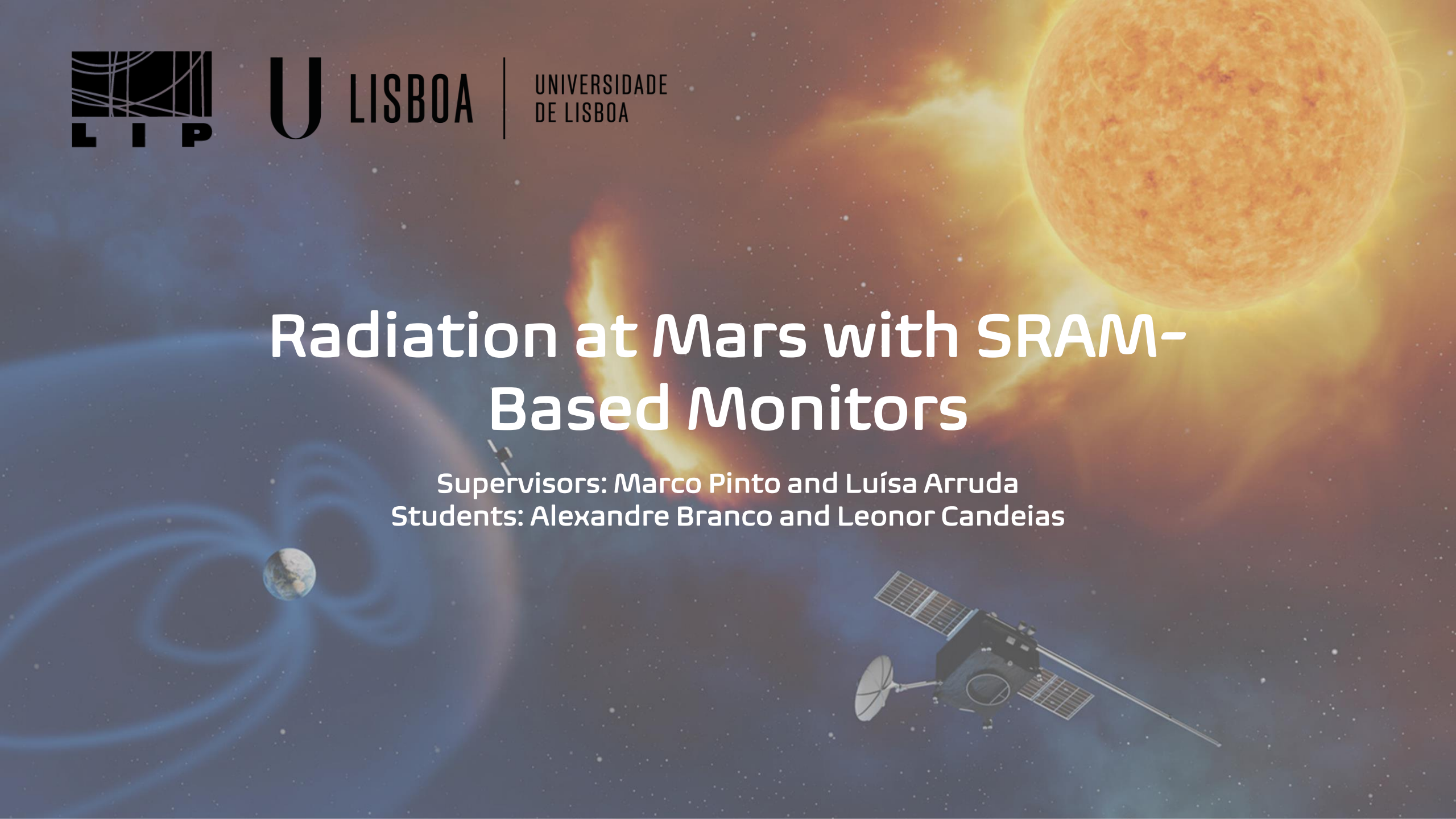

Radiation at Mars with SRAM-Based Monitors

Supervisors: Marco Pinto and Luísa Arruda
Students: Alexandre Branco and Leonor Candeias

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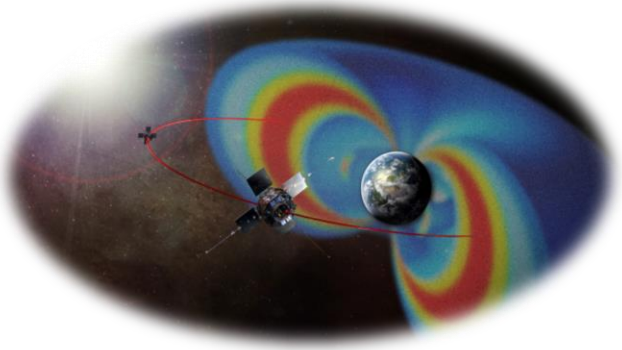
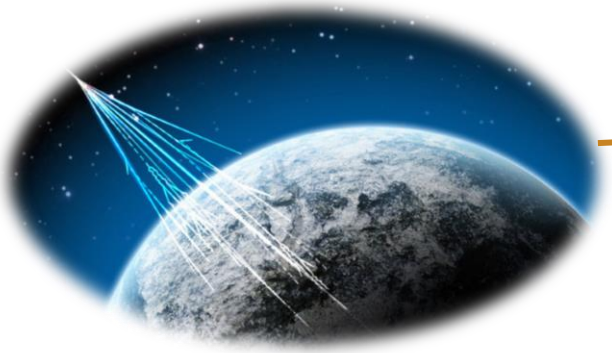
Space Radiation Environment

