Open Problems in Particle Astrophysics

Paolo Lipari, INFN Roma “Sapienza”

Workshop:
“Recent Developments in Astronuclear and Astroparticle Physics”

Trieste 19th november 2012 27th may 2011

1. DARK MATTER

2. Sources of
   High Energy Particles

Cold Dark Matter

Cornelia Parker. (Tate Gallery, London)

What is the nature
of the Dark Matter ?

Does Dark Matter Really Exist ?

Is “MOND” (Modified Newtonian Dynamics”) a viable alternative ?

see Xinhe Meng contribution later today

THE ASTROPHYSICAL JOURNAL, **270**:365–370, 1983 July 15

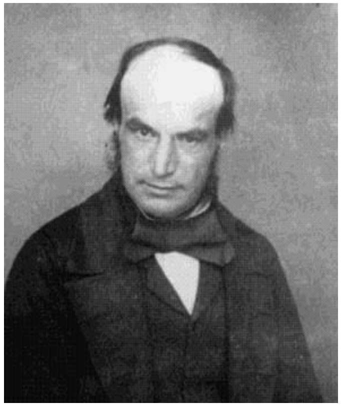
A MODIFICATION OF THE NEWTONIAN DYNAMICS AS A POSSIBLE ALTERNATIVE TO THE HIDDEN MASS HYPOTHESIS[1]

M. MILGROM
Department of Physics, The Weizmann Institute of Science, Rehovot, Israel; and
The Institute for Advanced Study
Received 1982 February 4; accepted 1982 December 28

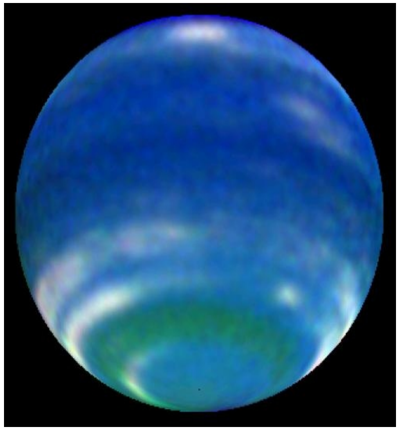
Uranus orbital anomalies

Prediction + Discovery of Neptune (23/24 september 1846)

Urbain Le Verrier

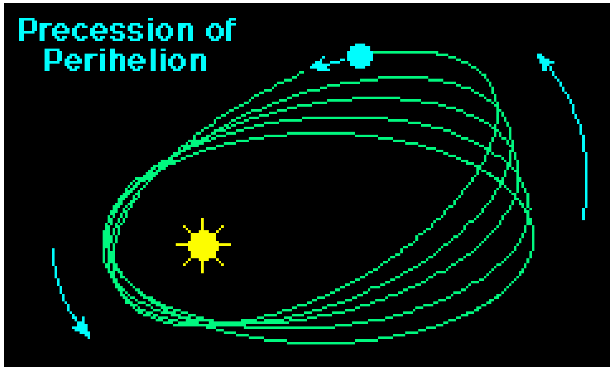


John Couch Adams

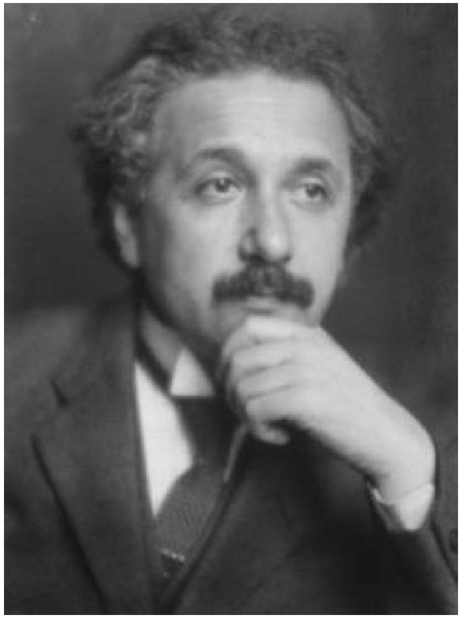


Mercury orbital anomalies

Extra 43''/century perihelion precession



New dynamics
General Relativity
(1916 Albert Einstein)



MOdified Newtonian Dynamics [MOND]

$$a_0 \simeq 10^{-8}\ \mathrm{cm/s^2}$$

$$F_{\mathrm{grav}} = \begin{cases} ma & \text{for } a >> a_0 \\ m\,\dfrac{a^2}{a_0} & \text{for } a << a_0 \end{cases}$$

Fundamental acceleration

$$a_0 \simeq c\,H_0/5$$

Coincidence?

$$\frac{G\,M}{r^2} = \frac{v^2}{r}$$

"Newtonian"

$$v_{\mathrm{rot}}^2 \to GM/r$$

$$\frac{G\,M}{r^2} = \left(\frac{v^2}{r}\right)^2 \frac{1}{a_0}$$

Modified Newtonian (small acceleration)

$$v_{\mathrm{rot}}^4 \to G M\, a_0$$

$$v_{\mathrm{rot}} \propto M^{1/4} \propto L^{1/4}$$

J. D. Bekenstein,
"Alternatives to dark matter: Modified gravity as an alternative to dark matter,"
arXiv:1001.3876 [astro-ph.CO].

1. Introduction

A look at the other papers in this volume will show the present one to be singular. Dark matter is a prevalent paradigm. So why do we need to discuss alternatives ? While observations seem to suggest that disk galaxies are embedded in giant halos of dark matter (DM), this is just an *inference* from accepted Newtonian gravitational theory. Thus if we are missing understanding about gravity on galactic scales, the mentioned inference may be deeply flawed. And then we must remember that, aside for some reports which always seem to contradict established bounds, DM is not seen directly. Finally, were we to put all our hope on the DM paradigm, we would be ignoring a great lesson from the history of science: accepted understanding of a phenomenon has usually come through confrontation of rather contrasting paradigms.

Why is "DARK MATTER" the "prevalent paradigm"

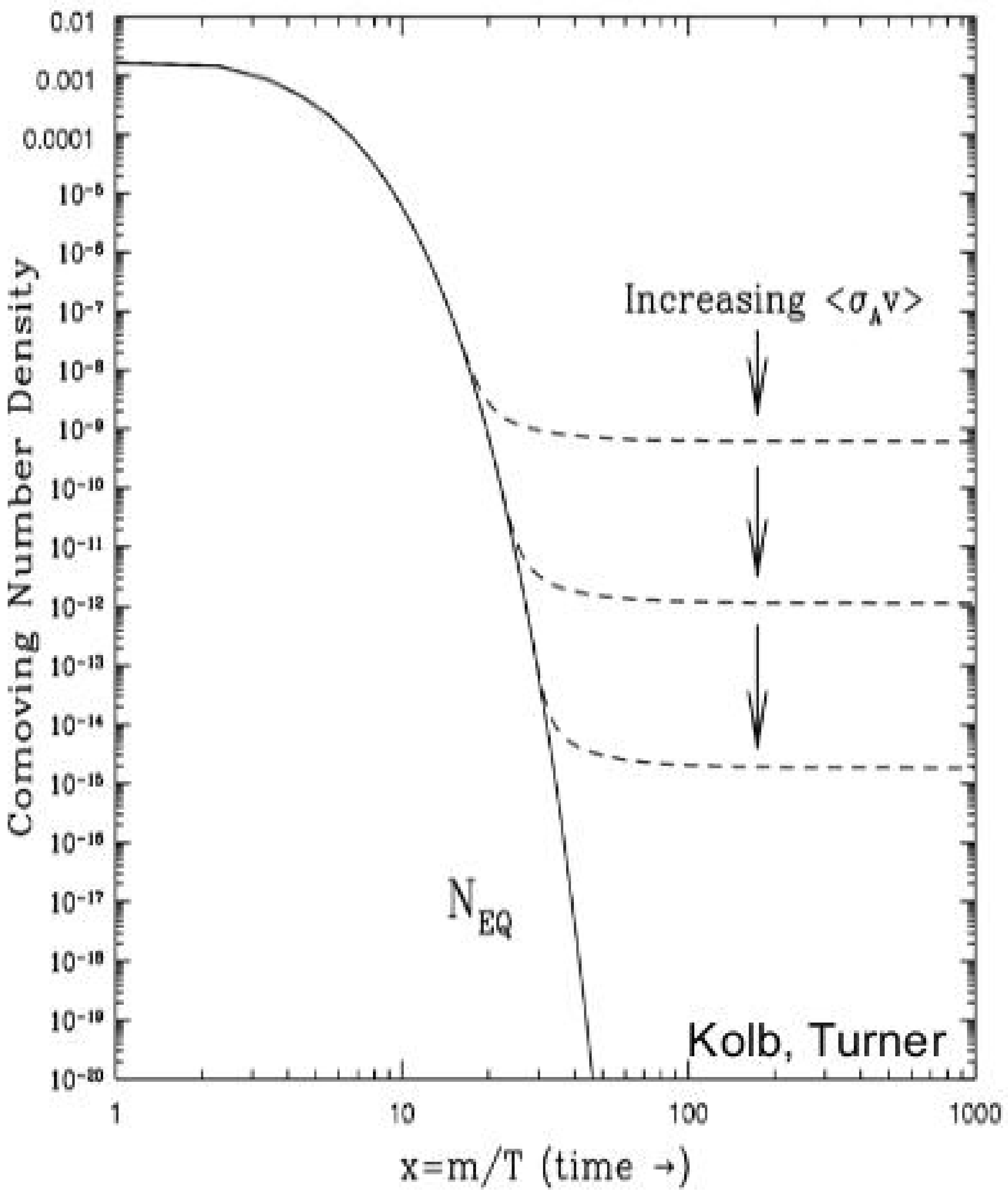
1. Theoretical difficulties in constructing
   a consistent, covariant theory. [Resolved by Bekenstein]

2. Remarkable success of the "Dark Matter" paradigm
   in describing the structure formation in our universe.
   Relation between the
   Large scale galaxy distribution.
   Anisotropies in the Cosmic Background Radiation.

3. The "BULLET CLUSTER" (Clowe et al 2006).
   (Cluster 1E0657-558: 2 colliding clusters at z=0.296)
   "A direct empirical proof of the existence of DM"
   Clear separation between Baryons and Mass.
   [other similar objects discovered (MACS J0025.4-1222)]

Counter examples ? The "Train wreck cluster"
(Abell 520)

Concept of thermal relic [WIMP] :



$$\chi + \chi \leftarrow f + \overline{f}$$

$$\chi + \chi \rightarrow f + \overline{f}$$

Annihilation cross section determines the "Relic Abundance"

$$\Omega_j^0 \simeq 0.3 \left[\frac{3 \times 10^{-26}\ \mathrm{cm}^3\,\mathrm{s}^{-1}}{\langle \sigma\, v \rangle} \right]$$

"Relic abundance" estimate in standard Cosmology (simplest treatment)

$$\Omega_\chi \simeq \left(\frac{16\,\pi^{5/2}}{9\,\sqrt{\pi}}\right)\ \frac{G^{3/2}\,T_0^3}{H_0^2\,(\hbar c)^{3/2}\,c^3}\ \frac{\sqrt{g^*}}{\langle\sigma\,v\rangle}$$

$$\Omega_\chi \simeq 0.2$$

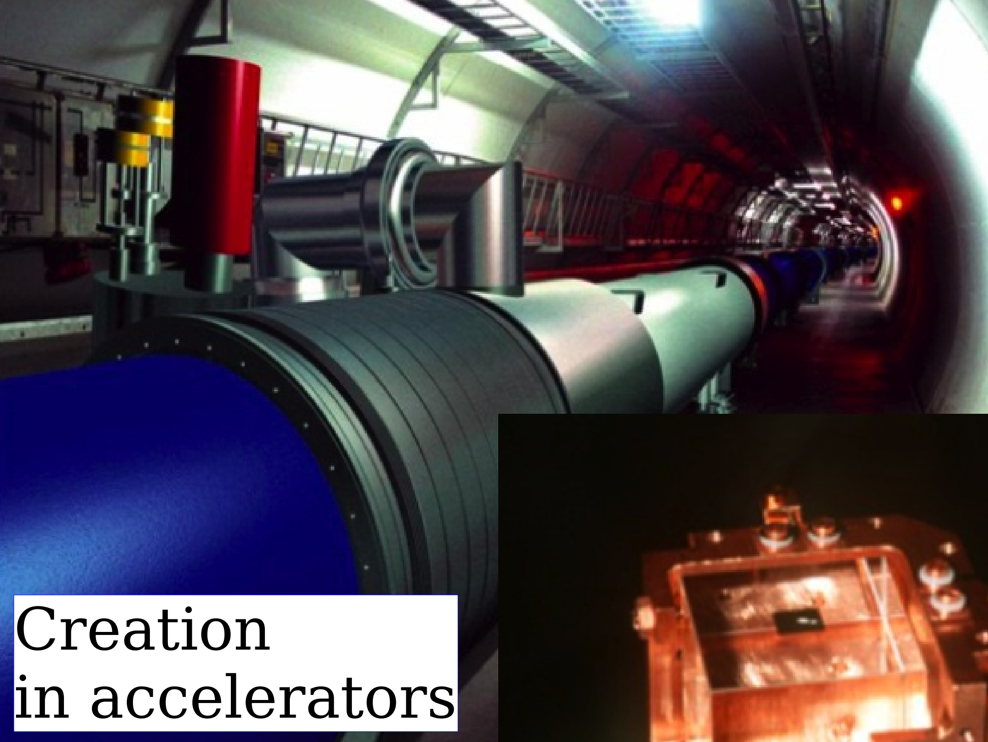
$$\langle\sigma\,v\rangle \simeq 3\times 10^{-26}\ \frac{\mathrm{cm}^3}{\mathrm{sec}}$$

$$\sigma \simeq \frac{\alpha^2}{M^2}$$

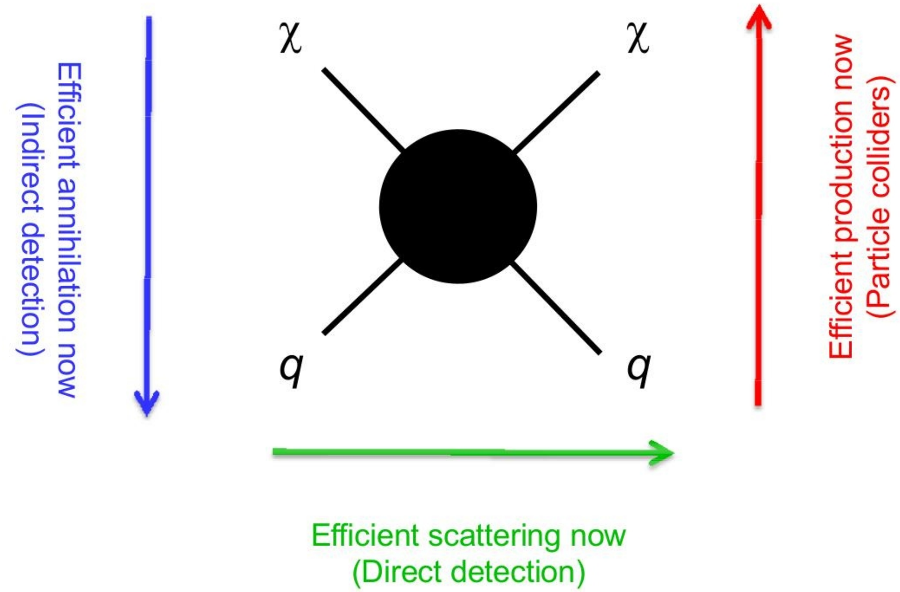
$$M \simeq \frac{\hbar\,c}{\sqrt{\sigma/\alpha^2}} \simeq 140\ \mathrm{GeV}$$

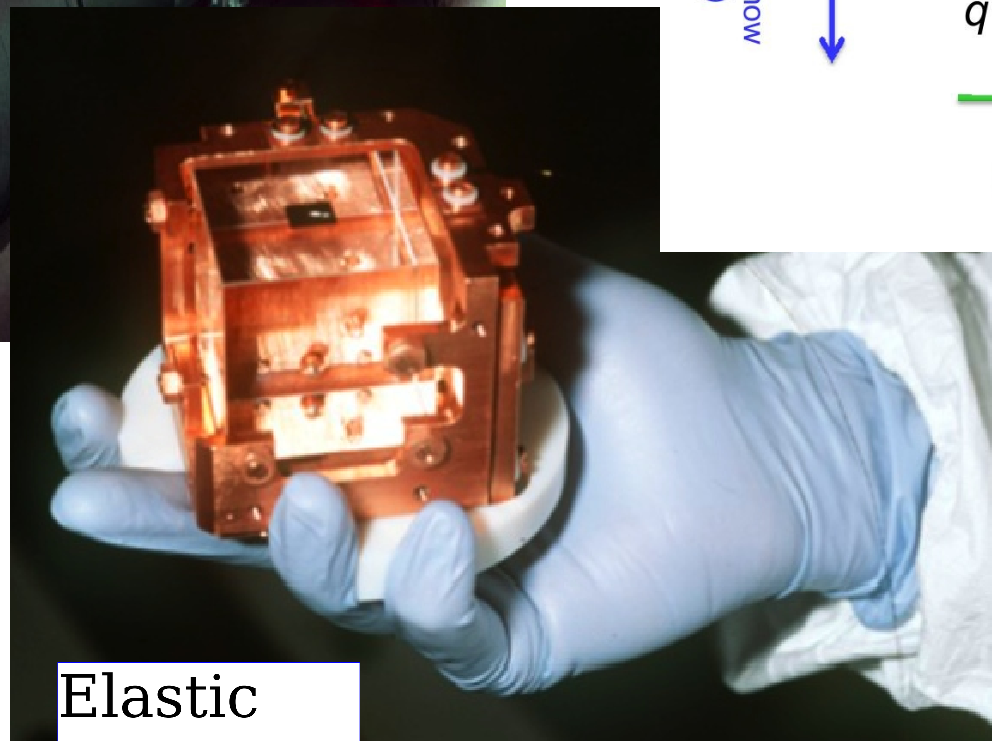
Connection with
Weak (Fermi) scale ?!
[and perhaps supersymmetry]

The "WIMP's Miracle" ?

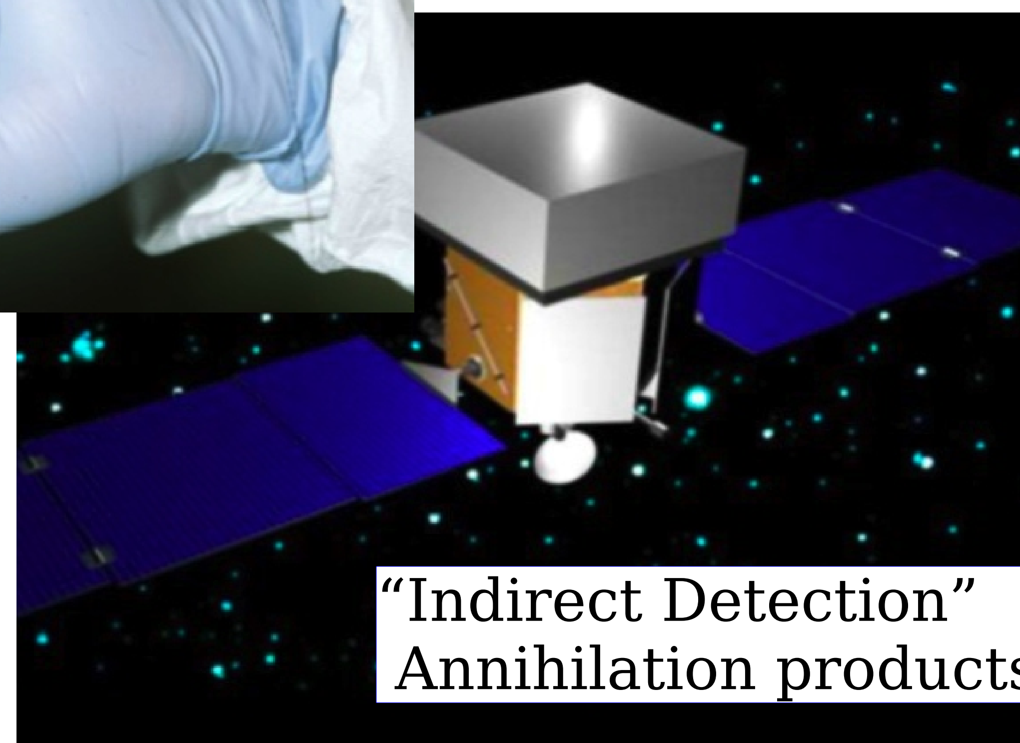


Creation
in accelerators





Elastic
scattering



"Indirect Detection"
Annihilation products

3 Roads to test the WIMP hypothesis

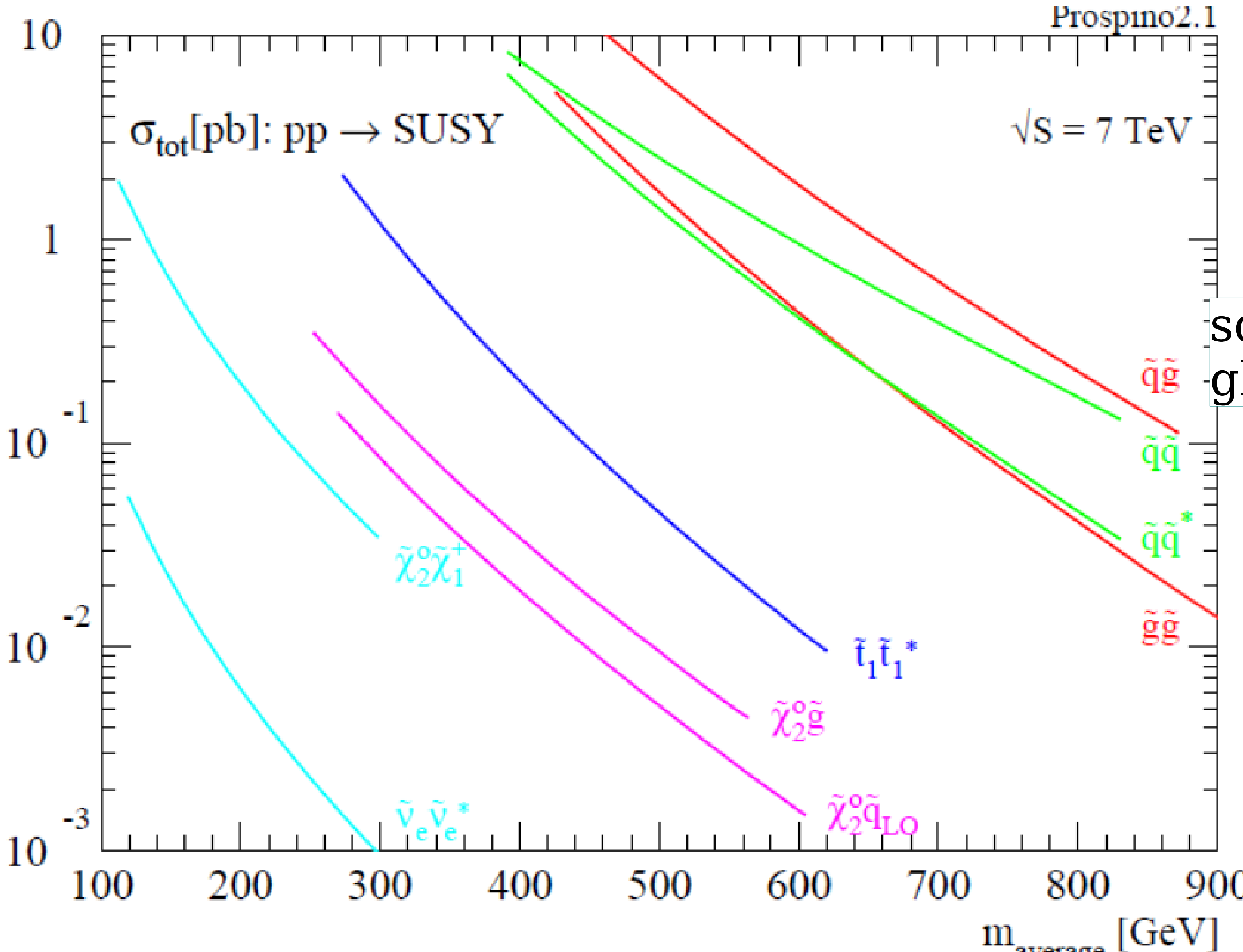
LHC 7 TeV   creation of Super-Symmetric Particles

5000

500

50

Events in 2011



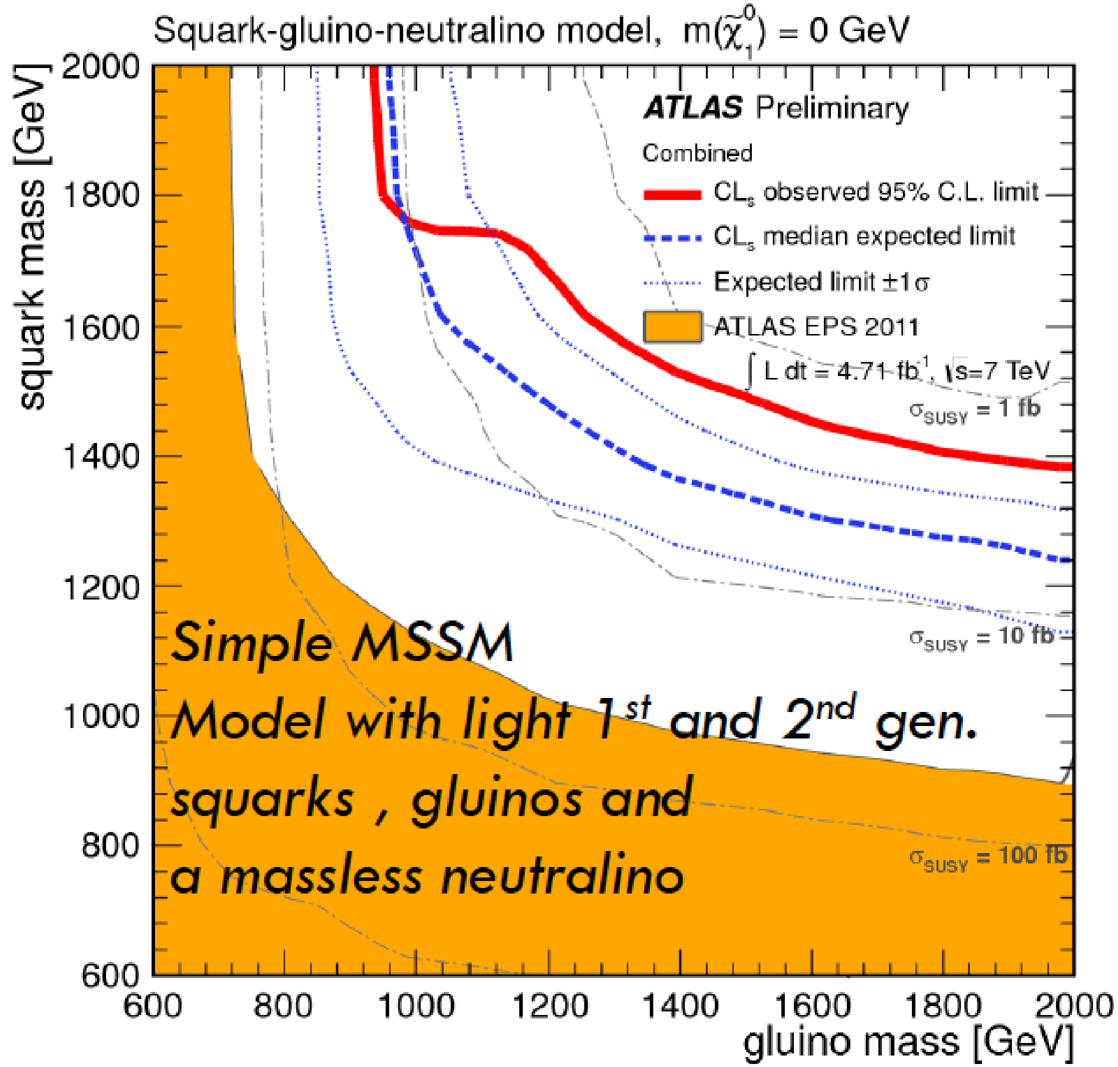
squark gluino

From ATLAS seminar (S. Caron)

ATLAS limits on the gluino and squark mass

(similar results from CMS)

No evidence for Supersymmetry at LHC with the 2011 data.



The lower limits on the masses of the supersymmetric partners of quarks and gluons (if they exist) are approaching 1000 GeV

What is the significance of the non-detection of Supersymmetry at LHC ?

Is SuperSymmetry “cornered”

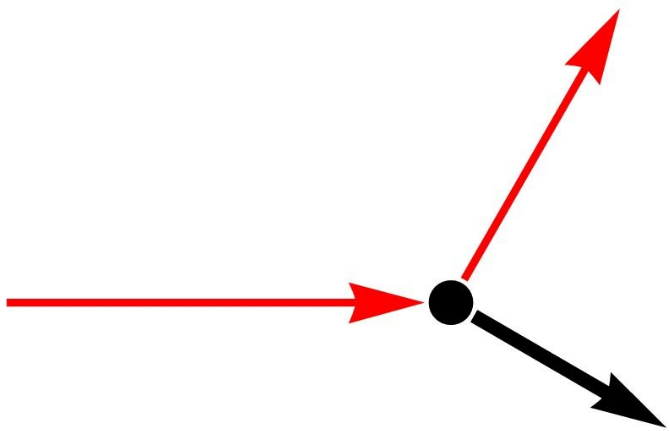
Is the “SUSY Paradigm”
(at least in its most *“Natural”* version)
seriously challenged ?

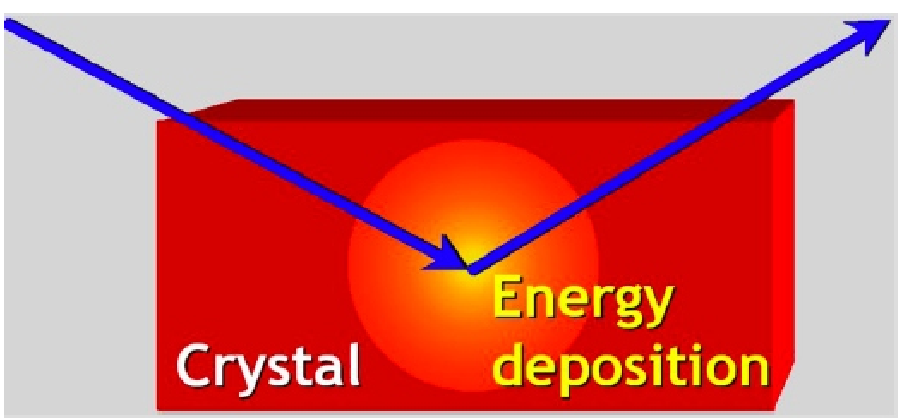
Open question.
(see Antonio Masiero friday)

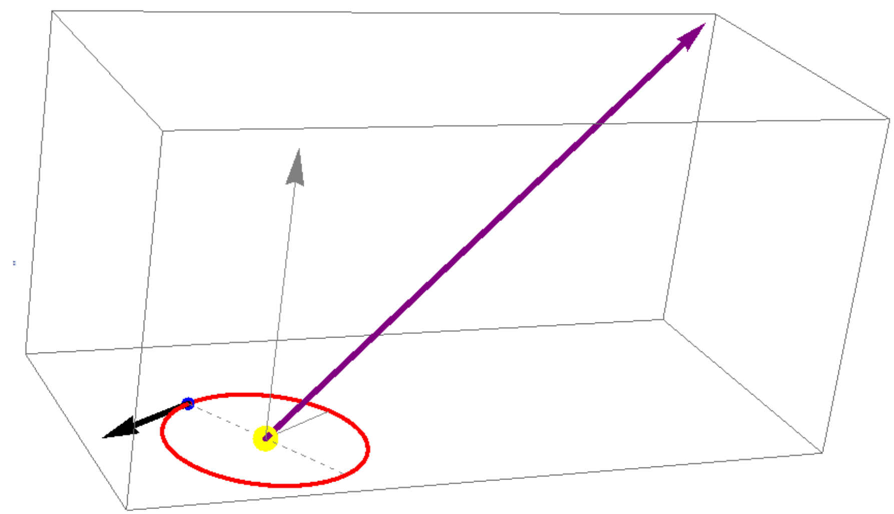
“Direct” Search for Dark Matter

Elastic scattering

$$\chi + A \rightarrow \chi + A$$







“Seasonal Modulation “

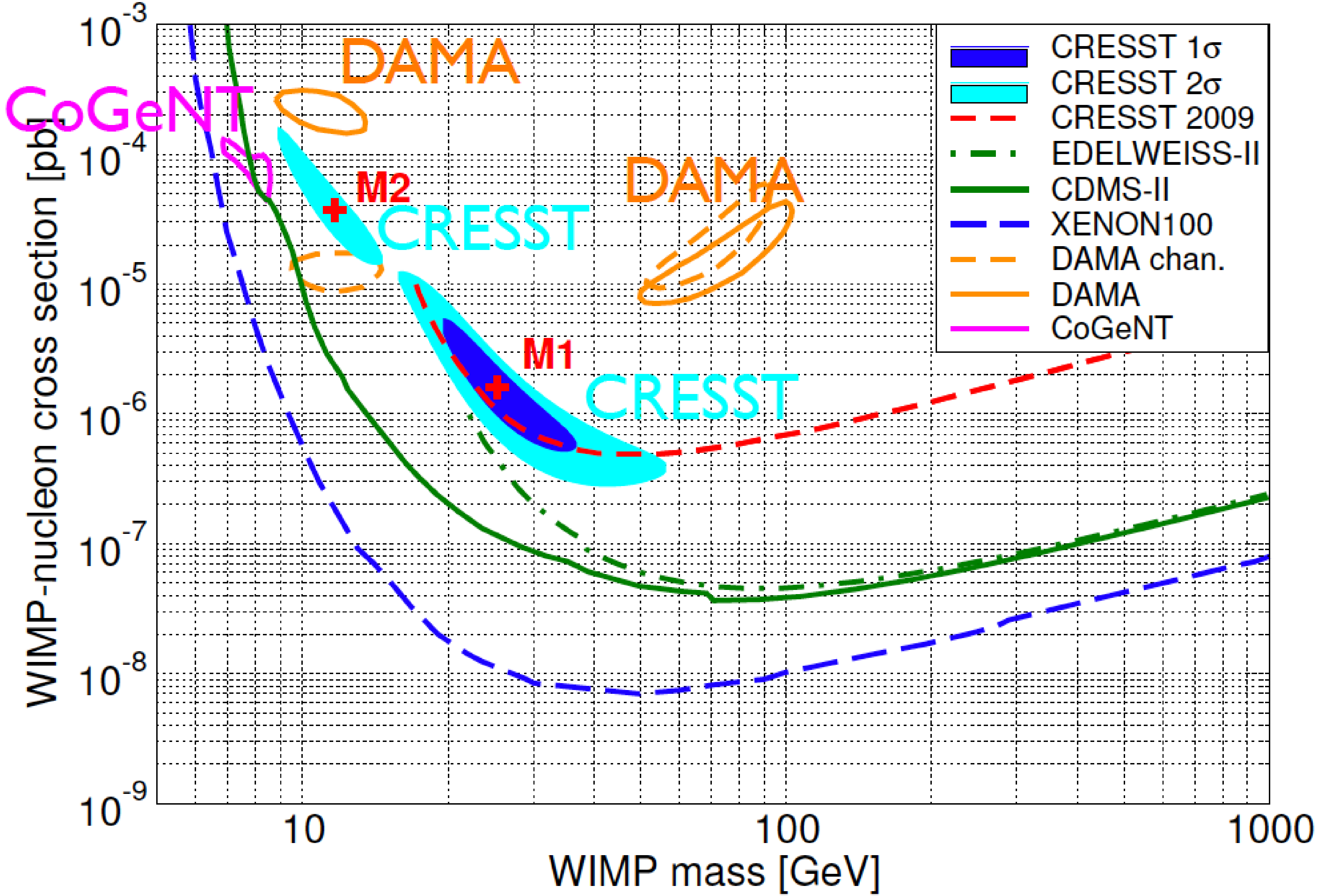
$$\vec{w}_{\oplus}(t) = \vec{w}_{\odot} + \vec{v}_{\rm orbit}(t)$$

$$w_{\oplus}(t) \simeq w_{\odot} + \sin\gamma \; v_{\rm orbit} \;\; \cos[\omega(t - t_0)]$$

DAMA/Libra effect+claim
Cogent, CRESST “hints”

Limits XENON, CDMS,..

Results in conflict (or serious tension).
How can one reconcile them?



“INDIRECT searches” for Dark MATTER

Positrons, Antiprotons and DM

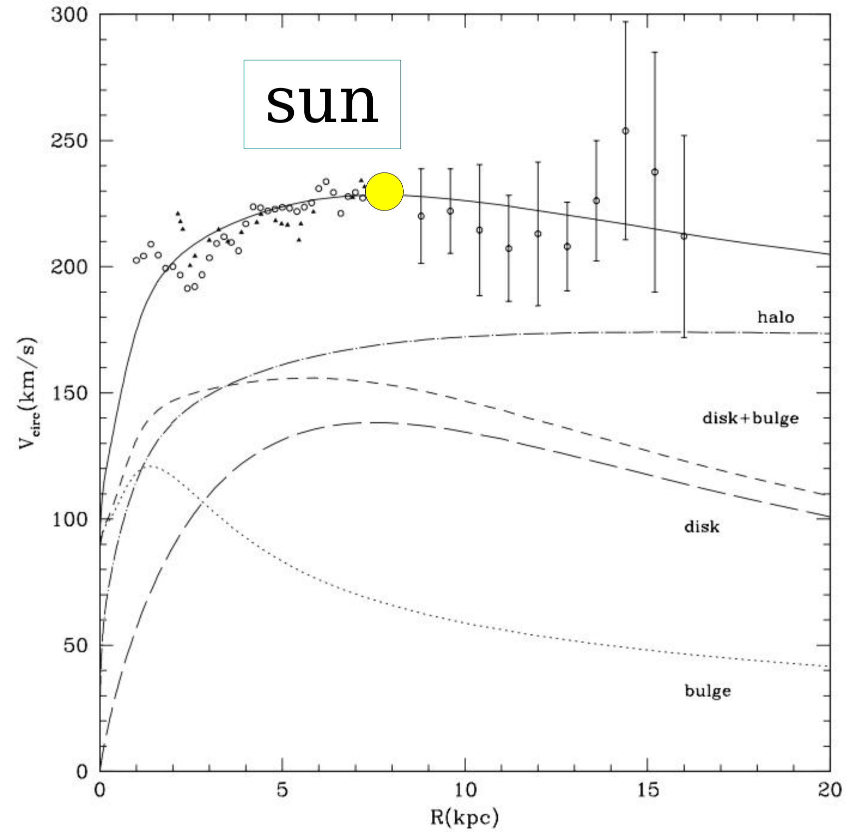
Pamela/Fermi Positron (electron) anomaly

Gamma Rays and DM

Evidence for lines ?!

Neutrinos and DM

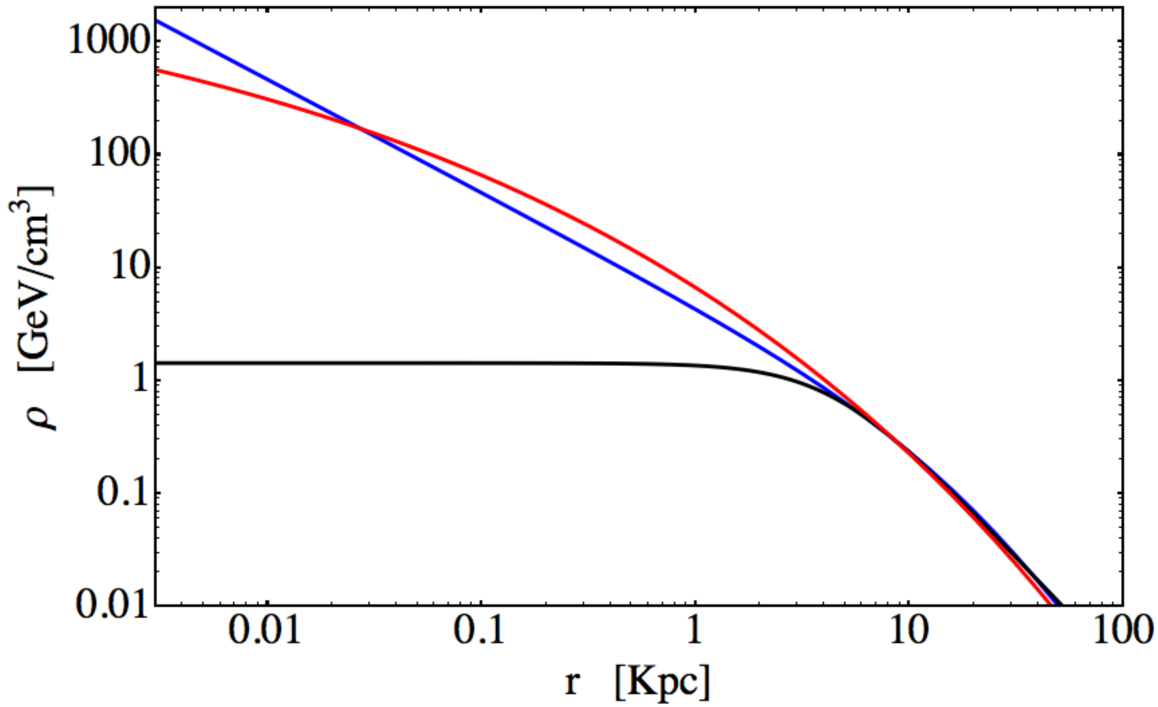
DM in the Milky Way



$$\rho_{\rm isothermal}(r) = \frac{\rho_s}{1+(r/r_s)^2}$$

$$\rho_{\rm NFW}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

$$\rho_{\rm Einasto}(r) = \rho_s \exp\{-(2/\alpha)[(r/r_s)^\alpha - 1]\}$$



Density distribution
determined by
Rotation velocity measurements

"Cusp" at GC
derived by N-body simulations

Problem of fluctuations
"Boost factor"

Power generated by DM annihilations in the Milky Way halo

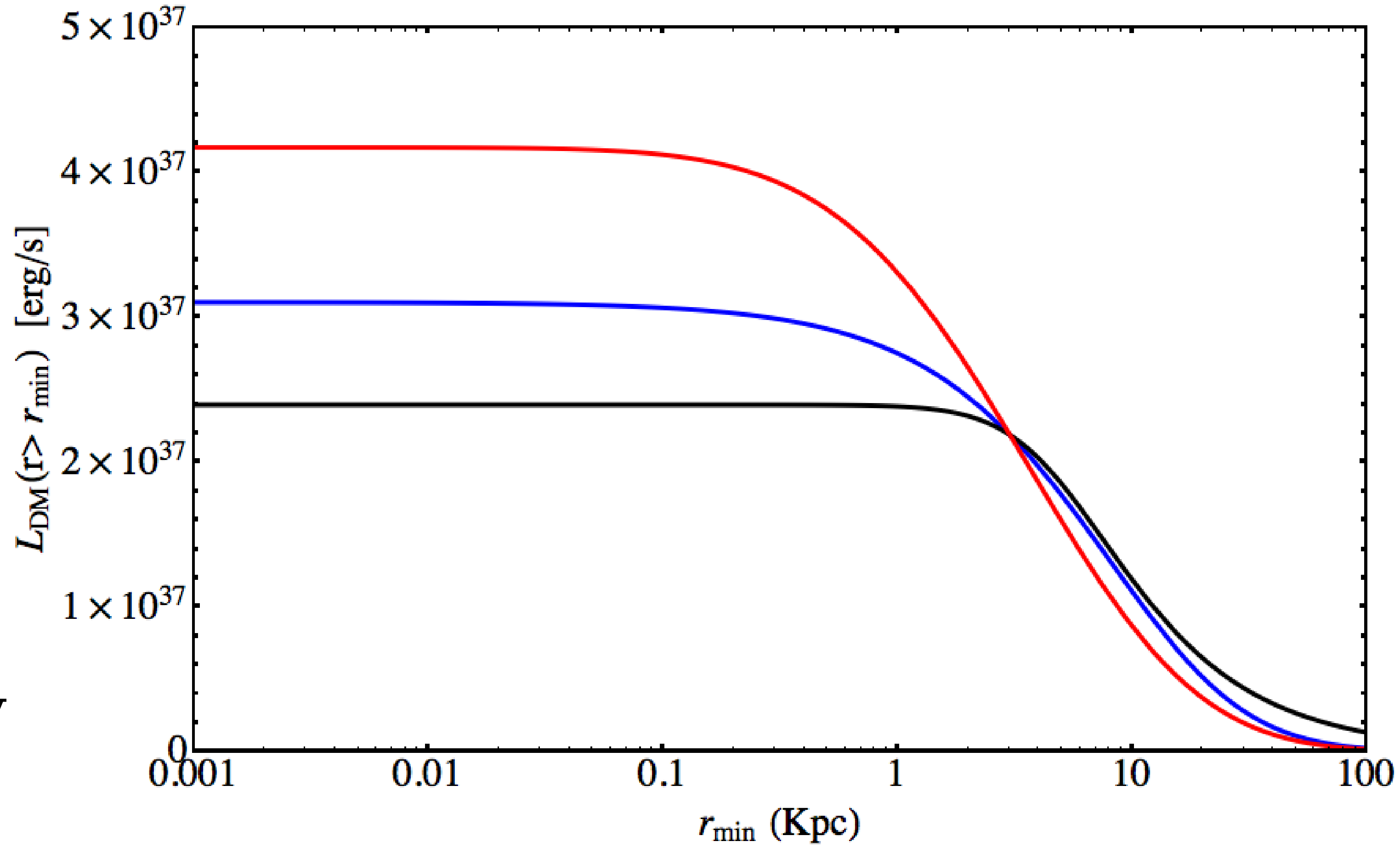
$$\frac{dN_{\chi\chi\to X}}{d^3x\,dt} = \frac{1}{2}\, n_\chi^2(\vec{x})\ \langle \sigma\, v\rangle$$

$$\frac{dL_{\rm DM}}{d^3x}(\vec{x}) = \frac{\rho^2(\vec{x})}{m_\chi}\ \langle \sigma\, v\rangle$$

$$L_{\rm DM} \propto \frac{\langle \sigma\, v\rangle}{m_\chi}$$

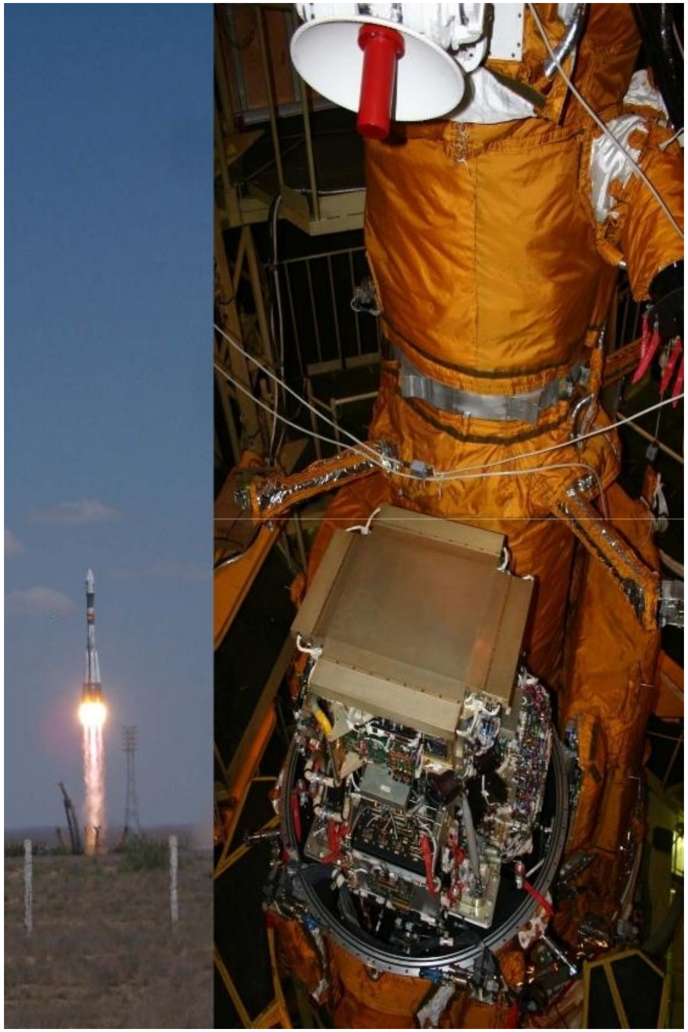
$$L_{\rm DM} \simeq 3\times 10^{37}\ {\rm erg\ s^{-1}}\ \left[\frac{\langle \sigma\, v\rangle}{3\times 10^{-26}\ ({\rm cm^3 s})^{-1}}\right]\ \left[\frac{100\ {\rm GeV}}{m_\chi}\right]$$

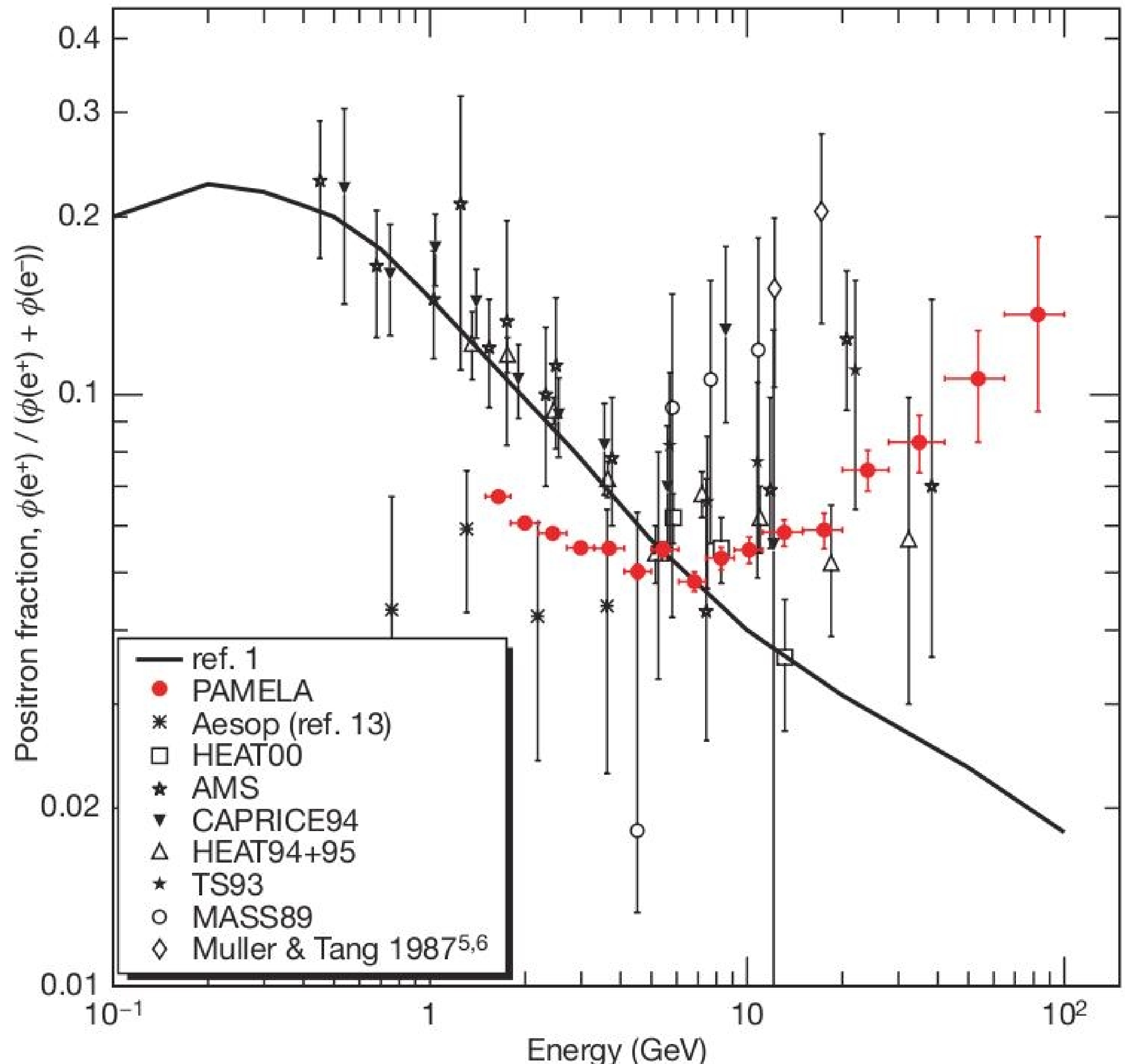
[Majorana particle]



small effect of "Cusp" on total luminosity

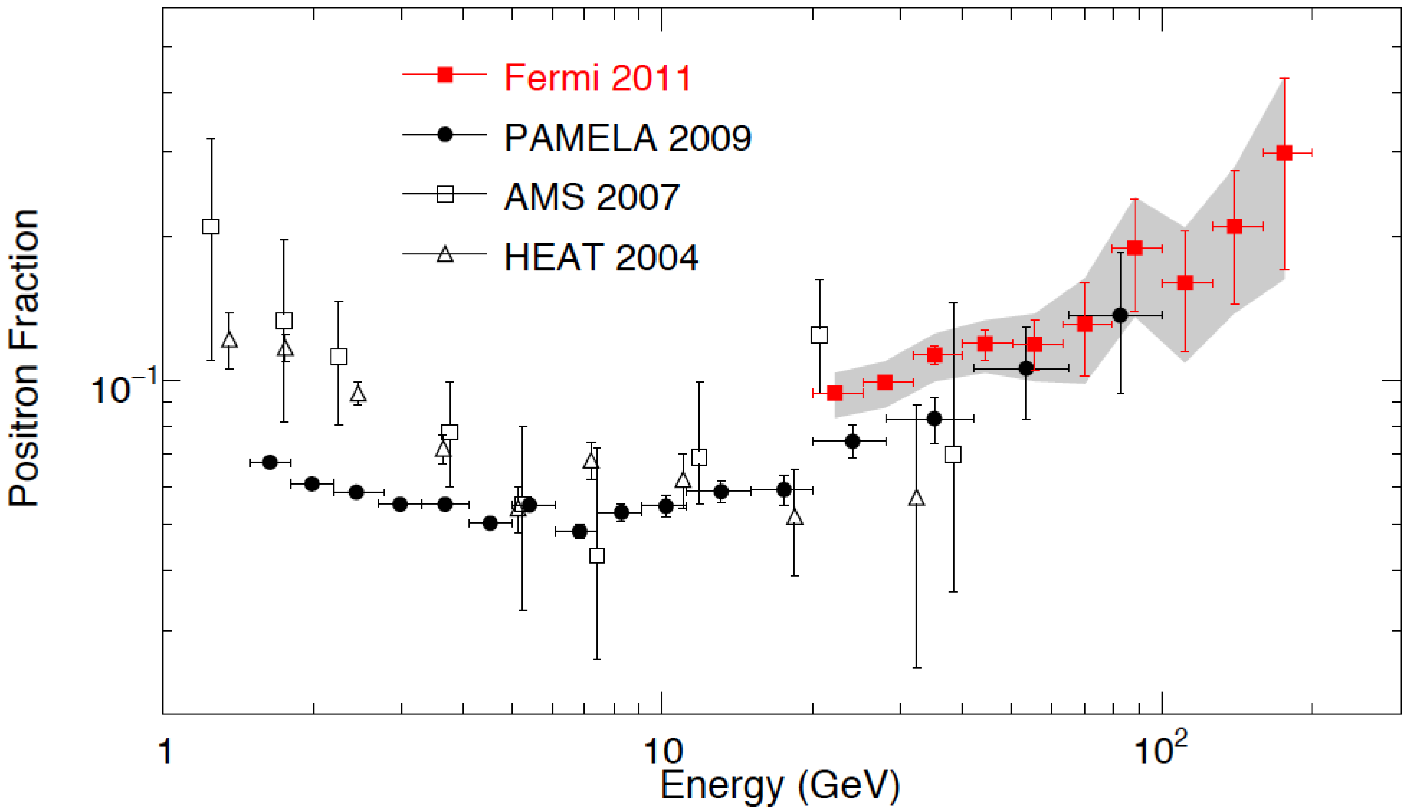
PAMELA
“anomalous positron abundance”
E = [3 - 100 GeV]





Emilano Mocchiutti
later today

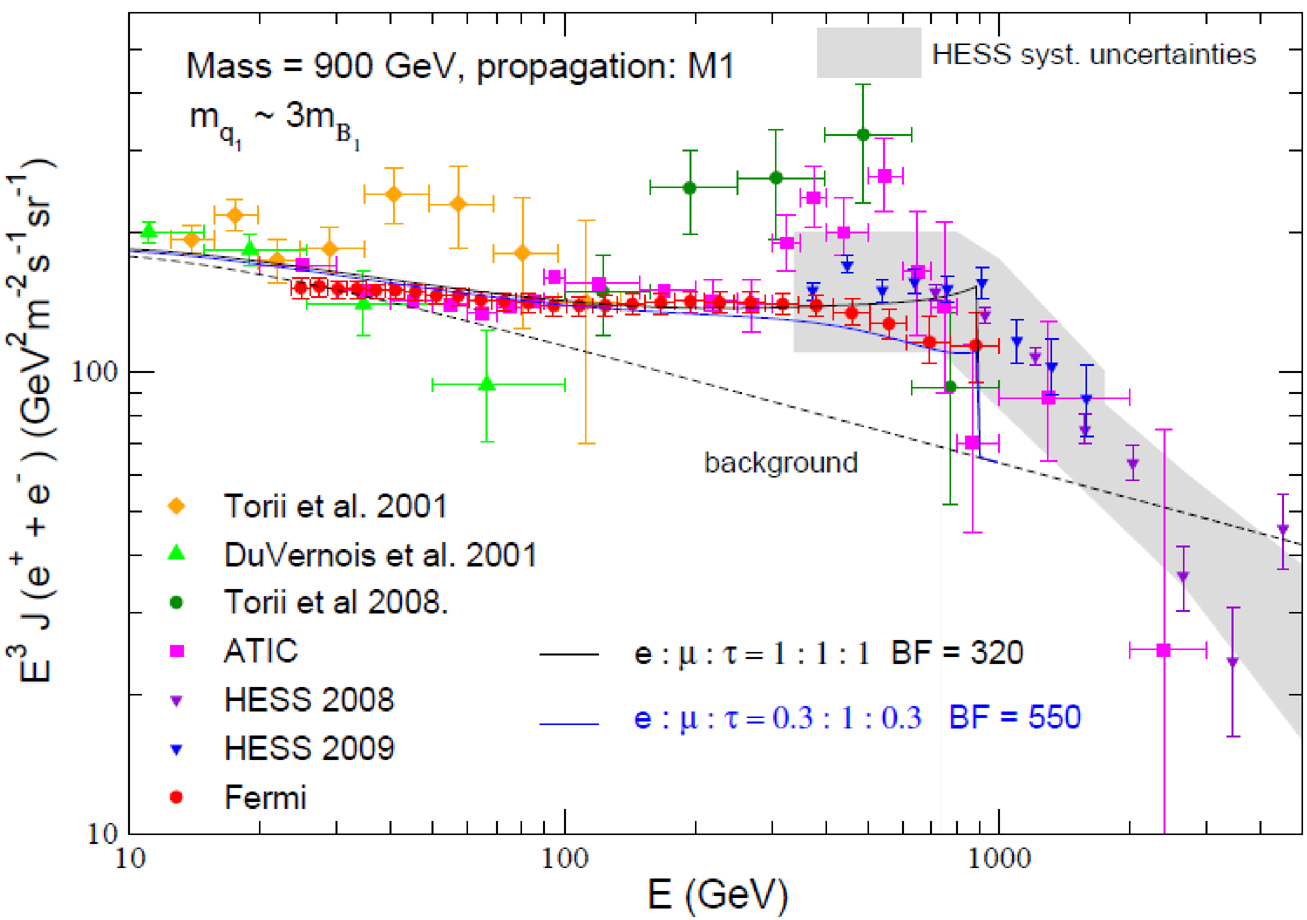
Result confirmed by FERMI ! (and extended to 200 GeV)
[using the Earth magnetic field to separate e- and e+]
{Hypothesis of systematic effect much less likely...}



Existence of a "new, hard source of positrons"
is a robust conclusion (very broad consensus).

Do we have also an “electron excess” ?

Very likely the “new source”
is approximately equal for e- and e+
and visible also in the (e- + e+) spectrum.
This allows to extend the observations to higher energy
(with FERMI + HESS)



New source energy spectrum extends up to (and not beyond) 1 TeV.

Can the PAMELA “positron excess”
be explained by Dark Matter annihilation?

…. yes, …. but not “naturally” ….

[No anti-proton excess!]

[very large $\langle \sigma v \rangle$ required]

Minimum model:

1. Mass of DM particle

2. Annihilation cross section

Annihilation channels

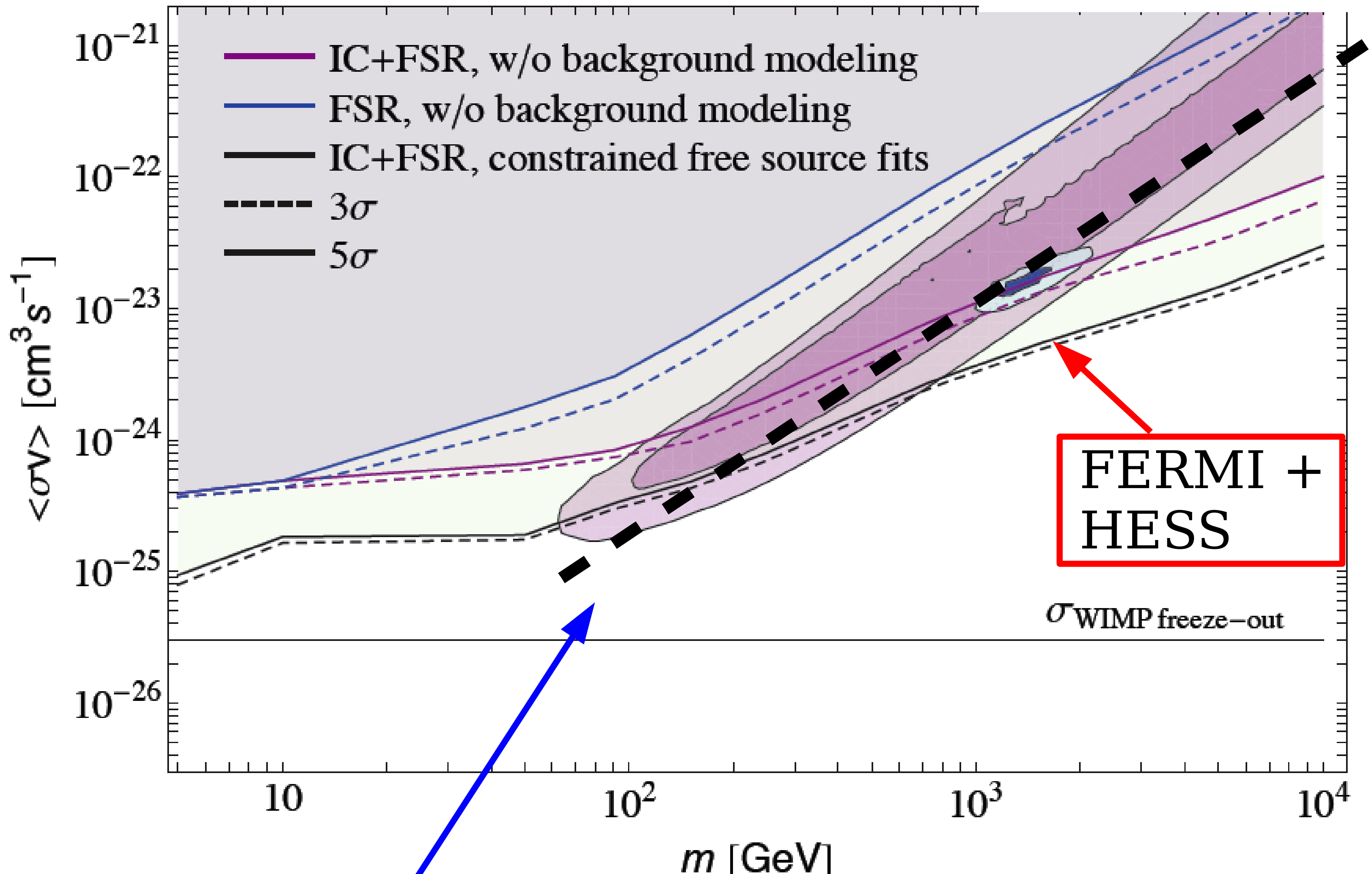
DM density distribution

+ CR propagation in MW moeli

Cirelli, Panci, Serpico [2010]

NWF

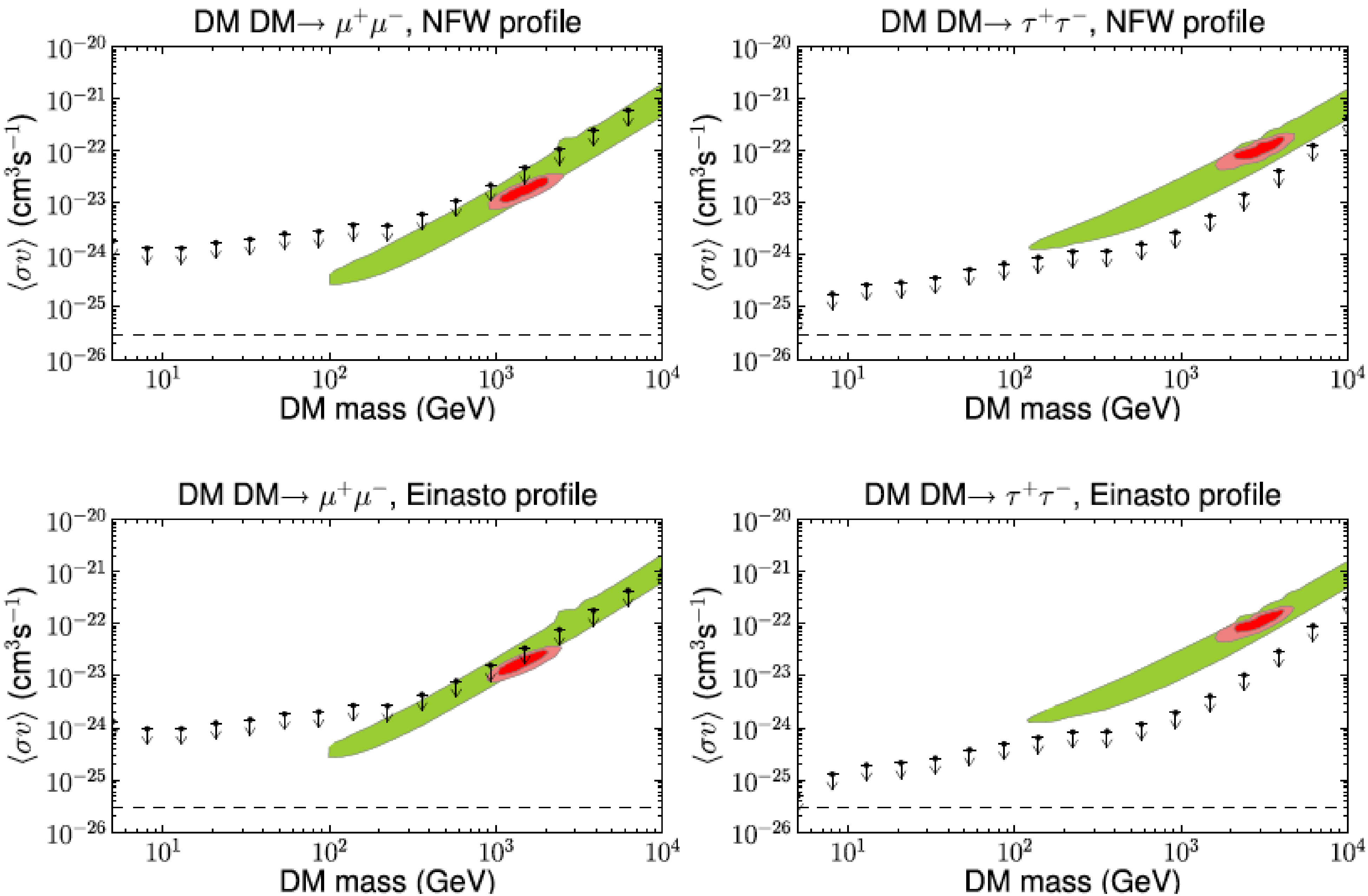
$\chi\chi \to \mu^+\mu^-$



Region that explains the PAMELA positron anomaly

$$\langle \sigma v \rangle \simeq 2.2 \times 10^{-23}\ \mathrm{cm^3 s^{-1}} \times \left(\frac{m_\chi}{1\ \mathrm{TeV}}\right)^{1.74}$$

P. Meade, M. Papucci, A. Strumia, and T. Volansky,
Nucl. Phys. B831, 178 (2010),



Pamela anomaly:

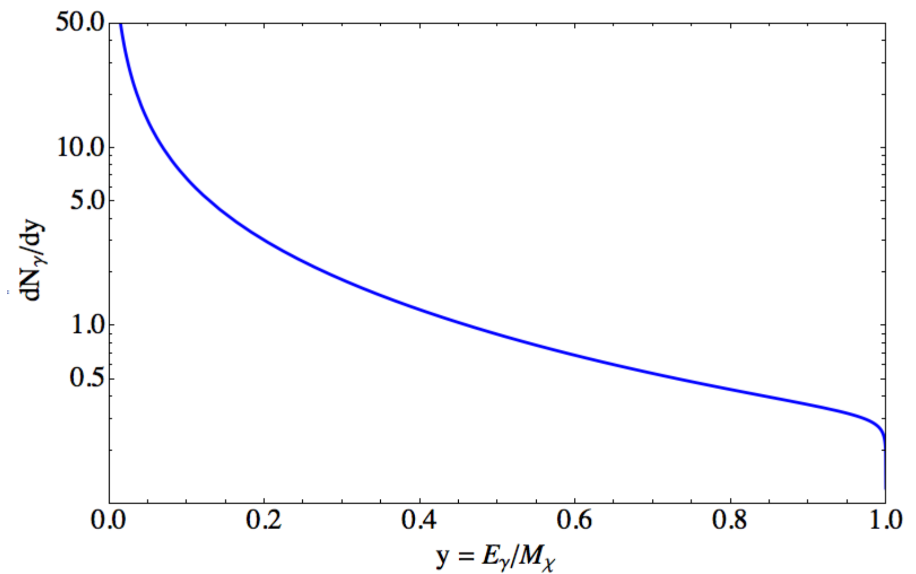
The positron emission MUST be accompanied by
a significant emission of photons.

[No "ad hoc hypothesis"
such as "leptophilic, photon-hating" DM is possible.....]

Positrons (and electrons) generate
Gamma rays by Inverse Compton scattering on the
Radiation fields of the Milky Way.

