

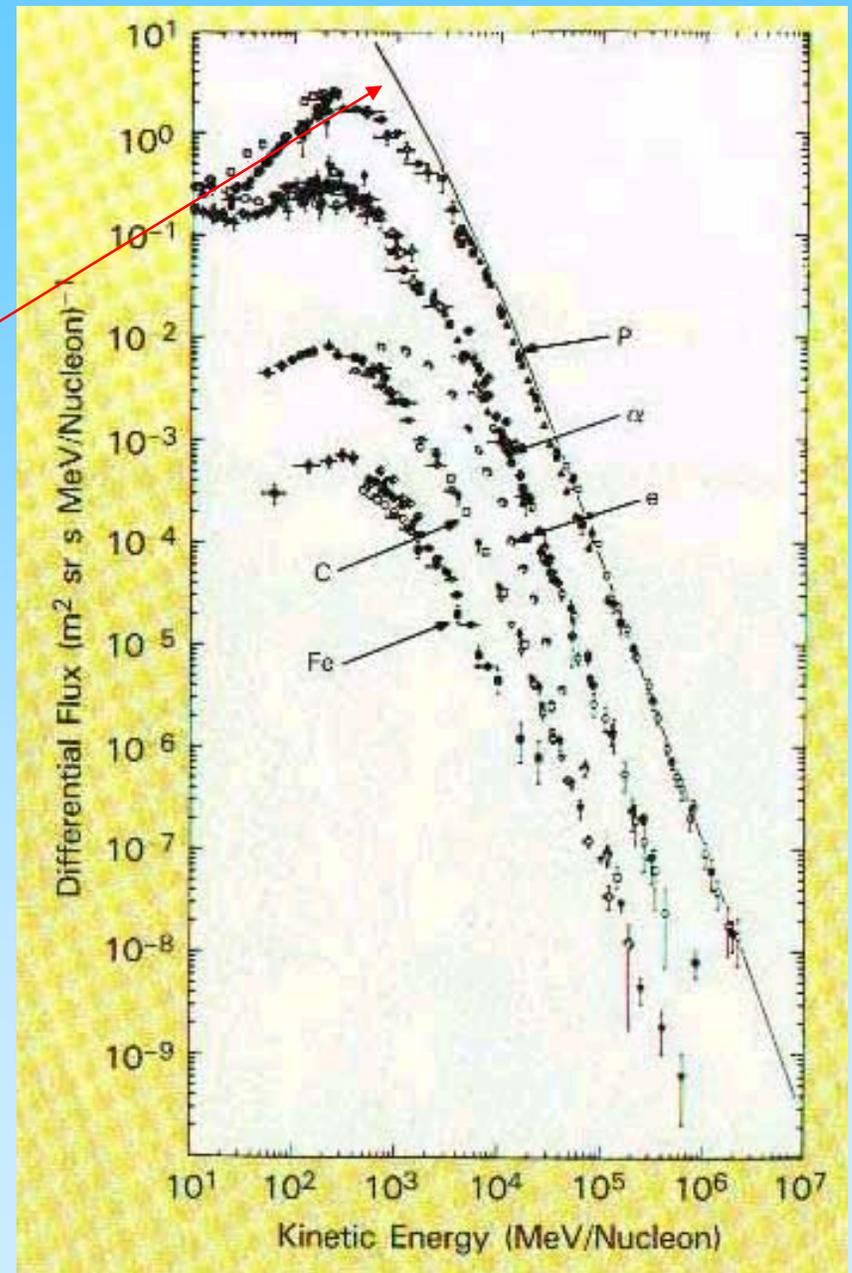
Raggi cosmici
Abbondanze relative

Abbondanze relative [1]

Composizione chimica dei raggi cosmici

Curva continua: distribuzione corretta
tenendo conto del taglio a basse energie
introdotto dal campo magnetico

Ref. M.S. Longair: vol. I; Cap. 9



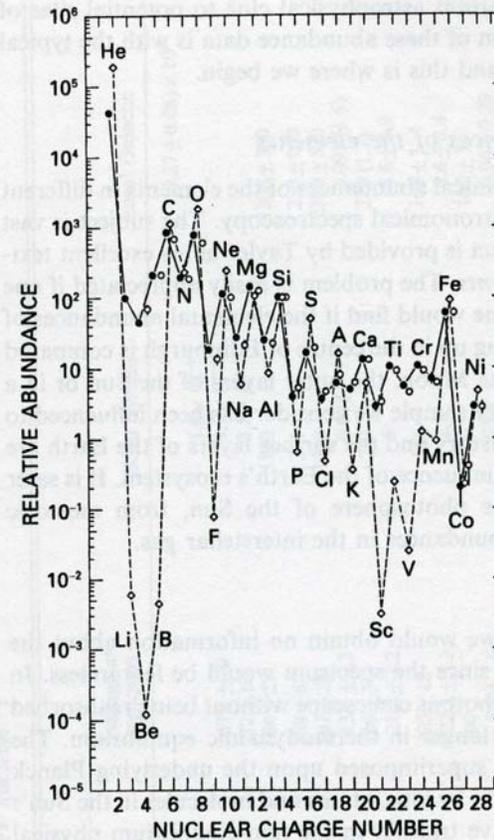
Abbondanze relative [2]

Informazioni sull'origine e la propagazione dei raggi cosmici

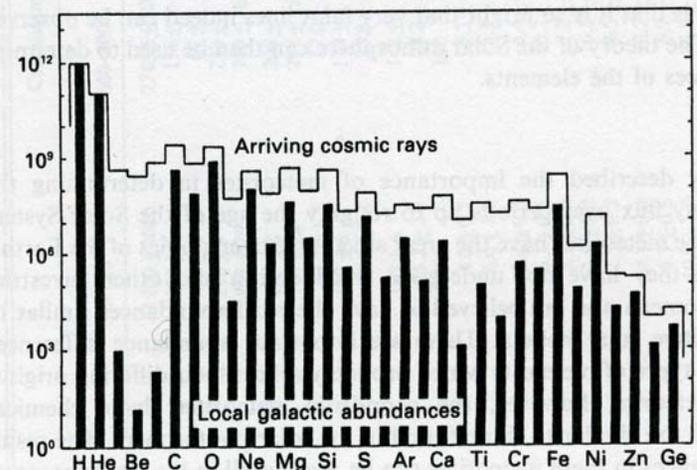
Deduzione della composizione nei siti di generazione → informazioni utili nel tentativo di individuare gli oggetti stellari che li generano

Confronto con le abbondanze relative misurate nella Galassia

Misure effettuate sul Sole e su meteoriti



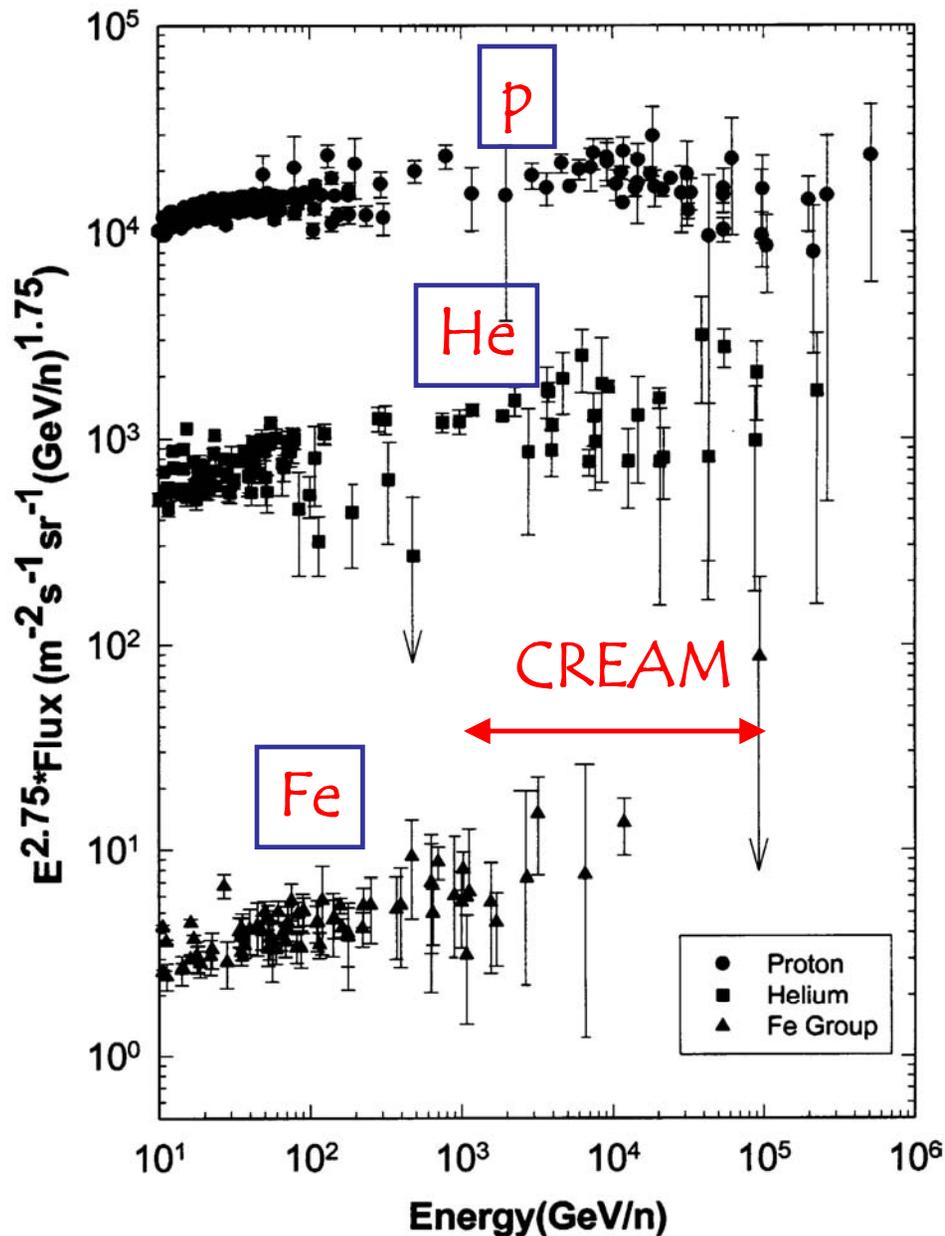
(a)



(b)

Misure "dirette"

Dipendenza della composizione dall'energia



Accelerazione in Supernovae

Energia massima determinata da:

- Campo magnetico B associato allo shock
- Tempo T di durata dello shock
- Velocità V dello shock
- Carica Z della particella

$$E_{\text{max}} \sim \beta Z e B V T$$

Per $B = 3 \mu\text{G}$; $T = 1000$ anni;

$$V = 5000 \text{ km/s} \rightarrow E_{\text{max}} = Z \times 10^{14} \text{ eV}$$

→ Protoni più abbondanti a basse energie; elementi pesanti (Fe) dovrebbero dominare ad energie superiori a 10^{15} eV

Misura dell'energia

- a) Rivelatore a radiazione di transizione
(Misura il γ della particella per $Z > 3$)
- b) Calorimetro
(misura l'energia della particella anche per $Z < 3$)

