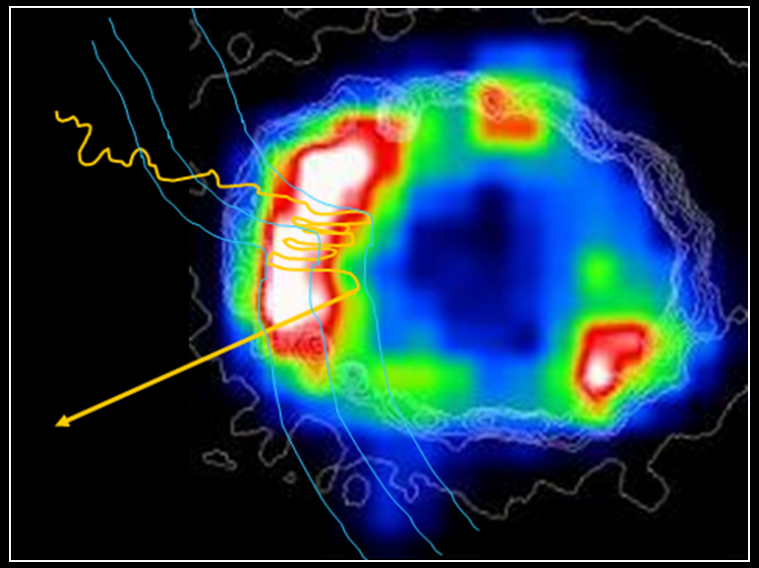
Review of direct measurements of cosmic rays

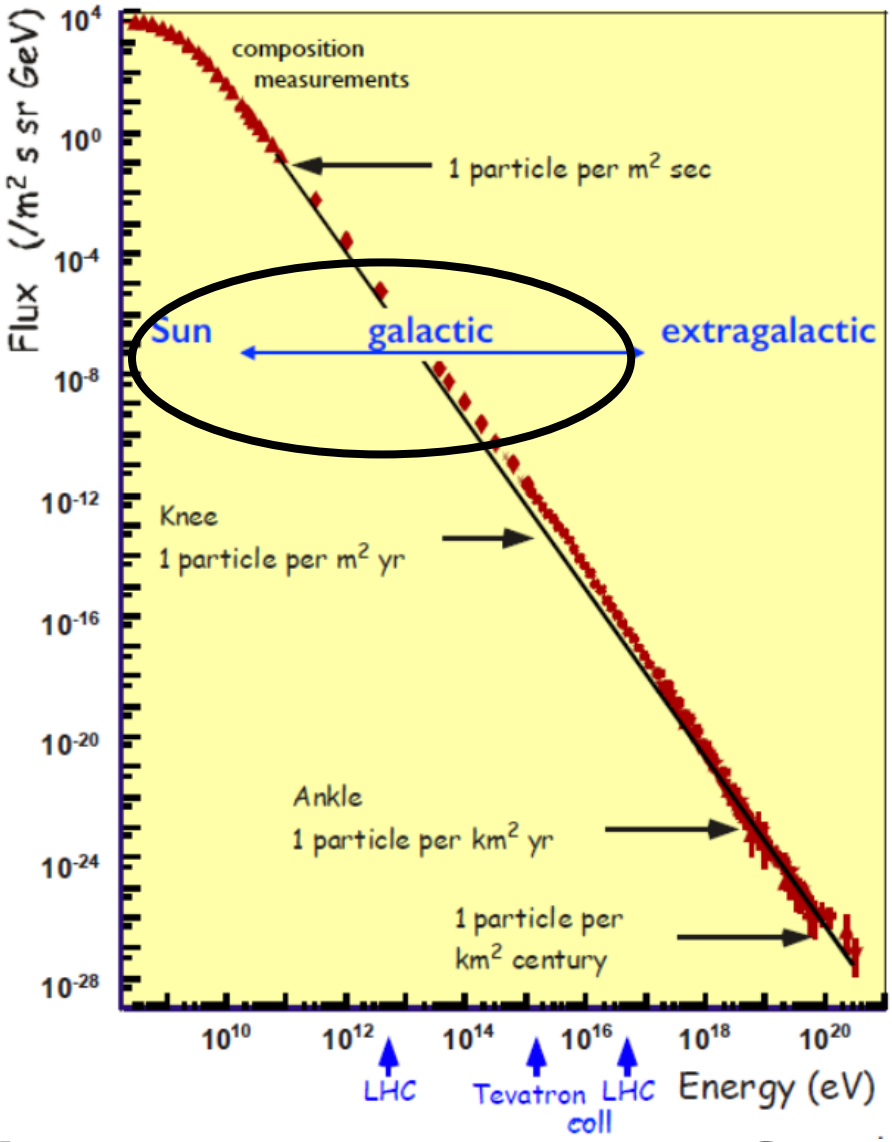


Mikhail Panasyuk

Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University

Sources of Galactic cosmic rays
APC, Paris - December 7-9, 2016

CR astrophysics main problems



Sources ?

Accelerators?

The power spectrum of cosmic rays

The basic paradigm of CR acceleration

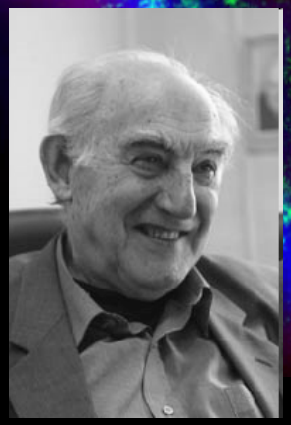
Supernovae

10^{52} er

Energy balance equation (Ginzburg & Syrovatskii 1964)

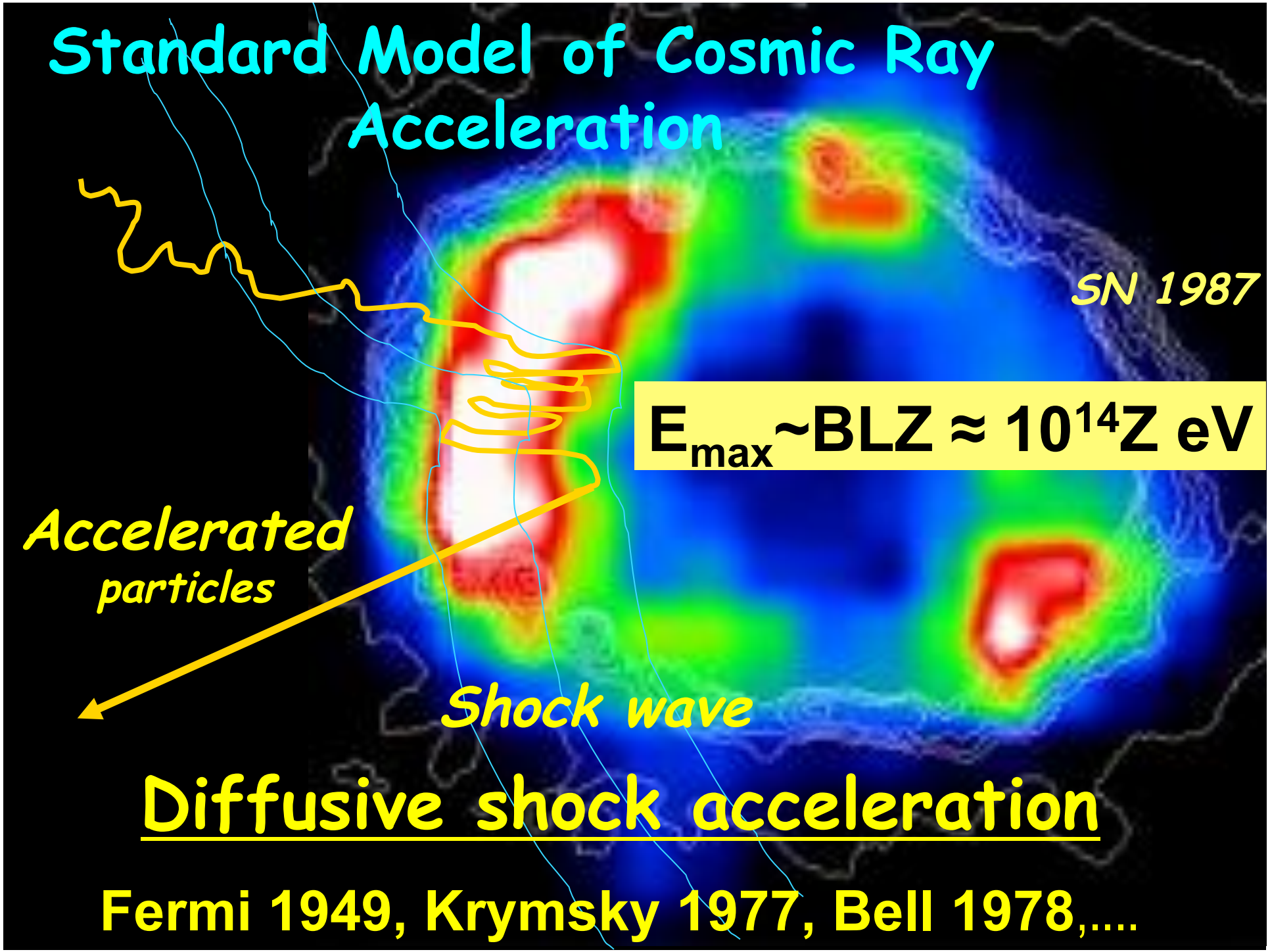
~ 10% of SN kinetic energy should go to cosmic rays to maintain observed w_{cr}

at $W_{sn}=10^{51}$ erg, $\nu_{sn} = 1/(30\ \mathrm{yr})$



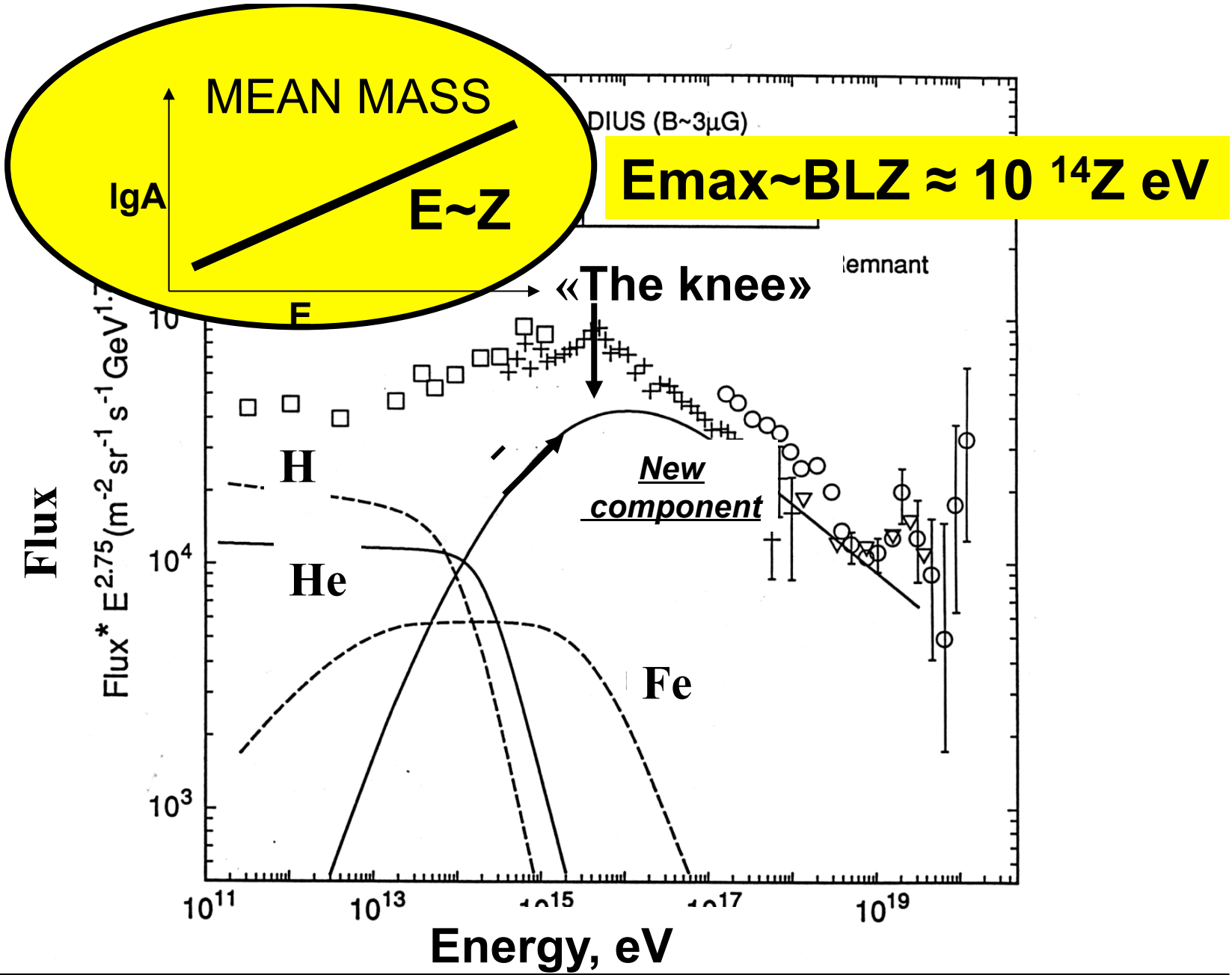
Ginzburg

Syrovatskii


Standard Model of Cosmic Ray Acceleration
SN 1987
E_{max}~BLZ ≈ 10^{14}Z eV
Accelerated particles
Shock wave
Diffusive shock acceleration
Fermi 1949, Krymsky 1977, Bell 1978,....

