LATTES Science Case

Surveying Unexplored Energy Domains

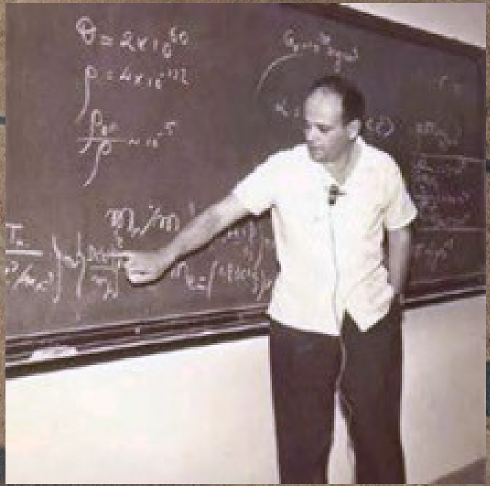
Giovanni La Mura

on behalf of the LATTES team

LATTES: MVA Workshop, Granada, September 14th 2018

Gamma-ray Astrophysics in multi-messenger era

- Status of gamma-ray observations
- Galactic Astrophysics
- Extragalactic Astrophysics
- How LATTES can contribute
- Concluding remarks



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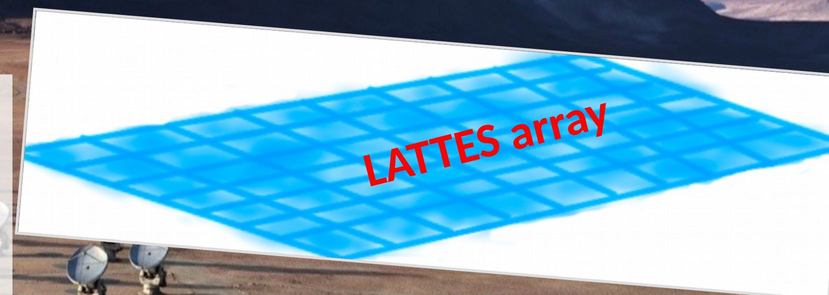

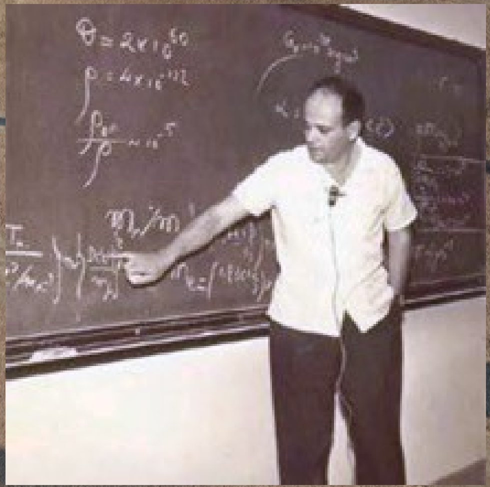

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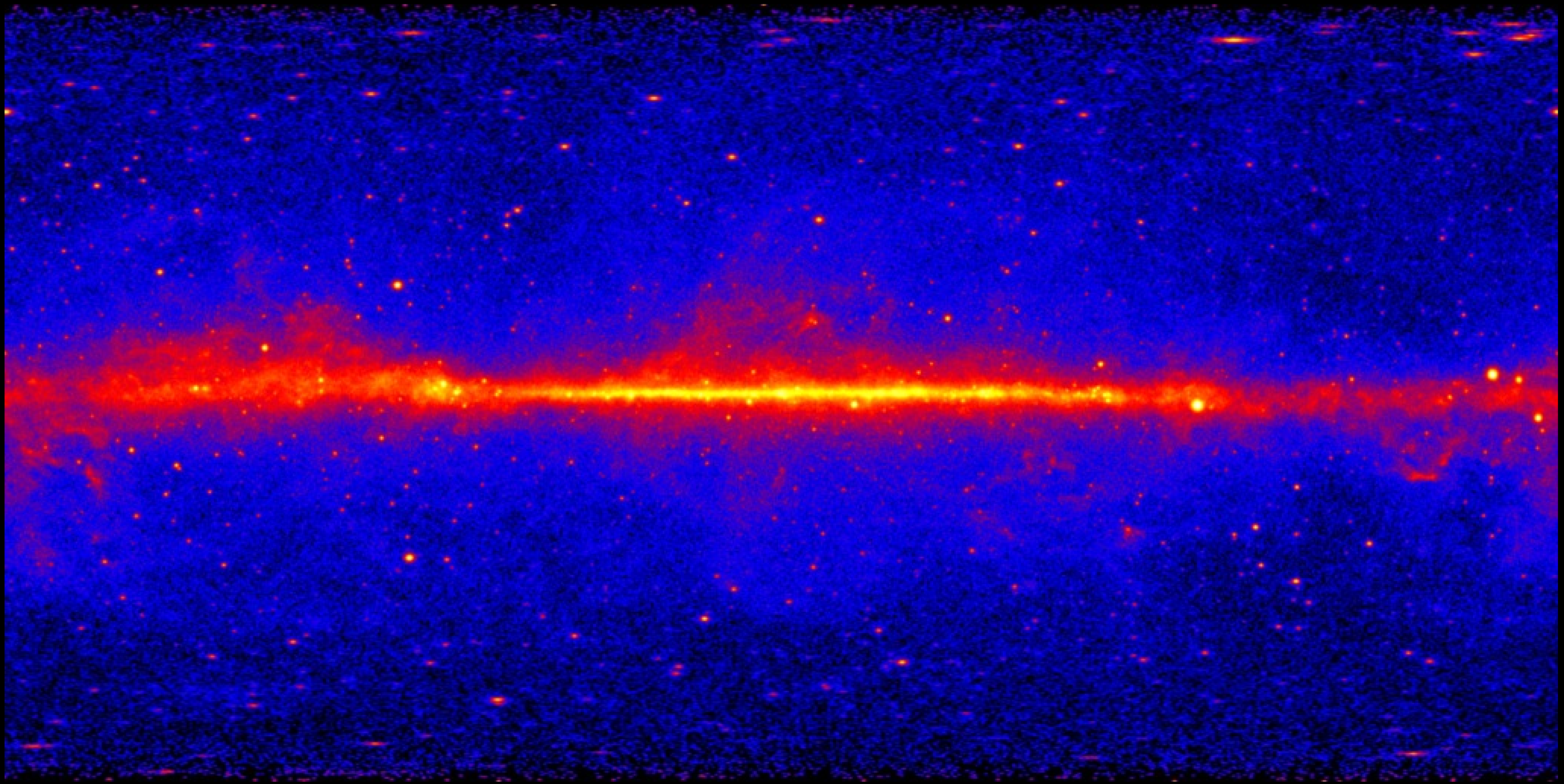
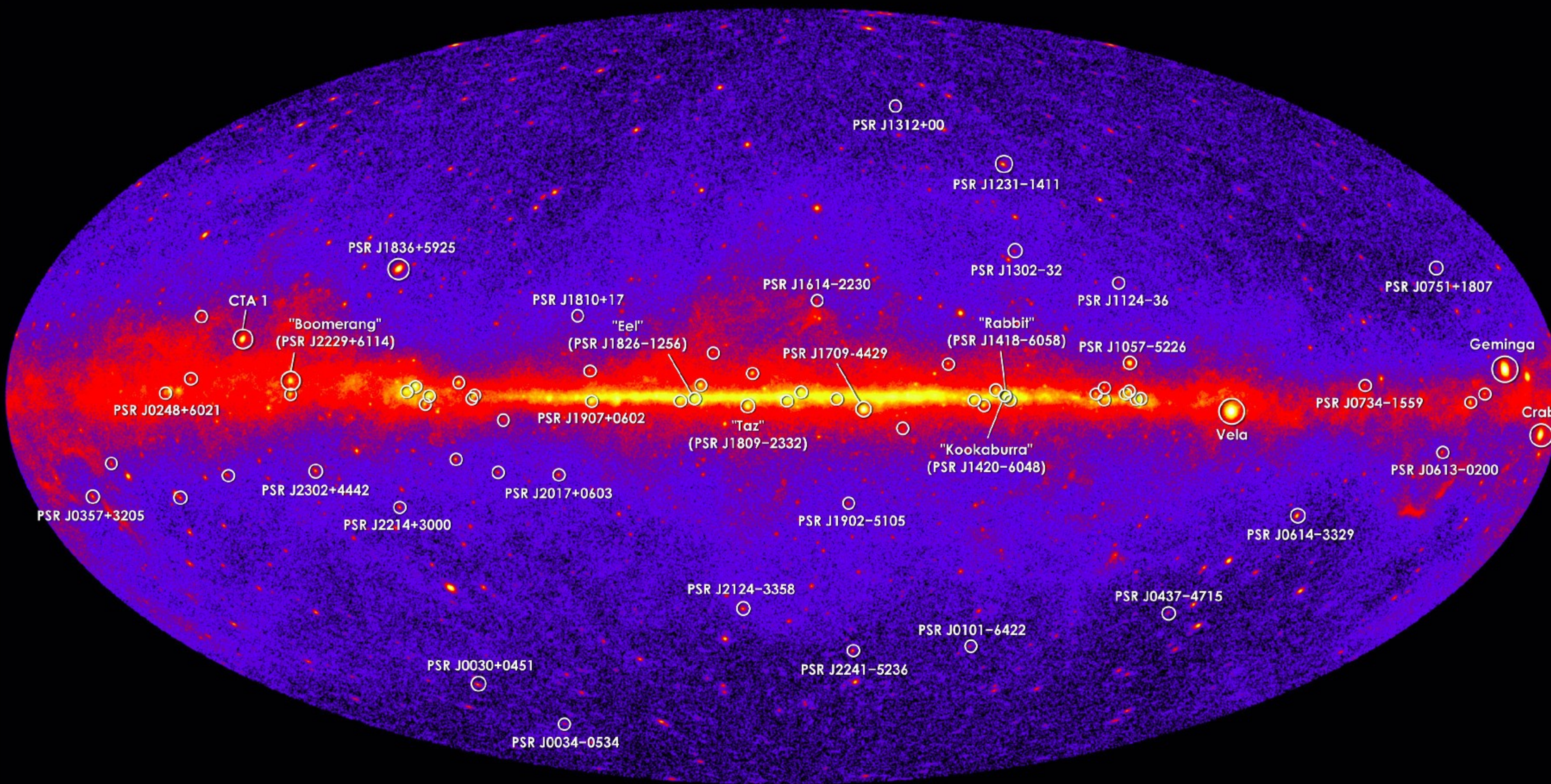
Status of Gamma-ray Observations



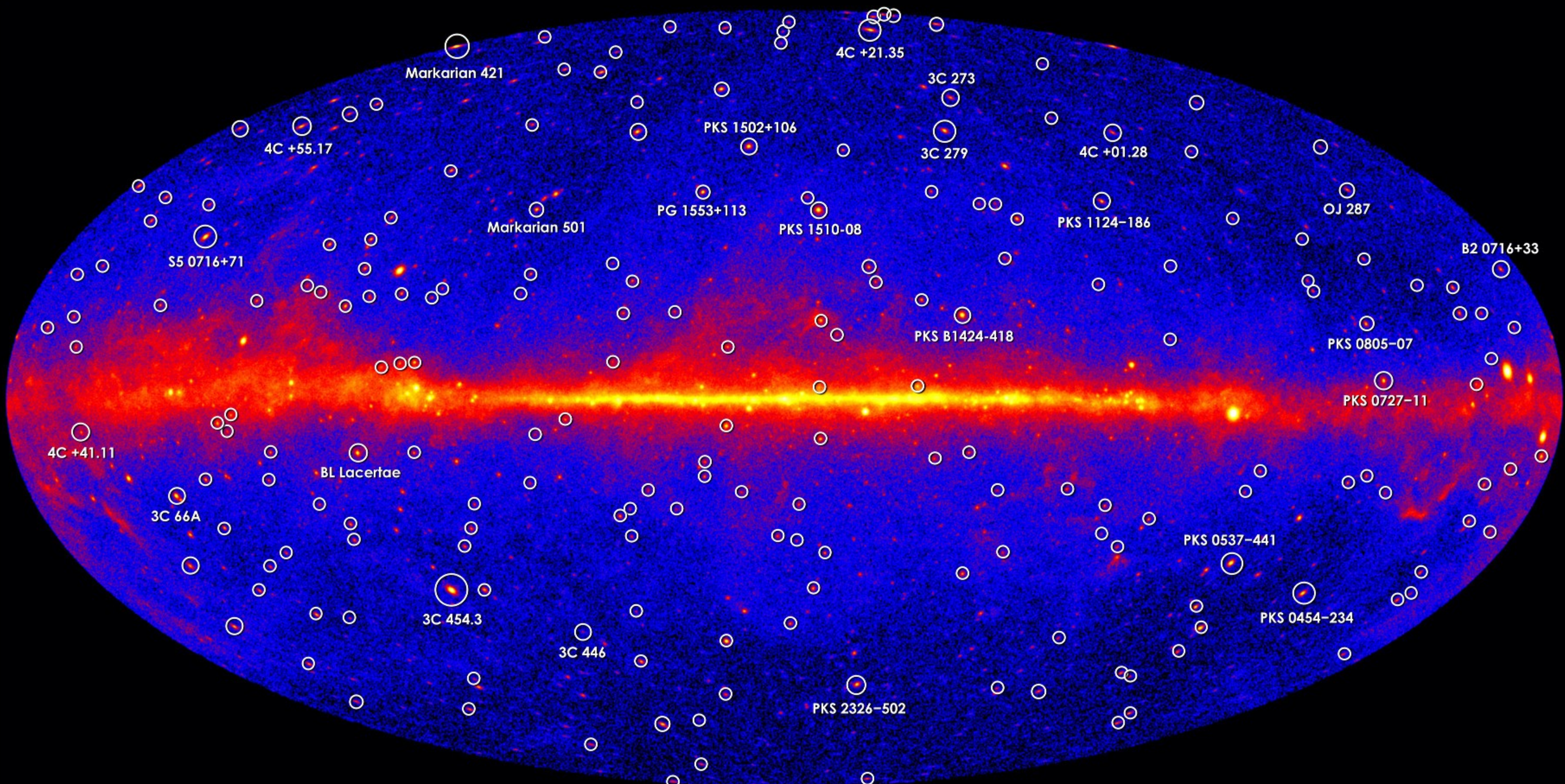
All-sky Cartesian projection of the Fermi/LAT gamma-ray observations above 1 GeV in photon energy, achieved after 5 years of monitoring. This is, to date, the **deepest published view** of the High-energy sky.

