Fermi LAT recent Results on AGNs

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on behalf of the Fermi-LAT collaboration

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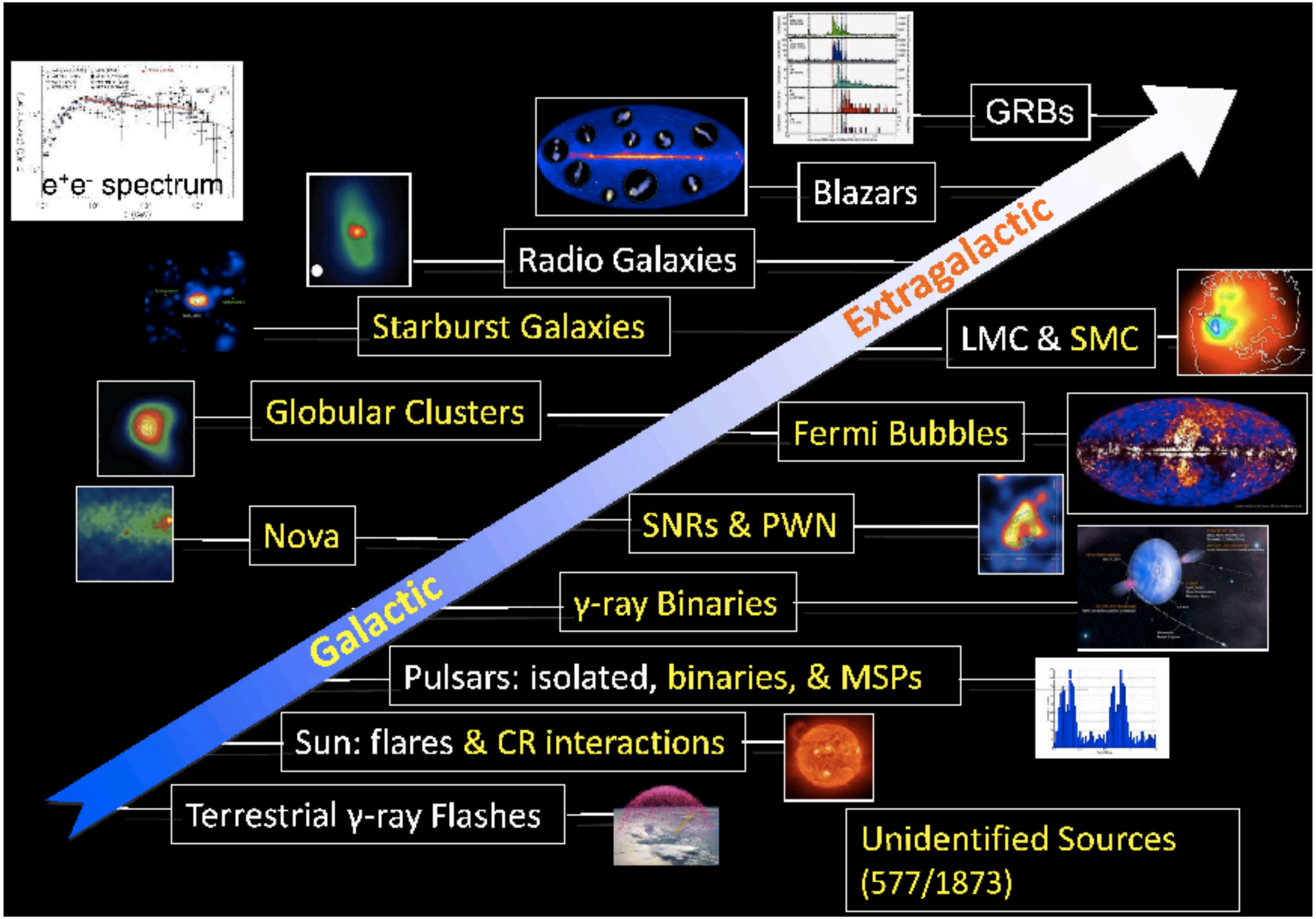
RICAP

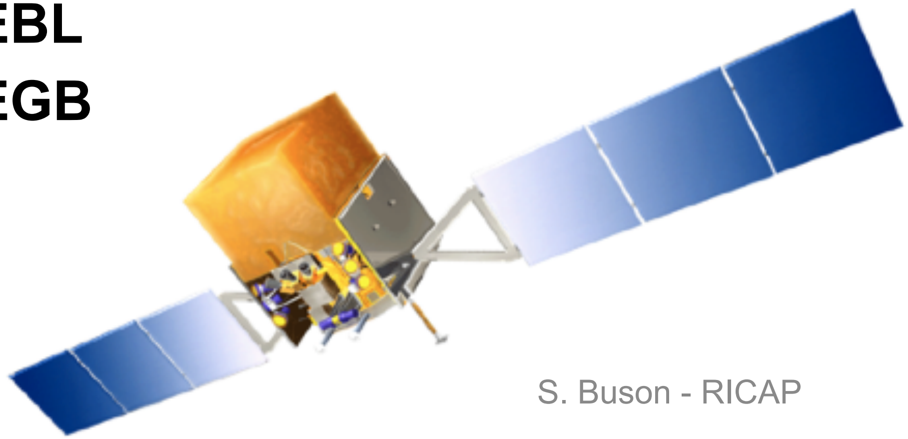
Rome, May 2013

Fermi Discoveries Highlight

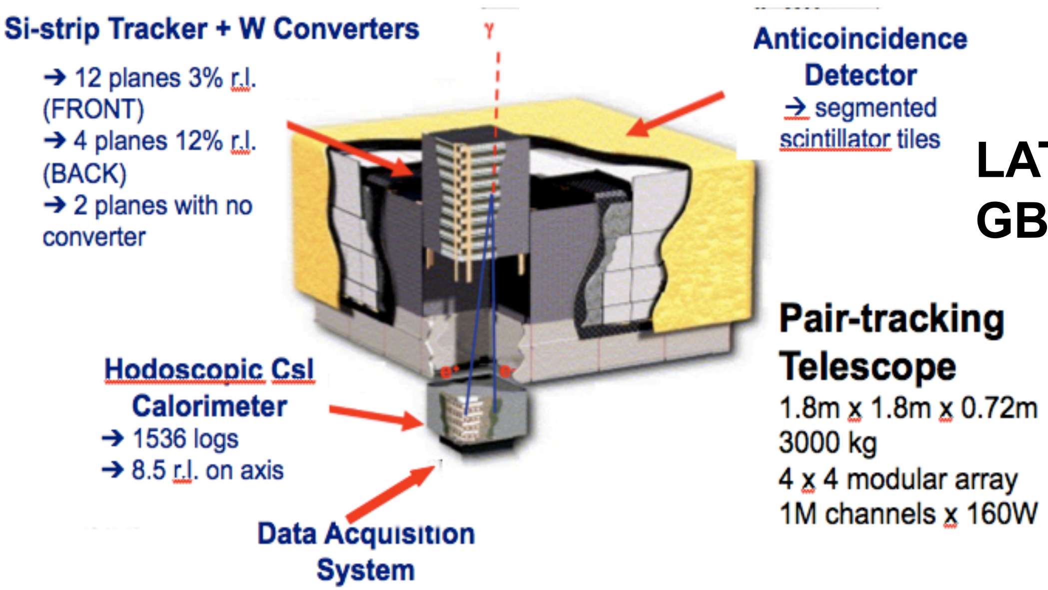


The golden years of gamma-ray Astrophysics

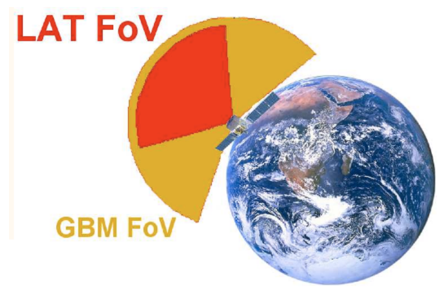
- Overview Fermi
- 2FGL: mostly Blazars
- .. but not only Blazar Science:
  - New gamma-ray emitters (novae, M82 starburst galaxy, Cen A lobes)
  - Gravitational lenses
  - GeV – TeV connection
  - EBL
  - EGB



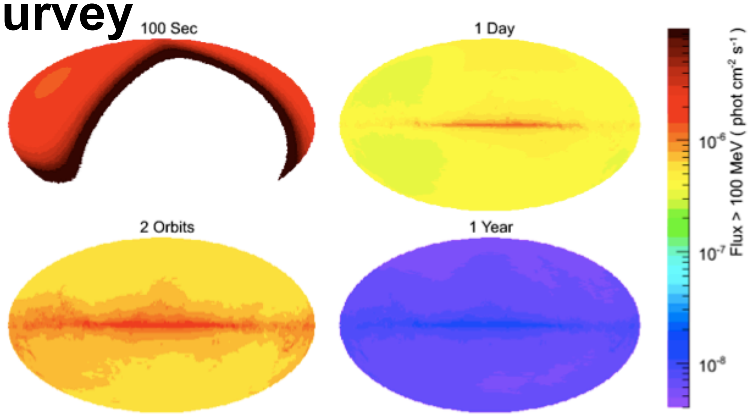
Fermi Survey Mode



LAT sees 1/5 of the sky at any time
GBM sees entire un-occulted sky

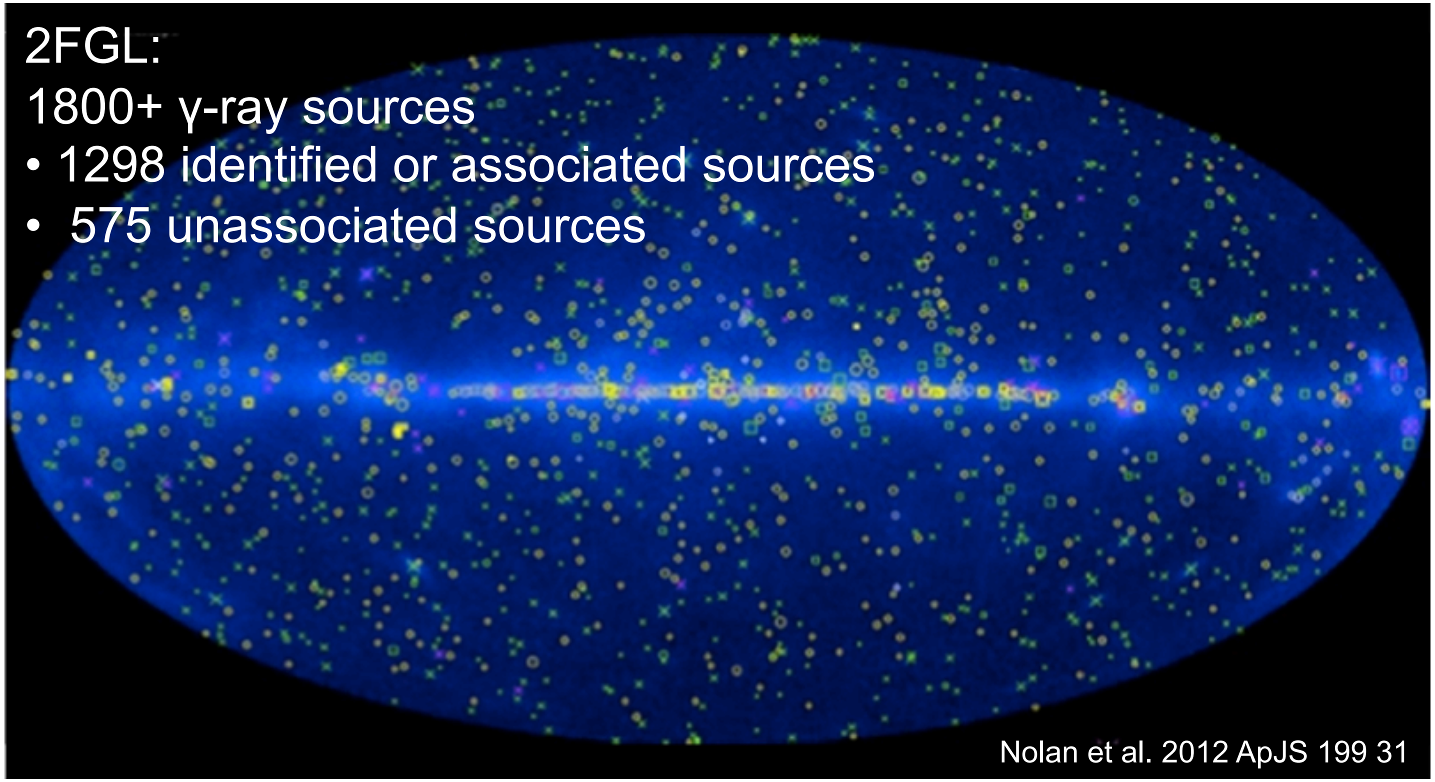


Fermi spends every other orbit rocked either north or south: **3 hours to survey entire sky**

