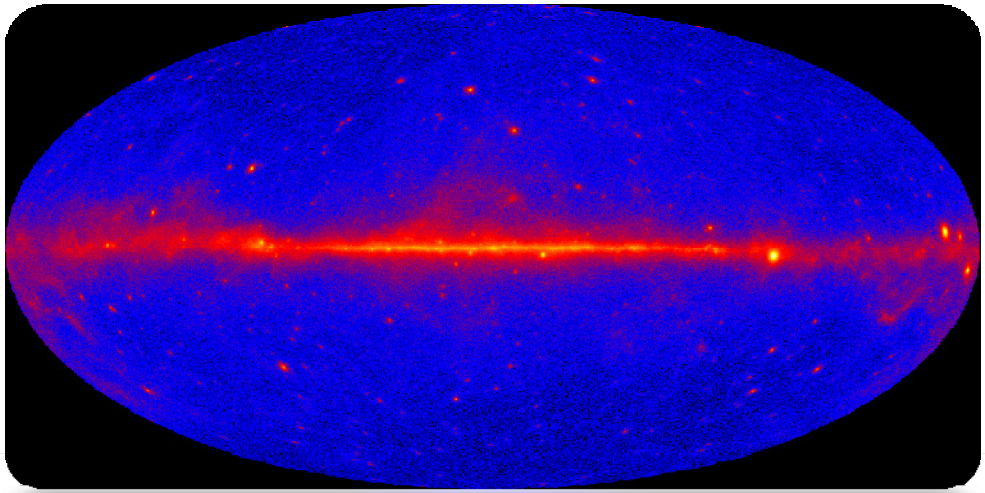
The Cosmic Diffuse Gamma-ray Background: a puzzle to unveil

Marco Ajello*

SLAC NATIONAL ACCELERATOR LABORATORY

KIPAC

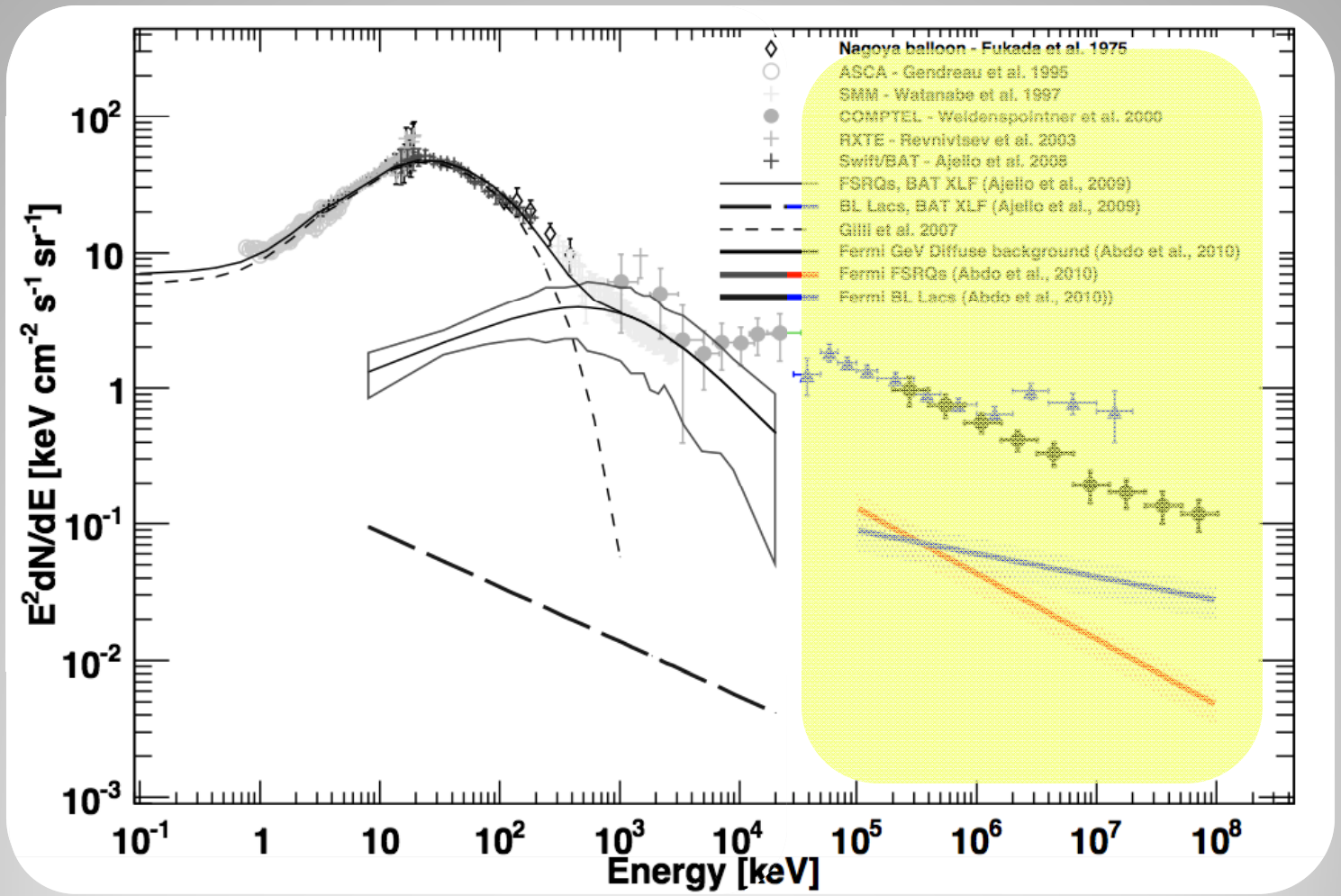
*on behalf of the Fermi/LAT collaboration



Outline

- The Cosmic Diffuse Gamma-ray background (or Extragalactic Gamma-ray background = EGB)
  - Introduction
  - *Fermi measurement*
  - *Contribution of blazars to the EGB*
  - *Other source contribution to the EGB*
- *Near Term exciting results:*
  - *Hunting the most distant blazars*
  - *FAVA = Fermi All-sky Variability Analysis unleashed*

