Cosmic Rays under the Knee

(Invited Paper)

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***Abstract*— Several experiments are currently in data analysis or in operation to explore the cosmic rays energy region between few tens of MeV/n and few tens of TeV/n. The main goals include the search for antimatter, dark matter signals and exotic particles, the study of the mechanisms of production, acceleration and transport of cosmic rays, the monitoring of the solar modulation and its effects on the electrical charge-sign of particles and nuclei. These experiments are providing very precise measurements of antiproton, positron and electron fluxes and a direct measurement of the chemical composition and energy spectra of cosmic-ray nuclei from proton to Iron. In this paper a review of the current experiments and of the results obtained will be presented, together with an overview of the future programs.**

I. INTRODUCTION

Cosmic rays are a sample of solar, galactic and extragalactic matter which includes the nuclei of all elements and their isotopes known in the periodic table, as well as electrons, positrons, and antiprotons. They are associated with the most energetic events and active objects in the Universe: supernovae explosion, pulsars, relativistic jets, active galactic nuclei.

All particle cosmic rays energy spectrum, shown in figure 1, represents one of the most impressive result of the experimental research in astrophysics. It ranges for about 32 orders of magnitude in the flux determination and more than 21 in the explored energy. The spectrum exhibits three spectral features, a first knee at an energy of 3 PeV, a second knee at about 0.5 EeV and an ankle beyond 10 EeV. This spectrum hides the answers to the main questions in the cosmic rays research. Where do the particles are coming from? How and where they are getting accelerated? How do they propagate through the interstellar medium and what kind of interaction do they encounter? What role do they play in the energy budget of the interstellar medium? Are they galactic or also extragalactic? Do we find hints of the existing of exotic particles as relic from the early Universe, as antimatter and dark matter?

The cosmic ray particles (CR), at least up to about 10^{15} eV, are considered of galactic origin and the power supply of their acceleration is usually ascribed to shock waves of expanding supernovae remnants. A direct evidence has been achieved in the recent years by SNR observation in gamma rays, probably of hadronic origin, by Cherenkov imaging telescopes [1] and in X-ray emissions from the borders of SNR [2] that gives proof of an efficient magnetic field amplification. It is, however, not well understood what kind of particles and which fraction of matter is actually selected from the ambient plasma for acceleration and finally injected as energetic particles into the interstellar space, where they spend about 10^7 years before escaping into the intergalactic space. This long confinement leads to expect a coupling to the galactic magnetic field, since the residence time along a line of sight through our galaxy would only be 10^3 years. Moreover, the scattering on random magnetic fields leads to a random walk in real space (diffusion) and in momentum space (diffusive reacceleration). An effective diffusion is confirmed by the high degree of isotropy shown from the cosmic radiation since cosmic rays streaming freely out of the galaxy or following strictly the galactic magnetic field pattern would be highly anisotropic, with most flux coming from the direction of the central region of the galaxy. Particles may also be spatially convected away by the galactic wind, that induces adiabatic losses, and lose energy when they interact with interstellar matter (ISM) or with the electromagnetic field and radiation of the galaxy.

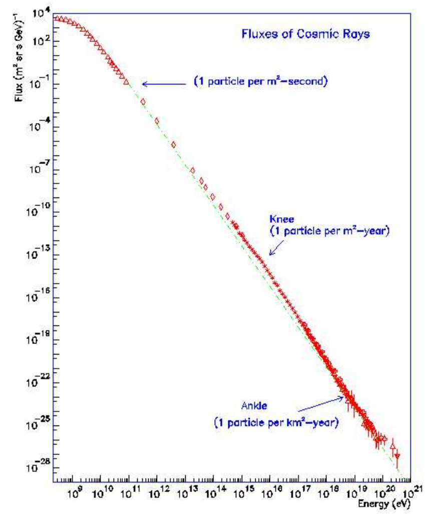

Fig. 1. All particle cosmic rays energy spectrum.

The interaction of the cosmic rays with the interstellar matter leads to the production of new particles and also to spallation products. In the framework of these observational constraints models of cosmic rays propagation have been implemented, with Leaky Box Model and Diffusion Halo Model mostly developed. From experimental point of view the cosmic rays energy spectrum can be divided in two large intervals; a first, below the knee, explored by direct space measurements, and a second one, over the knee, where the low particle flux makes feasible only indirect measurements, performed by very large on ground detectors.

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In this paper we will deal only with direct measurements, focusing attention on the chemical composition of the cosmic rays, the antimatter and dark matter research and the solar modulation.

The chemical composition of cosmic rays under the knee is extensively studied because it provides important information about the cosmic rays primary sources, secondary productions, acceleration processes and propagation through the interstellar medium. Furthermore, these data are used as input in Monte Carlo calculations of the development of the particle showers in the Earth's atmosphere, that are related to the atmospheric neutrino oscillation problem. The ratios between secondary and primary cosmic ray fluxes as B/C, Be/C, Li/C etc. are also of particular interest, because they provide a unique tool to characterize the diffusion property of the ISM. Finally, the secondary radioactive CR nuclei with decay time comparable with the confinement time play an important role in determining the diffusion coefficient and the halo size and also provide information on the mean gas density through which particles propagate.

