CR from space based observatories

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1 Abstract

Because of the increasing importance of CR research in nuclear physics and in astrophysics, a systematic research program was elaborated by NASA at the beginning of the eighties. The major points were based on experiments borne to space by the shuttle vehicles or on board of the Freedom Space Station (FSS). The loss of the Challenger in 1986, the ending of the FSS program in 1991 and the long lasting shortage of means of transportation to orbit halted the space based part of the program. In last two decades a moderate progress was obtained by balloon borne experiments and by ground based huge area detector arrays. Only recently part of the original program can be recovered in the observation of high energy gamma rays by the launch of the AGILE and GLAST instruments, and in the research on the antimatter component of CRs with the long duration balloon flights of BESS in Antarctica, the going on PAMELA mission and the preparation of the AMS-2 instrument. The preliminary results of the PAMELA are discussed, and the near and far future perspectives considered.

2 Historical introduction

About one hundred years ago cosmic rays (CR) offered to physicists projectiles with energies exceeding by more than three orders of magnitude those available by natural radioactivity[1]. The structure of the nuclei could be investigated, mesons discovered and studied, nuclear physics born. It took four decades of technological efforts to

[1] A consideration is here worthwhile: electron machines constructed in 19th century could accelerate charged particles up to several keV, i.e. millions of billions of times the higher reachable mechanical kinetic energies, such as the destructive projectile of a powerful gun. They allowed investigating the atomic structure of the matter, and the atomic physics was born. Other three orders of magnitude were offered at the beginning of 20th century by natural radioactivity, whose projectiles have energies up to several MeV and can arrive inside the atoms up to the nucleus. The CR energies are measured in GeV or higher multiple of the eV, what stands for three or more orders of magnitude further.

reproduce CR energy by accelerators and to compete in intensity. After three other decades the technical development of particle detectors allowed to study CR with energies largely exceeding those supplied by accelerators, and CRs again became a useful instrument for elementary particle physics and astrophysics.

Therefore in the seventies the National Academy of Sciences of USA complemented with a CR research program the plan of Great Observatories elaborated by NASA for exploiting the close taking service of the Shuttle fleet [1] [2]

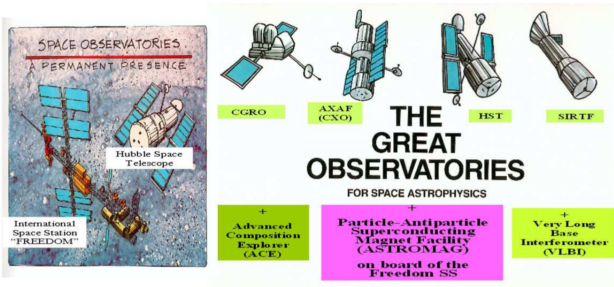

Figure 1: The Great Observatories (NASA brochure, adapted)

It was elaborated a comprehensive program of CR research for the decade 1985-1995 [2], where ground based experiments and theoretical studies were complemented by a robust program of research facilities in space, such that it could be assured a permanent presence in orbit of instruments for continuous monitoring the electromagnetic and ionizing particle radiation coming from the Universe. Fundamental pieces of this program were (see Figure 2): (a) the Advanced Composition Explorer (ACE) for studying low energy CRs (up to a few GeV/nucleon) outside the magnetosphere that prevents them to approach the Earth; (b) the superconducting magnetic spectrometer ASTROMAG [3] to be used as a facility for CR researches up to ener-

[2]As soon as scientific instruments could be operated outside the atmosphere the astronomical observation (previously confined to the narrow window of the visible band, and (in the last decades) to the young radioastronomy), could span all the wave lengths of the electromagnetic radiation reaching us from space. The image of the universe was upset, new questions arose, and for answering them it was necessary to provide a **continuous and possibly simultaneous presence in space** of astronomical observatories covering the whole electromagnetic spectrum. The new revolutionary mean of flight planned by NASA, the Shuttle, allowed such an ambitious program. In the '70s were planned and began the realization of the Great Observatories: the Compton Gamma Ray Observatory (CGRO) for gamma rays, launched in 1991, the Advanced X-ray Astrophysics Facility (AXAF) for the X-rays (divided in the two observatories XMM and CXO both launched in 1999), the Hubble Space Telescope (HST) for the optical portion of the spectrum, launched in 1990, and the Space InfraRed Telescope Facility (SIRTF) for the infrared wavelengths, launched in 2003. They were complemented by the Very Large Base Interferometer (VLBI) on ground for the radioastronomy, by the ACE explorer for low energy CR and the ASTROMAG and HNC facilities for the high energy CR on board of the FREEDOM Space Station (see Figure 1).

