The role of cosmic-ray nuclei and electrons in the LISA test mass charging rate

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LISA SUN DISTANCE RANGE: $149 \div 152\ 10^6$ km
(0.9933 AU ÷ 1.0133 AU)

LISA LATITUDINAL RANGE: 0.7 ÷ 1.0 degree

What does this mean for LISA?

SOLAR MINIMUM

A radial correction factor of the order of 10^{-3} %

A latitudinal correction factor of the order of 0.33%

Measurements near the Earth OK!

SOLAR MAXIMUM

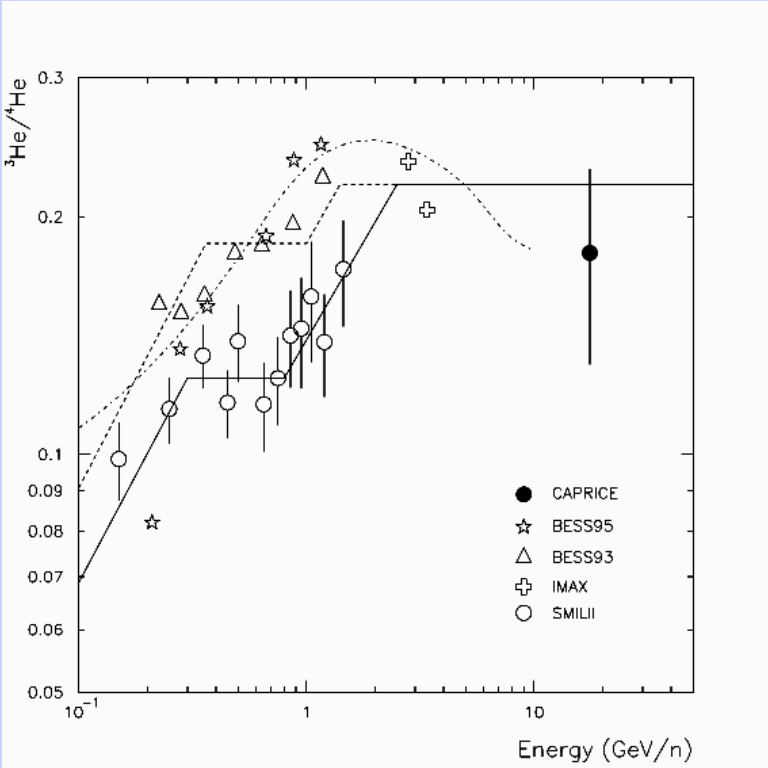
No latitudinal correction is needed

COSMIC-RAY COMPOSITION

Protons : 90%

Helium : 8%

$^3He/^4He$ Ratio