The 'Cosmic' gamma-ray background

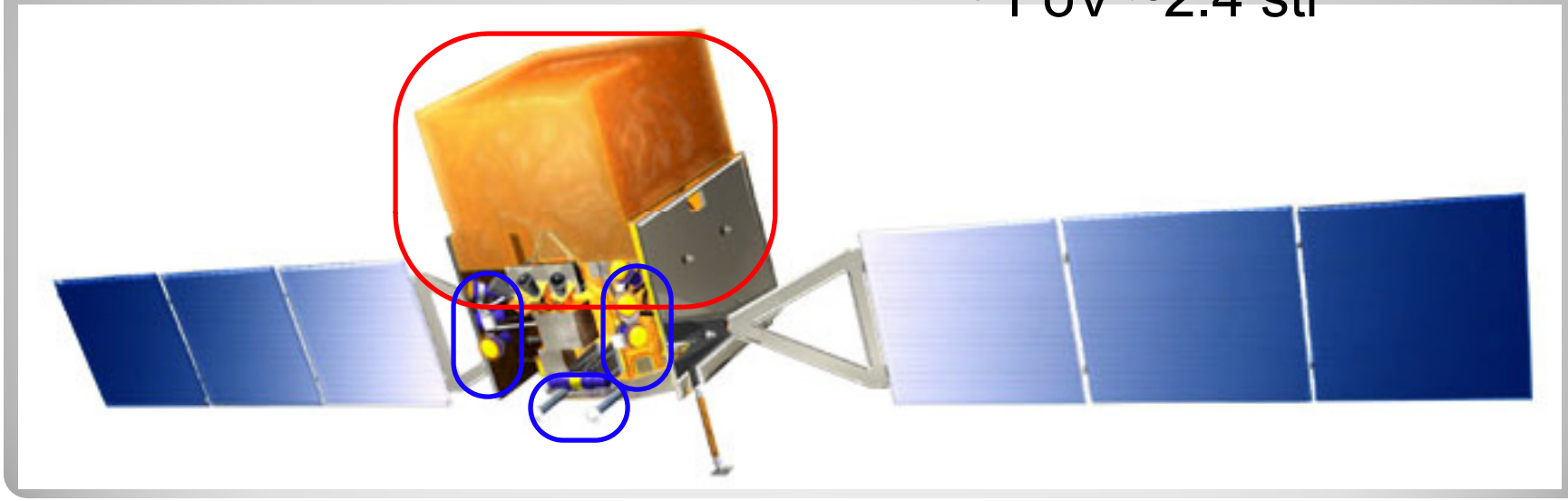


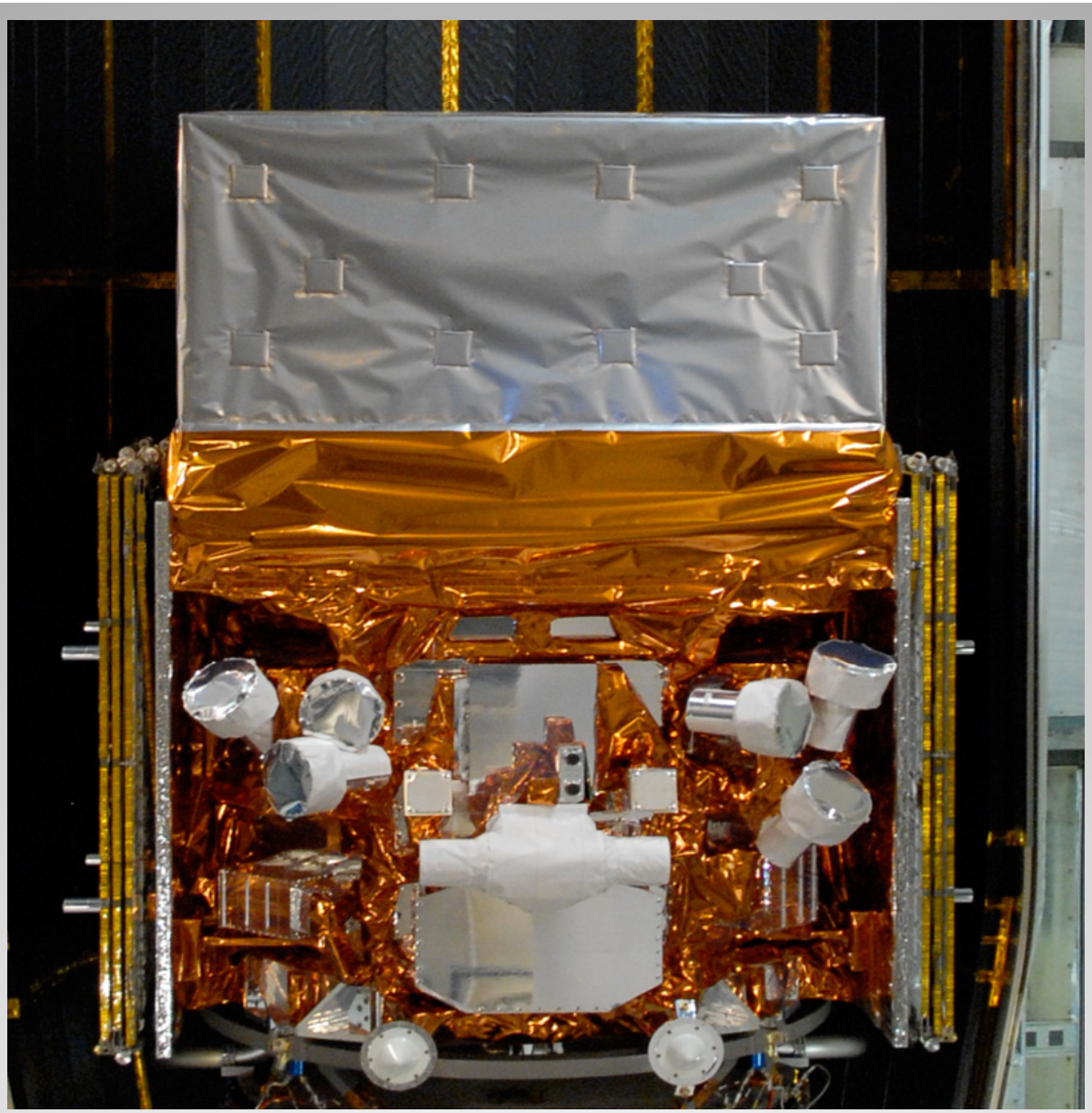
The Fermi observatory

- **Launch: June 11th, 2008**
- **Orbit: 565 km, 25.6° inclination**
- **Two instruments onboard:**

- Gamma-Ray Burst Monitor (GBM):
  - 8 keV -> 40 MeV

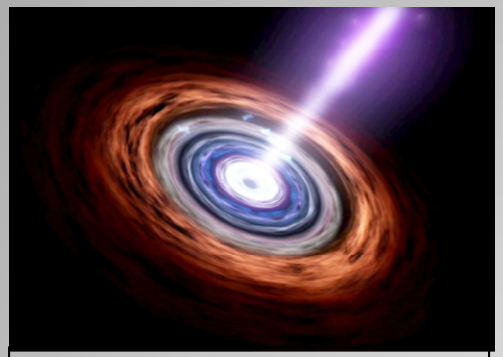
Large Area Telescope (LAT)
- 20 MeV -> 300 GeV
- FoV ~2.4 str





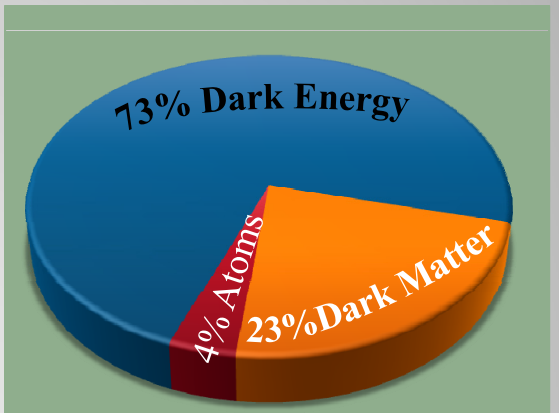
Why is this important ?

- **The Extragalactic Gamma-ray Background may encrypt the signature of the most powerful processes in astrophysics**



Blazars contribute 20-100% of the EGB (*Stecker&Salomon96, Mücke&Pohl00, Narumoto&Totani04, Dermer 07, Inoue&Totani09*)

Emission from star forming galaxies (*e.g. Pavlidou&Fields02*)

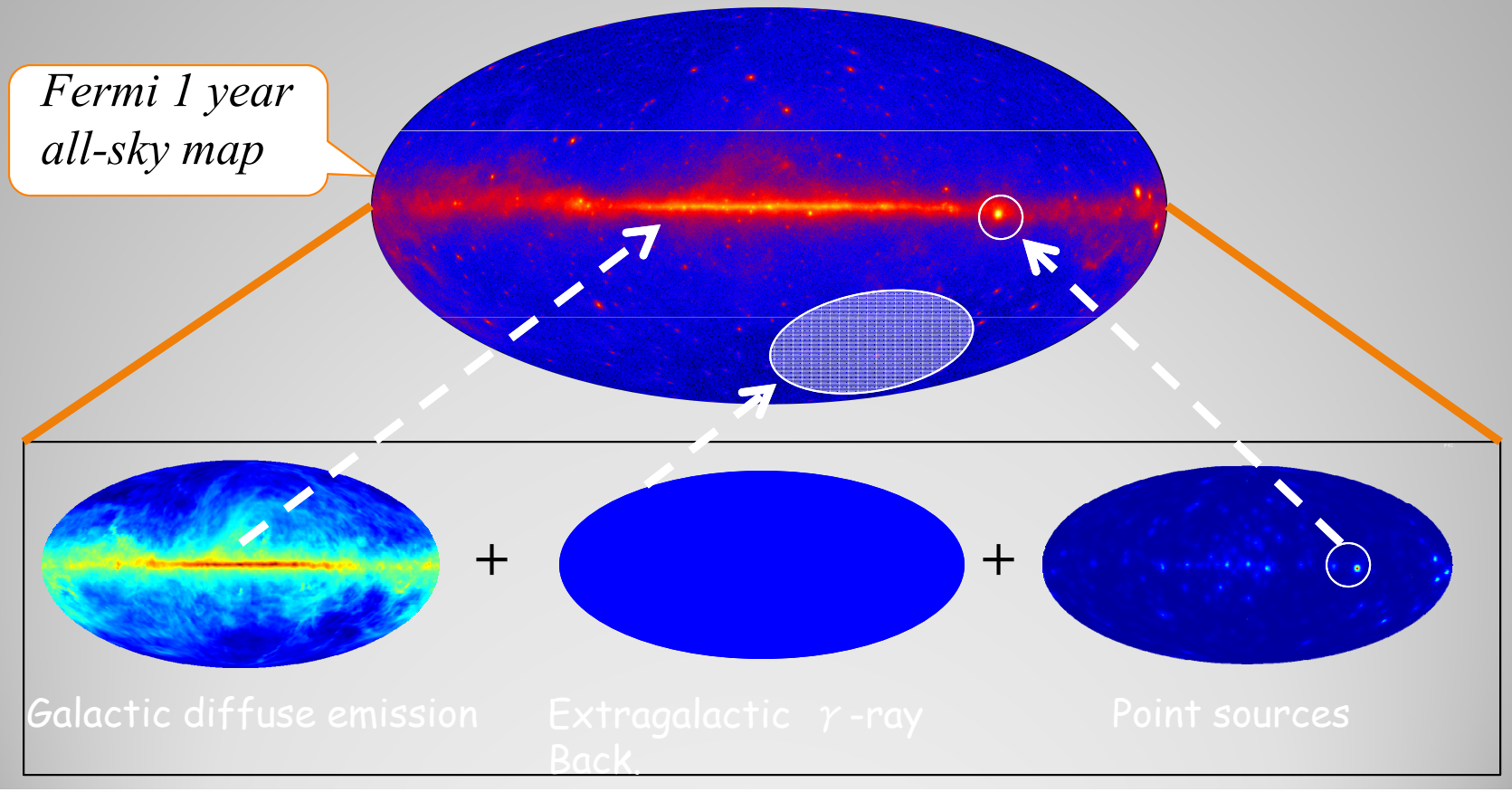


Emission due to the annihilation of Cosmological Dark Matter (*eg. Jungman+96*)

Emission from particle accelerated in Intergalactic shocks (*Loeb&Waxmann00*)

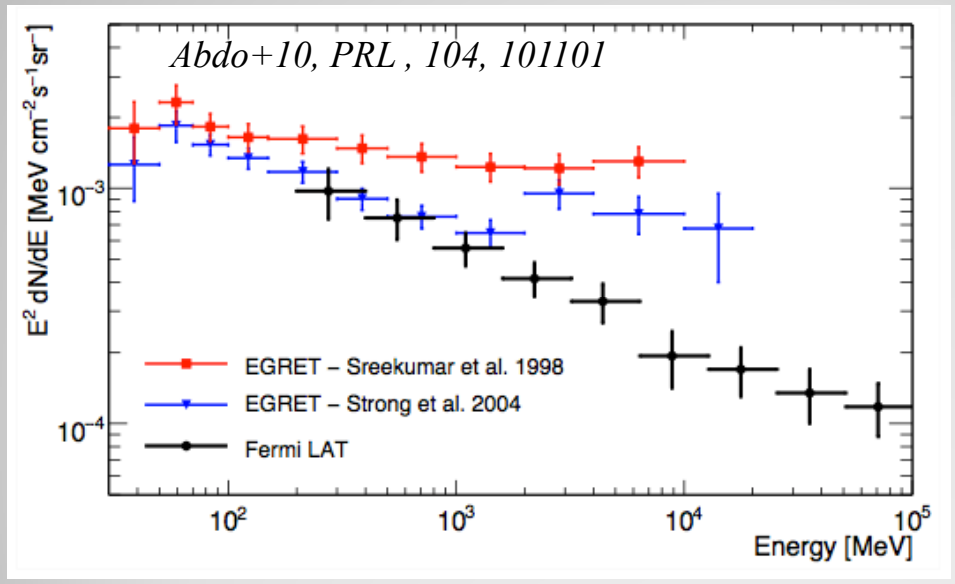
What is the Extragalactic Gamma-ray Background ?