Misura della carica

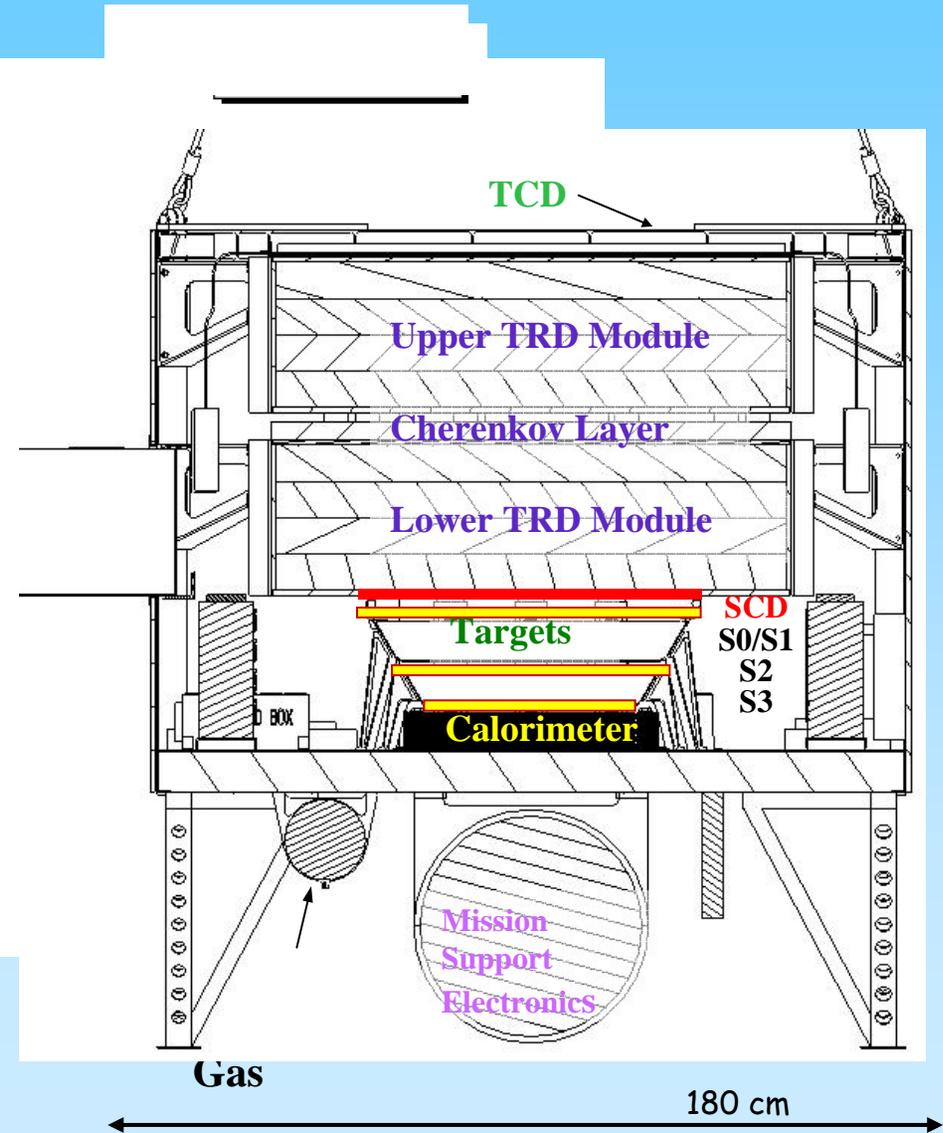
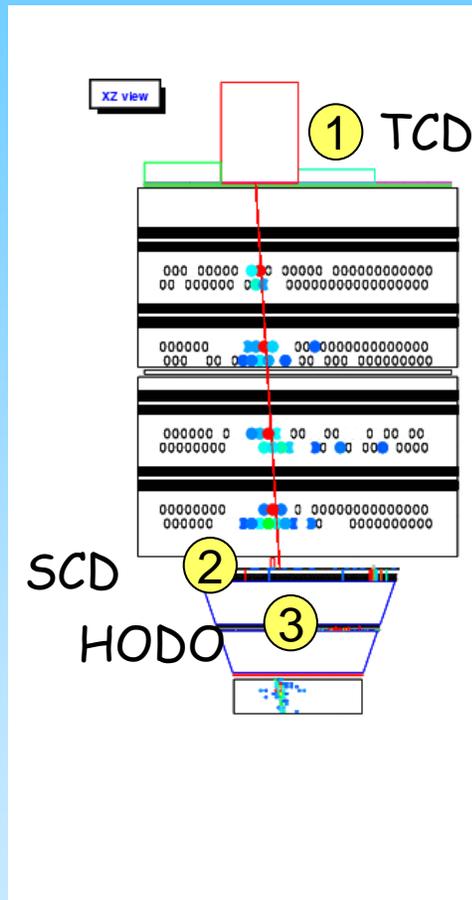
- a) Scintillatori plastici
- b) Rivelatori al Silicio

CREAM

Detector Concept

3 independent charge measurements :

- Timing-based Charge Detector (TCD)
- Pixelated Silicon Detector (SCD)
- Scintillating fiber Hodoscope



2 independent energy measurements :

- Transition Radiation Detector ($Z > 3$)
- Tungsten Sci/Fi calorimeter ($Z \geq 1$)

In-flight cross calibration of energy scale

Esperimento CREAM: Veduta schematica

Timing Charge Detector (scintillatori plastici)

Rivelatore a radiazione di transizione

Rivelatore Cerenkov

Rivelatore al Silicio

S0-S1-S2-S3 Rivelatori a fibre ottiche scintillanti

Calorimetro (tungsteno e fibre ottiche scintillanti)

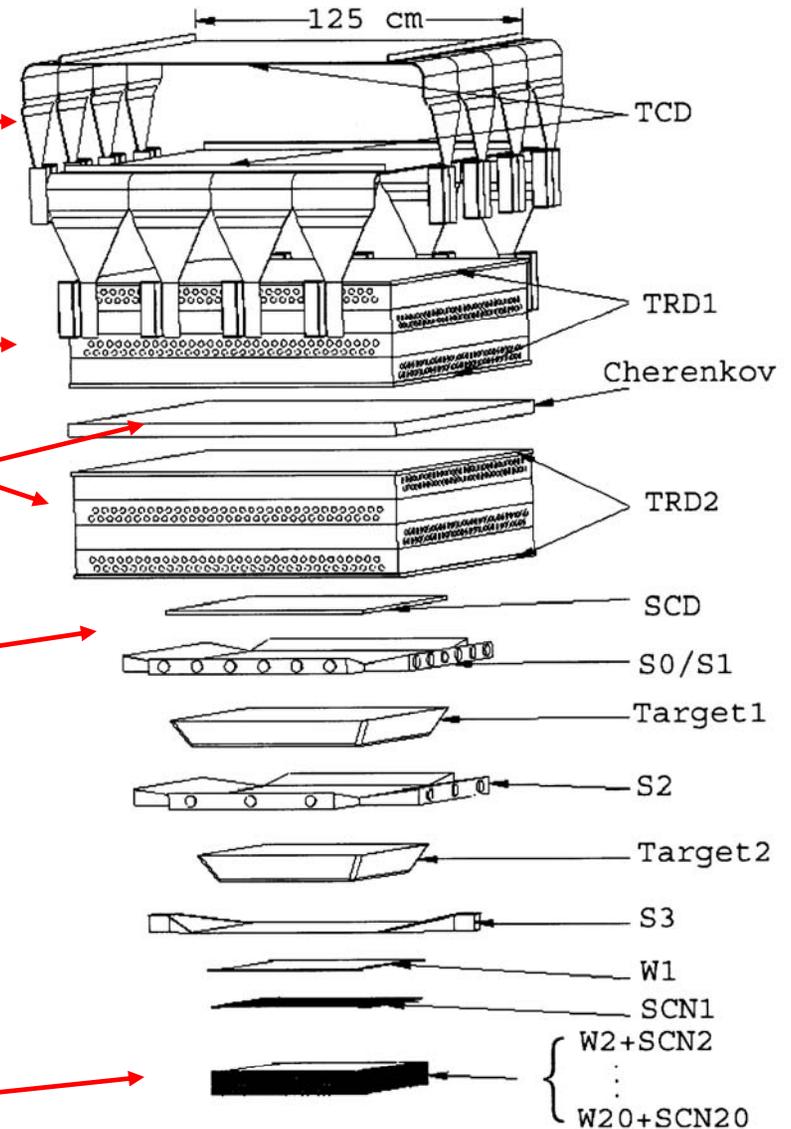


Fig. 2. Schematic of the CREAM instrument configuration.

