Cherenkov detectors in space

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International Conference
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Moscow, June 22-25, 2004

Outline

Cherenkov detectors in space:

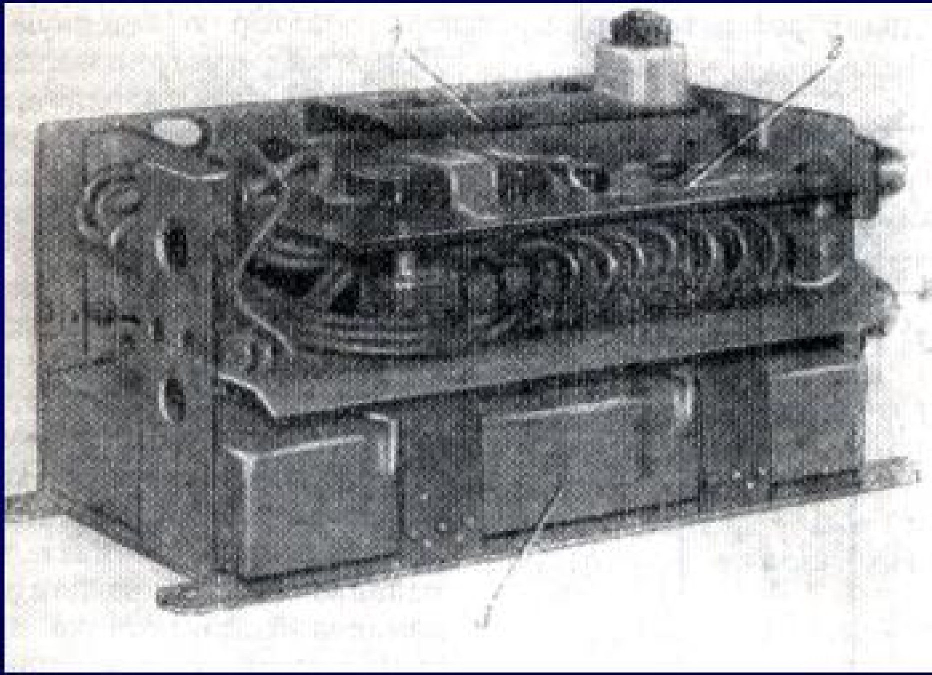
- Astroparticle physics – high-energy cosmic rays, gamma- rays in the Universe;
- Physics of heliosphere – solar energetic particles;
- Space physics – particles in the planet's magnetospheres;

Astroparticle physics

High-energy cosmic rays

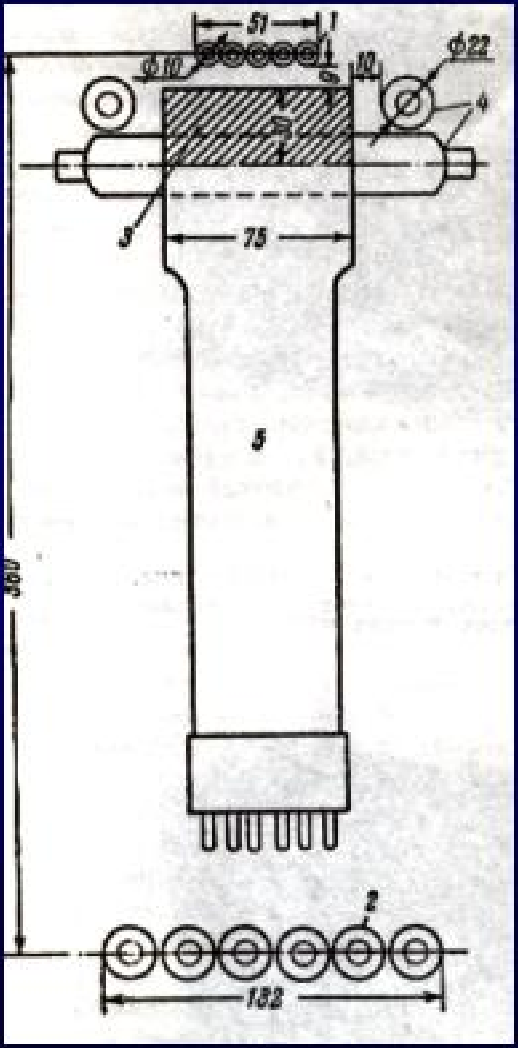
The first Cherenok in space

The Third Soviet satellite
Launched May, 1st 1958



"Integral type" Cherenkov detector, designed in Lebedev Institute

The first experiments in the space



The first differential Cherenkov detector in space

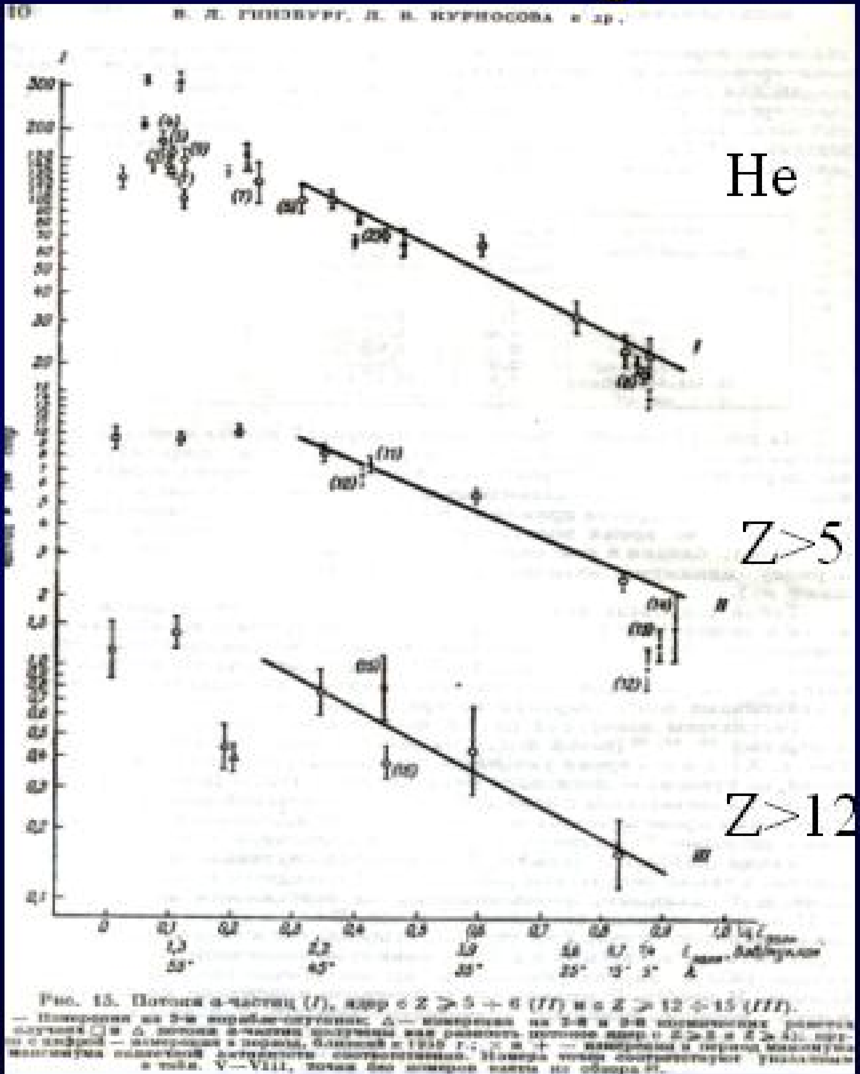
Ginzburg, Kurnosova, et al

The first experiments in the space

- solid state directional detectors (1)
- gas directional detectors (2)
- solid state omnidirectional detectors (3)

Satellite	Year	Detector's type	The goal	Institution
The III-d satellite	1958	1	Z-separation ;	LPI
Spaceships # 2, # 3	1959	1	cosmic rays	
Space probes:		1		
Luna 2, Luna 3	1959	1		
"Electron 2,4"	1966			

The first experiments in the space



Nuclear component
of cosmic rays
onboard

the 3d Soviet spaceship

Ginzburg, Kurnosova, et al

The first experiments in the space

...ными зарядами в первичных космических

Таблица IX

Символ элемента	Процентное содержание ядер различных элементов в космическом излучении (% от общего потока ядер с $Z\geqslant 3$)			
	по данным [40] (фотоэмульсии)*)	по данным [61] (черенковский счетчик), $E_{кин}\geqslant 0,5$ *Бэв/нуклон*	по данным [76] (фотоэмульсии)	по данным измерений на 3-м космическом корабле-спутнике **)
Li	3,9	—	5,3	4,0
Be	1,7	6,7	2,3	8,0
B	11,6	10,1	7,4	12,0
C	26,0	28,6	30,1	25,0
N	12,4	13,3	9,7	
O	17,9	17,9	19,4	
F	2,6	—	2,4	
$Z\geqslant 10$	23,9	16,6	23,4	
$Z>6$	56,8	47,8	54,9	52,5

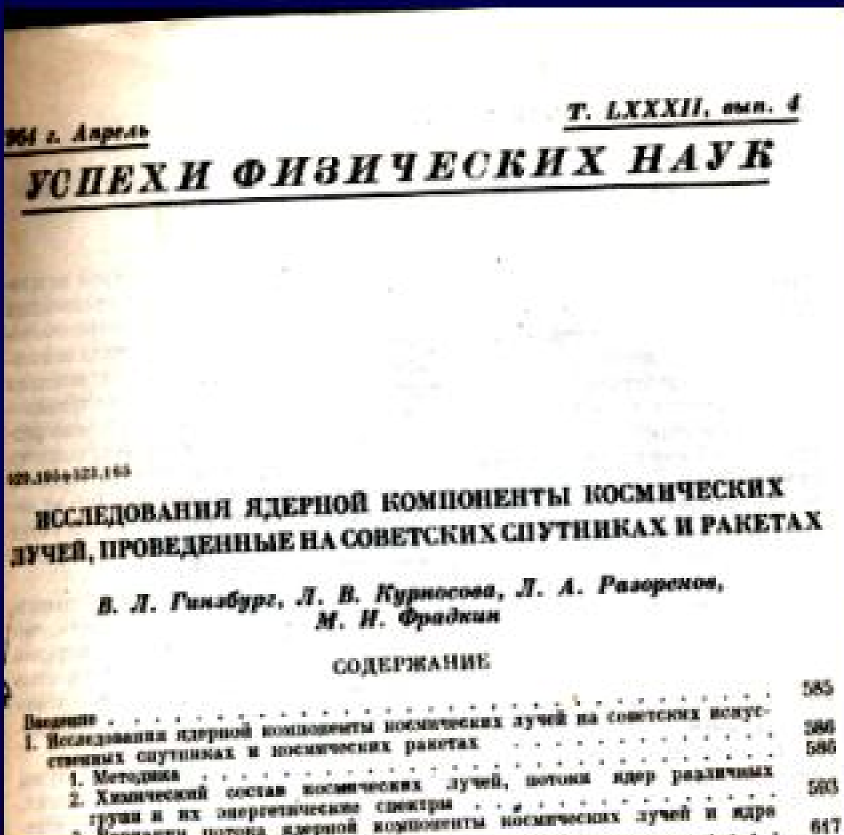
The most important results:

Chemical composition
– relative abundances
of cosmic ray

-Solar 11-year modulation

Ginzburg, Kurnosova, et al

The first experiments in the space



964 г. Апрель

Т. LXXXII, вып. 4

УСПЕХИ ФИЗИЧЕСКИХ НАУК

ИССЛЕДОВАНИЯ ЯДЕРНОЙ КОМПОНЕНТЫ КОСМИЧЕСКИХ ЛУЧЕЙ, ПРОВЕДЕННЫЕ НА СОВЕТСКИХ СПУТНИКАХ И РАКЕТАХ

В. Л. Гинзбург, Л. В. Курносова, Л. А. Разоренов, М. И. Фрадкин

СОДЕРЖАНИЕ

V. Ginzburg,
L. Kurnosova,
L.Razorenov,
M. Fradkin –

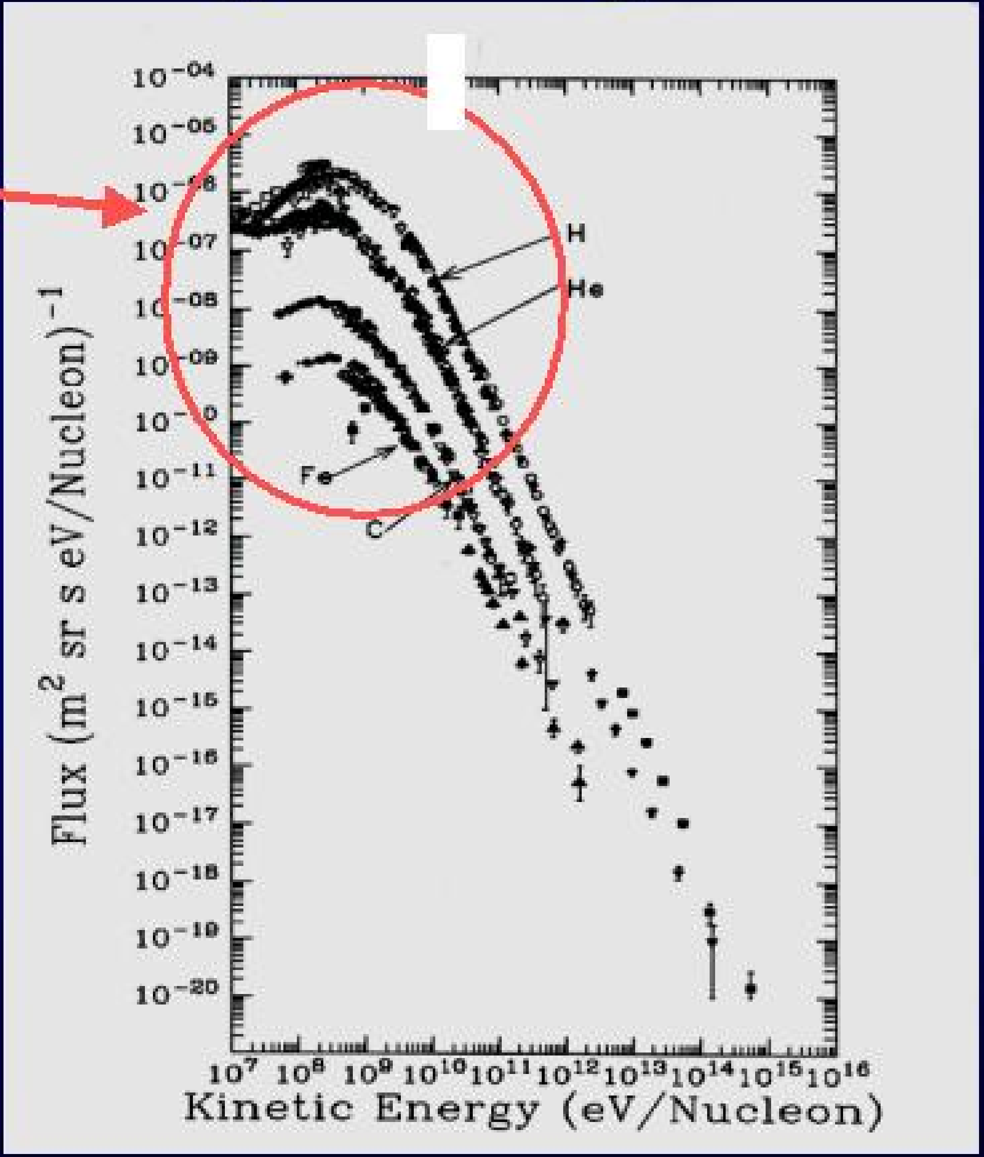
the authors
of the first review (1964) devoted to
nuclear component of
cosmic rays in space

Over 15 experiments with Cherenkov's detectors during the 10 first years of space exploration

“A quick look” at cosmic ray physics

Cosmic ray chemical composition/spectra

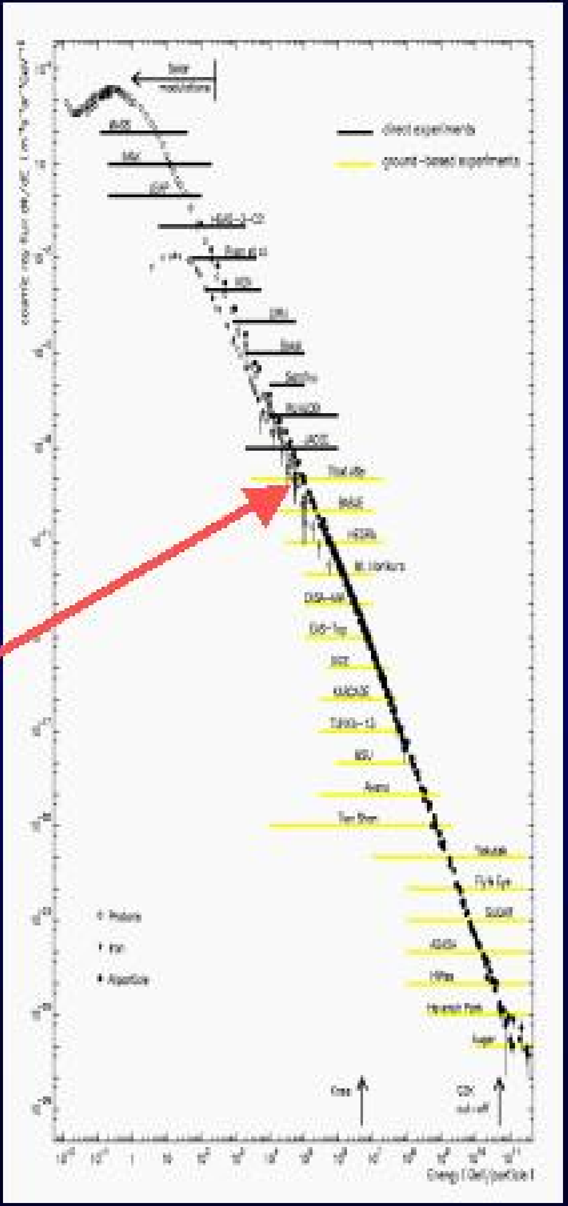
The first experiments



*Galactic and extra-Galactic origin.
* Practically all elements.
* Fully ionized.
* Omnidirectional
* 10^{8} - 10^{21} eV.
* Solar cycle modulation (11 years) at low energies.

