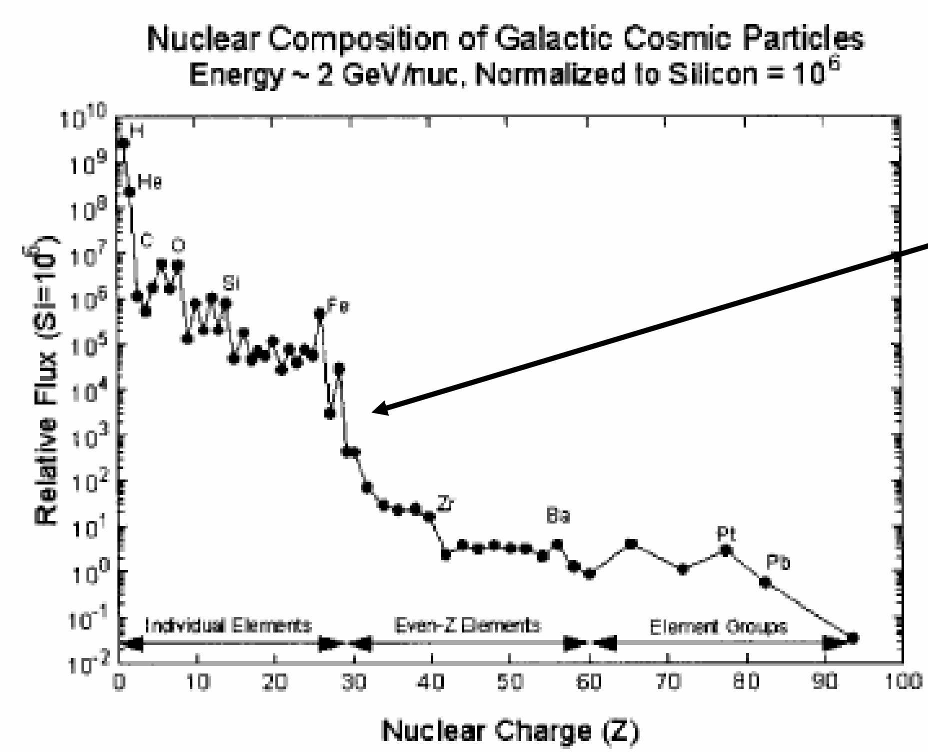
High LET ions in space

- How really critical are high LET ions ?
- Are there any observations from instrument measurements ?
- Are there indirect evidence from high LET threshold devices flown in space ?

- Review (probably, not exhaustive) of IEEE publications, other journals (JGR), and reference documents such as 1997 NSREC short course (section I – J. Barth, section III – E. Petersen) and 1996 NSREC short course (section I – Ritter)
- Use of on-line space environment tools (IPSAT)

Relative abundances of ions



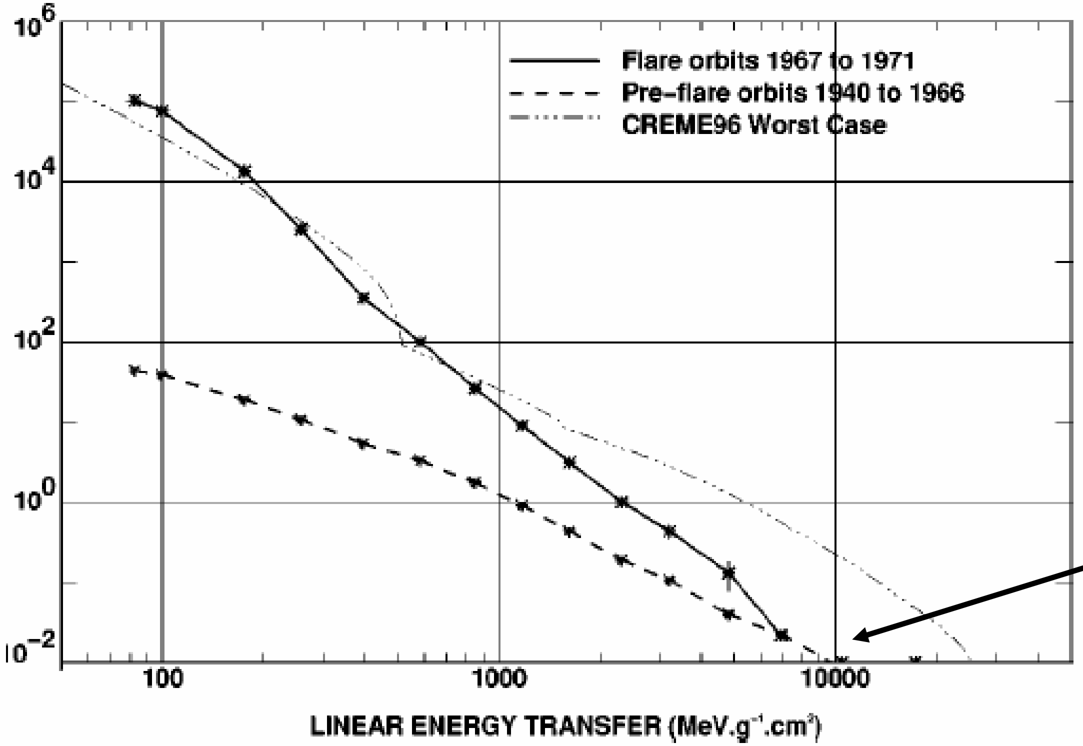
Extremely sharp decrease in relative abundance for elements heavier than Iron

- **Relative abundances at ~2 GeV/n reconstructed from satellite and balloon experiments, Medwadlt et al, 1988, from J Barth 1997 NSREC course**

R. A. Medwadlt, "Elemental Composition and Energy Spectra of Galactic Cosmic Rays," Proc. from Conference on Interplanetary Particle Environment, JPL Publication 88-28, pp. 121-132, JPL, Pasadena, CA, April 15, 1988.