gies beyond the PeV/nucleon; (c) the Heavy Nuclei Collector (HNC) [4] for the high charge (up to actinides) CRs. They were completed by a large Cosmic Dust collector. ASTROMAG, HNC and Dust collector were all planned on board of the Freedom Space Station (FSS) that was already under construction and had to take service in 1992 for celebrating the fifth century of the discover of America.

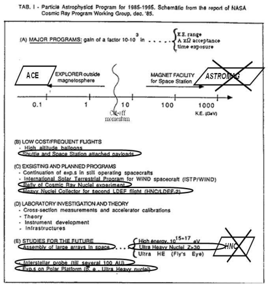

Figure 2: Schematic of the Particle Astrophysics Program for 1985-1995 (table I of the NASA report, adapted). The main facilities are enclosed in a rhombus. The never realized items are pointed out in an oval. The cancelled facilities are crossed.

The original, above mentioned [2], program envisaged by NASA at the beginning in the eighties afforded all the open thematic of CRs observation. They can be summarized in the following points:

- (1) measurement of the fluxes of high Z CR up to actinides (point (E) of the NASA program [2], HNC on FSS);
- (2) determination of the spectra of rare elements and of isotopes (beta decaying, electronic capture decaying) beyond a few GeV/nucleon;
- (3) determination of the spectra of antiparticles up to the hundred GeV region and search for antinuclei;
- (4) determination of the chemical composition around and beyond the knee;
- (5) high statistics measurement of the fluxes of ultra high energy CRs beyond the ankle (point (E) of the NASA program [2])

To the above categories it must be added the detection of the very high energy gammas ($\geq 1 \simeq$GeV), both because their production is tightly connected to the sources of very high energy CRs, as well for instrumental reasons, as gammas can be measured throughout the produced e+e- pair. The high energy gamma observation was part of the astromag program, with the ASTROGAM experiment [5] dedicated to extend up to about 300 GeV the observations performed by EGRET [6] on board of the CGRO.

For what concerns the electromagnetic observations the great observatories (CGRO, AXAF(CXO+XMM), HST, and SIRTF) were all constructed and launched. Also the ACE explorer for the study of low energy CRs outside the magnetosphere was realized and launched in 1999, and its instruments are producing a rich harvest of valuable data.

For the other facilities the final fate was different. The tragic explosion of the Challenger shuttle in 1986 slowed down the FSS program, which was definitely closed in 1991. The collaborations gathered around the programmed facilities were partially disbanded, and had to rescale their projects, continuing research by ballooning or on board of satellites.

3 What could be realized in the last two decades

Let discuss what has been the progress in the last two decades on the above listed items concerning the high energy CRs.

3.1 Very high energy gamma rays.

Let begin with very high energy gamma ray observation. Only this year, two decades later, the ASTROGAM program could finally be recovered by the launch of two large acceptance instruments (equipped by calorimeters, but without the help of the strong magnetic field of the astromag facility foreseen in the original program). The AGILE [7] instrument was launched in orbit in April 2008, followed a few months later by the launch of the GLAST [8] instrument.

For the development of the CR researches planned on board of the FSS, namely at the cancelled HNC and ASTROMAG spectrometer facilities, the situation is somewhat differentiated.

3.2 Flux measurement of extreme Z cosmic rays.

For the measurement high Z fluxes nothing could be done. The HNC had to follow the inauspicious fate of the FSS. The technique foreseen in this kind of experiment is passive, by recovering the exposed material and etching it for measuring the damage caused by the crossing particle. It was set up and improved in precursor experiments on the LDEF facility and on board of the MIR space station [9], but never could be used in an experiment of conveniently large acceptance. The HNC heritors projects, ENTICE and ECCO [10] planned for the HNX spacecraft, were never founded, and are now hampered by the coming casting off of the shuttle transportation system.

