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PHYSICS AND ASTROPHYSICS IN SPACE: FROM PRESENT TO THE FUTURE

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1 Introduction: from the past to the future

My duty of summarizing the works of this conference and discussing the future perspectives is greatly simplified by the previous talks of this session, which gave an exhaustive picture of the present and future space programs in Cosmology, Gravitational Waves and Fundamental Physics, and left me to deal with gamma rays and cosmic rays in space, a water where I am more used to swim. In these waters we cannot afford the future without going through the past. And for the past I will not go back to the pioneer research in these fields, but to the more recent 80's. In the 70's the realization of the Space Shuttle allowed a huge jump in the space access. At the end of the 70's several observatories in space were planned for the continuous and simultaneous observation of the Universe in the whole electromagnetic spectrum, complemented by the simultaneous observation of the charged component in its whole energy range, from the a few tens MeV up to the UHECRs [1]. It was the Astrophysics and Astronomy program of the NASA administration represented in fig. 1, adapted from the cover of the brochure that NASA dedicated to the Great Observatories: besides the 4 space Great Observatories and the Very Long Base Interferometer on ground dedicated to the various wavelength ranges of the electromagnetic spectrum to CR facilities were foreseen: the Advanced Composition Explorer (ACE) [2] for measuring the energy spectra of rare elements and radioactive isotopes at low energy, far away from the influence of the terrestrial magnetic

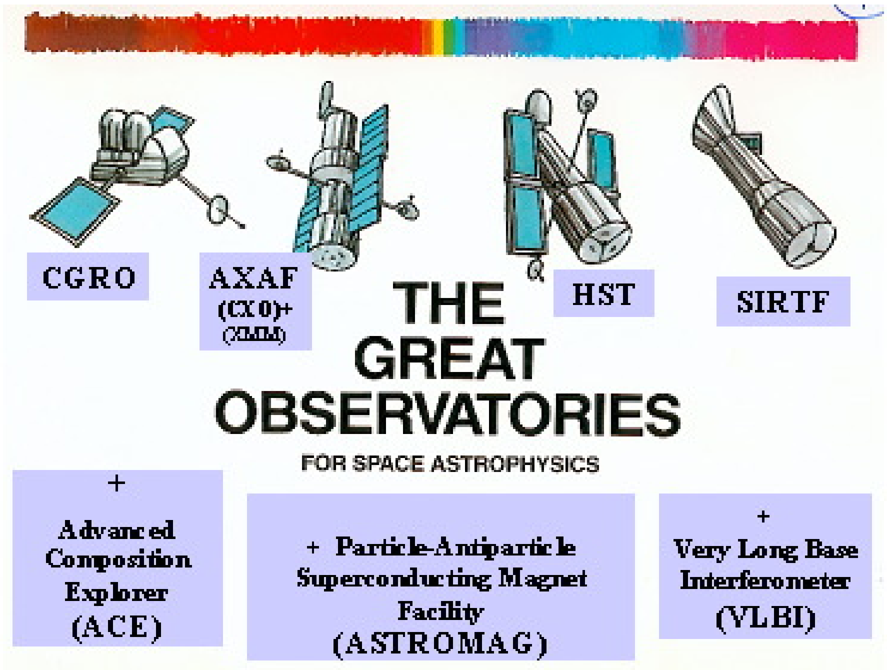

Figure 1: The Great Observatories for space astrophysics and the CR program

field, and the Particle-Antiparticle Superconducting Magnet Facility, initially foreseen for a free flier, and moved with the new name ASTROMAG [3] as a facility offered by NASA on board of the Freedom Space Station (FSS) after the announcement of its construction by the President of USA, Ronald Reagan, in 1983.

2 The 1985-1995 CR program of NASA

Appointing our attention to the cosmic ray part, it is of keen interest to examine today, twenty years later, the CR research program for the 1985-1995 decade [4] elaborated by NASA according to the recommendation of its Cosmic Ray Working Group [5]. It was a very complete and far-reaching program, still nowadays neither accomplished nor fully afforded for the next future. The summary page of this program is reproduced in fig. 2.

