Problems in High Energy Astrophysics

Perspectives for

Multi Messenger ASTROPHYSICS

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NOVE-2008
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Galactic versus Extragalactic Cosmic Rays

Magnetic Field
(in the Milky Way and in extragalactic space)

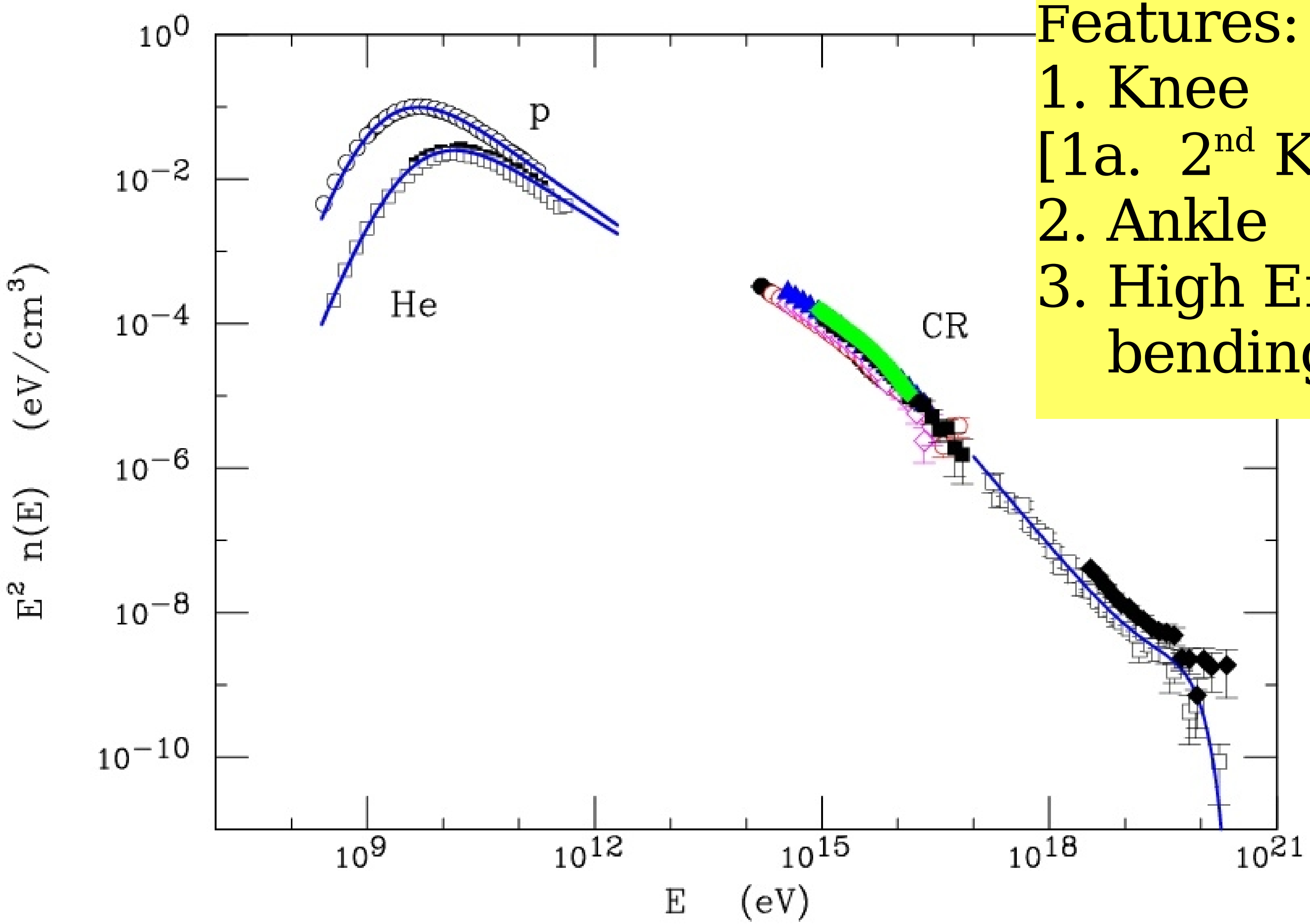
The "High Energy Suppression" of
the Cosmic Rays.

Hadronic Interactions and the UHECR

Possible Identification of the Sources of the
Extra-galactic Cosmic Rays.

Multi-Messenger Astrophysics

Cosmic Rays Spectrum



Features:

1. Knee

[1a. 2nd Knee]

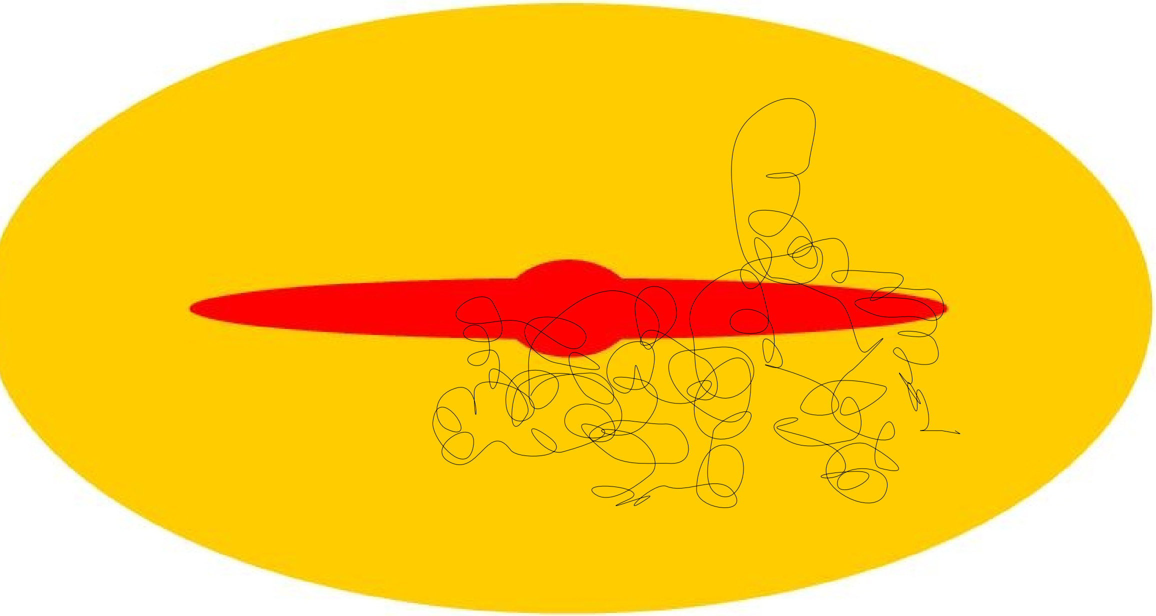
2. Ankle
3. High Energy bending

We do not have a fully convincing explanation for any of the features of the CR energy spectrum.

However the perspectives to finally obtain an understanding of the origin of the Cosmic Rays are excellent.

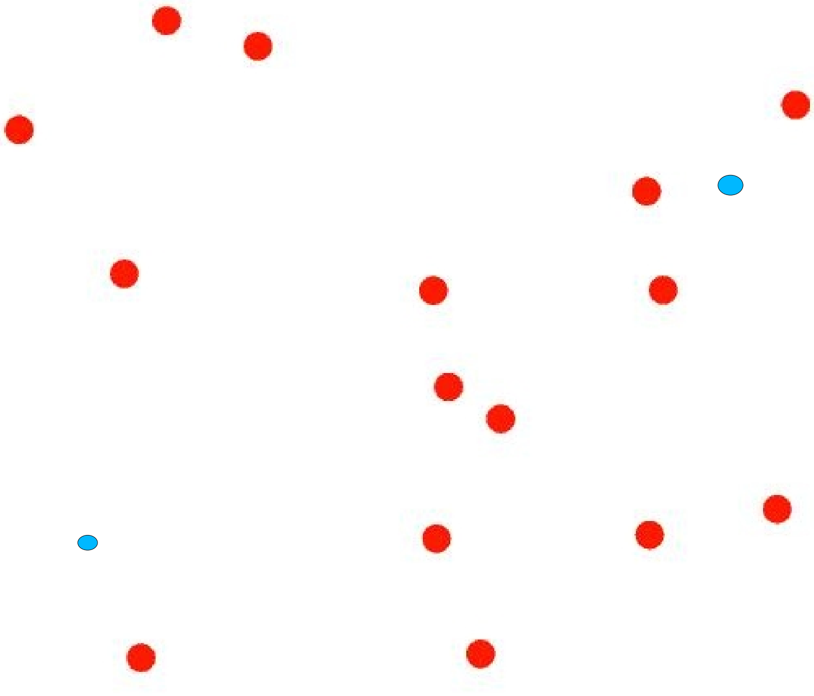
Multi-wavelength Astronomy
X-ray astronomy
Gamma-Ray Astronomy
CR ASTRONOMY [!! (?)]

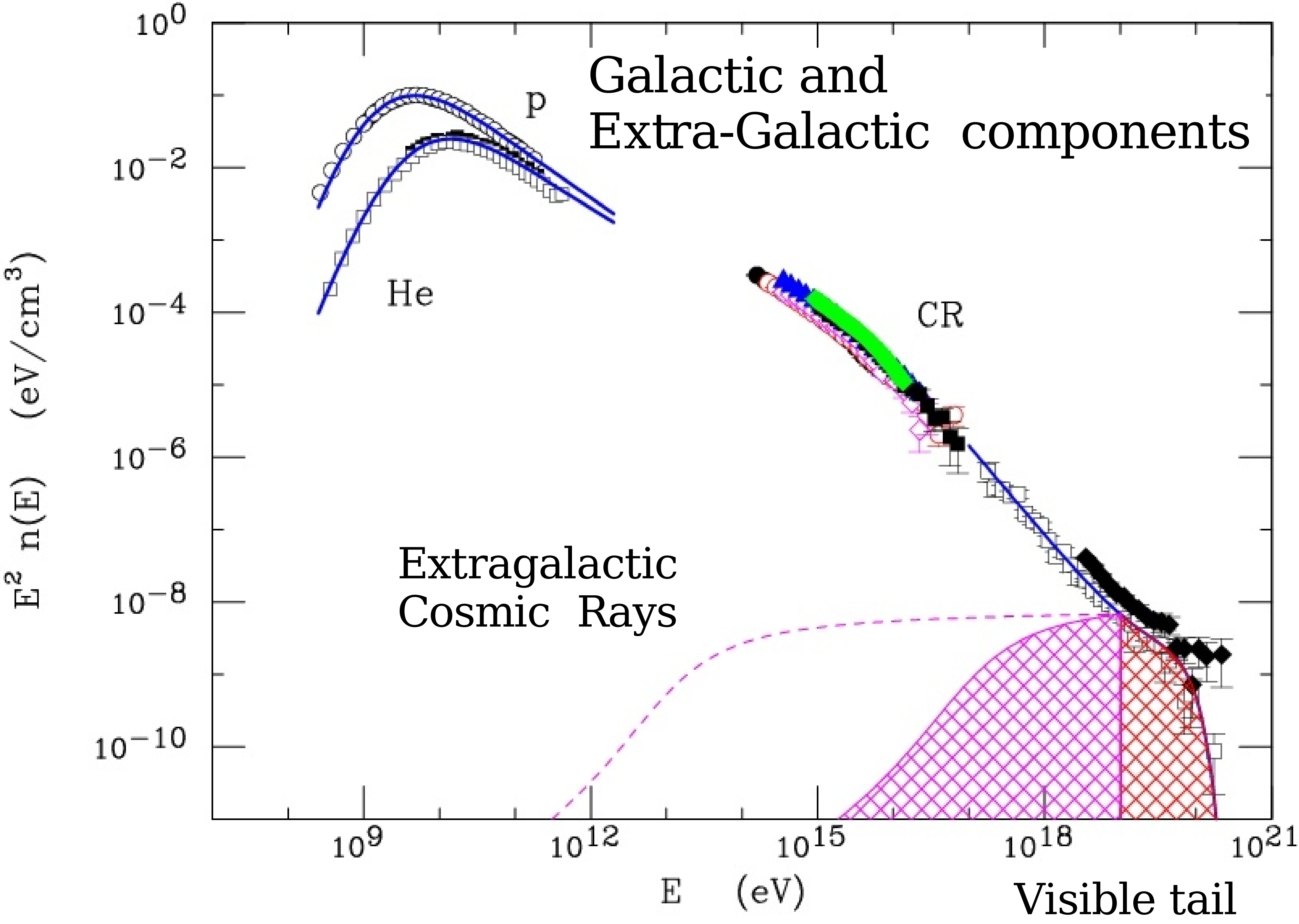
NEUTRINO Telescopes.



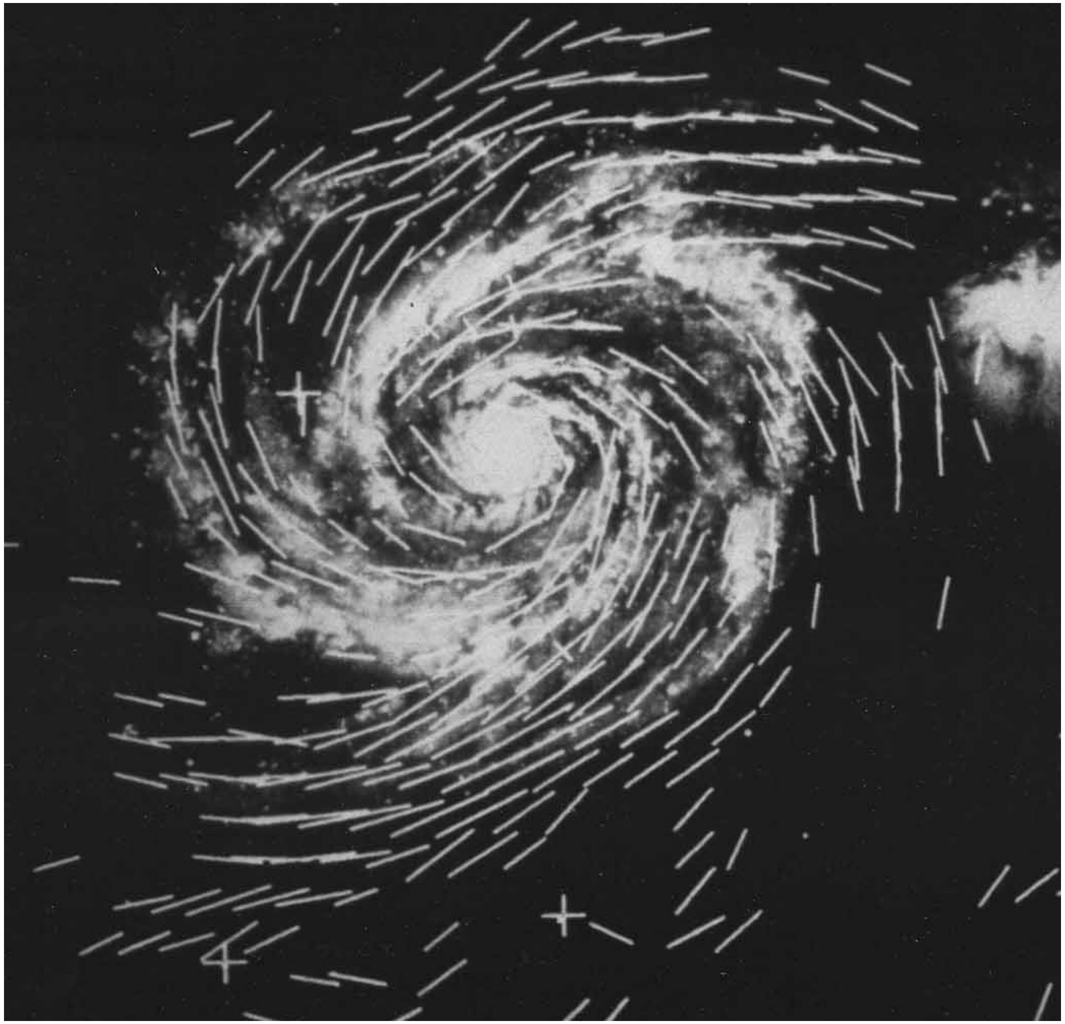
Galactic Sources
Injection Q(E,x)
D(E/Z, x) Diffusion

Extragalactic sources
Sources, q(E,x,z)
magnetic fields
Evolution of the universe





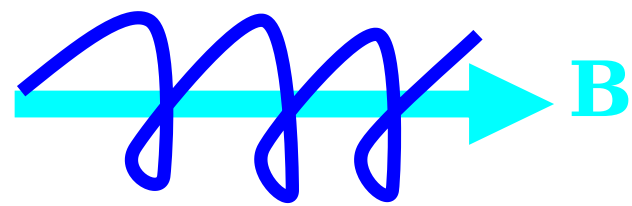
Galactic and
Extra-Galactic components
p
He
CR
Extragalactic
Cosmic Rays
E^2 n(E) (eV/cm^3)
E (eV)
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^9
10^{12}
10^{15}
10^{18}
10^{21}
Visible tail



We live in a "bubble" filled with Cosmic Rays.

A "magnetic bottle" where the CR density is enhanced by magnetic trapping.

$$\langle B_{\rm galactic} \rangle \simeq 3\ \mu{\rm Gauss}$$

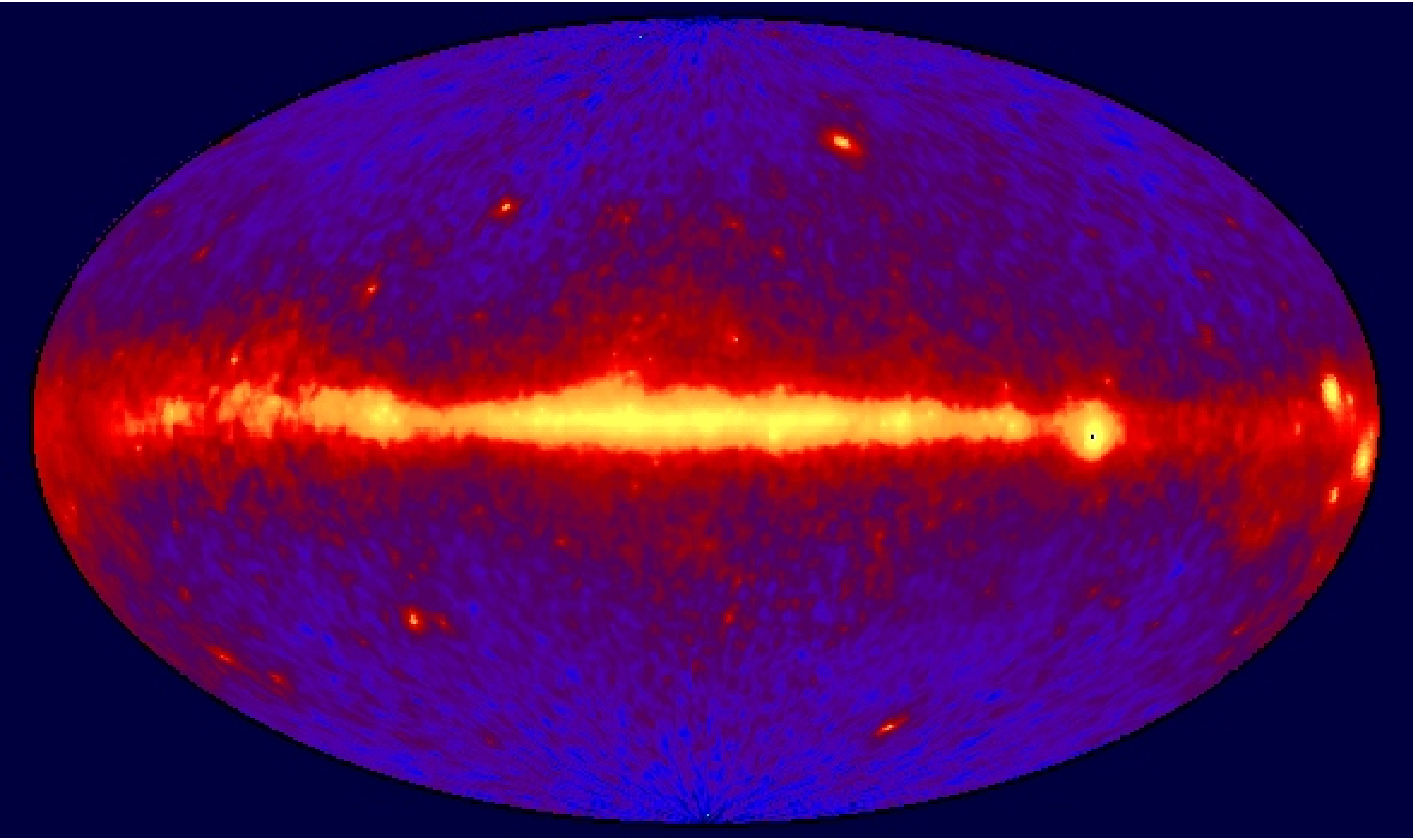


Extra-galactic space is filled by a much more tenuous gas of cosmic rays injected during the entire history of the Universe.
This "extragalactic population" emerges only at sufficiently high energy.

CR density in the Large and Small Magellanic Clouds much smaller than in our Milky Way

EGRET all Sky Map

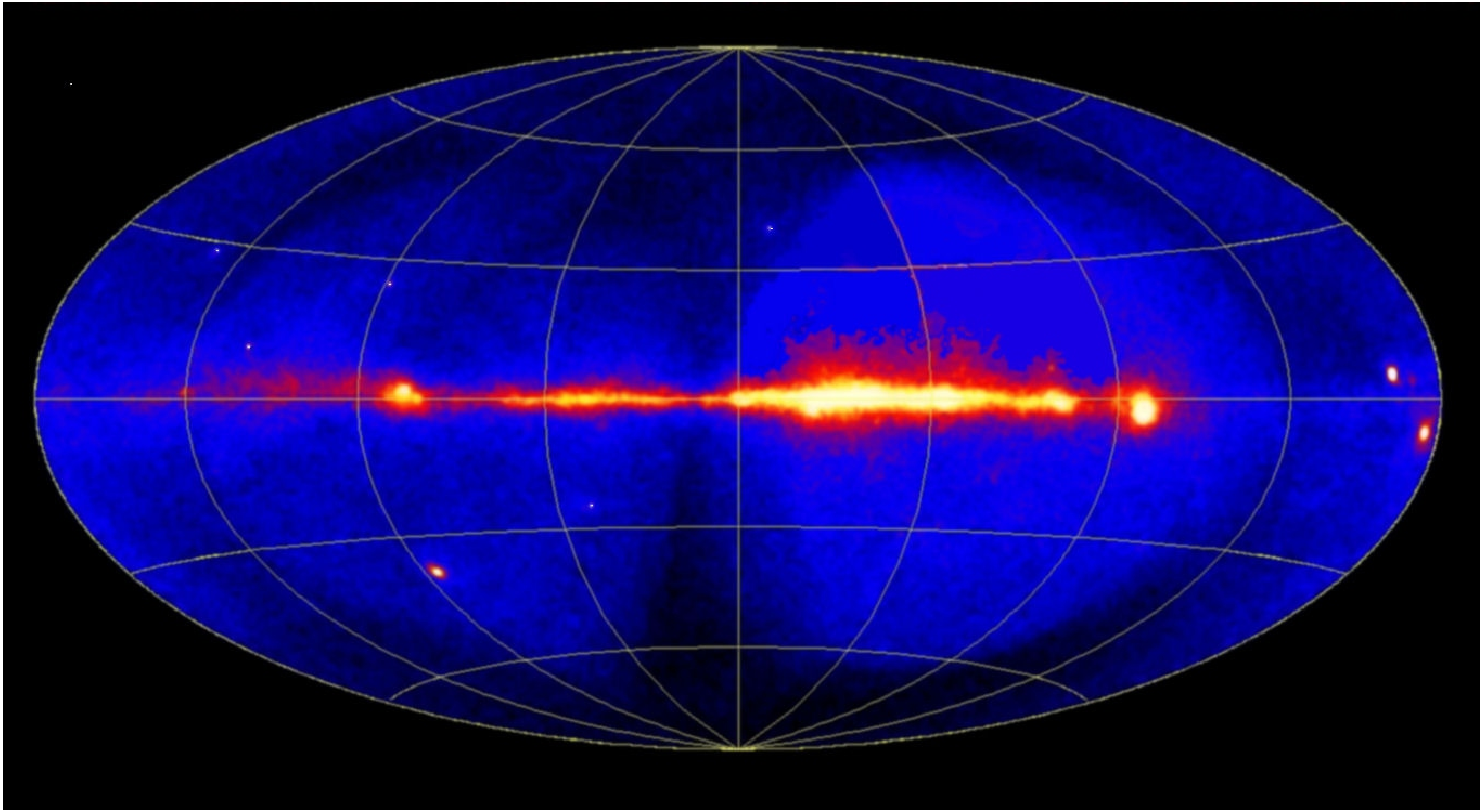
Image of our CR bubble



$E_\gamma > 100$ MeV

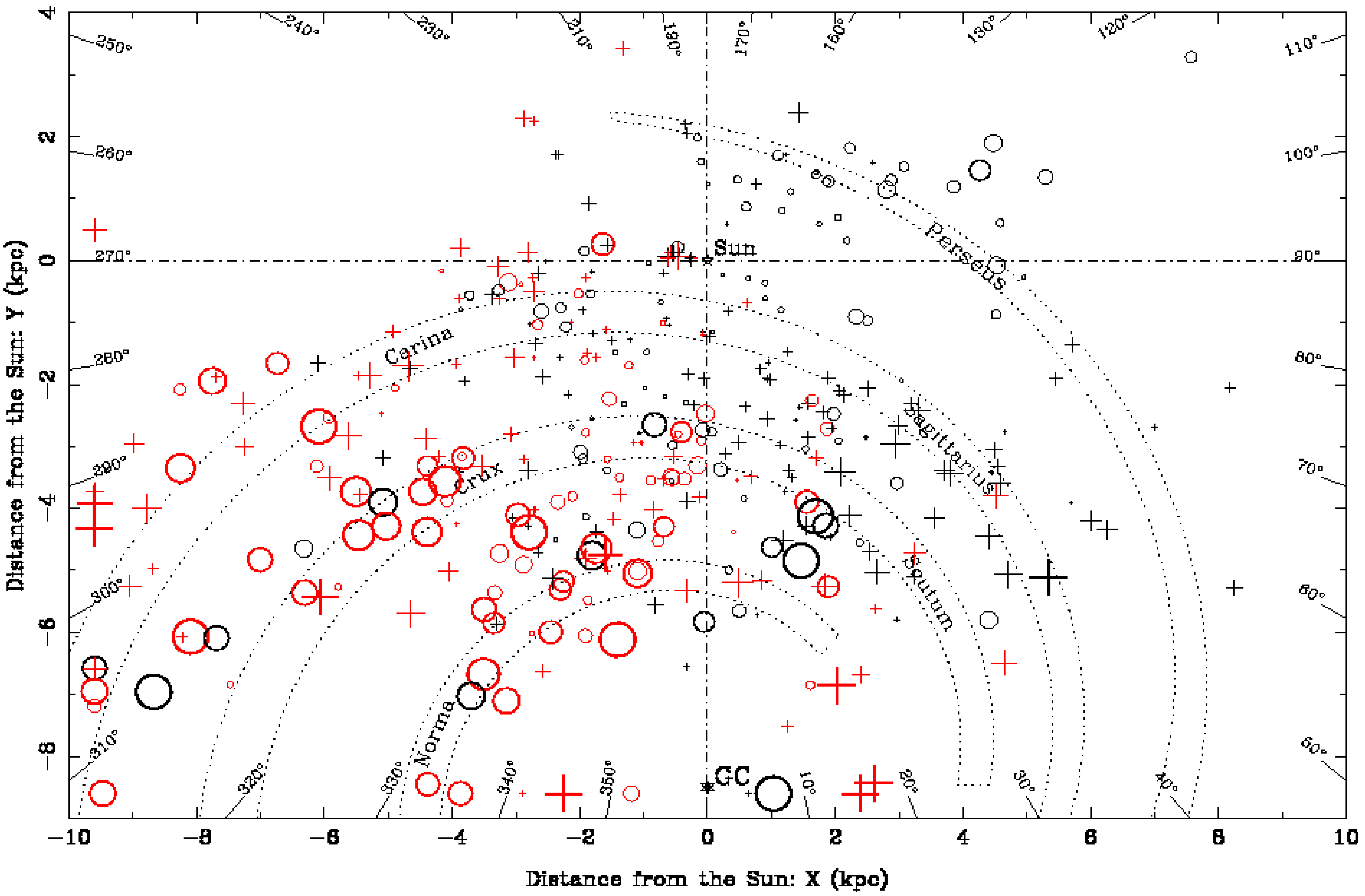
AGILE Count Map (E > 100 MeV)

Lauched 23rd april 2007



Glast Launch 16 may 2008

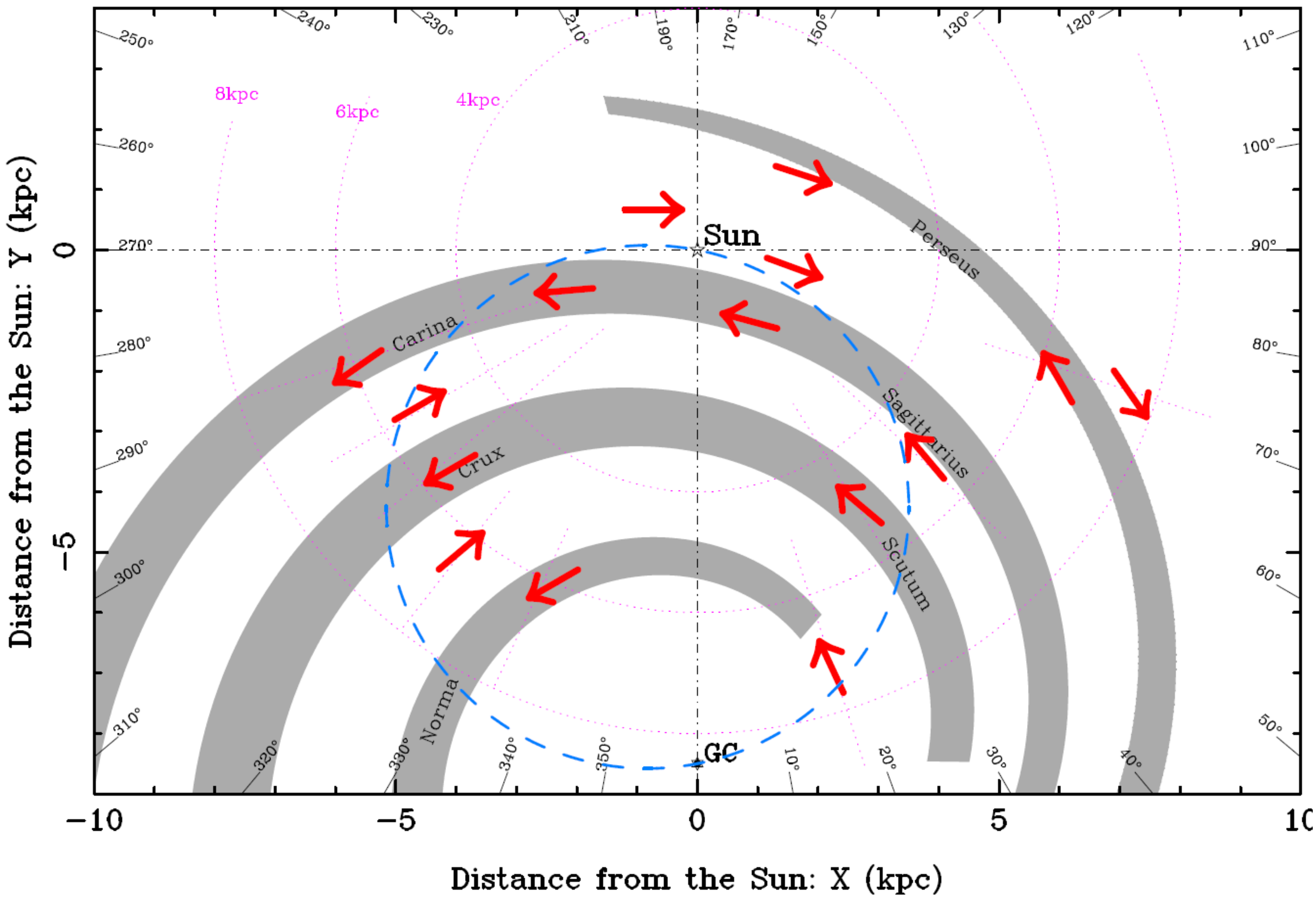
Faraday Rotation of the polarization of pulsars



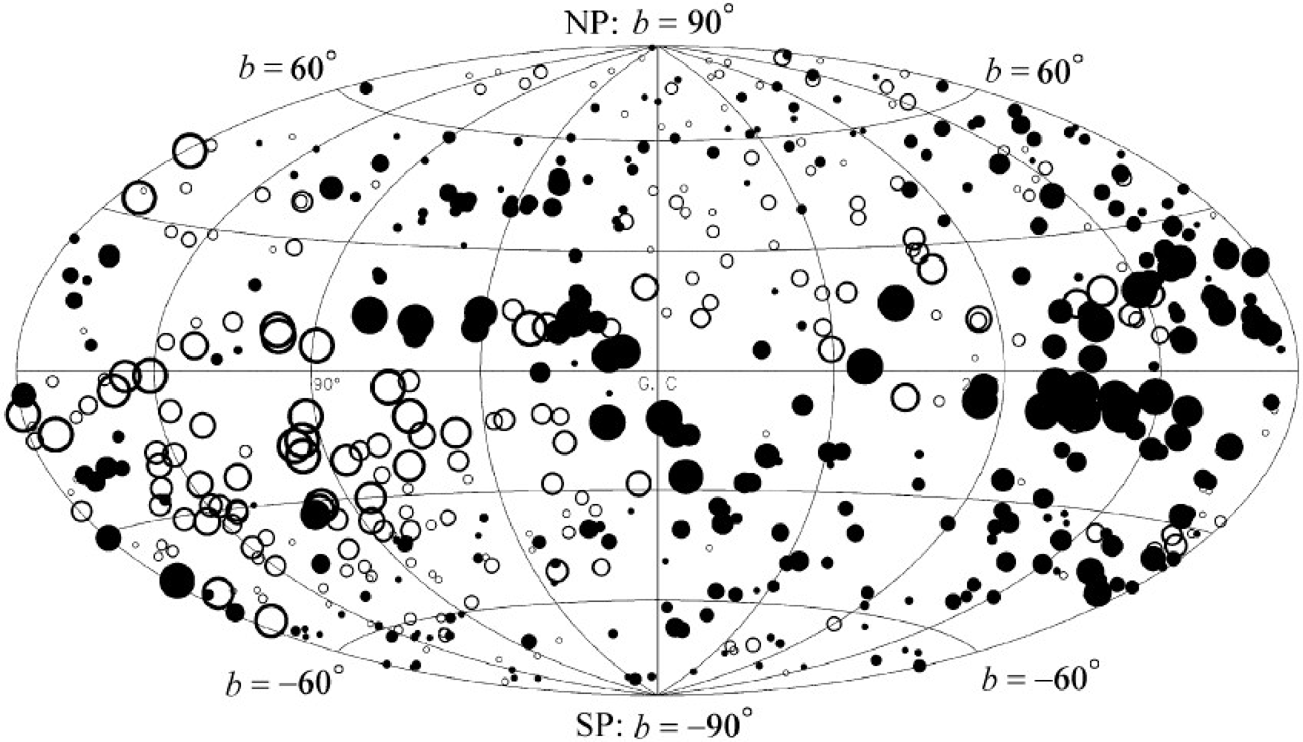
Field COUNTERCLOCKWISE in arm regions
(clockwise in interarm regions)