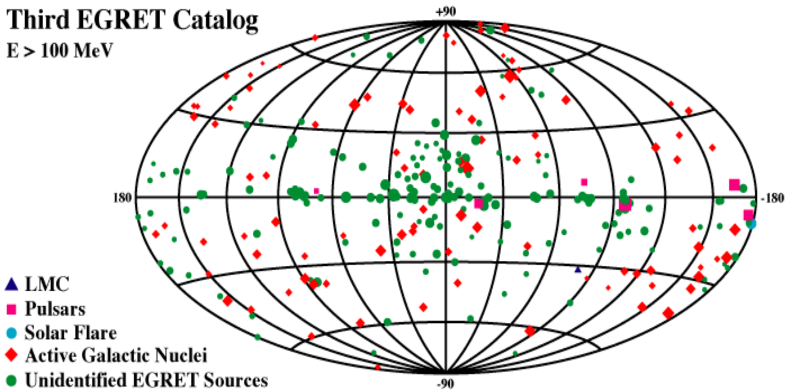


- ✓ ~100 MeV – 300 GeV
- ✓ Large FoV
- ✓ PSF ~45’ @ 1GeV
  ~15’ @ 10GeV

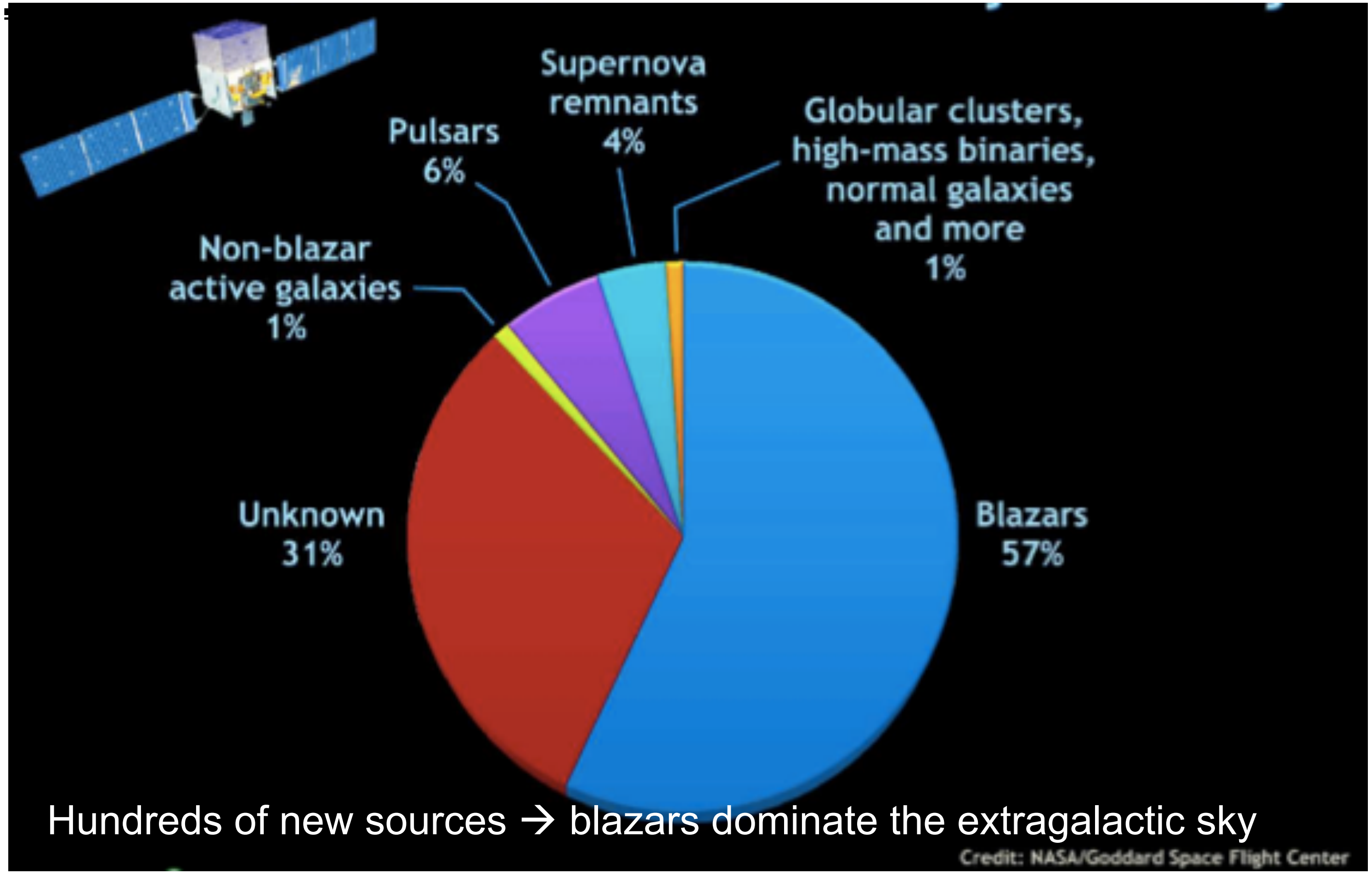
Second Fermi-LAT Catalog



EGRET skymap(1995)
271 point sources

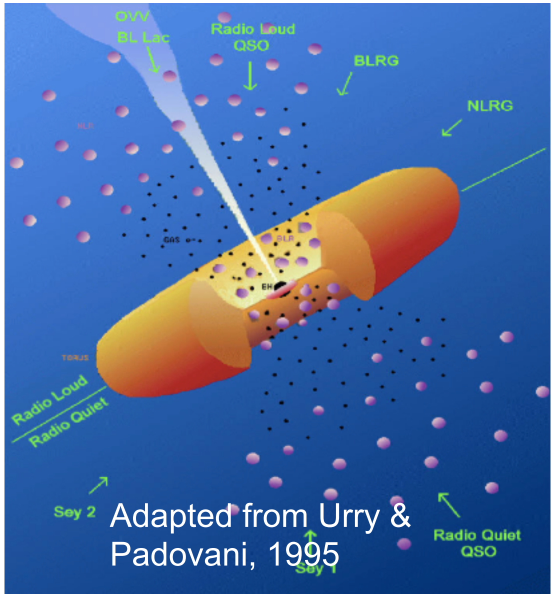


Fermi LAT is a blazar telescope!



- BL Lac objects
  (x~20 wrt EGRET), many are HSPs
- Flat Spectrum Radio Quasars
  (x ~5 wrt EGRET)
- majority of TeV AGNs

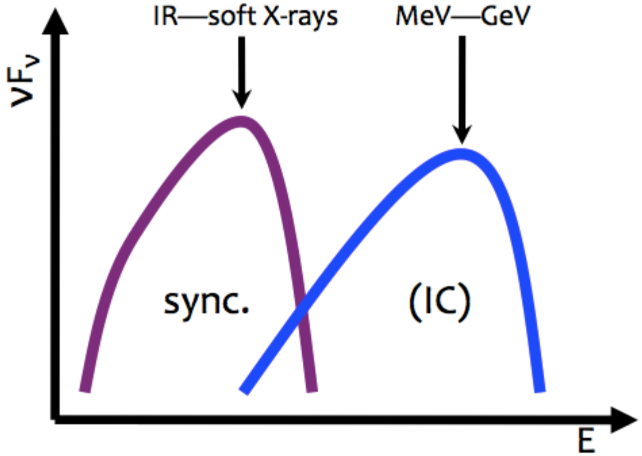
Blazar Structure/Emission processes

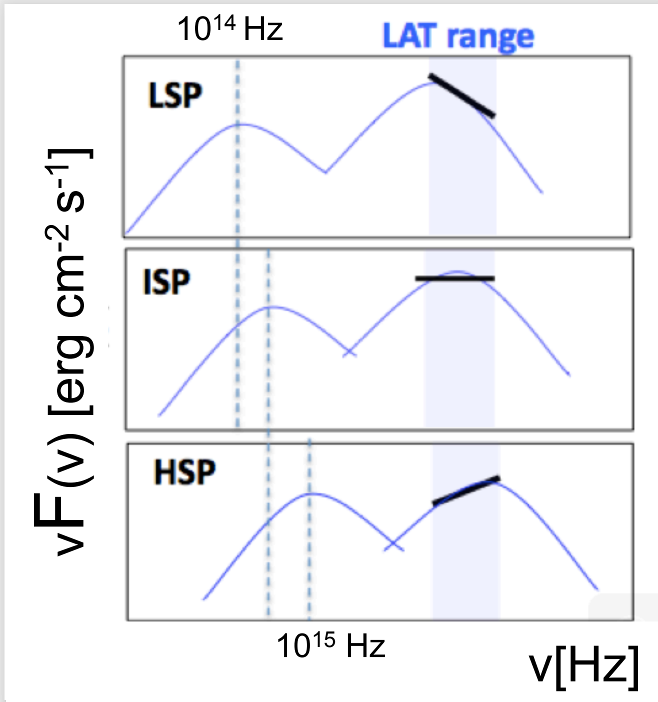


***BLAZAR** signature: relativistic jet pointing at angles close to the line of sight*

+

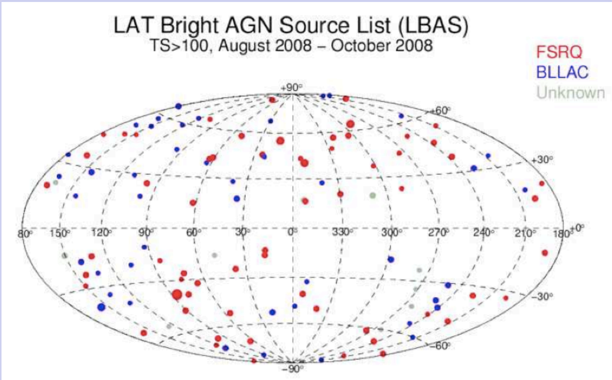
emission is dominated by relativistic effects





SED with two broad bumps:
Synchrotron and **IC** in **leptonic** models.
Also **hadronic** scenarios have been considered (e.g. Mannheim, Boettcher, Reimer, Dermer).