LET’S FOLLOW THIS PARADIGM

AND FORGET (FOR A WHILE) OTHERS ONES...



Definition of average mass below "the knee" – the real test for current models

Strong magnetic field in young SNRs

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

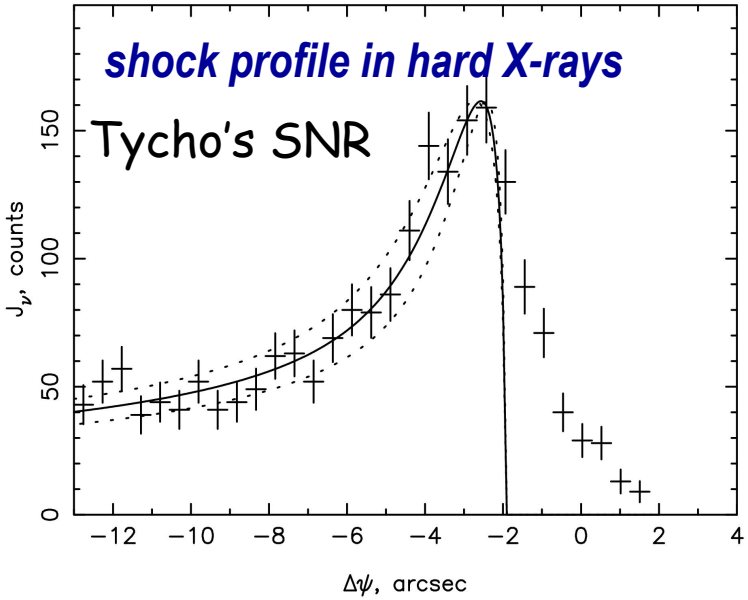
B ~ 300 μG, for **Tycho's SNR**

consistent with synchrotron spectrum from acceleration theory

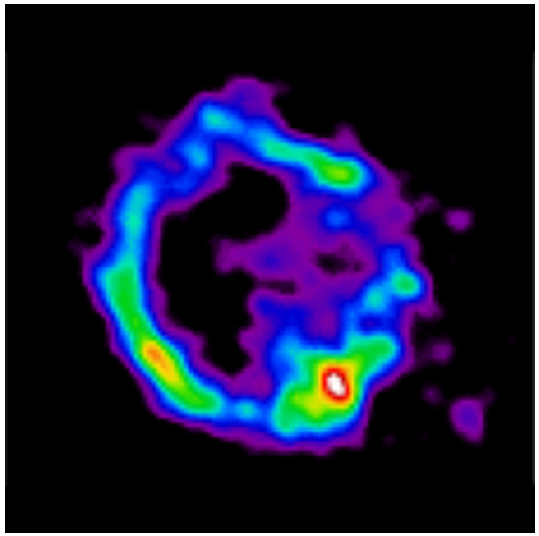
Similar amplification in all other SNRs where such data are available:

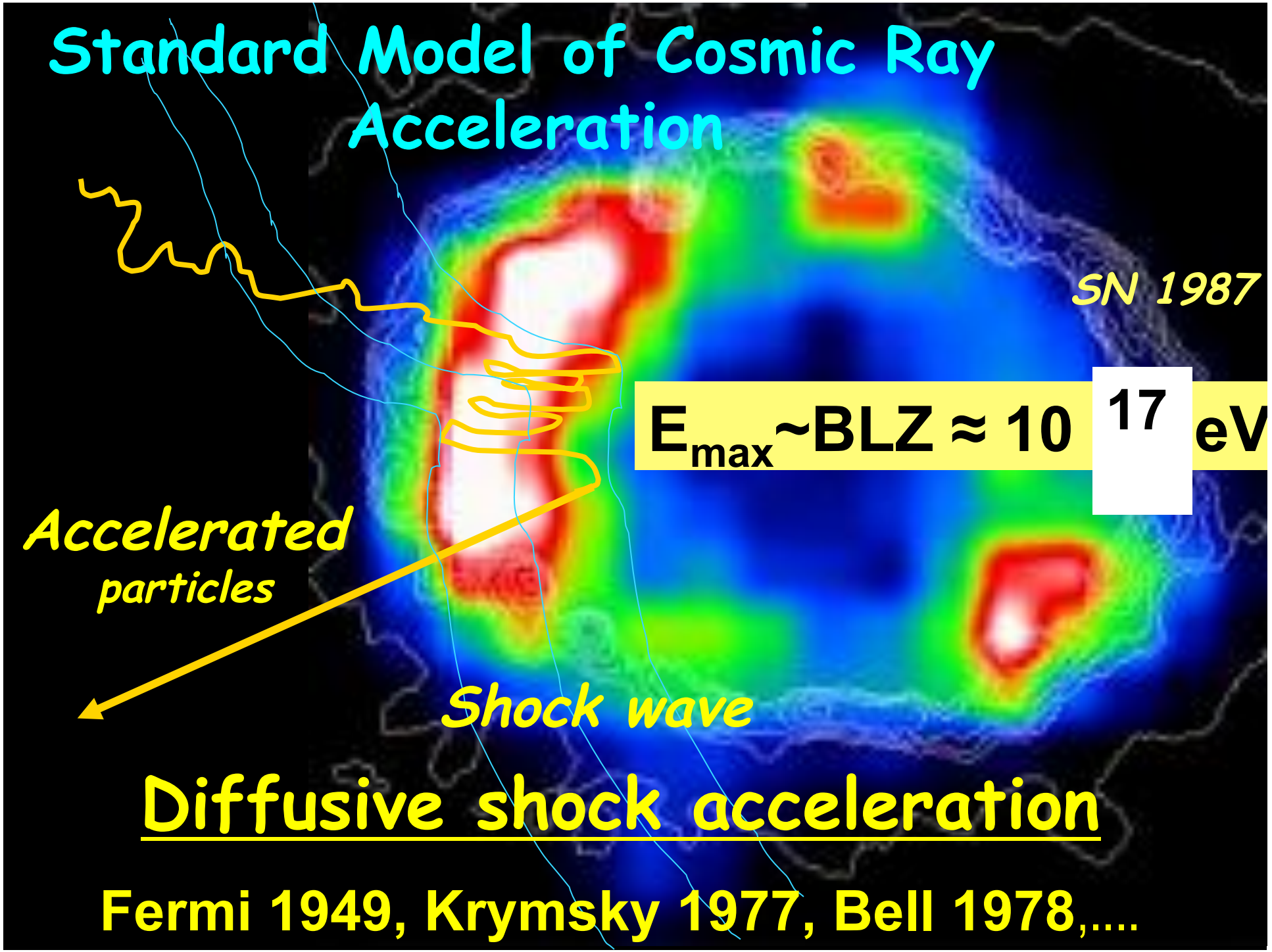
Cas A, **SN 1006**, Tycho, RCW 86, **Kepler**, RX J1713.7-3946, **Vela** Jr

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

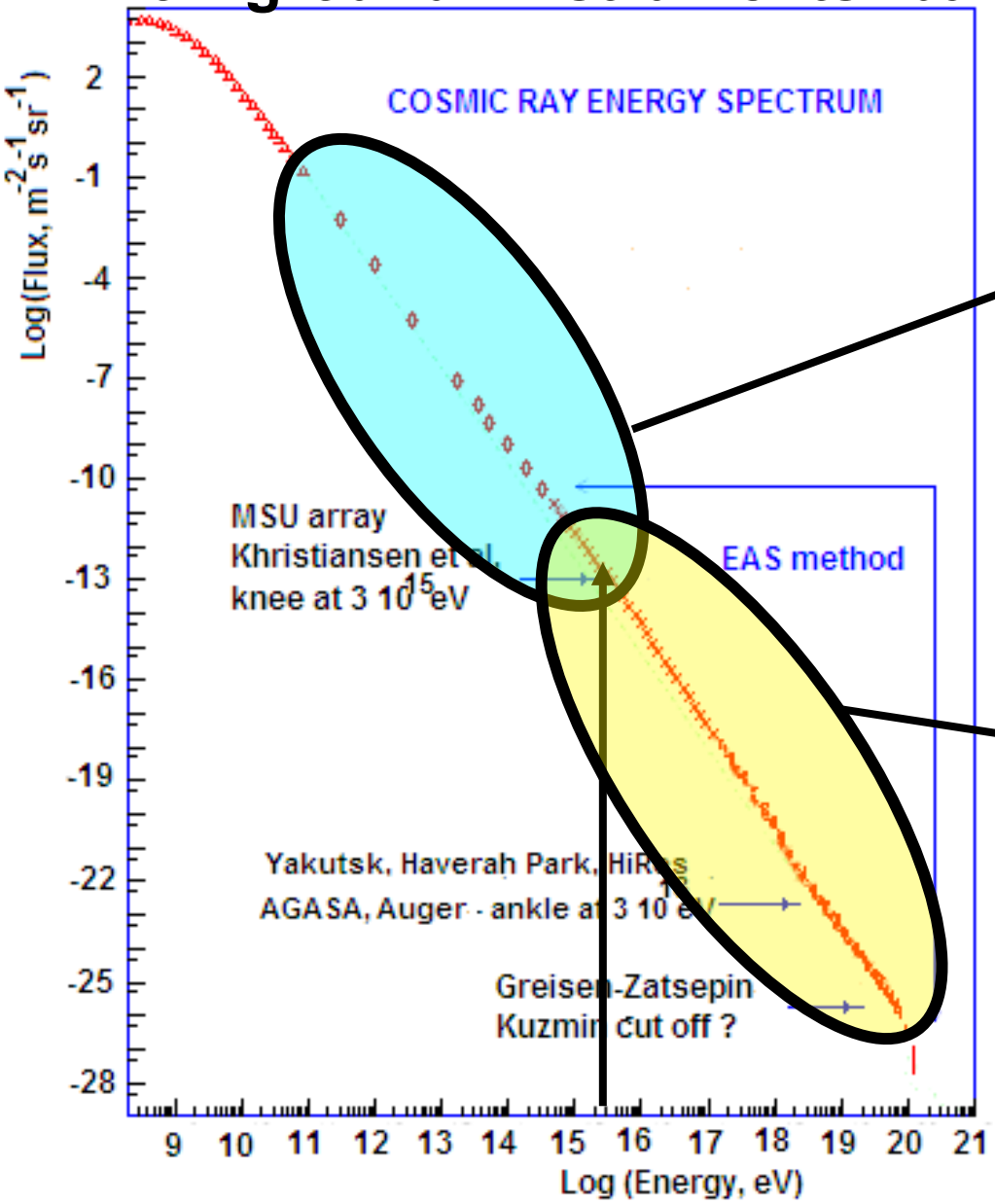


diffusive shock acceleration of electrons, including synchrotron losses gives observed scale




Standard Model of Cosmic Ray Acceleration
SN 1987
E_{max}~BLZ ≈ 10^{17} eV
Accelerated particles
Shock wave
Diffusive shock acceleration
Fermi 1949, Krymsky 1977, Bell 1978,....

