NEUTRONS in space: danger for space missions

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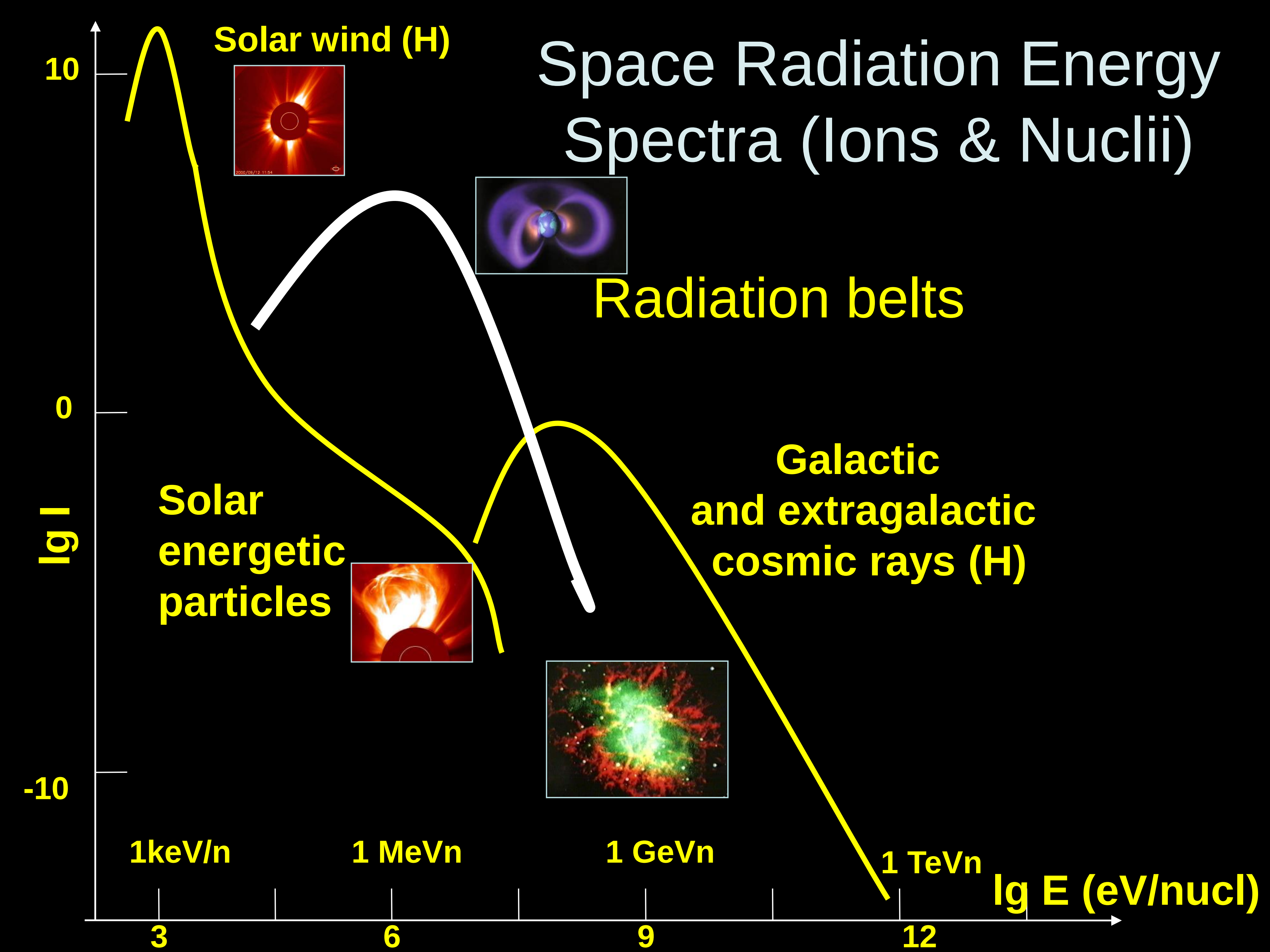
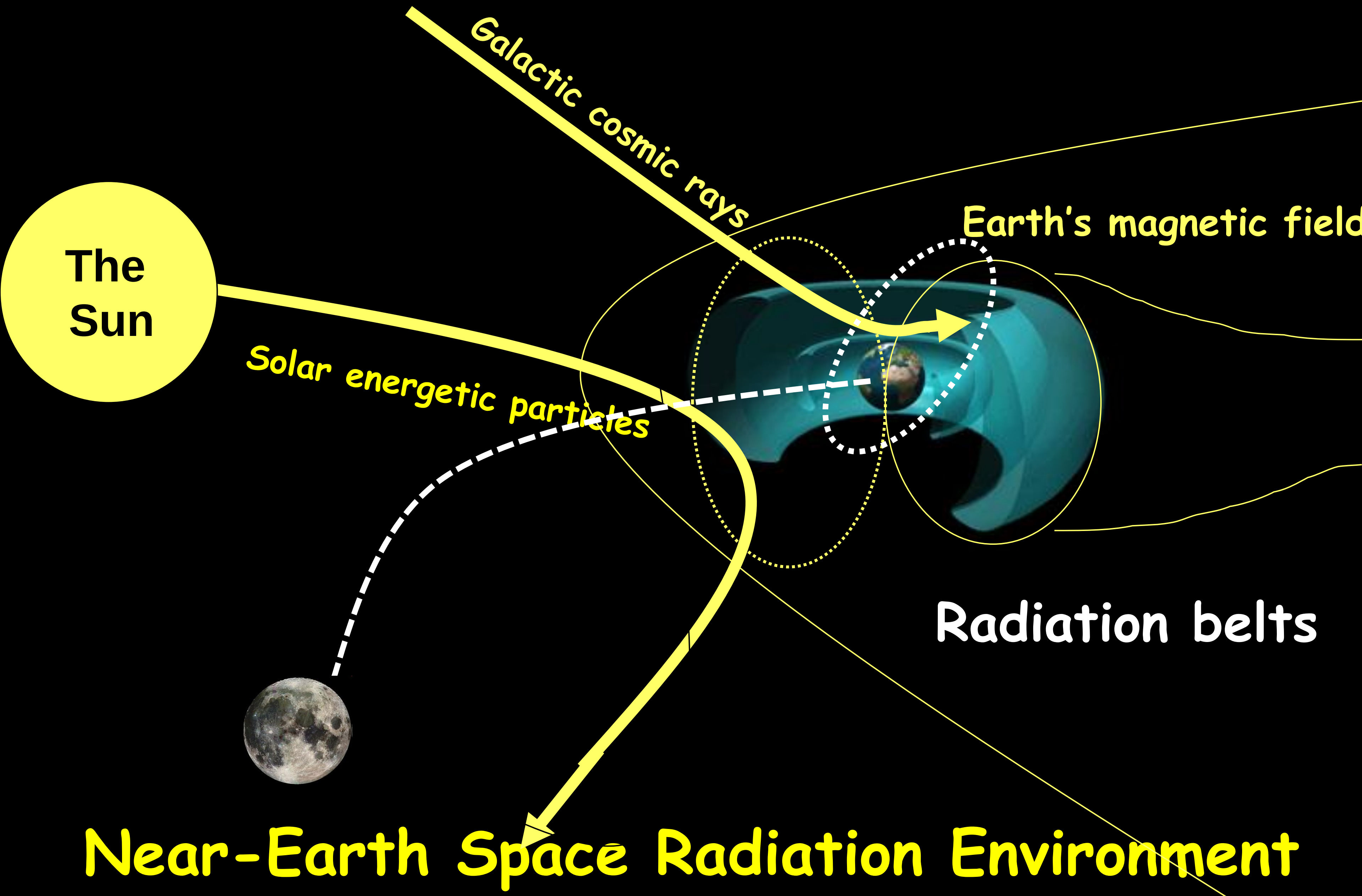
NEUTRONS

- The Sun (nuclear reactions)
- t~ 15 minutes!
- The Earth's atmosphere (nuclear reactions)
- The spacecraft's body!
- Planet's soil
- Planet's atmospheres



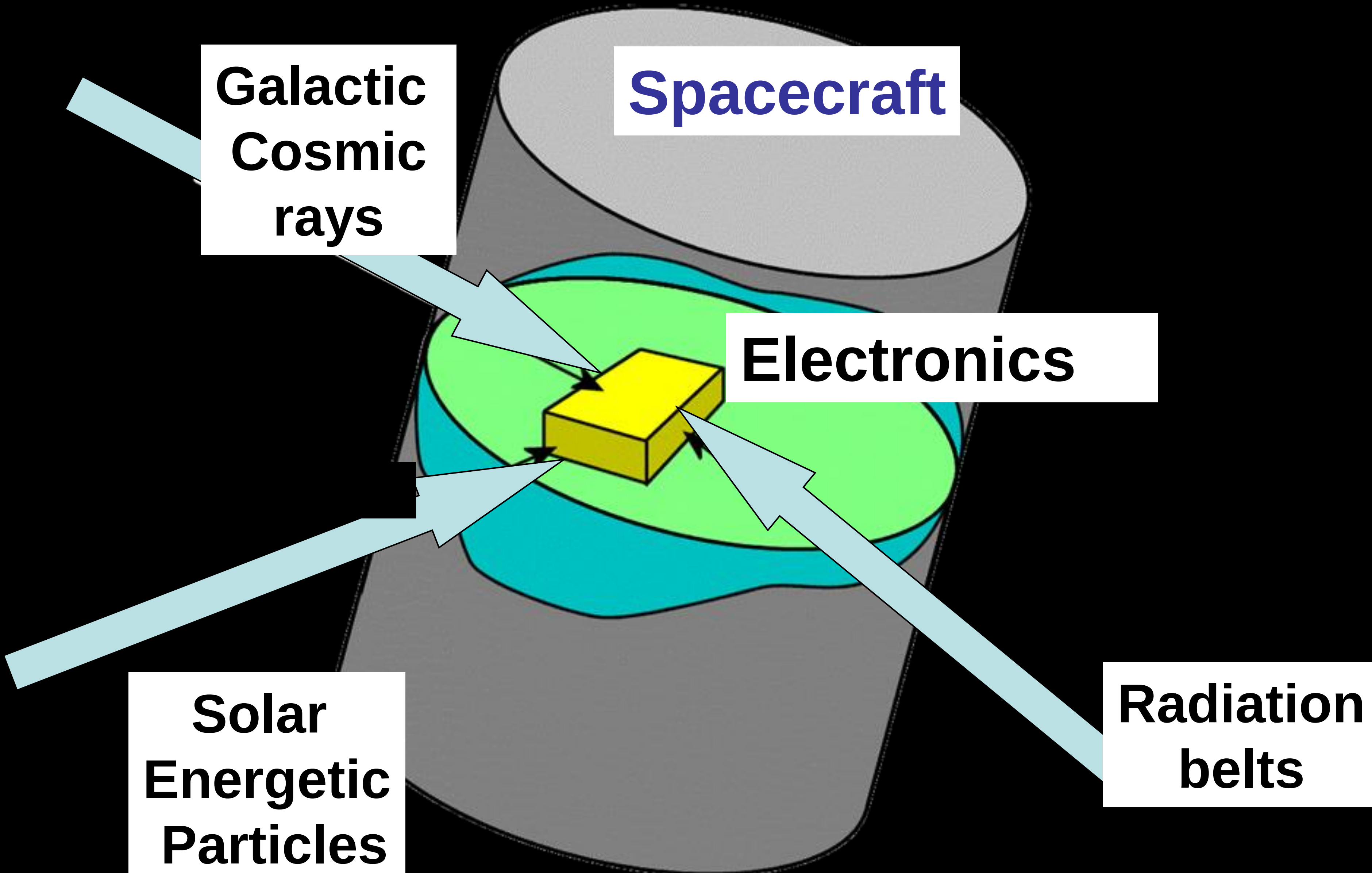
Space Radiation Energy Spectra (Ions & Nuclii)
Solar wind (H)
Radiation belts
Galactic and extragalactic cosmic rays (H)
Solar energetic particles
10
0
-10
lg I
1keV/n
1 MeVn
1 GeVn
1 TeVn
lg E (eV/nucl)
3
6
9
12

Космическая радиация вблизи Земли

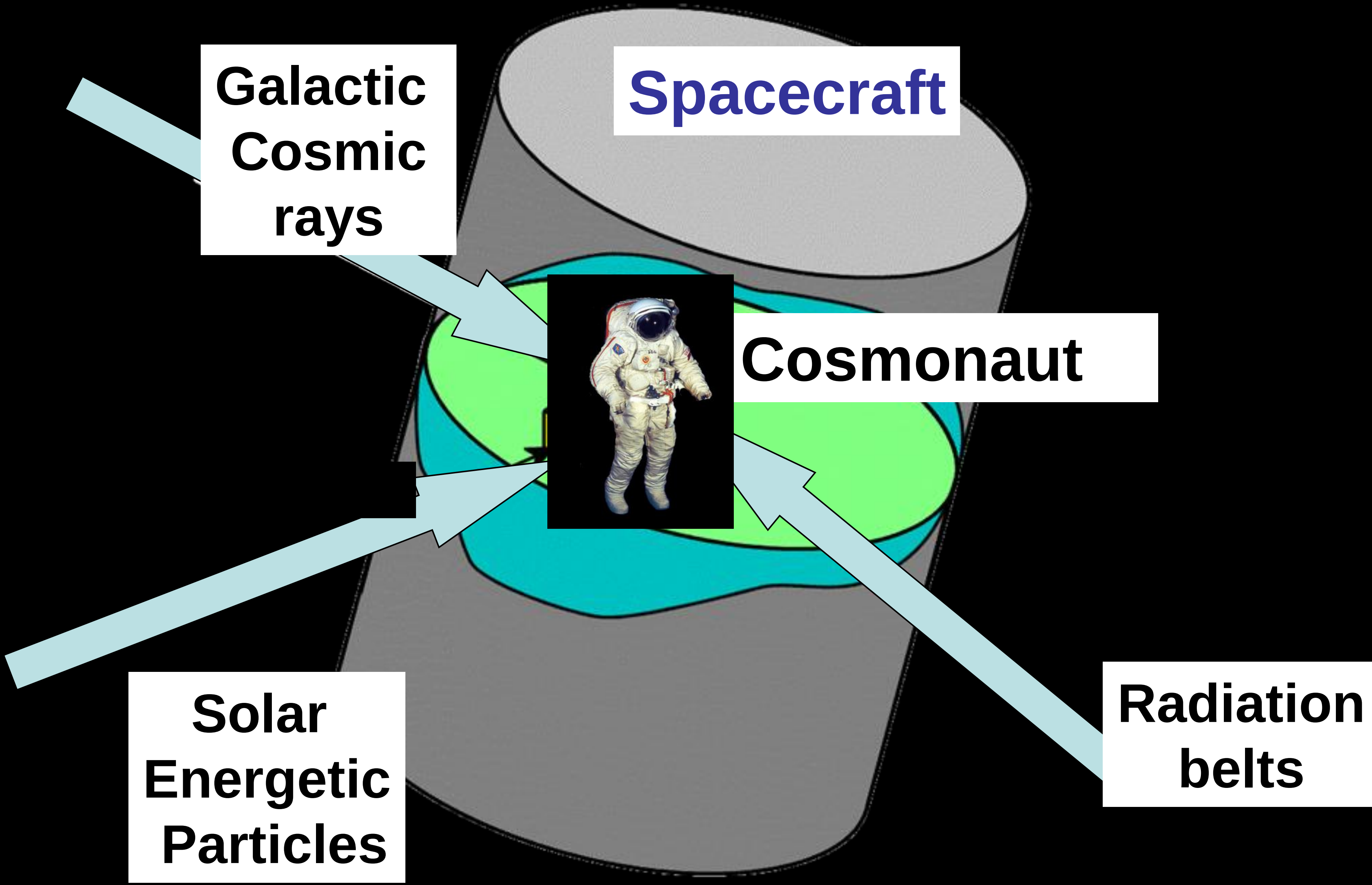


Near-Earth Space Radiation Environment

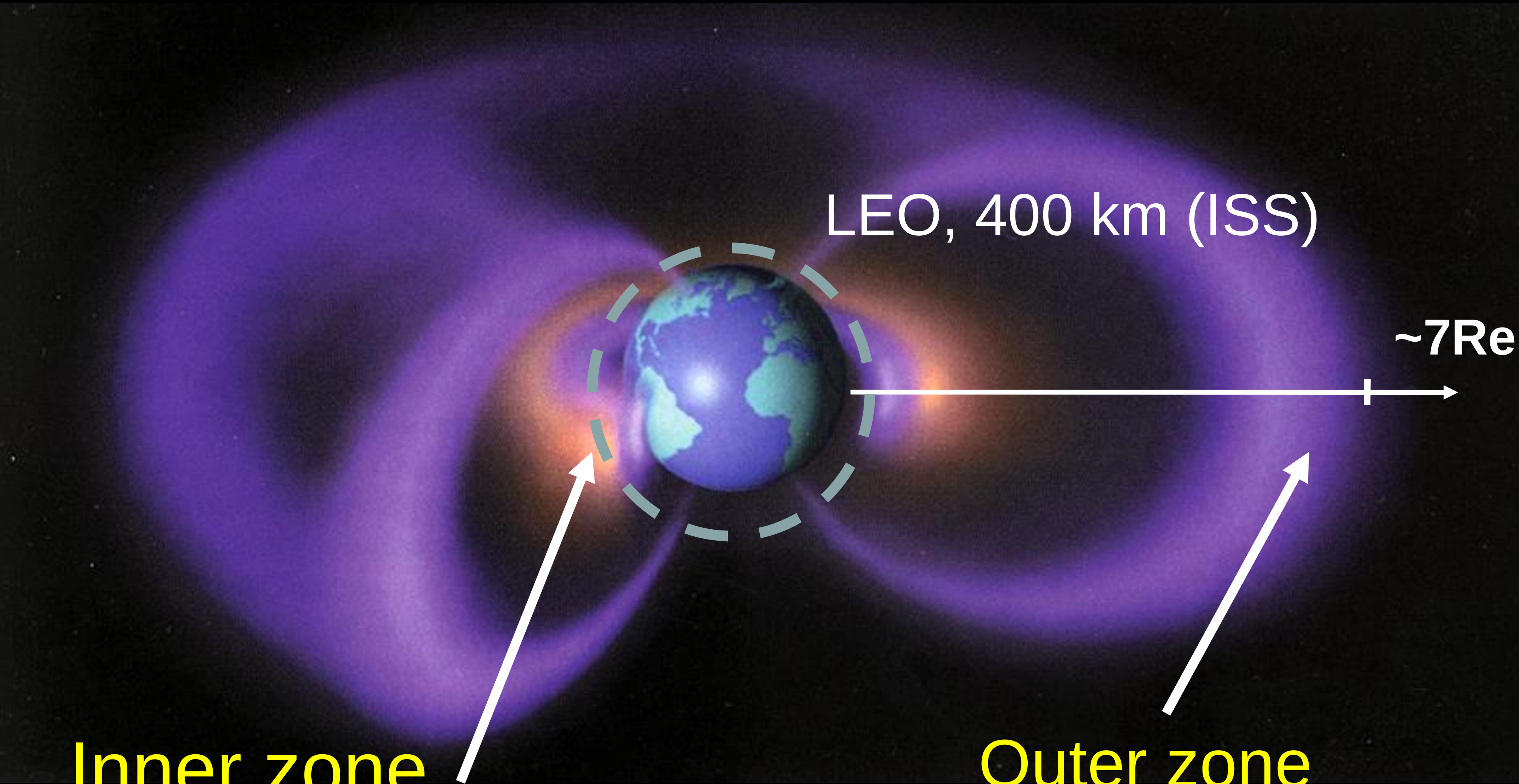
Space Radiation Impact



Space Radiation Impact



The Earth's Radiation Belts



Inner zone

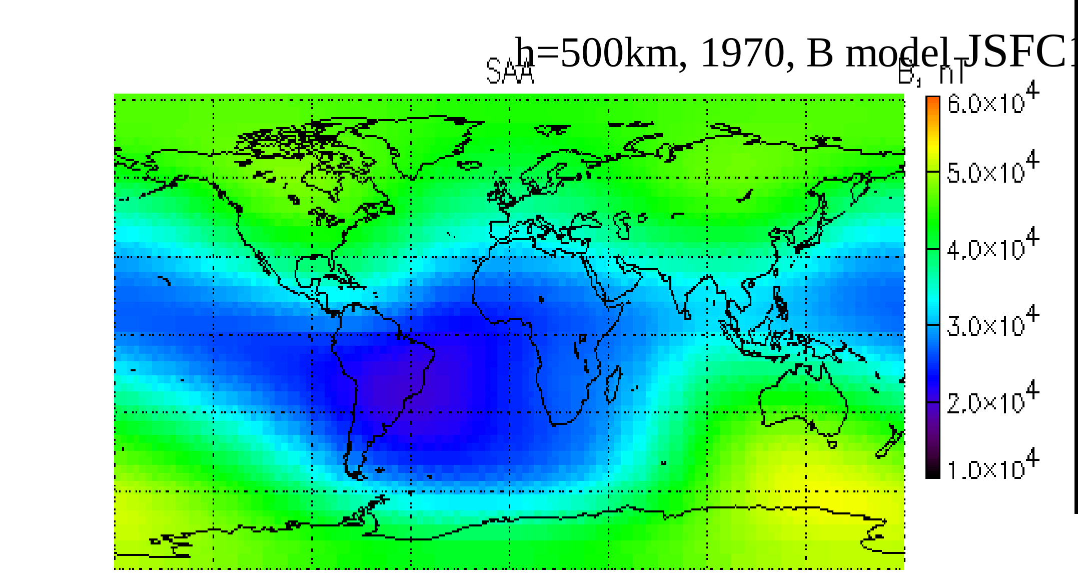
- p up to 100' MeV
- e up to several MeV

Outer zone

- p up to ~ MeV
- e to several MeV

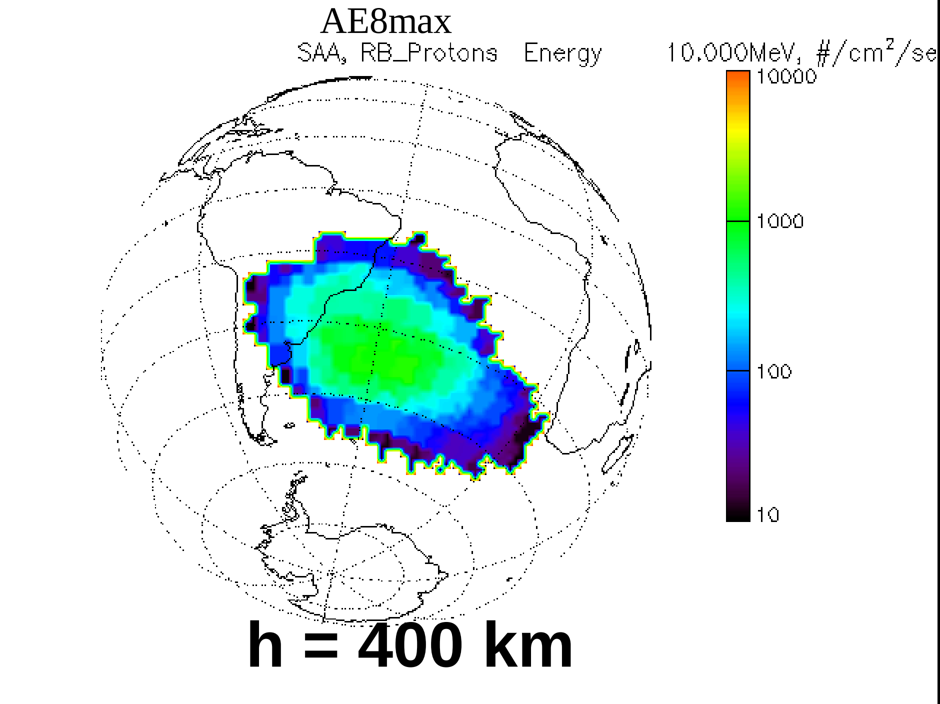
Low altitudes (LEO)

