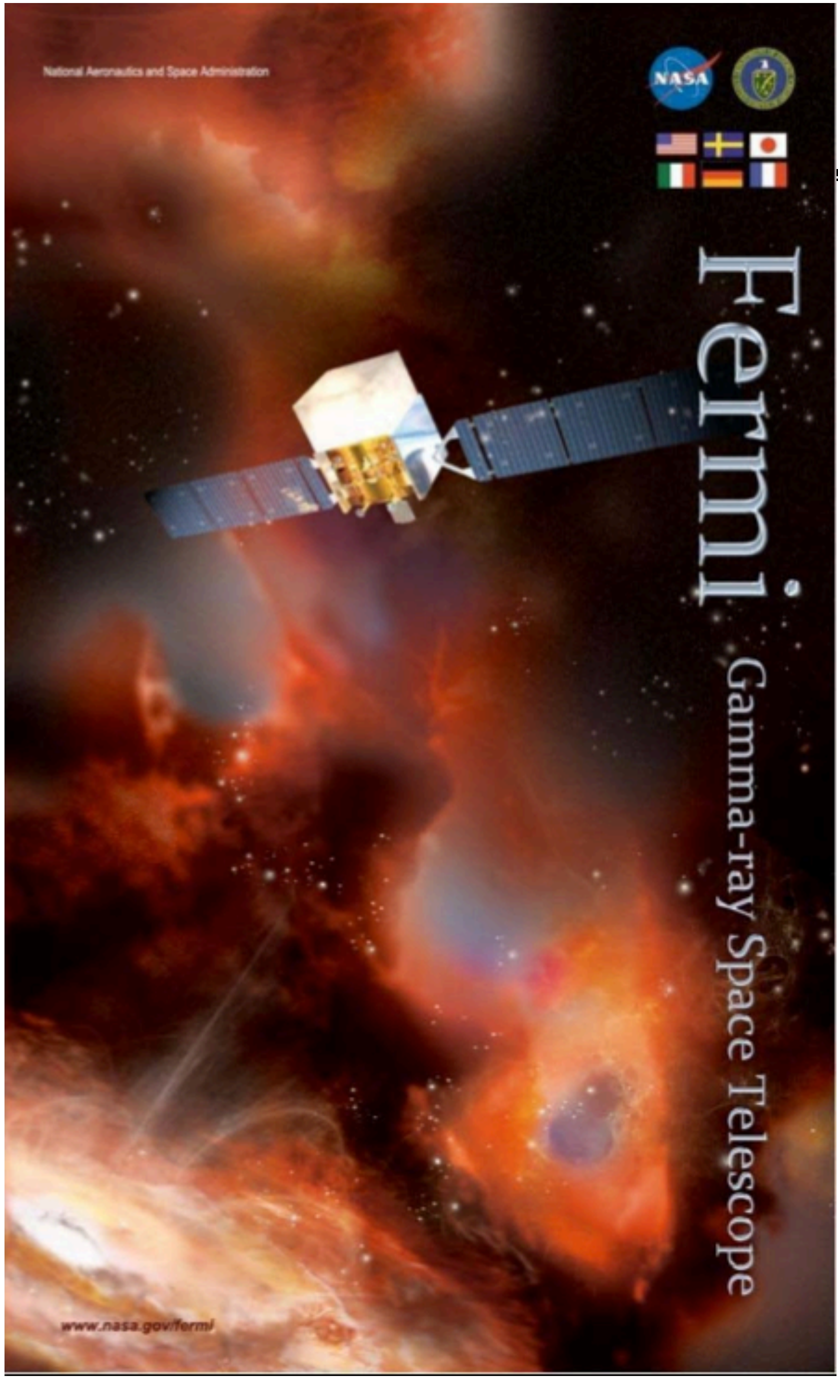
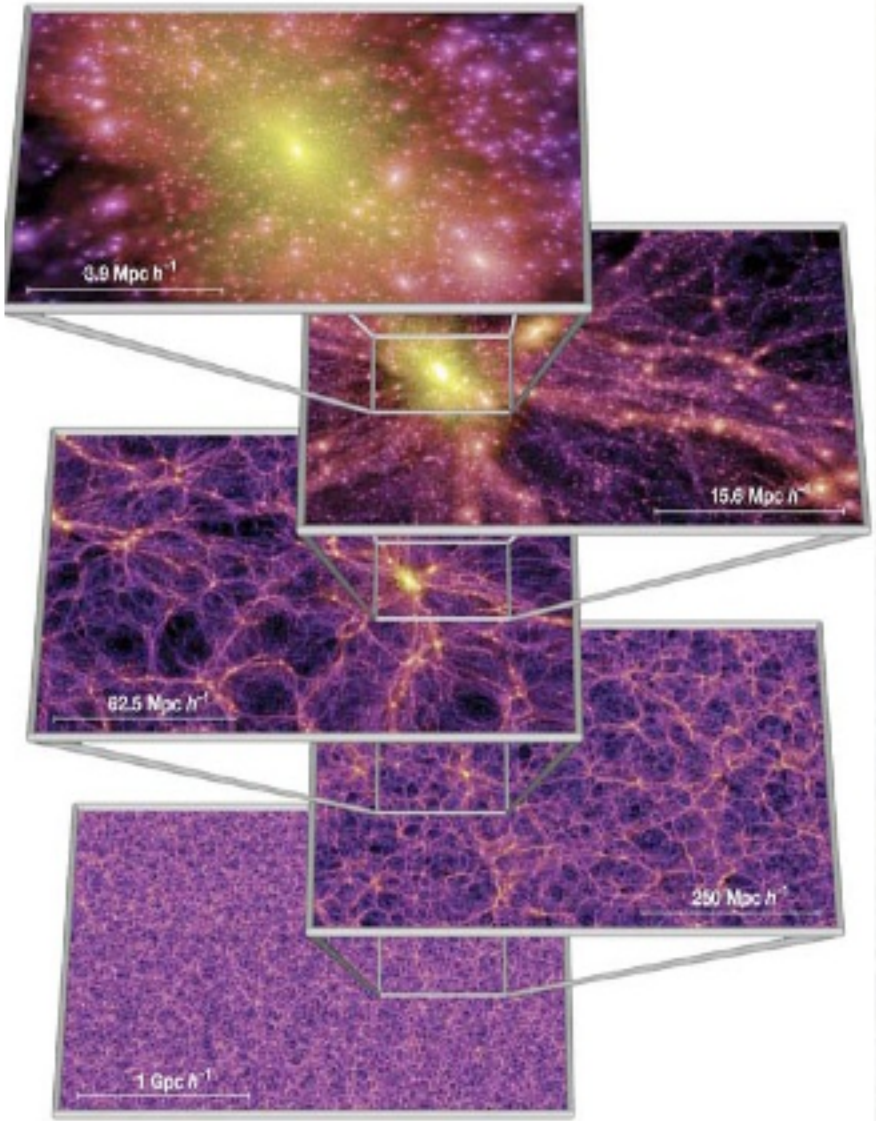


Impact of an extended Fermi-LAT operation phase: Active galaxies

Gino Tosti
University of Perugia/SLAC

Outline

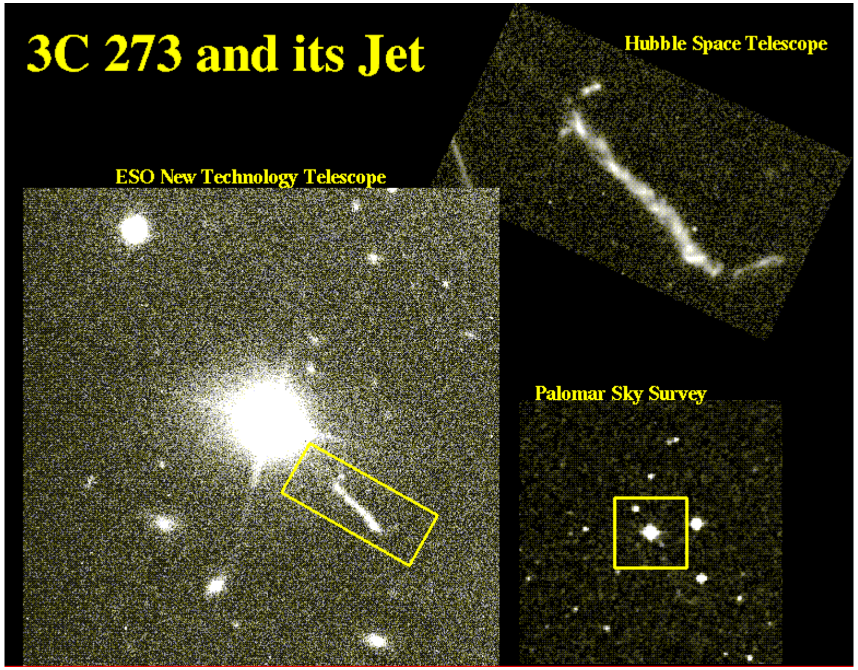
- The AGNs before Fermi
- The AGNs in the Fermi era: the first three years
- Gamma-ray source populations and the Isotropic Gamma-ray background (IGRB)
- The Intergalactic Magnetic Field (IGMF)
- Blazars and the Extragalactic Background Light (EBL)
- Blazars and the large scale structure (LSS) of the Universe
- Summary of the science cases supporting an extended Fermi LAT operation.

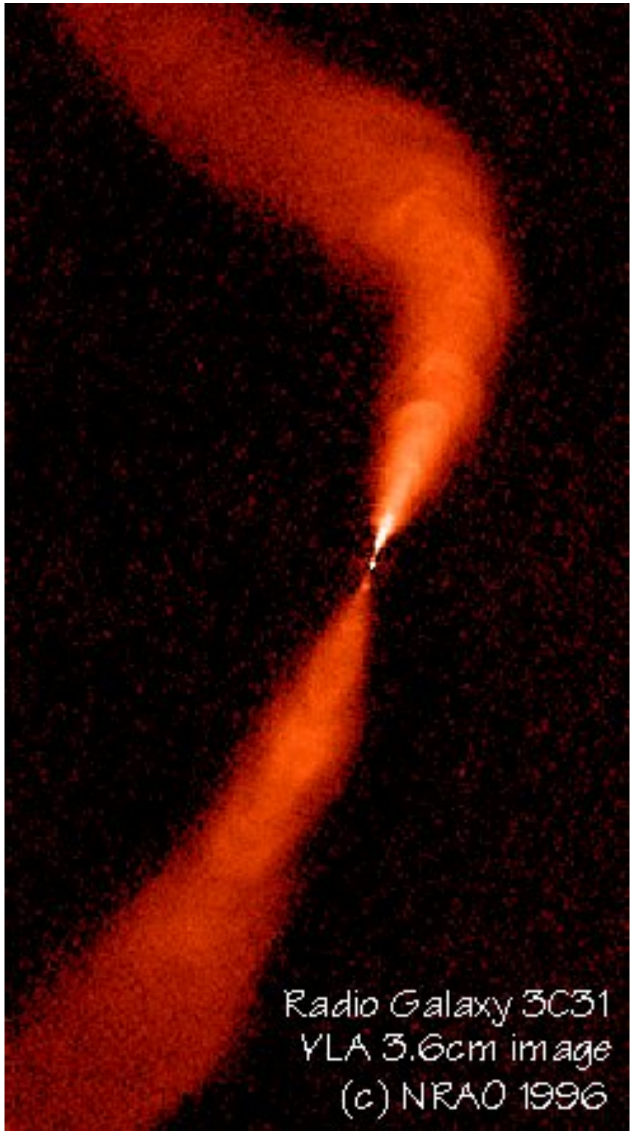


What is an AGN?

Galaxies that emit most of their radiation from the central region.

They are among the more powerful and distant object in the Universe





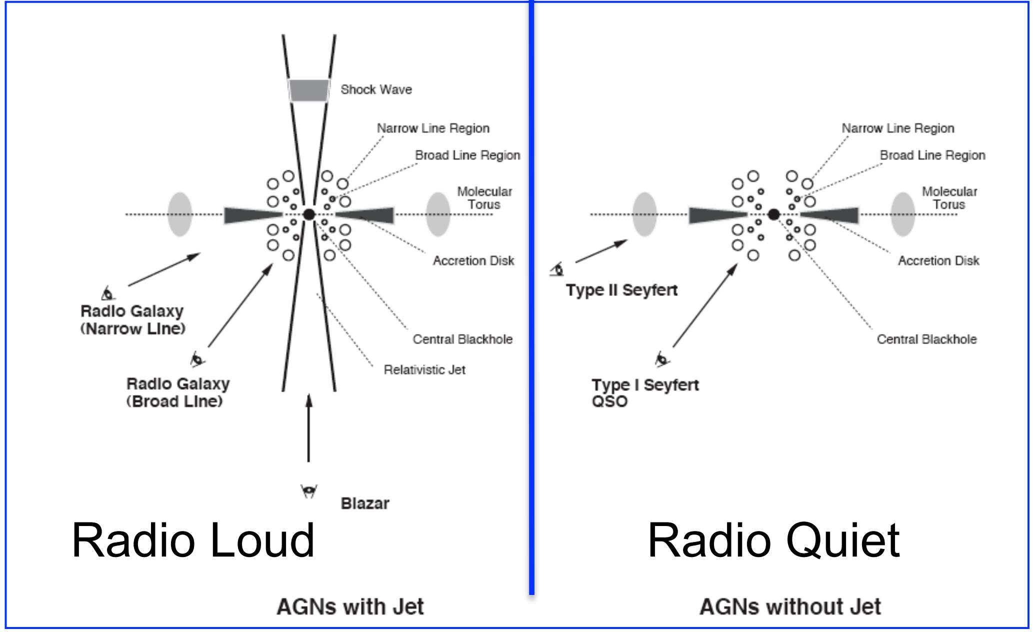
The AGN "Grand" Unification

Basic Ingredients:

- Black Hole ($10^{8\text{-}9}\ M_\odot$) with an accretion disk
- Regions of broad (BLR) and narrow (NLR) emission-line gas,
- Dusty IR torus

•Orientation of the source wrt the observer → Different view of the same object

(see Urry&Padovani 1995)



