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Cosmic Ray Spectrum and Composition; Direct Observation

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Cosmic Ray Spectrum and Composition ; Direct Observation

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Abstract

This paper covers anti-particles, positrons and electrons, isotopes, ultra-heavy nuclei, the energy spectrum and composition which have been obtained by direct observation, using mainly balloons and spacecraft. As the above title suggests, I would like to discuss particularly the source spectrum and “knee” problem from the direct observational point of view, based on the data presented in this conference as well as those reported previously.

1 Introduction

I have received 58 papers from the conference organizing committee, the subjects of which are

- ⊙ antiproton and antihelium : 10 papers (OG 7.3),
- ⊙ positron and electron : 15 papers (OG 7.1, 7.2),
- ⊙ isotope : 13 papers (OG 5.1, 5.2),
- ⊙ ultra-heavy nuclei (UHN) : 5 papers (OG 5.1),
- ⊙ composition and spectrum : 15 papers (OG 5.3, 6.1, 6.2),

among which OG 7.2.1-7.2.10 may be summarized in the rapportuer paper of V.S. Ptuskin, as they are much closer to his subject, “Cosmic ray propagation in the galaxy”. In addition to these contributions, I also touch on several papers related to my topic presented in OG 8.1, 8.2, and 10.3. In this paper, I summarize the experimental data presented in this conference and compare them with each other, and with those reported elsewhere previously.

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In this field which I am going to cover, the central problems of our present-day concern may be listed up as follows,

- 1) Are minor components, such as $\bar{p}$, e^+ , ^3He , ..., consistent with the secondary products created during the passage of primary components (p , He , ...) through our galaxy ? If not, what does the excess part come from ?
- 2) Does a cutoff in the electron energy spectrum appear somewhere beyond TeV region ?
- 3) Is the fraction of heavy isotopes to the stable nuclei at the source the same as that found in the Solar System ? If not, what kind of star could synthesize them effectively ?
- 4) How is the rate of UHN synthesized by rapid neutron capture process to that of slow capture at the source ? Is this rate similar to that estimated in the Solar System ?
- 5) Does an acceleration limit for galactic cosmic rays, particularly proton component, appear somewhere in higher energy region ?
- 6) What is the source spectrum of individual cosmic ray elements ? Do all elements have the same spectrum index at the source or different ones ?
- 7) Does the all-particle spectrum connect *smoothly* with that observed by air shower experiments ? If not, is the break so drastic as to suggest something "new" ?

All of these questions are fundamental ones in cosmic ray physics as well as the problem of GZK-cutoff[1] in connection with the energy limit of the Universe. The experimental data presently available are of course too poor, in both direct and indirect observations, to get a definite conclusion. This is a good opportunity for me to summarize the direct observational data presented both in this conference and previously, particularly those on the spectrum and the composition in the wide energy region from a few GeV to several hundred TeV, and to compare them with those obtained by air shower experiments.

I would like to point out in advance, however, that these considerations depend critically on the cross section for interaction of cosmic rays with the interstellar matter (90 % H, maybe with ~ 20 % of H being ionized[2, 30], and 10 % He by number), so that one should keep in mind that several data transferred to the galactic cosmic-ray source (GCRS) presented in this paper may change slightly if one uses another cross section. In such sense, I hope a proper rapporteur talk at the next conference reviewing the cross section in connection with the propagation of cosmic ray in ISM. In fact I find there are many important contributions in the OG 8.2 session for cross section measurements using heavy ion beam, some of which show quite different results from those currently used[3,4].

2 Antiproton and antihelium

In this conference, four groups presented $\bar{p}/p$ -ratio obtained from the super-conducting magnet on board balloons (CAPRICE experiment was not reported orally in the session), as summarized in table 1. I was very impressed by the data presented, which seem quite different from those reported in the early days of the antiproton puzzle[5, 6]. I skip here the detail of the performance of each experiment, as they have often been presented elsewhere (see proceedings if necessary).

Experiment	Launching date	SQT ($m^2 \cdot sr \cdot hrs$)	Energy range (GeV)	$N_{\bar{p}}$
MASS 2	'91 Sep	0.137	4 ~ 19	9
IMAX	'92 Jul	0.224	0.2 ~ 1.0	3
			1.0 ~ 2.6	8
			2.6 ~ 3.2	5
BESS	'93 Jul ('94, '95)	6.600	0.18~0.3	0
			0.3 ~ 0.5	4
CAPRICE	'94 Aug	0.560	1.5 ~ 2.3	6

Table 1. Balloon experiments for antiproton presented in this conference. BESS group reported orally the data of '94 and '95 (preliminary) in the session, detecting one $\bar{p}$ from '94 experiment, and 21 $\bar{p}$'s from '95 experiment.

In fig. 1, I show together all of the experimental data presented in this conference as well as those reported previously. It is remarkable that the BESS-group(OG 7.3.5) covered the very low energy region, down to 200 MeV, low enough for the threshold of $\bar{p}$ -production ~ 6 GeV in p-p interaction, and gave $\sim 6 \cdot 10^{-6}$ for $\bar{p}/p$ ratio (not upper limit !). I was indeed surprised at the speed of the data processing, even though it is preliminary, considering that the balloon campaign of the BESS'95 was performed just in this summer !

I remark also on two other results. One is a point (filled square) in the higher energy region, ~ 10 GeV, obtained by MASS2(OG 7.3.1), much lower than previous values[5], while the other (filled triangle) covered a very wide energy region, 0.2 to 3.2 GeV, obtained by IMAX(OG 7.3.2).

In fig. 1, I demonstrate together theoretical curves expected from the standard leaky box model (SLBM), obtained by Webber & Potgieter[7], and Gaisser & Schaefer[8]. The small difference between the curves maybe comes from the choice of the parameters necessary for the calculation, such as the mean escape length, solar modulation parameter, the cross section of $\bar{p}$ -production and/or the composition of interstellar medium. From this figure, we find the experimental data reported in this conference seem to be consistent with

Fig. 1. Comparison of the $\bar{p}/p$ ratios presented in this conference (filled symbols) with those reported previously (open symbols). Also shown are the calculated ratios. See OG 7.3.5 for previous data.

the theoretical curves expected from the secondary products during the passage of proton (helium, ...) in our galaxy.

Simon and Heinbach (OG 8.1.17) also reported numerical results based on the leaky box model with and without a reacceleration process. They emphasized that the $\bar{p}/p$ ratio is much boosted at low energies under the condition of diffusive reacceleration, compared to those expected from SLBM, showing quite favourable tendency for the observational data. In my rapporteur talk at the conference, I commented that their numerical results were not compatible with the data. But, examining the results carefully after based on the BESS'95 data, I find the discrepancy is not so significant as I commented in my talk, and it seems to be rather agreeable with each other, considering the difference

of the solar modulation value between the calculation ($\Phi=500\text{MV}$) and the observation ($\sim 750\text{MV}$ for BESS'95).¹ In fact, Mitsui et al.[9] find recently that the numerical calculations in the frame work of the diffusive reacceleration model developed by Simon and Heinbach[25] are consistent with the BESS data.

Now, standing on the contributions of both the experiments and the calculations presented in this conference, the $\bar{p}$ -puzzle asking to a novel mechanism based on the cosmological scenario might be unreasonable in the level of the experimental techniques of nowadays, even if it exists. I think, however, further observation of $\bar{p}$ will be still very important for both the study of the propagation of cosmic rays and the search for the excess in the higher energy region.

Here I would like to point out two problems inherent in the observation of $\bar{p}$. Firstly Labrador and Mewaldt(OG 7.3.3) recommended that the energy spectrum of $\bar{p}$ should be studied much more, in preference to the $\bar{p}/p$ ratio. Their comment seems quite reasonable, since the protons are much affected by the solar modulation, while the antiprotons are less so, because most of them come from primaries with energies more than several GeV/n. In fig. 2, modulated spectra for a) protons and b) antiprotons are shown over several solar activity cycles. As shown in fig. 2b, we no longer need to worry about the solar cycle variations. Therefore, as Labrador and Mewaldt emphasize, future $\bar{p}$ experiment should take these effects into account.

The second point I would like to make is concerning the effect of atmo-

Fig. 2. Interstellar spectra of a) proton and b) antiproton calculated by Webber & Poglieter[7] (dashed curve) and modulated (solid curves) to (from top to bottom) 1987, 1993, 1979, 1982, 1980, and 1990 levels.

