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Direct Measurements, Acceleration and Propagation of Cosmic Rays

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Abstract. This paper summarizes highlights of the OG1 session of the 30th International Cosmic Ray Conference, held in Merida (Yucatan, Mexico). The subsessions (OG1.1, OG1.2, OG1.3, OG1.4 and OG1.5) summarized here were mainly devoted to direct measurements, acceleration and propagation of cosmic rays.

Introduction

The OG1 session was splitted in 5 subsessions, devoted to direct measurements of cosmic rays by balloons and satellites (OG1.1), cosmic ray composition (OG1.2), cosmic ray propagation (OG1.3), cosmic ray acceleration (OG1.4) and intrumentations and new projects (OG1.5). The number of papers discussed in the OG1 session gives a feeling of the huge number of results presented during the conference: there were 138 papers presented (66 of which were oral presentations). About 37 of the oral presentations reported on observational results, while about 29 reported on theoretical or phenomenological work. It is obvious that a meaningful summary of this work implies a selection of highlights. An apology is due to all those that will not see their work properly discussed here. It should also be understood that in order to avoid doing a simple list of the results it is needed to put things in context, and this often requires weighing the results according to the opinions of the writer, which do not coincide necessarily with the opinions of the Community at large. I hope that this may be a starting point for further discussion on the topics that I will touch upon below.

The origin of cosmic rays is a problem that has been haunting scientists for almost one century now. Solving this scientific problem means putting together numerous pieces of a complex puzzle, in which the acceleration processes, the inner dynamics of the sources, the propagation, the chemical composition all fit together to provide a satisfactory and self-consistent global picture. We are not there yet, though an increasingly larger number of pieces are finding their place in the puzzle. The International Cosmic Ray Conference is a privileged place to observe the puzzle taking shape.

This rapporteur paper is organized as follows: in §2 I present a subjective bird's eye view of how things stand in the field, in order to make it easier for the reader to put in the right context the extremely wide range of results presented at the Conference. In §3 I summarize some important observational results about spectra and chemical composition of cosmic rays (including the electronic component) that have been presented. In §4 I illustrate some recent developments in the understanding of the acceleration of cosmic rays. In §5 I discuss the problem of relating the observed cosmic rays to the sources through propagation in the Galaxy. The transition from the galactic component to the extragalactic cosmic ray component is briefly discussed in §6 together with some issues related to the propagation of ultra high energy cosmic rays in the Galaxy and in the intergalactic medium. I conclude in §7.

A bird's eye view on cosmic rays

The best known property of cosmic rays is their all-particle spectrum. Most experiments agree, at least qualitatively, that the spectrum consists of four regions: 1) at low energies (below ~ 10 GeV) the observed spectrum is flat as it is affected by solar modulation. 2) For energies $10\text{GeV} \leq \text{E} \leq 3 \times 10^{15}\text{eV}$, the spectrum can be fit with a power law with slope ~ 2.7. 3) At energies between $3 \times 10^{15}\text{GeV}$ and $\sim 10^{18}\text{eV}$ the slope grows to ~ 3.1. 4) The upper boundary of region 3 is not well defined, so I will take some liberties in defining region 4. In terms of Physics this reflects our uncertainties in defining the region of transition to extragalactic cosmic rays (see §6).

The chemical composition of cosmic rays is a crucial piece of information and is becoming well determined at energies below the knee, where direct measurements can still be carried out, while it is more uncertain and model dependent at higher energies. The composition of low energy cosmic rays provides important hints to the acceleration processes and the propagation of cosmic rays through the interstellar medium (ISM). Especially important in this respect are the abundances and spectra of elements such as Boron, Beryllium and Lithium, which are mainly produced as secondaries of primary cosmic rays. The ratio of secondary to primary (for instance B/C) cosmic ray fluxes provides a unique tool to characterize the diffusion properties of the ISM. Existing measurements of this ratio as a function of energy suggest that the diffusion coefficient scales with energy as $D(E) \propto E^{\alpha}$, with $\alpha \approx 0.6$, at least at rigidities below ~ 10 GV, while it is not clear whether at higher energies the slope remains constant or there is a flattening.

Elements such as Ge and Ga can potentially allow us to discriminate between volatility based and first ionization potential based acceleration processes, and therefore provide information about the dominant acceleration sites. Other elements (e.g. ^{59}Co and ^{59}Ni) also provide us with precious information on the mean time between the production of the material which is accelerated and the actual time when it is accelerated to cosmic ray energies.

Current direct measurements are filling the gap to the knee region, thereby providing a way to match and cross-check the indirect measurements of spectrum and composition carried out by observing and modelling extensive air showers at energies across and above the knee. The data collected by the KASCADE experiment suggest that the knee in the all-particle spectrum may be an artifact of the superposition of sharper knees in the single components, mainly in the light chemicals, such as H and He. The proton spectrum measured by KASCADE has a pronounced knee at energy $\sim 10^{6}$ GeV. A knee in the He component is also seen, but the fluxes become more uncertain while moving to larger masses. It is not known as yet what could be the explanation for the knees in these components, though it is plausible that they may reflect inefficiency of the accelerator. In a strictly rigidity-dependent approach, a knee in the iron spectrum could be expected at $\sim 3 \times 10^{7}$ GeV. This simple argument opens the way to an equally simple but far reaching implication: the spectrum of Galactic cosmic rays should end at energies around $\sim 10^{17}$ eV, so that cosmic rays of larger energies must be accelerated in extragalactic sources. Unfortunately the KASCADE results are not fully consistent with those of some other experiments, especially the Tibet array. The main difficulty of all ground based experiments, including those operating in the ultra high energy range, is the poor understanding of cosmic ray interactions in the atmosphere, which may be very problematic to infer basic information as the chemical composition of the primary particles.

Three sets of measurements will help us figure out whether the physical picture suggested by the KASCADE data is correct (assuming that the data themselves find proper confirmation): 1) direct measurements of the cosmic ray spectra and chemical composition should extend as far as possible towards the knee and possibly across it; 2) additional data and reliable models for the description of the shower developments (possibly checked versus future LHC data) are crucial at energies around and above the knee; 3) the chemical composition in the energy region between 10^{17} eV and 10^{19} eV needs to be measured reliably.

Fortunately, important steps ahead in all these directions are being done and some important results will be discussed below.

What about the sources? The paradigm based on supernova remnants (SNRs) as the main sources of galactic cosmic rays remains the most plausible, but the smoking gun that would turn the paradigm into a well established theory is still missing. The most important news in this direction is represented by the recent observations of SNRs in gamma rays by Cherenkov imaging telescopes (see [1] and references therein for a recent review) and the high resolution observations of the X-ray emission from the rims of several SNRs (see [2] and references therein for a recent review). The former have presented us with some evidences of TeV gamma ray emission, possibly of hadronic origin. The latter have provided us with strong evidence of efficient magnetic field amplification, which is in turn required in order to reach the high energies observed in cosmic rays, and are a consequence of efficient cosmic ray acceleration. From the theoretical point of view, there have been several new developments in our understanding of the mechanism of diffusive shock acceleration in SNRs but also related to the propagation of cosmic rays both in the Galaxy and in the intergalactic medium. I will discuss some of these issues in more detail below.

New Measurements

The direct measurements of the flux of cosmic rays and of their chemical composition, carried out by using balloons and satellites, has always played a crucial role in advancing our understanding of both acceleration and propagation of cosmic rays, at least at energies below the knee. At higher energies the low fluxes due to the steeply falling spectrum make it necessary to use ground arrays which observe cosmic ray induced air showers. The two techniques are clearly complementary and one of the biggest problems has always been to cross-calibrate the two. For the first time this goal seems to be at least in sight, in that the direct measurements are extending to $\sim 10-100$ TeV, therefore approaching the knee region. Numerous new results on spectra of different chemical elements have been presented, from balloon flights (CREAM, ATIC, Tracer, TIGER, Bess-Polar, PPB-BETS), from satellites (preliminary results from PAMELA) and even some shower experiments (Tibet Array and HESS). The overlap between all these techniques in the energy region around the knee appears to be of crucial importance, especially to unveil the origin of the knee in the cosmic ray spectrum.

