Cosmic rays “Many Knees” Problems for Space/ Upper Atmospere Born Experiments Solutions

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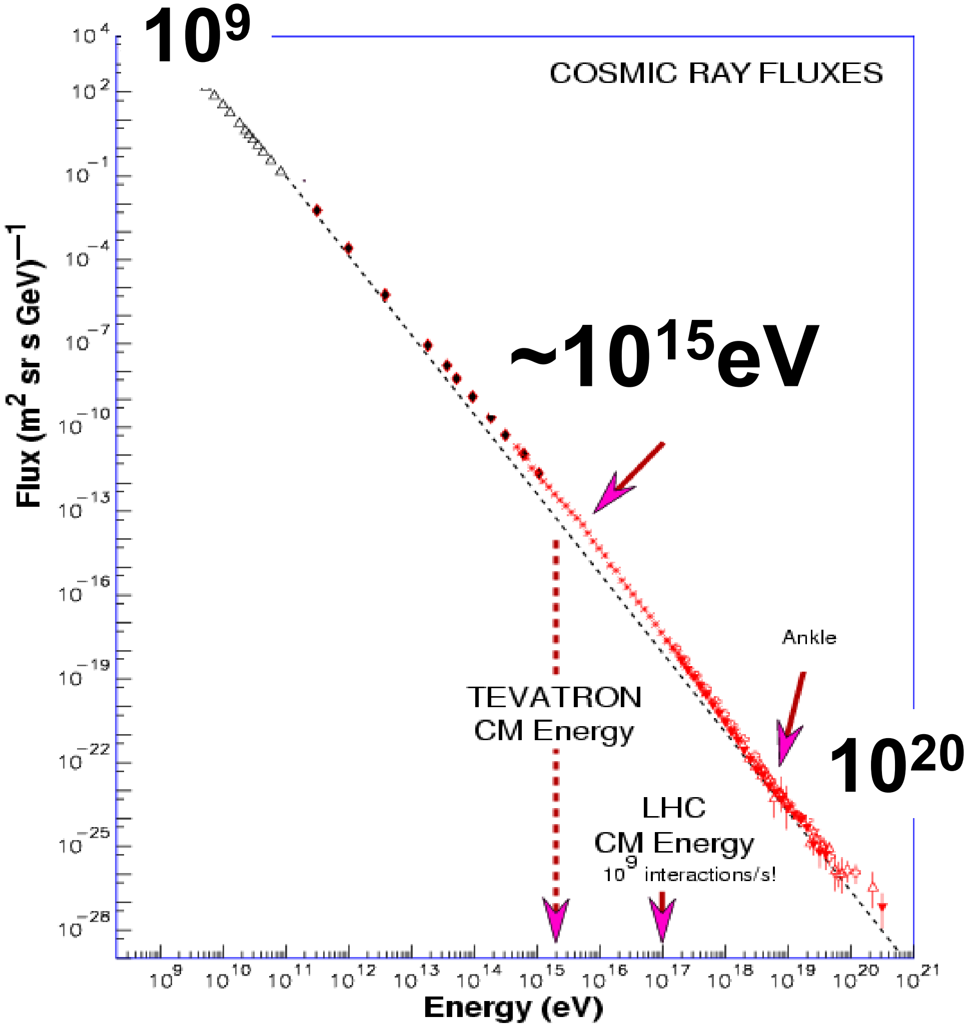
“Knees” in the CR energy spectra means “appearance of sharp irregularities” (bumps, cutoffs) in a more or less “smooth” shape of CR spectra, observed in experiment

Cosmic rays : nuclei



“Knees” in the CR energy spectra

CR astrofisics main probleems

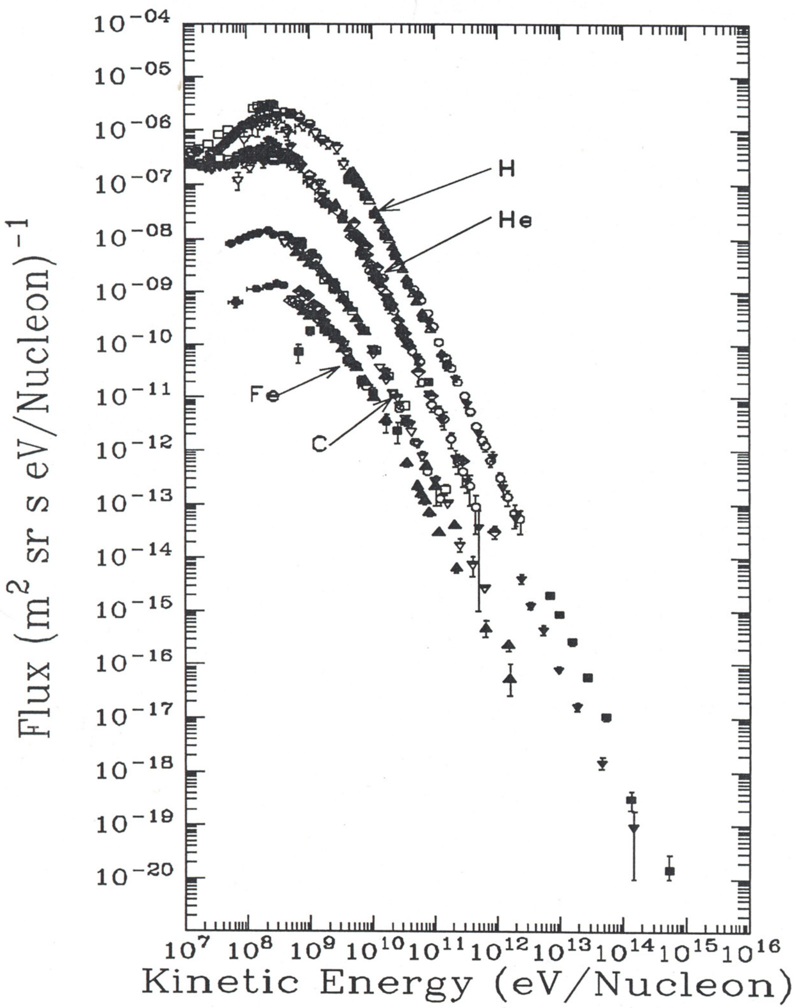
-Sources ?

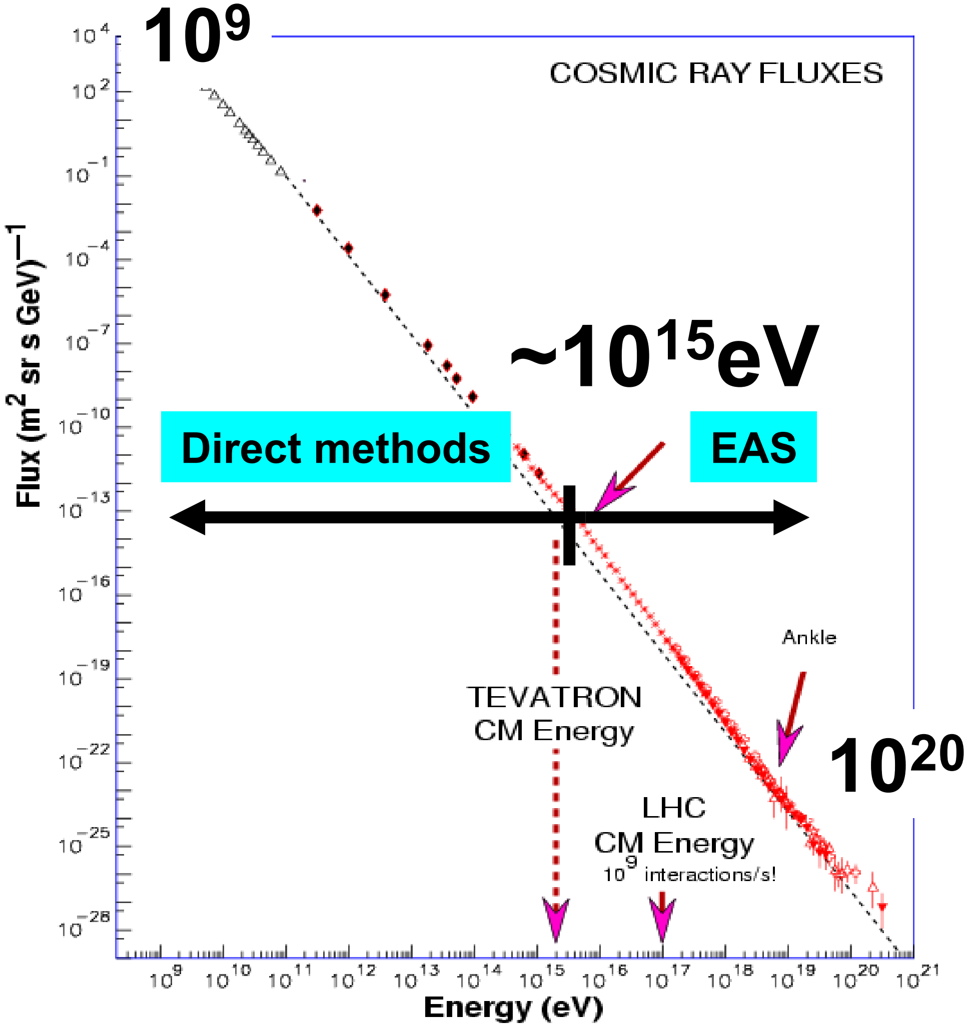
-Accelerators?

The First Knee

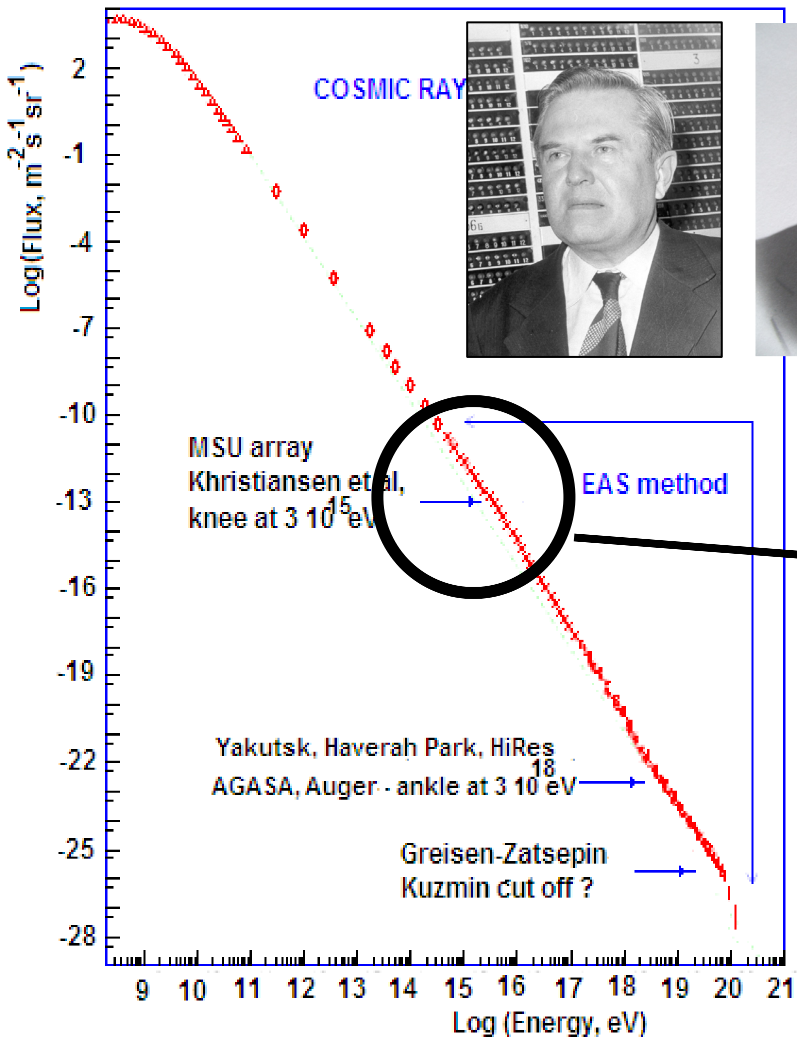
Nuclei

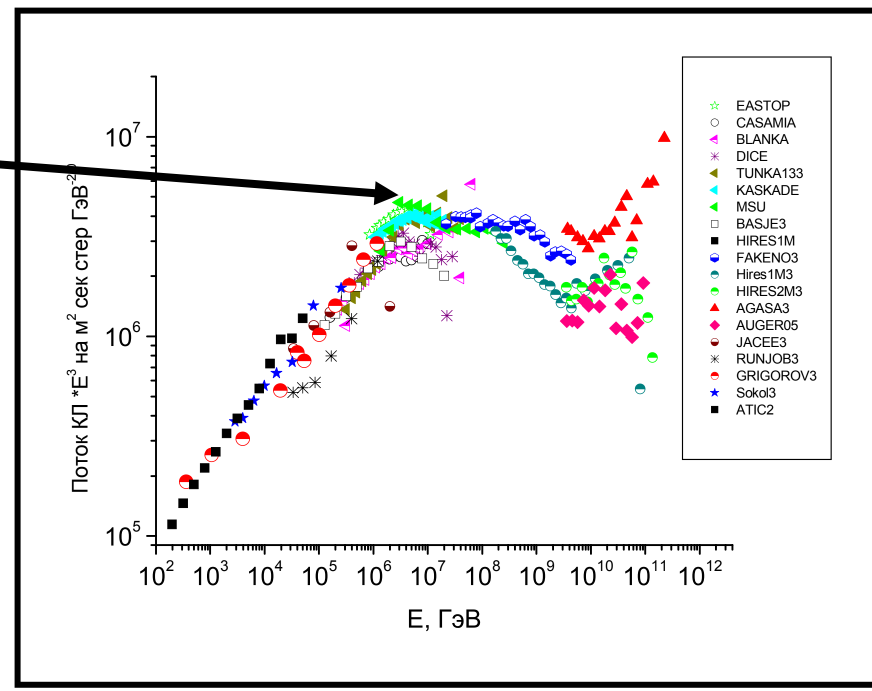
Cosmic rays : nuclei



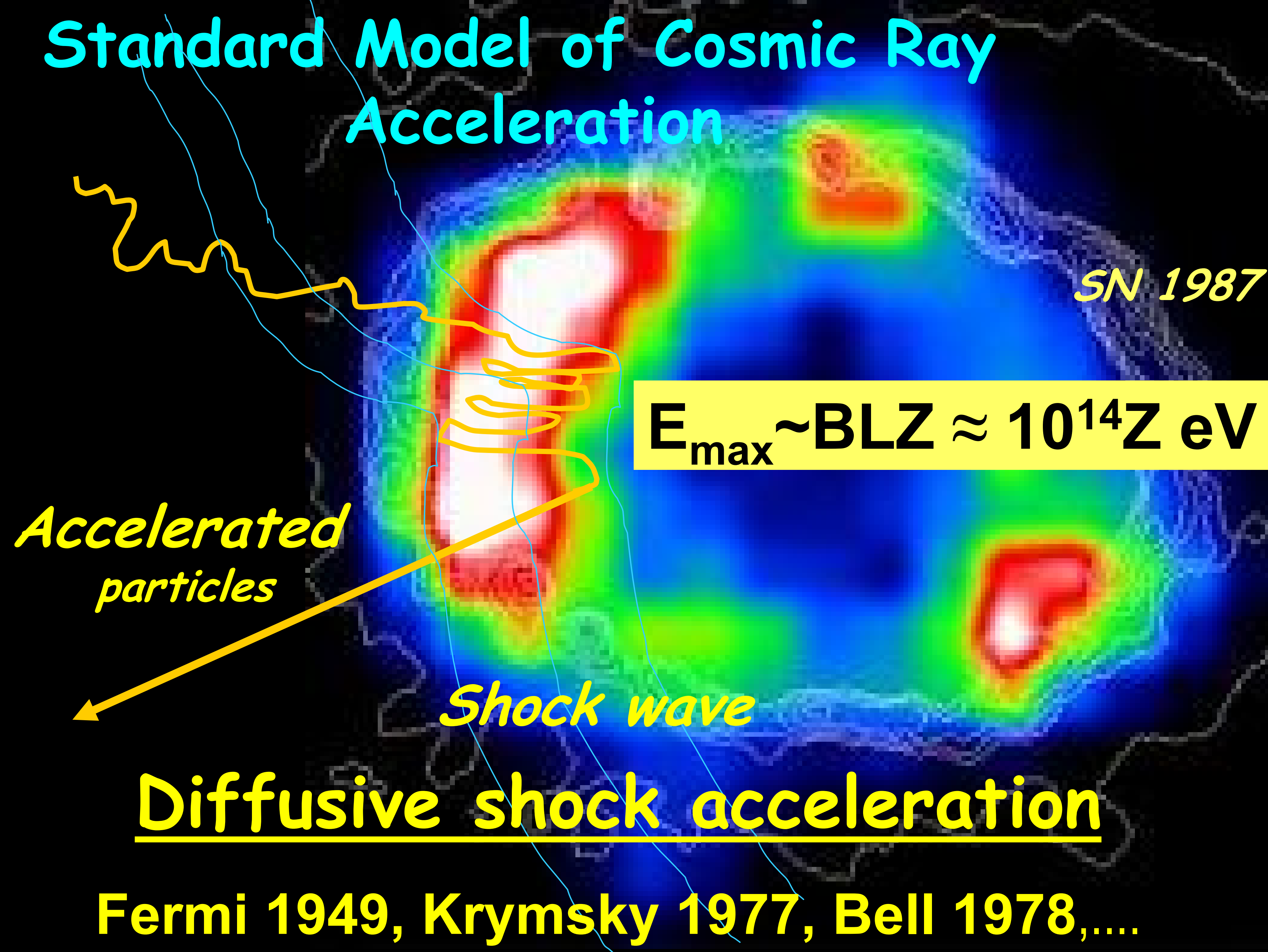


«The G.Khristiansen astrophysical knee»





Standard Model of Cosmic Ray Acceleration

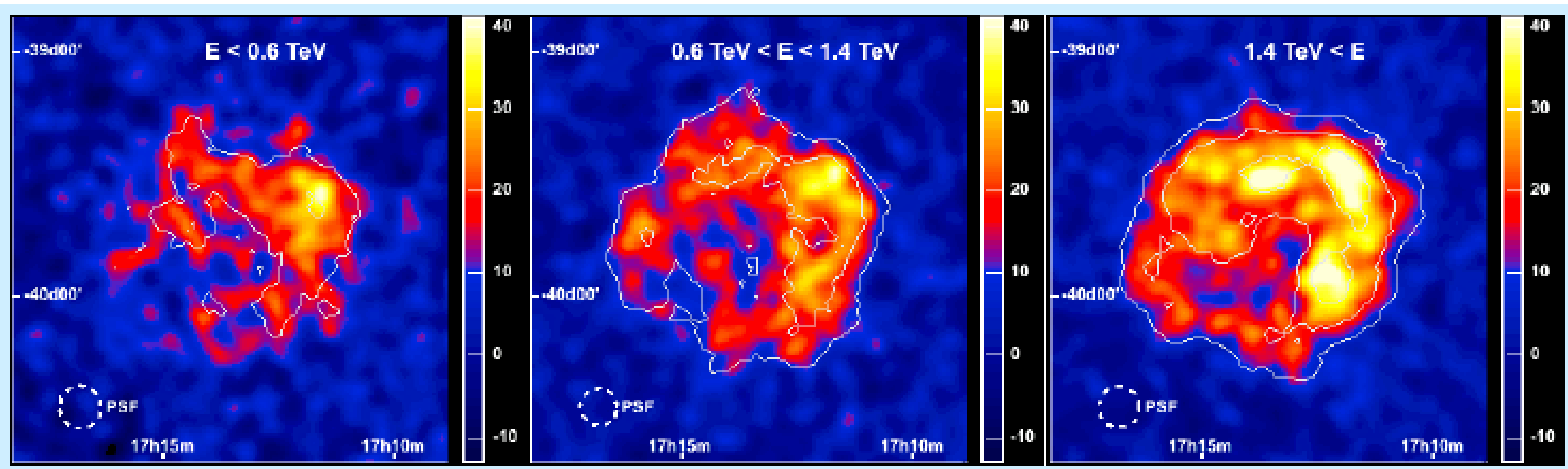


$E_{max} \sim BLZ \approx 10^{14} Z$ eV

Diffusive shock acceleration

Fermi 1949, Krymsky 1977, Bell 1978,....

