity with their US colleagues. Second, is the emergence of two Group-2 countries, ***China and India*** which openly announce and develop very ambitious programs, as shown for example on figure 9, which illustrates the Indian space program for the next 20 years. Third is the re-emergence of ***Russia*** in the post-soviet phase of its space programs. Russia has indeed demonstrated in the recent past a unique capability for developing imaginative and ambitious projects. Once back on track after the fall of the Berlin wall, it should be considered again as a very serious partner.

This new context offers a chance for all non-US space fairing nations to join forces and to create an alliance which would be capable of partnering with the US on a more equal basis than for any of them individually (see section 4.1 of next chapter). ***Brazil,*** with its present set of international partners, should benefit from this new trend and ***participate more actively*** in the ***establishment of common road maps,*** more particularly in the domains identified below. These road maps constitute an excellent tool for indicating the future directions of programs, contributing to better frame their ultimate goals. They also permit avoiding unnecessary duplications of efforts in the development of missions and of payloads, allowing all participating nations to visibly play their useful and unique role. Several opportunities particularly well adapted to international cooperative ventures should be considered as first priorities:

- ***Solar-terrestrial relations and the ILWS program***
- ***Astronomy, in particular visible and ultraviolet***

- ***Geosciences in general***
- ***Lunar and Martian exploration.***

We analyze in Section 5 how Brazil can increase its participation in these programs above the present level.

Figure 9: The Indian space program for the next 20 years (Credit: ISRO).

3.2 The role of space sciences vis-à-vis industry and to foster applications

As a special branch of science, space sciences offer powerful opportunities for industrial development in areas which prove to be extremely competitive, such as advanced technologies, information technologies, robotics, optics, mechanics, computer sciences, etc. For a country, space industry offers many challenging jobs and careers to the new generations because space techniques and space sciences in particular, have constantly to reach the highest levels in quality, robustness and reliability. Space sciences in addition are particularly well suited to the formation of future engineers and of future managers. They represent an excellent and unique school for training and learning how to manage big programs, budgets and risk.

Conversely, in particular in ***countries of Group-2***, space industry is an essential element in the chain of mission preparation. This not only applies to the development of the spacecraft itself but also to the payload, the ground segment and, in particular in the area of Earth observation, to the distribution and commercialization of data, whenever applicable. Wherever university or research institutes do not have yet the required and often very specific infrastructure and the necessary equipment to develop the payloads and their associated ground segments, space industry can offer its capabilities and expertise. ***This possibility should seriously be considered.***

The capacity of industry to develop the very demanding ***hardware*** for payload, subsystems and platforms, spreads through many sectors of industrial activities be they connected or not to space, increasing the capability and the technical level of both aerospace companies and of Small and Medium Enterprises (SME). A similar synergy exists also in the area of ***software***: the joint ESA- Swedish Space Corporation ***Smart-1*** lunar mission was carrying the most complex software system ever developed in Europe when it was launched in 2002. Industry has also the capability and the vocation to produce commercial ***data and added-value products***, in particular from the exploitation of Earth sciences missions. Finally, industry is in the best position to exploit all space development for ***spin-off*** products and activities, fostering ***applications*** on a scale not reachable by research institutes.

3.3 Connections between Earth sciences and space sciences

Both space geosciences and space science have ***science*** as their main common point of concern. Both also use ***space techniques*** to reach their goals. However there are substantial differences between both. Geosciences are focusing on a single object, the Earth, while space sciences do look after the rest of the Universe! The latter are often called classical or "pure" sciences in opposition to the former which are often considered as applied sciences.

Certainly, a major difference exists in this respect: observing the Earth from space has connections with applications of a strategic, or political, or commercial nature. In contrast, the only "application" of space science is for science, for education and for knowledge in general. In ESA for example, the data from Earth missions are not made available freely unless it is demonstrated that they are used for "pure" scientific purposes. Indeed, "pure" also applies to Earth sciences and many of the presently unsolved problems confronting earth scientists in trying to understand the Earth system are of a pure scientific nature. If both types are separated in agencies, such as is the case at ESA (and NASA for a long time, but not anymore these days), it is mostly arbitrary and often on the basis of that connection to applications and, to a lesser extent because the platforms used for Earth sciences are of a slightly different nature, being more easily standardized due to the uniqueness of the object that they study than is the case for astronomy or planetary exploration which deal with the whole Universe.

Nevertheless, all Group-1 space agencies do have a dual program of space sciences and geosciences, while Group-2 agencies (China, India, Brazil, and South Korea) give a clear priority to Geosciences. No qualitative conclusion can be drawn from that observation, but let us just insist at this point that the methods and procedures used in space sciences, because of the "pure" nature of these sciences are the most appropriate to generate and foster the necessary critical mind and scientific spirit which characterize them. In other words they offer the best school and opportunities to foster the scientific methodology which strives for excellence through competitive selection of ideas, and the peer review system. These methods, once mastered and applied to the case of Earth sciences, do directly contribute to raising their excellence and their quality. ***Developing a space science program*** in parallel with a program in Earth space science ***is strongly encouraged***. In fact, recently India and China have broadened their programs and are now involved in space science missions such as the ***Double Star*** set of satellites in China, ***Chadrayaan-1*** and ***ASTROSAT*** in India. The development of ***MIRAX*** by INPE shows that this approach has also been considered in Brazil even though the development of the mission is being delayed substantially.

From the "pure" scientific point of view, there exist a direct connection between space sciences and geosciences (in the INPE sense), and this is in the area of ***Sun-Earth relations.*** The Sun's influence on the Earth is raising a substantial number of "pure" science issues as discussed already in Section 2.2.1 (Theme 4), dealing with the Earth magnetism, Earth atmospheric electricity, atmospheric physics and aeronomy, which INPE is in fact addressing in priority in its programme. This ***involvement is strongly encouraged*** and the ***Living with a Star*** program (ILWS) opens plenty of very interesting opportunities for cooperation.

The methodologies are of course often very similar between these two fields of science. Let's point out as an example the exploitation of seismology equations developed for the study of the Earth's interior, which are now applied with enormous success to the Sun and other stars, making it possible to study their internal structure and dynamics, exemplifying in a remarkable way the success of such synergies. We could quote many other examples in particular radiation transfer, hydrodynamics and magneto-hydrodynamics.

From the hardware point of view, of course the procedures for developing platforms and payloads are very similar and, in particular in industry the same engineers are responsible for the management of both types of missions. For agencies where the number of missions is not very high (say, less than ten), there is great advantage to have a single technical group put in charge of all of them without distinction of their different nature. As mentioned already, space sciences would offer excellent opportunities to develop new technologies while the challenge in Earth sciences would rather be on the side of software, data handling and archiving over long periods of time. An important issue common to both is that of ***calibration*** without which it is impossible to properly quantify the phenomena studied. This is particularly critical and delicate in the case of natural solar forcing on the Earth where very ***accurate radiometry*** is essential for measuring both the total solar irradiance and the spectral irradiance.

3.4 Connection with Education. Capacity Building

Education is a vital priority for all societies of the planet whose future rests on advanced knowledge and on the understanding of the world, of its nature and of its people. Space sciences exist since 50 years, as the new child of the space era, following the launch of the first artificial satellite of the Earth. After 50 years, they have blossomed and revolutionized our knowledge of the Universe. They have as well allowed to explore all the planets of the Solar System and to better understand the Earth's system itself. A vast amount of data is now available either in the form of articles or scientific publications, in archives deposited in space agencies or in specialized institutes. They represent a wealth which no longer belongs to those who have developed the instruments and the missions that collected them, but can be considered as a patrimony of humanity for the benefit of the present and future generations to come. Today, space sciences have proven their power of discoveries and have demonstrated their enormous capabilities in the application of the laws of nature in very different contexts and in extreme conditions of time, gravity, temperature, vacuum, etc. They allow a direct contact with objects which have been considered as remote and unreachable to Man only as dreams since the beginning of humanity. They are a source of new ideas and of new concepts. They excite the imagination, forcing the brains to reflect, to understand and sometimes forecast.

The wealth of acquired space sciences data is unfortunately not fully exploited or analyzed, mostly because of the insufficient number of scientists in charge or, to a lesser extent, because of the lack of the required brain power. This power exists however everywhere in the world and also in countries which do not necessarily have a space program of their own. Involving these countries in the data processing exercise and in the interpretation of the data would fulfill two goals at the sane time. First, it would provide the required support for the analysis of the data, and second it would offer a unique opportunity for the scientists of these new or emerging space countries to get a unique hand-on experience through the exercise.