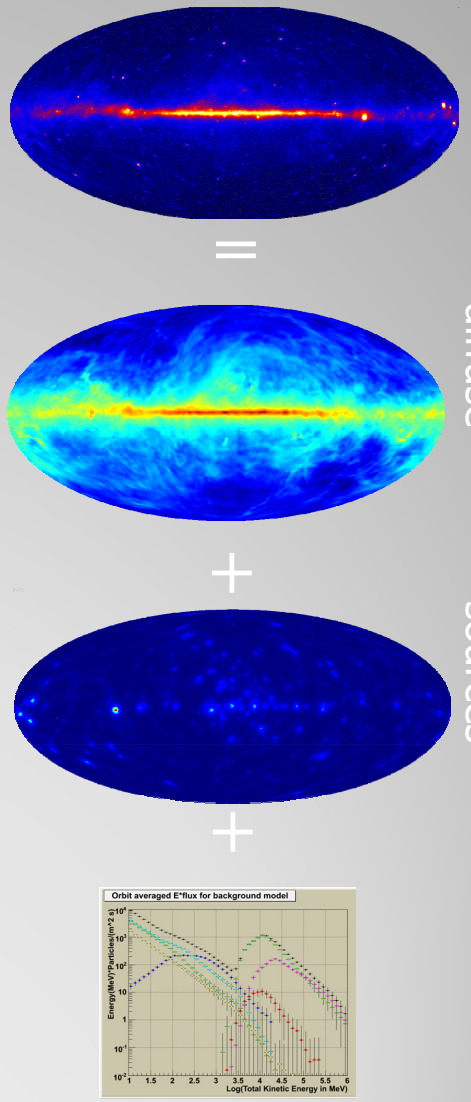
- **The gamma-ray sky as observed by Fermi represents the sum of different components: one of them is the Extragalactic Gamma-ray Background**



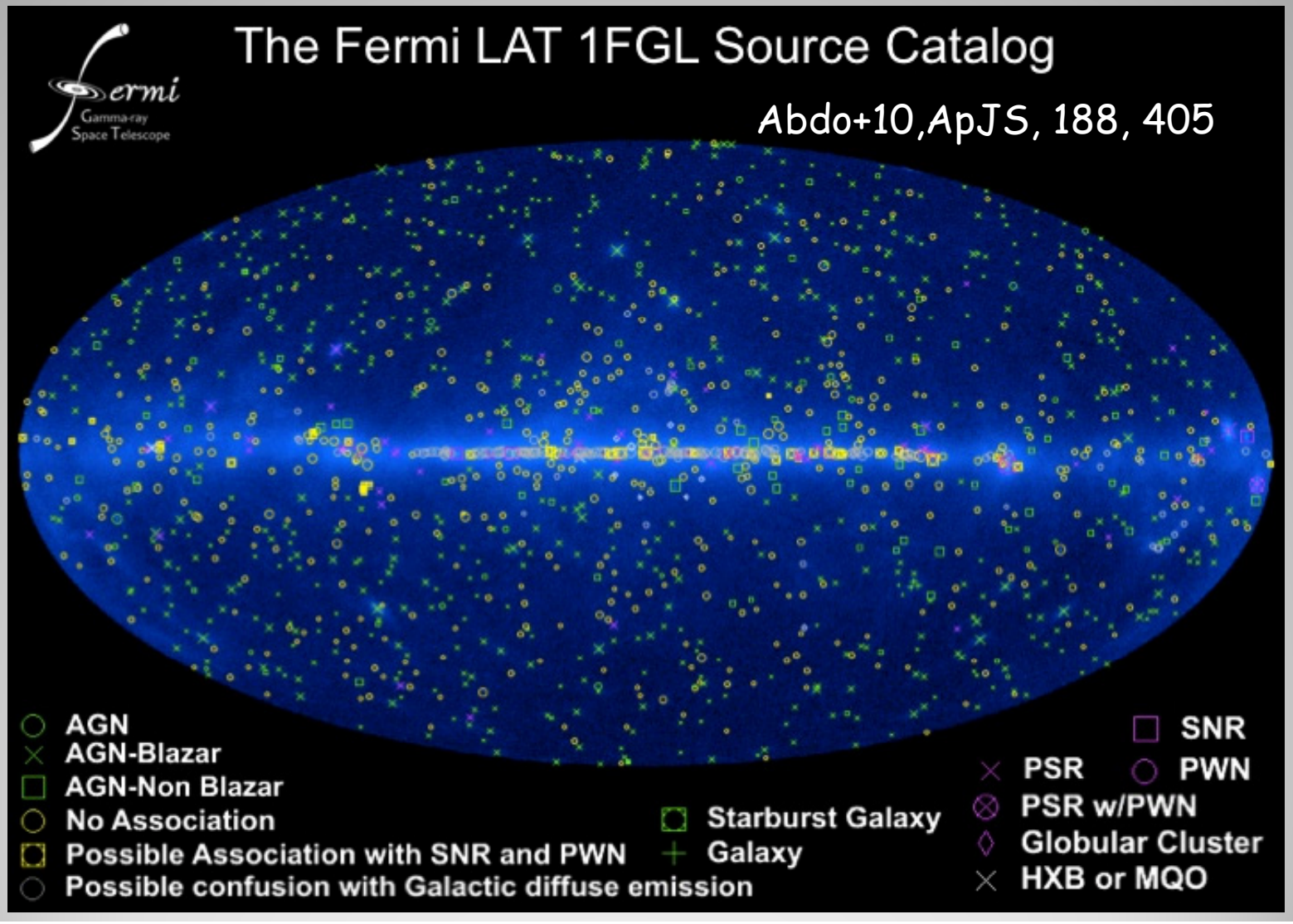
The new Fermi EGB

- **Simultaneous Maximum Likelihood fit to all |b|>10° sky with:**
  - Equal area pixels (0.8 deg^2)
  - Sky models compared to LAT data
  - All sources detected in 9months
  - 9 energy bind, 200 MeV<E< 100 GeV
  - 10 months of LAT data, 19 Ms exposure



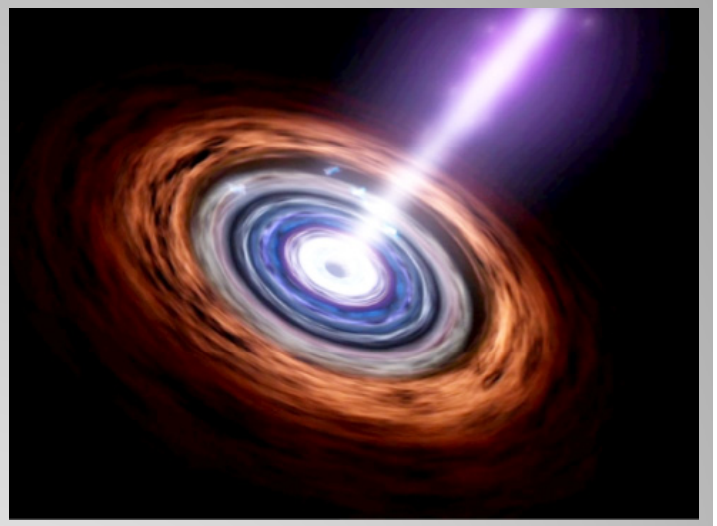


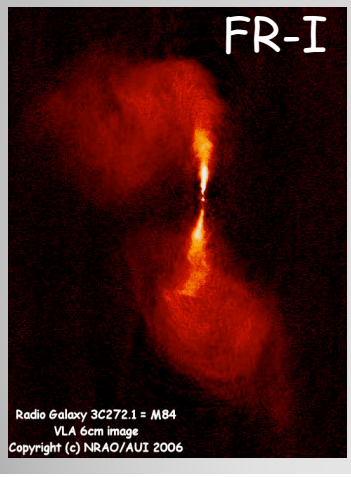
The 1st Fermi LAT Catalog



Blazars in 2 words

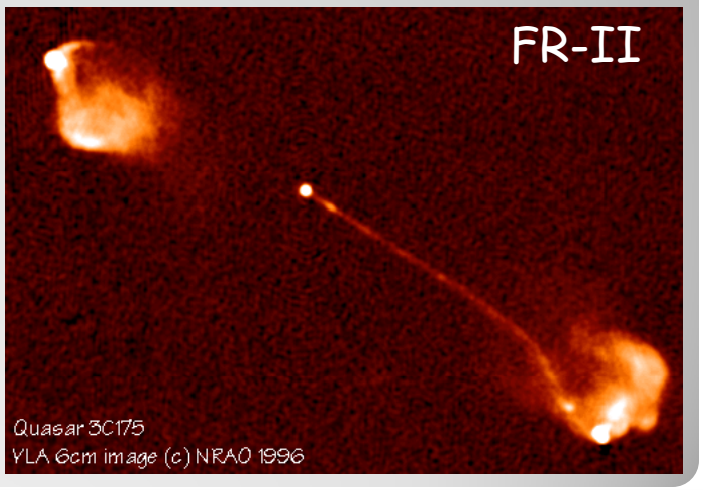
- Blazars are Active Galactic Nuclei with a collimated beam of relativistic particles (jet) pointing at us