Heavy Nuclei:1%
- Carbon
- Oxygen
- Nitrogen
- Magnesium
- Silicon
- Iron

Electrons: 1%

Proton Differential Flux

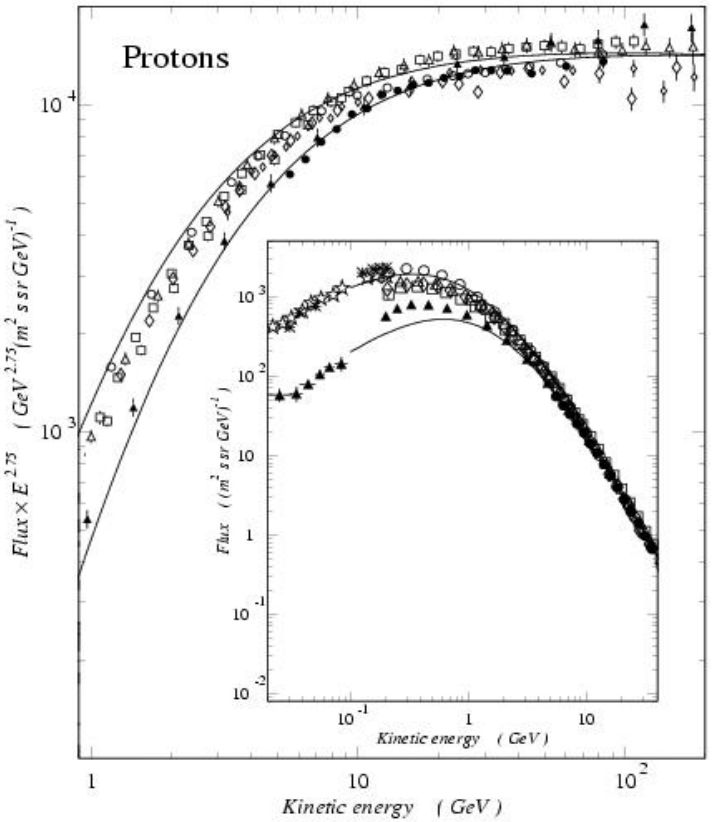


Figure from C. Grimani et al., Class. Quant. Grav., 21, S629, 2004

Helium Differential Flux

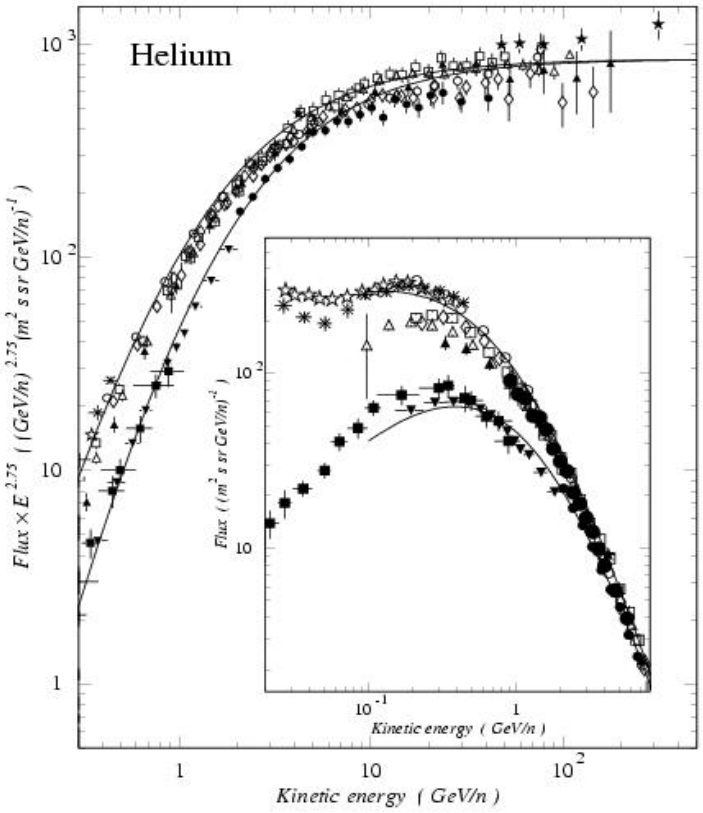


Figure from C. Grimani et al., Class. Quant. Grav., 21, S629, 2004

Carbon Differential Flux

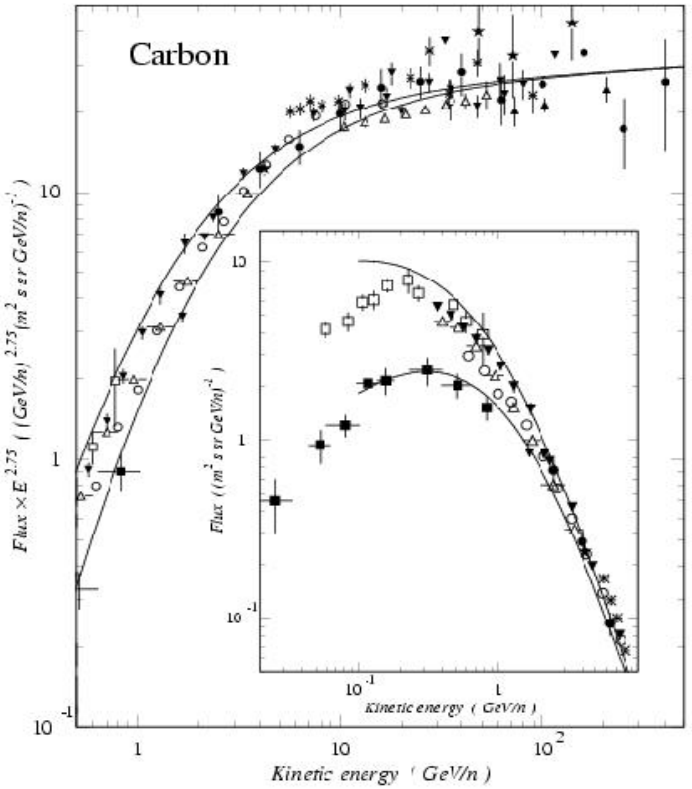


Figure from C. Grimani et al., Class. Quant. Grav., 21, S629, 2004

Oxygen Differential Flux

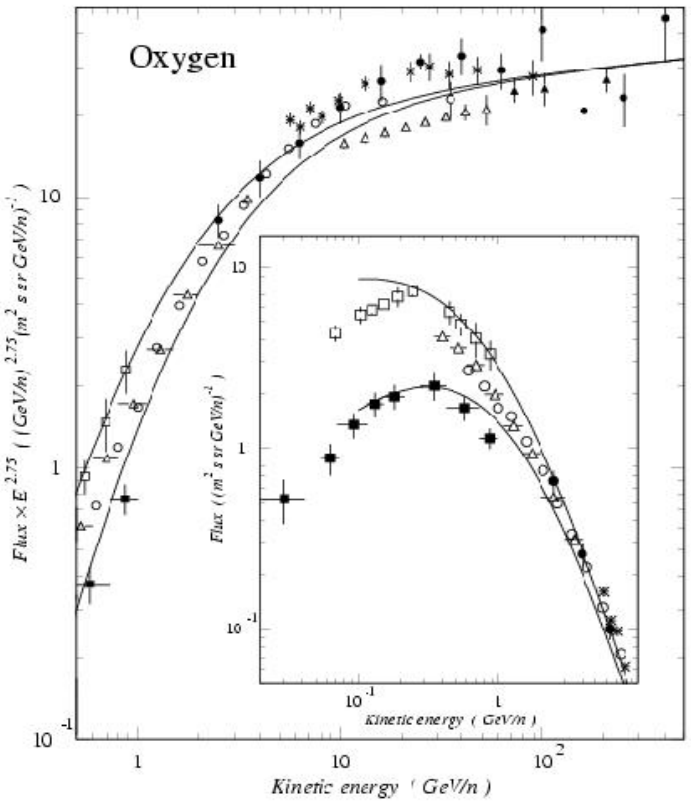


Figure from C. Grimani et al., Class. Quant. Grav., 21, S629, 2004

Primary cosmic-ray interpolation function

$$F(E) = A(E + B)^{-\alpha} E^{\beta}$$ Part/(m^2 sr s GeV/n)

Where E is GeV/n

Solar minimum

p	A 18000	B 1.09	α 3.66	β 0.87
He	850	0.99	3.10	0.35
C	23	0.95	3.00	0.29
O	21	0.95	3.00	0.32

Solar maximum

p	A 18000	B 1.55	α 3.90	β 1.11
He	850	1.25	3.60	0.85
C	23	1.22	3.40	0.69
O	21	1.22	3.40	0.72

Most Abundant Heavy Nuclei

Element	Z	Abundance (% O)
N	7	28%
Ne	10	16%
Mg	12	20%
Si	14	14%
Fe	26	9%

Simpson, J. A., Ann. Rev. Nucl. Phys. Sc., 33, 323, 1983
Stephens, S. A. and Streitmatter, R. E., Adv. Sp. Res., 27, 749, 2001