Since several years, COSPAR and the United Nations through the Office for Outer Space Affairs (OSSA), the UN Basic Space Science Initiative (UNBSSI) and UNESCO have organized international meetings and in particular ***Capacity Building workshops*** where the scientists of mostly Group-1 nations –but not only- do work together with the scientists of countries willing to get a space expertise through education of their future space scientists. ***Brazil*** has in the past benefited from this activity and may consider expanding its involvement through these workshops in new space science areas of interest. Noteworthy was the workshop co-organized by COSPAR and dedicated to X-ray astronomy and the use of XMM-Newton and Chandra data.

Of key importance for the organization of these workshops is the ***selection of the right blend of scientists:*** those who not only can handle and interpret the data, but also those who are knowledgeable of the development of experiments and of their calibration. Only through that blend can the workshops be used to the benefit of all, so that they convey experience and knowledge in order to form the generations of experimentalists to come, which will be essential for the development of future space projects. The danger indeed would be to form generations of scientists who would be unaware of the real problems and of the intrinsic risks of hardware development. The future of space science relies above all on new ideas of missions but also on ***trained experimenters.***

Brazil has also taken its own initiatives which are well appreciated, such as the EDUCA SeRe project using data from the CBERS satellite, and public and high school courses in application of teledetection for environmental studies and in astronomy and astrophysics as well.

3.5 Outreach and support for space programs

Finally, we should not underestimate the enormous importance of outreach and of ***publicizing the results*** of space and Earth science missions. Their success is the seed to getting the support of governments and administrations as they are the testimony of scientific excellence, of successful research and of discoveries. Both space and Earth sciences missions for their own sake do attract the attention of the public. The former because they discover the unknown and participate in the Endeavour of mankind to explore and formulate the laws of nature, the latter because they deal with immediate concerns of mankind to survive on our planet.

It is the responsibility of all those involved to take part in this effort of explanation and ***outreach***, since these efforts will determine the continuation and possibly the expansion of space research both at the national and at the international levels.

4. THE GENERAL CONTEXT AND THE PLACE OF BRAZIL

4.1 Comparison between the main space fairing nations

It would be unfair to discuss the accomplishments of the main space fairing nations without having a look at their respective yearly budgets. Table 3 compares these budgets for the main Group-1 and Group-2 countries. The numbers are from the 2006 Euroconsult study, a document which is available commercially. For China, Euroconsult gives a 2006 figure of 134 millions US $, a number which is extremely low and does not correspond to that usually quoted in the professional press and close to 1.7 billions US $ for the same year. This latter figure would better fit the Chinese civilian space program as we see it developing today. Consequently we have selected that number, which however ought to be considered with caution. For Brazil, Euroconsult gives a figure of 125 millions US $ for 2006 which is higher than the 100 millions quoted by INPE itself. We have nevertheless kept the Euroconsult figure since it is not too different from the INPE figure.

As a general comment, these numbers, especially for countries of Group-2, should be multiplied by a factor which would represent the cost of the workforce (manpower) in these countries, since what counts is the real and local purchasing power of the respective budgets. For example, India with a 2006 budget of 813 millions US $ and a manpower cost approximately 5 or 6 times cheaper than the European value, would in fact have a budget equivalent to some 4 to 5 billions when placed on the same scale as Europe, a number nearly equal to that of Western Europe and higher than that of ESA alone of 3.4 billions US $.

The numbers of Table 3 for all countries, except the US, when added together (even not taking into account the weighting manpower-cost factor discussed above), give a figure of 11.6 billions US $ which is not too different from the US value of 17.3 billions. Taking account of the weighting factor and the rather low efficiency of the US space organizations, we come very close to nearly identical figures. This shows that a consortium of these nations would represent a very serious contender to the US leadership, provided this consortium is properly organized and its programs properly managed. This remark tends to encourage these nations to pull their resources together and undertake a serious effort of coordination of their respective programs to reach a better efficiency in their overall program and get more value for their individual expenditures.

Countries	2001	2002	2003	2004	2005	2006
United States	*14,194*	*14,921*	*15,382*	*15,870*	*16,752*	*17,342*
Western Europe	*4,118*	*4,255*	*4,750*	*5,858*	*6,038*	*5,672*
Japan	*2,155*	*2,180*	*2,253*	*2,413*	*2,426*	*2,231*
Russia	*195*	*310*	*298*	*475*	*646*	*821*
India	*406*	*449*	*489*	*608*	*609*	*813*
China	*NA*	*NA*	*NA*	*NA*	*NA*	*1,700*
South Korea	*100*	*113*	*126*	*145*	*177*	*209*
Brazil	*89*	*56*	*56*	*79*	*96*	*125*
Argentina	*76*	*25*	*30*	*30*	*35*	*35*

Table 3: Civil space budgets of the main space fairing countries in US $ billions. Western Europe includes ESA, its Member states national programs and the European Commission. These numbers have been extracted from the Euroconsult 2006 study except for China where we use the higher figure found in the professional press (see text).

We give in Annex the list of already on-going missions or those in preparation in the main space agencies.

4.2: Comparing Space Sciences efforts in Group-2 countries

In this section, we analyze the Brazilian situation considering the size of its space sciences program (number of projects), the number of its space scientists, and as much as possible the level of appreciation of their peers in the international scientific community. We have tried to calibrate this effort by comparison with countries having a similar space budget.

4.2.1: Programs and projects

The effort of Brazil in space research is mostly focused on Geosciences. The tables provided by the CEOS are offering an excellent tool for comparing the sizes of the respective efforts of space agencies in this field. CEOS lists 23 agencies including 6 from Europe, 3 from the United States, 2 from Russia, 2 from China and 2 from Japan. In South America, only Brazil and Argentina are registered in the CEOS list. Table 4 compares the numbers of missions in Argentina, Brazil, China and India and shows that Brazil is conducting an active program in Earth observation, with substantial cooperation with China. This program makes Brazil one leading country in the field. However, the projects mentioned in Table 4 are more of an applied character than purely scientific.

Argentina (CONAE)	8	SAC-C, SAOCOM 1A, SAC-F, SAOCOM 1B, SAC-E/SABIA, SAOCOM-2B(2), SAOCOM-2B(1), SAC-CD/Aquarius (with NASA)
Brazil	8	SCD-1, SCD-2, SCD-3, SCD4, CBERS-2, CBRS-2B, CBRS-3, CBRS-4 (all CBERS missions with CAST)
China CAST China NRSCC	8 10	HJ-1A, HJ-1B, HY-1B, HJ-1C, CERBS-2,2B,3 and 4 FY-2C, FY-3A, FY-2D, FY-3B, FY-3C, FY-2E, FY-3D, FY-3E, FY-3F, FY-3G
India	12	INSAT-2E, IRS-P4, TES, KALAPANA, INSAT-3A, RESOURCESAT-1, CARTOSAT-1, CARTOSAT-2, INSAT-3D, RESOURCESAT-2, RISAT-1, OCEANSAT-2

Table 4: List of Earth Observation missions conducted in the main Group-2 countries. Credit: CEOS.

In the domain of scientific satellites, the situation is much less impressive as shown on Table 5, but this applies to nearly all Group-2 countries and not only to Brazil. In reality, there exists on top of these projects several bilateral or multilateral cooperative agreements at the level of payloads or CoI-ship such as the ***Brazilian contribution to the French COROT mission*** (CNES) just successfully launched, and which allow Brazilian scientists to be involved in some of the most advanced scientific projects worldwide. The ***MIRAX*** project to study variable X-ray sources and explosive events is conducted by Brazil in cooperation with several other countries. It should in principle reach very high spectral resolution and very high sensitivity, but we notice that this project is in development since several years now (apparently since 2001) and yet not launched, which seems to indicate difficulties of either a programmatic or a managerial nature.

Brazil	3	EQUARS (2008[*]), MIRAX (2010[*]), ITASAT (TBC)
China CAST	2	Double Star (in operation, with ESA), Chang'e-1 (2007)
India	3	Chandrayaan (2008), ASTROSAT (22x), Megha-

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[*] Planejamento Estratégico do INPE: Visão Geral

		tropiques (2009, with CNES)

Table 5: List of scientific approved missions (or in preparation) that are conducted by the main Group-2 countries.