Van Allen Radiation Belts

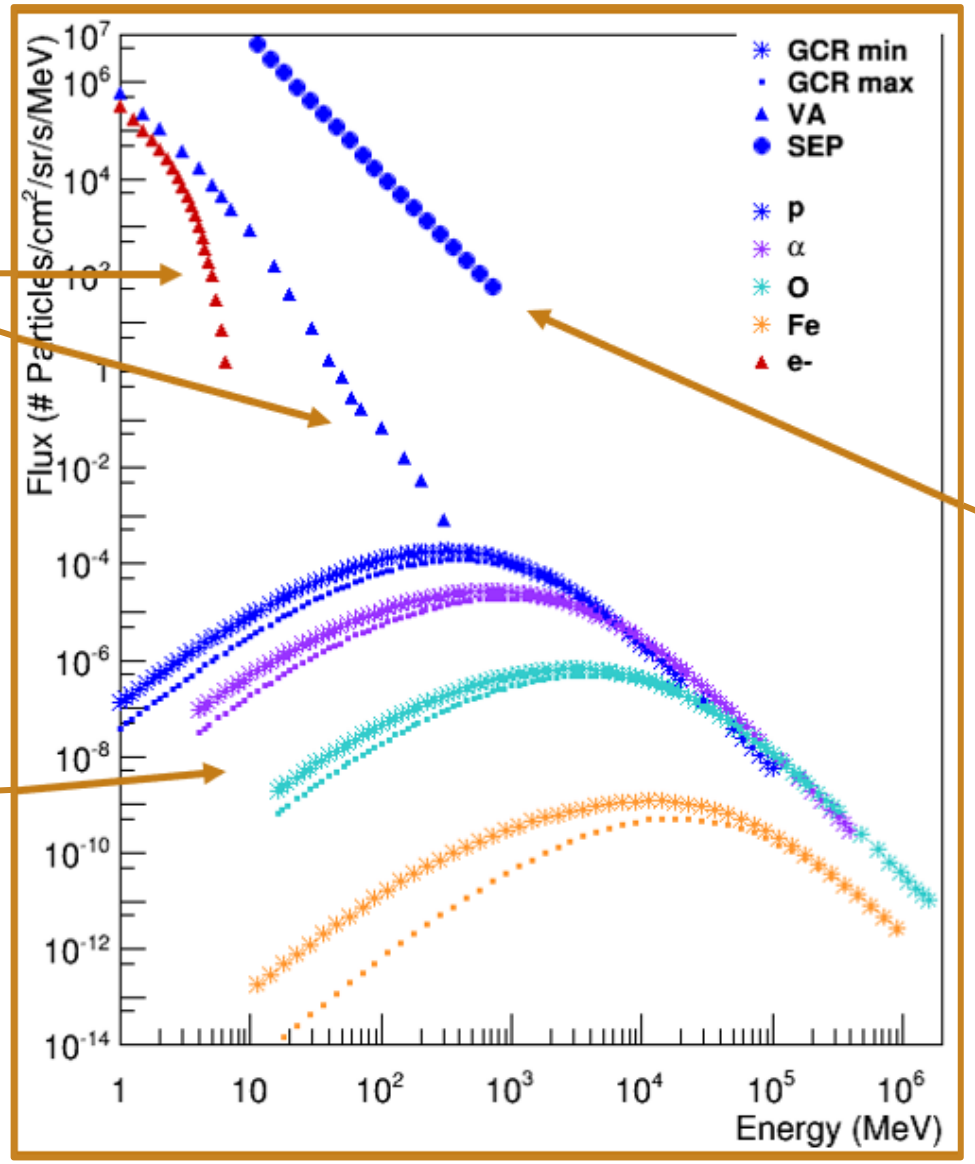


Protons and **electrons**

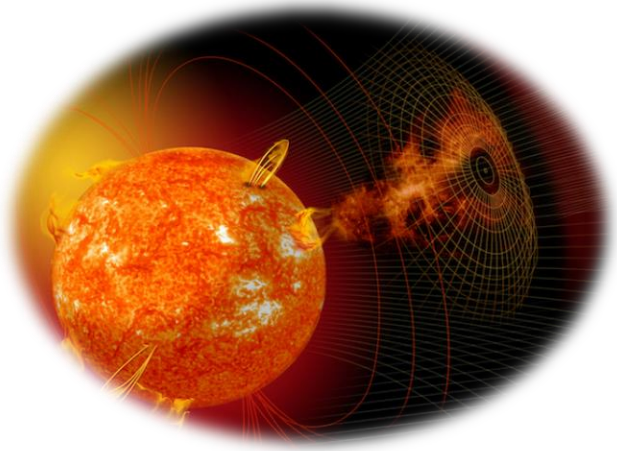
Galactic Cosmic Radiation



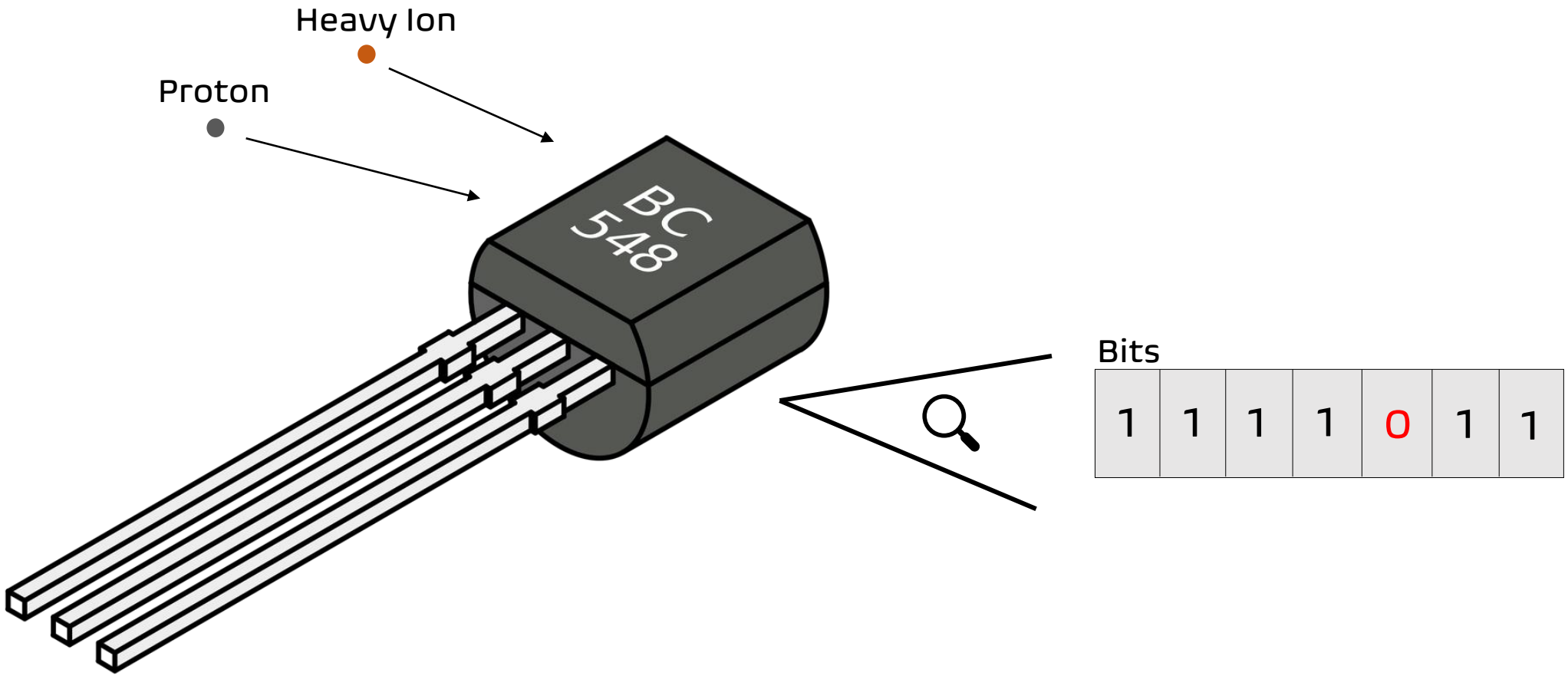
Mainly **protons** and **α particles**
Solar min: 2009
Solar max: 2014