Status of Gamma-ray Observations



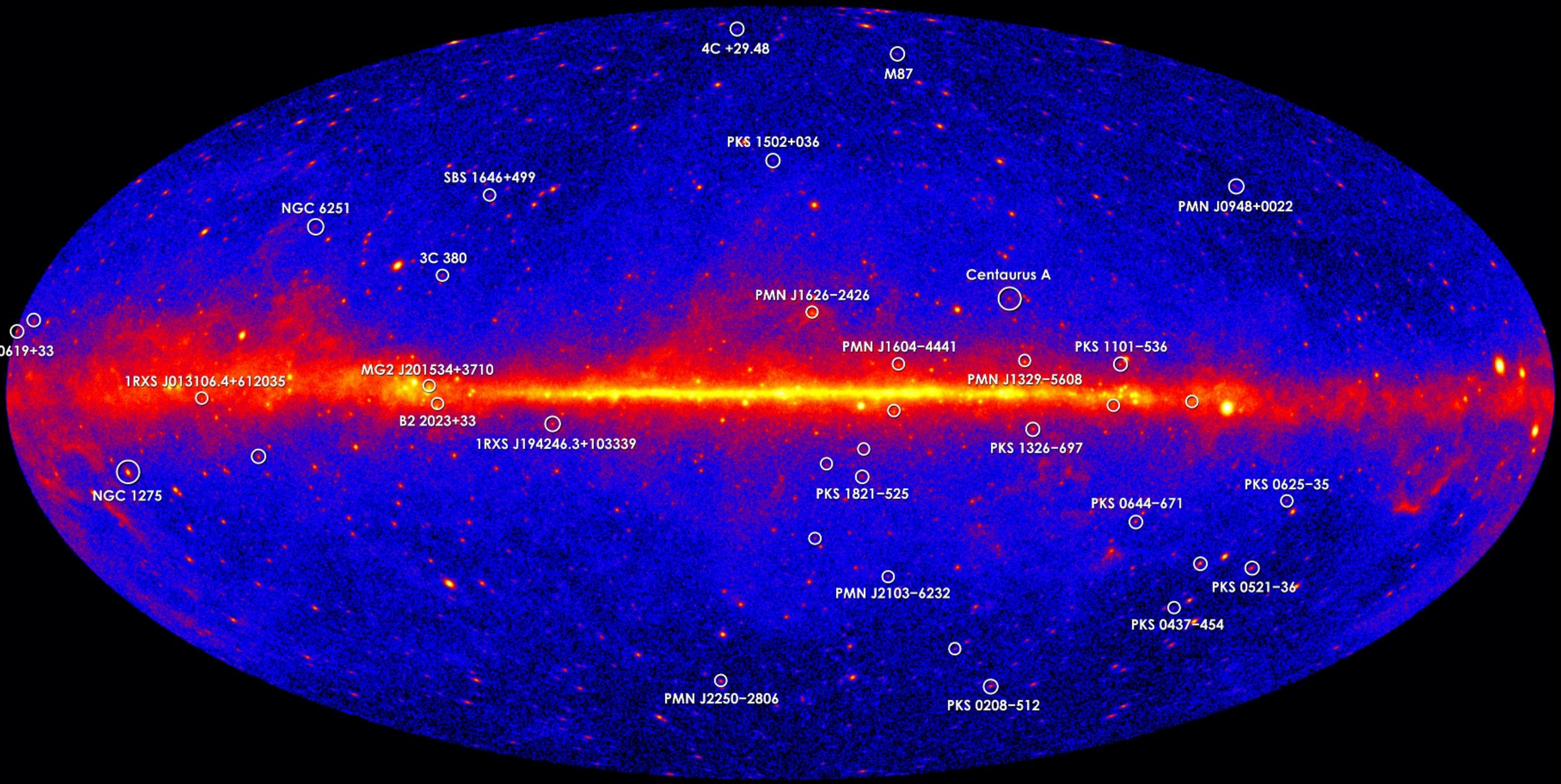
Distribution of the Fermi/LAT detected **pulsars**. They are the strongest Galactic point-like sources and they cluster close to the Galactic plane. Vela is the brightest in this family.

Status of Gamma-ray Observations



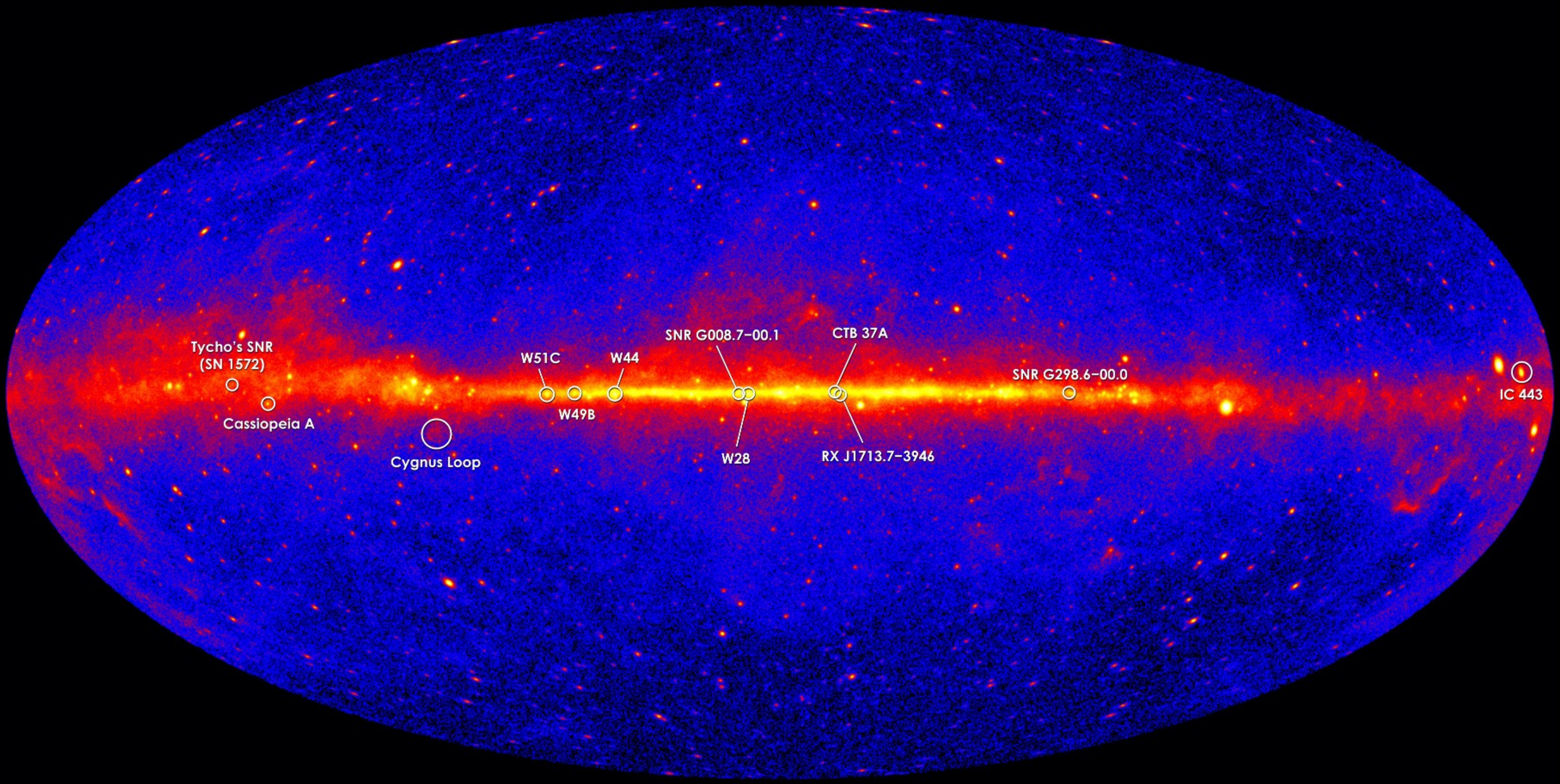
Map of the Fermi/LAT detected **BLAZARs**. These represent a specific class of Active Galactic Nuclei and they are the strongest long-lived Extragalactic sources, distributed in a nearly isotropic population.

Status of Gamma-ray Observations



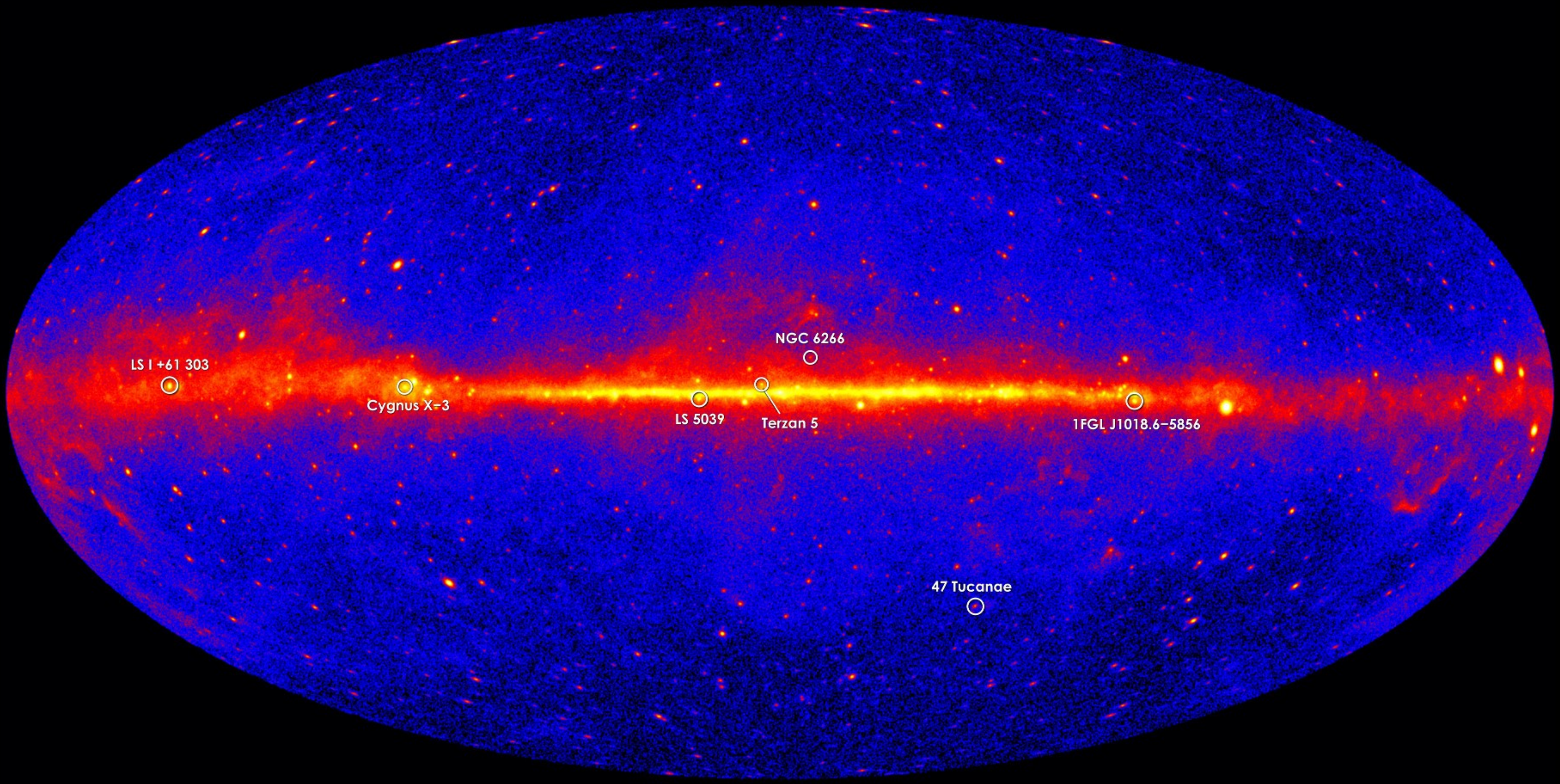
More general **Active Galaxies**, though intrinsically more frequent than BLAZARs, are under-represented in the gamma-ray sky. This is connected to the (not yet completely understood) gamma-ray production mechanism.

Status of Gamma-ray Observations



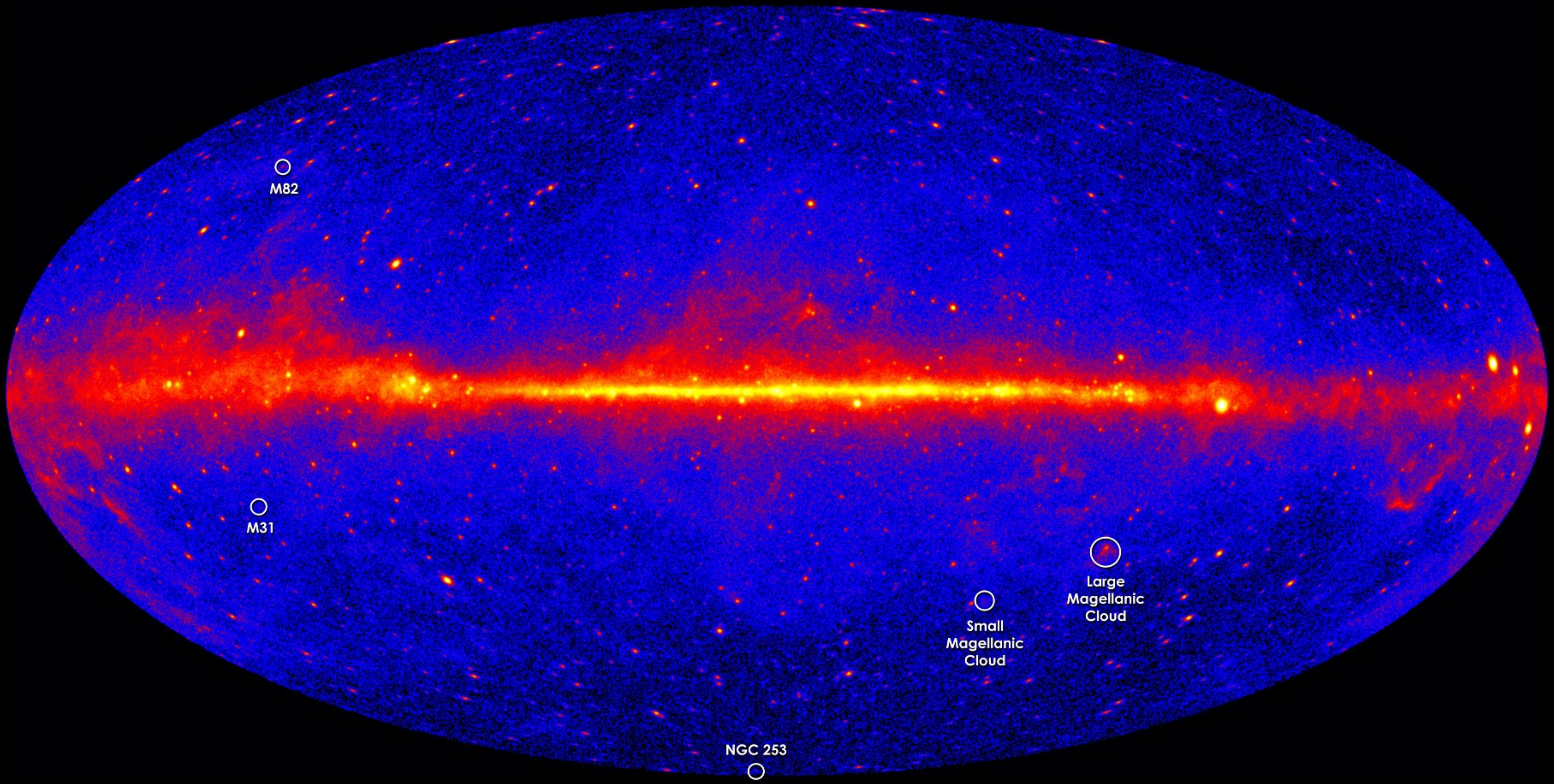
Super-nova Remnants are the most luminous known extended sources (putting aside the diffuse ISM glow). They are exclusively located in the Galactic Plane and, cosmologically speaking, represent a class of short-lived objects

Status of Gamma-ray Observations



High-mass binaries, typically found in star forming regions and in Globular Clusters, are a probe of the formation and evolution of multiple stellar systems, whose role is becoming more and more relevant in Cosmology.

