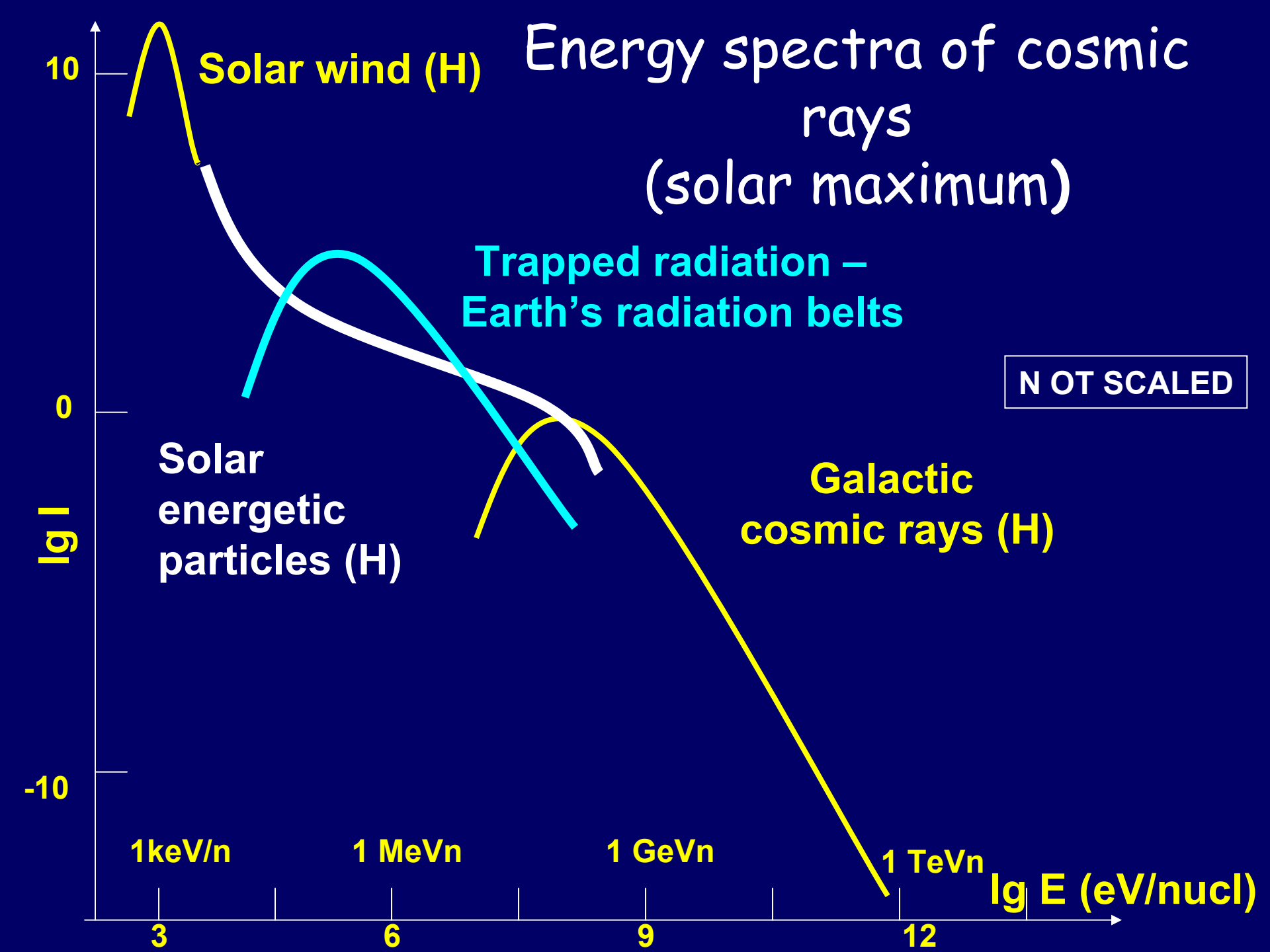
"Energetic particles acceleration in planet magnetospheres and in the Galaxy: unsolved problems"

Mikhail Panasyuk

Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University

September, 28, 2012

Energy spectra of cosmic rays (solar maximum)

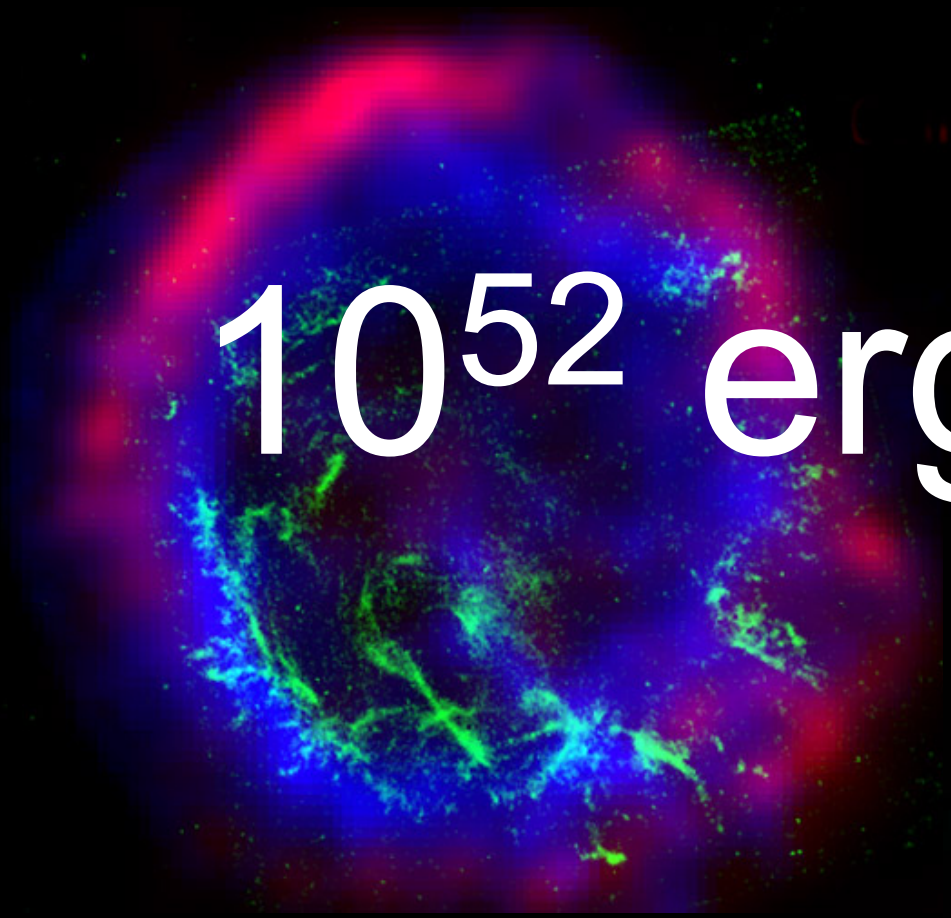


CR astrophysics main problems

Sources ?

-Accelerators?

Supernovae



10^{52} erg

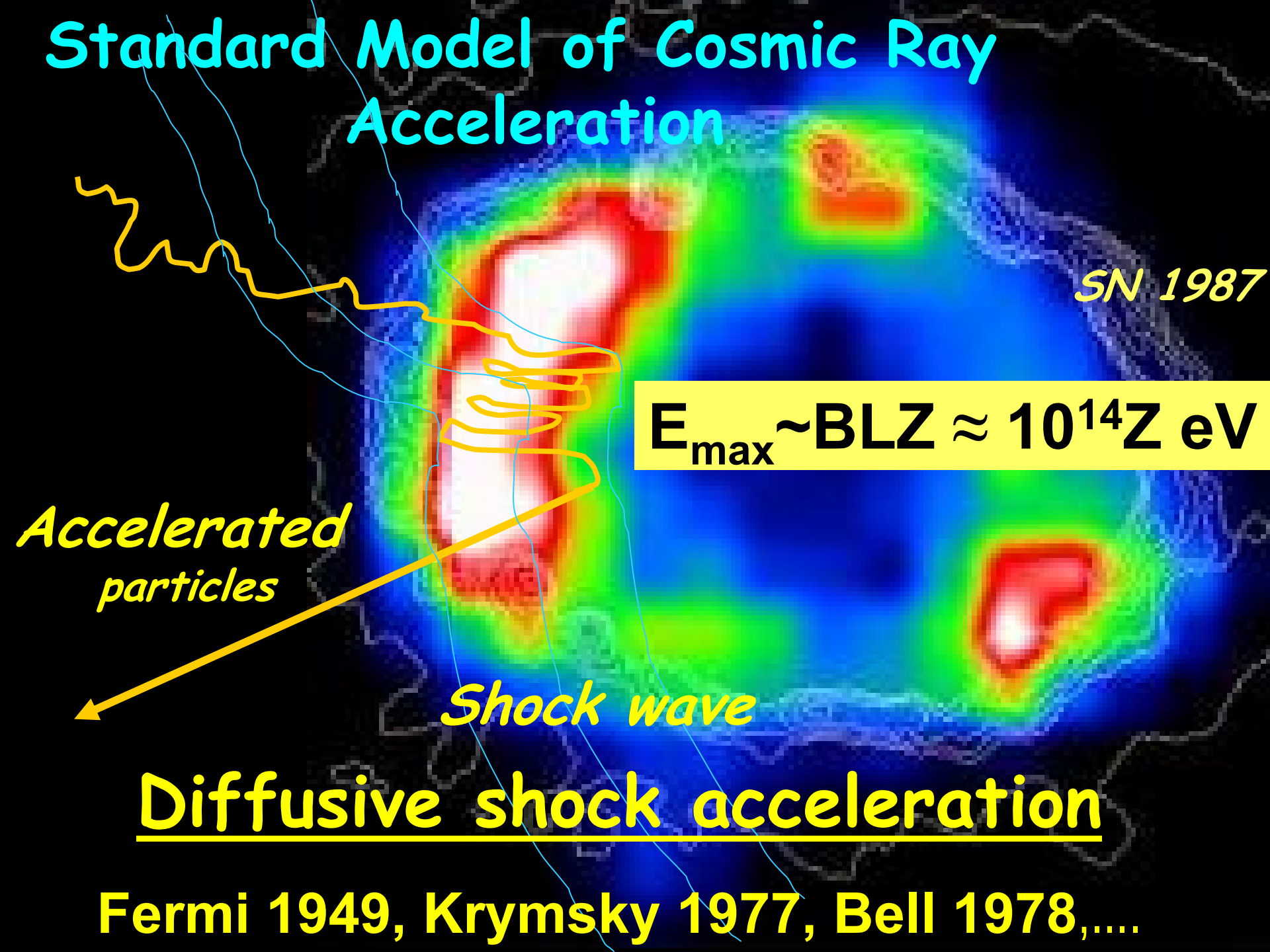
Energy balance

Ginzburg & Syrovatskii 1964

~ 15% **of SN kinetic energy should go to cosmic rays to maintain observed w_{cr}**

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

Standard Model of Cosmic Ray Acceleration



Diffusive shock acceleration

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

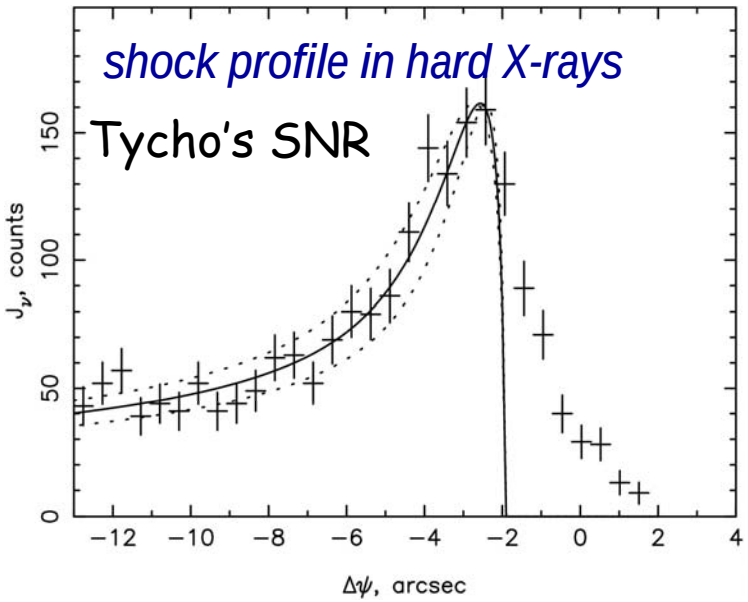
Сильные магнитные поля в остатках молодых сверхновых

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

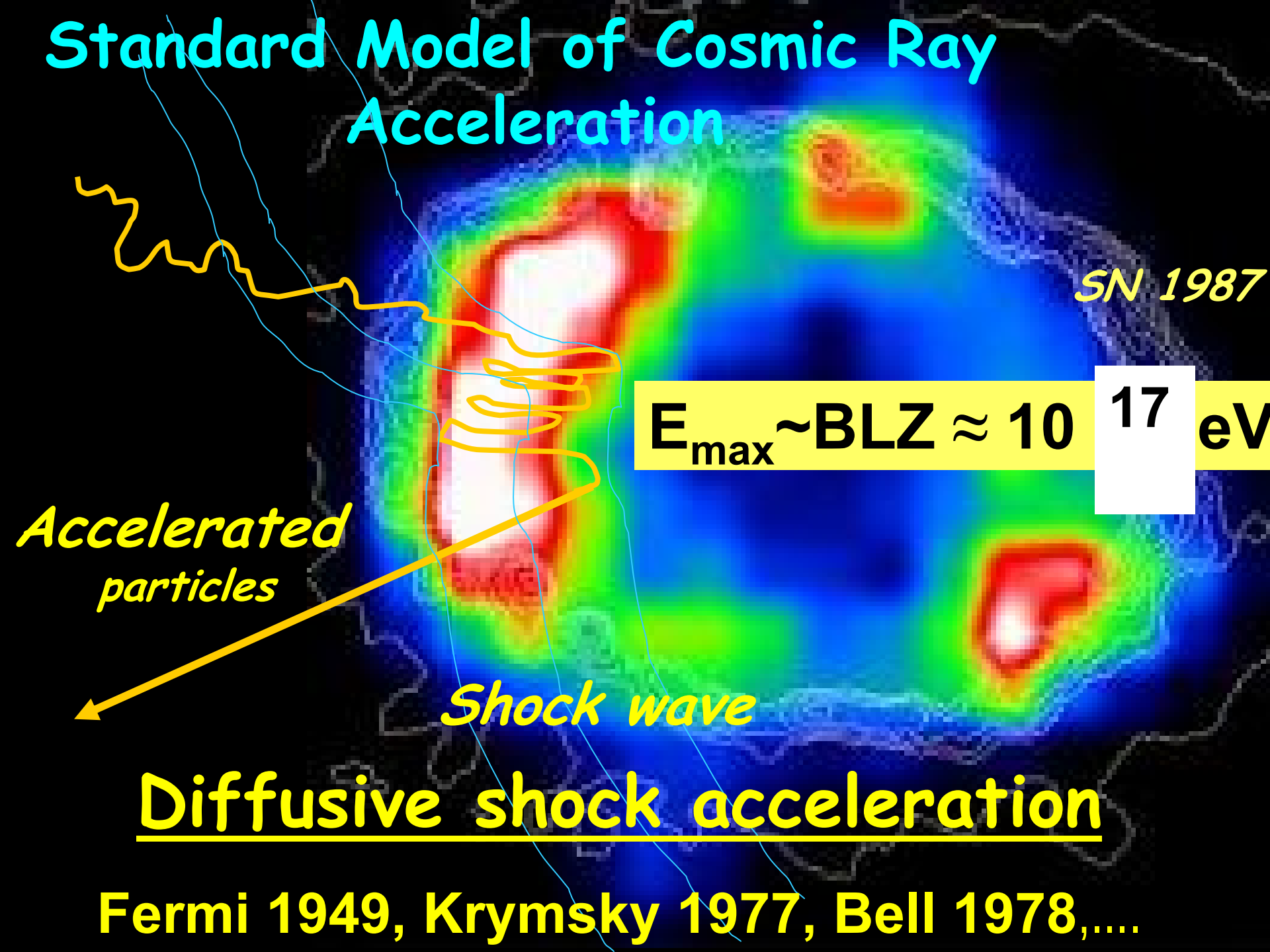
Similar amplification in all other SNRs where such data are available:
Cas A, **SN 1006**, Tycho, RCW 86, **Kepler**, RX J1713.7-3946, **Vela** Jr