Photon emission by radiative corrections
(at level of 1%)
during annihilation

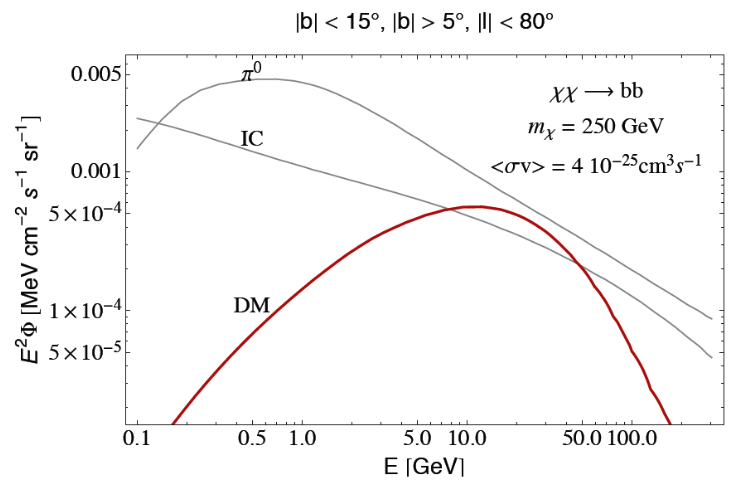
$$\frac{dN_\gamma}{dy} = \frac{\alpha}{\pi}\left(\frac{1+(1-y)^2}{y}\right)\left(\ln\left(\frac{s(1-y)}{m_\ell^2}\right) - 1\right)$$



GAMMA astronomy experimental study of the hypothesis that the DM is made of Thermal Relics.

1. Energy Spectrum signatures

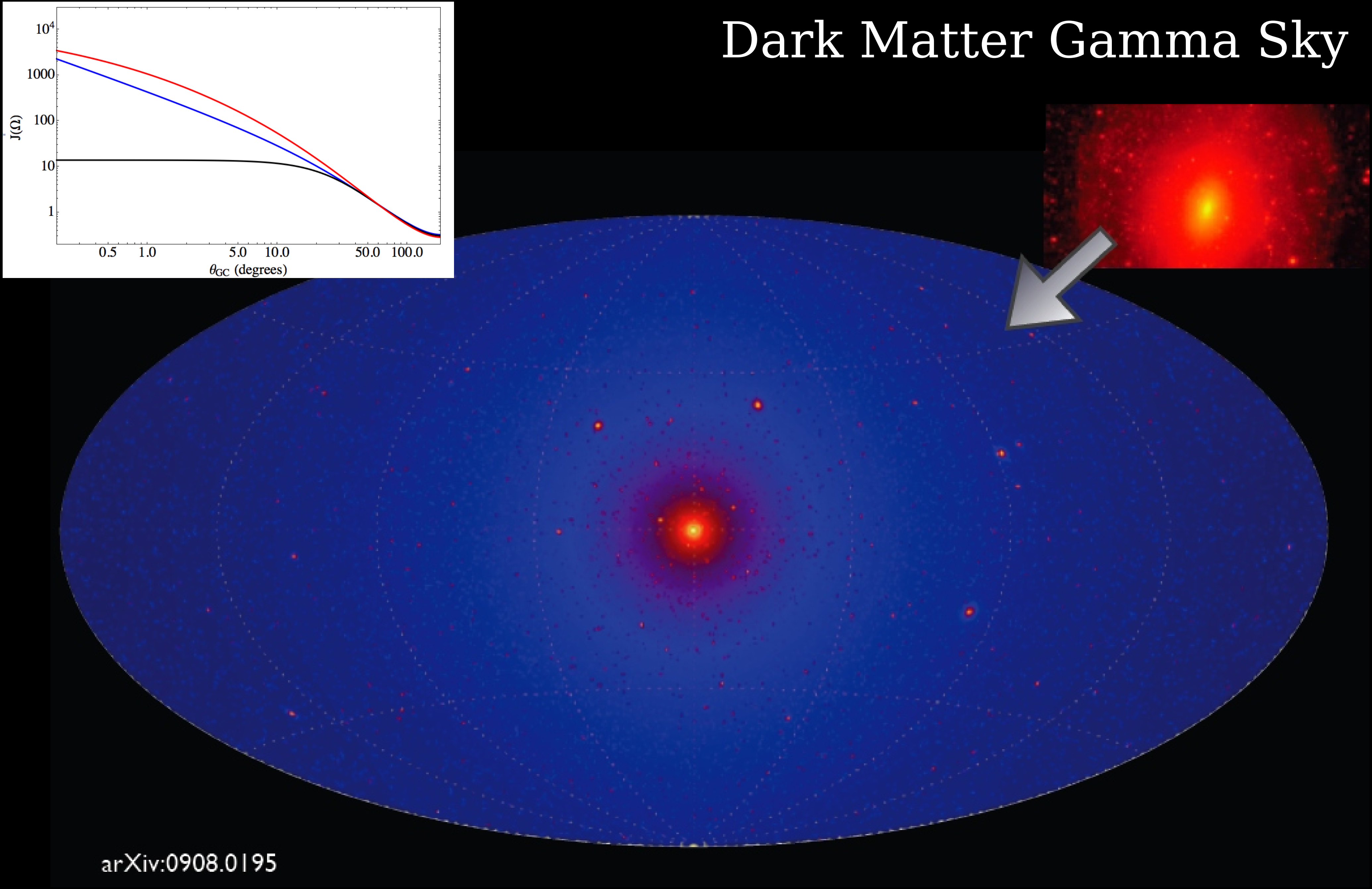
2. Angular distribution signatures

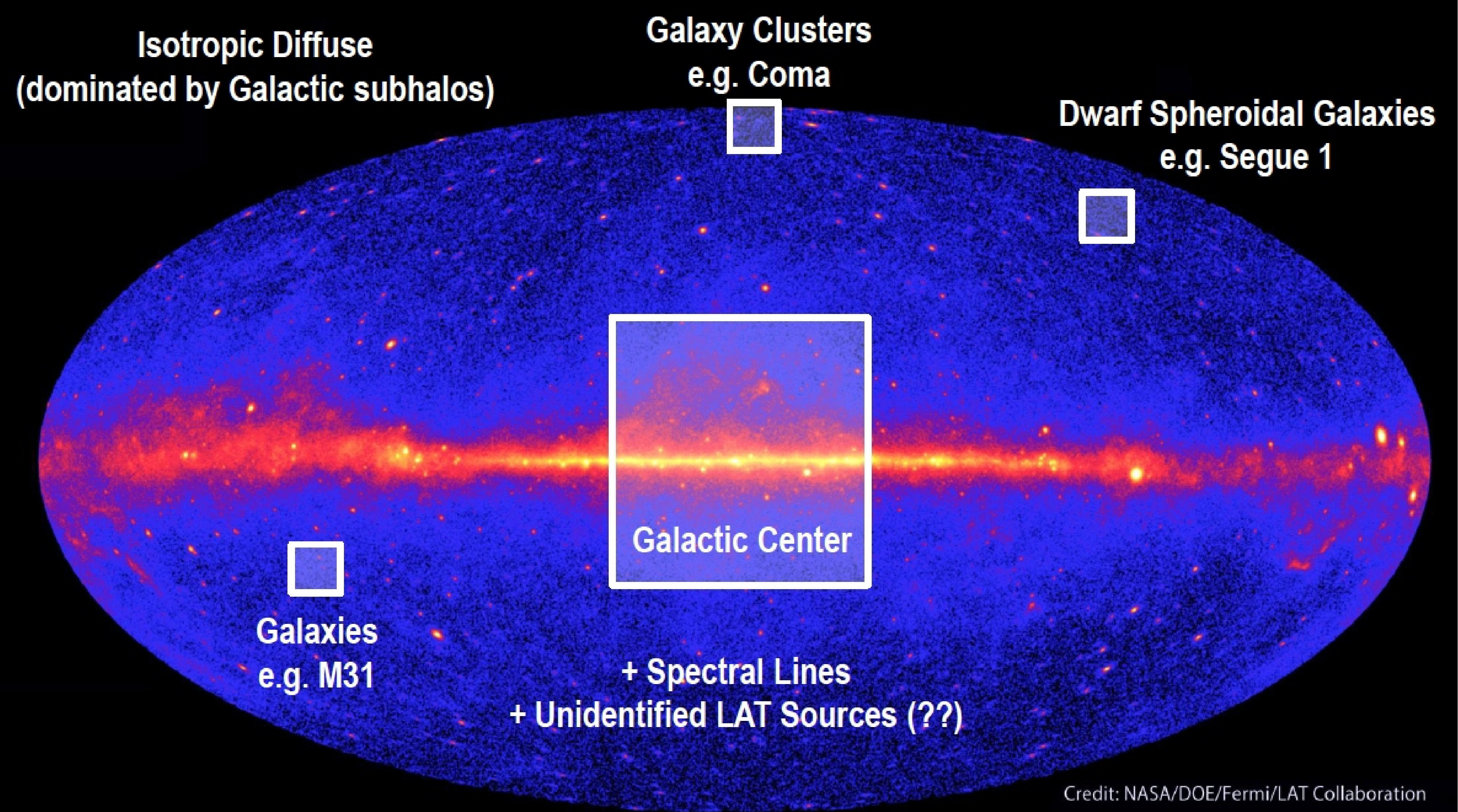


Goal B: Verify/Falsify the hypothesis that the "Pamela anomaly" is due to WIMP annihilation

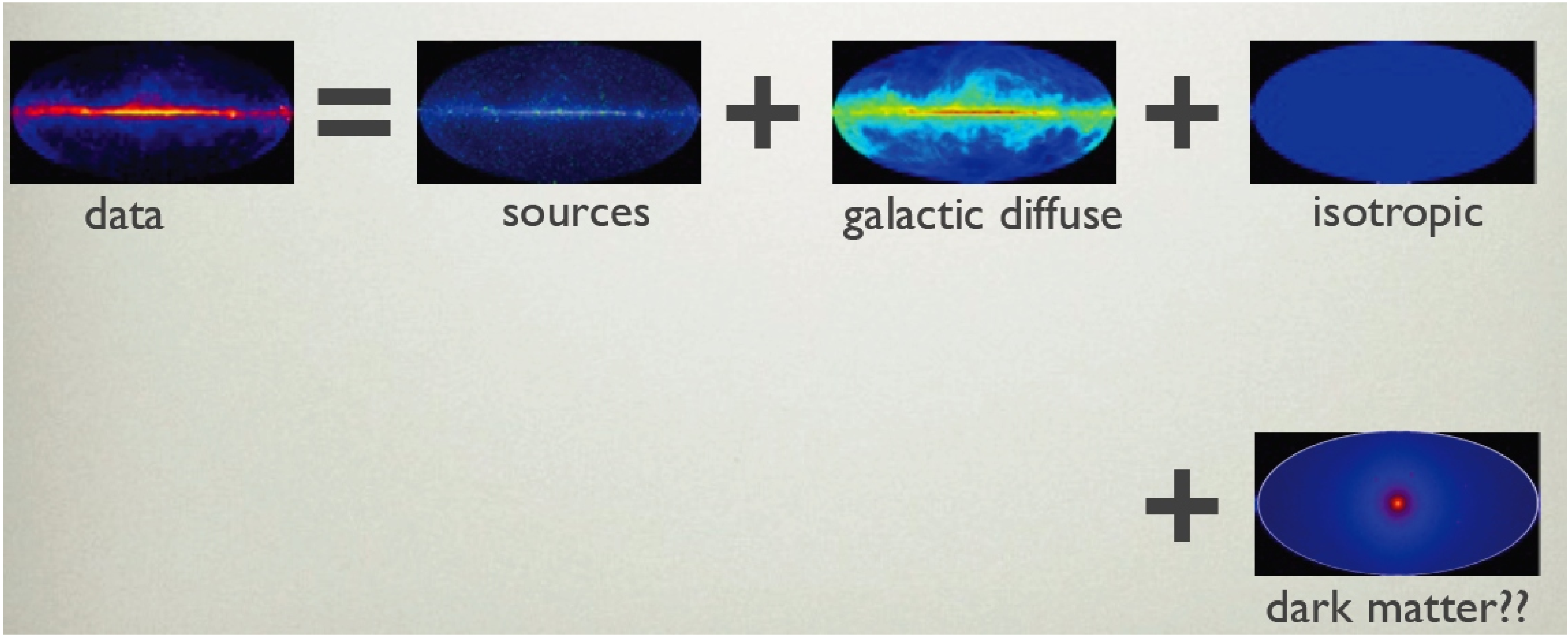
Goal A: Verify/Falsify the hypothesis that the DM is made of WIMP's

Dark Matter Gamma Sky





Trade-off between signal strength versus astrophysical background


data
sources
galactic diffuse
isotropic
dark matter??

Limits of DM from gamma rays: FERMI, HESS, MAGIC

arXiv:1205.6474v1 [astro-ph.CO] 29 May 2012

Constraints on the Galactic Halo Dark Matter from Fermi-LAT Diffuse Measurements

arXiv:1201.2691v1 [astro-ph.HE] 12 Jan 2012

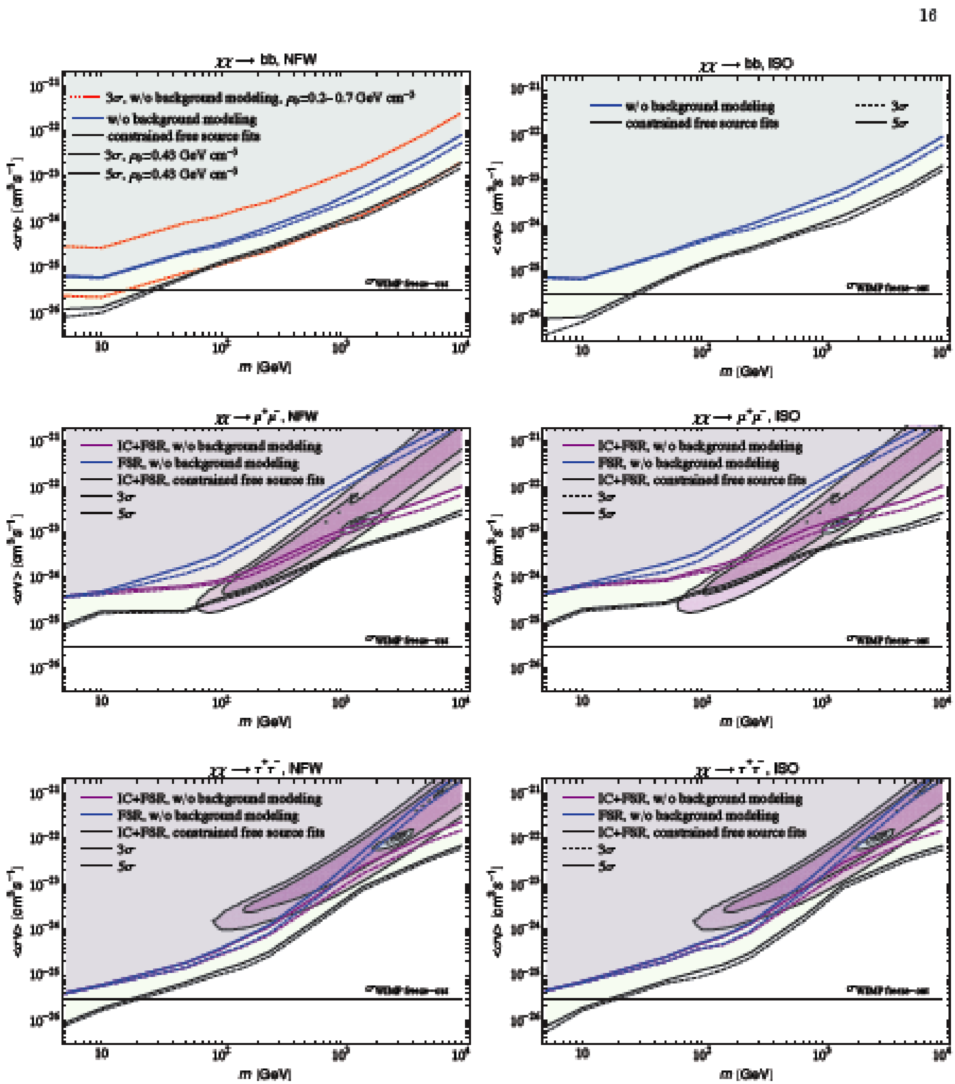
SEARCH FOR DARK MATTER SATELLITES USING THE FERMI-LAT

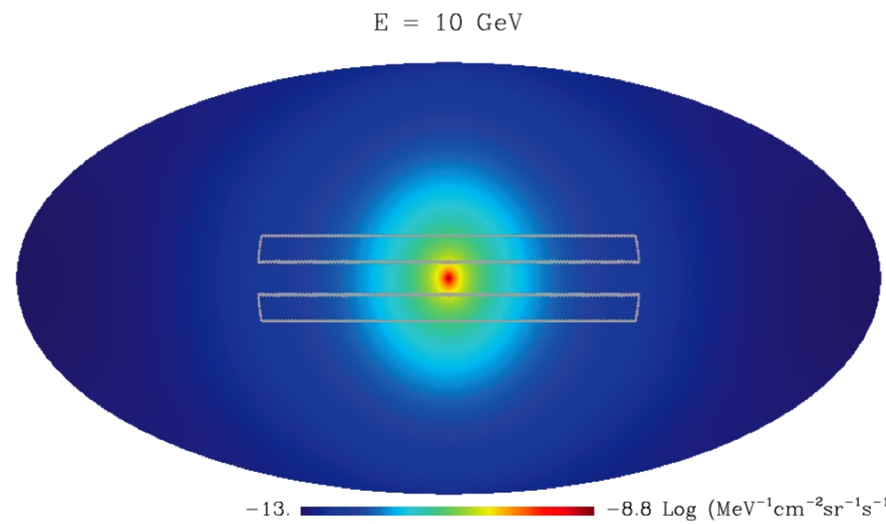
arXiv:1205.2739v1 [astro-ph.HE] 12 May 2012

***Fermi* LAT Search for Dark Matter in Gamma-ray Lines**
and the Inclusive Photon Spectrum

arXiv:1205.6474v1 [astro-ph.CO] 29 May 2012

Constraints on the Galactic Halo Dark Matter from Fermi-LAT Diffuse Measurements





The limit of the gamma ray observations are
In serious tension with the DM interpretations
Of the PAMELA anomaly.

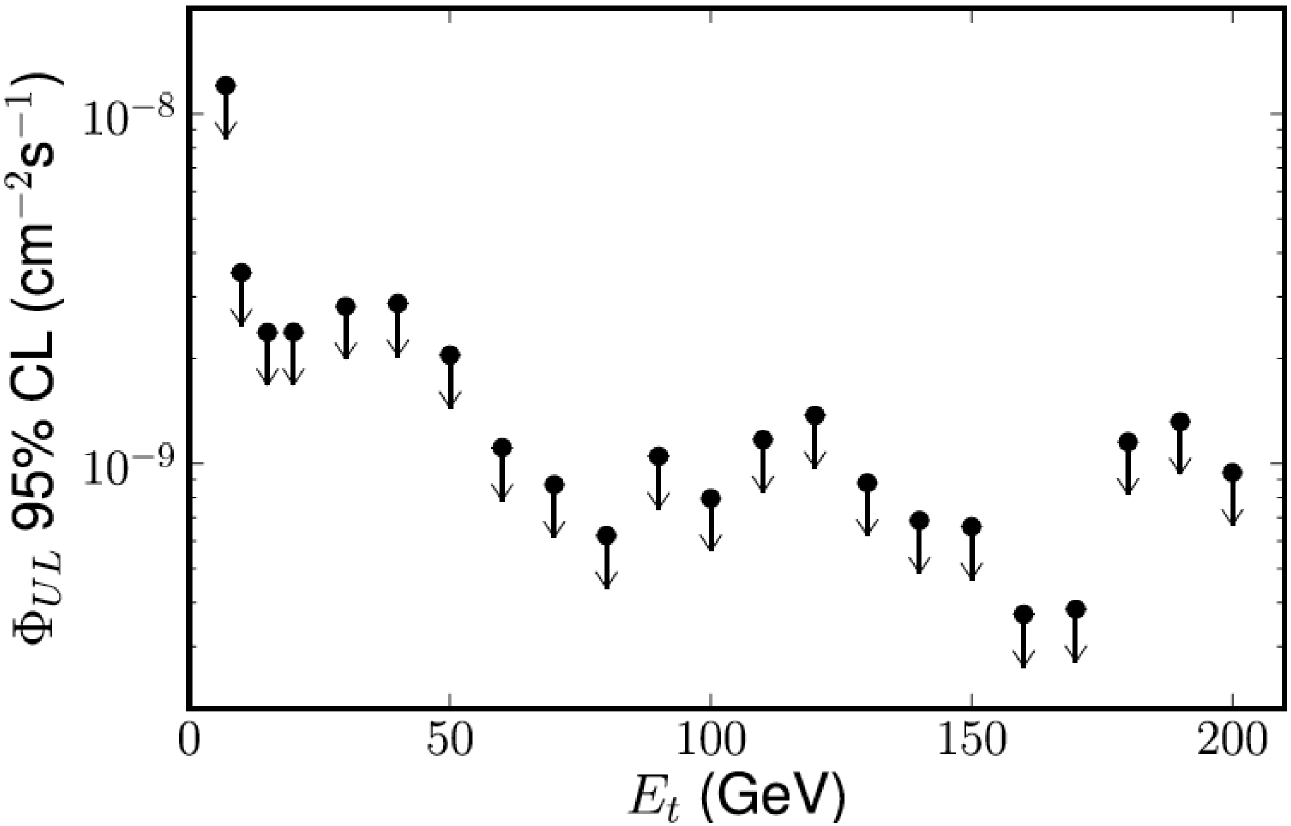
and start to explore the “orthodox range”
of annihilation cross sections.

What about the PAMELA anomaly then….

Pulsars ?
Other acceleration sites ?

arXiv:1205.2739v1 [astro-ph.HE] 12 May 2012

Fermi **LAT Search for Dark Matter in Gamma-ray Lines and the Inclusive Photon Spectrum**



Claims of detection of lines in the FERMI data…….

arXiv:1204.2797v1 [hep-ph] 12 Apr 2012

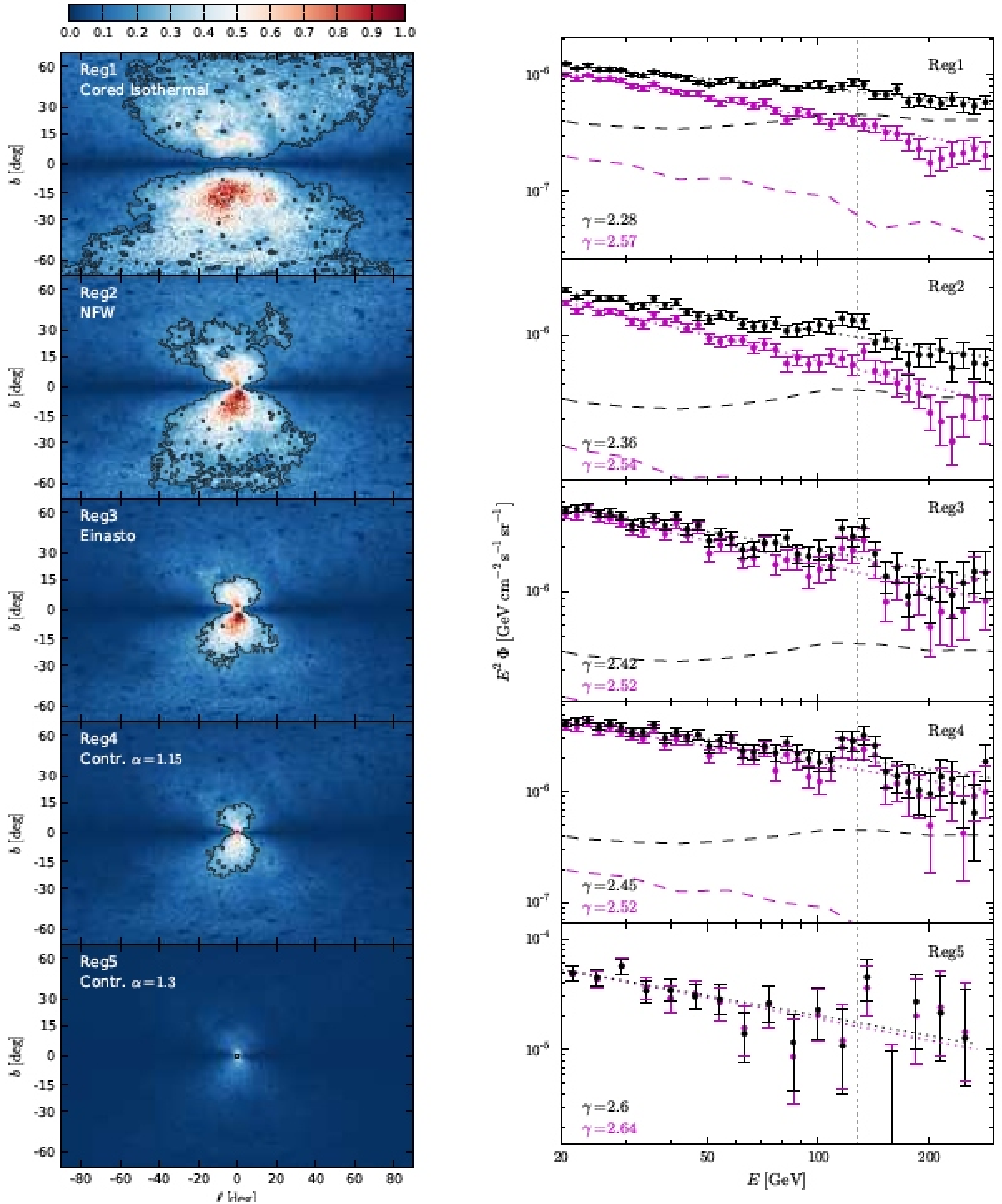
A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

Christoph Weniger

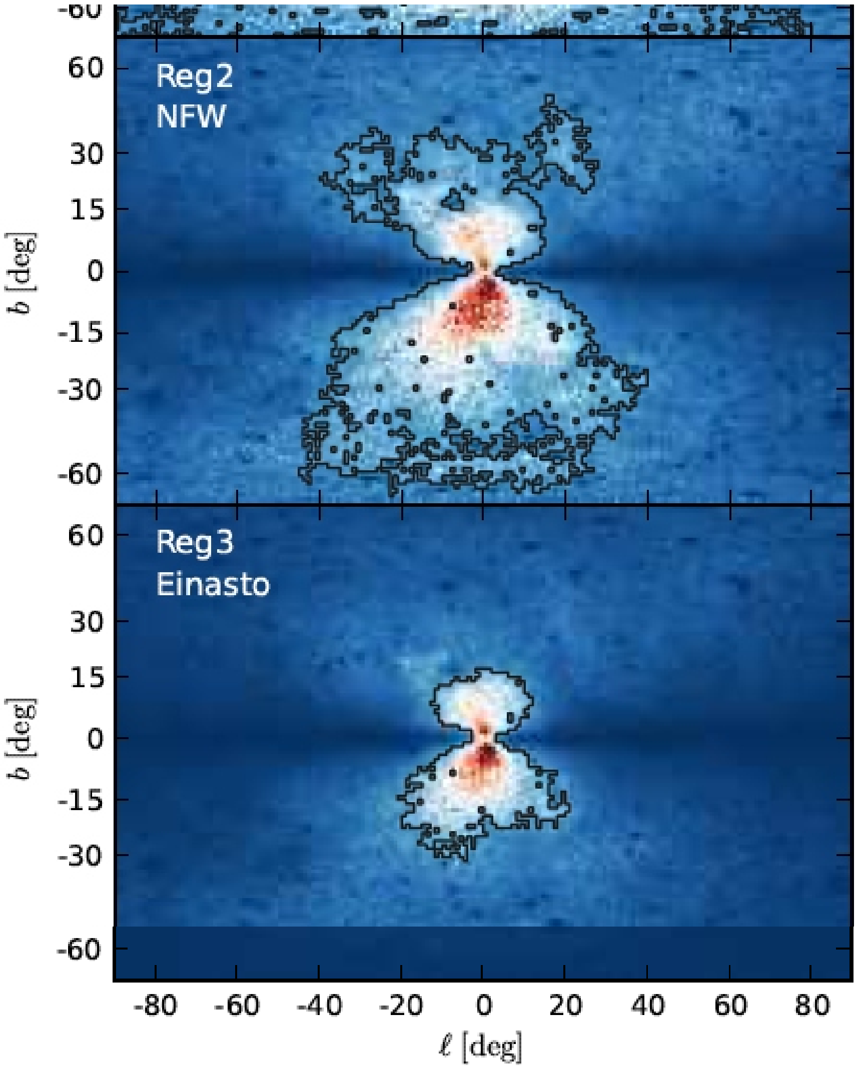
Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

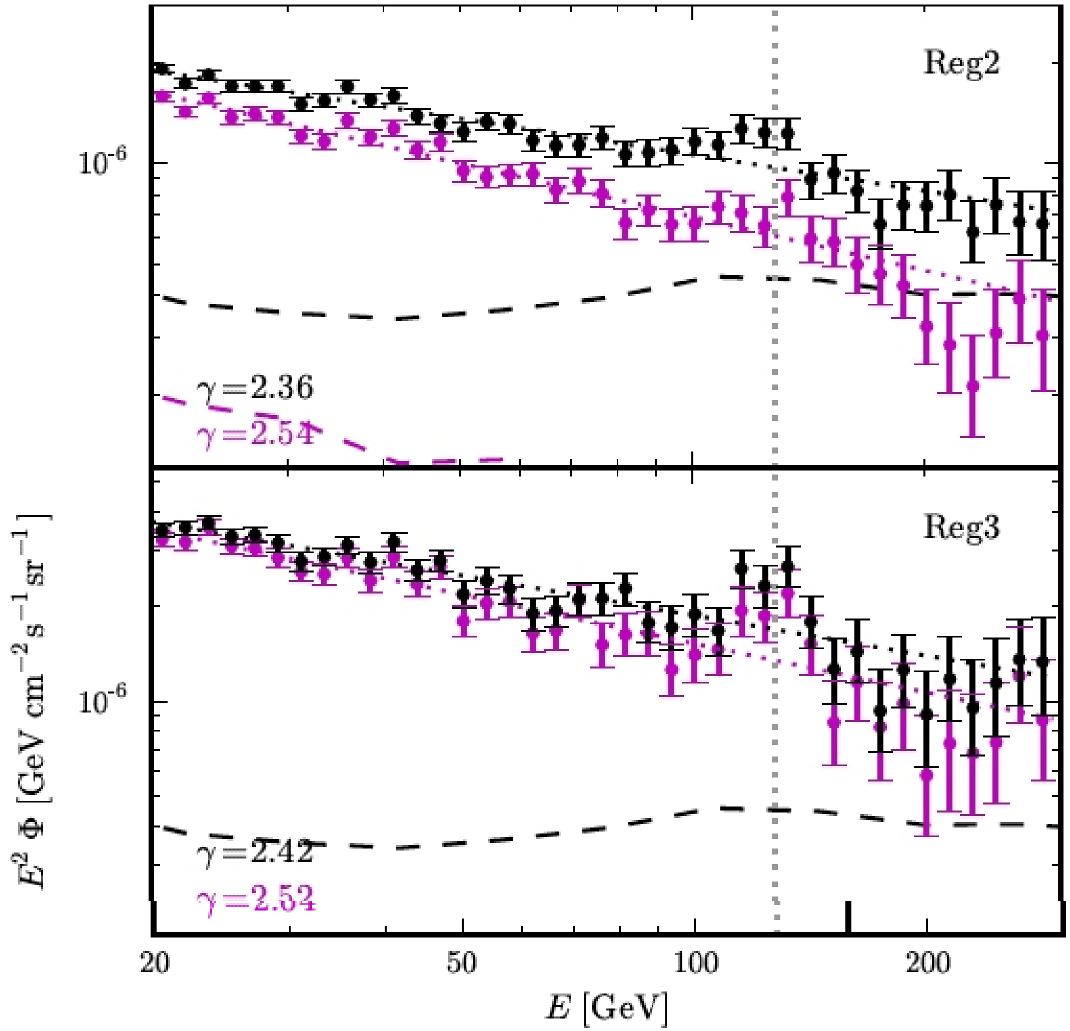
Determine angular region to optimize signal/noise

Region depends on assumptions about
DM distribution

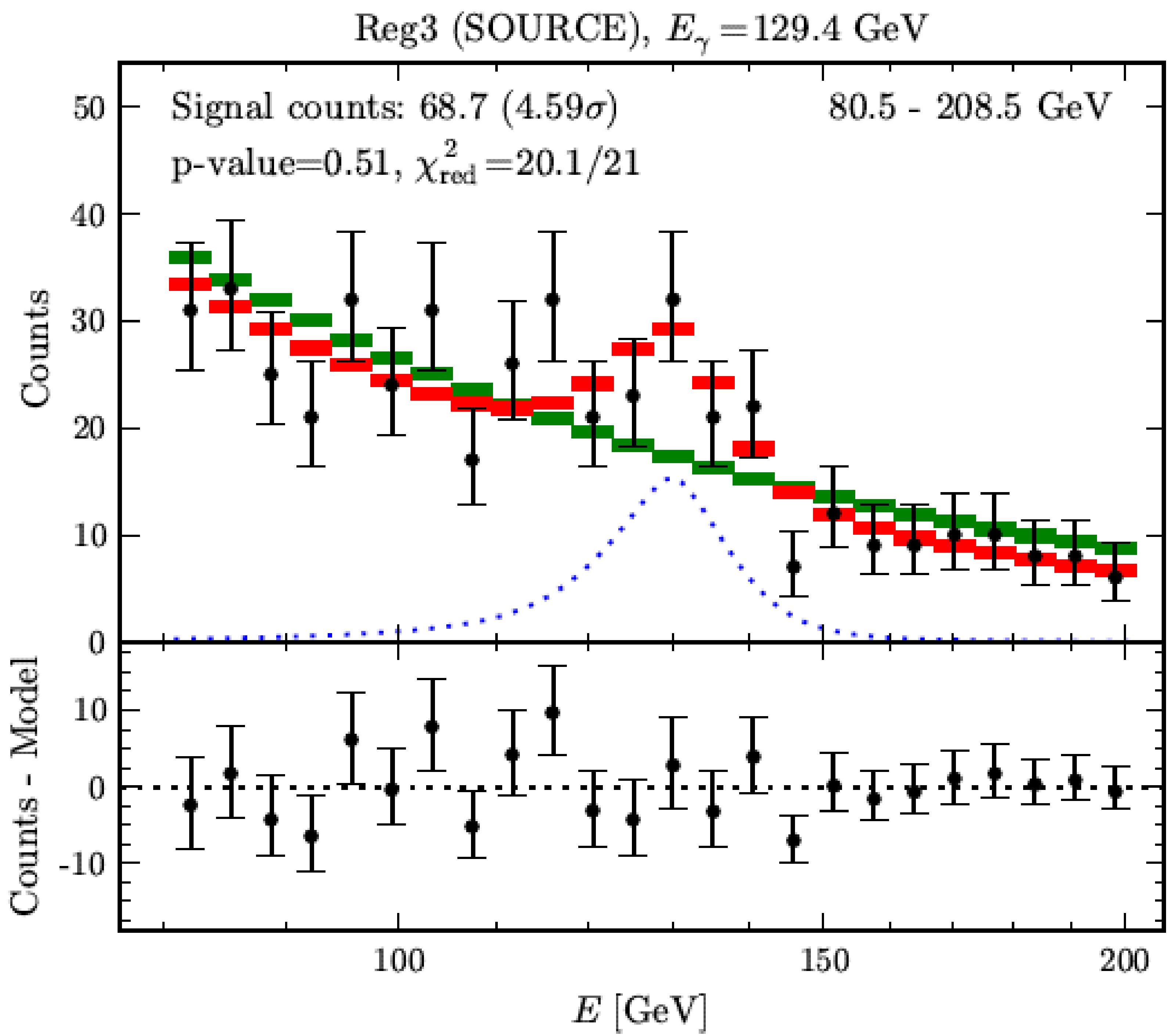


Best motivated models
NFW, Einasto





Line at 130 GeV ?


Reg3 (SOURCE), $E_\gamma = 129.4$ GeV
Signal counts: 68.7 (4.59σ)
80.5 - 208.5 GeV
p-value=0.51, χ^2_{red} =20.1/21
Counts
Counts - Model
E [GeV]
0
10
20
30
40
50
-10
100
150
200

4.6σ indication

look-elsewhere effect

the significance is 3.3σ

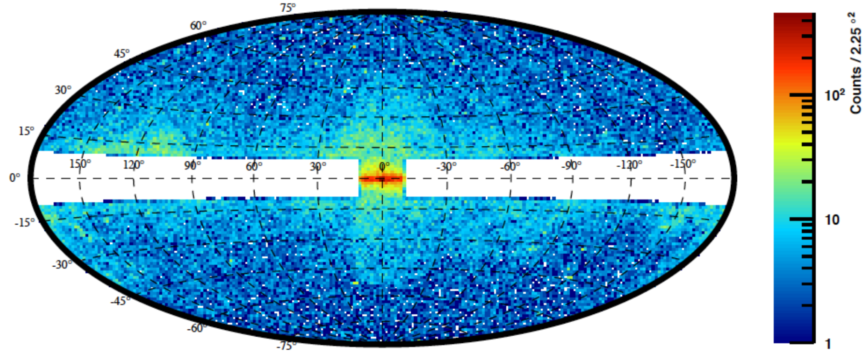
$$m_\chi = 129.8 \pm 2.4^{+7}_{-13}\ \mathrm{GeV}$$

$$\langle \sigma v \rangle_{\chi\chi \to \gamma\gamma} = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$ Einasto

$$\langle \sigma v \rangle_{\chi\chi \to \gamma\gamma} = (2.27 \pm 0.57^{+0.32}_{-0.51}) \times 10^{-27}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$ NFW

Large, considering expected Branching Ratio into channel

New Independent claim of (essentially) same effect



DRAFT VERSION JUNE 11, 2012
Preprint typeset using LaTeX style emulateapj v. 03/07/07

STRONG EVIDENCE FOR GAMMA-RAY LINES FROM THE INNER GALAXY

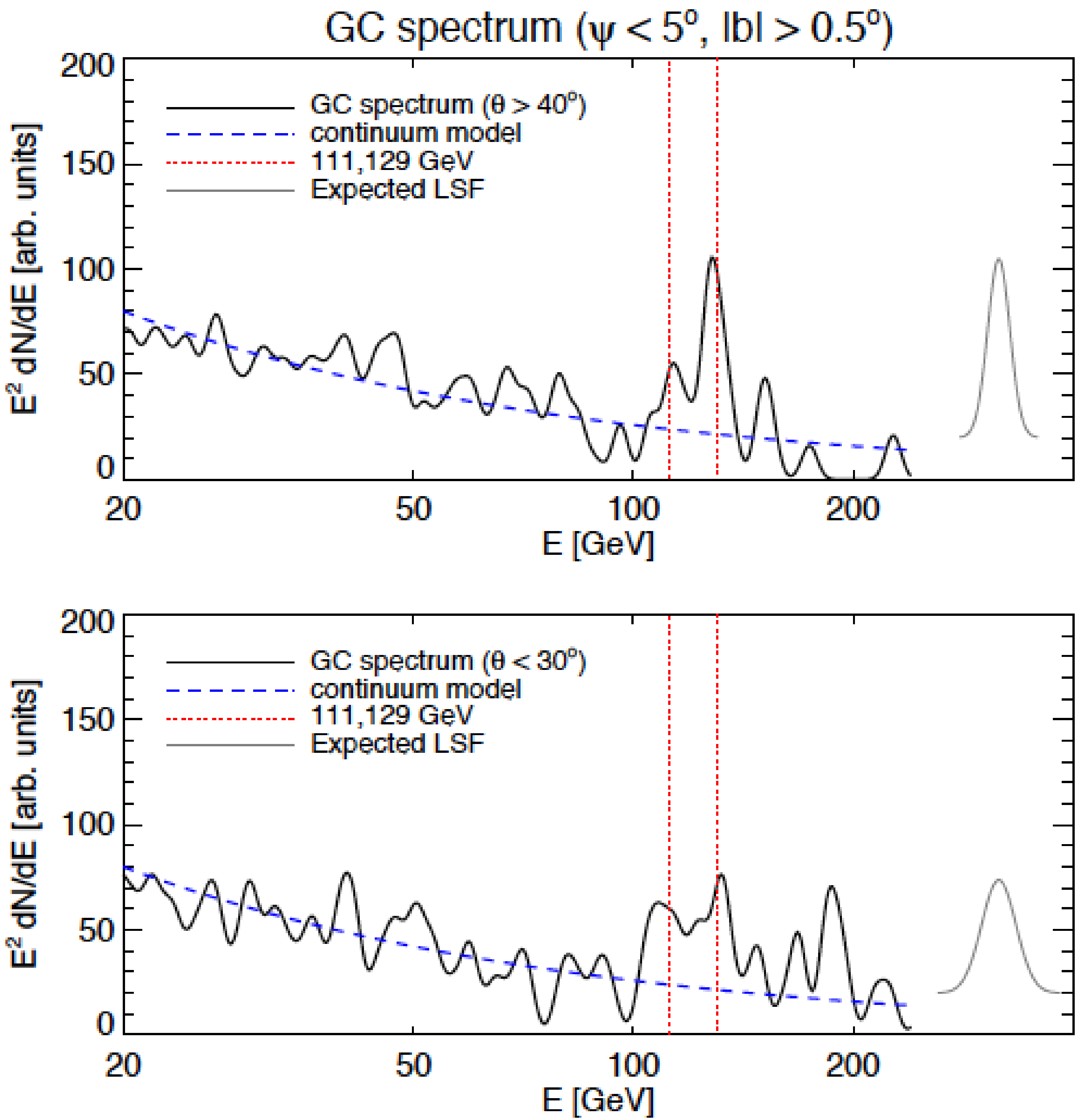
MENG SU[1,3], DOUGLAS P. FINKBEINER[1,2]

Draft version June 11, 2012

ABSTRACT

Using 3.7 years of *Fermi*-LAT data, we examine the diffuse gamma-ray emission in the inner Galaxy in the energy range 80 GeV $< E <$ 200 GeV. We find a diffuse gamma-ray feature at $\sim$ 110 GeV to $\sim$ 140 GeV which can be modeled by a $\lesssim 4°$ FWHM Gaussian in the Galactic center. The morphology is not correlated with the recently discovered *Fermi* bubbles. The null hypothesis of zero intensity is ruled out by 5.0σ (3.7σ with trials factor). The energy spectrum of this structure is consistent with a single spectral line (at energy 127.0 ± 2.0 GeV with $\chi^2 = 4.48$ for 4 d.o.f.). A pair of lines at 110.8 ± 4.4 GeV and 128.8 ± 2.7 GeV provides a marginally better fit (with $\chi^2 = 1.25$ for 2 d.o.f.). The total luminosity of the structure is $(3.2 \pm 0.6) \times 10^{35}$ erg/s, or $(1.7 \pm 0.4) \times 10^{36}$ photons/sec. The observation is compatible with a 142 GeV WIMP annihilating through γZ and γh for $m_h \sim 130$ GeV, as in the "Higgs in Space" scenario.

Subject headings: gamma rays — diffuse emission — milky way — dark matter



2 lines !??

Inclined photons (better energy resolution)

$$(3.2 \pm 0.6) \times 10^{35}\ \mathrm{erg/s}$$

$$(1.7 \pm 0.4) \times 10^{36}\ \mathrm{photons/sec}$$

Power
Of line emitter
Near GC.

142 GeV WIMP

$$m_h \sim 130$$

$$\gamma Z \qquad \gamma h$$

5.0 sigmas
3.7 sigmas
"with trials factors"

$$E_\gamma = m_\chi \left(1 - \frac{m_X^2}{4m_\chi^2}\right)$$

Is this credible ?

Is this real ?

Is this compatible with FERMI limits ? [YES]

Can this this have something to do with the
Pamela positron anomaly ? [very difficult]

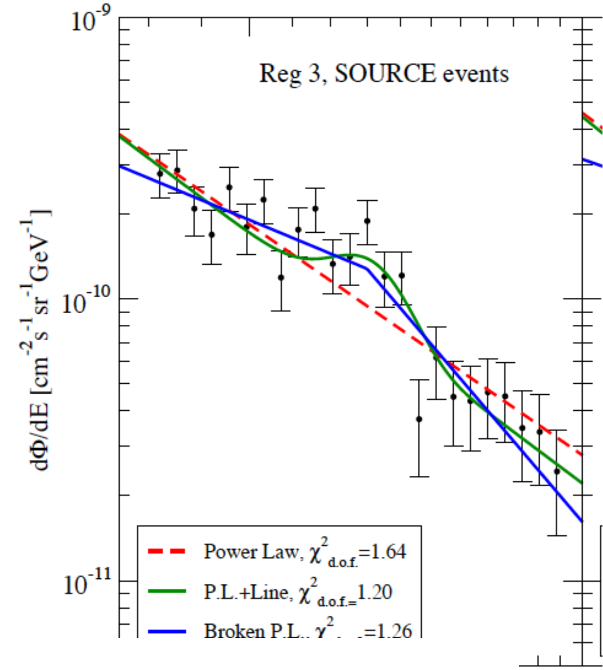
Signal displaced from Galaxy Center
by 1.5 degrees (200 pc).

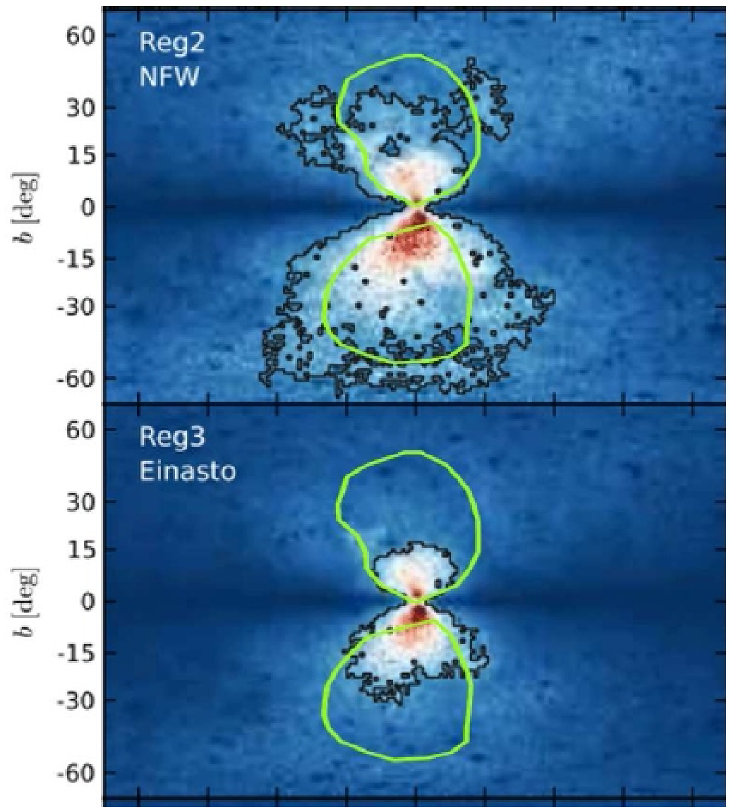
No official word from FERMI
Possibility of an instrumental effect
(hint of line in photons from Earth limb ?

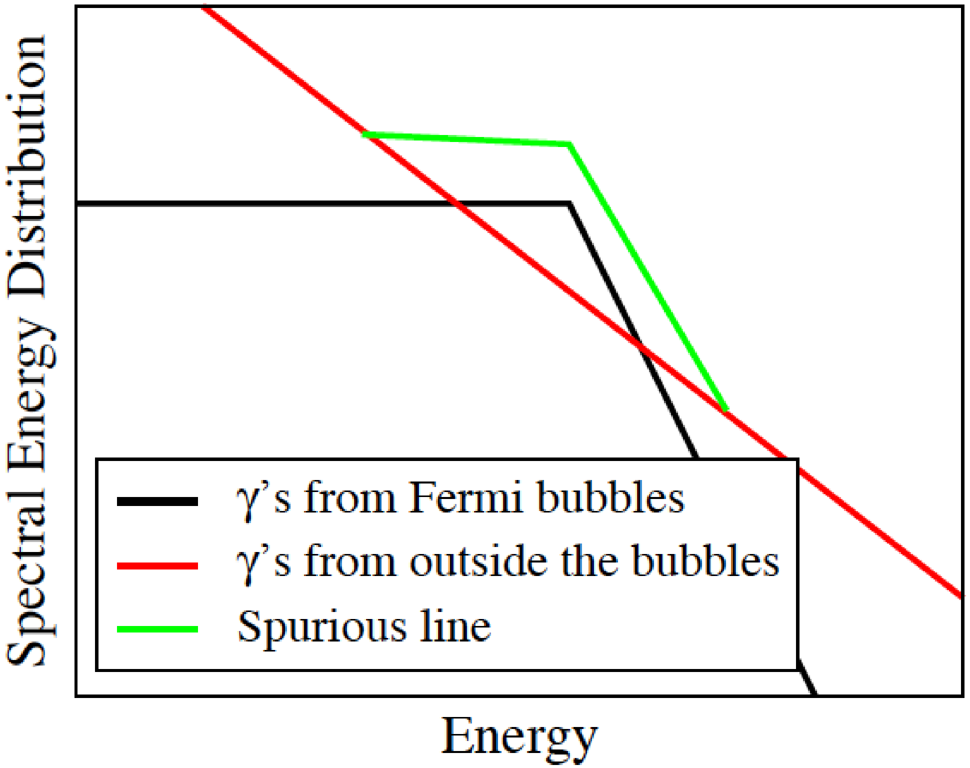
arXiv:1204.6047v1

GAMMA-RAY LINES IN THE FERMI DATA: IS IT A BUBBLE?

Stefano Profumo[1,2] and Tim Linden[1]



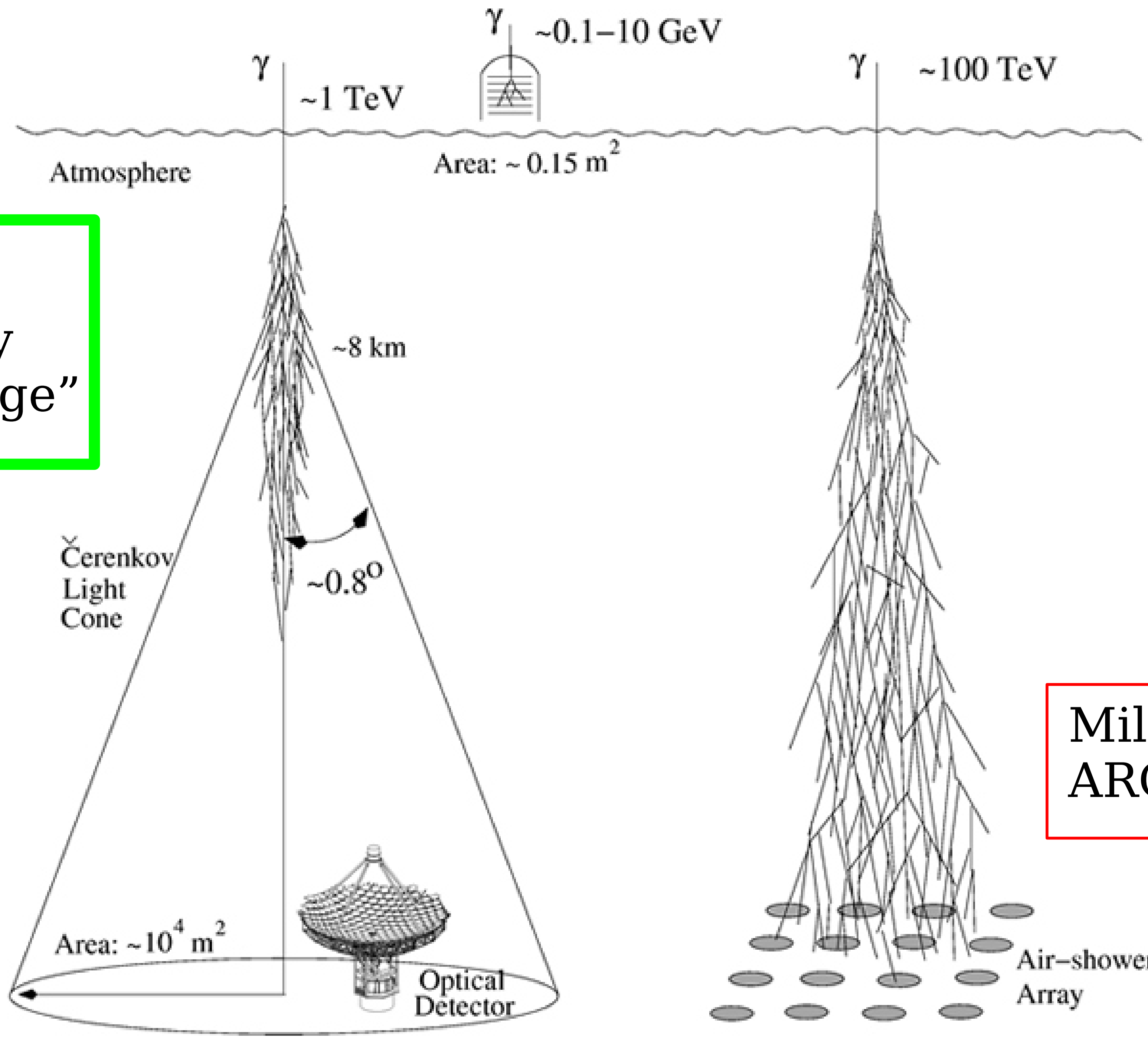




Sources of High Energy Particles in the Milky Way and the Universe

Egret
Agile
Fermi

Gamma
Astronomy
“Golden Age”



Milagro
ARGO

Hess
Magic
Veritas

Francesco Longo (AGILE)
Gino Tosti (Fermi)
Alessandro De Angelis (MAGIC + Cherenkov Telescopes)

Future of Gamma Astronomy is very promising !

CTA (Cherenkov Telescope Array

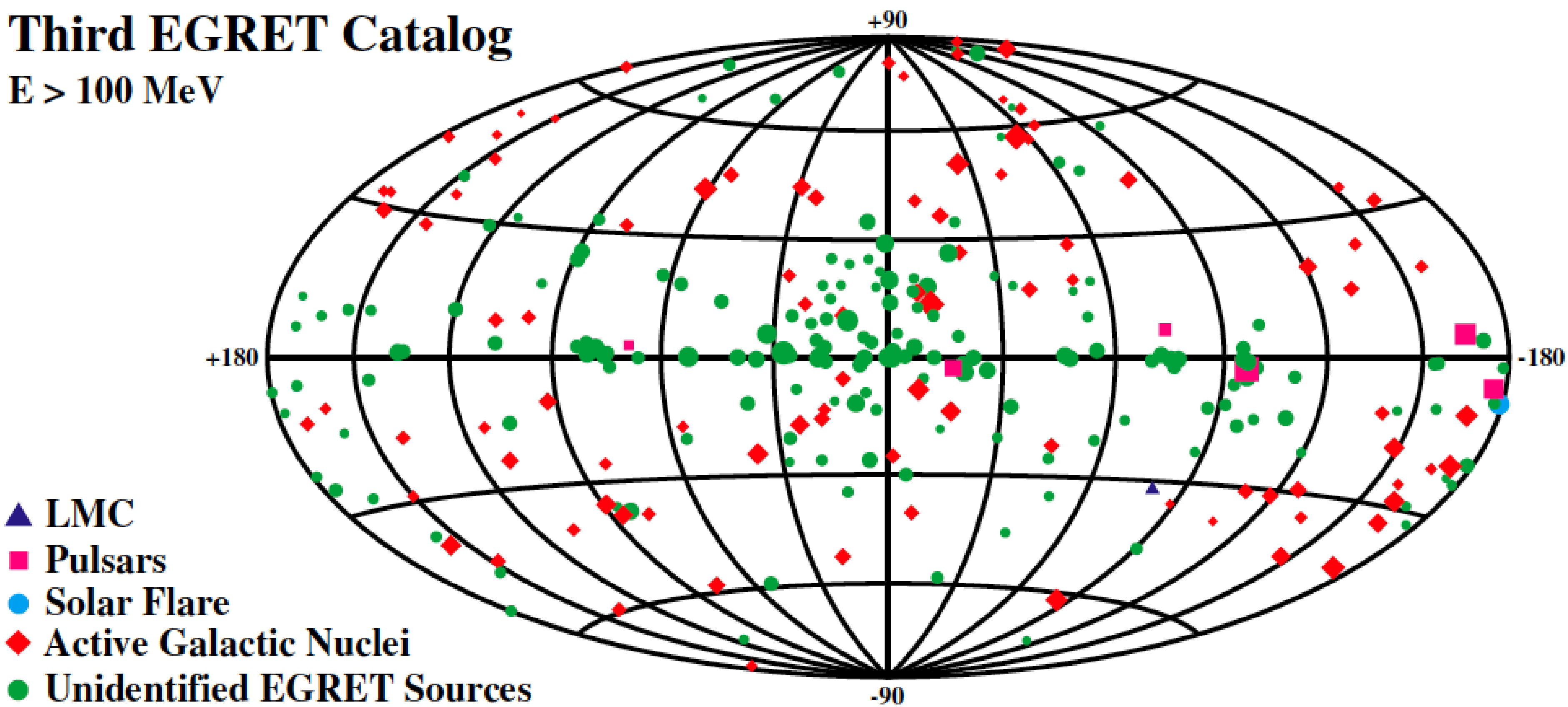
Alessandro De Angelis

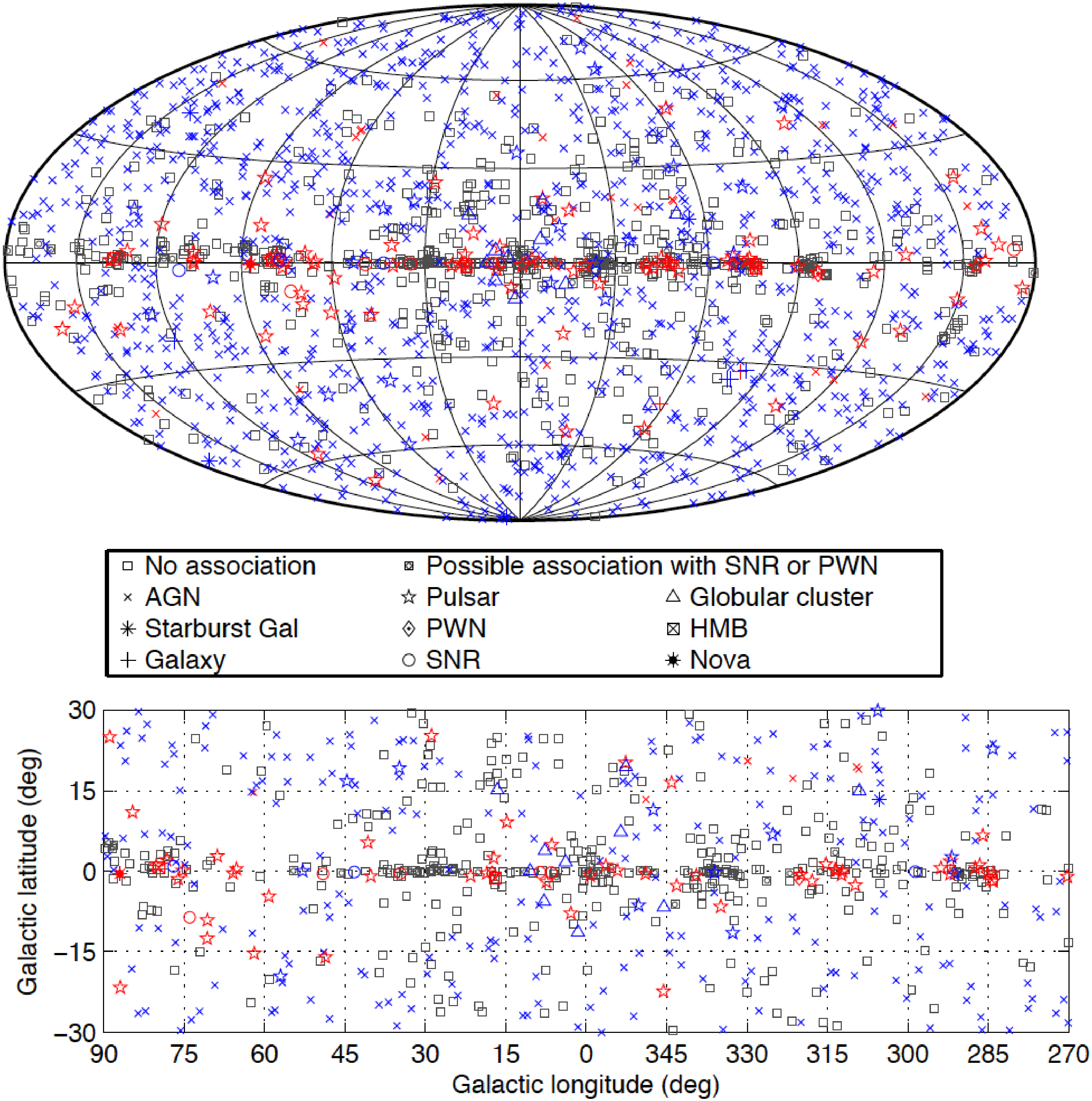
Gamma-400

Walter Bonvincini

.... Madamina il catalogo e' questo ....

Situation in year 2000





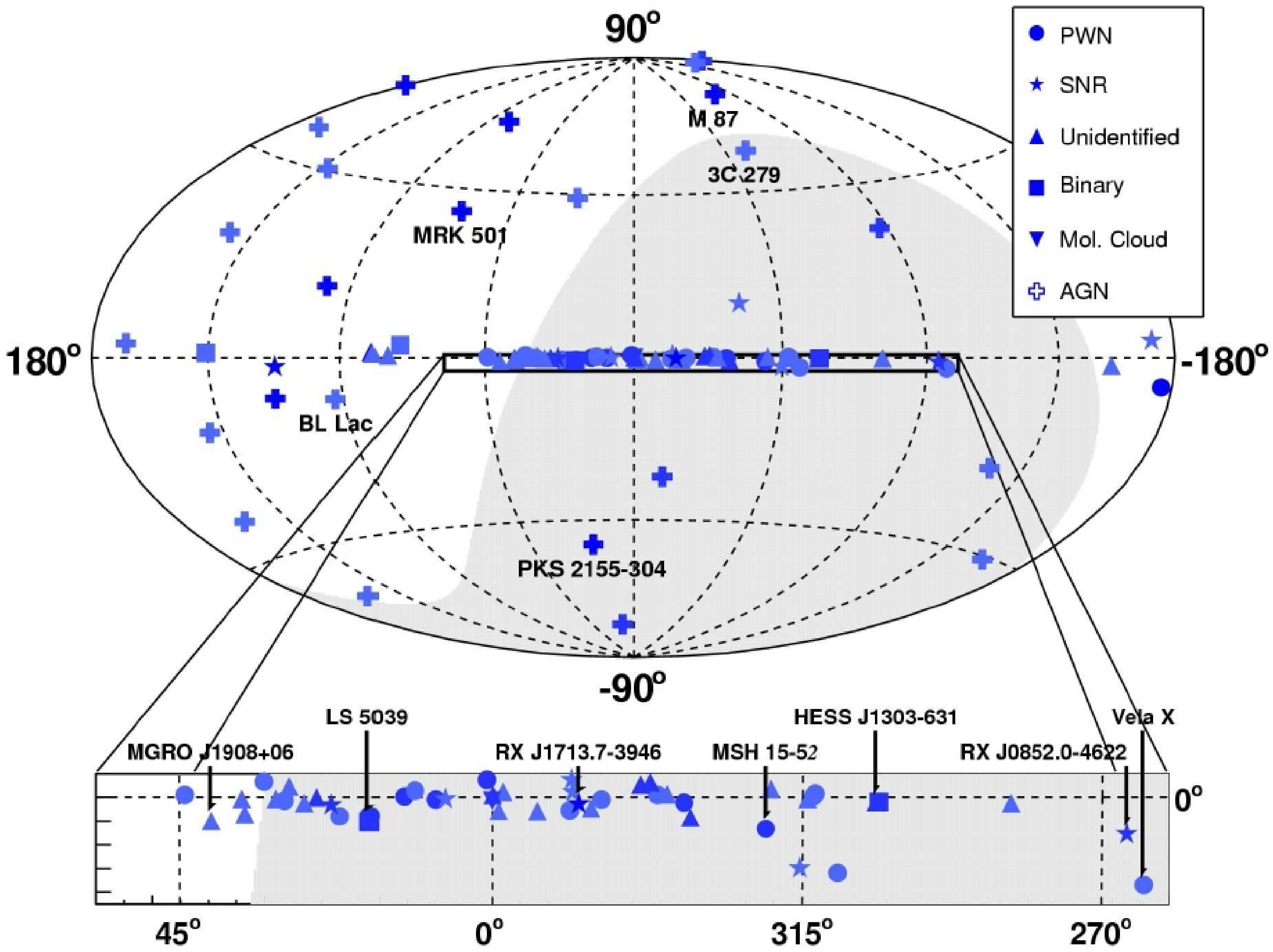
2FGL

2^{nd} FERMI Catalog

24 months
of observations

1873 sources

TEV SKY



90°
-90°
180°
-180°
PWN
SNR
Unidentified
Binary
Mol. Cloud
AGN
M 87
3C 279
MRK 501
BL Lac
PKS 2155-304
MGRO J1908+06
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
Vela X
0°
45°
315°
270°

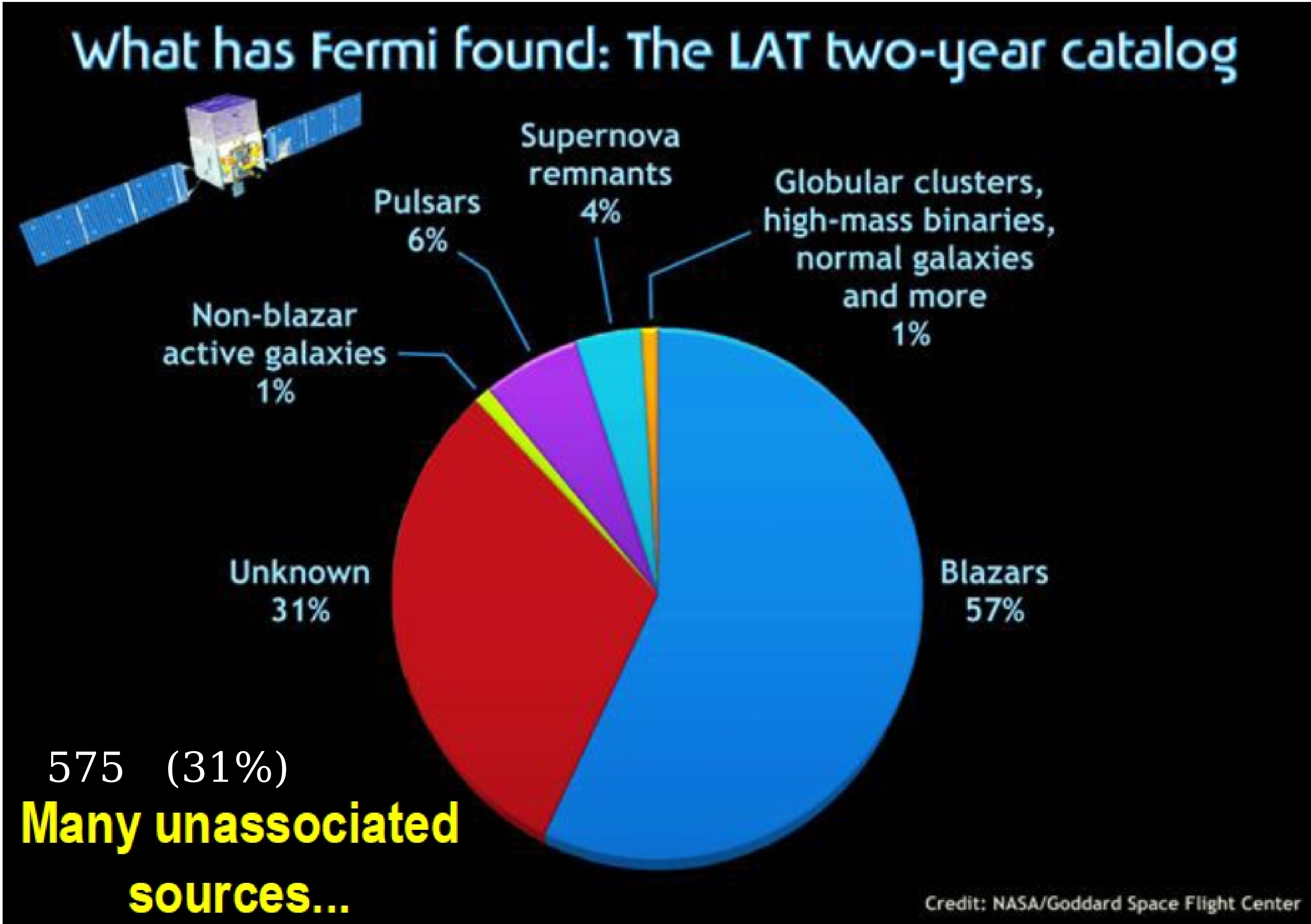

What has Fermi found: The LAT two-year catalog
Supernova remnants 4%
Pulsars 6%
Globular clusters, high-mass binaries, normal galaxies and more 1%
Non-blazar active galaxies 1%
Unknown 31%
Blazars 57%
575 (31%)
Many unassociated sources...
Credit: NASA/Goddard Space Flight Center

Table 6. LAT 2FGL Source Classes

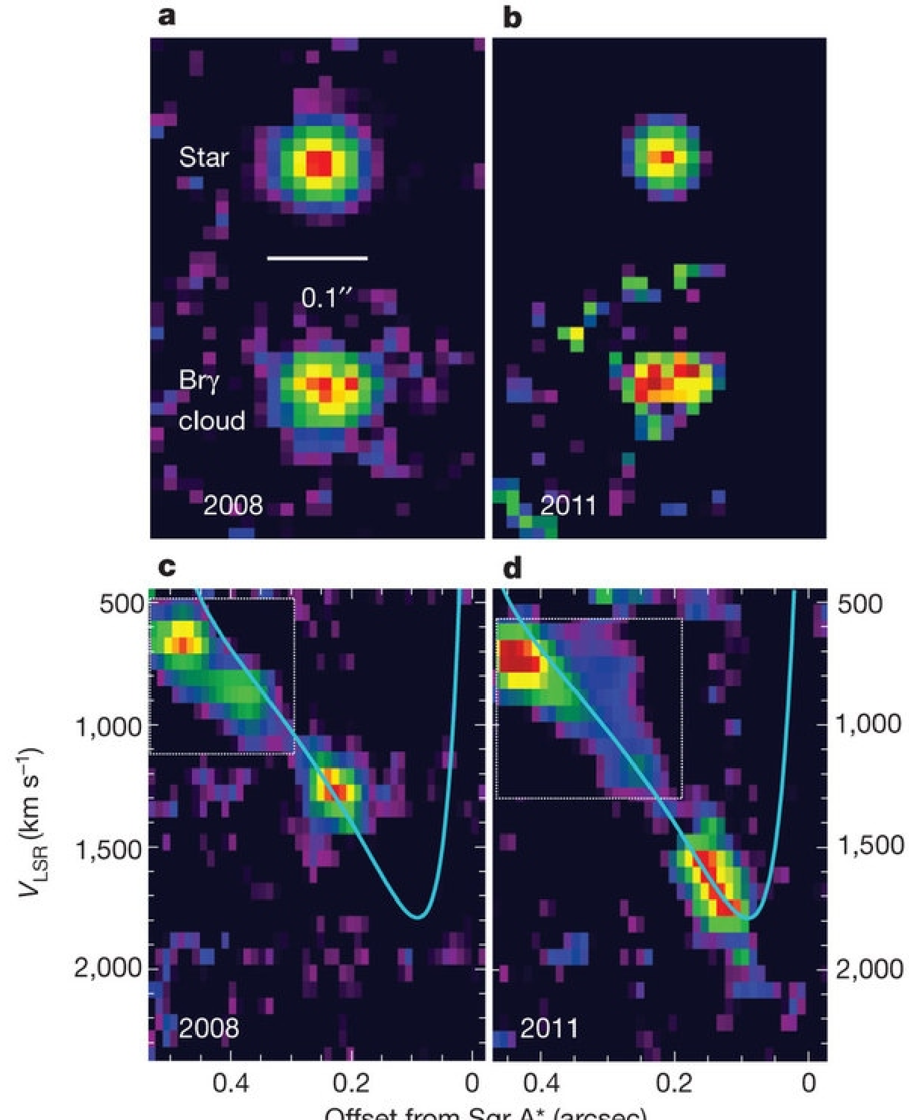
Description	Identified Designator	Identified Number	Associated Designator	Associated Number
Pulsar, identified by pulsations	PSR	83	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	25
Pulsar wind nebula	PWN	3	pwn	0
Supernova remnant	SNR	6	snr	4
Supernova remnant / Pulsar wind nebula	...	...	†	58
Globular cluster	GLC	0	glc	11
High-mass binary	HMB	4	hmb	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BZB	7	bzb	429
FSRQ type of blazar	BZQ	17	bzq	353
Non-blazar active galaxy	AGN	1	agn	10
Radio galaxy	RDG	2	rdg	10
Seyfert galaxy	SEY	1	sey	5
Active galaxy of uncertain type	AGU	0	agu	257
Normal galaxy (or part)	GAL	2	gal	4
Starburst galaxy	SBG	0	sbg	4
Class uncertain	...	...	...	1
Unassociated	...	...	...	575
Total	...	127	...	1746

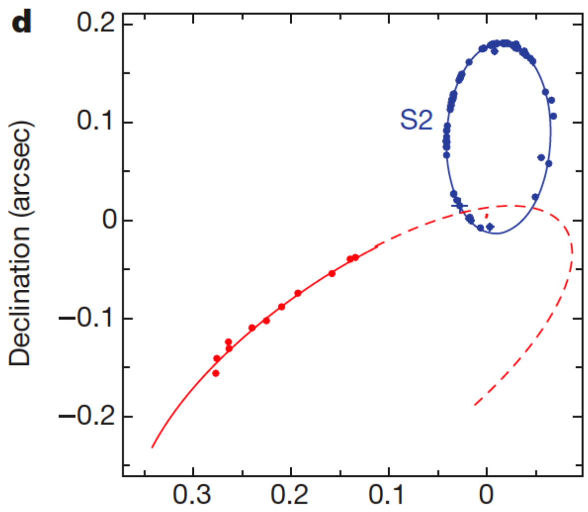
Galactic Center

doi:10.1038/nature10652

A gas cloud on its way towards the supermassive black hole at the Galactic Centre

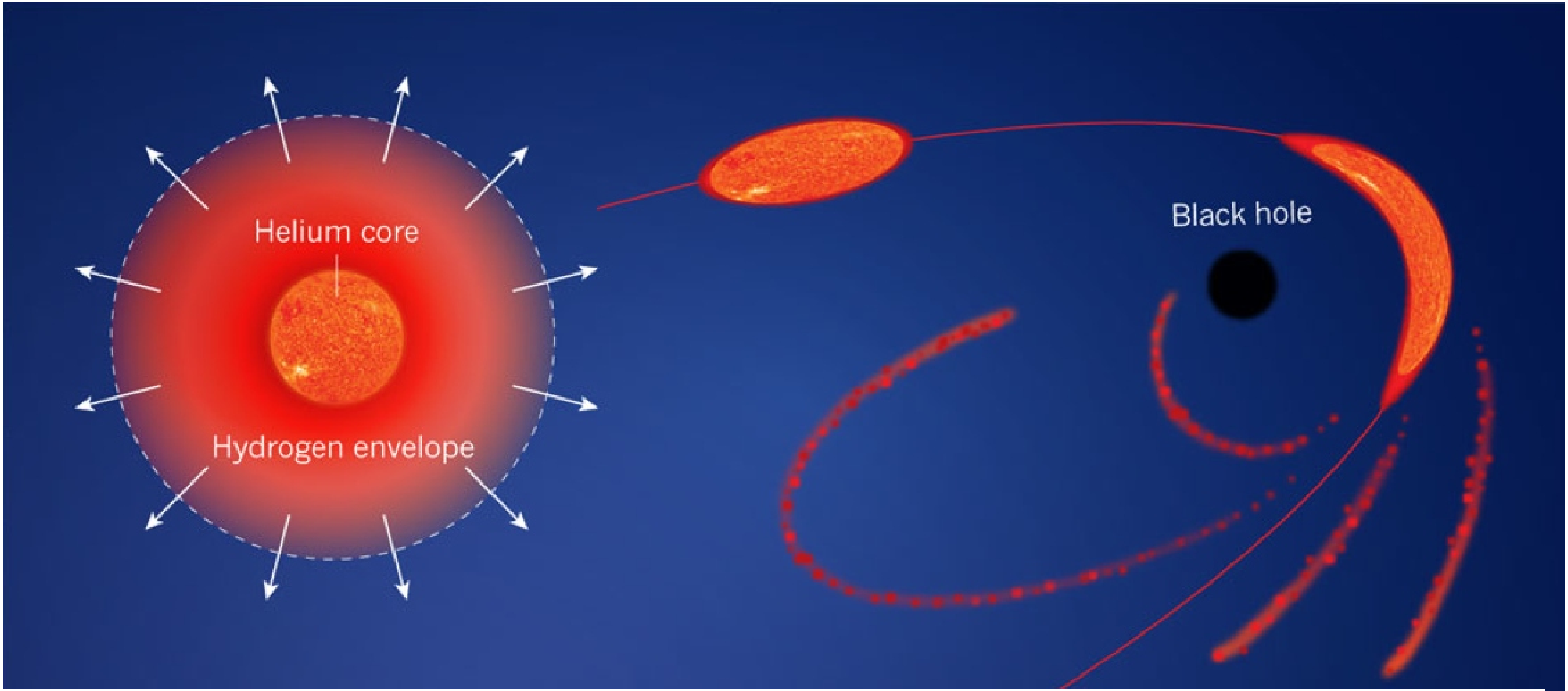
S. Gillessen[1], R. Genzel[1,2], T. K. Fritz[1], E. Quataert[3], C. Alig[4], A. Burkert[4,1], J. Cuadra[5], F. Eisenhauer[1], O. Pfuhl[1], K. Dodds-Eden[1], C. F. Gammie[6] & T. Ott[1]



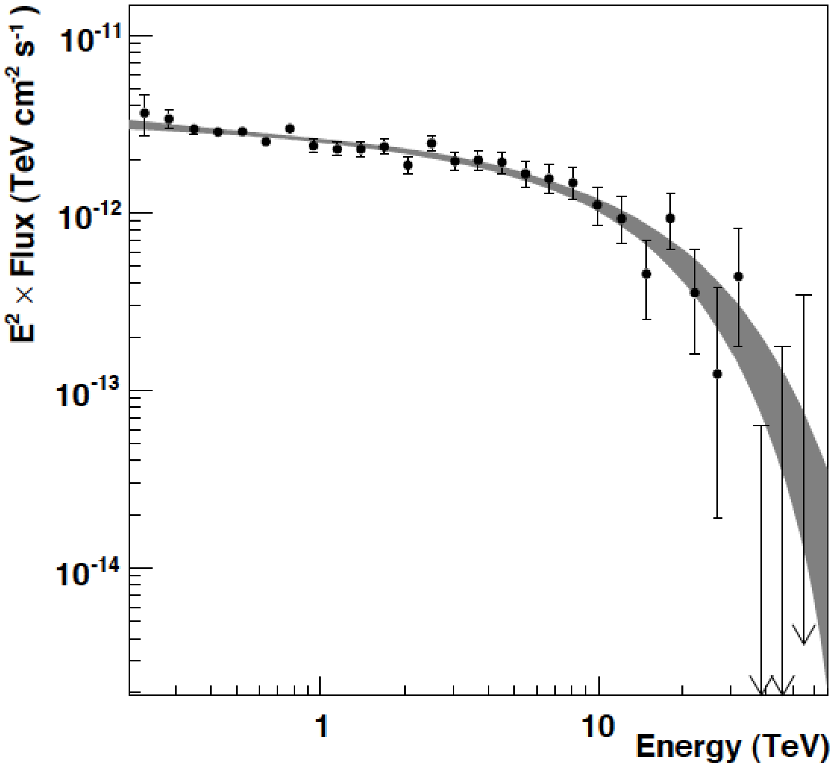


Infalling gas
from the disruption of a star.