The understanding of the nature of dark matter that pervades the universe and the apparent absence of cosmological antimatter are today two of the most compelling issues facing astrophysics and cosmology. Many balloon-borne, satellite and space station experiments have been performed or now working or in integration phase to detect gamma rays, positrons and antiprotons as possible signals of dark matter, together with antihelium and heavier nuclei as products of primordial and anti-stellar nucleosynthesis.

Solar modulation affects the low energy part of the cosmic ray and plays an important role in the precise determination of the cosmic rays interstellar energy spectrum and in the disentangling possible contributions of dark matter signals from standard antiparticles production. Several instruments on ground and in space are continuously monitoring solar modulation and are giving essential input for modelling the solar effects on the cosmic rays. In conclusion, understanding the origin and the propagation of cosmic rays in the galaxy requires the combination of many different observations over a wide range of energy.

II. ELEMENTAL COMPOSITION

An extensive work on chemical composition by direct measurement of cosmic rays in space or at the top of the atmosphere in the energy region between few tens of MeV/n and tens of TeV/n is conducted since many years, starting with the pioneer series of Proton satellite experiments of Grigorov [3] and, after, extended mainly by the JACEE and RUNJOB balloon-borne experiments and by HEAO and SOKOL on board satellites. At present ATIC, CREAM, TRACER, PPB-BETS and TIGER on balloons and PAMELA and ACE on satellites are producing new data. AMS-02 on board the ISS and NUCLEON on satellite are foreseen as new entries in the next years.

Primary spectra of protons and helium nuclei measured by many experiments are shown in figure 2 [4] compared with

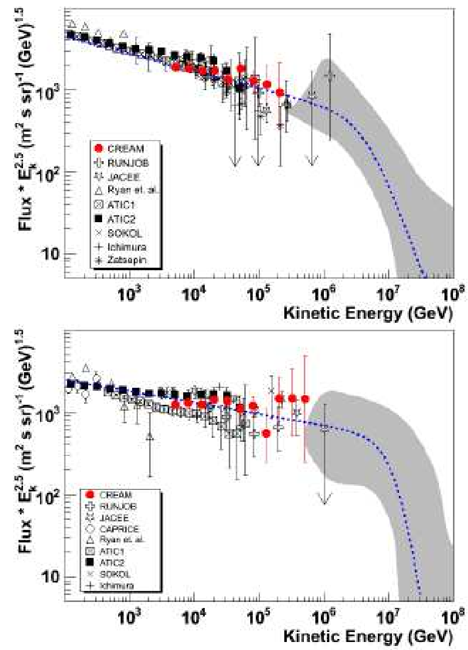
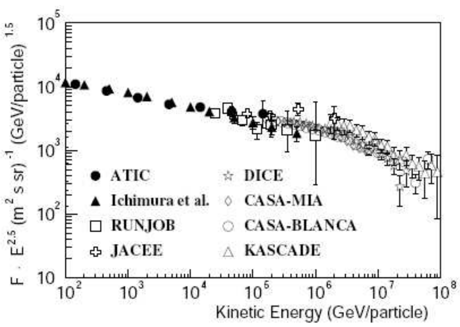


Fig. 2. Proton (top) and helium (bottom) spectra in energy per particle measured by many experiments (various symbols) [4], Horandel's empirical model (dotted curve) and ground based indirect measurements (shaded area) [5].

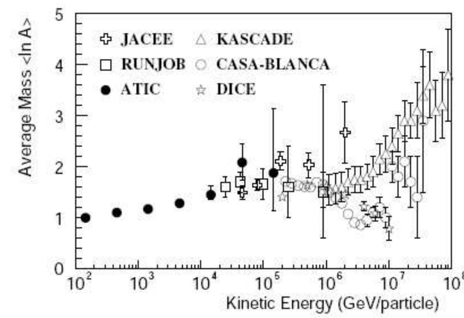
Hörandel's empirical model [5]. The shaded area indicates the band of incertitude of ground based indirect measurements; it is also to note as direct and indirect measurements are starting to overlap in the knee region. The proton spectrum is following a power law without much change up to $\sim$ 100 TeV. The spectra of He nuclei as measured by CREAM and ATIC 2 are in good agreement and accord with the Hörandel's empirical model which is based on data of previous experiments. An increase in the abundance of helium nuclei relative to protons appears in ATIC and CREAM spectra. The forthcoming data of PAMELA should clarify the energy region in which the helium slope changes.

The all-particle spectrum as measured by ATIC is shown in figure 3 [6] together with other direct measurements performed by Ichimura *et al.* [7], RUNJOB [8] and JACEE [9], and the indirect measurements by DICE [10], CASA-MIA [11], CASA-BLANCA [12] and KASCADE [13] [14]. In the right panel of figure 3 the mean logarithmic mass number found by ATIC in the energy range 10^2-10^5 GeV/particle shows a general trend to a heavier composition and appears to be in agreement with the results of the other experiments in the knee region.

