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Ferrando P., Goret P., Koch-Miramond L.,
Petrou N.. Soutoul A.
The Saclay-Copenhagen HEAO Collaboration
Service d'Astrophysique, Centre d'Etudes Nucleaires de Saclay
France

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ABSTRACT

We present results on mean masses of cosmic rays at energy about 3 GeV/n, for Ne, Al, Mg, Si, S, Ca, and Fe, derived from the data collected by the Danish-French experiment C2 on board HEAO3. We used a method based upon comparison between observed transmission function and a predicted one computed from a geomagnatic field model. We find enhancement factors of 2.9 +-.7 for 22Ne/20Ne, 2.1 +-.4 for (25Mg+26Mg)/24Mg, and 1.6 +-.8 for (29Si+30Si)/28Si at GCRS when compared to LG.

Introduction

Cosmic ray isotopic rather than elemental composition is a major clue to the understanding of cosmic rays history because while the elemental source composition can a priori be interpreted in terms of any kind of scenario involving either atomic or nuclear processes, isotopic anomalies almost certainly imply specific nucleosynthetic processes (at least for Z > 4). If elemental abundances and spectra are now well established /1,2/ and show remarkable similarities with Solar System abundances and Solar Energetic Particles /3/ , isotopic composition measurements available at low energy (<1 GeV/n) show significant differences when compared to Local Galactic material (see /4/ for a review). Measurements at higher energy present the advantage to be less dependent upon solar modulation; however they are more difficult to perform . Peters /5/ has developed a method allowing determination of mean masses with the help of the geomagnetic field; analysis of HEAO3-C2 data were already performed using the transmission function method /6,7/ but dealed with part of the data because of geomagnetic selections. In this study a different approach is used: we also start from the observed transmission function (OTF) which reflects the filtering effect of the geomagnetic field upon relativistic particles; this effect depends upon rigidity so that isotopes with different A/Z ratios show different OTF. The point of our method is that we compute the theoretical filtering effect in the frame of a geomagnetic field model (MAGSAT 4/81); we are then able to predict the various transmission functions corresponding to all possible isotopic fractions. Isotopic composition is derived by adjusting the predictions to the actually observed transmission function.

Method

Building an OTF requires the knowledge for each detected particle of the momentum by nucleon P and the main cut-off Rc corresponding to the position and direction of arrival in the instrument /6,7/. P is measured by the instrument and Rc is computed with a trajectory tracing method /8/. The number of particles observed with momentum by nucleon p° at a main cut-off Rc is given by :

$$d^2N/dp^*dRc = Tex(Rc). \sum_i \int_p F(Rc,Ri).Si.f(p).P(p,p^*)dp \quad (1)$$

with Ri= Ai.p/Z . Tex(Rc) is the exposure time at main cut-off Rc, f(p) the differential momentum spectrum of the element, Si the isotopic fraction of isotope Ai , and P(p,p*) the momentum resolution function of the instrument. Tex(Rc) and f(p) are derived from the data. F(Rc,R) is the mean geomagnetic filter function at main cut-off Rc. Let us recall that a particle can reach a given point of observation in a given direction only if it passes the geomagnetic field barrier, which may be described as a filter function ff(R) which only depends upon rigidity. For each point and direction there exists a main cut-off Rc so that ff(R)= 1 if R>Rc. For R<Rc one may have either ff(R)= 1, if the associated trajectory is allowed, or 0 if it is forbidden (penumbra region). The mean filter function F(Rc,R) represents the average of all filters ff(R) at a given Rc. Practically, for each particle, we compute Rc as the highest forbidden rigidity; then we randomly select 30 rigidities in the penumbra region for which we compute if they are allowed or forbidden. The mean filter function F(Rc,R) is obtained by averaging all these statistical penumbra at given Rc. Preliminary calculations have shown that the penumbra vanishes below .75 Rc for the region of interest here. To avoid biases in the computation of mean filters only particles with p/Rc>.6 were selected. Predicted transmission functions corresponding to given isotopic fractions are computed by summation of (1) at constant p/Rc.