BL Lac are FR-I and do not show optical lines

FSRQ are FR-II and show strong and broad emission lines



Addressing the Contribution from Blazars

- Blazars potentially represent 85-95% of the high-b populations
- How to quantify their diffuse emission ?
  - Derive luminosity function and integrate
  - → Derive logN-logS and integrate ←
- Select a 'clean' sample (TS>50, |b|>20°)
- To quantify selection effects 18 MC simulations were performed:
  - Receipt (e.g. Hasinger+93, Cappelluti+07):
    - Use up to date diffuse models and add a realistic source population
  - Detection:
    - Perform detection step as close as possible to real data (Abdo+09, ApJS 183, 46)
    - Use Maximum Likelihood to determine spectral parameters and significance

arXiv:1003.0895

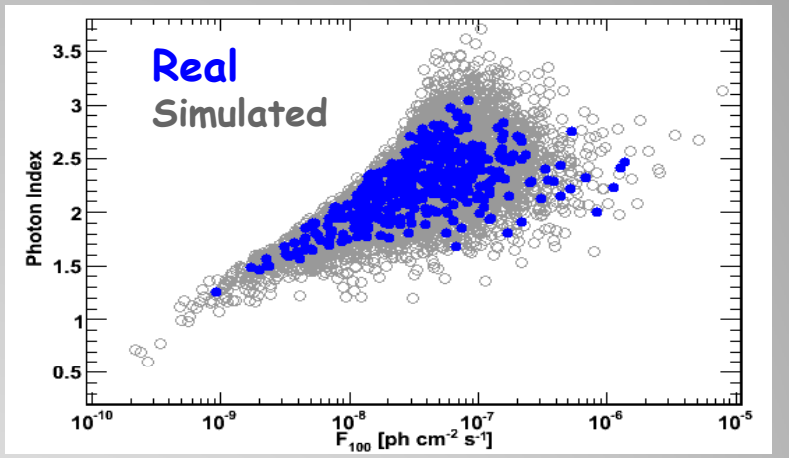
CLASS	# objects
Total	425
FSRQs	161
BL Lacs	163
Uncertain[a]	4
Blazar Candidates	24
Radio Galaxies	2
Pulsars	9
Others[b]	6
Unassociated sources	56

[a]Blazars with uncertain classification.

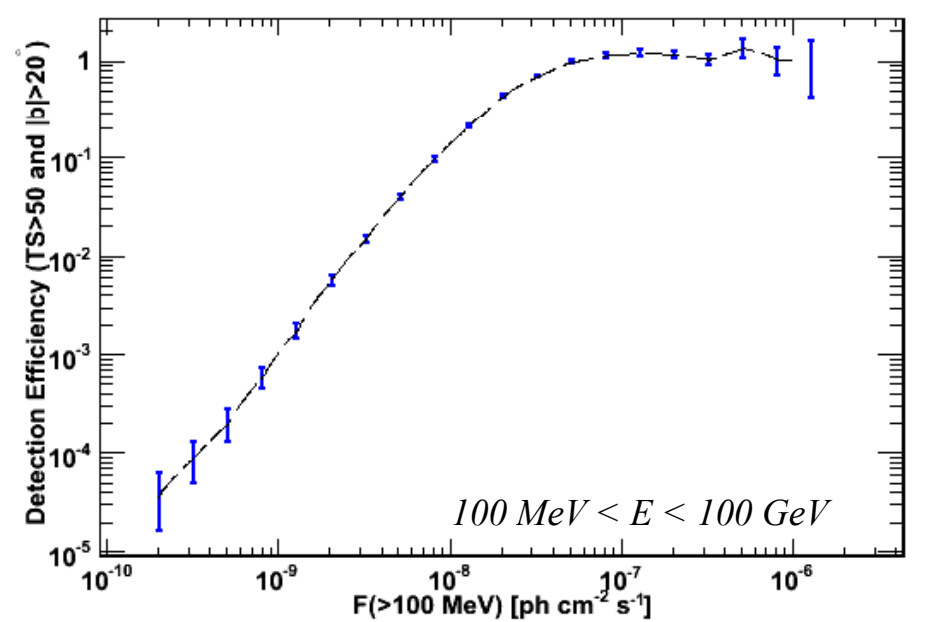
[b]It includes Starburst galaxies, Narrow line Seyfert 1 objects and Seyfert galaxy candidates.

Detection Efficiency of LAT

- Simulations reproduce well the photon-index dependent flux limit of LAT
- Confusion and Eddington bias affect <4% of the population



Detection Efficiency

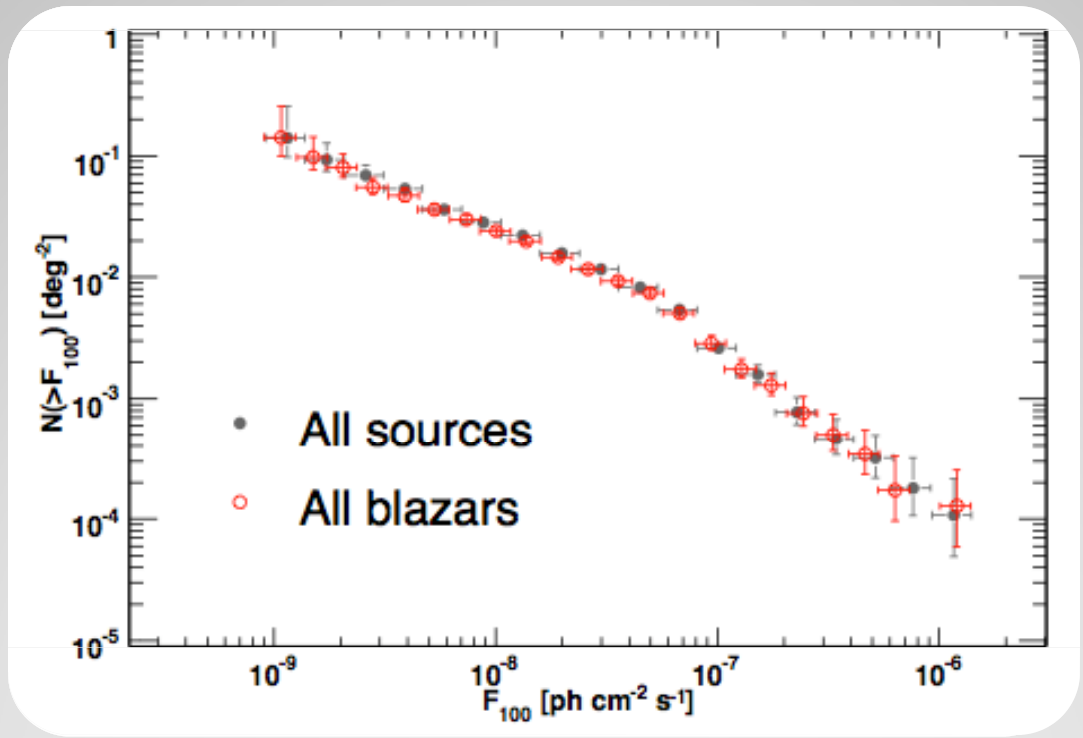


- Det. Efficiency evaluated in bins of flux as N^{det}/N^{sim}
- It becomes 10^{-3} @ $F_{100}=10^{-9}$ ph cm^{-2} s^{-1}

The logN-logS of point sources

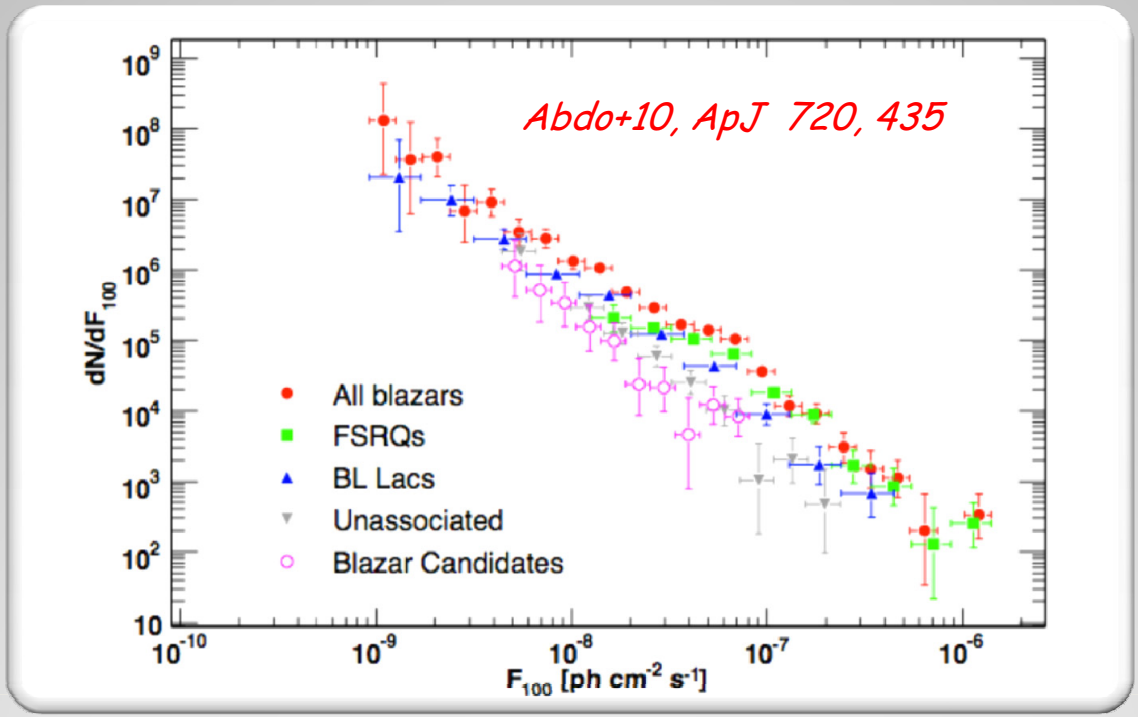
- Used 3 methods to build source count distribution in the 0.1-100 GeV band
- Compatible with Euclidean at bright fluxes: $N(>F) \sim F^{-3/2}$
- It is flatter below $F_{100} \approx 5 \times 10^{-8}$ ph cm^{-2} s^{-1}