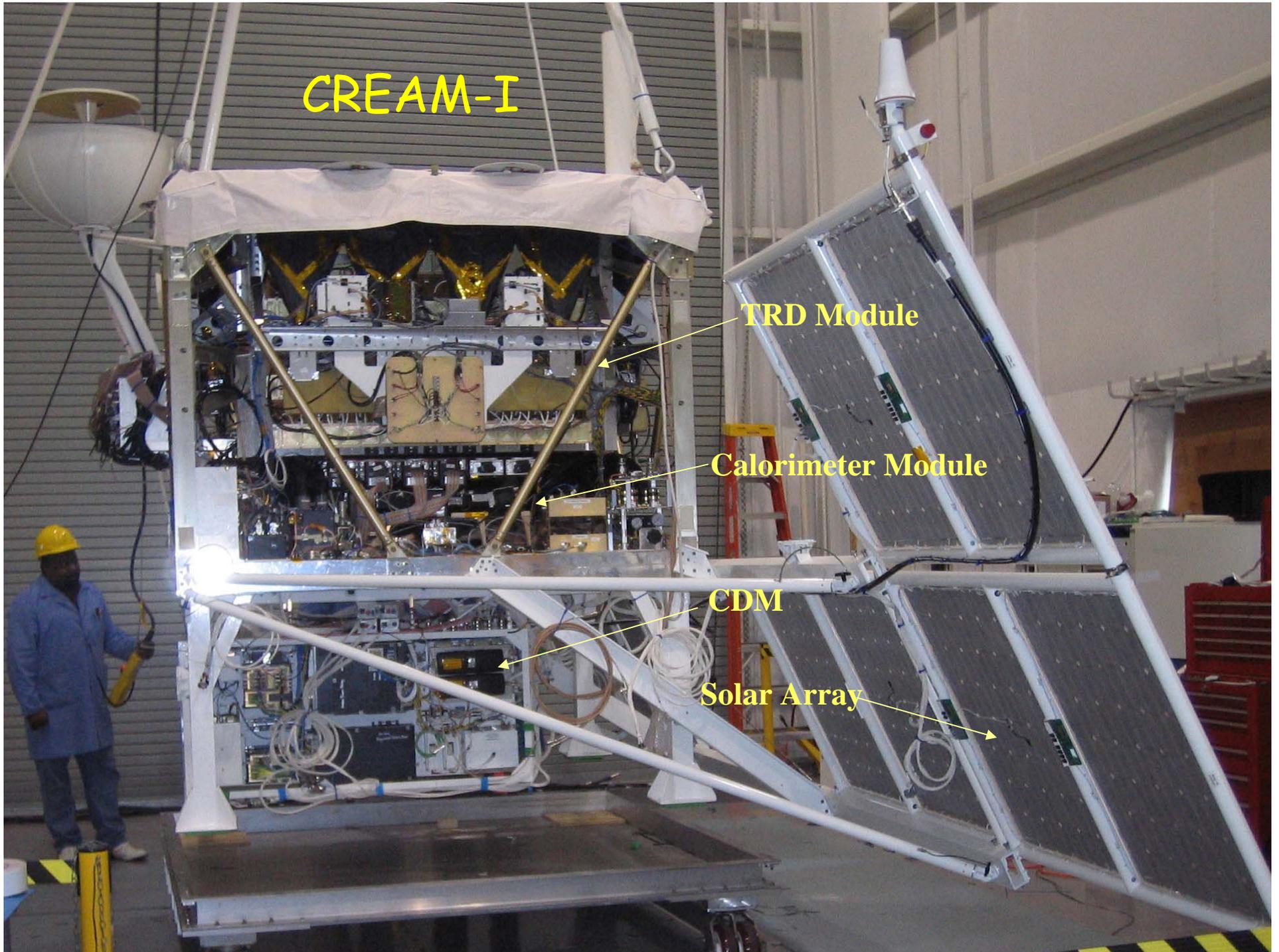
CREAM-I

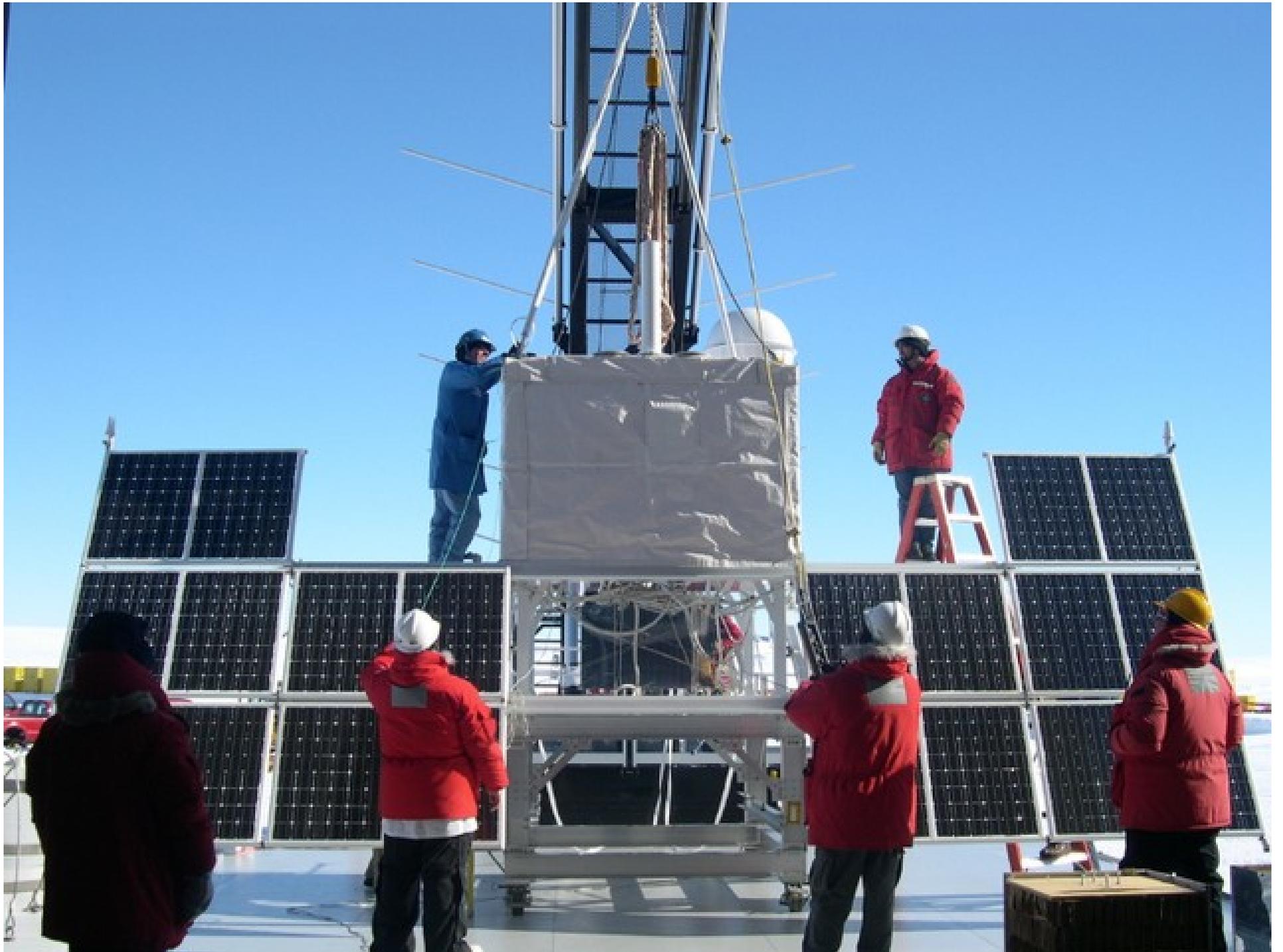
TRD Module

Calorimeter Module

CDM

Solar Array







2005/12/02

Cream

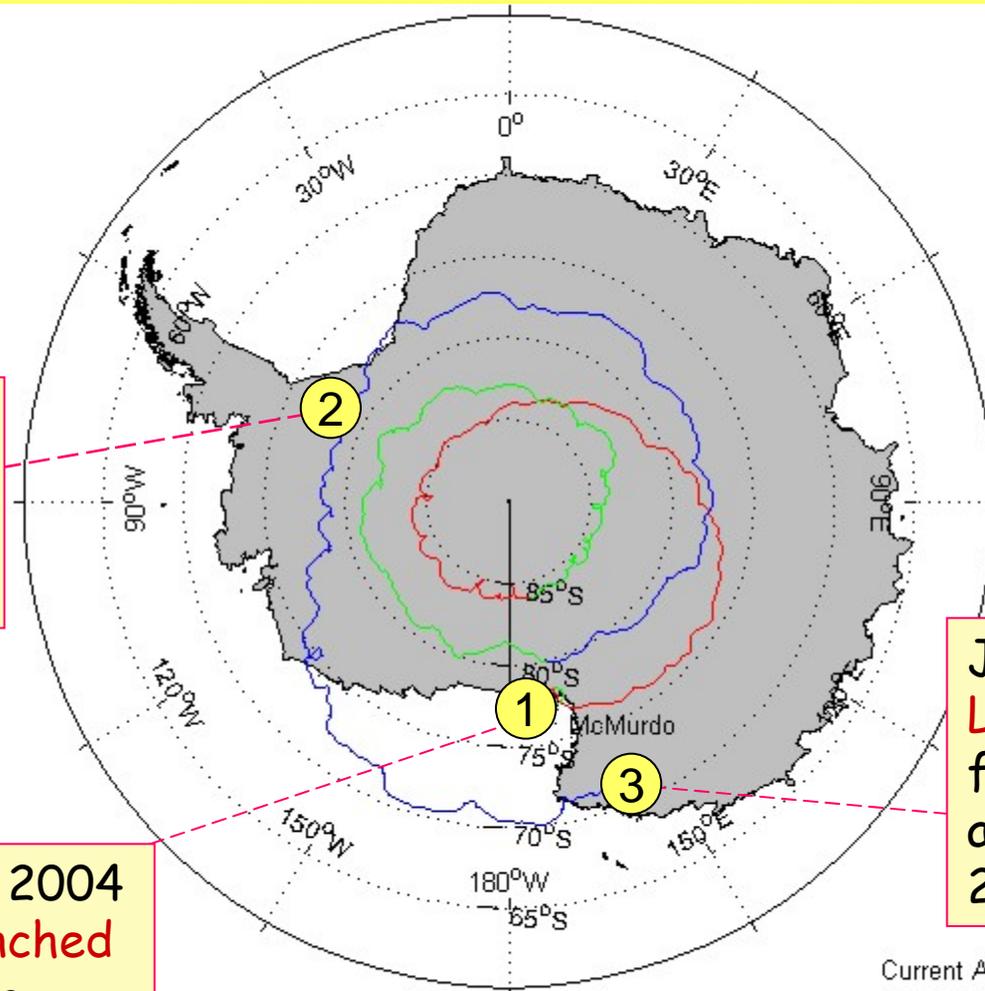


Primo volo di CREAM (Dicembre-Gennaio 2004)

January 16, 2005
Break the record
of 31 days and 20
hrs

December 16, 2004
CREAM is **launched**
from McMurdo

Current Lon: 157°52'54"



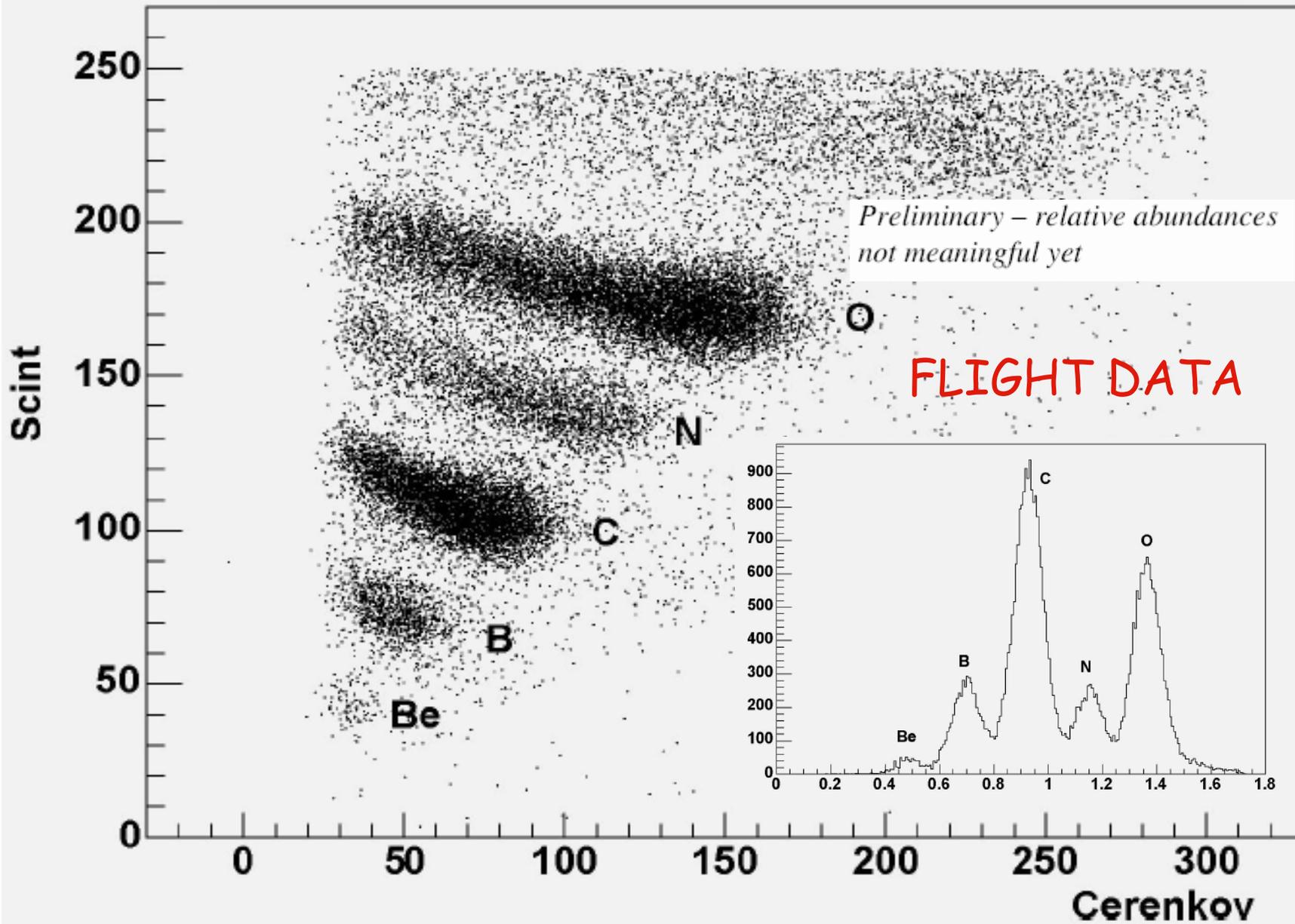
January 27, 2005
Landing 417 miles
from McMurdo
after 41 days and
21 hrs