Already one year after its release the Challenger tragedy gave a halt lasting several years to the USA access to space, and several aspects of the CR program were vanished. The consequent reconsideration of the assembling of structures in space hampered the realization of the Freedom Space Station (FSS), such

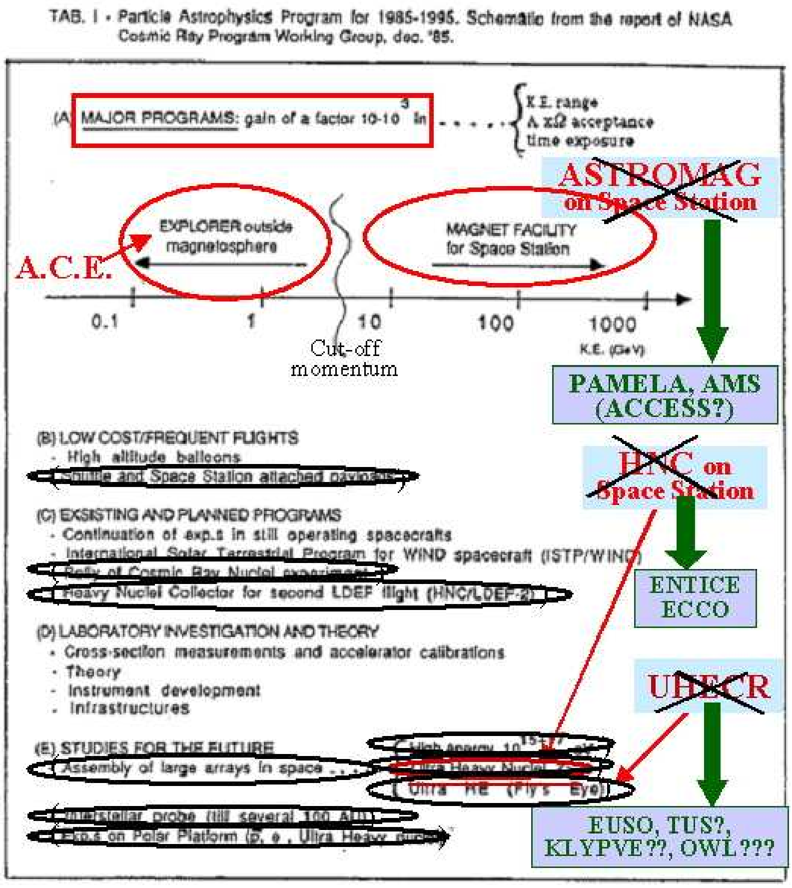

Figure 2: Particle Astrophysics Program for 1985-1995

as it was designed at that time, as well as the study of systems to be deployed or assembled in space, among them the systems for observing from space the UHECRs by the shower fluorescence of their showers.

Because of the Challenger disaster the FSS program was delayed and finally stopped in 1991. The consequences of this were devastating for the gamma and CR programs: the Heavy Nuclei Collector (HNC) [6] and the superconducting spectrometer for high energy CRs ASTROMAG [3], planned as facilities on board of the FSS, were cancelled, with the consequent dispersion of the programs and of the teams. In fig. 2, reproducing the original page of the summary of the program, the items postponed or cancelled because of the Challenger disaster are circled in an ellipse. On the right side of the figure the names of the stopped facilities and studies are added, indicated by a cross;

the arrows starting from these items point to a box with the acronyms of the experiments nowadays planned for recovering the original observational program.

It is important to remark at this point that the study of the ASTROMAG facility and the elaboration of its experimental program collected in one large international working group scientists from USA, Europe and Japan, allowing their small teams to converge in larger international collaborations joining several experimental techniques and many researchers, in a style similar to that operating in the Elementary Particle field. This is the main heritage of that period, also because the experimental program for the ASTROMAG facility included several important thematic typical of Astrophysics as well, for the first time, touching fundamental themes of the Elementary Particle physics. It is not exaggerated to say that it signaled the birthday of the Particle Astrophysics in space as presently we intend it.

3 The realization of the NASA program slows down

It is well known that the difficulties of the whole NASA space program at the end of the eighties and beginning of the nineties greatly affected the realization of the Great Observatories program. After the launch in 1990 of the HST optical observatory and of the CGRO for the gamma rays in 1991, the AXAF observatory, too difficult and expensive for performing the X-ray source spectroscopy and the search for faint sources by the same instrument, was shared with ESA and the two new instruments, CXO for the search of faint objects and XMM for the spectroscopy, were flown much later, both in 1999. Finally the IR Observatory SIRFT could be launched only last year, in 2003. Less known is that, after that in the meantime the CGRO had to terminate its mission in 2000, and the lack of the ASTROGAM instrument planned for the ASTROMAG facility left the gamma ray spectrum gap between 10 and 300 GeV unexplored, and nowadays we still are waiting for the GLAST mission for covering this gap.