Status of Gamma-ray Observations



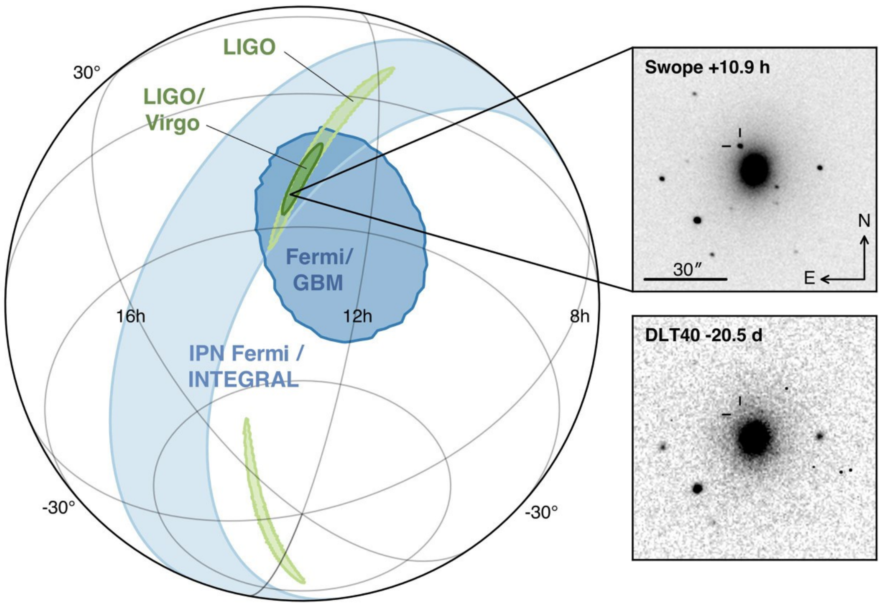
Some **normal galaxies** are also interesting gamma-ray sources. The stage is here dominated by the Milky Way and all the Physics of synchrotron, IC scattering, cosmic rays smashing in the ISM and other mechanisms producing gammas.

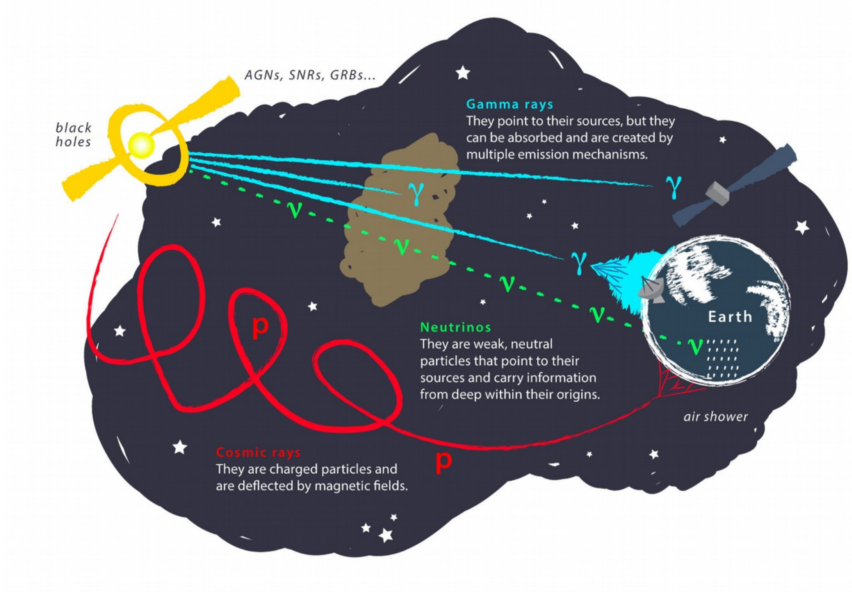
The era of multi-messenger observations

physicsworld BREAKTHROUGH OF THE YEAR 2017

Joint publication of LIGO, VIRGO, INTEGRAL, Fermi, IceCube, Pierre Auger …

Joint publication of Fermi, IceCube, MAGIC, HESS …





- Simultaneous observation of a Gravitational Wave + electromagnetic counterparts
- First detection of a VHE neutrino from a blazar flaring in gamma rays
- Study of transient phenomena **in all energy windows** is one of the main ingredients

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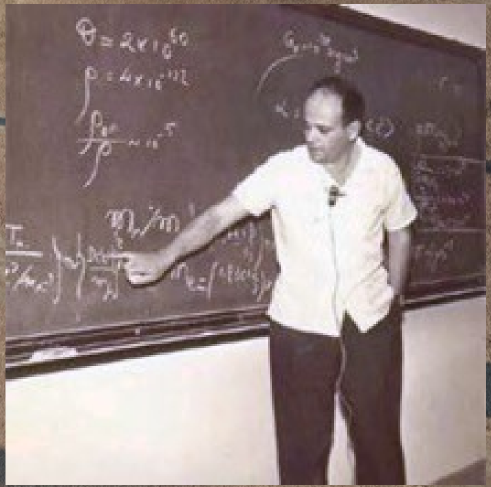

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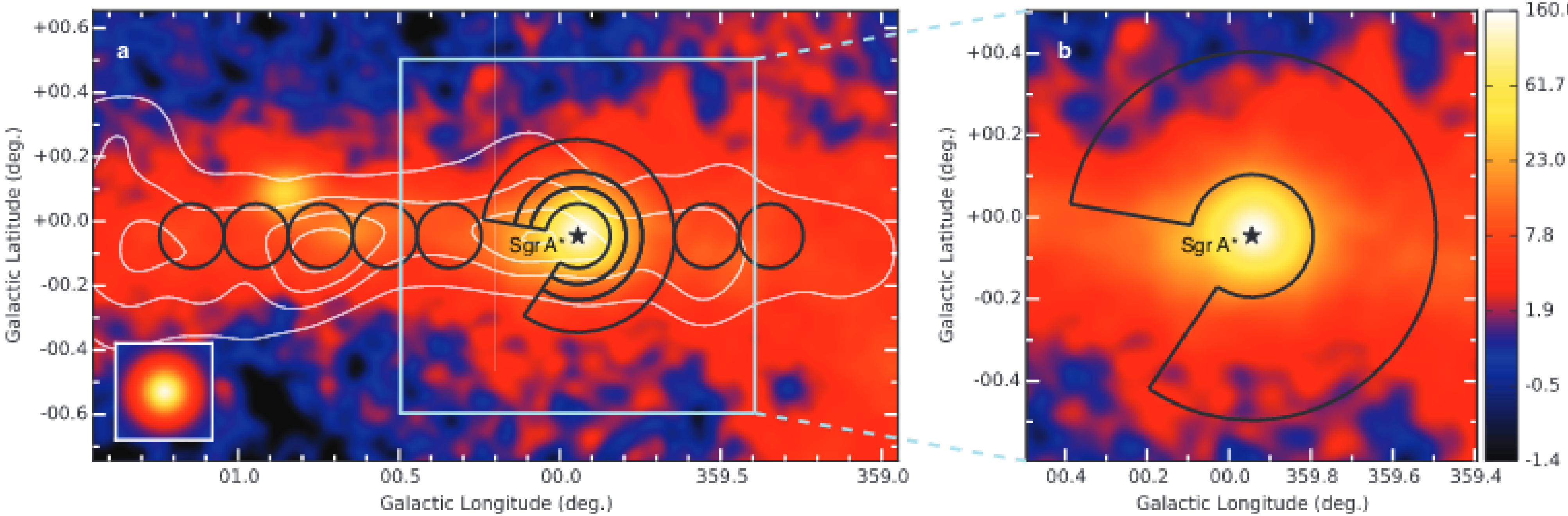
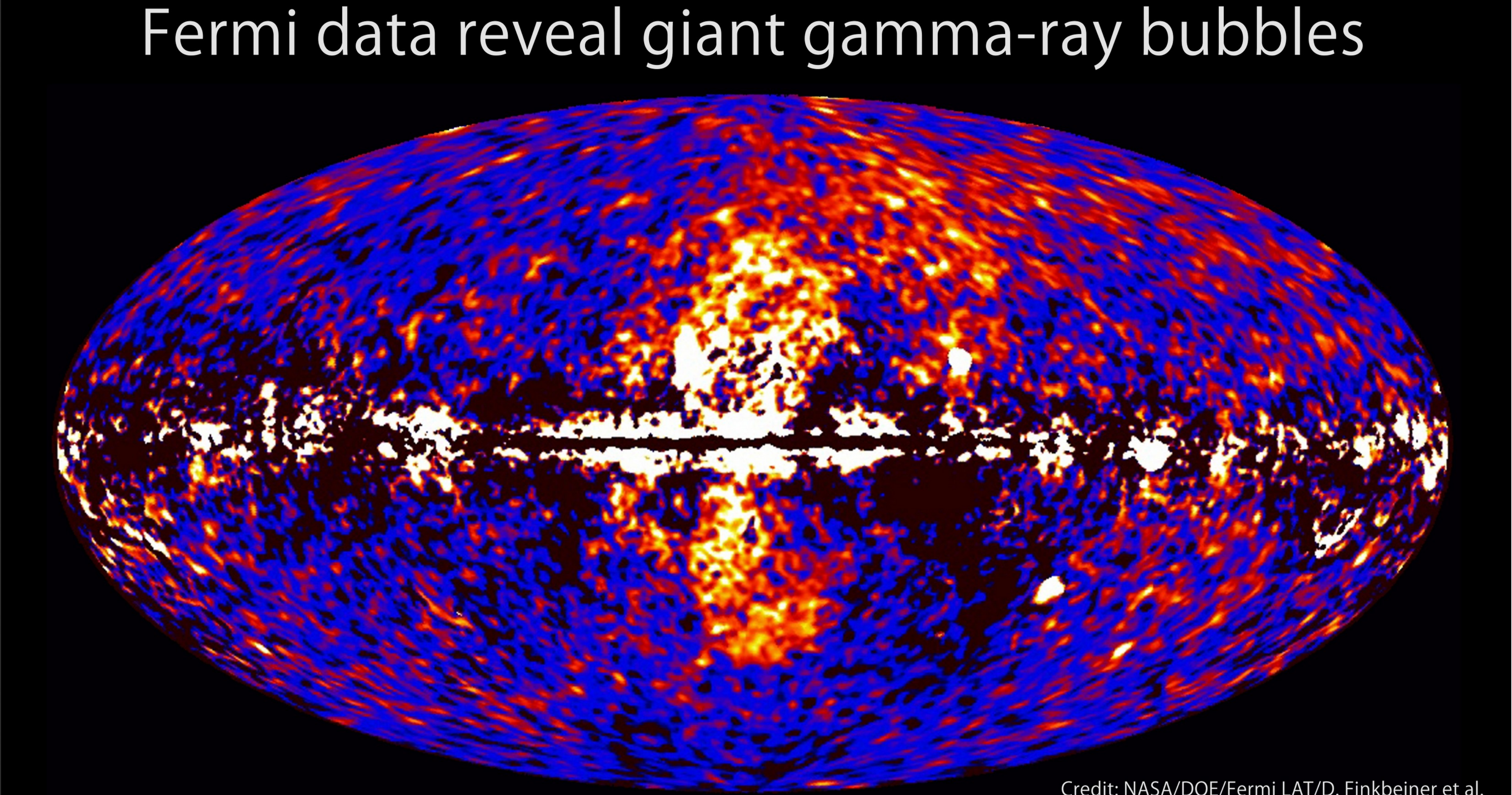
The Galactic Centre



A view of the Galactic Centre in the TeV domain, produced by a scan performed with HESS.

The Galactic Centre is an extremely complex region, expected site of the highest Dark Matter density in our vicinity, but also populated by stellar evolution remnants (neutron stars), the Sgr A* black hole, and dense clouds of gas, interacting with cosmic rays. It is identified as the site of a Pevatron (accelerator of particles up to the PeV domain).

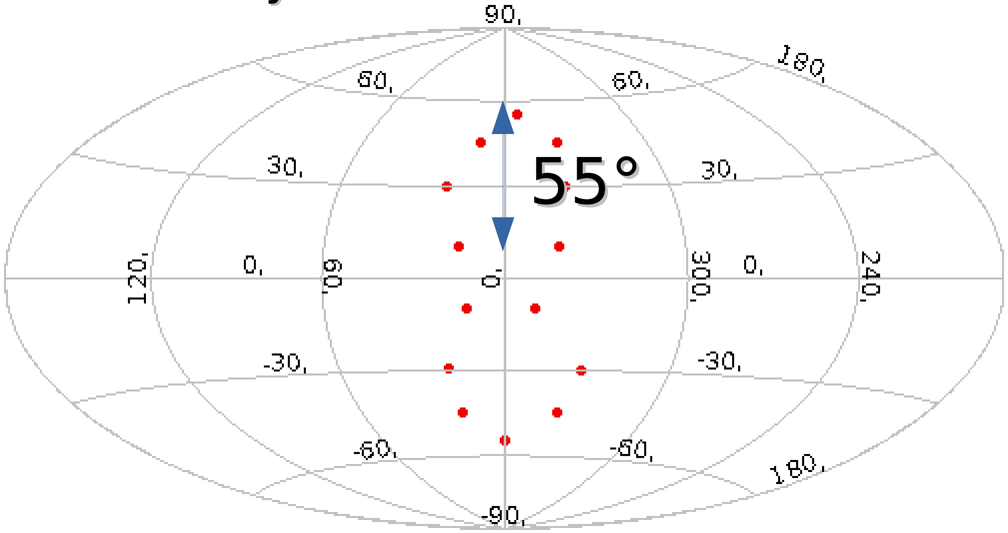
The *Fermi Bubbles*



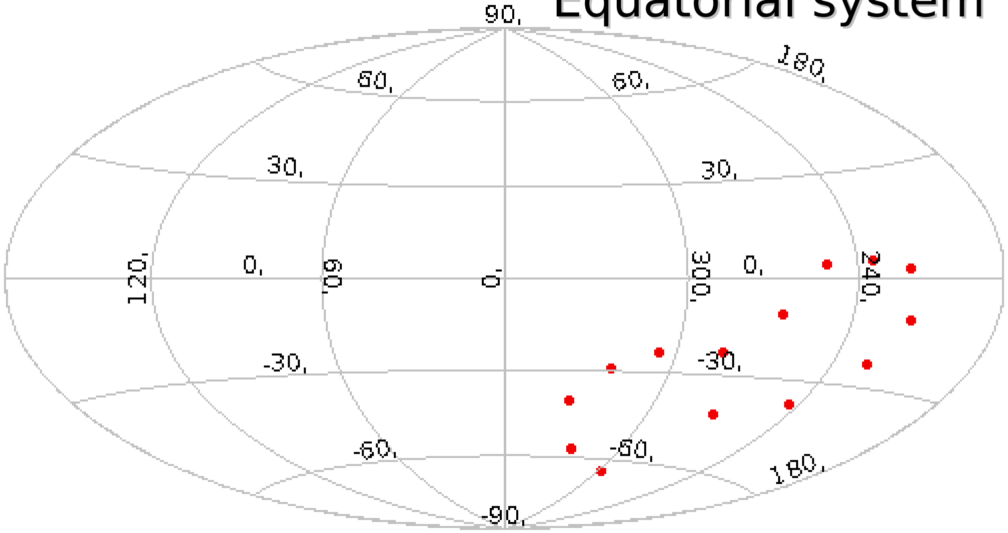
Fermi-LAT detected a glow of gamma-ray diffuse emission extending ~55° above and below the Milky Way centre. The spectrum is hard and the brightness nearly constant.

