Astroparticle Physics:

Status of current research [theory]

Paolo Lipari
Scineghe 2012

Lecce 19th - 22nd july 2012

1. DARK MATTER

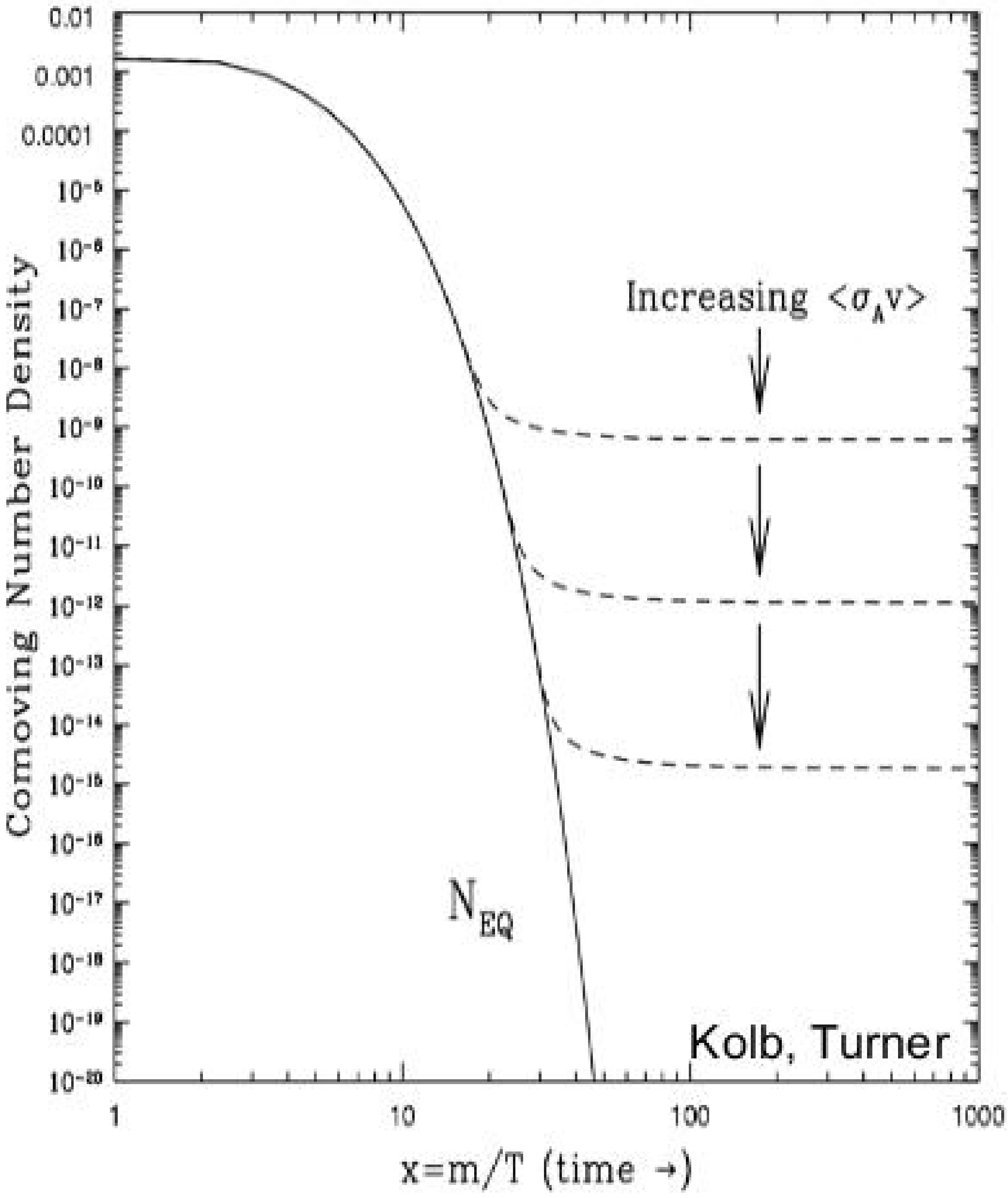
2. Sources of
   High Energy Particles

What is the nature
of the Dark Matter ?

Cold Dark Matter

Cornelia Parker. (Tate Gallery, London)

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]

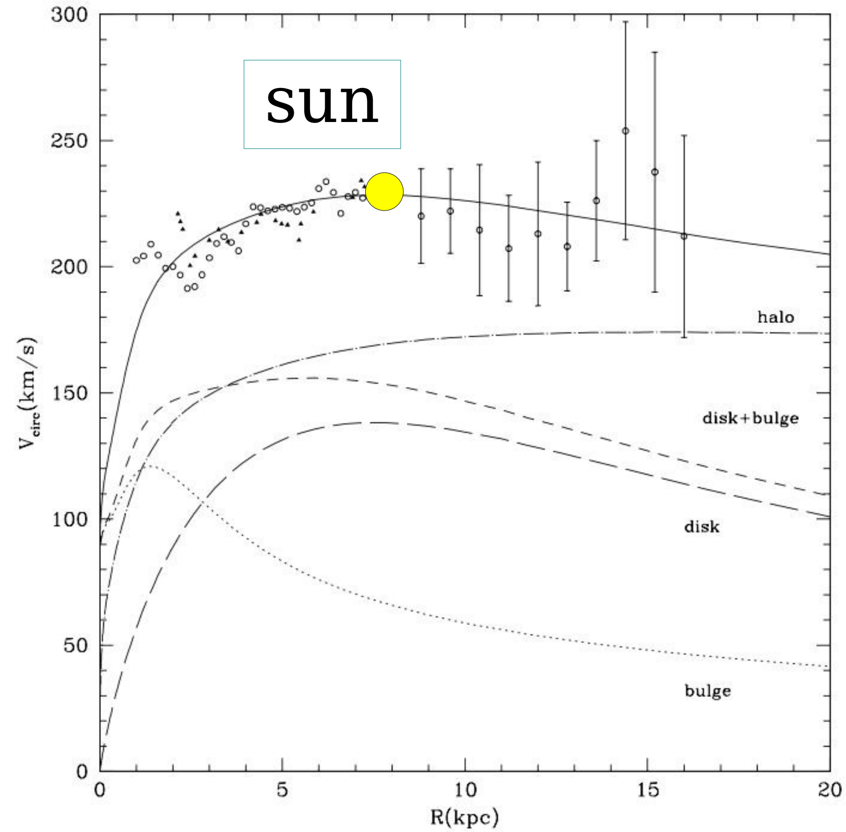
The "WIMP's Miracle" ?

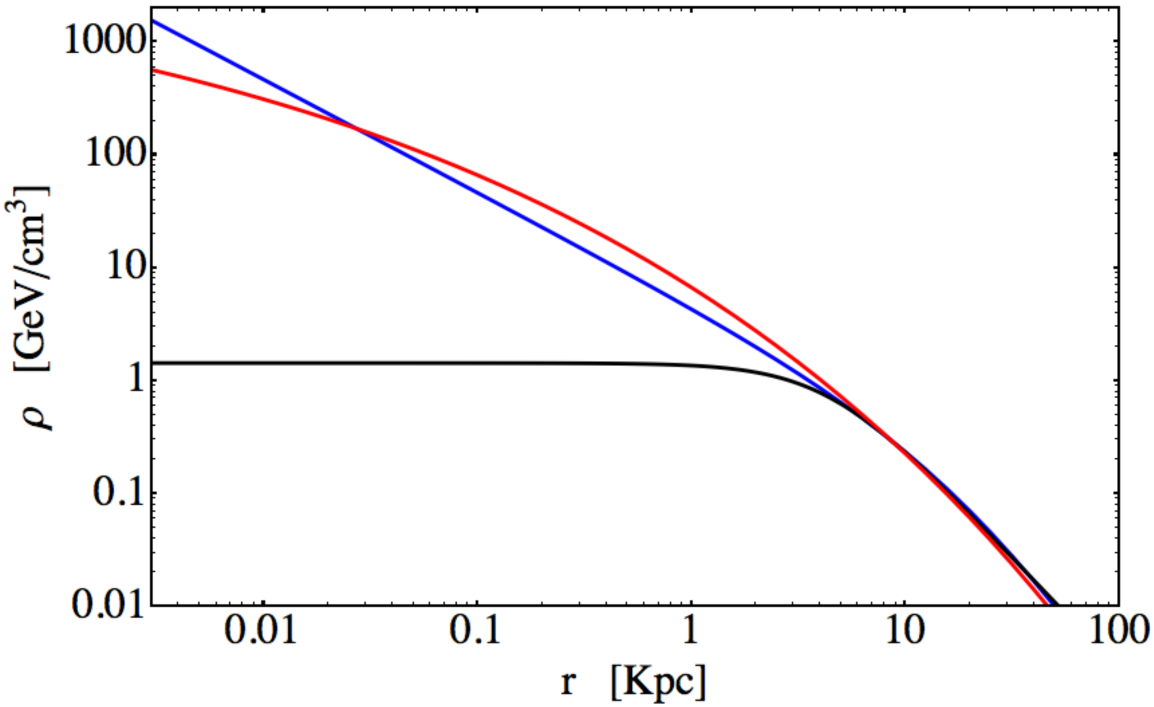
DM in the Milky Way

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

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

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





Density distribution
determined by
Rotation velocity measurements

"Cusp" at GC
derived by N-body simulations

Power generated by DM annihilations in the Milky Way halo

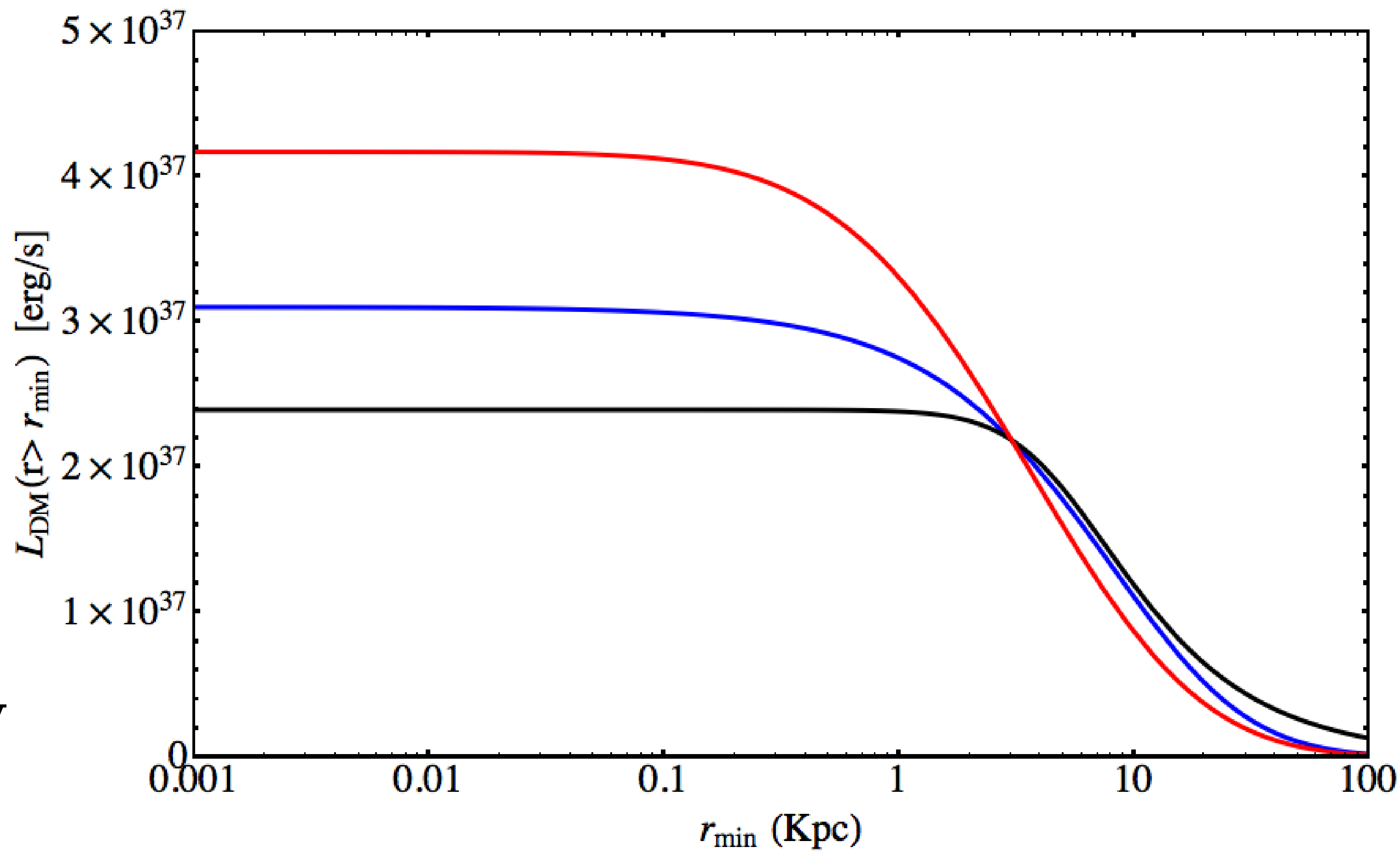
$$\frac{dN_{\chi\chi\to X}}{d^3x\,dt} = \frac{1}{2}\,n_\chi^2(\vec{x})\ \langle \sigma\, v\rangle$$

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

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

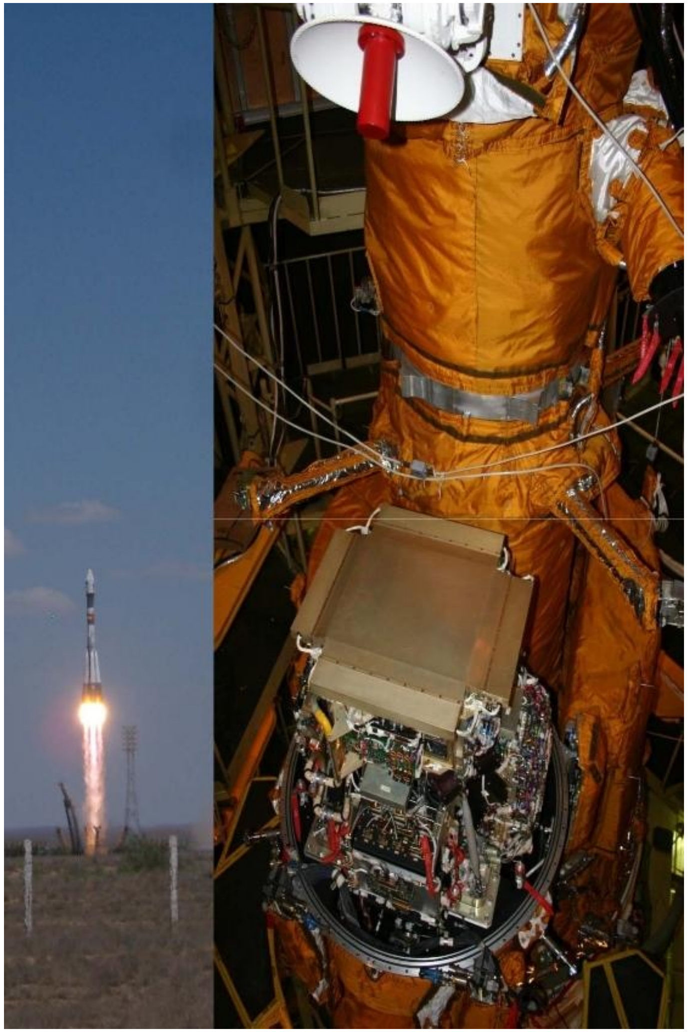
$$L_{\rm DM} \simeq 3\times 10^{37}\ {\rm erg\ s^{-1}}\ \left[\frac{\langle \sigma\, v\rangle}{3\times 10^{-26}\ ({\rm cm^3 s})^{-1}}\right]\ \left[\frac{100\ {\rm GeV}}{m_\chi}\right]$$

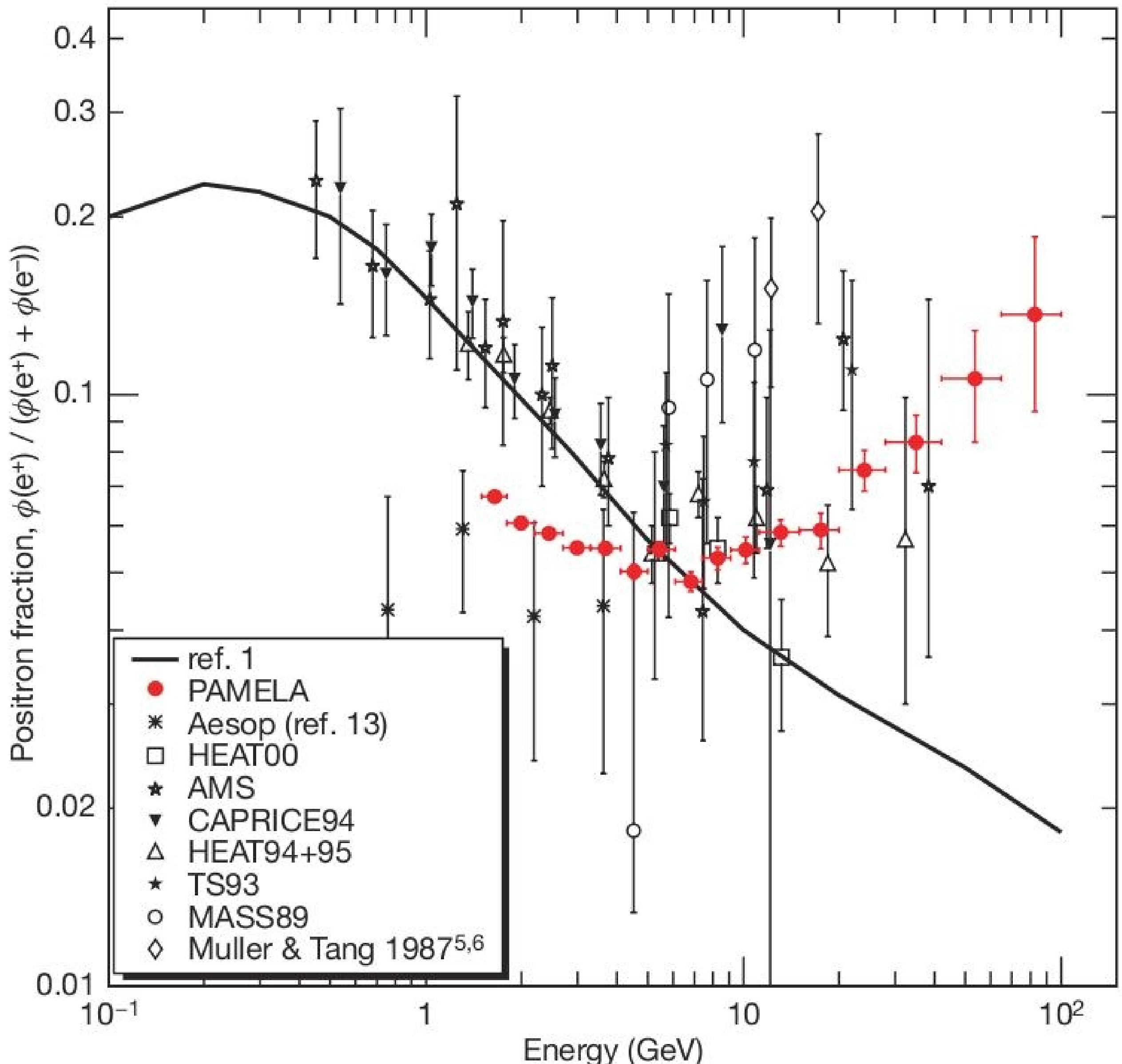
[Majorana particle]



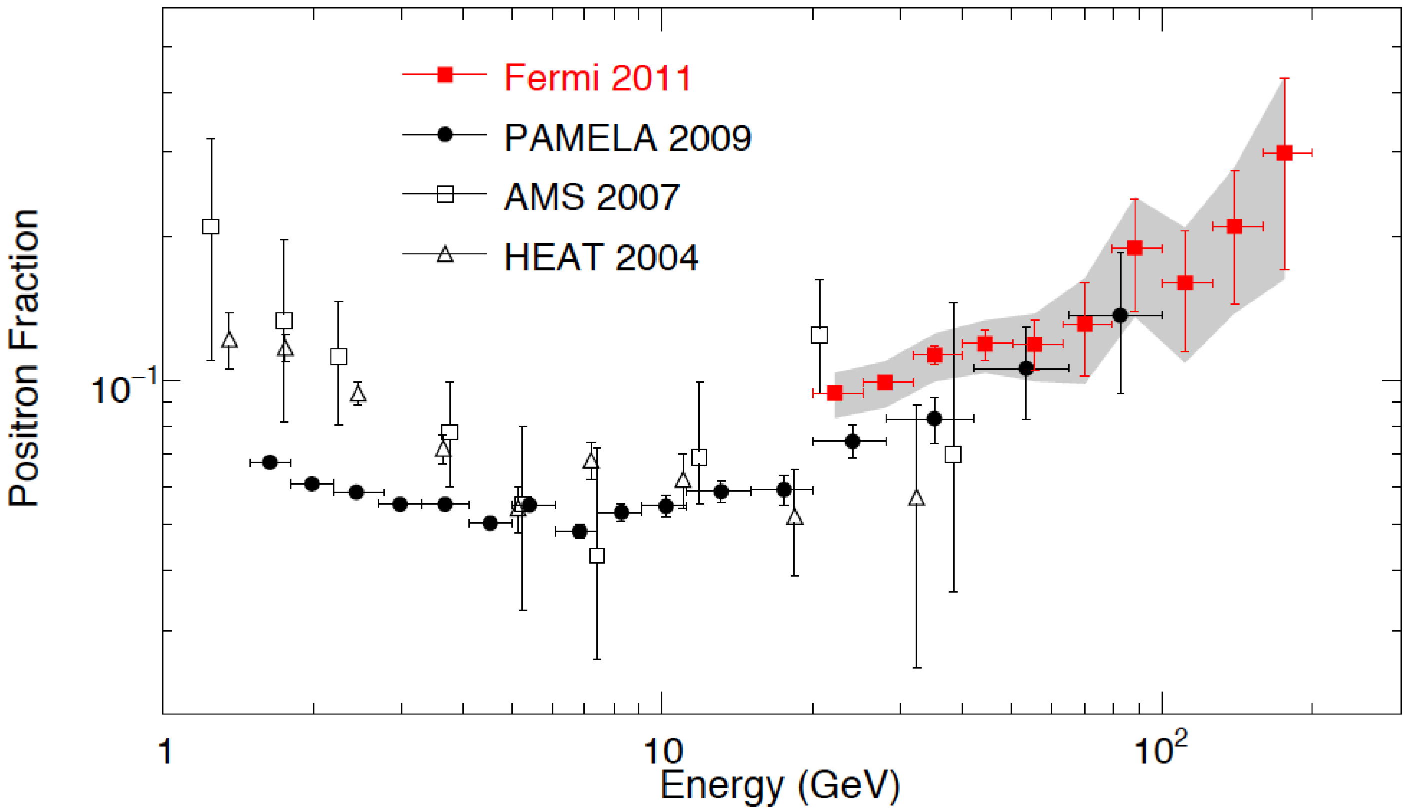
small effect of "Cusp" on total luminosity

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



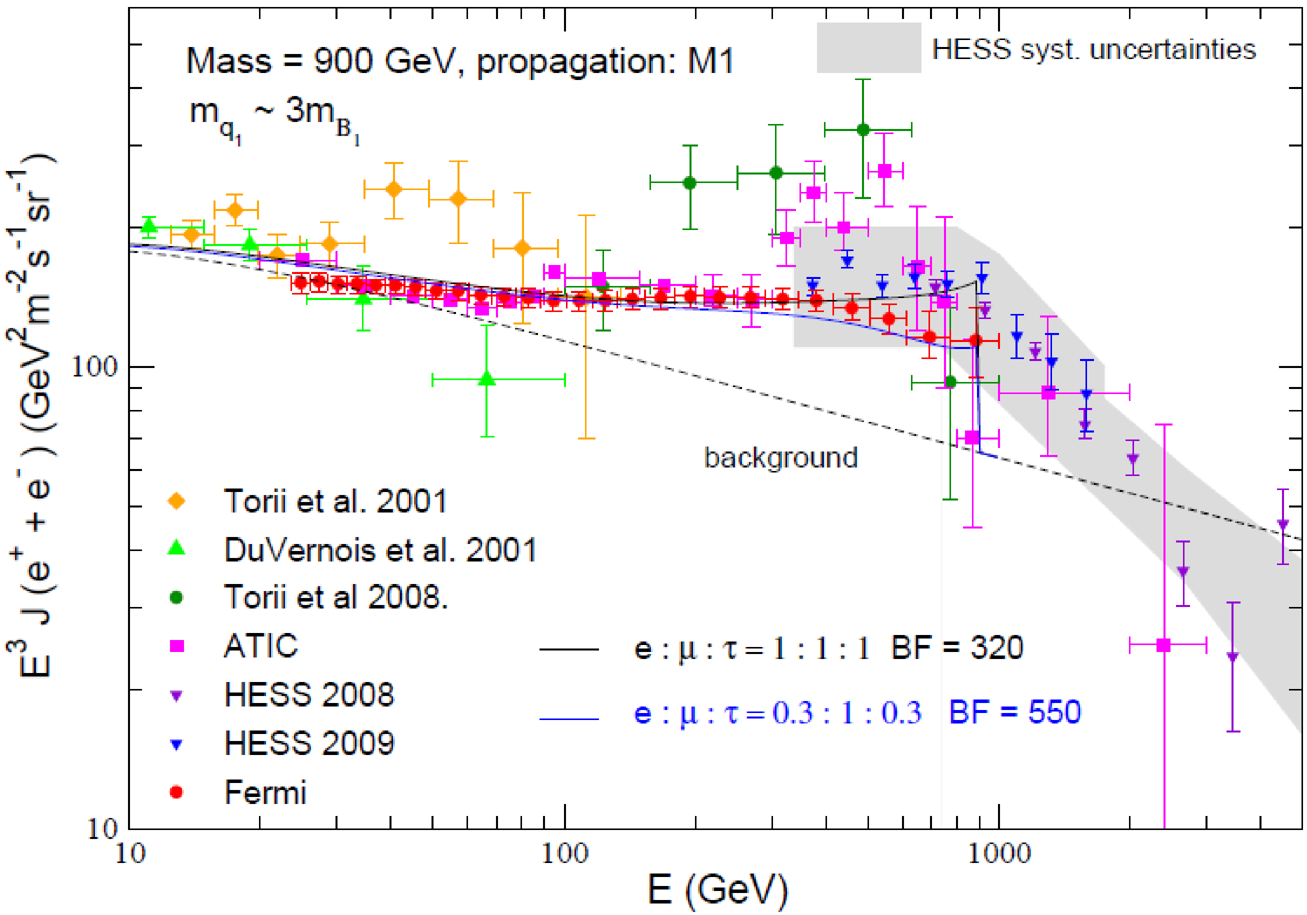


Result confirmed by FERMI ! (and extended to 200 GeV)
[using the Earth magnetic field to separate e- and e+]
{Hypothesis of systematic effect much less likely...}



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

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

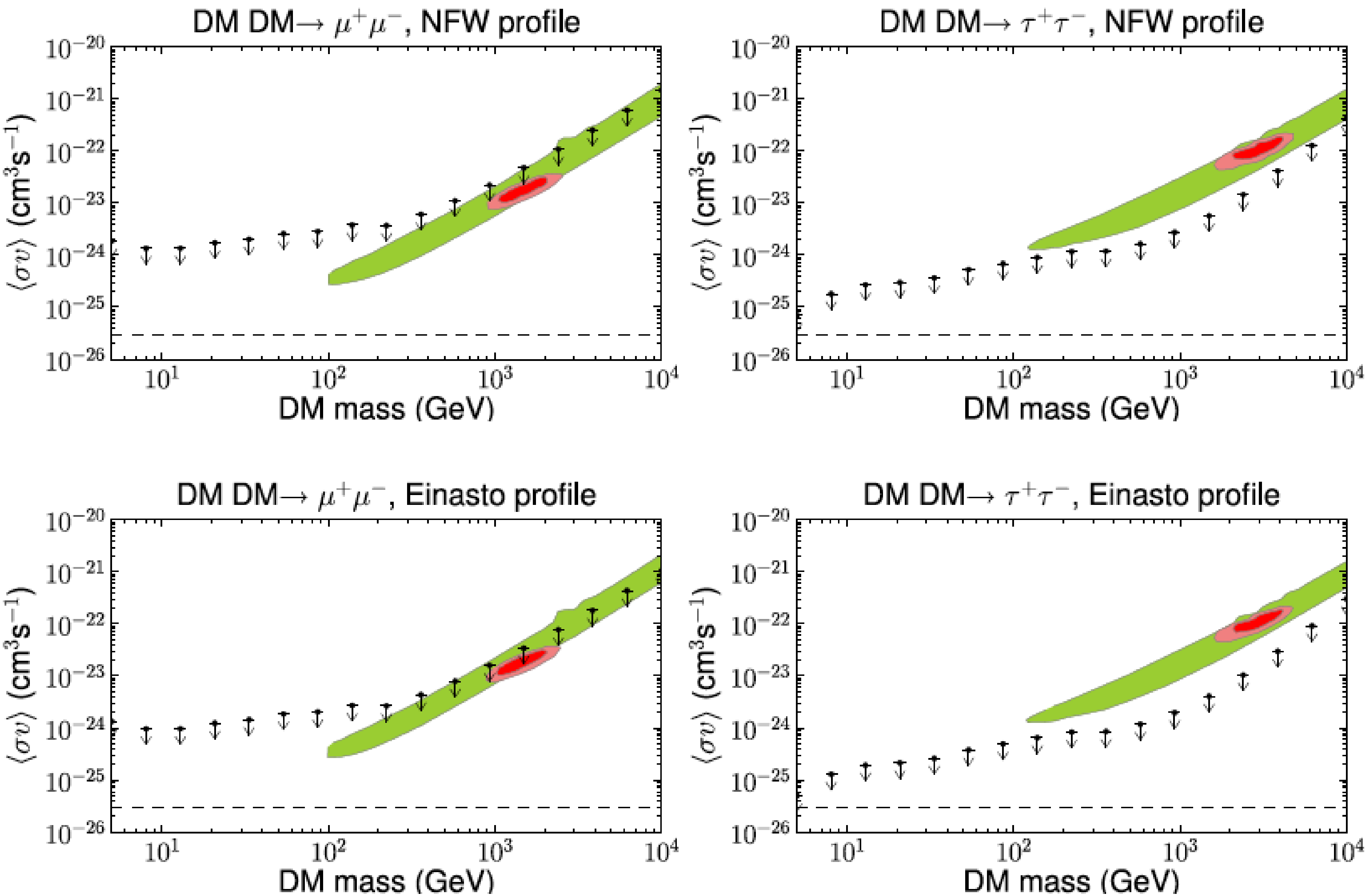
2. Annihilation cross section

Annihilation channels

DM density distribution

+ CR propagation in MW moeli

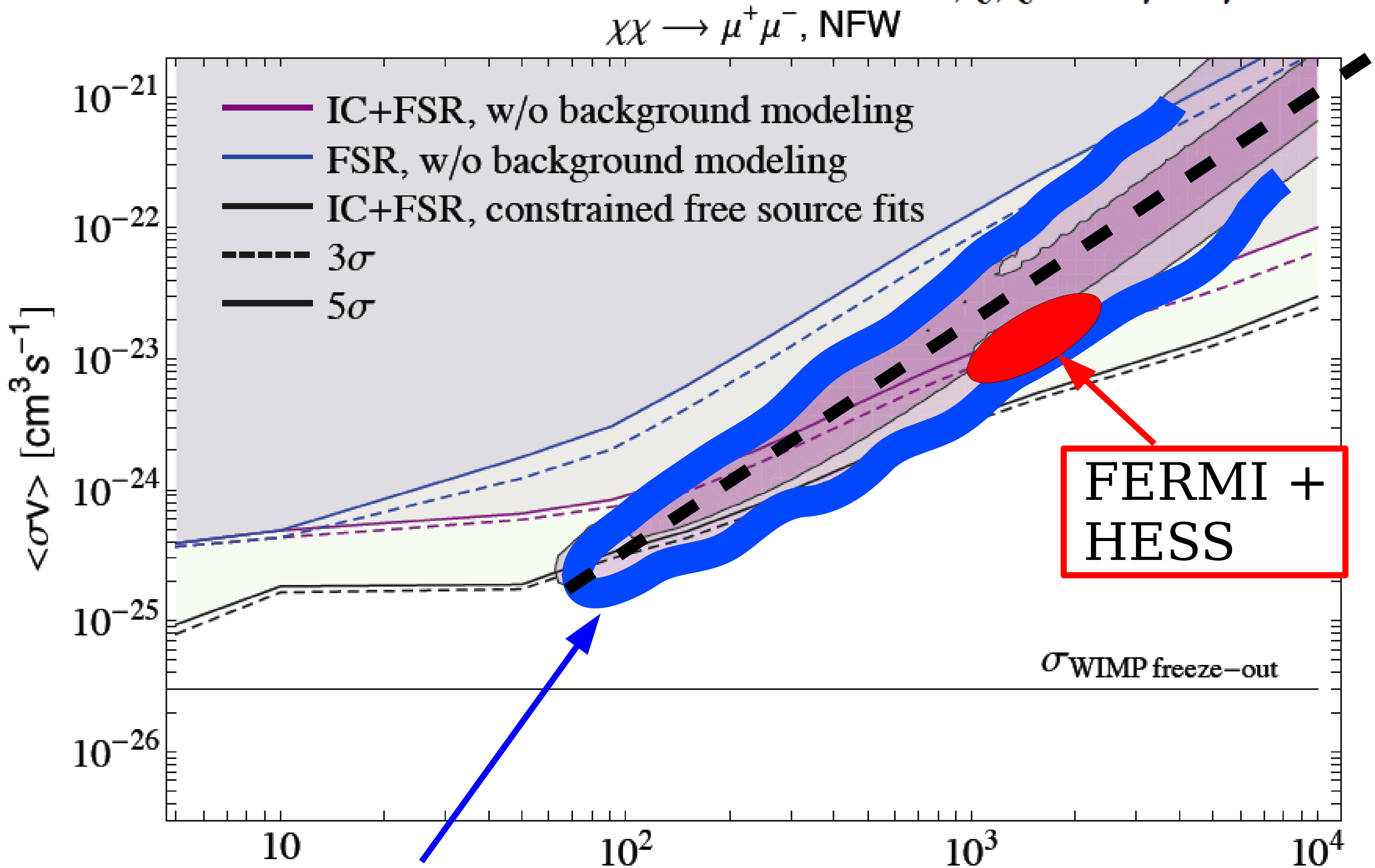
P. Meade, M. Papucci, A. Strumia, and T. Volansky, Nucl. Phys. B831, 178 (2010),



Cirelli, Panci, Serpico
[2010]

NWF

$\chi\chi \rightarrow \mu^+\mu^-$



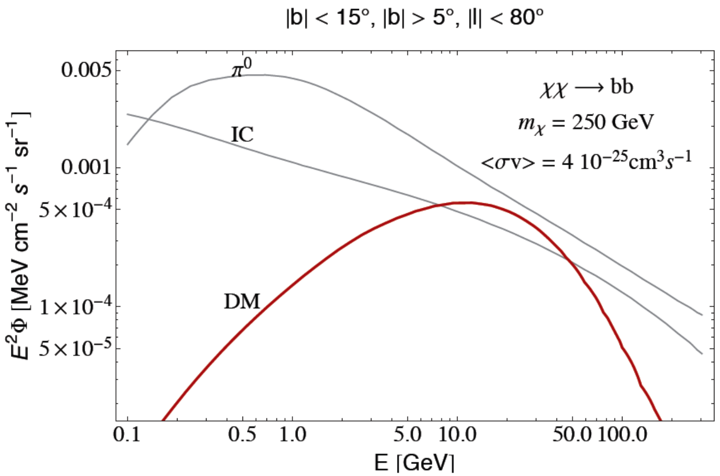
Region that explains the PAMELA positron anomaly

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

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

Pamela anomaly:

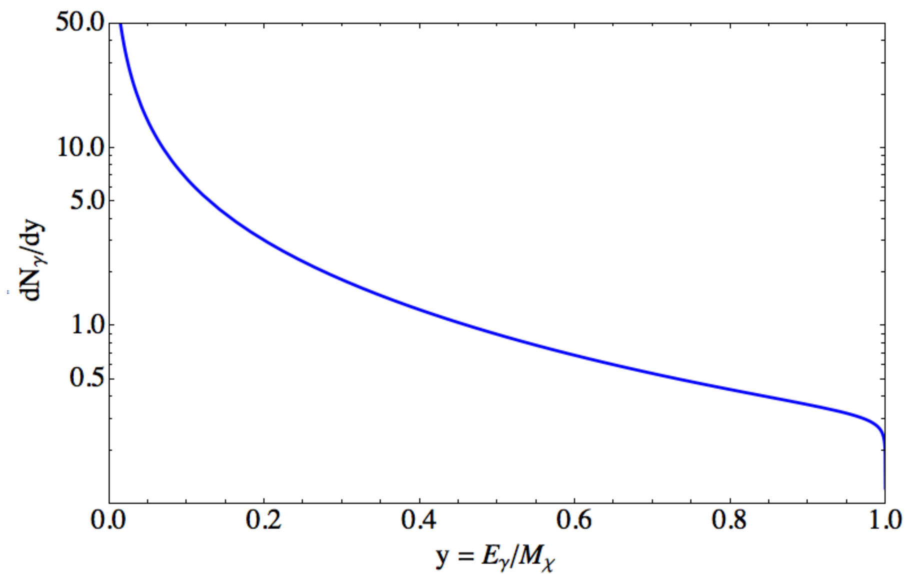
The positron emission MUST be accompanied by a significant emission of photons.

