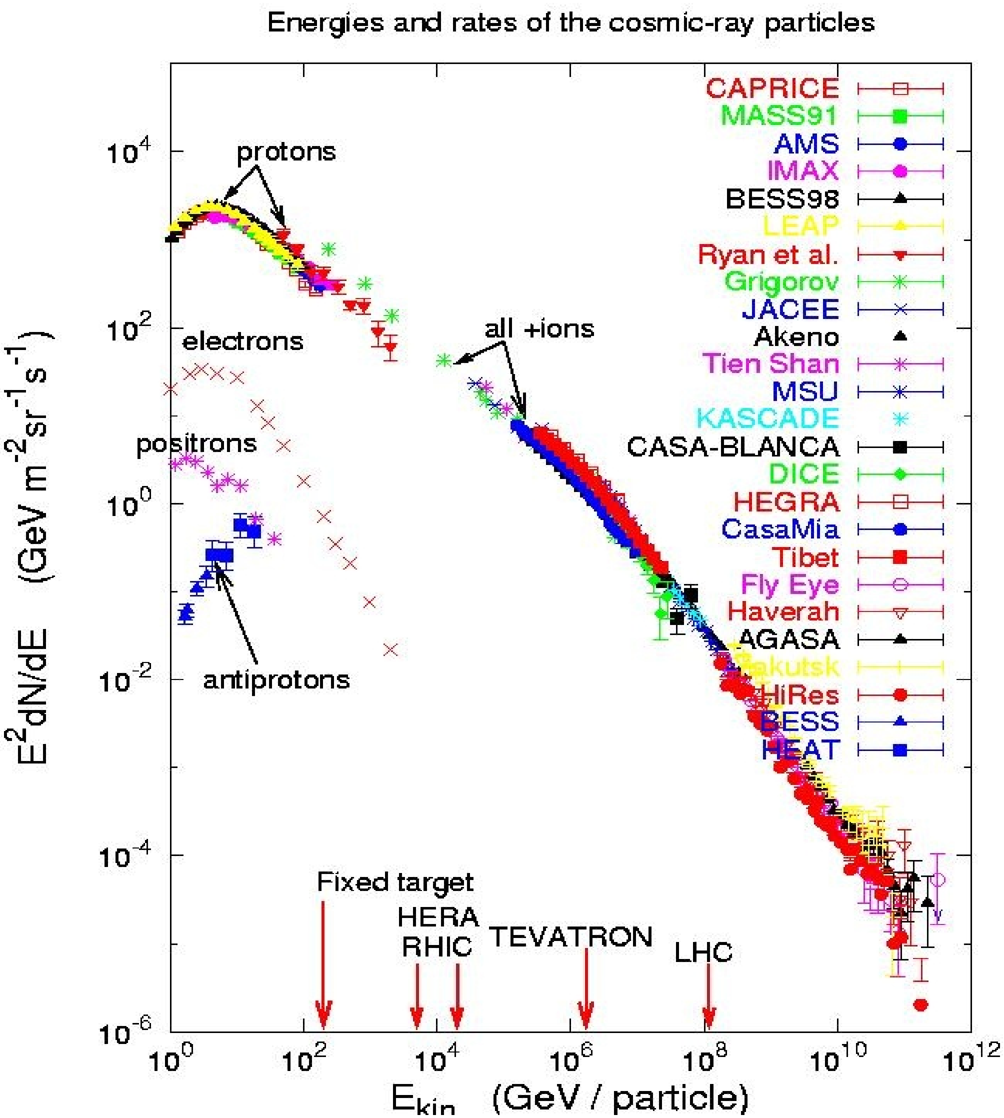
Origin of Cosmic Rays

What do we know about the Origin of Cosmic Rays?



Paolo Lipari INFN Roma 1

18th march 2011
NEUTEL 2011 Venezia

Outline:

1. The status of the "SuperNova Paradigm" for the acceleration of galactic cosmic rays.

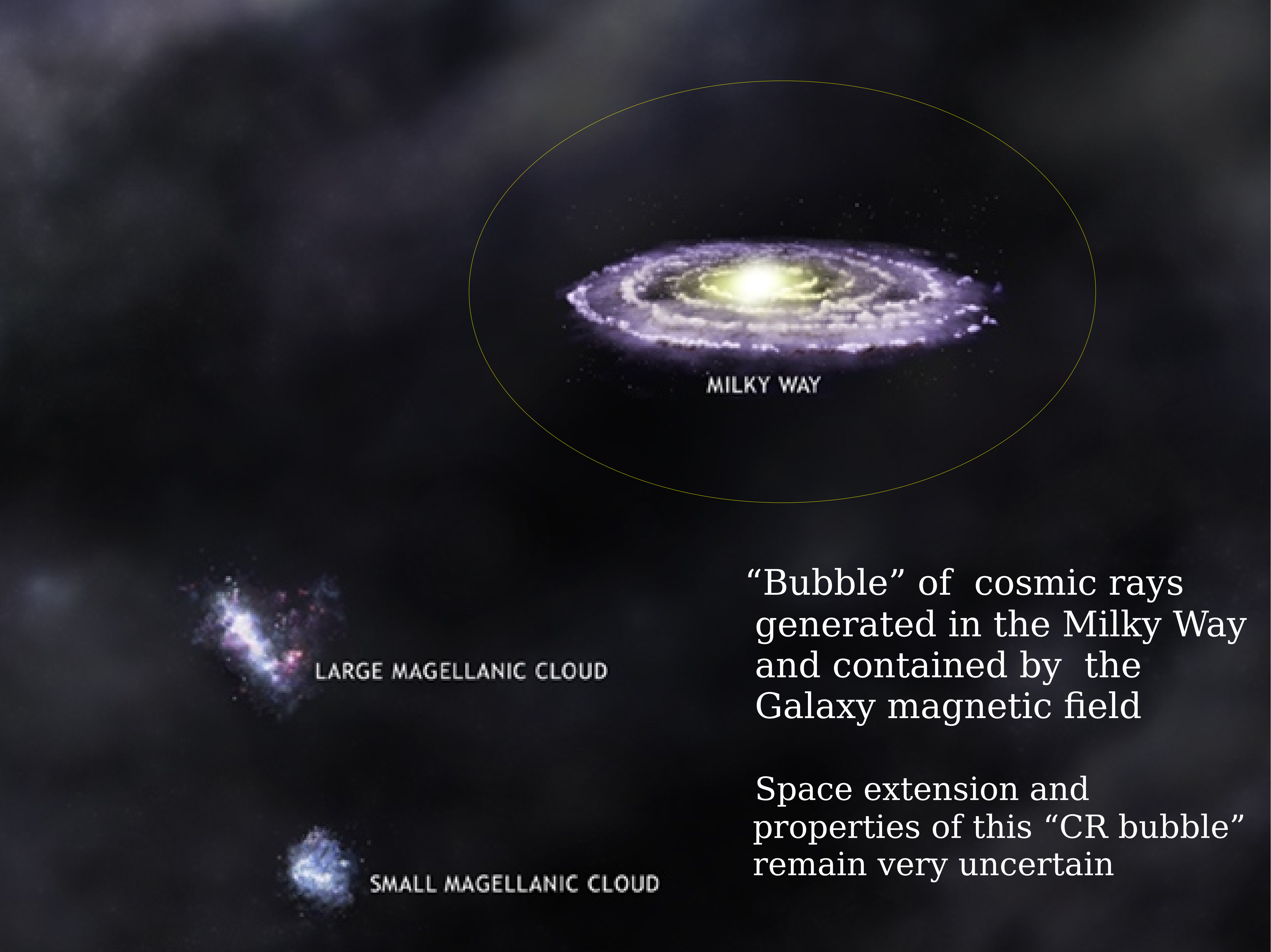
2. The "Fermi bubbles"

3. "Discrepant Hardening" of CR [Pamela p/He spectra]

4. The Pamela "positron anomaly"

5. Galactic to Extragalactic transition [(from the "Knee" to the "Ankle"]

6. The "end" of the spectrum



"Bubble" of cosmic rays generated in the Milky Way and contained by the Galaxy magnetic field

Space extension and properties of this "CR bubble" remain very uncertain

$$\phi_j(E) = \frac{c}{4\pi}\, n_j(E)$$

$$N_j(E) = \int d^3x \; n_j(E, \vec{x})$$

$$\boxed{N_j(E) = Q_j(E) \times T_j(E)}$$

$p, \quad \mathrm{nuclei}(Z, A)$

$\overline{p}, \quad e^-, \quad e^+$

Different particles

Injection
of cosmic rays

Containment
time

Injection
of cosmic rays

Containment
time

$$N_j(E) = Q_j(E) \times T_j(E)$$

$$L_j = \int dE \; E \; Q_j(E)$$

LARGE Power
Requirement

Spectral Shape
[Dynamics of acceleration process]

Source
Identification !

Injection
of cosmic rays

Containment
time

$$\boxed{N_j(E) = Q_j(E) \times T_j(E)}$$

Competition of different times:

$$T_{\rm int}^{p,A}(E) \propto [\sigma_j(E)]^{-1} \sim \text{slowly varying}$$

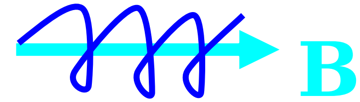
Interaction
(hadrons)

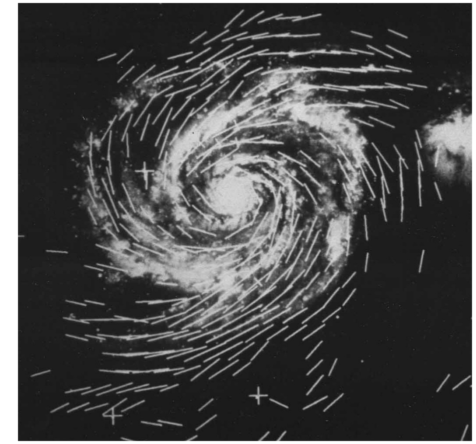
$$T_{\rm diffusion}\left(\frac{p\,c}{Z}\right) \propto \left(\frac{p\,c}{Z}\right)^{-\delta}$$

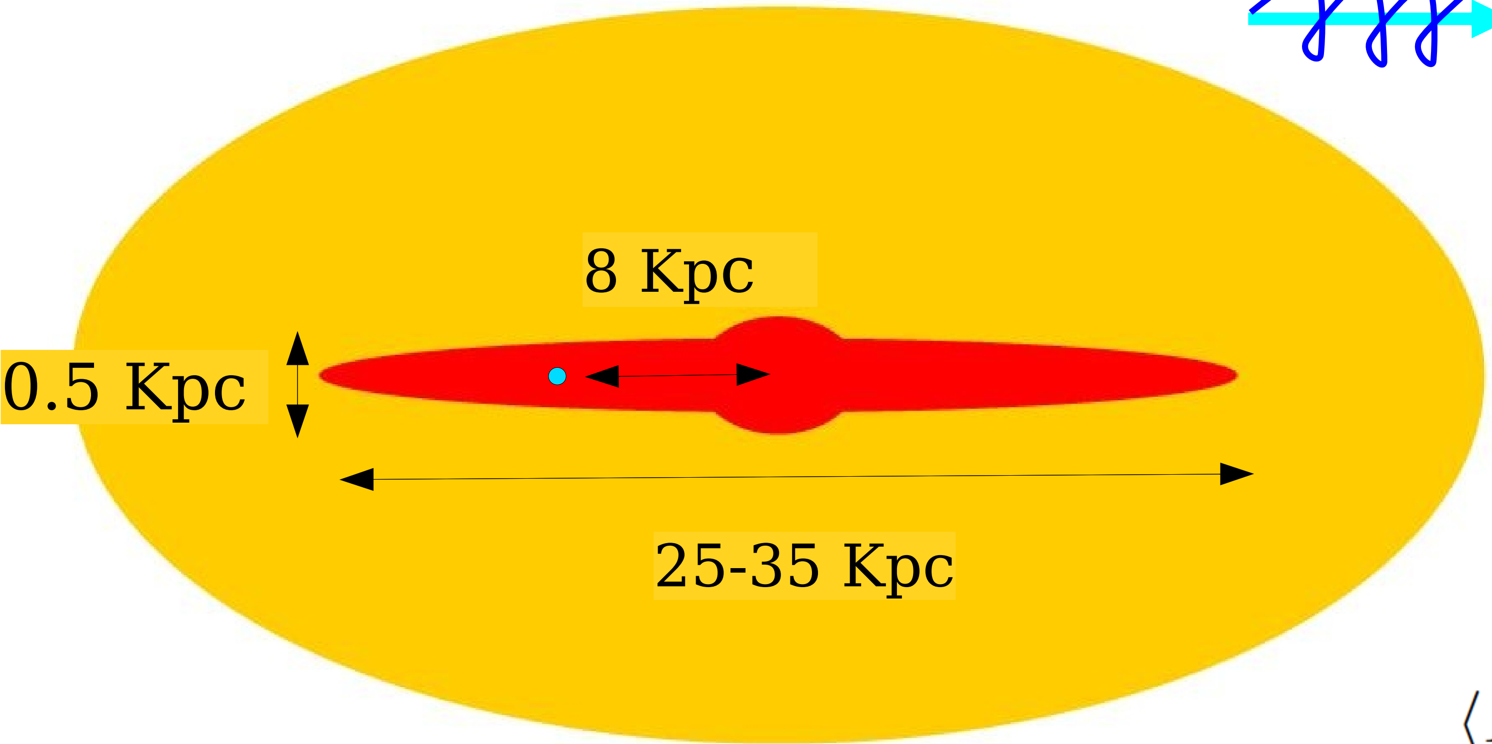
Escape
from Galaxy

$$T_{\rm loss}^{(e^{\mp})}(E) \propto \frac{1}{E}$$

Energy losses
(electrons/positrons)







$$r_L = \frac{p_\perp \, c}{q \, B}$$

$$\langle B_{\mathrm{MW}} \rangle \simeq 3 \ \mu\mathrm{Gauss}$$

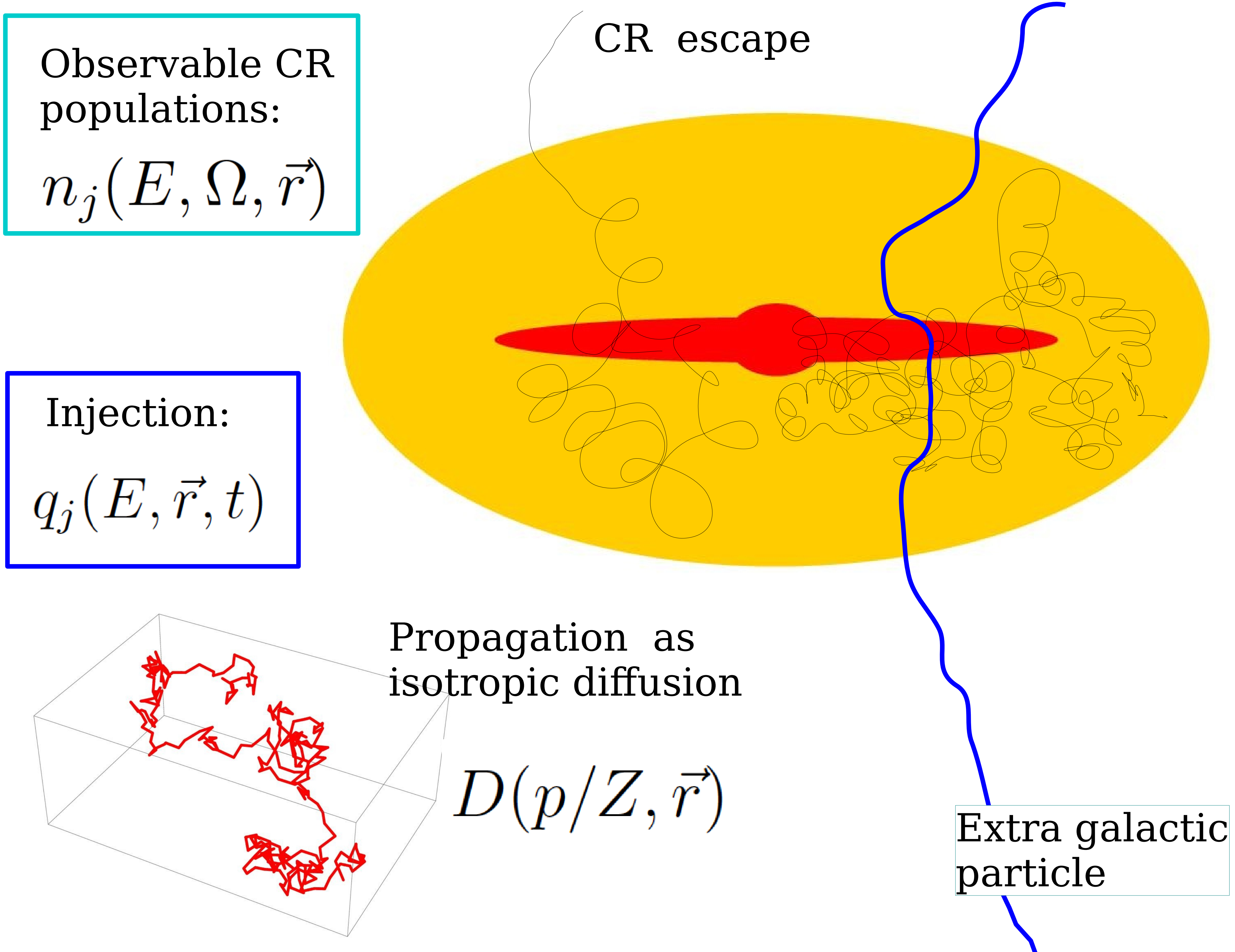
$$r_L = \frac{1.08 \ \mathrm{Kpc}}{Z} \left[\frac{E}{10^{18} \, \mathrm{eV}} \right] \left[\frac{\mu\mathrm{Gauss}}{B} \right]$$

$$r^p_{\mathrm{Larmor}}(100 \ \mathrm{GeV}) \simeq 3.6 \times 10^{-8} \ \mathrm{Kpc}$$

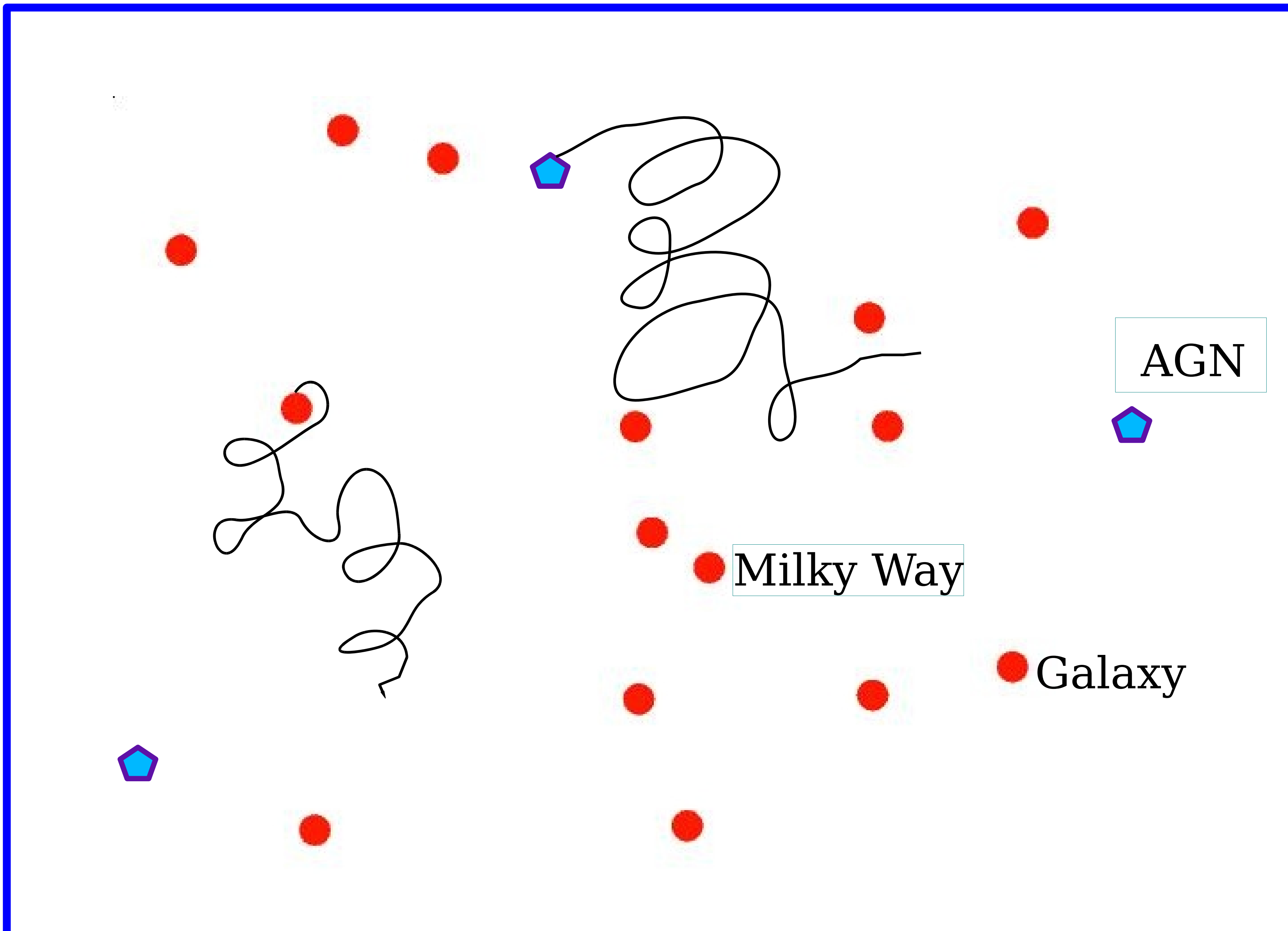
$$r^p_{\mathrm{Larmor}}(10^{20} \ \mathrm{eV}) \simeq 36 \ \mathrm{Kpc}$$

$$r^{\mathrm{Fe}}_{\mathrm{Larmor}}(10^{20} \ \mathrm{eV}) \simeq 1.4 \ \mathrm{Kpc}$$

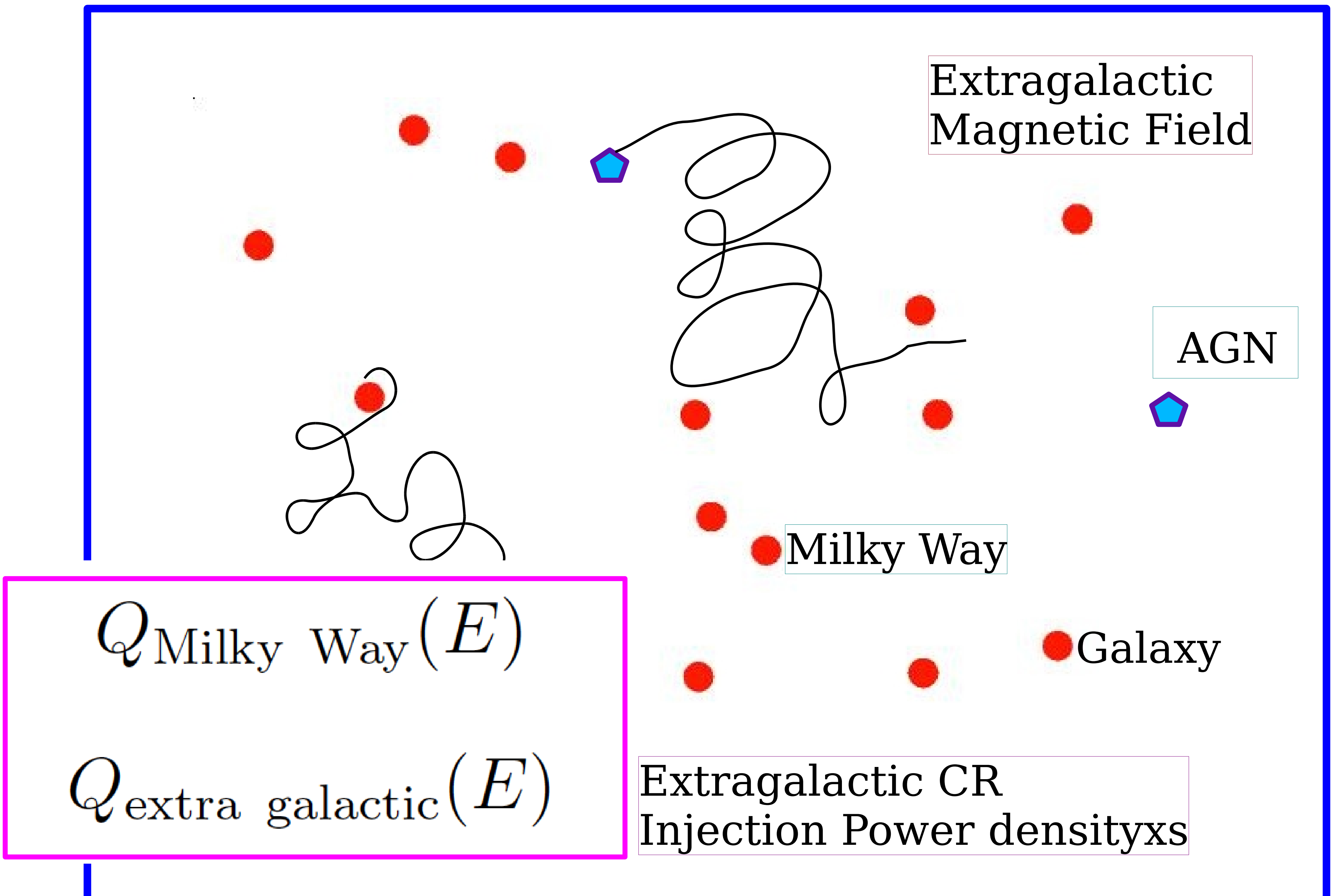
- Diffusion approximation
- Maximum energy for containment


Observable CR populations:
$n_j(E, \Omega, \vec{r})$
CR escape
Injection:
$q_j(E, \vec{r}, t)$
Propagation as isotropic diffusion
$D(p/Z, \vec{r})$
Extra galactic particle

Piece of extragalactic space: Non MilkyWay-like sources



Piece of extragalactic space: Non MilkyWay-like sources



Cosmic Ray Nuclear Composition

Overabundance of Li, Be, B

Sub-iron elements

Spallation effect:

Column density
Confinement time

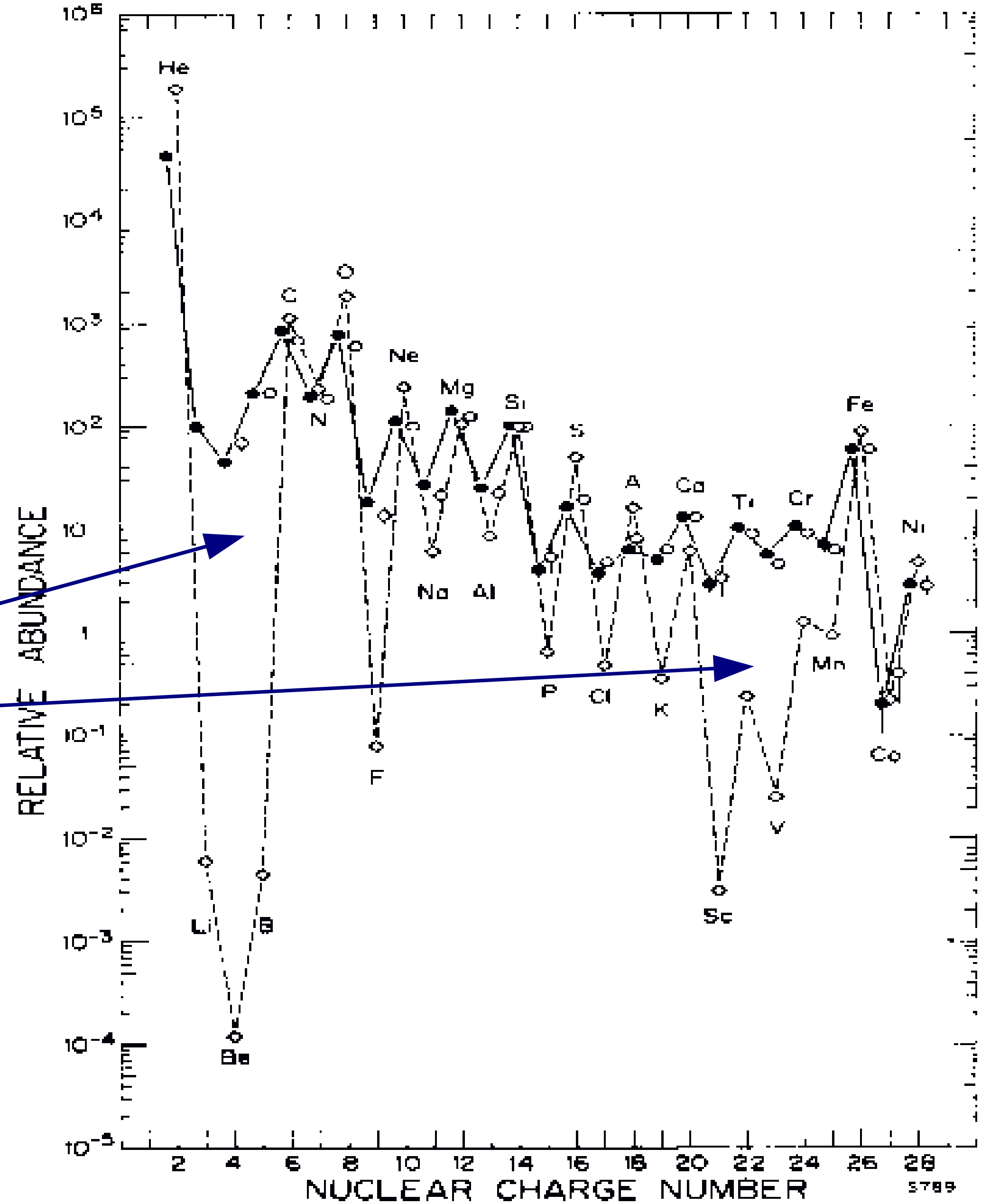
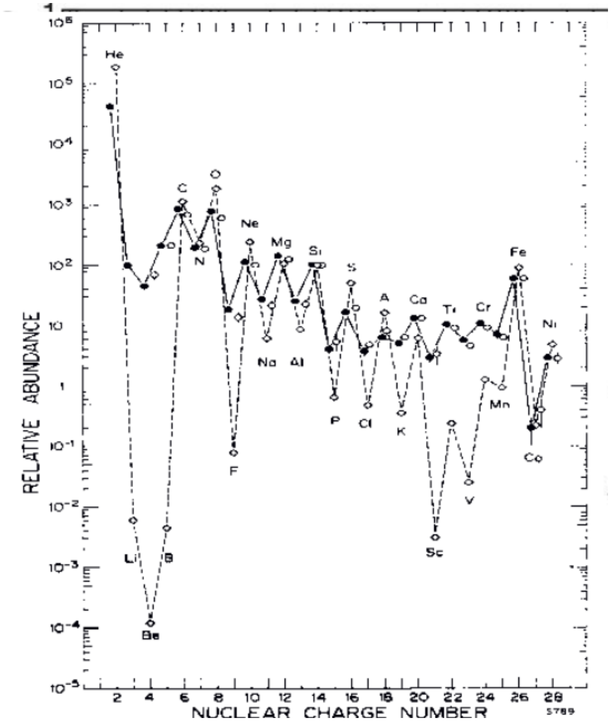
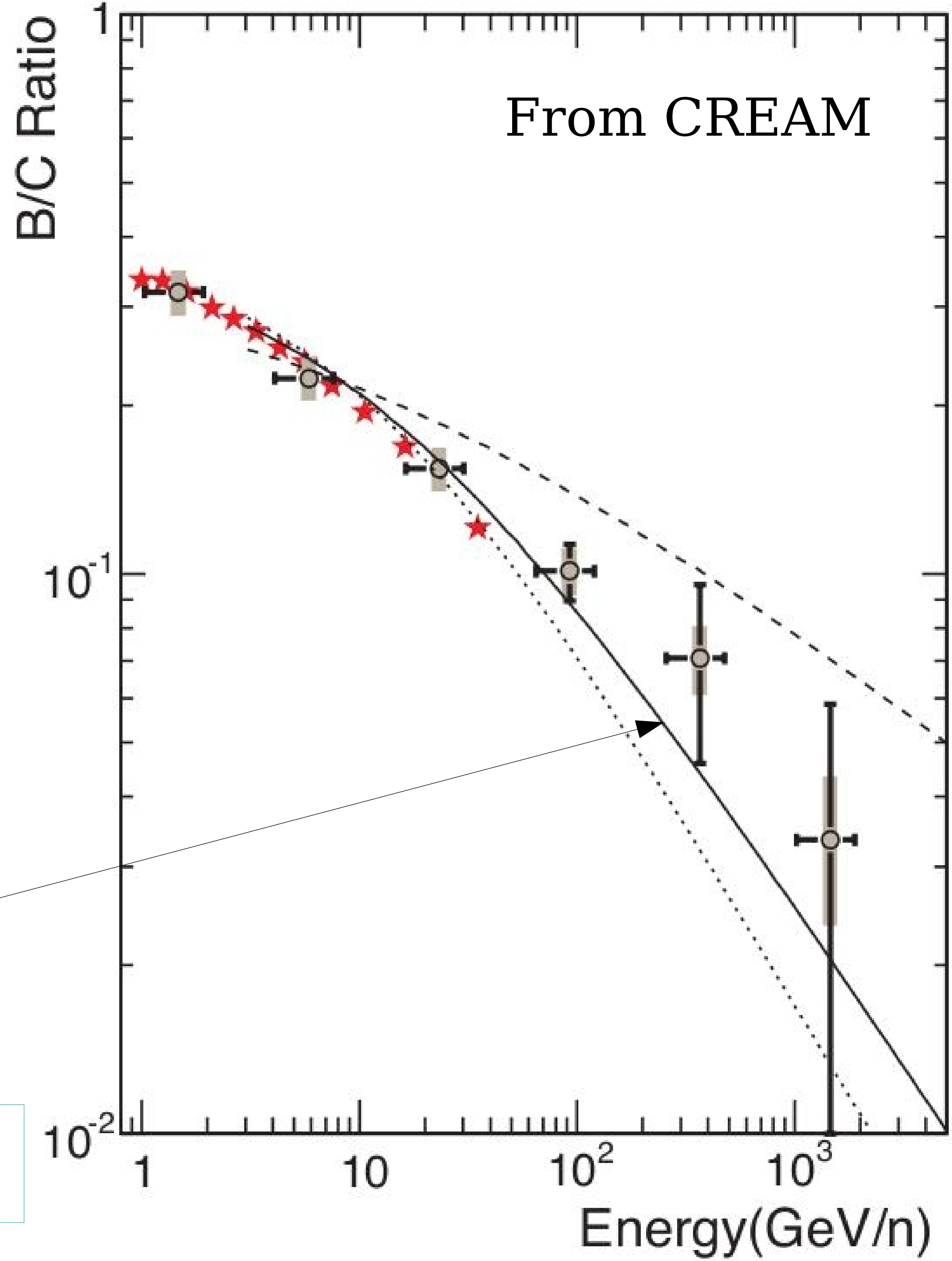


Figure 1. The relative abundance distribution of the elements in the cosmic radiation and in the solar system (normalized to Si = 100) from He to Ni (solid circles, 70–280 MeV per nucleon; open circles, 1000–2000 MeV per nucleon; open diamonds, solar system abundance distribution). [*Reproduced with permission from J. A. Simpson (1983)*. Ann. Rev. Nucl. Part. Sci. 33 *by Annual Reviews, Inc.*].

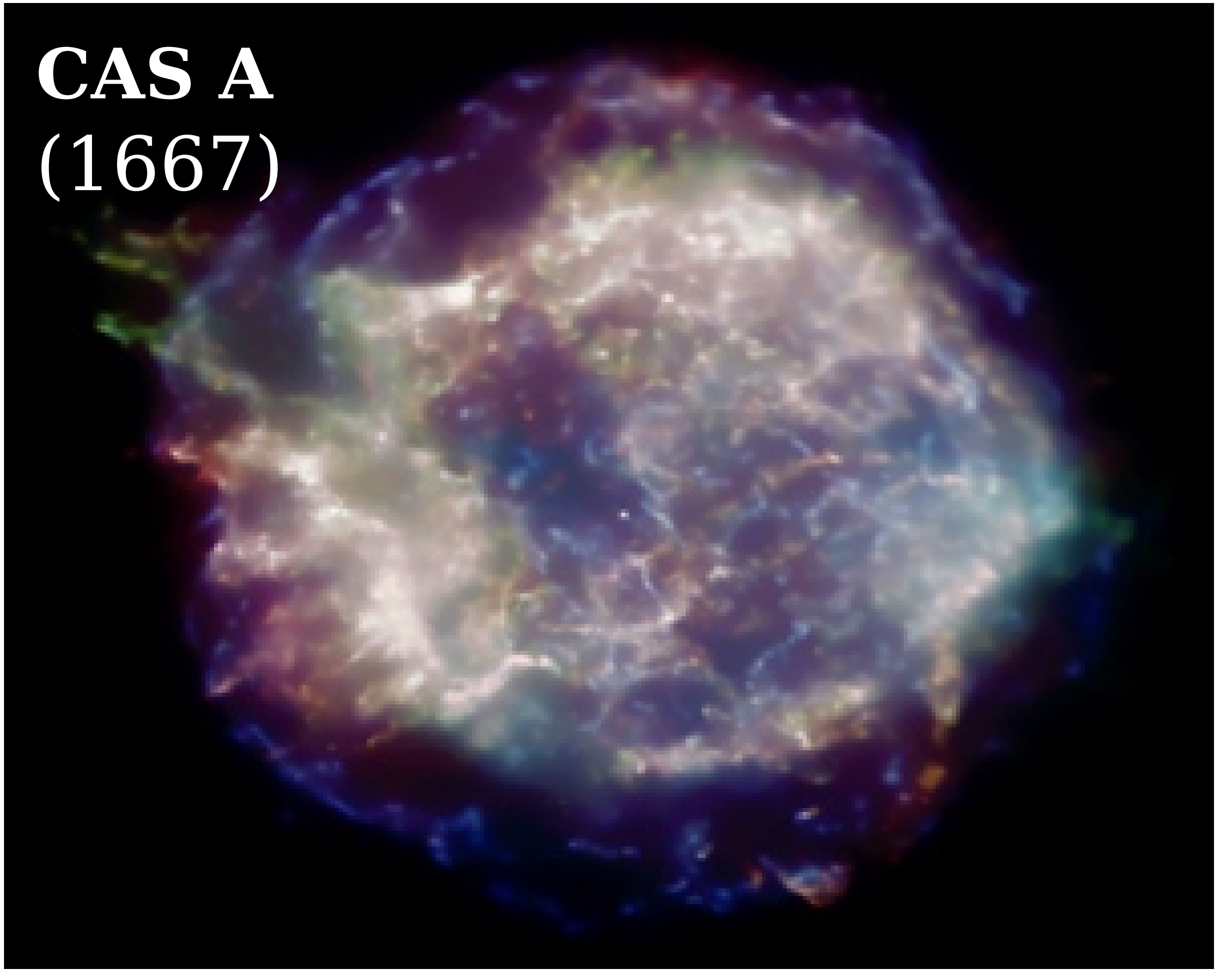




tau(E) ~ E$^{-0.6}$

Atomic clocks [Be-10]

The SuperNova "Paradigm" for CR acceleration



Powering the galactic Cosmic Rays

$$L_{\rm cr}(\text{Milky Way}) \simeq \frac{\rho_{\rm cr}\, V_{\rm conf}}{T_{\rm conf}}$$

$$\simeq 2 \times 10^{41} \left(\frac{\rm erg}{\rm s}\right)$$

$$\simeq 5 \times 10^7 \; L_\odot$$

- ENERGETICS
- DYNAMICS [Diffusive Shock acceleration]

$$L_{\mathrm{SN\ kinetic}}^{\mathrm{Milky\ Way}} \simeq E_{\mathrm{SN}}^{\mathrm{Kinetic}} \, f_{\mathrm{SN}}$$

$$L_{\mathrm{SN\ kinetic}}^{\mathrm{Milky\ Way}} \simeq \left[1.6 \times 10^{51}\ \mathrm{erg}\right] \left[\frac{3}{\mathrm{century}}\right]$$

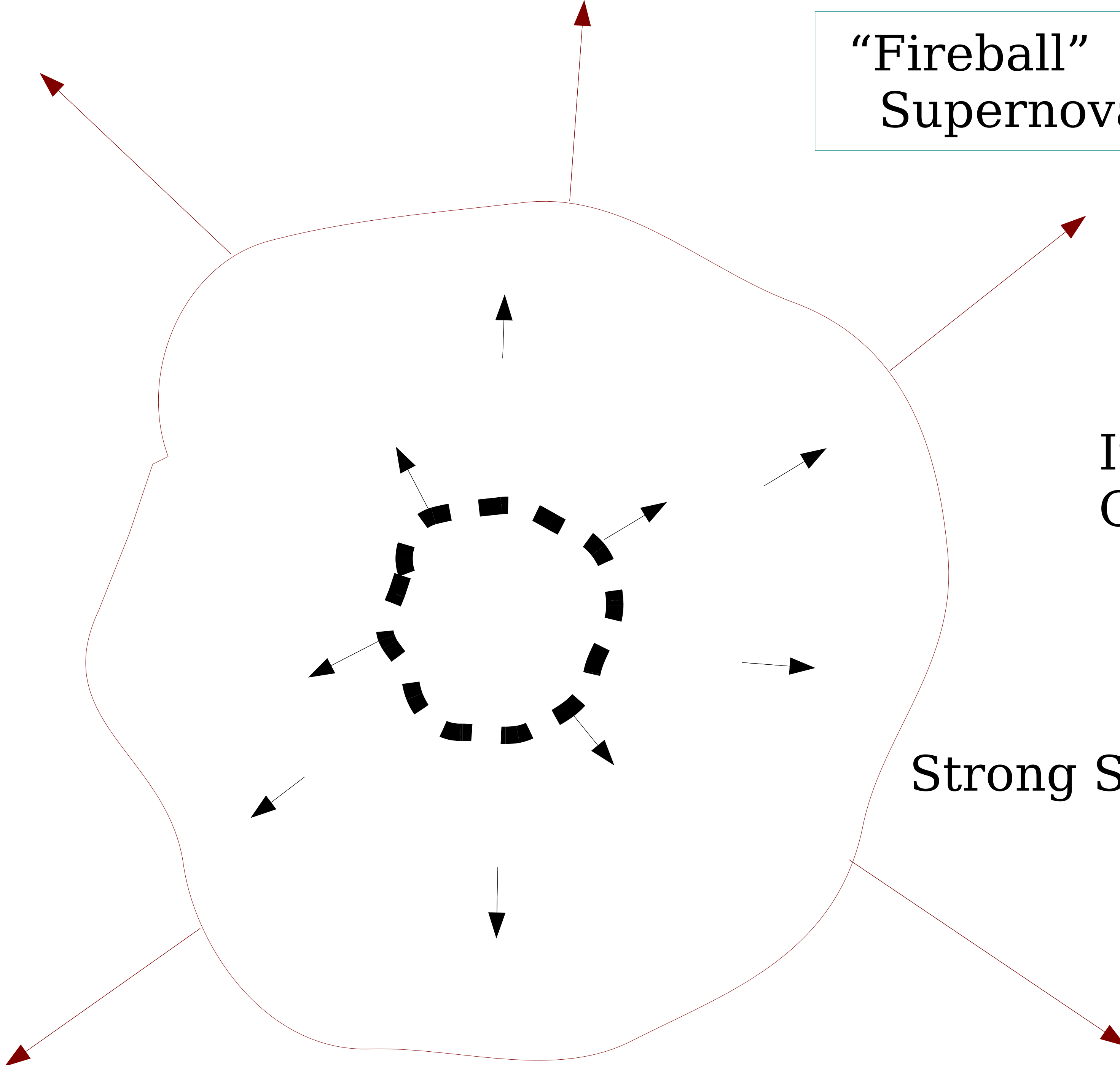
$$M = 5\ M_{\odot}$$

$$v \simeq 5000\ \mathrm{Km/s}$$

$$L_{\mathrm{SN\ kinetic}}^{\mathrm{Milky\ Way}} \simeq 1.5 \times 10^{42}\ \frac{\mathrm{erg}}{\mathrm{s}}$$

Power Provided by SN is sufficient
with a conversion efficiency of 15-20 %
in relativistic particles

“Fireball” of an Supernova explosion

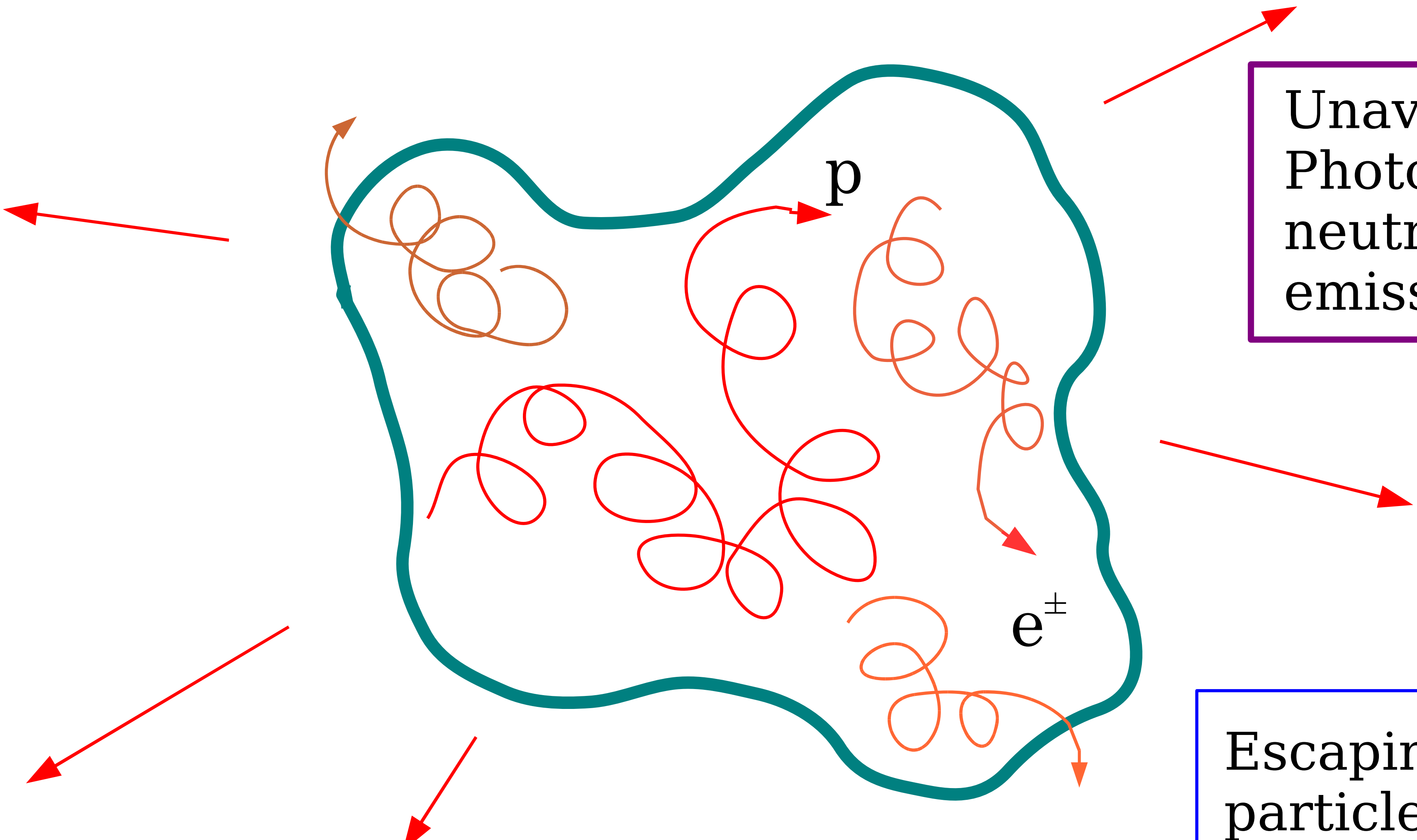


Fermi 1st order acceleration

$$q(E) \propto E^{-(2+\varepsilon)}$$

High Energy Astrophysical Source:

Object (or an “event”) that produces
(and for some time contains)
relativistic particles



Unavoidable
Photon,
neutrino
emission !