Fermi LAT AGN Catalogs



LBAS-high latitude:

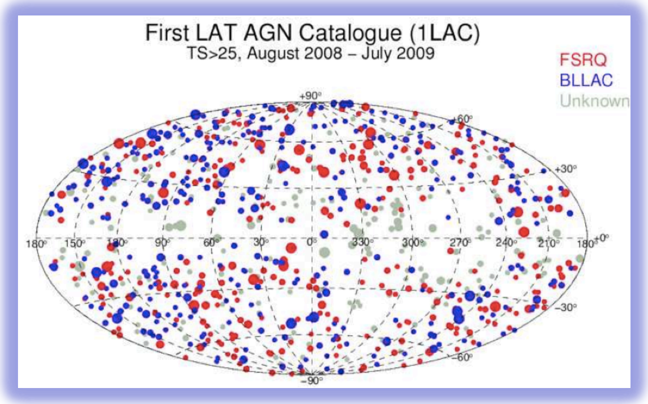
58 FSRQs

42 BL Lacs

6 AGNs

Abdo, A. A. et al. 2010, ApJ, 722, 520

BL Lacs outnumber FSRQs (Fermi-LAT detection limits)



1LAC-clean sample:

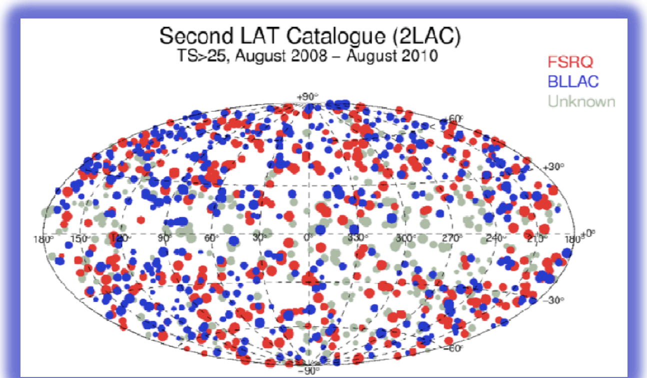
248 FSRQs

275 BL Lacs

50 unknown type Blazars

26 AGNs

Ackermann, M. et al. 2011, ApJ, 743, 171



2LAC-clean sample:

310 FSRQs

395 BL Lacs

156 unknown type Blazars

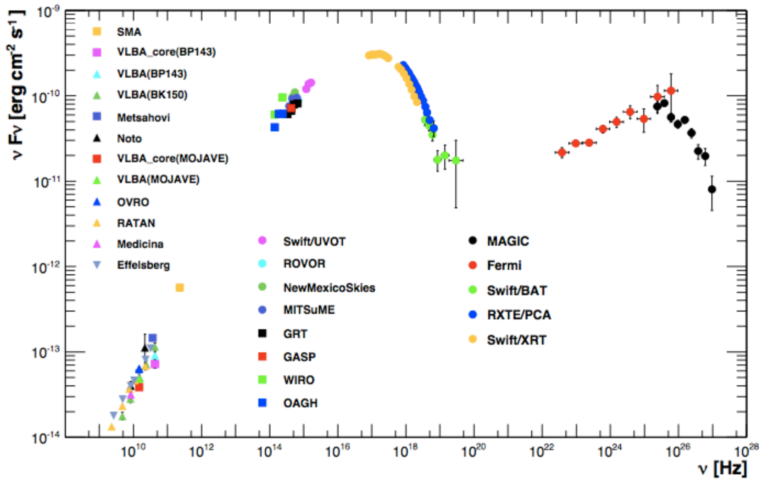
24 AGNs

Abdo, A. A. et al. 2010, ApJ, 715, 429

+286 sources wrt 1LAC, 48% increase

3LAC coming soon!!

GeV-TeV Connection: MKN 421



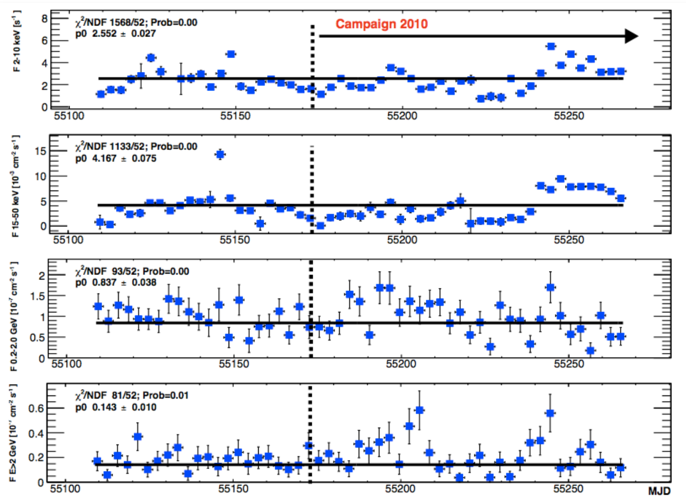
Abdo, A. A. et al. 2011, ApJ, 736, 131

Extensive multiwavelength campaign on MKN 421 (from 2009 Jan. 19 to 2009 Jun. 1)

SED emerging from this is the most **complete and accurate representation of the low/quiescent state of Mrk421**.
Two scenarios are proposed:
Hadronic and Leptonic

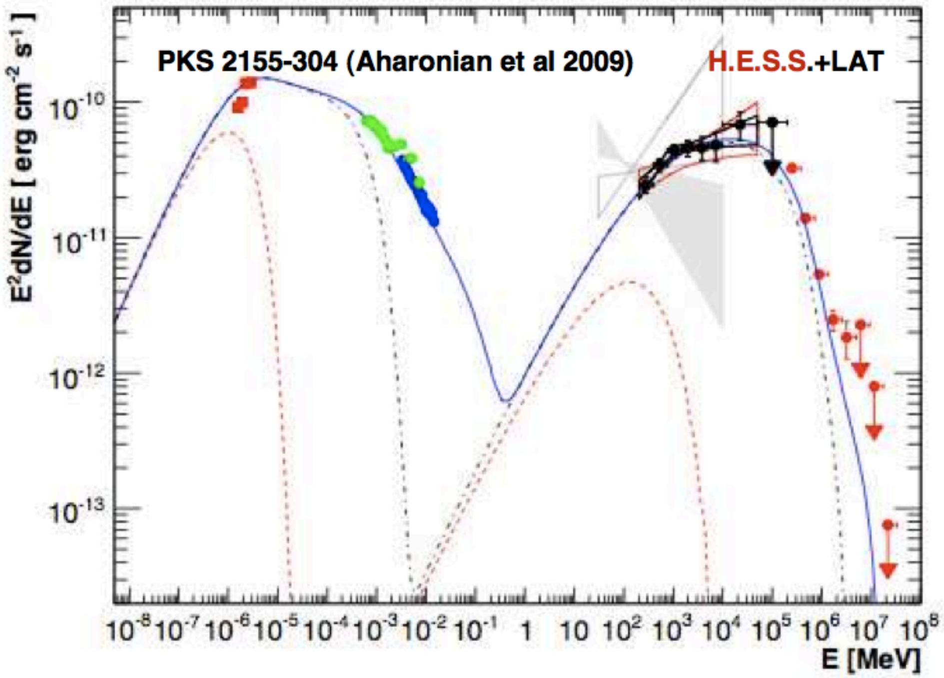
No indication of a correlated activity between X-ray and gamma-ray

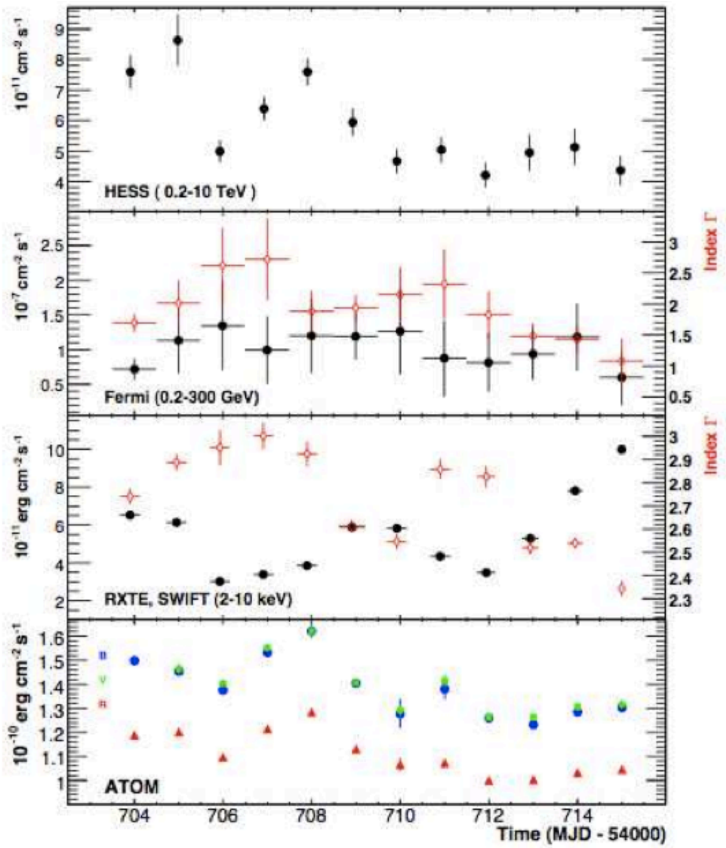
During this campaign, Mrk 421 showed a low activity at all wavebands



Multi-frequency light curves (X-ray:RXTE/ASM, Soft-Gamma: Swift-BAT, Gamma-ray: Fermi-LAT)

GeV-TeV Connection: PKS 2155-304



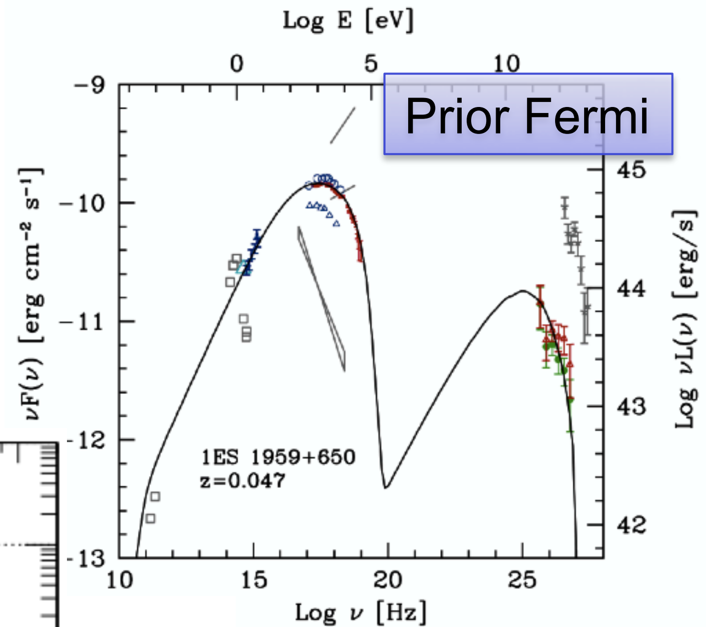


• One of few cases with SED modeled with **one-zone SSC**
• Indication of a correlation between Optical and VHE
• Anticorrelation between X-ray fluxes and Fermi-LAT spectral indices

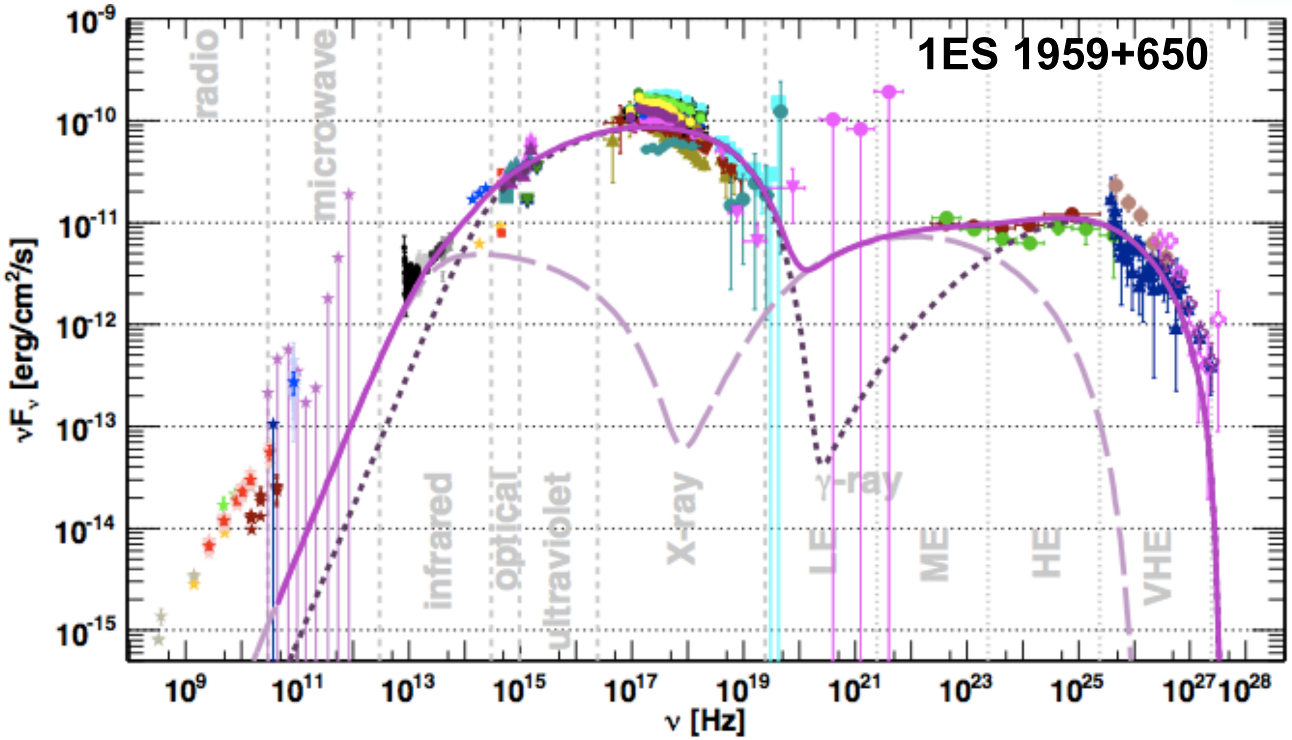
GeV-TeV Connection: 1ES 1959+650

Challenging the one zone leptonic model:
Flat VHE spectrum

A "standard" blazar (no EBL, no hard TeV,....)
- A HSP with an hadronic VHE bump?
- Leptonic multi-zones emission?