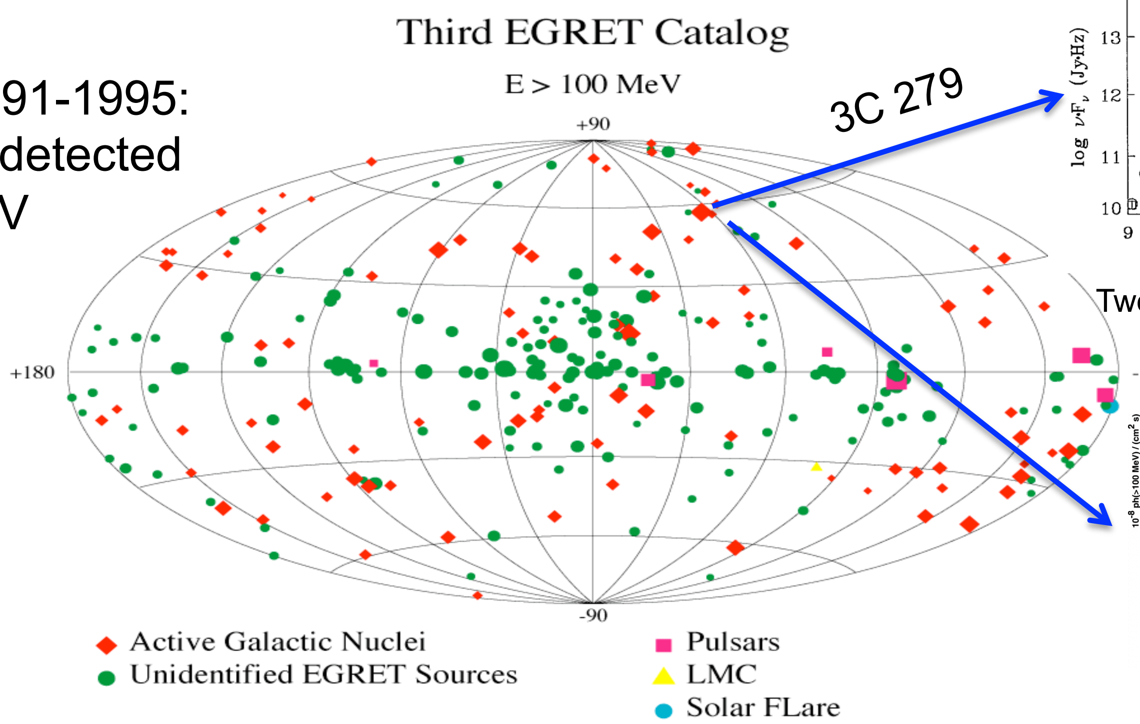
Open Question
Origin of the Radio Loud – Radio Quiet Dichotomy

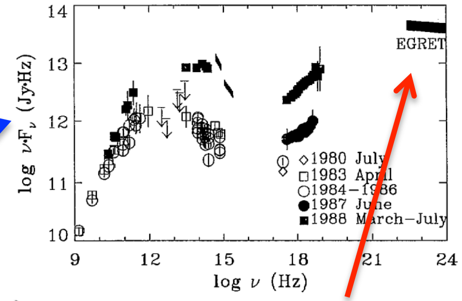
Radio-Loud AGN are the only ones detected at GeV-TeV energies

Basic numbers: (1pc=3×10^{16} m)
$r_S=10^{-5}\ (M/10^8\ M_\odot)$ pc
Disk size: 10^{-3} pc
Base of VLBI jet: 1-10 pc
Distance of the BLR: 0.01-0.1 pc
Distance of the NLR: 100-1000 pc
Torus radius: 100 pc
Galaxy diameter: 100 kpc
Radio lobes: 1 Mpc

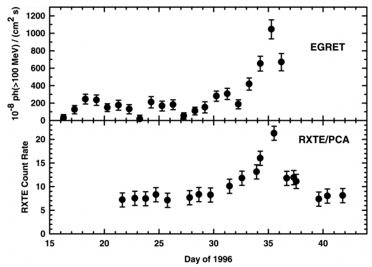
The EGRET extragalactic gamma-ray sky

Data from 1991-1995:
271 sources detected
at E>100 MeV





Two bumps in the Blazar SEDs

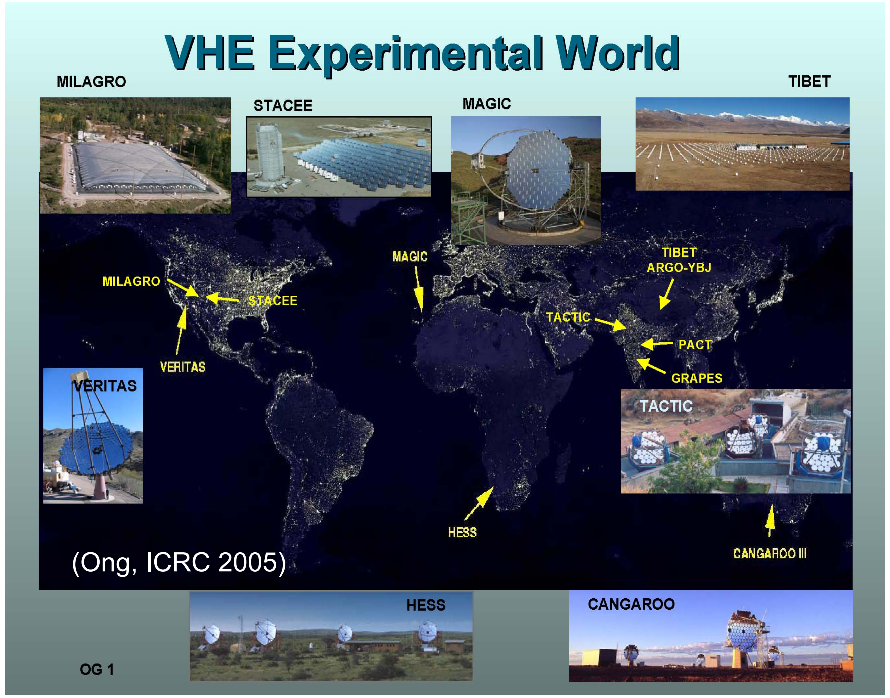


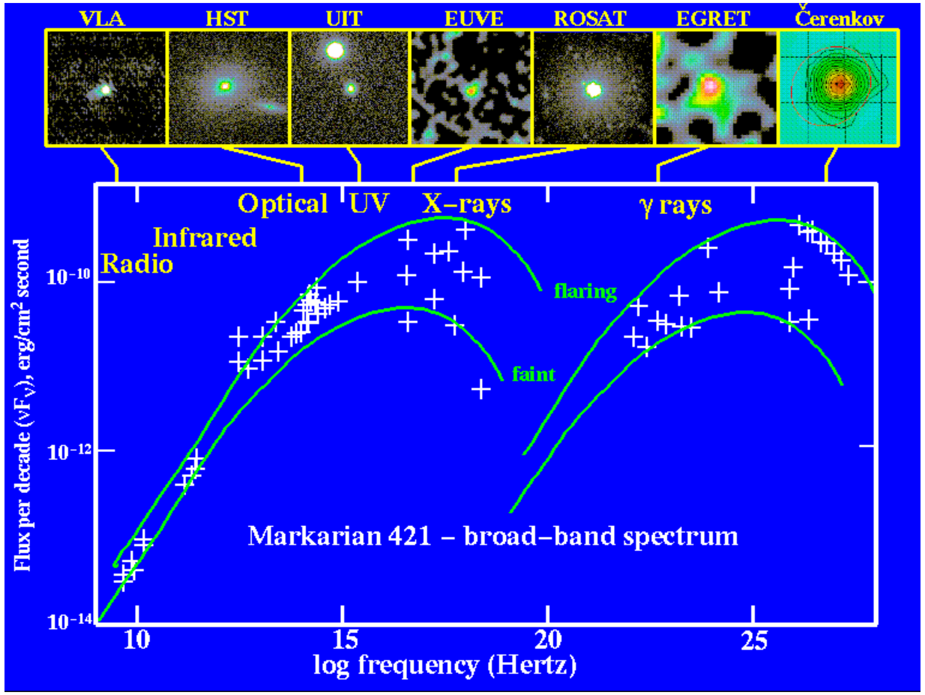
Fast variability (1^{d} or lees)

EGRET showed that AGNs (blazars) dominate the extragalactic MeV- GeV sky

- 66 high-confidence + 27 low-confidence Blazars in the 3rd Catalog (Hartman et al 1999)
- >100 Blazars in Sowards-Emmerd et al. 2003,2004
- Marginal detection of 1(2) radio-galaxies

Gamma-ray Astronomy at TeV Energies



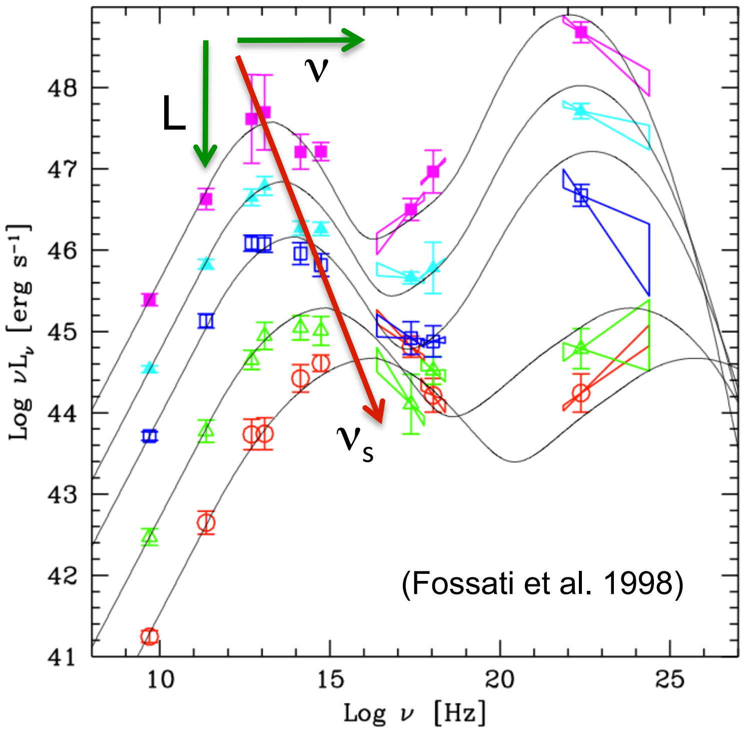


In 1990s ground-based air Cerenkov telescopes started to detected sources at E> 150-200 GeV.

Transparency of the Universe to Very High-Energy (VHE) gamma-ray → EBL studies

The Blazar Sequence

The "blazar sequence" (Fossati et al. 1998) is an attempt to organize the multiwavelength (MW) properties of blazars into a coherent theoretical framework.



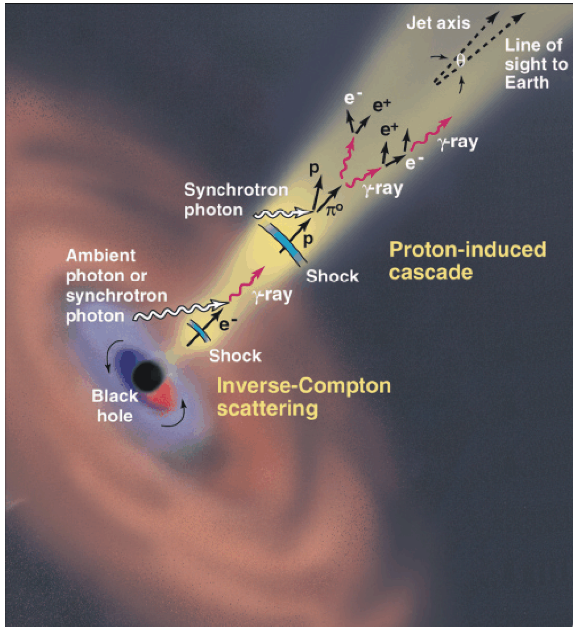
The two main components of the MW spectrum are explained by

- LEPTONIC MODELS (widely accepted)
  - The low-energy: Synchrotron radiation
  - The high-energy: Inverse-Compton scattering (SSC or ERC)

- HADRONIC MODELS
  - The low-energy emission Synchrotron radiation
  - The high-energy emission: proton, μ, and π synchrotron radiation; production of γ-rays initiated from neutral π decays and from e^+ and e^- generated in charged π decays that result from photon-hadron collisions. → neutrinos (?)

Questions for Fermi

- Jet Physics
  - Emission mechanisms (especially for high energy component)
  - Emission location
  - Particle acceleration mechanisms
  - Jet composition, confinement, power
  - Accretion disk-black hole-jet connection



- Effect of the blazar phenomenon on the host galaxy and the intergalactic environment

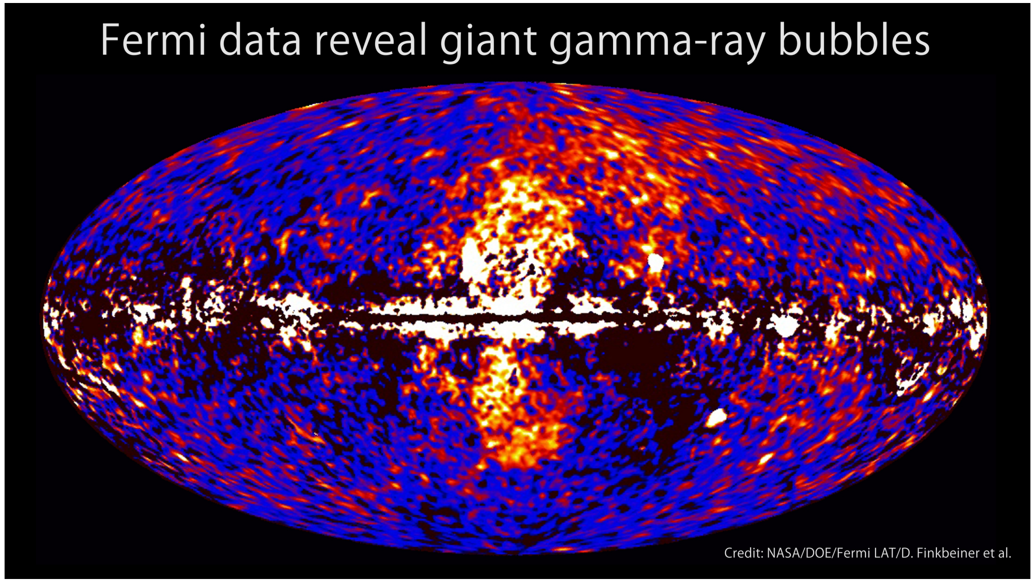
- Blazars and parent population (FRI, FRII) high-energy LogN-LogS and Luminosity Function; Radio-quiet