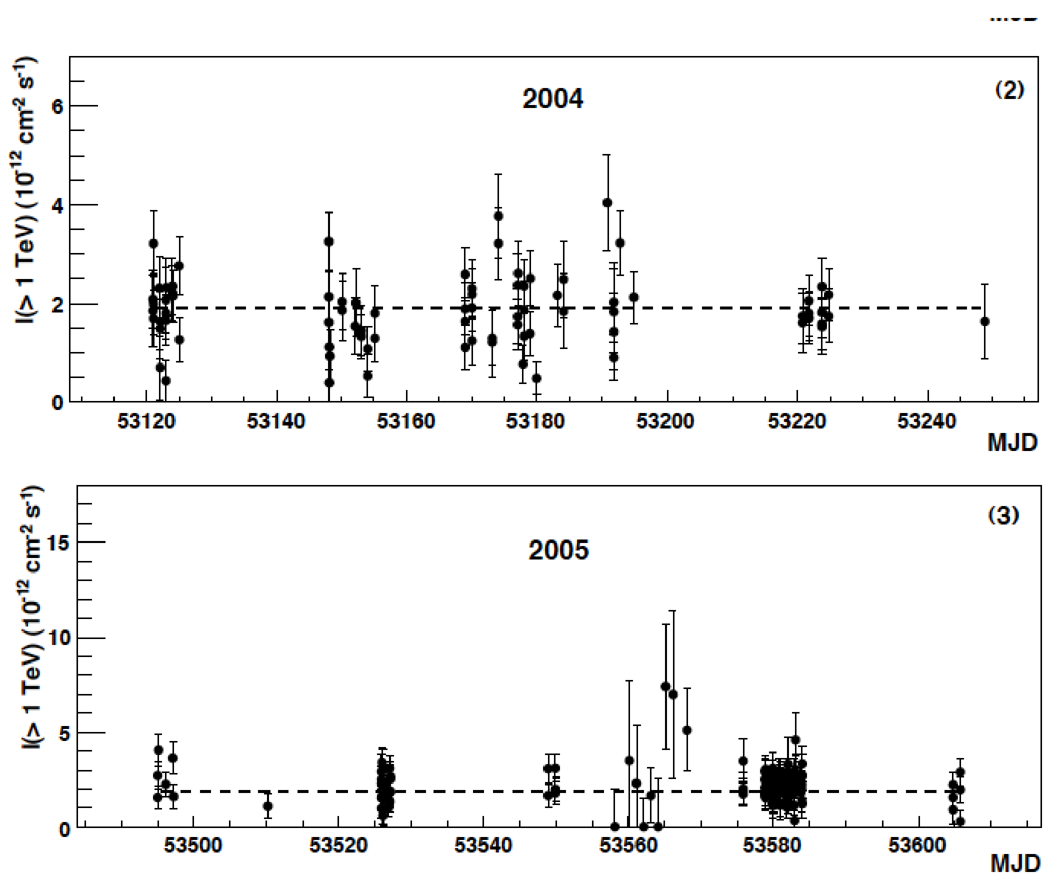
Gas will reach the BH horizon
In 2013



The helium-rich core of a red-giant star that had previously lost its hydrogen envelope moves on an almost parabolic orbit (red) towards a supermassive black hole. The sequence of blobs illustrates the progressive distortion of the star's core due to the tidal pull of the black hole. After the point of closest approach to the black hole, the core is completely disrupted, with part of the resulting debris being expelled from the system and part being launched into highly eccentric orbits, eventually falling onto the black hole. Accretion of this debris gives rise to the intense ultraviolet–optical flare that has been observed by Gezari and colleagues[1].

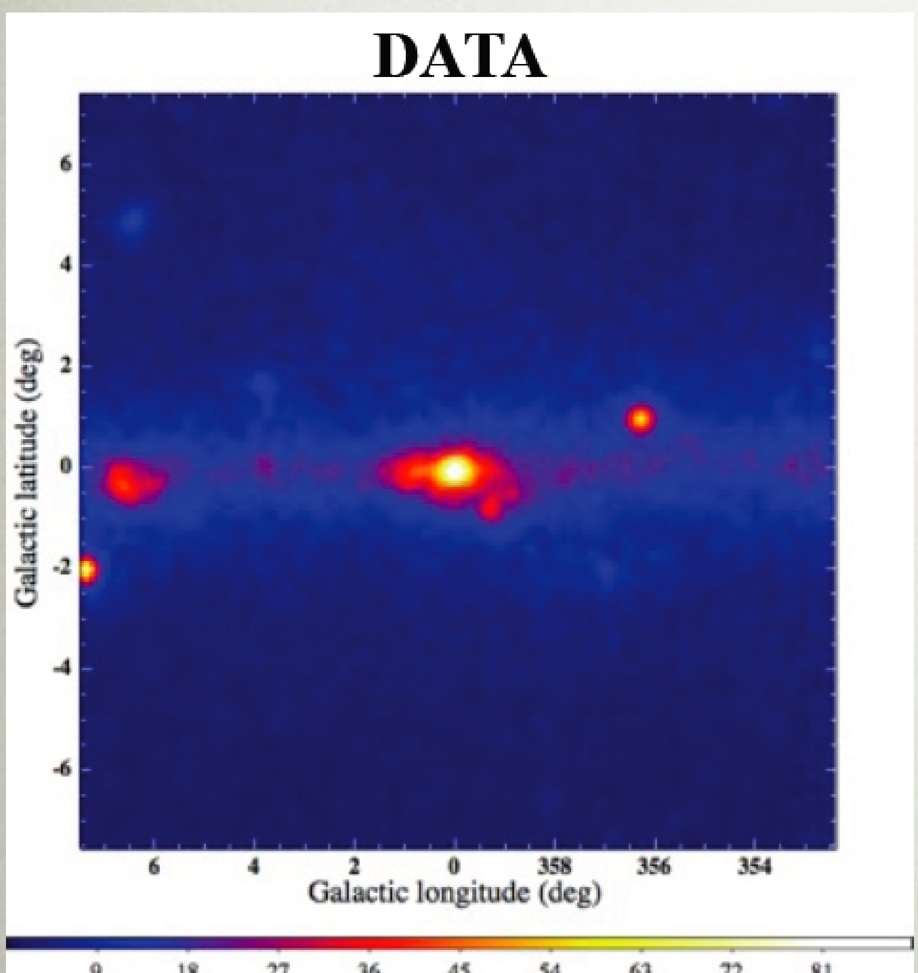


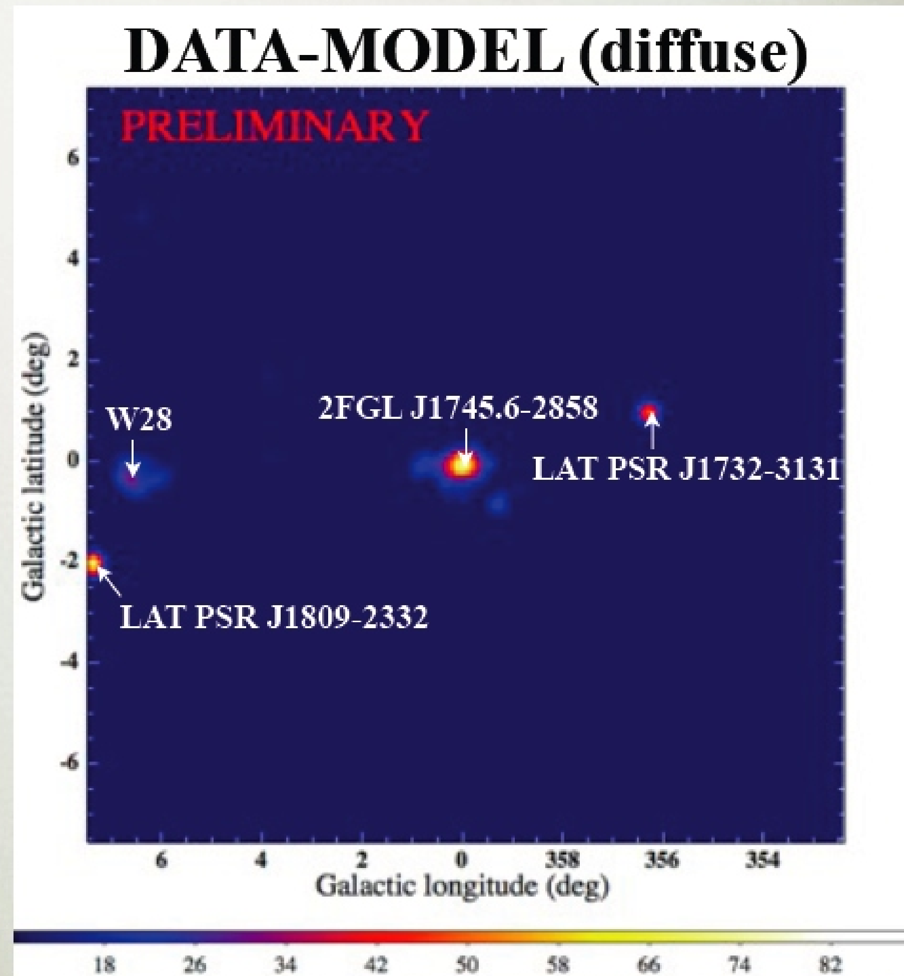
HESS observations
of Galactic Center
Sgr A*



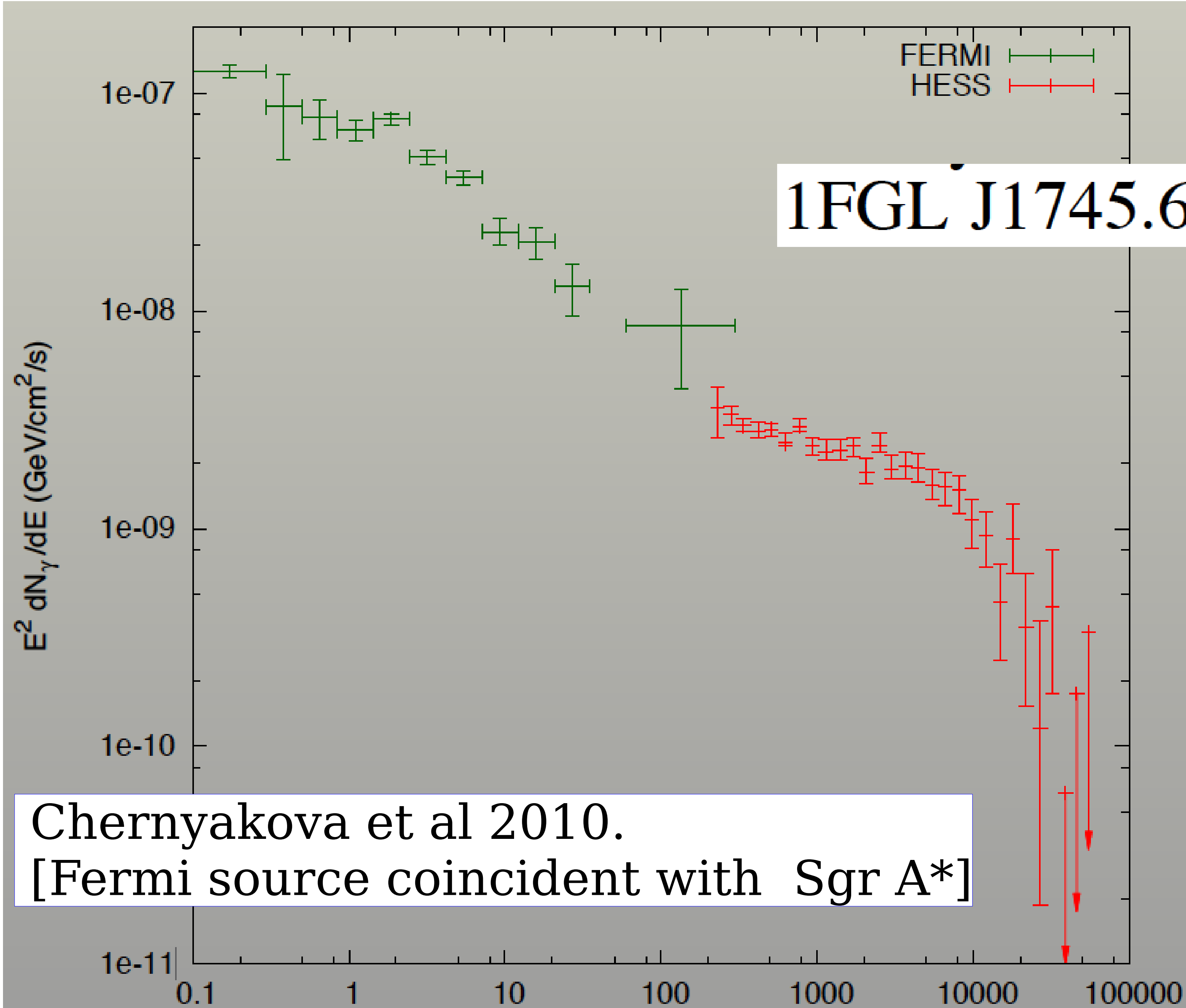
Fermi's View of the Inner Galaxy (15°x15° region)

Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT):



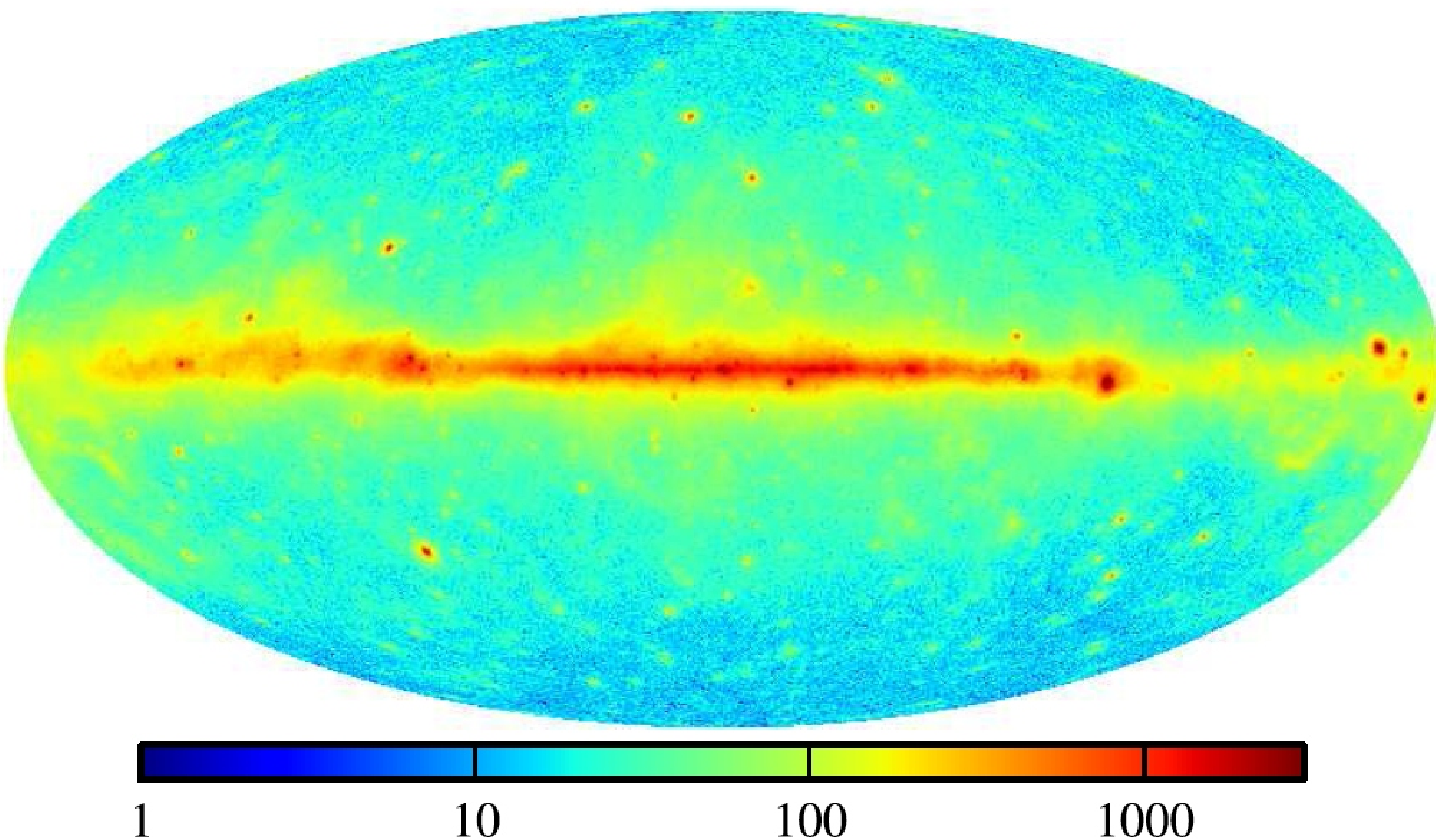


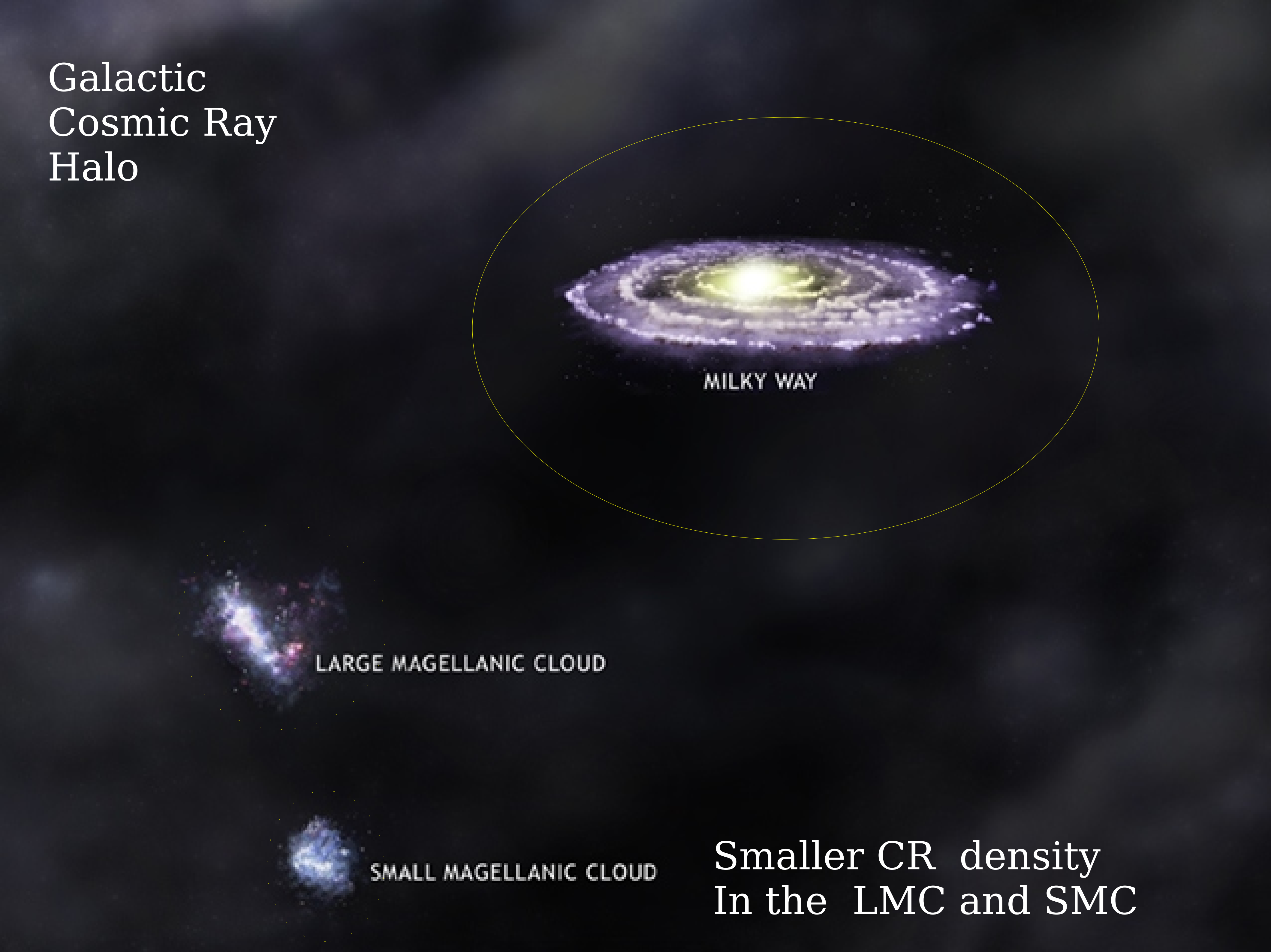
1FGL J1745.6-2900

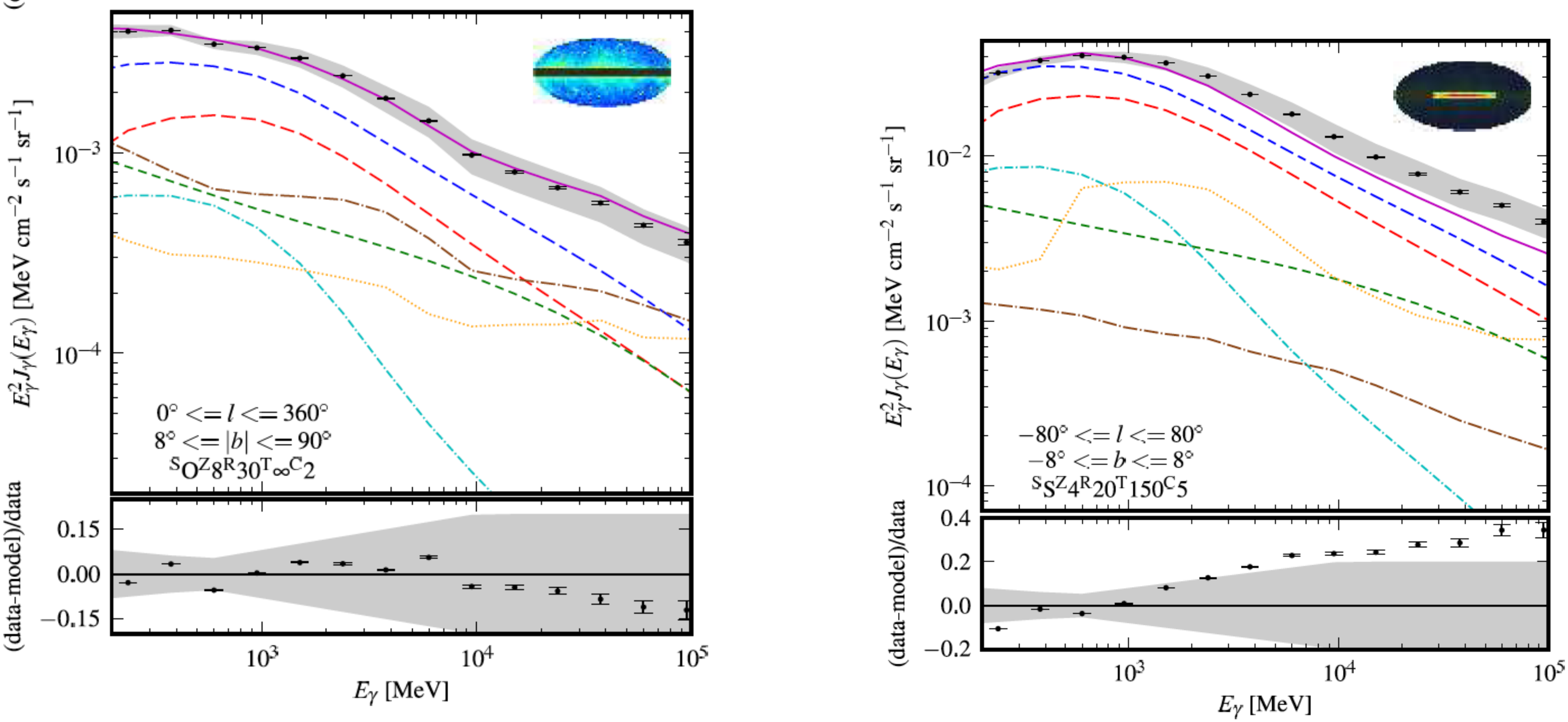


Chernyakova et al 2010.
[Fermi source coincident with Sgr A*]

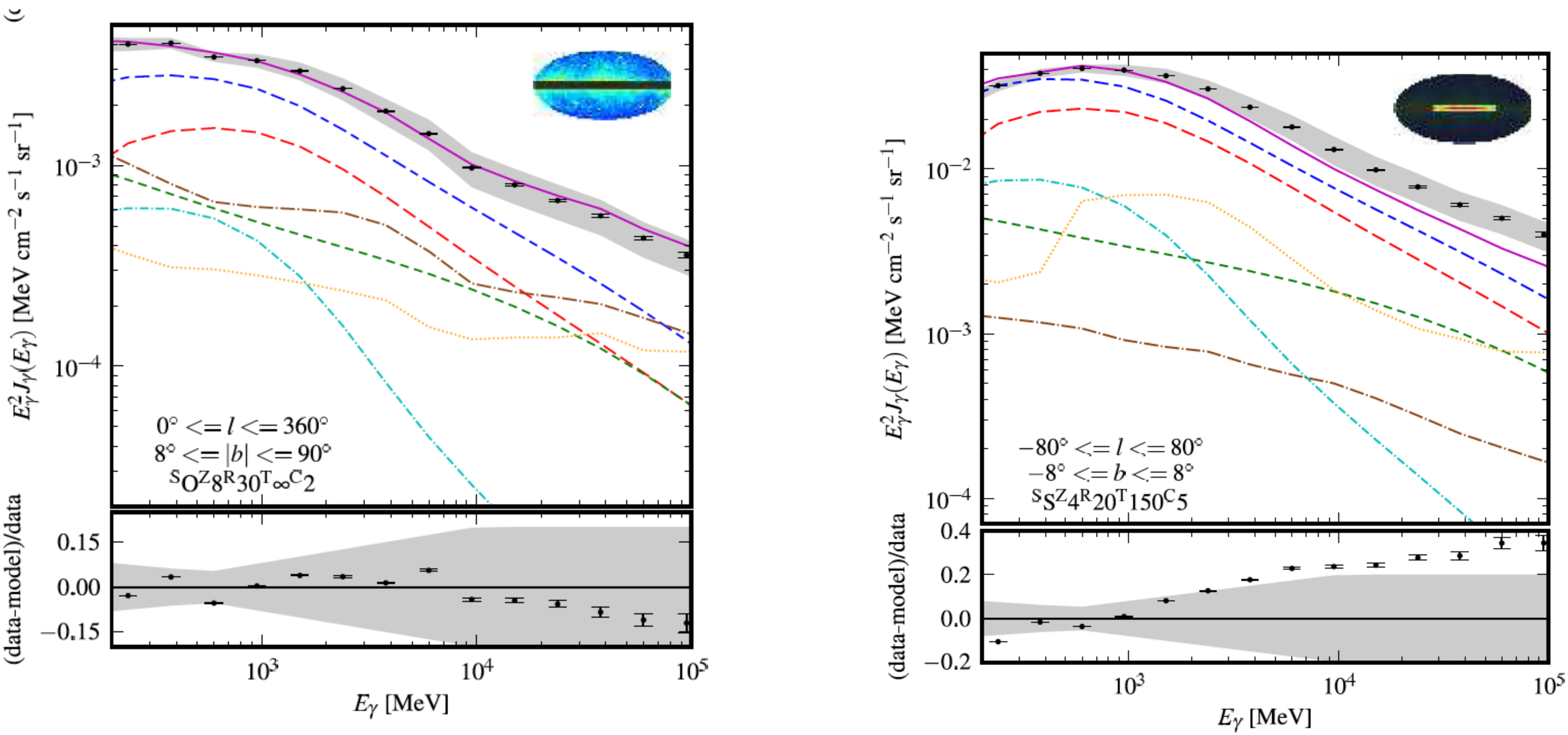
Fermi–LAT counts energy range 200 MeV to 100 GeV



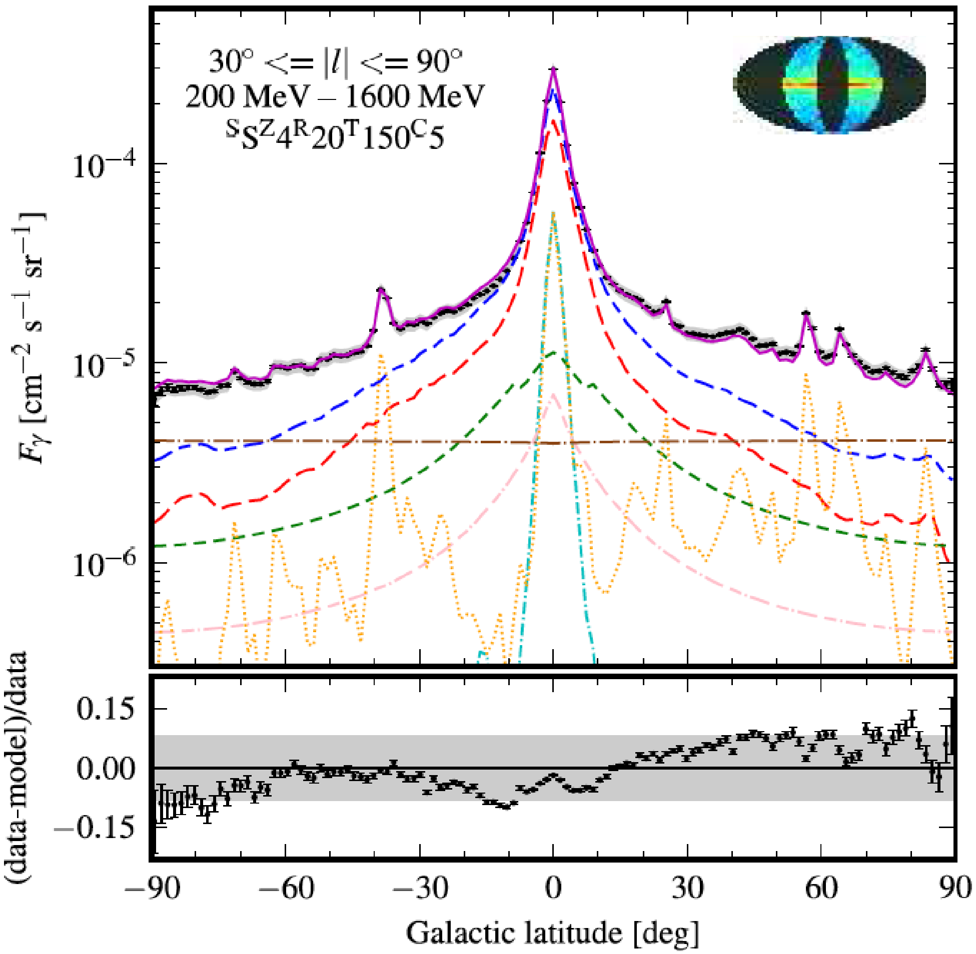

Galactic
Cosmic Ray
Halo
MILKY WAY
LARGE MAGELLANIC CLOUD
SMALL MAGELLANIC CLOUD
Smaller CR density
In the LMC and SMC

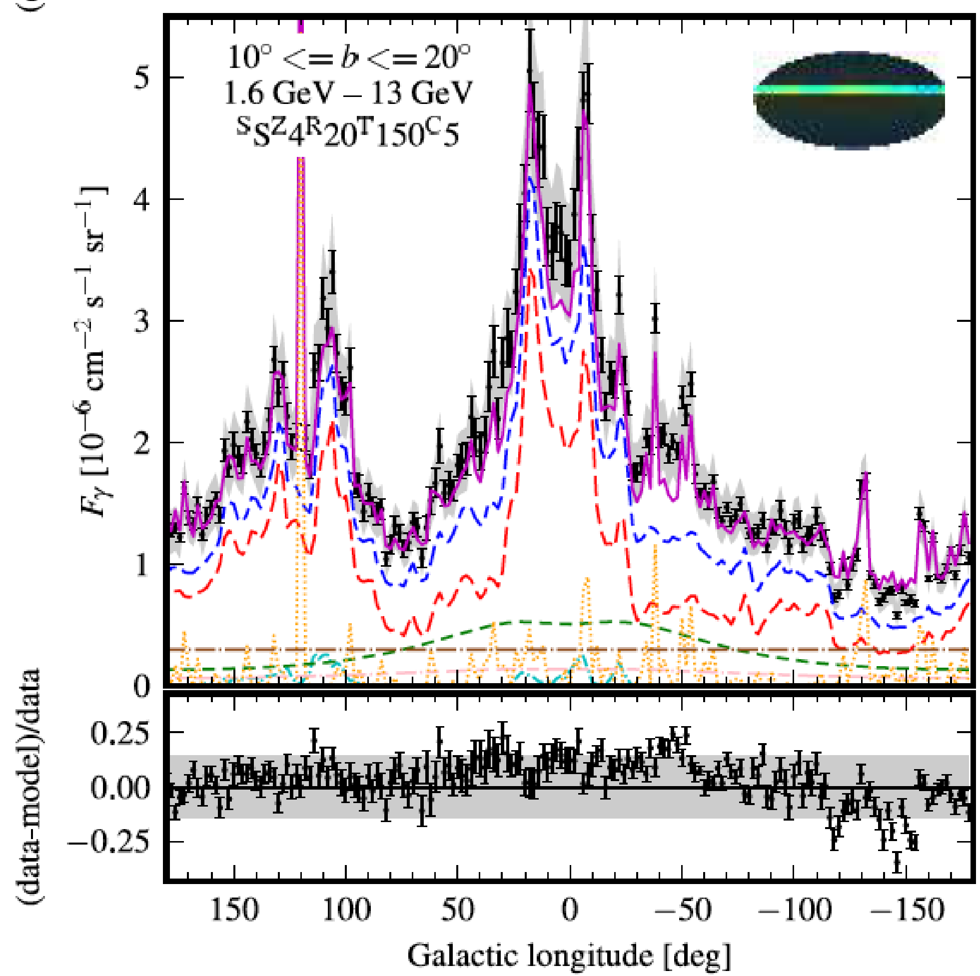


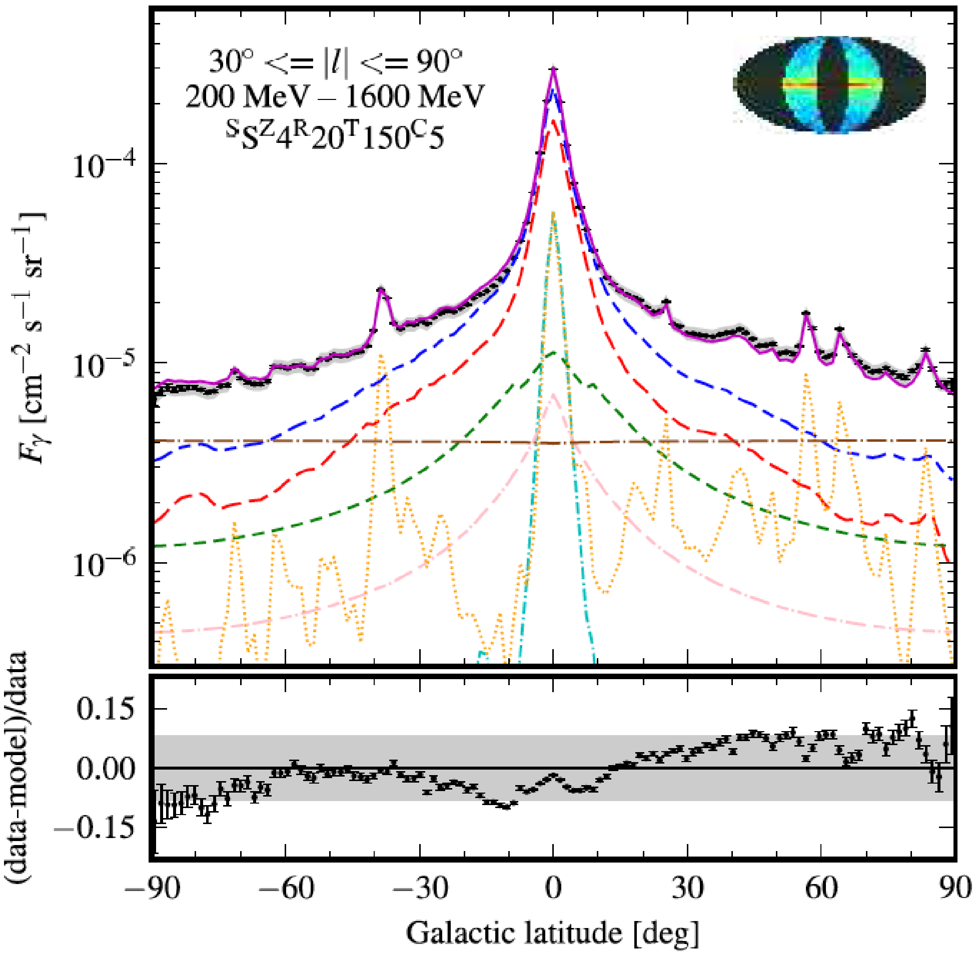
detected sources (orange, dotted). The models are split into the three basic emission components: π^0-decay (red, long-dashed), IC (green, dashed), and bremsstrahlung (cyan, dash-dotted). All components have been scaled with parameters found from the γ-ray-fits. Also shown is the total DGE (blue, long-dash-dashed) and total emission including detected sources and isotropic background (magenta, solid). The *Fermi*–LAT data are shown as points and the error bars represent the statistical errors only that are in many cases smaller than the point size. The gray region represents the systematic error in the *Fermi*–LAT effective area. The inset skymap in the top right corner shows the *Fermi*–LAT counts in the region plotted. Bottom panel shows the fractional residual $(data - model)/data$.

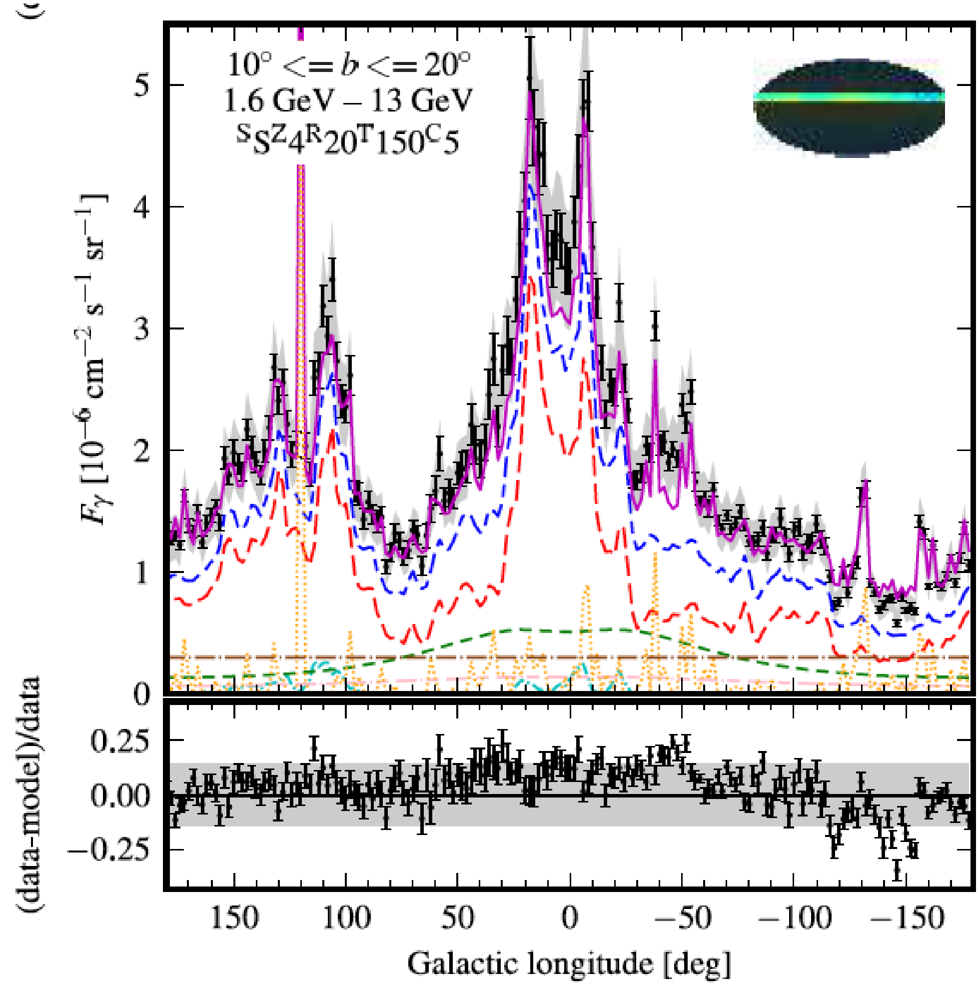


detected sources (orange, dotted). The models are split into the three basic emission components: π^0-decay (red, long-dashed), IC (green, dashed), and bremsstrahlung (cyan, dash-dotted). All components have been scaled with parameters found from the γ-ray-fits. Also shown is the total DGE (blue, long-dash-dashed) and total emission including detected sources and isotropic background (magenta, solid). The *Fermi*–LAT data are shown as points and the error bars represent the statistical errors only that are in many cases smaller than the point size. The gray region represents the systematic error in the *Fermi*–LAT effective area. The inset skymap in the top right corner shows the *Fermi*–LAT counts in the region plotted. Bottom panel shows the fractional residual $(data - model)/data$.


30° <= |l| <= 90°
200 MeV – 1600 MeV
$^{S}S^{Z}4^{R}20^{T}150^{C}5$
F_γ [cm^{-2} s^{-1} sr^{-1}]
(data-model)/data
Galactic latitude [deg]


10° <= b <= 20°
1.6 GeV – 13 GeV
$^{S}S^{Z}4^{R}20^{T}150^{C}5$
F_γ [10^{-6} cm^{-2} s^{-1} sr^{-1}]
(data-model)/data
Galactic longitude [deg]





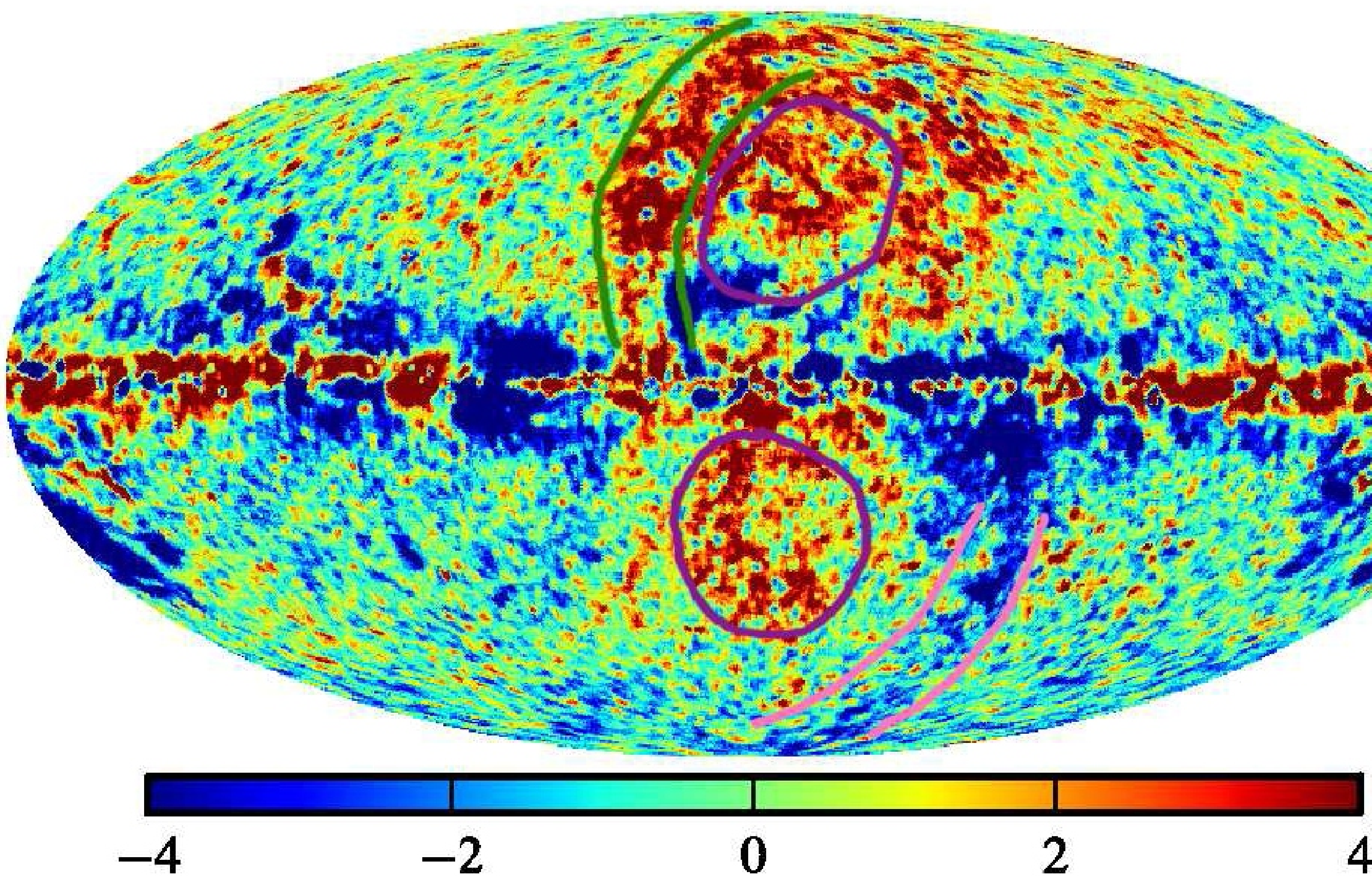
Description reasonably succcessful.
But several ambiguities and open problems remain.

Residual maps in units of standard deviation

model ${}^{S}S^{Z}4^{R}20^{T}150^{C}5$

Loop I (green)

Magellanic stream (pink)



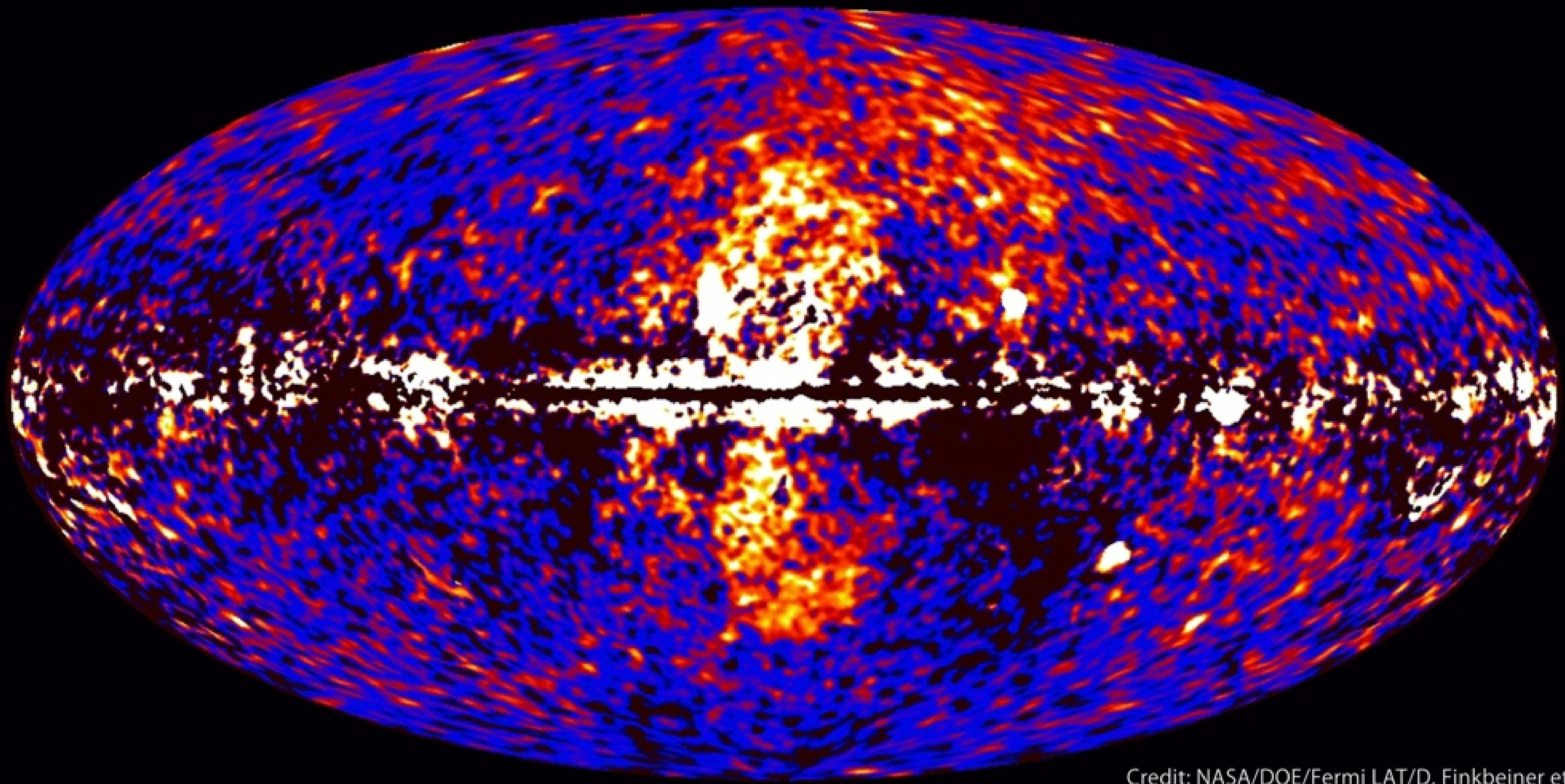
The

"FERMI BUBBLES"

"hidden in plain sight (!)"

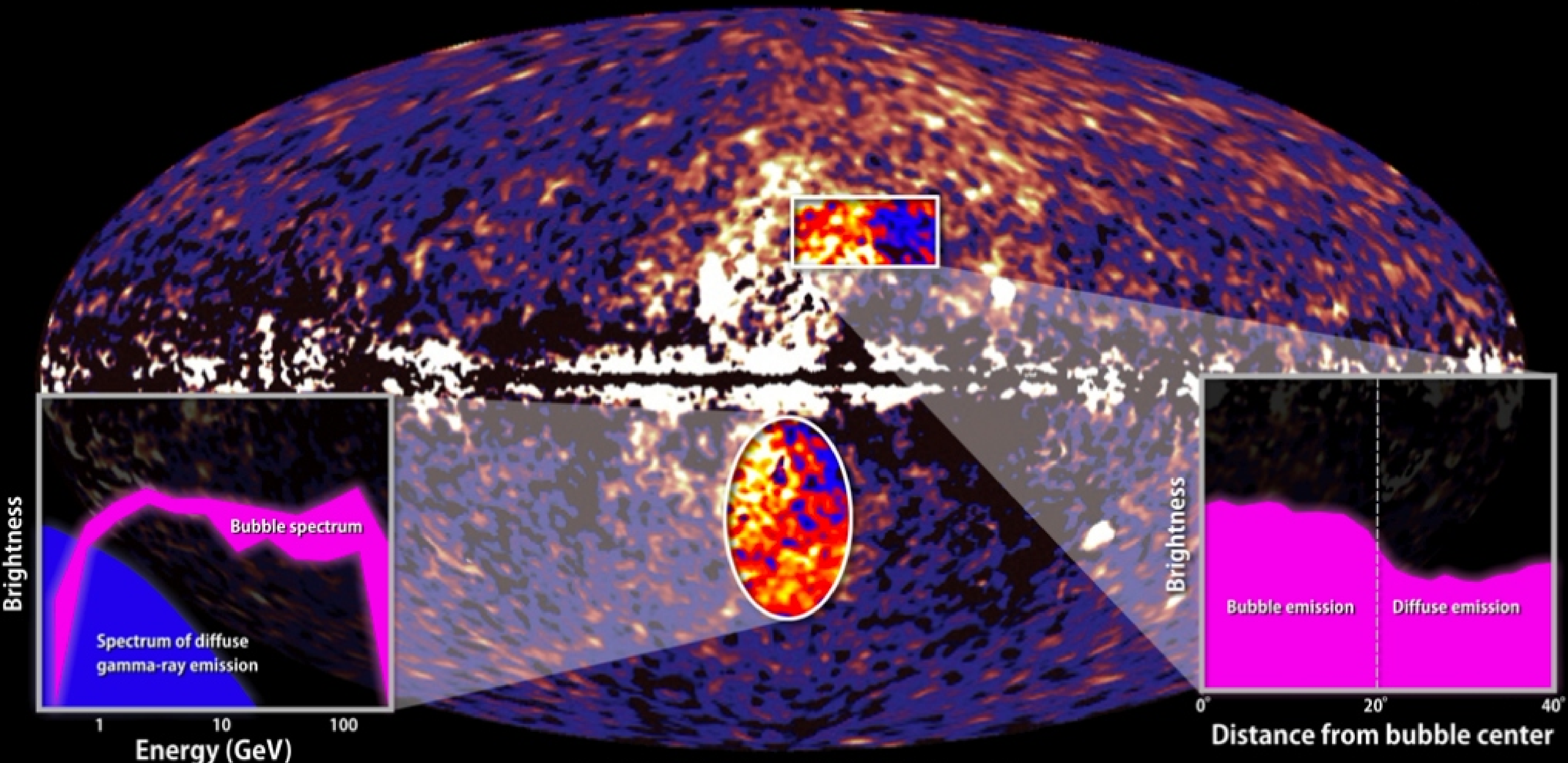
Scientific American news. Title:

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

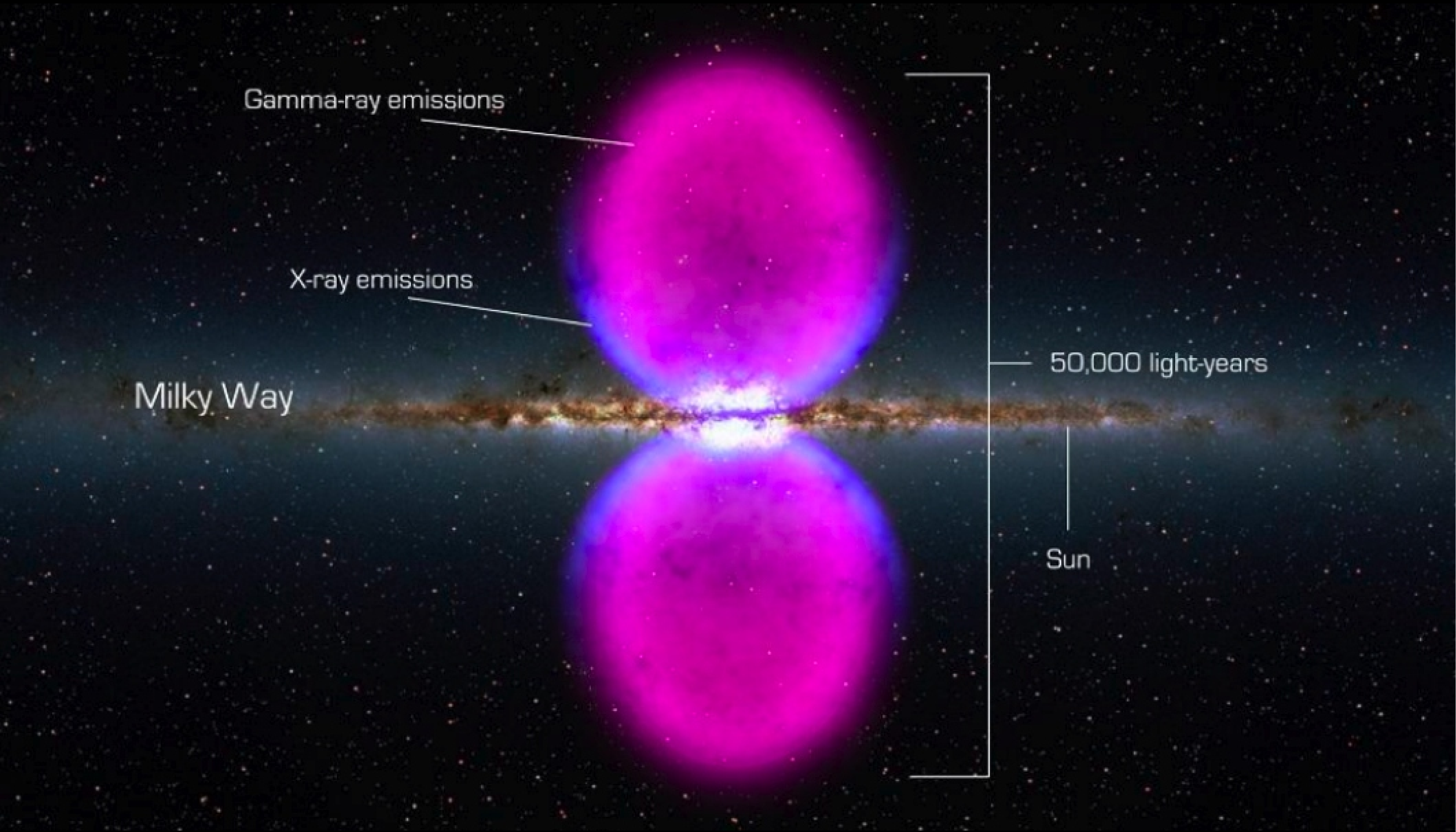


M. Su, T. R. Slatyer, D. P. Finkbeiner,
"Giant Gamma-ray Bubbles from Fermi-LAT: AGN Activity or Bipolar Galactic Wind?,"
Astrophys. J. **724**, 1044-1082 (2010). [arXiv:1005.5480 [astro-ph.HE]].

Bubbles show energetic spectrum and sharp edges



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



Artist's view of the “Fermi bubbles”

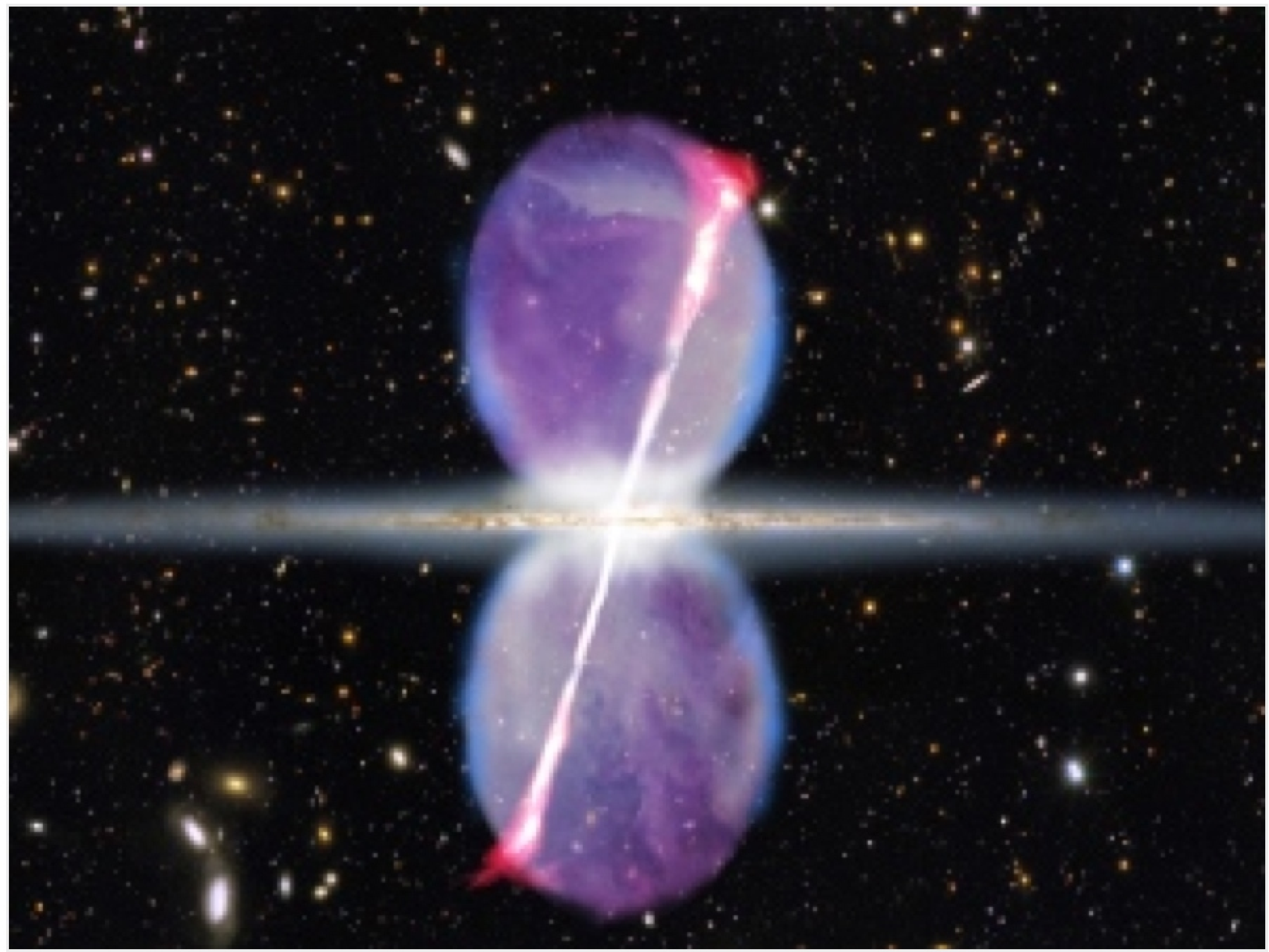
NATURE | NEWS

Ghostly jets seen streaming from Milky Way's core

Faint γ-rays indicate recent activity for Galaxy's supermassive black hole.

Ron Cowen

30 May 2012 | Corrected: 31 May 2012



Draft version May 29, 2012
Preprint typeset using LaTeX style emulateapj v. 03/07/07

EVIDENCE FOR GAMMA-RAY JETS IN THE MILKY WAY

Meng Su[1,3], Douglas P. Finkbeiner[1,2]

Draft version May 29, 2012

ABSTRACT

Although accretion onto supermassive black holes in other galaxies is seen to produce powerful jets in X-ray and radio, no convincing detection has ever been made of a kpc-scale jet in the Milky Way. The recently discovered pair of 10 kpc tall gamma-ray bubbles in our Galaxy may be signs of earlier jet activity from the central black hole. In this paper, we identify a gamma-ray cocoon feature in the southern bubble, a jet-like feature along the cocoon's axis of symmetry, and another directly opposite the Galactic center in the north. Both the cocoon and jet-like feature have a hard spectrum with spectral index ~ -2 from 1 to 100 GeV, with a cocoon total luminosity of $(5.5 \pm 0.45) \times 10^{35}$ and luminosity of the jet-like feature of $(1.8 \pm 0.35) \times 10^{35}$ erg/s at $1 - 100$ GeV. If confirmed, these jets are the first resolved gamma-ray jets ever seen.