Tagliaferri+ 2009



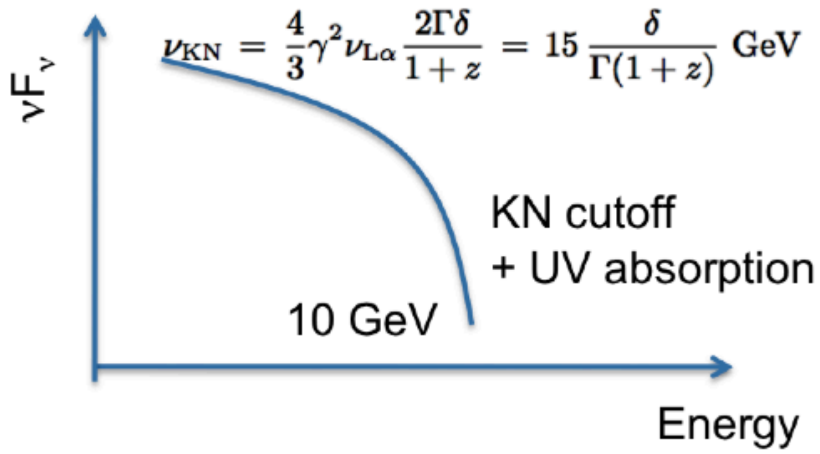
M. Backes+
AIP Conf. Proc.
1505, 522-525

Locating the blazar zone

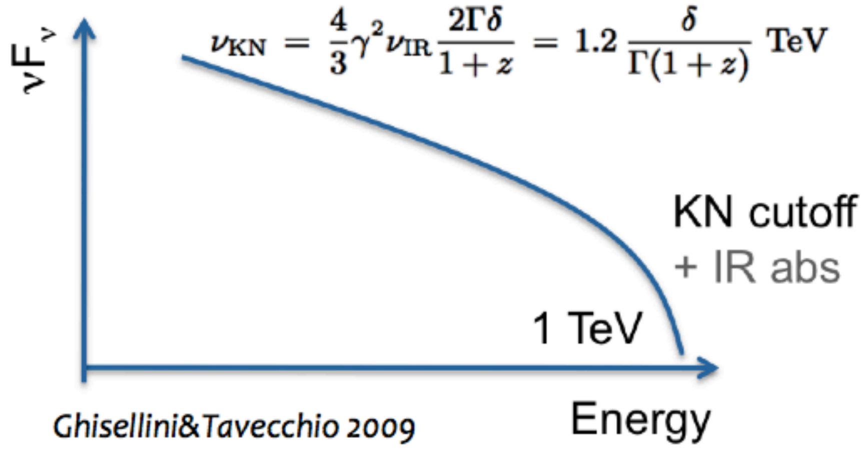
SED features in GeV - TeV spectrum, strong softening due to:

- ✓ Internal absorption
- ✓ Klein - Nishina break

Inside BLR



Outside BLR

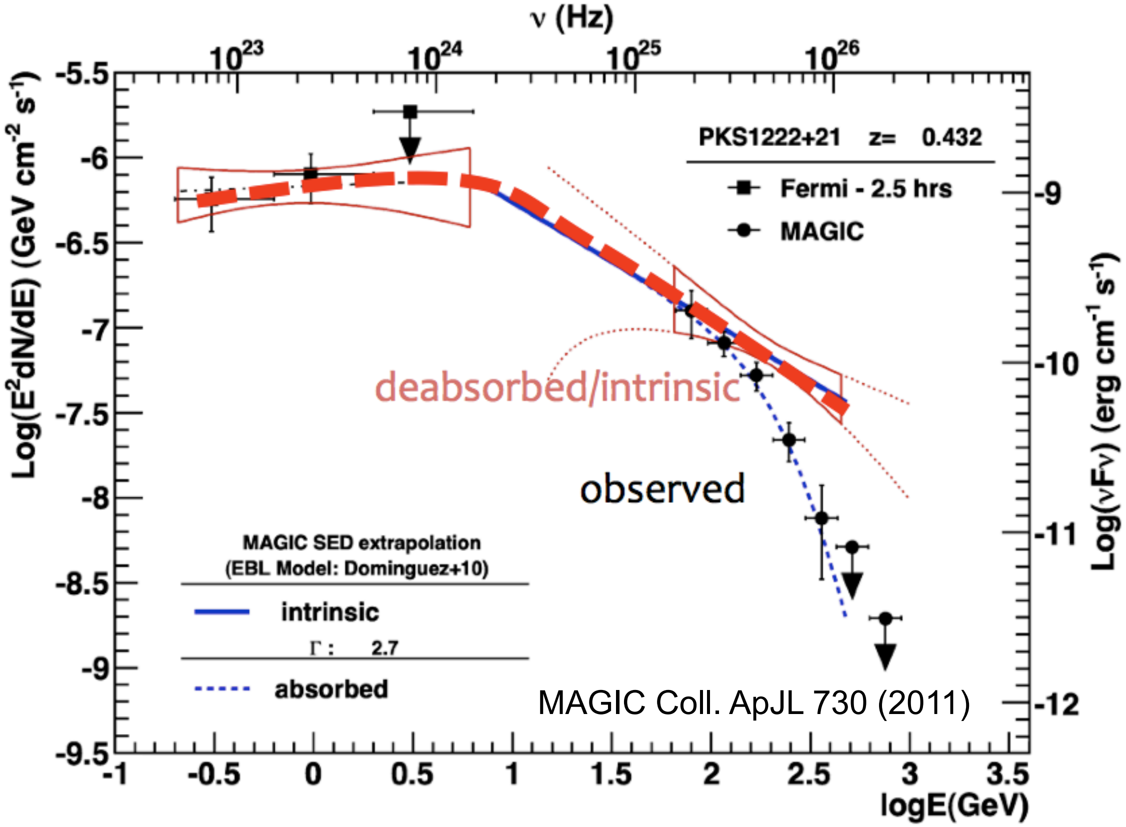


Ghisellini&Tavecchio 2009

Liu&Bai 2006

Locating the blazar zone

- PKS 1222+216 (FSRQ, aka 4C+21.35, z=0.435)
- MAGIC detection (2010) during high activity
- Simultaneous LAT 2.5 hrs encompassing MAGIC obs.



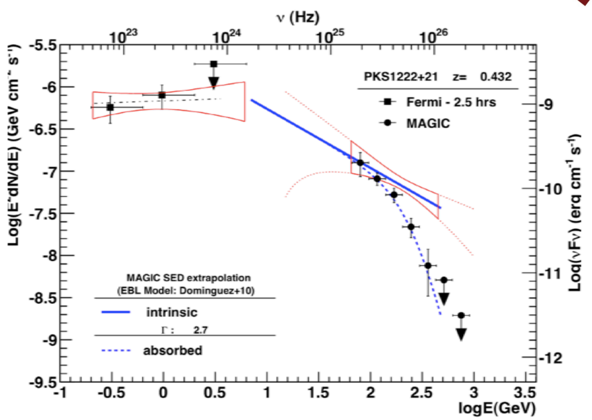
Result: single component from 2 to 400 GeV

cutoff excluded at E < ~130 GeV

Locating the blazar zone

SED features in GeV - TeV spectrum

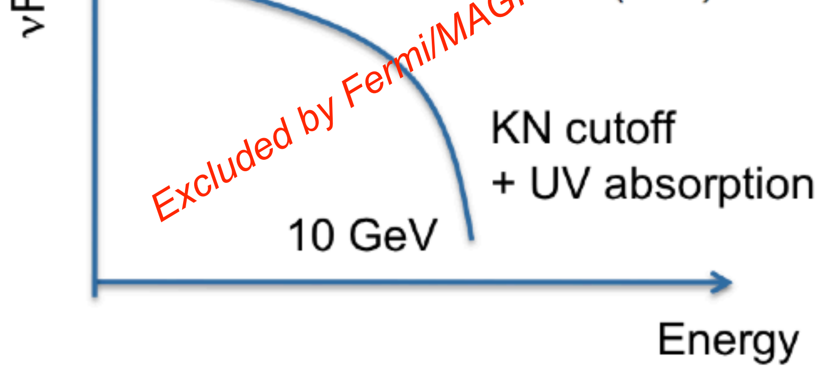
- ✓ Internal absorption
- ✓ Klein - Nishina break



~~Inside BLR~~

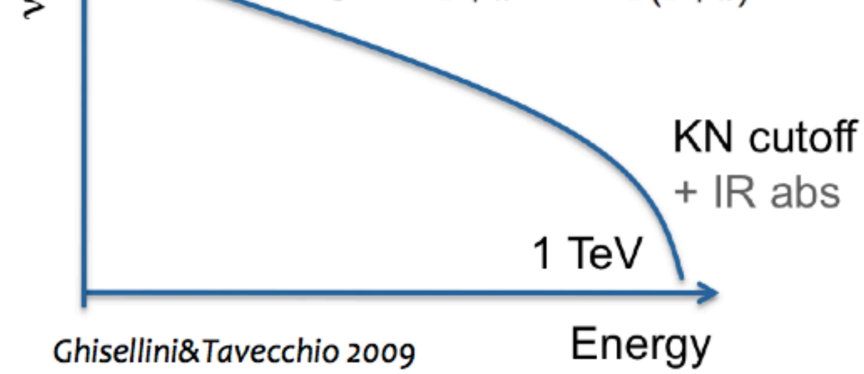
Excluded by Fermi/MAGIC data

$$\nu_{\rm KN} = \frac{4}{3}\gamma^2 \nu_{\rm L\alpha} \frac{2\Gamma\delta}{1+z} = 15 \frac{\delta}{\Gamma(1+z)} \ {\rm GeV}$$



Outside BLR

$$\nu_{\rm KN} = \frac{4}{3}\gamma^2 \nu_{\rm IR} \frac{2\Gamma\delta}{1+z} = 1.2 \frac{\delta}{\Gamma(1+z)} \ {\rm TeV}$$



