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ESTIMATION OF PATH–LENGTH DISTRIBUTION OF Fe PRIMARIES AT SOURCE USING STEADY–STATE LEAKY–BOX MODEL

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Using the steady–state leaky–box model for cosmic ray propagation in interstellar matter, along with the Alice Springs balloon flight data for sub Fe–Fe group, the escape length has been estimated and found to be 1.48 g/cm^2. The result is in fair agreement with the global fit to the escape length distribution surveyed by Ormes and Frier at the energy 100 GeV/n, which is comparable with our estimated source energy 86 GeV/n based on observed average energy and other propagational parameters.

1. *Introduction*

The steady–state leaky–box model (SSLB) is an appropriate model for the investigation of propagation for primary cosmic particles through interstellar medium (ISM). The astrophysical information on the equilibrium of cosmic ray Fe spectrum depends on the mean path–length and is based on the assumptions that the primary cosmic ray diffuses through the confined material contained in a leaky–box, whose volume is equivalent to the dimension of Galaxy, and encounters the boundary wall very often during its lifetime. One can fairly reliably calculate Fe spectrum at source by adopting SSLB model.

In a recent investigation, we have estimated the abundances of sub Fe–Fe components of primary cosmic rays near the top of the atmosphere using passive detectors like Fujii ET–7B nuclear emulsion and CR–39 plastic, flown from Alice Springs for 32 hours. Details of these measurements are presented in Ref. 1. We have used the leaky–box model to estimate the source composition by considering the conventional parameters like total and partial cross–sections and escape length. Recently, Doi et al. [2] have analysed the sub Fe–Fe flux ratio in the frame of the leaky–box model by considering their balloon–flight results along with the heavy nucleus–nucleus cross–sections and other fragmentation parameters of Webber et al. [3]. Their estimated escape length supports the energy dependence behaviour.

In the present study, we have used our estimated sub Fe–Fe fluxes, along with the total and partial charge–changing cross–sections from the formulation of Letaw et al. [4] and Tsao et al. [5], to evaluate the escape length of Fe at source. The matching of the result with the global survey of Ormes and Frier on the energy dependence of path–lengths [6] at source may give an indirect support to our estimated source energy.

2. Propagation model

We have adopted the conventional steady–state leaky–box model [7] which follows the form

$$Q_i = < X > N_i \left(\frac{1}{\Lambda_i} + \frac{1}{\Lambda_{esc}} \right) - < X > \sum_{j>i} \frac{N_j}{\Lambda_{ij}}, \tag{1}$$

where Q_i is the source term producing i–th particle/(cm^{3}s) in Galaxy, N_i and N_j are the density of species i and j, Λ_{ij} is the interaction path–length for species j $(> i)$ to fragment species i, Λ_i is the interaction path–length for species i in hydrogen and $< X >$ is the average column density.

The esacpe length depends on the rigidity of the nucleus. The simplified formulation of Doi et al. [2] follows the relation

$$\frac{1}{\Lambda_{esc}} = \frac{\sum\limits_{Z=21}^{Z=24} P_{\mathrm{Fe}\to z}}{\sum\limits_{Z=21}^{Z=24} I_Z} \frac{I_{\mathrm{Fe}}}{\Lambda_{int}^{\mathrm{Fe}}} - \frac{\sum\limits_{Z=21}^{Z=24} \frac{I_Z}{\Lambda_{int}^{Z}}}{\sum\limits_{Z=21}^{Z=24} I_Z}, \tag{2}$$

where $P_{\mathrm{Fe}\to z}$ is the fragmentation probability, usually the ratio of the partial to total cross–section of Fe, I_Z is the intensity of cosmic ray nuclei at source, I_{Fe} is the intensity of cosmic ray Fe nuclei at source, Λ_{int}^{Z} is the interaction mean free path of cosmic ray nuclei in hydrogen medium and $\Lambda_{int}^{\mathrm{Fe}}$ is the interaction mean free path of Fe nuclei in hydrogen. The sub–Fe nuclei have the charges Z ranging from

21 to 24. The values of parameters used in reactions (1) to (4) are given in Table 1.

The total charge changing cross–section for the element i is obtained after Letaw et al. [4], as follows:

$$\sigma_i = 45A_p^{0.7}\left[1 + 0.016\sin\left(5.3 - 2.63\ln A_p\right)\right] \quad \text{mb}, \tag{3}$$

where A_p is the mass of the projectile, and

$$\Lambda_{int}^{Z} = \frac{A_T}{6.023\times10^{-4}\times\sigma_{Z=i}(\text{mb})} \quad \text{gm/cm}^2, \tag{4}$$

where A_T is the target mass, and $\sigma_{Z=i}$ (mb) is the total charge changing cross–section for the element i. We choose $Z = 21,\ 22,\ 23$ and 24 as the elements present in the sub–iron group.