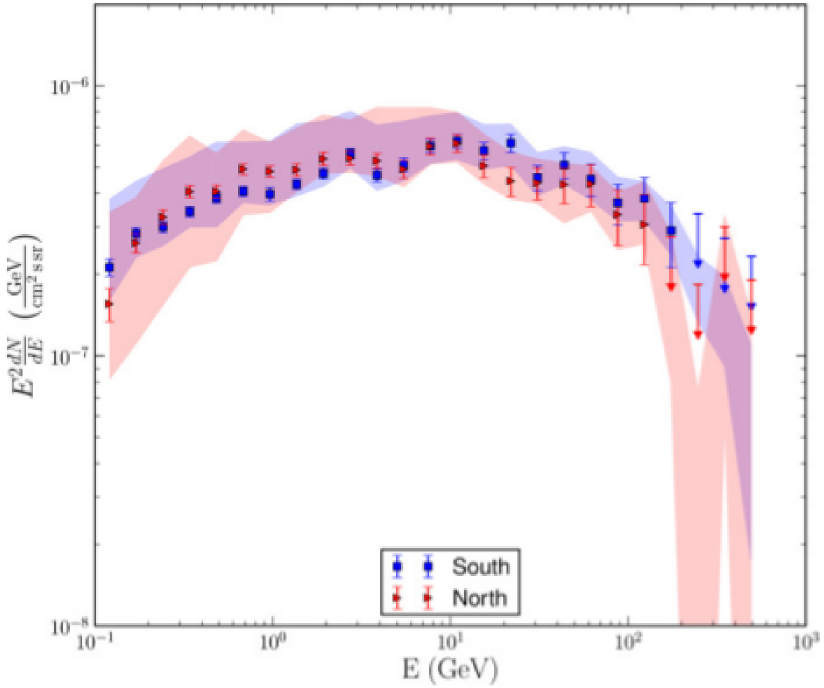
With its location in the Southern Hemisphere, LATTES is ideal to survey the Galactic Plane and the Galactic Centre regions

Galactic system



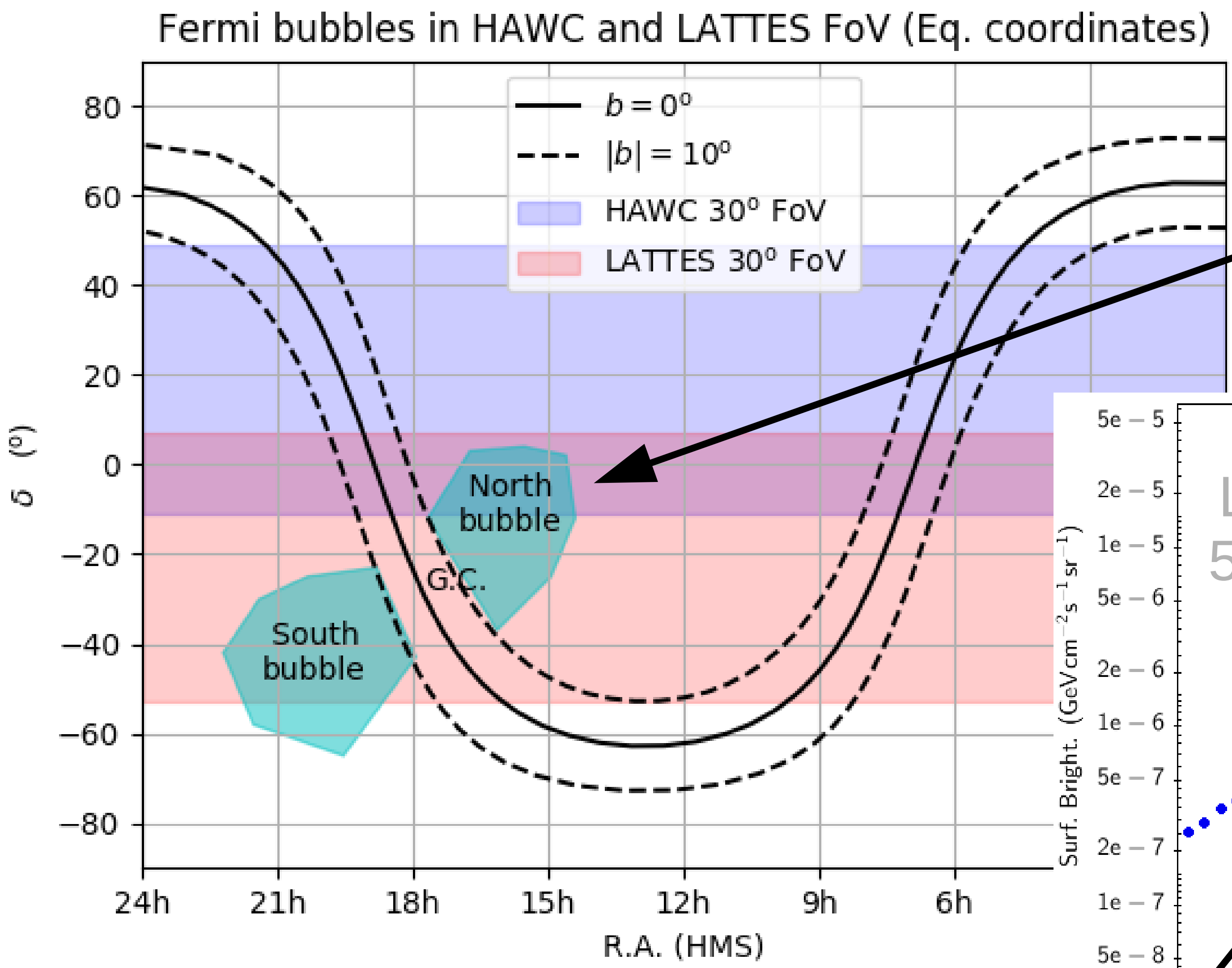
Equatorial system



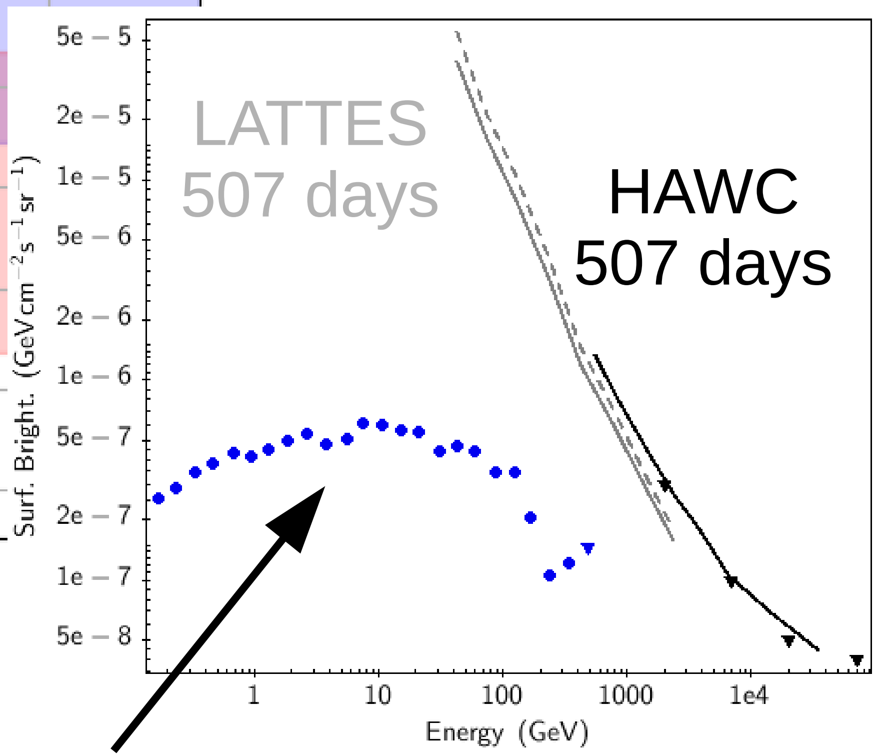


Origin of the gamma-ray emission is still unclear. The most likely spectra are log-parabola or hard cut-off power-law.
Cut-off may reside at **few 100 GeV.**
Spectrum is critical to discriminate **hadronic / leptonic** model.

