Universal Heliophysical Processes
Proceedings IAU Symposium No. 257, 2008
N. Gopalswamy & D.F. Webb, eds.

doi:10.1017/S1743921309029020

Next 50 years of space research

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Abstract. Forecasting the next 50 years of space research is a dangerous game and a somewhat irresponsible action. Fortunately, the past 50 years have evidenced what remains in the realm of realism and of the feasible and what definitely belongs to the realm of utopia. Nevertheless those who, like me today, take the risk of forecasting such a relatively long time trend are sure of one thing: to be wrong!

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1. What have we learnt from the past 50 years?

By observing the sky from above the Earth's atmosphere, we have accessed all the hidden portions of the electromagnetic spectrum: the UV, the X and the gamma rays, the infrared, and the sub-millimetric wavelengths. We have discovered black holes everywhere confirming in an unprecedented way the prediction of Einstein's theory of Relativity. We have started exploiting with an enormous amount of luck and success that nearly inexhaustible gold mine of discoveries, space astronomy, with telescopes always increasing in size, angular resolution and sensitivity. The revolution in knowledge and in our understanding of the Universe which resulted, has a dimension comparable -if not greater- to that opened by Galileo Galilei with the use of the telescope.

In parallel, we have extensively traveled through the Solar System. We have landed on the Moon, on Mars, Venus, Titan, and on asteroids. Soon, thanks to the Rosetta mission, we will land on the nucleus of a comet and plans are that we will explore more asteroids, the icy moons of Jupiter, return to the Moon and possibly also to Titan. We have discovered water everywhere, on the surface of Mars and underground, on Europa and the moons of Saturn. With the "Pioneers" and the "Voyagers" we have reached the limits of the heliosphere and are just starting to explore the virgin territories of deep space.

In the past 50 years, we have accessed the most thinkable physical extremes: extremes of distances, of temperature -from the several million degrees of the solar corona to the near absolute cold of the deep universe-, extremes of vacuum, of density and gravity, and of time.

May be even more essential for us has been the realization that space observations of the Earth represent one of the most promising tools ever invented to serve humanity. The most mediatic picture of the 20th century will remain for a long time to come the picture of the Earth taken by the Apollo Astronauts hanging above the lunar horizon. With no concerns about political barriers and borders, man-made satellites have proven their indispensable role for measuring our globe and its deformations, observing and forecasting the weather and soon the climate, the melting of ice, the rising of the sea level, the depletion of the ozone layer and the anthropogenic and natural hazards that threaten us more and more.

2. How was this possible?

I can identify four essential elements which helped the development of that genuine scientific revolution.

First, the fierce political competition between the Soviets and the United States, as none of them had any intention to let the control of space in the hands of the rival, injected a lot of money and resources in the development of space systems. That space race was enough to set the political framework and justify the enormous investments in technologies and warfare through a greedy aeronautical industry. The strong synergies between the civilian and the military sectors benefited strongly the scientific community, in particular through the use of declassified technologies.

Second, the creation of space agencies, such as NASA in particular, helped orchestrating the appropriate investments and the planning of the necessary technological developments or the use of existing devices after their adaptation to scientific space systems. That was the case for RTGs and for the development of the DSN without which long-distance missions such as the Pioneer 10 and 11, the Voyager 1 and 2, the two Viking missions to Mars, Galileo , Ulysses, SOHO, Cassini and New Horizons would not have been possible.

Conversely, whenever technological developments were not programmed on time, missions were not able to start. This was clearly the case of the NASA comet mission in the late 70's which required solar sail or electric propulsion, or the long awaited solar probe to which I will come back later.

Third, the education and the development of a very broad and active scientific community, able to take part in space experimentation, in the planning of missions, in their development as well as in their operations, secured the human and indispensable basis for an ambitious space program to start and expand.

Fourth, international cooperation! Of course, international cooperation bears in itself a large weight of political interests for the parties involved but it has also allowed the undertaking of a large number of joint space ventures, in particular between the US and Europe but also the Soviet Union-Russia and several other partners including Japan and recently China. In addition to permitting more ambitious endeavors than would be allowed by just using the cooperating partners' own resources, international cooperation is adding an indispensable element of stability among these partners. Without international cooperation, it is highly probable that Ulysses, SOHO and Cassini would not have been able to make it to the launch pad.