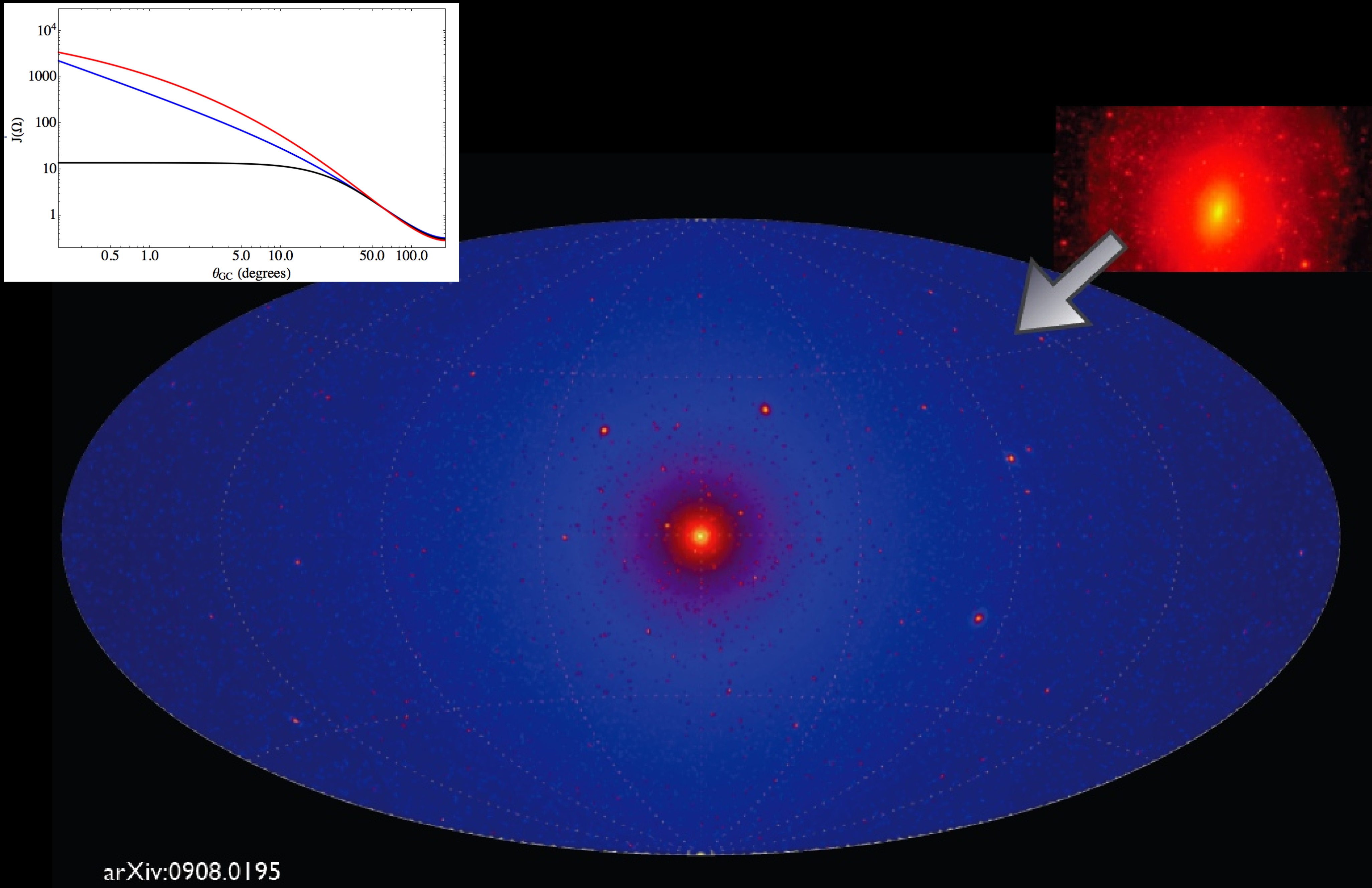
[No “ad hoc hypothesis” such as “leptophilic, photon-hating” DM is possible.....]

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

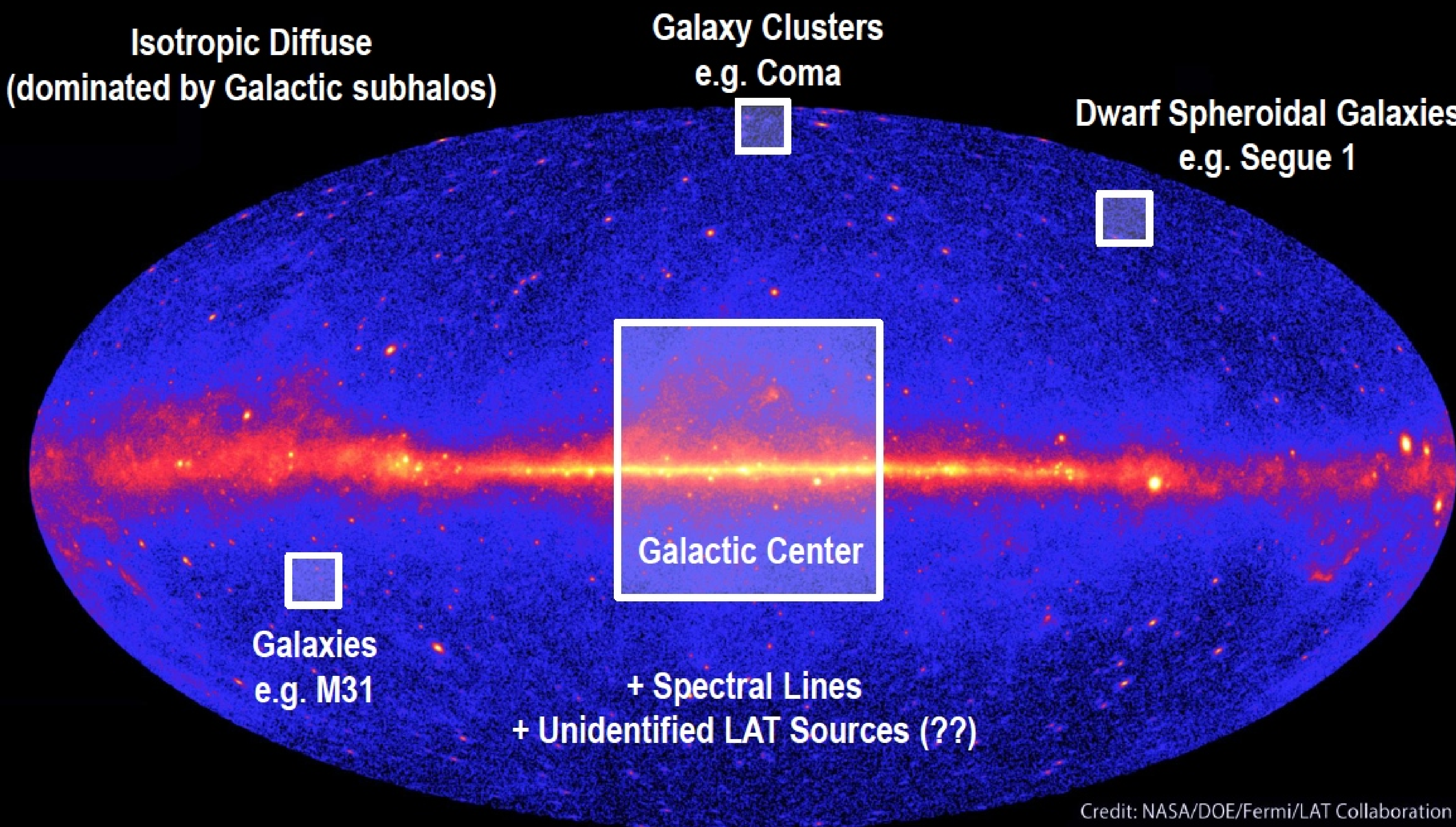
Photon emission by radiative corrections (at level of 1%) during annihilation

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

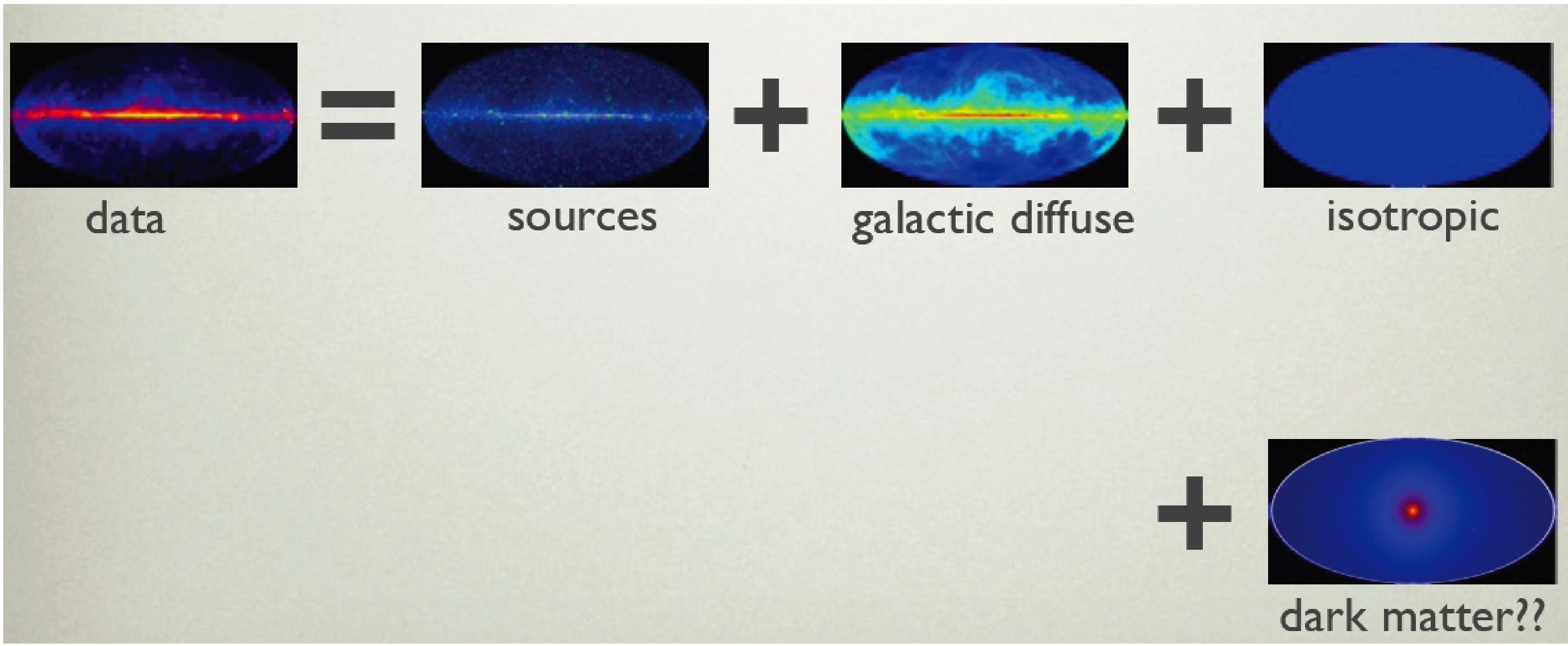




10^4
1000
100
10
1
J(Ω)
0.5
1.0
5.0
10.0
50.0
100.0
θ_{GC} (degrees)
arXiv:0908.0195



Trade-off between signal strength versus astrophysical background

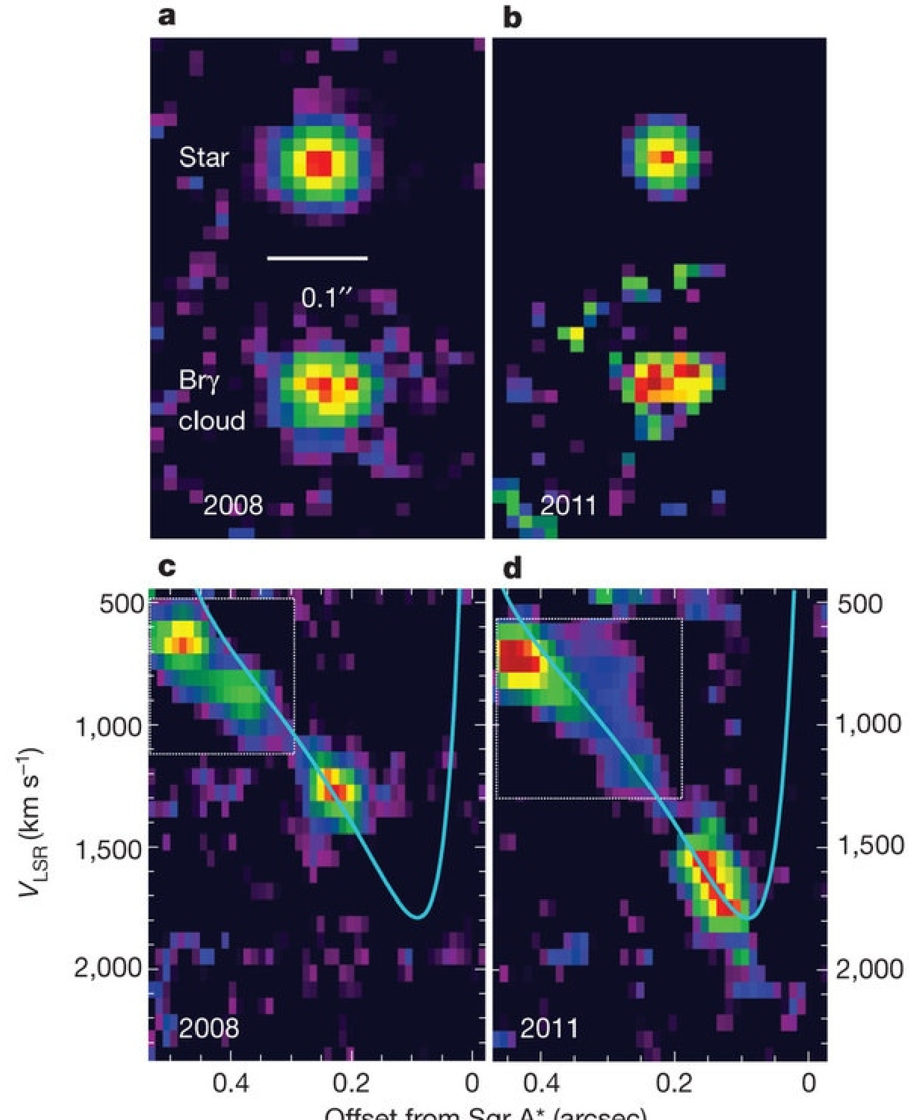

data
sources
galactic diffuse
isotropic
dark matter??

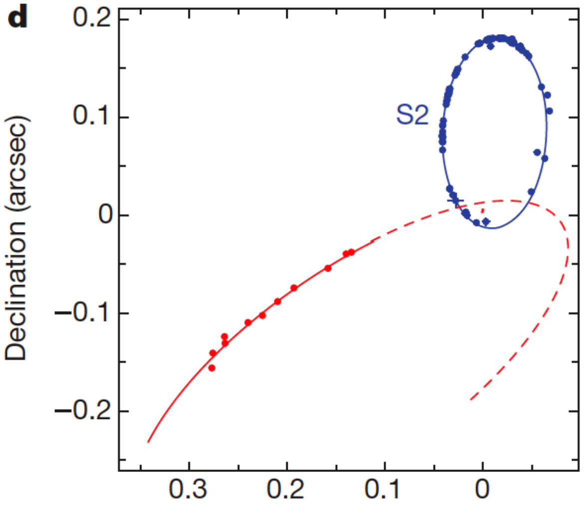
“Wild at Heart” the Galactic center!

doi:10.1038/nature10652

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

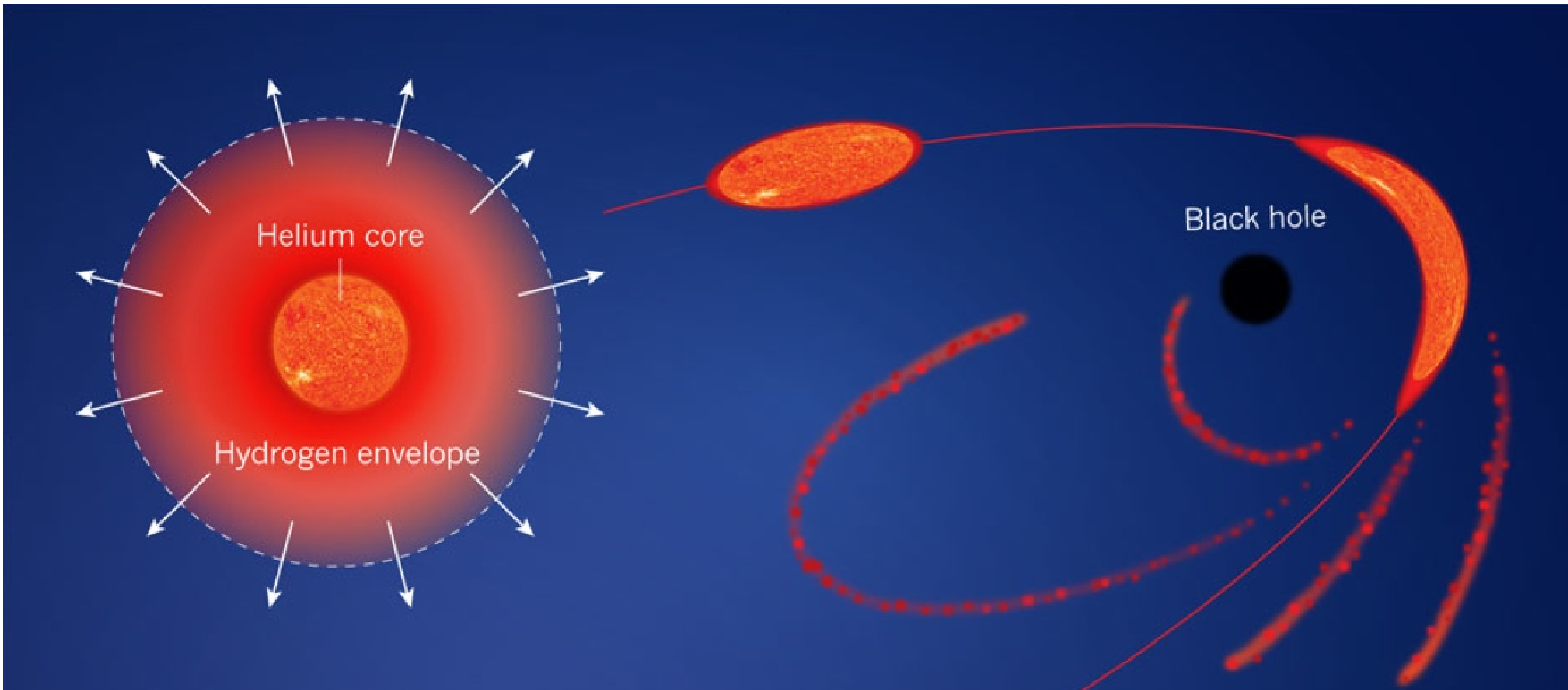
S. Gillessen[1], R. Genzel[1,2], T. K. Fritz[1], E. Quataert[3], C. Alig[4], A. Burkert[4,1], J. Cuadra[5], F. Eisenhauer[1], O. Pfuhl[1], K. Dodds-Eden[1], C. F. Gammie[6] & T. Ott[1]





Infalling gas
from the disruption of a star.

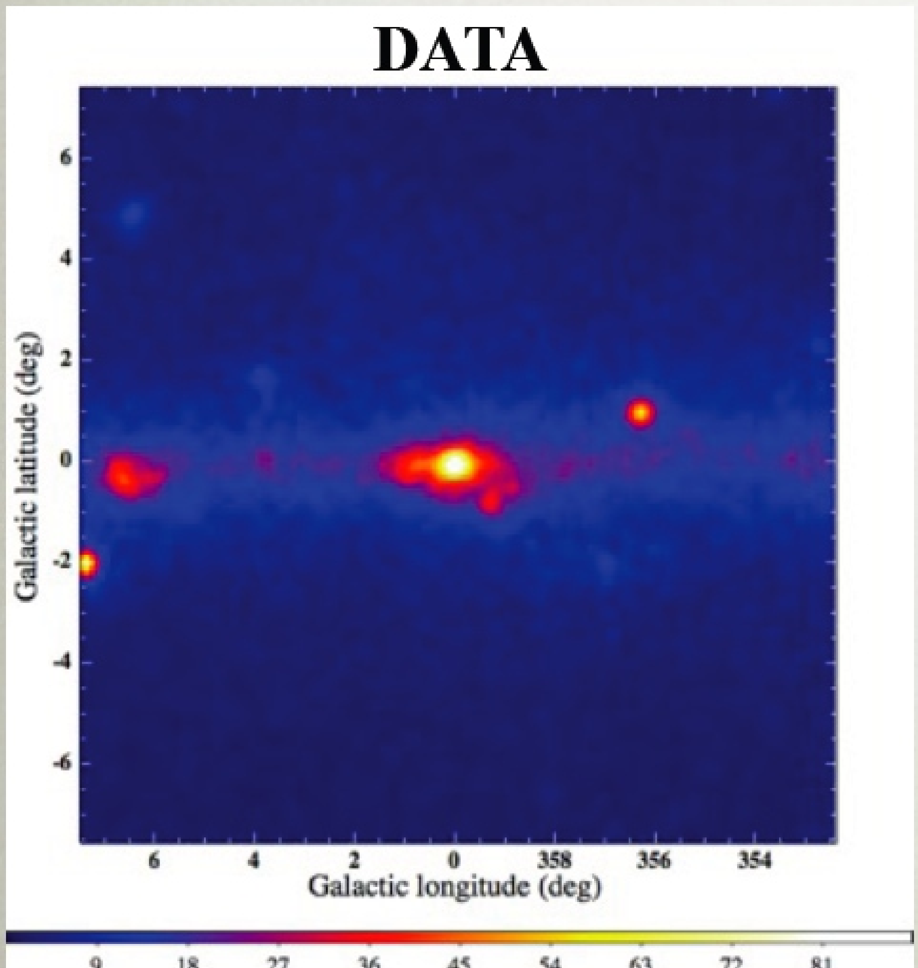
Gas will reach the BH horizon
In 2013

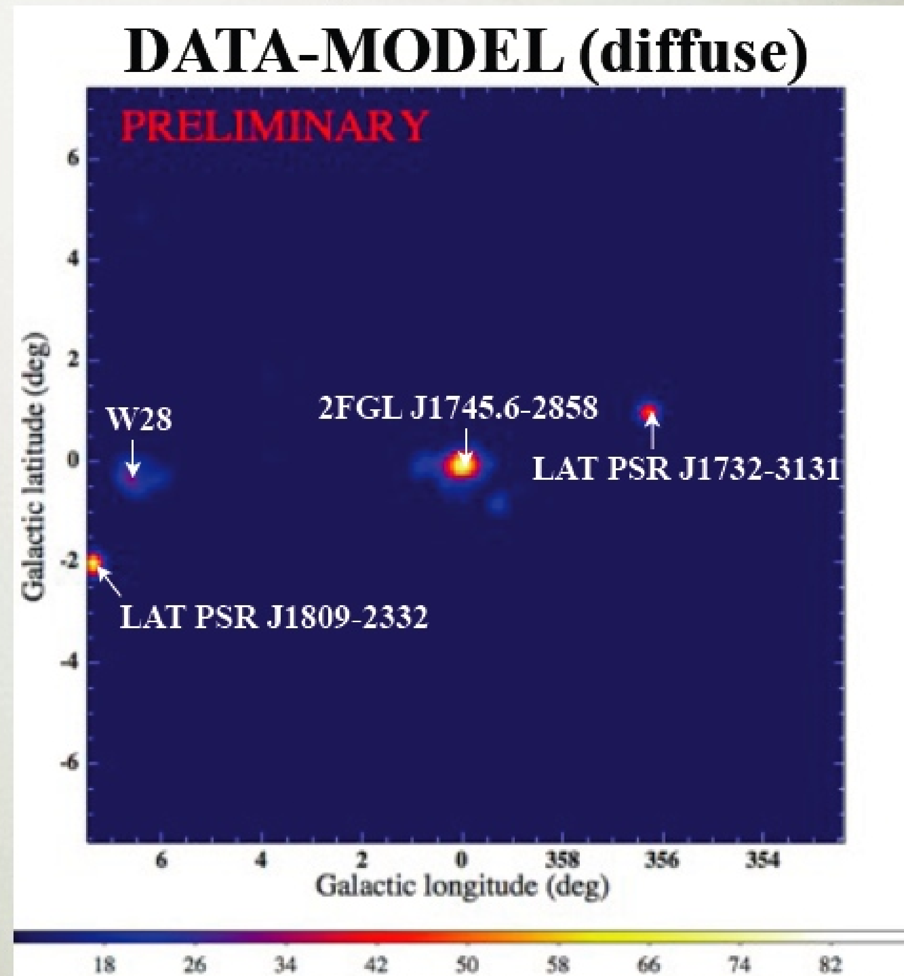


The helium-rich core of a red-giant star that had previously lost its hydrogen envelope moves on an almost parabolic orbit (red) towards a supermassive black hole. The sequence of blobs illustrates the progressive distortion of the star's core due to the tidal pull of the black hole. After the point 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].

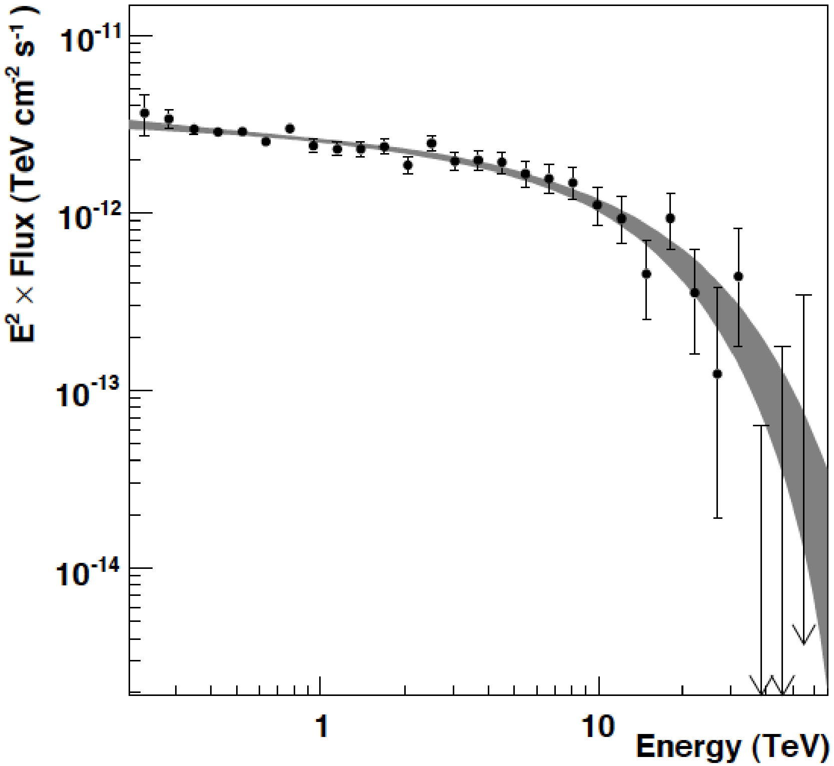
Fermi's View of the Inner Galaxy (15°x15° region)

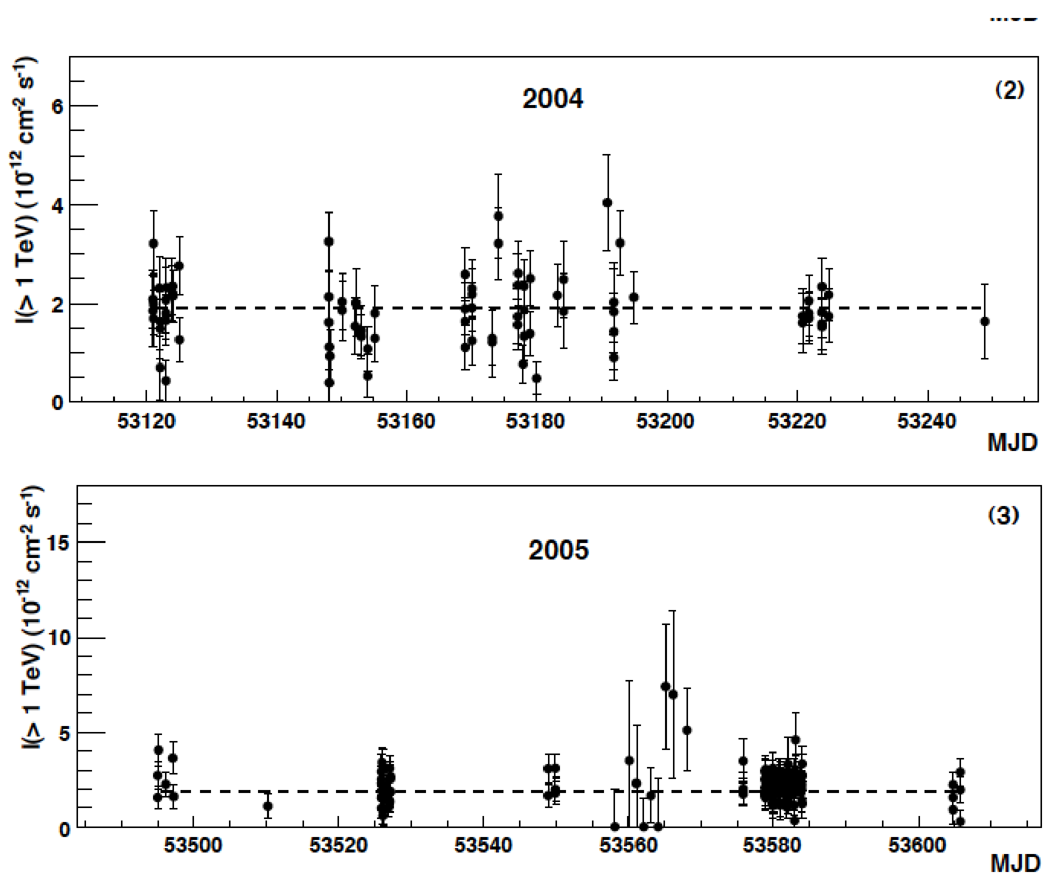
Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT):

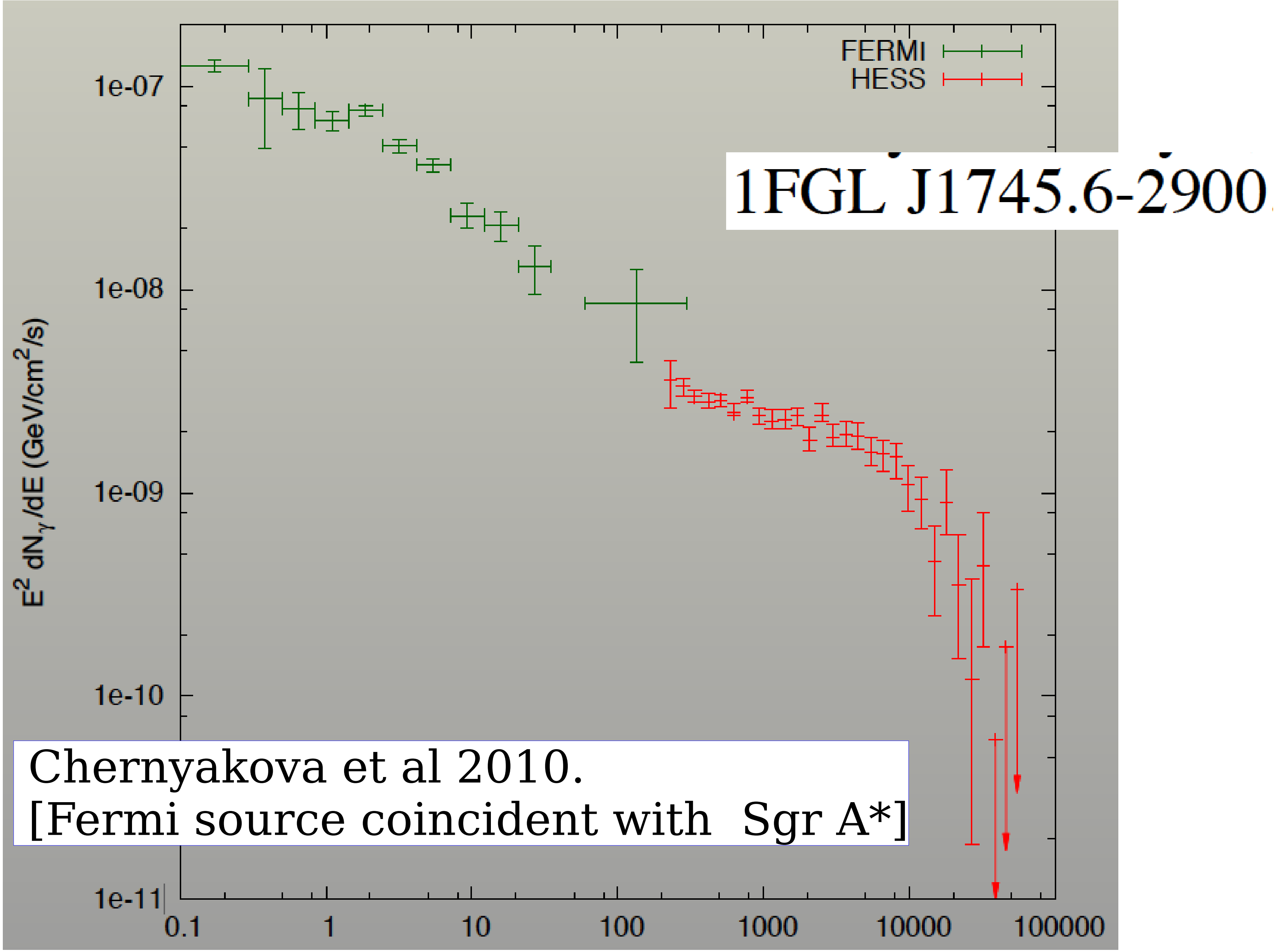




HESS observations of Galactic Center Sgr A*






1FGL J1745.6-2900
Chernyakova et al 2010.
[Fermi source coincident with Sgr A*]
FERMI
HESS
E2 dNγ/dE (GeV/cm2/s)
1e-07
1e-08
1e-09
1e-10
1e-11
0.1
1
10
100
1000
10000
100000