Balloons and Satellites

The CREAM Collaboration has presented impressive results collected during a total of 70 days of flight of their balloon experiment. The data were collected during the record breaking CREAM-I flight (42 days between 12/16/05 and 01/27/05) and a second flight (CREAM-II) lasted 28 days (between 12/16/05 and 01/13/06). Convincing evidence was presented of the excellent charge resolution of the experiment ($\Delta q \sim 0.2$ electron charge), precious tool to reconstruct the spectra of different chemicals (see [4, 5] for a technical discussion).

In Fig. 1 I reproduce the plots as shown by [3] (see also [6]) illustrating the spectra of protons and helium nuclei as measured by CREAM-I (red circles). The CREAM spectra are compared with those of other experiments as listed in the figure with different symbols. The spectrum of He nuclei as measured by CREAM is compatible with that measured by ATIC-2, but appears to be somewhat flatter than that measured by ATIC-1.

The spectra of Carbon and Oxygen measured by CREAM-II were presented by [7] and [8]. The results on the C/O ratio confirm the primary nature of both nuclear species [9]. An overview of the CREAM results and future developments (a third and fourth flight) were presented by [3]. The spectra of the chemicals presented by the CREAM collaboration do not show appreciable differences in the slope, with the possible exception of the helium spectrum that might be slightly harder than the proton spectrum. In fact this trend is probably present even in the ATIC-2 spectrum. In Fig. 1 the shaded area is supposed to show the range of fluxes as measured by ground arrays. The width of the shaded region provides an estimate of the uncertainties due to either the interaction models adopted for the analysis or systematics in the different experiments. An important point that this figure shows is that finally direct and indirect measurements are starting to overlap in the knee region. This will be of great importance to understand the reason for the appearance of the knee in the all-particle cosmic ray spectrum.

The ATIC balloon experiment has presented impressive results on the B/C ratio and mass com-

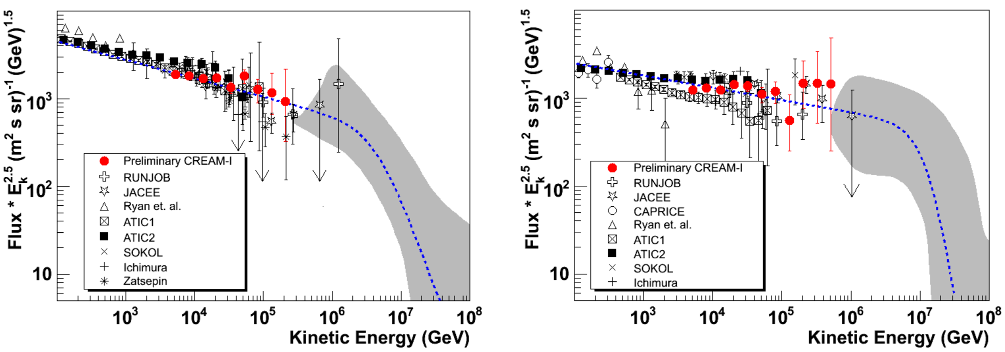

Fig. 1. Spectra of protons (left panel) and helium nuclei (right panel) as measured by CREAM-I (figure from [3]) compared with the results of other experiments.

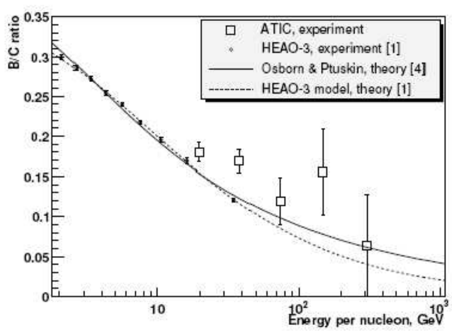

Fig. 2. B/C ratio as a function of energy per nucleon as measured by ATIC-2 (squares) [11] and compared with the results of HEAO-3 and the predictions of two theoretical models (lines).

position of cosmic rays below the knee. In fact the ratios N/O and C/O were also measured. The B/C ratio, as I discuss in §5, is a crucial indicator of the mode of cosmic ray propagation in the interstellar medium. Low energy measurements ($E < 30$ GeV) carried out by HEAO-3 [10] show that the B/C ratio scales with rigidity as $\sim R^{-0.6}$, usually interpreted as a proof of the primary (secondary) origin of Carbon (Boron) nuclei.

The ratio as measured by ATIC-2 is reported in Fig. 2 [11] together with the previous results of HEAO-3 and the predictions of two theoretical models (lines) (see [11] for some discussion and references). Despite the apparent flattening of the measured B/C ratio in the ATIC data, the error bars are still too large to infer solid conclusions on this issue.

The all-particle spectrum and the average mass number as a function of energy as measured by ATIC-1 are shown in Fig. 3 [12] compared with the results of other experiments, as indicated in the figure. There is a substantial agreement among all the data sets shown. At least in part the small offsets may be explained in terms of systemaic errors in the energy determination, amplified by the multiplication by $E^{2.5}$.

The mean logarithmic mass number found by ATIC in the energy range $10^2 - 10^5$GeV shows a general trend to a heavier composition and appears to match well with the results of RUNJOB, CASA-BLANCA, DICE and KASCADE in the knee region. At energies above the knee (not reached by ATIC) the other experiments show quite different trends. This prevents us from reaching a satisfactory explanation of the origin of the knee and of the transition from galactic to extragalactic cosmic rays (see §6).

Very accurate measurements of the flux of different chemical elements below the knee were presented by the TRACER Collaboration [13] and are shown in Fig. 4 (filled dots) for nuclei between Oxygen and Iron. The fluxes are multiplied by different normalization factors to make the plot clearer, and they are compared with the results of HEAO-3 and CRN. No appreciable difference between the slopes of the spectra of these nuclei was detected, all slopes being around ~ 2.7.

The TRACER Collaboration also presented the B/C ratio in the energy region around ~ 100 GeV/amu, being fully consistent with other measurements. The predicted error bars on the B/C

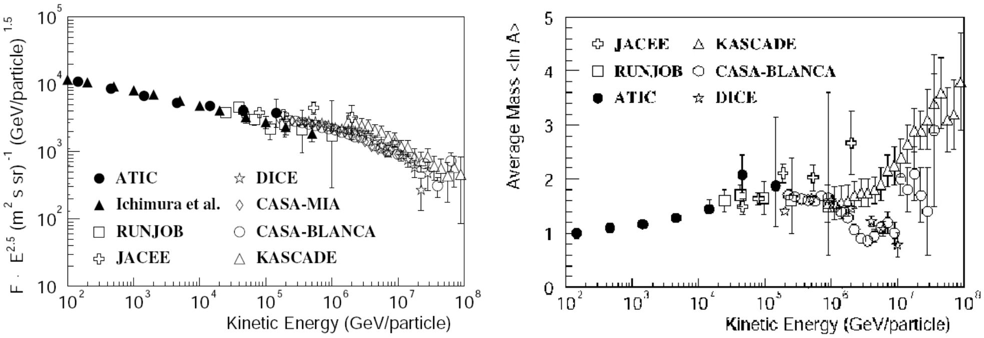

Fig. 3. All particle spectrum (left panel) and mean logarithmic mass number (right panel) as measured by ATIC [12].

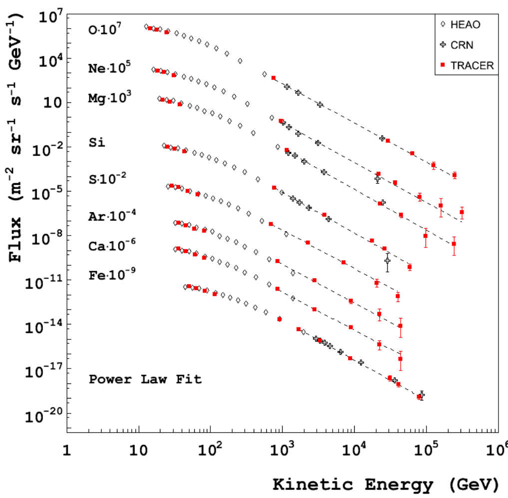

Fig. 4. Differential spectra of chemical elements from Oxygen to Iron as measured by Tracer [13] and compared with previous results from CRN and HEAO-3.

ratio with a 30 days balloon flight of TRACER should allow to finally pin down the slope of the ratio as a function of energy up to ~ 1 TeV/amu. While indicators such as the B/C ratio provide us with important information on the propagation of cosmic rays in the Galaxy, the abundances of super-heavy elements ($Z > 30$) tell us about the acceleration regions, though their flux is more than ~ 1000 times smaller than the Iron flux. The flux of these elements has been measured during two balloon flights by the TIGER Collaboration in 2001 and 2003 (a total of about 50 days of observations). The fluxes in the energy region between 0.3 and 10 GeV/nucleon are reported in Fig. 5 (from [14]). The lines represent the predictions of two models for acceleration, one based on first ionization potential (FIP) and the second on volatility, but both with a standard solar system composition of the ambient medium. The abundances of ^{31}Ga and ^{32}Ge appear to be inconsistent (if taken at the same time) with both theoretical models. One should however recall that a standard solar system composition near the accelerator is all but granted.