CR sourses by HESS observations



sources ~ 32:

11 – metagalaxy (AGN)
6 - known SNR
6 – Pulsar's wind
1 – microkquazar
1 – binary system

Power low spectra:
-1.8 – -2.6

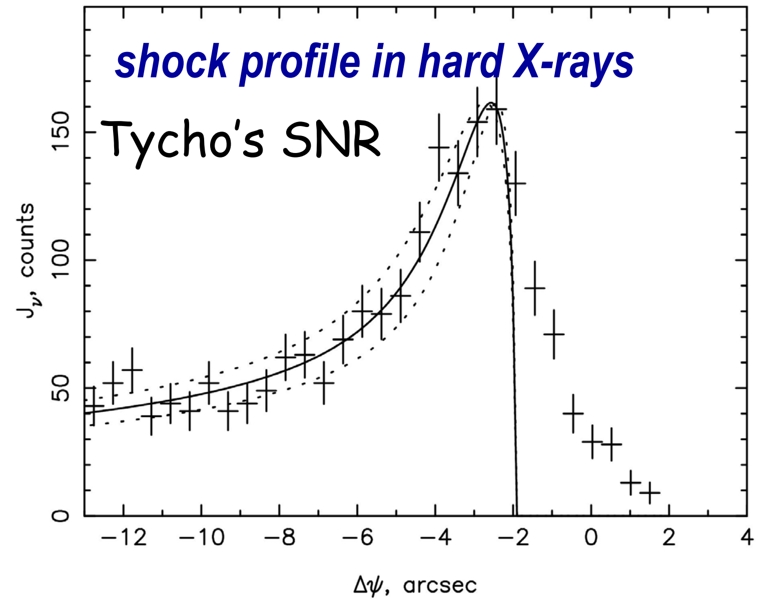
Strong magnetic fields in the SN remnants

Völk et al. magnetic field amplification in Tycho and other shell-type SNRs

B ~ 300 μG, for **Tycho's SNR**

consistent with synchrotron spectrum from acceleration theory

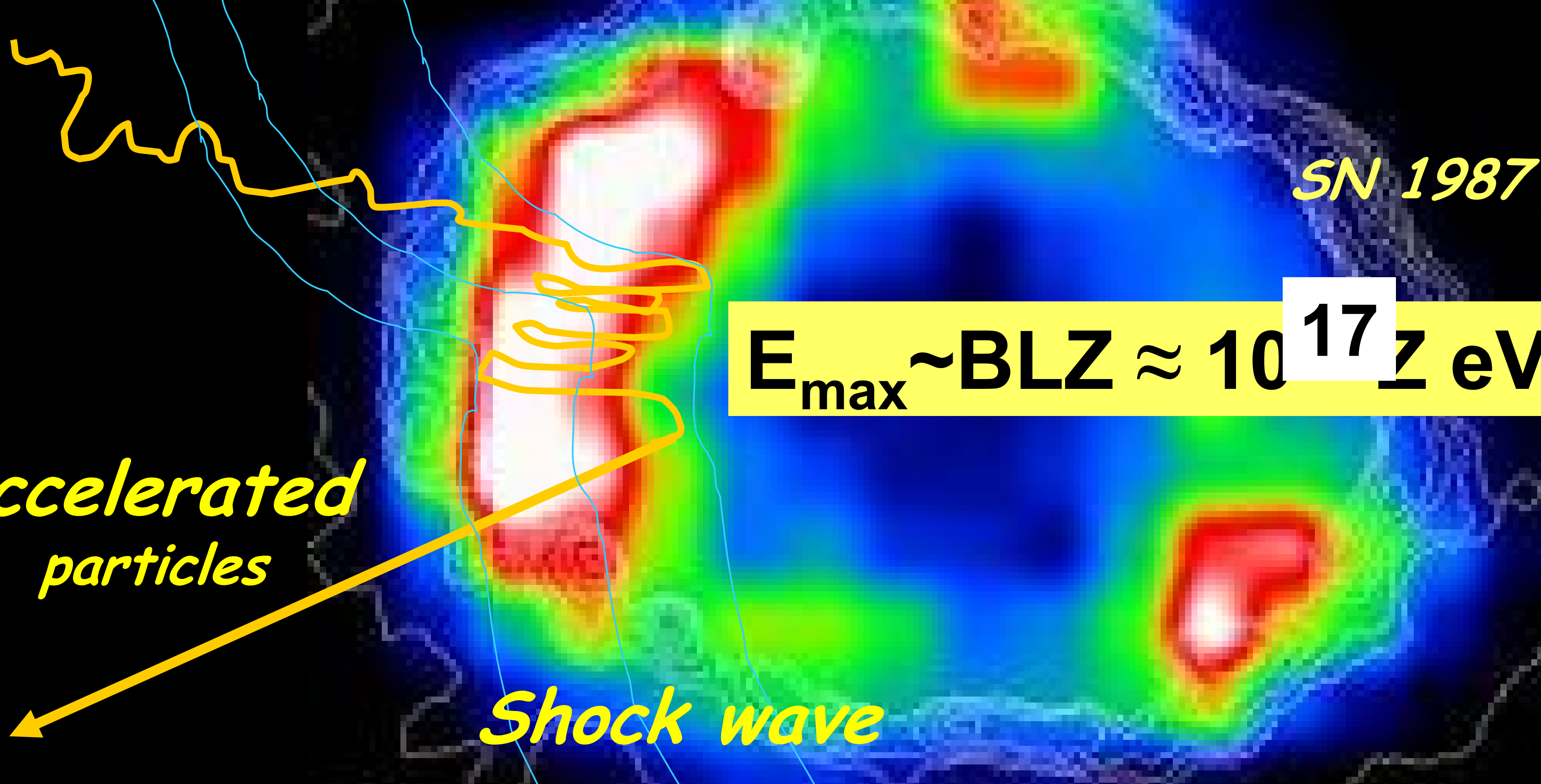
Similar amplification in all other SNRs where such data are available:
Cas A, SN 1006, Tycho, RCW 86, **Kepler**, RX J1713.7-3946, **Vela Jr**



diffusive shock acceleration of electrons, including synchrotron losses gives observed scale

→ **very strong magnetic field in young SNRs is indirect but strong evidence of proton acceleration**

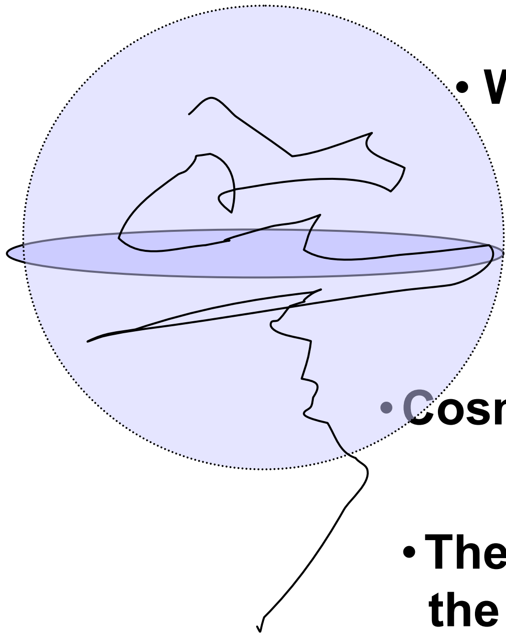
Standard Model of Cosmic Ray Acceleration



Diffusive shock acceleration

Fermi 1949, Krymsky 1977, Bell 1978,....

Models of cosmic rays propogation in the Galaxy



Leaky Box Model

- Cosmic rays confined to a box with leakage at the boundary.
- Within the box, cosmic only interact with interstellar gas

Halo Diffusion Model

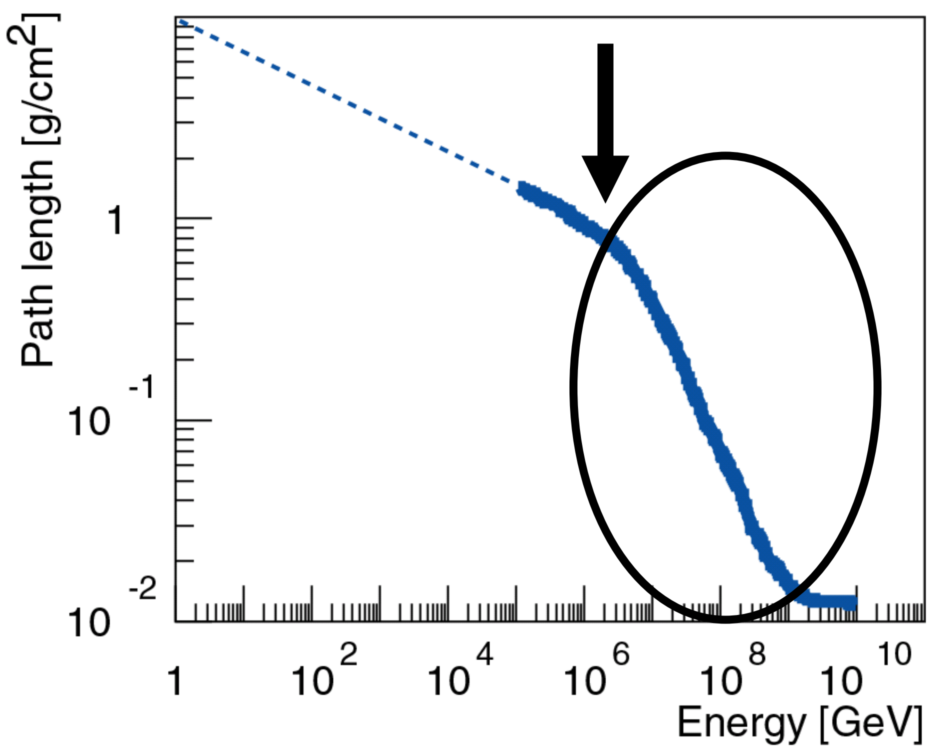
- Cosmic rays diffuse through magnetic scattering centers in the Galaxy
- The densities of scattering centers and gas are highest in the Galactic disk but extend into a halo above and below the disk
- Cosmic rays interact with the gas in the Galaxy and escape by diffusion

All of these models are rigidity dependent

CR Nuclei Propogation in the Galaxy: Interection with a Matter

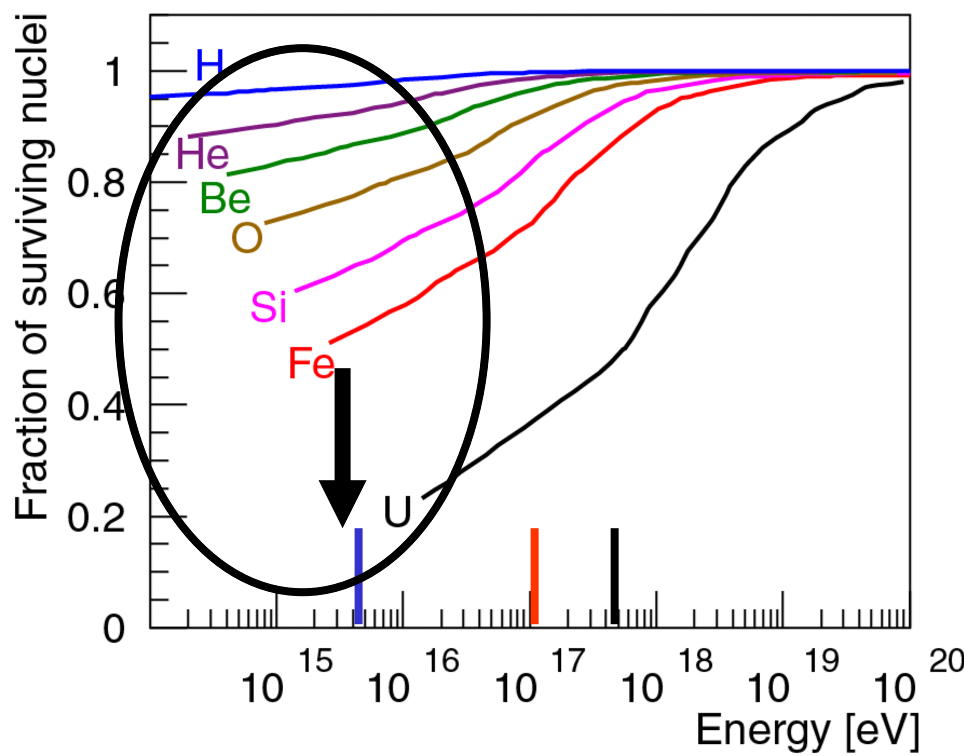
Matter traversed by protons

heavy nuclei → E~Z

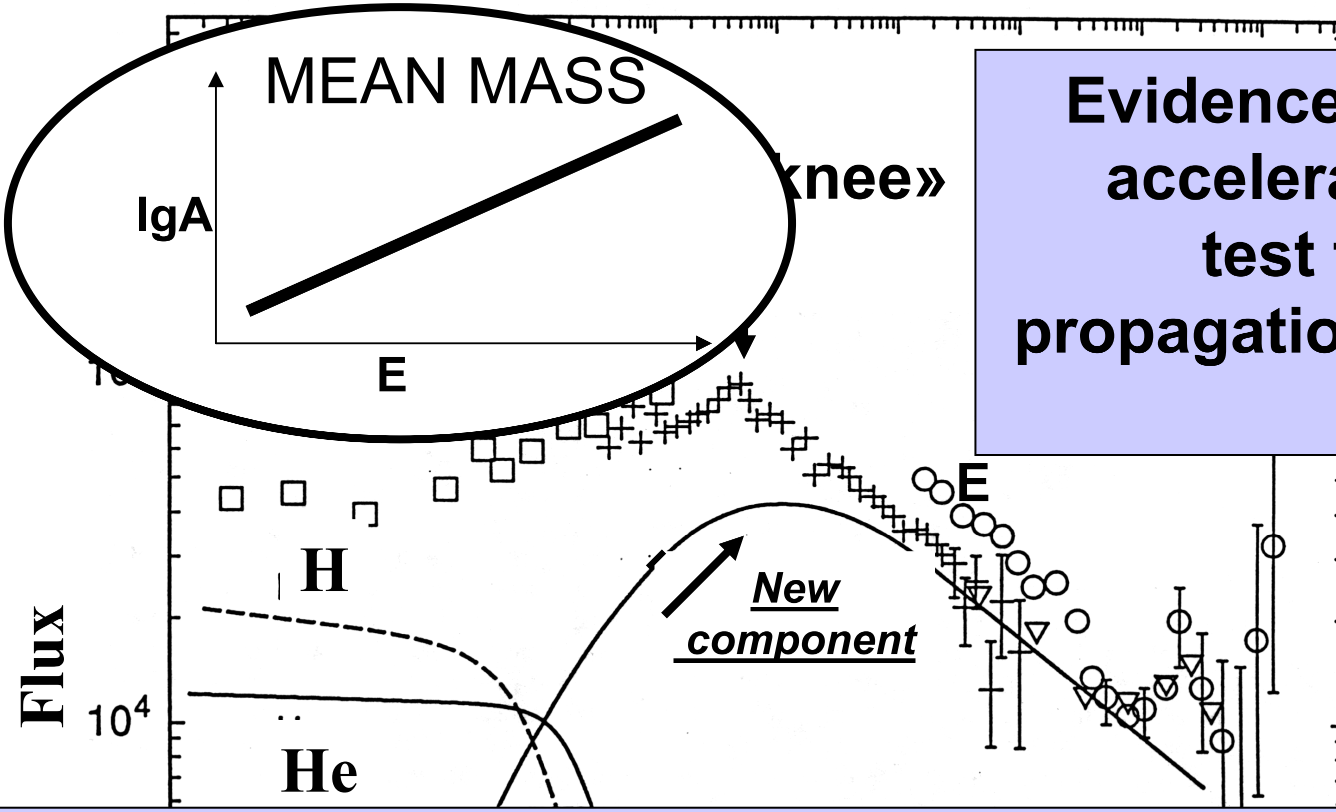


Fraction of surviving nuclei

QGSJET



Hörandel, Kalmykov, Timokhin, 2006



Evidence for SN acceleration, test for propagation models

Chemical composition around "the knee'

have to be changed because of consequences

both acceleration model and propagation one:

E~Z

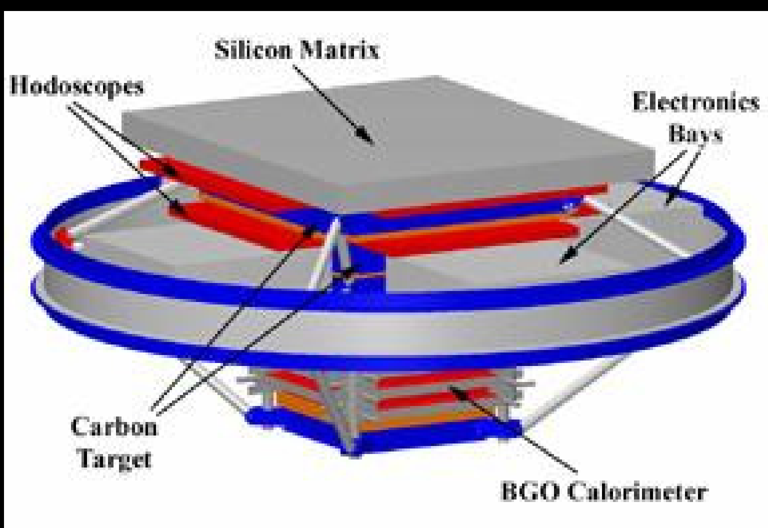
Experiments below the knee

(10^{12} – 10^{15} eV/particle)

- Proton (4 satellites) – 60’ SINP/Russia
- CRN (Space station) – 80’, US
- Mubee (balloon) - 80’ SINP/ Russia
- SOKOL (2 satellites) -80’ SINP/ Russia
- TIC (balloon) - 1994, SINP/ Russia
- JACEE (balloons) - 90’, US, Japan.....
- RUNJOB (balloons) - 80’ -90’, SINP/Russia, Japan
- ATIC (balloon) - 2001, 2004, 2008 US, SINP/Russia,...
- TRACER (balloon) – 2003, 2006 US
- BESS (balloon) - 2004 US, Germany, Japan,...
- CREAM (balloon) - 2005, 2008 US, Korea....