Heavy nucleus interpolation function

$$F(E) = A(E + B)^{-\alpha} E^{\beta}$$ Part/(m^2 sr s GeV/n)

Element	A	B	α	β
N	5.9	0.95	3.00	0.32
Ne	3.4	0.95	3.00	0.32
Mg	4.2	0.95	3.00	0.32
Si	2.9	0.95	3.00	0.32
Fe	1.9	0.95	3.00	0.32

Electron Flux Measurements

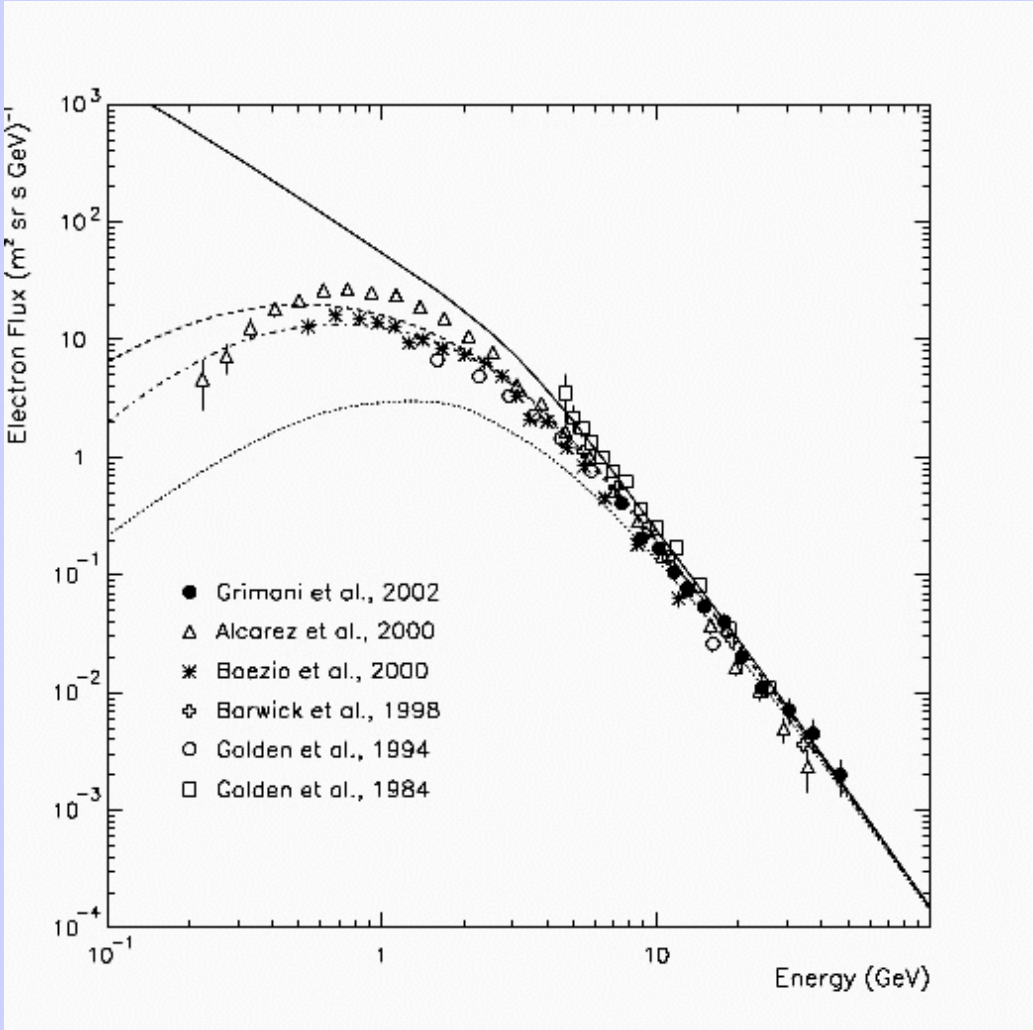
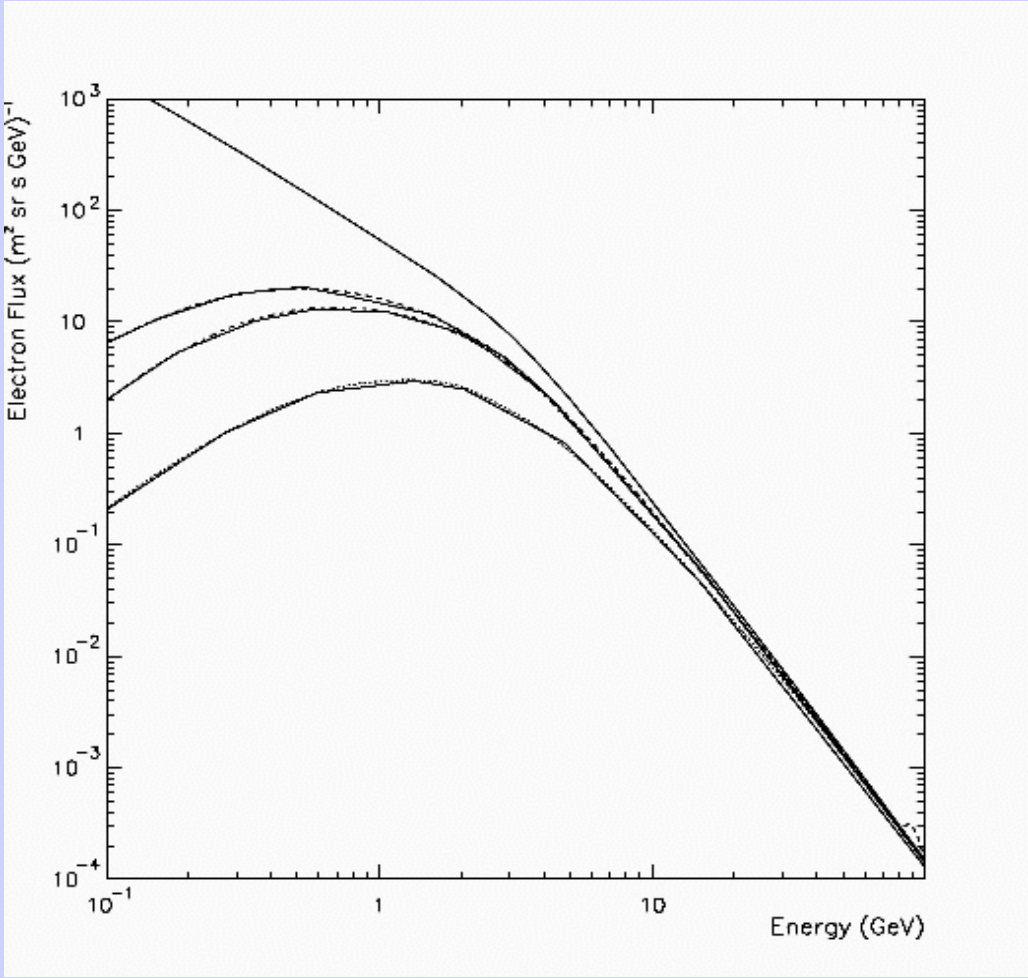