Most of the un-associated point sources are likely to be blazars



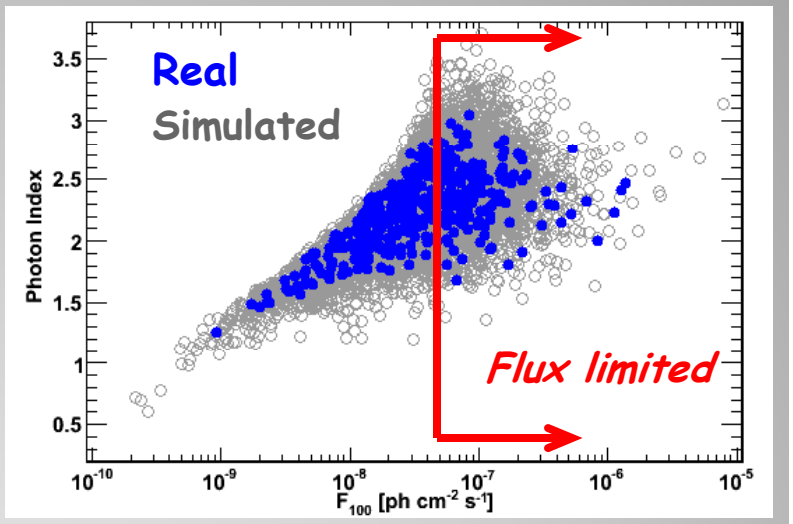
logN-logS for different classes

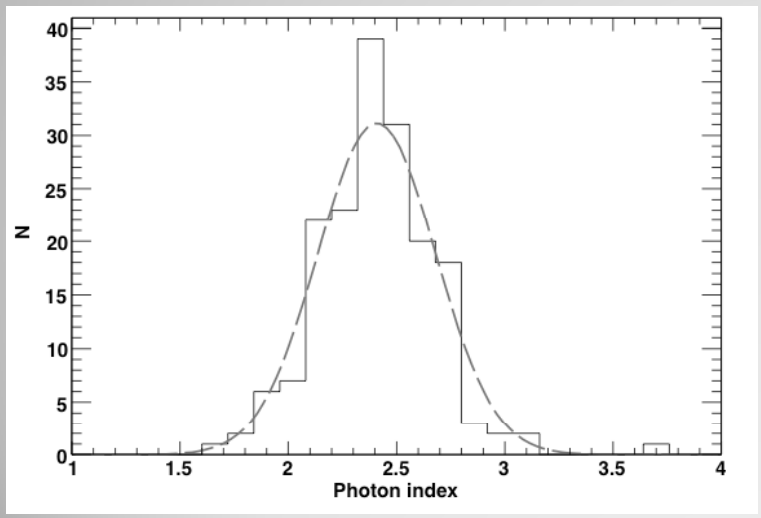
At low fluxes the Fermi sample is dominated by BL Lac which have better position accuracy

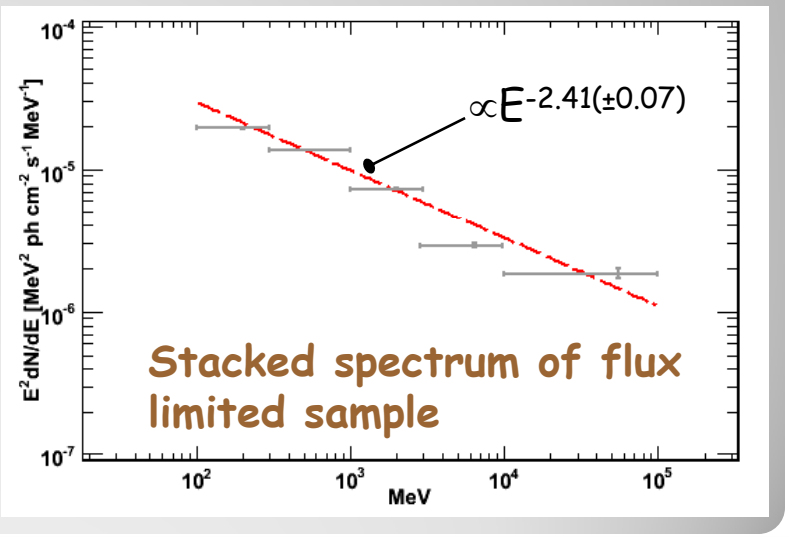


A look to the spectral properties

- **LAT detects preferentially hard faint sources**
  - Looking at the *flux-limited* sample: the average photon index is 2.40(±0.02) and not 2.24(±0.01)
  - Similar results from weighted average spectrum

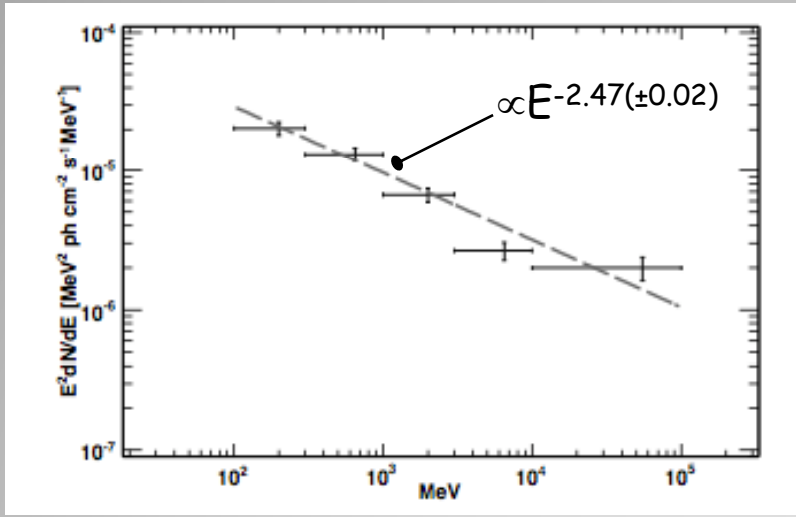


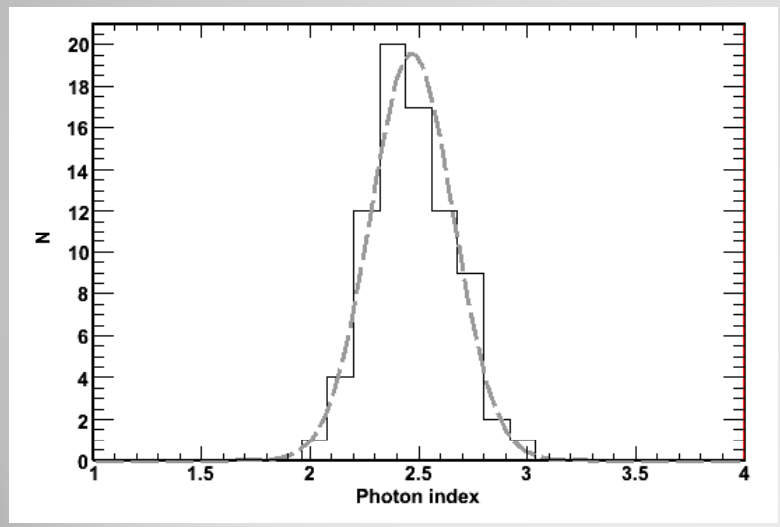




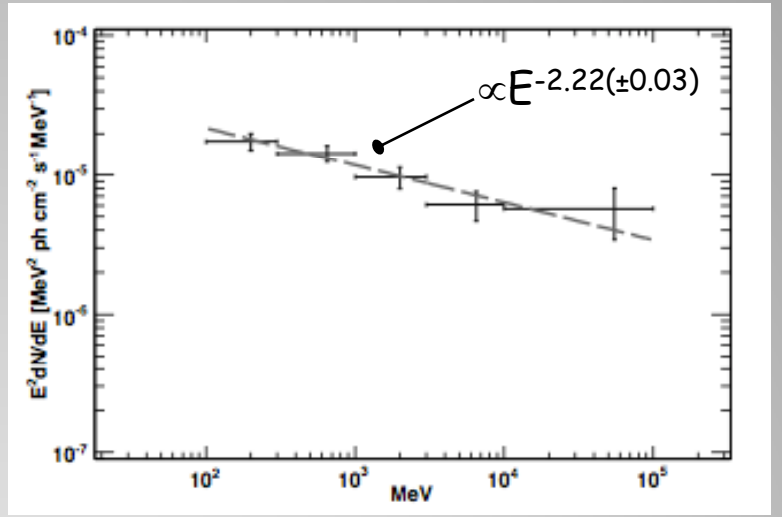
Spectral properties of FSRQs and BL Lacs