South Atlantic Anomaly

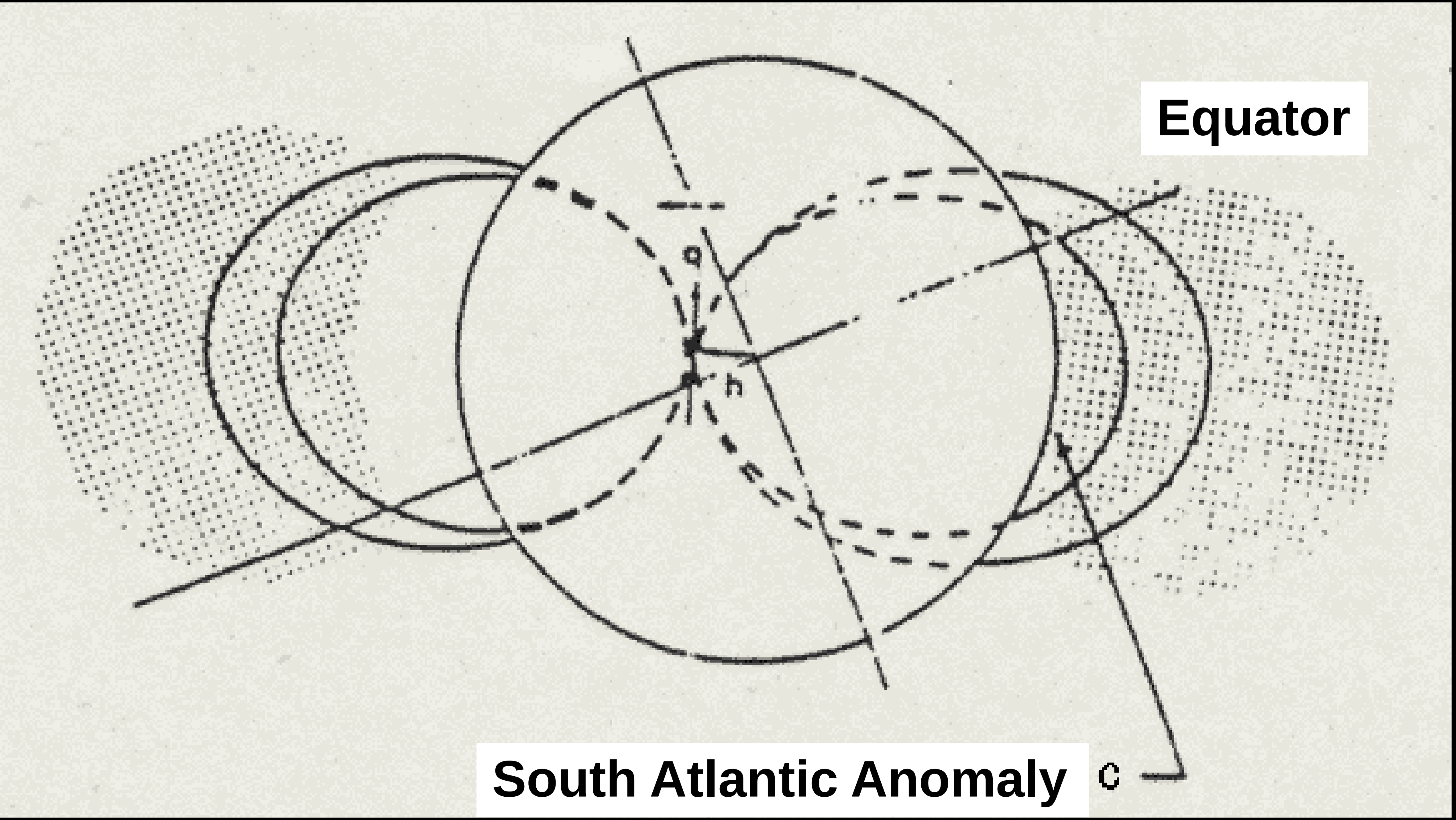


Magnetic field

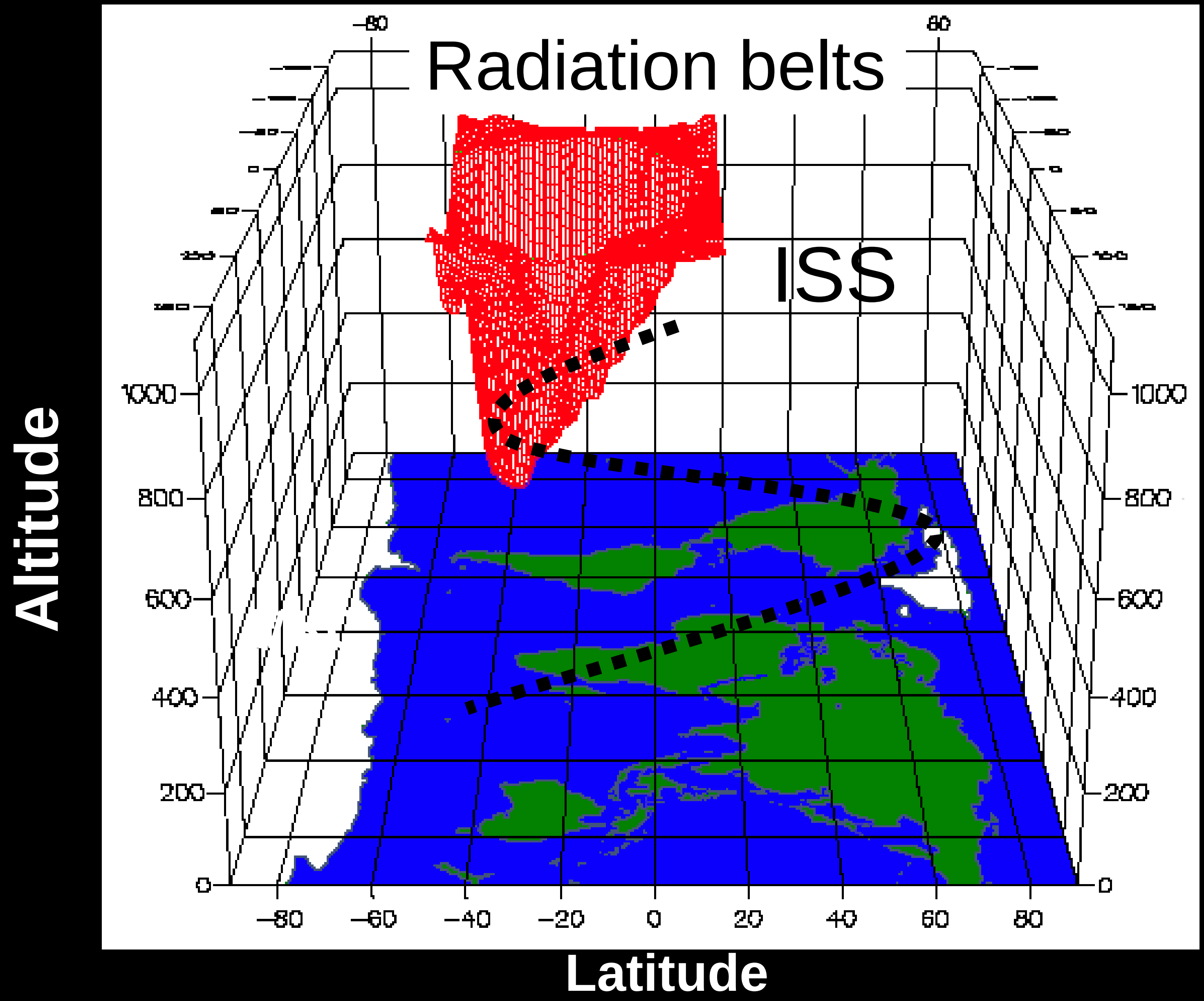
Protons



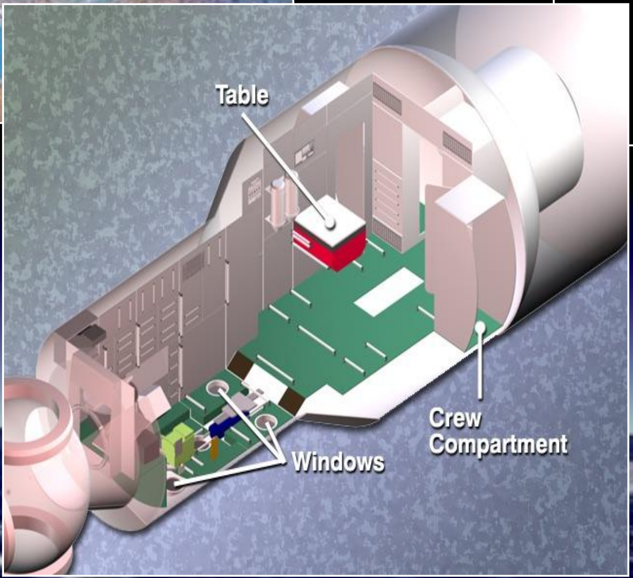
The Earth’s magnetic field

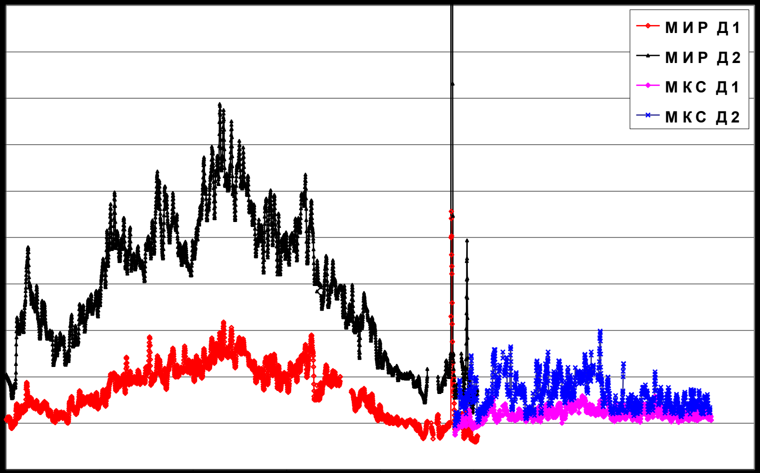


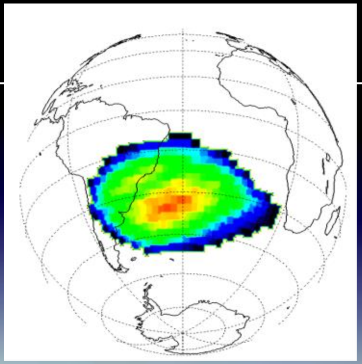
South Atlantic Anomaly and ISS trajectory

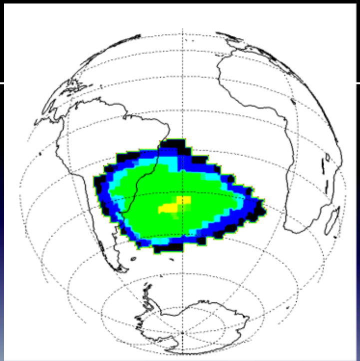


MIR Space Station Radiation Doses



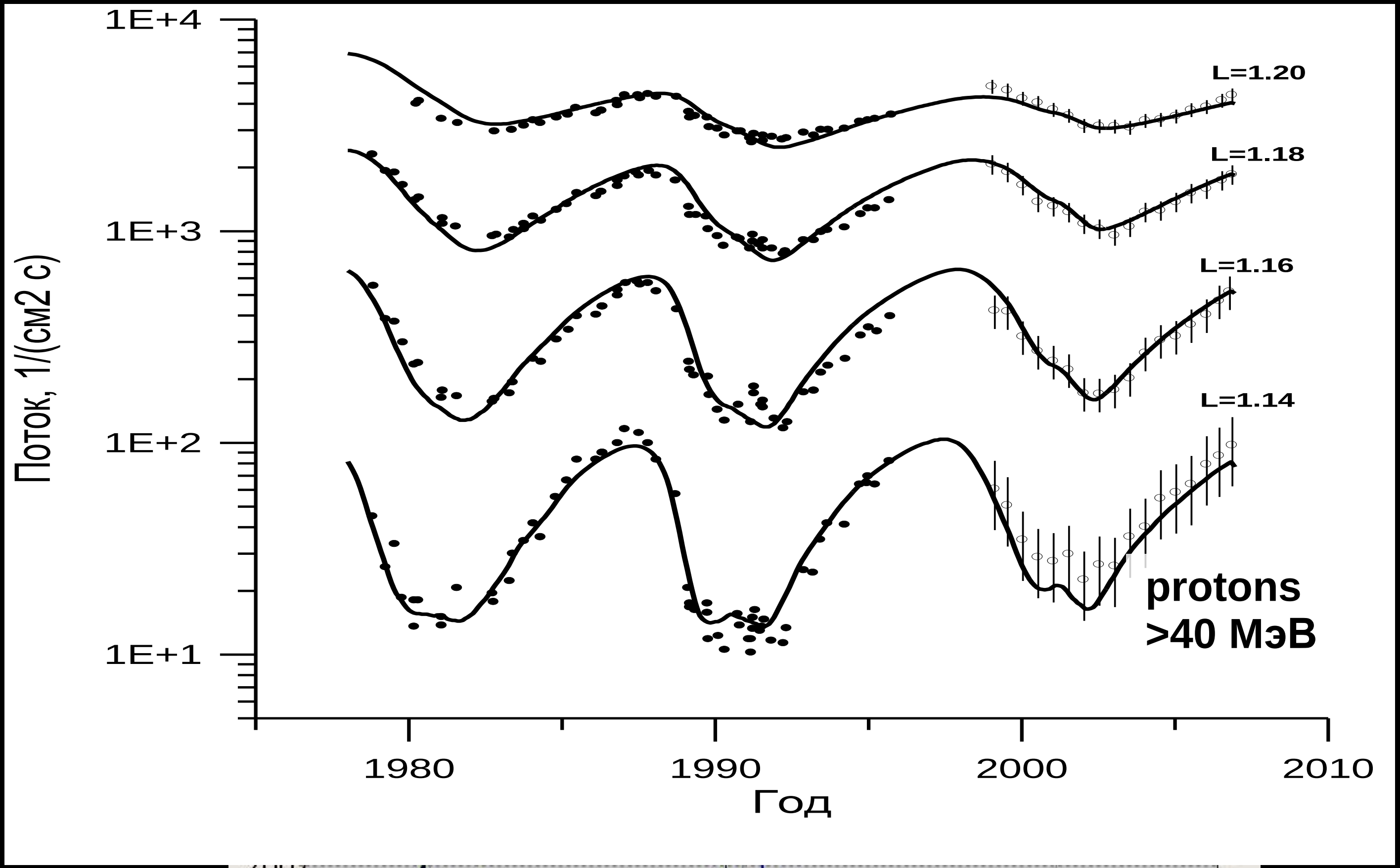


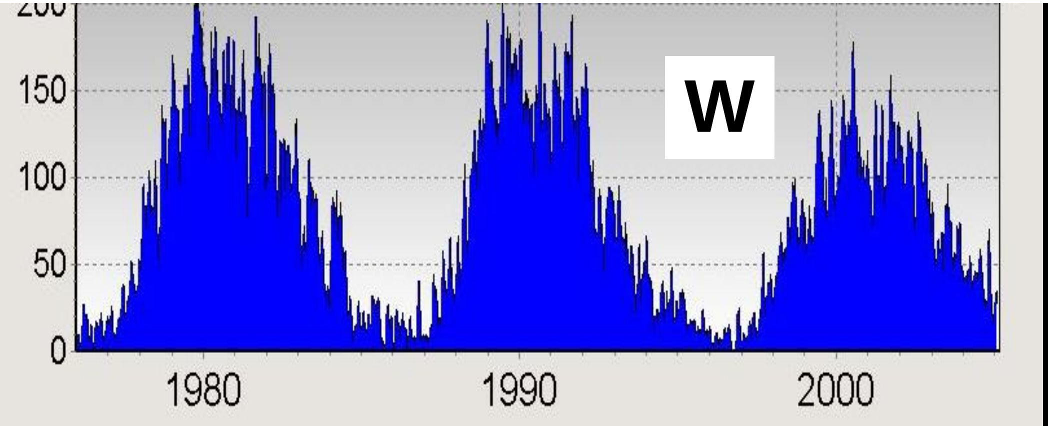




Since 70’, the radiation monitoring system has been operating on board the Space stations ,
designed and manufactured at the Moscow State University

Inner Radiation Belt Solar Cycle Dependence

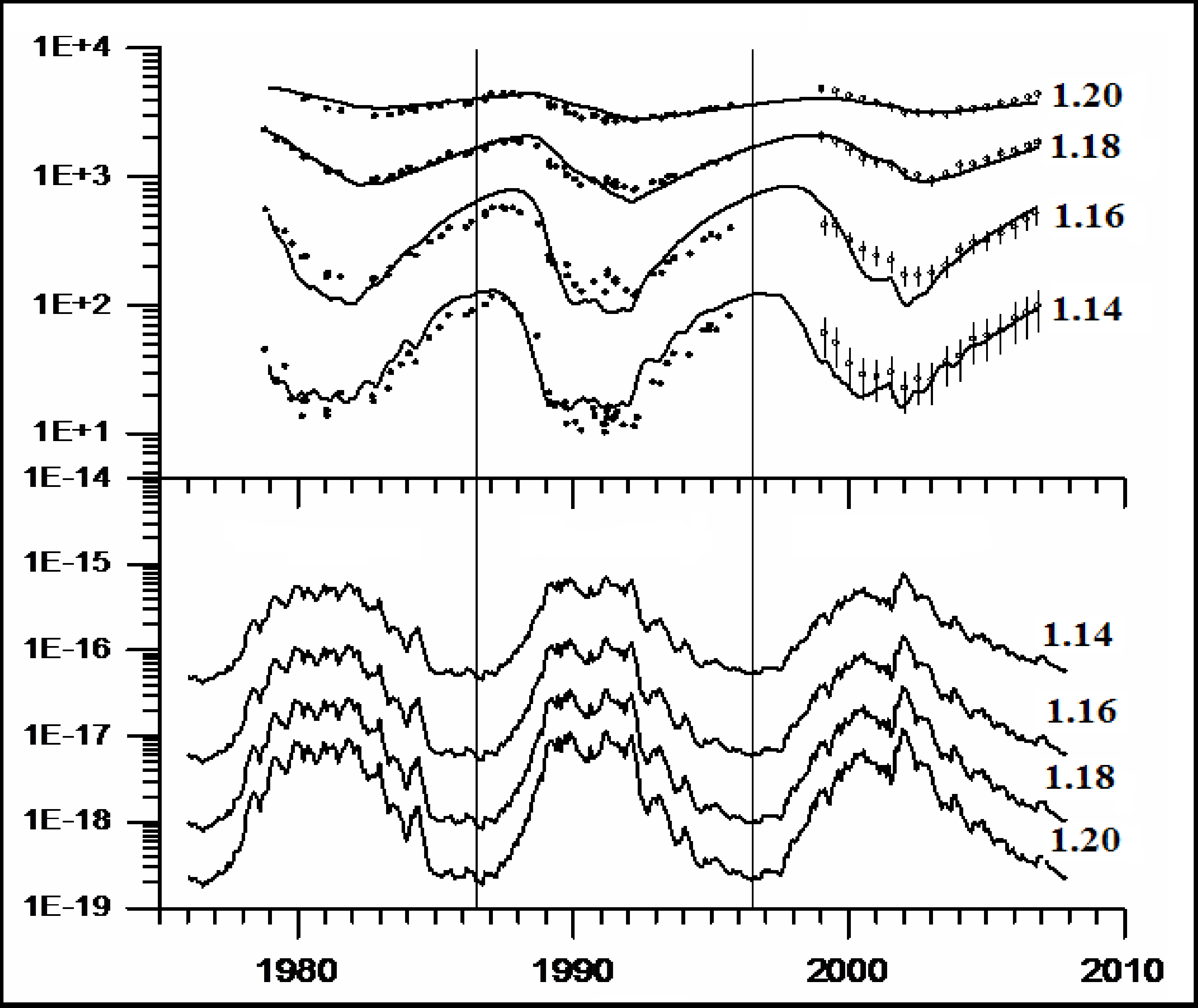




Inner Radiation Belt Solar Cycle Dependence.

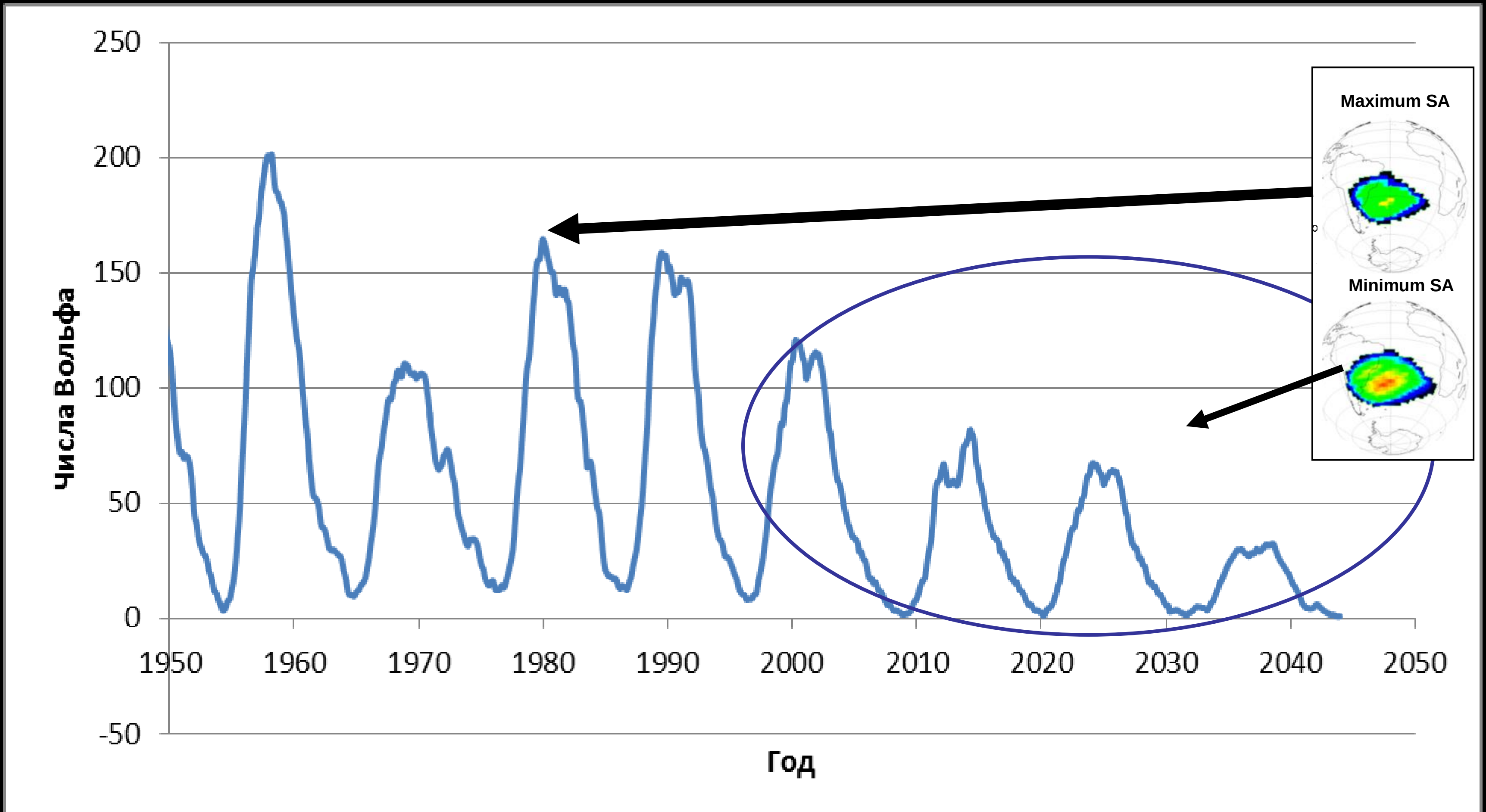
Proton flux

Atmospheric density

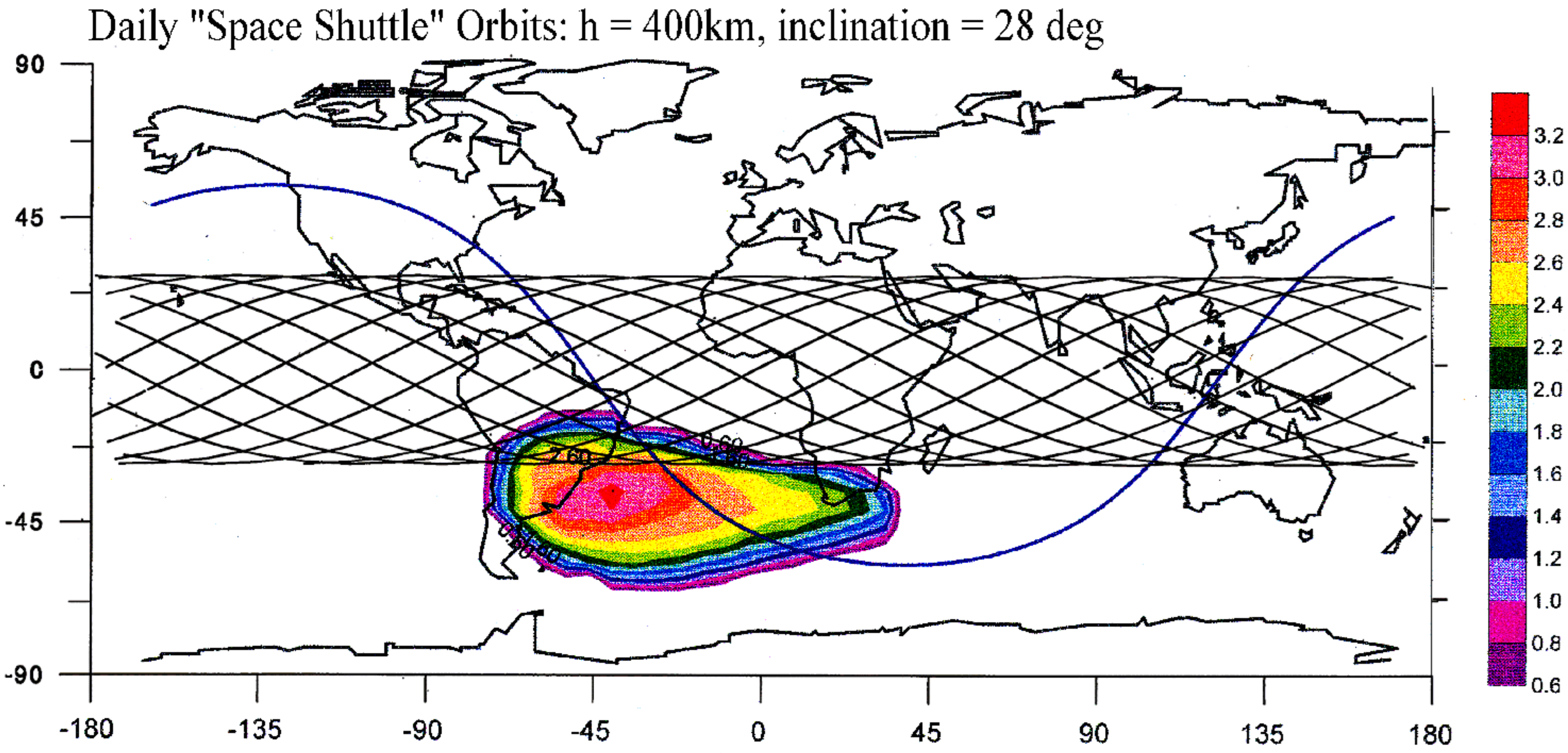


Importance of Solar Cycles Predictions

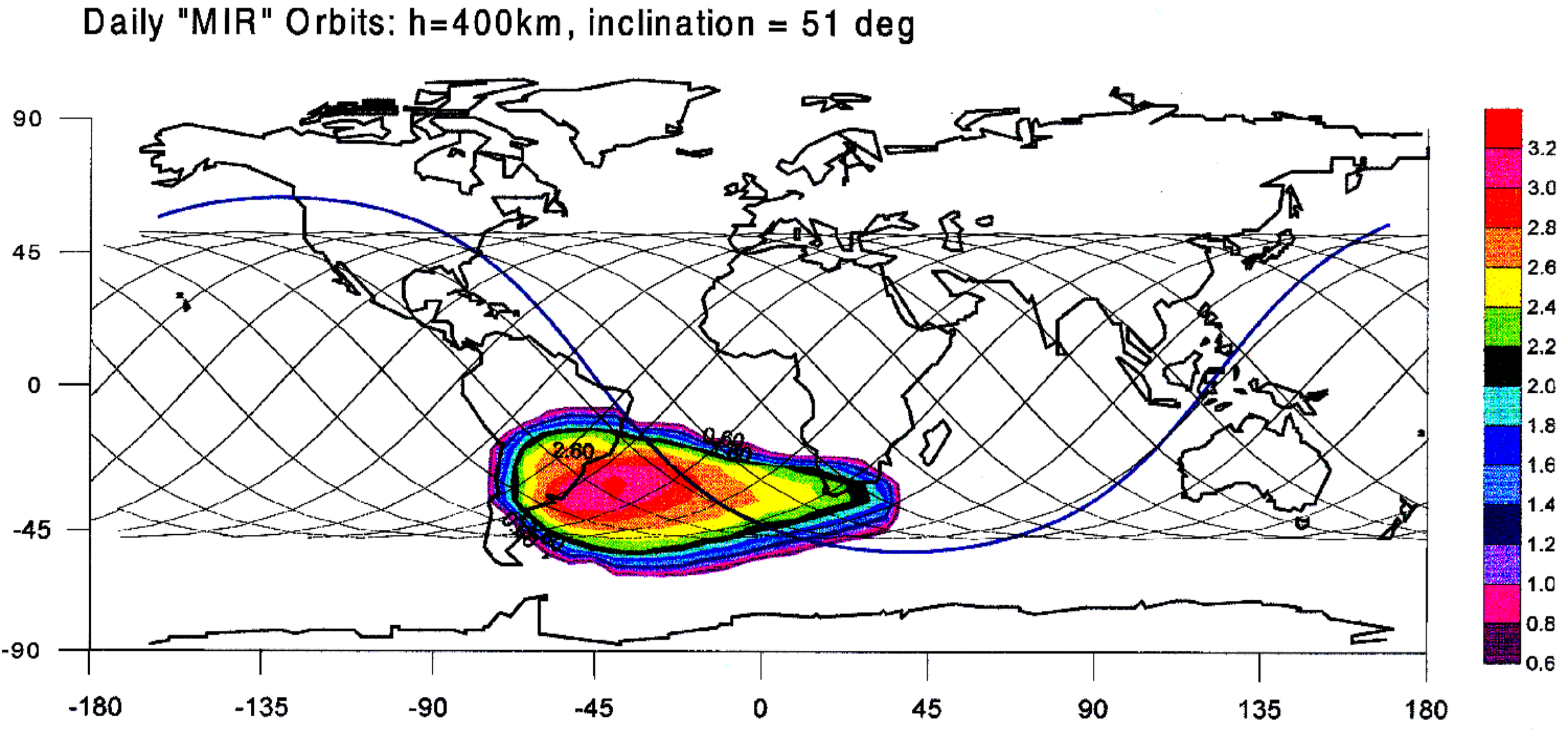
Near –Earth's radiation environment become more dangerous (increasing of GCR fluxes & atmosphere cooling) ???



