CR from space based observatories: history, results and perspectives of the PAMELA mission

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1 Historical introduction

About one hundred years ago cosmic rays (CR) offered to physicists projectiles for studying the microscopic structure of matter with energies exceeding by more than three orders of magnitude those available by natural radioactivity. It is worthwhile to synthesize in a historical scheme (see Fig. 1) what happened before the discovery of CR, and the evolution of their use in the following decades.

Electron machines constructed in 19^{th} century could accelerate charged particles up to several keV, an astonishing progress, i.e. millions of billions of times the higher reachable mechanical kinetic energies per unit mass, such as, for example, the destructive projectile of a powerful gun, or the chemical energy per unit mass. 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 20^{th} century by natural radioactivity, whose projectiles have energies up to several MeV and can arrive inside the atoms up to the nucleus.

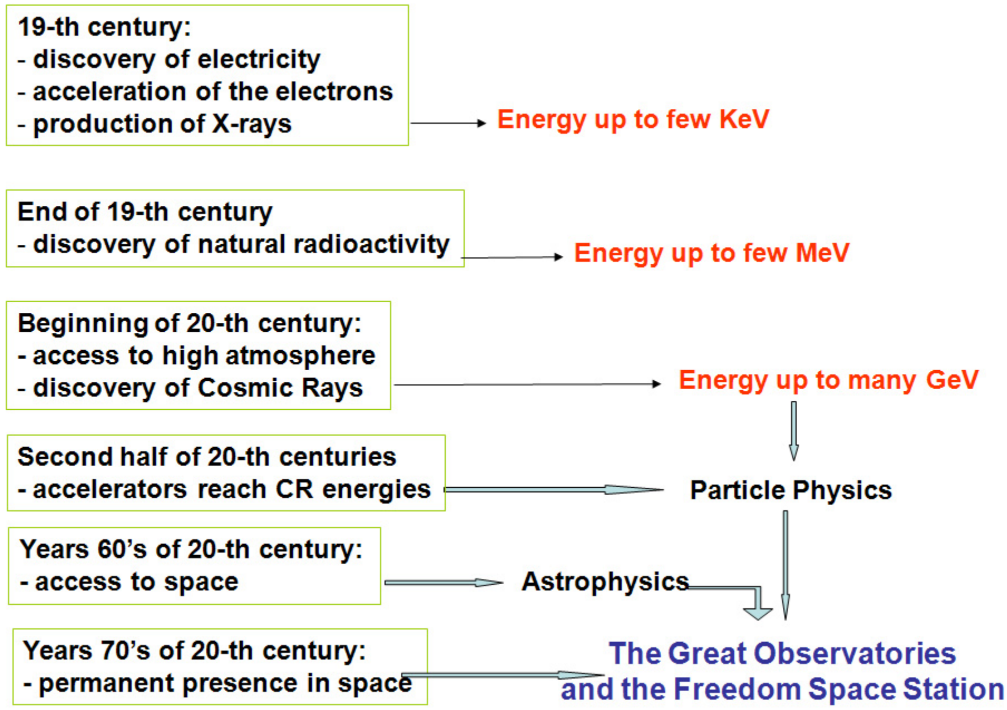

Figure 1: Synthetic historical scheme which draws attention to enormous steps in energy represented by CR, and to main stages of the origin of the astroparticle physics field and of the Great Observatories and CR NASA program.

Hardly can we imagine the surprise when particles coming from space (the CR's) were discovered, carrying energy per particle that must be measured in GeV or higher multiple of the eV, what stands for three or more orders of magnitude further. The structure of the nuclei could be investigated, mesons discovered and studied, "nuclear physics" born.

It took four decades of technological efforts to reproduce CR energy by accelerators and to compete in intensity. The experimentation at accelerators grew very fast, with increasing energy and intensity of the particle beams, a multitude of new methods for detecting particles, increasing of the dimensions and complexity of the instruments, increasing computational power, sharp decreasing of the cost per detection element. After some time it became possible the continuation of the detection of CR's with energies largely exceeding those supplied by accelerators, and CR's again became a useful instrument for elementary particle physics and astrophysics.

In second half of 20$^{\text{th}}$ century, as soon as scientific instruments could be operated outside the atmosphere, the astronomical observation, for centuries confined to the narrow window of the visible band, and, in last decades, to the young radioastronomy, could span all the wave lengths of the electromagnetic spectrum. The image of the universe was revolutionized, new questions arose, and for answering them it was necessary to provide the permanence in orbit of instruments for continuous monitoring the electromagnetic and ionizing particle radiation coming from the Universe.

In the seventies a new revolutionary mean of flight for delivering to orbit heavy (32t) and cumbersome (diameter 4.6m) payloads, the Shuttle Transportation System (STS), was realized by NASA for implementing such an ambitious vision.

For the observation of the electromagnetic spectrum the USA Academy of Sciences recommended and NASA elaborated the "Great Observatories" program [1], covering the whole e.m. wavelengths: 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 Infra-Red Telescope Facility (SIRTF) for the infrared wavelengths, launched in 2003. Radio-waves were observed on ground by a new great array of antennas, the Very Long Base Interferometer (VLBI).

The Great Observatories program was complemented by a vigorous program of observation of CR's, considered by NASA a fundamental tool of Astrophysics, but also aiming to answer fundamental questions of elementary particle physics [2]. Main pieces of the CR program were: (a) the Advanced Composition Explorer (ACE) for studying low energy CR's (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 energies beyond the PeV/nucleon; (c) the Heavy Nuclei Collector (HNC) [4] for the high charge (up to actinides) CR's. 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 discovery of place-country-regionAmerica.