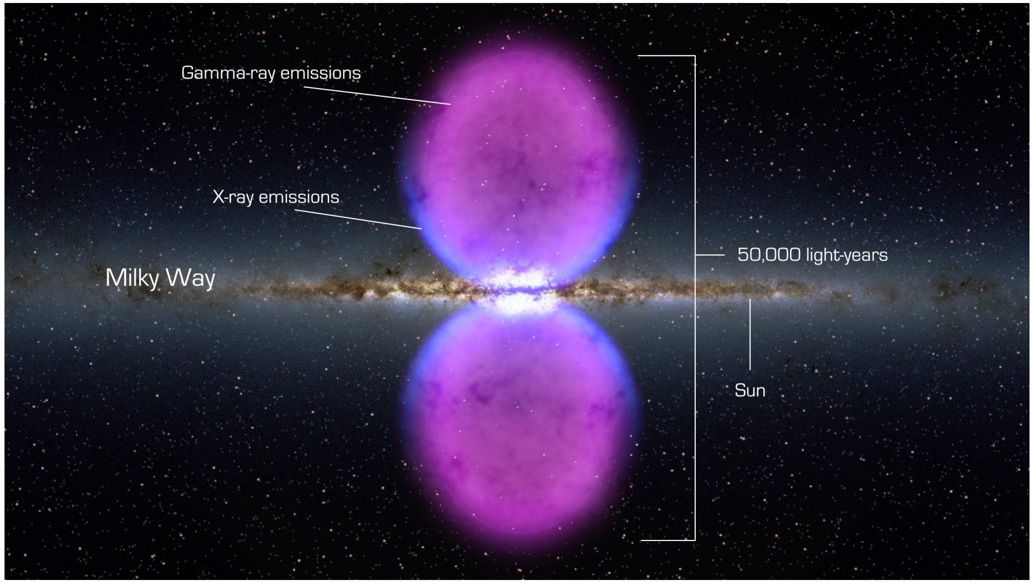
- Contribution of gamma-loud AGN to the Isotropic Gamma-ray Background

- Blazars as probes of the extragalactic background light (EBL)

Multiwavelength and Multimessengers observations key ingredients for any progress in our understanding the physics of the Active galaxies and their role in the formation and evolution of the structures in the Universe

Are we living in an AGN?





Centaurus A
(flipped and rotated)

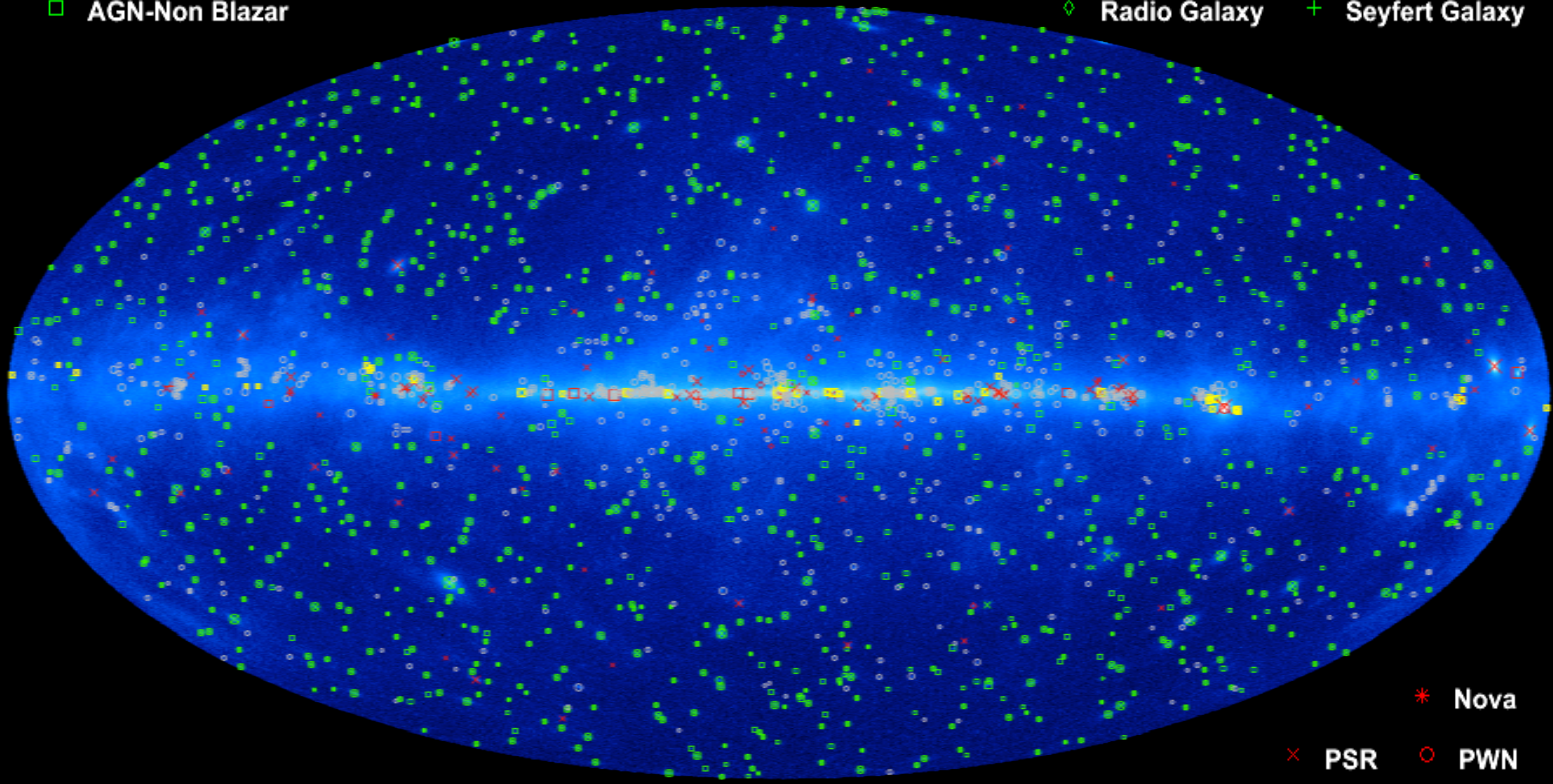
Fermi Large Area Telescope 2FGL catalog

○ AGN ⊗ AGN-Blazar

□ AGN-Non Blazar

× Galaxy ✳ Starburst Galaxy

◊ Radio Galaxy + Seyfert Galaxy



✳ Nova

× PSR ○ PWN

⊗ PSR w/PWN □ SNR

◊ Globular Cluster + HMB

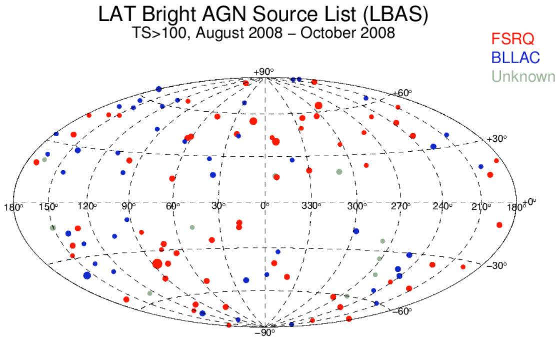
○ Unassociated

□ Possible Association with SNR and PWN

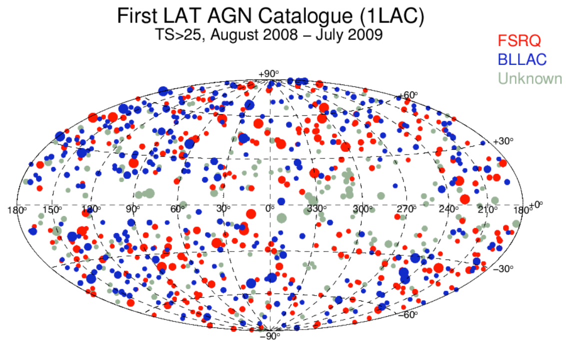
arXiv:1108.1435

Credit: Fermi Large Area Telescope Collaboration

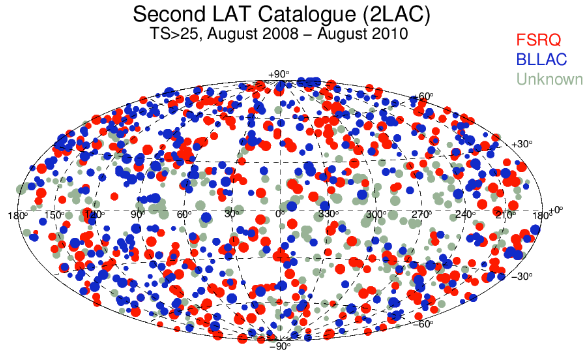
Fermi-LAT γ-ray Galaxies



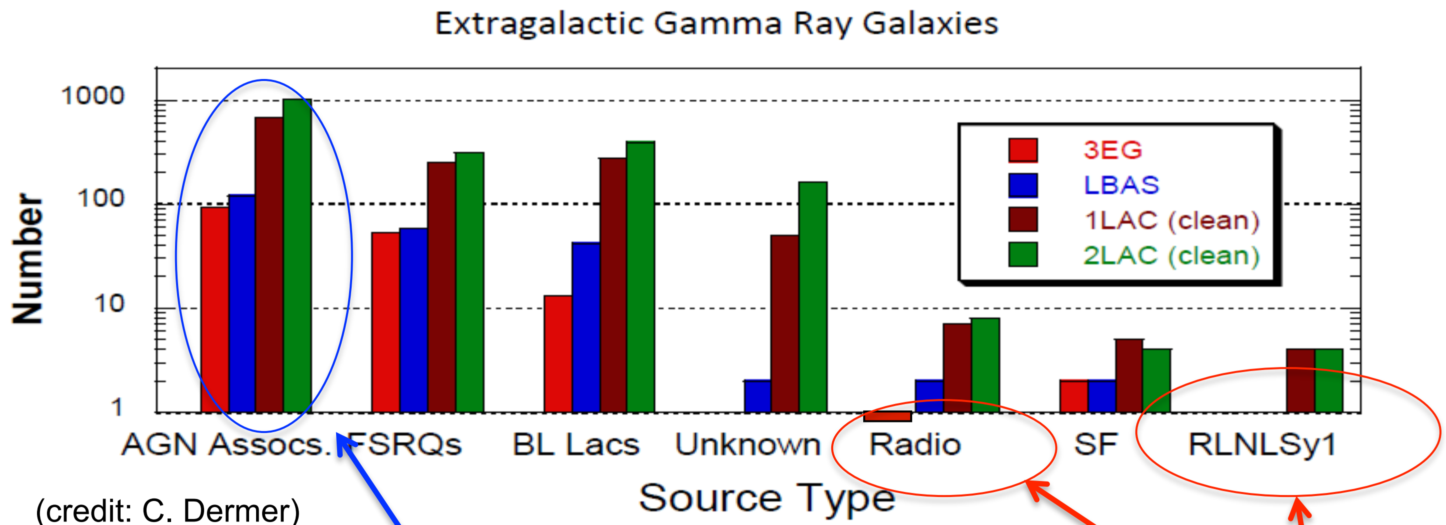
3 months:LBAS Abdo, et al. 2009, ApJ, 700, 597



1 year:1LAC Abdo, et al. 2010, ApJ, 715, 429



2 years2LAC Abdo, et al. 2011 accepted

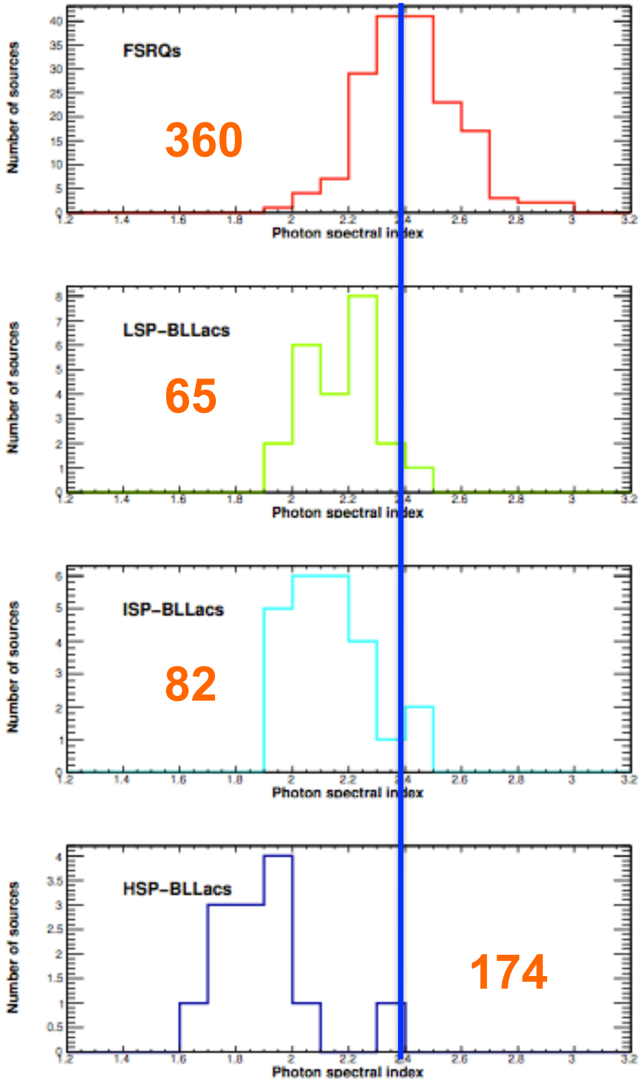


(credit: C. Dermer)

More than 1000 AGN!