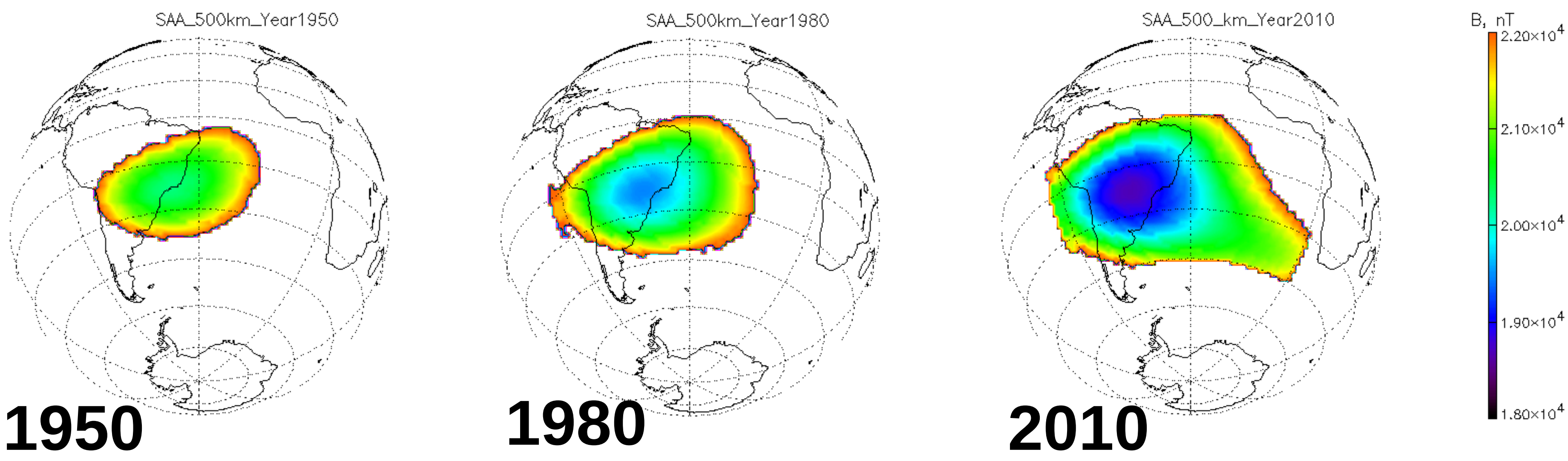
Shuttle: 28º inclination



ISS: 51,2^{o} inclination

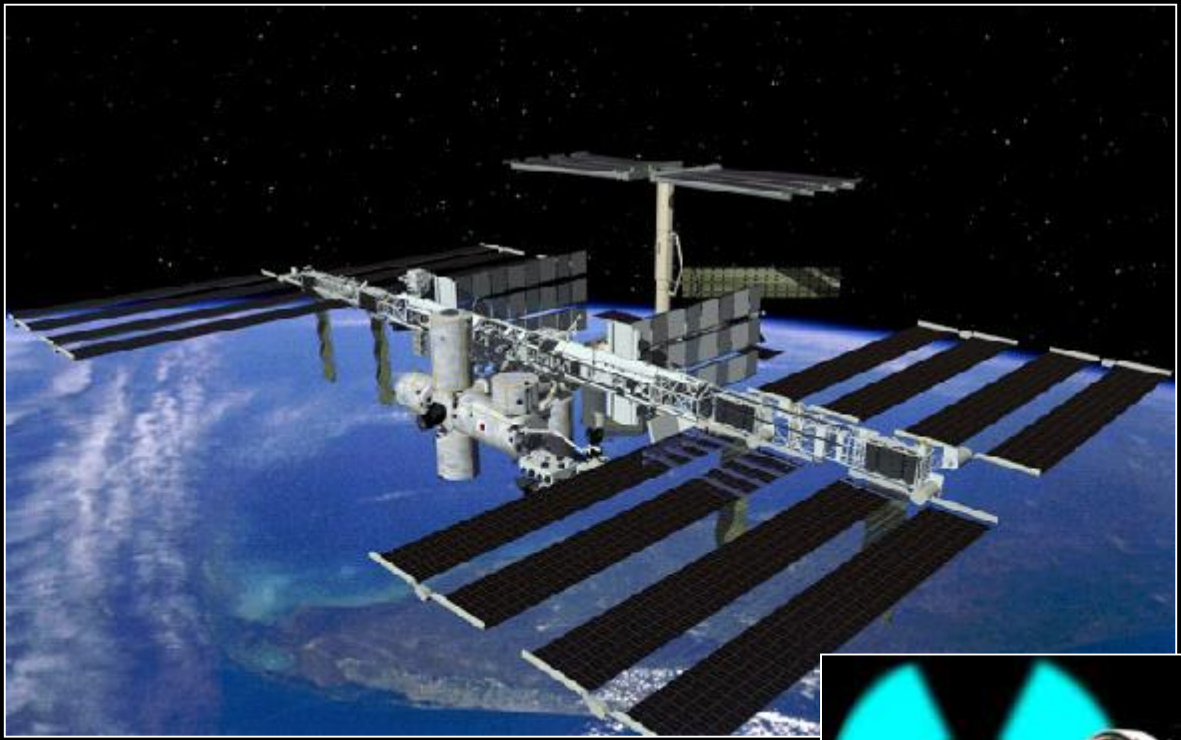


SAA: magnetic field secular variations



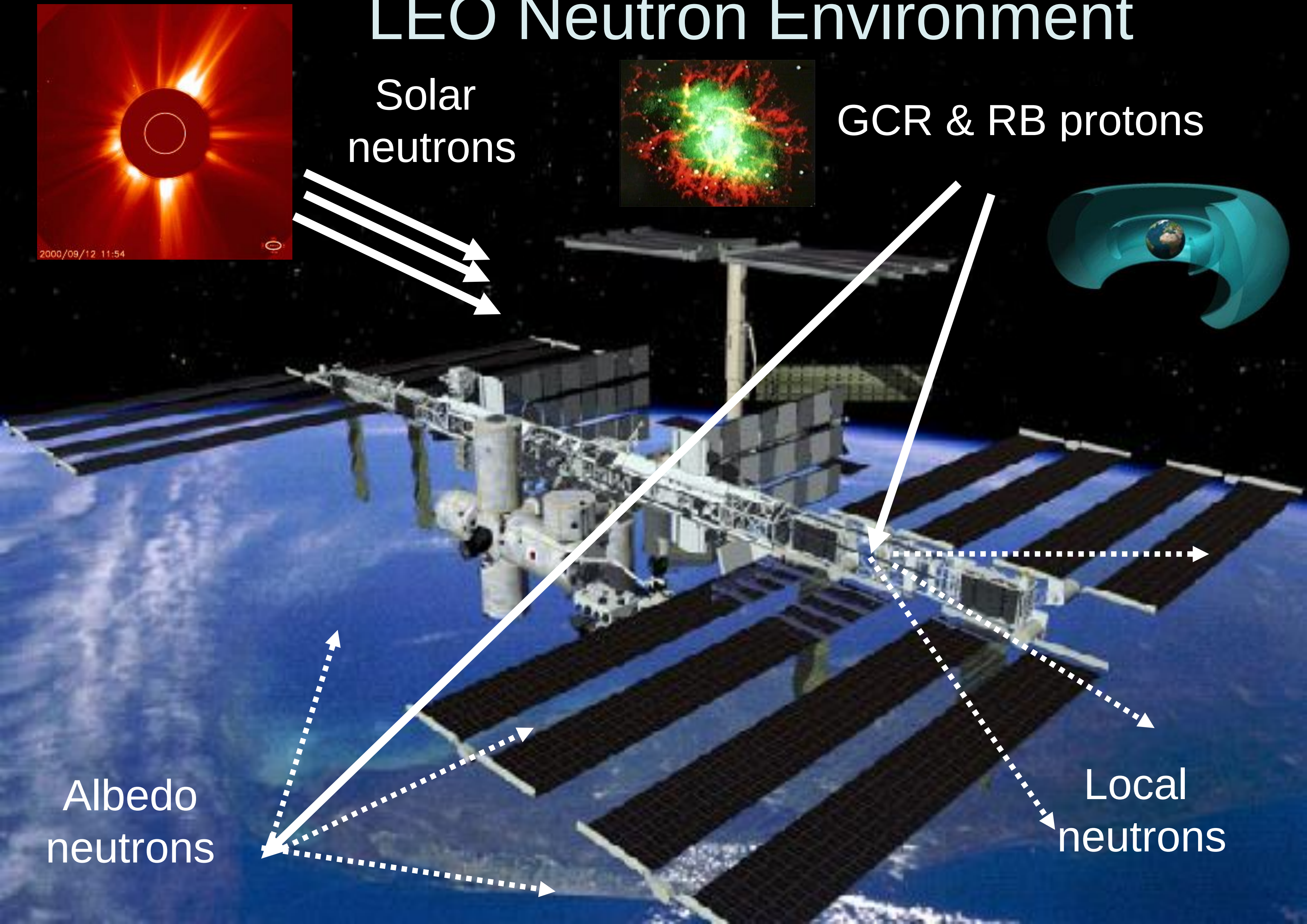
- Magnetic field become weaker (at h = const)
- SAA moving to the west

Neutron Environment in the Near-Earth's Space

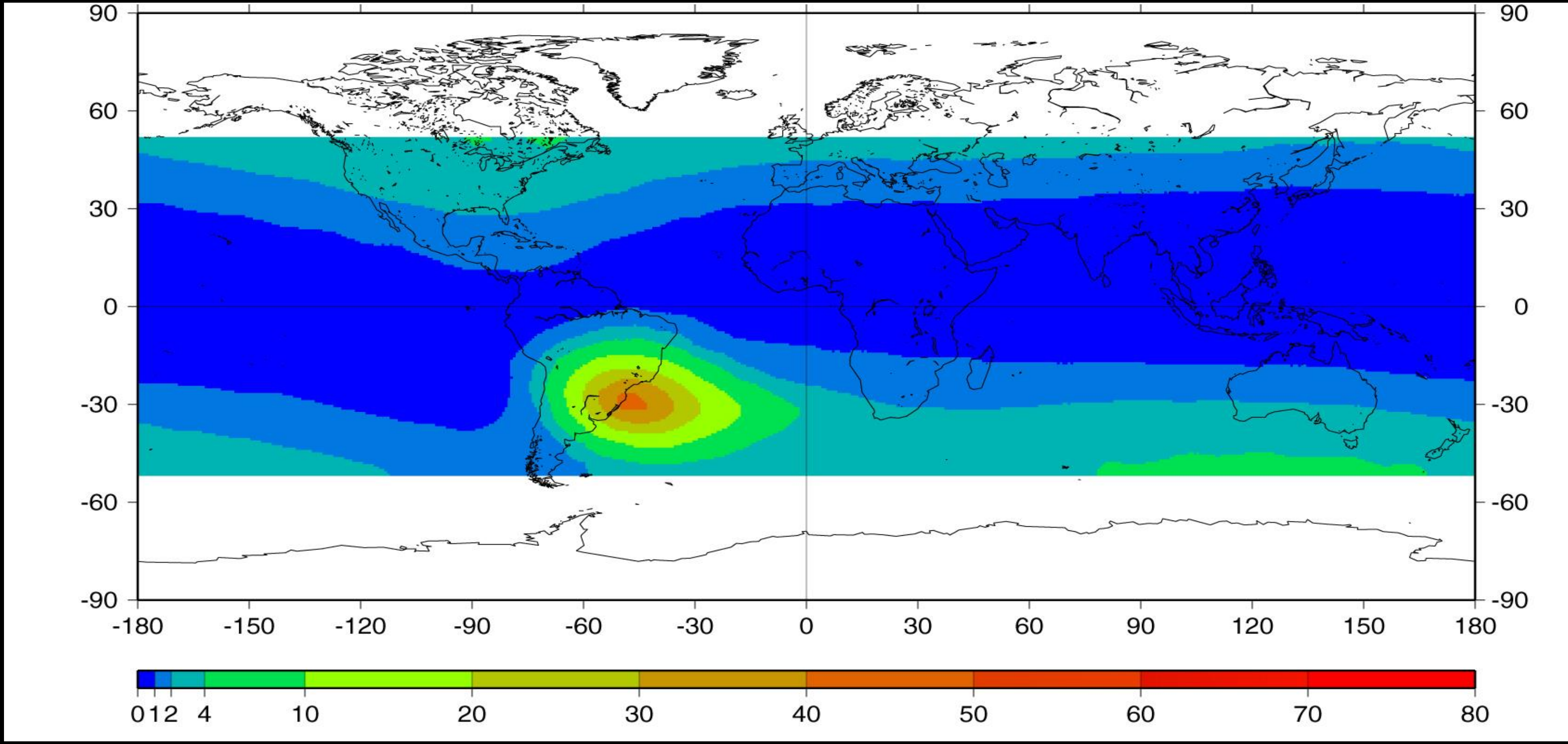


?

LEO Neutron Environment



Neutron dose equivalent (μSv/h)



Neutron dose equivalent (Goka et al)

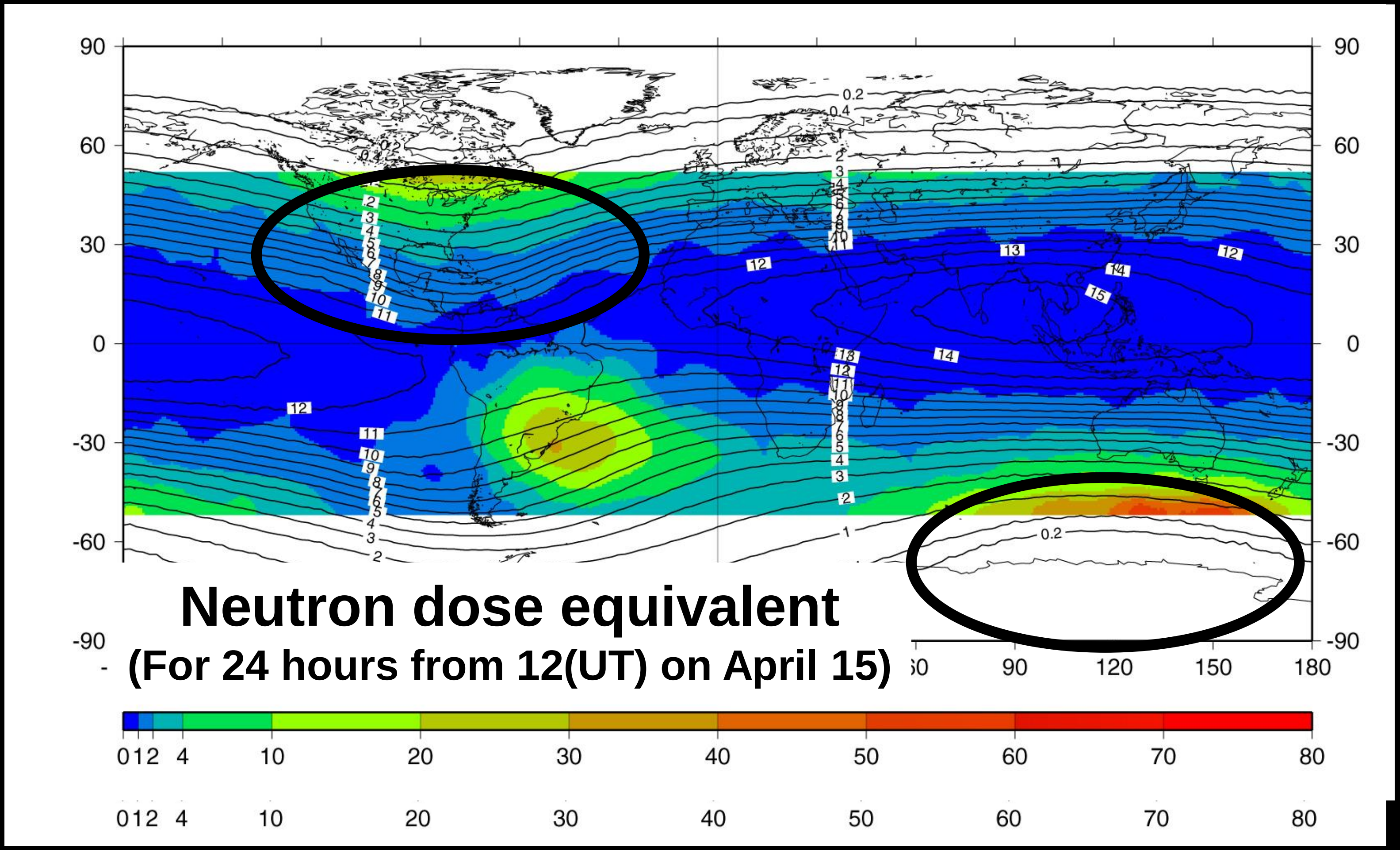
(From March 23 to July 7, All orbit)

“Neutron’s response” of solar flares

«Нейтронный отклик» солнечных вспышек

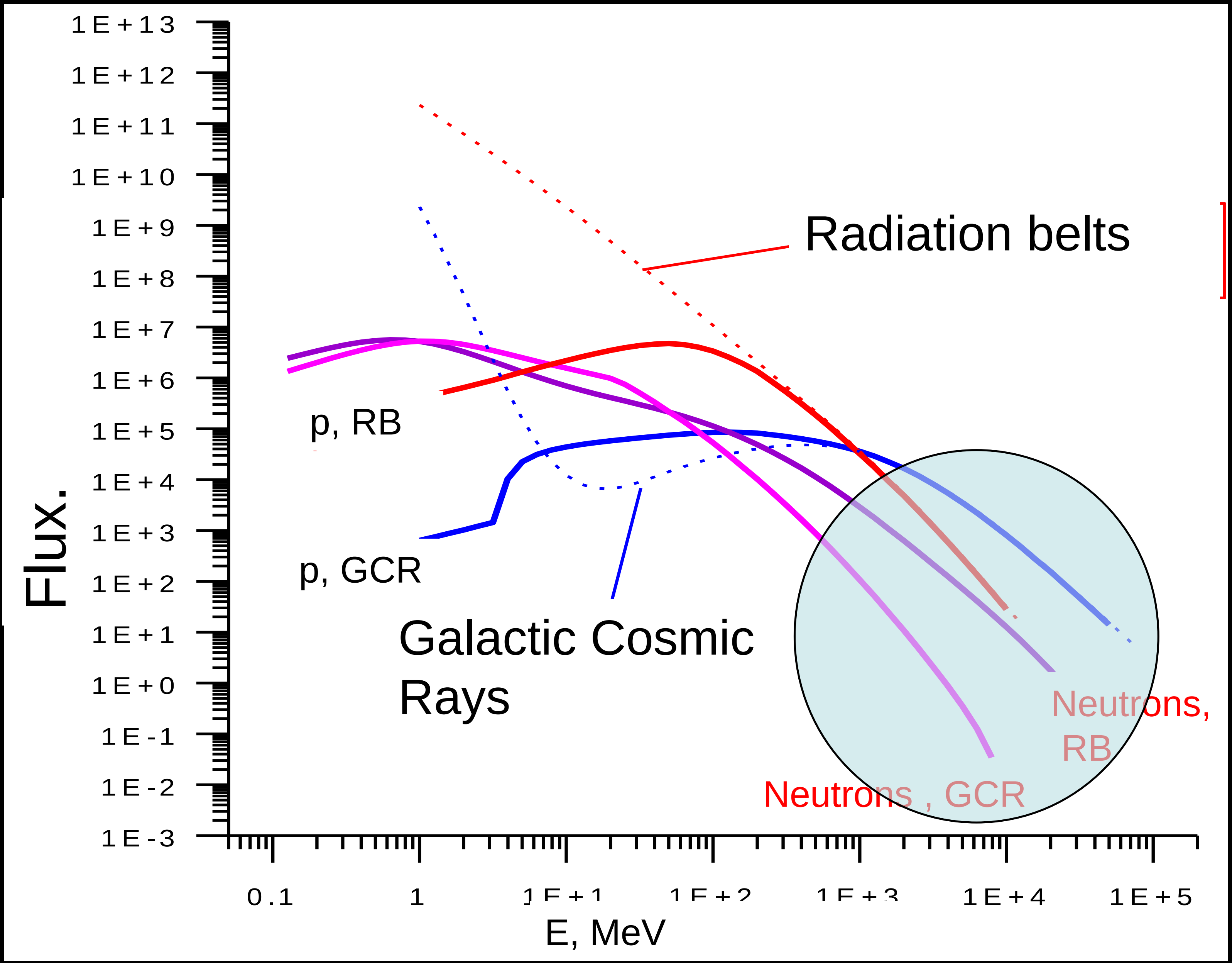
Neutron dose equivalent(μSv/h)

We have investigated the neutron dose equivalent inside the ISS on the influence of solar flare.

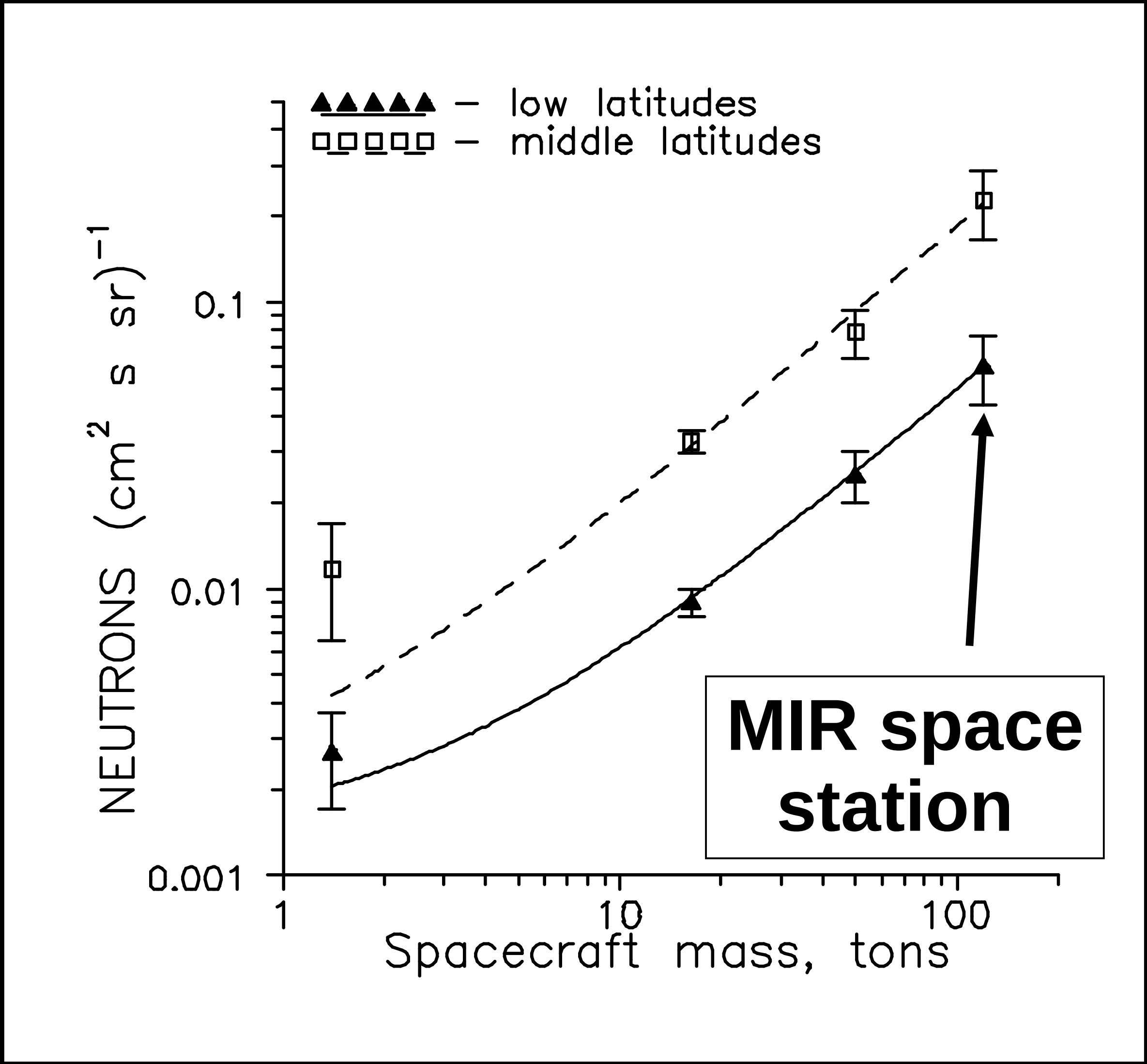


Neutron dose equivalent
(For 24 hours from 12(UT) on April 15)