Mostly, GCR can be measured using "off-ground" instruments: balloons&satellites

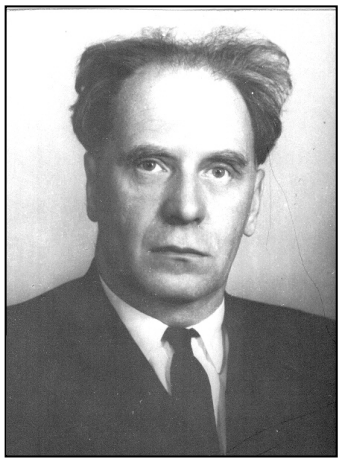


HE CR
Balloons
Satellites

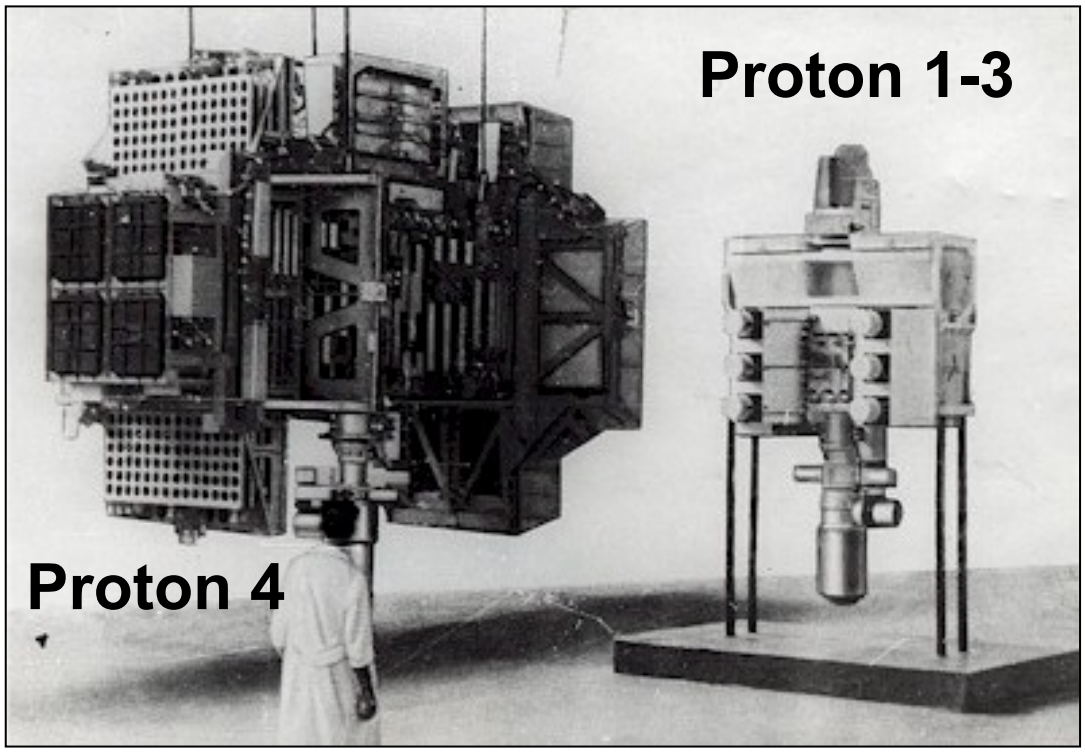
HE CR
on ground installations

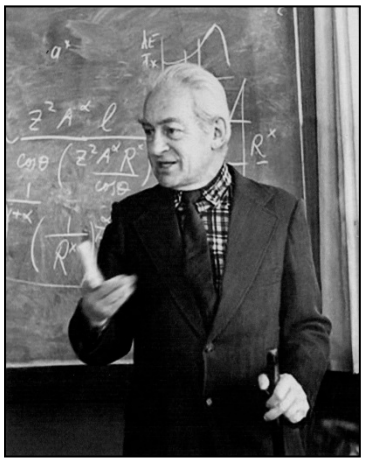
Эксперименты « Протон»

«Proton» experiment : 1965 – 1966



S. Vernov

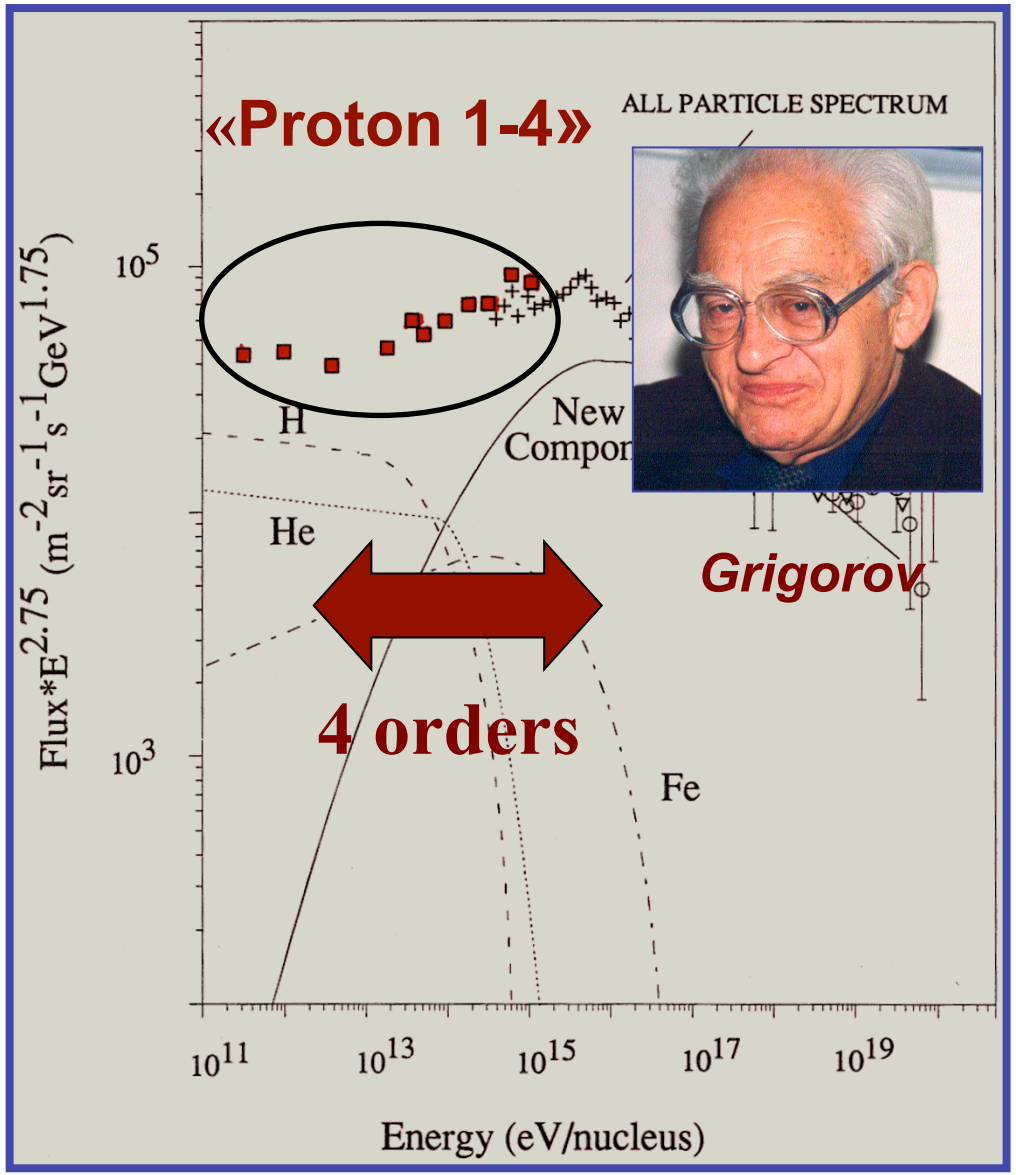




N. Grigorov

Experimental instruments – ionization calorimeters were designed at Moscow State University

«Proton's» results



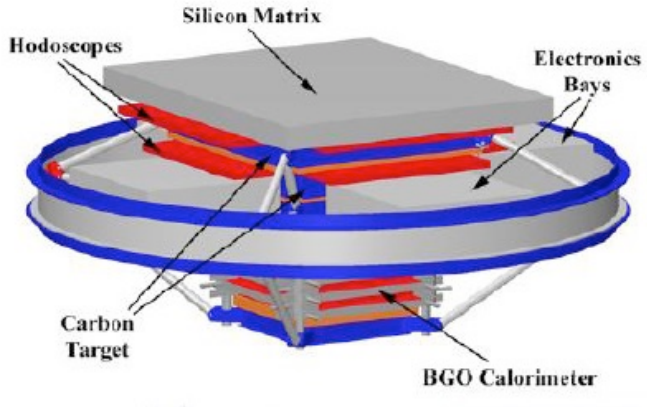
"Proton": all particle from 10*11 till 10*15 eV

Up to now we had no such possibility!

.