Regular Magnetic Field

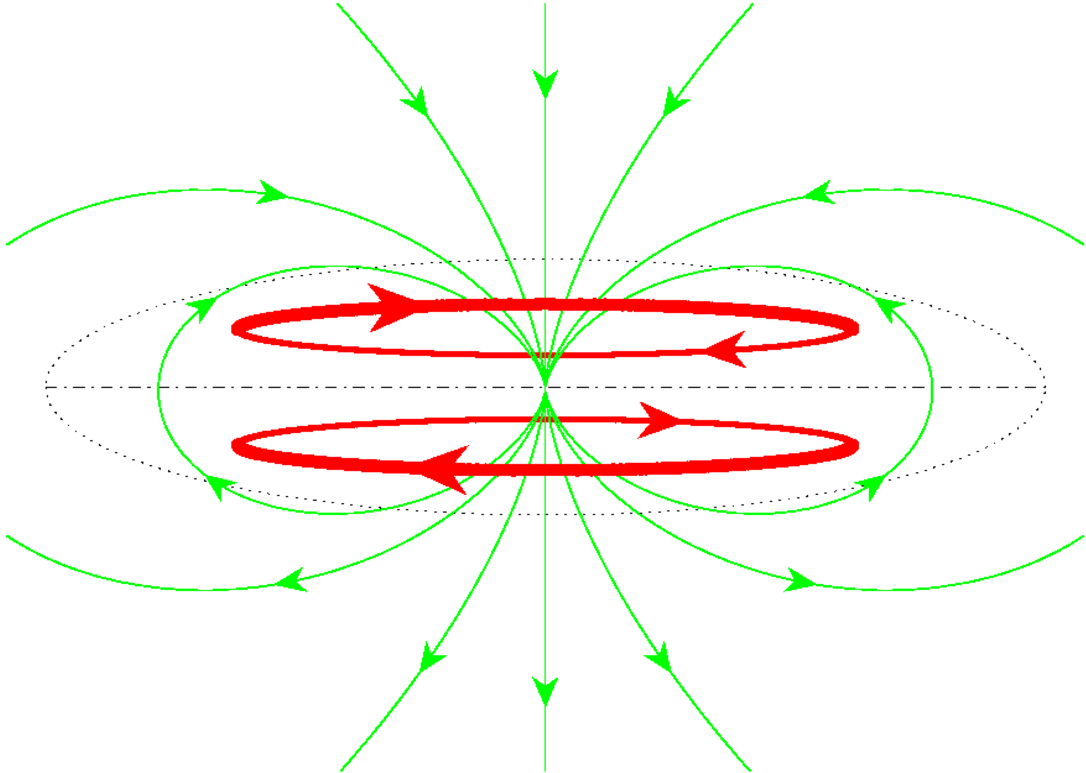
in the plane of the Milky Way



Han, Manchester et al. Ap.J. 642, 868 (2006)

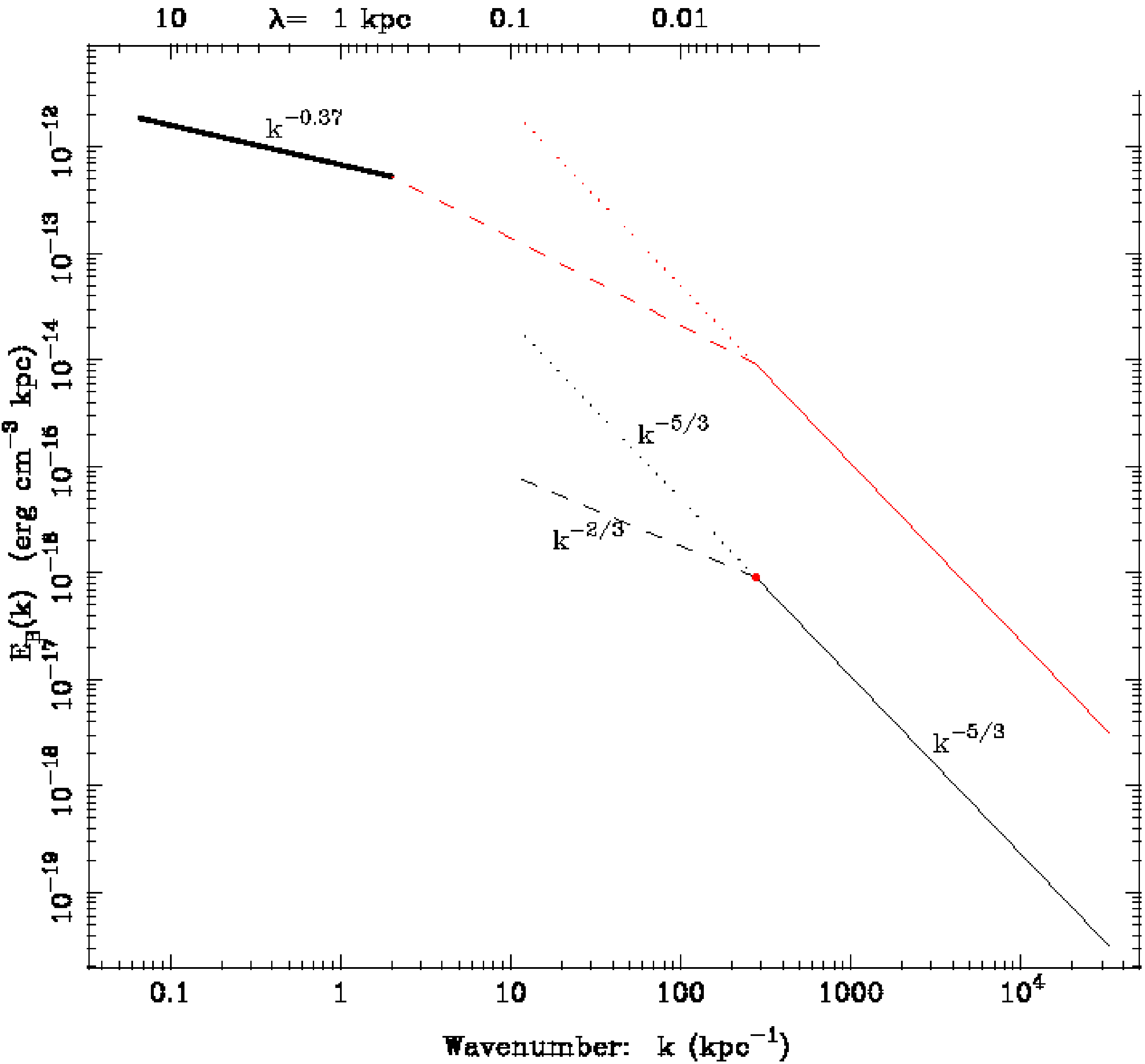


General Structure
of the Magnetic field
outside of the plane
of the Galaxy



Random Magnetic Field

$$\boldsymbol{B}(\boldsymbol{r}) = \int \tilde{\boldsymbol{B}}(\boldsymbol{k}) e^{2\pi i \boldsymbol{k}\cdot\boldsymbol{r}}\, d\boldsymbol{k}$$



Determines the rigidity dependence of the diffusion coefficient

and together with the global properties of the field the containment time

What are the SOURCES of COSMIC RAYS?

- ## ENERGETICS

  Where can one find the power to create the cosmic rays ?

- ## DYNAMICS

  How is the energy transformed into ultra-relativistic particles

Non-thermal
Non-equilibrium
"Violent" phenomena

POWERING THE GALACTIC COSMIC RAYS

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

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

$$\simeq 5 \times 10^{7}\, L_{\odot}$$

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

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

$$M = 5\ M_\odot$$

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

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

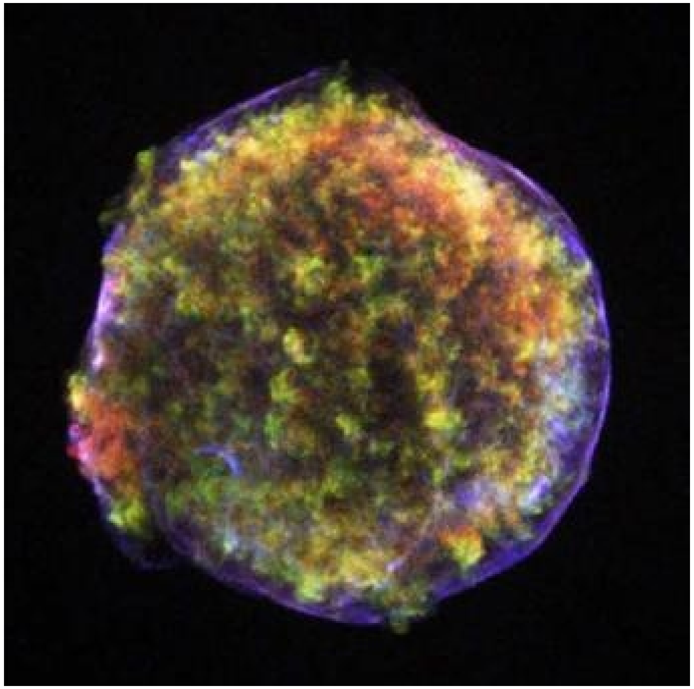
Power Provided by SN is sufficient
with a conversion efficiency of 15-20 %
in relativistic particles

SuperNovae types

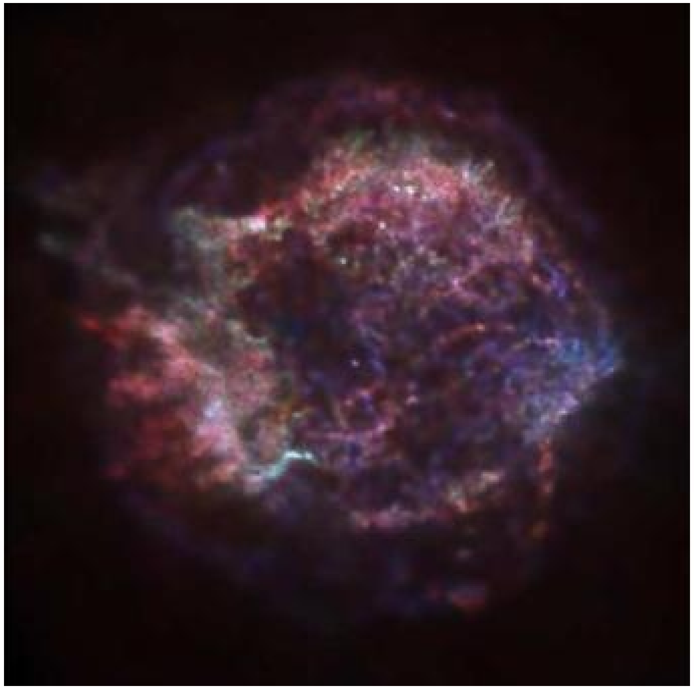
Type	fraction	Hydrogen	Star	Wind	Compact	example
Ia	15%	No	WD binary	–	–	Tycho
Ib	10%	No	16–20 $M_\odot$	> 1000 km/s	NS	Cas A
Ic	<5%	No	$\gg$20 $M_\odot$	Yes	BH	many GRBs
II	70%	Yes	>8 $M_\odot$	10 km/s	NS	SN 1993J

Chandra X-Ray images

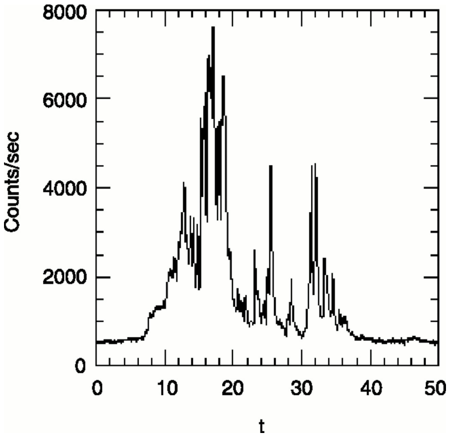
SN1006



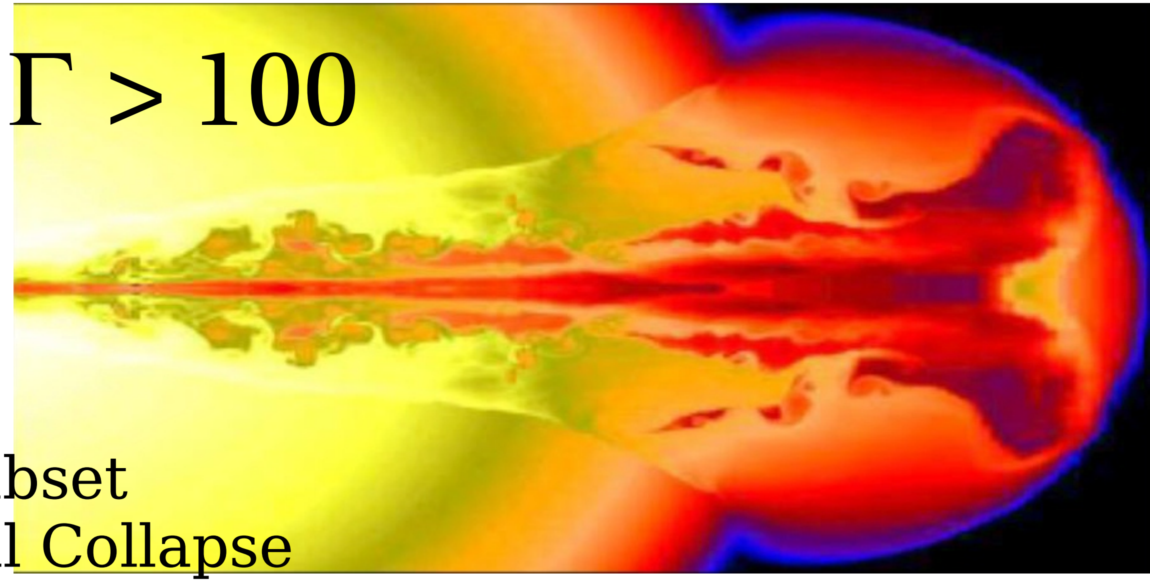
Tycho



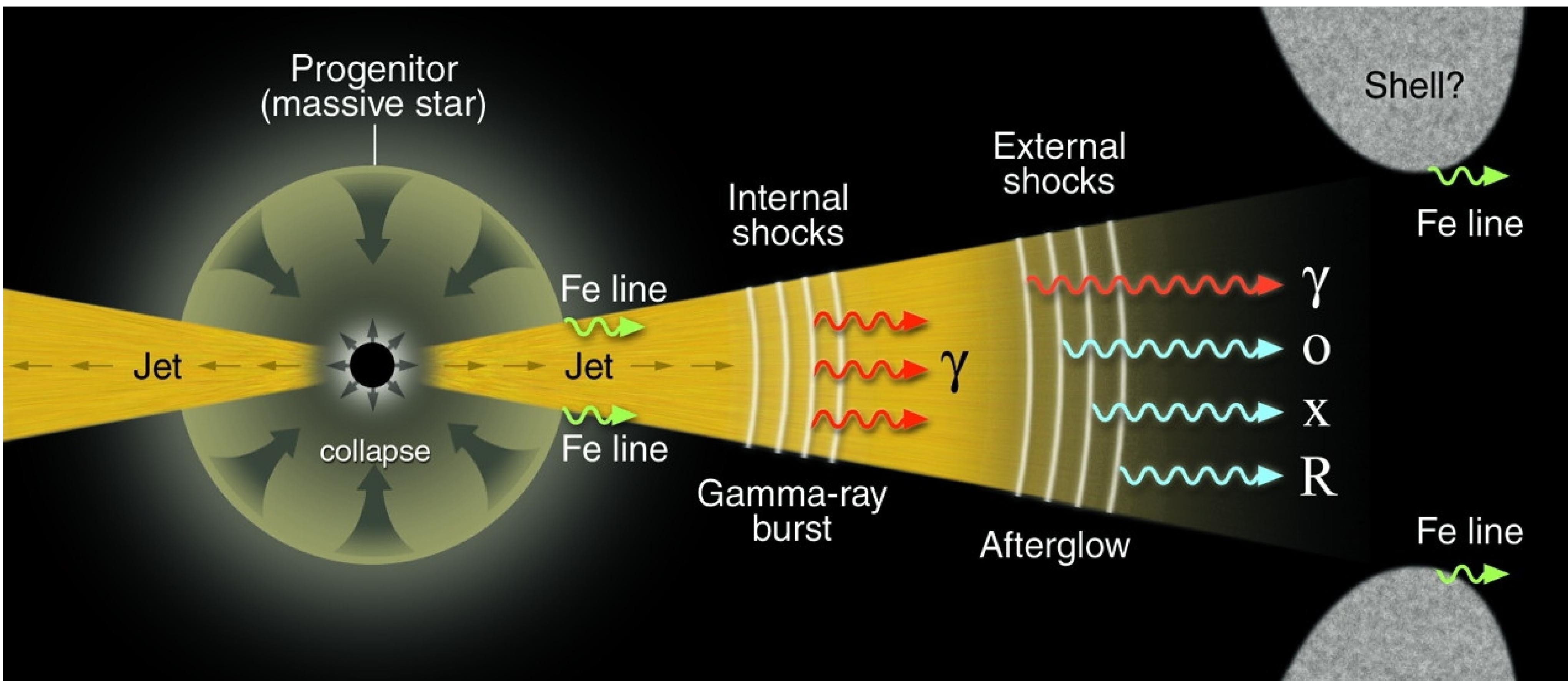
Cas A



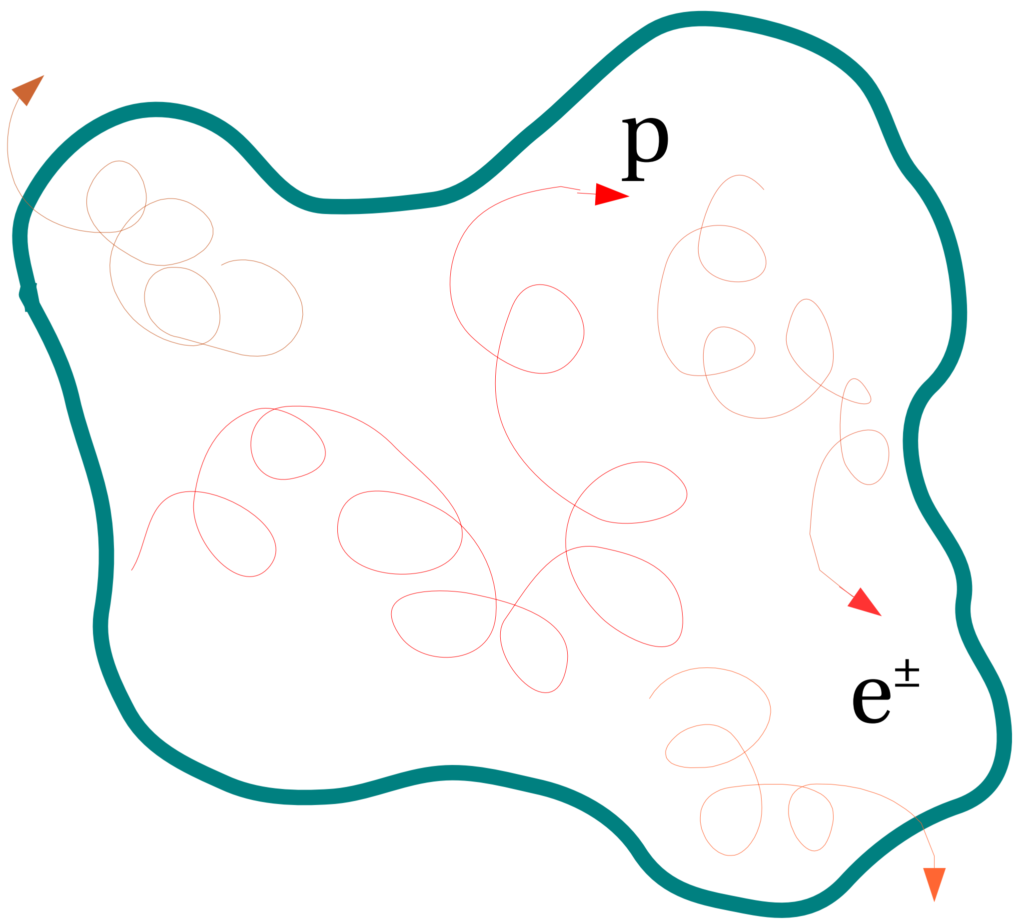
$\Gamma > 100$



GRB : associated with a subset of SN Stellar Gravitational Collapse



Astrophysical Sources of High Energy Radiation



Astrophysical Object containing:

Populations of relativistic protons, Nuclei electrons/positrons

Emission of:

γ rays

Neutrinos

Cosmic Rays

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

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

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

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

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

"Hadronic Emission"

"Leptonic Emission"

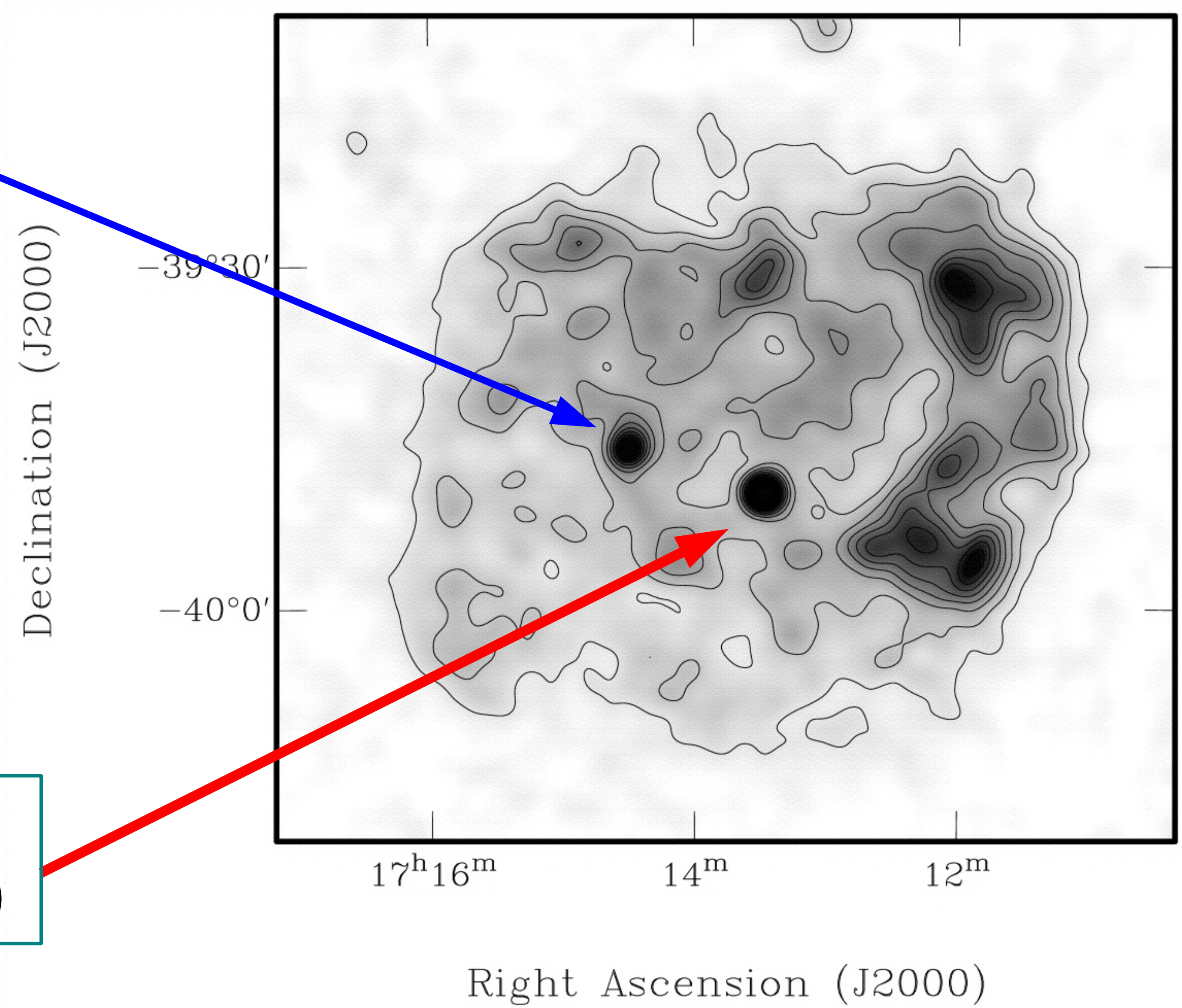
$$e^{\mp} + B \rightarrow e^{\mp} + \gamma_{\text{synchrotron}}$$

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

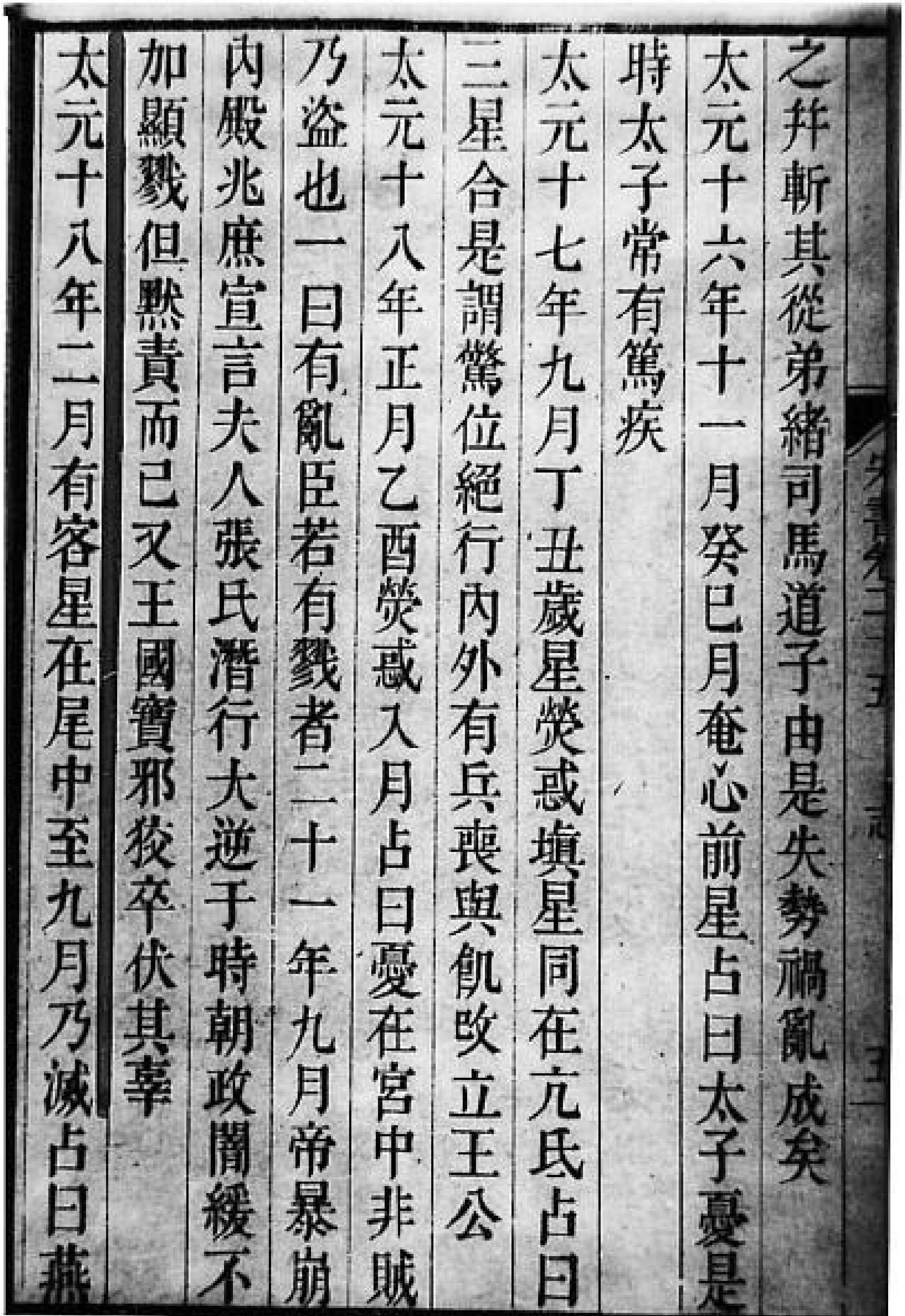
SuperNova RX J1713.7-3946

Discovered in 1996 by the Roentgen Satellite (Rosat)

Foreground star



Point Source (Neutron Star)


之幷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
三星合是謂驚位絕行內外有兵喪與饑改立王公
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
加顯戮但黜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

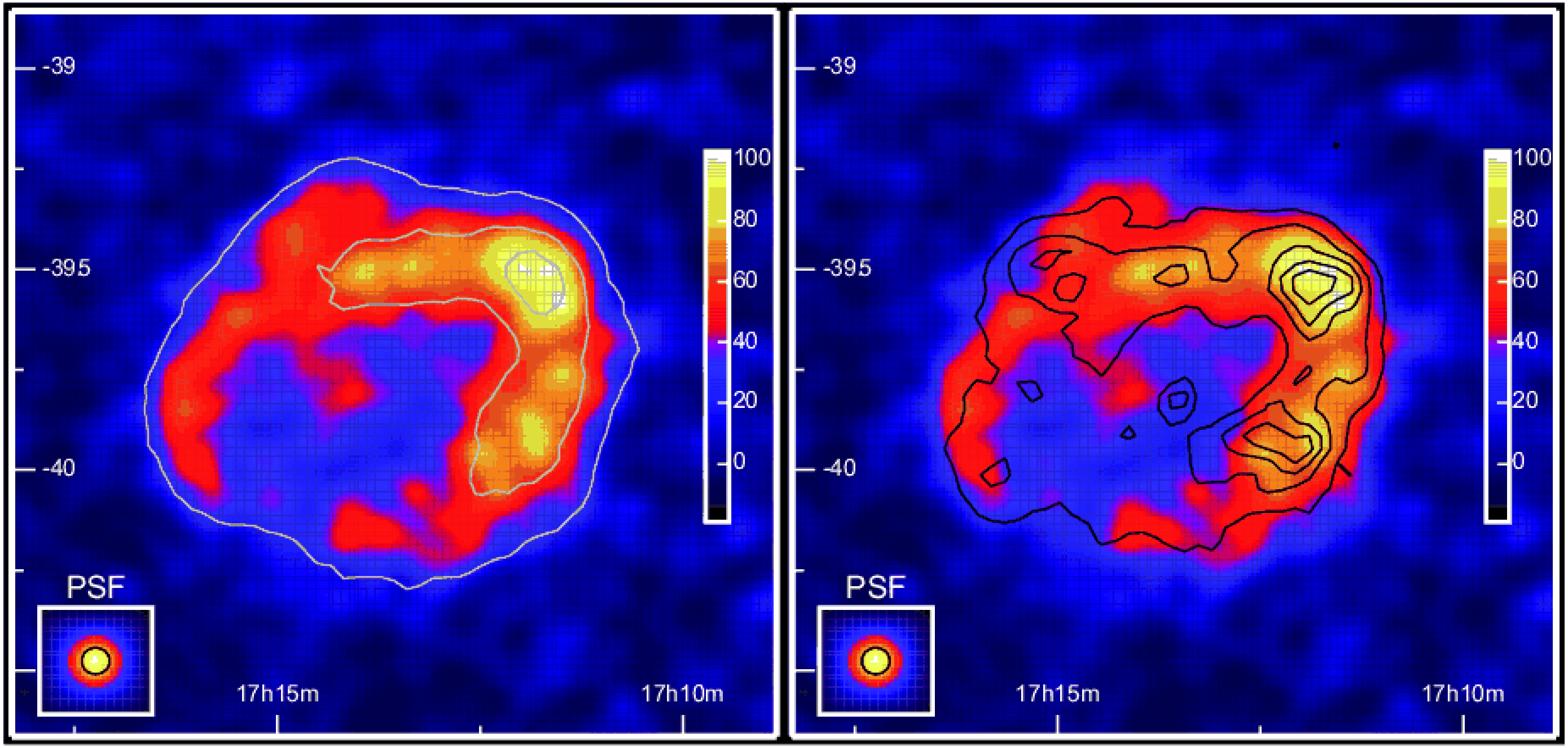
1st observation of RX J1713.7-3946

AD 393

A guest star appeared within the asterism Wei during 2nd lunar month of the 18th year of the Tai-Yuan reign period (february 27-march 28 AD 393),
and disappeared during the 9th lunar month (october 22 - november 19)

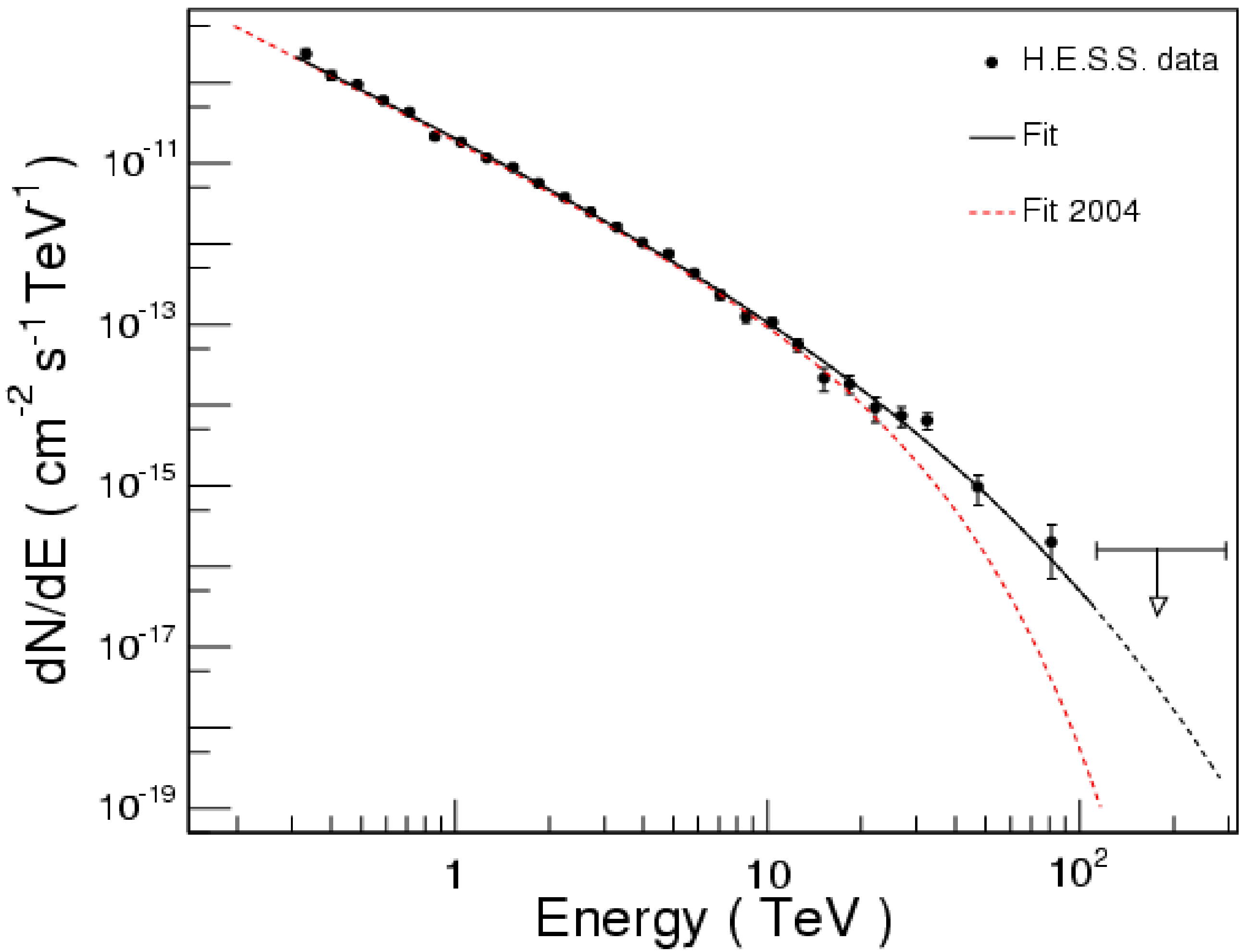
HESS Telescope

Observations with TeV photons



Comparison with ROSAT observation

ENERGY Spectrum



If gamma-rays are from π^0 decay, spectrum requires acceleration of protons to 200 TeV.