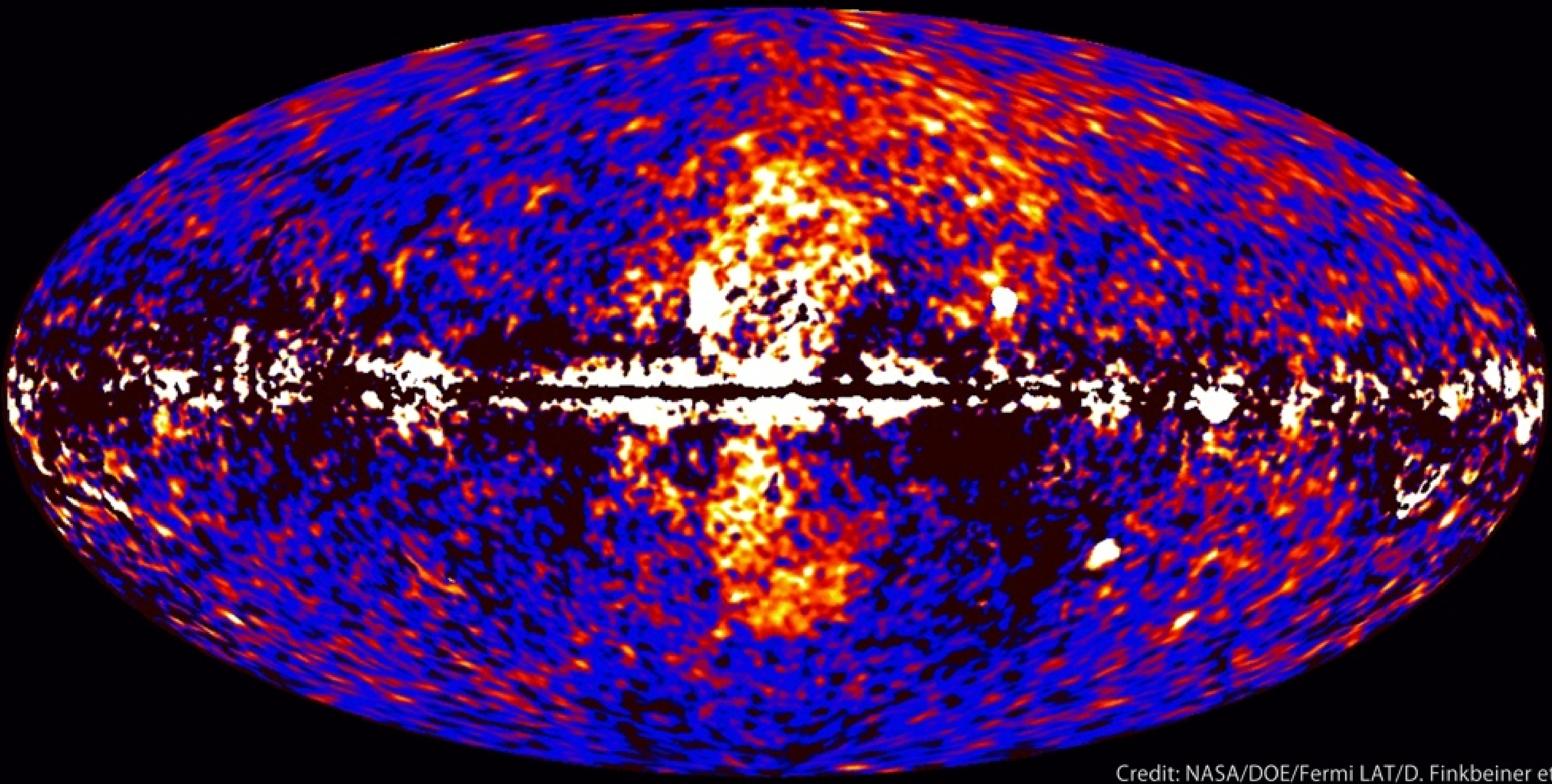
The

“FERMI BUBBLES”

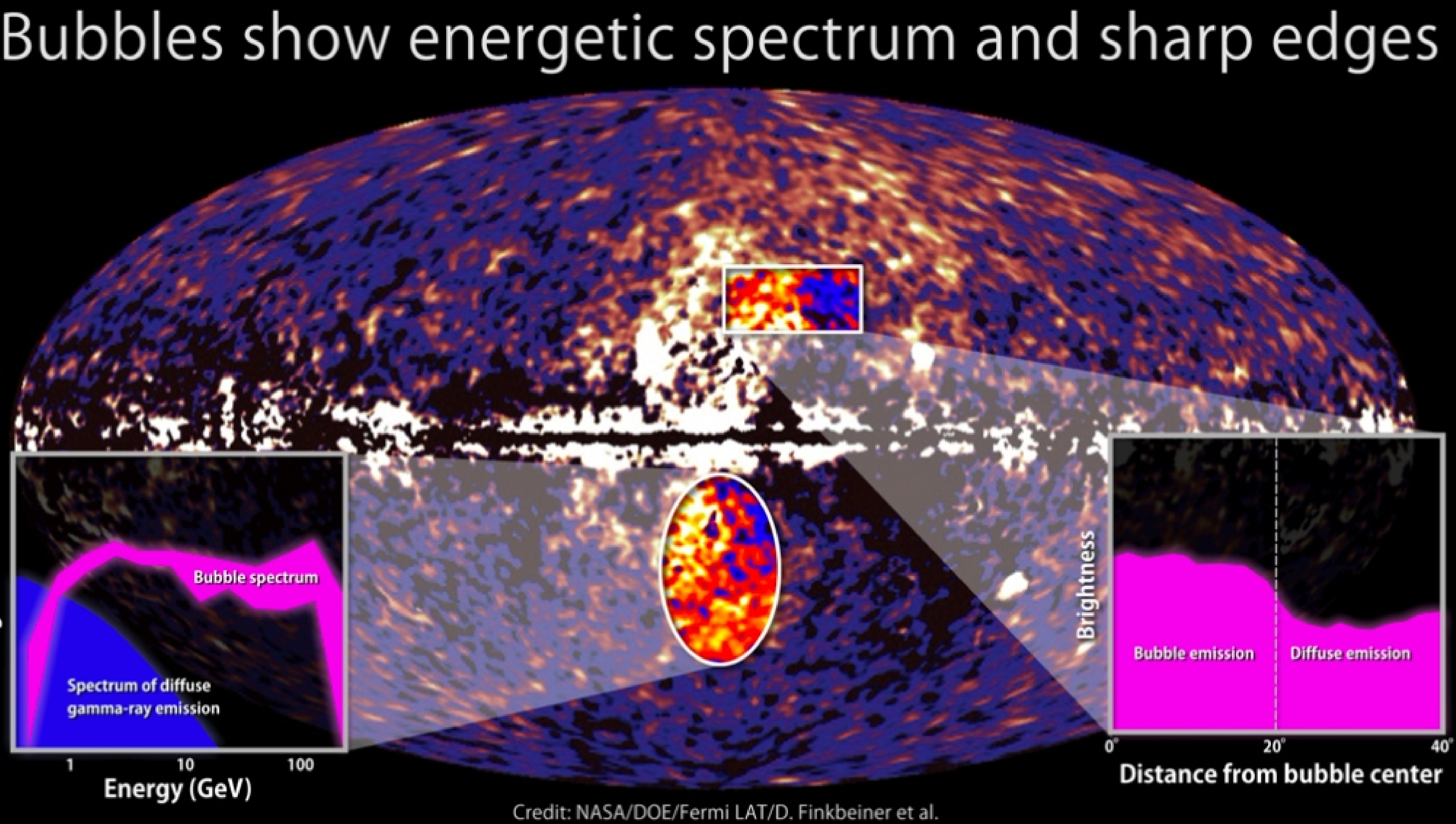
“hidden in plain sight (!)”

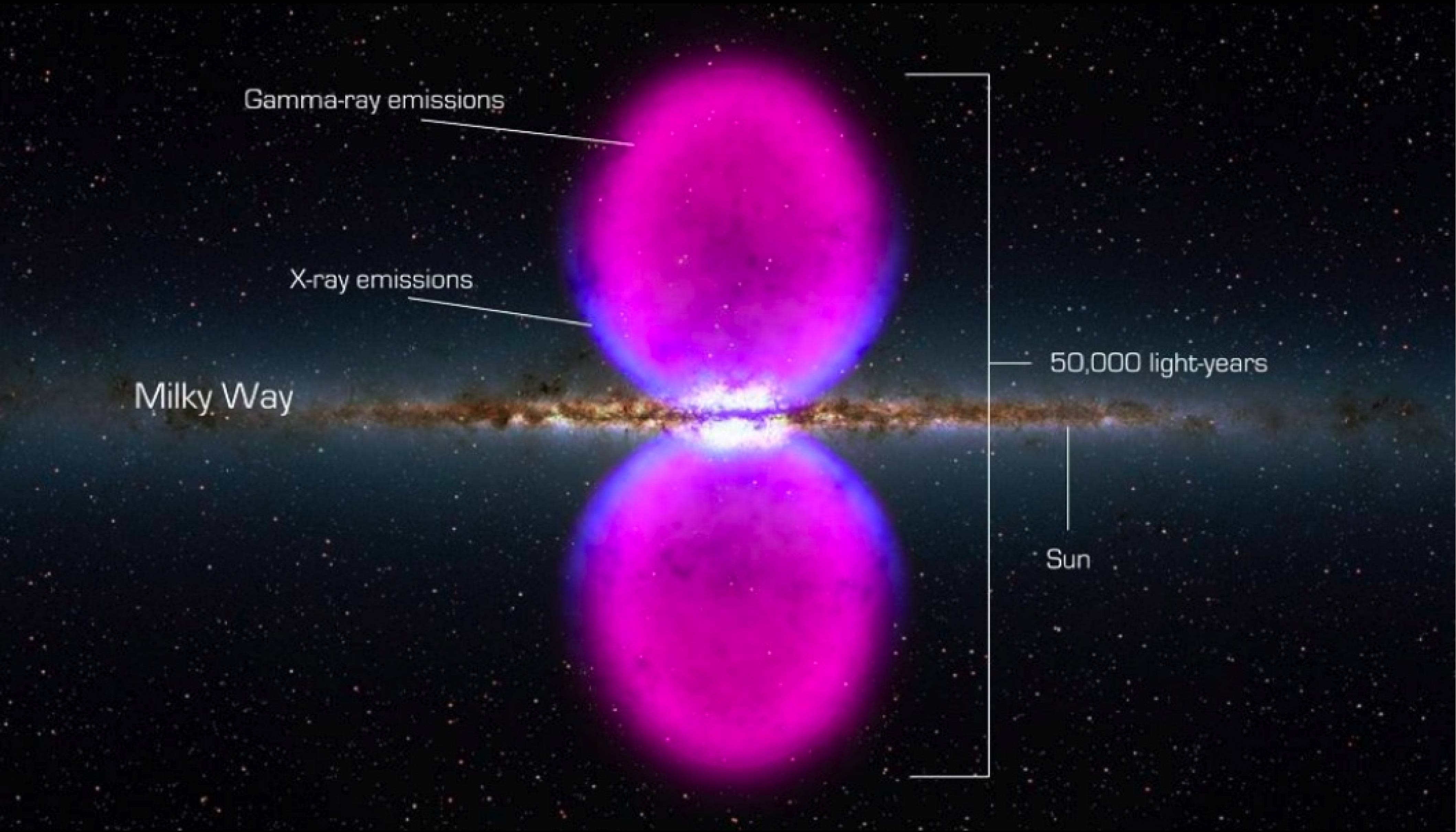
Scientific American news. Title:

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
Brightness
Bubble spectrum
Spectrum of diffuse
gamma-ray emission
1
10
100
Energy (GeV)
Brightness
Bubble emission
Diffuse emission
0°
20°
40°
Distance from bubble center
Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.



Artist's view of the “Fermi bubbles”

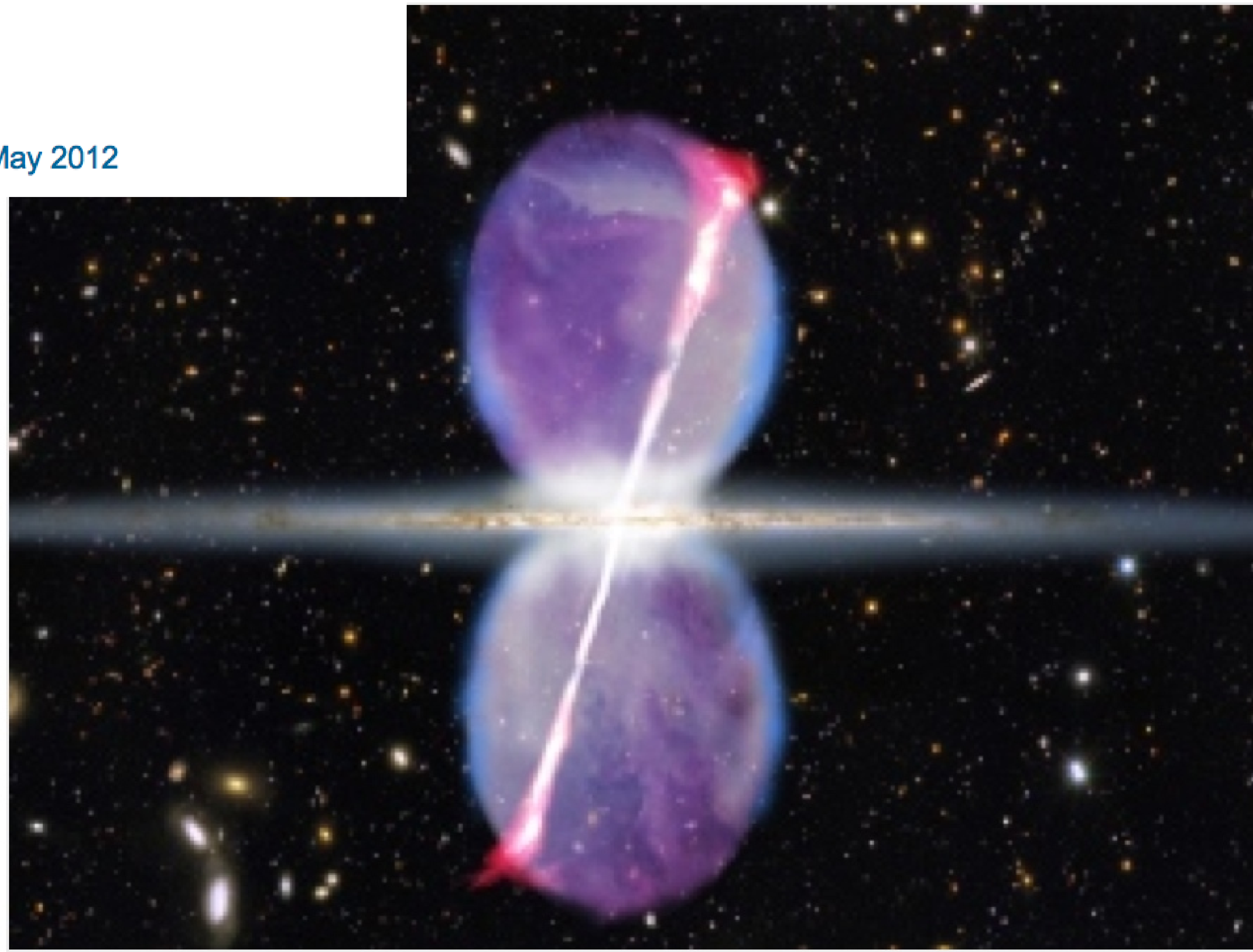
NATURE | NEWS

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

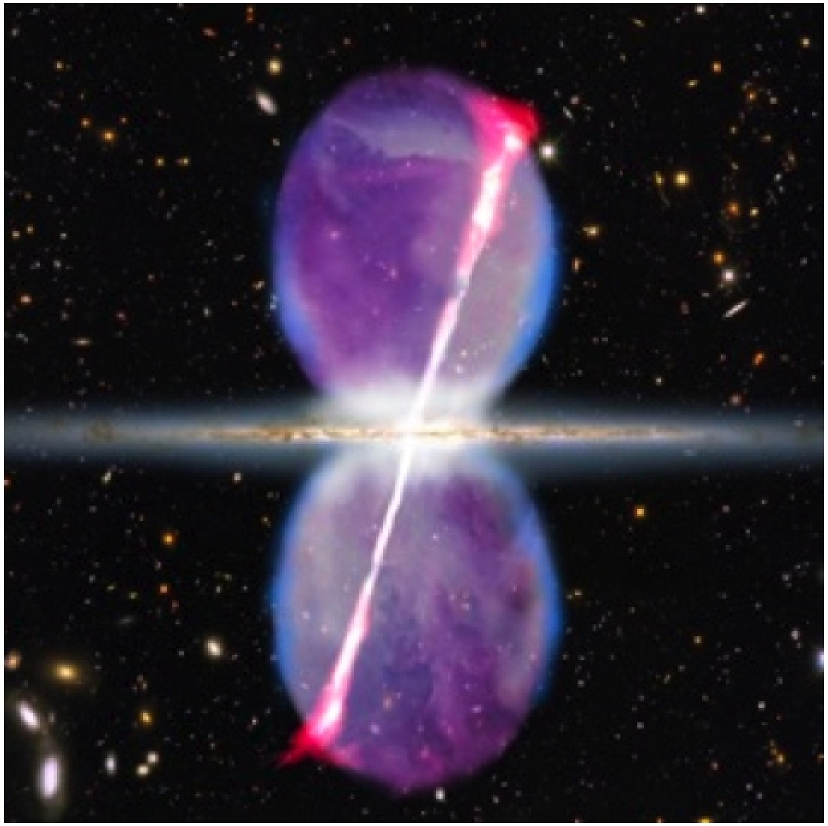


SCIENTIFIC AMERICAN™

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 in ours

By John Matson | June 1, 2012 | 10



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)

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

EVIDENCE FOR GAMMA-RAY JETS IN THE MILKY WAY

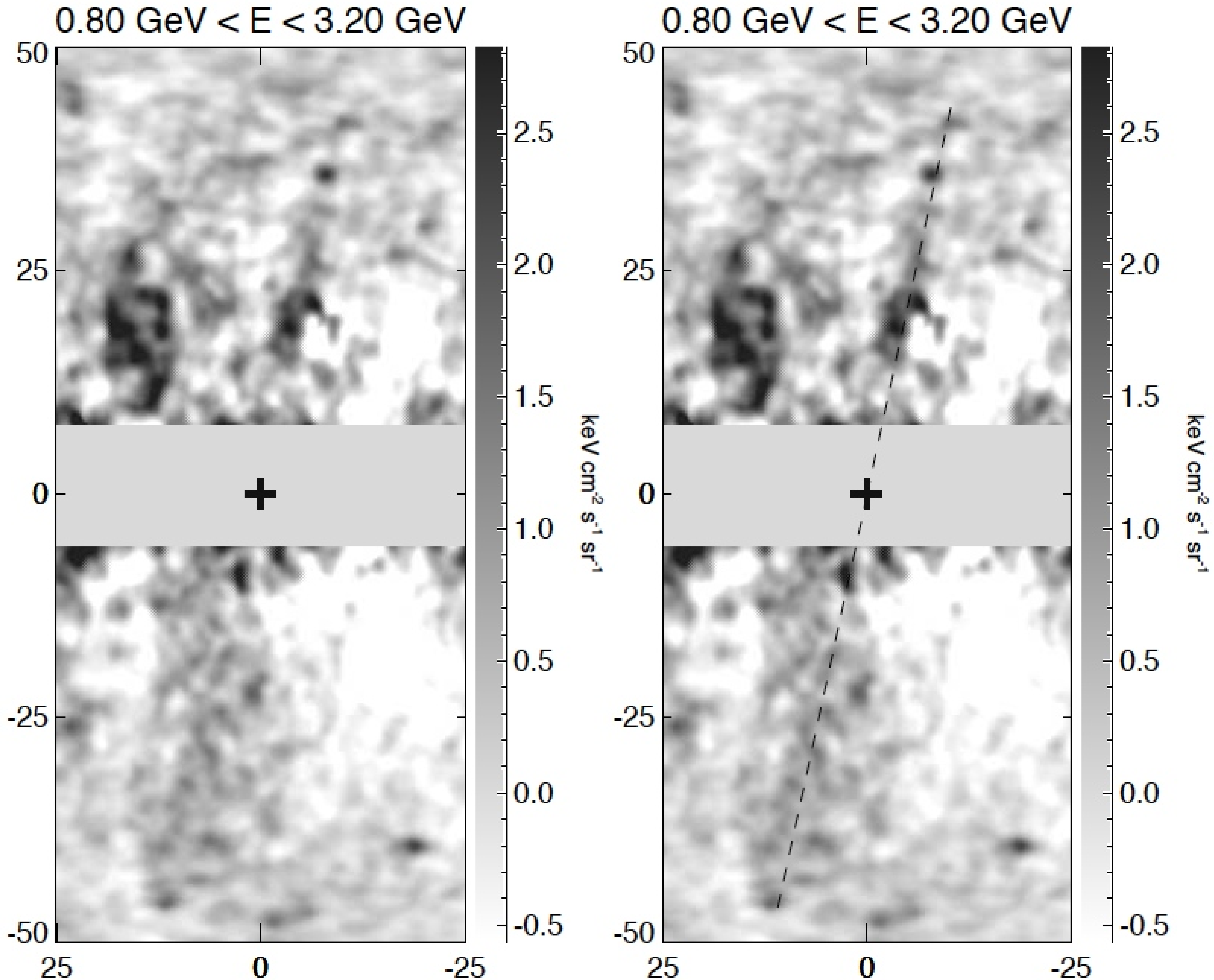
Meng Su[1,3], Douglas P. Finkbeiner[1,2]

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


0.80 GeV < E < 3.20 GeV
0.80 GeV < E < 3.20 GeV
50
25
0
-25
-50
25
0
-25
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
keV cm-2 s-1 sr-1

Many questions ?

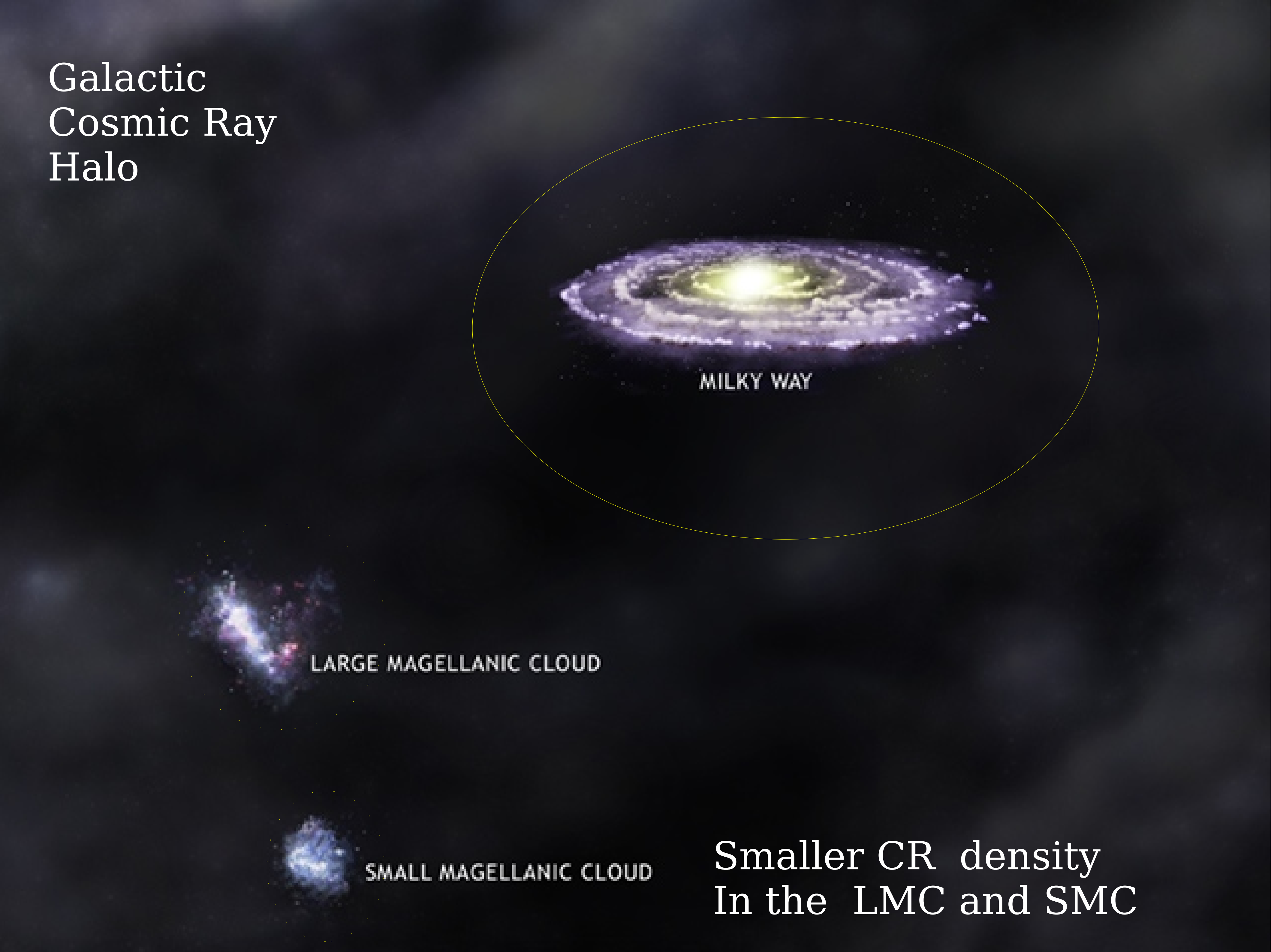
Are the jets real ?

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

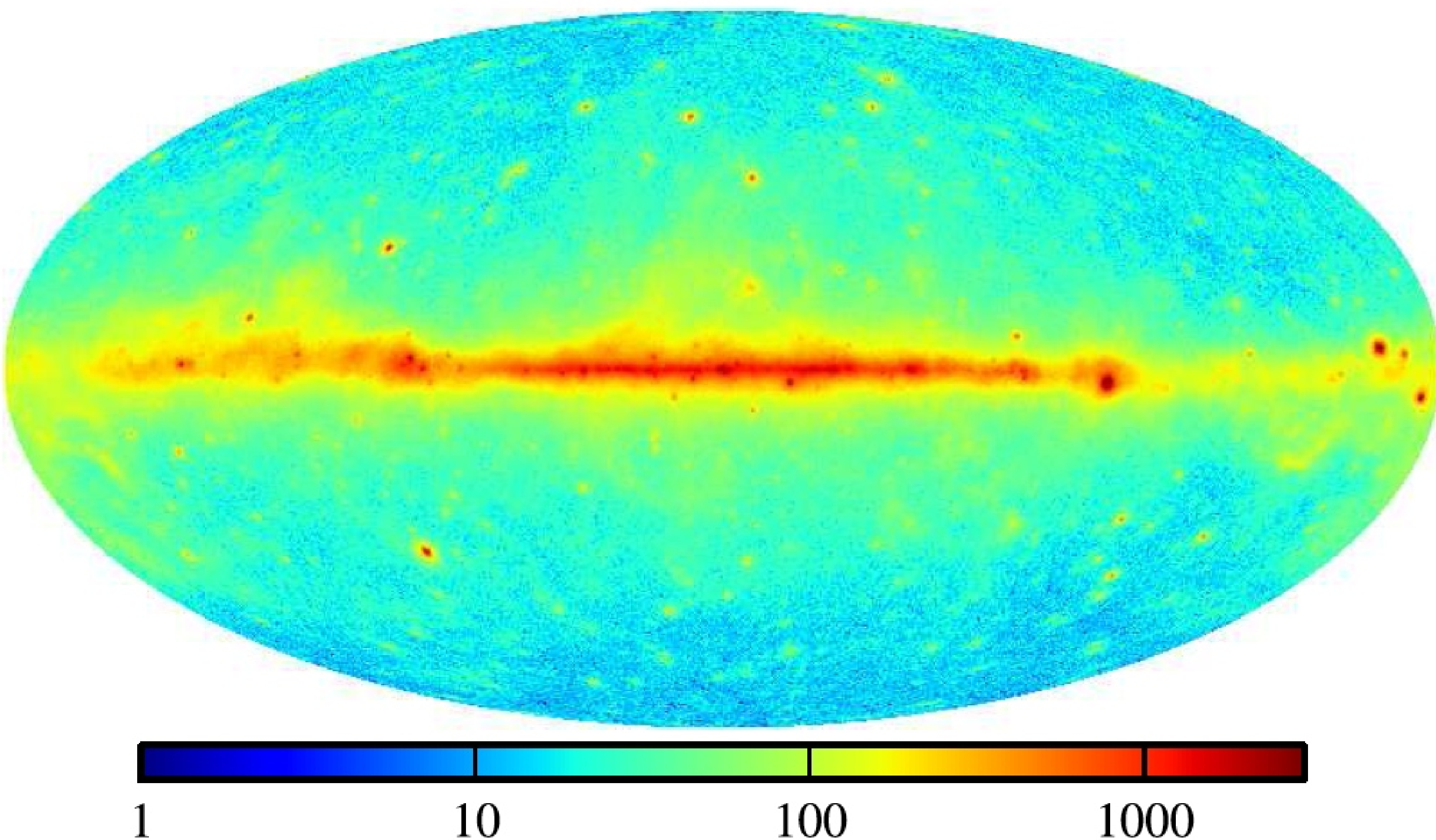
What is the nature of the bubbles + jets emission?

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 ?