¹I am grateful to Prof. J. Nishimura for valuable comments on this point.

spheric $\bar{p}$'s. Indeed, each group subtracts very carefully the secondary $\bar{p}$'s coming from both atmospheric and instrumental interactions, but this subtraction is performed in a *statistical* way and the effect of geomagnetic field is neglected, probably presuming a priori that the energy concerned is beyond the cutoff energy, say ~ 0.4 GV around Lynn Lake, while ~ 5 GV around Fort Summer. This presumption is, however, based on the *average* value, whereas strictly speaking, the cutoff energy depends on both the zenith and azimuth of the arrival direction. It has particularly strong energy dependence at low latitude as in the case of Fort Summer. While the BESS-group has checked these points[10] (I guess, however, the preliminary data of BESS'95 were not in time to check), the trajectory of each $\bar{p}$ detected should be reproduced *event by event*, tracing back to an arrival direction. If it could have gone outside the geomagnetic field, say 20 times the Earth radius, it surely must have come from space. On the other hand, if it is trapped in the geomagnetic field, or collides with the Earth, it must be a secondary products. I expect some other people also may be doubtful that the $\bar{p}$'s observed are definitely not secondary products coming from the atmospheric interaction, even after subtracting statistically them.

Two more contributions of the $\bar{p}$ observation were presented, though the both are indirect observational methods using the Sun and the Moon. Yamamoto(OG 7.3.7) presented the upper limit of $\bar{p}/p$, 22% at ~ 10 TeV, derived from the displacement of Sun shadow from its expected position, using the Tibet air shower array. It may be more interesting if the the upper limit is much reduced in the future, say as small as a few percent, as he suggested orally in the conference. Another interesting report was presented by Brunetti(OG 7.3.8), using charged pion albedo coming from the Moon regolith induced by cosmic ray antiprotons. Though the reality of this idea depends totally on the Moon facility programmed in the next century[11], if it is realized, the statistics of $\bar{p}$ will drastically increase, giving 150000 albedo charged pions/m² per day induced by antiprotons.

Bess-group (OG 7.3.9) reported also the $\bar{\text{He}}/\text{He}$ -ratio, combining the data of '93 with those of '94. In fig. 3 is shown the result together with previous limits, giving the ratio of $8 \cdot 10^{-6}$ (95% C.L.) in the rigidity range 1 to 19 GV. This limit is about a factor 10 improvement over the previous best one of Golden et al. '92[12].

Fig. 3. Upper limit on antihelium/helium flux ratio.

3 Positron and electron

In table 2 is summarized the $e^\pm$ -experiments reported in this conference. Figure 4 is the result of $e^+/[e^+ + e^-]$ obtained by four groups, where those reported by previous experiments are also plotted together. What is surprising in the HEAT-data (filled circles; OG 7.1.4) is that the fraction of e^+ clearly decreases as energy increases, even beyond 10 GeV, giving no evidence of a rise as found previously. According to Müller, the discrepancy in their own data between the previous[13] and the present experiments is because the former was obtained by E-W asymmetry effect in the arrival directions of e^+ and e^- .

Experiment	Launching date	S Ω T ($m^2 \cdot sr \cdot hrs$)	Energy range (GeV)
MASS 2	'91 Sep	0.137	2 ~ 15
TS 93	'93 Aug	0.375	4 ~ 50
HEAT	'94 May	0.780	4.5 ~ 50
CAPRICE	'94 Aug	0.560	0.8 ~ 1.5
AESOP	'94 Aug	0.022	1 ~ 2

Table 2. Balloon experiments for positron.

I should also remark that only two points, one from MASS2(OG 7.1.1) and the other from TS93(OG 7.1.3), show a high proportion of e^+ , but it seems they are not inconsistent with those of HEAT, taking the statistical fluctuation into account. The AESOP-group(OG 7.1.2) gives two points (filled squares) at 1 GeV. The upper point is the actual measurement, and the lower one corresponds to the measurement adjusted to the solar polarity state of the 1960's for comparison with earlier data.

So, looking again at fig. 4 as a whole, we find the fraction of e^+ to all electrons decreases significantly in the wide energy range from ~ 50 MeV to ~ 50 GeV. The drop of e^+ fraction found in the range $0.7 \sim 4$ GeV is probably due to different polarity state then compared to now. Therefore it is important to confirm the value of $e^+/[e^+ + e^-]$ in this energy region for the present state of solar polarity. In fact, HEAT-group is planning to cover this region in the near future[14].

In fig. 4, I show several examples of predicted curves[15,16] together, which are based on SLBM. The difference between the curves from three authors might come from the different choice of parameters necessary for the calucu-

Fig. 4. The positron fraction vs. energy. Filled symbols are presented in this conference and the open ones previously. Calculated curves are based on the leaky box model; solid curve: R.J. Protheroe[15], dashed curve: W.R. Webber[16], and chain curve: D. Muller et al.(OG 7.1.4). The curves labeled 90 and 120, respectively refer to a calculated dark matter contribution from WIMP masses of 90 and 120 GeV/c^2 . See OG 7.1.4 for previous data.

lation, particularly those related to solar modulation. Though the predicted curves are not always in close agreement with the experimental data, the overall trend is compatible, taking into account the uncertainty in both the measurements and the calculations.

While Müller argued that there still remains a possibility of positrons coming from primary sources, possibly as small as a few % of the total electrons as shown in fig. 5, I feel models proposing a *drastic* rise of positron ratio somewhere above 10 GeV should be ruled out. Of course we have to keep in mind that these considerations are not independent of the reliability of the propagation model for both the proton and electron components in our galaxy. In any case, further observation is necessary, particularly in the higher energy region $\gtrsim 10$ GeV, for the confirmation of the HEAT result.

Fig. 5. The all-electron differential energy spectrum (multiplied by E^3) compared with the proton spectrum and with the leaky box prediction for the secondary contribution $(e^+ + e^-)_{sec}$. The data points labeled $(e^+ + e^-)_{sec} + e^+_{prim}$ are based on the positron fraction measured by the HEAT instrument.

In this conference, unfortunately, no experimental data on the high energy electron spectrum, say $\gtrsim 500$ GeV, were reported. But some theoretical speculation on the anisotropy problem of very high energy electron component was done by several authors (OG 7.2.1, 7.2.3, 7.2.10), details of which might be summarized in the rapporteur paper of Ptsukin. In particular, Nishimura emphasized the importance of the observation of electrons in the TeV region, where only those coming from nearby source could be contributed because of drastic energy loss due to the synchrotron and inverse Compton effects.

In fig. 6 is presented the possible contribution of nearby sources to the high energy electron spectrum estimated by Nishimura et al.. They use the most recently revised data on the explosion time and location of nearby objects. They argued that the contribution of Monogem might be the most effective in the TeV region, while that of Loop I is much reduced in contrast to the previous speculations. This is because the revised explosion time for Loop I is $\sim 10^5$ yrs [17] instead of the previous $\sim 10^4$ yrs used commonly. Figure 7 is a diagram, age vs. distance, where the contribution of nearby objects can be easily seen.

Ptsukin and Ormes also discussed the anisotropy of very high energy electrons based on the diffusion from local SNRs. They gave extremely high anisotropy amplitude as large as 20% at 20~30 TeV for Vela, where all other sources could be cut off.

It is not an easy task however to obtain the electron spectrum in the high energy region above several TeV, because we need rejection power more

$\gamma = 2.4$	$\delta = 0.3$ ($E \geq 5$ GeV)	Dist. (kpc)	Age (yr)
	$\delta = 0$ ($E < 5$ GeV)	Vela	0.5
$b = 1$	$30 \times 10^{-16} (\text{GeV} \cdot \text{sec})^{-1}$	Monogem	0.3
	for $E > 500$ GeV	Loop 1	0.17
$D = .0 \times 10^{28} (E/5)^{\delta} \text{cm}^2/\text{sec}$		Geminga	0.3
$T_0 = 1.2 \times 10^8 \text{yr}$			3.4×10^5

Fig. 6. Possible contributions of nearby sources to the high energy electron spectrum. Vela contributes around 20 TeV, but the flux is so small locating outside of this figure.