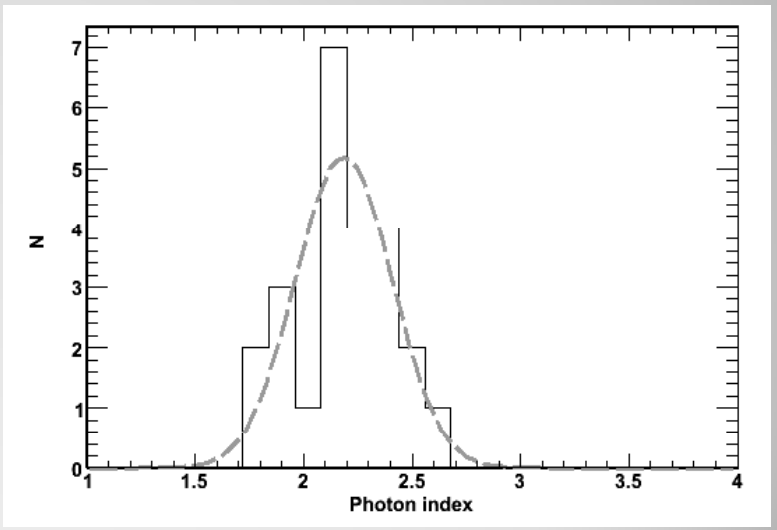
FSRQs





BL Lacs





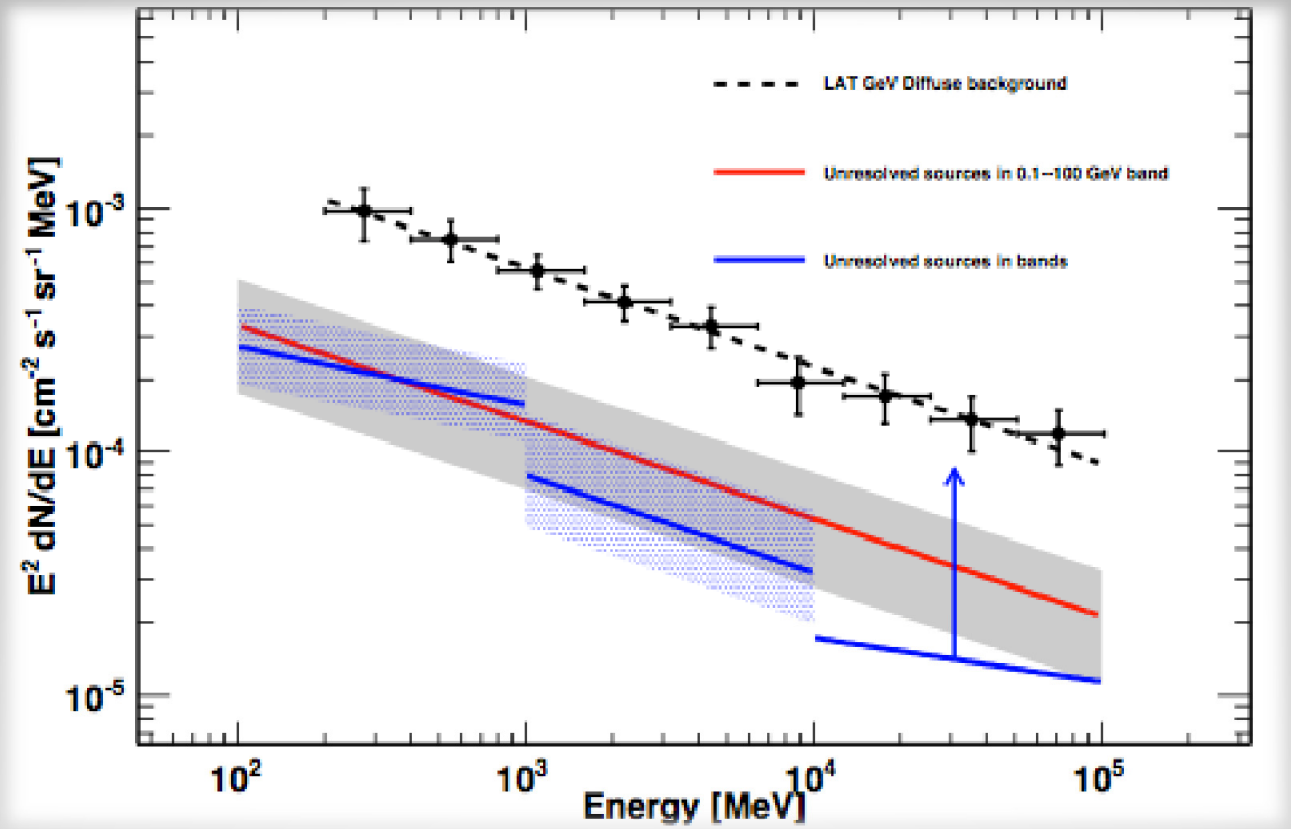
Diffuse emission from Blazars

To determine the diffuse flux from the blazar class one needs to integrate the logN-logS (e.g. dN/dS)

$$F_{diffuse} = \int \underbrace{dN/dS}_{\text{logN-logS}} \cdot \underbrace{S}_{\text{flux}} \cdot dS$$

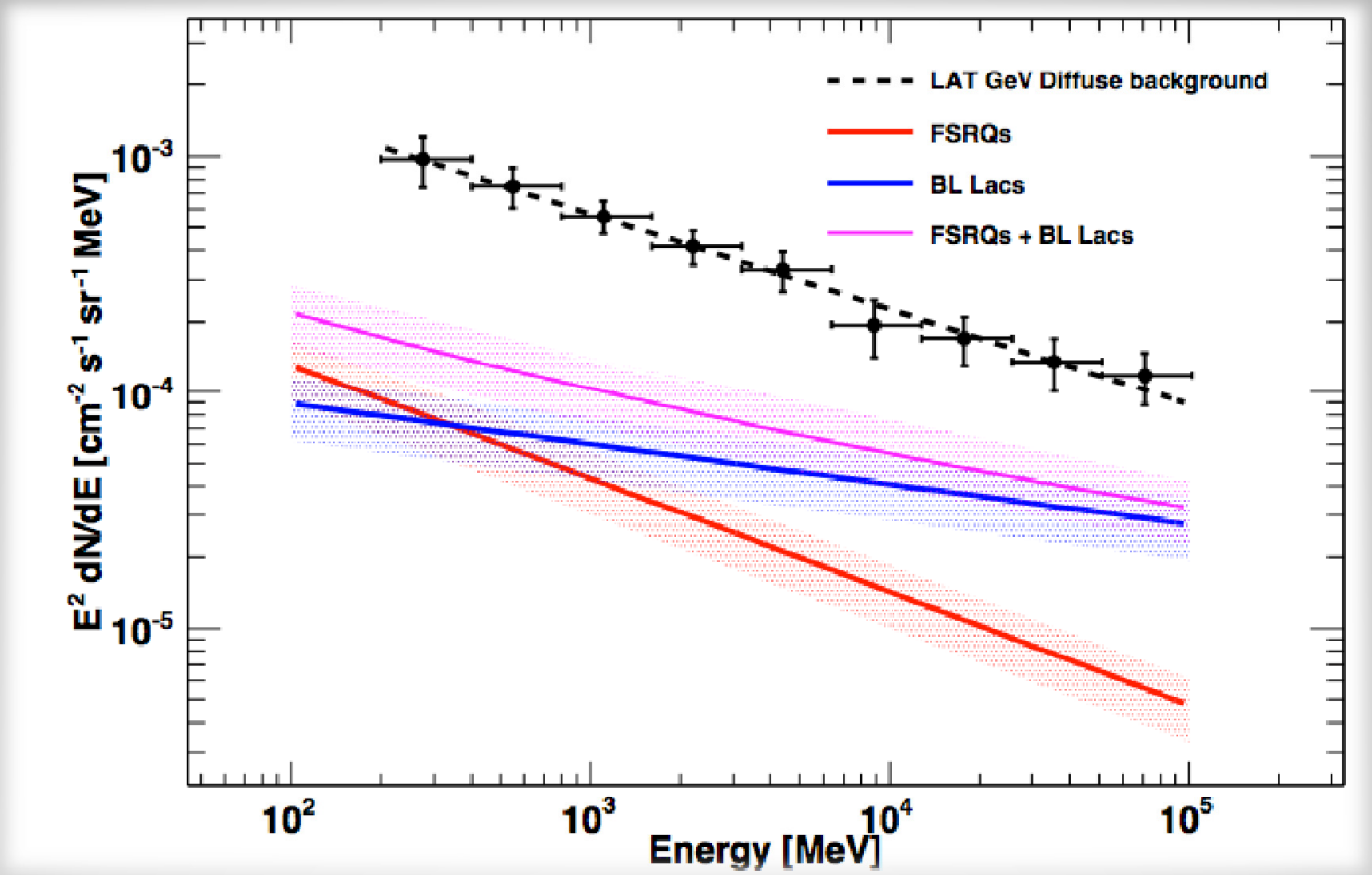
Contribution of blazars to the EGB

Blazars seem to account for <30% of the EGB for 0.1 GeV <E<100 GeV



FSRQ and BL Lacs

BL Lacs dominate at high-E (caveat: broad band analysis)



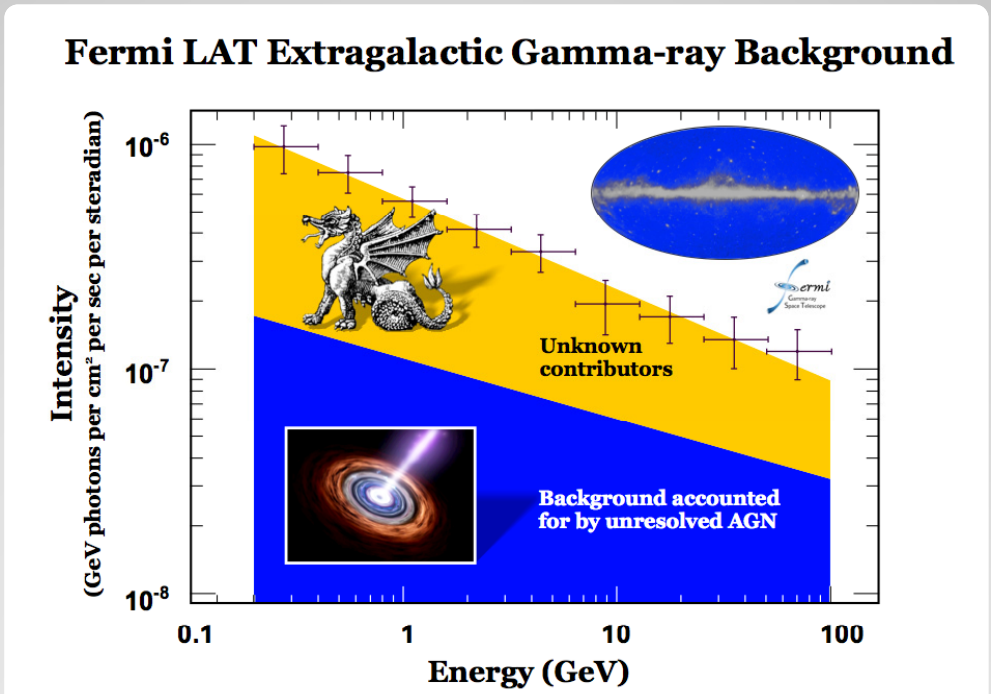
NASA's view of the thing...