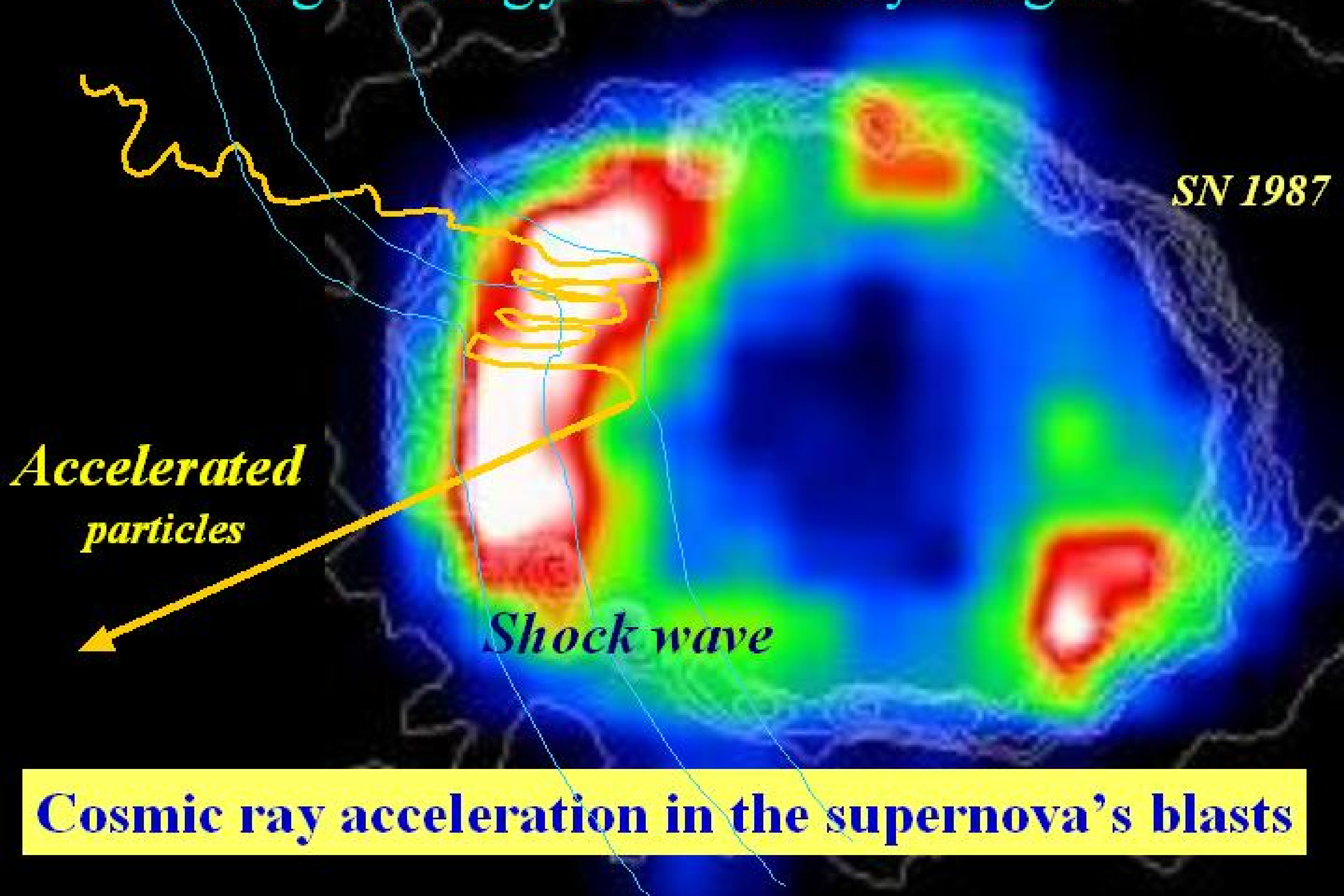
Energy spectrum of cosmic rays

Practically the same slope over the wide energy range



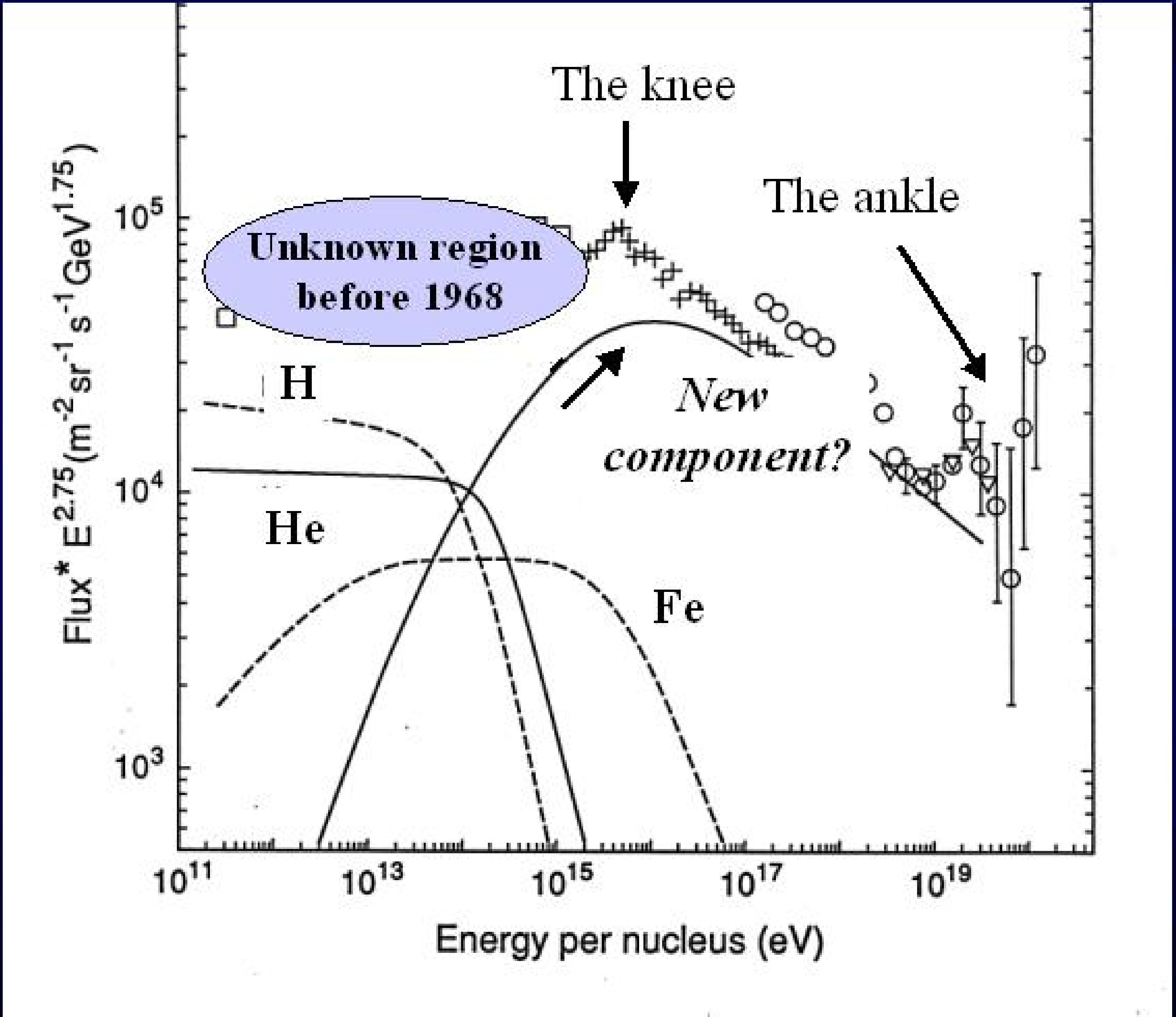
The knee

High Energy Cosmic Ray Origin



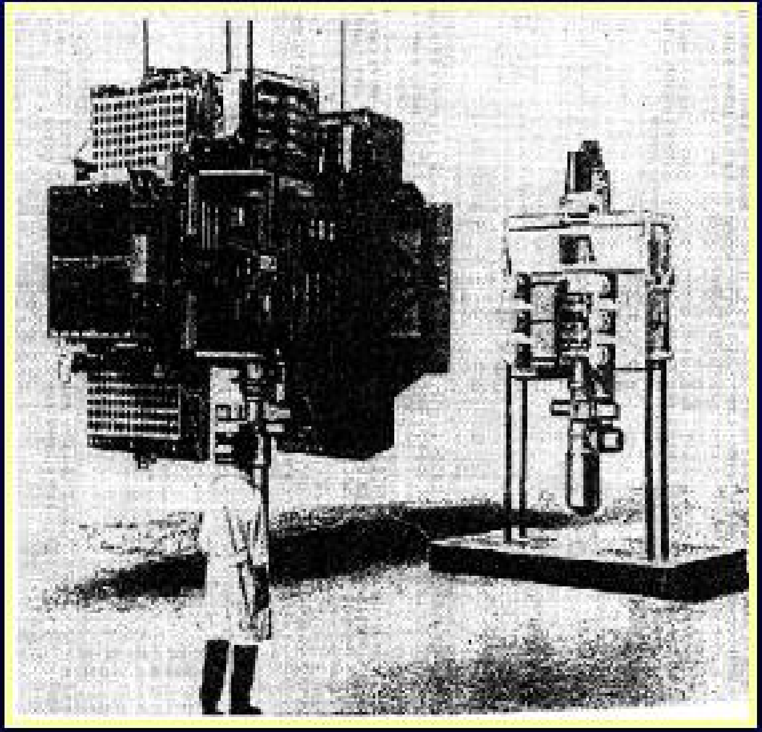
Cosmic ray acceleration in the supernova's blasts

Supernovae's acceleration limit



Cosmic rays below «the knee»

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



«Proton 1-4» experiment:

Active Calorimeter SINP/MSU

1968

Cosmic rays below «the knee»

«Proton 1,2 » experiment, 1968 :

SEZ -1 plastic Cherenkov detector with G~133 cm2 ster

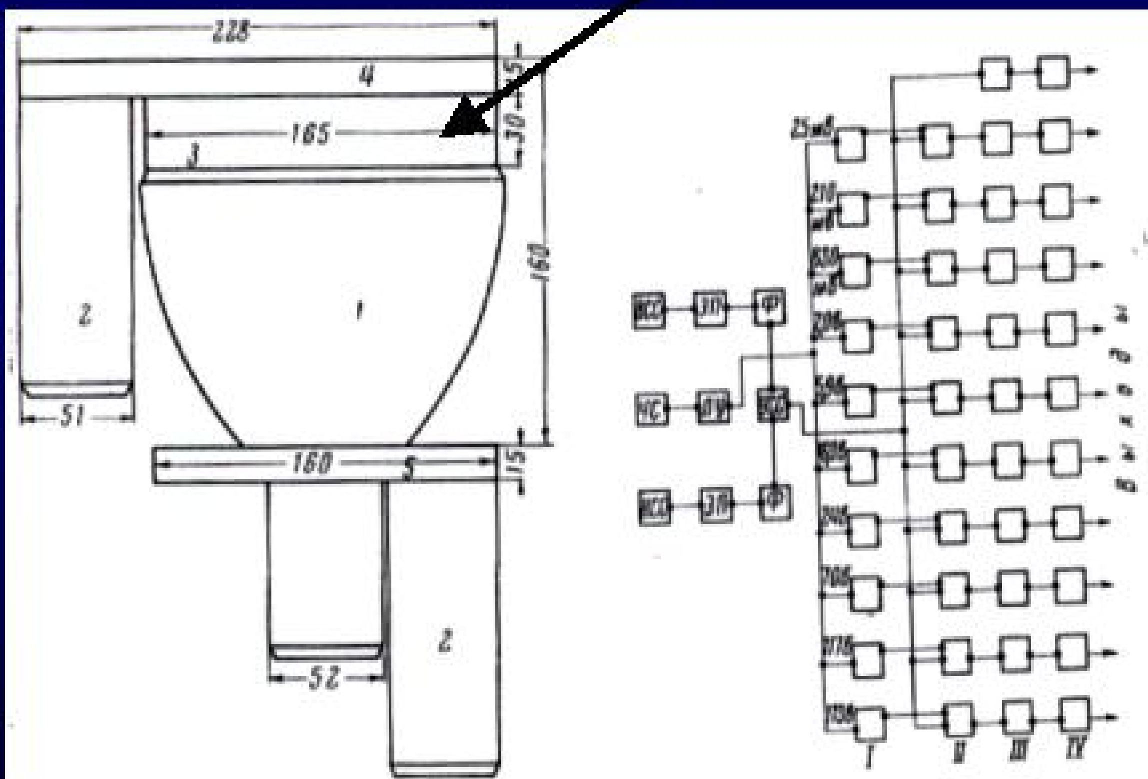
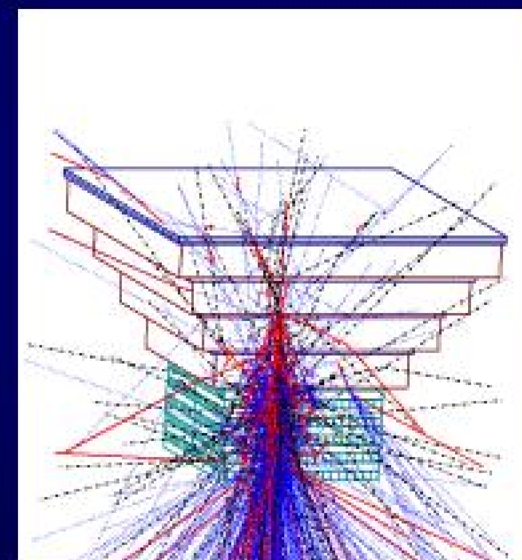


Рис. 1

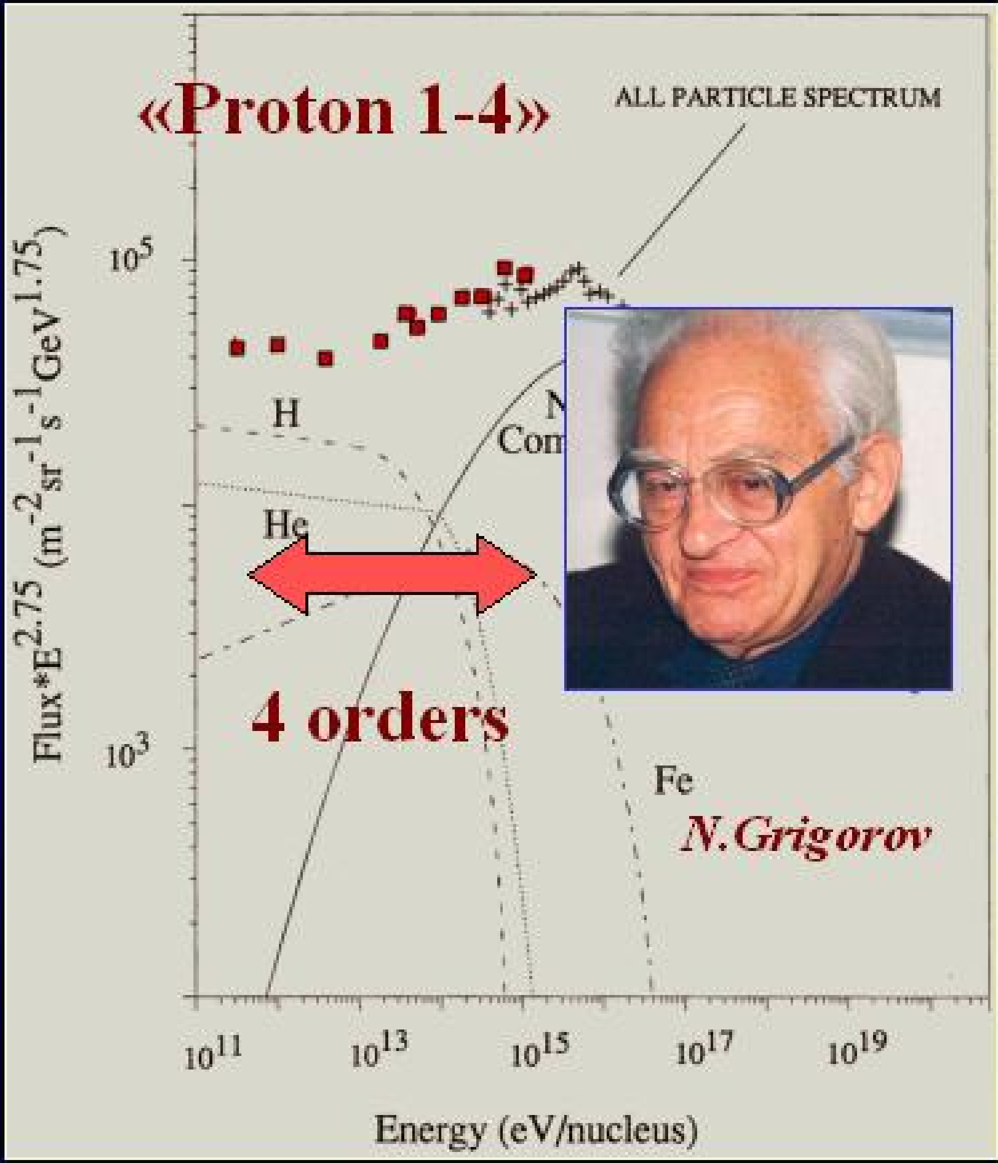
Рис. 2



Back current problem

SINP/MSU

«Proton's» results

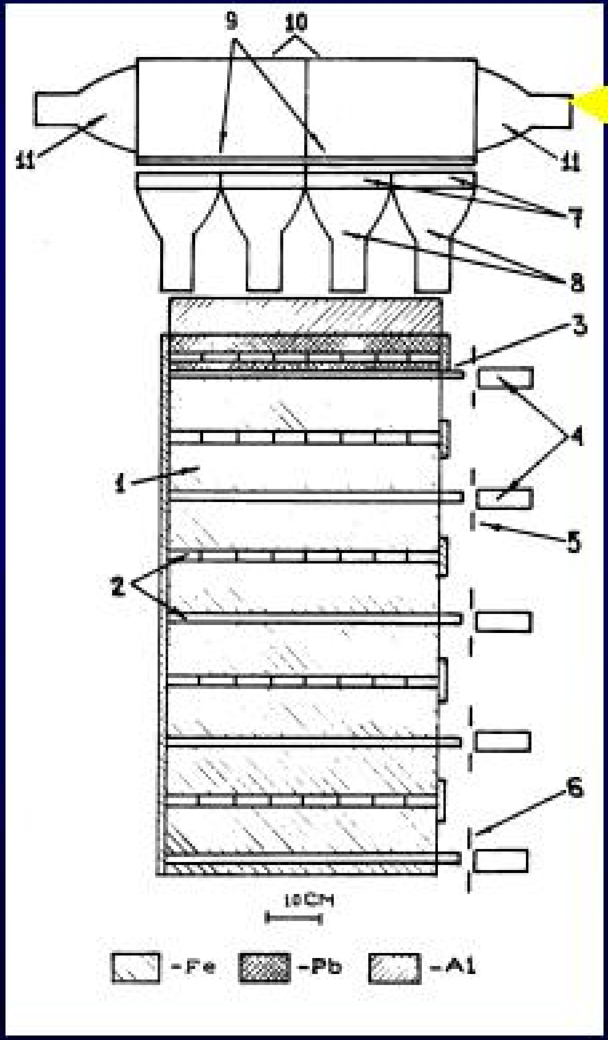


For the first time

all particle and proton spectra were measured in the wide energy range up to 1 PeV.

«SOKOL» 1984 - 1986

(Cosmos - 1543; Cosmos- 1713)



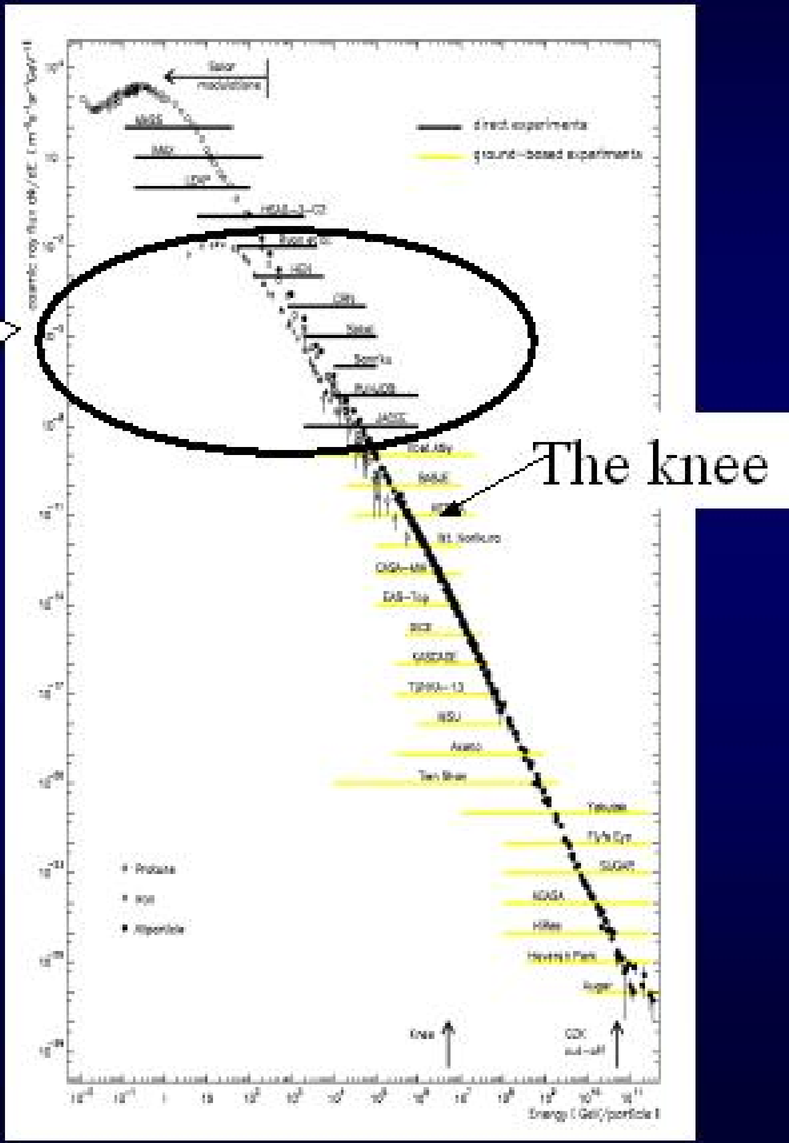
Cherenok – charge detector

SINP/MSU

Energy spectrum of cosmic rays

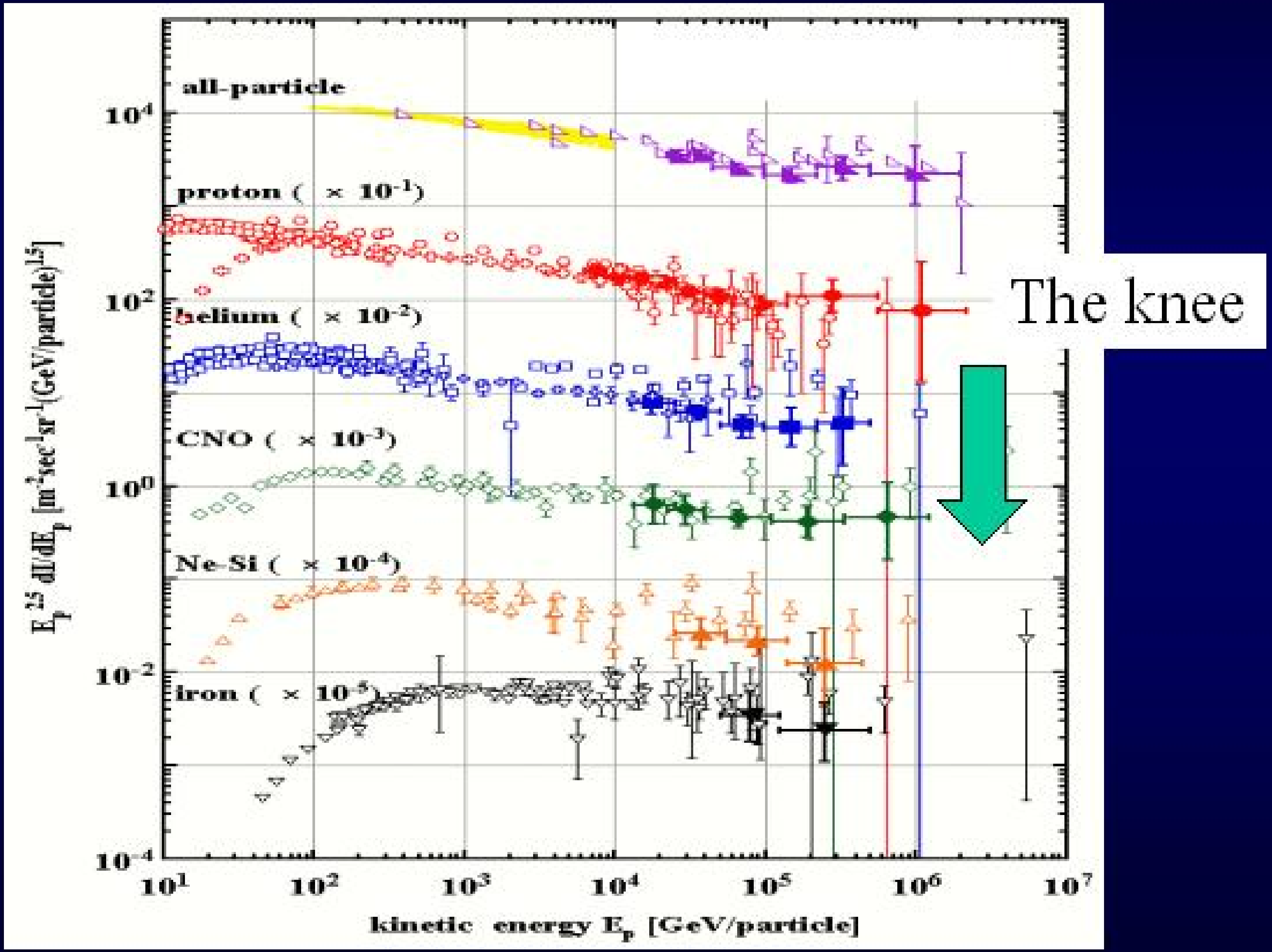
Direct experiments below "the knee" since 1968.