Current Altitude: 13828.7402 feet

Current MET: 41 days 21 hrs 31 mins 30.783 sec since launch

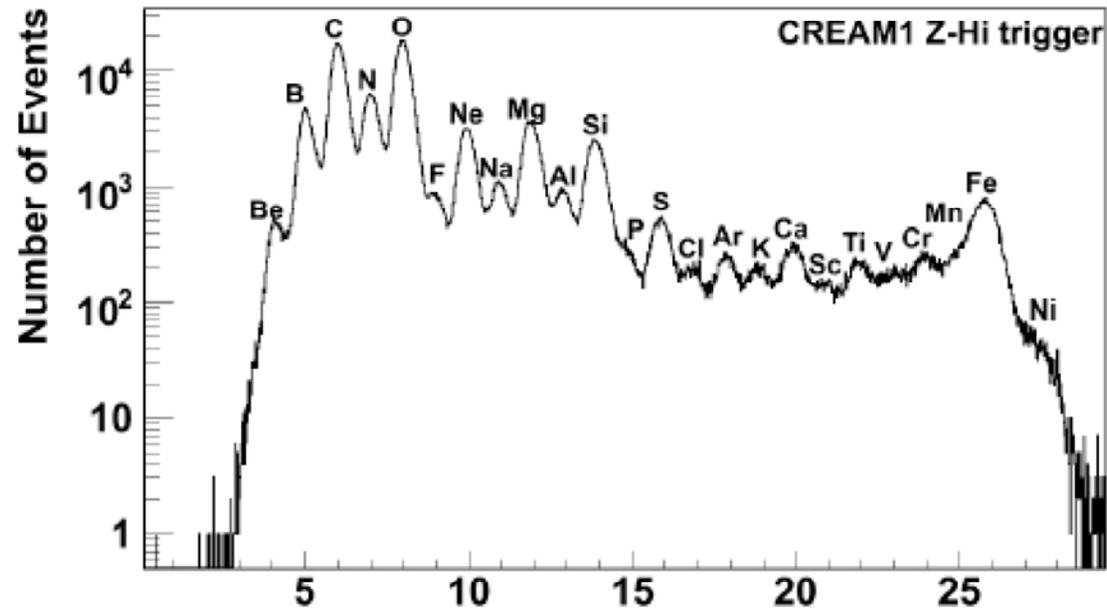
Current Time: 2005-01-27 02:00:31 UTC

Very preliminary charge identification : TCD vs Cherenkov

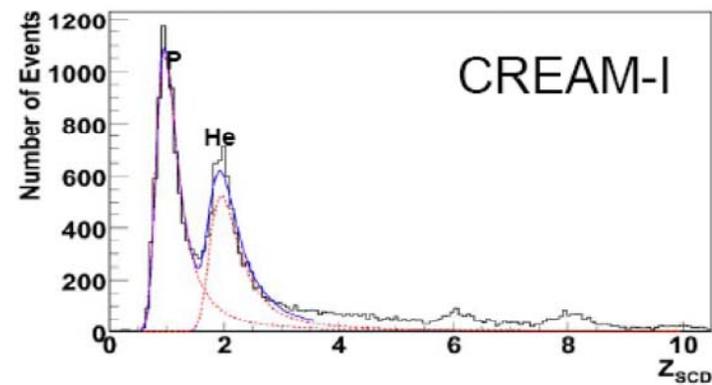


Risultati preliminari di CREAM

CREAM-I, Hi-Z with Silicon, TCD and Cerenkov

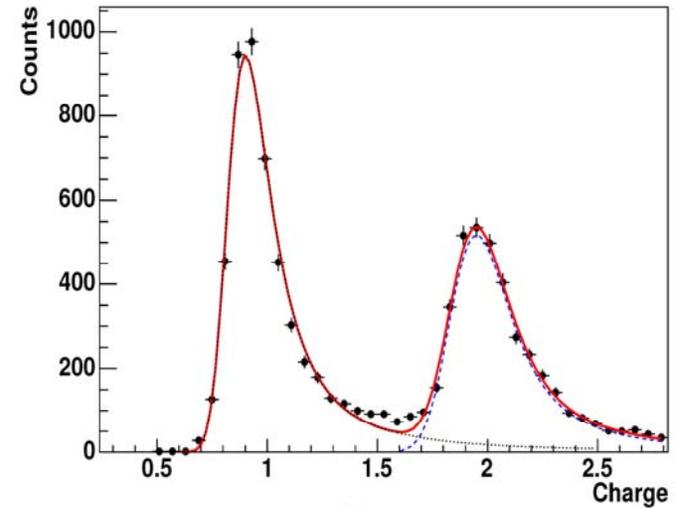


CREAM-I, Lo-Z trig

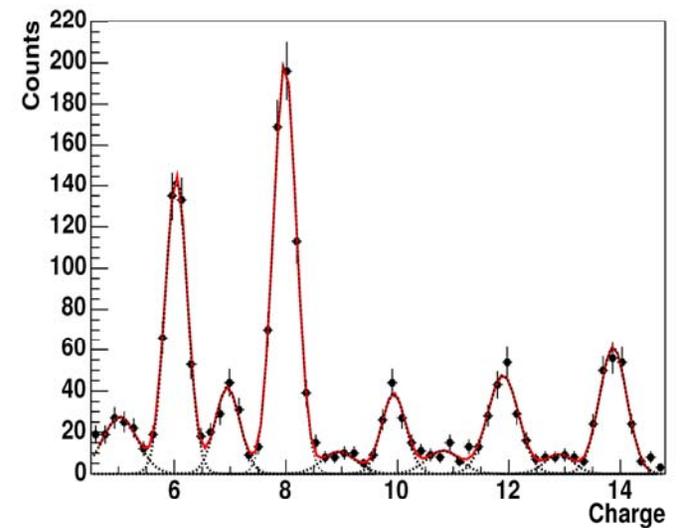


Protoni ed He

Elementi con $Z > 4$



(a)

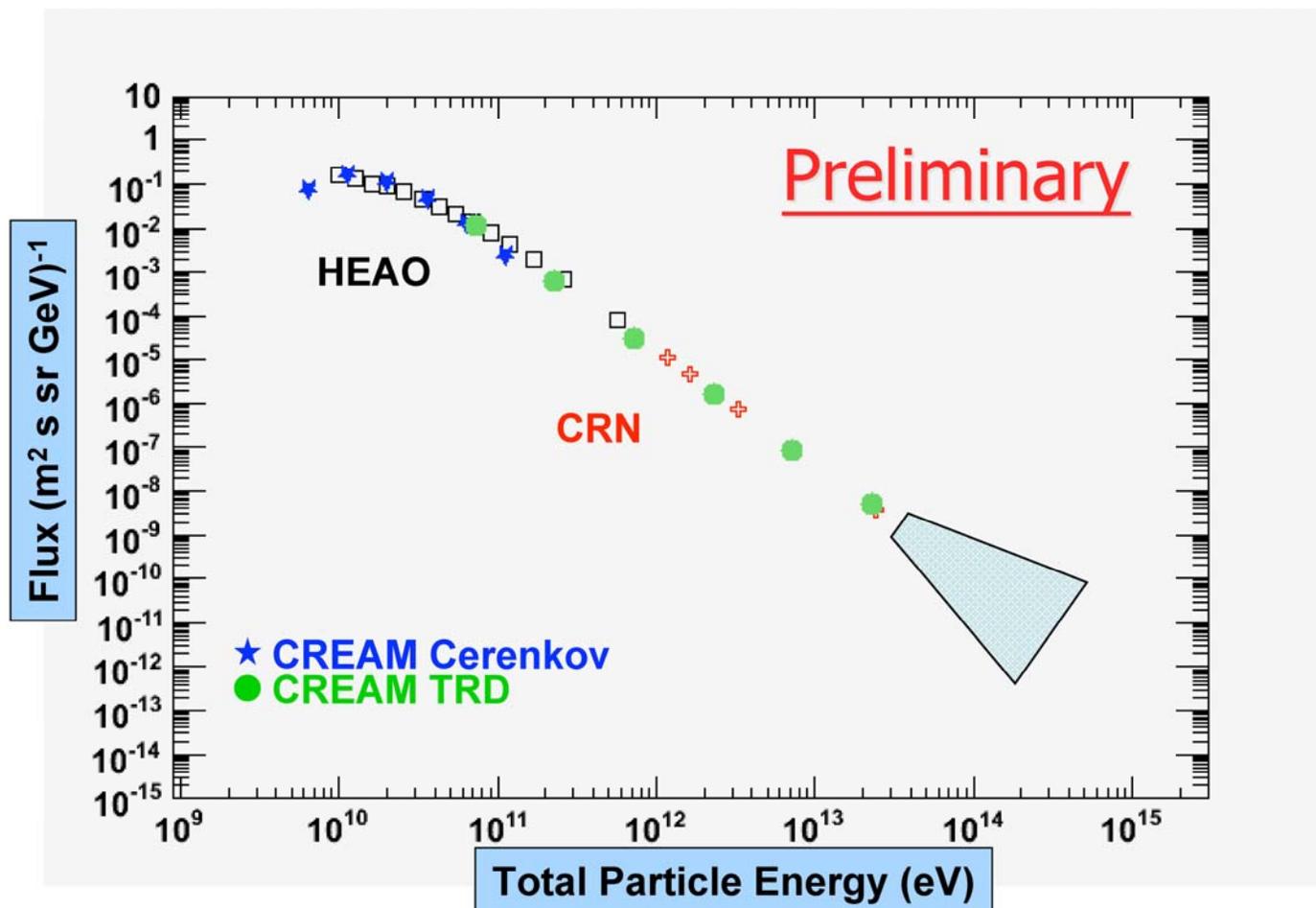


(b)

Fig. 6. Preliminary charge reconstruction of relativistic nuclei by the SCD using calorimeter tracking (the distributions are only indicative of the instrument charge resolution and relative elemental abundances are not meaningful) : (a) candidate protons and He nuclei (solid line : result of the global fit, dotted lines : individual fitted components); (b) candidate nuclei with charge $Z > 4$.

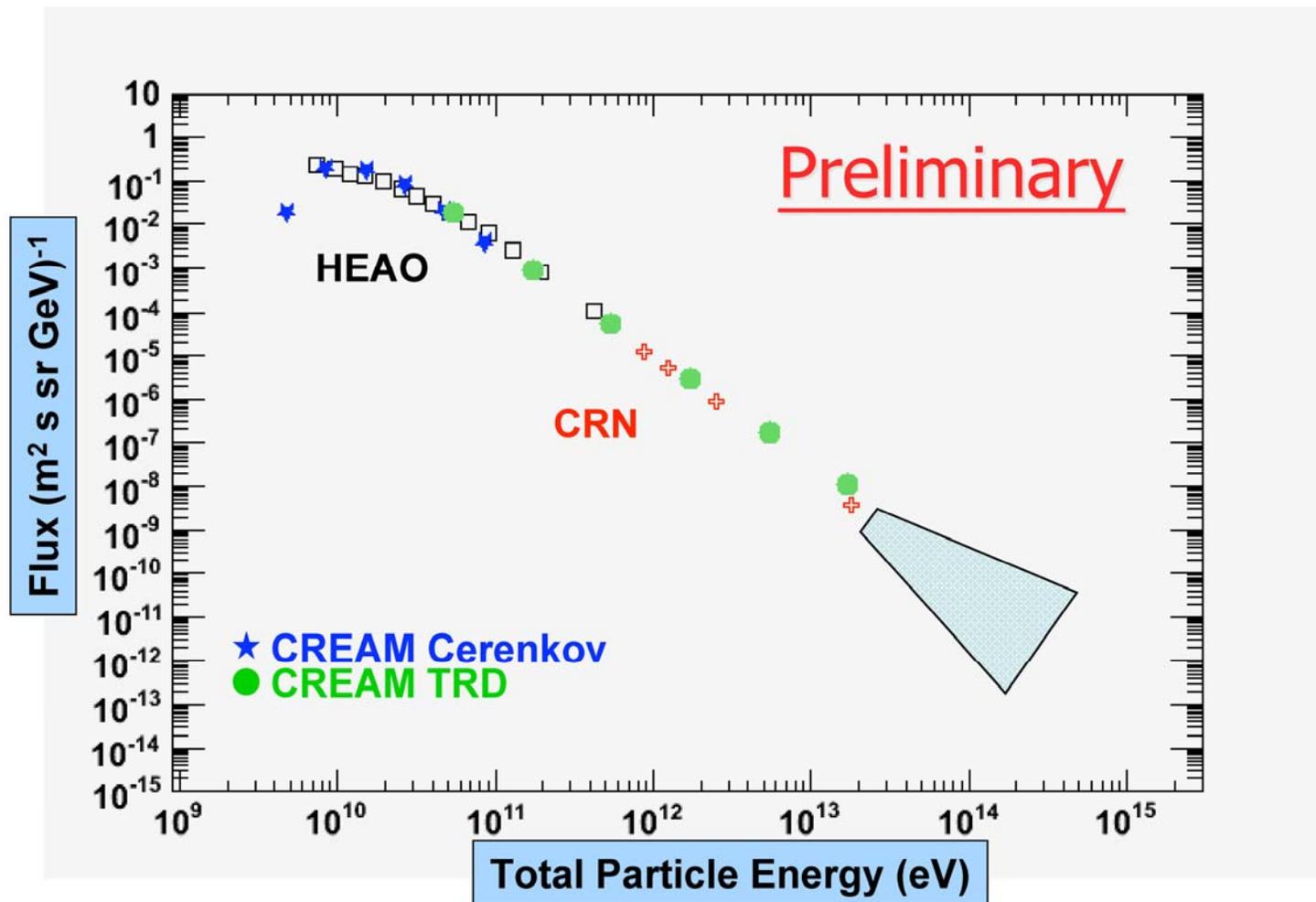
CREAM: Spettro energetico dell'Ossigeno

CREAM HiZ Oxygen Spectrum



CREAM: Spettro energetico del Carbonio

CREAM HiZ Carbon Spectrum



Abbondanze relative [3]

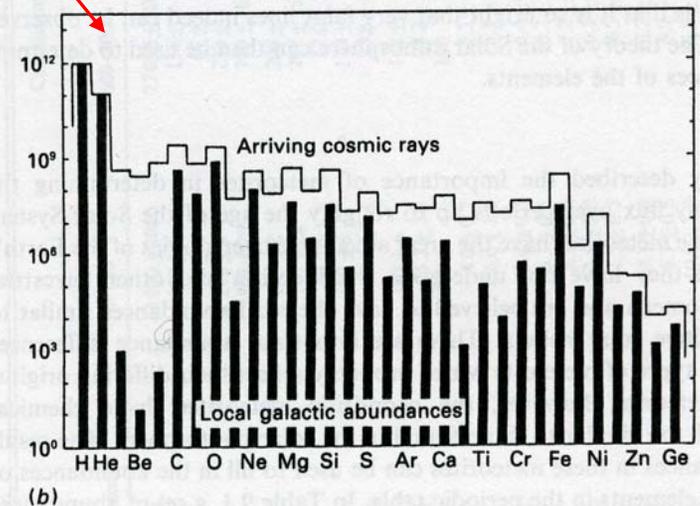
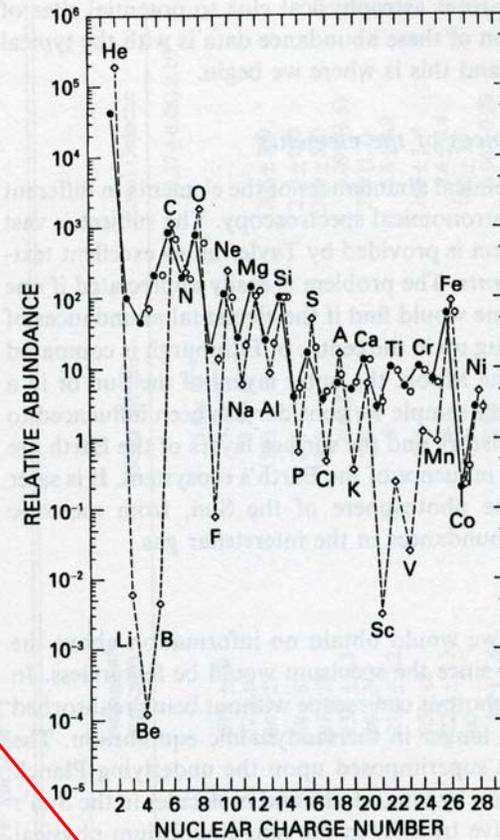
Confronto con le abbondanze relative misurate
nella Galassia (normalizzate all'H)

- gruppo del C, N, O, molto simili nei RC e nella Galassia
- Effetto even-odd molto meno accentuato nei RC
- Li, Be, B molto piu' abbondanti nei RC che nella Galassia
- elementi appena prima del Fe molto piu' abbondanti nei RC (Ca, Sc, Ti, V, Mn, Cr)
- H ed He molto meno abbondanti nei RC

Osservazioni b), c), d) spiegabili come effetto della "spallazione":



risultante dall'interazione del nucleo con un protone del gas Galattico



Abbondanze relative[4]

Osservazioni b), c), d) spiegabili come effetto della "spallazione":



risultante dall'interazione del nucleo con un protone del gas Galattico

RC accelerati nella sorgente \rightarrow attraversamento di una grande quantità di materia (mezzo interstellare) prima di arrivare ad essere osservati

Abbondanze relative [5]

Abbondanze relative per grandi numeri atomici (normalizzate al Fe).

