A NEW ANALYSIS OF COSMIC RAY ISOTOPES
AT 3 GeV/n FROM HEAO3-C2 DATA

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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 geoma-
gnatic 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 nu-
clear processes, isotopic anomalies almost certainly imply speci-
fic 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 avai-
lable 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 determi-
nation of mean masses with the help of the geomagnetic field;
analysis of HEAO3-C2 data were already performed using the trans-
mission 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 geoma-
gnetic 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 pre-
dictions to the actually observed transmission function.

Method
Building an OTF requires the knowledge for each detected par-
ticle of the momentum by nucleon P and the main cut-off Rc cor-
responding to the position and direction of arrival in the
instrument /6,7/. P is measured by the instrument and Rc is com-
puted with a trajectory tracing method /8/. The number of parti-
cles observed with momentum by nucleon p° at a main cut-off Rc is
given by :

$$d^2N/dp^odRc = Tex(Rc). \sum_i \int_p F(Rc,Ri).ßi.f(p).P(p,p^o)dp \qquad (1)$$

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, ßi
the isotopic fraction of isotope Ai , and P(p,p°) the momentum
resolution function of the instrument. Tex(Rc) and f(p) are deri-
ved from the data. F(Rc,R) is the mean geomagnetic filter func-
tion 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 pas-
ses 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 associa-
ted trajectory is allowed, or 0 if it is forbidden (penumbra re-
gion). 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 penum-
bra 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 cor-
responding 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 momen-
tum 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 func-
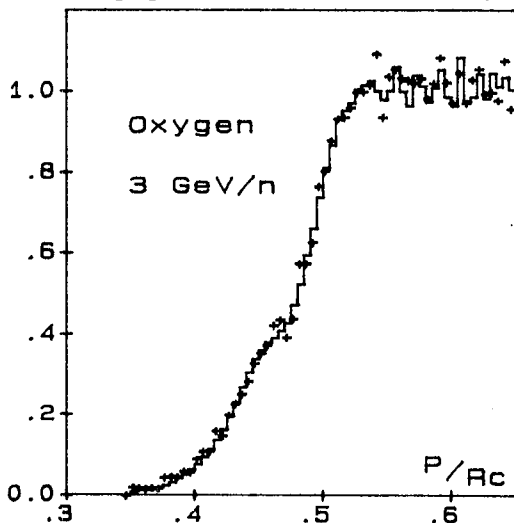tion P(p,p°) is taken as a gaussian function with a standard
deviation S. To account for a pos-
sible drift in momentum we intro-
duce another parameter, D, so
that p observed = D times p true.
To determine S and D oxygen is
used as a reference element assu-
ming 96% of 160, 2% of 170, and
2% of 180. However these two pa-
rameters 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 simulta-
neously optimized by minimising
the chi² between observed and
predicted transmissions. Values
of .990, 4.3%, and 1.18 are res-
pectively found for S,D and SF.
Fig 1 shows the agreement between
predicted and observed transmis-
sion functions for oxygen. The shift of 1% between actual and
observed momentum, which is compatible with the error on the mea-
surement 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.
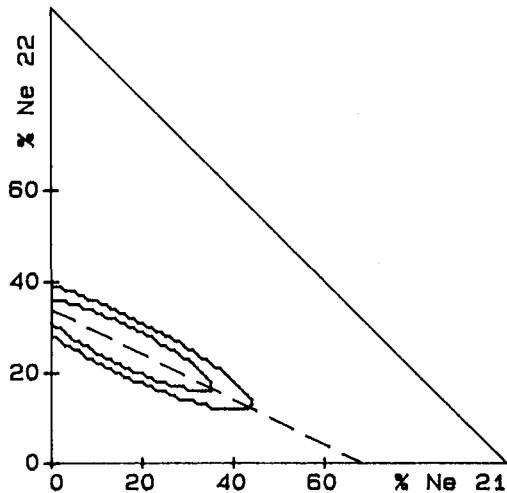
Results

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 chi^2 between OTF and prediction for all possible isotopic composition; the minimum chi^2 gives the measurement. Contours of 68 and 90% confidence level from chi^2 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 chi^2 increase

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 .

of 1.0 from minimum chi^2. 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 iso-
topic 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)

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