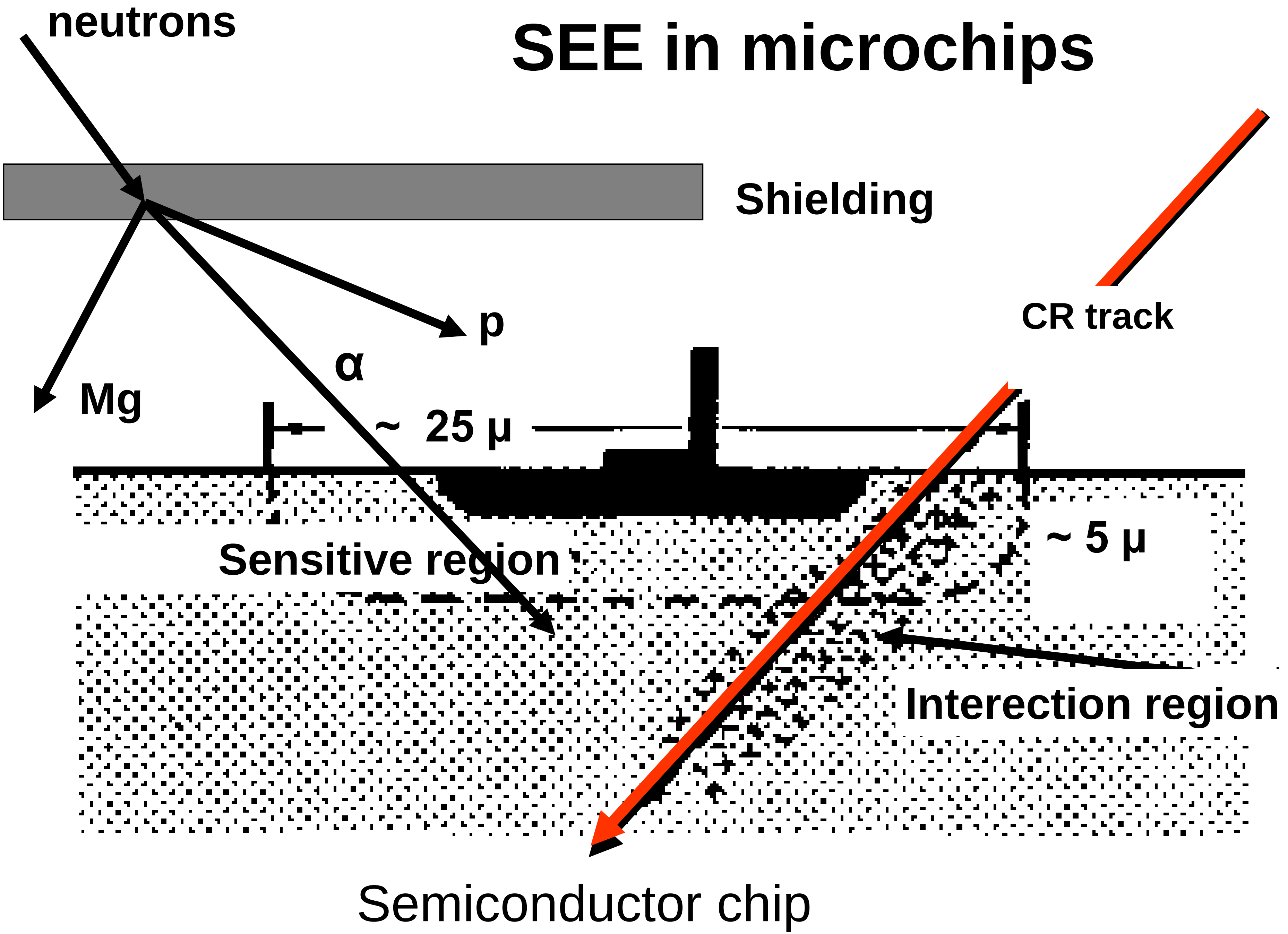
Secondary protons & neutrons at LEO



Local neutrons generation vs S/C mass

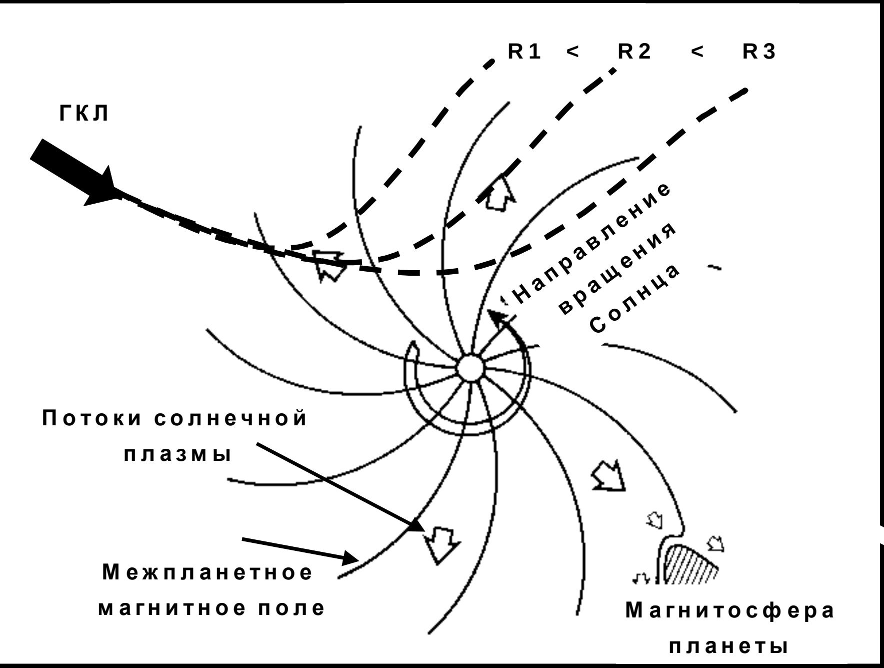


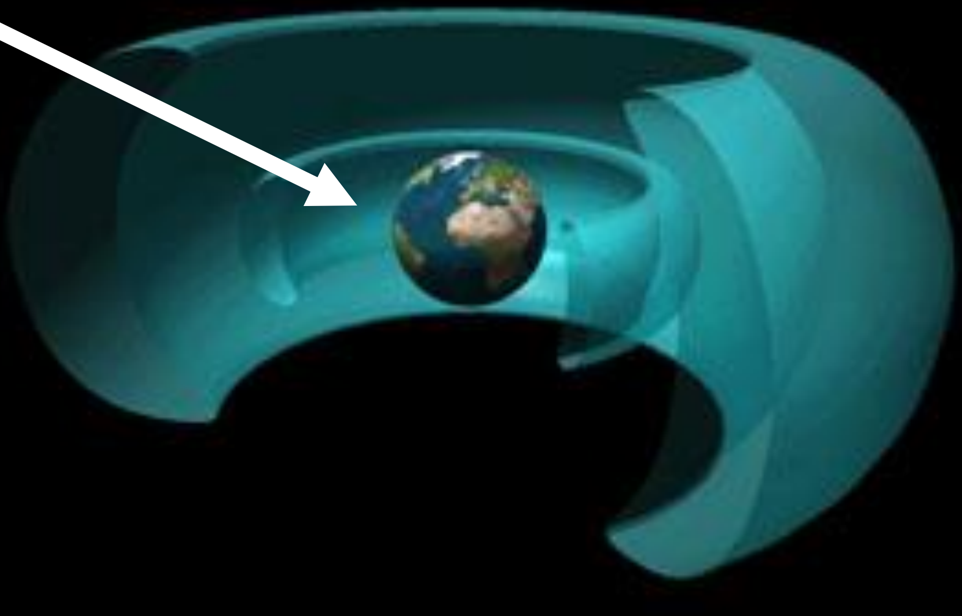
SEE in microchips

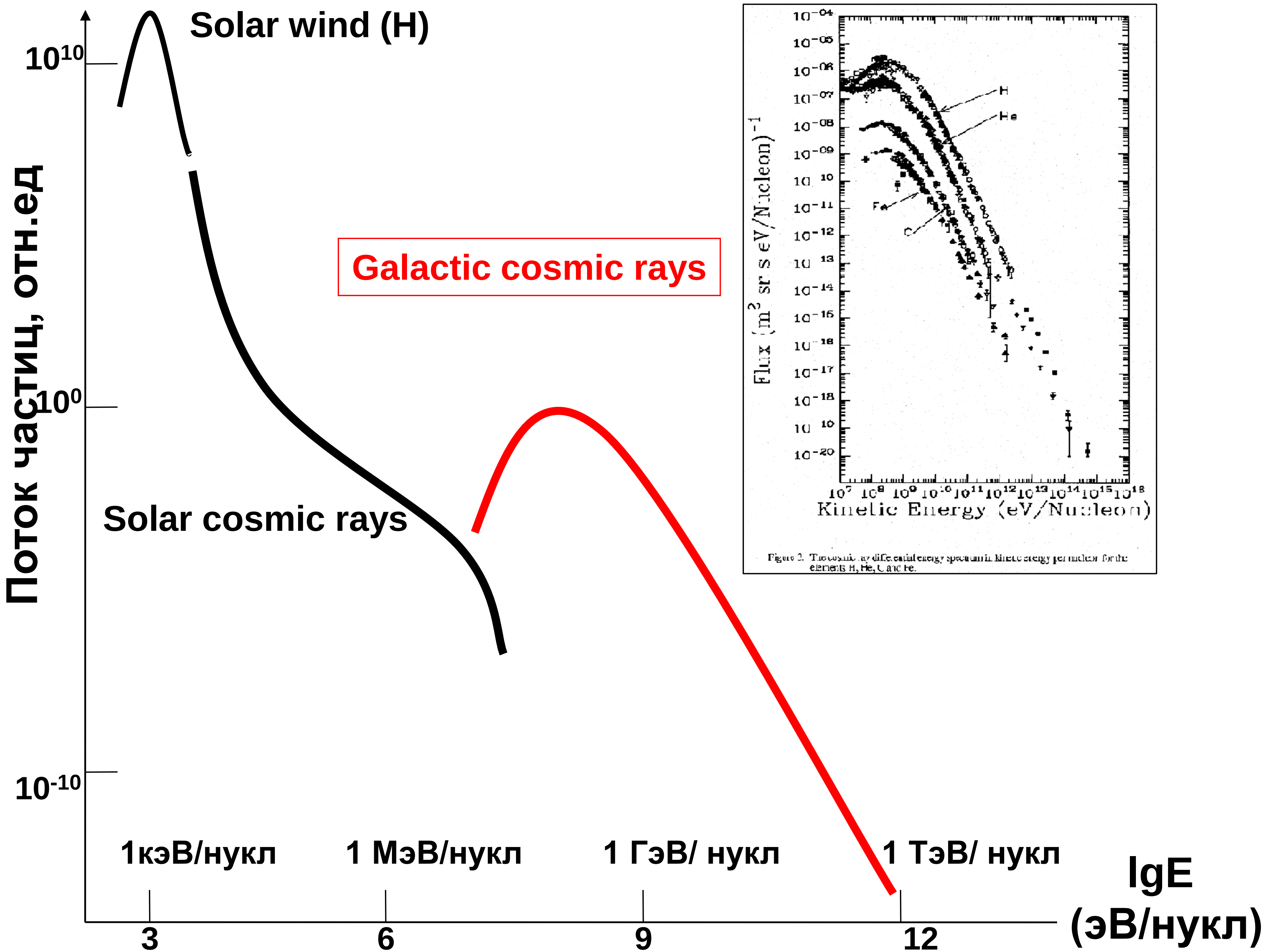


Galactic Cosmic Rays

Galactic cosmic rays







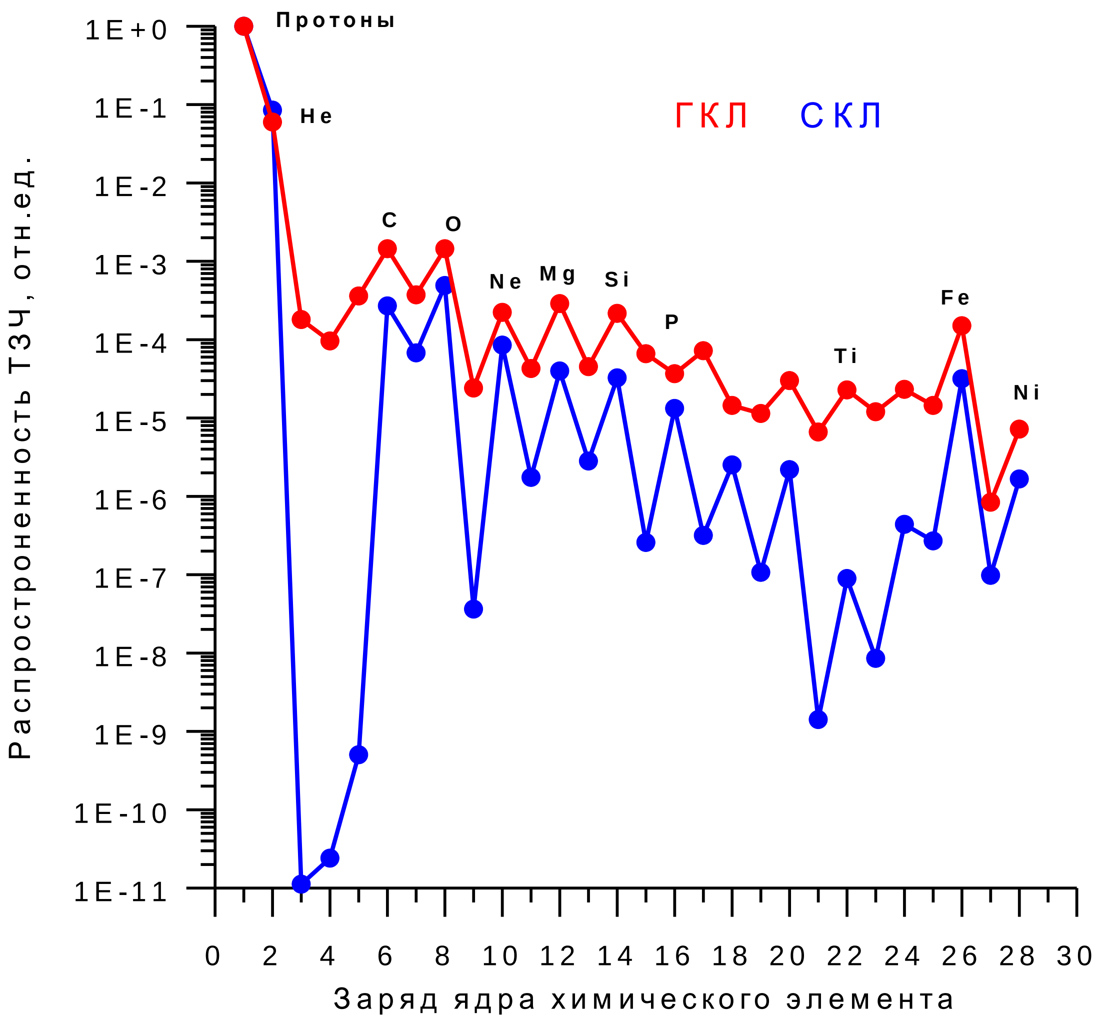
Solar wind (H)
Galactic cosmic rays
Solar cosmic rays
Поток частиц, отн.ед
10^10
10^0
10^-10
1кэВ/нукл
1 МэВ/нукл
1 ГэВ/ нукл
1 ТэВ/ нукл
3
6
9
12
lgE (эВ/нукл)
H
He
Fe
C
Flux (m^2 sr s eV/Nucleon)^-1
Kinetic Energy (eV/Nucleon)

Cosmic Rays Models

The main goal: prediction

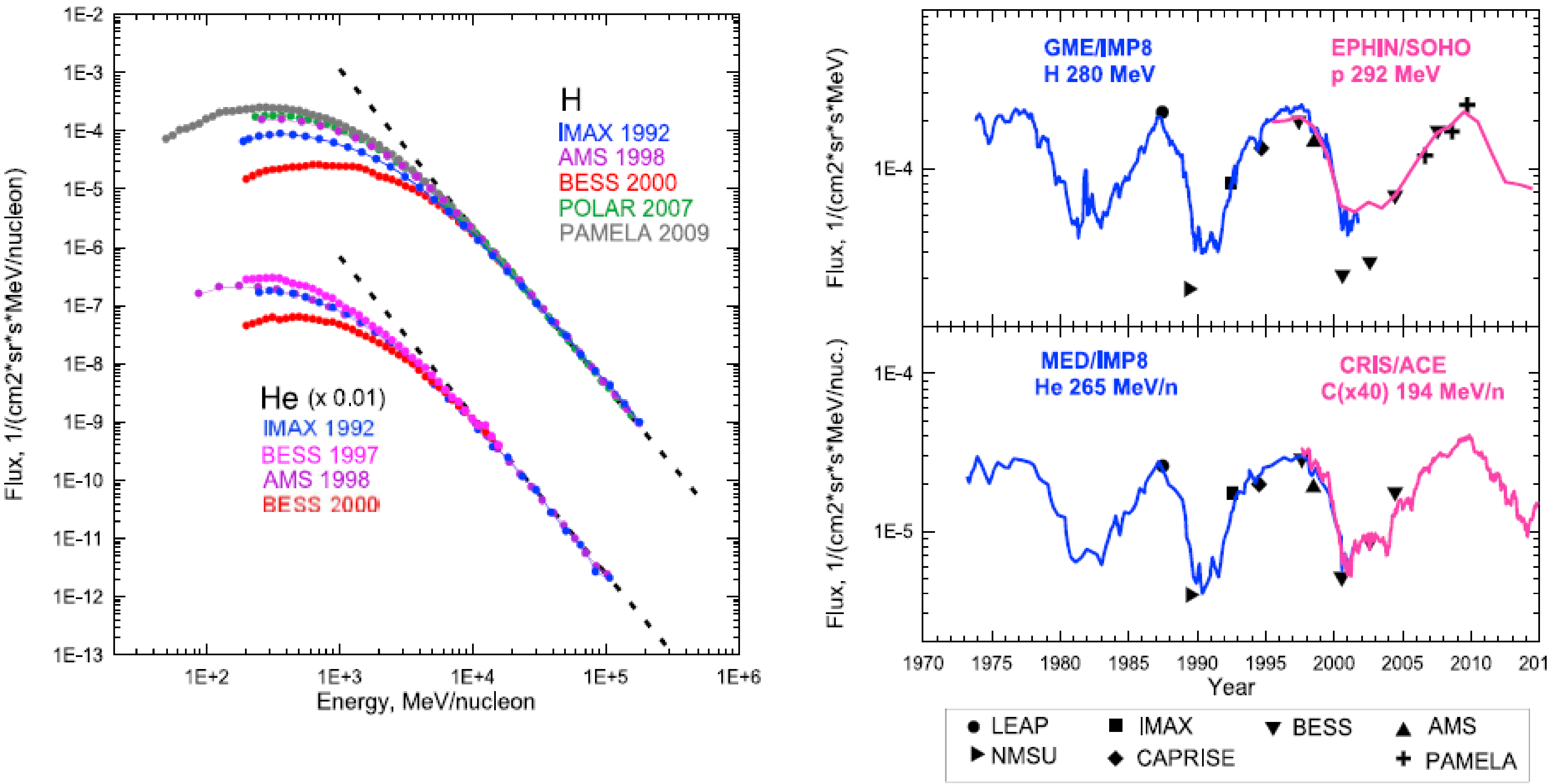
SEP/GCR composition

Элементный состав заряженных частиц ГКЛ и СКЛ



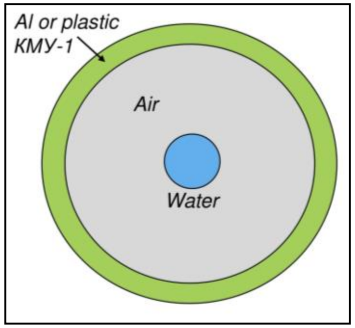
GCR

Галактические космические лучи
(экспериментальные данные)

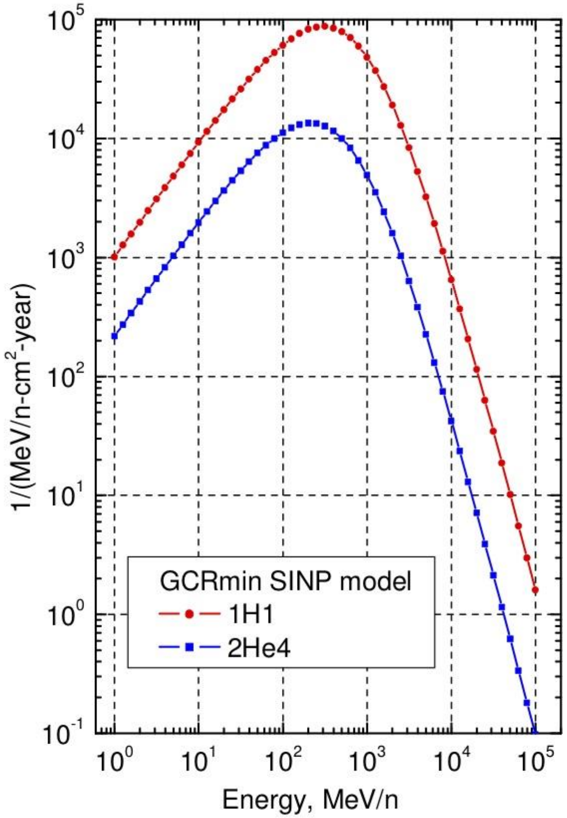


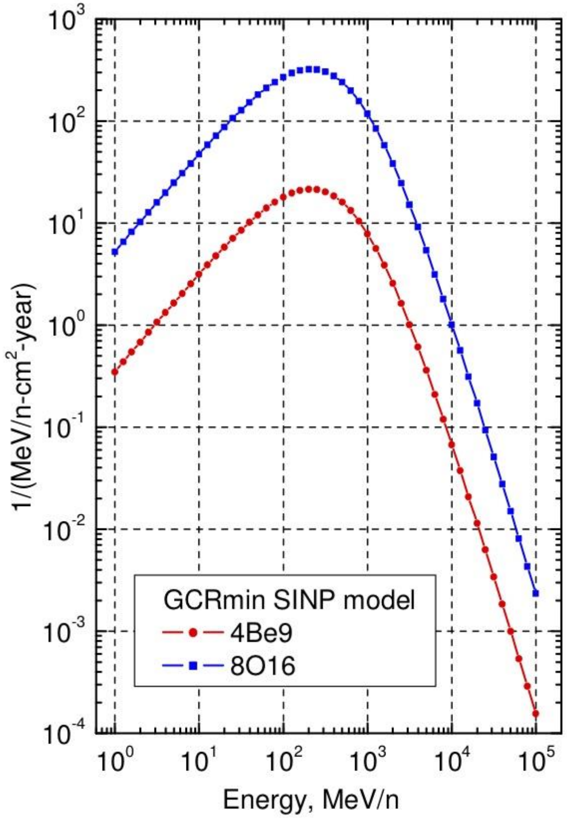
2. GCR spectra according to SINP MSU model of 2017

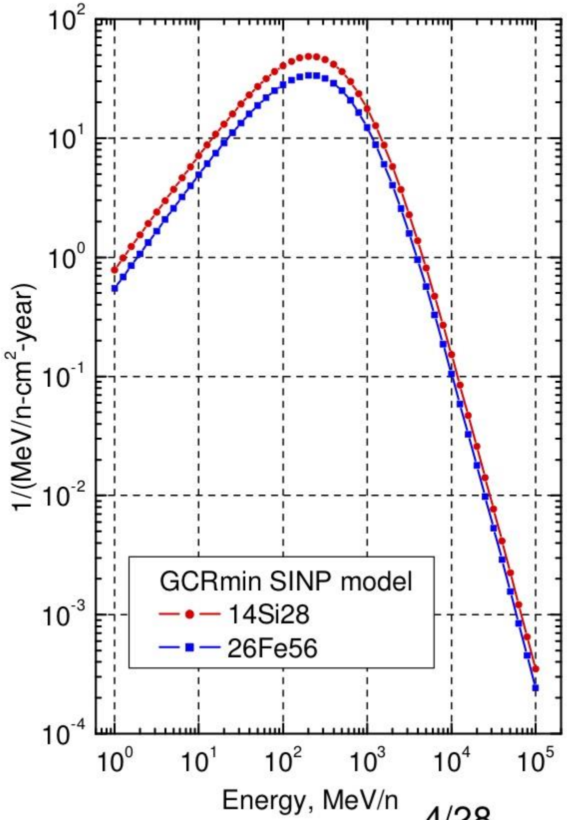
Kuznetsov, N.V., Popova, H., Panasyuk, M.I.
Empirical model of long-time variations of galactic cosmic ray particle fluxes.
J. Geophys. Res. Space Phys. **122** (2017) 1463-1472.



GCR projectile	$^{1}_{1}H$	$^{4}_{2}He$	$^{9}_{4}Be$	$^{16}_{8}O$	$^{28}_{14}Si$	$^{56}_{26}Fe$
Presents nuclei	$^{1}_{1}H$	$^{4}_{2}He$	Li, Be, B	C - Ne	Na - Ar	K - Ni
Weight factor	1	1	7.0	2.16	2.84	1.77

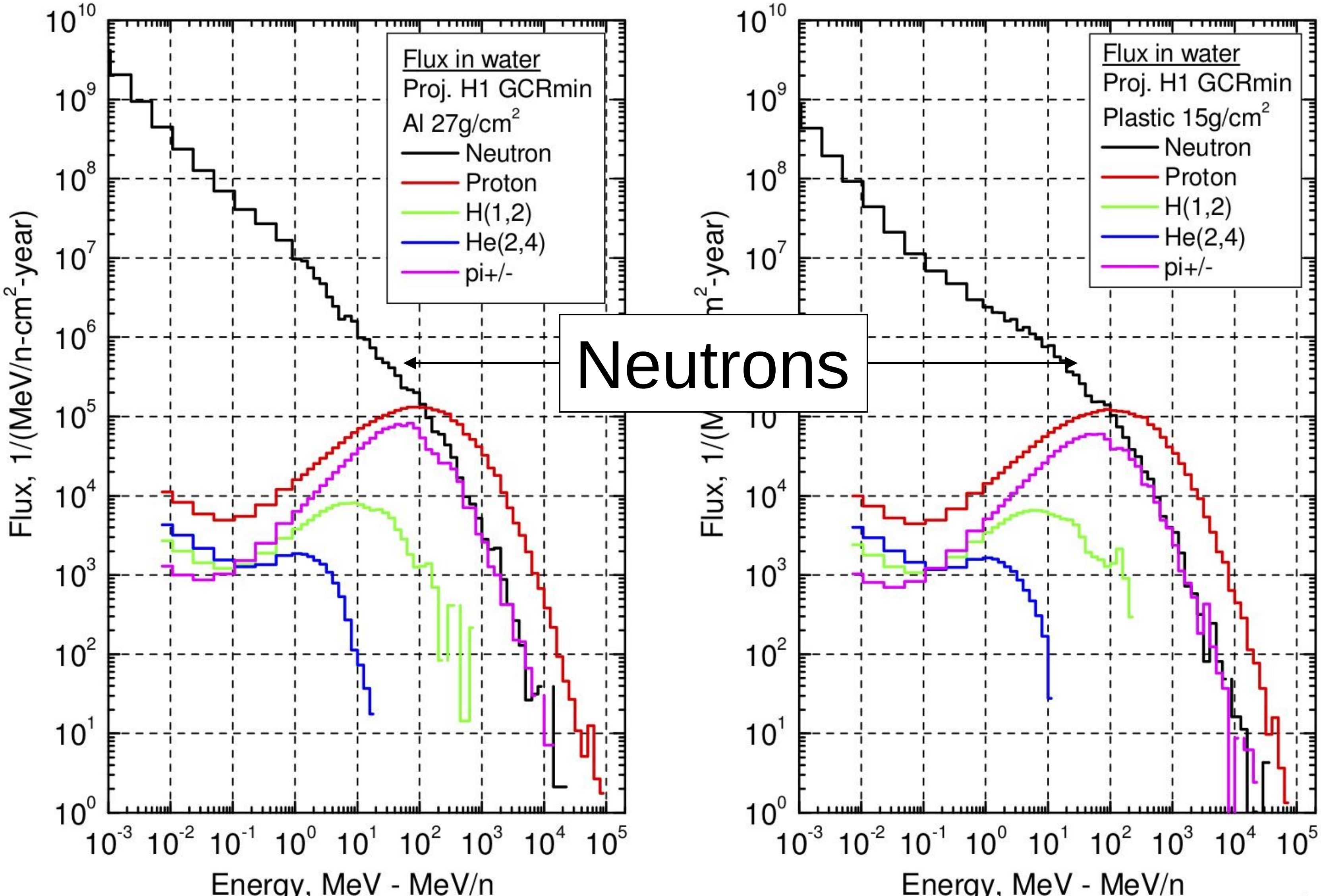






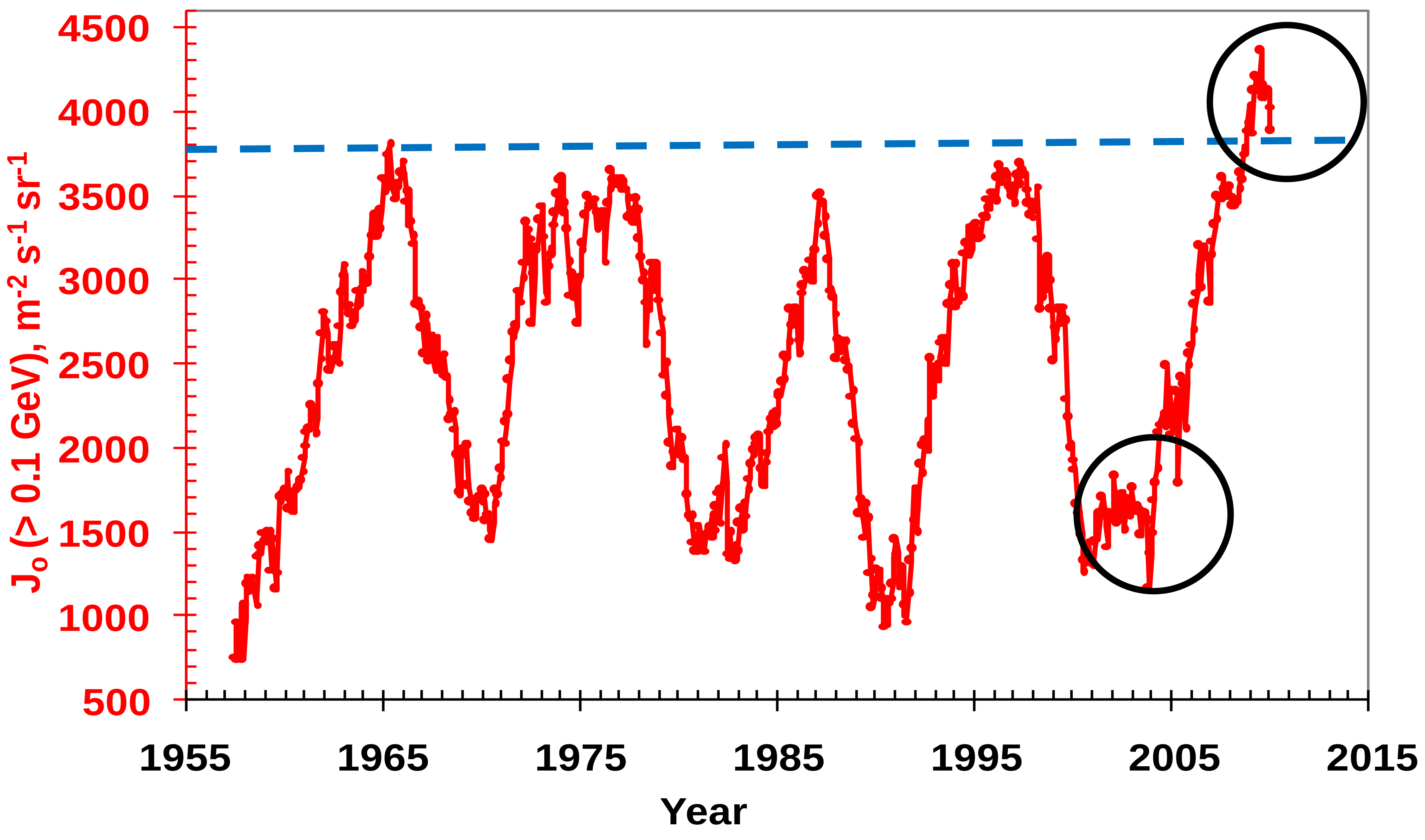
Comparison of fluxes in water behind **Al (27g/cm²)** and **Plastic КМУ-1 (15g/cm²)** screens.