Ghisellini&Tavecchio 2009

Liu&Bai 2006

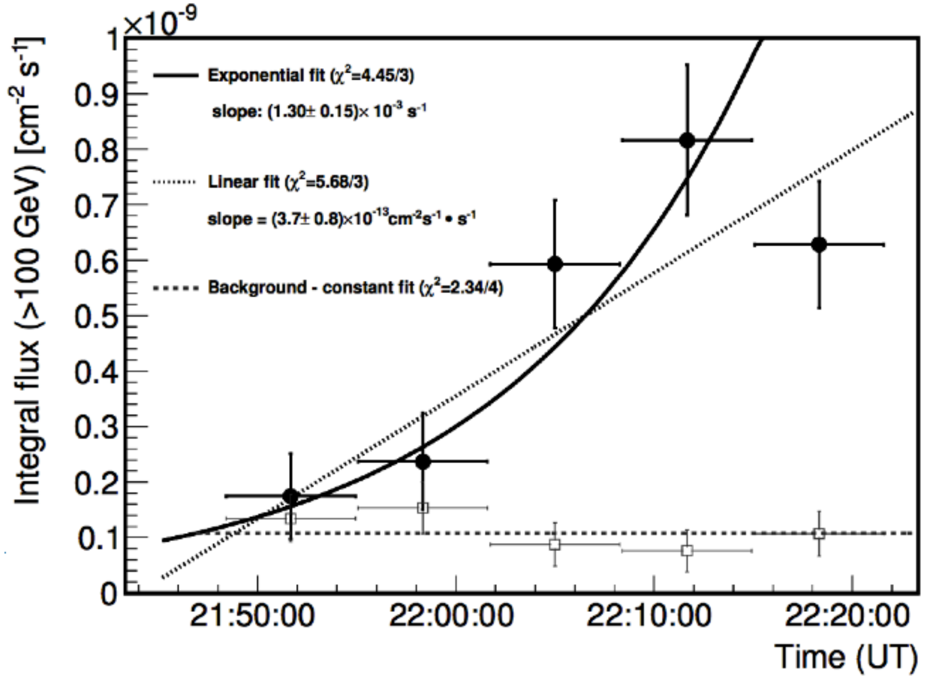
Size of the blazar zone

- Very fast variability
- Doubling flux scale
  9 minutes approx

→ Emission region size:

$$R < ct_{\mathrm{var}} \frac{\delta}{(1+z)} \approx$$

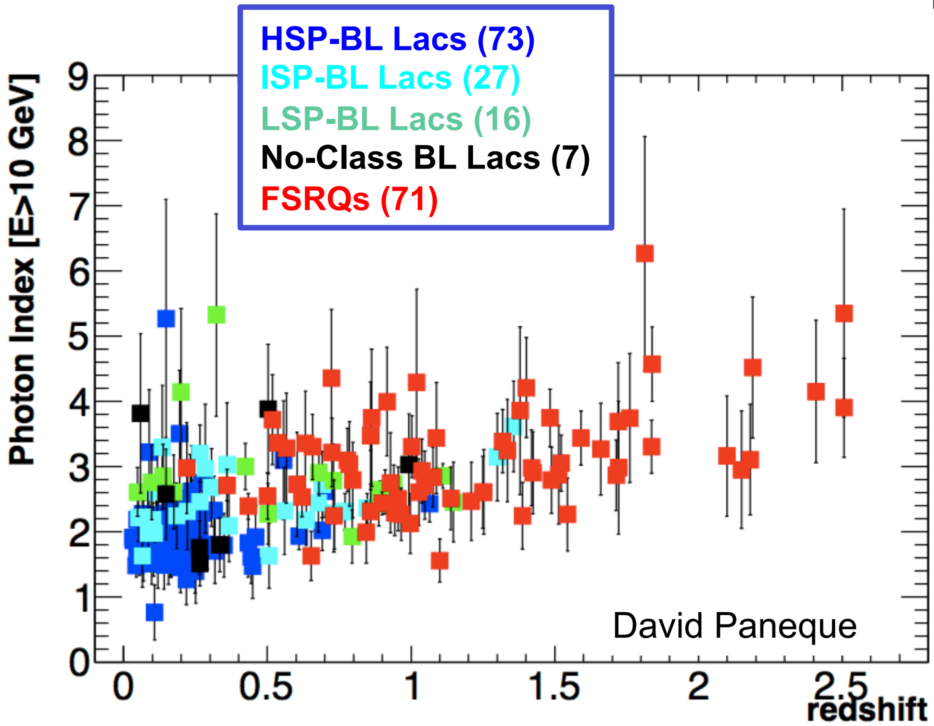
$$1.3 \times 10^{14} \left(\frac{\delta}{10}\right)\left(\frac{t_{\mathrm{var}}}{10\mathrm{min}}\right) \mathrm{cm}$$

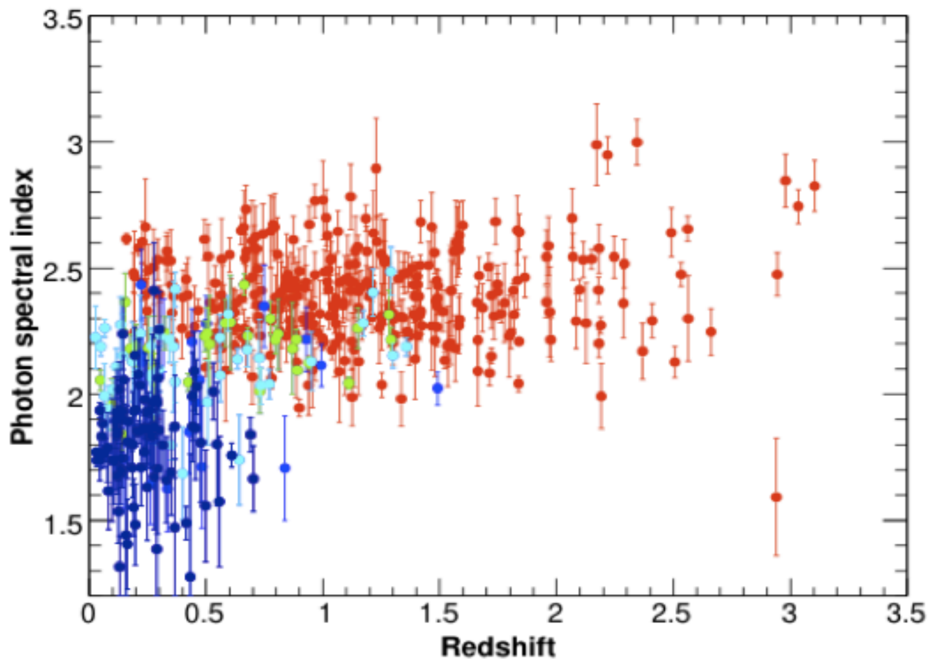


→ Difficulty: reconcile spectral information with fast variability
- Compact regions embedded within the large scale jet
  (such as proposed for PKS 2155-304, Ghisellini & Tavecchio)
- strong recollimation of the jet forming a small emitting nozzle

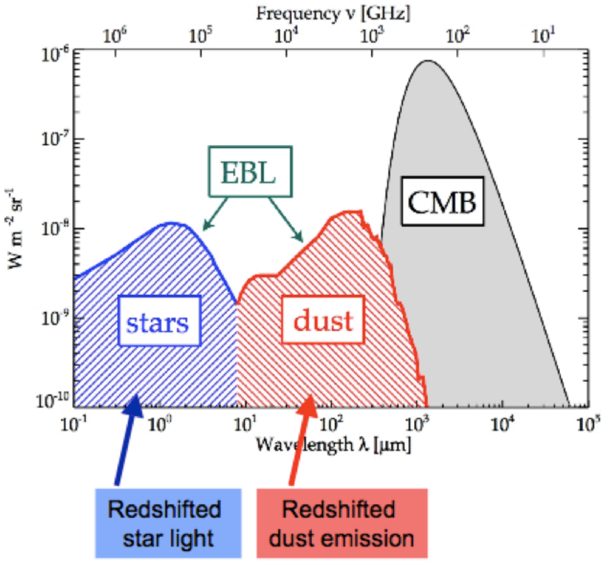
Extragalactic background light attenuation in Fermi LAT data?

- **Fermi Hard source List:**
  - sources get softer with increasing redshift
  - → possibly due to attenuation on optical/UV photons of EBL
    - » Such trend is less clear with photon index from E>100MeV (2LAC paper)





The Extragalactic Background Light



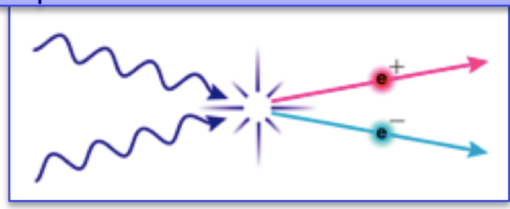
EBL studies central to:

→ put constraints on galaxy evolution, star formation activity, dust extinction processes

→ understanding cosmic structure formation and evolution

2 Photons convert into an electron-positron pair if :

$E_\gamma \times E_{EBL} \geq 2(m_e c^2)^2$



EBL with Fermi LAT AGN

- **AGN** produce Very High Energy γ rays
- γ rays with VHE and large redshift do not survive trip to Earth
- EBL photons extinguish extragalactic γ rays, pair cascades:

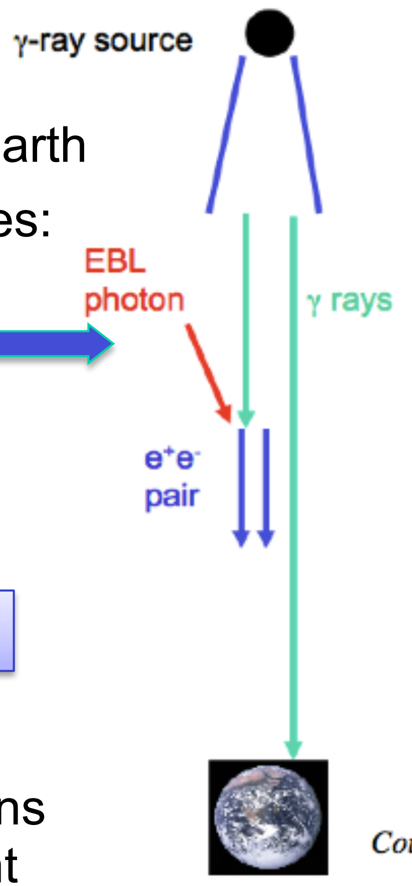
$\gamma_{ebl} + \gamma_{\gamma\text{-ray}} \rightarrow e^{-} + e^{+}$

Gamma rays we see are attenuated by:

$$F_{obs} = F_{int} \exp[-\tau_{\gamma\gamma}(E, z)]$$

EBL leaves an Imprint in the spectra of Blazars:

- We can constrain EBL models based on γ-ray observations of blazars: looking for an <u>unique redshift/energy dependent attenuation in the spectra of all blazars</u>



Courtesy J. Finke

EBL with Fermi AGNs

Fermi: first instrument to detect >500 sources above 10 GeV

• Advantages of Fermi:
  - Detects blazars up to high redshift
  - Fermi's bandpass gives unique coverage on "intrinsic" spectrum

• Continue all-sky observations allow to assess variability issues (none)

→ Use the best 150 BL Lacs to measure the EBL

(Ackermann+12, Science, 338, 1190)

Searching for a Collective Imprint

Look for collective deviation of the spectra of blazars from their intrinsic spectra

- 46 months of P7V6 1-500 GeV data
- 3 redshift bins with 50 sources each:

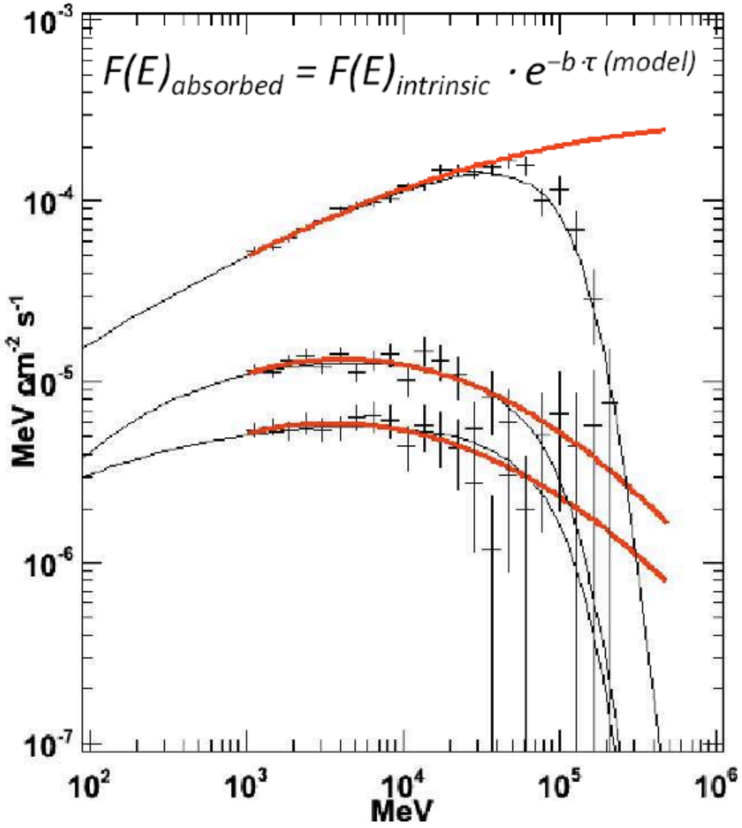
  z = 0-0.2 / 0.2-0.5 / 0.5 -1.6

- Fit each spectrum bin to

instrinsic spectra

*****

common absorption term, $e^{-b\,\tau(E,z)}$



τ(E,z) : optical depth predicted by EBL models

b is a free variable in the likelihood maximization that allows to assess two important scenarios:
→ there is no EBL attenuation (b=0)
→ the model prediction are correct (b=1)