INPE is also involved in atmospherics physics research through its ***Aeronomy Division***. Scientists there, conduct research through the study of ***meteor*** trails for measuring mesospheric winds. They also use the ***GPS*** for measuring the total electronic content, and study the ionosphere. The ***Geophysics Division*** is active in magnetospheric and heliospheric research and in studies of ***Sun-Earth relations*** in cooperation with JPL and the Max Planck Institute at Lindau. The ***Astrophysics Division*** conducts also balloon borne experiments for imaging ***X and gamma-ray*** sources (MASCO project). This Division is also active in optical and infrared astronomy in cooperation with the Brazilian National Astrophysical Laboratory and in interferometry in the radio range, as well as in gravitational waves detection. All these works seem to be well appreciated by the international peers, as shown in the following section.

4.2.2: Scientific community

Among possible factors, we have selected the number of space scientists as an indicator for assessing the level of a given nation in space research. Using the number of COSPAR associates as provided by the COSPAR secretariat, i.e. the number of scientists participating actively in COSPAR Scientific Assemblies and related symposia, we have established Table 6 where one finds the 2006 space budget per country, the number of COSPAR associates, the population and the ratio of COSPAR associates per million inhabitant. We have made a selection of countries whose space budgets range from ~ twice or ~half the space budget of Brazil.

This table puts in sharp focus the ***peculiar situation of Brazil*** with only 0.42 COSPAR associates per million, as compared with countries like Belgium or Norway which both are either slightly below or above 7. ***This is not a good sign for Brazil***. With a similar space budget, Switzerland has exactly the same number of COSPAR associates but reaches a ratio above 10. To be fair, of course, the small number for Brazil is due to its relatively large population. For China the ratio is equal to 0.37, i.e. lower than Brazil and this is of course due to the same phenomenon, China having a population of 1.306 billions. Nevertheless, China is forming every year some 1.5 million engineers and scientists, a proportion of which will certainly contribute to raise soon the Chinese ratio. There is no indication that Brazil is ongoing such a spectacular progression!

The repartition of associate members among the different COSPAR commissions is shown in Table 7 and evidences a fairly even distribution, which is good, with the exception of commissions dealing with microgravity and fundamental physics, which reflects an apparently rather low participation of Brazil in these activities and in the utilization of the International Space Station.

Country	*2006 budget*	*COSPAR Associates*	*Population (10^6 inhabitants)*	*COSPAR Associates per 10^6 inhabitants*
Spain	230	86	40,4	**2,13**
Belgium	213	72	10,4	**6,92**
South Korea	209	28	48,4	**0,66**
The Netherlands	111	125	16,4	**7,62**
Switzerland	117	79	7,5	**10,53**
Sweden	106	93	9,00	**10,33**
Taiwan	63	87	22,9	**3,80**
Ukraine	59	40	47,4	**0,84**
Brazil	125	79	186,11	**0,42**
Austria	55	64	8,18	**7,82**
Finland	57	70	5,22	**13,41**
Denmark	36	30	5,43	**5,52**
Argentina	35	23	39,54	**2,41**
Norway	48	35	4,59	**7,62**

Table 6: 2006 space budget, number of COSPAR associates, population and number of COSPAR associates per million inhabitants in countries involved in space research whose budgets range between the double and the half of the Brazilian value. The space budgets are quoted from the Euroconsult 2006 report. COSPAR data are those provided by the COSPAR secretariat.

COSPAR Commission	*Appellation*	*Associates*
SC A	Earth Surface, Meteorology & Climate	**21**
SC B	Earth-Moon System, Planets, Small Bodies	**17**
SC C	Earth upper Atmosphere, Planets	**32**
SC D	Plasmas in the Sol. System, Magnetospheres	**25**
SC E	Astrophysics	**20**
SC F	Life Sciences	**5**
SC G	Material Sciences	**0**
SC H	Fundamental Physics	**6**

Table 7: Number of COSPAR Associates per Scientific Commission for Brazil. Note that one scientist can participate in several Commissions, which explain that the sum is larger than the total number of 79 Associates from Brazil. Source: COSPAR Secretariat.

The statistics of the International Astronomical Union shown in Table 8 are also revealing for the astronomy community the same deficiency as noticed for space sciences. As a logical consequence, the participation of Brazilian scientists in international meetings is marginal. This is the case in particular of their participation in the activities of the International Space Science Institute in Switzerland.

Country	***N° of members***	***%Males***	***%Females***	***Members per 10^6 inhabitants***
Spain	255	81.18	18.22	6.31
Belgium	105	86.67	13.33	10.09
South Korea	97	89.69	10.31	2.00
The Netherlands	196	90.82	9.18	12.25
Switzerland	98	92.86	7.14	13.07
Sweden	112	86.61	15.39	12.44
Taiwan	42	92.86	7.14	1.83
Ukraine	176	76.30	23.70	3.71
Brazil	159	79.25	20.75	0.85
Austria	35	88.57	11.43	4.28
Finland	62	85.48	14.52	11.88
Denmark	65	87.69	12.31	11.97
Argentina	113	62.83	37.17	2.85
Norway	30	86.67	12.33	6.53

Table 8: Membership of the International Astronomical Union (IAU), shown for the same countries as in Table 4, evidencing the low numbers and proportion for Brazil. Credit: IAU secretariat.

The ***International Space Science Institute*** (ISSI) has since 11 years assumed with great success the responsibility of exploiting the space science data obtained by all scientists and space agencies of the world in a broad international context, cutting across many disciplines in view of opening new avenues of knowledge and of addressing problems of a multi-disciplinary dimension. In the past 11 years, ISSI has attracted more than 1700 scientists from more than 36 countries and it attracts the best scientists of the world to better fulfill its duties. As of now, only 4 Brazilian scientists have participated in ISSI activities, which is a small number. Per comparison, the total corresponding participants from Europe and the US were of 995 and 505 respectively.

This somewhat sporadic presence of Brazilian scientists at international meetings is also the consequence of financial limitations. However, their publication record is excellent as compared to other peers in Latin America. Brazilian scientists have also been active in the meetings of the Latin American Space Geophysics Association (ALAGE), which tend to be more local. There is also a strong connection to the Jet Propulsion Laboratory in the area of heliosphere physics, although their more traditional international collaborations have been with European and Japanese scientists.

As we see, and as mentioned in the INPE documents, these small numbers are not synonymous of any sign of poor quality of the Brazilian space sciences community. On the contrary, this community is usually well considered by its international peers as shown on the selection of quotes that we have been able to collect in the course of this exercise and that we reproduce in the text boxes below. This ***impressive recognition of quality*** should send a message to the government and encourage the relevant ministers to ***support more*** than is presently the case, ***the space program of Brazil.***

US scientist:

"It is clear that resources are a major limitation to INPE activities and its scientists and is a common denominator in many Latin American countries. Access to launch vehicles and launch opportunities has been a major limitation for all. Given this limitation it is fair to state that the level of the scientists is on a par with those of other countries with limited space research funding like Canada, Argentina and Mexico. In some areas (i.e. equatorial ionospheric and magnetospheric physics, solar radio astronomy) the "world class" denomination applies. The group in Santa Maria is extremely enthusiastic and eventually can develop into a strong contributor to the overall Brazilian effort. Both groups carry out significant educational post-graduate functions that are on a par with those conducted at recognized excellence academic institutions in the US and Europe."

German scientist:

"(Brazilian) post-docs have learned how to analyze and interpret Cluster data. They copied short periods of Cluster data to continue their work in INPE. Their papers have international standard."

US scientist:

"There are several groups that are quite active in magnetosphere and ionosphere research using ground-based facilities and on a theoretical basis (space plasma physics). At INPE and at a couple of universities, Brazilian researchers have also investigated space weather (practical applications) problems at low latitudes with some nice analyses and discussions. Particular strength has been in understanding the coupling of solar wind plasmas to the magnetosphere and the generation of magnetic storms and sub-storms. Some of this latter work has been in collaboration with researchers from JPL."

JPL scientist:

“The science productivity in the solar, interplanetary, magnetosphere and ionosphere areas is first rate. INPE has world leaders in these areas…. They are to be particularly …commended. Excellent work is also being done in the plasma turbulence area.”

Russian scientist:

“As for Brazilian cooperation it is according to my knowledge at very low level and we will be grateful if you find a way to encourage it...”