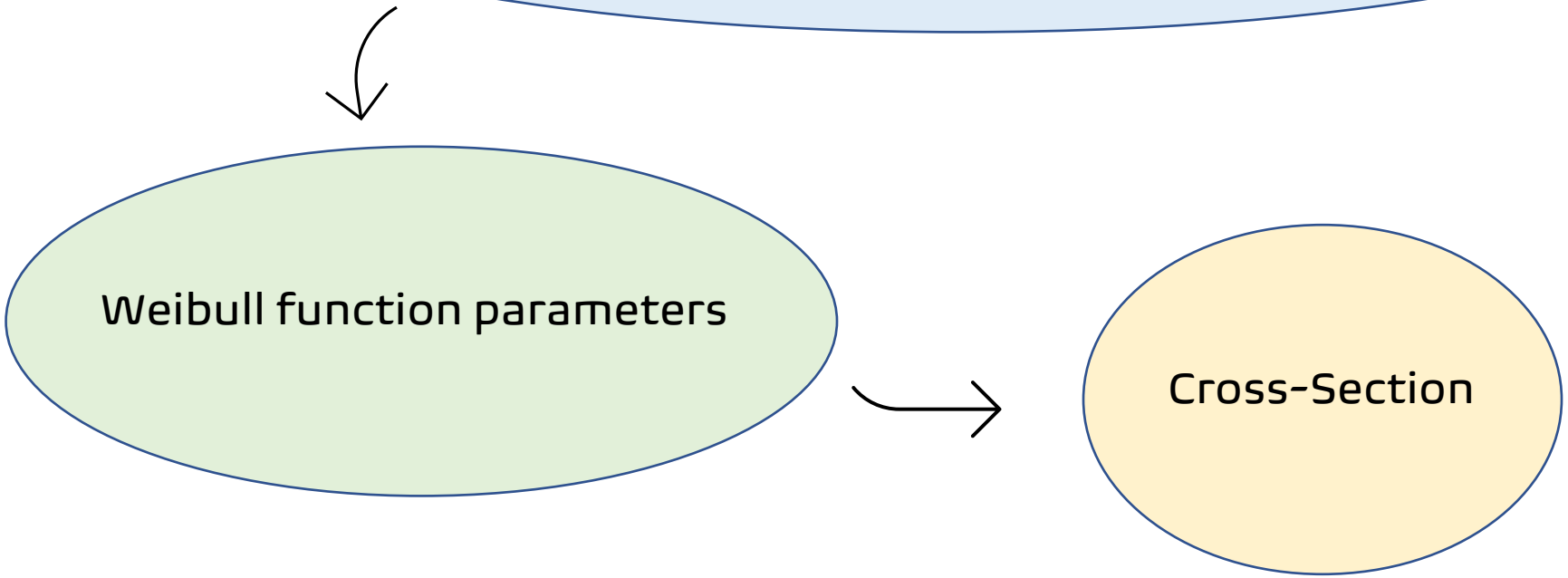
Solar Energetic Particle (SEP) Events



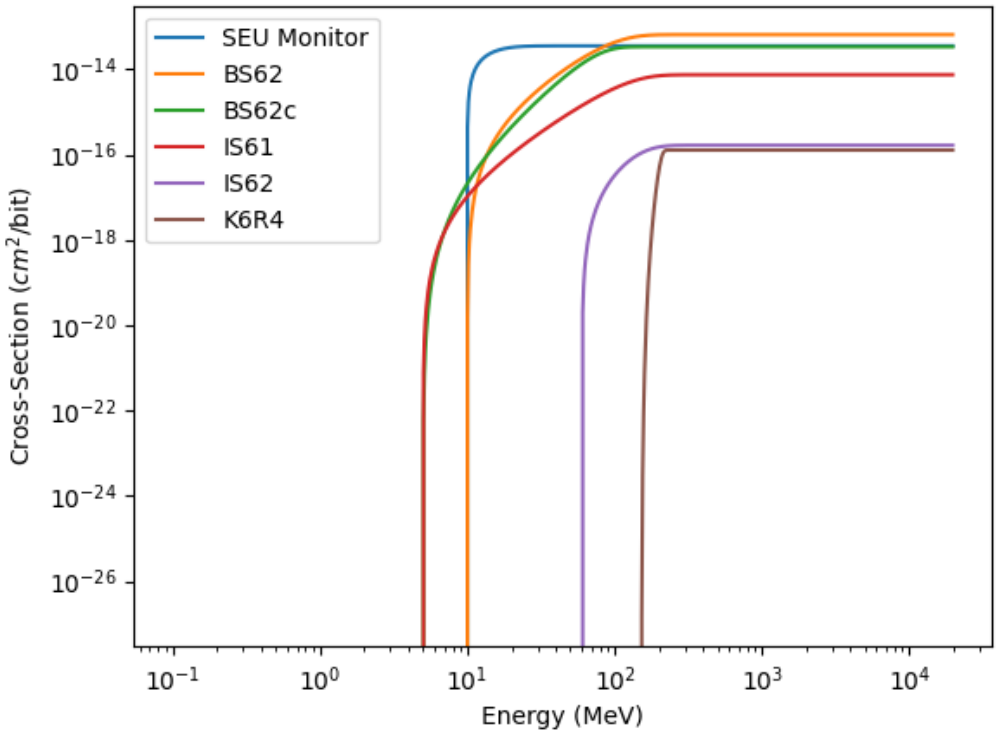
Protons
Integrated 14 day SEP event of December 2006


Heavy Ion
Proton
BC
548
Bits
1
1
1
1
0
1
1

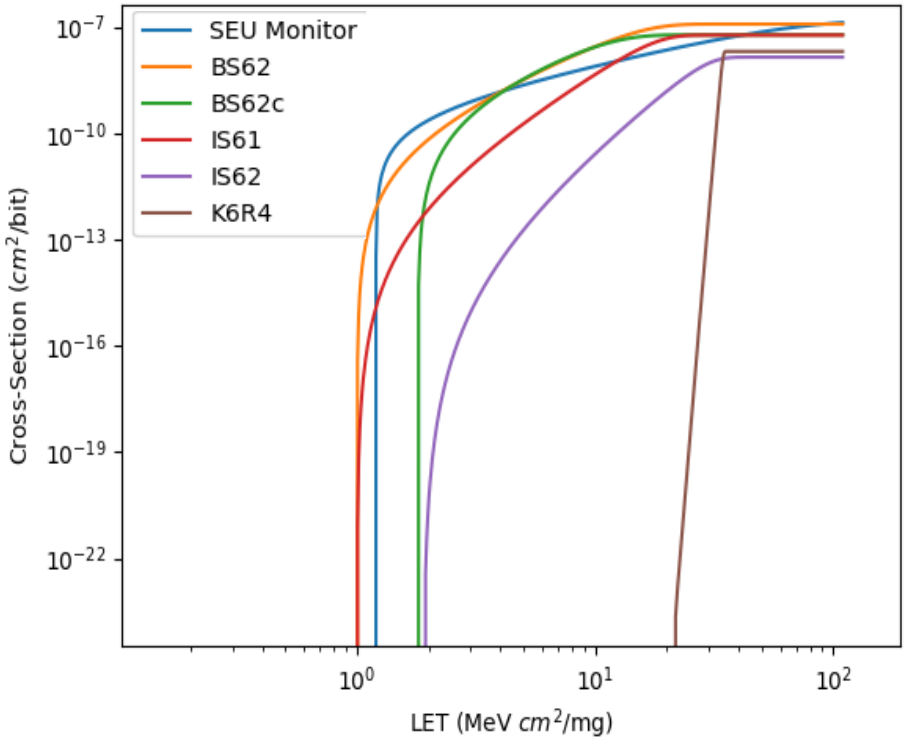
How did we predict the upsets on these devices?



Protons



Heavy Ions Total



Protons:

$$N = \int_{Emin}^{Emax} \frac{d\Phi}{dE}(E).\sigma_{nucleon}(E)dE$$

- Particle spectrum
- Weibull Curve

Heavy Ions:

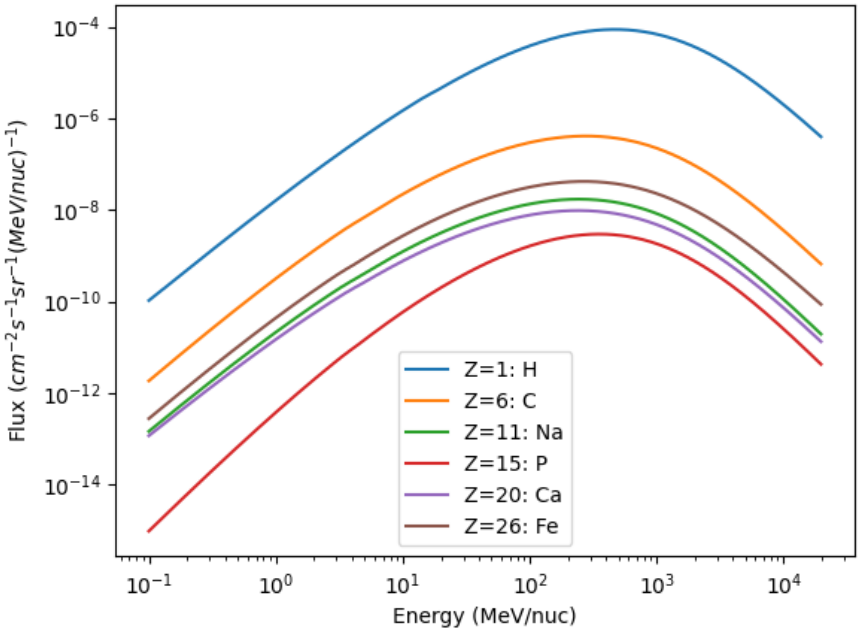
$$N_{RPP} = \frac{A}{4}\frac{E_c}{\rho}\int_{LET_{Min}}^{LET_{Max}} \frac{1}{LET^2}.\Phi(>LET).\frac{dP_{CL}}{dD(LET)}D(LET)).dLET$$

$$N_{IRPP} = \int_{LETi,Min}^{LETi,Max} \frac{d\sigma_{ion}}{dLET}(LET_i).N_{RPP}(LET_i)dLET_i$$