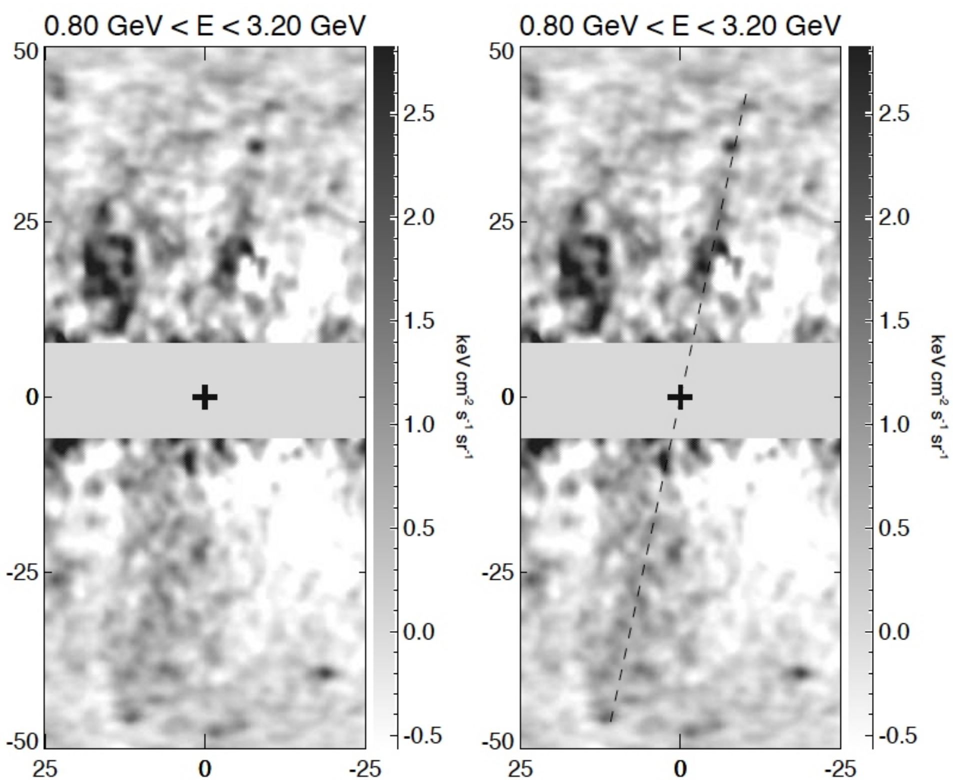
Subject headings: galaxies: active — galaxies: starburst — gamma rays — ISM: jets and outflows

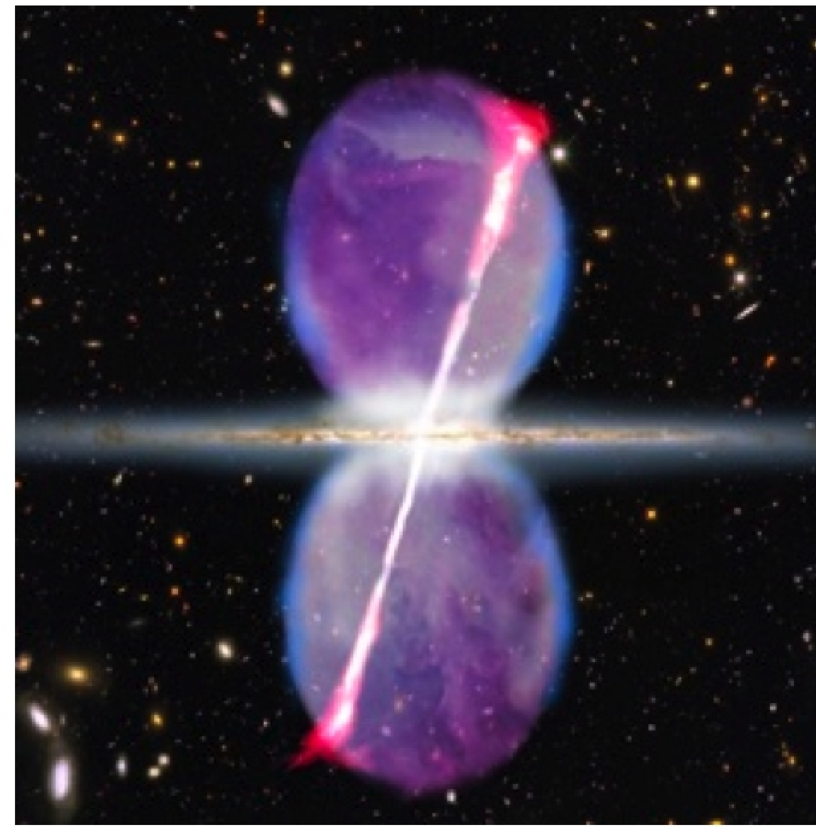
News | Space

Vestiges of Violence: Towering Gamma-Ray Jets Point to Past Outbursts from Milky Way's Black Hole

Black hole jets had previously been detected in other galaxies, but not in ours

By Jo





BUBBLES AND JETS: An artist's conception of the Milky Way shows the recently discovered Fermi bubbles, as well as the dual gamma-ray jets for which evidence has just emerged.
Image: David A. Aguilar (CfA)

Many questions ?

Are the jets real ?

Why are the jets inclined ?
[are we seeing the direction of the BH rotation axis?]

What is the nature of the bubbles + jets emission?

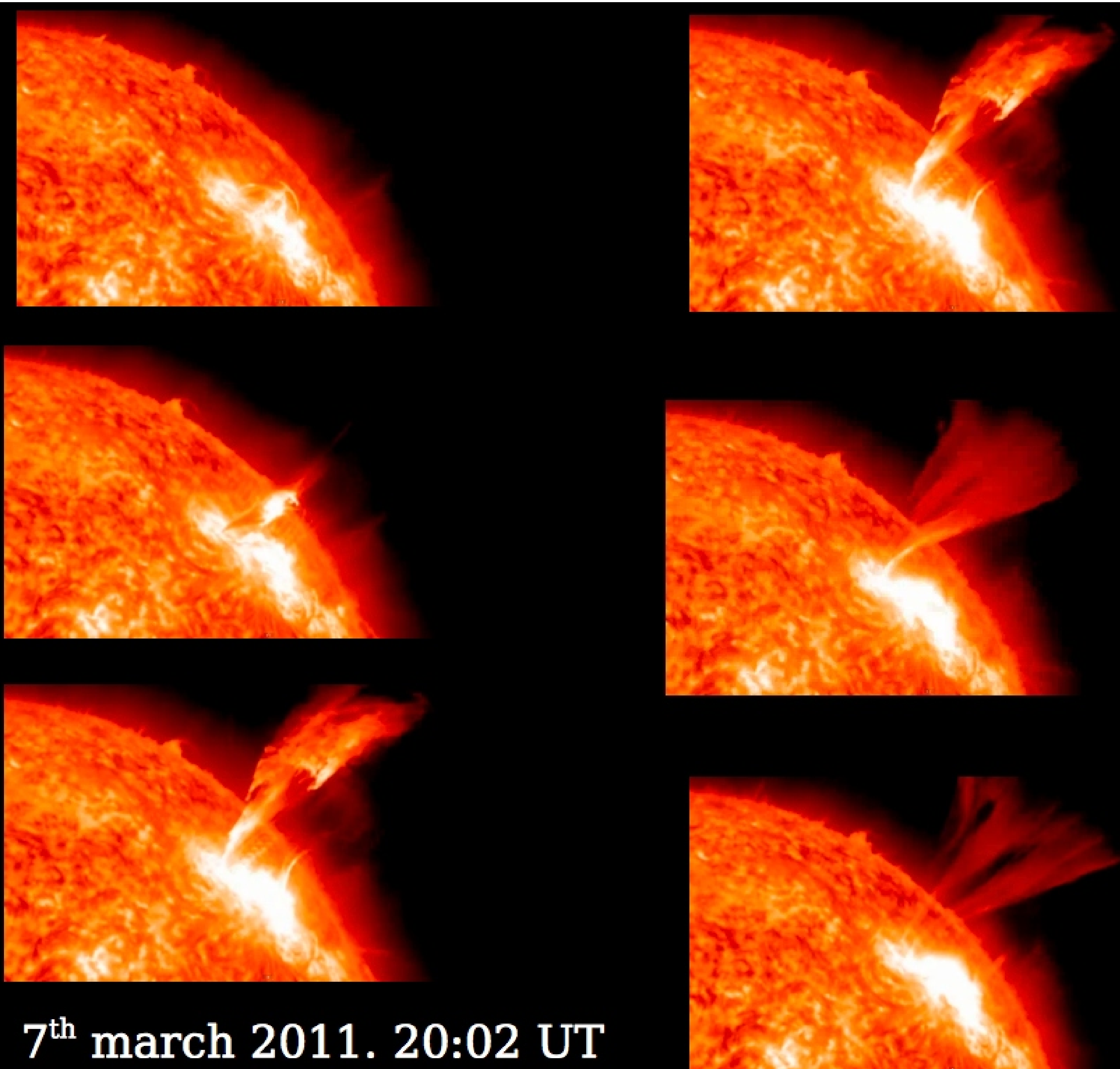
What is happening (or what – and when - happened) at the GC ?

Are we missing something important for the understanding of the Milky Way structure And magnetic confinement properties ?

- PULSARS (PSR)
- Pulsar Wind Nebulae (PWN)
- Binary Systems
- SuperNova Remnant (SNR)
- Active Galactic Nuclei (AGN)
- Gamma Ray Bursts (GRB)
- ….novae, globular clusters, starburst galaxies, …..

The SUN

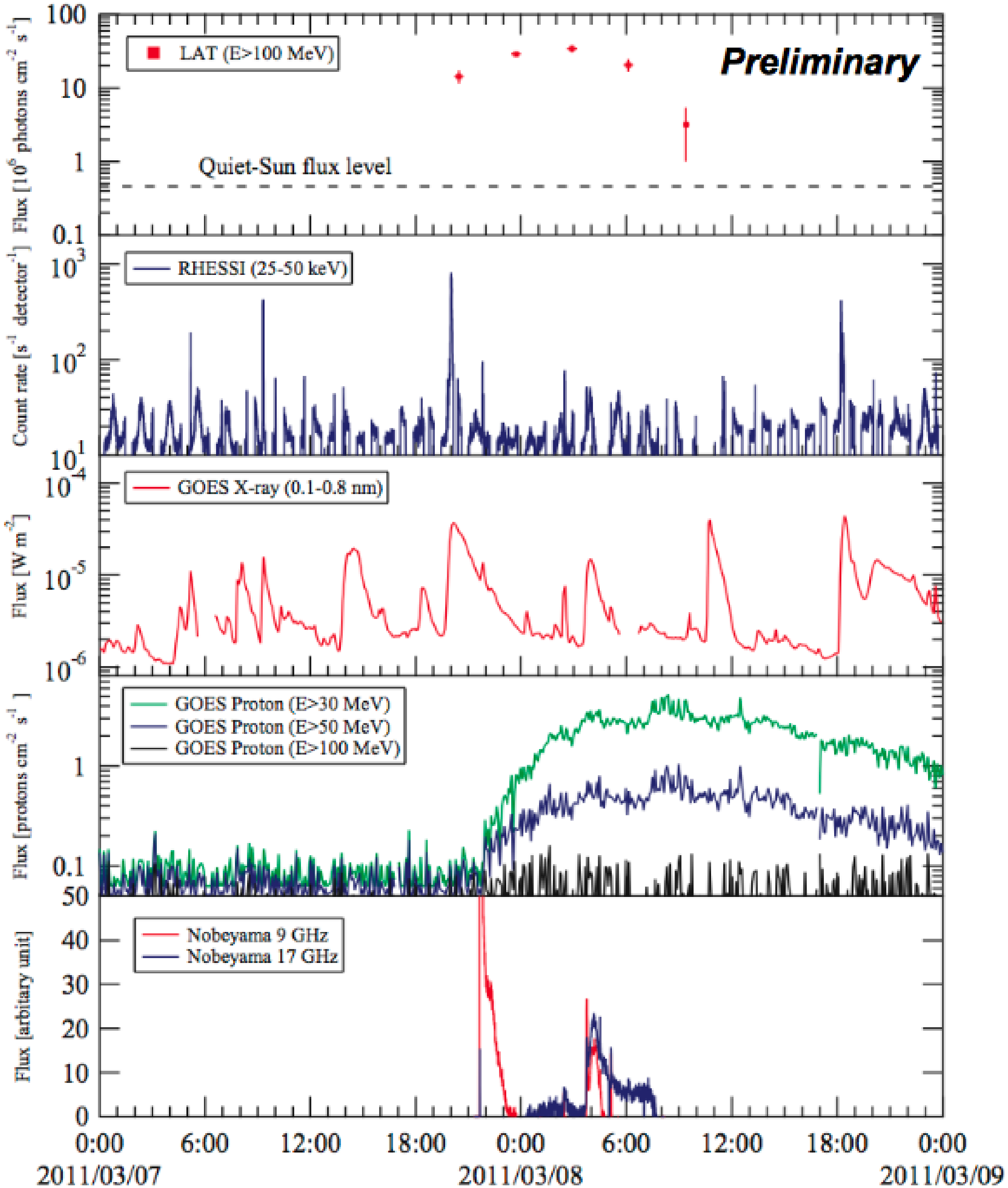
as a “laboratory” for CR Acceleration and Transport



7th march 2011. 20:02 UT

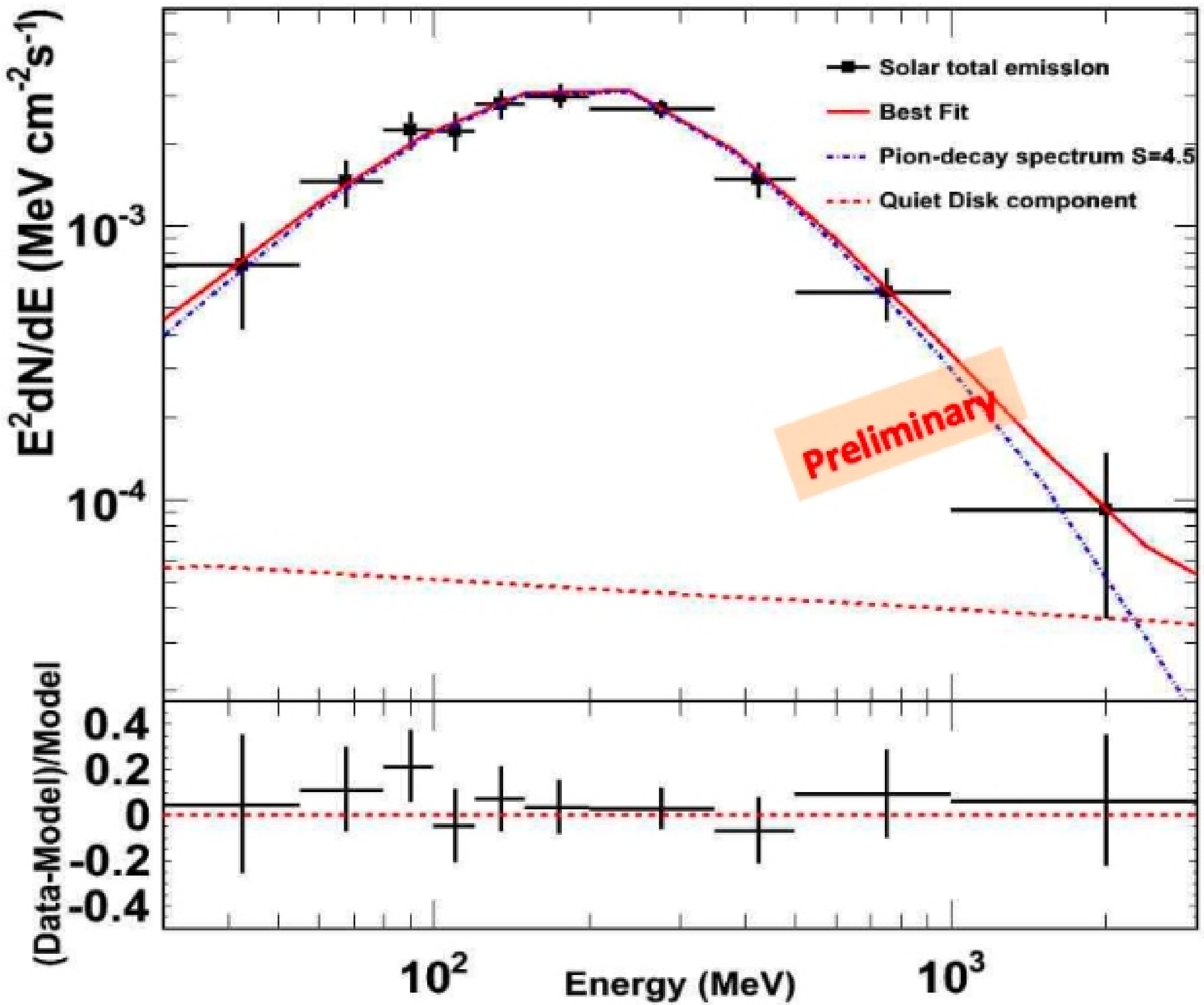
This aurora image was taken on March 10, 2011 by Zoltan Kenwell near Edmonton, Alberta, Canada.

Multi-wavelength light curve



- Following M3.7 flare at ~20 UT on March 7, Fermi-LAT detected long-lasting HE emission over ~12 hours
- LAT flux showed clear rising profile
- No corresponding long-lasting enhancements were seen in hard X-ray (RHESSI), soft X-ray (GOES), and radio (Nobeyama) bands
- GOES proton monitor at 1AU detected solar energetic protons above 50 MeV, suggesting that CME-driven shock indeed accelerated protons

LAT spectrum

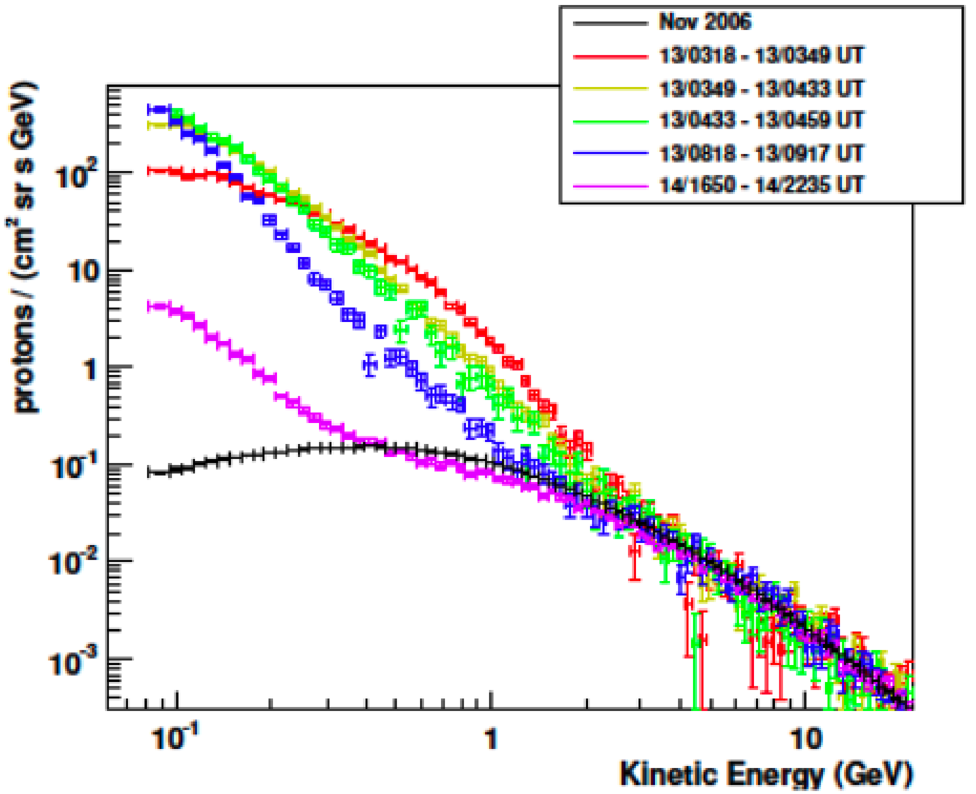


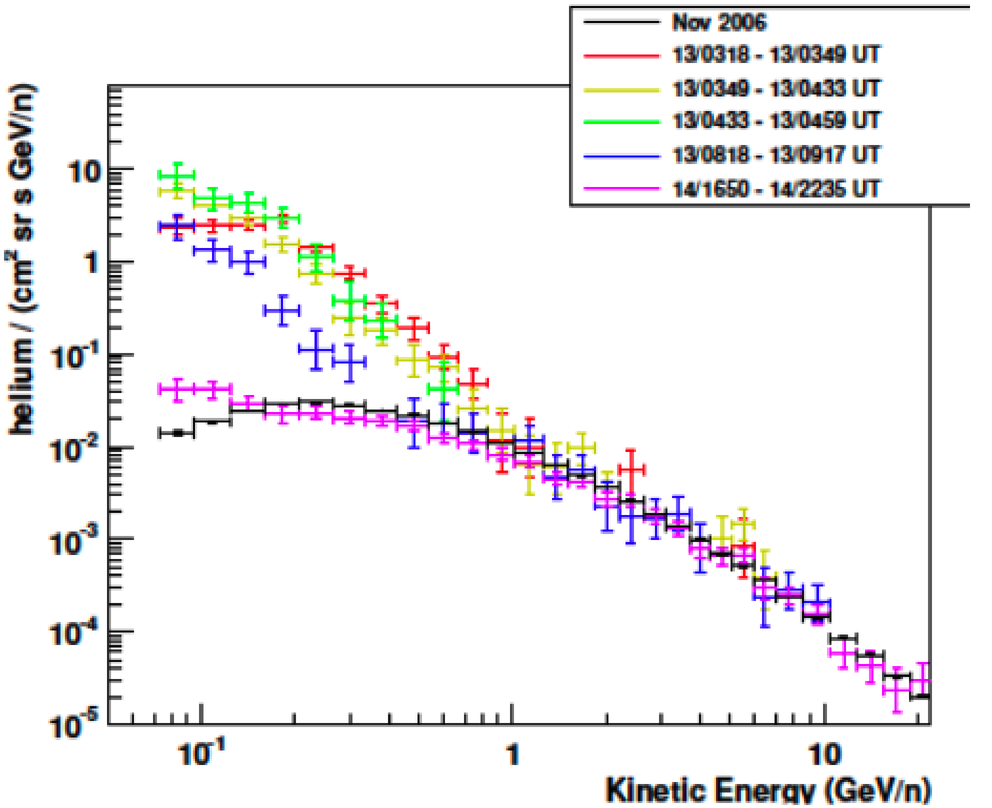
- The LAT data are accumulated for the whole flare duration
- The LAT spectrum showed clear turn over around 200 MeV

PAMELA: Solar Flare 13/dec/2006

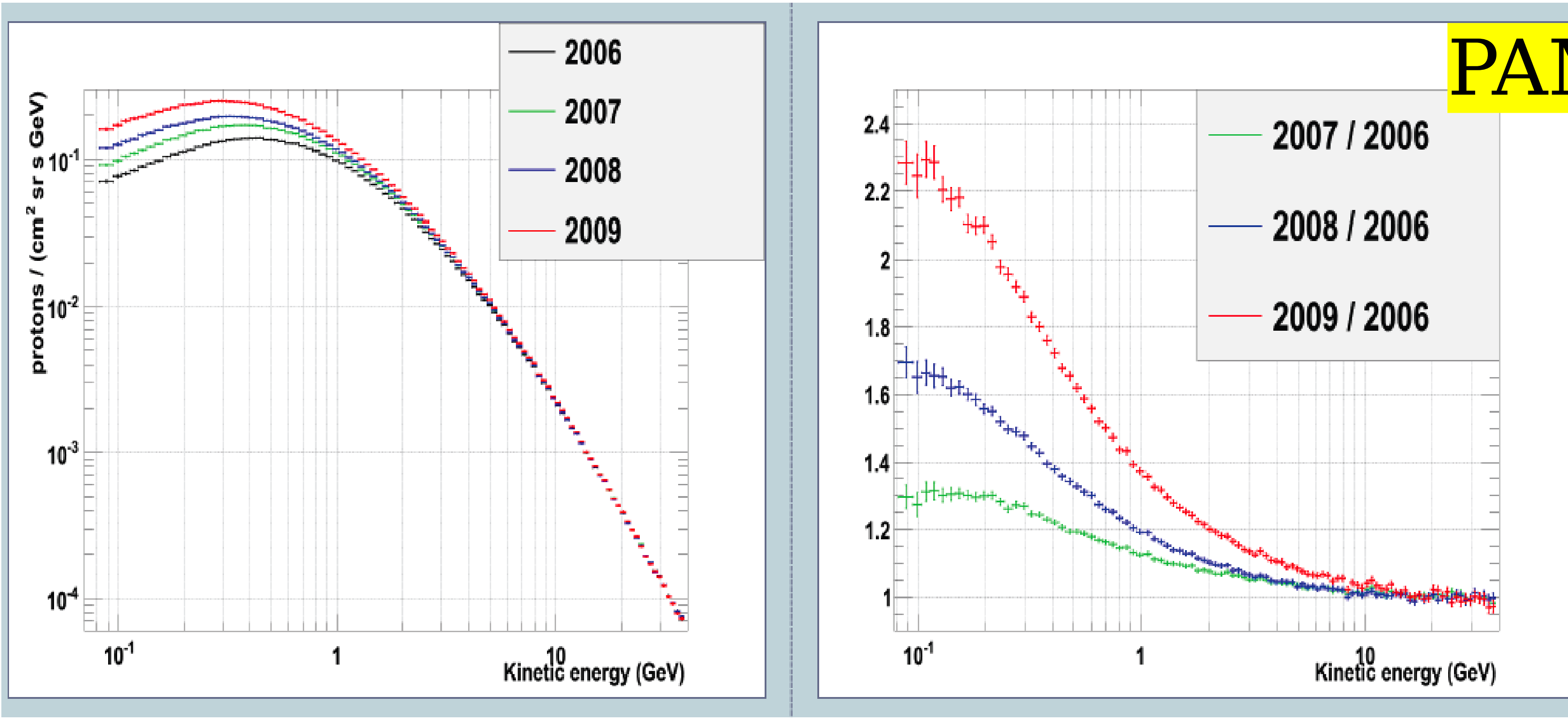
13 Dec 2006
Solar Flare

Adriani et al. – submitted to APJ

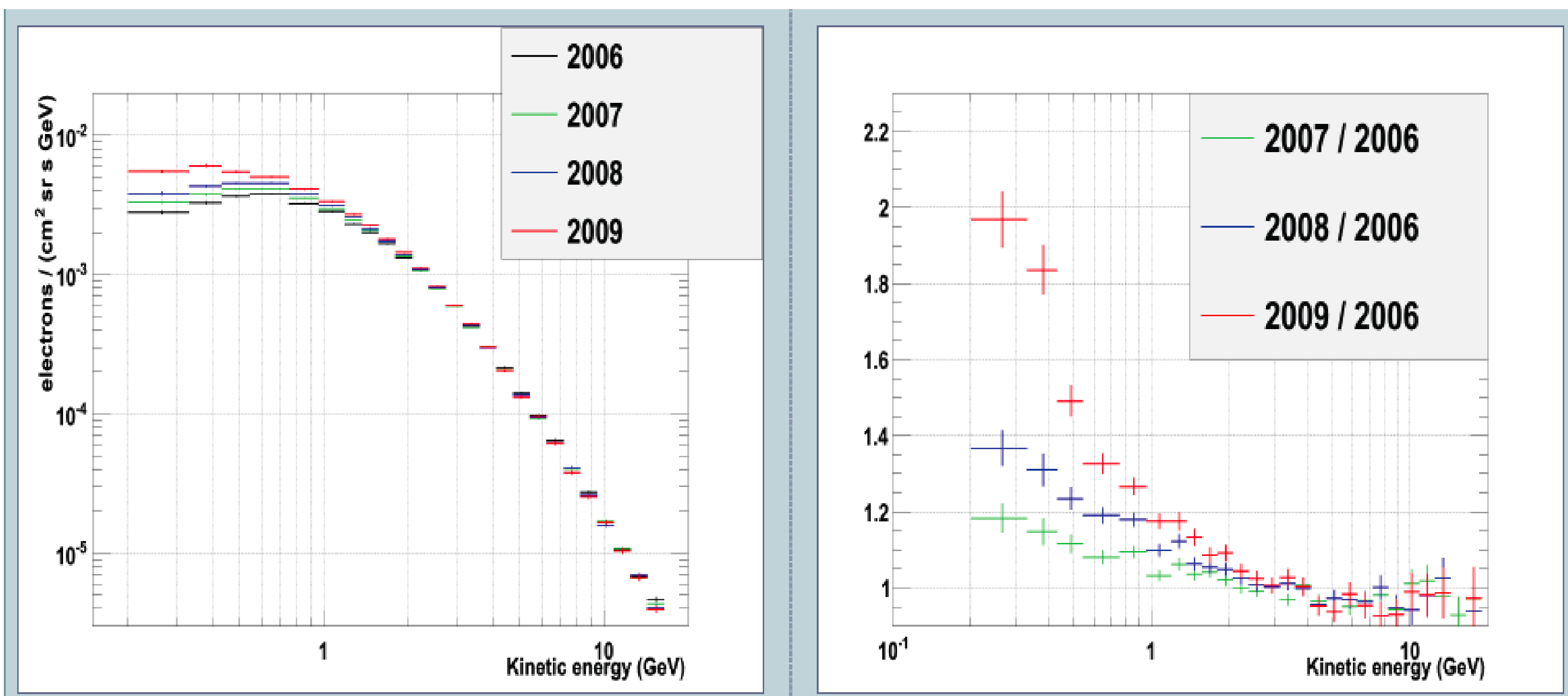




PAMELA


2006
2007
2008
2009
protons / (cm² sr s GeV)
Kinetic energy (GeV)
2007 / 2006
2008 / 2006
2009 / 2006
Kinetic energy (GeV)

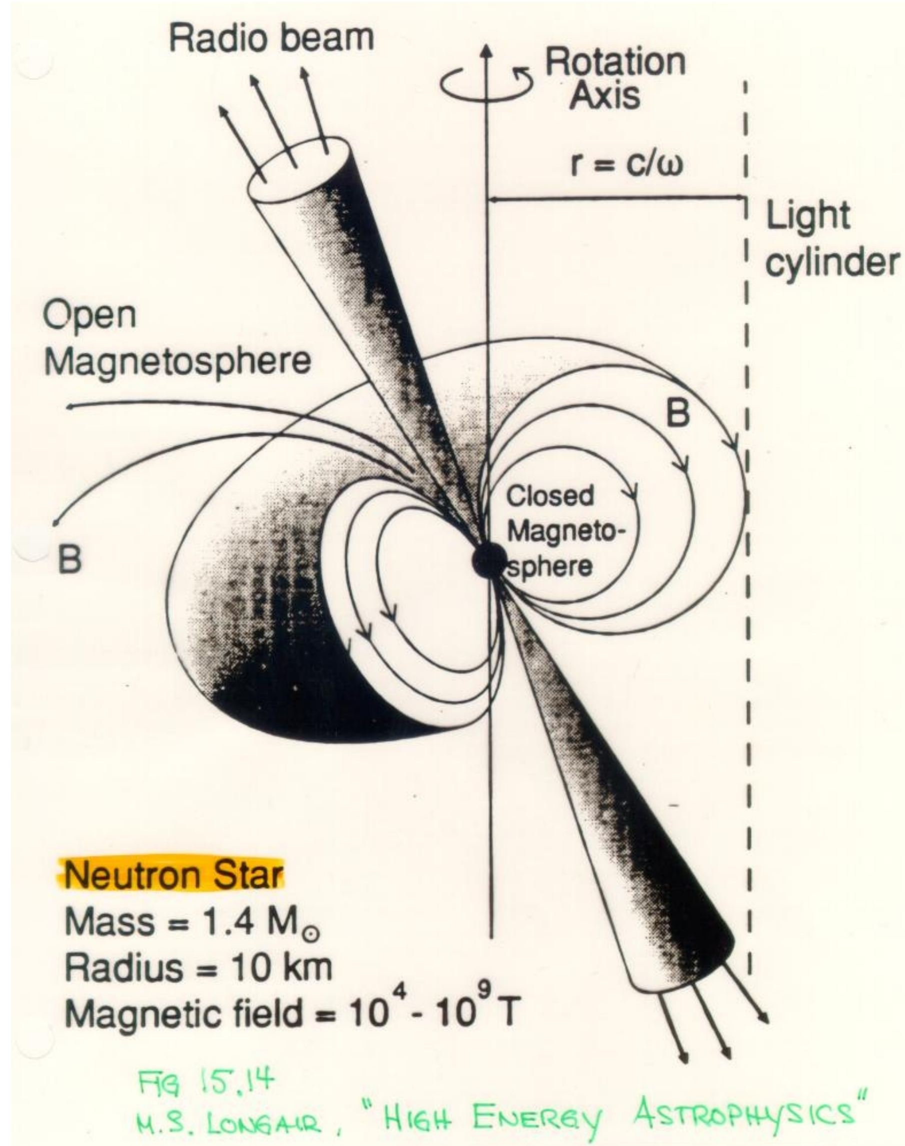
p


2006
2007
2008
2009
electrons / (cm² sr s GeV)
Kinetic energy (GeV)
2007 / 2006
2008 / 2006
2009 / 2006
Kinetic energy (GeV)

e

PULSARS

Proposed as possible Accelerators of e+ e-



CRAB Nebula

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

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

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

EGRET Pulsars

VELA	89.3 ms
GEMINGA	237
CRAB	33
1706-44	102
1055-52	197

108 well identified Pulsars

Mechanism understood ?

Very large variation in the fraction of Spin Down Energy going into gamma Rays

3 PWN

VELA

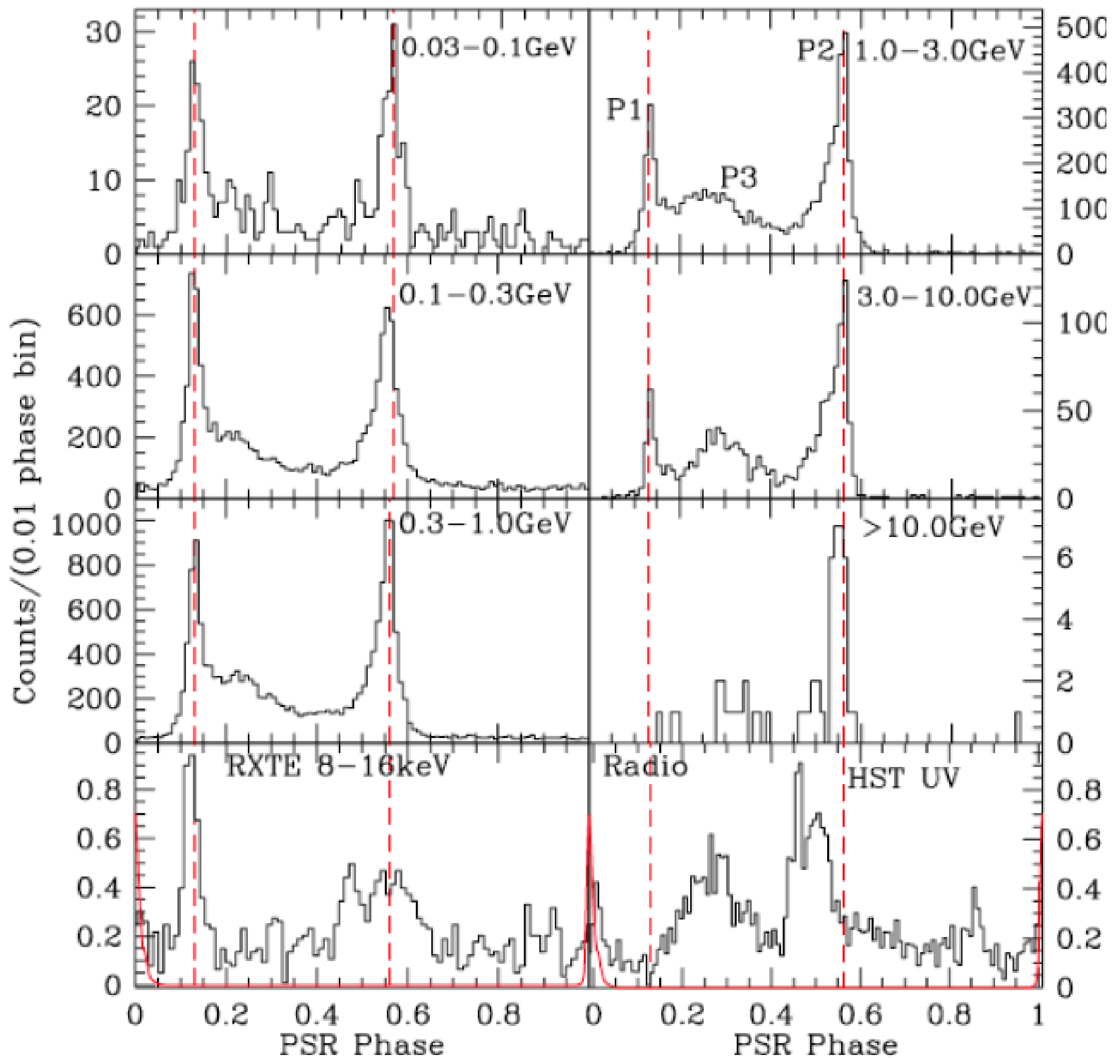
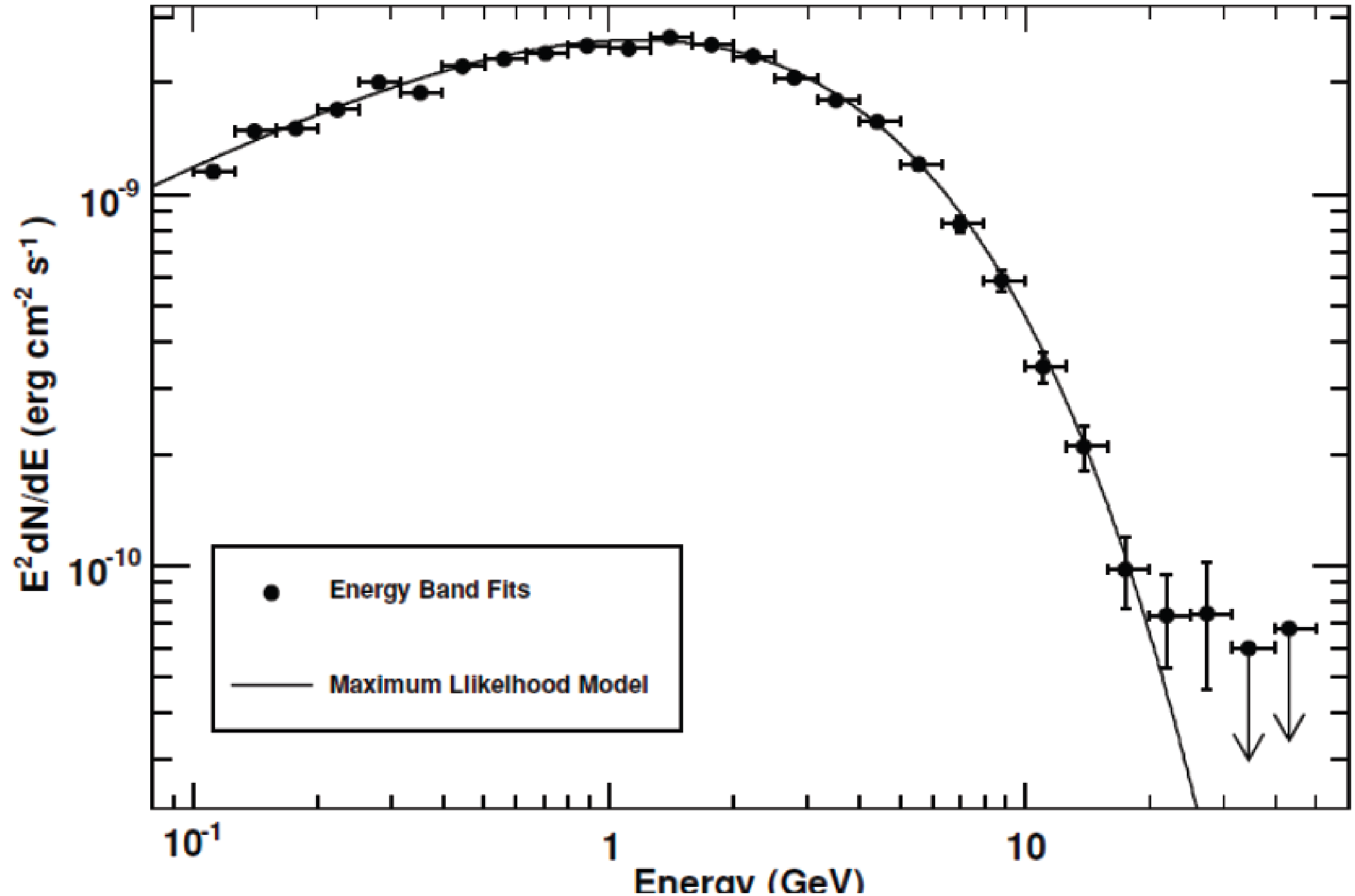


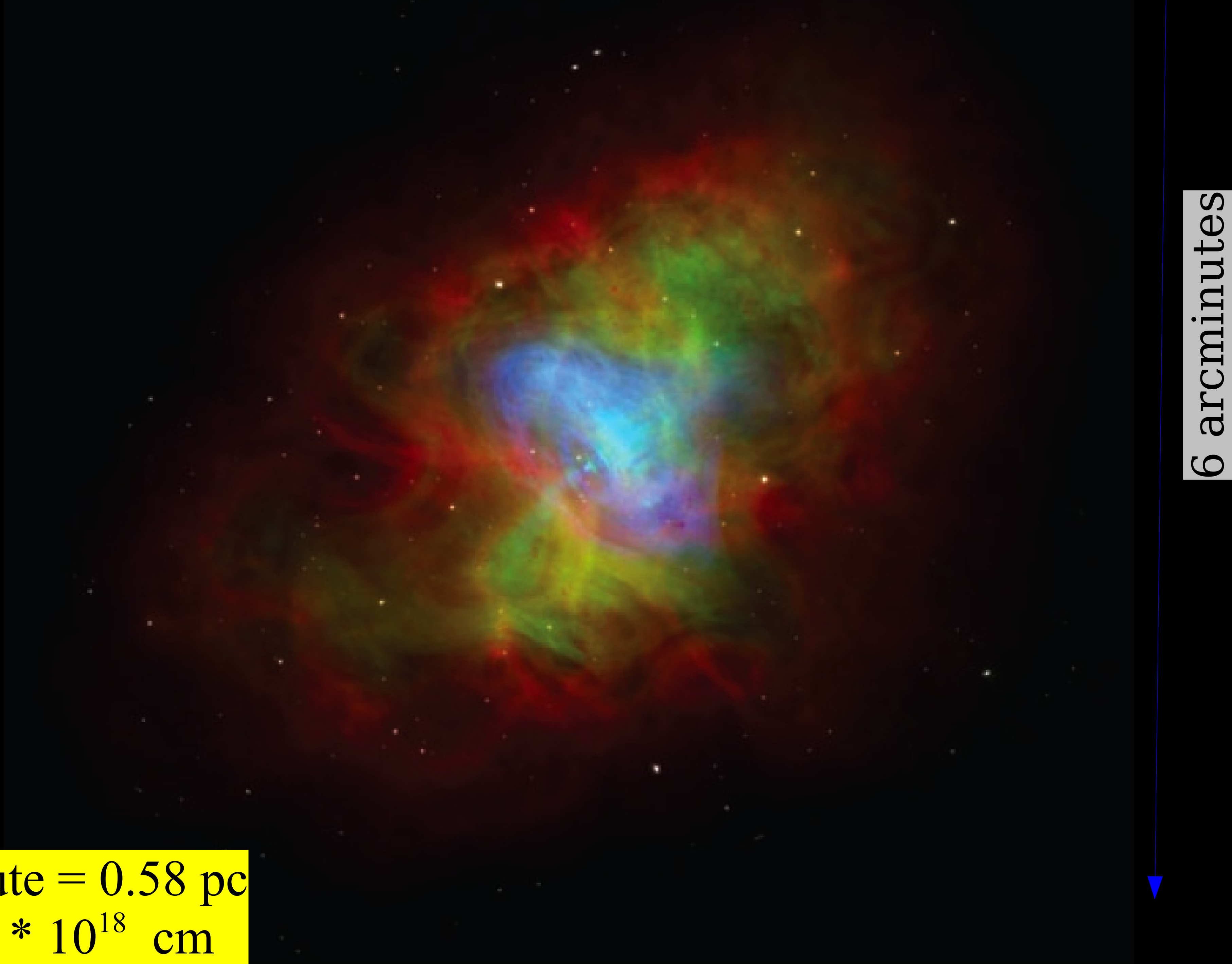
Fig. 4. Vela light curves at optical, X-ray, and γ-ray energies [58], binned to 0.01 of the pulsar phase. The main peaks P1, P2 and P3 are labeled in the top right panel. The bottom left panel shows the 8 – 16 keV *RXTE* light curve [59] along with the radio pulse profile (dashed lines). At lower right, the 4.1 – 6.5 eV *HST*/STIS NUV light curve [60] is shown.



VELA Energy Spectrum [characteristic shape For Pulsars]

$$N(E) \propto E^{-\Gamma_\gamma} \exp[-(E/E_c)^b]$$

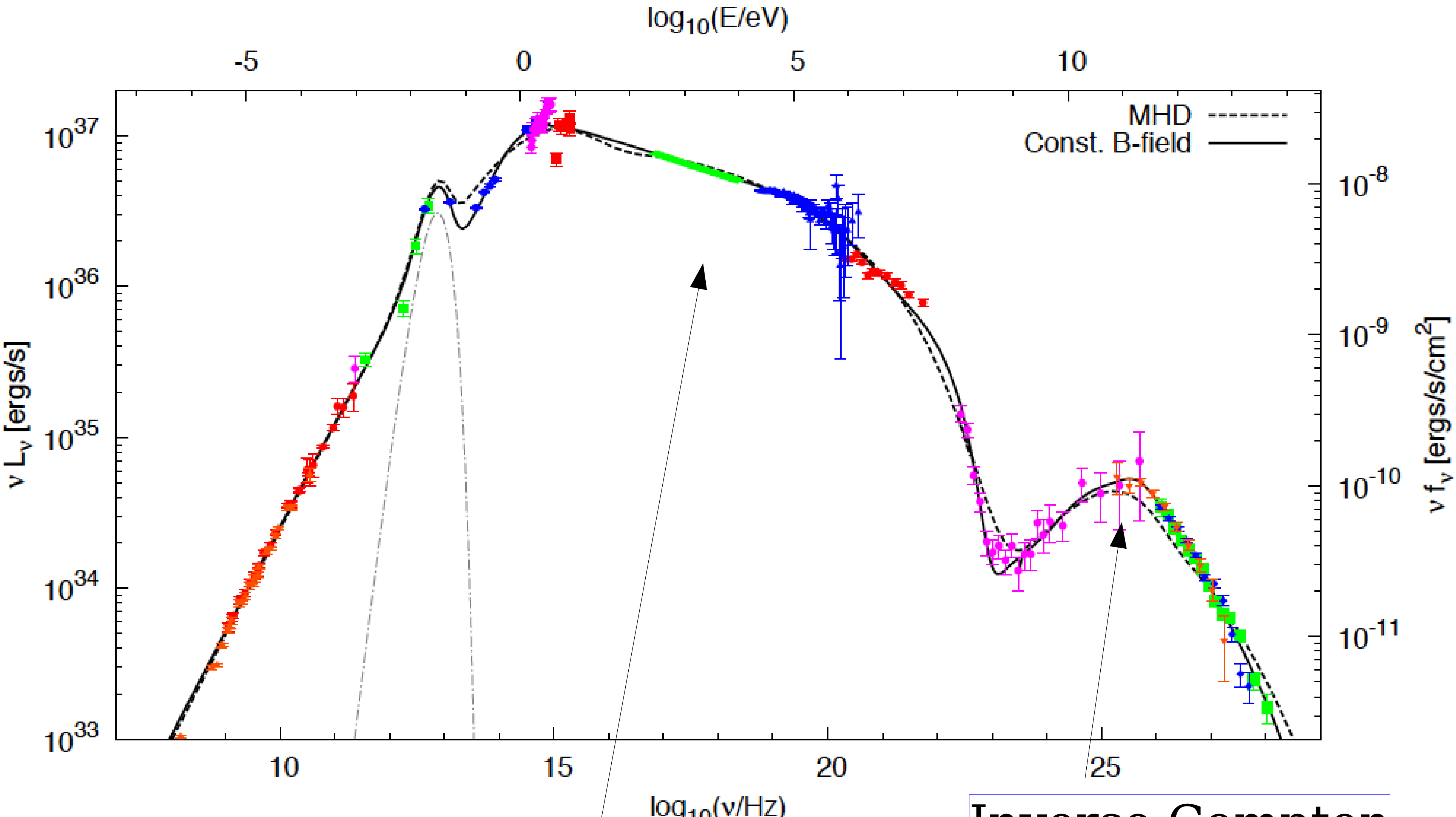
The CRAB Nebula



1 minute = 0.58 pc
= $1.8 * 10^{18}$ cm

CRAB Nebula Energy Spectrum

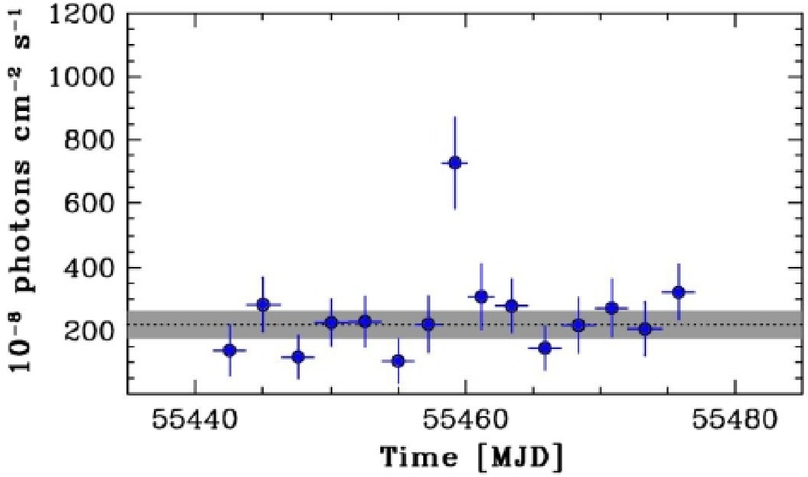
SSC (Self Synchrotron Coompton) model emission



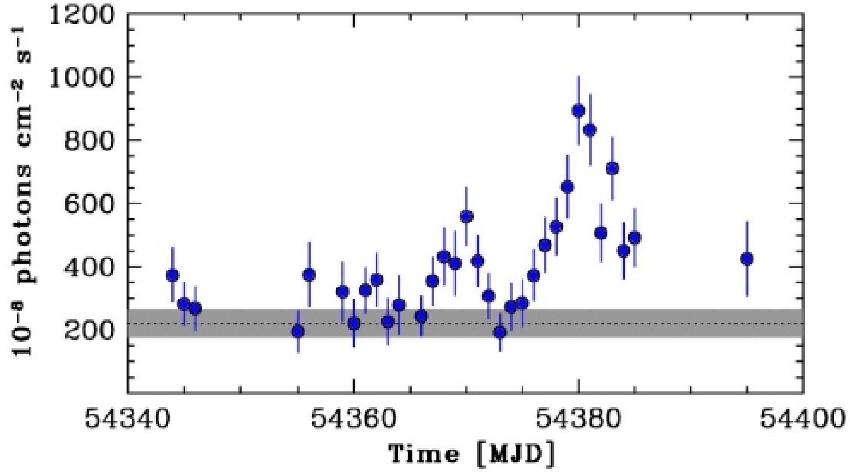
Synchrotron Radiation

Inverse Compton Scattering

AGILE discover of flaring of the CRAB

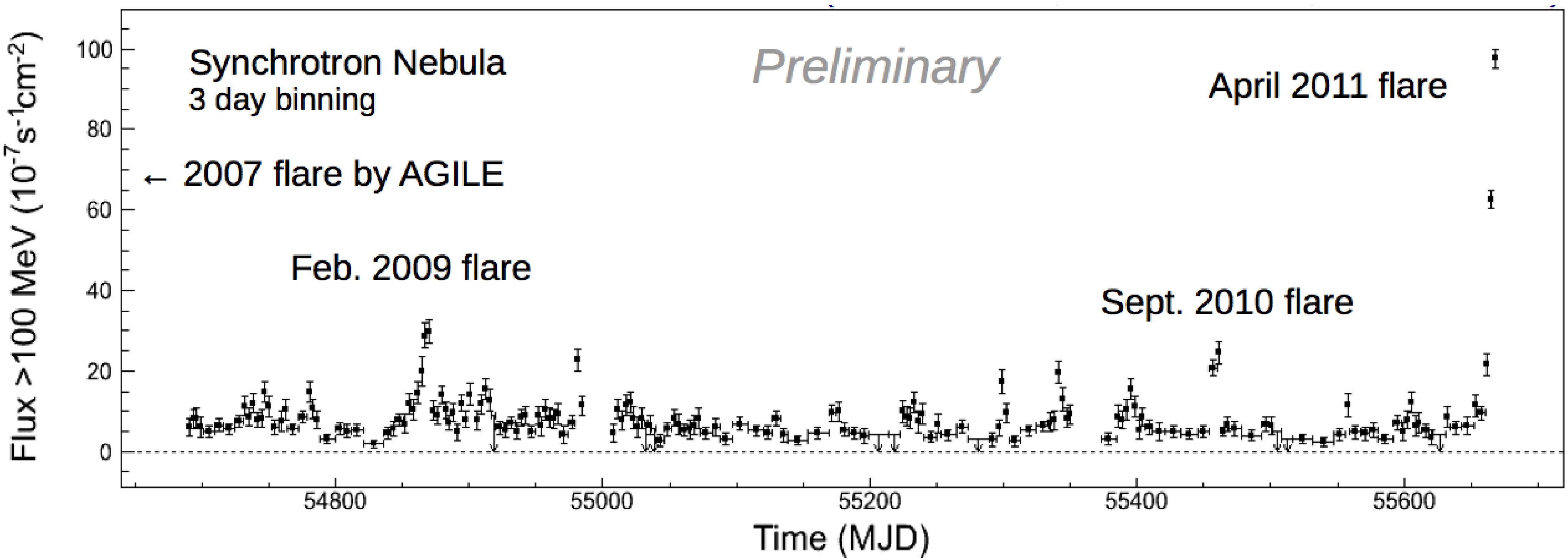


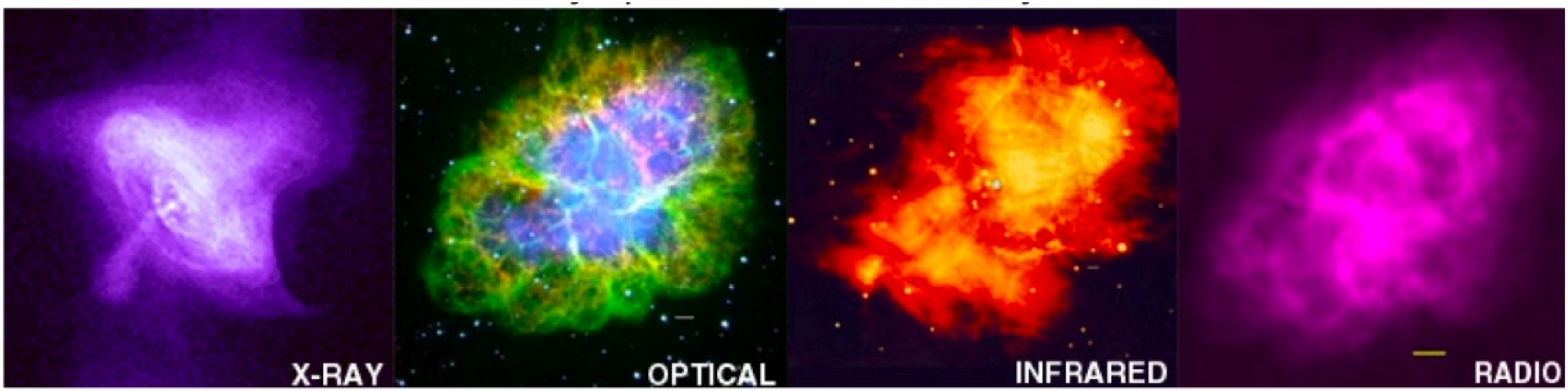
2sep – 8 oct 2010



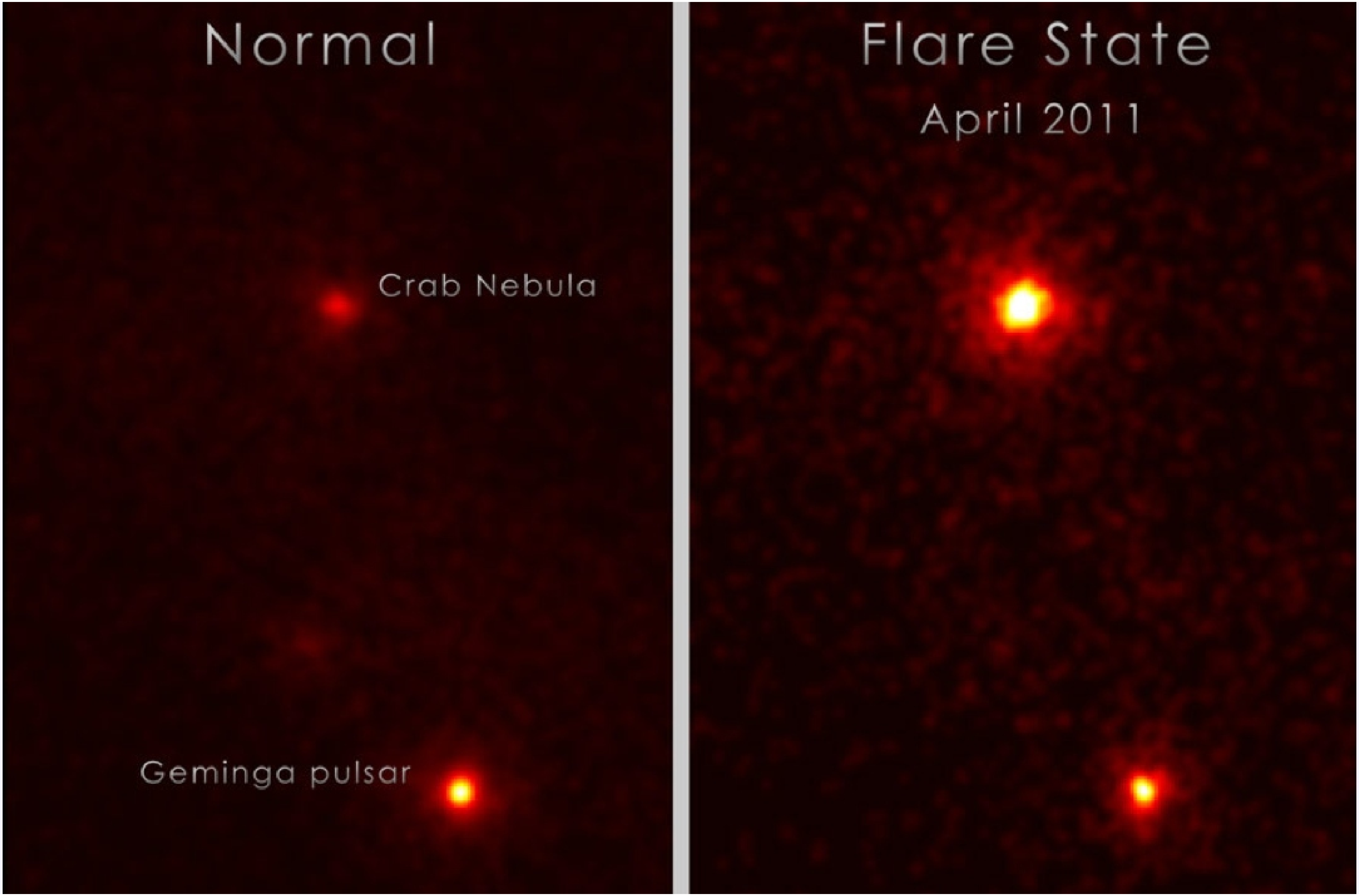
27sep – 12 oct 2007
[discovery “in the drawer”]

CRAB NEBULA Flaring [!]

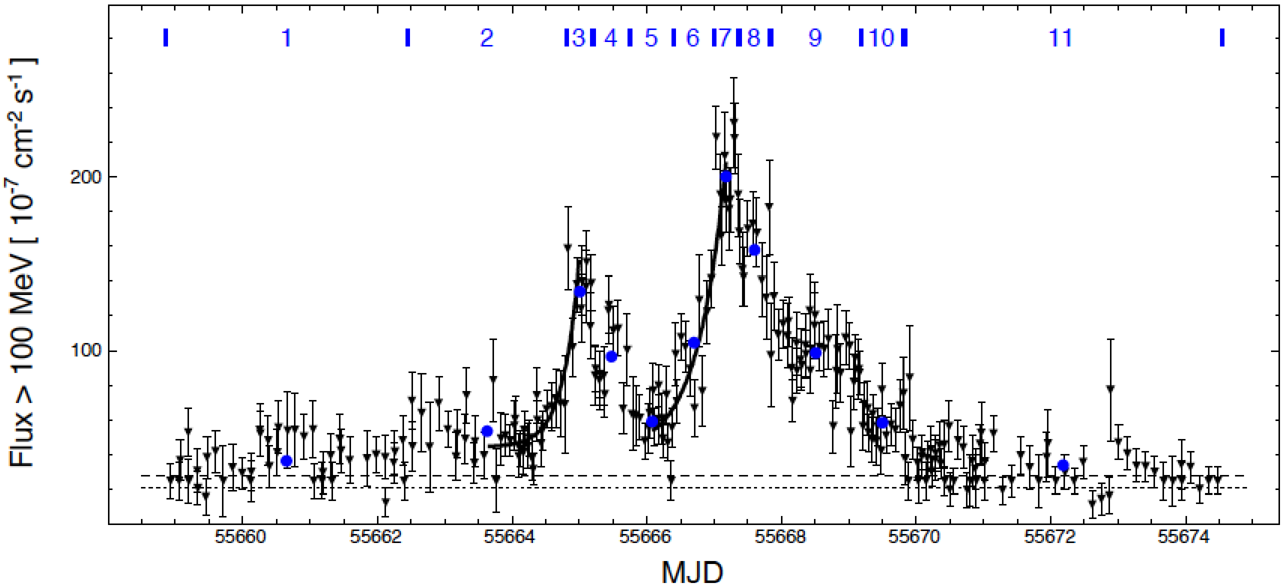




CRAB NEBULA Flaring [!]



April 2011 CRAB flare



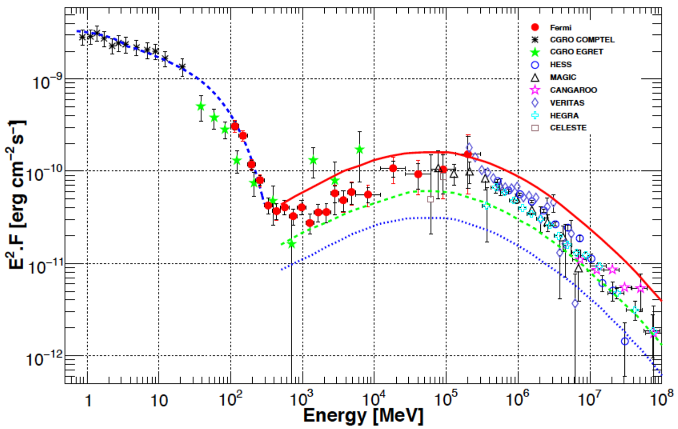
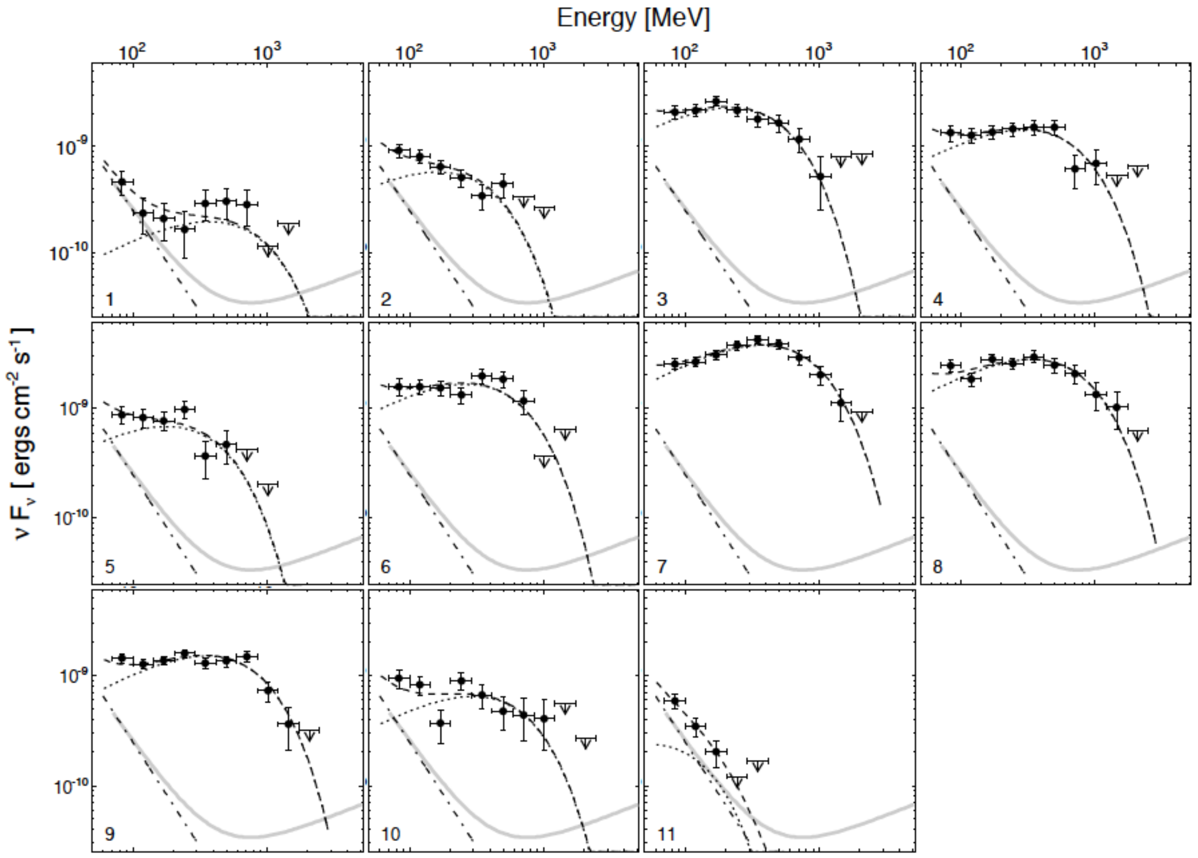


FIG. 9.— The spectral energy distribution of the Crab Nebula from soft to very high energy γ-rays. The fit of the synchrotron component, using COMPTEL and LAT data (blue dashed line), is overlaid. The predicted inverse Compton spectra from Atoyan and Aharonian (1996) are overlaid for three different values of the mean magnetic field: 100 μG (solid red line), 200 μG (dashed green line) and the canonical equipartition field of the Crab Nebula 300 μG (dotted blue line). References: CGRO COMPTEL and EGRET: Kuiper et al. (2001); MAGIC: Albert et al. (2008); HESS: Aharonian et al. (2006); CANGAROO: Tanimori et al. (1997); VERITAS: Celik (2007); **HEGRA: Aharonian et al. (2004); CELESTE: Smith et al. (2006)**



Identification of the Astrophysical Sources of COSMIC RAYS.

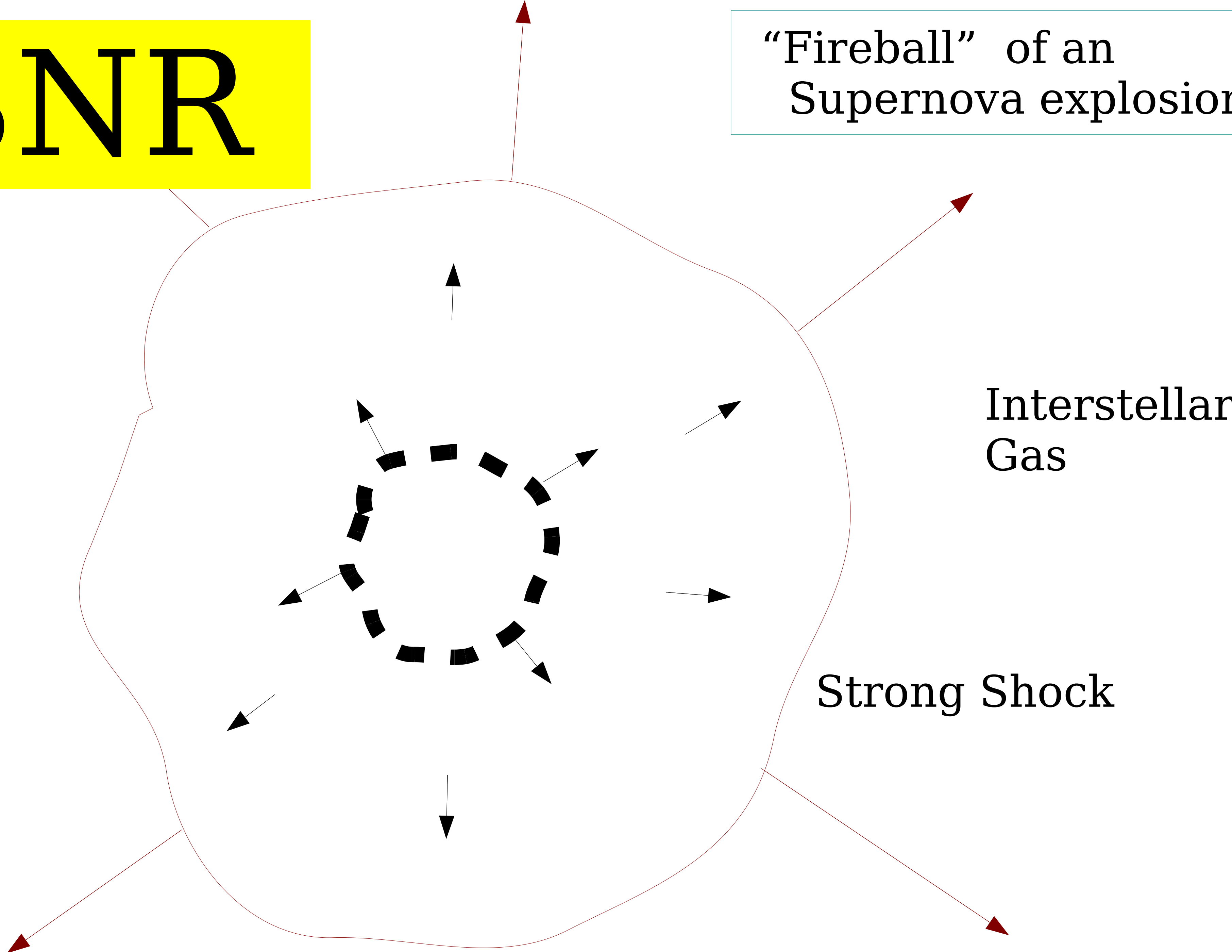
The “SNR paradigm”
for galactic Cosmic Rays

Debate about the acceleration sites of UHECR (Ultra High Energy Cosmic Rays).