GCR projectile – H1



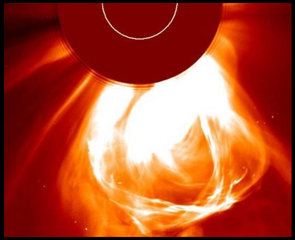
Problems of GCR modelling

GCR Temporal Variations



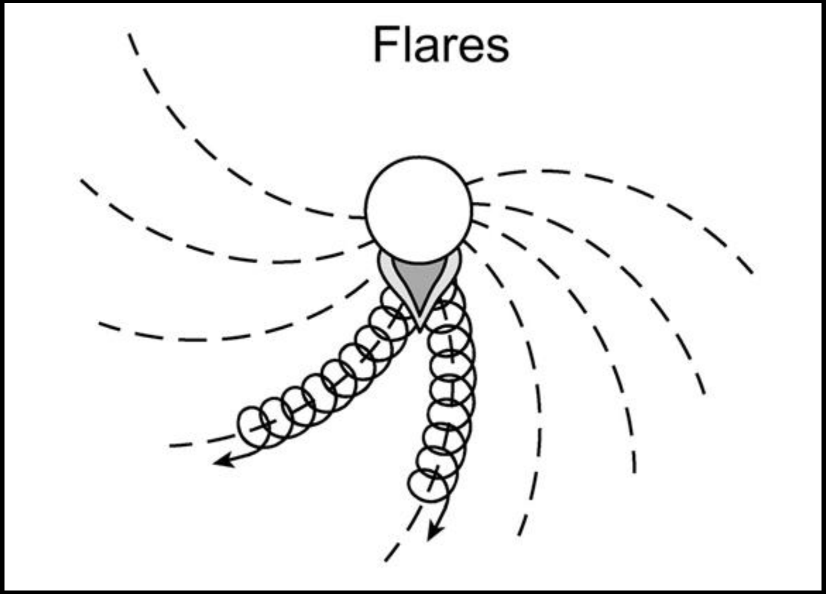
Solar Energetic Particles

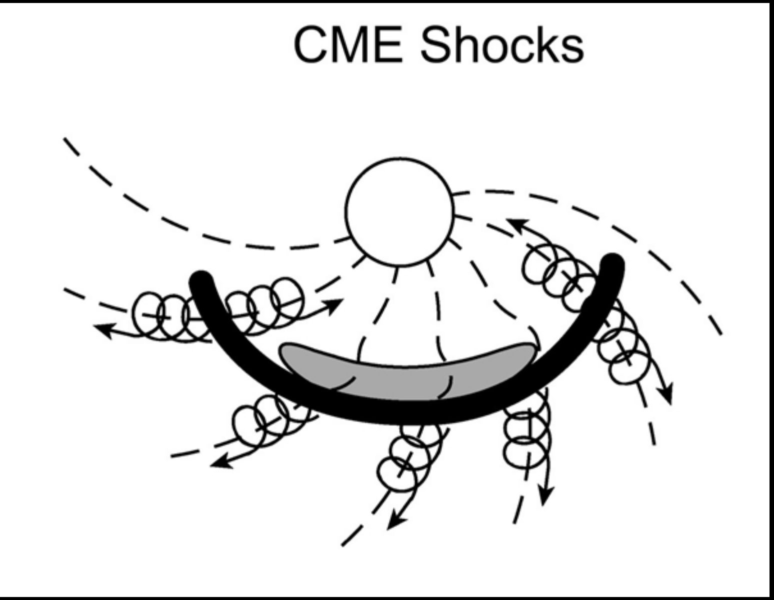
SEP's acceleration



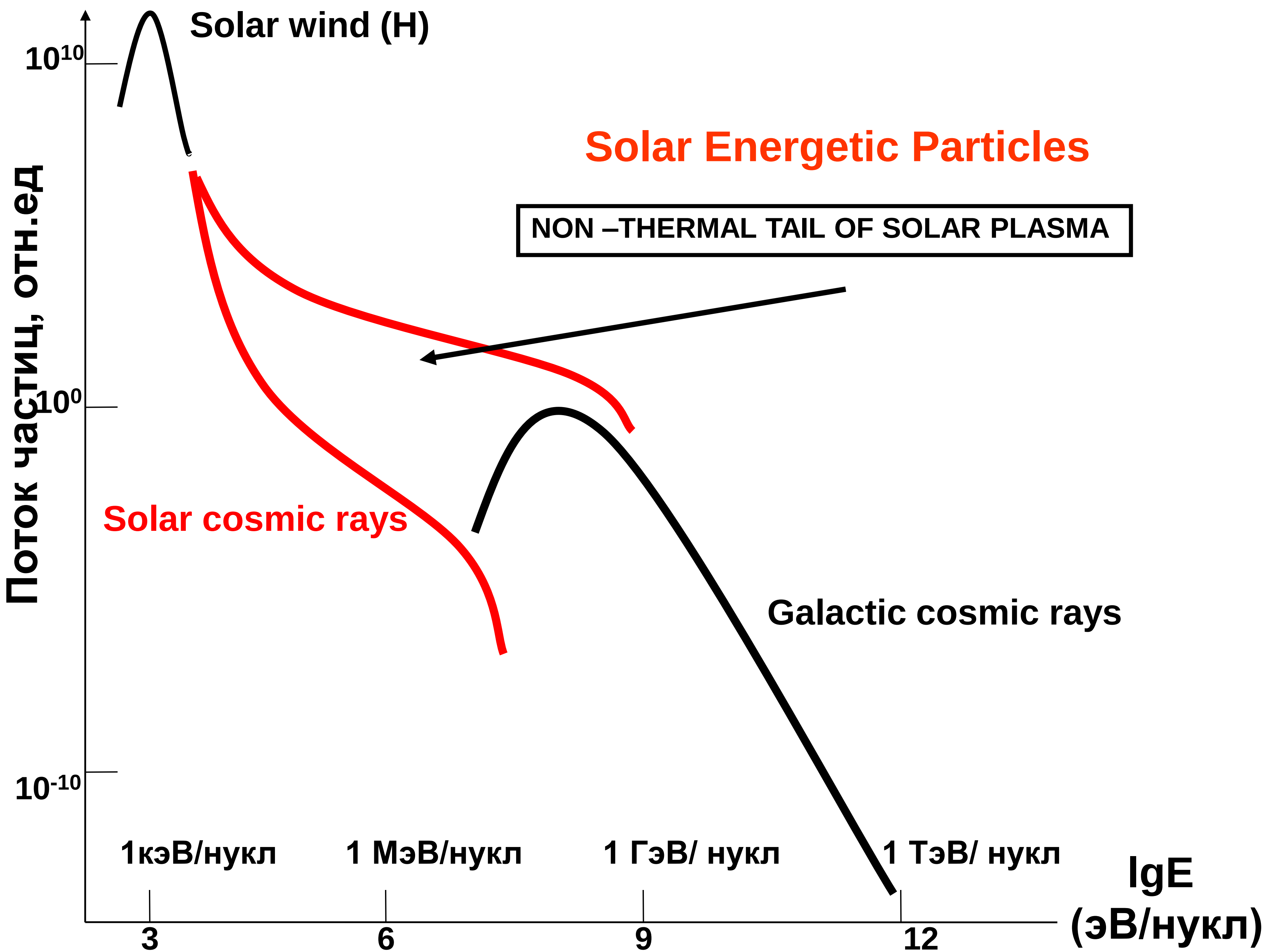
Flare Acceleration
3He-rich, Fe-rich
Narrow populated area
Impulsive injection

- **CME-drive shock acceleration**
  - **'nominal' composition (≠ SW)**
  - **Broad distribution**
  - **Evolving conditions**





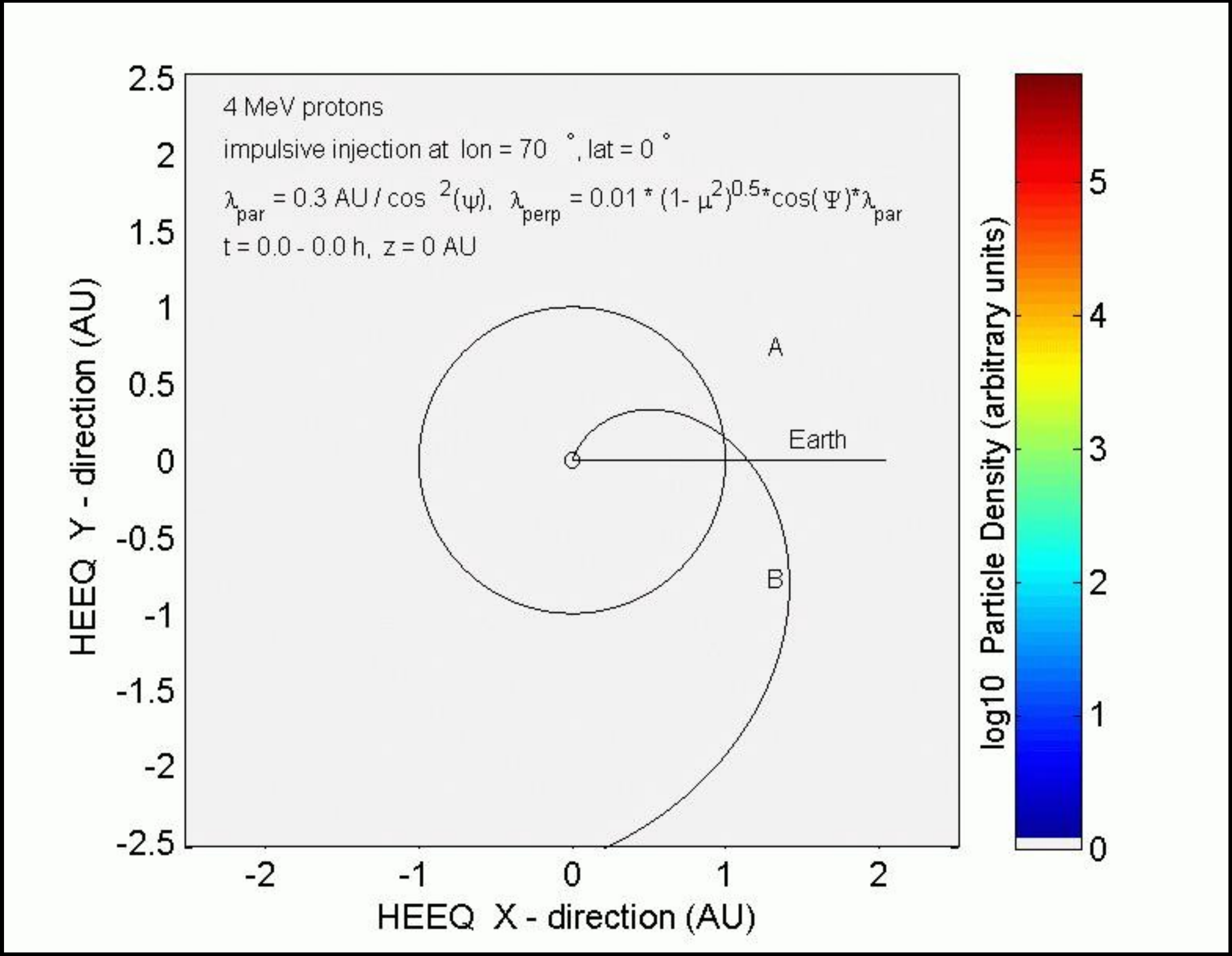
•CME-drive shock acceleration



Solar wind (H)
Solar Energetic Particles
NON –THERMAL TAIL OF SOLAR PLASMA
Solar cosmic rays
Galactic cosmic rays
Поток частиц, отн.ед
10^10
10^0
10^-10
1кэВ/нукл
1 МэВ/нукл
1 ГэВ/ нукл
1 ТэВ/ нукл
lgE
(эВ/нукл)
3
6
9
12

SEP’s transport

SEP's interplanetary transport



The key problems of SEP's modelling

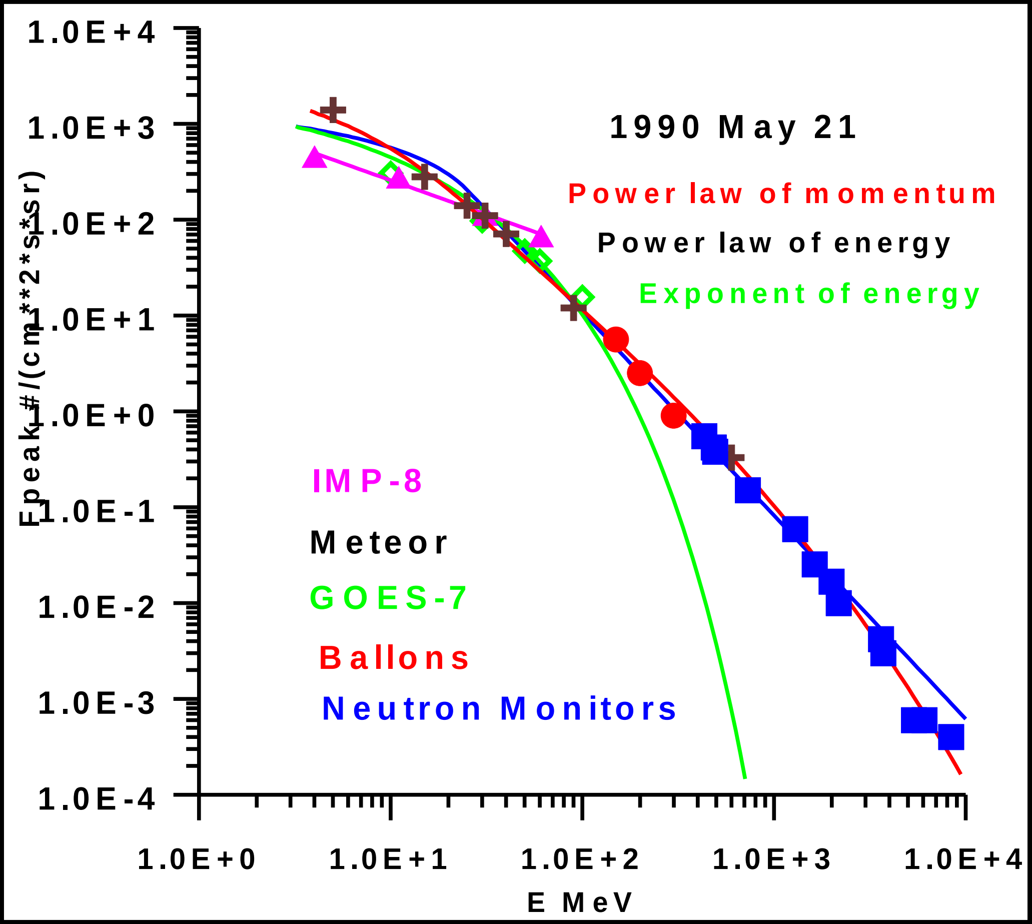
What SEP's characteristics have we to know

for the adequate model's development?

SEP’s Temporal/Energy Parameters

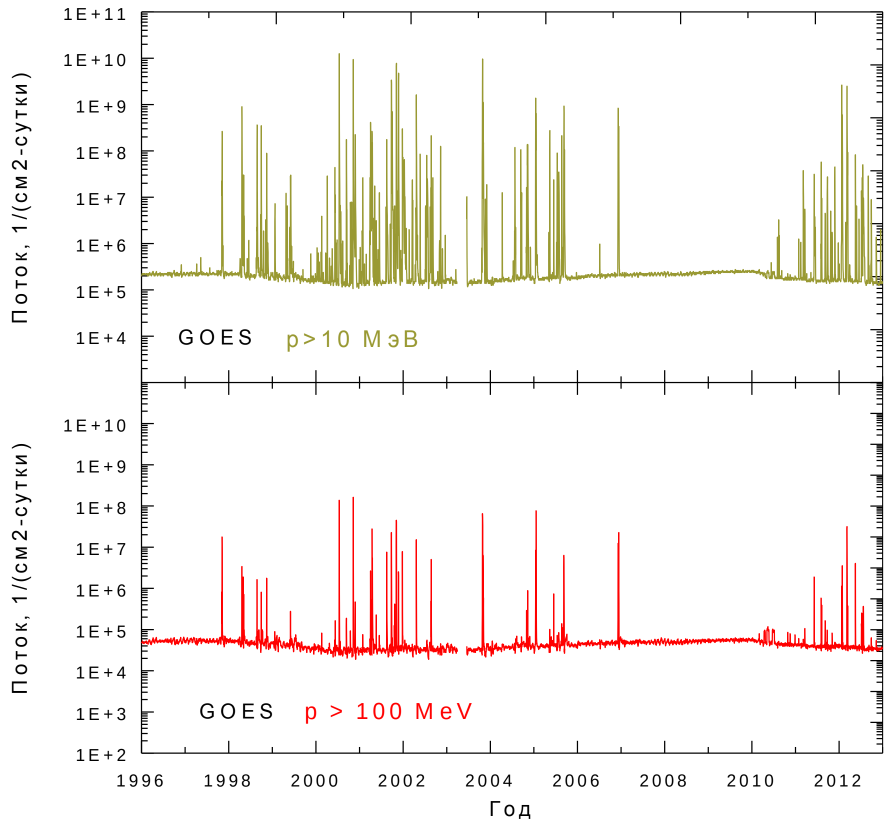
SEP's energy spectra

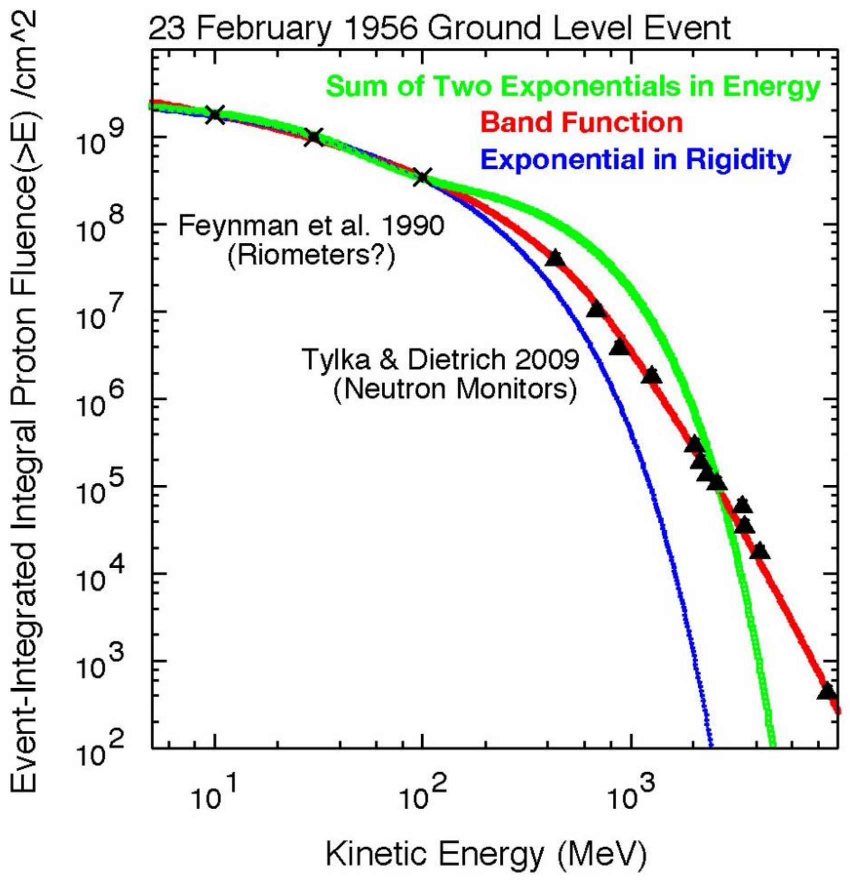
- The shape of SEP's spectra (exponential or power low)?