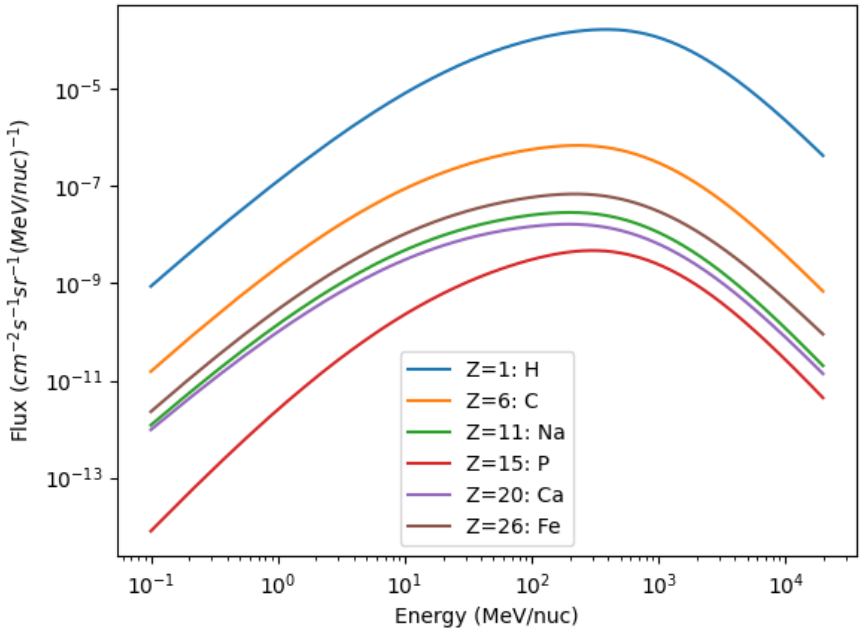
Element abundance effect on Galactic Cosmic Rays flux

- The fluxes data was obtained using the ISO standard 15390 model, which relies on the number of sun spots detected at Geostationary orbit

Solar Maximum - 2014



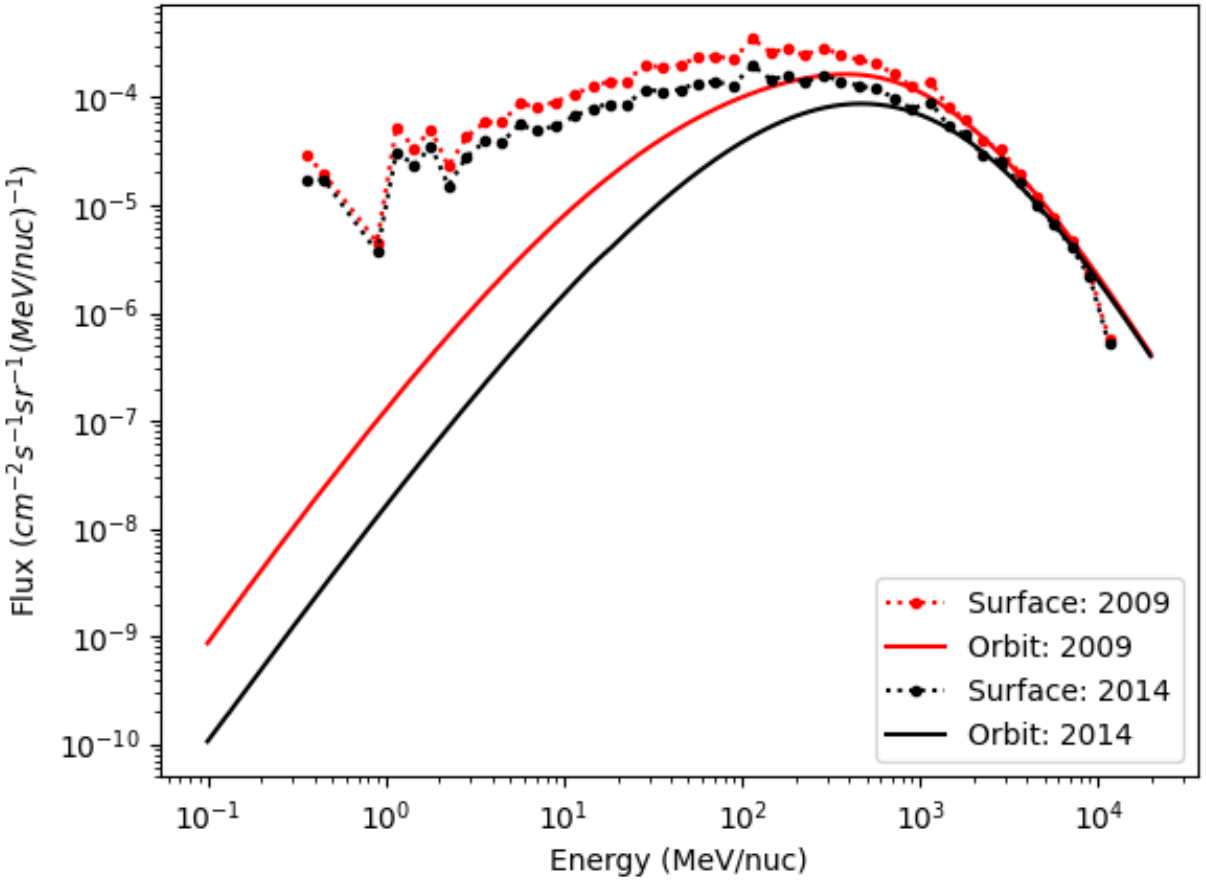
Solar Minimum - 2009



X	Atomic Number (Z)	[X]/[H]
H	1	1.000E+00
He	2	8.140E-02
Li	3	9.753E-05
Be	4	4.383E-05
B	5	2.157E-04
C	6	1.671E-03
N	7	2.444E-04
O	8	1.570E-03
F	9	5.123E-06
Ne	10	1.507E-04
Na	11	1.784E-05
Mg	12	2.264E-04
Al	13	3.302E-05
Si	14	1.898E-04
P	15	3.036E-06
S	16	2.087E-05
Cl	17	1.898E-06
Ar	18	4.554E-06
K	19	2.657E-06
Ca	20	1.195E-05
Sc	21	1.898E-06
Ti	22	1.101E-05
V	23	5.123E-06
Cr	24	1.374E-05
Mn	25	5.693E-06
Fe	26	1.152E-04
Co	27	6.519E-07
Ni	28	6.452E-06