But just 6 were onboard satellites, including Protons.

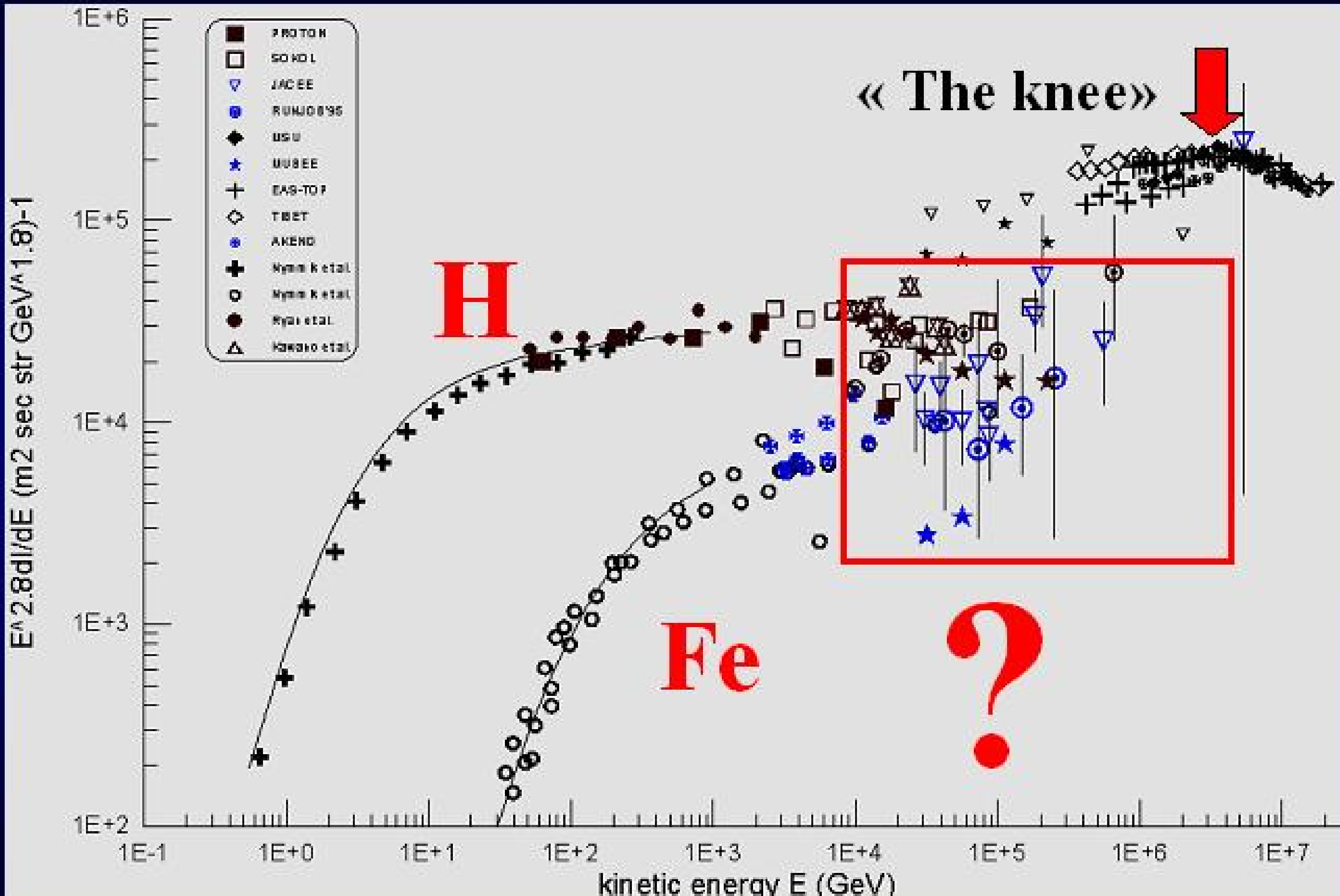


So, what we have now?....

Cosmic ray chemical composition below "the knee"



Energy spectra of cosmic rays below the knee



The future of direct measurements

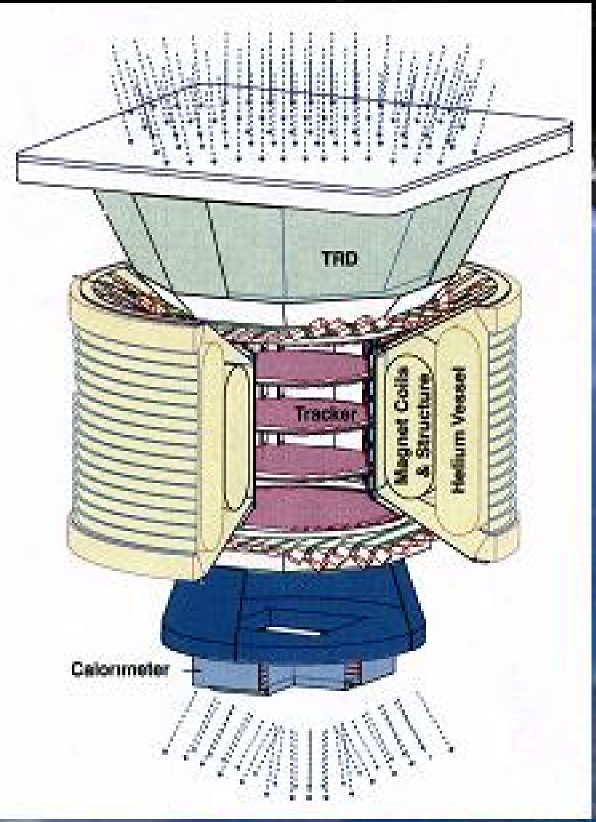
The future of direct measurements

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

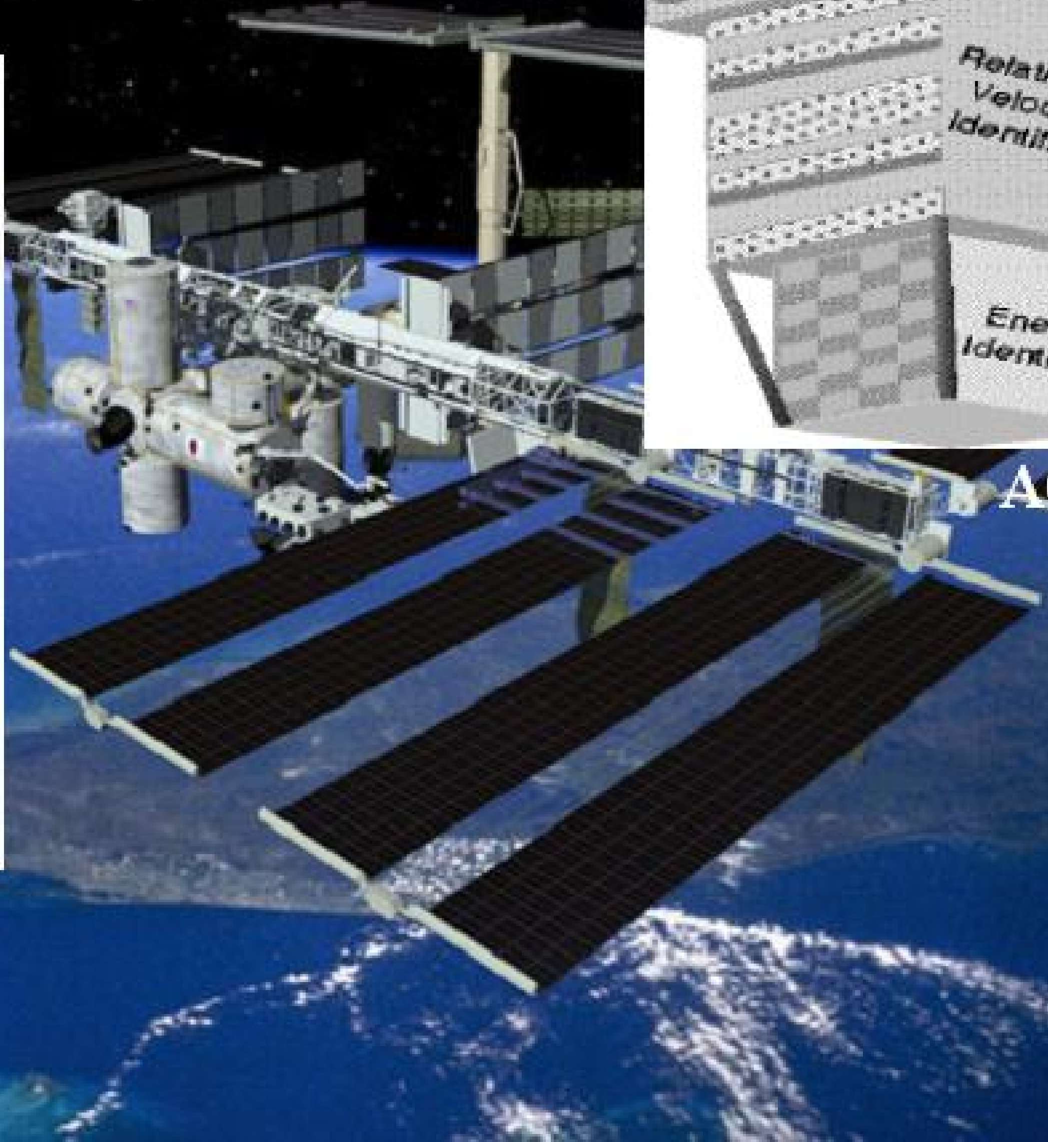
⇓

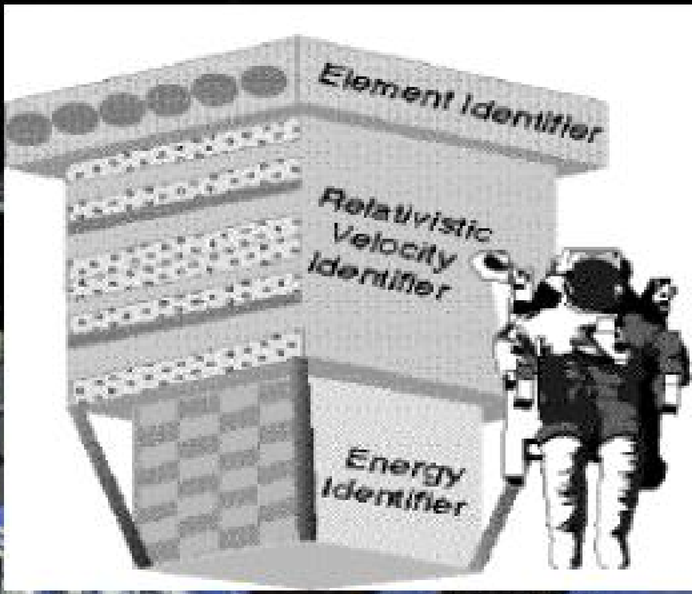
-more weight,
-more cost

ISS as a potential career for a future cosmic ray experiments



AMS 2



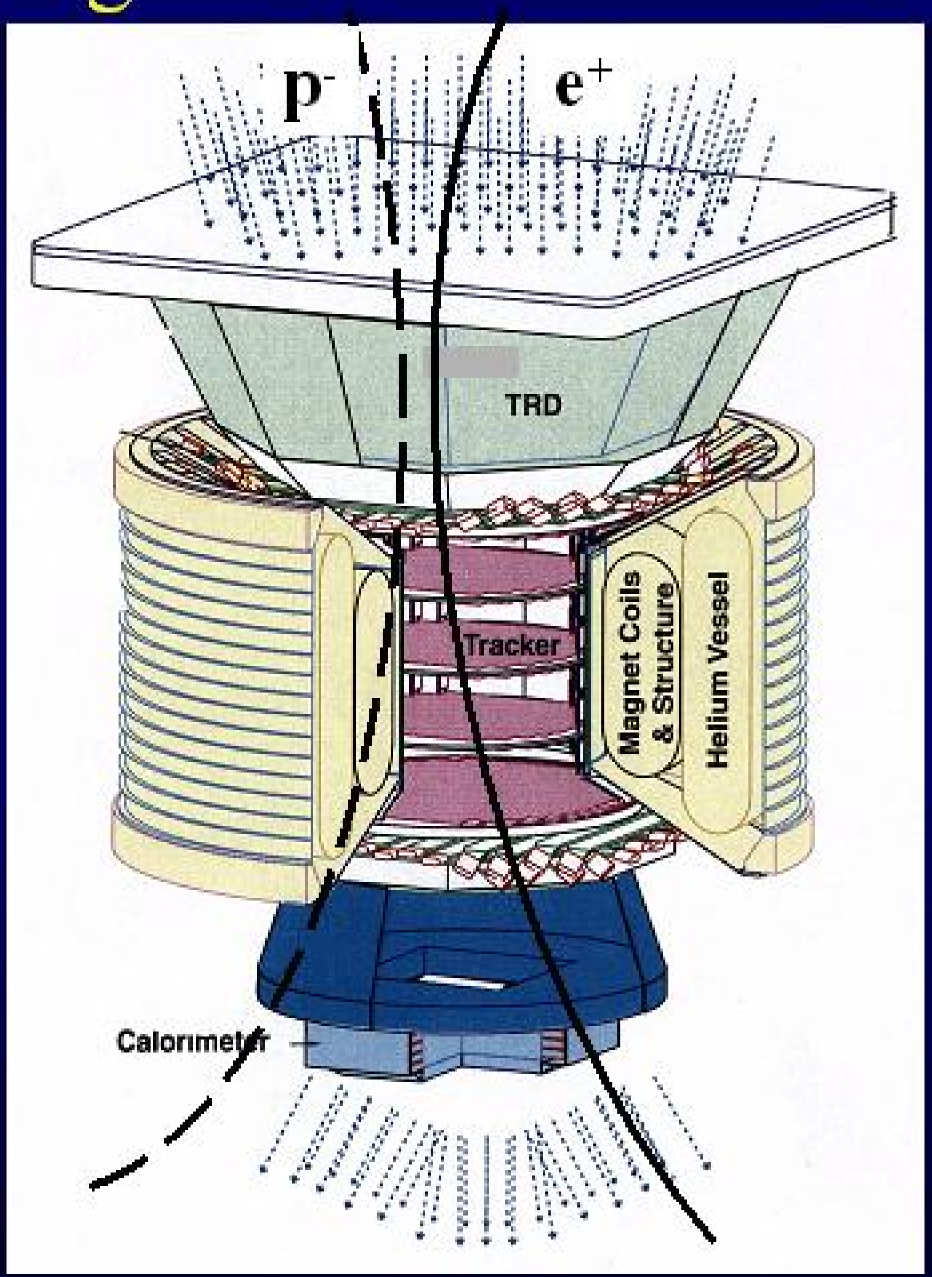


ACCESS

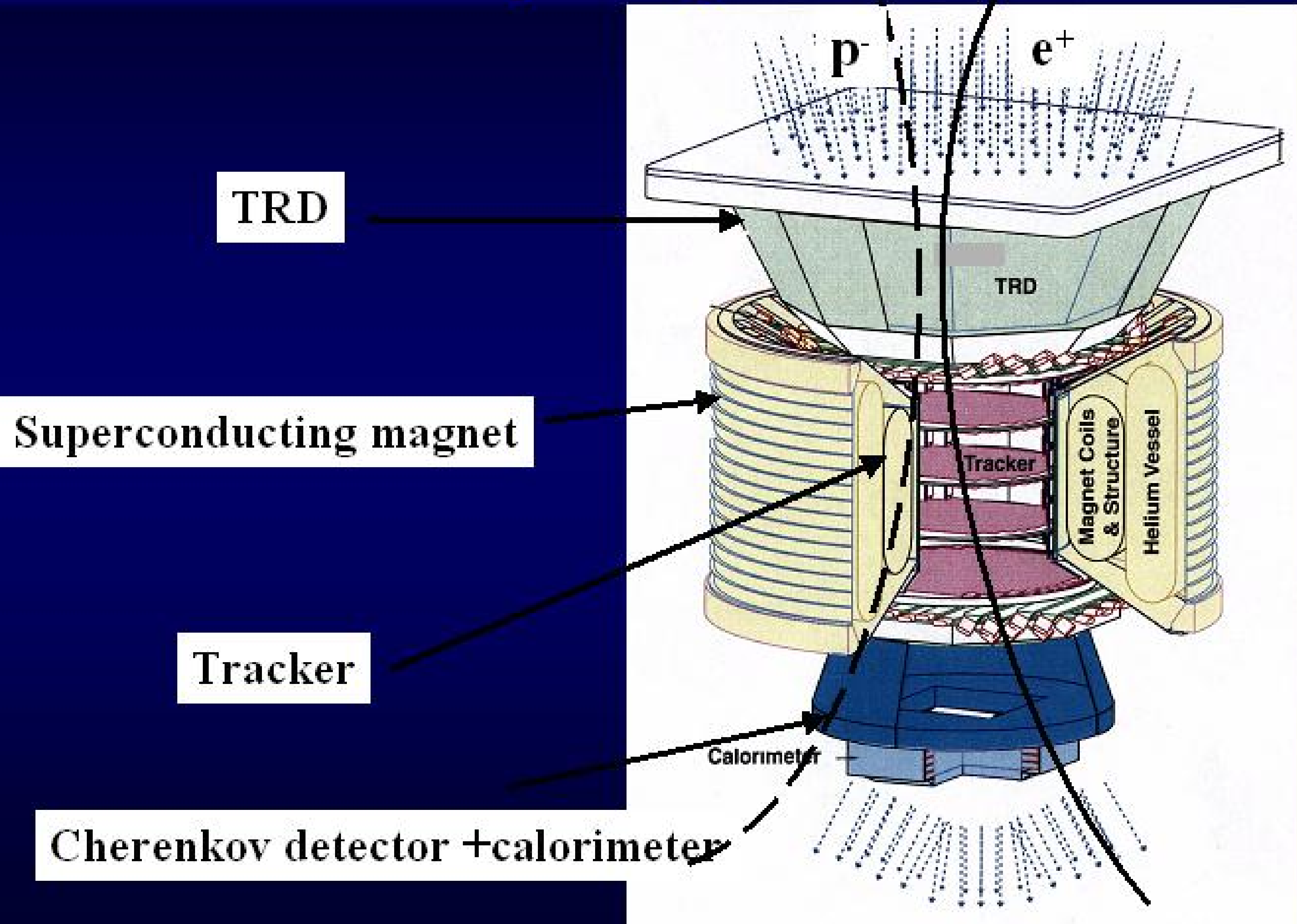
AMS 02 is planing to launch in 2008

Primary goals:

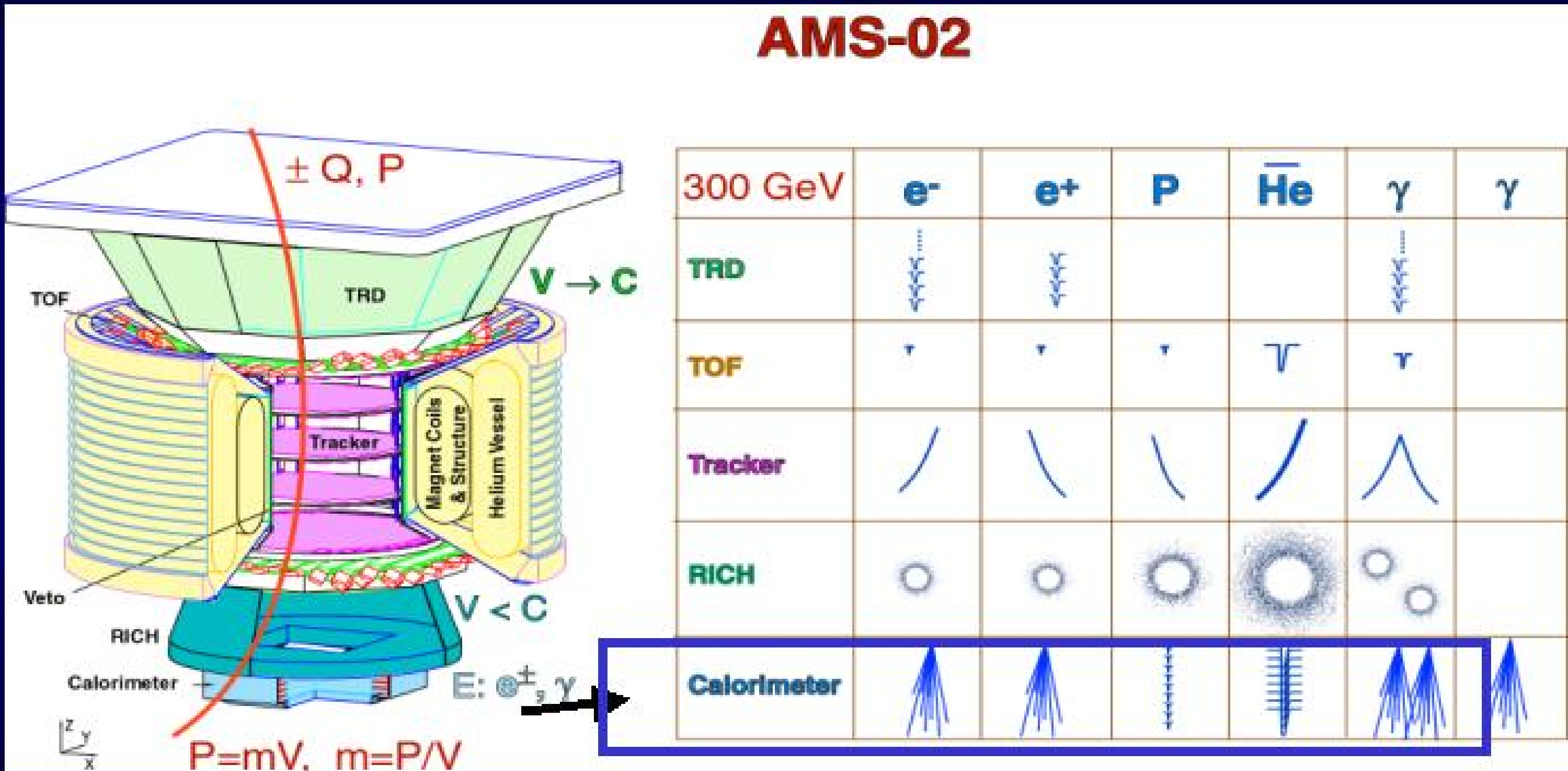
-dark matter,
-antimatter,
-cosmic rays



AMS 02 is planing to launch in 2008



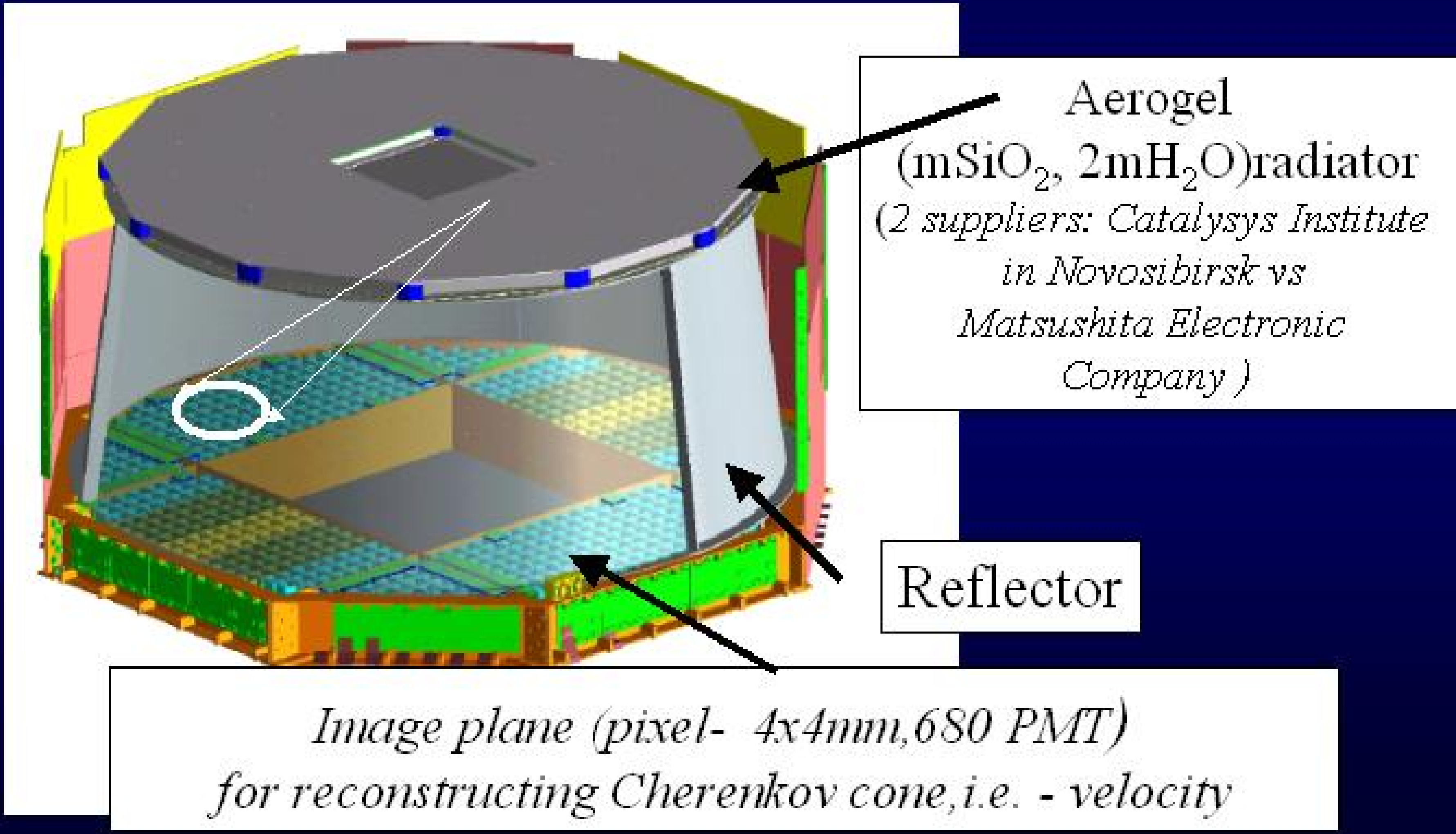
AMS 02 is planing to launch in 2008



RICH – precise measurements of mass: m =f(p,v)*

(Tracker gives p with ~1% accuracy)*

RICH -*R*ing *I*maging *Ch*erenkov Counter



Ring Imaging Cherenkov Counter

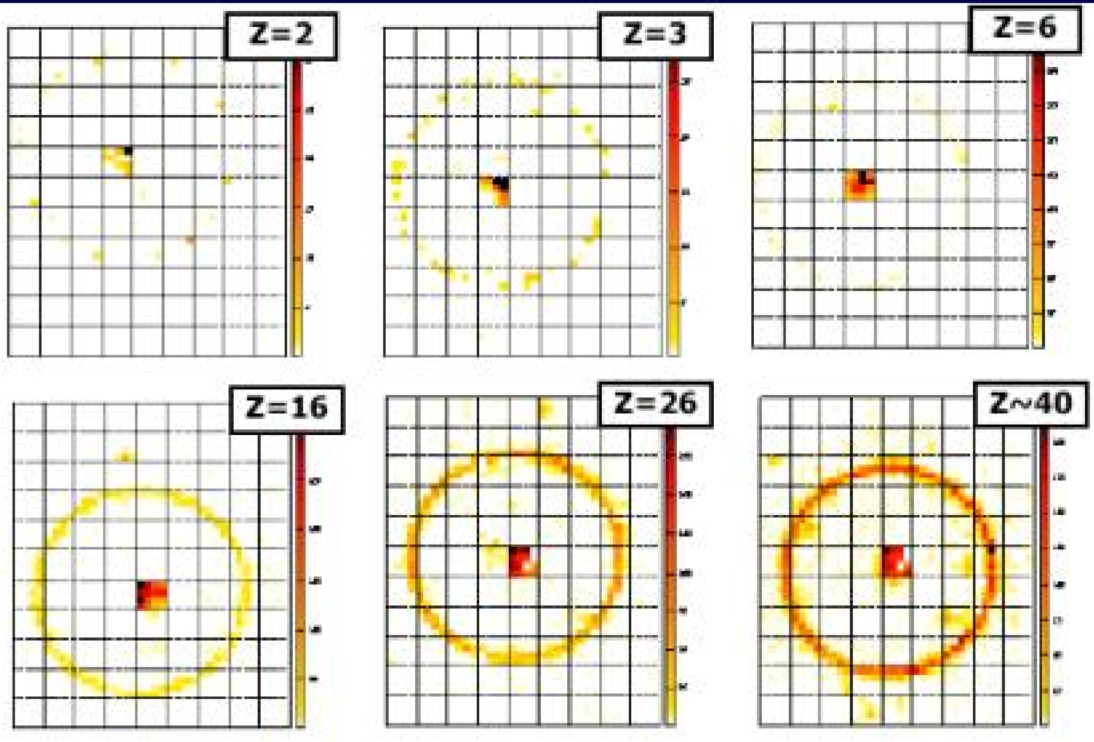


Figure 2.117: A sample of Cerenkov rings detected with single, A/Z = 2, ion events.

Cherenkov's rings from A/Z=2 particles as seen by RICH

Ring Imaging Cherenkov Counter

Radiator	n	Z = 1	Z = 2	Z = 6
MEC	1.03	0.194 ± 0.001	0.227 ± 0.001	0.252 ± 0.004
MEC	1.05	0.189 ± 0.002	0.201 ± 0.001	0.228 ± 0.006
CIN	1.03	0.197 ± 0.003	0.199 ± 0.001	0.217 ± 0.006
CIN	1.04	0.198 ± 0.003	0.193 ± 0.003	0.232 ± 0.007

Table 2.7: Charge resolution for the different radiators and Z=1, 2 and 6 beams.

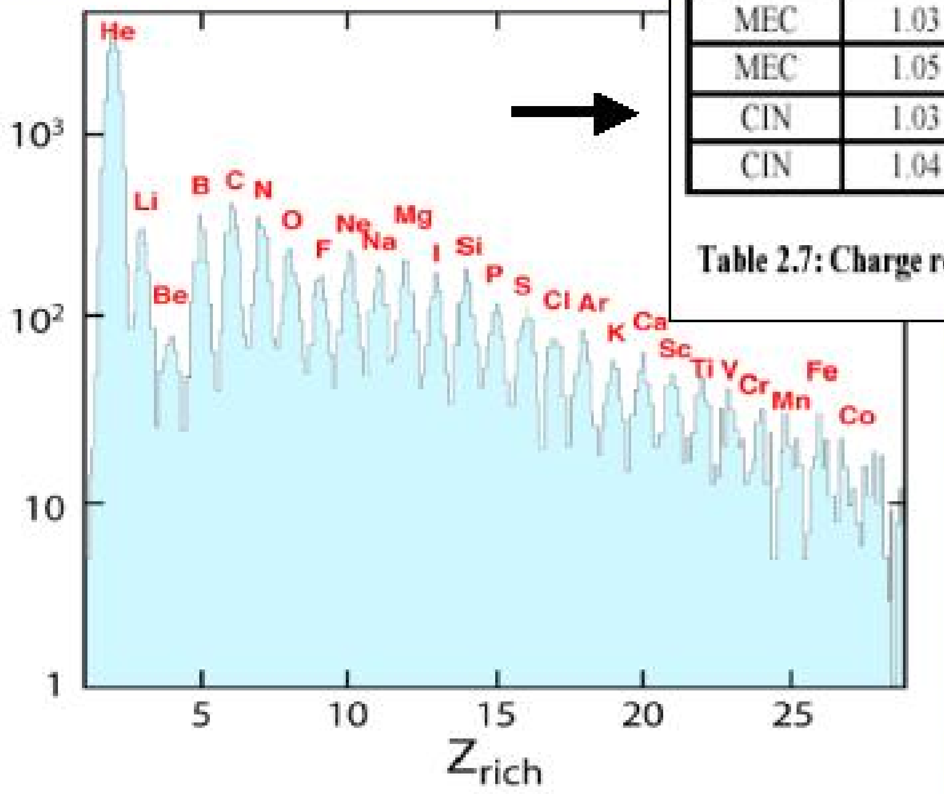


Figure 2.118: Measured distribution of charges (Z>1) for the CIN n=1.03 radiator.

Solar physics and physics of heliosphere

Solar physics and physics of heliosphere

Solar energetic particles-

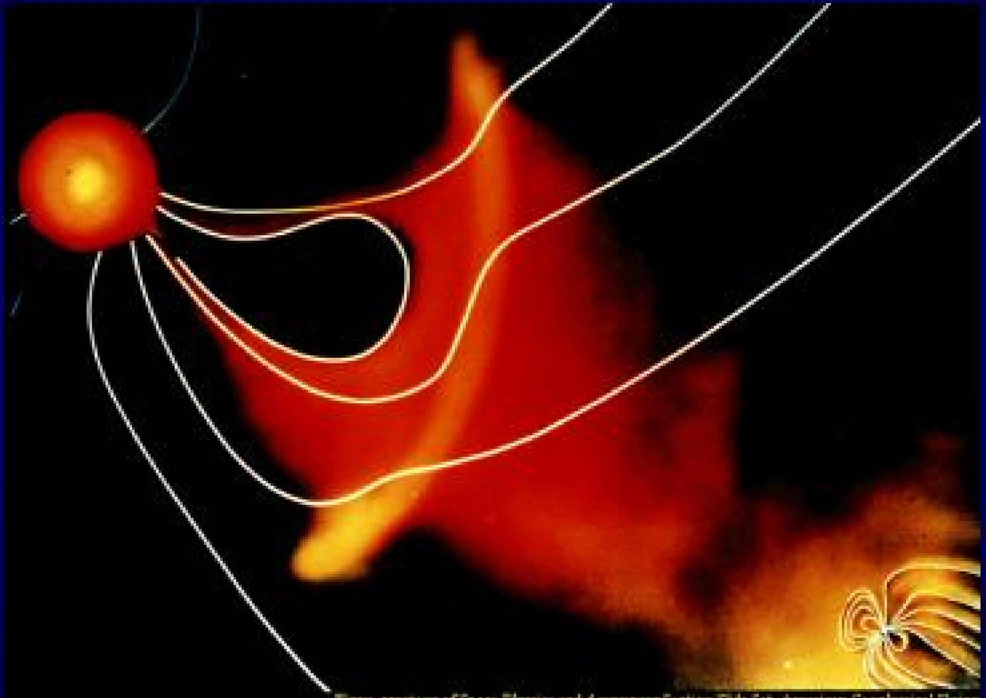
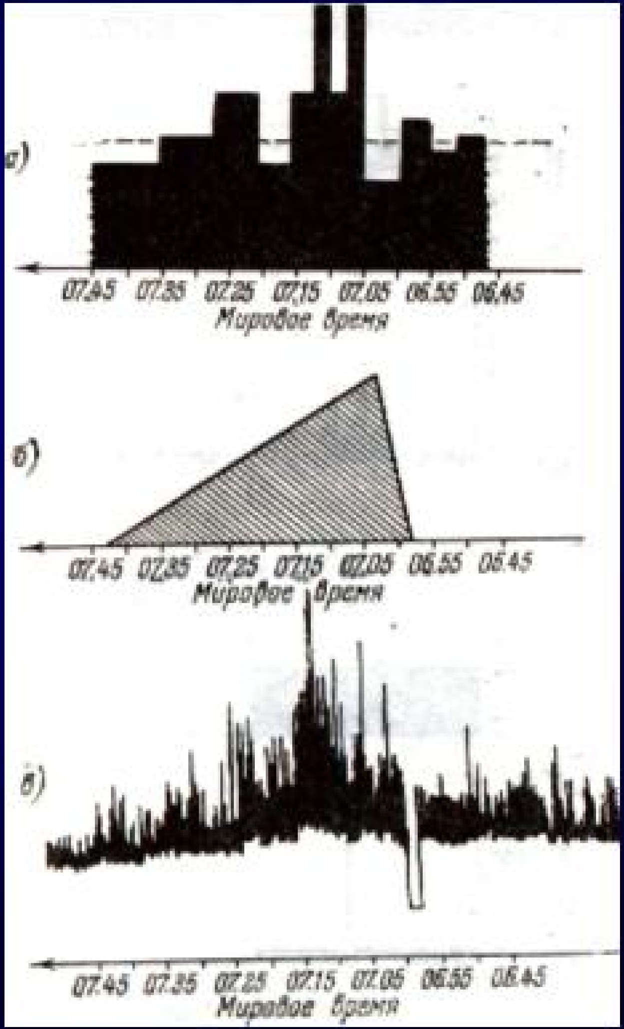


Figure courtesy of Space Physics and Aeronomy Section Slide Set, American Geophysical Union

problem of their origin is still existed

The first experiments in the space



The first solar flares particle study:
In 1959, onboard the 2nd soviet space rocket

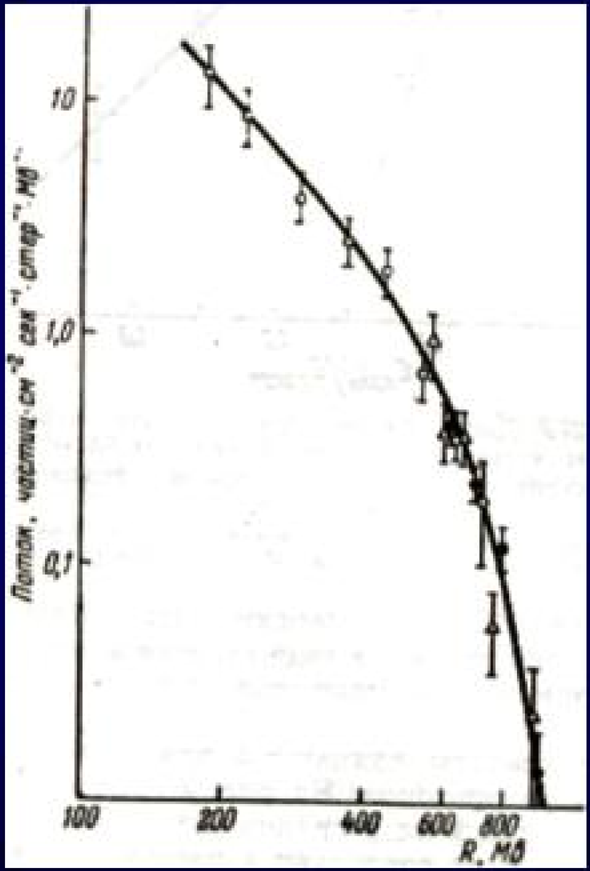
Ginzburg, Kurnosova, et al

He flux enhancement during the solar flare Sep.,13 1959

The first experiments in the space

Solar flares study

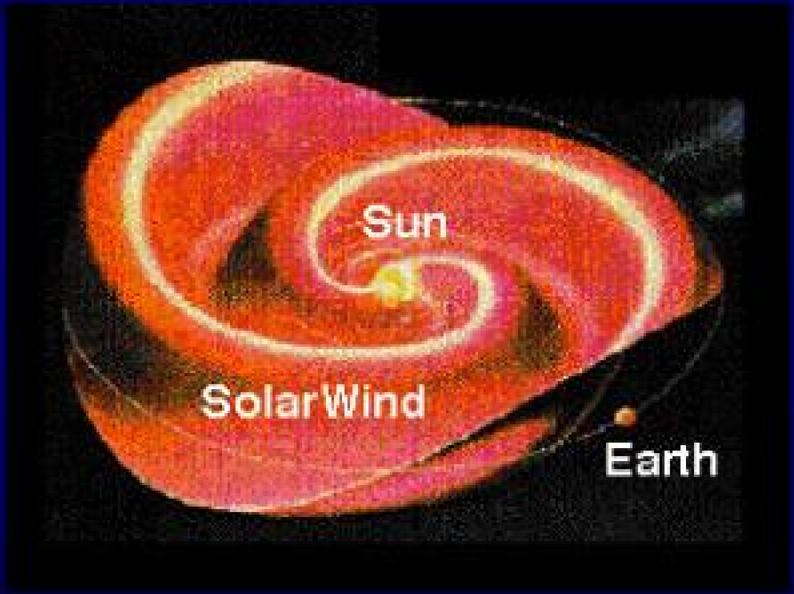
Energy spectra of different nuclei during Sep.,12 1960 solar storm



Ginzburg, Kurnosova, et al

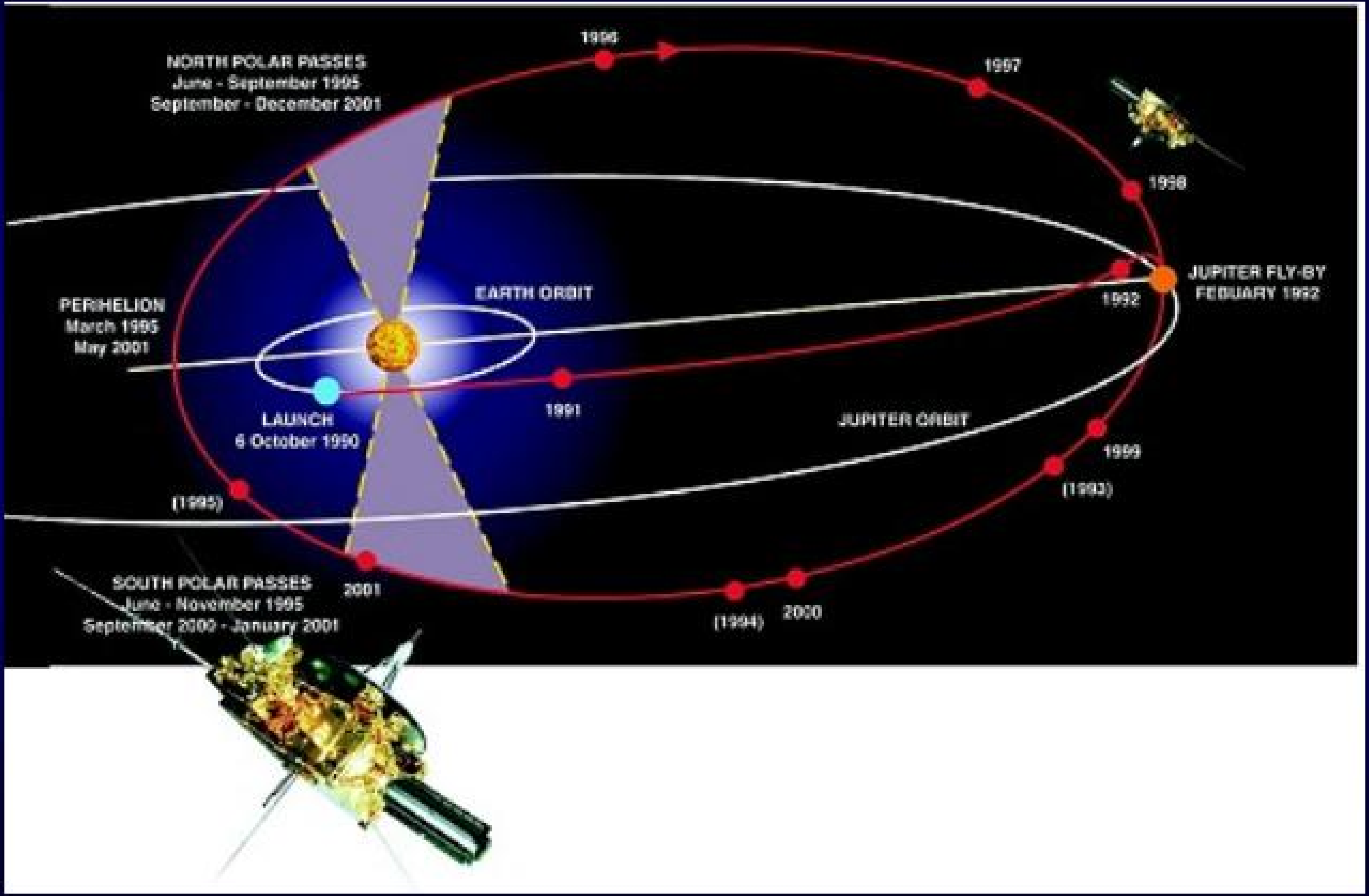
A current problems:

Just one:

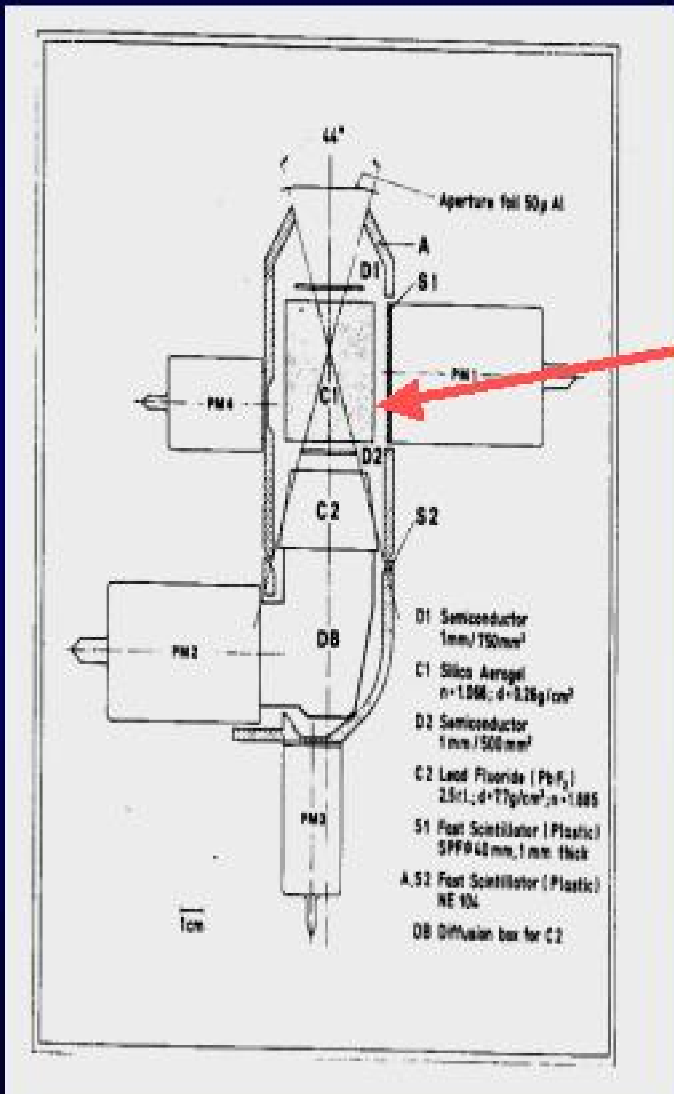


Particle acceleration
and modulation
in the **3-D heliosphere**

Ulysses : the first space probe out of ecliptic



Ulysses : the first space probe out of ecliptic

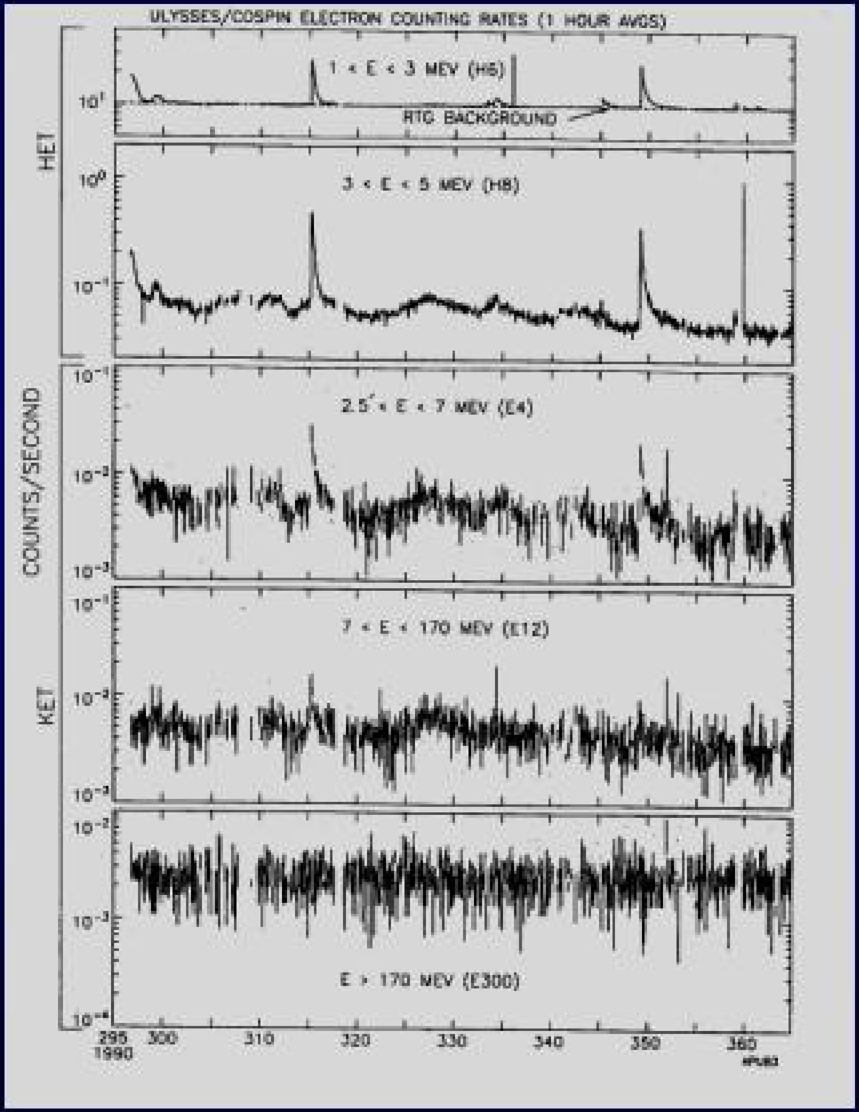


*K*iel *E*lectron *T*eleskop

Silica aerogel Cherenkov detector

e,p – separation

Ulysses : the first space probe out of ecliptic



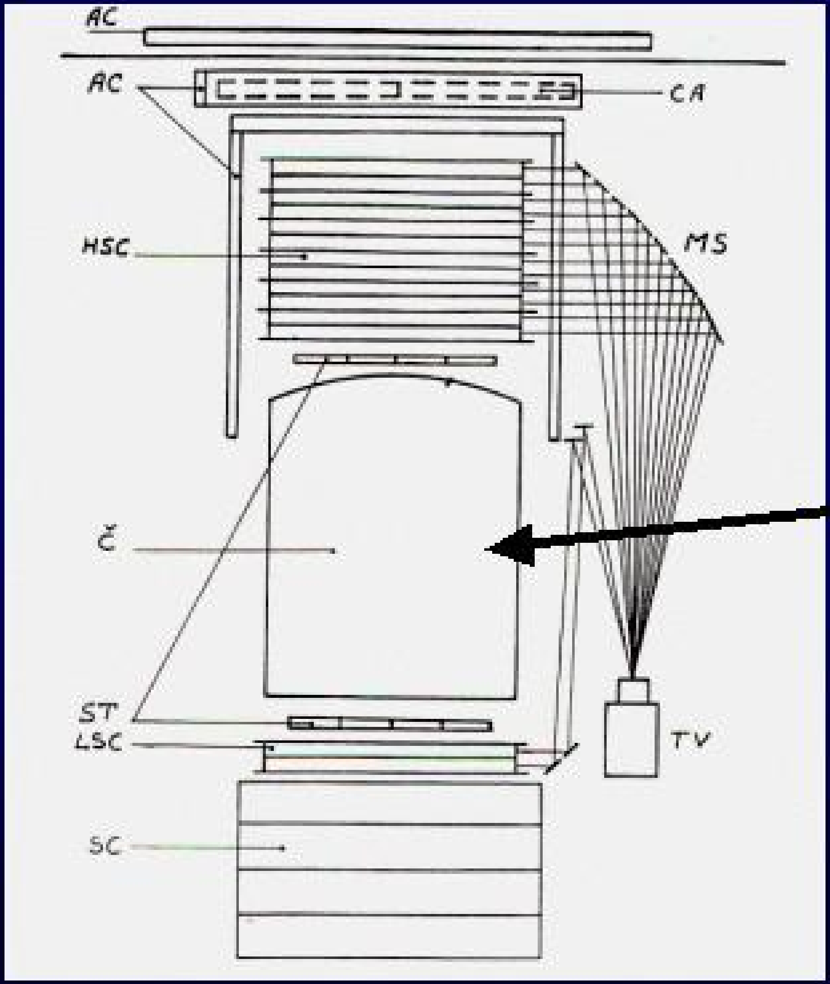
*K*iel *E*lectron *T*elescope

Measurements of electrons out of ecliptic with energy up to 200 MeV

Gamma-emissions of the Sun

Gamma-1 telescope

1991

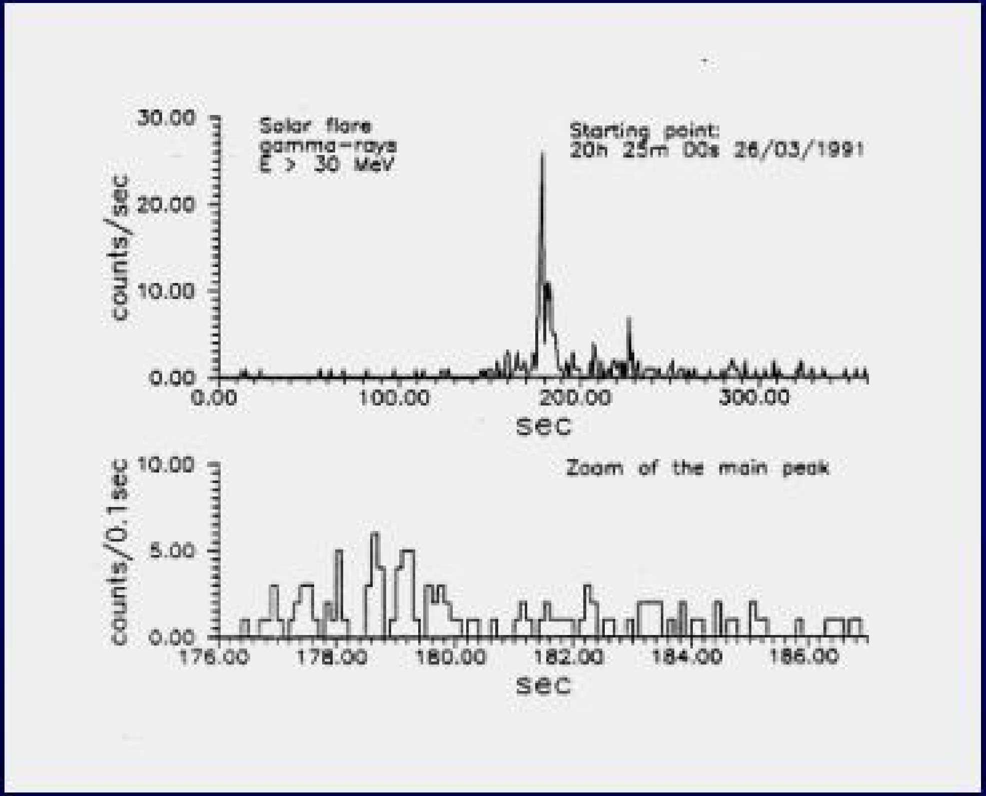


Geom. factor ~1480 cm2,
Sensitivity ~50 MeV - ~ 5GeV

Cherenkov gaz counter

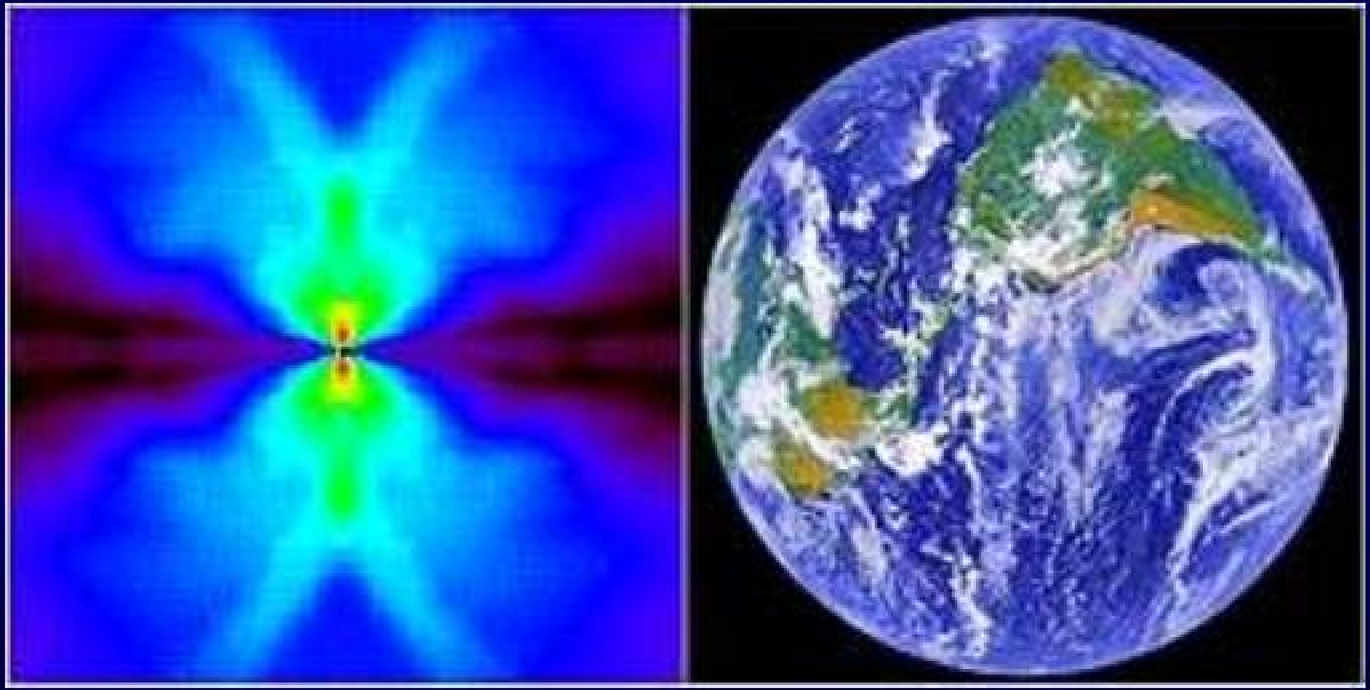
MEPhI, LPI, IKI

Gamma-1 telescope

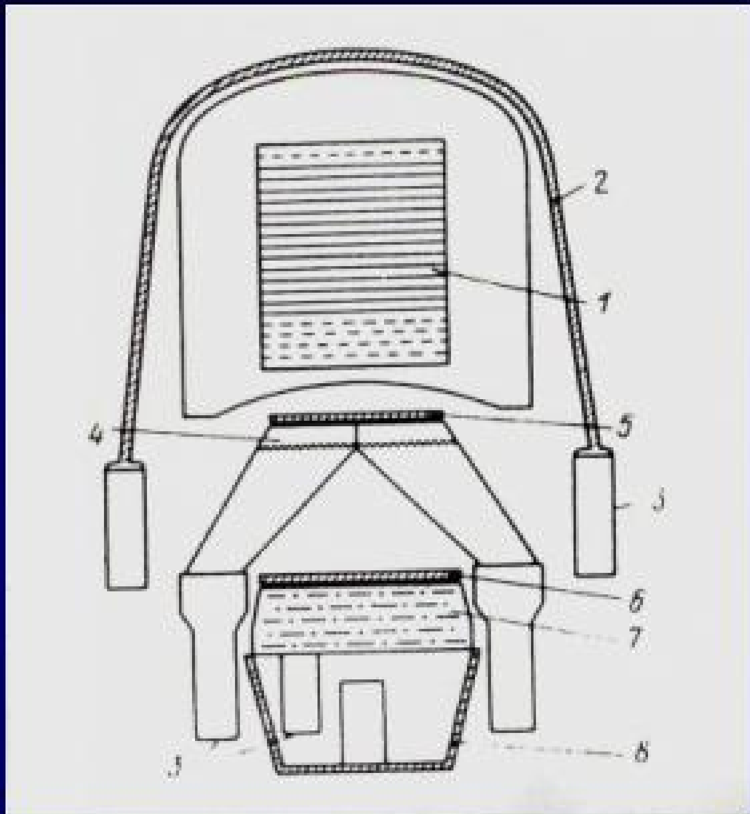


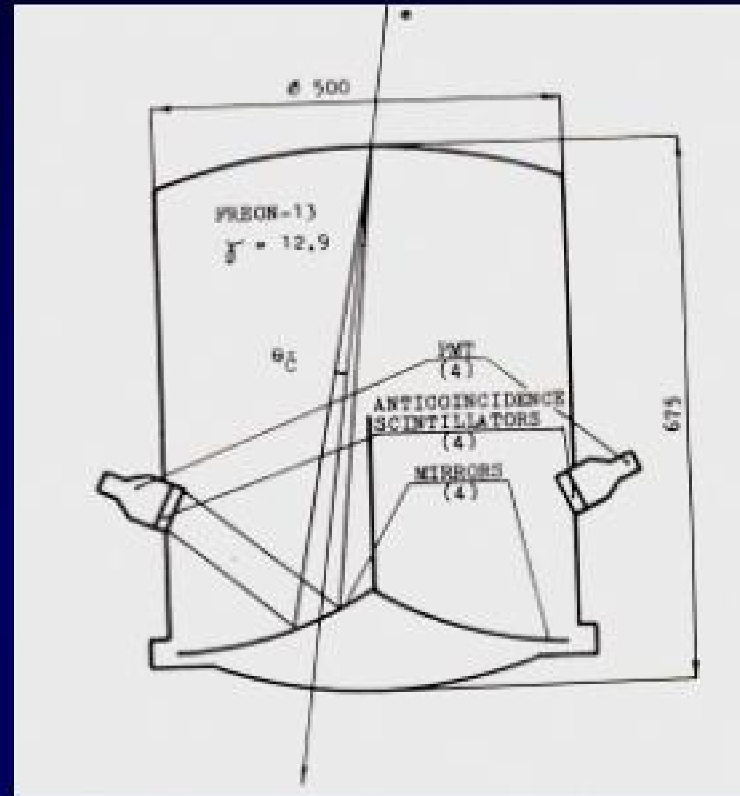
For the first time solar gamma-emissions with energy ~2 GeV observed by Gamma-1