Figure from Grimani C. et al., A&A, 2002, 392, 287

Electron Flux Straight Line Interpolation



LISA SPACECRAFT SIMPLIFIED GEOMETRY

(FLUKA MONTE CARLO PROGRAM)

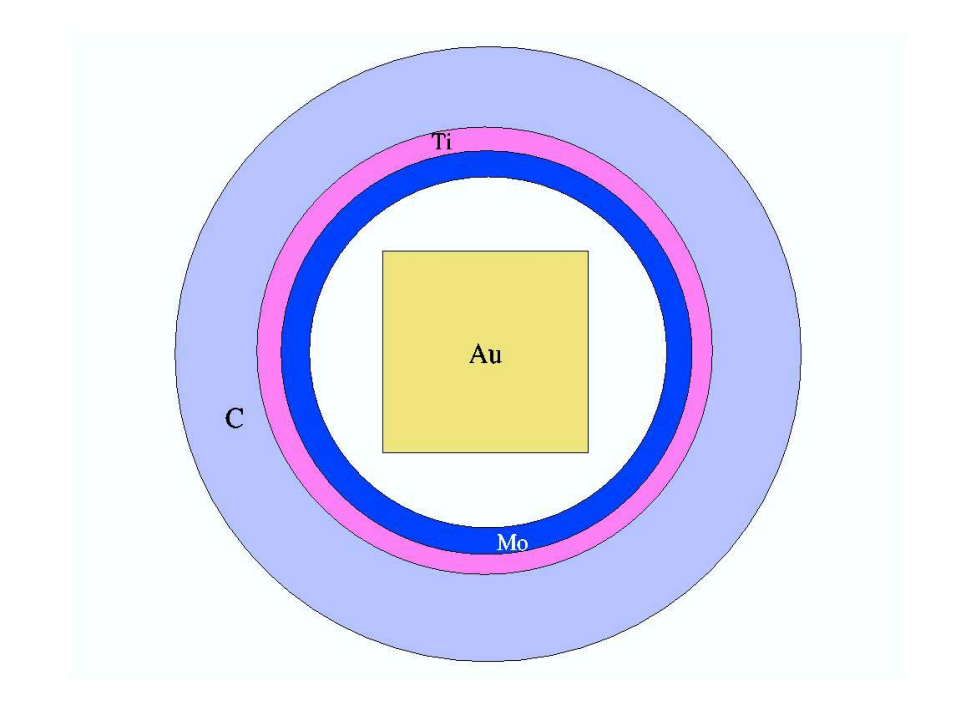


Figure from Vocca et al., Class. Quant. Grav. ,201, S665, 2004

- Test mass side: 4.6 cm
- Test mass material: gold
- Test mass depth : 89 g/cm^2

Material	Density ($g\ cm^{-3}$)	Thickness (cm)	Grammage ($g\ cm^{-2}$)
C	2.10	2.0	4.2
Ti	4.54	0.5	2.3
Mo	10.28	0.6	6.2
Au	19.32	4.6	88.9

FLUKA Monte Carlo Characteristics

Particle transport

	Secondary particles	Primary particles
Charged hadrons	1 keV ÷ 20 TeV	100 keV ÷ 20 TeV
Neutrons	Thermal ÷ 20 TeV	Thermal ÷ 20 TeV
Muons	1 keV ÷ 1 PeV	100 keV ÷ 1 PeV
Electrons (low-Z) (high-Z)	1 keV ÷ 1 PeV 150 keV ÷ 100 TeV	70 keV ÷ 1 PeV 150 keV ÷ 100 TeV
Photons	1 keV ÷ 1 PeV	7 keV ÷ 1 PeV

Net and Effective Charge Rate Definition

Test mass current: $I = e\,\lambda_{NET}$

Force noise proportional to: $S_Q^{1/2} = S_I^{1/2}/\omega$

Current shot noise: $S_I^{1/2} = \sqrt{(2\,e^2\,\lambda_{EFF})}$

Where:

$$\lambda_{NET} = \sum_{j=-\infty}^{+\infty} j\,\lambda_j \qquad \text{and} \qquad \lambda_{EFF} = \sum_{j=-\infty}^{+\infty} j^2\,\lambda_j$$