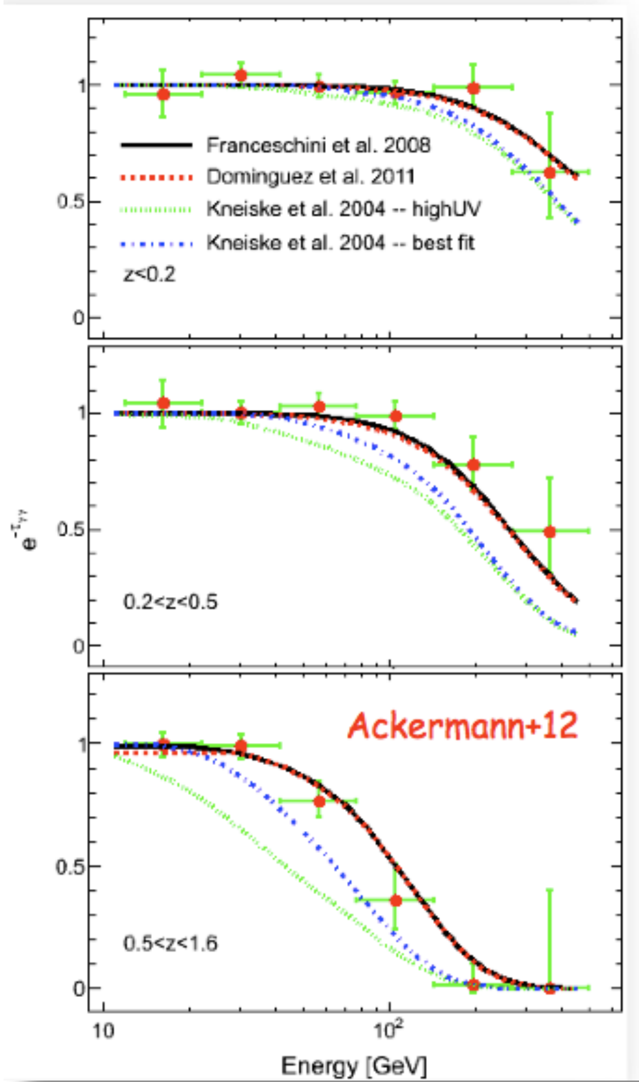
Detection of the EBL attenuation

Tested most of the EBL models (e.g. Franceschini08, Kneiske04, Kneiske&Dole10, Gilmore09-12, Dominguez11, Stecker06-12 etc)

~6σ detection of the EBL attenuation, compatible with low-opacity models

Results (wrt Franceschini+08 model):

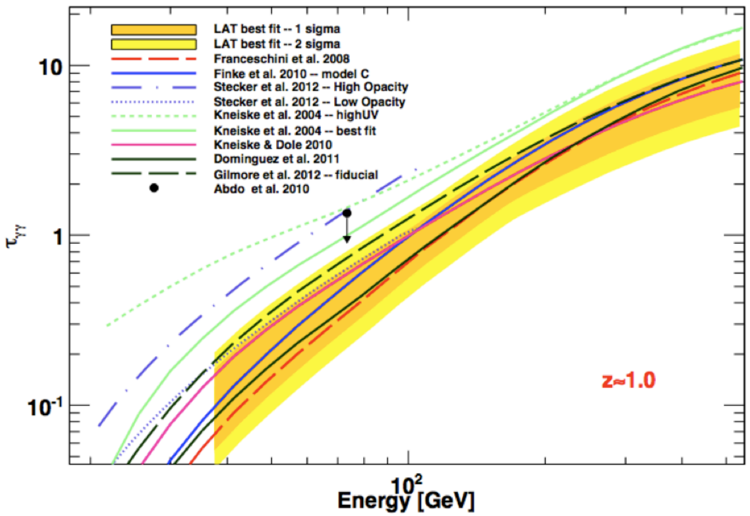
Redshift	Significance	Scaling factor b
z<0.2	~2	1.18(±0.94)
0.2<z<0.5	~2.7	0.82(±0.41)
0.5<z<1.6	~5	1.29(±0.42)
0<z<1.6	*~6*	*1.02(±0.23)*



Detection of the EBL attenuation

A significant steepening in Fermi blazars' spectra is detected

- This is consistent with that expected by a 'minimal' EBL:
  - i.e. EBL at the level of galaxy counts
  - 4 models rejected above 3sigma
- All the non-rejected models yield a significance of detection of
  5.6-5.9 sigma
- The level of EBL is 3-4 times lower than Fermi Collaboration previous UL (Abdo+10, ApJ 723, 1082)



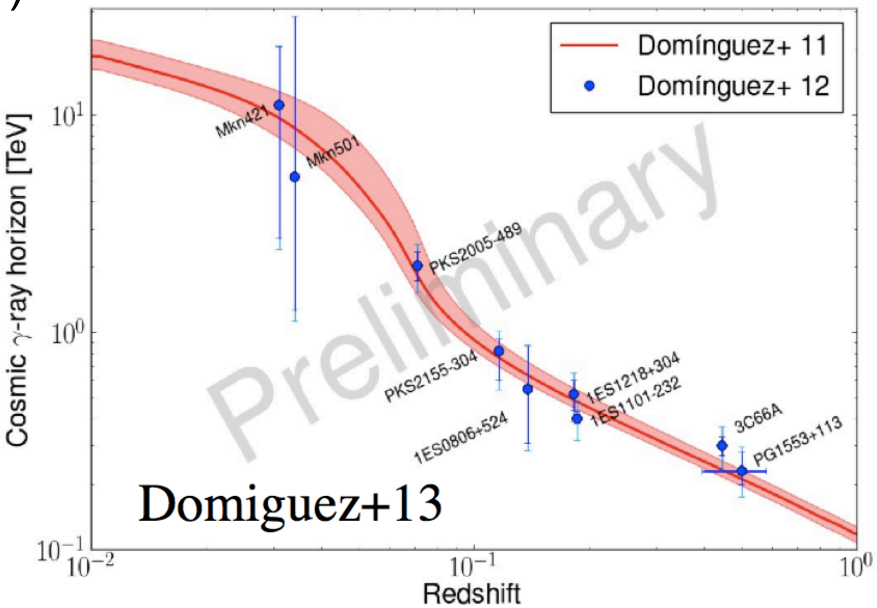
EBL Detection Significance | Model Rejection Significance

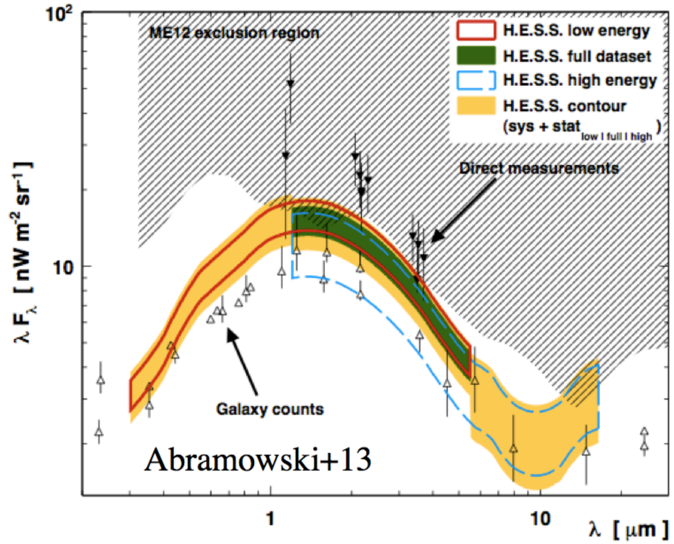
Model[a]	Ref.[b]	Significance of b=0 Rejection[c]	b[d]	Significance of b=1 Rejection[e]
Stecker et al. (2006) – fast evolution	(23)	4.6	0.10±0.02	17.1
Stecker et al. (2006) – baseline	(23)	4.6	0.12±0.03	15.1
Kneiske et al. (2004) – high UV	(22)	5.1	0.37±0.08	5.9
Kneiske et al. (2004) – best fit	(22)	5.8	0.53±0.12	3.2
Gilmore et al. (2012) – fiducial	(27)	5.6	0.67±0.14	1.9
Primack et al. (2005)	(56)	5.5	0.77±0.15	1.2
Dominguez et al. (2011)	(25)	5.9	1.02±0.23	1.1
Finke et al. (2010) – model C	(24)	5.8	0.86±0.23	1.0
Franceschini et al. (2008)	(7)	5.9	1.02±0.23	0.9
Gilmore et al. (2012) – fixed	(27)	5.8	1.02±0.22	0.7
Kneiske & Dole (2010)	(26)	5.7	0.90±0.19	0.6
Gilmore et al. (2009) – fiducial	(2)	5.8	0.99±0.22	0.6

Recent gamma-ray Measurements

Similar techniques applied to 7 bright TeV blazars yields a compatible level of the EBL (sampling the z~0 NIR EBL)

Spectral modeling of 15 TeV blazars allows to measure the cosmic gamma-ray horizon (Dominguez+13)



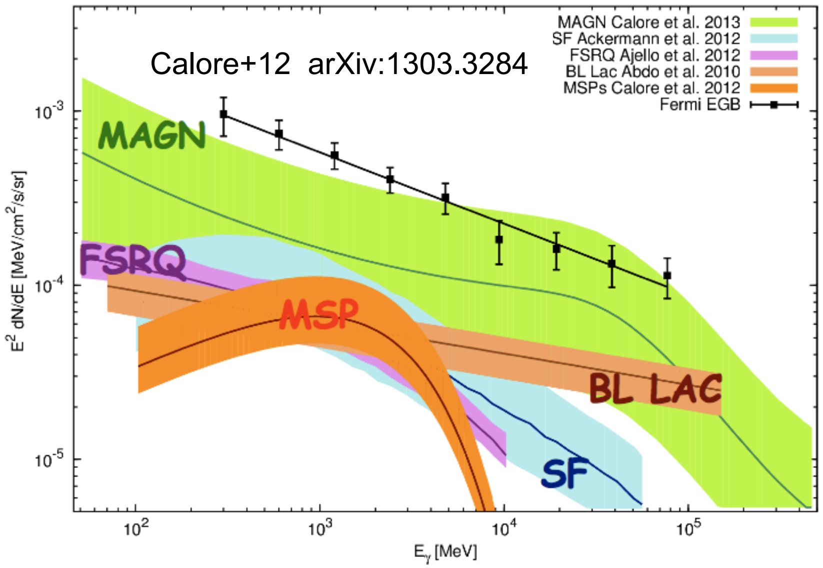


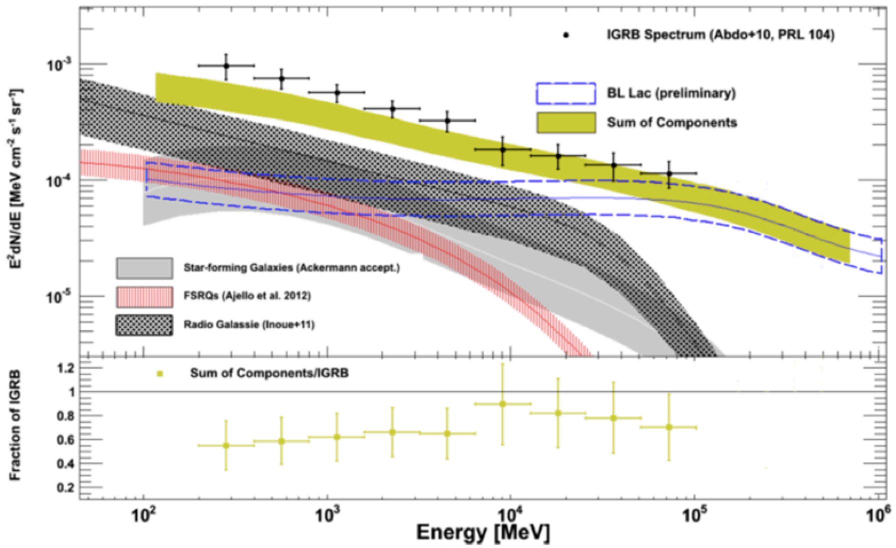
Contributions to EGB

- Star forming: 13% (±9%)
- FSRQs : 9.3% (±5%)
- Radio galaxies: 20%-30% (+58%/-16%)
- BL Lacs (to be refined) : 10-15%

→ TOTAL : 60%

Contributions from unresolved sources of known source classes can account for some or most of Isotropic background.