Direct ion measurements in space

- Measurements made with “common” monitors are limited by the very weak fluxes expected for high energy heavy species
- Fairly good knowledge of light element spectra, but few information on heavy elements



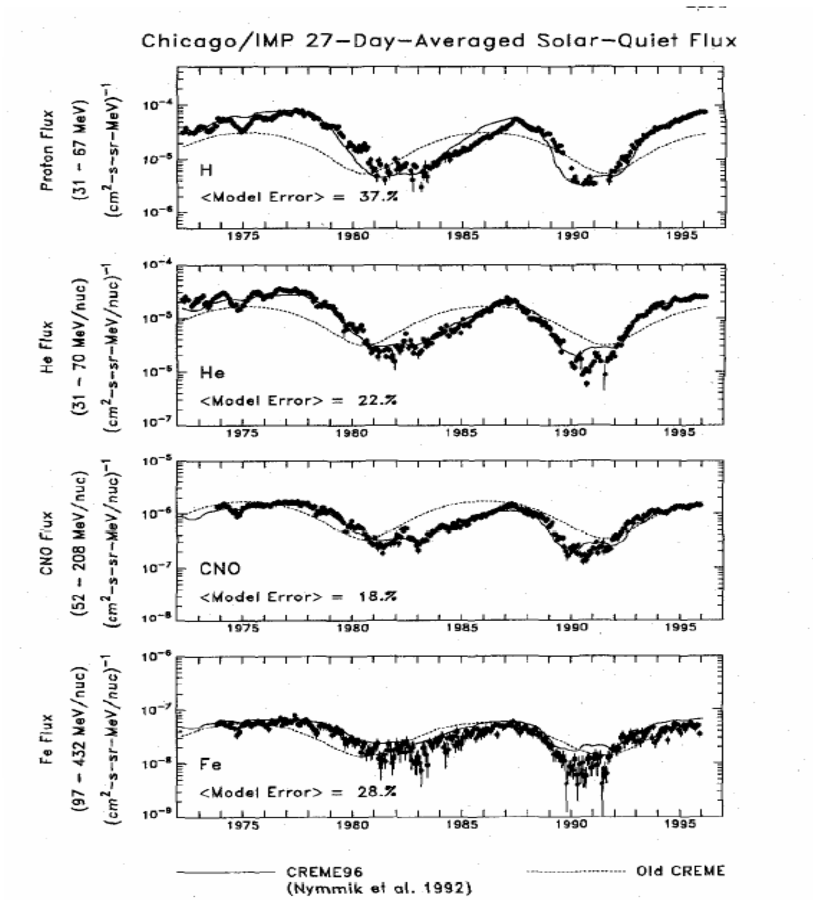
CREDO measurements on MPTB (C.S. Dyer, DERA now QinetiQ)

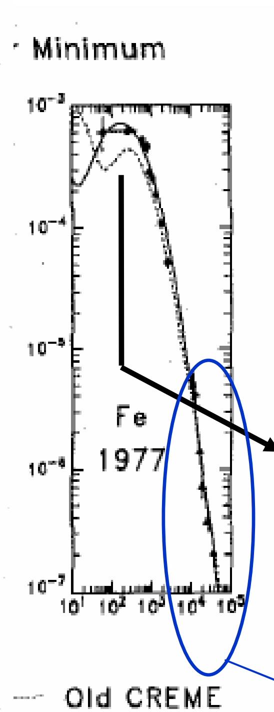
This means, in usual units,
<u>LET = 10 MeV.mg^{-1}.cm^2</u>

Radiation environment measurements from CREAM and CREDO during the approach to solar maximum, Dyer, C.S.; Truscott, P.R.; Sanderson, C.; Watson, C.; Peerless, C.L.; Knight, P.; Mugford, R.; Cousins, T.; Noulty, R.; IEEE Transactions on Nuclear Science, Volume 47, Issue 6, Part 3, Dec. 2000 Page(s):2208 - 2217

Direct ion measurements in space

- **Higher energy data available from few scientific payloads**
- **IMP-8 Chicago CRT (used in 1996 CREME revision) 1973-2002**





These spectra were used in the CREME96 / Nymmik model (solid curves). Old CREME is dashed curves.