Important information on the origin of cosmic rays and their propagation can also be indirectly gathered by observing electrons. Their propagation in the Galaxy is affected by diffusion, as for ions, and energy losses (mainly synchrotron and inverse Compton scattering losses). At energies larger than 20-100 GeV the loss time due to ICS and synchrotron becomes shorter than the diffusive escape time from the Galaxy, so that the spectrum steepens by one power compared with the source spectrum. At energies larger than ~ 1 TeV the flux of electrons at Earth is expected (and observed) to decline, presumably as a result of the discreteness in the spatial distribution of the sources. In this sense several groups have been engaged in a search for a possible signal of the closest sources of electrons around the solar system, the most promising sources being Vela, the cygnus loop and Monogem. The expected signal would consist of a bump in the diffuse flux of electrons at energies in excess of ~ 1 TeV. The proximity of the source would also result in a small anisotropy in the arrival directions. The spectrum and anisotropies have been presented by PPB-BETS.

To date, the spectrum [15] (Fig. 6) does not show evidence for the possible appearance of a

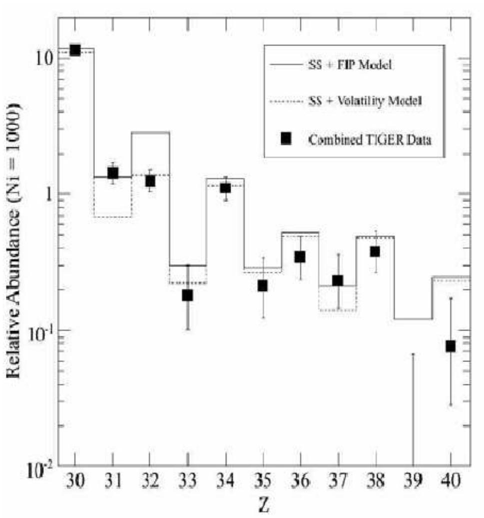

Fig. 5. Relative abundances of heavy elements as observed by the TIGER experiment [14].

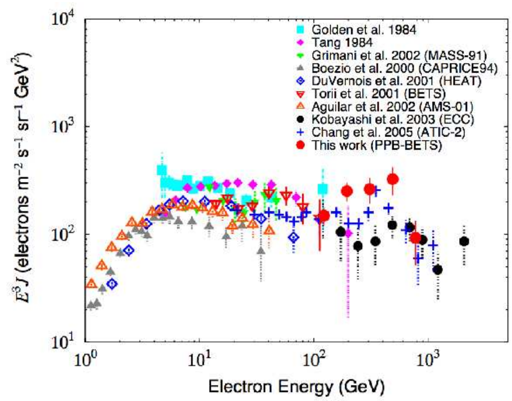

Fig. 6. Spectrum of electrons (multiplied by E^3) as observed by PPB-BETS [15] compared with the results of previous measurements.

nearby electron source. Even the anisotropy is claimed to be fully consistent with an isotropic distribution of arrival directions [15]. The BESS-Polar experiment has presented several interesting results, ranging from low energy cosmic ray spectra to spectra of antiprotons and limits to the flux of anti-helium nuclei. The flux of cosmic ray protons in the energy region below $\sim 10 - 30$ GeV is heavily affected by solar modulation. In Fig. 7 I report the results presented by [16]: the thick dots are the recent results of BESS-Polar, compared with those of BESS-1997 (open circles), at the time of the solar minimum. It is evident the effect of the enhanced solar modulation while the sun gradually approaches the next solar minimum. The upper solid line represents the spectrum of protons in the interstellar medium as inferred from BESS-98 measurements.

The propagation of cosmic ray nuclei in the interstellar medium also results in the production of many secondary products (nuclei, antiprotons, electron-positron pairs, gamma rays, neutrinos). Accurate measurements of these secondaries, especially antiprotons and positrons is instrumental to the search for faint signals, such as those coming from the annihilation of non-baryonic dark matter. The flux of anti-protons and the ratio of antiprotons to protons in the energy region below few GeV as measured by BESS-Polar is reported in Fig. 8. In the left panel, the antiproton spectrum is compared with some theoretical predictions of the same quantities for some models (solid line: propagation with GALPROP; dotted line: standard leaky box with solar modulation; dash-dotted line: black hole evaporation). In the right panel, the ratio antiproton/proton flux is compared with predictions of a drift model with different tilt angles of the solar magnetic field. The thick dots and empty circles refer again to BESS-Polar and BESS-1997 respectively. In the right panel the effect of a different solar modulation in the two periods is evident again. As expected, this effect almost completely disappears in the ratio of the antiproton/proton flux. The fluxes of antiprotons observed by BESS-1997 and BESS-Polar are both fully consistent with the one expected on the basis of a propagation model with solar modulation, thereby implying significant upper limits to the flux of antiprotons from, for instance, neutralino annihilation in the Galactic dark matter halo.

BESS has also focused on the detection of antinuclei. The quest for why our universe is (almost) completely made of matter instead of a mixture of matter and anti-matter is a fundamental one, as Nature is expected to have produced a (almost) symmetrical universe. Though it is likely that the small excess of matter over anti-matter is what now makes most of the present universe, the search for islands of antimatter or traces of anti-nuclei has never quite finished. The limit imposed by BESS-

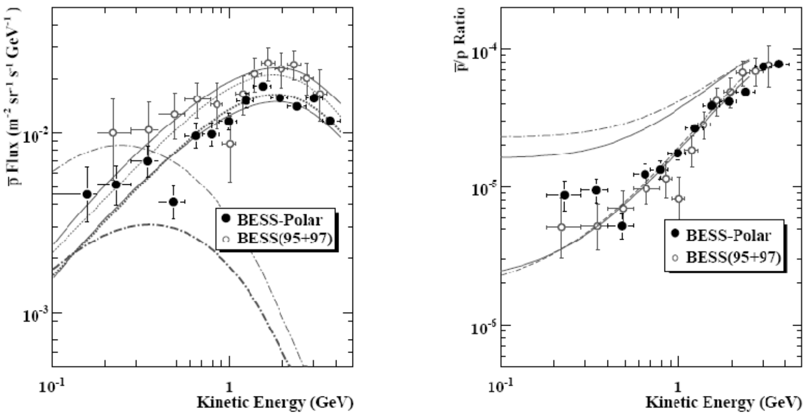

Fig. 8. Left Panel: Antiproton spectrum measured in BESS-Polar compared with BESS(95+97) results. The lines illustrate predictions of different theoretical scenarios. The lines that pass through the data points are the predictions of standard propagation calculations (GALPROP and leaky box models). Right Panel: $\bar{p}/p$ ratio measured by BESS(95+97) and BESS-Polar I (2004) compared with drift model calculations at various Solar magnetic field tilt angles.

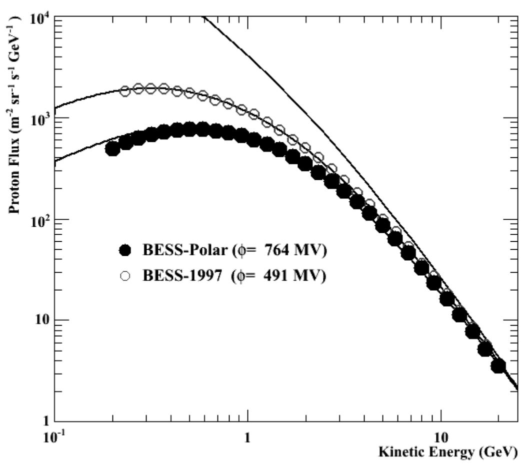

Fig. 7. Spectrum of protons as observed by BESS-1997 (empty circles) and BESS-Polar (filled circles) [16]. The difference between the two spectra is due to the different levels of solar modulation at the time of the measurements.