*Ottimo accordo per
 $Z < 42$*

$50 < Z < 58$

$78 < Z < 84$

*Abbondanze maggiori nei RC per
gli altri valori di Z.*

Effetto della spallazione

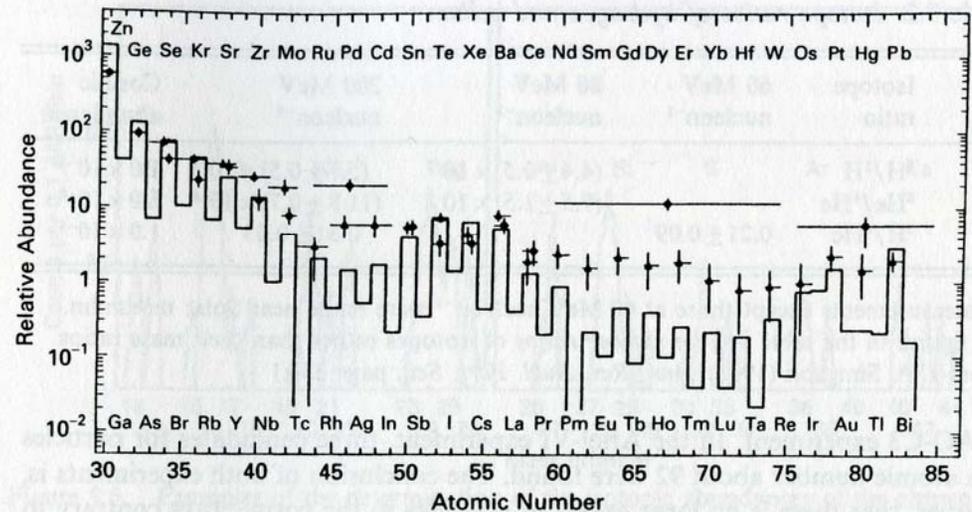


Figure 9.5. The abundances of the elements with very large atomic numbers in the cosmic rays. The abundances observed in the Ariel-VI observations are indicated by filled triangles and the HEAO-C3 observations by filled circles. The solid line indicates the cosmic abundances of the elements. In each case, the abundances are normalised to 10^6 iron nuclei. (J. P. Wefel (1988) *Genesis and propagation of cosmic rays*, eds. M. M. Shapiro and J. P. Wefel, page 1, D. Reidel Publishing Co, Dordrecht.)

Abbondanze isotopiche (rilevate attraverso misure di massa)

Abbondanze relative per:

${}^2\text{H} / {}^1\text{H}$

${}^3\text{He} / {}^4\text{He}$

Rapporto	80 MeV/Nucleone	200 MeV/Nucleone	Galassia
${}^2\text{H} / {}^1\text{H}$	$(4.4 \pm 0.5) 10^{-2}$	$(5.7 \pm 0.5) 10^{-2}$	$1.0 10^{-5}$
${}^3\text{He} / {}^4\text{He}$	$(9.5 \pm 1.5) 10^{-2}$	$(11.8 \pm 0.7) 10^{-2}$	$3.0 10^{-5}$

${}^2\text{H}$ ed ${}^3\text{He}$ molto piu' abbondanti nei raggi cosmici che nella Galassia
Isotopi "fragili", normalmente distrutti nelle stelle

Presenza nei RC spiegata come effetto della spallazione

Anomalie nella composizione

Maggiori abbondanze relative per:

Li, Be, B

$^3\text{He} / ^4\text{He}$

Elementi piu' leggeri del Fe

Abbondanze relative: effetto dei processi di spallazione[1]

Diffusion-Loss equation →

M.S. Longair vol. II
Cap. 20.2.1

$$\frac{\partial N_i}{\partial t} = D\nabla^2 N_i + \frac{\partial}{\partial E} [b(E)N_i] + Q_i - \frac{N_i}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} N_j$$

N_i = densita' dei nucleidi tipo i

$D\nabla^2 N_i$ = diffusione

$\frac{\partial}{\partial E} [b(E)N_i]$ = perdite e guadagni di energia dei nuclei

Q_i = rate d'iniezione dei nucleidi tipo i per unita' di volume

$\frac{N_i}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} N_j$ = effetti dei processi di spallazione

τ_i = vita media per spallazione dei nucleidi tipo i

P_{ji} = probabilita' che la spallazione del nucleo i dia il nucleo j

Abbondanze relative: effetto dei processi di spallazione[2]

Diffusion-Loss equation → trascuriamo alcuni dei termini

$$\frac{\partial N_i}{\partial t} = D \nabla^2 N_i + \frac{\partial}{\partial E} [b(E) N_i] + Q_i - \frac{N_i}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} N_j$$

Trascuriamo:

$D \nabla^2 N_i$ = diffusione

$\frac{\partial}{\partial E} [b(E) N_i]$ = perdite e guadagni d'energia dei nuclei

Q_i = rate d'iniezione dei nuclei di tipo i per unita' di volume

$$\frac{\partial N_i}{\partial t} = -\frac{N_i}{\tau_i} + \sum_{j>i} \frac{P_{ji}}{\tau_j} N_j$$

Poniamo:

$$\xi = \rho v t \quad ; \quad \xi_i = \rho v \tau_i \quad \Rightarrow$$

$$\frac{\partial N_i(\xi)}{\partial \xi} = -\frac{N_i(\xi)}{\xi_i} + \sum_{j>i} \frac{P_{ji}}{\xi_j} N_j(\xi)$$

ξ_i e ξ_j espressi in Kg/m²

Abbondanze relative: effetto dei processi di spallazione[3]

Elementi Be, Li e B (elementi "light" → L) ; C, N, O (elementi "medium" → M)

Elementi piu' rari

Elementi piu' abbondanti

$$\frac{\partial N_M(\xi)}{\partial \xi} = -\frac{N_M(\xi)}{\xi_M} \quad (a)$$

$$\frac{\partial N_L(\xi)}{\partial \xi} = -\frac{N_L(\xi)}{\xi_L} + \frac{P_{ML}}{\xi_M} N_M(\xi) \quad (b)$$

$$N_M(\xi) = N_M(0) \exp\left(-\frac{\xi}{\xi_M}\right)$$

Moltiplicando la (b) per $\exp\left(\frac{\xi}{\xi_L}\right) \Rightarrow$

$$\frac{\partial}{\partial \xi} \left[e^{\frac{\xi}{\xi_L}} N_L(\xi) \right] = \frac{P_{ML}}{\xi_M} e^{\left(\frac{\xi}{\xi_L} - \frac{\xi}{\xi_M}\right)} N_M(0) \quad ; \quad \text{soluzione:}$$

$$\frac{N_L(\xi)}{N_M(\xi)} = \frac{P_{ML} \xi_L}{(\xi_L - \xi_M)} \left[e^{\left(\frac{\xi}{\xi_M} - \frac{\xi}{\xi_L}\right)} - 1 \right]$$

Abbondanze relative: effetto dei processi di spallazione[4]

Elementi Be, Li e B (elementi "light" \rightarrow L) ; C, N, O (elementi "medium" \rightarrow M)

$$\frac{N_L(\xi)}{N_M(\xi)} = \frac{P_{ML} \xi_L}{(\xi_L - \xi_M)} \left[e^{\left(\frac{\xi - \xi_L}{\xi_M - \xi_L} \right)} - 1 \right]$$

Calcolo approssimato:

Sezione d'urto inelastica per elementi M: $\sigma_M = 280$ mb

" " " " L: $\sigma_L = 200$ mb (distruzione elementi L)

$$P_{ML} = 0.28$$

Cammino libero medio di M: $\xi_M = \rho \lambda$; dove:

$$\rho = n m_p; \quad \lambda = c \tau = \frac{1}{n \sigma} \Rightarrow \xi_M = \frac{m_p}{\sigma_M} = \frac{1.67 \times 10^{-27}}{280 \times 10^{-31}} = 59 \text{ kg/m}^2;$$

$$\xi_L = \frac{m_p}{\sigma_L} = \frac{1.67 \times 10^{-27}}{200 \times 10^{-31}} = 83 \text{ kg/m}^2$$

Noti ξ_M e ξ_L e le abbondanze relative di (Li, Be, B) rispetto a (C, N, O) (0.25) $\Rightarrow \xi = 48 \text{ kg/m}^2 \cong \xi_M$

Sostituiamo a $N_L(\xi)/N_M(\xi)$
Il valore sperimentale (0.25)
e ricaviamo ξ

Abbondanze relative: effetto dei processi di spallazione[5]

Analogo accordo per rapporto He³/He⁴



$$\xi \sim 50 \text{ kg m}^{-2}$$

In accordo con il risultato precedente

Abbondanze relative: effetto dei processi di spallazione[6]

Ma disaccordo per il Fe: ($\sigma_{Fe}=764$ mb ~ 2 volte il valore per gli elementi M)

→ Il Fe deve subire molto più pesantemente l'effetto della spallazione !!

$$\frac{\text{secondari}}{\text{primari}} = \frac{1 - \exp(-\xi / \xi_{Fe})}{\exp(-\xi / \xi_{Fe})}$$

Con $\xi = 50$ kg/m² e $\xi_{Fe} = 22$ kg/m² →

secondari (Mn,Cr,V)/primari = 8.7 !!

Spiegabile con il fatto che esiste tutta una distribuzione di valori dello spessore di materia attraversato

Distribuzione di spessore attraversato

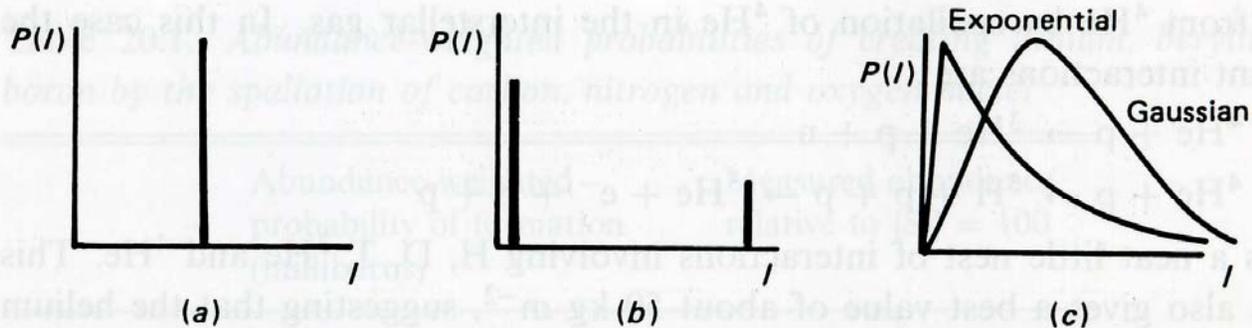


Figure 20.4. Models for the path length distribution for the propagation of high energy particles in the interstellar gas: (a) a 'slab' model, in which all high energy particles traverse the same path length of interstellar gas; (b) a model in which high energy particles arriving at the Earth traverse different path lengths of interstellar gas so that a wider range of spallation products can be explained; (c) a Gaussian distribution of path lengths expected in diffusion models and an exponential distribution with a low energy cut-off.