ϕ = ~ 8 10^{-4} m^{-2} s^{-1} sr^{-1} MeV/n^{-1}

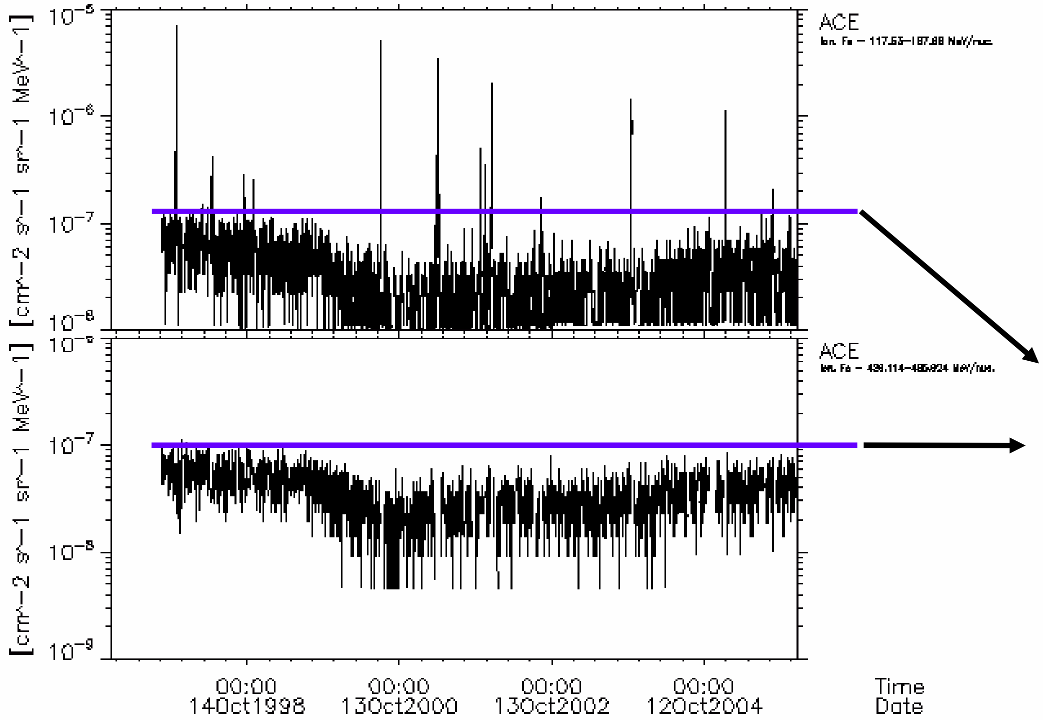
for a few 100 MeV/n at solar min

I was not able to find from where do these points come

CREME96: A Revision of the Cosmic Ray Effects on Micro-Electronics Code, Tylka, A.J.; Adams, J.H., Jr.; Boberg, P.R.; Brownstein, B.; Dietrich, W.F.; Flueckiger, E.O.; Petersen, E.L.; Shea, M.A.; Smart, D.F.; Smith, E.C.; IEEE Transactions on Nuclear Science, Volume 44, Issue 6, Part 1, Dec. 1997 Page(s):2150 - 2160

Direct ion measurements in space

- Higher energy data available from few scientific payloads
- IMP-8 (used in 1996 CREME revision) few 10 MeV/n 1973-2002
- ACE/SIS and CRIS up to 200 and 400 MeV/n Fe 1997- present



ACE Fe ~ 150 MeV/n and 350 MeV/n (resp SIS, above, CRIS, below)

Note : no display of CRIS data during solar flares

This means,

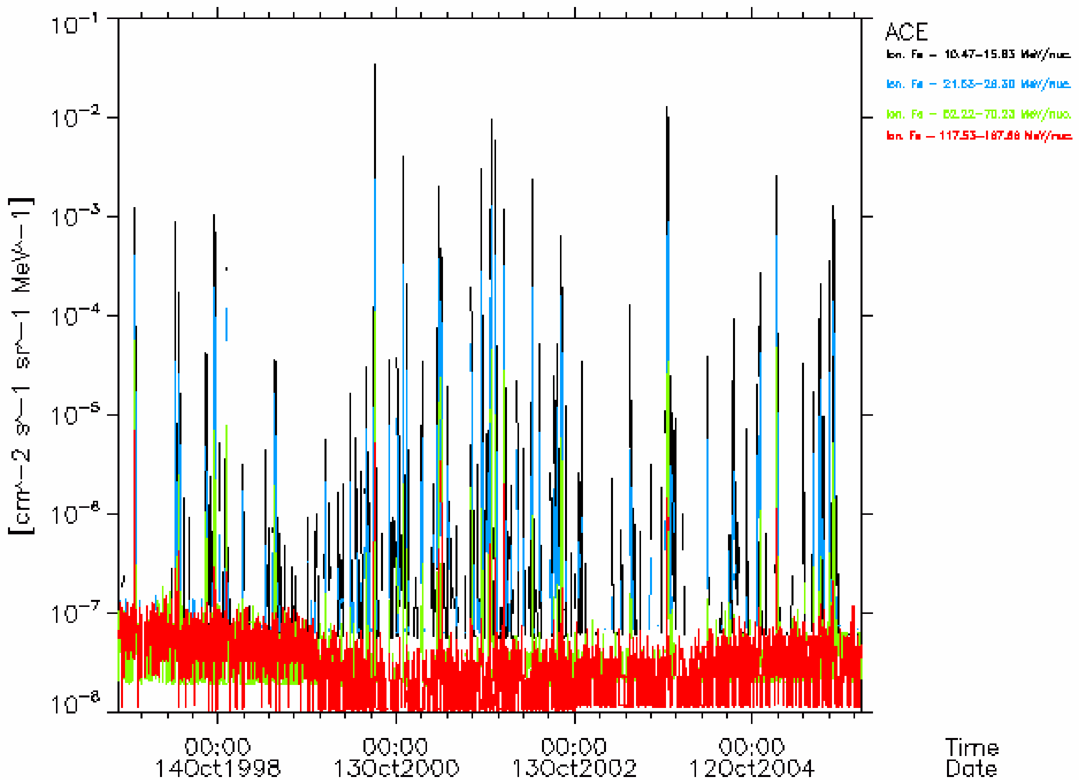
ϕ = ~ 10^{-4} m^{-2} s^{-1} sr^{-1} MeV/n^{-1}

for a few 100 MeV/n at solar max

Display from CNES-ONERA data analysis tool IPSAT, http://wwwe.onecert.fr/craterre/home.html , webmaster S. Bourdarie, ONERA-DESP