Candidate sites:
AGN's
GRB's

SNR

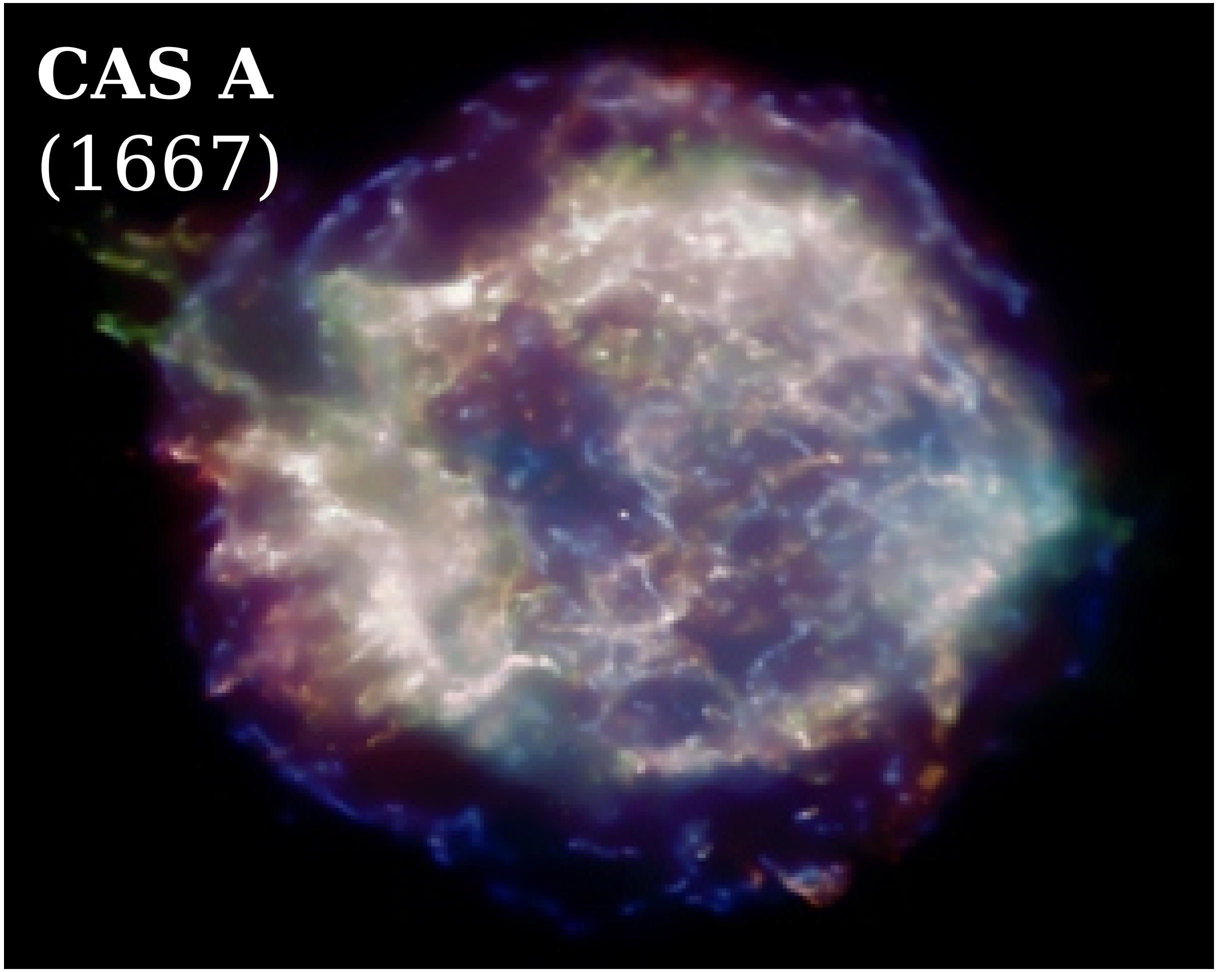
"Fireball" of an Supernova explosion



Fermi 1st order acceleration

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

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]

$$L^{\rm Milky\ Way}_{\rm SN\ kinetic} \simeq E^{\rm Kinetic}_{\rm SN}\ f_{\rm SN}$$

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

$$M = 5\ M_\odot$$

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

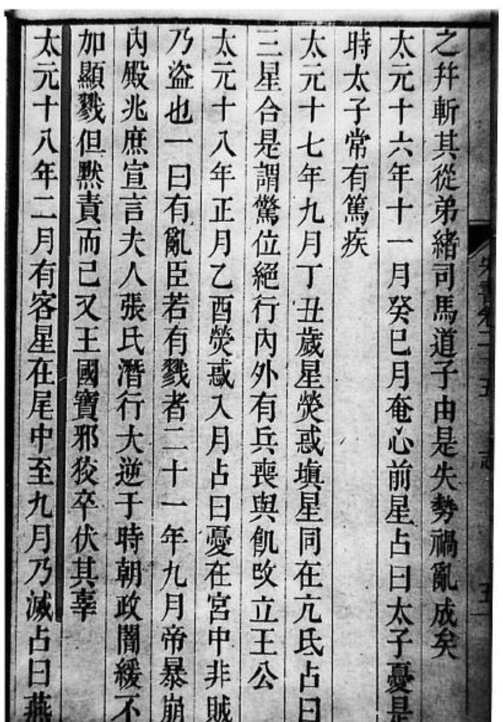
$$L^{\rm Milky\ Way}_{\rm SN\ kinetic} \simeq 1.5 \times 10^{42}\ \frac{\rm erg}{\rm s}$$

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

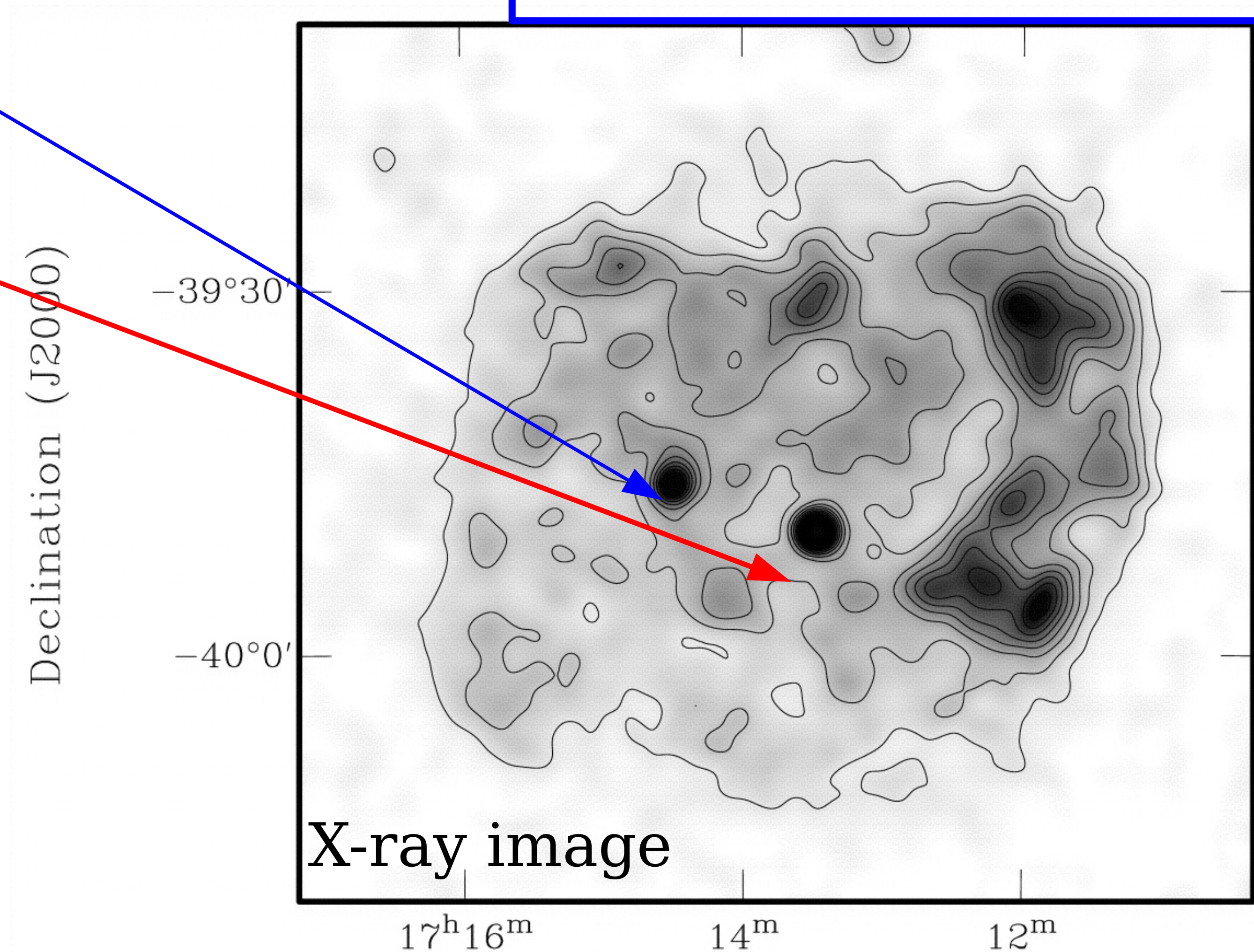
SuperNova 393A
RX J1713.7-3946

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

(Re)-discovered in 1996
by the Roentgen Satellite



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填星同在亢氐占曰
三星合是謂驚位絕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

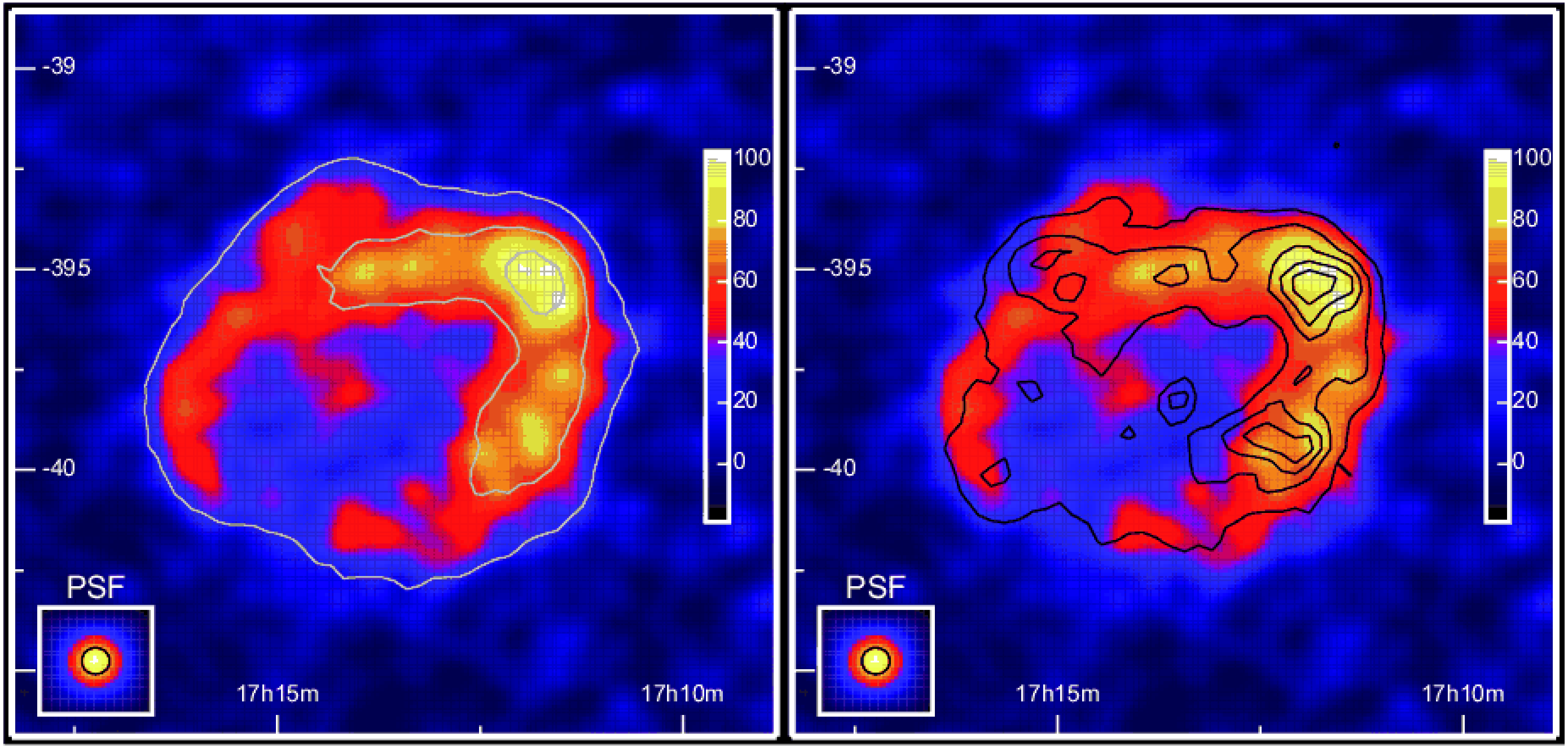


Detected in 2004 by HESS in TeV gamma rays

HESS Telescope

Observations with TeV photons

SuperNova RX J1713.7-3946

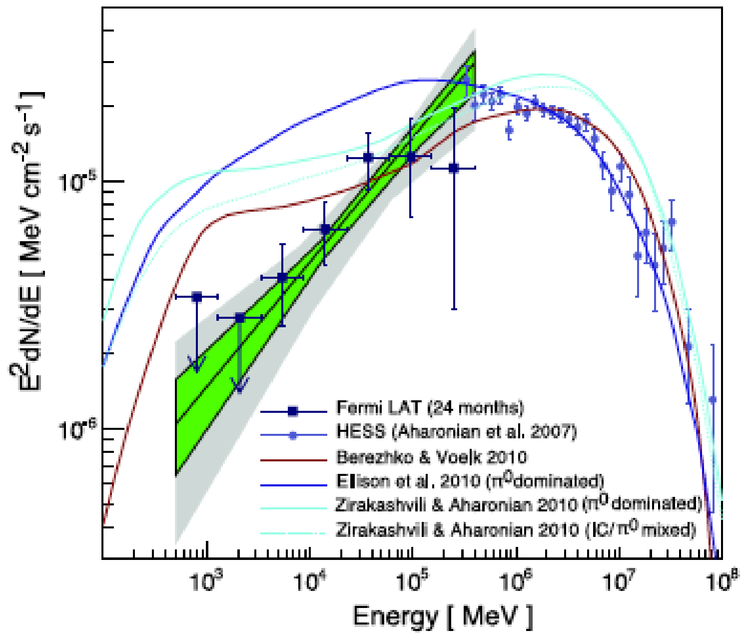


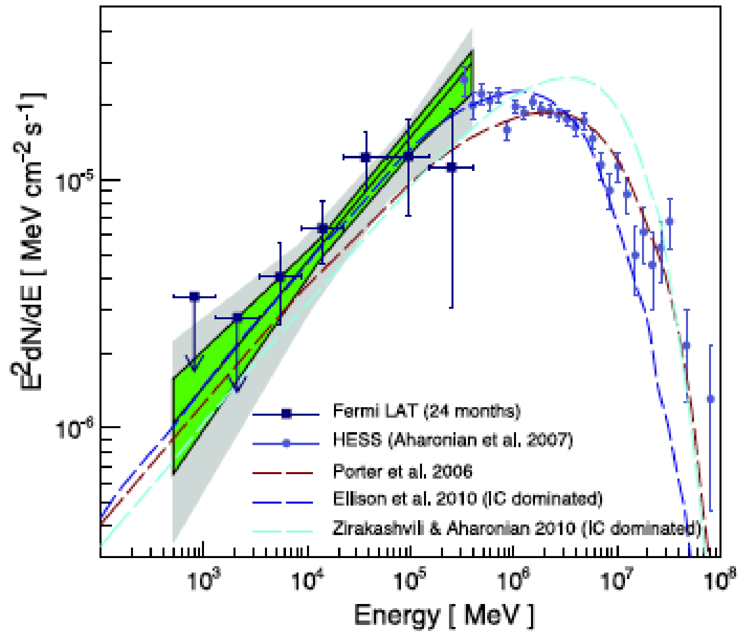
Comparison with ROSAT observation

Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

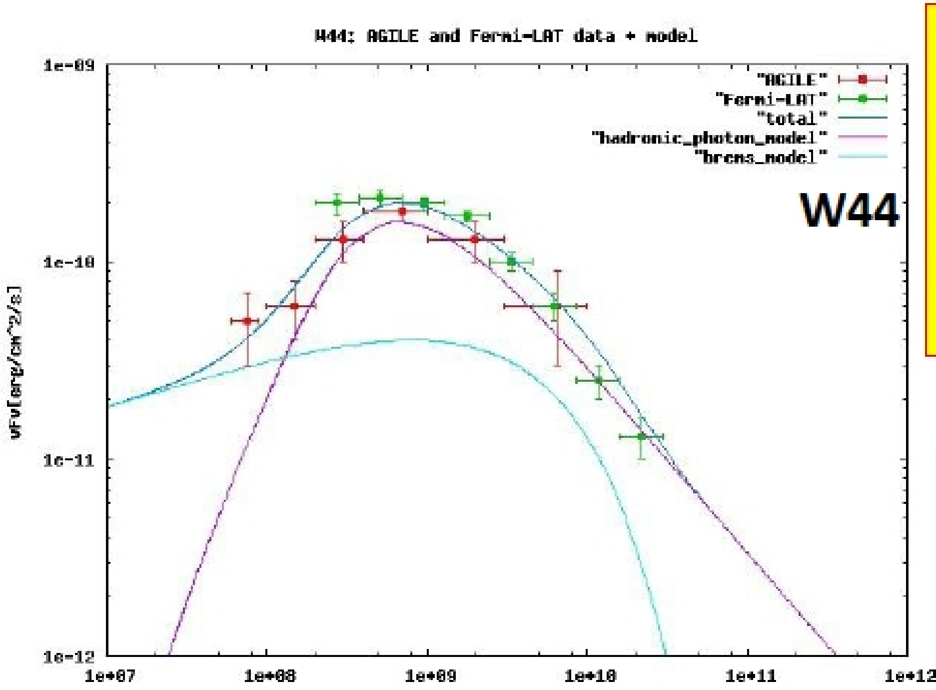
astro-ph/1103.5727.
29th march 2011

Favors
leptonic interpretation.





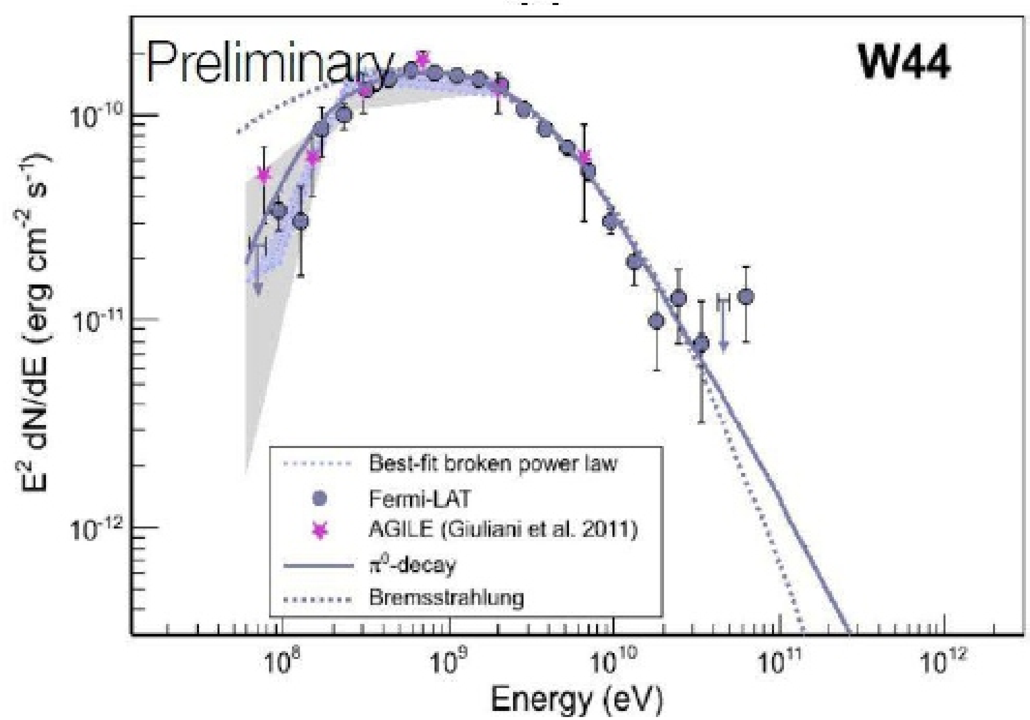
AGILE-GRID



PROOF OF HADRONIC COSMIC-RAY ACCELERATION IN THE SUPERNOVA REMNANT W44: THE π^o SPECTRUM

(Giuliani A., Cardillo M., et al., ApJ Letters, 742, L30, 2011)

***Fermi*-LAT**

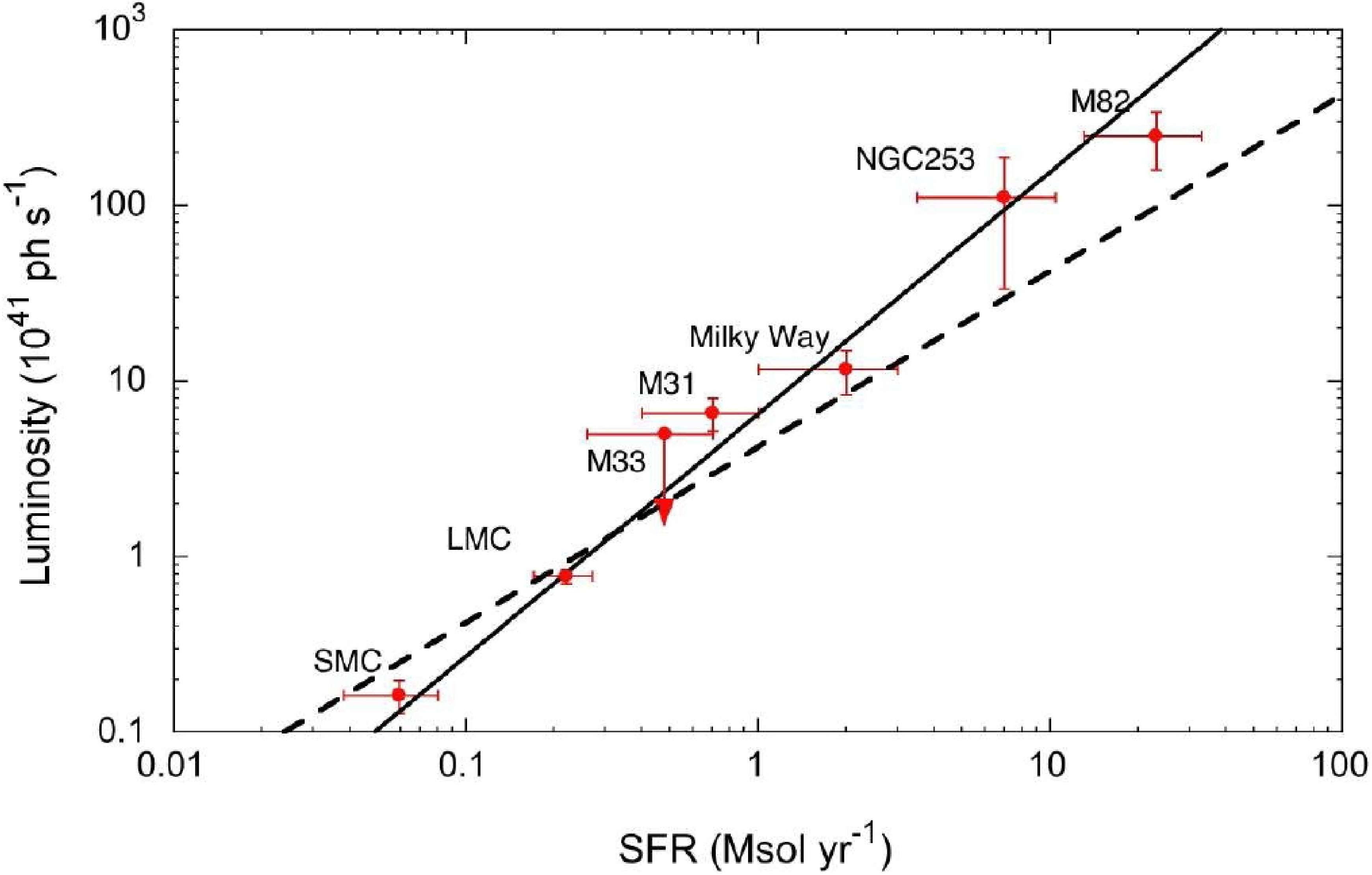


(Funk S. et al., Science, in press 2012)

From FERMI:

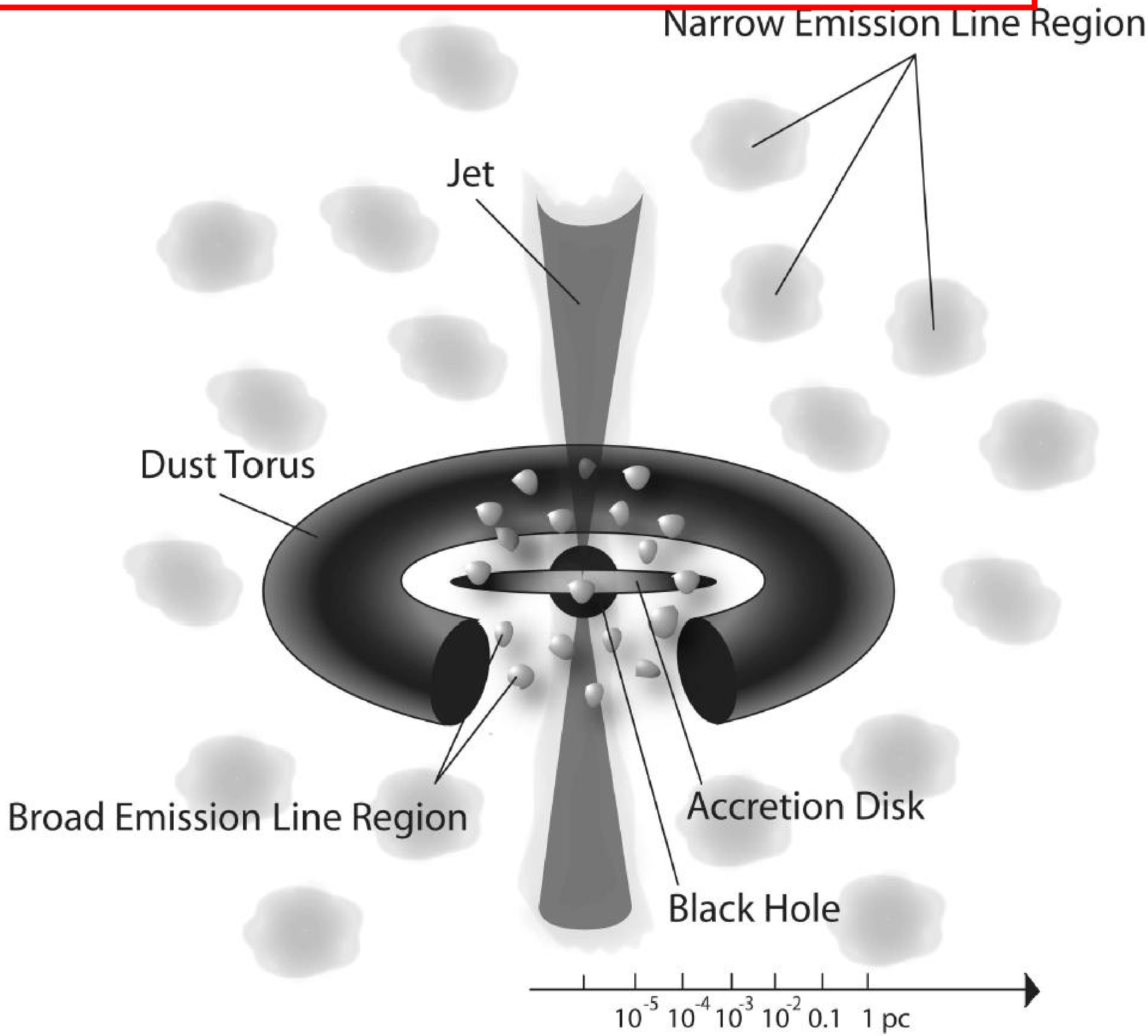
Table 1. Properties and gamma-ray characteristics of Local Group and nearby starburst galaxies (see text).

Galaxy	d kpc	M_{HI} 10^8 $M_\odot$	M_{H_2} 10^8 $M_\odot$	SFR $M_\odot$ yr^{-1}	F_γ 10^{-8} ph cm^{-2} s^{-1}	L_γ 10^{41} ph s^{-1}	$\bar{q}_\gamma$ 10^{-25} ph s^{-1} H-atom^{-1}
MW	...	35 ± 4(7)	14 ± 2(7)	1 – 3(19)	...	11.8 ± 3.4(28)	2.0 ± 0.6
M31	780 ± 33(1)	73 ± 22(8)	3.6 ± 1.8(14)	0.35 – 1(19)	0.9 ± 0.2	6.6 ± 1.4	0.7 ± 0.3
M33	847 ± 60(2)	19 ± 8(9)	3.3 ± 0.4(9)	0.26 – 0.7(20)	< 0.5	< 5.0	< 2.9
LMC	50 ± 2(3)	4.8 ± 0.2(10)	0.5 ± 0.1(15)	0.20 – 0.25(21)	26.3 ± 2.0(25)	0.78 ± 0.08	1.2 ± 0.1
SMC	61 ± 3(4)	4.2 ± 0.4(11)	0.25 ± 0.15(16)	0.04 – 0.08(22)	3.7 ± 0.7(26)	0.16 ± 0.04	0.31 ± 0.07
M82	3630 ± 340(5)	8.8 ± 2.9(12)	5 ± 4(17)	13 – 33(23)	1.6 ± 0.5(27)	252 ± 91	158 ± 75
NGC253	3940 ± 370(6)	64 ± 14(13)	40 ± 8(18)	3.5 – 10.4(24)	0.6 ± 0.4(27)	112 ± 78	9 ± 6



Luminosity (E >100 MeV) versus star formation rate (SFR).
Dashed line: Linear relation
Solid line : Power law best fit

ACTIVE GALACTIC NUCLEI



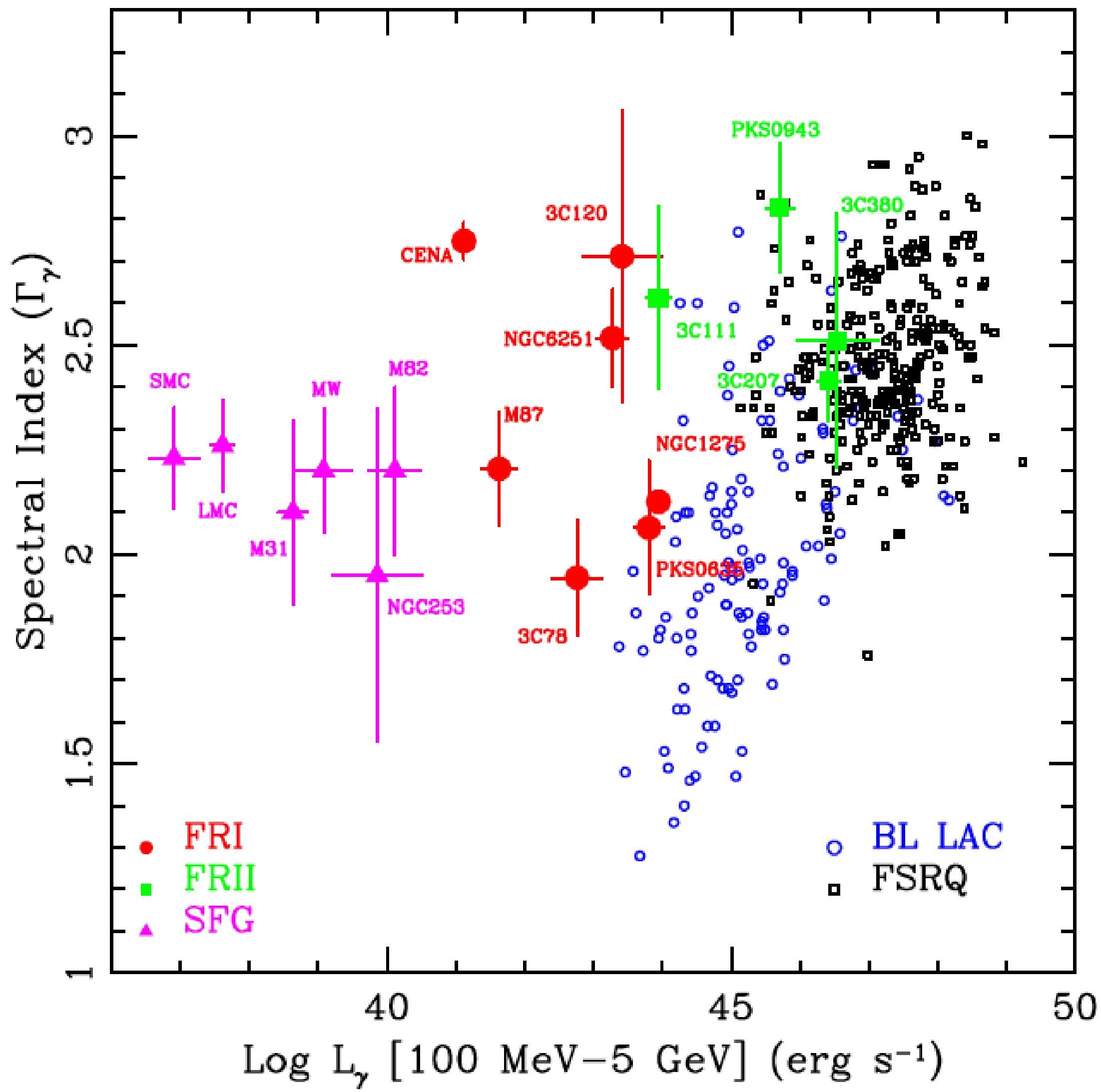
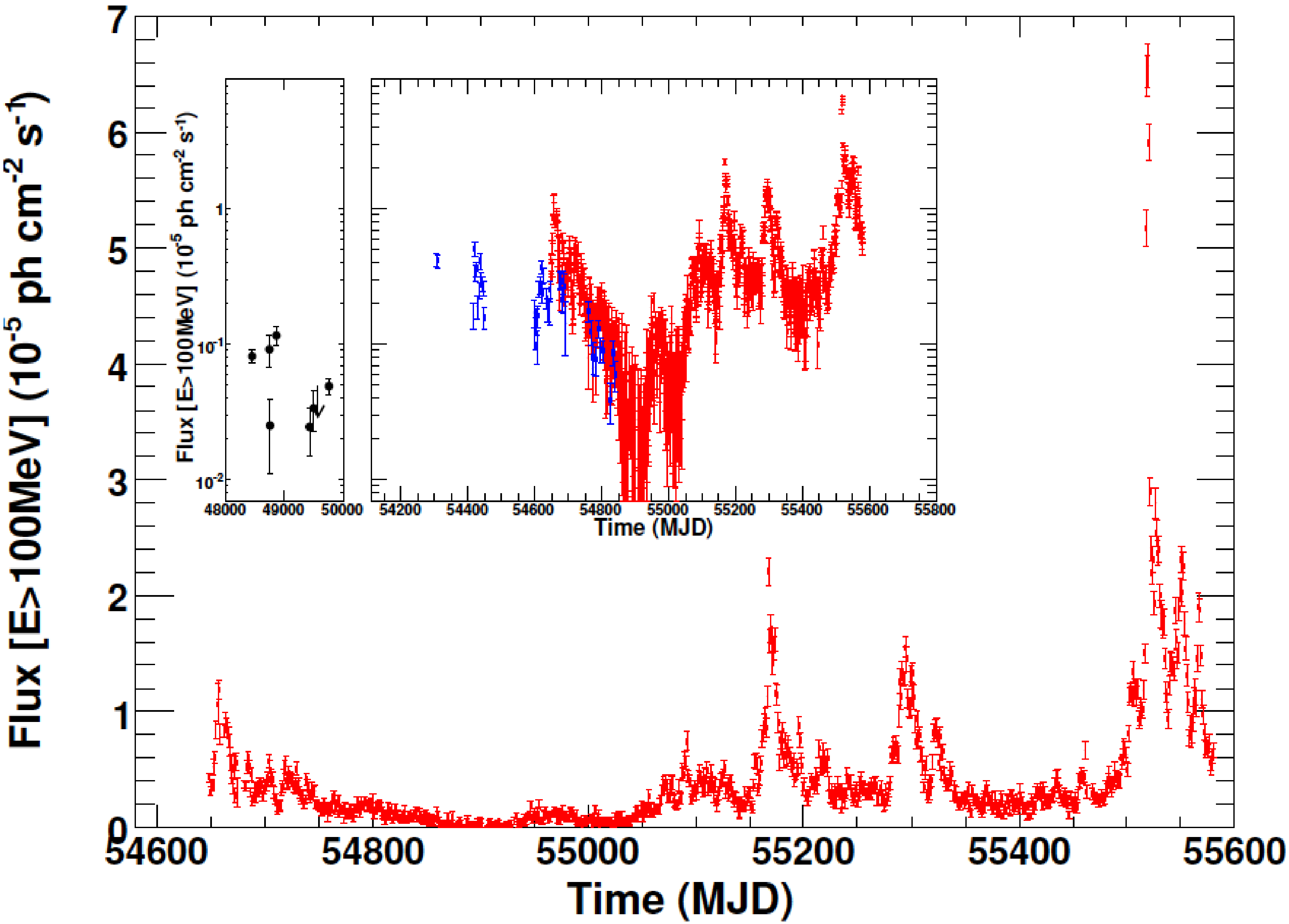


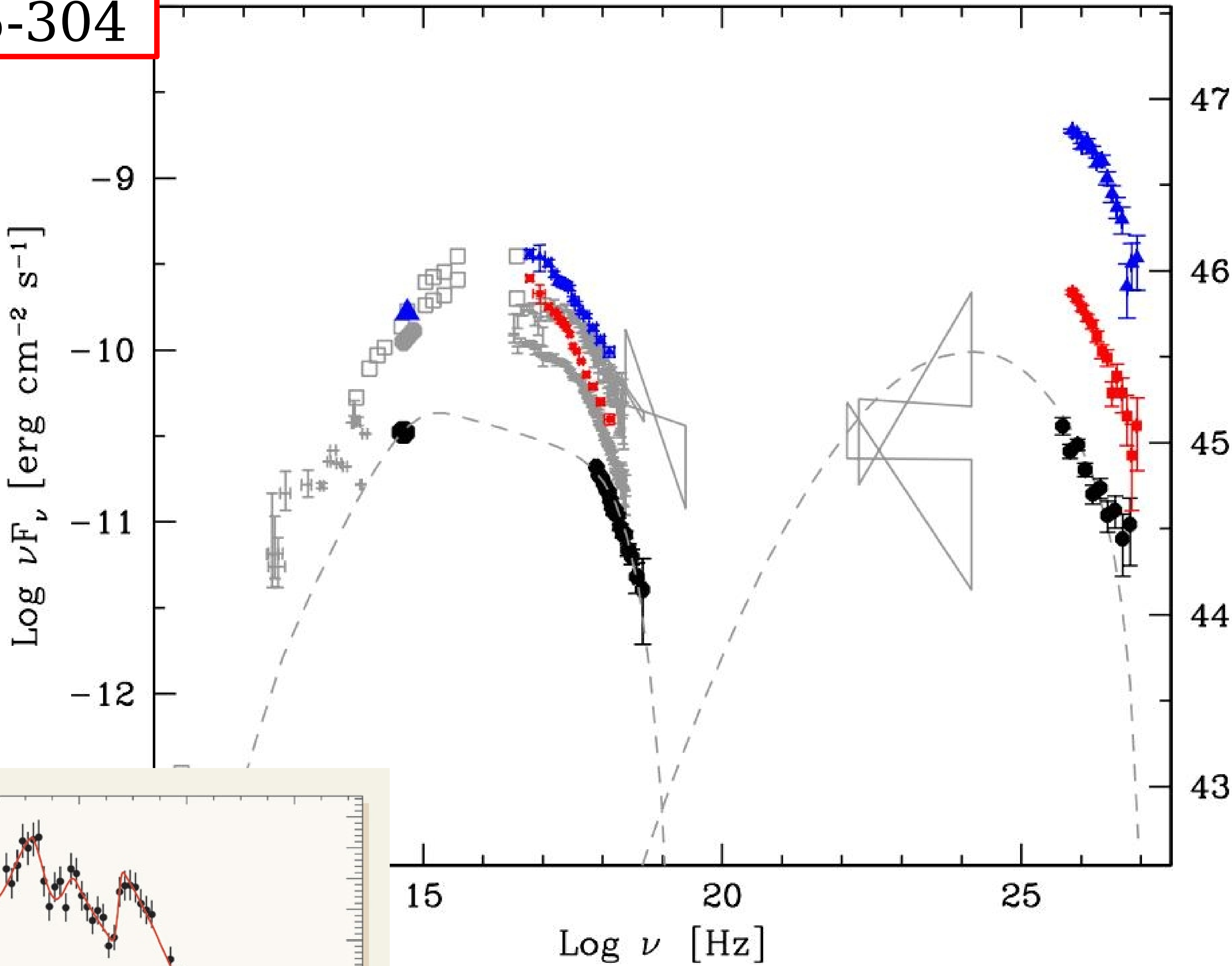
Fig. 7. Gamma-ray spectral slope Γ_γ of BL Lac objects (open blue circles), FSRQs (open black squares), FR1 radio galaxies (red circles), FR2 radio sources (green squares), and star-forming galaxies (magenta diamonds), are plotted as a function of their 100 MeV - 5 GeV γ-ray luminosity L_γ.

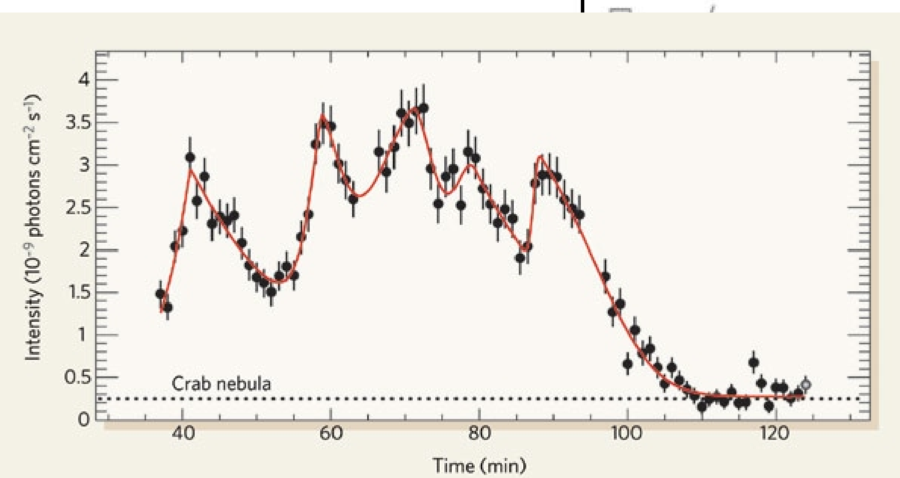
Mk 501

$$L_{iso} \approx 10^{50} \text{ erg s}^{-1}$$



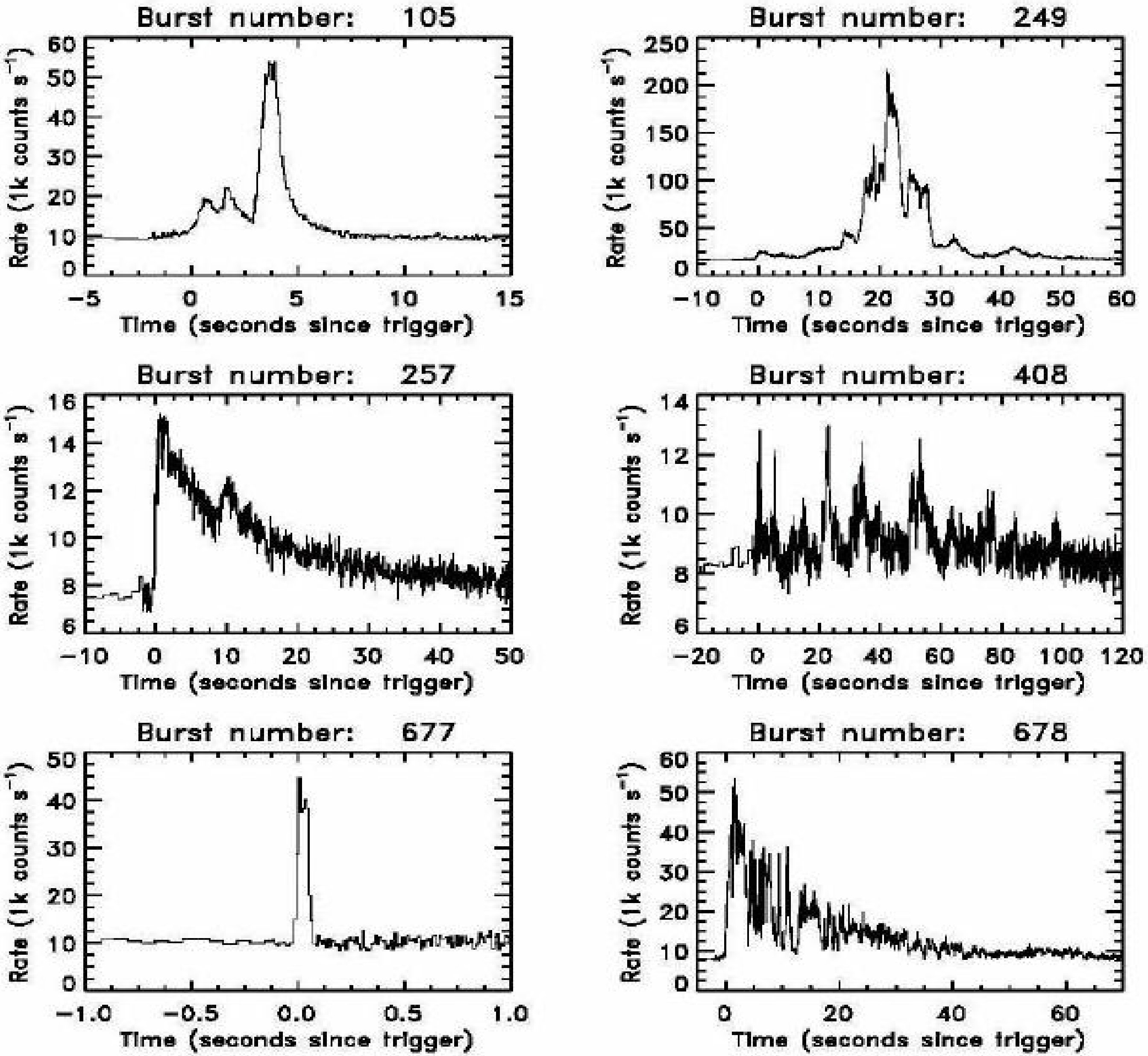
PKS 2155-304



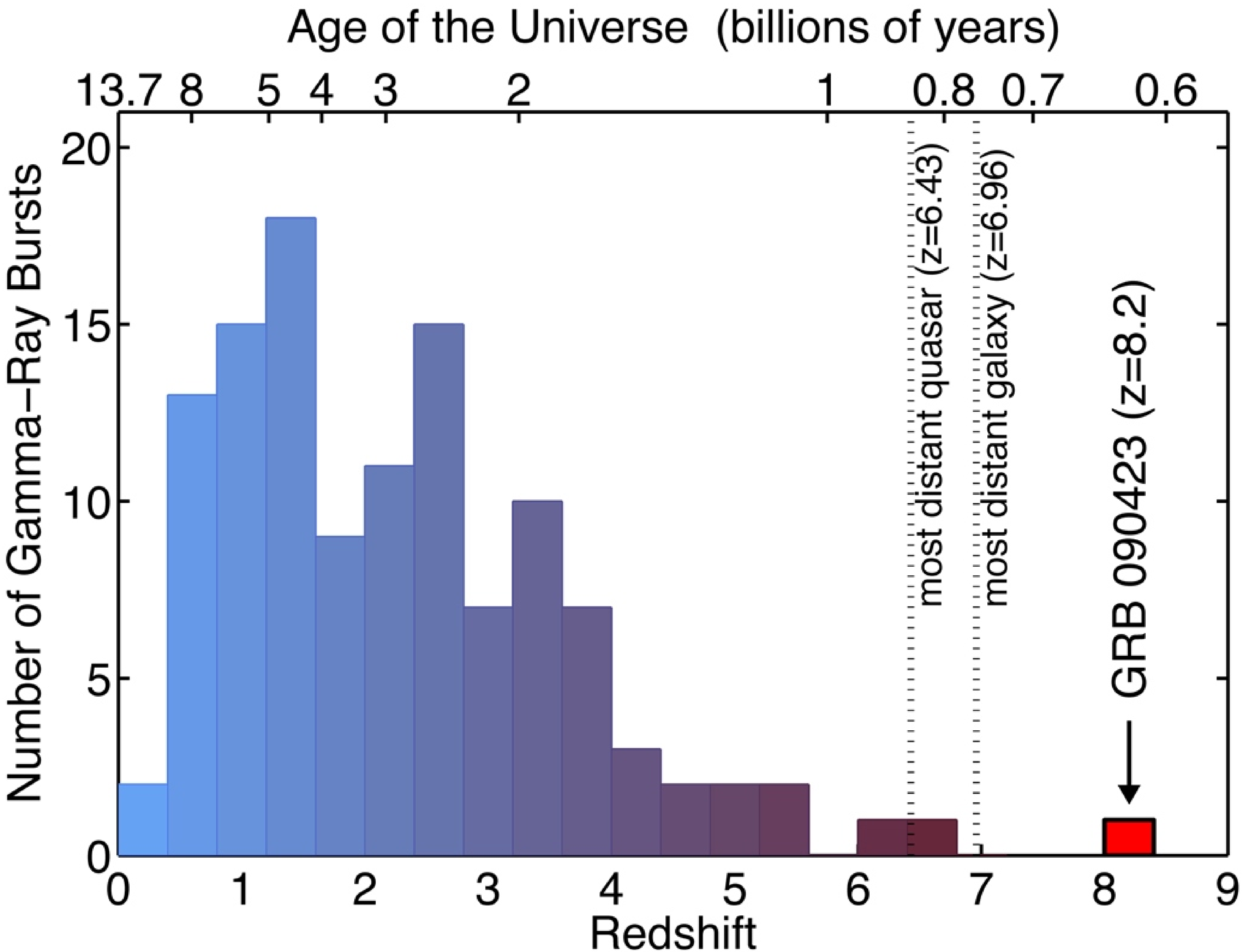


(Very rapid time variations)

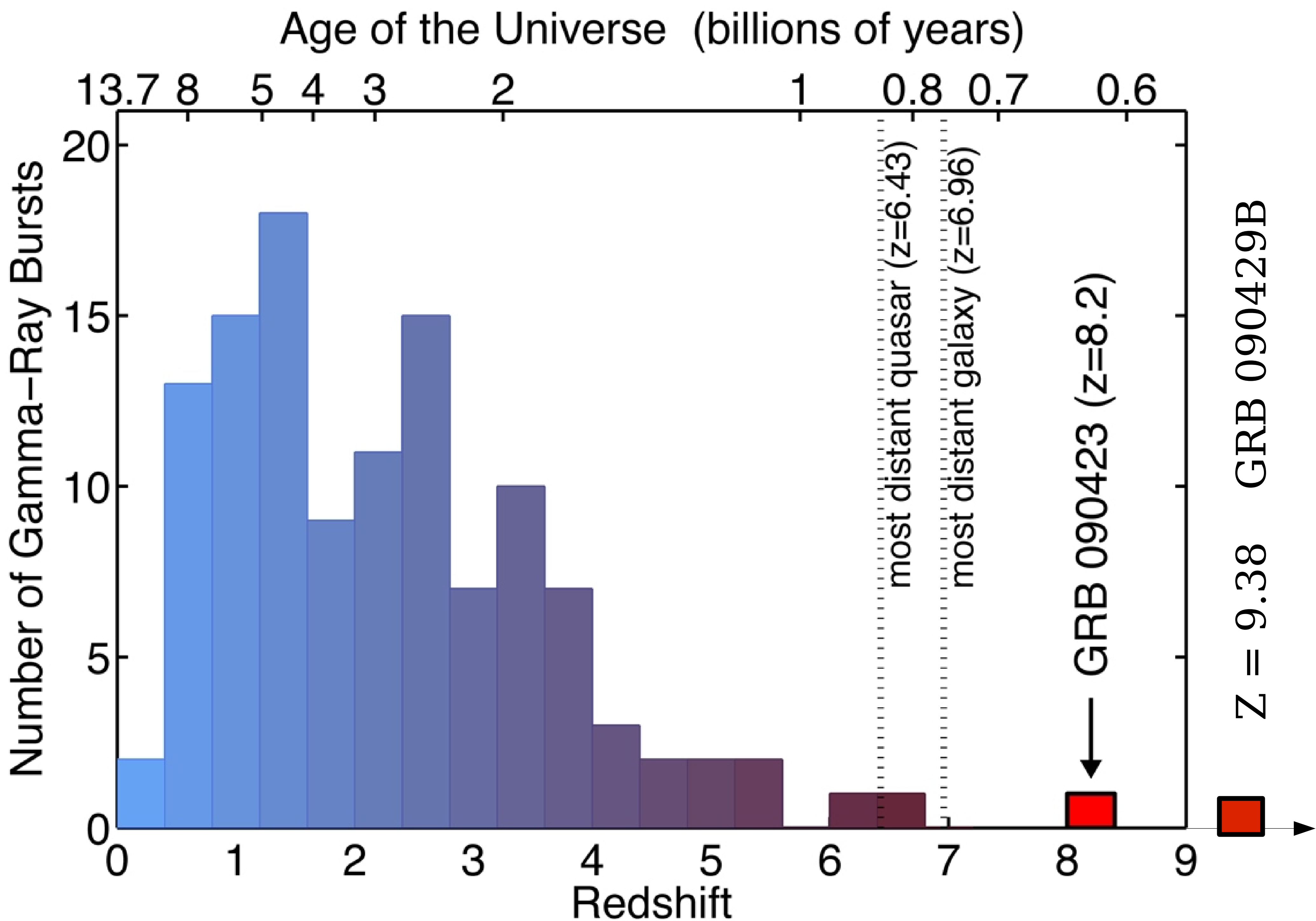
GAMMA RAY BURSTS (GRB's)

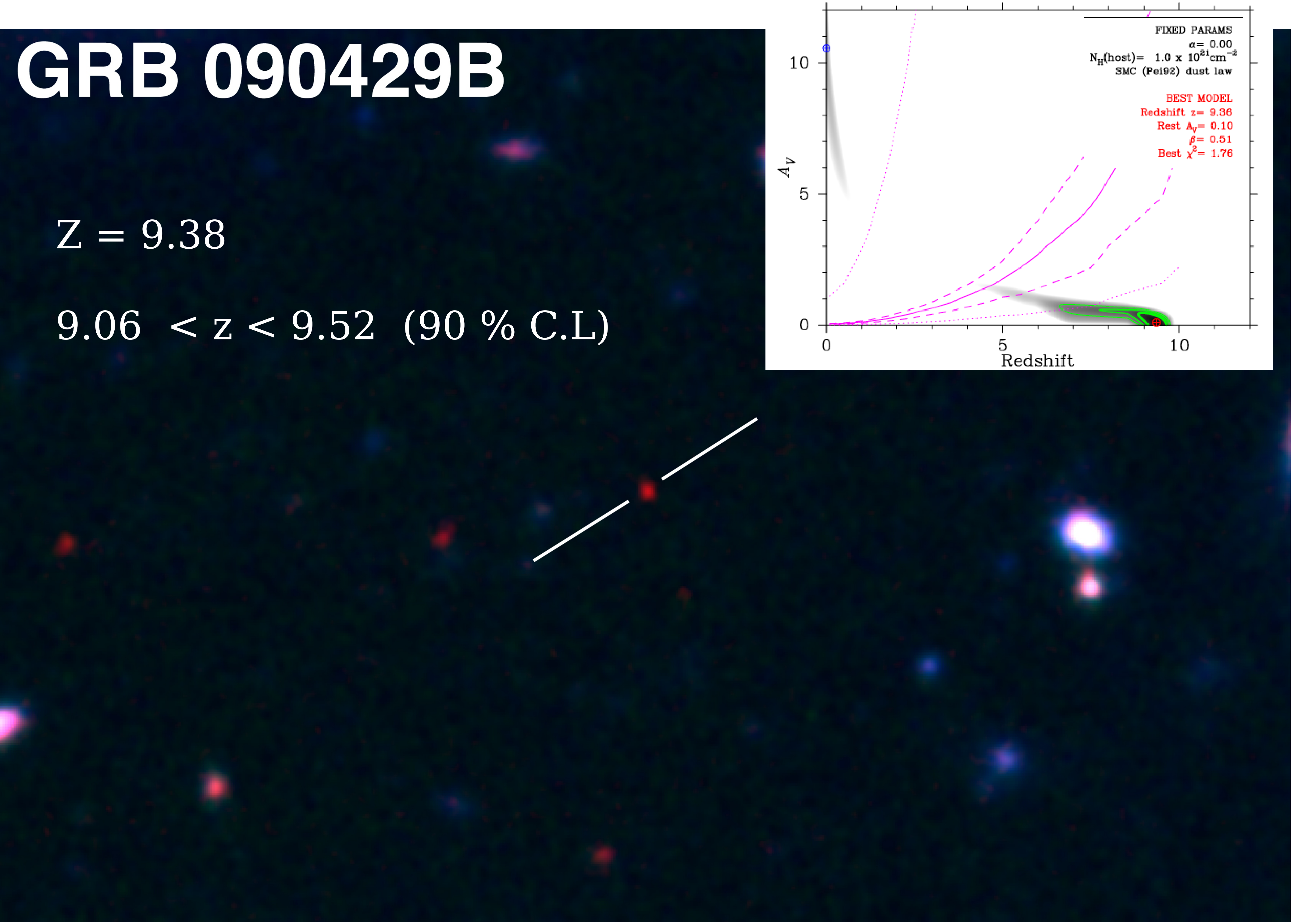


Proposed source
Of the CR



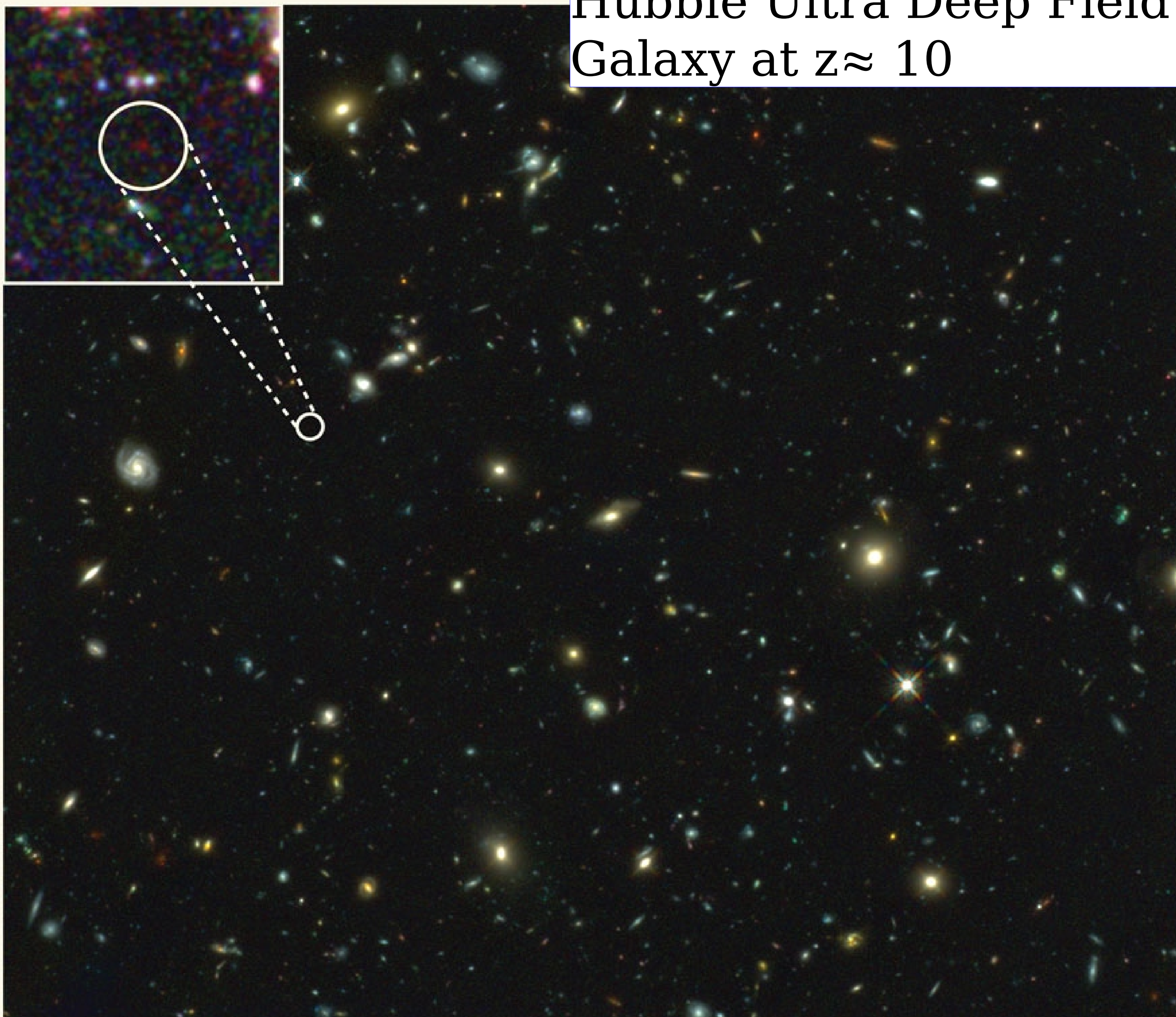
Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma-Ray Bursts
20
15
10
5
0
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
0
1
2
3
4
5
6
7
8
9
Redshift

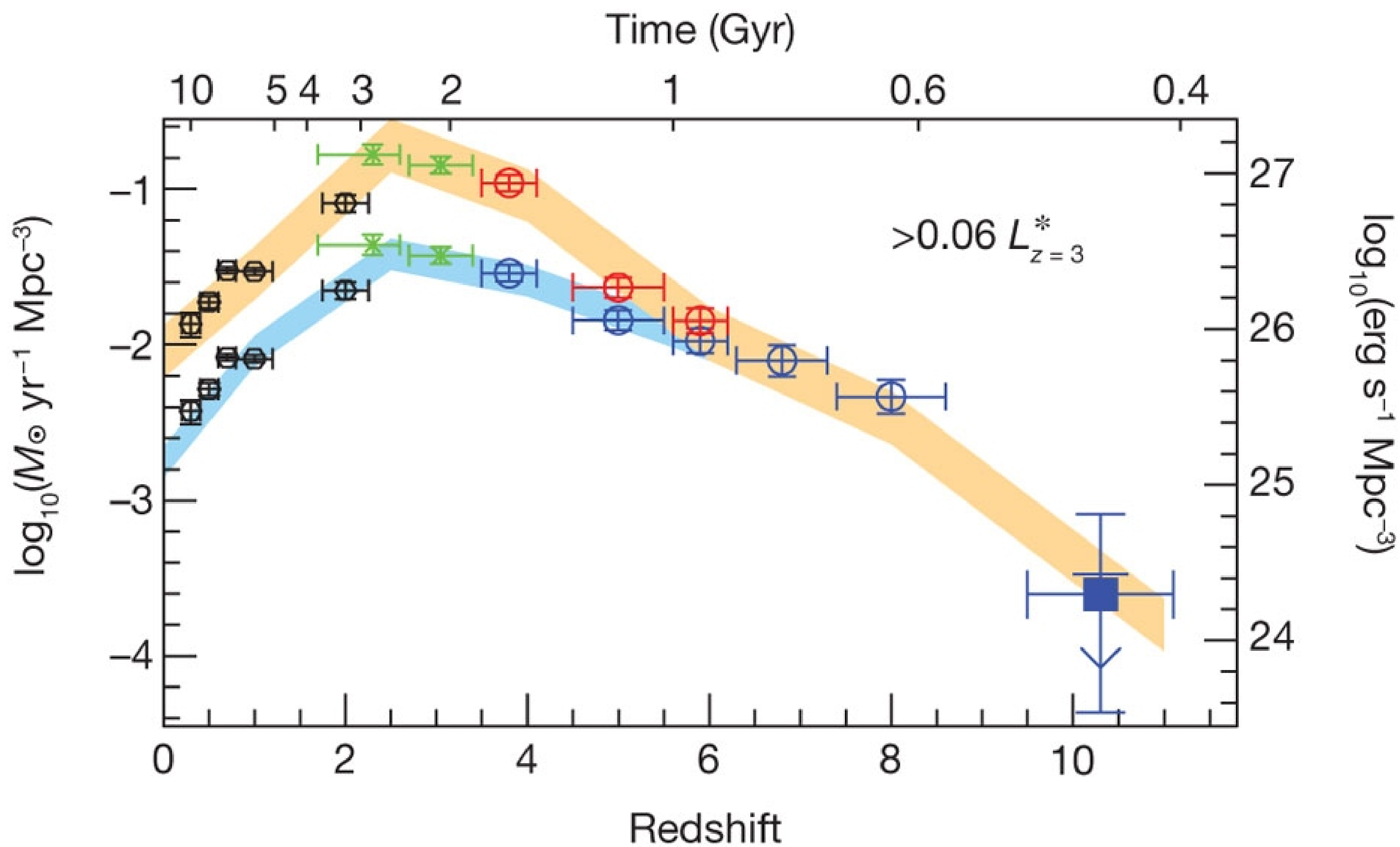

Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma-Ray Bursts
20
15
10
5
0
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
Z = 9.38 GRB 090429B
0
1
2
3
4
5
6
7
8
9
Redshift


GRB 090429B
Z = 9.38
9.06 < z < 9.52 (90 % C.L)
FIXED PARAMS
α= 0.00
N_H(host)= 1.0 x 10^21 cm^-2
SMC (Pei92) dust law
BEST MODEL
Redshift z= 9.36
Rest A_V= 0.10
β= 0.51
Best χ²= 1.76
A_V
10
5
0
0
5
10
Redshift

... Galaxy beat GRB's ...

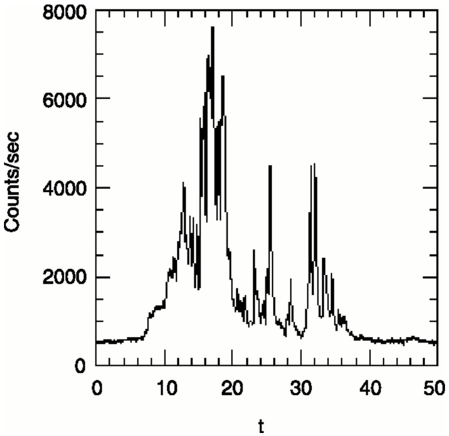
Hubble Ultra Deep Field HUD09
Galaxy at z≈ 10

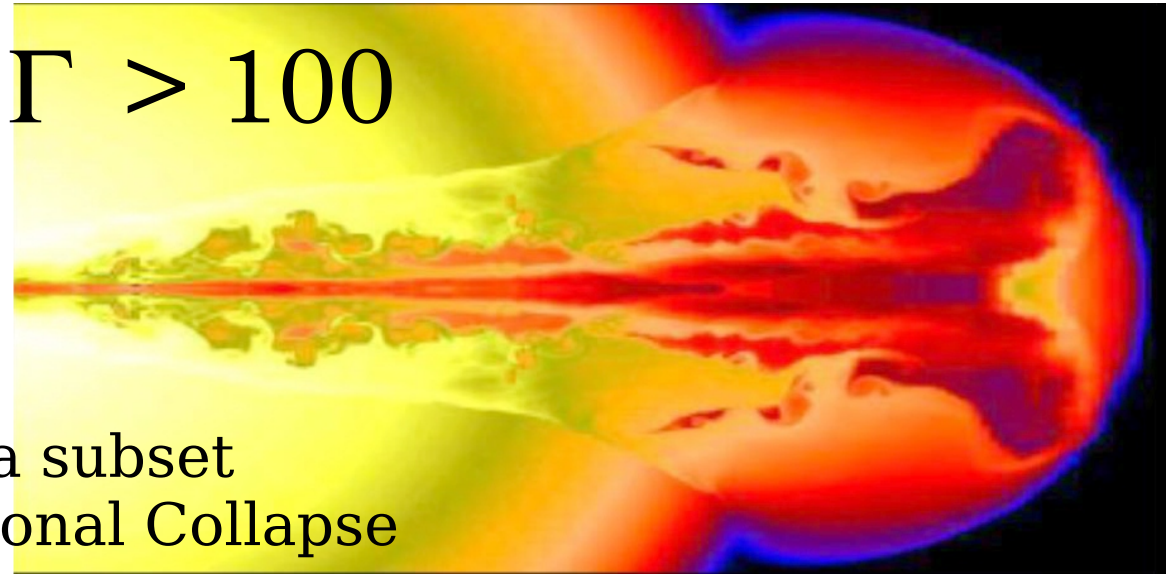




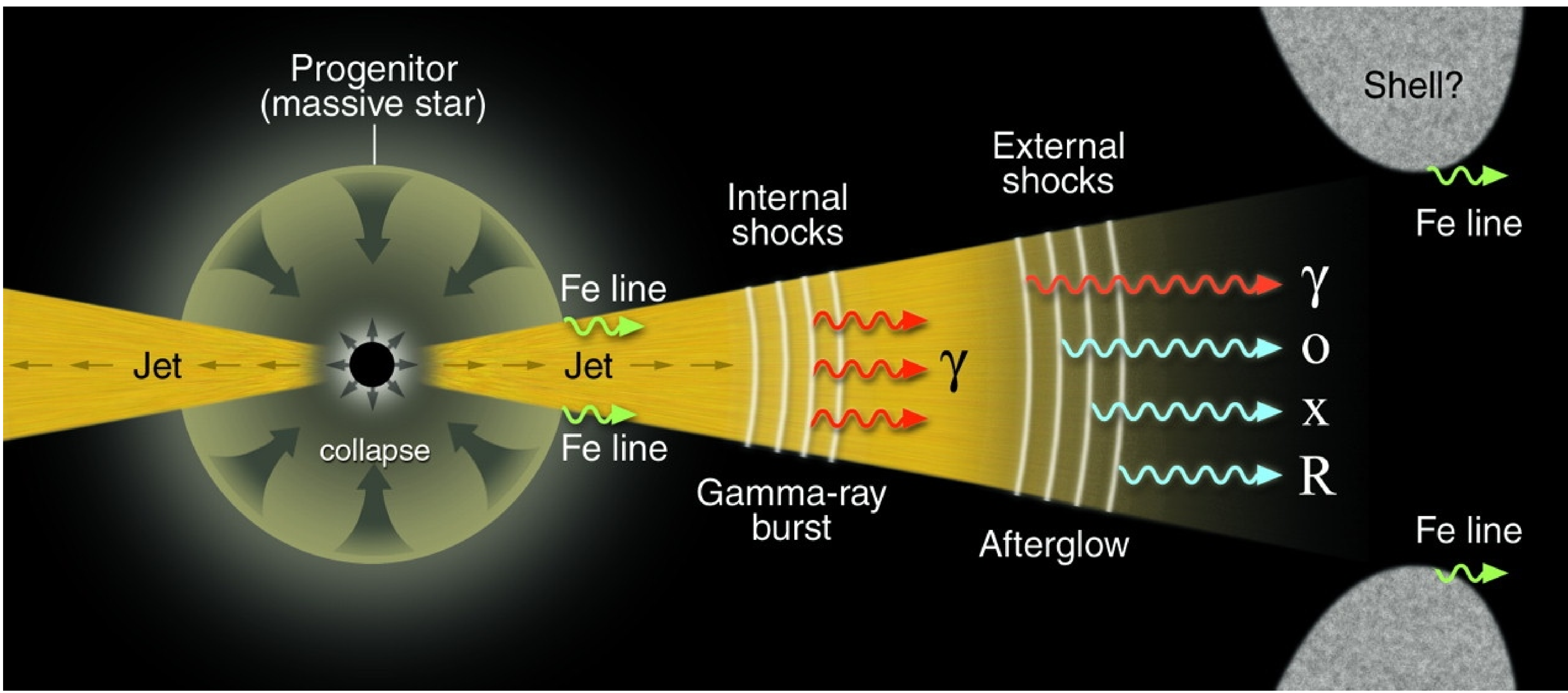
The first stars...