3.3 Energy spectra of isotopes and rare components.

The continuation at higher energies of the ACE measurements of the isotopes and rare components does not require a huge acceptance but rather a good determination of the mass, charge and momentum of the incoming nucleus, what makes the instrument somewhat complex. The total acceptance of the dedicated LISA [11] project on the astromag facility was ¡ $1m^2sr$, but it could profit of the high intensity of the magnetic field of the spectrometer. In order to pursue the physics program of LISA it was realized by NASA a balloon borne superconducting magnetic spectrometer, ISOMAX [12], that unfortunately was destroyed in a flight accident. No more projects are in view for the next decade and more. The (by-product) data from BESS-Polar long duration balloon experiment and from PAMELA and AMS satellite experiments (see below) promise a good progress for a better understanding of the propagation of the CR in the Galaxy, but will not exhaust the duty of a dedicated experiment.

3.4 Chemical composition at knee.

Let now consider the flux of the dominant components of CRs, i.e. the nuclei that can be synthesized in stellar processes, from helium to iron, and subsequently accelerated to be ejected as CR in the interstellar space.

Their chemical composition at very high energy (from 10^{14} to 10^{16} eV/nucleus) is the central problem (the knee problem) of the CR physics. Until now it could not be solved by measuring on the Earth surface the characteristics of the showers produced in the atmosphere. The characteristic of the initial particle cannot be extracted on an event-by-event basis, and the extraction on a statistical basis in strongly model dependent, with contradictory results from different experiments, in spite of the huge investments and long dating efforts of a large community in many countries.

The global primary CR chemical composition and the energy spectra of the most abundant ones can be adequately studied only by detecting them before their interaction with the terrestrial atmosphere, i.e. in balloon borne or satellite borne experiments.

The cancellation of the Freedom SS program in 1991 hampered the SCINATT-MAGIC [13] experiment on ASTROMAG, devoted to the study of the CR chemical composition at the knee. It had to be performed by a suitable application of the nuclear emulsion techniques, developed by members of the proponent Japan-USA collaboration in experiments at accelerators. The collaboration pursued its goal by the series of long duration balloon flights JACEE in Antarctica. These flights, as well those of several other collaborations (RUNJOB and CREAM balloon flight series) gave some precious results up to a few hundreds TeV/nucleus, still too far away from the energy of $3x10^{15}$ eV of the knee for solving the historical knee problem of CRs. Many satellite borne experiments were in the meantime proposed, ACCESS [14] in

USA and several in Russia, but no one was supported or could find the suitable flight occasion. In the next future it will be flown the small NUCLEON experiment [15], which will verify the KLEM method for measuring the energy of VHE shower by thin calorimeters. It will substantially improve the present experimental situation but it is too small for definitively solve the knee problem.

3.5 Particle and Antiparticles spectra and search for antinuclei.

Antiparticles are special rare CR components. The hope of observing contributions in their energy spectra (on top of the secondary antiprotons produced in the interactions of particles with the interstellar matter) due to their primordial existence, or to their production from steady sources, or a signal of the so called new physics, increases with energy, and could become significant in the hundred GeV energy region.

The WIZARD collaboration, formed for studying antiparticles and hunting for antinuclei on the astromag facility [16], did not disbanded at the closure of the FSS program, and afforded a program of balloon borne experiments. Several Russian institutions joined this collaboration to form the Russian Italian Mission (RIM) program. This collaboration, after several satellite and MIR borne experiments in life science and solar CRs[3], constructed and launched the PAMELA [17] experiment[4], dedicated to the antiparticle studies up to the 100 GeV region.

In the meantime a Japanese-USA collaboration used the prototype of the thin superconducting solenoid designed for the astromag facility in the series of the many balloon borne experiments BESS, mainly dedicated to the high statistic study of the antiparticle fluxes in the low energy region up to a few GeV.