Fig. 7. Diagram of age vs. distance of possible objects. The authors emphasize Monogem might be the most effective contribution in TeV region.

than 10^4 against protons, which exceeds the limit of current emulsion technology with microscopes, though the energy determinations are quite reliable, $\Delta E/E \lesssim 15\%$. To solve the problem, Nishimura (OG 10.3.3) reported a new type of emulsion chamber, called BETS (Balloon-borne Electron Telescope with Scintillating fibers), which consists of scintillating fibers, emulsion plates and lead plates. A long duration experiment of BETS is to be performed at Antarctica and/or from Wakkanai, the most northern area in Japan, to somewhere around central Asia, details of which were reported by Nishimura at the workshop, "Future Cosmic Ray Balloon Experiments", organized by S. Stochaj.

4 Isotopes and ultra-heavy nuclei

4.1 ^2H and ^3He

^2H and ^3He bring us critical information on the amount of matter traversed by H and He, the most abundant elements in cosmic ray nuclei. In the conference, five groups presented new data which I summarized in table 3. The BESS result (preliminary) was reported orally in another session. In fig. 8 is shown the $^2\text{H}/^4\text{He}$ obtained by Bogomolov et al. (OG 5.2.1) using a

Experiment	Launching date	Energy range (GeV/n)	SQT (cm ² · sr · hrs)
Bogomolov et al	'90 Jul	0.8 ~ 1.8	10.6
SMILI 2	'91 Jul	0.1 ~ 2.0	1.7 × 10 ³
IMAX	'92 Jul	0.2 ~ 3.6	2.2 × 10 ³
Voyager 1	'94 Jan~Sep	0.03 ~ 0.3	~3.2 × 10 ⁶
BESS	'93 Jul	0.2 ~ 0.6	6.6 × 10 ⁴

Table 3. Experiments for ³He/⁴He and ²H/⁴He. Voyager data is focussed on anomalous H and He components.

Fig. 8. Measured and calculated ²H/⁴He ratio in galactic cosmic rays. Solid circle point is presented by Bogomolov.

magnetic spectrometer on board a balloon. One should remember that the ratio is not much affected by the solar modulation because the both ²H and ⁴He have the same charge to mass ratio. Though the measured point exceeds the predicted curves slightly, the discrepancy does not seem to be too serious, taking the poor data on the cross section for ⁴He → ²H into account.²

Seo(OG 5.2.8) showed very clear evidence of anomalous hydrogen with solar minimum period from the Voyager 1 spacecraft at an average heliocentric distance of 56 AU, the detection of which is usually quite difficult since both galactic and anomalous H are singly charged. Though I think the detection of anomalous H is very important for the study of nucleosynthetic history, I skip

²If my hearing is correct, Bogomolov orally reported the revised data giving a somewhat reduced ratio in comparison with the value given in the proceedings.

the detail here because it deviates somewhat from my main subject. I report, however, that the observed ratio of $^2\text{H}/^3\text{He}$ is consistent with the calculated one, which is also not affected appreciably by the solar cycle.

Figure 9 is a combined plot of $^3\text{He}/^4\text{He}$ data obtained by the other three groups, together with the previous data. At a glance, IMAX(OG 5.2.6) and BESS(OG 5.3.3, preliminary) give higher ratios than SMILI2 and the previous data. One should remind that the period of SMILI2(OG 5.2.9) is the highest level of solar activity with $\Phi=1.5\text{GV}$. One may think that the discrepancy might come from the different level of the solar activity, for instance $\Phi = 700 \sim 750 \text{ MV}$ for the former two and $1.2 \sim 1.5\text{GV}$ for the others. But even taking this difference into account, the discrepancy still remains.

Fig. 9. Helium isotope ratios presented in this conference as well as those reported previously. Three curves show the model modulated to 1.2 GV (see proceedings for details).

In fig. 9, I show calculated curves with $\Phi=1.2\text{GV}$ together. The difference between two curves of Beatty et al.[18] comes from using either a kinetic-energy variable (dashed one) or the rigidity variable (chain one) for the power-like source spectrum and the dependency of escape length. I feel the two curves of Davis et al.(solid curve; OG 5.2.7) and Beatty et al. are not in agreement with each other in spite of their using the same modulation parameter. It is probable that they use different parameters for escape length and cross section. Seo noted orally that the BESS data is consistent with the calculation based on the reacceleration model with $\Phi = 700 \text{ MV}$, though she emphasized the results were preliminary.

So, I am somewhat confused by both the observational results and calcu-

lations, and can not conclude definitely at this stage whether the excess of ^3He is significant or not. I would like to report, however, my impression at the conference that each author's results seemed to be quite favourable with no contradiction of the SLBM as a whole.

4.2 Heavier isotopes ($\geq \text{C, N, O}$)

In the last conference at Calgary(1993), S. Swordy[19] summarized isotopes from carbon to silicon obtained by the various space missions, Voyager, CRRES and Ulysses, and concluded that the isotope ratios of Mg and Si are consistent with those in the Solar System (SS), and the ratio of $^{22}\text{Ne}/^{20}\text{Ne}$ is 2 to 3 times larger than the ratio in SS. By contrast, in this conference, three groups presented the isotope ratios of Fe and Ni, and one group gave the isotopic composition of anomalous cosmic rays (ACRs), N, O and Ne, which are summarized in table 5. The mass resolution for Fe is ~ 0.6 amu, ~ 0.3 amu and less than 0.44 amu for HET(Voyager; OG 5.1.3), HET(Ulysses; OG 5.2.2) and Trek(Mir; OG 5.2.11), respectively, where the first two were obtained by a silicon detector and the latter by a track-etch detector.

Experiment	Obs. Period	Energy range (MeV/n)	Elements
HET (Voyager1,2)	'77 ~ '94	100 ~ 300	Sc ~ Fe
HET (Ulysses)	'90 ~ '94	30 ~ 500	Fe, Ni
MAST (SAMPEX)	'92 ~ '94	15 ~ 150	C,N,O,Ne (ACRs)
Trek (Mir)	'91 ~ '93	160 ~ 400	$22 \leq Z \leq 28$

Table 4. Experiments for heavier isotope ($\geq \text{C, N, O}$). MAST data is focussed on anomalous C, N, O and Ne components.

In fig. 10, I plot together the isotope ratios of C to Ni reported in two conferences together, Calgary and Rome, onto the figure appeared in the rapporteur paper of Adelaide conference (1990) by Wiedenbeck[20]. One finds the isotope ratios of Fe and Ni are also much closer to those in the SS than those presented previously. The HET(Voyager 1, 2) experiment showed further that the isotopic compositions of Ti to Mn are consistent with propagated solar-like source composition except $^{50}\text{Ti}/\text{Ti}$ and $^{51}\text{V}/\text{V}$, each giving 2.7 ± 1.4 and 1.9 ± 0.4 , respectively, larger than the propagated solar fraction. One thing I worry about however is that the Voyager data are somewhat poor in

Fig. 10. GCRS/SS ratio for principal isotope ratios, C ~ Ni.

mass resolution (~ 0.6), which is essential for isotope identification. So some improvement in resolution might be necessary to get a definite conclusion.

As was emphasized by Swordy, we found again in this conference that most of the isotopic ratios in the range C to Ni in galactic cosmic rays are quite similar to those in the solar system, the only anomalous isotope being ^{22}Ne . Though the experimental data seem to be consistent with those expected from Wolf-Layet stars, the experimental data on the isotopic ratios of C and O are still quite poor, so that a definitive comment would be premature.

Here I would like to point out that these considerations depend greatly on the fragmentation cross section. In fact, the TRANSPORT collaboration (OG 8.2.5) reported in another session that the new results on $^{22}\text{Ne} + \text{H}$ differ considerably from those currently used, Silberberg & Tsao[3] and Webber[4]. So, the enhancement of ^{22}Ne seen in fig. 10 might change after the new data of TRANSPORT group is applied to the estimation of $^{22}\text{Ne}/^{20}\text{Ne}$ ratio at the source.

Lukasiak (OG 5.1.3) reported orally that the time delay between nucleosynthesis and cosmic-ray acceleration is probably larger than 10^5 yrs, based on the $^{59}\text{Co}/^{56}\text{Fe}$ ratio ($= 0.0043 \pm 0.0015 \gg 0.0007$: purely secondary contribution) obtained by the HET (Voyager 1, 2) experiment. One should remember that the observed isotopic composition of Fe and Ni bring us straightforwardly the nature of the source composition since the fragmentation of heavier nuclei

is negligible. In fig. 11 is shown the predicted and observed $^{59}\text{Co}/^{56}\text{Fe}$ ratios. The estimated time of $\sim 10^5$ yrs is long enough for the expansion of typical SNR to a radius $\gtrsim 50 - 100\text{pc}$, indicating that the acceleration may occur at a *late* stage in the expansion of SNR, i.e.; cosmic rays may not be originated in *fresh* SN materials directly accelerated, but may come from accelerated interstellar matter or coronal material as Likasiak pointed out.

