Корпускулярная радиация в космосе

М.И.Панасюк

НИИ ядерной физики им. Д.В.Скобельцына

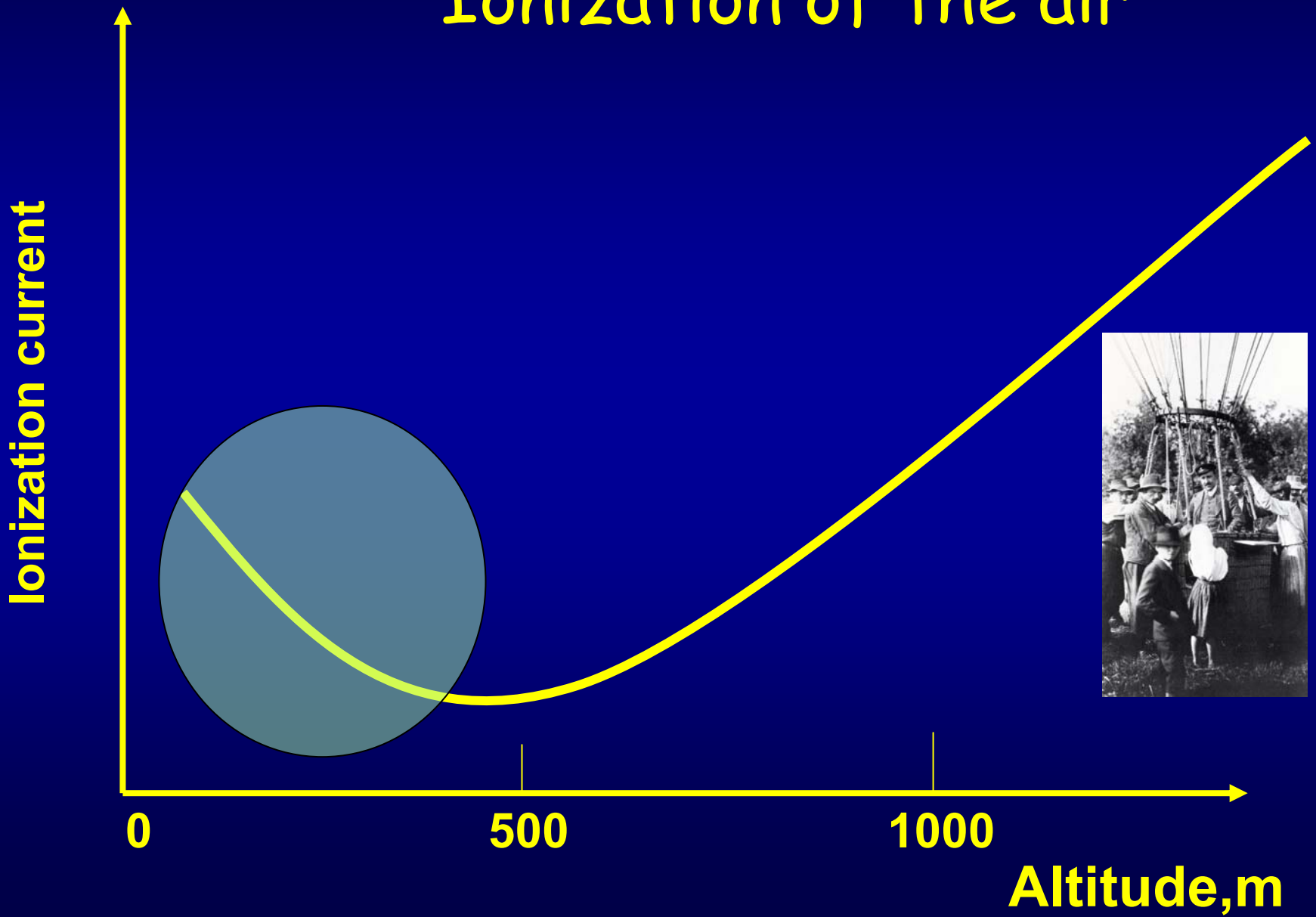
МГУ им. М.В.Ломоносова

«Концентрированные потоки энергии»
21.11. 2005

Cosmic radiation

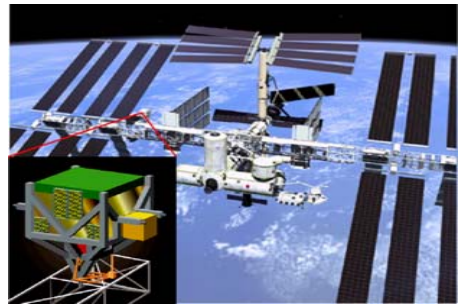
- Since 1912…..

Ionization of the air



Primary particle

Space



50 km

e/γ

μ

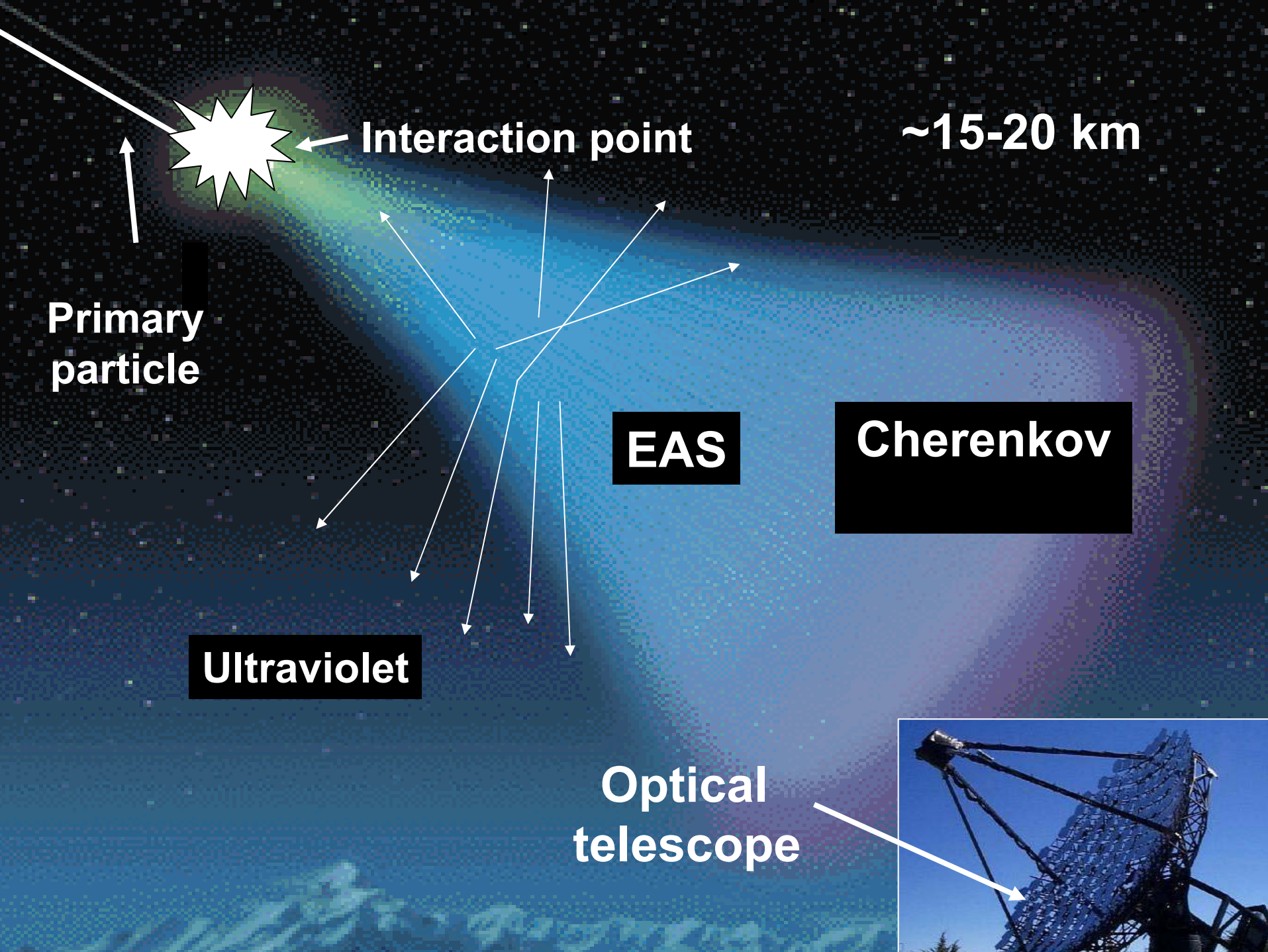
h

Atmosphere

0 km

Onground

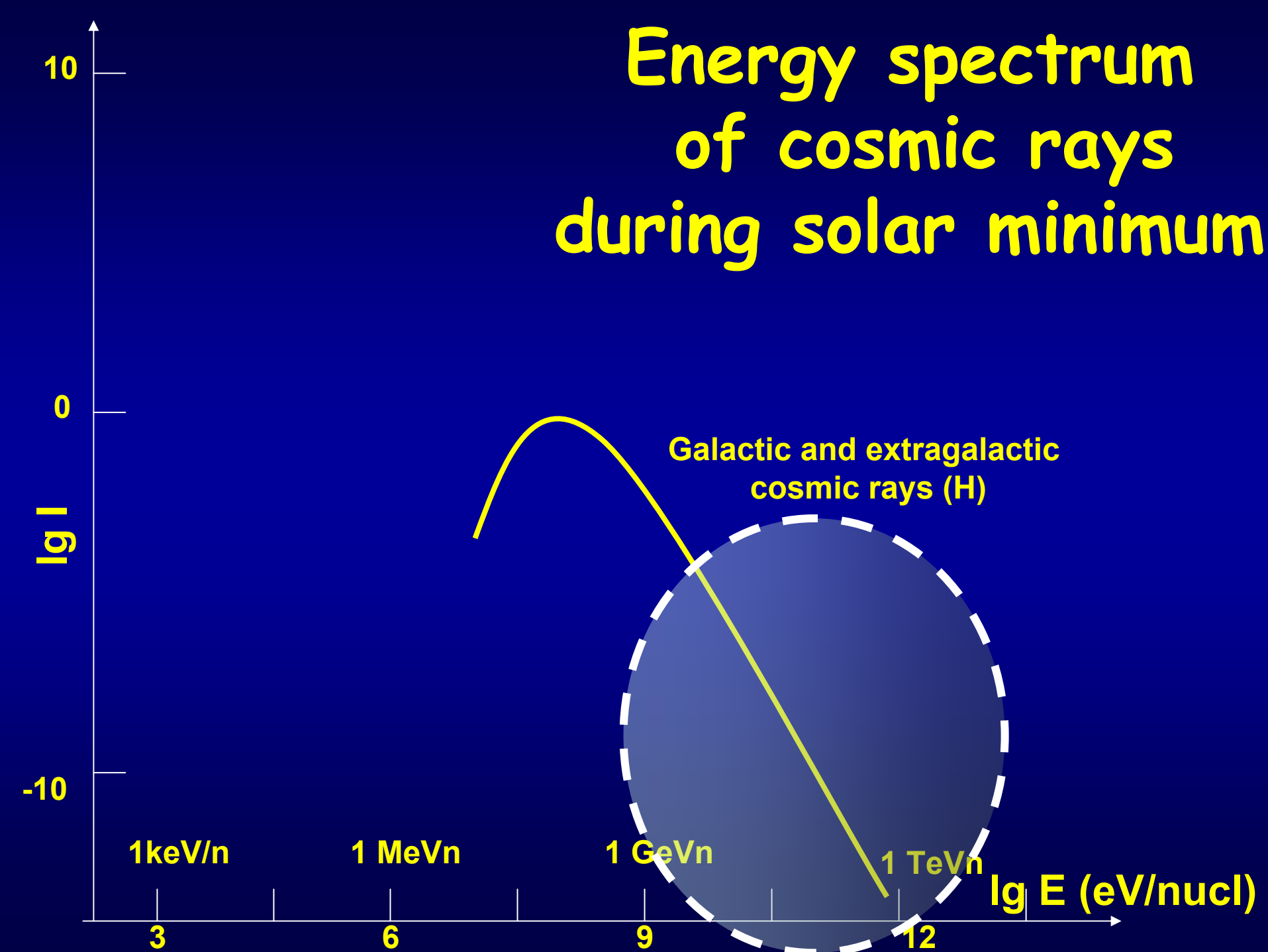
Underground


Interaction point
~15-20 km
Primary particle
EAS
Cherenkov
Ultraviolet
Optical telescope

The basic problems of cosmic radiation study:

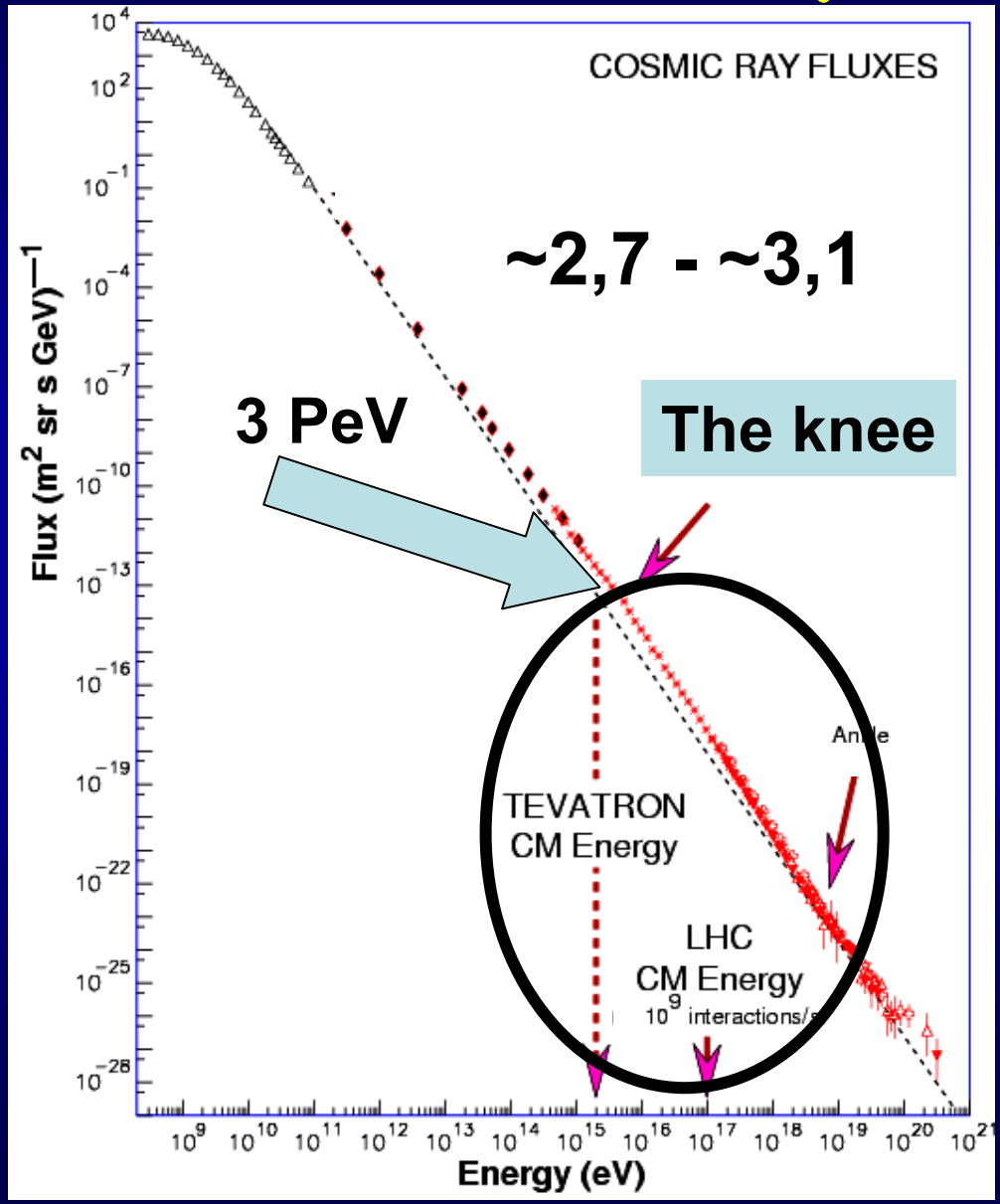
- ***Sources;***
- ***Transport and acceleration processes***

Energy spectrum of cosmic rays during solar minimum

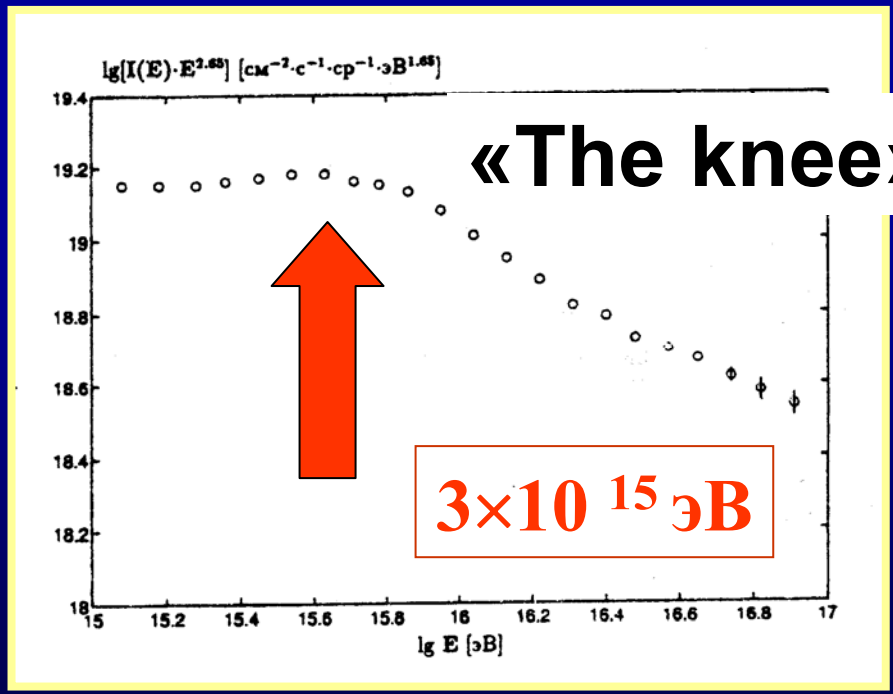


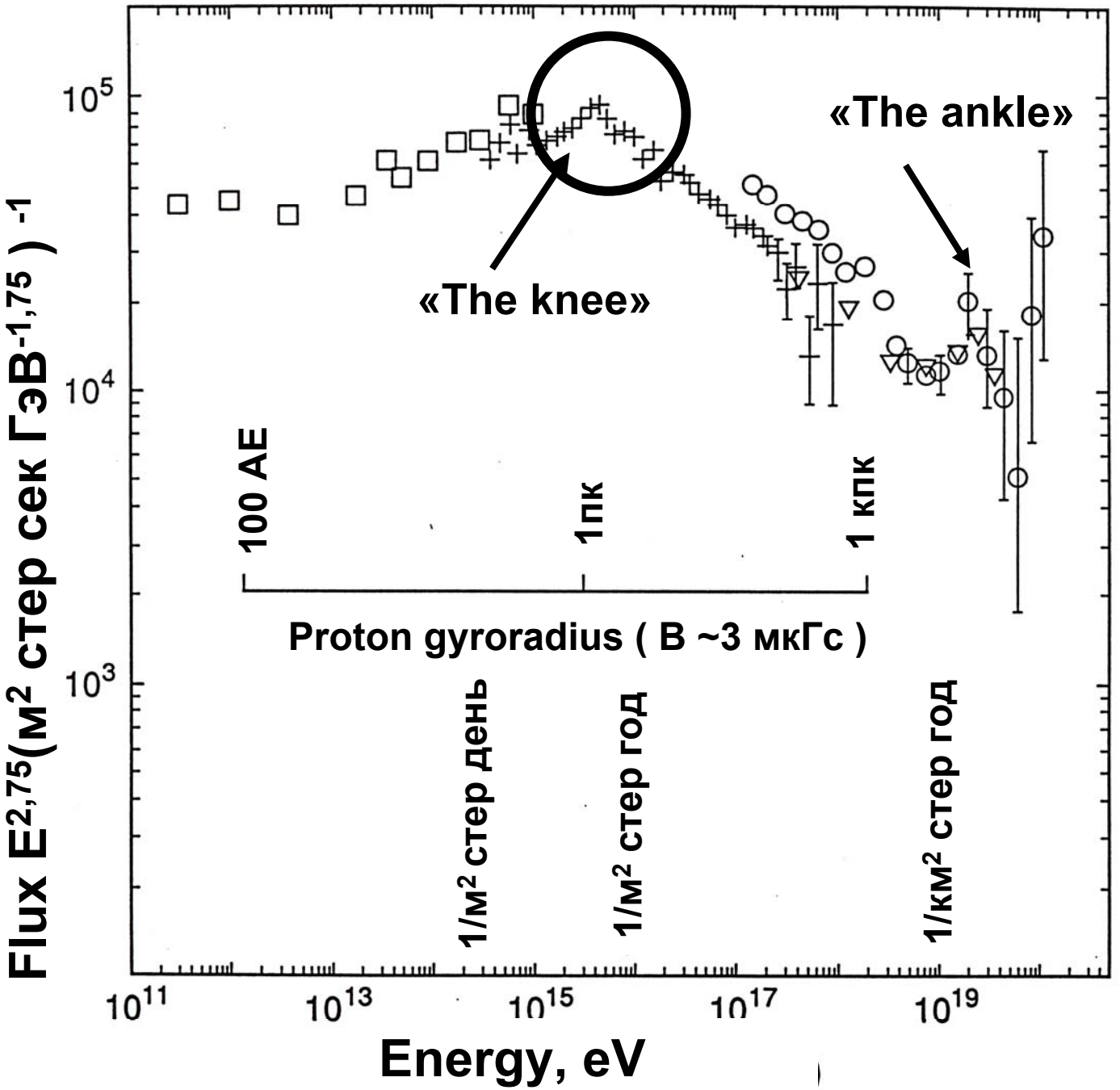
Energy spectrum of cosmic rays

Practically the same slope over the wide energy range

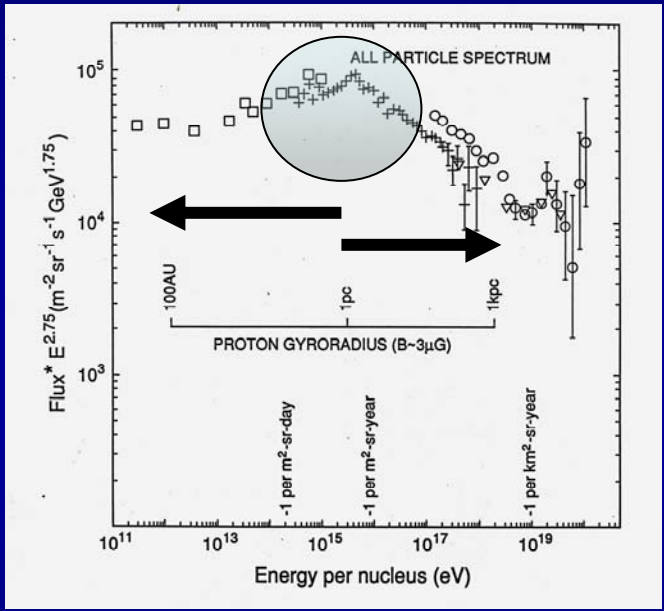


Energy spectrum of cosmic rays in the PeV energy range was discovered by G.Christiansen(MSU) in 1958




«The ankle»
«The knee»
100 АЕ
1пк
1 кпк
Proton gyroradius (B ~3 мкГс)
1/м² стер день
1/м² стер год
1/км² стер год
Flux E^2,75(м² стер сек ГэВ^-1,75) ^-1
Energy, eV
10^5
10^4
10^3
10^11
10^13
10^15
10^17
10^19

Mystery of the knee
MSU, 1958

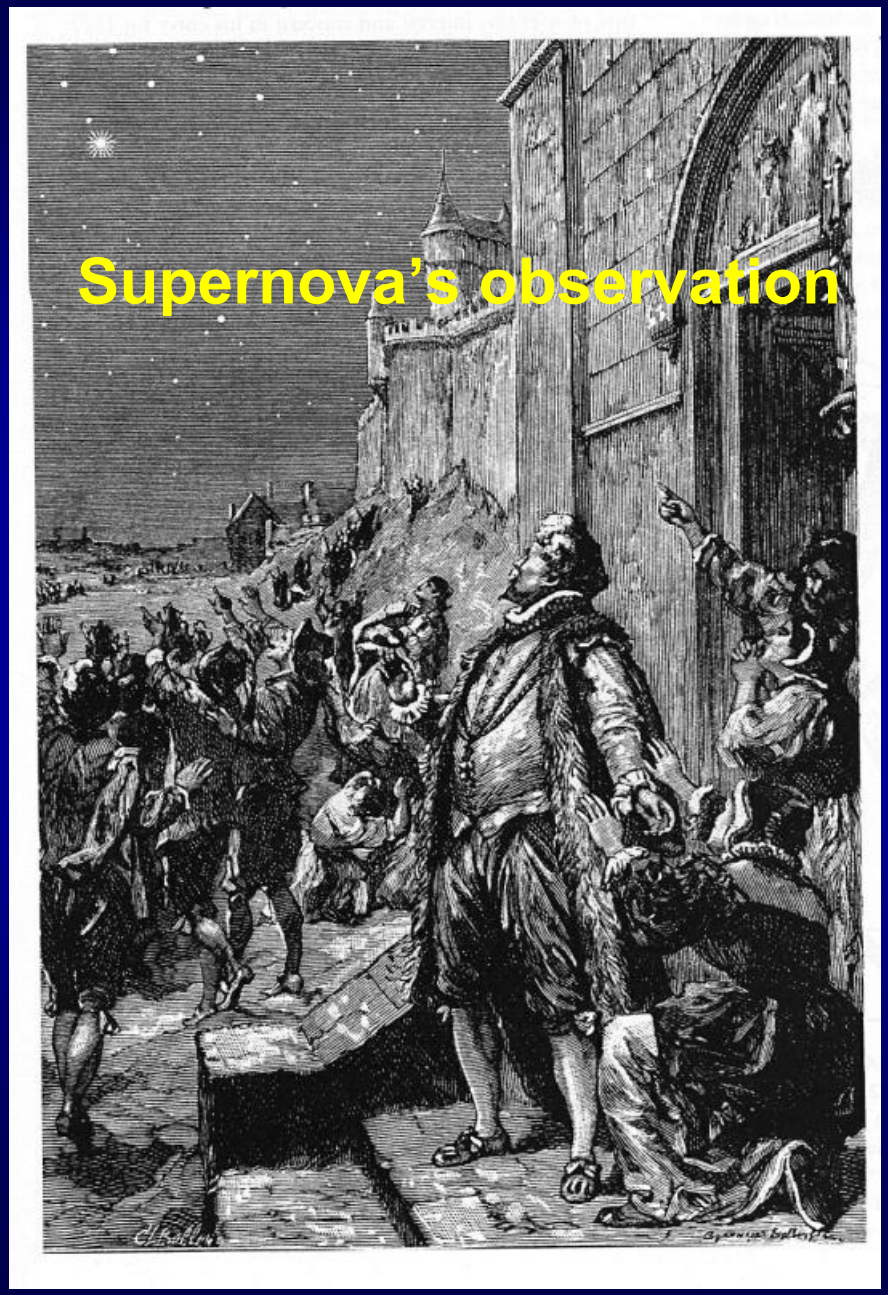


- Energy boundary between space (or balloons technics and onground measurement;

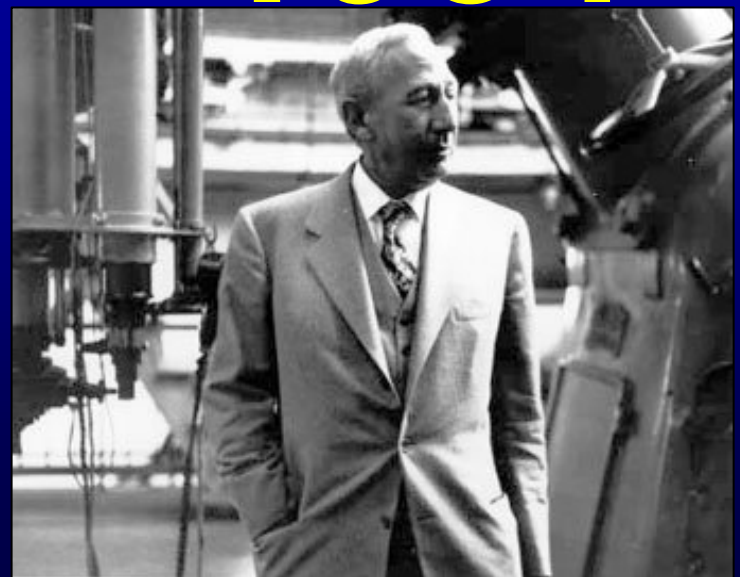
- Energy upper limit of existing colliders;

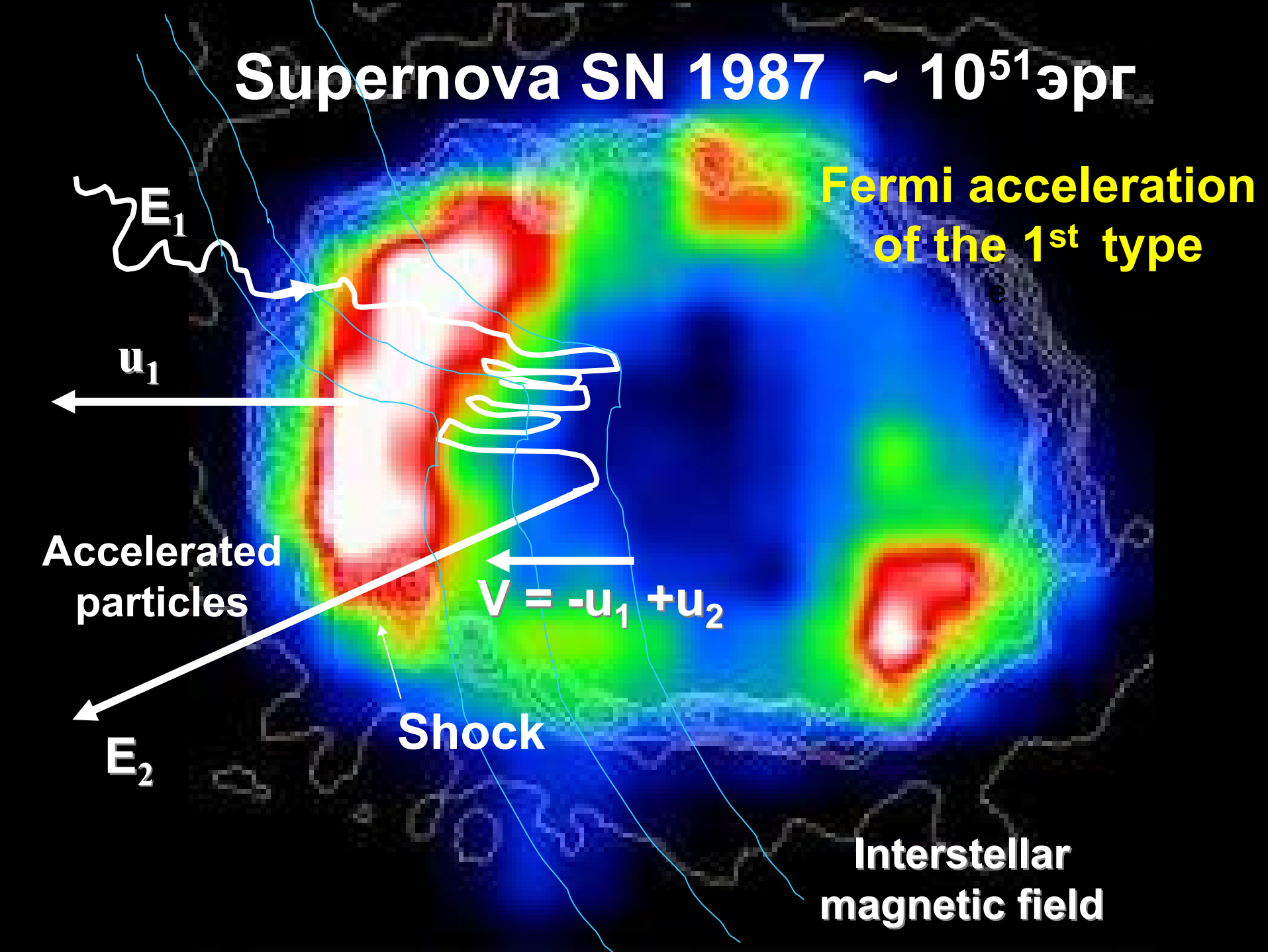
Energy boundary between different acceleration processes of CR in the Universe ?

Where is a Pevatron?