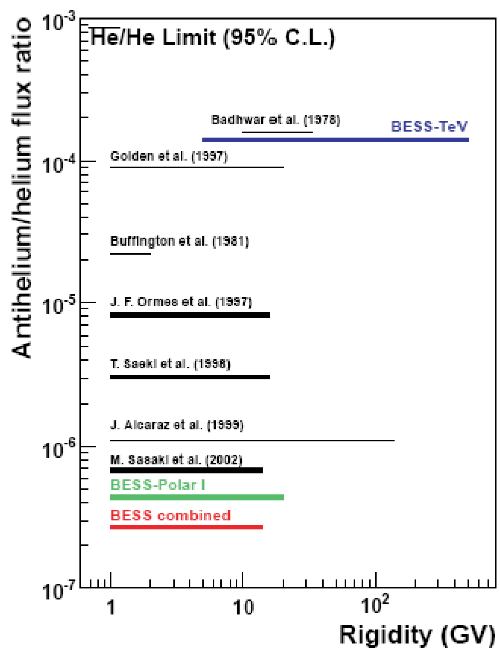

Fig. 9. Limits on the flux of anti-Helium obtained by BESS-Polar [16].

Polar and the limit that will possibly be reached by the next BESS flight are shown in Fig. 9, together with the results of previous measurements.

The measurement of the cosmic ray spectrum and chemical composition up to energies of ~ 1 TeV, the search for dark matter, anti-matter and exotic particles, and finally bits of solar and magnetospheric physics are among the goals of the PAMELA satellite, which has been succesfully launched on june 15, 2006. The instruments onboard are collecting data, but only preliminary results were presented at the conference. A review of PAMELA preliminary results and expectations has been presented in [17]. Particularly interesting, and suggestive of the quality of the results that we should expect, is the spectrum of protons and helium, reported in Fig. 10.

This preliminary analysis does not show evidence for any difference in the slopes of the spectra of H and He in the energy region below ~ 500 GeV. In both cases the best fit power law has a slope of 2.73.

Several simulated results were also presented by the PAMELA Collaboration, mainly aimed at showing the potential for discovery of indirect signals of dark matter annihilation (in the form of anomalous features in the antiproton and positron spectra), and the limits achievable in the search for anti-matter. The limit on the ratio $\bar{H}e/He$ is expected to improve by about 1 order of magnitude in about three years of PAMELA operation with respect to that achieved by BESS-Polar (see Fig. 9).

PAMELA is expected to play a crucial role in the identification of spectral features in the positron and antiproton spectra as they can possibly result from dark matter annihilation, provided the mass of the dark matter candidate particle is in the right energy range (below $500 - 1000$ GeV).

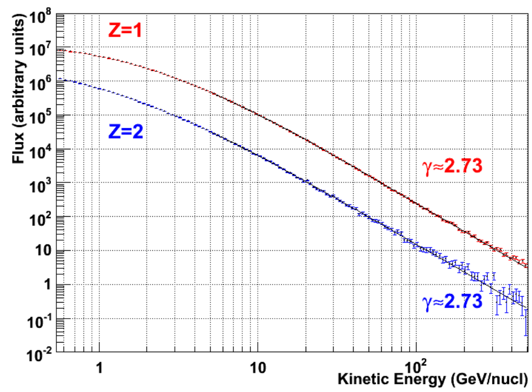

Fig. 10. Preliminary spectra of protons and helium from PAMELA.

Ground Experiments

Since most results from ground experiments were presented in other sessions of the ICRC, the talks on this subject in the OG1 session were sparse.

The HESS Collaboration has presented the results of a very interesting detection of the direct Cherenkov (DC) light from cosmic rays impacting the atmosphere. This technique, proposed as a possible tool to measure the chemical composition of cosmic rays above 10 TeV by [18], has been used by HESS to measure the flux of heavy nuclei (Fe-like). The direct Cherenkov light is produced by the primary nucleus while entering the atmosphere and before the first interaction that generates the shower. High up in the atmosphere the density of air is lower and therefore the Cherenkov cone is more collimated with respect to the Cherenkov cone of the light generated by lower energy particles in the shower. As a result the total Cherenkov emission from a shower is expected to have a broad region with a *hot* pixel corresponding to the DC light. This emission has in fact been successfully detected by HESS. Since the intensity of the Cherenkov signal scales with the square of the charge of the parent nucleus, it is best to seach for the signal from Fe nuclei provided the energy does not exceed a few hundred TeV, in order to avoid that the shower emission overshines the DC light. The spectrum of Iron nuclei as measured by HESS is reported in Fig. 11 [19] where it is compared with the results of other experiments. The two sets of data points refer to QGSJET and SIBYLL as interaction models.

The search for the DC light is also being pursued by VERITAS [20], while dedicated instruments are being planned (e.g. TrICE [21]).

The HESS Collaboration has also presented the preliminary results of their measurement of the electron spectrum [22], consistent with measurements carried out by other experiments within the systematic uncertainties.

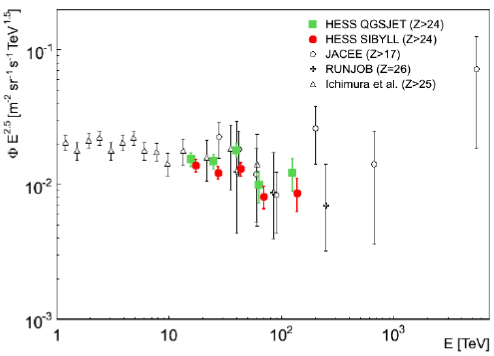

Fig. 11. Spectrum of iron nuclei (in fact nuclei with $Z > 24$ obtained by HESS using the detection of DC light. The HESS results (with SYBILL and QGSJET as models for interactions) are compared with the results of other measurements.

A relevant contribution to the understanding of the nature of the knee in the all-particle spectrum has been provided by Tibet Array. The Collaboration has presented the most recent measurements of the proton and helium spectra in the knee region, and the fraction of heavy nuclei as a function of energy, in the range $10^6 \leq E \leq 10^7$ GeV.

The measurements of the chemical abundances in this energy region are still controversial. The Tibet data on the proton spectrum appear in rough agreement with those of RUNJOB and JACEE (both with QGSJET and SIBYLL as interaction models) but in rather apparent contradiction with the KASCADE data, especially when the KASCADE data are analyzed using SIBYLL. The latter show a steeper spectrum of protons and a somewhat higher normalization of the flux. The discrepancies are even more evident in the case of the helium spectrum. The Tibet results on helium roughly match with those of RUNJOB, but not with data from JACEE and KASCADE. The absolute flux of helium as measured by KASCADE is almost one order of magnitude higher than that measured by Tibet Array. The situation in the knee region continues to be confused and this prevents the possibility of unveiling the origin of the knee.

Acceleration of Cosmic Rays

The main mechanism for the acceleration of cosmic rays (not only galactic) remains diffusive particle acceleration at shocks. Many contributions presented at the conference have focused on the determination of the efficiency of particle acceleration, the dynamical effect of the accelerated particles and the magnetic field amplification generated by the accelerated particles through streaming instability or due to turbulent amplification.

I will start by discussing some issues related to the acceleration of Galactic cosmic rays in SNRs, though some of the conclusions will be of wider applicability.

One of the most recent advancements in the theory of particle acceleration at non-relativistic shocks, especially for SNR shocks, has been the calculation of the dynamical reaction of the accelerated particles onto the background plasma. The effect has been discussed already in the 80's in the context of two-fluid models (see [23] for a review), and later addressed numerically by direct solution of the time dependent equation of diffusive tranport coupled with the equations of mass, momentum and energy conservation of the background plasma (see for instance [24]). In the late 90's a stationary semi-analytical solution of this set of equations was found in the form of an integral equation [25] for a spatially constant diffusion coefficient. A general semi-analytical method was recently proposed by [26], valid for any choice of the diffusion coefficient.

The structure of the shock is changed by the accelerated particles due to the pressure they exert on the background plasma, though in a collisionless manner. For ordinary diffusion coefficients, which are increasing functions of particle momentum, higher energy particles can travel further away than low energy particles: a fluid element approaching the shock surface therefore *feels* an increasing pressure due to accelerated particles and as a consequence it slows down. This leads to the formation of a *precursor* upstream of the shock (which is now called *subshock*) in which the fluid velocity, as seen in the (sub)shock reference frame decreases while approaching the shock. The effective compression factor *felt* by particles crossing the shock and precursor is now a function of momentum, being bigger at large momenta and smaller at low momenta. The immediate consequence is that the spectrum of particles accelerated at shocks is not a power law, as expected in test-particle theory, but rather a concave function of momentum, harder at high momenta and softer at low momenta. This nonlinear system is found to self-regulate itself and to be able to reach relatively high efficiency of particle acceleration.