Fig. 11. Comparison between the measured $^{59}\text{Co}/^{56}\text{Fe}$ ratio and the calculated one.

The Ulysses HET experiment also suggests that the ^{59}Ni has disappeared in the cosmic ray source ($^{59}\text{Ni} \rightarrow ^{59}\text{Co}$ with $\tau_{1/2} = 7.6 \times 10^4$ yrs), indicating a significant time delay between ^{59}Ni synthesis and acceleration.

Indeed both the Voyager and Ulysses results are quite important and suggestive concerning nucleosynthesis and the acceleration period, but we should remember also that the estimation of the time delay depends on both the propagational model and the energy spectra of Fe and Ni at the source.

The MAST experiment(OG 5.2.3) also gave impressive result on the isotopic components of ACR, N, O and Ne, which are thought to be accelerated samples of the local interstellar medium(ISM). This allows important comparisons between the solar, GCR source, and local ISM nucleosynthetic histories. In order to pick up a *pure* sample of ACR, they used the geomagnetic field as a rigidity filter. In fig. 12, I show a scatter plot of energy vs. invariant latitude for MAST quiet time O. GCRs are naturally populated in the allowed zone at higher latitudes, while trapped ACRs are concentrated at low latitudes. What they found in ACR components distributed in the mid-latitude interval is quite dramatic as shown in fig. 13; isotopic components have almost vanished ! They found the ACR isotopic abundances are $^{15}\text{N}/\text{N} < 0.032$, $^{18}\text{O}/^{16}\text{O} < 0.0057$, and $^{22}\text{Ne}/^{20}\text{Ne} = 0.087(+0.137, -0.026)$. These results may bring us something suggestive on the question of GCR origin. More statistics are highly desirable.

Fig. 12. Scatter plot of energy vs. invariant latitude for MAST quiet time Oxygen, showing cuts used to select a pure ACR sample at mid-latitudes.

Fig. 13. Mass histograms for "pure" ACR N, O, and Ne using the geomagnetic filter.

4.3 Ultra heavy nuclei (UHN)

Four papers (including two abstracts) were presented in proceedings, all of which used solid state track detectors, consisting of several tens of layers of plastic (CR-39 and/or Lexan polycarbonate) or glass and I summarize them in table 5. These experiments were performed on board the NASA LDEF (Long Duration Exposure Facility; OG 5.1.2, 5.1.4, 5.1.8) and Mir (OG 5.1.5). All the stacks on board LDEF had already been retrieved in January 1990, while one-third of the stacks on Mir were recovered in November 1993, and the remaining two-thirds were returned to earth by the US Shuttle ATLANTA after it docked with Mir in June this year.

Experiment	Obs. Period	Energy (GeV/n)	Charge	S Ω (m ² · sr)
HIIS (LDEF)	'84 ~ '90	≥ 1 (?)	> 45	2.0
Dublin -ESTEC (LDEF)	} 84 ~ '90	≥ 1	≥ 65	25
Barcelona (LDEF)				
Trek (Mir)	'91 ~ '93 (~ '95)	≥ 0.8	> 50	(1.2 m ²)

Table 5. Experiments for Ultra Heavy Nuclei. Only Barcelona group reported their result in the session.

Unfortunately only the Barcelona group gave an oral report of their preliminary results, based on measurements of $\sim 5\%$ of the total stacks. In table 6, I summarize the result on two abundance ratios, $(87 \leq Z \leq 100)/(74 \leq Z \leq 86)$ and $(81 \leq Z \leq 86)/(74 \leq Z \leq 80)$. The numerators of the first (actinides) are synthesized only by the r process, while the numerators of the second (Pb-group) are synthesized predominantly by the s process. The value 0.038, by Thompson et al.[21](Dublin-ESTEC), was reported in Calgary conference.

The Pb-group/Pt-group ratio of 0.26 is in agreement with those obtained by Ariel[22] and HEAO-3[23] data. Though the Barcelona group emphasized the overabundance of r -process synthesized material in the $Z \geq 65$ region in comparison to the propagated primordial Solar System abundance, we had better wait until after the measurement is completed for a firm conclusion. In fact, I feel the value 0.017 given by the Barcelona group is much closer to the Solar System abundance 0.013[24] than those reported previously, 0.024 $\sim$ 0.038.

Experiment	$\frac{87 \leq Z \leq 100 \text{ (Actinide)}}{74 \leq Z \leq 86 \text{ ([Pb+Pt]-G)}}$	$\frac{81 \leq Z \leq 86 \text{ (Pb-G)}}{74 \leq Z \leq 80 \text{ (Pt-G)}}$
Sky Lab ('78)	0.10	—
Ariel-6 ('85)	0.04	0.35
HEAO-3	0.01	0.25
Domingo et al. (LDEF)	0.017	0.26
Thompson et al. (LDEF)	(0.038)	—

Table 6. Abundance ratio obtained by several experiments.

However I would like to remark the collection power of UHN based on two facilities, LDEF and Mir. I show in fig. 14, where the statistics are rather approximate ones I estimate from the both present and previous papers. Thus, if the complete measurements of new experiment are performed, we must get decisive information for the excess (or deficiency) problems in the abundance ratios between those synthesized by r - and s -processes.

To do so, I think some automatic scanning system will be totally necessary as they have reported, otherwise it seems quite hard to complete the extensive measurement of etch-pit cones not in the distant future. I hope the remaining data will be reported in the near future, using some new measuring system they have developed.

Fig. 14. Collection power of UHN expected from LDEF (UHCORE, HIIS) and Mir (Trek) experiments.

5 Spectrum and composition

5.1 Low energy

The typical energy region we are concerned with here is ~ 1 GeV/n. Several effects such as ionization loss, energy dependence of interaction cross section and solar modulation, are not negligible, but the reliability for both charge (and/or mass) and energy determinations is naturally much better than that in the higher energy region, $\gtrsim$ several hundred GeV/n. In this conference five experiments (OG 5.1.1, 5.1.6, 5.1.7, 5.1.9 and 5.3.3) were presented as summarized in table 7. The BESS group spoke mainly of the $^3\text{He}/^4\text{He}$ ratio

Experiment	Obs. Period	Energy range (GeV/n)	Obs.
Anuradha (space-lab3)	'85 Apr ~ May	0.03 ~ 0.3	[Sc-Cr]/Fe
HET (ULYSSES)	~ '94	0.04 ~ 0.45	B/C, F/Ne, P/S [Sc-Mn]/Fe
Bhattacharyya et al. (Balloon)	'83 May	~ 5	Ne~Ni, [Sc-Cr]/Fe
Yanagita et al. (ISEE/ICE)	'78 Nov ~ '82 Oct	0.07 ~ 20	Li~O, B/C, Li/C
BESS (Balloon)	'93 Jul	0.2 ~ 10	P, He

Table 7. Experiments of spectrum and composition in the low energy region.

in the session (as discussed in sect. 4.1) although the energy spectra of H and He are presented in proceedings. So I don't consider the BESS data in detail here, but comment that the quality of energy spectra of H and He is quite excellent, probably even in the higher energy region ~ 100 GeV/n.

The other four groups presented secondary (B, Li, ..., sub-Fe) to primary (C, O, ..., Fe) ratios. I saw all the groups gave results nearly consistent with those obtained previously, and they are all in agreement with calculated ratios based on SLBM except a report by Yanagita(OG 5.1.6). He showed two abundance ratios, B/C and Li/C, as in fig. 15. The former data (15a) is in good agreement with the prediction, as has been confirmed for many years, while the latter data (15b) is systematically low by as much as 20 % from the predicted value in the lower energy region $\lesssim 1$ GeV/n. He argued that this deviation may be explained by a propagation model including diffusive reacceleration process, which has been extensively developed by Heinbach and Simon[25]. I also think it is very interesting and important to apply the diffusive reacceleration model for the Li/C ratio, as the model seems to be favourable for $\bar{p}/p$ ratio, particularly at low energies as discussed in sect. 2.