New Class of γ-ray emitters

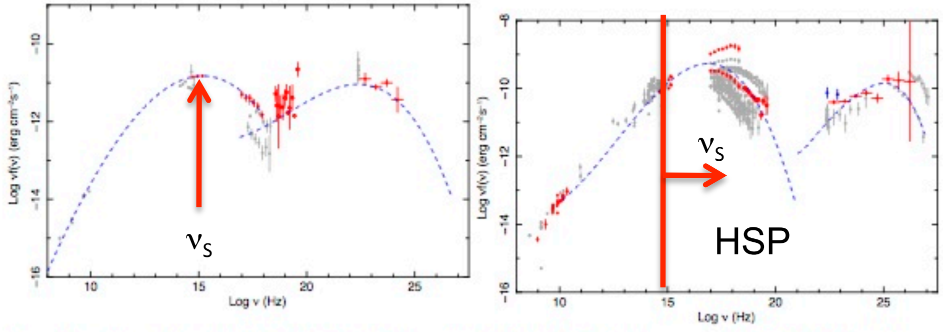
Blazar Class vs Spectral Index

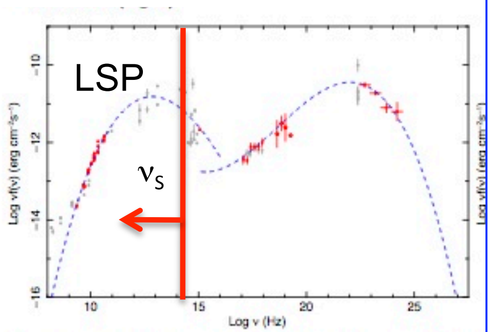


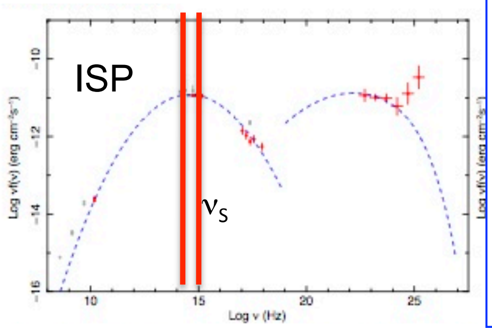
(Abdo et al. 2011)

TeV

- FSRQs: 3
- LSP-BLLacs: 4
- ISP-BLLacs: 4
- HSP-BLLacs: 31







- New Classification based on ν_S
  LSP, ISP, HSP: low-, intermediate-, high- energy peaked blazars, resp.
  - LSP: $\log(\nu_S) < 14$
  - ISP: $14 < \log(\nu_S) < 15$
  - HSP: $\log(\nu_S) > 15$

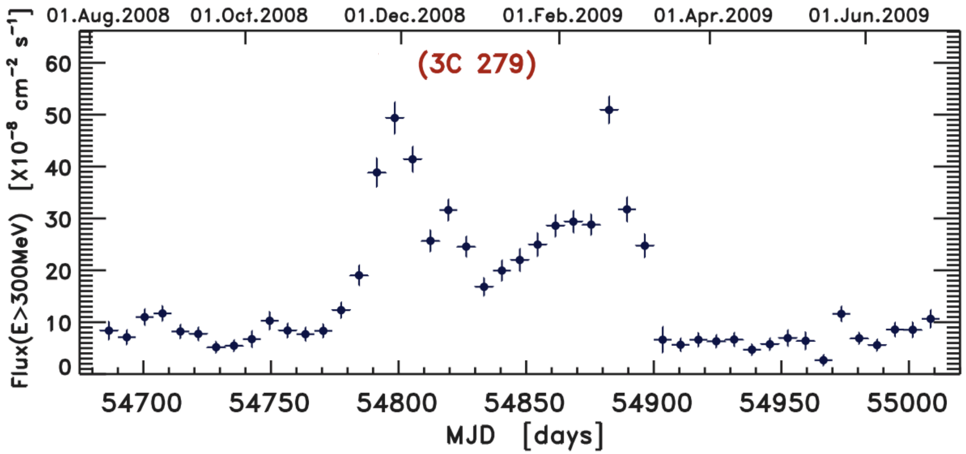
This classification is now widely used in the Literature.

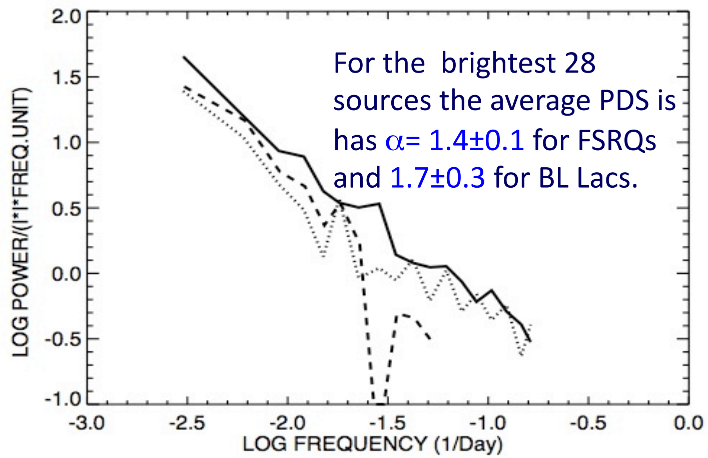
(Abdo et al. 2010)

Variability Properties of brightest Blazars

- ❑Gamma-ray variability timescales range from fractions of a day to months.
- ❑ From the analysis of the LBAS over a period of 11 months, resulted that:
    - ❑ FSRQs and LSP/ISP BL Lacs shows the largest variation amplitudes. HSP BL Lac objects show lower variability amplitudes
    - ❑ High states duration do not exceed 100-150 days.

(Abdo et al. 2010,ApJ,722,520)



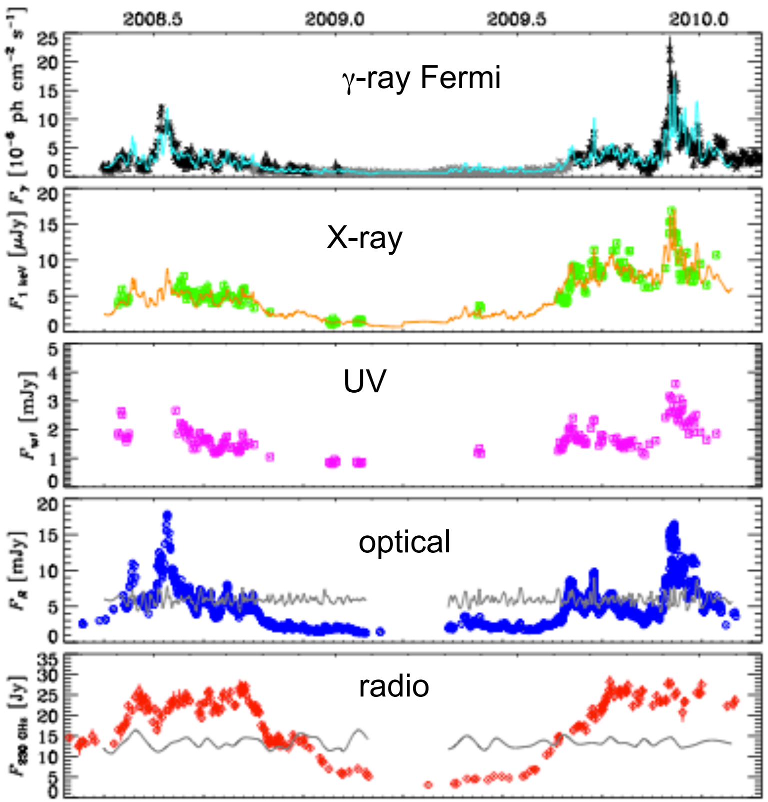


Longer time series are needed

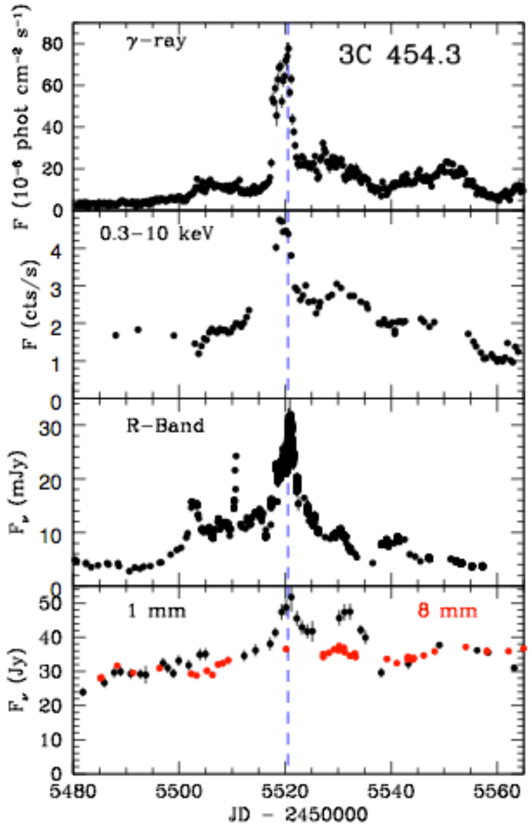
- Duty Cycles
- Variability amplitude: rms vs <Flux> ?
    - Is it linear as for X-ray binaries and radio-quiet AGNs?
- Power Density Spectra:
    - Slopes
    - Breaks (characteristic time scales)

MW Properties of the brightest sources

3C 454.3



(Raiteri et at. 2011)

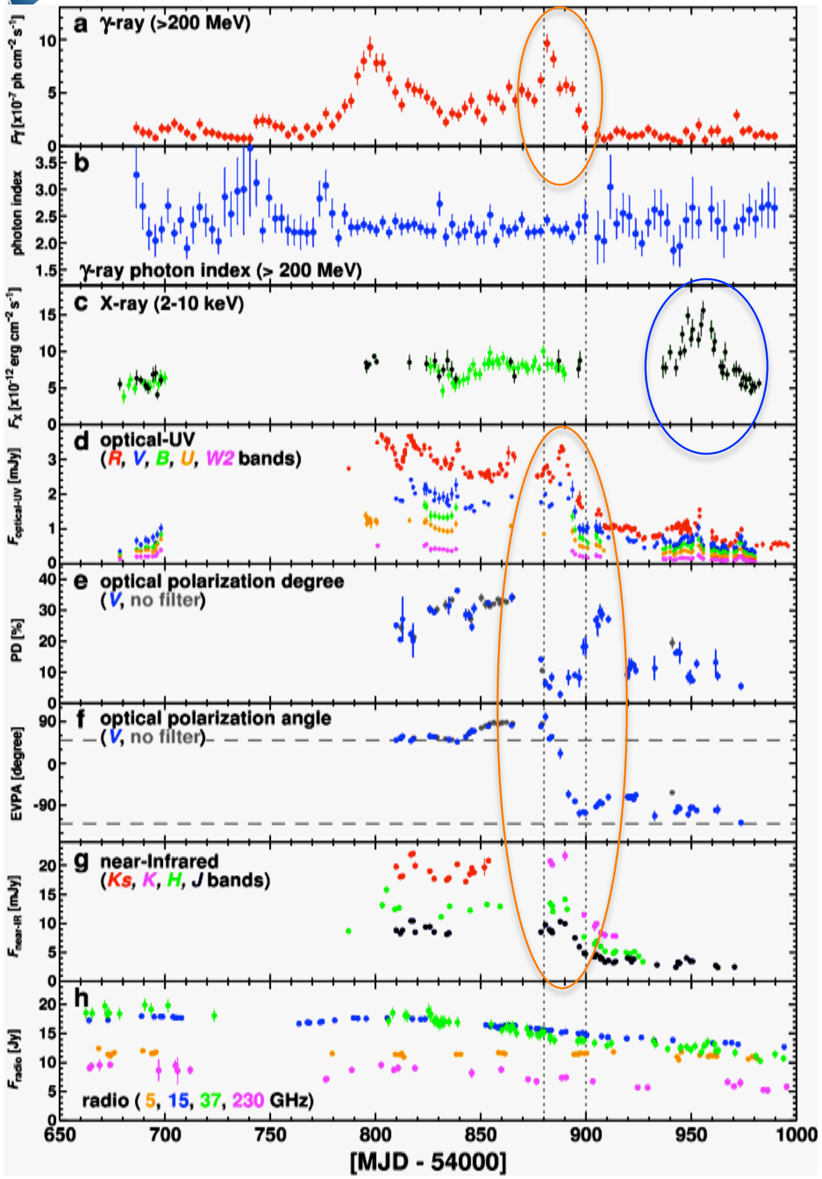


Quite nice correlation among flares at the different wavebands but quite different detailed fluctuations.

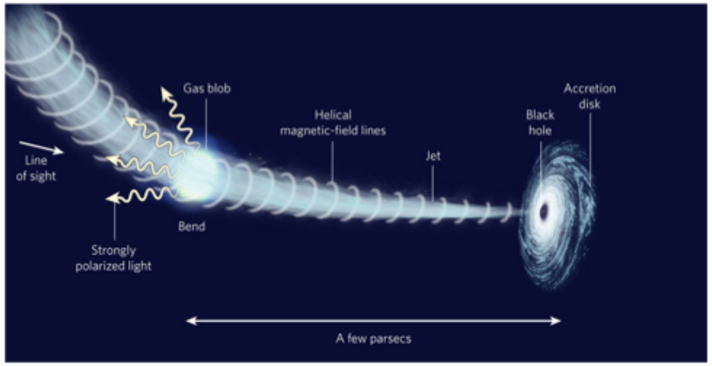
- Emission mechanisms at different frequencies?
- Location of the emission region (?)

Fermi Gamma-ray Space Telescope

MW campaign on 3C 279: 2009 Flare



- Gamma-ray emission is dominant and most variable
- Isolated X-ray flare
- Flux vs polarization degree (PD)
- Rotation polarization angle (PA or EVPA)

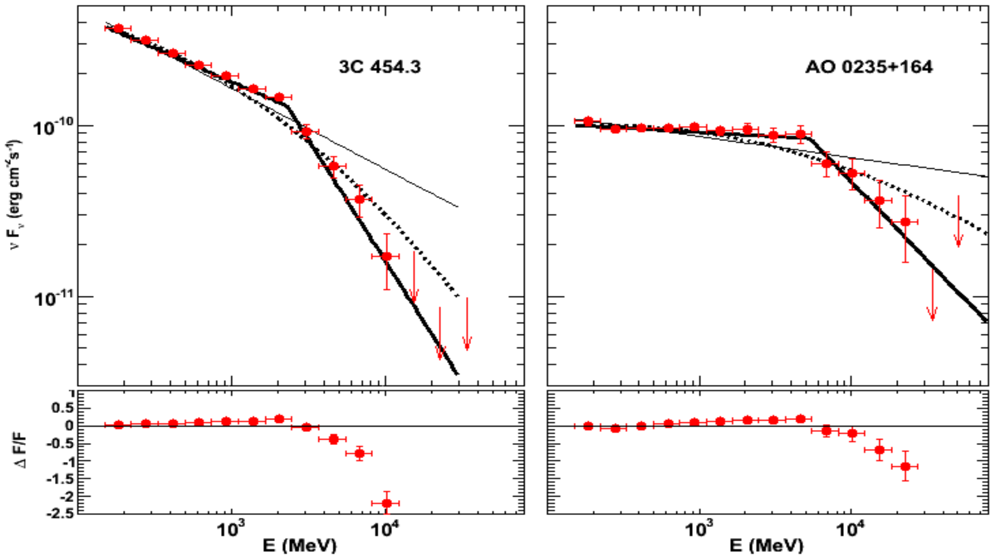


Abdo et al. 2009, Nature, 463,919

•Challenging for the models
•Dissipation region outside the BLR, EC from IR torus?