Furthermore a large number of physicists coming from elementary particle researches at accelerators gathered in a large collaboration that performed the precursor experiment AMS-1 [18] on board of the Shuttle and is preparing the AMS-2 [19] experiment that will be installed in the next 2-3 years on the International Space Station (ISS).

A few remarks must here be underlined.

- (a) Antimatter experiments require a strong magnetic field for separating negative particles from positive ones and very good particle identification. They are therefore heavy and can be brought at the top of the atmosphere only by the biggest available balloons, and for a limited time, not more than a few ten hours

[3]In years 1998-2005 were flown small telescopes dedicated to the study of solar CRs (NINA, NINA2) and to life-science studies (Si-eye-1 and Si-eye-2 on board of the MIR Station and Si-eye-3 on board of the ISS)

[4]PAMELA was launched in orbit from Baikonur spaceport in June 2006 and it is now producing the first experimental results (a few articles are in press).

in each mission. The main reason is that balloons are not closed, but open on the bottom, as mongolfiers, just a thin sheet separating the helium inside from the air outside and not supporting any difference in pressure. A large fraction of the helium is lost from the bottom when the temperature decreases, as it is at sunset, and the balloon falls down. The short duration of the flight hampers the possibility of collecting high statistics at energies higher than 10 GeV. Furthermore the balloons cannot float at altitudes higher than about 40 km, because of the decreasing of external temperature at this altitude; the residual atmosphere of about $5g/cm^2$ on top of the apparatus produces a background that exceeds the antiproton signal already at few tens GeV.

- (b) A large number of balloon borne experiments were performed in the last two decades, and their results (see them below in Figure 3, compared with new data from the PAMELA experiment) are the maximum that can be collected by the ballooning technique.

- (c) For progressing in statistics and energy range it is necessary a new generation of experiments, or by ballooning in Long Duration Balloon Flights (LDBF) in Antarctica (by flights lasting several weeks, what can largely improve the statistics, but not the covered range in energy because of the CR interaction in the residual atmosphere), or by satellite borne experiments, allowing to increase both the statistics and the explored energy range.

- (d) The above mentioned BESS collaboration is now conducting LDBFs in Antarctica, with a flight every two years. These flights are possible due to the continuous improvements of the superconducting solenoid and of the detectors, that allowed obtaining a payload enough light to be flown by closed balloons (the closed balloons do not loose helium, so that can flight longer, but can carry experiments much lighter than the 3 t carried by the open ones). It is this technical limitation than confines the research of antiparticles of BESS to the low energy region up to a few GeV.

- (e) For what concerns the satellite borne experiments, their realization is not an easy task, and not only for economical reasons. The techniques to be used are not simple and the physicists must have recourse to the help of very expensive industries for the preparation of part of the instrumentation. Furthermore, in general, the spacecraft and the launch vehicle are much more expensive than the instrument. Also the accessory expenditures, such as those for the launch operations, surface transportations and insurances, up and down links to satellite and other various services, are very high and exceed the budgets that particle physics and nuclear physics teams are used to handle. Finally the access to space is very limited, and of interest for many other fields of the human activities, and the research on the field of cosmic rays must compete for resources with other scientific and social investigations in Astrophysics, Astronomy, Physics, Chemistry, Life Science, Earth Observation, Medicine, etc...

The PAMELA and AMS experiment represent indeed the maximum effort that can be afforded on Low Earth Orbit (LEO) experiments. They promise the accurate study of the antiproton and positron spectra up to the hundred GeV energy region, as well a limit of $10^{-8} - 10^{-9}$ for the antihelium/helium ratio in hunting for antinuclei.

Because of the above mentioned activities, the determination of the spectra of antiparticles and the search for antinuclei are the only items that could register remarkable progresses in the last two decades, and it is worthwhile to have a look to last results and an outlook to the near future.

3.5.1 The Pamela experiment and its first preliminary results.

Before the flight of the Pamela experiment the experimental situation was founded on the results obtained by many balloon borne experiments. Only one experiment [18] was conducted in orbit for a relatively short time on board of the shuttle, precursor of the future AMS-2 experiment [19].

The flight of PAMELA is indeed a real step forward in the field.