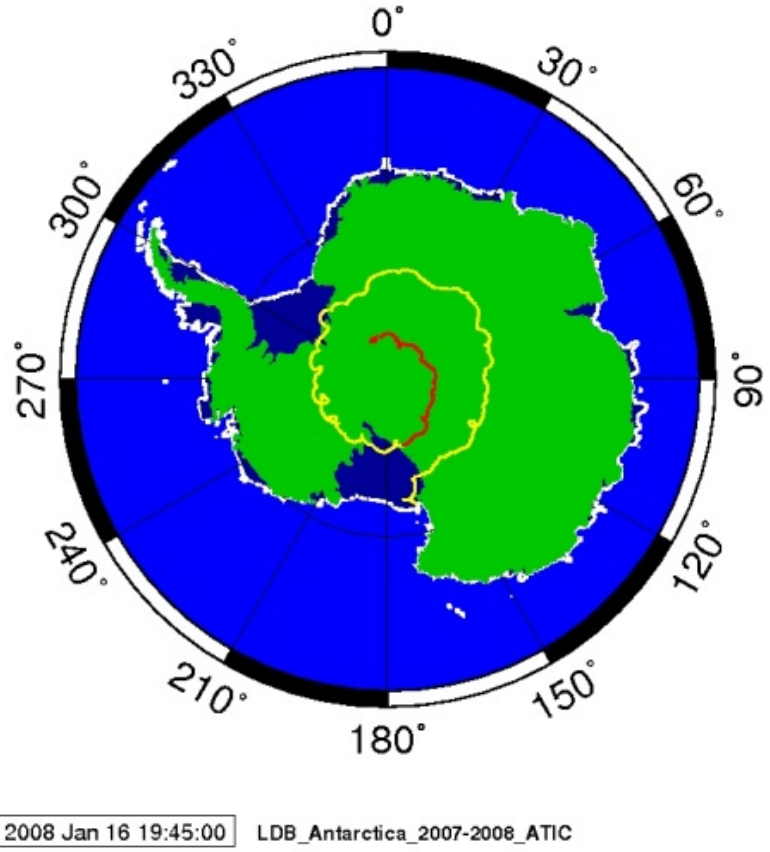
The beginning of 21 century gave us

absolutely new results from CR experiments



ATIC

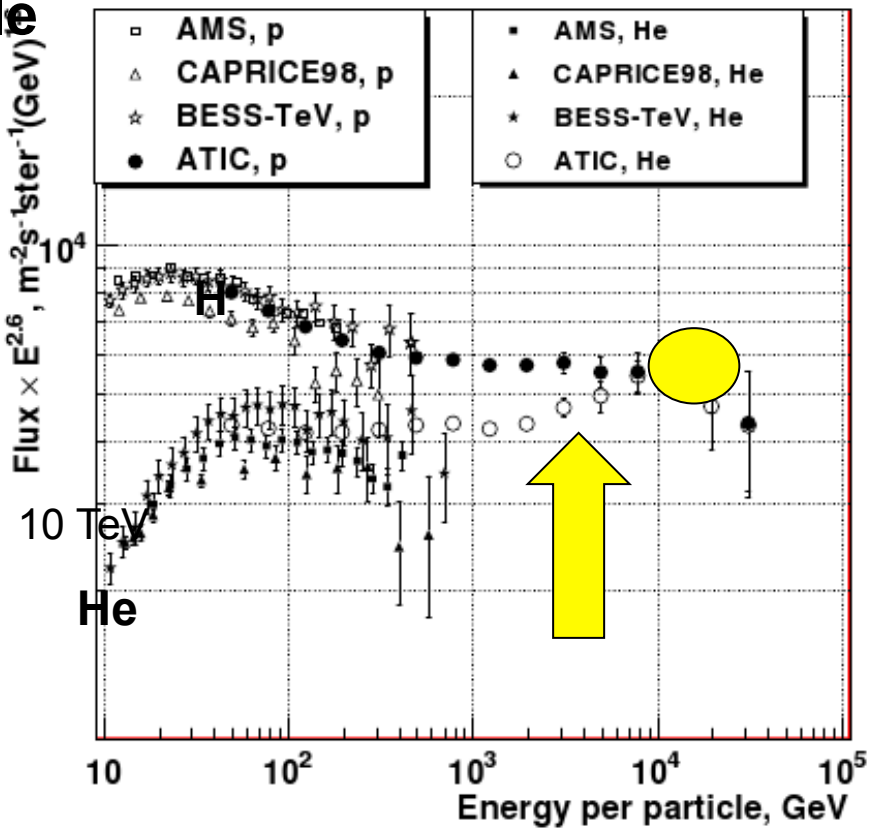
2000-2007



Proton and helium spectra: thin structure

Spectra for energy per particle

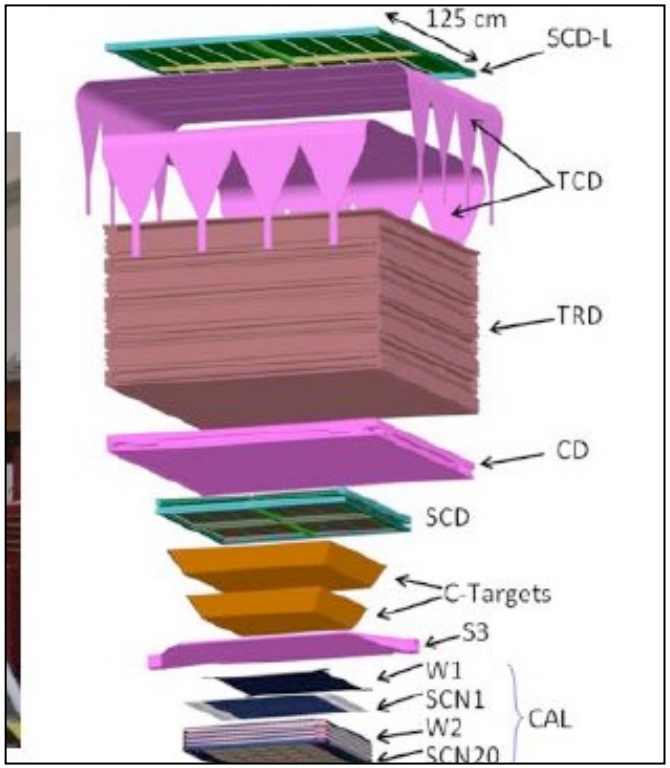
ATIC

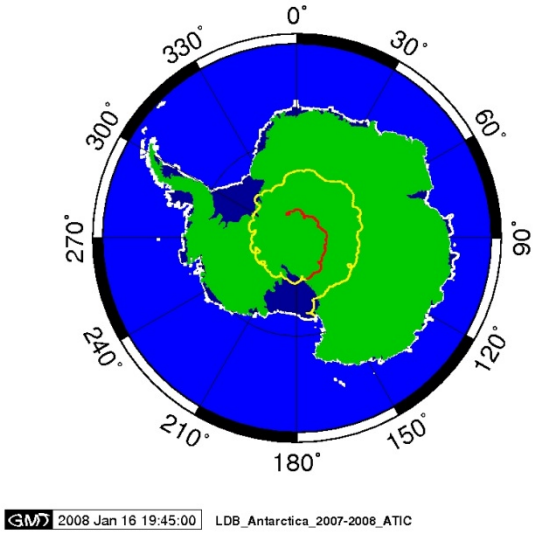


There is no single power law!

CREAM

2007 -2009

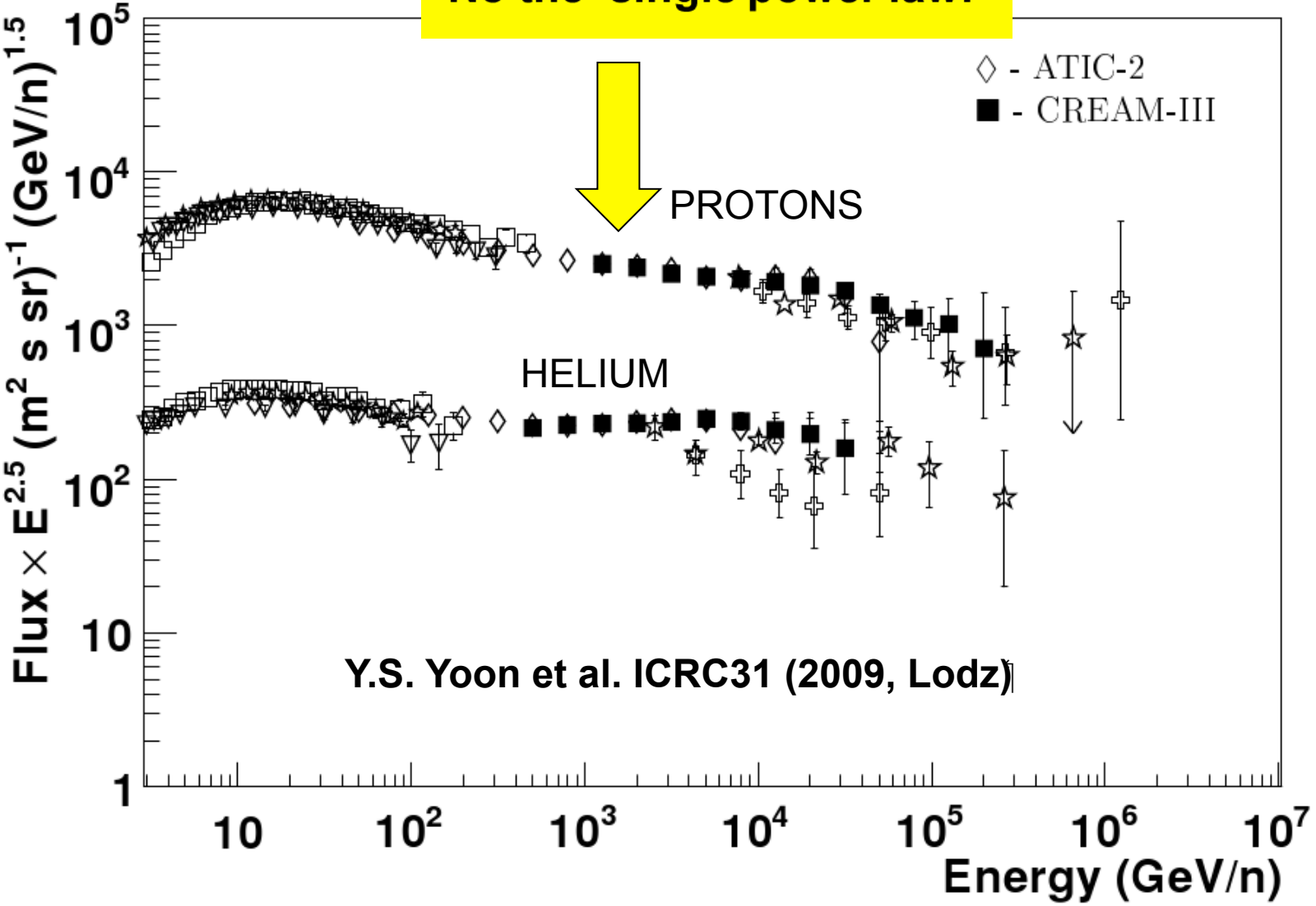




US + Korea

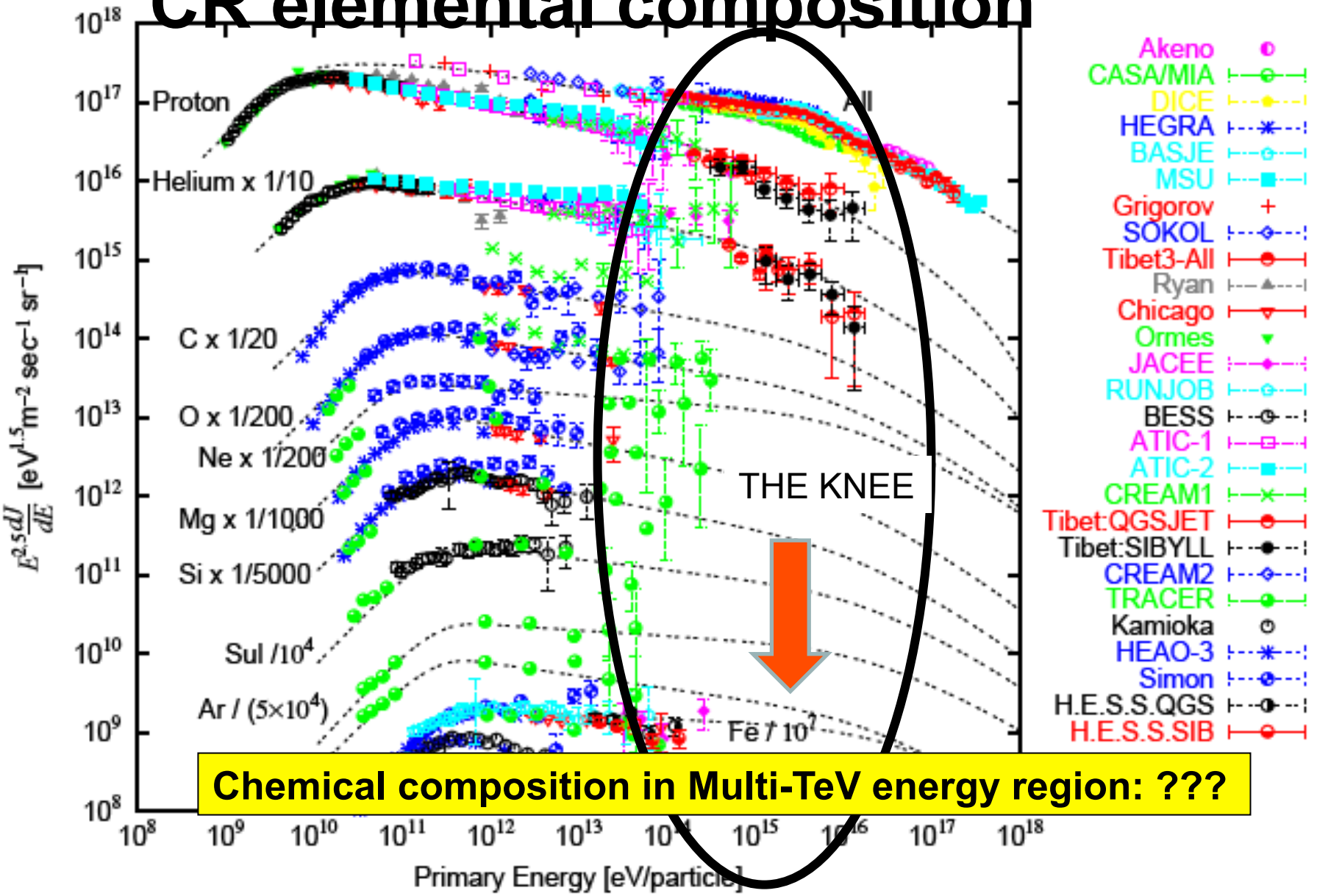
CREAM-III has confirmed ATIC result

No the single power law!

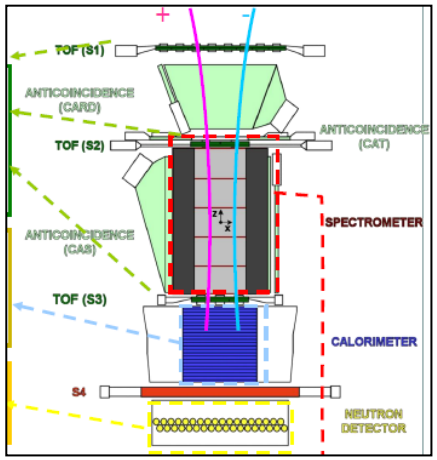


In the middle of 2000' :

CR elemental composition

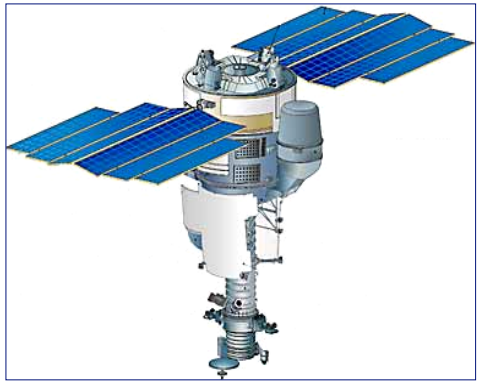


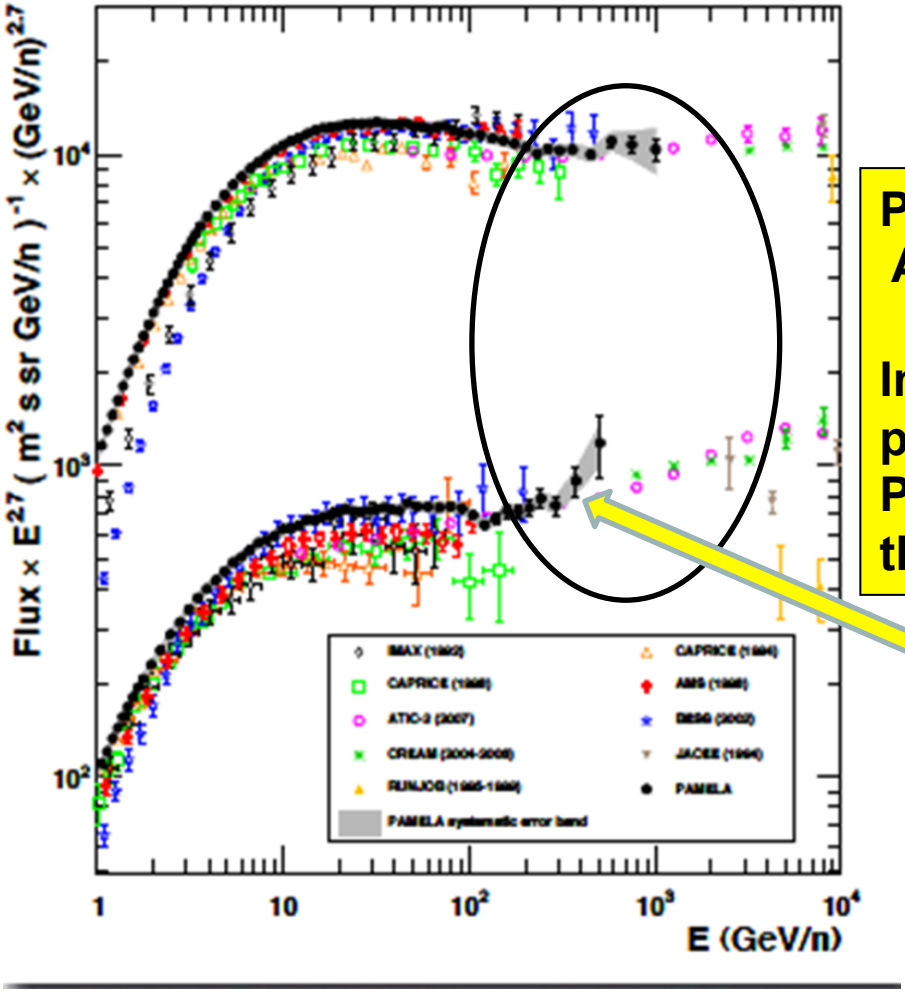
Chemical composition in Multi-TeV energy region: ???