Non-power law spectra

- First definitive evidence of a spectral break above 100 MeV
- General feature in FSRQs and many BLLac-LSPs
- Absent in BLLac-HSPs
- Broken power law model seems to be favored
- $\Delta\Gamma$~1.0 > 0.5 ⇒ not from radiative cooling

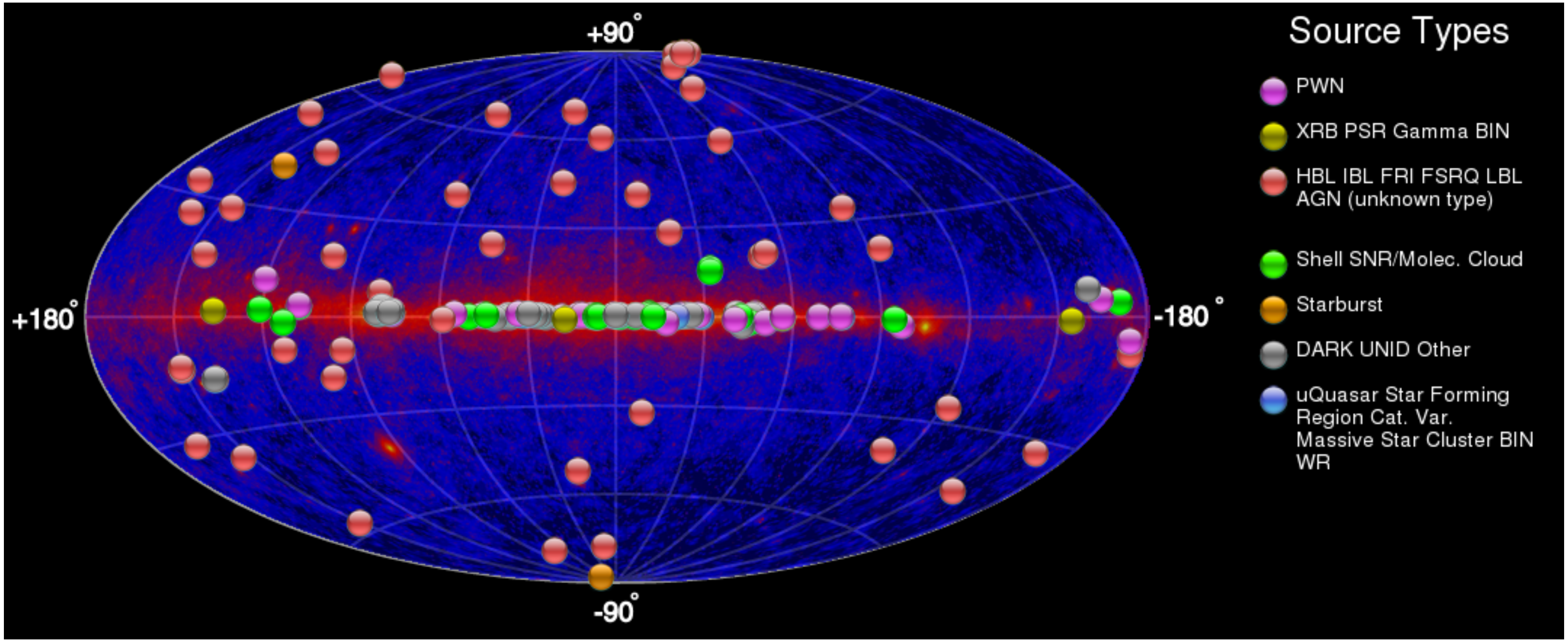


(Abdo et al. 2010,ApJ,710,127)

- Possible explanations:
  - "intrinsic" absorption via $\gamma\gamma$ opacity from accretion disk or BLR photons
  - feature in the underlying particle distribution
  - etc

• Challenge for models to account for the break
• Implications for EBL studies and blazar contribution to extragalactic diffuse emission

TeV Sky (http://tevcat.uchicago.edu/)



47 Extragalactic sources
- 3 FSRQs
- 31 BL Lac – HSP
- 4 BL Lac – ISP
- 4 BL Lac – LSP
- 3 Radio-galaxies
- 2 Star-Forming Galaxies

24 new Blazars detected by ACTs since Aug. 2008
~40% of these discoveries were triggered by Fermi results.

Only 4 TeV AGN are not in the 2 FGL:
1ES 0229+200,
PKS 0548−322, **1ES 1312−423**, HESS J1943+21

Marginally detected by Orr (2011) and on 3-yr at E>10 GeV

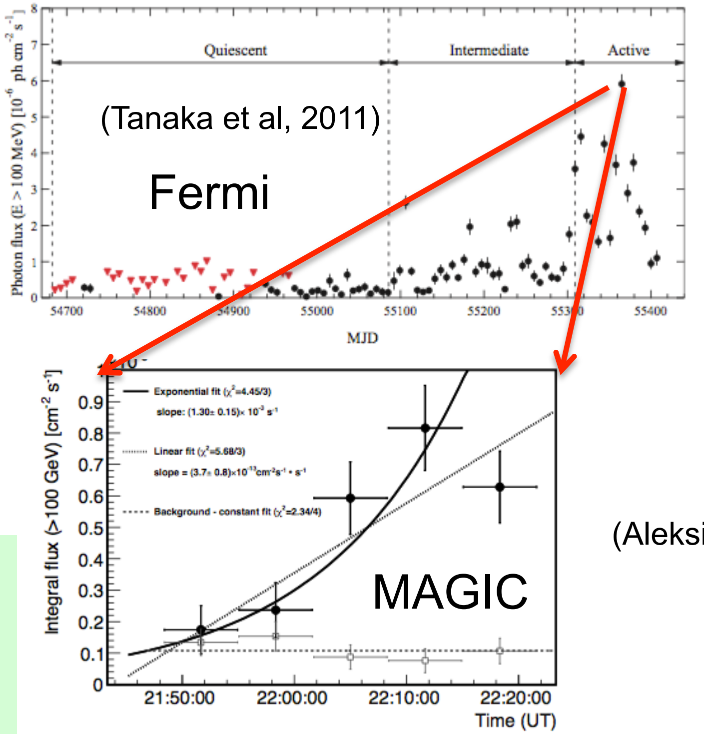
Detected on 3-yr at E>10 GeV

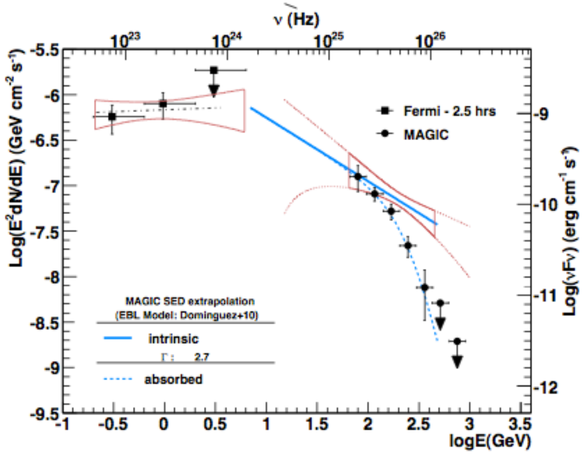
Rapid variability: 4C 21.35

The **FSRQ** PKS 1222+216 (4C +21.35, z = 0.432) **detected by MAGIC following an alert by Fermi-LAT.**

• Hard spectrum without a cut off in the band 70-400 GeV

• variability on timescale of ~ 10 min **challenges standard emission models.**



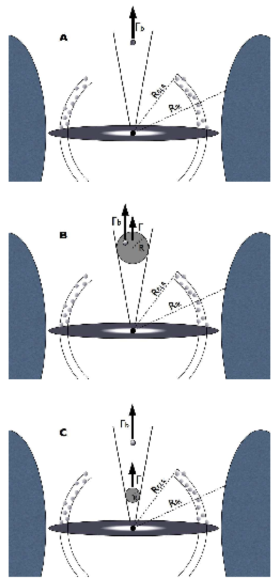


(Aleksic et al. 2011)

• The absence of a spectral cutoff → emission region outside BLR,
• Fast variability challenges emission models from jets in FSRQs.

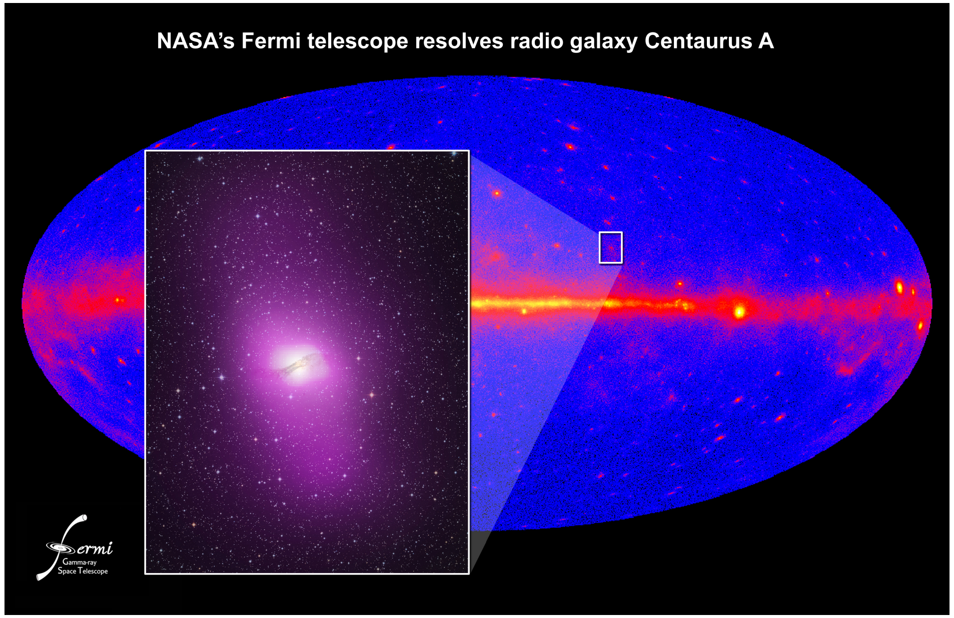
• Combined Fermi/LAT and MAGIC spectral: constraints on the density of the EBL in the UV-optical to near-infrared range.

Extending Fermi:
• Simultaneously observations with the upgraded Cherenkov telescopes (VERITAS, HESS-II, CTA).
• Testing different emission models.
• List of TeV source candidates

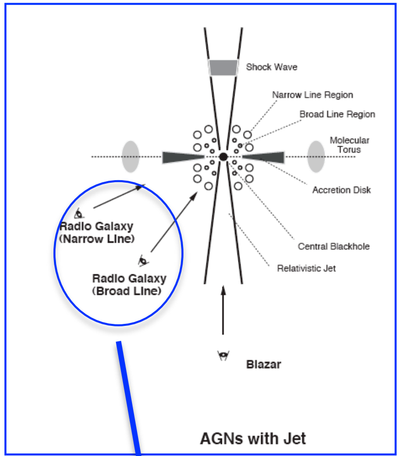


(Tavecchio et al. 2011)

Radio-Galaxies (Misaligned Blazars)



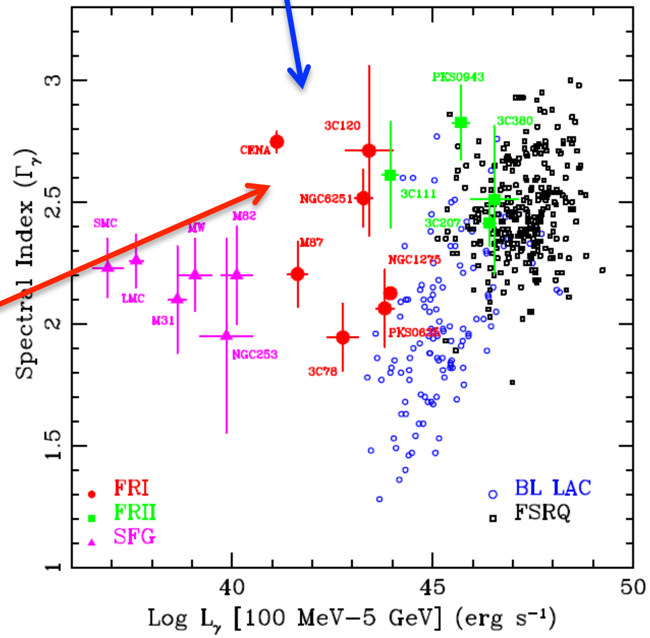
The FRI Cen A is the nearest AGN (3.7 Mpc)



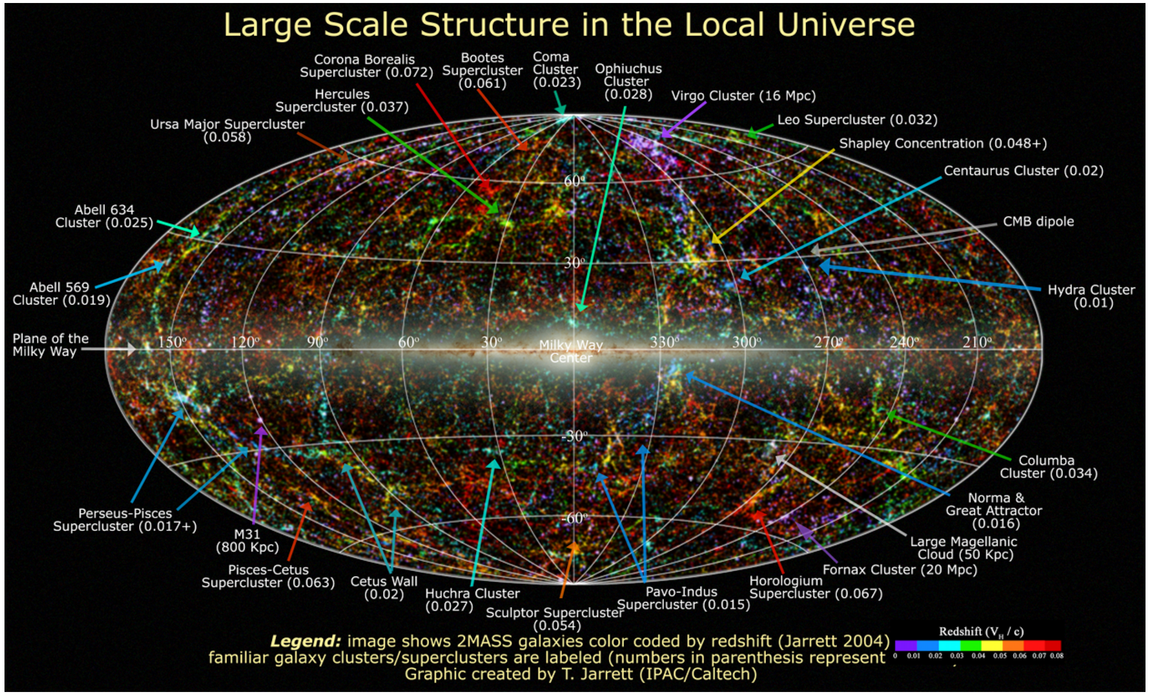
Misaligned AGN γ-ray emission challenging for modelers.