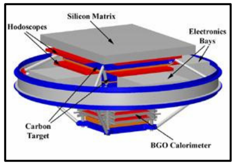
ATIC experiment
(2000 – 2007)

p,Z - up to tens TeV
e - up to one TeV



Antarctica, McMurdo

The ATIC Collaboration



J.H. Adams[2], H.S. Ahn[3], G.L. Bashindzhagyan[4], K.E. Batkov[4], J. Chang[6,7], M. Christl[2], A.R. Fazely[5], O. Ganel[3] R.M. Gunasingha[5], T.G. Guzik[1], J. Isbert[1], K.C. Kim[3], E.N. Kouznetsov[4], M.I. Panasyuk[4], A.D. Panov[4], W.K.H. Schmidt[6], E.S. Seo[3], N.V. Sokolskaya[4], J. Watts, J.P. Wefel[1], J. Wu[3], V.I. Zatsepin[4]

1. **Louisiana State University, Baton Rouge, LA, USA**
2. **Marshall Space Flight Center, Huntsville, AL, USA**
3. **University of Maryland, College Park, MD, USA**
4. **Skobeltsyn Institute of Nuclear Physics, Moscow State University, Russia**
5. **Southern University, Baton Rouge, LA, USA**
6. **Max Plank Institute für Space Physics, Lindau, Germany**
7. **Purple Mountain Observatory, Chinese Academy of Sciences, China**

ATIC

Need an instrument to measure:

⇒ Element type, Particle energy, and the Number of each element and energy

Measure before the cosmic rays break-up in the atmosphere

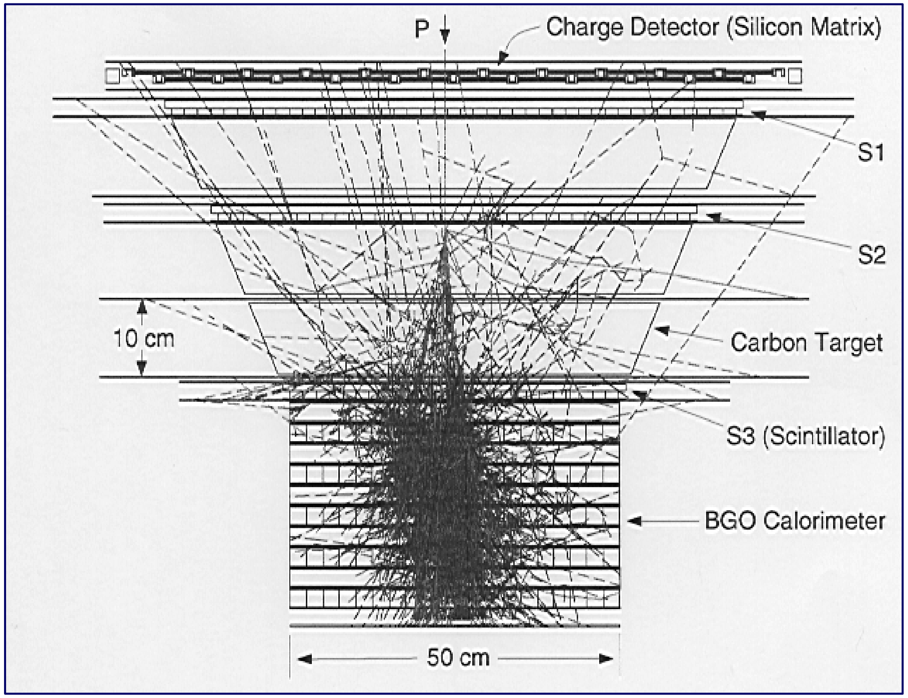
⇒ In space (expensive) or at least at very high altitude (balloon)

Need to measure for as long as possible

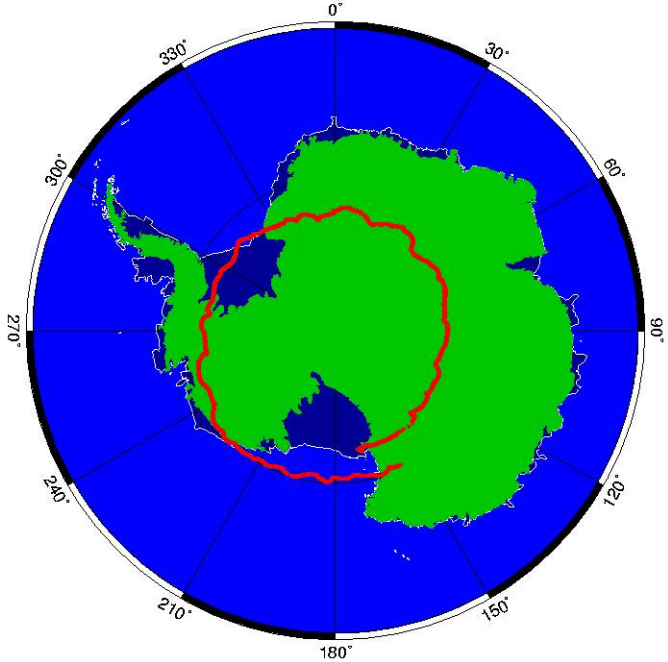
⇒ Use a long duration balloon to get 15 to 30 days of exposure

Principle of "Ionization Calorimetry"

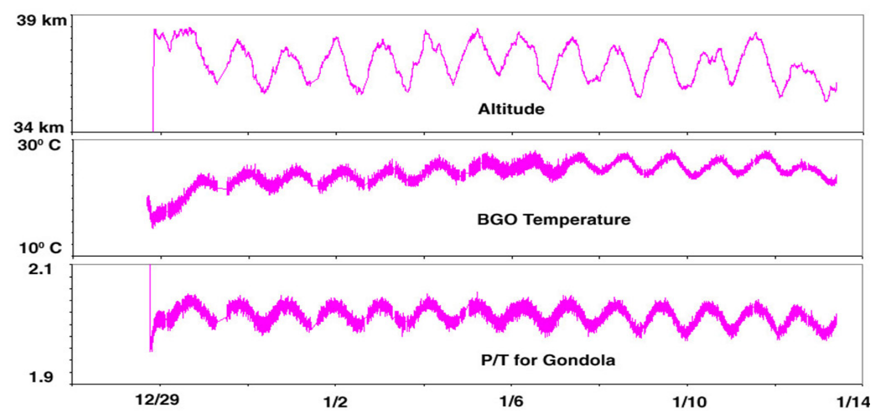
- ⇒ **Cosmic ray enters from top**
- ⇒ **Nuclear interaction in target section**
- ⇒ **'BGO Calorimeter' fosters a cascade (or shower) of many sub-particles**
- ⇒ **How this "cloud" of sub-particles develops depends upon the initial cosmic ray energy.**



ATIC-1 Test Flight from McMurdo - 2000



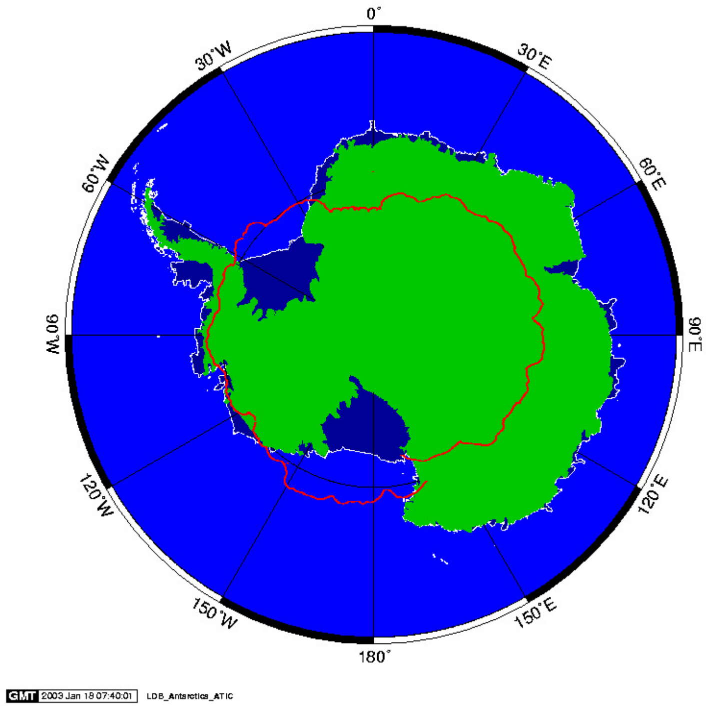
- 43.5 Gbytes Recorded Data
- 26,100,000 Cosmic Ray triggers
- 1,300,000 Calibration records
- 742,000 Housekeeping records
- 18,300 Rate records
- Low Energy Trigger > 10 GeV for protons
- >70% Live-time
- >90% of channels operating nominally
- Internal pressure (~8 psi) held constant
- Internal Temperature: 20 – 30 C
- Altitude: 37 ± 1.5 km



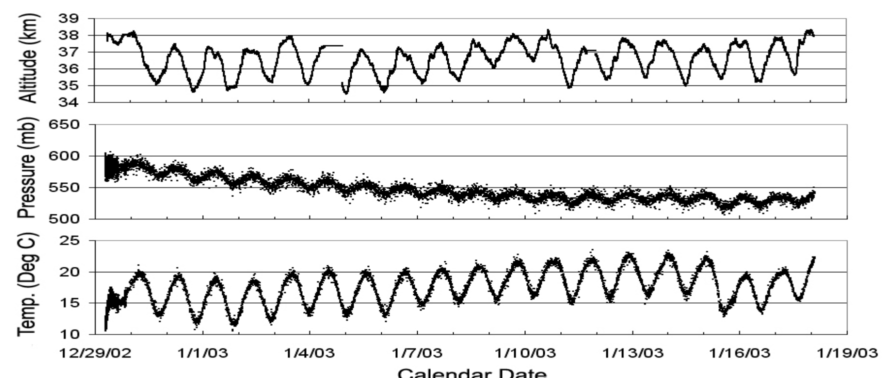
- Launch: 12/28/00 04:25 UTC
- Begin Science: 12/29/00 03:54 UTC
- End Science: 01/12/01 20:33 UTC
- Termination: 01/13/01 03:56 UTC
- Recovery: 01/23/01; 01/25/01

16 дней

ATIC-2 Science Flight from McMurdo - 2002



- 65 Gbytes Recorded Data
- 16,900,000 Cosmic Ray triggers
- 1,600,000 Calibration records
- 184,000 Housekeeping records
- 26,000 Rate records
- High Energy Trigger > 75 GeV for protons
- >96% Live-time
- >90% of channels operating nominally
- Internal pressure (~8 psi) decreased slightly (~0.7 psi) for 1st 10 days then held constant
- Internal Temperature: 12 – 22 C
- Altitude: 36.5 ± 1.5 km



- Launch: 12/29/02 04:59 UTC
- Begin Science: 12/30/02 05:40 UTC
- End Science: 01/18/03 01:32 UTC
- Termination: 01/18/03 02:01 UTC
- Recovery: 01/28/03; 01/30/03

21 день

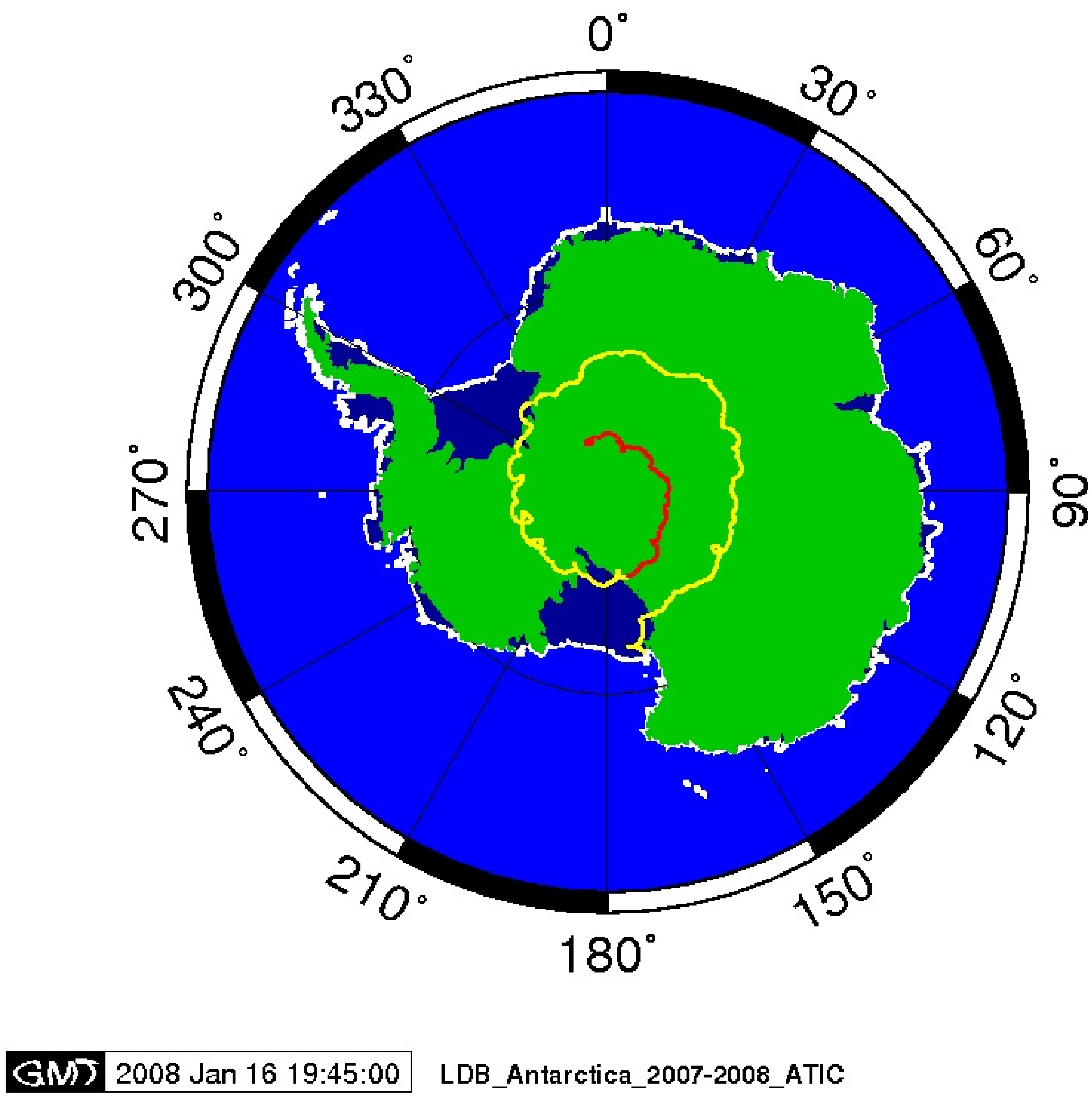
The ATIC-3 attempt ended in disaster!

- ATIC-3 was launched Dec. 19, 2005
- Balloon failure occurred almost immediately after launch
- Reached only 75,000 feet before starting down
- Had to quickly terminate as ATIC was headed out to sea
- Landed only 6 miles from edge of ice shelf

- The instrument was fully recovered instrument and refurbished in preparation for the 4th and final flight of ATIC in 2007.

Разрыв оболочки

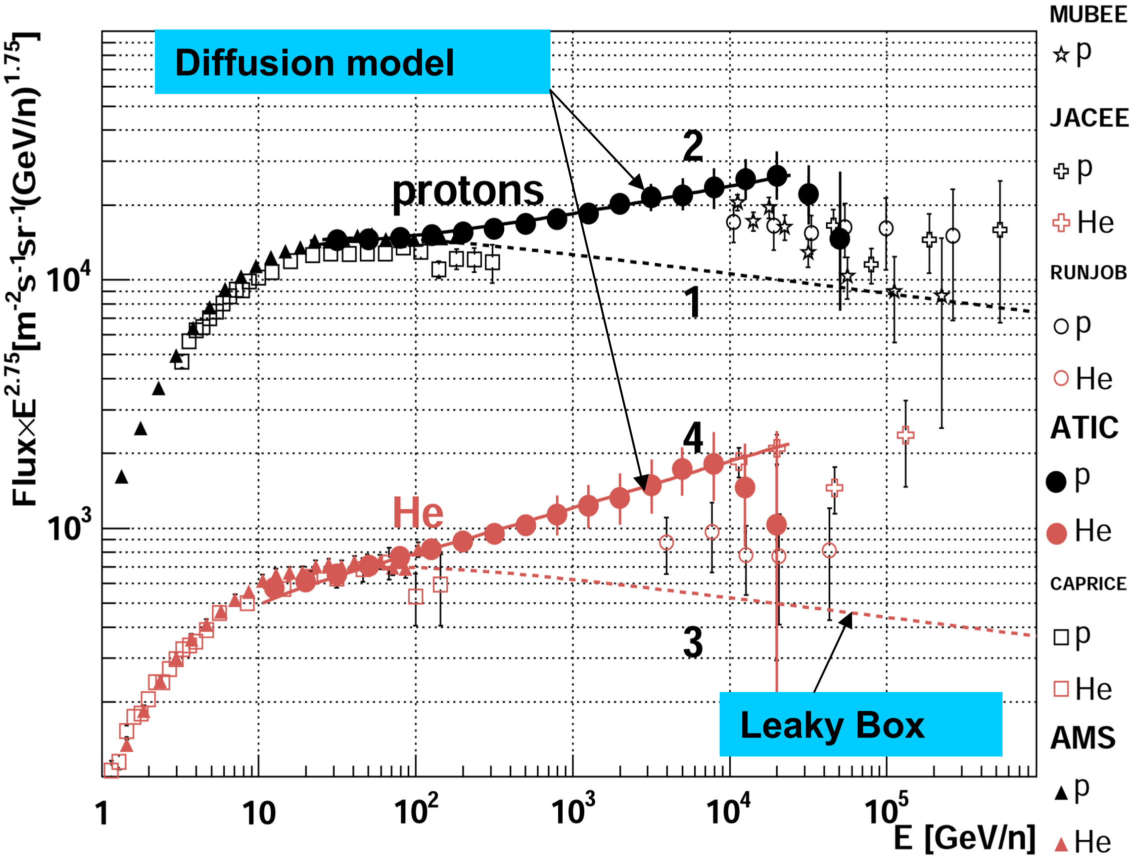
The ATIC – 4



Launch: 12/26/07
13:47 UTC
Science: 12/27/07
14:00 UTC
End Data: 01/11/08
02:00 UTC
Terminate:01/15/08
00:30 UTC
Recovery: 02/01/08
from South Pole

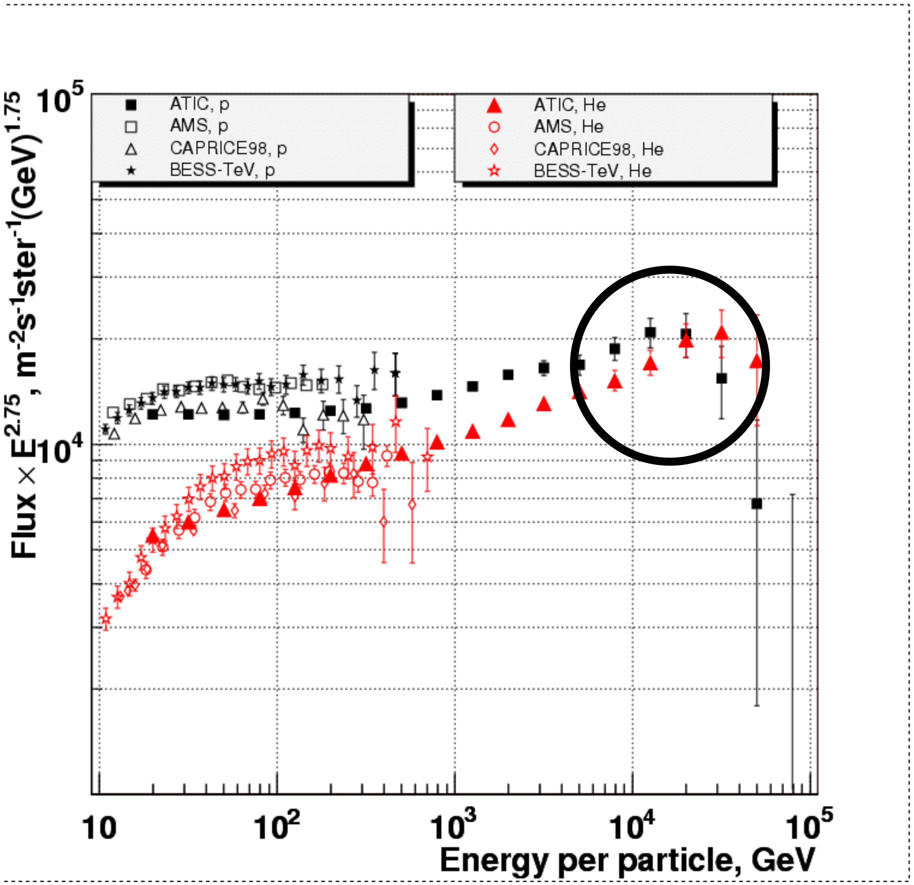
14.5 days of Data
about 75% of ATIC-2

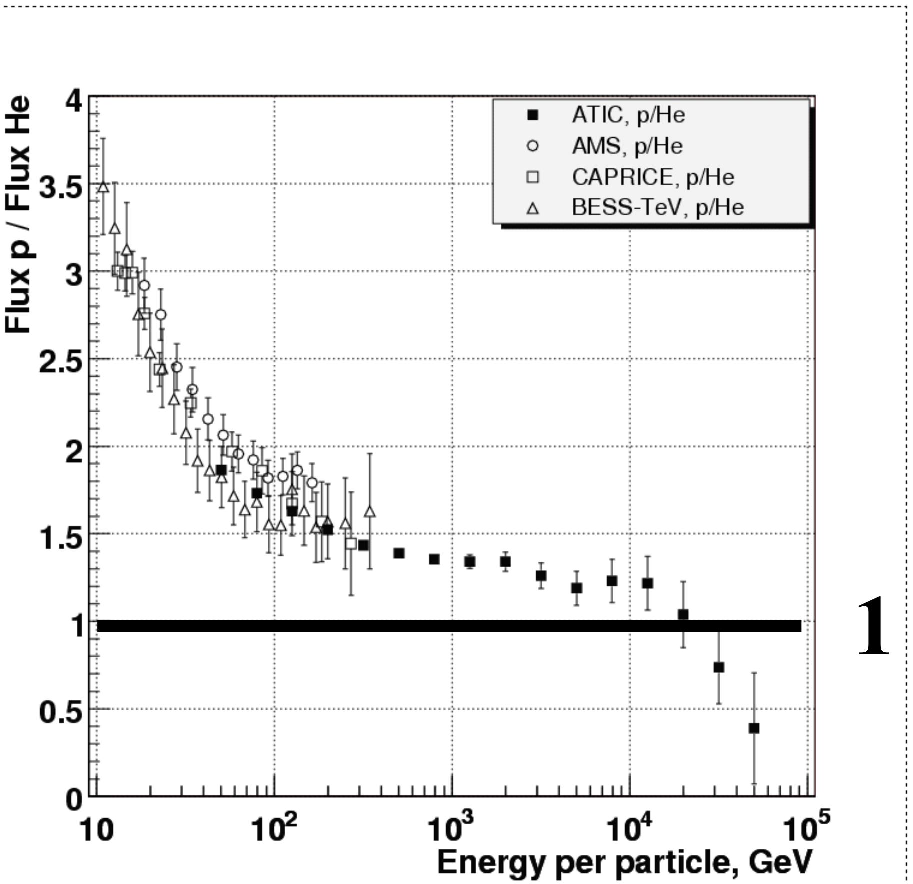
Результаты ATIC-2 в пользу диффузионной модели