The tragic explosion of the Challenger shuttle in 1986 and financial and political reasons linked to the international competition in space caused the cancellation of the FREEDOM Space Station program, and therefore halted the realization of its facilities, including the two, ASTROMAG and HNC, dedicated to CR observations. Furthermore there was a severe shortage of means to reach orbit that caused the cancellation of several other part of the CR program, many of them are still nowadays to be afforded (in Fig. 2 these cancellations are pointed out in an oval).

The origin of the PAMELA experiment must be regarded in the frame of this situation.

Before describing the PAMELA instrument and discussing its results it is worthwhile to give a panoramic look to the progress of the whole field of CR observation in last two decades, that is the main experimental "rib" of what is nowadays called astroparticle physics. described in the following section 2 is given in Fig. 2.

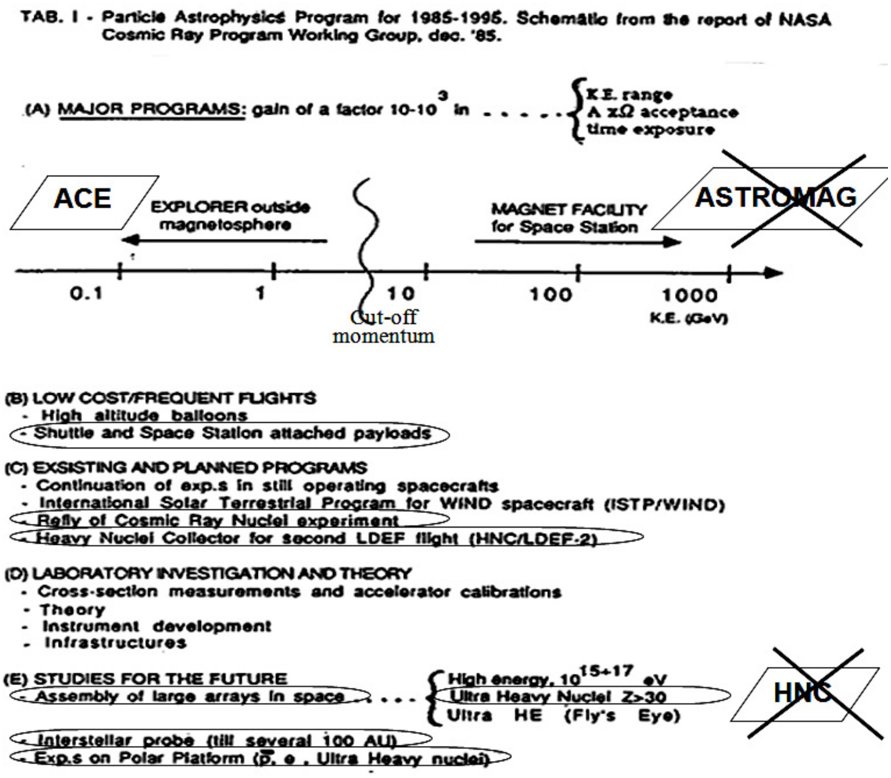

Figure 2: Schematic of the "Particle Astrophysics Program for 1985-1995" (table I of the NASA report, adapted). The main facilities are enclosed in a rhombus. The items of the program never realized are pointed out in an oval. The cancelled facilities are crossed.

2 What could be realized in the last two decades

The $\overline{p}/p$ ratio was determined up to 100 GeV [27]. It confirms, with much smaller errors, the previous results in the whole range (Fig. 3), and at higher energies does not contradict the models suggesting the secondary origin of antiprotons by interaction of primary CR's on the interstellar matter of the Galaxy.

Unexpected results were instead obtained for the $e^+/(e^- + e^+)$ ratio [28]. They are reported in Fig. 4 up to 100 GeV. It is much lower than previous experiments at low energies, agrees with them at about 10 GeV, afterward it substantially and continuously increases, contradicting all previous Let's start from the above mentioned NASA program of two decades ago. It afforded all the most relevant open thematic of CR observation, which can be summarized in the following points:

1. measurement of the fluxes of high Z CR's up to actinides (point (E) of the

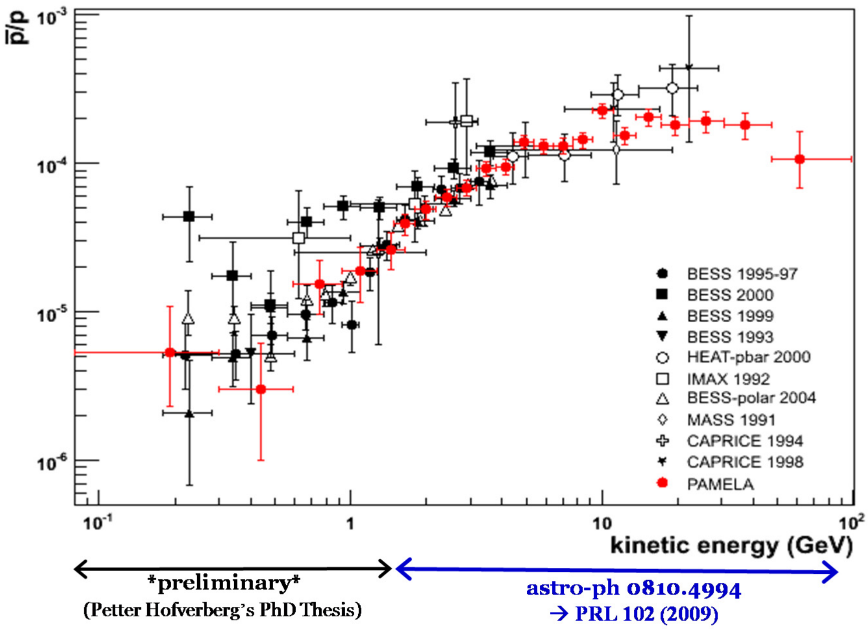

Figure 3: PAMELA experiment: measured antiproton/proton ratio compared with the previous measurements.