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

Fermi–LAT counts energy range 200 MeV to 100 GeV

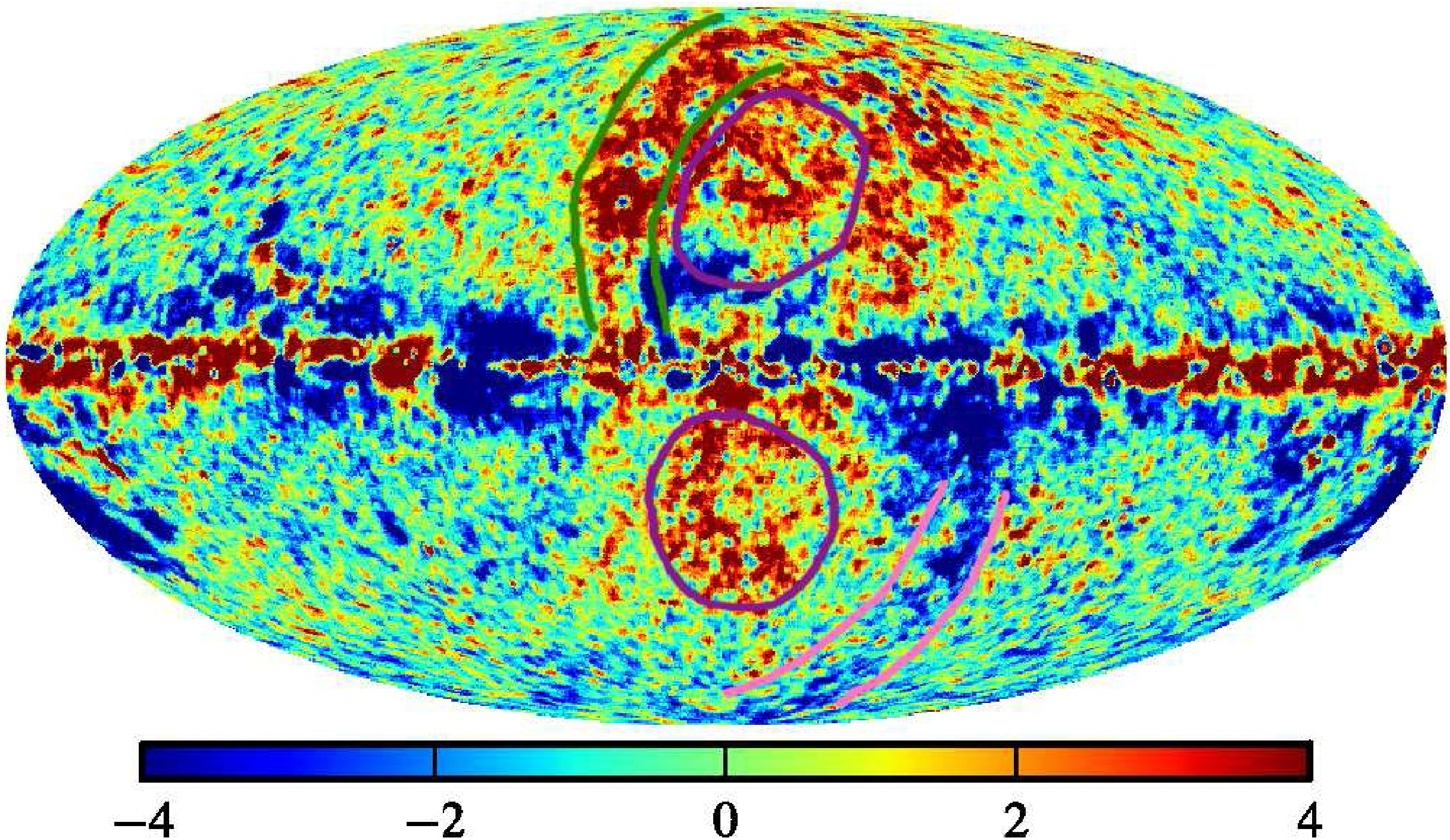


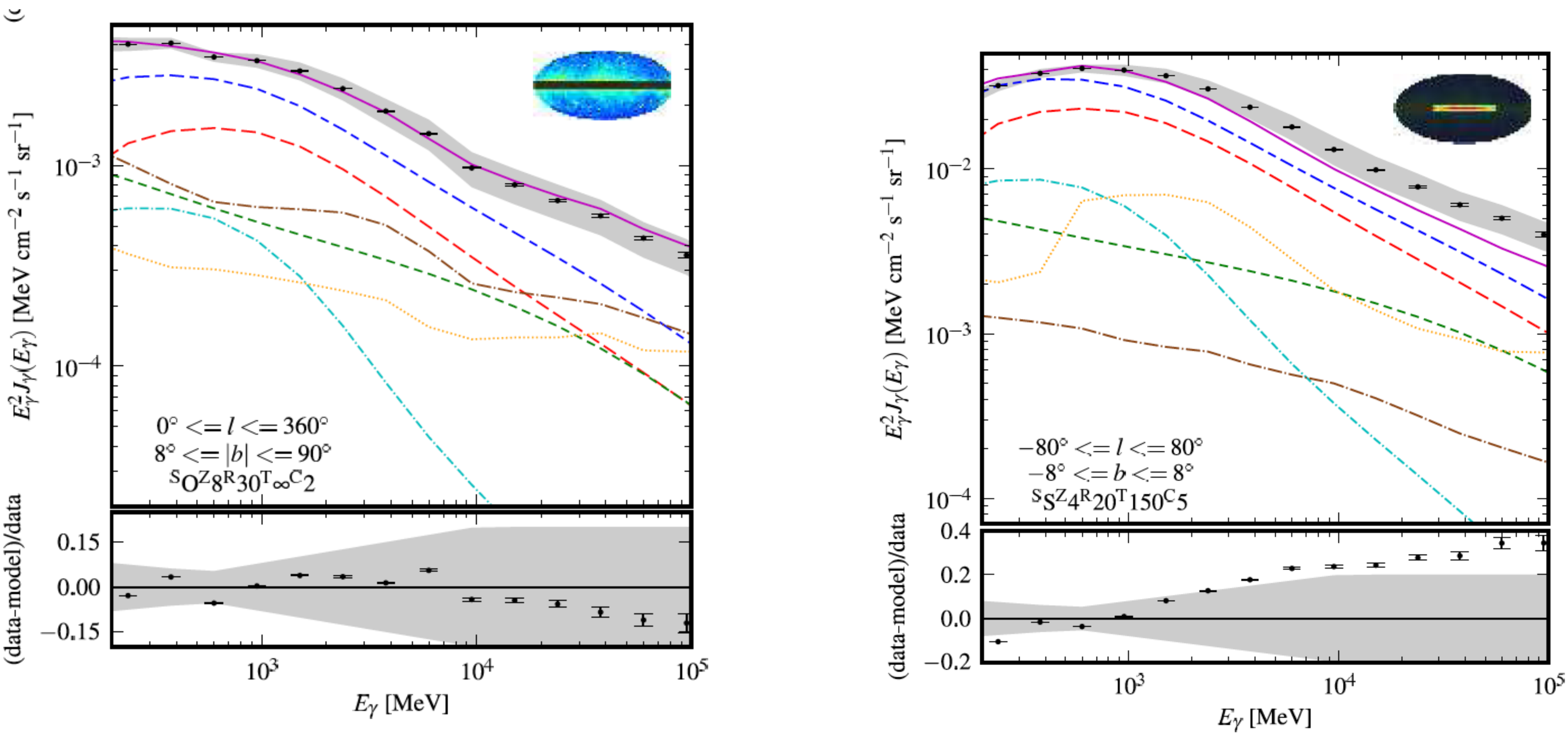
Residual maps in units of standard deviation

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

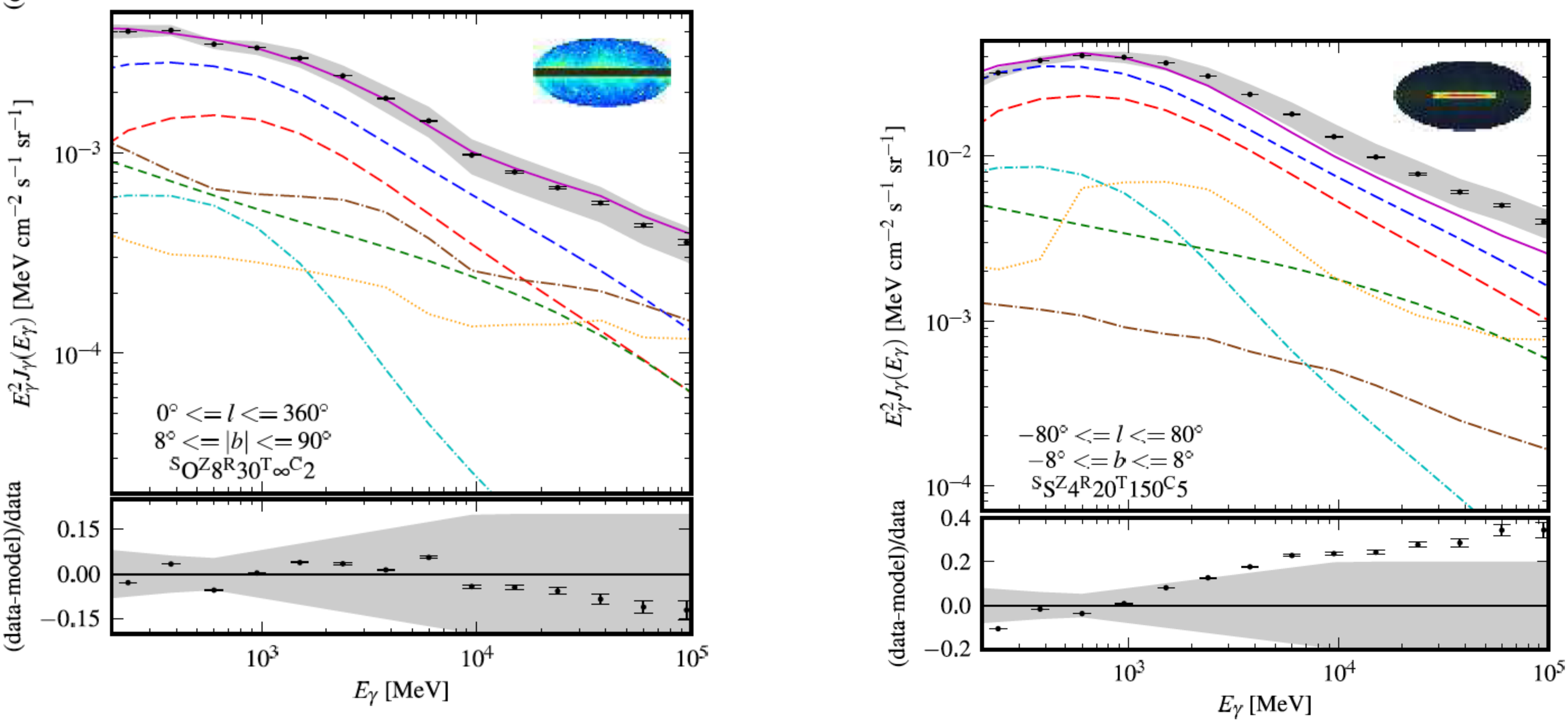
Loop I (green)

Magellanic stream (pink)





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 $(data - model)/data$.



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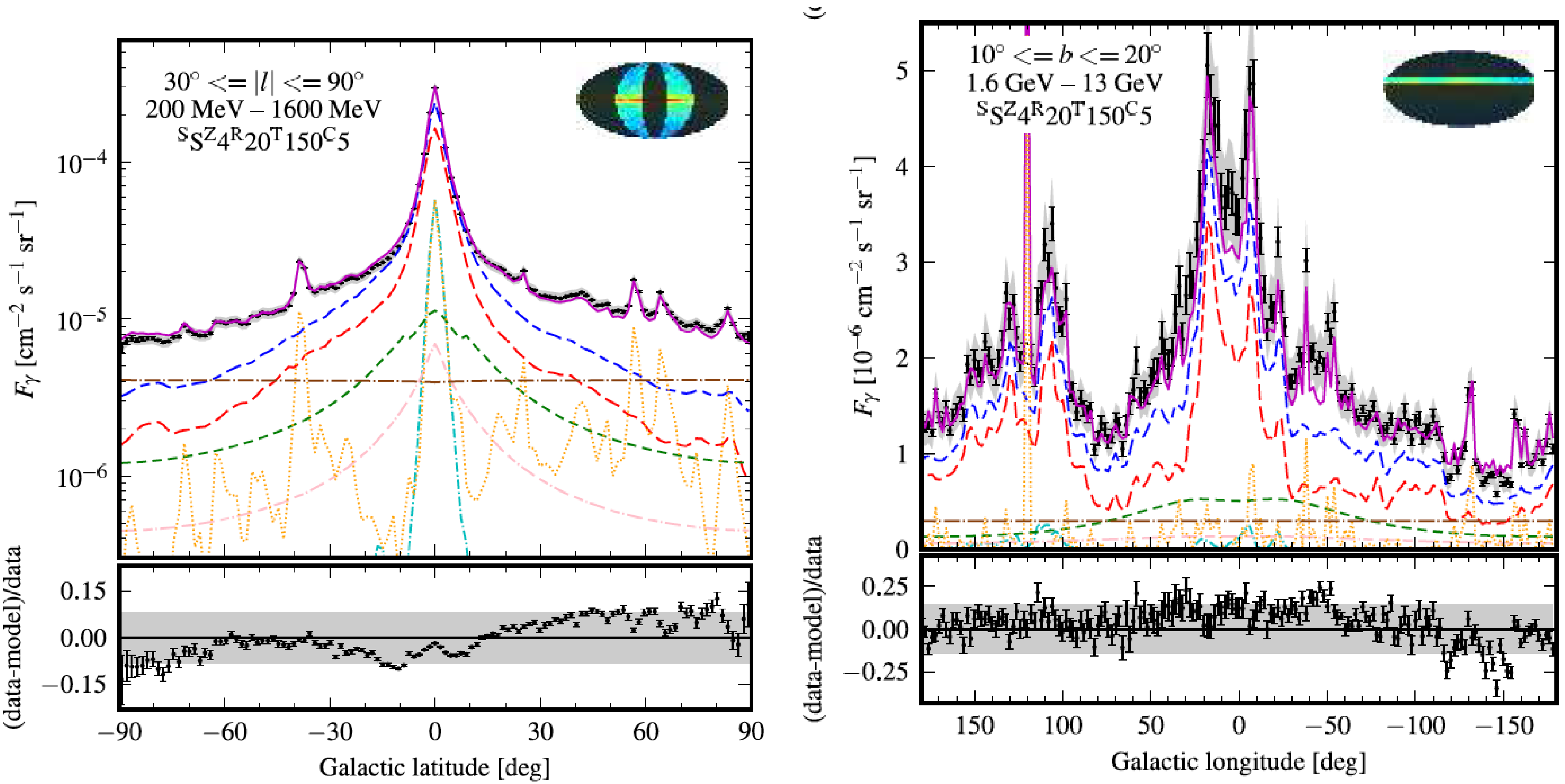
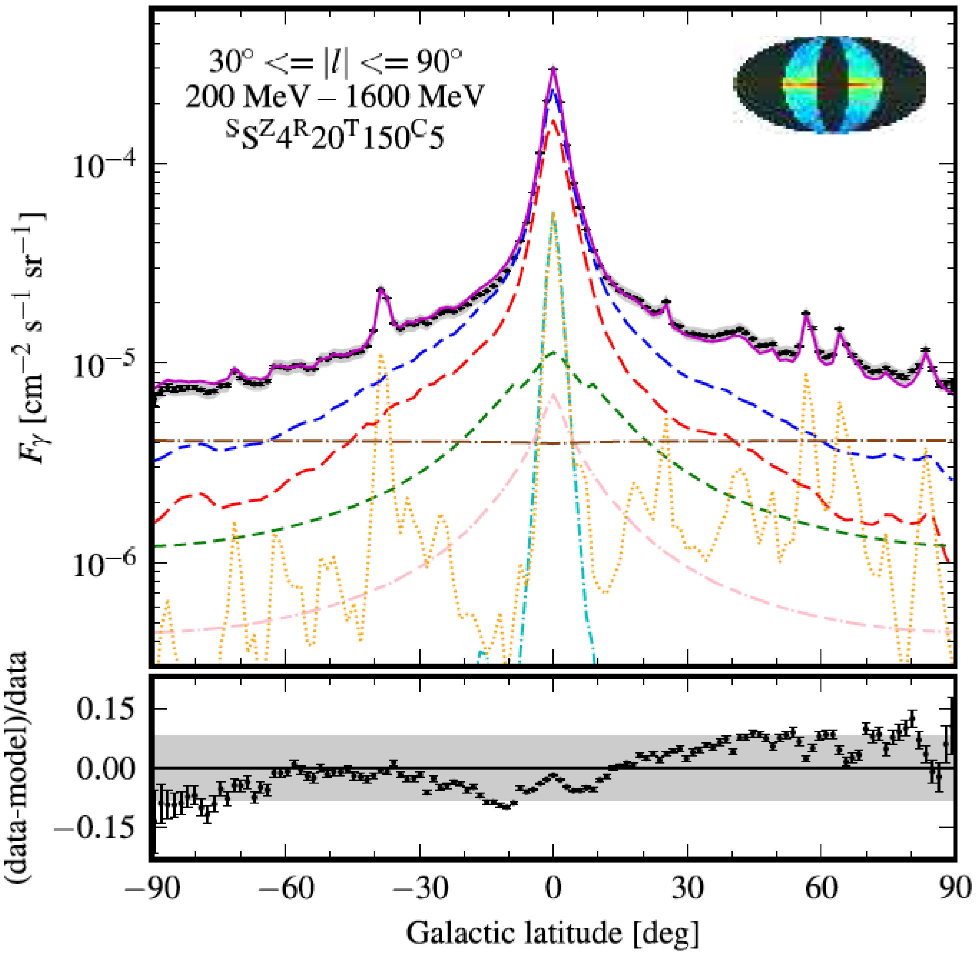
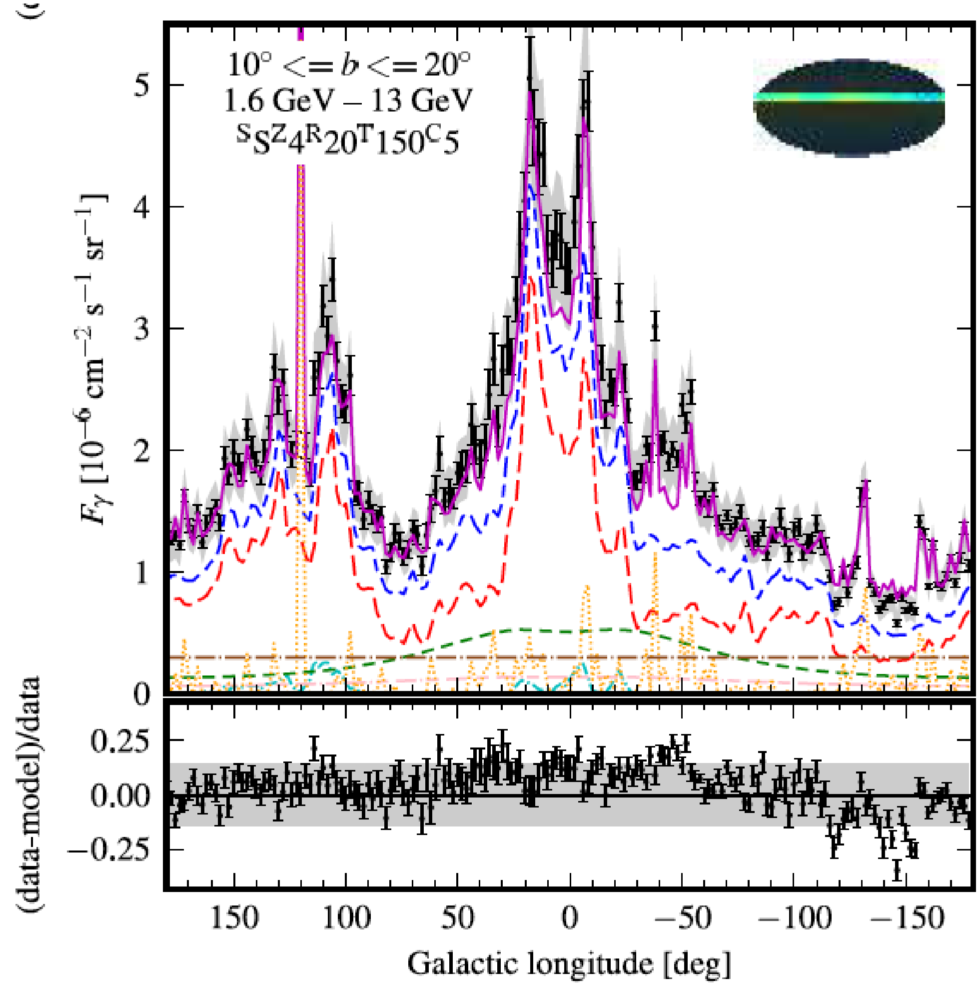


30° <= |l| <= 90°
200 MeV – 1600 MeV
$^{S}S^{Z}4^{R}20^{T}150^{C}5$
F_γ [cm^{-2} s^{-1} sr^{-1}]
(data-model)/data
Galactic latitude [deg]
10° <= b <= 20°
1.6 GeV – 13 GeV
$^{S}S^{Z}4^{R}20^{T}150^{C}5$
F_γ [10^{-6} cm^{-2} s^{-1} sr^{-1}]
(data-model)/data
Galactic longitude [deg]





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

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

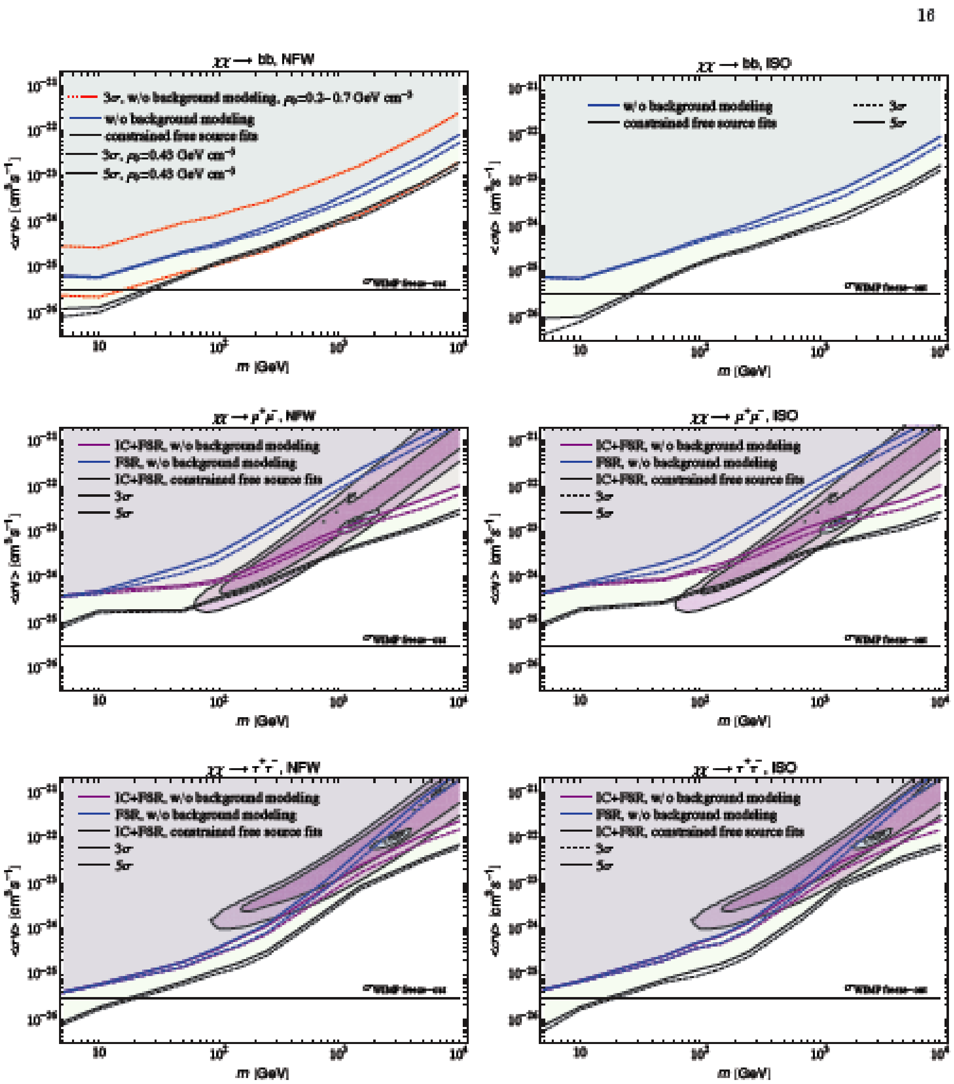
***Fermi* LAT Search for Dark Matter in Gamma-ray Lines and the Inclusive Photon Spectrum**

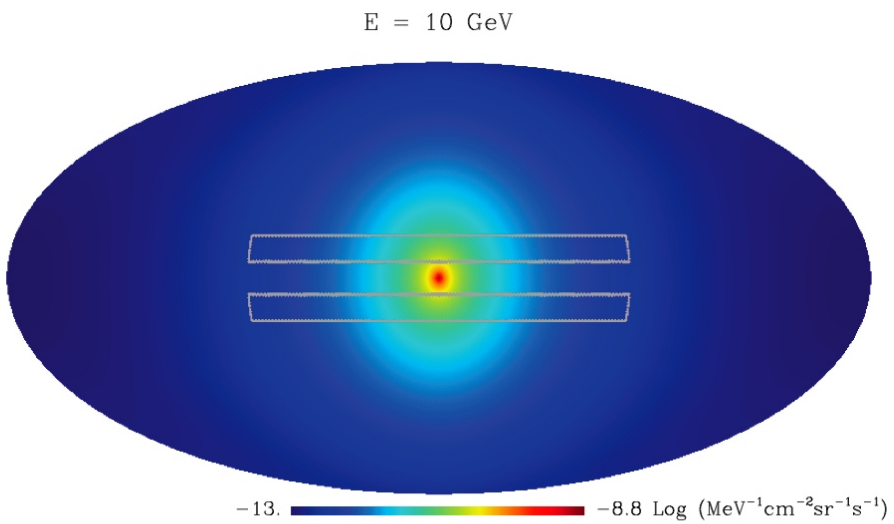
arXiv:1201.2691v1 [astro-ph.HE] 12 Jan 2012

SEARCH FOR DARK MATTER SATELLITES USING THE FERMI-LAT

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

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





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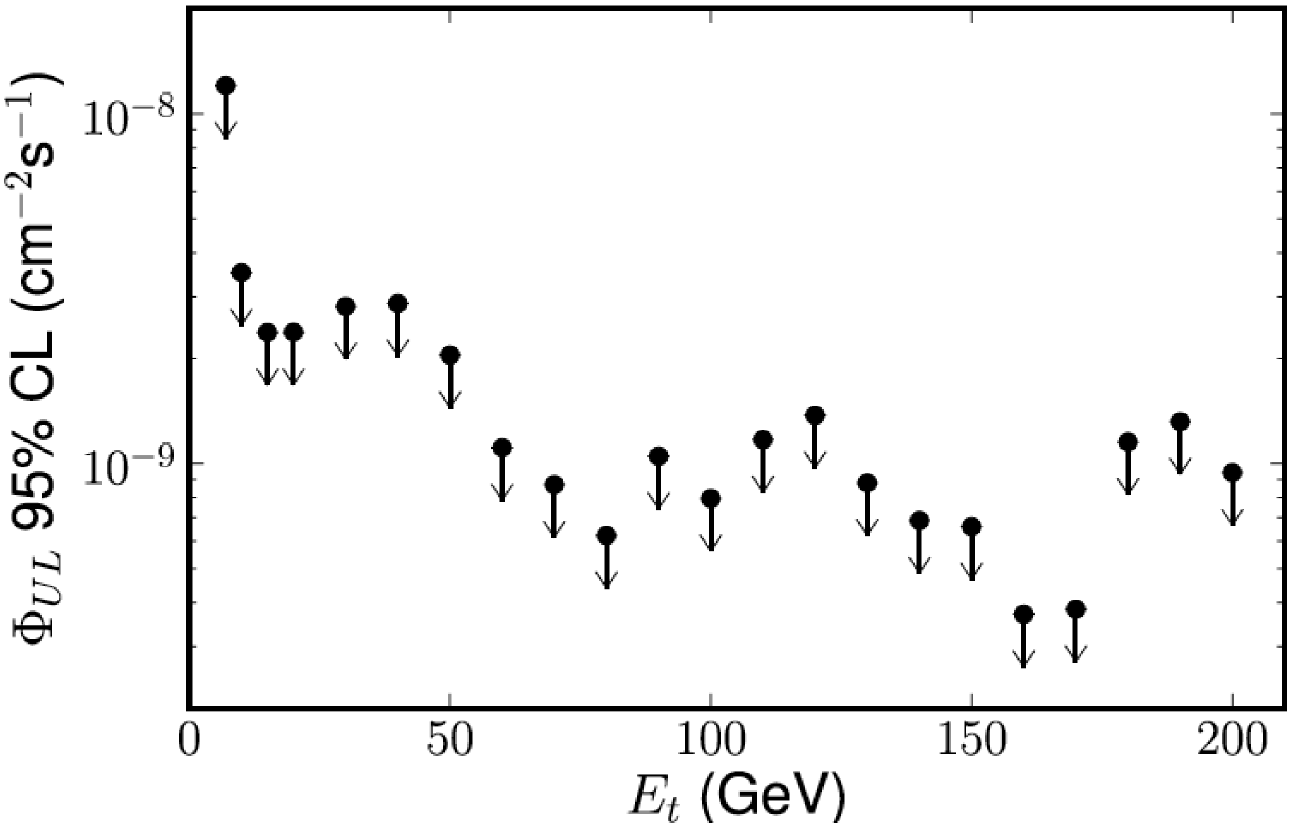
***Fermi* LAT Search for Dark Matter in Gamma-ray Lines and the Inclusive Photon Spectrum**



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.

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 ?

Warning !

Controversial results ahead .....

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

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

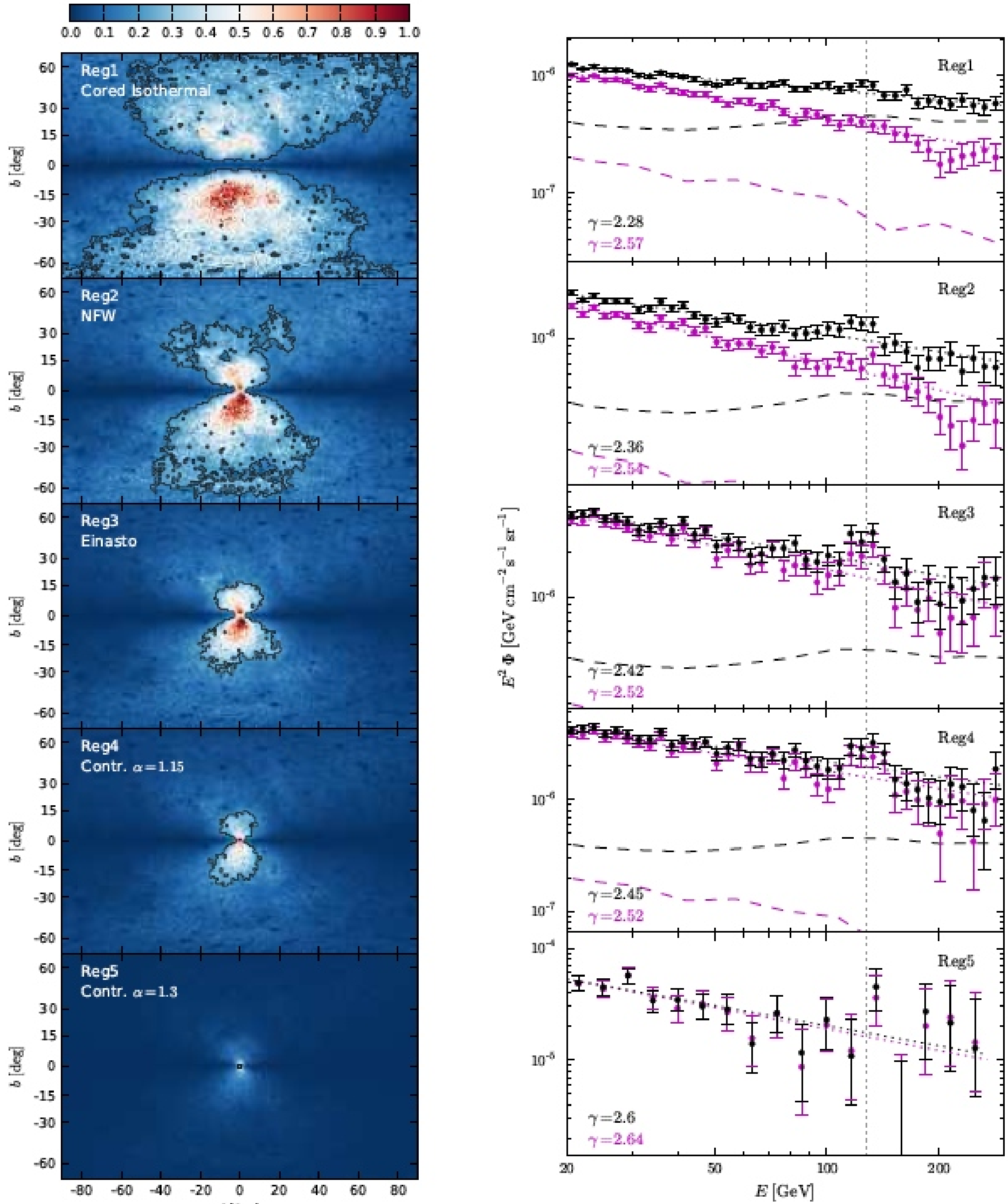
A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

Christoph Weniger

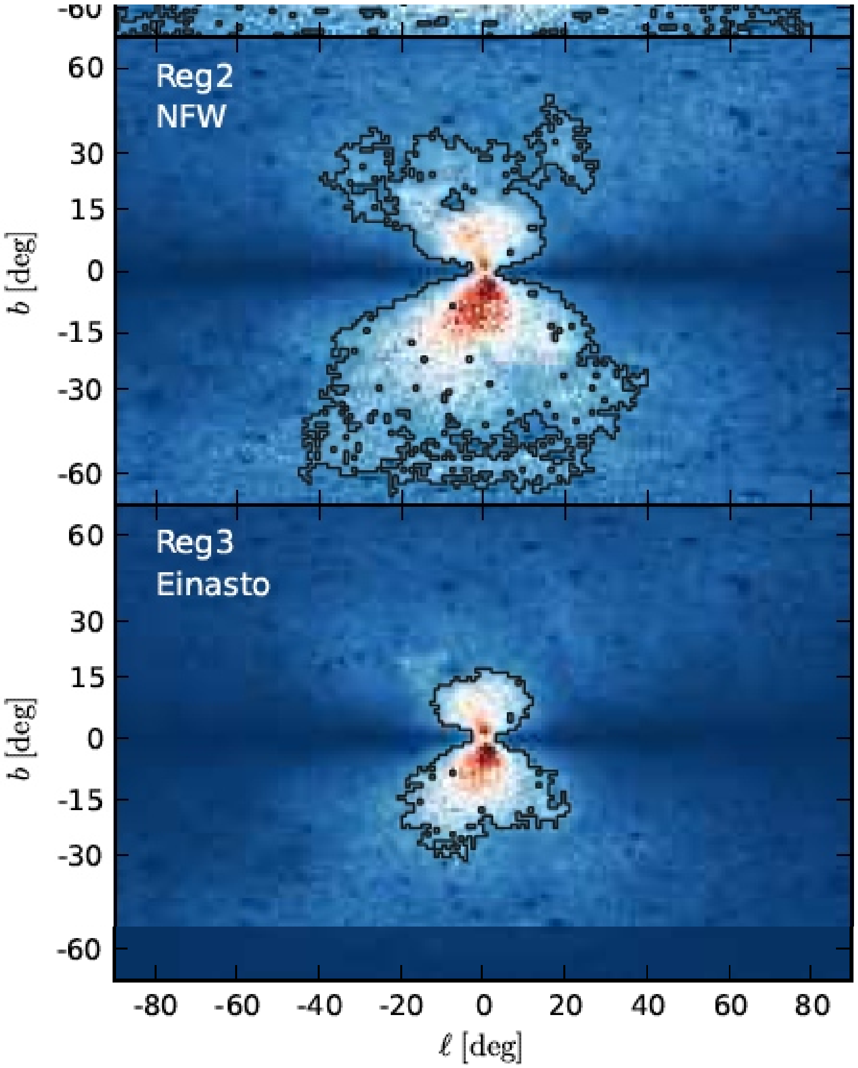
Max-Planck-Institut für Physik, Föhringer Ring 6, 80805 München, Germany

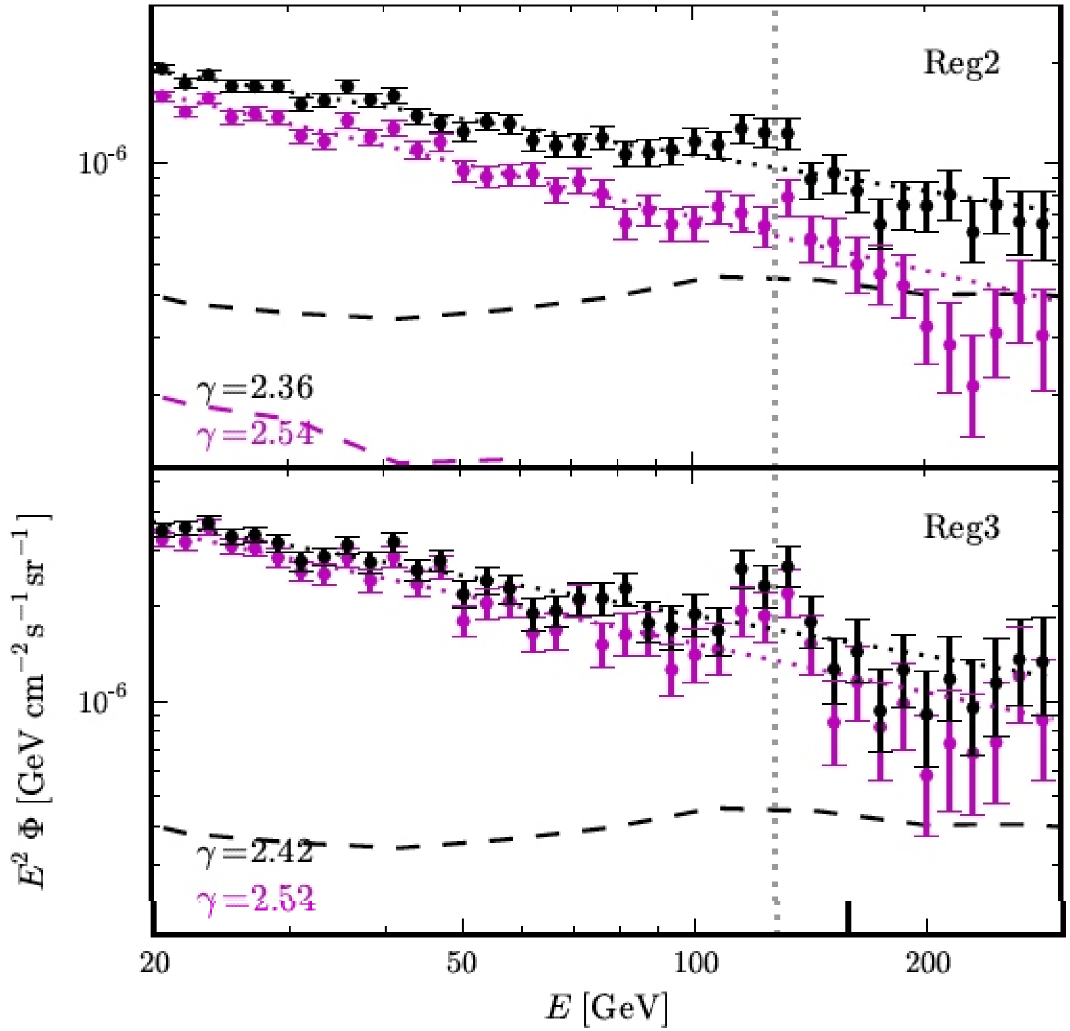
Determine angular region to optimize signal/noise