The ATIC H and He spectra are fit by a diffusion model that includes weak re-acceleration due to Kolmogorov turbulence (Osborne and Ptuskin, 1988)

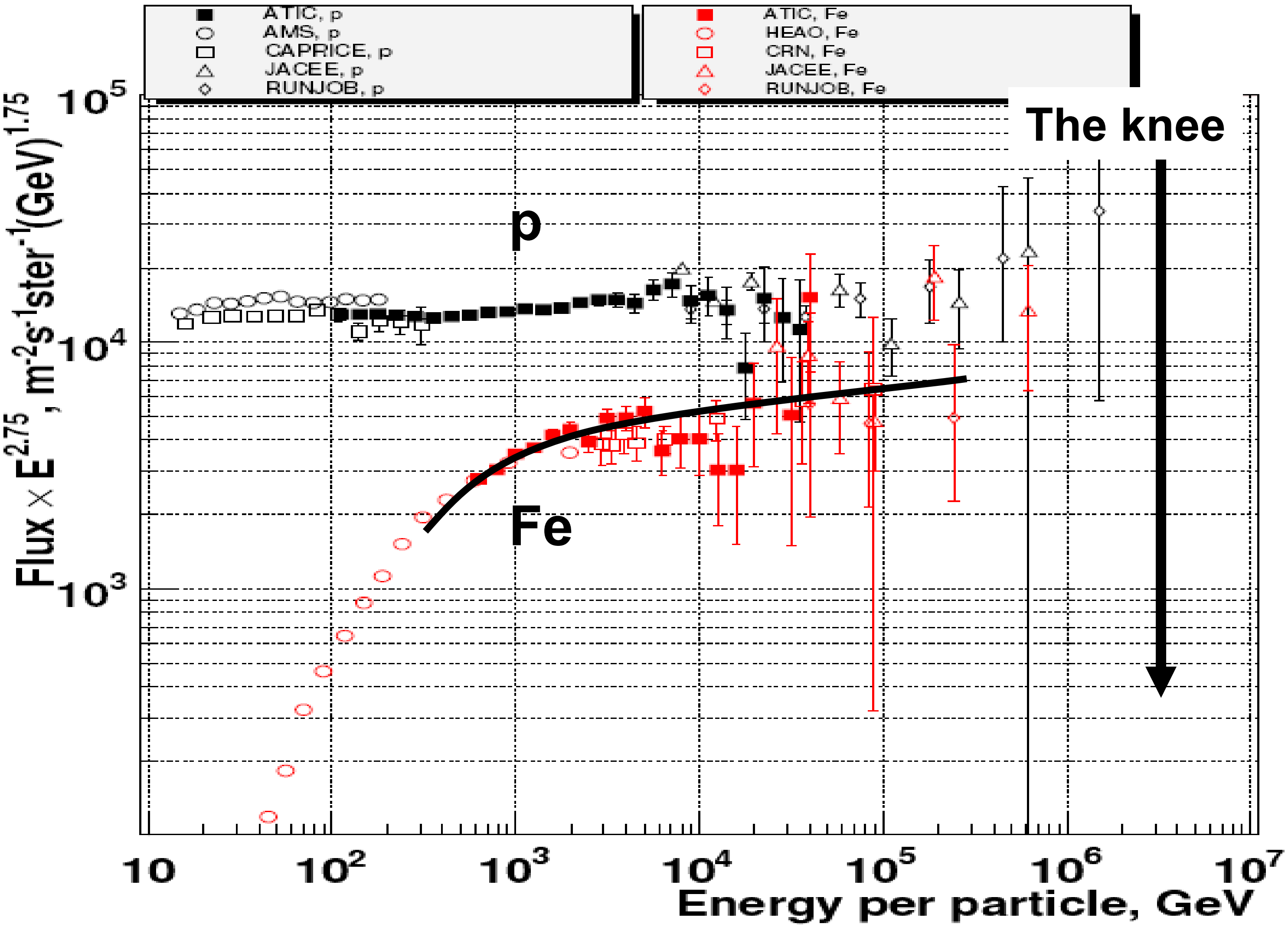
p/He ratio



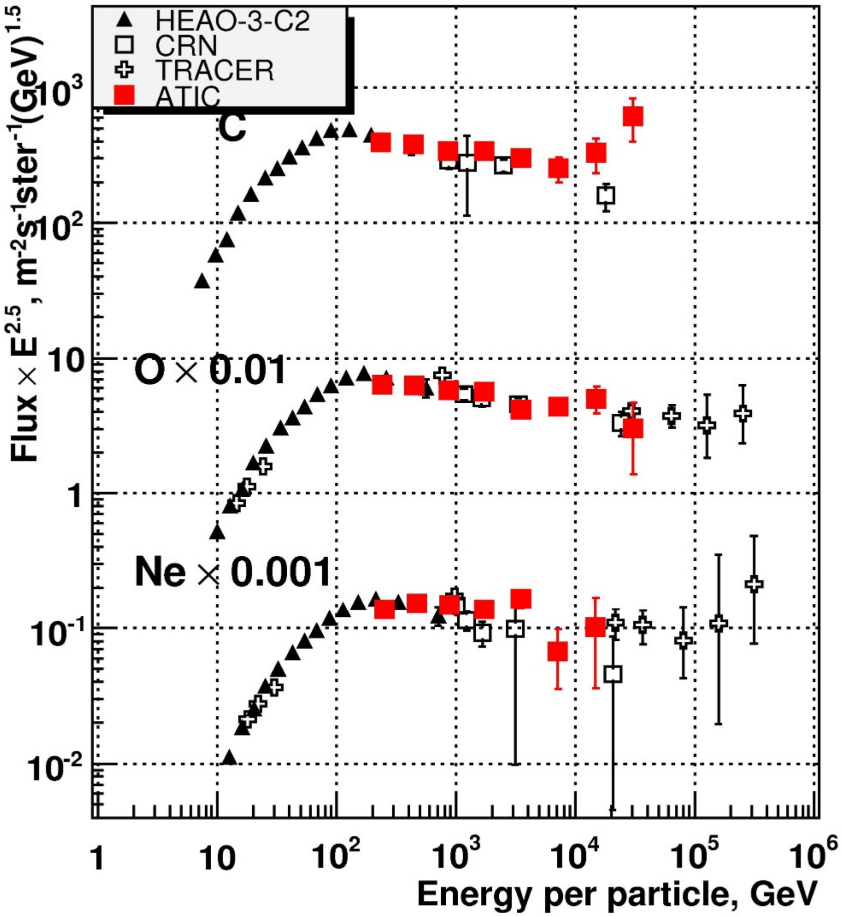


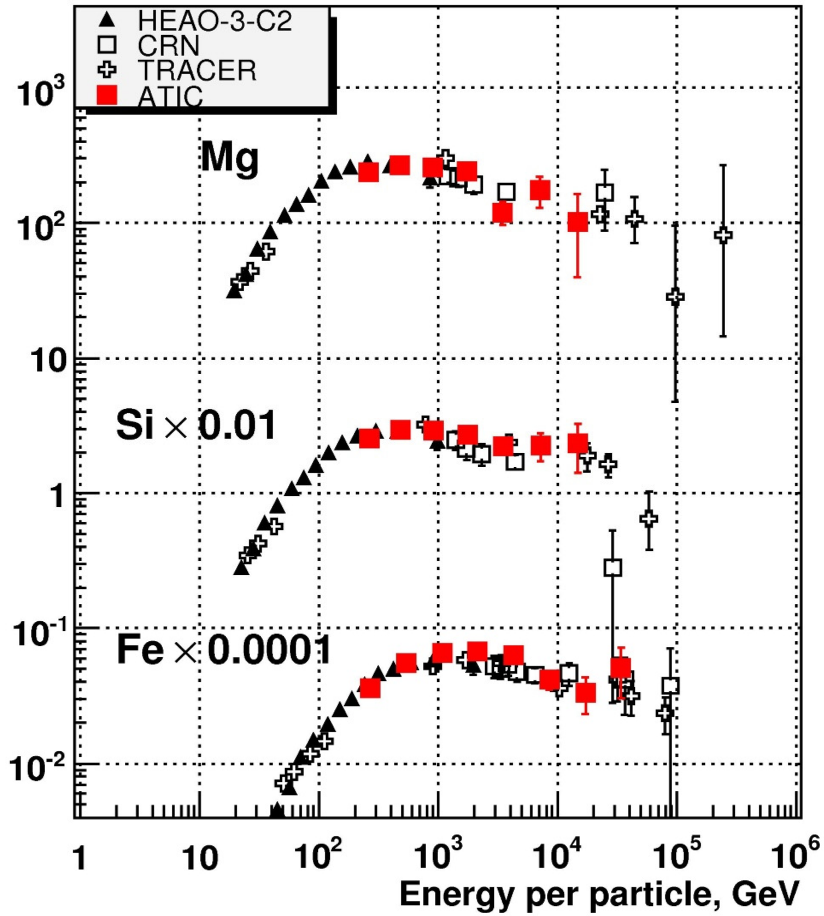
This experimental result - verification of any models

Average mass definition below "the knee" – the real test for current models

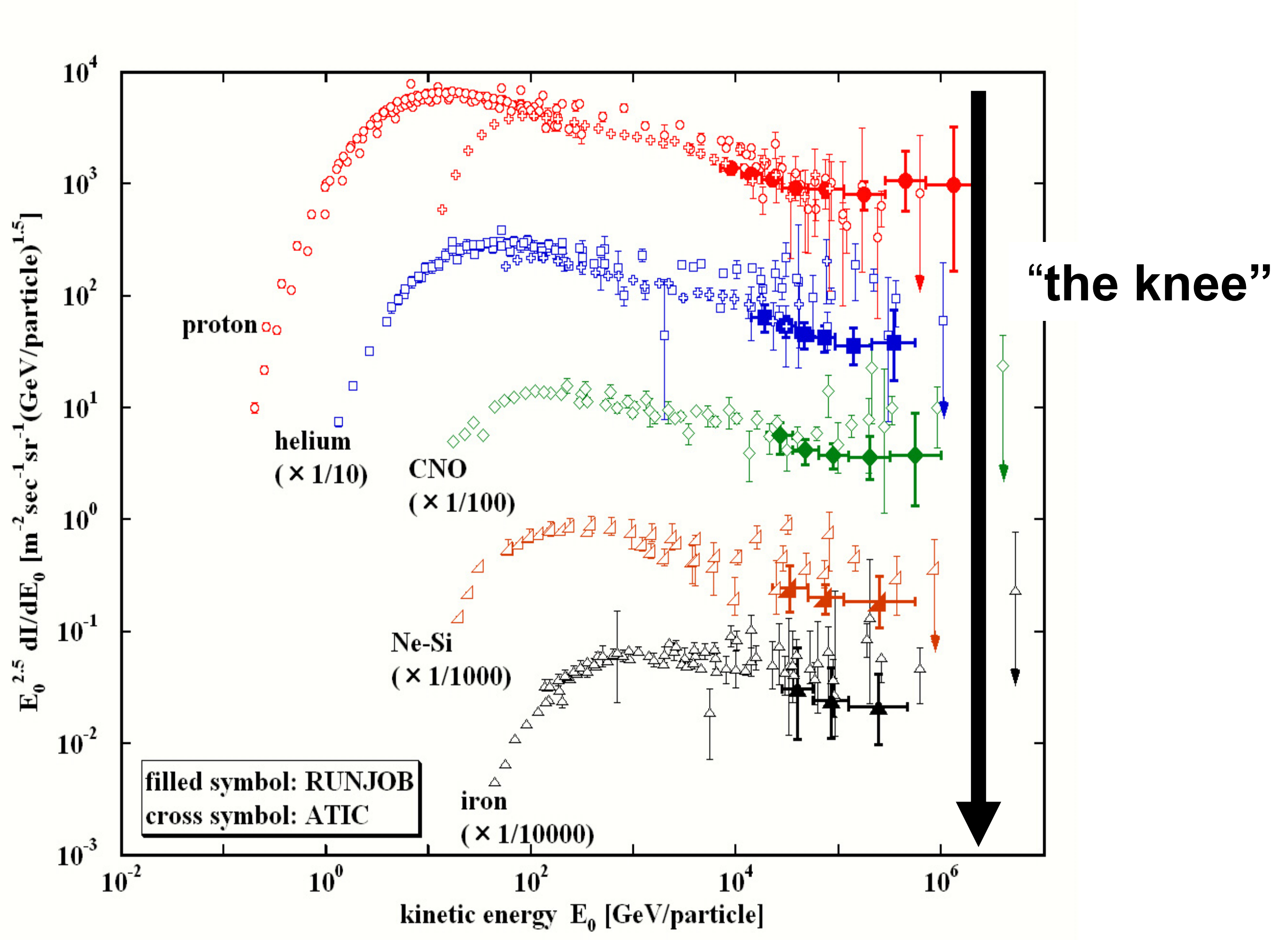


Heavy Nuclei





Химсостав космических лучей до «колена»

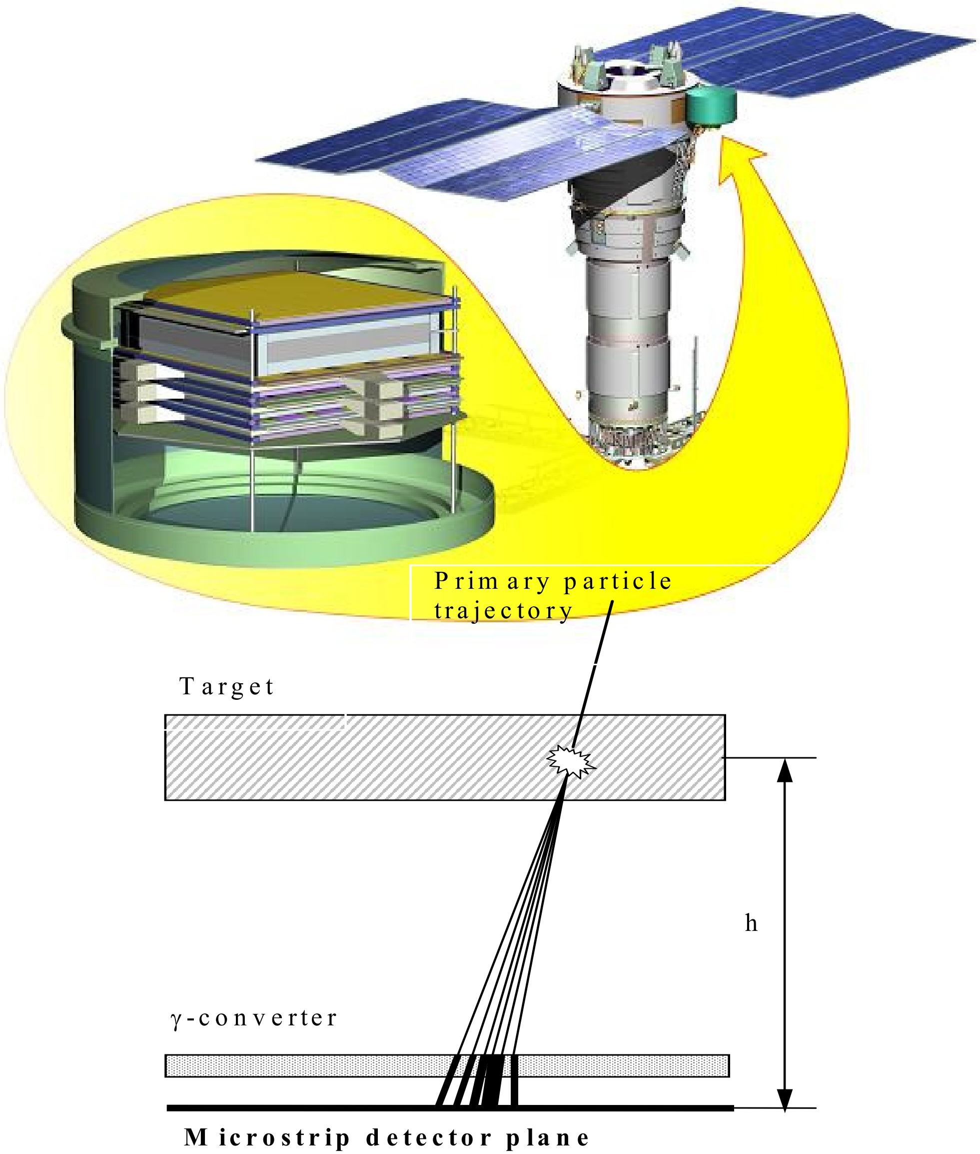


Better understanding of the chemical composition of GCR below “the knee”

ФКП: эксперимент «Нуклон»

НИИЯФ МГУ

ОИЯИ

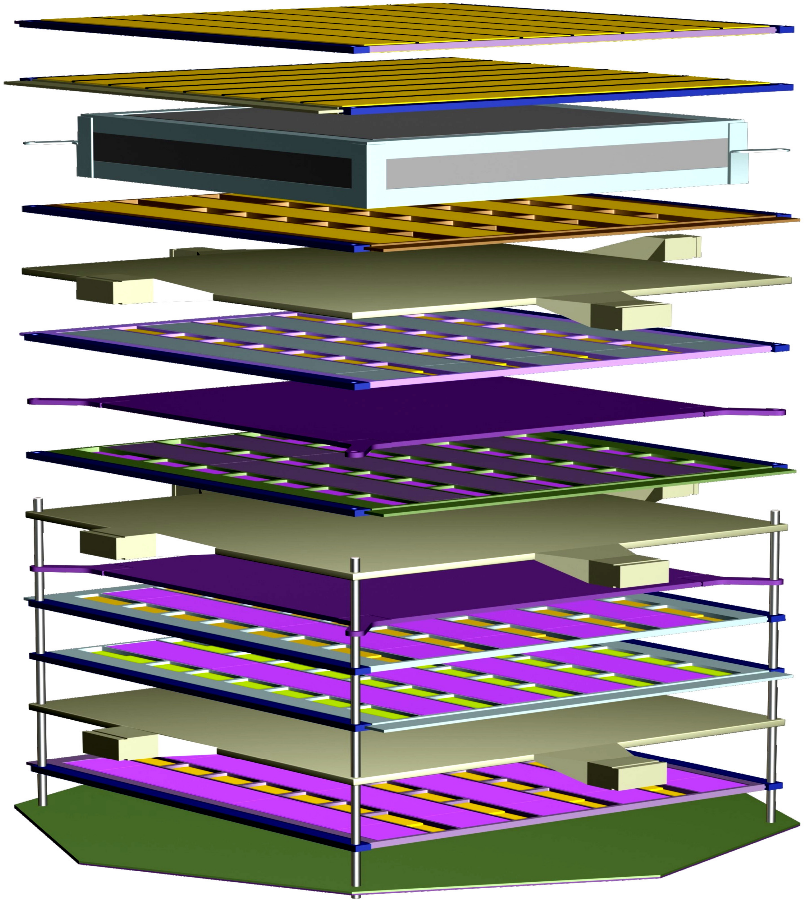


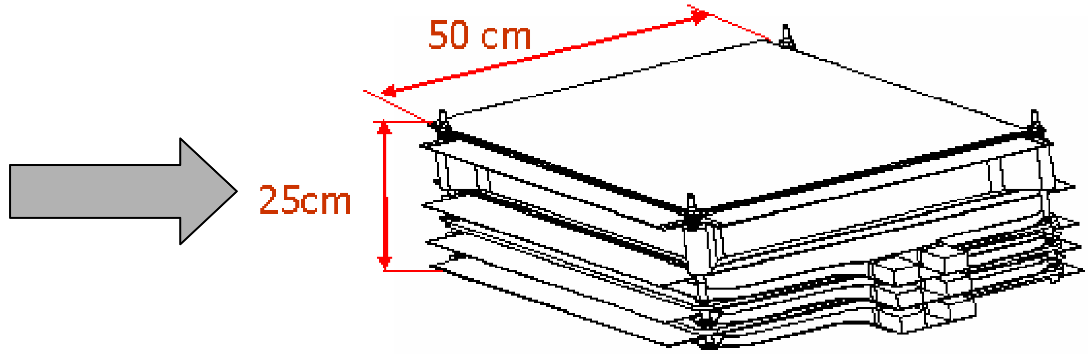
Characteristics :

Geometrical factor

>0.10 m2sr for the high-energy component;

>0.25 m2sr for the low-energy component





The NUCLEON device includes *charge measuring system*, *tracker* and *energy measuring system*, *the trigger system*, *control electronics*.