Direct ion measurements in space

- **ACE/SIS measurements in non-flare periods seem just above measurement noise**

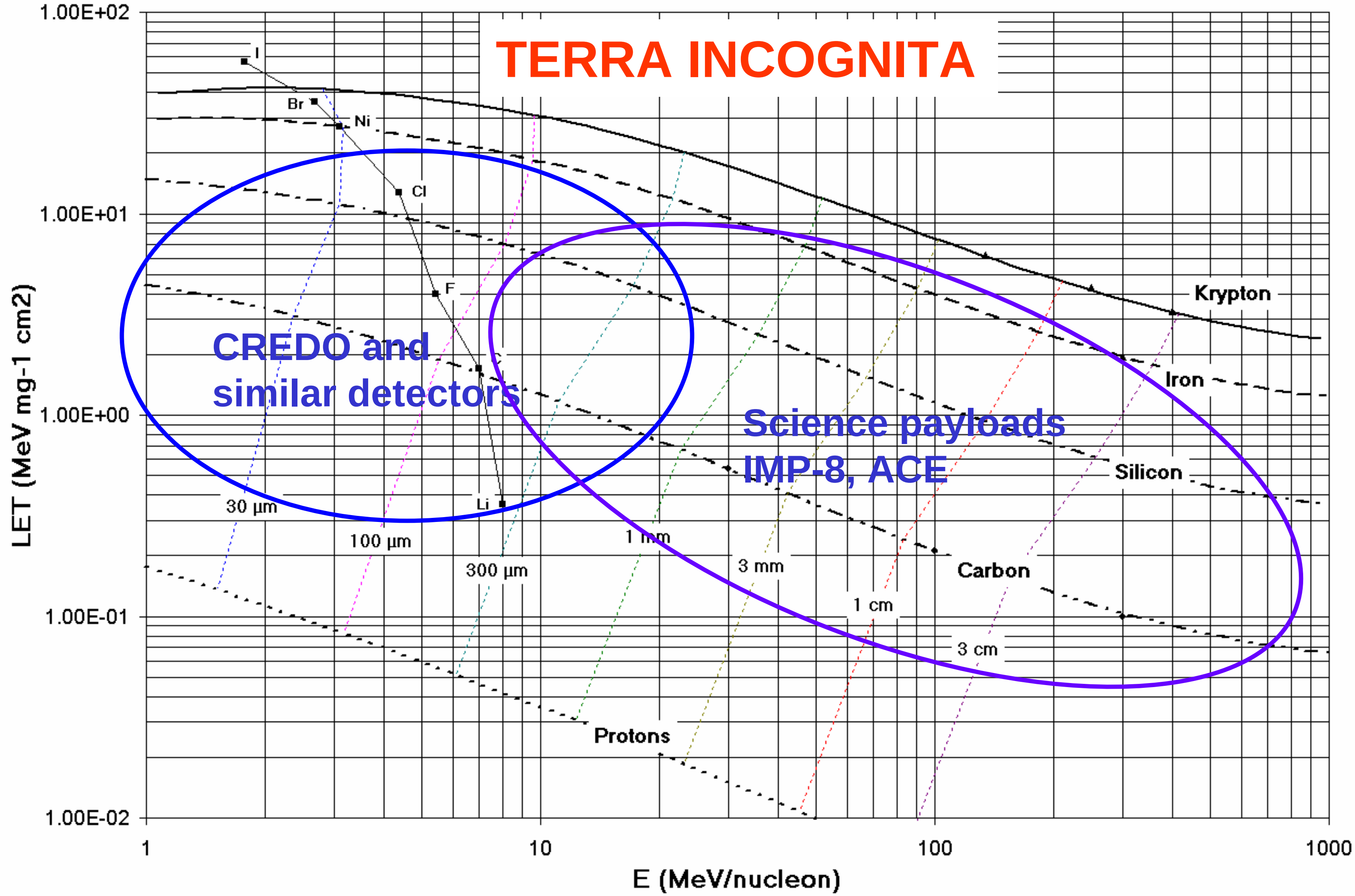


ACE/SIS data channels from 10 to 150 MeV/n

GCR background level seems independent of energy channel

Display from CNES-ONERA data analysis tool IPSAT, http://wwwe.onecert.fr/craterre/home.html , webmaster S. Bourdarie, ONERA-DESP

Where does that lead us ?