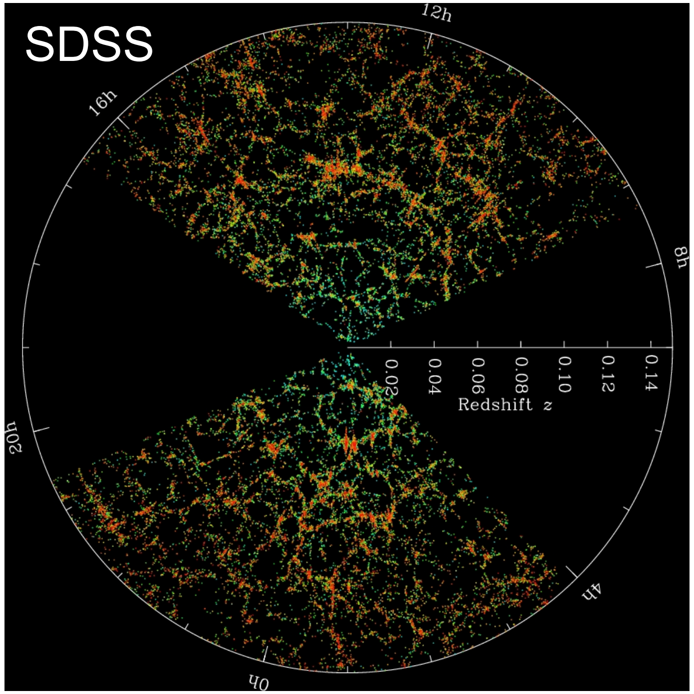
Possible site of production of UHECRs (E>10^{18} eV)

Extending the mission more RG will be detected and data with high S/N ratio will be collected. Test for emission and jet models



Large scale structure of the Universe





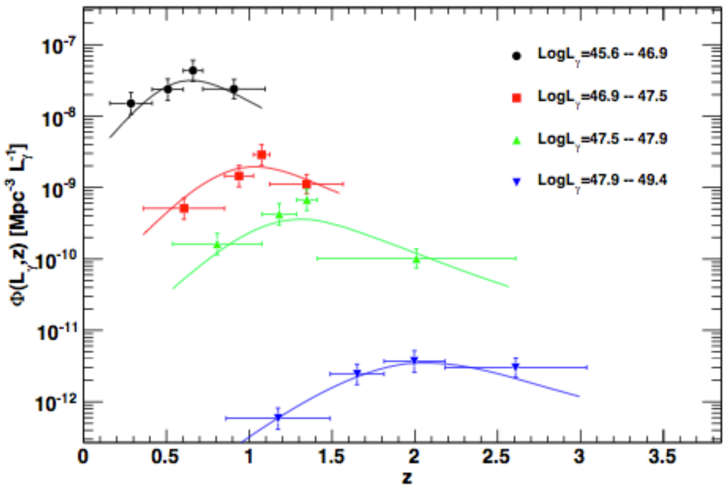
The study of the γ-ray populations allows to constrain:

- The source classes responsible of the Extragalactic Gamma-ray Background (EGB)
- The Extragalactic Background Light (EBL)
- The Intergalactic Magnetic Field (IGMF)
- The role of the HSP Blazars in the history of the Intergalactic medium (IGM) and structures formation.

Isotropic Gamma-ray Background (IGRB)

Luminosity Function of the FSRQs

(density of sources with a given luminosity per unit of co-moving volume)

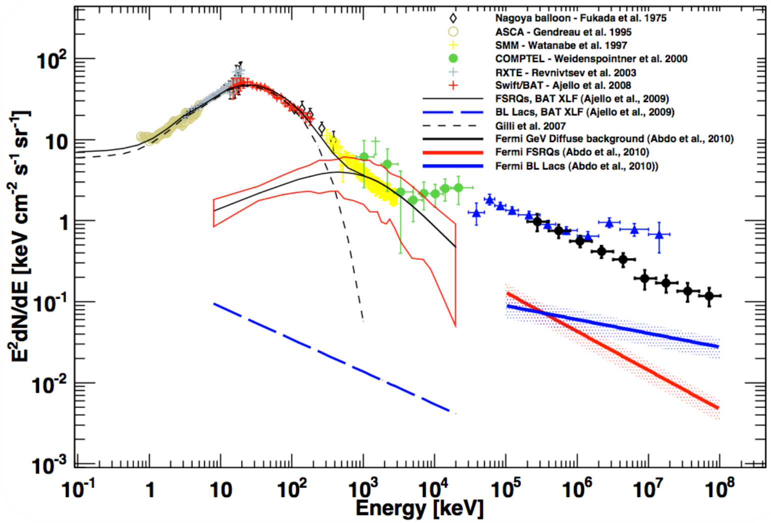


- The more luminous sources FSRQs reached their maximum space density earlier in the history of the universe

- The bulk of the population (the lower luminosity FSRQs) are more abundant at present times

(Ajello et al. 2011)

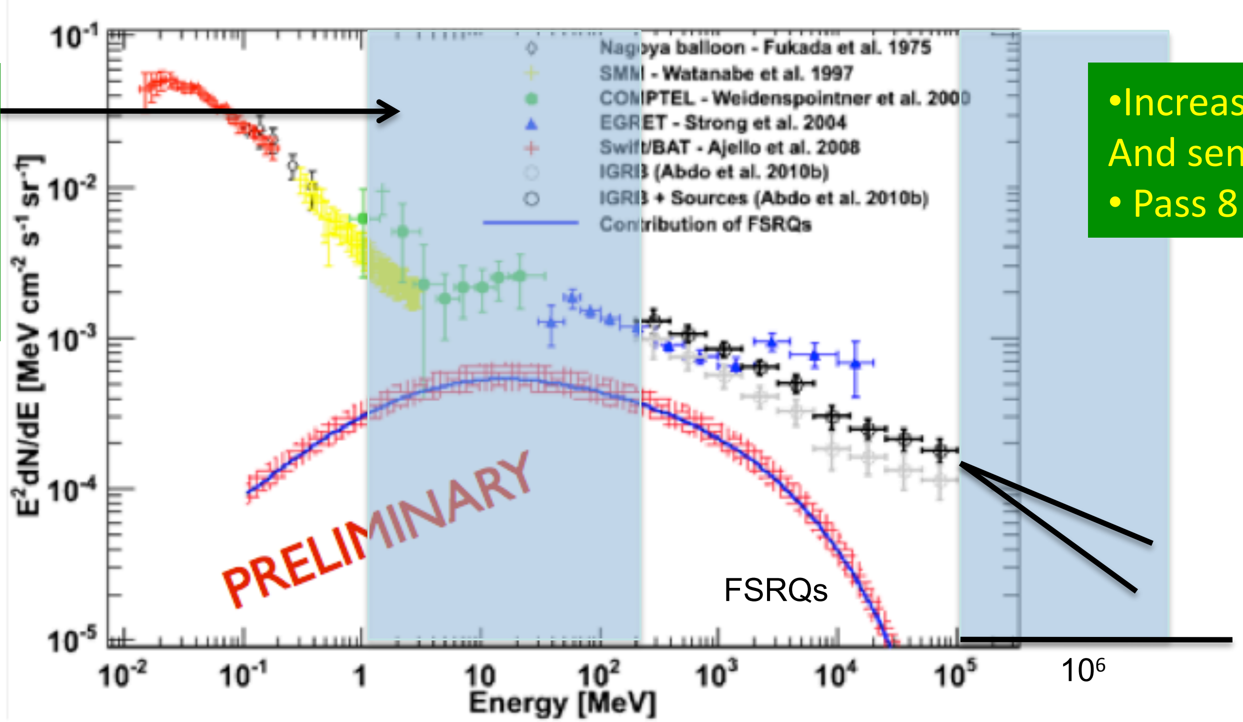
Total contribution from FSRQ + BL Lac + Radio galaxies + Star-forming galaxies: ~ 50% - 80% (25% uncertainty)



An extended Fermi LAT operation will refine the luminosity function of FSRQs and BL Lac objects, and help identify new populations of blazars, radio galaxies, and star-forming galaxies.

Isotropic Gamma-ray Background

- Pass 8
- Instrument configurations
- Analysis techniques

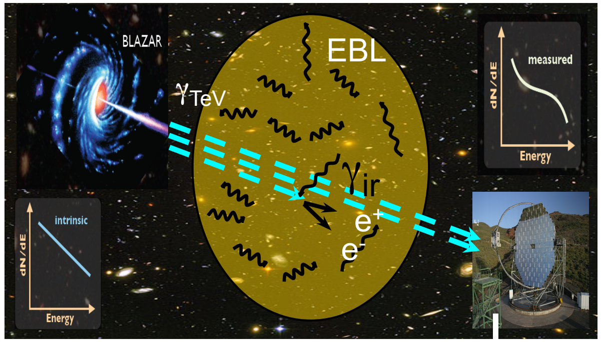


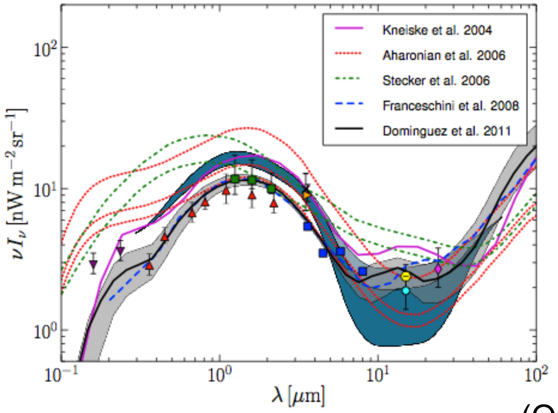
- Increase of exposure And sensitivity
- Pass 8

An extended Fermi mission will refine the luminosity function of FSRQs and BL Lac objects, and help identify new populations of blazars, radio galaxies, and star-forming galaxies.

- Which classes of unresolved sources contribute how much to the IGRB?
- Can unresolved sources alone explain the total IGRB intensity ?

Extragalactic Background Light (EBL)

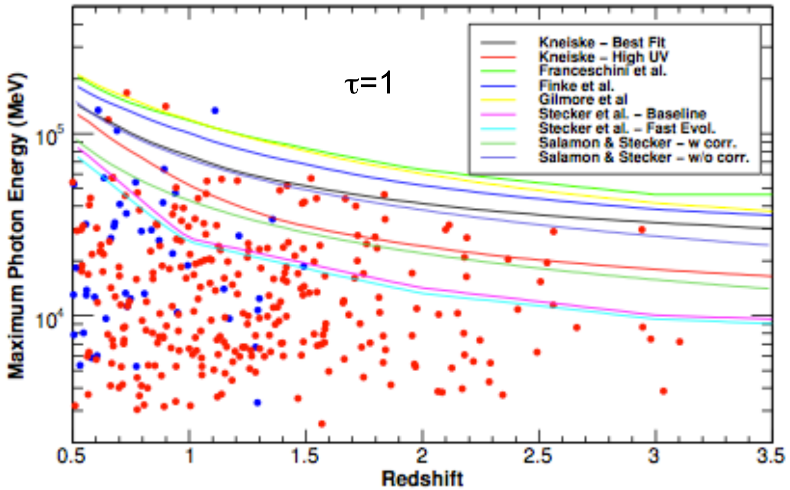




(Orr et al, 2011)

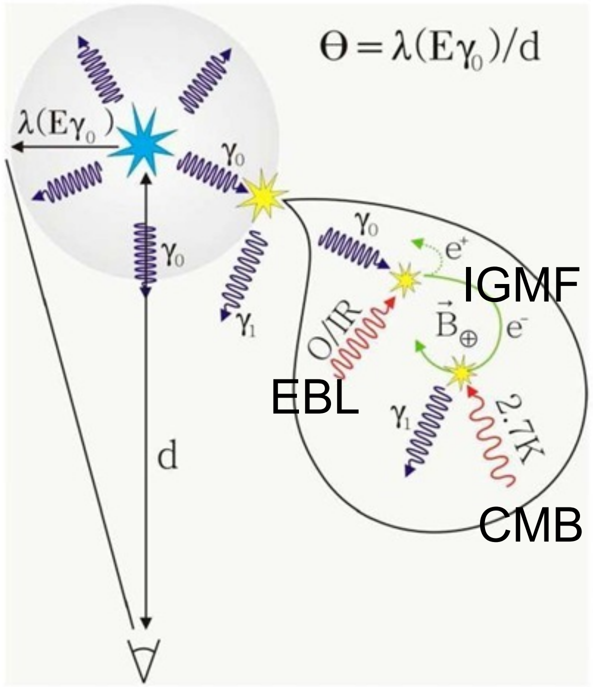
EBL softens the TeV spectra. Combining GeV - TeV observations: constrains to the EBL in IR-opt/UV

Extension of the Fermi mission:
•More photons from high-redshift sources that are most useful for constraining models of the EBL.
•MW observations with CTA and HAWC,
→EBL effects in low-redshift sources.