Escaping
particles: CR

$$p + \mathrm{target} \rightarrow \mathrm{many\ particles}$$

$$\rightarrow p(n) + \pi^{+} + \pi^{-} + \pi^{\circ}$$

$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$

$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \overline{\nu}_{\mu}$$

$$\pi^{\circ} \rightarrow \gamma + \gamma$$

"Hadronic Emission"

$$e^{\mp} + B \rightarrow e^{\mp} + \gamma_{\mathrm{synchrotron}}$$

"Leptonic Emission"

$$e^{\mp} + \gamma_{\mathrm{soft}} \rightarrow e^{\mp} + \gamma_{\mathrm{Inverse\ Compton}}$$

Multi-messenger Astrophysics

COSMIC RAY physics

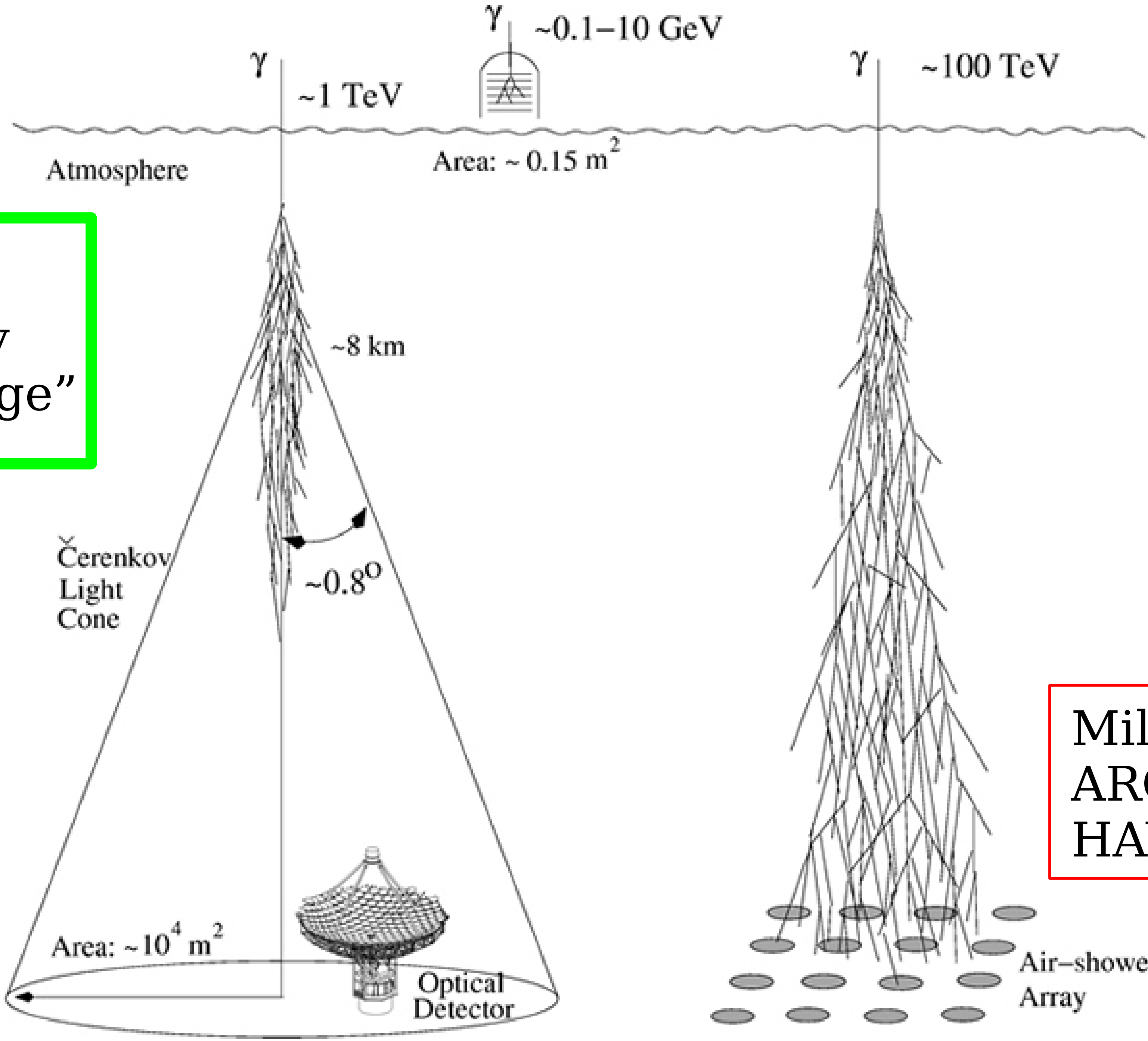
GAMMA Astronomy

NEUTRINO Astronomy

Accelerators associated with
Acceleration of astronomical masses.
Emission of Gravitational Waves

Egret
Agile
Fermi

Gamma
Astronomy
“Golden Age”



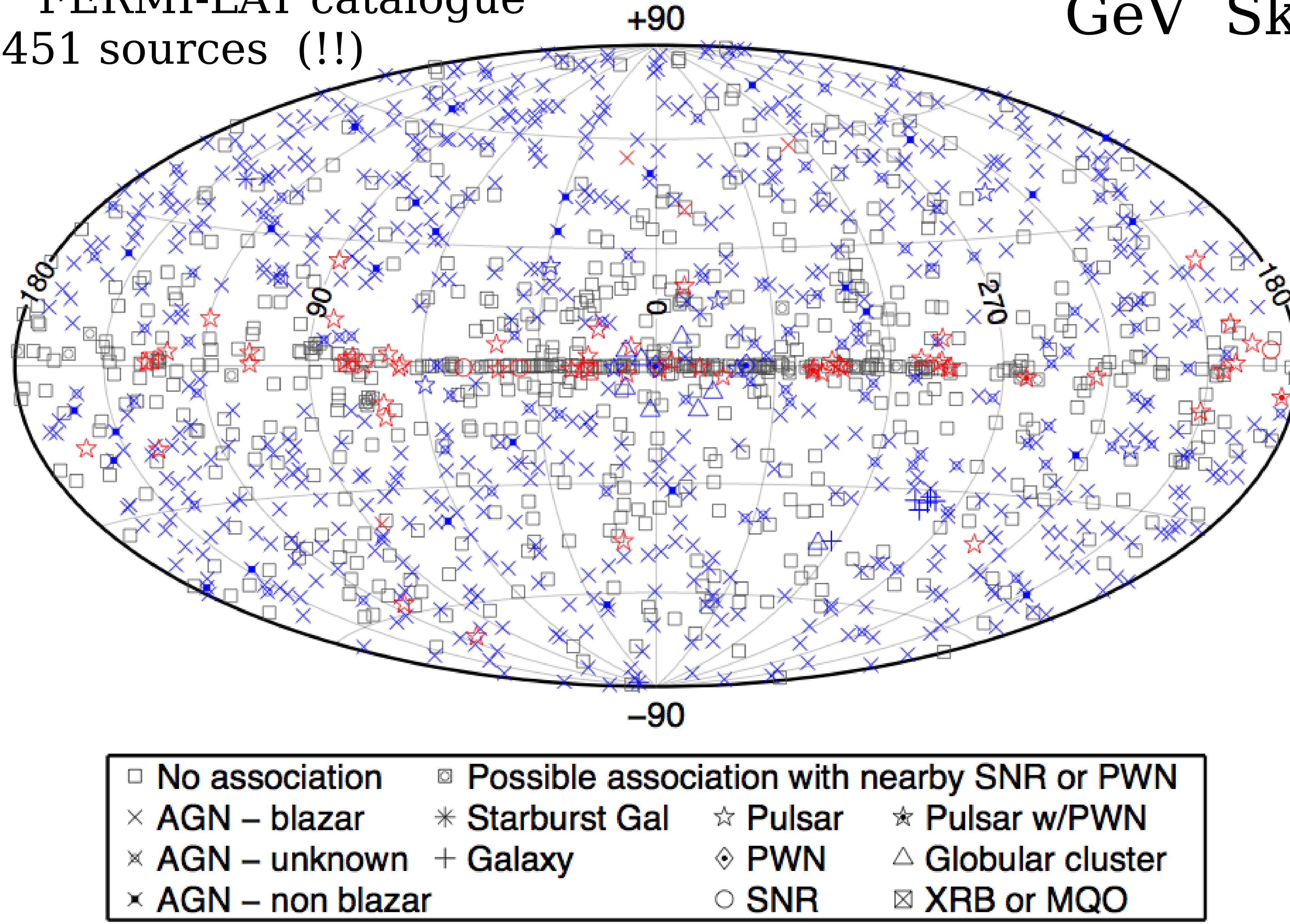
Milagro
ARGO
HAWC

Hess
Magic
Veritas

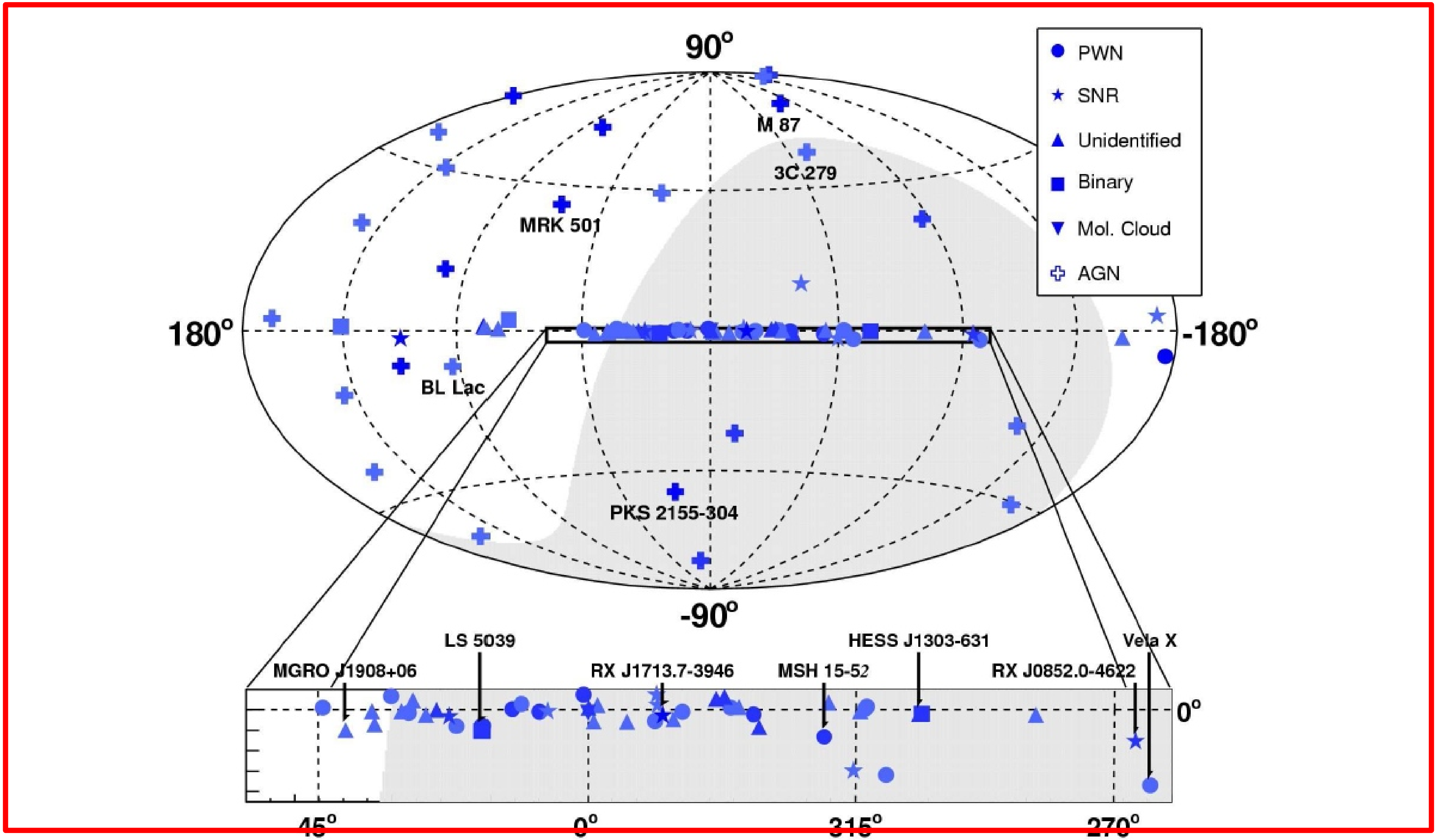
CTA

1st FERMI-LAT catalogue
1451 sources (!!)

GeV Sky

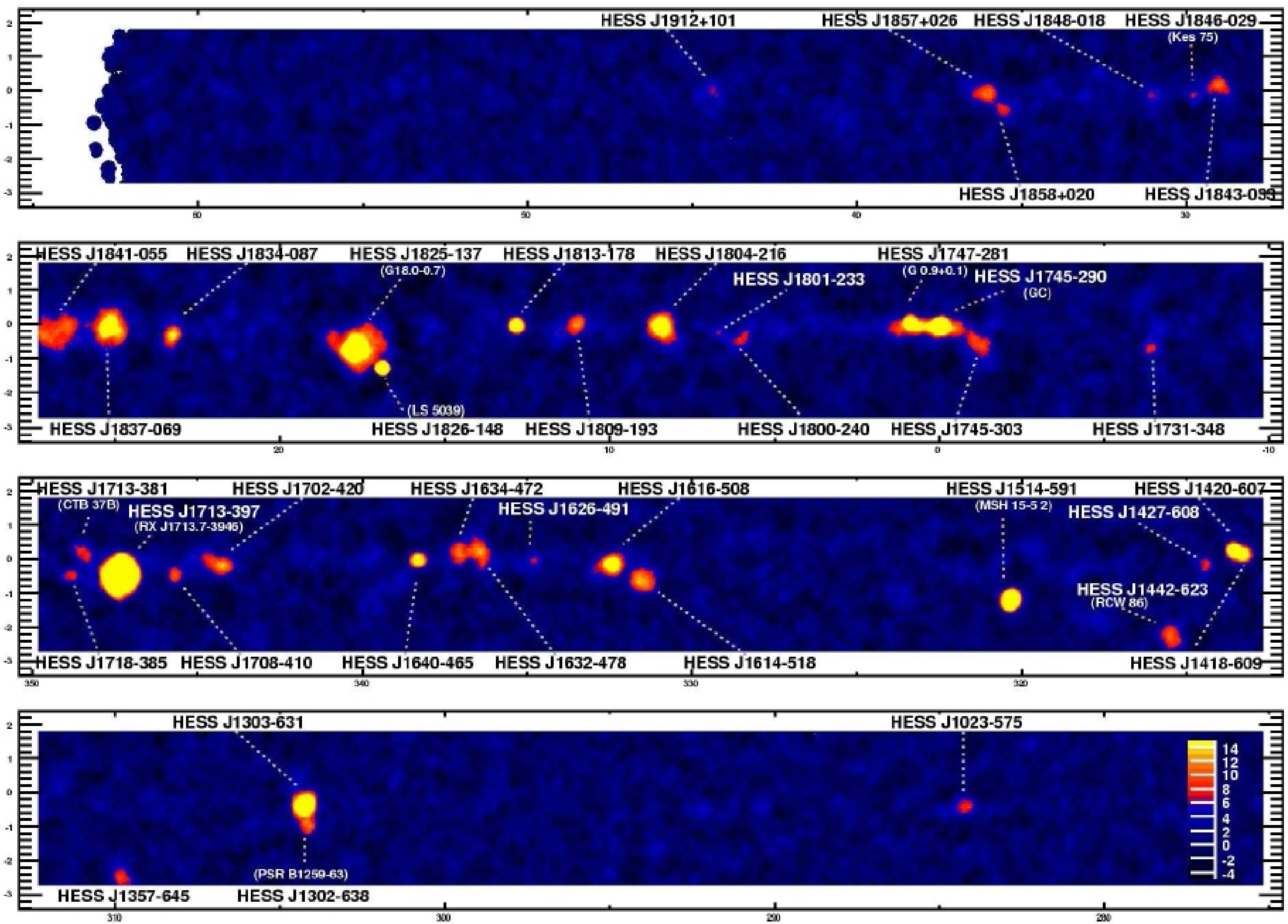


TEV SKY



The TeV sky is approaching 100 sources belonging to several different classes:

HESS scan of the Galactic plane



- PULSARS (PSR)
- Pulsar Wind Nebulae (PWN)
- Binary Systems
- SuperNova Remnant (SNR)
- Active Galactic Nuclei (AGN)
- Gamma Ray Bursts (GRB)

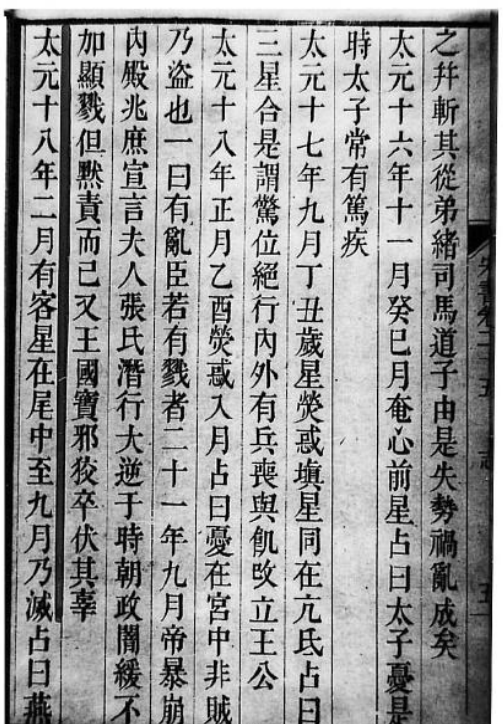
SuperNova 393A
RX J1713.7-3946

Observed in AD 393
By chinese court astromers
22-october, 19-november

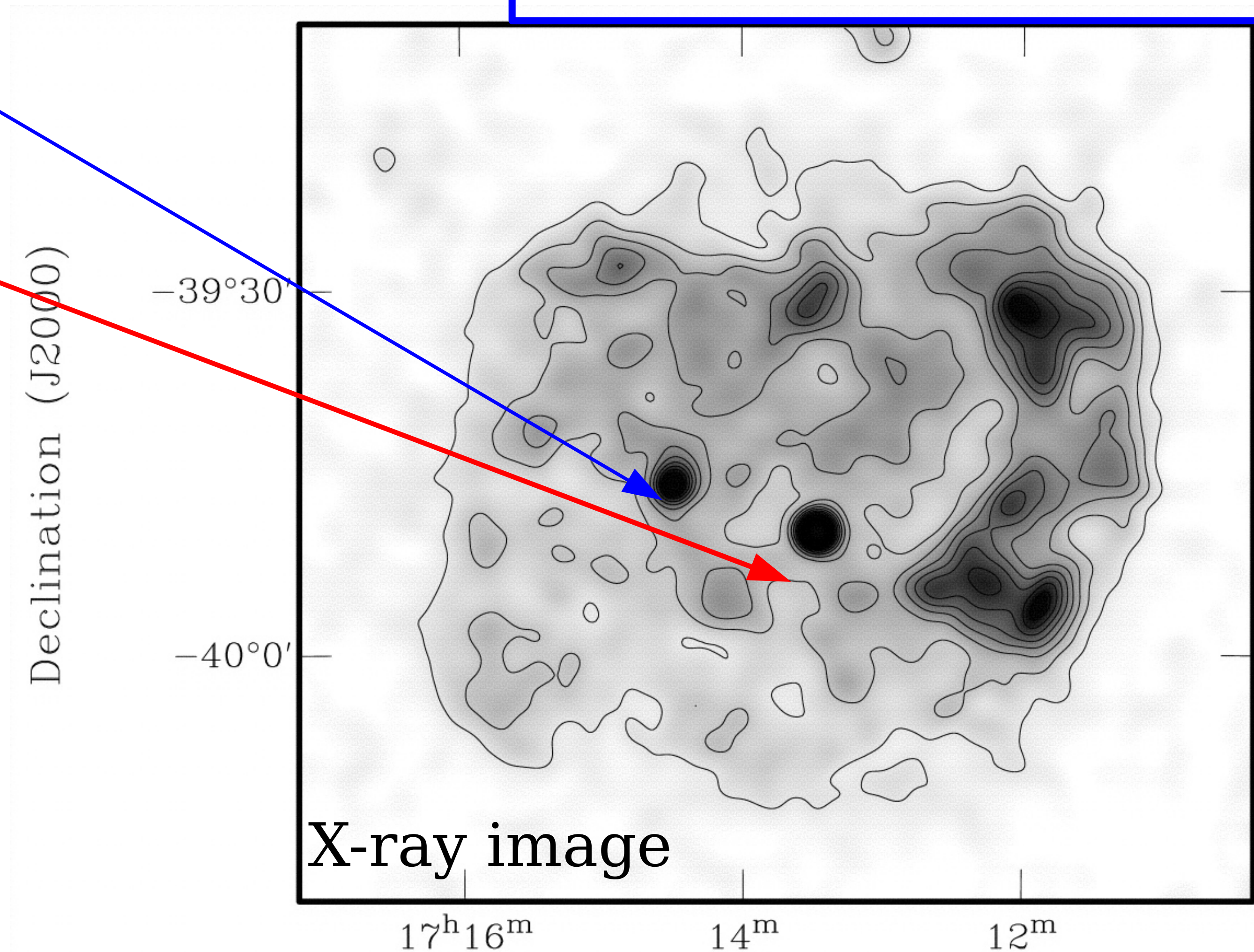
(Re)-discovered in 1996
by the Roentgen Satellite

Foreground
star

Neutron Star



之弁斬其從弟緒司馬道子由是失勢禍亂成矣
太元十六年十一月癸巳月奄心前星占曰太子憂是
時太子常有篤疾
太元十七年九月丁丑歲星熒惑塡星同在亢氐占曰
三星合是謂驚位絶行內外有兵喪與飢改立王公
太元十八年正月乙酉熒惑入月占曰憂在宮中非賊
乃盜也一曰有亂臣若有戮者二十一年九月帝暴崩
內殿兆庶宣言夫人張氏潛行大逆于時朝政闇緩不
加顯戮但默責而已又王國寶邪狡卒伏其辜
太元十八年二月有客星在尾中至九月乃滅占曰燕

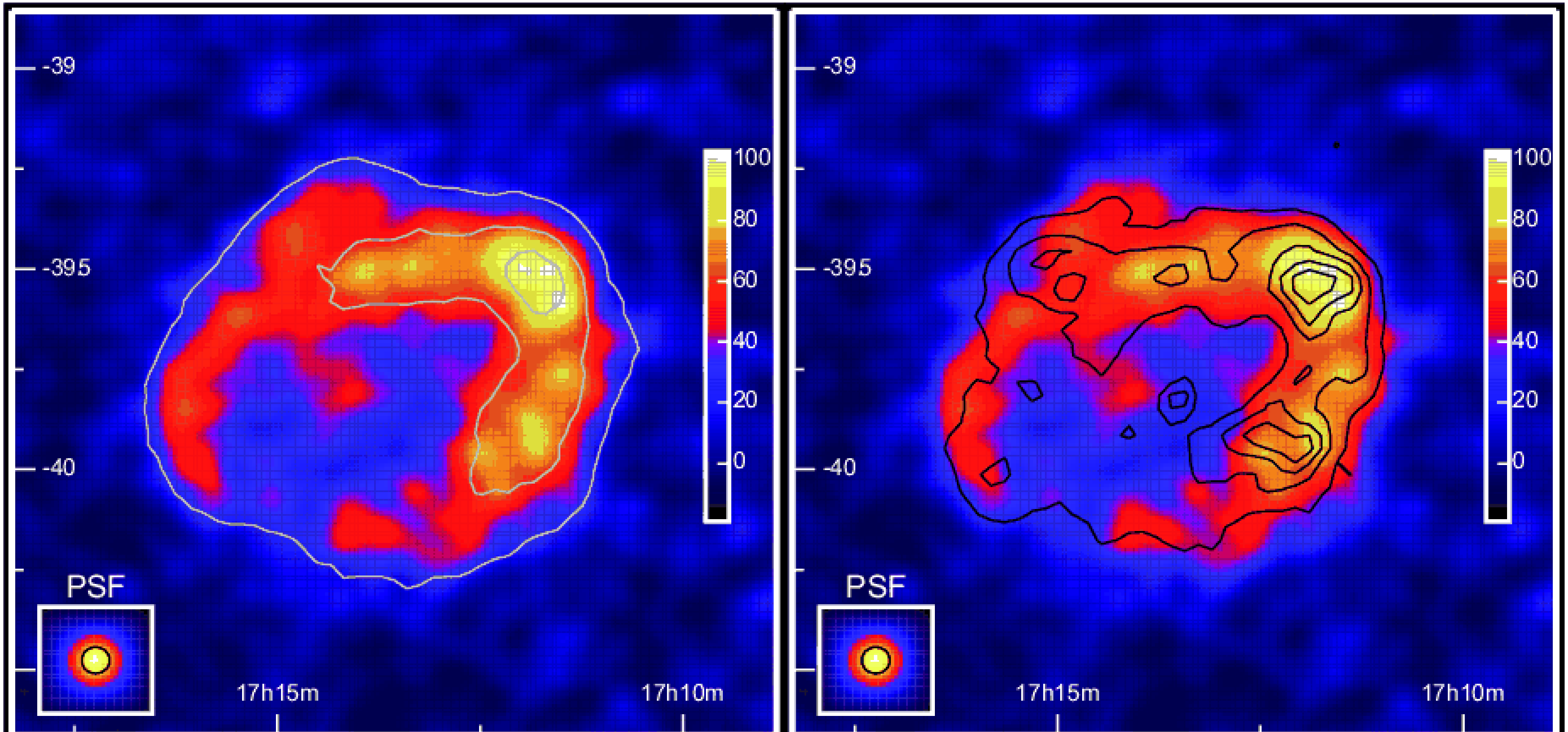


Detected in 2004 by HESS in TeV gamma rays

HESS Telescope

Observations with TeV photons

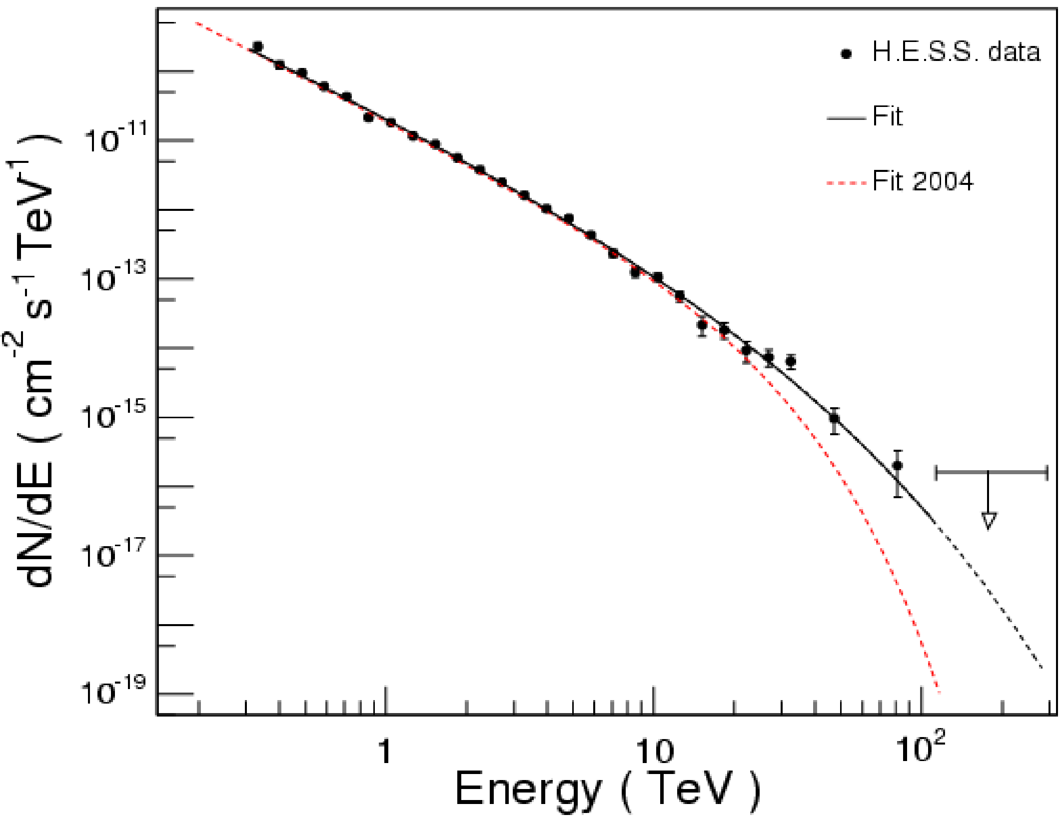
SuperNova RX J1713.7-3946



Comparison with ROSAT observation

Energy Spectrum

$$\phi_\gamma(>1\ \mathrm{TeV}) = (1.47 \pm 0.17 \pm 0.37) \times 10^{-7}\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}$$



$$\phi_\gamma(E) = K\,E^{-\Gamma}$$

$$\Gamma = 2.19 \pm 0.09 \pm 0.15$$

Assuming: (p)

$$\frac{dN_\gamma}{dt} \propto N_p \times n_{\mathrm{target}} \times \sigma_{pp}\, c$$

Hess estimate

$$E^{\mathrm{tot}}_{\mathrm{relativistic}\ p} \simeq 0.2 \times 10^{51}\ \mathrm{erg}$$

> 10% of the explosion kinetic energy → Relativistic protons.

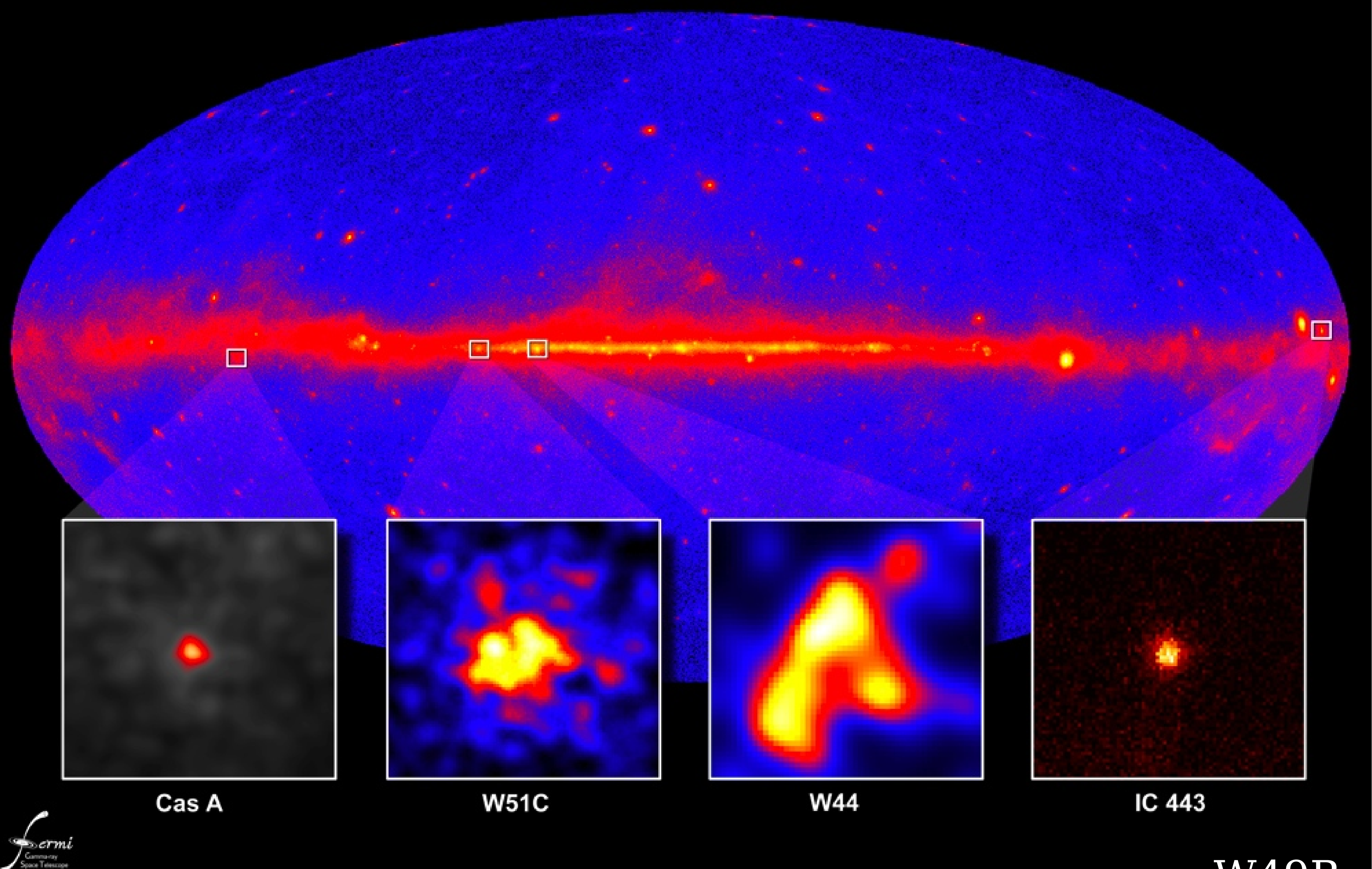
Have we proved that SNR are the source of the bulk of the Galactic Cosmic Rays ?

The evidence is accumulating.
Fermi, Hess results

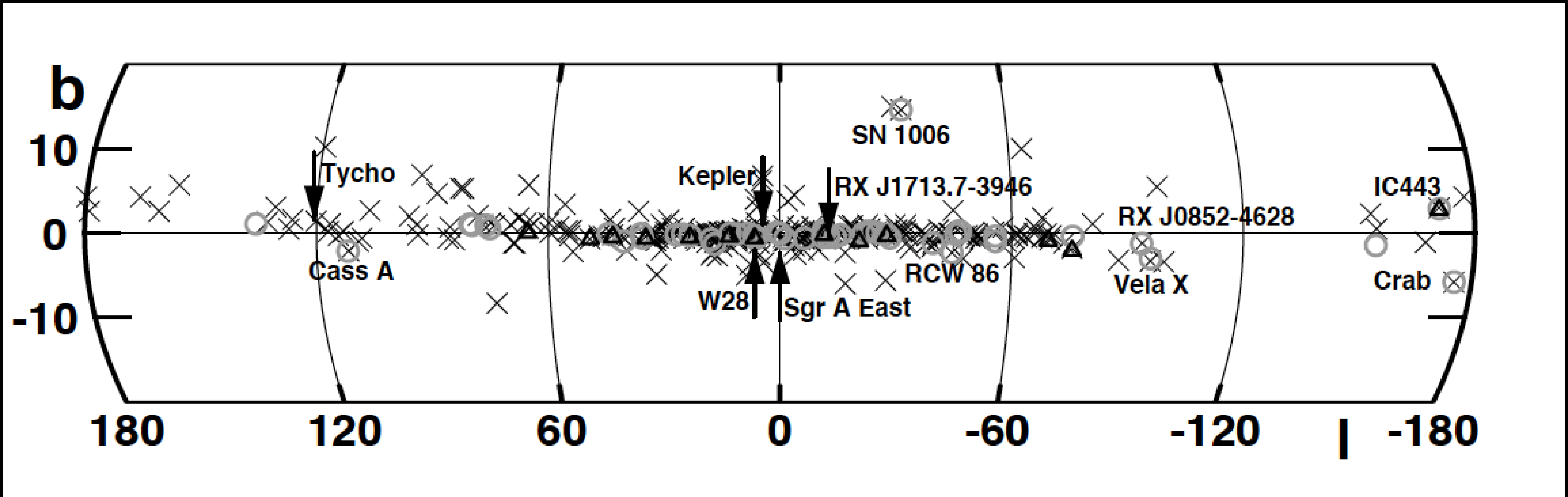
Perhaps case not closed...
[different opinions]

A picture more complex that the “simplest scheme” is probably emerging

NASA's Fermi telescope resolves supernova remnants at GeV energies



W49B



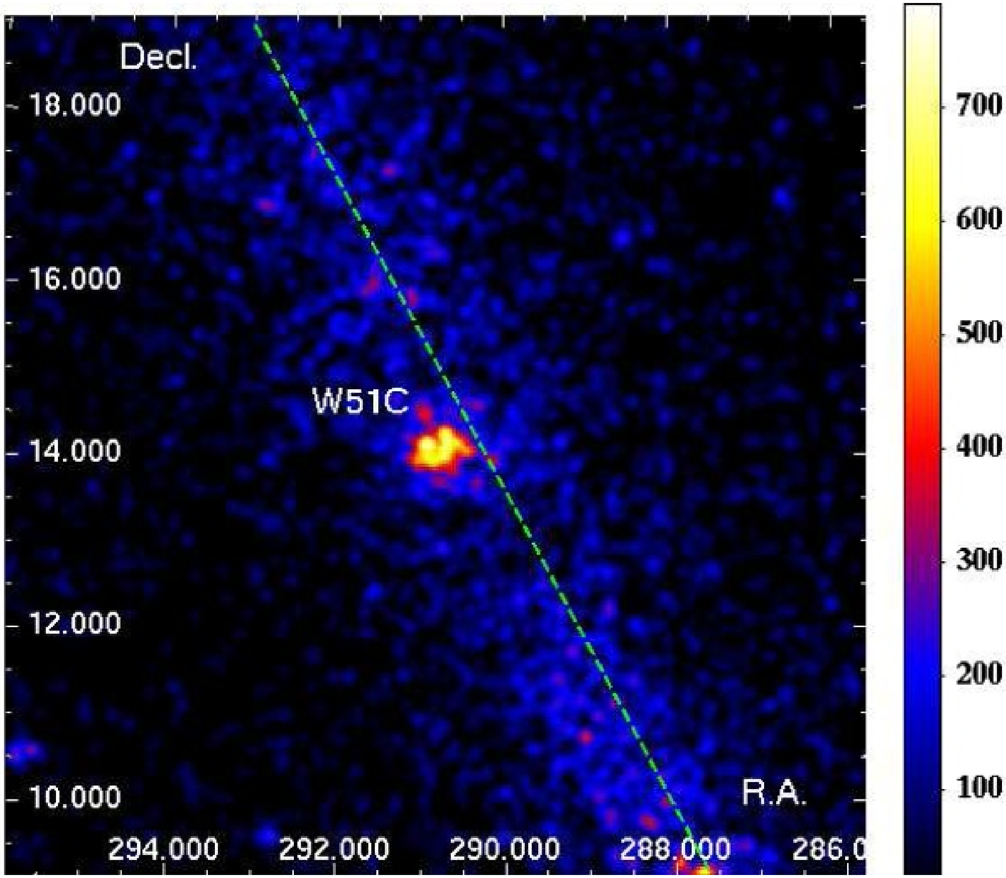
274 SNR remnants detected in radio (Green catalog)

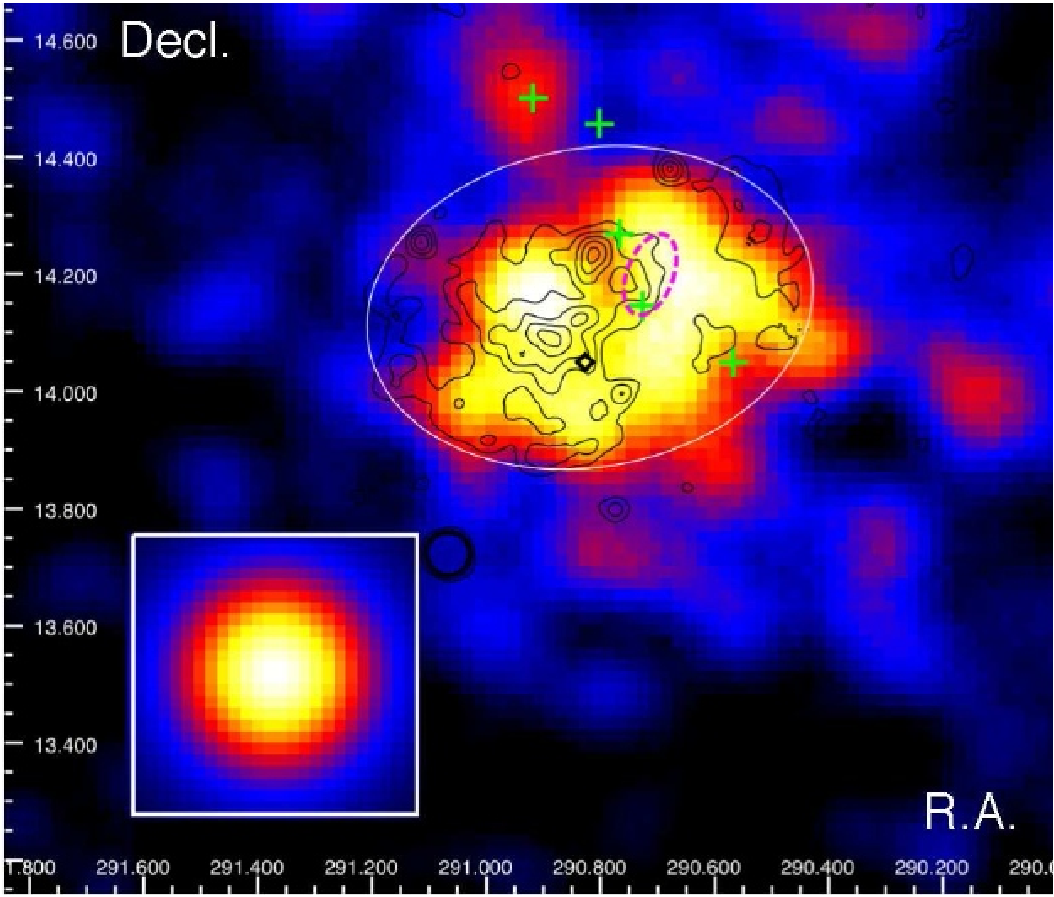
High energy gamma Rays detections.
Too few detections?
Properties as expected?