Individual energy spectra of cosmic-ray nuclei heavier than protons and helium at high energies were measured long time ago by two space missions: HEAO-3 which provided data with high statistical accuracy up to about 35 GeV amu^{-1} [15] and CRN on Spacelab 2 which performed the first measurements into the TeV amu^{-1} region [16]. More recently several balloon-borne instruments measured high-



(a)



(b)

Fig. 3. a) All-particle spectrum and b) average mass number as a function of particle energy measured by ATIC [6], Ichimura *et al.* [7], RUNJOB [8], JACEE [9], DICE [10], CASA-MIA [11], CASA-BLANCA [12] and KASCADE [13] [14].

energy cosmic-ray composition in this region: RUNJOB [17], ATIC [18], CREAM [6] [19], TRACER [20], HESS. The dataset shown in figure 4 includes the energy spectra of the major primary species, O, Ne, Mg, Si, S, Ar, Ca, and Fe, for an energy range between a few GeV amu^{-1} and more than 10^4 GeV amu^{-1}. The fluxes are multiplied by different normalization factors.

The agreement among the different experiments appears to be quite good in the regions of the overlaps. Data on the light primary cosmic ray components (protons, helium, and carbon) detected by AMS [21], ATIC [22], BESS [23] [24], CAPRICE [25], JACEE [26], RUNJOB [17] are displayed as well. A fit of the TRACER data to a power law $\propto E^{-\gamma}$ is reported in figure 4, while the resultant spectral indices with charge Z are shown in figure 5. No significant trend of the spectral indices with Z charge appears; all indices fit well to an average of $\gamma = 2.65 \pm 0.05$. This behaviour strongly suggests a common origin of all cosmic-ray species. However a more careful analysis should show that the competing action of physical escape from the galaxy, which depends on energy, and of loss by spallation in the interstellar medium, which depends on the nuclear charge Z (or more correctly, on atomic number A), leads to some changes in the spectral shape for individual nuclei that would be difficult to describe by a single power-law spectrum [27].

A. Relative abundances

The abundances of super-heavy elements, (Z > 30), should give hints to the studies on the acceleration processes and the prevalent acceleration sites, though their fluxes are more than $\sim$ 1000 times smaller than the Iron flux. They are reported in figure 6 [28] for the energy region between 0.3 and 10 GeV/nucleon, as measured during two balloon flights by the TIGER Collaboration in 2001 and 2003.

The lines represent the predictions of two models for acceleration, one based on first ionization potential (FIP) [29], and the second on volatility, but both with a standard solar system composition of the ambient medium [28] [30]. The nearly equal abundances of $_{31}$Ga and $_{32}$Ge appear to be inconsistent (if taken at the same time) with both theoretical models. While Ga results are consistent with the FIP model and inconsistent

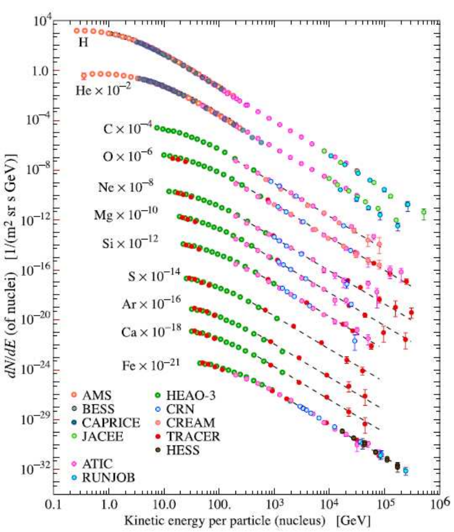


Fig. 4. Flux as a function of energy for the major components of the primary cosmic radiation: O, Ne, Mg, Si, S, Ar, Ca, and, Fe. The dashed line represents a power-law fit to the TRACER data above 20 GeV amu^{-1}. For references to the data presented in this plot see [15]- [26] and references therein.

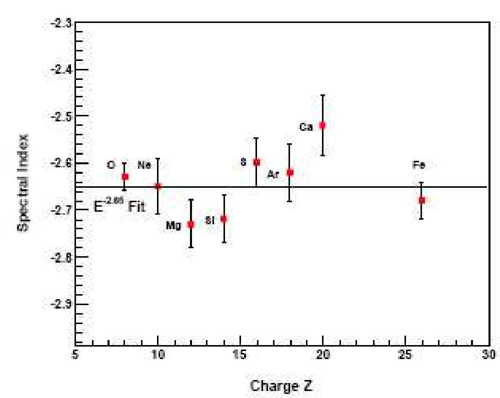


Fig. 5. Spectral indices of a best power-law fit to the combined TRACER data above 20 GeV per amu. The line indicates the an average spectral fit of E$^{-2.65}$ [20].