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

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

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

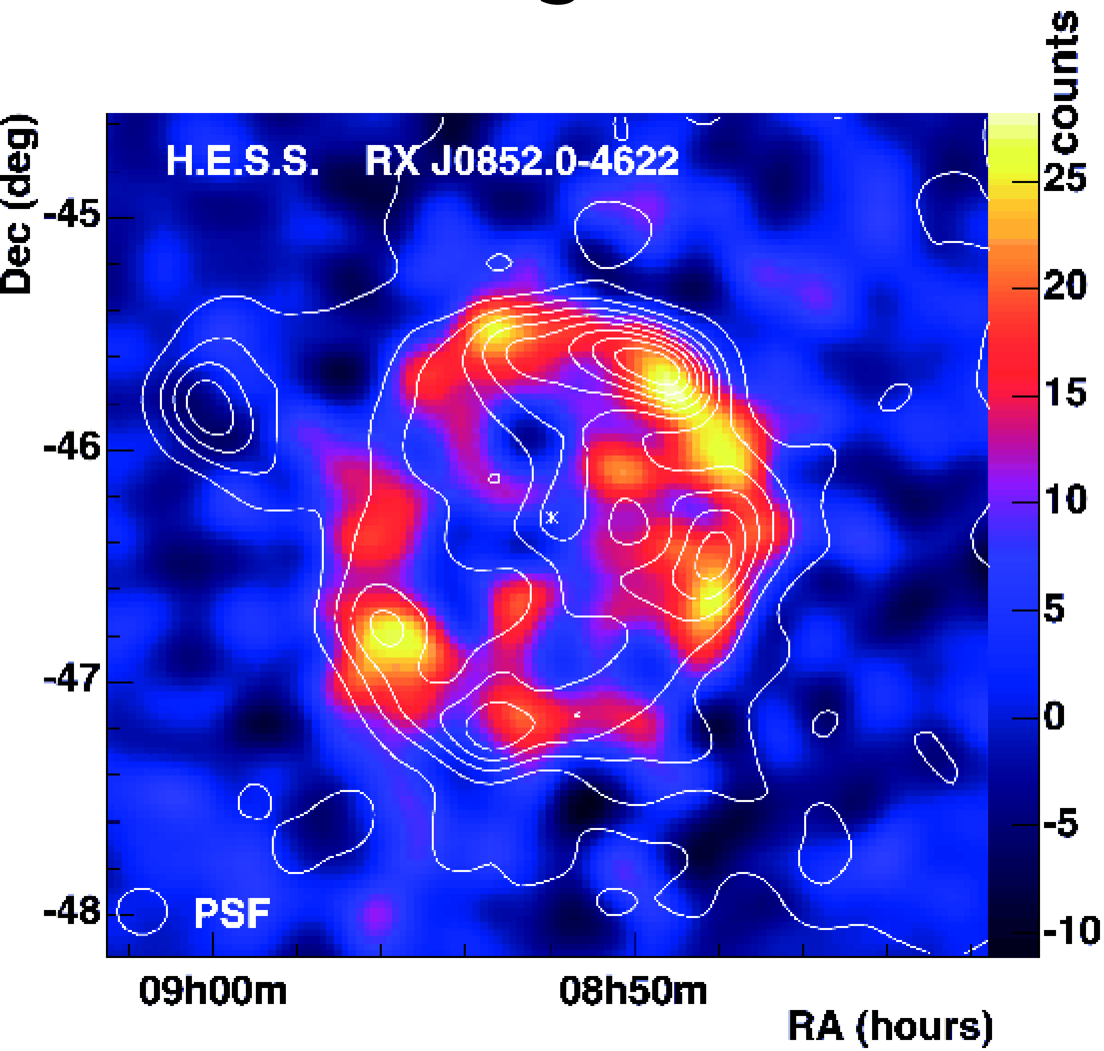
$$\frac{dN_\gamma}{dt} \propto N_p \times n_{\rm target} \times \sigma_{pp}\, c$$

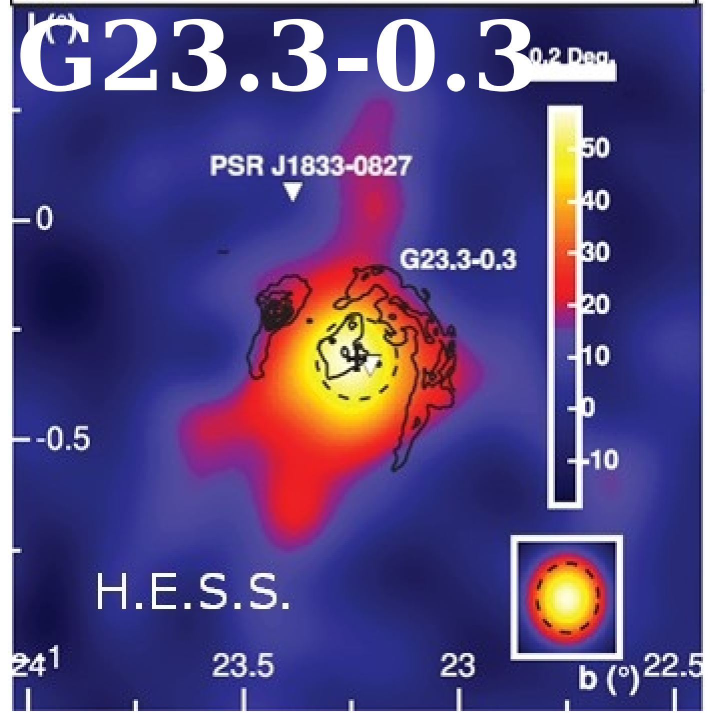
Hess estimate

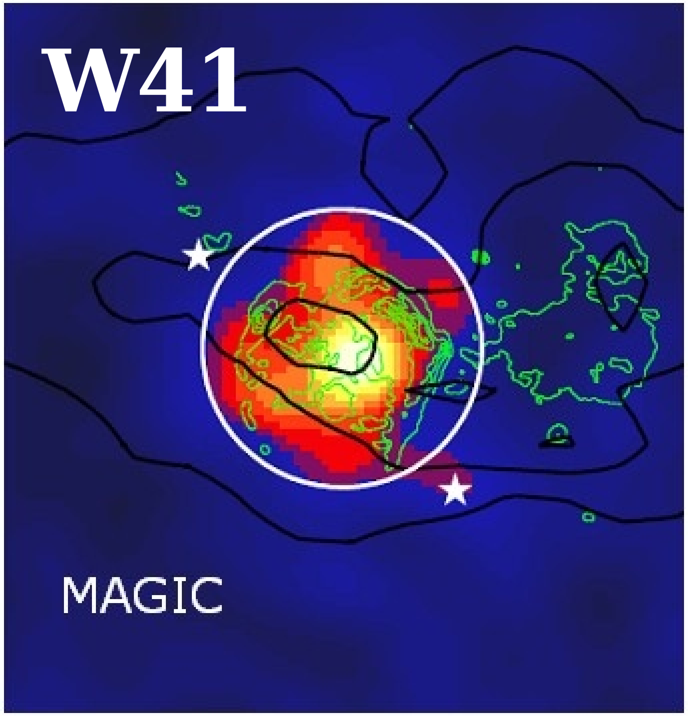
$$E^{\rm tot}_{{\rm relativistic}\ p} \simeq 0.2 \times 10^{51}\ {\rm erg}$$

Essentially compatible with the Ortodoxy (10% conversion of SN kinetic energy into relativisic particles)

VELA JUNIOR


H.E.S.S. RX J0852.0-4622
Dec (deg)
-45
-46
-47
-48
PSF
counts
25
20
15
10
5
0
-5
-10
09h00m
08h50m
RA (hours)


G23.3-0.3
0.2 Deg.
PSR J1833-0827
G23.3-0.3
0
-0.5
50
40
30
20
10
0
-10
H.E.S.S.
24
23.5
23
22.5
b (°)


W41
MAGIC

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

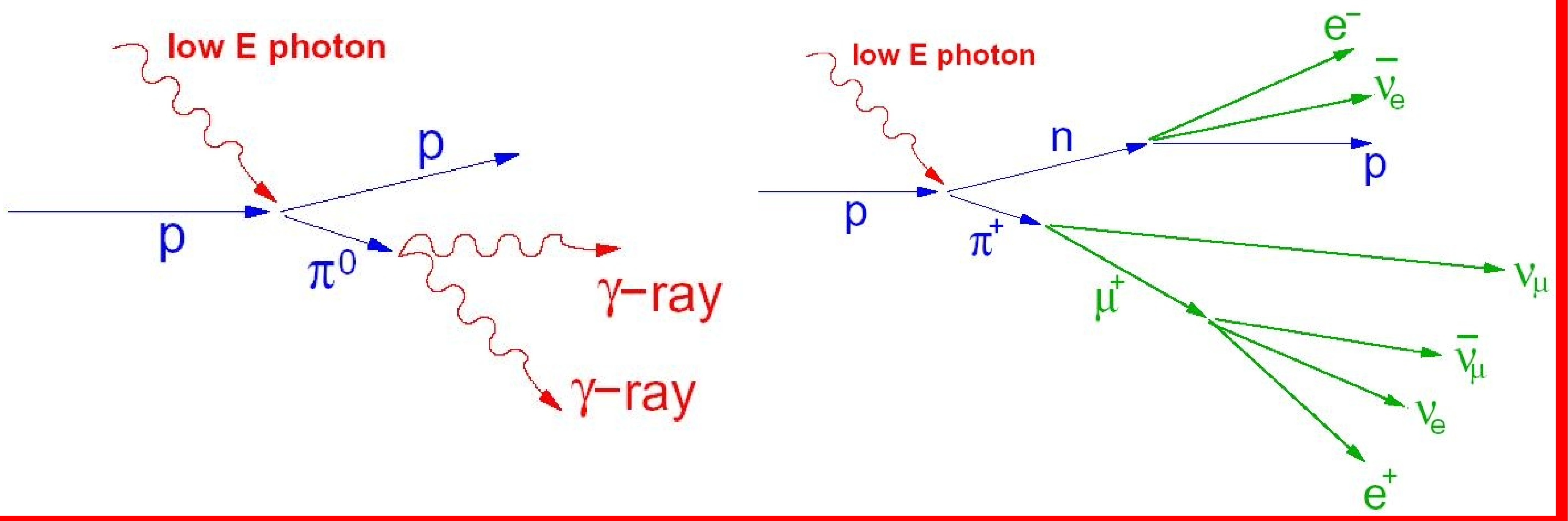
Important "Hints"
But conclusion Still Controversial.

Need additional Data.
Cherenkov telescopes, GLAST

NEED for ADDITIONAL SOURCES
at high Energy

The GZK “controversy”

A “smooth” continuation of the CR spectrum above 10^{20} eV would be surprising and very likely indication of “New Physics”



History:

Volcano Ranch
(John Linsley PRL 10 (1963).

Haverah Park

AGASA

Great excitement !

Several hundred
speculative theoretical works…

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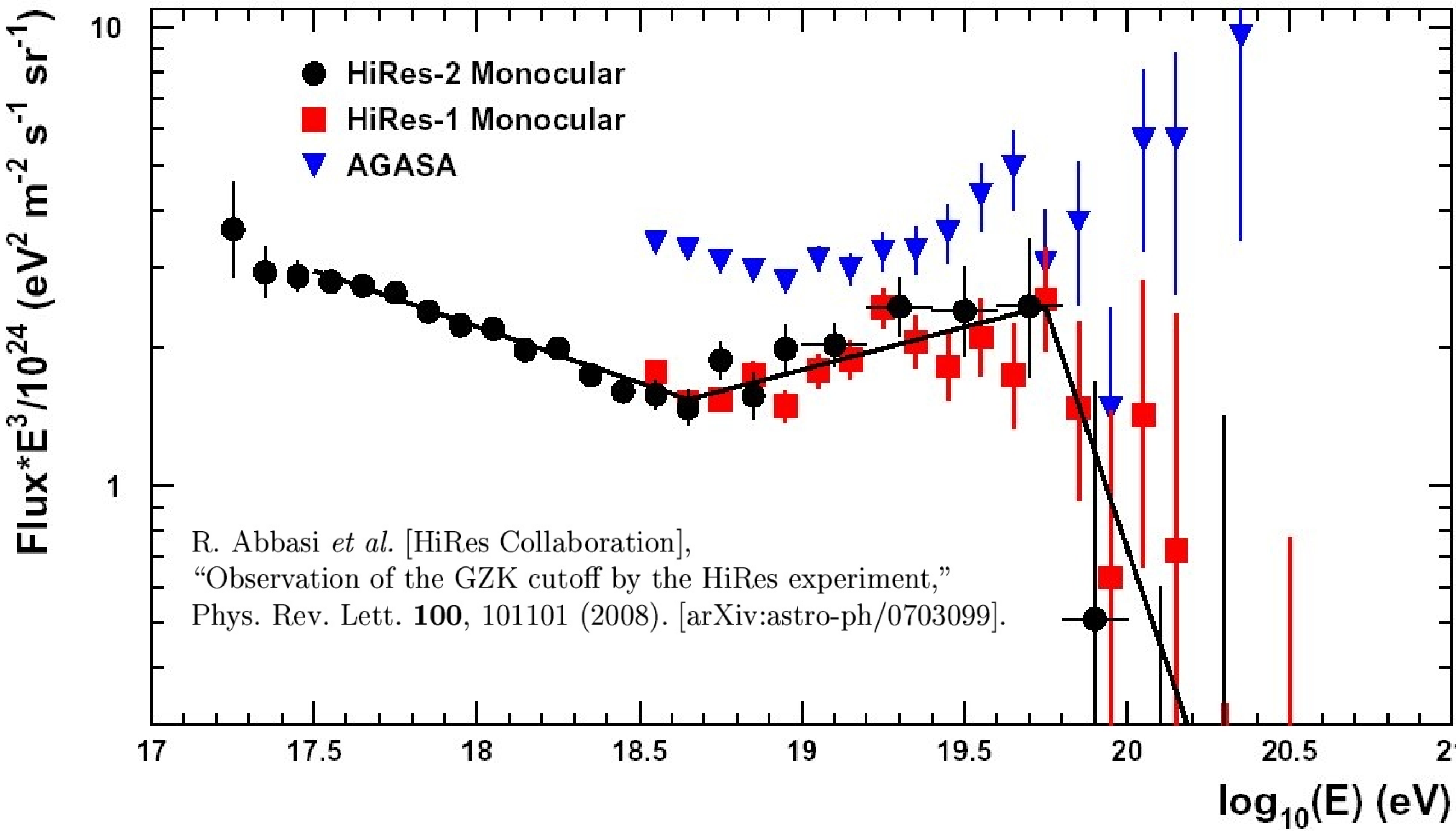
HIRES

AUGER

Claim of Evidence for the
Existence of the GZK suppression
by the HiRes Collaboration:



HiRes I , HiRes II , Agasa Energy Spectra

A “bending” in the UHECR spectrum is now convincingly observed by the HIRES and AUGER collaborations.

Its structure is CONSISTENT with the “GZK” bending for a spectrum of protons.

Its nature is not yet established.
Other explanations are also possible:
[the “accelerator limit”]
[Photo-disintegration of nuclei]

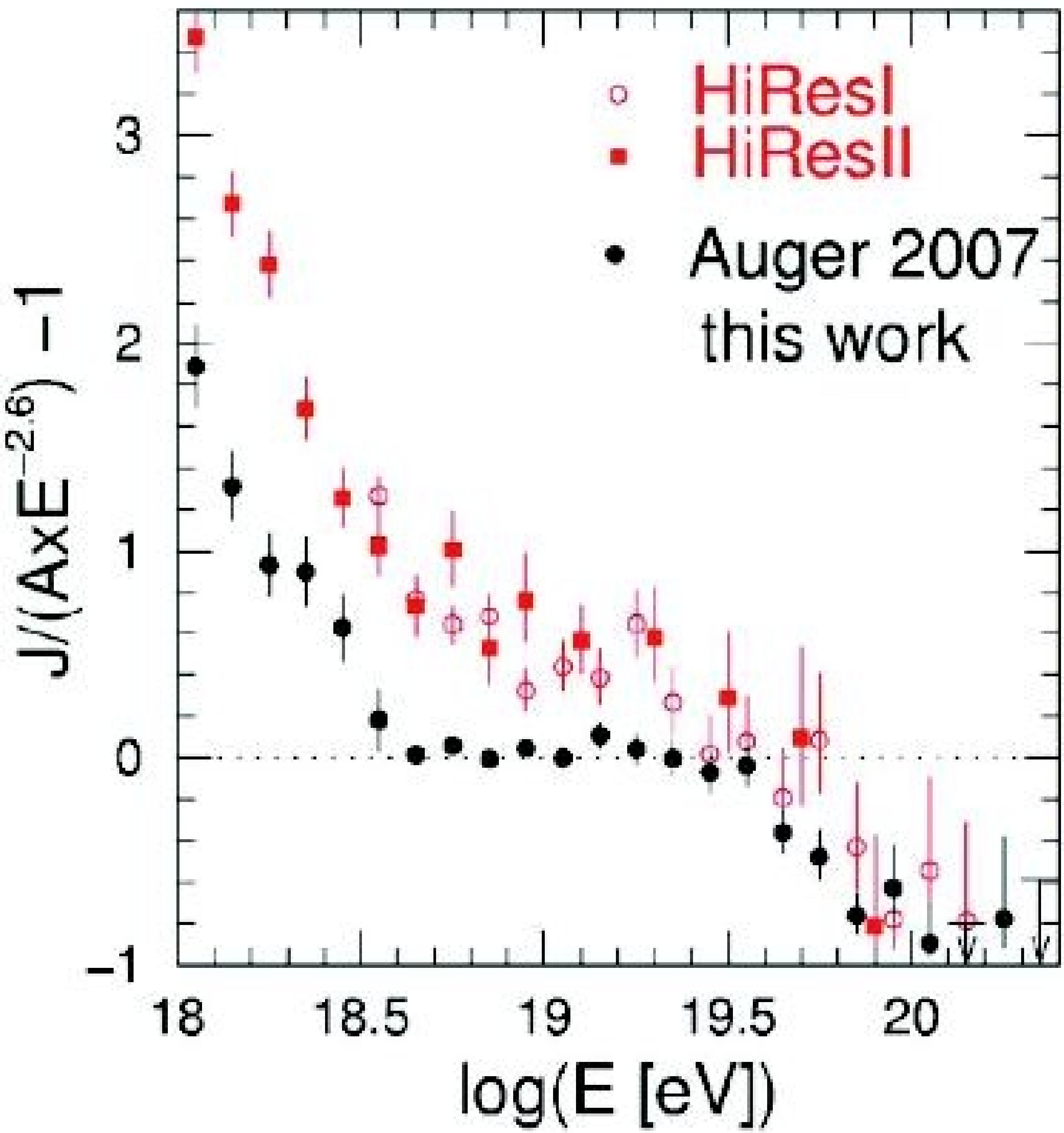
The "Scientific Landscape" is deeply modified.

The study of UHECR is now predominantly an essential branch of High Energy Astrophysics.

Speculations and searches for " New Physics" effects in UHECR can (and will) continue.

Some interesting ideas have been put forward and their test and study remain valid goals.

(Violation of LORENTZ INVARIANCE).
"TOP DOWN" Models.



Uncertainty in Energy scale is achieved to be <u>22%</u> and still being reduced.

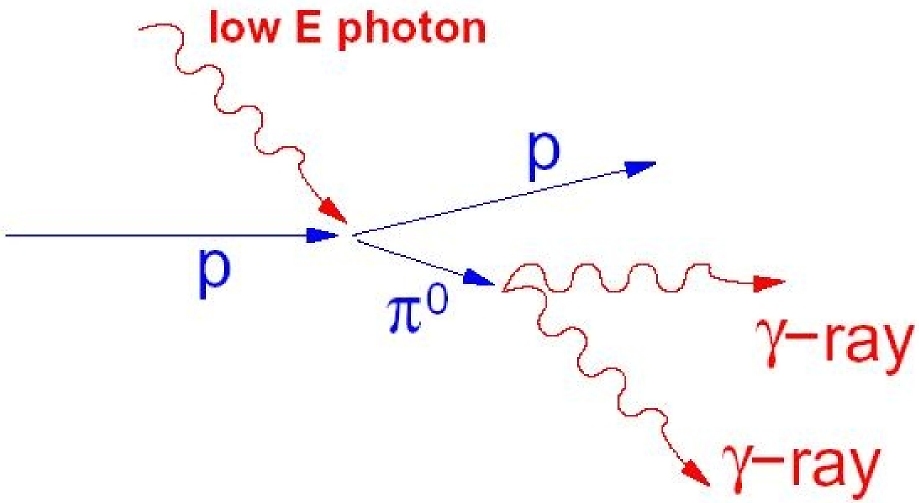
A significant difference from HiRes spectrum at below 10 EeV.

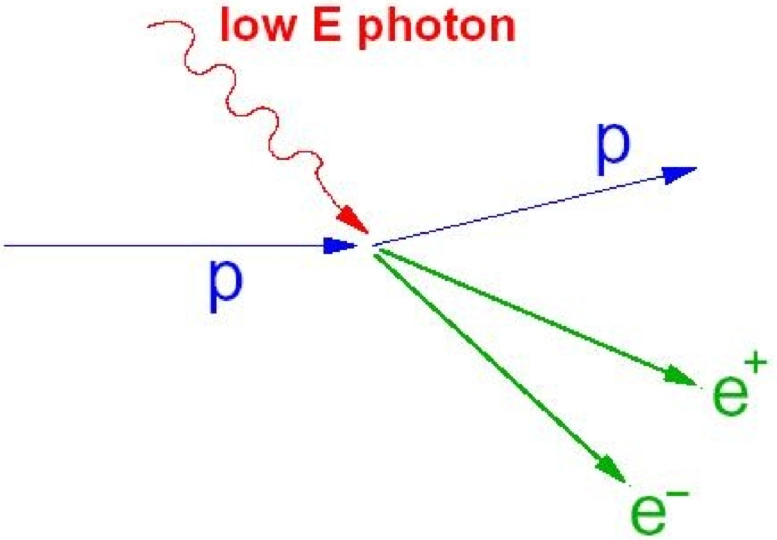
Slope at Highest End

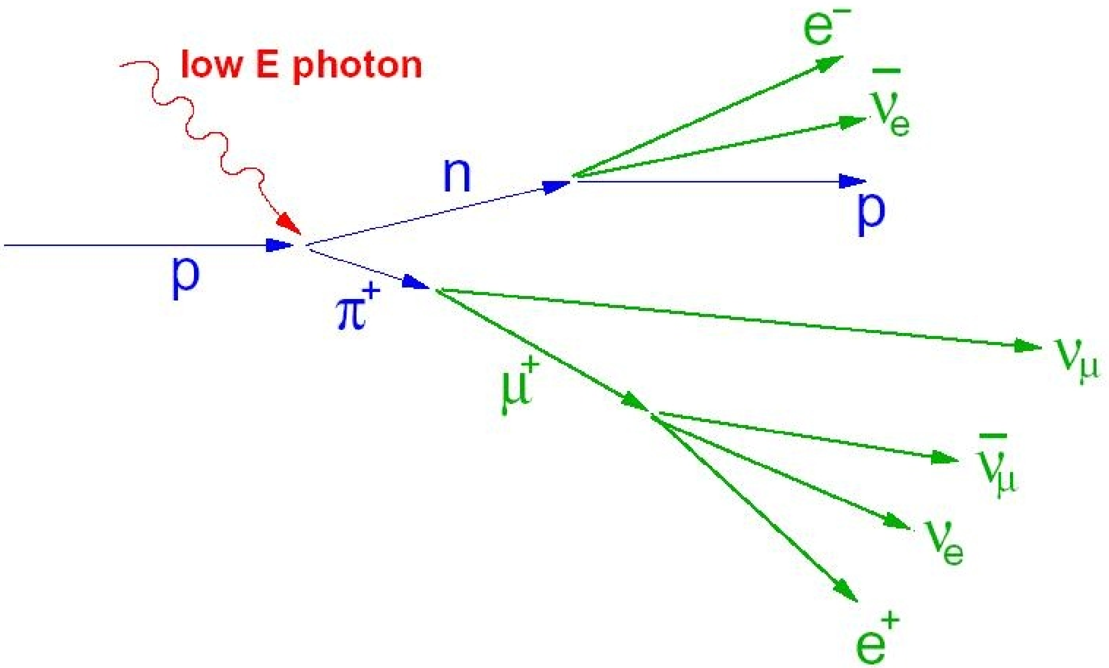
<u>Auger γ = -4.1±0.4</u>

<u>HiRes γ = -5.1±0.7</u>

Energy Loss Mechanisms for Protons:



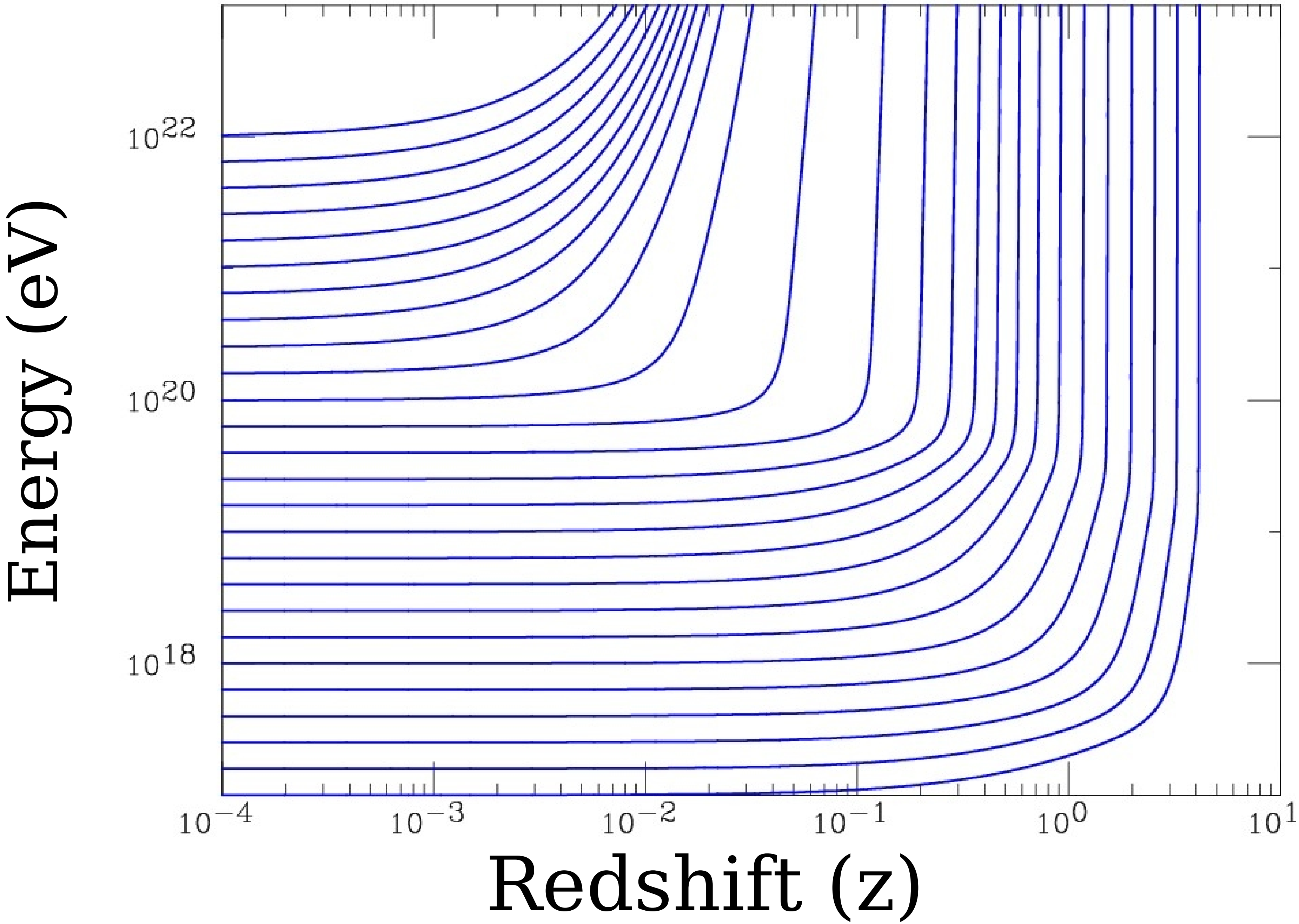




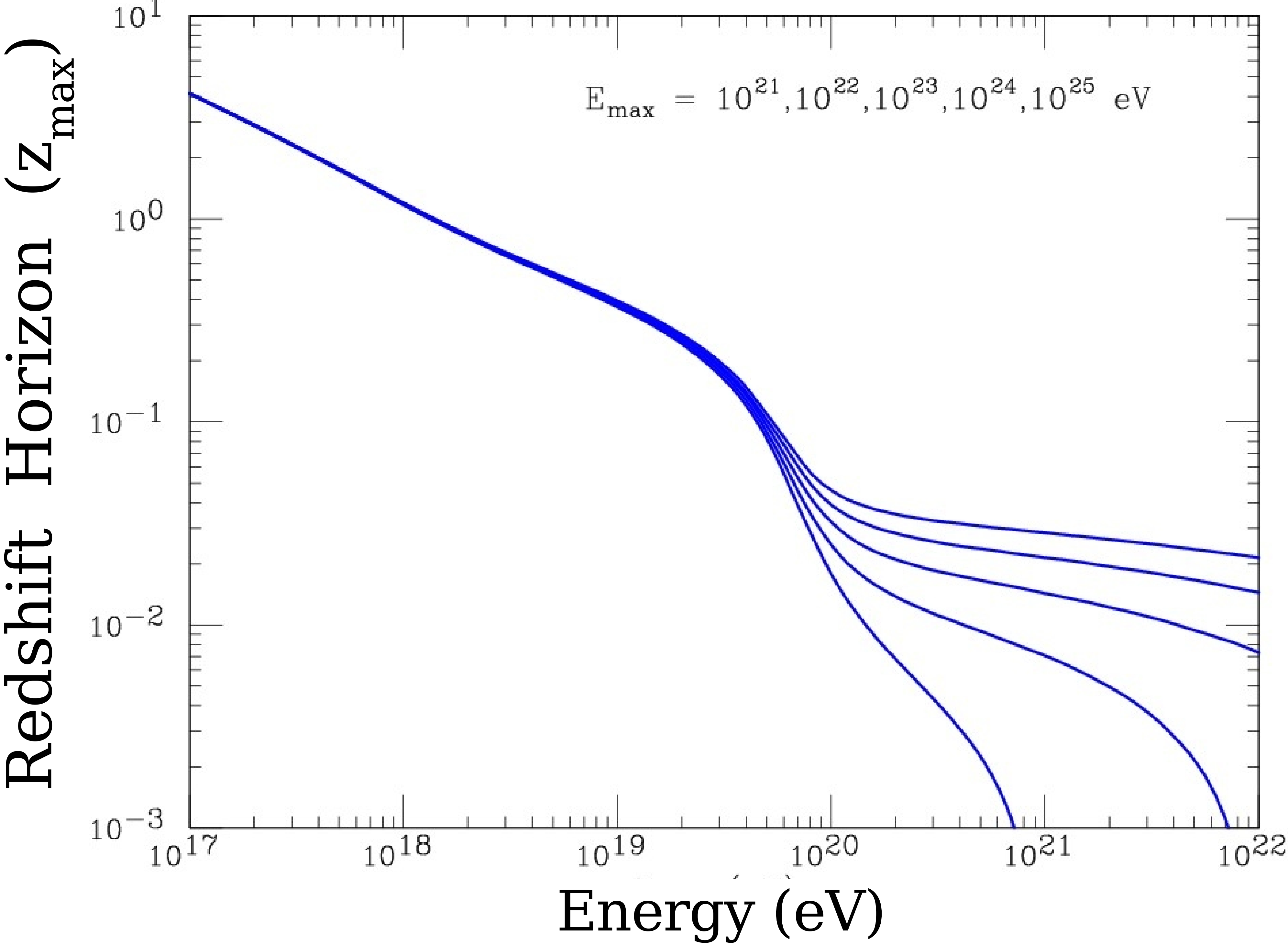
Greisen-
Zatsepin
Kuzmin

suppression

Proton Energy Evolution with Redshift



“Horizon” (in time) for protons



$$q(E,z) = q_0 \ E^{-\alpha} \ F_{\rm evolution}(z)$$

Power law injection of particles

$$\phi(E) = \frac{c}{4\pi} \frac{1}{H_0} \left[q_0 \ E^{-\alpha} \right] \ \xi(E)$$