Also one of the two main points of the CR program (item (A) in fig. 2), ACE, first proposed in 1983, had to wait several years to be finally launched in 1997. Nothing to do instead for the ASTROMAG facility, as well as for the HNC, both cancelled for the stop of their vehicle, the FSS. Many important observational programs were left, and still are, not afforded:

(a) the systematic measurement of the energy spectra of elements and isotopes beyond one GeV/nucleon, main thematic of the LISA proposal [7];

(b) the measurement of the elementary particles and antiparticles energy spectra up to very high energies and the search for antinuclei, main thematic of the WIZARD proposal [8];

(c) the elemental composition in the knee region, to which was dedicated the MAGIC/SCINATT proposal [9];

(d) the fluxes of the Ultra Heavy Nuclei beyond the iron group, up to the actinides group, for counting the supernovae rate in the Galaxy and evaluating the contribution of slow and rapid processes to their formation, thematic of the HNC facility;

(e) besides the above mentioned very high energy gamma ray observation.

4 CR and gamma ray themes implemented in the meantime or on the way in the next future.

What happened of these observations during in the following fifteen years?

(a) The measurement of the elemental and isotopic energy spectra was afforded by Japan-USA collaboration by ballooning. The superconducting spectrometer ISOMAX [10] that they realized with an activity lasted several years for improving the quality and the covered energy range was lost by accident and never reconstructed. This chapter of physics, fundamental for the understanding the structure and the evolution of the Galaxy is still unexplored, and there are no plans for it in the future; important, but anyway partial and scanty results will be obtained in next years by the PAMELA [11] and AMS [12] spectrometers as by products, but they could not recover the abundant wealth of results promised by LISA (see fig. 3).

(b) Much better it will be in few years the situation for the particle and antiparticle spectra and the search for antinuclei: after having exploited all the possibility allowed by a long ballooning activity, the two magnetic telescopes PAMELA and AMS promise to fill the observational gap left by the WIZARD proposal, while the BESS [13] spectrometer will define the observational situation by long duration ballooning in the low energy portion of the spectra.

(c) The situation for the elemental composition at the knee is instead in a much less promising status: many balloon missions were and still are slowly and patiently collecting information in the region up to 10^{14} eV, but the needed 10^{15} frontier is well beyond their possibilities, as well also beyond the possibility of the Ultra Long Duration Ballooning (ULDB) programs of the CREAM [14] and ATIC [15]experiments. Several enterprises were proposed for observations in orbit (NUCLEON [16], INCA [17], PROTON5 [18], ACCESS [19]), perhaps too many for allowing to have at least one in space. A possible convergence of all the proponent groups in one single enterprise could open the way toward its realization, but it will not be for now or for the near future. A significant step forward