SEP

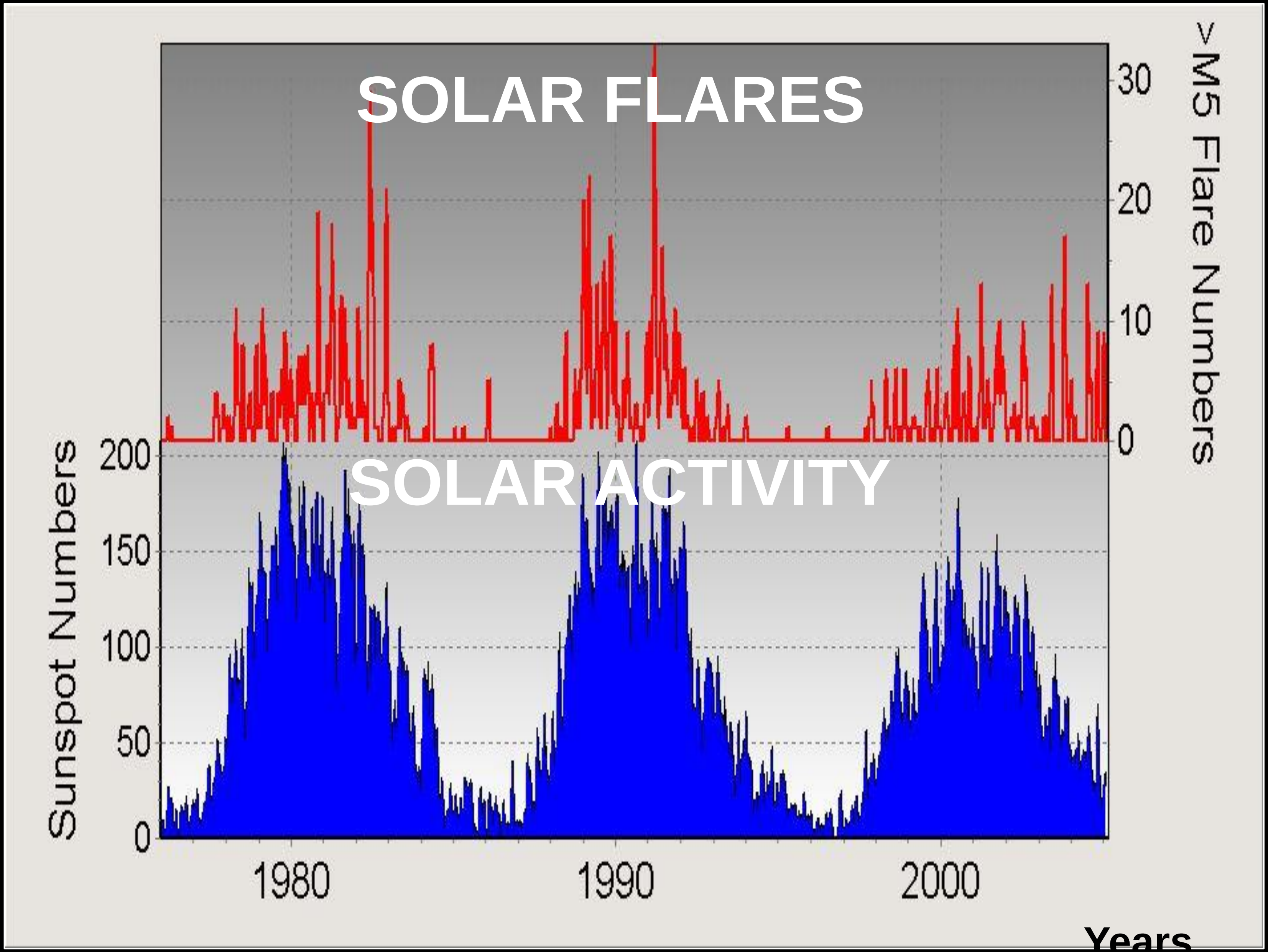
Солнечные космические лучи
(экспериментальные данные)





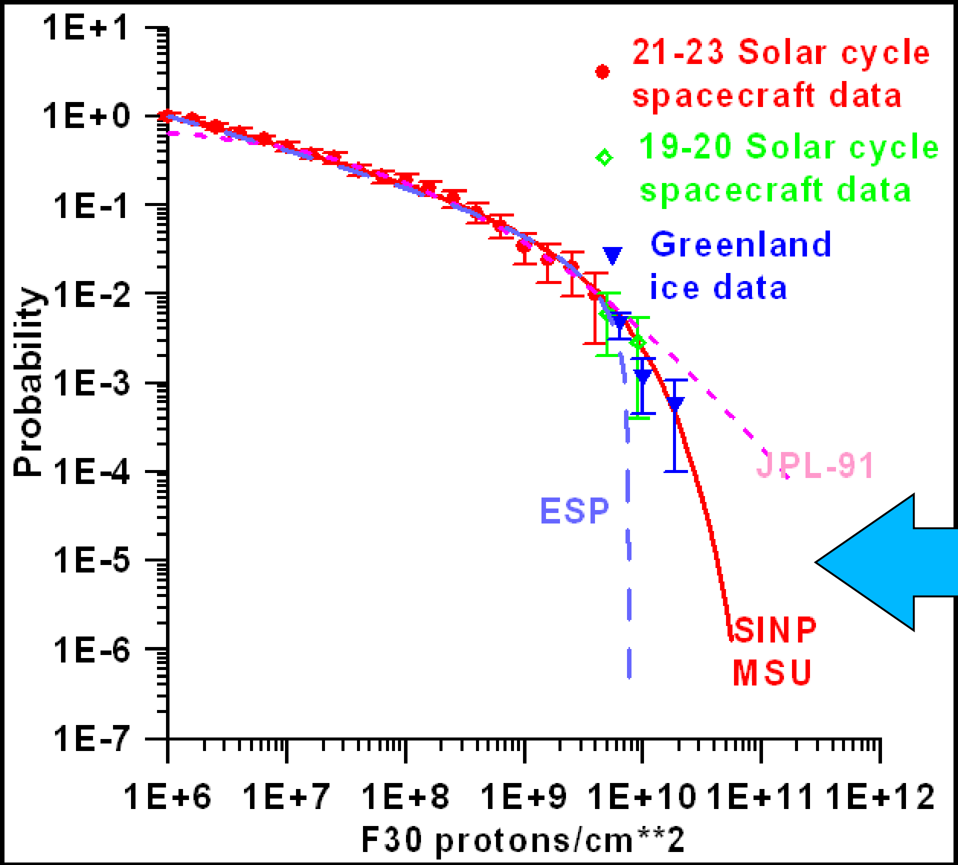
Tylka et al., 2010 Fall AGU Meeting
(San Francisco, 13-18 December)

SEP and Solar Activity



SEP's energy spectra

- Distribution function of fluence of protons with E more than 30 MeV

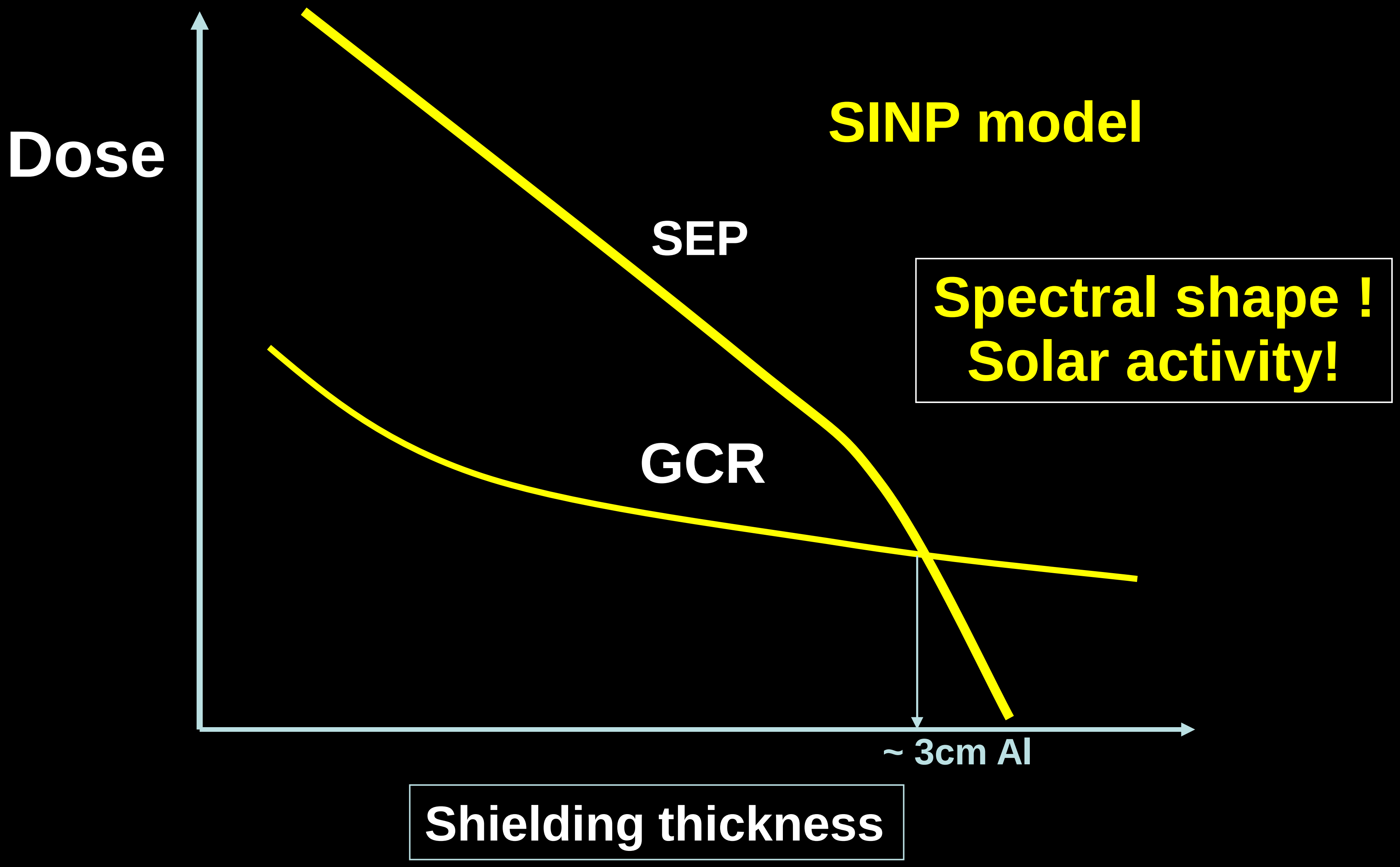


The key point!

RADIATION EFFECT FROM AUGUST 1972 SOLAR FLARE

GCR&SEP συνεργία (synergy): importance for long-duration space flights

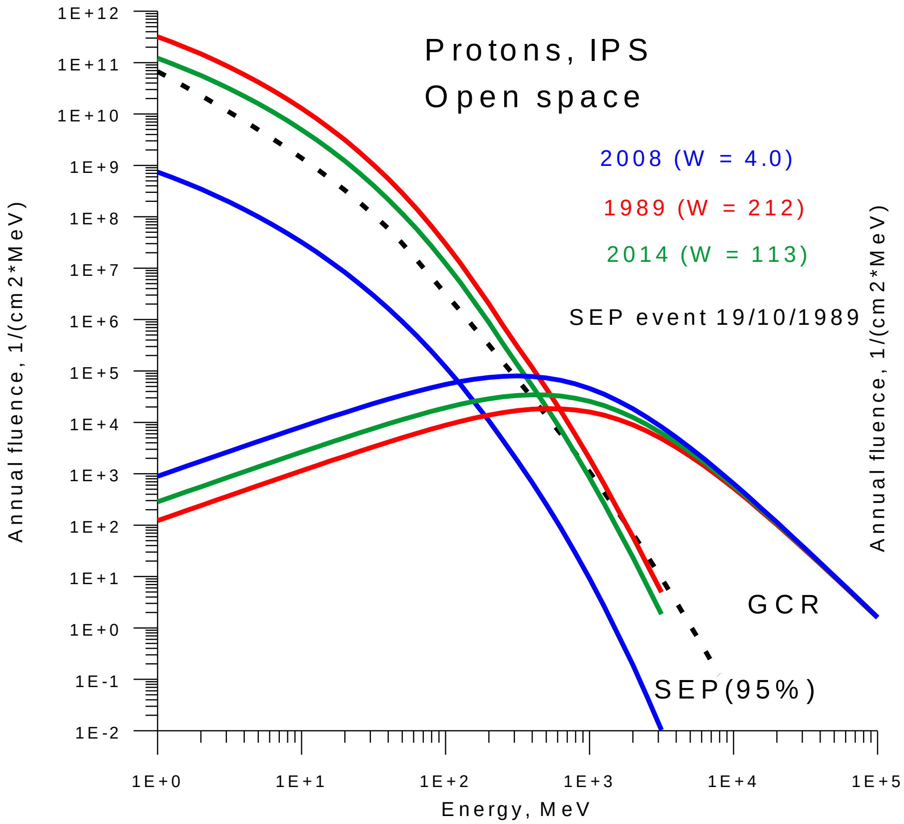
Radiation Doses for the Long- Time Interplanetary Flights

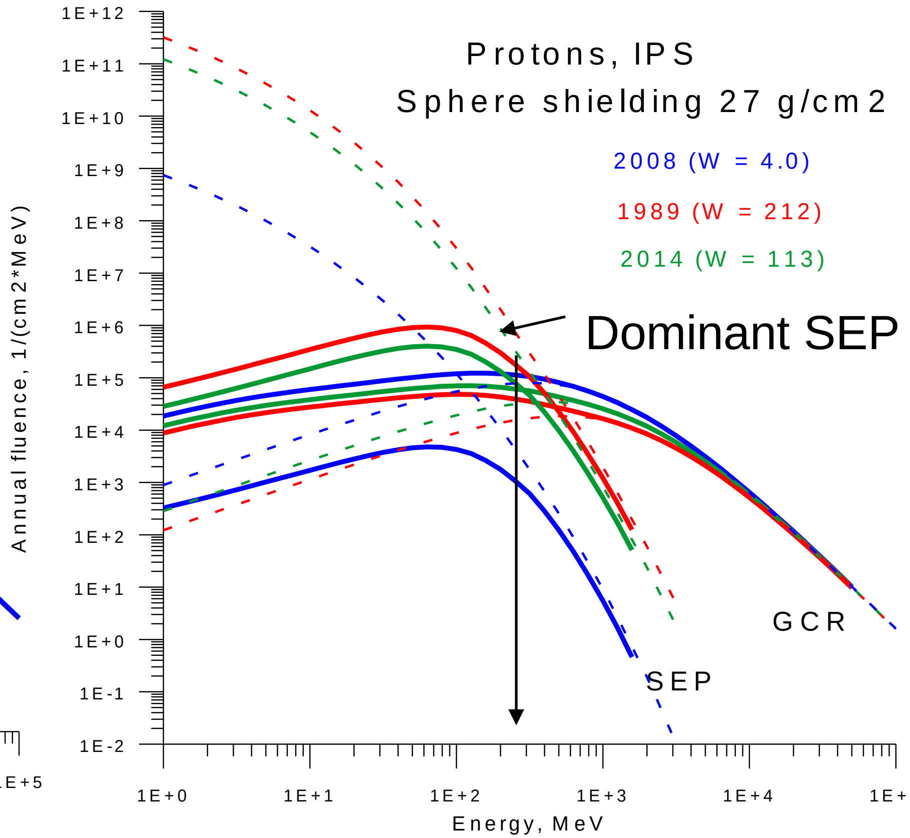


SEP/GCR in open space and under shielding

Радиационные условия в МПП

Сравнение модельных энергетических спектров ГКЛ и СКЛ





SEP/GCR absorbed doses

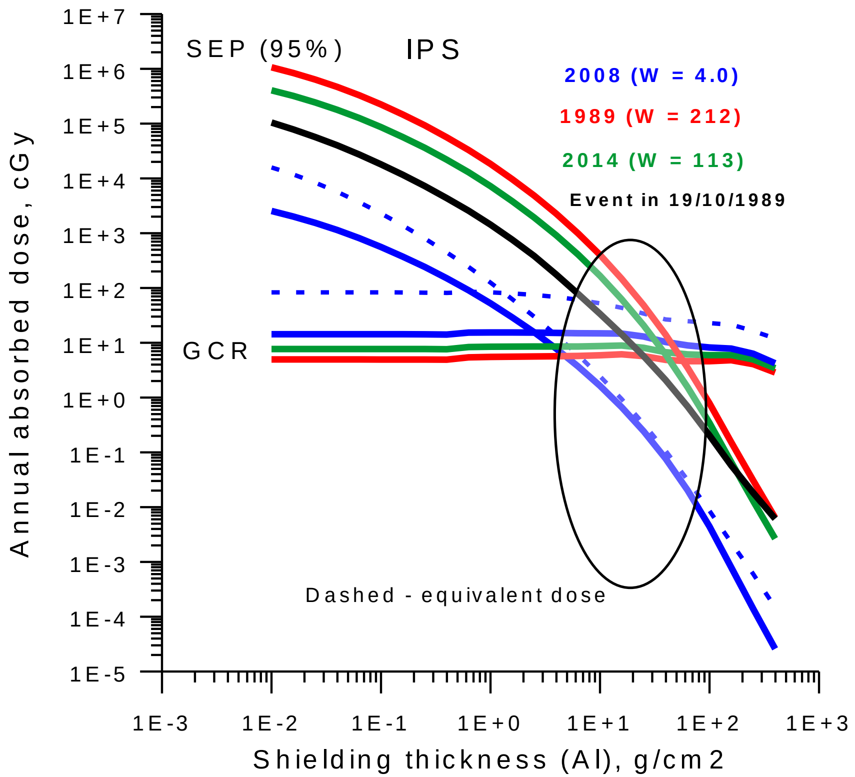
Характеристики радиационного воздействия

Поглощенная доза

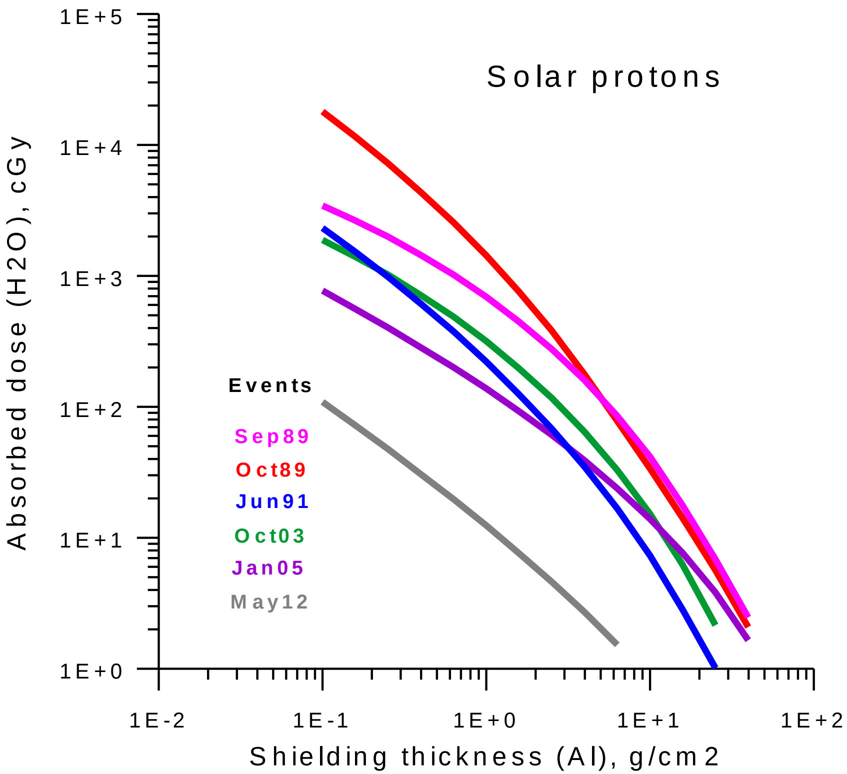
(сравнение вклада от потоков ГКЛ и СКЛ)

$$D = \sum_i \int_{E_{min}}^{E_{max}} L_i(E) \cdot \Phi_i(E)\, dE = \int_{L_{min}}^{L_{max}} L \cdot F(L)\, dL$$

Models

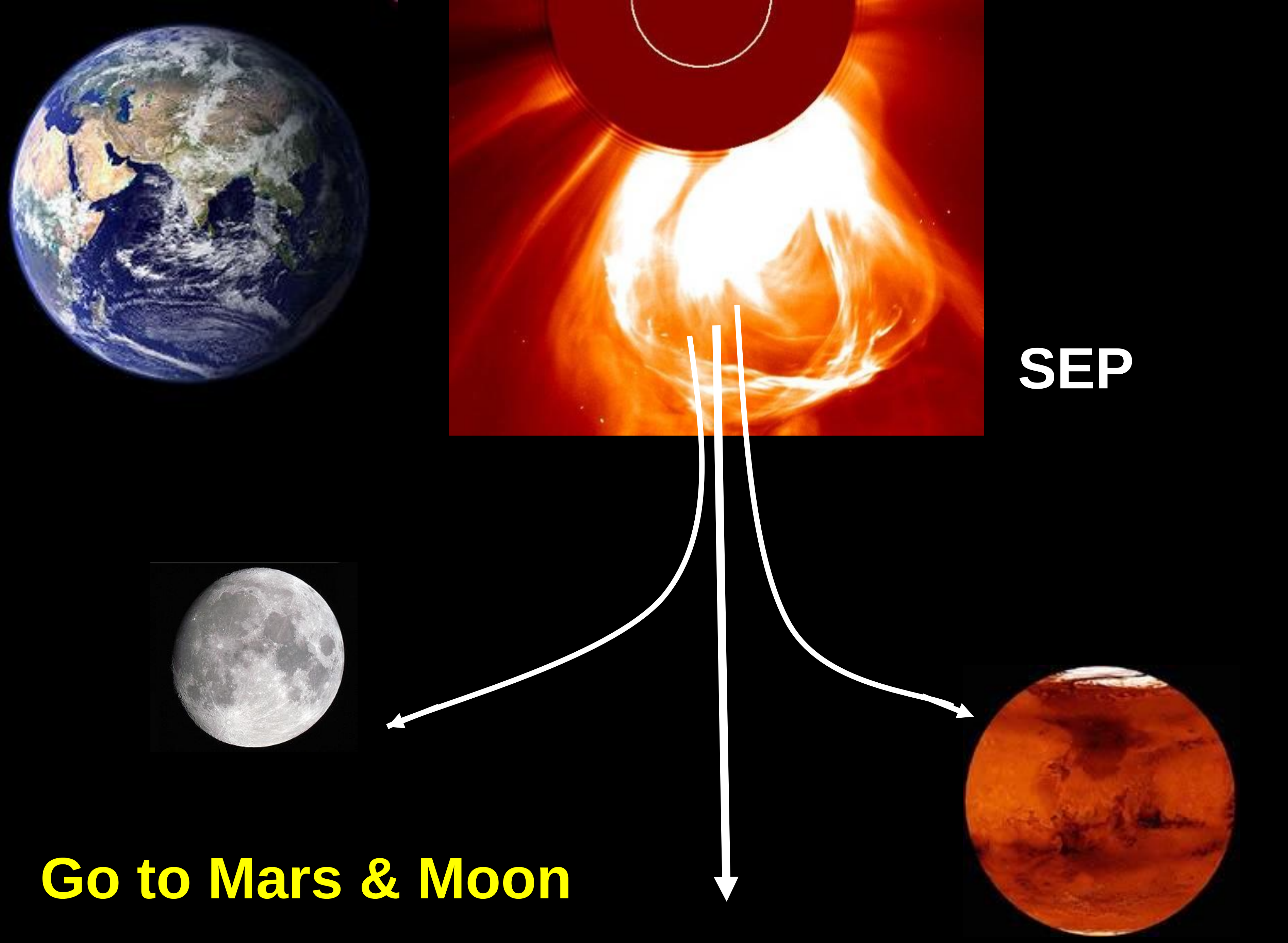


Selected events

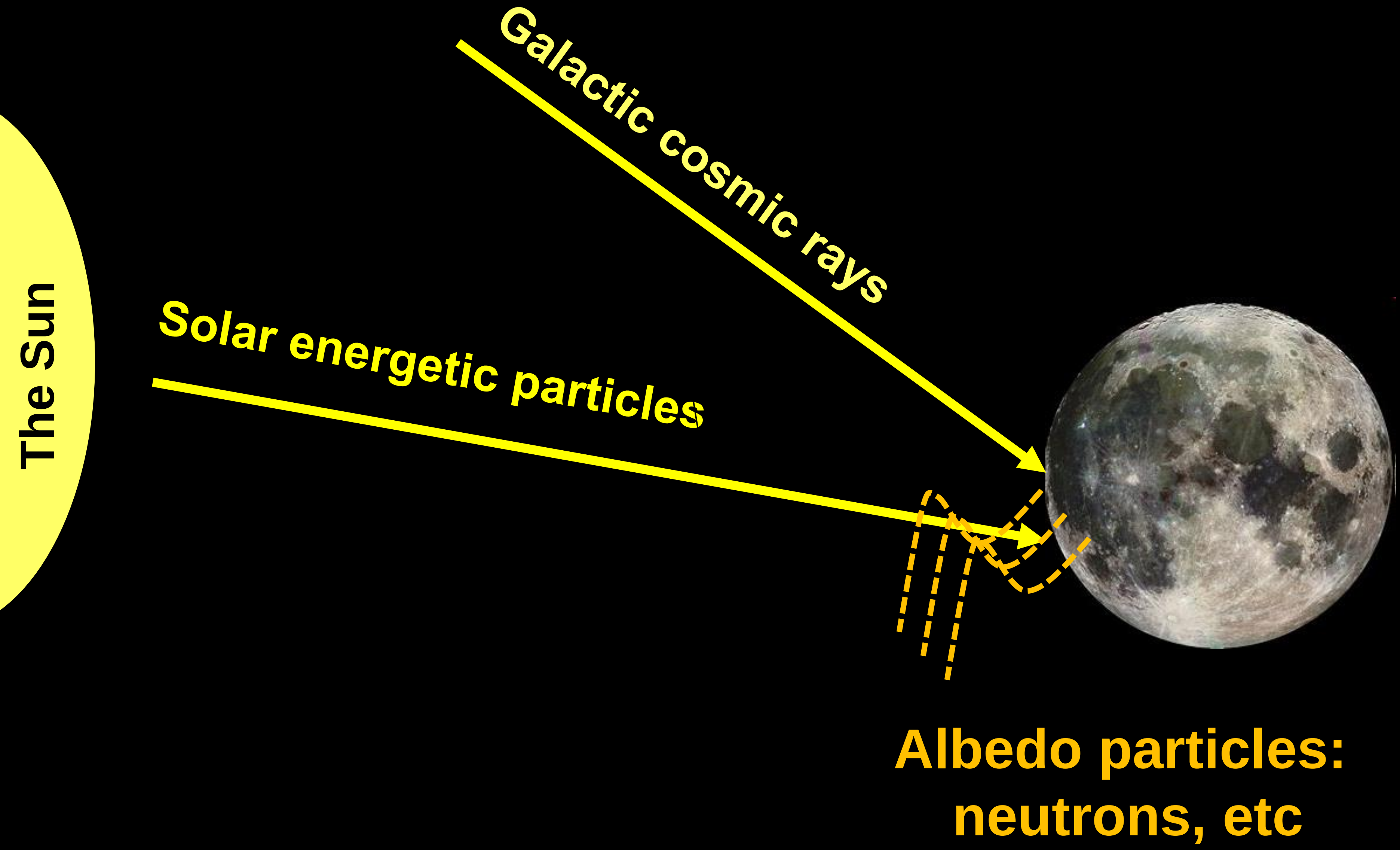


SEP & GCR doses

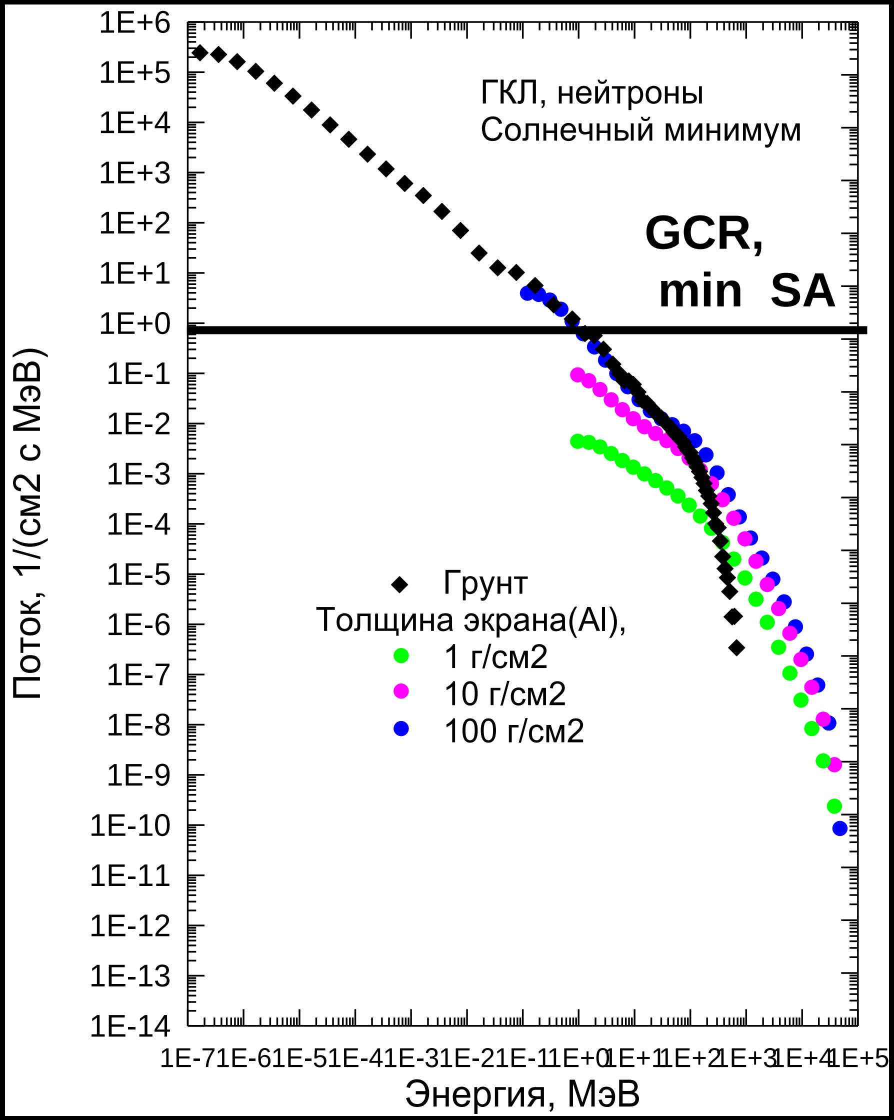
- The value of SEP annual doses expected by the particles of the SEP (probability = 1%), exceed the same values for GCR particles in the whole considered range of the thickness of the shielding during *high solar activity*, and for the thickness is less than 10 g/cm2 during *solar activity minimum.*