4.3 Regional aspects

Regional aspects are very important in space-related projects. They have played a key role in Europe, even leading to the creation and successful development of the European Space Agency. They are also important in Asia and we see that they can also contribute to create a leading space science pole in South America. We concentrate on the latter more specifically now.

There exist three highly rated scientific groups in Latin America:

(1) The Institute of Geophysics at the UNAM in ***Mexico*** (National University) which is broad based and involved in cosmic rays, planetary physics, space physics, geophysics, etc…
(2) The group at IAFE at the University of Buenos Aires in ***Argentina*** and
(3) The group associated with ***INPE*** in ***Brazil***.

INPE (San Jose dos Campos) has been focused primarily on geomagnetism and equatorial magnetospheric physics, ionospheric physics and heliosphere physics. INPE scientists use balloons, sounding rockets of local origin, and small satellites from international collaborations. This goes back to the days of the early measurements associated with the ***South Atlantic anomaly.*** INPE has also direct and indirect contacts with numerous universities and institutes inside and outside Brazil. The major universities are: UNICAMP, USP, UNESP, Mackenzie University (Sao Paulo, well known for their solar work), Santa Maria University (Rio Grande do Sul), Federal University of Rio de Janeiro, Federal Fluminense University (Rio de Janeiro), Federal University of Rio Grande do Norte, Federal University of Rio Grande do Sul. Other universities and institutes are also creating new research teams that are starting to study future possible space missions.

At various institutions in Brazil, several projects are being carried out which deal with atmospheric, ionospheric, magnetospheric and interplanetary physics, mainly related to the science and applications of ***Space Weather***. An effort was also started to develop a regional center of space weather forecasting, situated in Sao Jose dos Campos, and the regional center of formation to sciences and space techniques for Latin America and the Caraïbes. In atmospheric sciences, efforts to continue monitoring the ***ozone*** content and its variability and of several other key parameters at the low, middle and upper atmosphere have been successfully carried out.

Collaboration is fairly intense among the three Latin America countries mentioned especially between Brazil and Argentina and this is excellent! For example, the Argentinean SAC-C satellite was tested at the INPE facilities. Argentina and Brazil also jointly operate a Solar Sub-millimeter Telescope installed in the El Leoncito site, in the Argentinean Andes. The instrument is conceived to study the still unexplored submm-IR spectrum of solar emissions in quiet, quiescent and explosive conditions. It has already led to new discoveries on the relation between the sub-millimeter emission and gamma, X-rays and H alpha observations.

There are also other good options for further collaboration in South America since ***Argentina*** has recently installed an ozone ***Lidar***, now fully operational, and an existing aerosol Lidar, has been used to determine ozone and aerosol profiles over the city of Buenos Aires. These profiles were used to calculate ***regional UV irradiances*** and compare them with results from radiative transfer models. Aerosol research is also conducted by CONAE, in the AERONET project. Cooperation with Brazil should be encouraged also in this area if it is not already done.

5. POSSIBLE STRATEGIES FOR BRAZIL

The short English summary of the ***Program Nacional de Atividas Espaciais*** (PNAE) of INPE, provided to the reporter contains very nice sentences such as:

"On 3^rd^ August 2006, INPE completed 45 years old. Since its creation, it has been pioneer in investing in the qualification of skilled researchers and establishing cooperation with other countries. It was the third country to receive satellites images behind only the United States and Canada, and today, many of its projects are praised worldwide, such as the orbital monitoring of burnings and deforestation in Amazonia".

It also raises the very well thought question:

"How do we make the Space Program have the size of Brazil? How do we organize INPE to produce Impact Science and Technology"?

We consider of our duty in establishing the present report, to bring some elements of answer to this crucial question.

The mere fact that this report was requested shows to the evidence that the situation indeed needs improvement, and that some improvement is considered as possible. We try to suggest below a few lines –may be too few and too simple- of strategic actions which might contribute to place Brazil in the leading position where it should be given its size, its enormous potential of resources and its rich historical past.

5.1 The importance of the place and the role of Brazil on the world scene

With its population of nearly 190 millions inhabitants and its size, Brazil is one of the major nations of the world. This situation is strengthened by the economical weight of the country and the great diversity of its agriculture. Brazil does also possess very high concentrations of population and of industrial zones. Besides an extremely rich reservoir of resources, Brazil occupies a unique place because of the Amazon River and the presence of the largest tropical forests in the world. These two elements are essential not only for the nation itself but also for the whole planet due to their role in the maintenance of balanced global environmental conditions. From a pure scientific view point, Brazil is also the seat of the South Atlantic Anomaly which plays an important role in space communications, and still is not fully understood. Furthermore, the ***Lusitanian origins*** of the country represent an essential asset and can be used to bridge and narrow the gap between South America, Africa, Europe and Asia. There are many hopes that Brazil would play a leading role on the world scene, but also some disappointment that it does not fully adopt a more aggressive policy to that effect!

5.2 Is the present strategy in space sciences the correct one?

With a space budget of only a little more than 100 millions US$ per year, we can say right at the onset that the overall ***achievement of Brazil in space is remarkable*** and deserve to be admired. This is particularly striking in the area of Earth observation and remote sensing. The CBERS series is very successful, producing excellent results and distributing spectacular images of the planet worldwide (Figure 10). The Center for Weather Forecasts and Climate Studies (CPTEC) of INPE is among the ten largest meteorological centers of the planet. Its forecasts are given daily through the major means of communication and have reached a high level of reliability. It is able to exploit images from non-national missions such as NOAA-12, 14, 15 and 16 as well as GOES-E and Meteosat. The DETER system (Detecção em Tempo Real de Desmatamento na Amazônia Legal), which has been developed upon request of the Ministry of the Environment to support the control of deforestation in Amazonia, is in use and provides information on the apparition of new areas of deforestation on a basis of 30 days, which is quite an achievement!

The policy of INPE for international cooperation is fairly well balanced, with a remarkable joint Brazil-Chinese effort through the CBERS program. The Brazilian contributions to international projects are also usually well praised. However, not all is rosy!

Despite these successes it is quite obvious that ***space science is not a priority for Brazil***. Only a small fraction of the annual budget is allocated to these sciences (about 2%), the major share going in priority to infrastructure, applications (mostly meteorology and remote sensing) and for the development of remote sensing satellites along with satellite launchers. Of all the missions of INPE as reported in the PNAE (Figure11), ***none of the two space science missions EQUARS, MIRAX are launched*** yet and the latter sees its ***launch date abnormally shifting with time***. As one international scientist said concerning EQUARS: "*It is unfortunate, as this mission could have brought forth INPE science to even greater visibility and productivity*".

Another scientist in the course of discussing the future space program was quite critical also of the situation. Paraphrasing his own judgment, he is reported to have said: *"To my knowledge no progress was made in the last two years, neither in the area of cooperation in various international space science projects, nor in the joint development of experiments and instrumentation"*. To put the matter in sharp contrast, as of now, it could be said that Brazil produces only satellite imagers!