A. Letessier-Selvon, T. Stanev, "Ultrahigh Energy Cosmic Rays," [arXiv:1103.0031 [astro-ph.HE]].

SNR W51C

Fermi telescope map



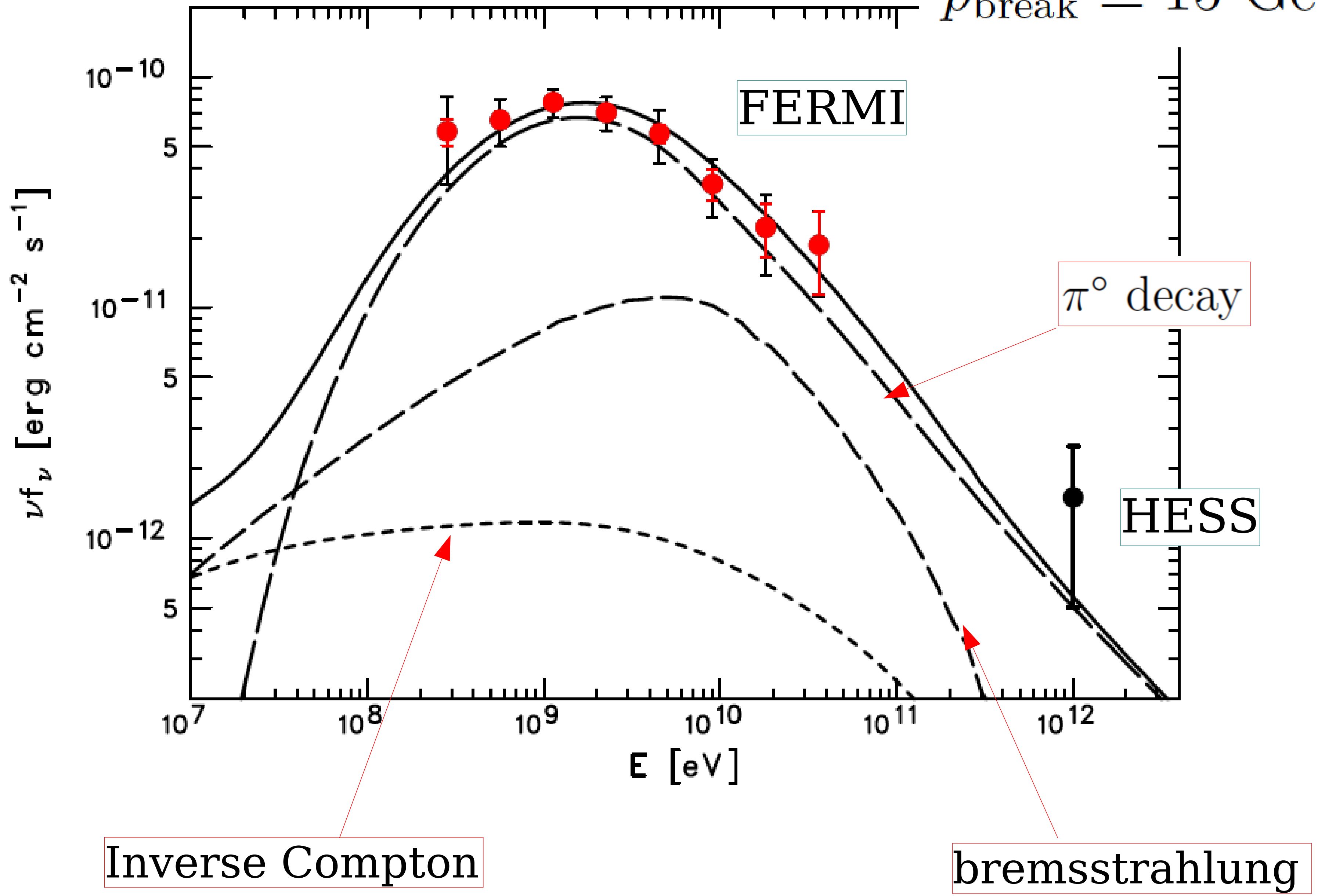


Galactic plane

SNR W51C

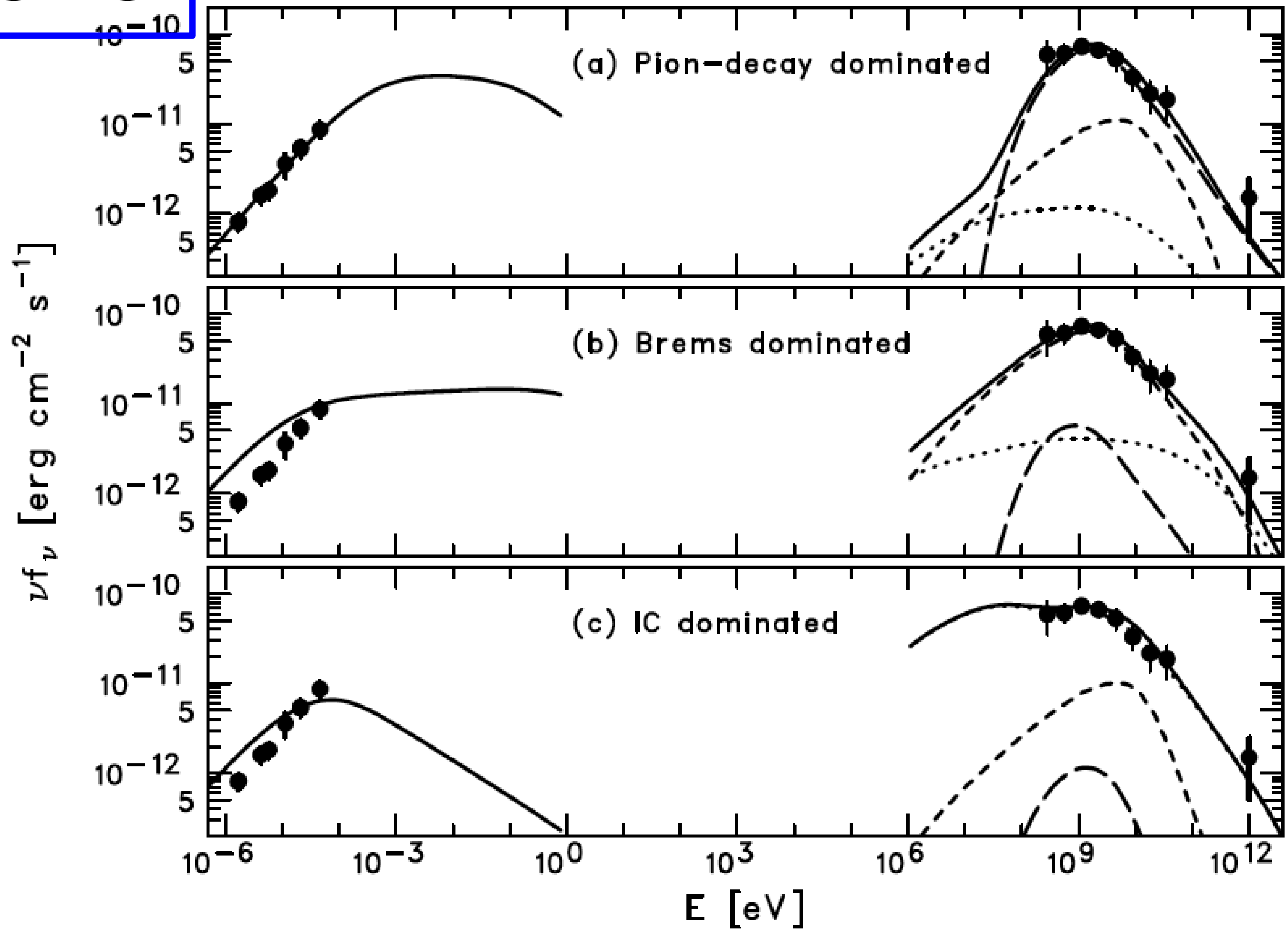
$$\bar{n}_{\rm H} W_p \simeq 5 \times 10^{51}\ (D/6\ {\rm kpc})^2\ {\rm erg\ cm}^{-3}$$

$$p_{\rm break} \simeq 15\ {\rm GeV}$$



SNR W51C

Alternative Interpretations



Model	Parameters					Energetics	
	a_e/a_p	Δs	$p_{\rm br}$ (GeV c^{-1})	B (μG)	$\bar{n}_{\rm H}$ (cm^{-3})	W_p (10^{50} erg)	W_e (10^{50} erg)
(a) π^0-decay	0.02	1.4	15	40	10	5.2	0.13
(b) Bremsstrahlung	1.0	1.4	5	15	10	0.54	0.87
(c) Inverse Compton	1.0	2.3	20	2	0.1	8.4	11

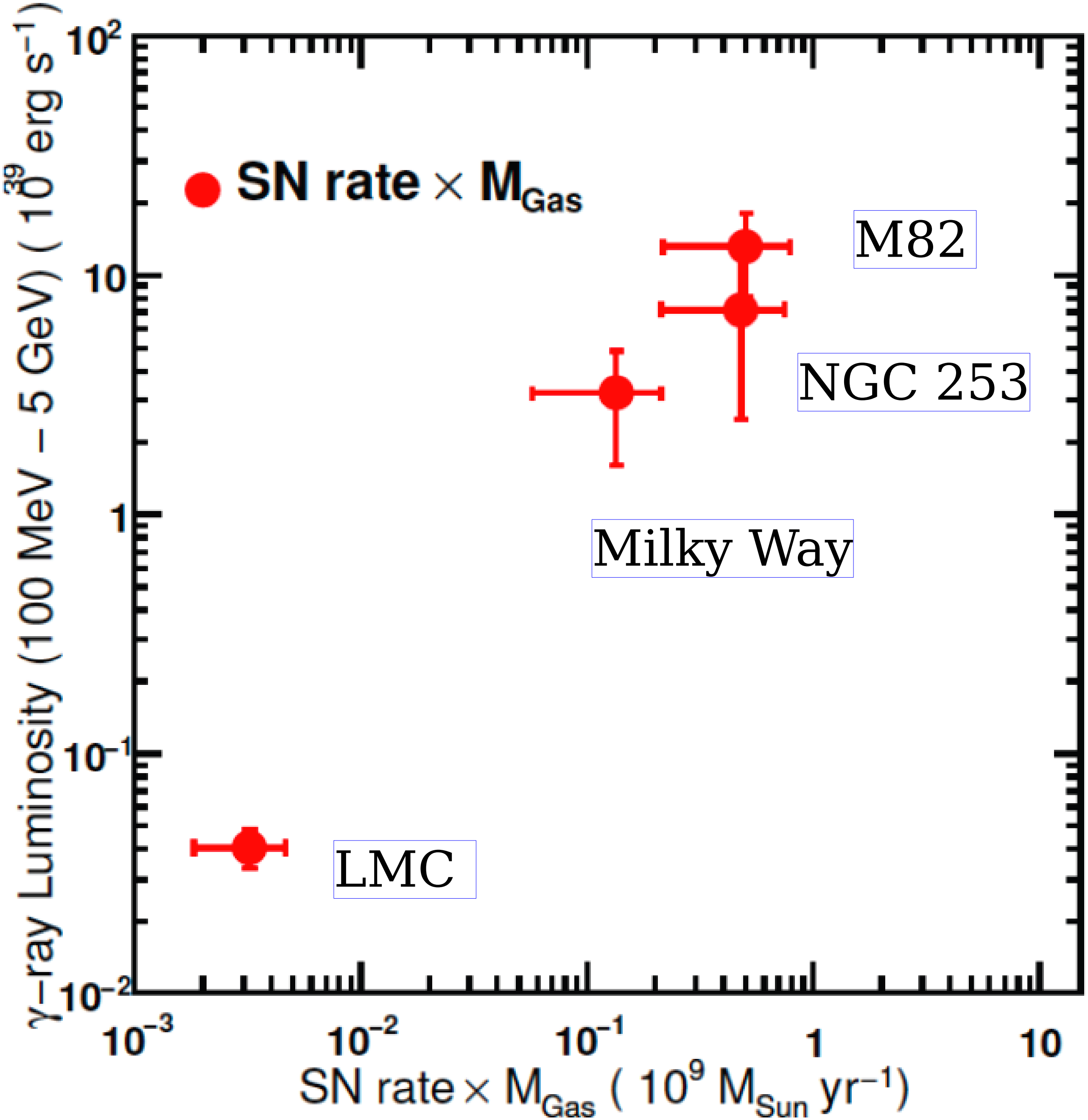
FERMI Telescope work:

Detection of Starburst galaxies

Gamma Ray Luminosities (> 100 MeV)

$$p + p_{\mathrm{ISM}} \rightarrow \pi^\circ$$

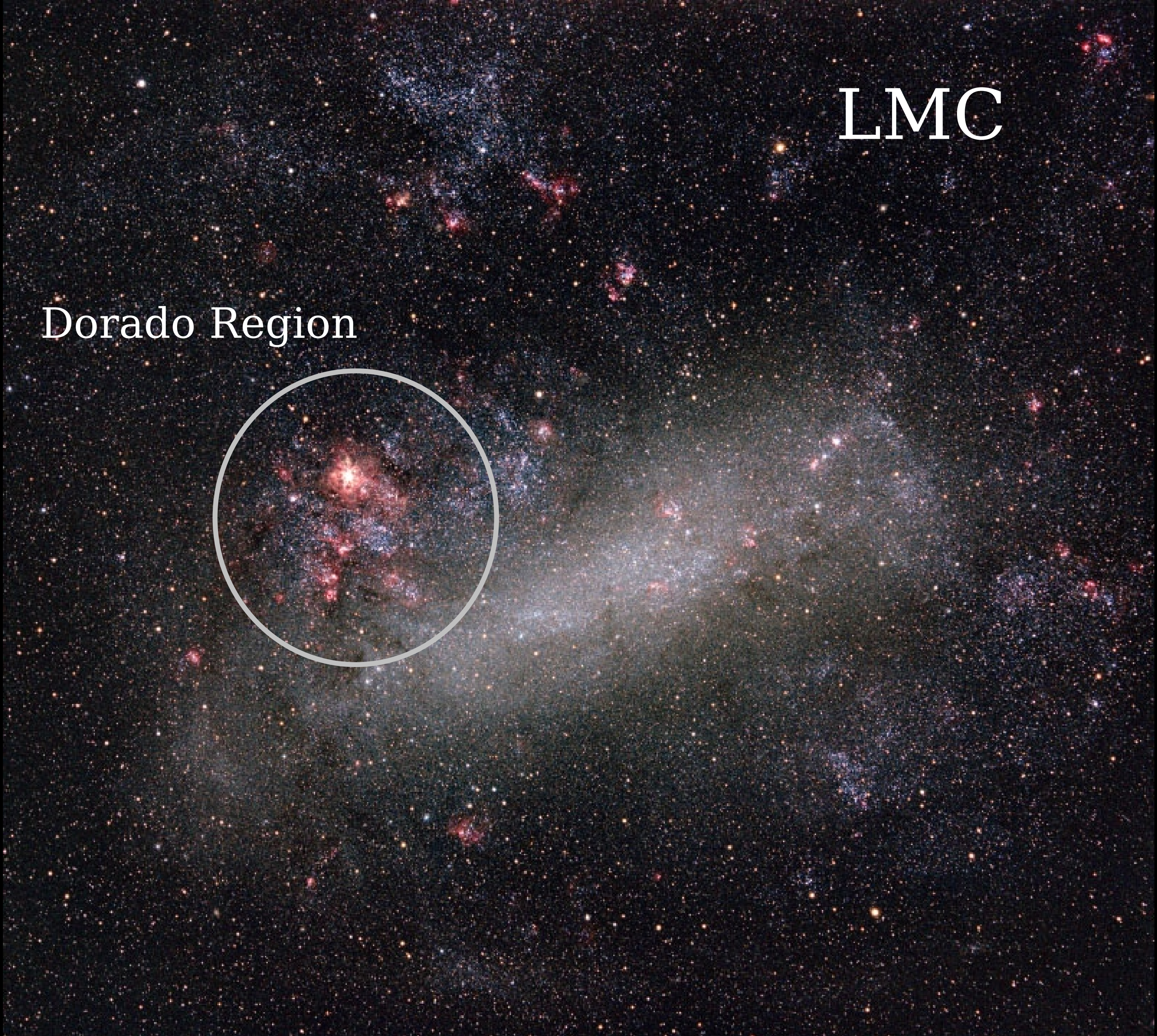
$$\pi^\circ \rightarrow \gamma\gamma$$



Determination of the Milky Way luminosity [consistent with π° Decay


M81, M82


M82


LMC
Dorado Region

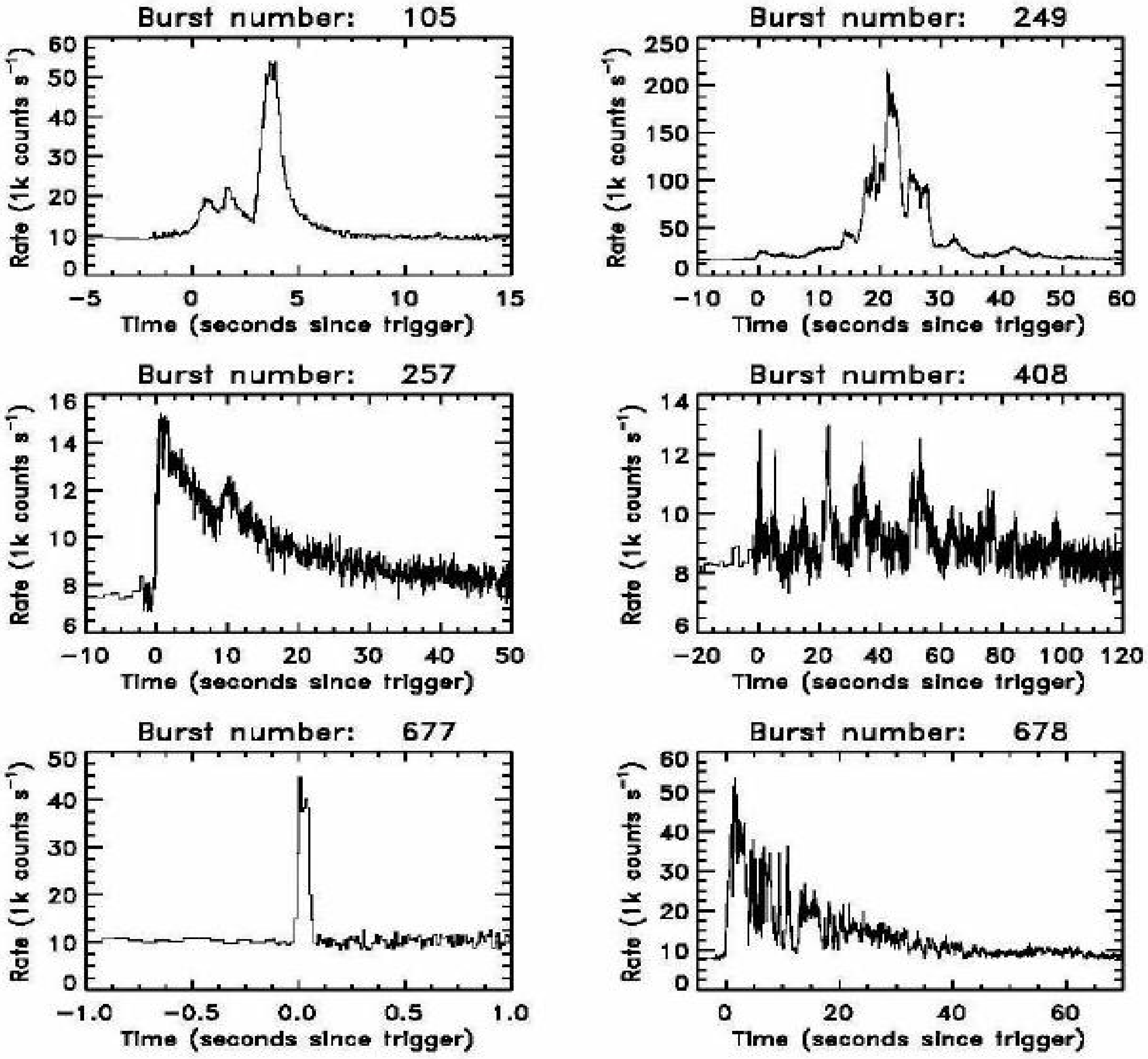
Bottom line:

The Acceleration of CR is very likely correlated
to the Star Formation Rate
(and therefore Star "Death" Rate)

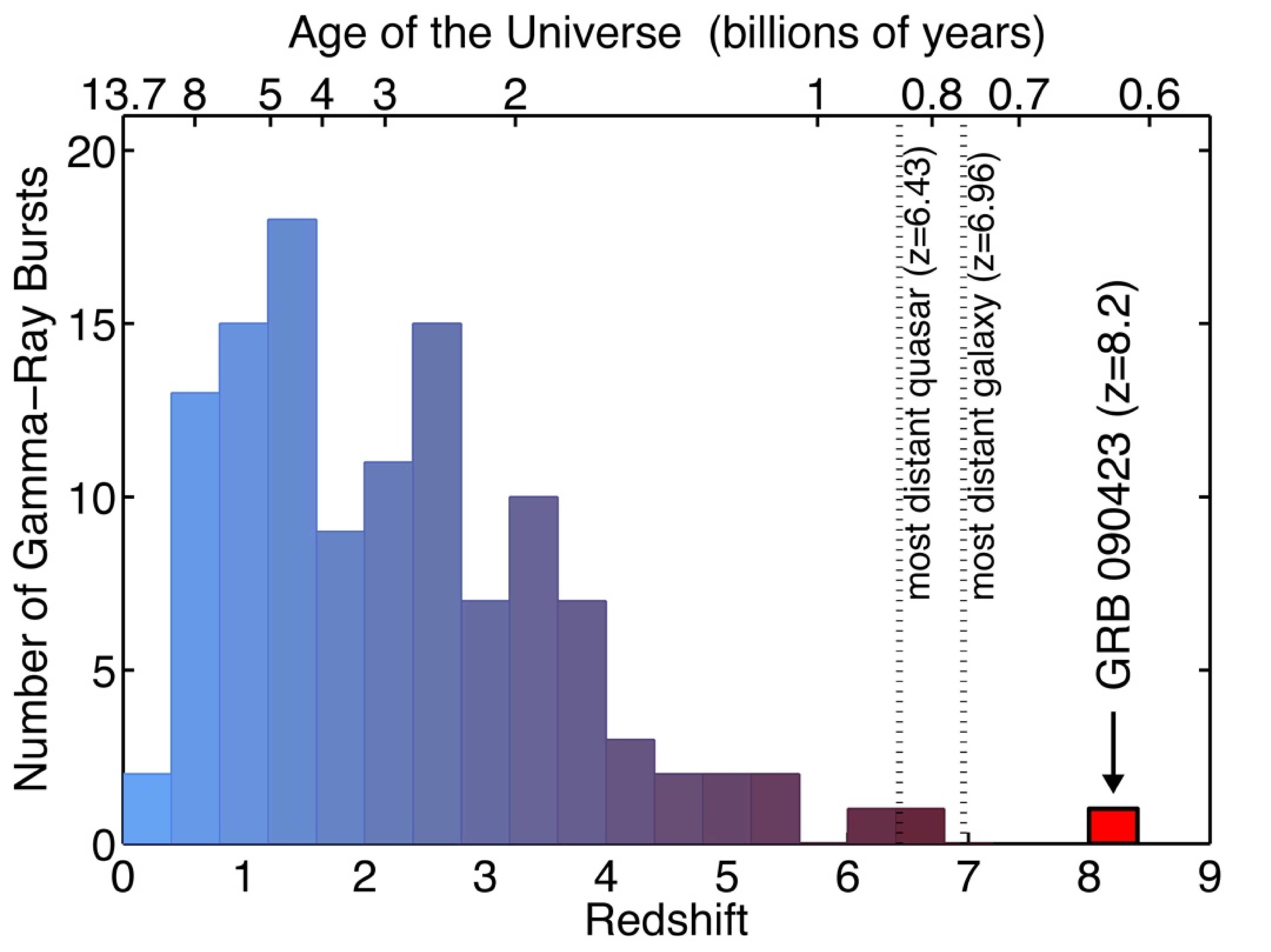
Compatible with the "standard scenario".

FERMI diffusive acceleration in SNR blast waves
is not the only possible solution.

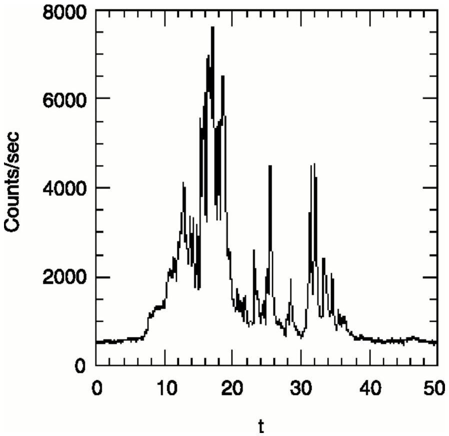
GAMMA RAY BURSTS (GRB's)



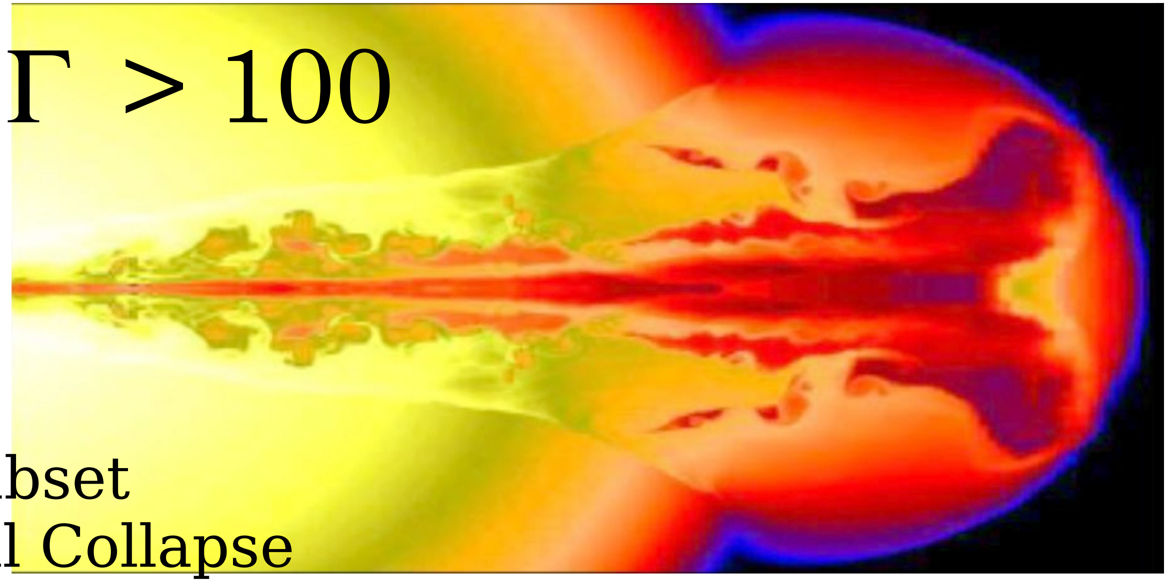
Proposed source
Of the CR



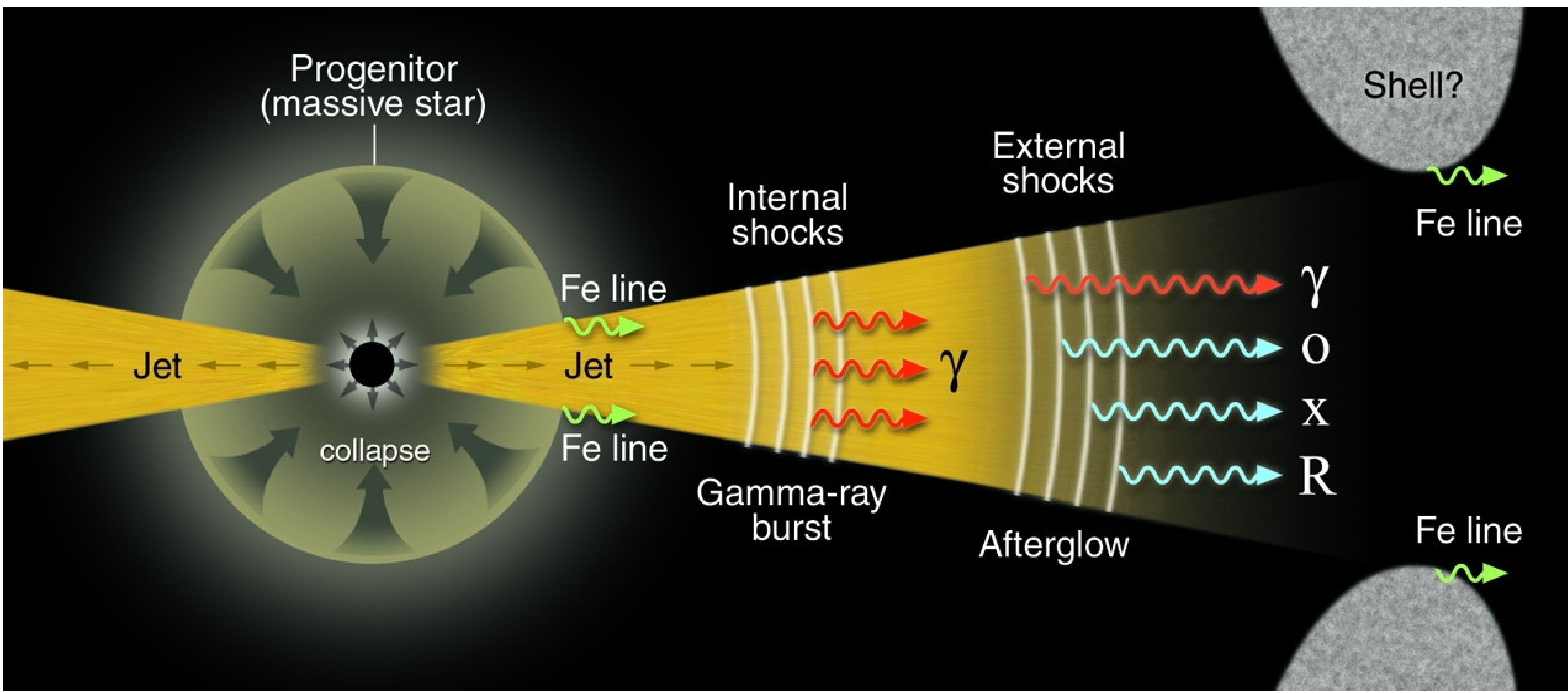
Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma−Ray Bursts
0
5
10
15
20
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
0
1
2
3
4
5
6
7
8
9
Redshift



$\Gamma > 100$

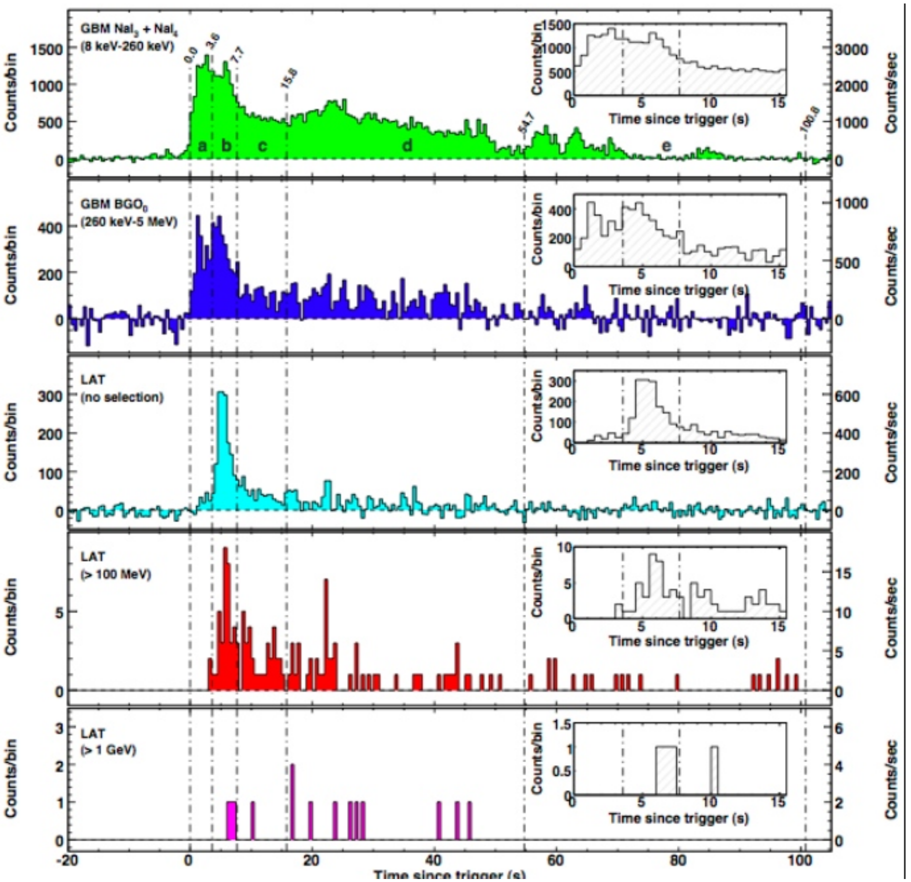


GRB : associated with a subset
of SN Stellar Gravitational Collapse



GRB 080916C
Z = 4.3
(Fermi)

Most Powerful emission
ever recorded
(assuming isotropy)

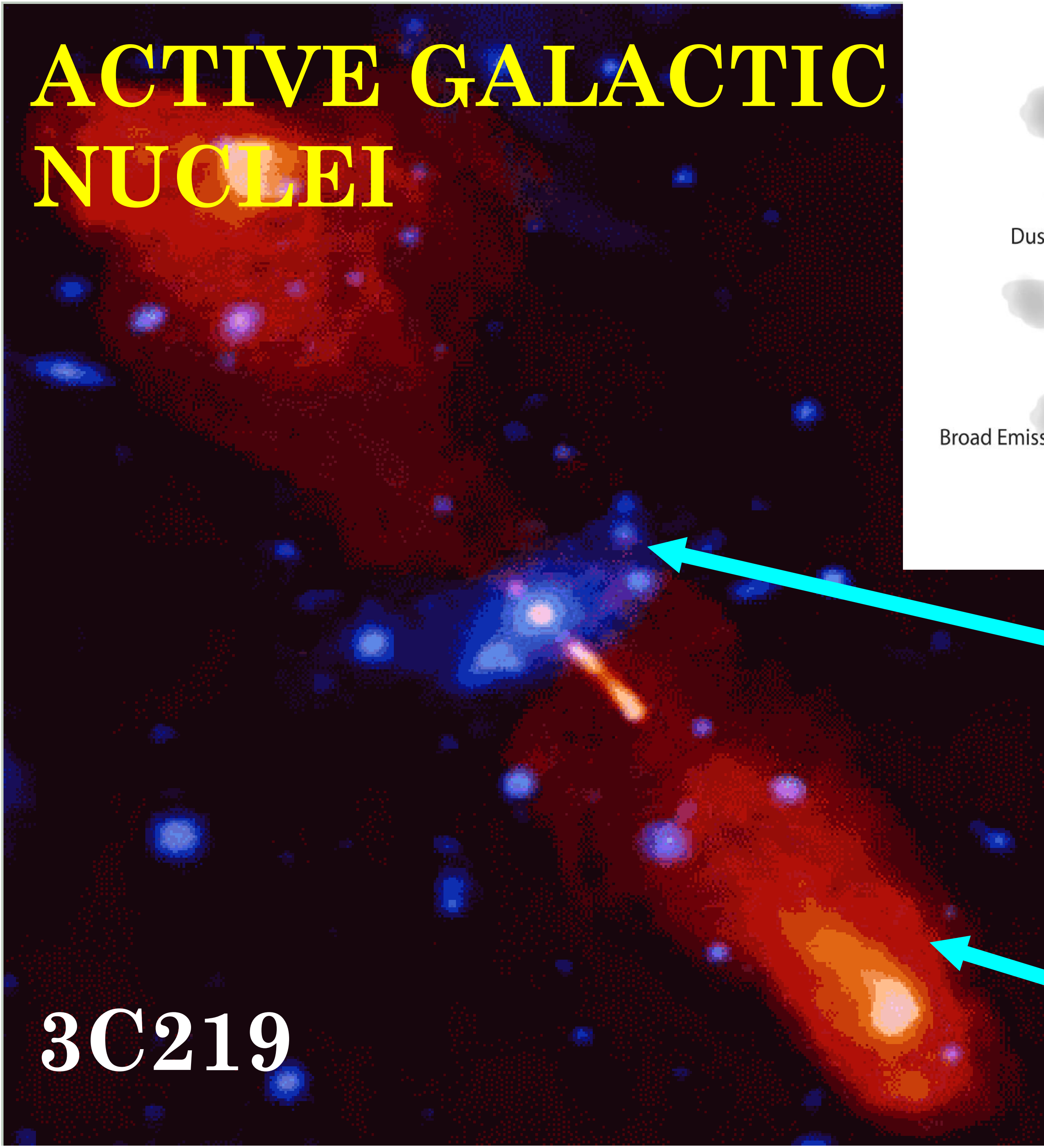


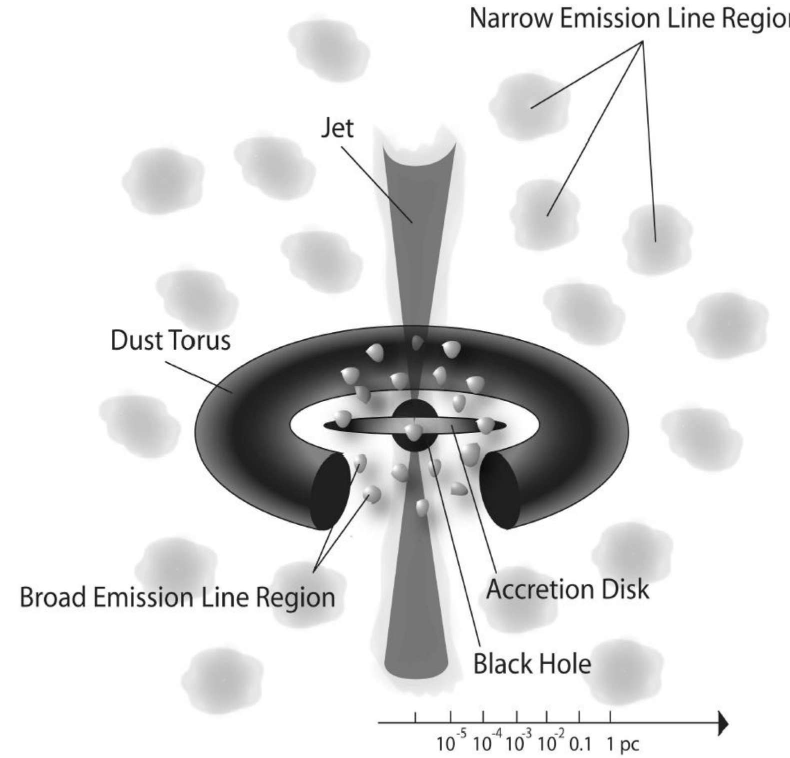
But:

A complete understanding of the mechanism
behind GRB's remains elusive.

Their possible role as the source of UHECR
(or even of ALL Cosmic Rays)
Remains only a speculation.