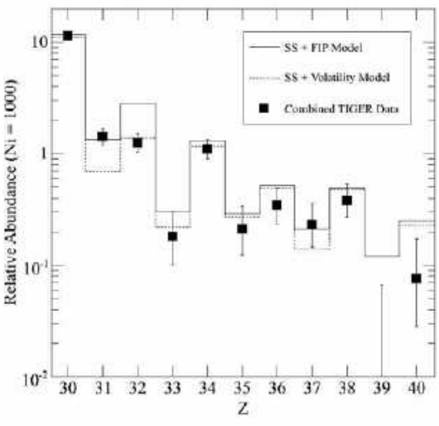


Fig. 6. Relative abundances observed at the TIGER instrument [28] compared with results of propagating two possible source models to the balloon's atmospheric depth.

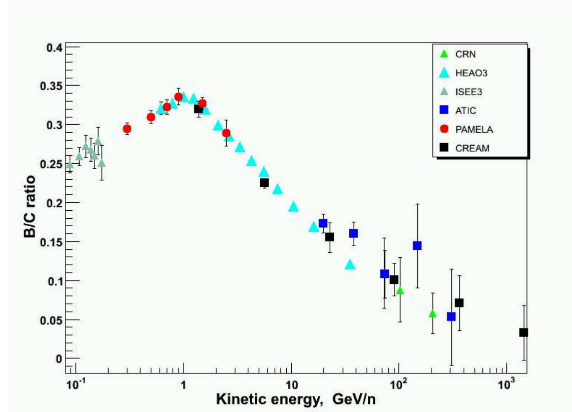


Fig. 7. Boron to Carbon ratio as a function of energy per nucleon as measured by many experiments: ATIC [33], HEAO3 [15], CREAM [32], PAMELA [34], ISEE3 [35], CRN [36].

with the volatility model, the Ge results are consistent with volatility and not with FIP. A similar result was reported from the HEAO-C2 instrument [31]. The cosmic rays abundance for element Z $<$ 30 are consistent with volatily-dependent acceleration, but since most refractory elements have low FIP, a FIP-dependent acceleration is not firmly ruled out by those abundances [28].

B. Propagation models and Cosmic Rays fluxes ratios

The energy dependent escape of particles from the galaxy leads to a difference between the spectra of cosmic rays at the source and those measured at Earth. This variation can be understood studying the acceleration processes and the propagation of cosmic rays trough the interstellar medium by precise measurements of the fluxes and energy spectra of secondary nuclei, that are produced mainly by spallation interaction of primary nuclei with the interstellar matter. In particular, the abundances and spectra of secondary elements such as Boron, Beryllium and Lithium and, specially, the ratios of secondary to primary (for instance B/C) are directly related to the encountered amount of matter and to the nuclei lifetime before escaping from the galaxy. Actually, the energy dependence of the B/C ratio is directly connected with the diffusion coefficient D(E), or more in general with the escape time, which scales as 1/D(E) if diffusion is the only process responsible for escape. The results of measurements of the B/C ratio performed by several experiments are shown in figure 7.

The most recent results of CREAM [32], ATIC [33] and TRACER (unpublished) extend to energies of 100 - 1000 GeV/nucleon. Such data provide a unique opportunity to understand what is the rate of escape of cosmic rays as a function of energy right below the knee. The data with small error bars at low energies of PAMELA and CREAM confirm the old HEAO3 data and suggest a scaling of the diffusion coefficient with energy as $D(E) \propto E^{\delta}$, with $\delta \approx$ 0.6, at least at rigidities below 10 GV. Since cosmic rays escape from the galaxy proportionally to E^{δ}, the power index value should change at high energy otherwise a too large anisotropy of cosmic rays at knee would be measured. The higher energy data of CREAM and ATIC have too large error bars to lead to a flatter behaviour of the escape time [30].

The N/O measurements by CREAM [32], reported in figure 8(a) together with those of HEAOC2-3 [15], show that Nitrogen is only partly secondary, with a residual abundance at the source. The solid line corresponds to a source N/O = 10$\%$, the long-dashed line corresponds to a source N/O=5$\%$ and the short-dashed line is for source N/O = 15$\%$.