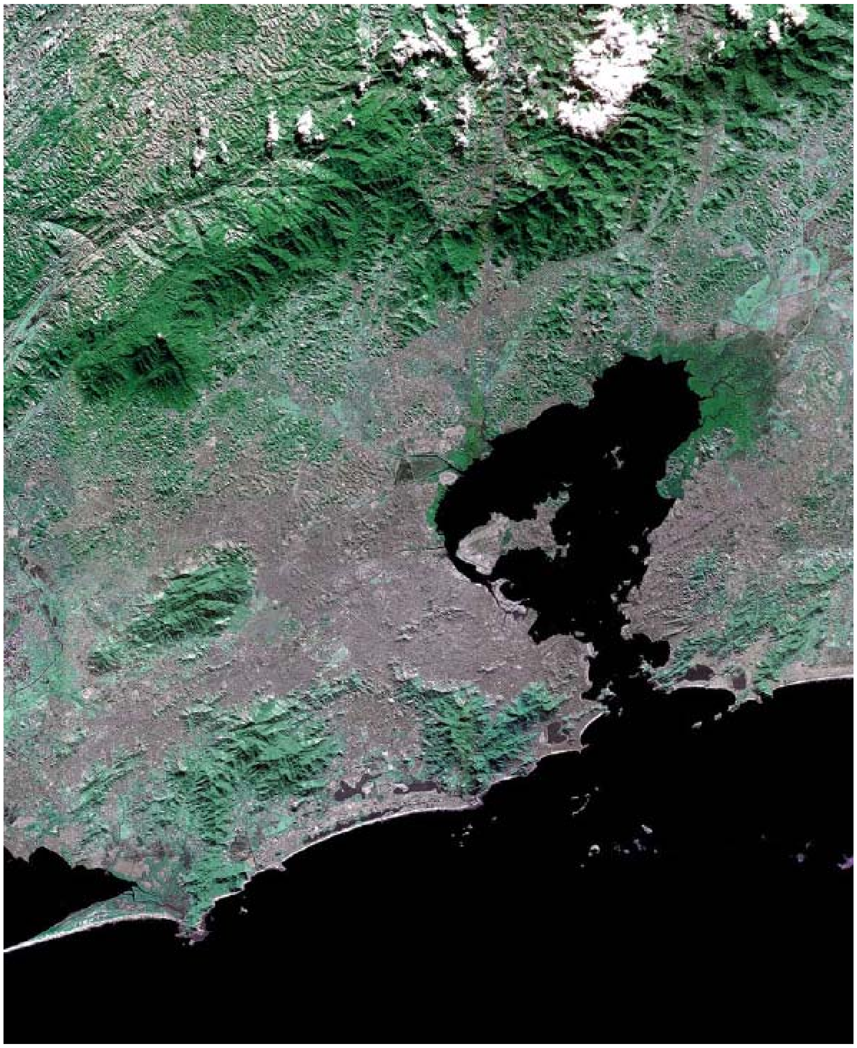

Figure 10: Beautiful picture of Rio de Janeiro made by CBERS.

Can Brazil do better? Considering the excellent international reputation of its scientific community as discussed in the previous chapter, and the size of the country, the immediate answer would be "yes"! However, this is not so simple. Increasing the level of involvement in space science cannot be done without considering the whole science policy of Brazil. Why should space sciences be privileged and benefit from an increased level of effort if this is not done also for the other sectors of science? One possible answer would be to consider ***space sciences as part of the space strategy of Brazil***. The present medium-term plans however do not indicate that this is the case.

Nevertheless, a ratio of only 2% of the space budget dedicated to space science is abnormally low. ***Brazil should therefore seriously consider following the example of India and of China*** and ***devote higher expenditures to its space science program***, if it wants to be considered as a serious international partner in the future. Both China and India have well understood that ***periodic space science missions are useful to sustain the interest of the space science community and also to attract new talents*** to the field of space based aeronomy, astronomy and space exploration The presence balance in the Brazilian program might be dictated by political considerations and reflect a certain strategy of the government. We are just saying here that this strategy is incomplete and that more money should go to space sciences missions, not necessarily at the expense of the other parts of the program which are already rather stressed. In clear ***the space budget should be increased*** and ***that increase should benefit in priority to the sector of space sciences!***

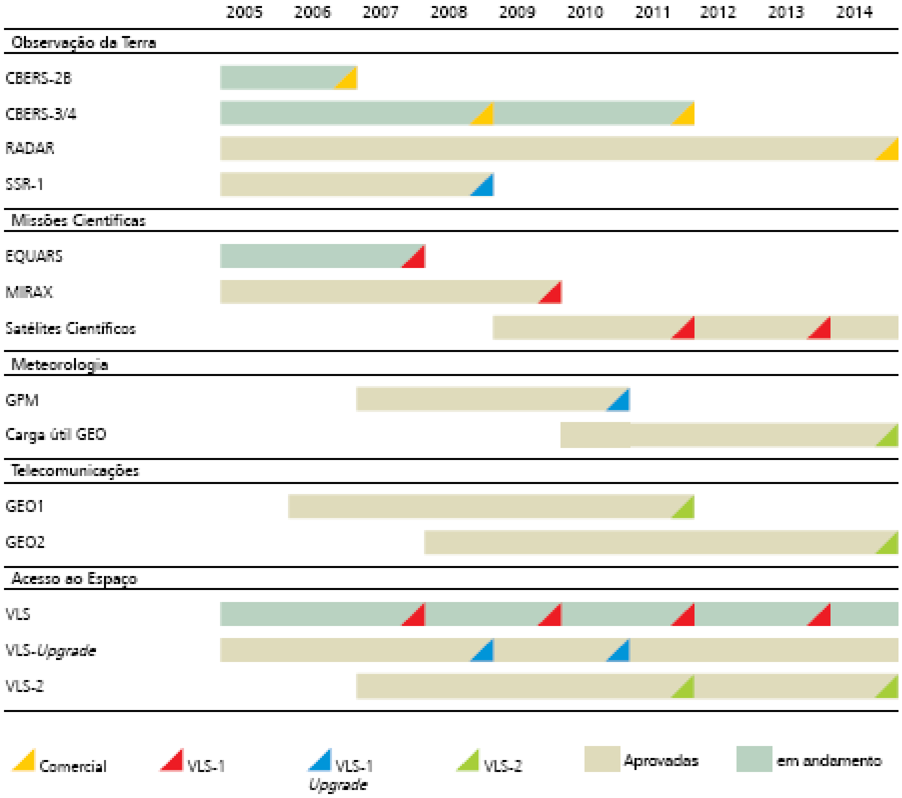

Figure 11: Planned missions of INPE until 2014. Credit: PNAE.

5.3 Some sectors of space science where Brazil could play a key role

We discussed in Section 3 and throughout this report where might Brazil consider reinforcing its space science involvement, taking account of its intrinsic capabilities, of its interests and of the worldwide context. Brazilian scientists are already fairly well involved and well appreciated in at least two important domains: Geosciences and Solar-terrestrial relations but we suggest that Brazil considers

broadening its involvement in space astronomy and also be part of the just starting ***Exploration initiative.*** However, ***the author*** cannot -and certainly does not want to- ***substitute himself to the scientific community.***

A good space program is a programme that responds to the modern trends of science but also to the wishes of the scientific community who will have to implement and to exploit it. Hence, the first action to take in any of the scientific areas covered below is to ***consult the Brazilian space science community*** either through ***specialized workshops*** or through ***calls for proposals*** that would be analyzed by the scientists themselves through generic or ad hoc committees as is done in most of the space agencies. This advice is given here without knowing whether or not INPE has such an advisory structure in place. The author just heard a scientist, whom he was interviewing in the course of the preparation of this report, complaining that the scientific community is not well informed of what is going on in the establishment of programs and that it would be advisable to establish a much more active consultation of the community at large. Consequently, ***what follows is voluntarily not specific but just serves as an indication of possible avenues where to explore the interest of the community whenever and wherever applicable***.

5.3.1: Geosciences

The present program is centered on aeronomy and atmospheric electricity and geomagnetism. These are strengths of the community. The only priority there is to ***get the EQUARS mission in orbit as soon as possible.*** Apart from this, the space agencies' programs are filled with missions of interest for Brazil as indicated in the tables of the annex. Several opportunities are indeed particularly well adapted to international cooperative ventures. The geographical position of the country calls on it to be a leading partner in the study of geomagnetism and of the South Atlantic anomaly. The present program is already focused on these topics and needs to be reinforced. Particularly interesting, and in line with the present involvement of Brazil in the Danish Örsted mission, would be the potential ***implication in ESA's Swarm mission.***

The ***water problem*** is one where Brazil could play a leading role for two reasons: the Amazon and the large Atlantic front, in the context of changing climatic conditions and the modifications of the soft water draining network and of the ***sea-level rise***. ESA and ISRO are particularly keen to addressing these issues through ENVISAT, ***SMOS*** and OCEANSAT-2 as well as Japan with missions such as GPM, GOSAT and EarthCare.

Implications in ***SMOS*** are also particularly advisable in view of its potential to ***study the biosphere*** where, as said, Brazil is also one of the most interesting countries to participate and to contribute to important advances in the field. If not already done, contacts should be established with ESA and ISRO for Brazil to cooperate at the level of data acquisition and analysis.

5.3.2 Solar Terrestrial relations

The Sun's influence on the Earth is raising a substantial number of "pure" science issues as discussed already in Section 2.2.1 (Theme 4). This domain is clearly one of excellence of the science community in Brazil which has participated in joint scientific work with Europe in particular on Cluster data, and with the United States. At ESA, Cluster will be succeeded with ***Swarm*** already mentioned which would offer an excellent opportunity to exploit the know-how of Brazilian scientists. Furthermore, this domain offers the very interesting possibility of ***developing small satellites*** in complement of other missions under the responsibility of other agencies.