Vedi M.S. Longair Vol. II, cap. 20

Abbondanze isotopiche

abbondanze osservate nei RC

Bianco: primari
Nero: prodotti di spallazione

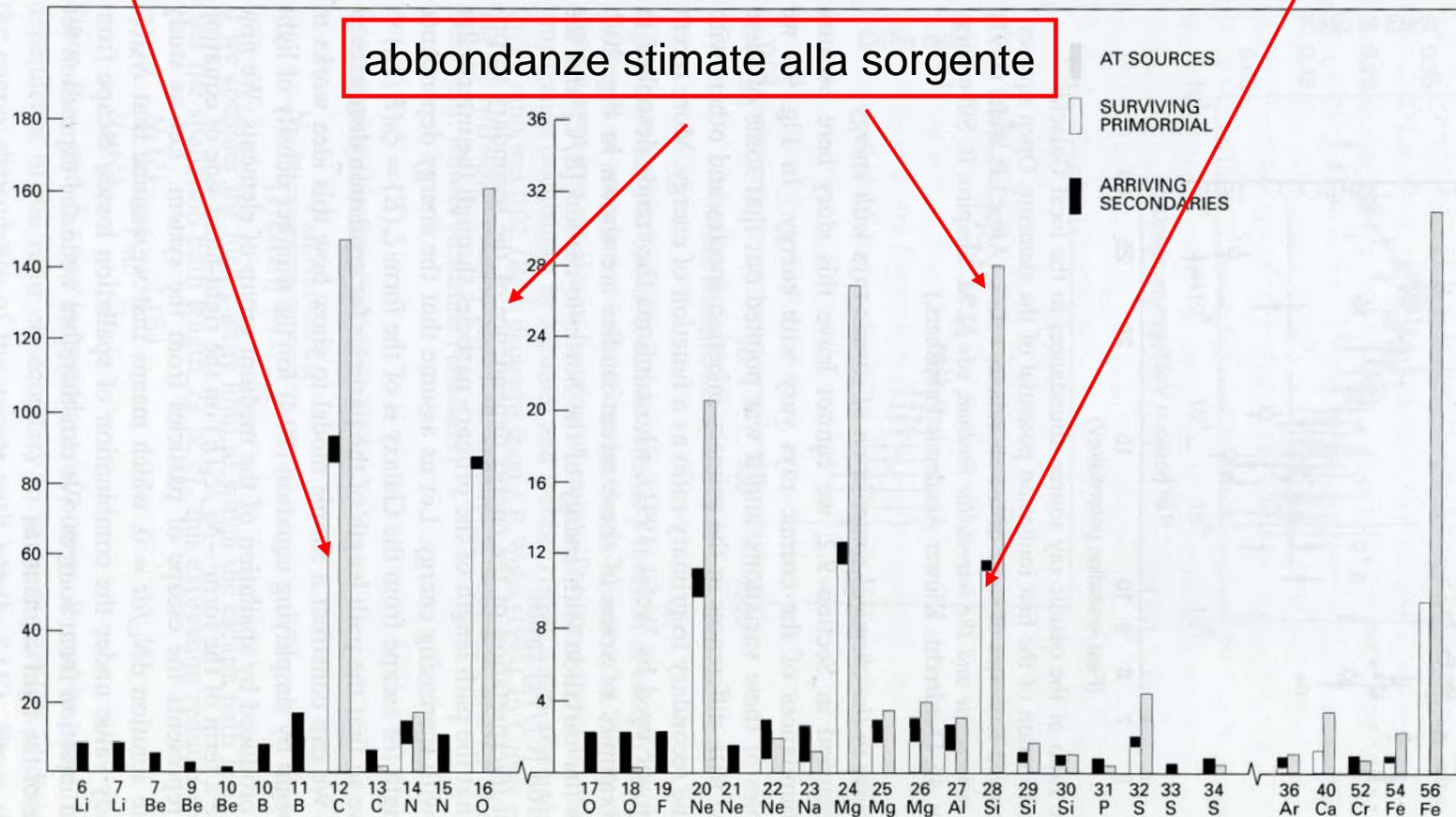


Figure 20.5. The relative isotopic abundances of the cosmic rays as observed near the Earth and as inferred to be present in their sources, once the effects of spallation between the sources and the Earth are taken into account. The abundances have been normalised to 100 for $^{12}\text{C} + ^{13}\text{C}$. The grey histograms show the inferred source abundances and the neighbouring histograms show the observed abundances, the open parts depicting the surviving primary elements and the black parts the amount produced by spallation. (From M.M. Shapiro (1991). In *Cosmic rays, supernovae and the interstellar medium*, eds M.M. Shapiro, R. Silberberg and J.P. Wefel, p. 14. Dordrecht: Kluwer Academic Publishers.)

Confronto delle
abbondanze alla
sorgente con quelle
Galattiche
(Normalizzate al Si)

**Elementi fino al Ne fortemente
soppressi nei RC**

**Effetto legato con le proprietà
atomiche di questi elementi
(Potenziale di prima ionizzazione)**

**Elementi con il potenziale di prima
ionizzazione maggiore di circa
10 eV soppressi di circa un fattore 5**

Table 20.2 Cosmic ray source abundances compared with the local Galactic abundances, both normalised to $[Si] = 100$

Element	Cosmic ray source abundance (1990 update)	Local Galactic abundance
H	$8.9 \pm 2.2 \times 10^4$	$2.7 \pm 0.3 \times 10^6$
He	2.4×10^4	$2.6 \pm 0.7 \times 10^5$
C	431 ± 34	1260 ± 330
N	19 ± 9	225 ± 90
O	511 ± 20	2250 ± 560
F	< 2.5	0.09 ± 0.06
Ne	64 ± 8	325 ± 160
Na	6 ± 4	5.5 ± 1.0
Mg	106 ± 6	105 ± 3
Al	10 ± 4	8.4 ± 0.4
Si	100	100
P	< 2.5	0.9 ± 0.2
S	12.6 ± 2.0	43 ± 15
Cl	< 1.6	0.5 ± 0.3
Ar	1.8 ± 0.6	11 ± 5
K	< 1.9	0.3 ± 0.1
Ca	5.1 ± 0.9	6.2 ± 0.9
Sc	< 0.8	$3.5 \pm 0.5 \times 10^{-3}$
Ti	< 2.4	0.27 ± 0.04
V	< 1.1	0.026 ± 0.005
Cr	2.2 ± 0.6	1.3 ± 0.1
Mn	1.7 ± 1.7	0.8 ± 0.2
Fe	93 ± 6	88 ± 6
Co	0.32 ± 0.12	0.21 ± 0.03
Ni	5.1 ± 0.5	4.8 ± 0.6
Cu	0.06 ± 0.01	0.06 ± 0.03
Zn	0.07 ± 0.01	0.10 ± 0.02
Ga	$5.6 \pm 2.8 \times 10^{-3}$	$\sim 3.7 \times 10^{-3}$
Ge	$7.4 \pm 1.0 \times 10^{-3}$	$\sim 11.4 \times 10^{-3}$

From J.P. Wefel (1991). In *Cosmic rays, supernovae and the interstellar medium*, eds M.M. Shapiro, R. Silberberg and J.P. Wefel, p. 44. Dordrecht: Kluwer Academic Publishers.

Dipendenza dal potenziale di prima ionizzazione

Dipendenza dei rapporti dal potenziale di prima ionizzazione

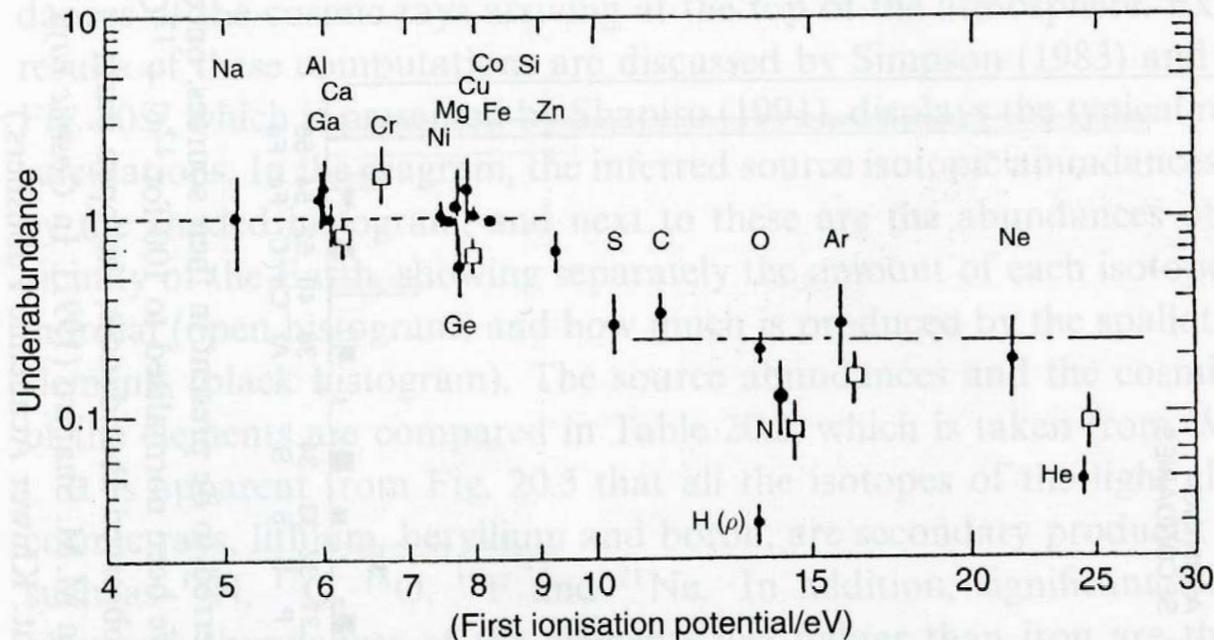


Figure 20.6. The ratio of the cosmic ray source abundances to the local Galactic abundances as a function of the first ionisation potential of the elements. Open squares show recent improved estimates of some of the abundance ratios. (After J.P. Wefel (1991). In *Cosmic rays, supernovae and the interstellar medium*, eds M.M. Shapiro, R. Silberberg and J.P. Wefel, p. 45. Dordrecht: Kluwer Academic Publishers.)

Spettri in energia per elementi diversi

Gli spettri energetici sono diversi per elementi diversi

e.g. Boro, Vanadio, Potassio hanno spettri molto piu' "ripidi" che non il Fe →

Fe ← prodotto dalle sorgenti
Altri elementi
← prodotti di "spallazione"

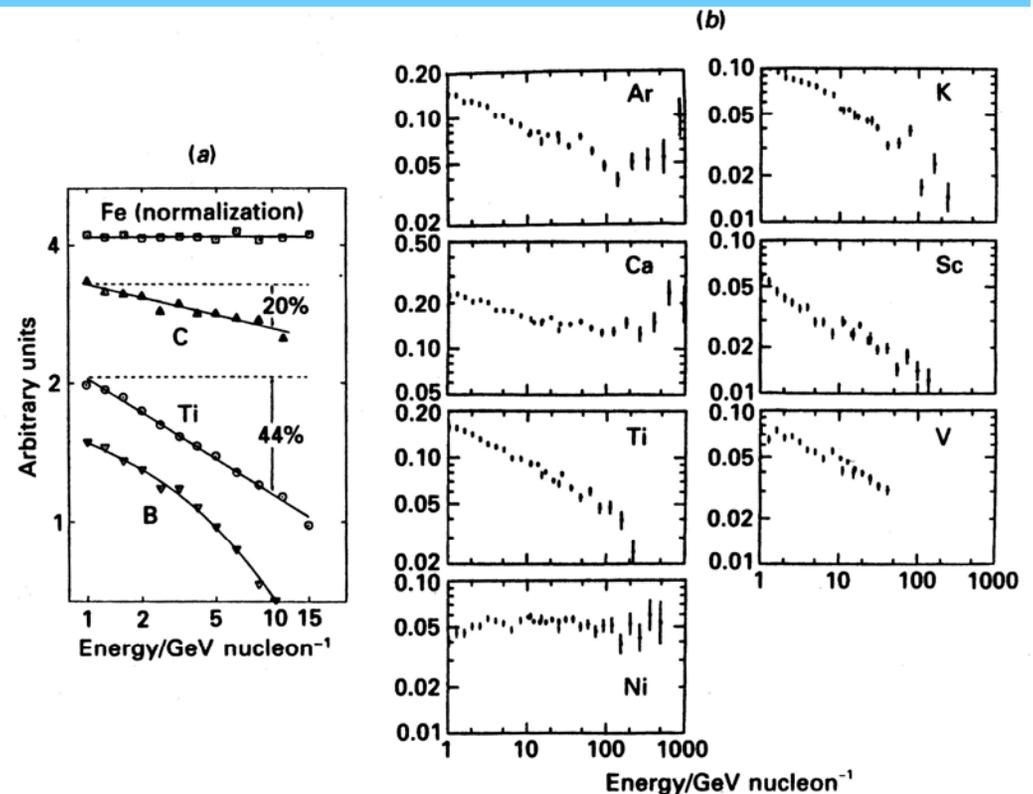


Figure 9.2. Examples of the variation of the differential energy spectra of cosmic rays of different elements. (a) Differential spectra of carbon, titanium and boron relative to iron. (From N. Lund. *Cosmic radiation in contemporary astrophysics*, ed. M. M. Shapiro, page 1, D. Reidel Publishing Co., Dordrecht, 1984.) (b) The differential spectra of argon, calcium, titanium, nickel, potassium, scandium and vanadium relative to iron. (From M. D. Jones, J. Klarmann, E. C. Stone, C. J. Waddington, W. R. Binns, T. L. Garrard and M. H. Israel (1985). *19th Intl. cosmic ray conference*, La Jolla, USA, Volume 2, page 28.)

Vedi M.S. Longair Vol. I, cap. 9

Sezioni d'urto di spallazione

Vedi M.S. Longair Vol. I, cap. 5

Table 5.1.(a) Partial cross-sections for inelastic collisions of selected heavy nuclei with hydrogen with $E = 2.3 \text{ GeV}$ per nucleon.