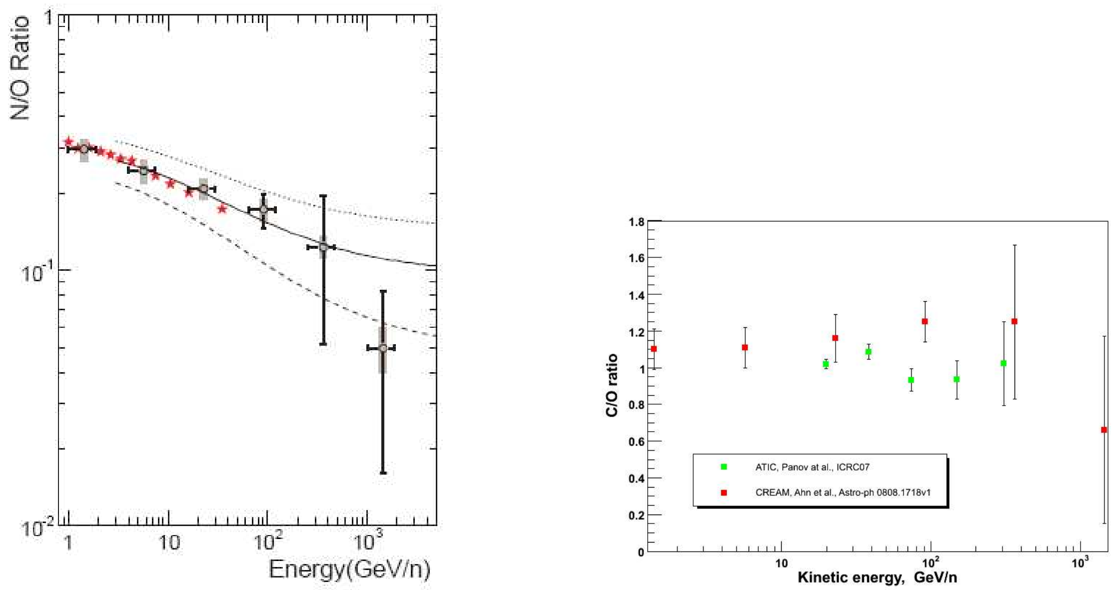
As to the primary nuclei, the Carbon to Oxygen ratio measured by CREAM-II [32] and ATIC [33] (figure 8(b)), appears to be close to constant with energy, confirming their origin in the cosmic ray source.

In the next future, the new Long Duration Flights of TRACER and CREAM instruments and the AMS-02 and NUCLEON space missions, together with the data PAMELA are already providing, will allow for fundamental improvements to the understanding of the origin and propagation of cosmic rays in the galaxy.

III. Antimatter and Dark Matter research

What was the role of matter and antimatter in the early Universe? Is the present Universe baryon symmetric or baryon asymmetric? Is the matter only baryonic? These are the questions today addressed exploiting cosmic particles with balloon borne, satellite and ISS experiments.

The Big Bang origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning. On the other side, indirect searches of antimatter performed analyzing the distortion of the CBR spectrum and the spectrum of the Cosmic Diffuse Gamma exclude the presence of large domains of antimatter in a baryon symmetric Universe at least for distance of 100 Megaparsec. Moreover, after the discovery of the CP violation in the weak interactions [37], Sakharov, in a famous JEPT letter of 1967 [38], formulated the three well known hypotheses, today only partially confirmed, to be



(a) (b)

Fig. 8. a) Nitrogen to Oxygen ratio as a function of energy for CREAM [32] and HEAO-C2-3 [15] experiments. The lines represent model calculations of this ratio with the escape parameter α=0.6. The different curves correspond to different assumptions on the amount of nitrogen in the source material. These are: solid line source N/O = 10%, long-dashed line source N/O = 5%, short-dashed line N/O = 15%. b) Carbon to Oxygen ratio as a function of energy for CREAM-II [32] and ATIC [33] experiments. The ratio is expected to remain close to constant with energy.

assumed to explain the observed predominance of matter over antimatter in the early Universe.

The idea that space measurements of cosmic radiation could give the possibility of direct antimatter observation escaped as a cosmic ray from a distant antigalaxy received a huge boost from the Golden *et al.* [39] and Bogomolov *et al.* [40] balloon-borne experiments. In 1979 Robert Golden and Edward Bogomolov carried out the first historical discovery of antiprotons on the top of the atmosphere triggering a wide program of direct antimatter research. Actually, the measured rate of antiprotons was much higher than expected from interactions of cosmic rays with the interstellar matter (figure 9). Straightaway various ideas of theoretical interpretation were developed, as primary antimatter coming from antimatter domains in a baryonic symmetric Universe (blu line) [41], evaporation for Hawking effect of primordial mini black holes, exotic particles annihilation (red curve) [42]. In the same years the results of the positron/electron ratio measurements were somewhat similar, with experiments giving a too high flux of positrons at energies higher than 10 GeV, explained with some exotic productions.

The discovery of one nucleus of antimatter (Z$\geq$2) in the cosmic rays would have profound implications for both particle physics and astrophysics. If there was primordial antimatter, antihelium would be the most likely form to be detected in cosmic rays, likewise in matter primordial nucleosynthesis in which helium is the next abundant element to hydrogen. On the other side the detection of antinuclei with Z>2 in cosmic rays would provide, instead, direct evidence of the existence of antistellar nucleosyntesis. Moreover, several authors [43] [44] suggest that small bubbles with very high baryonic asymmetry could be produced by the presence of stochastic or dynamical violation of CP also in a baryon dominate universe.