DuVernois(OG 5.1.7) reported the sub-iron to iron (Sc-Mn/Fe) abundance ratios from the Ulysses High Energy Telescope(HET), which is in good agreement with the modulation curves from the propagation curves with single exponential pathlength distribution (PLD). However the double exponential PLD over-produces secondary elements.

Fig. 15. a) B/C and b) Li/C ratios in galactic cosmic rays. Open rectangles are presented in this conference, and see OG5.1.6 for other data.

5.2 High energy

In table 8, I summarize the high-energy experiments presented in this conference. Since the Calgary conference, two balloon programs have been started to make clear the energy spectrum and composition around “knee” region, which is a key problem in primary cosmic ray physics. The first one is the JACEE Antarctic campaign ('90: test flight, '93, '94: full observation with 200-300 hrs exposure; OG 10.3.13), the details of which are discussed later. The second one is RUNJOB campaign (RUSSIA-Nippon JOint Balloon program; OG 10.3.2), launched from Kamchatka and landed around the western area in Russia ('95 summer: RUNJOB-1 with 130 hrs and RUNJOB-2 with 170 hrs). Both programs will operate every year for the next several years.

Experiment	Launching date	Energy range (TeV/n)	Elements
HEAT	'94 May	0.01 ~ 0.2	p, He
TIC	'94 Aug	0.1 ~ 10	all-particle
Kuramata et al.	'89 May '91 May	0.001 ~ 1.0	$\geq$ Si
JACEE	'90 Dec '93 " '94 Dec	p: $\geq$ 10 α : $\geq$ 2 Heavy: $\geq$ 1.0	all
RUNJOB	'95 Jul	p: $\geq$ 20 Heavy: 0.1 ~ 10	all

Table 8. Experiments of spectrum and composition in the high energy region. RUNJOB experiment is reported only on the performance of this summer campaign in OG 10.3.2

The TIC (Thin Ionization Calorimeter; OG 5.3.2) balloon experiment was performed in Canada by an American-Russian collaboration. TIC consists of five steel plates (5×5 cm), each followed by a 1 cm thick scintillator. It is viewed from both sides by 15cm diameter photomultiplier tubes. The purpose of TIC is to make an accurate measurement of the *all-particle* spectrum from 100 GeV to 10 TeV in order to confirm the measurement of Grigorov[26] performed in 1989. In the conference they reported only very preliminary result so my comments are limited.

Swordy(OG 5.3.4) reported the energy spectra of proton and helium using the HEAT-detector, though the primary goal of HEAT was the measurement of $e^\pm$ as discussed in sect. 2. Both spectra are shown in fig. 16, where the HEAT data is normalized to a point at 25 GeV/n with the proton data of Seo et al., because the absolute detection efficiency for their data has not yet been calculated. He argued the rigidity spectrum of helium at the source is described by $\propto R^{-2.02}$, while that of protons is described by $\propto R^{-2.12}$, and

Fig. 16. Fluxes of proton and helium multiplied by $E^{2.75}$. Filled symbols are the results presented in this conference.

the difference in source spectral index of 0.1 seems to match with the prediction from the non-linear shock acceleration[27]. Though his interpretation is very interesting, we had better wait for better statistics for both protons and helium in the higher energy region $\gtrsim 10$ TeV/n. In fact, Olson presented a flux of helium in the energy region $\gtrsim 20$ TeV/n, $\sim 15\%$ less than those shown in Calgary, and with a rather smooth proton spectrum in contrast to the sharp kink reported previously around ~ 50 TeV. This problem is discussed further below, and in sect. 6.2.

Kuramata³(OG 5.3.1) and Ichimura(OG 8.1.2) presented the energy spectra of heavy components ($\geq \text{Si}$) in the wide energy range from a few GeV/n to a few TeV/n, shown in fig. 17. The analysis of the experimental data is discussed in detail later.

This conference was the first time for the JACEE group to report the data obtained by a full Antarctic balloon campaign. Several important results were

³Kuramata commented there remained uncertainty in the absolute flux of sub-iron components. His calculation gave values less by $\sim 20\%$ than those reported by Ichimura, while other components are consistent with each other. This may be due to a different treatment for the fragmentation process of iron ($\rightarrow$ sub-iron) in the atmosphere. A complete version will be presented elsewhere soon[42]

Fig. 17. Fluxes of a) Si to Ca and b) Fe and sub-Fe multiplied by $E^{2.5}$.

presented. Olson(OG 6.2.8) gave a) proton and b) helium spectra obtained from JACEE-10, as shown in fig. 18. Although it was just a test flight, it is significant that the data covers rather a wide energy range, $10 \sim 200$ TeV for protons and $4 \sim 80$ TeV/n for helium, with a *single* flight. Both results are in agreement with those reported in Calgary [26] within the statistical error, but the sharp kink previously found in the proton spectrum seems to be rather

Fig. 18. Fluxes of proton and helium multiplied by $E^{2.5}$. Filled symbols are the results obtained by JACEE-10.

smoother now. I also remark that the helium flux is $\sim 15\%$ less than the previous spectrum⁴ at 10 to 40 TeV/n. This is due to a 15% difference in the helium-nucleus cross-sections[29] used here and previously.

Tominaga(OG 6.1.14) presented a summary talk on the energy spectra and elemental composition of nuclei obtained from a series of JACEE experiments including the Antarctic program. The results are shown in fig. 19. Although the spectral index of protons is much softer than that of helium in the higher energy region $\gtrsim 50$ TeV/n, I point out that the both components give nearly the same spectral index ~ 2.7 in the region $\lesssim 50$ TeV/n. I would like to discuss this point again in the following section. One finds that the elements C to O show a rather hard spectrum in comparison with the others, while the Ne-S spectrum is slightly softer than reported previously. It is somewhat difficult to conclude whether the "Iron" ($Z \geq 17$) component either increases, remains flat or decreases with energy. In any case we need better statistics.

Now I would like to comment on the proton spectrum in the highest energy region observed by JACEE, $\gtrsim 400$ TeV, corresponding to $\Sigma E_\gamma \gtrsim 100$ TeV

Fig. 19. Combined fluxes of JACEE 1-12 for individual elements.

⁴) found the two points (open circles) of the helium spectrum at 40 and 100 TeV seen in fig. 18b to be 20 to 40 % less than those plotted in the same figure at Calgary[28].

released into electromagnetic component. Here I point out that these high energy events with $\Sigma E_\gamma \gtrsim 100$ TeV are those with large zenith angle, i.e., in this case the effective thickness of lead absorbers is enlarged enough to cover the shower maximum. On the other hand, in the case of those events with small zenith angle, the effective thickness is merely $7 \sim 8$ radiation length (common thickness in vertical for the emulsion chamber on board the balloon), which is not heavy enough to catch the shower maximum, $T_{max} \sim 13$ rad. length, for the high energy event we interest here. This means that only those events with large zenith angles are selected for the highest energy region, while those with lower energy are *evenly* detected, without any loss bias, irrespective of the zenith angle ($7 \sim 8$ rad. length is thick enough to cover the shower maximum). This inevitably leads to an energy dependence for the detection efficiency, particularly in the very high energy region, when calculating absolute intensity. Though this matter is somewhat complicated, we should keep the effect in mind for future observation. Anyway it is remarkable that the JACEE-group is now reaching such a high energy region that the above effect becomes significant.

6 Source spectrum

6.1 Escape length

Ichimura(OG 8.1.2) presented rigidity-dependent escape length, based on [Sc-Cr]/Fe ratio,⁵ as shown in fig. 23, together with those obtained by Engelmann et al.[30] using the B/C and [Sc-Cr]/Fe ratios. Using the straight line in fig. 20 given by Engelmann et al., (Λ_e : in g/cm², and R : in GV)

$$\begin{aligned}\Lambda_e &= 34.1 \times R^{-0.6} \quad \text{for } R \geq 4.4\text{GV}, \\ &= 14.0 \times v/c \quad \text{for } R < 4.4\text{GV},\end{aligned}\tag{1}$$

he concluded that all the primary elements, p to Fe, have a common rigidity spectrum (see fig. 21a in the next subsection) expressed by $\propto R^{-(2.1 \sim 2.3)}$ in the wide energy region from a few GV to 10 TV and match the prediction from the current acceleration model of strong shock, apart from a fact that the helium data seems to flatten beyond ~ 100 GV.