The characteristics of the PAMELA instrument are described elsewhere [**?**]. Here I wish only to underline two its main characteristics: (a) the extraordinary precision of the multistrip silicon tracker, better than 3 micron per point in the bending view of the magnetic spectrometer, allowing to the magnetic spectrometer to reach a Maximum Detectable Rigidity (MDR) of 1 TV; (b) the high granularity of the multistrip silicon calorimeter, 2 mm in each of the 44 layers, supplying a great identification of the electromagnetic particles up to the highest energies.

In this work the preliminary results are presented, based on the data collected from July 2006 to March 2008, a total of about 500 days during the long period of minimum solar activity. All the data are preliminary, because in some case the analysis is still in progress and only statistical error are reported.

The antip/p ratio was determined up to 100 GeV. It confirms, with much smaller errors, the previous results in the whole range (Figure 3), and at higher energies does not contradict the models suggesting the secondary origin of antiprotons by interaction of primary CRs on the interstellar matter of the Galaxy.

Unexpected results were instead obtained for the e+/(e-+e+) ratio. They are reported in Figure 4 up to 10 GeV. It is much lower than previous experiments at low energies and agrees with them at about 10 GeV. Data at higher energies are not reported in the figure because the analysis is still in progress, however we know that the ratio is substantially and continuously increasing up to 100 GeV. This result cannot be explained by secondary production on interstellar matter, but invokes different sources, such as the contribution of a nearby powerful source or dark matter annihilation.

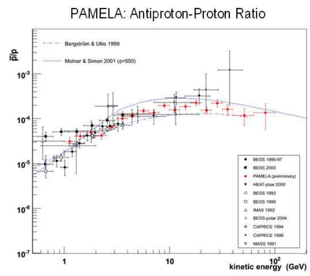

Figure 3: PAMELA: antiproton-proton ratio (preliminary)

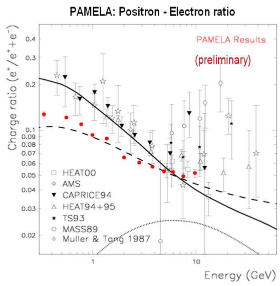

Figure 4: PAMELA: e+/(e-+e+) ratio (preliminary)

The fluxes of antiprotons and positrons are very low, of the order of $10^{-4} - 10^{-5}$ of proton flux, what implies the collection of a huge number of protons, several hundreds millions, and of light nuclei, whose spectra can be precisely measured up to very high energies. The spectra registered for proton and helium nucleus are reported in Figure 5. It must be underline that the statistical error is very small in the whole range from a few hundred MeV up to several hundred GeV, what allows to obtain a very precise measurement of the spectral shape and makes possible to study time variation and transient phenomena.

At lower energies, down to the threshold of 80 MeV, the proton spectrum allows to study in detail the decrease of the fluxes of galactic CR due to the solar wind (modulation), which varies depending from the solar activity. As an example, in Figure 6 the proton spectra registered in different times during the period of minimum solar activity are reported.

Many characteristics of the Galaxy can be inferred from the propagation of CRs, the fundamental tool being the energy spectra of the different nuclei and of different isotopes and their ratios. In Figure 7 is reported the ratio between the B and C nuclei, that can be precisely measured on a very wide energy range, from 300 MeV to 200 GeV in the figure. Analysis for the other nuclei and for light isotopes is in

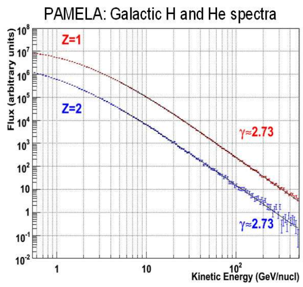

Figure 5: PAMELA: proton and helium energy spectra (prelimnary)

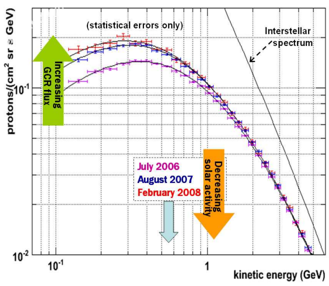

Figure 6: PAMELA: modulation of galactic protons due to solar activity (preliminary)

progress.