Product nucleus	Parent nucleus									
	Z	A	¹¹ B	¹² C	¹⁴ N	¹⁶ O	²⁰ Ne	²⁴ Mg	²⁸ Si	⁵⁶ Fe
Lithium	3	6	12.9	12.6	12.6	12.6	12.6	12.6	12.6	12.6
		7	17.6	11.4	11.4	11.4	11.4	11.4	11.4	11.4
Beryllium	4	7	6.4	9.7	9.7	9.7	9.7	9.7	9.7	8.4
		9	7.1	4.3	4.3	4.3	4.3	4.3	4.3	5.8
		10	15.8	2.9	1.9	1.9	1.9	1.9	1.9	4.1
Boron	5	10	26.6	17.3	16.0	8.3	7.1	6.2	5.3	5.3
		11	—	31.5	15.0	13.9	12.0	10.4	9.0	8.1
Carbon	6	10	—	3.9	3.3	2.9	2.1	1.6	1.2	0.5
		11	0.6	26.9	12.4	10.6	7.9	5.9	4.5	1.3
		12	—	—	38.1	32.7	13.5	10.1	7.6	4.7
		13	—	—	10.5	14.4	10.7	8.0	6.0	3.7
Nitrogen	7	13	—	—	10.7	3.6	2.7	2.0	1.5	0.5
		14	—	—	—	26.3	10.9	8.1	6.1	2.9
		15	—	—	—	31.5	10.0	7.5	5.7	4.3
		16	—	—	—	—	3.4	2.6	1.9	1.6
Oxygen	8	14	—	—	—	3.4	2.5	1.9	1.4	0.3
		15	—	—	—	27.8	11.8	8.9	6.7	1.0
		16	—	—	—	—	27.0	13.5	10.2	3.9
		17	—	—	—	—	15.5	11.6	8.7	4.1
Fluorine	9	16	—	—	—	—	—	4.5	4.7	3.5
		17	—	—	—	—	—	1.4	1.1	—
		18	—	—	—	—	—	8.5	6.4	4.8
		19	—	—	—	—	—	14.4	10.8	8.1
Neon	10	18	—	—	—	—	—	21.0	10.9	8.2
		19	—	—	—	—	—	—	4.2	3.1
		20	—	—	—	—	—	—	4.2	3.1
		21	—	—	—	—	—	—	2.8	2.1
Sodium	11	18	—	—	—	—	—	—	17.3	5.3
		19	—	—	—	—	—	—	—	4.0
		20	—	—	—	—	—	—	—	17.8
		21	—	—	—	—	—	—	—	13.4
Magnesium	12	20	—	—	—	—	—	—	—	14.0
		21	—	—	—	—	—	—	—	10.6
		22	—	—	—	—	—	—	—	5.8
		23	—	—	—	—	—	—	—	8.2
Sodium	11	23	—	—	—	—	—	—	—	1.3
		24	—	—	—	—	—	—	—	—
		25	—	—	—	—	—	—	—	1.5
		26	—	—	—	—	—	—	—	1.1
Magnesium	12	20	—	—	—	—	—	—	—	7.7
		21	—	—	—	—	—	—	—	5.6
		22	—	—	—	—	—	—	—	16.8
		23	—	—	—	—	—	—	—	12.7
Magnesium	12	23	—	—	—	—	—	—	—	21.0
		24	—	—	—	—	—	—	—	12.0
		25	—	—	—	—	—	—	—	5.2
		26	—	—	—	—	—	—	—	5.2
Magnesium	12	23	—	—	—	—	—	—	—	29.8
		24	—	—	—	—	—	—	—	1.6
		25	—	—	—	—	—	—	—	17.1
		26	—	—	—	—	—	—	—	18.5
Magnesium	12	26	—	—	—	—	—	—	—	14.4
		27	—	—	—	—	—	—	—	7.6

Product nucleus	Z	A	Parent nucleus								
			¹¹ B	¹² C	¹⁴ N	¹⁶ O	²⁰ Ne	²⁴ Mg	²⁸ Si	⁵⁶ Fe	
Aluminium	13	25	—	—	—	—	—	—	—	6.3	—
		26	—	—	—	—	—	—	—	13.3	2.0
		27	—	—	—	—	—	—	—	21.0	6.7
		28	—	—	—	—	—	—	—	—	5.7
Silicon	14	27	—	—	—	—	—	—	—	—	2.5
		28	—	—	—	—	—	—	—	—	6.0
		29	—	—	—	—	—	—	—	—	10.4
		30	—	—	—	—	—	—	—	—	3.1
Total inelastic cross-section			237.8	252.4	280.9	308.8	363.3	415.7	466.0	763.4	

Cross-sections measured in units of millibarns = 10^{-31} m^2 .
Data kindly supplied by Drs R. Silberberg and C. H. Tsao.

e.g. $^{12}\text{C} \rightarrow ^{11}\text{B}/^{10}\text{B}$

Rapporti tra elementi diversi in funzione dell'energia

Il C (il cui prodotto di spallazione e' Il B) ha un tempo medio di contenimento nella Galassia che dipende dall'energia.

Cammino medio di diffusione fuori dalla Galassia dipendente dall'energia :

$$\xi_e(E) = \xi_0 \left(\frac{E}{E_0} \right)^{-\alpha} \quad [\alpha > 0]$$

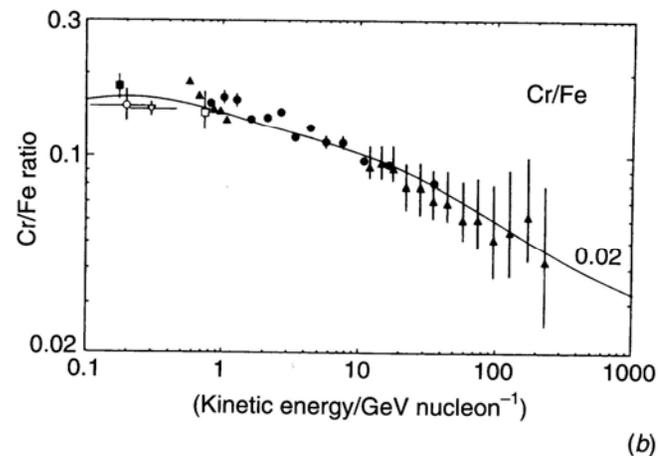
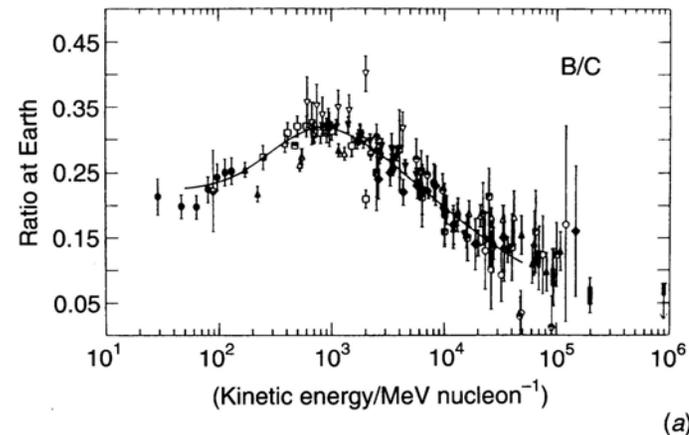


Figure 20.7. (a) The boron-to-carbon ratio as a function of energy. The curve shows the results of propagation calculations by Garcia-Munoz *et al.* (1987). (b) The chromium-to-iron ratios as a function of energy. The curve shows the results of full propagation calculations by Mewaldt and Webber (1990), which assumed that the source Cr/Fe ratio was 0.02. (Both diagrams from J.P. Wefel (1991). In *Cosmic rays, supernovae and the interstellar medium*, eds M.M. Shapiro, R. Silberberg and J.P. Wefel, p. 38. Dordrecht: Kluwer Academic Publishers.)

Rapporti tra elementi diversi in funzione dell'energia

L'equazione relativa alla produzione dell'elemento L da parte dell'elemento M, va modificata per render conto della diffusione

fuori dalla Galassia \Rightarrow aggiunta di un termine : $-\frac{N_L}{\xi_e(E)}$

$$\frac{dN_L(\xi)}{d\xi} = -\frac{N_L(\xi)}{\xi_L} + \frac{P_{ML}}{\xi_M} N_M(\xi) - \frac{N_L}{\xi_e(E)}$$

Soluzione stazionari a $\Rightarrow \frac{dN_L(\xi)}{d\xi} = 0 \Rightarrow$

$$-\frac{N_L}{\xi_L} - \frac{N_L}{\xi_e(E)} + \frac{P_{ML}}{\xi_M} N_M(\xi) = 0 \Rightarrow N_L = \frac{P_{ML} \frac{N_M(\xi)}{\xi_M}}{\frac{1}{\xi_e(E)} + \frac{1}{\xi_L}}$$

Per alte energie, quando $\xi_e \ll \xi_L \Rightarrow$

$$\frac{N_L(\xi)}{N_M(\xi)} = P_{ML} \frac{\xi_e(E)}{\xi_M}$$

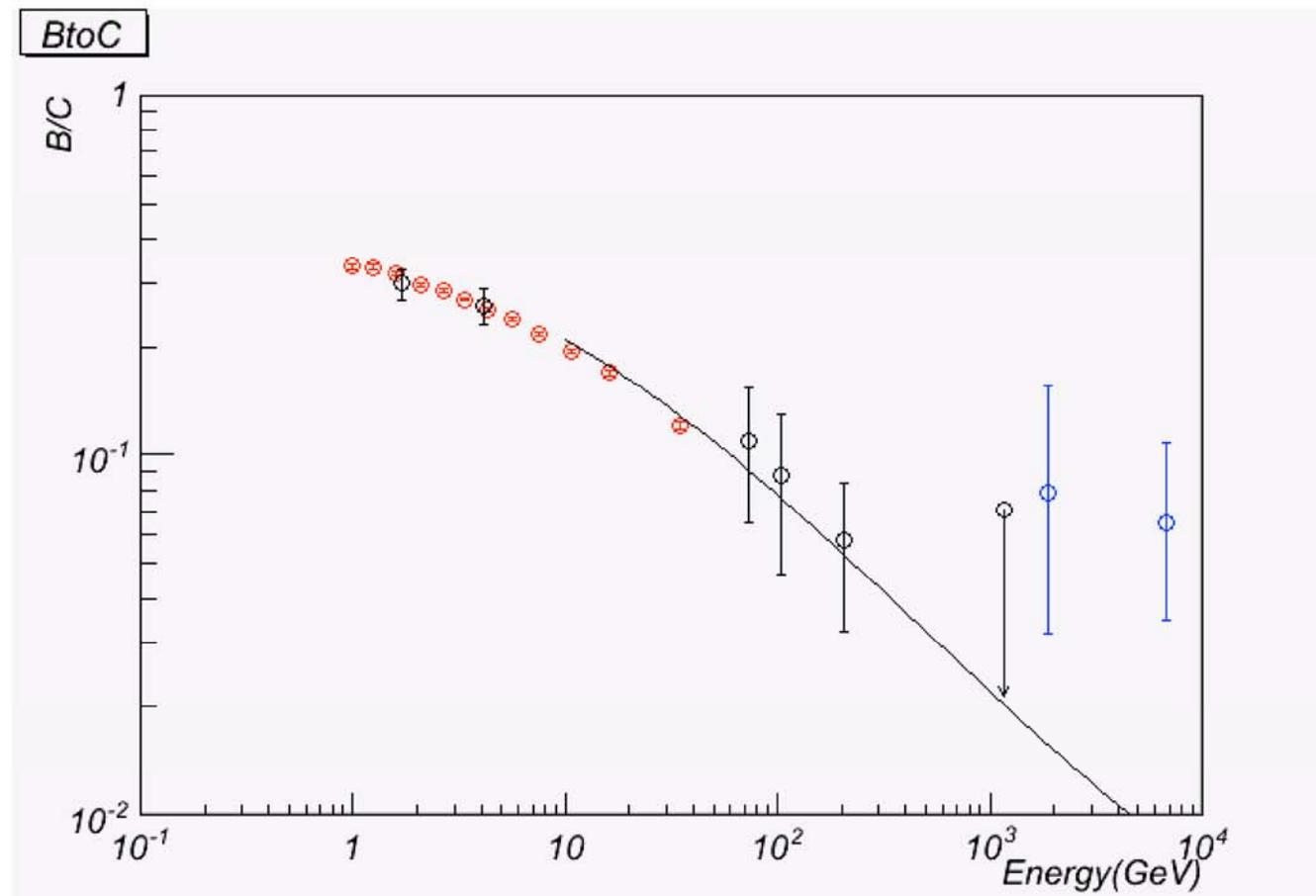
Poiche' sia P_{ML} che ξ_M sono indipendenti dall'energia, segue che la dipendenza dall'energia del rapporto riflette la dipendenza dall'energia di $\xi_e(E)$