1934




Supernova SN 1987 ~ 10^51эрг
E1
Fermi acceleration
of the 1st type
u1
Accelerated
particles
V = -u1 +u2
E2
Shock
Interstellar
magnetic field

Acceleration limit for cosmic ray in supernova remnants

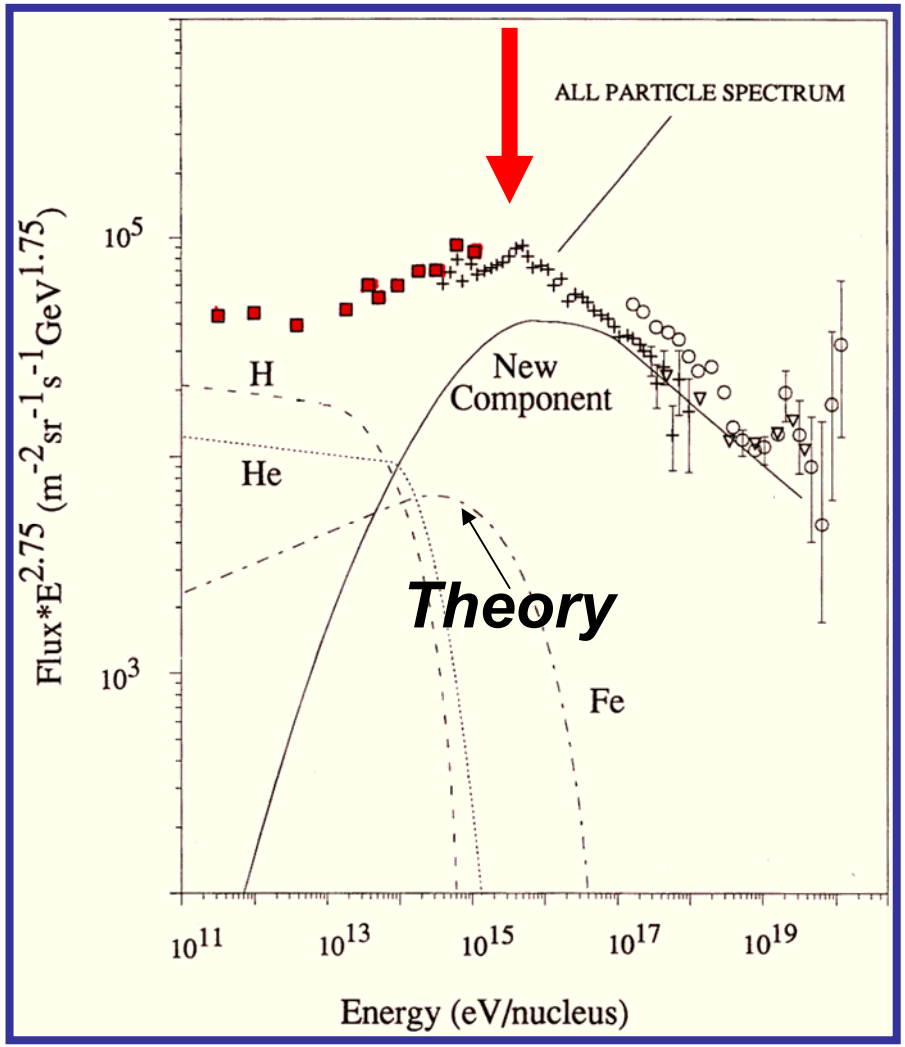
«The knee» ($3 \cdot 10^{15}$eV)

The first-order Fermi acceleration and diffusive propogation implies: maximum energy for typical supernova parameters is about

$Emax=BLZ=3*10^{14}$ eVZ.

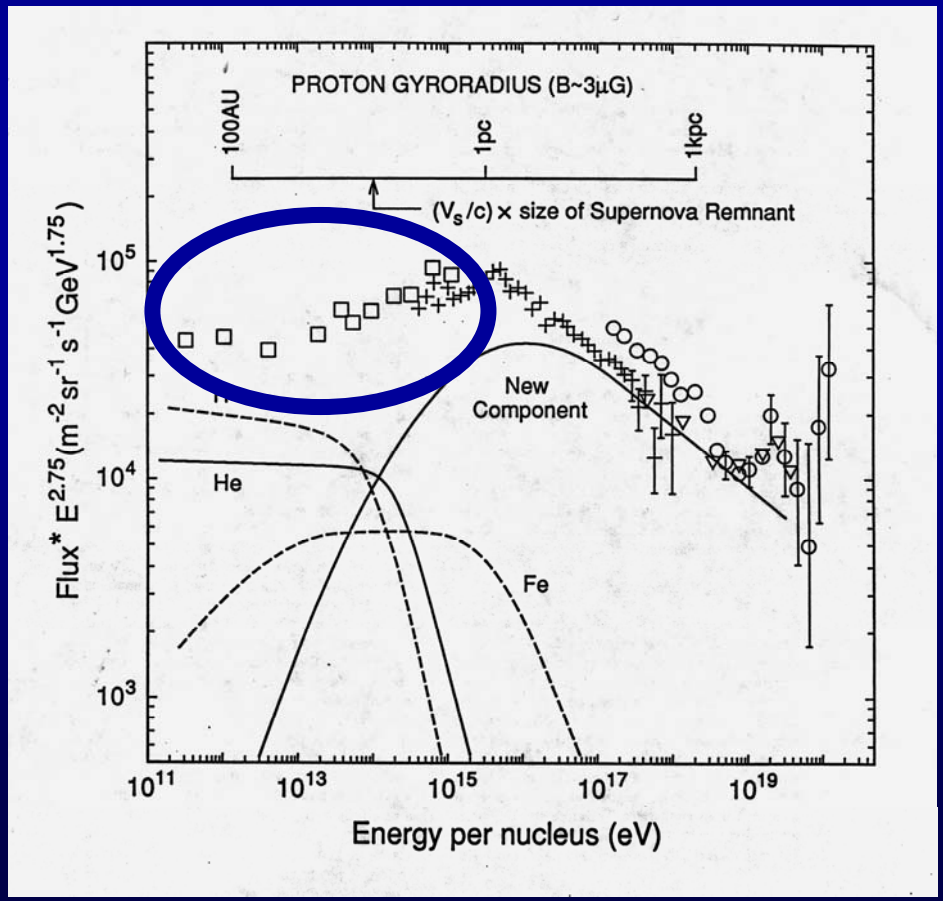
Aditional sources or acceleration mechanisms are needed to reach >10^{16} eV?

Test for models of acceleration by supernova shocks.



Cosmic rays below «the knee»

Just only «direct»measurements outside the atmosphere can provide information on energy spectra and composition of particles



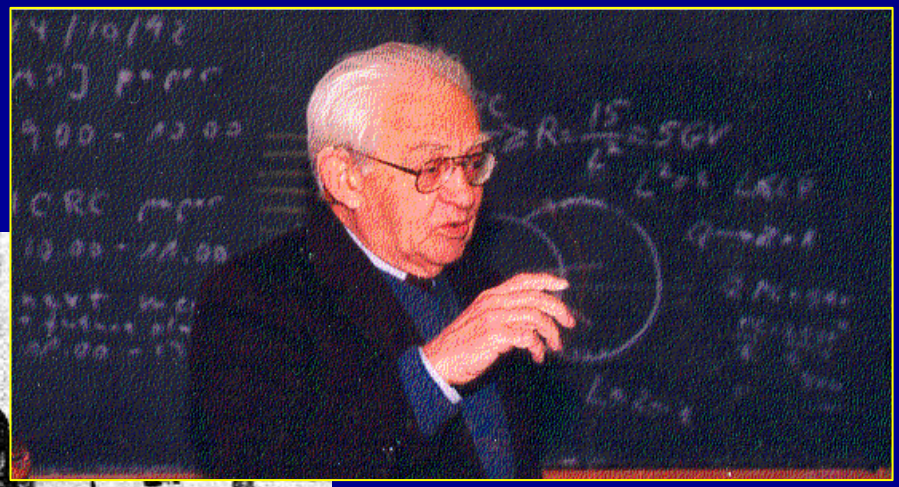
«Proton» experiment:

Active Calorimeter SINP/MSU

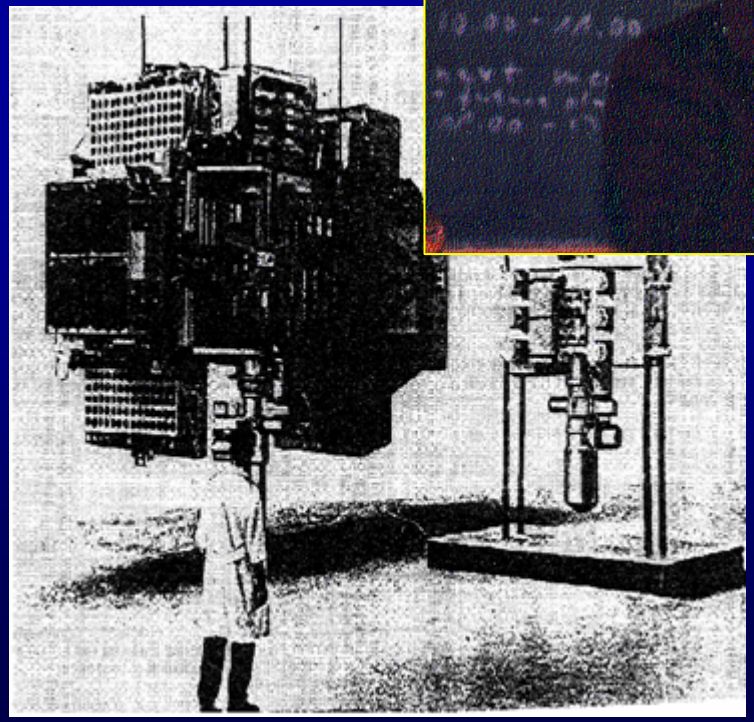
1968

Cosmic rays below «the knee»

Just only «direct»measurements outside the atmosphere can provide information on energy spectra and composition of particles



N.L. Grigorov



«Proton» experiment:

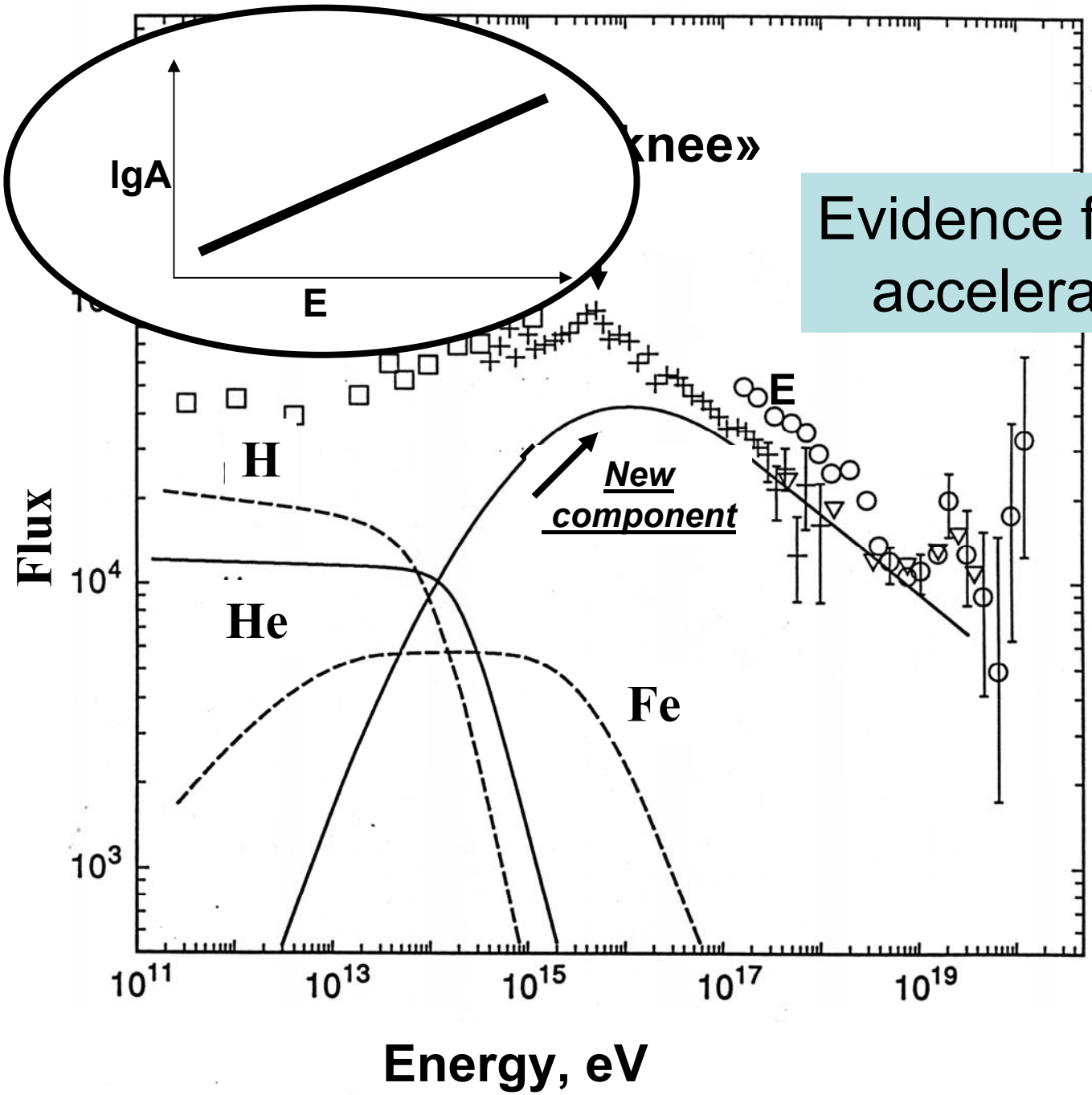
Active Calorimeter

SINP/MSU

1968

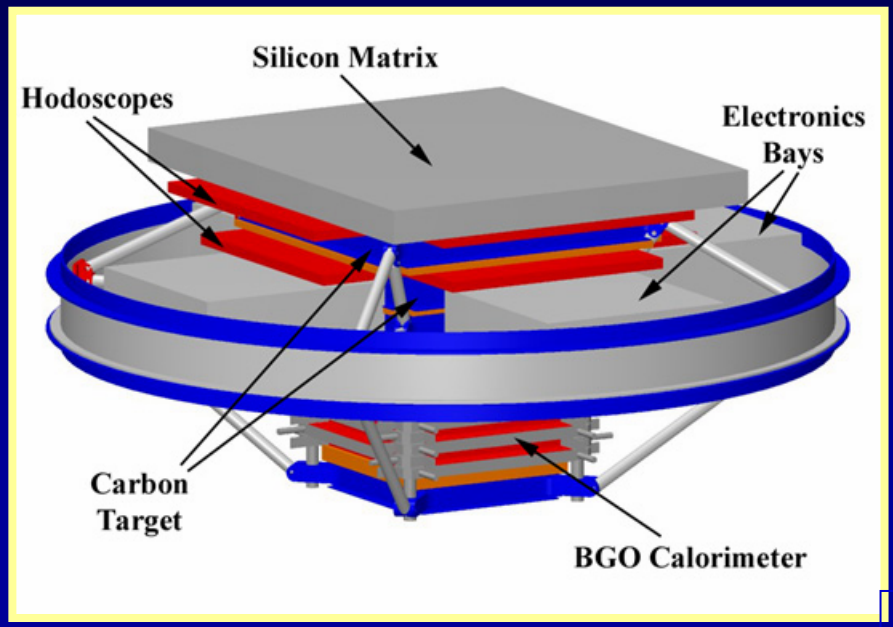
The recent direct experiments:

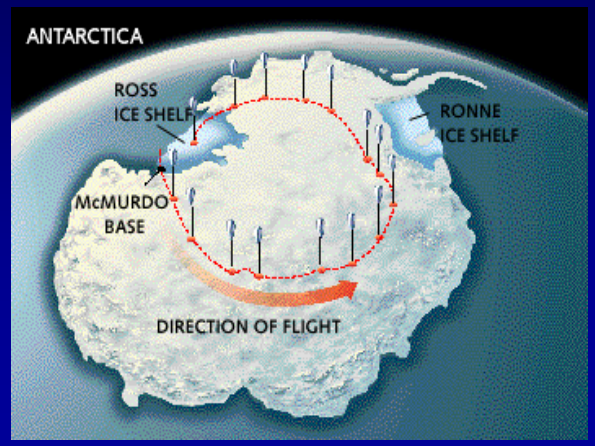
From all particle energy spectra to mass composition & energy spectra

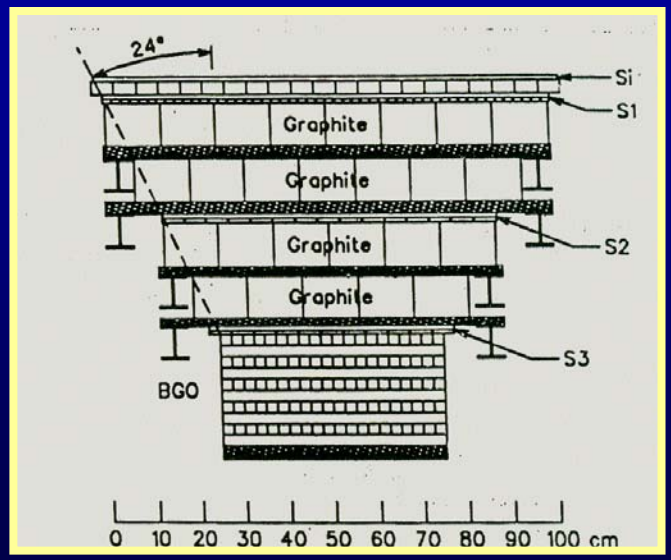


Evidence for SN acceleration

ATIC (2000 - 2004)

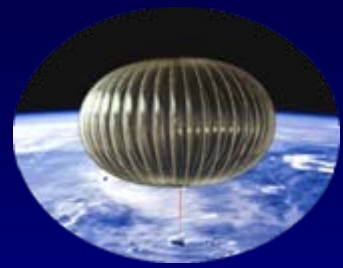




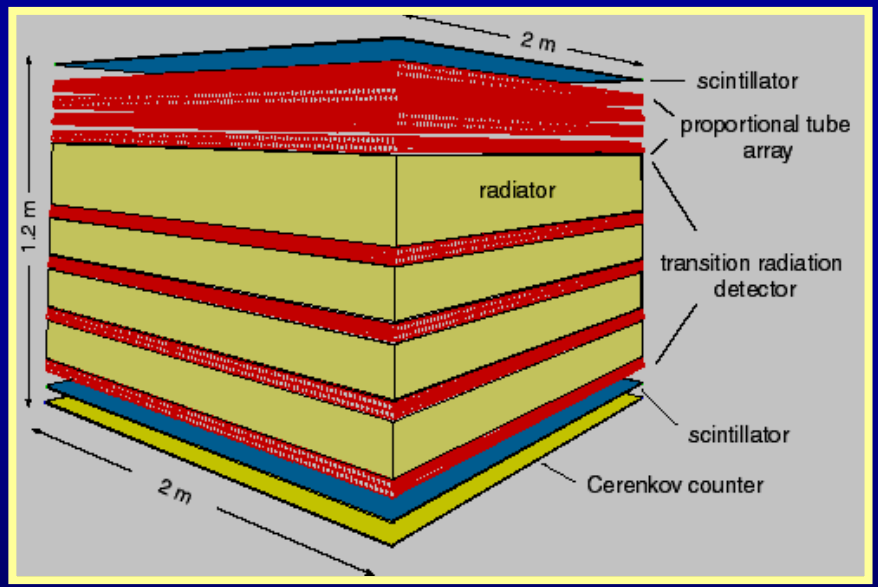


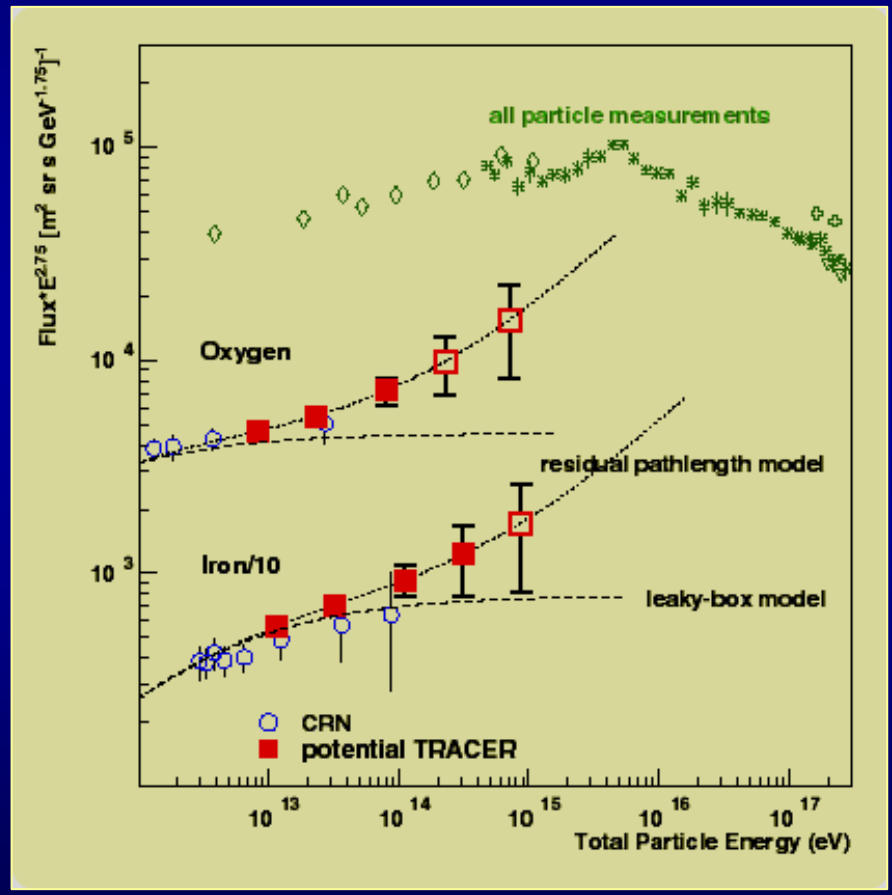
Lousiana State Univ.,
Maryland State Univ.,
MSFC,
Moscow State Univ.,
etc

LDBF over the Antarctica region 2004



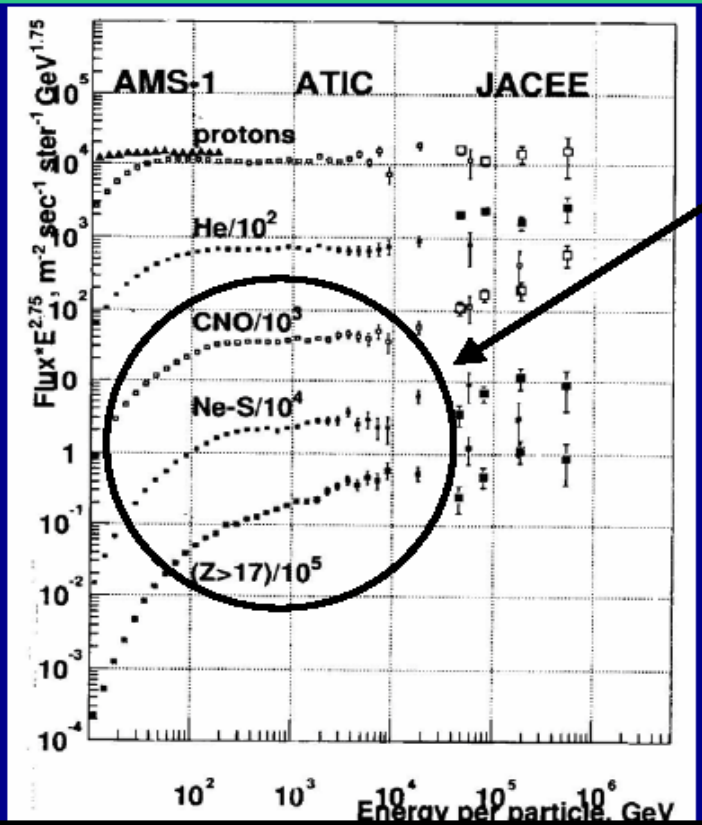
TRACER

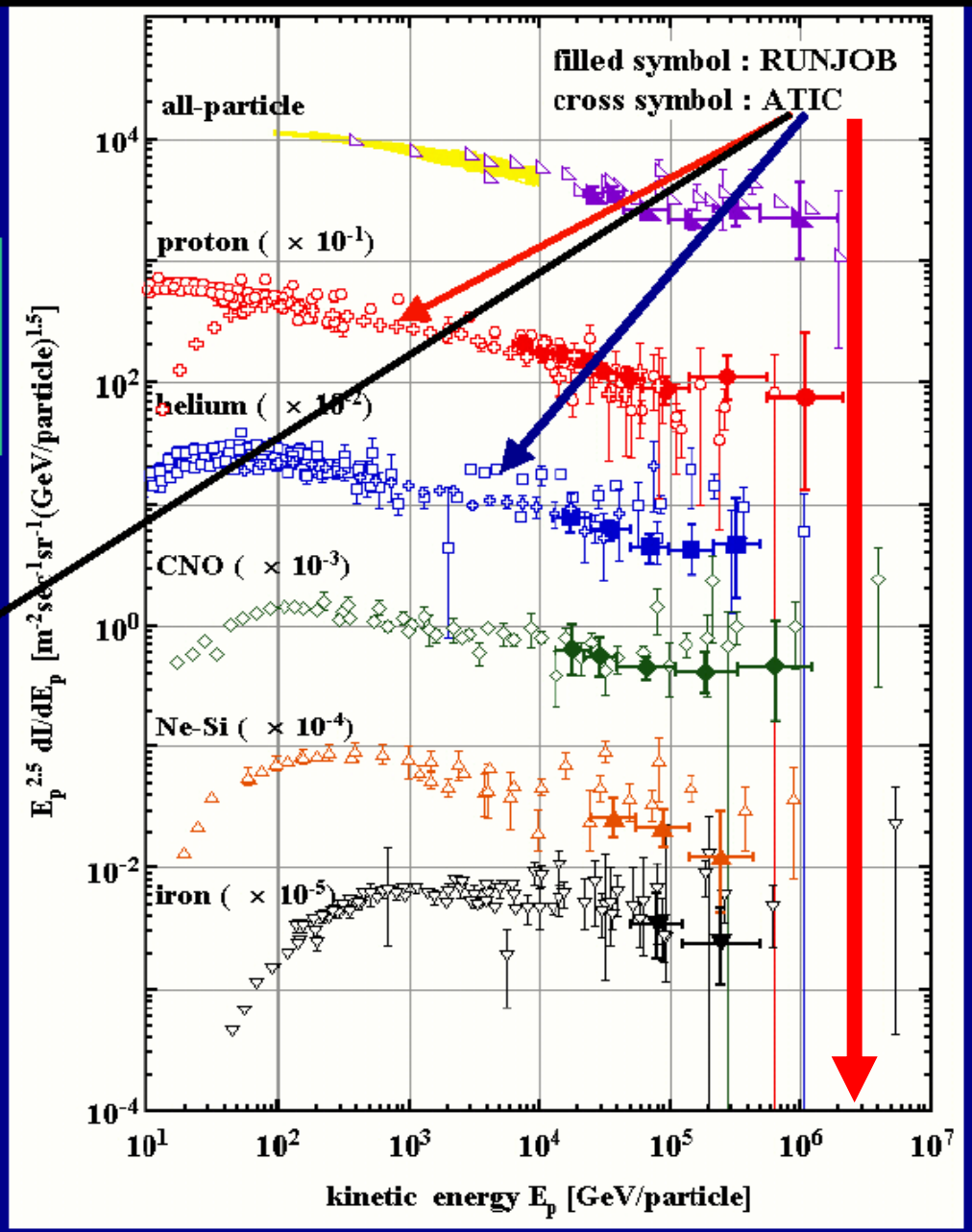




TRD
Univ. of Chicago

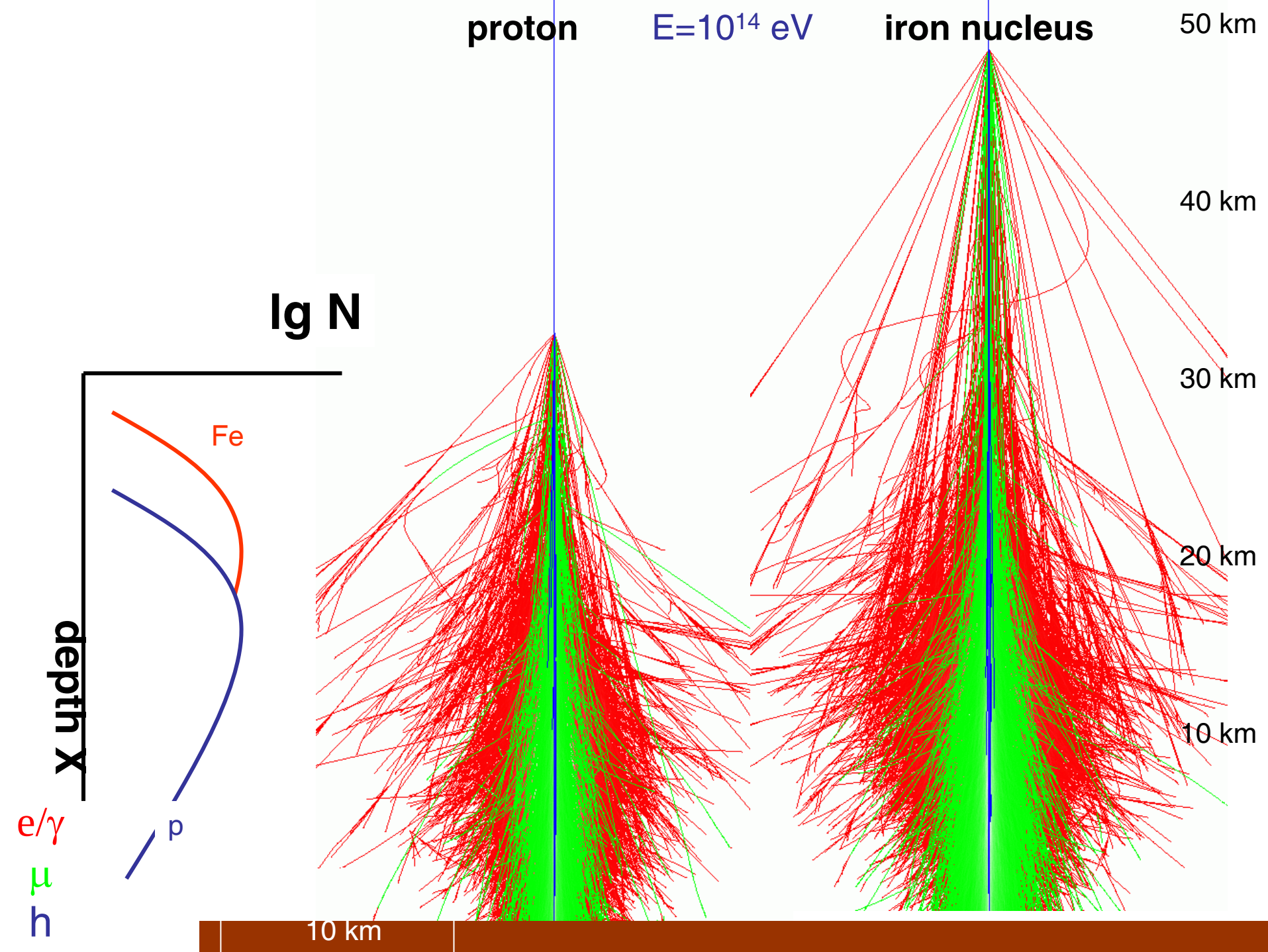
Better understanding of the CR composition approaching the knee region





Above the knee

Extensive Air Showers Technics

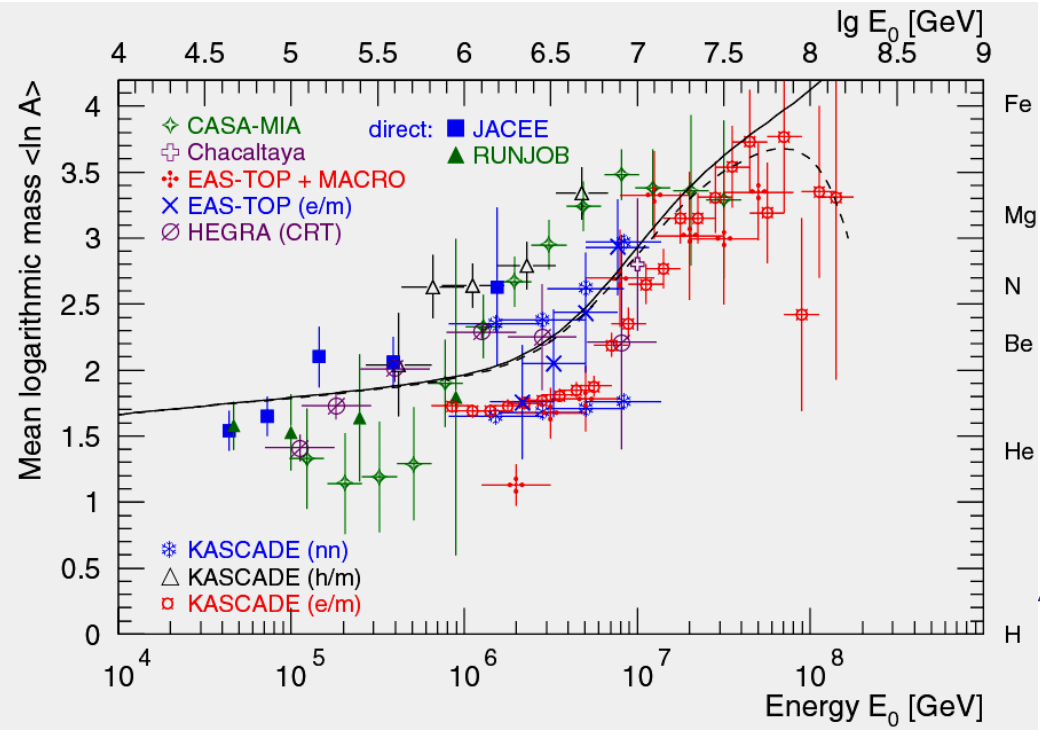

proton
E=10^14 eV
iron nucleus
50 km
40 km
30 km
20 km
10 km
lg N
Fe
p
depth X
e/γ
μ
h
10 km

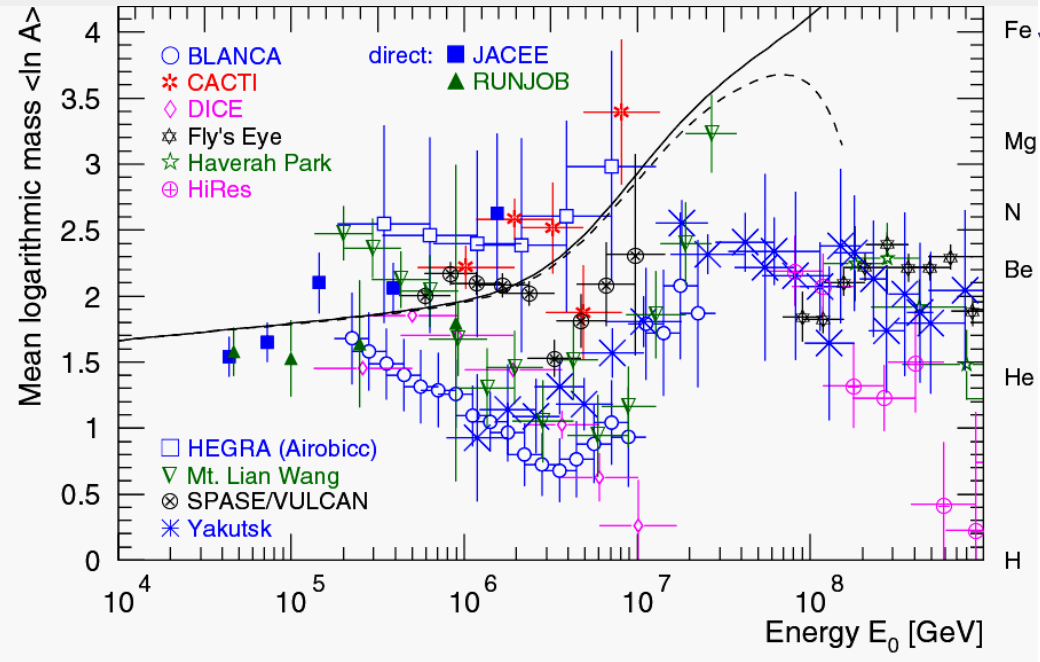
Mean logarithmic mass vs energy

CORSIKA/QGSJET interpretation

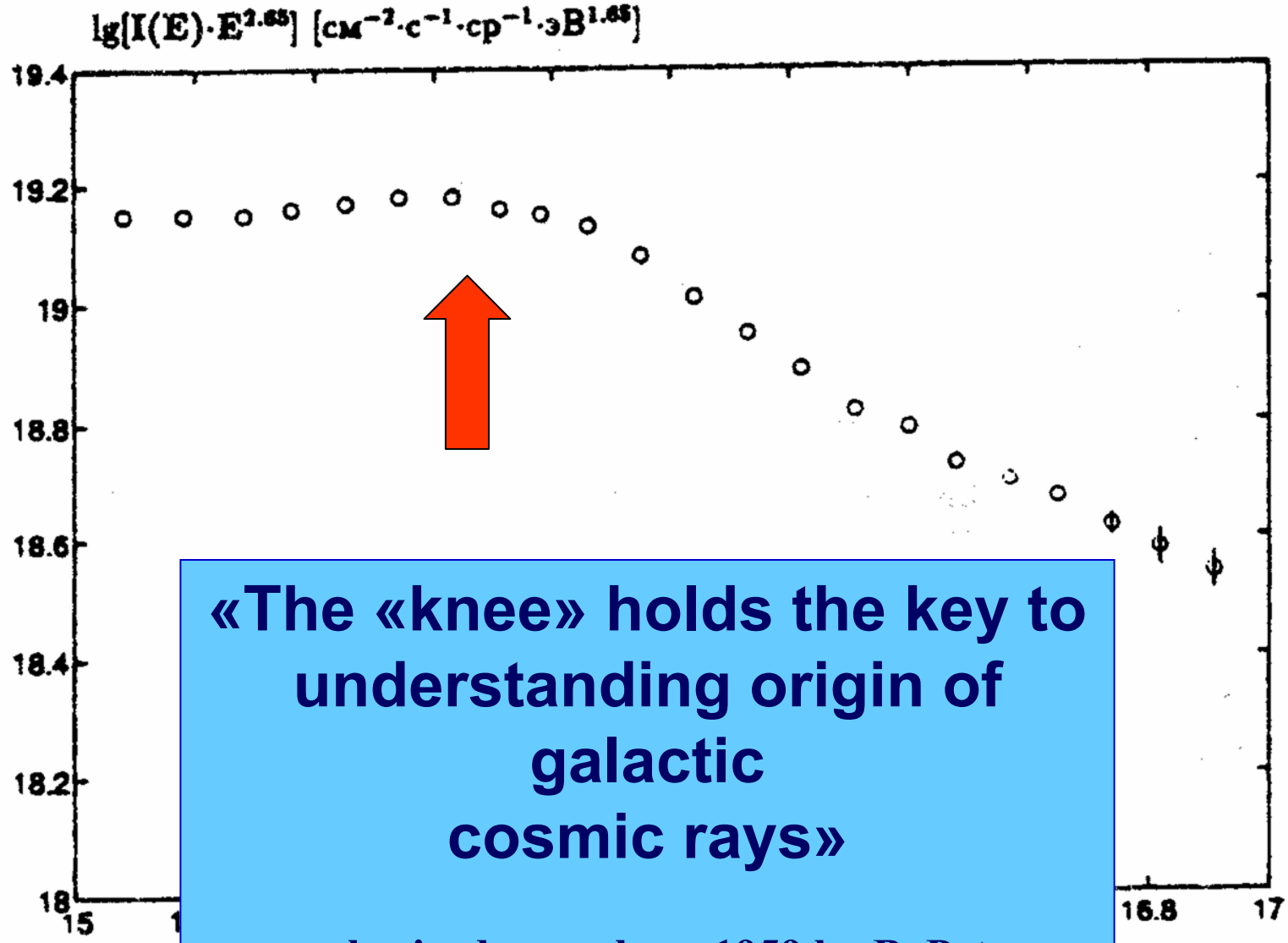
electrons, muons, hadrons at ground level

!?