The high statistics and low energy threshold allow investigating other phenomena, such as the trap inside the terrestrial magnetosphere of a portion of the particles (mainly protons) produced in the interactions of primary CR on the terrestrial atmosphere, or the nuclei of solar origin trapped in the radiation belts and approaching the Earth in the region of the Atlantic ocean between South America and Africa (South Atlantic Anomaly, SAA). The study of the CR energy spectrum inside the SAA is extremely interesting, as it is linked to the solar activity and to the propagation of particles through the heliosphere (see in Figure 8 the energy spectra of protons in different SAA regions registered by PAMELA in its over flights).

Finally the low energy threshold of the instrument (50 MeV for electrons and 80 MeV for protons) allows observing in detail the high energy tail of solar CR, supplying unique information on their propagation through the heliosphere. In Figure 9 it is reported the variation in short intervals of time of the energy spectrum of protons during the solar event of 13 December 2006. It permits an accurate hint on the mechanisms of acceleration of the particles in the vicinity of the Sun.

Pamela experiment is continuing collecting data, at least until the end of 2009, increasing the statistics and the energy range explored, in the interesting period of

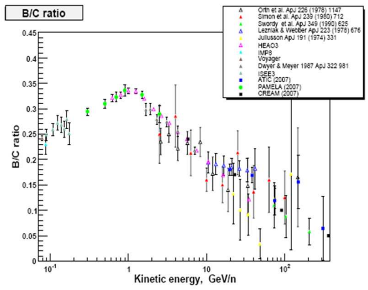

Figure 7: PAMELA: B/C ratio from 300 MeV/n up to 200 GeV/n (preliminary

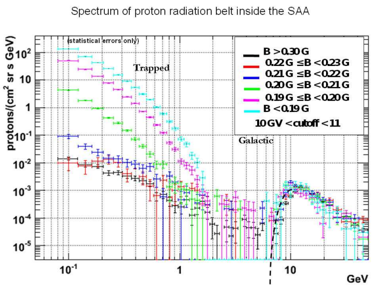

Figure 8: PAMELA: proton energy spectra inside the SAA (preliminary)

the expected sharp increasing of the solar activity.

3.5.2 The AMS-2 and an outlook to the near future.

The AMS-2 experiment has a layout similar to PAMELA, but a much larger acceptance, since it was mainly dedicated to hunting for antinuclei, for reaching a limit of 10^{-9} on the antihelium/helium ratio. The large acceptance will greatly improve the statistical errors at the highest energy, allowing also extending the explored energy range beyond the nominal performance of the detector.

PAMELA and AMS-2, both for the wide covered range in energy and the identification capability of the detectors, must be regarded not as thematic experiments but as Space Observatories, which either separately or together will give information on several thematic at 1 AU from the Sun.

The list of the observations, besides the above mentioned measurements of the energy spectra of galactic CRs, up to the TeV region for the proton, and of the antiparticles up to several hundreds GeV, the hunt for antinuclei, the study of the galactic CR modulation in the heliosphere, the study of the time evolution of solar energetic particle fluxes, includes also the search for the dark matter annihilation

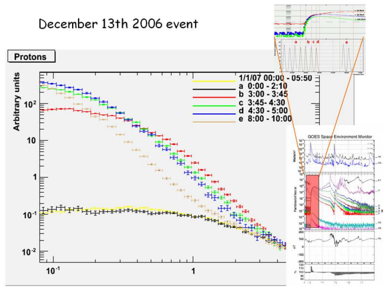

Figure 9: Energy spectra of protons registered by PAMELA in different time intervals (of 45' and 30') during the solar event of December 13th 2006 (preliminary)

effects, such as the primary Black Holes evaporation , the variations of the terrestrial radiation belts and of the energetic secondary particle trapped by magnetosphere in correspondence to the different solar events, especially in the SAA region, the acceleration at the heliospheric terminal shock and diffusion through the heliosphere of the anomalous CRs, the existence of nearby electron sources, and the measurement of the Jovian electrons.