This complex nonlinear system has however additional interesting aspects, concerning the maximum momentum that the particles can be accelerated to. As was recognized first in [27, 28], the maximum momentum achieveable in SNRs is exceedingly low compared with the knee energy unless the diffusion coefficient is Bohm-like and magnetic field amplification takes place. Even in this case the maximum energy falls short of the knee energy by a factor ~ 100, unless the amplification turns strongly nonlinear, namely $\delta B/B \sim 100$. An investigation of the process of particle acceleration at cosmic ray modified shocks with self-generation of strong turbulence was discussed in [29, 30] and presented at this Conference by [31].

The most important clue in this field has however come in the last few years from high resolution X-ray observations of the rims of several SNRs. The thickness of the rims is related to the loss length of high energy electrons radiating X-rays by synchrotron emission. The observed brightness profiles lead to estimates of the downstream magnetic field of the order of a few hundreds μG [32]. These estimates were confirmed and presented here by [33, 34] together with their implications for multifrequency observations of specific SNRs.

These calculations are based on a numerical time-dependent solution of the problem of particle acceleration at modified shocks. The strength of the magnetic field is not self-consistently calculated but rather fit to the observations at a given time (the observation time) and not evolved in time. The calculations of [34] show that the multifrequency data for supernova RXJ1713.7-3946 are explained rather well from radio to X-rays and gamma rays (Fig. 12 from [34]). In particular the gamma ray data from HESS are interpreted as the result of pion production and decay. The magnetic field required for the fit is $126\mu G$, again consistent with the general trend of strong magnetic field amplification observed in other remnants.

The strong magnetic field causes the electron density to be low, thereby reducing the flux of ICS gamma rays. Similar consequences can be inferred for the RX J0852.0-4622 (Vela Jr.) [33]. It is also worth noticing, in Fig. 12 (and others that have been presented for other SNRs) that both the predicted radio-X and gamma ray spectra show a clear indication of a curvature (concavity). This characteristic, as discussed above, is one of the most distinctive consequences of particle acceleration at modified shocks. Signatures like this should be carefully looked for in future, better data at all wavelengths. In particular, future gamma ray observations with GLAST might allow us to confirm or reject the hadronic origin of the gamma ray emission.

Two models have been discussed for the amplified magnetic field observed in several SNRs. Quantitatively they potentially lead to the same level of magnetization, but the principle is different in the two cases.

The traditional explanation is based on streaming instability induced by the accelerated particles. The instability leads to resonant growth of Alfven modes [35] and typically $\delta B/B \sim 20-30$ [29]. By using the results of quasi-linear theory for the growth rates, [31] showed how to determine the diffusion coefficient and implement it in a self-consistent solution of the problem of acceleration at modified shocks. At the beginning of the Sedov phase this type of instability leads to reach approximately proton energies of $\sim 10^6$ GeV, while at later stages of the SNR evolution, the maximum momentum decreases in a way that depends on how the magnetic field amplification drops.

In [36] it was proposed that non resonant modes may grow faster than resonant modes in some circumstances. The analysis of Bell was based on a MHD treatment of the background plasma and the non resonant modes are often considered as strictly related to this assumption. The presentation of [37] has demonstrated that the same dispersion relation is obtained in the context of a purely kinetic approach, if particle acceleration is efficient, as it is expected at cosmic ray modified shocks. The imaginary and real parts of the frequency of the propagating waves are plot-

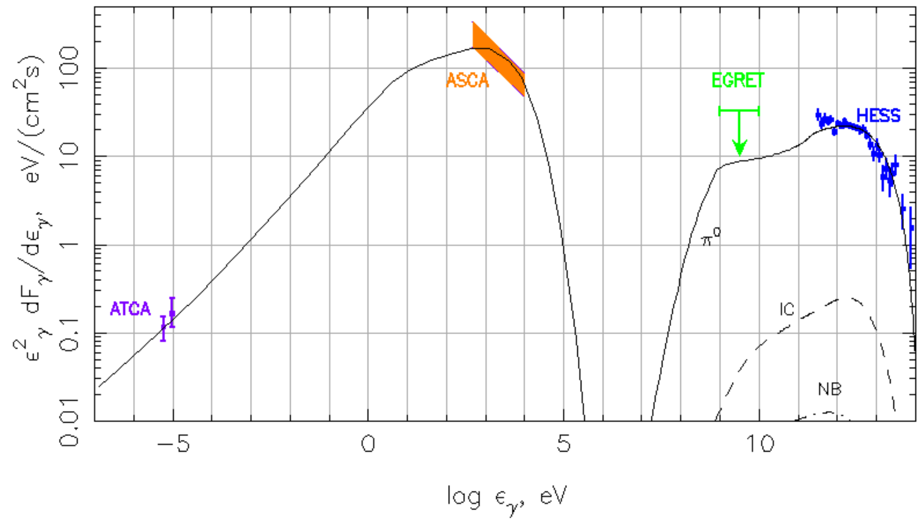

Fig. 12. Multifrequency spectrum of the SNR RXJ1713.7-3946 and the best fit of the calculations of [34].

ted in Fig. 13 in units of $V_s^2/cr_{L,0}$ as a function of the wavenumber k in units of $1/r_{L,0}$. Here $r_{L,0}$ is the Larmor radius of the particles in the background magnetic field and V_s is the shock velocity, taken here as $10^9 \mathrm{cm\ s}^{-1}$. The efficiency in acceleration was assumed to be $\eta \equiv U_{CR}/\rho V_s^2 = 0.1$. The peak of the growth rate if not at $kr_{L,0} \sim 1$ which is again a confirmation that the faster growing modes are non resonant. However the same authors of [37] also showed that the peak moves towards $kr_{L,0} \sim 1$ when either the shock velocity decreases or η decreases. This suggests that at later epoques during the SNR evolution the resonant mode may become dominant.

The search for the non resonant modes found by [36] was also carried out by using Particle-in-Cell (PIC) simulations. The results of such studies were presented by [38]: no evidence was found of the fastly growing *Bell mode* in their simulations. It remains to be seen whether this result is due to the anomalous values of the parameters adopted by the authors (for instance the large density of non thermal particles needed to satisfy the condition of efficient acceleration and the artificial value of the ratio m_e/m_p), or if actually shows that the instability may be suppressed due to some physical mechanism yet to be identified.

It is important to stress that streaming instability generates the magnetic field amplification upstream of the shock front. The turbulent field is then advected downstream and the perpendicular components are compressed at the shock surface.

A second model for the generation of strong field was discussed by [39]: the model is based on the (realistic) assumption that density perturbations $\delta\rho/\rho \sim 1$ are present upstream (see Fig. 14 for a schematic view). The density perturbations induce corrugations in the shock structure which in turn produce turbulent eddies that twist the field lines frozen in the plasma leading to magnetic field amplification. The numerical simulations that the authors illustrated show that $\delta B/B \sim M_A$, where M_A is the Alfven Mach number. In conditions which are typical of SNRs one may easily expect $\delta B/B \sim 100 - 1000$ downstream of the shock.

The effects of such amplified magnetic field on the acceleration of particles need some further discussion: if the field in the upstream region is mainly parallel to the shock normal, and there is no streaming instability (as assumed in [39]) then the acceleration process is inefficient, being weakly affected by the downstream strong fields alone. In fact the acceleration time is the sum of the diffusion times upstream and downstream. If the field is

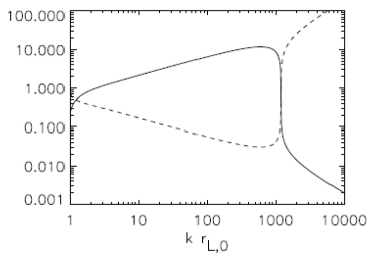

Fig. 13. Real and Imaginary part of the frequency of the waves excited by the streaming of cosmic rays at a shock with velocity 10^9cm s^{-1} and efficiency of particle acceleration $\eta = 0.1$. For these parameters the peak of the growth rate occurs at $kr_L \gg 1$, showing the non resonant nature of the instability [37].