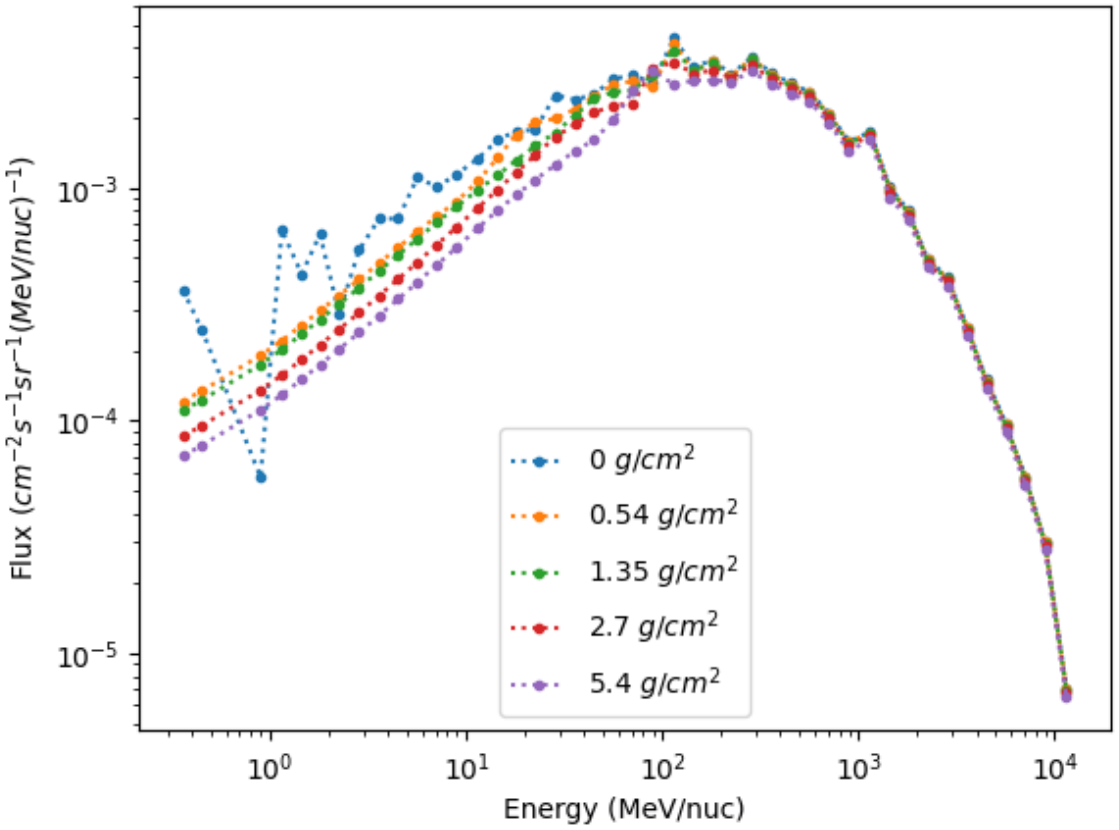
Proton flux for Solar minimum (2009) and maximum (2014) at the **Surface of Mars**

- The fluxes data for the surface of Mars was produced with the detailed Martian Energetic Radiation Environment Model **(dMEREM)** developed by LIP for the European Space Agency (ESA);
- This model does a martian **atmosphere propagation of particles**;
- The **atmosphere of Mars** was estimated to have a **density of 20 g/cm²**.

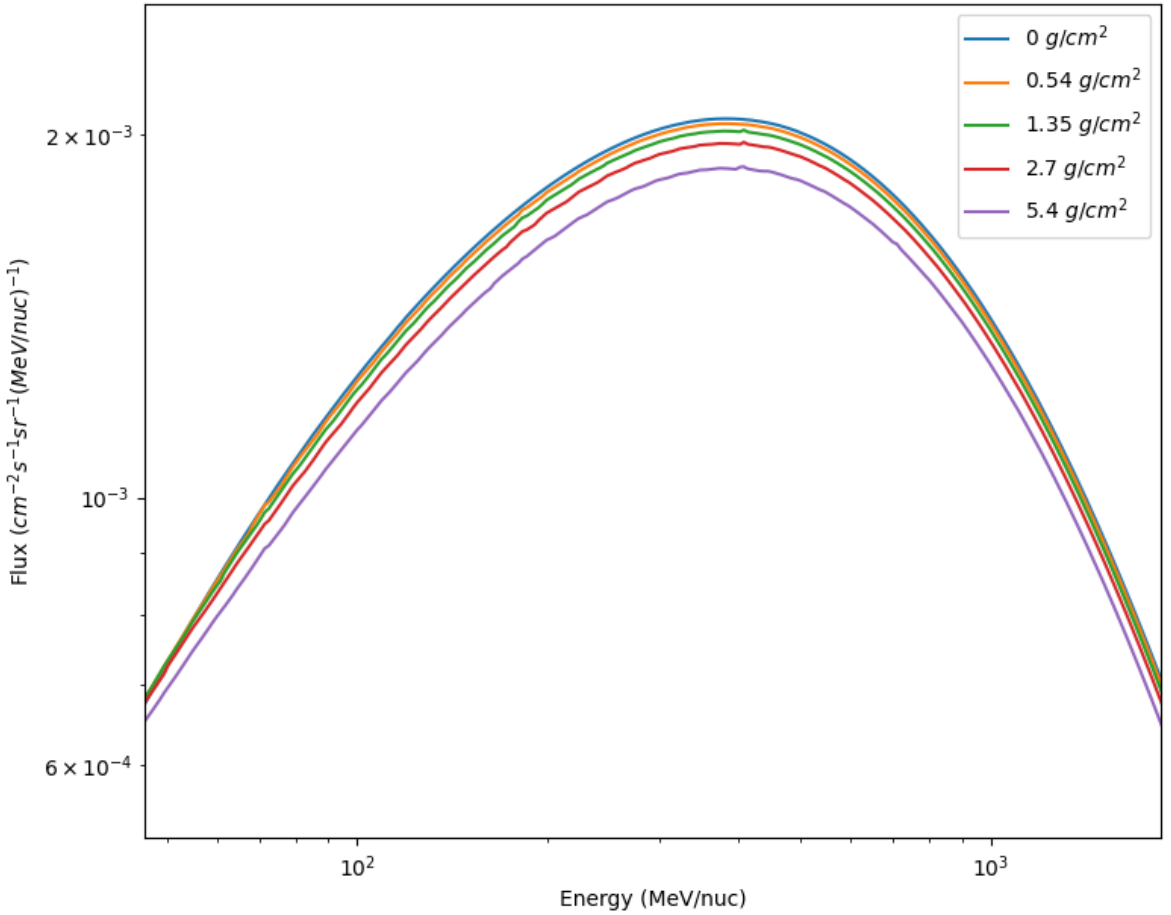


Aluminium Shielding Effect on **Proton** flux for Solar minimum (2009)