Region depends on assumptions about DM distribution

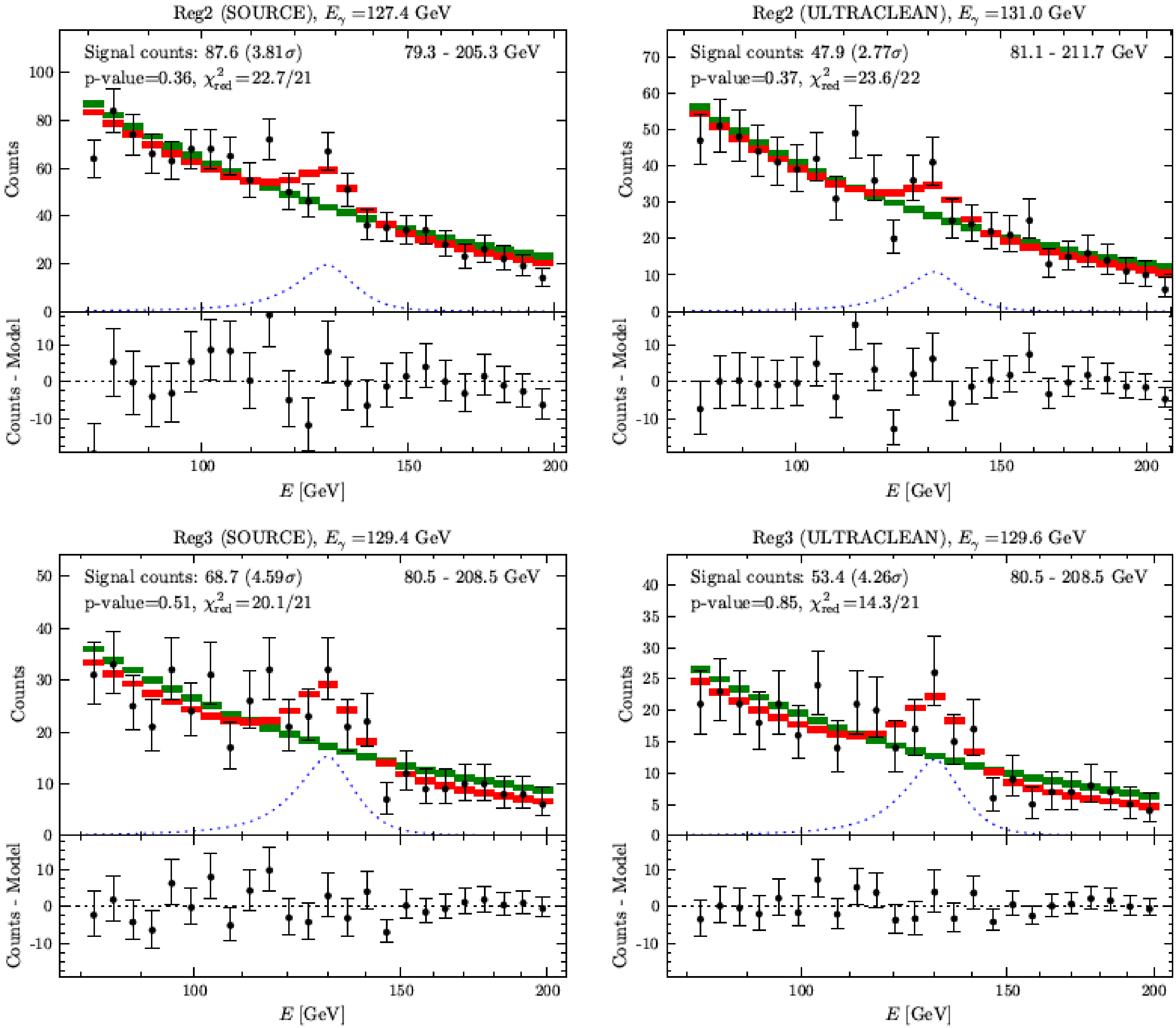


Best motivated models
NFW, Einasto

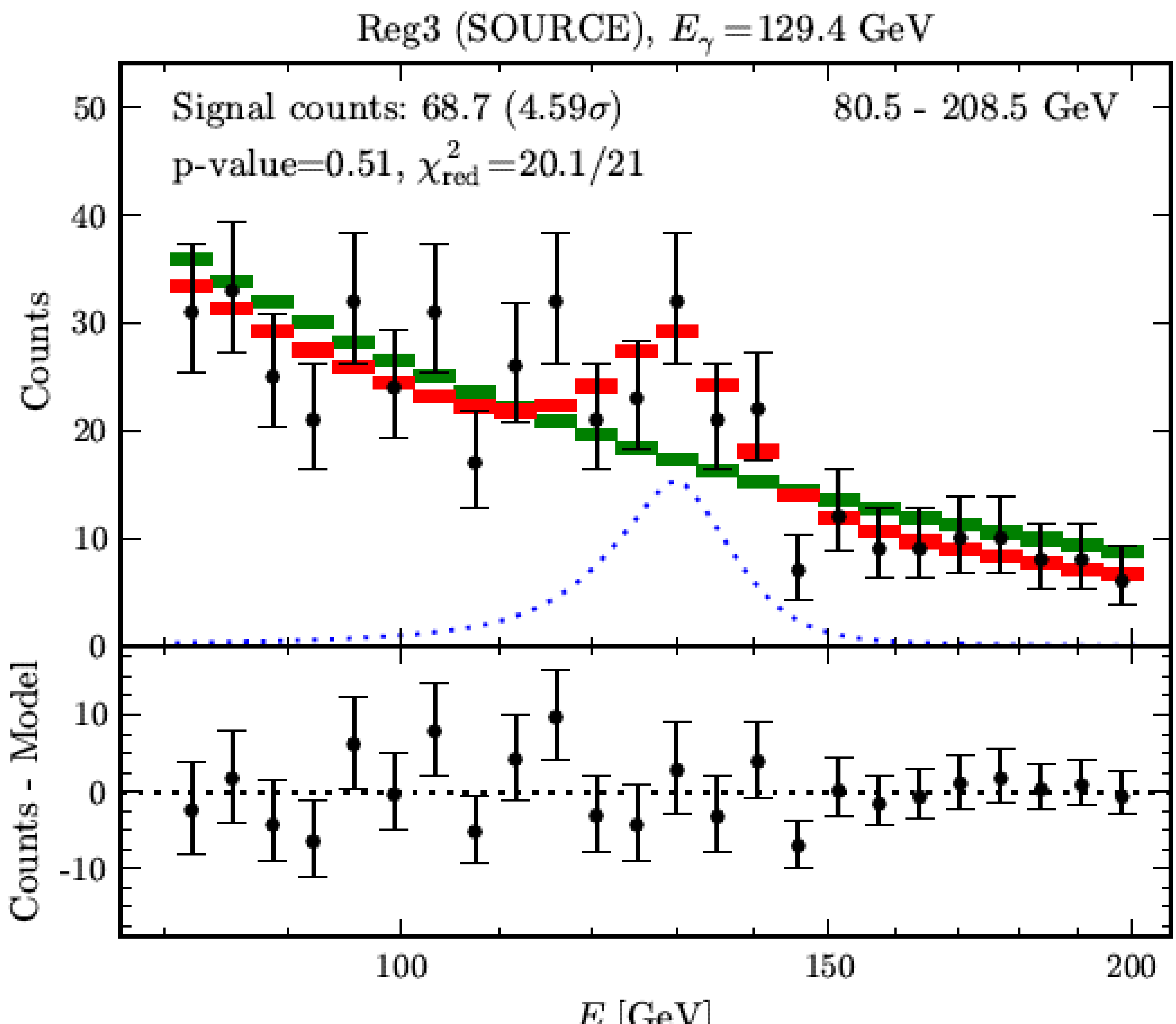




Line at 130 GeV ???



Reg2 (SOURCE), E_γ =127.4 GeV
Signal counts: 87.6 (3.81σ)
79.3 - 205.3 GeV
p-value=0.36, χ^2_{red} =22.7/21
Reg2 (ULTRACLEAN), E_γ =131.0 GeV
Signal counts: 47.9 (2.77σ)
81.1 - 211.7 GeV
p-value=0.37, χ^2_{red} =23.6/22
Reg3 (SOURCE), E_γ =129.4 GeV
Signal counts: 68.7 (4.59σ)
80.5 - 208.5 GeV
p-value=0.51, χ^2_{red} =20.1/21
Reg3 (ULTRACLEAN), E_γ =129.6 GeV
Signal counts: 53.4 (4.26σ)
80.5 - 208.5 GeV
p-value=0.85, χ^2_{red} =14.3/21
Counts
Counts - Model
E [GeV]



Reg3 (SOURCE), $E_\gamma = 129.4$ GeV
Signal counts: 68.7 (4.59σ)
80.5 - 208.5 GeV
p-value=0.51, $\chi^2_{\rm red} = 20.1/21$
Counts
Counts - Model
E [GeV]

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

Is this credible ?

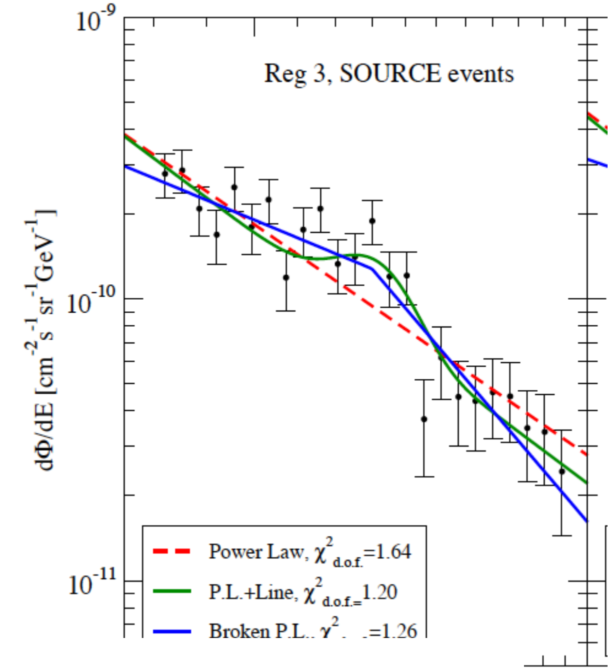
Is this real ?

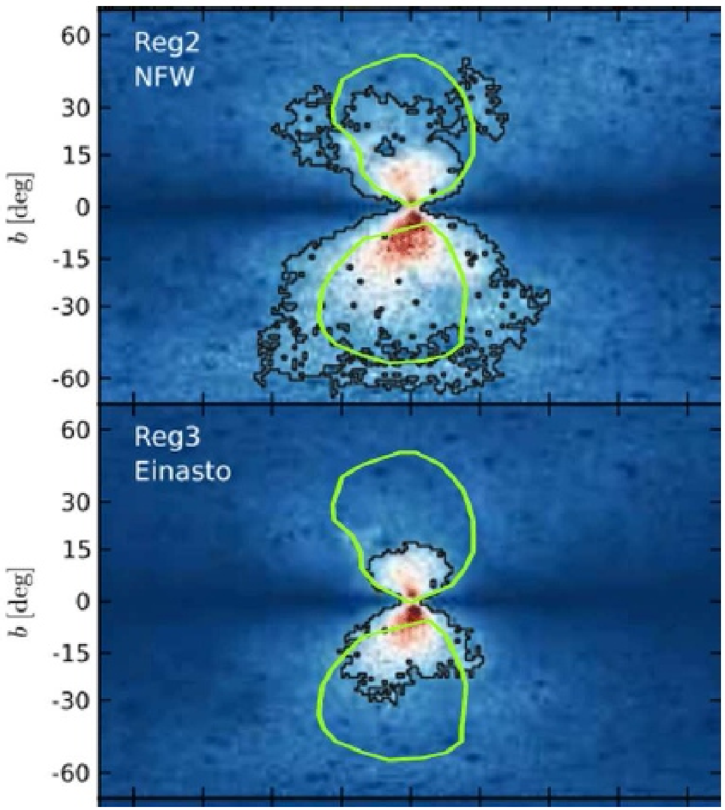
Is this compatible with FERMI limits ?

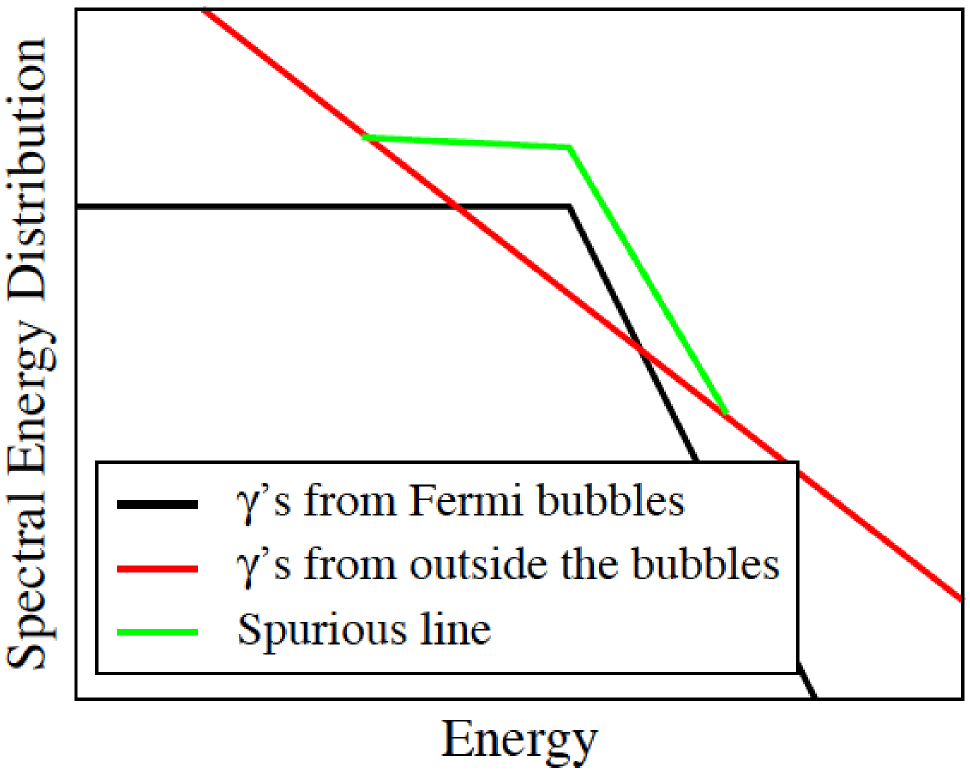
Can this this have something to do with the Pamela positron anomaly ?   [very difficult] arXiv:1204.6047v1

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

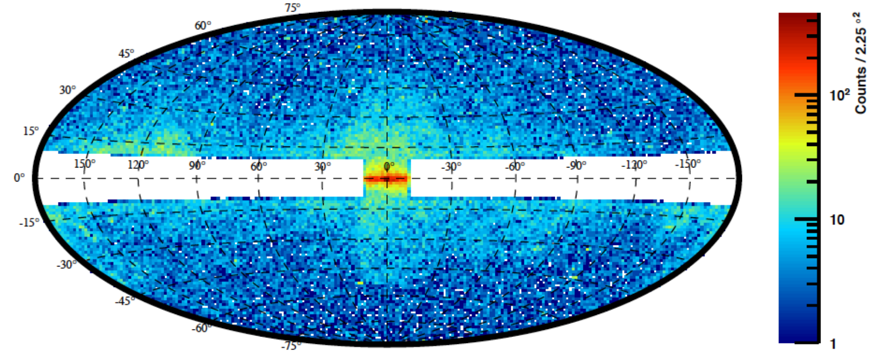
STEFANO PROFUMO[1,2] AND TIM LINDEN[1]







New Independent claim of (essentially) same effect



arXiv:1206.1616v1 [astro-ph.HE] 7 Jun 2012

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

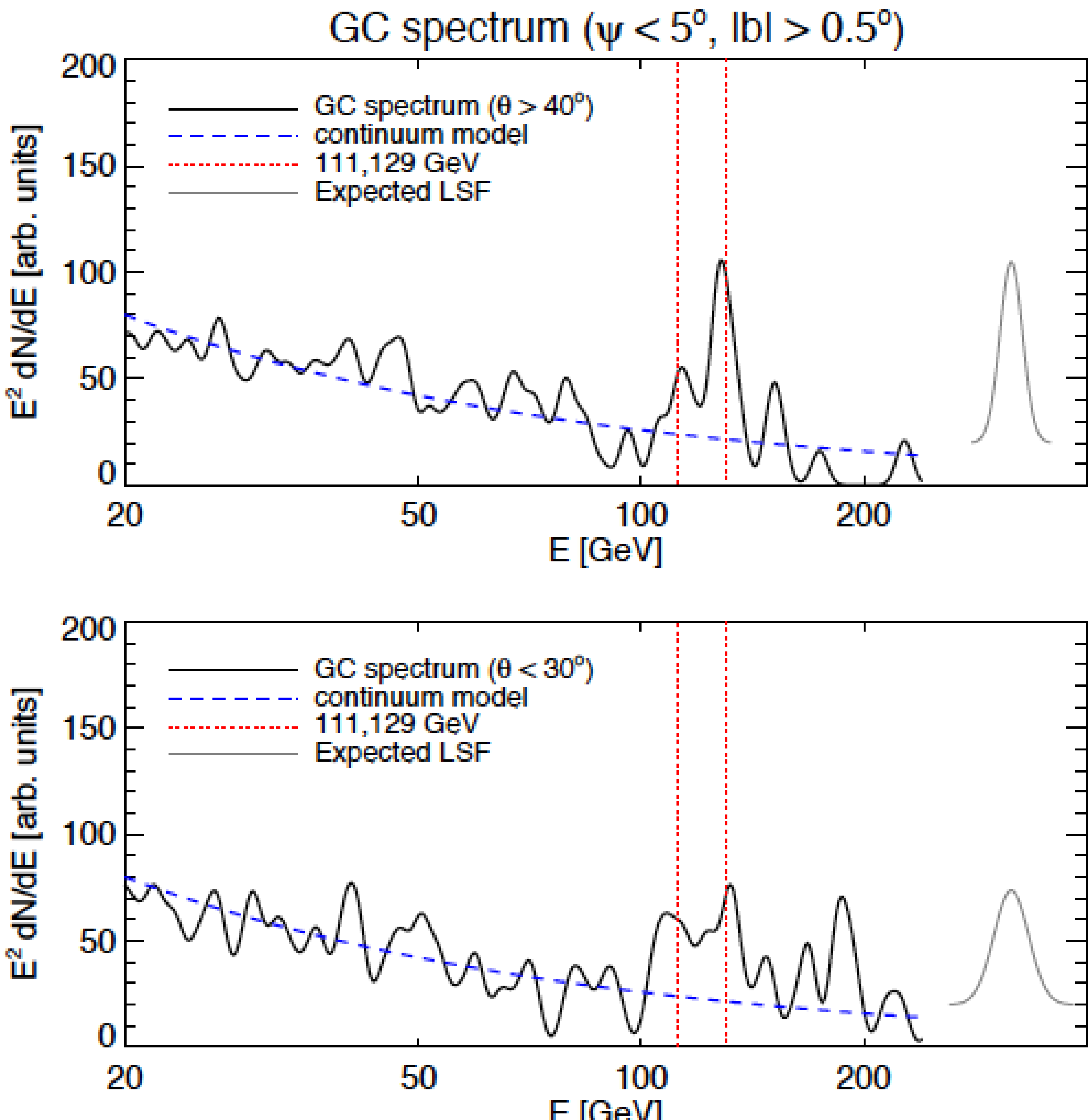
Meng Su[1,3], Douglas P. Finkbeiner[1,2]

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 $\lesssim 4^\circ$ 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)

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

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

Power
Of line emitter
Near GC.

142 GeV WIMP

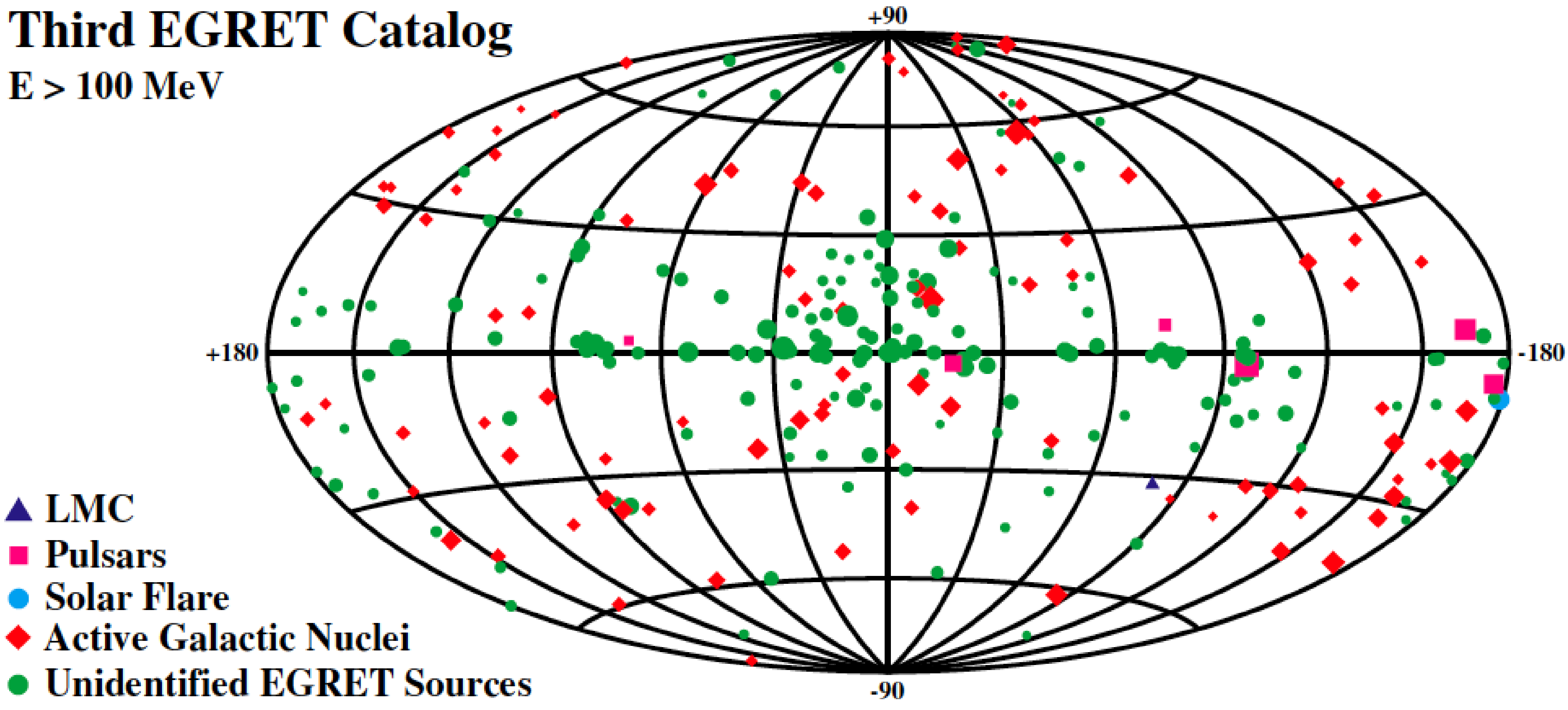
$$m_h \sim 130$$

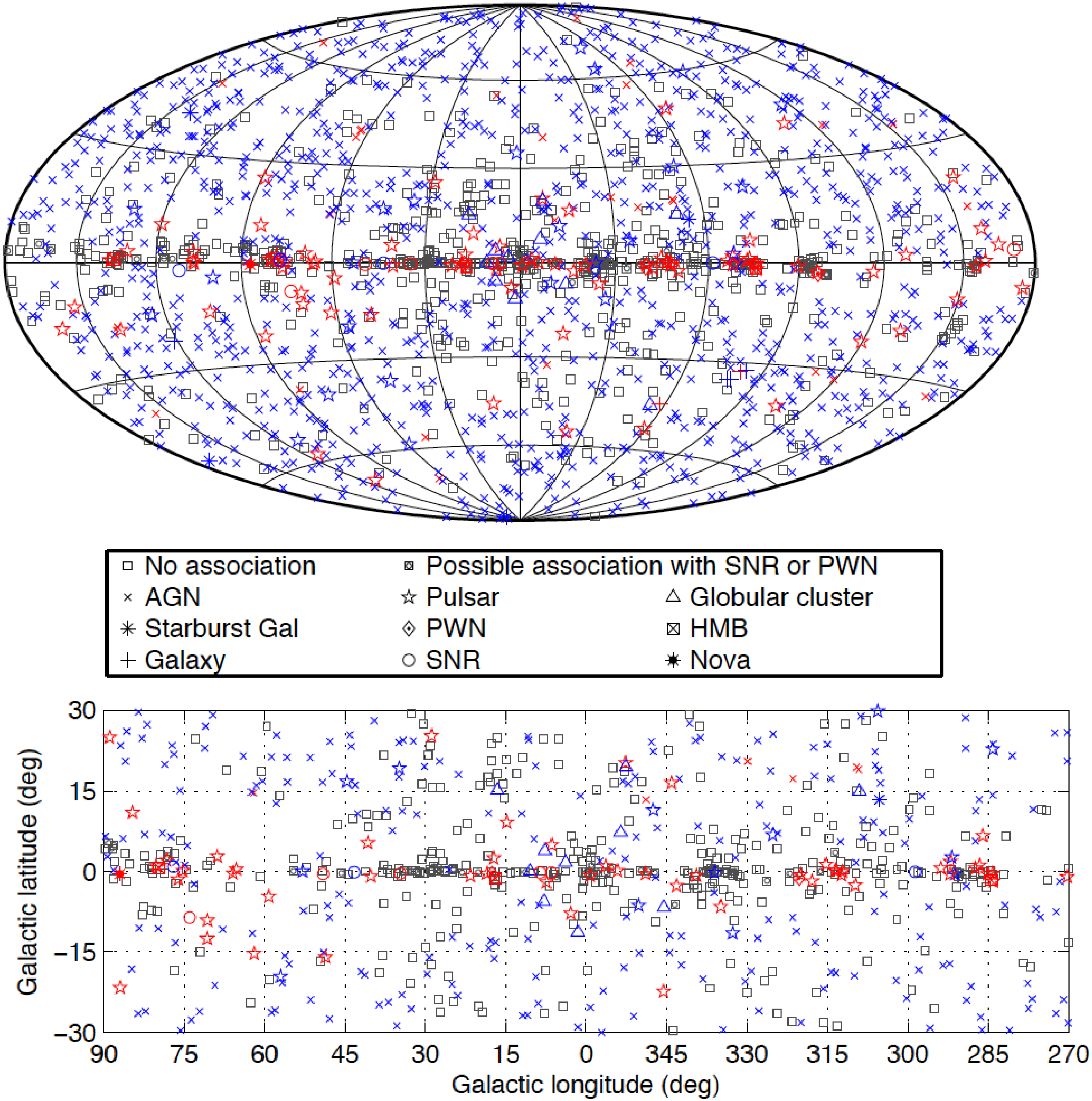
$$\gamma Z \qquad \gamma h$$

5.0 sigmas
3.7 sigmas
"with trials factors"

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

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





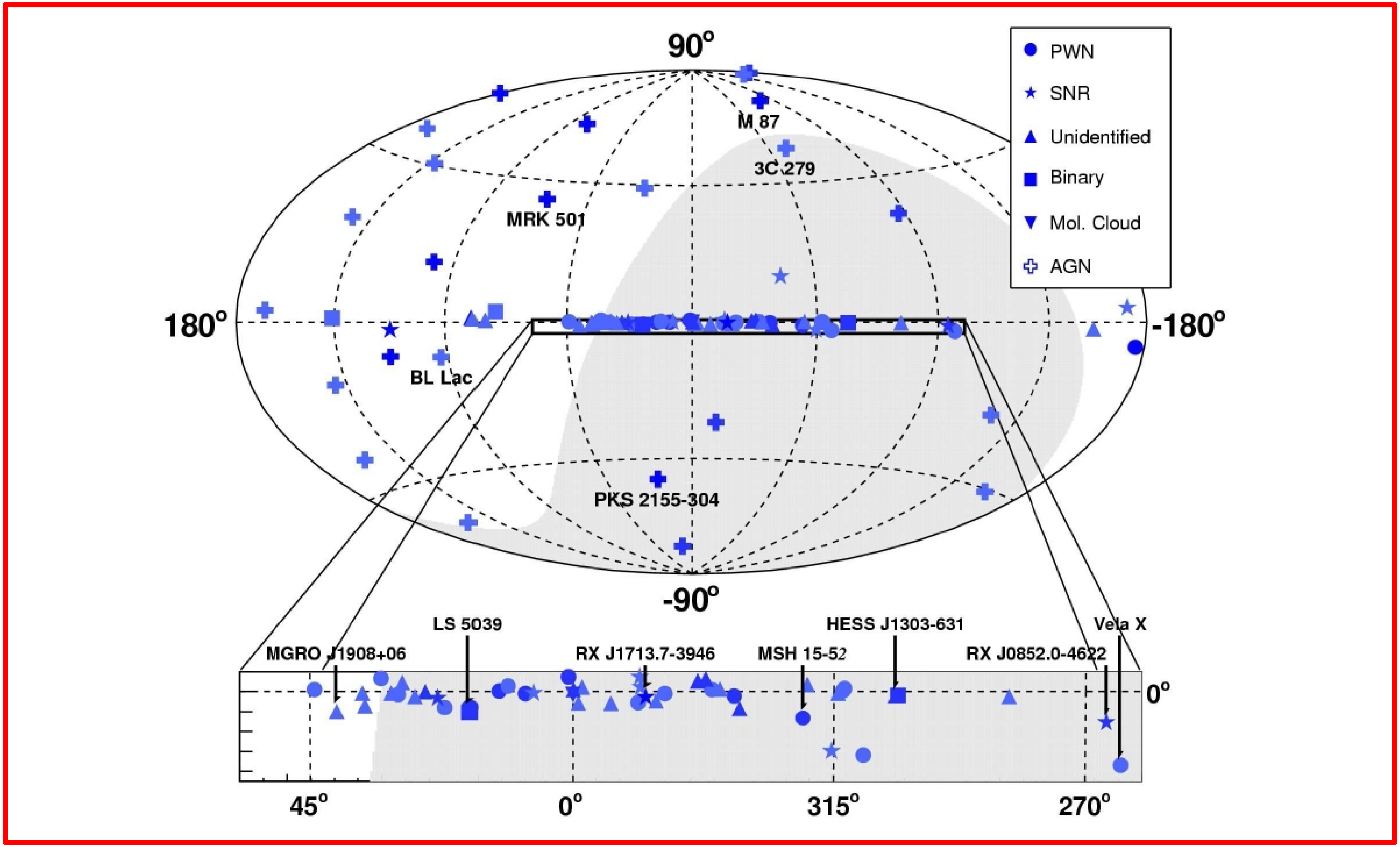
2FGL

2nd FERMI Catalog

24 months of observations

1873 sources

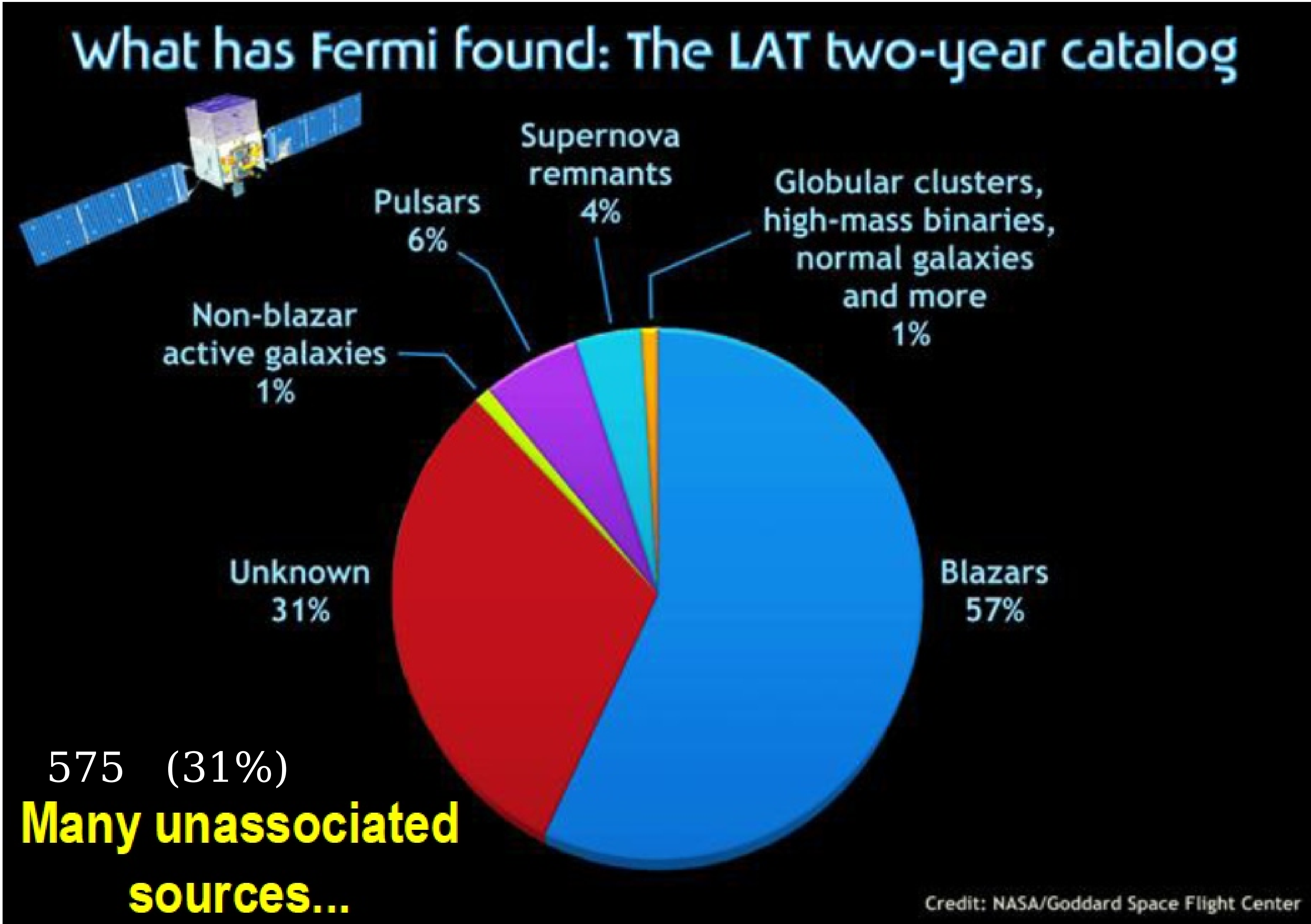
TEV SKY



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

Table 6. LAT 2FGL Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	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



Many unassociated sources...