Searches for very-high-redshift galaxies over the past decade have yielded a large sample of more than 6,000 galaxies existing just 900-2,000 million years (Myr) after the Big Bang (redshifts $6 > z > 3$; ref. 1). The Hubble Ultra Deep Field (HUDF09) data[2,3] have yielded the first reliable detections of $z \approx 8$ galaxies[3–9] that, together with reports of a γ-ray burst at $z \approx 8.2$ (refs 10, 11), constitute the earliest objects reliably reported to date. Observations of $z \approx$ 7-8 galaxies suggest substantial star formation at $z >$ 9-10 (refs 12, 13). Here we use the full two-year HUDF09 data to conduct an ultra-deep search for $z \approx 10$ galaxies in the heart of the reionization epoch, only 500 Myr after the Big Bang. Not only do we find one possible $z \approx 10$ galaxy candidate, but we show that, regardless of source detections, the star formation rate density is much smaller (~10%) at this time than it is just ~200 Myr later at $z \approx 8$. This demonstrates how rapid galaxy build-up was at $z \approx 10$, as galaxies increased in both luminosity density and volume density from $z \approx 8$ to $z \approx 10$. The 100-200 Myr before $z \approx 10$ is clearly a crucial phase in the assembly of the earliest galaxies.

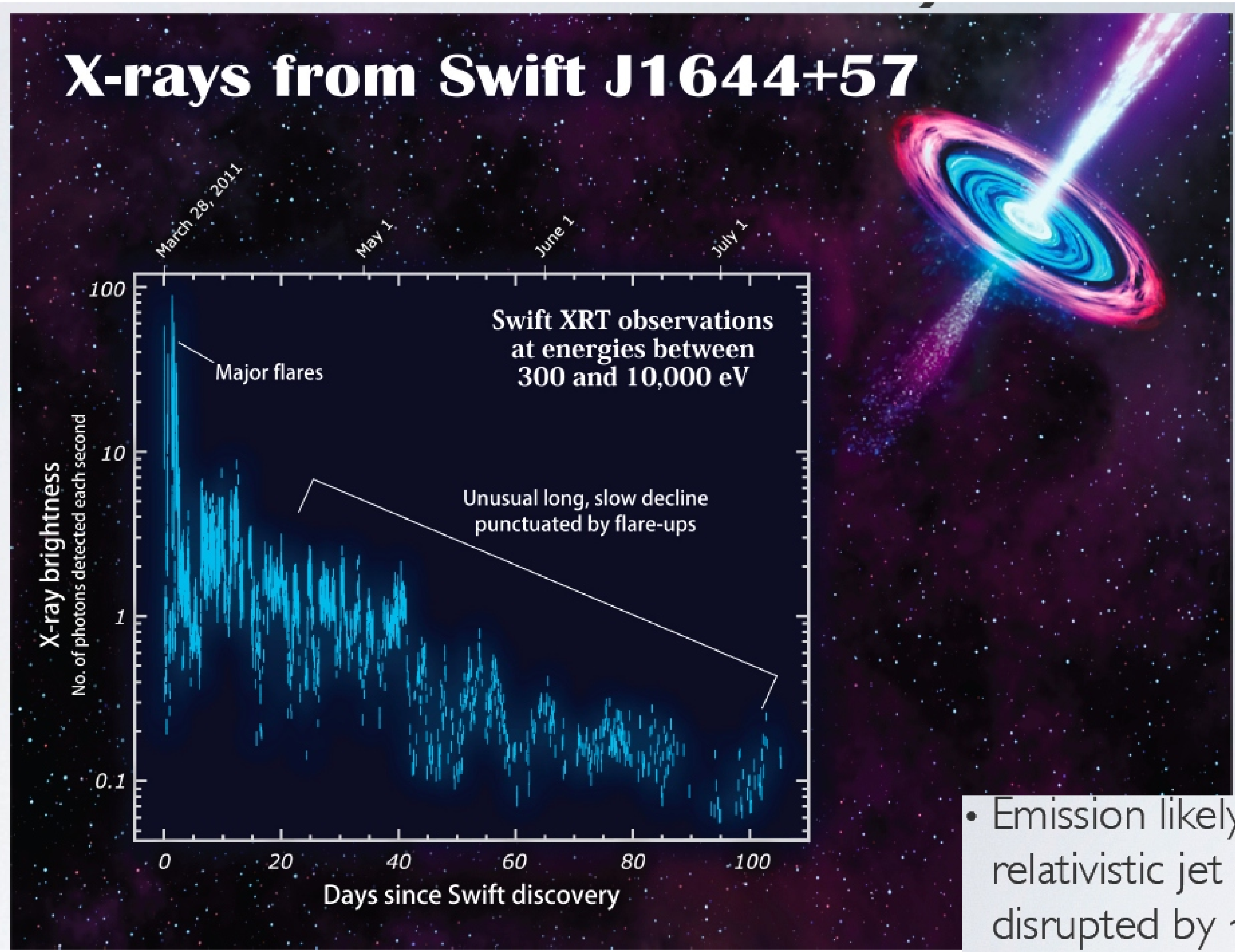




GRB : associated with a subset
of SN Stellar Gravitational Collapse



Tidal Disruption Events (initially mistaken for GRBs)

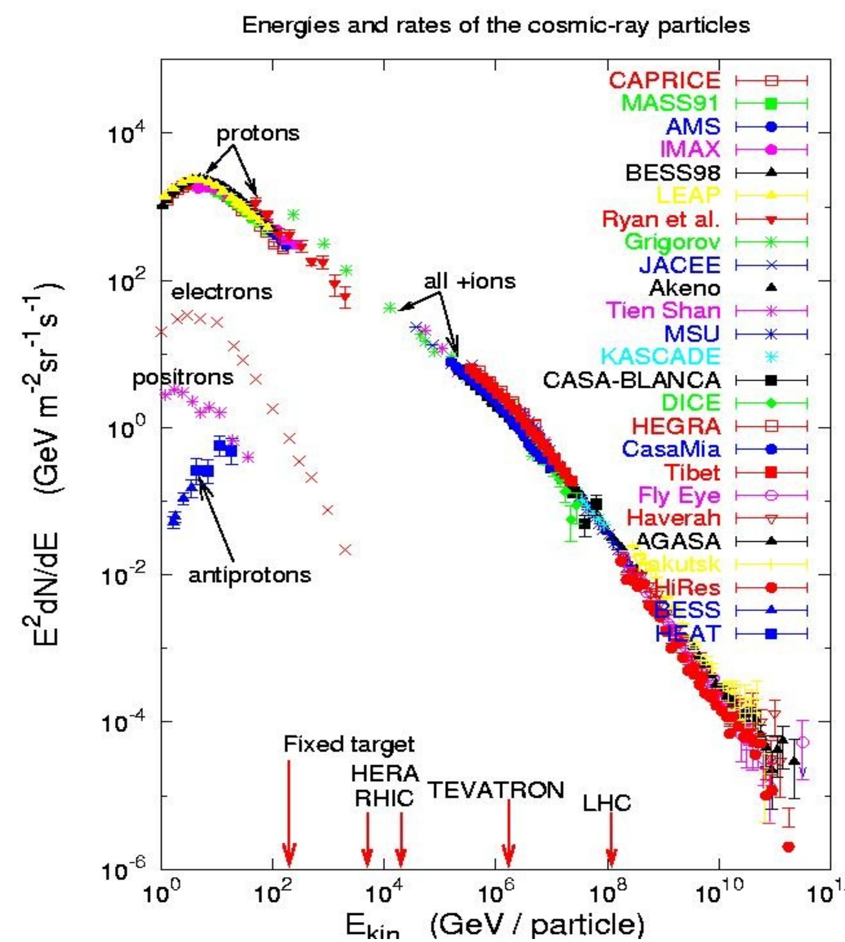


- Emission likely due to a relativistic jet from a star disrupted by ~10^6 M black hole

Cosmic Rays

Victor Hess
before the balloon flight of 1912

Discovery of Cosmic Rays
beginning of
High Energy Astrophysics



The Cosmic Ray spectrum

Sharp feature at 230 GV [Pamela] [?!]

proton/nuclei/electron/positron/antiproton acceleration

Anisotropies [Milagro, Argo, IceCube, ...]

The Knee

From the “knee” to the “ankle” [Kascade Grande]
2 knees ? 3 knees ?? ......

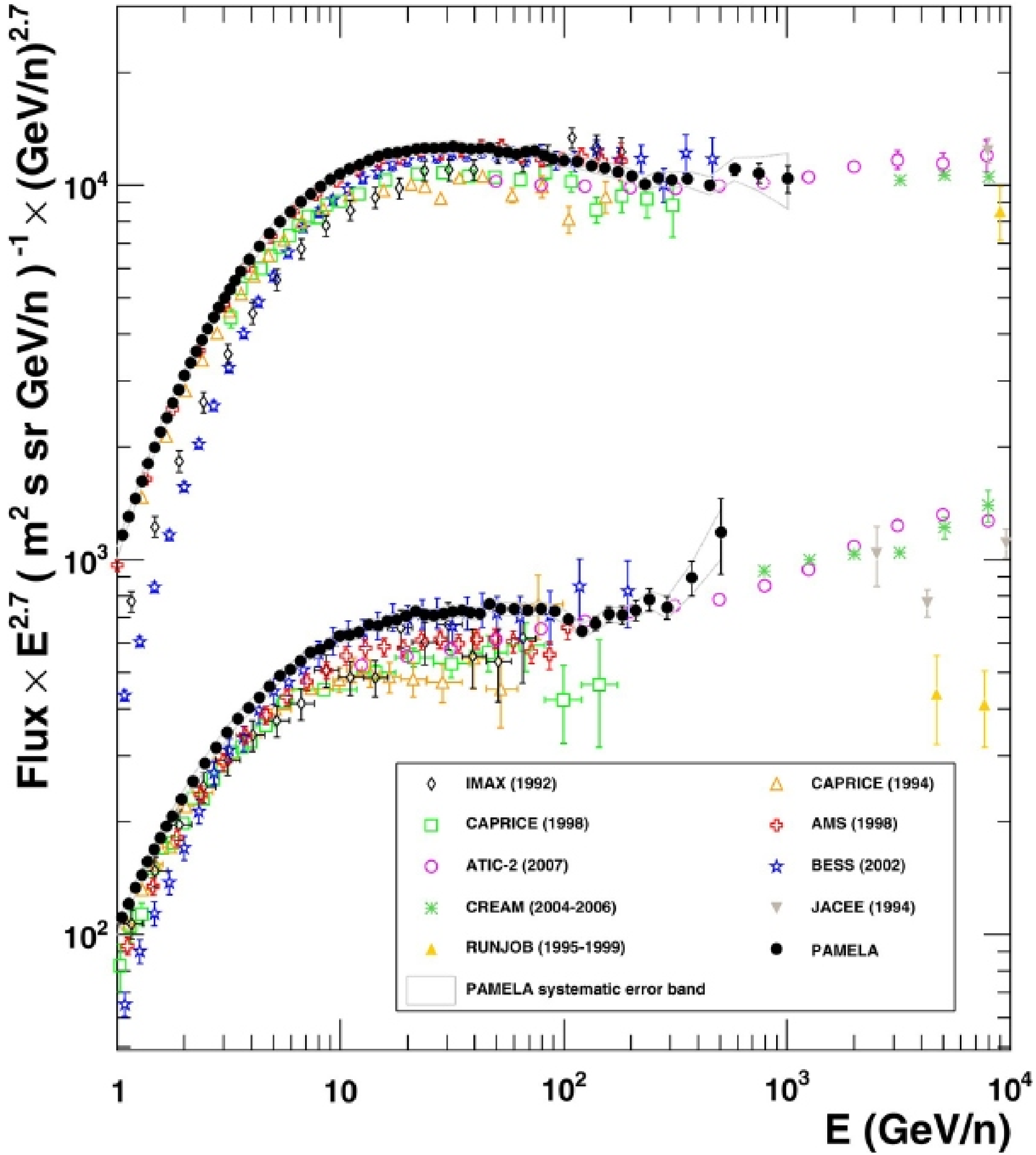
Galactic to extra-galactic transition

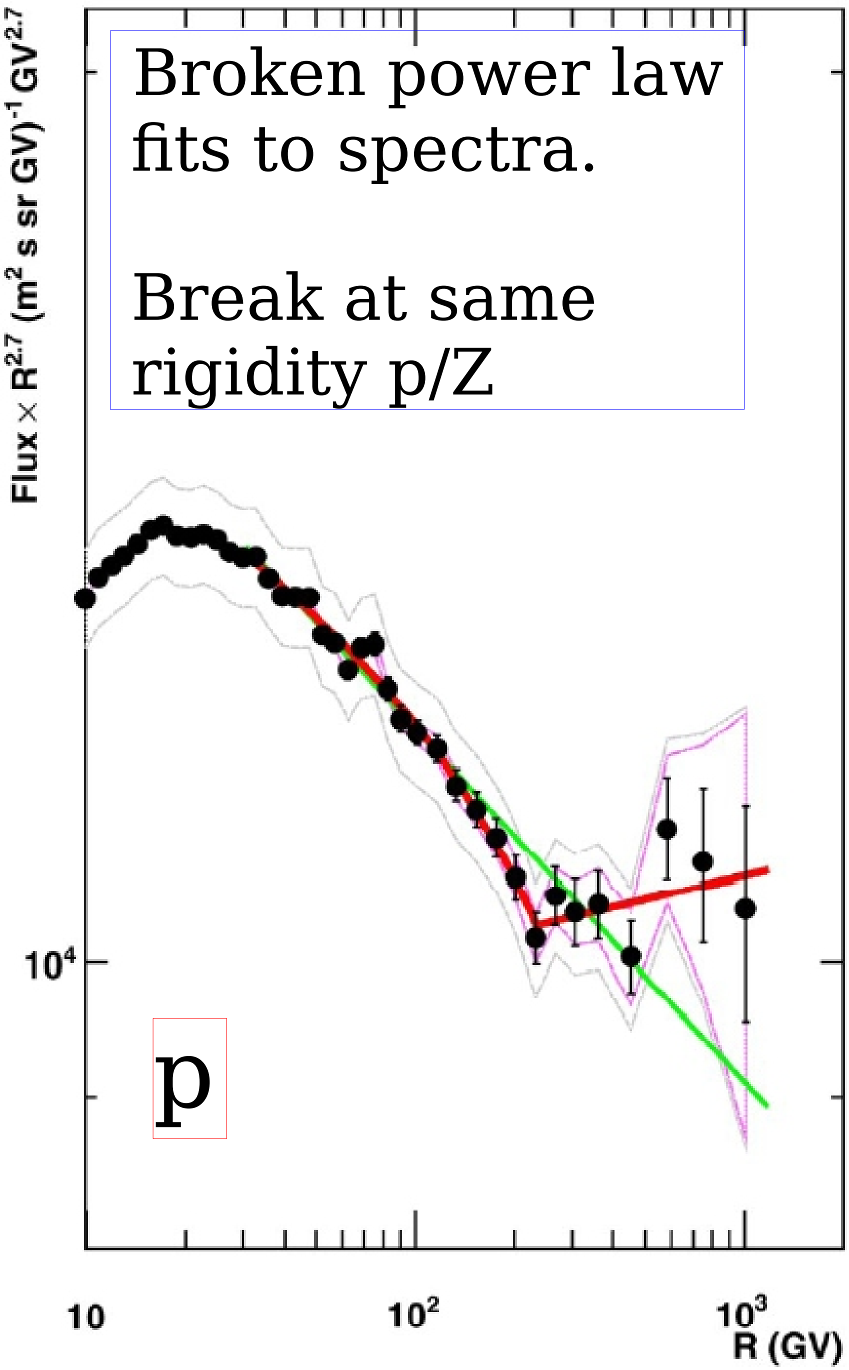
UHECR [Auger, HiRes, Telescope Array]

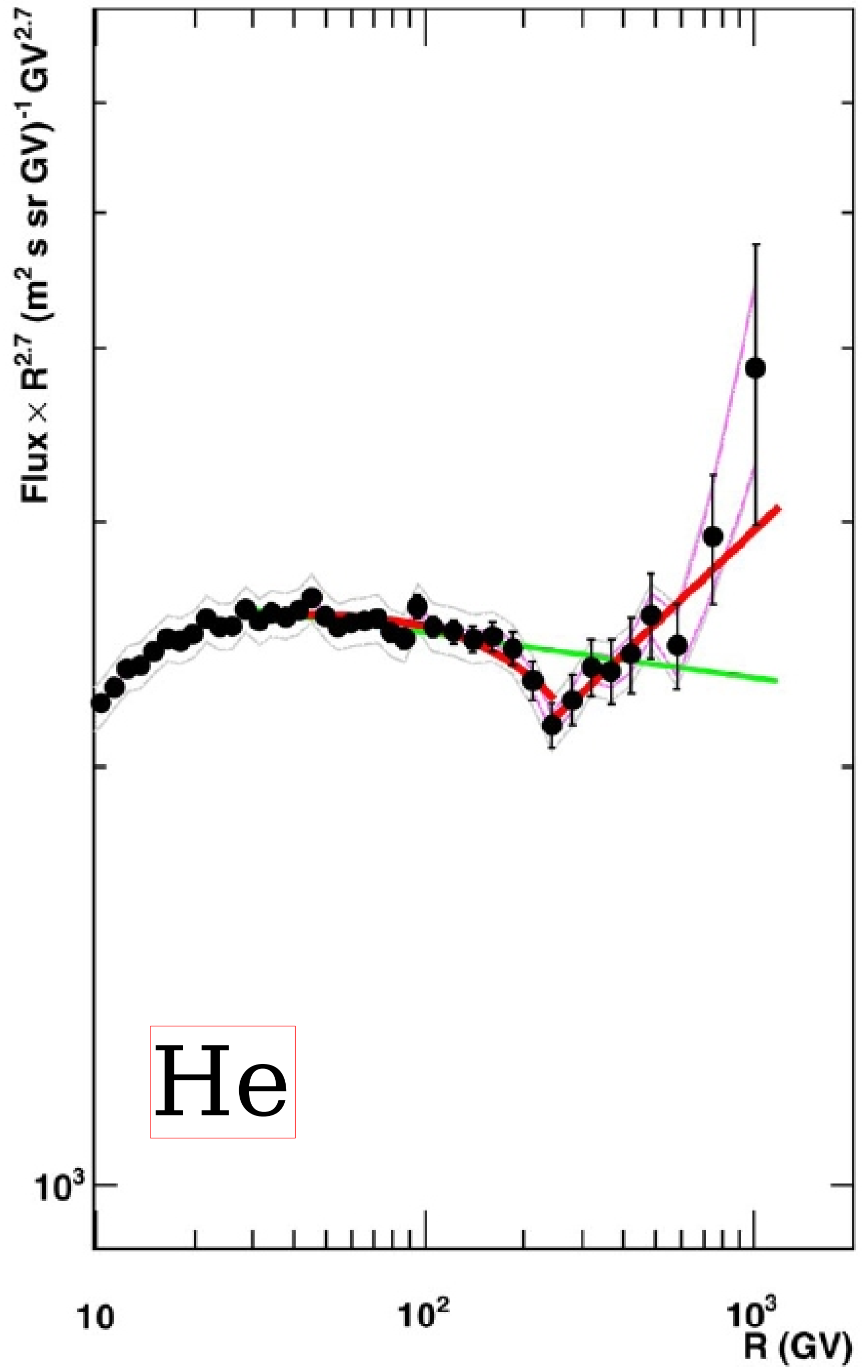
PAMELA

Proton/Helium
CR fluxes
1 GV – 1.2 TV

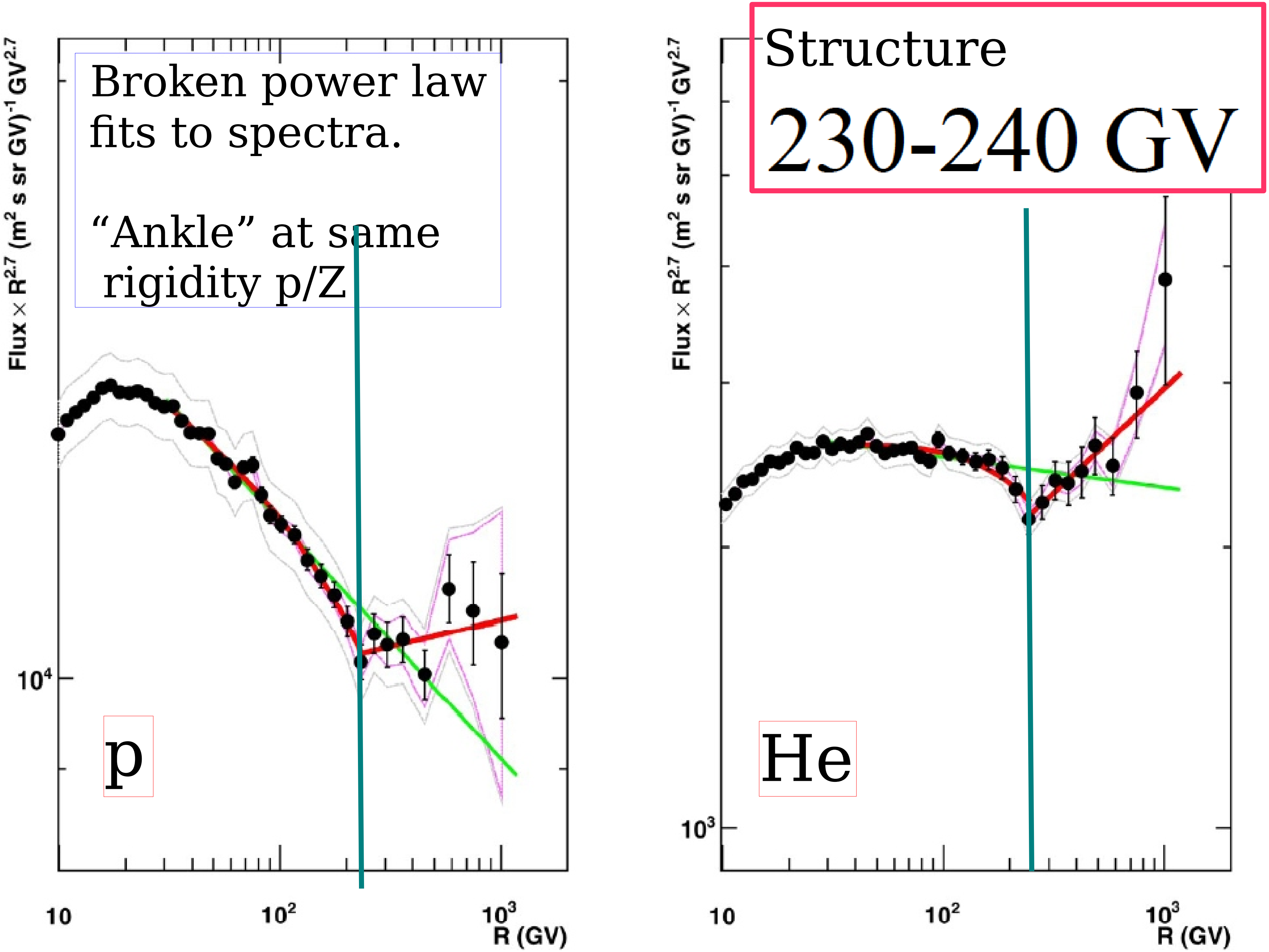
Science in press
(march 2011)





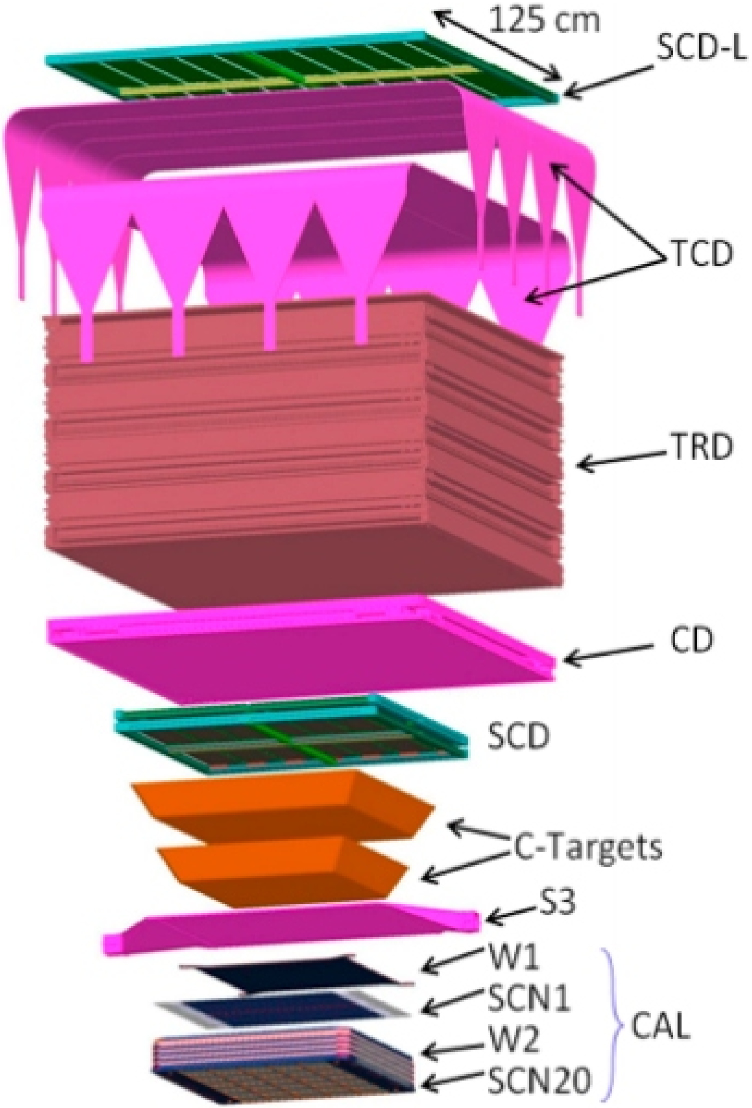


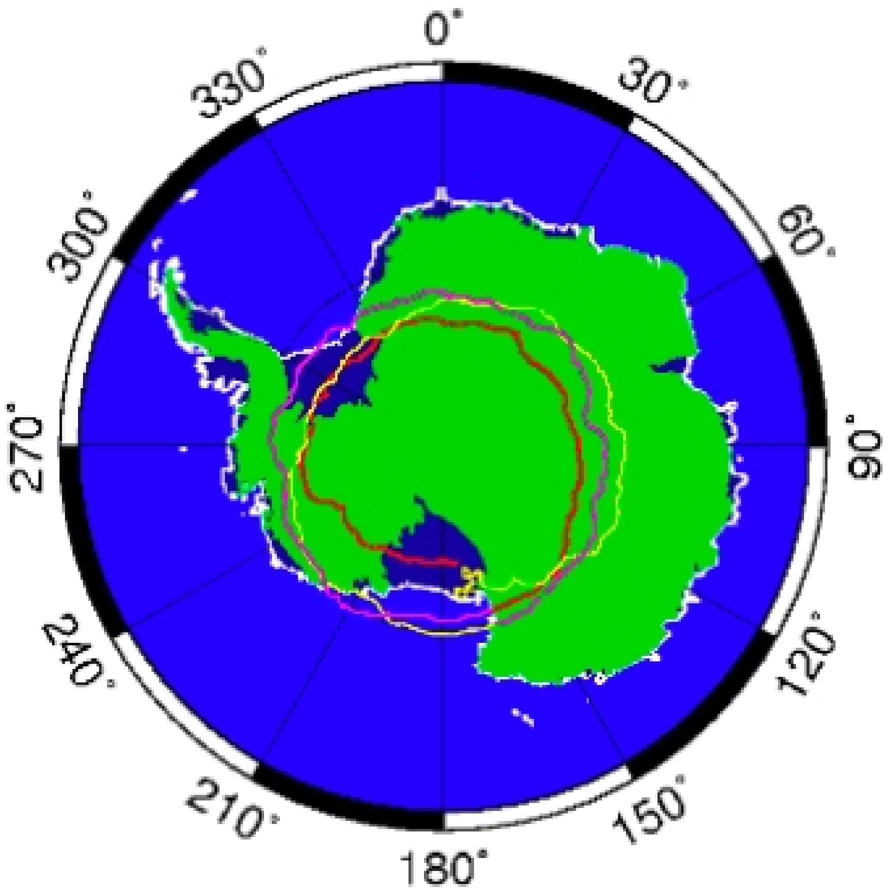
Surprising and important result.



Surprising and important result.

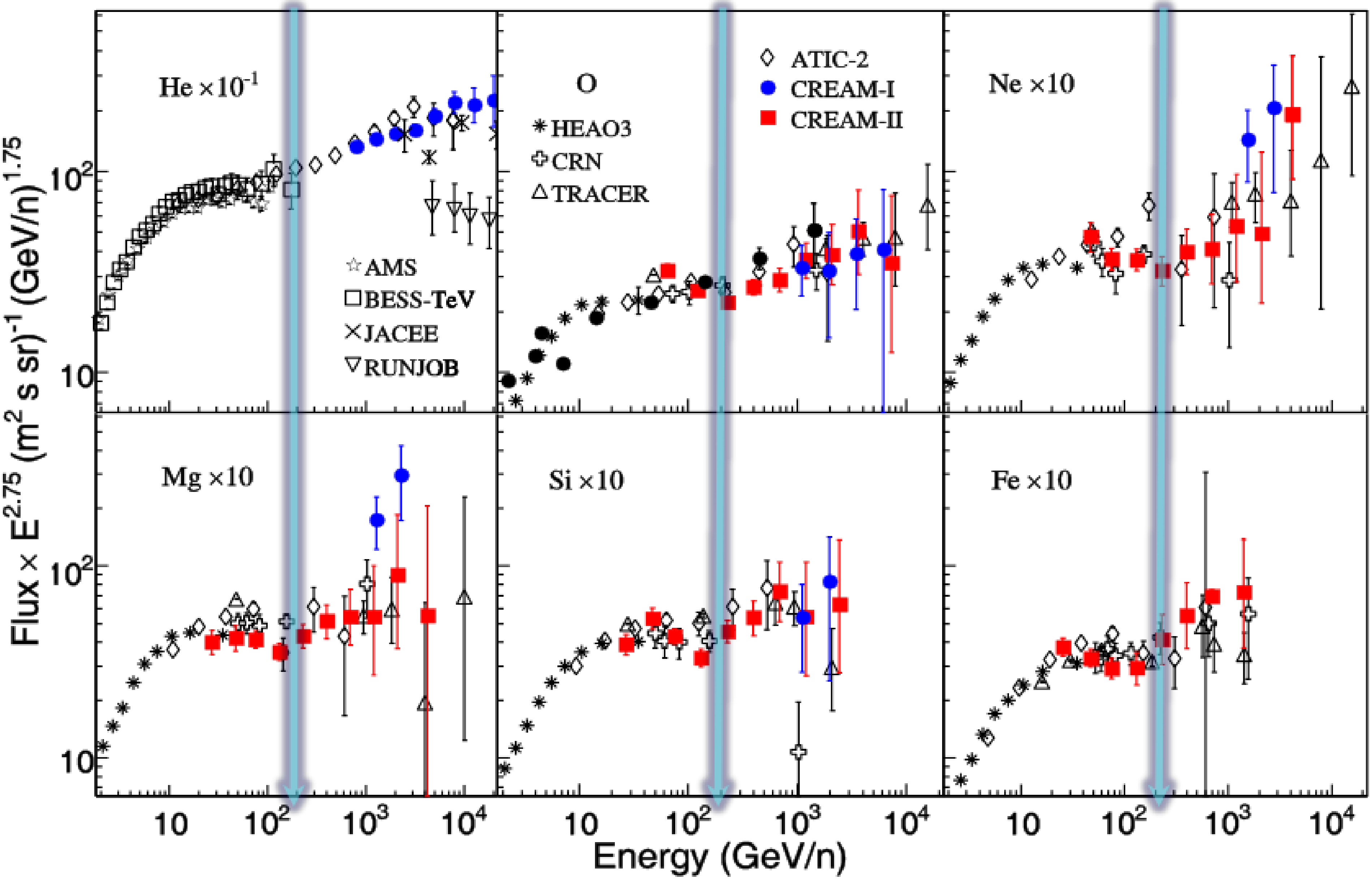
CREAM (calorimeter on balloon)
(5 flights in Antartica. Total of 156 days)

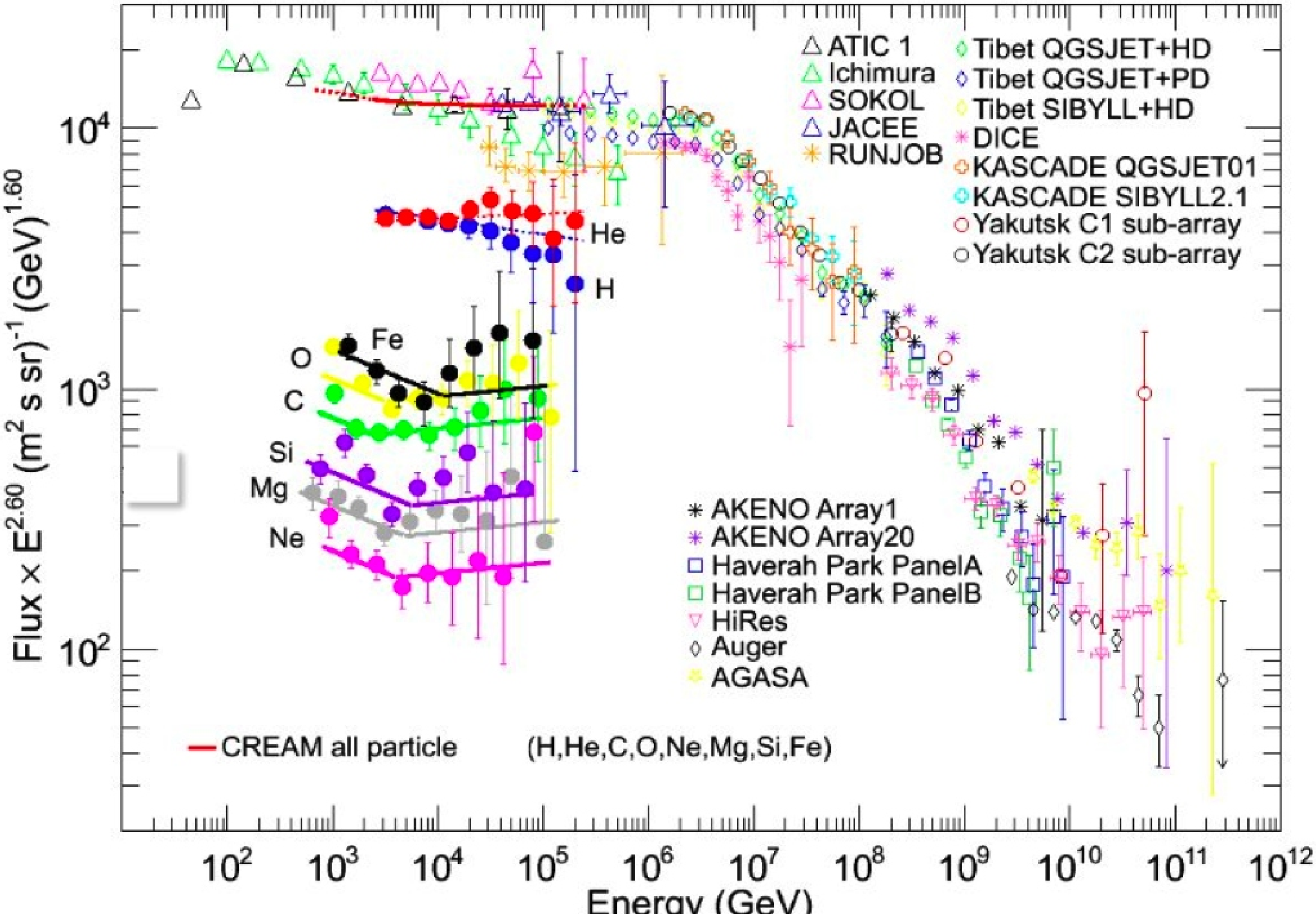




Cream 5 trajectory
37 days 12/2009-01/2010

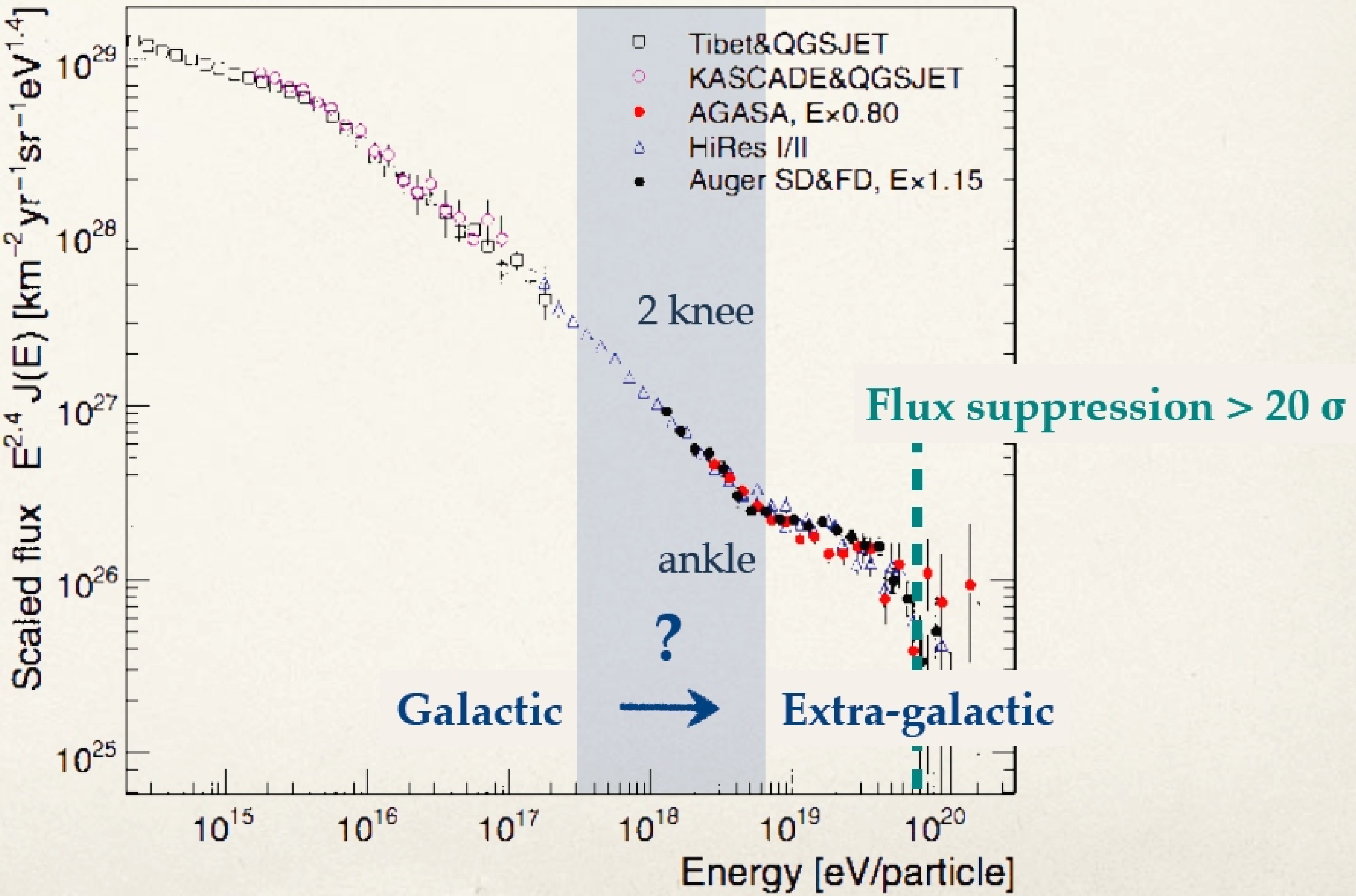
Discrepant hardening





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)

Roberto Battiston
thursday.


Tibet&QGSJET
KASCADE&QGSJET
AGASA, E×0.80
HiRes I/II
Auger SD&FD, E×1.15
2 knee
ankle
?
Flux suppression > 20 σ
Galactic
Extra-galactic
Scaled flux E^2.4 J(E) [km^-2 yr^-1 sr^-1 eV^1.4]
Energy [eV/particle]
10^25
10^26
10^27
10^28
10^29
10^15
10^16
10^17
10^18
10^19
10^20

COSMIC RAY

ANISOTROPIES

TIBET AS-Gamma

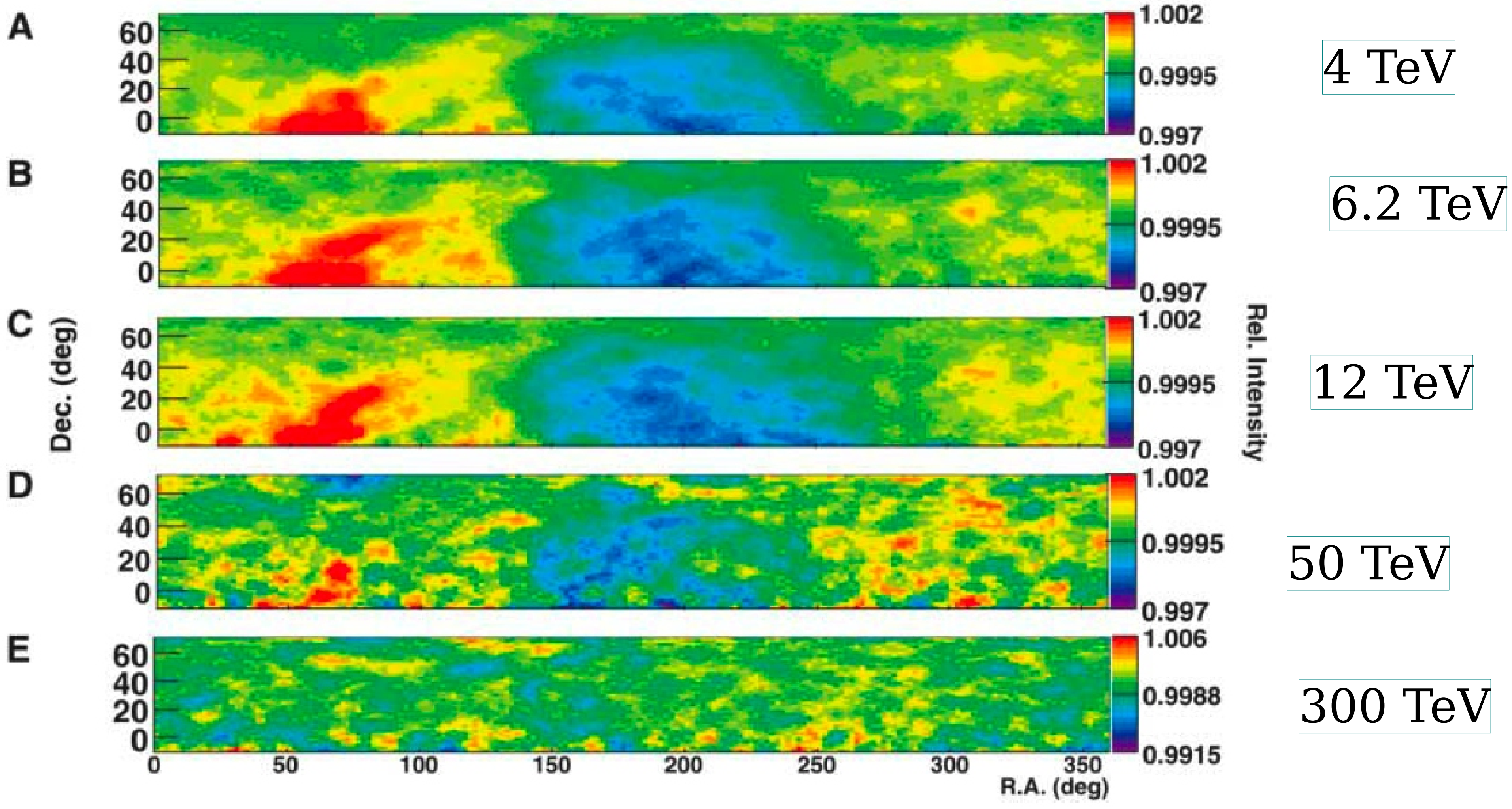
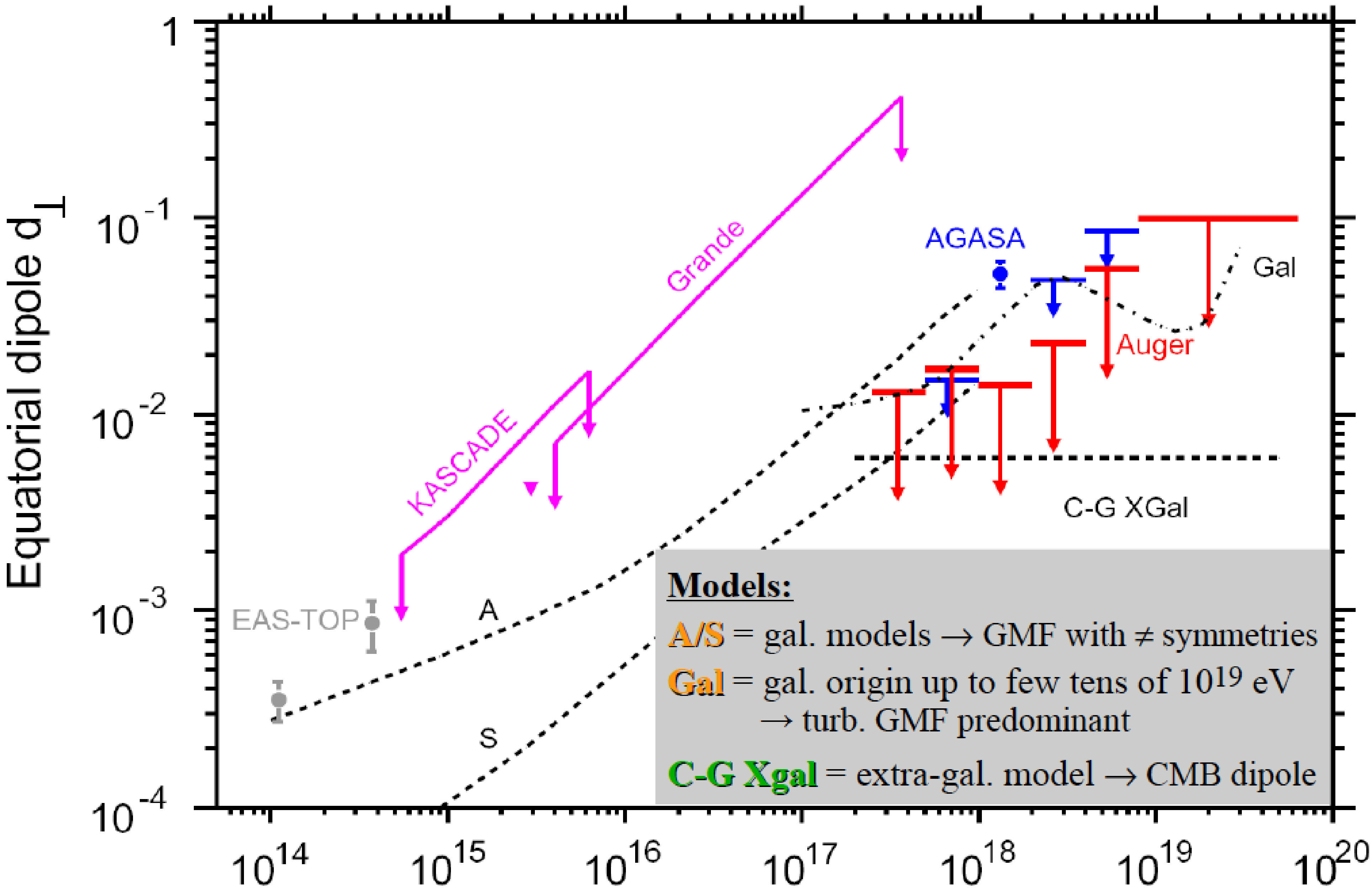


Fig. 3. Celestial CR intensity map for different representative CR energies. (**A**) 4 TeV; (**B**) 6.2 TeV; (**C**) 12 TeV; (**D**) 50 TeV; (**E**) 300 TeV. Data were gathered from 1997 to 2005. The vertical color bin width is 2.5×10^{-4} in [(A) to (D)] and 7.25×10^{-4} in (E) for different statistics, all for the relative CR intensity.

AUGER

Upper limits



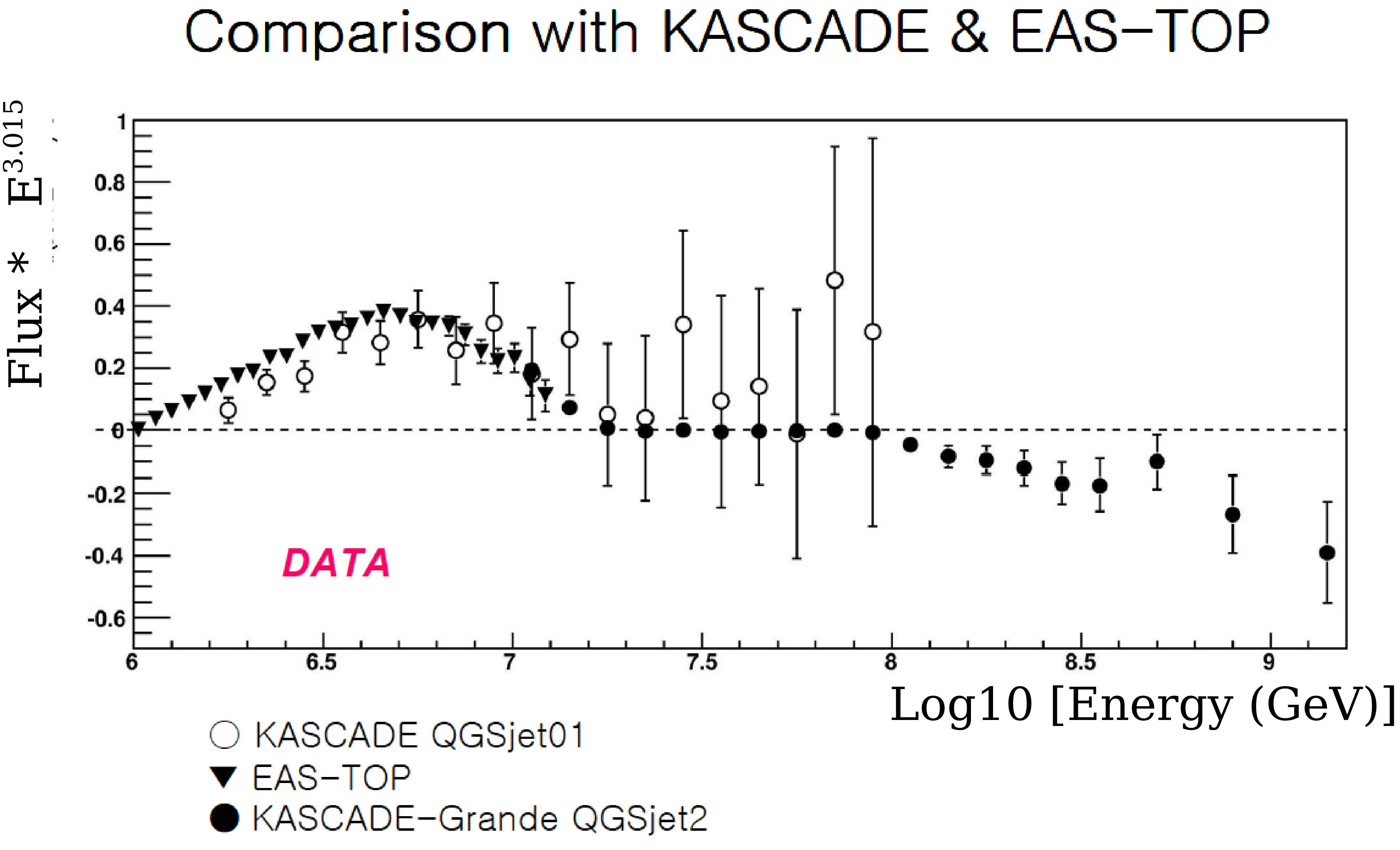
Models:

A/S = gal. models → GMF with ≠ symmetries

Gal = gal. origin up to few tens of 10^{19} eV
→ turb. GMF predominant

C-G Xgal = extra-gal. model → CMB dipole

Structure of the "Knee"



UHECR

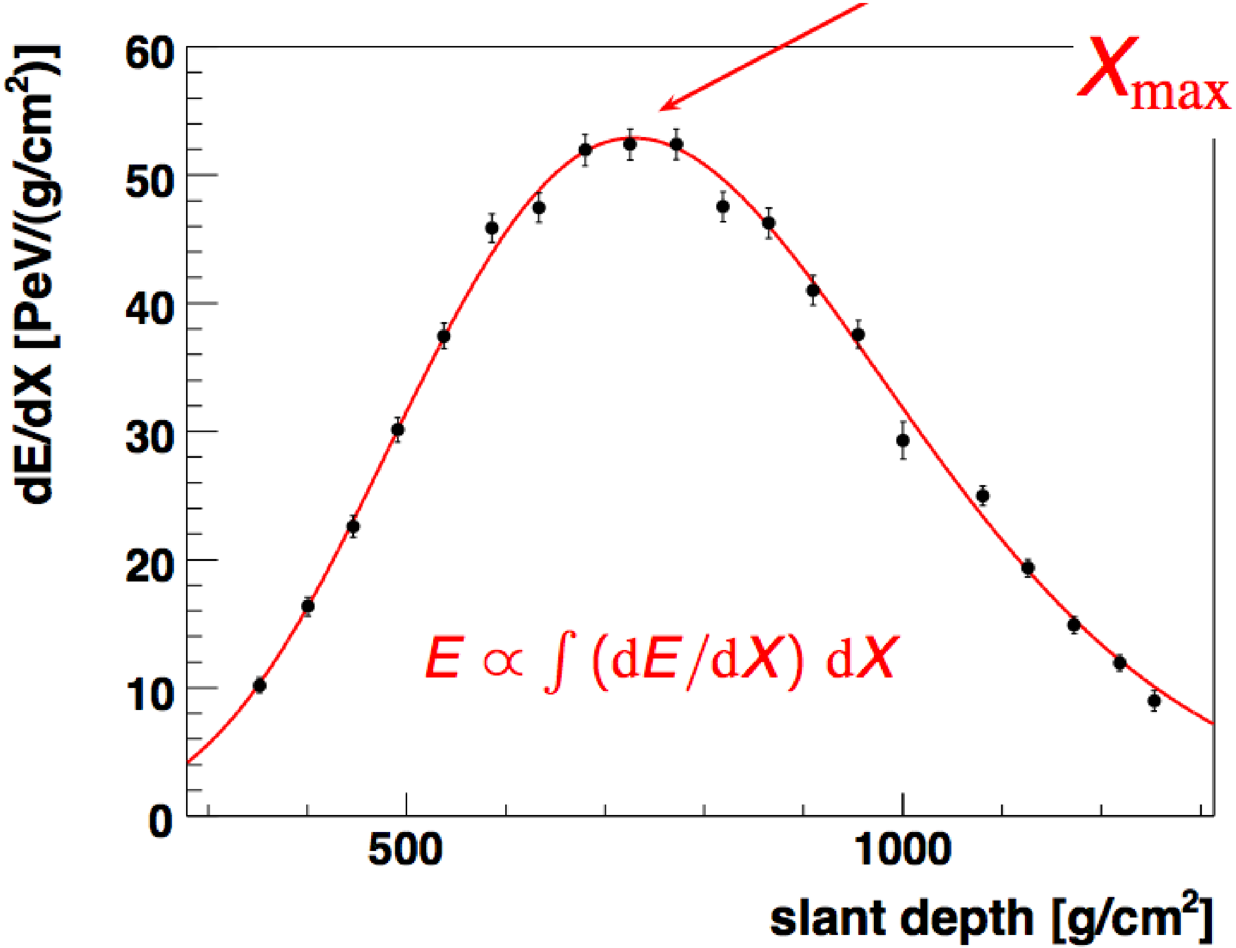
Crucial Problem:

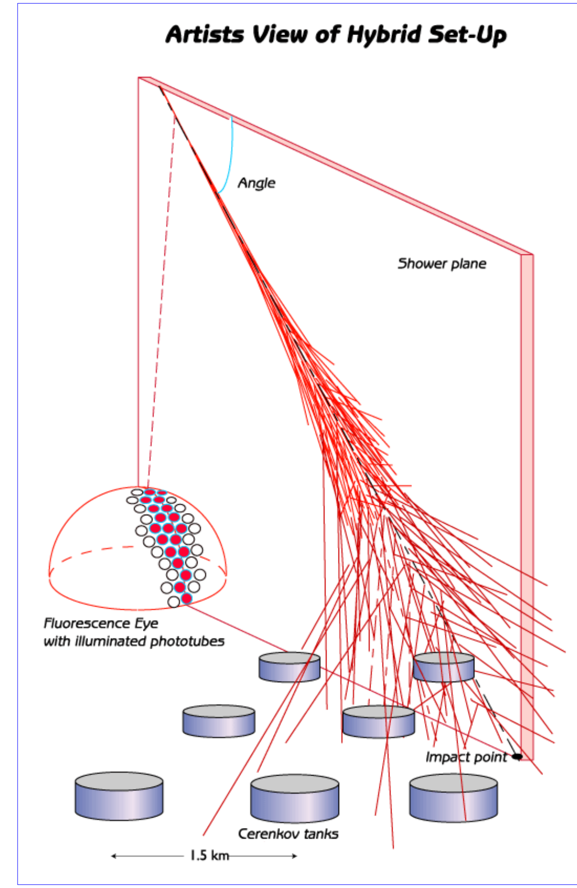
Galactic
Extragalactic
transition

1. Energy Spectrum

2. Anisotropy

3. Composition



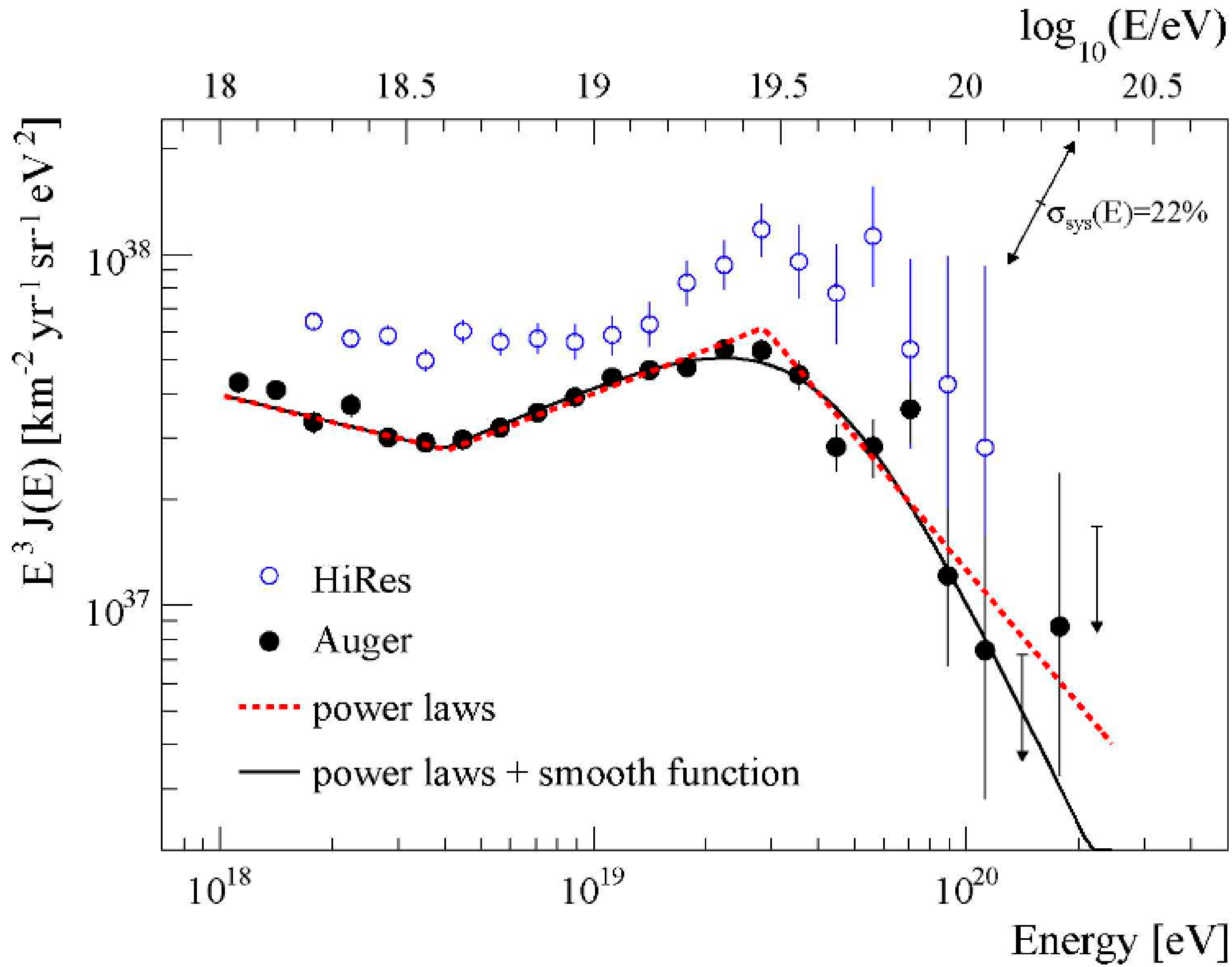


$$E_{\text{ionization}} = \int dX \; N_e(X) \left\langle -\frac{dE}{dX} \right\rangle$$

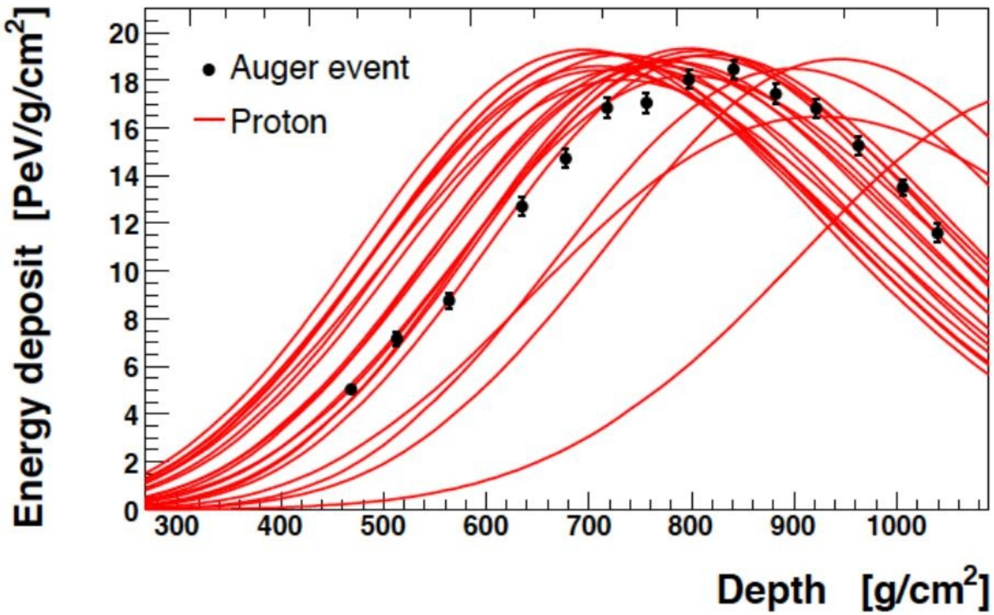
Area $\propto$ Energy

Shape depends on :
- Primary Identity
- Interaction Model

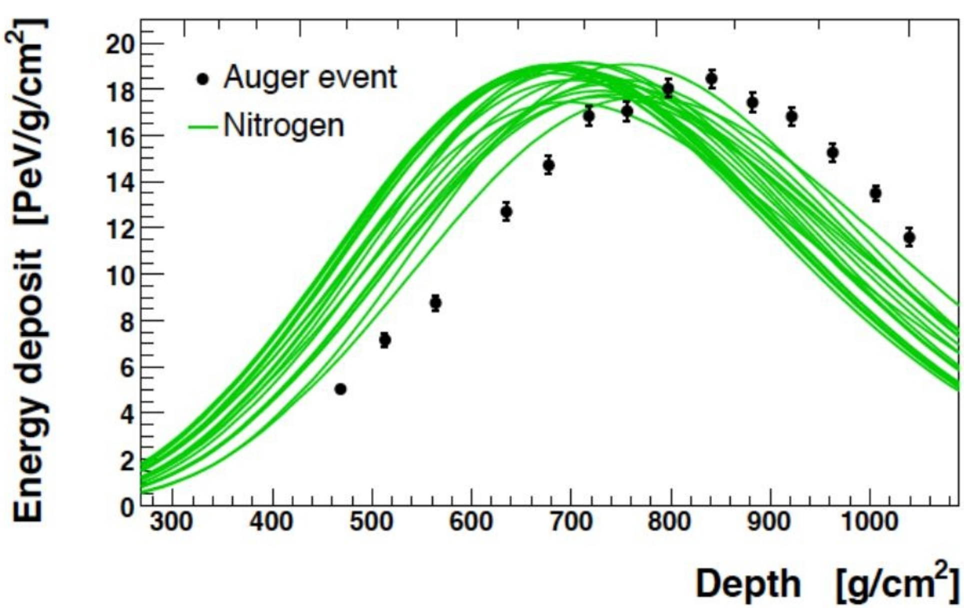
About 20 % energy scale difference !

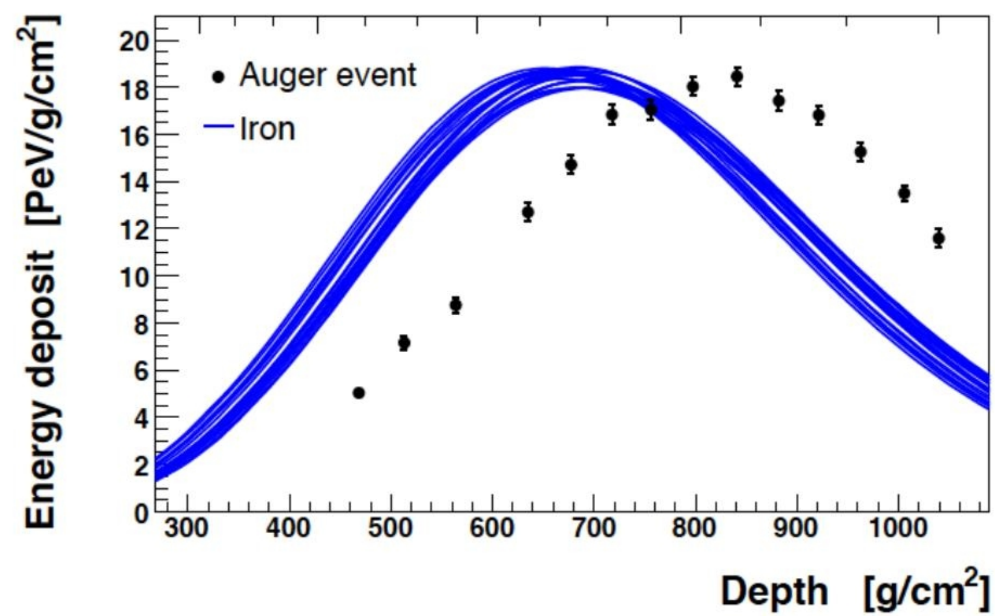


HiRes/TA/Auger observe a High Energy Suppression
Consistent with the GZK suppression
[or photo-disintegration of Iron]
[or Source Cutoff]

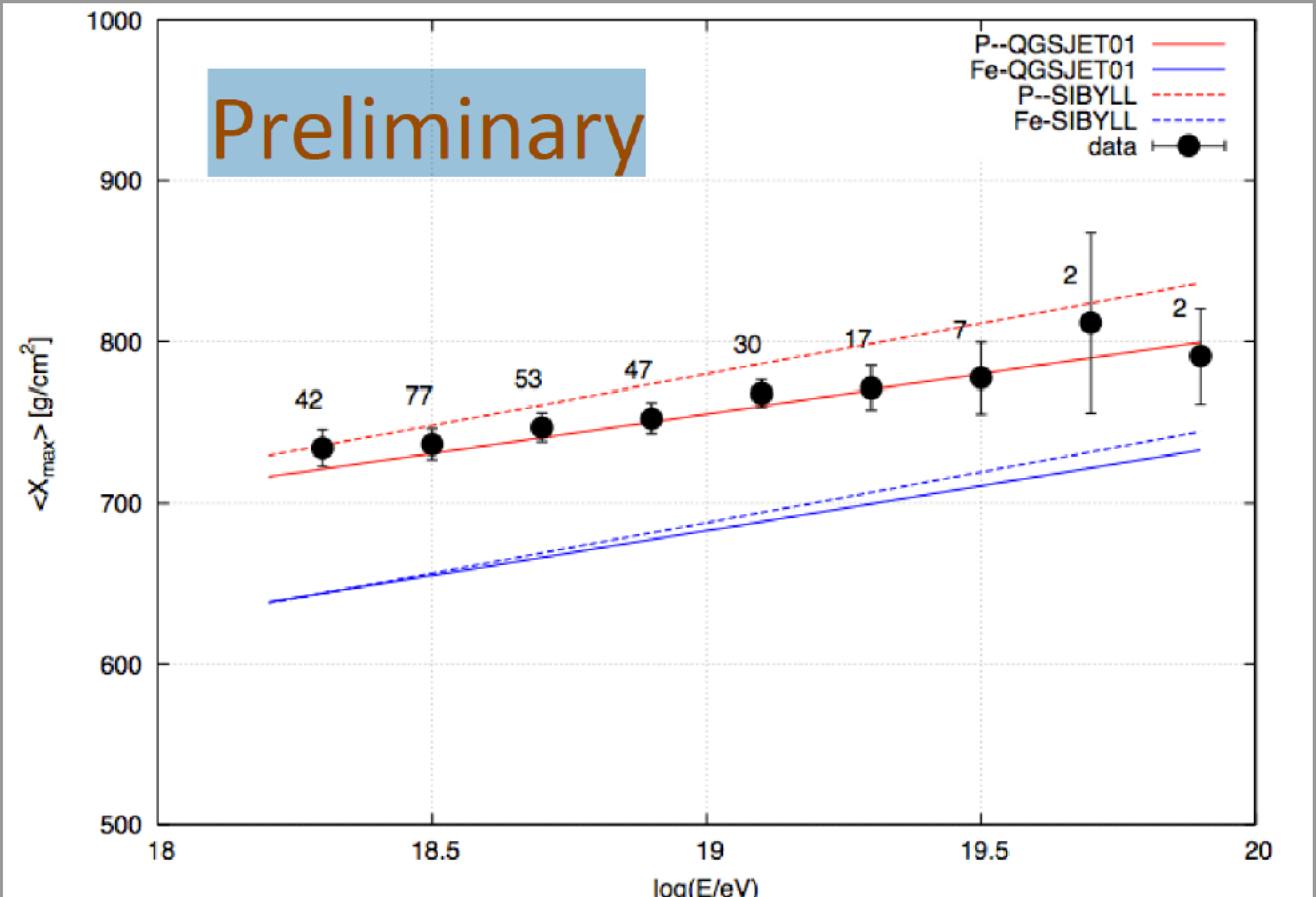


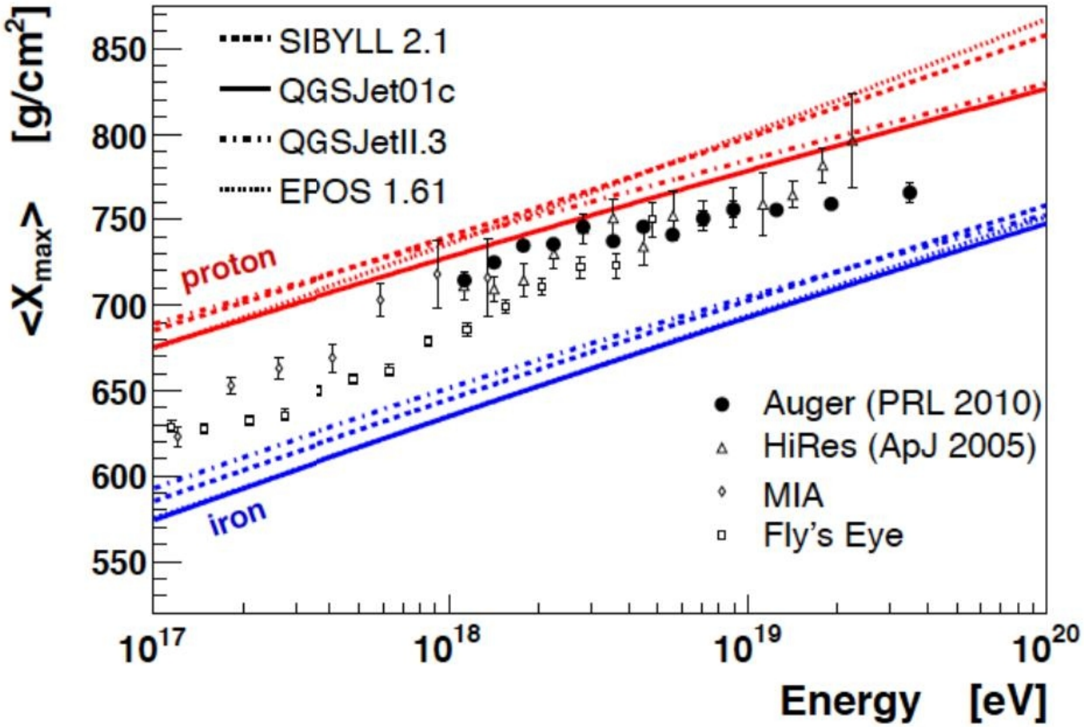
$$E \simeq 10^{20}\ \mathrm{eV}$$





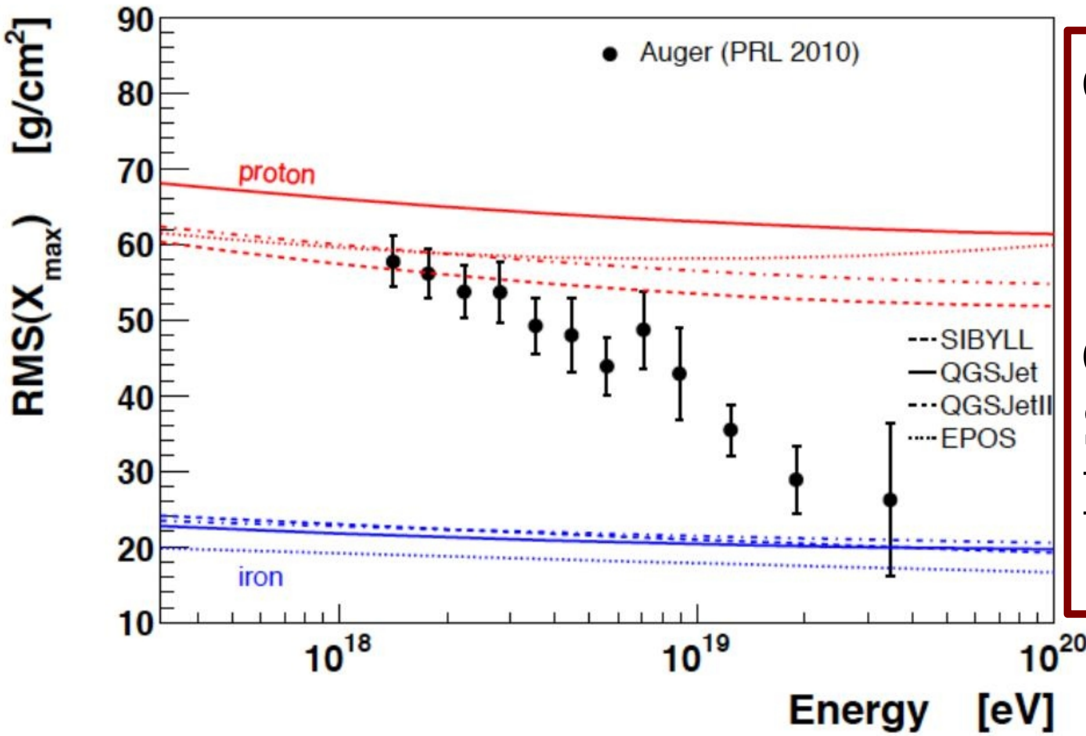
Telescope Array stereo result





Mass Composition
becoming heavy ?
at very high energy ?