NATIONAL GEOGRAPHIC Daily News

Home Animals Ancient World Energy Environment Cultures Space/Tech Weird News Photos News Video News Blogs

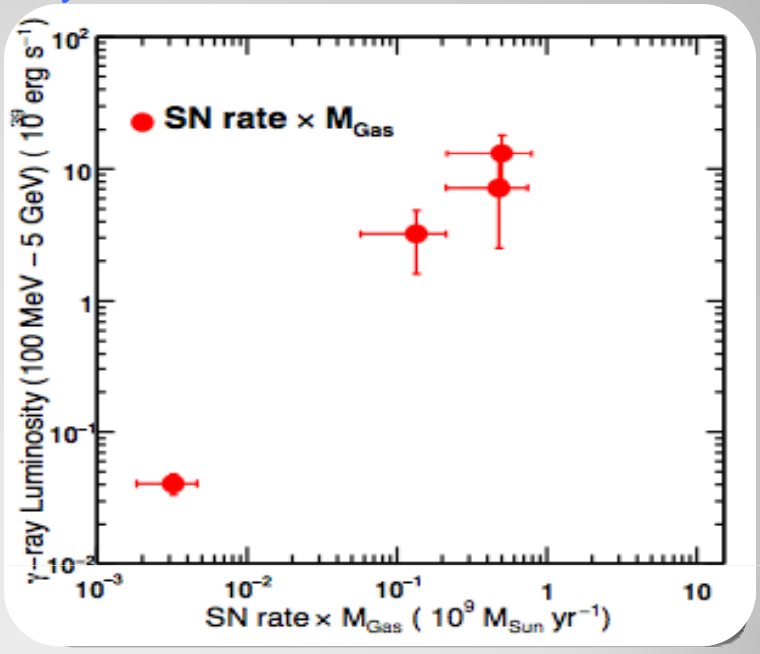
Mysterious "Dragons" Make Universe's Gamma Ray Fog

New Fermi space telescope results deepen cosmic mystery.



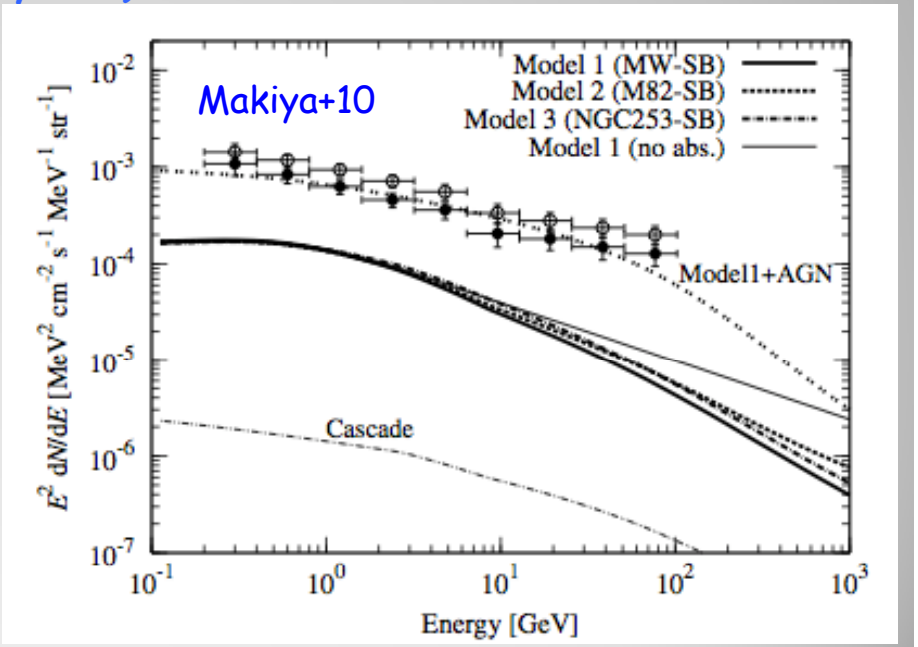
Other Populations ?

- Star forming galaxies emit γ-ray due to the interaction of CR and gas/radiation (e.g. like in our own Milky Way)
- *Fermi* detected already NGC 253, M82, LMC, SMC, NGC 1068, NGC 4945, etc.
- SF-galaxies can contribute up to 30% (e.g. Pavlidou&Fields02, Thompson+07, Lacki+10, Fields+10, Makiya+10)



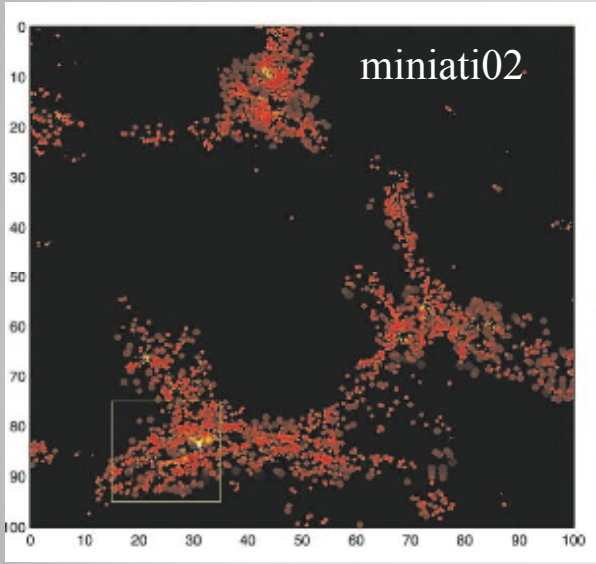
Other Populations ?

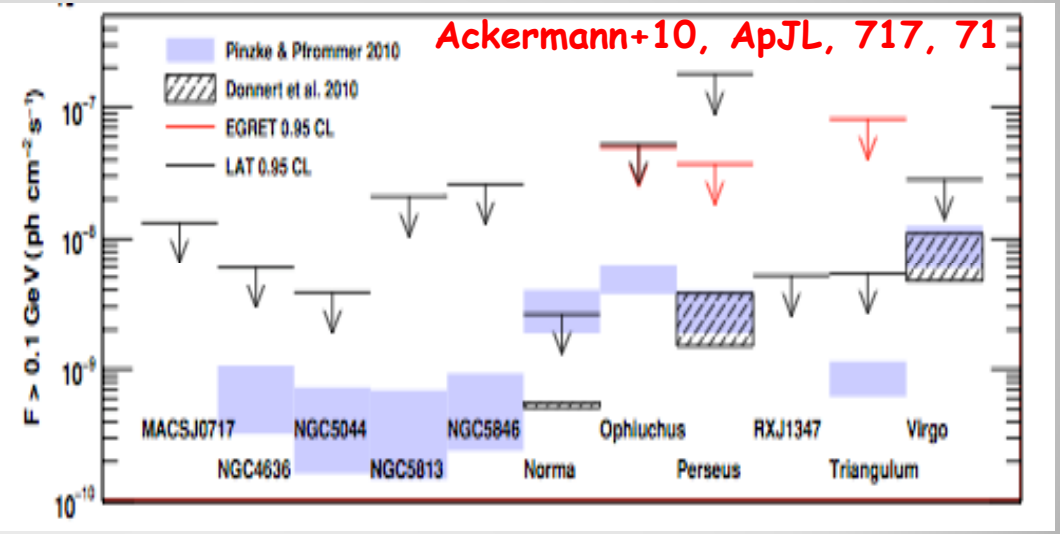
- Star forming galaxies emit γ-ray due to the interaction of CR and gas/radiation (e.g. like in our own Milky Way)
- *Fermi* detected already NGC 253, M82, LMC, SMC, NGC 1068 (?), NGC 4945 (?), etc.
- SF-galaxies can contribute up to 30% (e.g. Pavlidou&Fields02, Thompson+07, Lacki+10, Fields+10,Makiya+10)



Cosmological Shocks ?