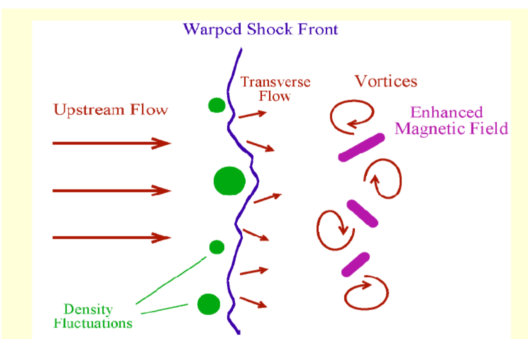

Fig. 14. Schematic view of the turbulent magnetic field amplification scenario proposed by [39].

only amplified downstream, the acceleration time is dominated by the upstream region, and it remains too long to lead to efficient acceleration. The problem can be avoided by assuming that the shock is perpendicular. In this case the upstream acceleration time is substantially shorter because the perpendicular diffusion coefficient is smaller than the parallel one [40], thereby mimicking amplification of the magnetic field from the point of view of acceleration. For perpendicular shocks the amplification by streaming instability is expected to be suppressed, therefore the two mechanisms could be considered as complementary and might take place together though with different efficiencies as related to the relative orientation of the shock normal and the ambient magnetic field.

Efficient particle acceleration at SNR shocks modified by the dynamical reaction of cosmic rays, together with the amplification of the magnetic field provide a consistent picture of the origin of cosmic rays: protons in the SNR environment can be accelerated to $\sim 10^6$ GeV, while elements with higher charge (Z) may be accelerated to energies which are Z times larger. The maximum energies are reached at the beginning of the Sedov phase while at later stages the maximum energy decreases, mainly because the magnetic field amplification is less efficient (at least for amplification due to streaming instability). The spectrum of cosmic rays observed at the Earth is the superposition of the cosmic rays trapped behind the shock and released after adiabatic decompression and the particles which may leave the system from upstream due to lack of confinement in the accelerator.

The calculations presented by [41] represent the first attempt to convolve the results from particle acceleration with given diffusion properties of the interstellar medium to determine the all-particle spectrum of Galactic cosmic rays. Good agreement with data is obtained after summing over all chemical elements, though there are numerous parameters that can be tuned to obtain the fit. The most important point is however that the end of the Galactic spectrum is expected to be at energies around a few 10^{17} eV. I will discuss this point in more detail in §6.

Our understanding of cosmic ray acceleration at SNR shocks has certainly improved considerably in the last few years, as also shown by the impressive quality of the fits to multifrequency observations of SNRs from radio to gamma ray wavelengths. However, it may be useful to briefly discuss some aspects of the problem that are not so well understood and that are nevertheless crucial to explain observations and to have a consistent picture of the origin of cosmic rays. I will limit myself to mentioning three of such aspects.

1. A general trend of the non linear theories of particles acceleration at modified shocks is to lead to very large total compression factors, incompatible with the values (~ 7) which provide a good fit to data. It is usually believed that this reduction may be attributed to turbulent heating in the precursor [42, 43]. However to date we have no reliable theory of how to treat this phenomenon, initially put forward to avoid magnetic field amplification to $\delta B/B \gg 1$ and currently used also in cases where the amplification is

strongly non linear. One can adopt recipes that qualitatively work, but do not ensure the correctness of the quantitative results.

2. The flux of particles that may escape the shock region from upstream of a modified shock can be an appreciable fraction of the energy flux. We do not know as yet how to carry out a detailed calculation of this flux, despite the fact that cosmic rays detected at the Earth might be dominated by this component rather than by the ones trapped behind the shock. The spectrum of particles that escape a SNR at each time during the Sedov phase is expected to be very peaked at energies around the maximum momentum achievable at that specific time. As proposed by [44] the observed flux might be due to an overlap of these peaked spectra integrated on the SNR evolution.

3. As discussed above, the crucial element which makes cosmic ray acceleration possible in SNR shocks is the magnetic field amplification. If this process does not take place, SNRs can hardly be the sources of Galactic cosmic rays. The amplification may however take place in different ways (resonant and non resonant streaming instability, firehose instability, turbulent amplification, and possibly others). Each amplification process leads to a different saturation level and different scaling laws with the age of the SNR. More specifically, at different times in the SNR evolution, different amplification processes may operate. This makes the calculation of the actual spectrum of CRs from SNRs highly non trivial.

It is remarkable that all the work done and presented at the Conference on shock modification and its phenomenological consequences was mainly concentrated upon non relativistic shocks and more specifically SNR shocks.

A paper was presented [45] in which the authors stress the difficulty of accelerating particles at relativistic shocks (in the test particle approximation), which reflects into very steep spectra. This finding adds to the fact, which is becoming increasingly more recognized, that the dependence on ambient conditions is very important for the case of relativistic shocks. For instance, even the simple compression of the perpendicular component of a turbulent magnetic field crossing a shock surface may induce a substantial steepening of the spectrum in the relativistic case (see also [46]), while being unimportant for non relativistic shocks.

Propagation of Cosmic Rays

The propagation of cosmic rays in the Galaxy is dominated by diffusion (possibly anisotropic) and advection if there is a wind blowing outwards. Qualitatively it is very easy to illustrate what might be expected. Let us assume that the sources inject cosmic rays into the ISM with a rate $Q_p(E) \propto E^{-\gamma}$, where the index p stays for *primary*. At the *leaky box* level, the equation which describes the stationary density of cosmic rays in the Galaxy is

$$Q_p(E) = \frac{n_p(E)}{\tau(E)},$$

where $\tau(E)$ is the time needed for escaping the Galaxy. If the escape is solely due to diffusion and the diffusion coefficient scales as $D(E) \propto E^{\alpha}$, then $\tau(E) \propto E^{-\alpha}$. It immediately follows that $n_p(E) \propto Q_p(E)\tau(E) \propto E^{-(\alpha+\gamma)}$. During propagation in the ISM secondary nuclei are produced at a rate $Q_s(E) \approx n_p(E)\sigma n_H v(p) \propto E^{-(\alpha+\gamma)}$ (assuming $v(p) \sim c$). It follows, again at the leaky box level of approximation, that the equilibrium density of secondaries is $n_s(E) \approx Q_s(E)\tau(E) \propto E^{-(\alpha+2\gamma)}$. Therefore the ratio of the secondary to primary equilibrium densities is $n_s/n_p \propto E^{-\alpha} \propto 1/D(E)$. This is the case of the B/C ratio discussed in §3: measuring the energy dependence of the B/C ratio we can infer the diffusion coefficient, or more in general the escape time as a function of energy, which scales as $1/D(E)$ if diffusion is the only process responsible for escape while it is somewhat more complex if there are other processes involved (for instance advection in a wind).

As discussed in §3 the most recent measurements of the B/C ratio by CREAM, ATIC and TRACER extended to energies of $100 - 1000$ GeV/nucleon, thereby providing us with a unique opportunity to understand what is the rate of escape of cosmic rays as a function of energy right below the knee. It is worth recalling that the data points with small error bars at energies smaller than ~ 30 GeV/nucleon (see Fig. 2) return a slope of the B/C ratio ~ 0.6. The higher energy data presented by the three Collaborations have too large error bars so far to understand if such a slope remains unchanged. On the other hand one should recall that if indeed cosmic rays escaped from the Galaxy proportionally to $E^{-0.6}$, and normalizing the escaping time in the 10 GeV/nucleon region, one would infer a too large anisotropy of cosmic rays around the knee [47]. It is therefore likely that somewhere below the knee the behaviour of the escape time with energy changes to a flatter behaviour. On the other hand, if this transition exists then one should expect the appearance of a feature in the all-particle spectrum, which does not seem to be there. The problem remains open.

The importance played by diffusion in the investigation of the origin of cosmic rays is also clear from the wealth of presentations at the Conference, concerning different ways to treat diffusion. The standard way to describe diffusion of cosmic rays in the Galaxy has become the GALPROP code, which was used also in the work presented by [48] in order to calculate the elemental abundancies throughout the periodic table. GALPROP is also used to determine spectrum and spatial distribution of the secondary emissions, especially radio and gamma, which provide information on the distribution of magnetic field and gas respectively.

Some *random-walk*-like approaches to diffusive motion have been presented in [49, 50] and then applied for specific purposes such as the calculation of the diffuse galactic gamma ray background or the gamma ray emission from diffuse sources such as the HESS source in the galactic bulge.