Surface



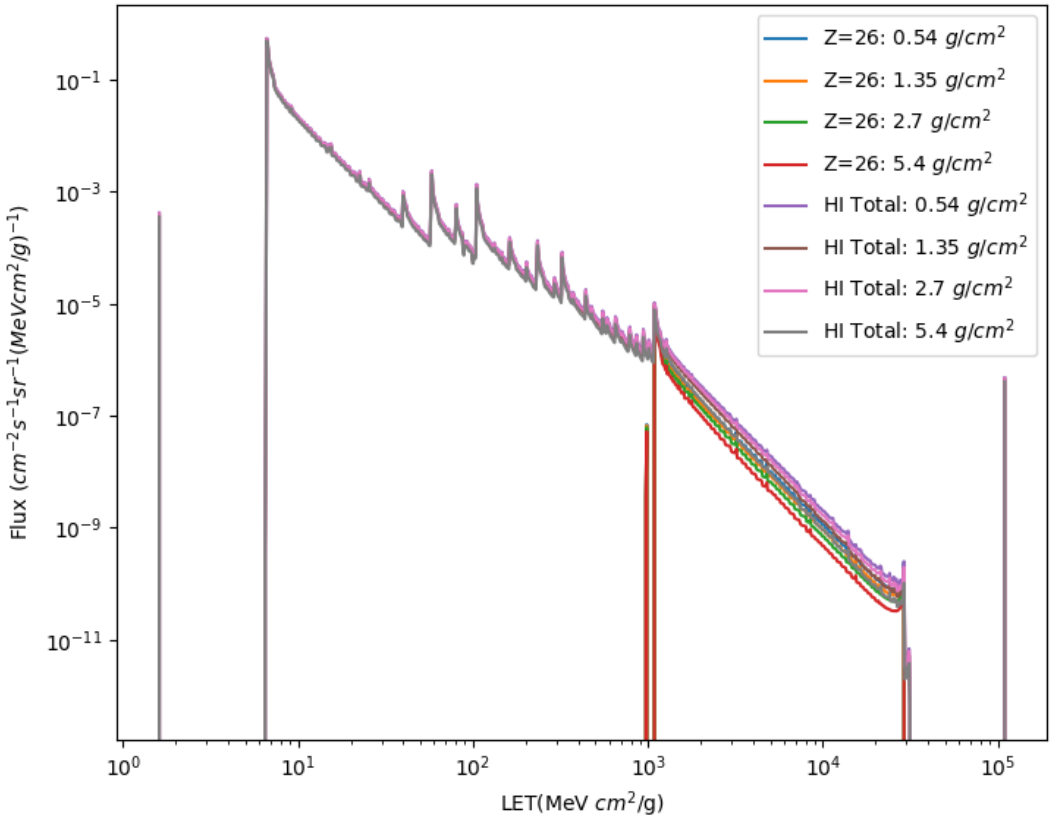
Orbit



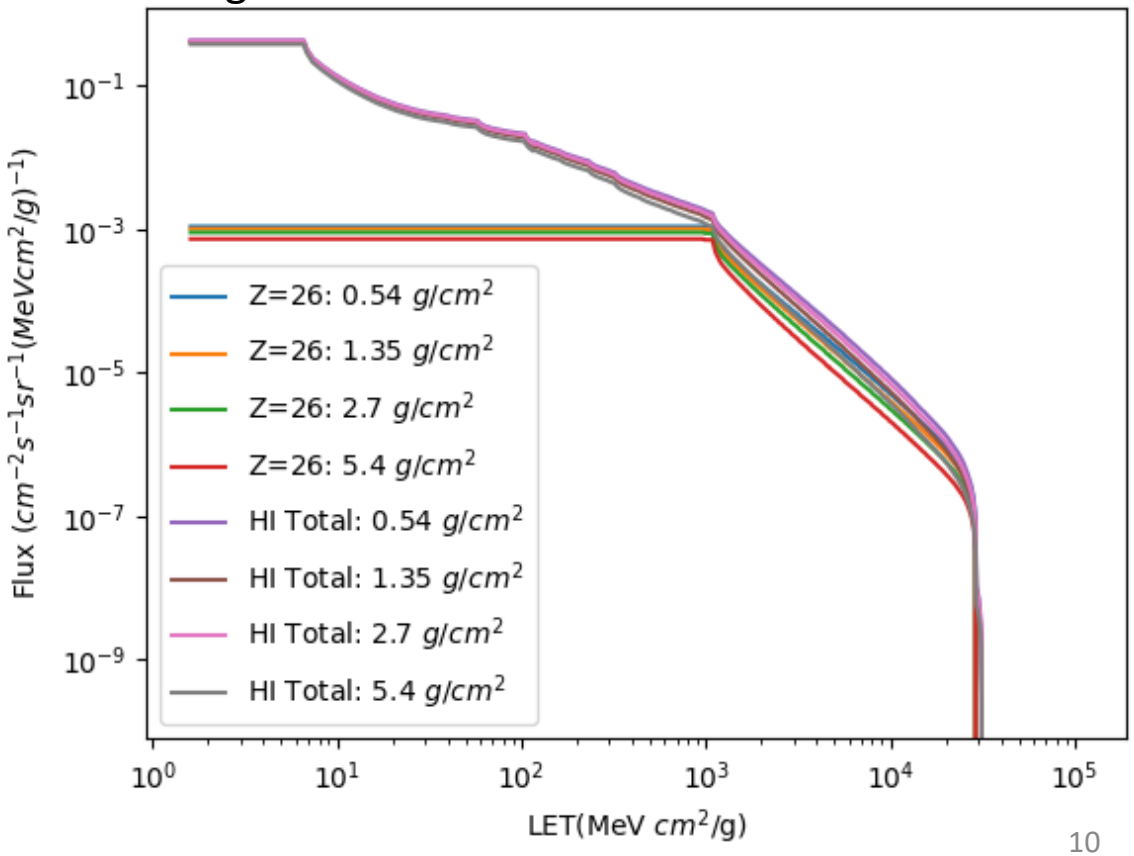
Shielding Effect at Orbit for Iron and Total Heavy Ions fluxes in LET

- The **Stopping Powers** are in relation to **silicon**;
- Stopping Powers depend on the type of shielding material considered.