Magnetospheric studies are ideally conducted with ***constellations of small satellites*** whose development is well within the technical and financial competence of INPE and of its scientists. The ***ILWS*** program is also ideal since it allows any agency which wants to do so to join the international venture in a true spirit of cooperation. This program is very important for assessing the ***dangers of solar radiation*** and for the ***forecasting of solar events*** in the context of ***manned exploration missions*** to the Moon or to Mars. There is room for Brazil to cooperate at the level of robotic missions with all the agencies involved in the Lunar Exploration initiative. Brazil could contribute either a small satellite or payload elements for solar monitoring or magnetospheric studies. This ***involvement is strongly encouraged.***

The ***balloon and rocket program*** of INPE might be of strong interest for supporting some of these projects since these means do not exist in every agency. With them Brazil does possess a powerful asset that it should exploit.

5.3.3 Astronomy

If the astronomy community of Brazil is backing the ***MIRAX*** mission, it should ***be more proactive*** to get a firm development plan and a firm launch date. It is difficult to assess whether in 2010 -the present official launch date-, the mission will still be interesting in view of the developments foreseen in this highly competitive field. An ***in-depth review of the status of MIRAX*** should therefore be made rapidly to that effect.

The development of big astronomical observatories is clearly out of the capabilities of Brazil given its present budget and resources. However, there are some areas of space astronomy where smaller satellites can do a performing job. This is the case in particular of ***UV astronomy*** where the international astronomy community is lacking a modern UV facility: the JWST is tuned for the near and far infrared, and after the closure of the International Ultraviolet Explorer (IUE) several years ago, only the FUSE mission of NASA is operating in this range. ***Brazil might*** consider forming a consortium of agencies with in particular Argentina, Mexico and several others to ***develop such a facility*** which is critically needed. The first step would be to consult the community and assess if there is a strong interest in Brazil for such an undertaking. Other possible missions might be identified from such a call.

5.3.4 Manned Lunar and Martian exploration. Asteroids

Here, the international effort is not yet properly organized, while the situation is evolving rapidly and not necessarily in a predictable direction. Therefore ***it would be prudent not to jump too rapidly in apparently interesting opportunities.*** However, the example of India and China as well as of Russia and Japan shows that there is room for opportunities in payload development or for small automated stations carried to the Moon or to Mars with other missions. Brazil should assess whether its scientific community might be interested in such an activity, highly visible, which can certainly contribute to scientific progress. This leads to strongly advising ***INPE and the Brazilian scientific community*** (if it feels any interest in this venture) ***to actively participate*** in the presently ongoing international discussions and ***in the establishment of common road maps*** where the participation of Brazil might clearly show up more clearly.

Asteroids are likely to become very privileged targets for the future and their exploration will be accessible with modest missions. ***Brazil might consider developing payload elements*** on board an international mission

5.4 Re-enforcing international cooperation

The limited budget of INPE automatically forces Brazil to cooperate with international partners if it wants to be present in several domains of science and not just one or even a few. In fact, INPE officials and the government authorities have well understood that necessity since Brazil cooperates already extensively with some of the key space fairing nations (Section 3.1). However, we consider that there should be a ***re-enforcement of the cooperation*** between the three main space countries of South America, namely, ***Brazil, Argentina and Mexico***. It would be worthwhile to study whether an embryo of what could become later a ***Latin America Space Agency*** might yield to better efficiency and to developing bigger projects than any single of these nations alone.

Furthermore, three nations require special attention, namely China, India and Russia. Brazil is already involved extensively with China in particular, but both India and Russia do present particularly interesting opportunities.

There are many similarities between the space science interests of ***India*** and Brazil, nearly a one-to-one correspondence across the scientific fields as can be seen in the text box above. The Indian scientific community has shown a strong interest in their national ongoing program which presently includes the ***ASTROSAT*** and ***Chandrayaan-1*** projects. In view of this situation, ISRO is studying the possibility of planning a periodic development of scientific missions on a five year basis which would ***open the possibilities of joint planning*** with Brazil. We cannot but only encourage Brazil to extend its cooperation with India, a country which shares which Brazil so many points of common interest.

Cooperation with ***China*** has been extremely well exploited by Brazil in the field of Earth observation with the successful CBERS series. The success of this joint venture strongly justifies that it be continued in all areas of interest including the new Chinese plan for lunar exploration (Section 5.3.4). As far as ***Russia*** is concerned, it is surprising that cooperation with this country seems to be in a dormant stage. We refer to the remark of a Russian scientist quoted in Section 4.2.2. This state of affair is not necessarily the responsibility of Brazil and might well be the result of the dormant stage of the Russian program itself. Now that Russia seems to go for a new phase of its program (Section 2.3), Brazil might consider re-opening discussions with Russia. Our understanding is that ***at the level of the Russian Academy of Sciences, the willingness to cooperate with Brazil is strong.***

ISRO scientific interests:

- Equatorial electrojet and spread-F ionisation irregularities using magnetometers/radio probing techniques/sounding rockets/satellites
- Ozone, aerosol and atmospheric chemistry
- Middle atmospheric radiation, chemistry, dynamics and electrodynamics
- Solar emissions (flares/CMEs) and terrestrial impacts
- IR, X-ray, γ-ray astronomy
- Planetary science/exploration
- Earth's climate/weather science: due to strong emphasis on atmospheric modeling and climate change studies, many specific missions are also under study

5.5 Re-enforcing the industrial policy for scientific instrumentation and added-value products

Industry is the active arm of any nation's space programs. It is in industry that we find the broadest range of expertise in the areas of hardware and software development. In view of an ***expansion of scientific activities,*** there is a real need and possibly a common interest in ***developing further the contacts between the scientific community and the industrial world.*** Such a policy has been extremely successful in the United States, in Japan and also in Europe, especially when the research institutes are missing the technical capabilities and the investment to develop their experiments. We have discussed in Section 3.2 what in our opinion are the great assets of joint work between industry and the academic world. It is not necessary to repeat this here. Let's just stress that there is here an opportunity for both to work together and develop a very fruitful relationship in view of participating at the highest level of technology in the development of the future space science missions. These missions offer main technological challenges (Section 2.3). T***here is ample room for progress*** here.

This does not apply only to the development of hardware be it for the spacecraft or for the ***payload,*** but also to the ***ground segment***, in particular in the area of Earth observation, and to the ***distribution and commercialization of data,*** whenever applicable. There is the feeling however, that these ***activities in the commercial sense are not well organized locally***. There are users for the products, but no real interest in the development of this kind of product by private companies. One reason might be that there is no long-term policy on this subject. Unfortunately, it does not seem that any action is taken to formulate such a policy in the future. ***Given the great contribution of Brazil to Earth observations, we strongly recommend establishing this policy*** if of course there is some truth in this statement!

5.6 Re-enforcing the role of the scientific community

The leadership of a modern nation depends for a strong part of its involvement in scientific research and technological development. Space research with its high level of technology, its rich potential of discovery and its contribution to the development of a nation plus its very high visibility does contribute in a unique way to strengthen this leadership. But there is no application of science without science, and there is no science without scientists. As discussed at several places in the course of this report, there is a ***strong need for Brazil to increase the number of its space scientists***. This is a necessary condition as shown by China and India. But this is not enough!

There is no doubt that Brazil does have the potential to recruit lots of bright young people. Most of the Brazilian space scientific community is indeed made of bright young scientists. But they need to be properly trained and gain more experience. To that effect they must participate in the preparation of their instrumentation or in the analysis of their data in teams where these experienced people do exist. This may mean that a few experienced scientists and engineers have to come to Brazil and work in the institutes, or in the Universities, or at INPE. It means also that the Brazilian scientists be offered the ***possibilities to travel abroad***. Such a policy requires financial means which are certainly difficult to find in the present small budget envelope. Nevertheless, these means should be unblocked for supporting an activity which is so promising for Brazil.

Last but not least, since science cannot advance without the scientists, the ***scientific community should be*** the main inspirer of missions. This means that it must be ***regularly consulted*** and involved in all the steps of program or mission preparation, including submission of concepts, mission and payload selection, and data analysis.

6. SUMMARY OF RECOMMENDATIONS

In the main body of this report, we have everywhere possible identified a few areas which INPE and Brazil might consider for action or for correcting what in the eyes of the reporter recommends should be corrected. Among these, we summarize below the most urgent and the most important.