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**

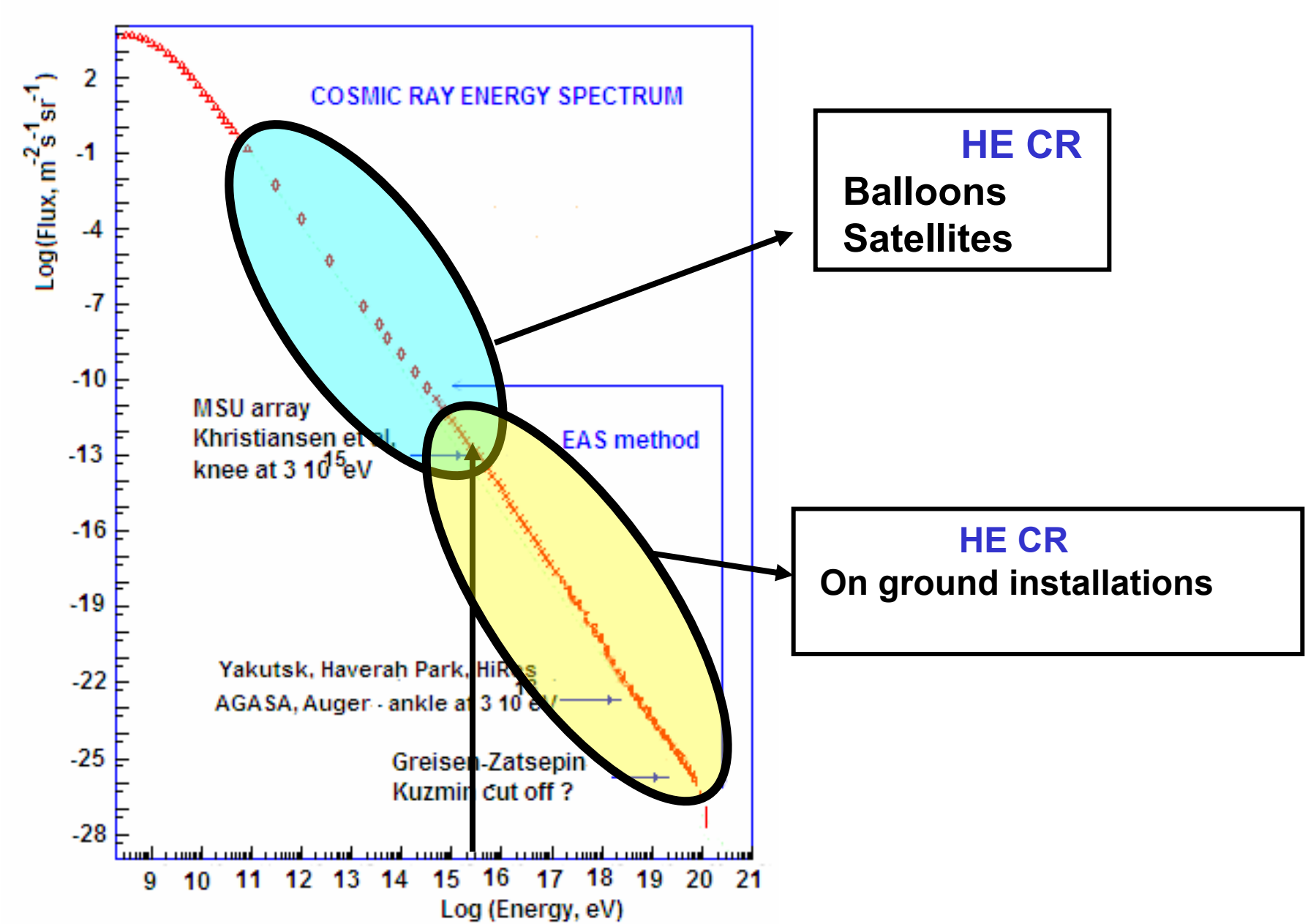
Standard Model of Cosmic Ray Acceleration

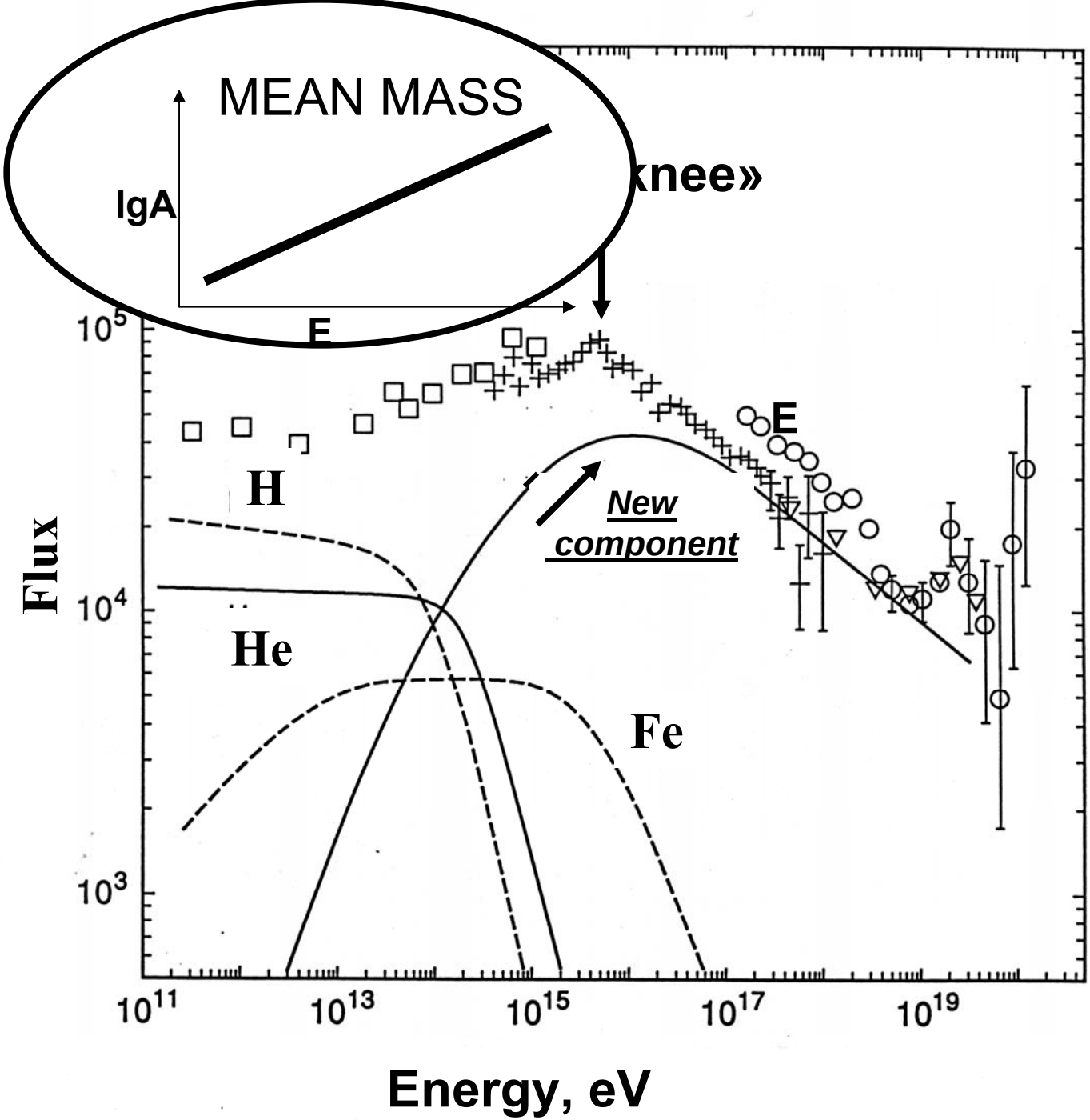


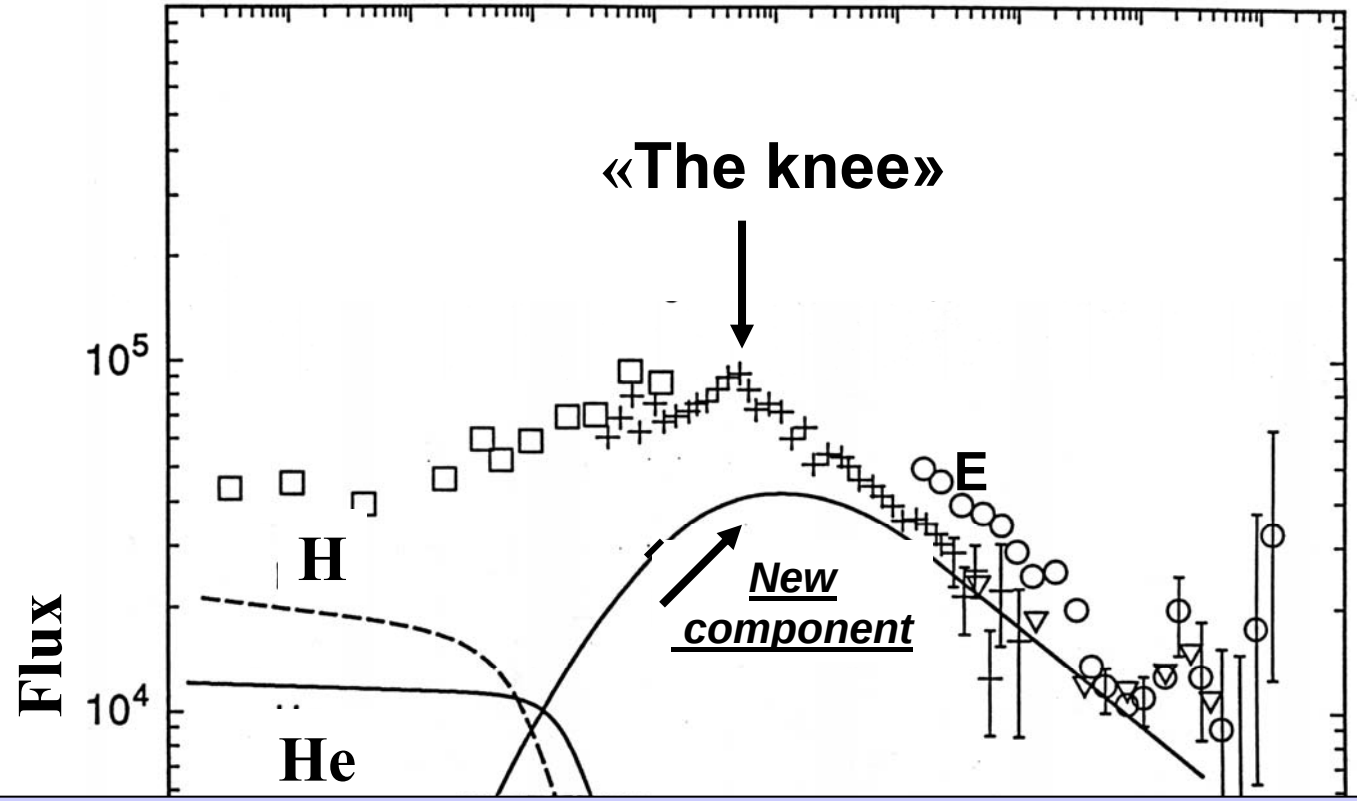
Diffusive shock acceleration

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

CR nuclei spectra




MEAN MASS
lgA
E
knee»
E
H
He
Fe
New
component
Flux
Energy, eV
10^5
10^4
10^3
10^{11}
10^{13}
10^{15}
10^{17}
10^{19}