Fermi LAT Extragalactic Results

- Many **new non-blazars sources** have been detected (Radio galaxies, NRLSy1, NGC 1275, etc.)
- The emission of gamma-rays from the **lobes of Cen A** has been discovered
- AGN Physics:
  - Investigation of blazar **spectral properties** (correlation of photon index with blazar class, spectral breaks) and **variability time scales (**observed ranging from sub-day to several months)
  - Gamma-ray flares from **gravitationally lensed blazars** discovered
  - Some cases with evidence for large distances gamma-ray emission regions from BH although the location of the gamma-ray emitting region in the jet is still ambiguous
  - Radio-to-gamma-ray SEDs are forcing us to look for models beyond the standard one-zone leptonic models
  - Many multifrequency studies have provided time-resolved SEDs and interband (radio, optical, X-ray, TeV) temporal correlation
- **Constraints on EBL** opacity and **EGB** have been obtained.

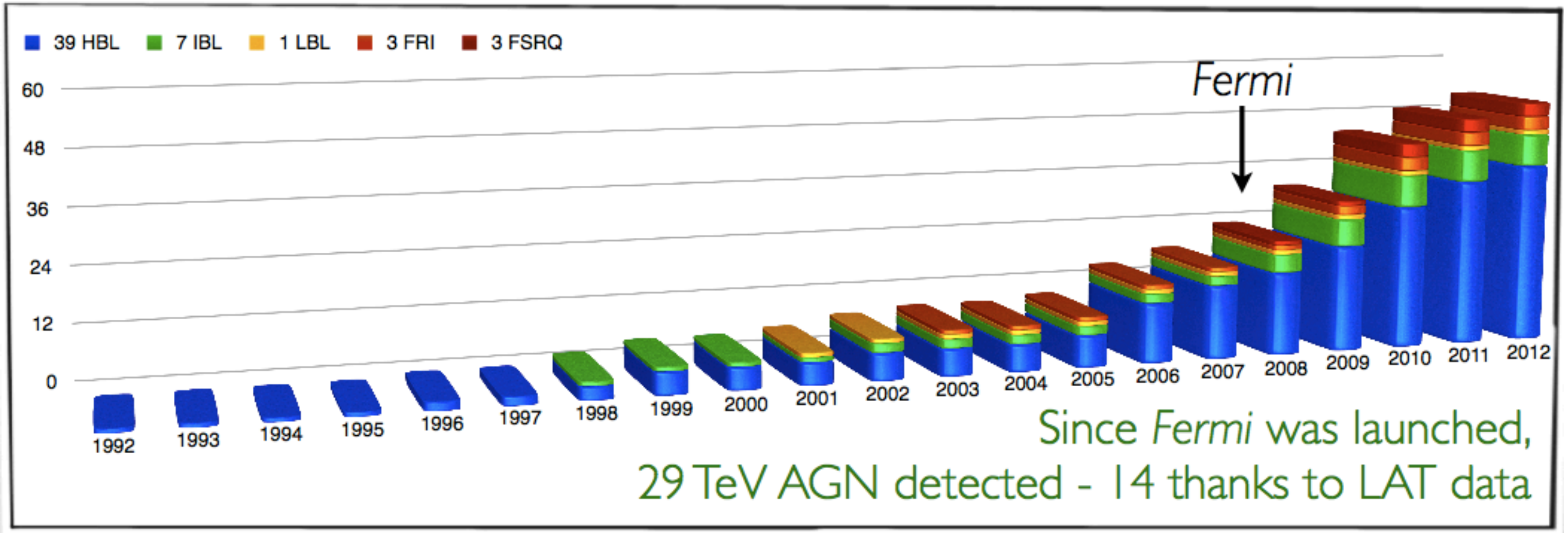
BACKUP SLIDES

Conclusions

- Flexibility and versatility of Fermi (and AGILE) + Cherenkov instruments and operations are producing a wide range of results

- While continuing improving in both exposure depth and energy range

→ Preparing a solid base for next generation instruments



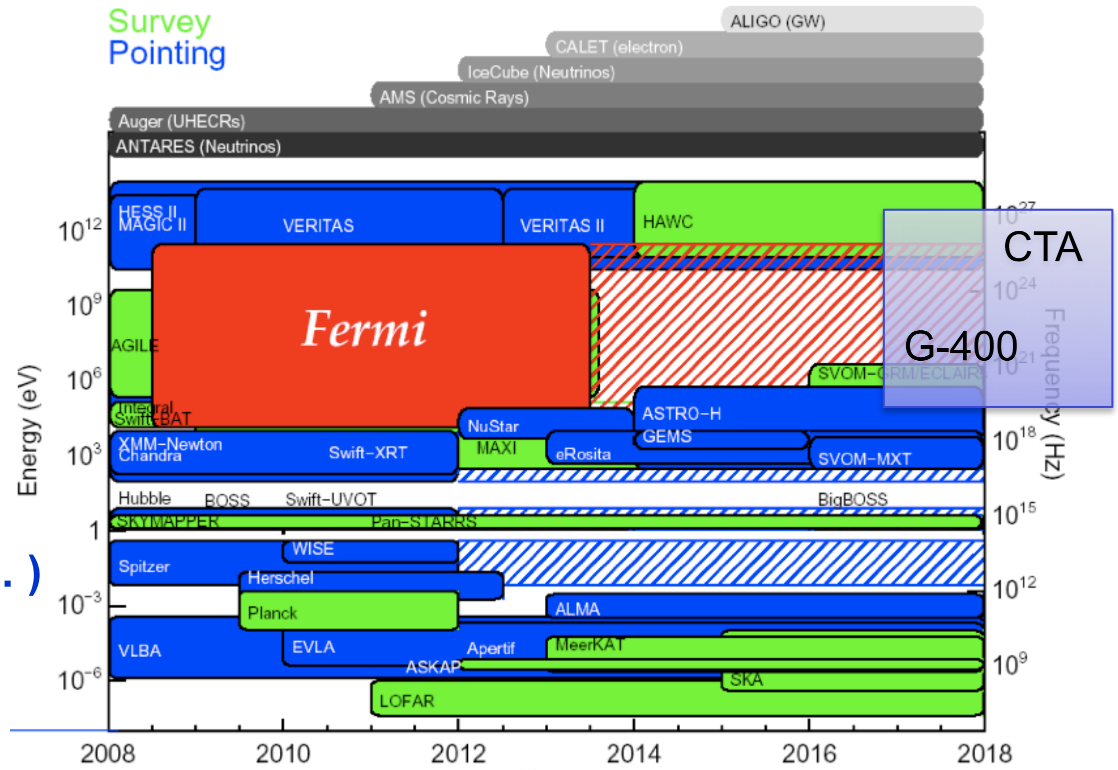
Future Blazar Science

Multiwavelength and theoretical studies are essential to gain insights in extragalactic gamma-ray sources

Among the main goals:

(VHE) sources/population studies

- **(HE-VHE) emission processes**
- **Jet physics**
- **AGN related topics, e.g. :**
  - **EBL, IGMF**
  - **UHE cosmic rays, Exotics (axions, hints of new physics …)**



γ-ray emission from Cen A lobes

Cen A: the largest discrete non-thermal extragalactic radio source visible from the Earth; pair of extended radio lobes (total angular extent of ~10°)

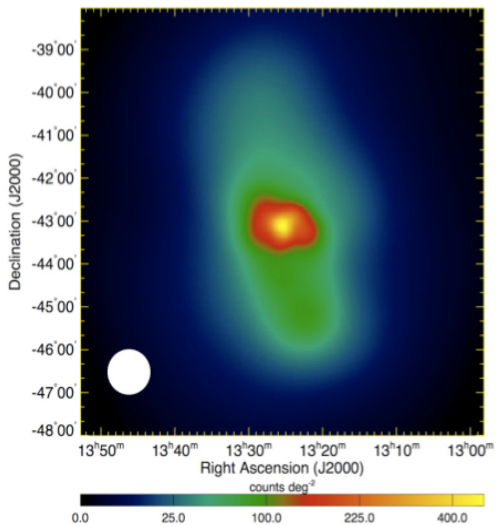
→ lobes clearly separated from the central active source
→ In contrast to all other active γ-rays galaxies detected so far, the lobe flux constitutes a considerable portion (>1/2) of the total source emission

<u>Lobes gamma-ray emission interpretation:</u>

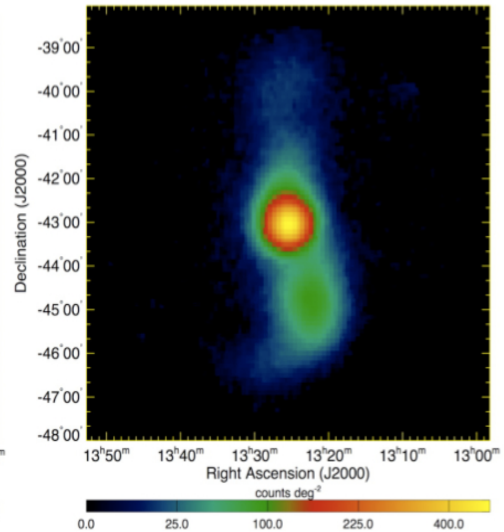
Lobes fueled by relativistic jets produced by accretion activity in a super-massive black hole residing at the galaxy's center;

γ-rays originated by inverse Compton scattered relic radiation from CMB + contribution at higher energies from EBL

Requires 0.1-1 TeV electrons in giant "relic" lobes: accelerated in-situ or efficient transport from center



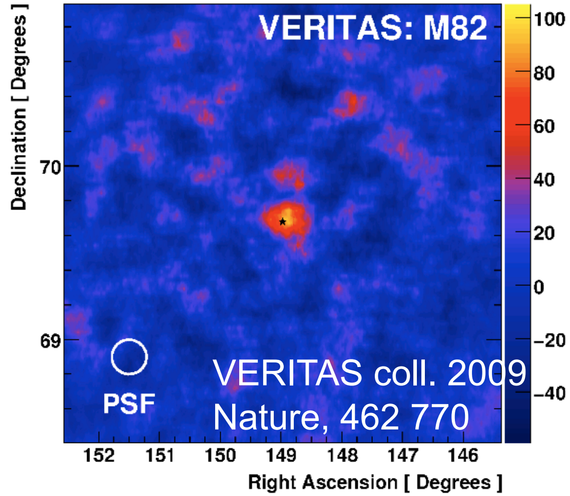
Fermi-LAT γ-ray (>200 MeV) counts maps centered on Cen A



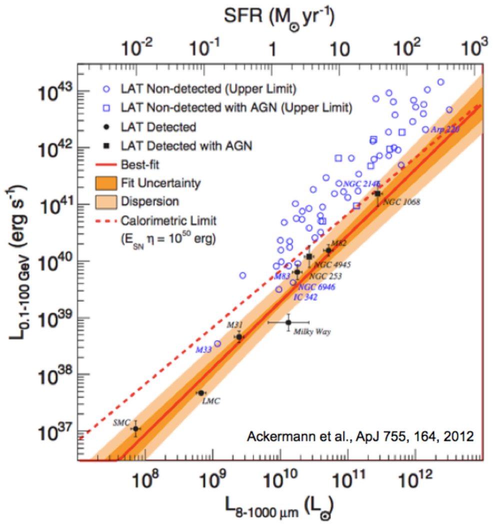
WMAP image

Abdo, A. A. et al. 2010, Science, 328, 725

A starburst galaxy M 82 at γ-ray



- Veritas 2007-2009 observations: first detection of gamma-ray signal (at 5σ) from M 82
- Strong **correlation** between the **star-formation activity** and the **cosmic-ray production** in M82.
- Star forming → cosmic rays → interact with interstellar gas and radiation → production of diffuse gamma rays
- Results strongly support that cosmic-ray acceleration tied is to star formation activity