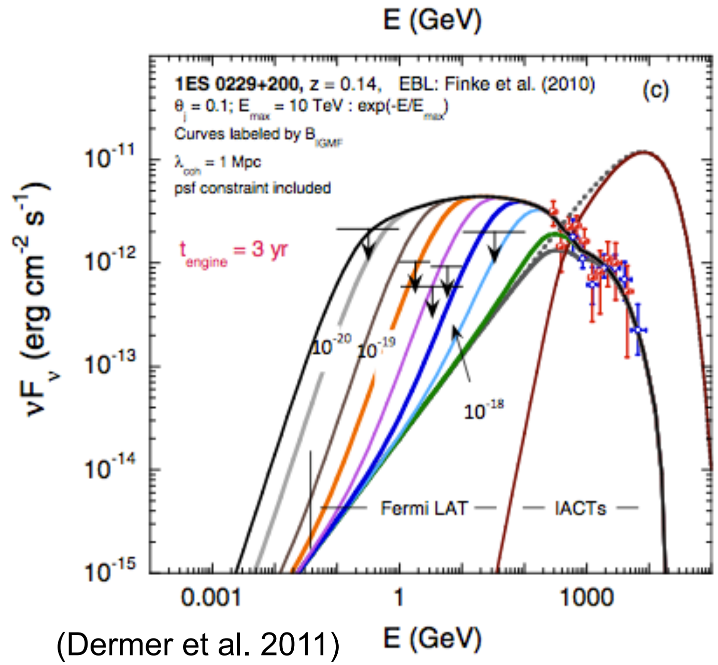
(Abdo et al, 2011)

The Intergalactic Magnetic Field (IGMF)



The TeV photons produced by blazars interacting with IR EBL, produce pairs. Interaction of the pairs with the IGMF and with the CMB produce effects visible at GeV energies (e.g. pair-halo emission)

Typical limits for B derived from Fermi not detection of these effects are in the range from 10^{-19} G to 10^{-15} G.

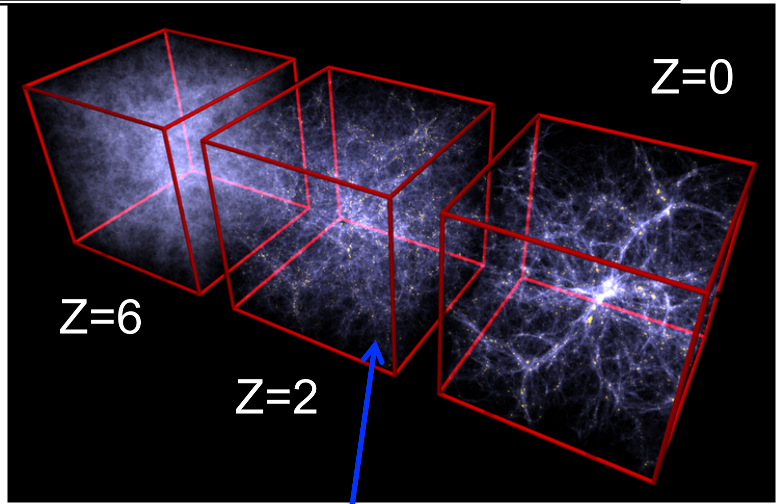


(Dermer et al. 2011)

Extension of the Fermi LAT operation: Improve limits on or measure of the IGMF with improved statistics on the GeV spectra and angular sizes (pair-halo) of TeV blazars.

HSP blazars and structures formation

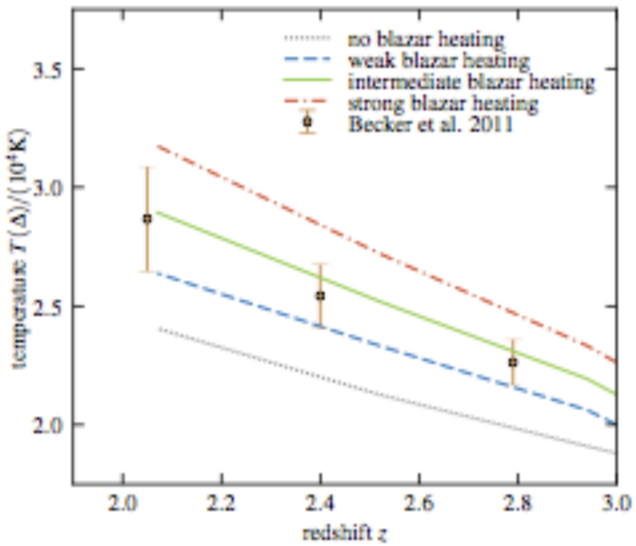
The pairs produced in the interaction of TeV ph with the EBL could heats the intergalactic medium at z~2 (due to plasma bean instabilities)



Credit: Volker Springel

This has implications on galaxy clusters formation.

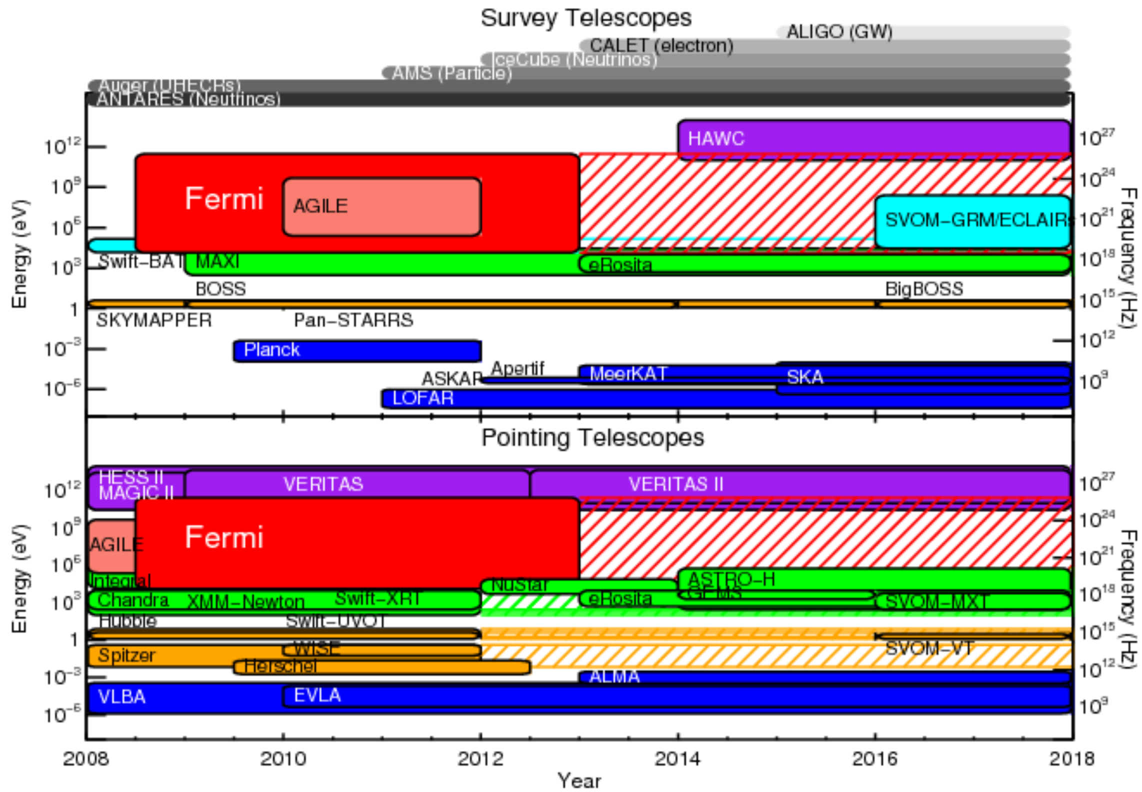
The reasoning is based on the Luminosity Function of the HSP blazars and on results so far obtained on EBL and IGMF.



(Puchwein et al. 2011)

Extension of the Fermi LAT operation:
- Increase the number of HSP blazars
- Better understanding of the HSP Luminosity Function

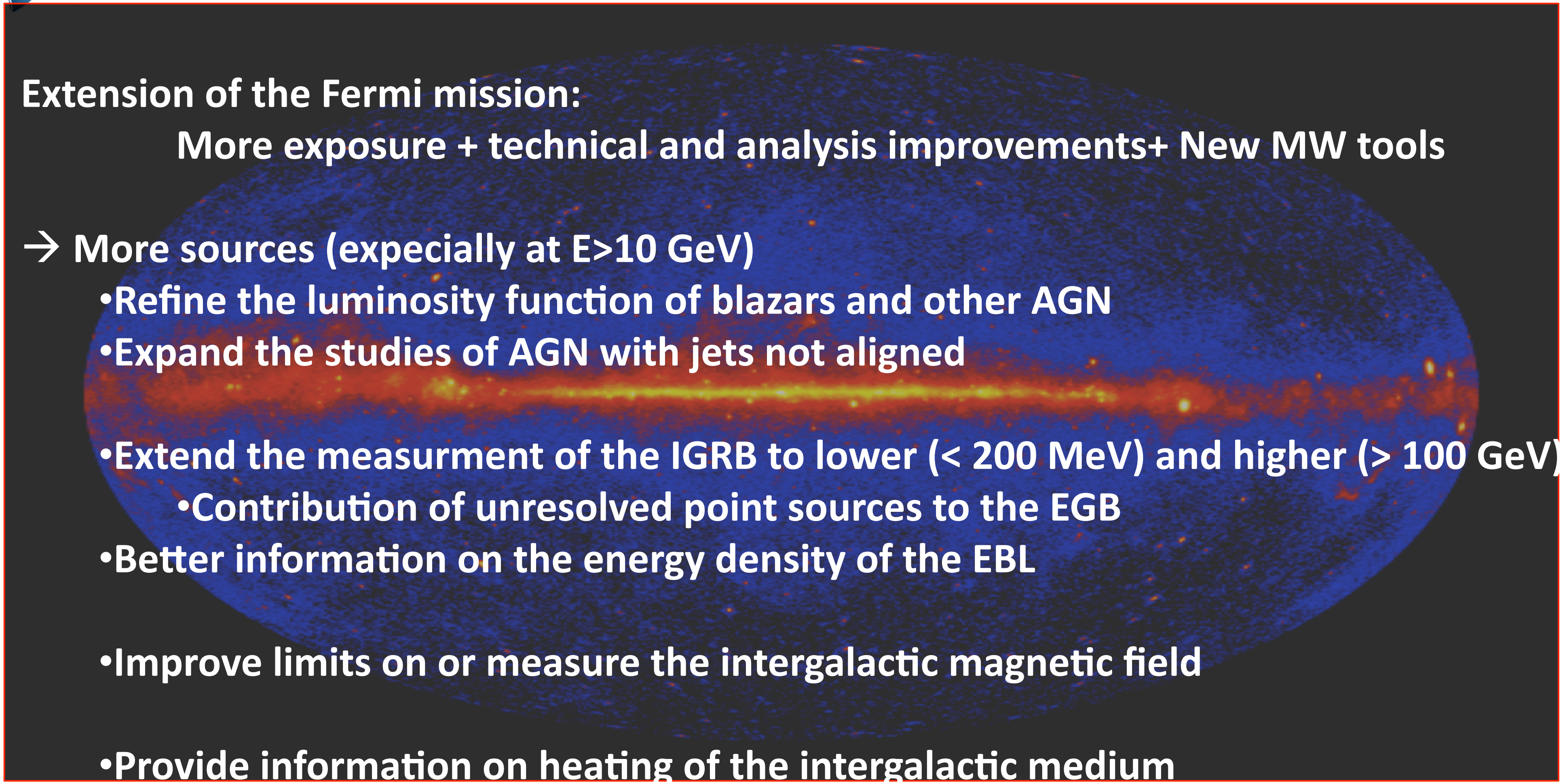
Fermi and the next MW – MM facilities



An extended mission will also benefit of the synergies with the upcoming multi-wavelength and multi-messenger facilities indispensable for the studies of Active Galactic Nuclei.

Fermi and neutrino detector observations will be able to constrain the high-energy hadron content of jets, the impact of the jet on the environment of the host galaxy and the origin of the UHECRs.

Summary



Extension of the Fermi mission:

More exposure + technical and analysis improvements+ New MW tools

→ More sources (expecially at E>10 GeV)

- **Refine the luminosity function of blazars and other AGN**
- **Expand the studies of AGN with jets not aligned**

- **Extend the measurment of the IGRB to lower (< 200 MeV) and higher (> 100 GeV)**
  - **Contribution of unresolved point sources to the EGB**
- **Better information on the energy density of the EBL**

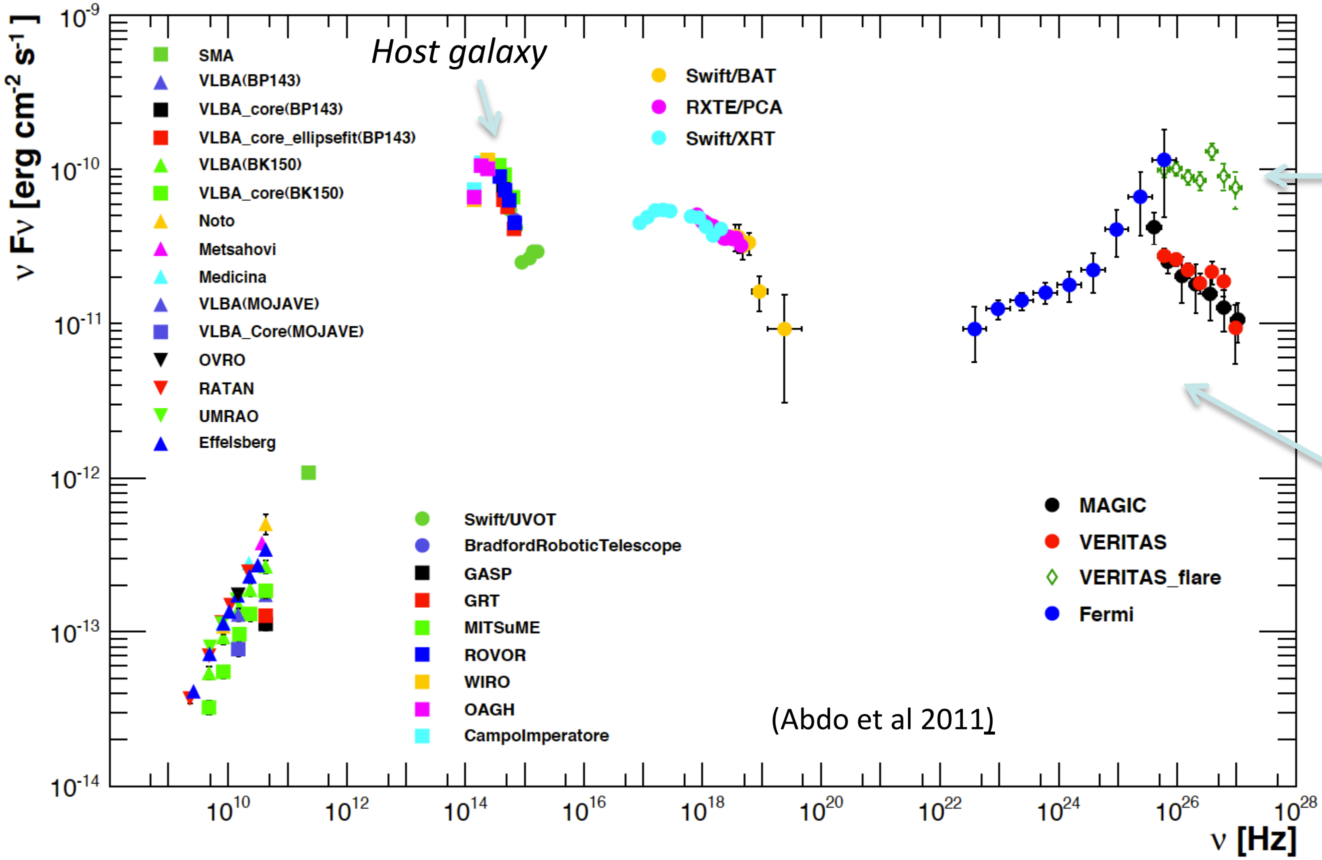
- **Improve limits on or measure the intergalactic magnetic field**