Differential Fluxes at 2009

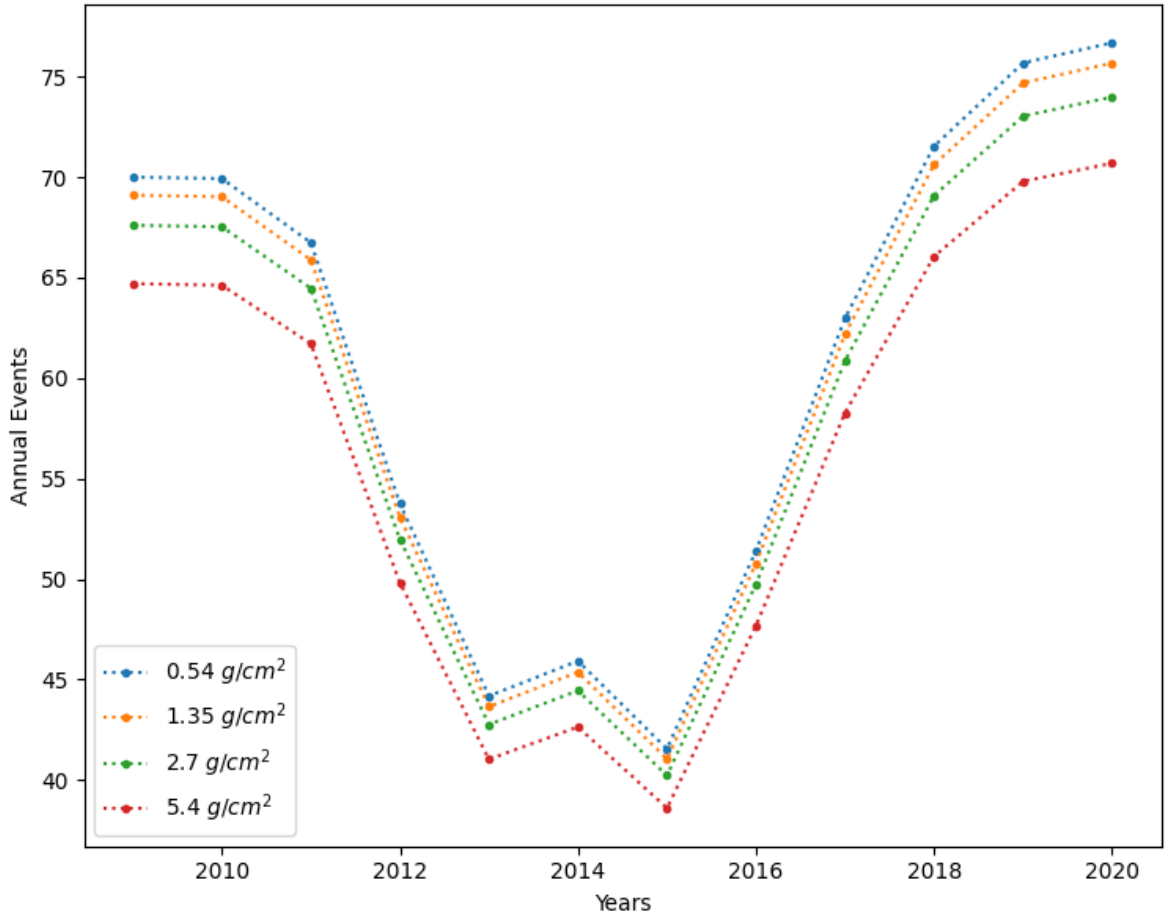


Integral Flux at 2009

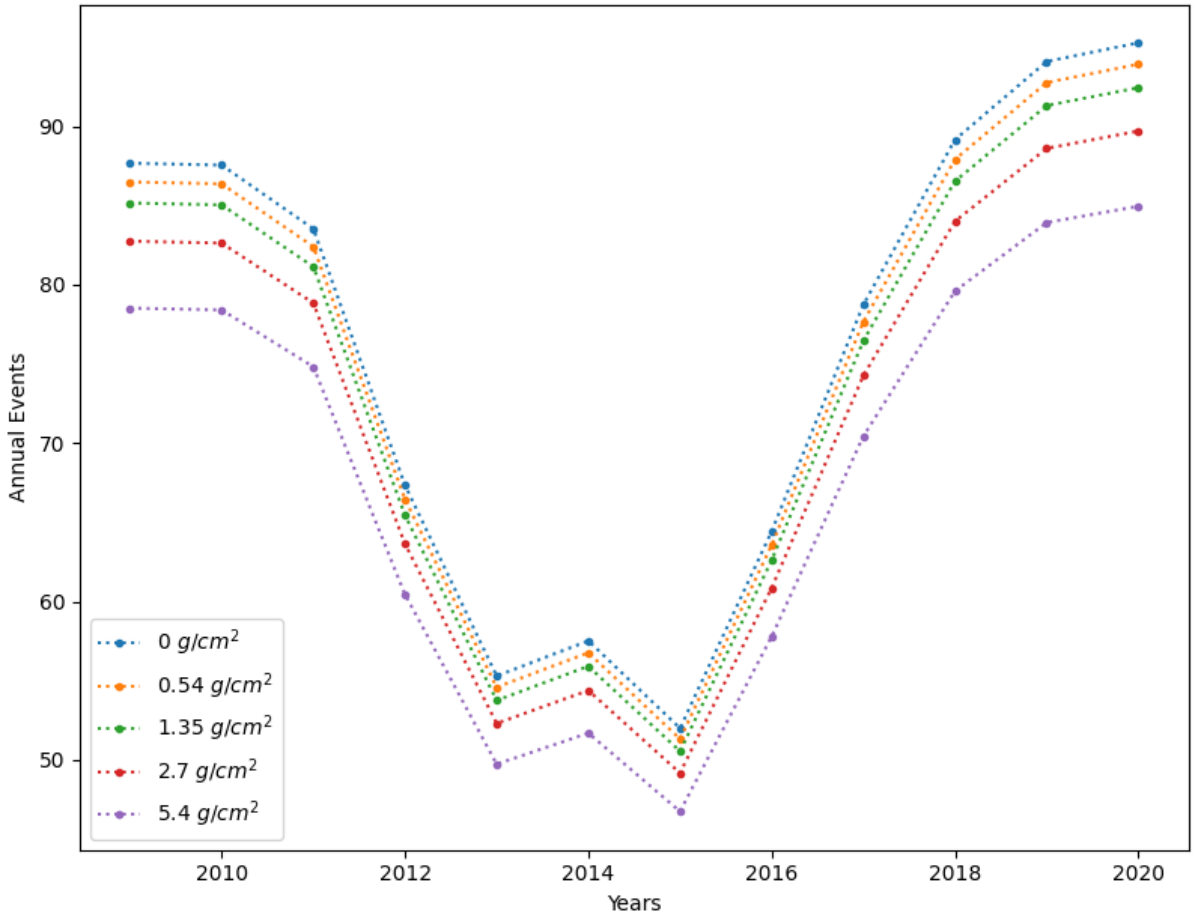


Annual events on SEU Monitor during Solar Cycle 24

Orbit – Proton Contribution

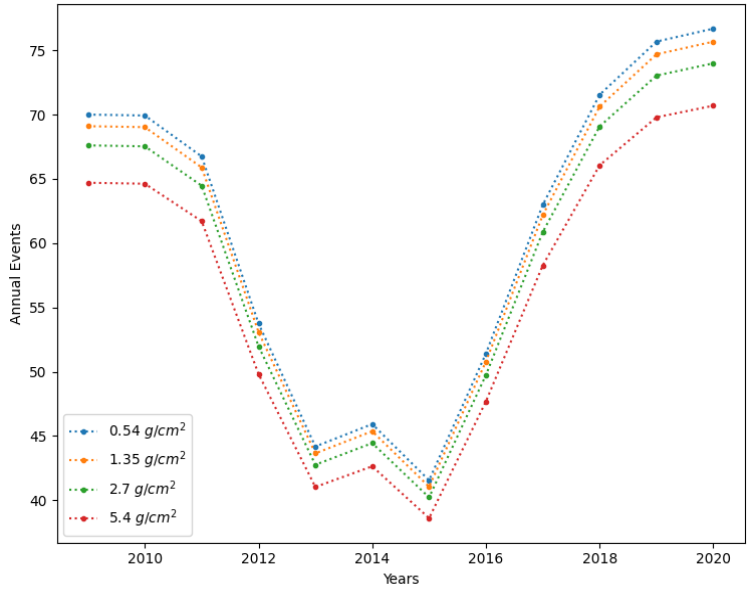


Surface – Proton Contribution

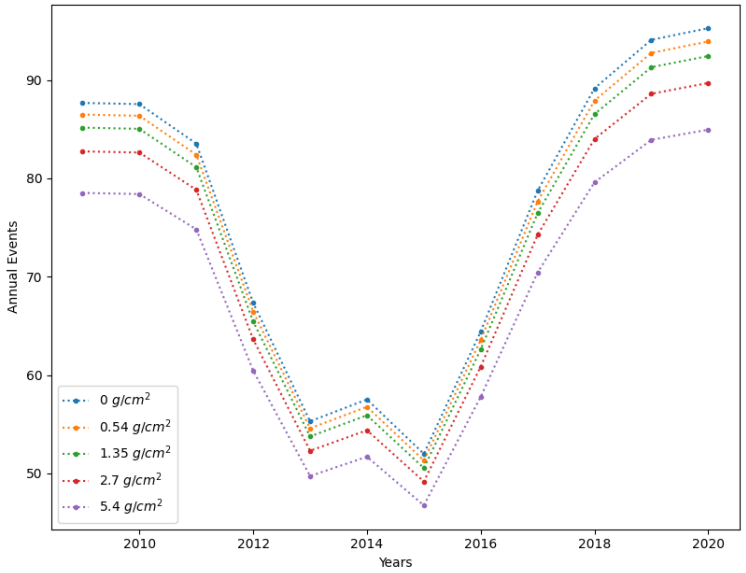


Annual events on SEU Monitor during Solar Cycle 24

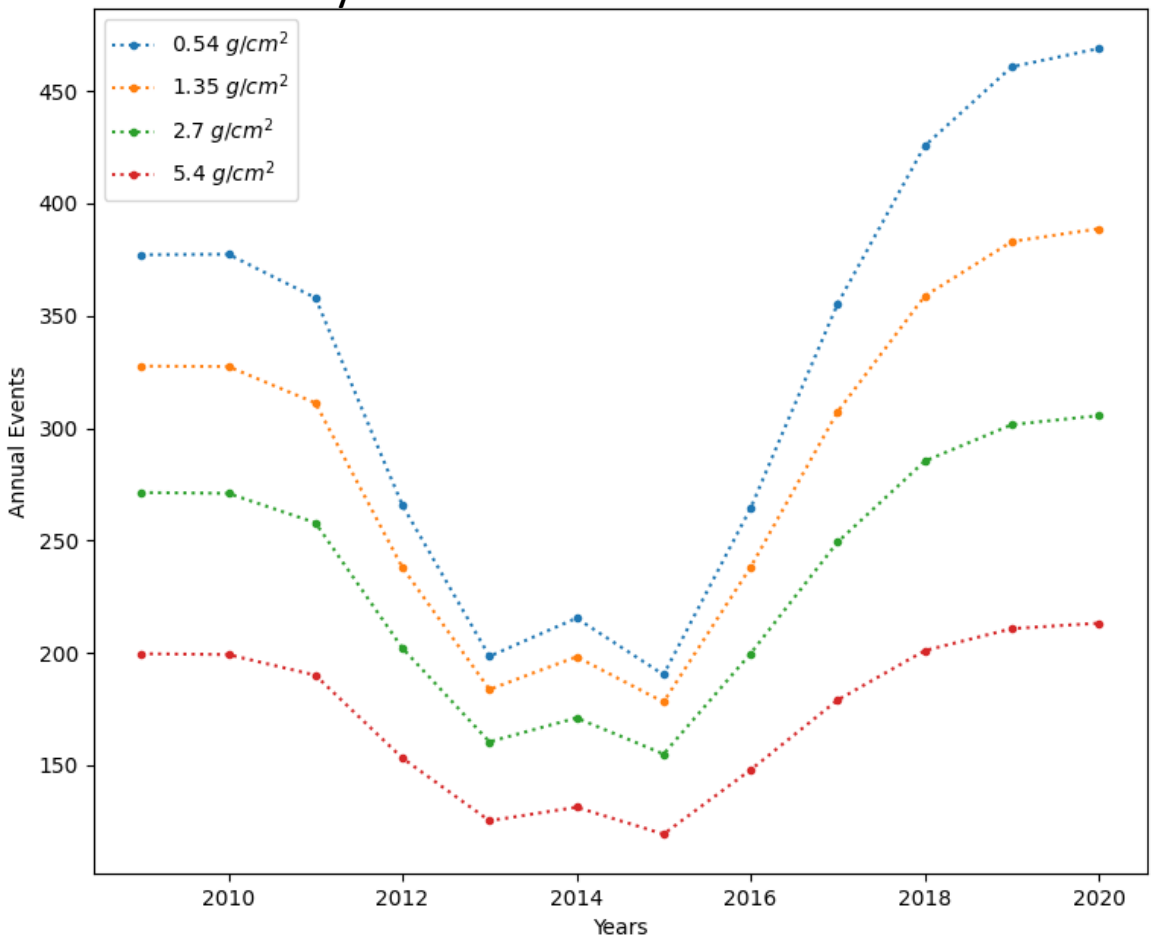
Orbit – Proton Contribution



Surface – Proton Contribution



Orbit - Heavy Ions Total contribution

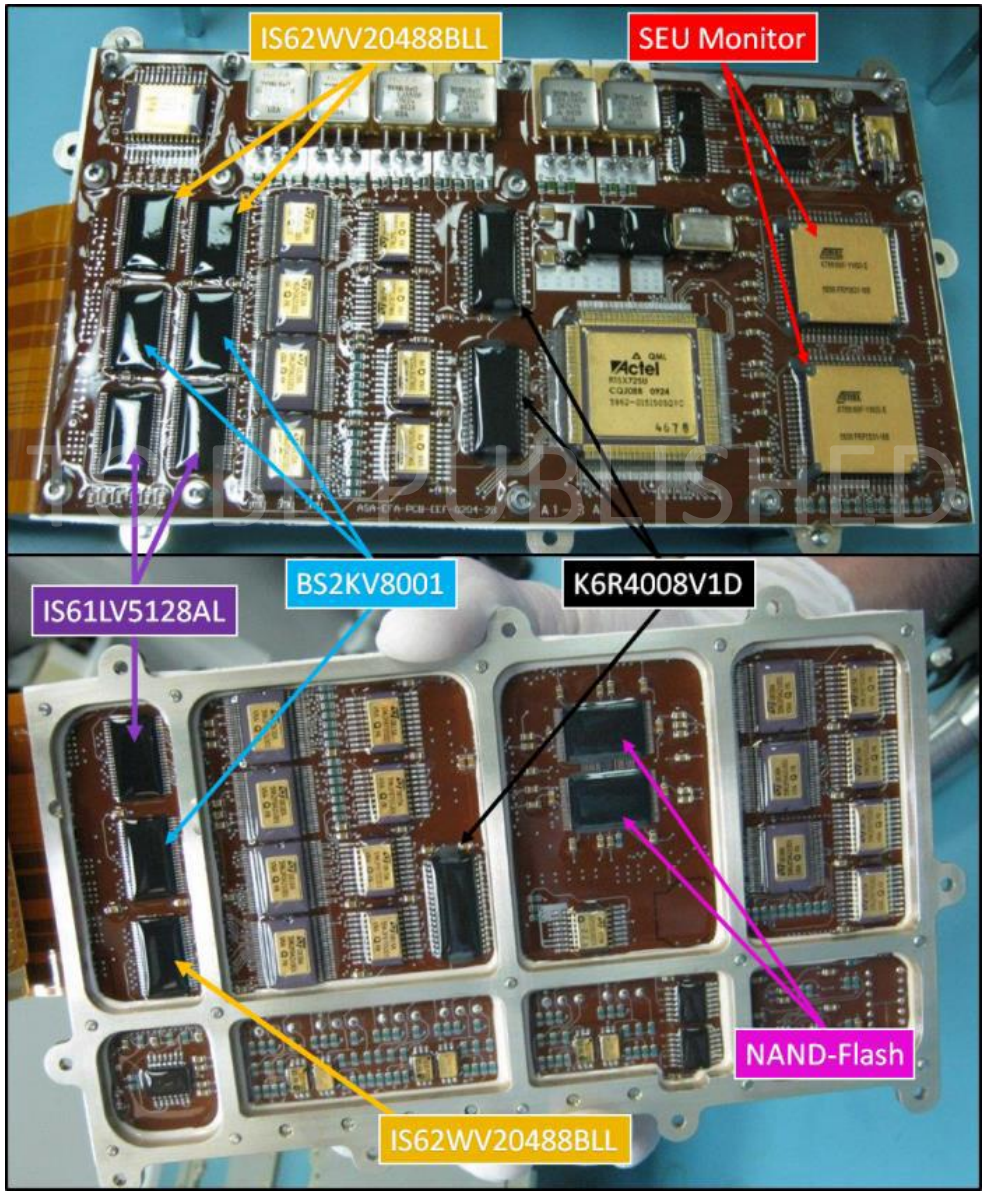


Annual events on possible SRAM-based Monitors

		Number of Errors Detected at Orbit							
		Shielding: 0.54 g/cm^2		Shielding: 1.35 g/cm^2		Shielding: 2.70 g/cm^2		Shielding: 5.40 g/cm^2	
Component Name	Year	Z=1	HI Total	Z=1	HI Total	Z=1	HI Total	Z=1	HI Total