ACTIVE GALACTIC NUCLEI



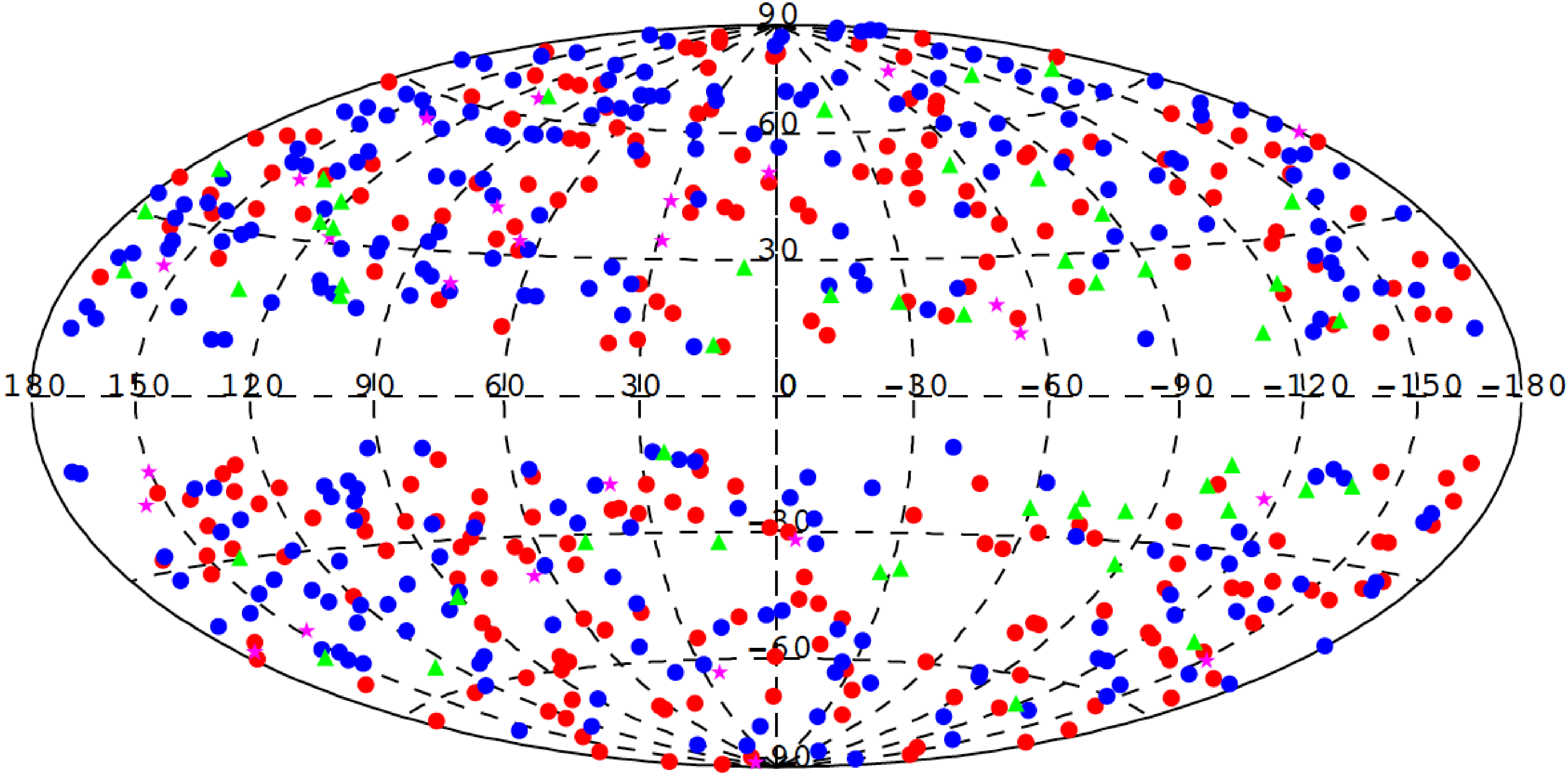


Optical

Radio

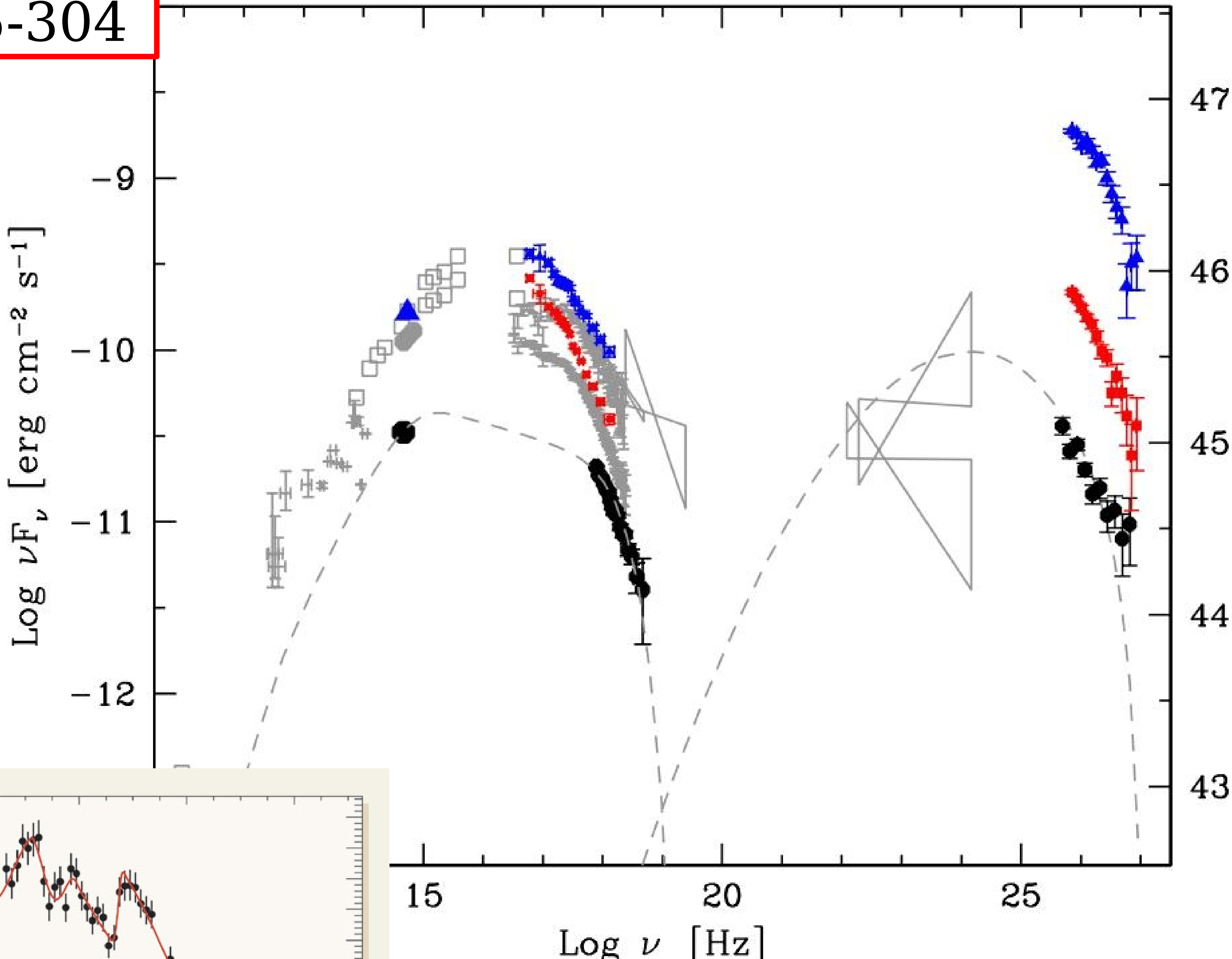
AGN observed by FERMI:

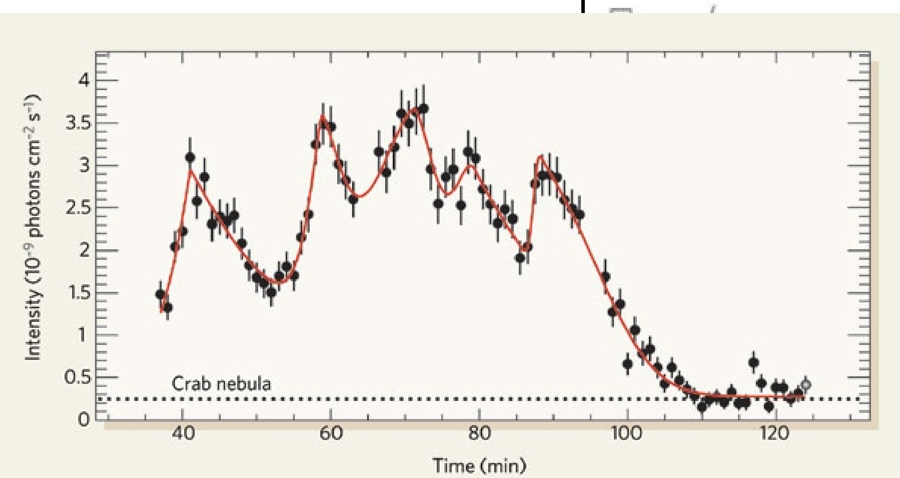
671 AGN's



Red: FSRQ
Blue: Blac
Magenta: Radio Galaxies

PKS 2155-304



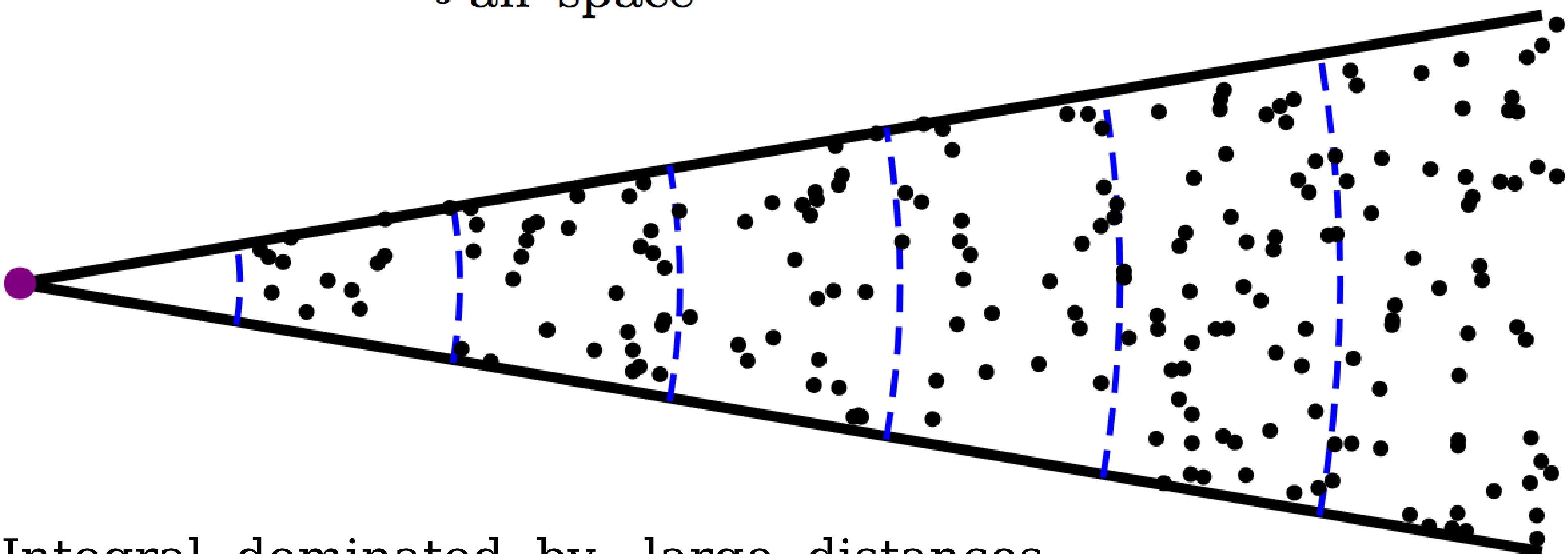


(Very rapid time variations)

INCLUSIVE Extra-Galactic Photon Flux

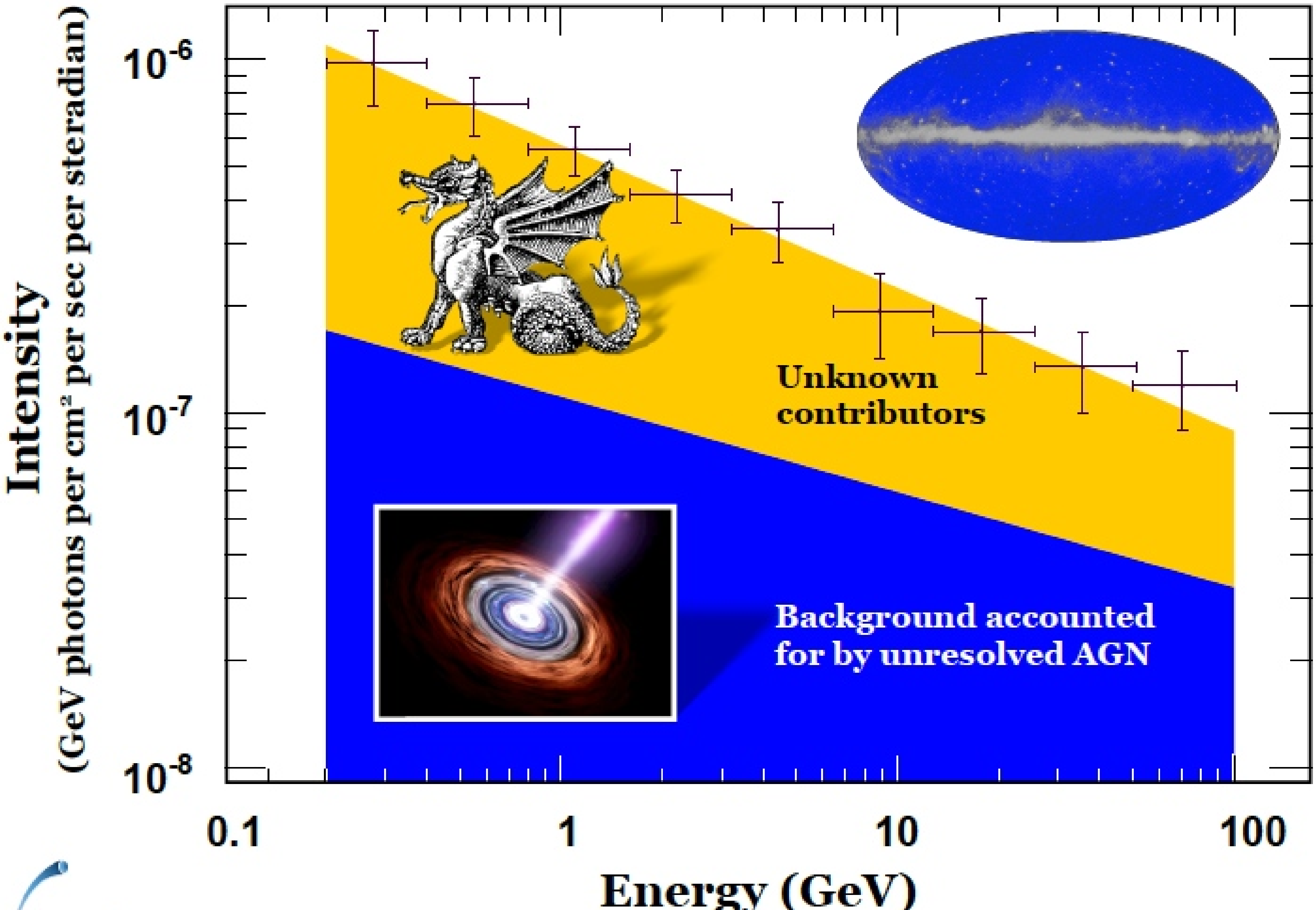
$$\phi_{\text{inclusive}} = \sum_{\text{all sources}} \phi_{\text{single source}}$$

$$\phi_{\text{inclusive}} = \int_{\text{all space}} d^3r \; \phi_{\text{source}}(\vec{r})$$

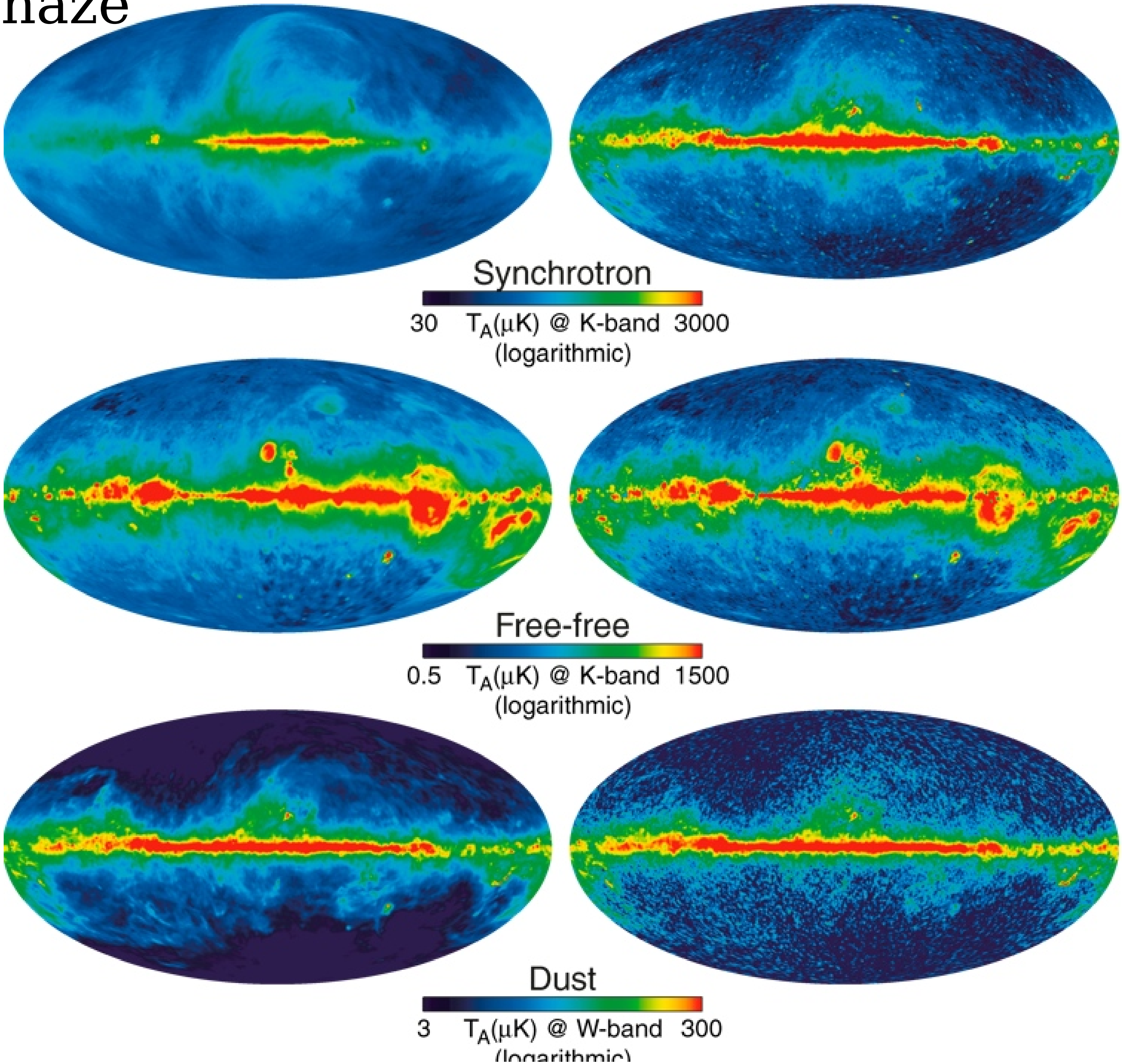


Integral dominated by large distances

Fermi LAT Extragalactic Gamma-ray Background

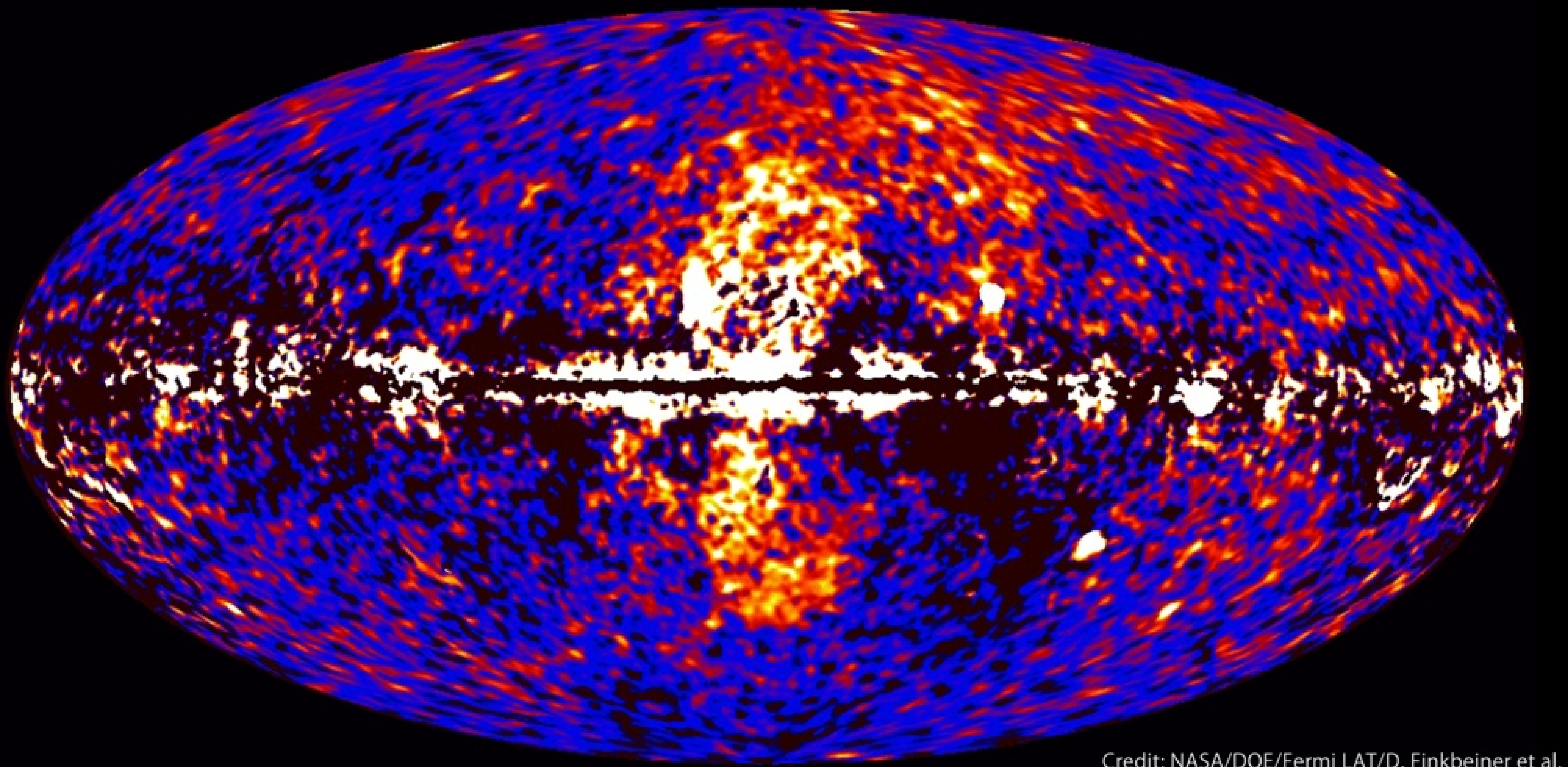


WMAP “haze”


Synchrotron
30 T_A(μK) @ K-band 3000
(logarithmic)
Free-free
0.5 T_A(μK) @ K-band 1500
(logarithmic)
Dust
3 T_A(μK) @ W-band 300

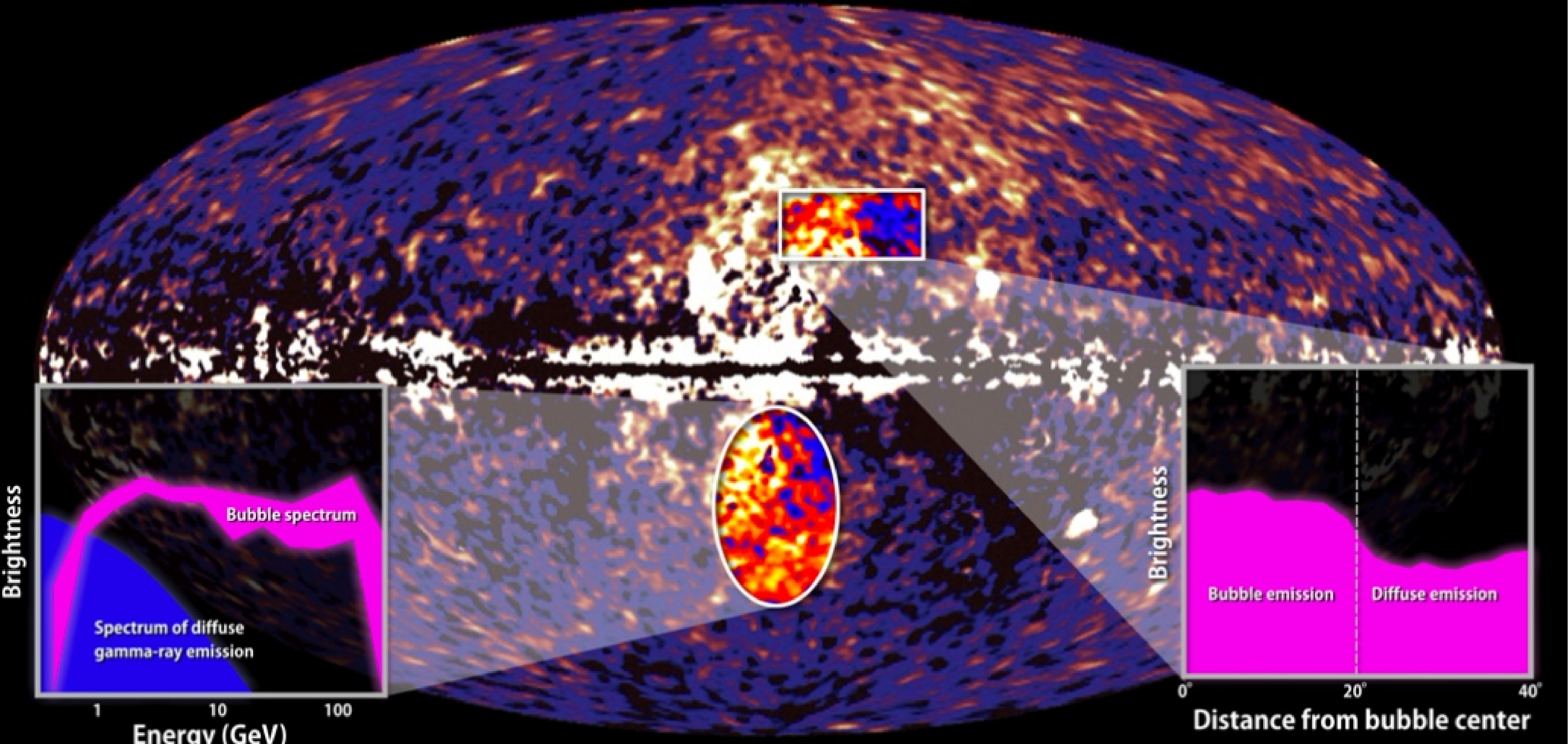
Scientific American news. Title:

Hidden in Plain Sight: Researchers Find Galaxy-Scale Bubbles Extending from the Milky Way

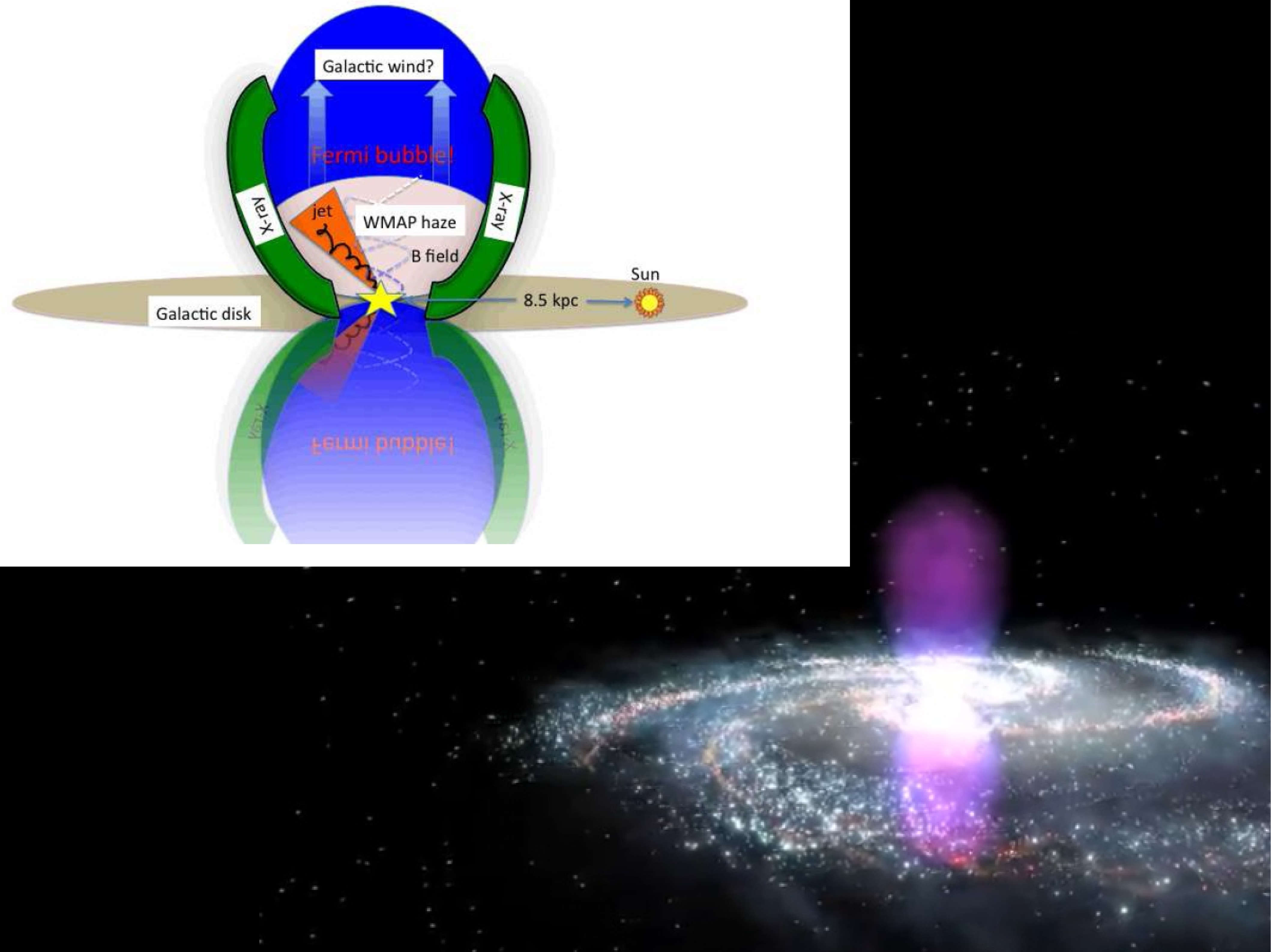


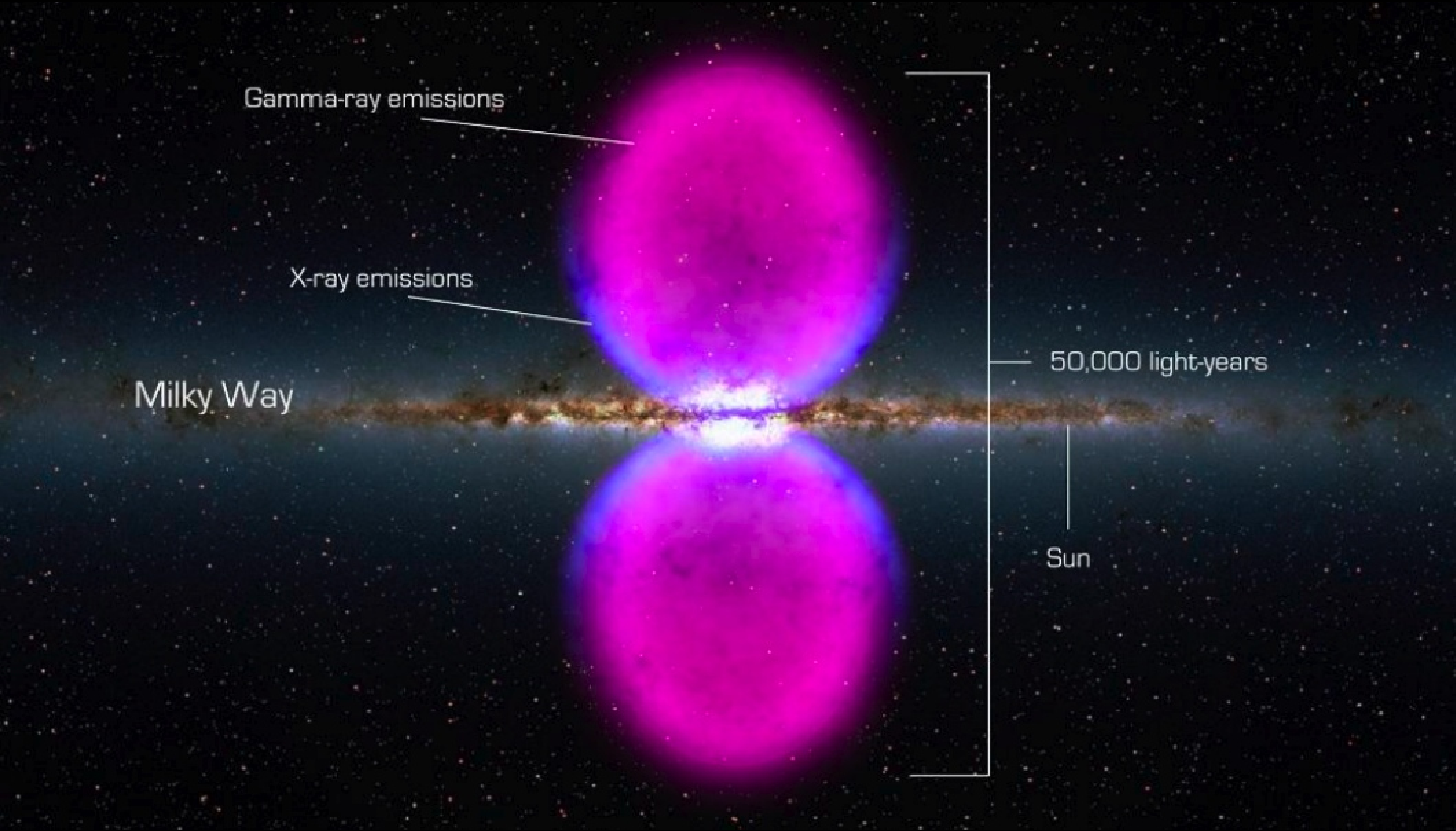
M. Su, T. R. Slatyer, D. P. Finkbeiner,
"Giant Gamma-ray Bubbles from Fermi-LAT: AGN Activity or Bipolar Galactic Wind?,"
Astrophys. J. **724**, 1044-1082 (2010). [arXiv:1005.5480 [astro-ph.HE]].

Bubbles show energetic spectrum and sharp edges



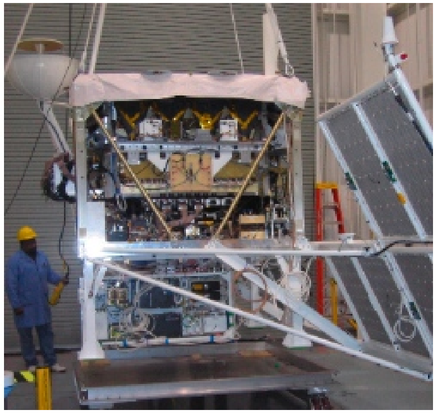
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

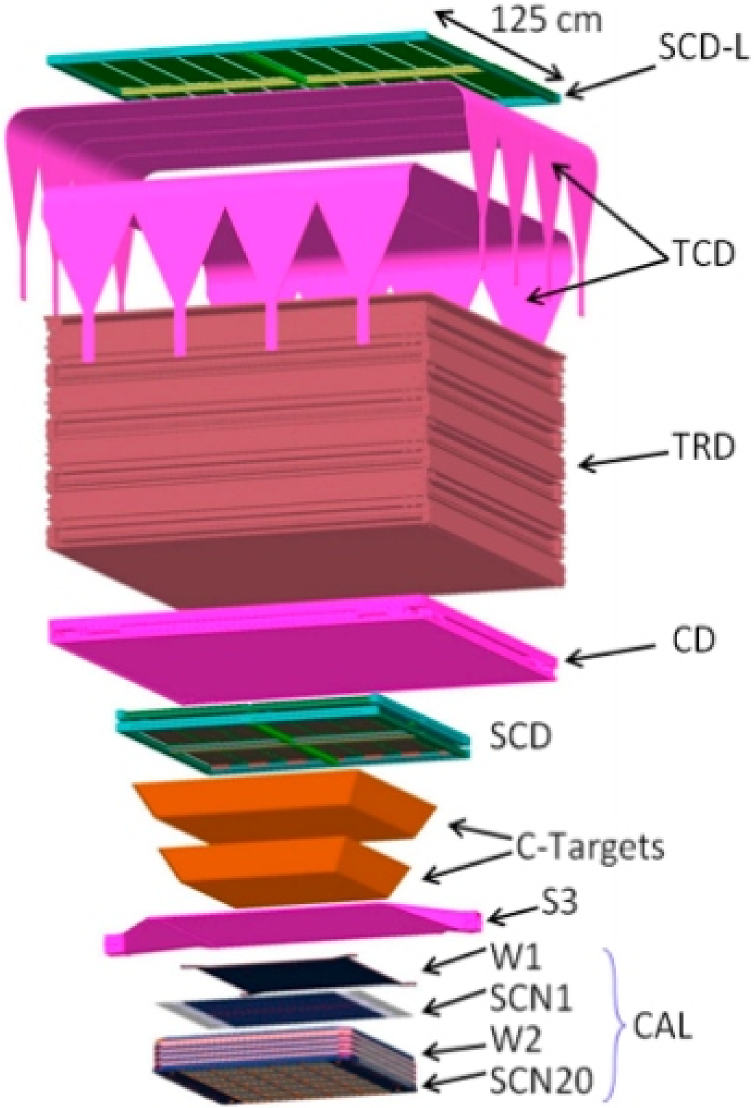

Galactic wind?
Fermi bubble!
X-ray
jet
WMAP haze
X-ray
B field
Sun
8.5 kpc
Galactic disk

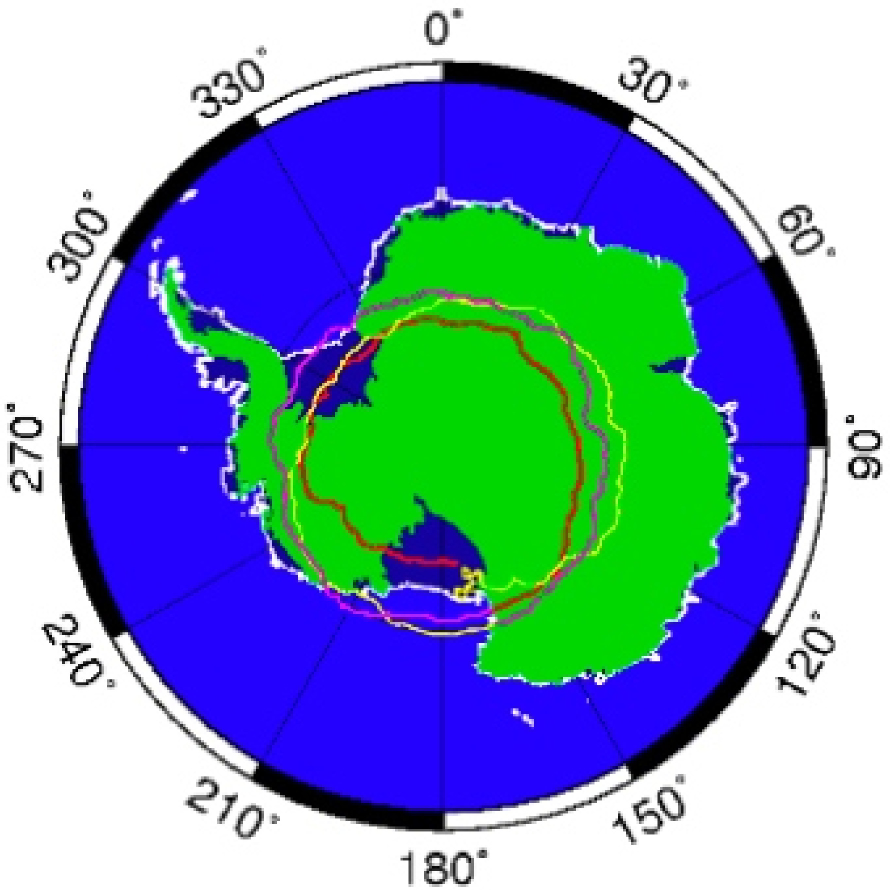


R. M. Crocker, F. Aharonian,
"The Fermi Bubbles: Giant, Multi-Billion-Year-Old Reservoirs of Galactic Center Cosmic Rays,"
[arXiv:1008.2658 [astro-ph.GA]].

CREAM (calorimeter on balloon)
(5 flights in Antartica. Total of 156 days)

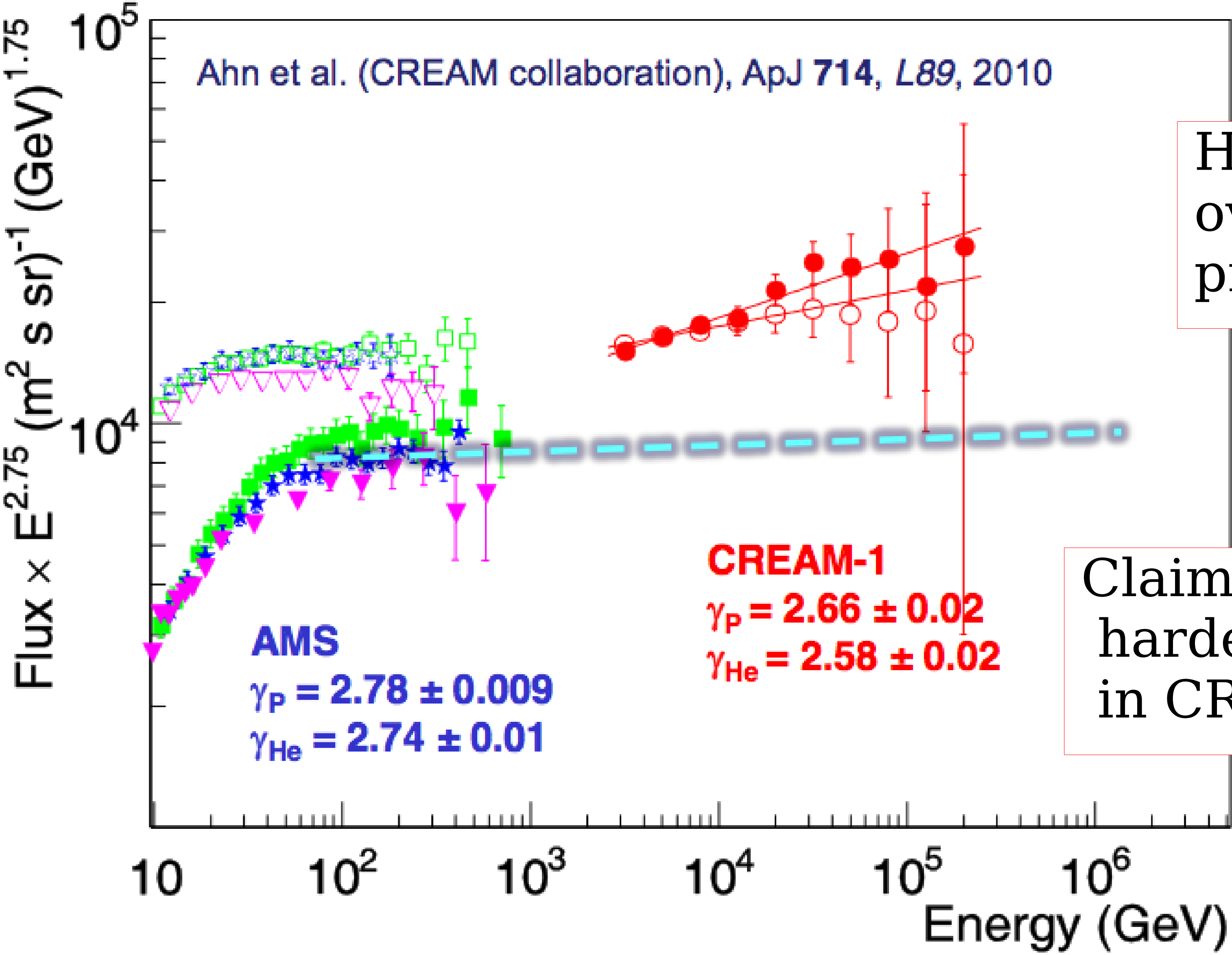






Cream 5 trajectory
37 days 12/2009-01/2010

TeV spectra are harder than spectra < 200 GeV/n



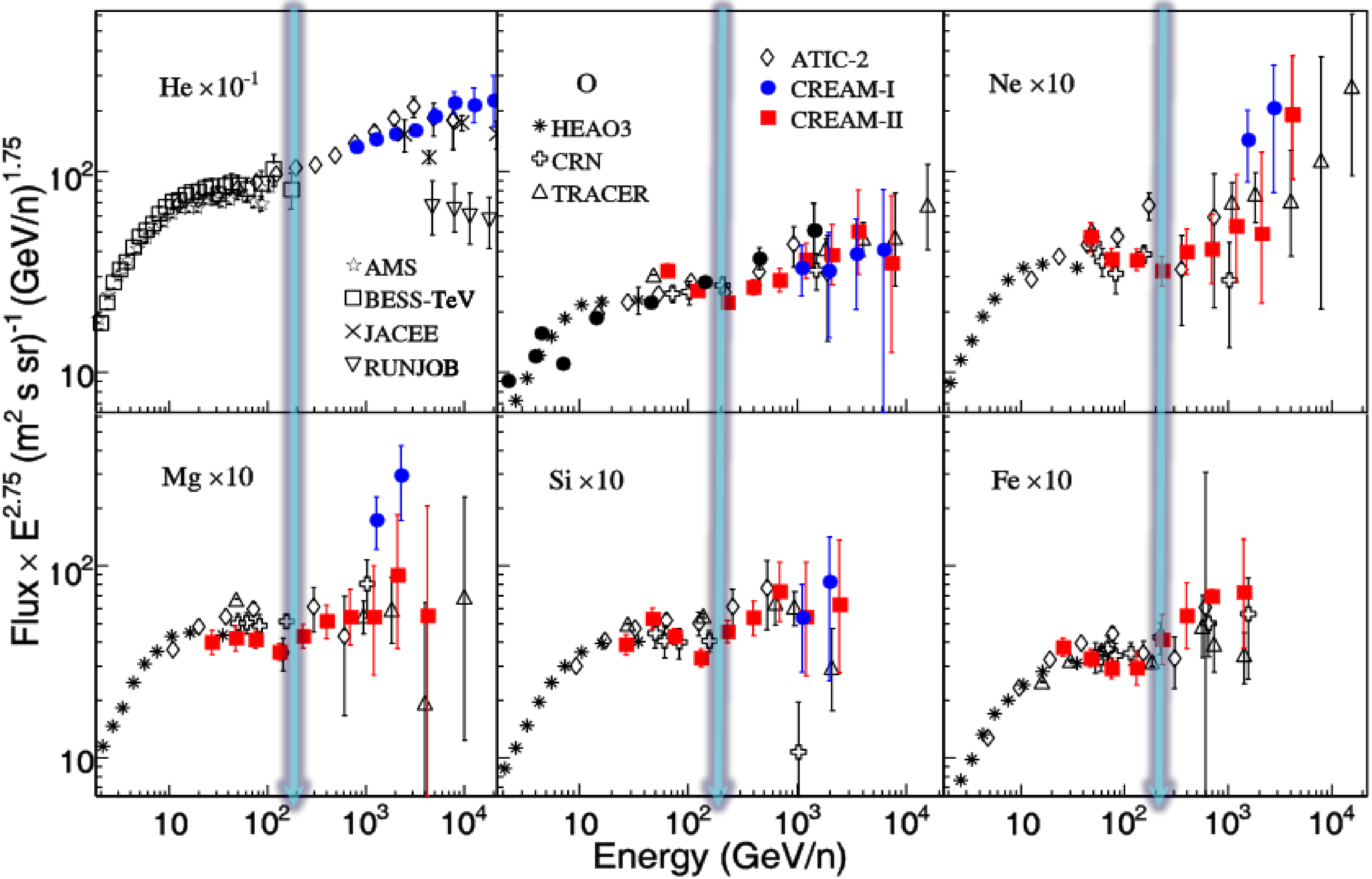
Helium overtakes protons (!)