The Fermi Bubbles: comparison with HAWC

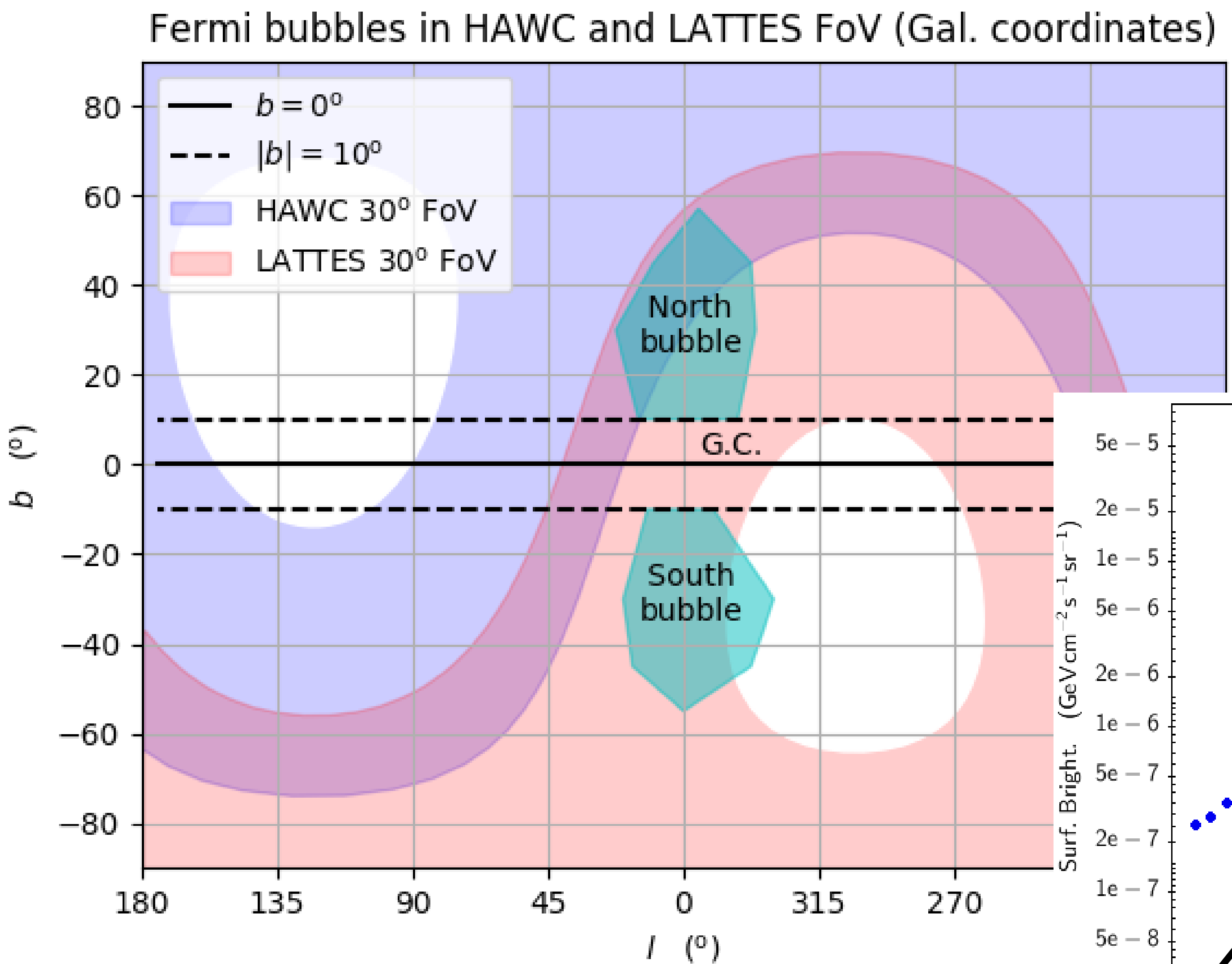


Estimate obtained assuming the **same integration area!**

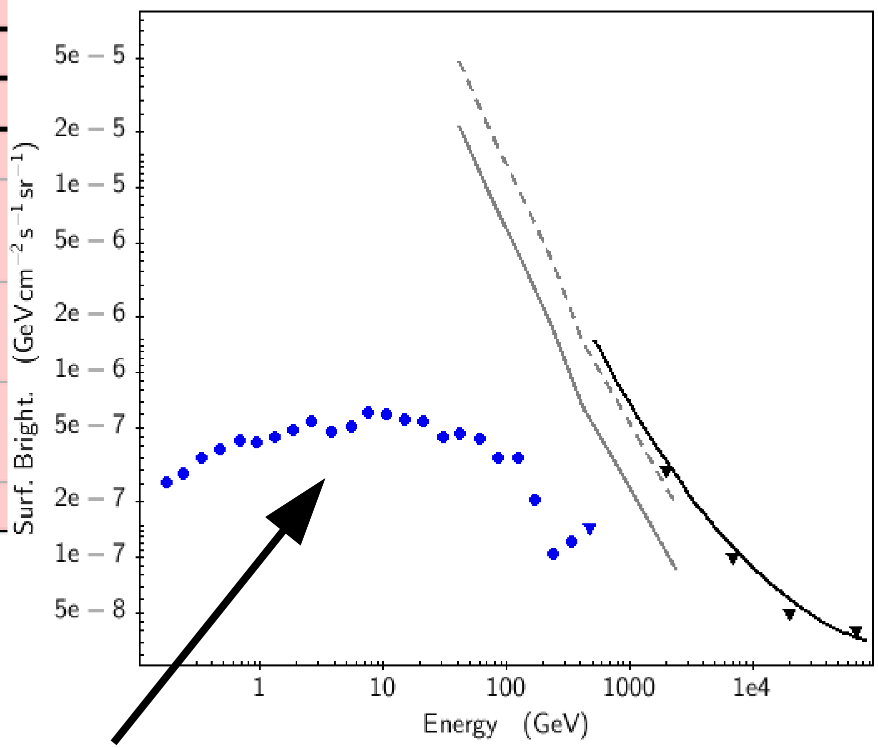


Fermi/LAT spectrum

The Fermi Bubbles: perspectives

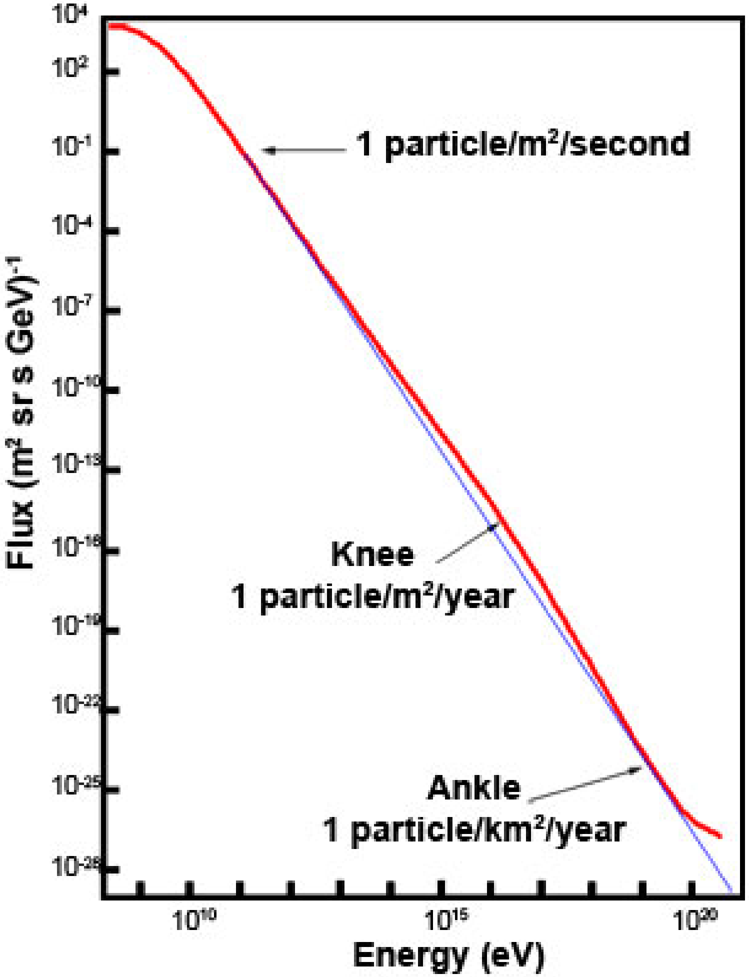


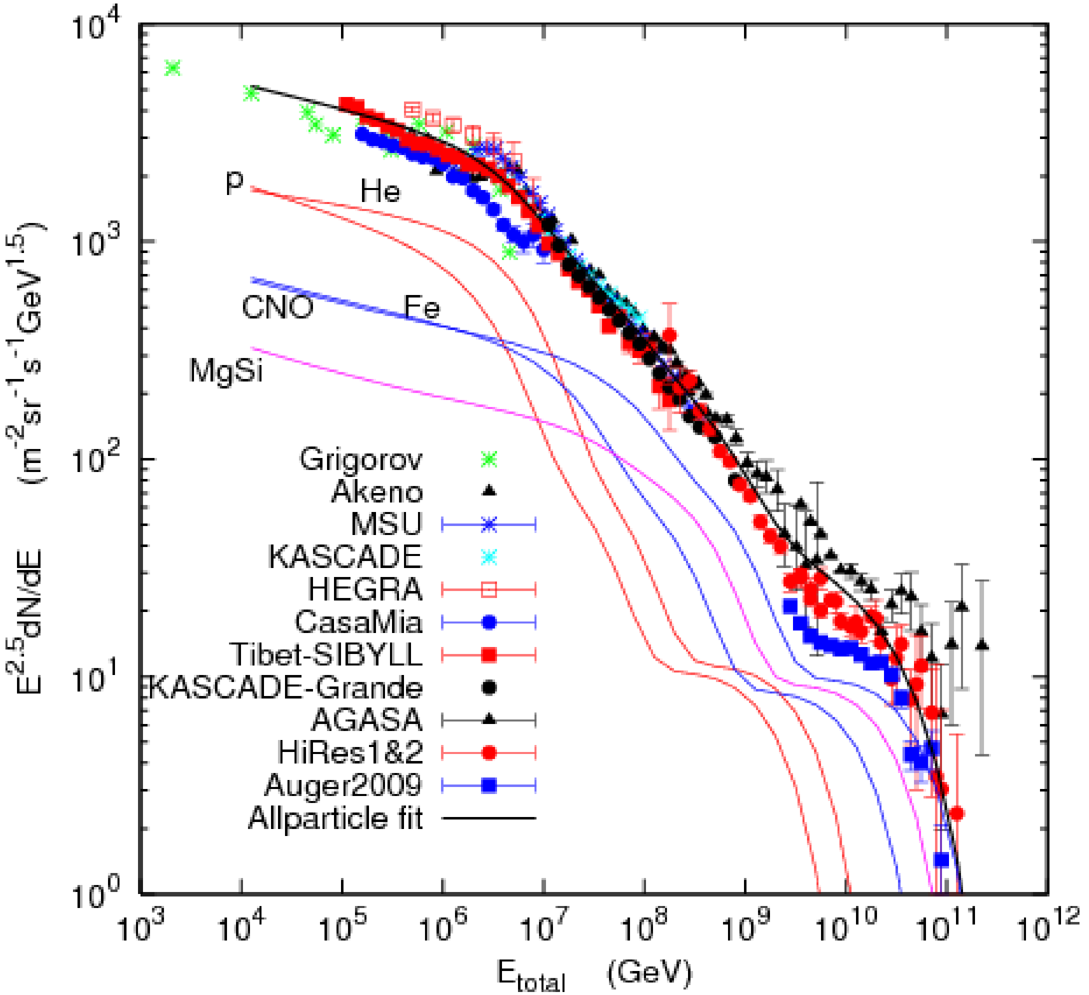
Accounting for integration over the whole visible structure



Fermi/LAT spectrum

Acceleration of Cosmic Rays





A full understanding of the acceleration sites of cosmic rays and their connection with the production of gamma rays is also related to the observed spectral features and to the possibility to extensively monitor the Galactic Plane and the Galactic Centre.

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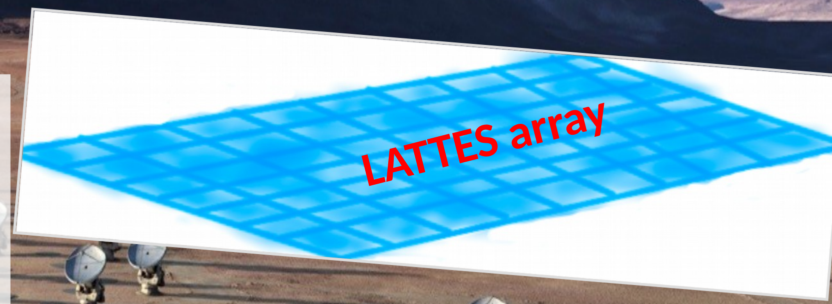

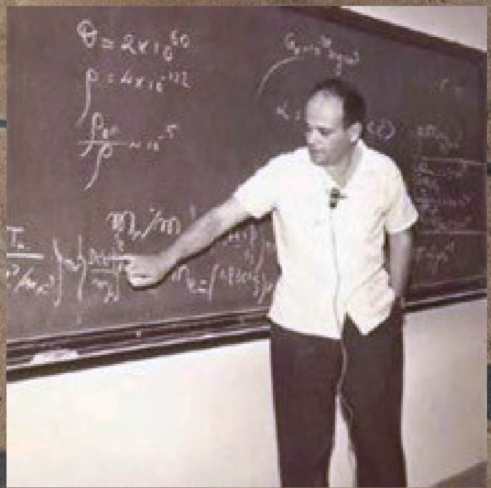

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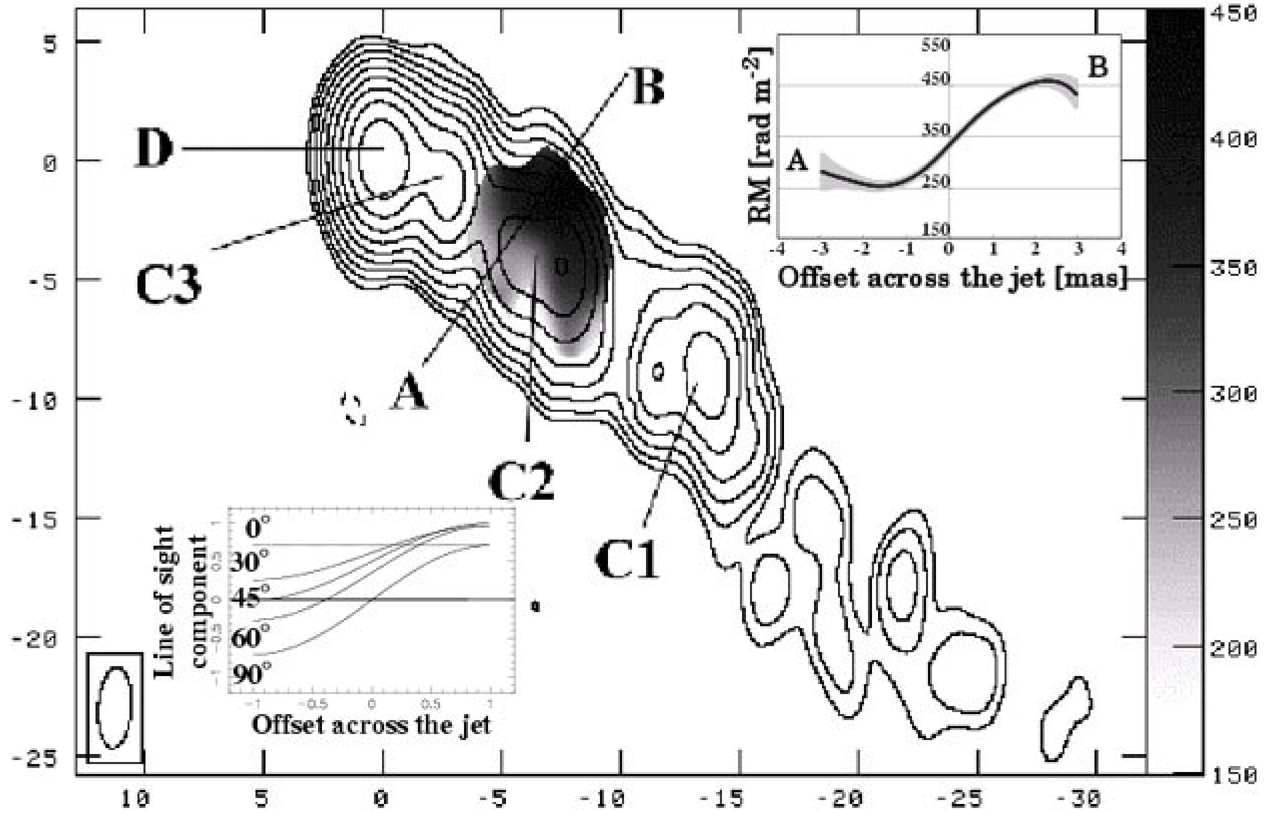
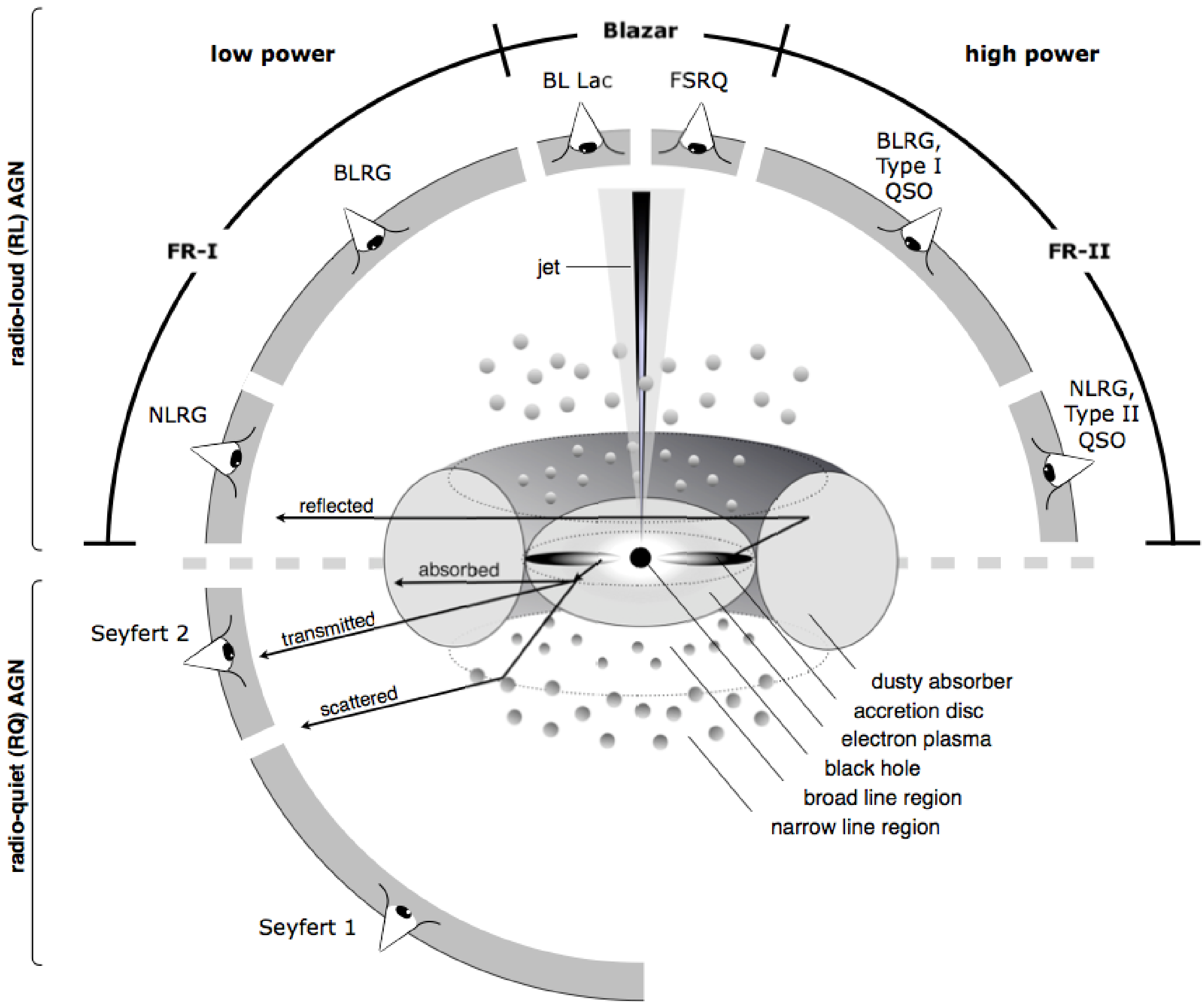
Jets from Active Galactic Nuclei



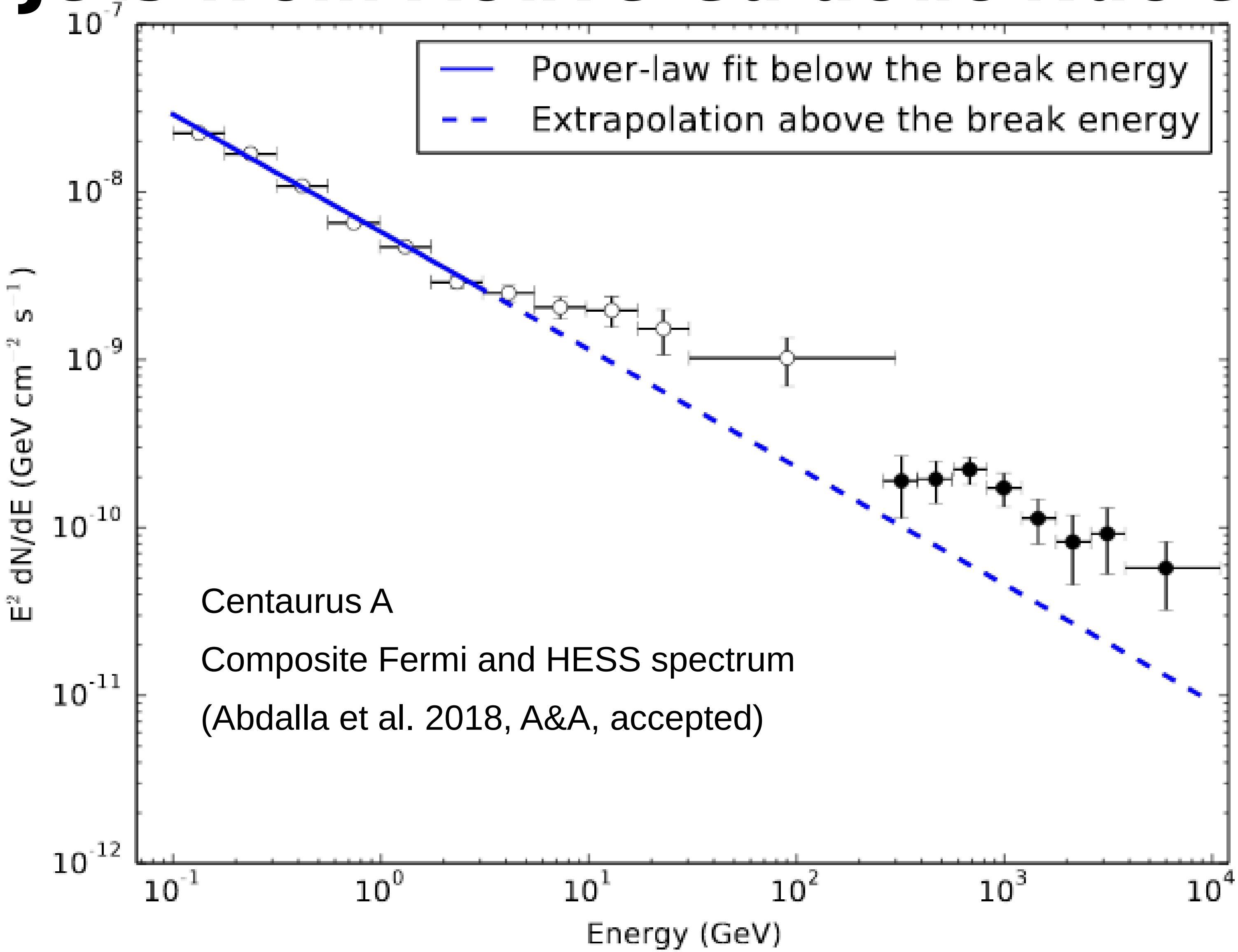
The **helical structure** of the magnetic field *B* in the jet of 3C 273, as detected by the variation of the **Faraday Rotation Measure** (RM, grey scale), super-imposed to the jet radio intensity map. The RM profile is extracted along the line of sight and across the jet, showing a twisted structure that takes part to the confinement of the jet plasma.