Weber, W. J. Et al., gr-qc/0309067

CHARGE RATE ON THE TEST MASSES - HEAVY NUCLEI

Solar minimum

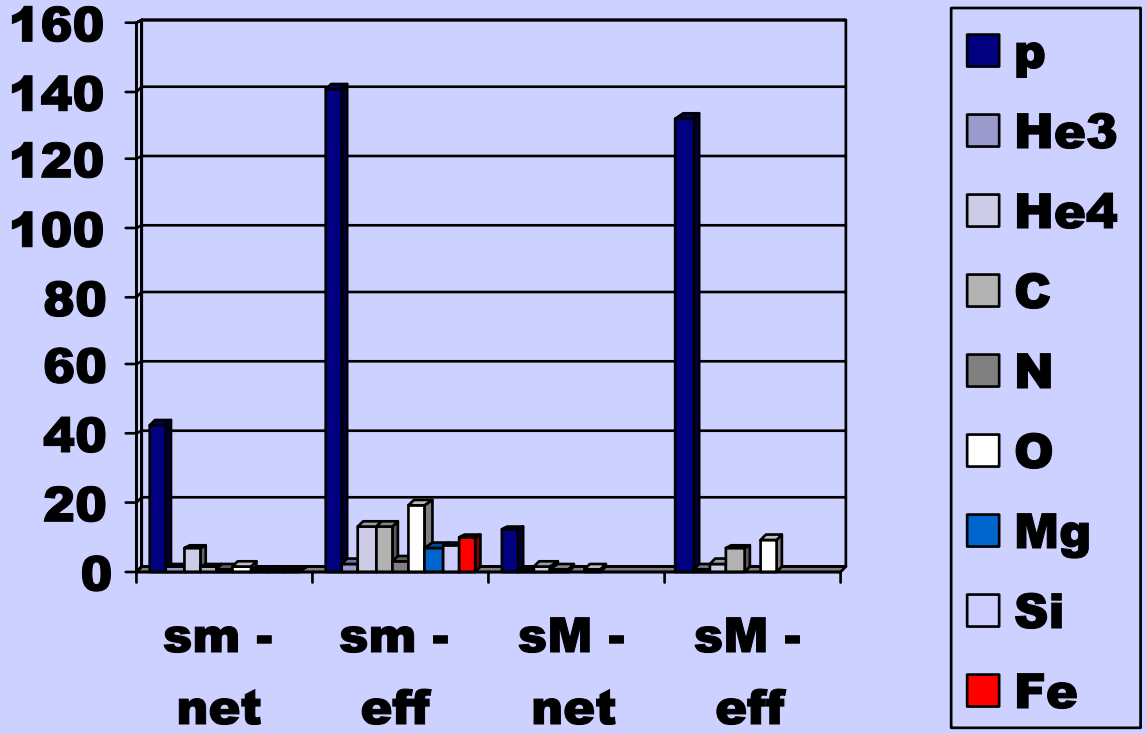
Element	Z	Absolute charge rate (e^+/s)	Effective charge rate (e/s)
^{3}He	2	0.97	1.97
^{4}He	2	6.46	12.95
C	6	1.03	13.10
N	7	0.45	3.00
O	8	1.34	19.40
Mg	12	0.26	6.81
Si	14	0.20	7.12
Fe	26	0.15	9.64

CHARGE RATE ON THE TEST MASSES - HEAVY NUCLEI

Solar maximum

Element	Z	Absolute charge rate (e^+/s)	Effective charge rate (e/s)
^{3}He	2	0.17	0.37
^{4}He	2	1.13	2.17
C	6	0.37	6.40
N	7	<<0.1	
O	8	0.37	9.00
Mg	12	<<0.1	
Si	14	<<0.1	
Fe	26	<<0.1	

	Absolute charge rate (e^-/s)	Effective charge rate (e/s)
Electron (solar minimum)	0.59	9.01
Electron (solar maximum)	0.34 (+)	5.71


160
140
120
100
80
60
40
20
0
sm - net
sm - eff
sM - net
sM - eff
p
He3
He4
C
N
O
Mg
Si
Fe

CONCLUSIONS

* Heavy nuclei release about 25% of the charge generated by protons in the LISA test masses at solar minimum

* Heavy nuclei release about 15% of the charge generated by protons in the LISA test masses at solar maximum

* Electrons release about 1% of the charge generated by protons at both solar minimum and maximum