The knee



«The «knee» holds the key to understanding origin of galactic cosmic rays»

-emphasized as early as 1959 by B. Peters

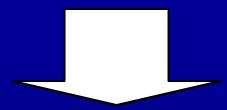
"The knee" summary

Difficulties in using «direct» techniques in the TeV-PeV energy range primarly associated with *the enormous dimensions of the required satellite instruments*, and, on the other hand,

insufficient knowledge of particle interaction processes at such high energies, makes it currently impossible to establish the origin of cosmic rays in this very important energy range.

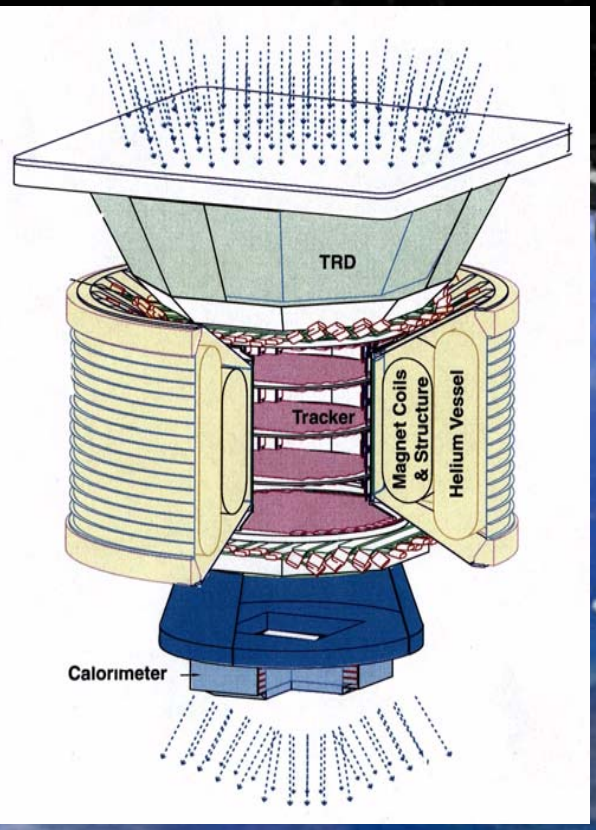
The future of direct measurements

Future instrument's needs:
-larger geometric factor
-more precize mass and energy spectra

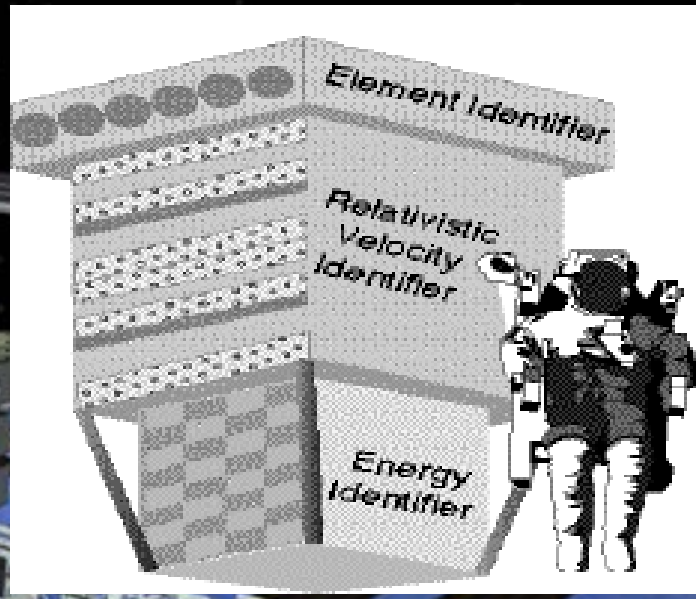


-more weight,
-more cost

ISS as a potential career for a future cosmic ray experiments

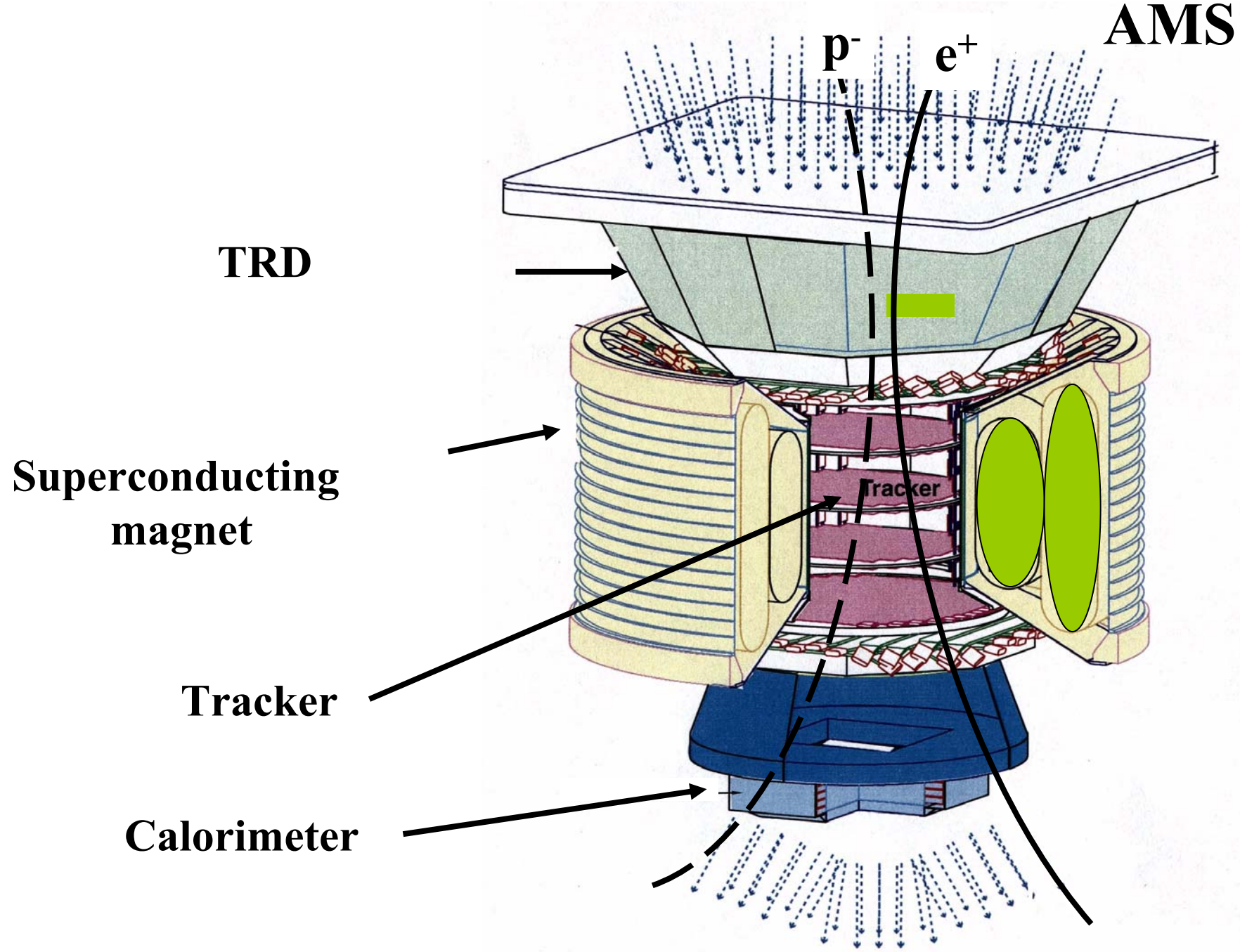


AMS 2



ACCESS

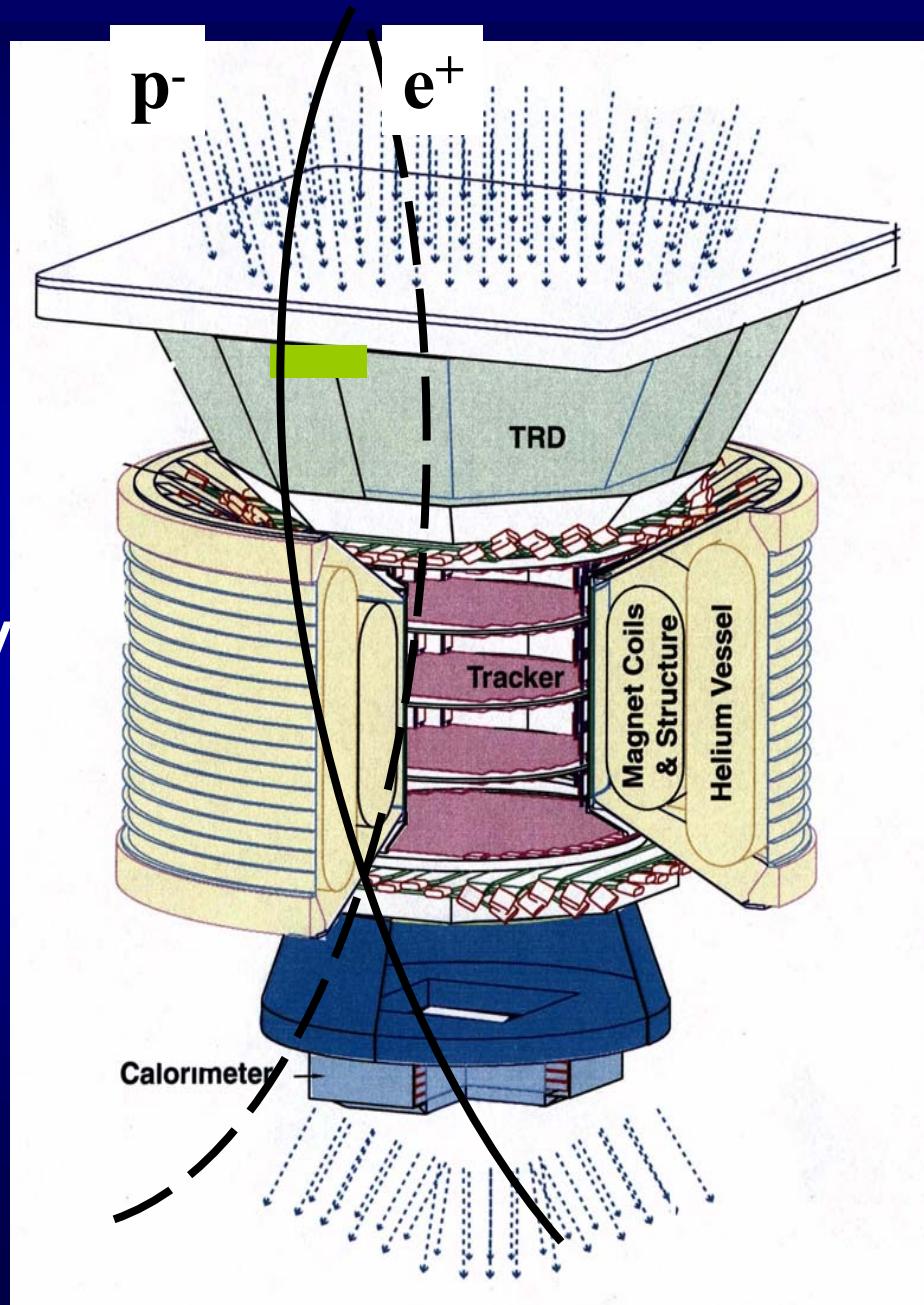
AMS 02

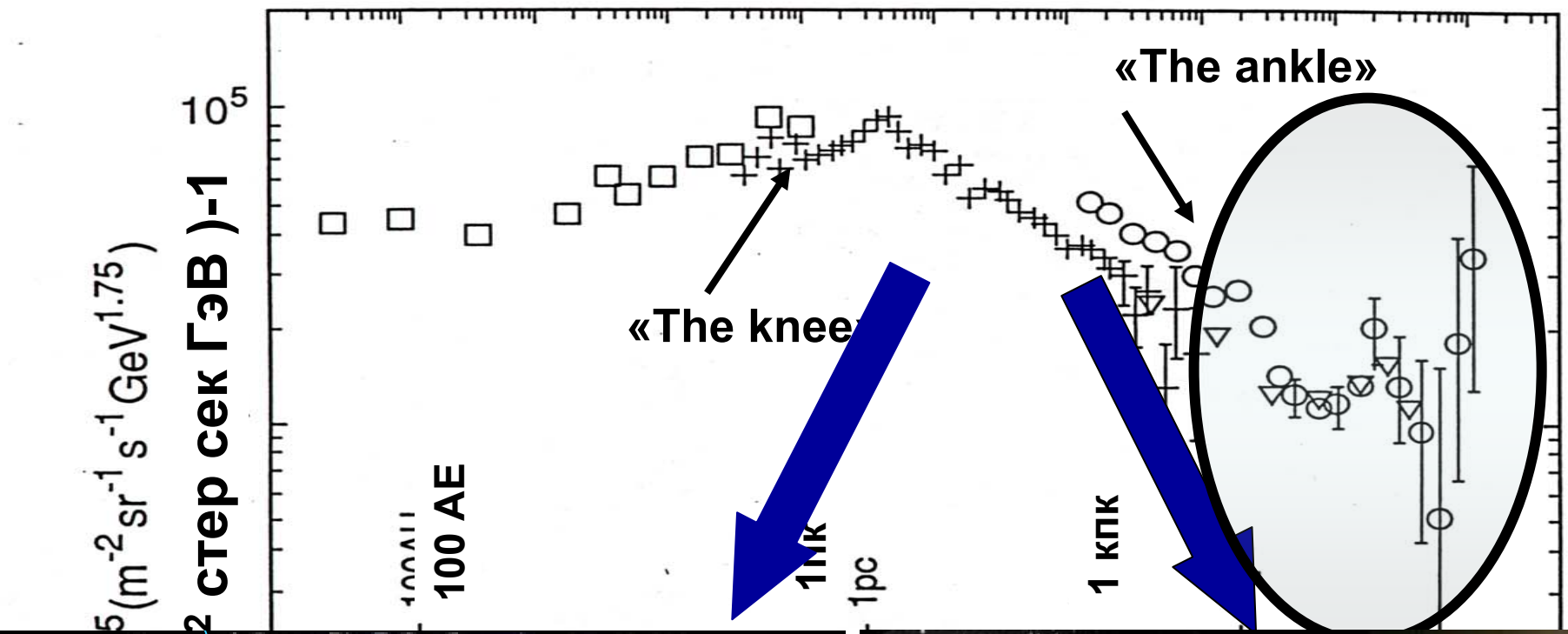

p-
e+
TRD
Superconducting magnet
Tracker
Tracker
Calorimeter

AMS 02 is planing to launch in 2008

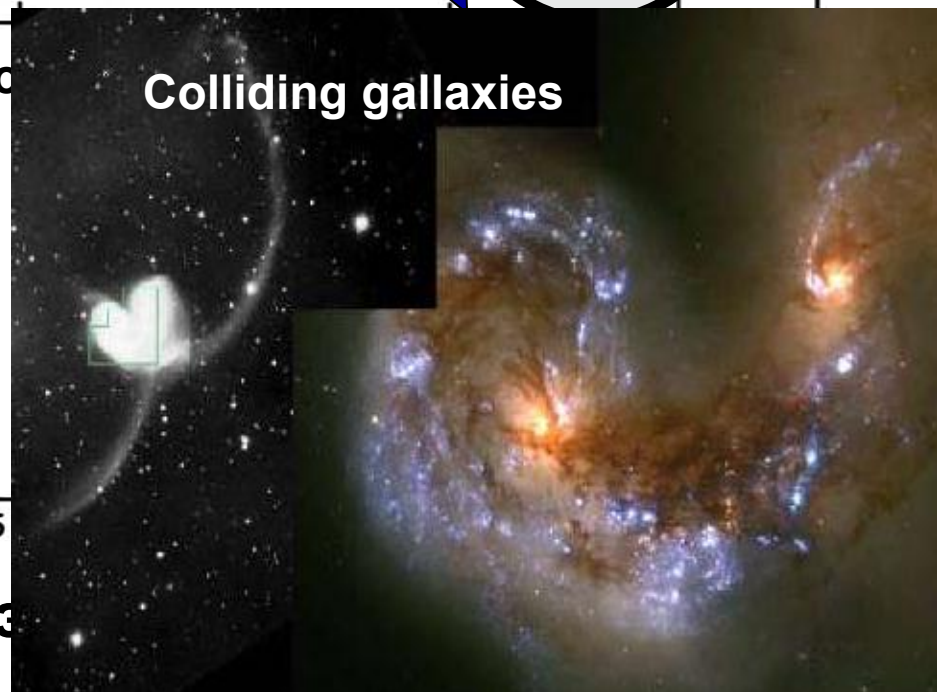
Primary goals:

-cosmic rays < 10^{14}eV
-dark matter,
-antimatter,




«The ankle»
«The knee»
10^5
$(m^{-2} sr^{-1} s^{-1} GeV^{1.75})$
2 стер сек ГэВ)-1
100 АЕ
1пк
1pc
1 кпк

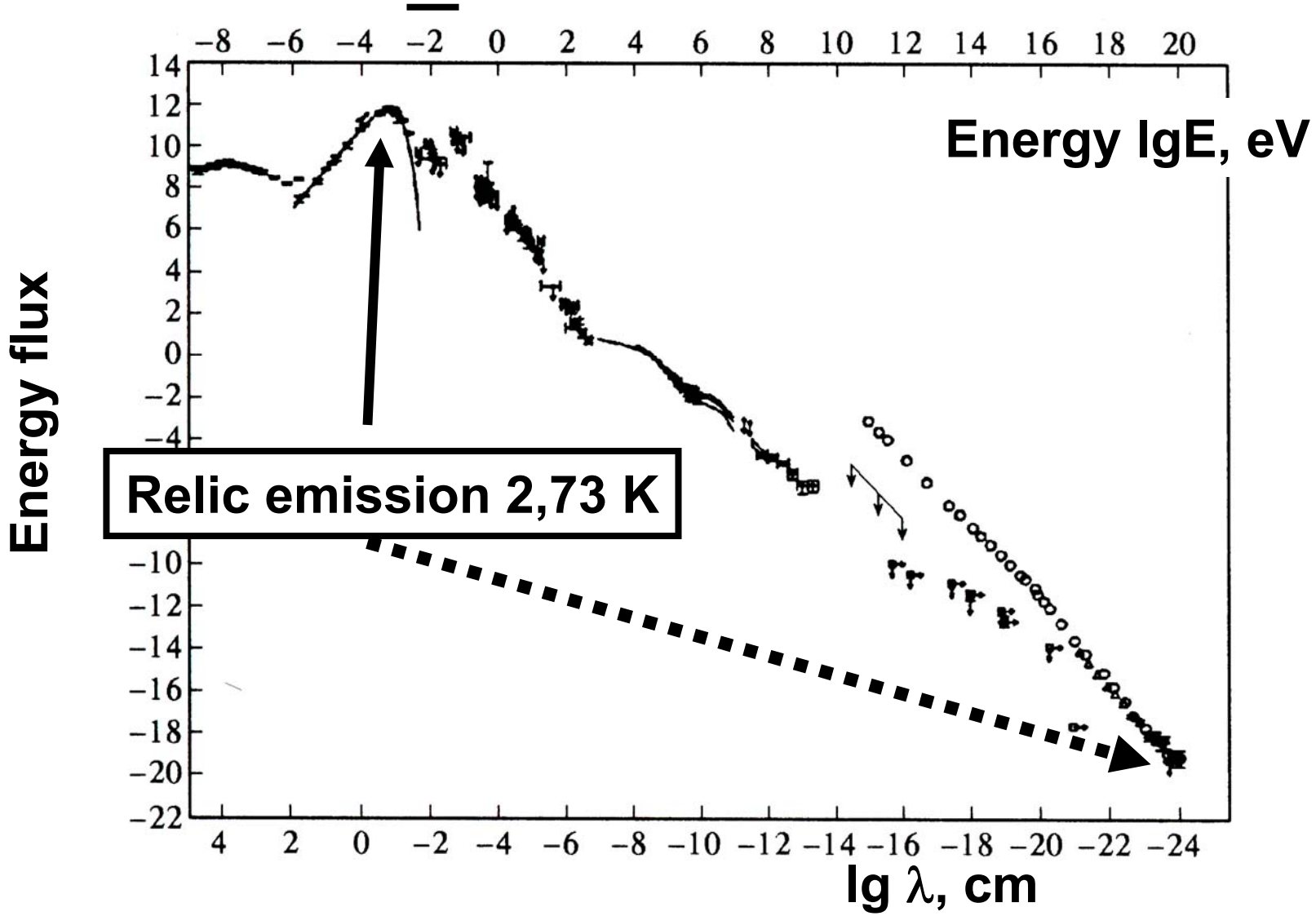

Supernova 1987
E_1
u_1
Ускоренные частицы
$V = -u_1 + u_2$
E_2
Ударная волна
Межзвездное магнитное поле


Colliding gallaxies

The ankle

Where is a Zevatron?

GZK- effect


Energy lgE, eV
Energy flux
Relic emission 2,73 K
lg λ, cm
−8 −6 −4 −2 0 2 4 6 8 10 12 14 16 18 20
14 12 10 8 6 4 2 0 −2 −4 −10 −12 −14 −16 −18 −20 −22
4 2 0 −2 −4 −6 −8 −10 −12 −14 −16 −18 −20 −22 −24

GZK-effect

For protons:

$p + \gamma(2{,}7K) \rightarrow N + \pi$

Cross-section of interaction is σ=10-28 cm2

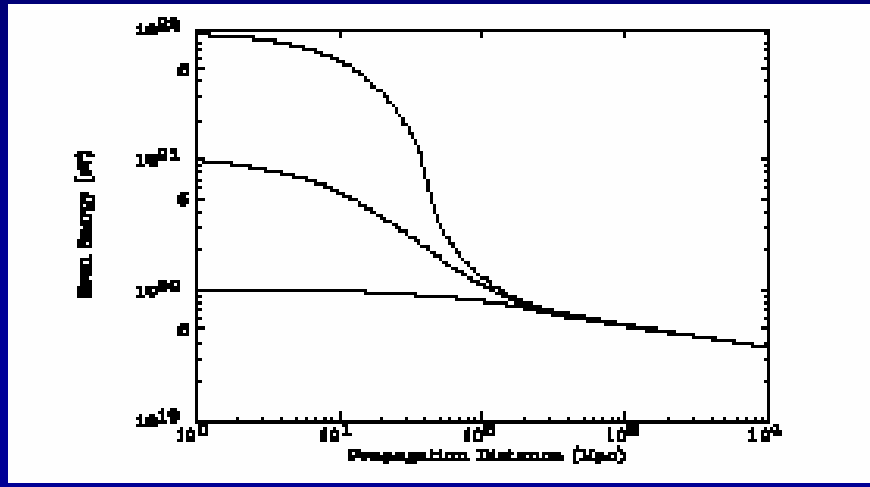
Interaction free path $L = 1/\sigma\, \rho_{ph}$ =70 Mpc

Emax=5.10^{19} эВ; dmax>50 Мпк,

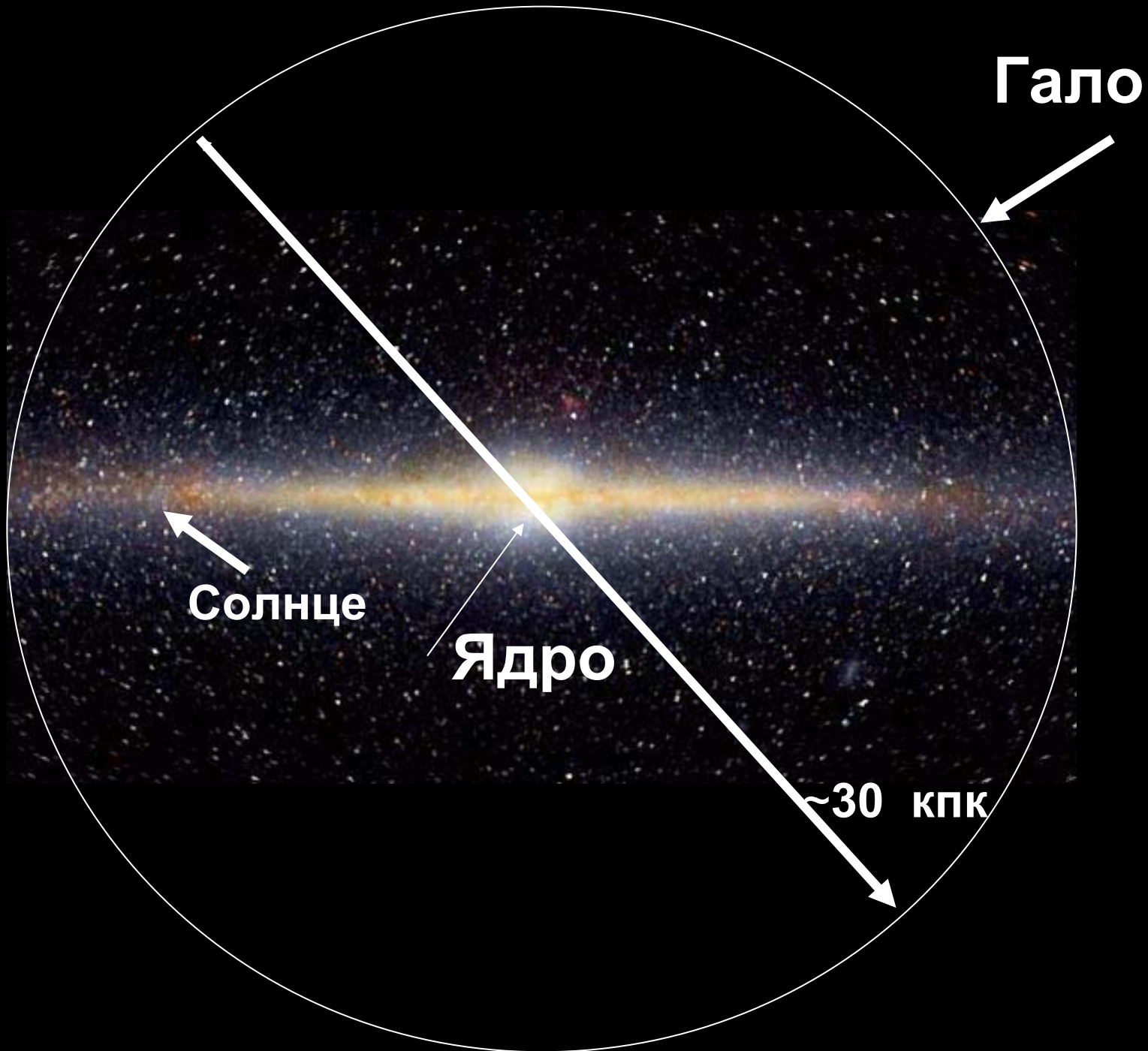
For nuclei :