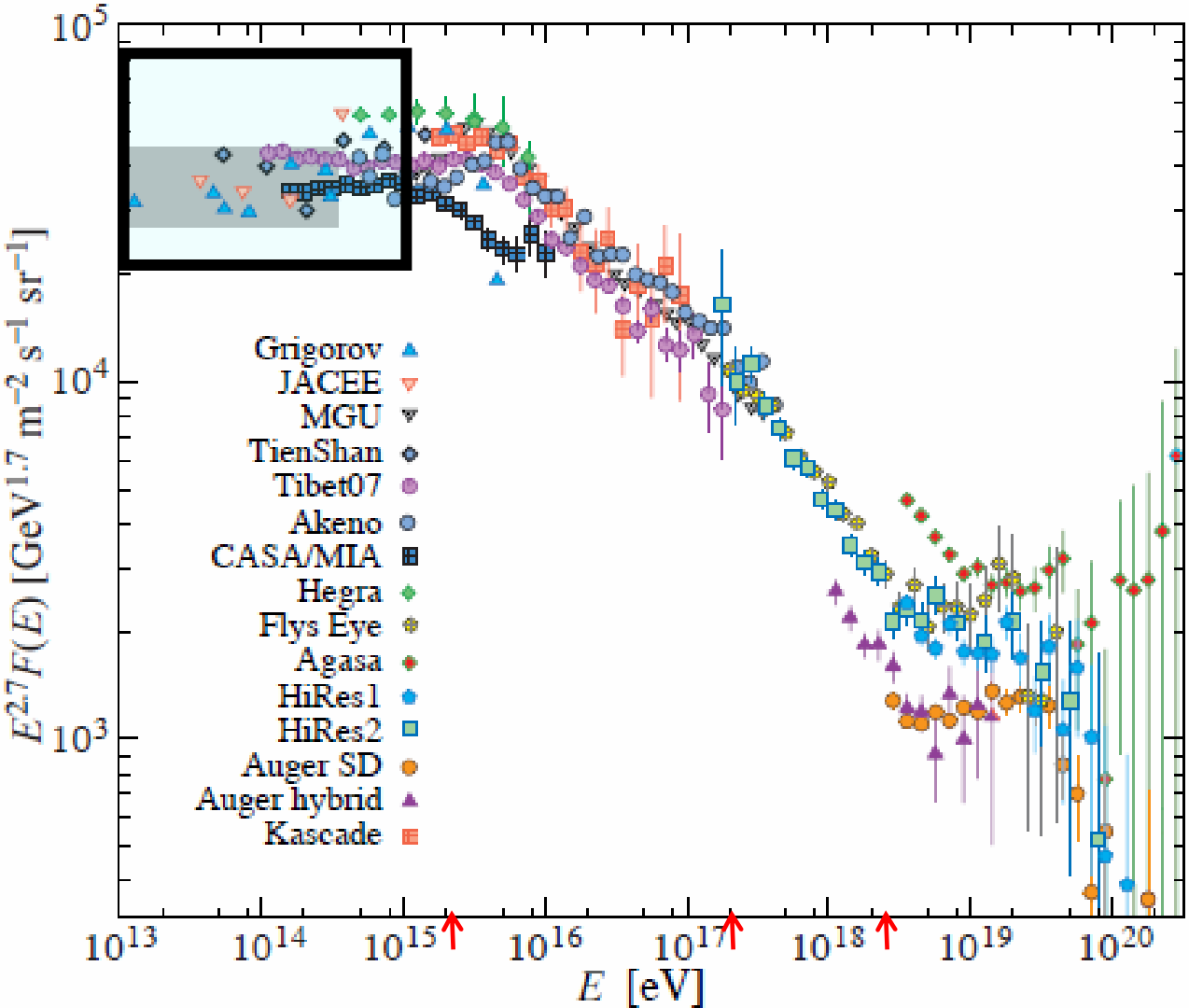
Chemical composition around 10*15 eV

have to be changed because of consequences

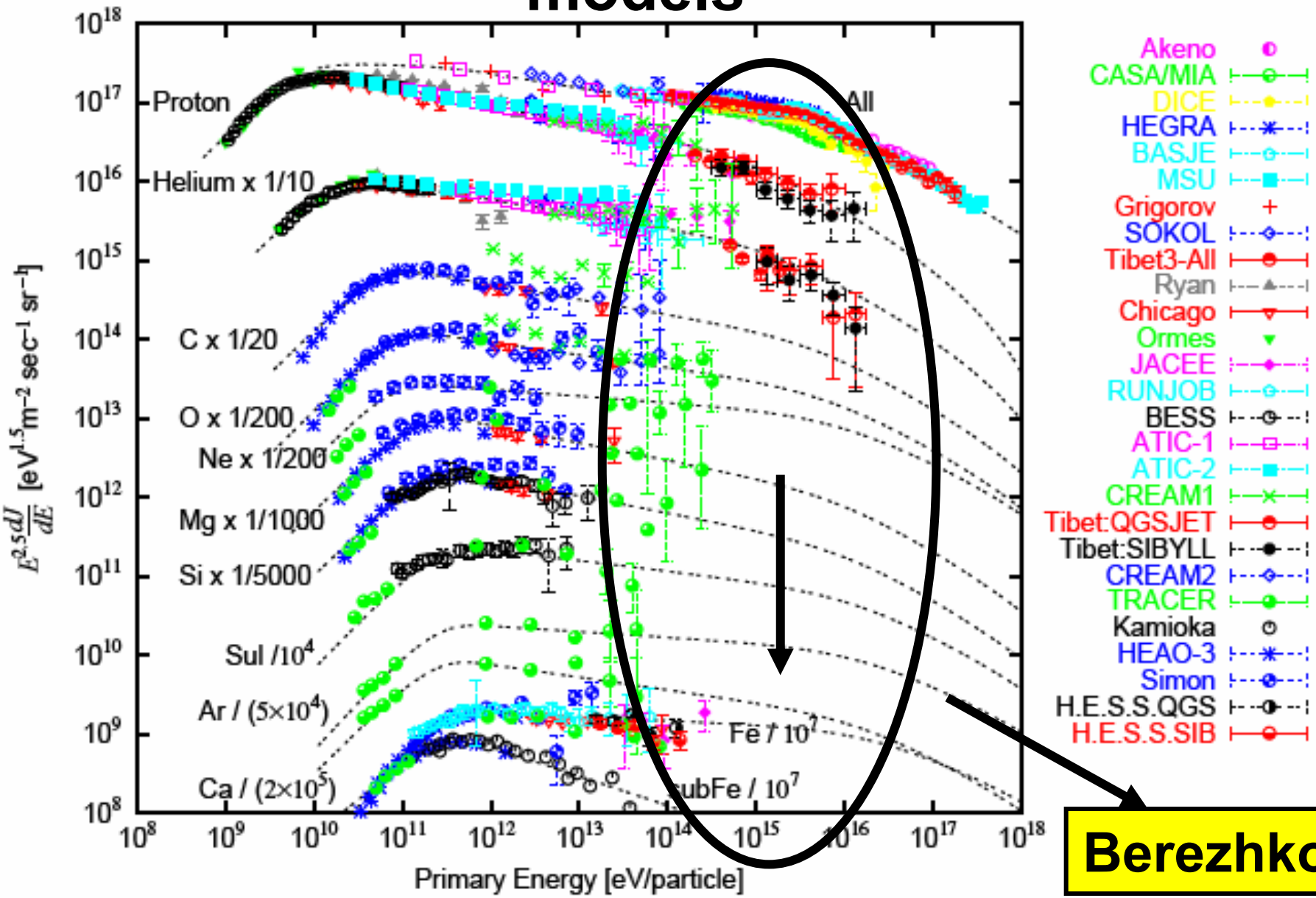
acceleration model :

E~Z

Energy spectrum of CR

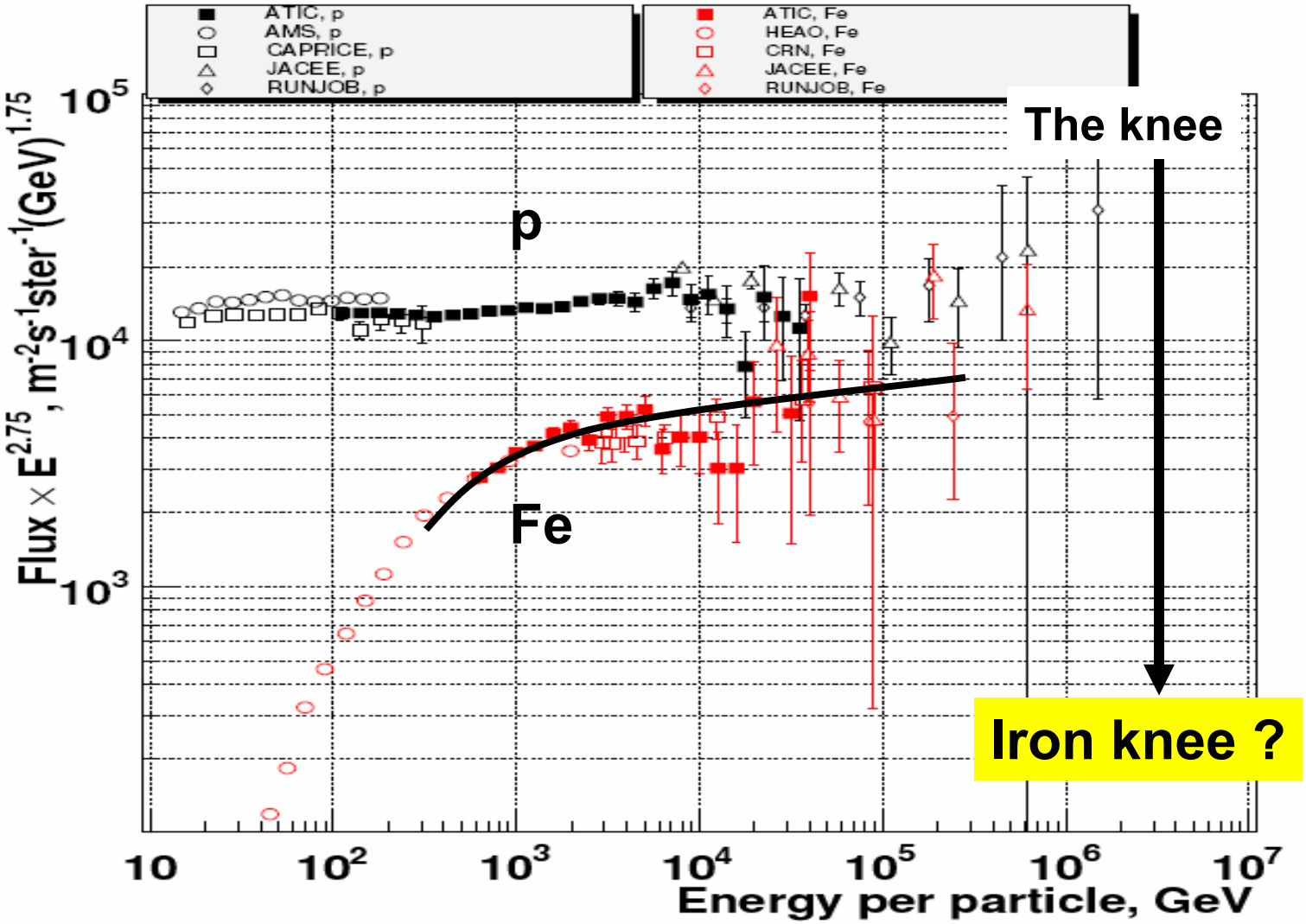


CR chemical composition & SN acceleration models



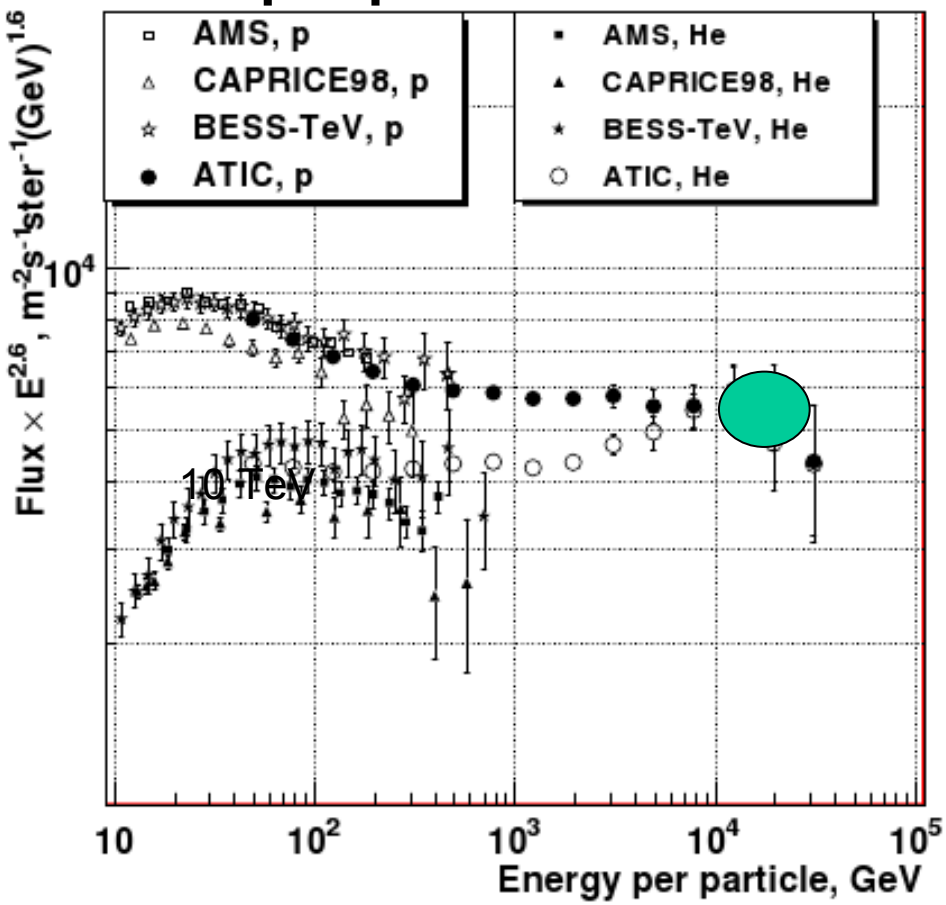
Berezhko

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



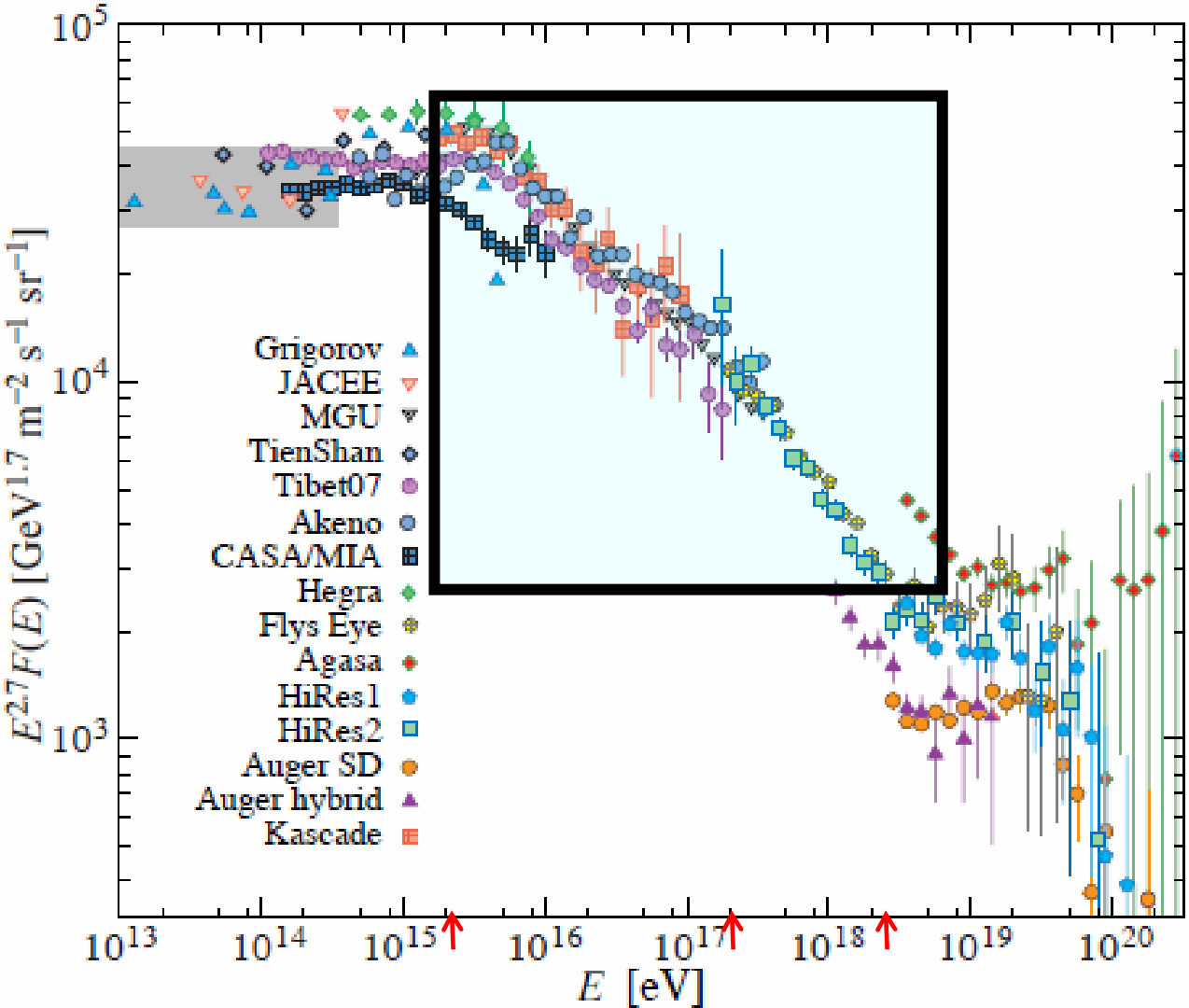
Proton and helium spectra and the multiplicity of types of cosmic ray sources