Resulting spectrum at the presen epoch is deformed

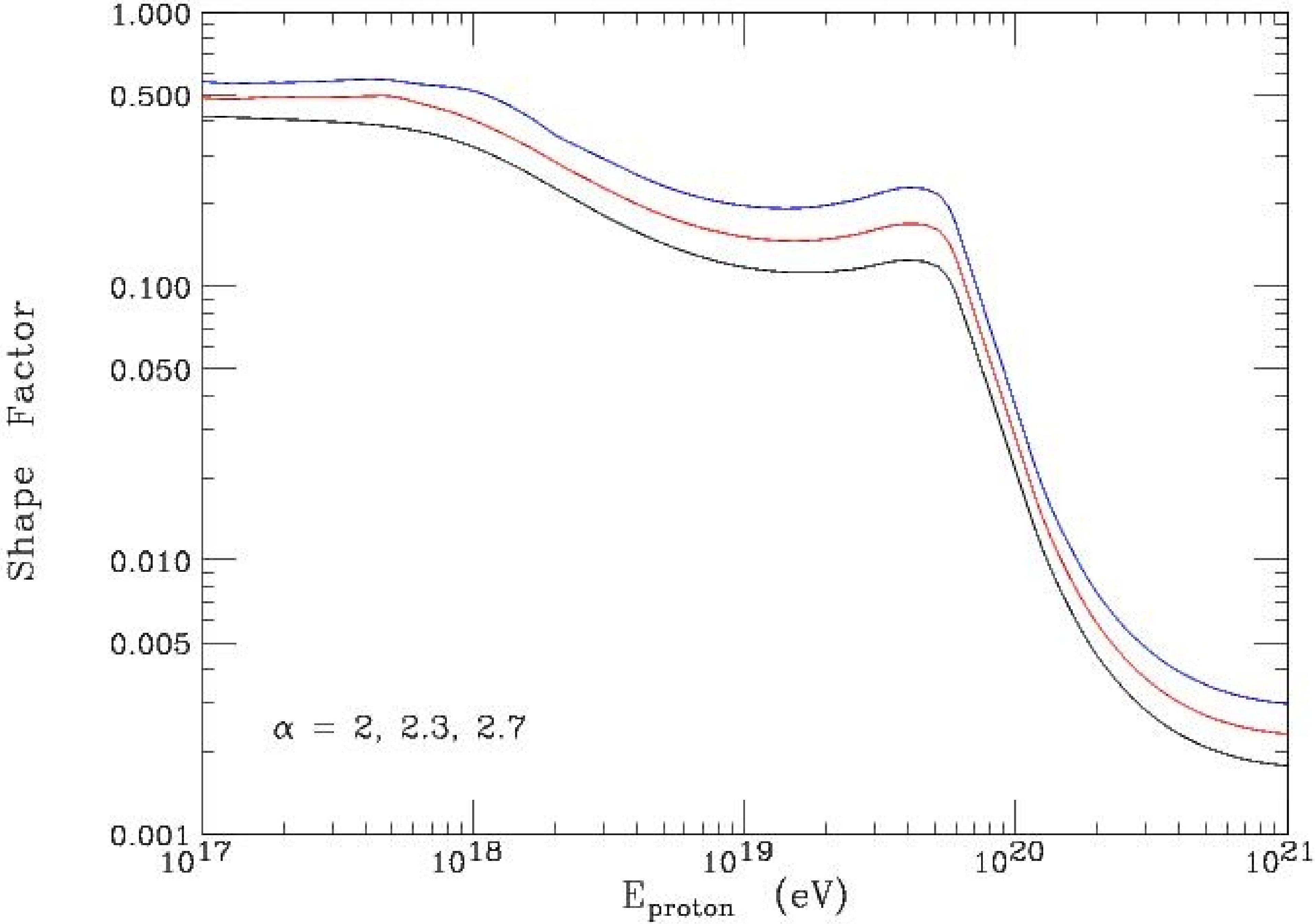
Adimensional Shape Factor

$$\xi(E) = \int_0^\infty dz \ \left| \frac{dt}{dz} \right| \frac{q[E_g(E,z)]}{q(E)} \ \frac{dE_g[E,z]}{dE} \quad F_{\rm evolution}(z)$$

$$\xi(E) = \int_0^{E_{\rm max}/E-1} dz \ \frac{H_0}{H(z)} \ (1+z)^{-\alpha}$$

Only Redshift losses: Constant

Shape factor (Berezinski "Modification factor") for different power law indices. (No cosmic evolution)



The “Olbers (Kepler) Paradox”

Why is night sky dark ?

Eternal, infinite
Euclidean Universe

n of identical sources

Q particles per unit time

Infinite flux

$$\Phi = \frac{1}{4\pi} \int_0^\infty dr \; (4\,\pi\, r^2\; n) \; \frac{Q}{4\pi\, r^2}$$

$$\Phi = \frac{n\;Q}{4\pi} \int_0^\infty dr \; 1 \quad \to \infty$$

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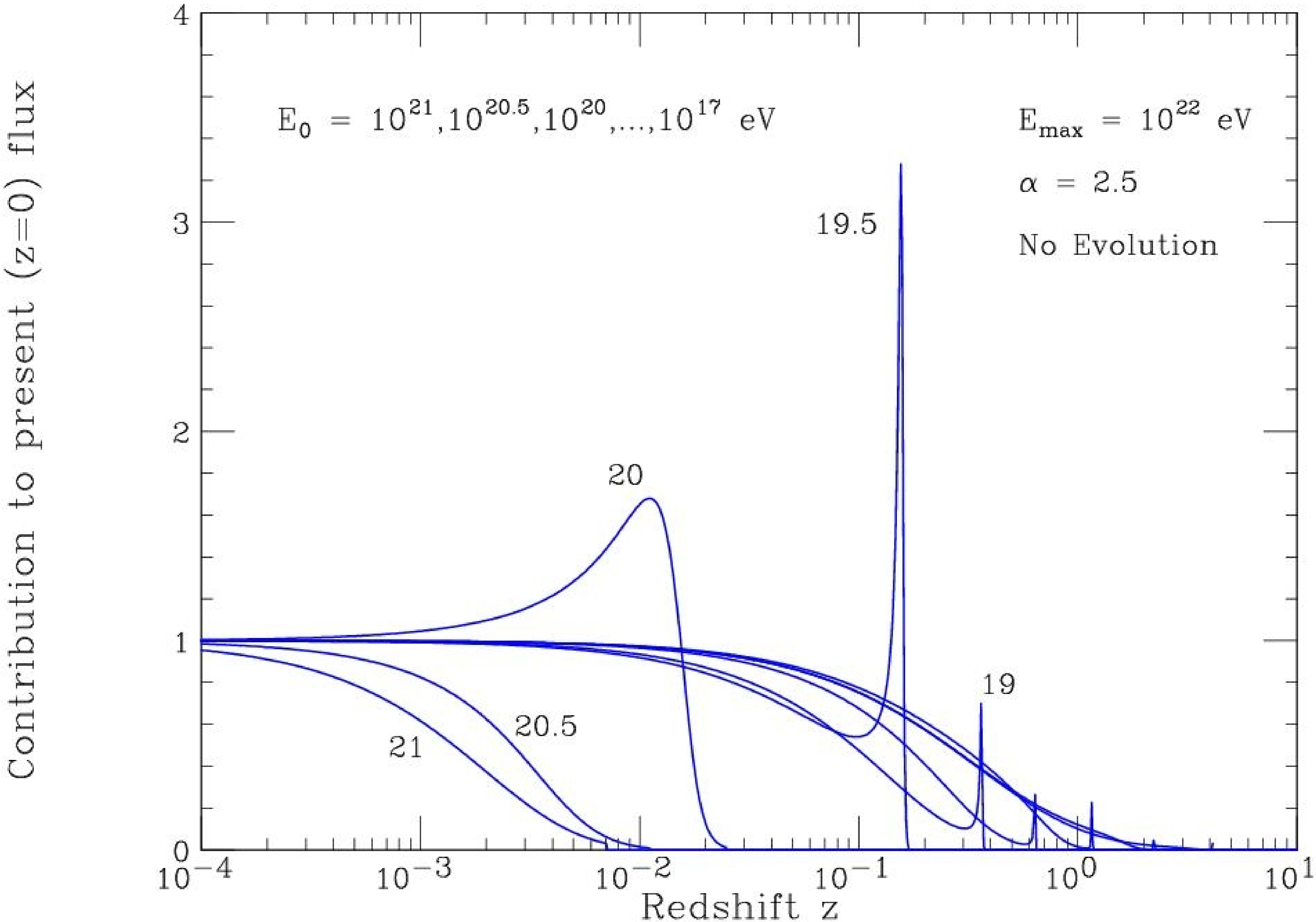
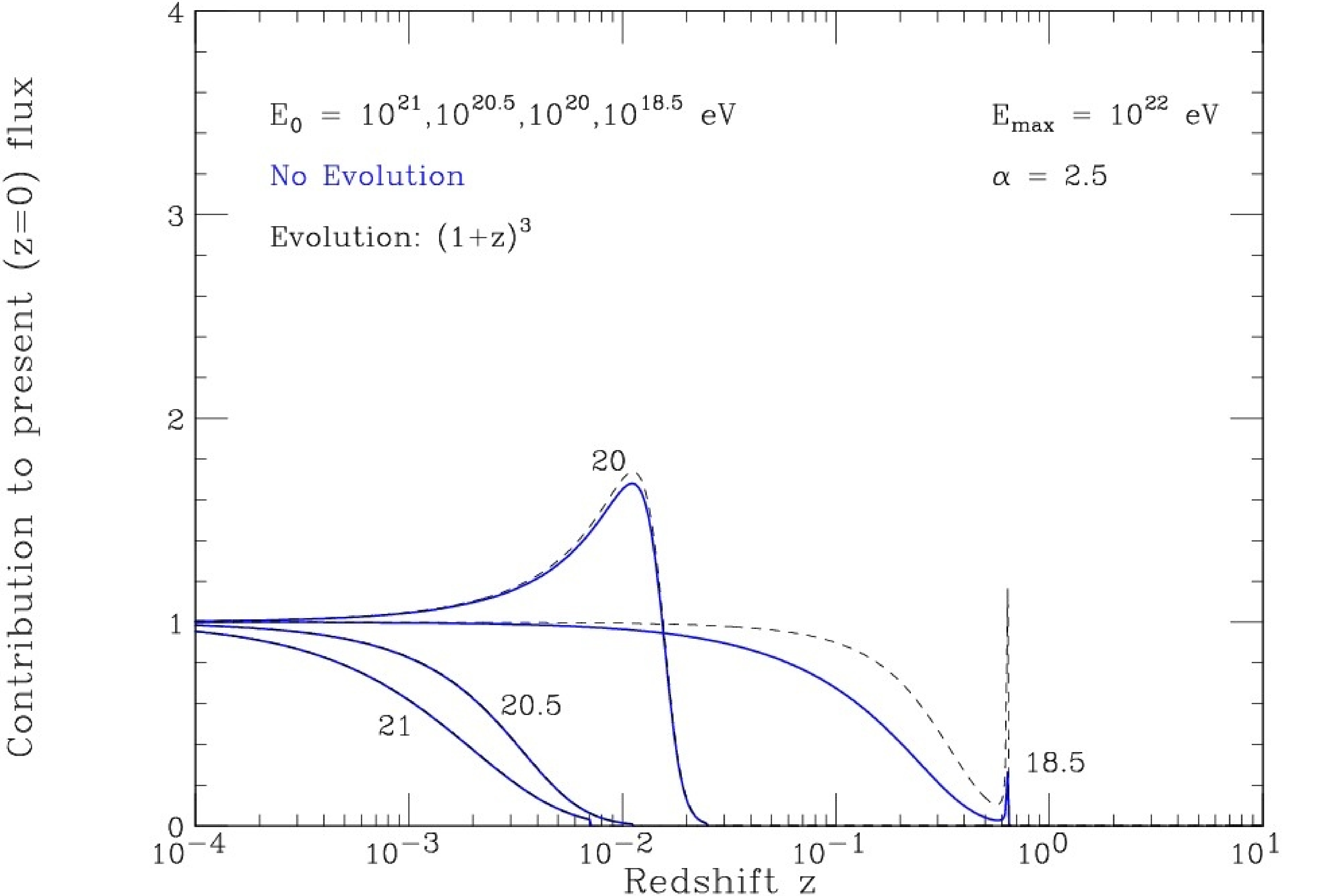
Infinite flux

Solution : Finite time for the universe
Redshift effects.

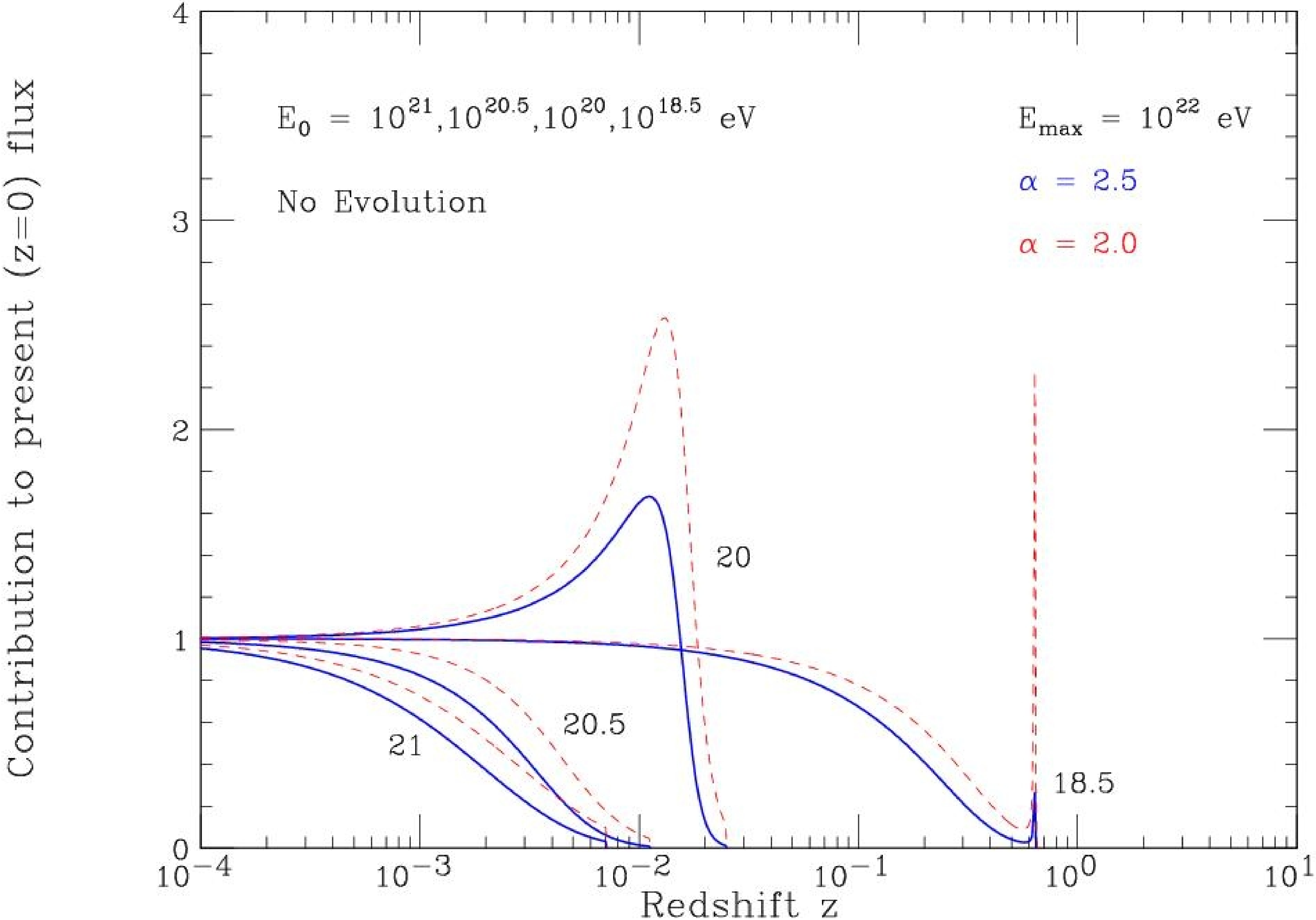
Homogeneous distribution of sources



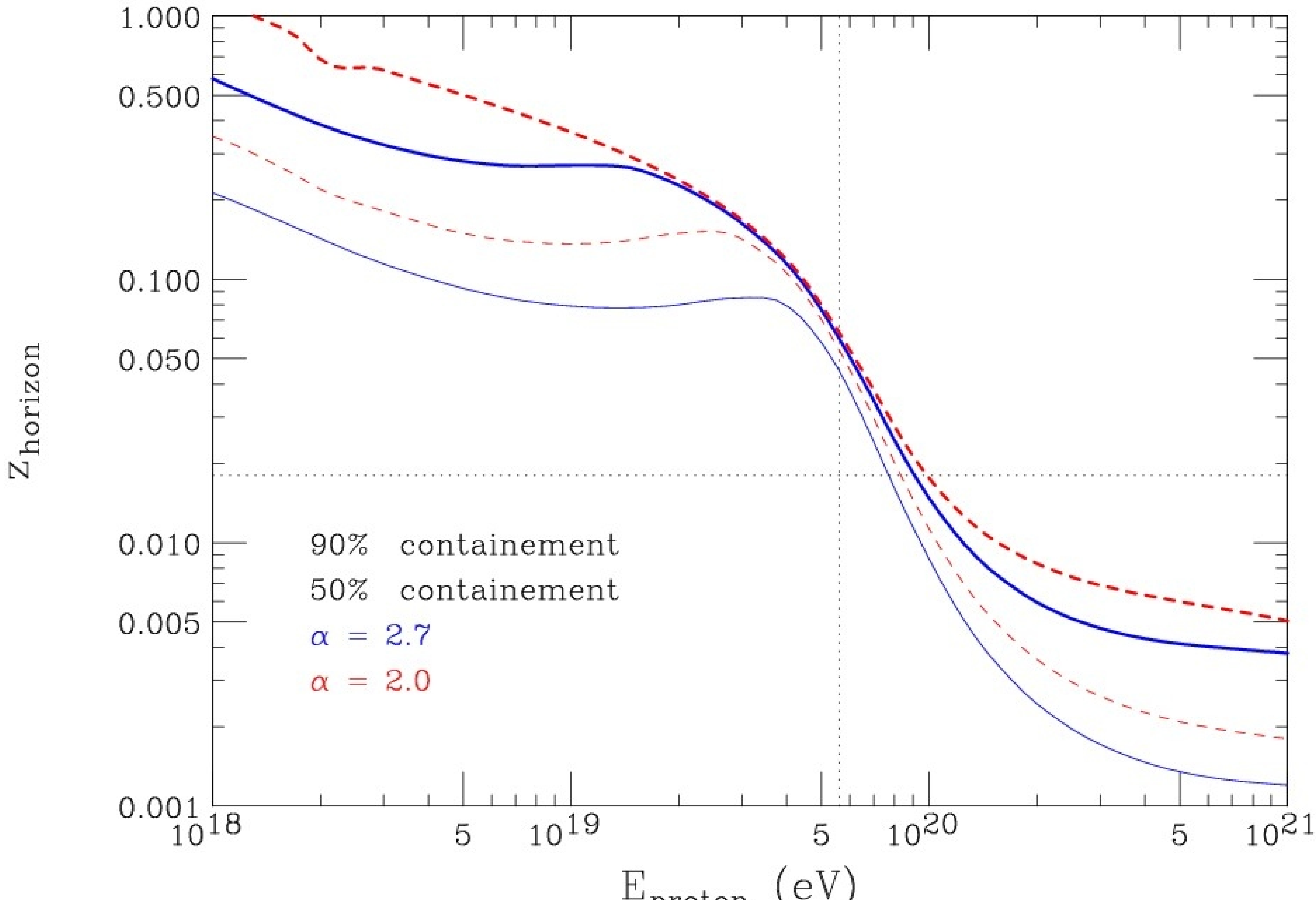
Possible effects of evolution



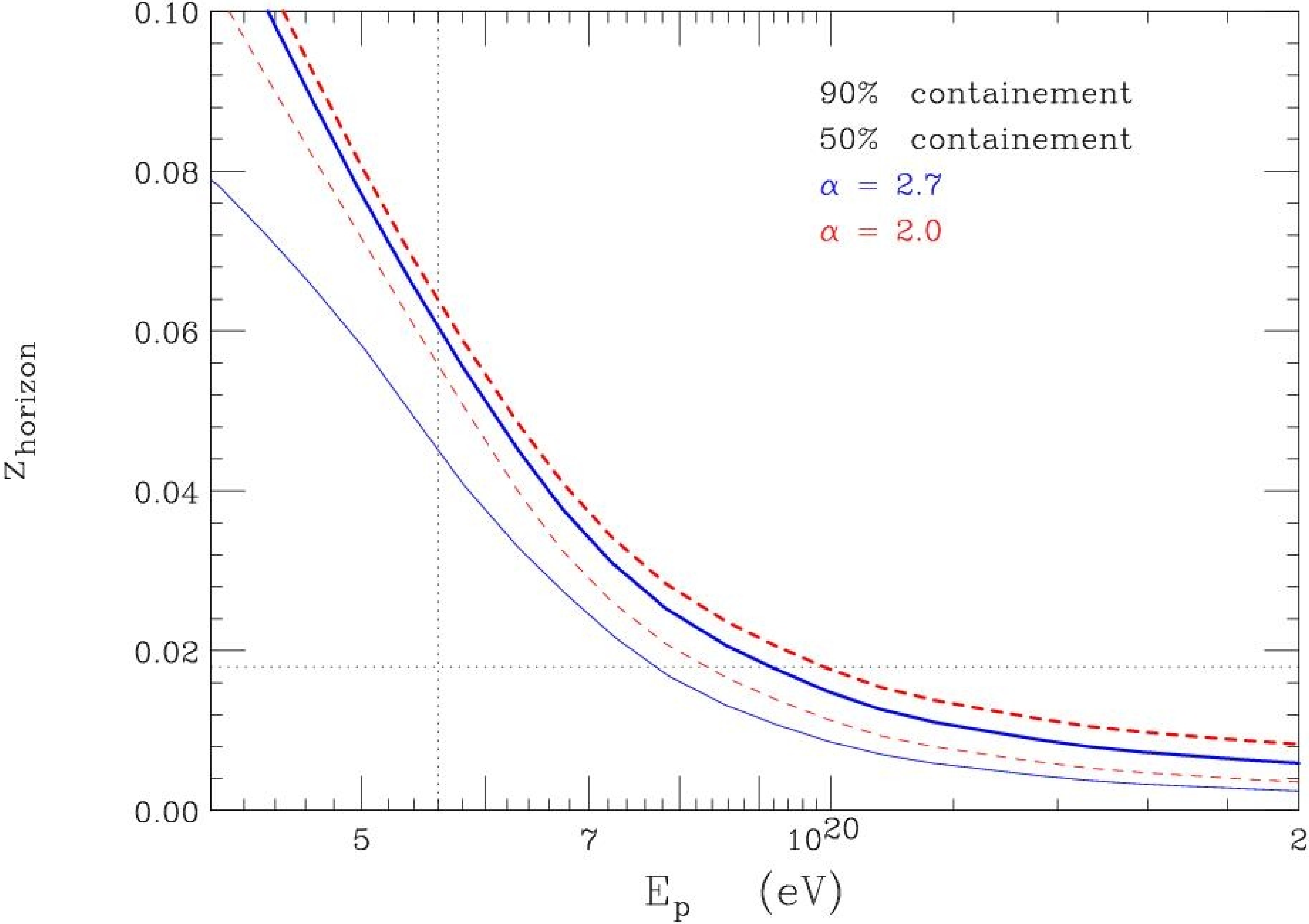
Different Injection spectra



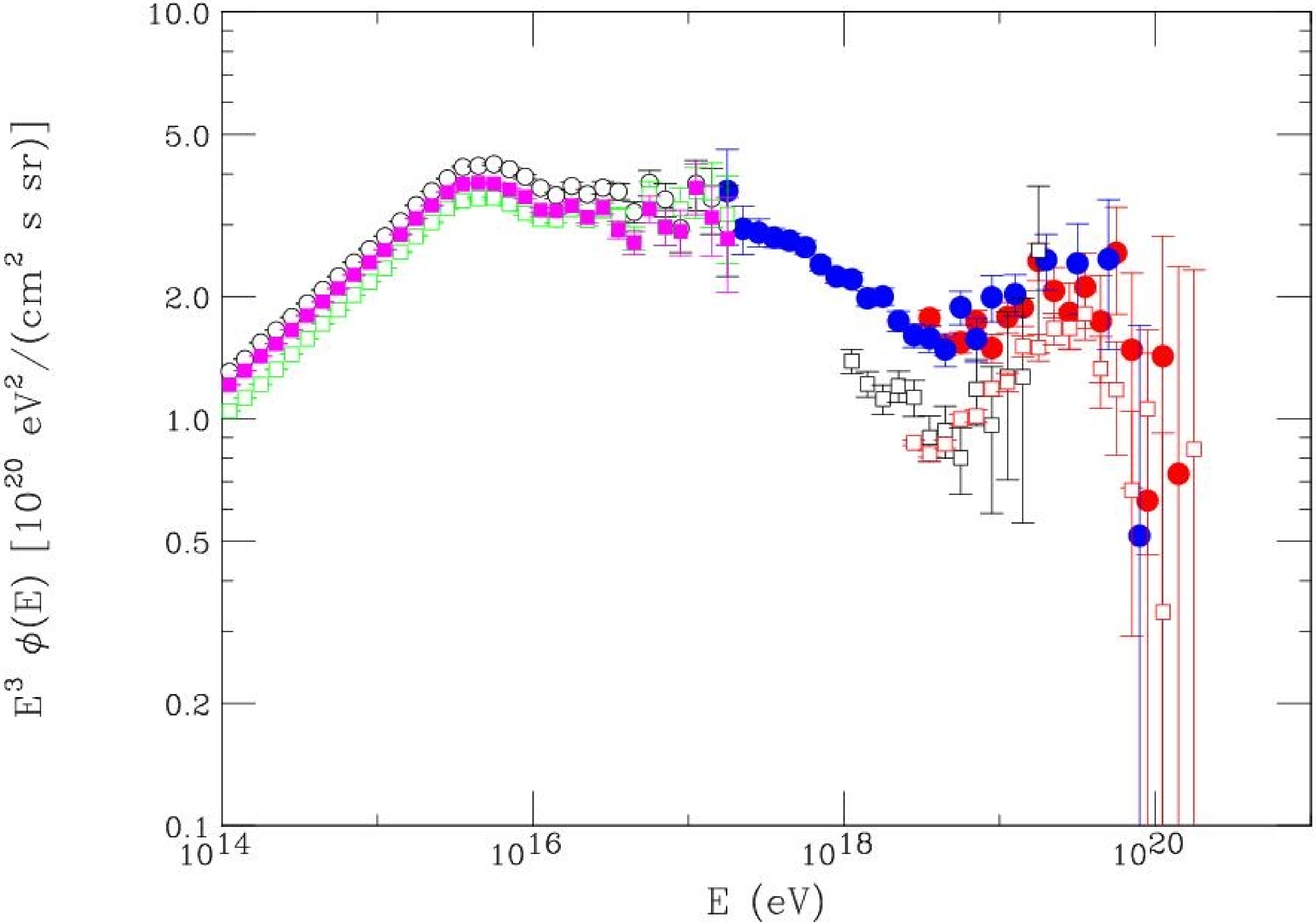
Better definition of "horizon" (90% containment z)



Puzzle in the Auger data. Observed Horizon "too close"



UHECR Flux * E^3 representation.