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

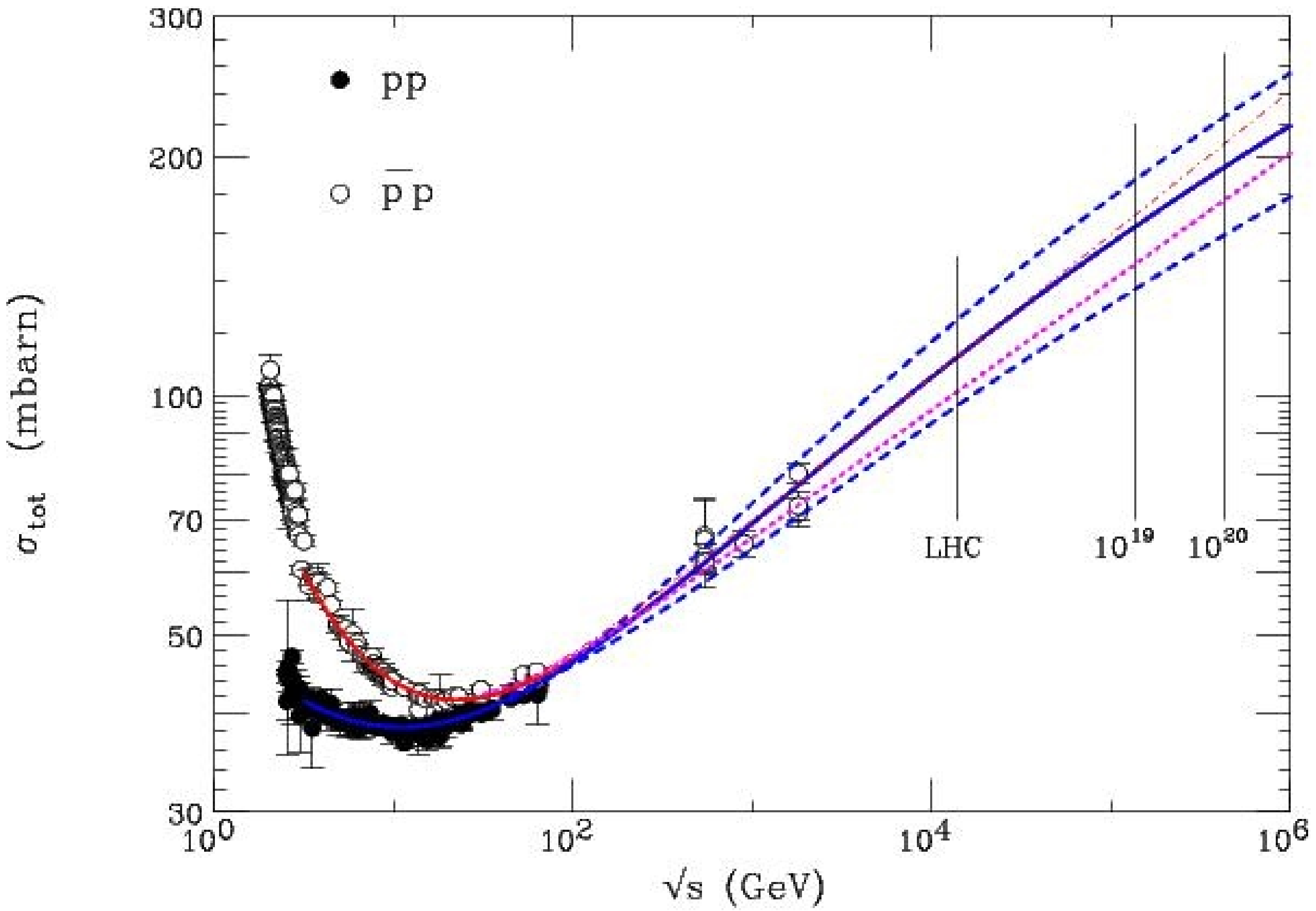


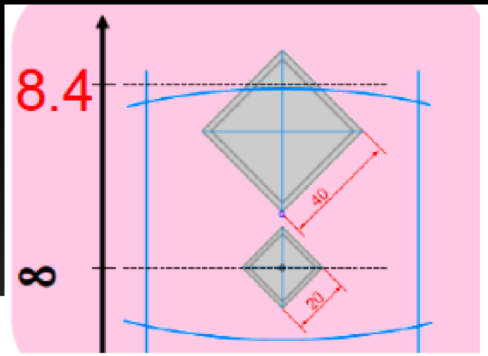
Observational controversy
NON confirmation
of HiRes

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

LHC and Ultra-High Energy Cosmic Rays

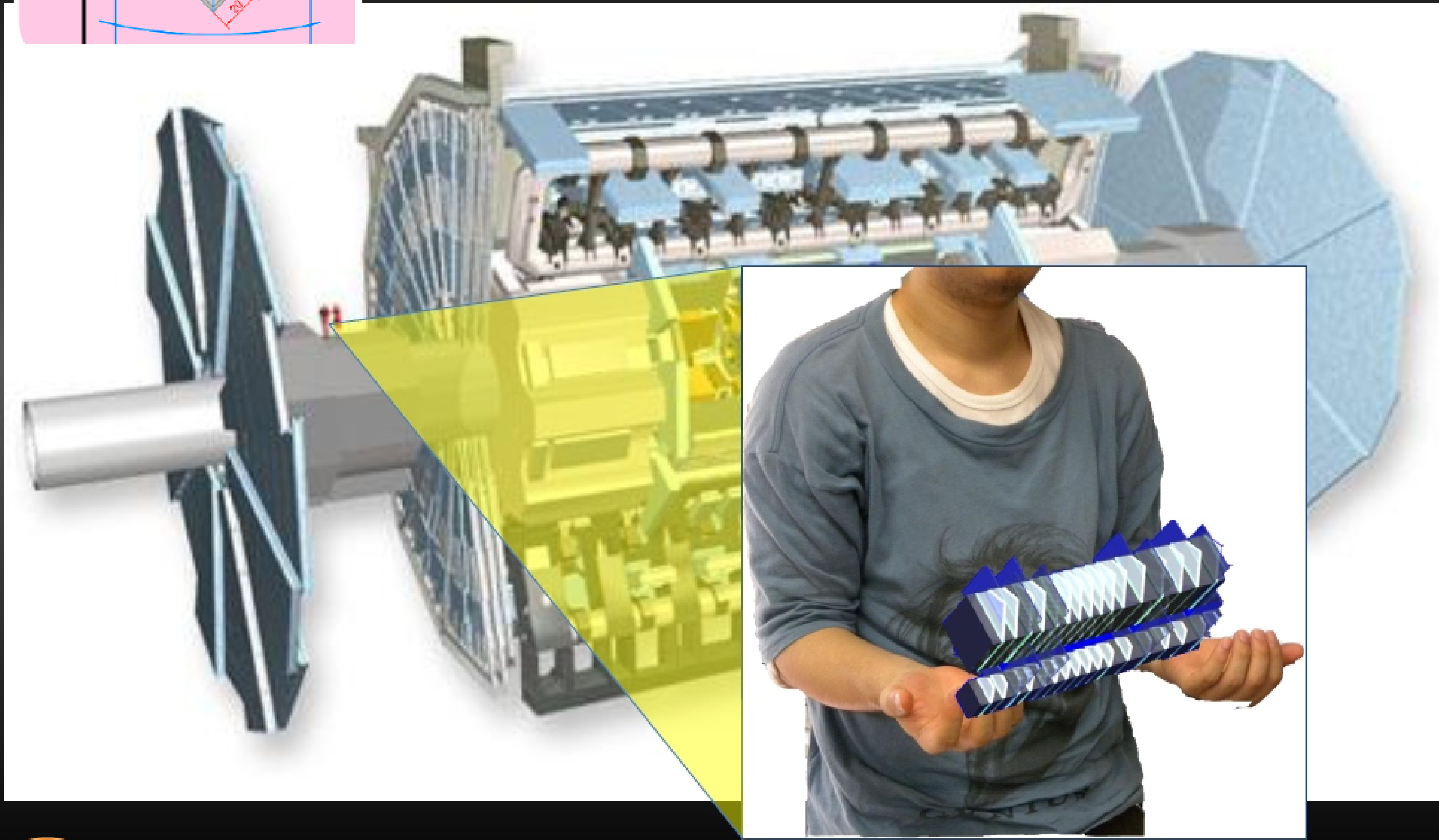
Total pp Cross Section



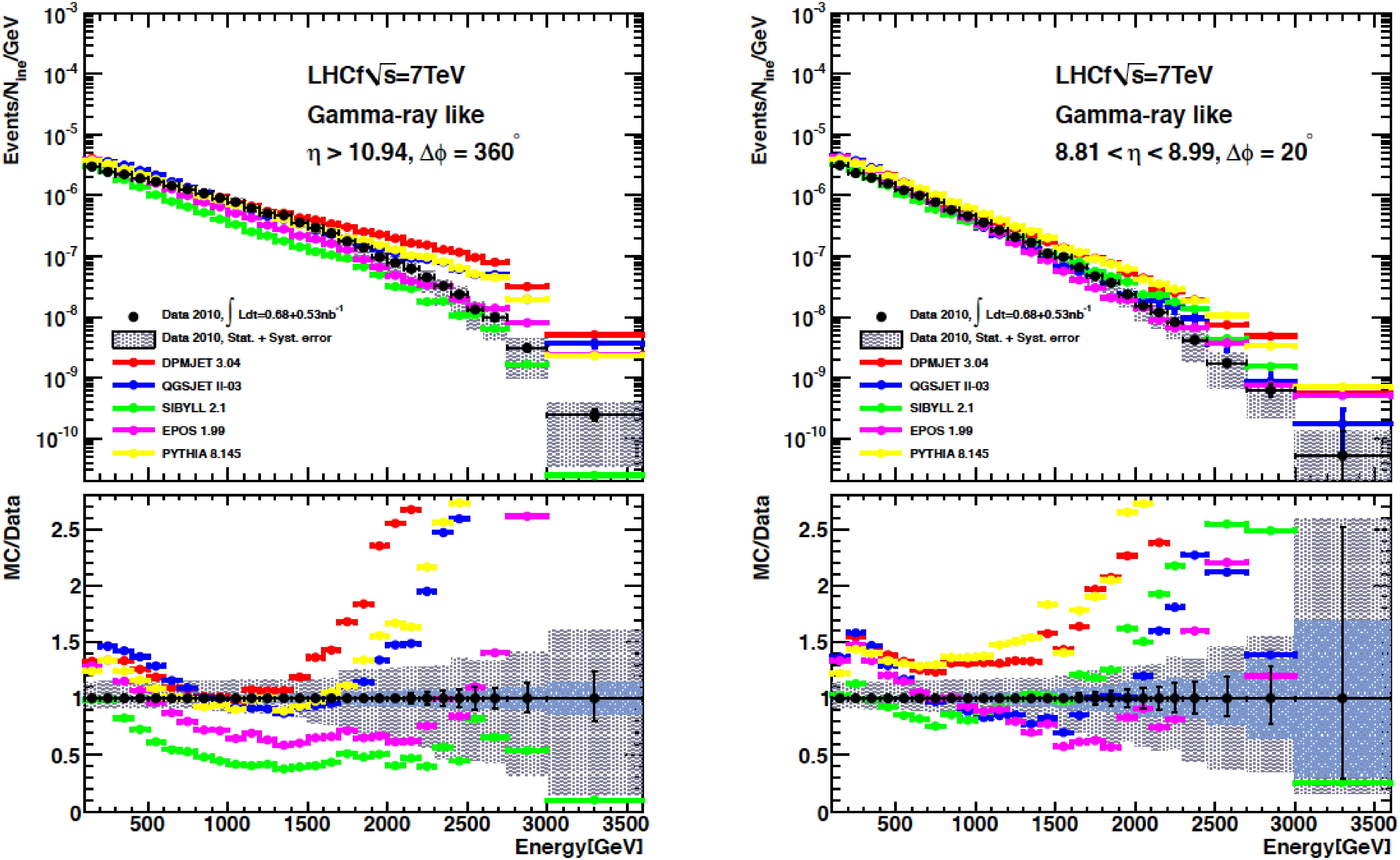


ATLAS & LHCf

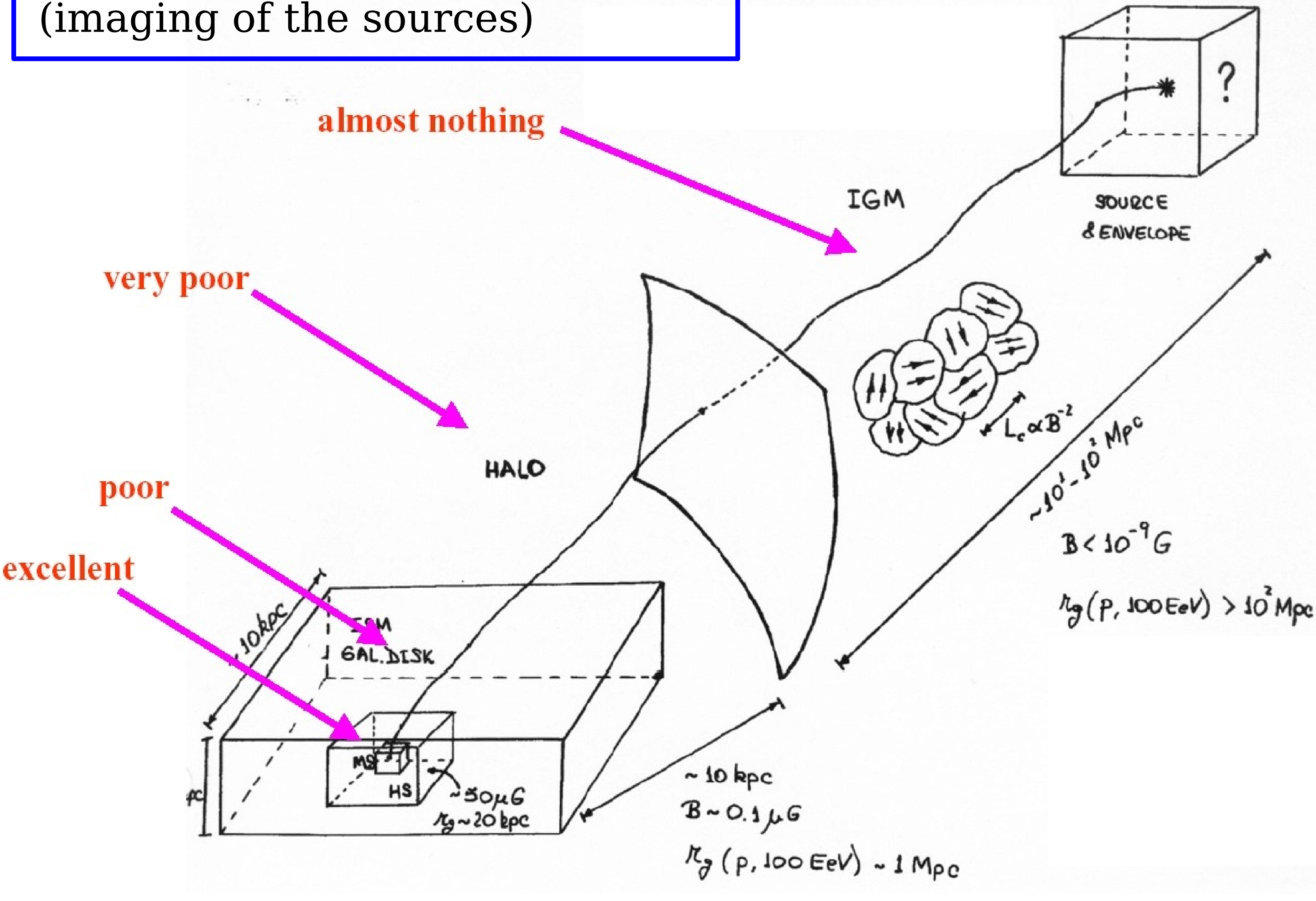
140 m from interaction point



LHCF first DATA publication



COSMIC Ray ASTRONOMY [?!]
(imaging of the sources)

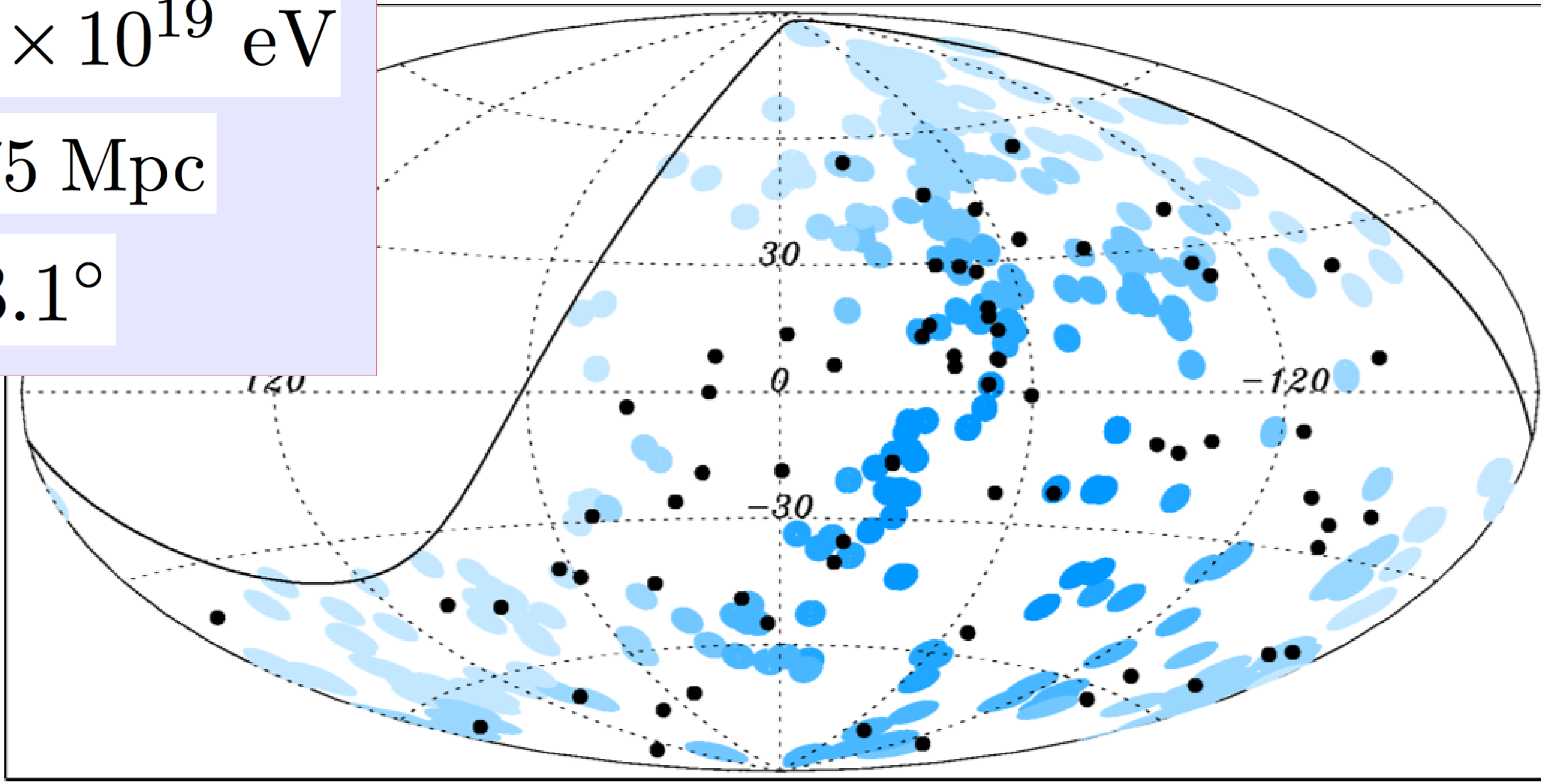


AUGER result on Correlations with the VCV AGN catalogue
November 2008. Update september 2010.

6×10^{19} eV

75 Mpc

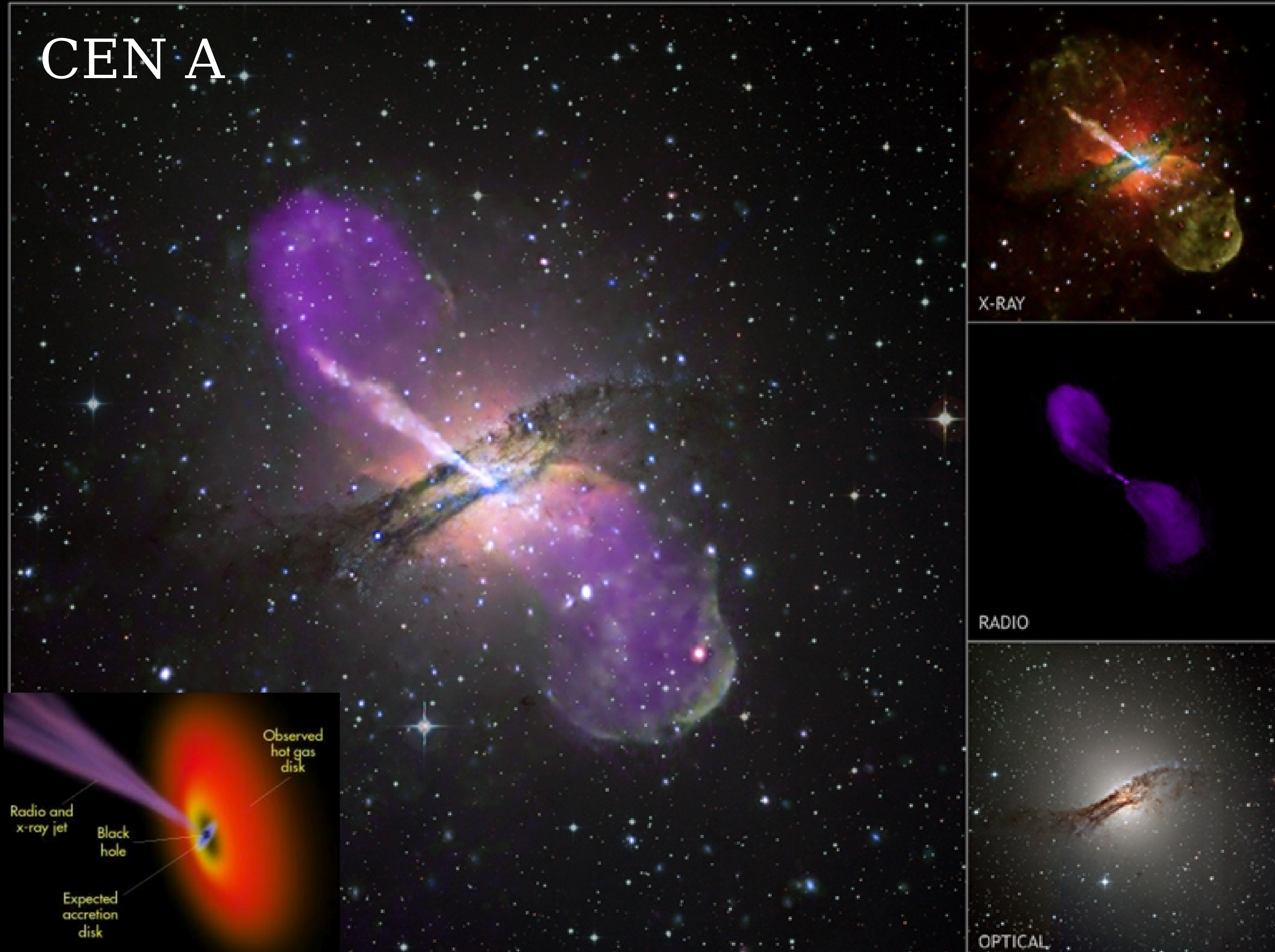
$3.1°$



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)

CEN A



X-RAY
RADIO
OPTICAL
Observed hot gas disk
Radio and x-ray jet
Black hole
Expected accretion disk

Importance of larger exposures
to study the highest energies

Detection of Cosmic Rays from Space

See: Piergiorgio Picozza
(tomorrow morning)
JEM/EUSO mission

NEUTRINO ASTRONOMY

New dramatic expansion of
our method to "SEE" the Universe

Use of New Particle as
"MESSENGER" from the Universe

Photons

Neutrinos

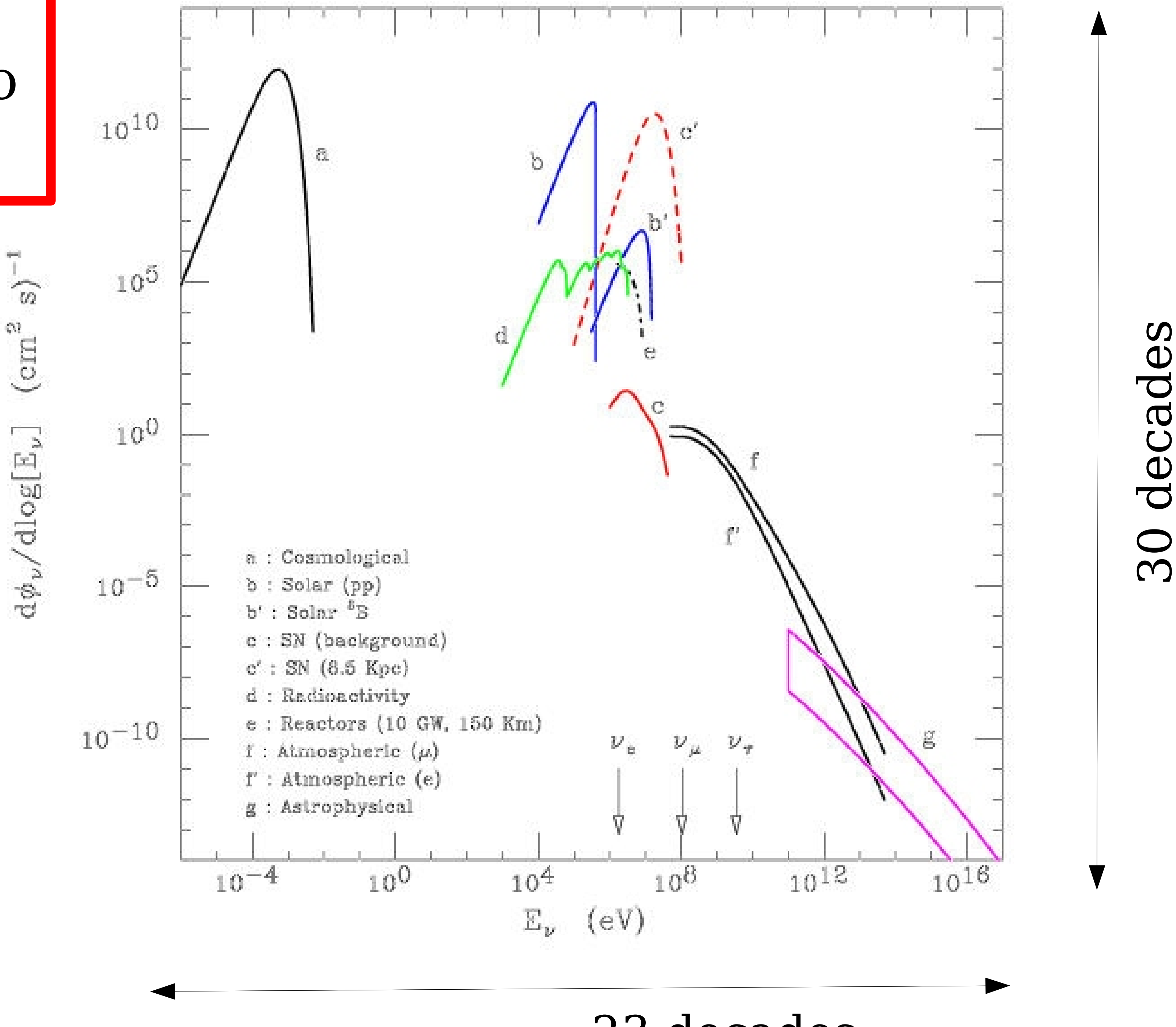
Cosmic Rays

Gravitational Waves

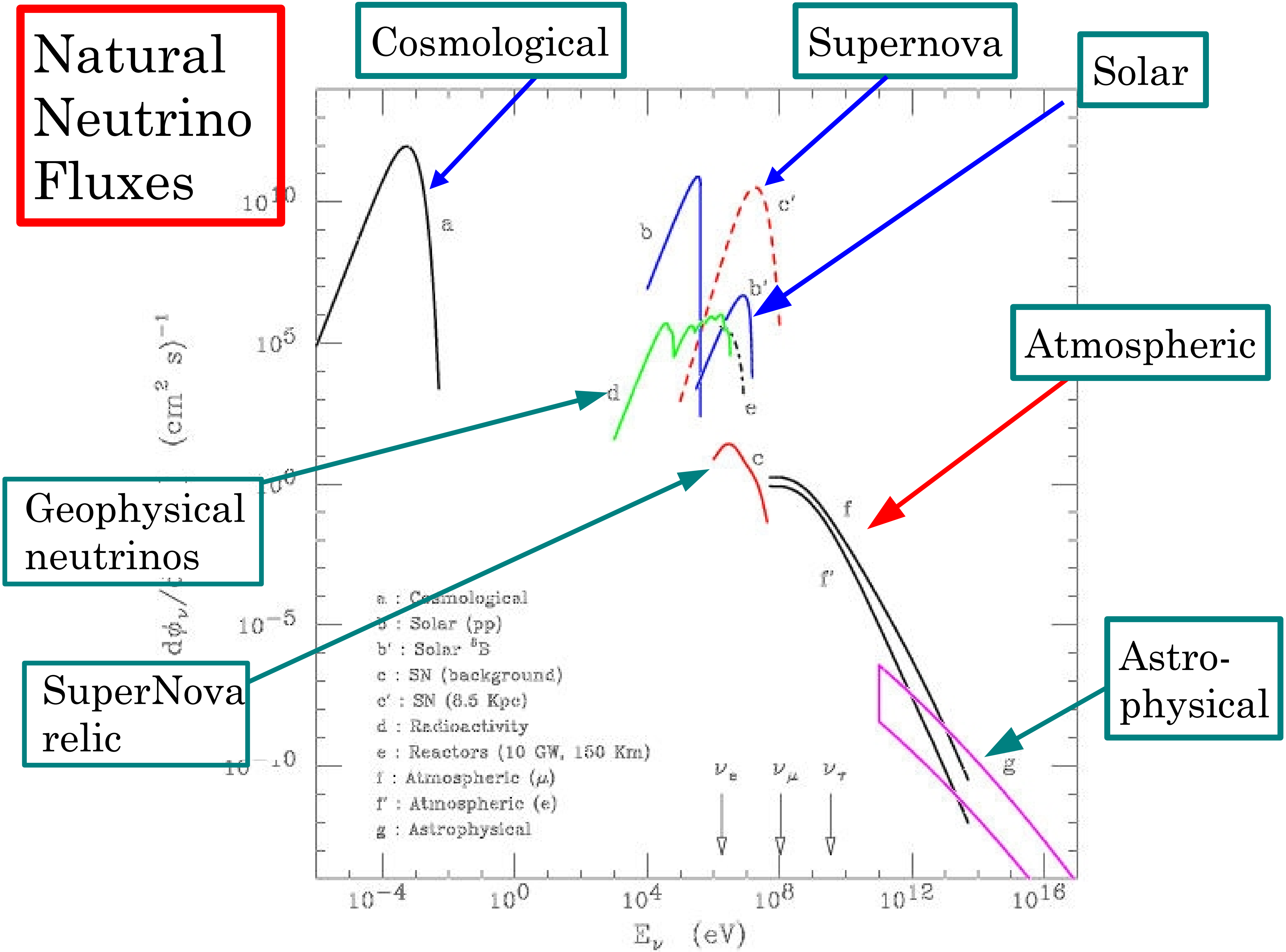
A "Messenger"
with very different properties
that will allow us to
"SEE" the universe
in a profoundly different way

Very small cross section.
neutrinos arrive from
the "deep interior"
of astrophysical sources

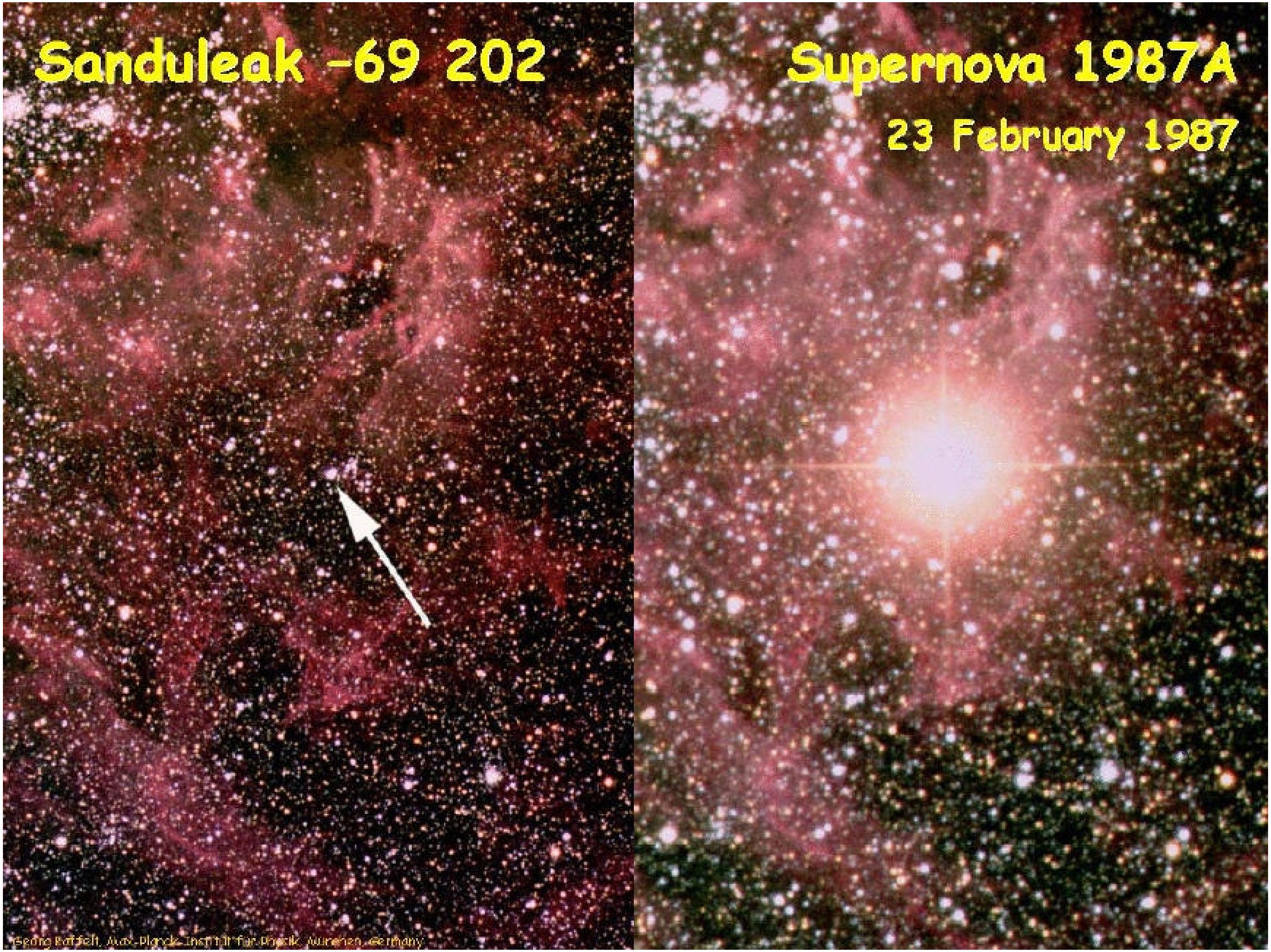
Natural Neutrino Fluxes



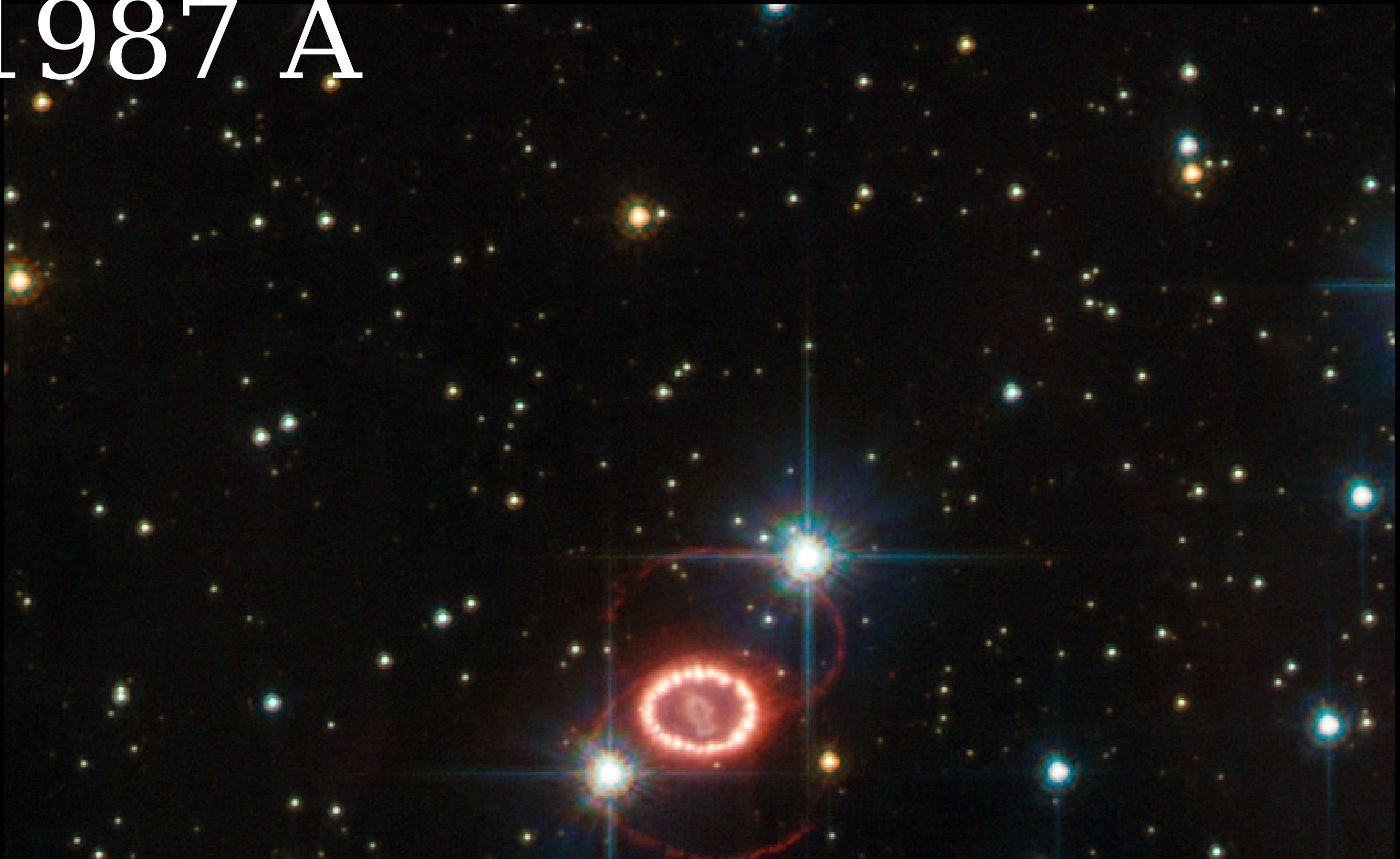
Natural Neutrino Fluxes

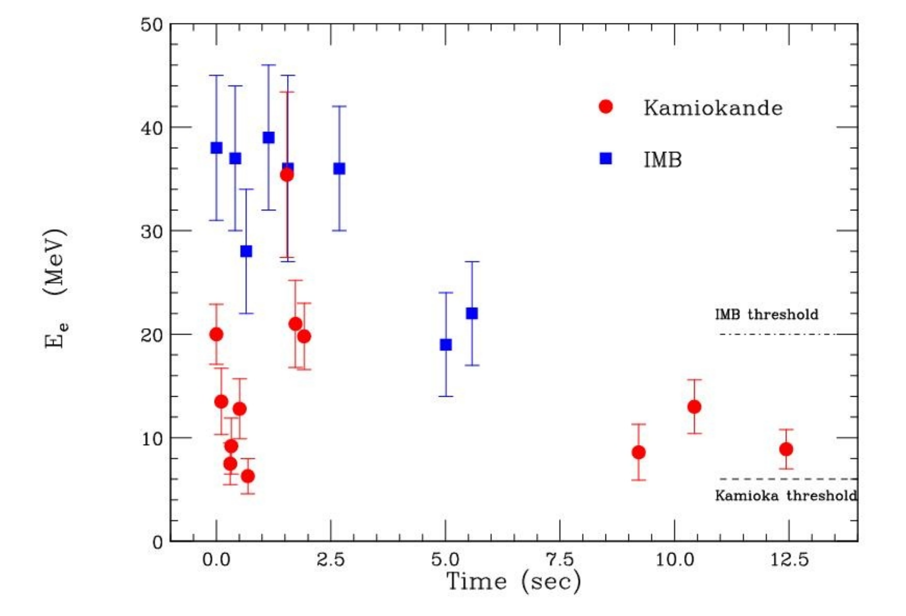


Neutrinos from Supernovae



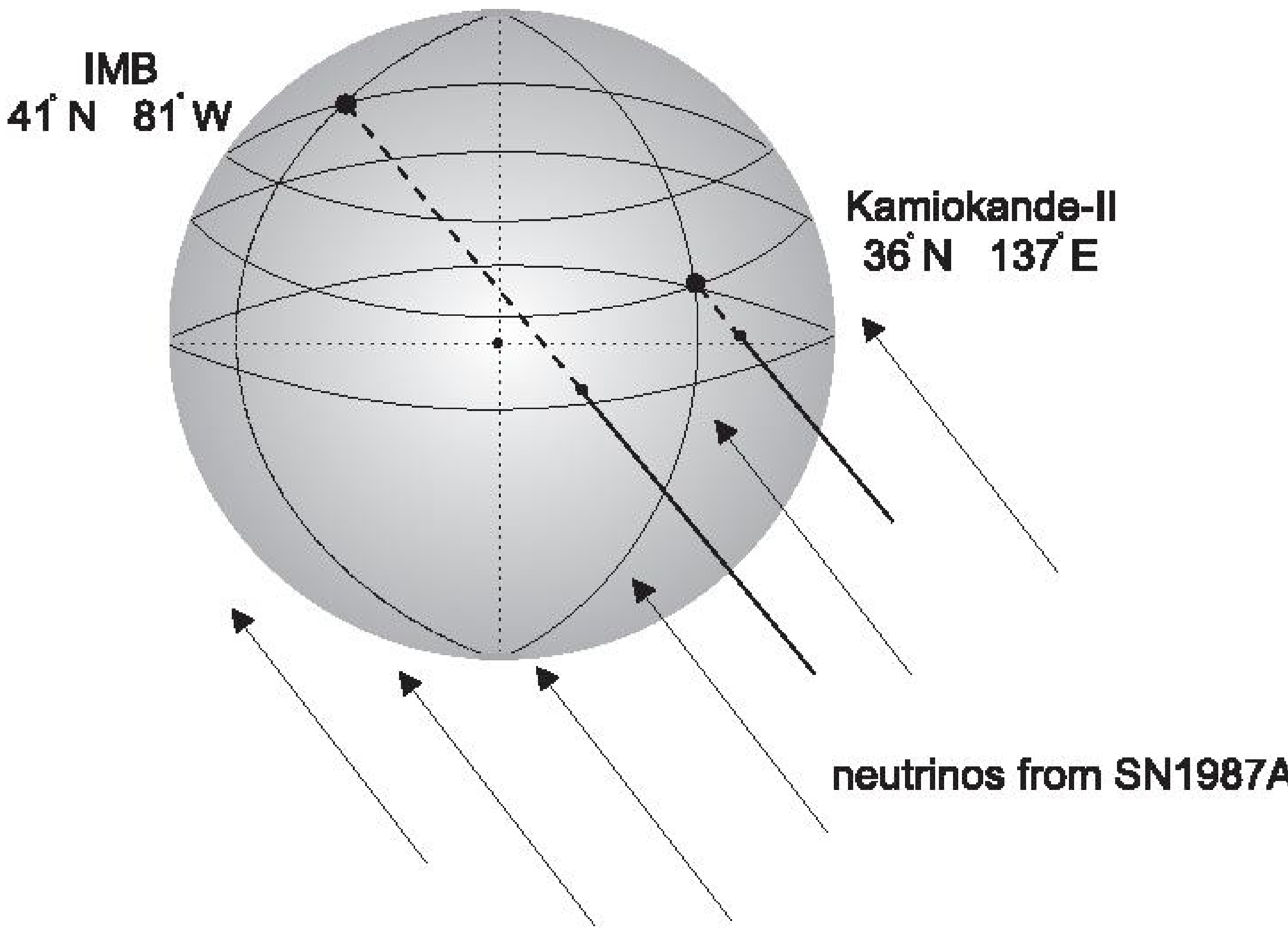
SN 1987 A





Kamiokande
IMB
IMB threshold
Kamioka threshold
E_e (MeV)
Time (sec)
0
10
20
30
40
50
0.0
2.5
5.0
7.5
10.0
12.5

The neutrinos from SN1987A
still the subject of many works every year !



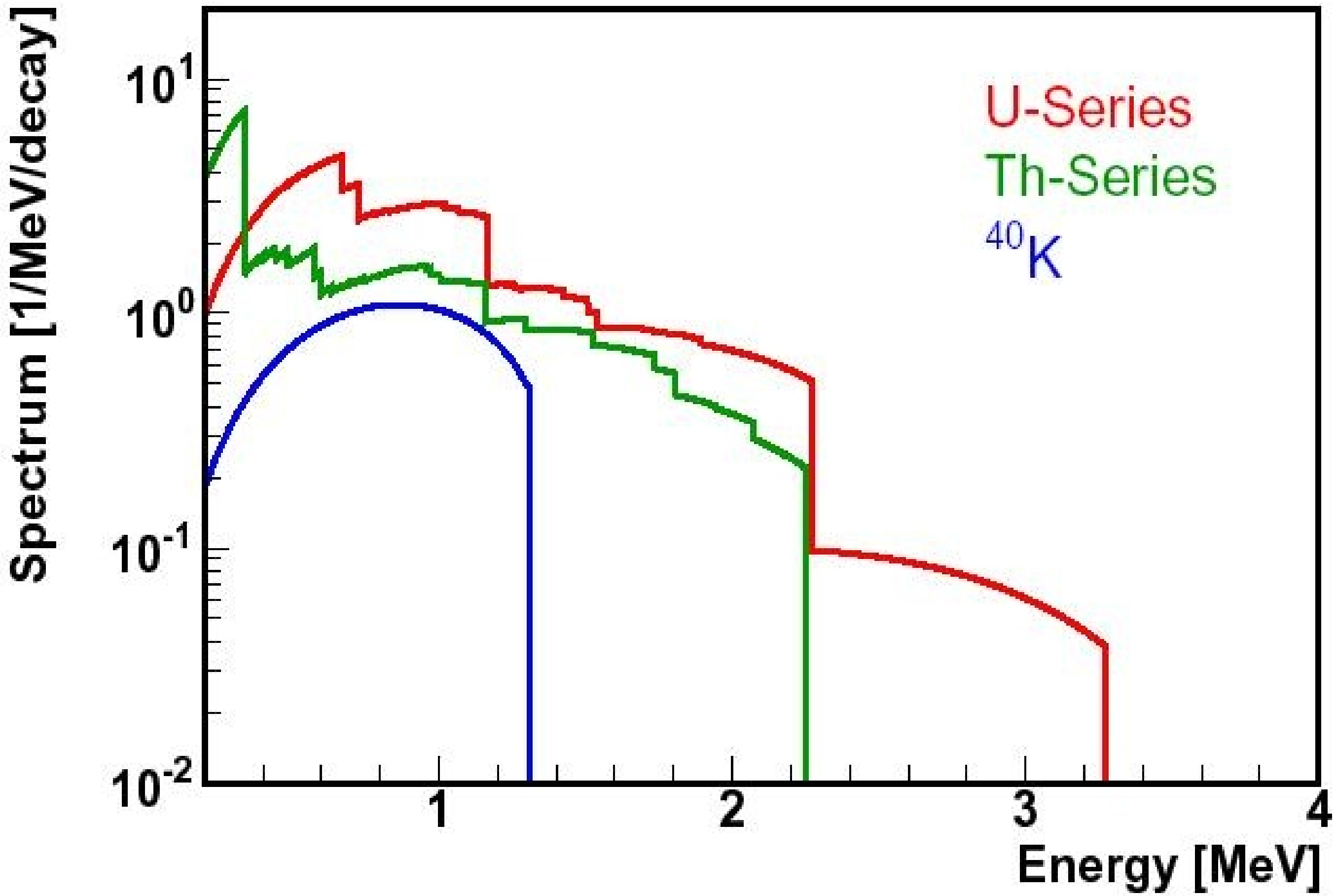
23 february 1987

26 years ago

$$^{238}\mathrm{U} \xrightarrow[100\%]{} {}^{206}\mathrm{Pb} + 8\,{}^{4}\mathrm{He} + 6e^{-} + 6\bar{\nu}_e + 51.7\ [\mathrm{MeV}]$$

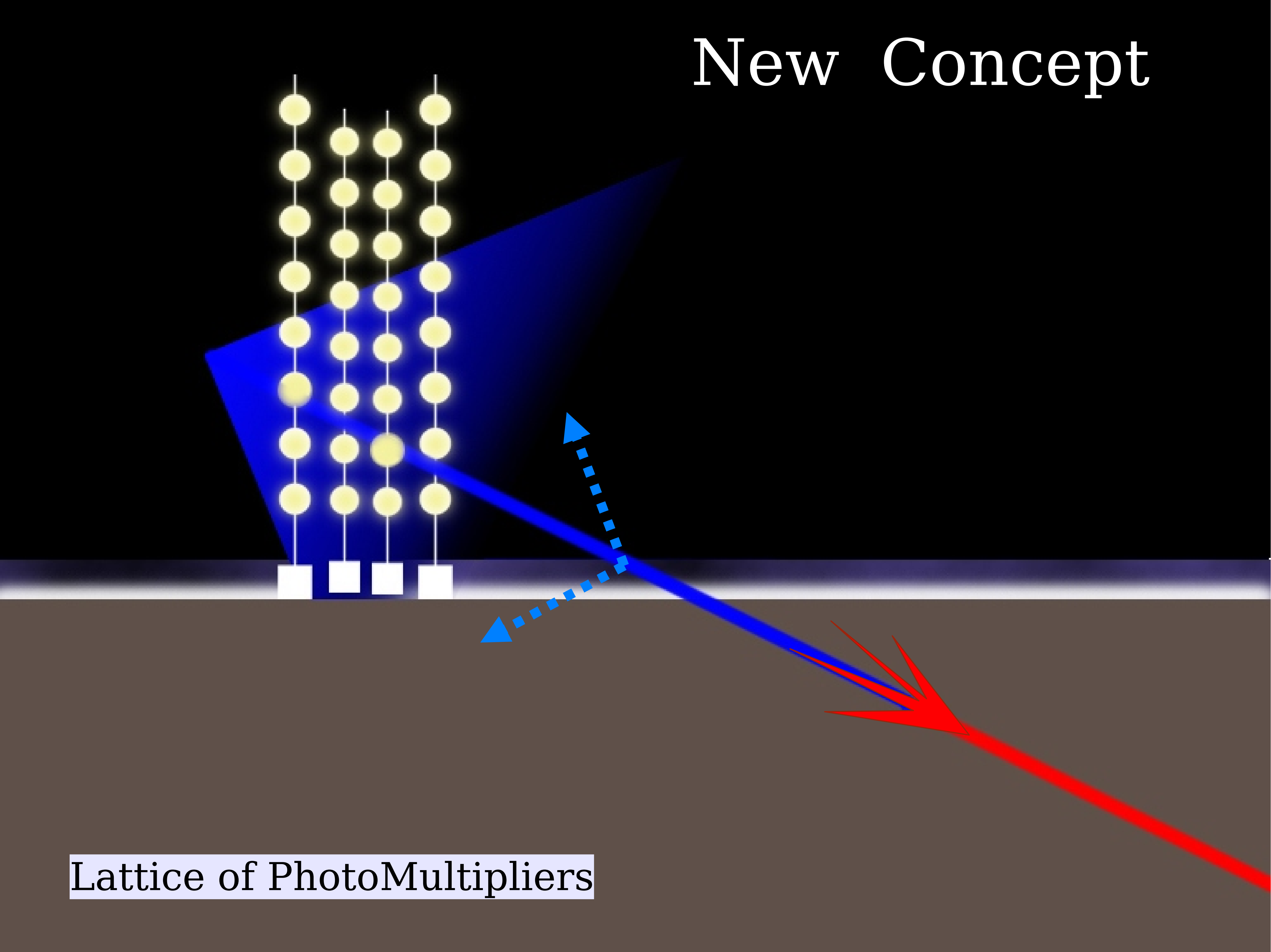
$$^{232}\mathrm{Th} \xrightarrow[100\%]{} {}^{208}\mathrm{Pb} + 6\,{}^{4}\mathrm{He} + 4e^{-} + 4\bar{\nu}_e + 42.7\ [\mathrm{MeV}]$$

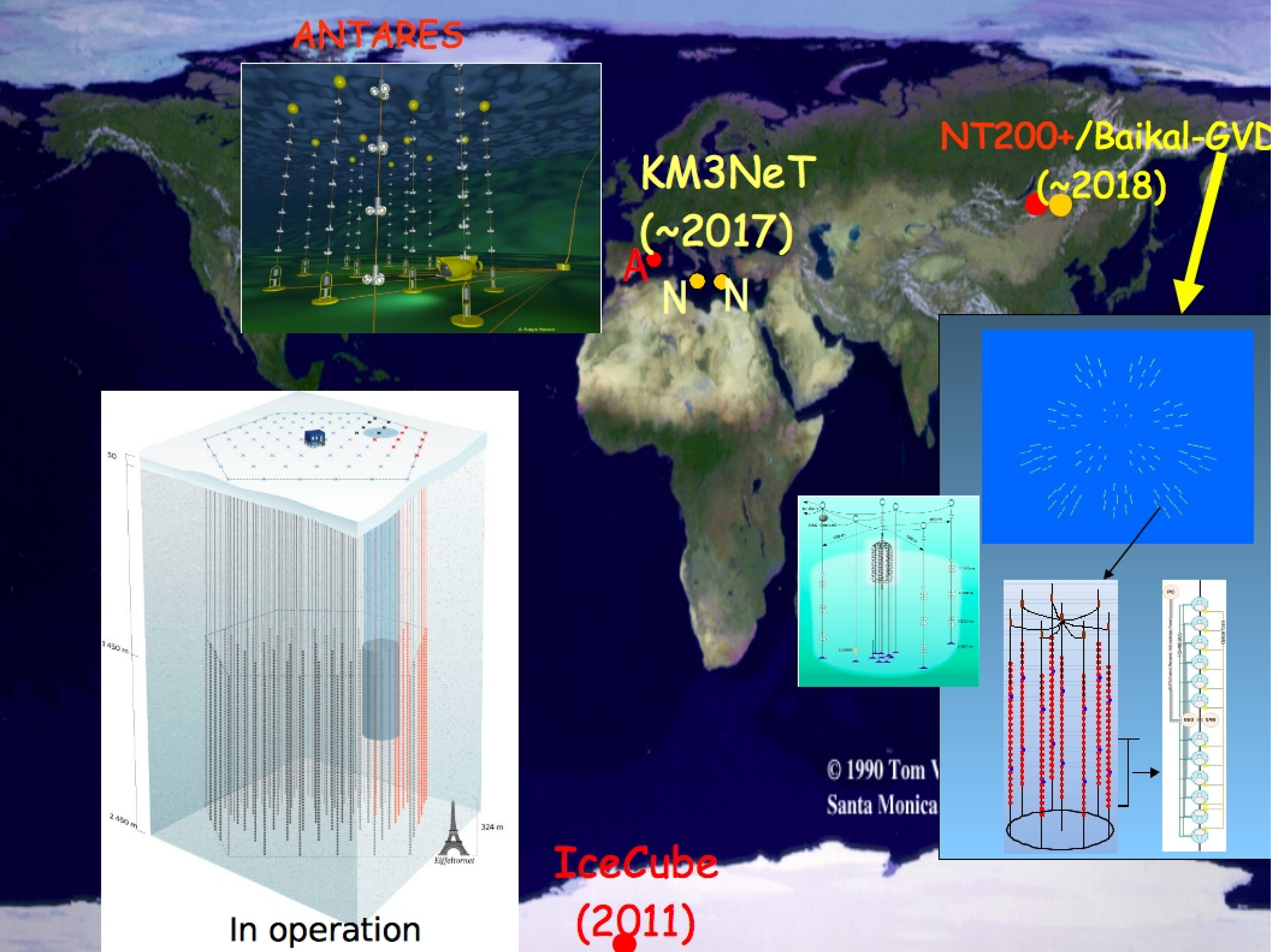
$$^{40}\mathrm{K} \xrightarrow[89.28\%]{} {}^{40}\mathrm{Ca} + e^{-} + \bar{\nu}_e + 1.311\ [\mathrm{MeV}]$$

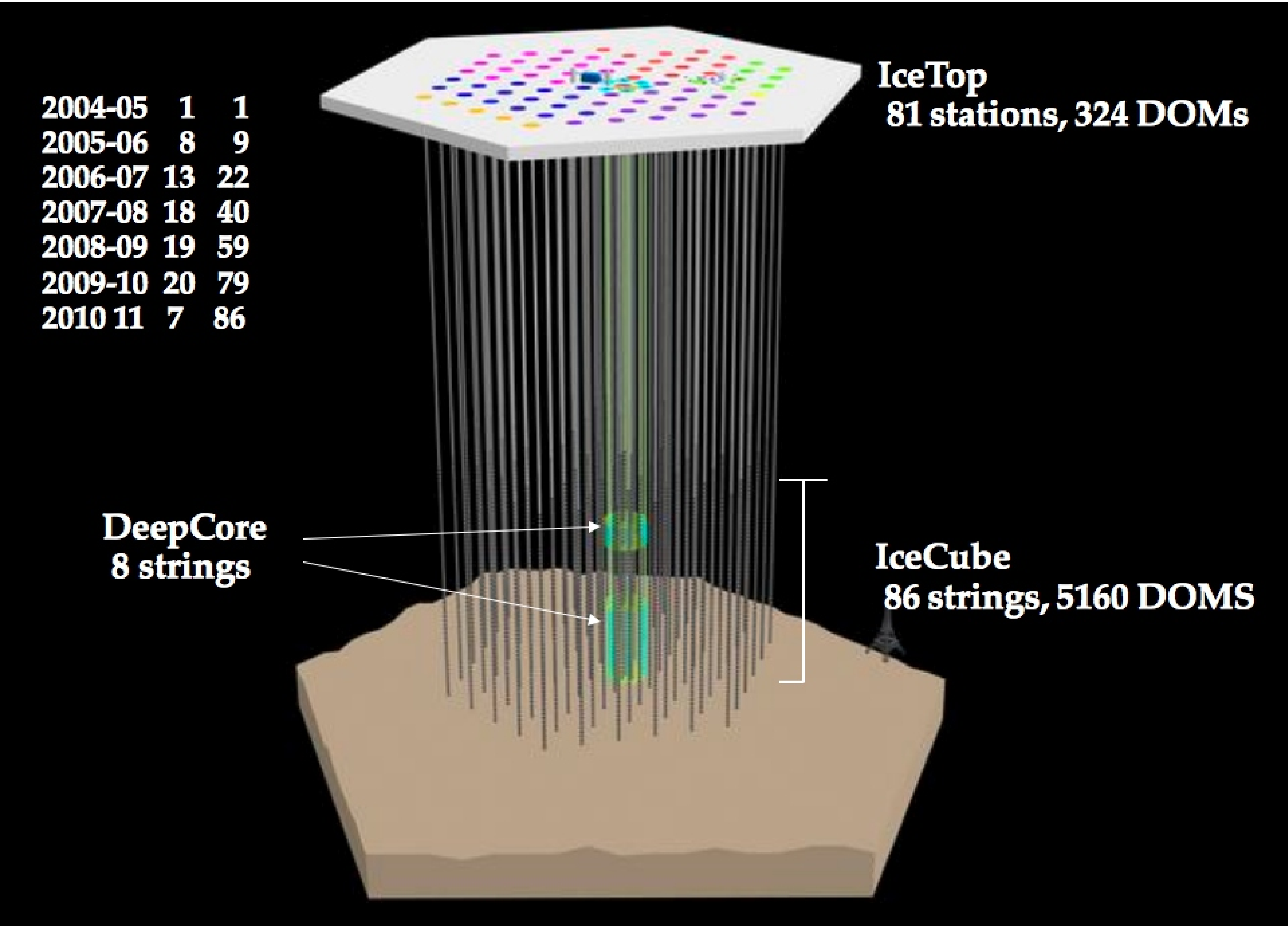


GEOPHYSICAL
NEUTRINOS

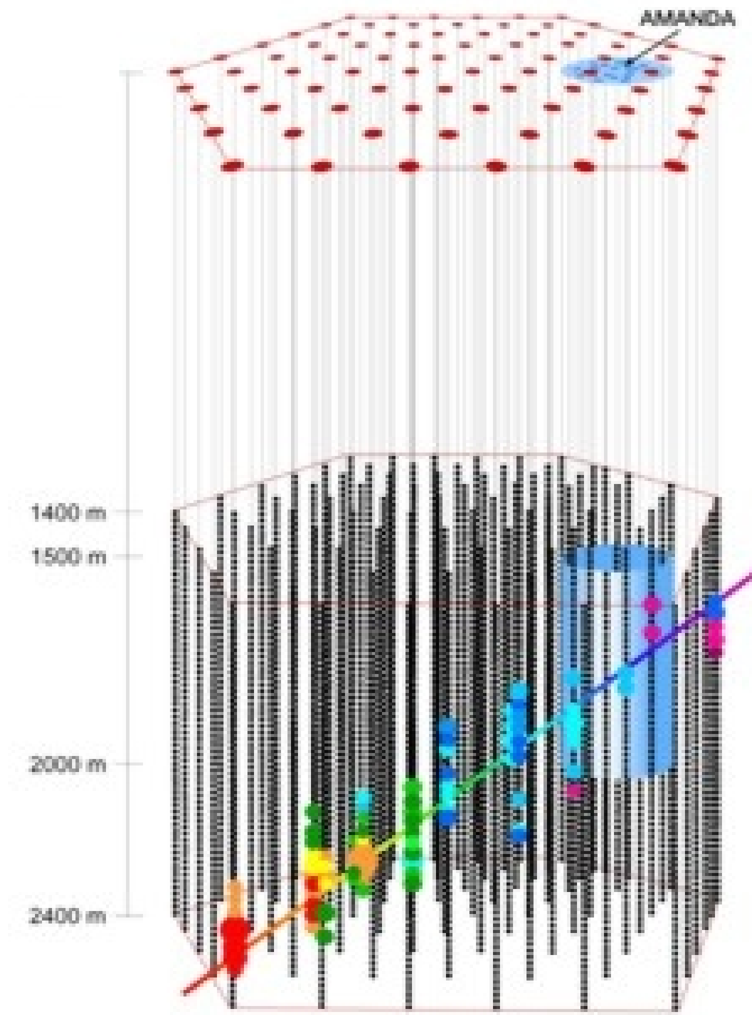
see: Gianni Fiorentini friday


New Concept
Lattice of PhotoMultipliers


ANTARES
KM3NeT
(~2017)
A
N
N
NT200+/Baikal-GVD
(~2018)
IceCube
(2011)
In operation
324 m
© 1990 Tom V
Santa Monica

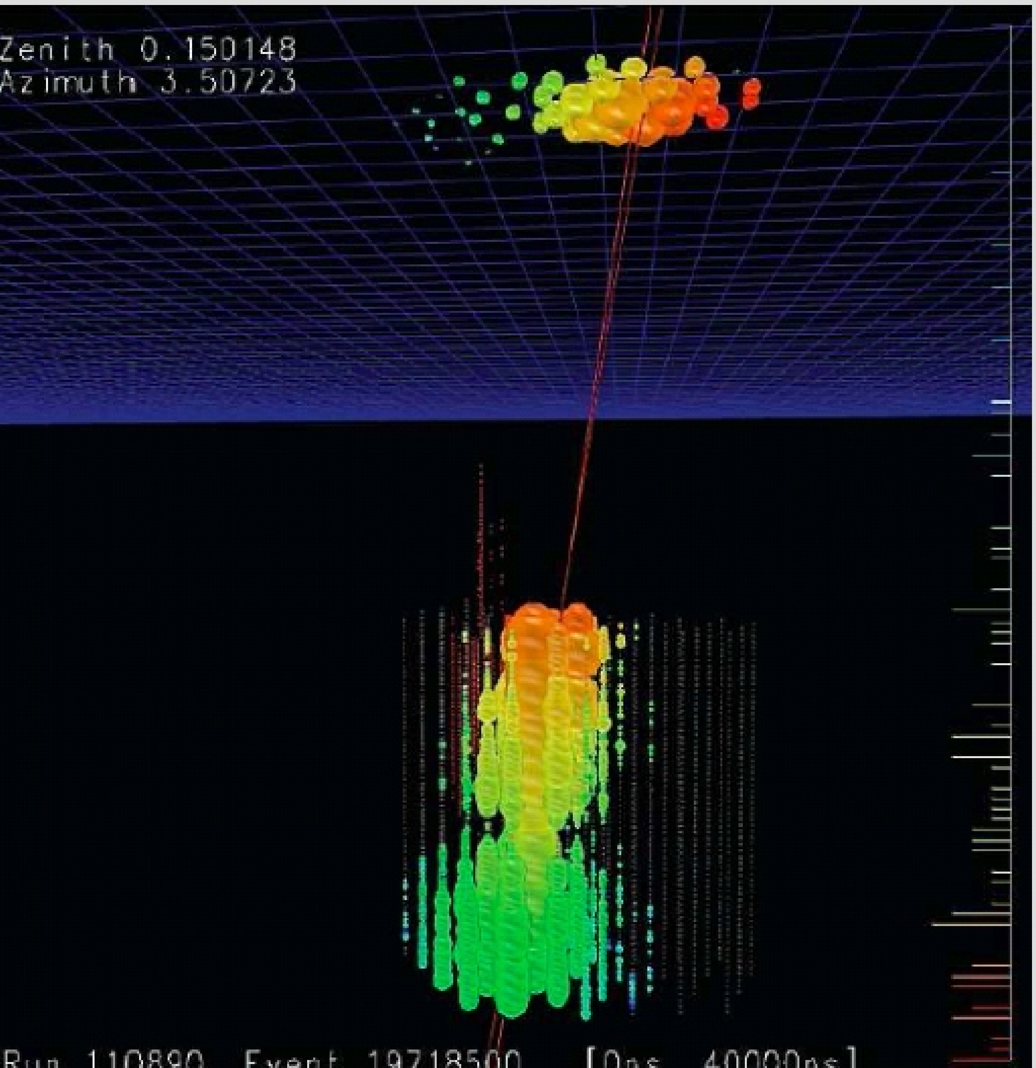

2004-05 1 1
2005-06 8 9
2006-07 13 22
2007-08 18 40
2008-09 19 59
2009-10 20 79
2010 11 7 86
IceTop
81 stations, 324 DOMs
DeepCore
8 strings
IceCube
86 strings, 5160 DOMS

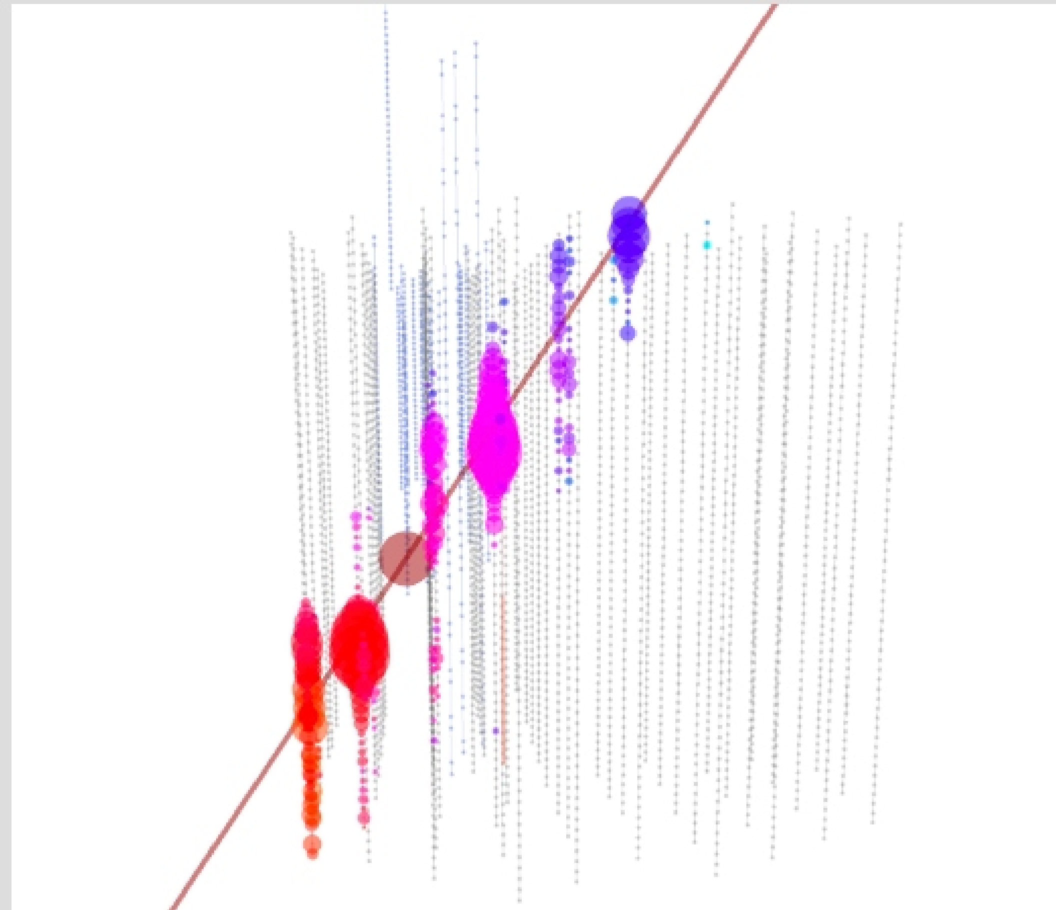
Deployment of the strings



High-energy events in IceCube-40

~ EeV air shower

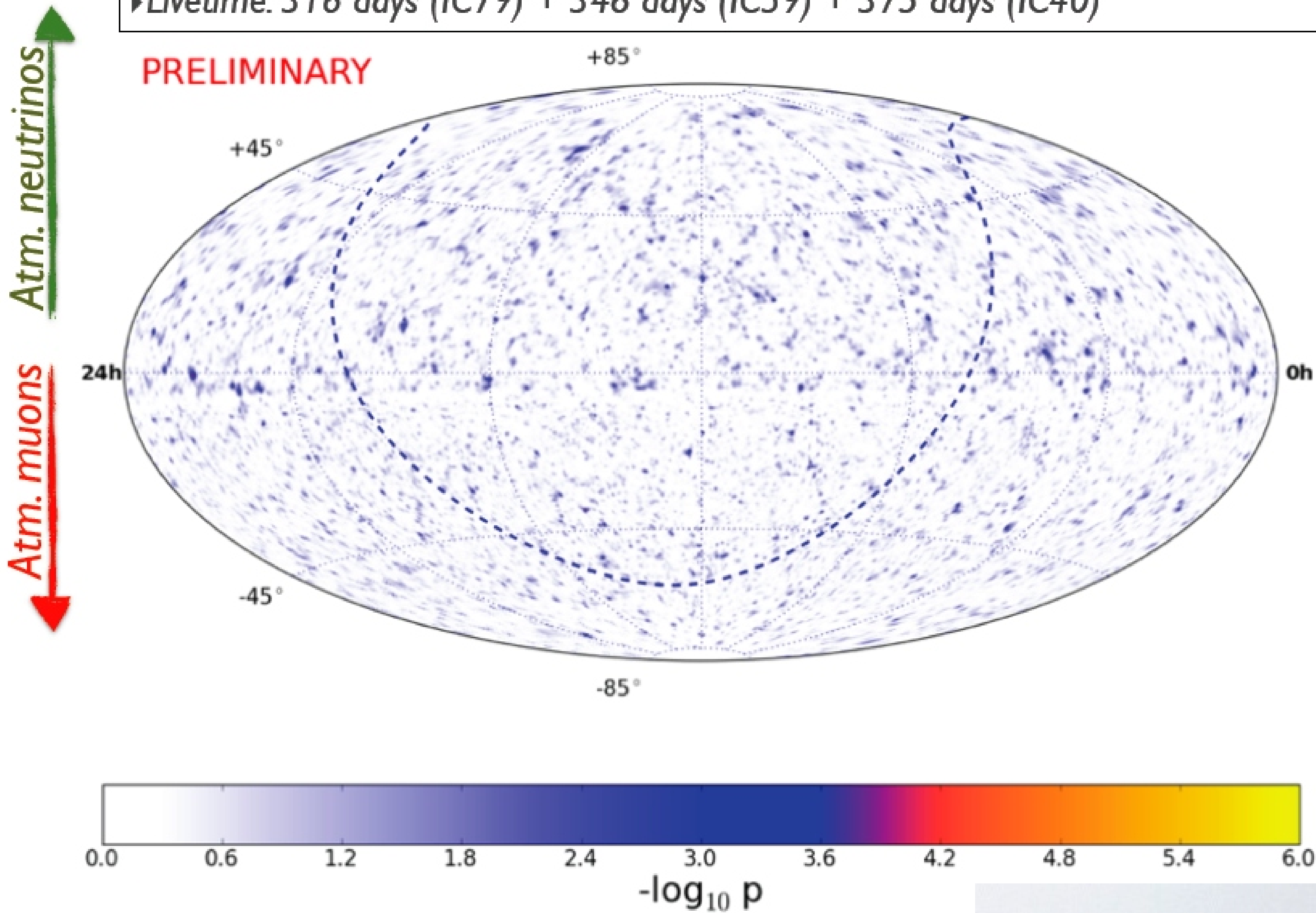




~100 TeV nm induced muon

+IC79 SKYMAP

- *Total events (IC40+IC59+IC79): 108317 (upgoing) + 146018 (downgoing)*
- *Livetime: 316 days (IC79) + 348 days (IC59) + 375 days (IC40)*



IceCube selected sources

(13 galactic SNR etc, 30 extragalactic active galaxies, etc.)