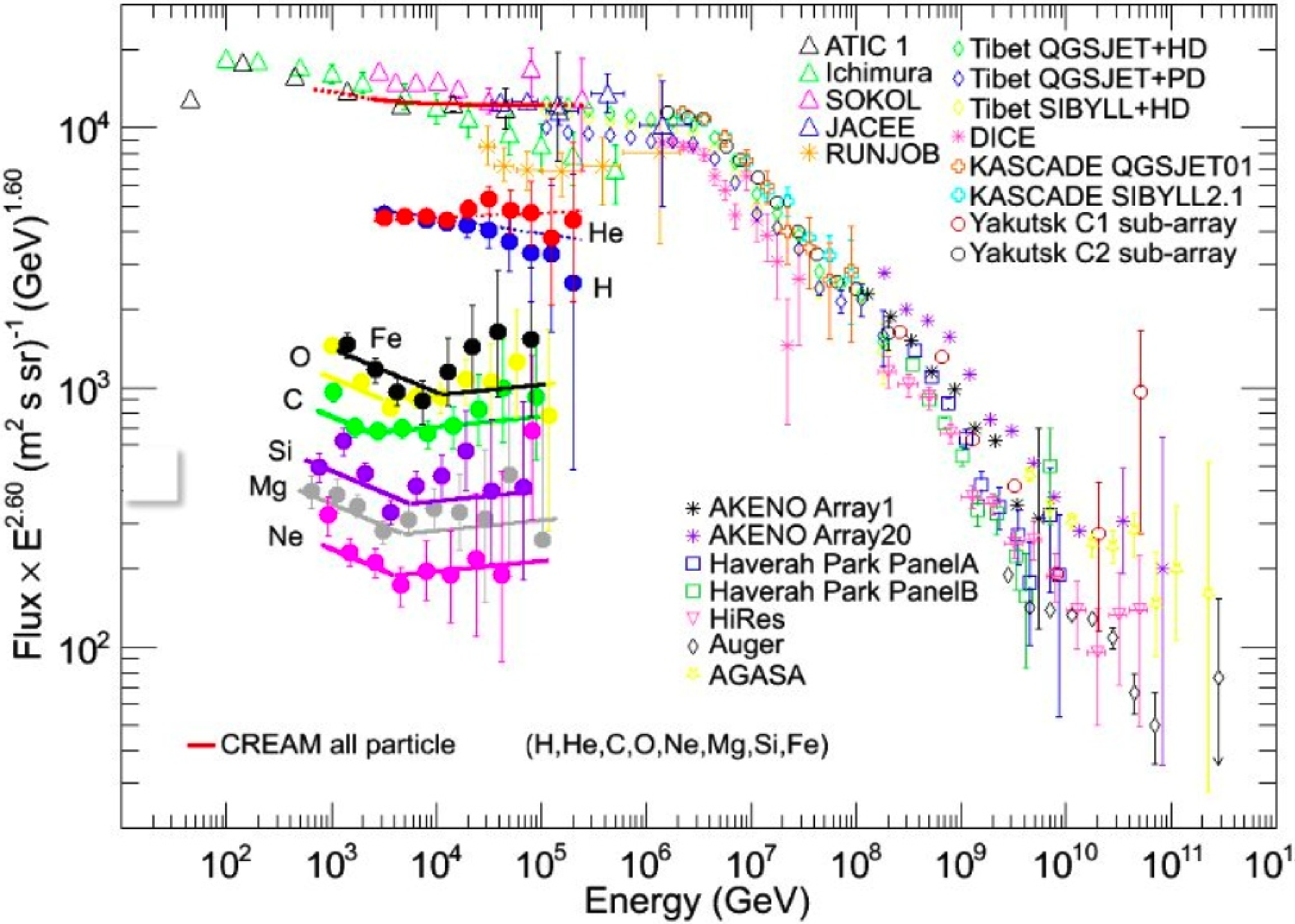
Claim of "break" hardening in CR spectra

[1] E. Seo, H. S. Ahn, P. Allison, M. G. Bagliesi *et al.*,
"Discrepant hardening observed in cosmic-ray elemental spectra,"
Astrophys. J. **714**, L89-L93 (2010). [arXiv:1004.1123 [astro-ph.HE]].

The balloon-borne Cosmic Ray Energetics And Mass (CREAM) experiment launched five times from Antarctica has achieved a cumulative flight duration of about 156 days above 99.5% of the atmosphere. The instrument is configured with complementary and redundant particle detectors designed to extend direct measurements of cosmic-ray composition to the highest energies practical with balloon flights. All elements from protons to iron nuclei are separated with excellent charge resolution. Here we report results from the first two flights of ~ 70 days, which indicate hardening of the elemental spectra above 200 GeV/nucleon and a spectral difference between the two most abundant species, protons and helium nuclei. These results challenge the view that cosmic-ray spectra are simple power laws below the so-called knee at $\sim 10^{15}$ eV. This discrepant hardening may result from a relatively nearby source, or it could represent spectral concavity caused by interactions of cosmic rays with the accelerating shock. Other possible explanations should also be investigated.

Discrepant hardening



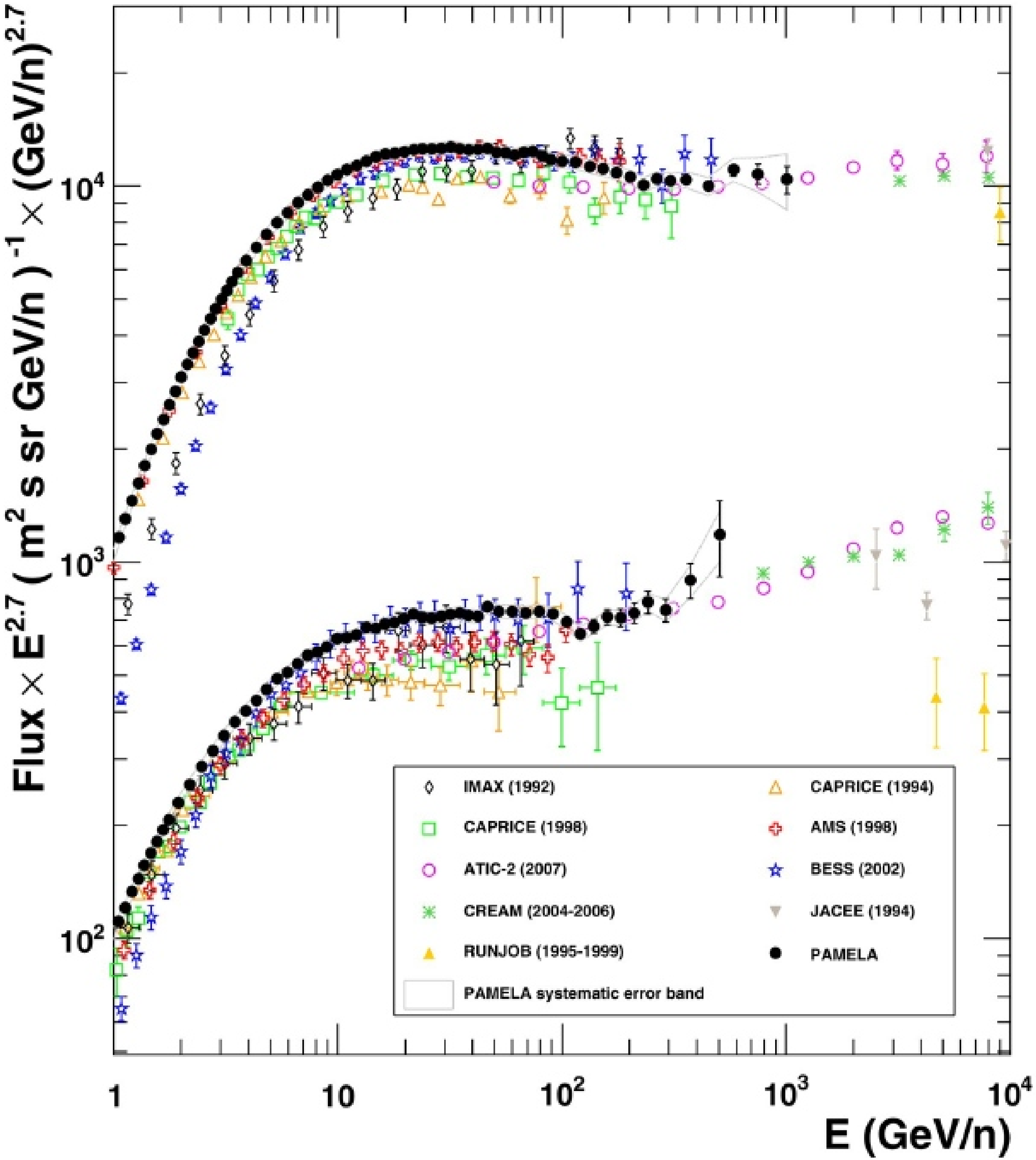


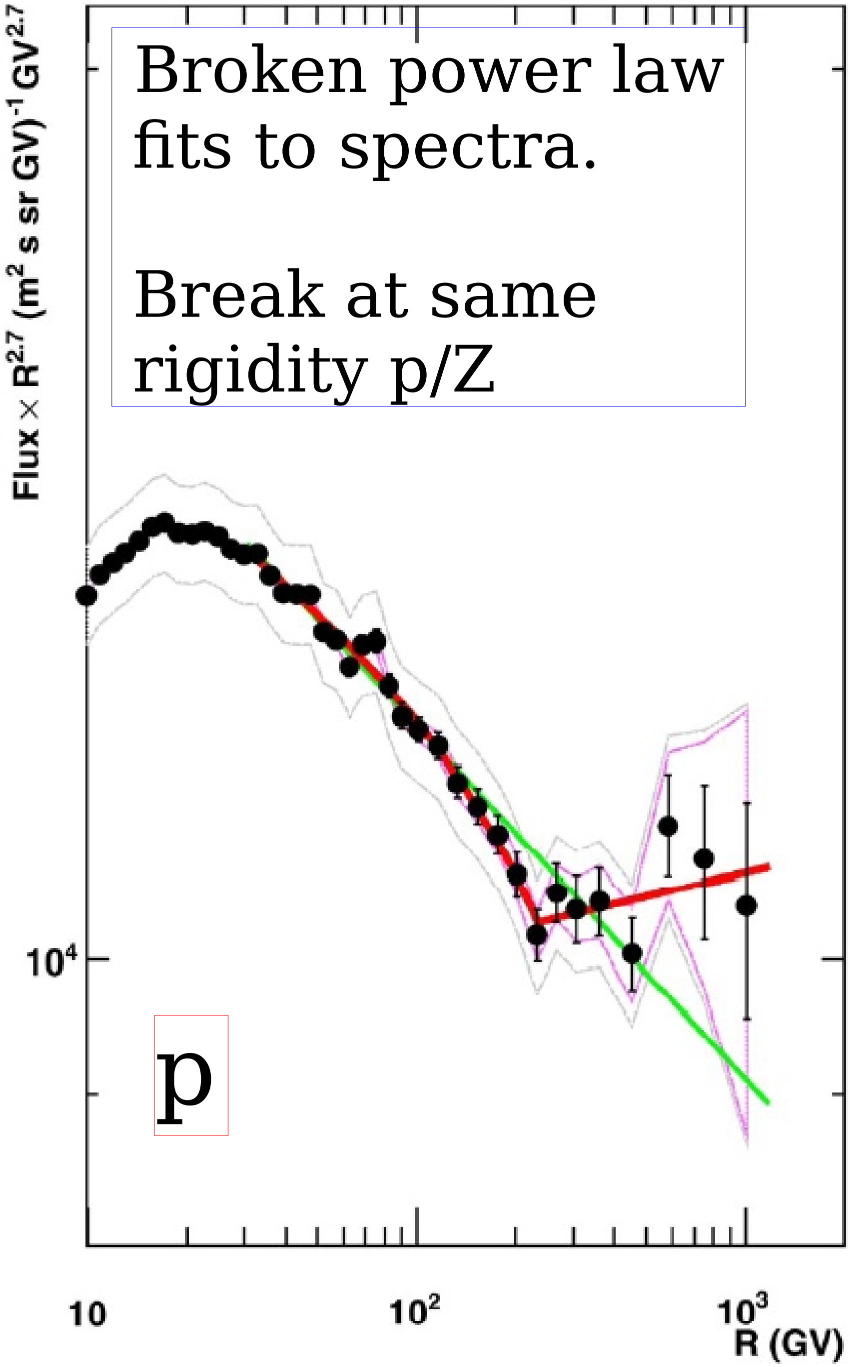
ATIC 1
Ichimura
SOKOL
JACEE
RUNJOB
Tibet QGSJET+HD
Tibet QGSJET+PD
Tibet SIBYLL+HD
DICE
KASCADE QGSJET01
KASCADE SIBYLL2.1
Yakutsk C1 sub-array
Yakutsk C2 sub-array
He
H
Fe
O
C
Si
Mg
Ne
AKENO Array1
AKENO Array20
Haverah Park PanelA
Haverah Park PanelB
HiRes
Auger
AGASA
CREAM all particle
(H,He,C,O,Ne,Mg,Si,Fe)
Flux × E^2.60 (m^2 s sr)^-1 (GeV)^1.60
Energy (GeV)

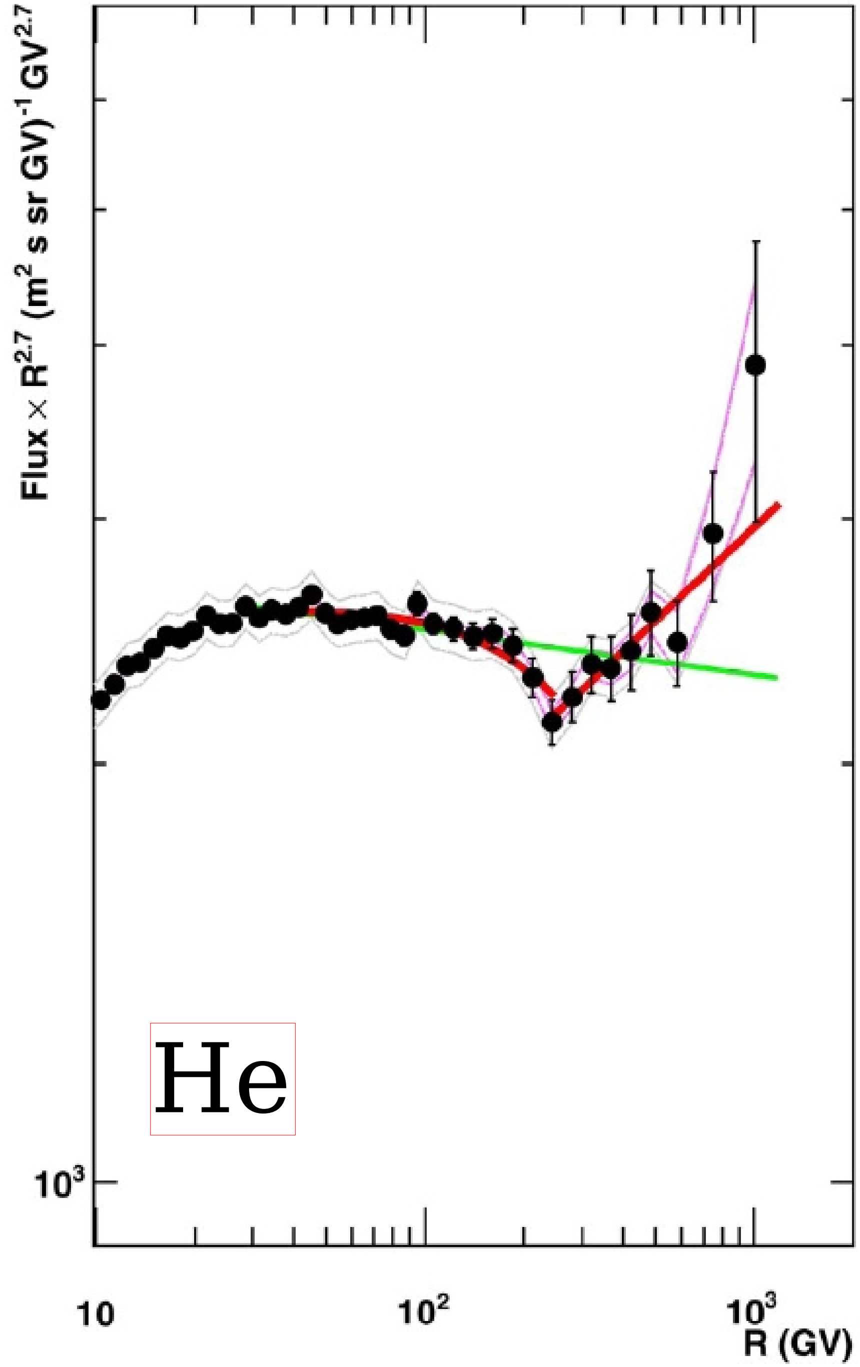
PAMELA

Proton/Helium
CR fluxes
1 GV – 1.2 TV

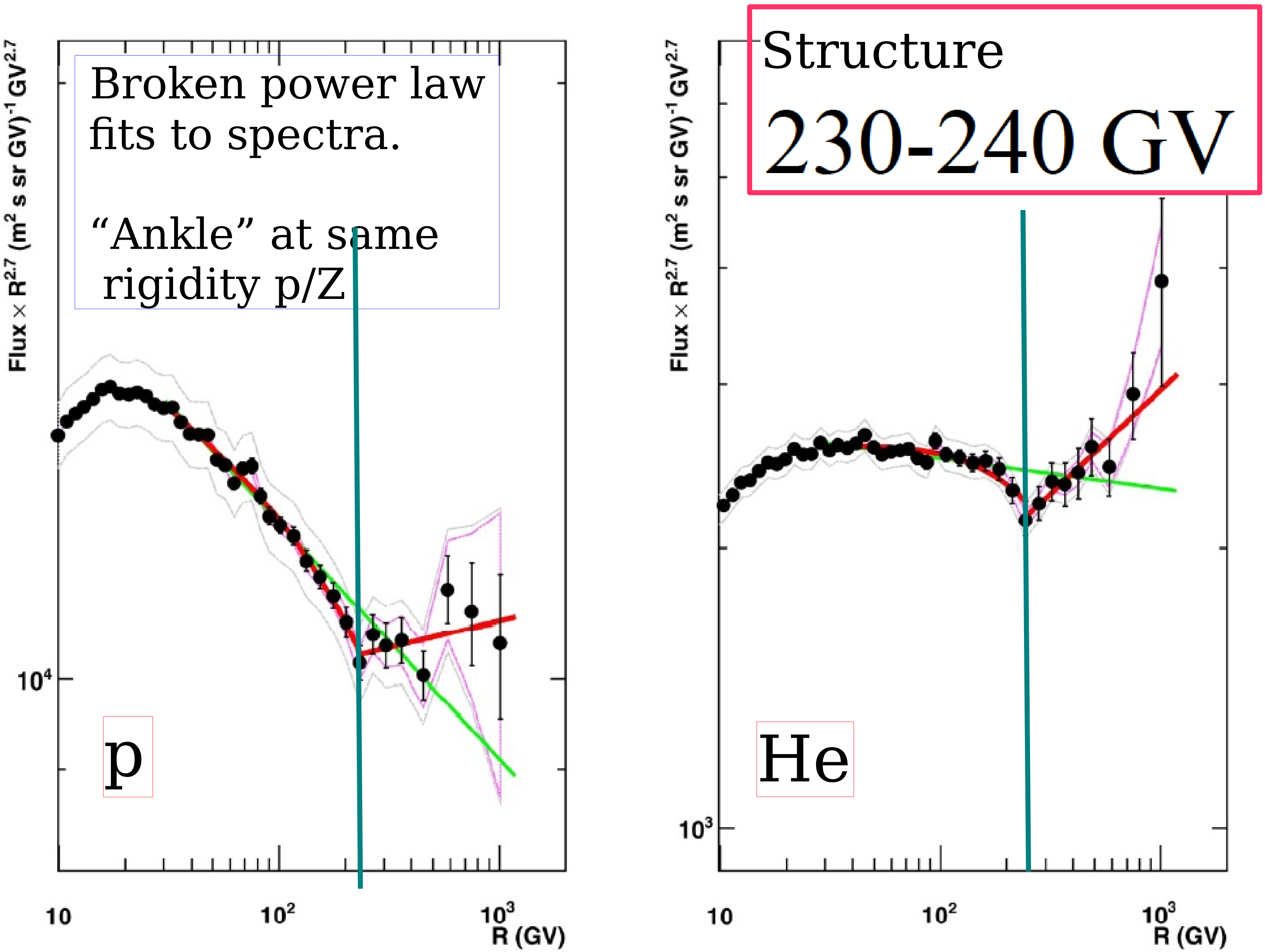
Science in press
(march 2011)







Surprising and important result.



Surprising and important result.

Sciencexpress Report

PAMELA Measurements of Cosmic-Ray Proton and Helium Spectra

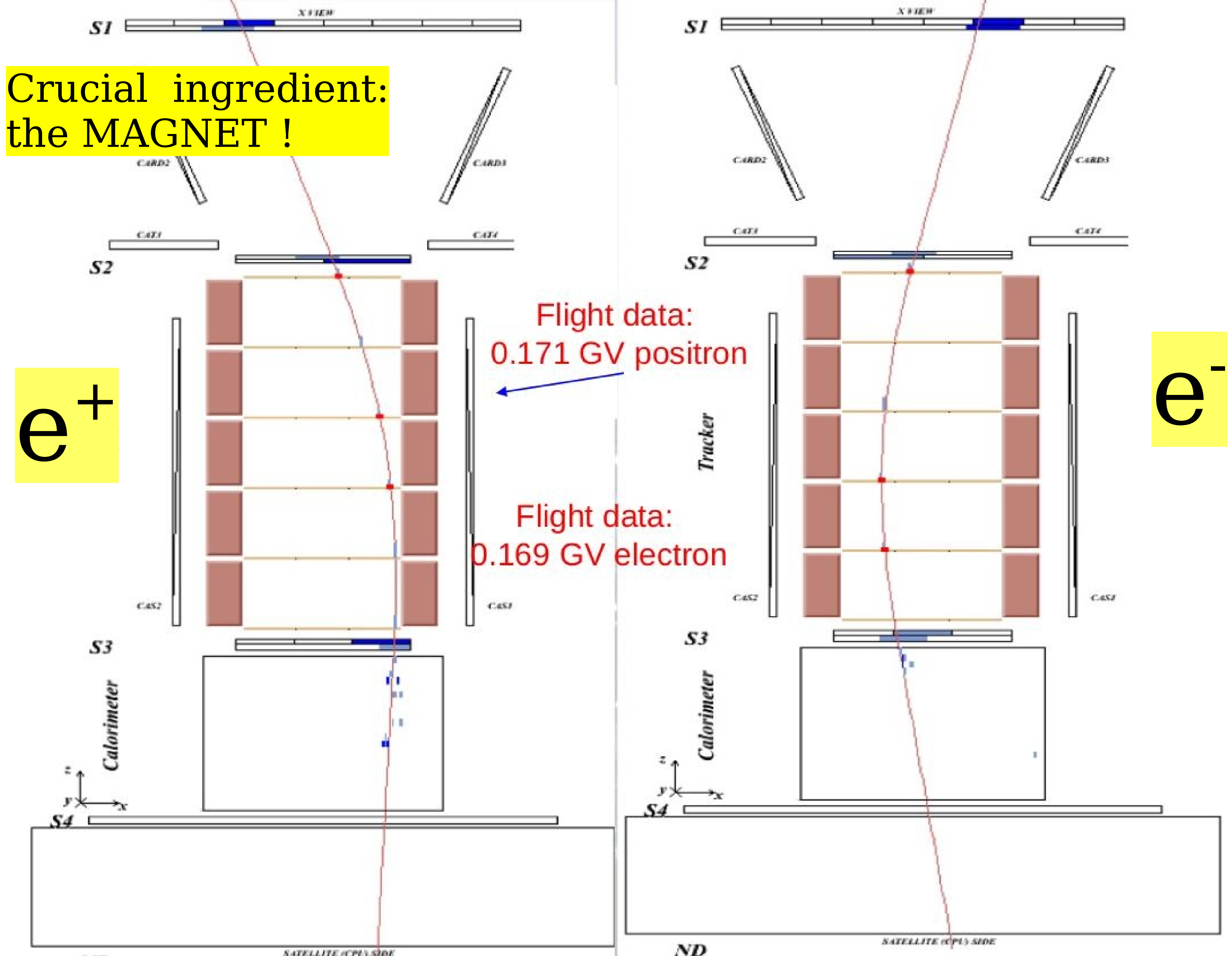
We report precision measurements of the proton and helium spectra in the rigidity range 1 GV-1.2 TV performed by the satellite-borne experiment PAMELA. We find that the spectral shapes of these two species are different and cannot be well described by a single power law. These data challenge the current paradigm of cosmic-ray acceleration in supernova remnants followed by diffusive propagation in the Galaxy. More complex processes of acceleration and propagation of cosmic rays are required to explain the spectral structures observed in our data.

PAMELA

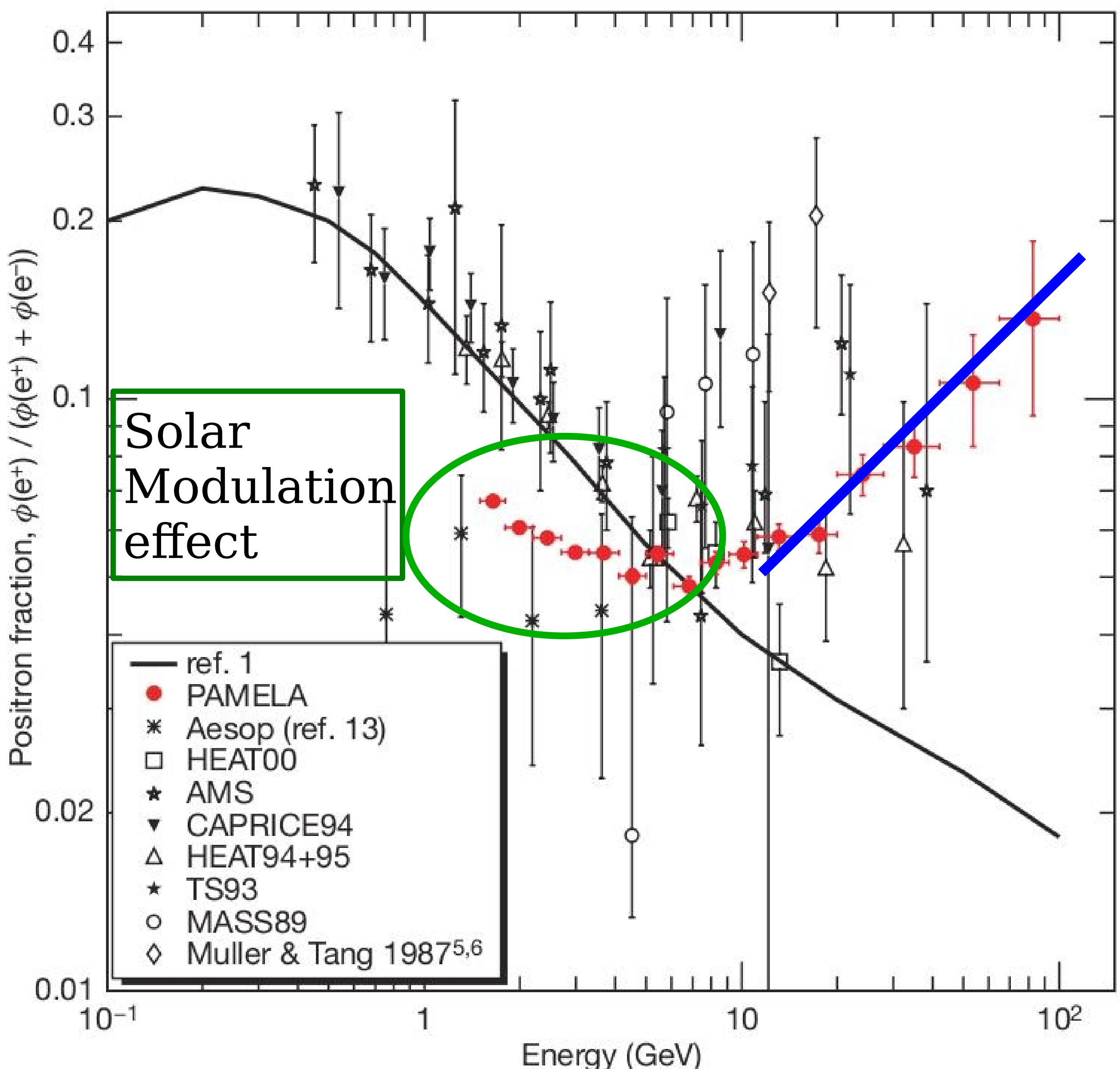
detector

Launch
15th june 2006

The “positron excess”:
Evidence for DM ??
or astrophysical effect ?


Crucial ingredient:
the MAGNET !
e^+
e^-
Flight data:
0.171 GV positron
Flight data:
0.169 GV electron
S1
S2
S3
S4
X VIEW
CARD2
CARD3
CAT3
CAT4
CAS2
CAS3
Tracker
Calorimeter
SATELLITE (CPU) SIDE
ND

An anomalous positron abundance in cosmic rays with energies 1.5–100 GeV

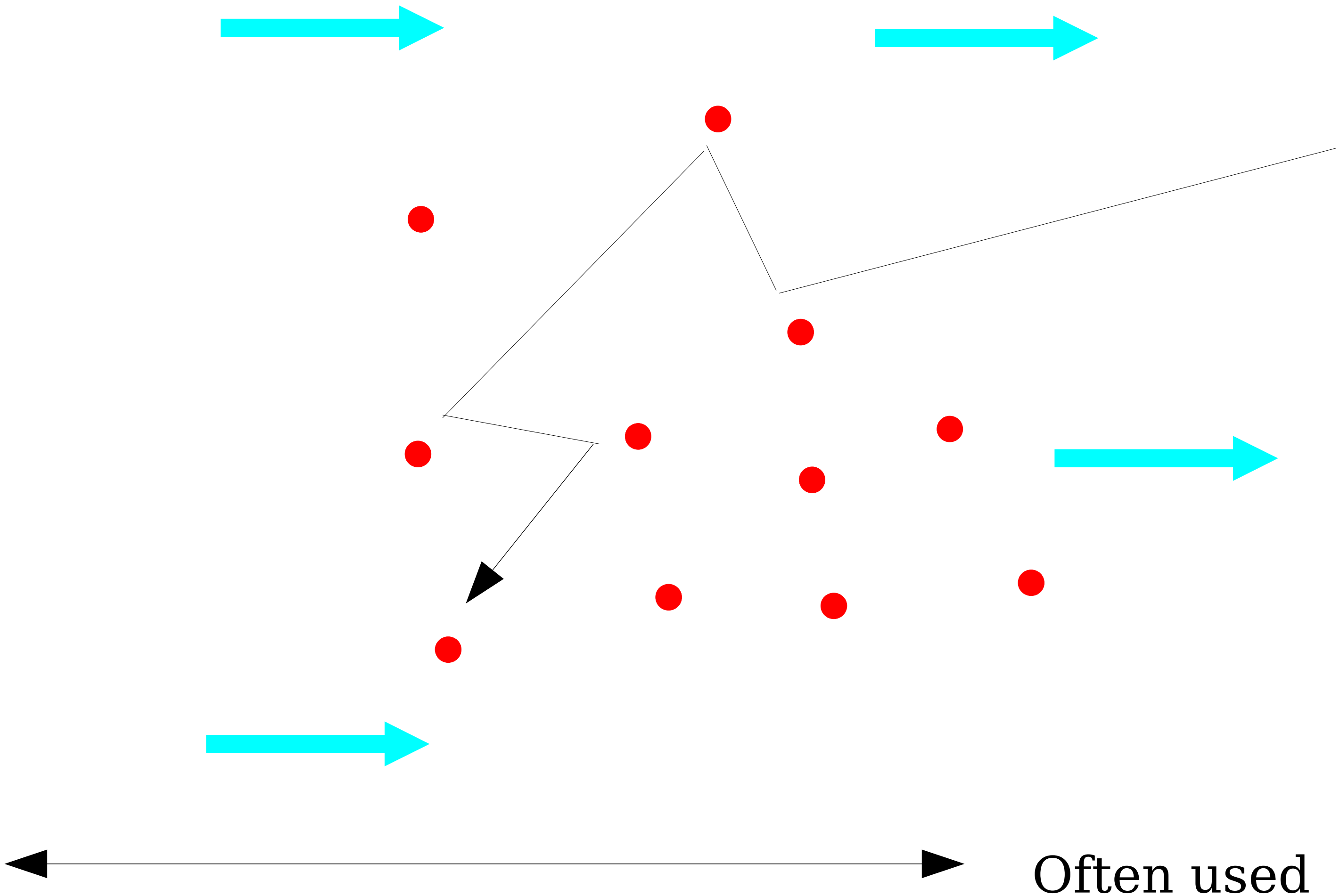


High energy:
ratio e+/e-
grow with E !!

$$\frac{\phi_{e^+}}{\phi_{e^-}} \propto E^{0.52}$$

Very unexpected result !

Moving magnetic scattering centers



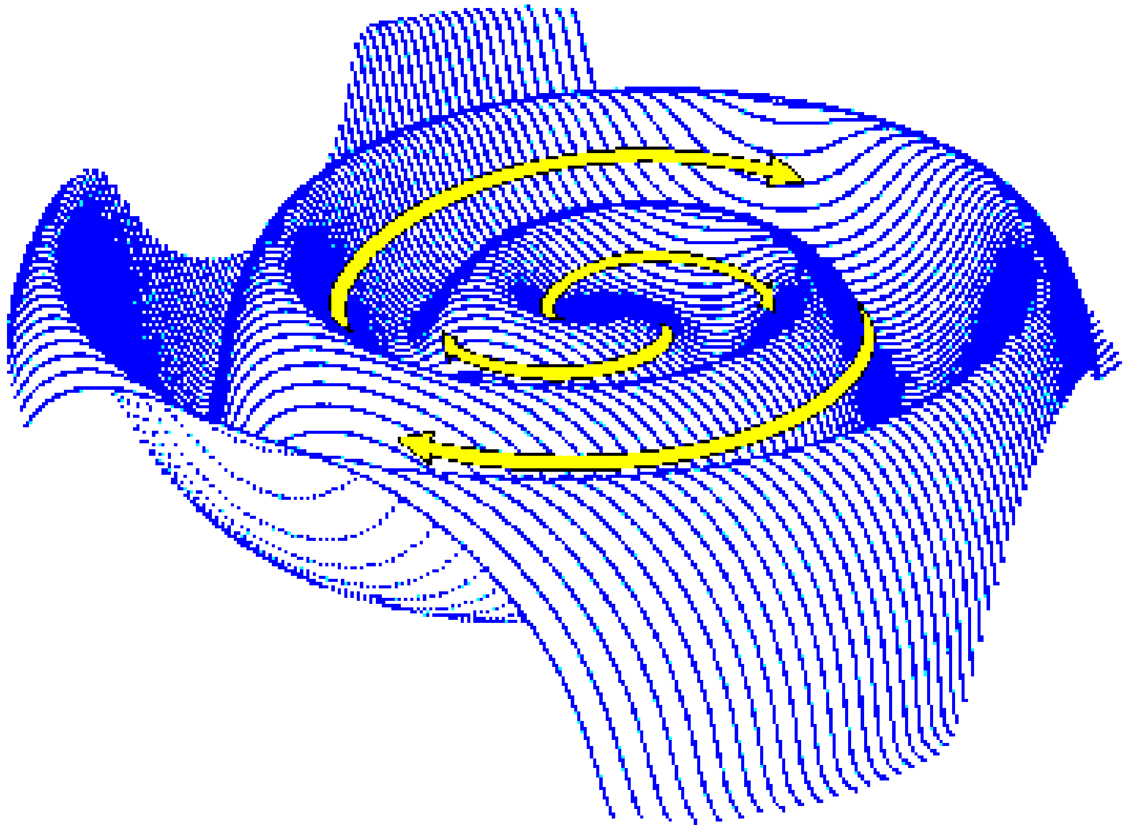
Often used approximation:

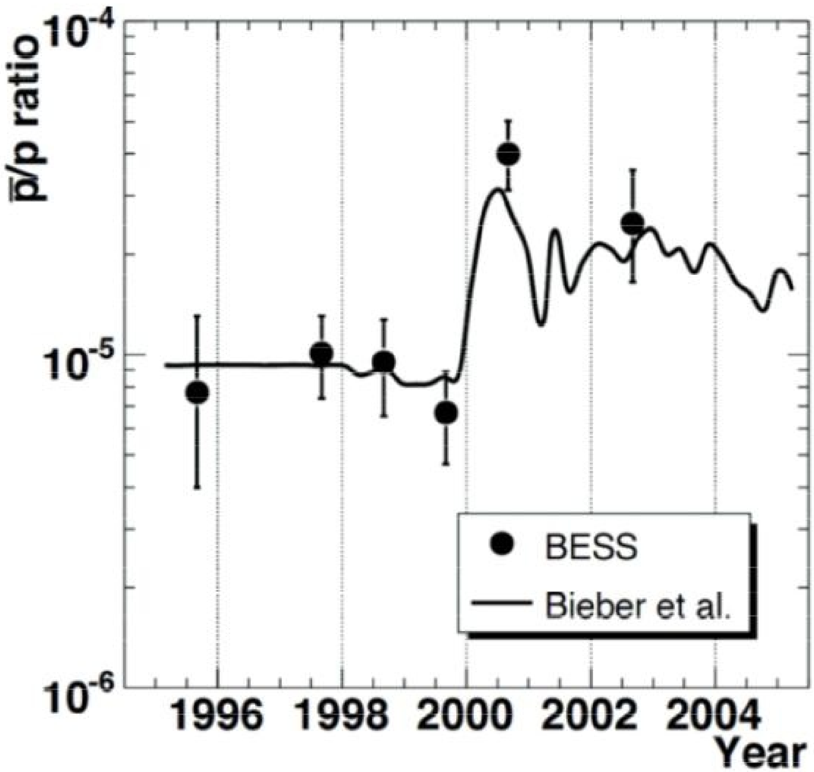
$$E_f = E_i - Z\,\Delta V$$

The effect of the solar wind
is equivalent to a POTENTIAL
with particles losing an energy
$\Delta E = Z V$

Charge dependent Solar Modulation

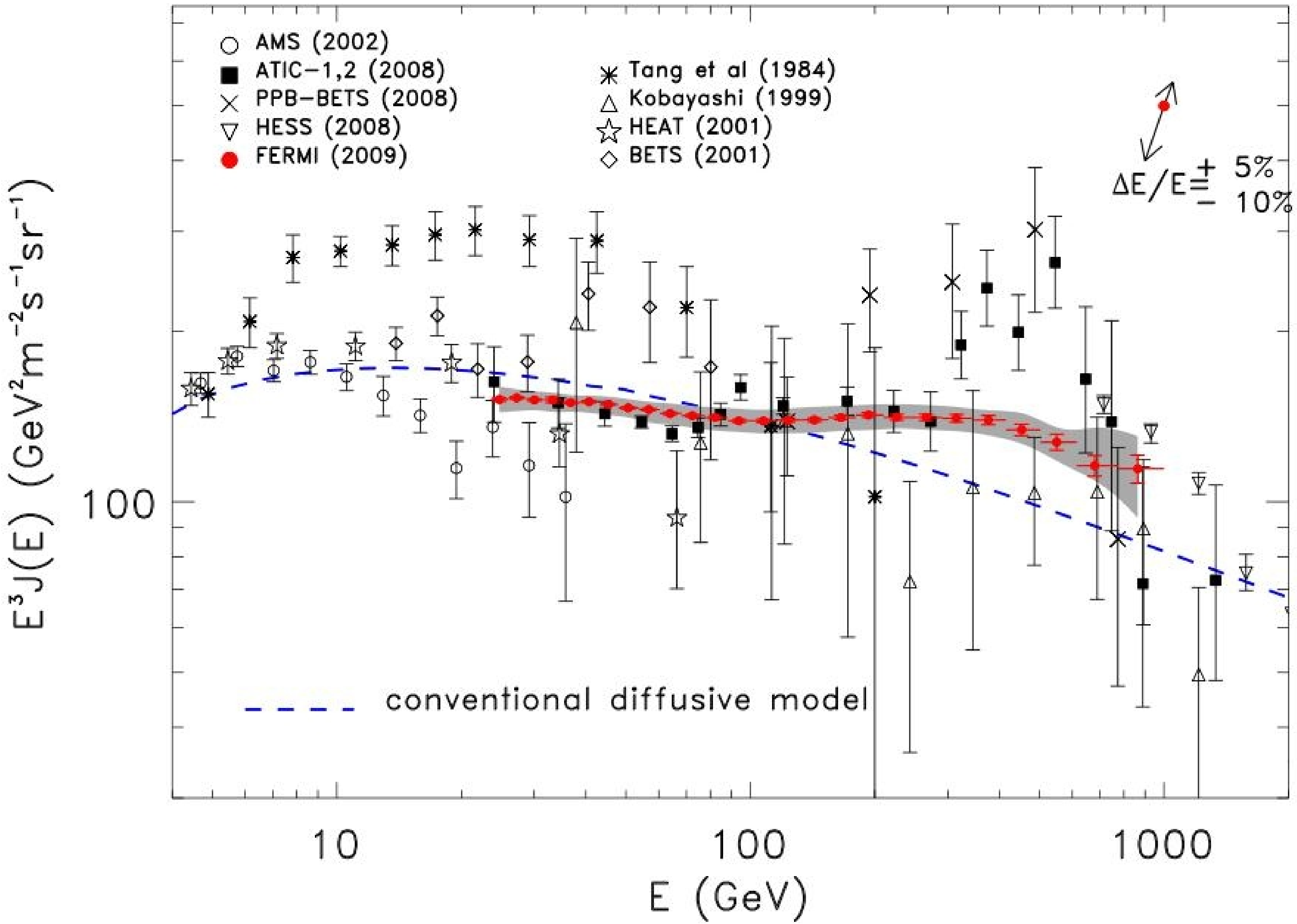
Particle Drift, Reversal of Magnetic field in the Sun





Magnetic Field reversal
At solar Maximum
11 + 11 years cycle

FERMI: electron + positron flux

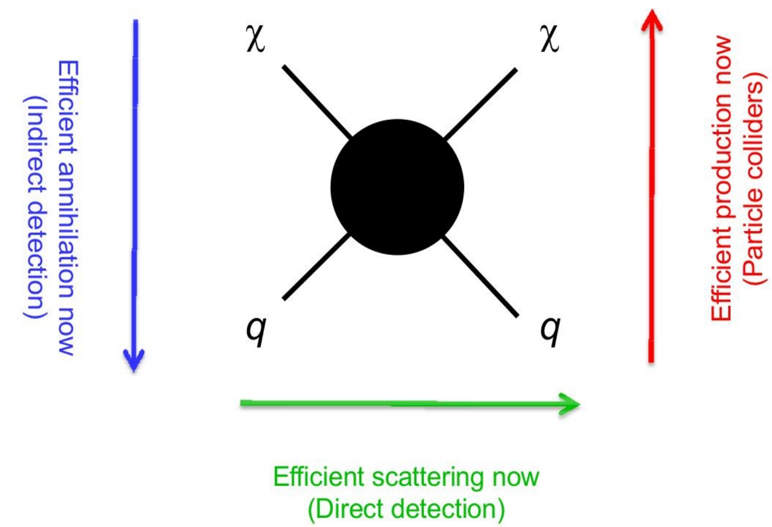


Three roads to the study of the "WIMP" hypothesis:

1. Direct Detection

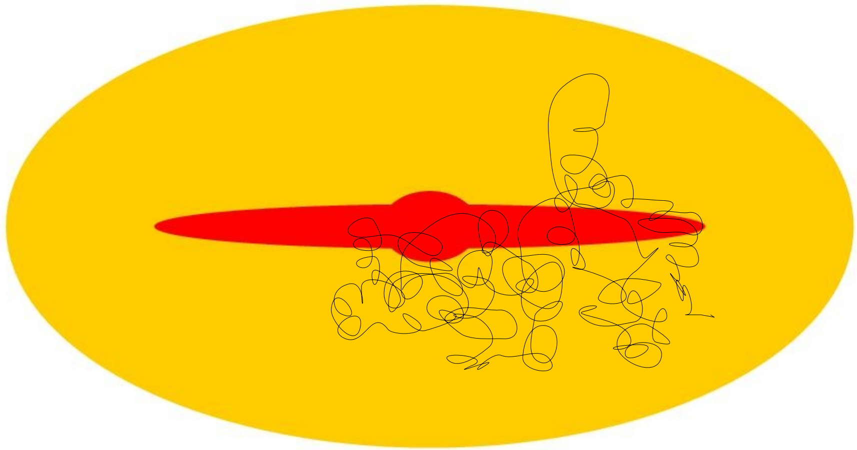
2. Indirect Detection
[Observation of annihilation products
In our own Galaxy]