Spectra for energy per particle

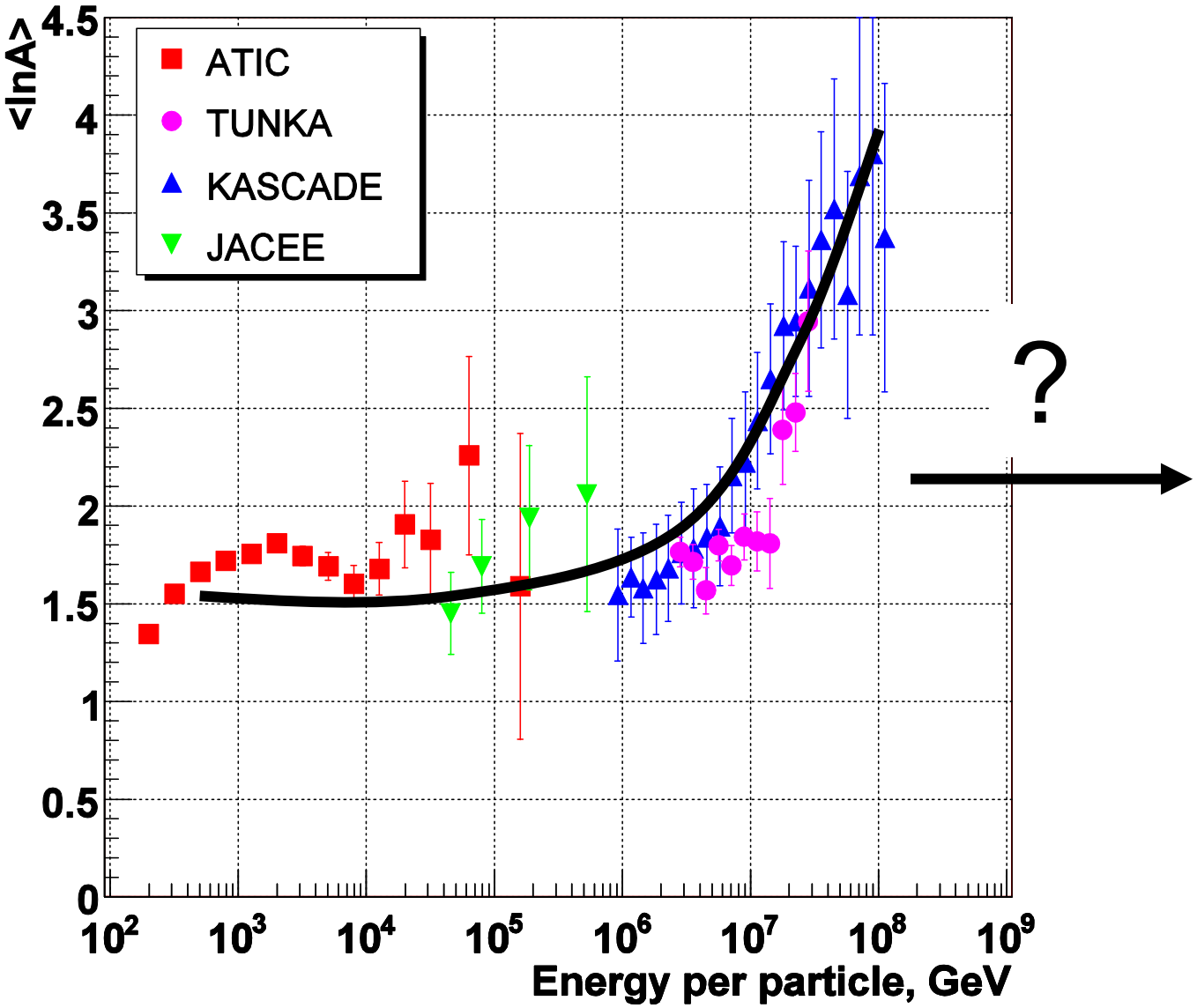


Beyond the 10*15 eV

Energy spectrum of CR

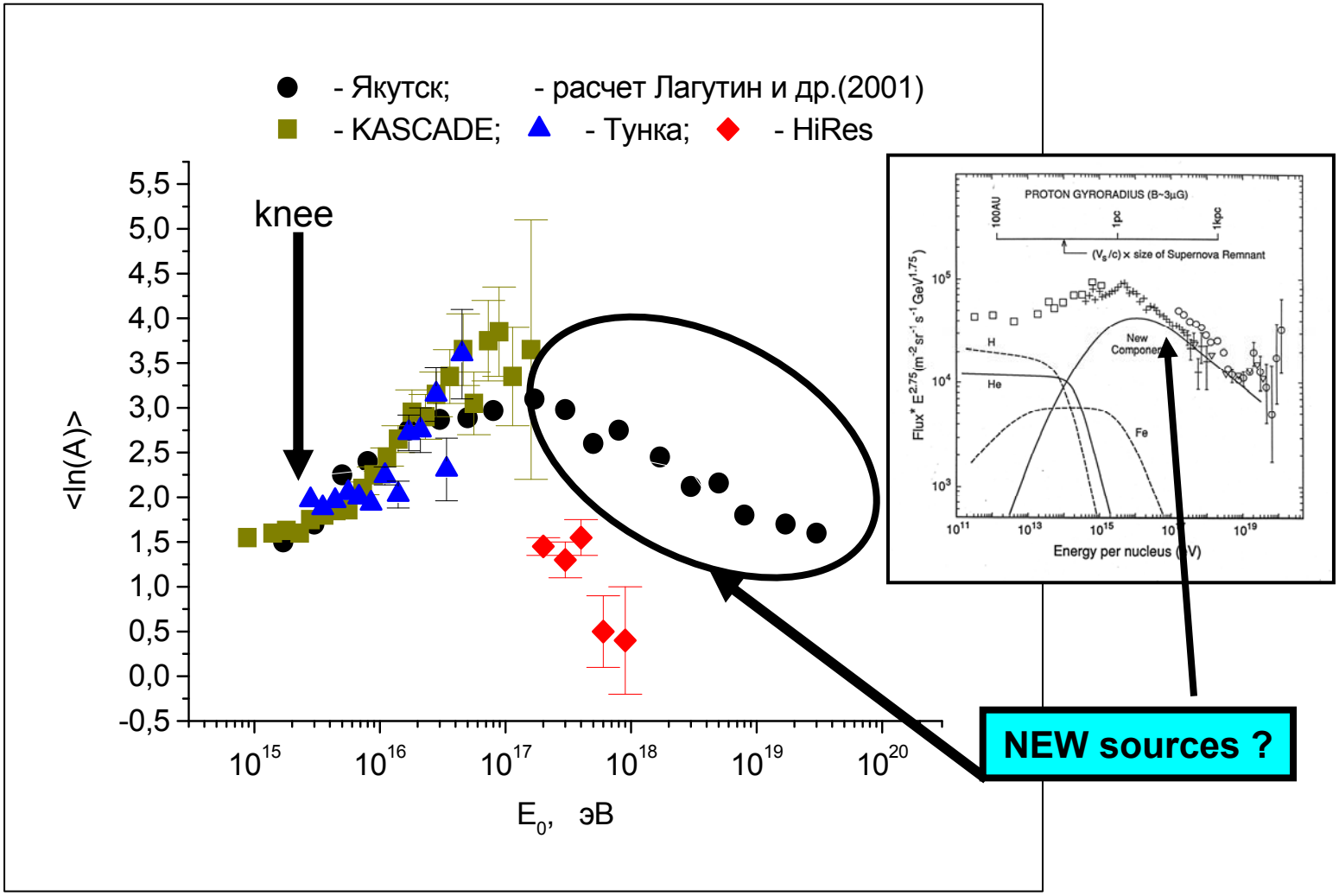


Mean mass composition dependence show enrichment by heavy ions



Beyond the 10*17 eV

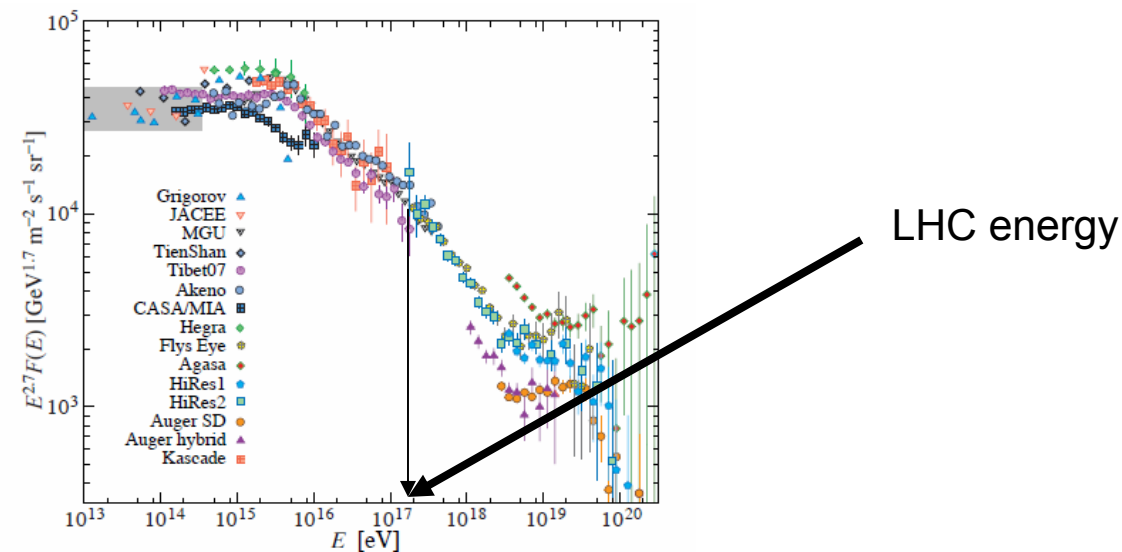
Chemical composition become more lighter beyond 10^17 eV?



So,

- Up to 10*17 eV– the transition region from light elements to heavier ones

- Beyond 10*17 eV - the transition from heavier elements to light ones, or from **galactic sources to extragalactic ones…**



Instead of conclusions -

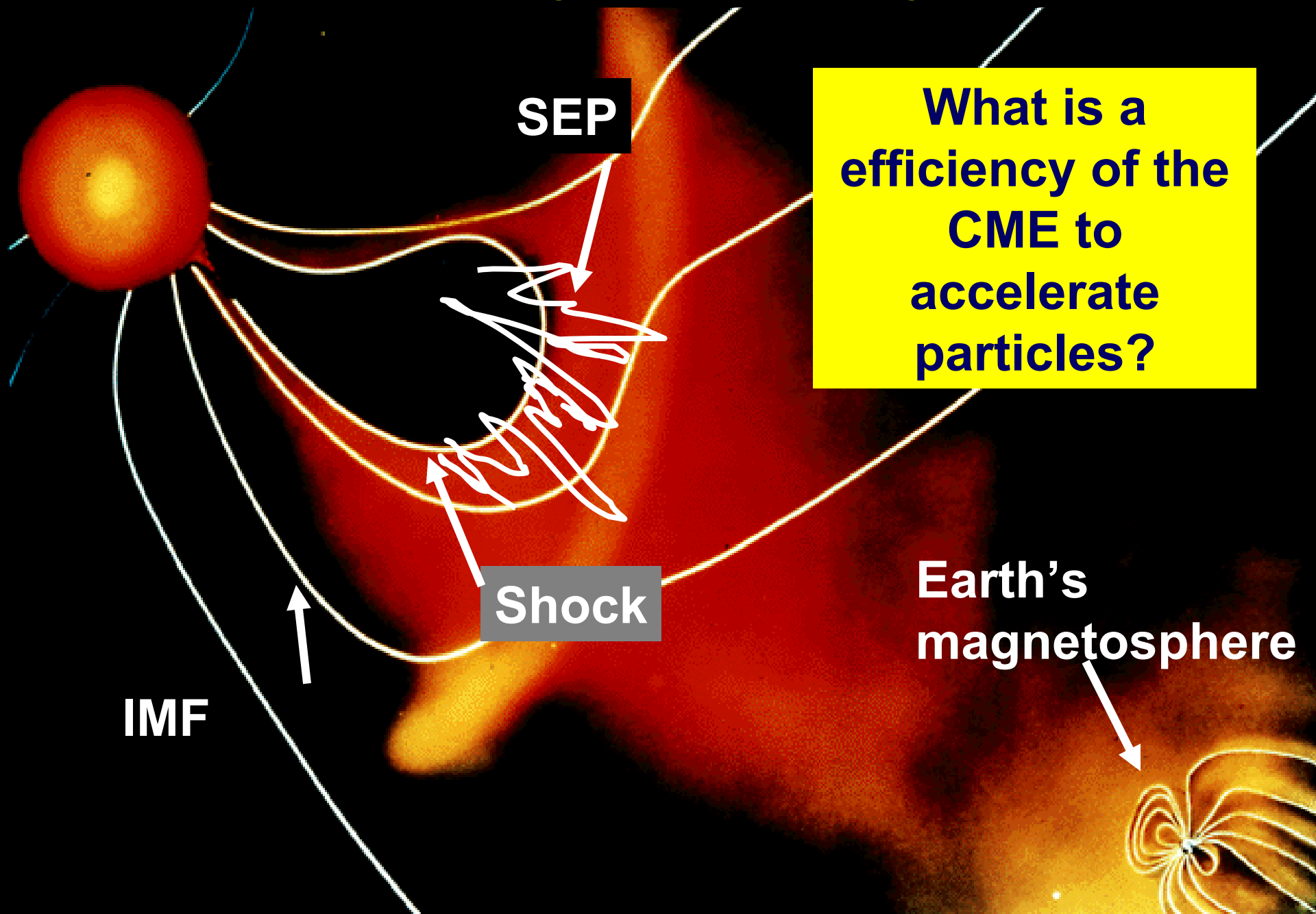
- Have we found the transition region between galactic and extragalactic sources already?

- Have we observed the LIMIT OF POWER of Galactic Accelerator egual to ~ $10^{15}Z$?

- What kind of accelerators are responsible for the origin of particles at 10*17 eV???

Do we know other shocks in the Universe?