The charge measuring system consists of 4 silicon detectors layers.

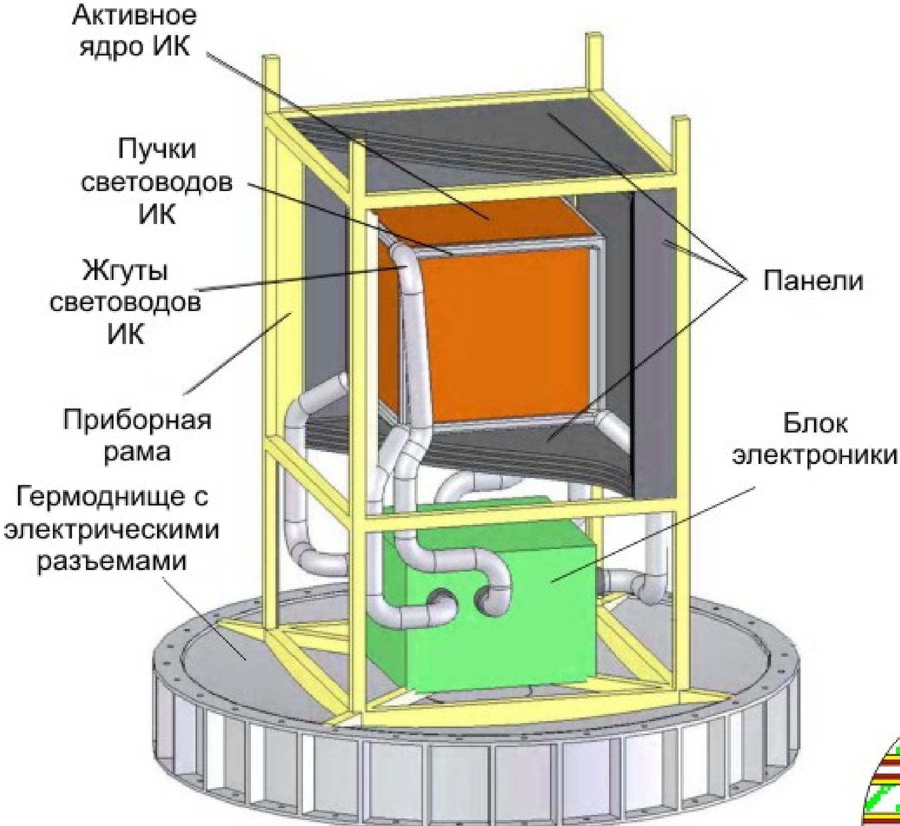
The tracker and energy measuring system consists of: the carbon block with the size 50×50×9 cm3 served as a target, 6 identical layers of micro-strip silicon detectors, 2 identical tungsten layers with the size 50×50×0.7 cm^3 served as a gamma-converter.

The trigger system (SC1-SC6) consists of three double layer 16-strip scintillator detectors (size ~ 500×30×0.5 mm^3) with a few 1 mm WLS fibers.