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 (UHE) CR's 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 (≥ 1 GeV), both because their production is tightly connected to the sources of very high energy CR's, 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 several hundreds GeV the observations performed by EGRET [6] on board of the CGRO.

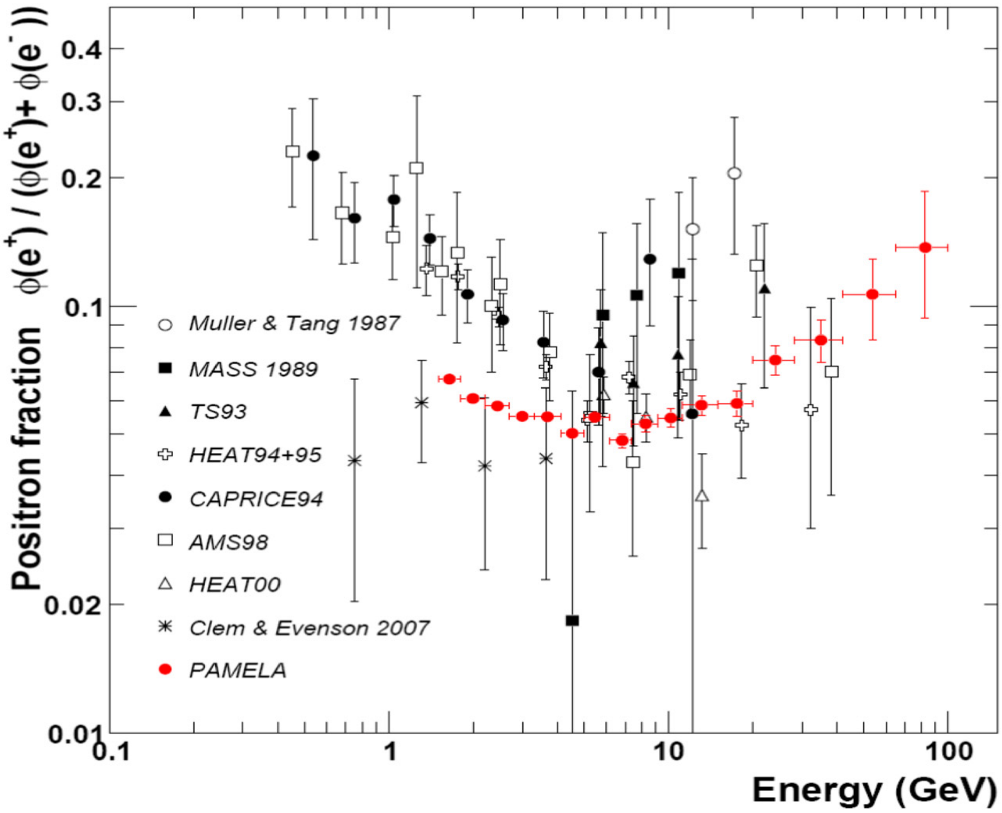

Figure 4: PAMELA experiment: measured $e^+/(e^- + e^+)$ ratio compared with the previous measurements.

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 CR's outside the magnetosphere was realized and launched in 1999, and its instruments are still nowadays producing a rich harvest of valuable data.

For the other facilities the final destiny fate was different. The FSS program slowed down, and 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.

2.1 Very high energy gamma rays.

This year, two decades later, the ASTROGAM program could 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 FERMI- GLAST [8] instrument. For what concerns the development of the other CR researches planned on board of the FSS, namely at the cancelled HNC and ASTROMAG spectrometer facilities, the situation is somewhat differentiated.

2.2 Flux measurement of "extreme Z" cosmic rays.

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. In conclusion, nothing could be done for the measurement of high Z fluxes, an important information for evaluating the rate of supernovae in the Galaxy..

2.3 Energy spectra of isotopes and rare components.

The continuation to 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 $< 1m^2$ sr, 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, ISO-MAX [12], that unfortunately was destroyed in a flight accident. No more projects are planned for the next decade and more. The (by-product) data from BESS-Polar long duration balloon experiment and from PAMELA and AMS-2 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.

2.4 Chemical composition at knee.

Let now consider the flux of the dominant components of CR's, 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 is 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 placeAntarctica. 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 3×10^{15} eV of the knee for solving the historical "knee problem" of CR's. Many satellite borne experiments were in the meantime proposed, ACCESS [14] in place-country-regionUSA and several in place-country-regionRussia, but no one was supported or could find the suitable flight occasion. In the next future it will be flown the 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 solving the knee problem.

2.5 Ultra High Energy CR

Before discussing the measurements of particle and antiparticle spectra and the search for antinuclei, object of the PAMELA experiment, let's have a look to the measurements of the fluxes of ultra high energy (UHE) CR's beyond the ankle. The program of deployment in space of large structure, such as lenses or mirrors (point (E) of the above mentioned NASA program), was hampered by the shortage of means of flight after the Challenger disaster, so that nothing could be realized in space or from space.

However after the pioneer experiments of the sixties and seventies the statistics of the collected events began to increase thanks to the High-Res and AGASA ground based experiments, and finally recently to the much larger AUGER-South experiment. The construction of the AUGER-North will allow a further increase of the statistics in the 10^{19}-10^{20} eV energy range and beyond.