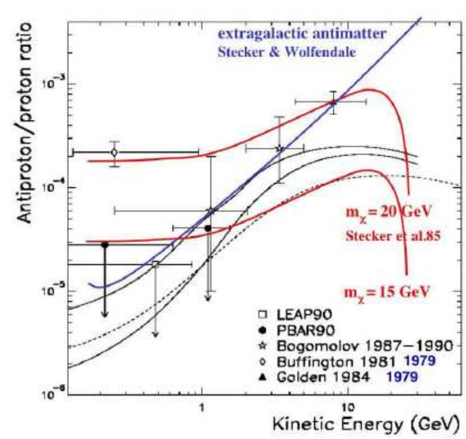


Fig. 9. Antiproton/proton ratio together with theoretical interpretation: primary antimatter coming from antimatter domains in a baryonic symmetric Universe (blu line) [41], exotic particles annihilation (red curve) [42].

Many balloon-borne experiments followed these pioneer ones using novel techniques developed for accelerator physics, mainly by the WiZard, HEAT and BESS collaborations (see table I). In 1998 AMS-01 got cosmic rays data by a large instrument installed on board the Shuttle. The experimental limits obtained by these missions for the $\bar{H}e/He$ ratio are presented in figure 10: the current lowest limit is of the order of 3×10^{-7} obtained combining all the BESS flights data. As

1979	First Observation (Golden *et al.*)
1979	Russina PM (Bogomolov *et al.*)
1981	Excess reported (Buffington *et al.*)
1985	ASTROMAG Study Started
1987	LEAP, PBAR (upper limits)
1989	MASS89
1991	MASS91
1992	IMAX
1993	TS93, BESS
1994	CAPRICE94, HEAT94
1997	BESS
1998	CAPRICE98, MS01
1999	BESS
2000	HEAT–pbar, BESS
2004	BESS Polar I
2007	BESS Polar II

TABLE I

ANTIMATTER AND DARK MATTER IN COSMIC RAYS

for the antiproton/proton ratio, the first pioneer results were not confirmed later.

Meanwhile new results and new suggestions came from the

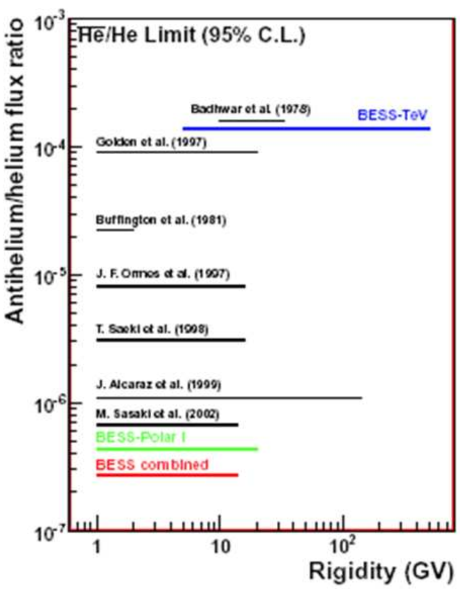


Fig. 10. Experimental limits for the $\bar{H}e/He$ ratio.

analysis of the cosmic microwave background anisotropies that provided for a cosmologic average for the abundance of baryons and matter the values $\Omega_b h^2$ = 0.0220 and $\Omega_M h^2$ = 0.131, respectively, with small error bars. It is nowadays supposed that the energy budget of the Universe is shared among baryonic matter (4%), dark matter (23%), and dark energy (73%). The nature of the astronomical dark matter is still unresolved. The favourite candidate for the non baryonic component is a neutral weakly interacting massive particle (WIMP) with a mass in the range between 10's of GeV to TeV. It would naturally appear as one of the thermal leftovers from the early Universe and its presence is predicted in several classes of extension of the Standard Model of particle physics. The most popular candidate is the lightest neutralino χ, in R-parity conserving supersymmetric models.

Considerable effort has been put into the search of dark matter WIMPs in the last 15 years with several complementary techniques. One of the techniques worth being explored is the search of WIMPs annihilations by indirect signatures. Neutralinos should pervade the Milky Way halo and be concentrated at the galactic centre. As they mutually annihilate, they should produce high energy photons and antimatter cosmic rays. However, these contributions are mixed with a huge background produced in the interactions of cosmic rays with the ISM, so that they should appear as a distortion of antiproton, positron and gamma energy spectra due to this secondary production. In figure 11 experimental results for the

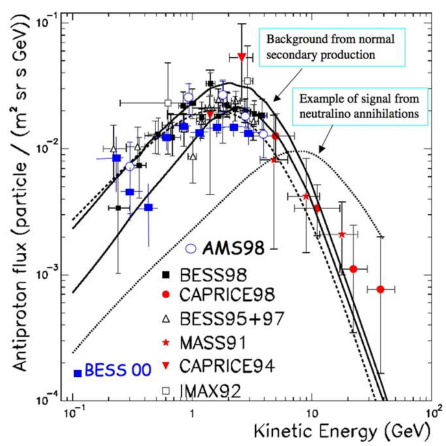


Fig. 11. Experimental data for the $\bar{p}$ flux together with calculations accounting for a pure secondary component (Simon *et al.* [45], Bergström *et al.* [46]) and for a possible contribution from $\chi\chi$ annihilation (Ullio [47]).