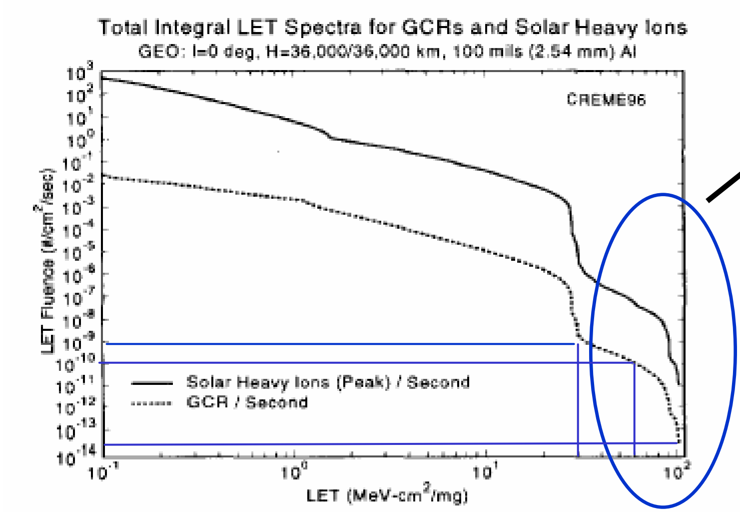


How is it translated into models ?

- Present consensus is, that for Z=1 to 28 (H/He, CNO, Fe groups), GCR models are quite good (especially the CREME96 version with improved fluxes and solar modulation).
- More debate on SCR fluxes in this range, but again CREME96 is a major improvement.
- Anomalous cosmic rays (ACR) seem not to be a concern.

- For Z > 28 and consequently high LETs (above 30-40 uu) we are in Terra incognita
- All GCR spectra and fluxes for these species are extrapolated from abundance ratios and spectral shapes from other species, roghly the same methods were applied here for CREME86 and 96
- Furthermore, these assumptions are more or less the same for reconstructing flare spectra

How is it translated into models ?



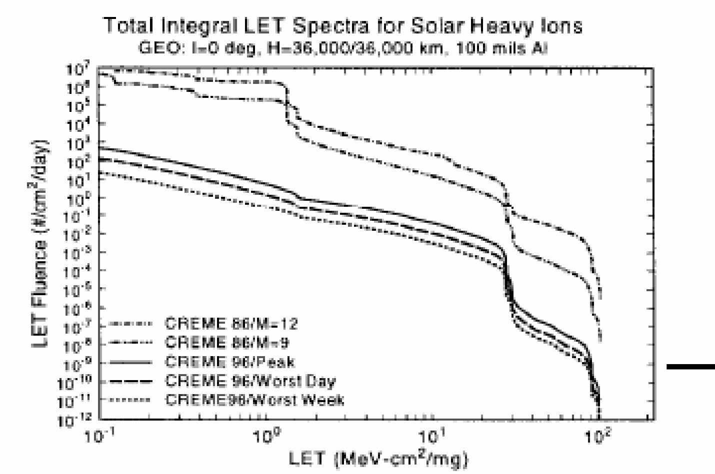
This part of the spectrum is extrapolated

LET = 30 uu : 1 p/cm² ~ 30 years

LET = 60 uu : 1 p/cm² ~ 300 years

LET = 100 uu : 1 p/cm² ~ 3 million years

For the time being, the latter number cannot be verified experimentally, it would need a gigantic detector array.



Use of CREME86 solar flare options not recommended

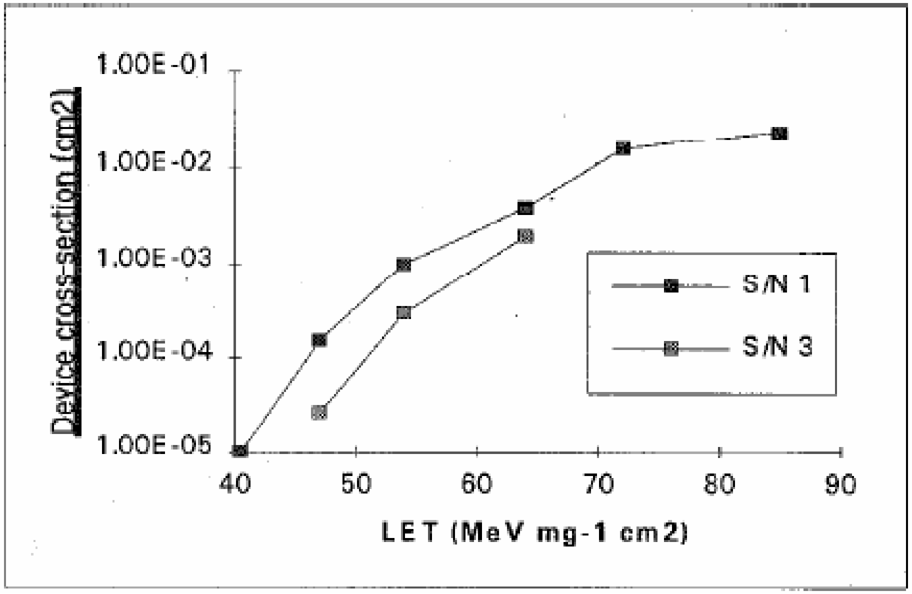
Modelling space radiation environments, Janet Barth, NASA/GSFC, 1997 NSREC short course