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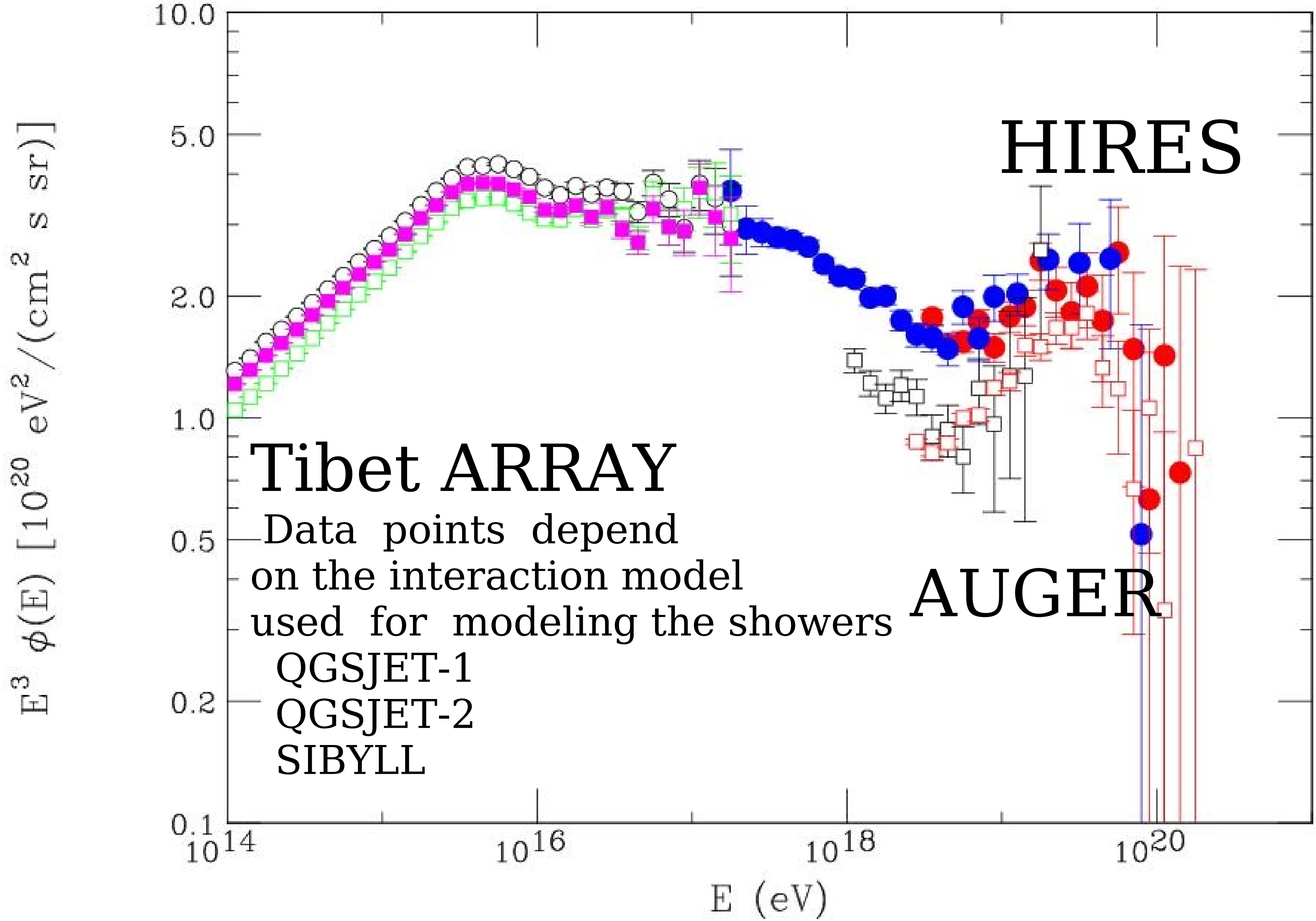
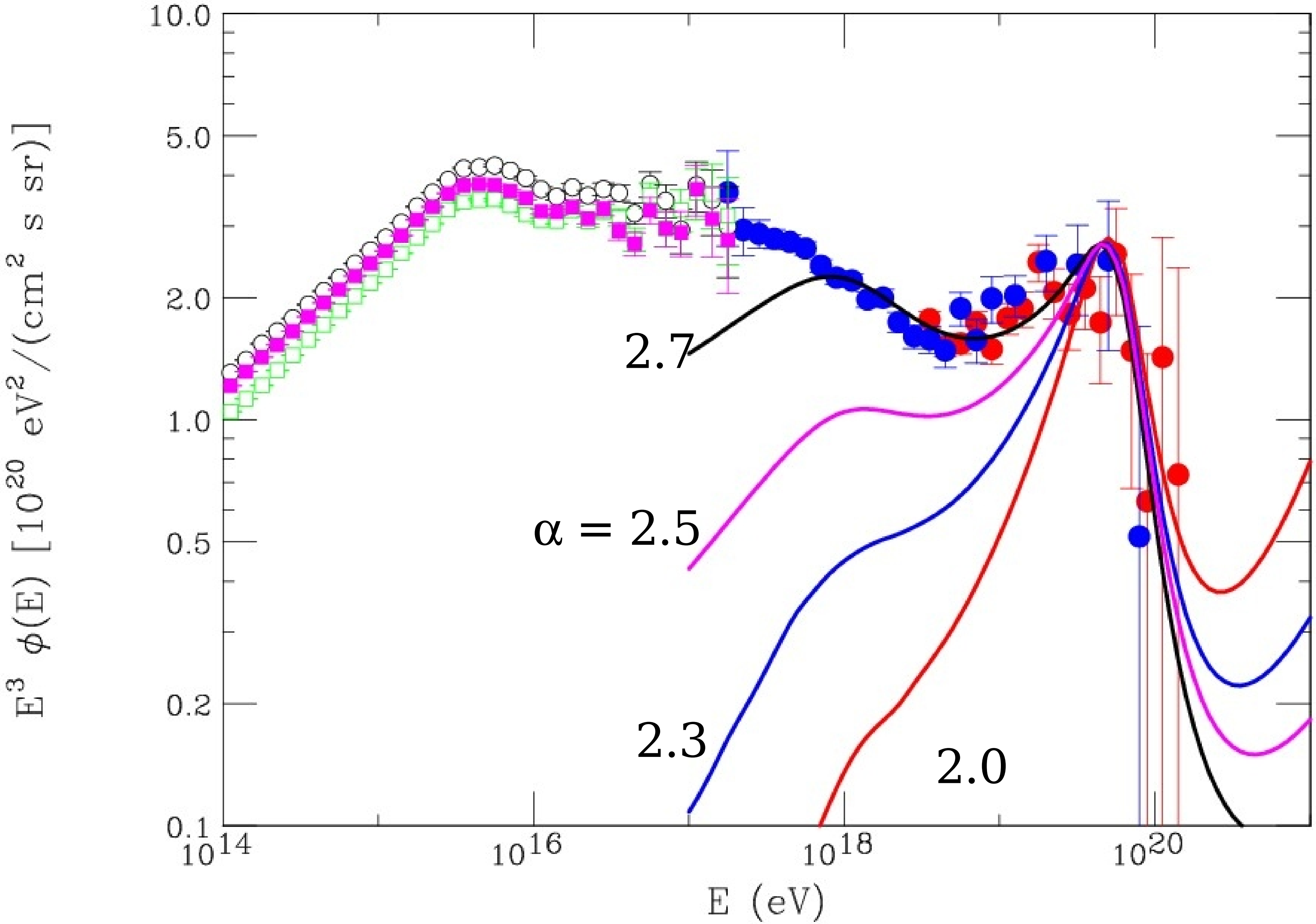
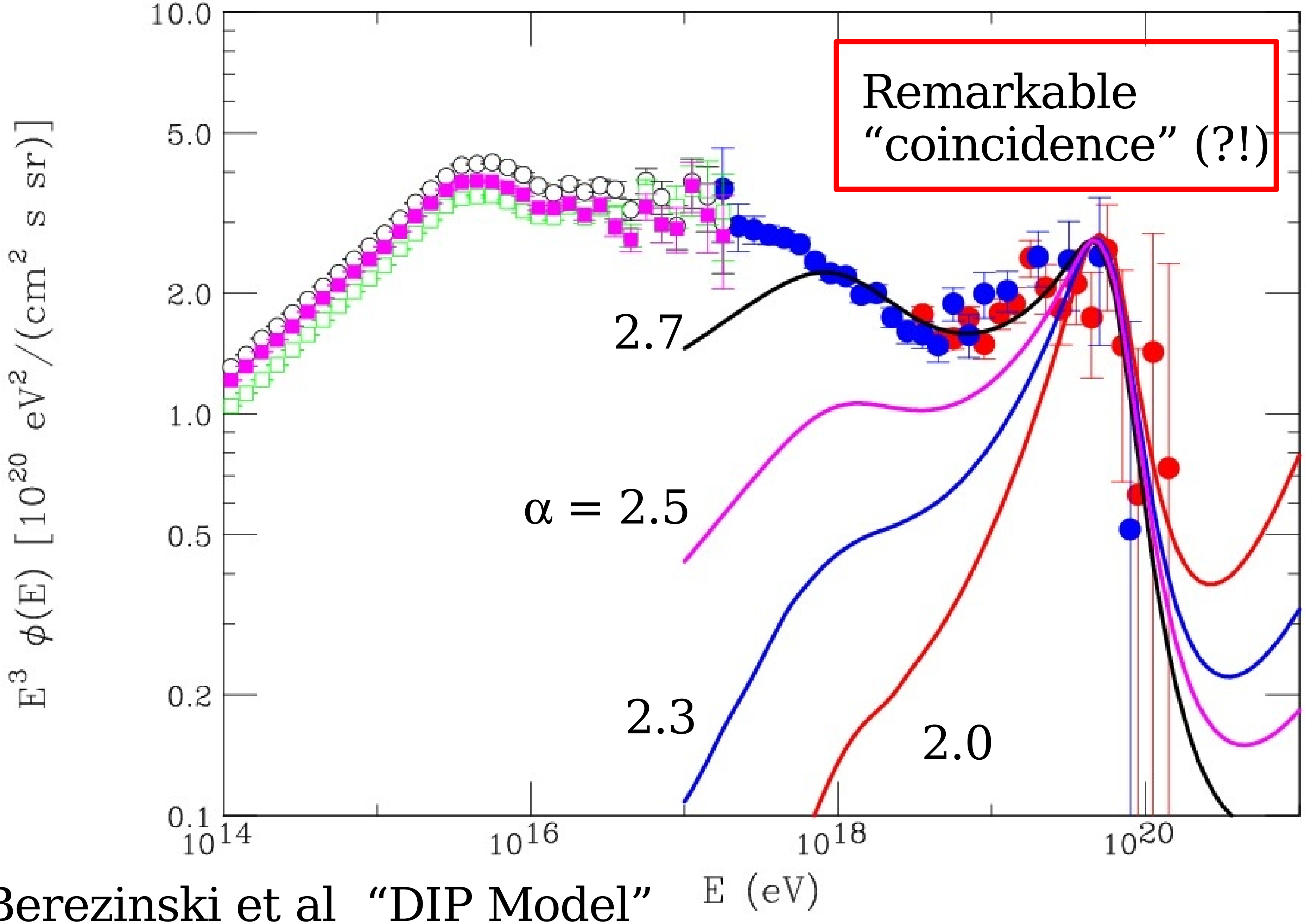


Power Law Injection (No Cosmic Evolution)

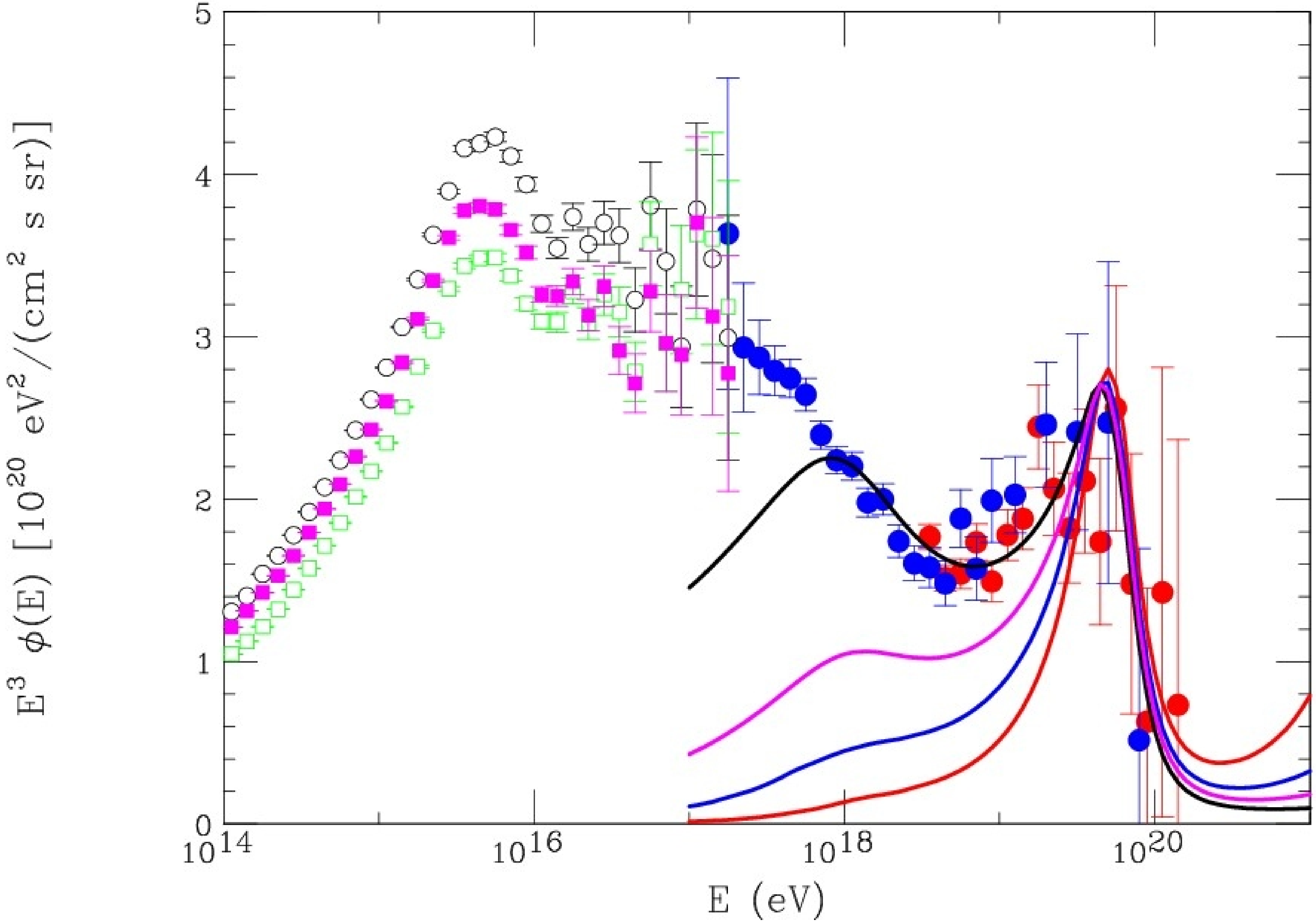


Power Law Injection (No Cosmic Evolution)

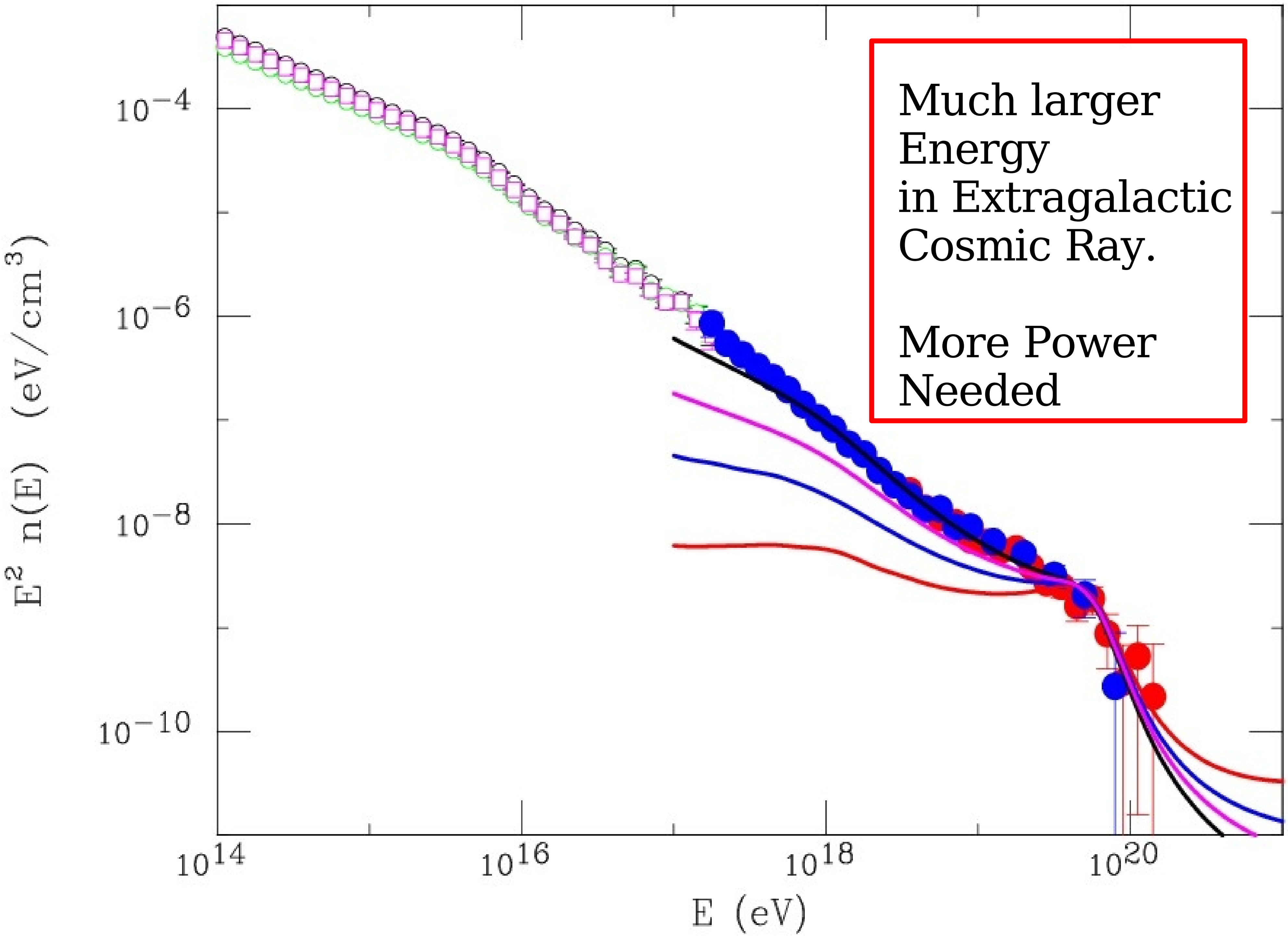


Berezinski et al “DIP Model”

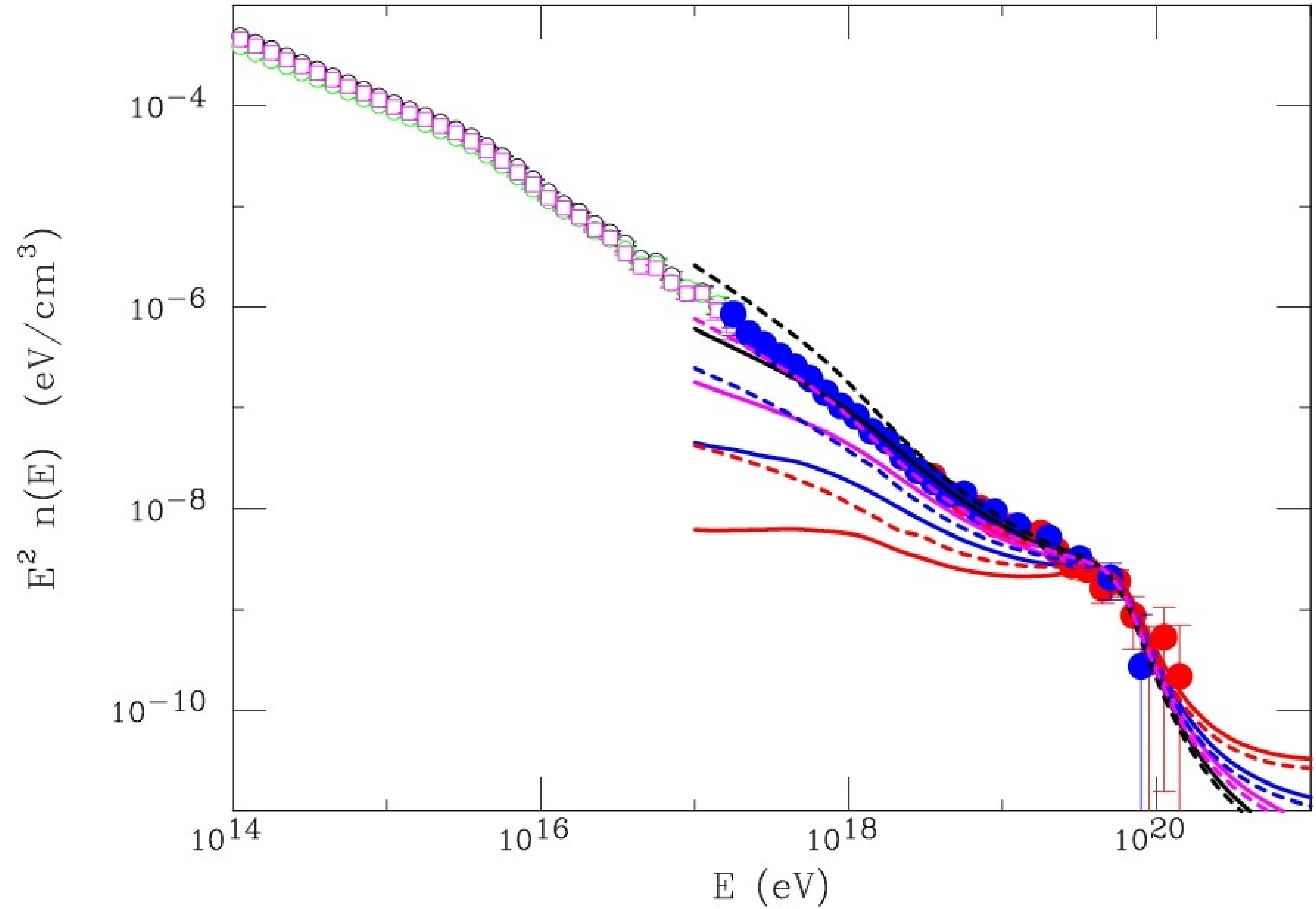
Linear Scale

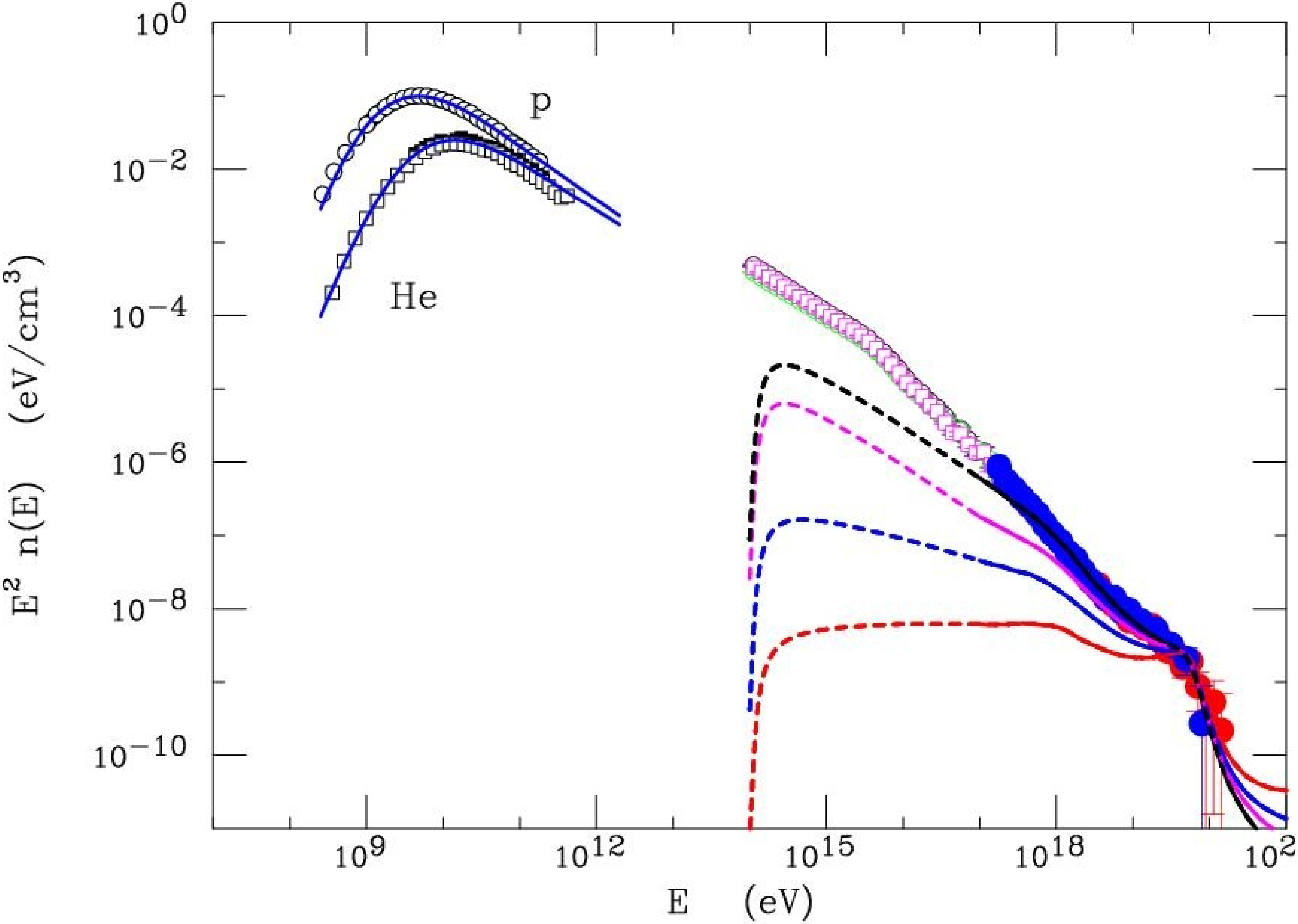


Cosmic Ray Energy Density



Introduction of Cosmic Evolution





10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
p
He
E^2 n(E) (eV/cm^3)
10^{9}
10^{12}
10^{15}
10^{18}
10^{21}
E (eV)

Power Density Requirements to Generate the Extra-Galactic Cosmic Rays:

$\alpha=2$

$$\mathcal{L} \simeq 1.1 \times 10^{37} \left[1 - \ln\left(\frac{E_{\min}}{10^{18}\ \mathrm{eV}}\right)\right] \frac{\mathrm{erg}}{\mathrm{s\ Mpc}^3}$$

3000 Solar luminosities

$\alpha=7$

$$\mathcal{L} \simeq 3.4 \times 10^{37} \left(\frac{E_{\min}}{10^{18}\ \mathrm{eV}}\right)^{-0.7} \frac{\mathrm{erg}}{\mathrm{s\ Mpc}^3}$$

9000 Solar luminosities

“Average Power Density”
needed to produce
the Extra-Galactic Cosmic Rays

$$\mathcal{L}_{\rm cr}^{\rm ExtraGalactic} \sim \left(10^3 \div 10^5\right) \frac{L_\odot}{\rm Mpc^3}$$

$$\mathcal{L}_{\rm stars} \simeq 10^9 \frac{L_\odot}{\rm Mpc^3}$$

$$\mathcal{L}_{\rm SN}^{\rm Kinetic} \simeq 4 \times 10^6 \frac{L_\odot}{\rm Mpc^3}$$

Possible Sources

$$\mathcal{L}_{\rm AGN}^{\rm bolometric} \simeq 2 \times 10^7 \frac{L_\odot}{\rm Mpc^3}$$

$$R_{\rm SN}^{\rm observed} \simeq 7.6^{+6.4}_{-2.0} \times 10^{-4}\ ({\rm Mpc}^3\ {\rm yr}^{-1})$$

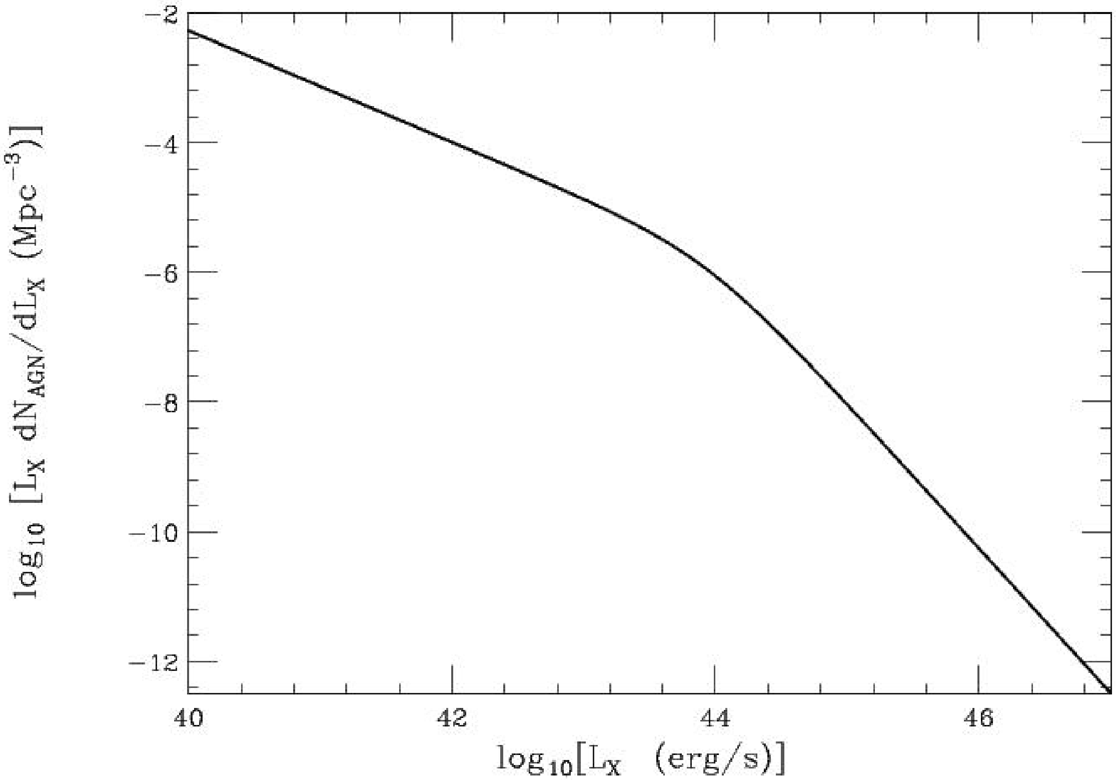
$$R_{\rm SN} \;=\; \psi(0)\ \frac{\int_8^{100}\ dM\ \frac{dN}{dM}}{\int_{0.08}^{100}\ dM\ M\ \frac{dN}{dM}}$$

$$\simeq\ 7.9^{+2.4}_{-3.9} \times 10^{-4}\ ({\rm Mpc}^3\ {\rm yr}^{-1})$$

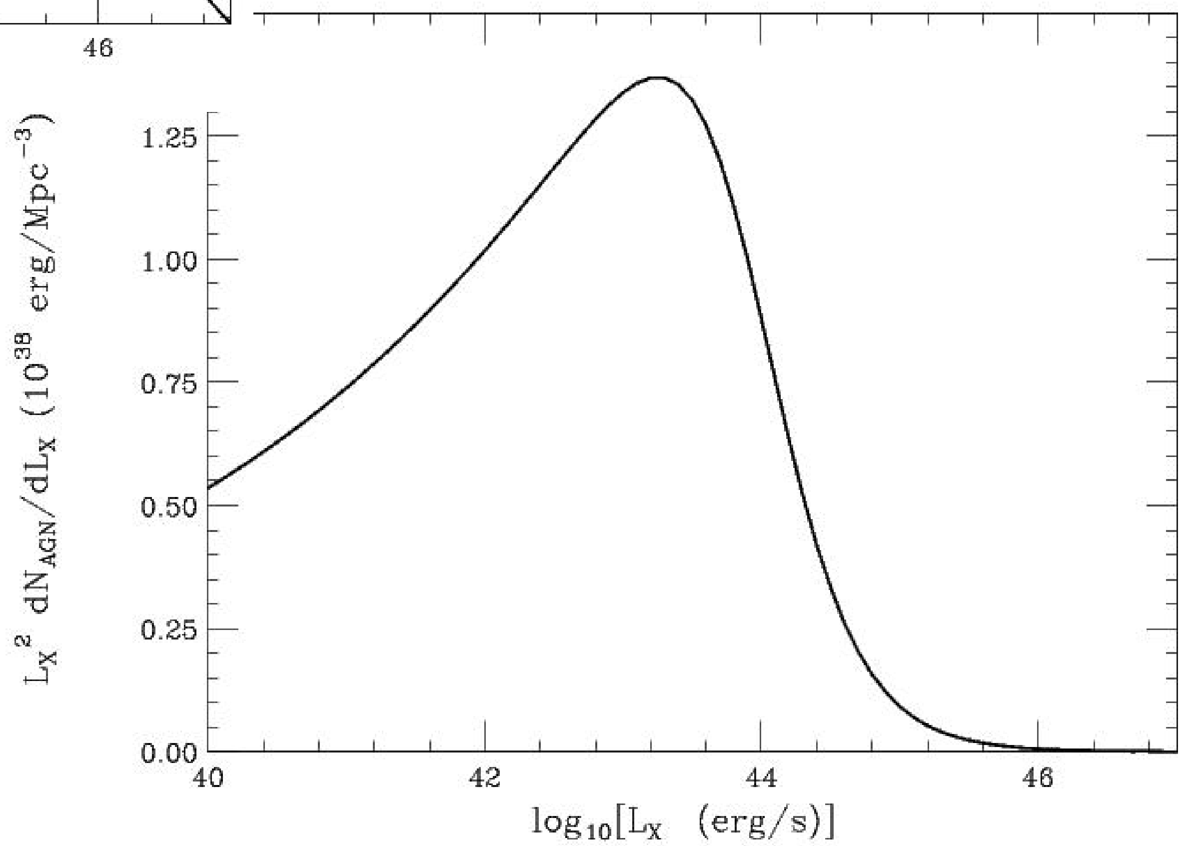
$$(\mathcal{L})_{\rm SN,kin} \;\simeq\; 1.6 \times 10^{40}\ \frac{\rm erg}{\rm s\ Mpc^3}$$

$$(\mathcal{L})_{\rm SN,kin} \;\simeq\; 4.2 \times 10^{6}\ \frac{L_\odot}{\rm Mpc^3}$$

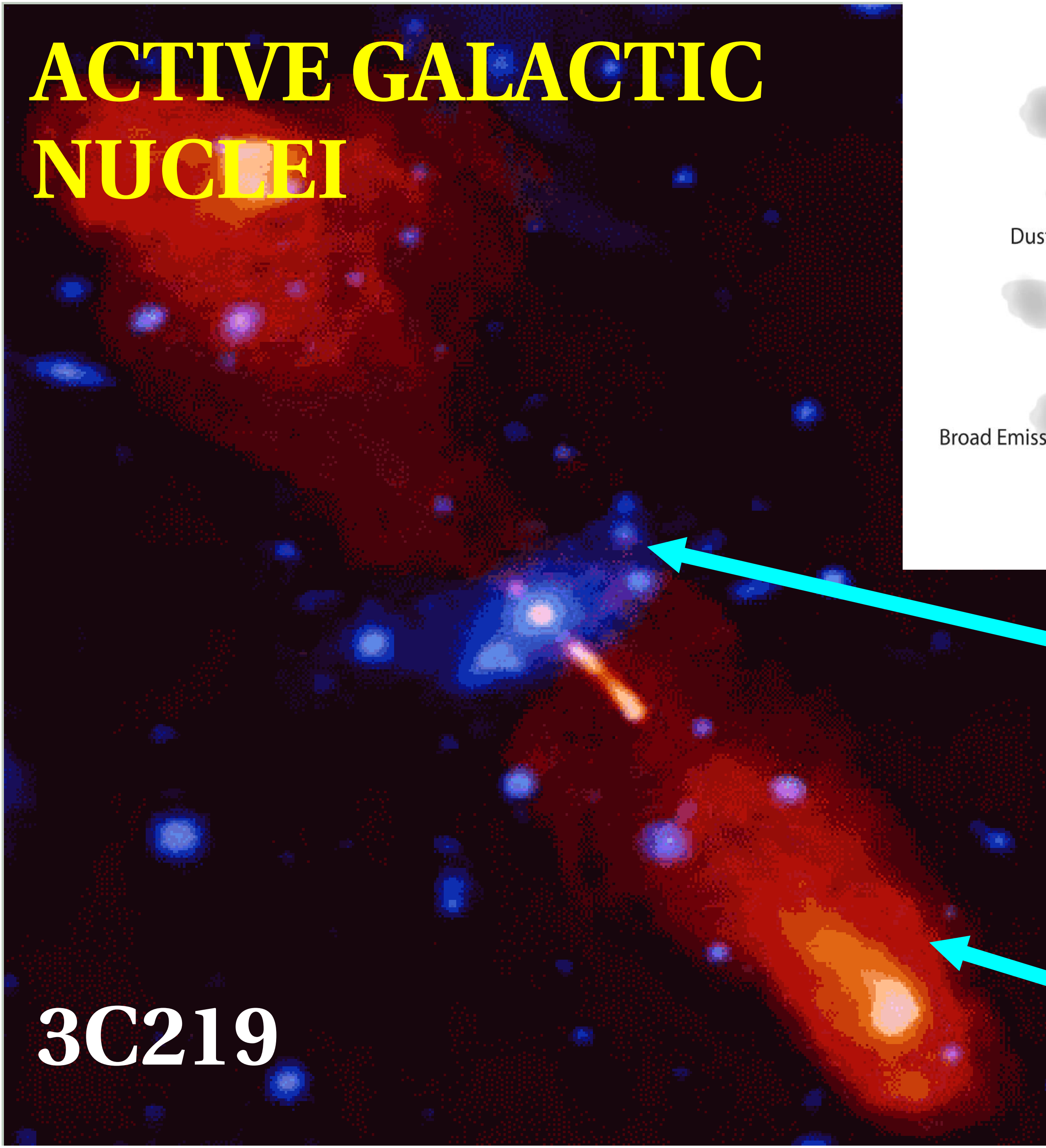
X-Ray Luminosity
2-10 KeV band

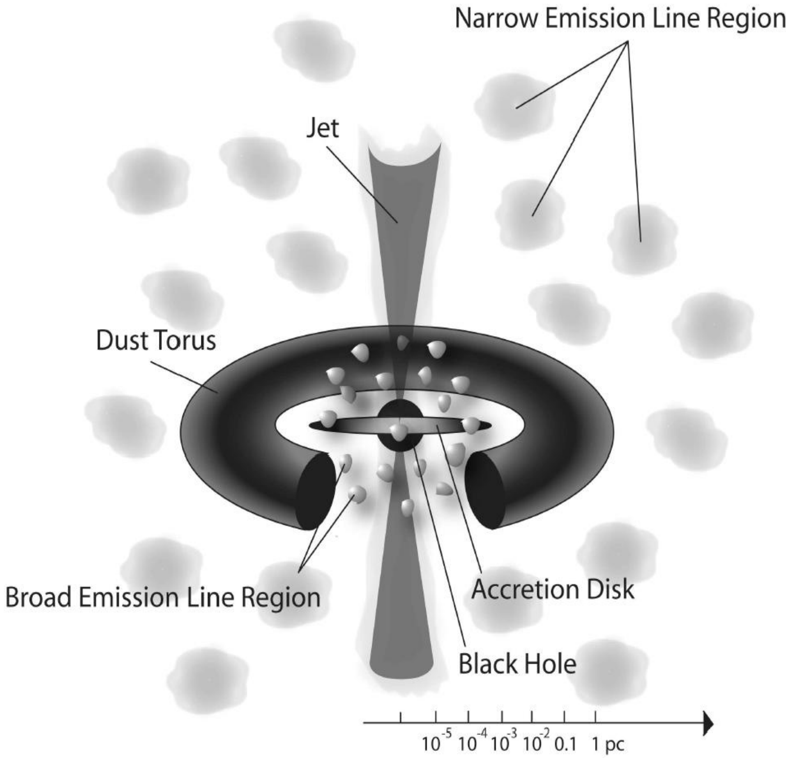


Ueda, Akiyama, Ohta
and Miyaji
Prog. on Theor.l Physics
(S155) 2004.