Space platform
to carry payload with a big mass

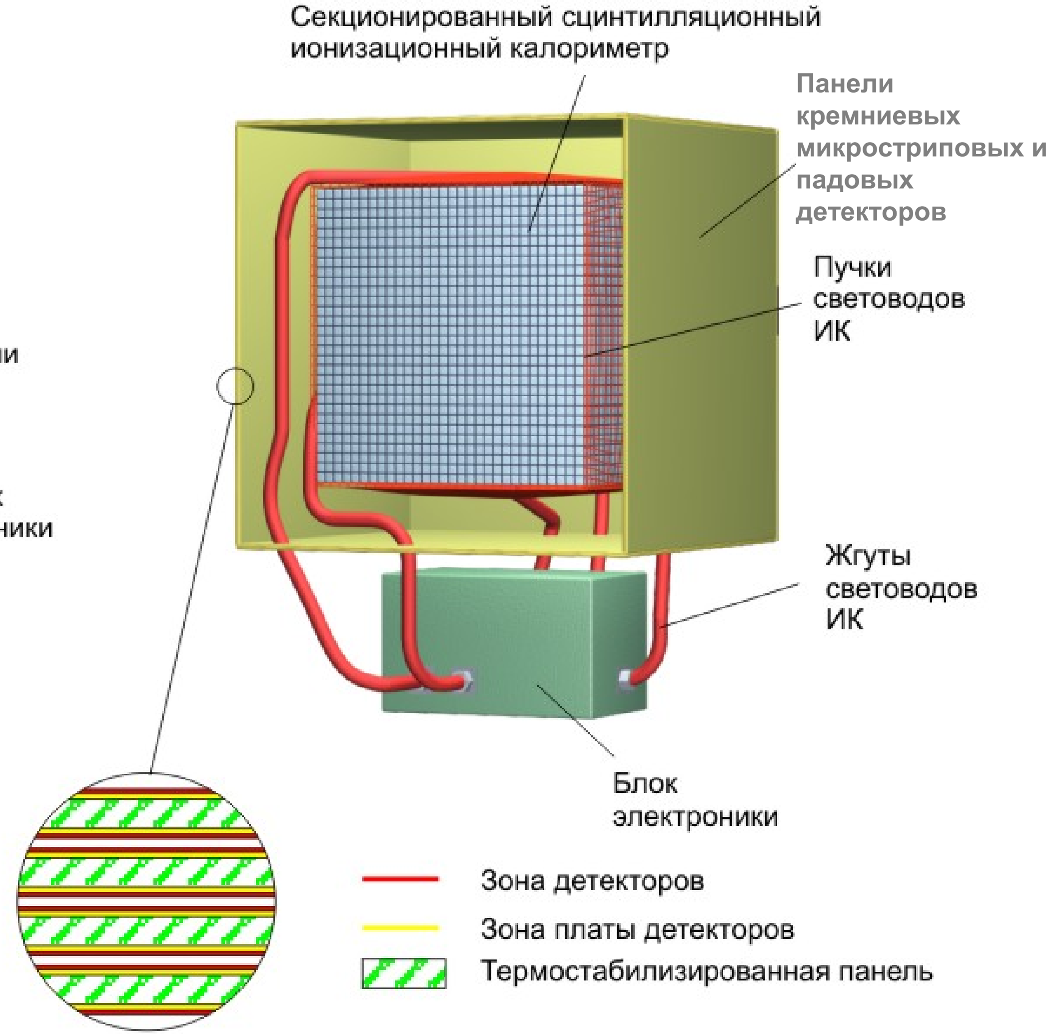
ИЯИ РАН
НИИЯФ МГУ
ОИЯИ

Cubic ionization calorimeter



Размещение аппаратуры

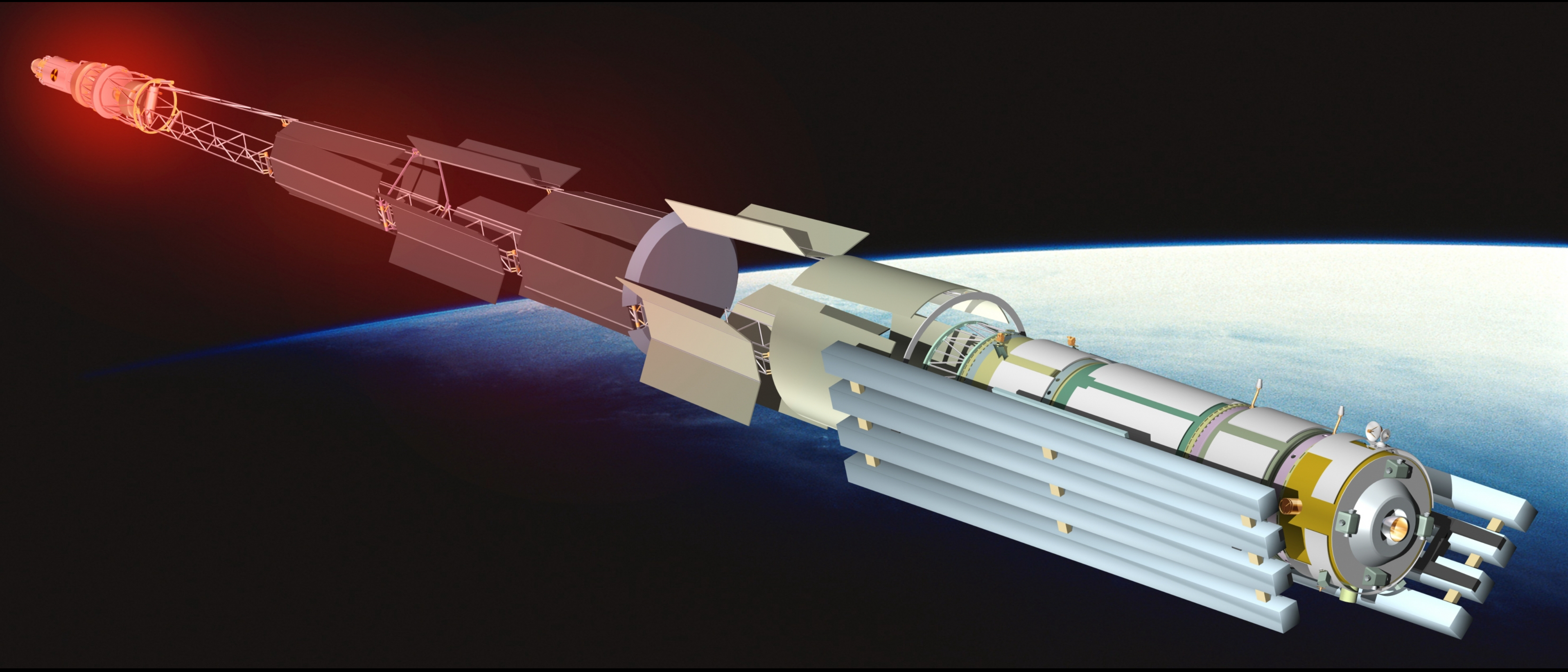
На приборной раме КА



Состав аппаратуры

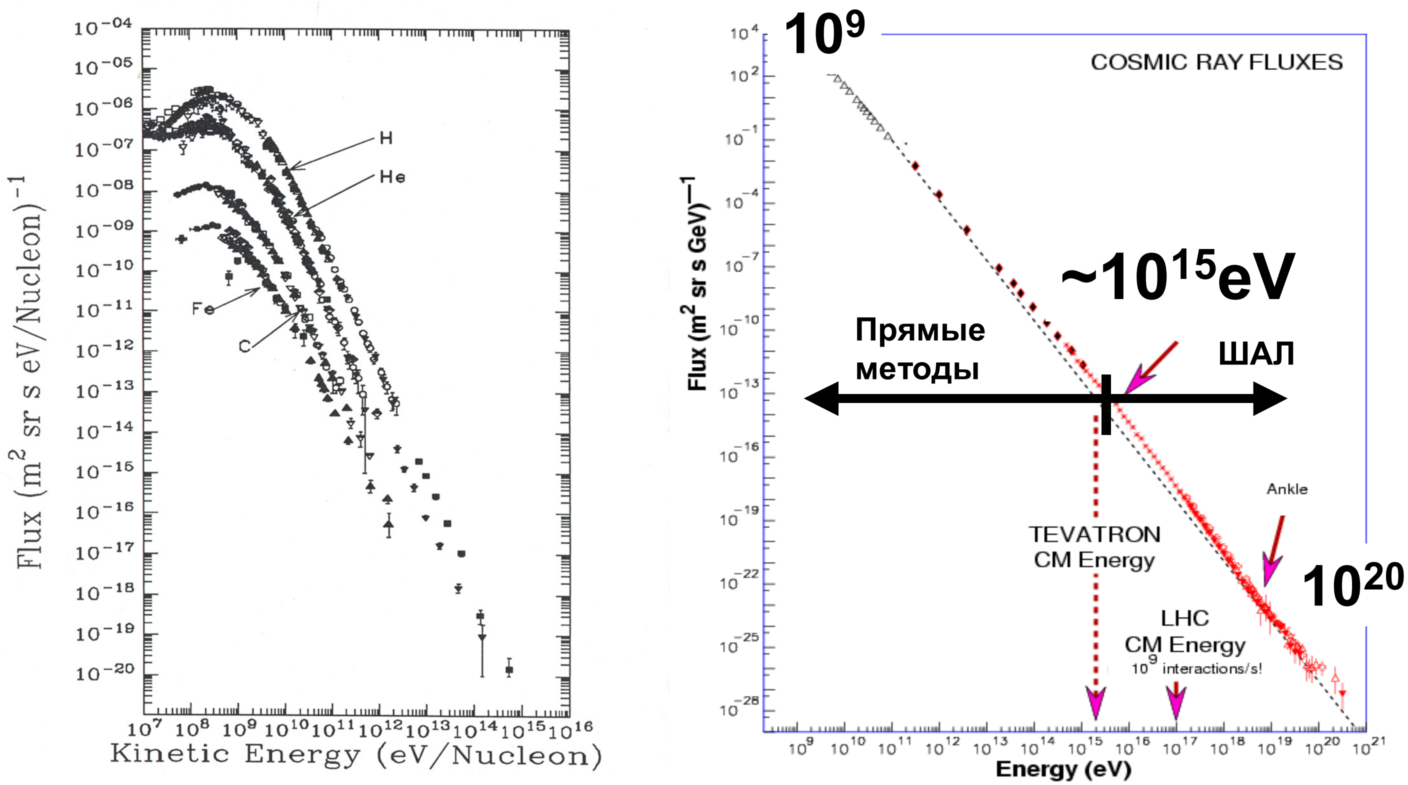
The new spacecraft, to launch in 2015

1. Orbit – 800-2000 км,
2. Payload <1500 kg,
3. Power – 16,5 kW
4. Payload demensions: R=1250 мм, H=1250 мм



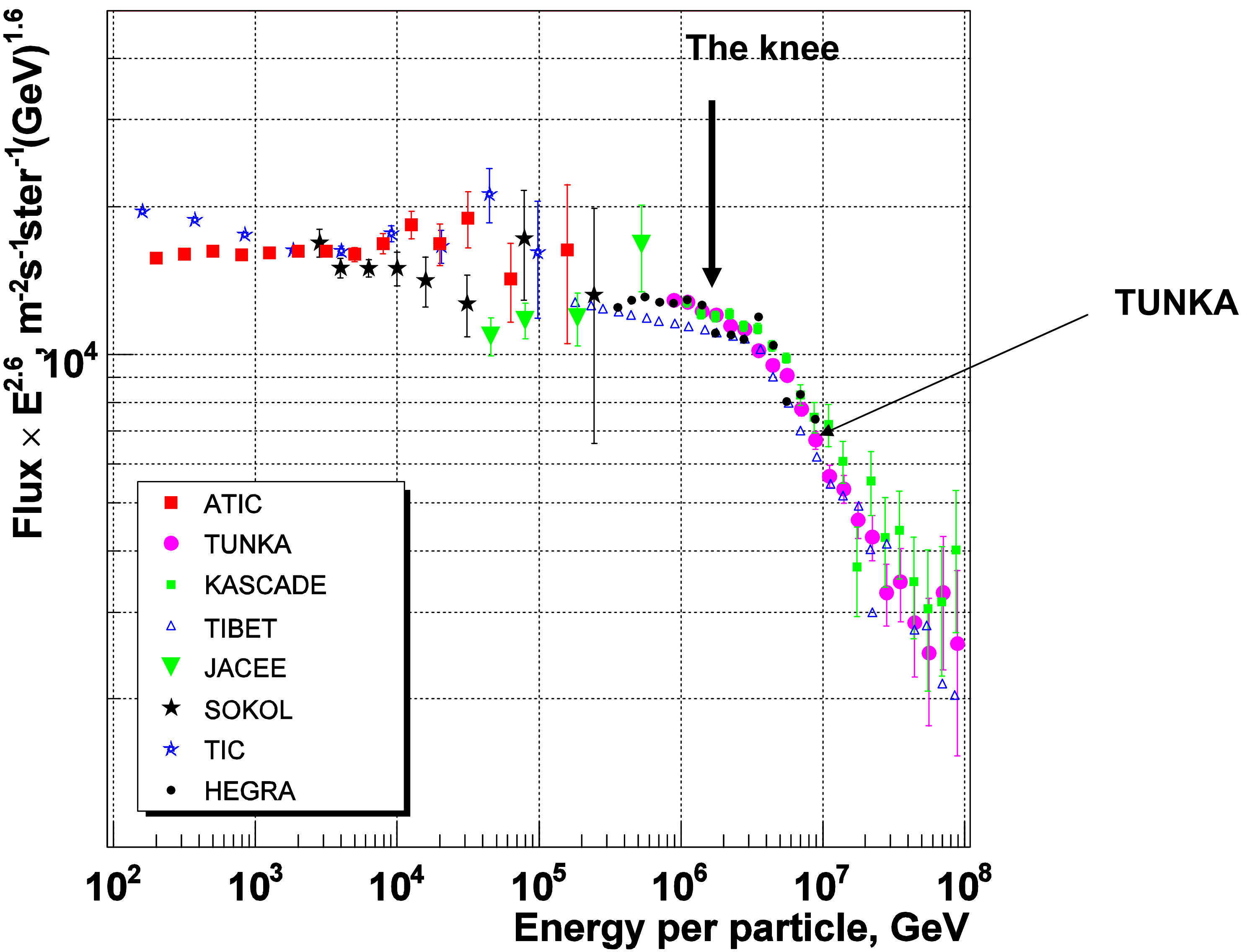
CR chemical composition above the knee

Космические лучи

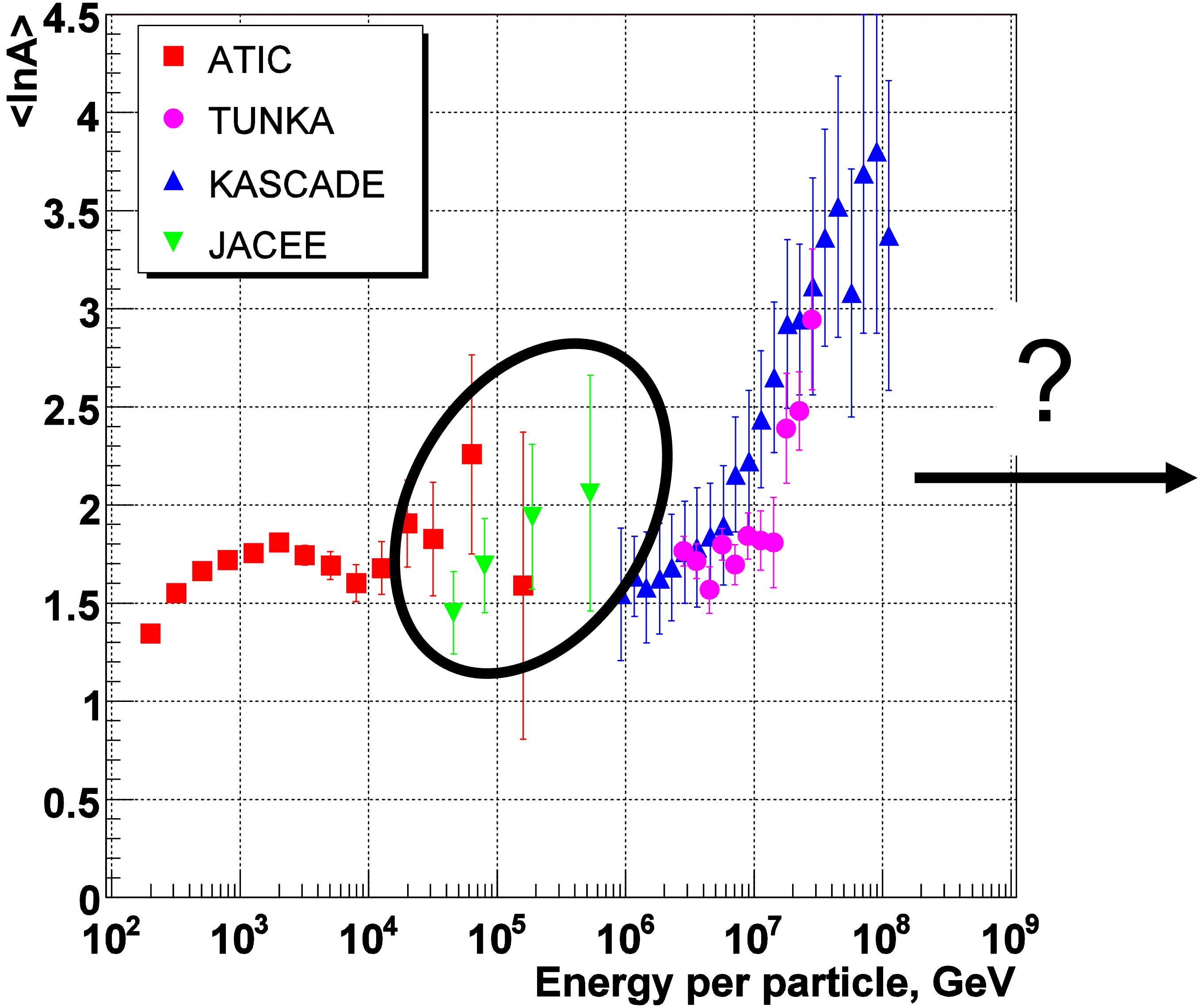


Cosmic Rays

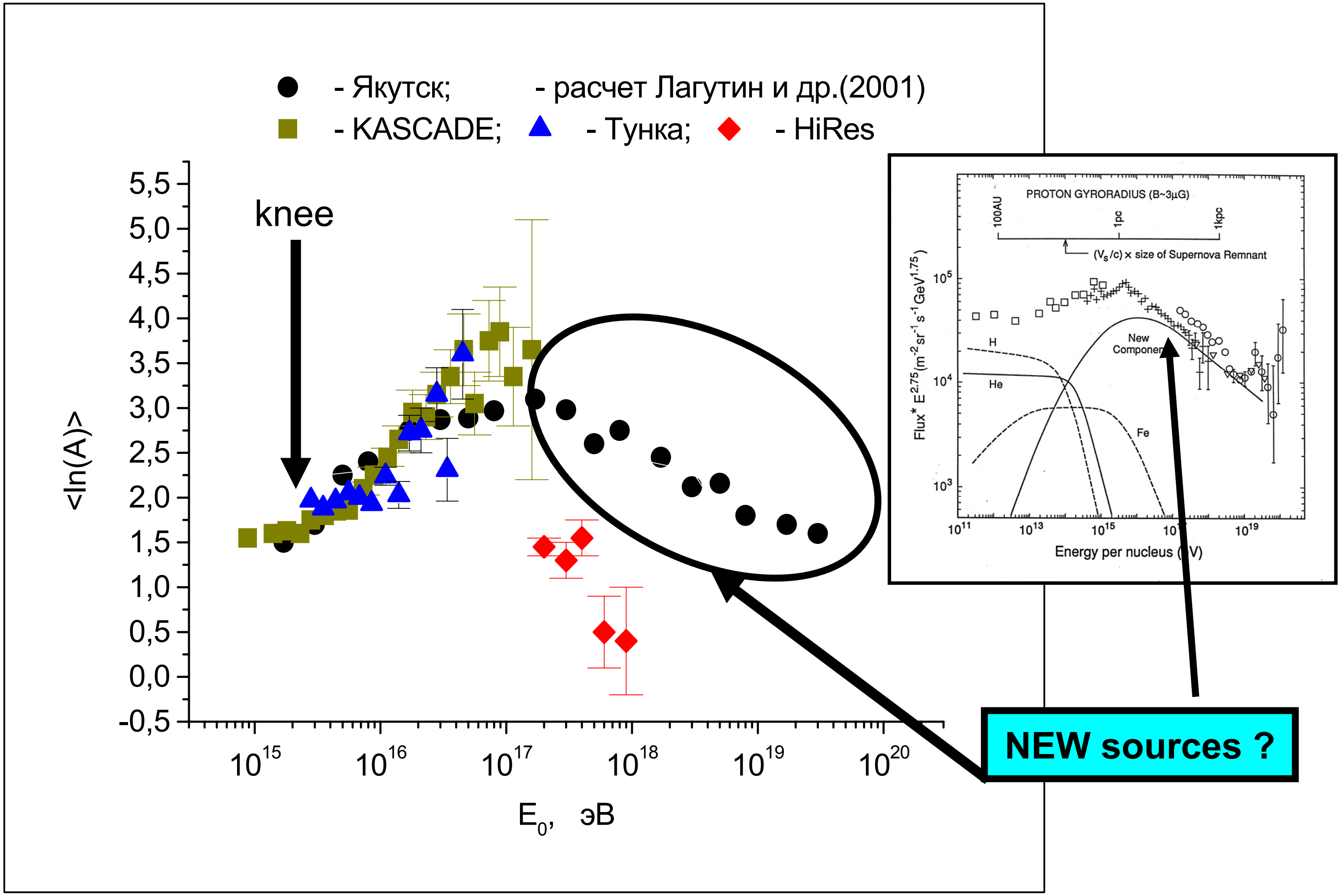
All particle spectra around the knee



Mean mass composition



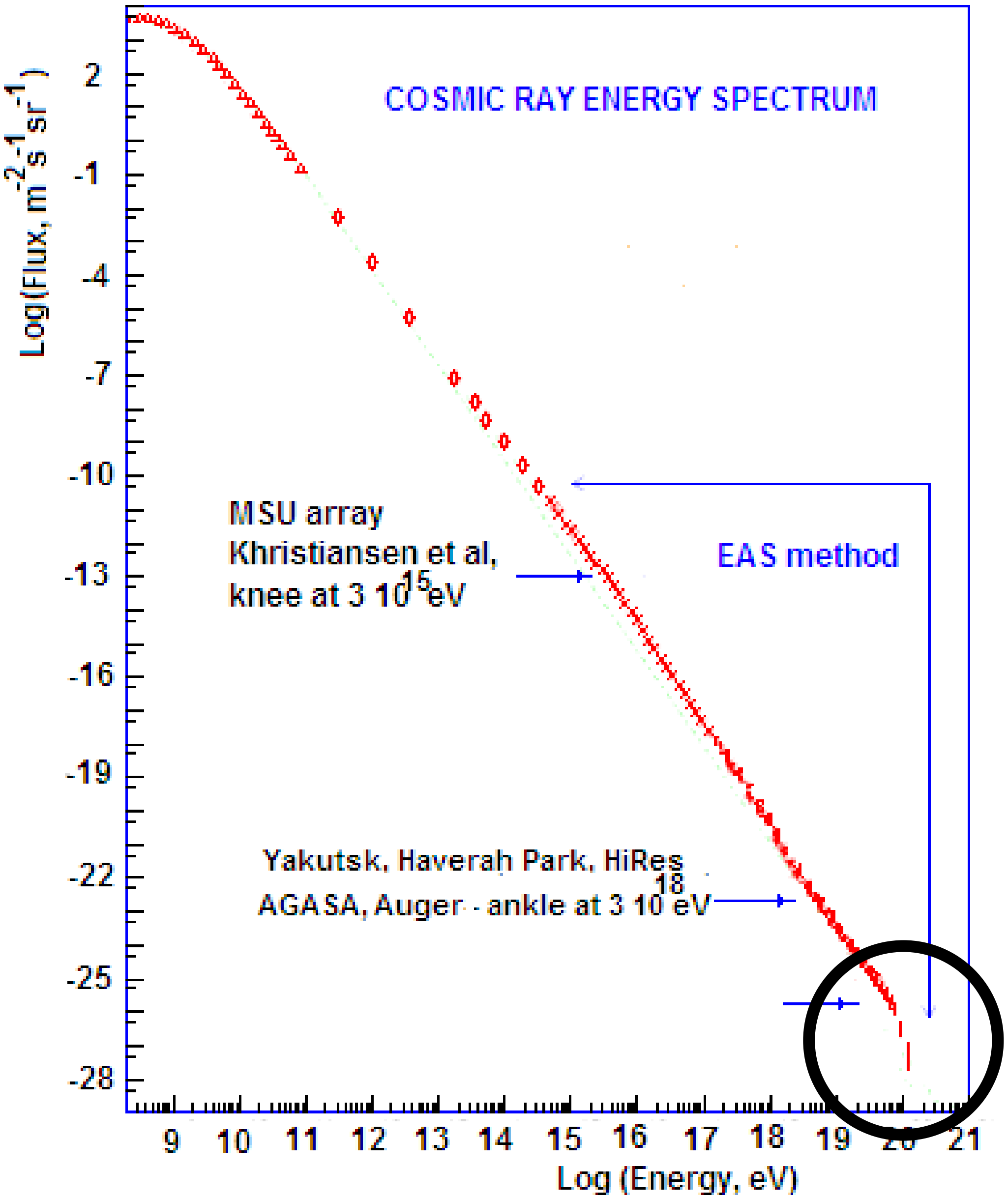
Chemical composition become more light above 10>17 eV?