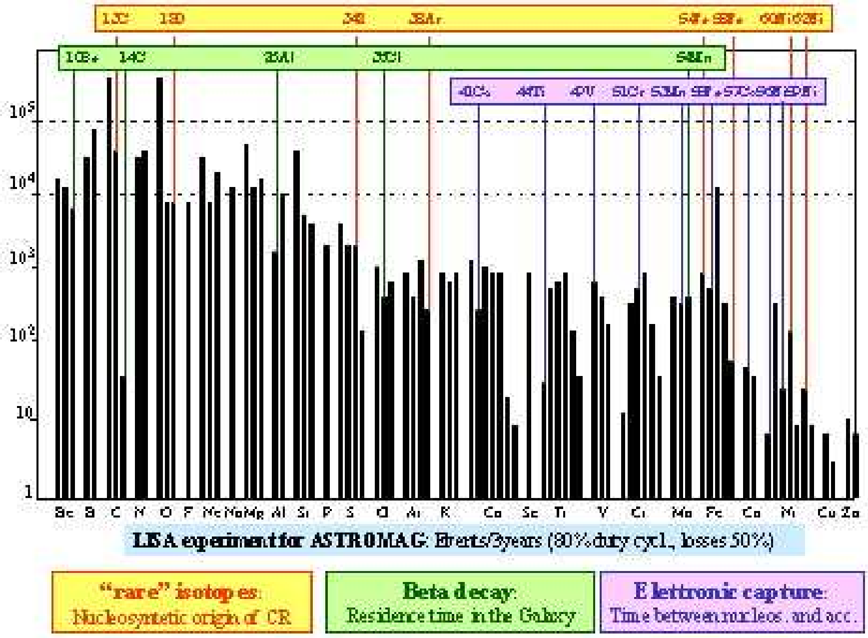

Figure 3: Expected rates for isotopes for the LISA experiment

could be given by the NUCLEON, which has a somewhat limited mass and acceptance, but it is the only one that seems to have a concrete flight opportunity in the next 4 or 5 years.

(d) A Heavy Nuclei Explorer (HNX) [20] is in the plan of NASA for recovering the physics of the HNC for the FSS, but as long as we know now still didn't go beyond the feasibility study status.

(e) About the gamma ray program, with AGILE [21] and GLAST [22] to be flown in next few years, we said above.

(f) What about the last important item of CR observation left behind, the UHECRs? For several years there was only the OWL [23] concept put at the end of the road map proposed by the SEUS committee of NASA. New concepts came out in last years in Europe (EUSO [24]) and Russia (TUS [25] and KLYPVE [26]). The EUSO proposal was selected by ESA for a phase A study just concluded. The EUSO instrument should be accommodated on board of the ISS and avoid the difficulties connected with the assembling and deploying structures in space which halted this kind of studies after the Challenger disaster. It should take data for at least 3 years, giving about 1000 events around and beyond 10^{20} eV energy. This experiment, together with the AUGER [27] experiment on ground, is a huge step forward for understanding the fundamental mechanisms responsible of the ultra high energy acceleration in the Universe, and the related questions of fundamental physics. Perhaps it could be not conclusive for answering to all the open problems, however any possible follow-up experiment could hardly substantially improve the statistics and quality of data, and EUSO must now be regarded as a unique occasion for pushing forward our exploration in the extreme energy region.

5 What "space" still for the "particle astrophysics" in space?

Let now try to understand what could be the development of particle astrophysics in space in the future, say 10 or more years from now.

5.1 The high energy gama rays

For what concerns gamma rays after a long preparatory period the experiments AGILE and GLAST in space will retrieve the ASTROGAM [28] program on ASTROMAG, planned in the 80's for covering the energy gap between EGRET [29] on CGRO (10 GeV) and the ground experiments (about 300 GeV). The evolution of the many ground based experiments promises to fill the energy gap with complementary observations.

A new step forward after the INTEGRAL [30], AGILE, GLAST and SWIFT [31] mission is not foreseen in the far future, at least as long as new ideas allow to substantially improve the angular resolution. An observatory of the CGRO class could strengthen the planned instruments and possibly save part of the investment, but presently no people or organization has the means and the strength to think to an observatory.

5.2 The cosmic rays up to a few GeV/nucleon

For what concerns the low energy CRs, up to a few GeV/nucleon, ACE is continuing its mission supplying a flood of data, fundamental tools for the astrophysics of the Galaxy.

An interstellar probe touching the frontiers of the heliosphere and beyond would be a fundamental instrument for understanding the acceleration mechanisms of CRs in their interaction with plasmas. Several groups have proposed it in the past and its study also appeared in the CR above-mentioned program of NASA (item (E) in fig. 2). However its realization is improbable if in the future new propulsion techniques will not allow to reach the limits of the heliosphere in much less than the thirty and more years presently foreseen.

5.3 The cosmic between a few GeV/nucleon and several TeV/nucleon

It is in the energy range between a few GeV/nucleon and several TeV/nucleon that the "Particle Physics" new theories can enter in the CR observations. For what concerns the rare particles and antiparticle components of CRs important but not conclusive results were obtained, mainly in the last decade, by ballooning. They are however not conclusive for what concerns the antiparticle energy spectra, either because of the limited statistics and the residual atmosphere background or because the possible contribution of the so-called new physics channels can become sensible at energies higher than those reachable by ballooning.