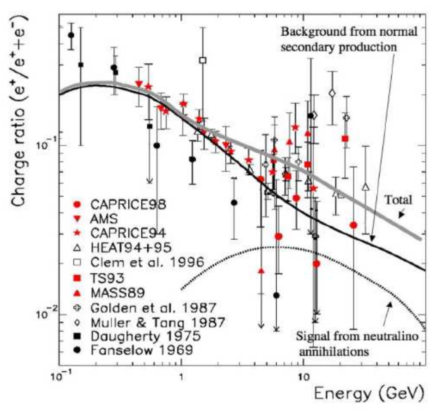


Fig. 12. Experimental data for $e^+/(e^+ + e^-)$ ratio, together with calculations for a purely secondary production, for a possible contribution from $\chi\chi$ annihilation and the sum of the two.

antiprotons flux, obtained by the balloon borne and AMS-01 experiments, are reported together with different calculations accounting for a pure secondary component [45] [46] and for a possible contribution from $\chi\chi$ annihilation (dotted line [47]). The spectrum has a distinct peak around 2 GeV, showing the characteristic feature of secondary antiprotons produced by

the interaction of Galactic cosmic-rays with the interstellar medium. The energy spectrum of these secondary antiprotons should decrease rapidly toward lower energies reflecting the kinematic constraints on antiproton production [48] and toward higher energies reflecting the steep power-law spectra of primary particles producing the antiprotons. In addition to these secondary antiprotons, there might be a source of primary, but the large error bars at high energy, the solar modulation effects at low energy and the uncertainties in the background calculation strongly limit the data interpretation in terms of dark matter signals.
In figure 12 the experimental data for $e^+/(e^+ + e^-)$ are shown, together with calculations for a purely secondary production, for a possible contribution from $\chi\chi$ annihilation (dotted line) and for the sum of the two (solid line). The combined data set suggests the presence of a feature in the positron fraction in the energy range from 7 to 20 GeV. Exotic and astrophysics positron production mechanisms that would lead to an excess of positrons in this energy region have been proposed, but the uncertainties in the data do not permit a definite conclusion.

To widen the research for primary antimatter and to try to disentangle possible exotic components from the standard production, several space missions and LFD (Long Duration Flight) balloon experiments have been conceived for measurements at higher energies, with high statistic and during different solar modulation phases. These missions are shown in figure 13.

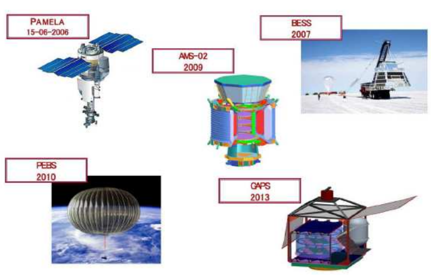


Fig. 13. Antimatter and Dark Matter Experiments.

The magnetic spectrometers PAMELA, in flight since June 2006 on board the Resurs-DK1 satellite, and AMS-02, that will be installed outside the ISS in 2010, can be considered as Observatories at 1 AU. Their primary scientific objectives are the search for heavy antimatter and nonbaryonic particles outside the Standard Model. In particular they can search for antihelium (primordial antimatter), heavy anti-nuclei (anti-stars), new matter in the Universe (strangelets?). They can perform also precise measurements of the antiparticle energy spectrum and precision studies of light nuclei and their isotopes to test cosmic-ray propagation models. Concomitant goals include the study of solar physics and solar modulation, the investigation of the interaction of cosmic-rays with the Earth's magnetosphere and the search for high energy electrons to discover local sources.

The antiproton-to-proton flux ratio as measured from PAMELA in the energy range between 200 MeV and 100 GeV is shown in 14 compared with the previous experiments and some background calculations (Molnar *et al.* [49], Moskalenko *et al.* [48]). The flux increases smoothly with energy up to about 10 GeV, in agreement with previous experiments, and then levels off. The data follow the trend expected from secondary production calculations and significantly constrain contributions from exotic sources, e.g. dark matter particle annihilations. Data for positron/electrons ratio are shown in figure 15 for an energy interval between some hundred MeV to 10 GeV. The low energy data show a significant charge-sign dependence for solar modulation while in the 7-10 GeV region the HEAT structure has not been confirmed.

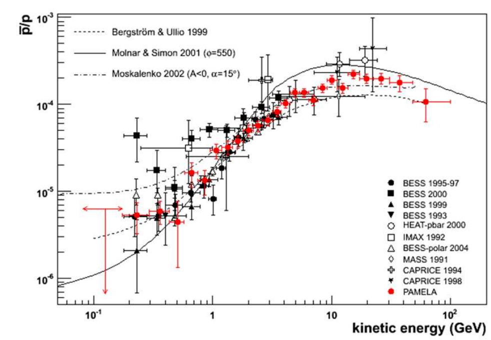


Fig. 14. Preliminary antiproton/proton ratio measured by PAMELA and some background calculations (Molnar *et al.* [49], Moskalenko *et al.* [48].