PULSARS

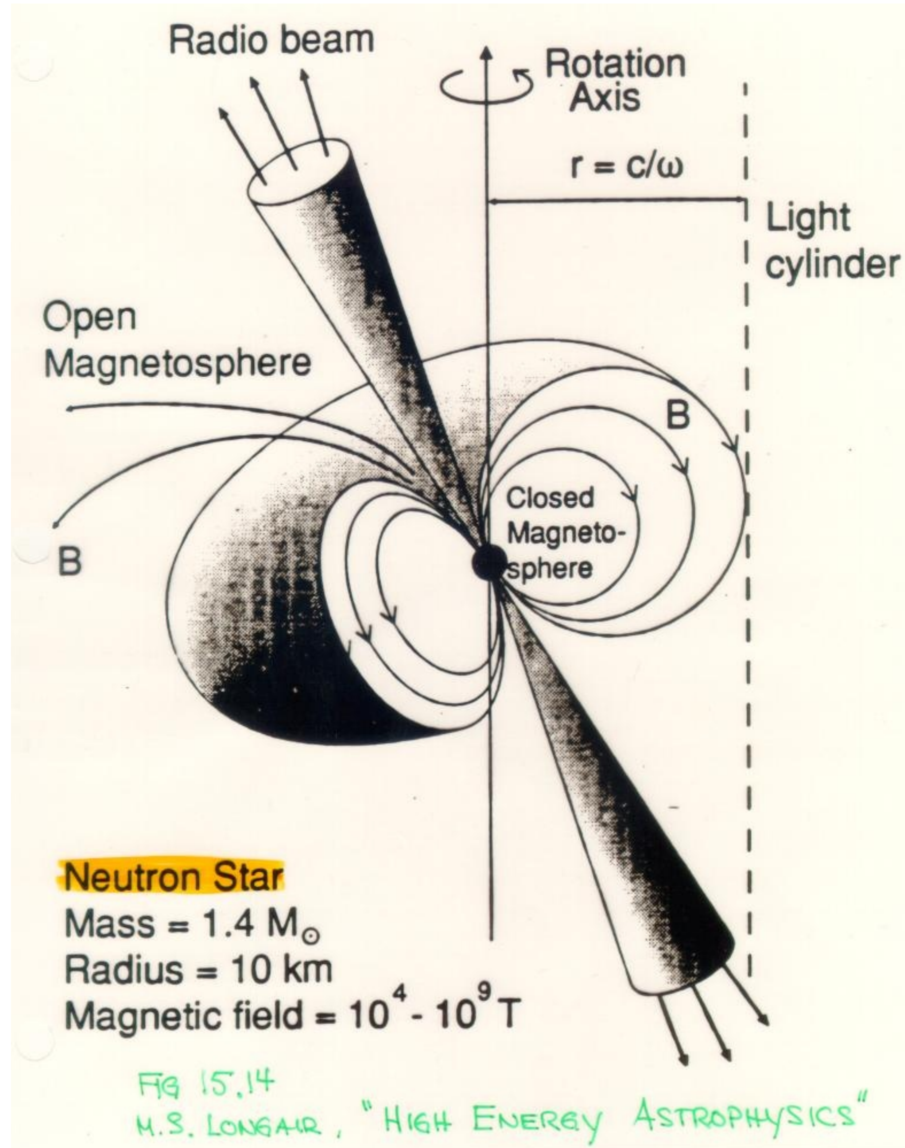
Proposed as possible Accelerators of e+ e-

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

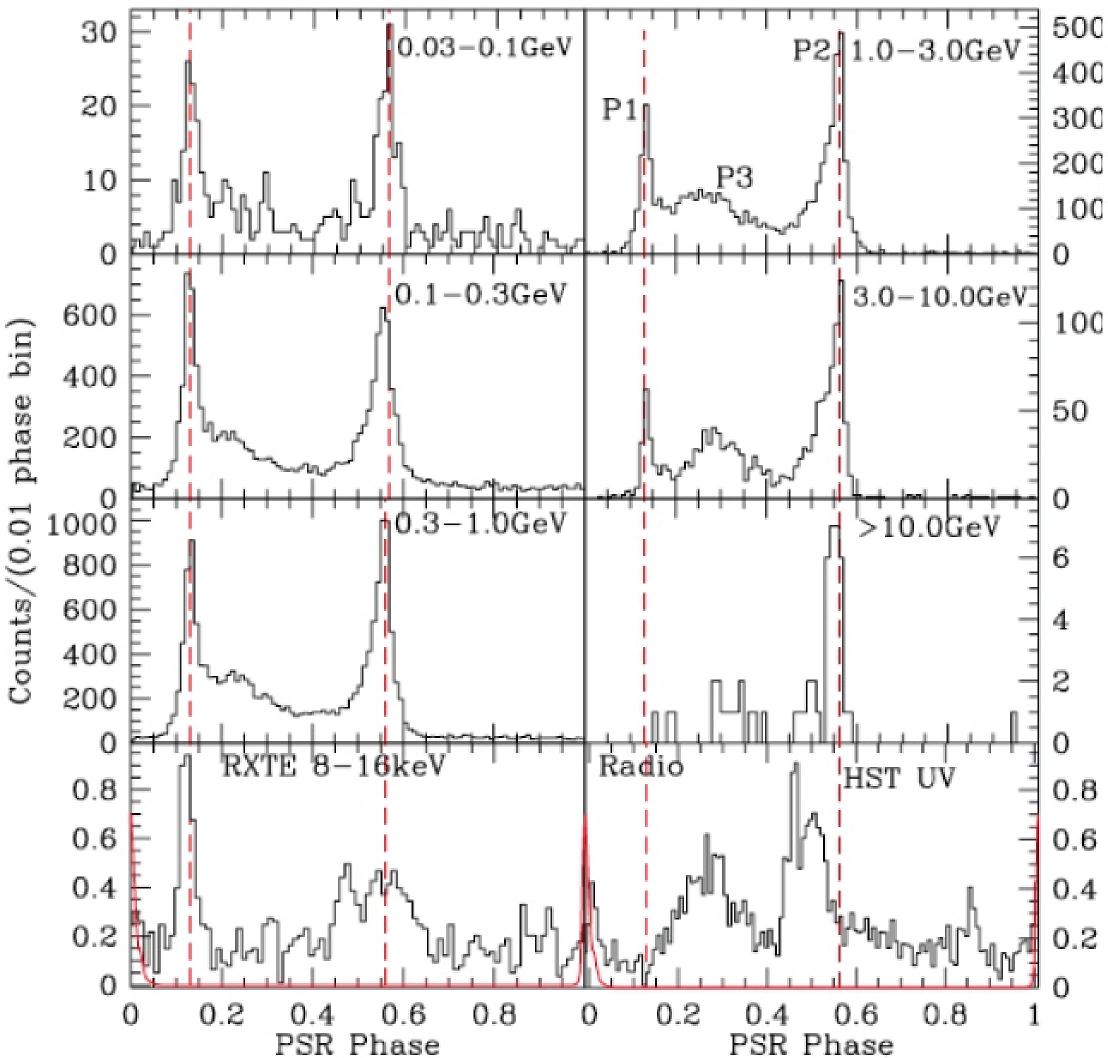
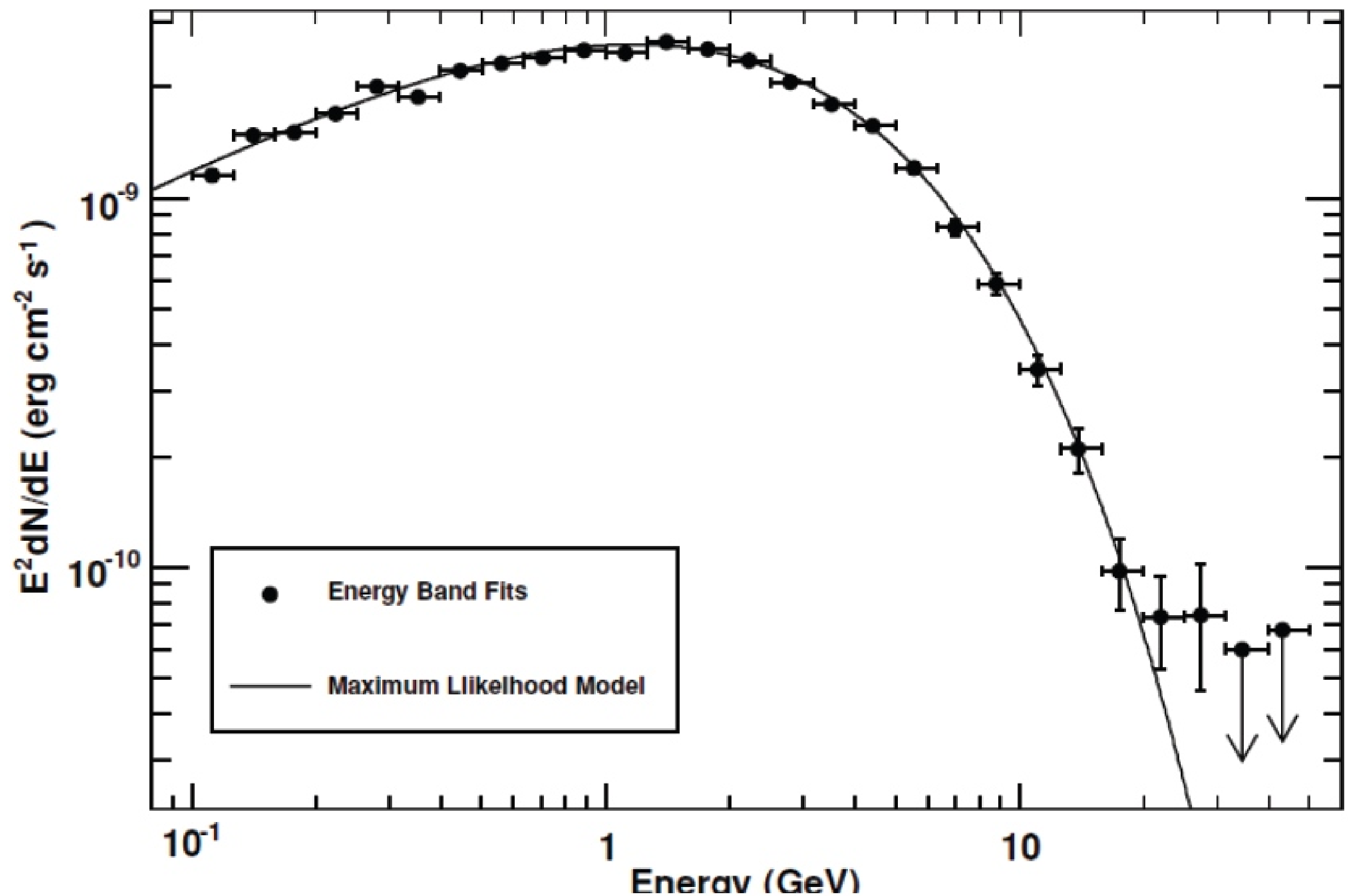


Fig. 4. Vela light curves at optical, X-ray, and γ-ray energies [58], binned to 0.01 of the pulsar phase. The main peaks P1, P2 and P3 are labeled in the top right panel. The bottom left panel shows the 8 – 16 keV *RXTE* light curve [59] along with the radio pulse profile (dashed lines). At lower right,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



VELA Energy Spectrum [characteristic shape For Pulsars]

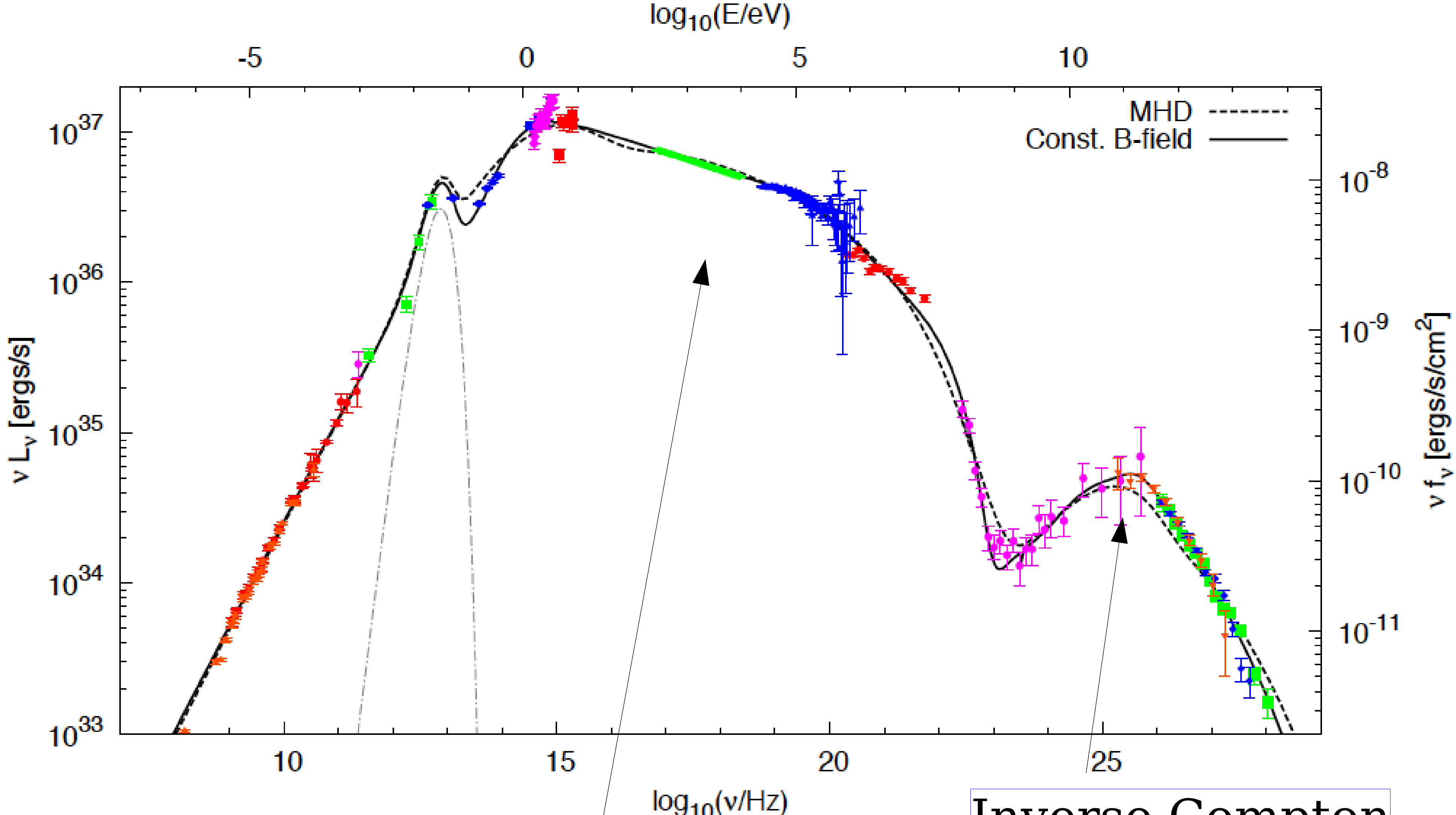
$$N(E) \propto E^{-\Gamma_\gamma} \exp[-(E/E_c)^b]$$

The CRAB Nebula

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

CRAB Nebula Energy Spectrum

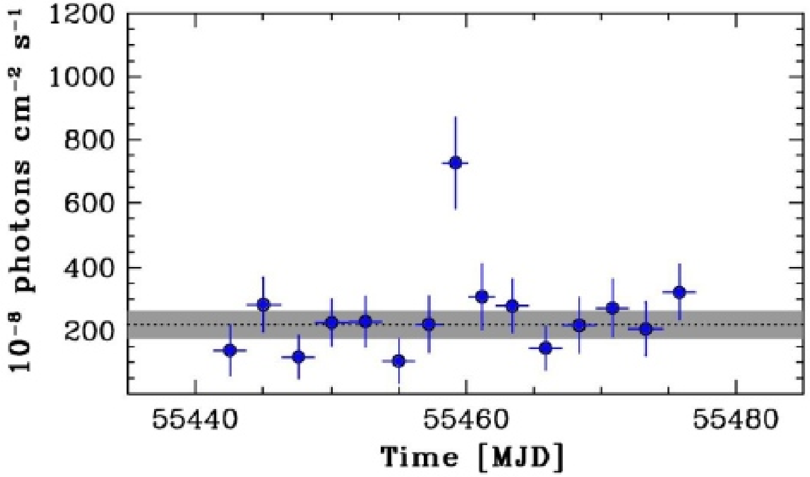
SSC (Self Synchrotron Coompton) model emission



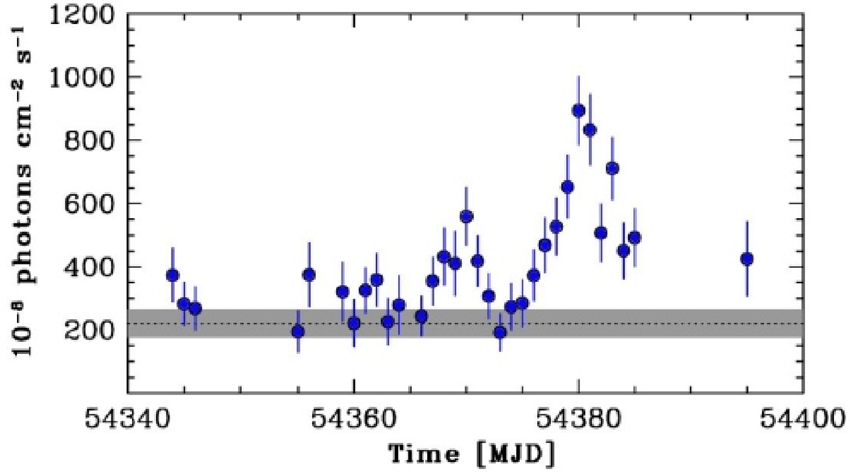
Synchrotron Radiation

Inverse Compton Scattering

AGILE discover of flaring of the CRAB



2sep – 8 oct 2010



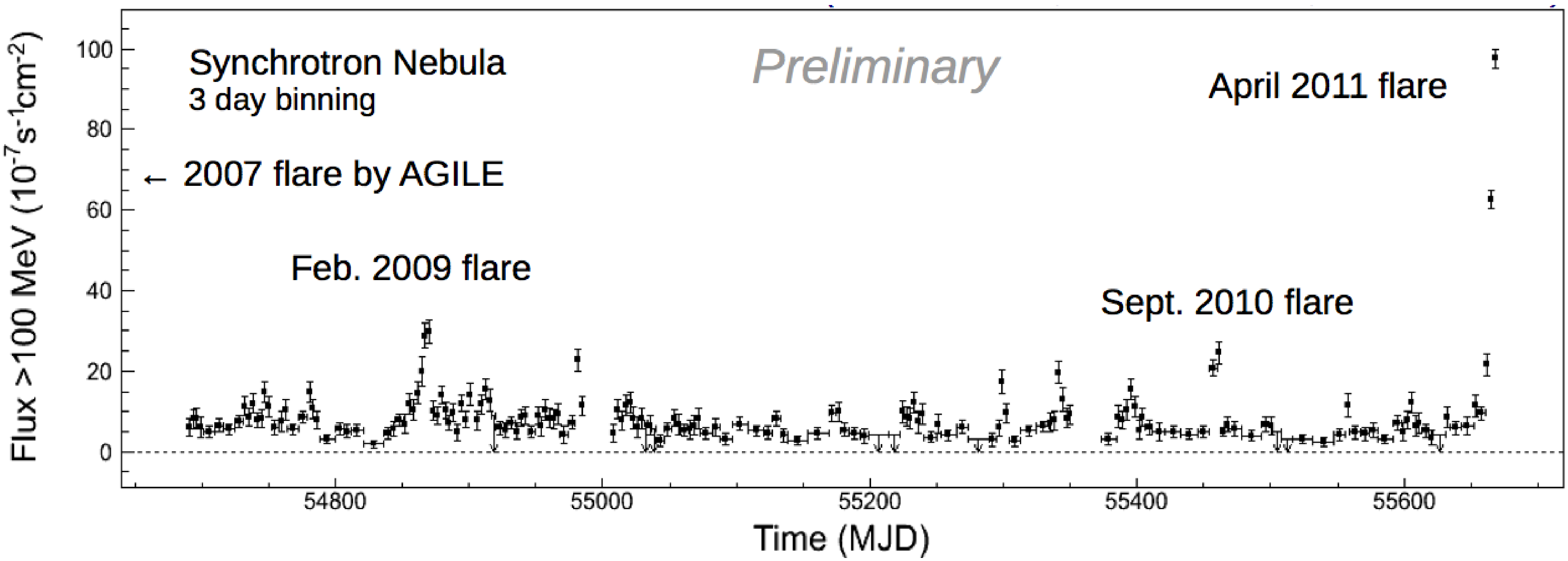
27sep – 12 oct 2007
[discovery “in the drawer”]

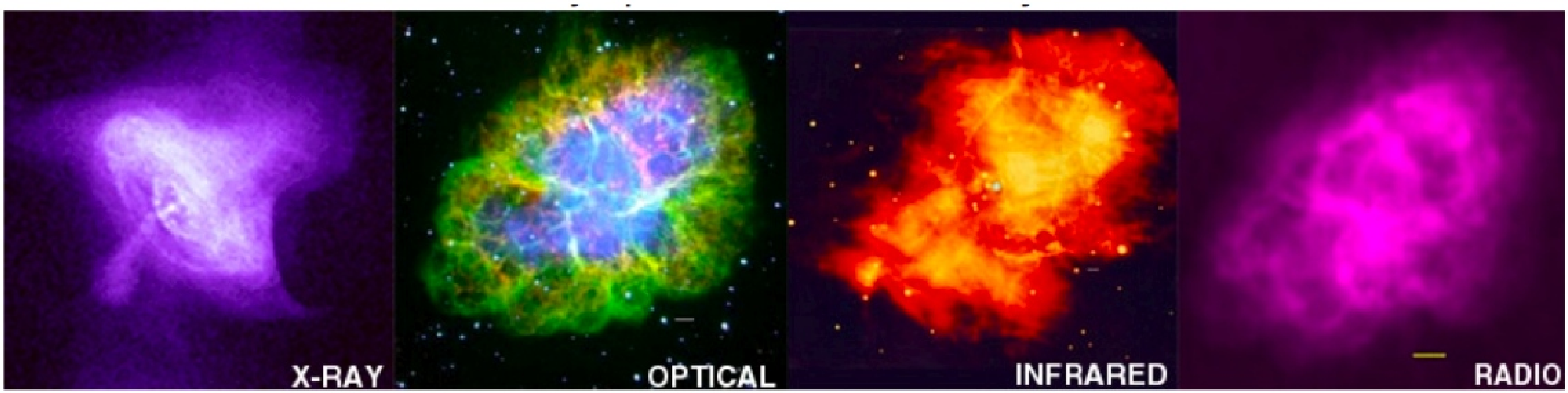
2012 Bruno ROSSI Prize

To Marco Tavani and the AGILE team

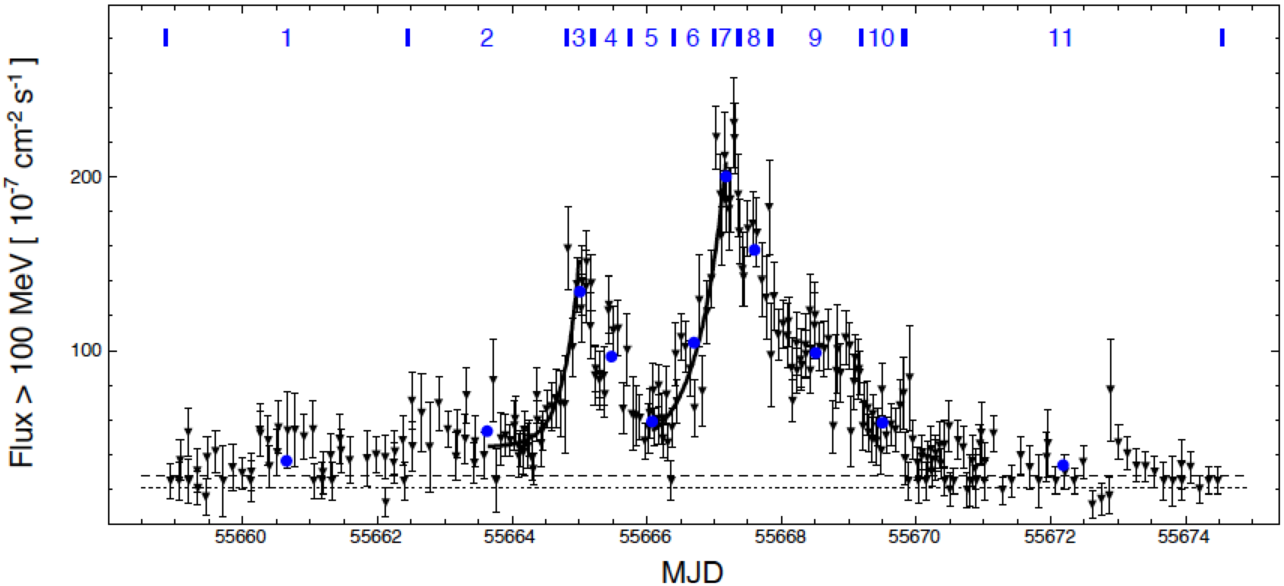
- 2012 Marco Tavani and the AGILE team
- 2011 Bill Atwood, Peter Michelson, and the Fermi Gamma Ray Space Telescope LAT team
- 2010 Felix A. Aharonian, Werner Hofman, Heinrich J. Voelk and the H.E.S.S. team
- 2009 Charles D. Bailyn, Jeffrey E. McClintock, and Ronald A. Remillard
- 2008 Steven Allen, J. Patrick Henry, Maxim Markevitch, Alexey Vikhlinin
- 2007 Neil Gehrels and the Swift Team
- 2006 Tod Strohmayer, Deepto Chakrabarty, and Rudy Wijnands
- 2005 Stan Woosley
- 2004 Harvey Tananbaum and Martin Weisskopf
- 2003 Robert Duncan, Christopher Thompson, & Chryssa Kouveliotou
- 2002 Leon Van Speybroeck
- 2001 Andrew Fabian and Yasuo Tanaka
- 2000 Peter Meszaros, Bohdan Paczynski, & Martin Rees
- 1999 Jean Swank & Hale Bradt
- 1998 The BeppoSAX Team & Dr. Jan van Paradijs
- 1997 Trevor C. Weekes
- 1996 Felix Mirabel & Luis F. Rodriguez
- 1995 Carl Fichtel
- 1994 Gerald Fishman
- 1993 Giovanni Bignami & Jules Halpern
- 1992 Gerald H. Share
- 1991 John A. Simpson
- 1990 Stirling A. Colgate
- 1989 Members of the IMB & Kamioka Experiment Teams
- 1988 Rashid A. Sunyaev
- 1987 Michiel van der Klis
- 1986 Allan S. Jacobson
- 1985 William R. Forman & Christine Jones

CRAB NEBULA Flaring [!]





April 2011 CRAB flare



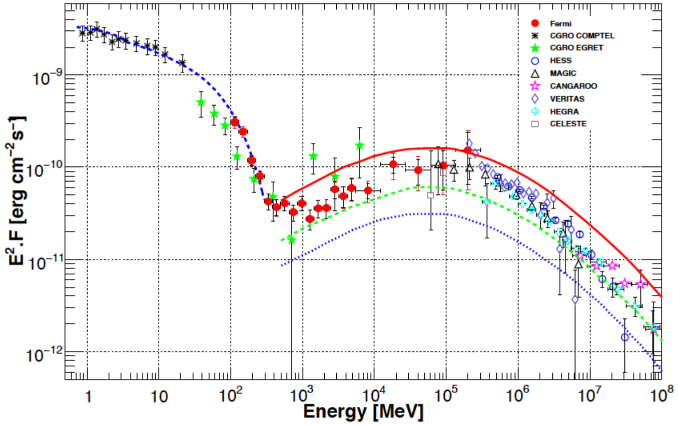
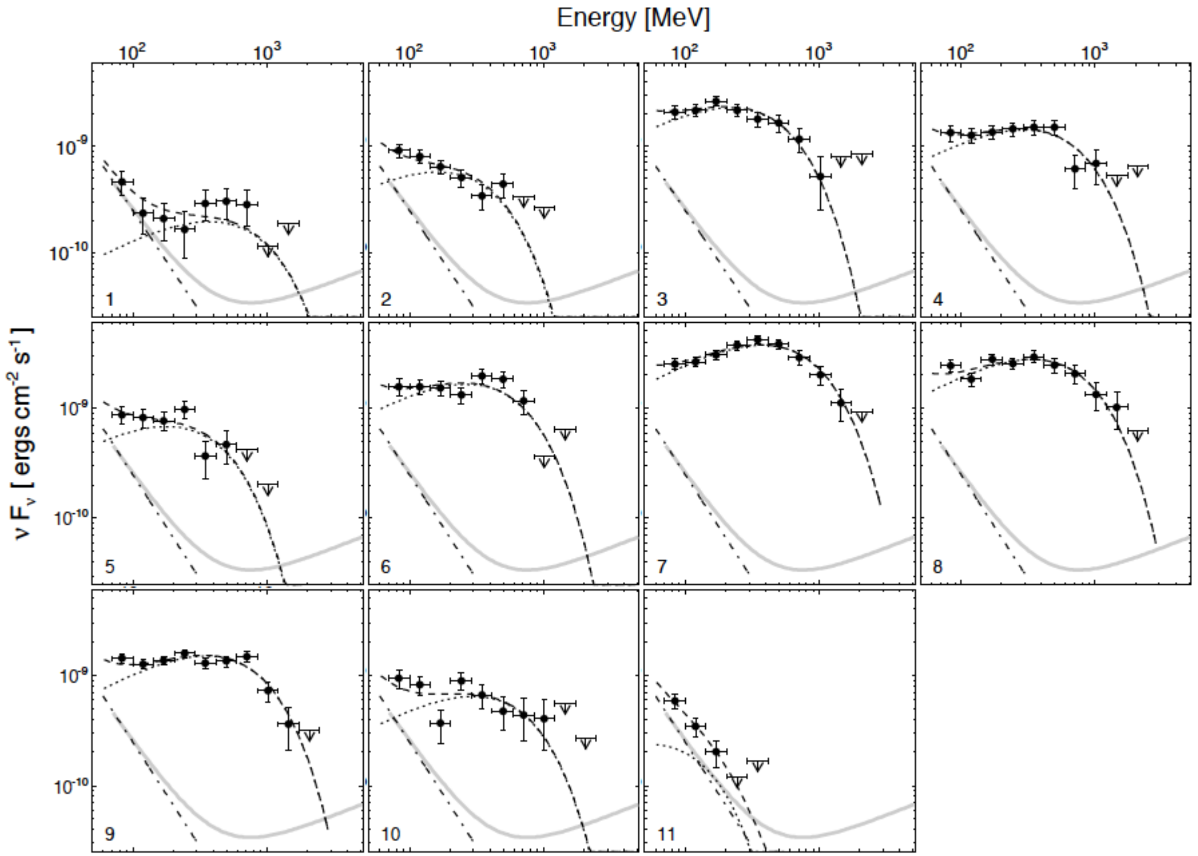


FIG. 9.— The spectral energy distribution of the Crab Nebula from soft to very high energy γ-rays. The fit of the synchrotron component, using COMPTEL and LAT data (blue dashed line), is overlaid. The predicted inverse Compton spectra from Atoyan and Aharonian (1996) are overlaid for three different 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.