The Second Knee

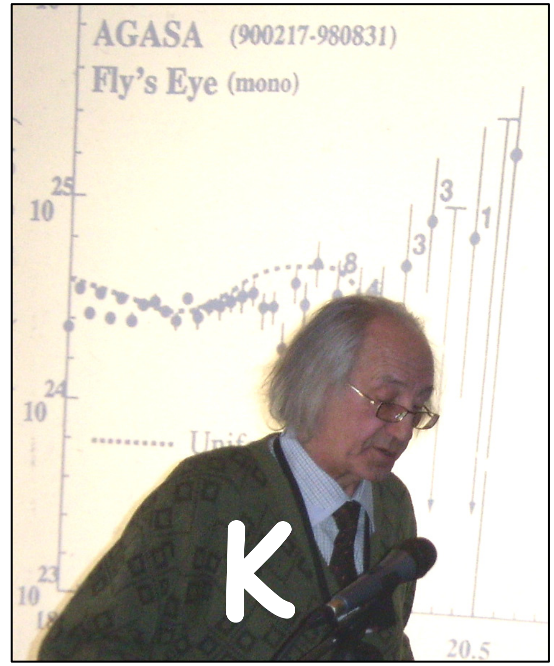
CR nuclei

UHECR, > 10^{19} eV

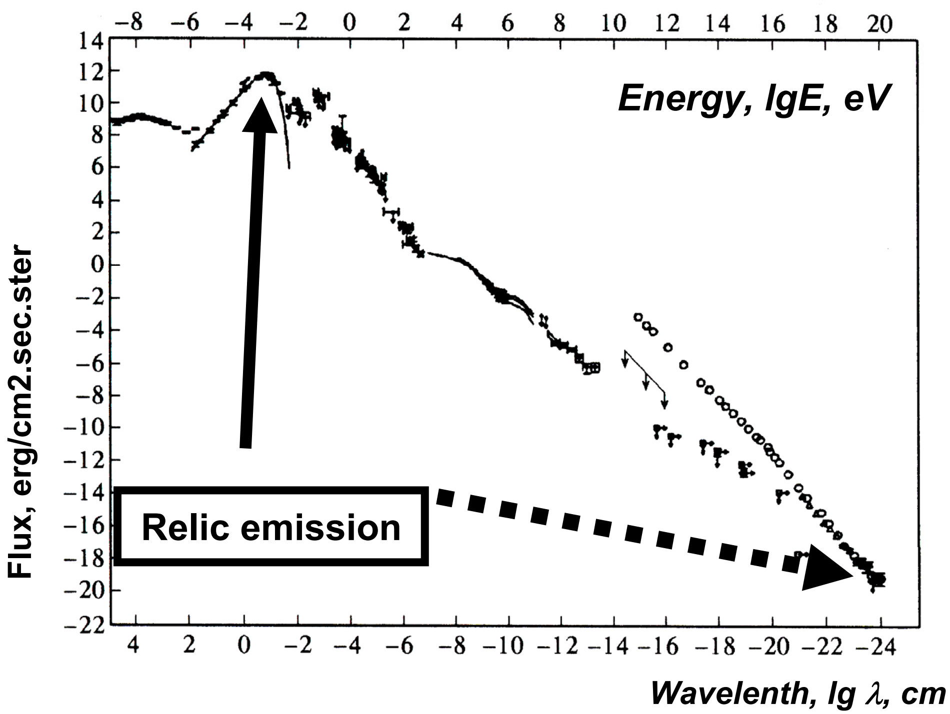


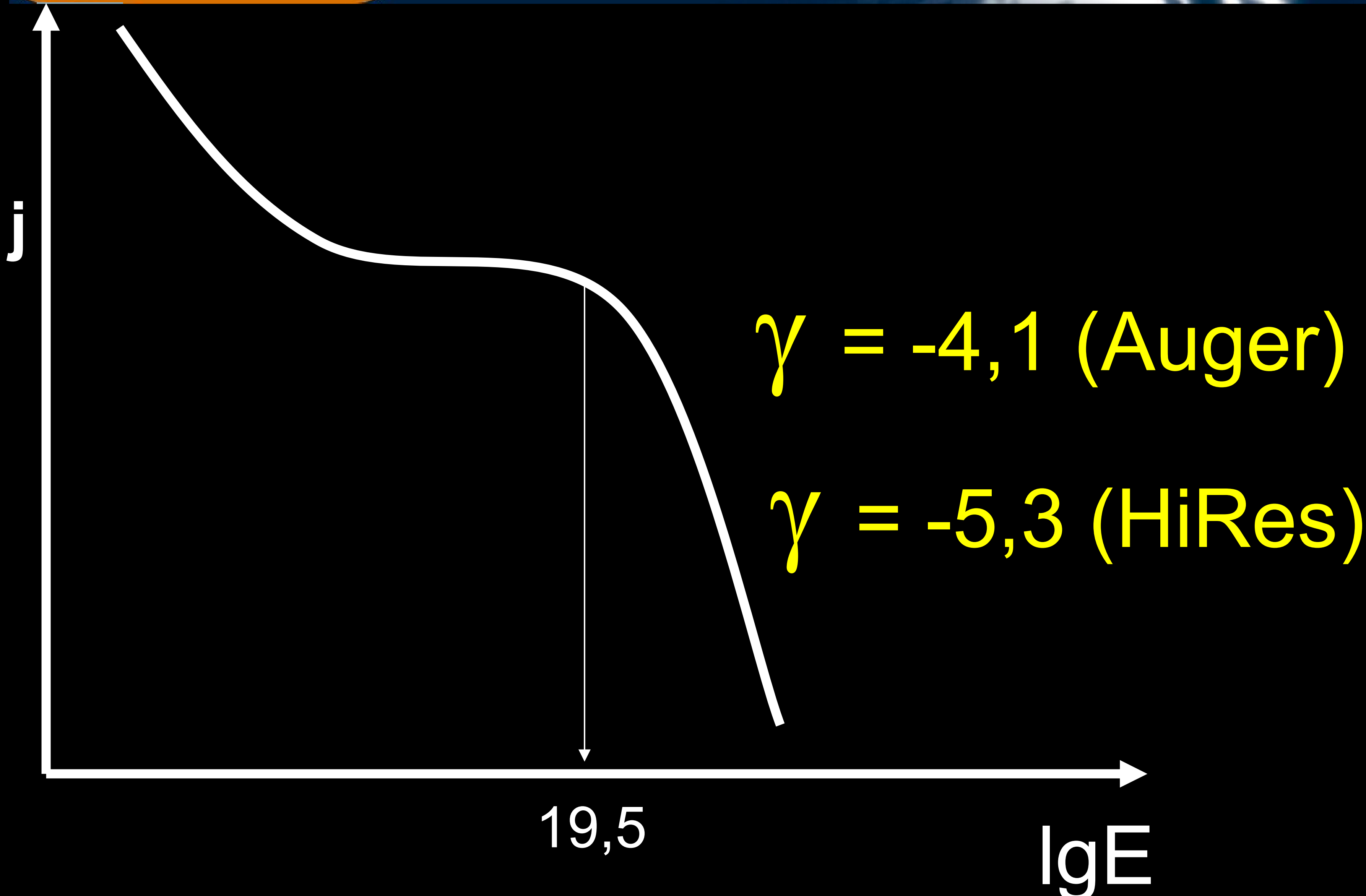

G


Z

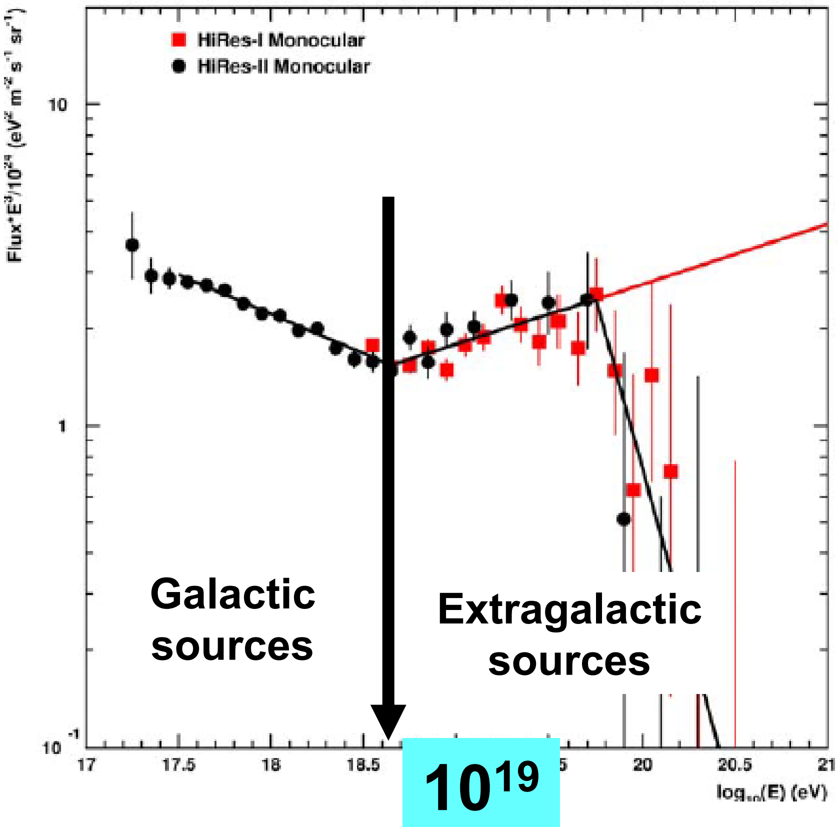

AGASA (900217-980831)
Fly's Eye (mono)
K

effect


Energy, lgE, eV
Flux, erg/cm2.sec.ster
Relic emission
Wavelenth, lg λ, cm


j
γ = -4,1 (Auger)
γ = -5,3 (HiRes)
19,5
lgE

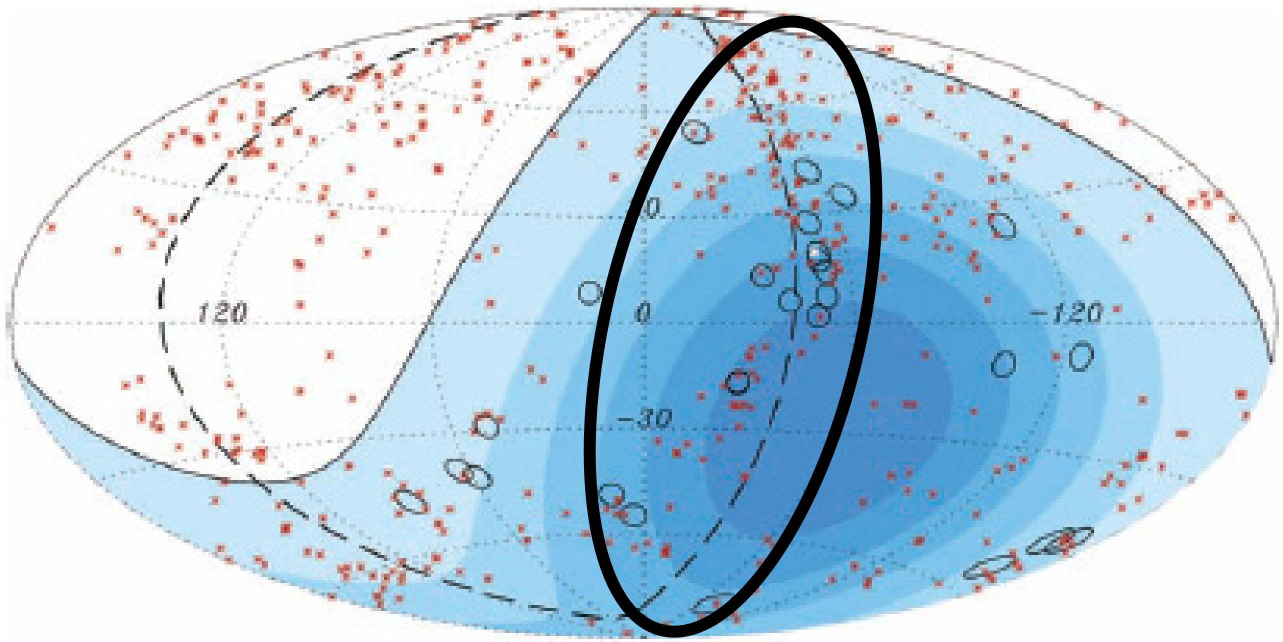
Проблема GZK – решена?



Composition?

Where is Zevatron?

Самые последние данные (9 ноября 2007 г.) установки Оже указывают на возможную корреляцию направления прихода протонов с энергией выше предела ГЗК с направлением на активные ядра местного скопления- «супер-галактики».



Открывается новое «окно» излучения для наблюдения самых мощных объектов Вселенной- «протонная» астрономия
по данным о частицах космических лучей ультравысоких энергий.

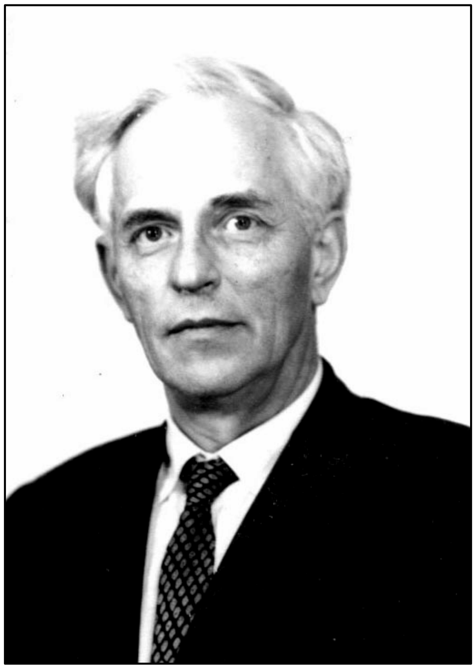
Изучение КЛПВЭ из космоса?

UHECR measurements from space?

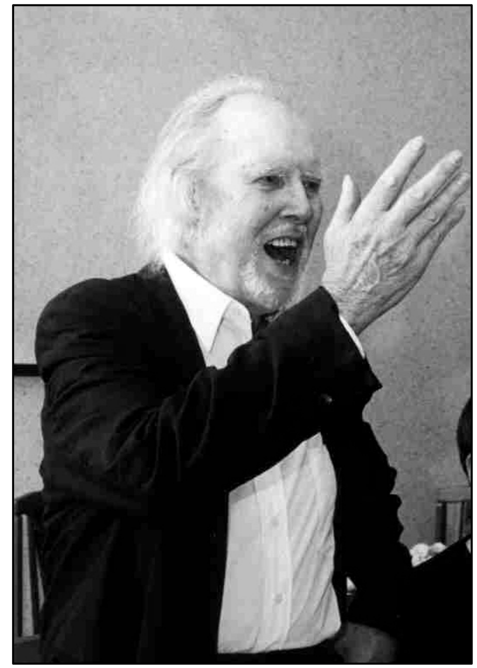
Изучение КЛПВЭ из космоса?

UHECR measurements from space?

UV emissions from UHECR EAS

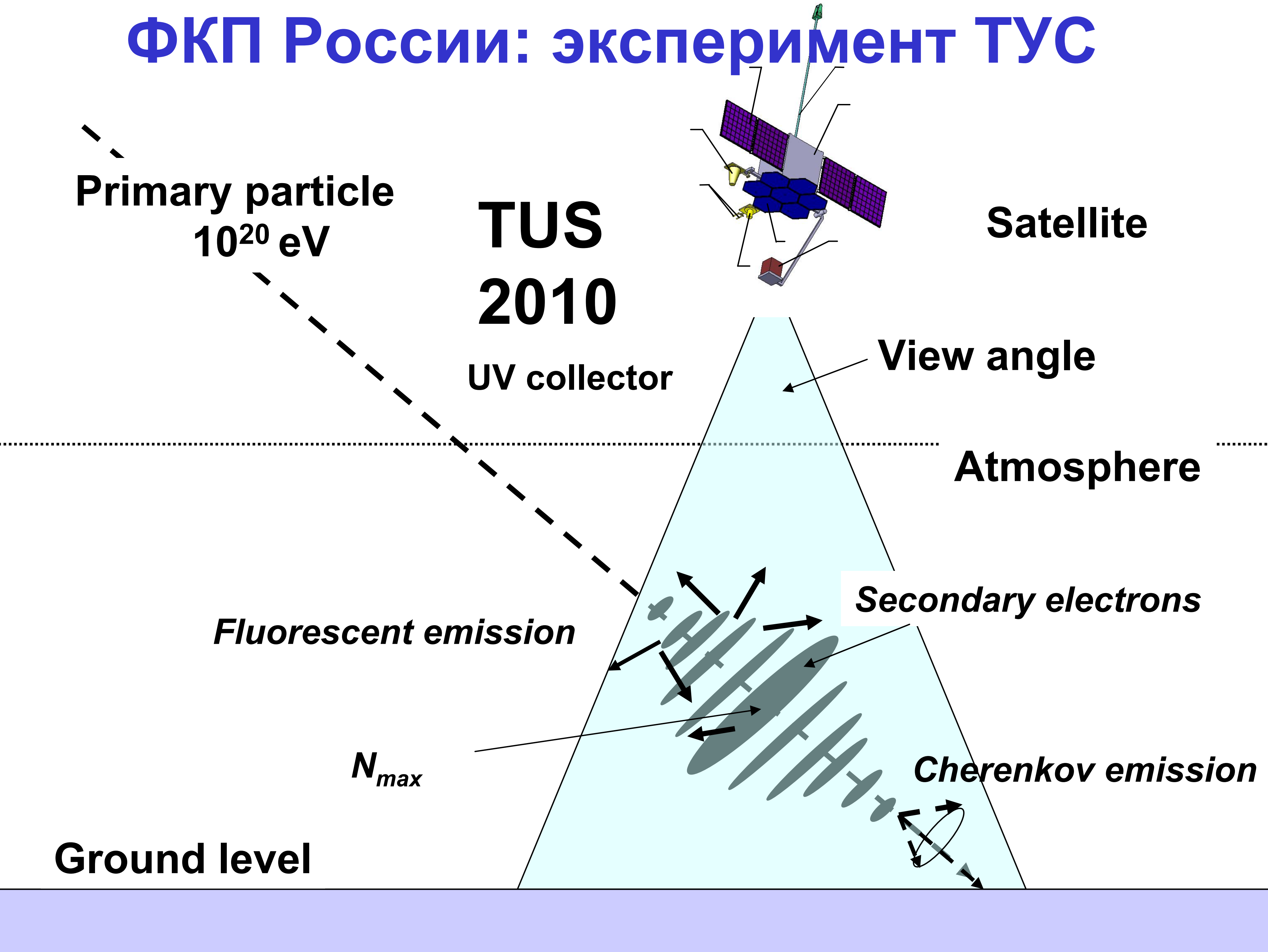


Aleksandr Chudakov
(mentioned in1955, published in 1962,simulteneously with Suga,1962) proposed the idea of measurements of atmospheric scintillation(300-450nm) from CR

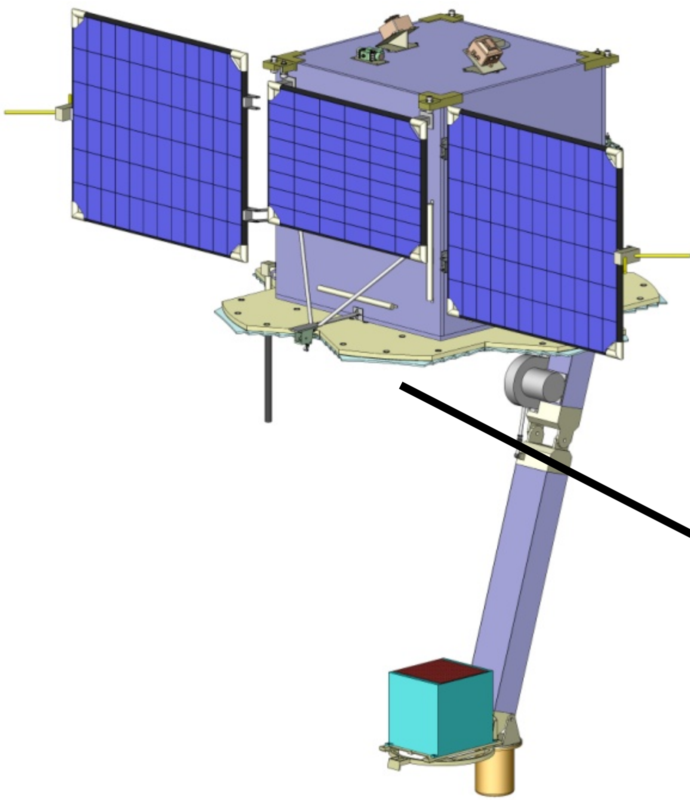


John Linsley's (1980) idea:
to measure ultraviolet emissions from space(AIRWATCH project)

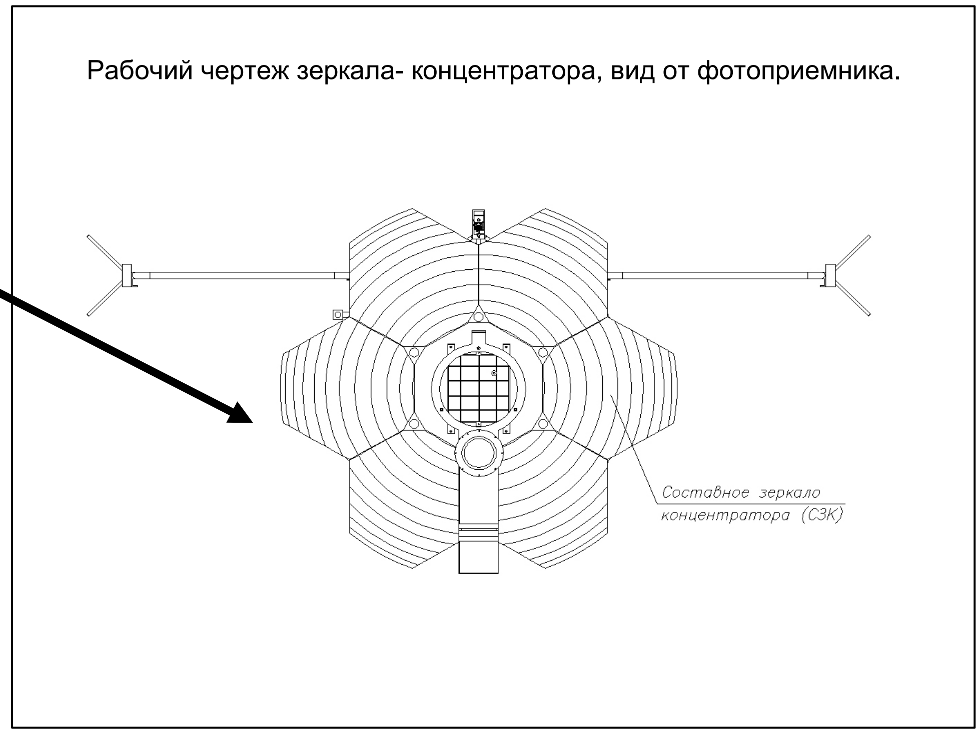
ФКП России: эксперимент ТУС



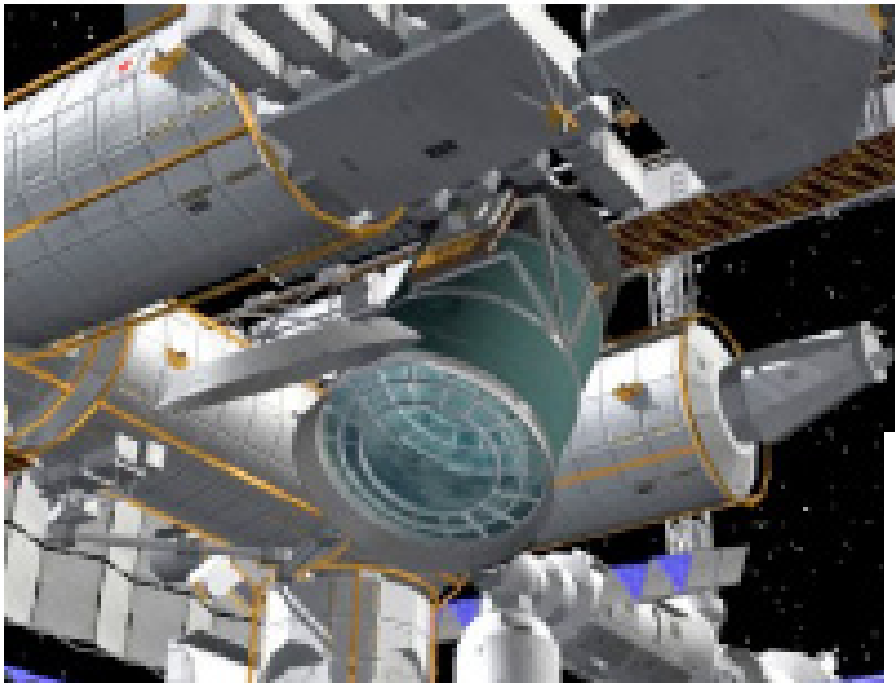
Space fluorescence detectors TUS for study of UHECR

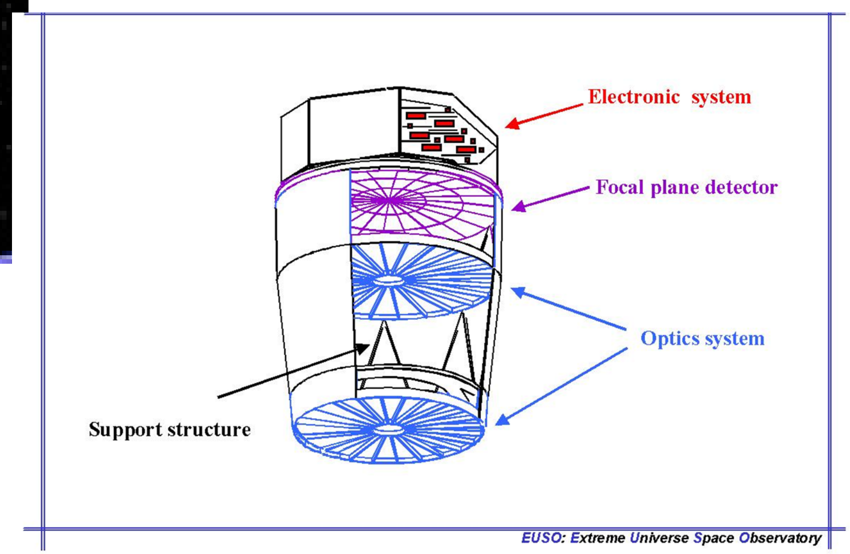


TUS telescope is consisted of 6 Fresnel type mirror segments.



JEM-EUSO: 2013(?)



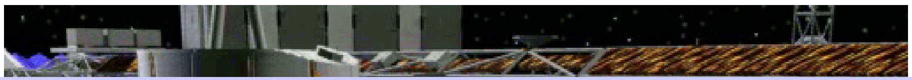


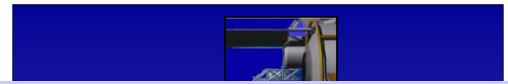
Планируемые эксперименты на МКС по изучению КЛПВЭ

Extreme Universe Space Observatory in 2012

JEM-EUSO

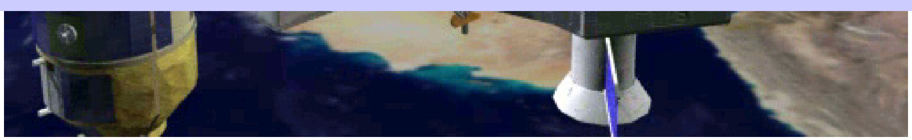
UHECR/ GZK neutrino study

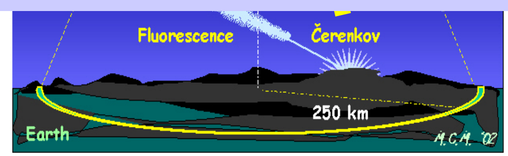




Then , after 2015, – Super EUSO?

Development of new space technology:
large mirror-concentrators,
large Fresnel lenses, highly efficient photo sensors.