3. The realm of utopia

In parallel to these serious achievements, we could witness the development of what I call utopian concepts. For example, in the wake of the Apollo missions to the Moon, G.K. O' Neill, professor of physics at Princeton University, invented the concept of the "space cities", some kinds of gigantic space stations. The seriousness of that concept can be assessed a posteriori, nearly 40 years after Apollo, looking at the intended original goals and at where we stand today.

The original claim of O'Neill was that: *"Careful engineering and cost analysis shows we can build pleasant, self-sufficient dwelling places in space within the next two decades (i.e. before 1994)"*, solving many of Earth's problems. At first, a space colony of 10,000 people would have been in place in 1988 (i.e. two years after the Challenger accident!) and colonies between 200,000 and 20 million people would be able to live in such habitats in 2008, the year when this IAU symposium is held! The model would lead to

https://doi.org/10.1017/S1743921309029020 Published online by Cambridge University Press

establishing by 2050 a space population of about 14 billions and decrease that remaining on Earth from a maximum of 16 billions (according to his estimate) to a stable (?) level of 2 billions onward! For comparison with the real world, we are painfully assembling the International Space Station which is on average occupied by no more than a handful of astronauts, and the operation costs of the station are so high that they may lead to its abandonment.

A very modest example of something akin O'Neill's idea but on Earth was the *Biosphere* project in Arizona, an experiment for a sustainable, isolated human outpost. Surely, building a "space city" on Earth looks a priori simpler than doing it in space. Unfortunately, the project has been abandoned because it was judged much too expensive and requiring enormous amounts of power for maintaining adequate living conditions underneath the dome. Survival was indeed the main activity of the crew of 8 who volunteered to participate in the project, as the life-support system was constantly put into question. The fact that the crew emerged from their 2-year closure still speaking to each other and apparently in better health than when they started was considered at that time as an accomplishment!

The second example shows that even space agencies as serious as NASA are not protected against that kind of utopia. In the early 1970's, at the time when I was involved in the original studies of what was then called the Space Transportation System, STS, which included the Space Shuttle developed by NASA and Spacelab developed by ESA, the flight model included 52 shuttle flights per year and Mr. J. Fltecher, the then NASA administrator lost all sense of humor when such a goal was disrespectfully questioned! Utopia had reached the highest levels of the most powerful space agency. And the story does not end here as we witness today with the manned exploration program.

Ten years ago, the French Space agency CNES under the request of the Minister of Research was committed to develop in cooperation with NASA a Mars sample return mission within the existing and already over-committed French space budget. The project, considered unfeasible, was then offered to ESA to become part of its Aurora Exploration program. Recent talks between ESA, CNES and NASA have led to a cost estimation of the mission ranging between 5 and 8 billion of dollars and the mission is qualified as "the most audacious and technologically challenging space mission since the Apollo lunar landing".

This leads me to ask whether the dreams of sending humans to Mars are still realistic today? The farthest distance to Earth Man has ever been is the Moon, at one light-second. The astronauts on the ISS are circling the Earth at a distance smaller than that which separates Washington from New York, or a little more than a thousandth of a light-second, and the nearest star is still 4 light-years away, reachable, if ever, in some 50,000 to 70,000 years with the most rapid rockets we are able to build presently! In the last 50 years, we have not invented a faster rocket than the Semiorka which sent Sputnik-1 into orbit.

I dare guessing that in the next 50 years the deserts of the Red Planet may well be populated by undefined quantities of robots of different nationalities but most probably not by international colonies of human beings. What should Man do on Mars? As the Late Hubert Curien often said: "we will go there not to do science but for pleasure, or for sport" or, I may add, just because if one goes there the others will follow.

4. So, what will the next 50 years be?

The discoveries of the first 50 years have opened new questions on the evolution of the Universe, on its content, on the existence of Dark Matter and of Dark Energy. Not less fascinating is the prospect of detecting other planets similar to the Earth orbiting other stars, and probably not so long in the future, some signs of life on some of them, responding to the anguishing question of our loneliness in the Universe. These new discoveries require new missions to be developed, large telescopes and space interferometers.