$A + \gamma(2{,}7K) \rightarrow (A-1) + n$

Emax=10^{20} эВ и dmax>100 Мпк

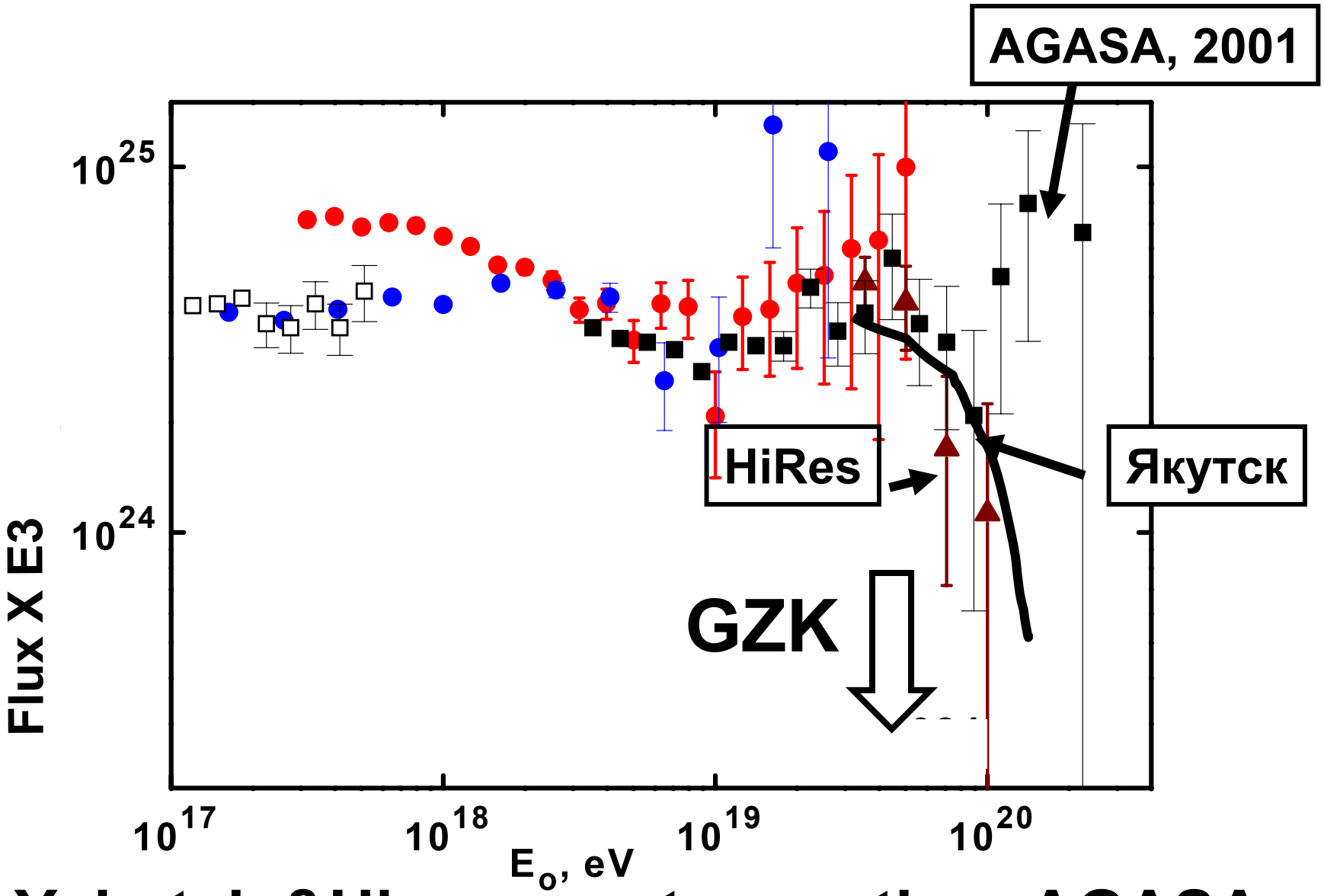


One should not expect any UHECR sources at d_{max}>100Мпк


Гало
Солнце
Ядро
~30 кпк

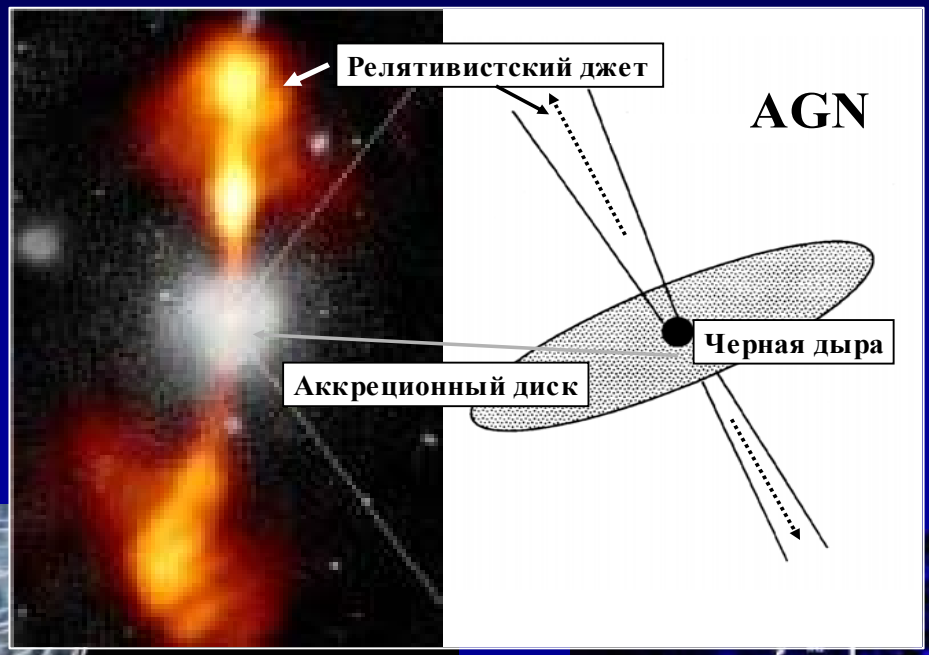
«The ankle» in details

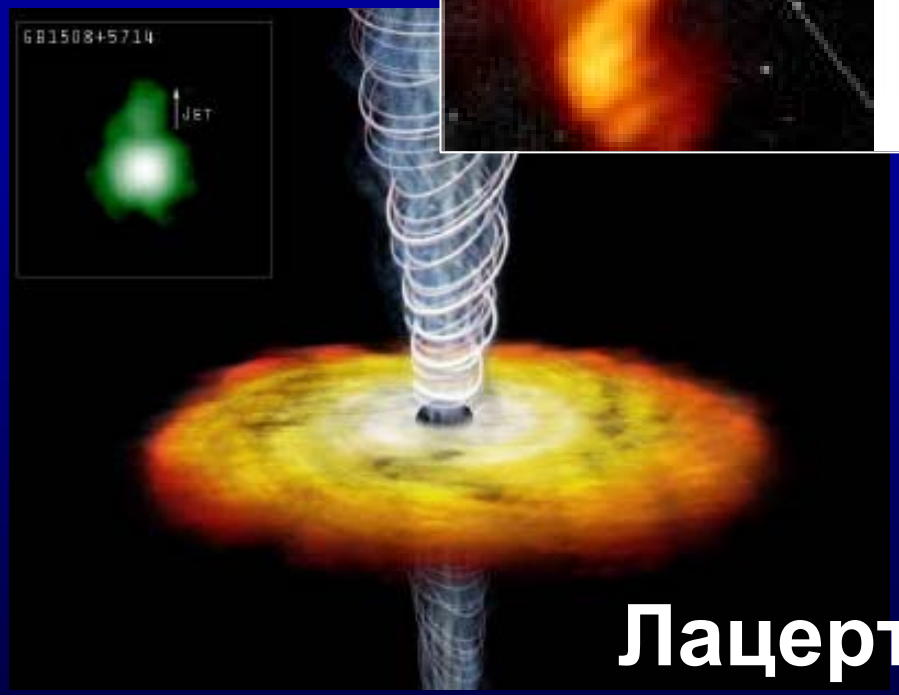
Experimental data

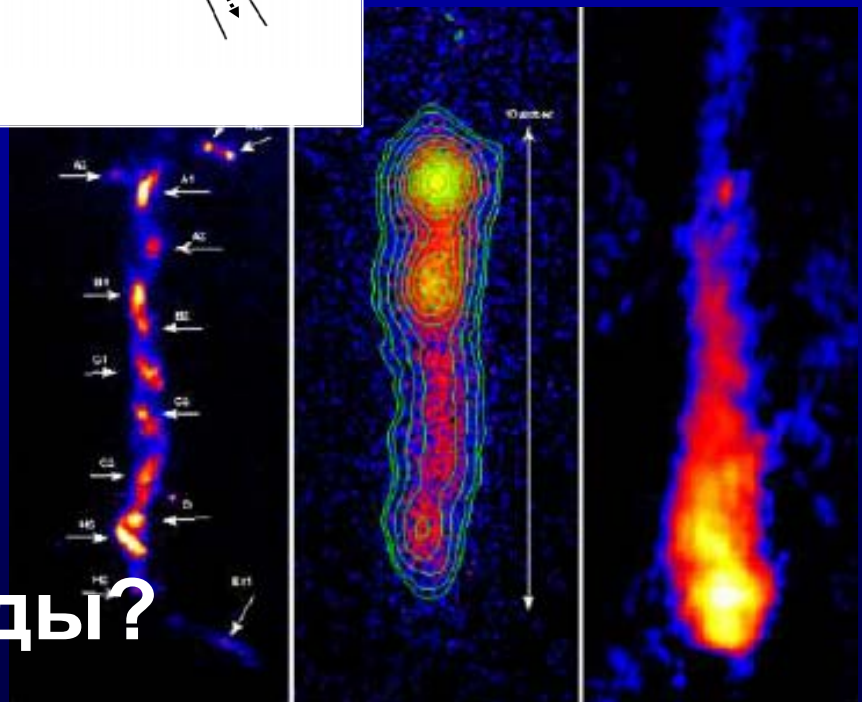


Yakutsk &Hires are steeper than AGASA

Possible sources: Zevatrons - the objects with the relativistic shocks.



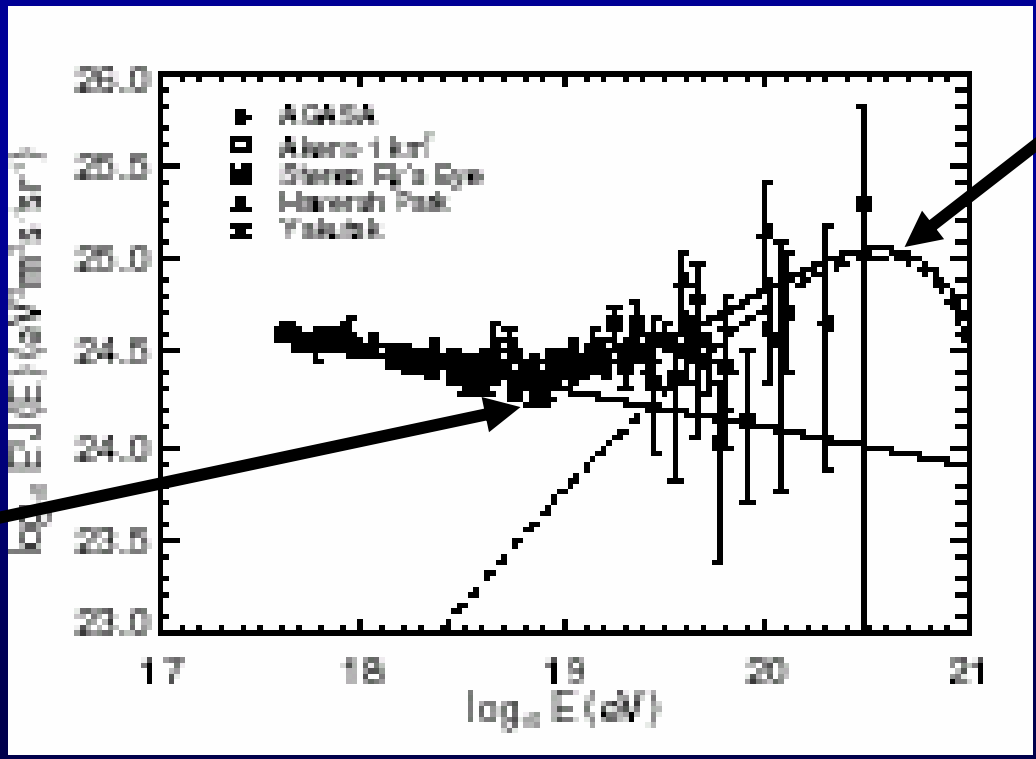




Лацертиды?

The alternative sources of UHECR are the massive particles (M~10^{24} eV) – relics of the Big Bang

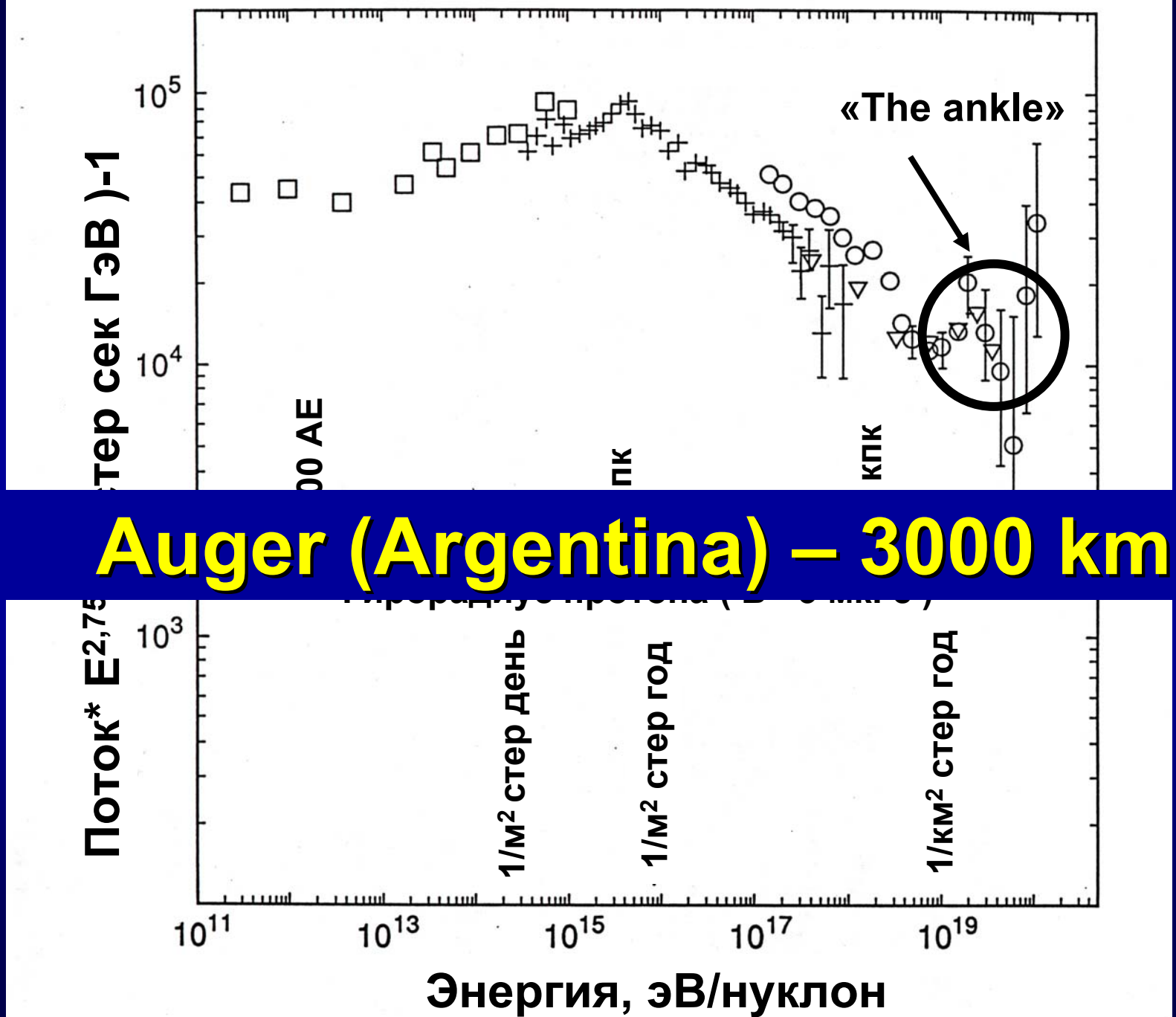
Dark Matter: The UHECR protons (or gamma quanta) are products of their decay.



Extragalaxy

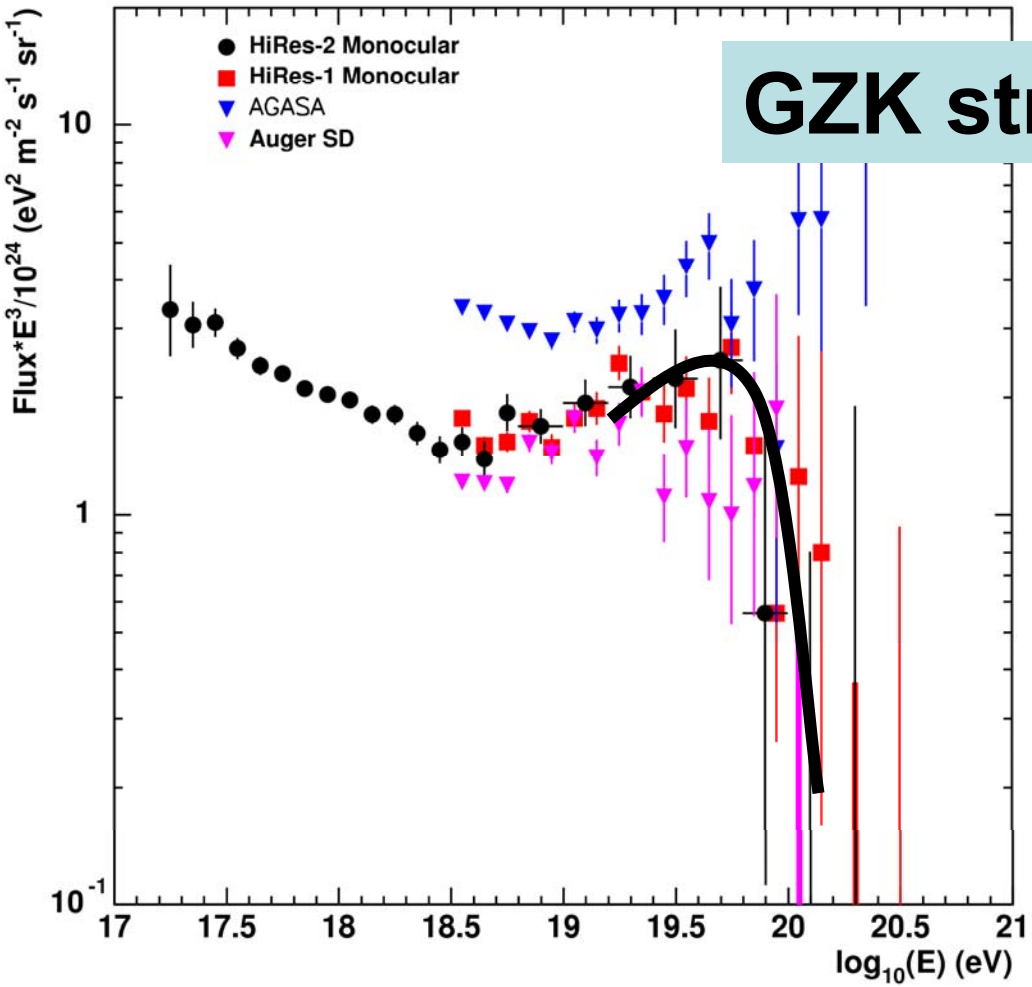
Galaxy

Low statistics – big speculations



Auger (Argentina) – 3000 km2

Auger spectrum



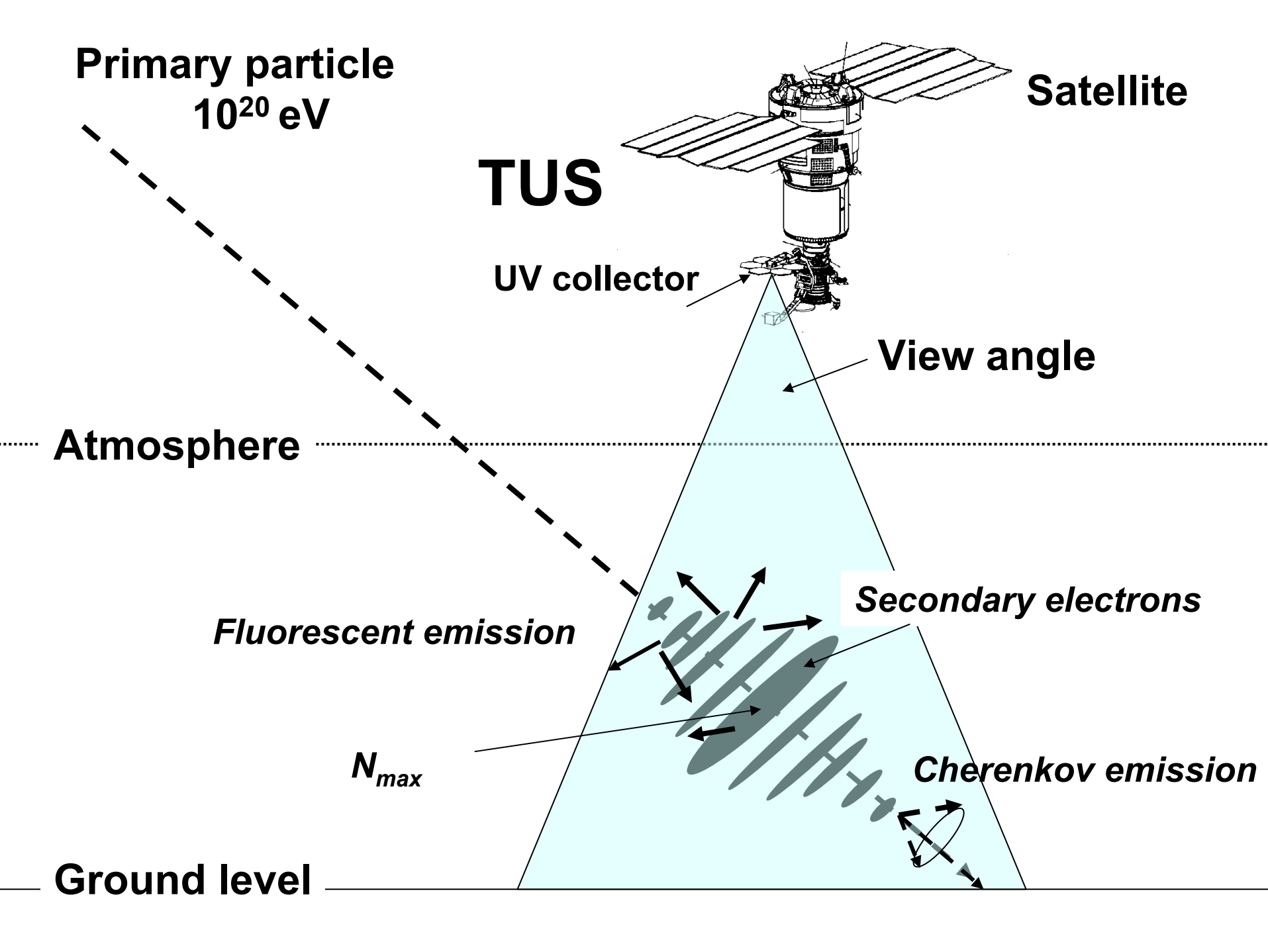
GZK strikes back!

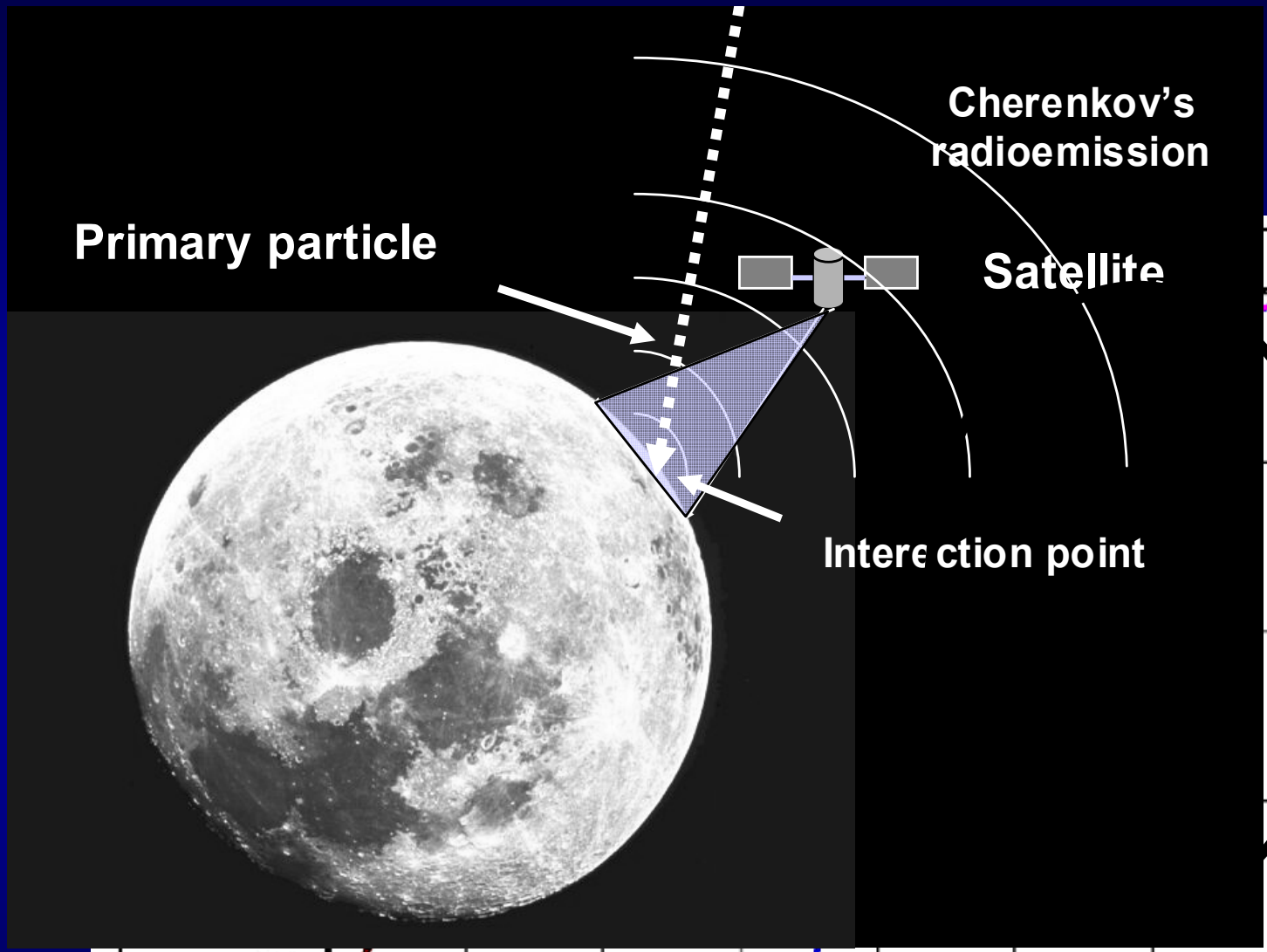
Needs cautions on energy scale, but the spectrum is consistent with the cutoff

Future Outlook

- **Auger: 7 x AGASA by 30th ICRC**

How to enlarge geometric factor?


Primary particle
10^{20} eV
TUS
Satellite
UV collector
View angle
Atmosphere
Secondary electrons
Fluorescent emission
N_{max}
Cherenkov emission
Ground level



1000

00

10

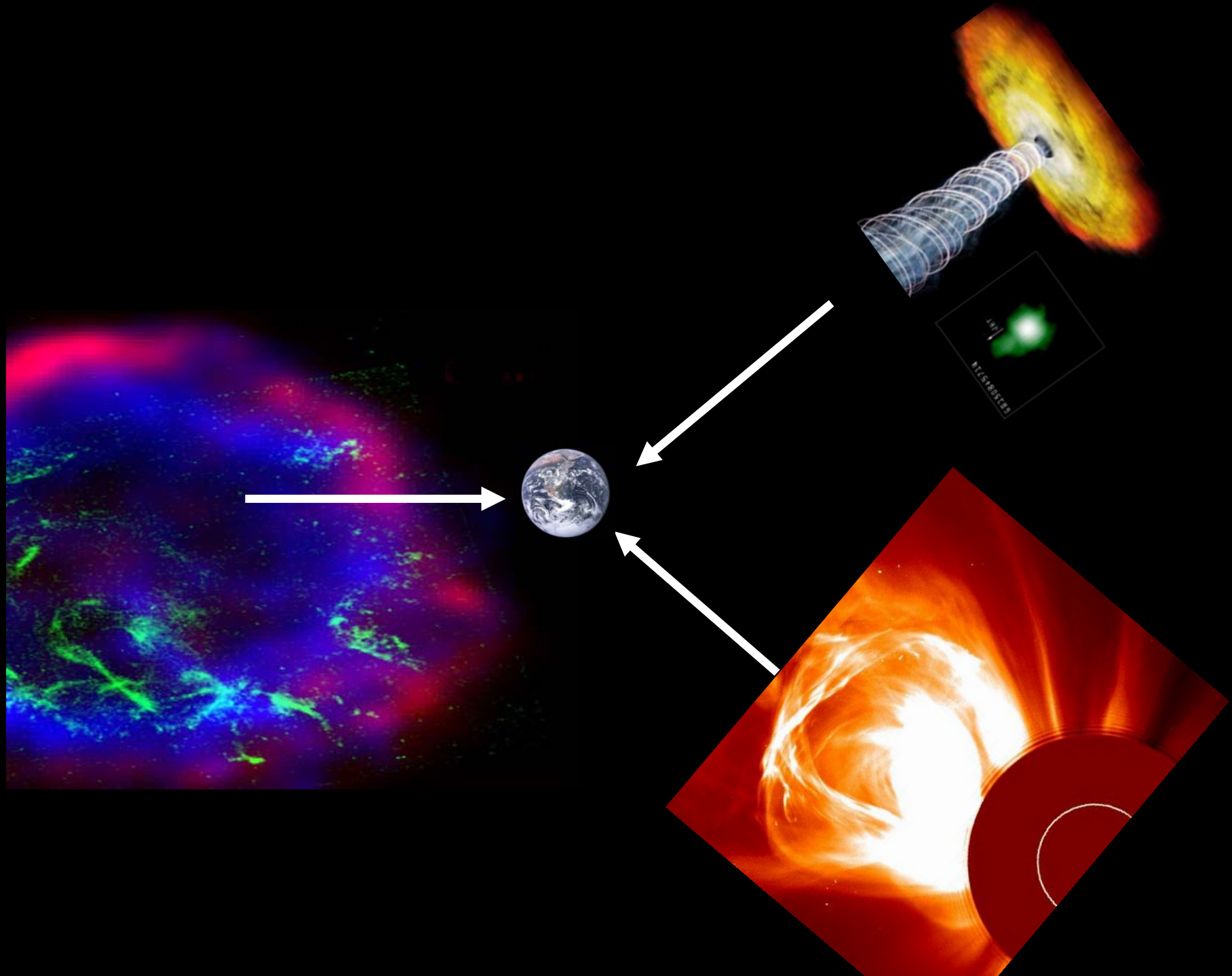
1

Events E>10^{20} eV

100

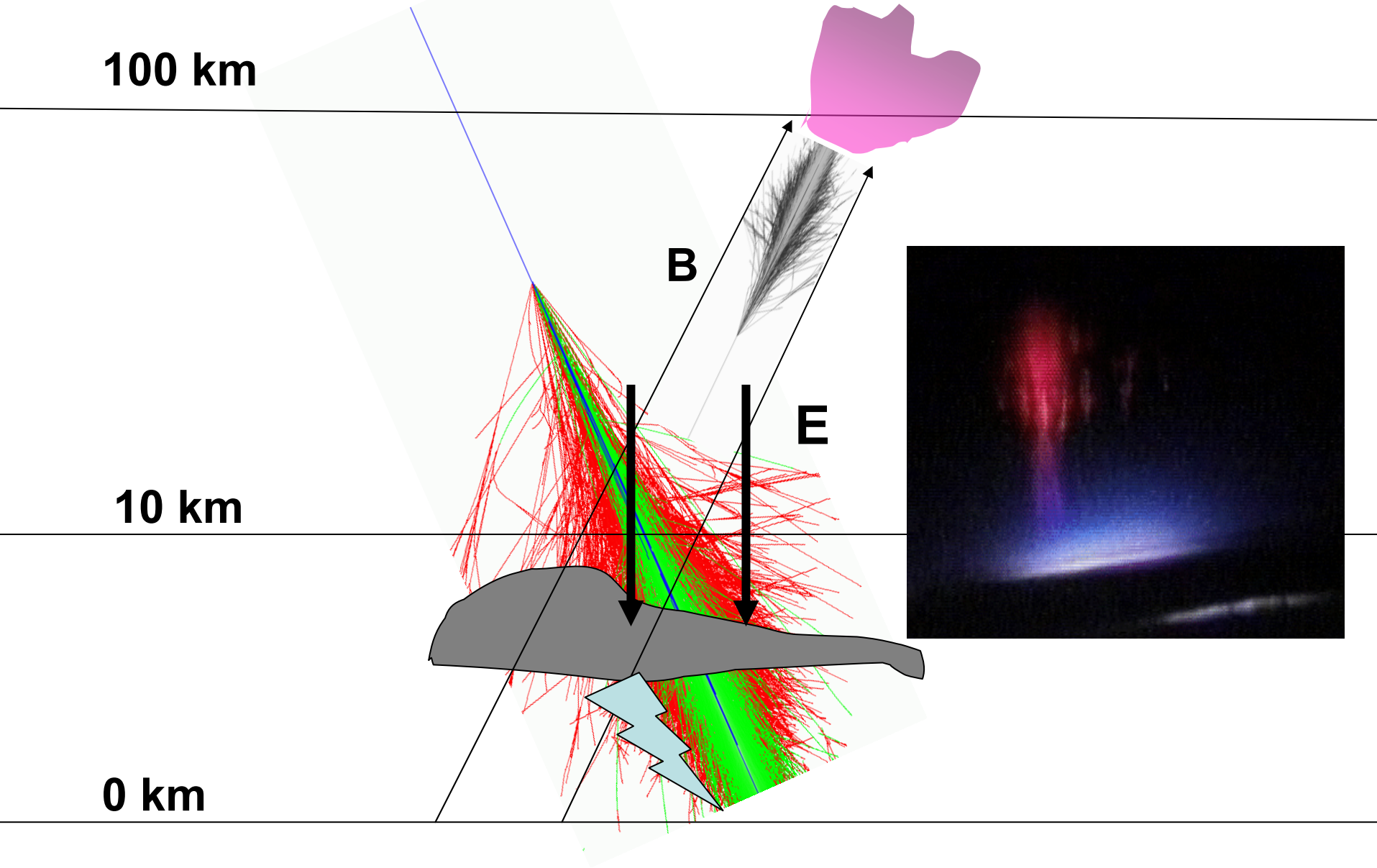
1985 1990 1995 2000 2005 2010 2015 2020

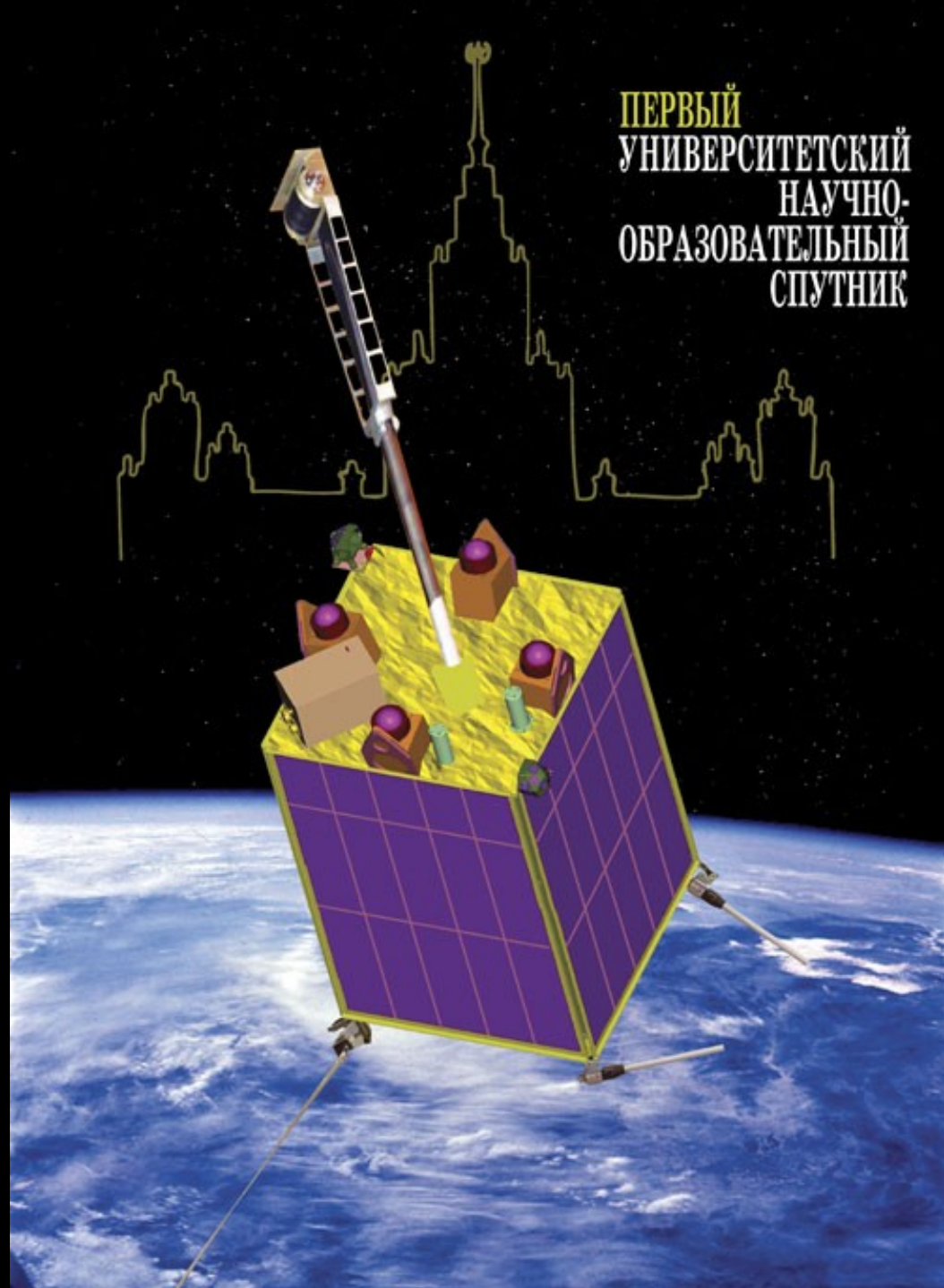
Year



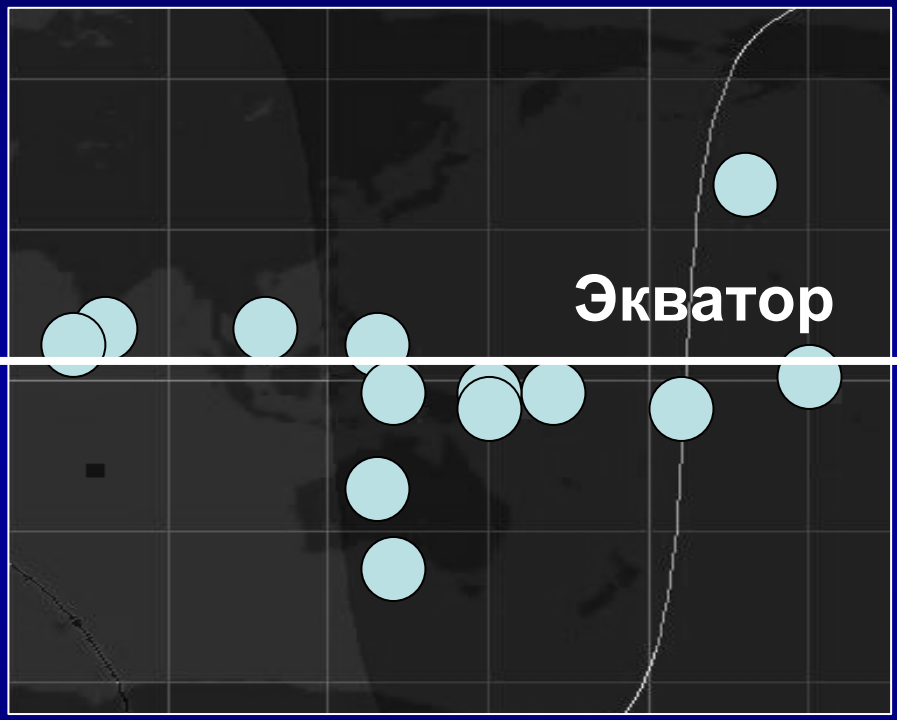
Can the Earth be a source of cosmic rays???