- **Provide information on heating of the intergalactic medium**

(36-m, E>1 GeV; Credit: S. Digel)

BACKUP SLIDES

The 2009 MW campaign on Mrk501



Most complete SED ever collected for Mrk501

Mk501 was in low state during most of the campaign

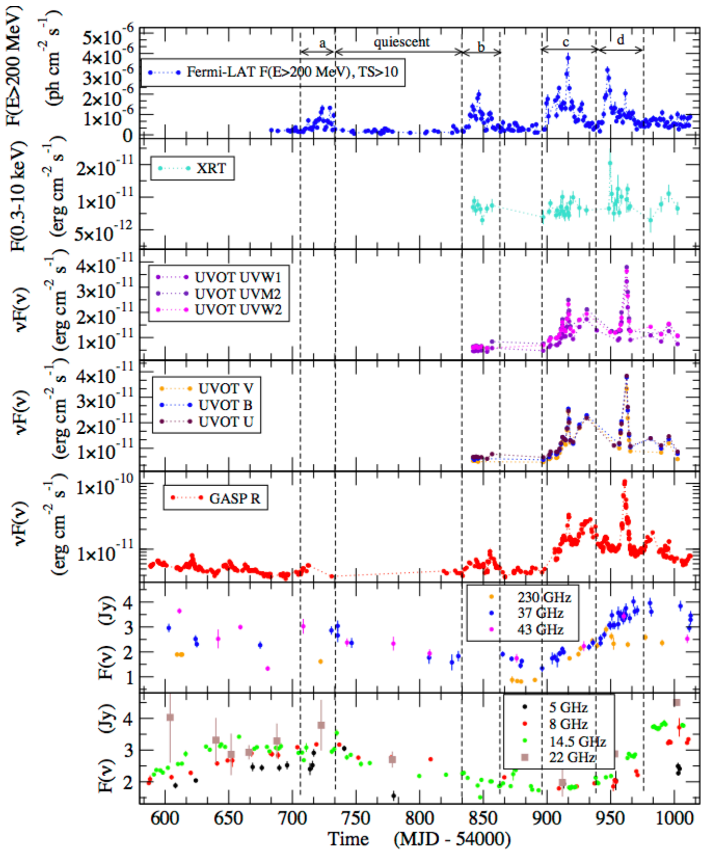
3-day spectrum from TeV flaring activity

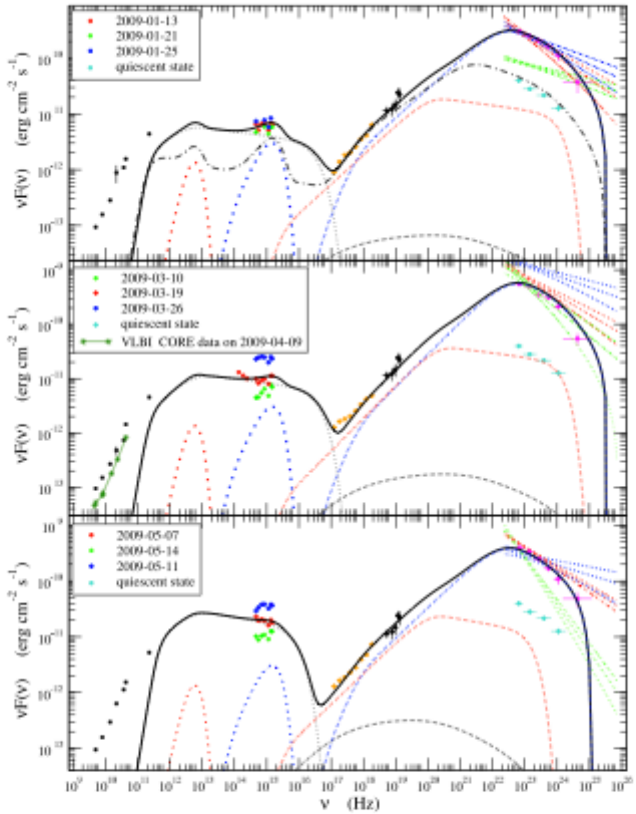
For first time, Fermi MAGIC/ VERITAS spectra cover the complete high energy component over 5 orders of magnitude without gaps

Agreement in overlapping energies among instruments (with different time coverage) indicates that we managed to get the true average SED of Mrk501 during the 4.5 months campaign.

MW campaign on PKS 1510-089

- Complex MW variability
- X-ray less variable
- UV/Optical seems to follow the γ, but there is a possible lag in the optical data lagging behind the γ-ray ~ 13 days
- Radio, self-abs.+ external layers of the jet...

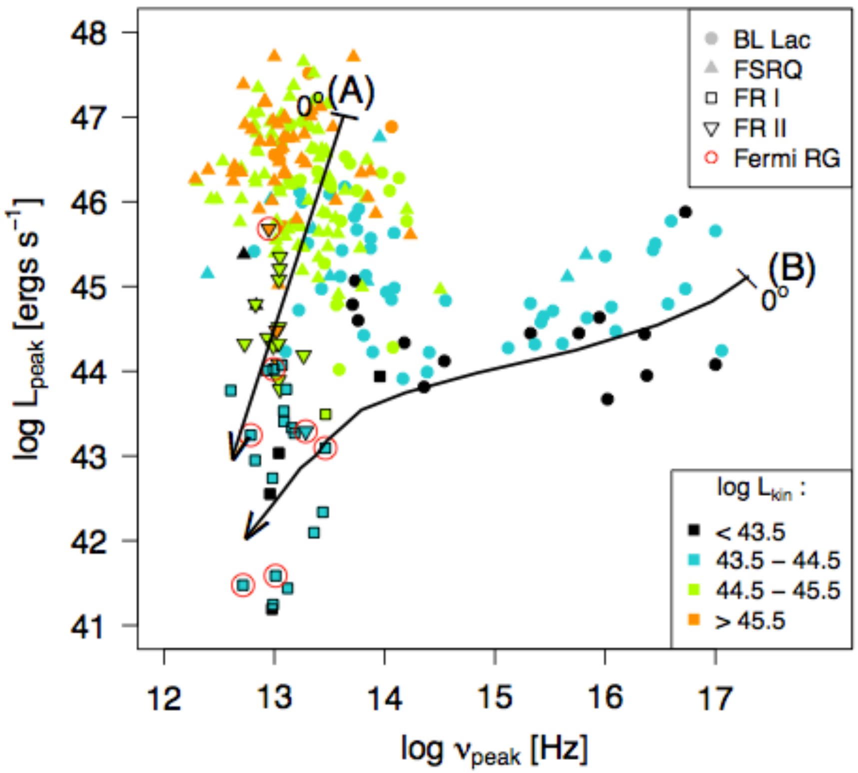


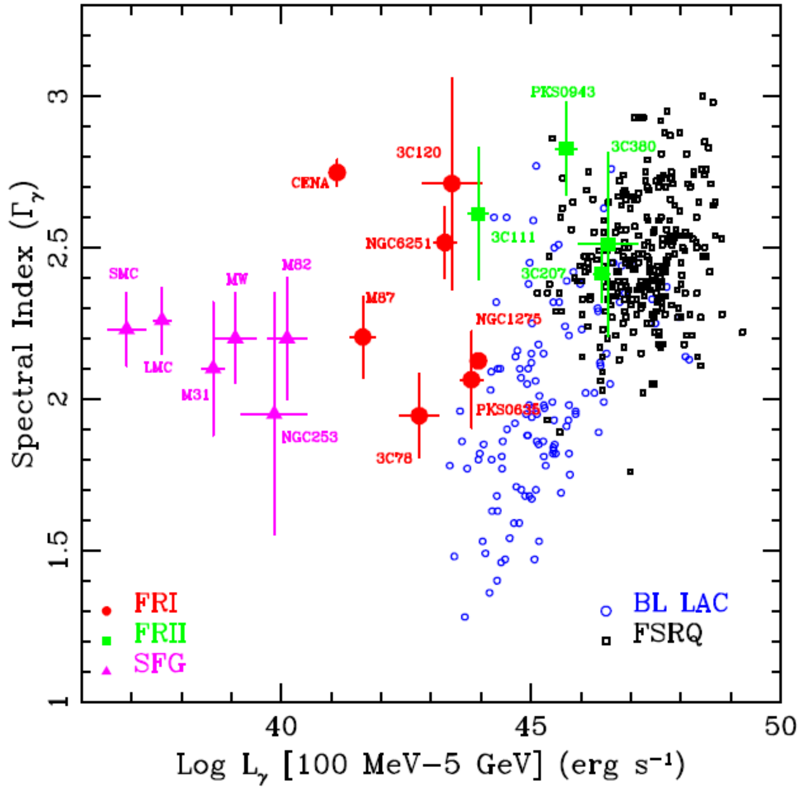


- Compton dominance=L_{IC}/L_S > 10 during flares
- No strong evolution in the peak of the IC component among different flare-averaged SEDs
- Strong BBB also during the huge optical flare
- X-ray seems uncorrelated

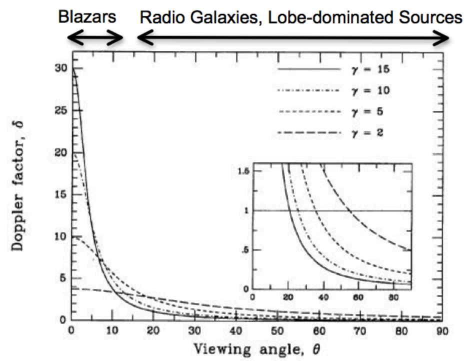
(Abdo et al. 2010)

Blazar Sequence and The Spectral Index – Luminosity plane





Extending the mission more RG will be detected: Test for the new “blazar envelope”



from Urry & Padovani (1995)

MW campaign on PKS 2155-304

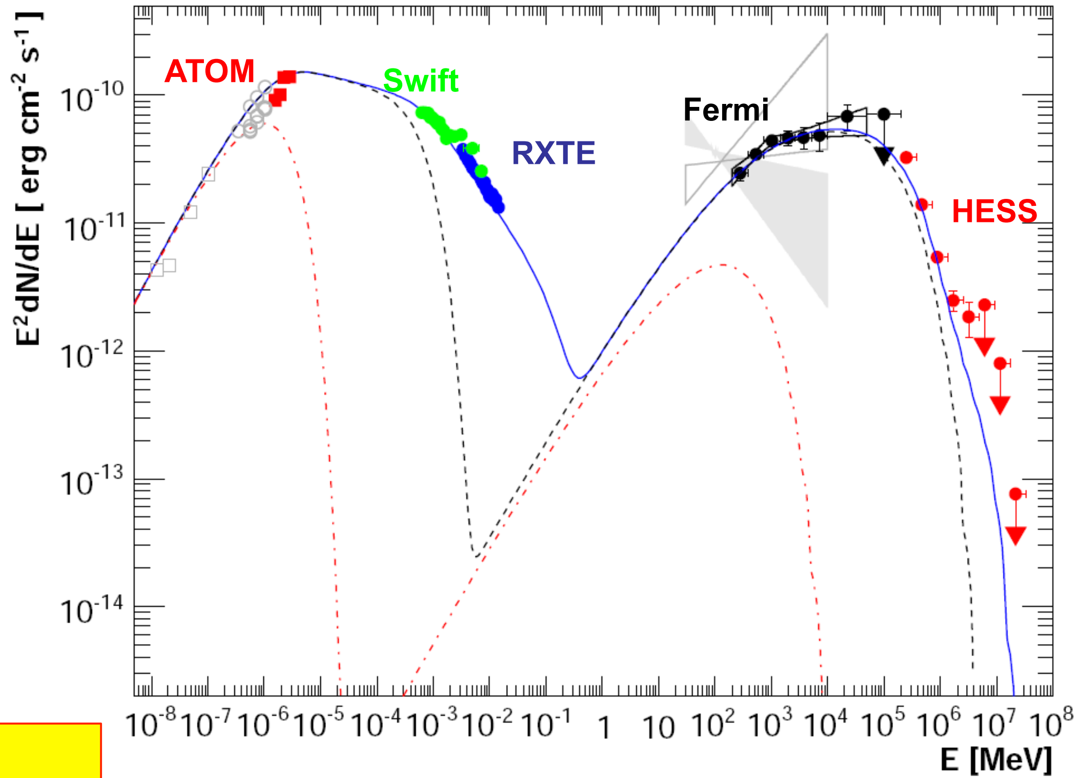
PKS 2155-304: BLLac-HSP, z=0.116
First simultaneous
SED including GeV-TeV data

Unexpected correlations:

- Strong correlation between optical and TeV fluxes

- X-ray flux varies independently of TeV flux

- Correlation between X-ray flux and GeV photon index



Challenge simple SSC models usually used to model the SEDs of BL Lacs

(Aharonian, F. et al. 2009, ApJL, 696 L150)