ACTIVE GALACTIC NUCLEI





Super-Massive Black Hole

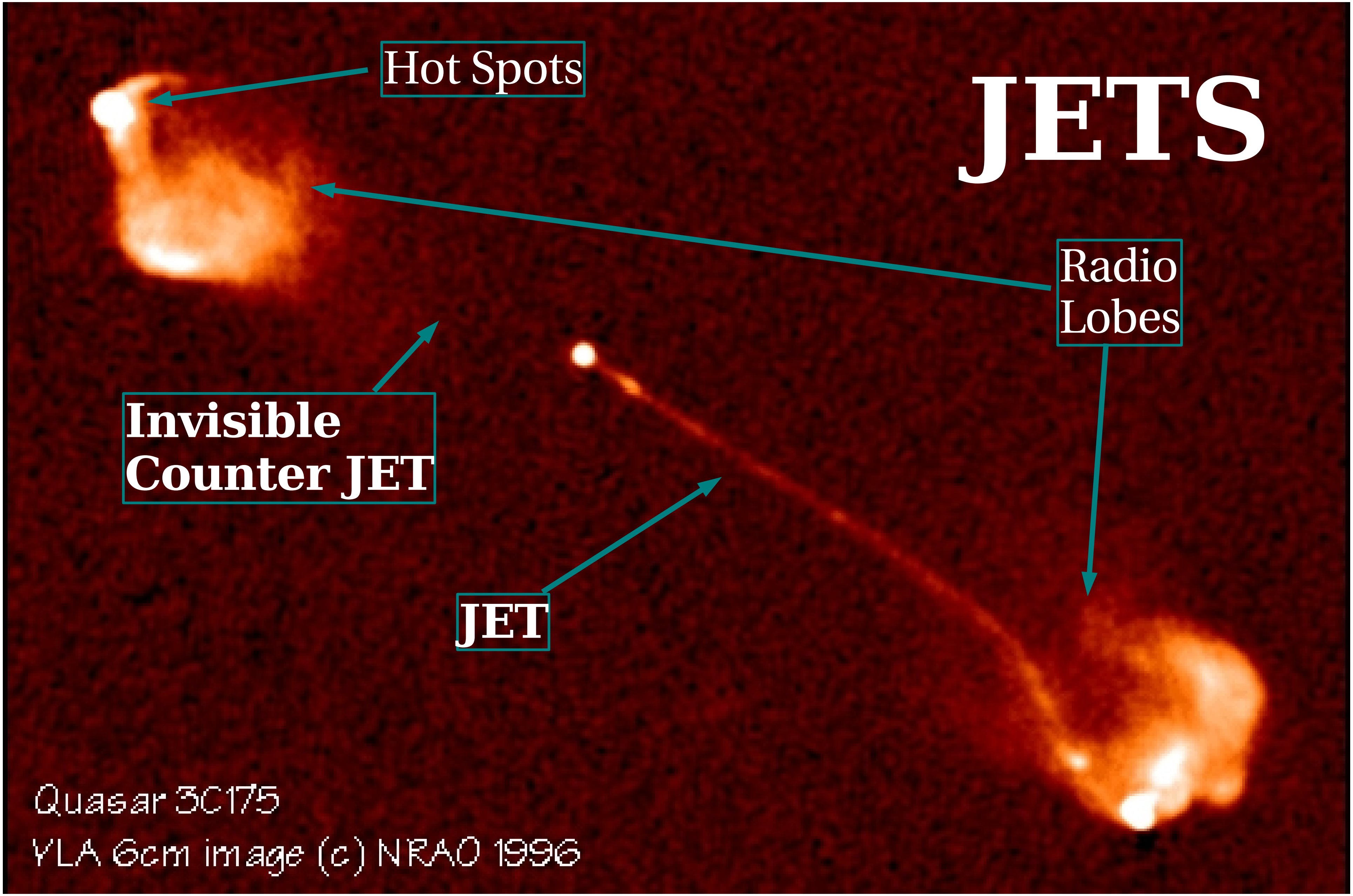
$$M = 10^4 \div 10^{10}\ M_\odot$$

Accretion Power

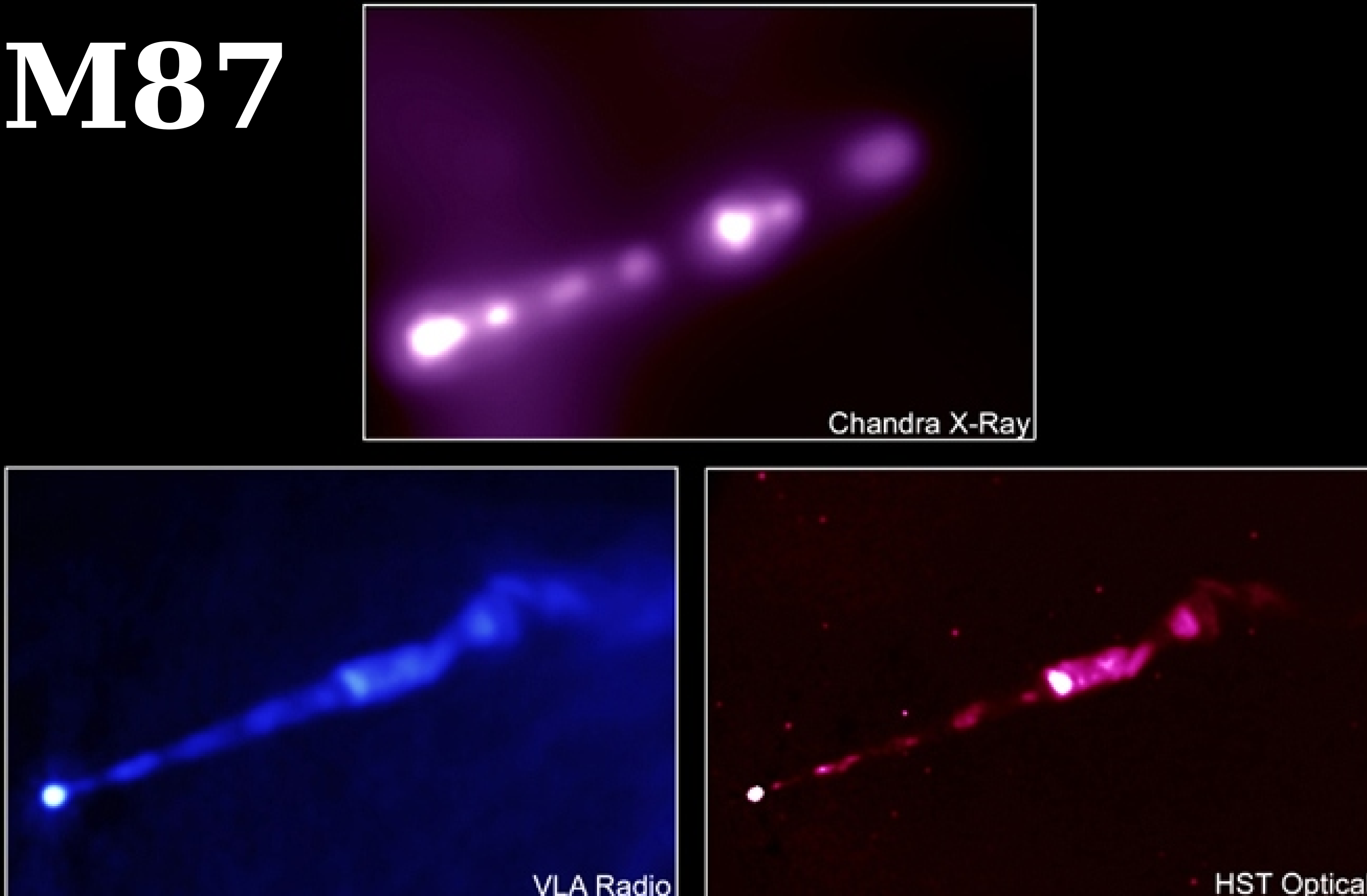
$$L = \frac{G\ M\ \dot{m}\, c^2}{R}$$

$$R \sim 5 R_{\mathrm{Schwarzschild}} = 10\ G\ M$$

$$L \sim 0.1\ \dot{m}\, c^2$$


JETS
Hot Spots
Radio Lobes
Invisible Counter JET
JET
Quasar 3C175
VLA 6cm image (c) NRAO 1996

M87



Cosmic Ray Composition

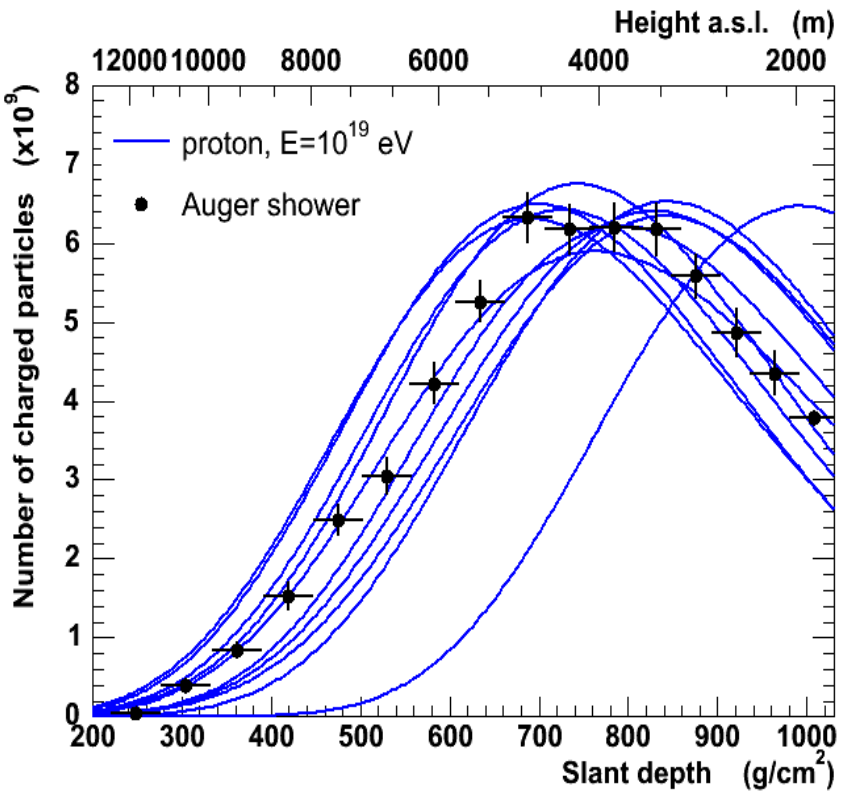
and

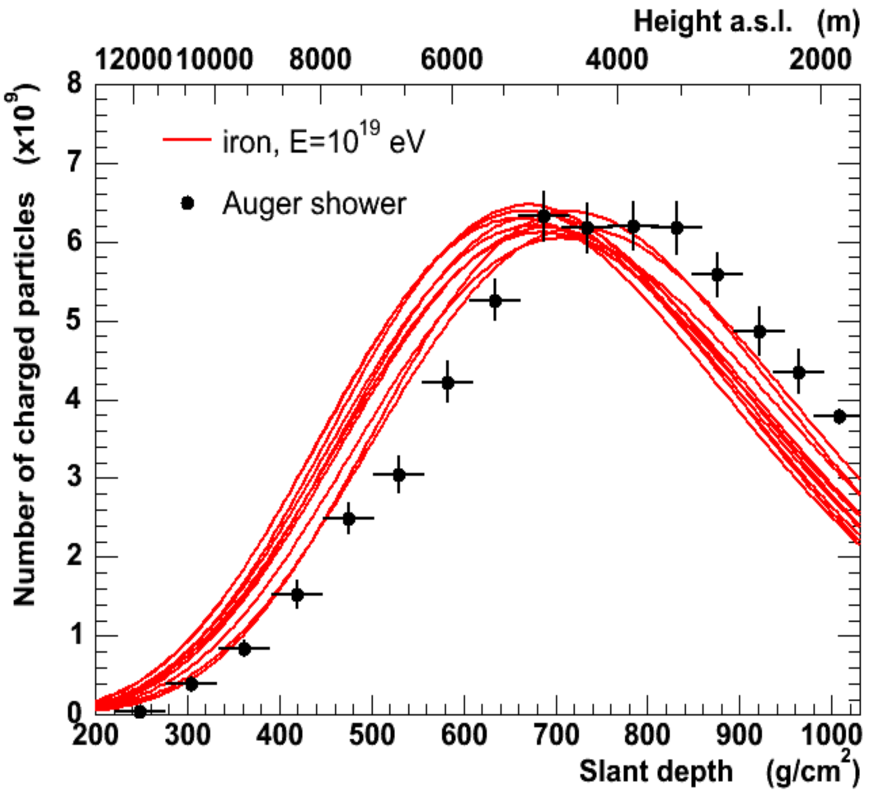
Hadronic interactions

Fluorescence Light Composition Measurements

SHAPE of the Shower Longitudinal Development dependences:

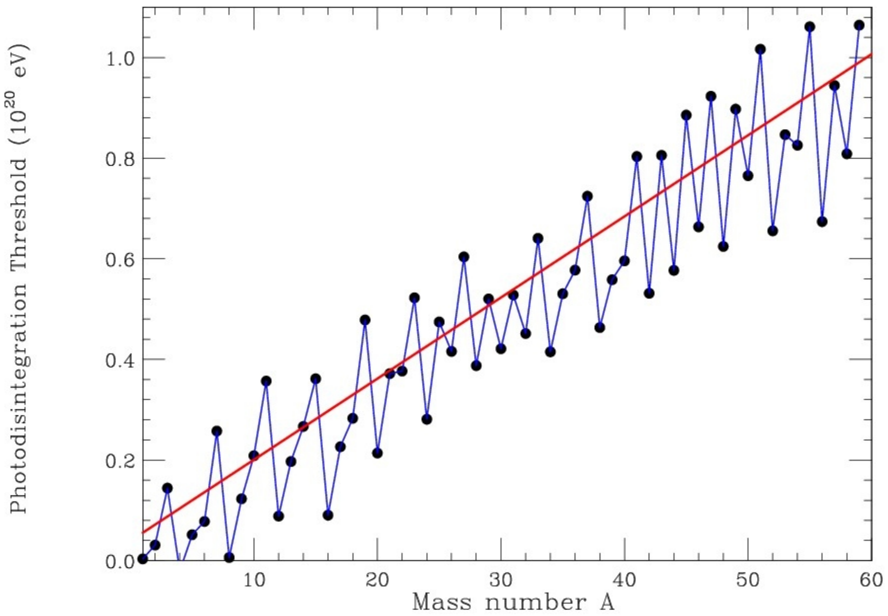
Composition
Hadronic Interaction Modeling





Nuclear Photo-disintegration

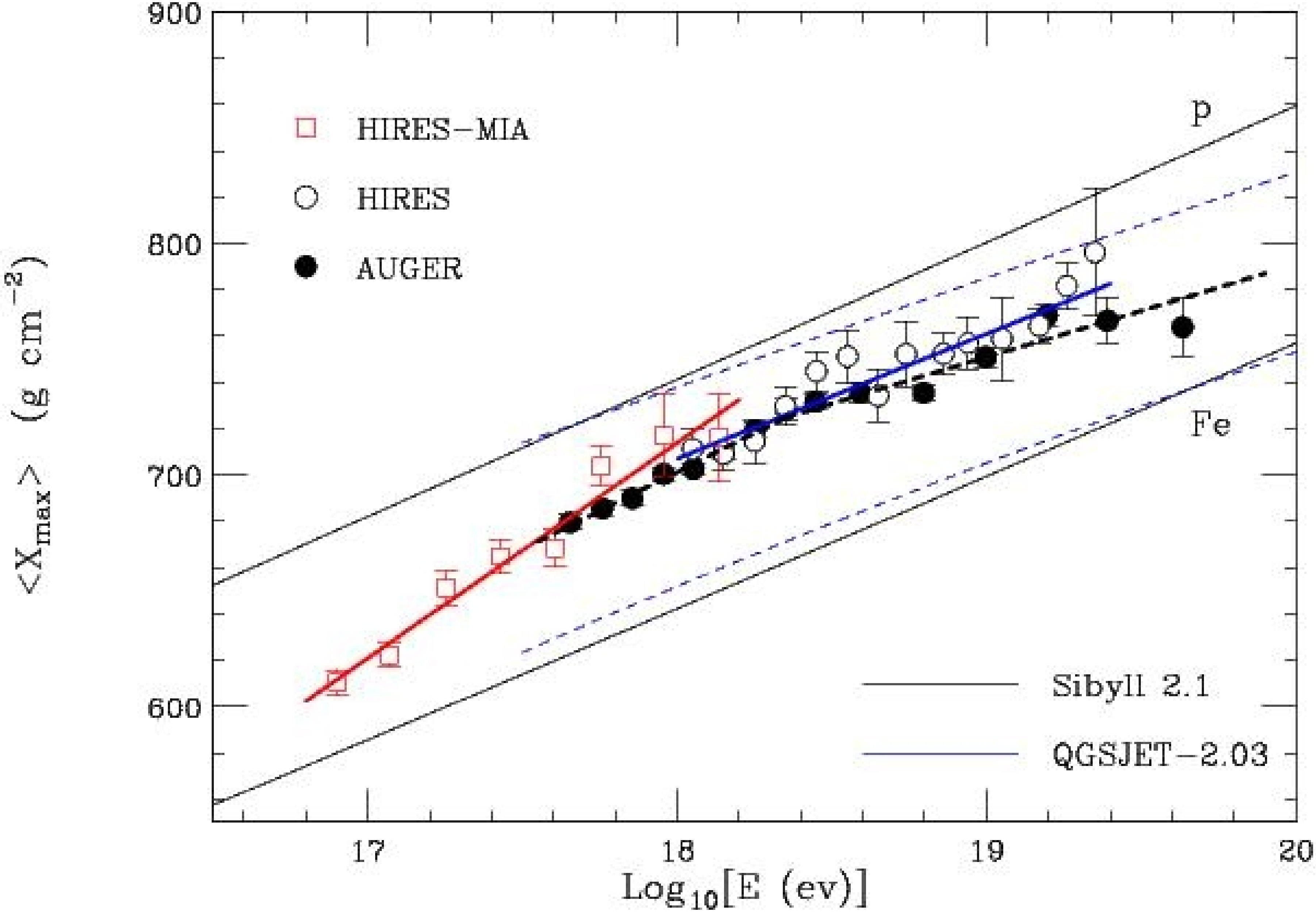
$$A + \gamma \rightarrow (A-1) + N$$



$$E_A \geq \frac{(m_{A-1} + m_N)^2 - m_A^2}{2\,\varepsilon_\gamma\,(1-\cos\theta_{p\gamma})}$$

$$m_A \simeq A\ (m_N - \epsilon_B)$$

$$E_A \gtrsim \frac{A\,m_N \epsilon_B}{2\,\varepsilon_\gamma\,(1-\cos\theta_{p\gamma})} \simeq \frac{A}{56} \times 10^{20}\ \text{eV}$$



HIRES−MIA
HIRES
AUGER
p
Fe
Sibyll 2.1
QGSJET−2.03
900
800
700
600
17
18
19
20
$\langle X_{max} \rangle$ (g cm^{-2})
Log$_{10}$[E (ev)]

X_{max} and the Composition of Cosmic Rays

Proton Showers

$$X_{max}^{p}(E) = X_{max}^{p}(E^{*}) + D_{p}(E^{*}) \ \ln\left(\frac{E}{E^{*}}\right)$$

Logarithmic growth of average X_{max} with energy

$$X_{max}^{A}(E) \simeq X_{max}^{p}\left(\frac{E}{A}\right)$$

Mass dependence

$$\langle X_{max}(E)\rangle \simeq X_{max}^{p}(E) - D_{p}(E) \ \langle \ln A\rangle$$

Obtain the average mass
and its variation
with energy

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

$$\langle \ln A \rangle_E = \frac{\langle X_{\max}(E) \rangle - X_p(E)}{D_p}$$

$$\frac{d \langle \ln A \rangle_E}{d \ln E} = 1 - \frac{D_{\exp}}{D_p}$$

Sibyll-Interpretation

$$\langle \log_{10} A \rangle_{\rm Sibyll} \simeq 0.83 \pm 0.21$$

$$\langle \log_{10} A \rangle_{\rm Sibyll} \simeq \log \left[6.8 \, {}^{+4.1}_{-2.1} \right]$$

$$\left[\frac{p}{\rm Fe} \right]_{\rm Sibyll} = 1.1 \pm 0.2$$

SYSTEMATIC UNCERTAINTY ??

Composition is Mixed

50% p
50% Fe

$$\left[\frac{d\langle \log A \rangle}{d \log E} \right]_{\rm Sibyll} \simeq 0.32 \pm 0.07$$

$$[\beta]_{\rm Sibyll} = -0.7 \pm 0.15$$

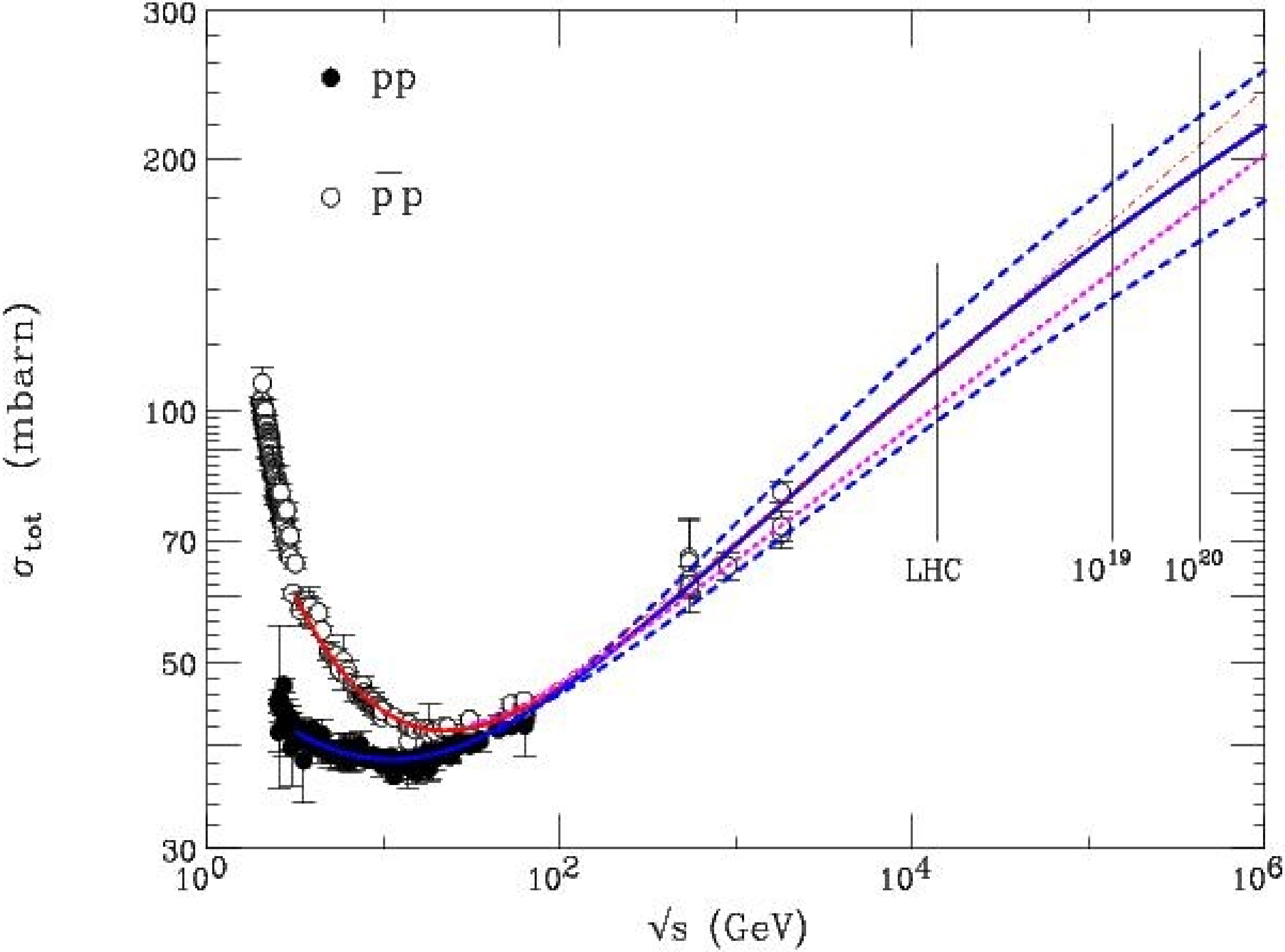
Composition become heavier with increasing Energy

Data

$$\langle \ln A \rangle_E = \frac{\langle X_{\max}(E) \rangle - X_p(E)}{D_p}$$

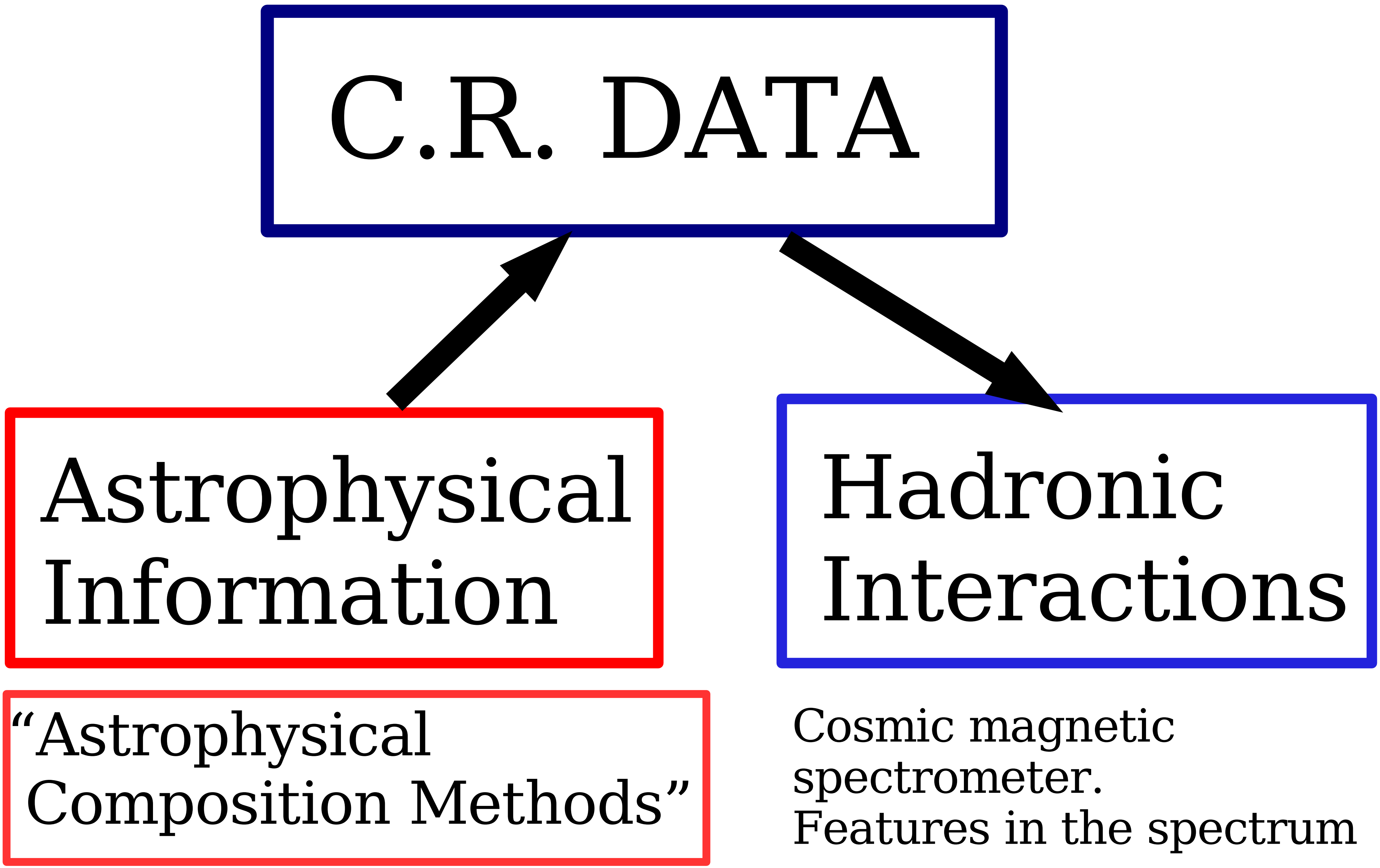
Astrophysical Information

Hadronic Interactions

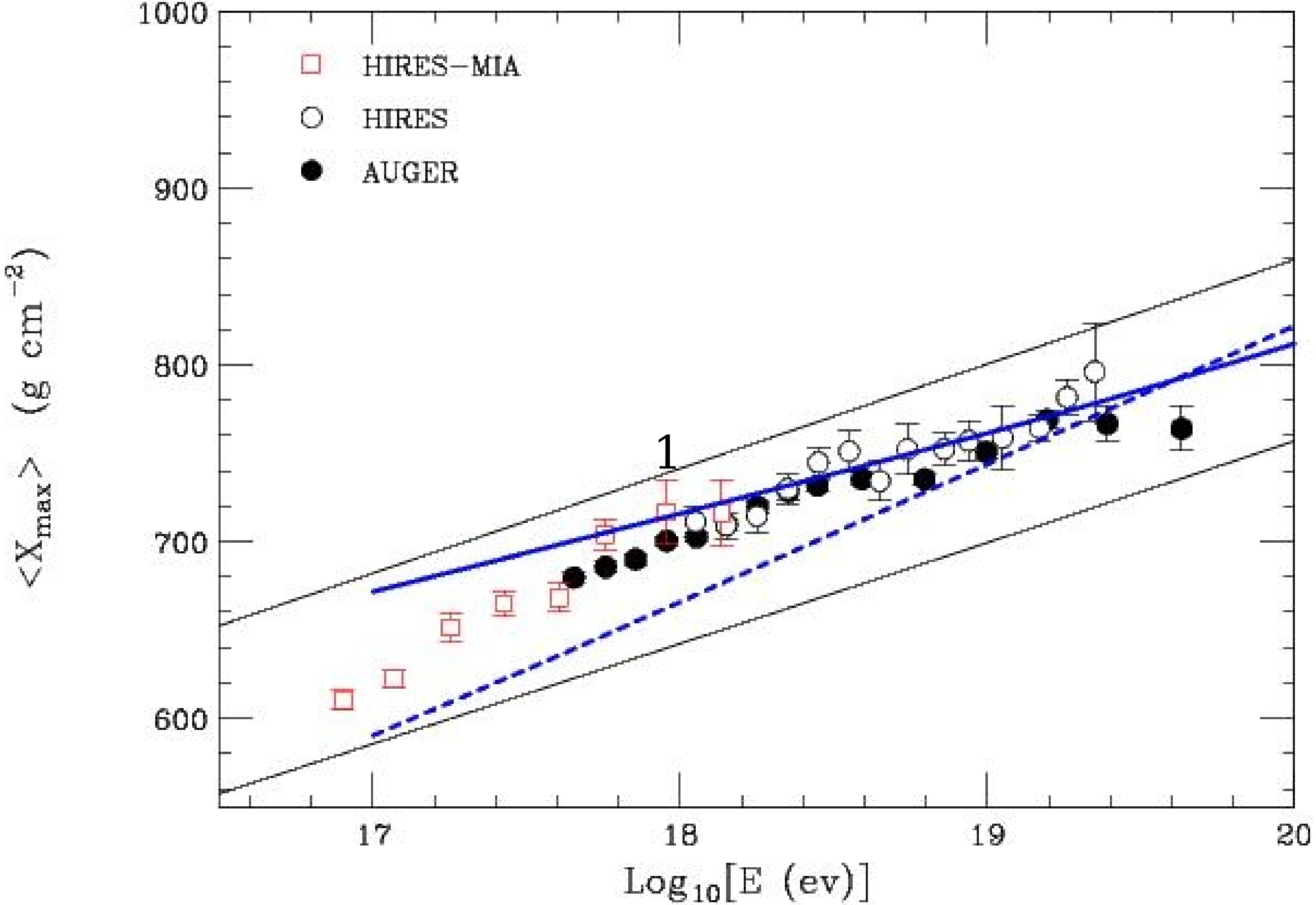


pp
$\bar{p}p$
300
200
100
70
50
30
σ_{tot} (mbarn)
LHC
10^{19}
10^{20}
10^0
10^2
10^4
10^6
$\sqrt{s}$ (GeV)

From Cosmic Ray Data → Hadronic Interactions



Introduce Energy dependence In Particle Production



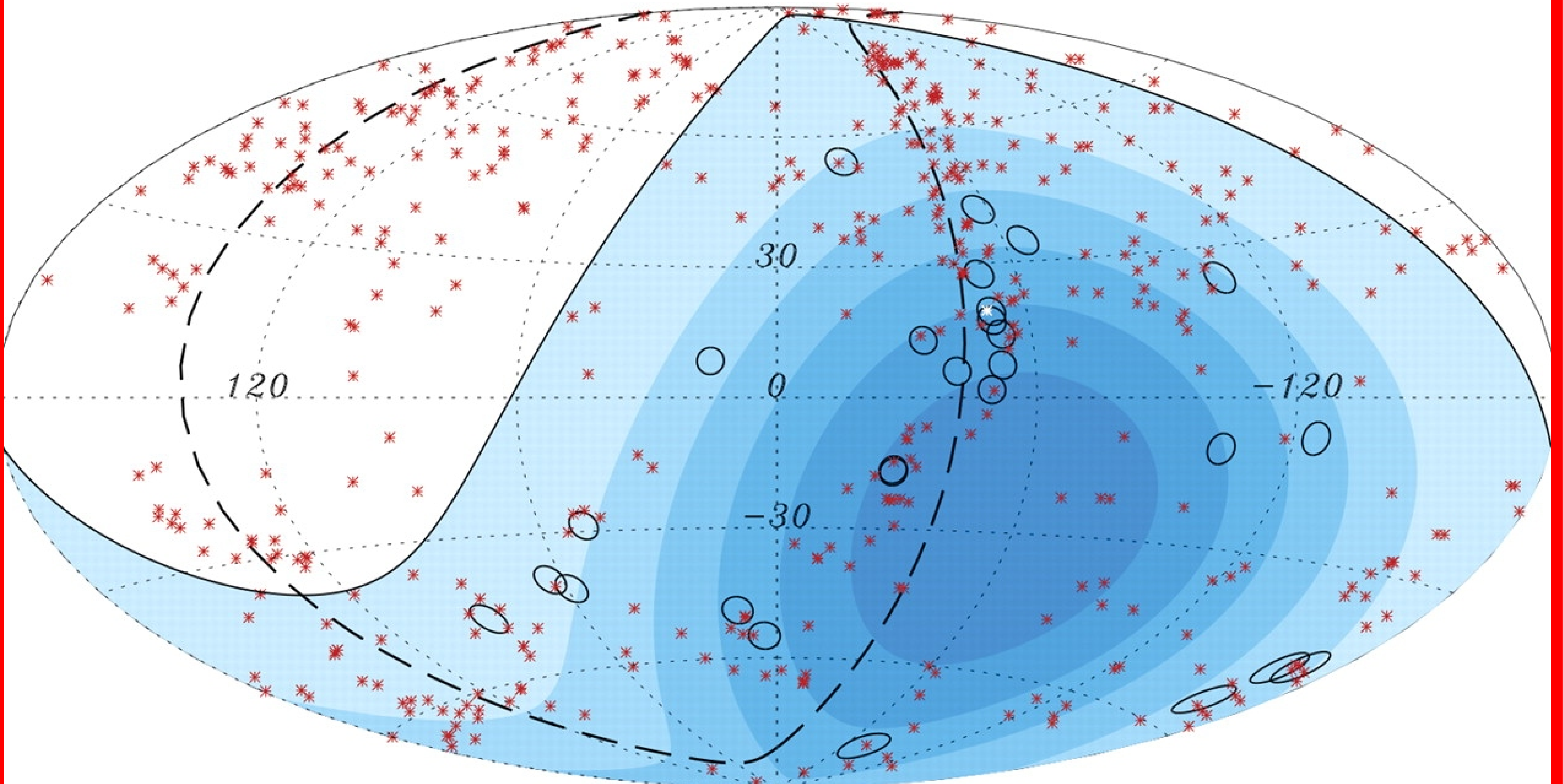
AUGER RESULT

$D \lesssim 75$ Mpc

CR come from
3.1 degrees from the sources
20/27 coincident with near AGN

$E \gtrsim 0.56 \times 10^{20}$ eV

$\delta\theta \lesssim 3.1^\circ$



The New Result of AUGER on Correlations between the direction of the highest energy showers and close AGN
[or less specifically
normal matter in the
near Universe.]