TABLE 1.
The cross–sections, mean free path, intensity of sub Fe–Fe *nuclei used in the present investigation.*

Element Z	Total cross–section σ_Z (mb)	Interaction mean free path Λ_{int}^{Z} (gm/cm^2)	Elemental intensity at source (m^{2}s sr)$^{-1}$	Partial cross–section $\sigma_{P\to s}$ (mb)	$P_{\text{Fe}\to Z} = \frac{\sigma_{P\to s}}{\sigma_{i=\text{Fe}}}$
Sc	645.49	2.60	0.0012	45.15	0.066
Ti	675.26	2.48	0.0050	58.74	0.086
V	704.53	2.38	0.0051	43.93	0.064
Cr	715.18	2.34	0.0107	75.93	0.111
Fe	753.26	2.45	0.1810	70.22	0.103

The partial cross–section is taken from the latest semiempirical formulation of Tsao et al. [5].

The intensity of cosmic ray nuclei is taken from our earlier observation on the elemental abundance of primary cosmic rays over Alice Springs [1].

Using relations (1) to (4), the escape length of Fe nuclei at source is estimated and found to be 1.48 gm/cm^2. We have compared this escape length value with the expected result from the fit to global path–length distibution surveyed by Ormes and Frier [6] given by

$$\Lambda_{esc} = (7\pm1\ \text{gm/cm}^2)\left(\frac{E}{2}\right)^{-0.4\pm0.1}, \quad E\ \geq 1\ \text{GeV/n} \tag{5}$$

where E is the energy of cosmic–ray Fe nuclei.

The above form yields the Fe energy at source $E_s = 100$ GeV/n corresponding to the estimated path–length $\Lambda_{esc} = 1.48$ gm/cm^2 which is also shown in Fig. 1.

In our earlier observation [1], we have shown extrapolated source energy which was found to be 86 GeV/n obtained from observed average energy 8 GeV/n at top of the atmosphere. So, the present escape length is supported by the global survey at source energy of 100 GeV/n, and this also gives an indirect support to our derived extrapolated source energy of 86 GeV/n from the observed data.

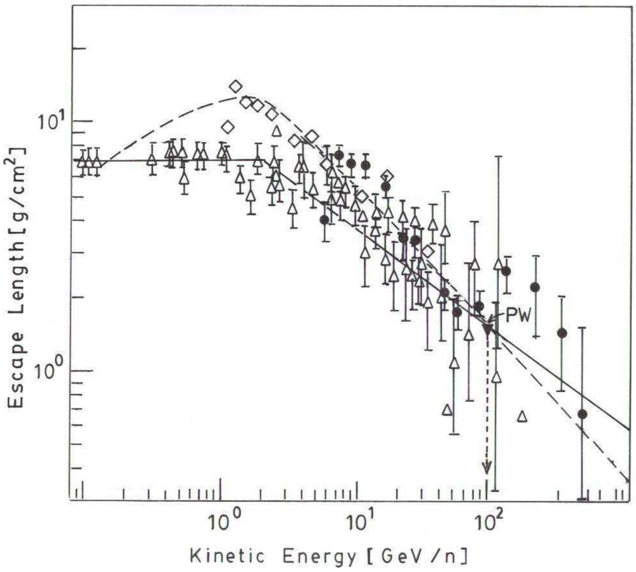

Fig. 1. Escape path–length as a function of energy using full propagation calculation as derived from the observed results: ○ – Doi et al. [2], △ – Ormes and Frier [6], ◇ – Engelmann et al. [8], ▽ – present work. Full line is the fit obtained from Ormes and Frier [6]. The result agrees with the fit at the arrow mark point on the energy scale indicating 100 GeV/n *energy.*

3. Conclusion

The path–length distribution at source, expected from SSLB model for Fe primaries, based on the sub Fe–Fe results, has been estimated from the global survey of path–length distribution at energy 100 GeV/n, which is close to our calculated value 86 GeV/n.

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OCJENA RASPODJELA DULJINA PUTEVA PRIMARNIH Be PRI IZVORU PRIMJENOM MODELA STACIONARNOG STANJA U PROPUSNOJ KUTIJI

Primjenjen je model stacionarnog stanja u propusnoj kutiji za širenje kozmičkog zračenja u međuzvjezdanom prostoru, te je s podacima dobivenim s emulzijama koje su bile izložene pri letu balonom u Alice Springsu, za podgrupu Fe–Fe određena duljina bijega od 1.48 g/cm^2. Taj je rezultat u skladu s općom prilagodbom raspodjele duljina bijega prema pregledu Ormesa i Friera na energijama 100 GeV/n. Njihova je energija usporediva s našom ocjenom izvorne energije od 86 GeV/n, zasnovane na prosjeku opaženih energija i drugim parametrima za širenje kozmičkog zračenja.