No significant detections at this point

Source	RA (deg)	Dec (deg)	Type	Distance	P-value
Cyg OB2	308.08	41.51	UNID	-	–
MGRO J2019+37	305.22	36.83	PWN	-	–
MGRO J1908+06	286.98	6.27	SNR	-	0.38
Cas A	350.85	58.81	SNR	3.4 kpc	–
IC443	94.18	22.53	SNR	1.5 kpc	–
Geminga	98.48	17.77	Pulsar	100 pc	–
Crab Nebula	83.63	22.01	SNR	2 kpc	–
1ES 1959+650	300.00	65.15	HBL	z = 0.048	–
1ES 2344+514	356.77	51.70	HBL	z = 0.044	–
3C66A	35.67	43.04	Blazar	z = 0.44	0.42
H 1426+428	217.14	42.67	HBL	z = 0.129	–
BL Lac	330.68	42.28	HBL	z = 0.069	0.4
Mrk 501	253.47	39.76	HBL	z = 0.034	0.19
Mrk 421	166.11	38.21	HBL	z = 0.031	–
W Comae	185.38	28.23	HBL	z = 0.1020	–
1ES 0229+200	38.20	20.29	HBL	z = 0.139	0.39
M87	187.71	12.39	BL Lac	z = 0.0042	0.38
S5 0716+71	110.47	71.34	LBL	z > 0.3	0.49
M82	148.97	69.68	Starburst	3.86 Mpc	–
3C 123.0	69.27	29.67	FRII	1038 Mpc	–
3C 454.3	343.49	16.15	FSRQ	z = 0.859	0.48
4C 38.41	248.81	38.13	FSRQ	z = 1.814	0.3
PKS 0235+164	39.66	16.62	LBL	z = 0.94	0.18
PKS 0528+134	82.73	13.53	FSRQ	z = 2.060	0.49
PKS 1502+106	226.10	10.49	FSRQ	z = 0.56/1.839	–
3C 273	187.28	2.05	FSRQ	z = 0.158	–
NGC 1275	49.95	41.51	Seyfert Galaxy	z = 0.017559	–
Cyg A	299.87	40.73	Radio-loud Galaxy	z = 0.056146	0.44
Sgr A*	266.42	-29.01	Galactic Center	8.5 kpc	0.49
PKS 0537-441	84.71	-44.09	LBL	z = 0.896	0.44
Cen A	**201.37**	**-43.02**	**FRI**	**3.8 Mpc**	**0.14**
PKS 1454-354	**224.36**	**-35.65**	**FSRQ**	**z = 1.42**	**0.14**
PKS 2155-304	329.72	-30.23	HBL	z = 0.116	–
PKS 1622-297	246.53	-29.86	FSRQ	z = 0.815	0.27
QSO 1730-130	263.26	-13.08	FSRQ	z = 0.902	–
PKS 1406-076	212.24	-7.87	FSRQ	z = 1.494	0.36
QSO 2022-077	306.42	-7.64	FSRQ	z = 1.39	–
3C279	194.05	-5.79	FSRQ	z = 0.536	0.45
TYCHO	6.36	64.18	SNR	2.4 kpc	–
Cyg X-1	299.59	35.20	MQSO	2.5 kpc	–
Cyg X-3	308.11	40.96	MQSO	9 kpc	–
LSI 303	40.13	61.23	MQSO	2 kpc	–
SS433	287.96	4.98	MQSO	1.5 kpc	0.48

CONCLUSIONS

- ***No evidence of a neutrino point source*** has been found in the combination of 3 datasets: IC79+IC59+IC40
- The ***IC59 untriggered flare*** analysis have the most significant result but still compatible with a background fluctuation.
- More analysis on the IC79 dataset are still on-going: time-dependent searches, stacking sources, extended sources skymaps.
- IceCube sensitivity is getting in the region where a non-discovery from a point-source is becoming meaningful.

EXTRA-GALACTIC NEUTRINOS

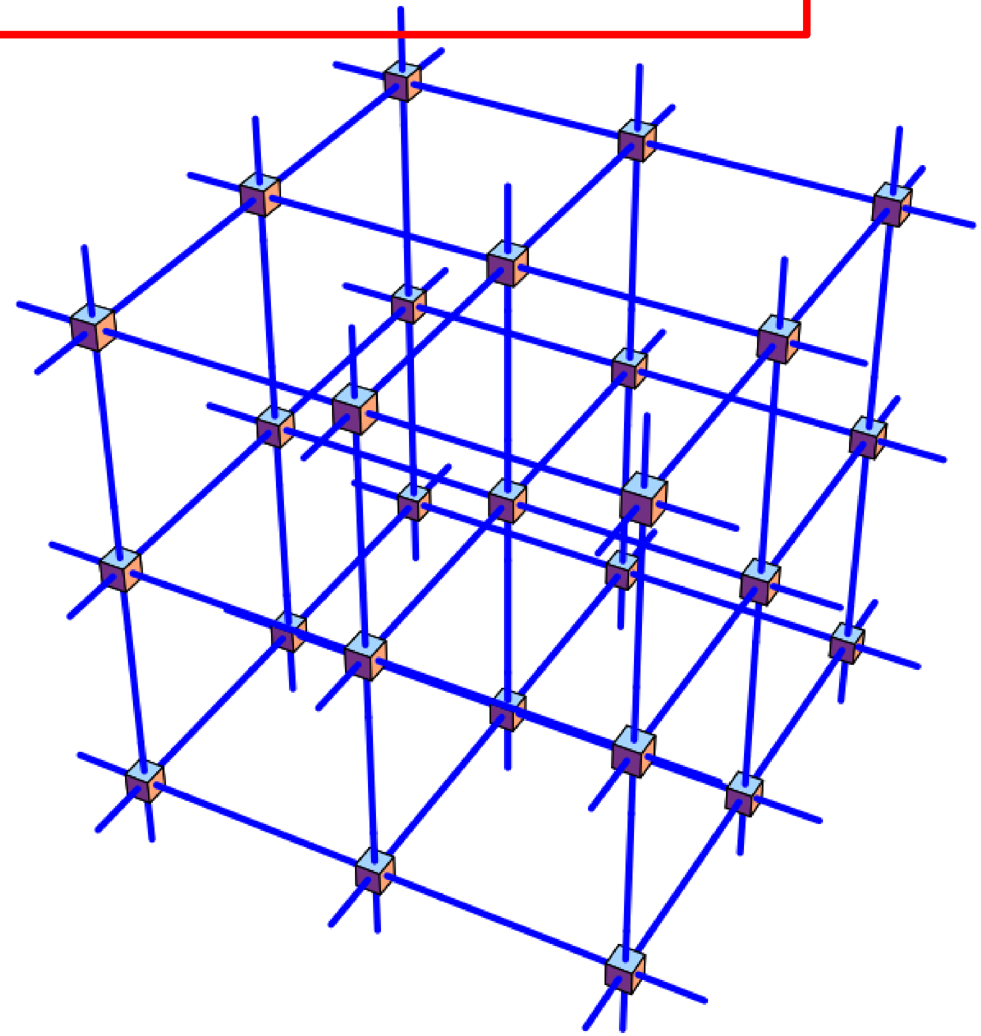
UNRESOLVED FLUX

Sum of all High Energy
Neutrino Sources

Individual Sources

AGN
GRB's

The 3-dimensional lampposts ensemble "paradox" [Kepler – Olbers paradox].



Linear sequence of lampposts:

Most of the light you receive from the nearest lamppost

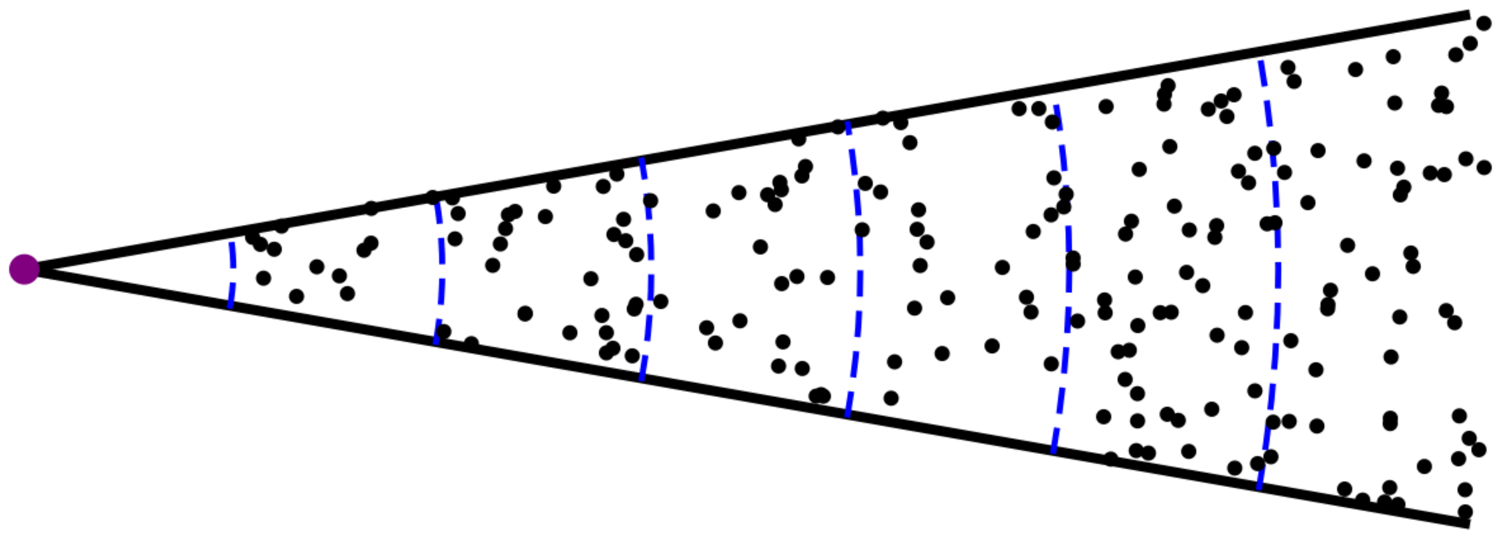
3D ensemble of lampposts: [Euclidean static space]

Light diverges !

INCLUSIVE Extra-Galalactic Neutrino Flux

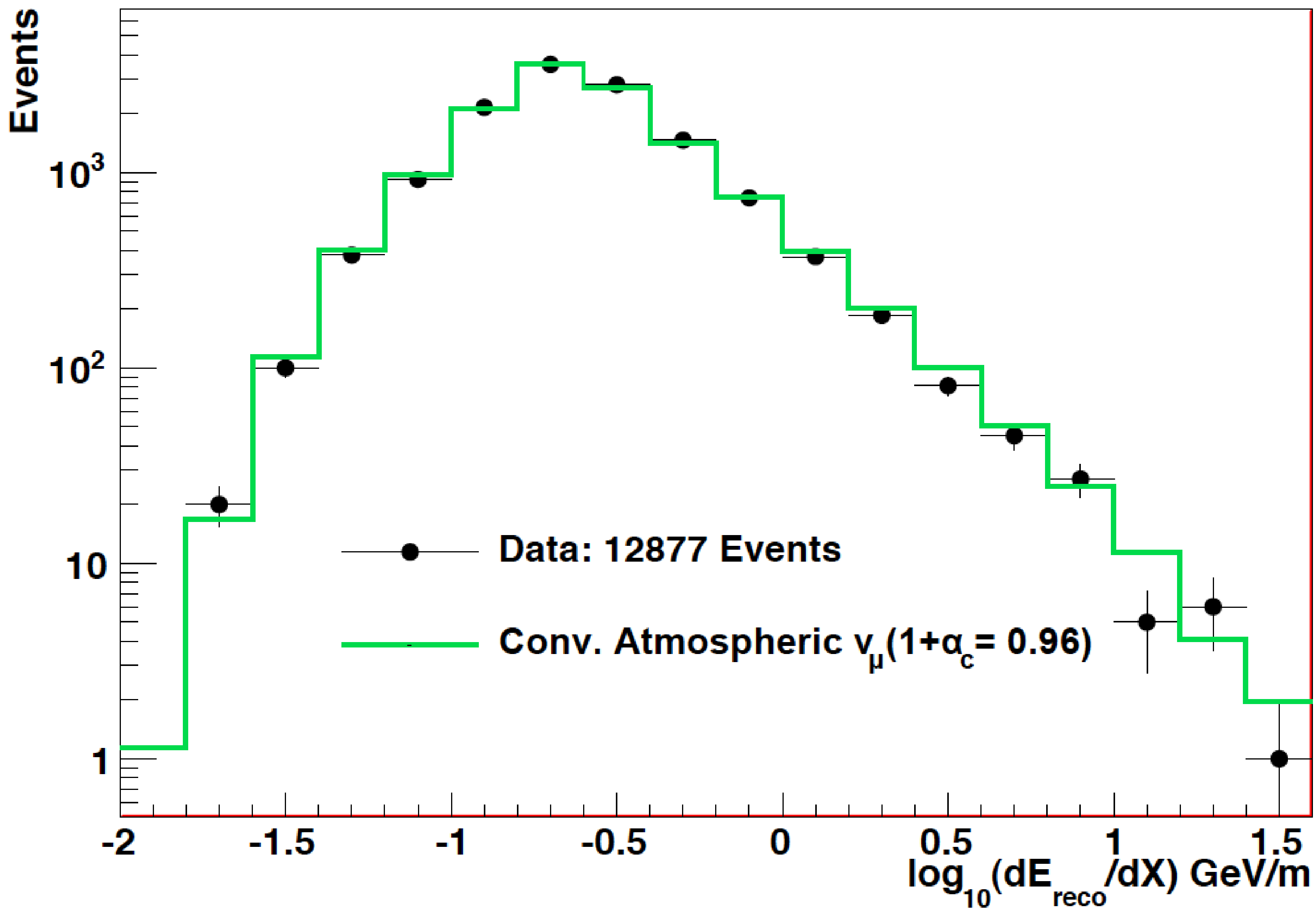
$$\phi_{\rm inclusive} = \sum_{\rm all\ sources} \phi_{\rm single\ source}$$

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



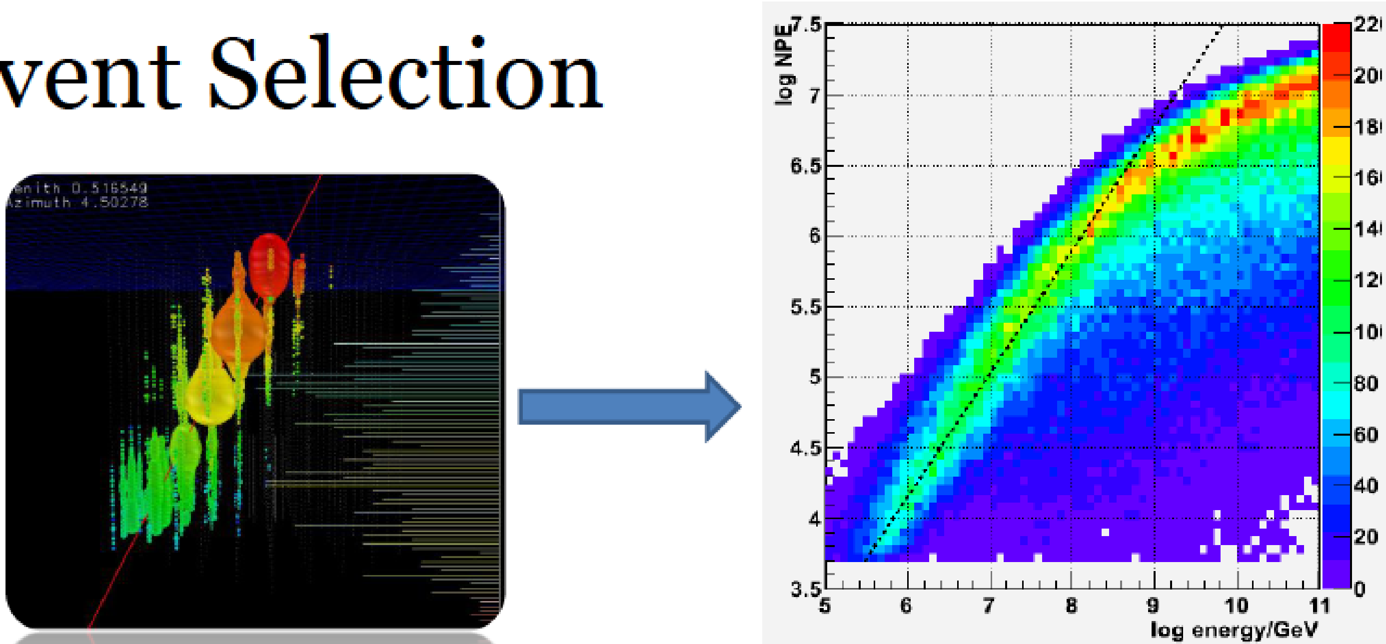
Integral dominated by large distances

A Search for a Diffuse Flux of Astrophysical Muon Neutrinos with the IceCube 40-String Detector



No excess over atmospheric neutrinos

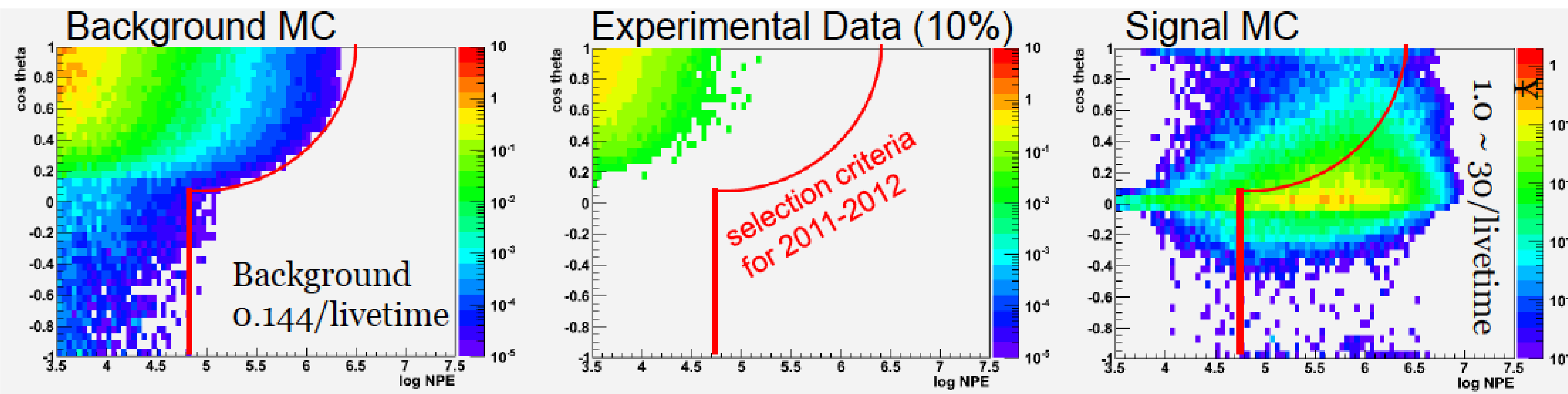
The Event Selection



channel # > 300

Energy of incoming particle ∝ Energy-losses in detector ∝ number of photo electrons (NPE)

- Optimization based MC and MC verification based on 10% experimental ‘burn’ sample

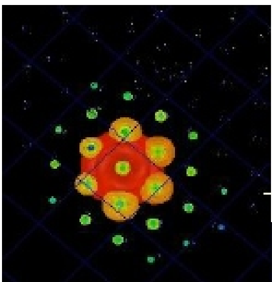


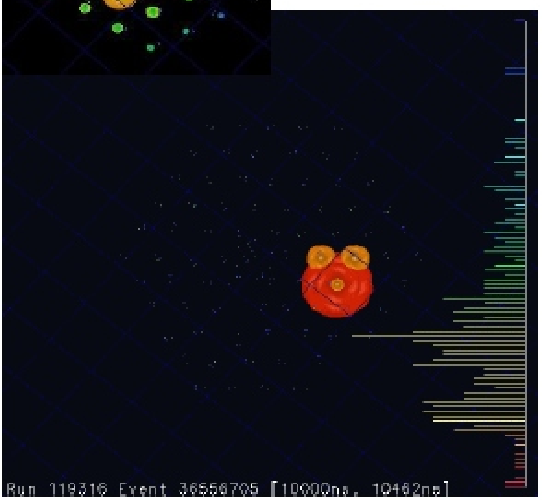
Two events passed the selection criteria

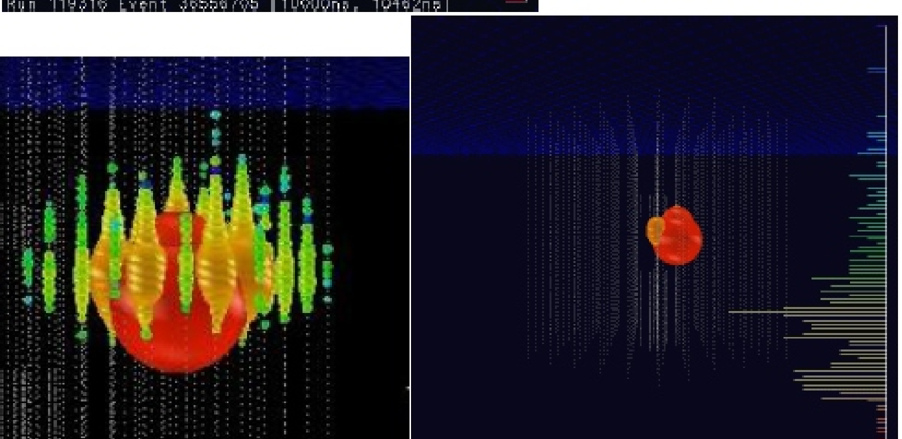
2 events / 672.7 days - background (atm. μ + conventional atm. ν) expectation 0.14 events

preliminary p-value: 0.0094 (2.36σ)

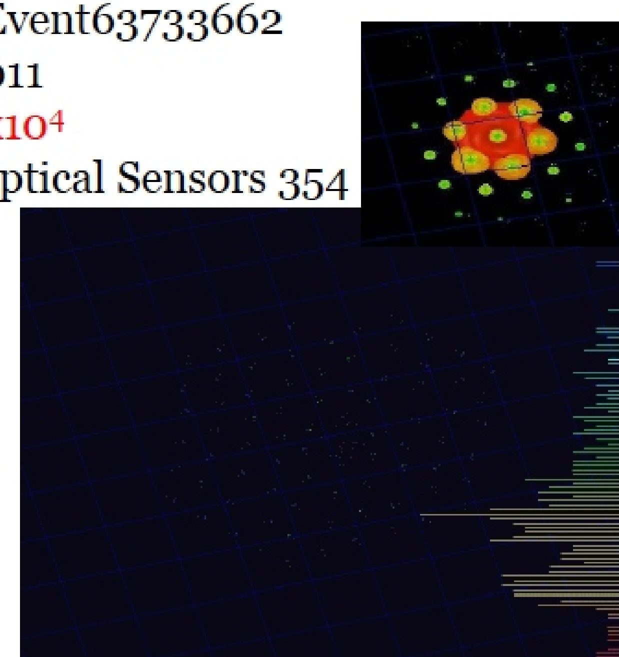
Run119316-Event36556705
Jan 3rd 2012
NPE 9.628×10^4
Number of Optical Sensors 312

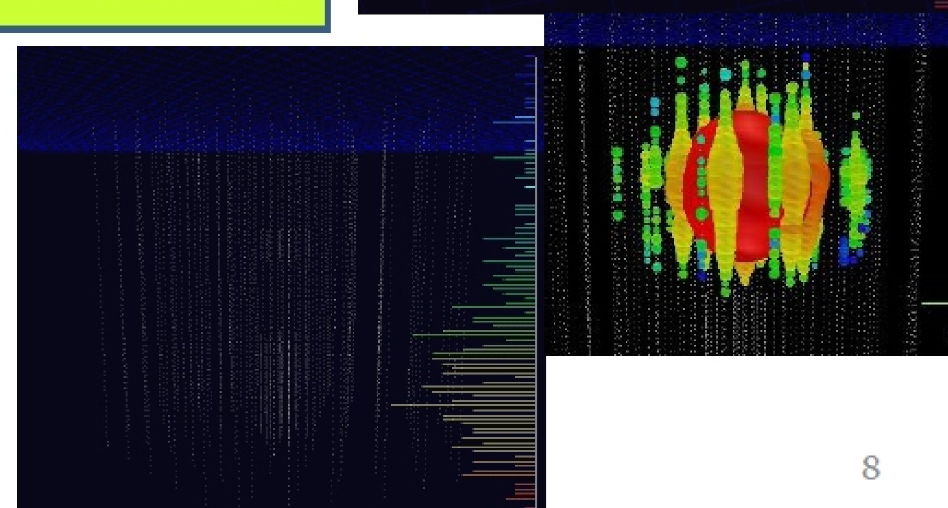




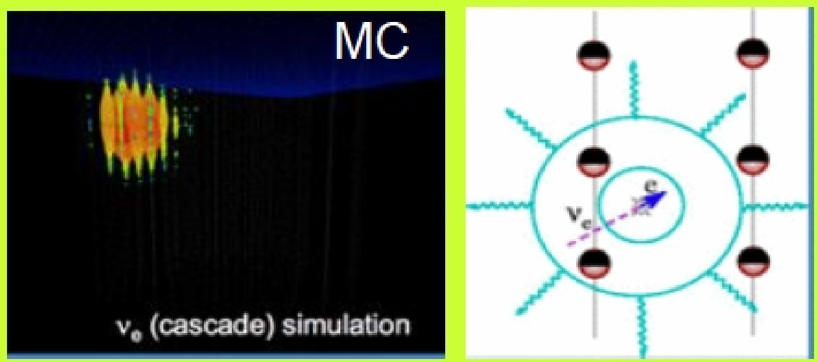


Run118545-Event63733662
August 9th 2011
NPE 6.9928×10^4
Number of Optical Sensors 354



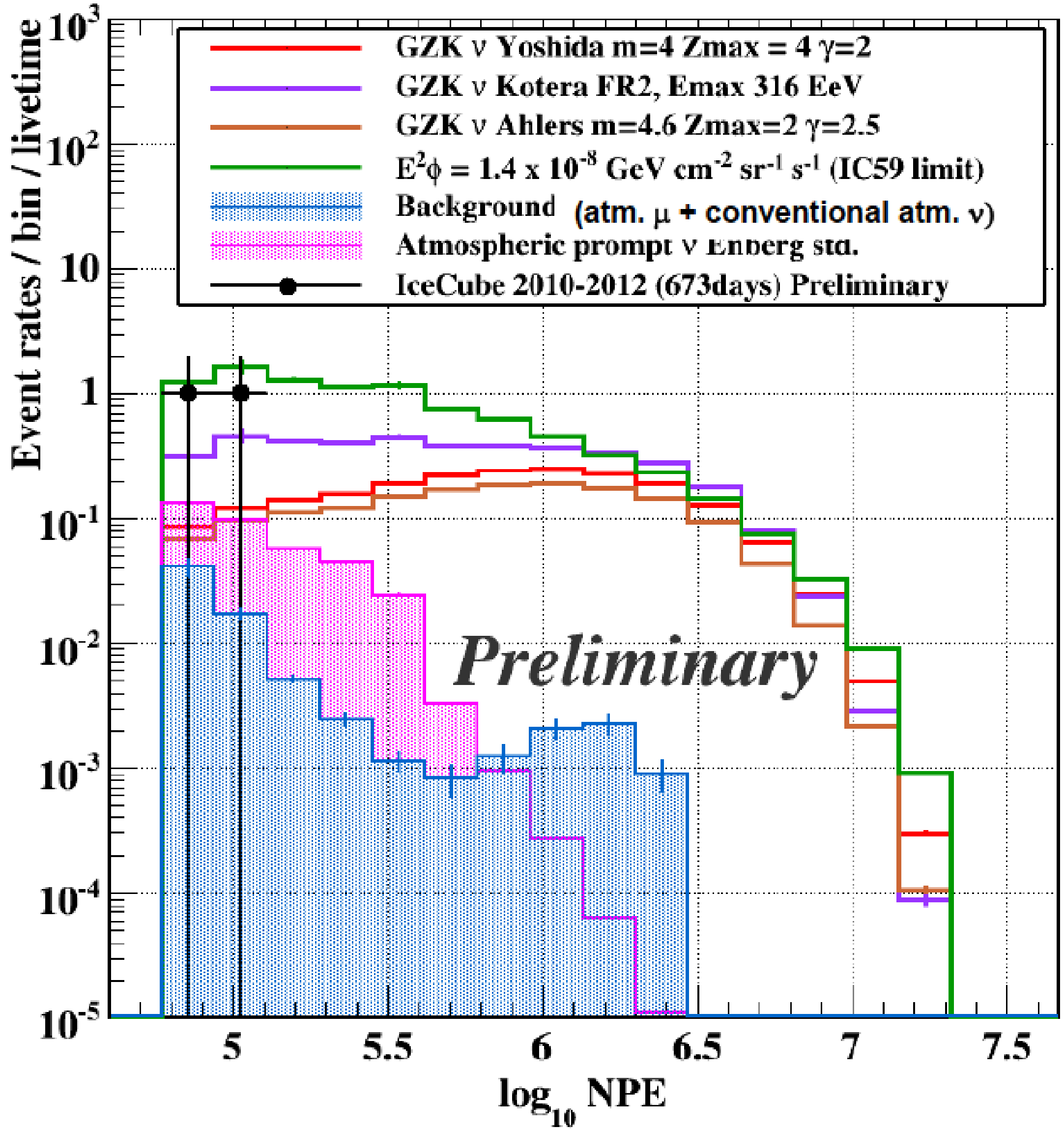


CC/NC interactions in the detector



2 events with Large energy depositions in IceCube (Neutrino 2012)

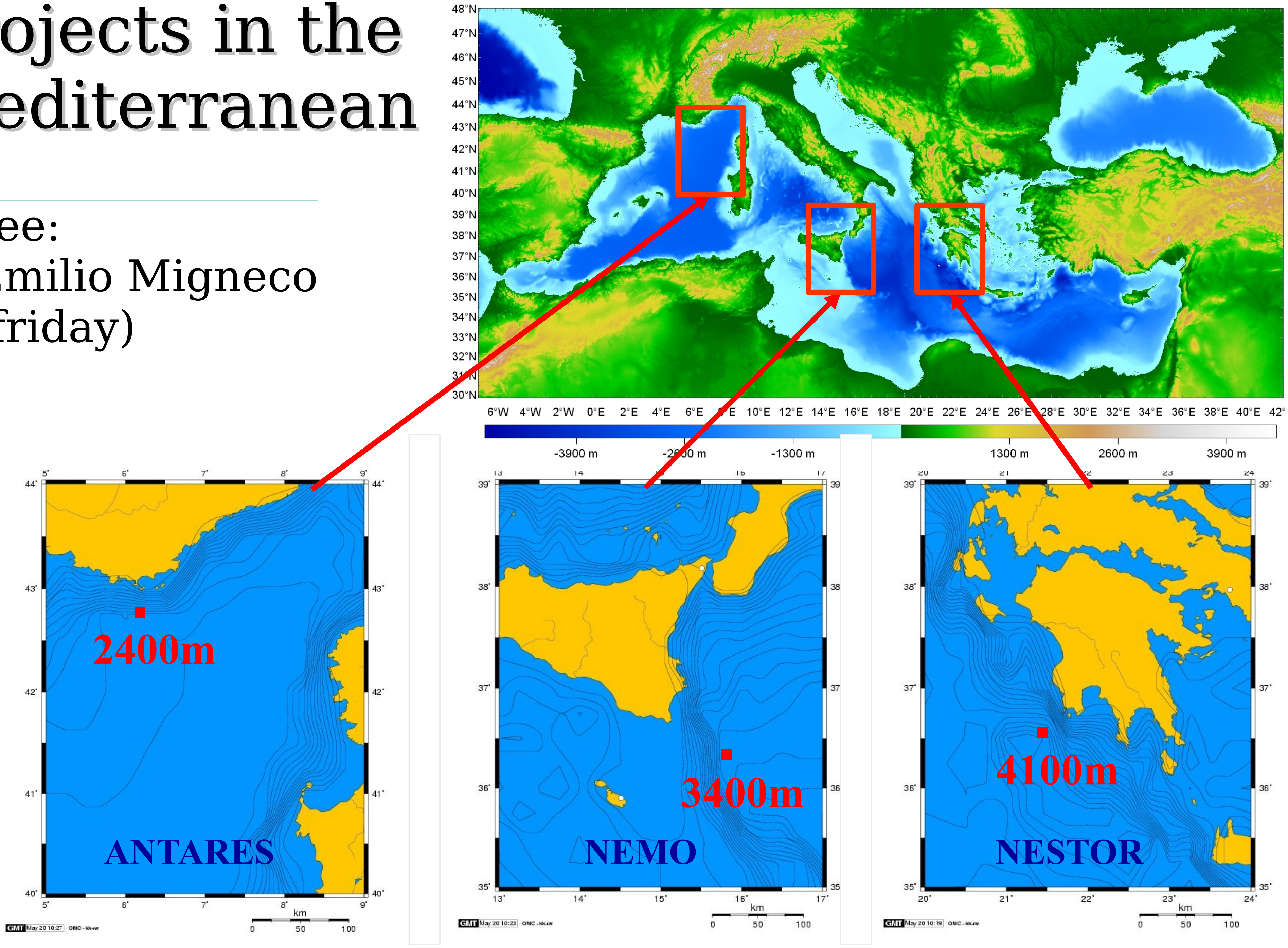
Event Brightness (NPE) Distributions 2010-2012

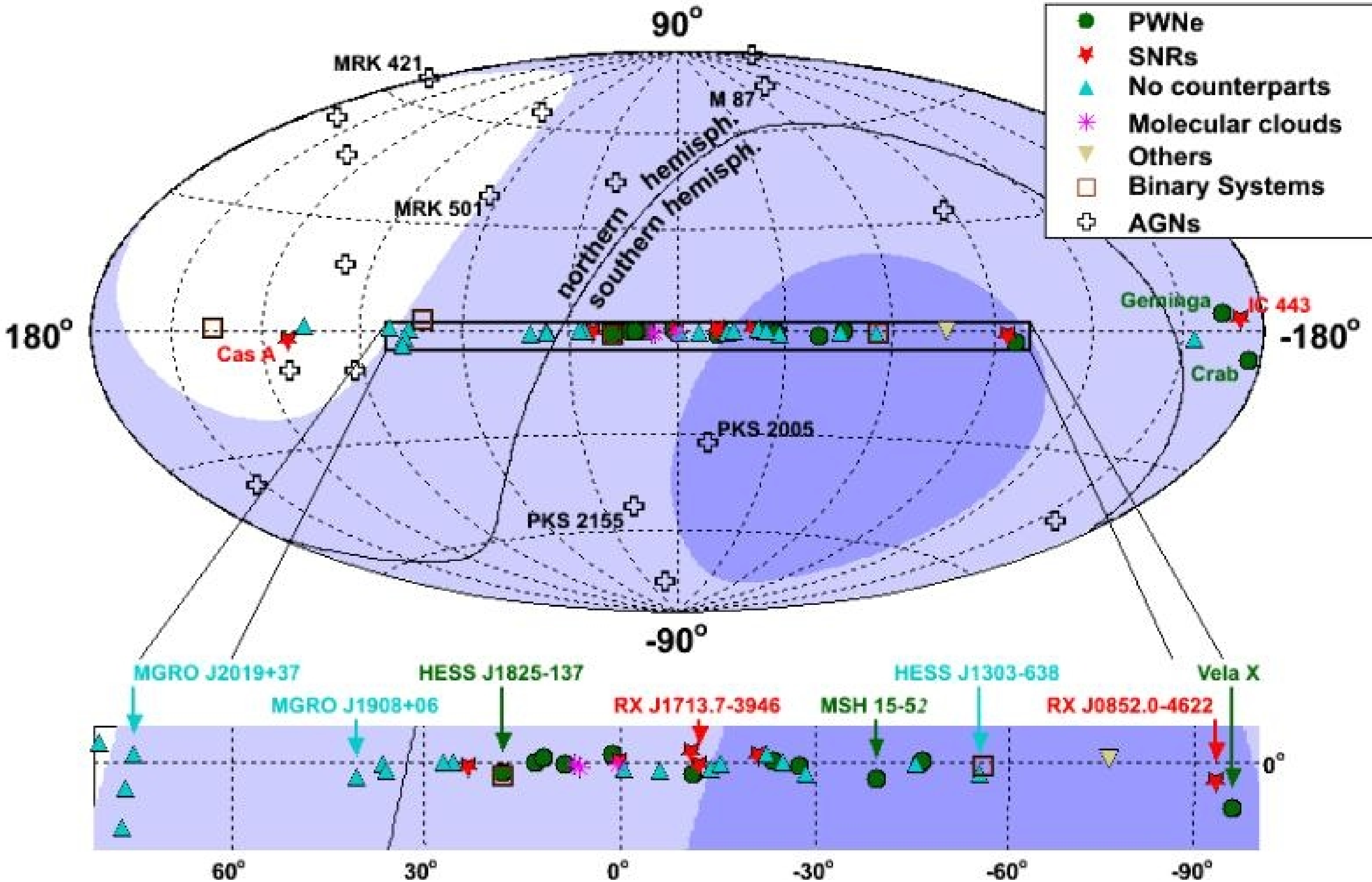


- Observed 2 high NPE events near the NPE threshold
- **No** indication
  - that they are instrumental artifacts
  - that they are cosmic-ray muon induced
- Possibility of the origin includes
  - cosmogenic ν
  - on-site ν production from the cosmic-ray accelerators
  - atmospheric prompt ν
  - atmospheric conventional ν

Projects in the Mediterranean

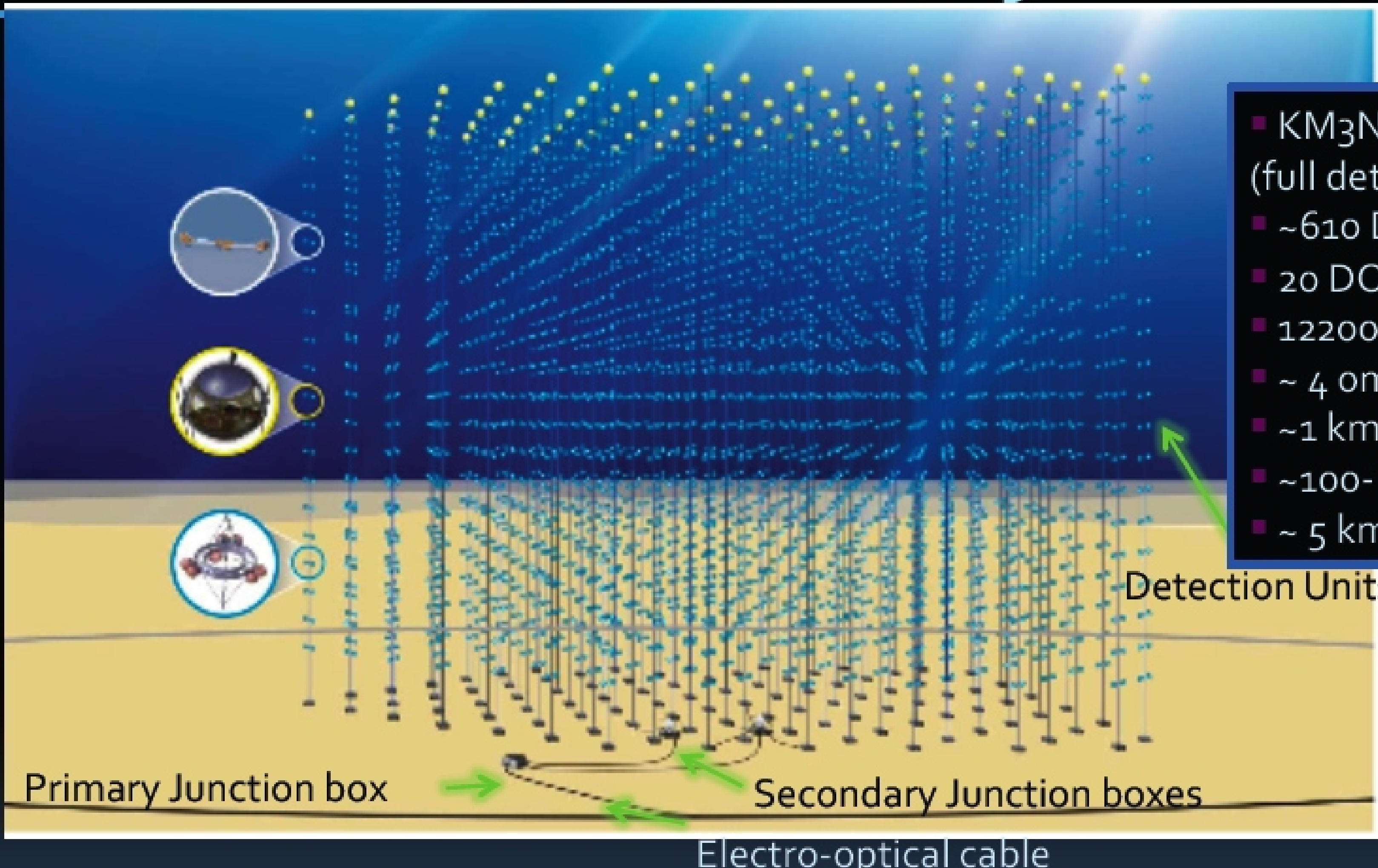
see:
Emilio Migneco
(friday)





PWNe
SNRs
No counterparts
Molecular clouds
Others
Binary Systems
AGNs
90°
-90°
180°
-180°
MRK 421
M 87
MRK 501
northern hemisph.
southern hemisph.
Geminga
IC 443
Cas A
Crab
PKS 2005
PKS 2155
MGRO J2019+37
HESS J1825-137
HESS J1303-638
Vela X
MGRO J1908+06
RX J1713.7-3946
MSH 15-52
RX J0852.0-4622
0°
60°
30°
0°
-30°
-60°
-90°

KM3NeT lay-out



- KM3NeT in numbers (full detector)
- ~610 DU
- 20 DOM/DU
- 12200 DOM
- ~ 40m DOM spacing
- ~1 km DU height
- ~100- 180 m DU distance
- ~ 5 km^3 volume

Optical Module (OM) = pressure resistant/tight sphere cointaining photo-multplier

Detection Unit (DU) = mechanical structure holding OMs, enviromental sensors, electronics,... *DU is the building element of the telescope*

Construction in several blocks => Multi-site option

It is wrong to talk about:

NEUTRINO ASTRONOMY

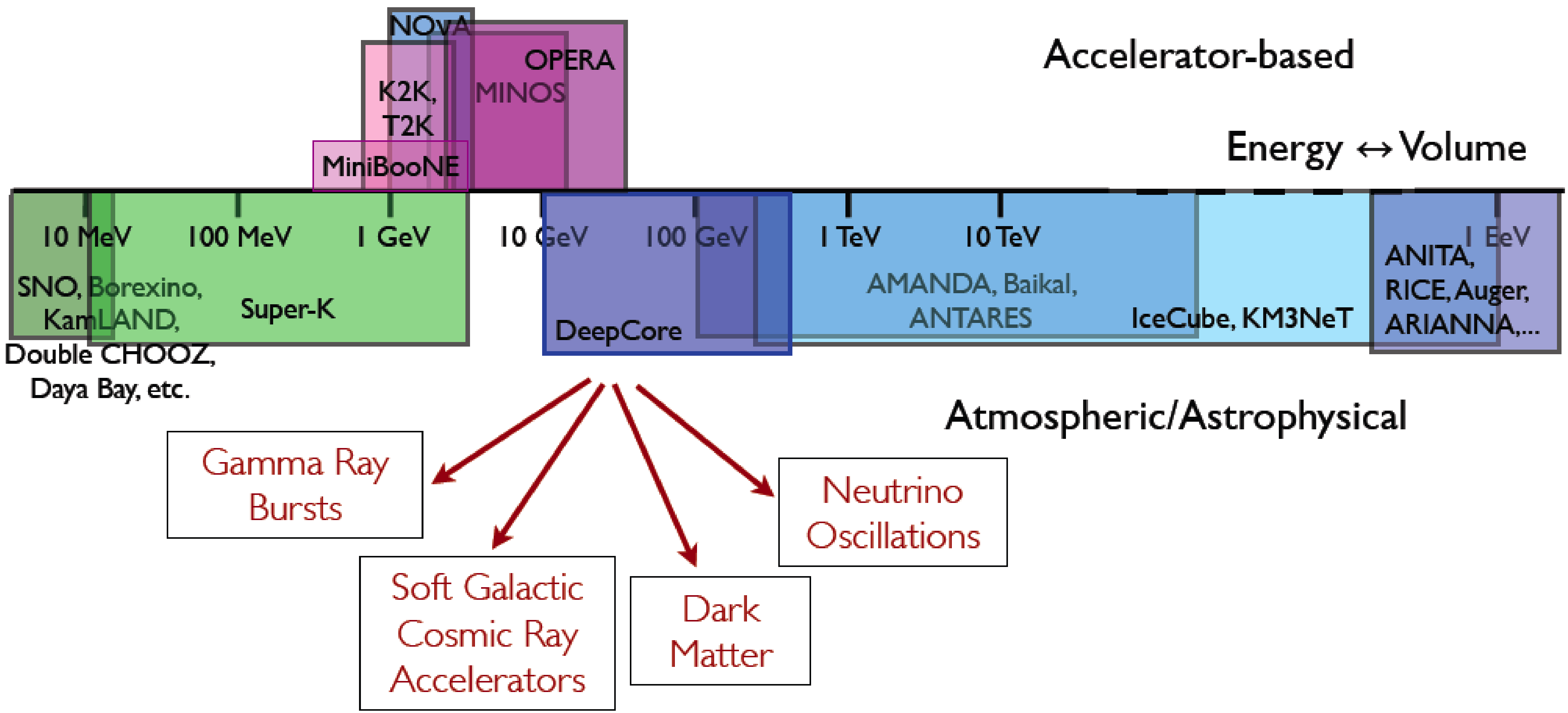
We should talk about

NEUTRINO ASTRONOMIES

10-100 GeV (DM)
1-100 TeV (Galactic Sources)
EeV (Radio, EAS...)

....

Deep Core



NOvA
OPERA
K2K,
T2K
MINOS
MiniBooNE
Accelerator-based
Energy ↔ Volume
10 MeV
100 MeV
1 GeV
10 GeV
100 GeV
1 TeV
10 TeV
1 EeV
SNO, Borexino,
KamLAND,
Double CHOOZ,
Daya Bay, etc.
Super-K
DeepCore
AMANDA, Baikal,
ANTARES
IceCube, KM3NeT
ANITA,
RICE, Auger,
ARIANNA,...
Atmospheric/Astrophysical
Gamma Ray
Bursts
Soft Galactic
Cosmic Ray
Accelerators
Dark
Matter
Neutrino
Oscillations

Neutrino Astronomy: beyond the "Km3 concept"

Radio, Acoustic,.....

Radio Detection of neutrinos

ANITA-II over Antarctica

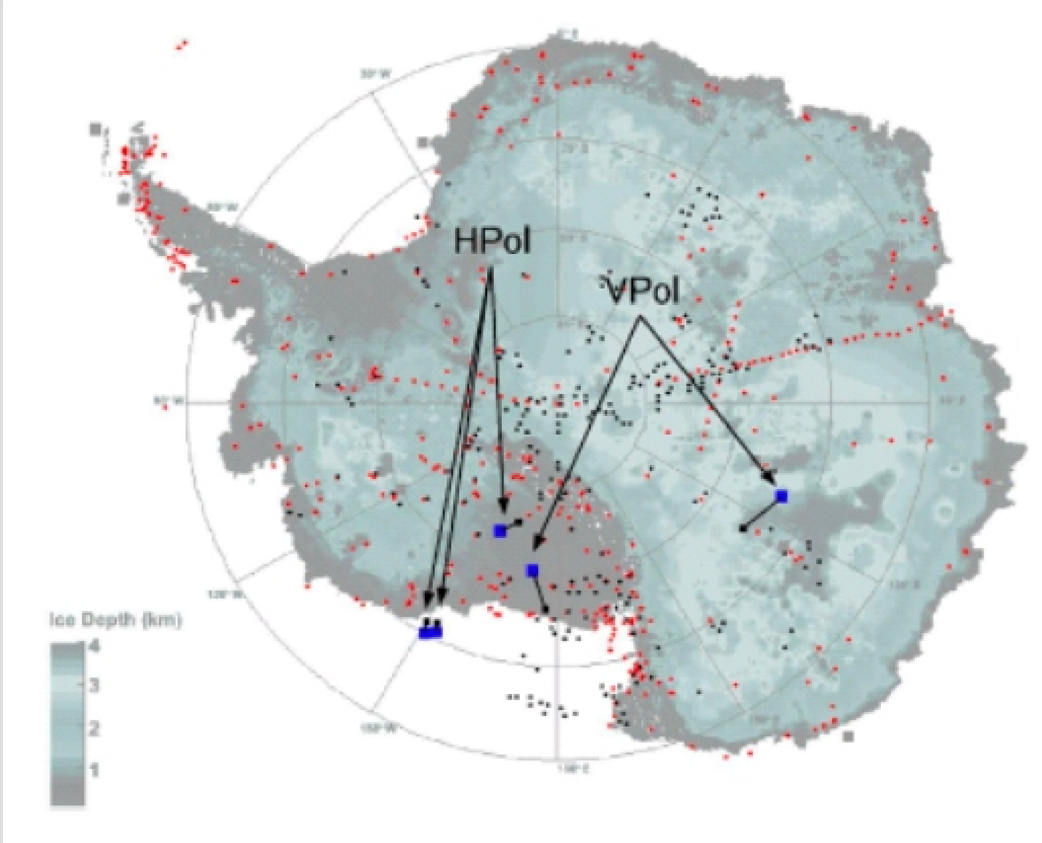


FIG. 3: Events remaining after unblinding. The Vpol neutrino channel contains two surviving events. Three candidate UHECR events remain in the Hpol channel. Ice depths are from BEDMAP [12].

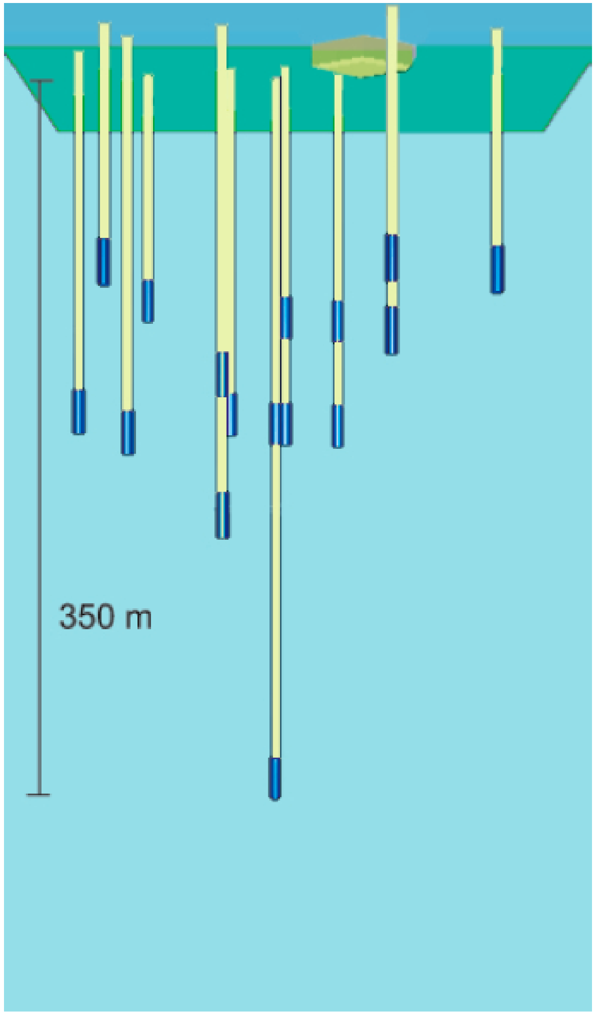
http://arxiv.org/abs/1003.2961

Vpol:1 neutrino candidate;

HPol:3 >5 1019 eV

RICE experiment architecture

- Antarctic ice is neutrino target
- In-ice array of radio antennas
- 20 channels, 200-500 MHz
- Depths 100-300 meters
- Signal digitized at the surface
- Deployed near South Pole Station



10^7 to 10^{11} GeV: Radio ice Cherenkov detection

Askaryan Radio Array (ARA)

- a very large radio neutrino detector at the South Pole

Ref: Allison et al., Astropart.Phys. 35 (2012) 457-477, arXiv:1105.2854 (Design and performance paper)

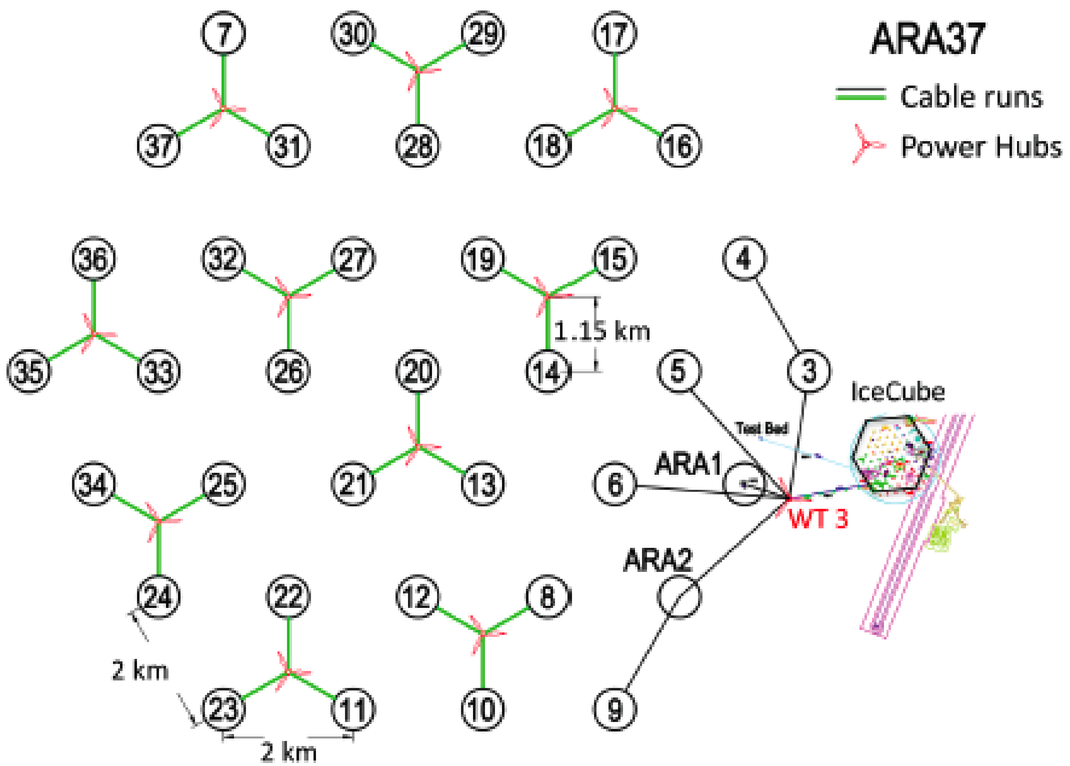
Poster session at this conference:
→ H. Landsman, ARA Design and Status
→ J. Davies, ARA prototype and first station

Scientific Goal:

- Discover and determine the flux of highest energy cosmic neutrinos.
- Understanding of highest energy cosmic rays, other phenomena at highest energies.

Method:

Monitor the ice for radio pulses generated by interactions of cosmic neutrinos with nuclei of the 2.8km thick ice sheet at the South Pole



Areal coverage: ~150km^2

10^7 to 10^{11} GeV: Radio ice Cherenkov detection

ARA field activities on the ice

Status:

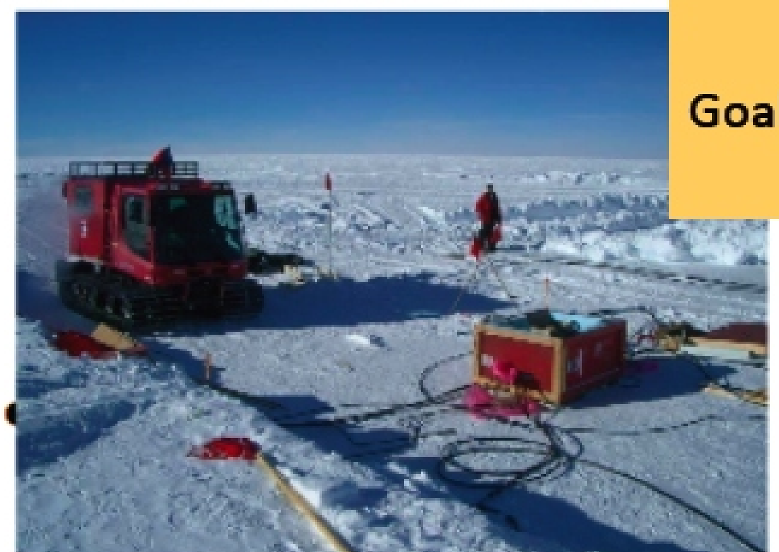
2010/11: Test detector deployed

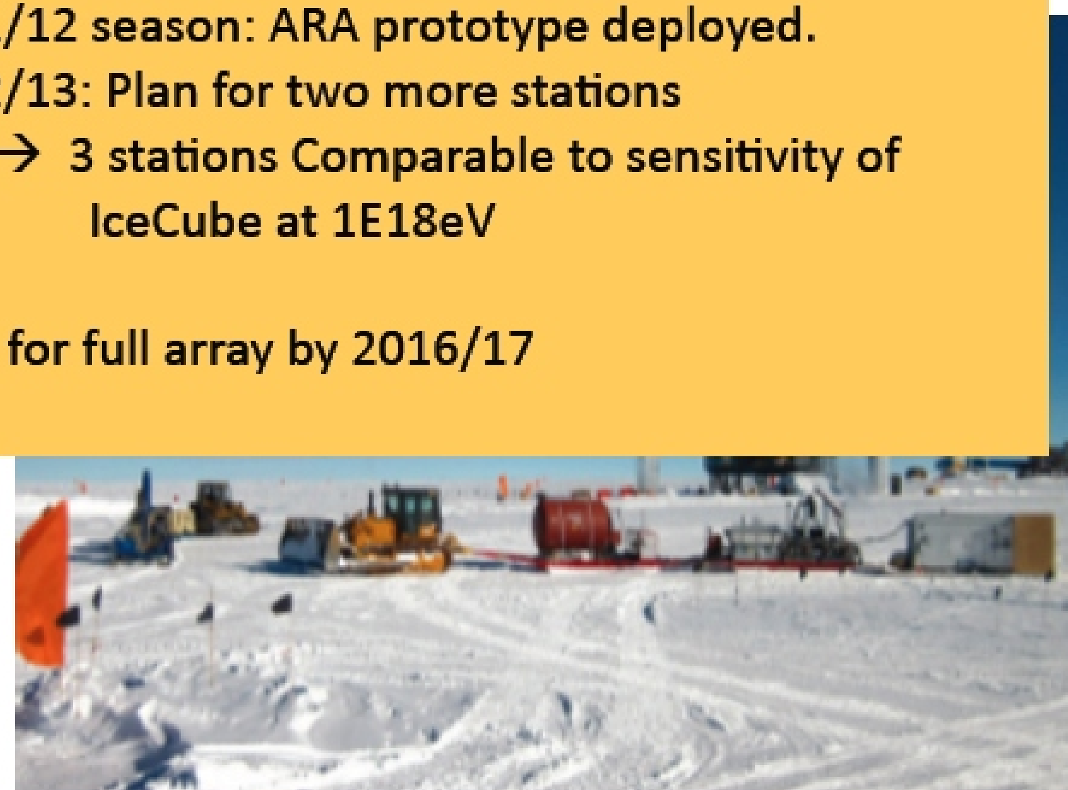
2011/12 season: ARA prototype deployed.

2012/13: Plan for two more stations

→ 3 stations Comparable to sensitivity of IceCube at 1E18eV

Goal for full array by 2016/17



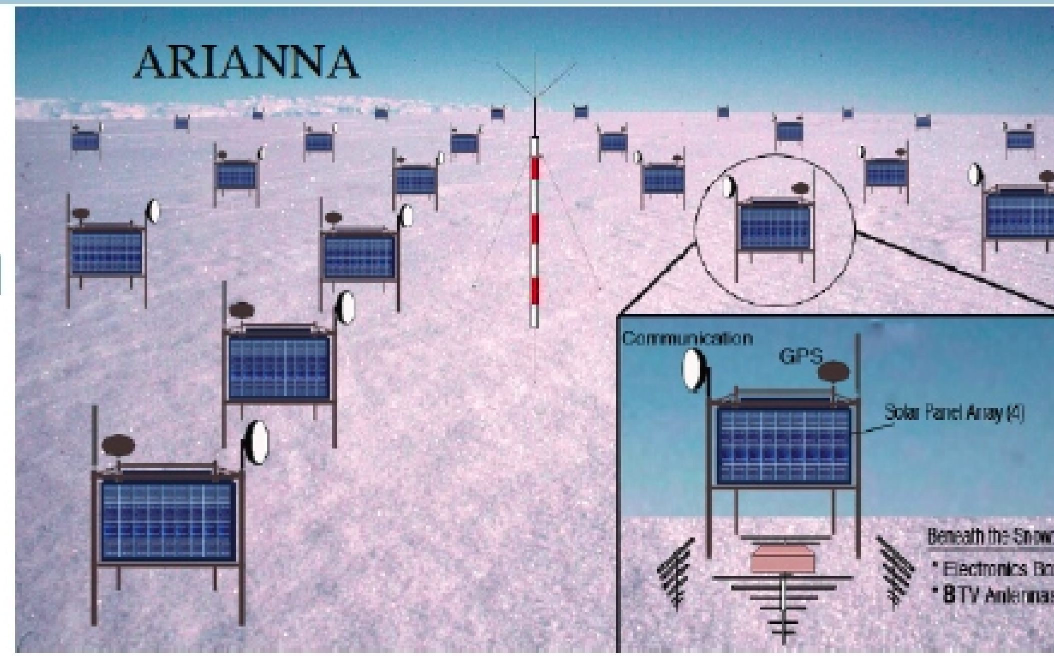


10^7 to 10^{11} GeV: Radio ice Cherenkov detection

ARIANNA

- L. Gerhardt et al., Nucl.Instrum.Meth. A624 (2010) 85-91
- Poster 18-3: J. Tatar. S. Barwick

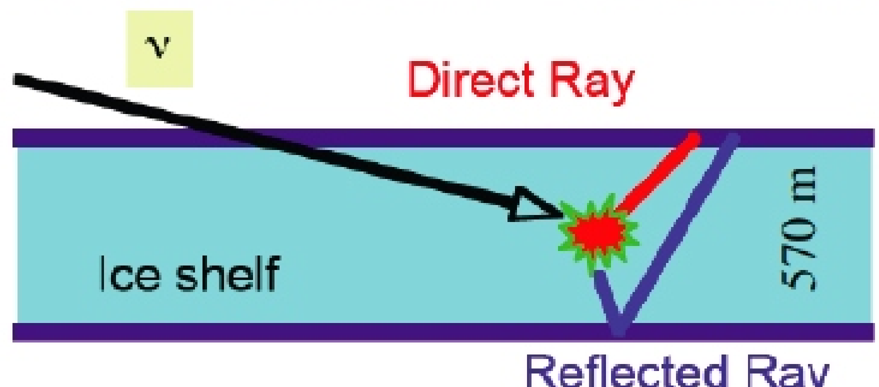
31 x 31 array
[30 km x 30 km]



ARIANNA

US, S. Korea, England, New Zealand

Barwick, astro-ph/0610631



Final Remarks

- The "Dark Matter problem" is one of the deepest and most fundamental questions in physics.

  The "WIMP" (thermal relic) paradigm can be explored in depth with a "3-roads" approach [LHC/Direct/Indirect methods].
  [Perhaps Nature is more "subtle"
  "Dark Matter" could be something else
  (Axions, super-massive particles, ...)
  we should also be ready for alternative paradigms.]

- 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.
  [Multi-Messenger studies are essential]