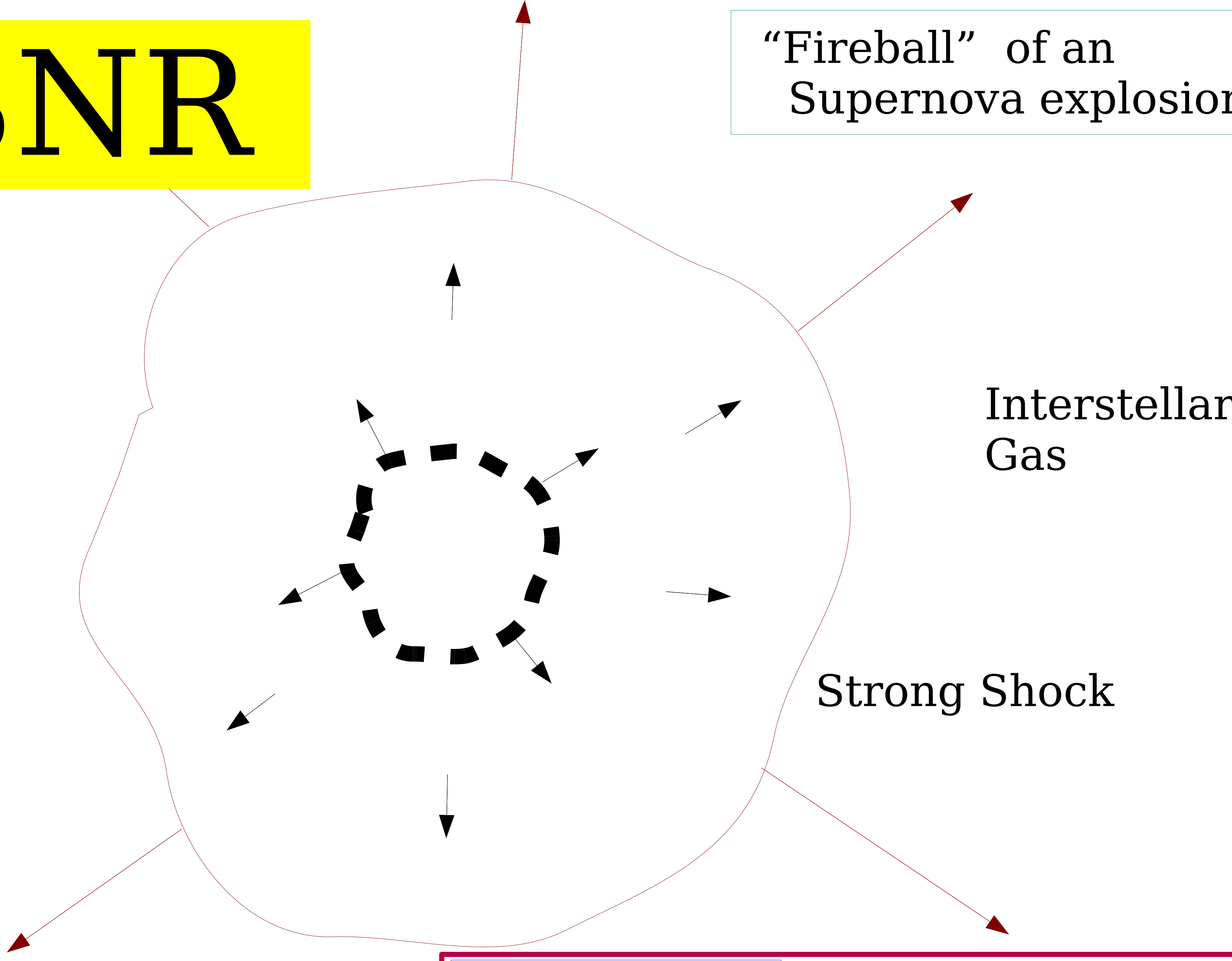
The “SNR paradigm”
for galactic Cosmic Rays

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

Candidate sites:
AGN's
GRB's

SNR

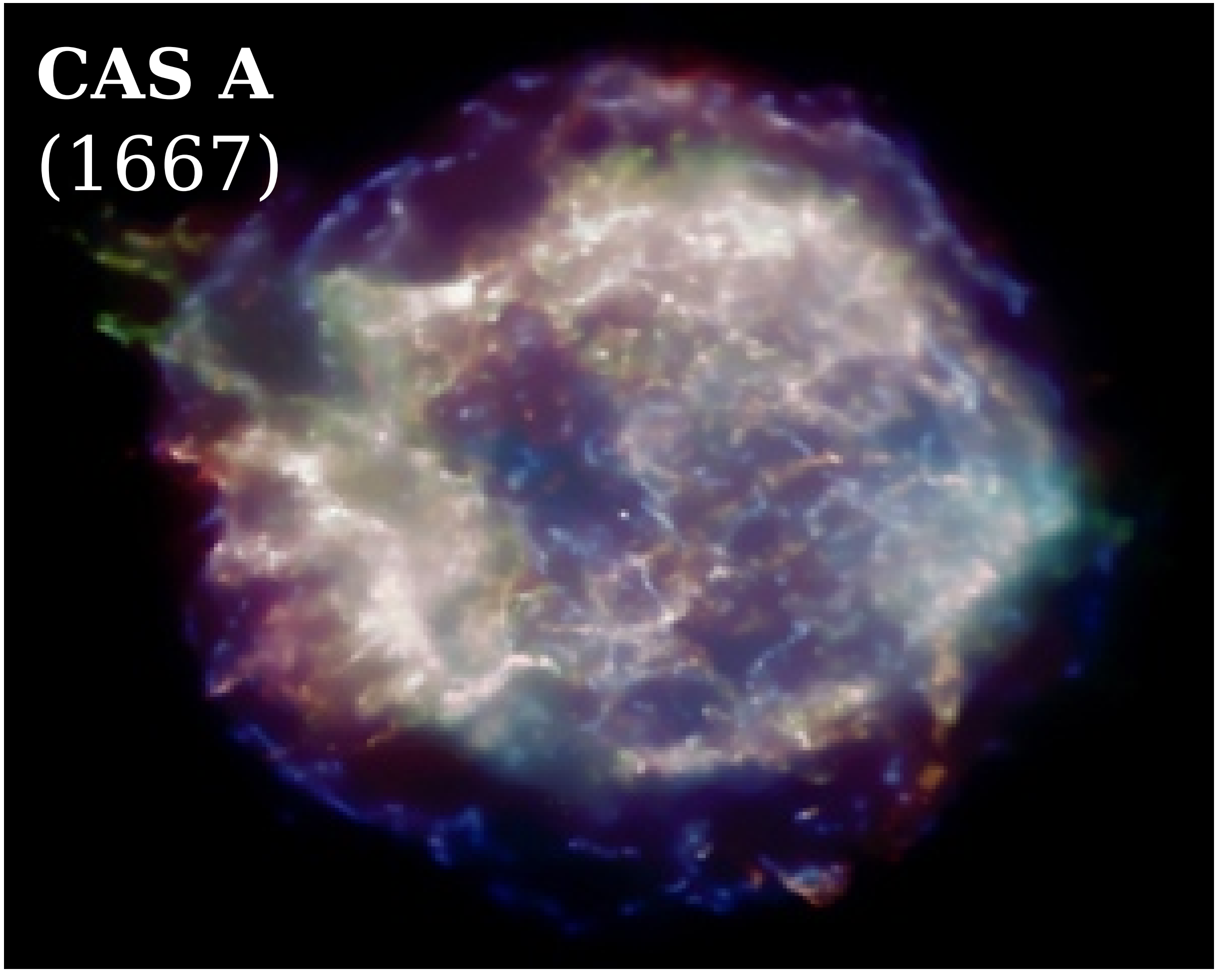
"Fireball" of an Supernova explosion



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]

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

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

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

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

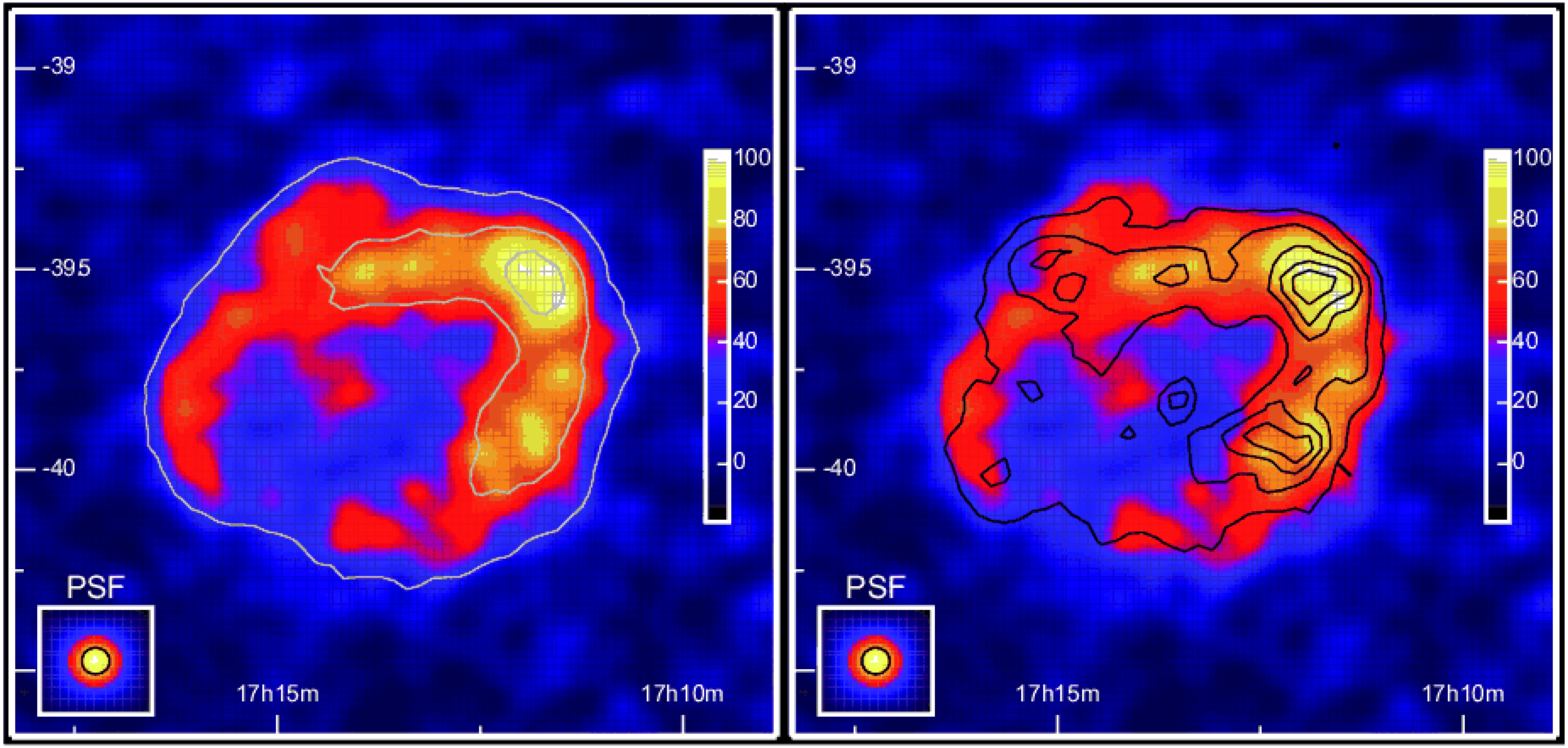
$$L_{\text{SN kinetic}}^{\text{Milky Way}} \simeq 1.5 \times 10^{42} \; \frac{\text{erg}}{\text{s}}$$

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

HESS Telescope

Observations with TeV photons

SuperNova RX J1713.7-3946



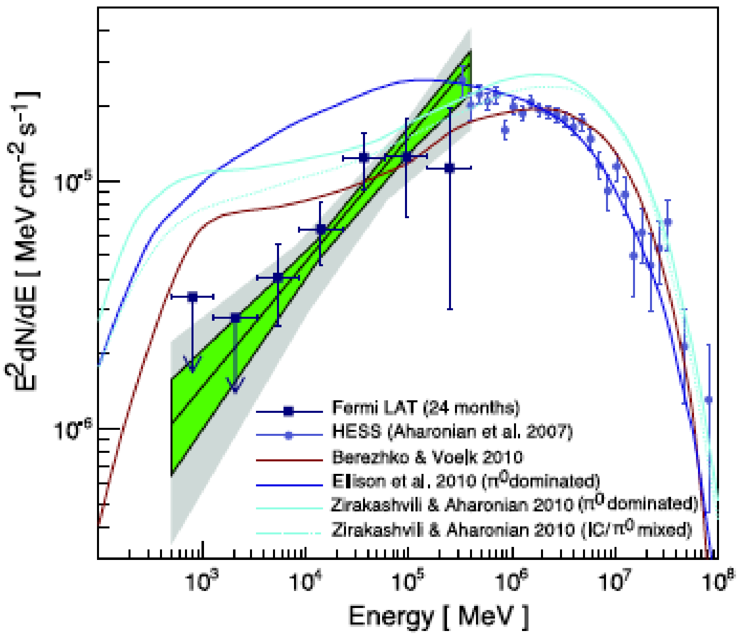
Comparison with ROSAT observation

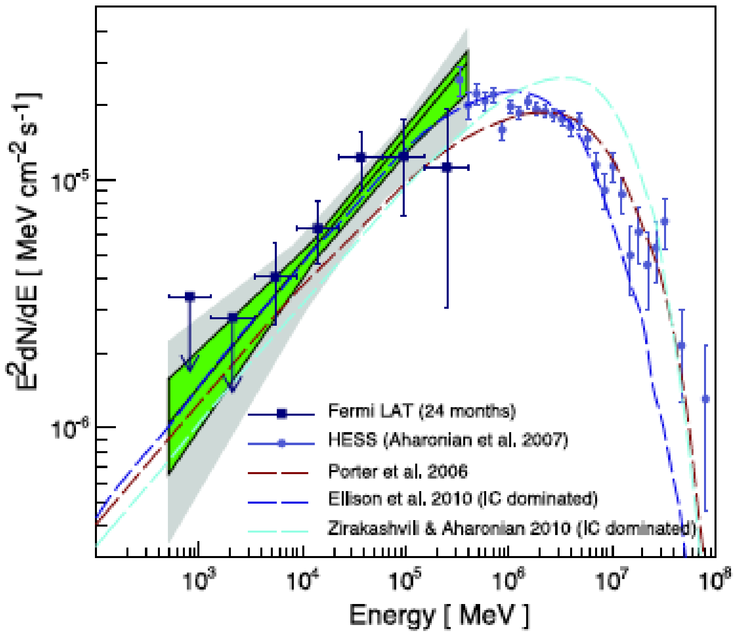
Observations of the young Supernova remnant RX J1713.7−3946 with the *Fermi* Large Area Telescope

astro-ph/1103.5727.

29th march 2011

Favors
leptonic interpretation.

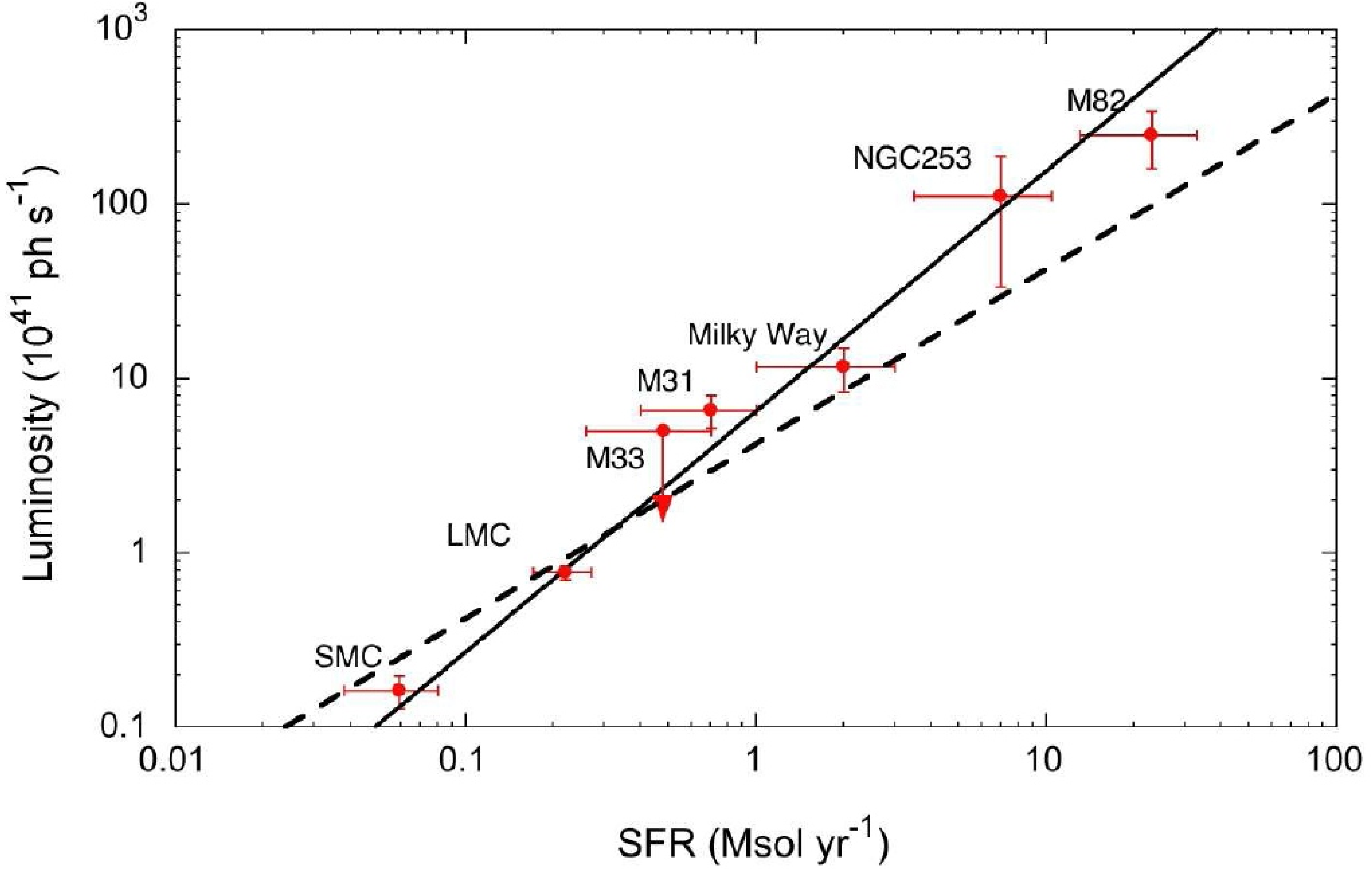




From FERMI:

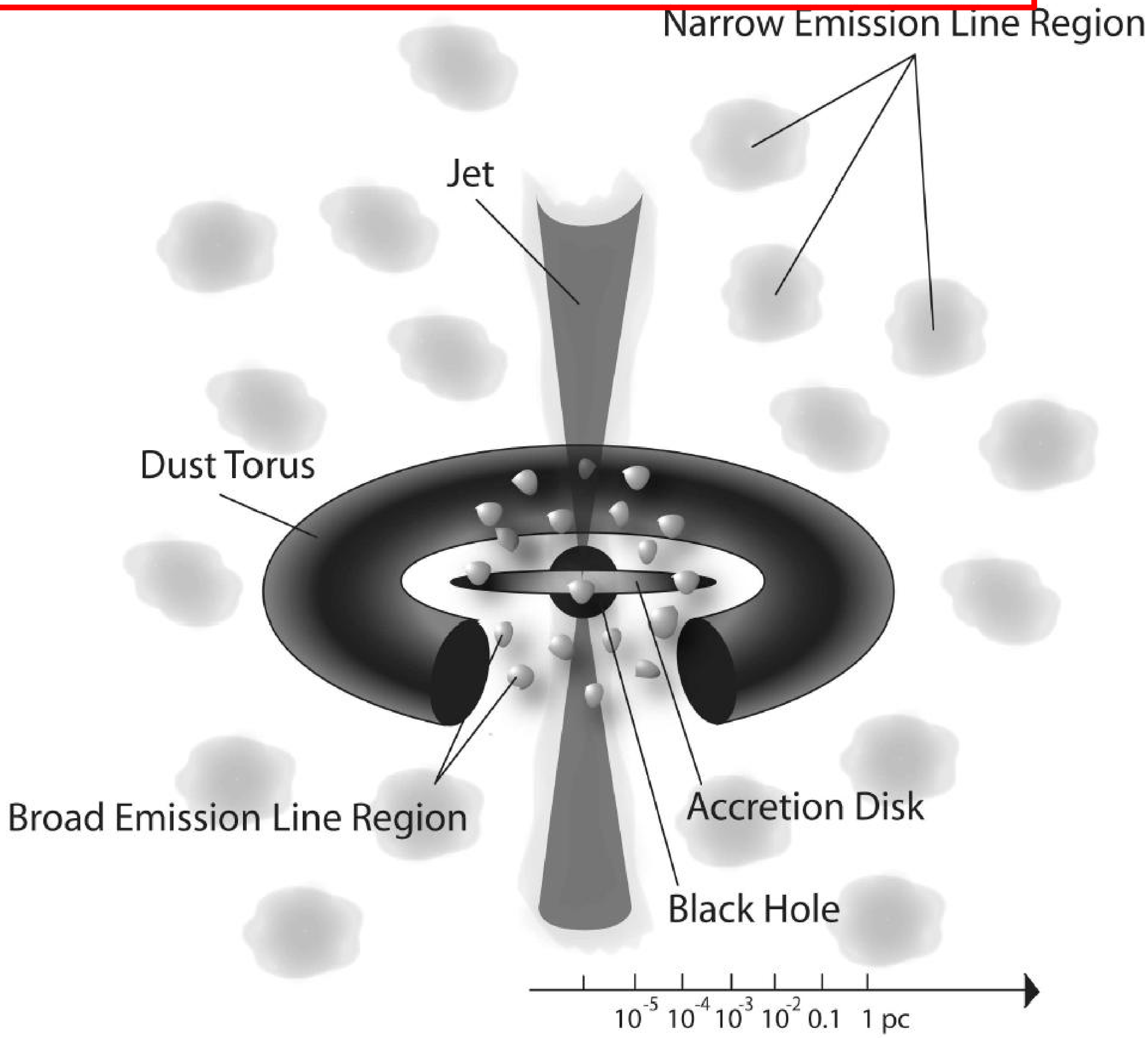
Table 1. Properties and gamma-ray characteristics of Local Group and nearby starburst galaxies (see text).

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



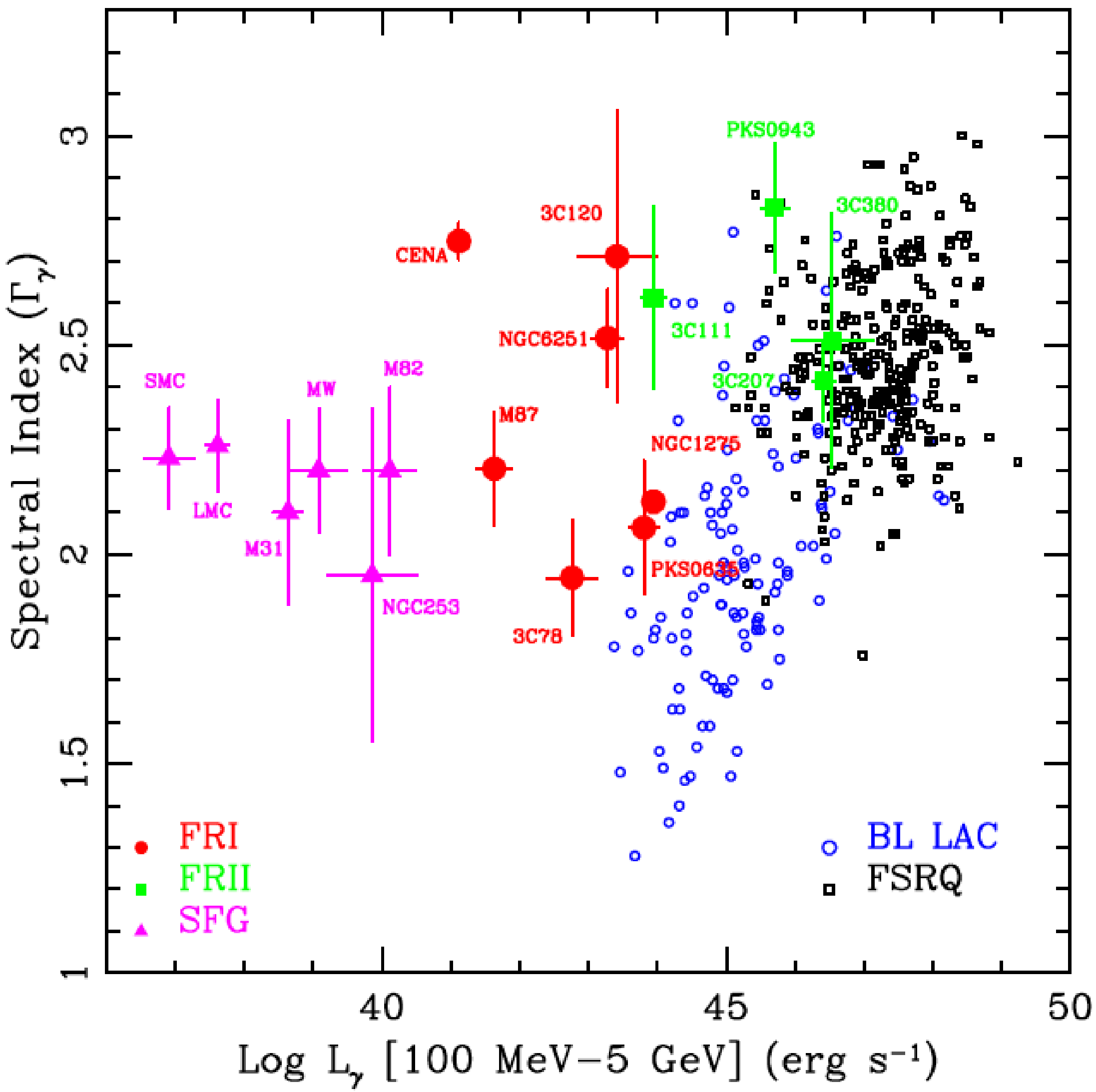
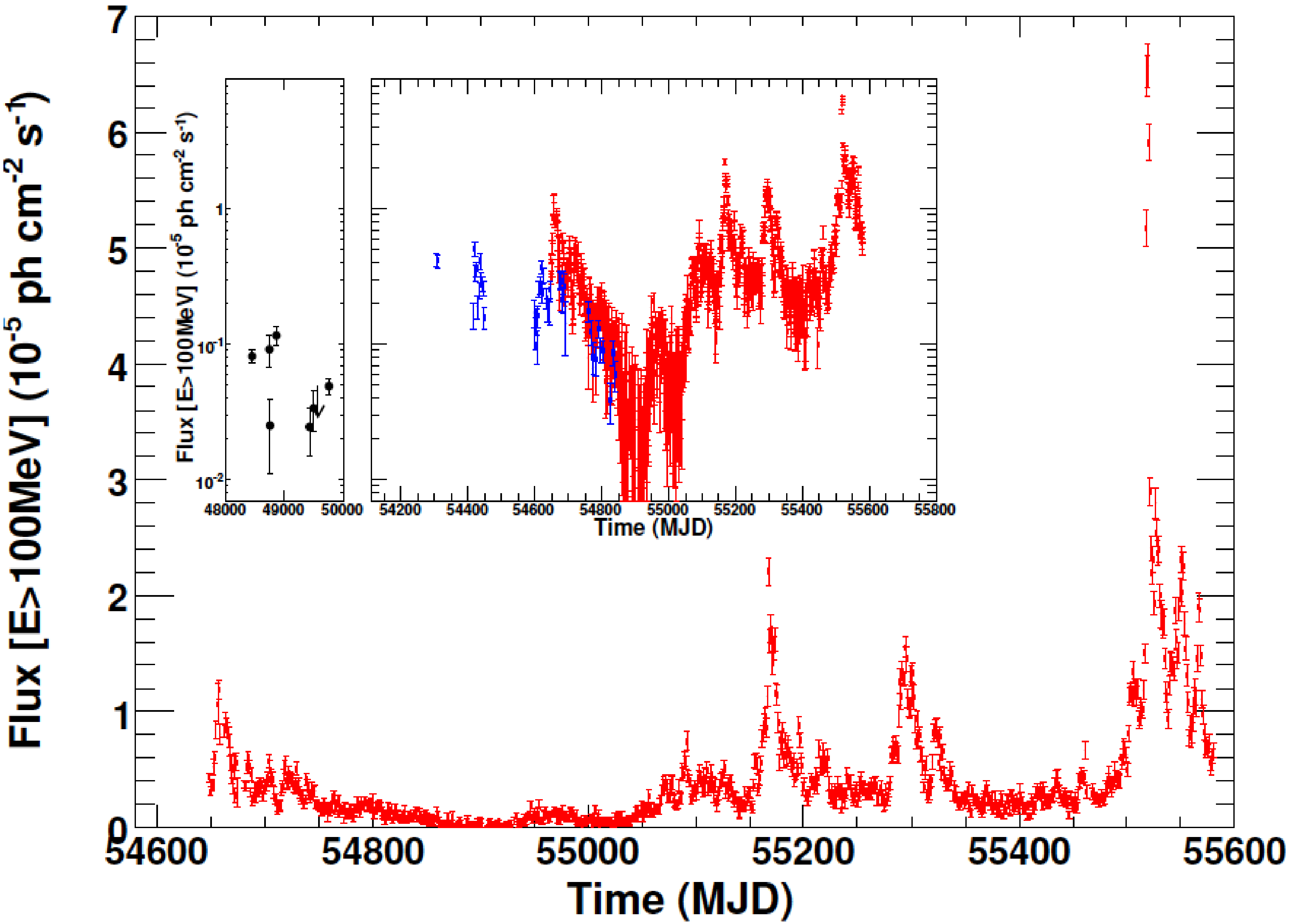


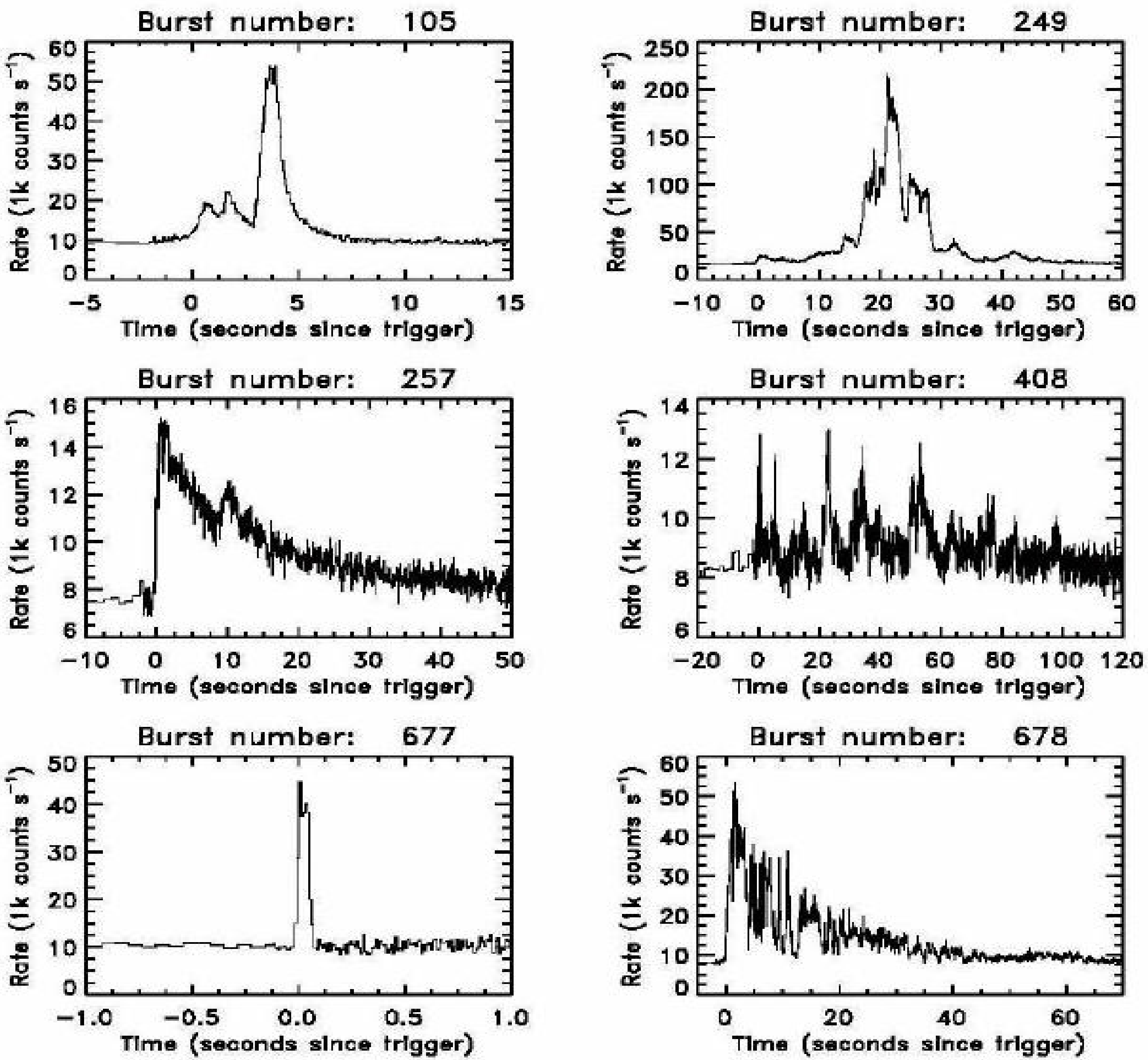
Fig. 7. Gamma-ray spectral slope Γ_γ of BL Lac objects (open blue circles), FSRQs (open black squares), FR1 radio galaxies (red circles), FR2 radio sources (green squares), and star-forming galaxies (magenta diamonds), are plotted as a function of their 100 MeV - 5 GeV γ-ray luminosity L_γ.