A real "new era" will be opened in this theme by the PAMELA and AMS-2 experiments in space, which before the end of this decade should supply the positron and antiproton energy spectra up to several hundred GeV, well inside the energy region where new effects could be expected. These experiments will also hunt for antinuclei at high energy and with unprecedented sensitivity. No plans at the moment are foreseen for the far future, either because the development direction should be indicated by the expected results, or because in any case a huge instrumental effort would result in a not correspondly increase of the acceptance and of the covered energy range.

As above noted, after the loss of the ISOMAX instrument new results for rare event energy spectra and isotopic energy spectra will be obtained only as by-product of the PAMELA and AMS experiment. The quality and quantity of expected result is important, also if far away from the wealth of the results expected by the old LISA proposal (see again fig. 3). As already remarked no plan exist for recovering such physics theme also in the far future, the main difficulty being the dispersion of the interested community in other enterprises.

Also the measurement of the fluxes of the high Z nuclei, and of the actinides group in particular, seems difficult to be recovered, and the ECCO [32] and ENTICE [33] proposals on the HNX explorer are still pending in the NASA program.

Finally a specific comment must be dedicated to the many experiments on ground and in space dedicated to the study of the so-called "knee" region of the CR energy spectrum, i.e. between 10^{13} and 10^{16} eV. The ground experiments are improving their instrumentation as well as the interpretation computational machinery, but still give inconclusive results for what concerns the main goal of their activity, i.e. the energy spectra of the separate elements. From space the answer to this problem should be straightforward, but the steep energy spectrum of the flux requires an instrument accepting particles on a few m^2sr for several years. Several concepts of such an instrument were presented in USA (ACCESS in a two versions) and in Russia (INCA, PROTON5), but no one obtained until now a support going beyond the feasibility study. The impression is that the interested community has some difficulty to work together toward one international project, a needed approach for being supported by several space agencies and institutions. In this situation the research must relay on ballooning. In Antarctic continent the JACEE collaboration going on with its periodic long duration balloon (LDB) launches, while the CREAM collaboration planned several ultra long duration balloon (ULDB) launches in next years, but for the moment must wait the setting up of this new technique. It is in any case a long and patient work that will require one or more decades to reach the statistical relevance useful to answering to the afforded physics questions. A noticeable step forward promise to be given in the meantime by the NUCLEON experiment on board of the Resurs-DK satellite, mainly supported by Russian agencies, conceived for catching a suitable occasion of launch and as prototype of a possible larger instrument for definitively solving the "knee" problem.

6 A new actor on the scene?

The possibility of observing large statistics of UHECR events focused the attention on the already long ago foreseen GKZ effect produced by the interactions of the UHECR with the cosmic microwave background (CMB), with consequent degradation of their energy and generation of a high flux of UHE neutrinos. Because of this origin these neutrinos are called "cosmogenic". Their flux can be foreseen with an approximation of about one order of magnitude [34], and can be considered the "less uncertain" flux among the neutrino fluxes expected by many different models proposed in Astrophysics and Elementary Particle physics (see fig. 4). Surely the neutrinos as probes of the deep Universe are the most promising particles. Their interaction length is, also at UHE, one order longer than the dimensions of the Universe, and therefore their observation opens the door to a new powerful astronomical tool. On the basis of the results of the phase A study of EUSO it can easily evaluated that a neutrino observatory suitable to give between 10 and 100 observed neutrinos per year could have parameters for the detector not far away from those of the EUSO instrument if a dedicated optical system for collecting the fluorescence light of the neutrino produced showers would be provided.

In fig. 5, (from [35]) the EUSO parameters are compared with those of a possible neutrino observatory for several values of the FoV of the optical system, and assuming that in the following 10-15 year the efficiency of the light detectors in the region of the fluorescence wavelengths could reach 50% (laboratory prototypes are not far away from this value). Probably the definition of a mission dedicated to the realization of a UHE neutrino observatory should wait for the accomplishment of the EUSO mission. In any case it will be necessary that all the teams nowadays proposing several approaches for the