Jets from Active Galactic Nuclei



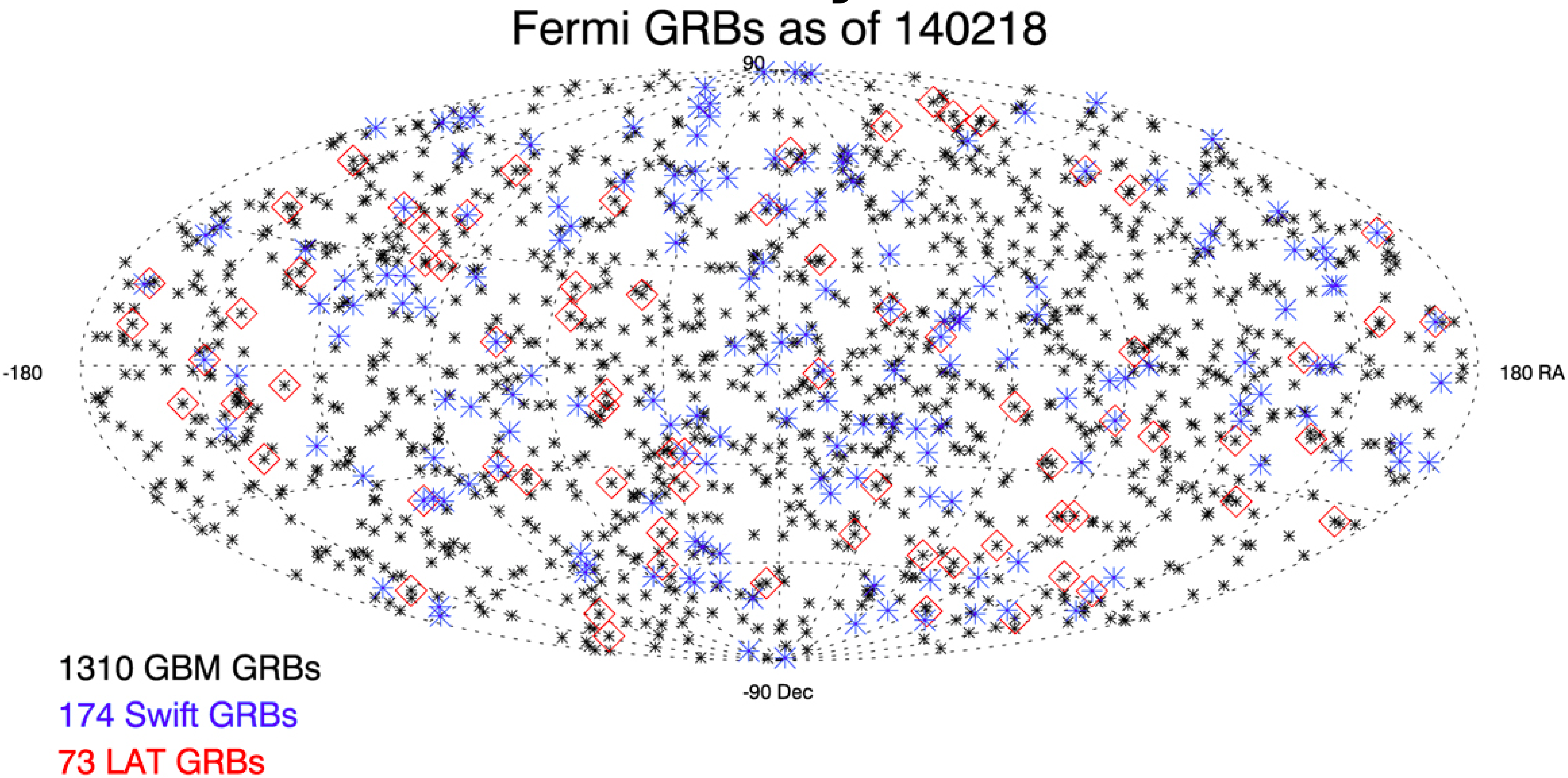
The relativistic jet is directly observed in hundreds of AGNs. It is the production site of most of the radio, X-ray and gamma-ray emission. It is a prominent feature of QUASARs and Radio Galaxies and, when seen along the axis, results in the form of a BLAZAR.

Jets from Active Galactic Nuclei



Jet Physics is not a proprietary field of BLAZARs: misaligned sources, such as Radio Galaxies, are fundamental to understand how the jet radiates. A monitoring instrument is necessary for this.

Gamma Ray Bursts



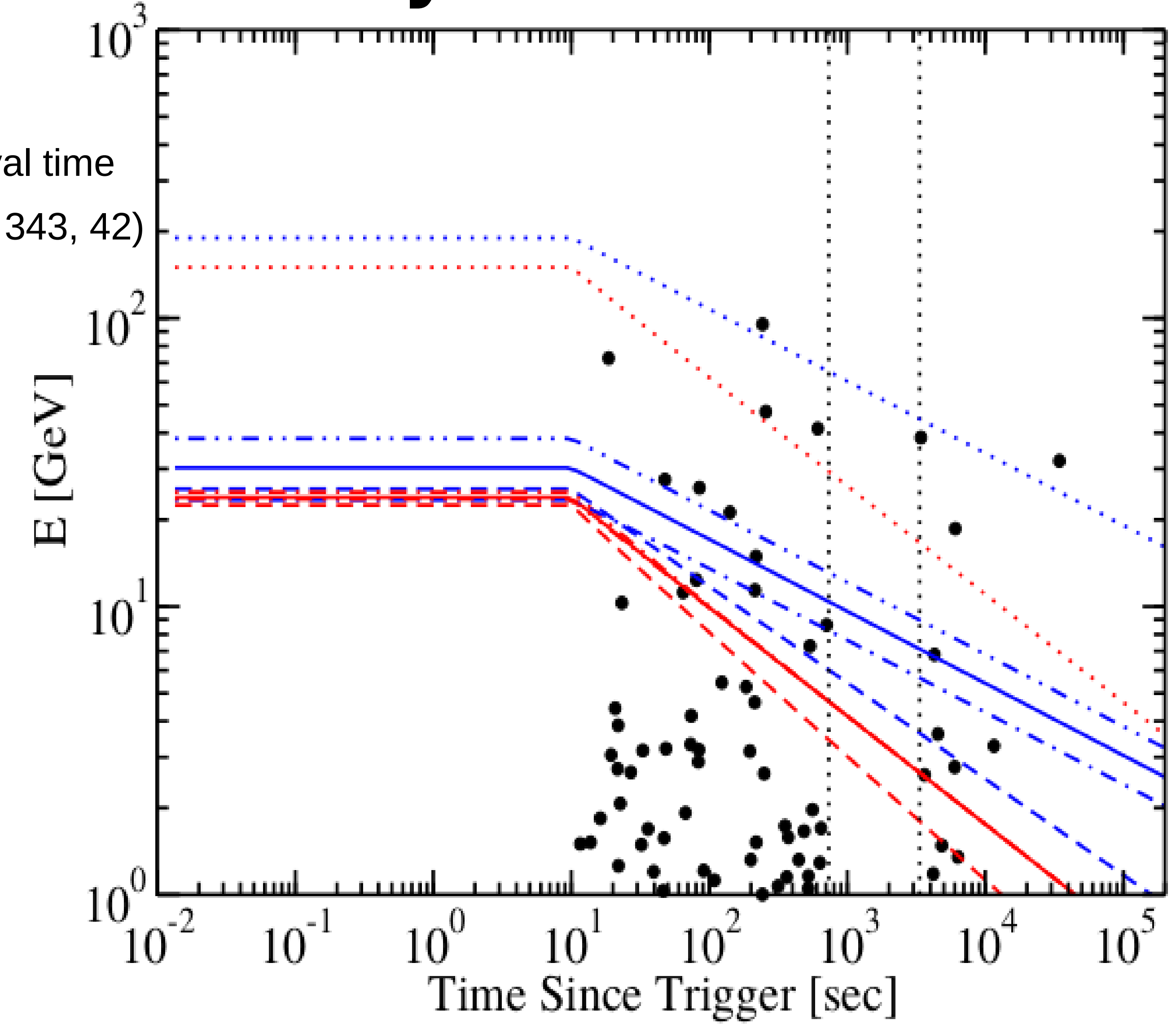
Gamma-ray Bursts are flashes of radiation occurring randomly in the sky. They last from less than 1s up to some hours. There is, on average, more than 1 event per day and their energy peak is typically in the sub-MeV domain.

Gamma Ray Bursts

GRB 130427A

Photon energy as function of arrival time

(Ackermann et al. 2013, Science, 343, 42)



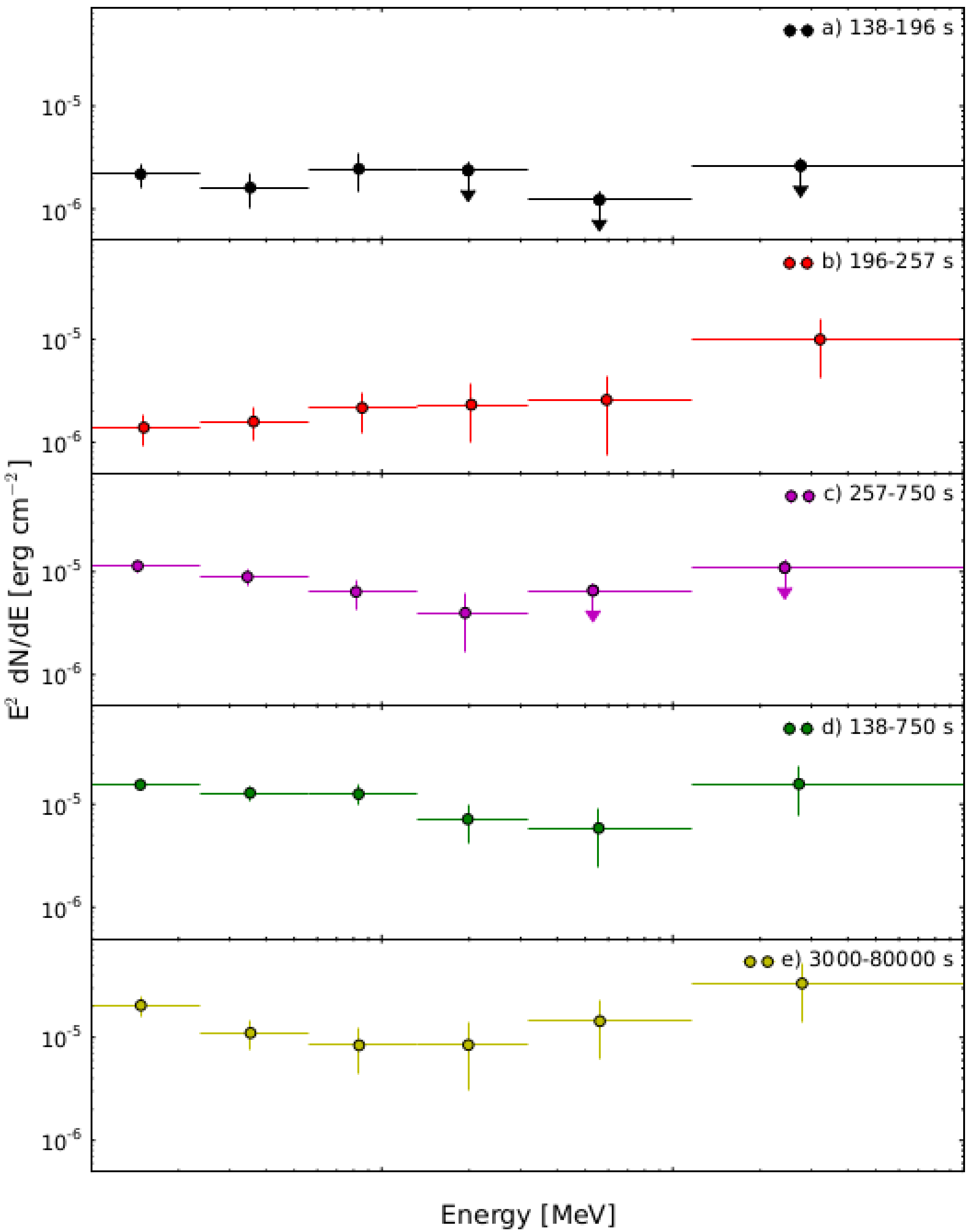
Some Gamma-ray Bursts have been shown to produce a glow of high-energy emission, typically tens to hundreds seconds after the main event trigger. This is likely due to the GRB blast wave interactions.

Gamma Ray Bursts

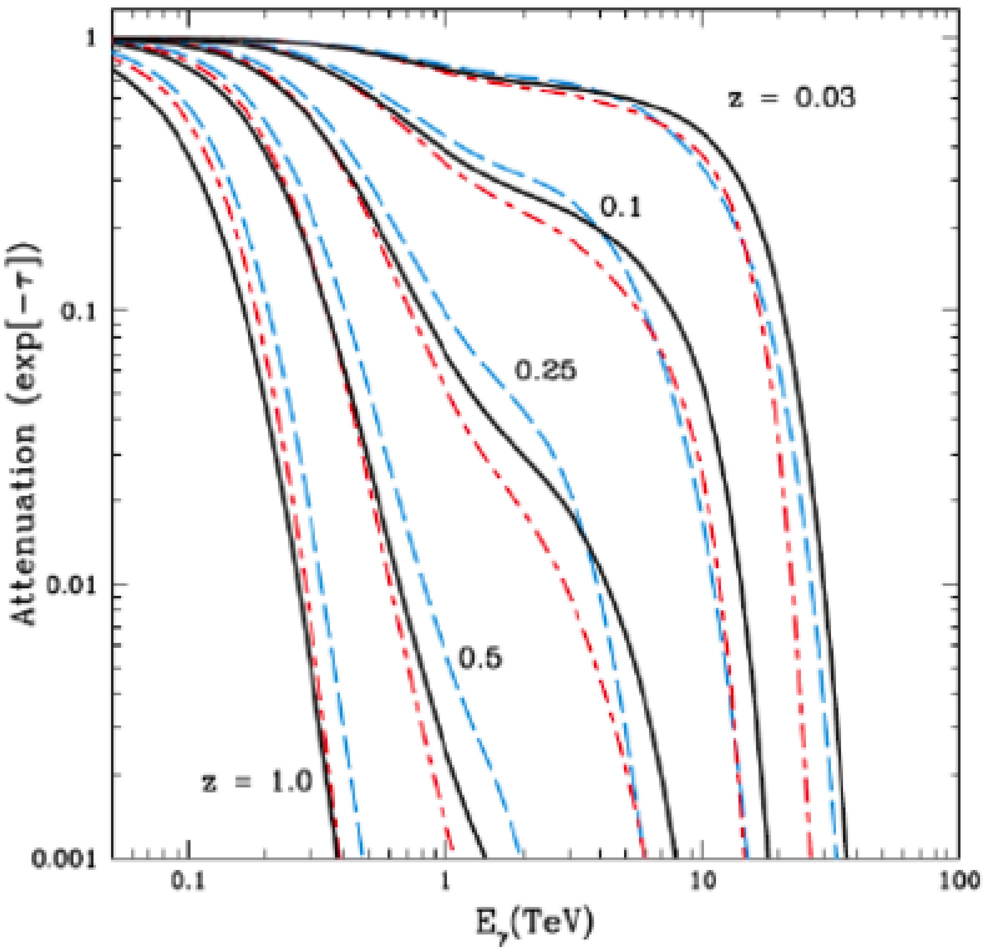
SED of GRB 130427A in different time bins.