Mk 501

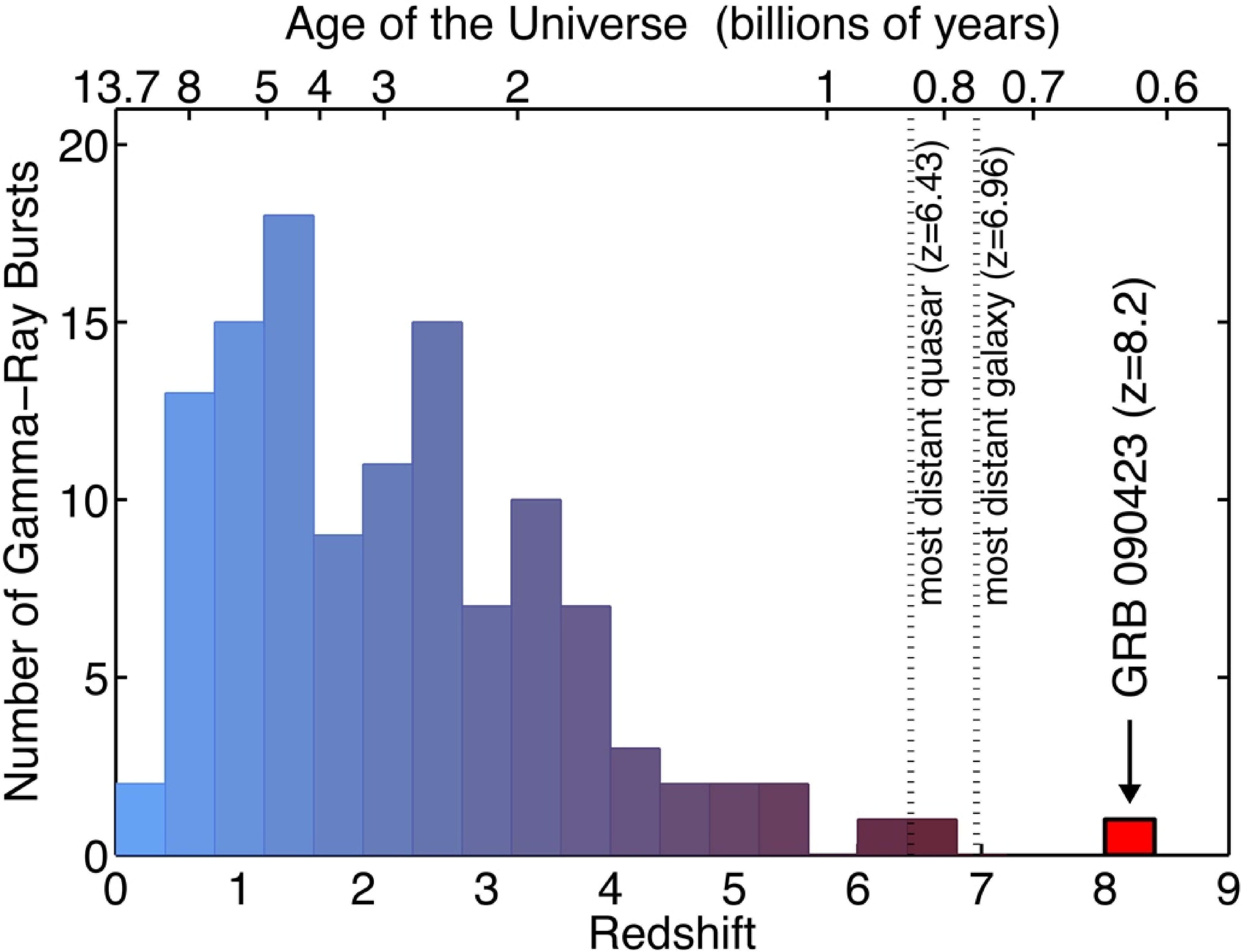
$$L_{iso} \approx 10^{50} \text{ erg s}^{-1}$$



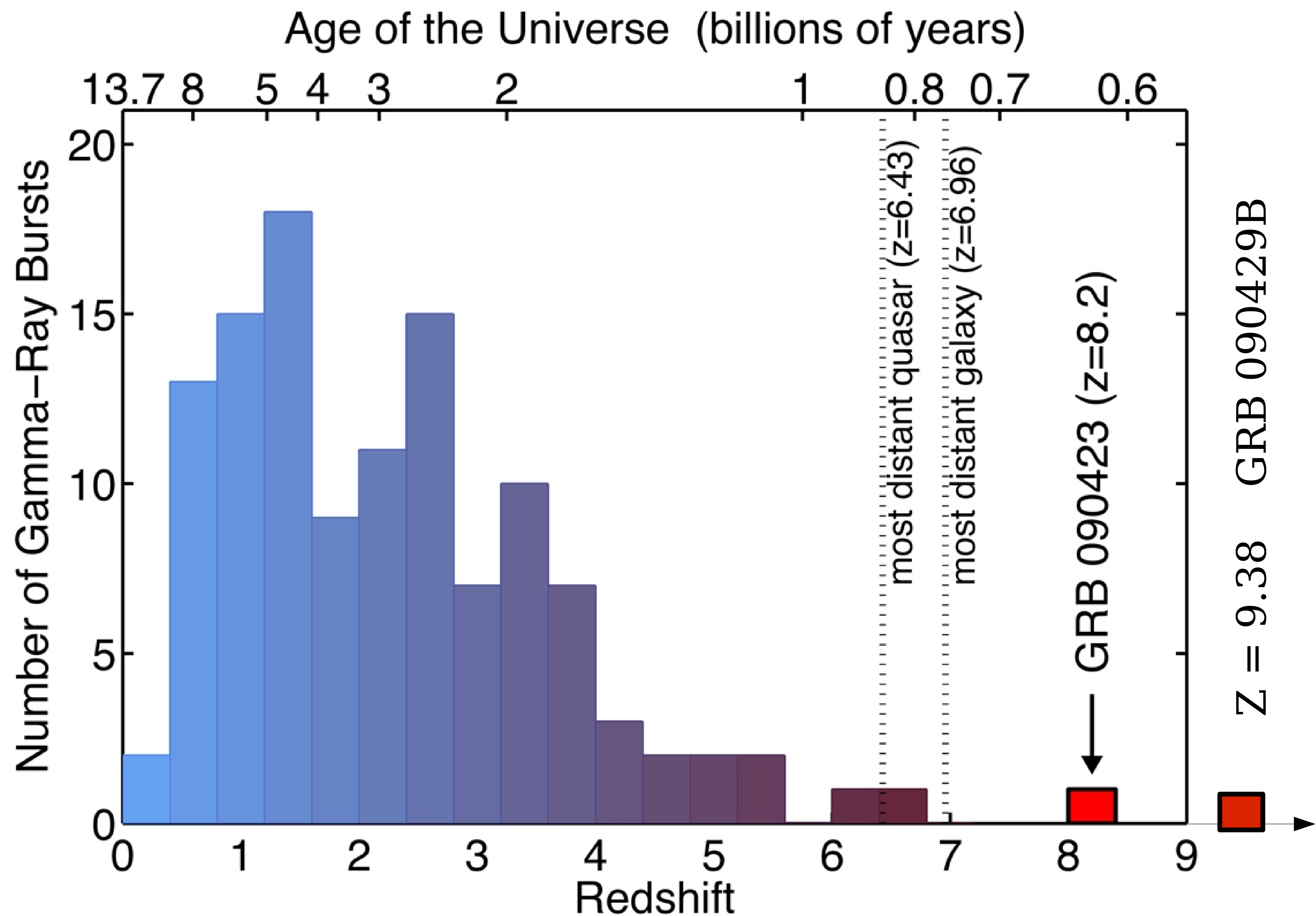
GAMMA RAY BURSTS (GRB's)



Proposed source
Of the CR



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

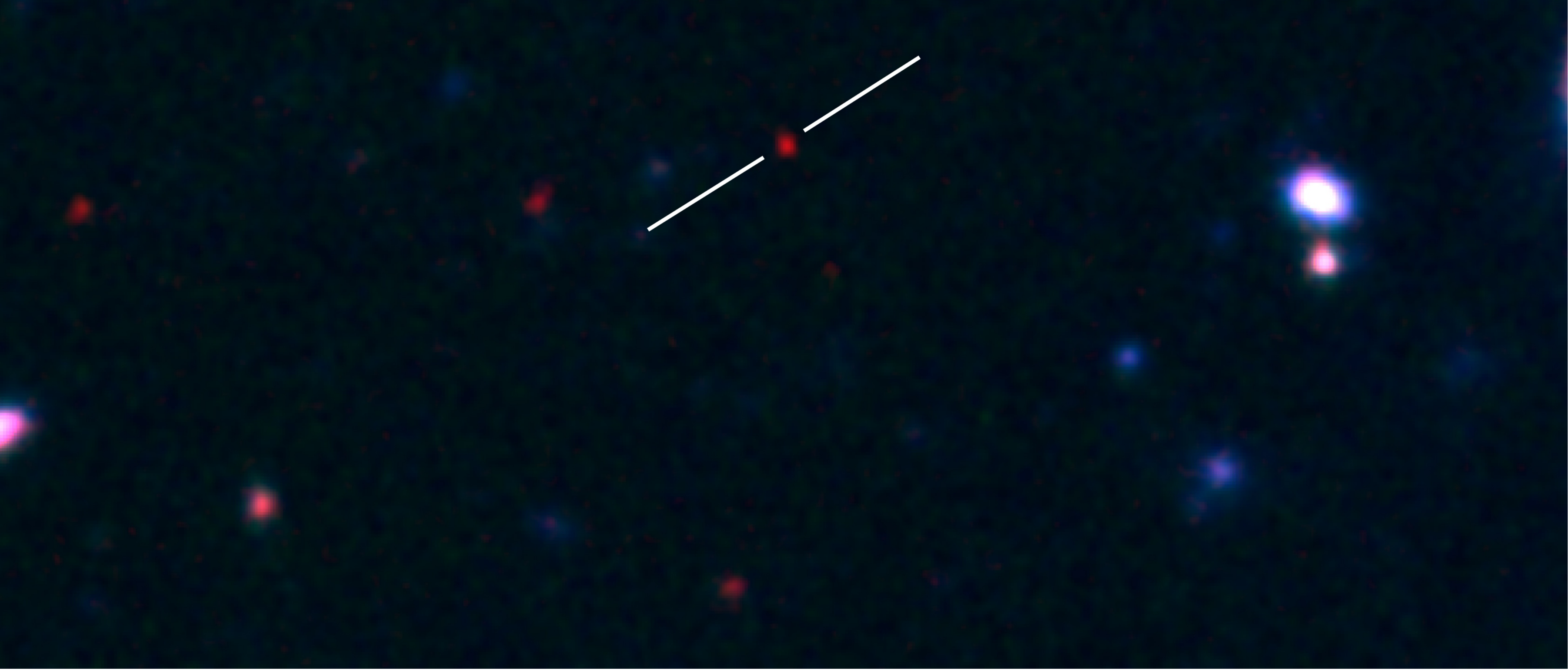


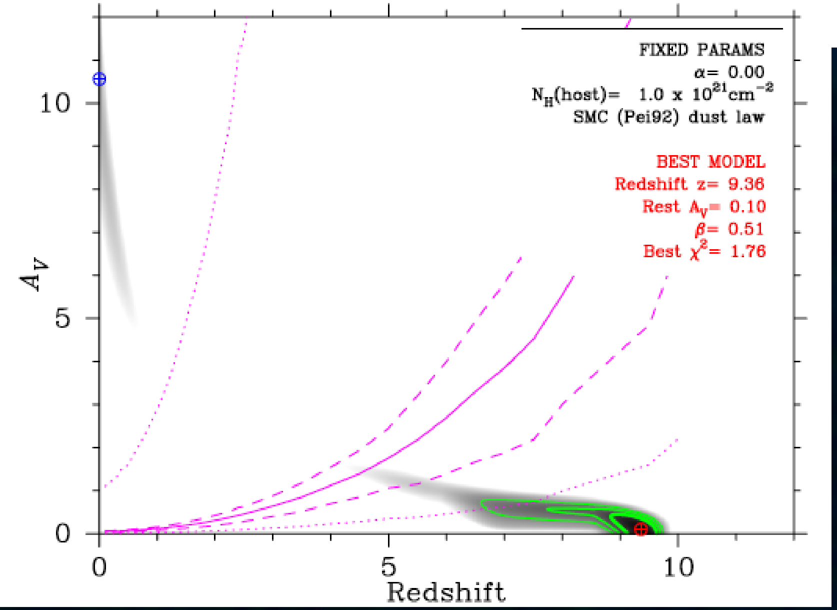
Age of the Universe (billions of years)
13.7
8
5
4
3
2
1
0.8
0.7
0.6
Number of Gamma−Ray Bursts
Redshift
most distant quasar (z=6.43)
most distant galaxy (z=6.96)
GRB 090423 (z=8.2)
Z = 9.38 GRB 090429B

GRB 090429B

Z = 9.38

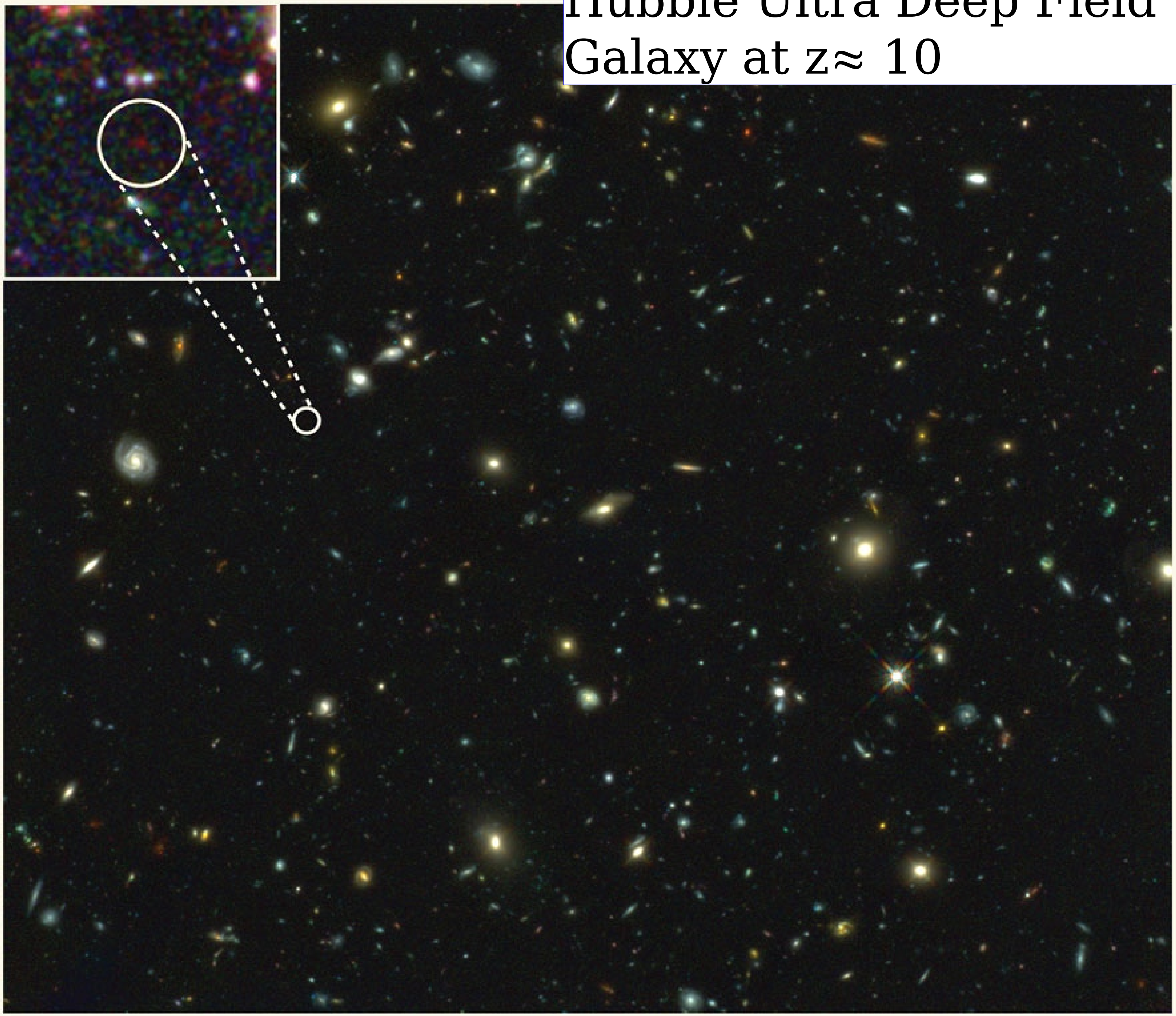
9.06 < z < 9.52 (90 % C.L)

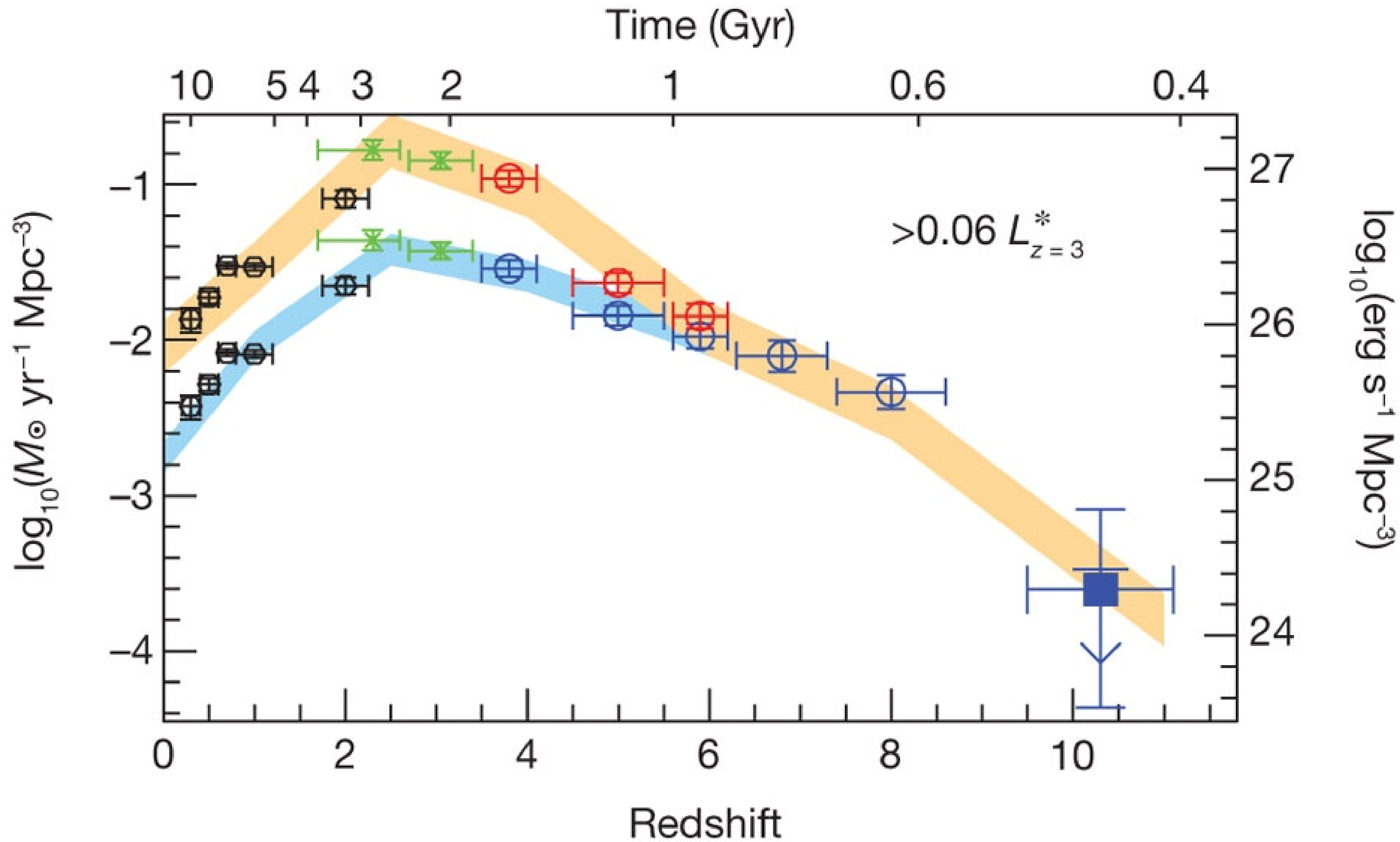




... Galaxy beat GRB's ...

Hubble Ultra Deep Field HUD09
Galaxy at z≈ 10



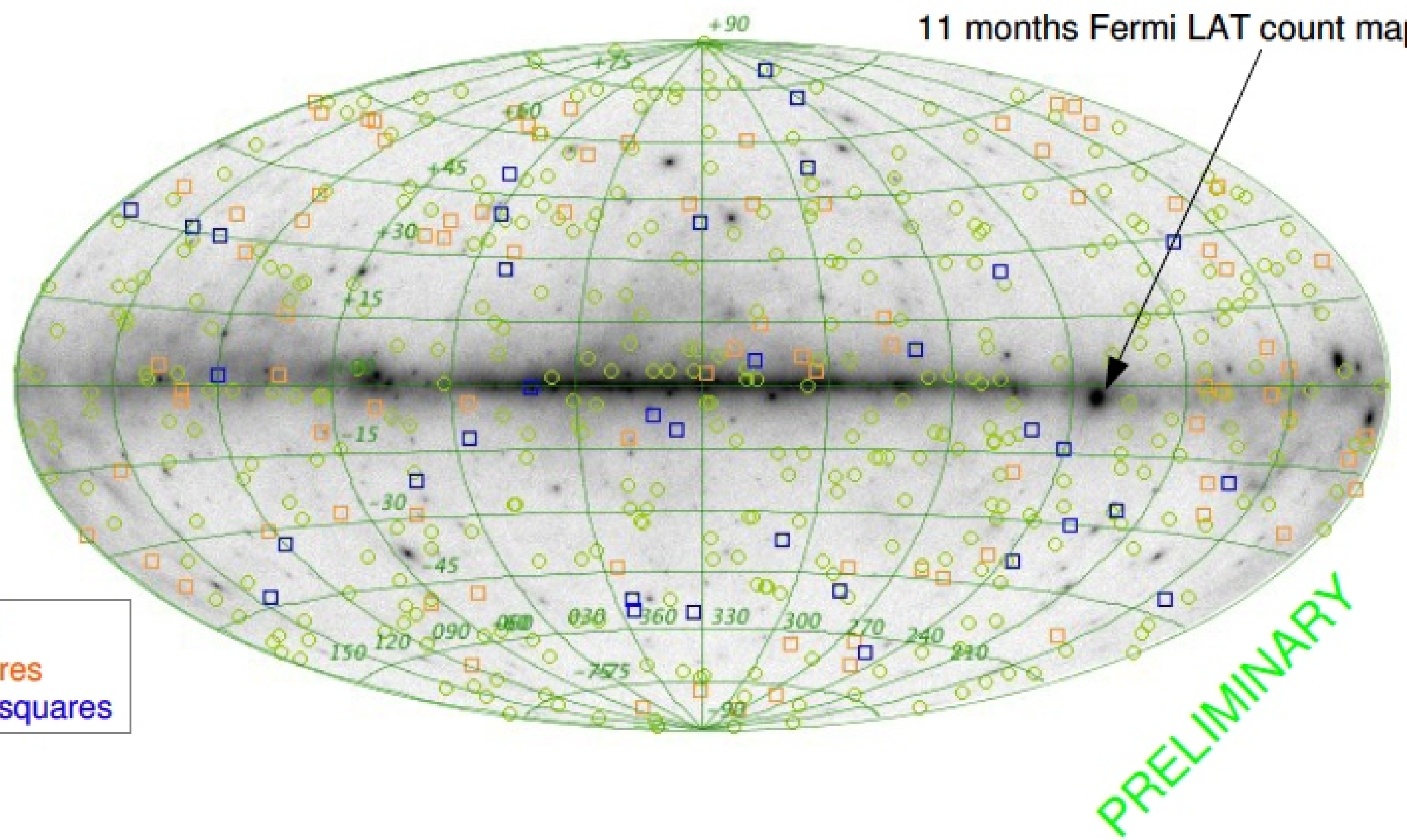


The first stars...

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 ($\sim$10%) at this time than it is just $\sim$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.

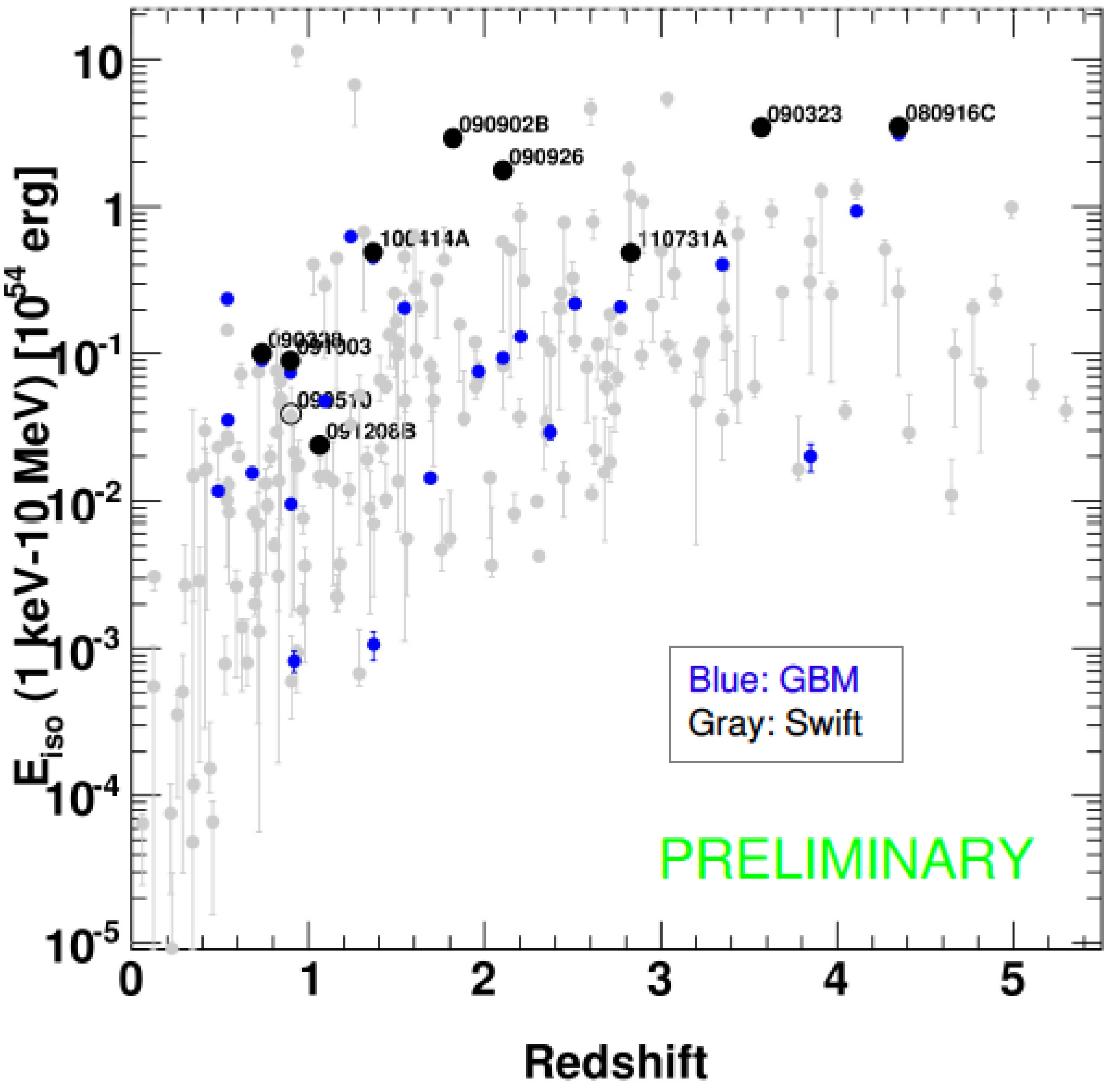
Fermi GRB detection statistics

GBM 2-year catalog
LAT 3-year catalog

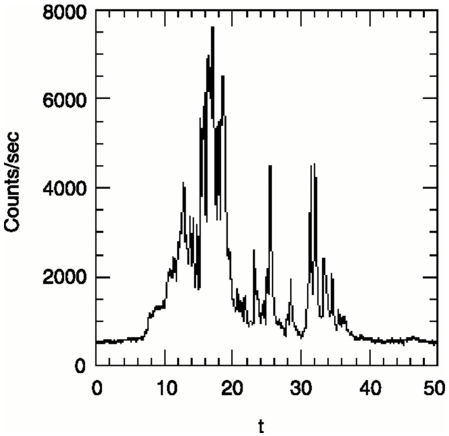


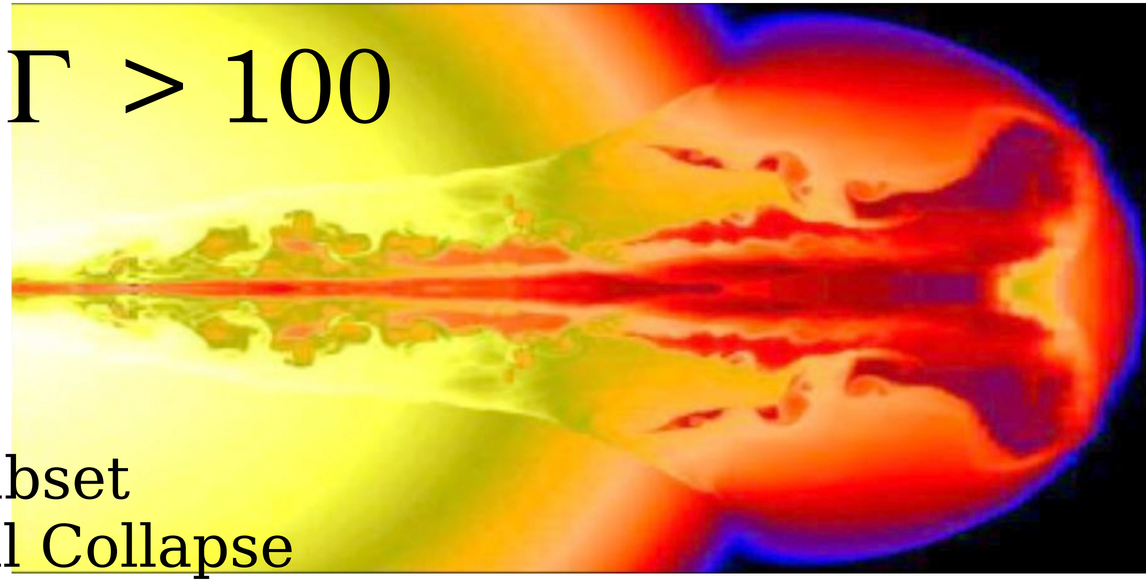
GBM LGRB: green circles
GBM SGRB: orange squares
LAT detections (35): blue squares

- The GBM detects ~250 GRBs / year, ~half in the LAT FoV
- The LAT detected 35 GRBs in 3 years (30 long, 5 short), including 7 "LLE-only" GRBs
  - ~Half with more accurate follow-up localisations by Swift and ground-based observatories (GROND, Gemini-S, Gemini-N, VLT)
  - 9 redshift measurements, from z=0.74 (GRB 090328) to z=4.35 (GRB 080916C)

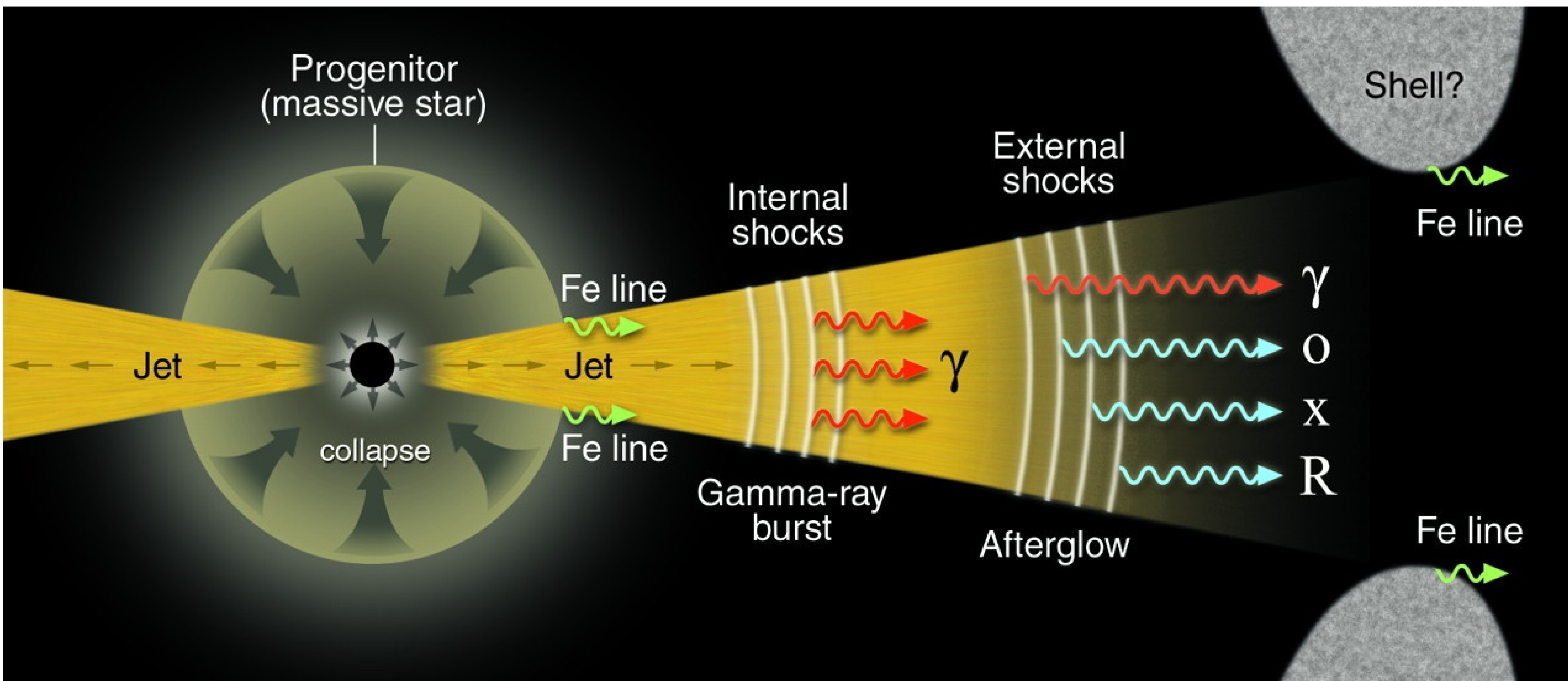


- 9 GRBs with redshift
- E_{iso} (1 keV-10 MeV) in "GBM" time window vs. redshift
  - LAT GRBs vs. GBM (Goldstein et al. 2012) and Swift (Butler et al. 2007) samples
- LAT GRBs are among the most energetic bursts
- GRB 090510 is also one of the most energetic short bursts
- No particular trend in redshift (small sample)

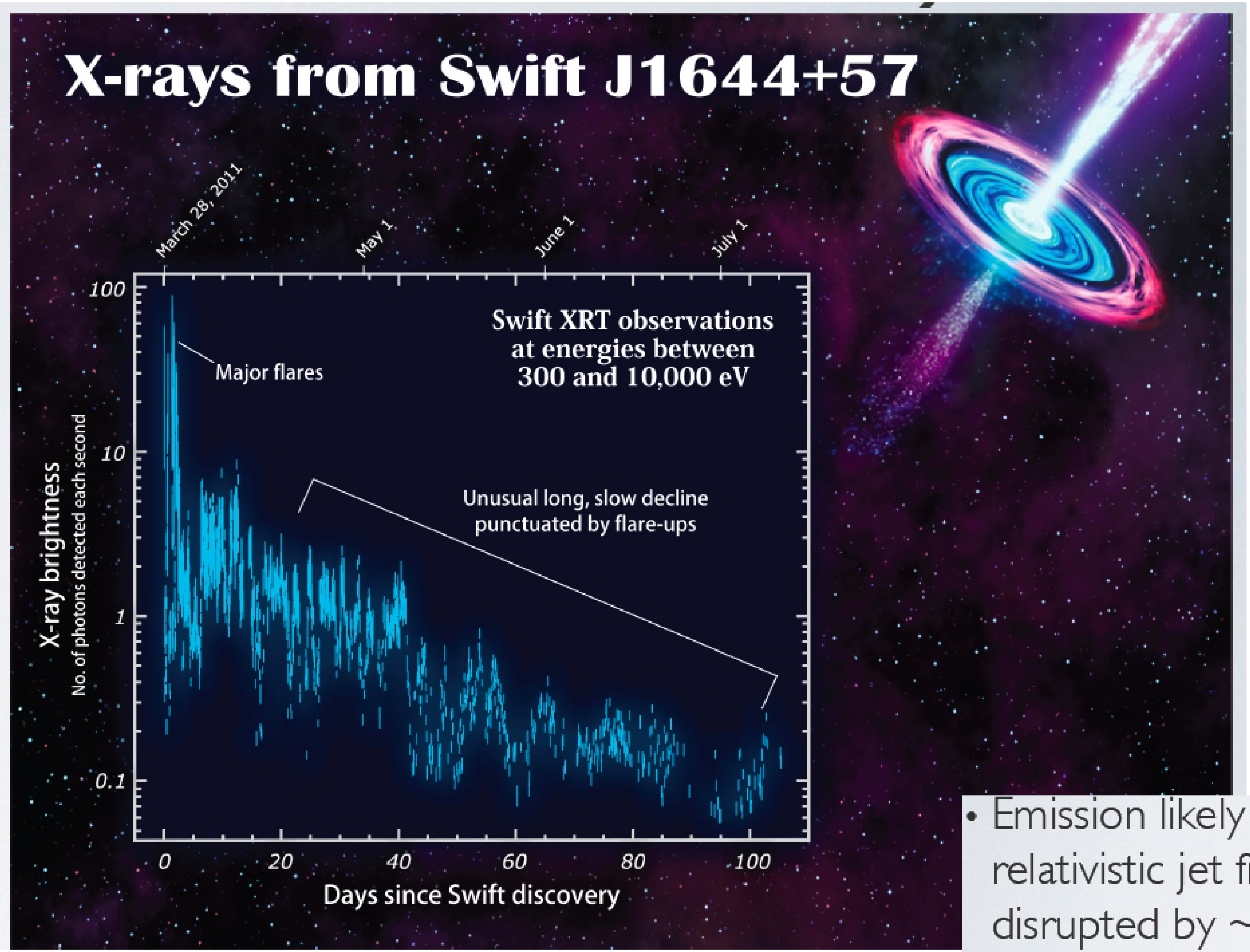




GRB : associated with a subset
of SN Stellar Gravitational Collapse



Tidal Disruption Events (initially mistaken for GRBs)



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

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]