For what concerns the observation from the orbit of UHE CR showers nothing has been until now realized. The OWL project [16], already proposed two decades ago by NASA, is still on paper. The same is for the KLYPVE [17] Russian project for the International Space Station (ISS), whose small scale precursor TUS [18] is however in construction and will be flown in near future. The EUSO proposal [19] born in placeEurope could not proceed beyond phase A for budget difficulties in ESA. Recently it received the interest and the support of the Japanese space agency (JAXA) with the name JEM-EUSO [20], and it is waiting the final decision to be installed on the Japanese facility JEM on board of the ISS. It must be observed that, also if the AUGER South + North promises a competitive statistics of UHE CR if operated for a long period of time (ten or more years), the observation from orbit promises to reach a volume of observed atmosphere so huge to allow the observation of UHE neutrino events, that should be there in the range of 10^{18}-10^{19} eV, produced by the interaction of ultra high energy CR with the microwave background filling the Universe. This thematic is included in the S-EUSO proposal [21] for the ESA cosmic vision program.

3 Particle and antiparticles spectra and search for antinuclei

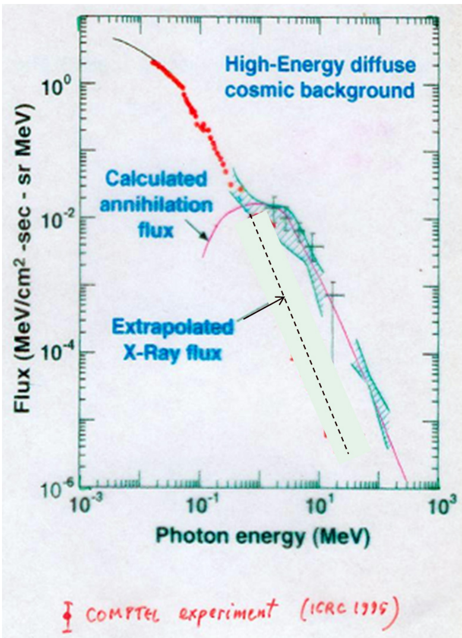

Figure 5: X-ray galactic background

Antiparticles are special rare CR components. The hope of observing in their energy spectra (on top of the secondary produced in the interactions of particles with the interstellar matter) contributions 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 attention for this thematic was particularly keen in the eighties either for the preliminary results in balloon borne experiment, showing an excess of antiproton production of some significant statistical evidence, or for the excess of X-ray background in the universe in the region of 1-10 MeV (Fig. 5), that could be explained by a red-shifted abundant pizero production shortly after the decoupling of matter from radiation.

The X-ray excess, obtained in several difficult balloon experiments, was definitely denied only in 1995 by the COMPTEL experiment on board of the CGRO. The antiparticle and antimatter study had indeed a high priority, and the experiments WIZARD [22] (dedicated to particle and antiparticle observation and antinuclei search) and LISA (which also could do such observations) were selected for the first phase of the ASTROMAG utilization.

The ASTROMAG facility was constituted by a superconducting magnetic system that could serve simultaneously two experiments, and many experiments were proposed to be alternated in the two available locations. For the first phase to be conducted in the first three years of operation (1992-1996) were selected the experiment WIZARD in one location, mainly dedicated to the study of particles and antiparticles and search for antinuclei, and in the other location the SCINATT-MAGIC experiment that had to study the composition at knee for the first 6 months followed in the same location by the LISA experiment for measuring the elements and isotopes energy spectra. They should be followed by a second phase where, among other, the gamma ray sources and spectra should have been studied by the above mentioned (section 2.1) ASTROGAM instrument up to energy of several hundreds GeV in order to continue the successful discoveries and measurement of the EGRET instrument on board of the CGRO.

4 From WIZARD to PAMELA

The PAMELA experiment can be considered the heritor of the WIZARD experiment. In fact, following the ASTROMAG facility cancellation, the Wizard collaboration didn't disband. The proposal of flying the instrument on board of a dedicated free-flayer could not be supported, and the collaboration went on to continue the programmed observations by balloon launches. The ballooning activity was already begun during the work for the WIZARD project, both for going on in producing physics results, as well for testing new instruments, such as imaging calorimeters equipped by multistrip silicon sensors, distinguishing mark of the WIZARD instrument and a novelty in the CR instrumentation.

The Wizard collaboration continued to seek around for an occasion to fly in orbit the instrument, and in 1992 found the interest of several Russian institutions, which helped in finding the flight occasions on board of someone of the Russian earth observing satellites. It was therefore constructed the Russian-Italian Mission (RIM) program, to whom participated the former Wizard collaboration and several Russian institutions. It was this collaboration that, after several satellite and MIR borne experiments in life science and solar CR's[1], constructed and launched in June 2006,

[1] In years 1998-2005 were flown microstrip silicon telescopes dedicated to the study of solar CR's (NINA, NINA2) and to life-science studies (Si-eye-1 and Si-eye-2 on board of the MIR Station and

as final step of the RIM program, the PAMELA [23] experiment, dedicated to the particle and antiparticle studies up to the 100 GeV region, but also conceived as an observatory of the galactic nuclei and of solar phenomena.

In the meantime a Japanese-USA collaboration (nicknamed BESS) used the prototype of the thin superconducting solenoid designed for the ASTROMAG facility in the series of the several balloon borne experiments, 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 [24] on board of the Shuttle and is preparing the AMS-2 [25] experiment that will be installed next 2-3 year on board of the International Space Station (ISS).

5 Some important technical considerations.

For better understanding the need of a technological step in the study of the antiparticle component in CR it is necessary to take into consideration a few remarks.

1. 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 duration of time, not more than a few ten hours 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 opening 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 unavoidable residual atmosphere of about 5 g/cm^2 on top of the apparatus produces a background that exceeds the antiproton signal already at few tens GeV.

2. A large number of balloon borne experiments were performed in the last two decades, and their results (see them in Fig. 5 below, compared with the recent data of the PAMELA experiment) are the maximum that can be collected by the ballooning technique.

Si-eye-3 on board of the ISS).

3. 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.