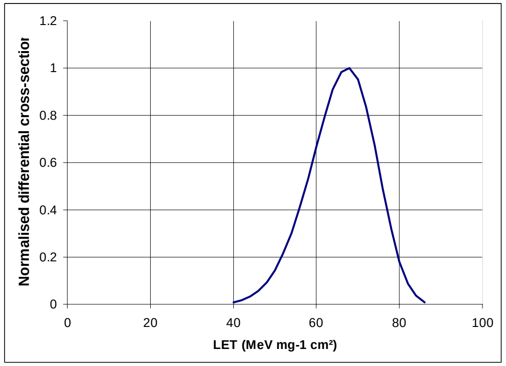
Search for indirect evidence

- **An indirect way of verifying flux calculations for high LET ions is to search in-flight SEE data on high LET threshold components**
- Most of the published SEE data since the end of the 1980's (ESA, NASA/GSFC, JPL, JAXA, CNES, SSTL, DERA, USAF, NRL) and results from MPTB, APEX and other payloads mostly deal with medium or low threshold devices (< 15 uu) and the high LET contribution cannot be extracted.
- **This is not surprising with respect to expected fluxes (see previous slide)**
- For finding evidence of high LET SEEs in space, we should dig in older data from 1970-1980 projects using technologies of that time, and with enough "detector array" (total exposed surface) for having a chance to count an event.
- **The author was not able to find such data, except one case on a CNES project.**
- **Other sets may be available, identifying them would be great !**

The case of SPOT 1,2,3 memories

- The first generations of SPOT satellites were equipped with an on-board computer memory made out of 1440 Phillips HEF 4736 1-kbit SRAMs procured in the 1980’s (SPOT-1 was launched in 1986), 1088 of which were power supplied
- We did observe in-flight SEUs





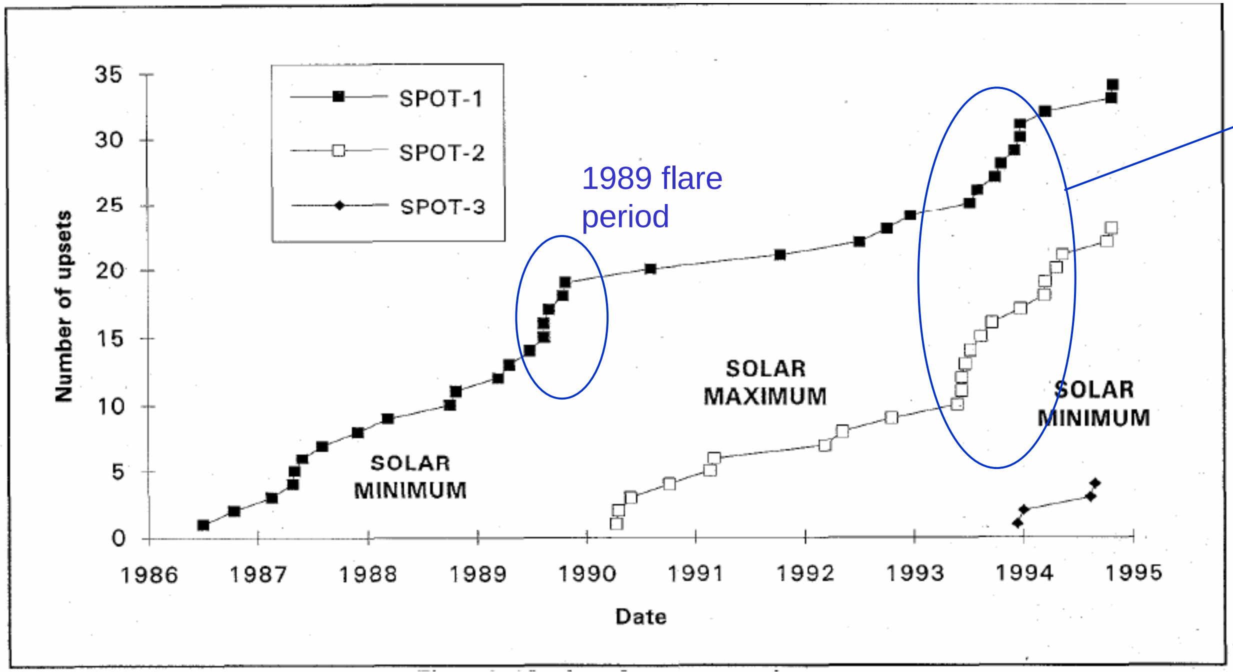
Those SRAMs had an LET threshold of ~ 40 uu

Maximum of sensitivity distribution was around 70 uu

Influence of solar cycle on SPOT-1,-2,-3 upset rates, Ecoffet, R.; Prieur, M.; Del Castillo, M.F.; Duzellier, S.; Falguere, D.; IEEE Transactions on Nuclear Science, Volume 42, Issue 6, Part 1, Dec. 1995 Page(s):1983 - 1987

The case of SPOT 1,2,3 memories

- **Upset count versus time**



Still unexplained :

-Why do rates rise in this period ?

-Why don't they rise at the same time for the two satellites following each other in the same orbital plane ?