A DREAM is FULFILLED !!

The New Result of AUGER on Correlations between the direction of the highest energy showers and close AGN
[or less specifically normal matter in the near Universe.]

This Ambiguity is of course very significant

A DREAM is FULFILLED !!

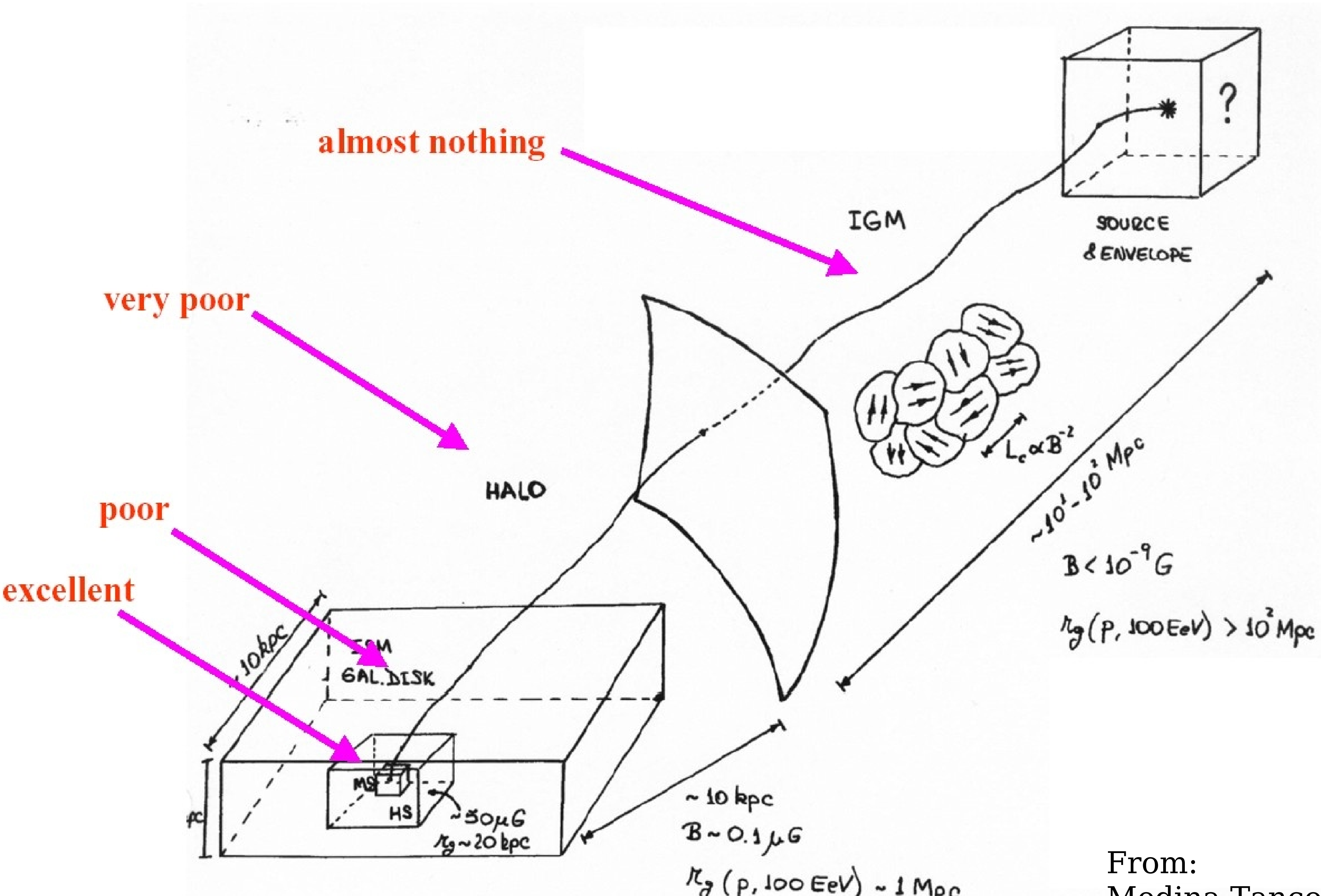
Very important result must be very critically analyzed

“Puzzles” for the interpretation of this results

Non confirmation from HIRES

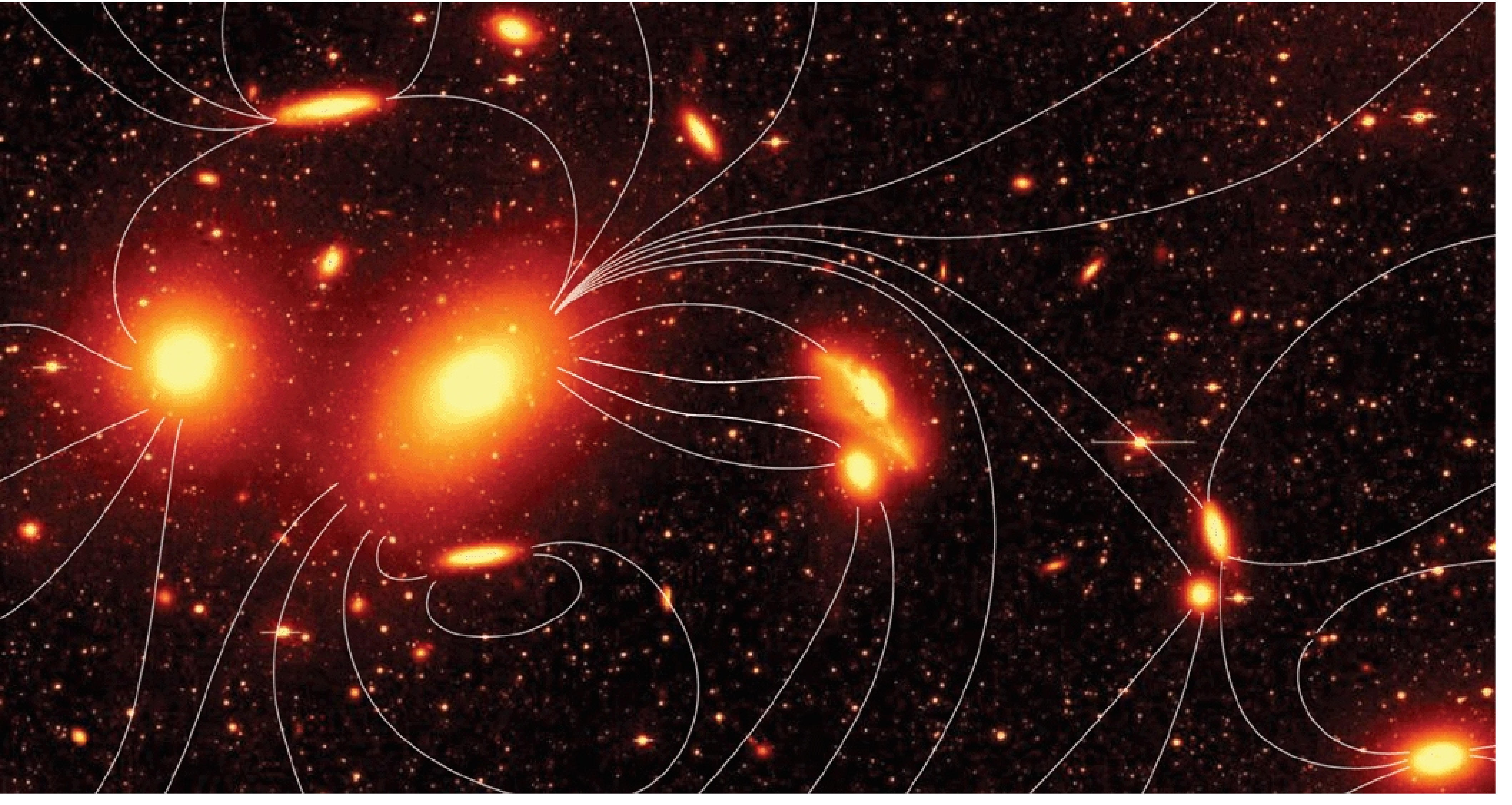
Absence of signal from VIRGO

Smallness of the “horizon”

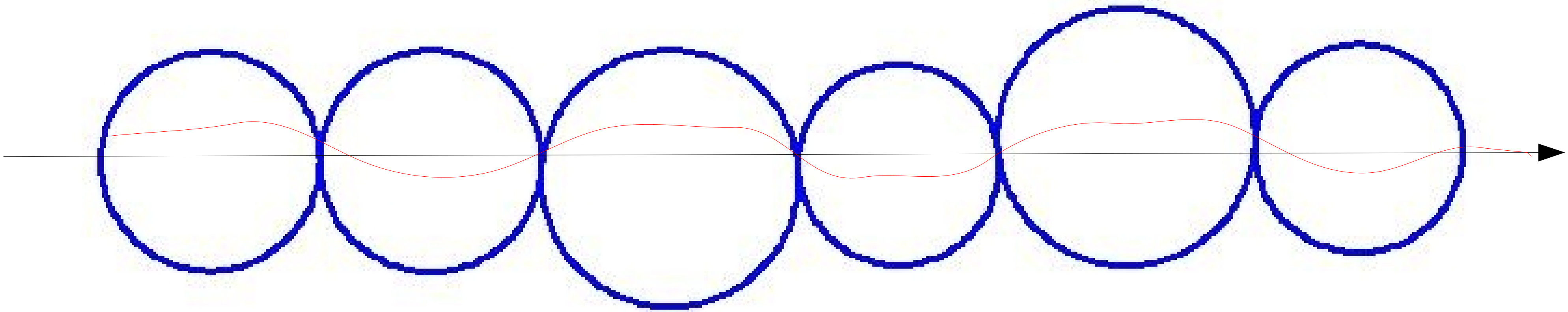


From:
Medina Tanco

Extra-Galactic Magnetic Fields



$$(\delta\theta)_{\mathrm{ExtraGalactic}} \simeq \frac{d}{r_{\mathrm{L}}} \sqrt{N_{\mathrm{regions}}} \simeq \frac{d}{r_{\mathrm{L}}} \sqrt{\frac{D}{d}}$$



D Distance of source

$$r_{\mathrm{Larmor}} = \beta_{\perp} \frac{E}{q\ B}$$

d Coherence Length of Magnetic Field

$$(\delta\theta)_{\mathrm{ExtraGalactic}} = \frac{0.53^\circ}{Z} \left(\frac{10^{20}\ \mathrm{eV}}{E}\right) \left(\frac{\sqrt{D\ d}}{\mathrm{Mpc}}\right) \left(\frac{\mathrm{nGauss}}{\langle B \rangle_{\mathrm{Extra}}}\right)$$

$$D \lesssim 75\ \mathrm{Mpc}$$

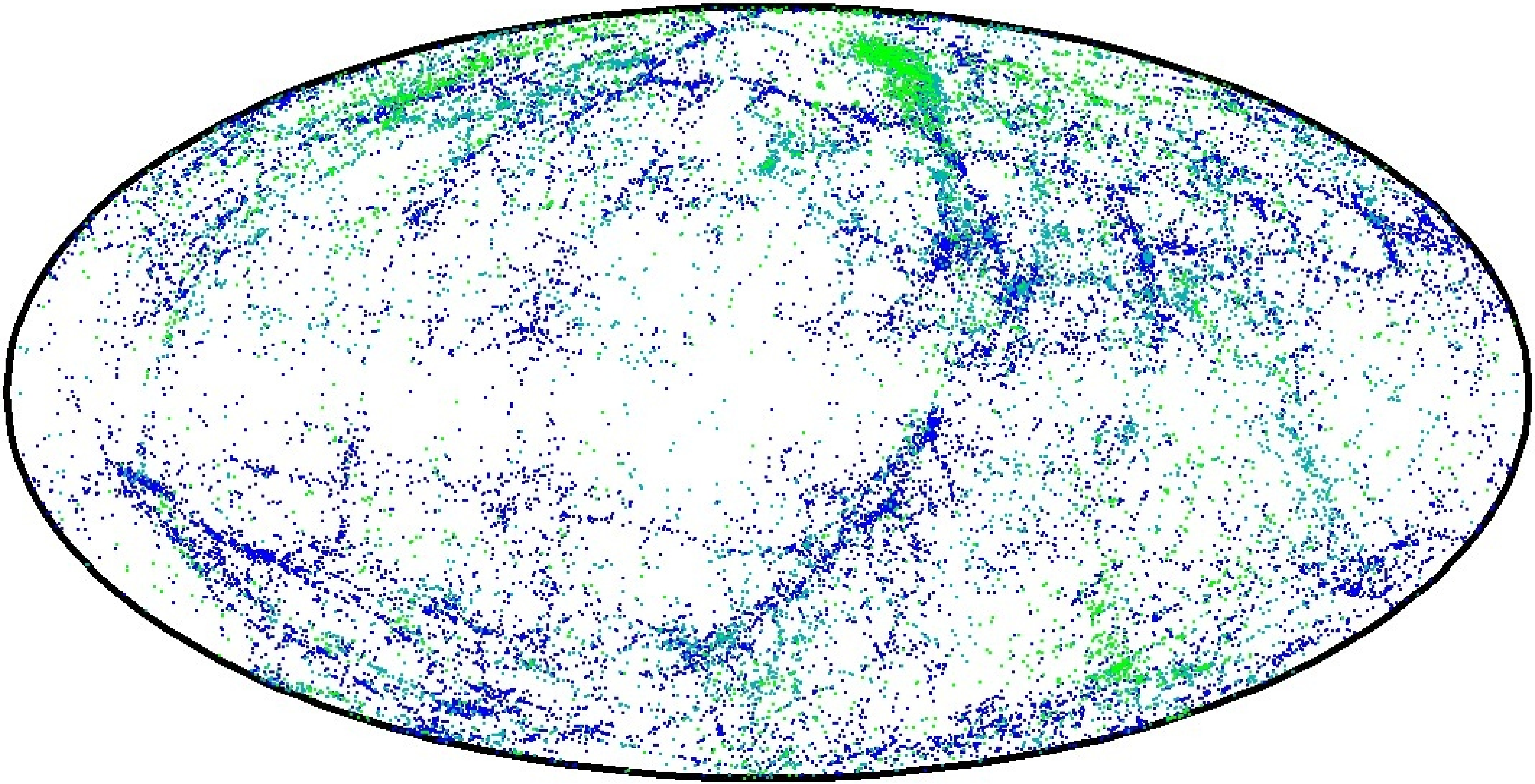
$$E \gtrsim 0.56 \times 10^{20}\ \mathrm{eV}$$

$$\delta\theta \lesssim 3.1^\circ$$

$$\langle B \rangle_{\mathrm{Extra}} \lesssim \frac{0.38}{Z\ \sqrt{d_{\mathrm{Mpc}}}}\ \mathrm{nGauss}$$

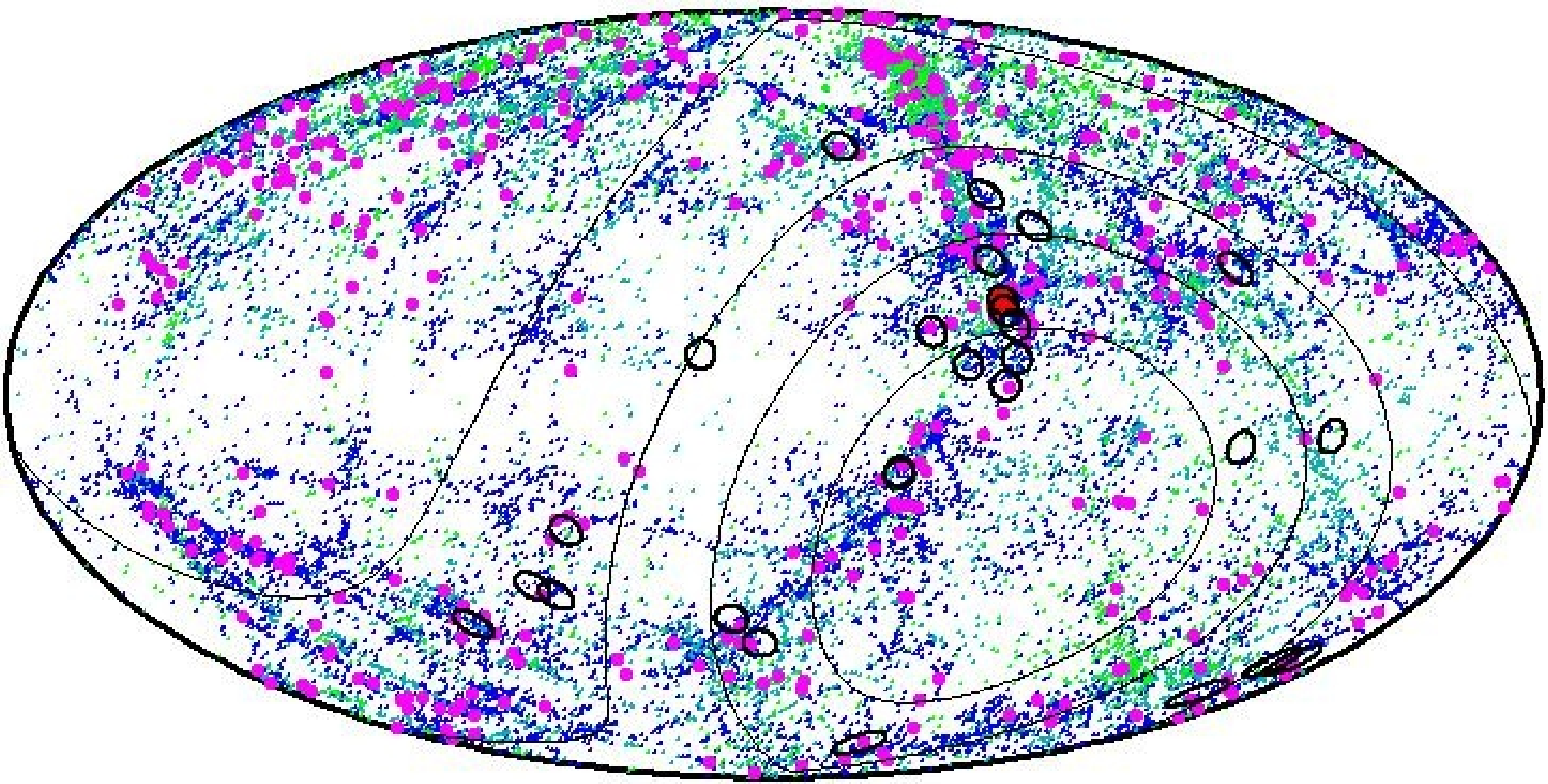
Estimate of the Extragalactic Magnetic Field

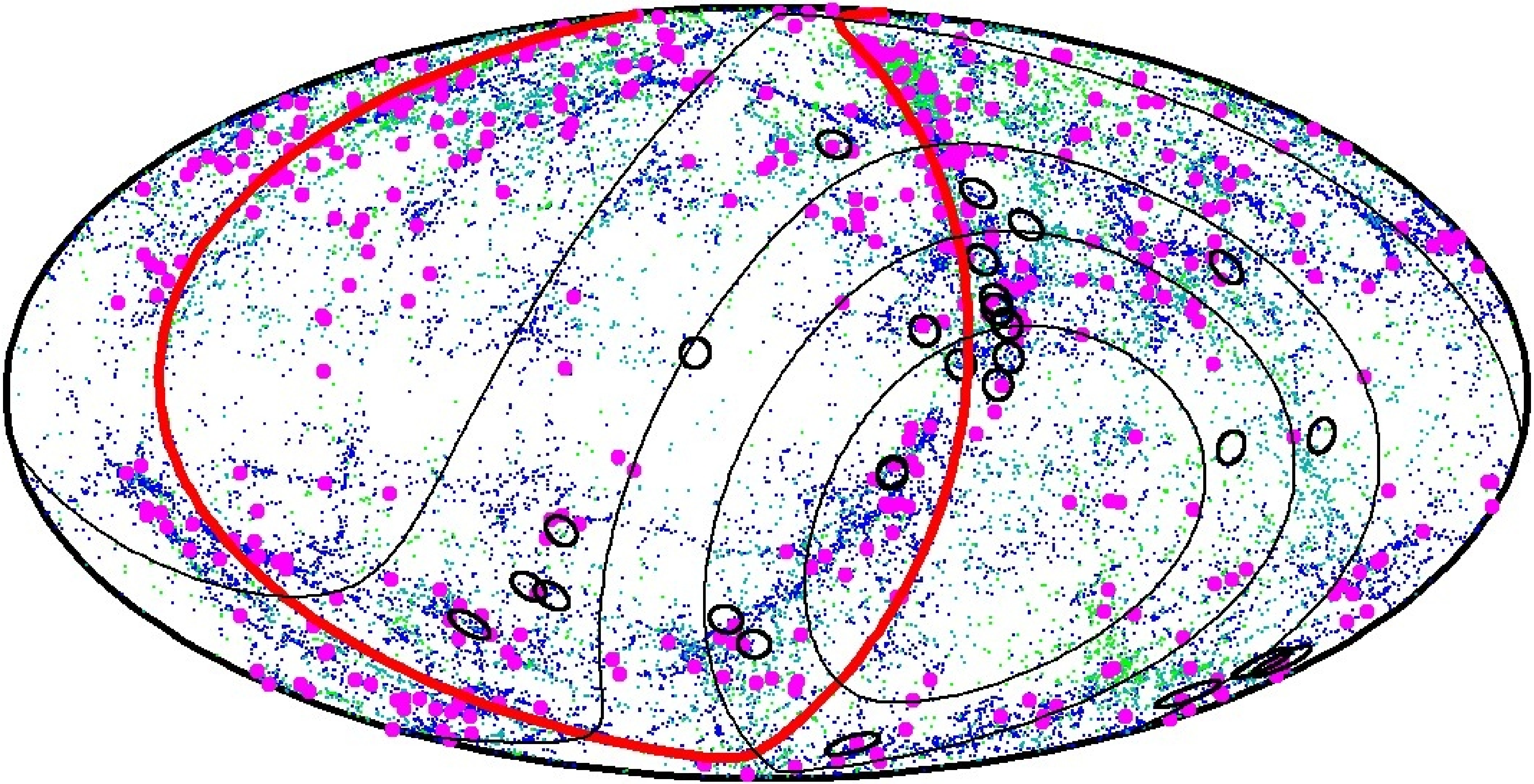
Galaxies with Redshift z < 0.018



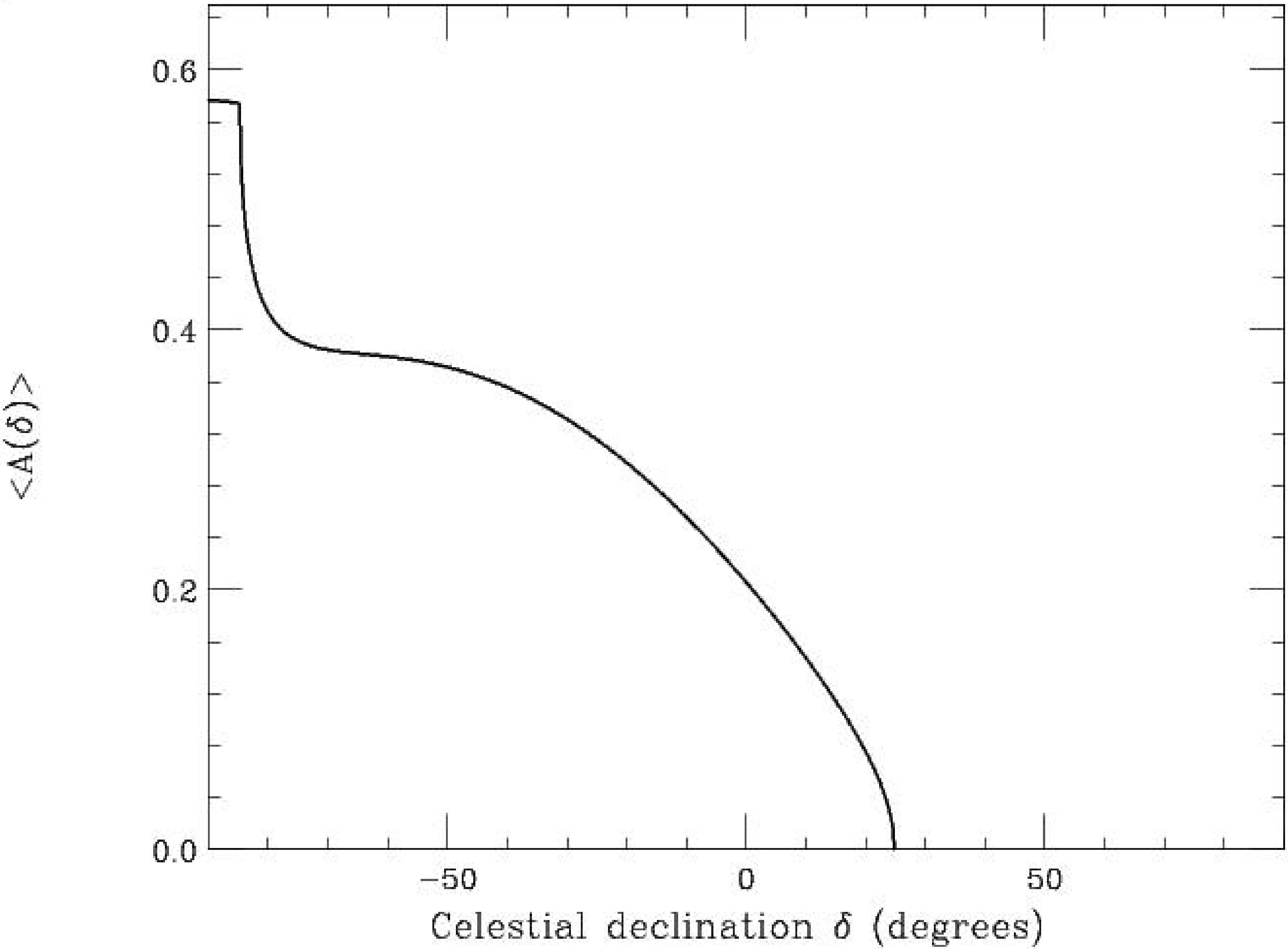
- Graphics -

Galaxies with Redshift z < 0.018
AGN in same Volume
Auger Events



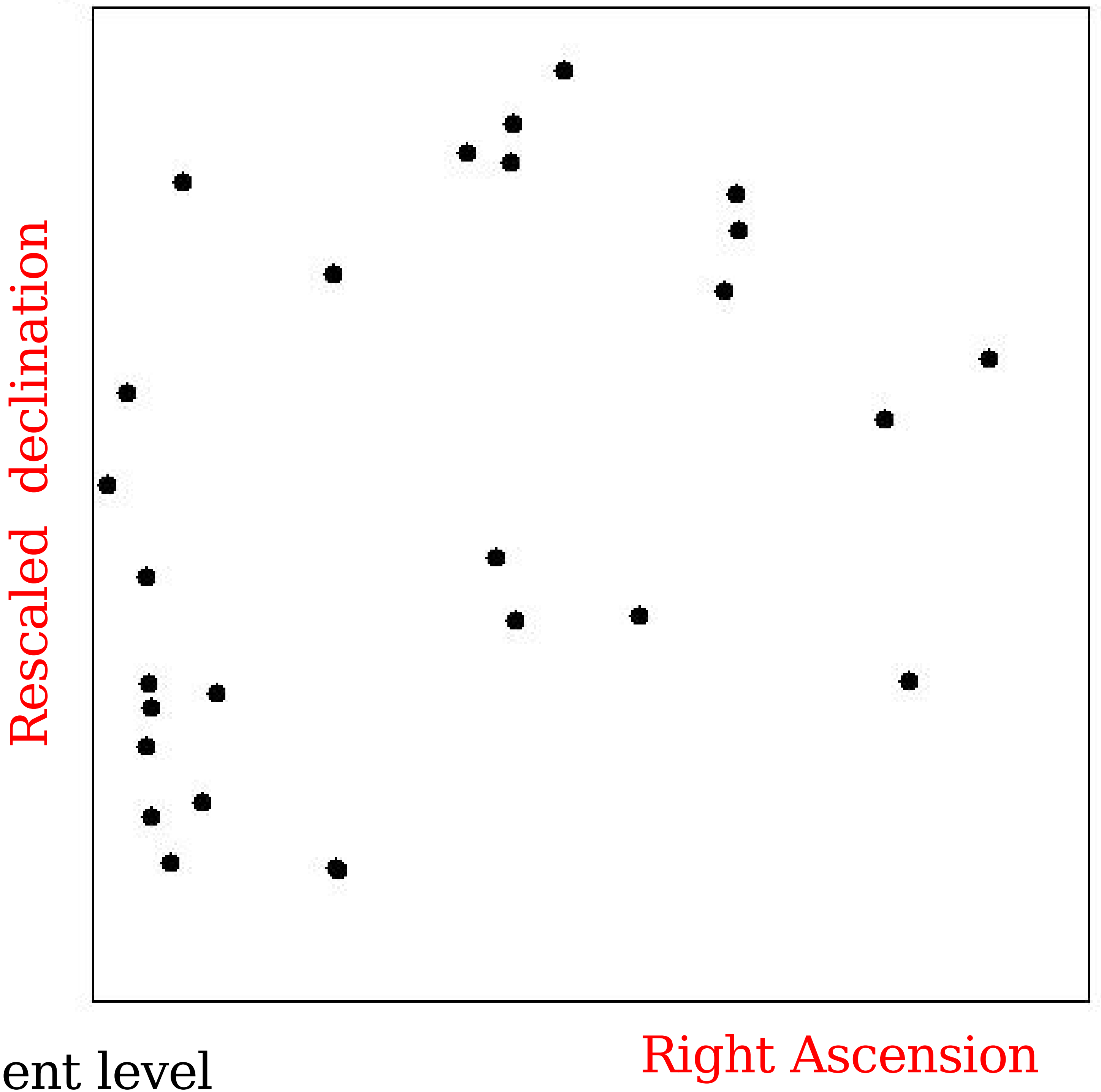


Exposition of the Auger experimen t <cos θ> (averaged over a sidereal day)



Rescaled
portion
of the celestial
sphere
seen
by AUGER

Should be
populated
uniformly
if the flux is
isotropic



Events are
isotropic
only at few percent level

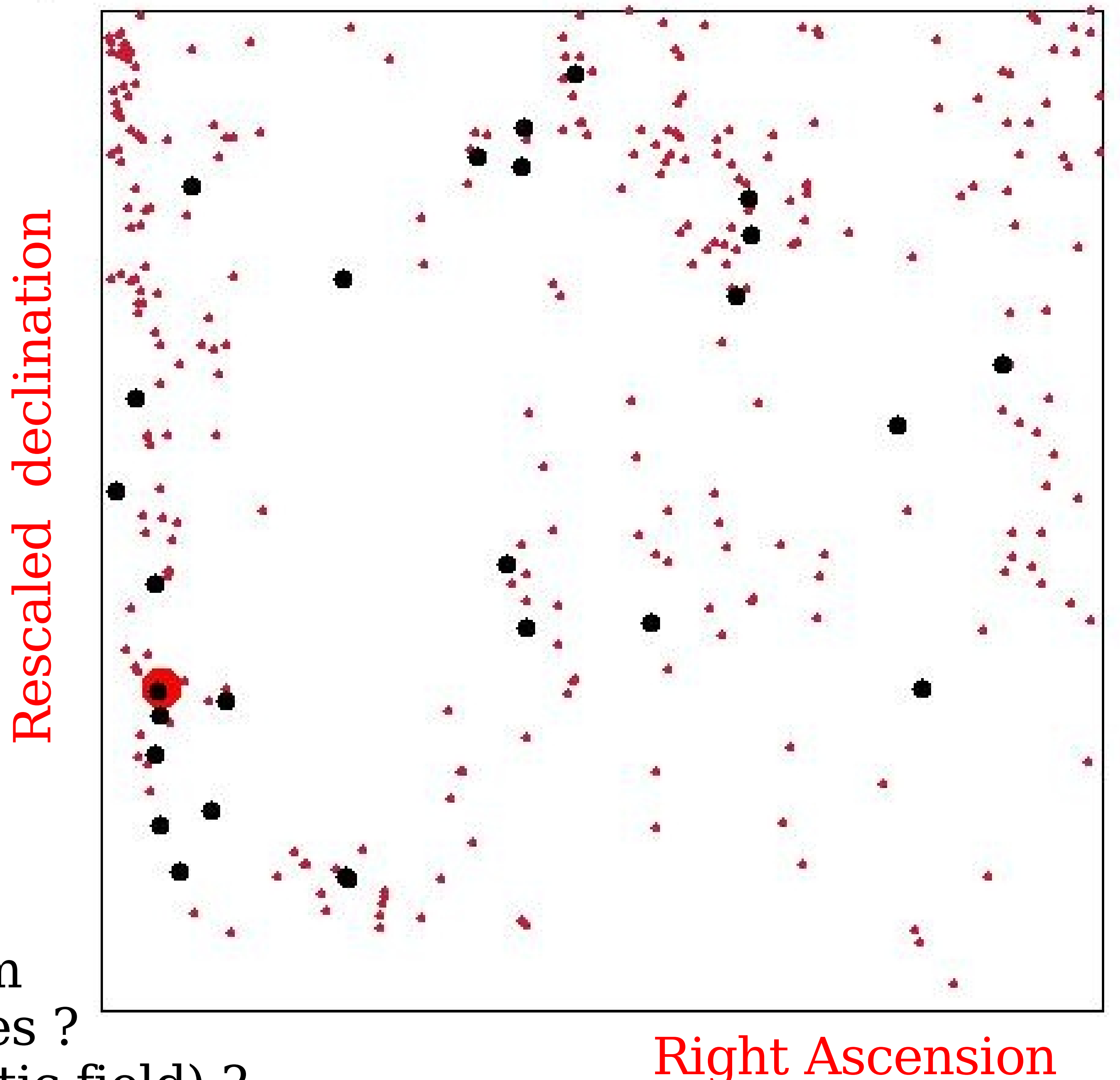
Auger
Events

AGN
position

2 dimensional
Kolmogorov-
Smirnov test

for the same
distribution

Significant
contribution from
one (few) sources ?
(stronger magnetic field) ?