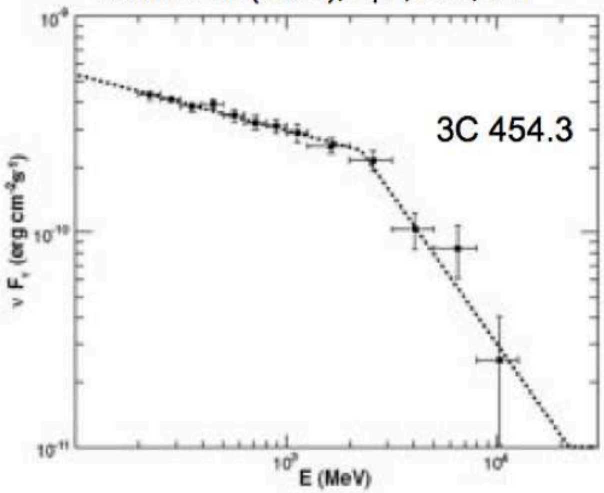


- 8 galaxies detected by the LAT
- Almost linear correlation between γ-ray luminosity and tracers of star formation
  - bolometric infrared luminosity
  - 1.4GHz radio continuum emission

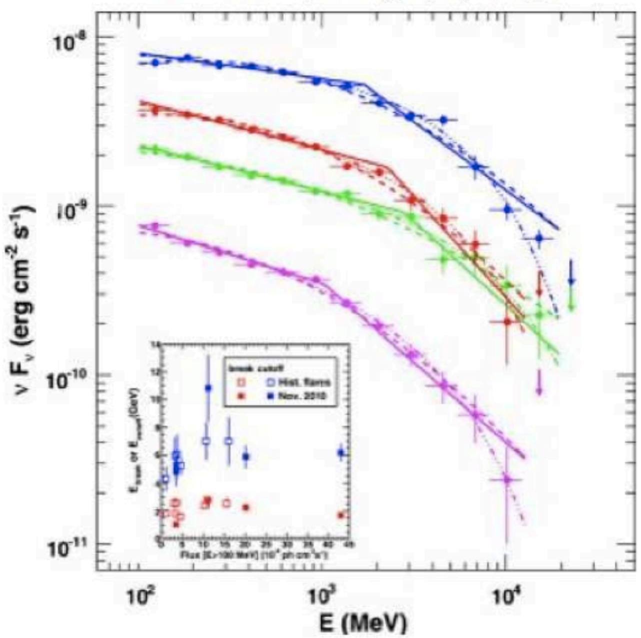
Features of Fermi LAT AGN spectra

- Spectral breaks at ~ few GeV have been found in the γ-ray spectra of many LSP FSRQs and BL Lacs, most prominently in the extremely bright 3C454.3.
  - γ-γ attenuation from He II line photons (Poutanen et al. 2010)
  - intrinsic electron spectral breaks (Abdo et al 2009, ApJ 699, 817)

Abdo et al. (2009), ApJ, 699, 817



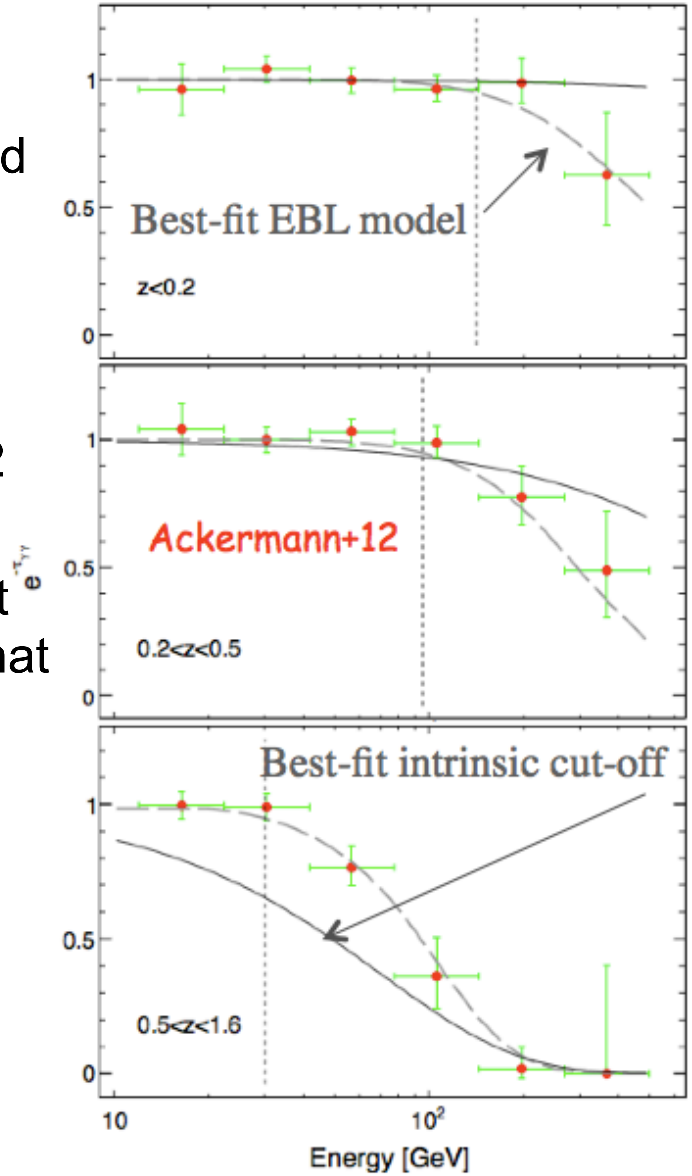
Abdo et al. (2011), ApJ, 733, L26



Can the cut-off be Intrinsic ?

- The cut-off moves in z and energy as expected for EBL absorption (for low opacity models)
- It is difficult to explain this attenuation with an intrinsic property of BL Lacs:

1. BL Lacs required to evolve across the z=0.2 barrier
2. Attenuation change with energy and redshift cannot be explained by an intrinsic cut-off that changes from source to source because of redshift and blazar sequence effects



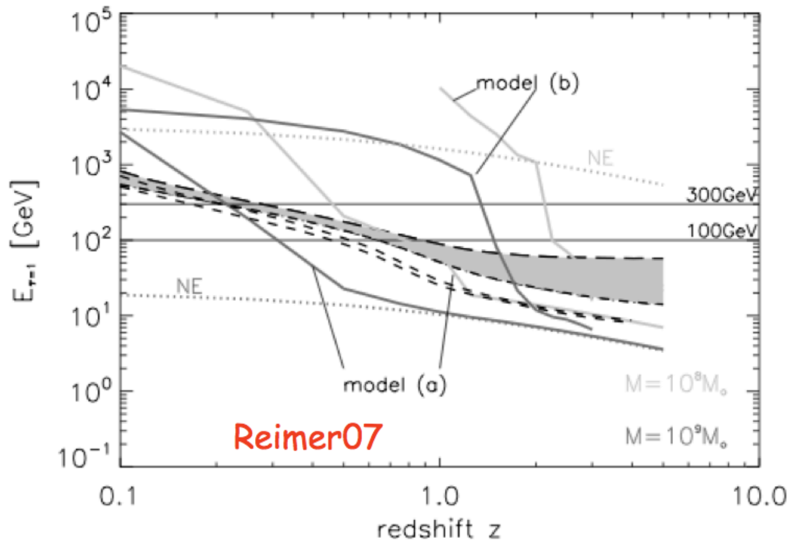
Intrinsic Absorption

• Absorption of gamma rays on the photons of the BLR/disk might show a redshift dependence due to the accretion history of the Universe (Reimer07)

• However:

– Redshift dependence is not the same as that of EBL

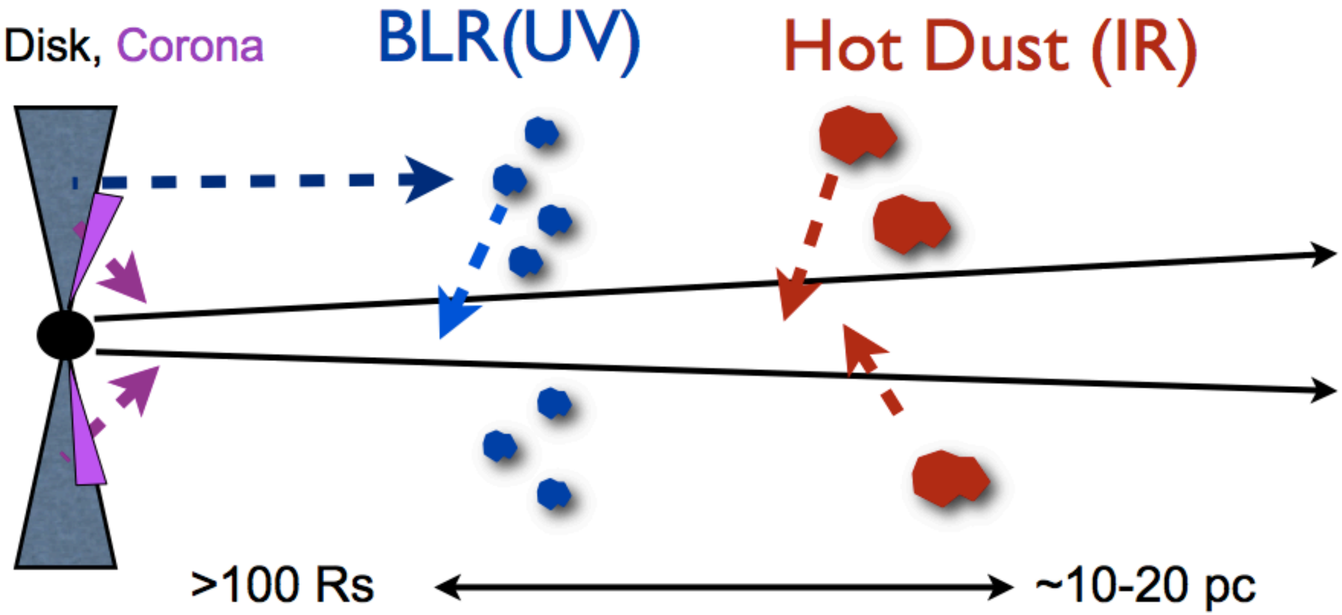
– If the emission region is far from the core, then no absorption is expected



2FGL catalog

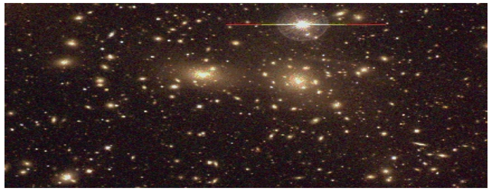
Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

EC Scenario

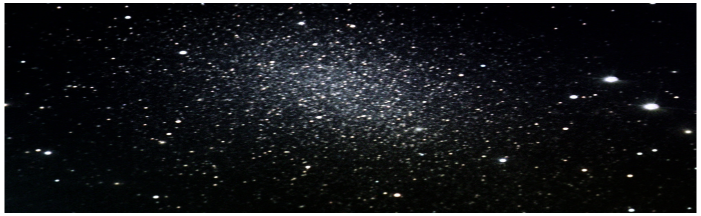


Broad Line Region (UV, Lyα, CIV, Mg II) or **Hot Dust** (IR) **photons** are used as **target** for External Compton mechanism. These same photons **cause** huge **internal γ-γ absorption !**

What is Not Seen Can Also Be Important



Some clusters of galaxies were predicted to be gamma-ray sources. None are seen in the Second LAT Catalog, indicating that the predictions were too optimistic.



Dwarf spheroidal galaxies are thought to be largely composed of dark matter. If dark matter consists of some types of Weakly Interacting Massive Particles (WIMPs), such galaxies would be gamma-ray sources visible to Fermi LAT. Their absence puts constraints on dark matter models.