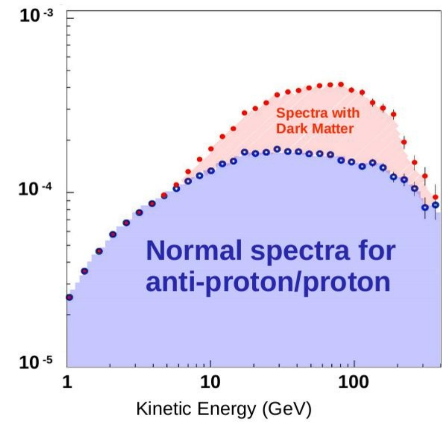
3. Discovery of a new stable particle
In an accelerator [LHC]

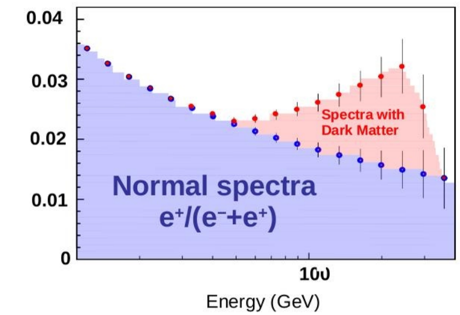


$$L(\vec{x}) = \frac{\rho(\vec{x})^2}{{M_\chi}^2} \; \langle \sigma \; v \rangle \; M_\chi$$

$$\chi + \chi \to \gamma \qquad e^+ \qquad \overline{p} \qquad \nu_\alpha$$







SOURCE(s) + Propagation $\rightarrow$ Observable Cosmic Rays

$$p + p_{\text{ISM}} \rightarrow e^+ \ldots$$

$$p + p_{\text{ISM}} \rightarrow \pi^+ \ldots$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

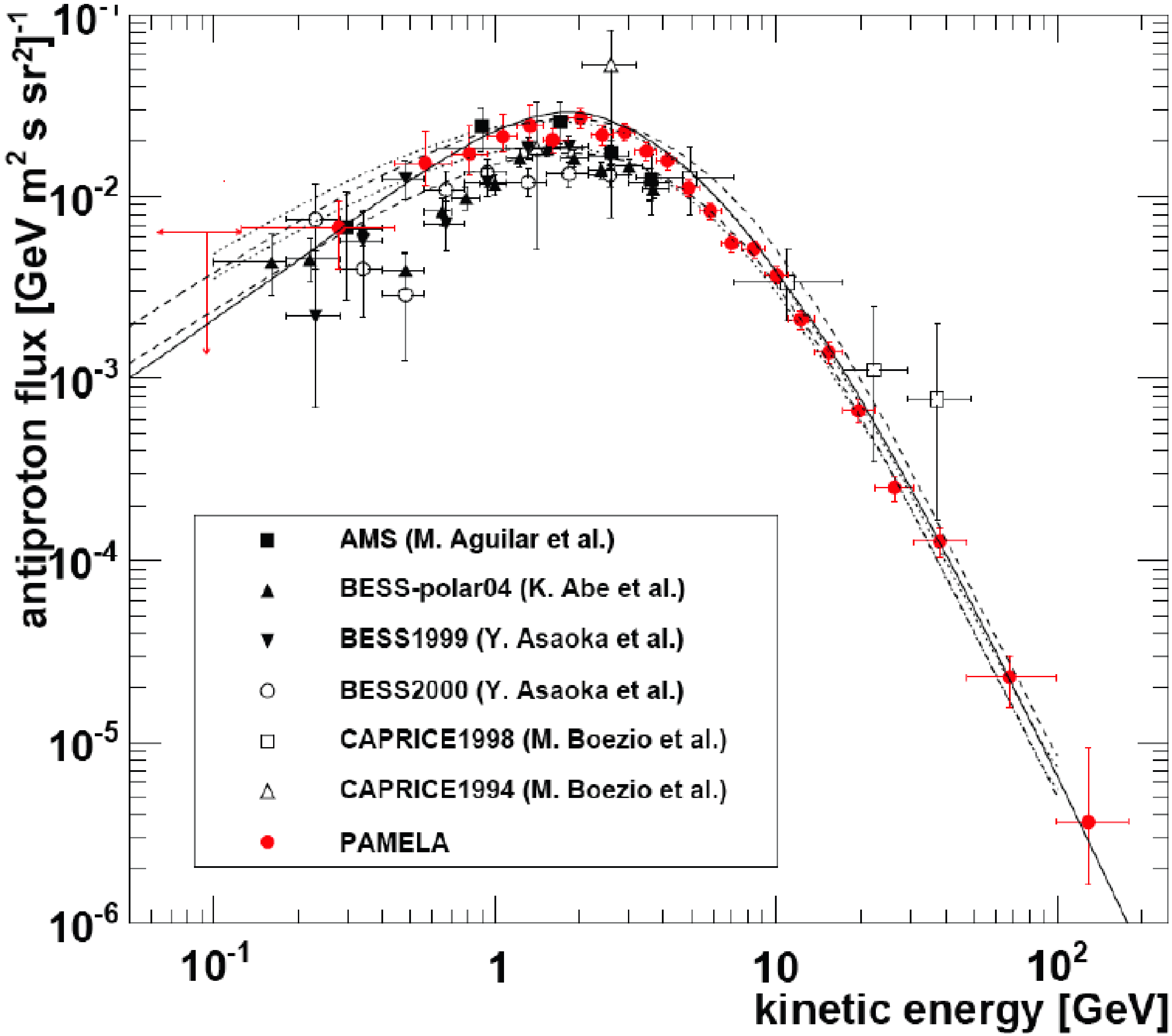
$$\mu^+ \rightarrow e^+ + \nu_e + \overline{\nu}_\mu$$

$$\chi + \chi \rightarrow e^+ + \ldots$$

Possible
positron accelerators

Antiproton result

Agreement
With standard production
mechanism



From : Cirelli

Results

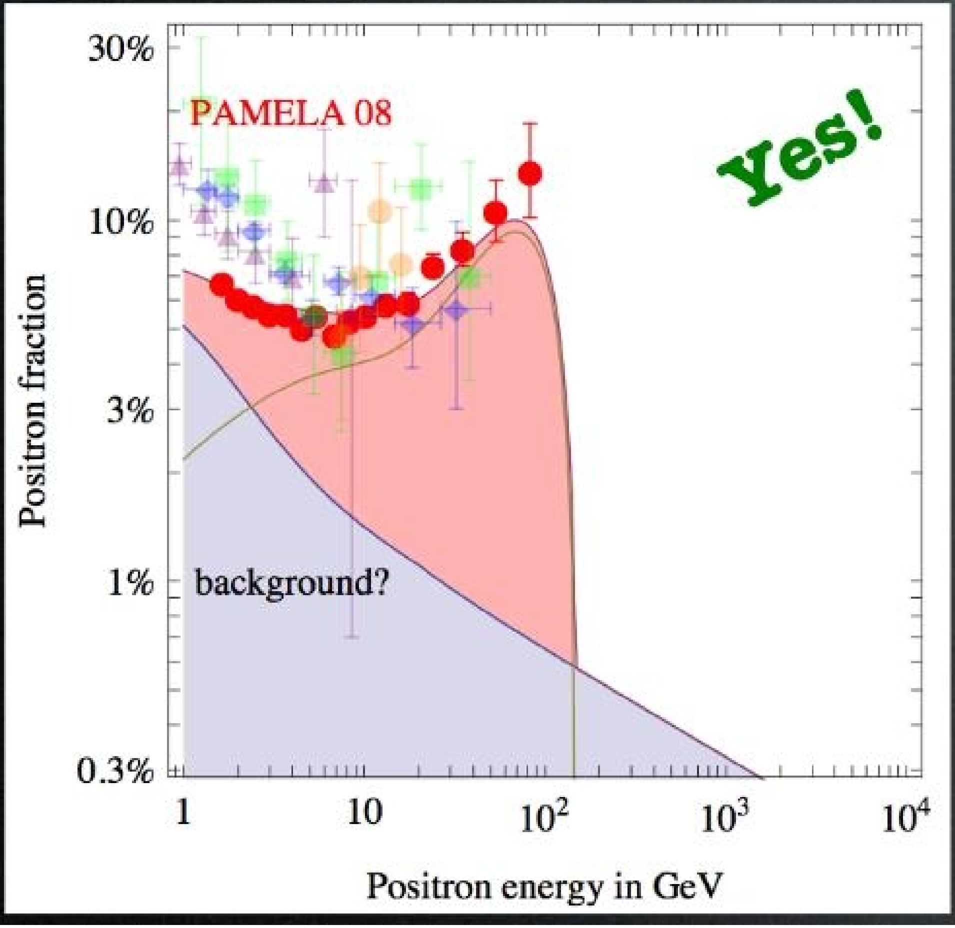
Which DM spectra can fit the data?

E.g. a DM with: -mass $M_{\rm DM} = 150\,{\rm GeV}$

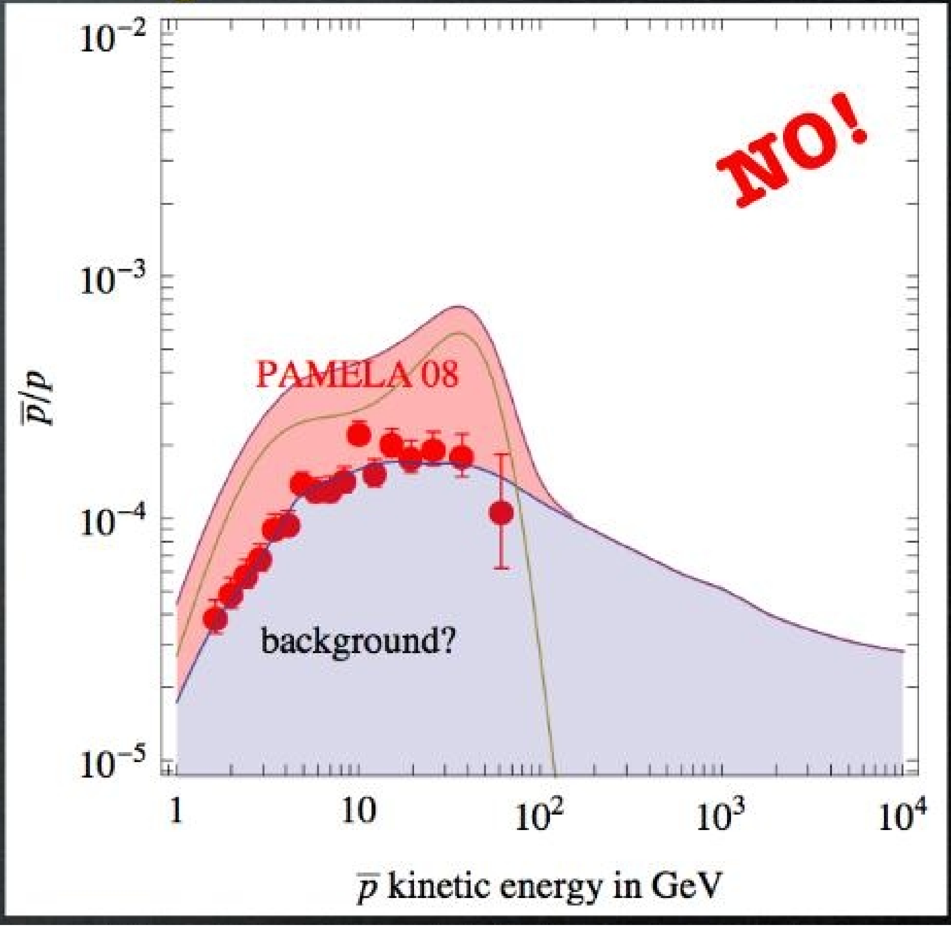
-annihilation $\text{DM DM} \to W^+W^-$

(a possible SuperSymmetric candidate: wino)

Positrons:



Anti-protons:

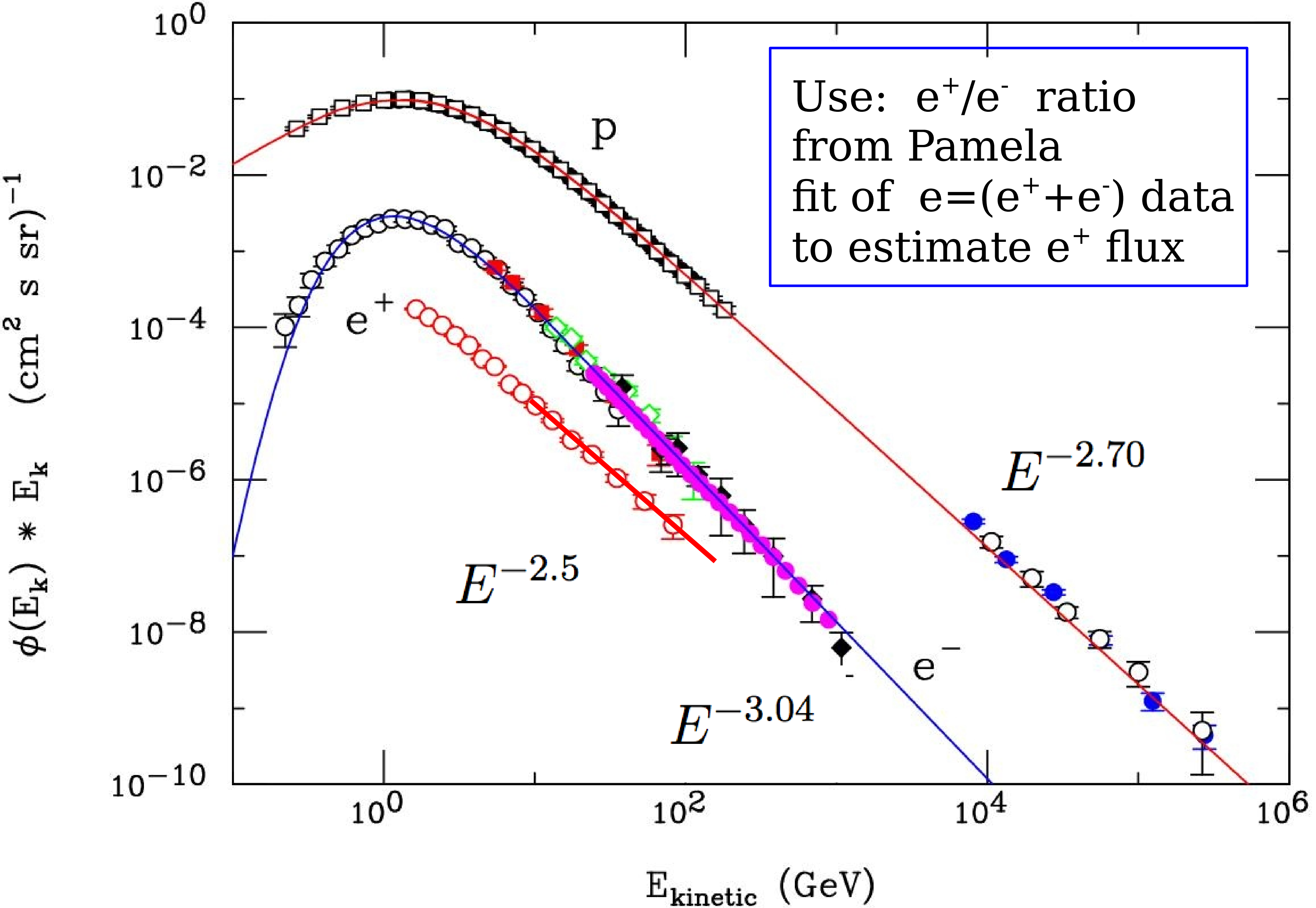


Dark Matter explanation of the
“Pamela positron excess” in terms of the
“WIMP” model is possible, but not in its
Simplest, most natural version.

[1.] The DM annihilation does not produce antiprotons
“Leptophilic” Dark Matter [?]
(no convincing dynamical explanation)

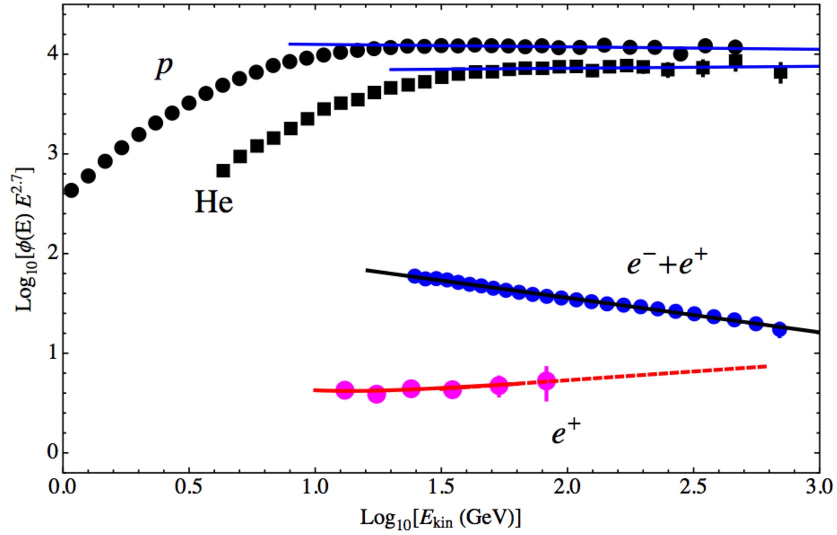
[2.] Include a large “Boost factor”
to increase the rate of the DM annihilations.
Very “clumpy” dark matter.
(very lucky in being close to a big DM clump)
“winning the jackpot” [?]

Proton and electron + Positron energy spectra



Spectra approximately of form:

protons	$E^{-2.70}$
electrons	$E^{-3.04}$
positrons	$E^{-2.5}$



$$\boxed{E^{-3.1} \quad E^{-3.5}}$$

Completely unexpected result

Rough expectation
For the positron slope
SOFTER than electrons

PULSARS

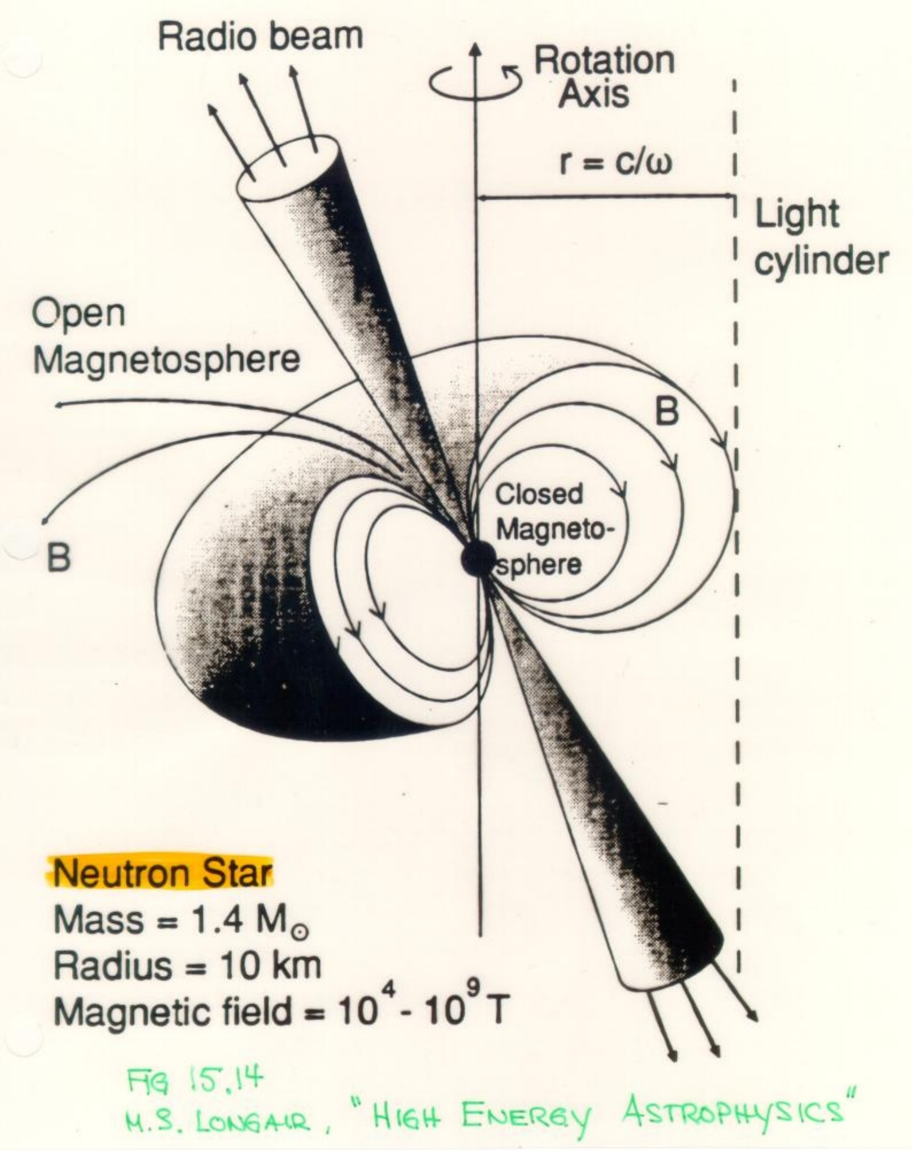
Proposed as possible Accelerators of e+ e-

CRAB Nebula

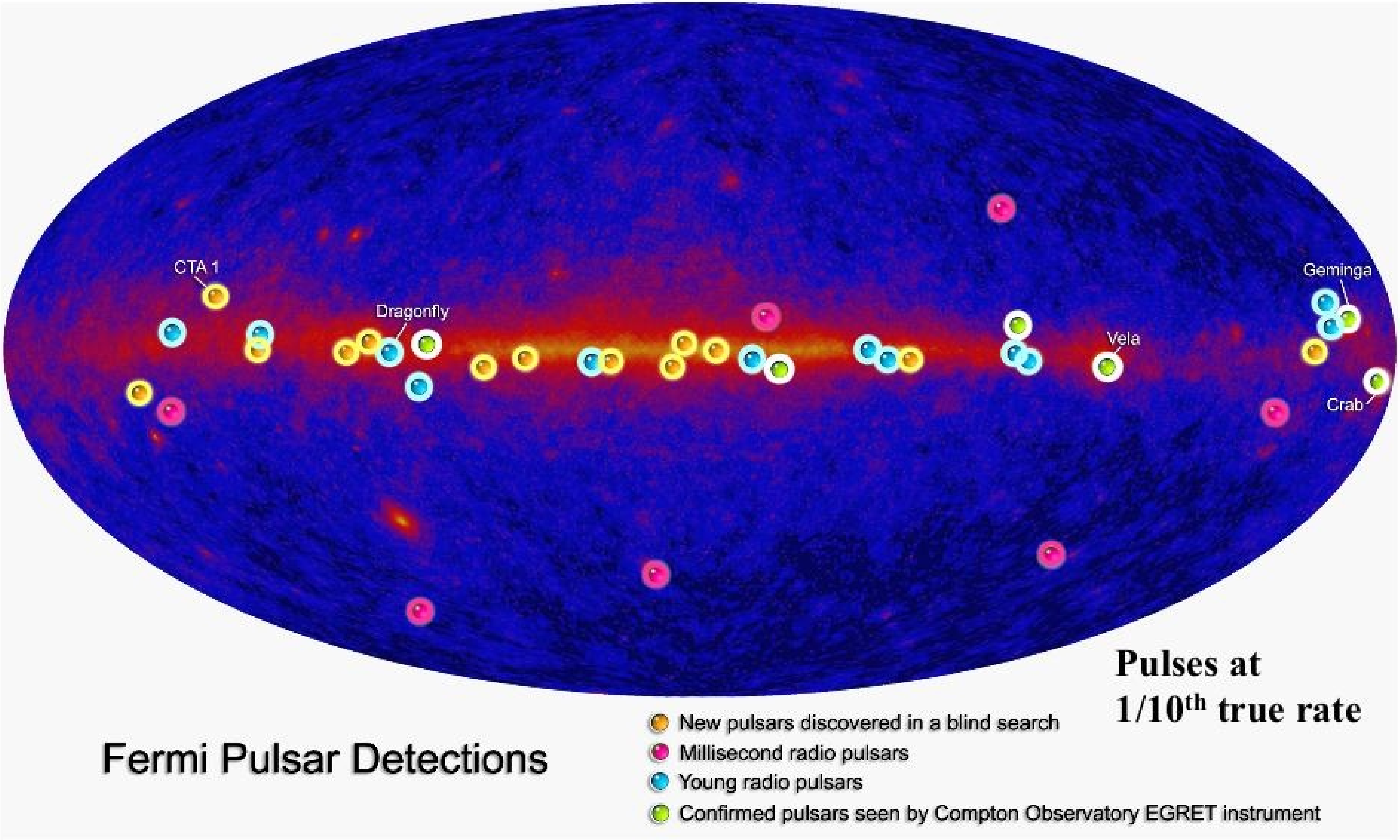
$$P_{\rm Crab} = 0.0334 \text{ s}$$

$$\dot{P}_{\rm Crab} = 4.2 \times 10^{-13} \text{ s}$$

$$(\Delta P_{\rm Crab})_{\rm year} = 13.2 \times 10^{-6} \text{ s}$$

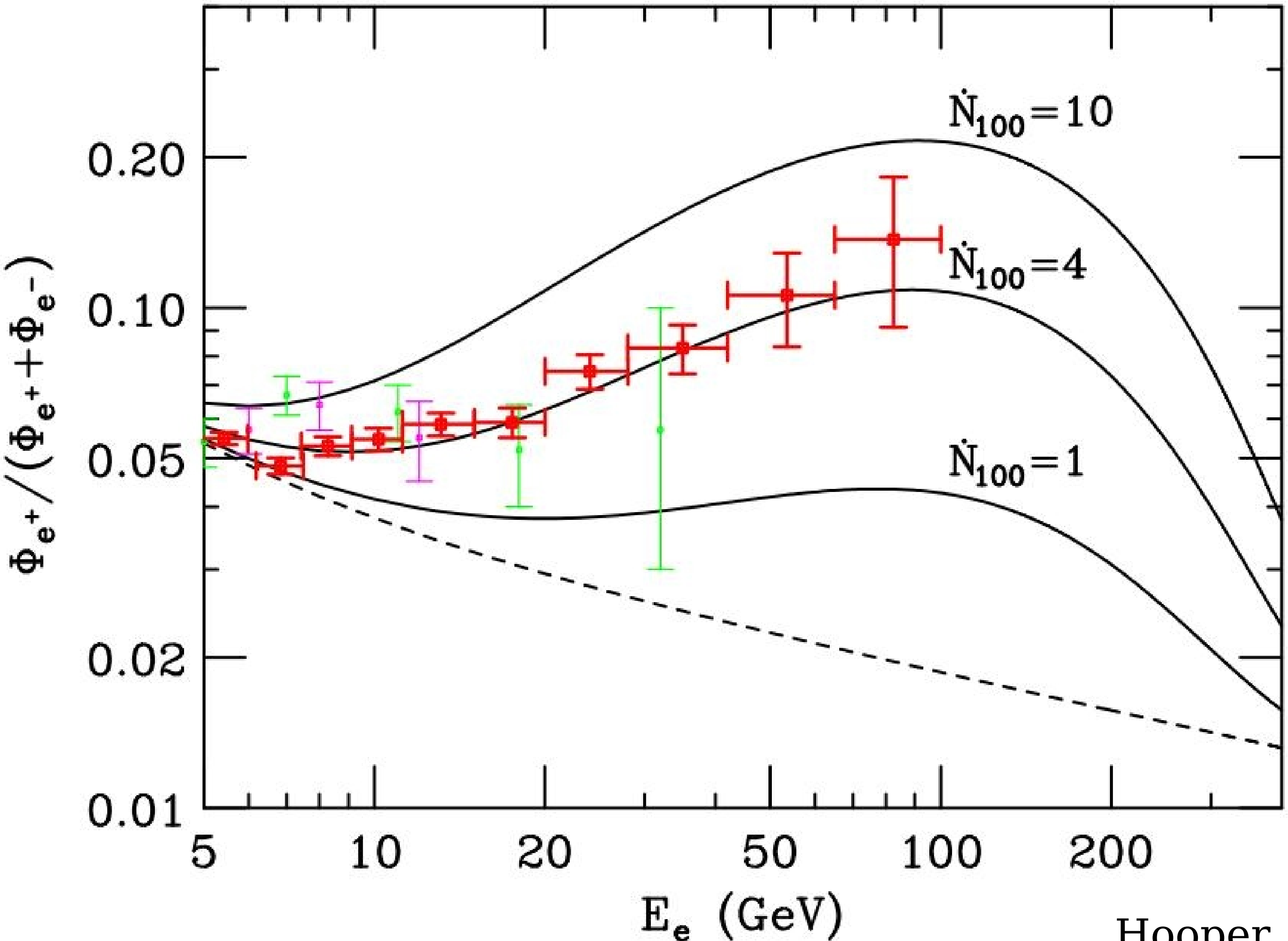


Fermi Pulsar detection



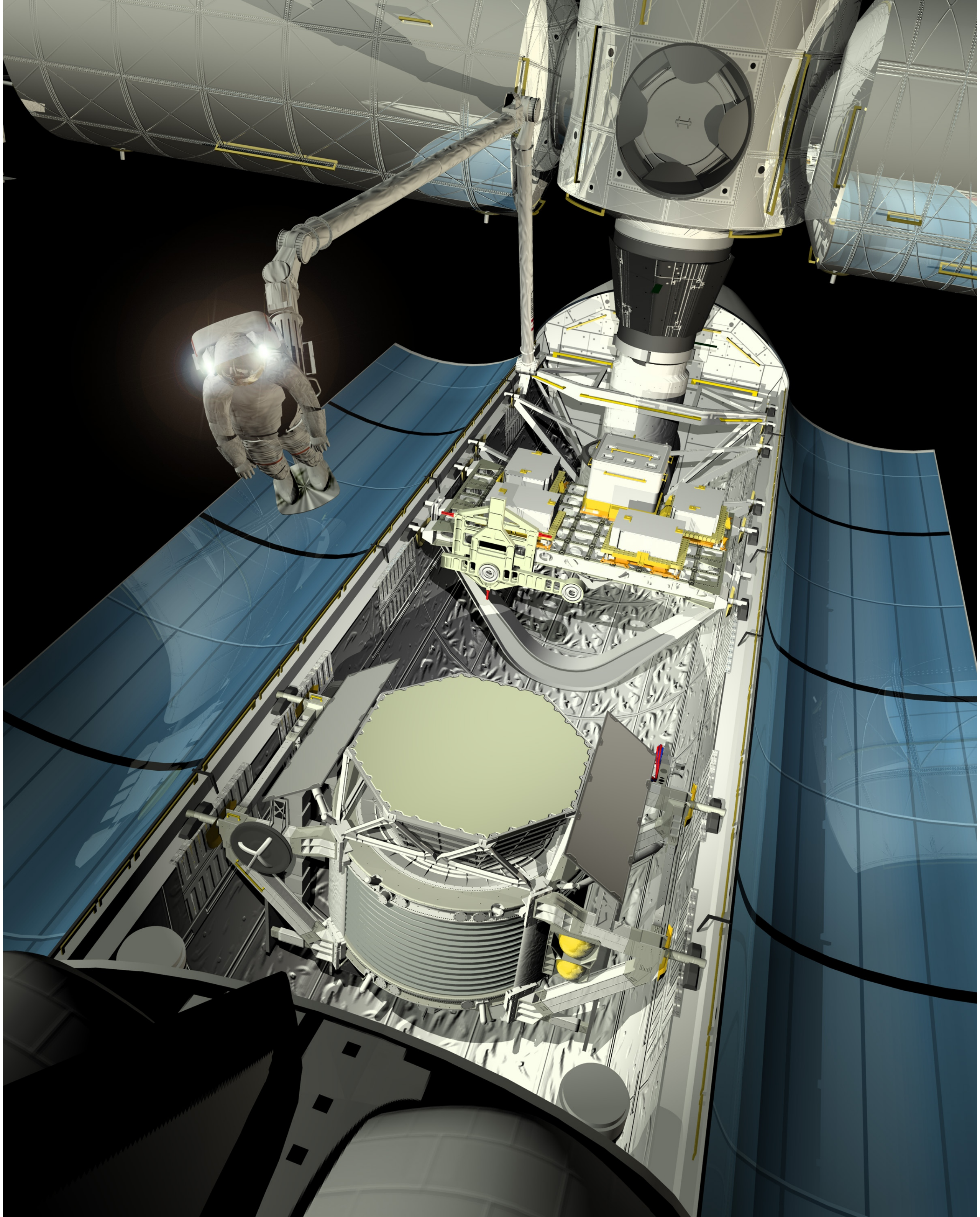
Explanation of the
"PAMELA POSITRON EXCESS"

Contribution
from all Pulsars



Hooper, Blasi, Serpico 2008

$$\frac{dN_e}{dE_e} \approx 8.6 \times 10^{38}\,\dot{N}_{100}\,(E_e/\mathrm{GeV})^{-1.6}\,\exp\left(-E_e/80\,\mathrm{GeV}\right)\,\mathrm{GeV}^{-1}\,\mathrm{s}^{-1}$$



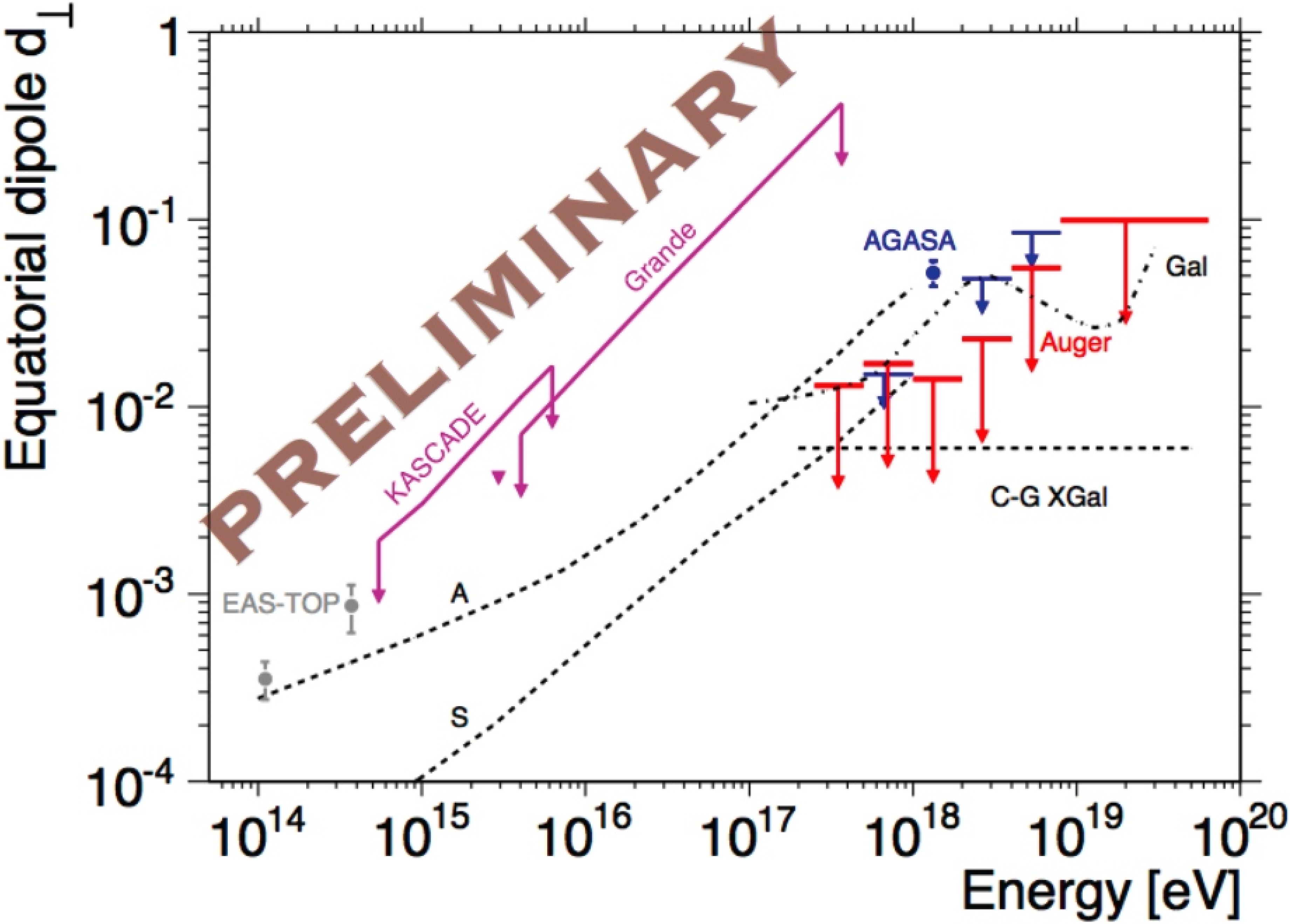
Importance of

AMS

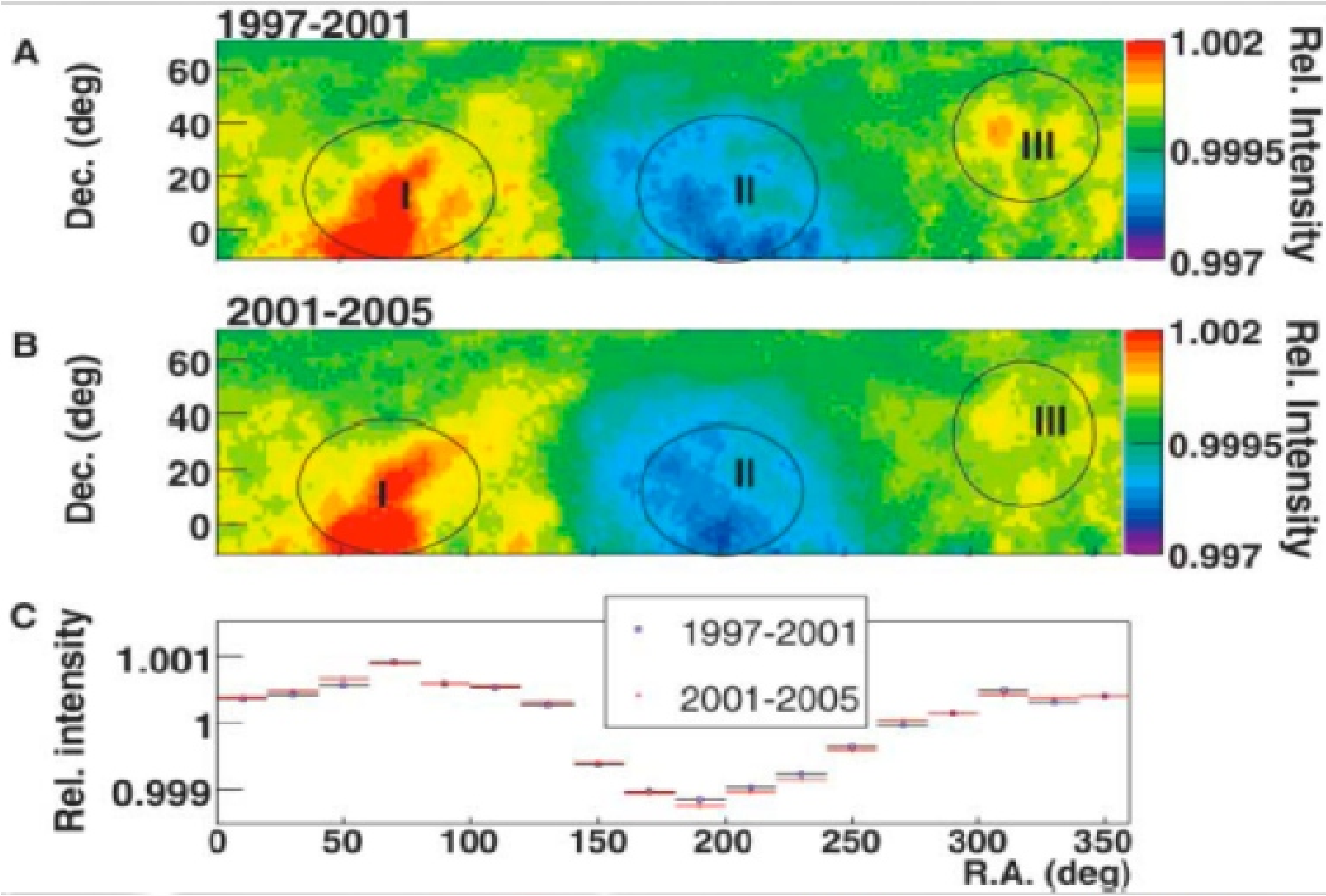
Mission.

Launch scheduled:
19^{th} April 2011

Letessier-Selvon [Nagoya dec/2011]

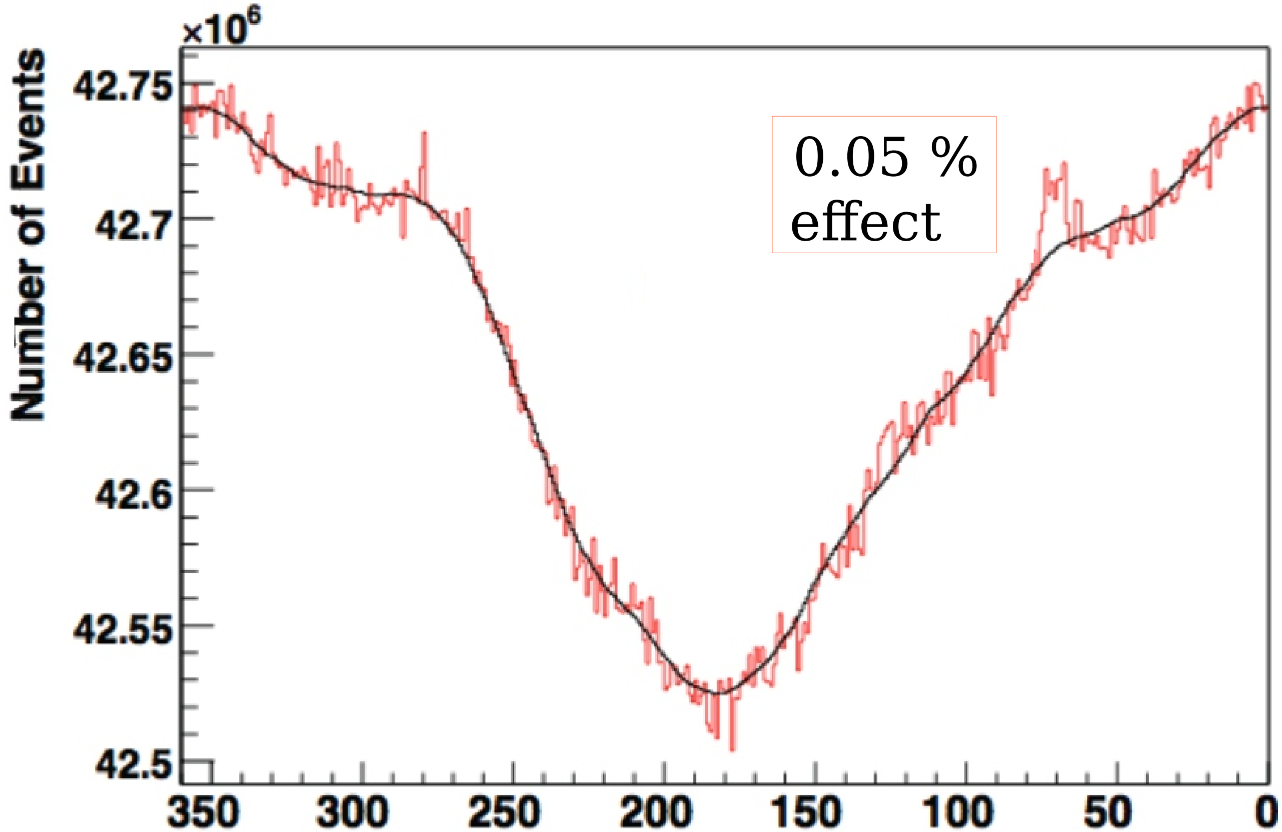


Tibet ASγ (verified by ARGO + IceCube)



M. Amenomori et.al. Science, 2006

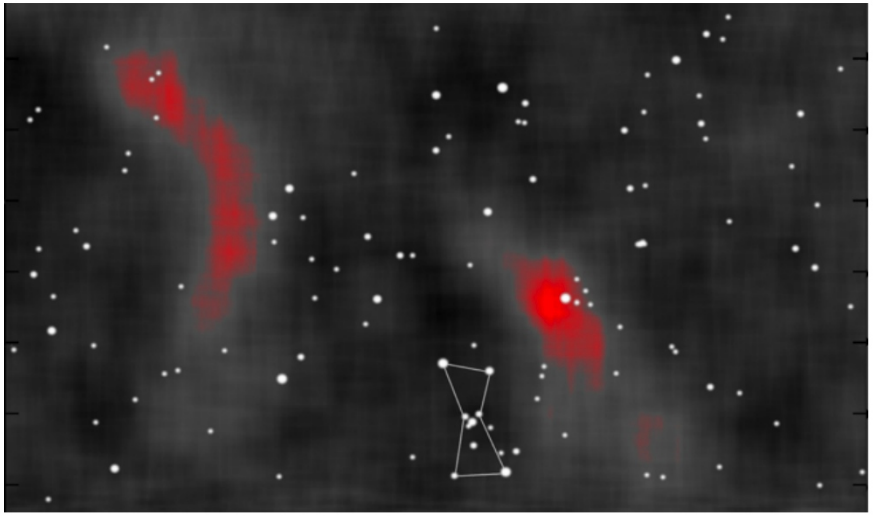
MILAGRO data (10 TeV hadrons).