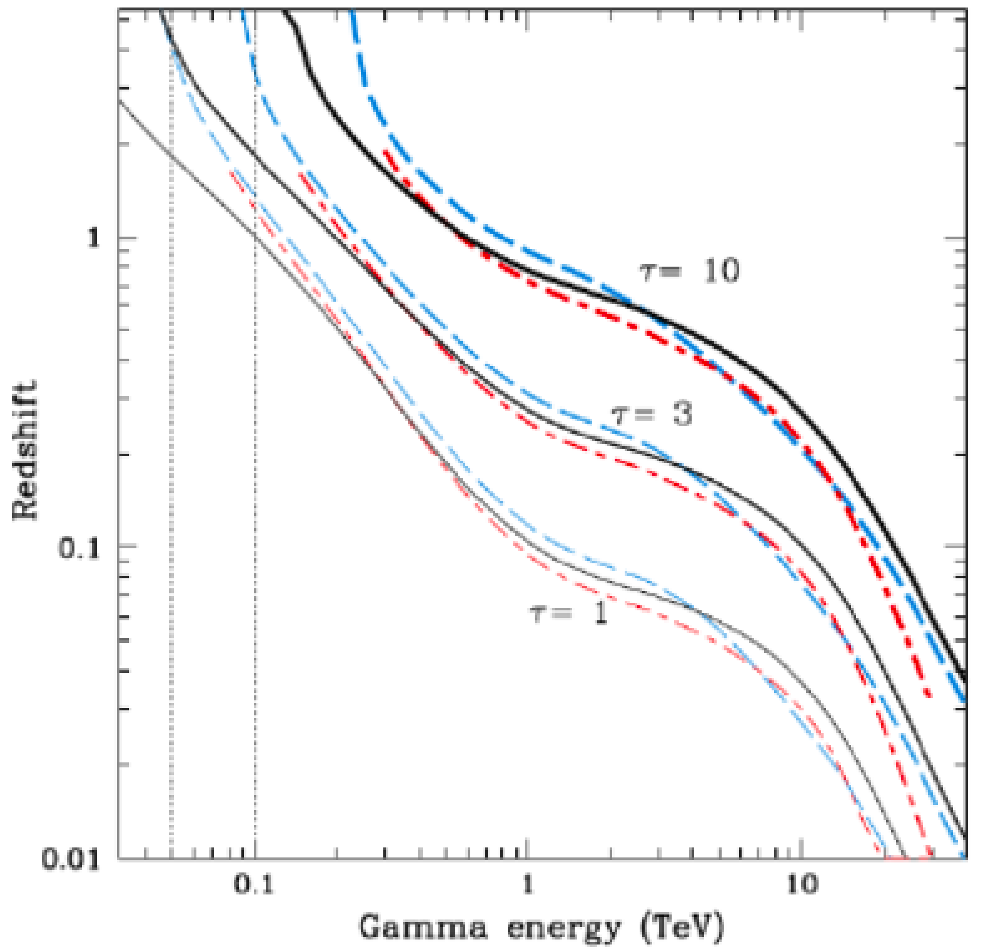
(Ackermann et al. 2013, Science, 343, 42)

We are currently lacking a large FoV instrument that may assess the existence of spectral breaks, which, for events of known redshift, are directly connected with the Universe's gamma-ray opacity.



Gamma Ray Bursts





The sub-TeV energy domain is crucial to discriminate among the different models of Extragalactic Background Light that predict the Universe gamma-ray opacity. Such models are a fundamental cosmological constraint.

(Fig. from Primack et al. 2011; DOI: 10.1063/1.3635825)

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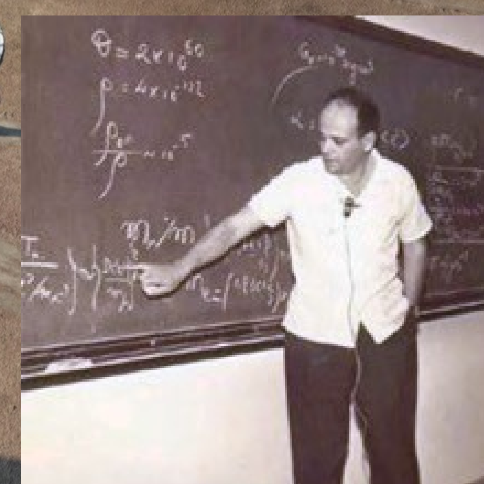

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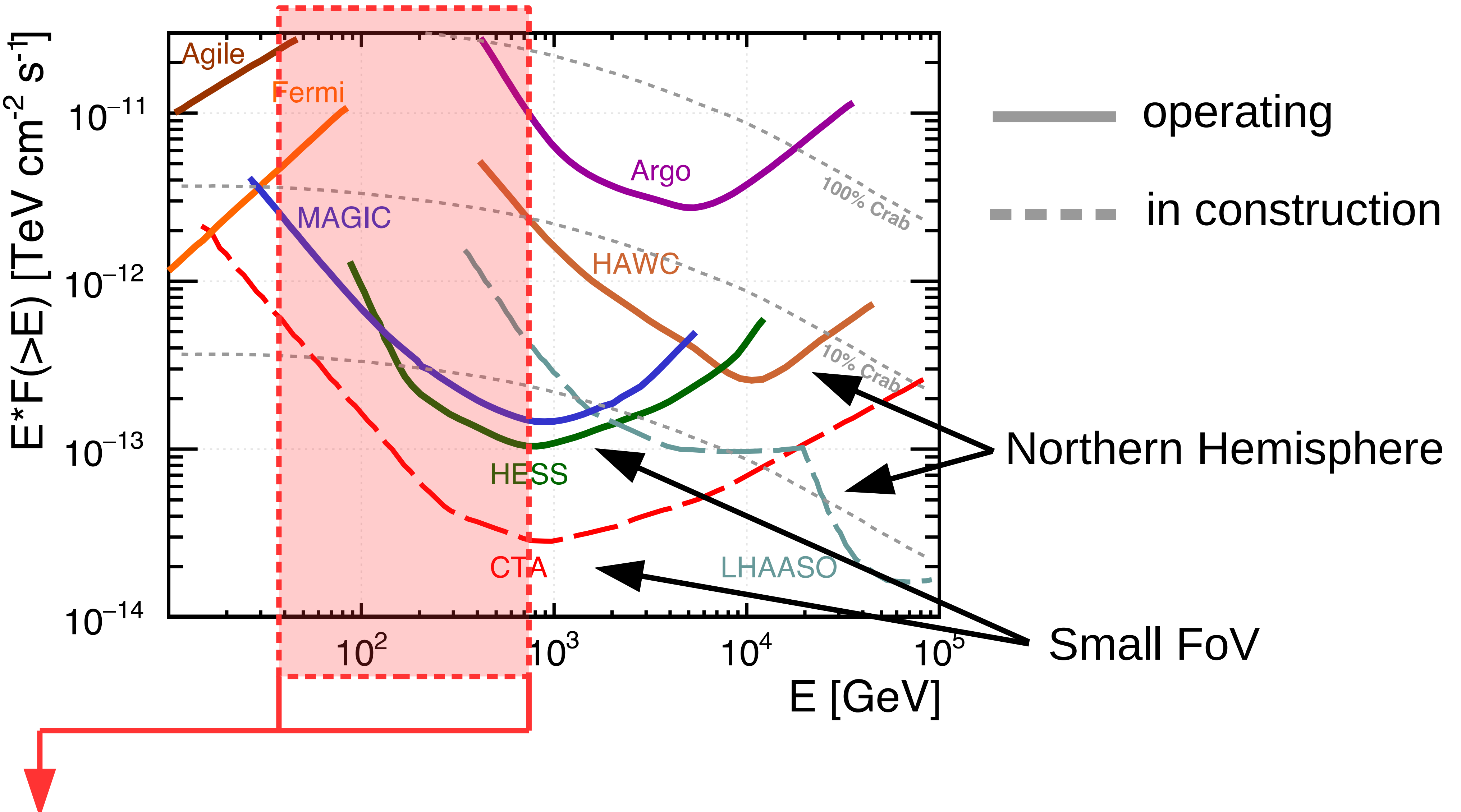
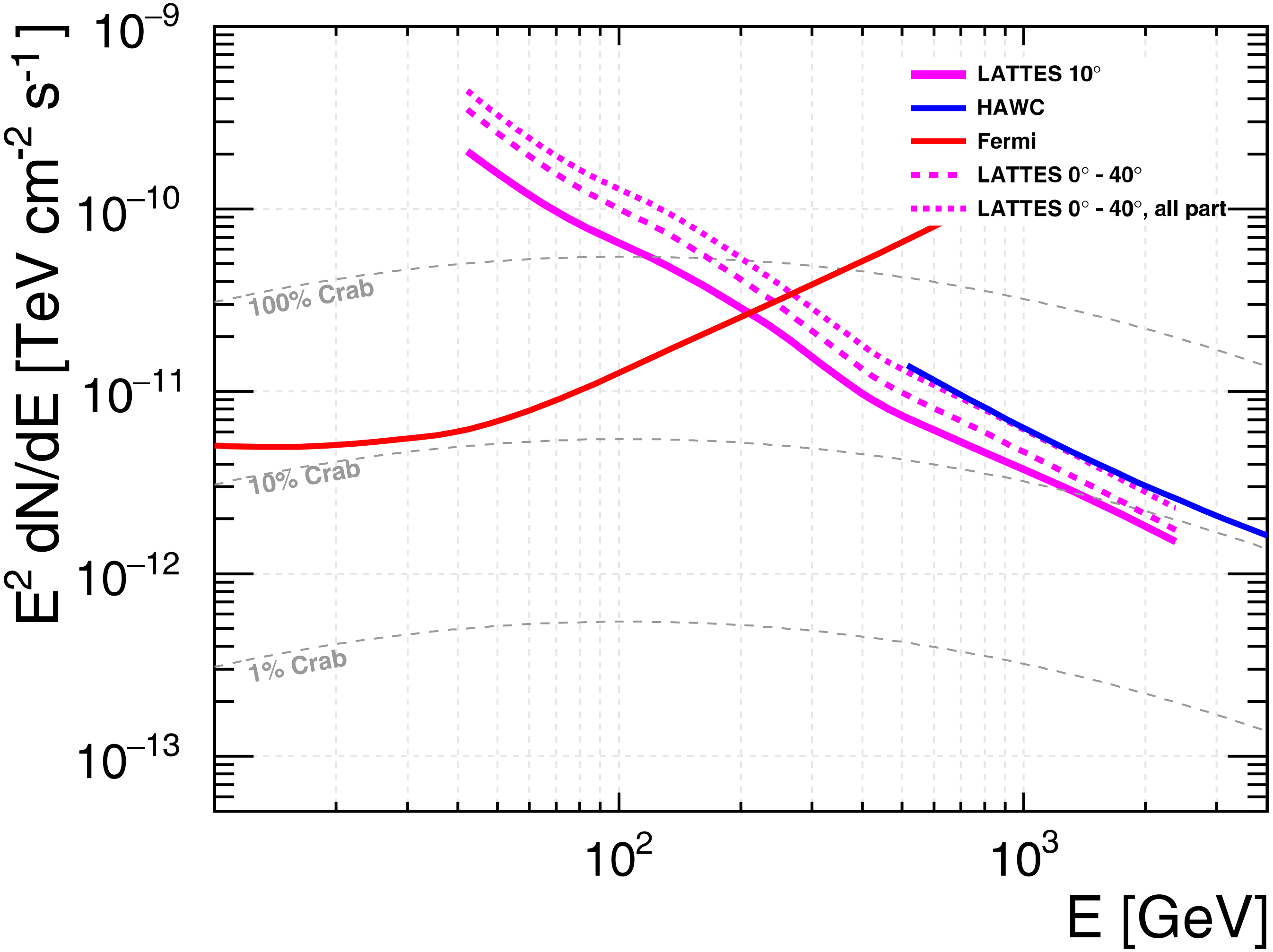
Monitoring the spectrum is a priority!



- No wide FoV instrument working in the Southern Hemisphere
- Gap between satellite and ground-based observations

LATTES sensitivity



- Sensitivity to steady sources in one year of operation
- *The ability to reach the lowest energies is critical to most of the science discussed so far*

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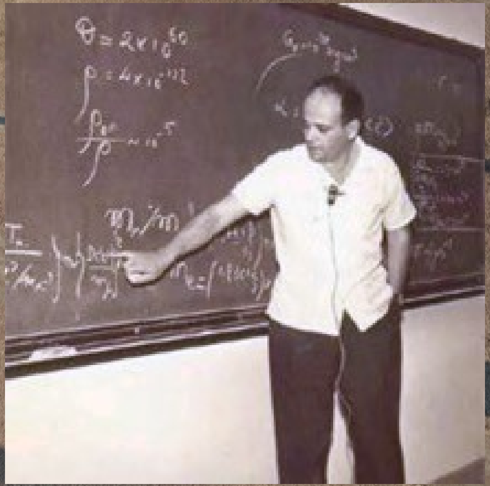

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Concluding remarks

- There is a wide population of Galactic and Extragalactic sources that should be monitored and investigated in high-energy gammas (E > 100 GeV)
- *LATTES* is ideal to monitor the Galactic Plane and Centre
- *LATTES* has very good possibilities to address questions as cosmic ray acceleration, AGN jet physics and Universe gamma-ray opacity
- Many of the scientific goals above are best pursued by including the sub-TeV domain in the instrument capability

Acknowledgements

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

REPÚBLICA PORTUGUESA

LIP

TÉCNICO LISBOA

Backup slides

“Fermi didn’t see it ...”

does not imply IT is not there!

E.g. 2HWC J2006+341

The Astrophysical Journal, 843:40 (21pp), 2017 July 1
https://doi.org/10.3847/1538-4357/aa7556

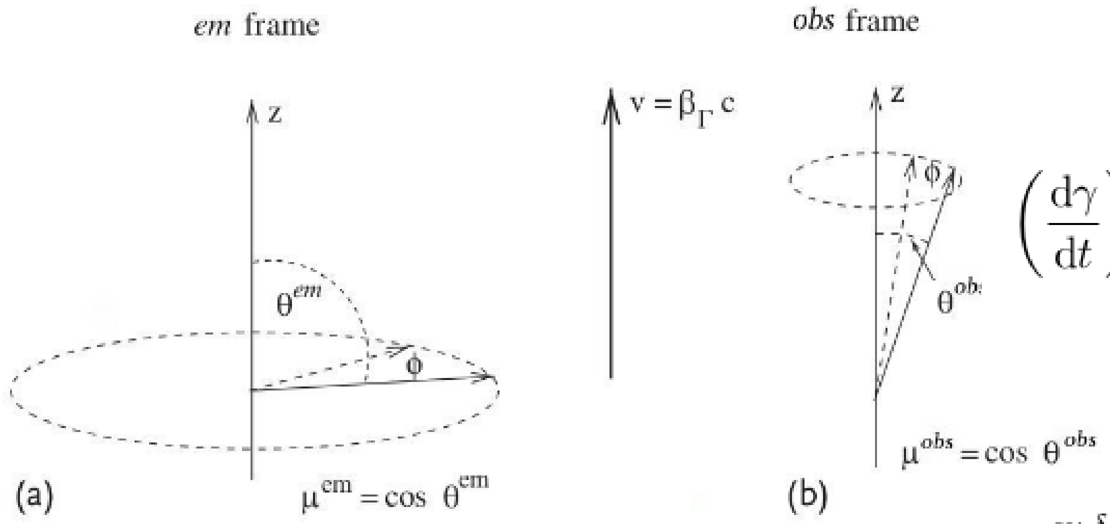
CrossMark

The 2HWC HAWC Observatory Gamma-Ray Catalog

A. U. Abeysekara[1], A. Albert[2], R. Alfaro[3], C. Alvarez[4], J. D. Álvarez[5], R. Arceo[4], J. C. Arteaga-Velázquez[5], H. A. Ayala Solares[6], A. S. Barber[1], B. Baughman[7], N. Bautista-Elivar[8], J. Becerra Gonzalez[9], A. Becerril[3], E. Belmont-Moreno[3], S. Y. BenZvi[10], D. Berley[7], A. Bernal[11], J. Braun[12], C. Brisbois[6], K. S. Caballero-Mora[4], T. Capistrán[13], A. Carramiñana[13], S. Casanova[14,15], M. Castillo[5], U. Cotti[5], J. Cotzomi[16], S. Coutiño de León[13], E. de la Fuente[17], C. De León[16], R. Diaz Hernandez[13], B. L. Dingus[2], M. A. DuVernois[12], J. C. Díaz-Vélez[17], R. W. Ellsworth[18], K. Engel[7], D. W. Fiorino[7], N. Fraija[11], J. A. García-González[3], F. Garfias[11], M. Gerhardt[6], A. González Muñoz[3], M. M. González[11], J. A. Goodman[7], Z. Hampel-Arias[12], J. P. Harding[2], S. Hernandez[3], A. Hernandez-Almada[3], J. Hinton[15], C. M. Hui[19], P. Hüntemeyer[6], A. Iriarte[11], A. Jardin-Blicq[15], V. Joshi[15], S. Kaufmann[4], D. Kieda[1], A. Lara[20], R. J. Lauer[21], W. H. Lee[11], D. Lennarz[22], H. León Vargas[3], J. T. Linnemann[23], A. L. Longinotti[13], G. Luis Raya[8], R. Luna-García[24], R. López-Coto[15], K. Malone[25], S. S. Marinelli[23], O. Martinez[16], I. Martinez-Castellanos[7], J. Martínez-Castro[24], H. Martínez-Huerta[26], J. A. Matthews[21], P. Miranda-Romagnoli[27], E. Moreno[16], M. Mostafá[25], L. Nellen[28], M. Newbold[1], M. U. Nisa[10], R. Noriega-Papaqui[27], R. Pelayo[24], J. Pretz[25], E. G. Pérez-Pérez[8], Z. Ren[21], C. D. Rho[10], C. Rivière[7], D. Rosa-González[13], M. Rosenberg[25], E. Ruiz-Velasco[3], H. Salazar[16], F. Salesa Greus[14], A. Sandoval[3], M. Schneider[29], H. Schoorlemmer[15], G. Sinnis[2], A. J. Smith[7], R. W. Springer[1], P. Surajbali[15], I. Taboada[22], O. Tibolla[4], K. Tollefson[23], I. Torres[13], T. N. Ukwatta[2], G. Vianello[30], L. Villaseñor[5], T. Weisgarber[12], S. Westerhoff[12], I. G. Wisher[12], J. Wood[12], T. Yapici[23], P. W. Younk[2], A. Zepeda[4,26], and H. Zhou[2]

We should also remember that Hubble Deep Field was obtained by pointing HST exactly where nothing had been seen before.