The simple arguments reproduced above, which illustrate the basic aspects of the leaky box approaches, are a wild oversimplification of a phenomenon which is in fact very complex. Below I will discuss some of these complications and how to describe at least some of them.

In general, diffusion acts on top of a regular motion of charged particles moving in a large scale magnetic field and is due to a turbulent component δB. In the case of the Galaxy the large scale field has a complex structure, made of spiral arms and a poorly known halo. Diffusion parallel to the background magnetic field is faster than diffusion in the direction perpendicular to the ordered field. The difference between the diffusion coefficients in the two directions (parallel and perpendicular) decreases when the level of turbulent field increases.

The parallel diffusion coefficient can be evaluated in the context of quasi-linear theory provided $\delta B/B \ll 1$. In the non linear regime there is no definite theory for the determination of the diffusion coefficients and numerical simulations become invaluable tools. In the weakly non linear regime analyical techinques can still be applied and lead to rather unexpected results: for instance a similar theoretical approach presented by [51] and consisting of a weakly non linear approach to parallel diffusion, results in a scaling of the parallel diffusion coefficient with energy as $D_{\parallel} \propto E^{0.6}$ despite the fact that the spectrum of turbulence is Kolmogorov-like. This might have an important impact on the interpretation of the observed slope in the B/C ratio, though this slope would still remain incompatible with the observed anisotropy of cosmic rays at the knee.

For typical magnetic fields of few μG, as in the Galaxy, numerical simulations can be used to derive the propagation properties of cosmic rays down to energies of $10^{14} - 10^{15}$ eV. The results of one such investigation were presented by [52] and revealed several interesting new aspects of the problem. The simulation consists of propagating a large sample of charged particles and determine their escape time from *toy models* of the magnetic field of the Galaxy. At the same time, in order to better understand and interpret the results the authors also calculate the diffusion coefficients (parallel and perpendicular to the direction of the regular magnetic field).

The simulations cover the range of turbulence strength $0.5 \leq \delta B/B \leq 2$ always assumed to be distributed according with a Kolmogorov spectrum, $\delta B(k)^2 \propto k^{-5/3}$. The authors find that the energy dependence of the perpendicular and parallel diffusion coefficients is different: $D_{\perp} \propto E^{\alpha}$, with $\alpha \approx 0.5 - 0.6$ and $D_{\parallel} \propto E^{1/3}$ (basically the same slope obtained from quasi-linear theory despite the non linearity).

The results of the calculations of the escape times from the Galaxy clearly illustrate the diffuculty of the problem. The authors investigated several toy geometries of the regular magnetic field of the Galaxy, starting with a purely azimuthal field, from which particle escape can only take place through diffusion perpendicular to the field (and therefore to the disc). Even in this simple case, the escape time is affected not only by (perpendicular) diffusion, but also by drifts induced by gradients in the regular field. The gradients may be simply the ones associated with the curvature of field lines but could also be due to gradients along the radial direction in the disc, and along the z-axis perpendicular to the disc. The full set of results are discussed in [52, 53].

In Fig. 15 I reproduce the escape times (top panel) and the grammage traversed by cosmic rays (bottom panel) as presented by [52] for the simple case of a purely azimuthal regular field. A few interesting results are apparent: first, the escape time obtained with all values of $\delta B/B$ have a slope ~ 0.6, consistent with the fact that the escape time in this field configuration is $\propto H^2/D_\perp$, where H is the thickness of the magnetized halo. Second, at $E \sim 10^{17}$ eV the escape time is appreciably affected by the drift induced by the curvature of the regular magnetic field lines (solid line). Third, the grammage inferred from the simulation is of order $0.5 - 3\text{g cm}^{-2}$ at 10^{15} eV. If extrapolated to 10 GeV with a slope 0.6 this would lead to exceedingly large grammage (or equivalently too long escape times) in the energy region where this parameter can be inferred from B/C ratio and is $\sim 20g\ cm^{-2}$. A similar problem, though at higher energies, was previously found by [54]. Many other cases discussed by the authors confirm the generality of these few conclusions and show that the problem of propagation has still many aspects which are poorly understood and can hardly be included in phenomenological approaches including simple ones such as the leaky box models or more complex ones such as GALPROP. The propagation of ultra-high energy cosmic rays in the intergalactic space is in a way simpler to describe, though a major source of uncertainties is due to our ignorance of the magnetic field (strength and topology) possibly existing between the sources and our Galaxy. An appreciable intergalactic magnetic field can affect both the spectrum and the anisotropy of cosmic rays. While the overall

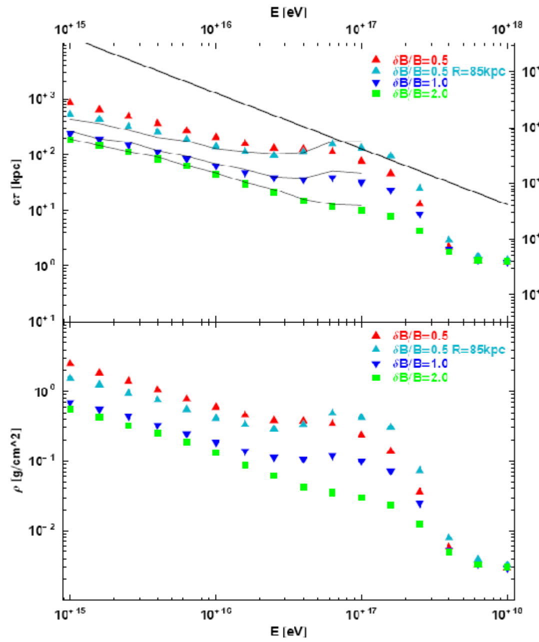

Fig. 15. Escape times (top panel) and grammage (bottom panel) for cosmic rays propagating in a toy model of the Galaxy [52].

shape of the spectrum is left almost unchanged, because of the universality shown by [55], some features may appear in the observed spectrum because of the so-called magnetic horizon [56, 57]: at the lowest end of the cosmic ray spectrum, the propagation time from the nearest source may exceed the age of the universe thereby suppressing the flux of cosmic rays. For magnetic fields of less than ~ 1 nG, this effect typically appears below 10^{18} eV (the details depend on the topology of the field and the diffusion properties of the particles). At higher energies the presence of the magnetic field mainly affects the anisotropy (especially on small scales) in the arrival directions. In fact at energies $\geq 10^{19.6}$ eV the flux received at Earth is expected to come from nearby sources, and the arrival directions to point back to the sources. However there has been a lot of discussion on whether this is actually the case (see for instance [58] and [59] for two rather different results), because of the uncertainties on the strength of the magnetic field. A paper was presented at the Conference [60] in which the propagation in a structured magnetic field was discussed in the assumption that some fraction of the energy in the hydrodynamic flows leading to large scale structure formation is converted to magnetic fields. The authors reach a conclusion which is somewhat in between those of [58] and [59]: only some of the UHECRs should point back to their source. All these results should however be taken with a grain of salt, the uncertainties in the determination of the magnetic field being very large. From the observational point of view, if a correlation was found between arrival directions of UHECRs and a class of sources, this would be the best proof of the weakness of the magnetic fields in the intervening intergalactic medium. It would be harder to conclude one way or the other in case of absence of correlations.

The uncertainties in the galactic magnetic field are also rather disturbing and affect appreciably our ability to obtain realistic results on the propagation of cosmic rays. In [61] the authors proposed to use data on the polarization of the CMB photons to infer information on the large scale structure of the galactic magnetic field. Such a goal would certainly justify the effort.

Where do Cosmic Rays become extragalactic?

The theoretical arguments illustrated in §4 suggest that if cosmic rays are accelerated in SNR shocks then the maximum energy of nuclei of charge Z should be $\sim Z \times 10^{15}$ eV. This conclusion is based on the evidences for magnetic field amplification at SNR shocks, as inferred from X-ray observations. A similar conclusion could however be reached based on direct observation of the proton spectrum by the KASCADE experiment. The proton spectrum as measured by the Tibet-Array experiment at energies above the knee is harder than that measured by KASCADE, but the two agree on the fact that at $\sim 10^{15}$ eV there is a softening of the proton spectrum. Moreover, both agree, at least qualitatively, on the fact that the chemical composition becomes heavier above the knee in the all-particle spectrum.