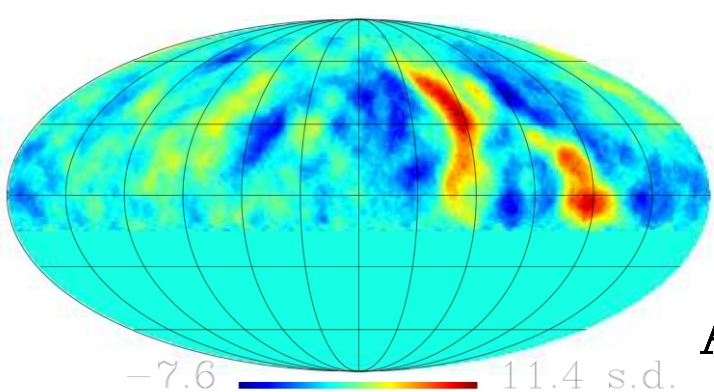
0.5 % effect

Right

Milagro “hot spots”



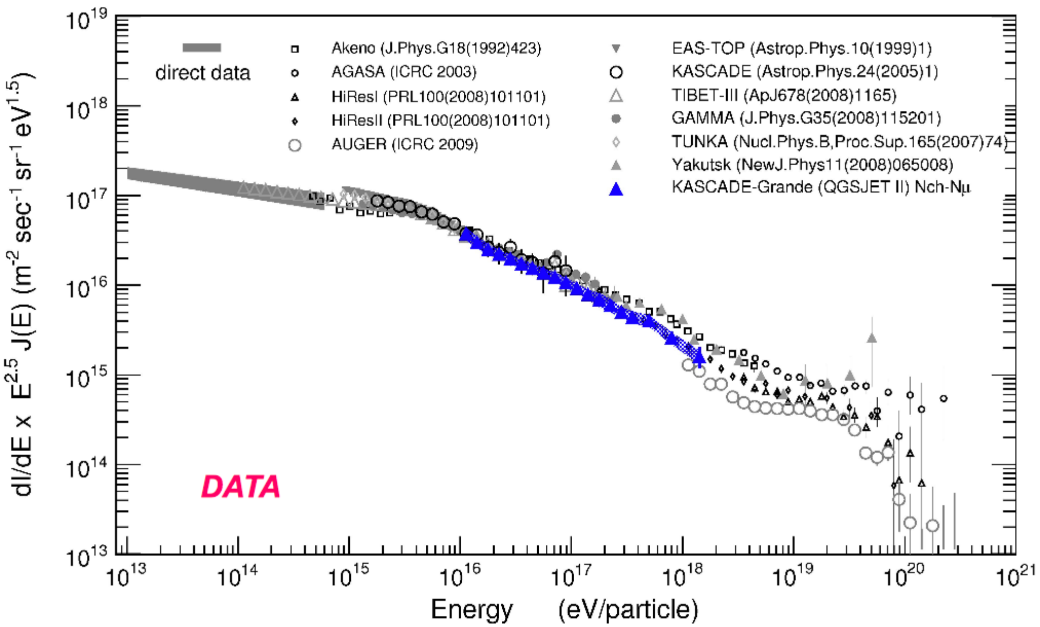
2



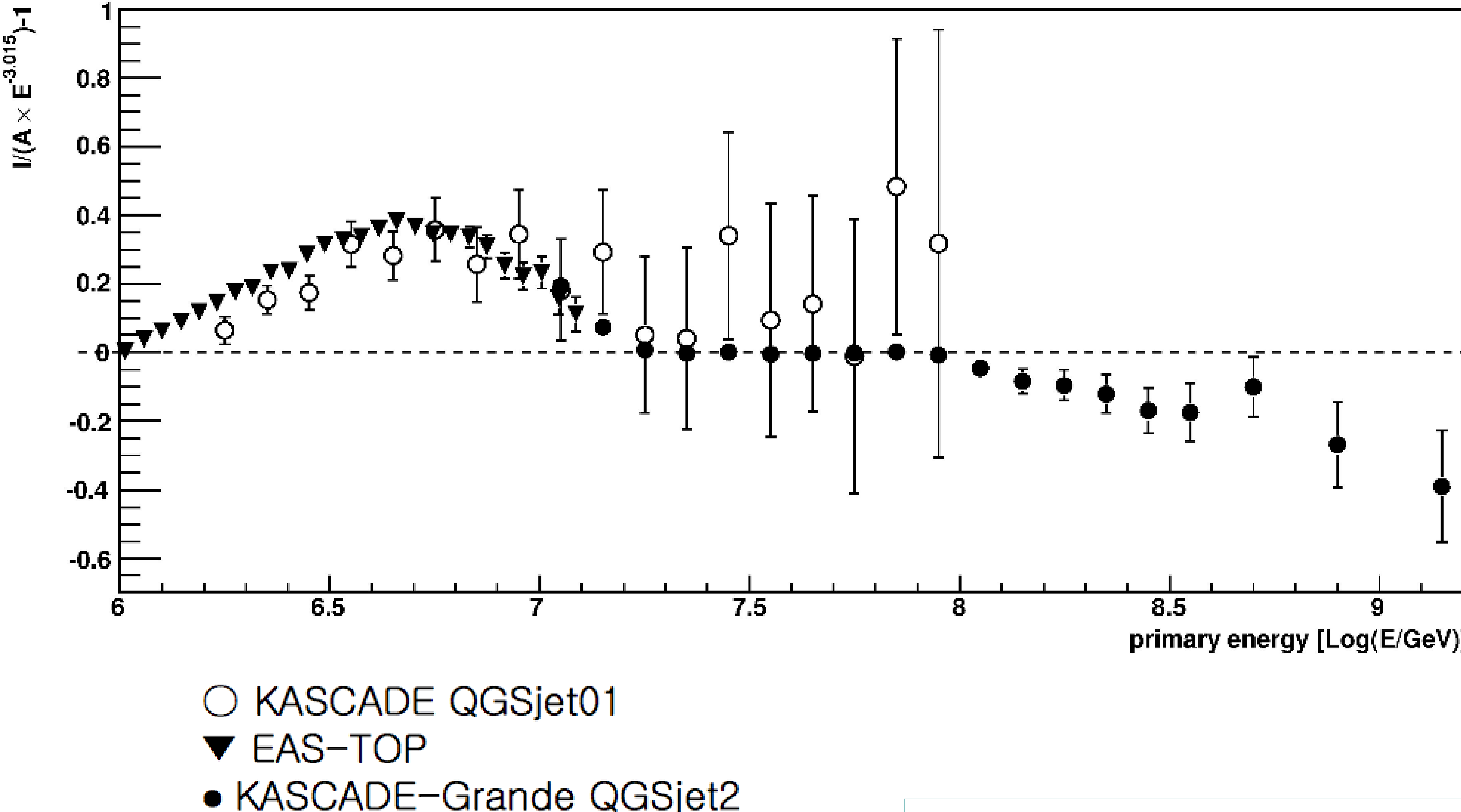
Argo

Going to higher energy:

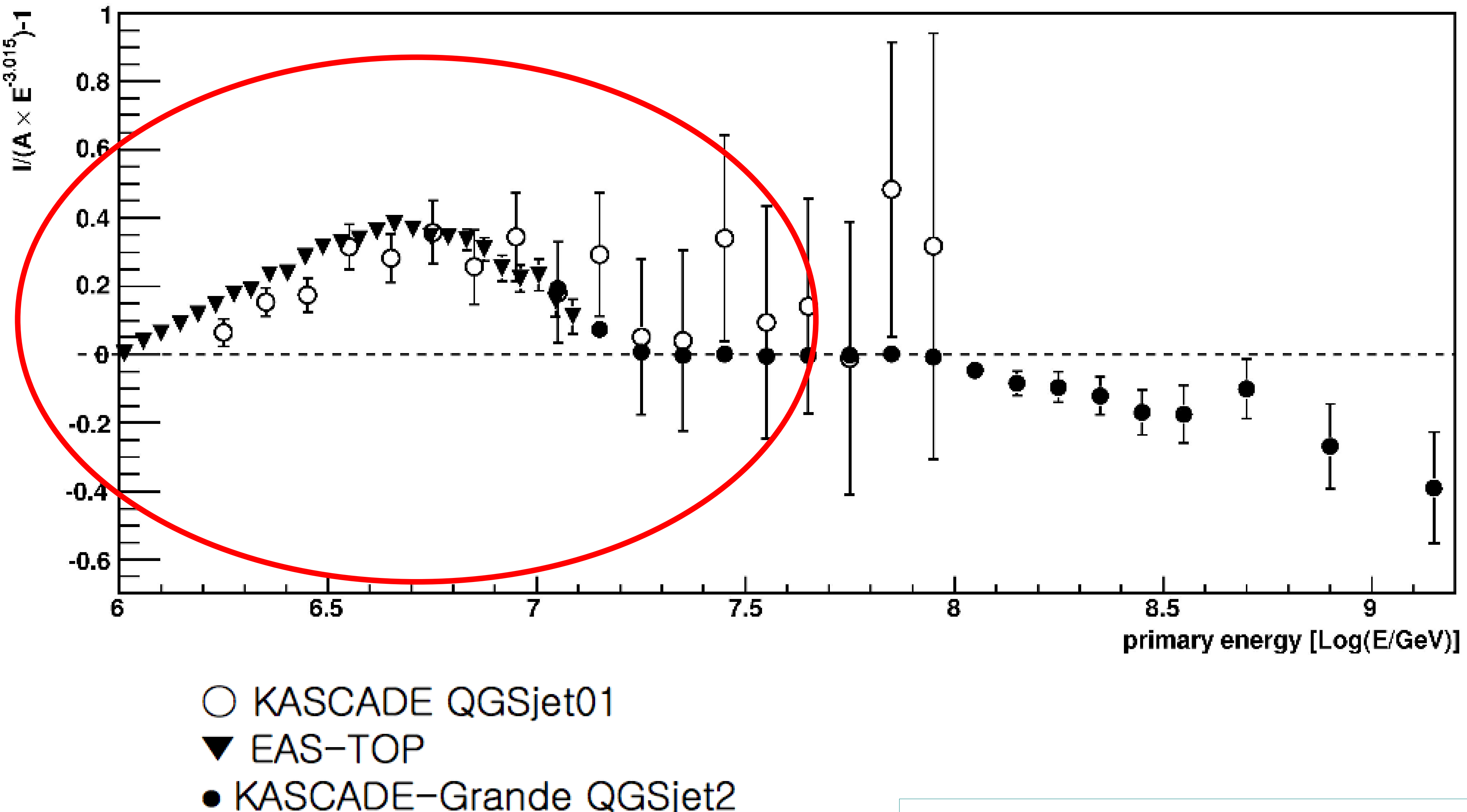
(EAS showers,
Indirect measurements)



- The Knee
- More structures ?
  (2nd Knee, other knees??)
- Galactic to Extragalactic Sources Transition
  [Extragalactic Sources]
- The “END of the SPECTRUM”

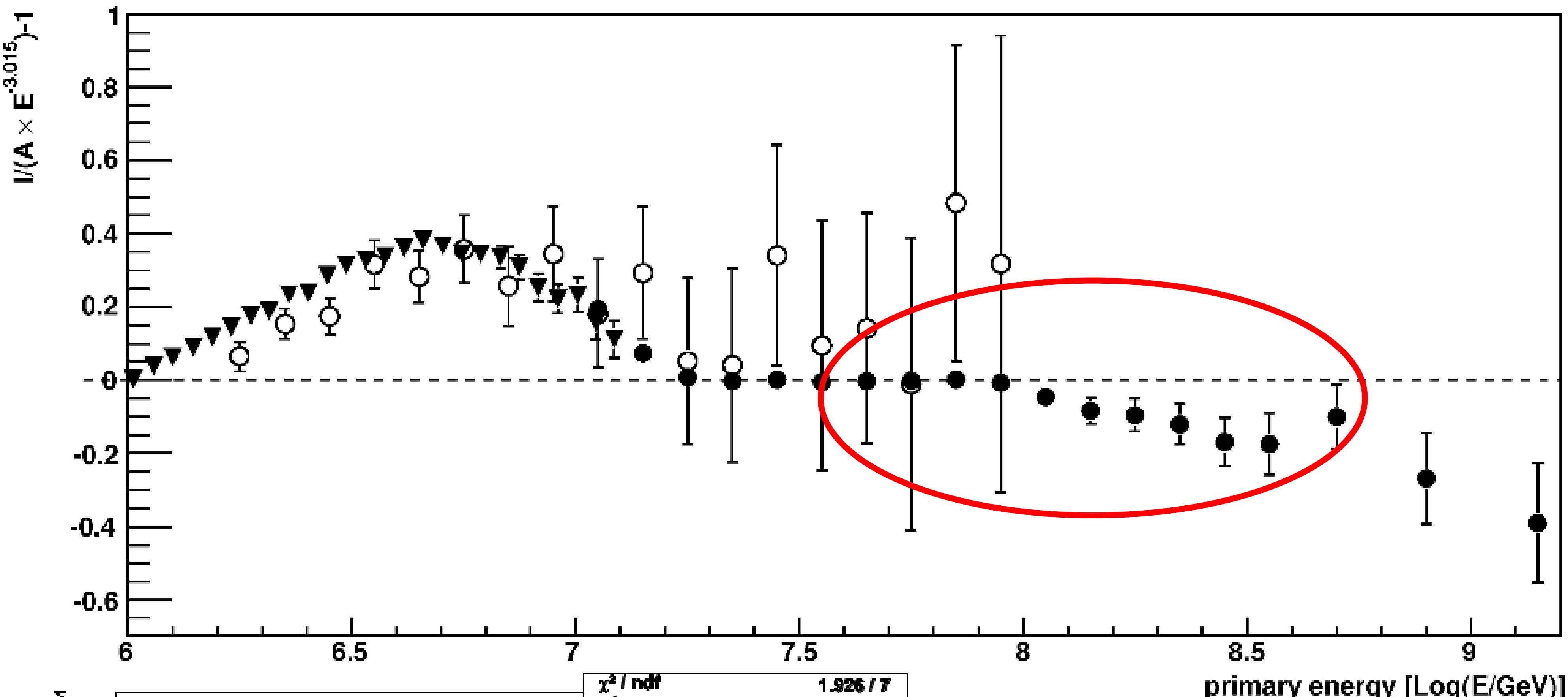


Kascade Grande
(Karlsruhe KIT)

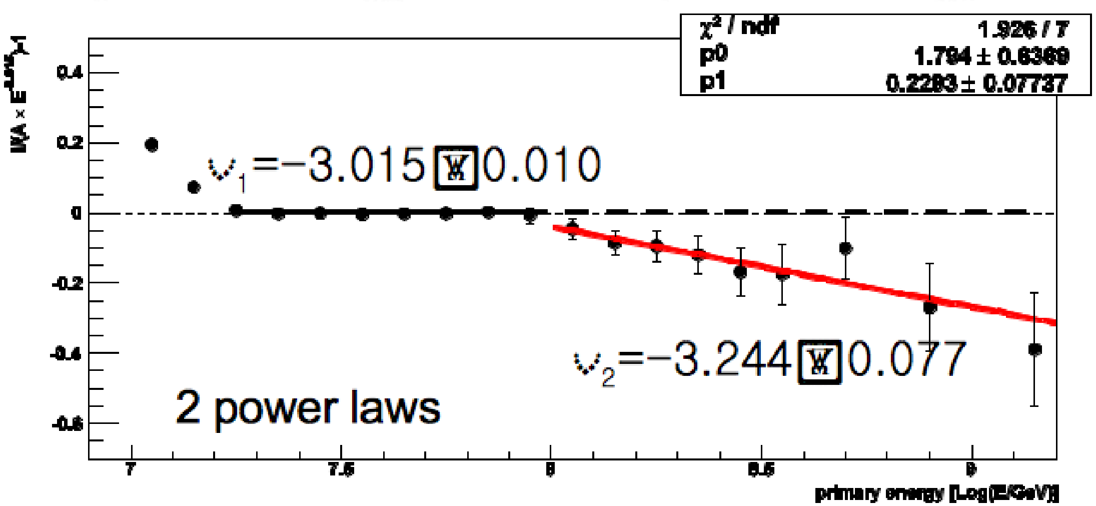


“Shape of the Knee” (?!)

Kascade Grande
(Karlsruhe KIT)

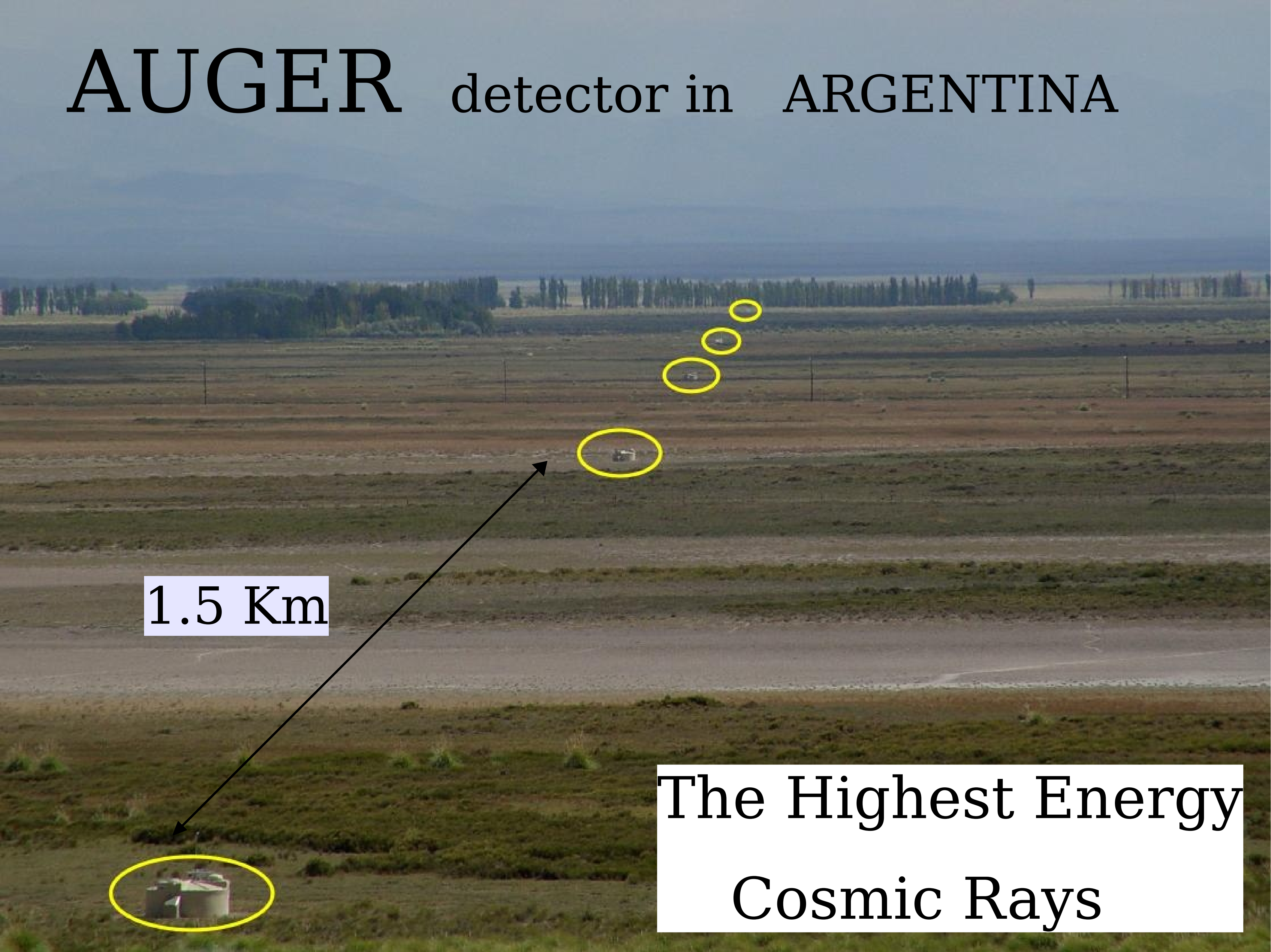


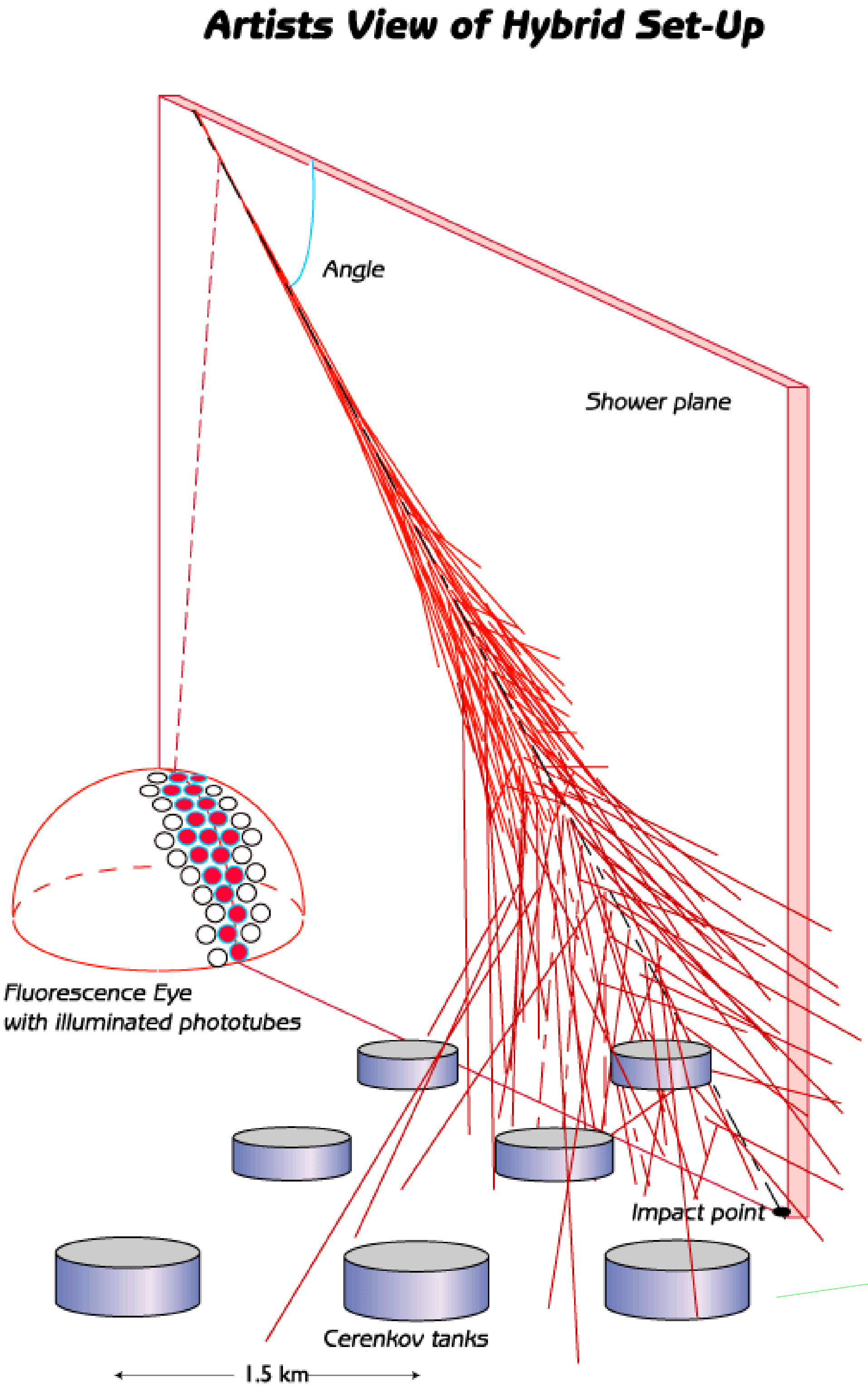
I/(A × E^-3.015)-1
primary energy [Log(E/GeV)]



χ² / ndf 1.926 / 7
p0 1.794 ± 0.6369
p1 0.2283 ± 0.07737
=−3.015
0.010
=−3.244
0.077
2 power laws
primary energy [Log(E/GeV)]

“Steepening”

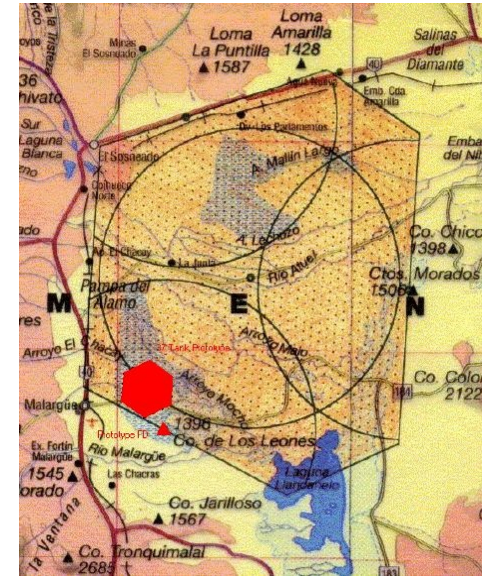

AUGER detector in ARGENTINA
1.5 Km
The Highest Energy
Cosmic Rays



AUGER detector

3000 Km^2

(Argentina)



Hybrid system

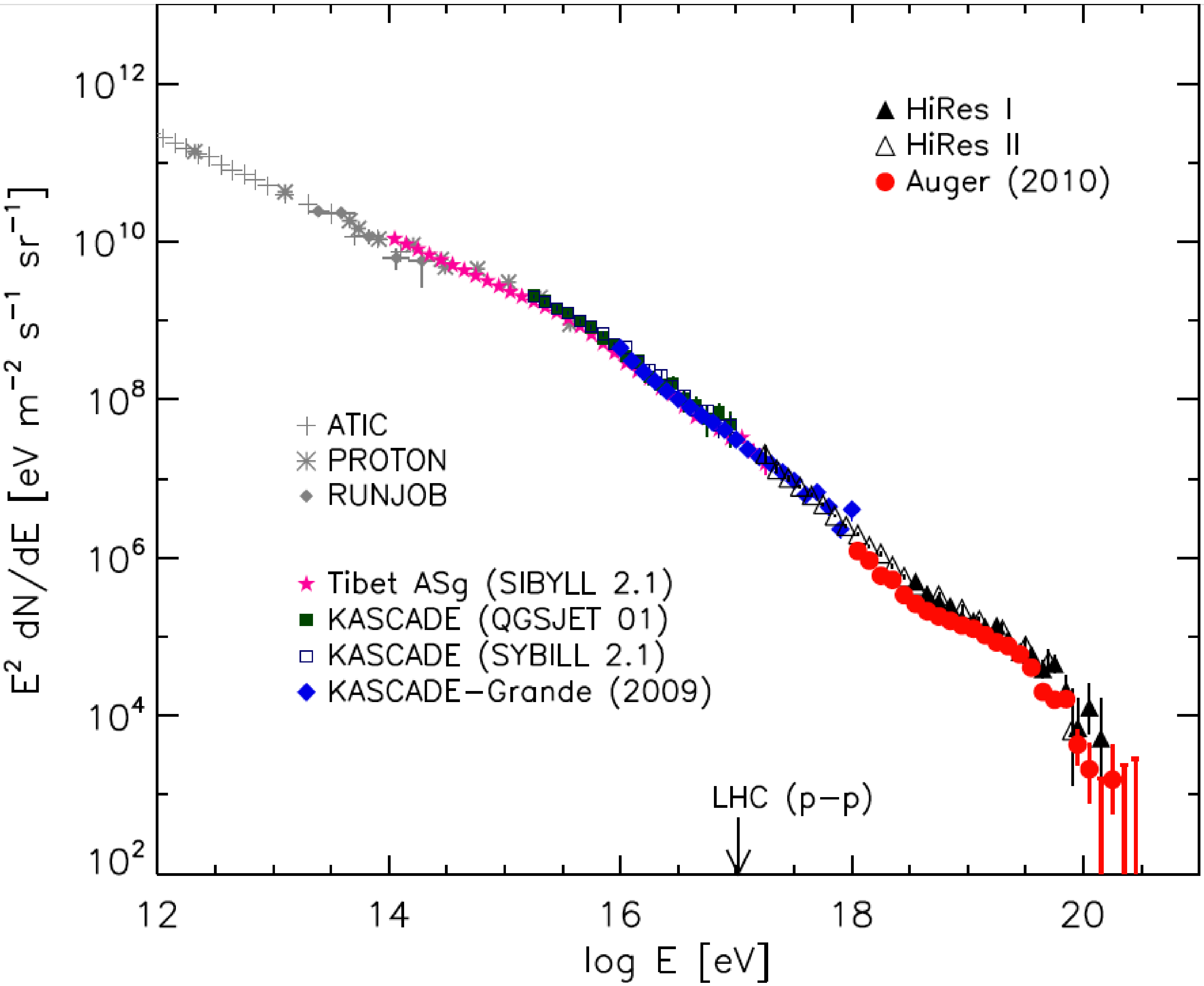
UHECR

1. Energy Spectrum
2. Anisotropy
3. Composition

Significant
Experimental
Discrepancies

Auger/Hires

Confusing
situation.



High energy Suppression

UHECR

1. Energy Spectrum

- Clear identification of a high energy suppression
  [the “END” (... well the “suppression”)
  of exotic/fundamental physics modeling for UHECR].

- Excellent agreement between experiments
  [“small” but important question about the energy scale].

- Physical interpretation strongly coupled to (2., 3.)
  (anisotropy + composition). [proton GZK ?]

"GZK" suppression: Proton-Photon Interaction

$$\boxed{p + \gamma \rightarrow N + \pi}$$

Inelastic photon-proton interactions.

$$\varepsilon^*_{\mathrm{rest}} = m_\pi + \frac{m_\pi^2}{2\,m_p} \simeq 0.150\ \mathrm{MeV}$$

Proton rest-frame

$$E_p\ \varepsilon\ (1 - \cos\theta_{p\gamma}) \geq m_p\ \varepsilon^*_{\mathrm{rest}}$$

$$E_p \gtrsim \frac{m_p\ \varepsilon^*_{\mathrm{rest}}}{\langle\varepsilon\rangle}$$

$$E_p \gtrsim \frac{m_p\ \varepsilon^*_{\mathrm{rest}}}{6\ K_B\, T_0} \simeq 1.0 \times 10^{20}\ \mathrm{eV}$$

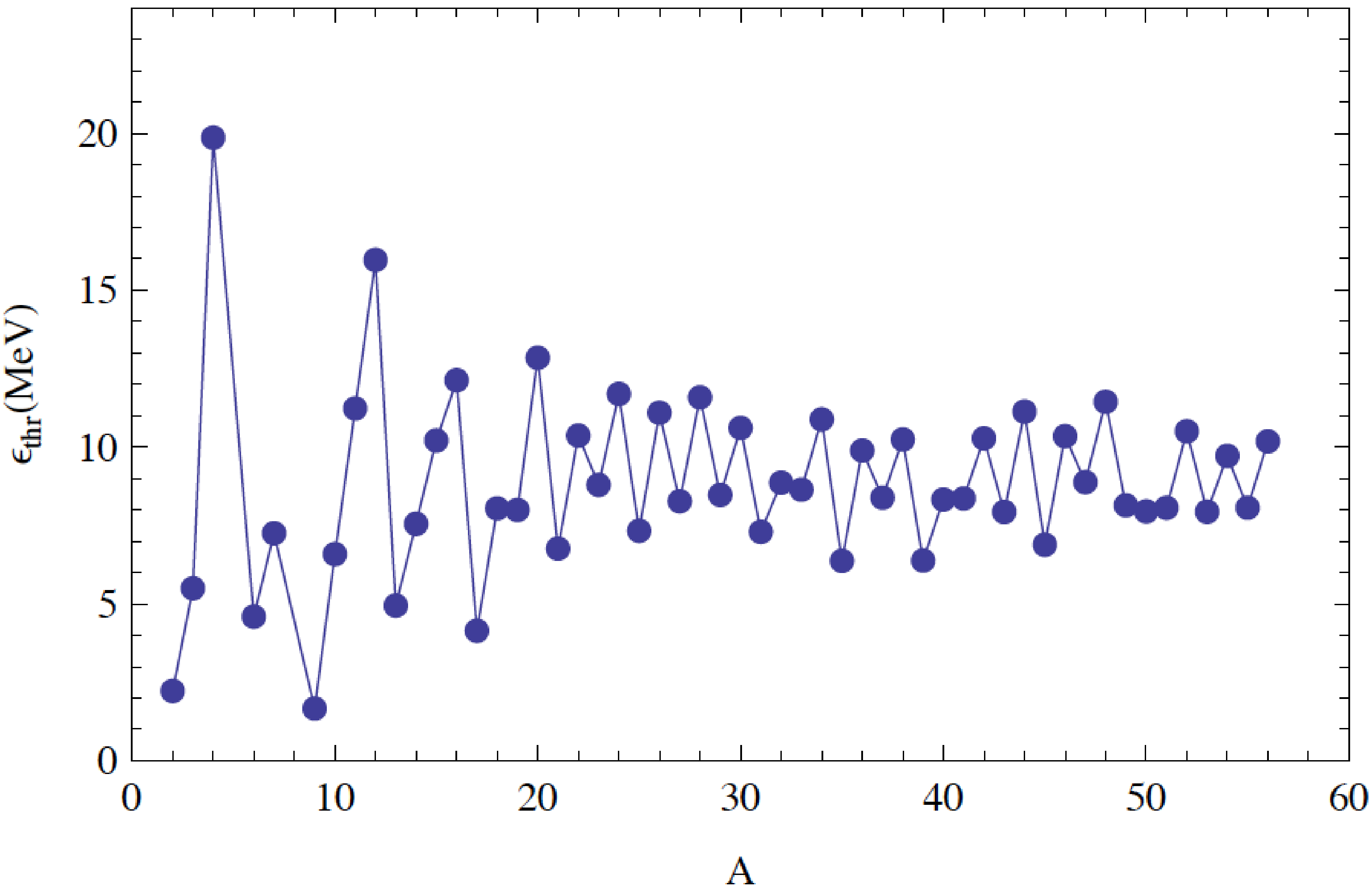
"Laboratory" frame

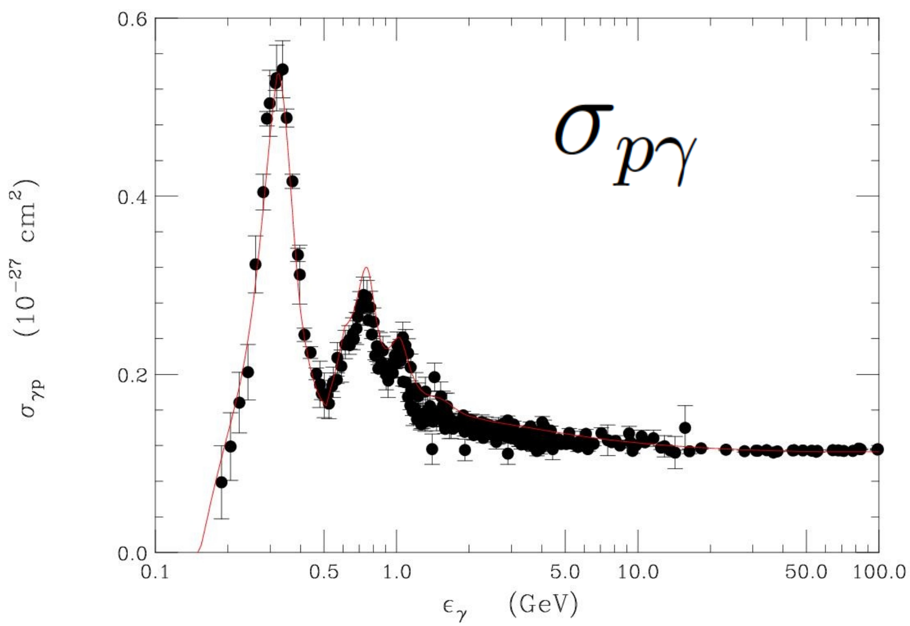
Photon disintegration

$$\boxed{A + \gamma \rightarrow (A-1) + N}$$

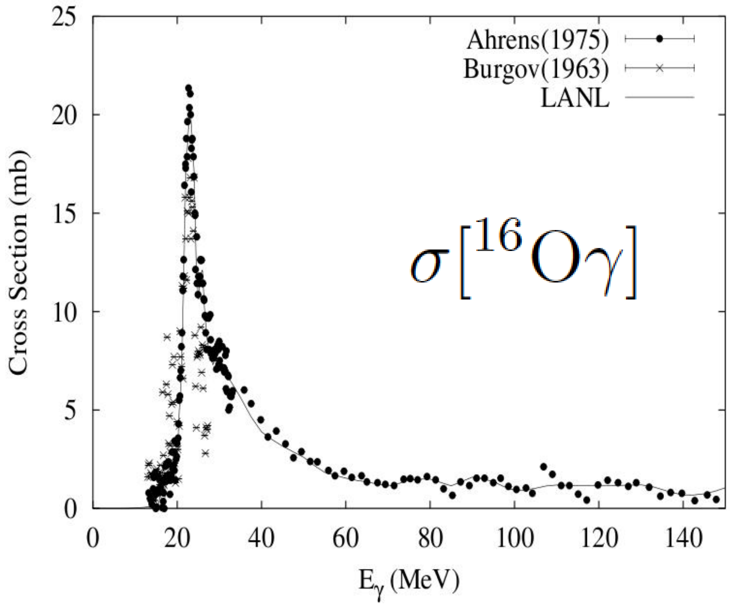
$$E_A \gtrsim \frac{M_A\ \varepsilon^A_{\rm rest}}{\langle \varepsilon \rangle}$$

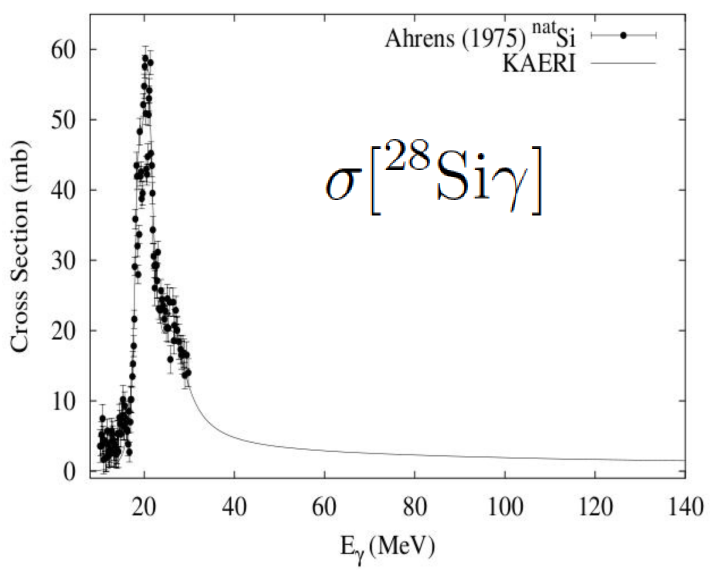
$$\varepsilon^A_{\rm rest} \sim 10\ \mathrm{MeV}$$





Cross section
for photo=disintegration
is a factor 100 higher
than
$\sigma_{p\gamma}$



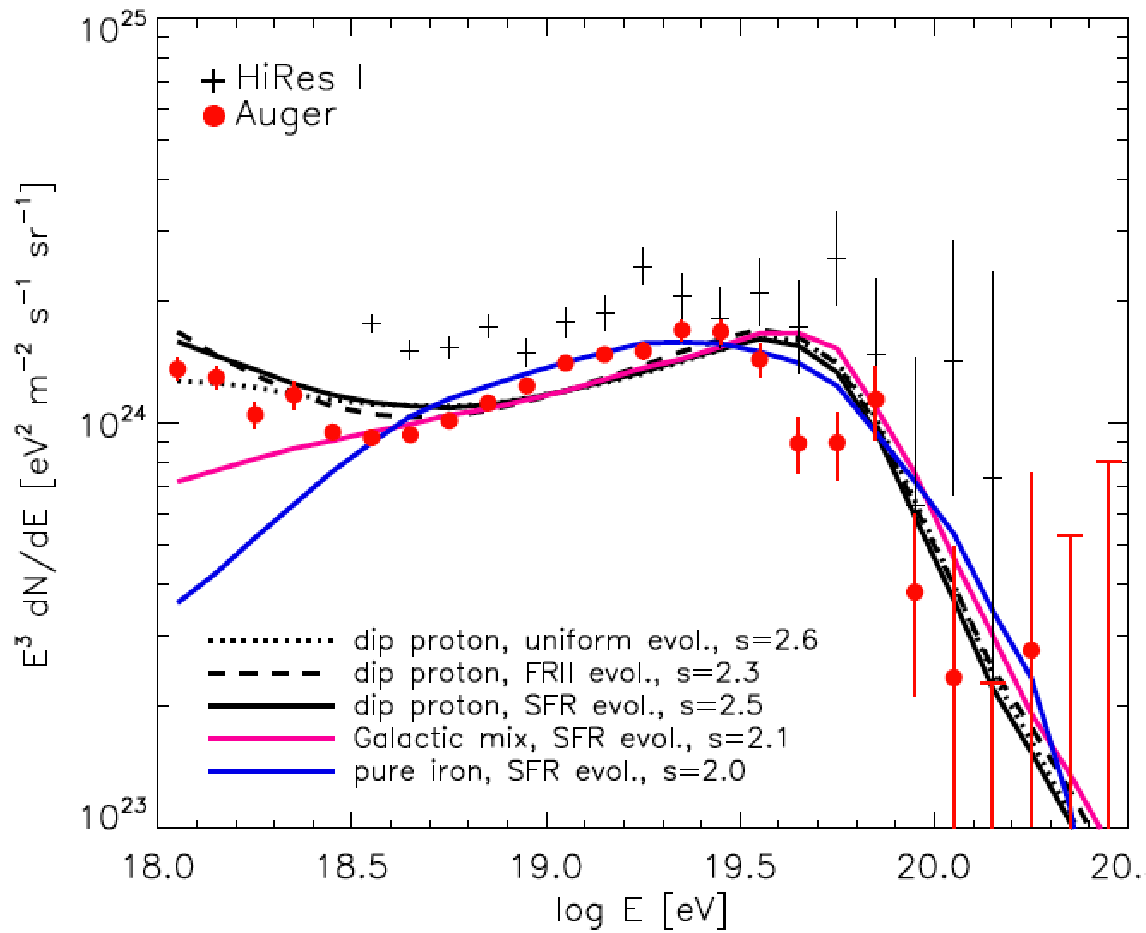


Three possible interpretations for the high energy suppression of UHECR:

1. Proton “GZK” suppression

2. Iron photo-disintegration

3. Maximum energy of the Sources



UHECR

1. Energy Spectrum

2. Anisotropy

3. Composition

Consistent interpretation of AUGER results is problematic.

“CRISIS” (?)