Sprites, elves and other devils (TLE)

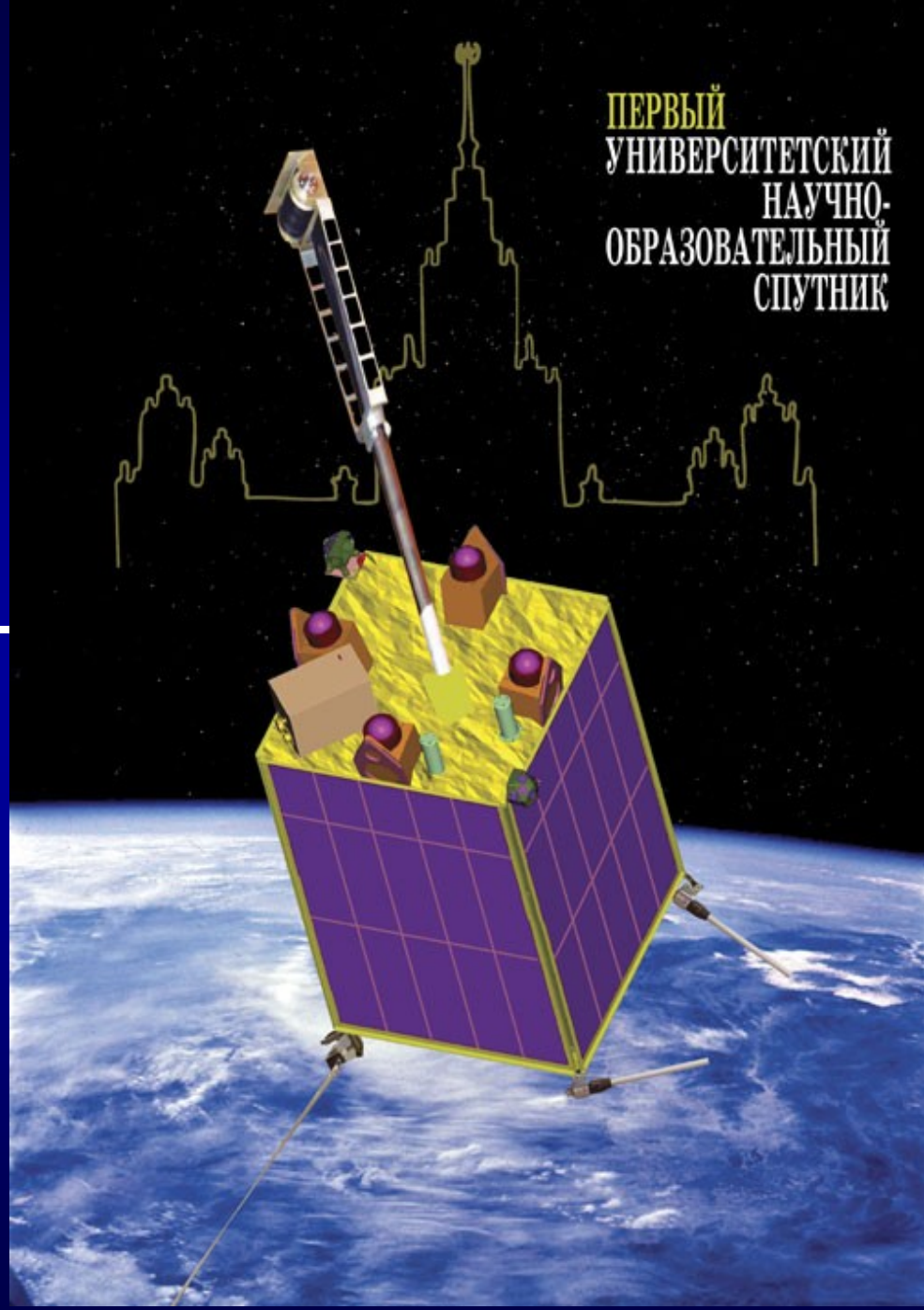



ПЕРВЫЙ
УНИВЕРСИТЕТСКИЙ
НАУЧНО-
ОБРАЗОВАТЕЛЬНЫЙ
СПУТНИК

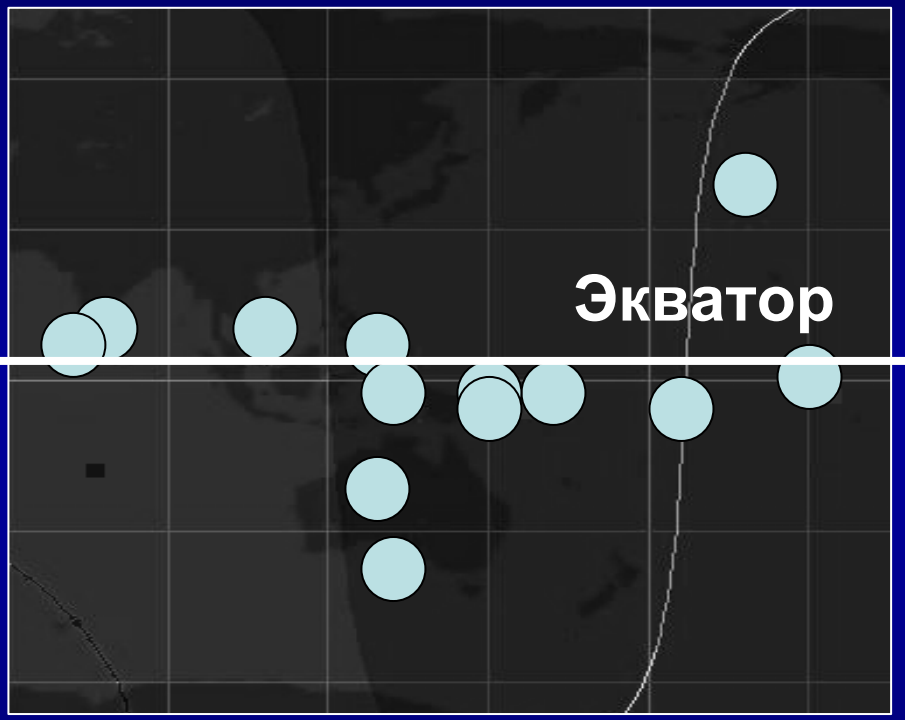
UV- flashes ~10's msec



"Universitetskii – Tatiana"
Febrauary, 2005



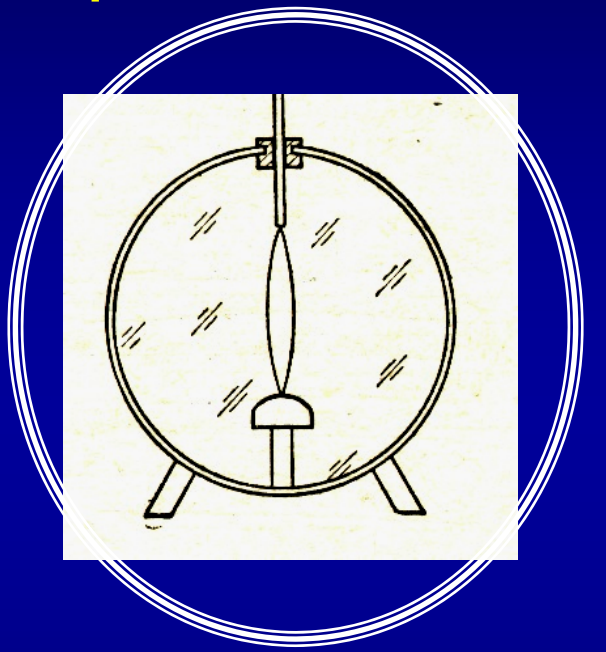
UV- flashes ~10’s msec



“Universitetskii – Tatiana”
Febrauary, 2005

The first indication on the near-earth origin of cosmic rays

Wilson's experiments with electroscope



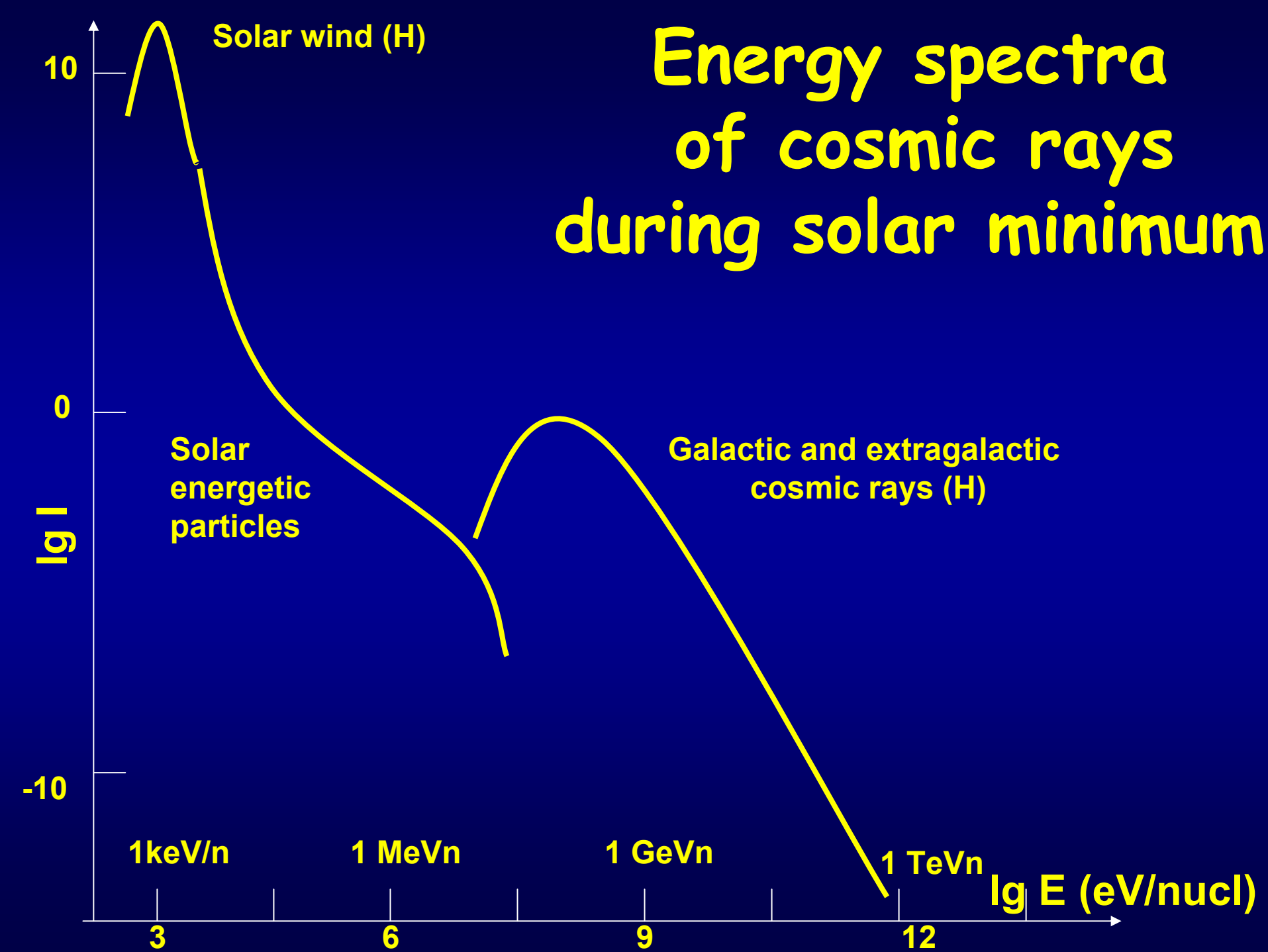
-existance of additional current;

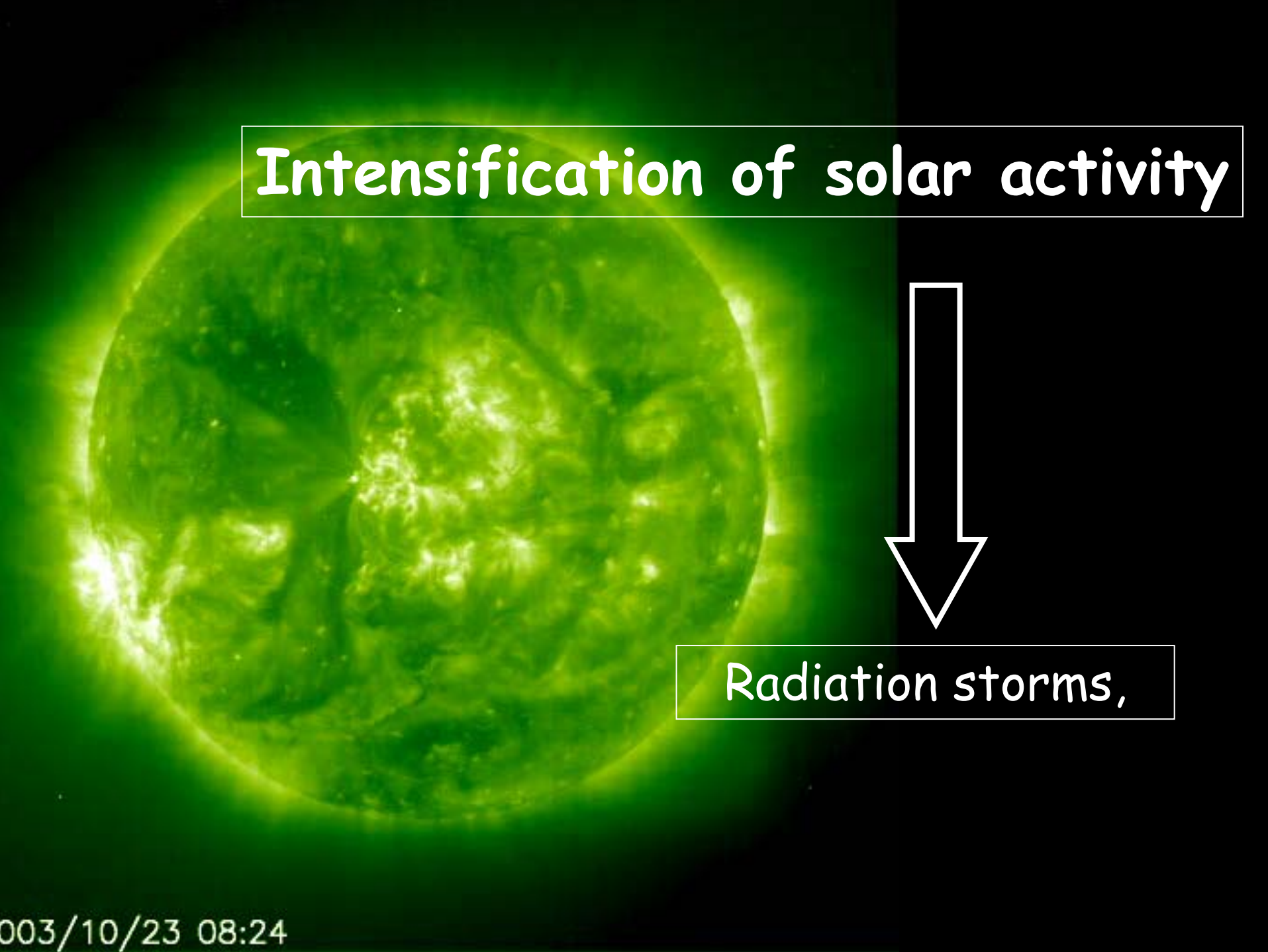
-high energy particles accelerated in electric fields of thunderstorm's clouds

It was in 1900 !

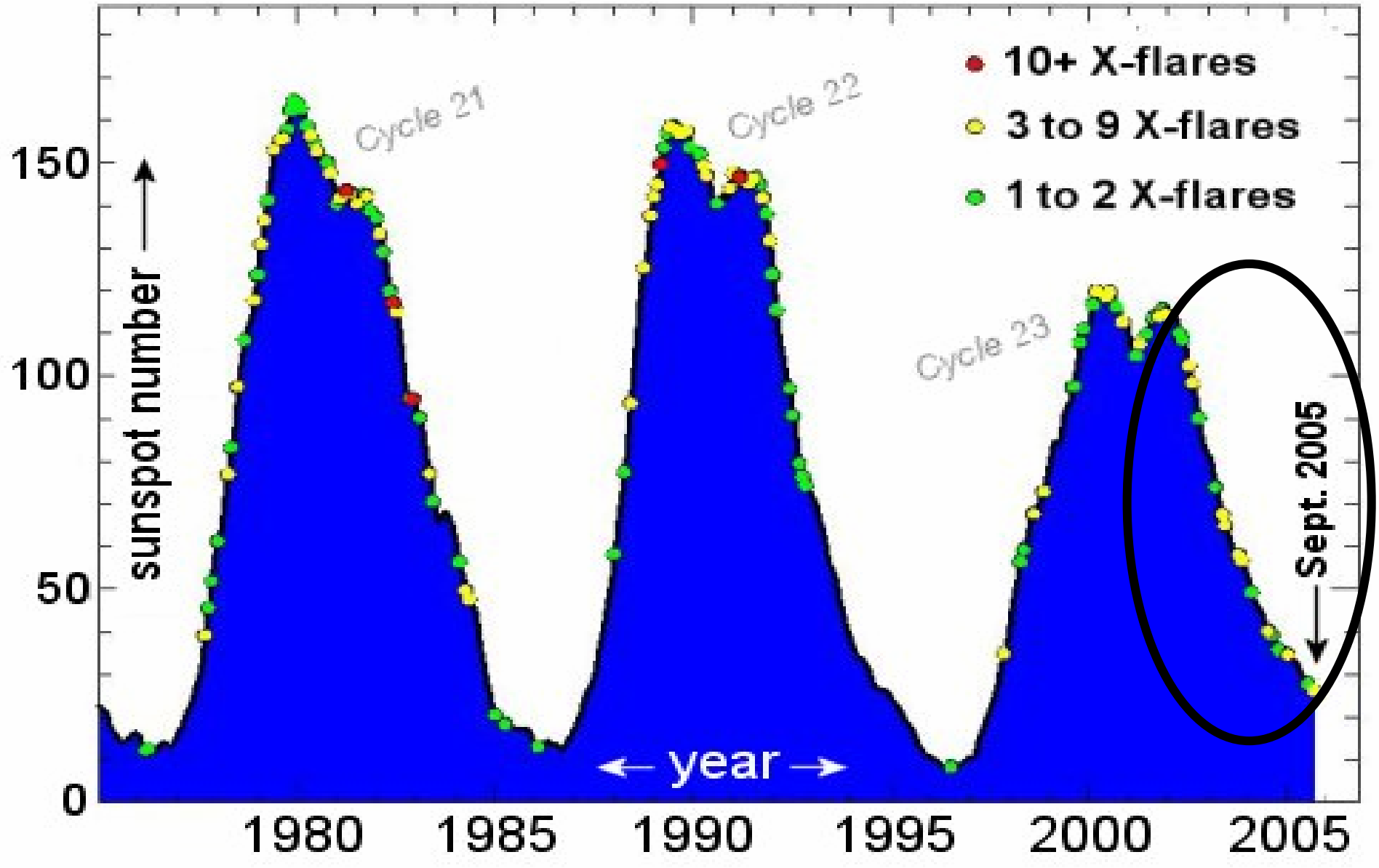

Солнечные
космические лучи
Ударная волна
Магнитосфера
Земли
Межпланетное
магнитное поле

Energy spectra of cosmic rays during solar minimum



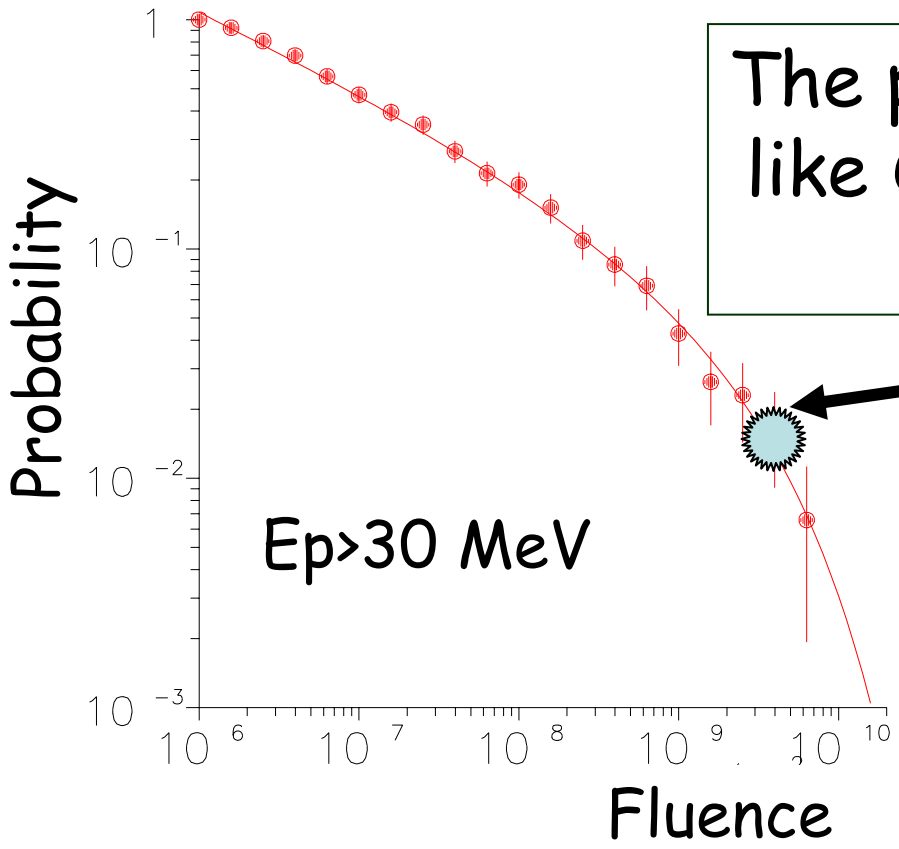

Intensification of solar activity
Radiation storms,
003/10/23 08:24

Solar Minimum Explodes



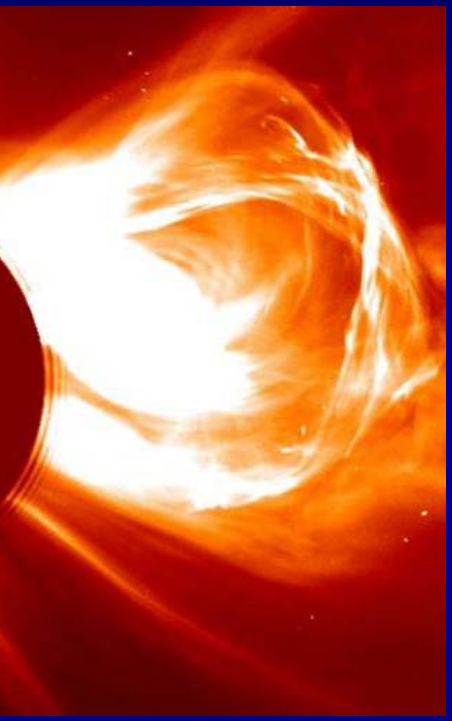
SEP modelling

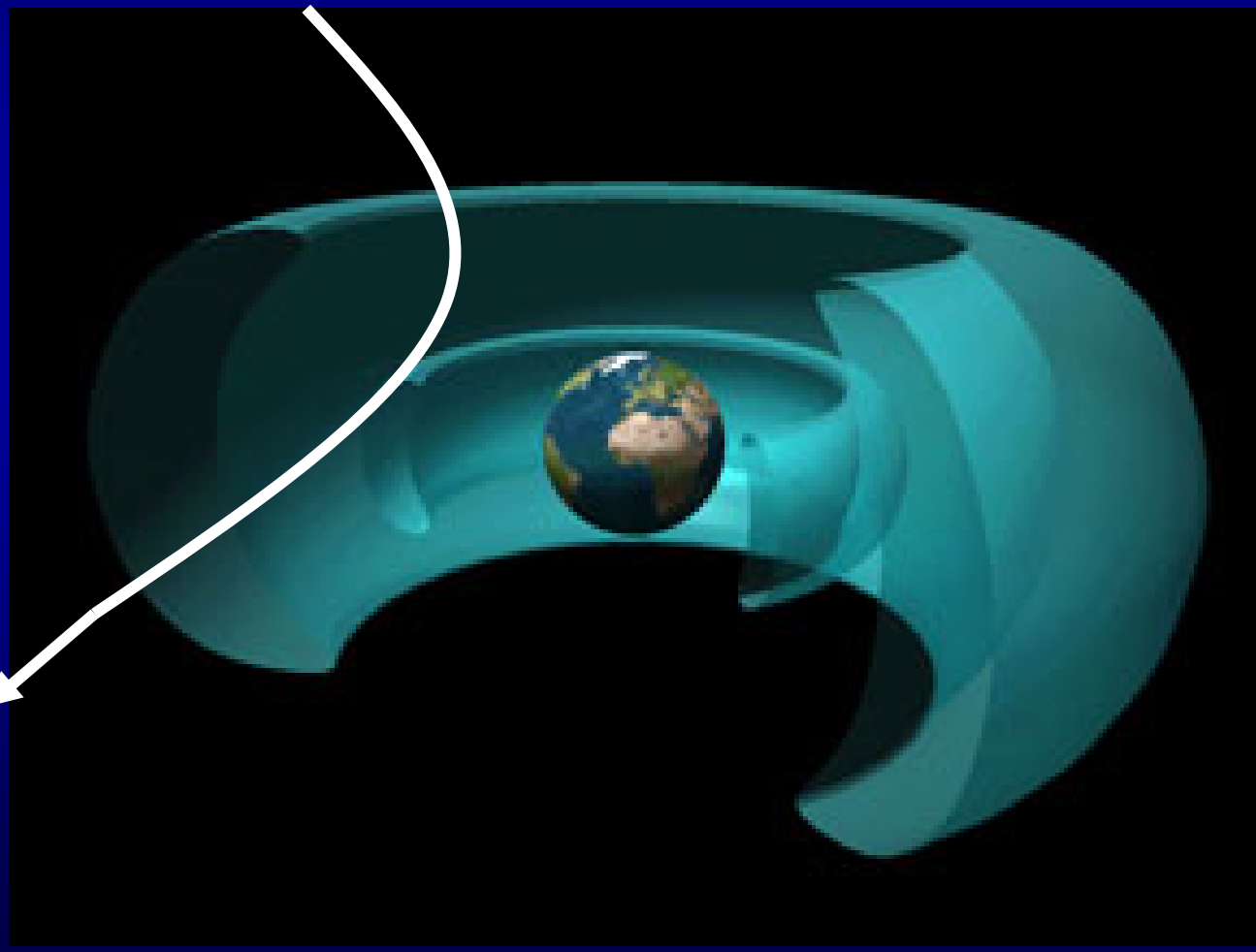
From Nymmik's SINP/MSU SEP model:



The probability of event like Oct.,28, 2003 level is ~2%!