3.6 What can be foreseen for the far future?

Nothing is foreseen for the measurement of the fluxes of the extremely high Z nuclei. The possibility of exposing on the Moon surface large areas of passive detectors makes this research very attractive as a first generation experiment on the Moon, to be conducted in the phase of the robotic lunar exploration, before the human exploration phase.

No dedicated experiments are foreseen for the measurement of the energy spectra of rare elements and of isotopes. Abundant information will come as by-product of the Pamela and AMS-2 missions and the continuation of the BESS polar flights. However a complex, but relatively small dedicated device on the ISS would be worthwhile, greatly enriching the information on the structure of the Galaxy.

The measurement of the chemical composition at knee can relay, also for the far future, in the improvement of the prevision of the computational model (also profiting of the new data expected from the LHC experiments), the patient accumulation of statistics in the existing on ground arrays and the realization of someones of the proposed new arrays, and the further flights in Antarctica of the CREAM spectrometer.

For the study of antiparticles and the hunting for antinuclei, nothing better than Pamela and AMS-2 is foreseen, and perhaps cannot be foreseen because of insurmountable technical limits. It is in fact not easy to conceive satellite or ISS borne experiments that could significantly move toward higher energies, because mass and complexity dizzy rise with the reachable energies.

For the far future, ten or more years from nowadays, a spectacular progress could be attained for the observation of ultra high energy CR. The construction of the Auger-North array will increase the statistics and energy range of Auger-South. A big step forward will be obtained observing from space the fluorescence light emitted by the huge showers developed by ultra high energy CRs on the terrestrial atmosphere, as the EUSO program [21] (by its steps JEM-EUSO [22], S-EUSO [23] and the precursor TUS [24]) propose to do. If the whole program will be realized up to the end it could be possible to evolve toward an ultra high energy neutrino observatory [?], a new powerful actor in the observation of our Universe, up to its extreme space and time limits, where other probes cannot arrive.

Worthwhile of attention it is also the observation from space of the radio signal of the UHE showers on the regolith of the Moon limb. The methodological experiment LORD [26] will be operated in a few years on board of the LUNA-GLOB lunar satellite for developing the project of a possible UHE neutrino observatory based on this technique.

References

[1] Field Committee on Space Astronomy and Astrophysics of the National Research Council of the USA National Academy of Sciences, A strategy for space astronomy and astrophysics for the 80s, USA NAS report, 1979 Astronomy Survey Committee of the USA National Academy of Science, Astronomy and Astrophysics for the 1980s, USA NAS report, August 1982.

[2] NASA Cosmic Ray Program Working Group, Cosmic Ray Program or the 1980s, NASA report, August 1982, and The particle astrophysics program for 1985-1995, NASA report, October 1985.

[3] M.A. Green et al., IEEE Transactions in Magnetics, MAG-23, n.2 (1987) 1240 Astromag Definition Team, The Particle Astrophysics Magnet Facility ASTROMAG, NASA report, May 1988 G. Basini et al., Il Nuovo Cimento, 102B (1988) 5.

[4] P.B. Price, Particle astrophysics: the NASA cosmic ray program for the 1990s and beyond (A92-20526), New York, 1990, American Institute of Physics, pp 63-66.

[5] J. Adams and D. Eichler, Very high energy gamma ray spectroscopy, Astrophys.J. 317 (1987) 551.

[6] P. Sreekumar et al., Astrophys. J. 494 (1998) 494.

[7] A. Morselli, et al., XXVI ICRC, OG 4.2.6, 1999 - A. Morselli, et al., Nuclear Physics B 85 (2000) 22 - M. Tavani, et al., AGILE Collaboration, Science with the new generation high energy gamma-ray experiments, in: A. Lionetto, A.Morselli (Eds.), Frascati Physics Series, 45 (2007) 1.

[8] A.Morselli, XXXII Rencontres de Moriond, Very High Energy Phenomena in the Universe, Les Arc, France, January 1825, 1997,Editions Frontiers, p. 123 - P. Michelson, et al., in: First GLAST Symposium, Stanford, 2007, AIPCP921, 2007 - A. Morselli, Nucl. Instr. and Meth. A 530 (2004) 158.