For his presentation, however, several critical comments were made, pointing out that the model immediately faces a serious problem related to the anisotropy of cosmic rays. I also think they are quite natural questions. It has been confirmed that the anisotropy amplitude δ is almost constant and as small as or less than 0.1 % [31] in the energy range 1 to 100 TeV, though it

⁵As noted in the footnote to the last subsection, Kuramata gives values ~ 20 % less than those (solid circles) shown in fig. 20. But the essence of the discussion here is not changed.

Fig. 20. Escape length vs. rigidity obtained by HEAO-3 and Ichimura et al.. Straight line is given by Engelmann et al., while the chain curve is phenomenological one incorporating reacceleration process (see text for the details).

is not always as simple as having a constant amplitude. In the framework of diffusion model, the anisotropy amplitude is given approximately by

$$\delta \simeq \Lambda_0 / \Lambda_e, \quad (2)$$

where Λ_0 depends on the source distribution, the structure of the magnetic field, and of course on the configuration of the Galaxy, such as its gas density, and both its disc and halo thicknesses[32]. Then it is clear that if we extrapolate the straight line drawn in fig. 20 up to the higher energy region, δ exceeds well over the value observed currently, $\sim 10^{-3}$, in the energy region 1 to 100 TeV.

Indeed the leaky box model is quite “useful” for us in that it is very simple, with only one free parameter, the mean escape length Λ_e , and yet it describes surprisingly well the observational data for all stable nuclei components and possibly the minor elements as well, $\bar{p}$ and light isotopes(^3He , ...).⁶ As has

⁶Ptshukin discussed this question in his rapporteur talk - why such a simple model matches so well with the observational data. See his paper on this point.

been argued by many authors[25,33,34,35], however, this model is a simplified version of the diffusion model, a more physycal (or basic) one, and is far from realistic situation, leading to several difficulties in the study of unstable-nuclei, the anisotropy problem, and so on.

Incorporating the Fermi-type of reacceleration into a leaky box model, Ferrando and Soutoul[35] showed the following approximate equality between the two escape lengths, Λ_e (without reacceleration) and λ_e (with reacceleration),

$$\frac{1}{\Lambda_e} \simeq \frac{1}{\lambda_e} - \frac{1}{\lambda_a}, \quad (3)$$

where λ_a is the characteristic path length for the energy gain. The above relation also holds approximately for the diffusion model with a reacceleration process. Though there are several models for the reacceleration process, I refer here to the proposal by Osborne and Ptsukin[33], based on the diffusion model and incorporating the energy gain coming from gyroresonant interactions with an isotropic ensemble of hydromagnetic waves.

They showed that λ_e and λ_a are not independent, but are strictly related as follows,

$$\lambda_e(R) \cdot \lambda_a(R) = \text{constant}, \quad (4)$$

where the constant term depends on gas density, the thickness of the disk and so on, but is independent of R . For the Kolmogorov type of spectrum in the interstellar magnetic turbulence, they can be expressed as

$$\lambda_e(R) = a \cdot R^{-\mu} \quad \text{and} \quad \lambda_a(R) = b \cdot R^{\mu} \quad \text{with} \quad \mu = 1/3. \quad (5)$$

Returning to fig. 20, we fit eq. 3 coupled with eq. 5 to the straight line above 40 GV so that it continues smoothly to the line given by eq. 1 in the lower rigidity region $\lesssim 40$ GV, where one should remind that eq. 3 breaks down in the region $\lesssim 10$ GV. I set the parameters in eq. 5 as $a=9.35$ and $b=3.00$ (R : in GV), which is drawn in fig. 20 together. I feel the flattening shape drawn here is rather favourable to the data given by Ichimura et al..⁷ I expect the JACEE data will also support this trend in the higher rigidity region, because they have reported a rather high intensity of “iron-group”, though they don’t present the sub-iron component from *pure* iron separately.

Now, from the view point of the diffusion model with a reacceleration process, I think the $R^{-0.6}$ behaviour of the escape length seen in the range $5 \sim 200$ GV would be “accidental” and not fundamental. The fundamental behaviour should be $-1/3$ which can be seen in the higher rigidity range, where the reacceleration contribution becomes minor.

⁷I found in the proceedings that a similar consideration was reported by Swordy in another session[OG 6.1.10], while he assumed constant escape length in the higher energy region, leading to a constant anisotropy amplitude.

6.2 Source spectrum

Figure 21a is the source spectra multiplied by $R^{2.0}$ of typical primary components, presented orally by Ichimura et al., using eq. 1 without reacceleration, while fig. 21b is those obtained by the use of the chain curve in fig. 20, incorporating the reacceleration process *phenomenologically* as discussed before. Here the modulation parameter $\Phi = 600$ MV is assumed in all cases and the ionization loss is neglected, but the both effects are minor except in the small rigidity region below a few GV. Fragmentation cross sections are based on Webber's code[4] provided by T.K.Guzik through the network.

In both figures all components appear as approximately straight lines in the region $R \lesssim 10$ TV, with exponents $\gamma = 2.1 \sim 2.3$ for fig. 21a, and $2.3 \sim 2.4$ for fig. 21b. The difference here comes of course from the choice of different rigidity dependence of escape length. Looking carefully at fig. 21a, however, I note that both helium and iron components flatten in the region $\gtrsim 100$ GV, giving $\gamma = 2.0 \sim 2.1$. This value seems to coincide with the result reported by Swordy(OG 5.3.4) as discussed in the last sub-section. Though this flattening might come from either some new source as suggested by Biermann et al.[36], or the effect of nonlinear shock acceleration as proposed by Ellison[27], I note a key difference between fig. 21a and 21b, that the source spectra of all elements in fig. 21b conform to a common straight line without any flattening over a wide rigidity range, obtained by assuming *weaker* rigidity-dependent escape length at higher rigidity. I feel the source spectra in fig. 21b are more natural than those in fig. 21a for various reasons as discussed in the last subsection.

Another point I would like to note in fig. 21b is the slight deviation of the proton points from the straight line in the highest rigidity region $\gtrsim 100$ TV, though the drop here is not so drastic as reported by JACEE in the last conference at Calgary[28]. In order to see the situation in much higher rigidity region, in fig. 22 I plot the rigidity source spectra of typical three elements, proton, helium and iron, expected from indirect observational data, onto the direct observational data shown in fig. 21b, where Fuji-Kanbala data[37] (shaded quadrangles; hereafter called F-K data) are available only for the proton component, and the BASJE data(big square; OG 6.1.5, presented in the poster session) for the three components (see original data on the energy spectra in fig. 23). In the iron data obtained by the BASJE-group, I reduced the original flux value by 15%, eliminating the contamination of sub-Fe ($Z=17-25$).

In order to transfer the F-K and the BASJE data to the rigidity spectra at the source, I have used the rigidity-dependent escape length shown in fig. 20 (chain curve). Of course one may doubt whether the $R^{-1/3}$ -dependence of escape length is applicable in such a high energy region, but it is not inconsistent with the gradual increase of the anisotropy amplitude for $\gtrsim 100$ TeV found in air shower experiment[31, 38], apart from the absolute amplitude.

Fig. 21. Source rigidity spectra for individual primary elements obtained by the use of rigidity-dependent escape length, expressed by a) the straight line ($\propto R^{-0.6}$) and b) the chain curve ($\propto R^{-1/3}$ for $R \rightarrow \infty$) as appeared in fig. 20. I plot each data without distinguishing between observers (if necessary see fig. 22).

Fig. 22. Source rigidity spectra for p, He and Fe, including higher rigidity data obtained by the indirect observations, emulsion chamber and the air shower array at high mountain altitude. The escape length used here is the same as in fig. 21b.

○: Ormes et al., □: Ryan et al., ▽: Müller et al.,
 ○: Ichimura et al., △: JACEE1-12, ▲: JACEE10,
 ◇: Ivanenko et al.('93), ◊: Ivanenko et al.('90),
 +: Engelmann et al., ×: Simon et al.;
 shadowed quadrangles: Fuji-Kanbala, □: BASJE.

Explicit volume numbers of the references for individual authors are summarized in ref. 46. For helium components, all the data are plotted in the form of filled symbols, corresponding to open ones appeared in proton and iron.

Curves are those drawn from eqs. 6 and 8, assuming following pairs of values for $[\gamma, \epsilon]$.

----- : [2.30, 0.467]
 ————— : [2.35, 0.417]
 — · — · — : [2.40, 0.367].

Some people might naturally claim that since there include many uncertainties in the indirect observational data, particularly in the identification of the primary component, the data of the above two groups in fig. 22 should not be compared equally with those obtained by the direct observational ones. So I briefly comment on this point.