Gamma-ray astronomy



COS-B satellite Cherenkov counter

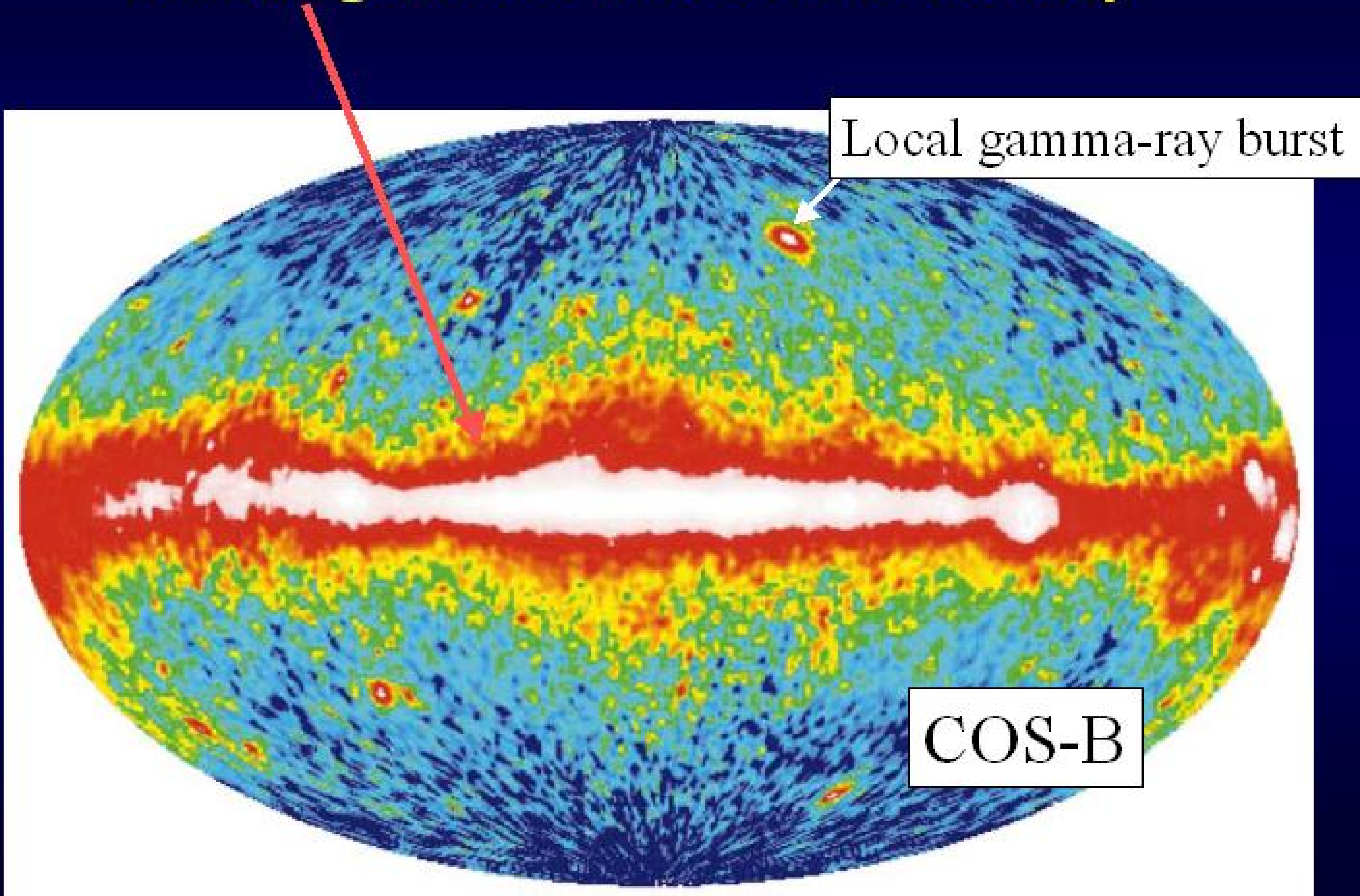




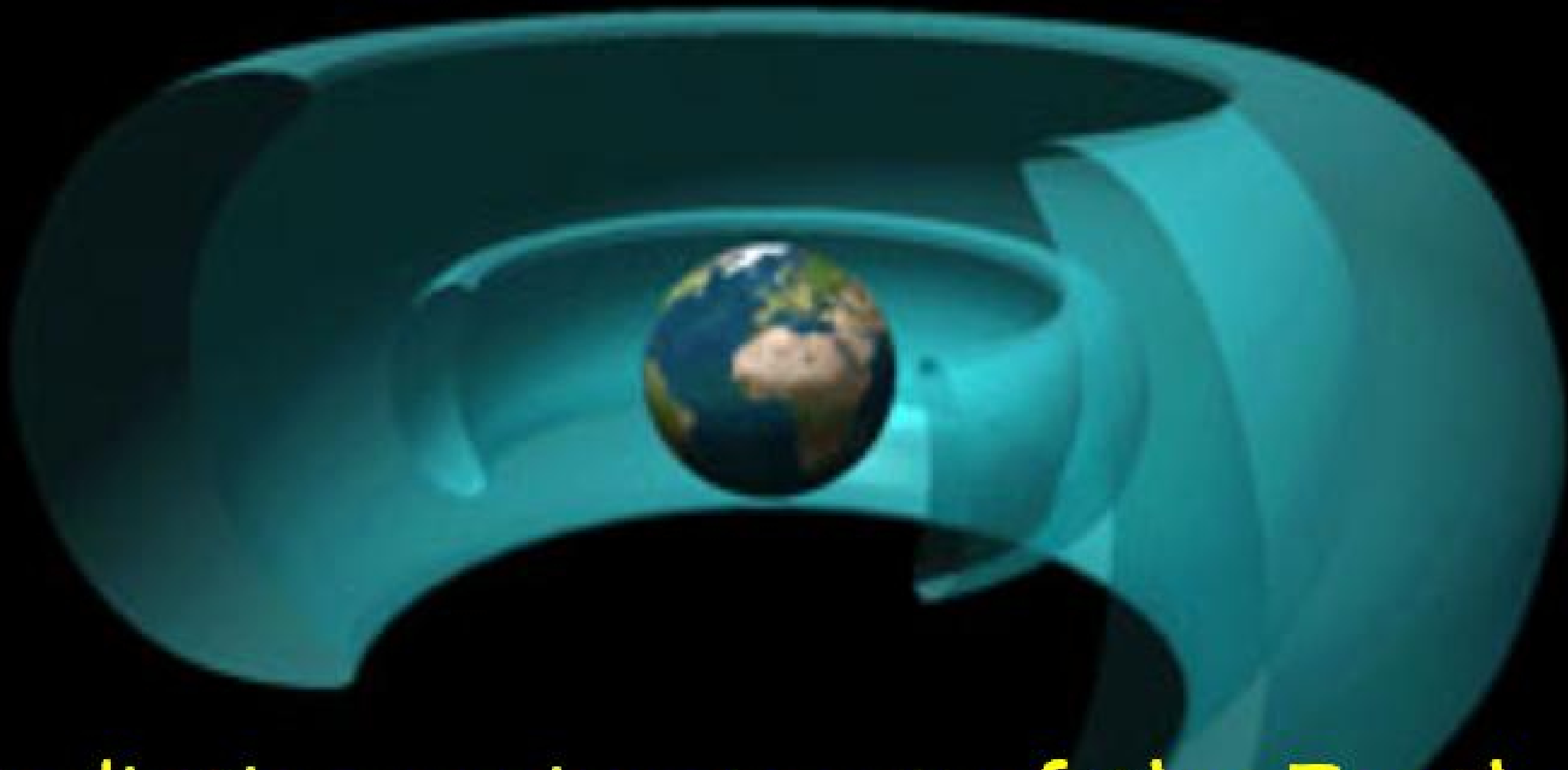
The Cherenkov gaz (freon-13 counter)

Sensitivity: ~50 MeV - ~1 Gev

Diffuse gamma- sources of the Galaxy

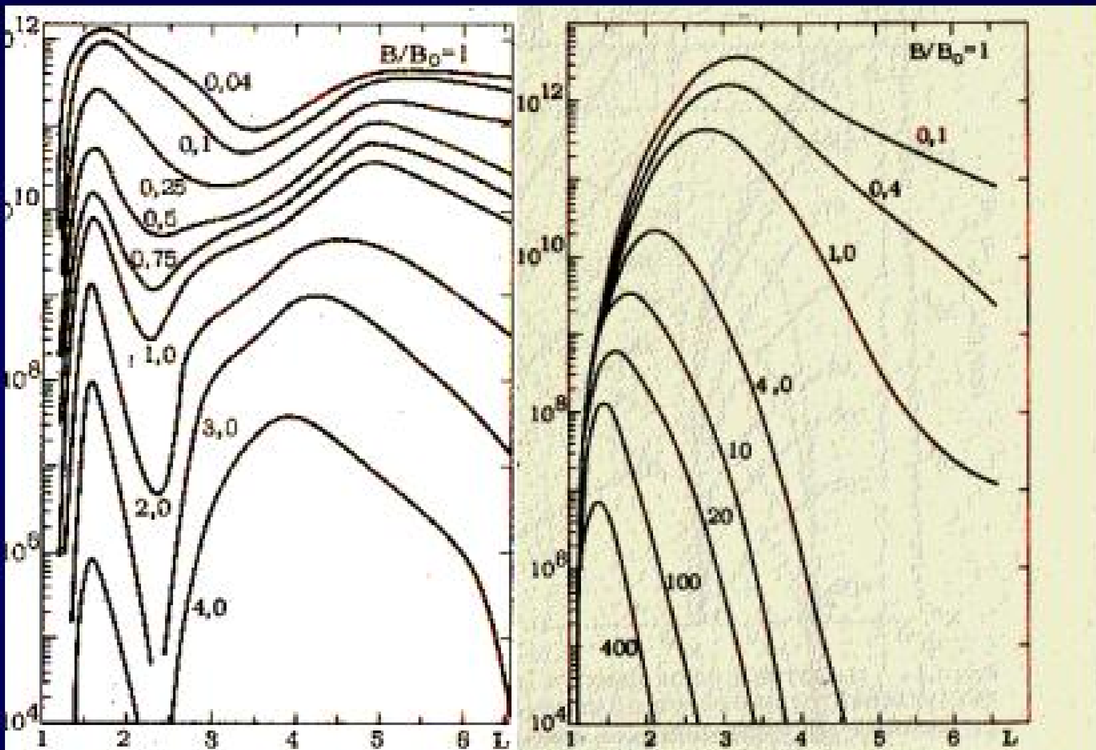


Space Physics



Radiation environment of the Earth – trapped radiation

Earth's radiation belts



Electrons *Protons*

- *Origin: solar plasma, ionospheric plasma and secondary particles.

- * Electrons and protons are most abundant.

- * Ions up to Fe with different charge states.

- * Energies from 100 kev - 10's MeV for electrons and 100 keV/n - 100's MeV/n for ions.

- * Energy of RB particles increases with decreasing distance from the Earth

- *Characteristic time of variation from seconds to tens of years.

Radiation belts current problem

- Rapid (during seconds-minutes) energization of relativistic electrons (up to ~15 MeV)

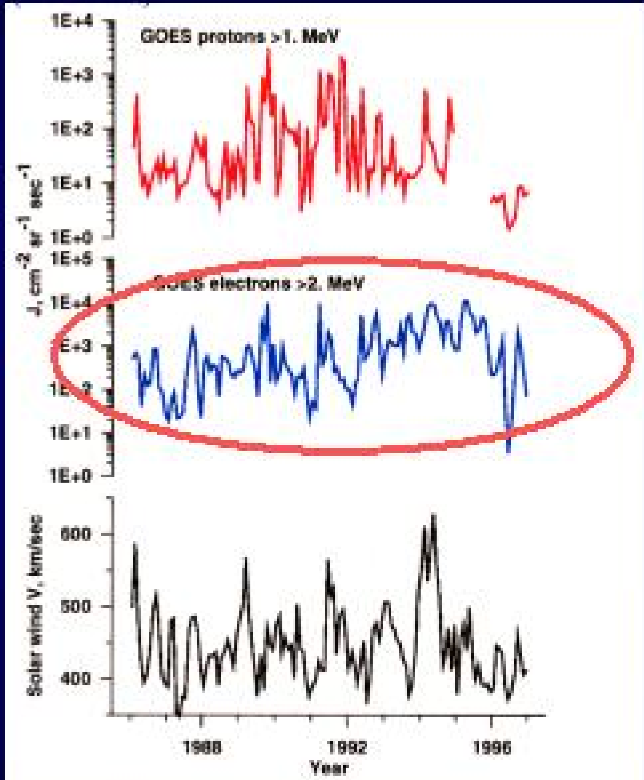
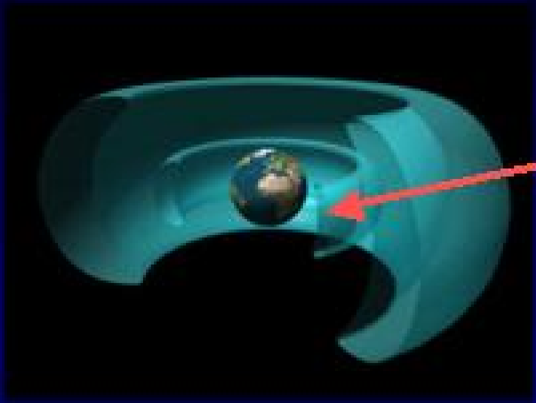


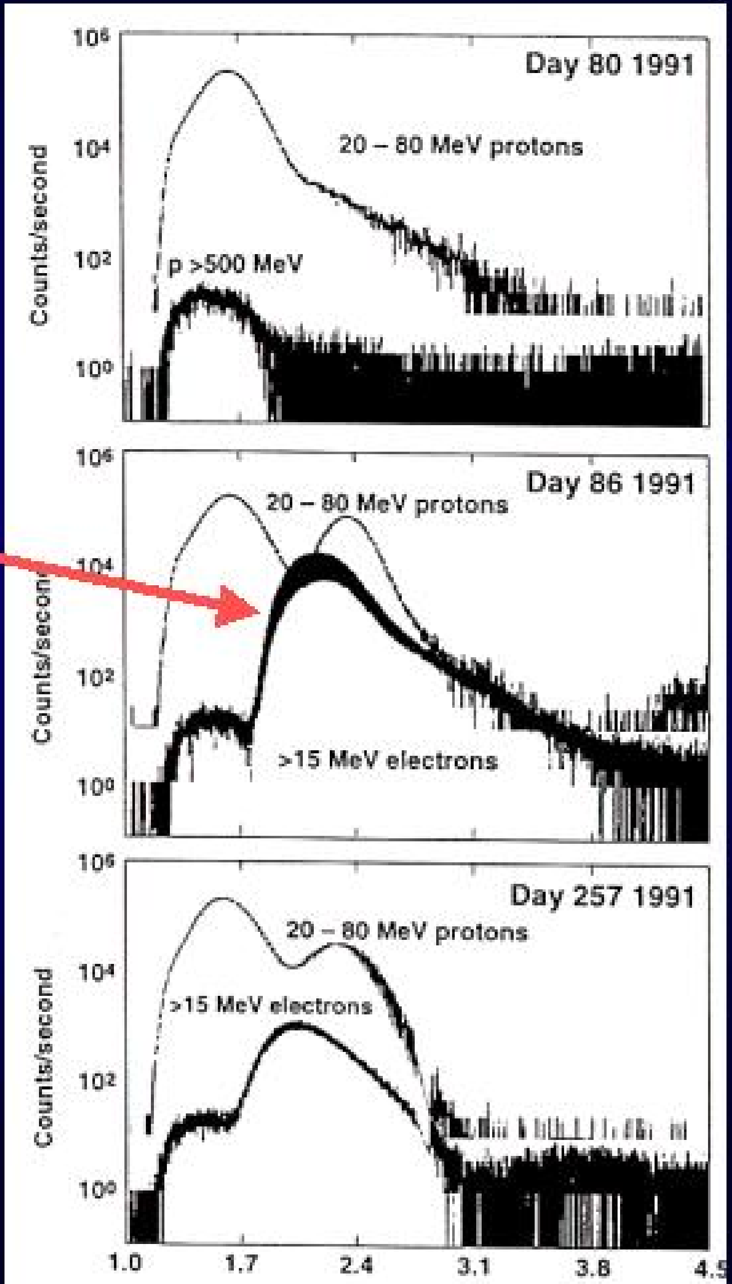
Fig. 2. GOES data on fluxes of protons with E>1.MeV and electrons with E>2 MeV fluxes and velocity of solar wind for the period of 1984-1996.

The first obsevation onboard Soviet "Cosmos-900 "satellite using plastic Cherenkov detector E.Gorchakov, SINP,1977

CRRES-effect, March,24,1991

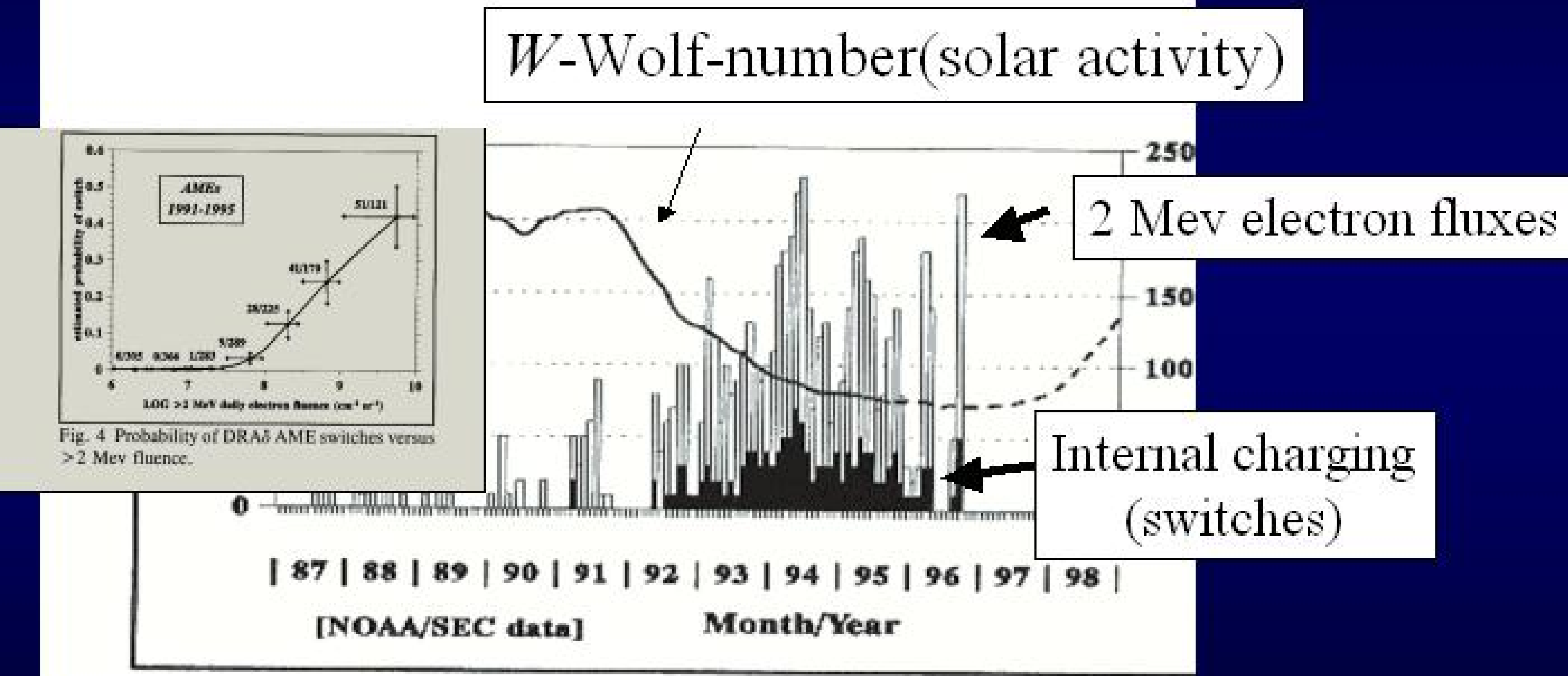


Prompt acceleration by interplanetary shocks: rapid (in minutes) energization of protons, ions and electrons as a consequence of shock (SSC) impact on the magnetosphere ,cause magnetopause shift to 3-4 Re and intense MHD wave fronts.



Relativistic electrons as a satellite's killers

Satellite's malfunctions, due to relativstic electrons



Internal charging and switches

Wrenn, et al, 1996

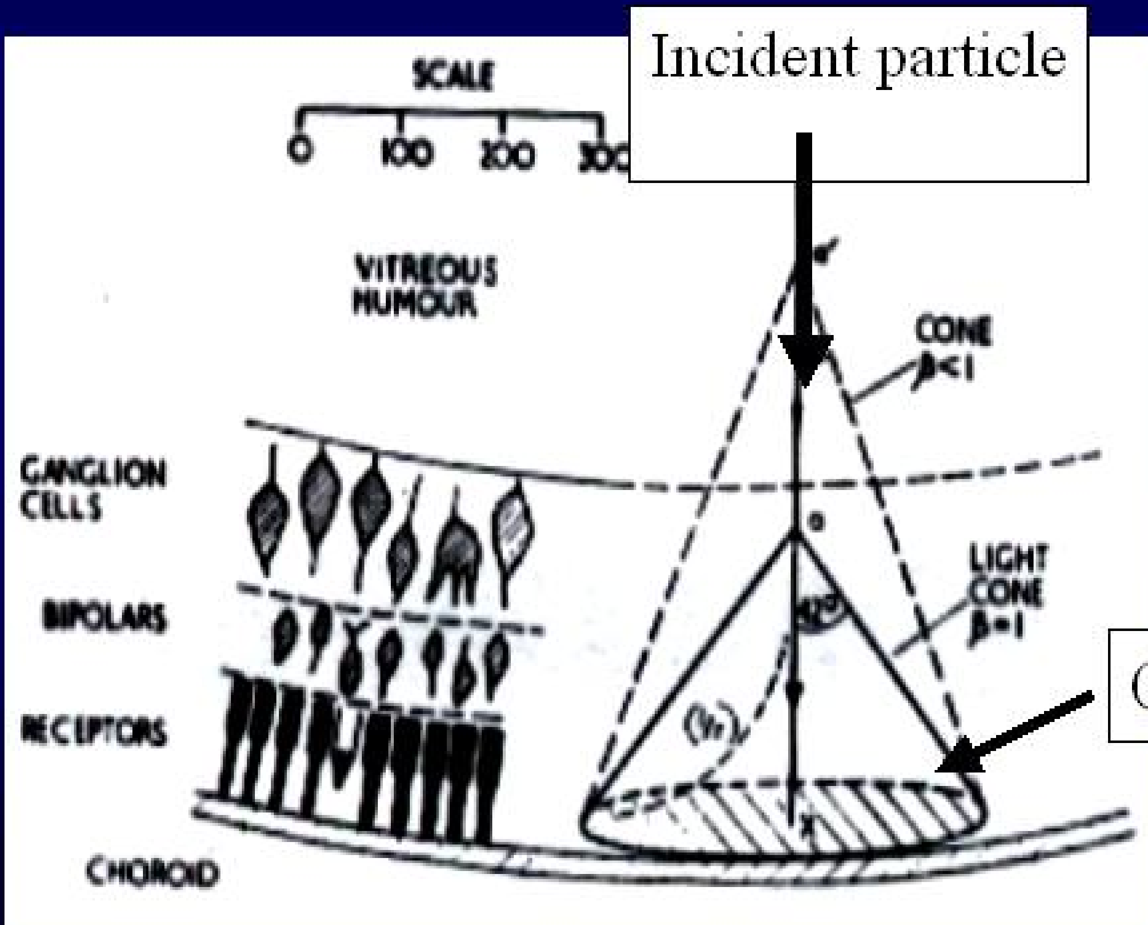
One more example from space explorations…..

Apollo' effect

During translunar space flights onboard Apollo11, Apollo12, Apollo 13 astronauts observed bright flashes in their eyes ….

Niel Armstrong: up to 100 flashes, ~1 per minute…

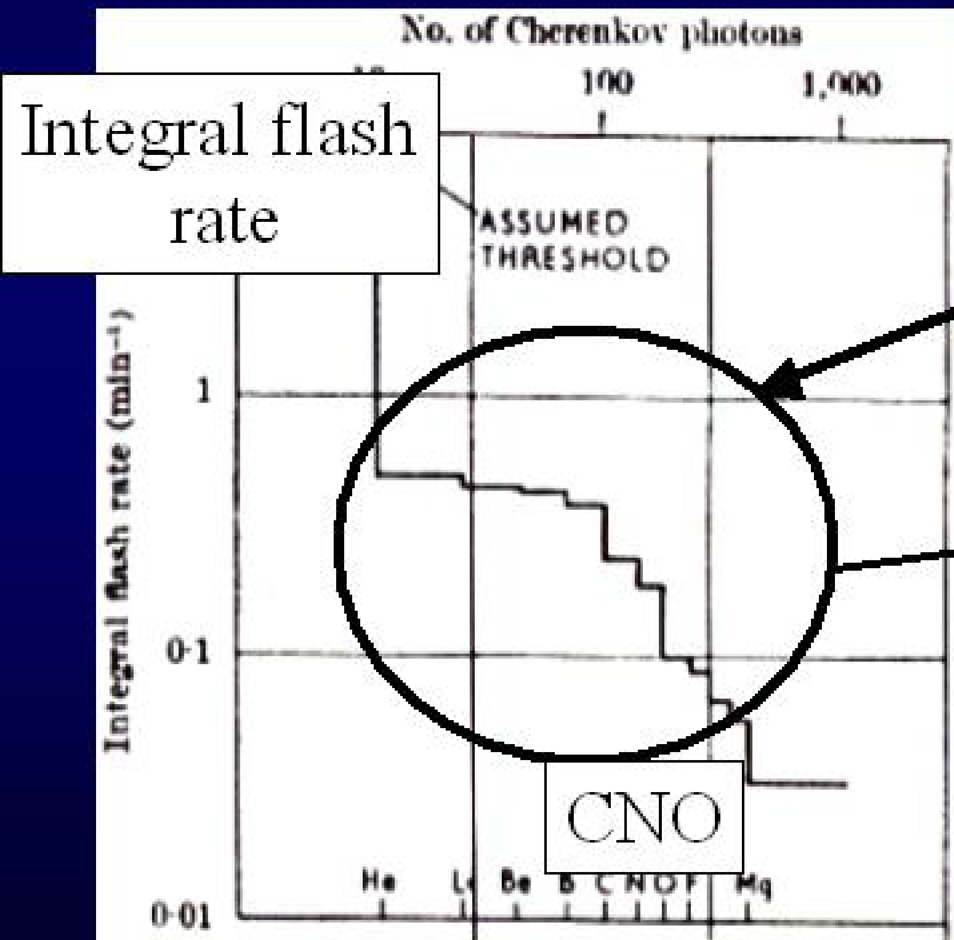
Apollo' effect

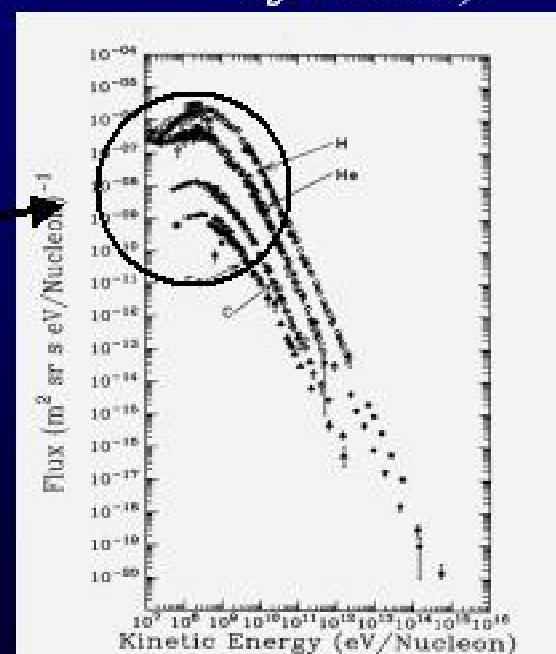


Dominant mechanism:
these flashes were
caused by high –Z
energetic
galactic cosmic rays
(with high LET)
penetrating inside
ocular media of the eye.