[9] A.J. Weaver et al., Nature, 357 (1998) 50 A.J. Westphal et al., Nucl. Instrum. and Meth., B145 (1998) 409 - A.J. Westphal et al., XXVI Int. Cosmic Ray Conf., 4 (1999) 160, Salt Lake City.

[10] A.J.Westphal et al., XXVI Int. Cosmic Ray Conf., 4 (1999) 160, Salt Lake City.

[11] J.F. Ormes et al., A Large Isotope Spectrometer for Astromag, NASA GSFC, Nov. 1988.

[12] J.W.Mitchell et al., XXVI Int. Cosmic Ray Conf., 3 (1999) 113, Salt Lake City; M.Hof et al., Nucl. Instrum. and Meth., A454 (2000) 180; T.Adams et al., XXVII Int. Cosmic Ray Conf. (2001) 1655, Hamburg.

[13] T.A.Parnell et al., Spectra, Composition and Interactions of Nuclei above 10 TeV,NASA MSFC, Nov.1988

[14] ACCESS-NRA, NASA Research Announcement, NRA 97-OSS-13 J.P. Wefel et al., XXVI Int. Cosmic Ray Conf. (1999) 84, Salt Lake City.

[15] D. Podorozhnyi et al., XXVII Int. Cosmic Ray Conf. (2001) 2188, Hamburg.

[16] R.L. Golden et al., Wizard: a proposal to measure the cosmic rays including antiprotons, positrons, nuclei and to conduct a search for primordial antimatter, College of Engineering, Editor NMSU, 1988 P. Spillantini et al., Il Nuovo Cimento. 103B (1989) 625.

[17] O. Adriani et al., XXIV Int. Cosmic Ray Conf., 3 (1995) 591, Rome. [18]

[18] S. Alhen et al., Nucl. Instrum. and Meth., A350 (1994) 351.

[19] R. Battiston for the AMS collaboration, XXVII Int. Cosmic Ray Conf. (2001) 2192, Hamburg.

[20] O. Adriani et al., Nucl. Instrum. and Meth., A478 (2002) 114.

[21] L.Scarsi et al., Extreme Universe Space Observatory (EUSO) proposal for ESA F2/F3 missions, 2000 EUSO Design Report, ESA/MSM-GU/2000.462/RDA, Dec. 2000 O. Catalano et al., XXVIII Int. Cosmic Ray Conf., 1 (2003) 1081, Tsukuba.

[22] T. Ebisuzaki et al., The JEM-EUSO project: Observing extremely high energy cosmic rays andneutrinos from the International Space Station, Nucl.Phys.Proc.Suppl.175-176 (2008) 237-240.

[23] A. Santangelo et al., S-EUSO: a proposal for a space-based observatoryof Ultra-high-Energy cosmic particles, submitted to the ESA CosmicVision 20152025 Program (2007).

[24] V.V. Alexandrov et al., XXVII Int. Cosmic Ray Conf. (2001) 831, Hamburg - G.K. Garipov et al., Bull. Russ. Acad. Sci. 66 (2002) 1817.

[25] S.Bottai and P.Spillantini, From the Extreme Universe Space Observatory (EUSO) to the Extreme Energy Neutrino Observatory, 11th Lomonosov Conference on Elementary Particle Physics, August 2003, Moscow, Nuovo Cim. 120B (2005) 887 P.Spillantini et al., EUnO: A neutrino space observatory, 19th European Cosmic Ray Symposium (ECRS 2004), August 2004, Florence, Int.J.Mod.Phys. A20 (2005) 6974. - S.Bottai et al., HE neutrino detection from space. Toward a dedicated neutrino observatory, XXIX Int. Cosmic Ray Conf. 5 (2005) 55, Pune.

[26] V.A. Tsarev, Detection of ultrahigh-energy cosmic rays by radio method, Physics of Elementary Particles and Nuclei, 35 (2004) 1 V.A. Tsarev, An overview of the LORD experiment, ARENA Workshop, Zeuthen, 2005 V. Chechin, Concept of the LORD instrument, ARENA Workshop, Zeuthen, 2005.