NEUTRINOS

One new way
to look at the sky

SUN
SN1987A

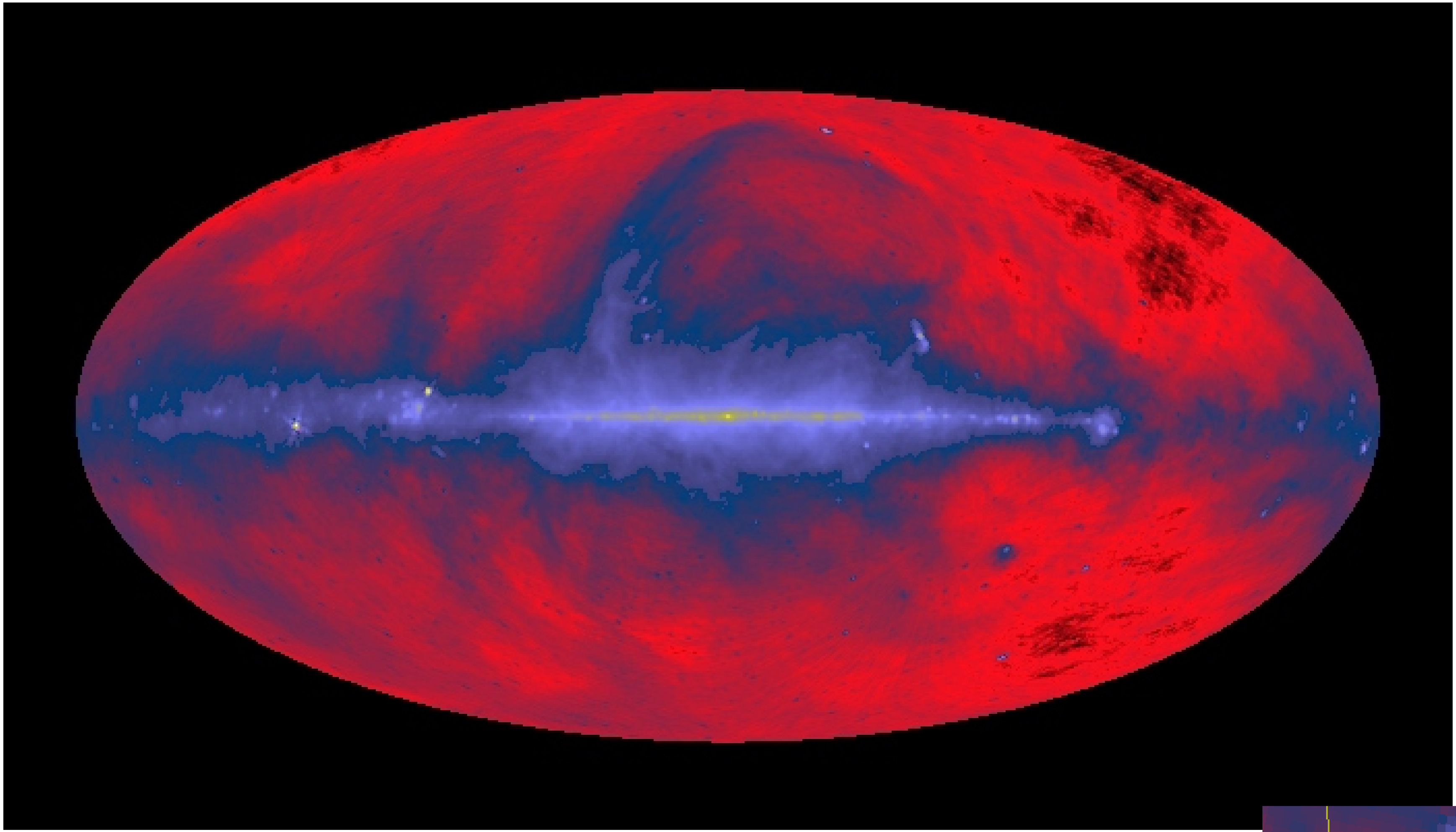
Multi Messenger Astrophysics

- GAMMA RAY's
- NEUTRINO's
- COSMIC RAY's
- GRAVITATIONAL WAVES

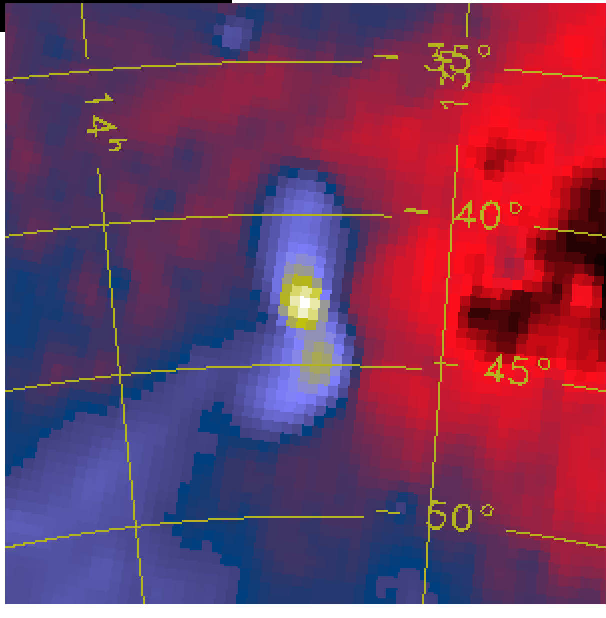
CENTAURUS A

(with very high probability)

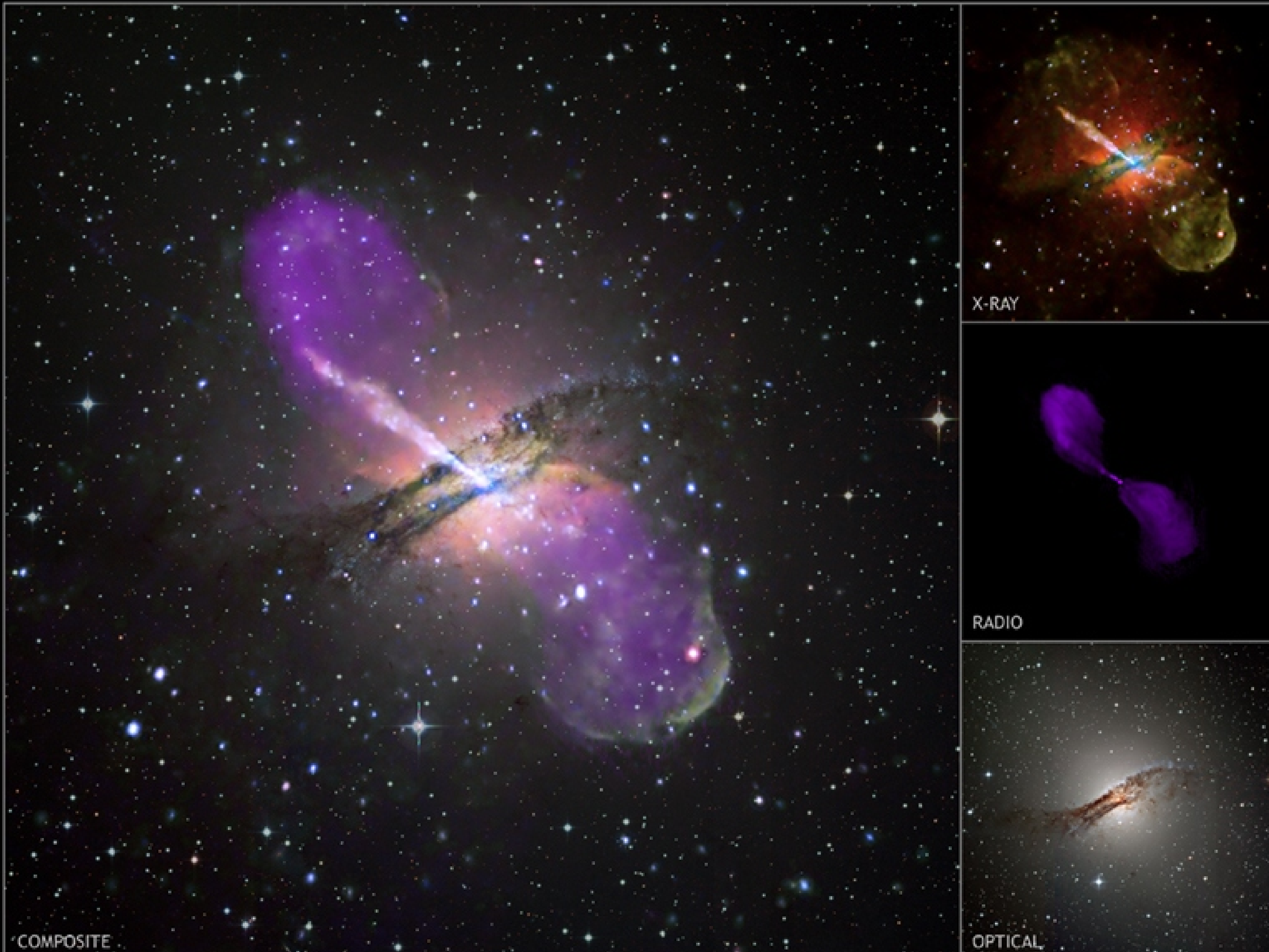
First object imaged with Cosmic Rays

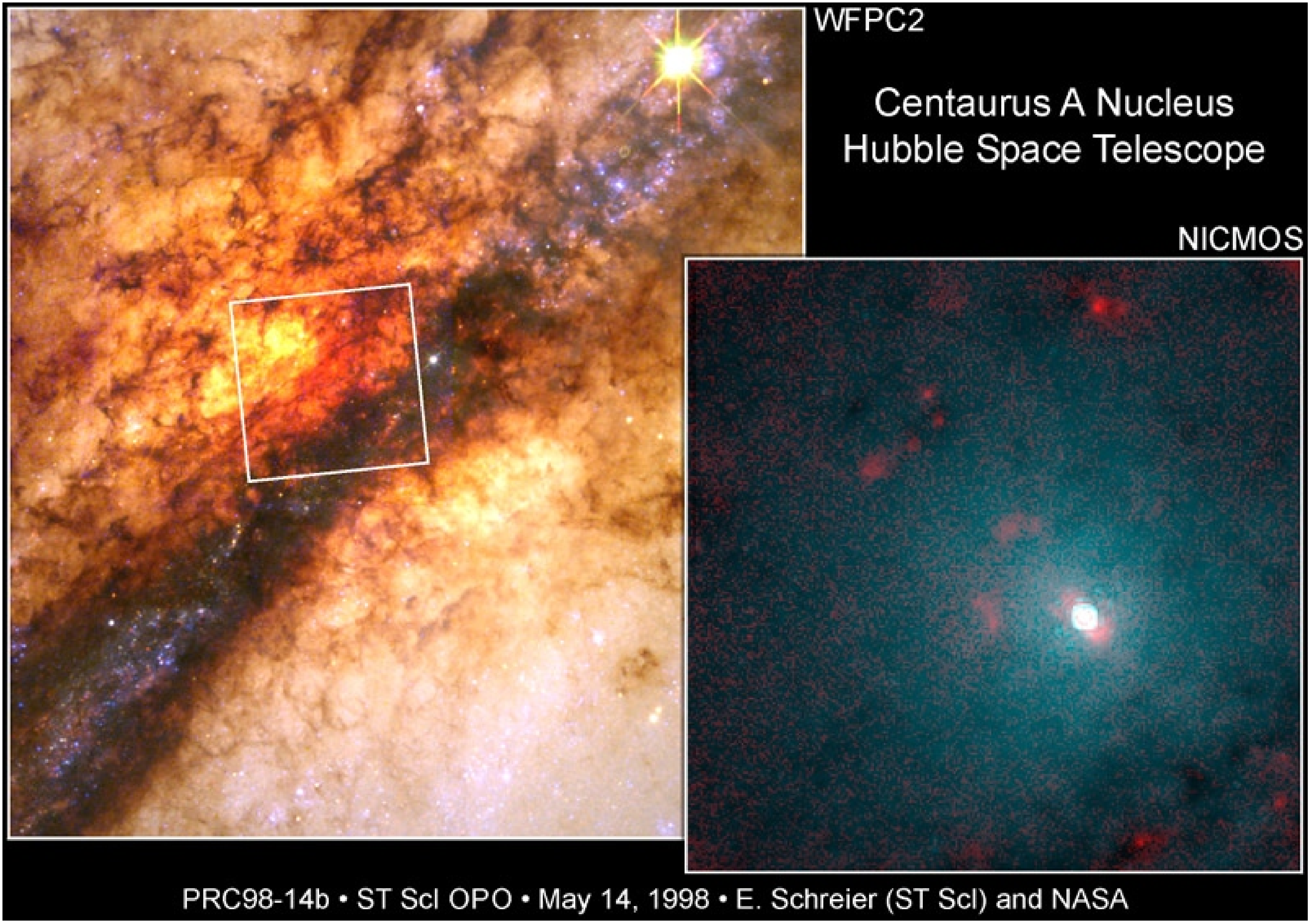


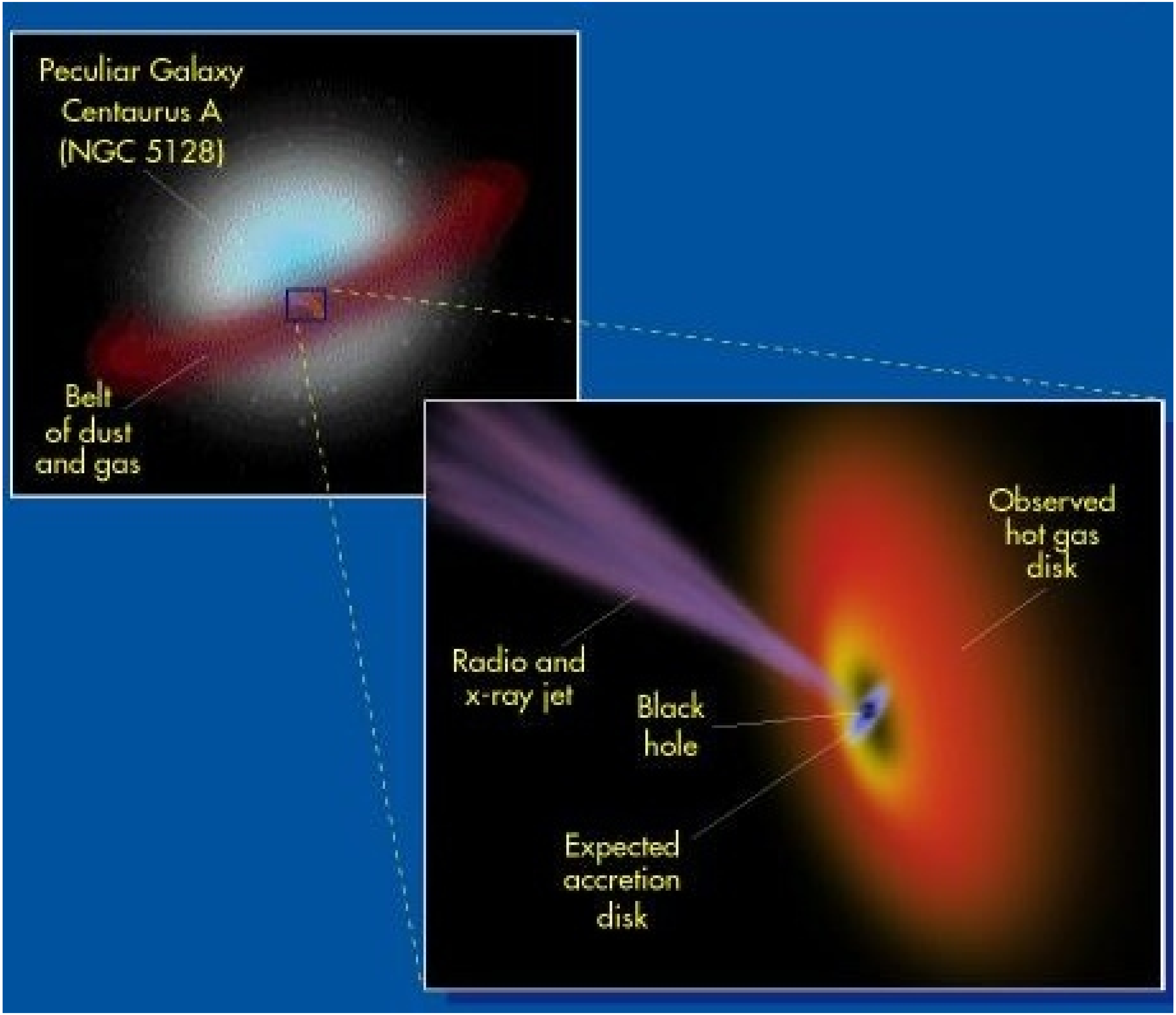
Radio Image
408 MHz



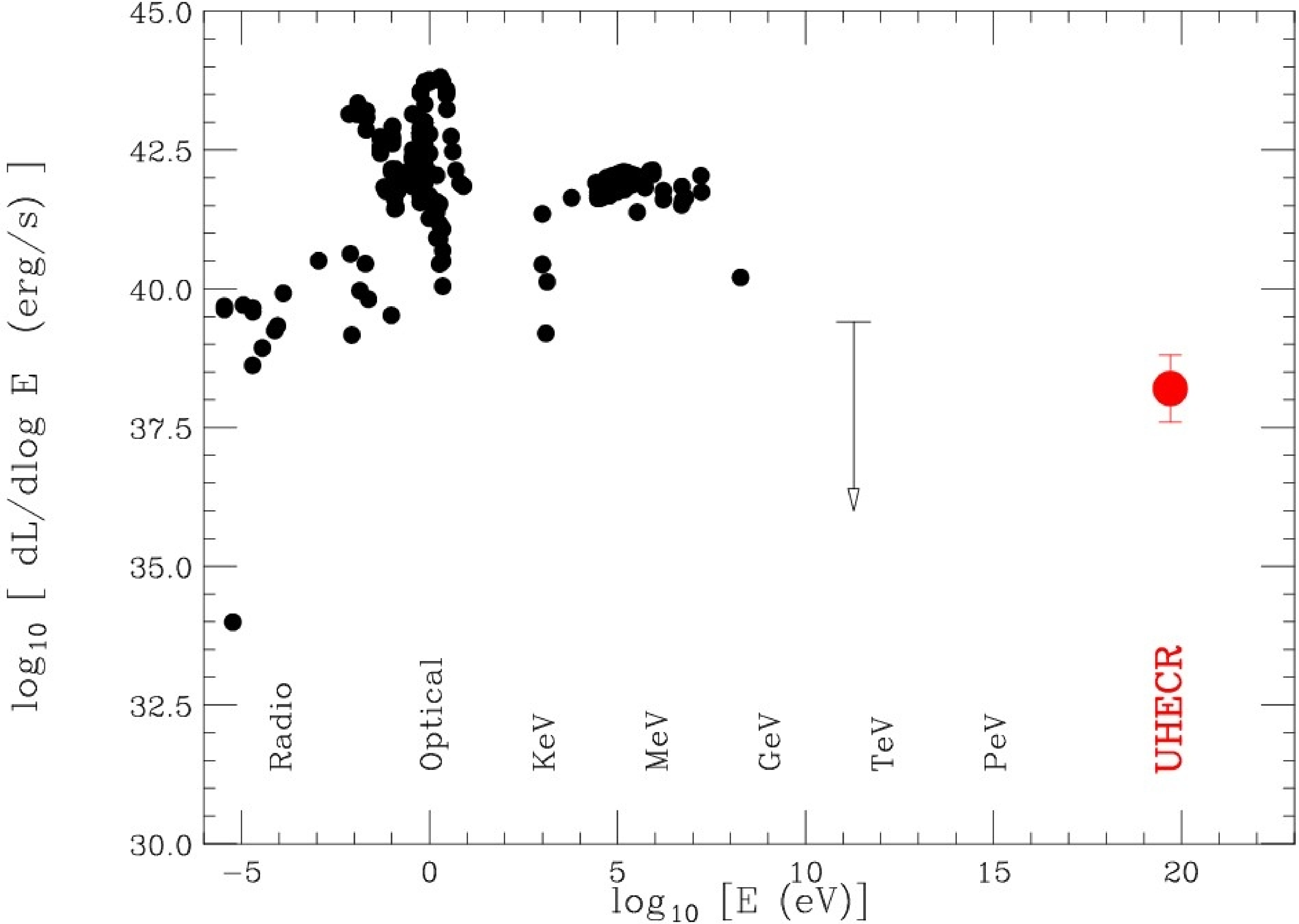
Chandra X-ray image

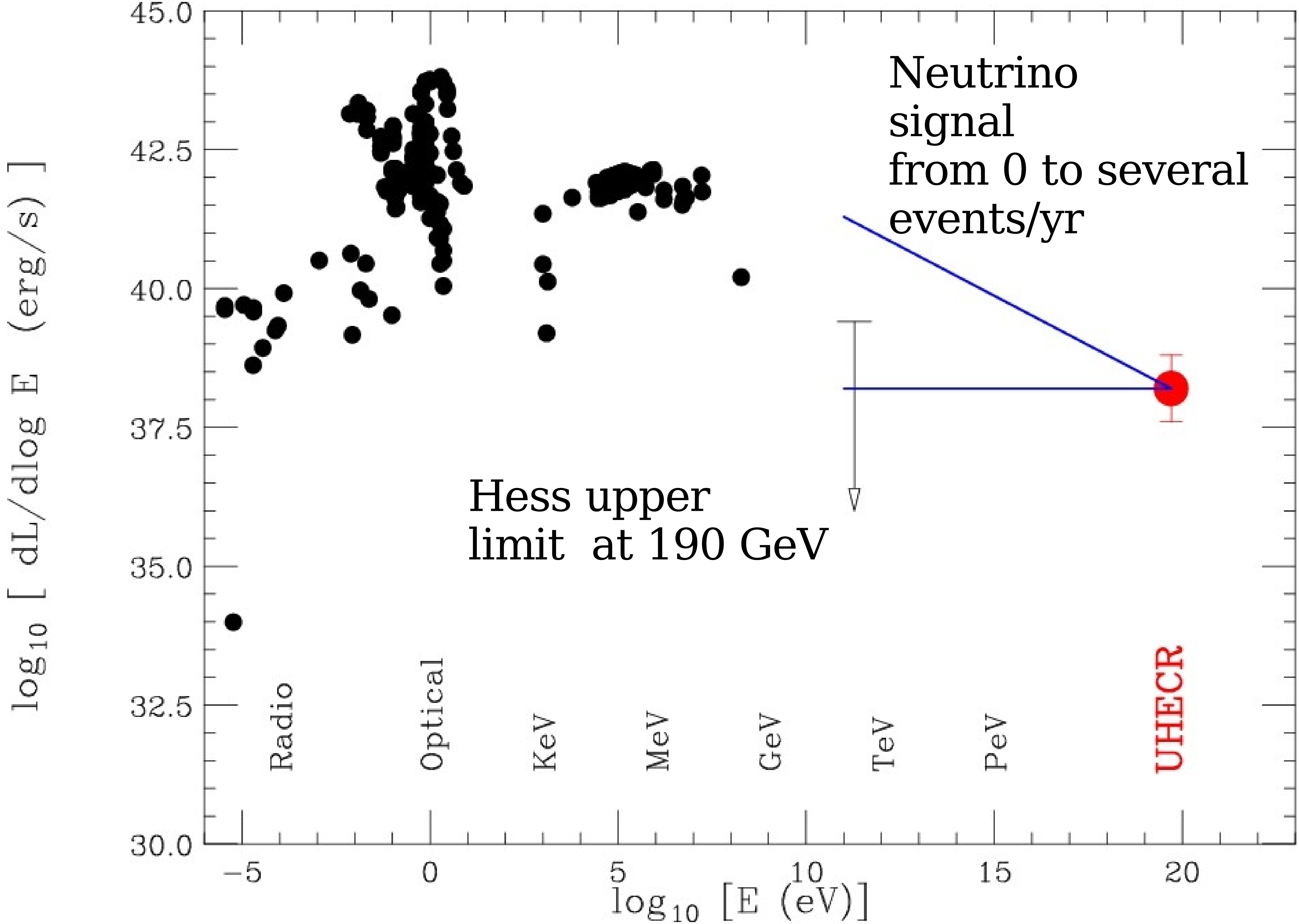

X-RAY
RADIO
OPTICAL
COMPOSITE


WFPC2
Centaurus A Nucleus
Hubble Space Telescope
NICMOS
PRC98-14b • ST ScI OPO • May 14, 1998 • E. Schreier (ST ScI) and NASA


Peculiar Galaxy
Centaurus A
(NGC 5128)
Belt
of dust
and gas
Observed
hot gas
disk
Radio and
x-ray jet
Black
hole
Expected
accretion
disk

Spectral Energy Distribution of CEN A





Neutrino
signal
from 0 to several
events/yr
Hess upper
limit at 190 GeV
Radio
Optical
KeV
MeV
GeV
TeV
PeV
UHECR
45.0
42.5
40.0
37.5
35.0
32.5
30.0
−5
0
5
10
15
20
$\log_{10}$ [dL/dlog E (erg/s)]
$\log_{10}$ [E (eV)]

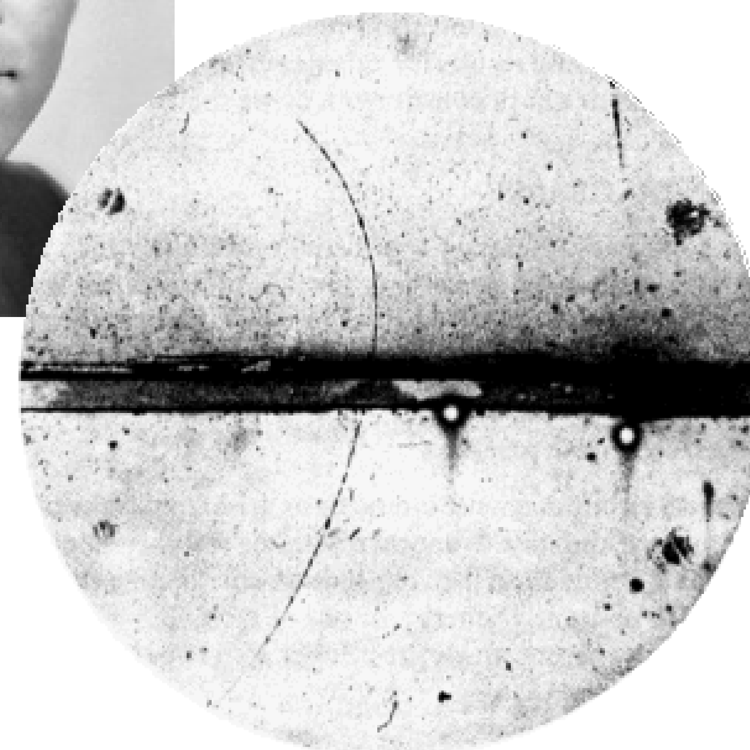
It is remarkable
that we are in a situation where we can (and in fact we HAVE to) discuss how to model the structure of an Active Galactic nucleus using multi messengers.

A demonstration of the maturity of high Energy Astrophysics.

Nobel Prize in Physics 1936

Victor Hess
Discovery of Cosmic Rays

Carl Anderson
Discovery of the positron



Balloon Flights
of 1911/1912
h > 5000 meters.

Understand the Dynamics of relativistic particles

Discover new Particles (π^+, K, Λ)

Origin of CR remains "elusive"... but we are getting close a deep understanding

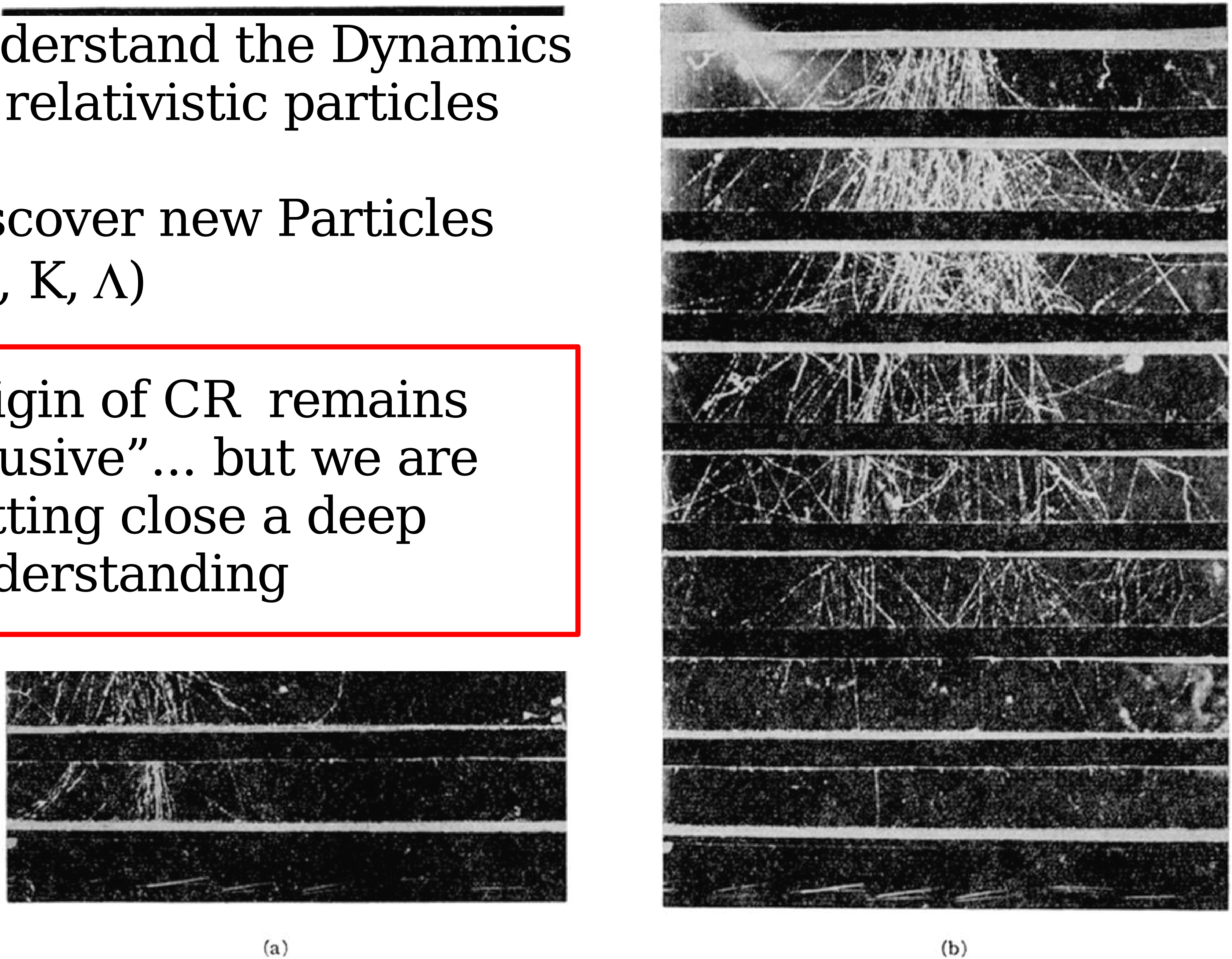


FIG. 3. Four pictures obtained by C. Y. Chao at M.I.T. by means of a cloud chamber containing 8 lead plates ½ inch thick. (a) An ionizing penetrating particle undergoes a nuclear interaction in which several heavily ionizing particles, several penetrating particles, and an electron shower are produced. (b) A large shower containing electrons and penetrating