Physics of AGN jets

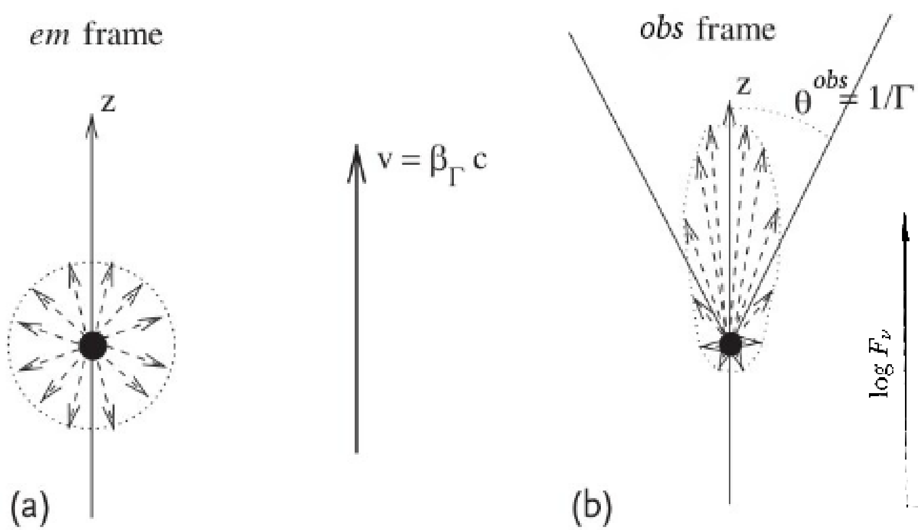


Particle energy loss

$$\left(\frac{\mathrm{d}\gamma}{\mathrm{d}t}\right)_{sy} = -\frac{4}{3} c \sigma_T \frac{u_B}{m_e c^2} Z^4 \left(\frac{m_e}{m}\right)^3 \beta^2 \gamma^2$$

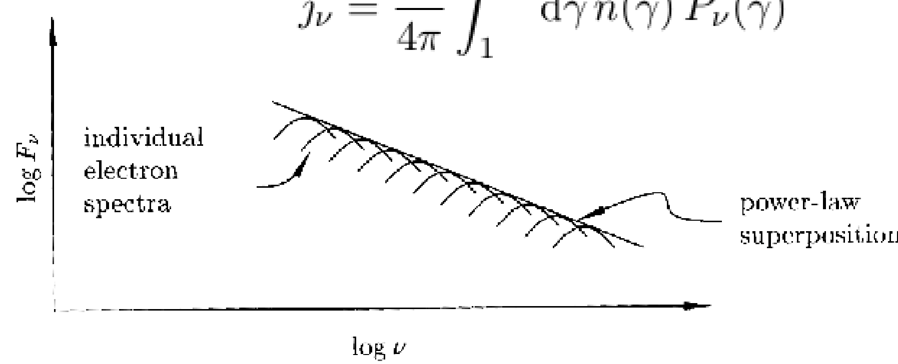
δ - approximation

$$P_\nu^{sy,\delta}(\gamma) = \frac{32\pi}{9} \left(\frac{q^2}{mc^2}\right)^2 u_B \beta^2 \gamma^2 \delta(\nu - \nu_c)$$



Composite spectrum

$$j_\nu = \frac{1}{4\pi} \int_1^\infty \mathrm{d}\gamma\, n(\gamma)\, P_\nu(\gamma)$$



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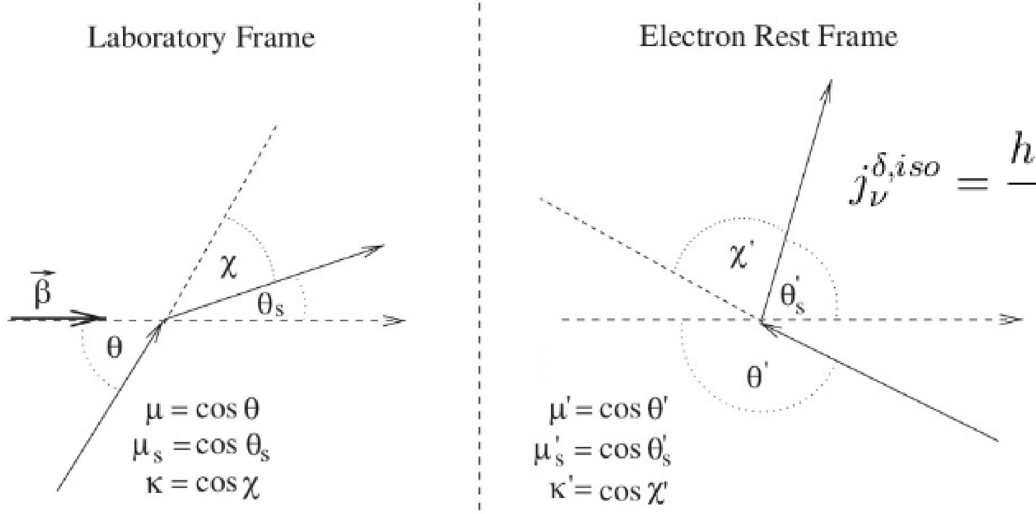
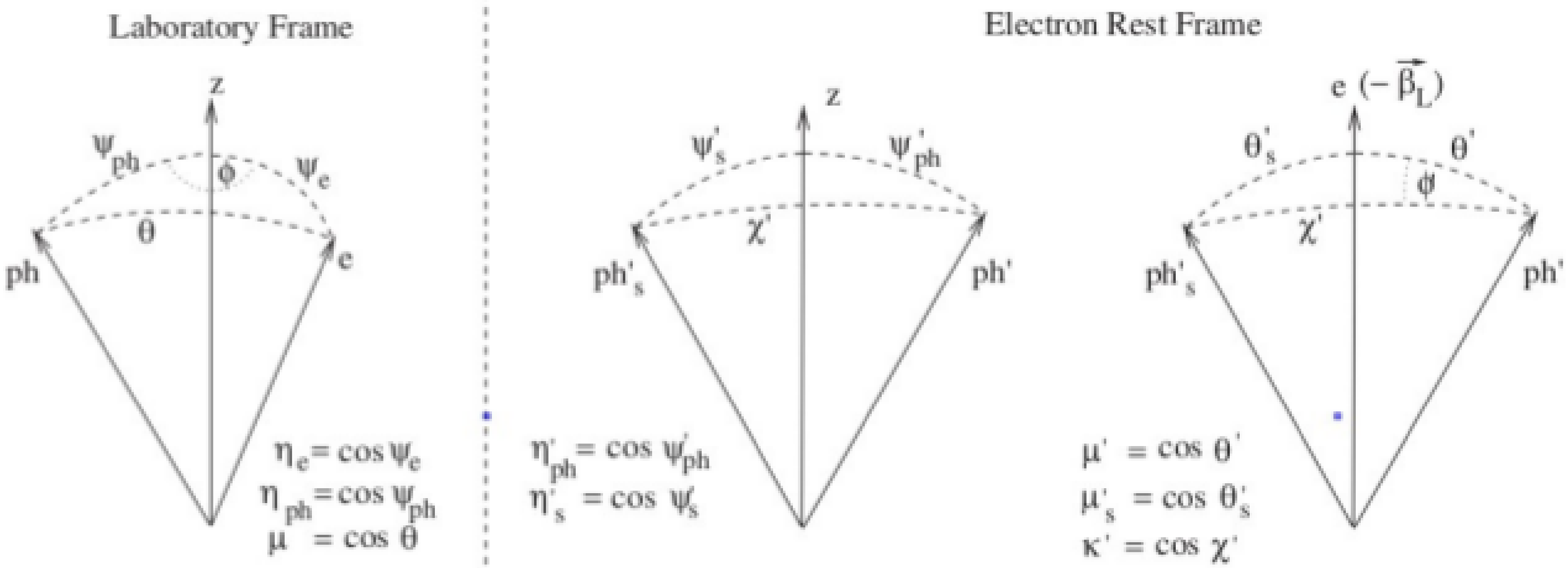


Compton emissivity

$$j_\nu^{\delta,iso} = \frac{h\,c\,\sigma_T\,\varepsilon_S^2}{8\pi} \int_{\varepsilon_S}^{\infty} \mathrm{d}\gamma\, \frac{n_e(\gamma)}{\gamma^4} \int_{\varepsilon_S/(2\gamma^2)}^{\infty} \mathrm{d}\varepsilon\, \frac{n_{ph}(\varepsilon)}{\varepsilon^2}$$

$$L_{IC} / L_{sync} \approx u_{ph} / u_B$$



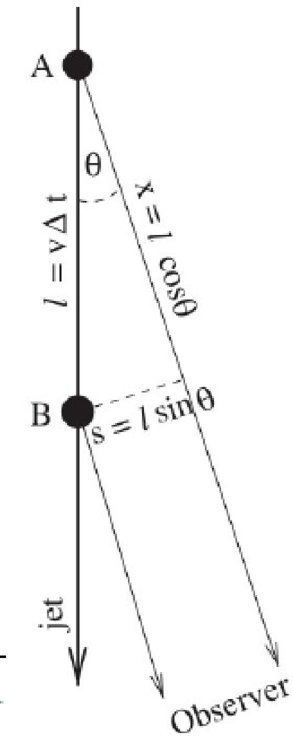
Physics of AGN jets

The relativistic Doppler factor: $\delta = \dfrac{1}{\Gamma(1-\beta_\Gamma \mu^{obs})}$ $\longrightarrow$ Approaching sources are **boosted**, receding ones are **dimmed**.

Relativistic boosting: $F^{obs}_{\nu^{obs}} = F^{em}_{\nu^{em}}\,\delta^3$ and, in the case of power-law spectra: $F^{obs}_{\nu^{obs}} = F^{em}_{\nu^{obs}}\,\delta^{3+\alpha}$

Super-luminal motions (predicted by Special Relativity for sources approaching close to the line of sight):

$$v_{\perp,app} = \frac{s}{\Delta t_{obs}} = \frac{v\sin\vartheta}{(1-\beta_\Gamma\cos\vartheta)}$$



The maximum apparent velocity is achieved under the condition:

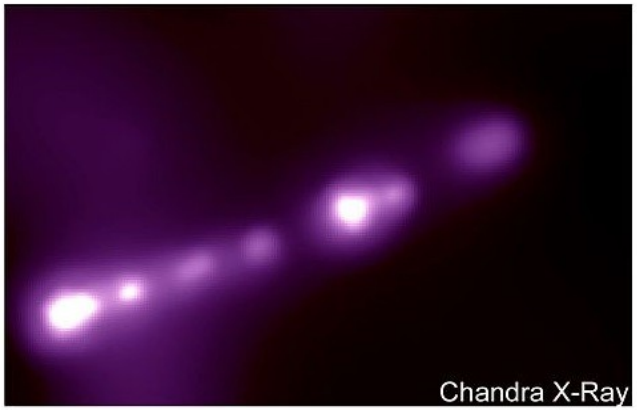
$$\frac{\mathrm{d}}{\mathrm{d}\cos\vartheta}(v_{\perp,app}) = 0 \quad \Longleftrightarrow \quad \cos\vartheta_{sl} = \beta_\Gamma$$

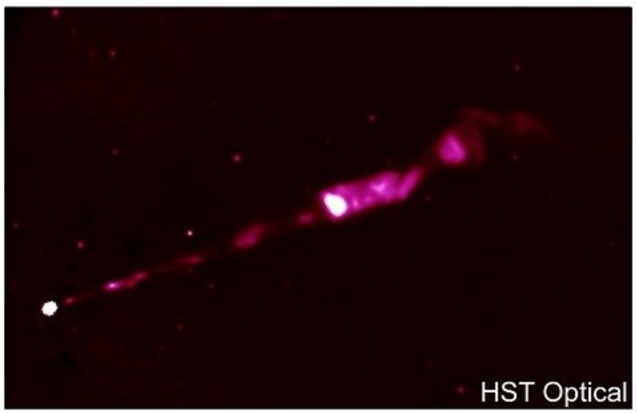
which defines a direction of maximal boosting:

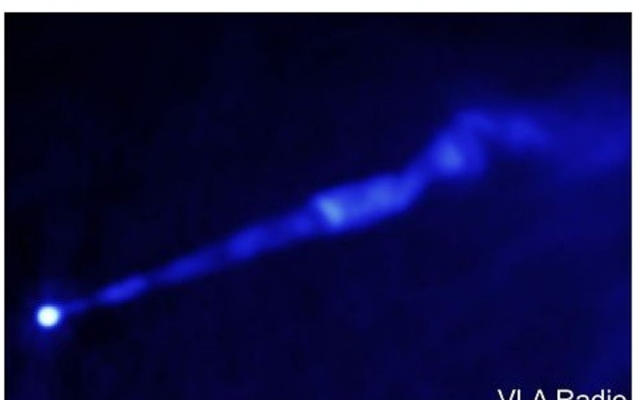
$$\sin\vartheta_{sl} = \sqrt{1-\cos^2\vartheta_{sl}} = \sqrt{1-\beta_\Gamma^2} = \frac{1}{\Gamma}$$

Finally it results that: $v_{\perp,app}(\vartheta_{sl}) = \dfrac{\frac{v}{\Gamma}}{1-\beta_\Gamma^2} = \Gamma v = c\beta_\Gamma\Gamma = c\sqrt{\Gamma^2-1}$

Physics of AGN jets







As it is predicted for relativistic charged particles in a **magnetic field *B***, we detect synchrotron spectrum radiation from the **radio frequencies** all the way up to **x-ray energies**.

The jets of nearby AGNs, like M87, can be resolved in their structure and they show a **knotty, multi-component** morphology.

The **high frequency** jet turns out to be composed by **distinct plasma blobs**, ejected by the nucleus at different epochs, rather than by a continuous stream. The **low frequency** jet appears **smoother**, with a rather complicated **spine-sheath structure** that reveals different kinematics.