Apollo' effect

Light flashes in astronaut's eyes were initiated by these GCR particles *(Cherenkov radiation +exitation of retina)*





Summary

Space Cherenkov detectors have played the crucial role in our understanding

-of cosmic ray nature,

and

-near-Earth radiation environment.

Moreover, in many cases these experiments could have a title

Summary

"The first"

Summary

and

Lidiya Vasil'evna Kurnosova –

Lady The First

of this field

Thank you

for your attention

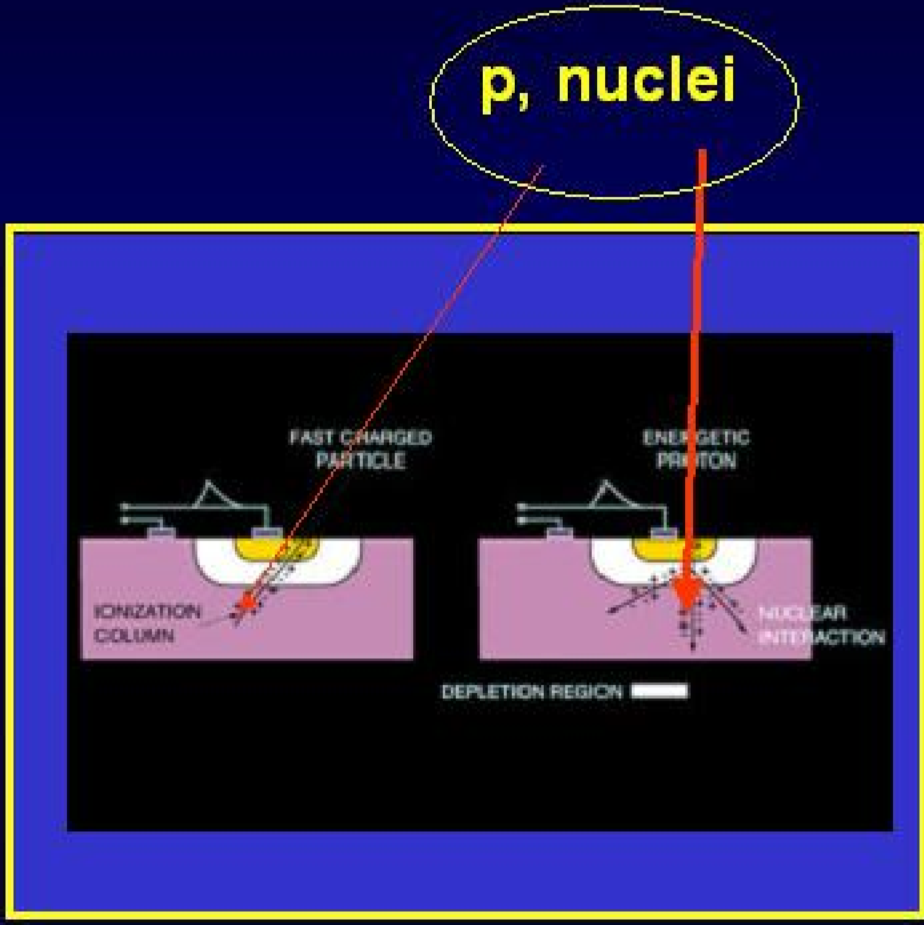
Cherenkov detectors in space

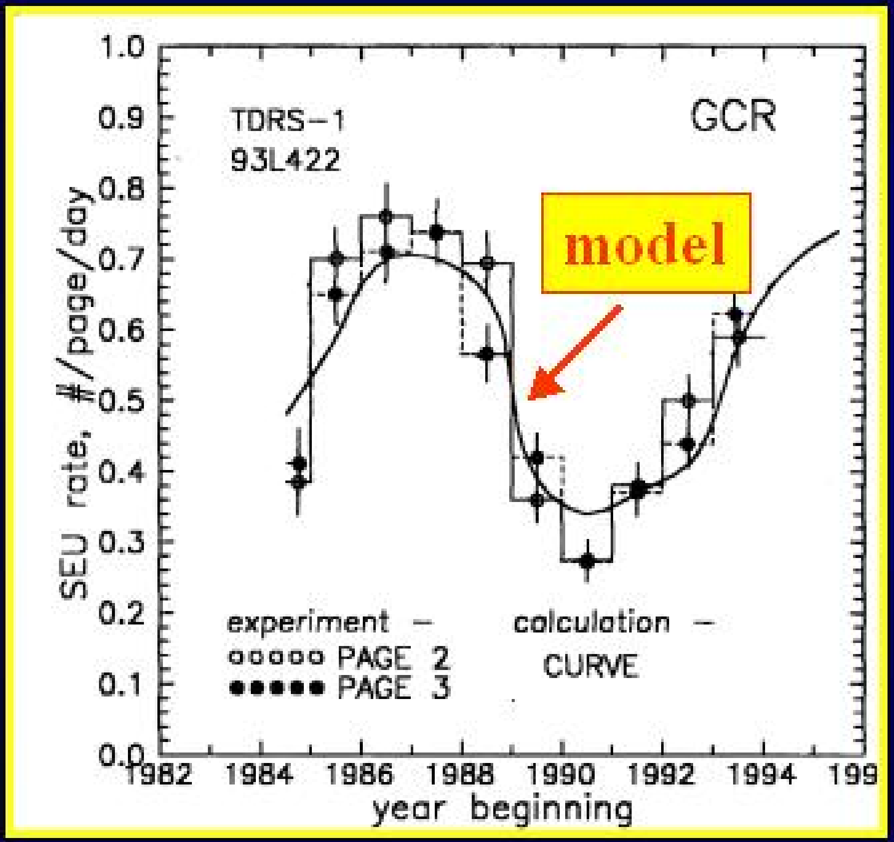
Mikhail Panasyuk

Skobeltsyn Institute of Nuclear Physics
of Moscow State University

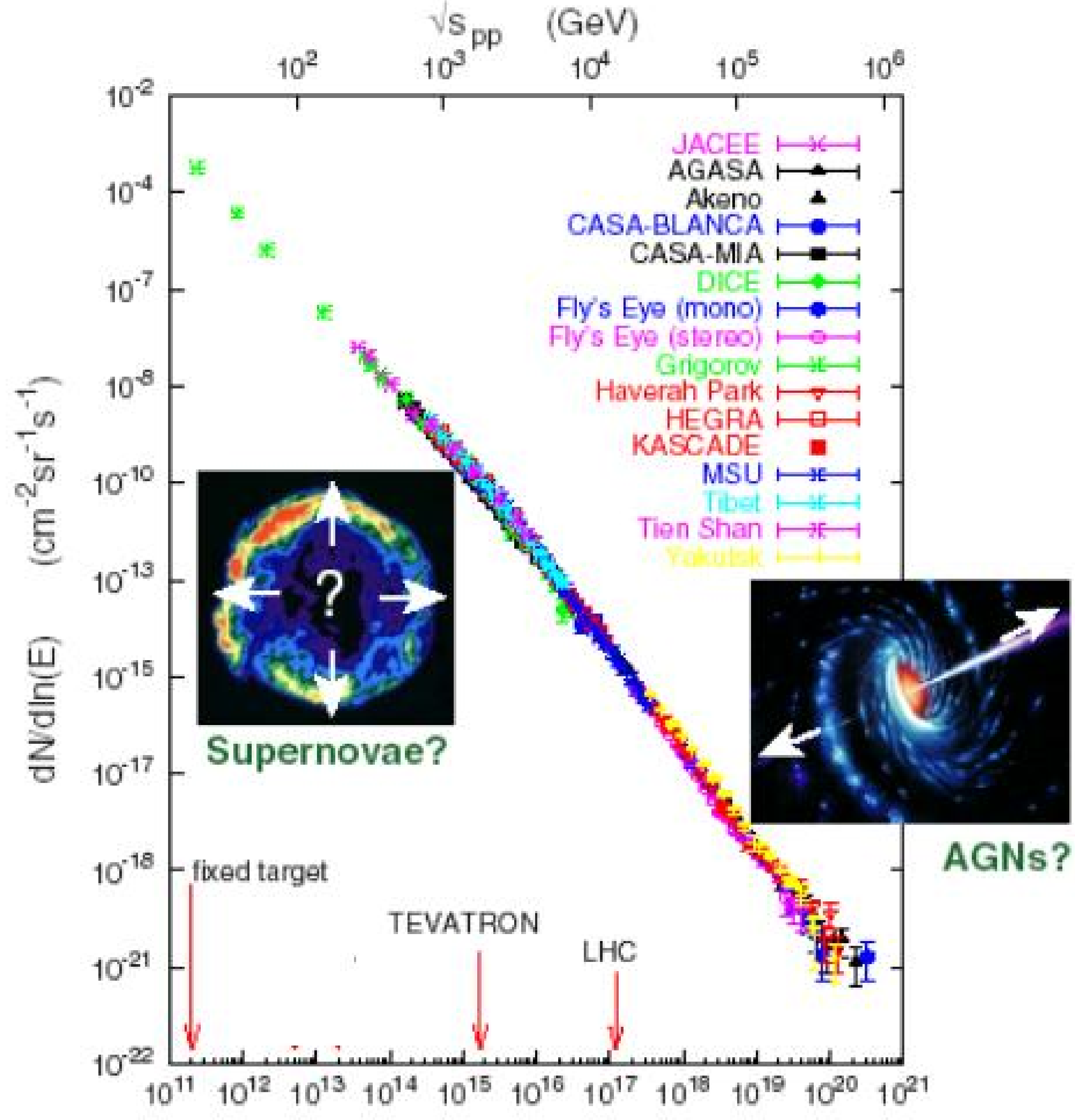
International Conference
P.A. Cherenkov and Modern Physics,
Moscow, June 22-25, 2004

Single Events Effects



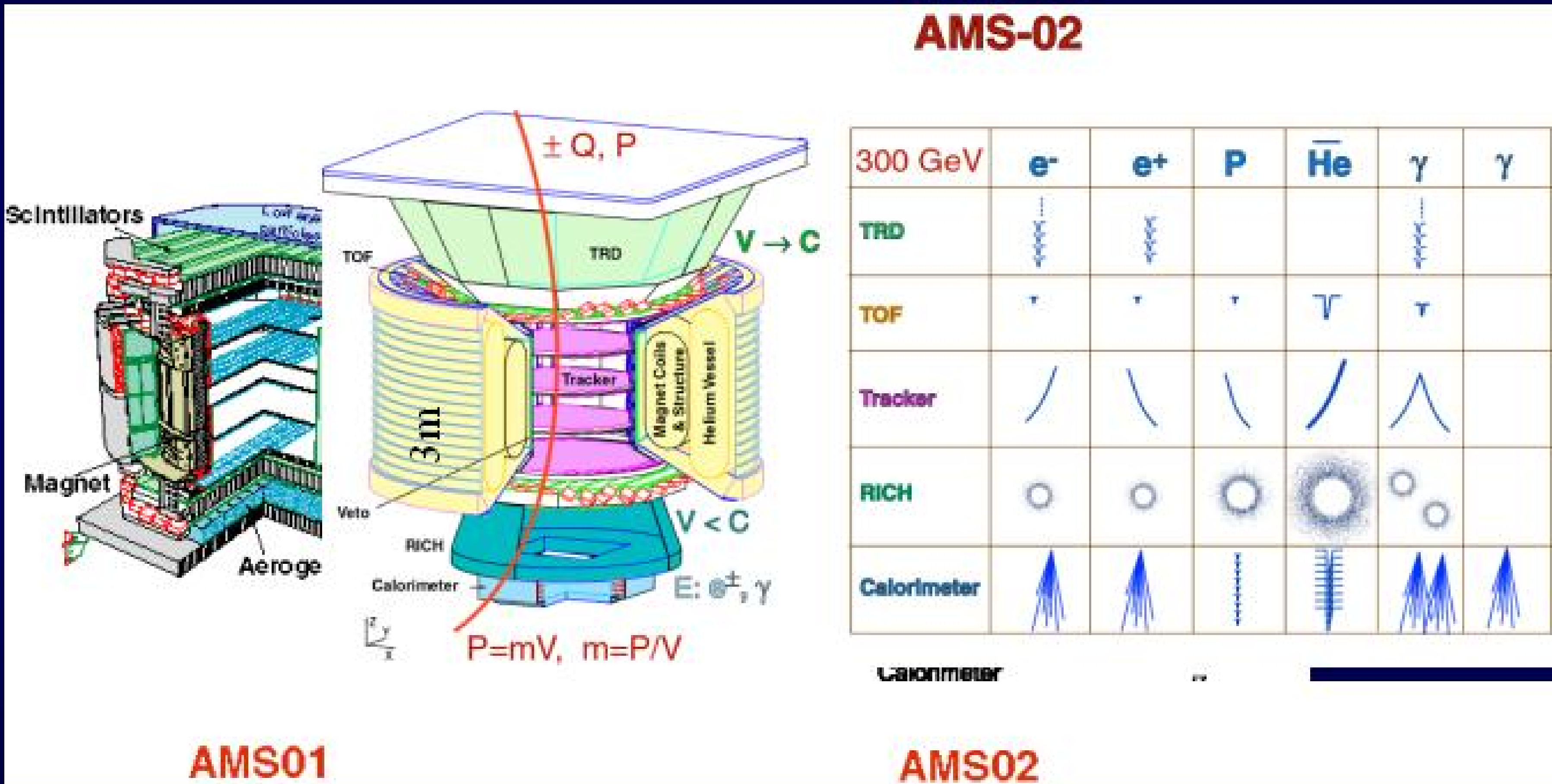


Kuznetsov, et al,1999



√s pp (GeV)
10^2 10^3 10^4 10^5 10^6
JACEE
AGASA
Akeno
CASA-BLANCA
CASA-MIA
DICE
Fly's Eye (mono)
Fly's Eye (stereo)
Grigorov
Haverah Park
HEGRA
KASCADE
MSU
Tibet
Tien Shan
Yakutsk
dN/dln(E) (cm^-2 sr^-1 s^-1)
10^-2 10^-4 10^-7 10^-8 10^-10 10^-13 10^-15 10^-17 10^-18 10^-21 10^-22
Supernovae?
AGNs?
fixed target
TEVATRON
LHC
10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20 10^21
E (eV / particle)

AMS01 vs AMS02



Improved detector (larger acceptance, 5 times stronger magnetic field)

Largely improved particle id (TRD, RICH, EM Calorimeter)

Long-term relativistic proton/electron variations in geostationary orbit

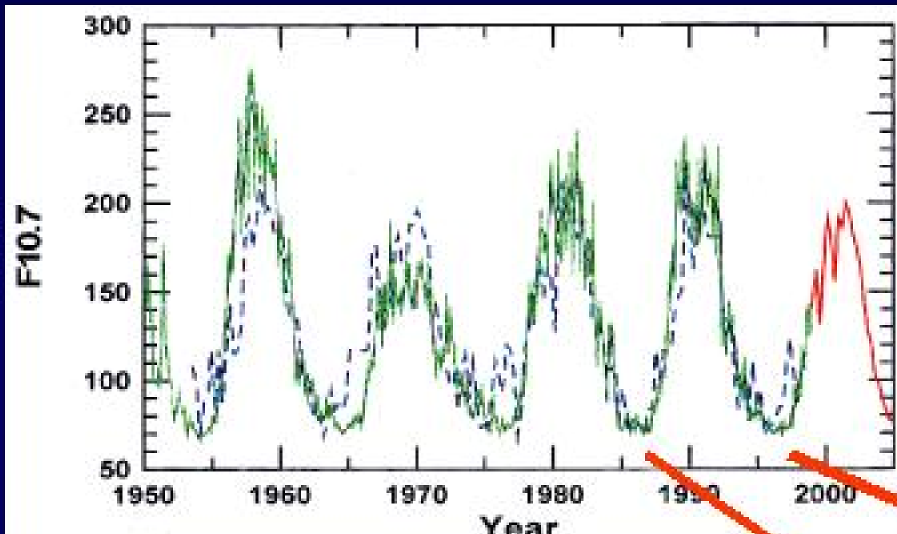


Fig. 4. RNN modeling of 100 days averaged mean values of solar radio flux F10.7 (solid line). RNN results on training and testing sets are shown by thin dashed and hard dashed lines respectively. F10.7 flux forecasting on 1999-2005 is presented by hard line. This line is monthly averaged mean of F10.7 flux.

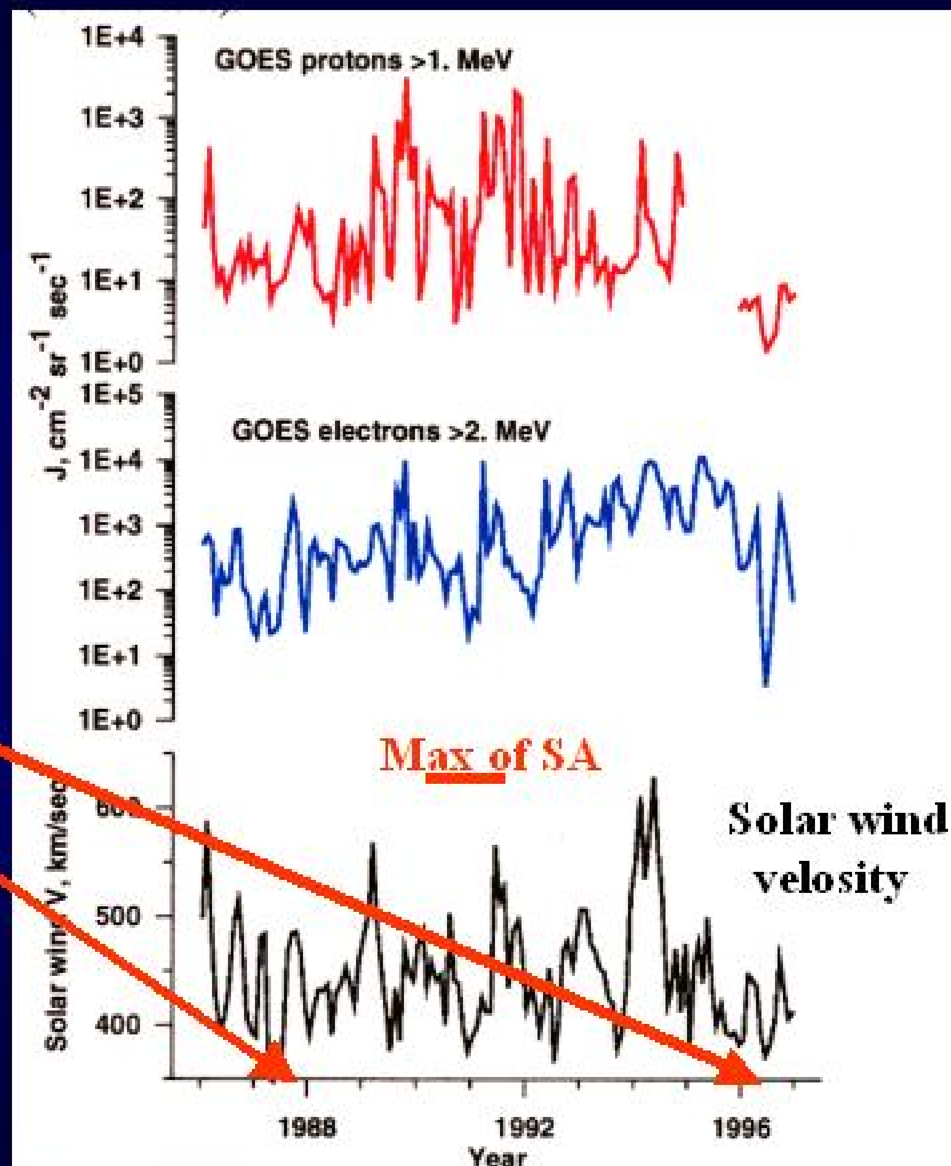


Fig. 2. GOES data on fluxes of protons with E>1.MeV and electrons with E>2 MeV fluxes and velocity of solar wind for the period of 1984-1996.

Electron variations. Outer zone

Electron fluxes in the outer zone are highly variable on a daily time scale (factor about 10 -100).