4. The above mentioned BESS collaboration is now conducting Long Duration Balloon Flight’s (LDBF) in placeAntarctica, with a flight every two years. These flights are possible due to the continuous improvements during nearly 20 years 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 that confines the research of antiparticles of BESS to the low energy region up to a few GeV.

5. 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 of interest for many other fields of the human activities, and the research on the field of cosmic rays must compete for the very limited 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 during the last two decades, and it is worthwhile to have a look to last results and an outlook to the near future.

6 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 [24] was conducted in orbit for a relatively short time on board of the shuttle, "precursor" of the future AMS-2 experiment [25].

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

The characteristics of the PAMELA instrument are described elsewhere [26]. It is based on five permanent magnets interleaving six high precision double sided multi-strip silicon detectors, complemented by a high granularity imaging silicon-tungsten calorimeter, a number of scintillation counters hodoscopes, a thick "penetration" scintillation counter, a He^3 neutron counter hodoscope, and enclosed around by a system of scintillation counters in anticoincidence. Here only three its main qualifying performances must be underlined: (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 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; (c) for the first time a neutron counter hodoscope was used in an experiment, and its performance was excellent.

In this work the preliminary results are presented based on the data collected from July 2006 to March 2009, a total of about 1000 days during the long period of minimum solar activity. Some of the data are preliminary, because in some case the analysis is still in progress and only statistical predictions. The increase of the positron fraction is real, and not imputable to a decrease of the e^- flux (see Fig. 6, where the preliminary results for the $e^- + e^+$ total spectrum are shown to agree with the measurements of ATIC and FERMI-GLAST experiments). The increase of the positron fraction cannot be explained by secondary production on interstellar matter without ad-hoc models; it invokes different sources, such as the contribution of a nearby powerful source, or dark matter annihilation.

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 therefore precisely be measured up to very high energies.

The spectra registered for proton and helium nucleus are reported in Fig. 7. It must be underlined that the statistical error is very small in the whole range from a few hundred MeV up to several hundred GeV, what allows obtaining a very precise measurement of the spectral shape and makes possible to study time variation and transient phenomena that could happen during the period of observation of the

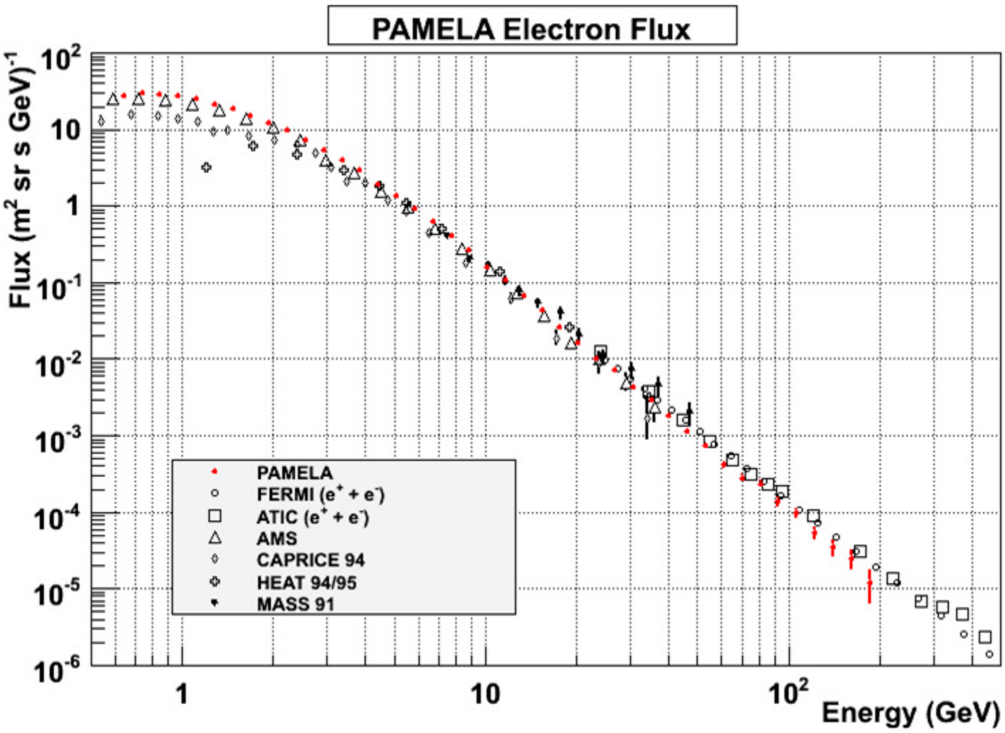

Figure 6: The energy spectrum of the preliminary electron+positron measurements agrees with that measured by the other experiments.

experiment.

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 Fig. 8 the proton spectra registered in different times during the period of minimum solar activity are reported. Also the apparent disagreement of the $e^+/(e^- + e^+)$ ratio at energies lower than 5 GeV is due to solar modulation of GCR depending from the different solar activity in the period of observation of the different experiments.