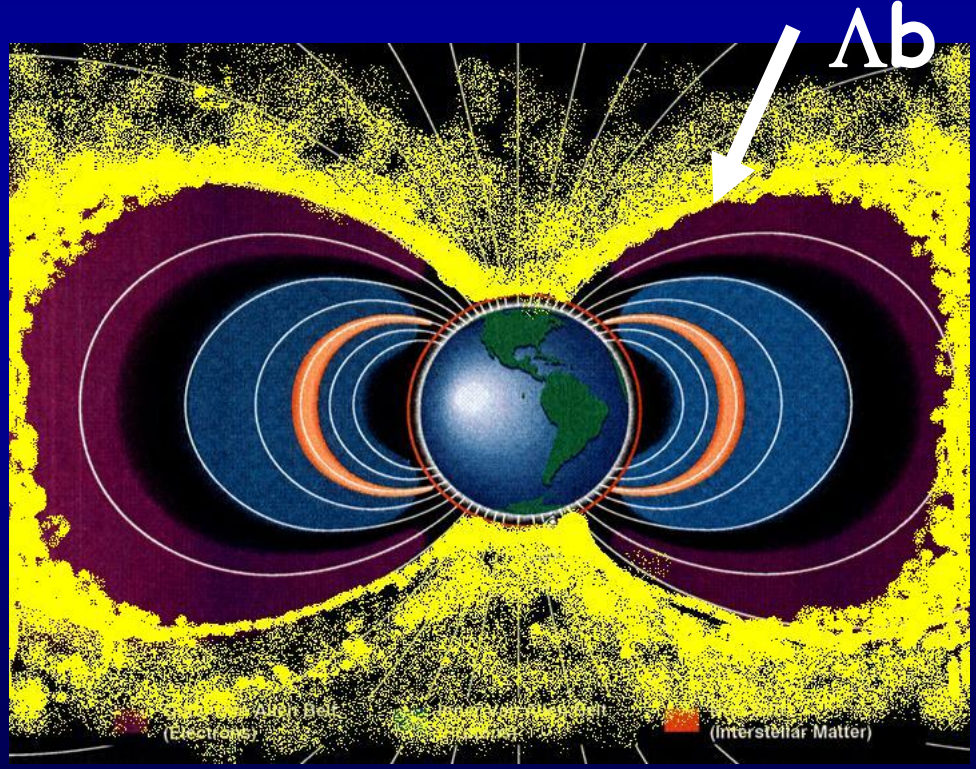
Solar energetic particles

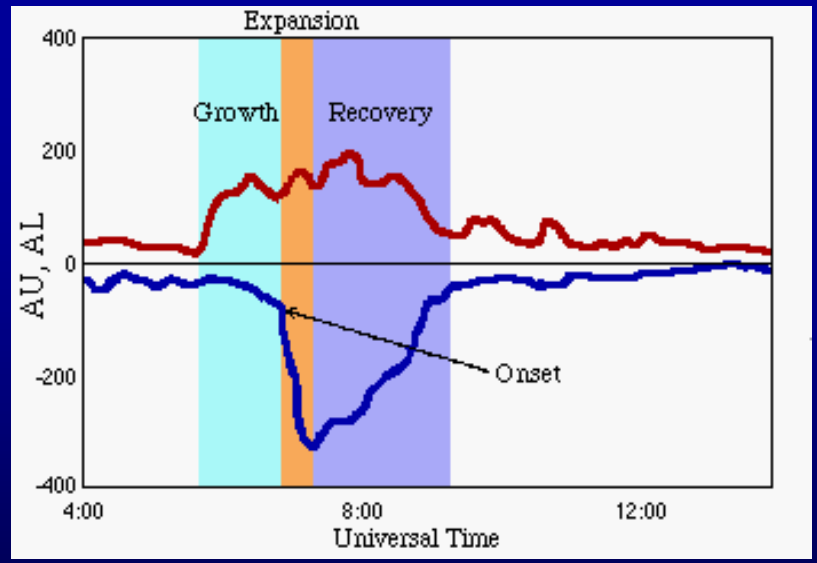




Transmission function during quiet/stormy magnetosphere

Effective rigidity of penetrating particles decreases during magnetic storm periods





October- November Radiation Storm

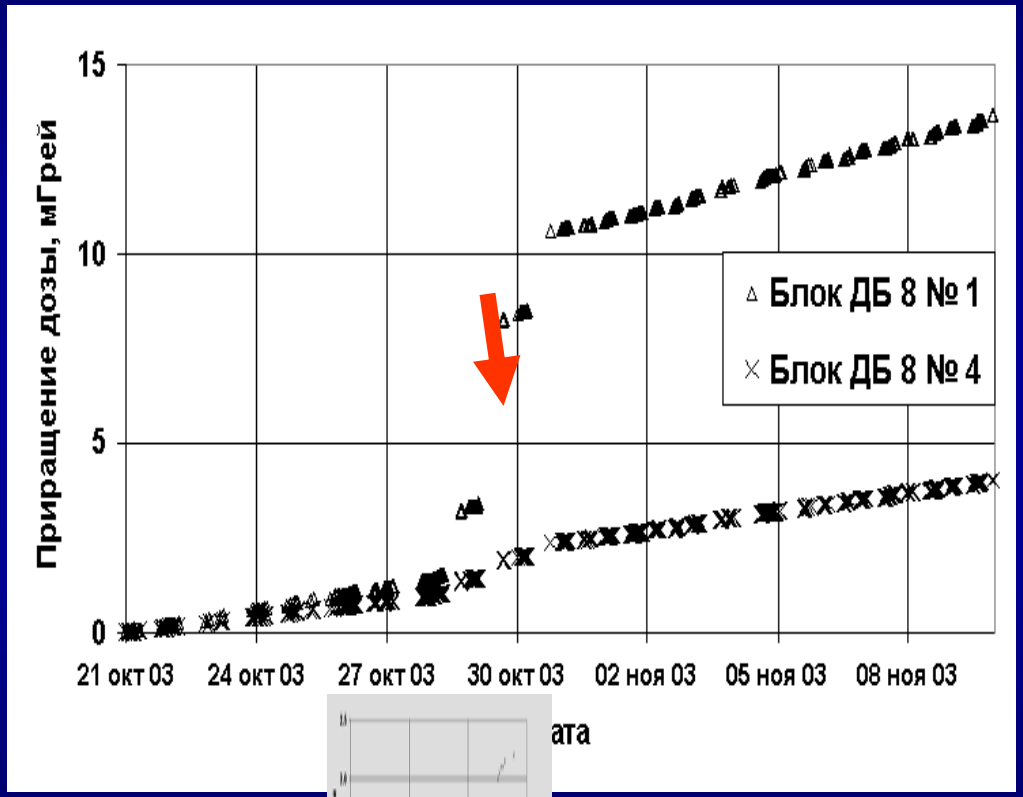
ISS dosimetry

ISS/SRC, R16
data,
SINP, IMBP

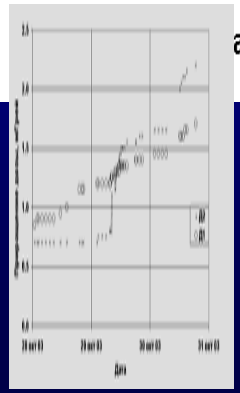
October- November Radiation Storm

ISS dosimetry

ISS/SRC, R16 data, SINP, IMBP

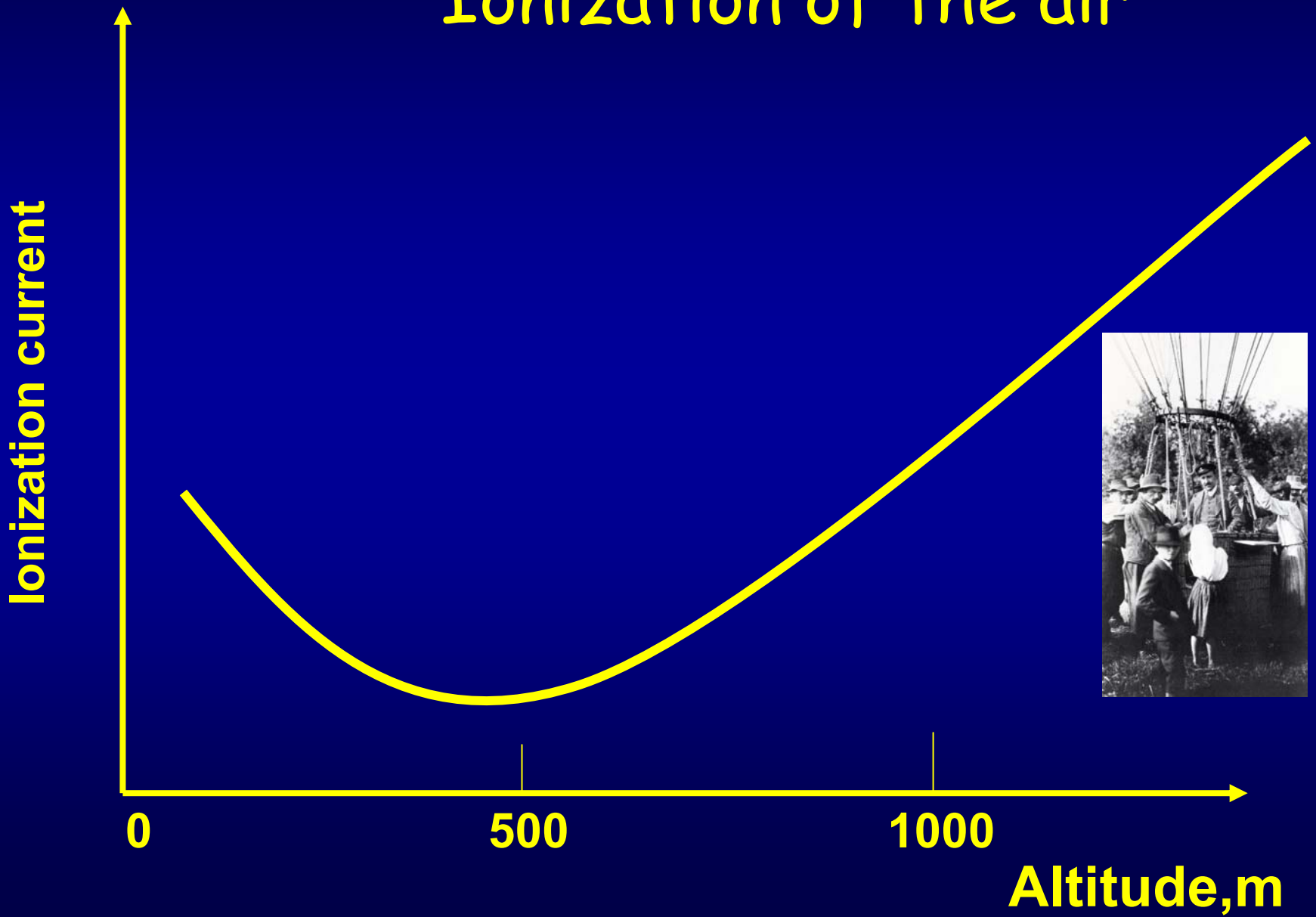


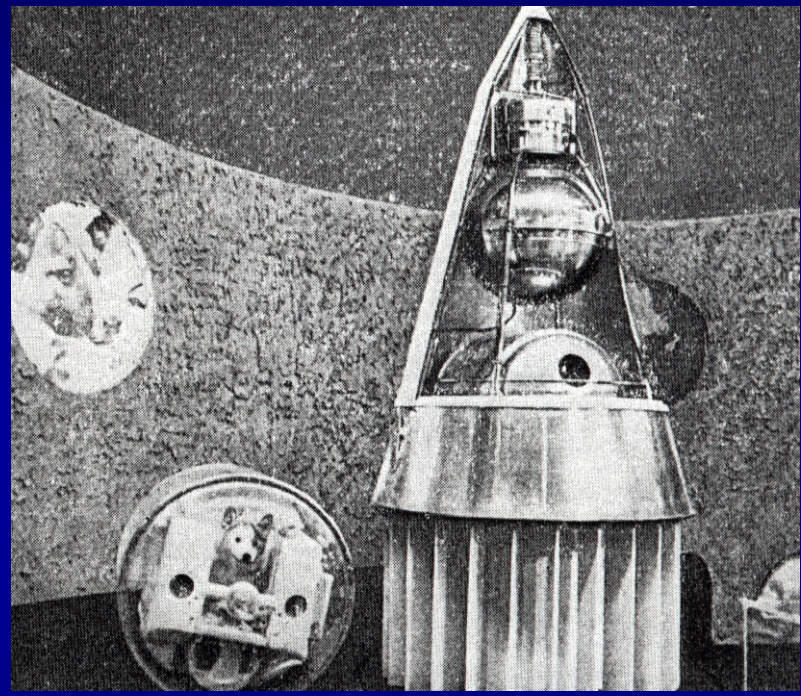
DB-8



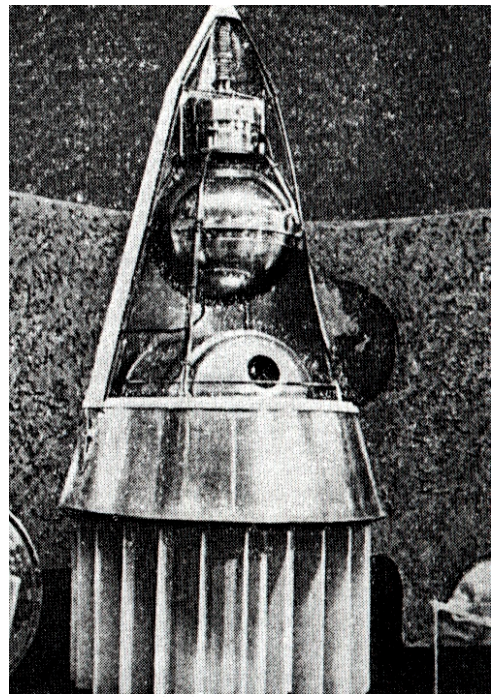
R16

Ionization of the air





Academician Sergey Vernov



Эксперимент

Ожидаемая зависимость

Поток частиц, отн. ед.

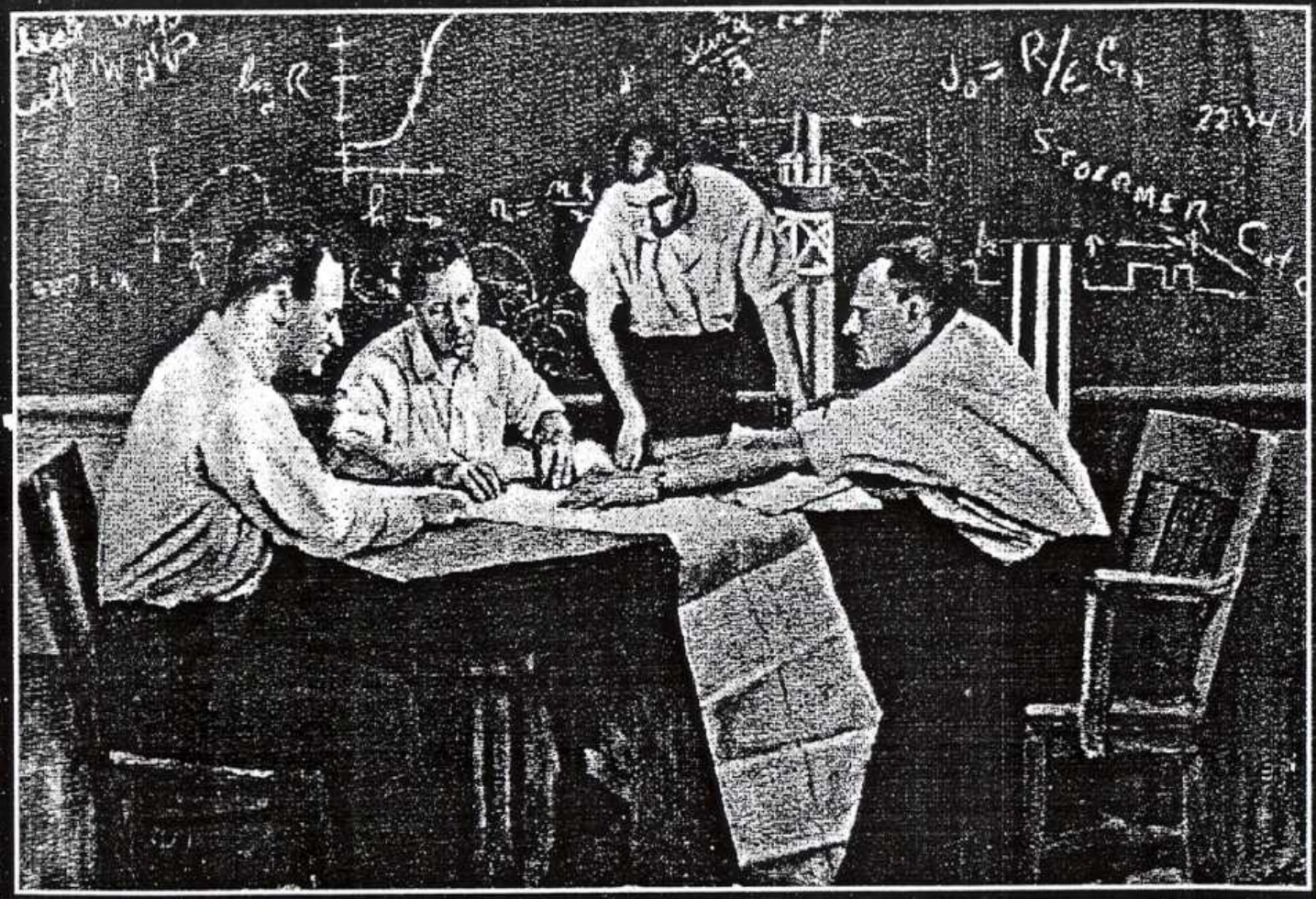
10

1

40 50 60 65 60

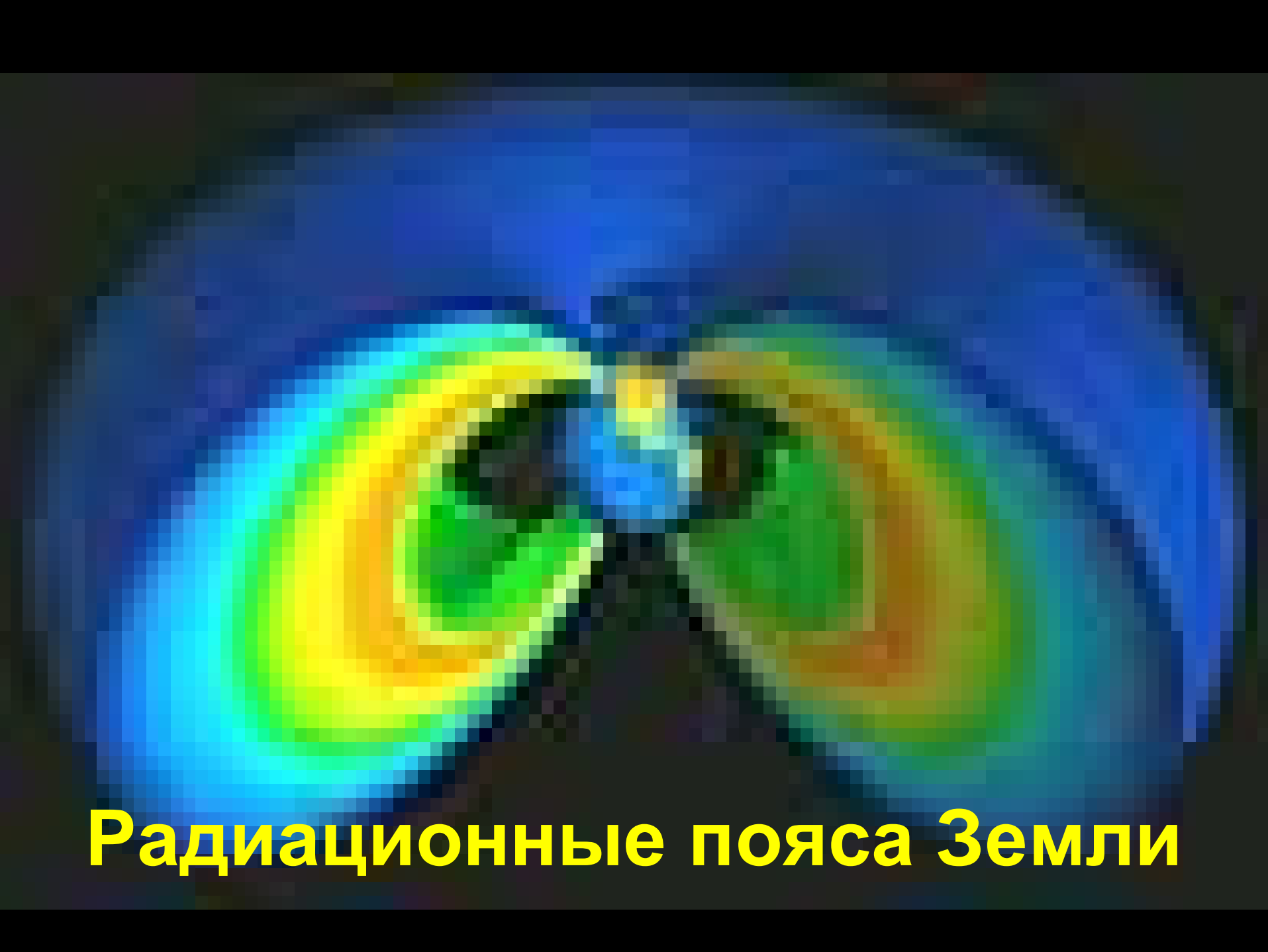
Широта, градусы

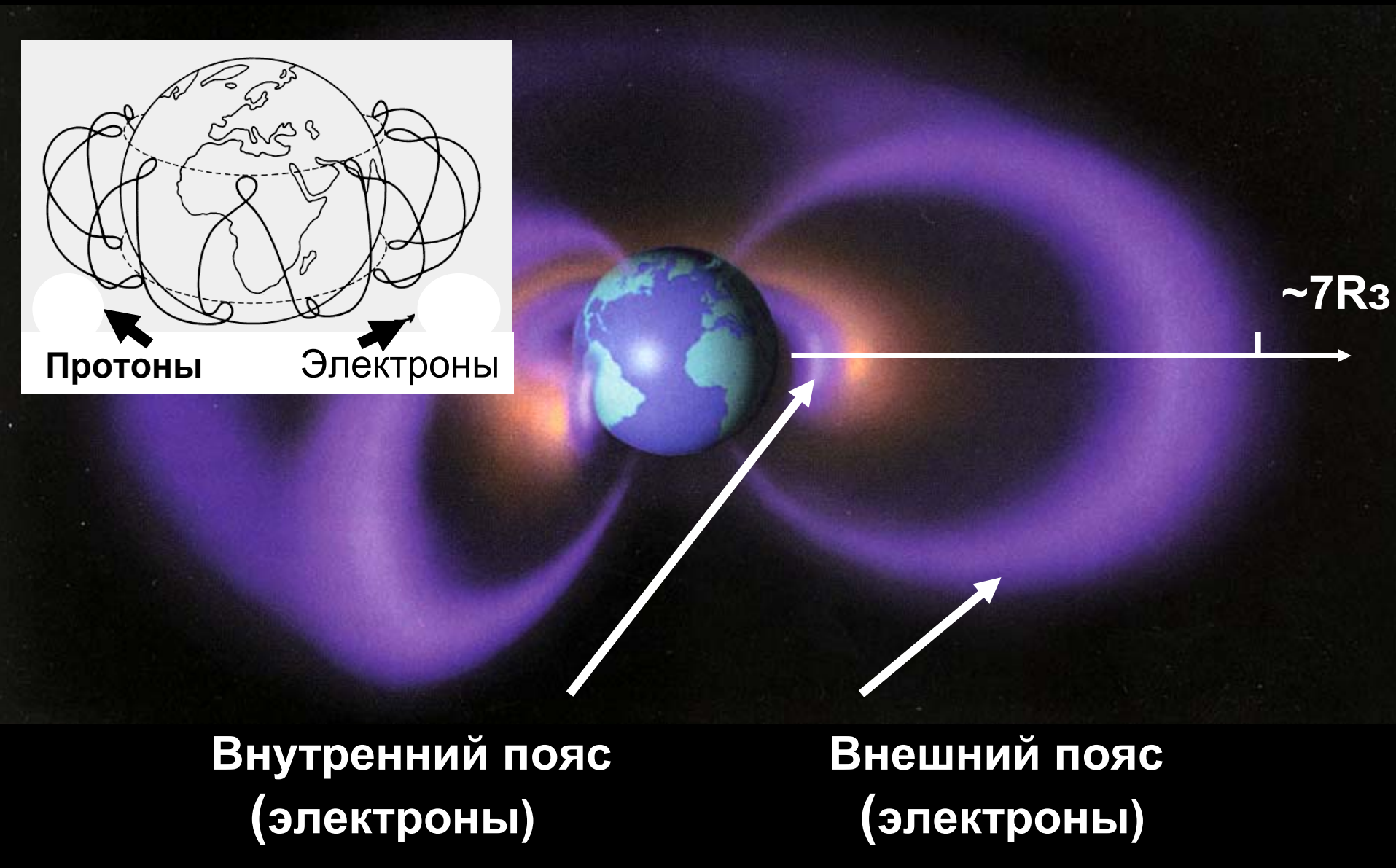
J.Van Allen



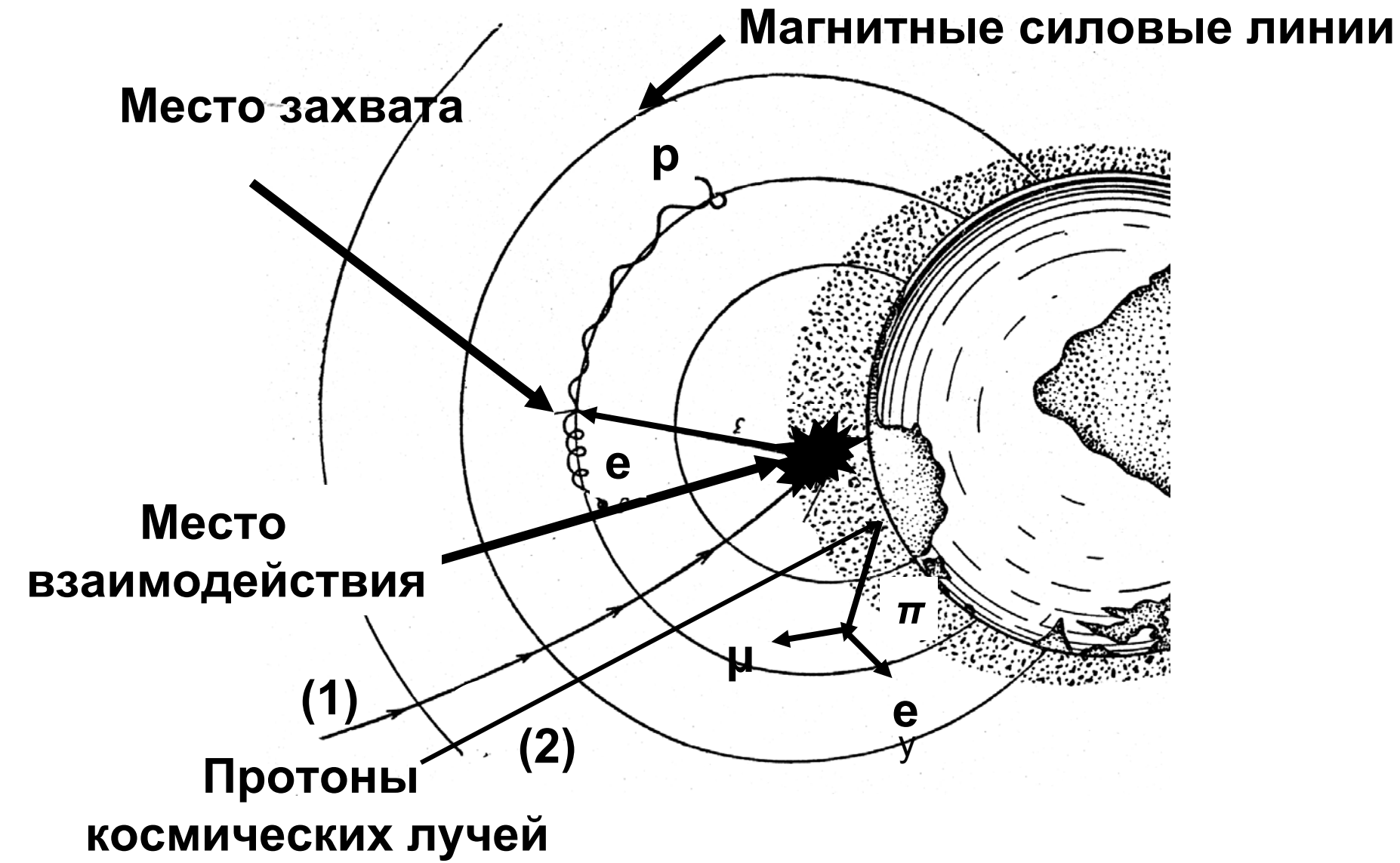
"My God, space is radioactive!"

Dr. Ernest C. Ray
March 28, 1958

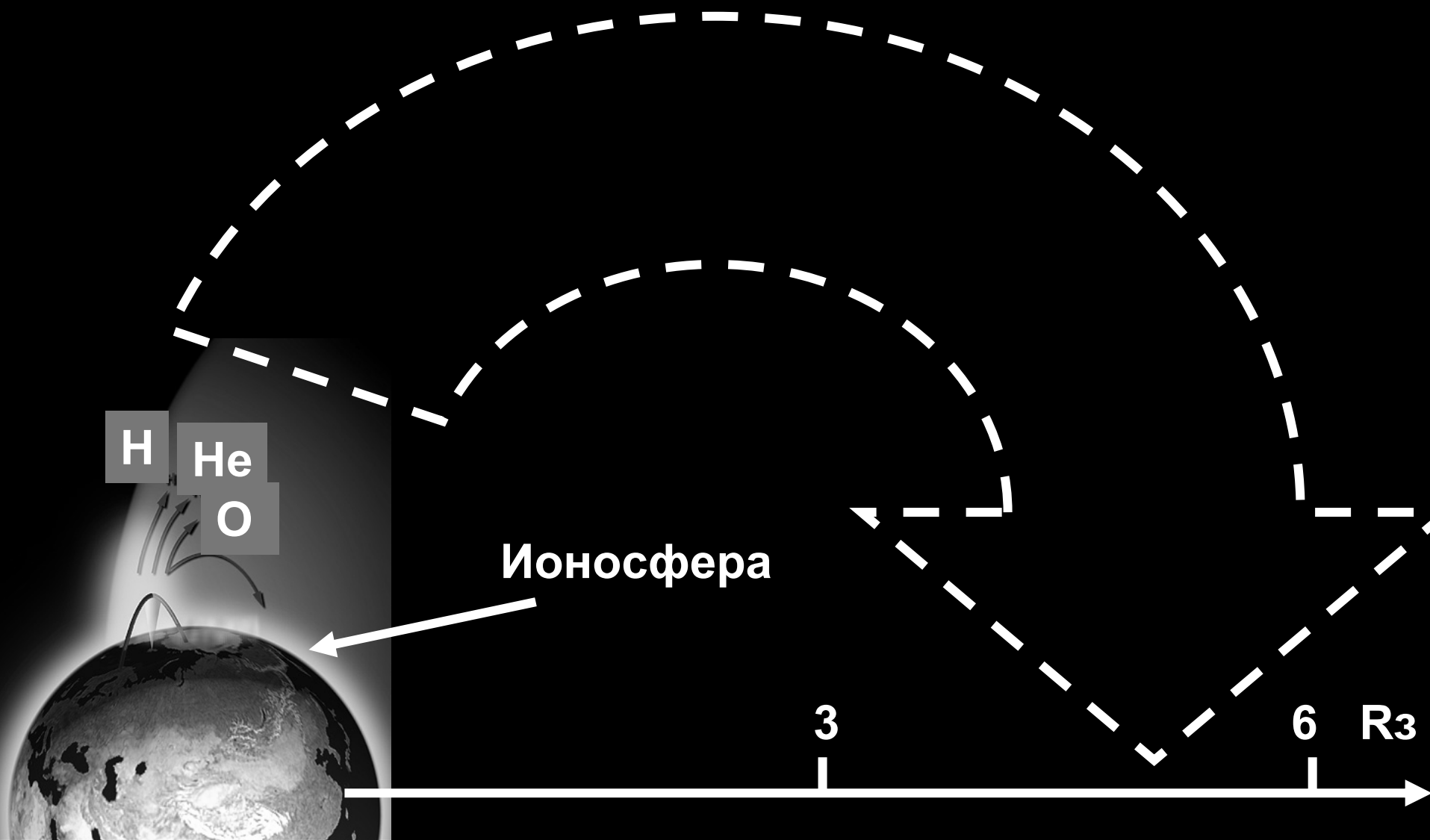

Радиационные пояса Земли


Протоны
Электроны
~7R3
Внутренний пояс
(электроны)
Внешний пояс
(электроны)