-On 26 Dec. 1993, two upsets within 31s on two different packages at Lat +70° Long +45°

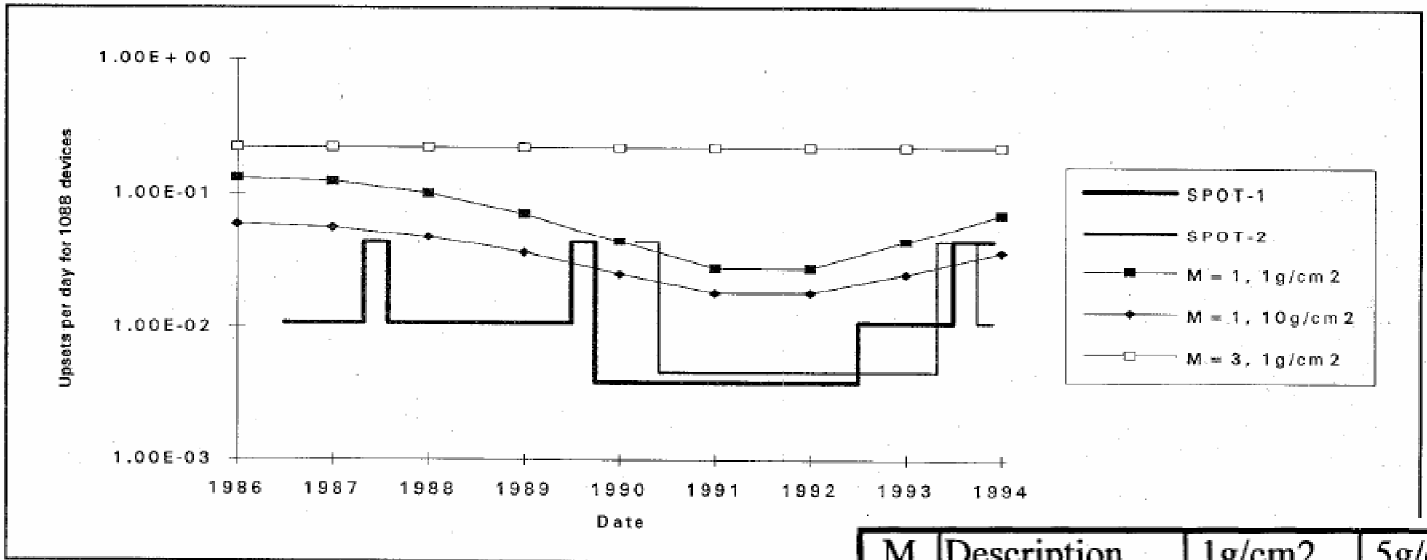
-Who's the ghost ? Killer electrons ? GCR entries in disturbed solar field periods ? Mere chance ?

- **Correlations with SEPs (uncertainty : memory dump delay)**
  - August 1989 : 2 upsets
  - October 1989 : 1, maybe 2 upsets
  - March 1991 (CRRES event) : none

Hardly statistically significant

The case of SPOT 1,2,3 memories

- Comparison with CREME (86) estimations : still not too bad



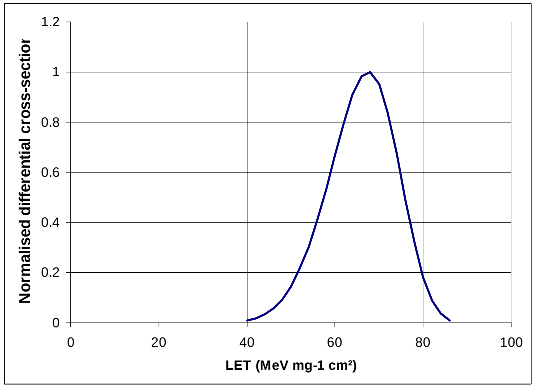
50 x 50 x 2 µm considered for sensitive volume

M	Description (see [4])	1g/cm2	5g/cm2	10g/cm2
5	ordinary mean	7.3	0.090	0.034
6	ordinary wc	32.3	0.211	0.038
7	10% wc mean	38.4	0.230	0.038
8	10% wc wc	207	0.690	0.050
9	4aug72 mean	2807	47.3	3.9
10	4aug72 wc	16211	196	15.2
11	compwc mean	2916	435	218
12	compwc wc	14144	2296	1088

- M=1 (~ CREME 96) still on the safe side
- Comparison with CREME (86) solar heavy ion rates
  → Shielding has a dramatic influence on estimations