Many characteristics of the Galaxy can be inferred from the propagation of CR's, the fundamental tool for this being the energy spectra of the different nuclei and of different isotopes and their ratios. In Fig. 9 is reported the ratio between light nuclei (B/C, Li/C, Be/C), that can be precisely measured on a wide energy range, from 1 GeV to 50 GeV in the figure. Analysis for the other nuclei and for light isotopes is in 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

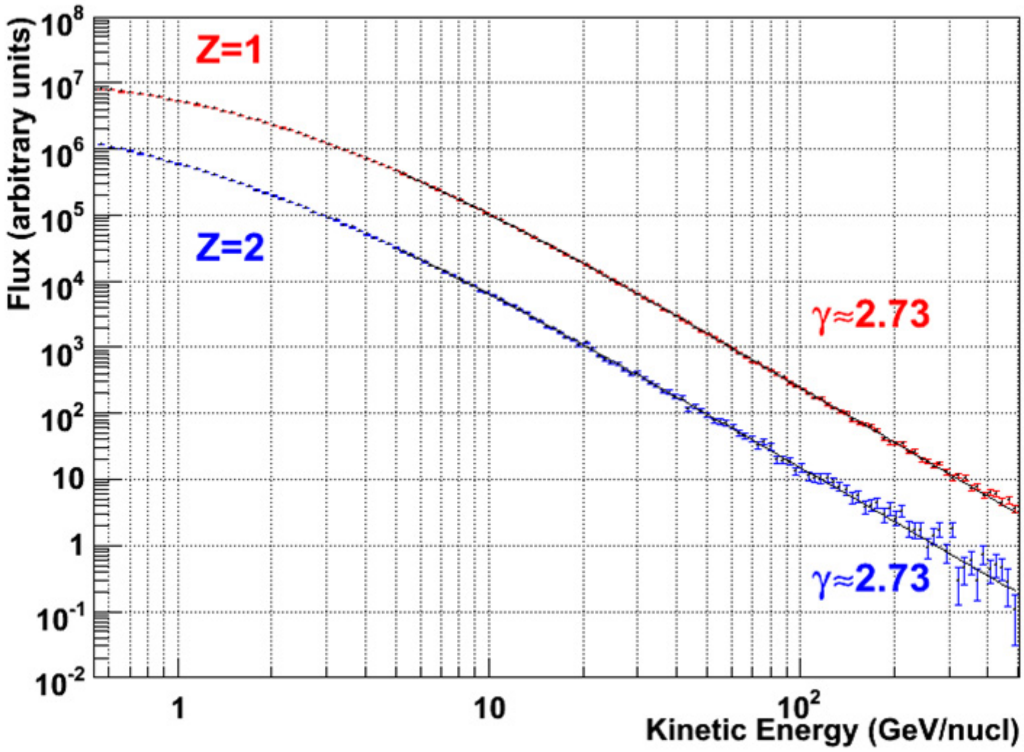

Figure 7: Preliminary measurements of the H and He galactic spectra.

(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 Fig. 10 the energy spectra of protons in different regions of the SAA 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's, supplying unique information on their propagation through the heliosphere. In Fig. 11 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 in the following years, at least until the end of 2012, increasing the statistics and the energy range explored, in the interesting period of the expected sharp increasing of the solar activity.

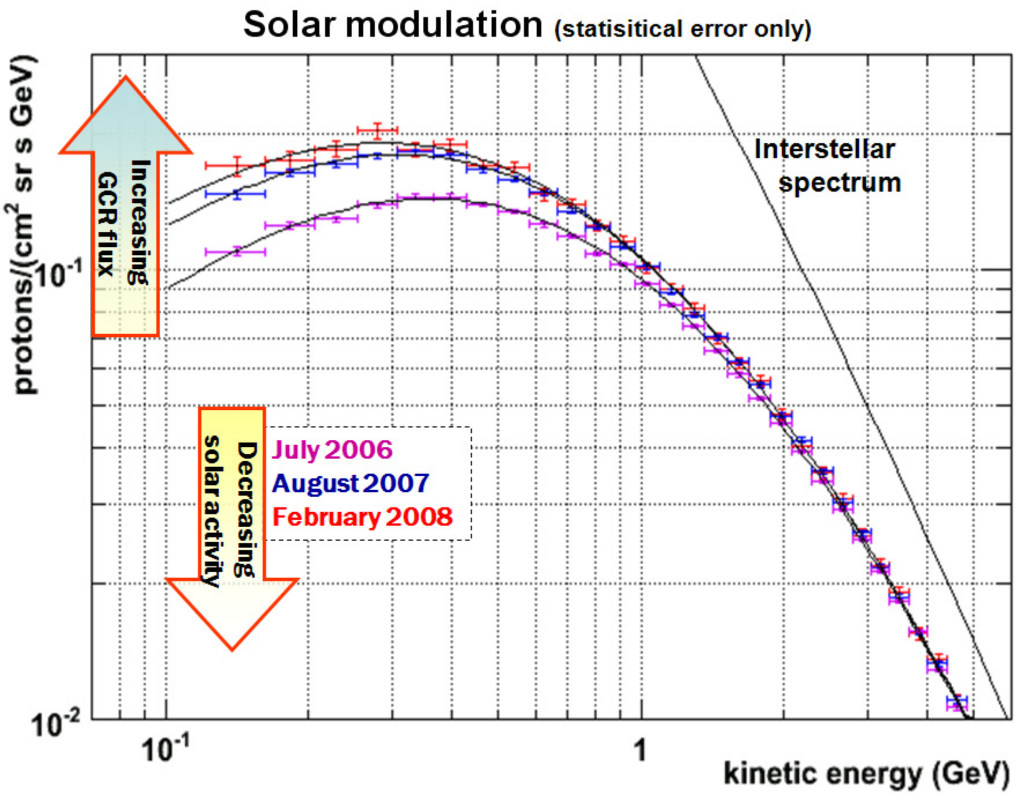

Figure 8: Modulation of galactic CR's between June 2006 and February 2008.