The F-K data is obtained by means of the emulsion chamber experiment at high mountains (Mt. Fuji in Japan and Mt. Kanbala in China), observing high energy hadron, gamma-rays, and gamma-ray families (bundle). I would like to emphasize here that the atmosphere plays the role of filter against heavy components, so that most of the particles detected in the form of cascade shower come from proton primaries at the top of the atmosphere, nearly irrespective of the primary abundance. This fact enables us to estimate the primary spectrum of the proton components without worrying about the choice of the primary abundances.

The BASJE data is obtained by measuring the arrival time distributions of air Cherenkov light associated with air showers. In this conference they reported the energy spectra for the five major element groups: p, He, CNO, Ne-S, and Fe-group ($Z=17-28$), which are estimated by comparing the time-interval distributions, observed at Mt. Chacaltaya during the period from June 21st to August 3rd this year, with simulational results.

The Both groups have performed the observations at high mountains with the atmospheric grammage of $520 \sim 540 \text{ g/cm}^2$, nearly corresponding to the depth of shower maximum for the longitudinal development of the air shower in the knee region. So, the both experiments are quite favourable for the study of primary spectra around the knee region.

Now, looking over the entire rigidity region in fig. 22, it is remarkable that both the direct and indirect data continue smoothly, and no *drastic* break in rigidity spectrum appears anywhere around 100 TV. I would like to point out, however, that the energy spectrum of primary protons obtained by the mountain experiments, particularly by F-K group, depends crucially on the assumption of a scaling property in the fragmentation region, which is still in debate among high energy physicists. If the scaling property breaks in the forward region, the source spectrum of proton primary in fig. 22 would recover to be somewhat harder in the air shower region. So, one should regard the source spectrum of the protons estimated from the indirect observational data in fig. 22 as a lower limit. Anyway we can say definitely that the source spectrum of proton does not drop drastically around the "magic" rigidity, $50 \sim 100 \text{ TV}$, but decreases gradually.

For the purposes of discussion in the next section, I fit the following empirical function to data on the rigidity source spectrum for protons,

$$\left(\frac{dQ}{dR}\right)_{source} = q_0 R^{-\gamma} \cdot \Theta(R). \quad (6)$$

Here $\Theta(R)$ relates to the acceleration limit, for instance in the case of current shock wave model it may be expressed

$$\Theta(R) = \theta(R_c - R), \quad (7)$$

where R_c is the rigidity of the acceleration limit, typically ~ 100 TV and θ is the step function.

Since there is no such drastic cutoff in fig. 22, I assume[45]

$$\Theta(R) = \frac{1}{(1 + R/R_c)^\epsilon} \quad (8)$$

Remembering $\Lambda_e \rightarrow R^{-\mu}$ for $R \rightarrow \infty$ (see eqs. 3 and 5), ϵ satisfies the following relation,

$$\gamma + \epsilon + \mu = \beta_\infty, \quad (9)$$

where $\beta_\infty = 3.0 \sim 3.2$, denoting the spectral index of proton rigidity spectrum for $R \rightarrow \infty$ at the *Earth*. So the spectral index γ_∞ of the proton spectrum in the high rigidity region in fig. 22 is given by

$$\gamma_\infty \equiv \gamma + \epsilon = \beta_\infty - \mu \simeq 2.77 \quad (10)$$

I would like to point out that in the shock wave model with acceleration limit R_c , eq. 6 coupled with eq. 8 is no longer the “source” spectrum, but should be regarded as a “modulated” source spectrum. In alternative models, for instance that proposed by Ptsukin[37], eq. 8 may be regarded as a modulation function related to an enhanced escape rate above the knee. Here I don’t discuss the origin of reboosted (or reduced) modulation in the rigidity spectrum for $R > R_c$, though it may be a principal problem in the knee puzzle, coming from either a new component, or a second stage acceleration, or something else.

I assume three pairs of values, $[\gamma, \epsilon] = [2.30, 0.467]$, $[2.35, 0.417]$, and $[2.40, 0.367]$ with $R_c = 2000$ TV, which correspond to $\beta(\equiv \gamma + \mu) = 2.63, 2.68$, and 2.73 , respectively, denoting the spectral indices of proton rigidity *below* the knee at the Earth. Though the choice of characteristic rigidity R_c is rather free in this stage, I set so that it reproduces well both the proton and helium rigidity spectra in fig. 22.

Three curves have been drawn also onto the data of helium and iron source spectra in fig. 22. Though the proton data obtained by the indirect observation

a lower limit flux as I mentioned above. While the helium data seems to creep above the curve with $\gamma=2.35$ in the region $\gtrsim 10$ TV, I feel it is still consistent with the curves. In short, my guess on the rigidity spectra of the three components at the source shown in fig. 22 is as follows: they are reproduced quite well by a power law with a common spectral index $2.3 \sim 2.4$, within statistical error.

Here I will, however, have to give a glance to an alternative view in which it is inferred that there may exist some difference between protons and heavier components. In fact, if, in fig. 22, we take up the experimental results literally, we will have $\gamma = 2.35 \sim 2.40$ for protons and $\gamma = 2.30 \sim 2.35$ for heavier components, the proton spectrum being a little steeper, by $\Delta\gamma \sim 0.05$, than those of heavier components. The discrepancy may very well be expected, because, for example, heavier components have twice as large mass-to-charge ratio A/Z as that of protons. In this connection, I feel much attracted by a non-linear shock acceleration model proposed by Ellison[27], which predicts higher acceleration efficiency for higher A/Z components, resulting in a spectral index difference $\Delta\gamma \sim 0.05$ between protons and heavier components.

But the spectrum business is a one which requires extreme care and, indeed, we have several experiences of appreciable ups and downs in spectral indices in the past. Therefore I want to entrust future experiments of better statistics with any definite conclusions on the above-mentioned component-wise fine differences in spectral indices.

7 “Knee” problem

7.1 All-particle spectrum

In general, it is not so easy to get the all-particle spectrum by direct observational methods unless we place a heavy absorber in the detector, thick enough to materialize all the kinetic energy of the incident particle in the form of an electromagnetic shower. For instance, in the case of the Proton-satellite experiment performed by Griogorov et al.[39], the material grammage amounts to Pb of 140g/cm^2 and Fe of 855g/cm^2 , corresponding in total to ~ 80 radiation length and 9 collision m.f.p. against proton primary. Without enough material, we have to observe individual elements separately and sum all of them in individual energy bins, although even in this case, we still need much grammage for calorimeter-type emulsion chamber in the higher energy region as I comment in the end of sect. 5.2.

So, before going to the all-particle spectrum, I summarize the energy spectra of individual elements observed at the Earth. Of course these spectra are

Fig. 23. Individual energy spectra for p, He, C, O, Si, sub-Fe, and Fe multiplied by $E^{2.5}$, observed at the Earth. Curves drawn are obtained by eqs. 6 and 8, assuming following pairs of values for $[\gamma, \epsilon]$, - - - - : [2.30, 0.467], — : [2.40, 0.367].

equivalent to the source spectra using a rigidity variable presented in the last section, but are naturally much more familiar to us than those at the source.

In fig. 23, I plot the energy spectra for individual elements in the very wide energy range, $1 \sim 10^8$ GeV/particle (Unfortunately I could not plot JACEE data for C $\sim$ sub-Fe [$Z=17 \sim 25$] because each element has not been separately presented). I show also the calculated curves expected from eqs. 6, 8 and the escape length discussed in the last section. Naturally they are in good agreement with experimental data since the figures are equivalent to those in fig. 21b.

One may remark that the shape of the sub-iron ($Z=17 \sim 25$) curve is a little bit different from the other *primary* elements in the higher energy region. This is because most of them are fragment products from the passage of iron through the Galaxy, while the sub-irons synthesized at source (mainly Ar, Ca, Cr) become dominant in the higher energy region $\gtrsim 100$ TeV/particle, so that the spectral index of these elements approaches to those of the *primary* components at very high energy.

I would like to note one more feature in the energy spectra of individual elements such as N, Ne, Mg and S, which did not appear in figs. 23 because of

insufficient space. Though most of these are also consistent with the calculated curves with $\gamma = 2.3 \sim 2.4$, the nitrogen data is significantly different from the expected curve. I shall not discuss in detail whether this is due to statistical fluctuation, or some other reason related to the cosmic-ray origin, but we should keep this fact in mind. This problem is, however, not critical for the estimation of the all-particle spectrum below, because the contribution of nitrogen to it is minor.