In the next 50 years, we will continue observing our Solar System. We will probably land again on the Moon. We will explore Mars extensively, and also the moons of Jupiter and Saturn, we will land on asteroids and comets.

50 years is indeed a long time to come and to forecast but you all know very well that it may not be long enough for making the right decisions or developing the indispensable technologies. The Solar Probe for example was already under study in the mid seventies, and it is still under study – although in a different incarnation. It took nearly 25 years to get the Hubble Space Telescope from the study stage to the launch pad and it is still in operation as of today. Ulysses which was under study in the mid seventies is just ending its operational life some 30 years later.

We are presently taking little risks and unfortunately, we witness very little progress in the development of new technologies while it is technologies and risk-taking which made it possible to accomplish what we have accomplished in the past 50 years.

5. What are we missing in heliospheric physics?

First: the gravity field. It is in principle simple and understood, except that we are still struggling with the so-.called Pioneer anomaly. We need to understand it. We need more probes flying at long distances. Maybe, New Horizons will help!

Second: The magnetic field. It pervades the whole volume and its sources need to be properly monitored and possibly forecasted: the solar source, the planetary sources and the interstellar source. This requires before all, measuring the solar magnetic field and the solar wind throughout the whole volume of the heliosphere. That can be done (for the Sun) through helioseismology, magnetographs and magnetometers, coronagraphs as well as in situ measurements in the Interstellar medium.

The third "field" is solar radiation. The Sun provides energy to the planets and exerts its influence on the interplanetary and on the interstellar atoms and on dust particles through radiation pressure and absorption. It should be monitored precisely and continuously in all parts of the spectrum.

All three domains require different instruments and different types of missions for studying the Sun, the interplanetary medium and the extreme limits of the heliosphere. There have been a relatively large number of such instruments in operation in the past. However, some are now out of operation and others have never been out of the drawing board. We assume that missions like Yohkoh, SOHO, TRACE, Stereo, ACE, HINODE, Wind and magnetospheric missions and their successors will continue to be implemented in the future. They are relatively modest in size and their supporting technologies are also relatively well in hand. The LWS or ILWS program encompassed a lot of these. This program should be resurrected!

However, on top of these, three missions are constantly mentioned as necessary and are regularly coming back again and again to the discussion and planning table of agencies and academies. They are:

(*a*) The Solar Probe already mentioned.

(*b*) A new Out-of-Ecliptic mission, the successor of Ulysses, but with imaging capabilities.

(*c*) The Interstellar Probe.

6. What will make these missions possible?

6.1. *New technologies*

Because the heliosphere is the largest volume of space ever explored and the largest we can envisage to explore, long travel time characterize these missions and determine their duration.

Heliospheric missions are among the most demanding as far as new technologies are concerned: for going faster, for going further, for going higher. None of the three missions mentioned above will be implemented without an early investment in the necessary technologies and the development of new in situ experiments.

- Investments in new techniques of propulsion are an obvious priority. As already said, in the past 50 years our rockets are not more rapid than the Semiorka which was used to launch Sputnik-1. Here, let me express some concerns. Both the Out-of-Ecliptic mission and the Interstellar Probe claim the utilization of solar sails. But I wonder whether solar sailing is not another utopia. It has been with us for many decades but has never been implemented successfully. If solar sailing is so indispensable, then the first priority should be to plan its development and usage in a proper way. If not, there should be another plan. I am not far from thinking that nuclear propulsion would be a more suitable plan! Since 2001, three successive attempts to fly a demonstrative solar sail have failed: the last one, called Nano Sail-D, was launched recently in August.
- Operating satellites at long distances require non-solar power energy sources. A new generation of RTG is indispensable. Consequently and naturally, the development of nuclear energy systems is required for both fast propulsion and energy sources.
- Operating satellites at long distances with high data rates require also the development of high gain communication systems on board as well as on the ground.

6.2. *International cooperation*

It is obvious that the only organization which is presently able to undertake these missions is NASA. But none of these missions would be realized if NASA goes it alone. This is proven by past history. Past history also tells us that international cooperation is a better approach, even though the success of such joint ventures is never fully guaranteed, in particular against changes in political or budgetary priorities. Nevertheless international cooperation is an absolute necessity.