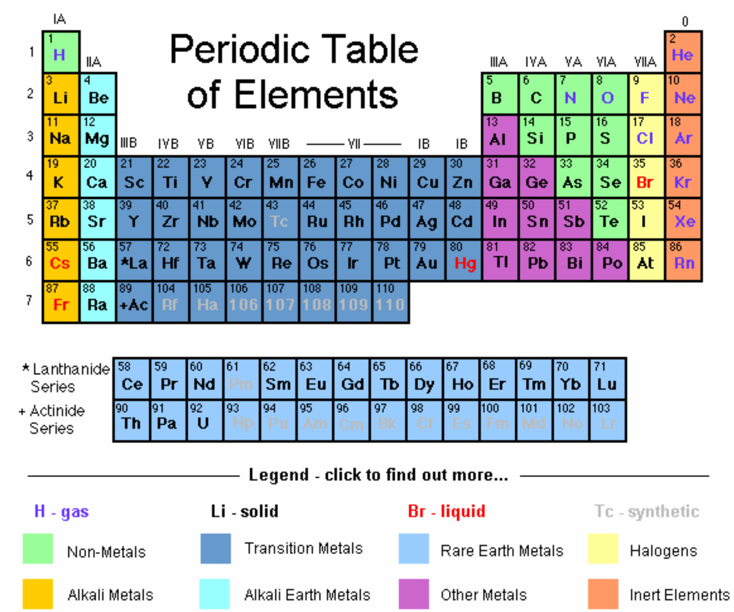
The case of SPOT 1,2,3 memories

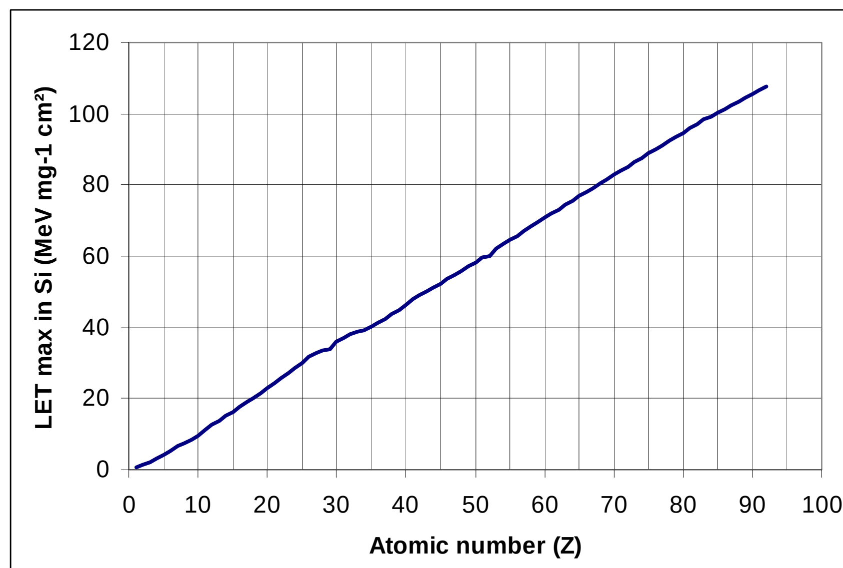
- **What ions were we detecting ?**



At first glance, we may believe we have an “LET detector” around 70 uu (high LET, heavy species) but could also be non normal incidence lower LET ions

RPP was about 50 x 50 x 2 µm, Qc = 0.1 pC





The case of SPOT 1,2,3 memories

- What ions were we detecting → effect of non normal path lengths
- CREME 86 simulations with different Z ranges

Z range	% of calculated rate
H to U	100.00
H to Zn	99.33
C to Zn	99.33
Si to Zn	87.25
Ti to Zn	67.11

(scaling of M=3, 1 g/cm², of CREME calculations as implemented in the OMERE software)

We were detecting non normal incidence ions basically from the Iron group.

The appropriate quantity is the charge deposited over the path length and not the LET. We have a charge, not a LET detector.

- Use of ions with Z > 30 (Zn) : no influence on the results (<1%)
- The Iron group (Ti to Zn) accounts for 2/3 of the rate
- Adding intermediate group Al, Si gives 9/10 of the rate
- Some 10% contribution from the CNO group
- Conclusion : here again, <u>using CREME itself</u>, no evidence for significant effects of very high LET ions

cnes

CREME 96 recommendations

- **From CREME 96 web site on line help :**

- **Elements Included in FLUX Ionizing-Radiation Environment Calculations**
- You must specify the range of elements to be included in your FLUX calculations of the external space ionizing-radiation environment.
- By default, this range is set at:
- minimum atomic number: Z = 1 (protons)
- maximum atomic number: Z = 28 (nickel)
- For the large majority of SEE applications, this range is adequate: cosmic rays and solar energetic particles with Z > 28 are very rare and generally may be neglected.
- However, for SEE rate calculations:
- in devices with high thresholds (effective LET > 15 MeV-cm2/mg);
- for applications demanding very low SEE rates (< 10-8 SEEs/bit/day);
- in low-Earth, low-inclination orbits, where the usual source of high LET particles (low-energy Fe group nuclei) is geomagnetically excluded;
- you should consider increasing the maximum atomic number to Z=92. But please note that including Z > 28 elements in your calculations may significantly slow down the nuclear transport code TRANS.

- **On our SPOT example, Z <= Fe group gives good results even for LET much above 15 uu.**

Conclusions

- The author was not able to find evidence, either in space ion measurements or in flight SEE records, for any observation of heavy, high LET ions
- Even the SPOT memory case can be explained, using CREME and RPP modelling, without use of such ions

- The author is an engineer, not a space environment scientist, and thus would recommend to set up a working group, on an agency initiative (ESA, NASA,...), composed of space scientists and engineers for :
  - the careful re-examination of space ion data and especially the ACE data (not used for CREME 96) by appropriate people a consequent adaptation, if necessary, of the environment models
  - the careful examination of older in-flight data from the 1970's and 1980's, by space engineers, for trying to find other clues than those presented here

Conclusions

- **Our feeling at this point is that heavy, high LET species have a minor impact on space SEE rates even for components with quite high LET thresholds**
- **Now, and the SPOT case may help support this statement :**
- **High LET ions may be convenient for SEE ground characterisation – *even if we characterise with ions that will not be responsible for the actual space rate (e.g. the SPOT case)* - the other alternative for SPOT would have been high energy angular measurements with Fe group species – it might not have been cost effective**
- **High LET ions may also be convenient for simulating large charge depositions, particularly in the case of long collection length phenomena (30-100 µm, SET,…). It may be more convenient here to use a high LET lower energy ion than a lower LET higher energy ion for simulating the same charge deposition. The question is, charge collection in the two cases may not obey to the same mechanisms.**

- **<u>Understanding of the SEE phenomena mechanisms</u> is the key for appropriate test specifications. LET is (was) only a convenient "proxy" for SEE sensitivity, the real issue is charge deposition and collection.**