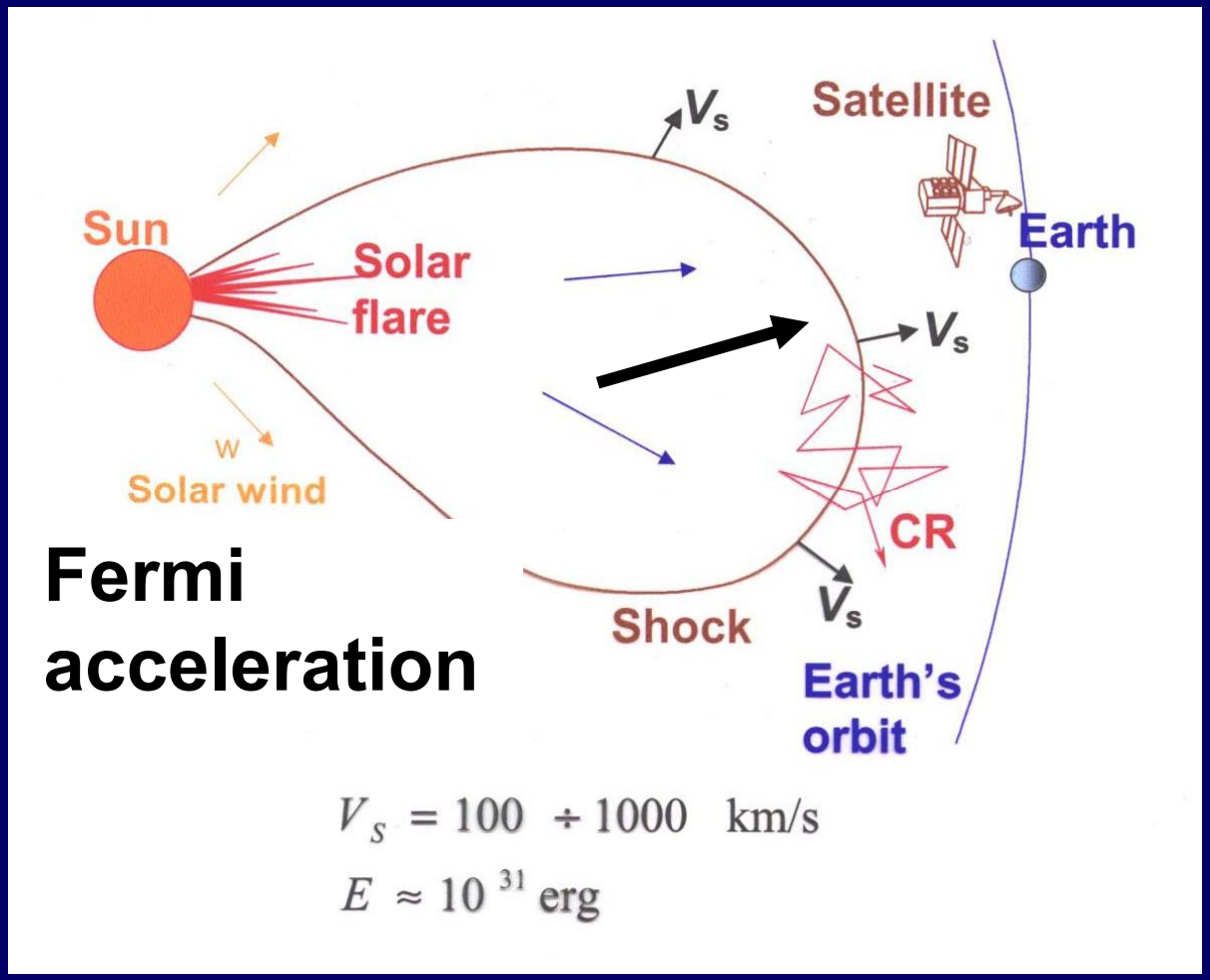
SEP acceleration by interplanetary shock waves



What is a efficiency of the CME to accelerate particles?

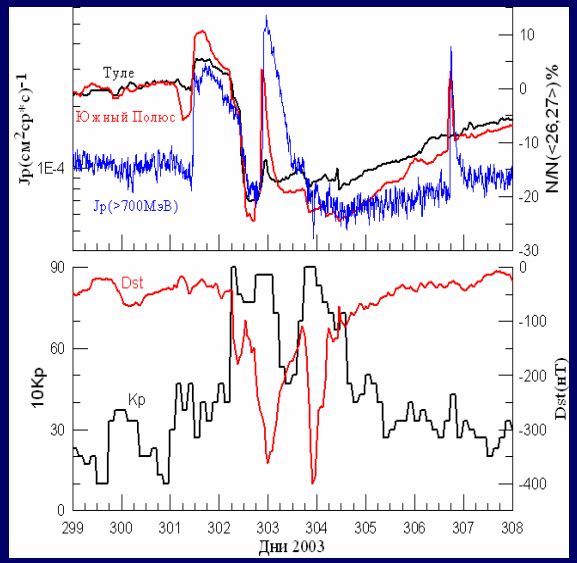
Acceleration of SEP during propagation

CME acceleration

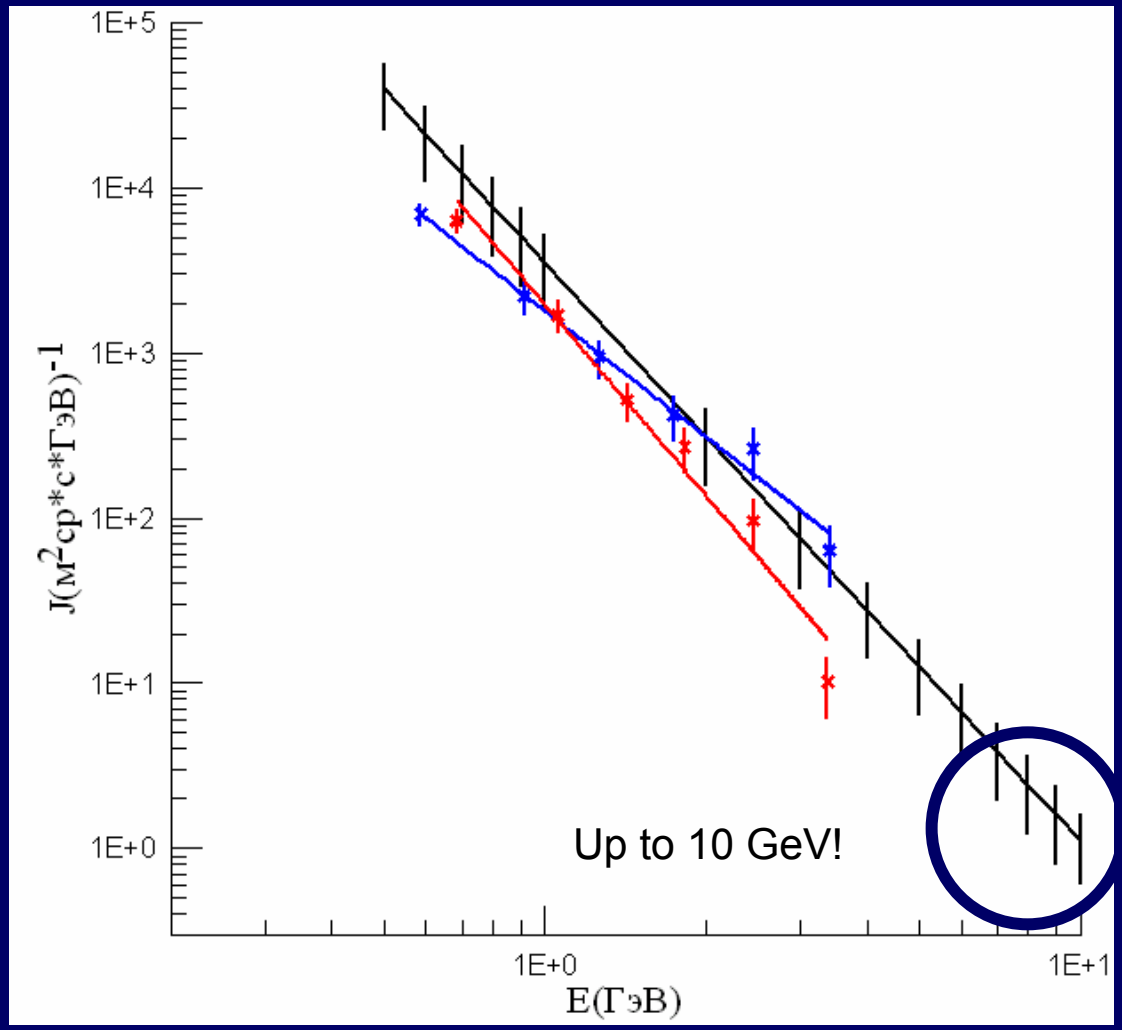


Berezhko (1999) :*ions energy up GeV!*

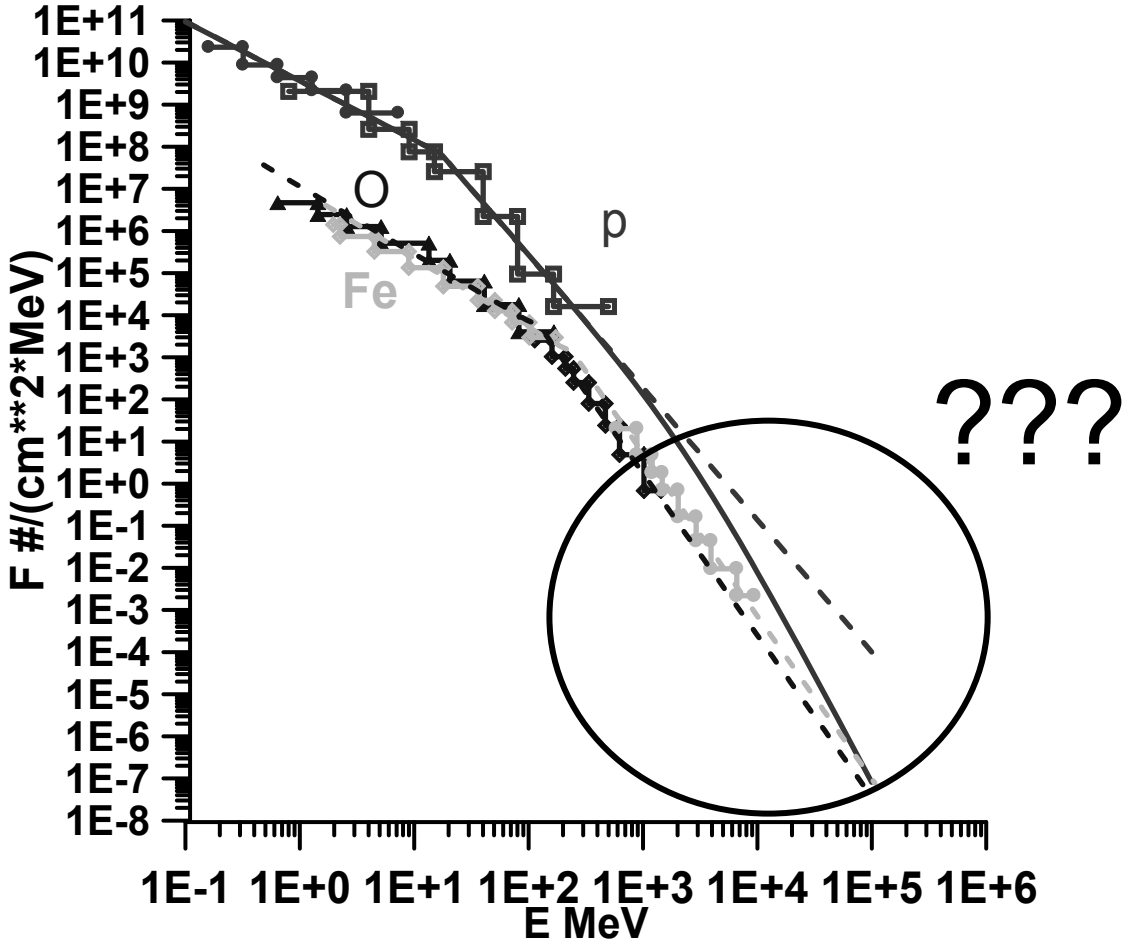
SEP spectra from cutoff (sat. data)



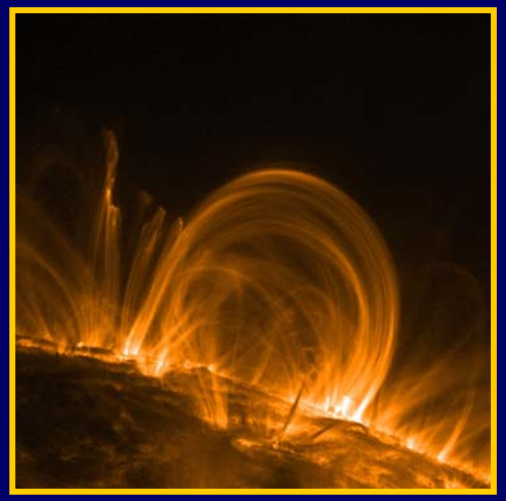
Coronas –F data



Solar energetic particle's spectra



Alternative (or complementary) approach:



Magnetic reconnection as a main force for solar flare particle acceleration

↓

Solar flare standard model

Scenario of acceleration process

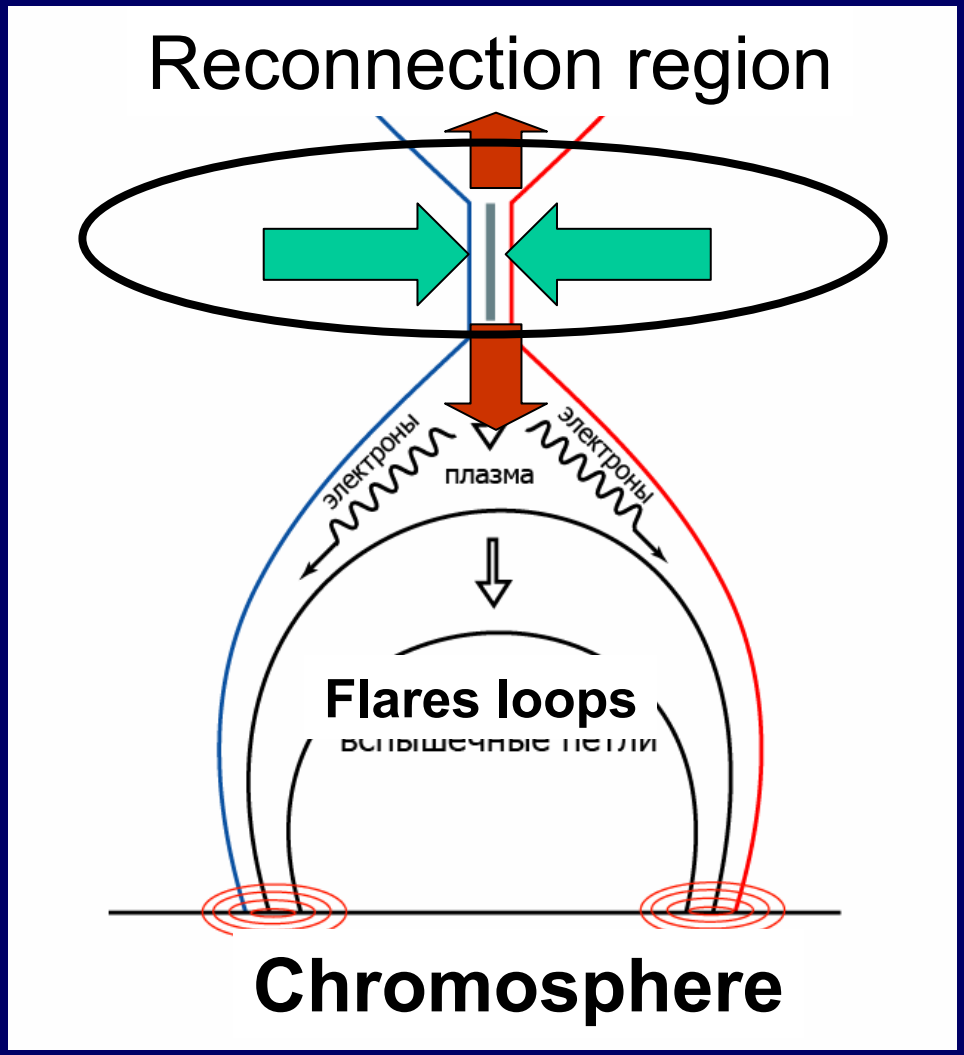
After Somov & Bogachev

- Magnetic field lines move to the X-type neutral point

-The electric field is induced and accelerates particles

$$\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{A}}{\partial t},$$

Magnetic reconnection as an injector

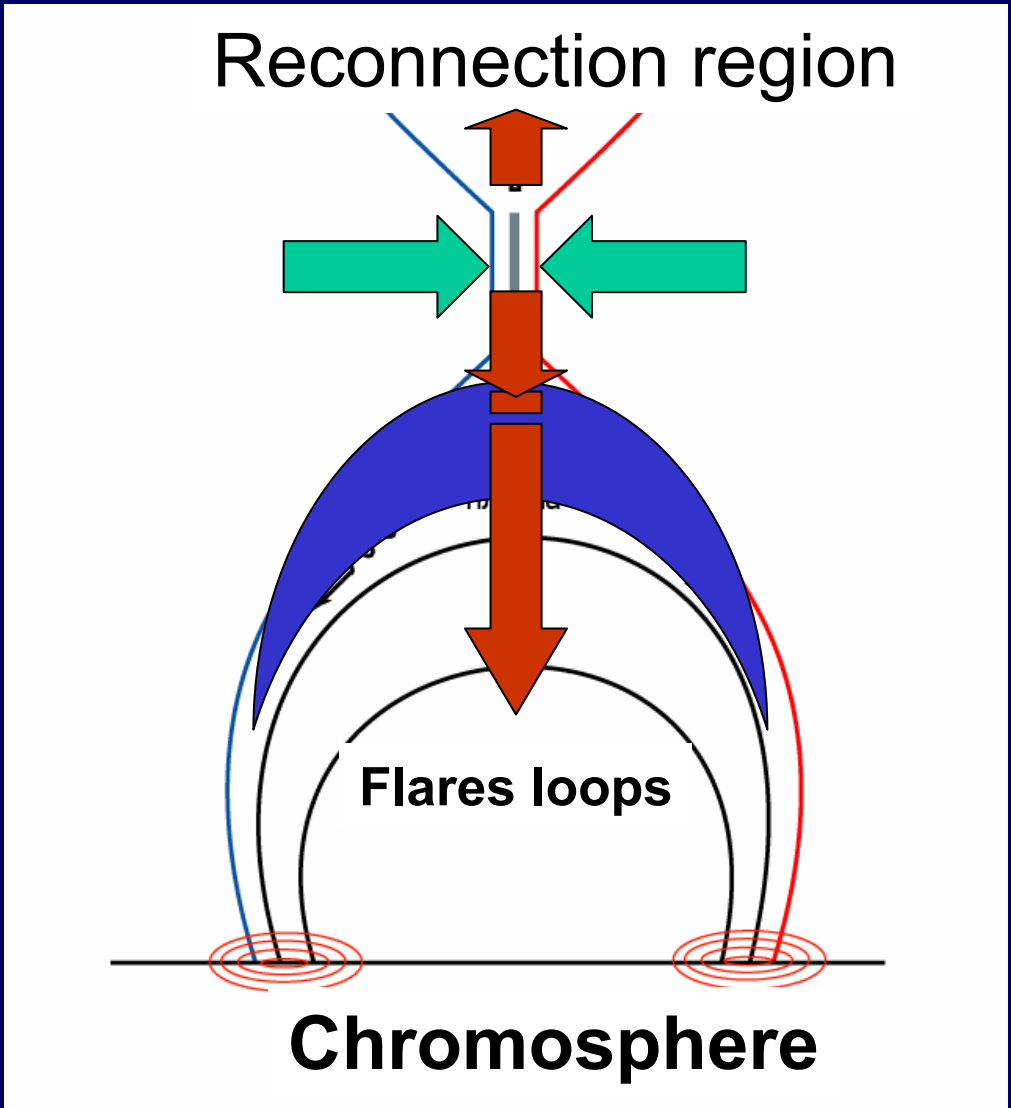


Scenario of acceleration process

1.Magnetic reconnection
as an injector

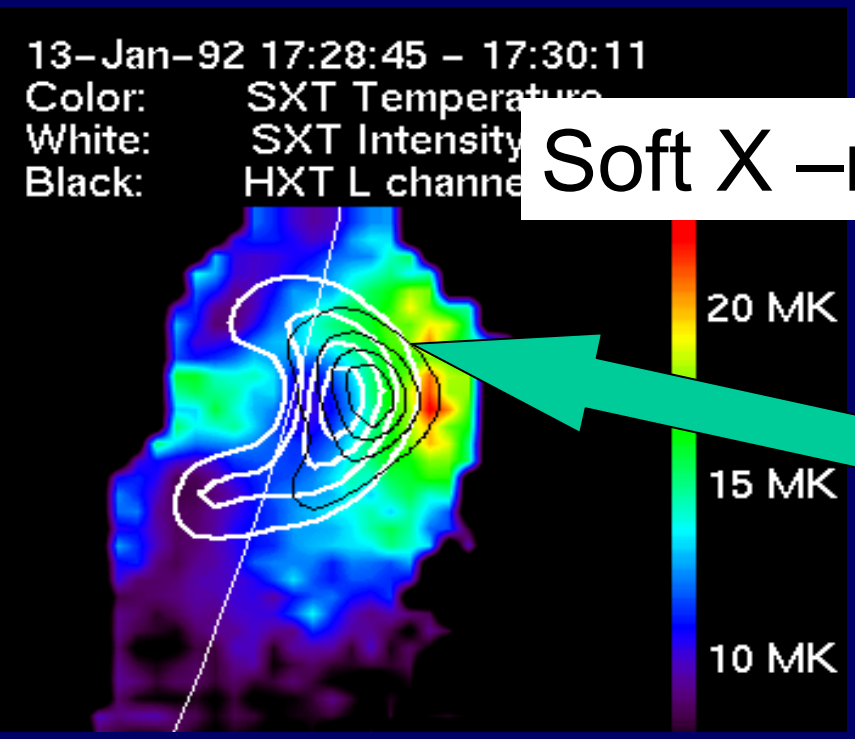
2.Electron capture
and collaps of magnetic
trapping region

Bethatron acceleration
connected with collapse
of magnetic loops
with simultaneous
Fermi acceleration
(stochastic acceleration)

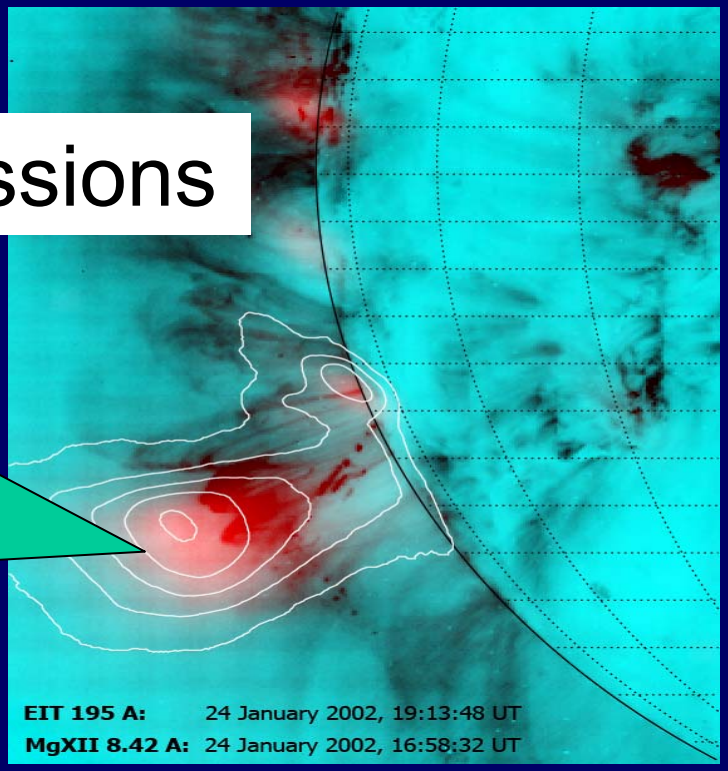


Evidences from observations

•Thermal and non-thermal HXR emission from the corona, can be interpreted as reconnecting super-hot turbulent-current layer (SHTCL)



Soft X –ray emissions



1991-2001
Yohkoh data
Tsuneta S., Kosugi T.

2001-2006 **SPIRIT/CORONAS-F I**. Zhitnik, C.Kuzin

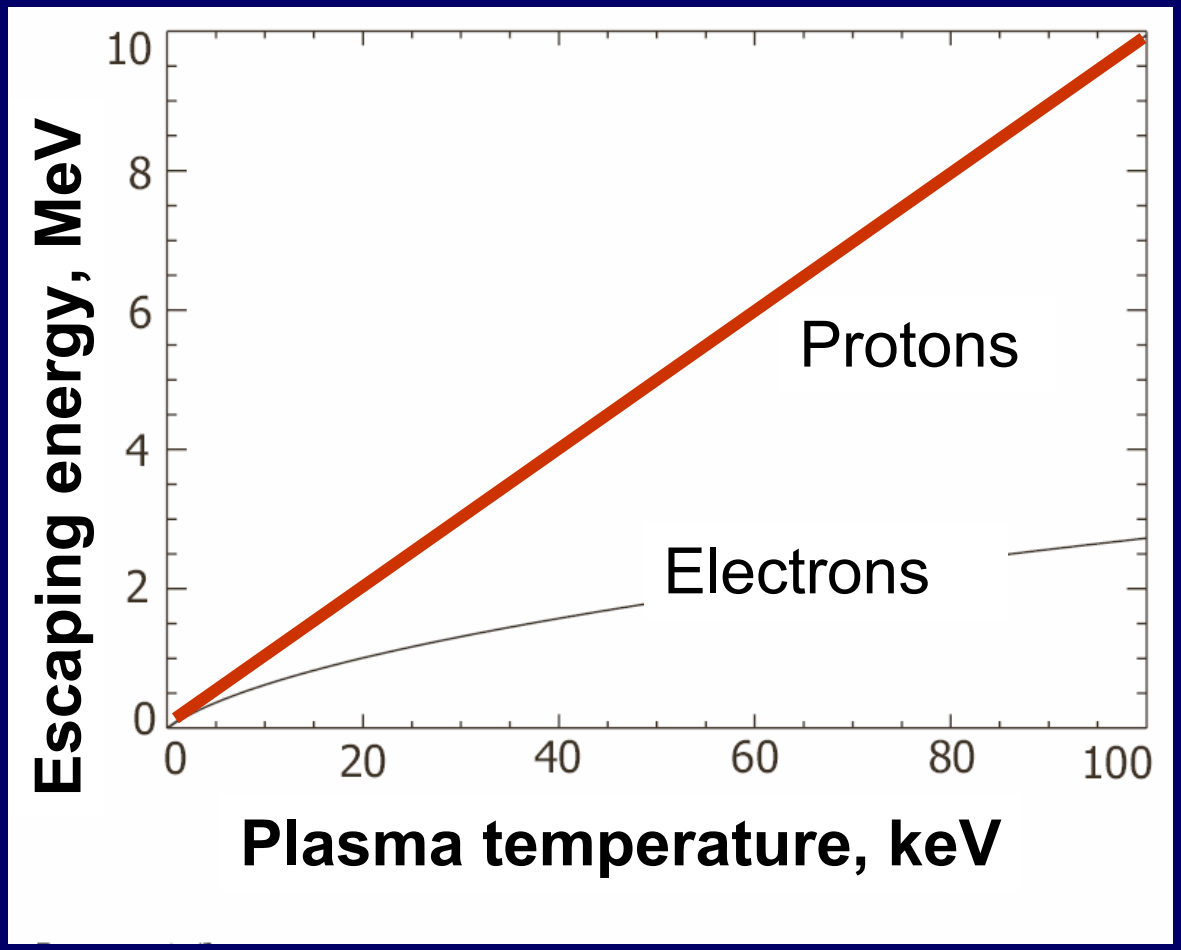
SEP acceleration mechanism should explain experimental data:

Acceleration of

- *Protons up to 1-10s 300MeV- ~several GeV*
- *Electrons up to ≈0.5s 60-100MeV*

SM gives →

Acceleration of protons and electrons



Dependent on the plasma parameters

Protons can be accelerated up to GeV, but electrons **only** up to several MeV

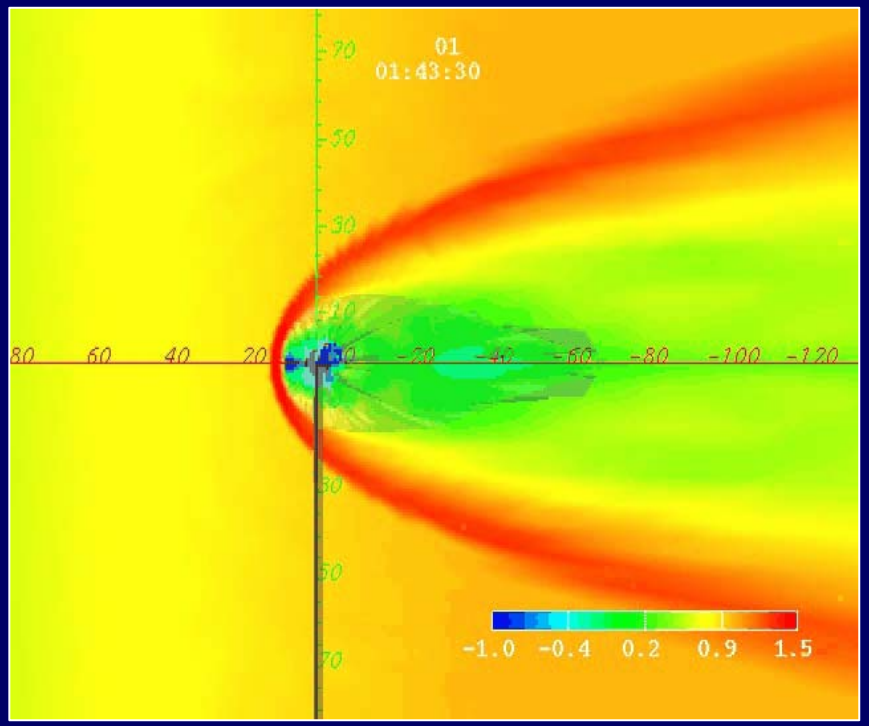
Bogachev, et al

The question “does a shock wave propagating in the Corona accelerate particles up to ultra-relativistic energies “ is being discussed

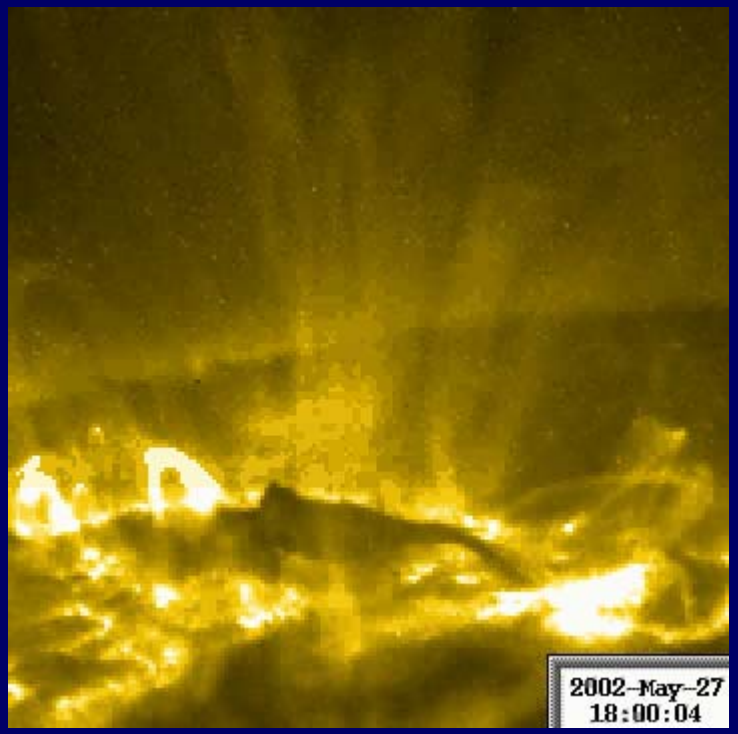
- **Do we have reconnection somewhere else?**