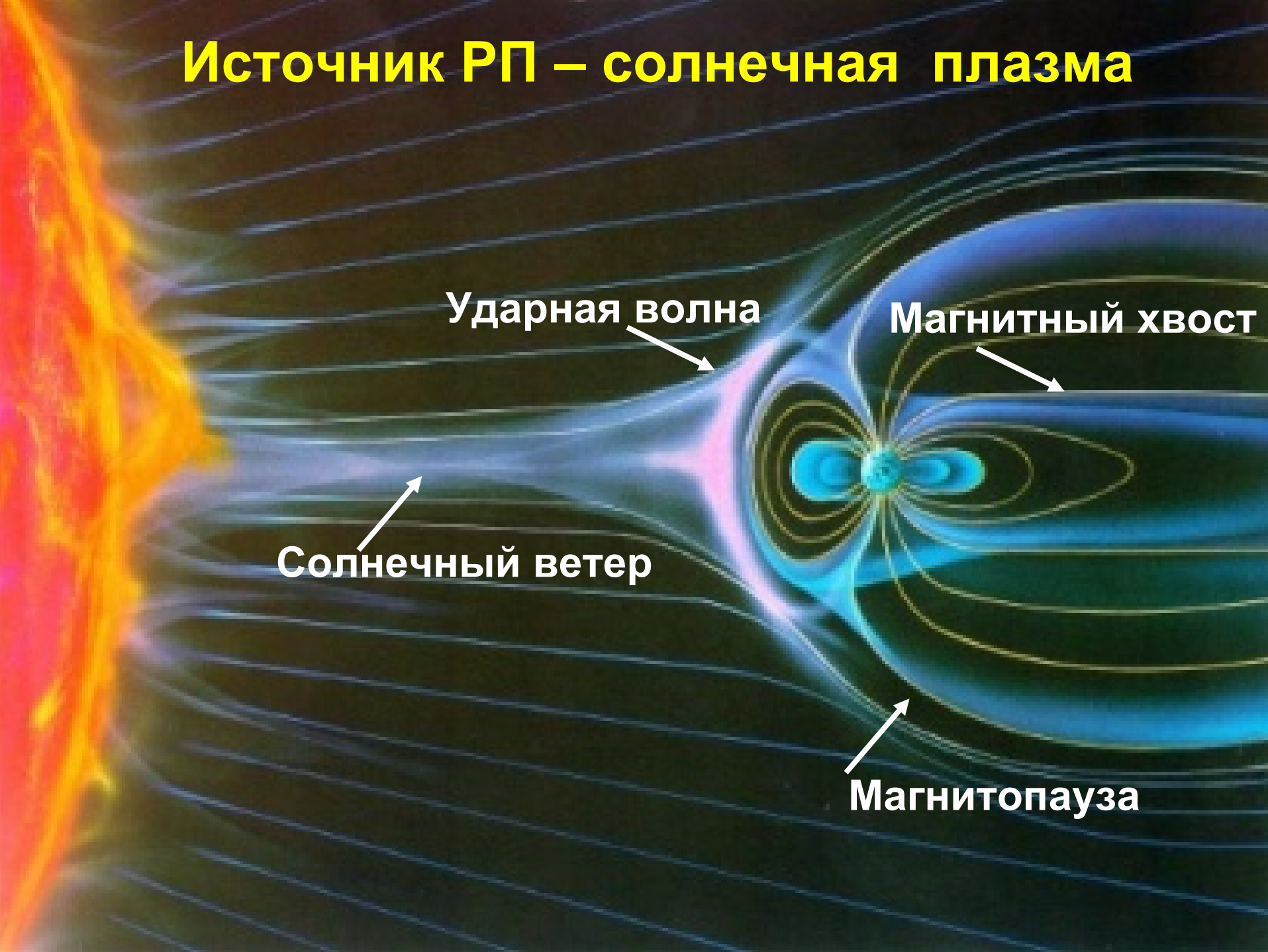
Источник РП – космические лучи



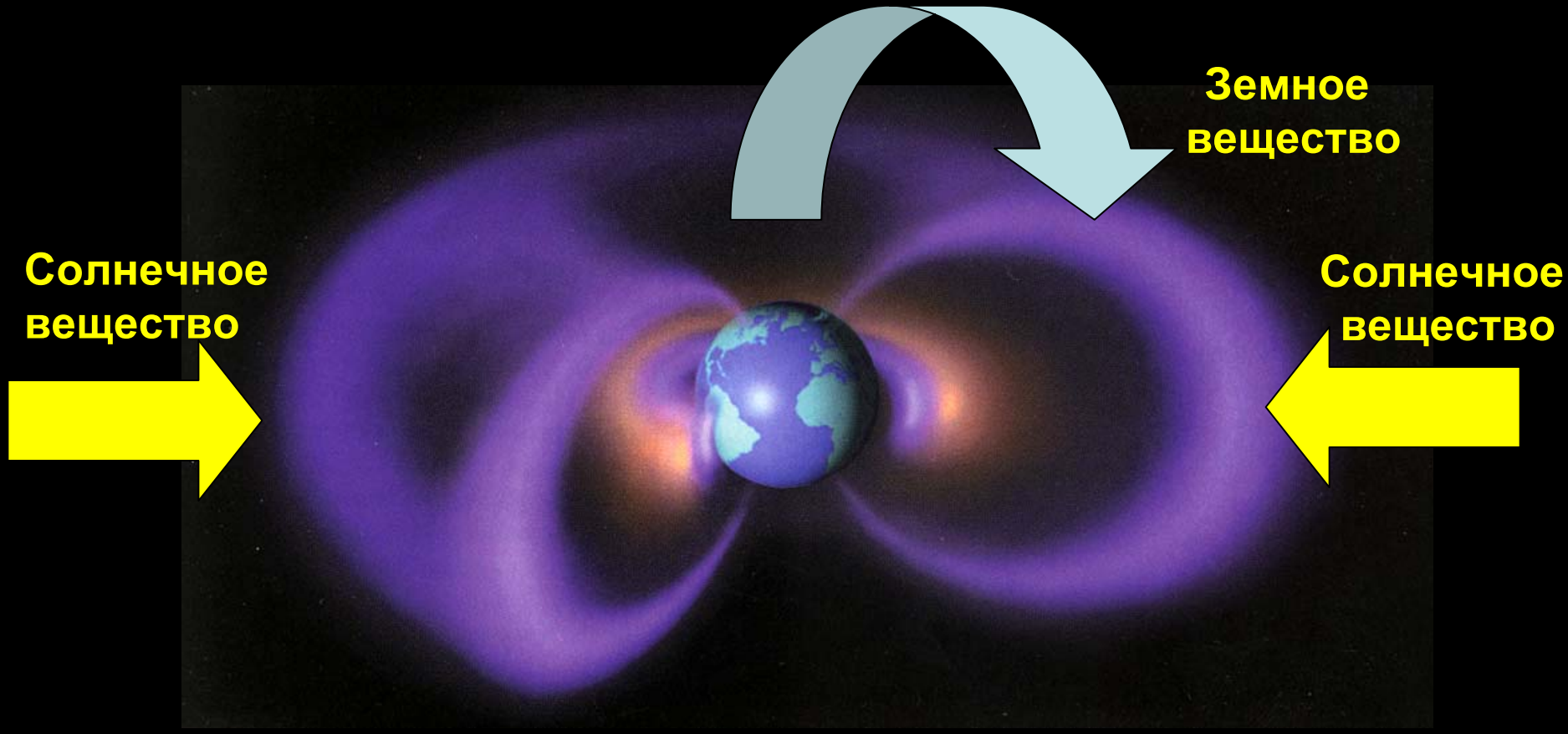
Источник РП – ионосферная плазма



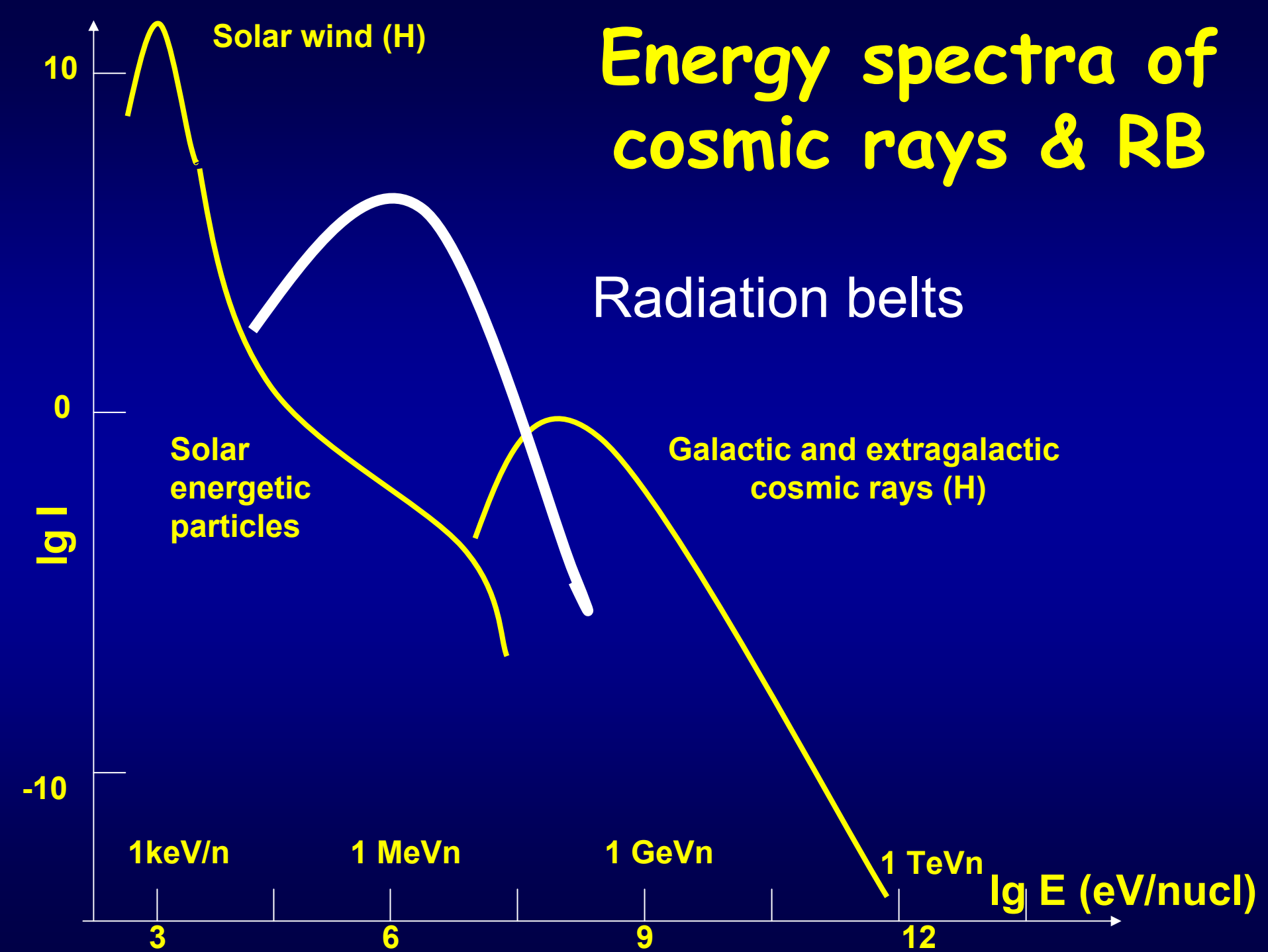
Источник РП – солнечная плазма



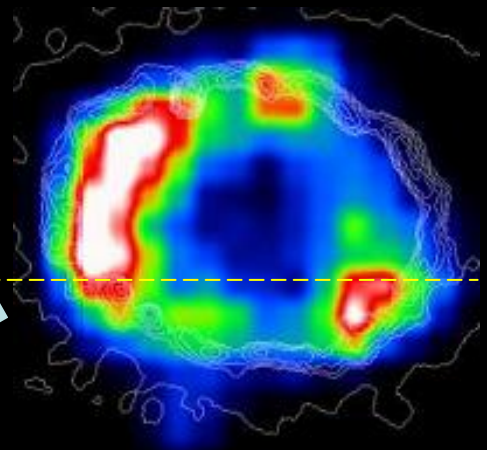
Радиационные пояса Земли



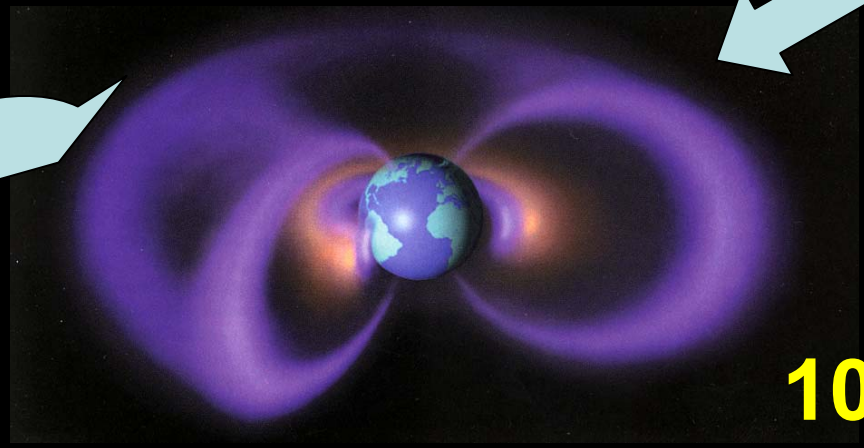
Energy spectra of cosmic rays & RB



Радиационное окружение Земли



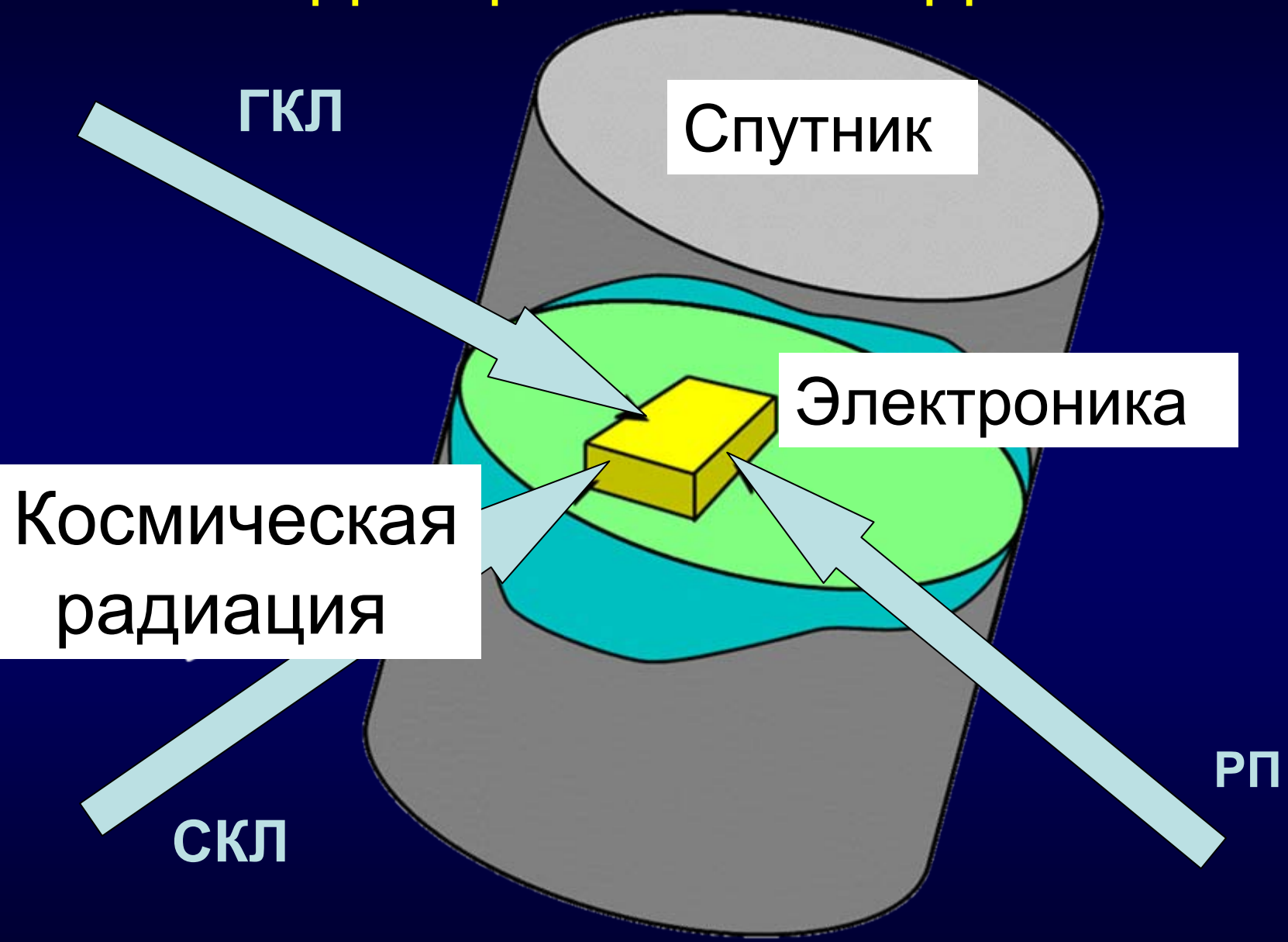
~10 ^{45} дж



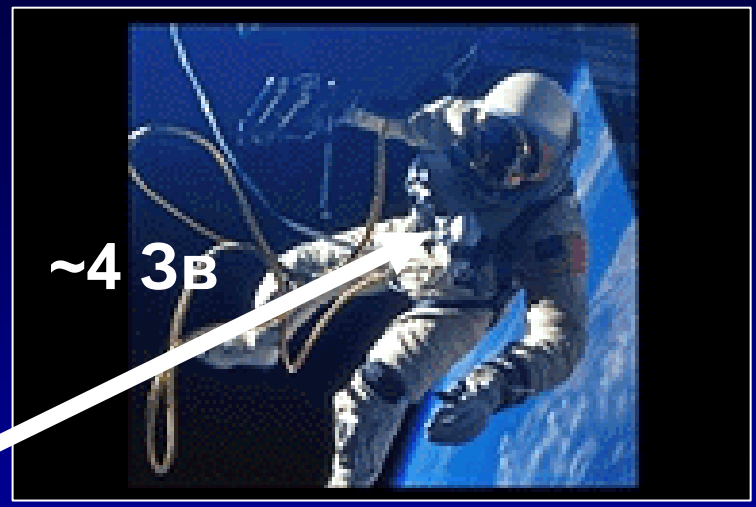
10 ^{22} дж

10 ^{25} дж

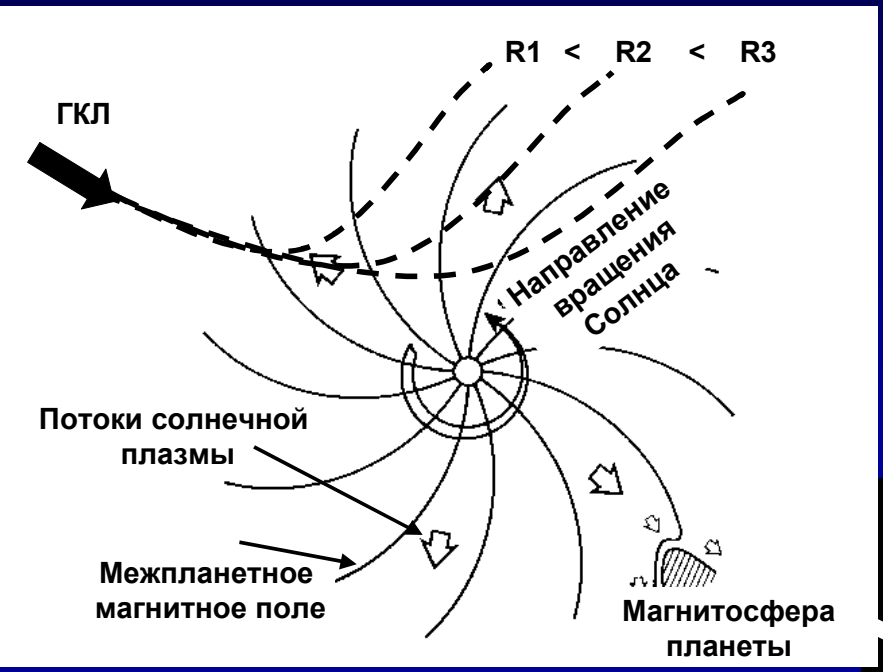
Радиационное воздействие

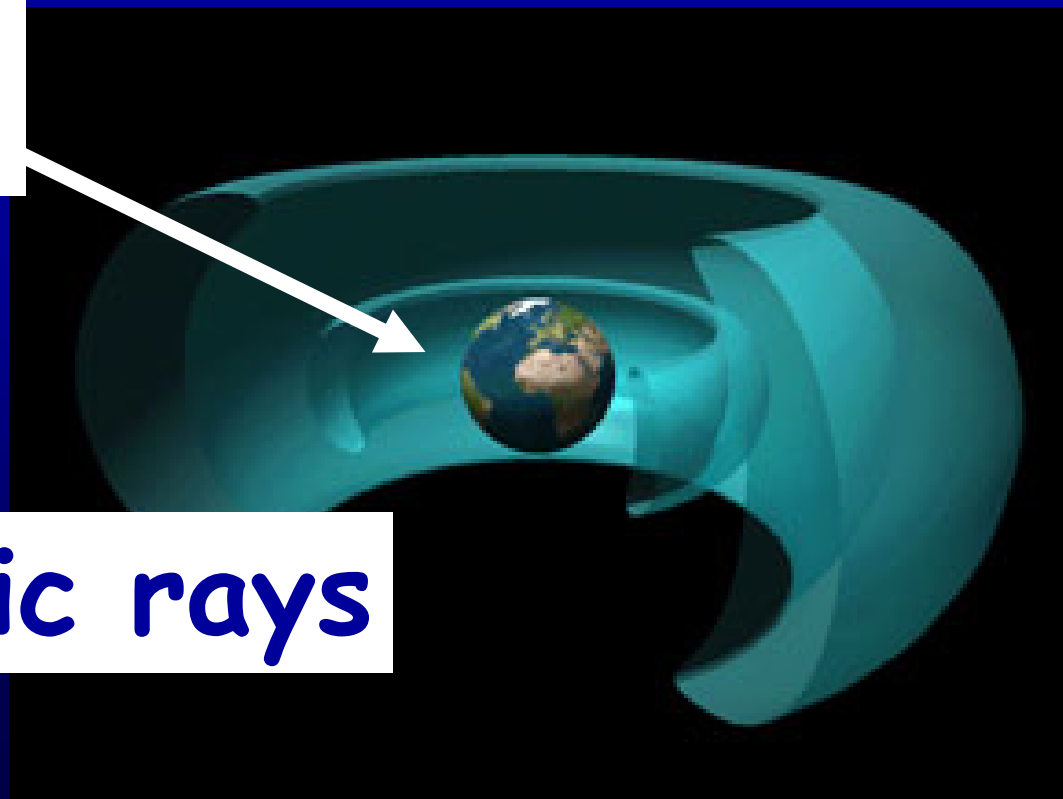


Радиационный эффект вспышки типа августа 1972



Earth's Radiation Environment

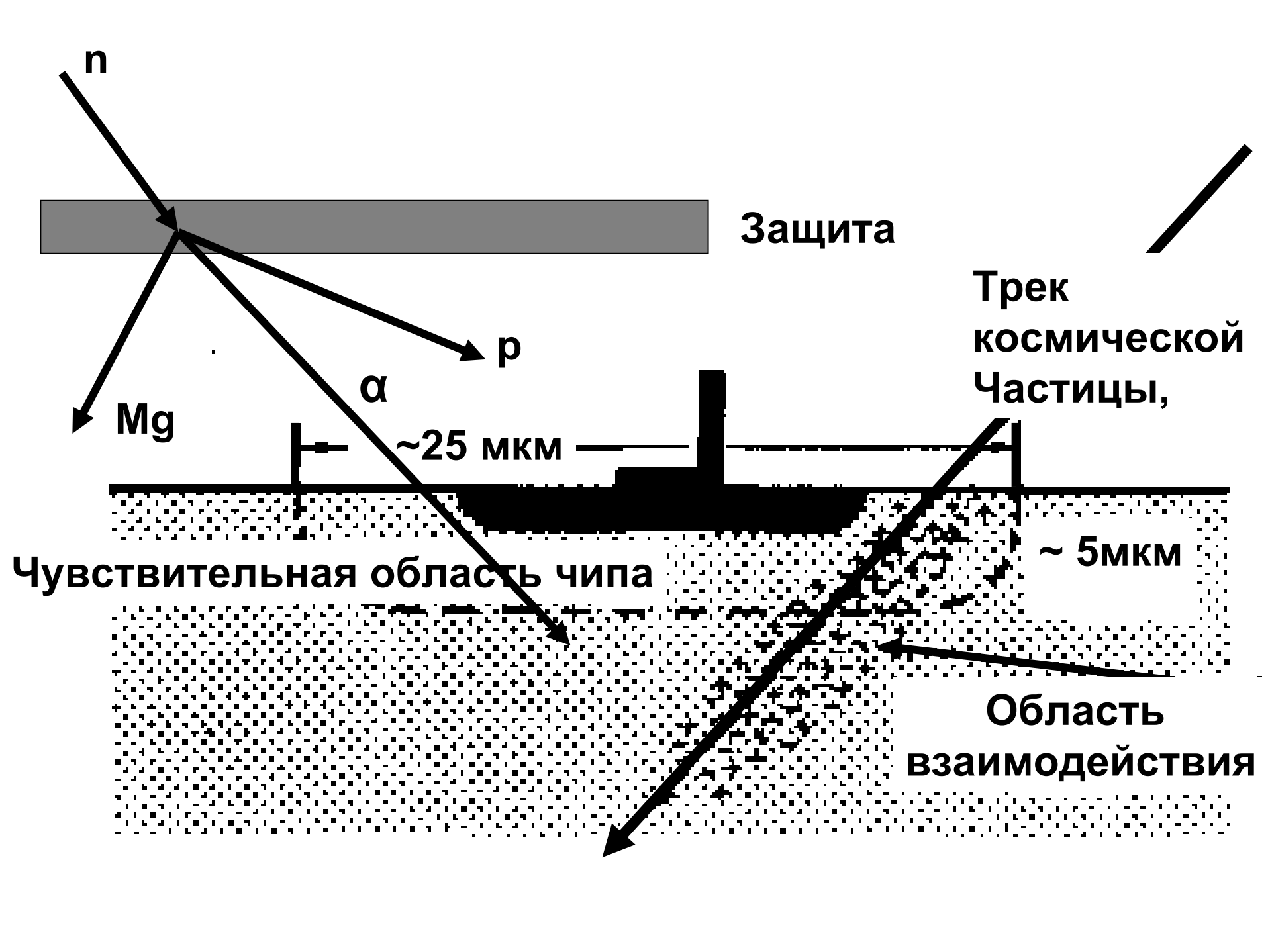


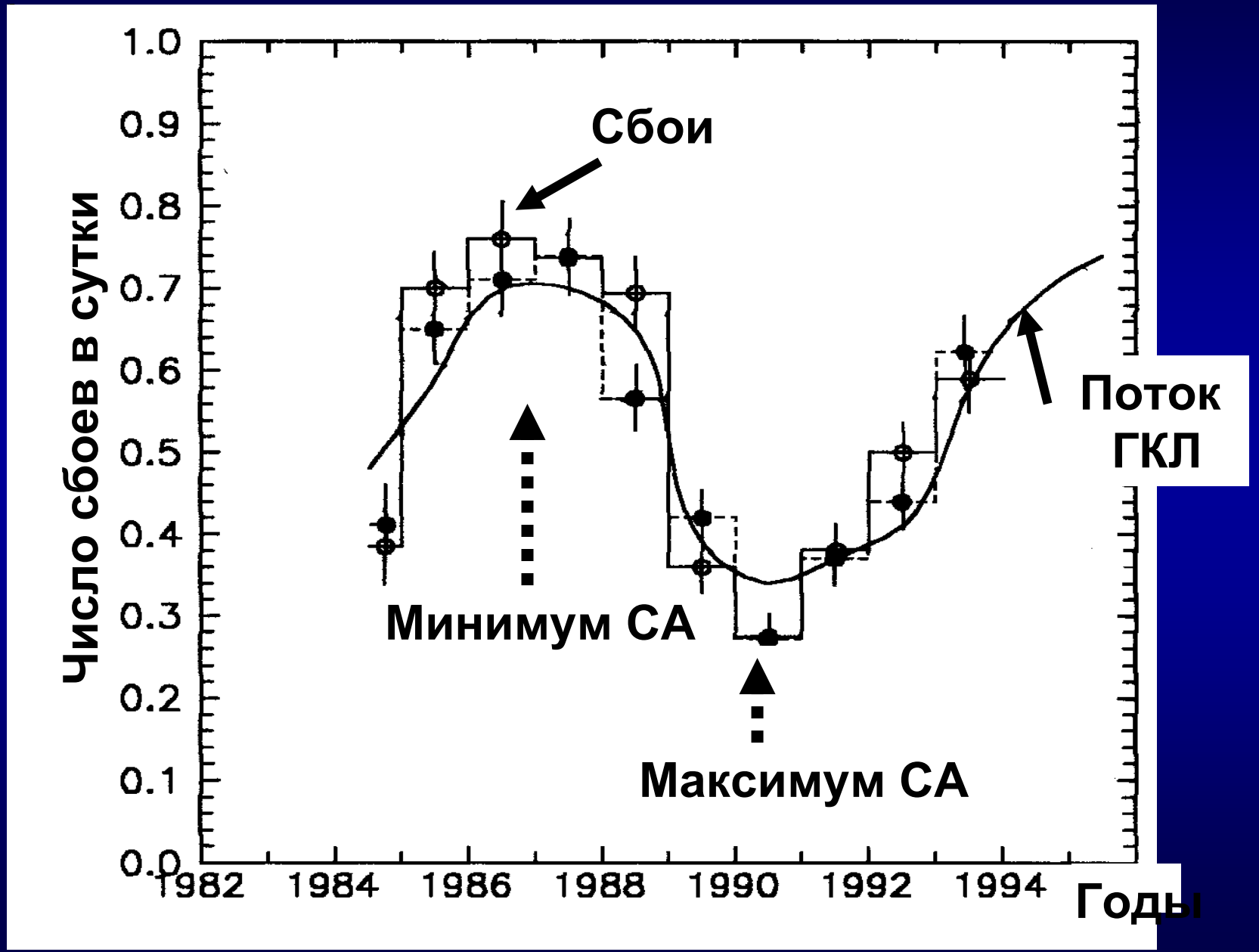


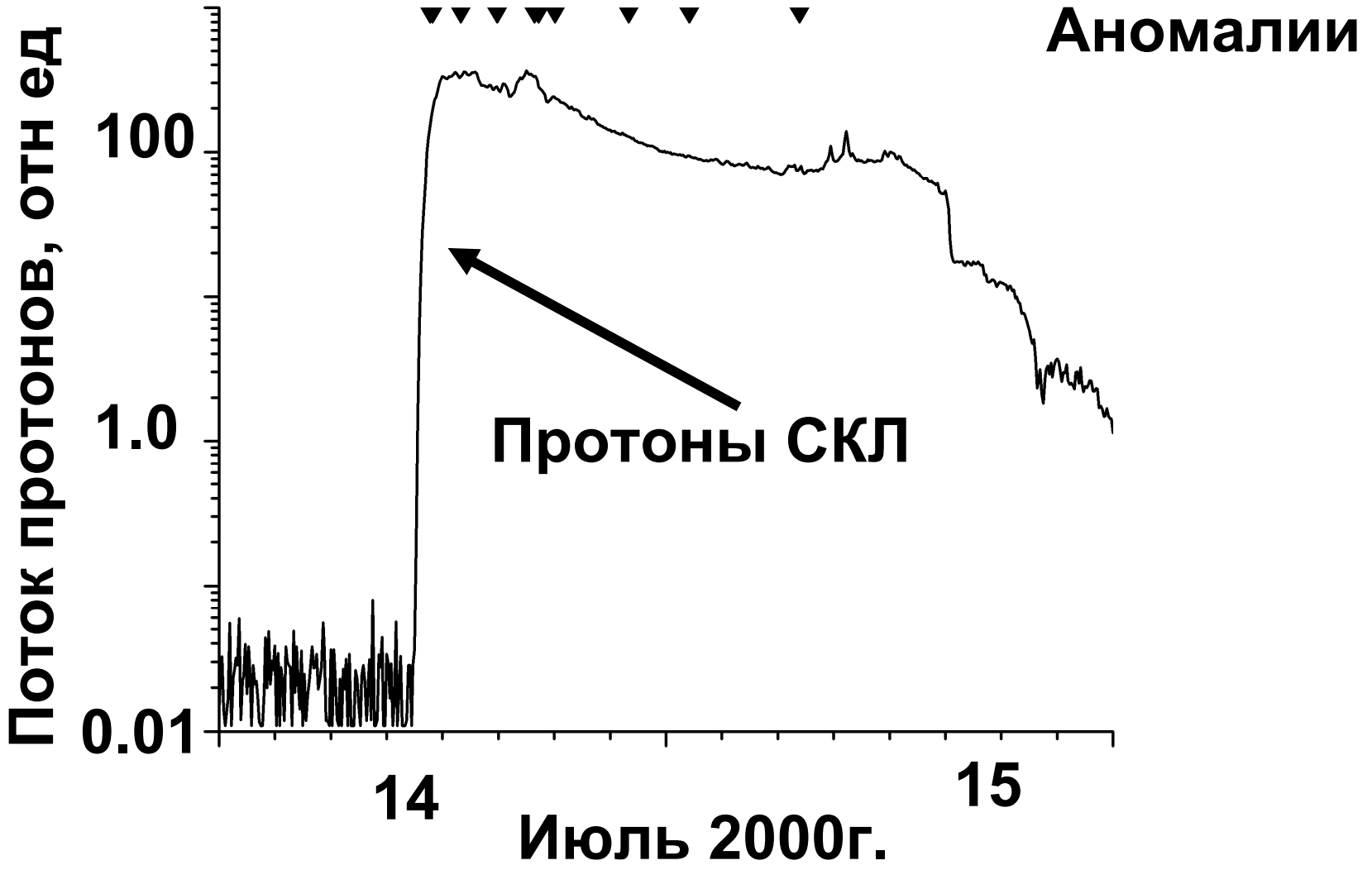
Galactic cosmic rays

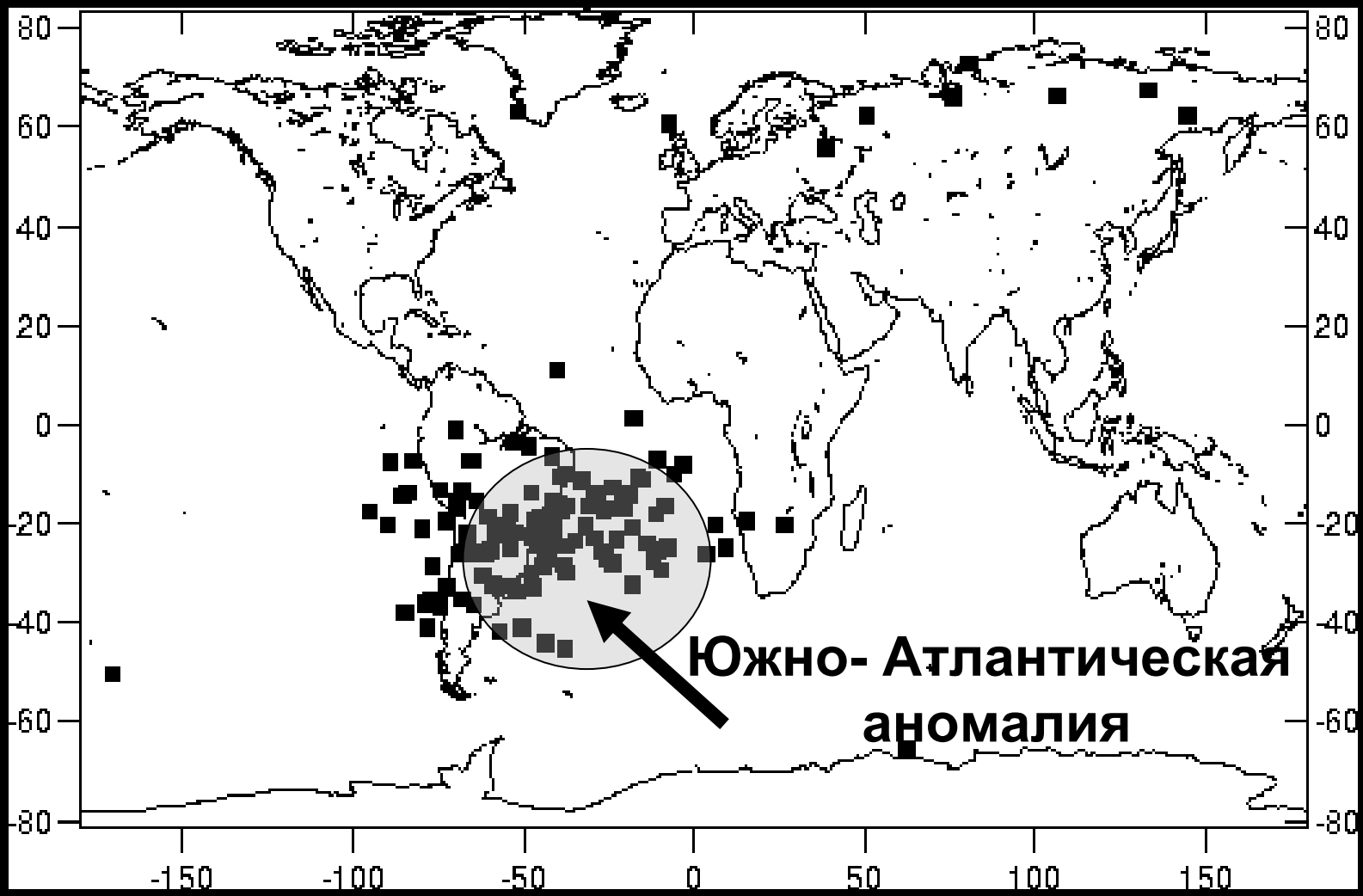
Apollo –11

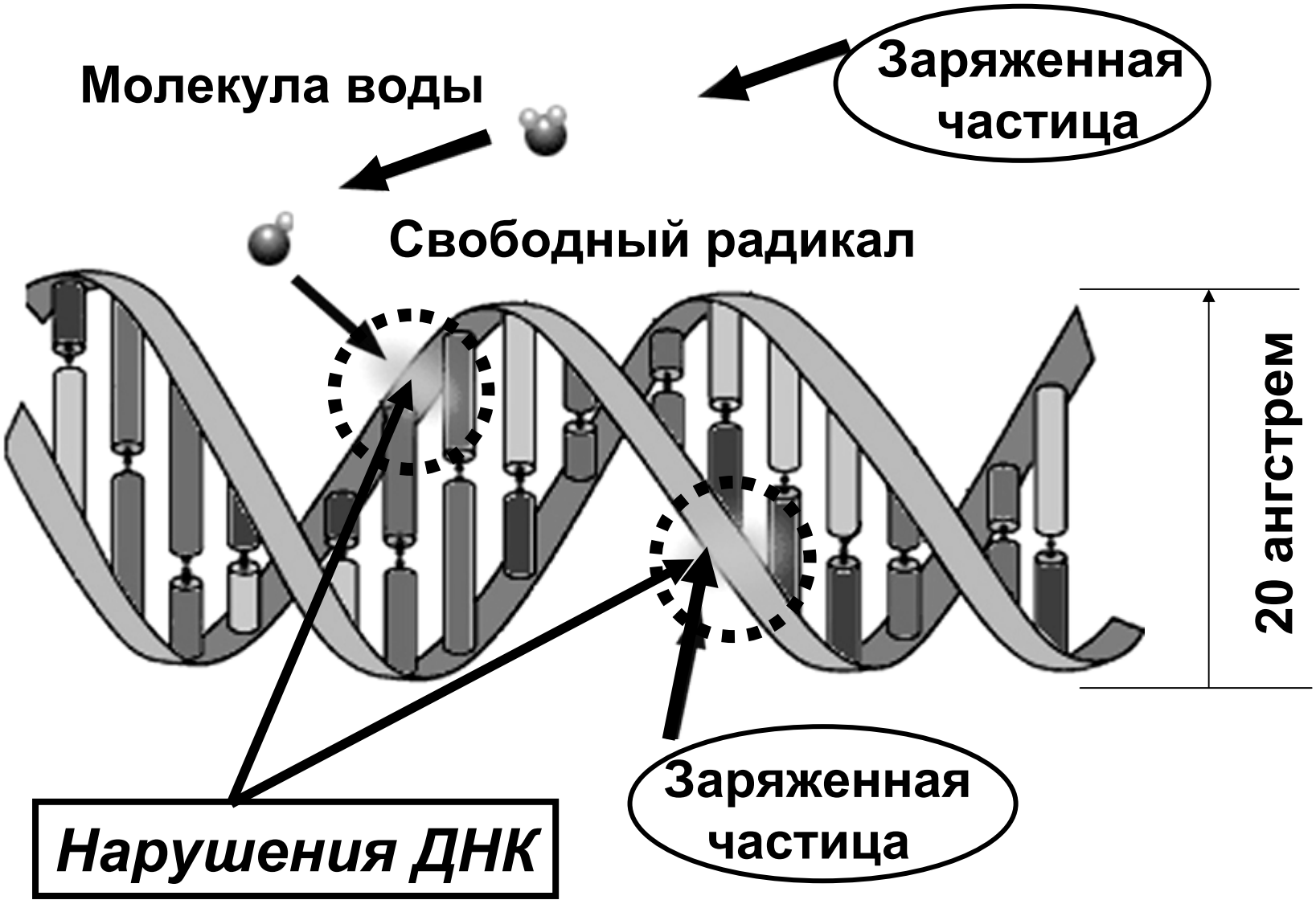
Нил Армстронг


n
Защита
p
α
Mg
~25 мкм
Трек
космической
Частицы,
~ 5мкм
Чувствительная область чипа
Область
взаимодействия