PAMELA

2006 →



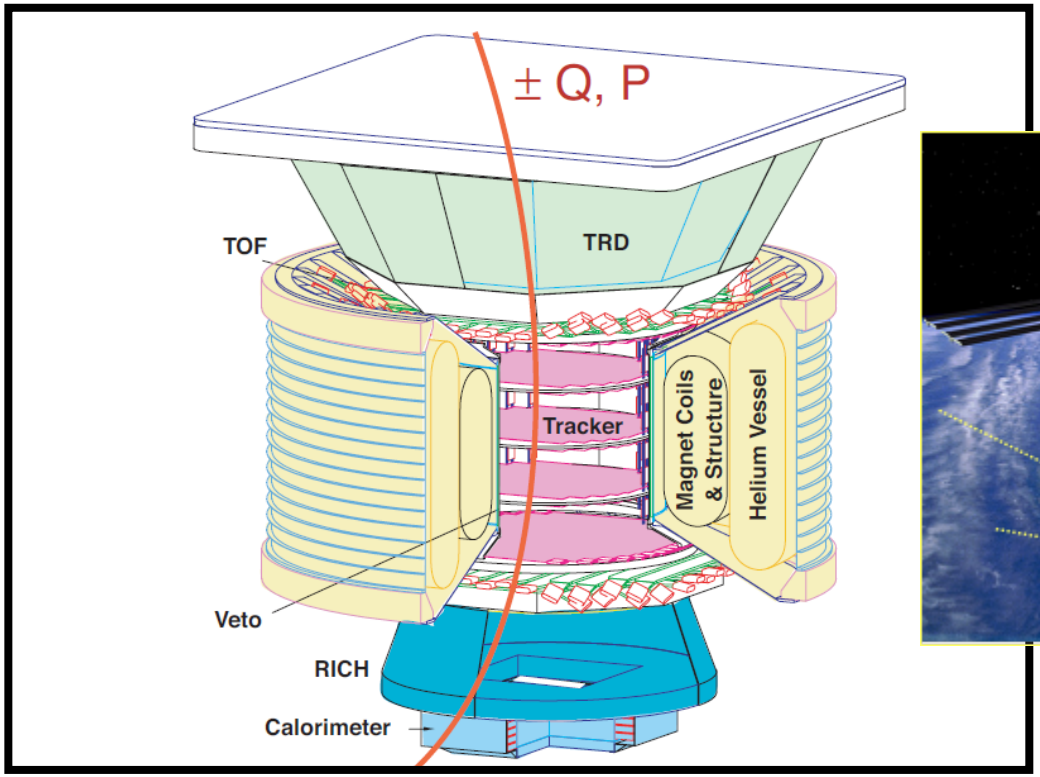


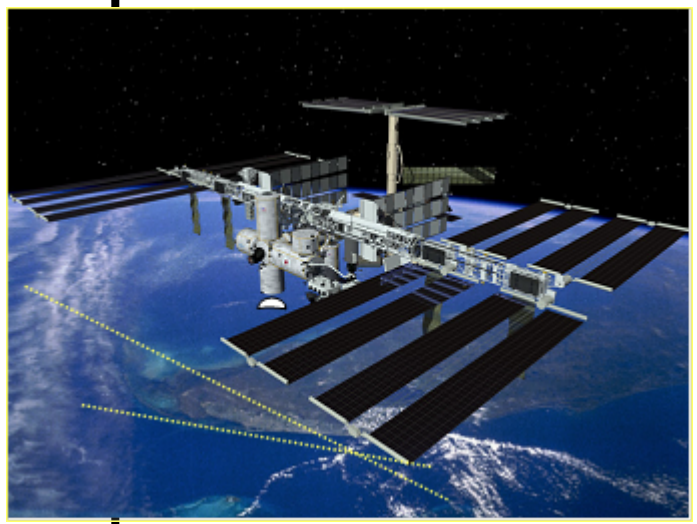
Pamela confirmed ATIC& CREAM data

In comparison to the previous experiments PAMELA found the break position

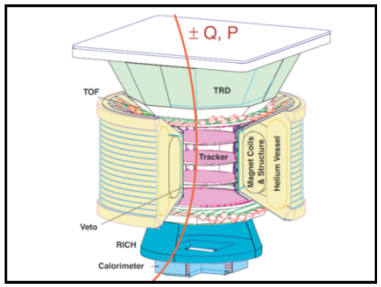
AMS-02

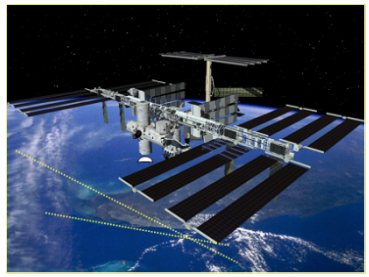
2012 ⟶


± Q, P
TOF
TRD
Tracker
Magnet Coils & Structure
Helium Vessel
Veto
RICH
Calorimeter

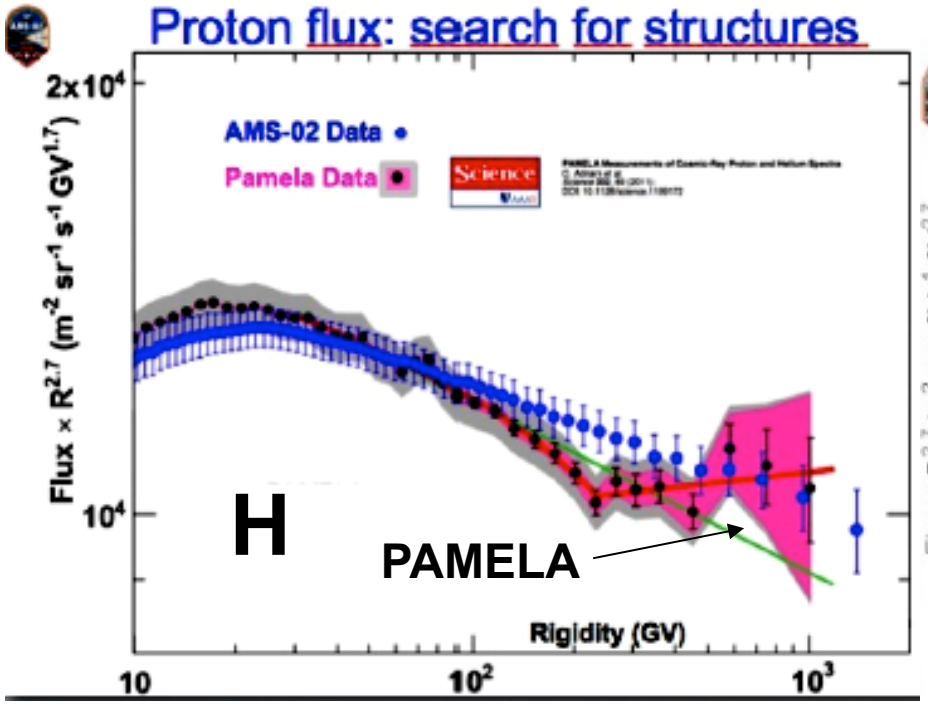


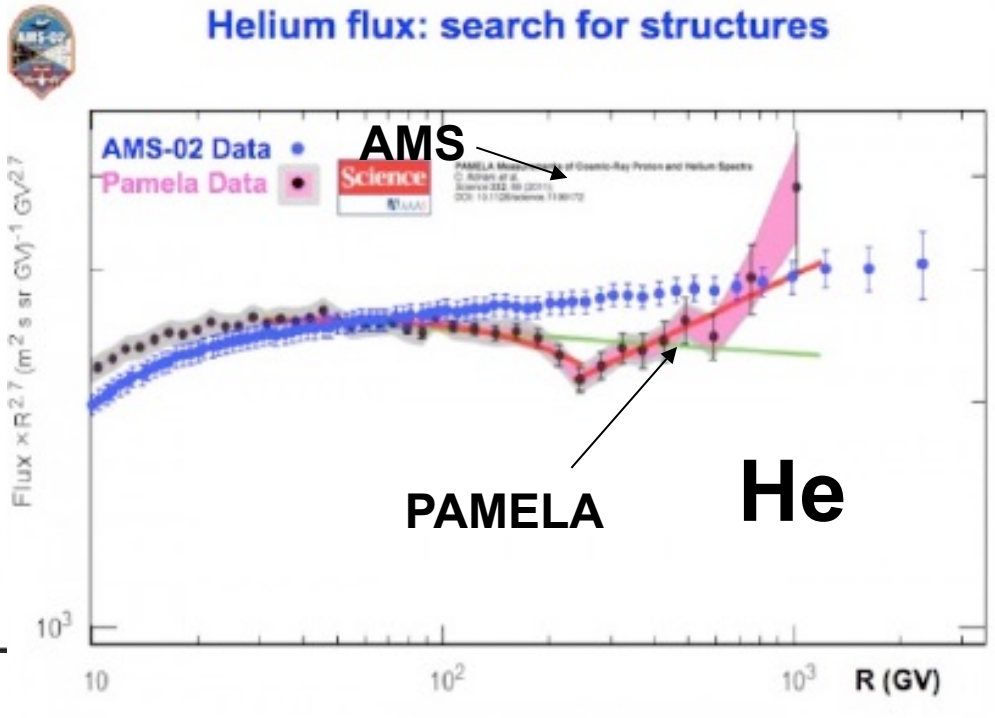
AMS-02 (ICRC2013): no slope's change!