Reconnection is everywhere

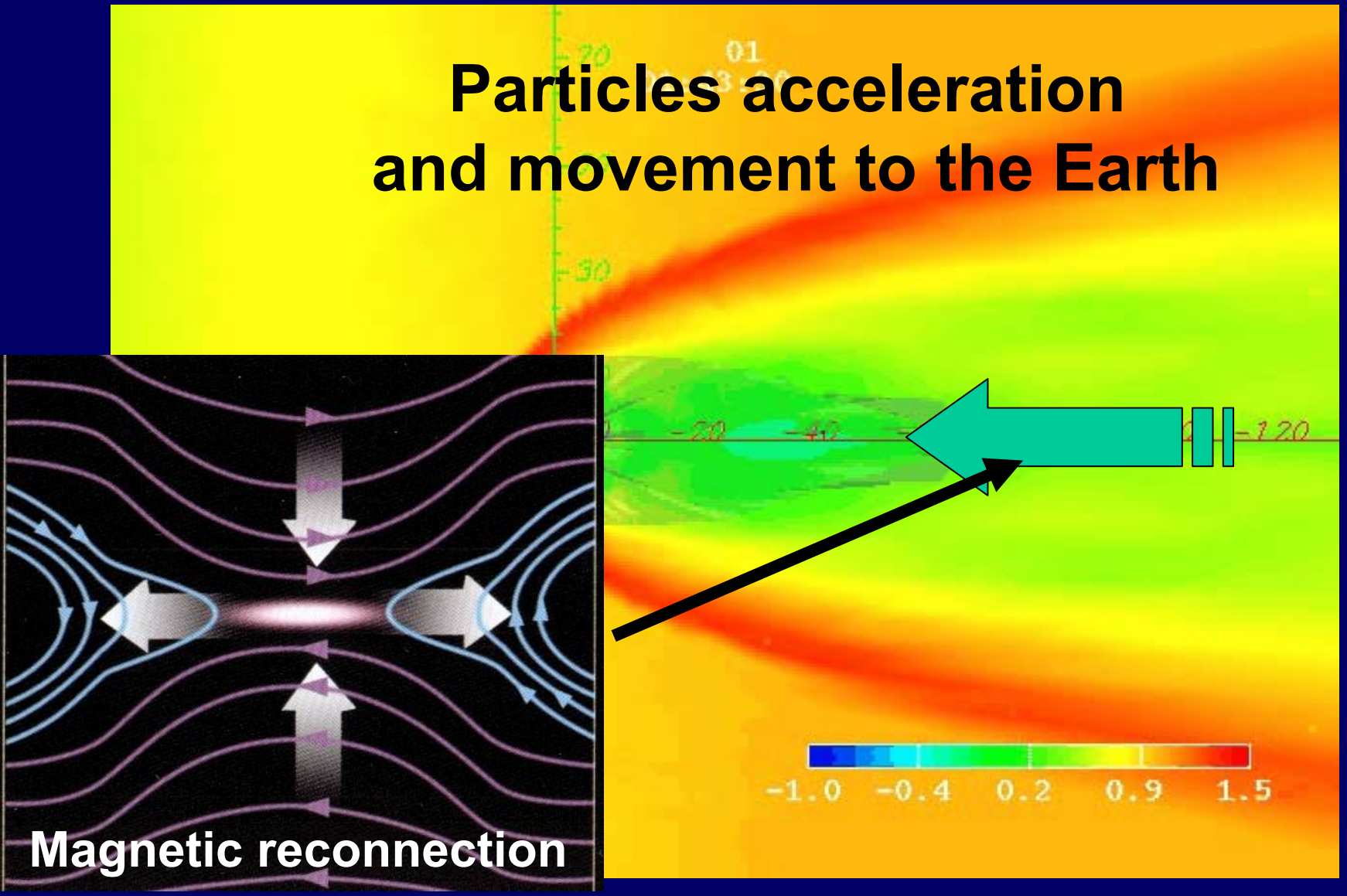
In the magnetospheres



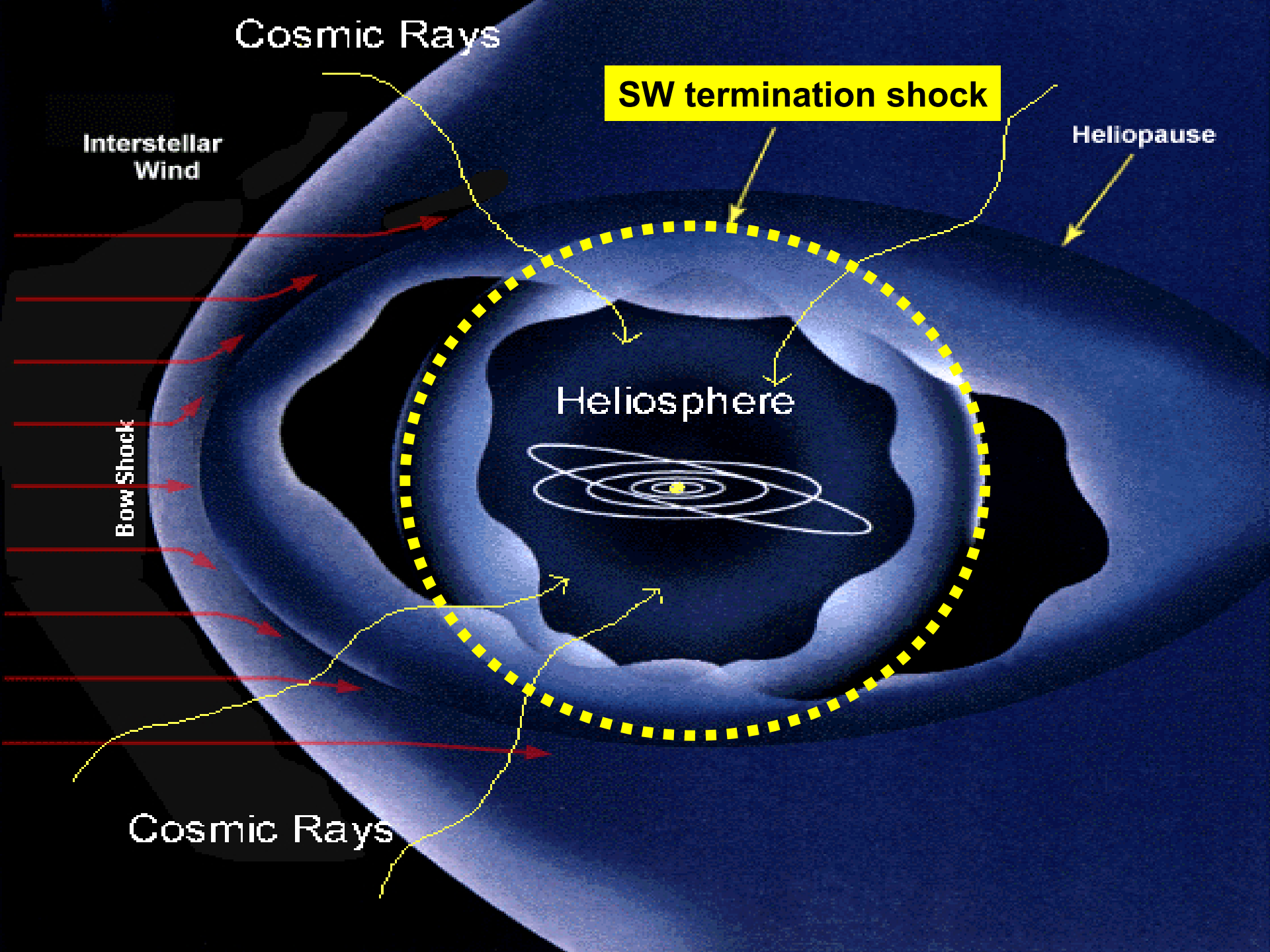
At the Sun



Magnetic substorms/storms reconnection

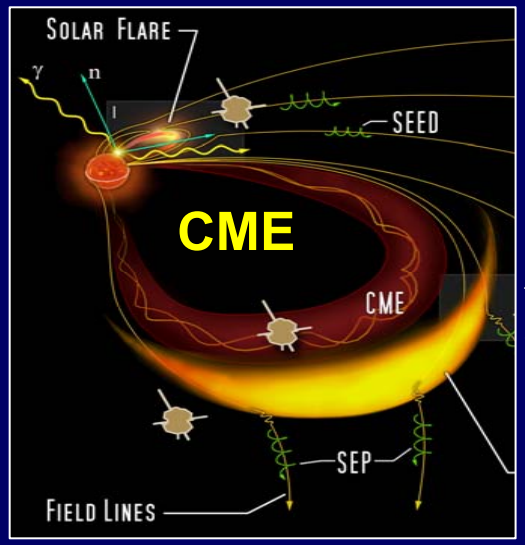


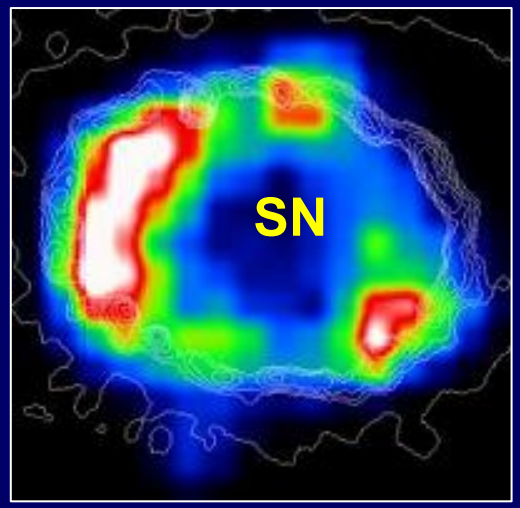
- Shock’s acceleration is everywhere as well!


Cosmic Rays
SW termination shock
Heliopause
Interstellar Wind
Heliosphere
Bow Shock
Cosmic Rays

Shock's acceleration is everywhere as well!

	SW	GCR
N	~ $1 cm^{-3}$	10^{-3} cm-3
B	~ 1nT	10^{-2} nT
T ion	~ 10 eV	10^{3} eV
Mach	~ 5	100
T	~ hours	minutes



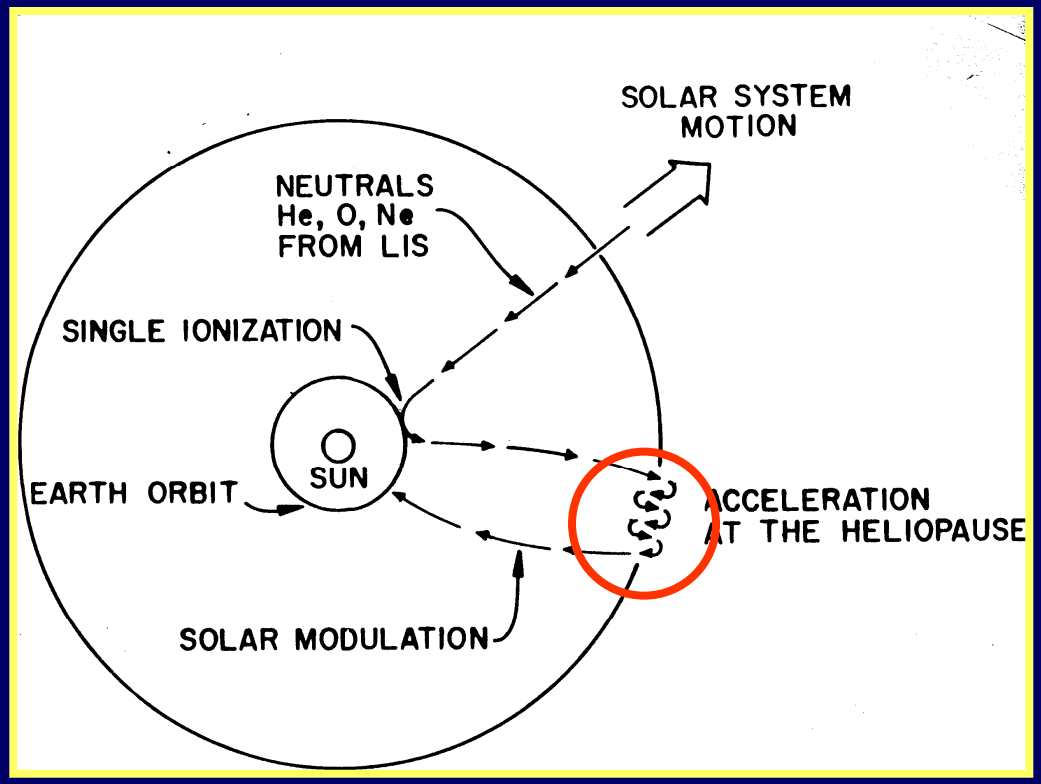


The anomalous cosmic ray component

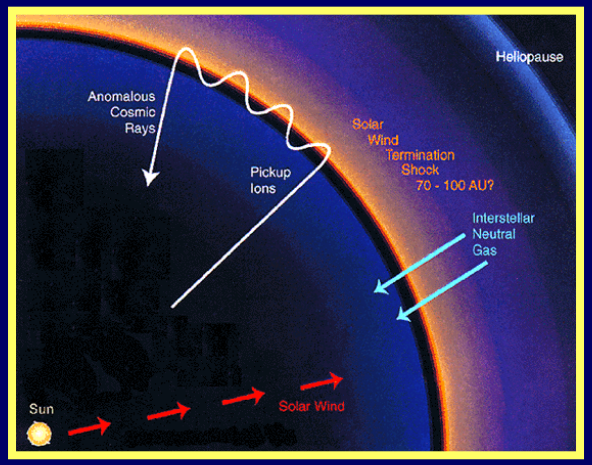
The main statements of the Fisk, Kozlovski Ramaty theory

Then…

- Acceleration of ionized neutrals, 'picked-up' by the solar wind from ~4 keV/nucleon to >10 MeV/nucleon at the heliopause (termination shock);