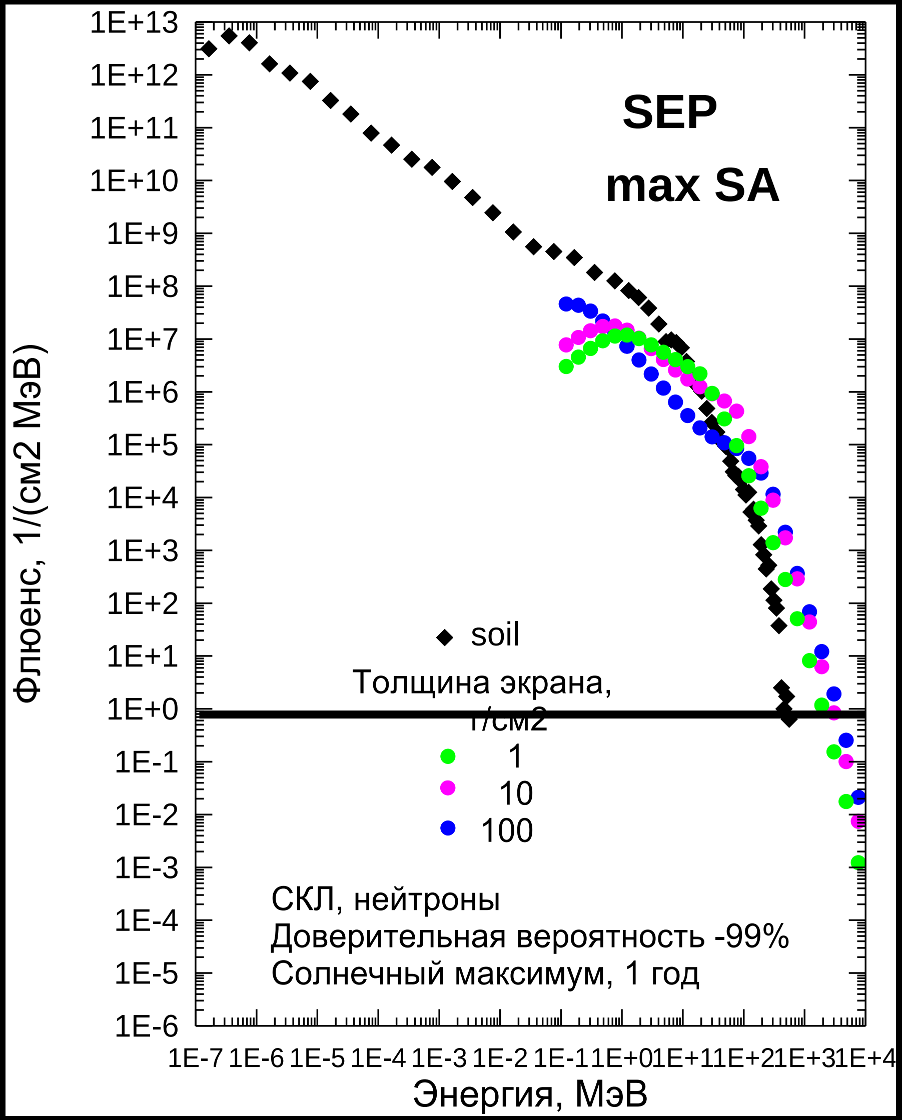

SEP
Go to Mars & Moon

The Moon radiation environment



Neutrons generation in regolith (under the shielding)

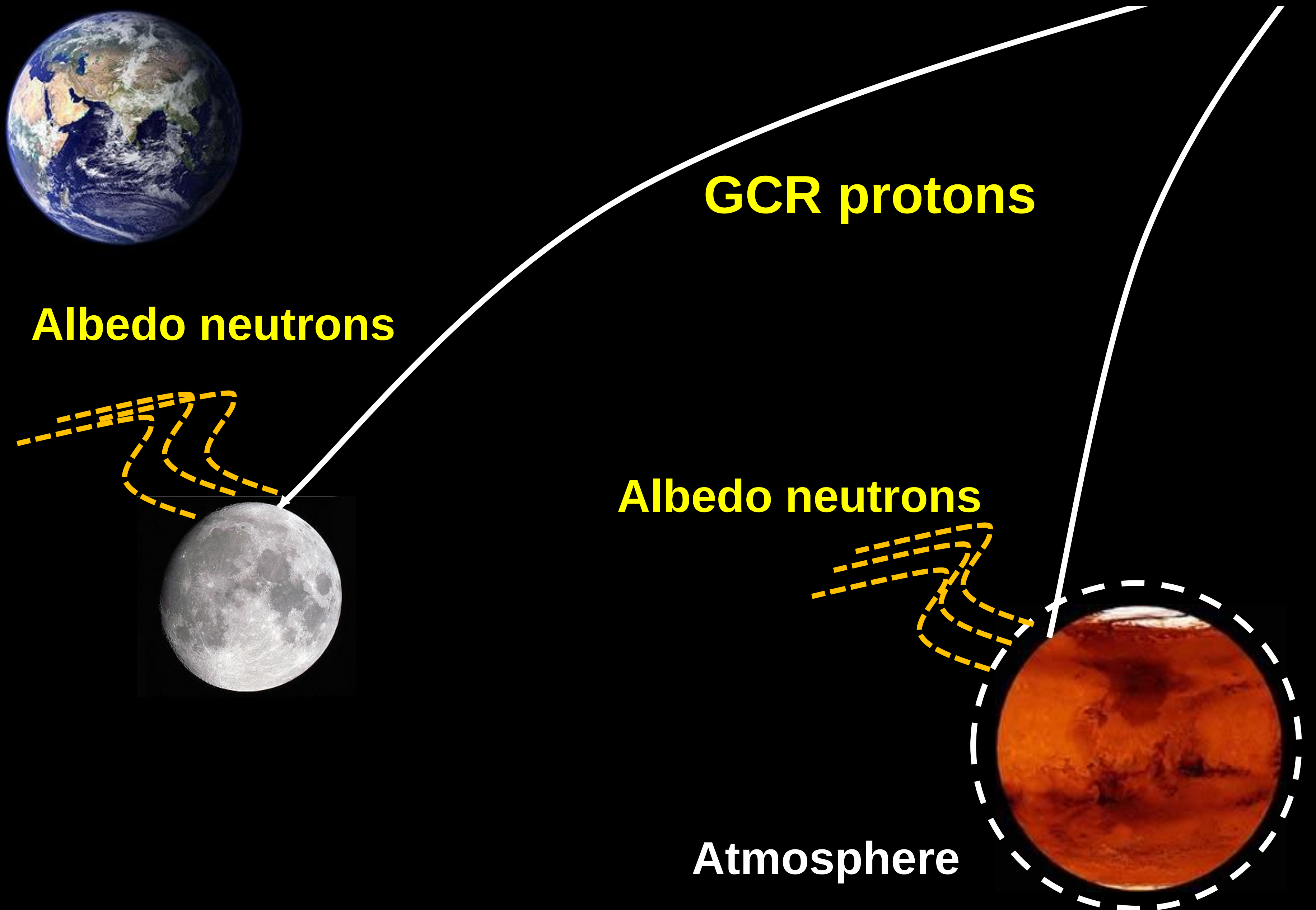




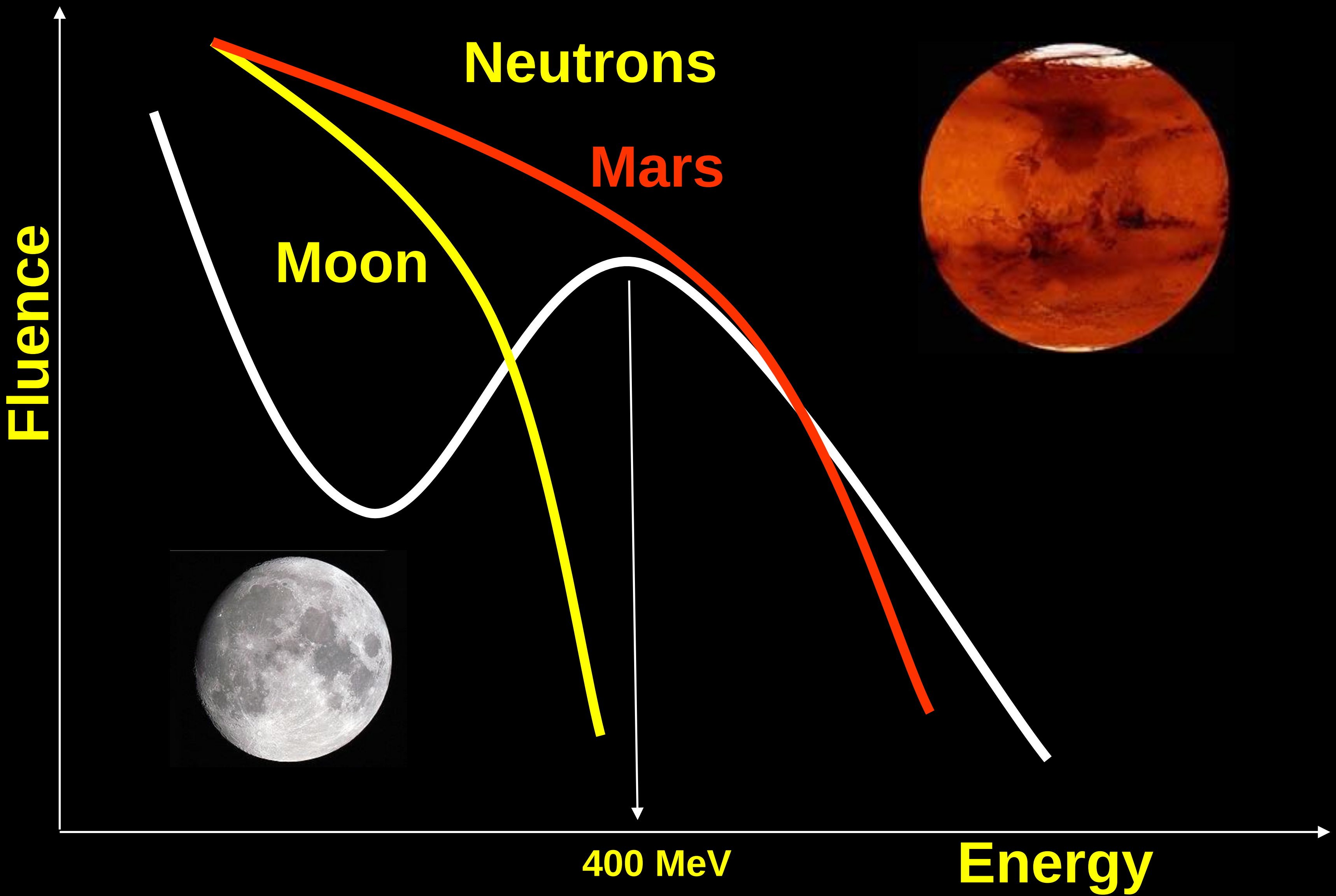
Medium-tissue equivalent dose (H) of GCR, SEP and neutrons

- The contribution of neutrons to the H value is much less than the contribution of charged particles at the thickness of the aluminum screen less than ~30 g / cm2 and is comparable at a greater thickness of the shielding;

The Mars& Moon radiation environment

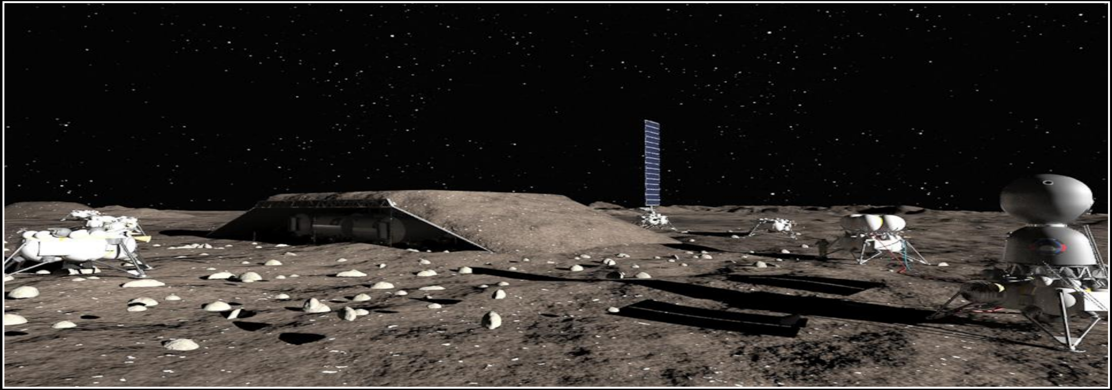


Neutrons of Mars and Moon



Radiation risk for long-duration habitation missions

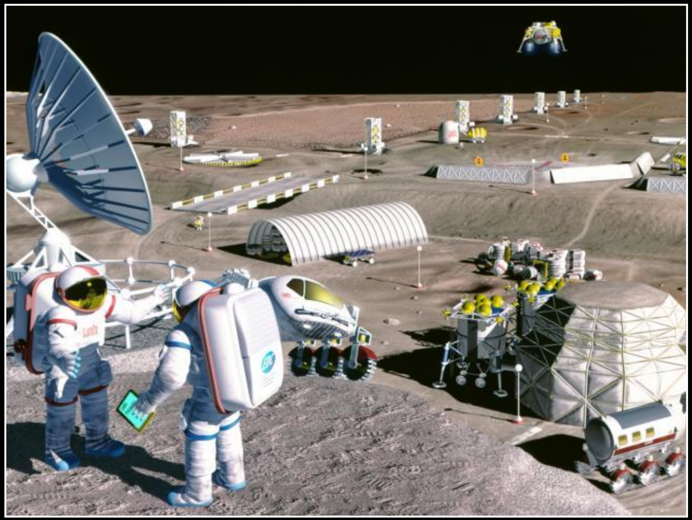
The Moon habituation orbital



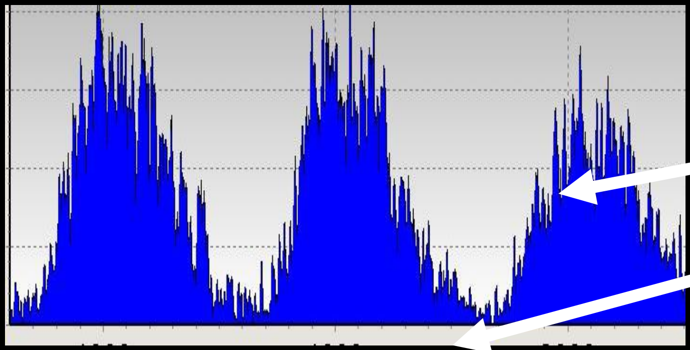
The Moon habituation facility

The Mars habituation facility

The Moon base



MSU model for 10 г/см-2

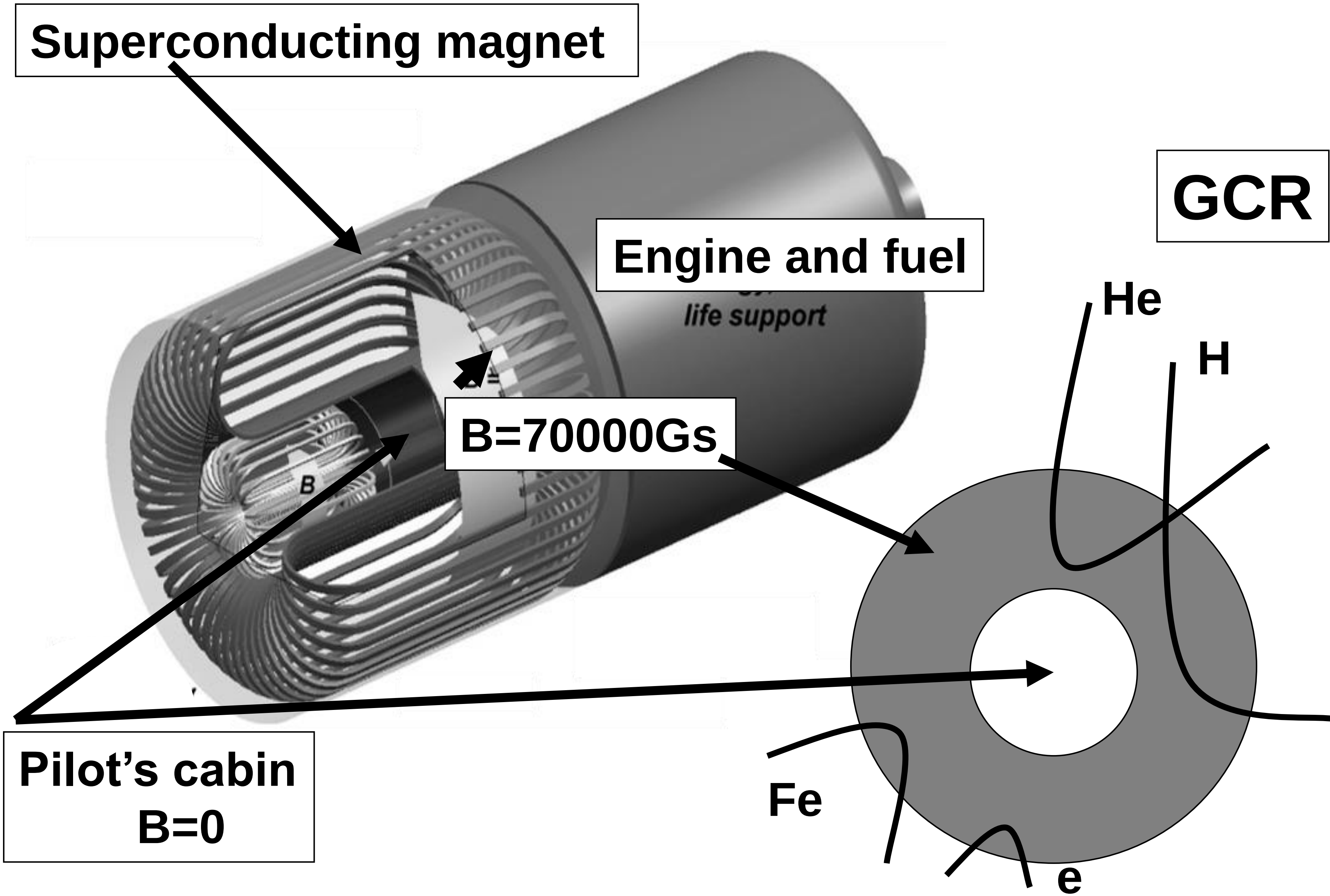


Up to 1,5 month

Up to 1 year

At solar minimum (Y2028-2030), lunar missions to 90 days allowed; for solar max – 210 days

Magnetic shielding for spacecraft to Mars



The main conclusion:

- *Time of mission – the effective shielding against radiation.*

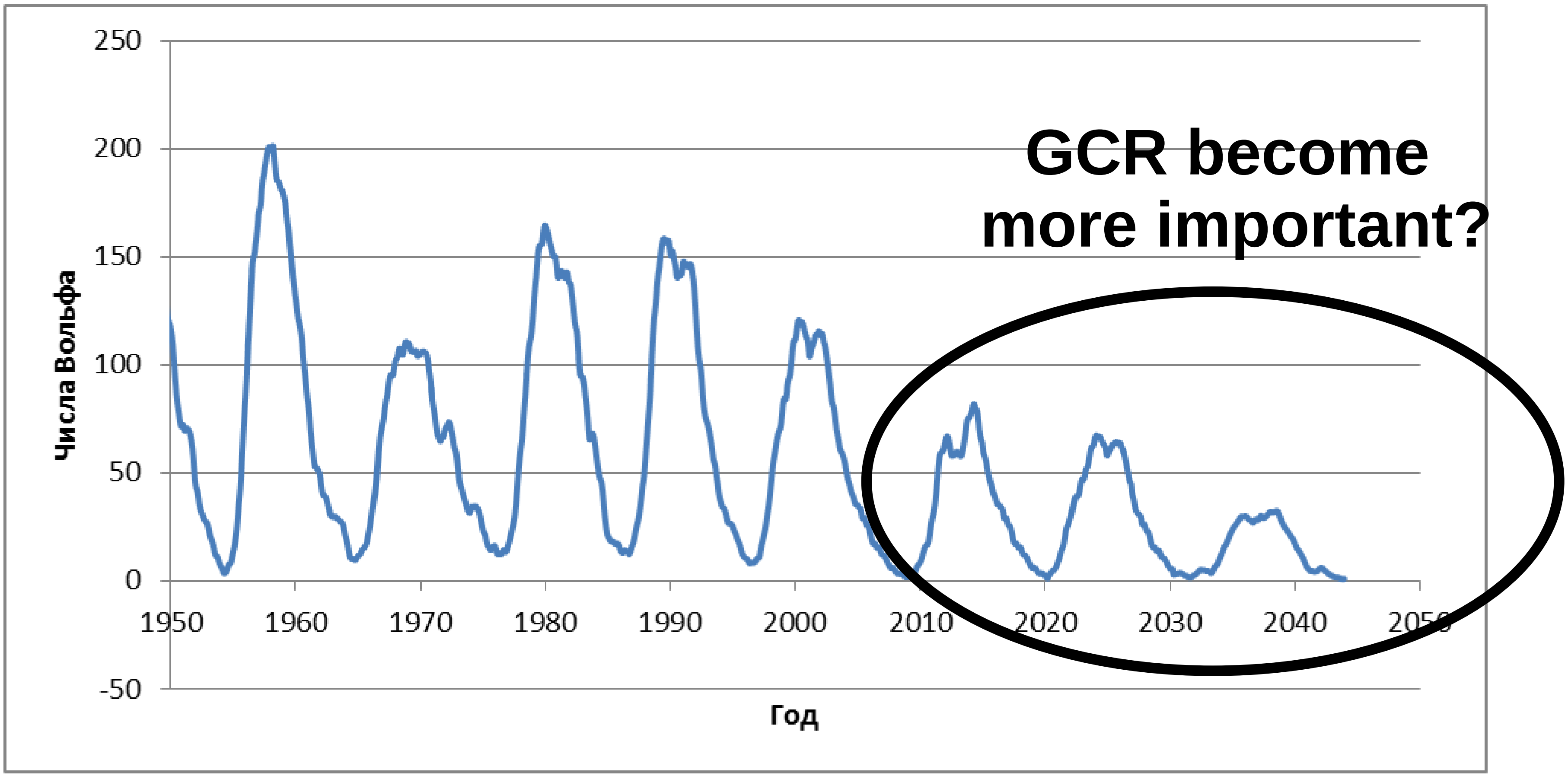
- The values of radiation doses of the secondary neutron component of cosmic radiation are large enough in comparison with the doses from the charged component and they cannot be neglected in the assessment of the radiation risk of space missions.

Thank you

BACK UP

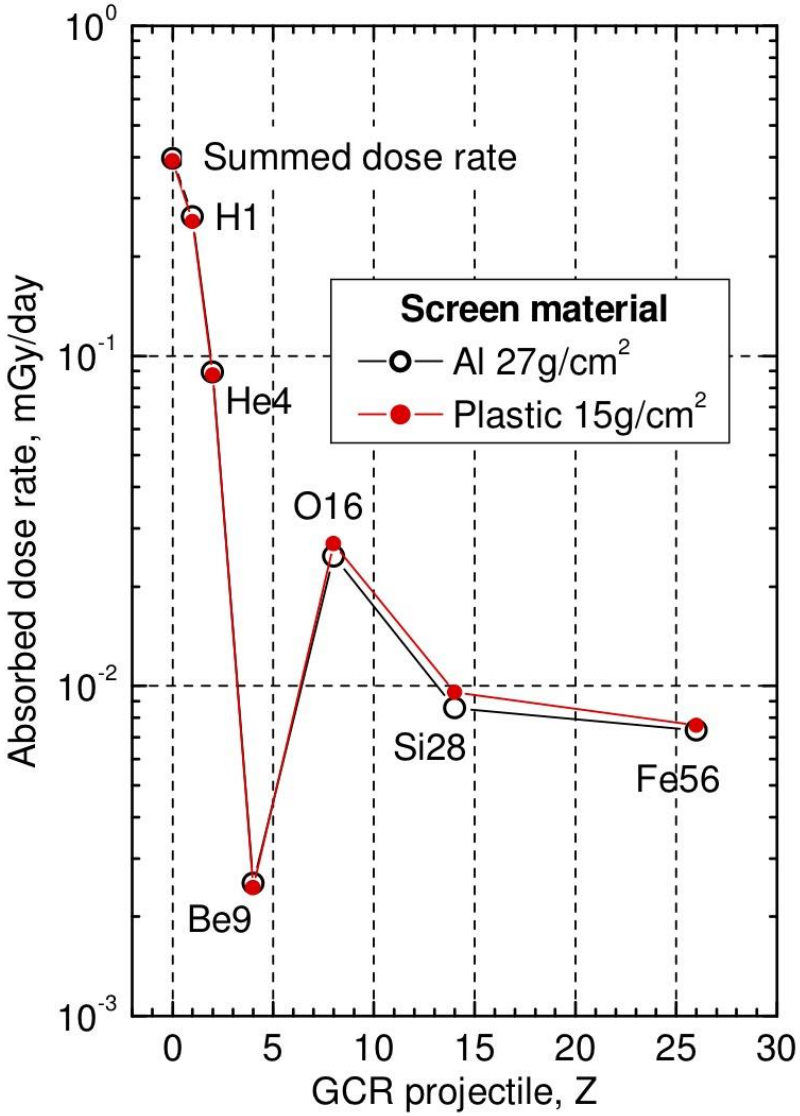
SOLAR ACTIVITY

- **The key** parameter for every model of radiation environment!