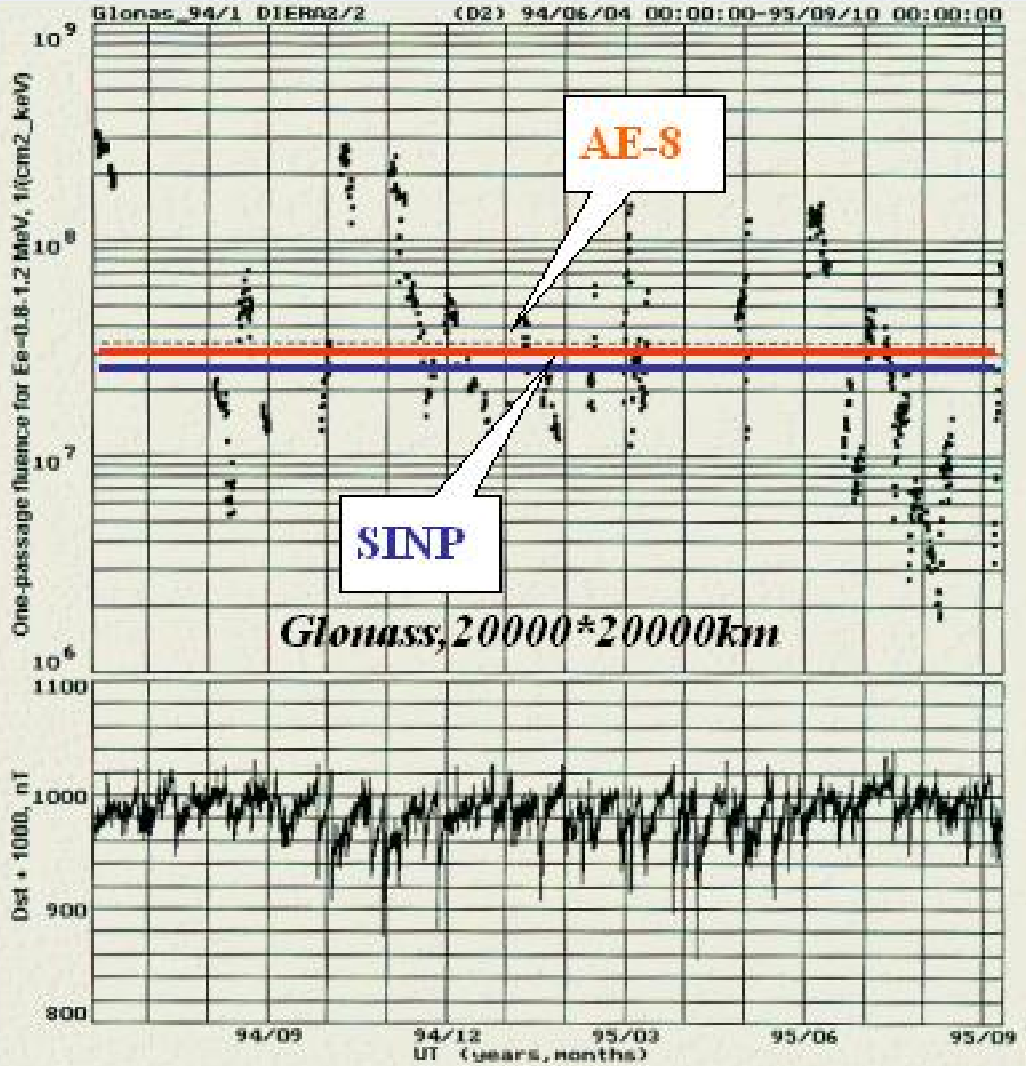
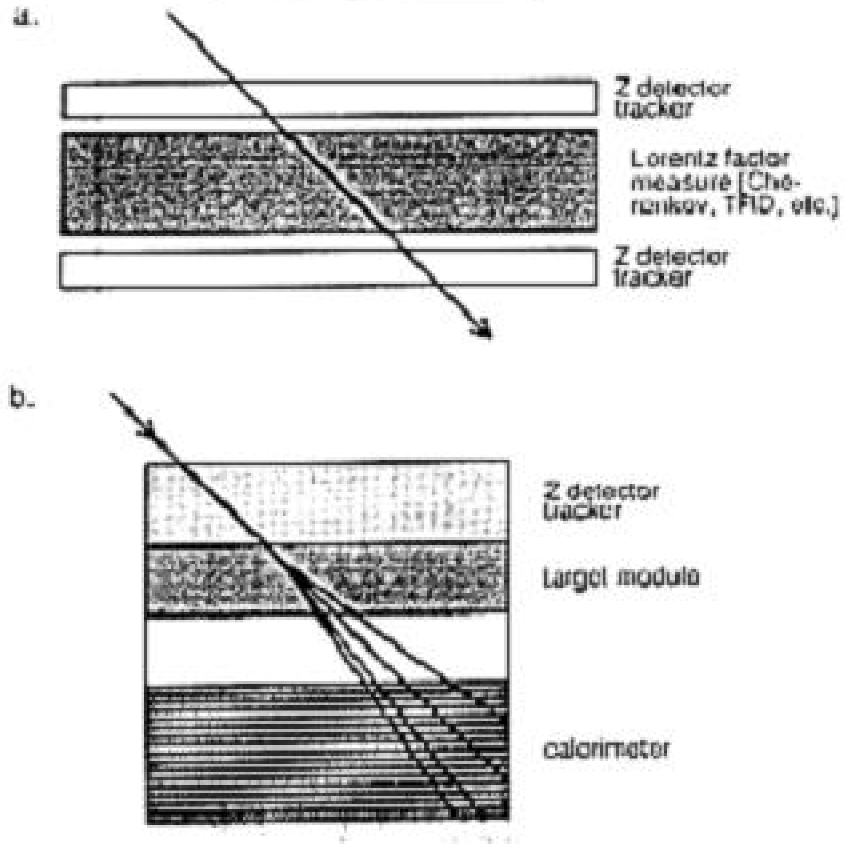


Figure 2. The 0.8–1.2 MeV electron flux as measured on GLONASS-94/1. The data is represented in the terms of fluence per a passage through the belt. The respective model estimates give the set of points located between the two dashed lines. INP-91 and AE-8 model are used. D_{st} is presented in bottom.

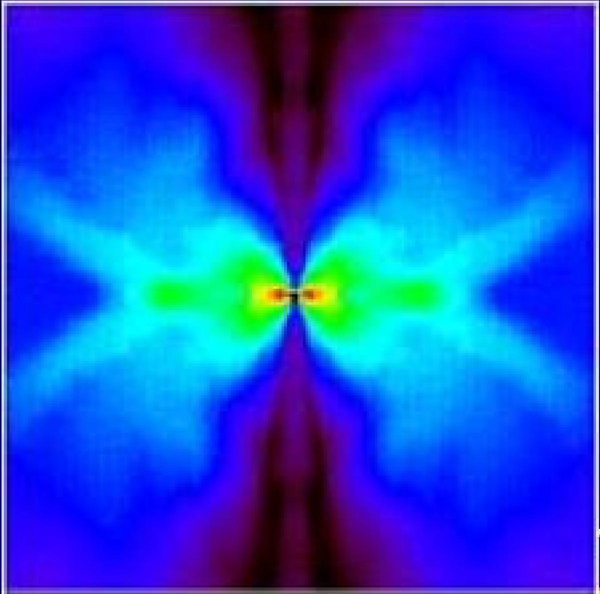
Perspectives for the future experiments.



General requirements for instrument

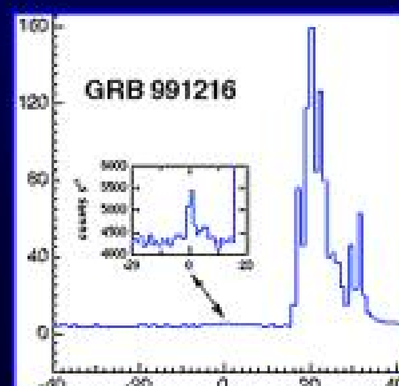
1. Large geometric factor

Z	$G(\approx 10^{15}$ eV)
1	300 m^2·ster·days
>1	5000-1000 m^2·ster·days

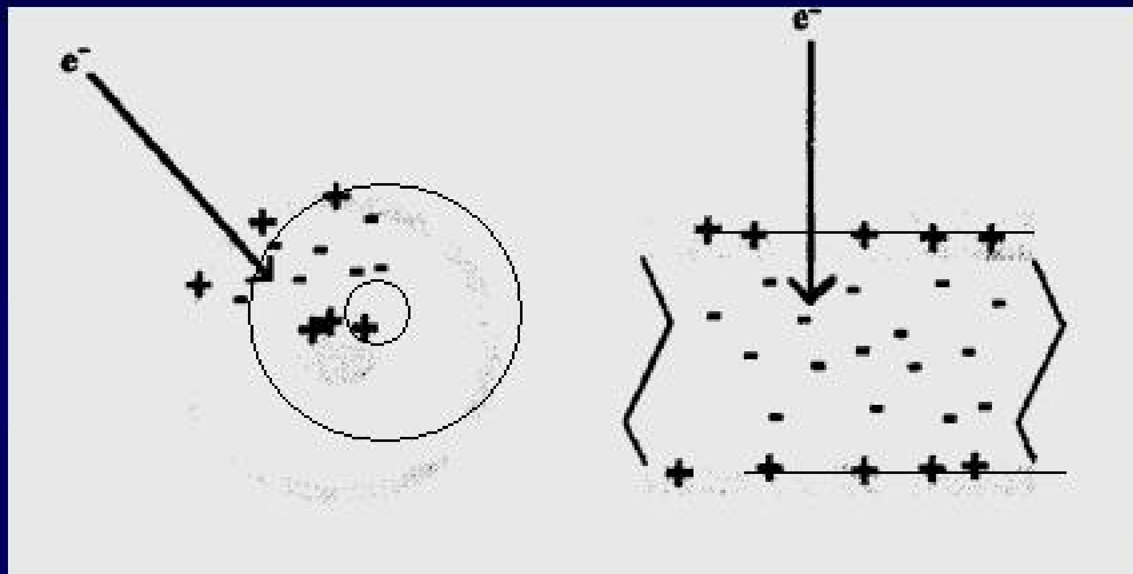


Gamma bursts

One of the leading theories for the cause of gamma ray bursts is the collapsar or failed supernova theory.A super-massive star, after bruning all of its nuclear fuel, starts to explode as a supernova, but the overlying atmosphere is too massive to blow off, and the explosion collapses, forming jets of matter that burrow out through the poles and then rip the star apart. The scale of the evnets at the core are about the same size as our Earth



Internal (bulk) electrostatic charging mechanism in complex structures



Incident high-energy electrons embed within the bulk of the thick dielectric (cable)producing an image charge on the inner and outer connectors, building up a potential sufficient to cause a discharge.

Electrons embeding in multilayer circuit board produce image char-ges in the conductive layers. Brakedown will be similar to the case a).

Ring Imaging Cherenkov Counter

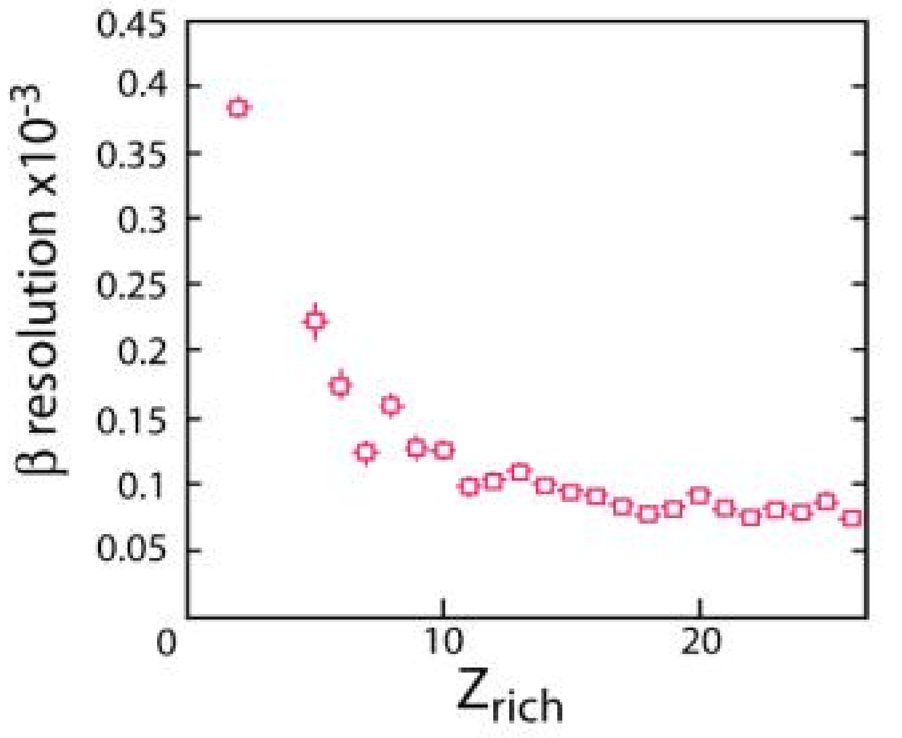


Figure 2.120: Dependence of the velocity resolution on the charge of the nuclei for the CIN n=1.03 radiator.

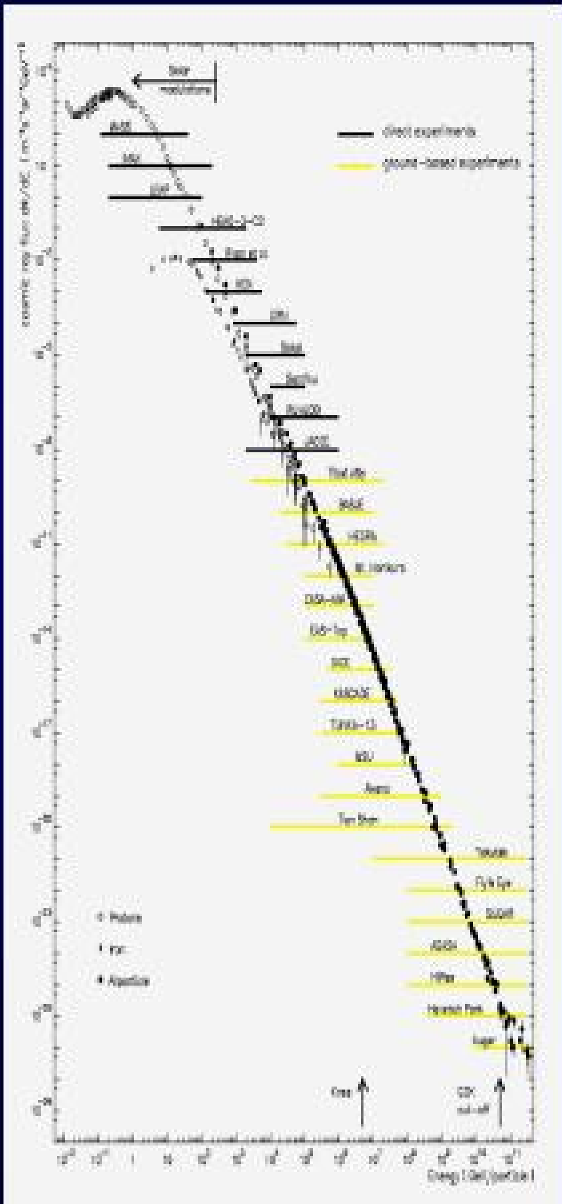
The first experiments in the space

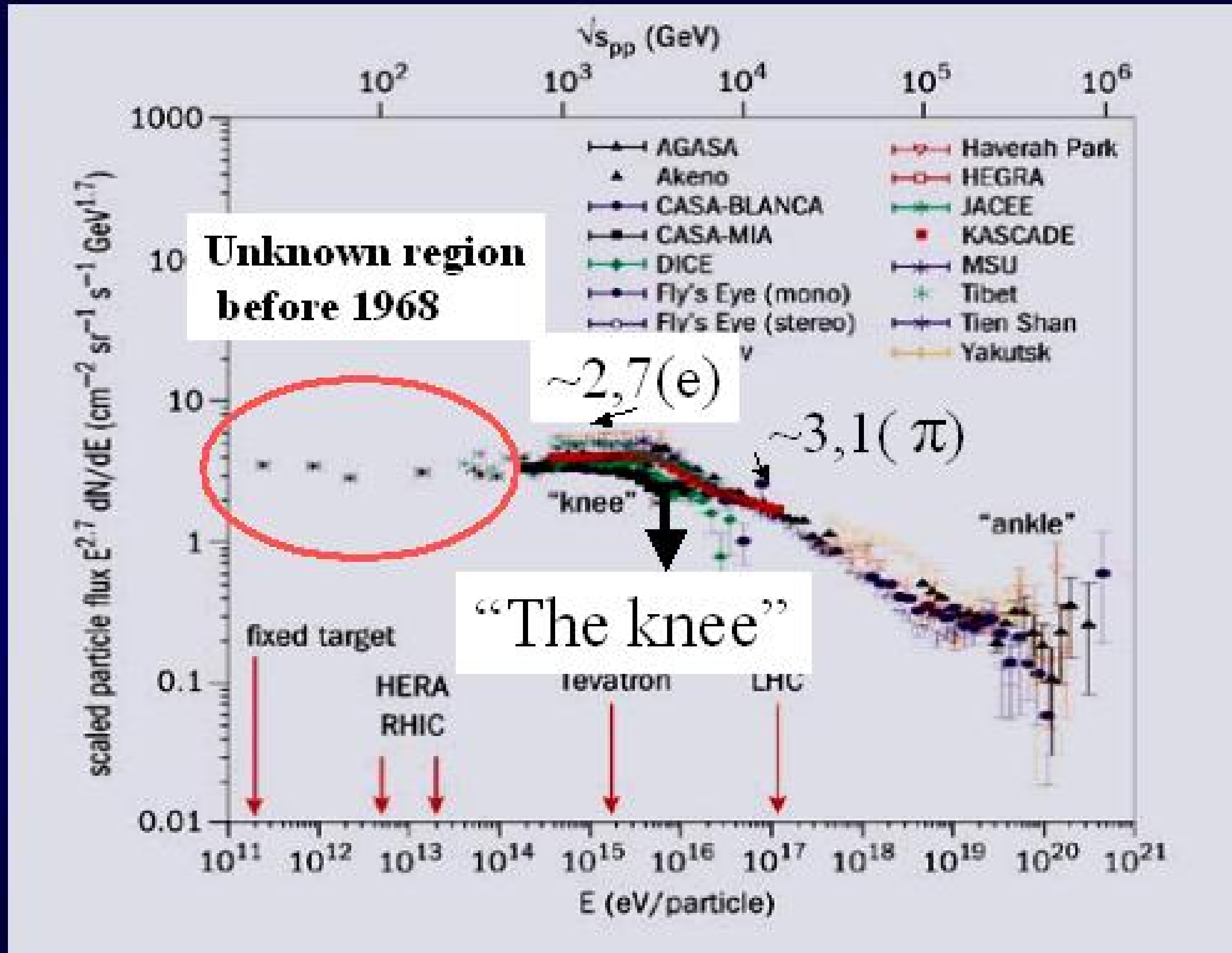
Satellite	Year	Detector's type	The goal	Institution
Cosmos 208 Cosmos 225 Cosmos 410 Cosmos 443 "Salyut" space station		1 1,2 1 1 1	Gamma-rays measurements e, p separation, near Earth radiation Z-separation of cosmic rays	SINP LPI LPI

The first experiments in the space

Satellite	Year	Detector's type	The goal	Institution
Cosmos 490 Cosmos 555 Proton 1-4 Sokol 1,2 (Cosmos 1543, 1713) Gamma-1		1 1,2 1,3 2	e,p-separation near-Earth radiation Z-separation, Cosmic ray nuclei Near-Earth radiation Z-separation Cosmic-ray nuclei Gamma-rays	SINP LPI SINP SINP MEPhI LPI

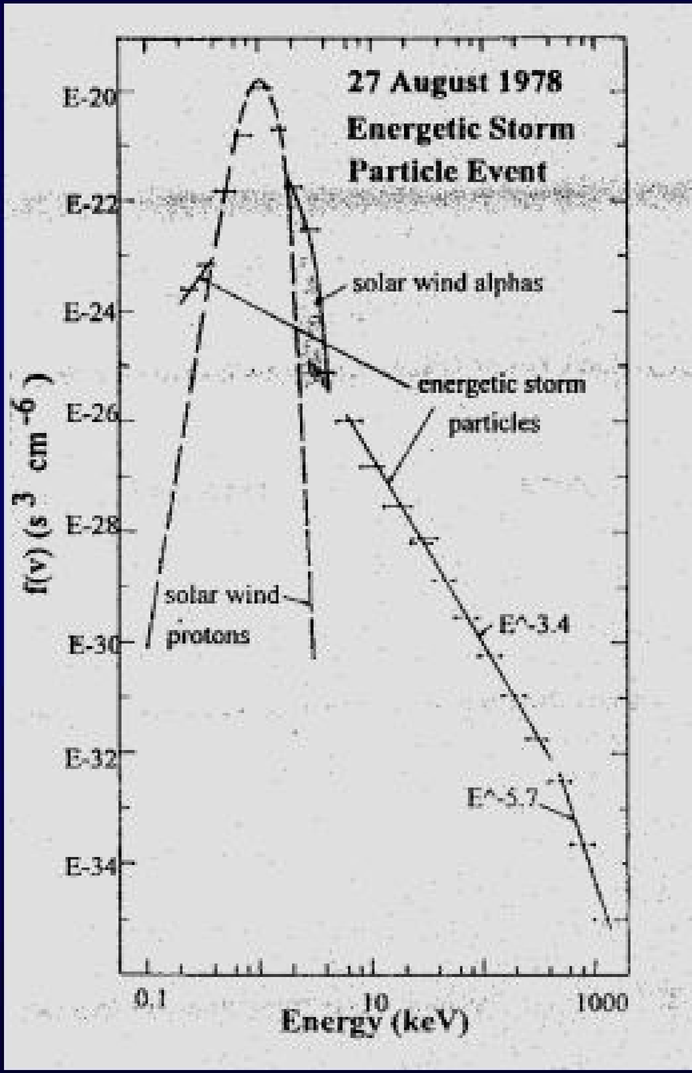
Energy spectrum of cosmic rays





«The knee» of cosmic rays

Solar energetic particles



*Originate mostly during solar flares and CME with corresponding acceleration.

*Energies up to 100's MeV/n, sometimes upto Gev/n.

*Ionization state from fully ionized for light ions (He) to partially ionized for heaviers (Fe).

*Time variation dependent on solar activity .