Determination of experimental parameters

We analysed data with rigidity between 7 and 9 GV and momentum between 3.2 and 6.1 GeV/cn; the fit region (p/Rc= .4 to .52) corresponds to a mean energy of 3 GeV/n. 21 mean filters were computed by step of 0.1 GV from 7 to 9 GV. The instrumental function P(p,p*) is taken as a gaussian function with a standard deviation S. To account for a possible drift in momentum we introduce another parameter, D, so that p observed = D times p true. To determine S and D oxygen is used as a reference element assuming 96% of 16O, 2% of 17O, and 2% of 18O. However these two parameters alone do not allow us to account for the OTF of oxygen which is systematically higher than prediction in the penumbra. The discrepancy is removed by assuming a scaling factor SF by which we multiply all computed F(Rc,R) in the region R/Rc < 1.0. The three parameters are simultaneously optimized by minimising the chi² between observed and predicted transmissions. Values of .990, 4.3%, and 1.18 are respectively found for S,D and SF. Fig 1 shows the agreement between predicted and observed transmission functions for oxygen. The shift of 1% between actual and observed momentum, which is compatible with the error on the measurement of the refractive index of the Cerenkov detector, indica-

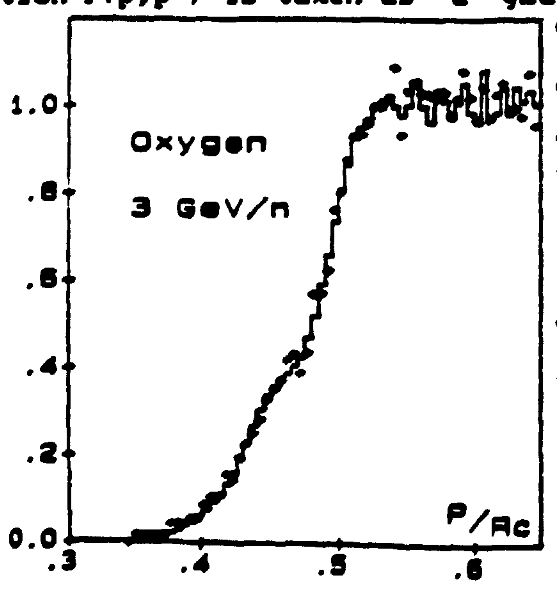

Fig 1: Observed transmission function (+), and best fit prediction (full line).

tes that the geomagnetic field model gives an accurate estimate of the main cut-off. The value of SF shows that more than 80% of the penumbra is well accounted for by the model; the missing 20% may come either from complex trajectories not handled properly by the tracing program, or from possible instrumental background. S is twice higher than the value expected from the statistics of Cerenkov photoelectrons alone. It reflects other effects like delta rays, and a possible slight distorsion in the shape of the estimated mean filters.

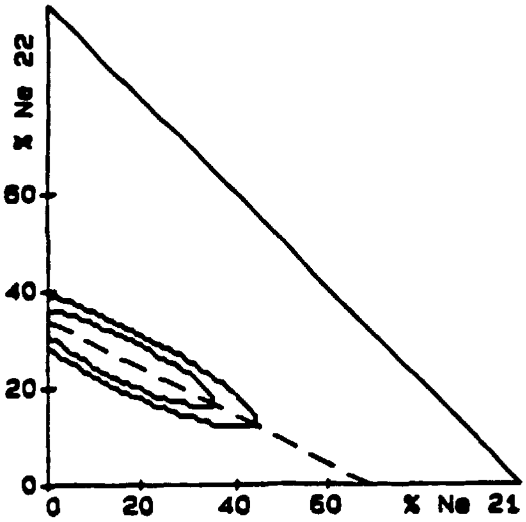

Fig 2: 68 and 90% confidence level regions for observed fractions of 21Ne and 22Ne. Broken line is the line of mean mass 20.68 .

Results

The same parameters D and SF derived from O were used to analyse higher elements. A 1/Z dependence of S was found suitable; it's value has only a little influence on mean masses. We computed all chi² between OTF and prediction for all possible isotopic composition; the minimum chi² gives the measurement. Contours of 68 and 90% confidence level from chi² analysis are plotted in fig 2 for Ne isotopes. The strongly elliptical form of the contours is the sign of highly correlated parameters; the major axis of ellipses are aligned with the equal mean mass lines, showing that the fundamental parameter of the method is the mean mass. Results are therefore given as mean masses with quoted errors corresponding to a chi² increase of 1.0 from minimum chi². A check is provided by Na (which has a single isotope), 311 Na are predicted, in agreement with the 324 observed in the fit region. In table 1 we report our results together with the mean masses obtained from a propagated solar source (SS) composition. S,Ca, and Fe have an observed mean mass quite compatible with a propagated SS composition, while Ne (confirmed by /9/, also from HEAO3-C2 data, but with a different method), Mg, and possibly Si are found to be neutron enriched.