SEU Monitor	2009	70,00	377,15	69,10	327,59	67,61	271,32	64,70	199,58
	2014	45,93	215,43	45,37	198,23	44,45	171,02	42,64	131,26
BS62c	2009	16,41	177,92	16,20	151,37	15,84	122,51	15,16	87,50
	2014	10,82	95,53	10,68	87,27	10,46	74,04	10,03	55,39
IS62	2009	0,32	4,89	0,31	3,96	0,31	3,08	0,29	2,10
	2014	0,21	2,49	0,21	2,24	0,20	1,84	0,20	1,32

		Number of Errors Detected at the Surface (Z=1)				
Component Name	Year	Shielding: 0 g/cm^2	Shielding: 0.54 g/cm^2	Shielding: 1.35 g/cm^2	Shielding: 2.70 g/cm^2	Shielding: 5.40 g/cm^2
SEU Monitor	2009	87,68	86,49	85,16	82,75	78,52
	2014	57,52	56,77	55,91	54,39	51,69
BS62c	2009	20,18	19,93	19,66	19,13	18,19
	2014	13,27	13,12	12,94	12,61	12,01
IS62	2009	0,38	0,37	0,37	0,36	0,34
	2014	0,25	0,25	0,25	0,24	0,23

Thank you for your attention



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