On the observational side this situation suggests that future accurate measurements of the chemical composition at energies above the knee will be crucial to solve the problem of the origin of cosmic rays. From the theoretical side, the most striking conclusion is that the galactic component of cosmic rays should end at around $\sim \mathrm{a\ few}\ 10^{17}$ eV and in this energy region be iron dominated. This is in clear contradiction with the traditional ankle model of the transition, which postulates that the transition takes place at $\sim 5 \times 10^{18}$ eV as a result of the intersection of a steep galactic spectrum and a flatter extragalactic (proton dominated) spectrum.

Recently two other models have been proposed, both of which locate the transition region at energies $\sim 10^{17} - 10^{18}$ eV, the *dip model* [62] and the *mixed composition* model [63]. They are described at length in the rapporteur paper on session HE and in the Review paper by V.S. Berezinsky, therefore here I will limit myself to a short description.

In the dip model [64] the extragalactic spectrum is proton dominated (not more than 15% of He nuclei are allowed). The effective injected spectrum at the extragalactic sources is required to be $E^{-\gamma}$ with $\gamma = 2.6 - 2.7$. The dip appears as a feature due to pair production losses of protons on the cosmic microwave background radiation and its location in energy is very well defined and model independent. The shape of the dip is also very weakly dependent upon most parameters, with the exception of the chemical composition of the extragalactic component, as mentioned above. The extragalactic spectrum extends down to lower energies, and at the position of the so-called second knee it is predicted to flatten. This is the region of the transition from a steep galactic to a flatter extragalactic cosmic ray component. The chemical composition in the transition region is predicted to suffer a sharp transition from iron dominated to proton dominated [65], and the transition is completed at energy $\sim 10^{18}$ eV.

In the mixed composition model the extragalactic component corresponds to a flatter injection spectrum $\sim E^{-2.3}$, with a composition which is a mixture of different chemicals with abundances that are roughly comparable with the source compositions inferred for SNRs but with much freedom in this respect. The propagation of these components from the sources to Earth leads to the formation of a complex spectrum that may fit the all particle spectrum fairly well. The transition from galactic to extragalactic cosmic rays in this model is more gradual and is completed at energy $\sim 3 \times 10^{18}$ eV. The chemical composition is expected to vary slowly in the transition region, shifting from iron dominated (at low energies) to gradually lighter towards higher energies.

The main discriminating factor between the two models is the chemical composition in the transition region. Present measurements do not allow to make this discrimination as yet.

In the two models illustrated above, the Galactic cosmic ray component is obtained by subtraction of the predicted extragalactic flux from the measured all particle spectrum. In the presentation by [66] the authors have tried a different approach, namely that of calculating the galactic component by assuming a source spectrum and using GALPROP to descrive propagation in the ISM. The main goal was to show that in general, for both models, the superposition of the galactic and extragalactic components leads to the appearance of strong features in the all-particle spectrum. The authors claim that the features are more evident in the mixed composition scenario. This result should of course be taken as an interesting suggestion to be further investigated. We do not have enough information about the shape of the spectrum of the different chemicals and their maximum energies in order to run GALPROP and obtain results which can be interpreted in a unambiguous way.

Conclusions

The collection of high quality data is the main drive for the field of cosmic ray research. In the very low energy region (below ~ 10 GeV) the accurate measurements of the cosmic ray flux by BESS has, among other things, allowed to achieve an excellent understanding of the effects of solar modulation. At energies below the knee in the all-particle spectrum, several experiments (CREAM, ATIC, Tracer) are providing us with large statistics of data and correspondingly excellent quality spectra of nuclei spanning the all periodic table. The domain of ultra-heavy nuclei is being covered by the TIGER experiment. These direct measurements are gradually approaching the energy range around the knee thereby providing us with a test of consistency (or inconsistency) of data collected indirectly by ground experiments using atmospheric showers induced by the cosmic ray interactions. One of the goals of the research in this field in the years to come should be (and in fact it is already) to match the results of direct and indirect measurements of cosmic ray fluxes and chemical composition. Thinking of the possibility of ultra-long duration balloon flights to reach closer to or across the knee appears as a worthy effort.

The achievement of accurate measurements of cosmic ray spectra is also opening the way to the search for weak signatures of rare phenomena, such as propagation of antimatter from nearby regions of the universe and annihilation of dark matter in the Galaxy. The latter has profound implications on the spectra of positrons and antiprotons especially, besides creating features in gamma rays and at other wavelengths. The launch of the PAMELA satellite in 2006 has been a milestone in this direction, and hopefully next ICRC will have plenty of presentations of exciting new results.

The picture that emerges from direct cosmic ray measurements can be summarized as follows. There is a satisfactory agreement on the all-particle spectrum as measured by different experiments. The spectra of the chemical species do not show statistically significant differences in the slopes. The abundances of Ga and Ge do not seem immediately compatible with acceleration scenarios based on pure first ionization potential or volatility. Different determinations of the B/C ratio are consistent with each other up to the highest measured energy (~ 1 TeV), but the error bars are still large enough to leave open the possibility of a flattening in the slope of the B/C ratio as a function of energy. A long duration flight, for instance of Tracer, is likely to settle this issue. We recall that from the theoretical point of view a naive extrapolation of the observed B/C ratio to the knee region would lead to exceedingly large anisotropy.

A few results of measurements carried out with ground experiments, such as HESS and the Tibet hybrid detector were presented in the OG session. The HESS collaboration presented the positive detection of the direct Cherenkov radiation, and used it to infer the spectrum of iron nuclei (more correctly of nuclei with charge $Z > 24$) with energy up to ~ 100 TeV. The measured spectrum appears to be in good agreement with other results in the same energy region.

The Tibet Collaboration discussed the results of a measurement of the proton and helium primary spectra as obtained with the Tibet hybrid experiment. The discrepancy between these results and those of the KASCADE experiment are clear, especially for the helium spectrum. As stressed above, one way of facing these problems is to extend the direct measurements with high statistics of events to the knee region.

The calibration of the ground arrays by an overlap with direct measurements is a crucial goal to pursue, not only to understand the origin of the knee but also to describe correctly the transition from galactic to extragalactic cosmic rays. The two problems are tightly related to each other.

There have been numerous presentations at the Conference on the theory of acceleration of cosmic rays. From the phenomenological point of view it is clear that several independent pieces support the possibility that the bulk of galactic cosmic rays are accelerated in SNRs: 1) X-ray observations have shown that effective magnetic field amplification at SNR shocks takes place; 2) multifrequency observations of SNR RXJ1713 and Vela junior are best fit if the observed gamma ray emission is of hadronic origin; 3) the spectra of radio and gamma rays show some evidence, though probably not conclusive, of curvature (concavity), a phenomenon which is expected in non linear theories of particle acceleration at shock waves, when the dynamical reaction of the particles is not negligible, namely when acceleration is very efficient.

From the theoretical point of view, the origin of the magnetic field amplification is being widely investigated. Two mechanisms might be at work at the same time: streaming instability induced by the efficiently accelerated cosmic rays and turbulent amplification in a shocked medium with density inhomogeneities. Other instabilities, such as firehose instability, might also be at work. There have been several contributed papers on the growth rate of the non resonant streaming instability in the context of a kinetic approach, and as simulated with the help of PIC simulations. The latter do not seem to confirm the large growth rates predicted by quasi-linear theory, but additional work is needed to make sure that the initial conditions are set in a physically meaningful way.

Efficient magnetic field amplification, when it is due to streaming instability, also implies efficient particle acceleration, which in turn induces a concavity in the spectra of both the accelerated particles and the radiations produced by them. Efficient magnetic field amplification is also required in order to explain cosmic ray energies at least in the knee region for protons and correspondingly higher for nuclei with higher charge.

All these ingredients are put together in multifrequency investigations of SNRs, where evidence for magnetic field amplification comes from X-ray astronomy. Convincing evidence was presented that such multifrequency spectra, from radio to gamma rays, can be explained in the framework of particle acceleration at modified shocks. It was also claimed that the propagated spectra of different chemical components, when summed together provide a good fit to the observed all-particle spectrum of cosmic rays.

Unfortunately propagation in the Galaxy is all but well understood, mainly because of our ignorance of both the regular and turbulent components of the galactic magnetic field: the competition between parallel and perpendicular diffusion, the presence of a wind, the topology of the magnetic field in the spiral arms and in between the arms all affect the escape times and their dependence on energy. A hint of what might be going on could come from future extensions of the primary to secondary ratios to higher energies, possibly approaching the knee region.

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