6.1 Financial means

- The overall space budget should be increased and that increase should benefit in priority to the sector of space sciences! This is justified by the very modest involvement of INPE in space sciences (only 2% of the budget), by the impressive quality of the scientific community, and by comparison with India and China which have recently decided to increase their programs and their budgets. A proportion of ***15%*** of the overall space budget would place Brazil on a more equal basis in comparison with the other space organizations.

6.2 Space sciences community

- The number of space scientists should be increased in proportion with the increase of the space budget. Combined with the impressive high quality level of the present population of space scientists this increase would contribute to raise Brazil space sciences above the sub-critical level (in number) where it presently is.
- Brazilian scientists should be offered more possibilities to travel abroad and to interact with their peers.
- The scientific community should be the main inspirer of missions through regular consultations, and should be involved in all steps of program and mission preparation, including submission of concepts, mission and payload selection, and data analysis.
- More universities and institutes should be encouraged to creating new research teams and being involved in the study and preparation of future possible space missions.

6.3 Management of the present program

- The EQUARS mission is running very late and a special effort should be made to place it in orbit as soon as possible.
- Given the delays of MIRAX and the presently announced launch date, there is a strong risk that in 2010 -the present official launch date-, the mission may have lost part of its interest in view of the developments

foreseen in this highly competitive field. An in-depth review of the status of MIRAX should therefore be rapidly undertaken to that effect. In that context, the astronomy community of Brazil backing the MIRAX mission should be more proactive to get a firm development plan and a firm launch date.

6.4 New programs

- Developing a space science program in parallel with a program in Earth observation is strongly encouraged, as is presently be done in India and China.
- In the establishment of new programs, the scientific community of Brazil should be consulted at all levels of the process.
- Brazil should consider integrating its future programme in Earth magnetism, atmospheric electricity, atmospheric physics and aeronomy, into the ILWS program which opens plenty of very interesting opportunities for cooperation.
- Brazil should consider broadening its involvement in space astronomy in particular ultraviolet astronomy and should consider forming a consortium of agencies, in particular with Argentina, Mexico and several others to study the development of a small ultraviolet observatory.
- Cooperation with ESA and ISRO should be expanded to study the water problem through data analysis from SMOS and OCEANSAT-2. Similarly Japan missions such as GPM, GOSAT and EarthCare might also be considered.
- Cooperation with ESA's Swarm mission should be envisaged.
- Brazil might consider being part of the Lunar and Martian Exploration initiative at the level of robotic missions.
- Brazil might consider developing payload elements on board future international missions to asteroids.

6.5 International Cooperation

The new international context in space research offers a chance for all non-US space faring nations to join forces and to create an alliance which would be capable of partnering with the US on a more equal basis than for any of them individually. Under these circumstances,

- Brazil, with its present set of international partners, should benefit from this new trend and participate actively in the establishment of common road maps more particularly in the following domains:
    - Solar-terrestrial relations and the ILWS program
    - Astronomy,
    - Geosciences,

    - Exploration (Moon, Mars, astroïdes).
- It would be worthwhile to study whether an embryo of a Latin America Space Agency might yield to better efficiency and to developing bigger projects than any single of these nations could do alone.
- Brazil should re-enforce its cooperation with:
    - India,
    - Russia,
    - ESA
- Brazil should consider joining Europe (and the US) in their Grid network for Earth observation data analysis and data exchange.

6.6 Industrial policy

- In view of an expansion of scientific activities, there is a real need and possibly a common interest in developing further contacts between the scientific community and the industrial world.
- The possibility for industry to be involved in the development of scientific payloads and their associated ground segments should be considered wherever university or research institutes do not have yet the required infrastructure and the necessary equipment to do so.
- INPE should establish a policy for the private sector to be involved in the production and commercialization of data and added-value products.

ANNEX 1

ONGOING AND FUTURE SPACE SCIENCE AND GEOSCIENCE MISSIONS OF THE MAIN SPACE AGENCIES

1. NASA

Current

Mission	Field	Launch
Advanced Composition Explorer (ACE)	Measurement of the composition of energetic particles from the Sun, the heliosphere, and the Galaxy	**25.8.1997**
AIM Aeronomy of Ice in the Mesosphere	Exploration of the Polar Mesospheric Clouds (PMCs),	**29.3.2007**
Aqua	Earth Science – Earth's water cycle	**22.4.2002**
Aura Mission	Earth's atmosphere	**07.2004**
CALIPSO NASA/CNES	Climate observation	**28.04.2006**
Cassini-Huygens NASA/ESA	Saturn	**15.10.1997**
Chandra X-ray Observatory	X-ray telescope/Astronomy	**1999**
CloudSat	Global survey of cloud and aerosol profiles	**28.4.2006**
Cosmic Hot Interstellar Plasma Spectrometer (CHIPS)	Ultraviolet spectrograph to study the "Local Bubble"	**12.1.2003**
Constellation and the Vision for Space Exploration	New generation of spacecraft (manned)	**First flight 2014**
Cluster ESA/NASA Mission	Detailed three-dimensional map of the magnetosphere	**16.7.2000**
Deep Impact	Exploring Comet Tempel	**12.1.2005**
Earth Probe Total Ozone Mapping Spectrometer (EPTOMS)	Ozone retrieval	**25.7.1996**
Earth Observing-1	Land imaging observatory	**4.10.2004 ?**
Expedition 14	**ISS**	
Fast Auroral Snapshot Explorer (FAST)	Study of Earth's aurora	**21.8.1996**
Far Ultraviolet Spectroscopic Explorer (FUSE)	Cosmic origins	**24.6.1999**
Galaxy Evolution Explorer (GALEX)	Mapping the history of star formation in the Universe	**28.4.2003**
Geostationary Operational Environmental Satellites (GOES)	Earth monitoring satellite	**24.5.2006**
Geotail mission	Study of the Earth's magnetotail	**24.7.1992**
GLAST	Gamma-ray astronomy	**Fall 2007**

Gravity Probe B (GPB)	Relativity gyroscope	**20.4.2004**
Gravity Recovery and Climate Experiment	Measurement of Earth's gravity field	**17.3.2002**
High Energy Transient Explorer-2 (HETE-2)	Detection and localization of gamma-ray bursts	**4.11.1996**
Hubble Space Telescope (NASA/ESA)		
Ice Cloud and Land Elevation Satellite (ICEsat)	Earth Observing System	**12.1.2005**
Interational Space Station		
Jason-1	Measurement of cean surface totography	**7.12.2001**
Landsat	Earth-observing satellite	**1972 (landsat-1)**
Mars Exploration Rovers	Exploration of the Martian surface	**2003**
Mars Global Surveyor	return data regarding Mars' surface features	**7.11.1996**
Mars Odyssey	Mapping the mineralogy and morphology of the Martian surface	**7.4.2001**
Mars Reconnaissance Orbiter	Study of the History of Water on Mars	**12.8.2005**
MESSENGER	Study of Mercury	**8.3.2004**
New Horizons	Flyby studies of Pluto and its moon	**19.1.2006**
NOAA-M Environmental Satellite	Improvement of weather forecasting	**21.4.2002**
Phoenix Mars Lander	Exploration of the Martian arctic	**August 2007**
Pioneer		
Pioneer Venus	Investigation of the Venus's solar wind and mapping	**8.6.1978**
Polar Mission	image the aurora	**24.2.1996**
RHESSI	Exploration of solar flares	**5.2.2002**
Rossi X-ray Timing Explorer (RXTE)	Observation black holes etc.	**30.12.1995**
SOHO (ESA/NASA)	Study of the Sun	**2.12.1995**
SORCE	Measurement of the Sun's output	**25.1.2003**
STEREO	Sun imaging mission	**17.10.2006**
Space shuttle		
Spitzer Space Telescope	Study of the Universe in infrared	**25.8.2003**
Stardust	Return of samples from Comet Wild 2 to Earth	**7.2.1999**
Swift	Gamma-ray bursts	**20.11.2004**
TacSat-2		**16.12.2006**
THEMIS	Substorms in Earth's Magnetic field	**Febr. 2007**
TDRS	System of satellites and ground stations	**7.12.2001**
TRACE	explores the magnetic field in the solar atmosphere	**4.1998**
TRMM (NASA/JAXA)	Monitoring tropical rainfall	**26.11.1997**