Discussion

Results were propagated back to Galactic Cosmic Ray Sources (GCRS) in a leaky-box model, including energy losses, radioactive decay, in a pure H (density 0.3 cm⁻³) I.S.M. . An escape length equal to 22.R-0.6 (6.2 g/cm⁻² at 3 GeV/n), and a modulation parameter ϕ = 600 MV were assumed according to /2/. We also assume 0 % of 21 Ne, an equal fraction of 25 and 26Mg, an equal fraction of 29 and 30Si in GCRS. Errors only include statistical measurement uncertainties. In table 2 the ratios of GCRS abundances to Local Galactic (LG, from /10/) are given for Ne, Mg and Si. It is seen that Ne and Mg are definetely neutron enriched in GCRS, with enhancement factors comparable to the low energy results of 4.1 (+.8,-.6) for Ne, and 1.6 (+.3,-.2) for Mg, at ≈ 200 MeV/n, /4/. There is therefore no evidence for an energy dependence of these isotopic source anomalies. The poorer resolution for Si isotopes does not allow us to distinguish between a LG composition or a neutron rich one. These results are compatible with the suggestion that the bulk of Cosmic Rays is injected in the acceleration process from solar like stellar coronae with normal abundances, while a minor part of it (2-3 %) would come from sites having experienced more evolved nucleosynthesis. Wolf-Rayet stars could explain the neutron rich component for Ne and Mg, as well as the overabundance of C but predicts a normal isotopic composition for Si, /11/. If the enhancement factor for Si, found at low energy, is confirmed, metal rich supernovae could also contribute to GCRS isotopic anomalies, /12/. Isotopic ratios such as 36S/32S, 57Fe/56Fe, 58Fe/56Fe ,still to be measured, could help distinguishing between various models.

Table 1: Observed mean masses at 3 GeV/n

Element	Number in the fit region	Observed mean mass	Propagated SS composition
Ne	1681	20.68 (+-.06)	20.48 +-.08
Mg	1910	24.59 (+-.06)	24.42 +-.04
Al	323	26.91 (+.09,-.16)	26.90 +-.03
Si	1373	28.25 (+-.07)	28.19 +-.035
S	275	32.70 (+.22,-.20)	32.56 +-.16
Ca	210	41.80 (+.35,-.30)	41.65 +-.22
Fe	1114	55.75 (+-.20)	55.82 +-.03

Table 2:

Enhancement factors GCRS ratios/LG ratios

22Ne/20Ne	:	2.88 (+.77, -.65)
(25Mg + 26Mg)/24Mg	:	2.03 (+.49, -.42)
(29Si + 30Si)/28Si	:	1.55 (+.84, -.74)

References

/1/: Lund N., 1984, Adv. Space Res. Vol4, n°2-3, p. 5.
/2/: Engelmann J.J., & al, to be published in Astron. Astrophys.
/3/: Meyer J.P., 1985, Ap.J. Suppl. 57, 173.
/4/: Wiedenbeck M.E., 1984, Adv. Space Res. Vol4, n°2-3, p. 15.
/5/: Peters B., 1974, Nucl.Instr.Meth; 121, 205.
/6/: Soutoul A., & al, 1981, 17th ICRC, Paris, 9, p.105.
/7/: Koch-Miramond L., 1981, 17th ICRC, Paris, 12, 21.
/8/: Mac Cracken K.G., & al, 1962, MIT Techn. Rep. 77 NYO 2670
/9/: Lund N., Herrstroem N.Y., this conference.
/10/: Cameron A.W.C., 1982, in "Essays in Nuclear Astrophysics" eds C. Barnes, D. Clayton and D. Schramm, Cambridge University Press, p.23.
/11/: Prantzos, 1984, Adv. Space Res. Vol4, n°2-3, p. 109.
/12/: Woosley S.E., Weaver T.A., 1983, Ap. J. 243, 651.