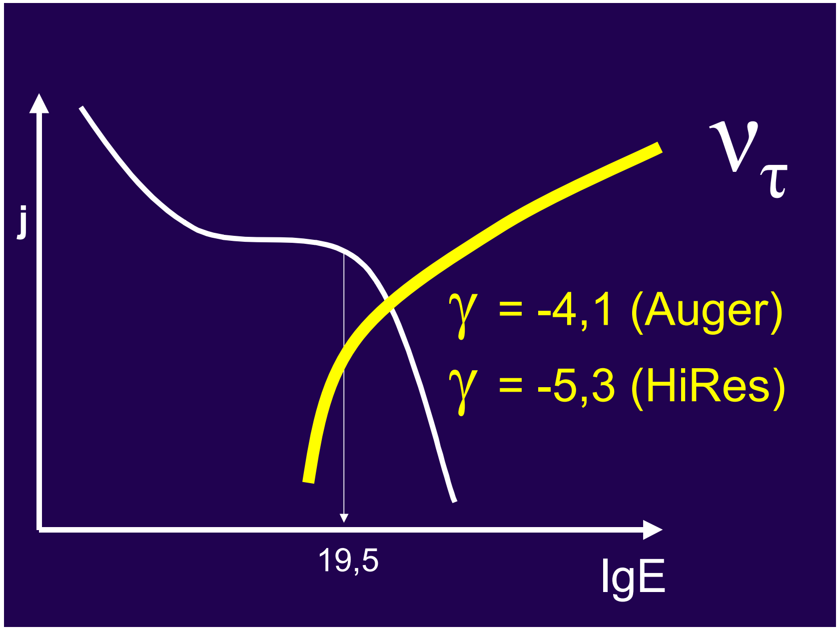


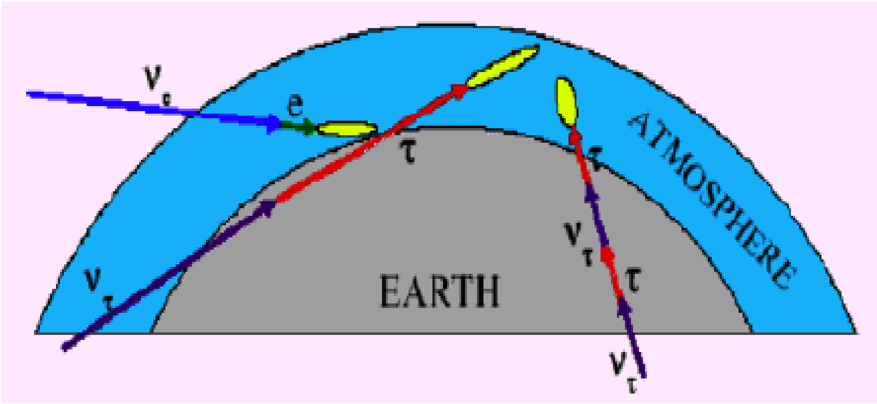
SO1→ Extension of the measurement of the UHECP energy spectrum beyond 10^{20} eV, reaching E > 10^{21} eV.

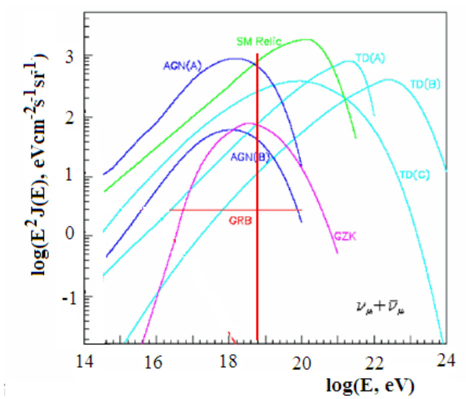
SO5→ Measurement of the flux of compact and diffuse sources of Ultra-High Energy Neutrinos; search for horizontal and skimming showers induced by tau neutrinos; estimate of neutrinos cross sections at UHE.

Нейтринная астрономия экстремальных энергий

Neutrino Astronomy at Extreme Energies







Active Galactic Nuclei (AGN)

Topological Defects (TD)

Supermassive Dark Matter (SM)

Proton-photon collisions (GZK)

Gamma Ray Bursts (GRB)

Signature of neutrinos

Special role of tau neutrino, $\nu_\tau \rightarrow \tau \rightarrow \nu_\tau$.

III

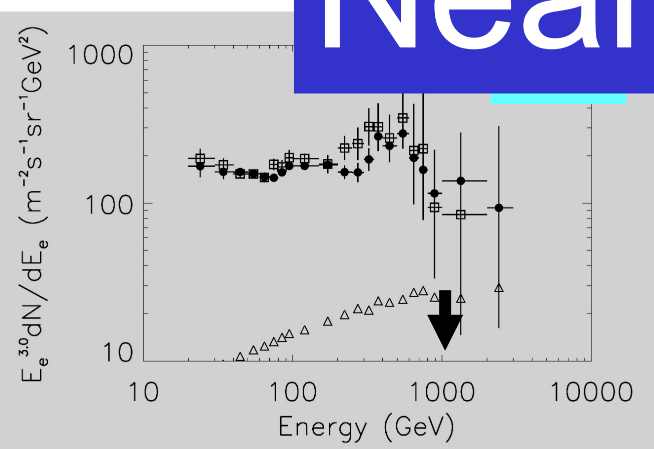
Lepton component of CR,

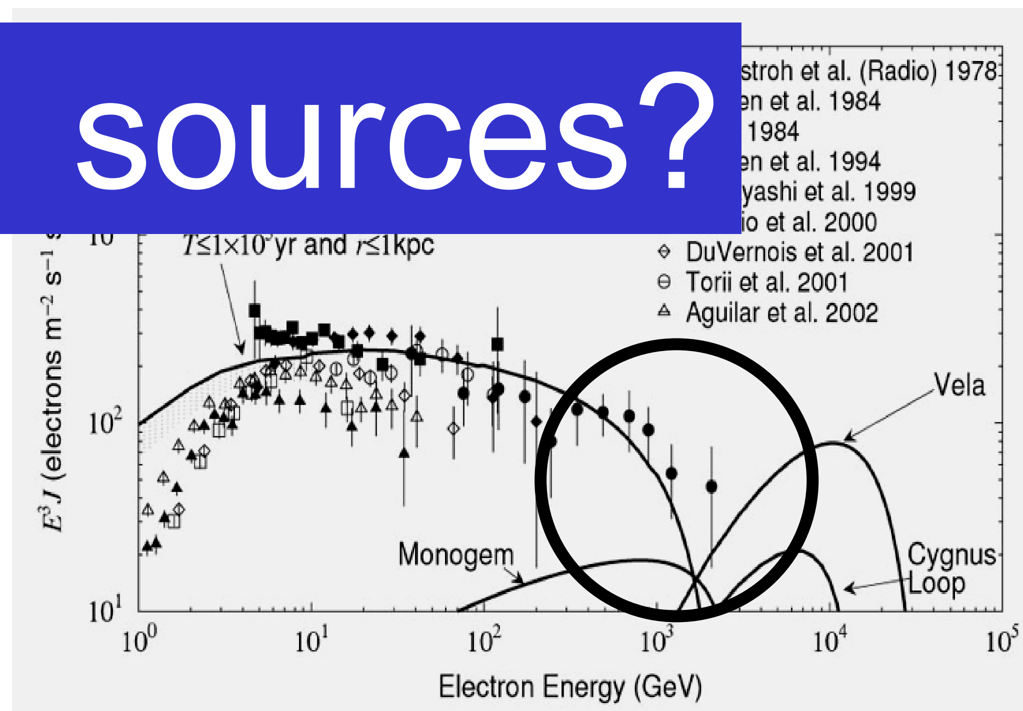
or the 3d knee problem

Electrons can provide additional information about the GCR source

- High energy electrons have a high energy loss rate ∝ E^2
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away

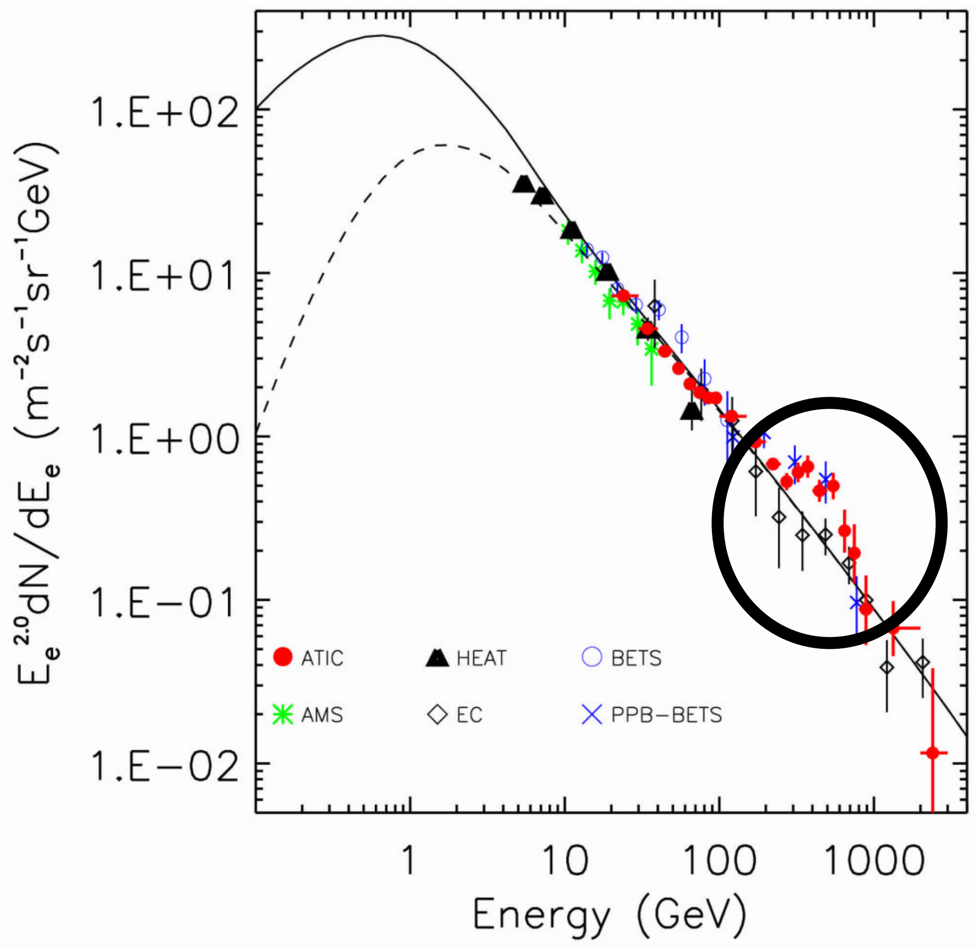
Near sources?



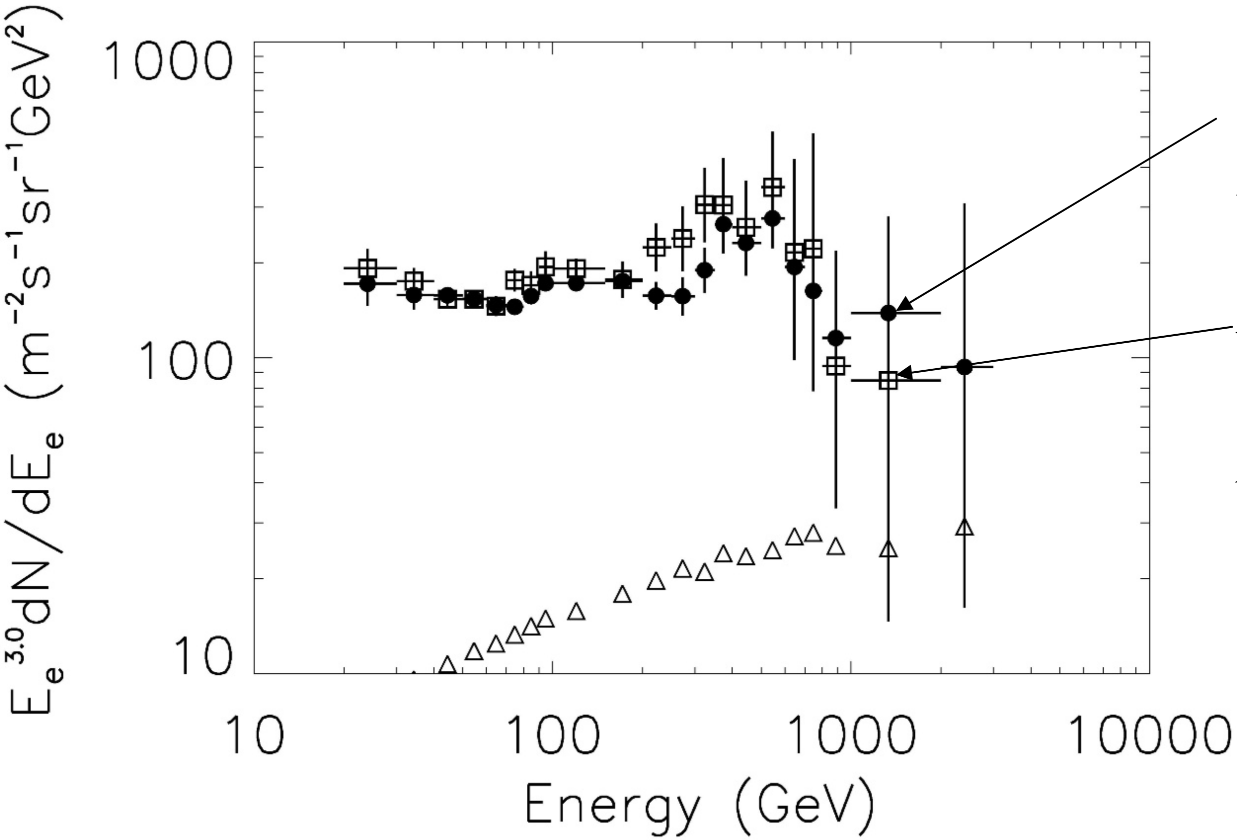


The ATIC electron results exhibits a feature

- Curves are from GALPROP diffusion propagation simulation code
  - Solid curve is local interstellar space
  - Dashed curve is with solar modulation (500 MV)
- “Excess” at about 300 – 600 GeV
- Also seen by recent PPB-BETS



Results from ATIC – 1 and ATIC – 2



Solid = ***ATIC-2*** with 2.5 m2-sr-days

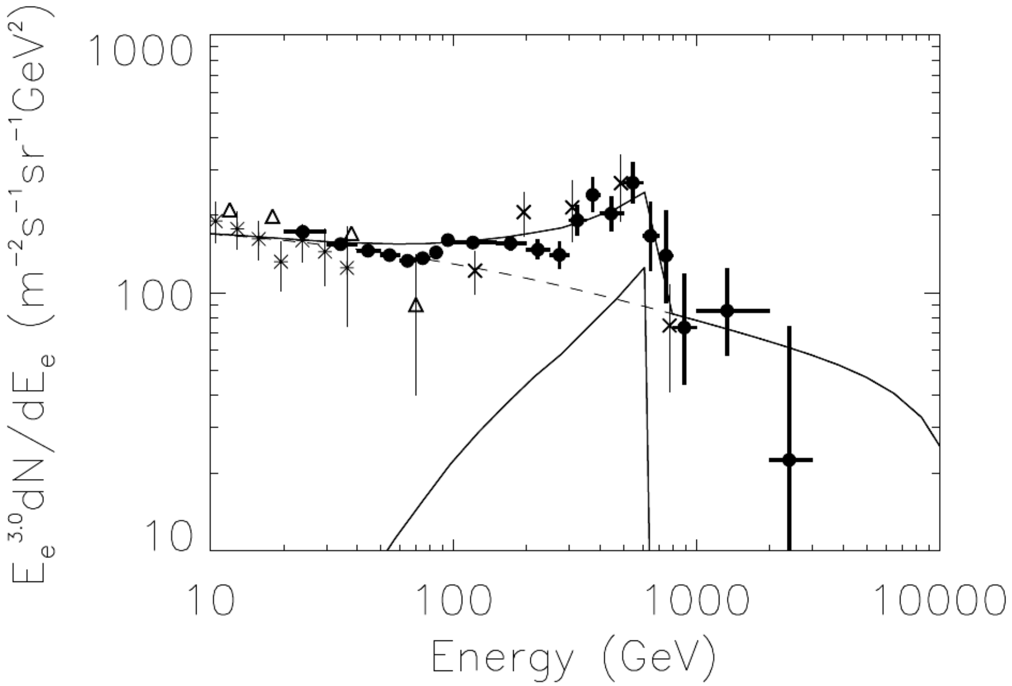
Open square = ***ATIC-1*** with 0.6 m2-sr-days

Triangles = combined background

Most exotic explanation is "Dark Matter"

- Neutralinos and Kaluza-Klein particles can annihilate to produce e^+ and e^-
  - › Mass and branching ratio cross sections not well defined
- Use the KK particle generator built into GALPROP to test the parameter space.

- Mass = 650 GeV
- Scale height = 4 kpc
- Mass density = 0.43 GeV / cm^3
- Annihilation cross section = 10^{-23} cm^3/s
- About 200 times more than expected!



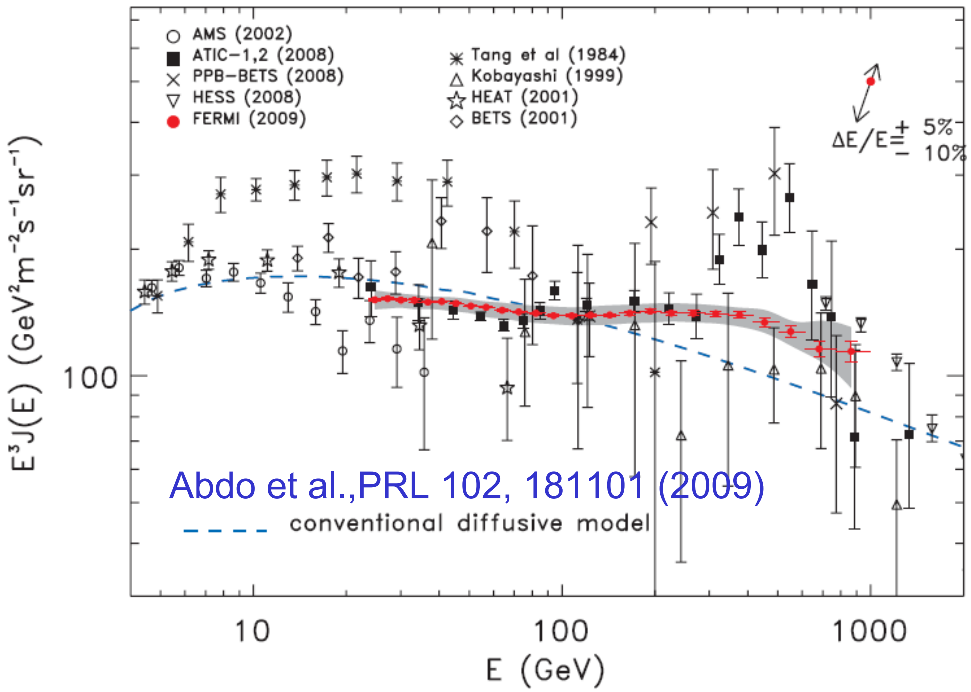
ATIC vs. Fermi discussions

- ATIC BGO calorimeter
  - 18 - 22 Xo
  - fully contains the electron shower
  - energy resolution of ~2 %

- Fermi CsI calorimeter
  - **Thinner**, 8.6 Xo
  - showers are not fully contained
  - distribution of the reconstructed energy is asymmetric with a longer tail toward lower energies
  - **Poorer energy resolution** ~20%

<u>Analysis method</u> comparison

- ATIC analysis uses quantities measured during flight (e.g. atmospheric secondary gammas) to set selection cuts and determine background rates.
- In Fermi much of the electron identification and background rejection is based on simulations only.



Other models...

1/Cosmic ray electrons and positrons from supernova explosions of massive stars

P. L. Biermann, J. K. Becker, A. Meli, W. Rhode, E. S. Seo, and T. Stanev

….cosmic ray electron and cosmic ray positron excess components and their cutoffs to the acceleration in the supernova shock in the polar cap of exploding Wolf Rayet and Red Super Giant stars…..

2/ Pulsars?

3/ Natural explanation for the anomalous positron to electron ratio with supernova remnants as the sole cosmic ray source

Nir J. Shaviv1, Ehud Nakar2,3 & Tsvi Piran1

Thank you