Summing these curves all together, I give the expected all-particle spectrum in fig. 24. Plotted are the JACEE data presented in this conference(OG 6.1.14) as well as the well-known Grigorov data[39] and air shower data compiled by Nagano[40]. I plot also the energy spectra of protons, iron together for reference. In this figure I would like to note two points.

Firstly, carefully looking at the Grigorov data, one will find the flux points drop significantly at ~ 4 TeV/particle, and flatten thereafter. I think this originates in the sudden steepening of the proton spectrum above ~ 1 TeV

Fig. 24. All-particle spectrum obtained by both direct and indirect observational method. Energy spectra of typical elements, p and Fe, are also plotted for reference. Curves drawn are the same as in fig. 22.

▣ : Grigorov et al., ■ : JACEE(OG6.1.14), □ : AKENO.

($\beta \simeq 3.25$!) as reported by the authors,⁸ leading to the enhancement of heavier components in the flattening region 4 to 1000 TeV/particle. Nowadays, however, the proton spectrum has been shown to decrease as a power law with an exponent of 2.75 from ~ 10 GeV to ~ 10 TeV as shown in fig. 23, and the average primary mass remains also constant in this energy region, so I cannot agree with a straightforward interpretation of the flattening in the region, 4 $\sim$ 1000 TeV, which appeared in Grigorov data. I believe rather in the two lines with $\gamma=2.35$ and 2.40 based on the summation of energy spectrum data for individual elements, which show monotonic decrease without flattening below 100 TeV/particle.

Secondly, after AKENO group published the data[40] shown in fig. 24, the sharp kink, clearly seen around 5×10^{15} eV, has been considered clear evidence of a knee. While the AKENO group did not emphasize the “sharpness” so strongly, many authors doing air shower studies have tried to have simulational calculations reproduce the sharp kink as well as “flattening” below the kink, connecting to the “flattening” appearing in the Grigorov data. I find, however, in this conference several air shower experiments performed on *high mountain* present somewhat different results, which follow in the next sub-section.

7.2 “Knee” problem

The Knee problem was pointed out by B. Peters[43] more than 35 years ago, and its importance has continued to increase, in step with study of the origin and the acceleration limit of galactic cosmic-rays. Nevertheless the situation is not yet clear even with much better modern observational techniques. I think this is probably because the both direct and indirect observations are technically particularly difficult in the knee region around $10^{14} \sim 10^{16}$ eV. With direct methods, it is difficult to have an exposure long enough to collect good statistics, and of course reliability of the energy determination is troublesome, while with indirect methods, detection bias and core-location uncertainty make the reliability of the primary spectrum poor, particularly at sea level, where the observation level is far beyond the depth of shower maximum in the knee region, $500 \sim 700$ g/cm². These problems seem to have caused considerable confusion concerning the knee feature, with some group showing extreme bumps, while others propose rather mild shapes.

I found two typical and interesting opinions on this problem in the proceedings of International Symposium held at Kofu(Nov. 1990), by Axford[44]

⁸They claim the proton spectrum obtained by the emulsion chamber is considerably deformed due to detection loss bias in the lower energy region $\lesssim 40$ TeV, which would lead to a harder spectrum ($\beta \simeq 2.75$) than the “true” one[41]. But this argument is based on a mis-understanding of the scanning search for showers on X-ray film, details of which will be discussed elsewhere[42].

and Gaisser[45]. I quote their comments in the following.

There is a suggestion that there might be a bump in the spectrum in the region of the knee but this is at most a factor 2. An examination of reported compilations of the data suggests that the total energy spectrum in the region of the knee is a continuous and monotonic decrease in the intensity from one power to a steeper one: there is no clear evidence for a drop in the spectrum.

(W.L. Axford)

The physical origin of a new component, if it indeed exists, remains to be determined. Jokipii and Axford argued at this conference against a second component on the grounds that fine tuning would be needed to adjust it to take over just where the low energy mechanism fails in such a way as not to produce too much of a bump in the spectrum. They prefer a single mechanism to explain the cosmic rays both below and above the steepening. As persuasive as their argument is, it is a philosophical argument. We still need experiment to settle whether or not there is in fact a new component in the region of the knee. (T.K. Gaisser)

I believe everybody agrees that the all-particle spectrum changes significantly at the knee. The problem is how it changes, i.e., does the spectrum shape around knee show a drastic bump, or flattening before steepening, or does it smoothly continue to steepen in the higher energy region? Of course at this stage I cannot give a definite conclusion because of the poor data, particularly the direct observational one. In this conference, however, there are reported several new data sets obtained by air shower experiments at high mountain altitude, details of which are summarized in the rapporteur paper of S. Petrera.

In fig. 25, I plot the all-particle spectrum presented in this conference [OG 6.1 13, OG 6.2.4, OG 6.2.14, OG 6.2.1]. From this figure, both the direct and indirect data seem to connect smoothly, even though the air shower data fluctuate considerably from author to author.

I think each author would agree that there is some uncertainty in the conversion from shower size to primary energy, at least as large as $10 \sim 20\%$, leading to a $15 \sim 31\%$ uncertainty in the flux value when multiplied by $E^{2.5}$. So, I normalize the all-particle spectrum to those obtained by BASJE, adjusting the energy scale slightly for two other groups, reducing it by 15% for Tibet, and increasing it 15% for TACT, and show the result in fig. 26. One finds the all-particle spectrum continues smoothly from direct experiment side to indirect experiment side without any significant bump, though it is difficult to say whether or not the flattening is significant below the knee. Both the direct and indirect data seem to be distributed on the line expected from the spectral indices of source rigidity -2.35.

Fig. 25. Same as fig. 24, but air shower data are only those presented in this conference.

Fig. 26. Same as fig. 25, but the TIBET and TACT data are slightly shifted (see text for detail). The curves drawn are the same as in fig. 24.

8 Concluding remarks

It was rather fortunate to have this opportunity to do the rapporteur talk on spectrum and composition based on the direct observation at this time, as so many fruitful and important results have been reported in this conference. In particular, the new data from both the antiproton and positron experiments are very impressive, showing us quite different features from we had previously understood to be there. Based on these new data, the study of antiproton and positron origins will progress and become much more reliable and persuasive, even though most of $\bar{p}$'s and e^+ 's may come from secondary products during the passage of protons through the Galaxy. We expect more data from both experiments in higher energy region, where some new features might appear.

Space mission observations also bring us critical informations about isotope ratios of both GCRs and ACRs, and the time delay between nucleosynthesis and acceleration, giving us something suggestive on GCR origin and nucleosynthetic history. We expect also UHN data obtained by LDEF and Mir will be completely processed in the near future, and will bring us decisive information about the relative contribution of the r and s neutron capture processes to the nucleosynthesis.

While most of the results on composition and energy spectrum are consistent with leaky box model, the diffusion model incorporating a reacceleration process agrees much better with the data (and is more reasonable), both in the low and high energy regions. To clarify the propagational model, more data on escape length is desirable in the higher rigidity region $\gtrsim 1$ TV with use of either B/C or sub-Fe/Fe ratios.

Though all the results summarized in sects. 2 ~ 7 are naturally connected with each other, and everybody wants to build an unified picture of the subjects covered in this paper, it is too big a job for me to give such a clearcut summary. It may, however, be worthwhile to comment that behind these studies, we always face the uncertainty in the data of fragmentational cross section. So, I feel a more complete understanding of the cross section, both in experiment and theory, is necessary to reach the goal of solving the spectrum and composition problems.

Finally the discussion appeared in sects. 6 and 7 is perhaps a somewhat biased and subjective view, and some my arguments may be off the point. Nevertheless, I ventured to comment on the knee problem in order to improve the foggy situation in both experimental data and interpretation somewhere around 10^{15} eV. I feel the *drastic* bump (or sharp kink) around knee region has now disappeared in this conference, but the composition around the knee is still not clear. We need experiment more for a firm conclusion. Particularly the direct observational data on the individual energy spectra in the knee region are quite desirable to answer for these problems.

Under these situations, it was a good news that JACEE-group has succeeded constantly in balloon campaign in Antarctica, and the RUNJOB-program started this summer. Both programs aim at direct observation of cosmic rays in the knee region. So, we may reasonably hope that the energy spectrum and composition will be revealed not in the distant future, but within this century.

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