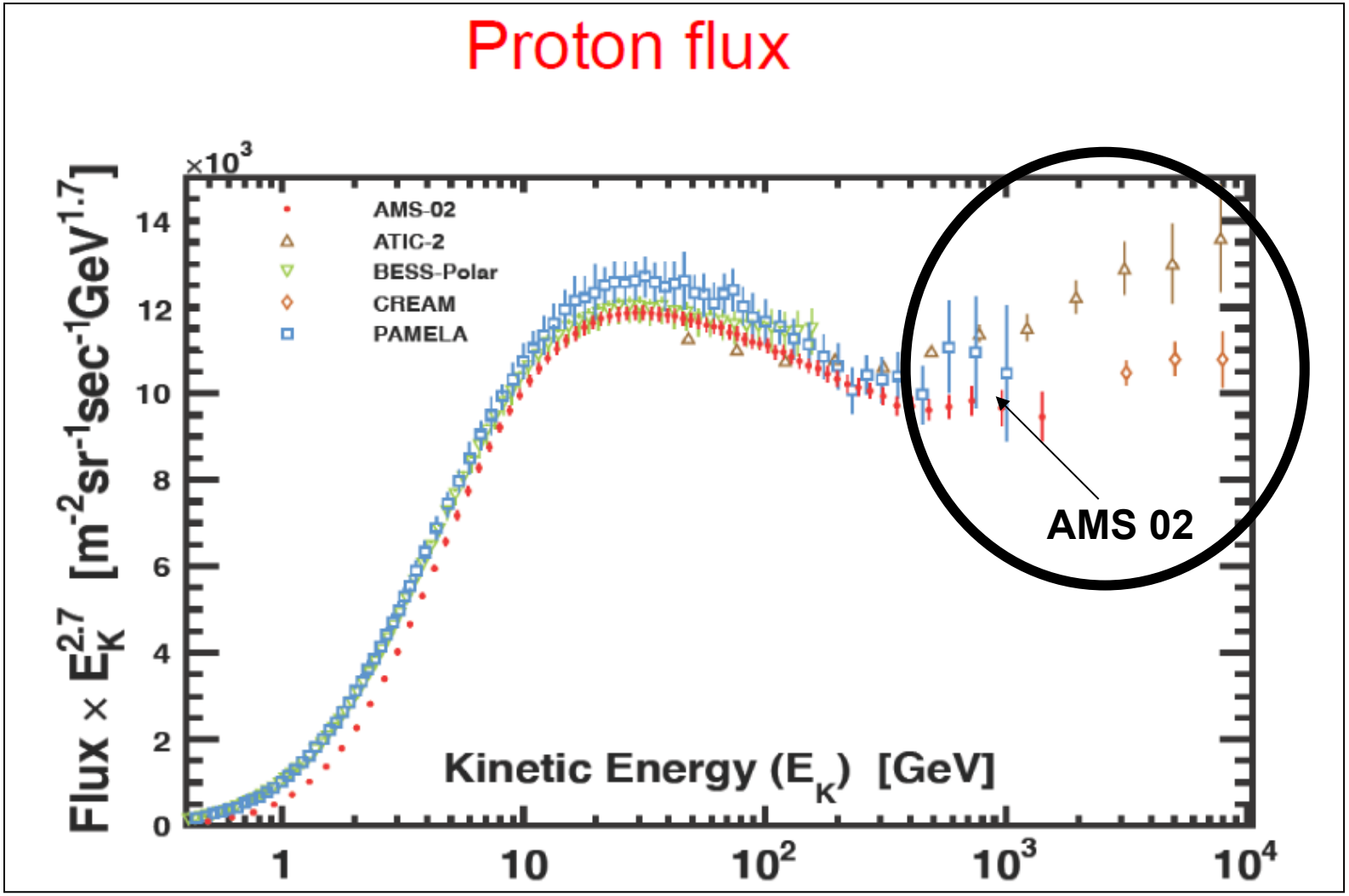
AMS





During 2 years AMS team changed their conclusions

Today:in TeV's energy range spectra is changing

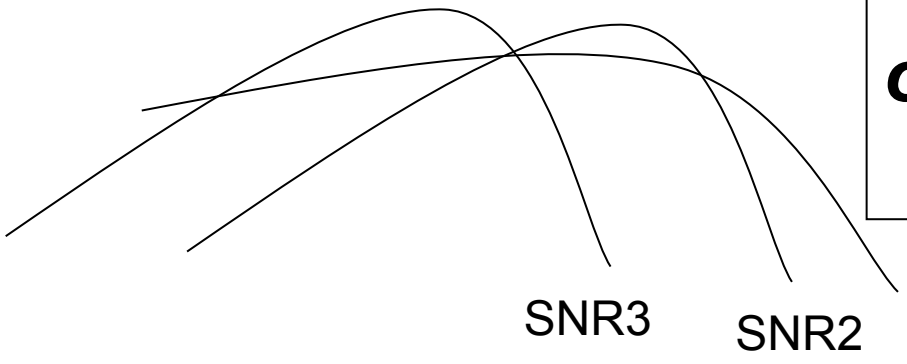


The basic questions around *"no-single - power spectrum"*

1/ Is it specific source acceleration?

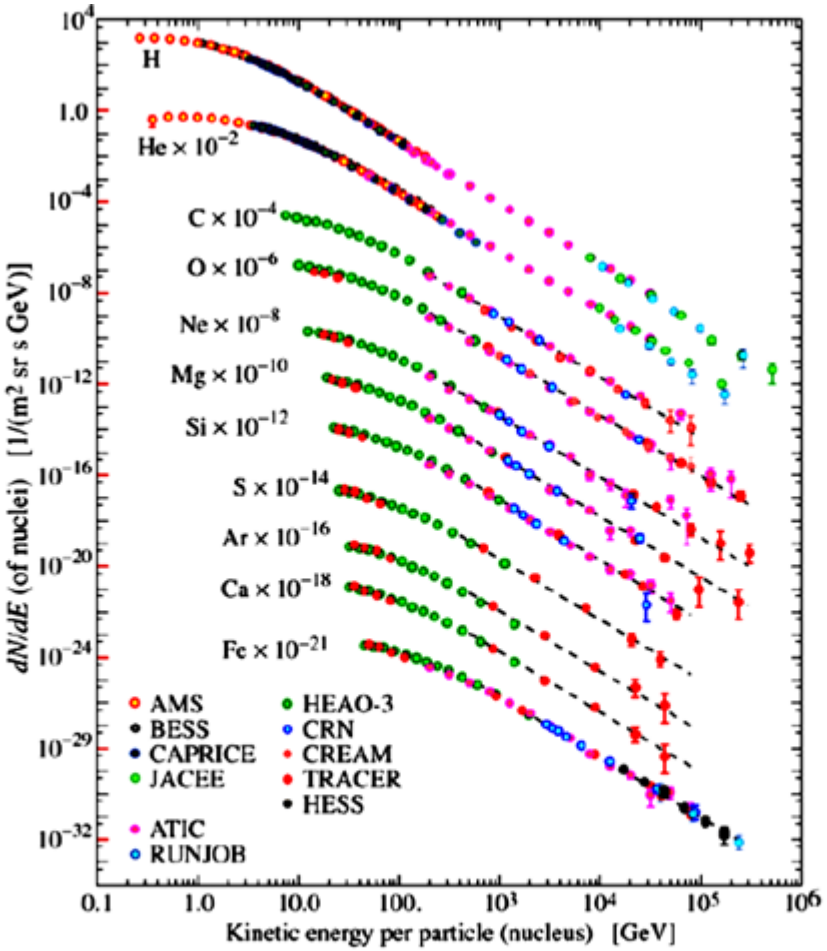
2/ Is it propagation effect?

3/ Is it effect of multiply sources of GCR?



"interference of local (different) sources"

Based on the basic paradigm of CR acceleration we have to follow the conclusion that Diffusive Shock Acceleration produces the power law of CR

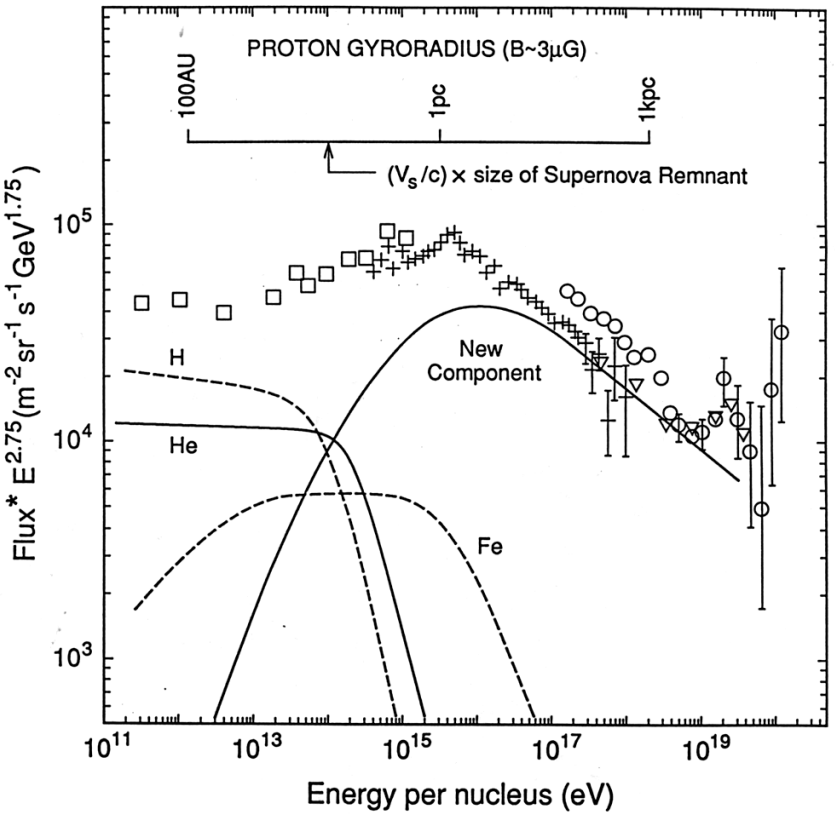


direct measurements

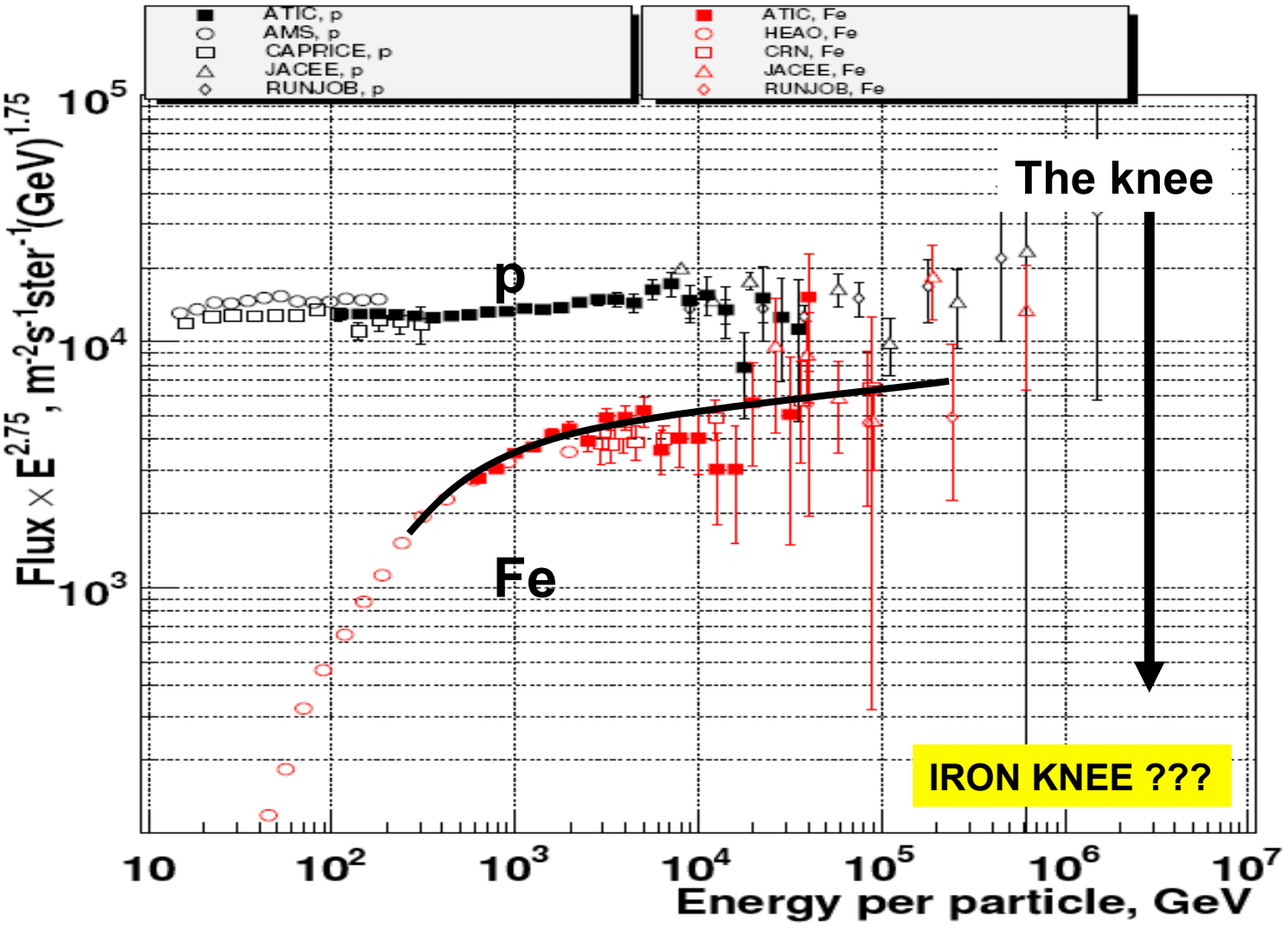
Figure 28.1: Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus using data from Refs. [2–13]. The figure was created by P. Boyle and D. Muller.