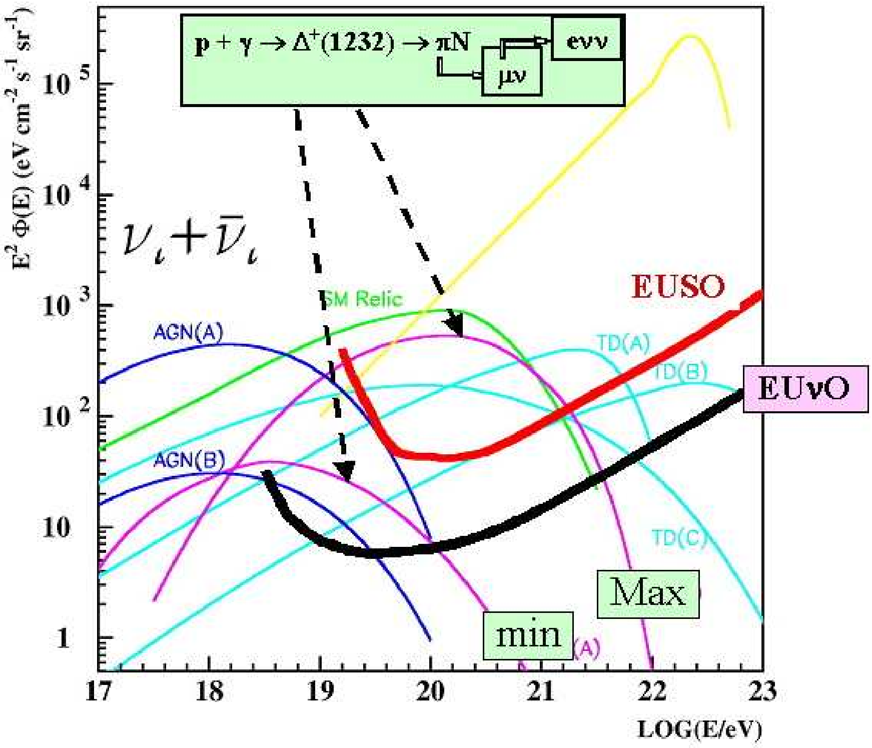

Figure 4: Neutrino fluxes foreseenby different models

UHECR observation from orbit join in one collaboration team.

7 The other (old) actors, and final considerations.

Other important themes, some of them very old, are present in Physics and Astrophysics in Space, and make the whole field so exiting and rewarding.

We heard fascinating talks in the days of the symposium, with the CMB experiments grasping toward the primordial "seeds" of the Universe, the Gravitational Wave (GW) detection seeking to observe from very near the Big-Bang, Fundamental Physics experiments questioning General Relativity and other fundamental laws of nature, and the new observatories for IR, Optical and X radiation in service and in program promising a wealth of information overlapping with topics of fundamental physics. For all these themes several missions are in program for the next as well for the far future, and a wide and exhaustive panorama was described in the previous talks of this session of the

	EUSO like		Multi-mirror		
H (km)	400		400		
Total FoV (°)	60		90		
Radius on ground (km)	235		413		
Area on ground ($10^3 km^2$)	173		536		
Pixel on ground (km * km)	0.8 x 0.8		1.6 x 1.6		
Ø pixel on detector (cm)	0.6		2.0		
Area/pixel (≈n. of pixels)	270k		238k		
Pupil diameter (m)	2.0	2.0	5.0	7.5	10.0
Photo detection efficiency	20%	50%	50%	50%	50%
E threshold (EeV)	50	20	5.5	3.2	2.3
Proton events/year,					
GKZ + uniform source distrib.	1200	8000	300k	900k	1800k
with E_p >100 EeV)	100	100	310	310	310
Neutrino events per year (≈ min)	**0.6**	**1.5**	**18**	**30**	**42**
Neutrino events per year (≈ Max)	**12**	**18**	**108**	**120**	**138**

Figure 5: EUSO parameters compared with the parameters of a possible neutrino observatory for several values of the FoV of the optical system

symposium.

What about gamma ray and CR physics in space in this context?

For high energy gamma astrophysics I can say as conclusive remark that a lot of work is in progress and is in program, also if not necessarily from space, but there are not "vision" proposed for the far future.

For CRs many important themes left back from the past wait to be afforded, however no programs have been formulated for the far future, in some cases (as for antinuclei and antiparticles) waiting for the coming results of the planned experiments, but also waiting for an enlargement and better convergence of the CR community. The new fact for the far future is linked to the new "actor", neutrino observation from space. An UHE neutrino observatory can be envisaged, and this could be a sufficient reason for attracting several teams to collaborate in one mission dedicated to its realization.

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