UHECR

Crucial Problem:

Galactic Extragalactic Transition

1. Maximum Energy of
   Milky Way sources

2. Power of Extragalactic CR sources

3. Shape of injection spectrum
   of extragalactic CR

Energy Spectrum "feature"

Composition change

Isotropy effect

UHECR

Crucial Problem:

Galactic
Extragalactic
Transition

1. Maximum Energy of
   Milky Way sources

2. Power of Extragalactic CR sources

3. Shape of injection spectrum
   of extragalactic CR

Energy Spectrum
“feature”

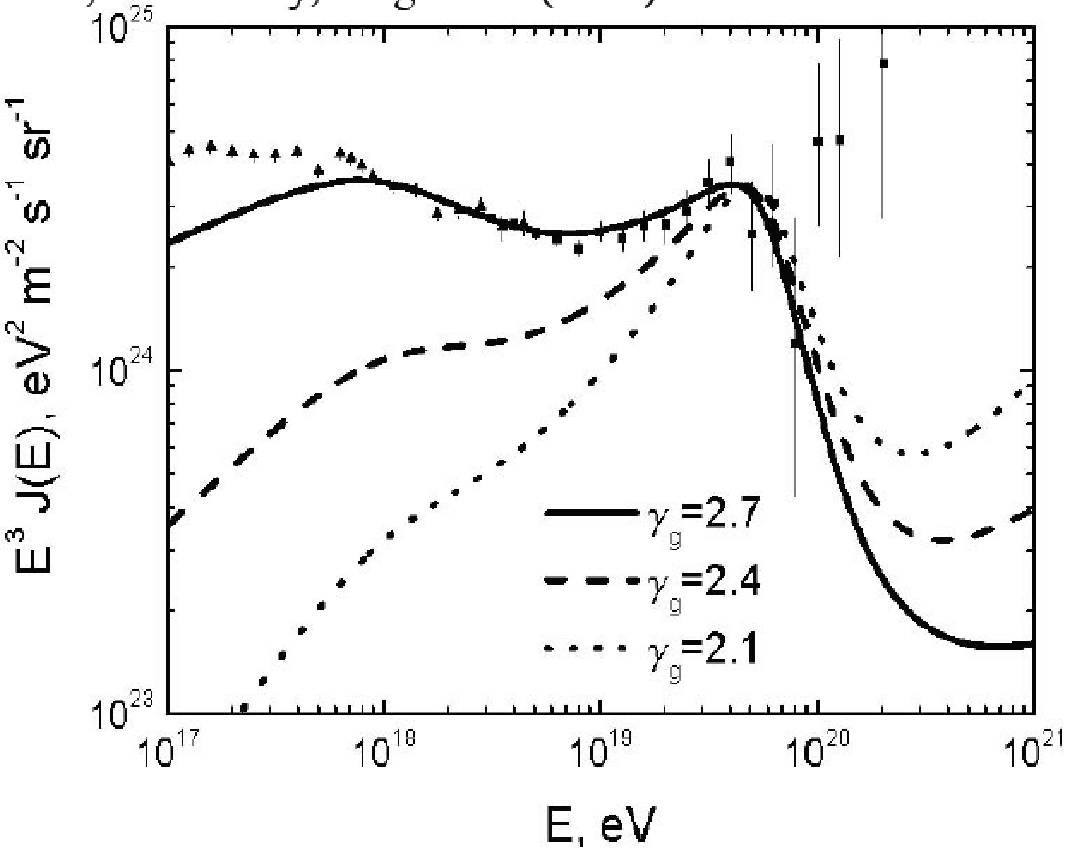
Composition change

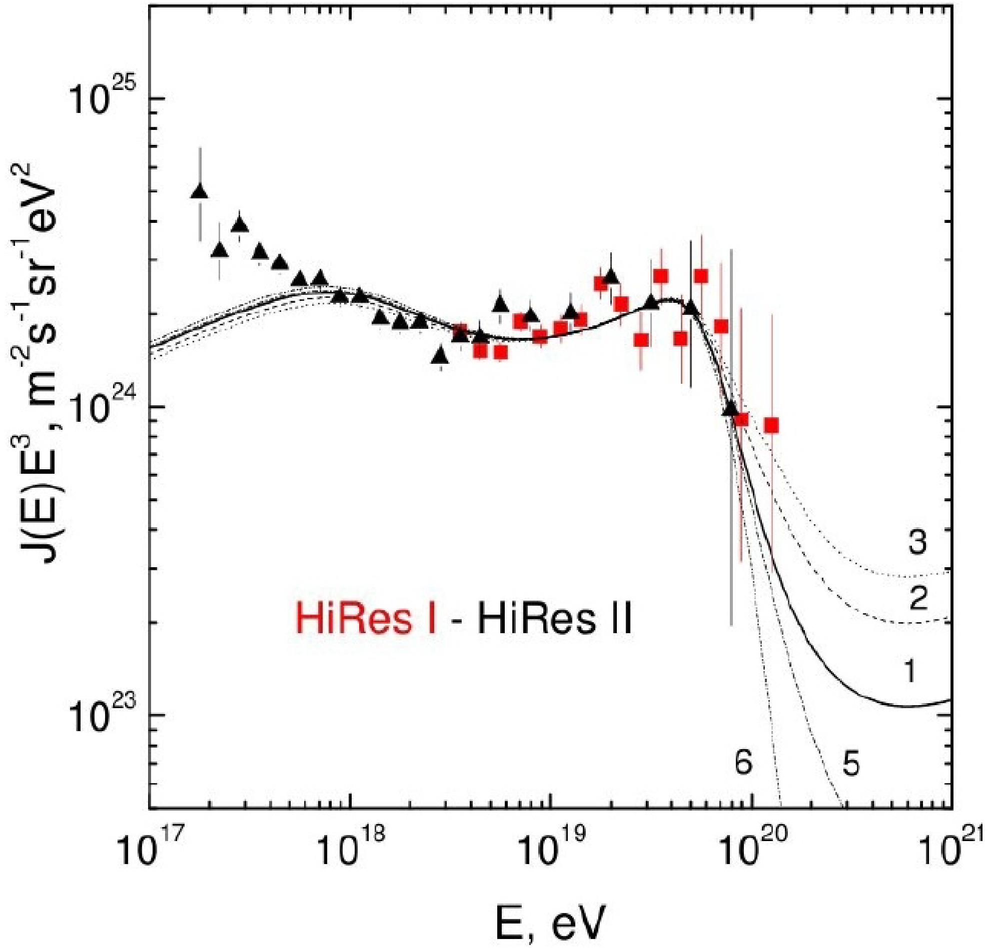
Isotropy effect

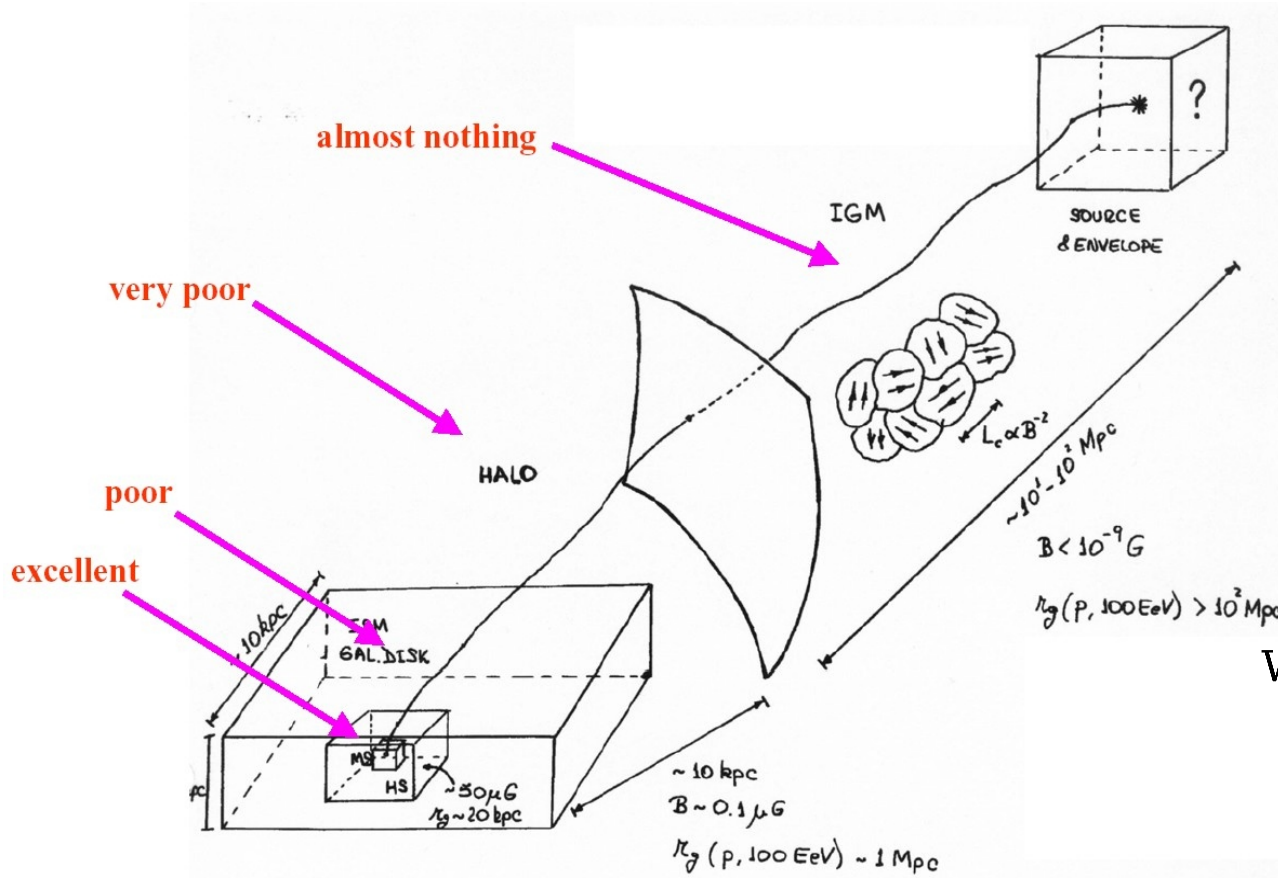
Not detected
Poorly predicted
MW large scale field

Berezinsky “DIP Model”

RA, Berezinsky, Grigorieva (2009)



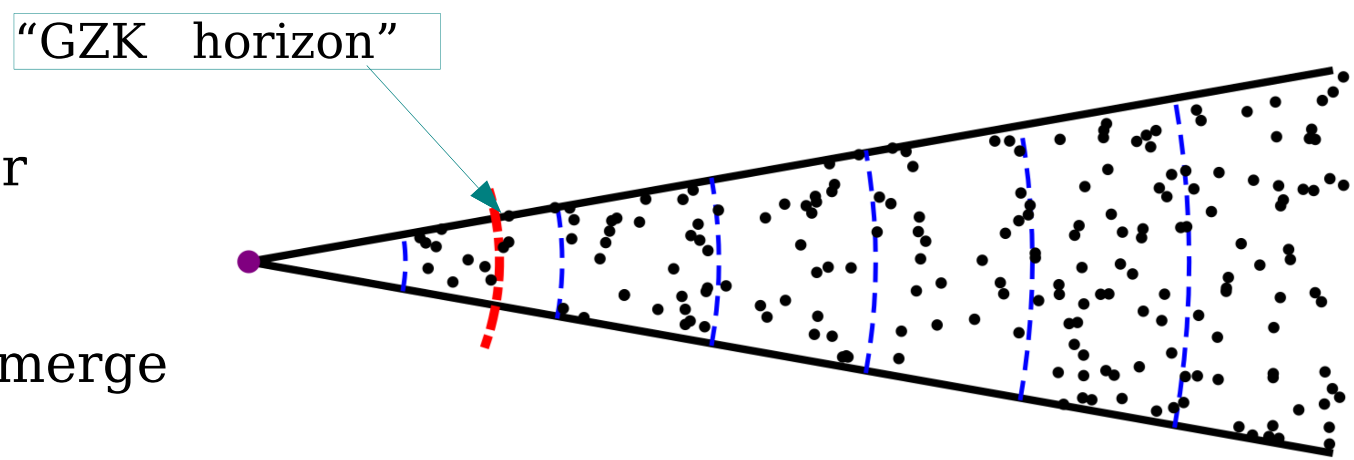




W.Essey, S.Ando, A.Kusenko,
``Determination of intergalactic magnetic fields from gamma ray data,''
[arXiv:1012.5313].
[Controversial !]

Higher Energy:
Horizon becomes closer
Rigidity increases.

Point Sources should emerge

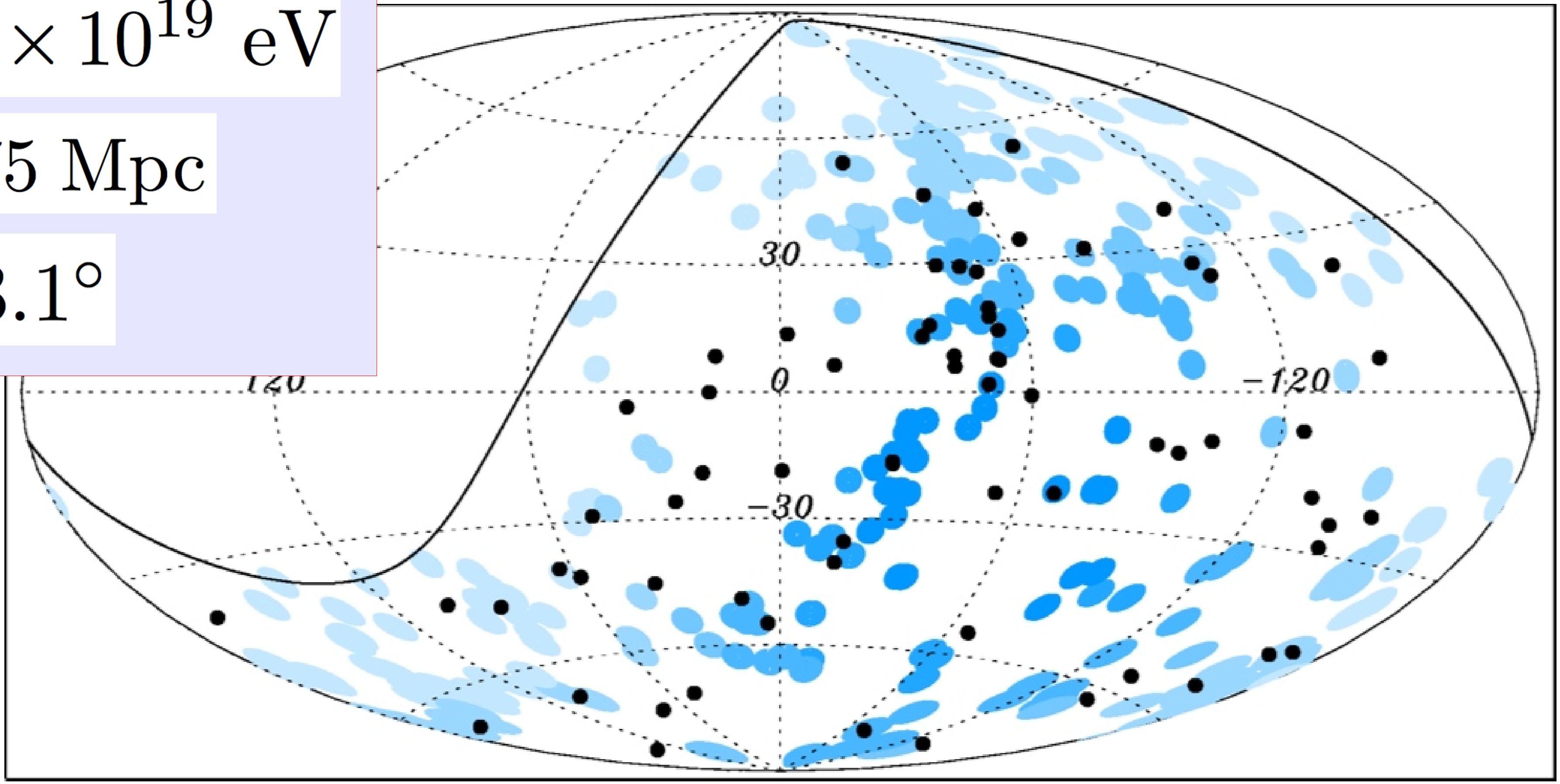


AUGER result on Correlations with the VCV AGN catalogue
November 2008. Update september 2010.

6×10^{19} eV

75 Mpc

3.1°



Significant dilution
[but not disappearance]
of the statistical significance

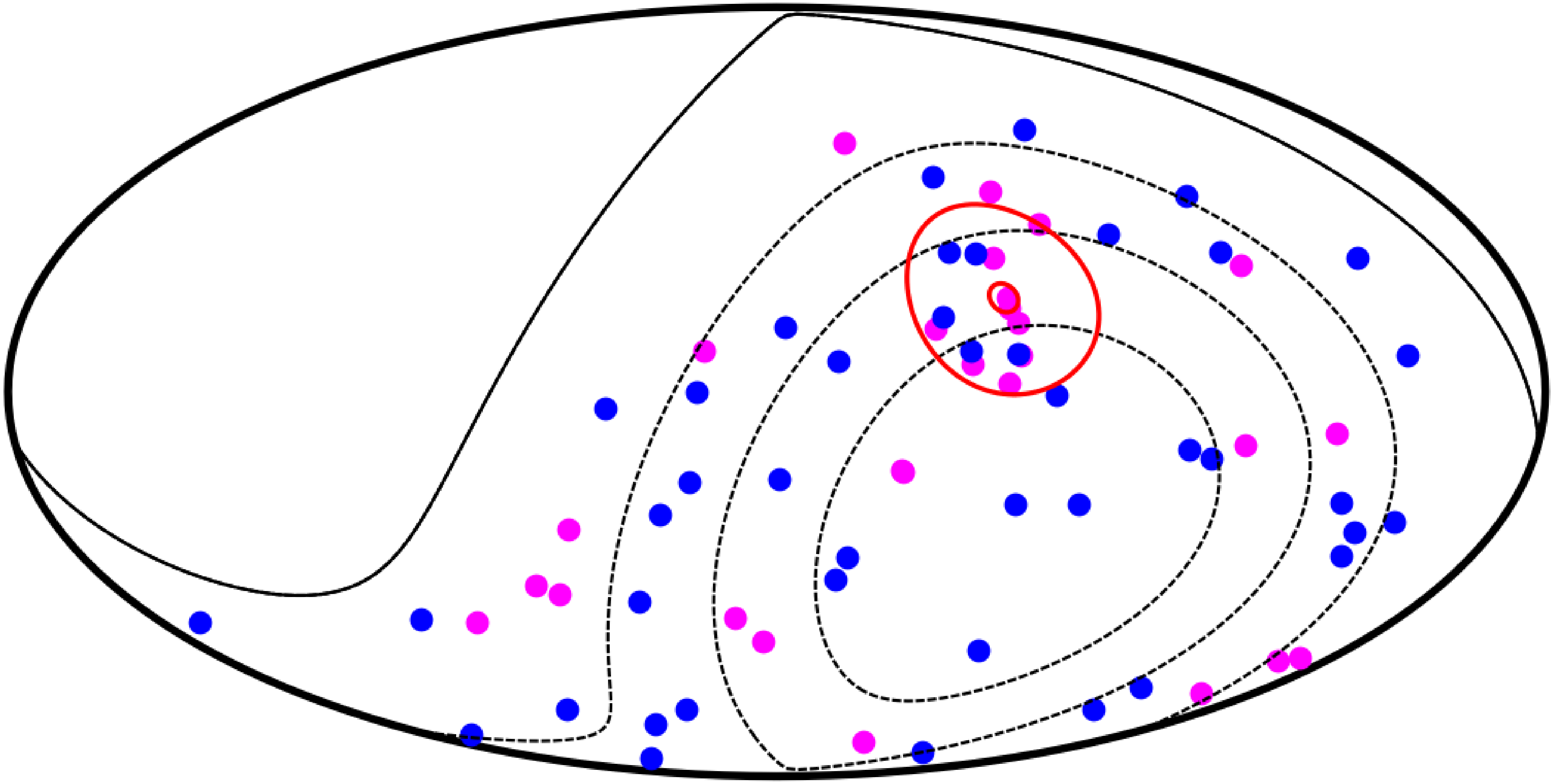
14 ev. 8 coincid. (2.9)
13 ev. 9 coincid. (2.7)
42 ev. 12 coincid.(8.8)

Discussion on CEN A

The AGN closest to us.

3 events within 3 degrees
8 events within 18 degrees

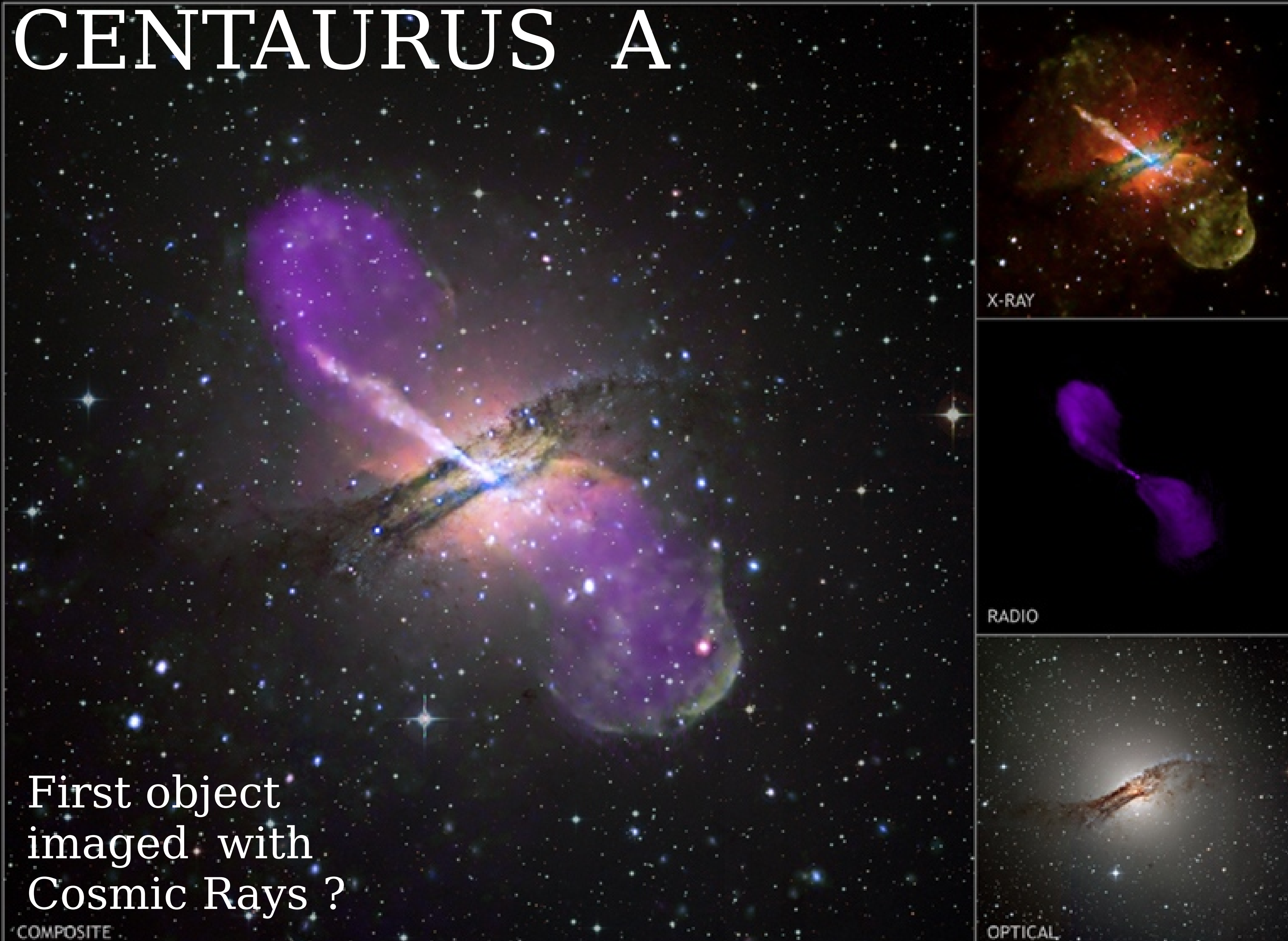
+0 events within 3 degrees
+5 events within 18 degrees



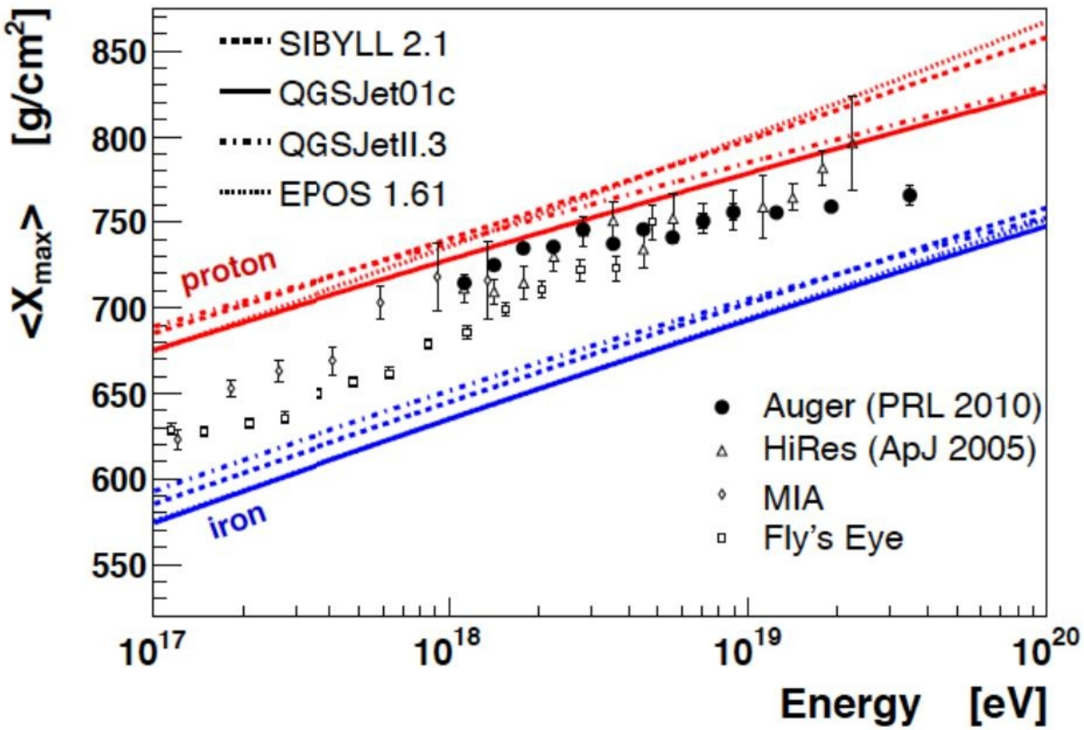
November 2008 (13 + 14 events)
Update september 2010 (+42 events)

3, 20 degrees circles

CENTAURUS A

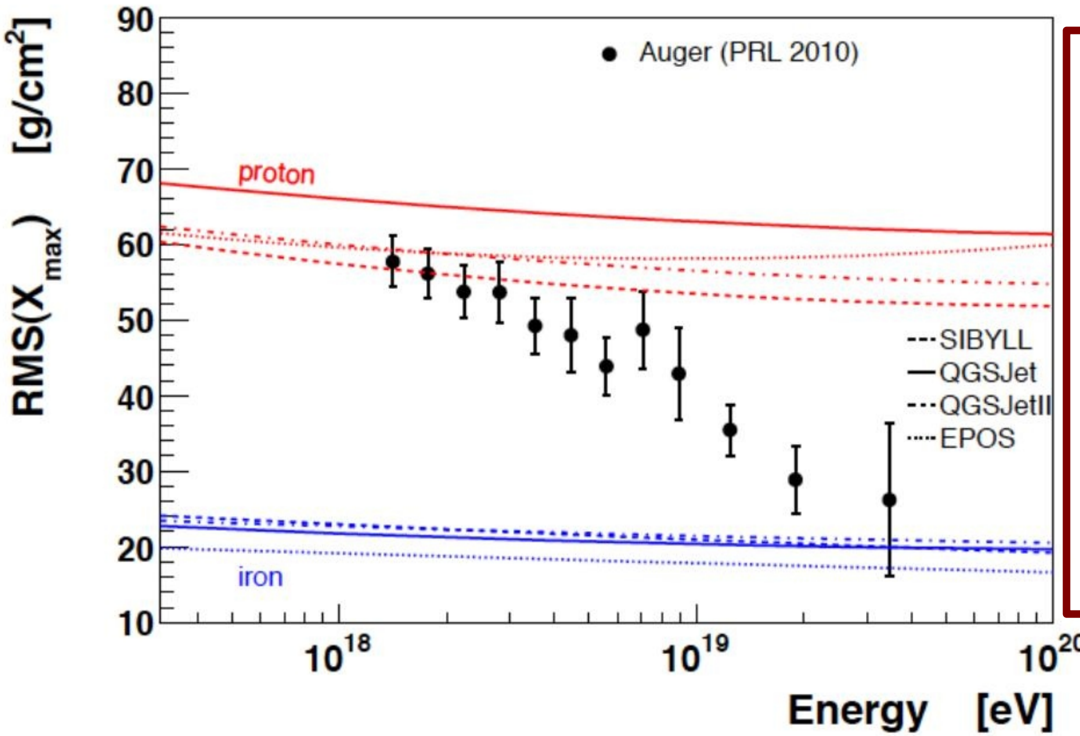


First object
imaged with
Cosmic Rays ?



Mass Composition
becoming heavy ?
at very high energy ?

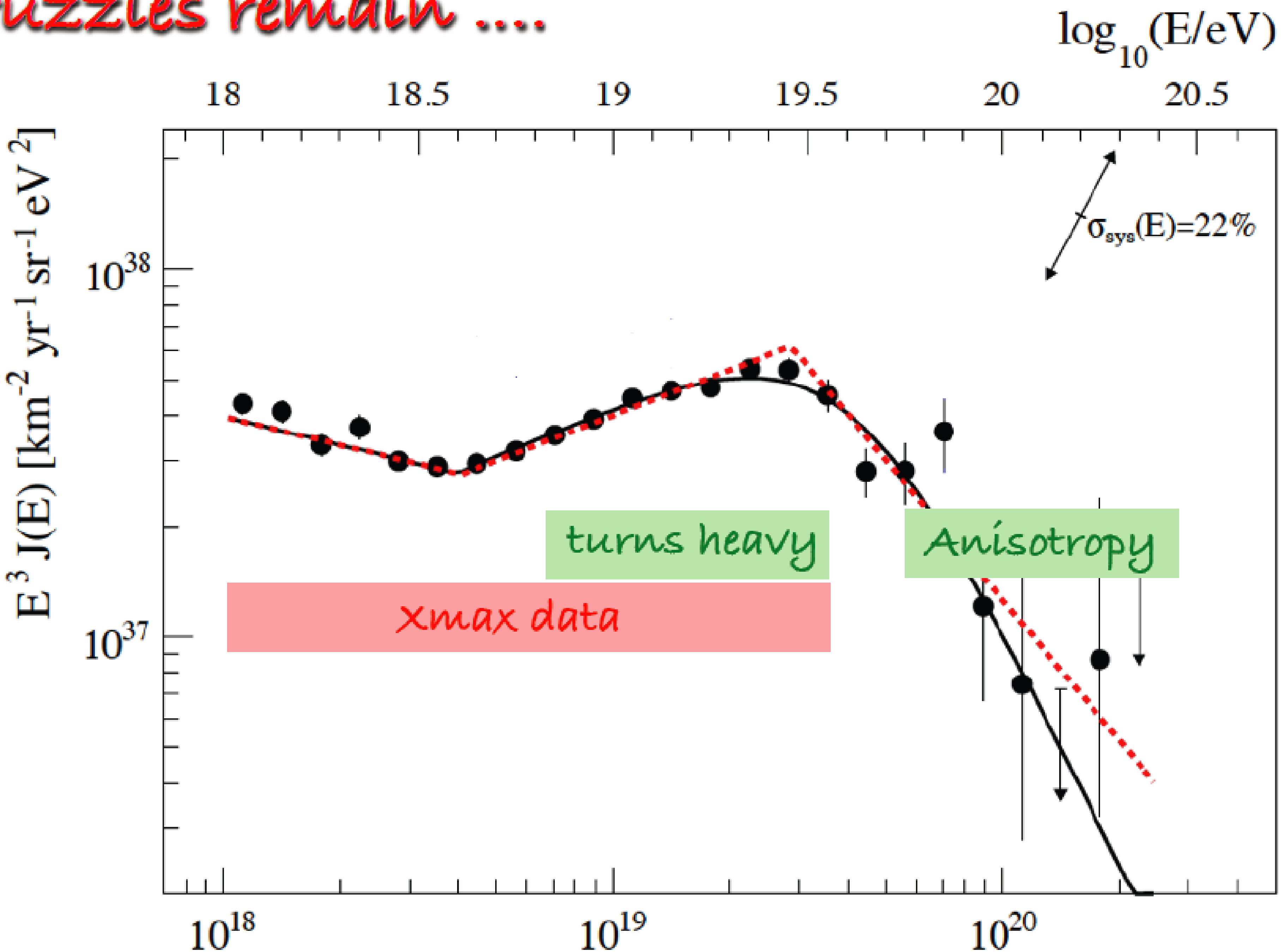
Significance would be
very important !
Constraints on the
structure and properties
of the astrophysical sources.



Observational controversy
NON confirmation
of HiRes

Correlation with sources
Small deviation in magnetic
Fields (Z < 3 ?)

Puzzles remain ....

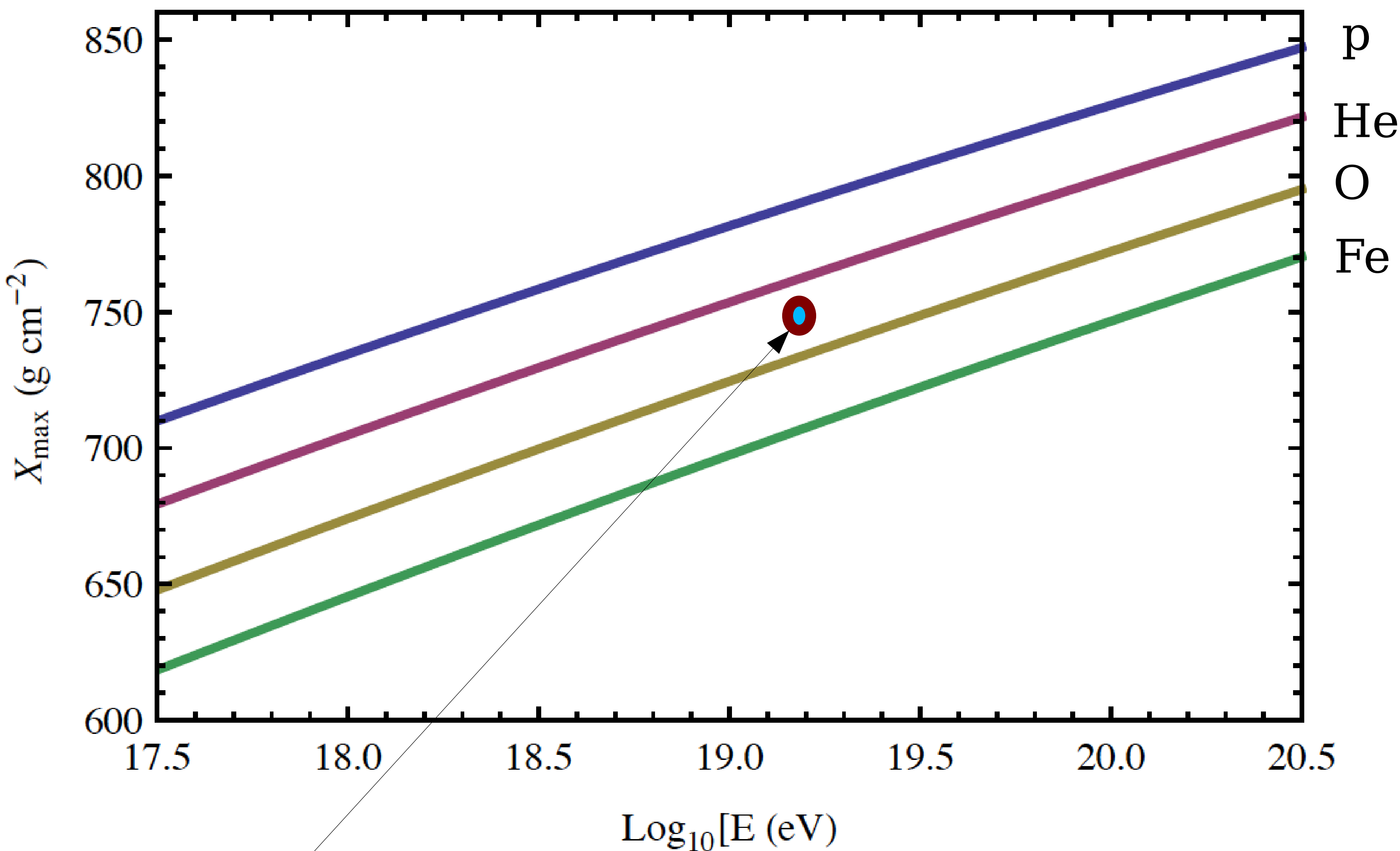


Johannes Knapp

J. Cronin: astro-ph/0911.47141

"If these trends persist to the
highest energies there would appear to be a conflict
between conclusions that can be drawn from
the anisotropy and the conclusions drawn
from the elongation rate measurement."

"These results also demand a more careful review of
what seemed to be an obvious conclusion that iron nuclei
could not show an anisotropy because of galactic
and perhaps extragalactic magnetic fields."

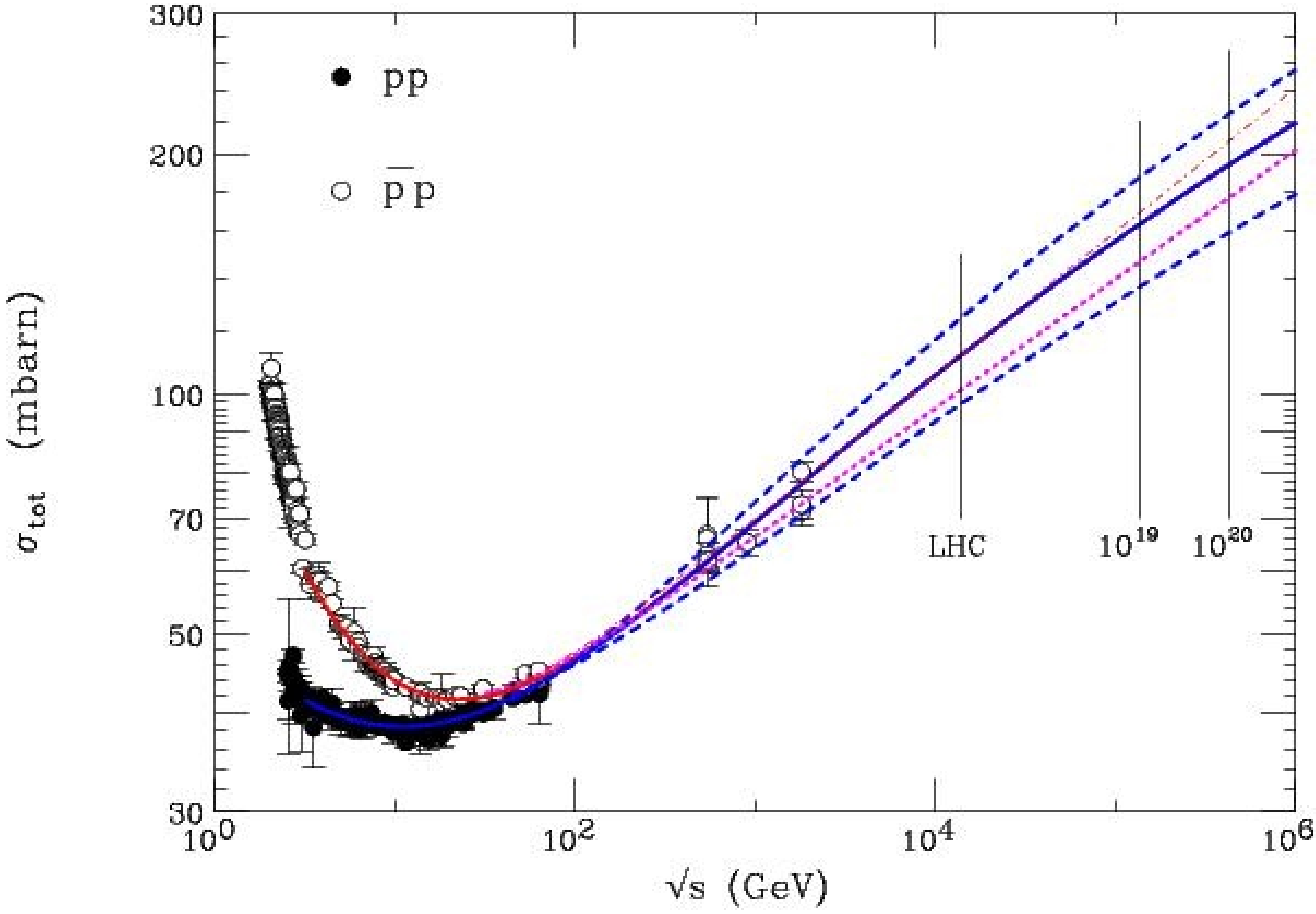


Measurements of

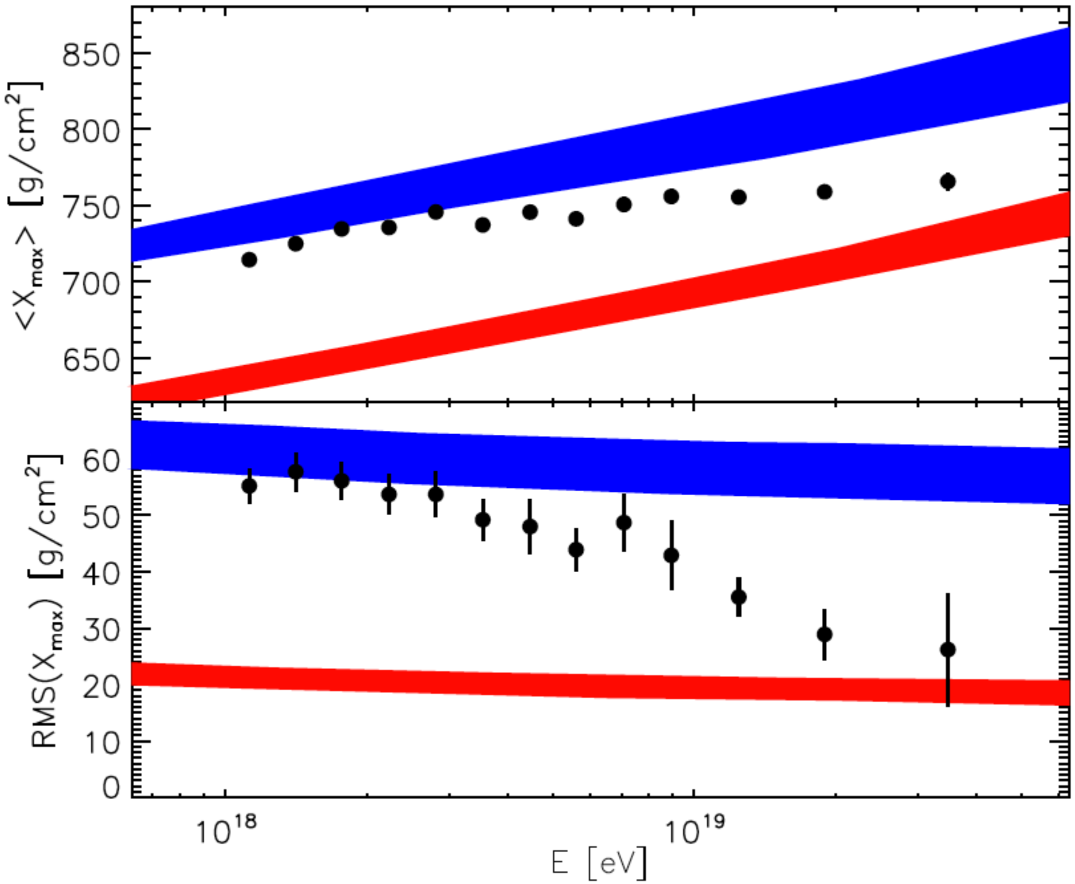
$$\langle \log A \rangle$$

$$\langle \ln A \rangle_E = \frac{\sum_A \phi_A(E)\ \ln A}{\sum_A \phi_A(E)}$$

Total pp Cross Section



Systematic uncertainty due to hadronic interactions.



Lessons from LHC!

D. d'Enterria, R. Engel, T. Pierog, S. Ostapchenko, K. Werner, "Constraints from the first LHC data on hadronic event generators for ultra-high energy cosmic-ray physics," [arXiv:1101.5596 [astro-ph.HE]].

B. Alessandro, D. Bergman, M. Bongi, A. Bunyatyan, L. Cazon, D. d'Enterria, I. de Mitri, P. Doll *et al.*, "Hadron-Hadron and Cosmic-Ray Interactions at multi-TeV Energies," [arXiv:1101.1852 [hep-ex]].

Final Remark:

The efforts to understand the objects and
the mechanisms that generate
high energy relativistic particles
in our Galaxy and in the universe
form a vibrant field with continuous
surprises and new discoveries.

This is beautiful Science, still very much
controlled by the data, with theorists puzzled
and “in the dust” again and again ….

Multi-messenger astrophysics is essential
and [….sooner or later…]
Neutrino Telescopes will play a key role.

WELCOME TO NUSKY 2011!

INTERNATIONAL WORKSHOP ON COSMIC RAYS AND COSMIC NEUTRINOS: 'LOOKING AT THE NEUTRINO SKY'

Trieste, June 20 - 24, 2011

Alexey Smirnov

http://users.ictp.it/~smr2246/