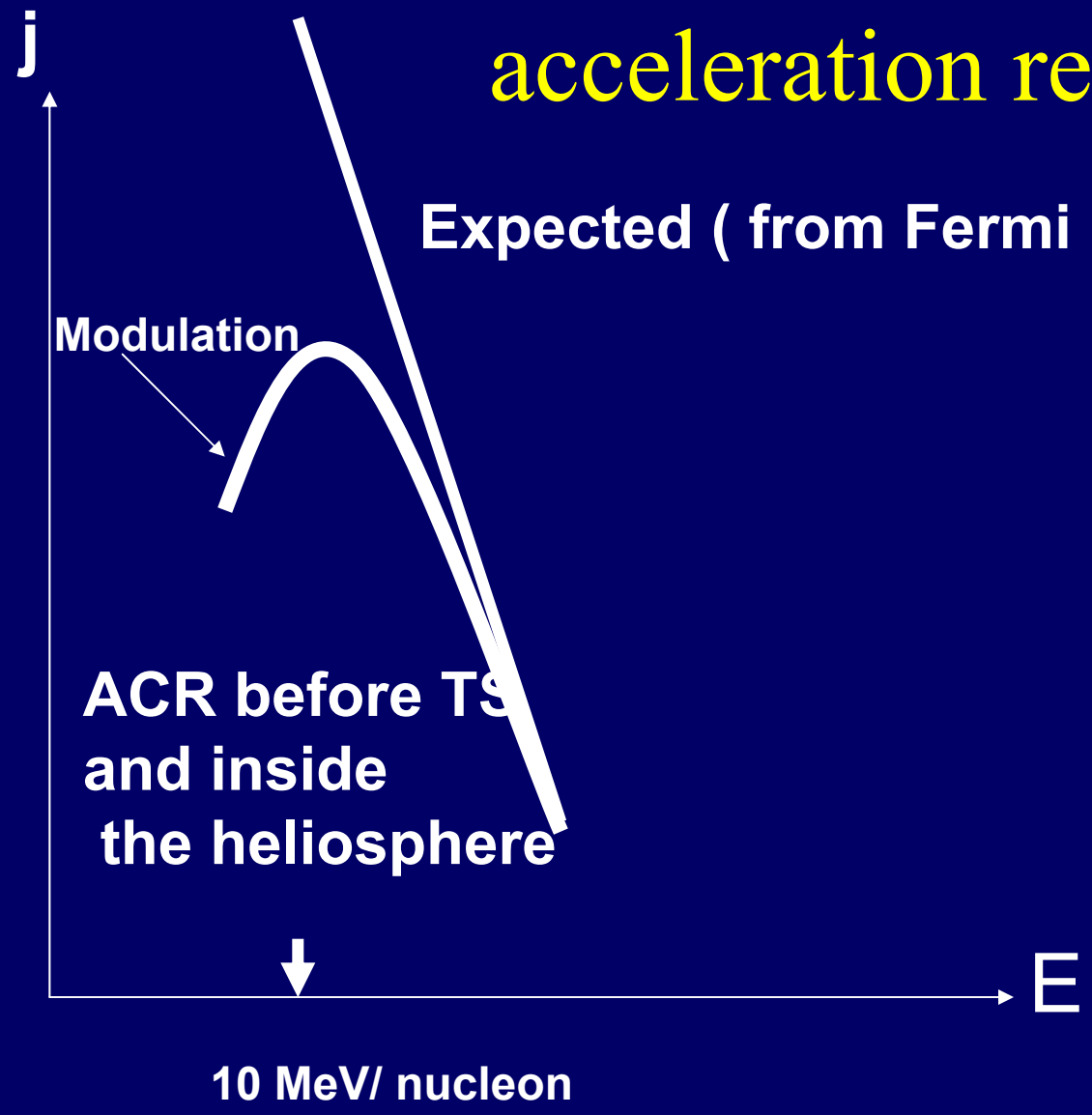
The anomalous cosmic ray acceleration



Krymski (1977), Axford *et al.* (1977) and Blandford and Ostriker (1978):

FIRST ORDER FERMI
OR COMPRESSIVE SHOCK ACCELERATION

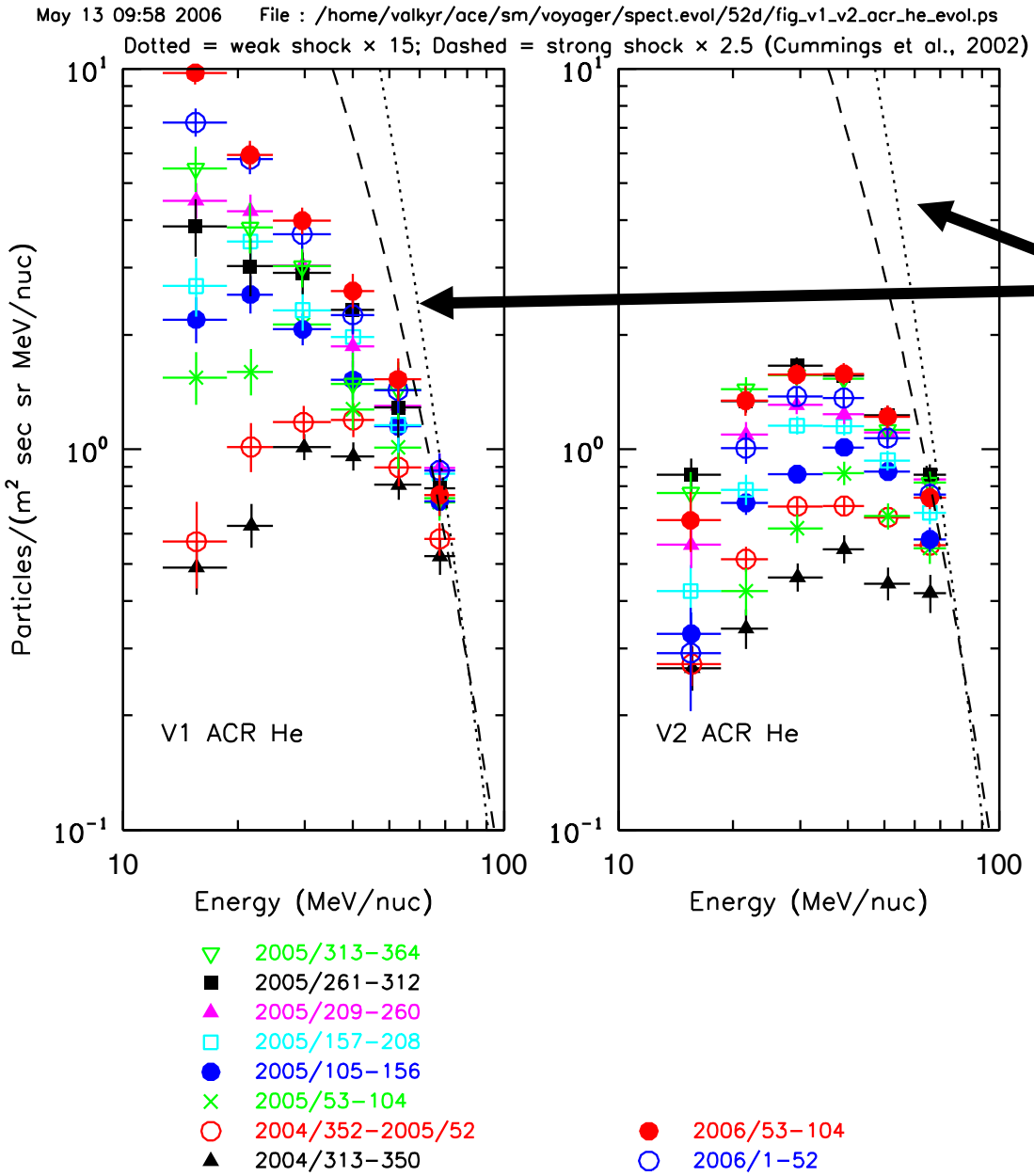
ACR spectra near an outer acceleration region



Direct observation of ACR acceleration:

Voyager data

ACR He Spectral Evolution



V1 crossed shock on 2004/351

Expected source spectrum was not observed at time of shock crossing

Where is the ACR source?
Near the ecliptic?
Along the flanks?
In the heliosheath?

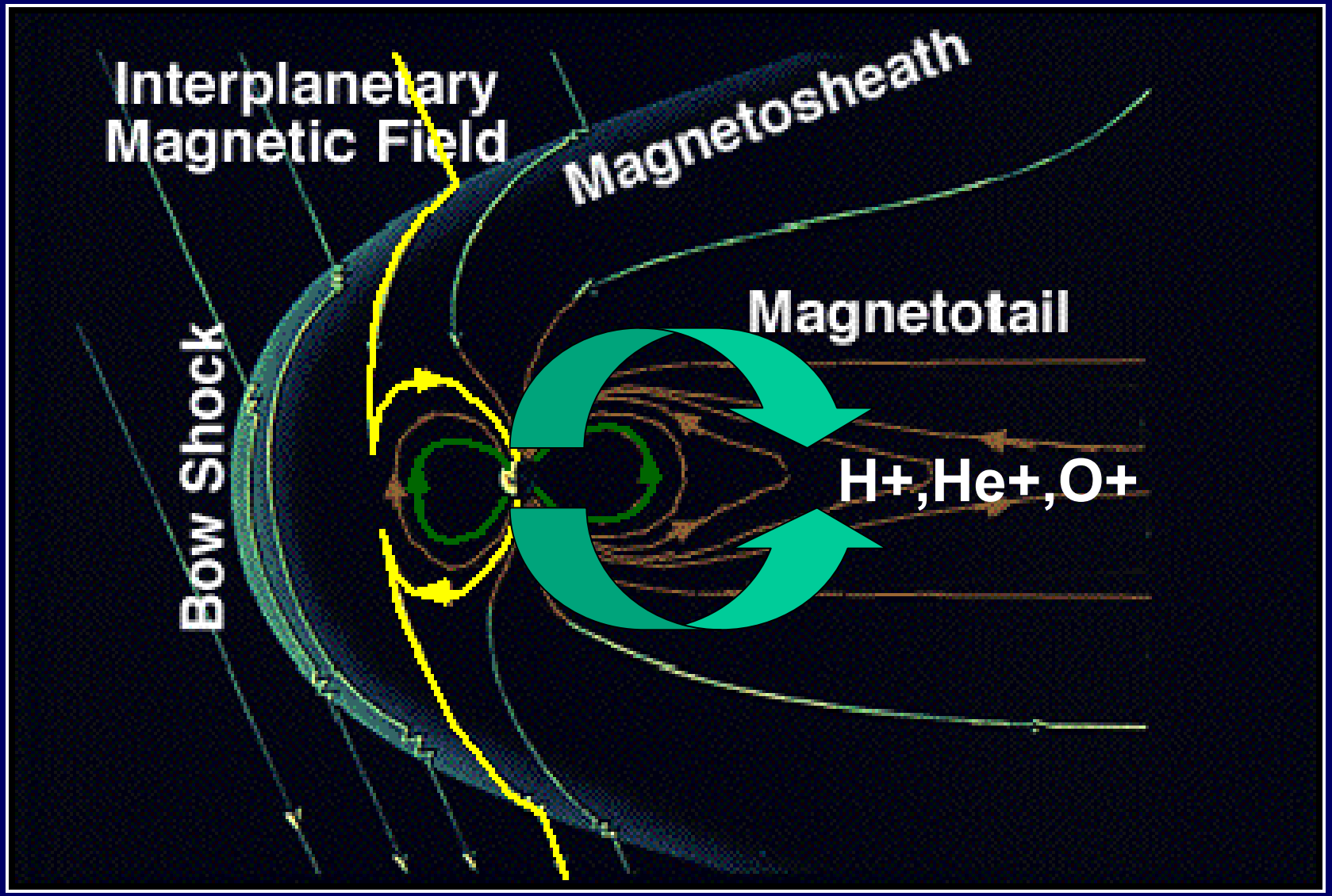
Stone et al. Science 2005 Cummings & Stone COSPAR 2006

ACR source(s)

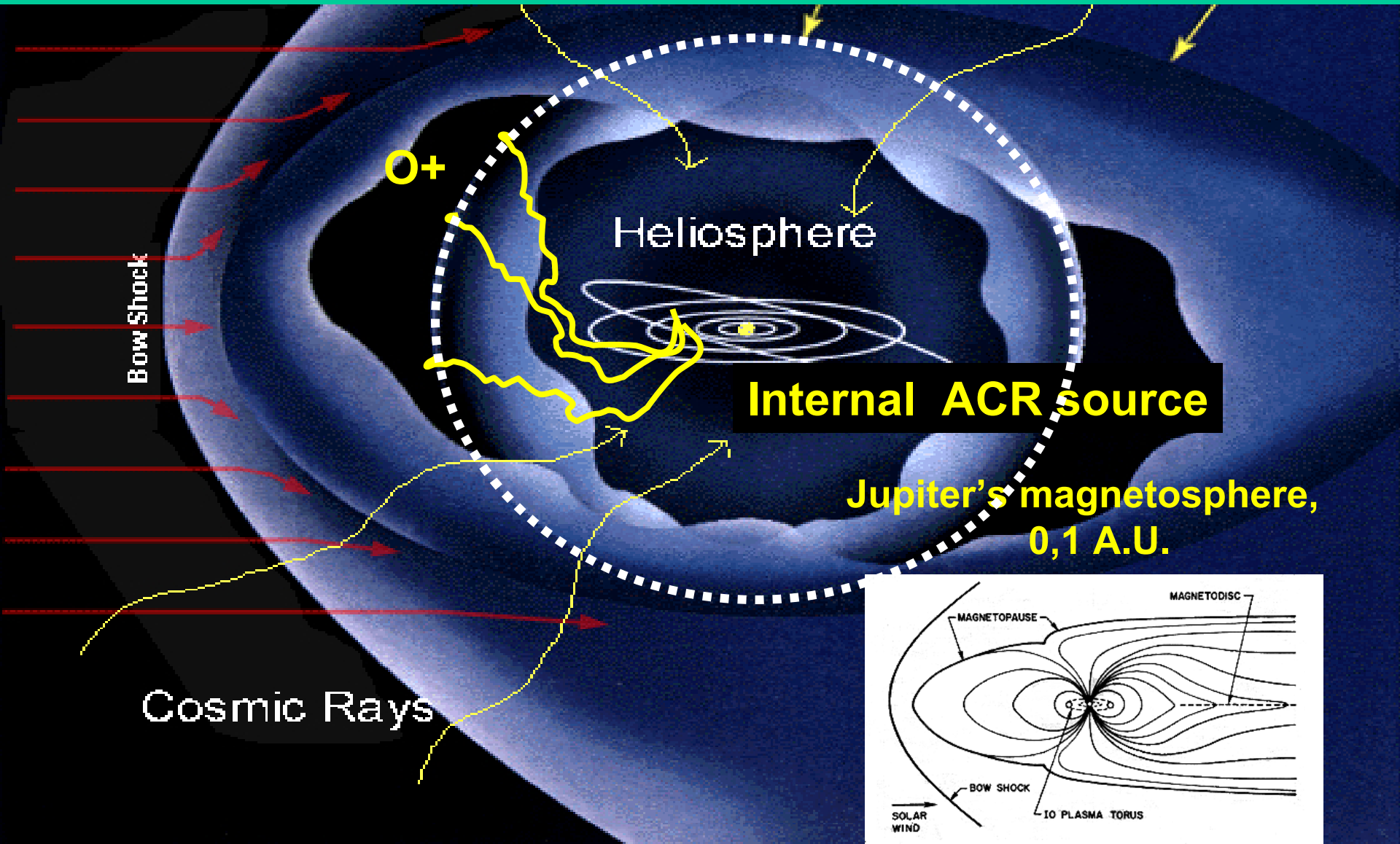
Alternative (or complementary) approach:

Ionosphere plasma of “magnetic” planets enriched by O+ can be a source for ACR

Ionosphere as a source of plasma in the Earth's magnetotail



Double acceleration of ACR: during reconnection process in the magnetospheres of the giant planets plus acceleration at heliospheric TS




Научно–Исследовательский
Институт Ядерной Физики
имени Д.В. Скобельцына

Thank you