Le analisi portano ad una dipendenza della forma : $\xi_e(E) \propto E^{-0.6}$

B/C vs Energy

Escape from the Galaxy is energy dependent (secondary/primary ratio decreases with energy, if $E^{-0.6}$ the source is $dN/dE \sim E^{2.1}$)

New measurements on B/C from RUNJOB (blue) seem high (red -HEAO, Black-CRN)



C vs Energy

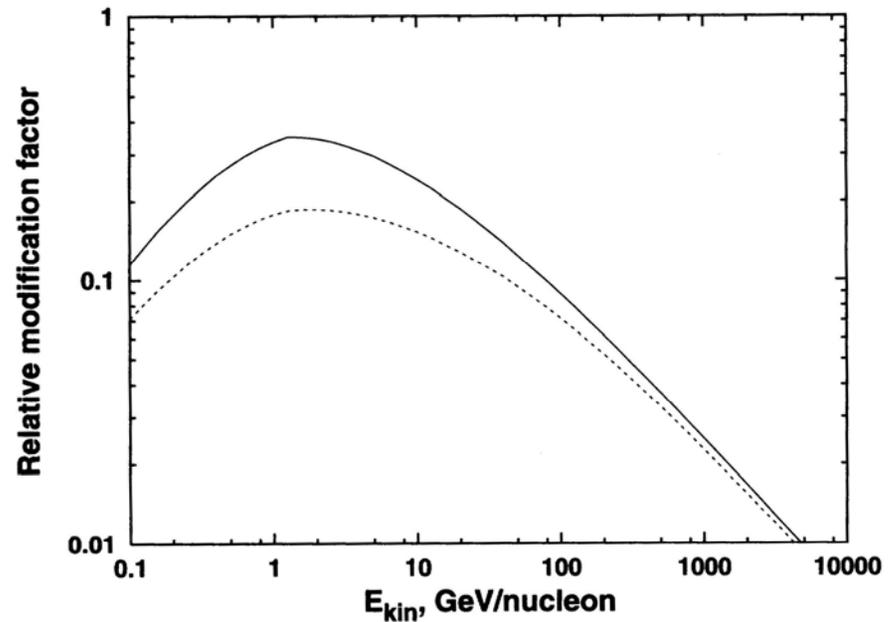


Fig. 4.7. Modification of the shape of the energy spectrum of carbon (solid line) and iron (dashed line) nuclei after propagation on the assumption of no particle gain. Only the relative shape of the spectrum of the two nuclei is correct, because the normalization depends on the average interstellar density during propagation.

Abbondanze dei raggi cosmici alla sorgente

Table 20.2 Cosmic ray source abundances compared with the local Galactic abundances, both normalised to $[Si] = 100$

Element	Cosmic ray source abundance (1990 update)	Local Galactic abundance
H	$8.9 \pm 2.2 \times 10^4$	$2.7 \pm 0.3 \times 10^6$
He	2.4×10^4	$2.6 \pm 0.7 \times 10^5$
C	431 ± 34	1260 ± 330
N	19 ± 9	225 ± 90
O	511 ± 20	2250 ± 560
F	< 2.5	0.09 ± 0.06
Ne	64 ± 8	325 ± 160
Na	6 ± 4	5.5 ± 1.0
Mg	106 ± 6	105 ± 3
Al	10 ± 4	8.4 ± 0.4
Si	100	100
P	< 2.5	0.9 ± 0.2
S	12.6 ± 2.0	43 ± 15
Cl	< 1.6	0.5 ± 0.3
Ar	1.8 ± 0.6	11 ± 5
K	< 1.9	0.3 ± 0.1
Ca	5.1 ± 0.9	6.2 ± 0.9
Sc	< 0.8	$3.5 \pm 0.5 \times 10^{-3}$
Ti	< 2.4	0.27 ± 0.04
V	< 1.1	0.026 ± 0.005
Cr	2.2 ± 0.6	1.3 ± 0.1
Mn	1.7 ± 1.7	0.8 ± 0.2
Fe	93 ± 6	88 ± 6
Co	0.32 ± 0.12	0.21 ± 0.03
Ni	5.1 ± 0.5	4.8 ± 0.6
Cu	0.06 ± 0.01	0.06 ± 0.03
Zn	0.07 ± 0.01	0.10 ± 0.02
Ga	$5.6 \pm 2.8 \times 10^{-3}$	$\sim 3.7 \times 10^{-3}$
Ge	$7.4 \pm 1.0 \times 10^{-3}$	$\sim 11.4 \times 10^{-3}$

From J.P. Wefel (1991). In *Cosmic rays, supernovae and the interstellar medium*, eds M.M. Shapiro, R. Silberberg and J.P. Wefel, p. 44. Dordrecht: Kluwer Academic Publishers.

There is now good agreement about the results of detailed calculations of the primary abundances of the high energy particles in their sources and about the types of path length distributions which can account for the overall chemical abun-

Abbondanze isotopiche per isotopi radioattivi [1]

^{10}Be : $\tau = 3.9 \cdot 10^6$ anni ; osservatore in quiete : $\tau_{\text{obs}} = \gamma \tau$

^{10}Be e' circa il 10% del Be prodotto in processi di spallazione del C ed O.

Decadimento β in ^{10}B

Misure delle percentuali di ^{10}Be e di ^{10}B \rightarrow eta' t dei RC

In pratica si misura il rapporto $N(^{10}\text{Be})/N(^7\text{Be})$

Nota l'eta' dei RC e la materia attraversata ($\xi=50 \text{ Kg/m}^2$) si puo' calcolare la densita' media nella Galassia:

$$\xi = \rho c t \rightarrow \rho = \xi / ct$$

Abbondanze isotopiche per isotopi radioattivi [2]

$$\frac{N(^{10}\text{Be})}{N(^7\text{Be})} = \frac{1/\tau_e(^7\text{Be})}{1/\tau_e(^{10}\text{Be}) + 1/\tau_r(^{10}\text{Be})} \frac{C(^{10}\text{Be})}{C(^7\text{Be})}$$

M.S. Longair, vol. II, Sez. 20.3.1

dove:

$$C(^{10}\text{Be}) = \sum_{j > (i=^{10}\text{Be})} \frac{P_{ij}}{\tau_j} N_j; \quad C(^7\text{Be}) = \sum_{j > (i=^7\text{Be})} \frac{P_{ij}}{\tau_j} N_j$$

P_{ij} = probabilita' che nella spallazione degli elementi j venga prodotto l'elemento i

τ_j = vita media dell'elemento j

N_j = numeri di nuclei/unita' di volume dell'elemento j

$\tau_r(^{10}\text{Be})$ = vita media del ^{10}Be

$\tau_e(^{10}\text{Be})$ = tempi di "escape" del ^{10}Be ; $\tau_e(^7\text{Be})$ = tempi di "escape" del ^7Be

Percentuali isotopiche del Be

324 20 The origin of high energy protons and nuclei

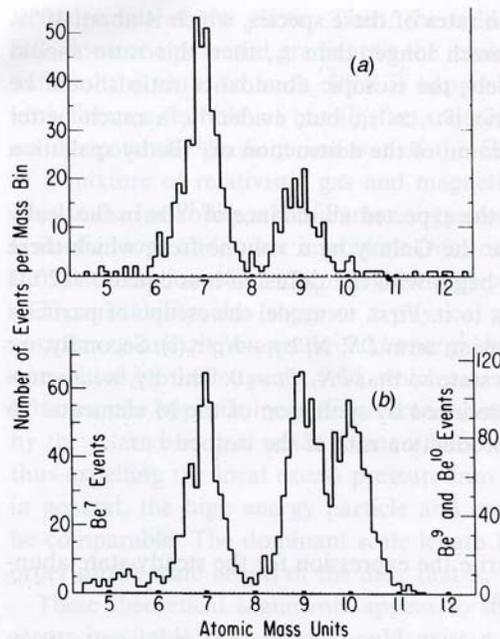


Figure 20.10. (a) The isotopic mass distribution of the isotopes of beryllium as observed by the cosmic ray telescopes on board IMP-7 and IMP-8. (b) Calibration of the expected distribution of beryllium isotopes in laboratory experiments showing the ability of the telescopes to distinguish the isotopes ${}^9\text{Be}$ and ${}^{10}\text{Be}$. (From M. Garcia-Munoz, G.M. Mason and J.A. Simpson (1977). *Astrophys. J.*, **217**, 859.)

Misure del rapporto :

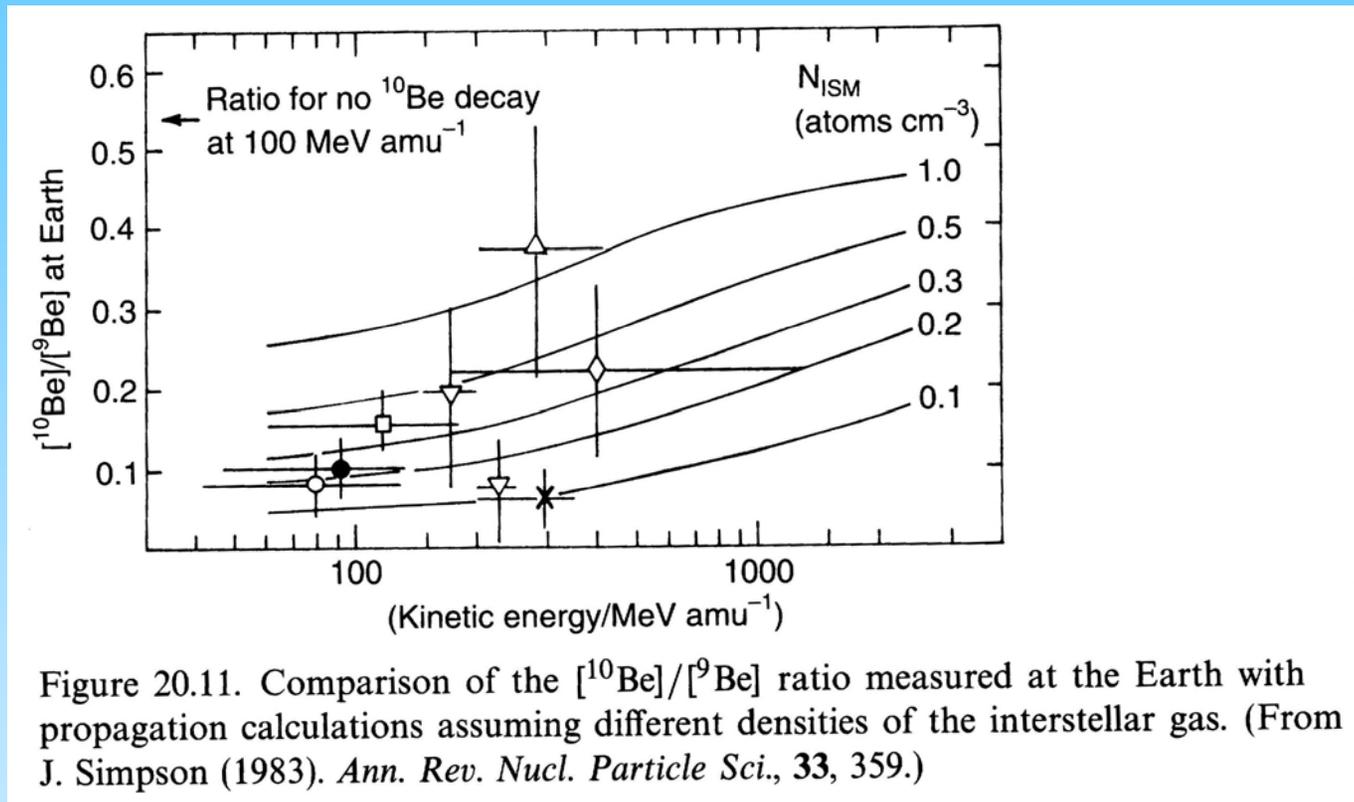
$$\frac{{}^{10}\text{Be}}{{}^7\text{Be}+{}^9\text{Be}+{}^{10}\text{Be}} = 0.028 \Rightarrow \tau_e = 10^7 \text{ anni}$$

Si puo' ora calcolare la densita' ρ :

$$\rho = \frac{\xi}{c \tau_e} = \frac{50 \text{ kg/m}^2}{3 \times 10^8 \text{ m/s} \cdot 3.15 \times 10^{14} \text{ s}} = 5 \times 10^{-22} \text{ kg m}^{-3}$$

$$m_p = 1.67 \times 10^{-27} \text{ kg} \Rightarrow n = 3 \times 10^5 \text{ m}^{-3}$$

Percentuali isotopiche del Be



Risultati di un calcolo dettagliato confrontato con i dati. La dipendenza del Rapporto tra ^{10}Be e ^9Be dall'energia e' calcolata per diverse ipotesi sulla densita' della materia Galattica (in atomi cm^{-3})

FINE