7 The AMS-2 experiment and an outlook to the near future

The AMS-2 experiment has a layout similar to PAMELA, but a much larger acceptance, since initially it was intended to be mainly dedicated to hunting for antinuclei, with a sensitivity of 10^{-9} on the antihelium/helium ratio. The large acceptance will greatly diminishing 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 only 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 CR's, 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

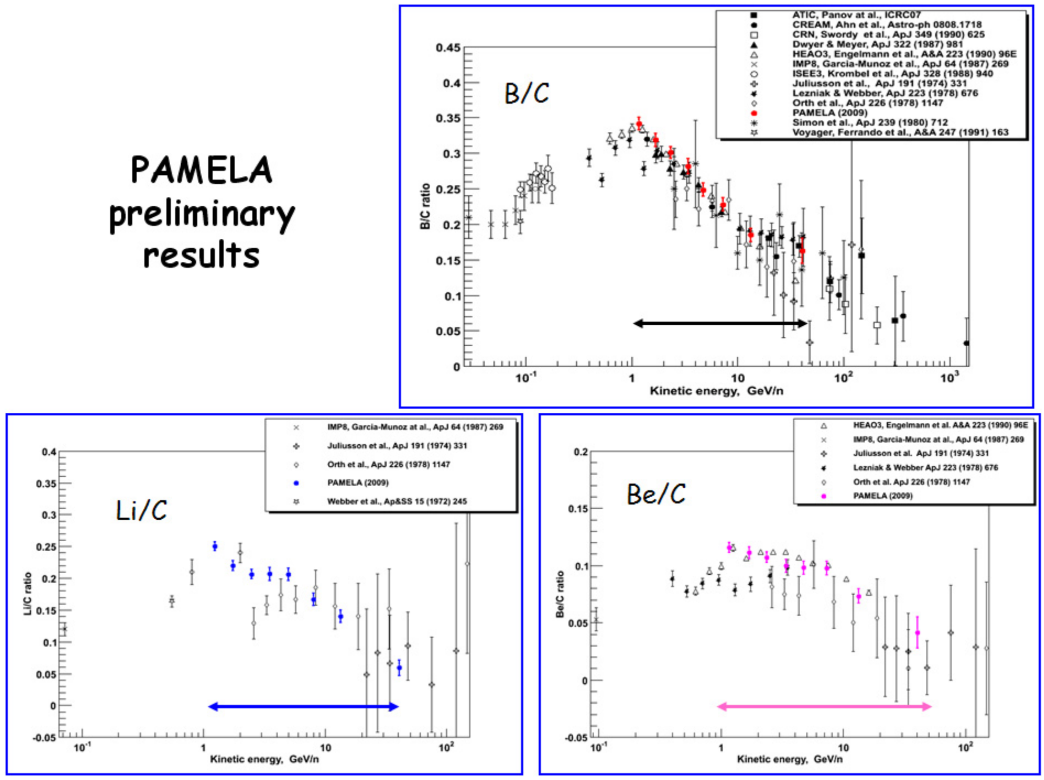

Figure 9: PAMELA preliminary measurements of the B/C, Li/C and Be/C in the energy range 1-50 GeV/nucleon compared with the results of previous experiments.

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 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 CR's, the existence of nearby electron sources, and the measurement of the Jovian electrons.

8 What can be foreseen for the far future?

For the near future nothing is foreseen for the measurement of the fluxes of the extremely high Z nuclei. The possibility of exposing and recovering large areas of passive detectors on the Moon surface makes this research very attractive as a first generation experiment on the Moon. It could be already conducted in the phase of

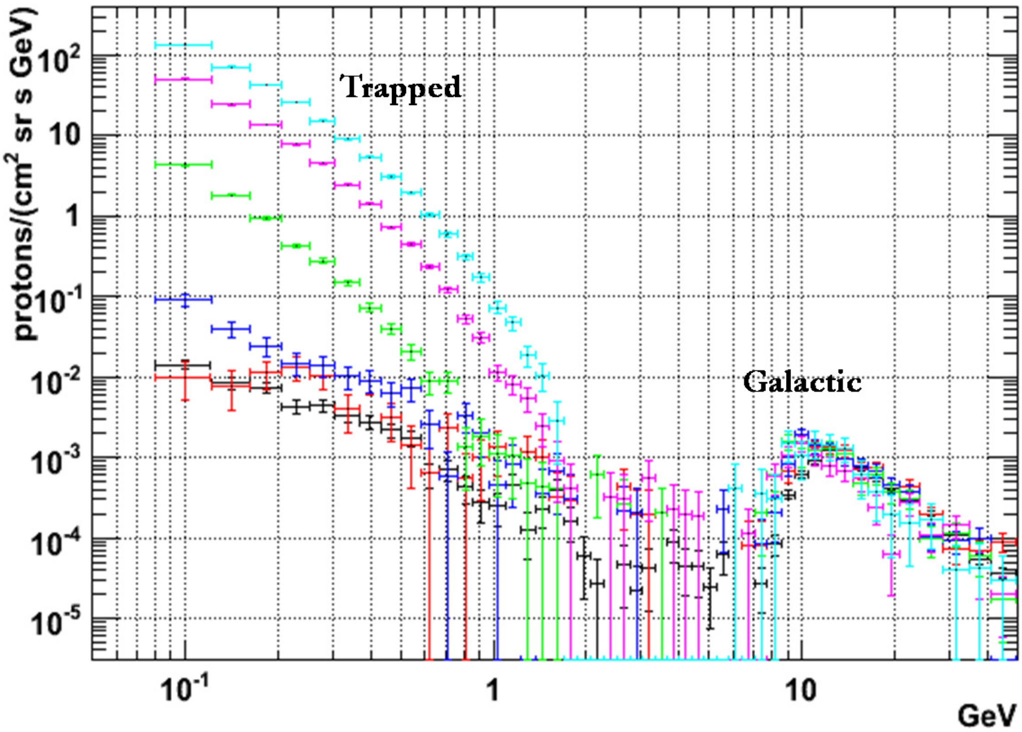

Figure 10: Energy spectra of protons measured in different regions of the SAA registered by PAMELA in its over flights.