HEAVY NUCLEI BEFORE THE KNEE

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

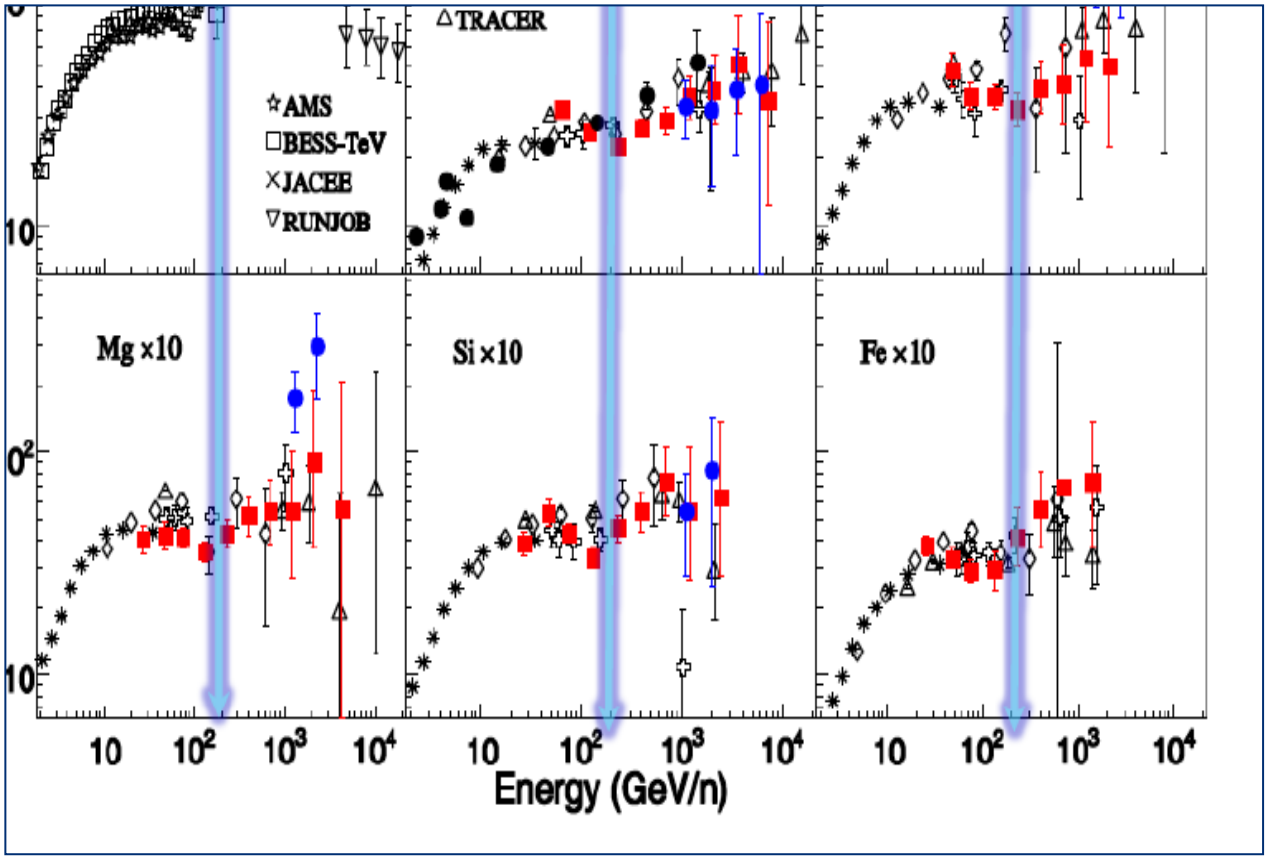


Average mass definition below “the knee” – the real test for current models



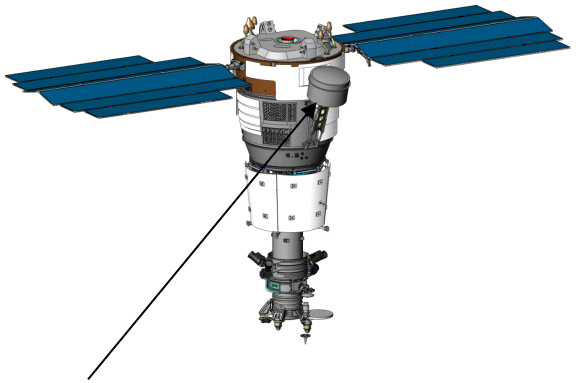
Panasyuk, 1998

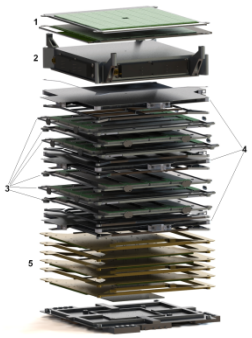
ICRC 2015: Heavier nuclei

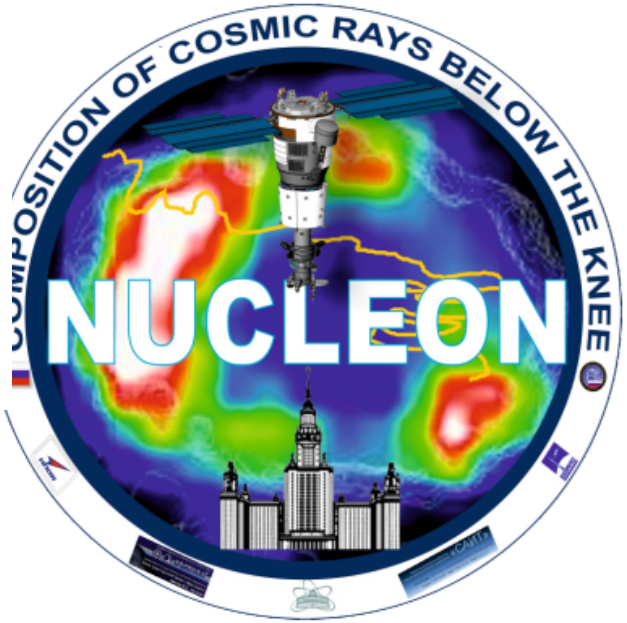


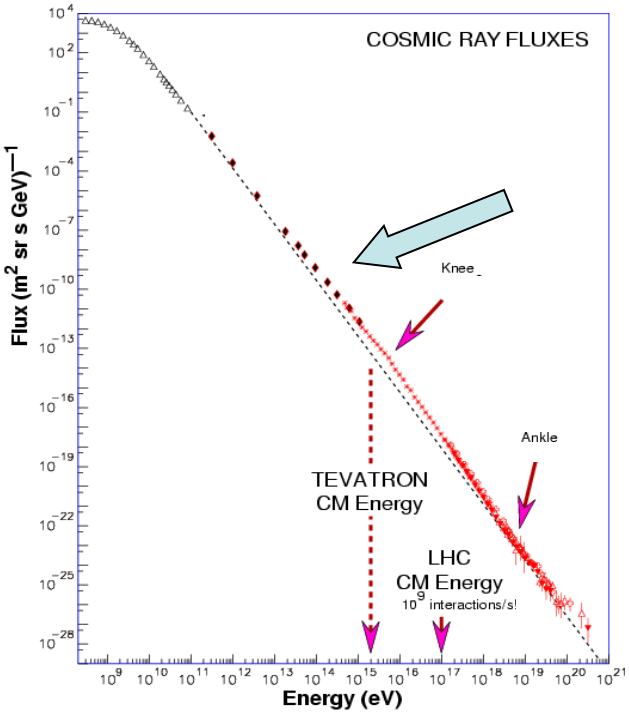
Heavier elements energy dependence: HARDENING!

On Dec., 26, 2014 satellite RESOURSE-P #2 was launched with NUCLEON instrument to study chemical composition of high-energy galactic cosmic rays



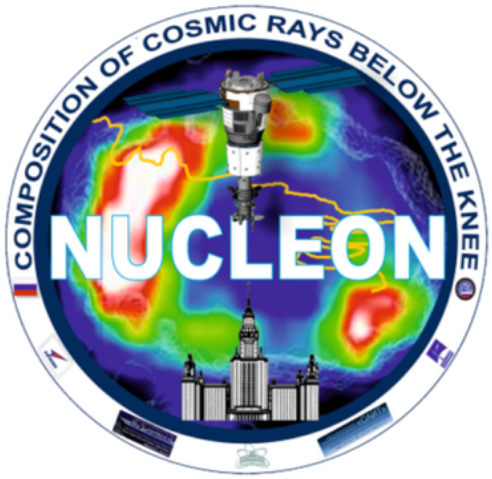




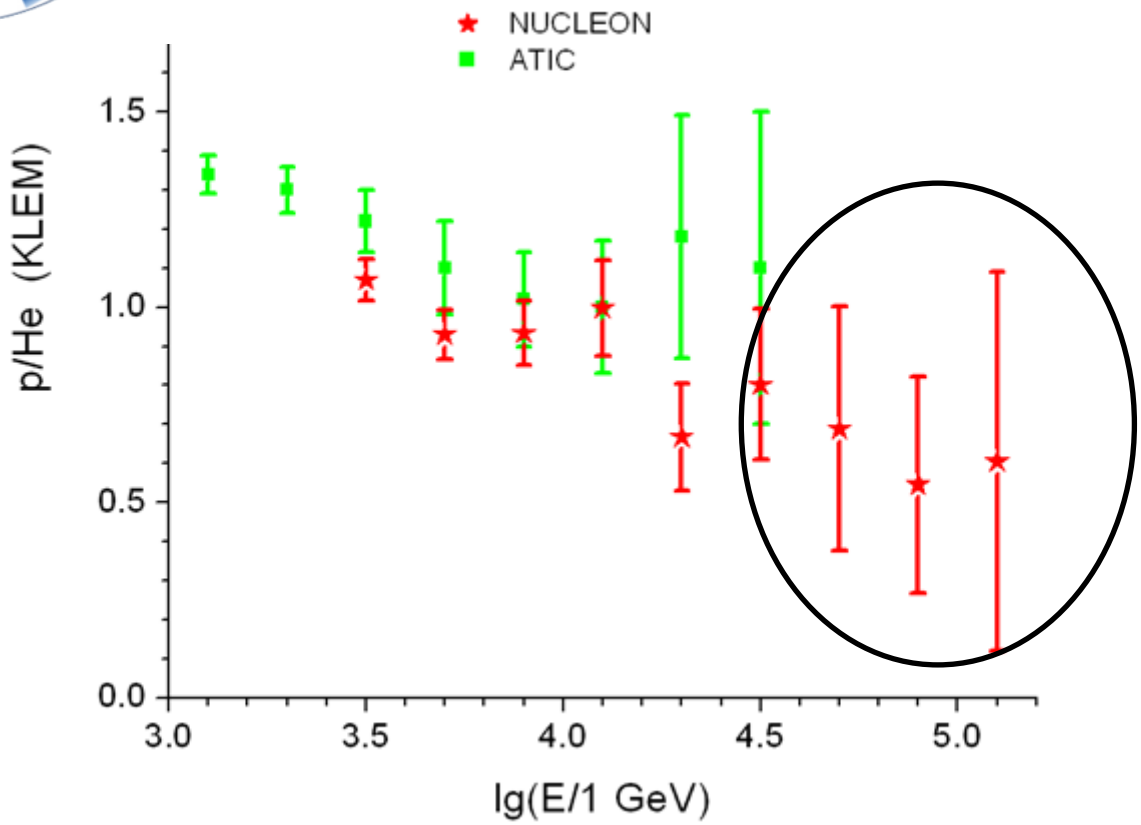


Listen Podorozhnyi talk during this session!

Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University



NUCLEON: THE FIRST RESULTS (2016)



Nucleon: multi-TeV energy range approaching

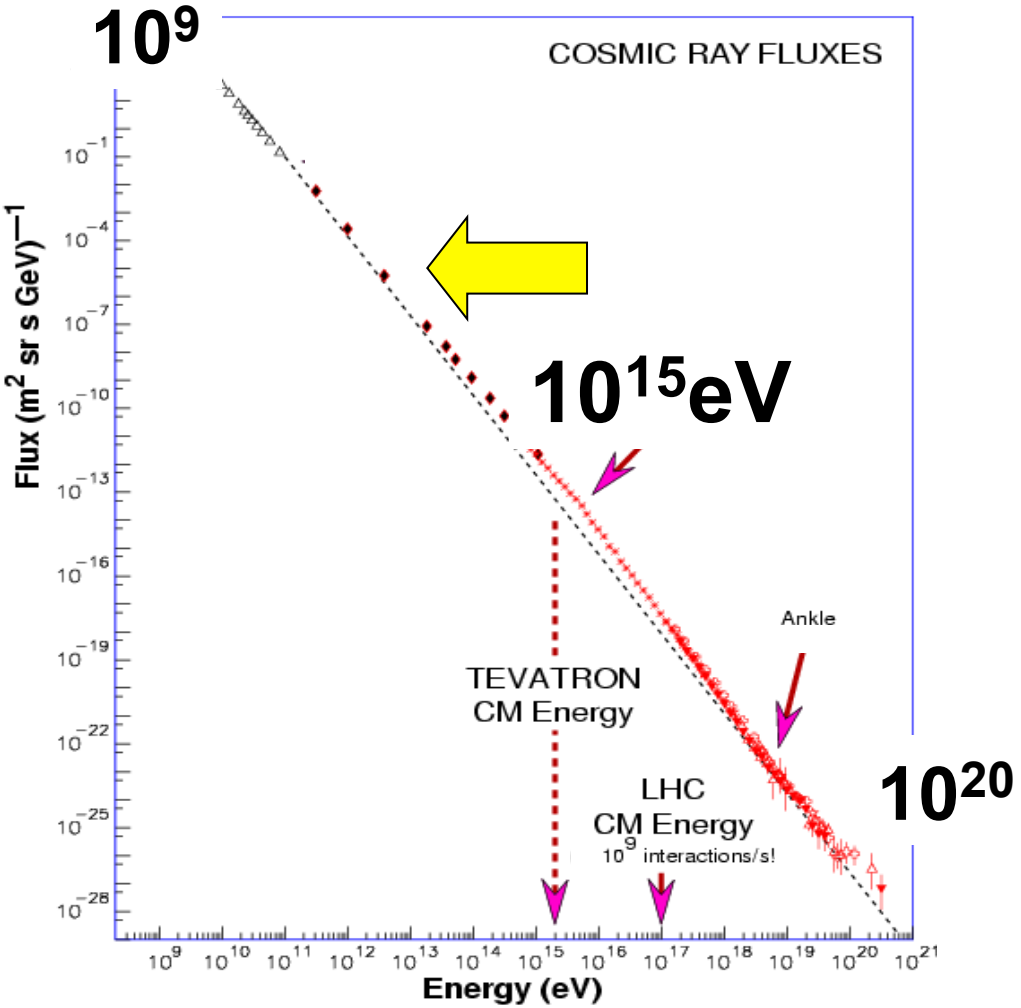
Космические лучи.