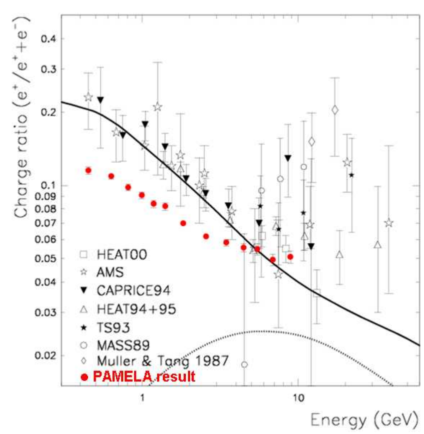


Fig. 15. Preliminary positron fraction measured by PAMELA.

The PPB-ETS (Polar Patrol Balloon) results about all electron energy spectrum (positrons + electrons), multiplied by the cube of energy, observations [50] from 10 GeV to 800 GeV are shown in figure 16 together with others data. The energy spectrum exceeding 100 GeV is crucial to detect the nearby SNRs as discussed by Kobayashi *et al*. (2004) [51], and electron-positron pairs from Kaluza-Klein dark matter annihilations [52]. The statistics of PPB-BETS data are insufficient to discuss the details of the contribution of nearby SNRs and/or WIMP dark matter, but may indicate a sign of a structure in the several 100 GeV region. Similar structure in the all electron energy spectrum is reported by the ATIC-2 observations.

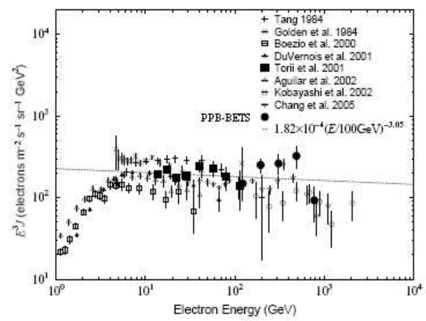


Fig. 16. Electron energy spectrum observed with PPB-BETS (solid circles) [50].

IV. Solar modulation

The energy spectra of cosmic rays are modified by the solar wind within the solar system, mainly at energies lower than 10 GeV. This solar modulation depends on solar activity, and it is most evident at solar maximum, when the low energy cosmic ray flux it at a minimum. Furthermore, the solar modulation effects depend on the cosmic rays sign-of-charge and on the positive or negative phase of the sun and it is due to gradient, curvature and neutral sheet drift effects. These mostly affect low mass particles such electrons and positrons and are important mainly during solar minimum conditions. In the positive phase of the sun, that is when the mechanical rotation axis of the sun and the sun magnetic dipole have the same versus, positive charges experiment a lower solar modulation than the negative ones. In the negative phase are the negative particles to be less affected. This is clearly shown in figure 15, in which la difference in the positron to electron fraction between the PAMELA data, collected in the negative phase of the sun, and the other ones, acquired by different experiments in the positive phase of the sun, appears to agree with this theoretical interpretation. As regards to antiproton to proton ratio, shown in figure 14, the low energy data of the BESS experiments, detected by balloon flights in different tilt angles, that is the angle between the rotation axis of the sun and its magnetic dipole, and in the both solar phases, reveal a more complex behaviour compared to the positron to electron ratio. This disparity is due to the different energy spectra of protons respect to antiproton and to the large difference in mass compared to the electrons. According with Clem and al. [53] and Bieber *et al.* [54] these effects are due to two systematic deviations from reflection symmetry of the interplanetary magnetic field:

1) The Parker field has opposite magnetic polarity above and below the equator, but the spiral field lines themselves are mirror images of each other. This antisymmetry produces drift velocity fields that for positive particles converge on the heliospheric equator in the positive state or diverge from it in negative state. Negatively charged particles behave in the opposite manner and the drift patterns interchange when the solar polarity diverge.
2) Systematic ordering of turbulent helicity can cause diffusion coefficients to depend directly on charge sign and polarity state.

V. Conclusion

The high quality cosmic rays data achieved in these last years in a very wide range of energies by balloon-borne and satellite experiments show a good agreement on the all-particle spectra. The spectra of the chemical species do not show major differences in the slope. Furthermore these direct measurements are approaching the energy region around the knee This goal could be reached by the planned new long duration flights of the TRACER and CREAM collaborations, allowing a cross calibration with the results from the on ground based experiments. New measurements on the secondary to primary ratio for different nuclei performed by CREAM, TRACER and PAMELA will allow for a better estimation of the lifetime of the cosmic rays in the galaxy. Data from PAMELA on the antiproton to proton ratio significantly constrain contribution from exotic. Solar modulation effects are also studied by BESS and PAMELA .

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