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 the realization of someone's of the proposed new arrays, the further flights in Antarctica of the CREAM spectrometer and hopefully on the expected in orbit measurements of NUCLEON.

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

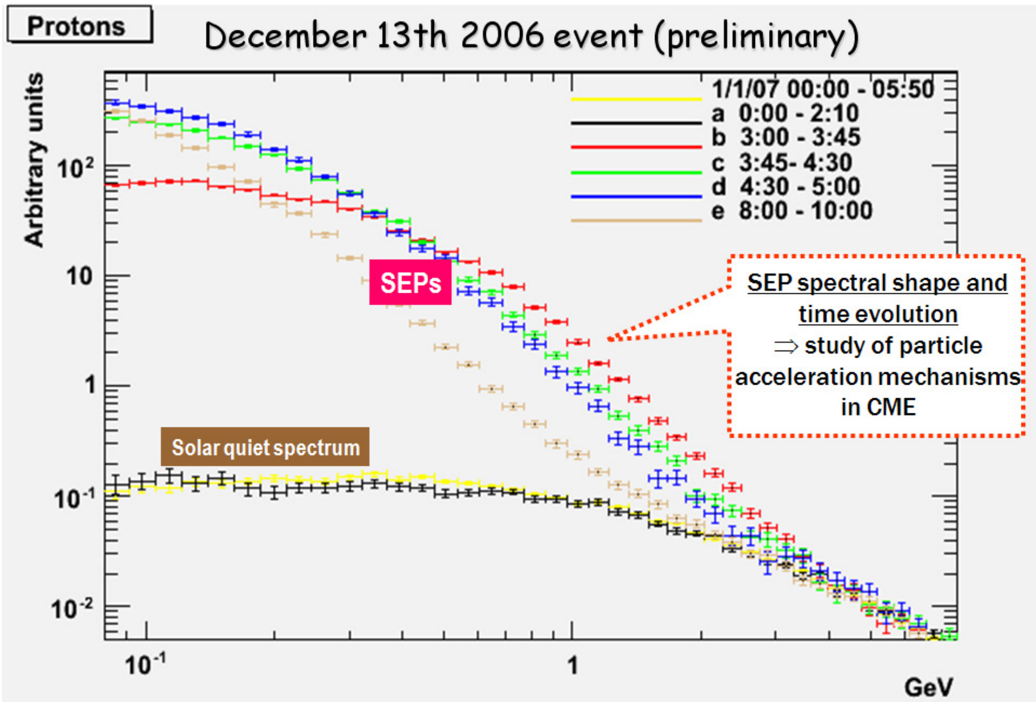

Figure 11: Spectra of protons registered by PAMELA in different time intervals (of 45' and 30') during the solar event of 13$^{\text{th}}$ December 2006.

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 CR's on the terrestrial atmosphere, as the EUSO program [19] (by its steps JEM-EUSO [20], S-EUSO [21] and the precursor TUS [18]) 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 [29], 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 [30] 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.

As a conclusion of this lesson, let me give in Fig. 12 a scheme, which intends to express in graphical form be a didactic summary of the field of the experimental astroparticle physics.

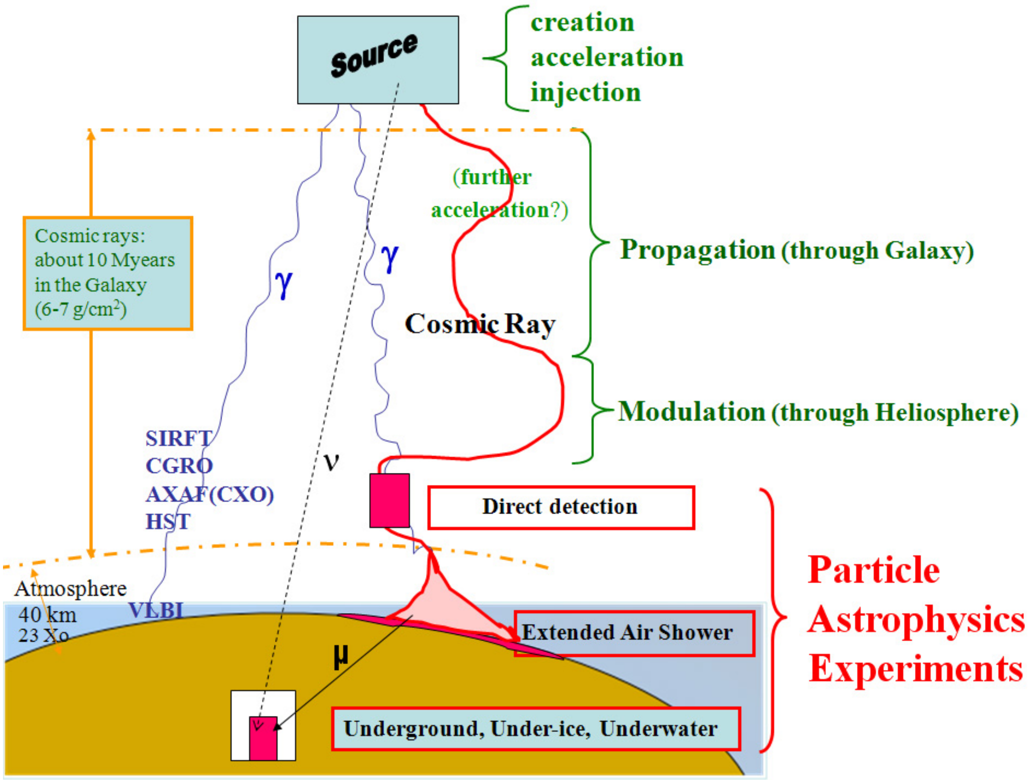

Figure 12: Didactic summary of the field of the experimental astroparticle physics.

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