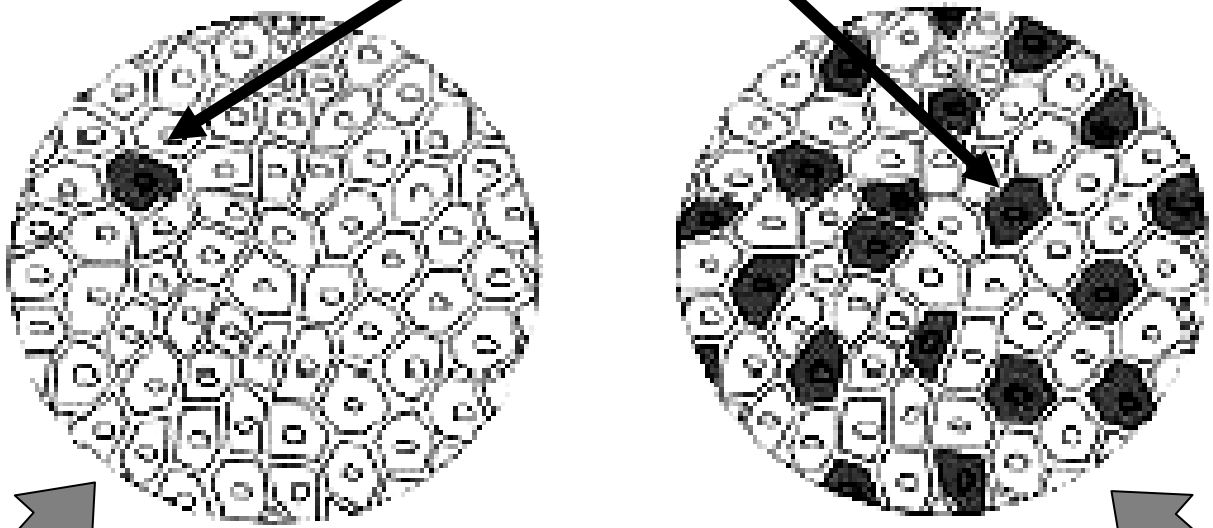

Число сбоев в сутки
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1982
1984
1986
1988
1990
1992
1994
Годы
Сбои
Минимум СА
Максимум СА
Поток ГКЛ


Аномалии
Поток протонов, отн ед
100
1.0
0.01
Протоны СКЛ
14
15
Июль 2000г.


80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Южно- Атлантическая аномалия


Молекула воды
Заряженная частица
Свободный радикал
20 ангстрем
Заряженная частица
Нарушения ДНК

Повреждённые клетки



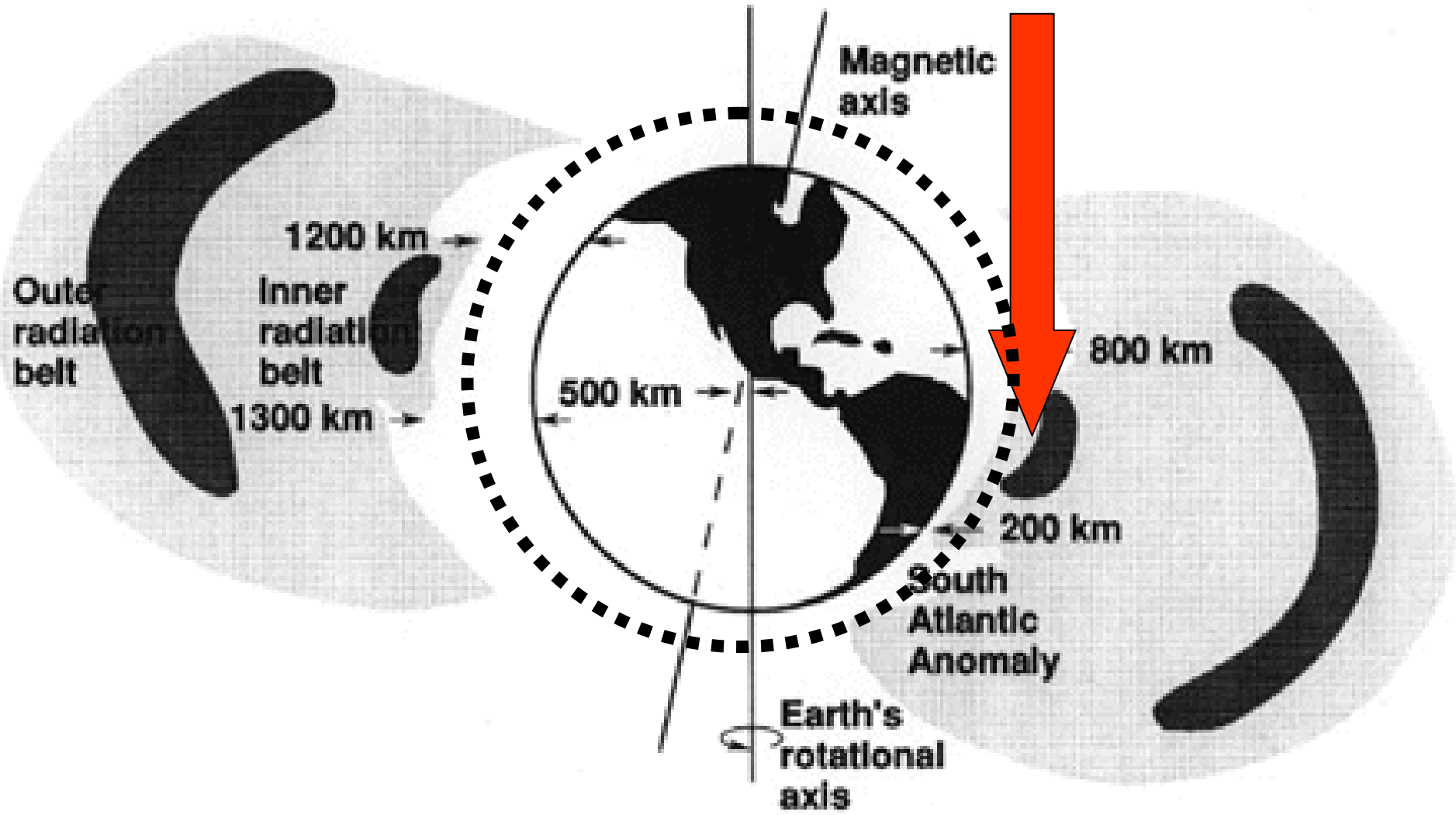
Поглощённая доза 0,5 Зв

Электроны

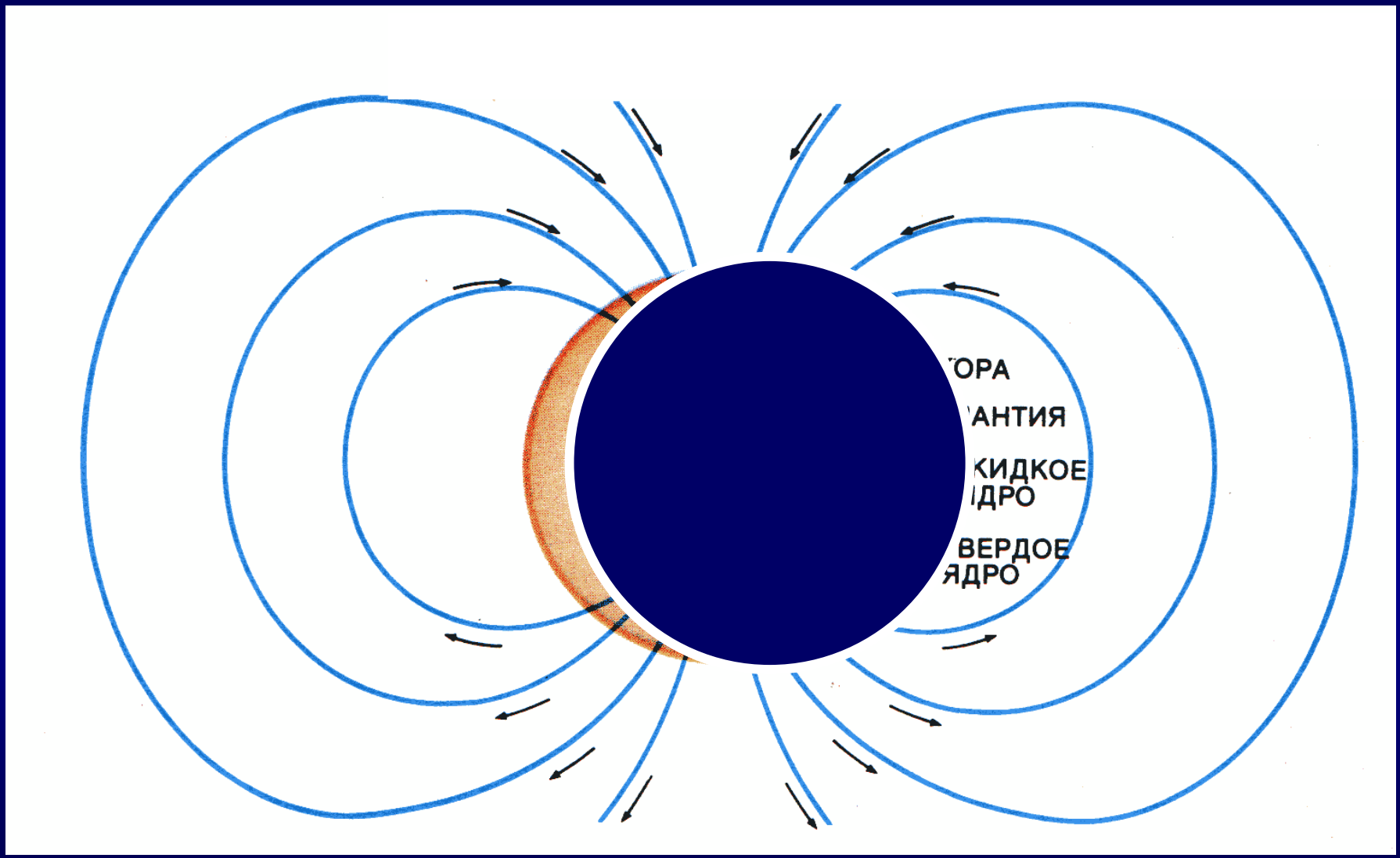
Альфа – частицы,
тяжёлые ядра


Солнечные нейтроны
Протоны ГКЛ
Нейтроны альбедо
Локальные нейтроны

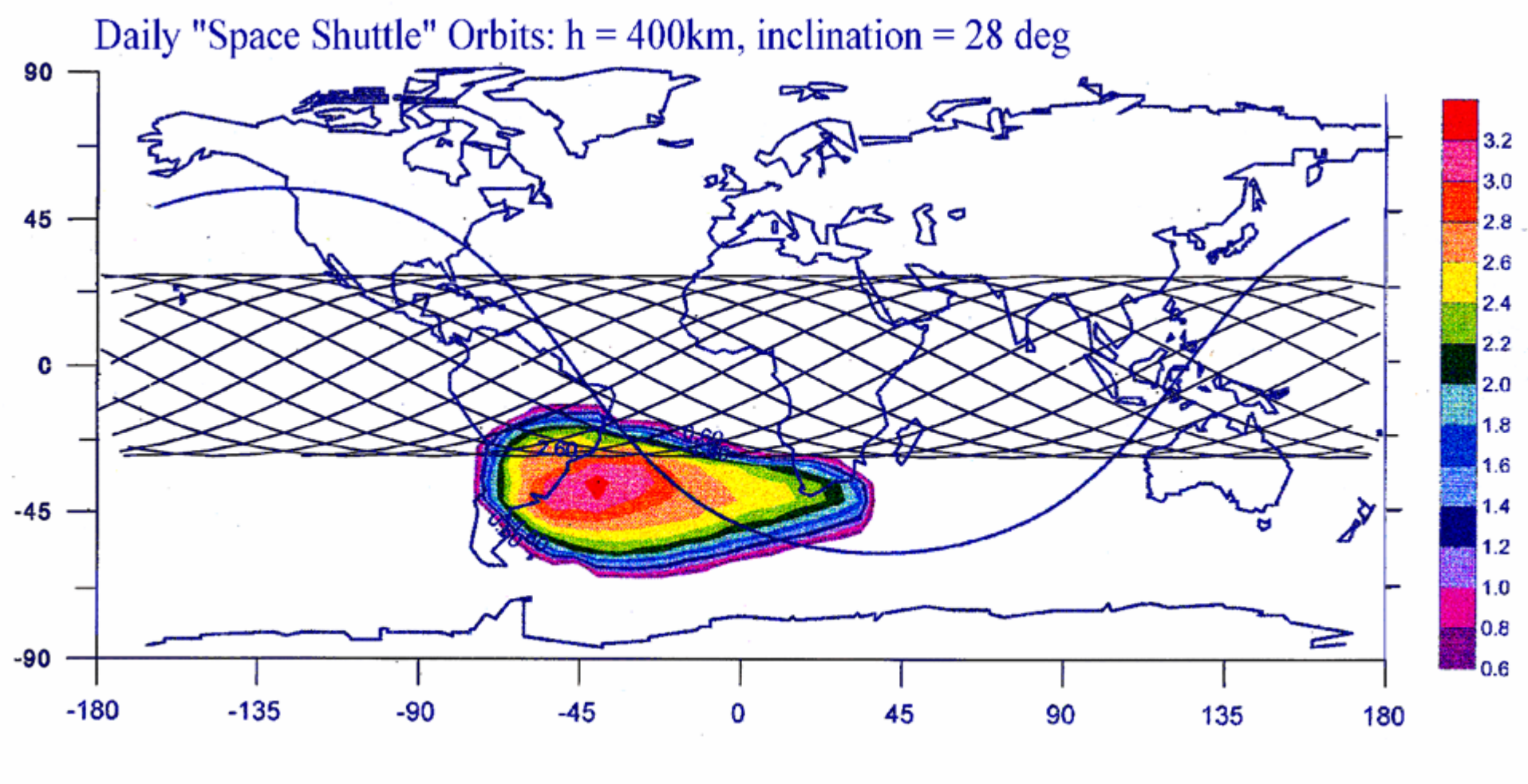
Спасибо за внимание


Magnetic axis
1200 km
Outer radiation belt
Inner radiation belt
1300 km
500 km
800 km
200 km
South Atlantic Anomaly
Earth's rotational axis

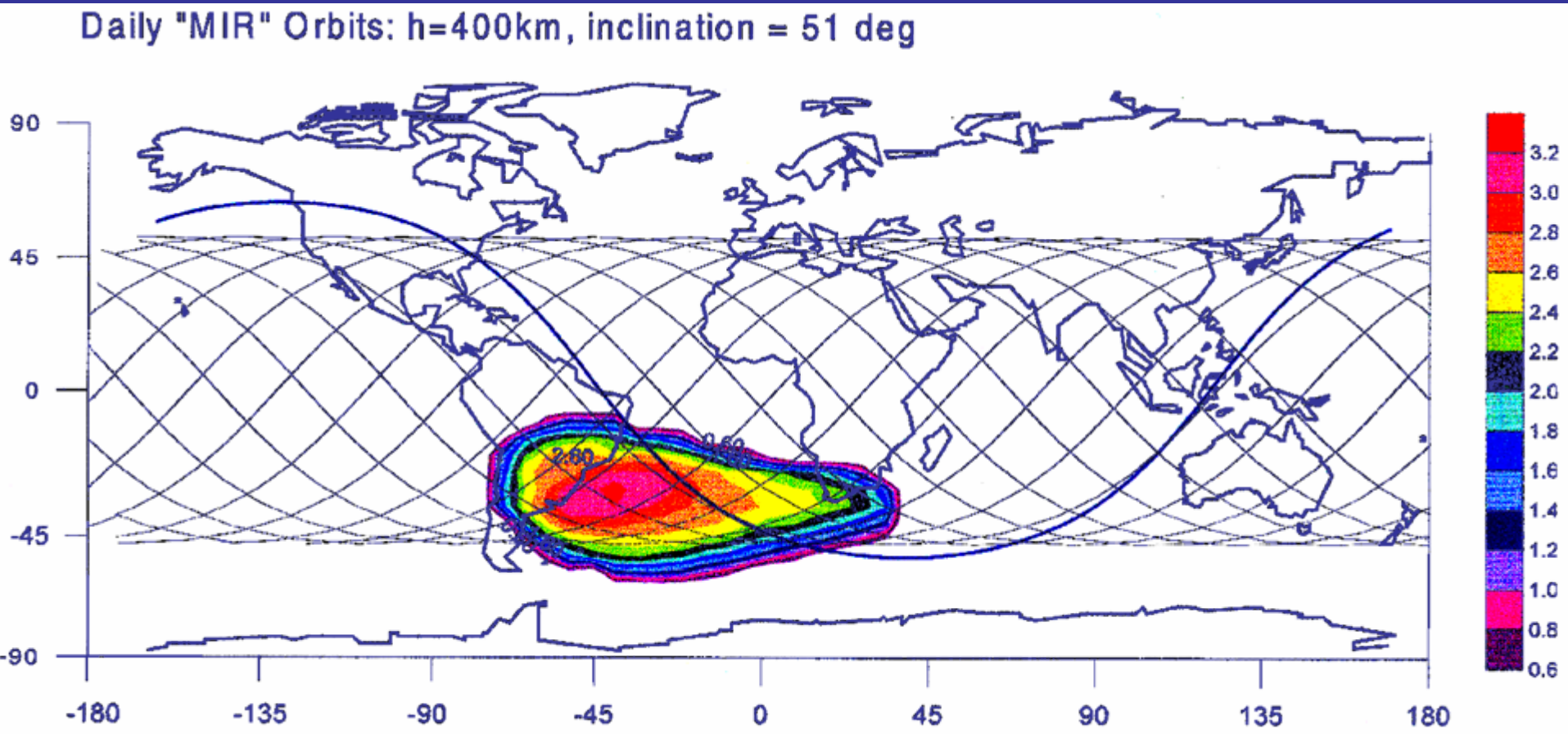
Магнитное поле Земли



28° inclination

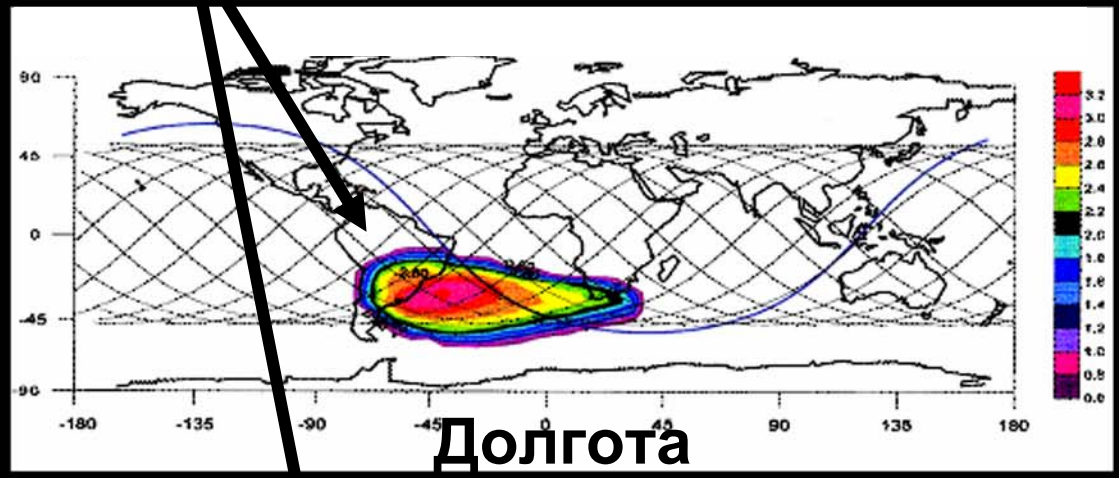


51,2° inclination

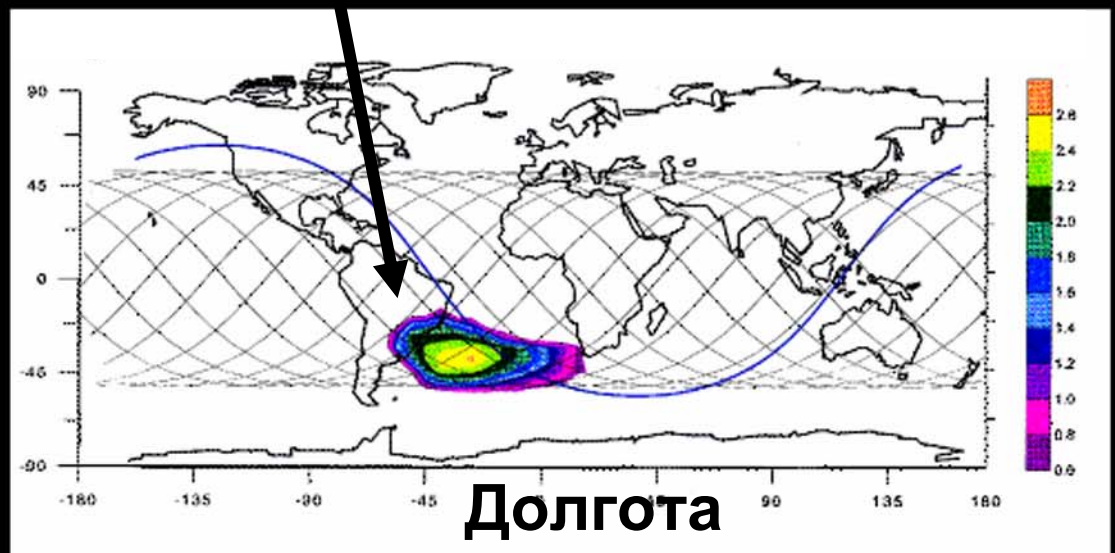


Южно-Атлантическая Аномалия

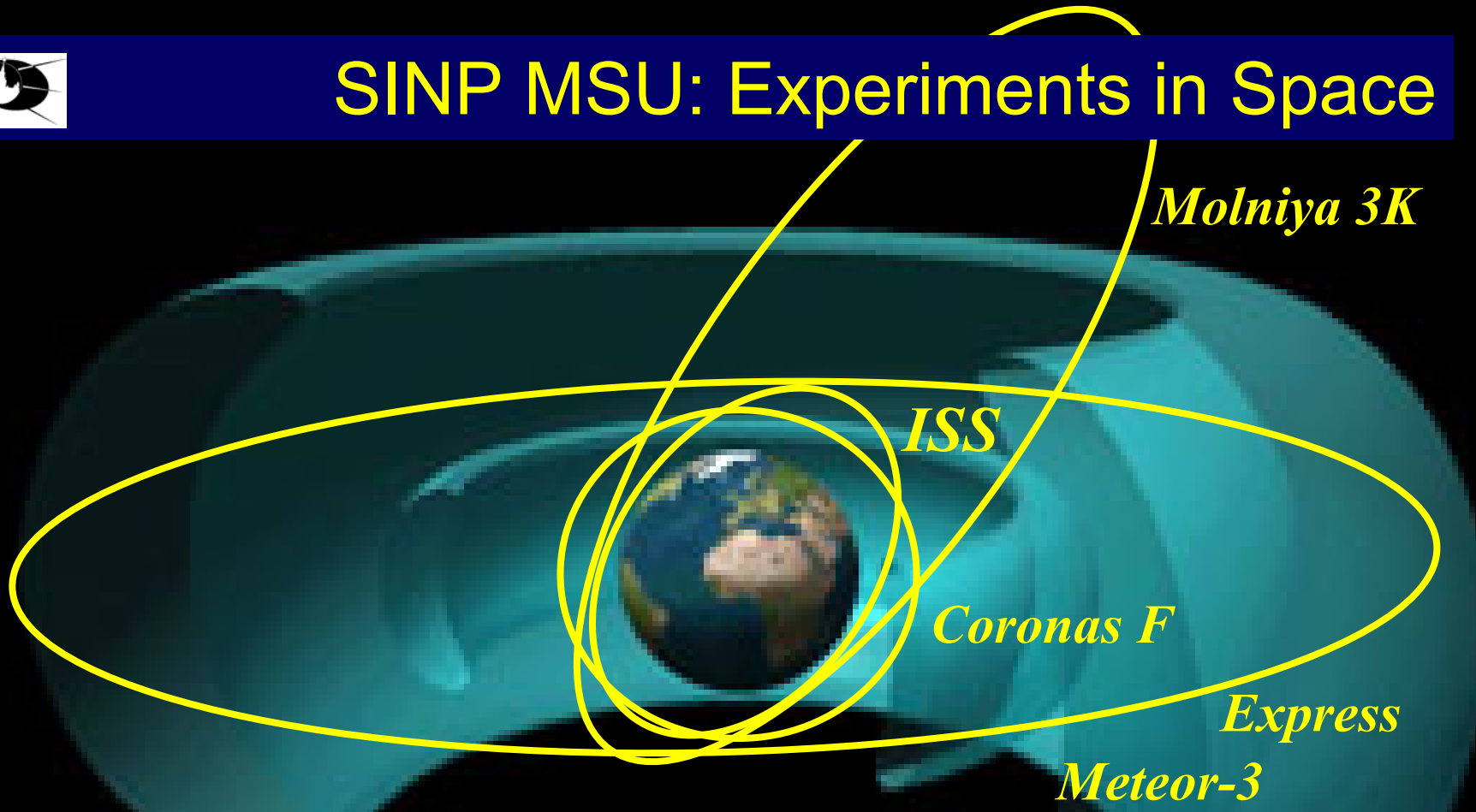
Минимум СА



Максимум СА



SINP MSU: Experiments in Space

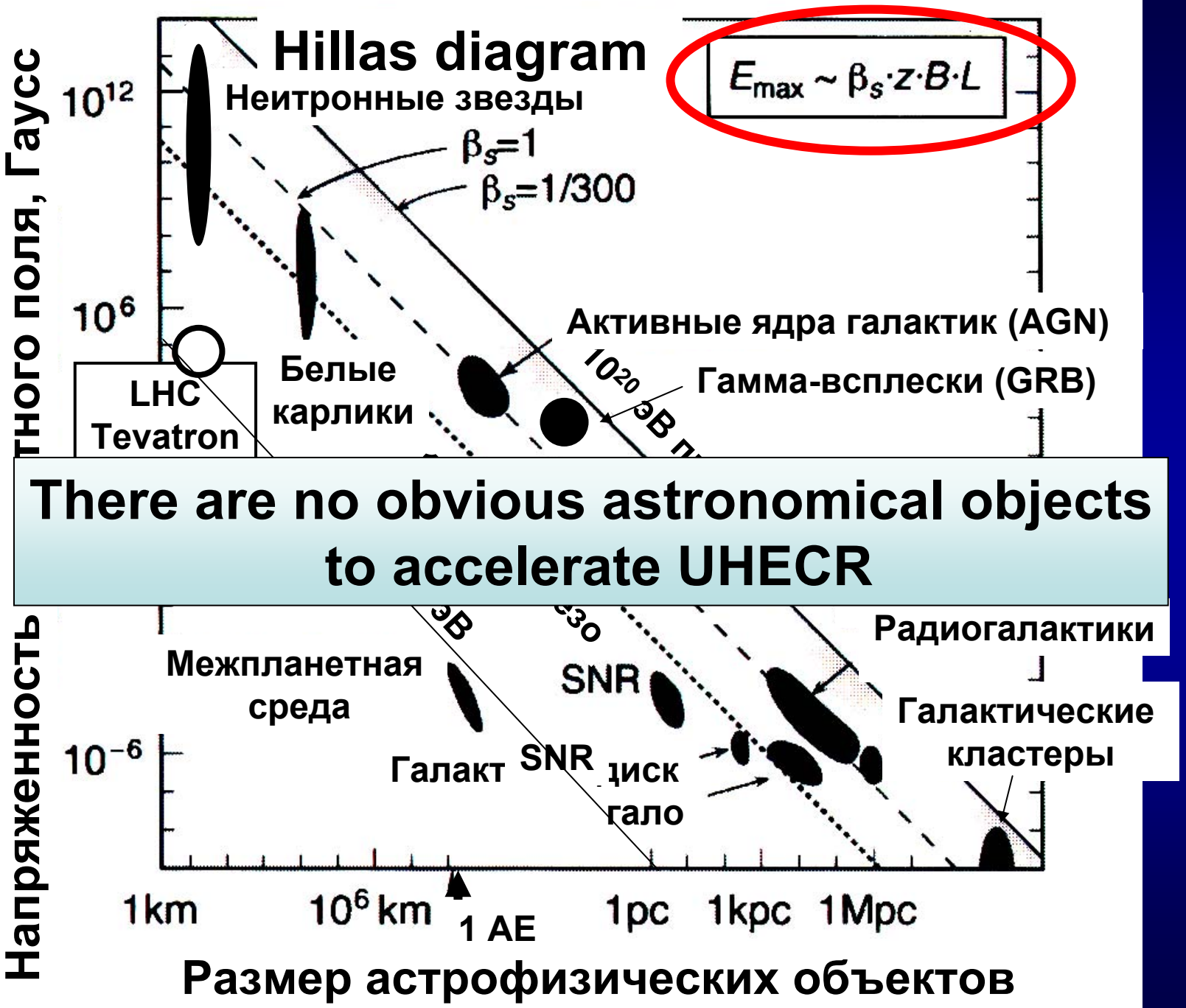


Measurements of:

- hot plasma,
- medium and high energy electrons, protons & doses.

Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University

Space activity since 1957


Hillas diagram
$E_{max} \sim \beta_s \cdot z \cdot B \cdot L$
Неитронные звезды
β_s=1
β_s=1/300
10^{12}
10^{6}
10^{-6}
Напряженность магнитного поля, Гаусс
Активные ядра галактик (AGN)
Гамма-всплески (GRB)
Белые карлики
LHC
Tevatron
There are no obvious astronomical objects to accelerate UHECR
Радиогалактики
Межпланетная среда
SNR
Галактические кластеры
Галакт
SNR
диск
гало
1km
10^6 km
1 AE
1pc
1kpc
1Mpc
Размер астрофизических объектов

Earth's radiation environment