Ulysses (ESA/NASA)	Study of the Sun	**10.6.1990**
Voyager		**1977**
WMAP	A detailed picture of the Early Universe	**30.6.2001**
Wind	Investigation of the solar wind and its impact in the near-Earth environment	**1998**

2.ESA

Current

Mission	Field	Launch
Huygens (with NASA)	Saturn's moon Titan	**1997**
Cluster (with NASA)	Interaction Sun - Earth	**2000/2009**
Double Star (ESA/China)	effects of the Sun on Earth's environment Magnetotail	**2 satellites started in 2003/2004**
COROT (with CNES)	Searching for rocky planets outside our Solar System	**end 2006**
ENVISAT	Earth observation	**2002**
ERS-2	Earth observation	**1995**
Hinode (Solar-B) (with JAXA)	Exploring the Sun's magnetic field and outer atmosphere	**23.9.2006**
Hubble (with NASA)	Expanding the frontiers of the visible Universe	**1990**
Integral (with Russia)	Gamma ray astrophysics	**2002**
Mars Express		**2003**
Rosetta	Comet encounter	**2004**
SMART-1 (with the Swedish Space Corporation)	Testing solar-electric propulsion and other deep-space technologies	**2003**
SOHO (with NASA)	Sun	**1995**
Ulysses (with NASA)	Charting the poles of the Sun	**1990**
Venus Express	Surface of Venus	**2005**
XMM-Newton	black holes to the formation of galaxies	**1999**

Future

Mission	**Field**	**Launch**
Bepi Colombo	History of Mercury	**2008-2013**
Cluster	Interaction Sun - Earth	**2000/2009**
Darwin	Finding Earth-like planets	**~ 2013**
Double Star (ESA/China)	effects of the Sun on Earth's	**2 satellites**

	environment Magnetotail	**started in 2003/2004**
Gaia	Mapping our Galaxy	**~ 2011**
Herschel	Exploring formation of stars and galaxies	**2008**
Hyper	Gravity and electromagnetism	**2008-2011**
JWST	Observing the first light	**~ 2010**
LISA	Search for gravitational radiation from astronomical sources	**in development**
Planck	Examination of cosmic microwave background radiation	**2008**
LISA Pathfinder	Testing in space the very concept of gravitational wave detection	**2009**
Solar Orbiter	Close-up high-resolution studies of our Sun and inner heliosphere	**Assessment**
XEUS	X-ray observatory	**in development**
MSG-3 **MSG-4**	Weather satellites	**2011** **2013**
METOP-B **METOP-C**	Polar-orbiting satellites dedicated to operational meteorology	**2010** **2015**
CYROSAT-2	Determination of variations in the thickness of the Earth's continental ice sheets	**2009**
GOCE	Gravity Field and Steady-State Ocean Circulation Explorer	**2007**
SMOS	Soil Moisture and Ocean Salinity	**2007**
ADM-AEOLUS	Atmospheric Dynamics Mission-Aeolus	**2008**
SWARM	Study of the dynamics of the Earth's magnetic field and its interaction with the Earth system	**2010**
EARTHCARE	Earth, Clouds, Aerosol and Radiation Explorer	**2012**

3.JAXA

Current

Mission	Field	Launch
HINODE (SOLAR-B)	Solar physics satellite	**2006**
AKARI (ASTRO-F)	All-sky survey at infrared wavelengths	**22.2.2006**
REIME	Auroral observation	**2005**
SUZAKU (Astro E II)	Study of wide variety of X-ray sources	**July 2006**

HAYABUSA	Observation and collect samples from the asteroid's surface (Itokawa)	**2003**
GEOTAIL	Study of the structure and dynamics of the tail region of the magnetosphere	**July 1992**
AKEBONO	Aurora observation satellite	**Febr. 1989**
ALOS	Earth observation SAR	**2006**
GMS-5	Meteorology	**1995**

Future

Mission	**Field**	**Launch**
SELENE	Obtain scientific data on lunar origins and evolution; development of the technology for future lunar exploration.	**2007**
LUNAR-A	Study of the lunar interior	**Undecided**
PLANET-C	Climate system of Venus	**2010**
ASTRO-G	Baseline Interferometry for radio astronomy	**Undecided**
Bepi Colombo	Mercury	**~ 2012**
GPM	Water Cycle Observation Satellite	**2010**
GOSAT	Greenhouse Gas Observing Satellite	**2008**
EarthCare	Earth, Clouds, Aerosol and Radiation Explorer	**2012**
GCOM-W/AMSR	Water Cycle Observation	**2009**
GCOM-C-SGLI	Climate Change Observation	**2010**

4. CNES

Current

Mission	Field	Launch
COROT	Stellar seismology	**2006**
ODIN	Study of astronomical objects and terrestrial atmosphere	**2001**
CALIPSO	Infrared Pathfinder Satellite	**2006**
DEMETER	Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions	**2004**
JASON 1	Oceanography / climate	**2001**

POLDER	POLarization and Directionality of the Earth's Reflectances	**1996/2002**
SCARAB	Scanner for Radiation Budget	**1994/1995**
SPOT	System for EO	**86/90/93/98/02**
TOPEX	Observation of the oceanic circulation	**1992**

Future

Mission	Field	Launch
Microscope	Fundamental physics	**2010**
PICARD	Meteorological measurement of the diameter of the Sun	**2009**
DORIS	Oribitography	**?**
IASI	Infrared atmosph. interferometry	**2006-2015**
JASON 2	Oceanography / climate	**2008**
MEGHA-TROPIQUES	Tropical atmosphere	**?**
PLEIADES	EO	**2008**
VENUS	Environment monitoring on Vegetation and a New Micro-Satellite	**2009**

5. DLR

Current

Mission	**Field**	**Launch**
CHAMP	Earths'magnetic field and atmos. physics	**2000**
BIRD	Detection of wood fires	**2001**
GRACE	Gravity Recovery and Climate Experiment	**2002**
PAMELA	Search for Dark Matter	**2006**

Future

Mission	**Field**	**Launch**
TerraSAR-X	X-SAR/SIR EO	**2007**
RapidEye	Cartography 5 satellites, Land	**2007**
SoIaces	UV spectrometer on ISS	**2007**

6. ASI

Current

Mission	Field	Launch
BEPPO SAX	X-ray Astronomy	**1996**
AGILE	Hi En.Astronomy small satellite	**TBC**
LAGEOS II	X-ray Laser Geodynamic Satellite	**1992**
UV-STAR	UV Spectrograph Telescope	**1995/97/98**
COSMO SkyMed	Environmental monitoring / 4 small satellites/Climate/EO	**2007 (2S/C)** **2008 (1S/C)** **2009 (1S/C)**

Future

Mission	Field	Launch
MARS MISSIONS	Mars Exploration	**2003/2010**
Hyperspectral Mission	Studies of land surface etc.	**2009**
COSMO SkyMed	Environmental monitoring / 6 small satellites/Climate/EO	**?**

6. BNSC (UK)

Mission	Field	Launch
UK-DMC	Disaster management , Visible Imager	**2003**
TopSat	Prototype, Low cost Hi resol Imager	**2005**
Terra-SAR-L	SAR imagery, agriculture, forestry	**2006**

7.MISCELLANEOUS

CSA (Canadian Space Agency

Mission	Field	Launch
RADARSAT-1	EO satellite / Disaster management	**1995**
RADARSAT-2	marine surveillance, ice monitoring, disaster management, environmental monitoring, resource	**2007**

	management and mapping in Canada and around the world	
SCISAT	From dawn to twilight – ozone layer	**2003**
CloudSat	Looking at clouds in 3-D	**2006**
HERO	Hyperspectral remote sensing	
SCISAT/ACE	Ozone layer	
MOPITT	Tracking carbon monoxide in the atmosphere	**1999**
VLBI Space Observatory	Links Earth and sky	**1997**
MOST	Micro satellite measuring the ages of stars	**2003**

Danish Space Research Institute

Mission	Field	Launch
Ørsted	Measurement of the Earth's magnetic field	**1999**

CDTI (Spain)

Mission	Field	Launch
First Spanish Satellite	Earth Observation Optical, High resolution	**2010**

Swedish National Space Board

Mission	Field	Launch
ODIN	Study of star formation and early solar system	**2001**
MUNIN	Collection of auroral activity on northern and southern hemisphere	**2000**
SMART-1 (With ESA)	Small Lunar Mission to test SEP	**2003**