GCR become more important?
250
200
150
100
50
0
-50
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Числа Вольфа
Год

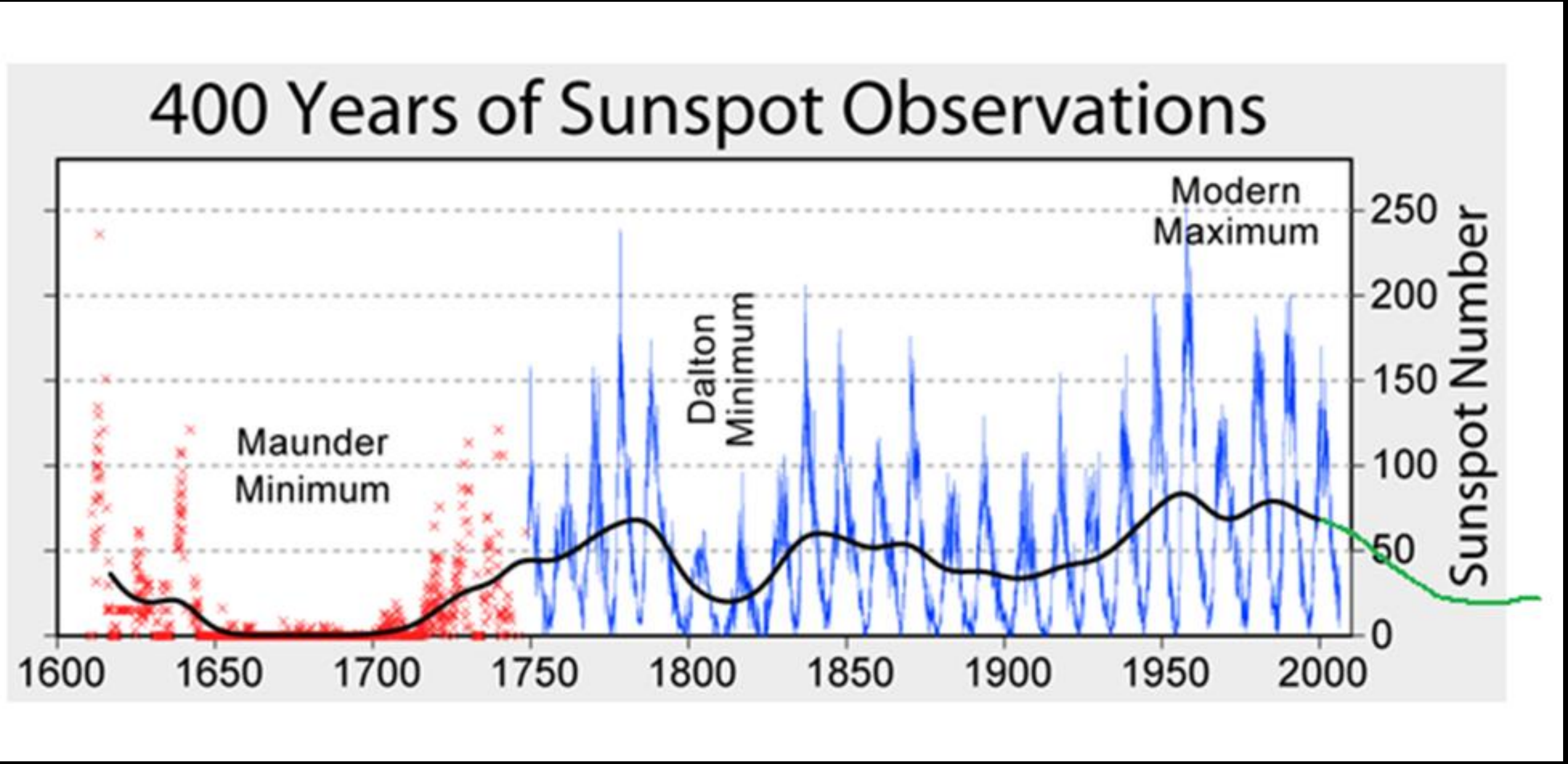
Absorbed dose rate in water sphere at GCR irradiation. Contributions of all projectiles p, He4, Be9, O16, Si28 and Fe56 are summed taking into account the weight of each projectile. **Plastic thickness 15 g/cm².**



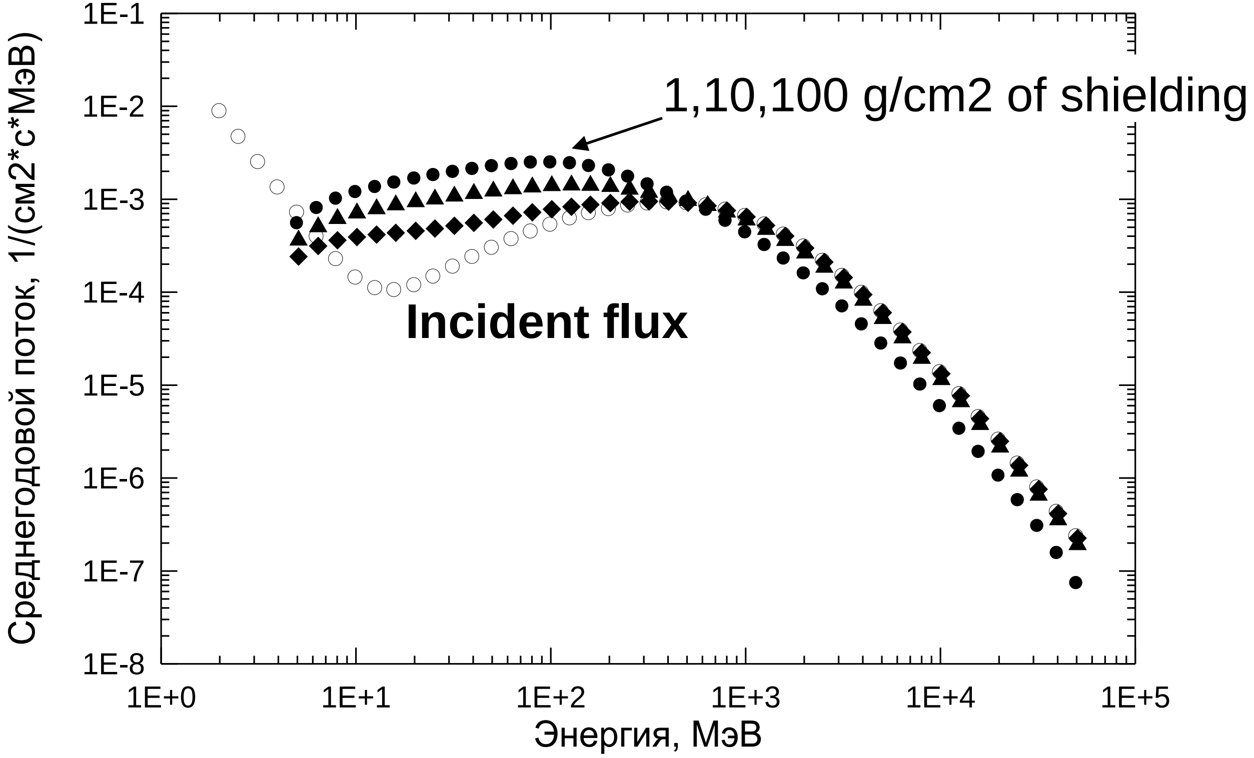
Dose rate from all GCR projectiles			
Screen material		Al 27g/cm²	Plastic 15g/cm²
GCR proj.	Weight	mGy/day	mGy/day
H1	1	2.64E-01	2.55E-01
He4	1	8.92E-02	8.74E-02
Be9	7.0	2.52E-03	2.45E-03
O16	2.16	2.47E-02	2.69E-02
Si28	2.84	8.58E-03	9.57E-03
Fe56	1.77	7.33E-03	7.58E-03
Summed dose rate		3.96E-01	3.89E-01

Contribution of p, d, α, π to dose rate for GCR H1		
Screen material	Al 27g/cm2	Plastic 15g/cm2
Contribution from:	mGy/day	mGy/day
Total	2.64E-01	2.55E-01
p	2.22E-01	2.19E-01
d	5.84E-03	4.71E-03
α	2.58E-03	2.26E-03
π+/-	2.60E-02	2.22E-02

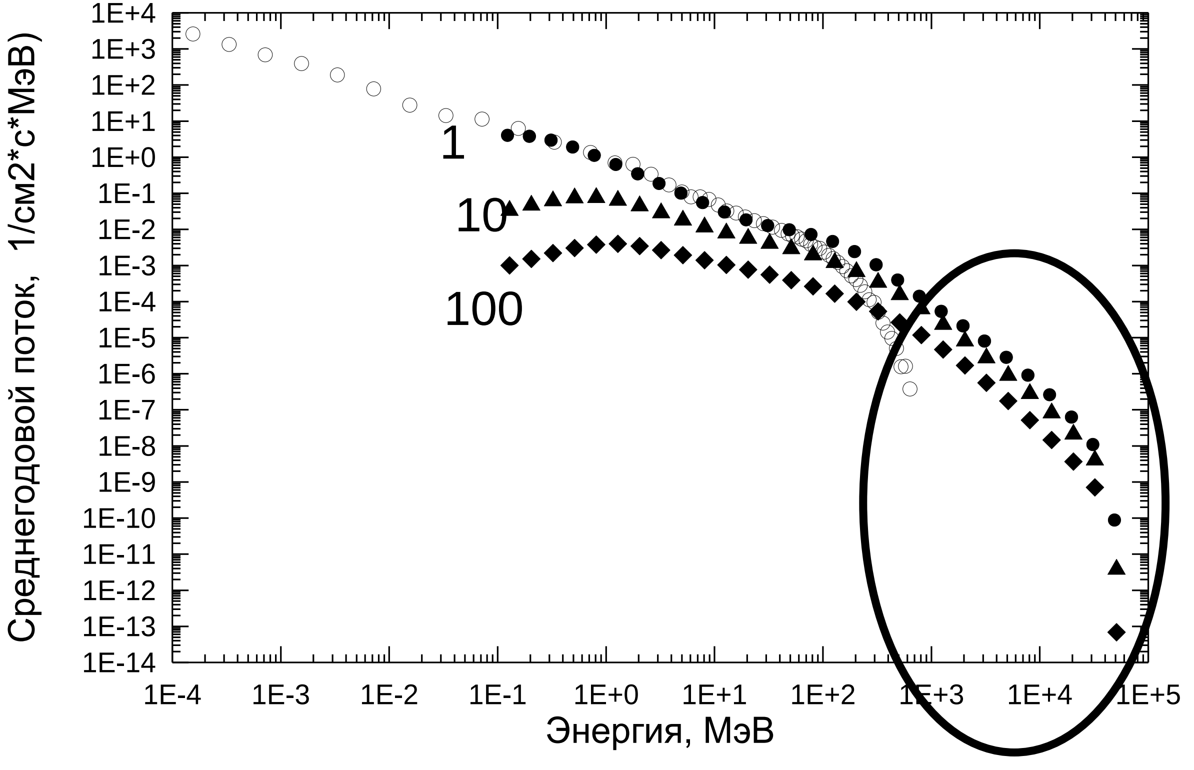
Importance of Solar Cycles Predictions



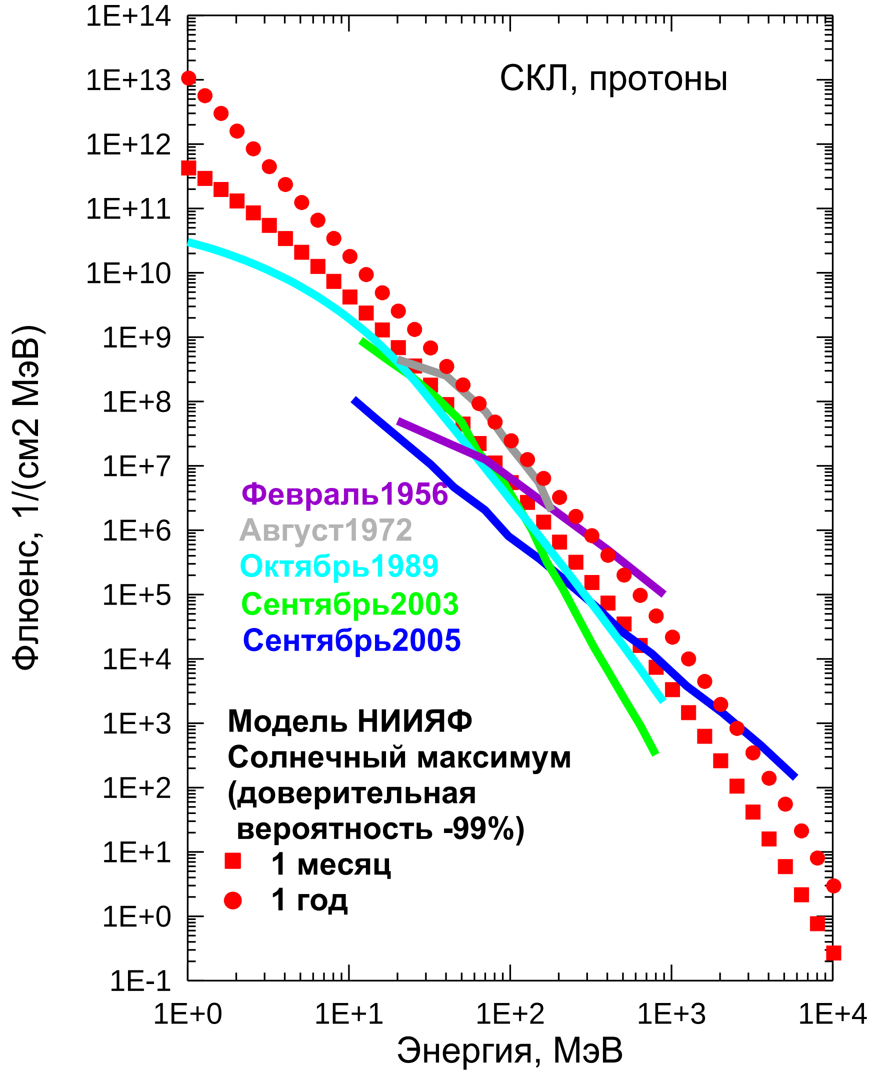
GCR spectra under the shielding

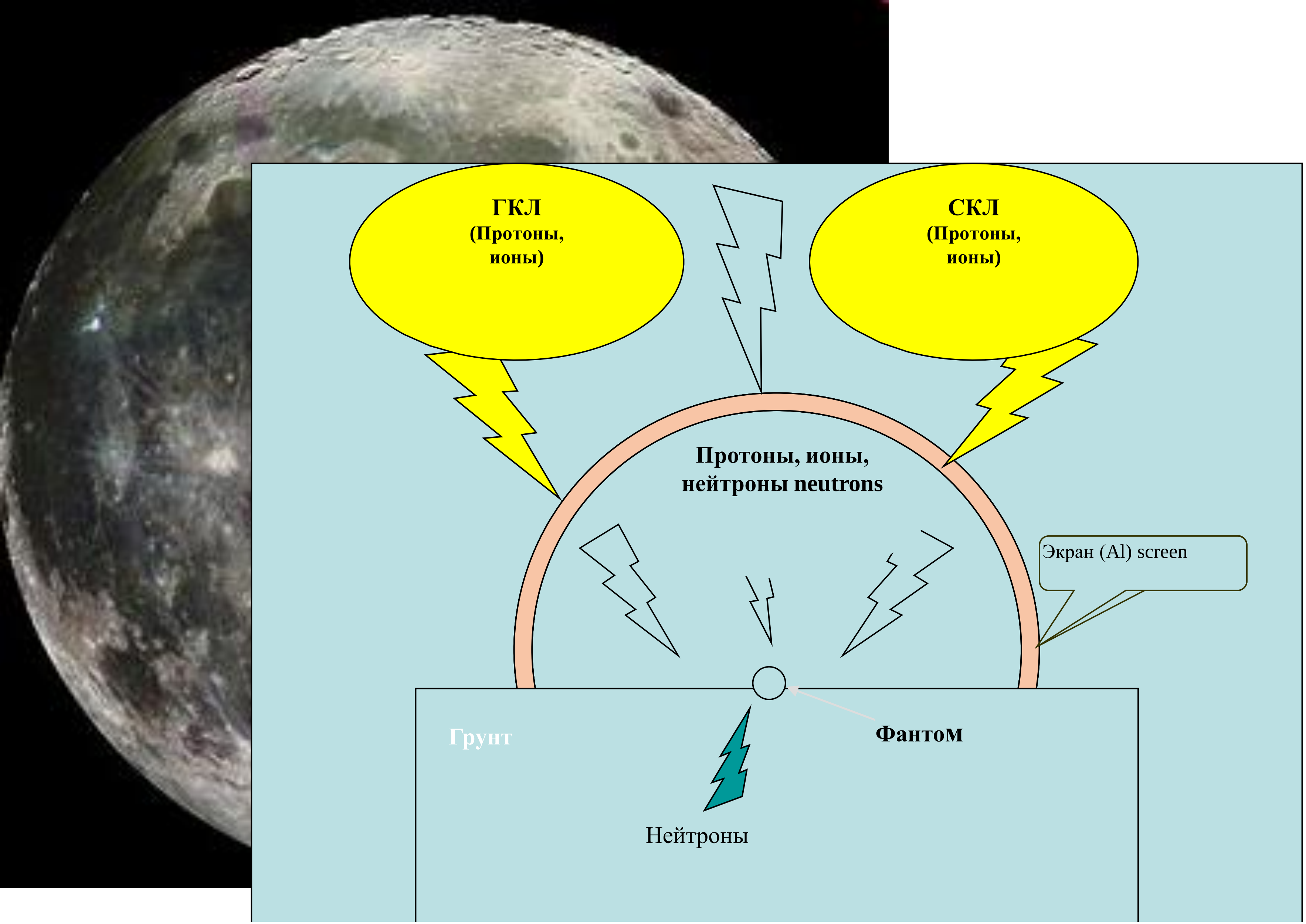


Albedo neutrons spectra under the shielding



Calculated and experimental fluences of SEP protons





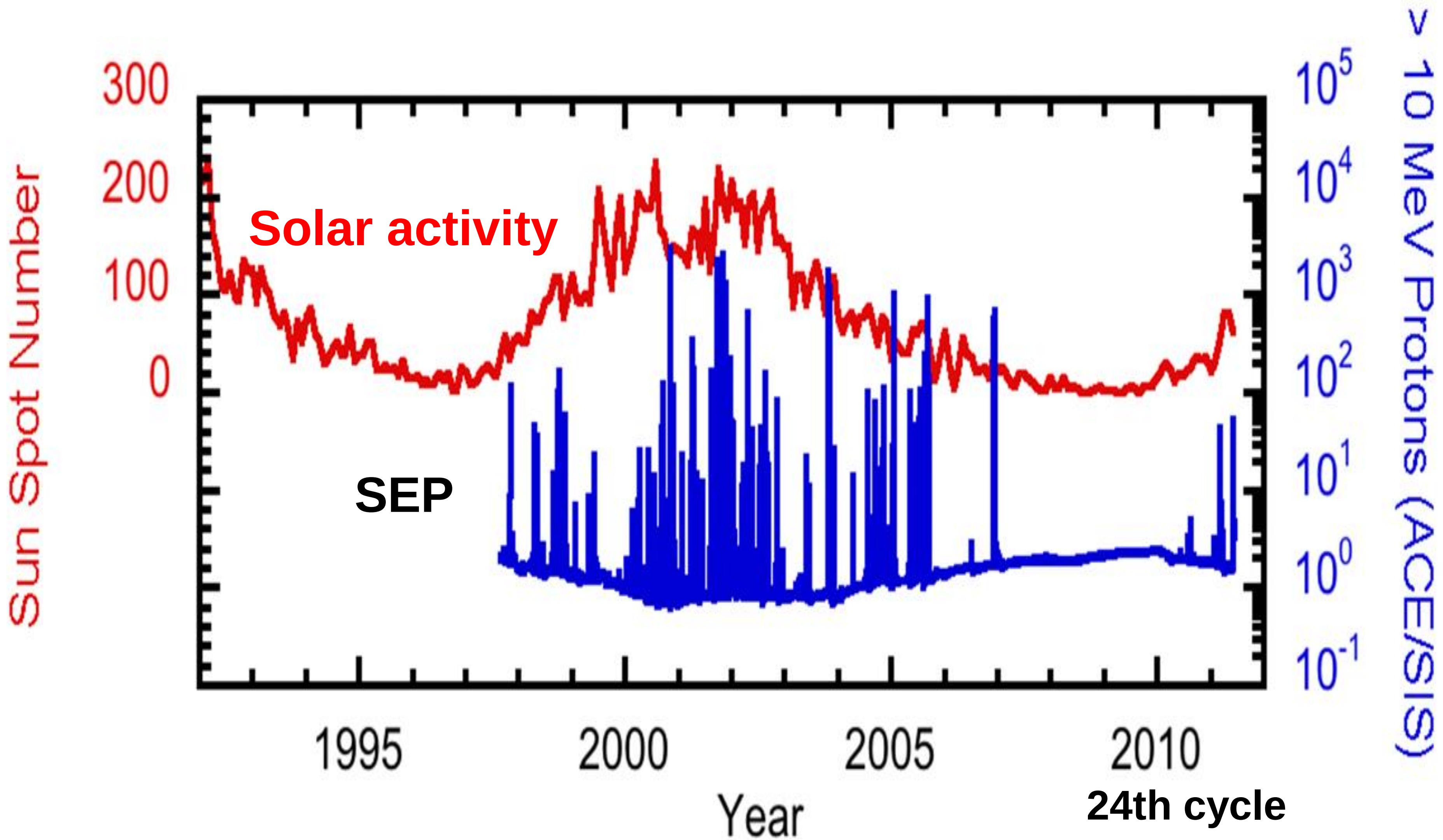
Оценка радиационного риска для человека на Луне выполнена для разной продолжительности лунных экспедиций и с учетом нахождения на поверхности Луны защитного экрана.

Среднетканевая эквивалентная доза (Н) *от ГКЛ, СКЛ и нейтронов*

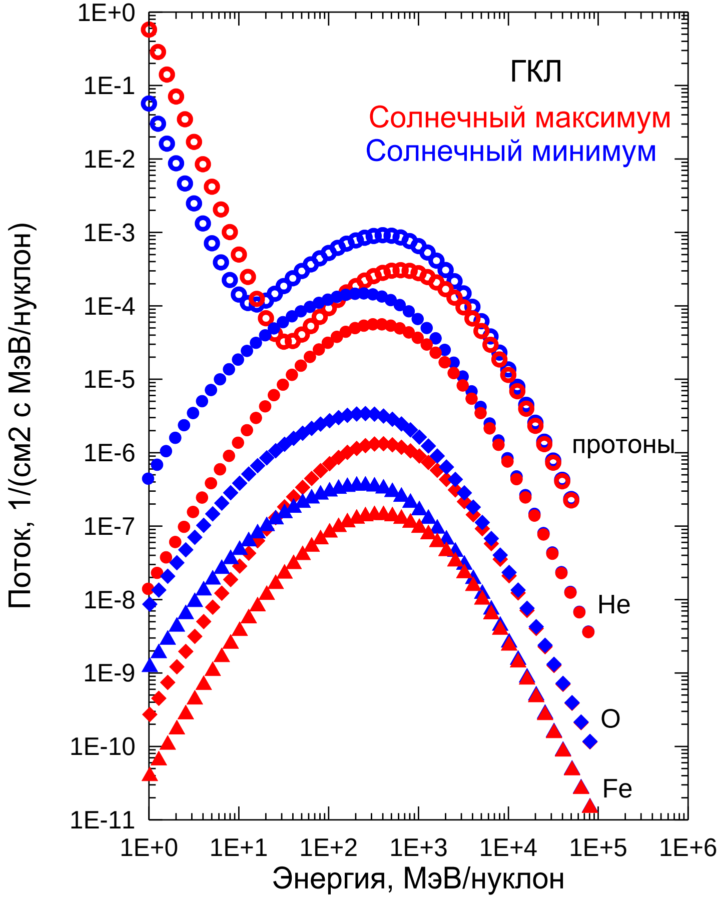
- Вклад нейтронов в значение *H* значительно меньше вклада заряженных частиц при толщине алюминиевого экрана менее ~30 г/см2 и сравним при большей толщине экрана;
- значение $H_{СКЛ}$, ожидаемое за год от частиц СКЛ (r = 1%), выше значения $H_{ГКЛ}$, создаваемое частицами ГКЛ во всем диапазоне рассмотренных толщин экрана во время максимума солнечной активности, и при толщине экрана менее 10 г/см2 - во время минимума солнечной активности.

Н.В.Кузнецов и др., в печати

SEP and Solar Activity



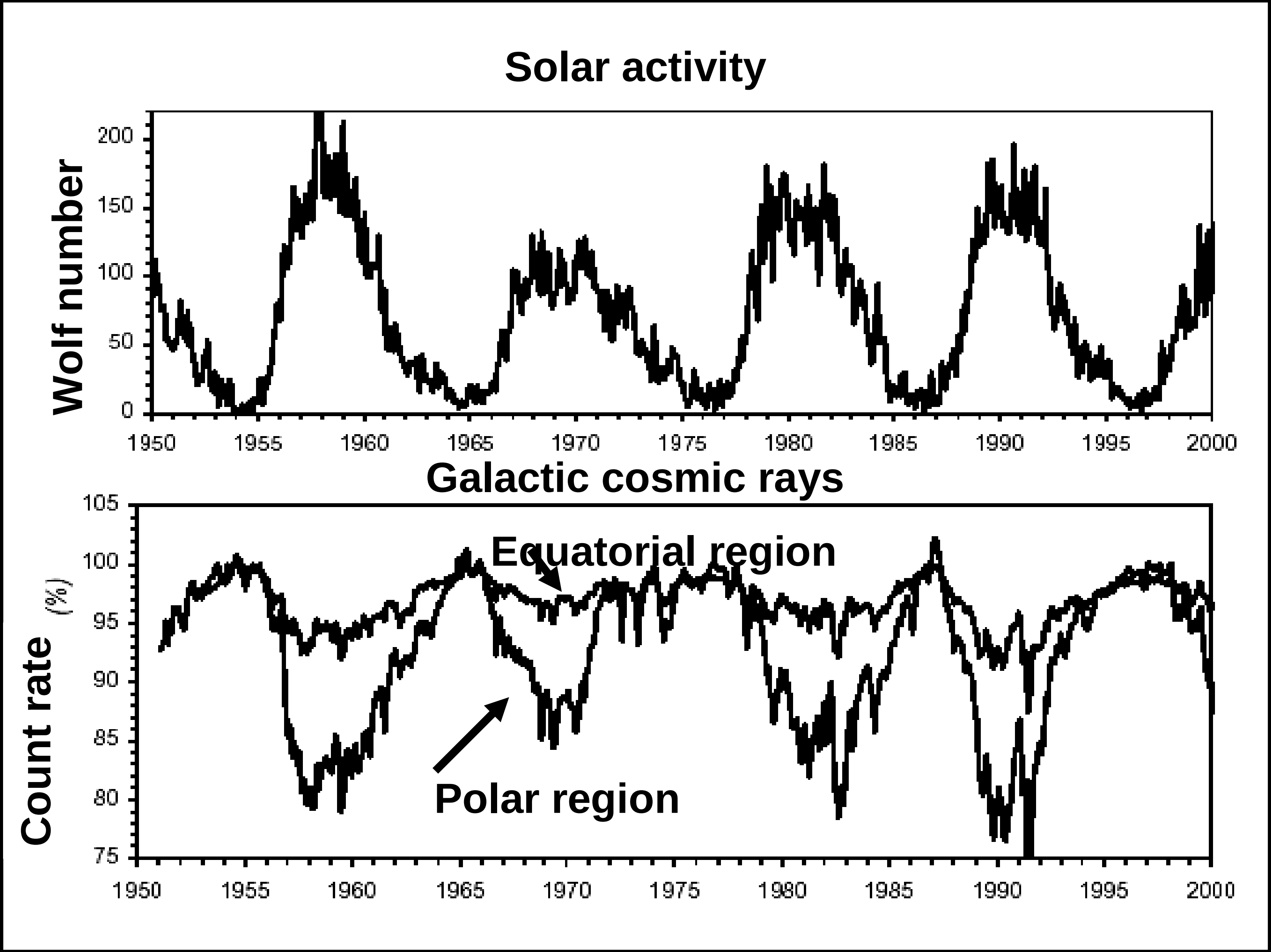
GCR/ SINP MSU model



International standard since…. ~ 10 years

Модели устанавливают изотропные потоки частиц в межпланетном пространстве в районе орбиты Земли (1 а.е.). Они учитывают зависимость потоков частиц от солнечной активности, которая задается среднемесячными числами Вольфа W.

Galactic Cosmic Rays Modulation



SEP's Largest Events (GLE)