6.3. *Involving new partners*

What will be possible in the next 50 years will be determined by a context profoundly different from the one which so successfully framed the development of space research in the last 50 years. The early dominance of the United States and of Russia followed by the appearance of strong European and Japanese programs, which formed a very strong East-West dipole, will be succeeded by a multipolar configuration with the development of the Indian and Chinese space programs and possibly others. This will most likely induce new alliances on a front much broader than has been witnessed until now. This is a unique chance and a safeguard against the present tendency to erode space science programs as they are -and will be- more and more confronted to changes in national and international priorities.

6.4. *Joint planning and joint road maps*

International cooperation is also a chance. It should be properly orchestrated and the scientific community through the Space Studies Board of the NAS, the Space Committee of the ESF, COSPAR and other national or international organizations holds in its hands the best tools for managing the scenarios of cooperation. As has been proven by the past 50 years, space research is a vector of international cooperation and integration. It helps the dialogue among countries which are not necessarily politically aligned.

Indeed, the next 50 years will see major changes on this planet and in the way of living of its inhabitants: the gradual disappearance of oil as the main source of energy, with all the multiple consequences on the economy that we are already witnessing today. Several other primary resources will also gradually disappear, such as lithium, platinum, copper, tin etc... The unprecedented evolution of the climate and the acceleration of its changes will require drastic and global measures and more financial support from all governments to counteract these rapid trends. This may well be at the expense of other endeavors considered – wrongly may be- to be of lower priorities. Space agencies for sure will be more and more under pressure to undertake missions to planet Earth in priority. This cannot be criticized as our future is at stake and the management of Planet Earth rests more and more on space systems.

6.5. *Re-juvenilization of the scientific community*

Our future also relies on more science and on Education. The scientists who will be in charge of the missions identified above are still at school today or are not even yet born. This is the condition for space research to survive. This requires vision, faith in the role of space science for education and discovery, the reliance on approaches which have already proven to be successful in the past but will be more and more necessary in the next 50 years, as well as the courage of risk-taking.

By exploring the largest volume of space accessible to our machines, heliospheric physicists offer a unique challenge to future generations, and the only possibility to go where nobody has ever been before.

7. Conclusions

Let me now summarize and conclude.

The space era which started 50 years ago will continue to determine our future, our well being and our knowledge of the Universe and of our galactic environment for many years to come. Its development in the next 50 years will have to take into consideration:

- The necessary and undisputable global effort in Earth sciences which may absorb a substantial amount of the funds allocated to space research.
- The new international context which will involve new and potentially powerful partners.
- The necessity of serious technological preparation which should be undertaken with determination, vision and realism.
- The necessity to involve early the new generations of scientists

In this context, heliospheric sciences with their unique characteristics and highly demanding technologies present important challenges to both the community and the agencies. All should rely very strongly on international cooperation. In that respect, initiatives such as the IHY are welcome and offer great potentialities for organizing the international scientific community.

Because NASA is at present the only Agency with the capability of undertaking most of the required missions, there is a unique opportunity there for intelligent leadership. The future administration to be elected next November is offered an opportunity not to miss.

Discussion

Usoskin: Do you think ground-based observations with low cost and long duration should be continued through the ages?

Bonnet: In several if not all domains of space science there is a tight complementarity between ground based and space based measurements. This is clearly the case for solar physics, Earth sciences, astronomy in general. As a matter of principle we should not do in space what can be done from the ground with similar outcomes. So, by all means, it is very important to maintain the complementarity and contemporarity of ground and space based observations.

Crosby: At present not enough young people are going into degrees such as space sciences and engineering. What should we do about this problem?

Bonnet: As just said, there is no future assured to space science without the education and the formation of future generations of scientists and engineers. For that, the prospects of scientific careers must be made much more appealing. Certainly by emphasizing the challenges of space, the potential of discoveries, and truly for heliospheric physics, the unique capability of going where nobody has ever been before. Careers must also be appealing for scientists. Because science is so essential to our future, the salaries of scientists must be raised at a level that they become attractive. How to do this? A challenge is necessary which only scientists can solve. Challenges will not be missing in the 21st century!