Since 2000 –

ATIC
CREAM
PAMELA
AMS 02

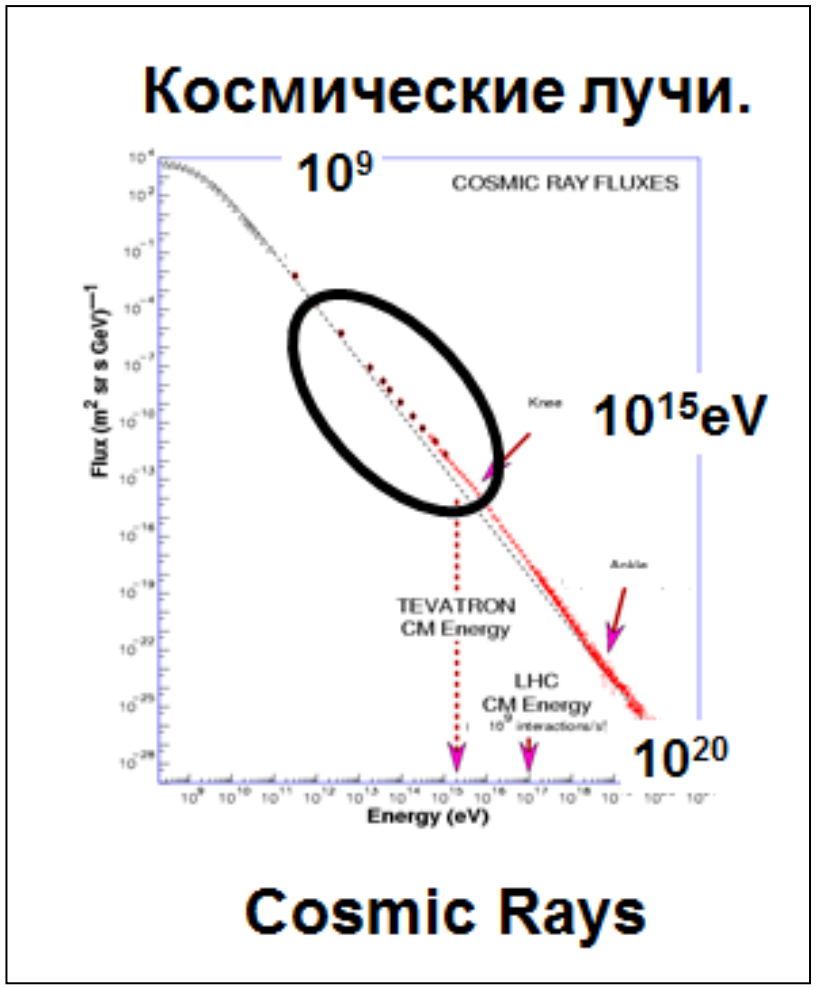
NUCLEON 2014

DAMPE 2015
CALET 2015
ISS CREAM 2017?

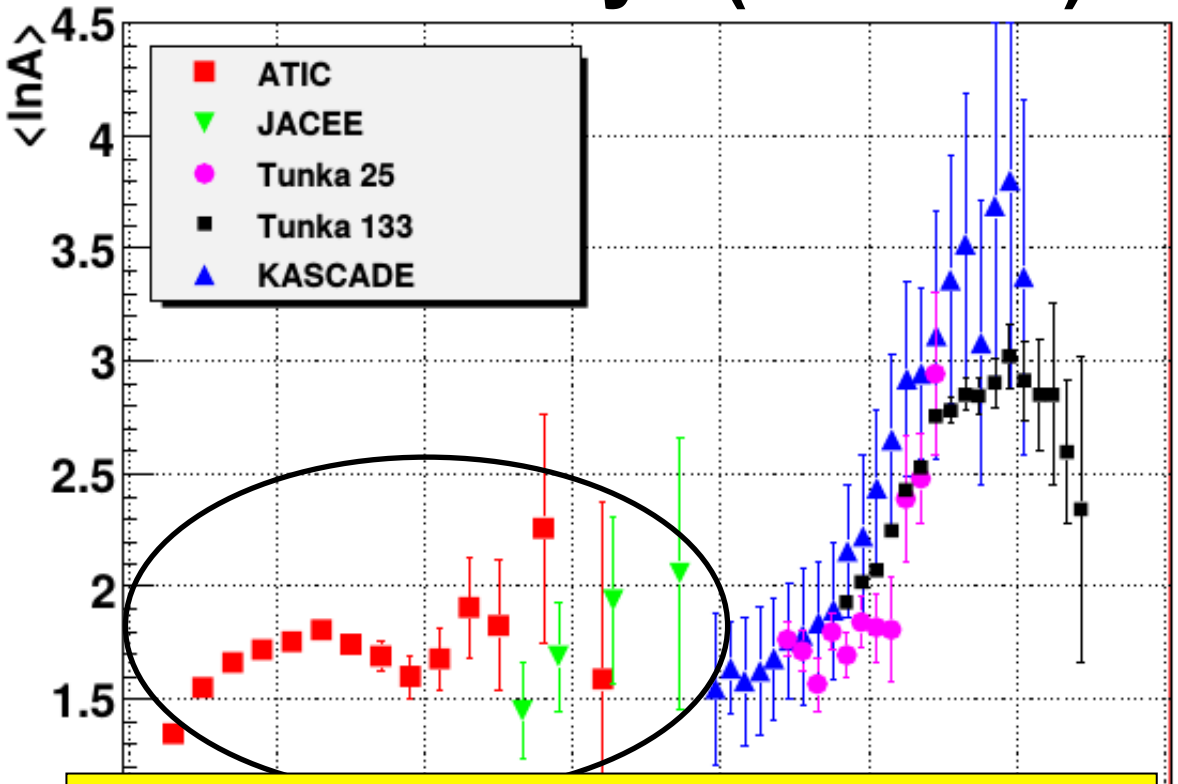


Cosmic Rays

Why is there such an interest in this energy range of GCR (10^{11}- 10^{15} eV), in spite of more than 50 years of research?



The elemental composition of cosmic rays (till 2016)



Протоны

component

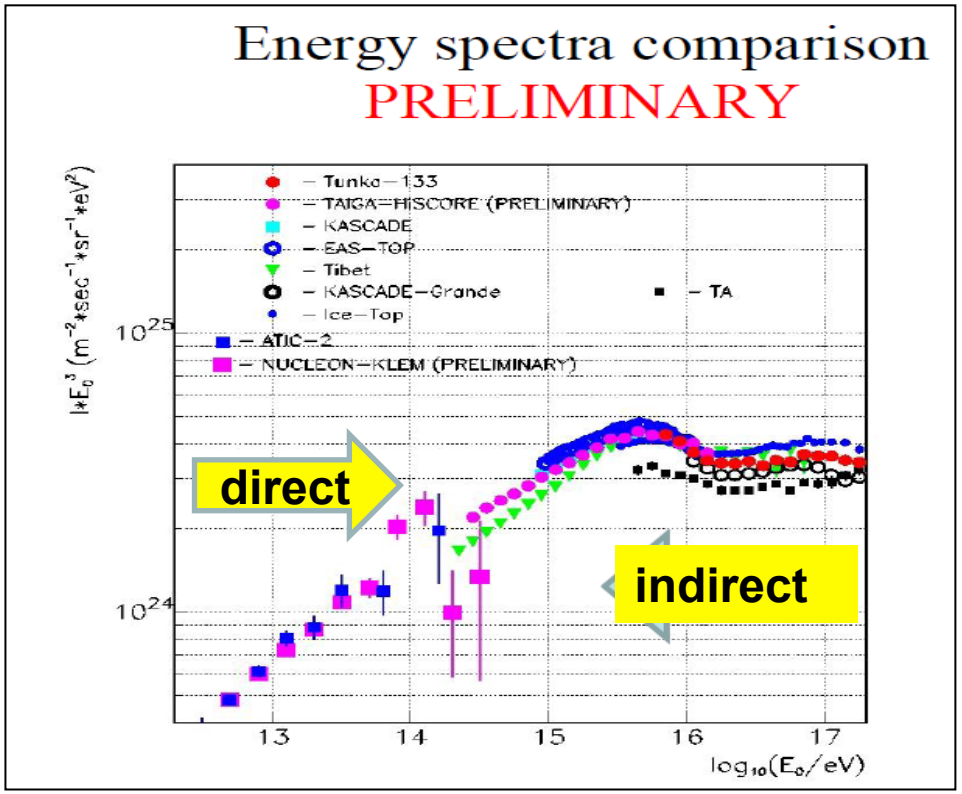
10^9

The answer (1): Abnormal behavior(non –consistent with the main paradigm) **of the elemental composition of cosmic rays**

The answer (2):

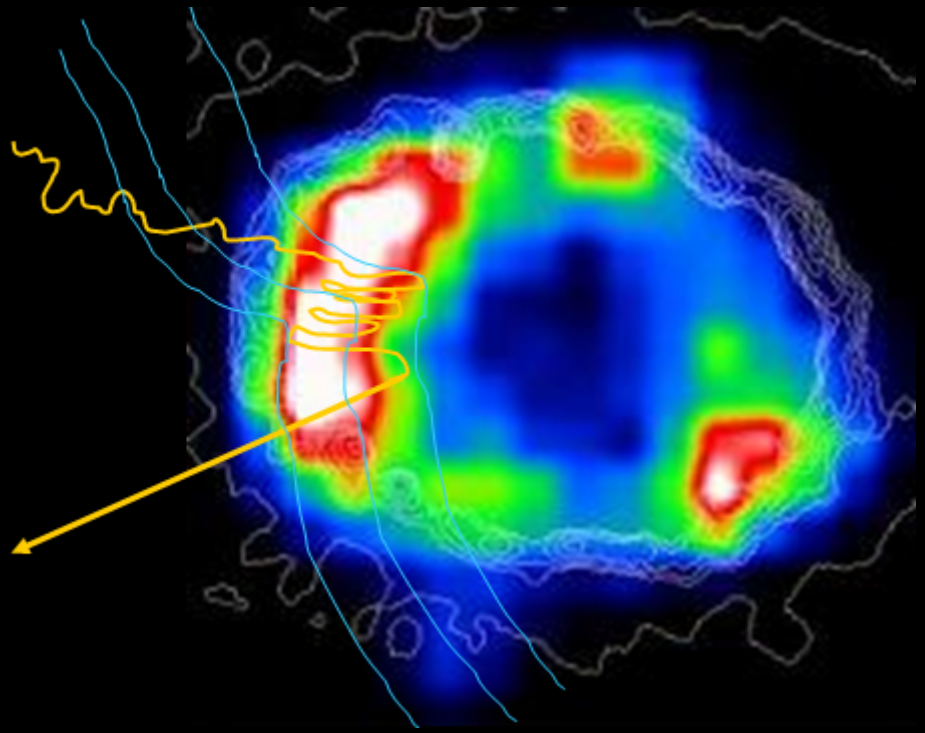
“Application of new nuclear-physical technologies in practice of the space experiment allowed us to receive new *PRECISION experimental information* about the nuclear composition of cosmic rays in terms of quality comparable to ground-based accelerator experiments".

CONCLUSION



Currently, direct measurements tend to higher energies , and indirect - to the lower ones. However statistics, below the knee is still not good enough to draw final conclusions about the elemental composition near the knee.

This means that the mechanism of acceleration of cosmic rays in supernova remnants definitively experimentally proven.



Thank **you**