- Intergalactic shocks and Cluster shocks might provide a significant (~10%) contribution to the γ-ray background (e.g.miniati02, keshet+02)
- Intergalactic shocks emission dominated by Inverse Compton of e^- off CMB photons
- Cluster's emission dominated by hadronic interaction (p-p collisions), but *Fermi does not detect clusters ….*

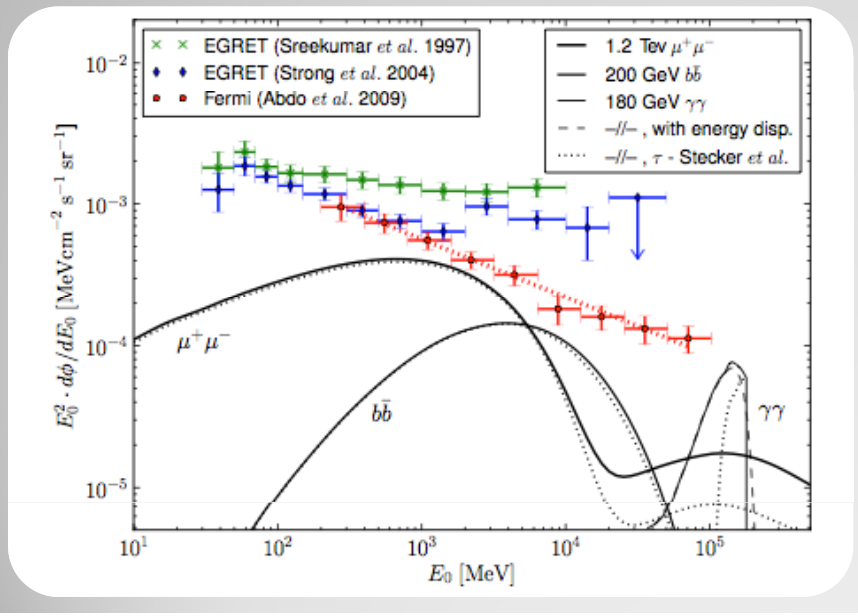


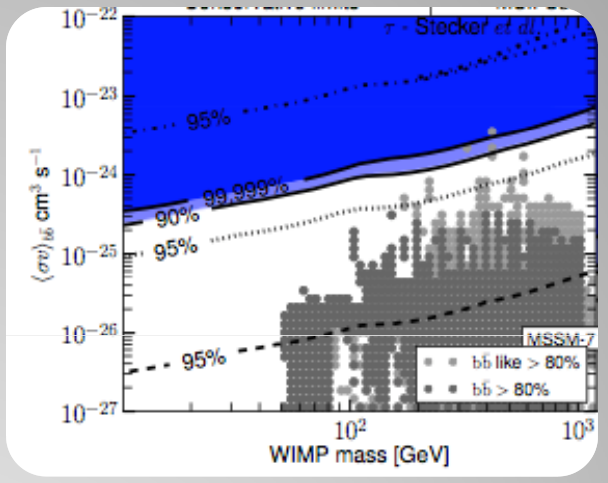


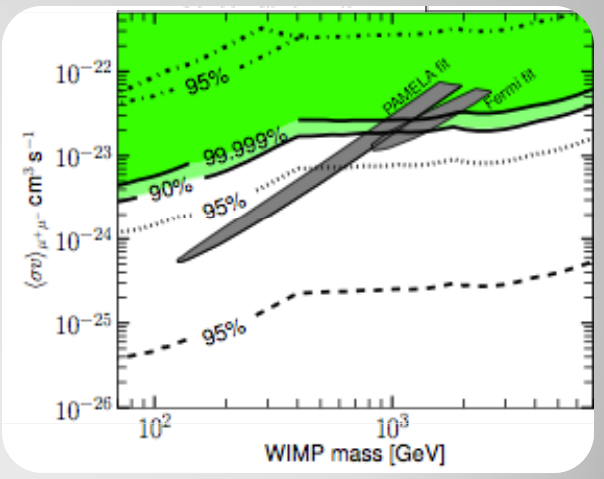
Limits on DM annihilation

Abdo,JCAP 2010, 014

- **DM annihilation limits can be obtained imposing that the EGB spectrum is not violated**
  - **Degeneracy between the cross-section and the clustering scenario**
  - **Limits close to those expected for a thermal relic neutralino**

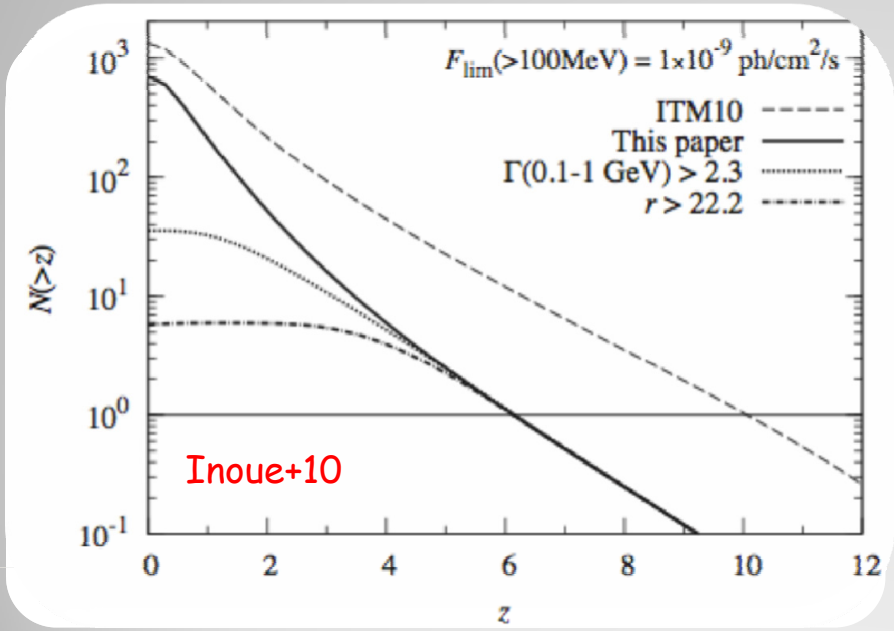


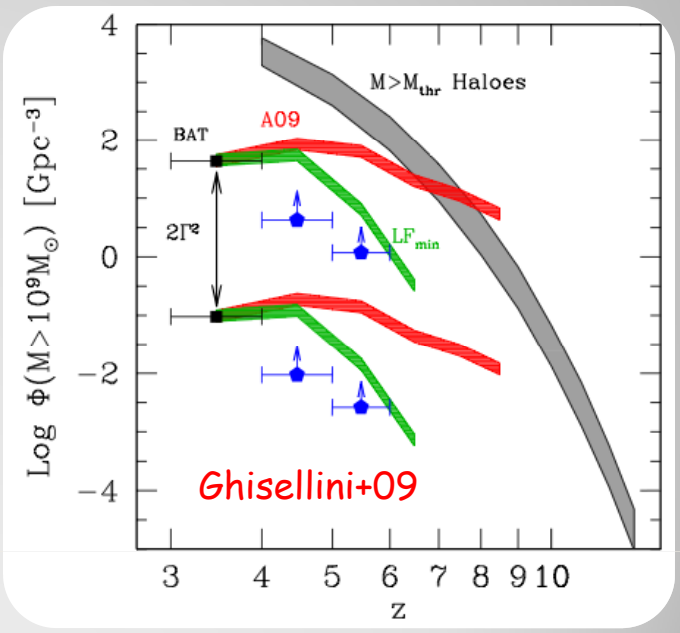




Blazars at high redshift

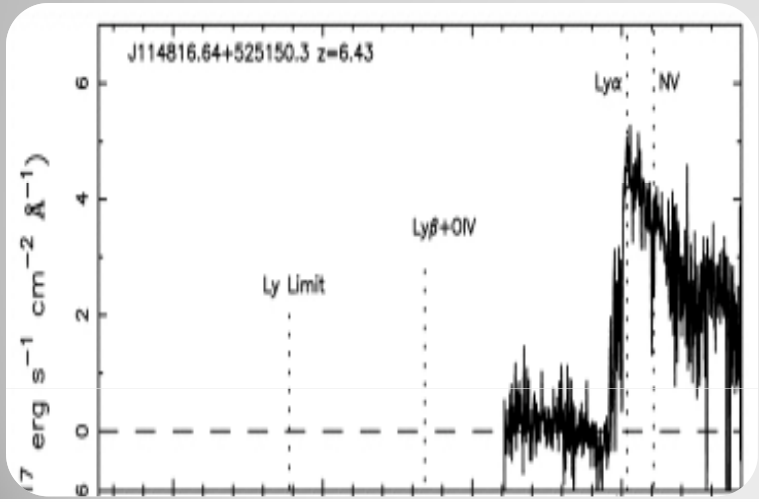
- How far does the blazar pop. extend in redshift ?
  - E.g. how early in the Universe did the first blazars form ?
  - How can a 10^{8-9} M_{sun} black hole form so early ?

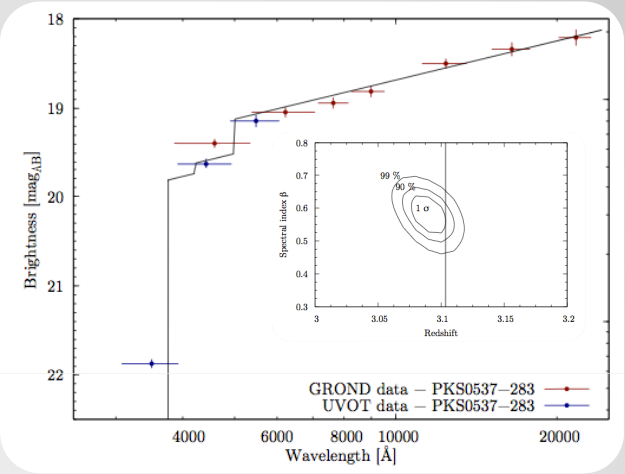




Hunting Blazars at high redshift

- **The task is complex:**
  - **High-z objects are faint and requires 'hours' of exposure at a 8m telescope to perform spectroscopy**
  - **Some Blazars do not show lines! So no redshift measurement is possible**
- **Idea! Use Ly_α break (caused by the absorption of Intergalactic Medium) to derive a redshift measurement**
  - **Advantages: does not require lines, can use small telescopes**





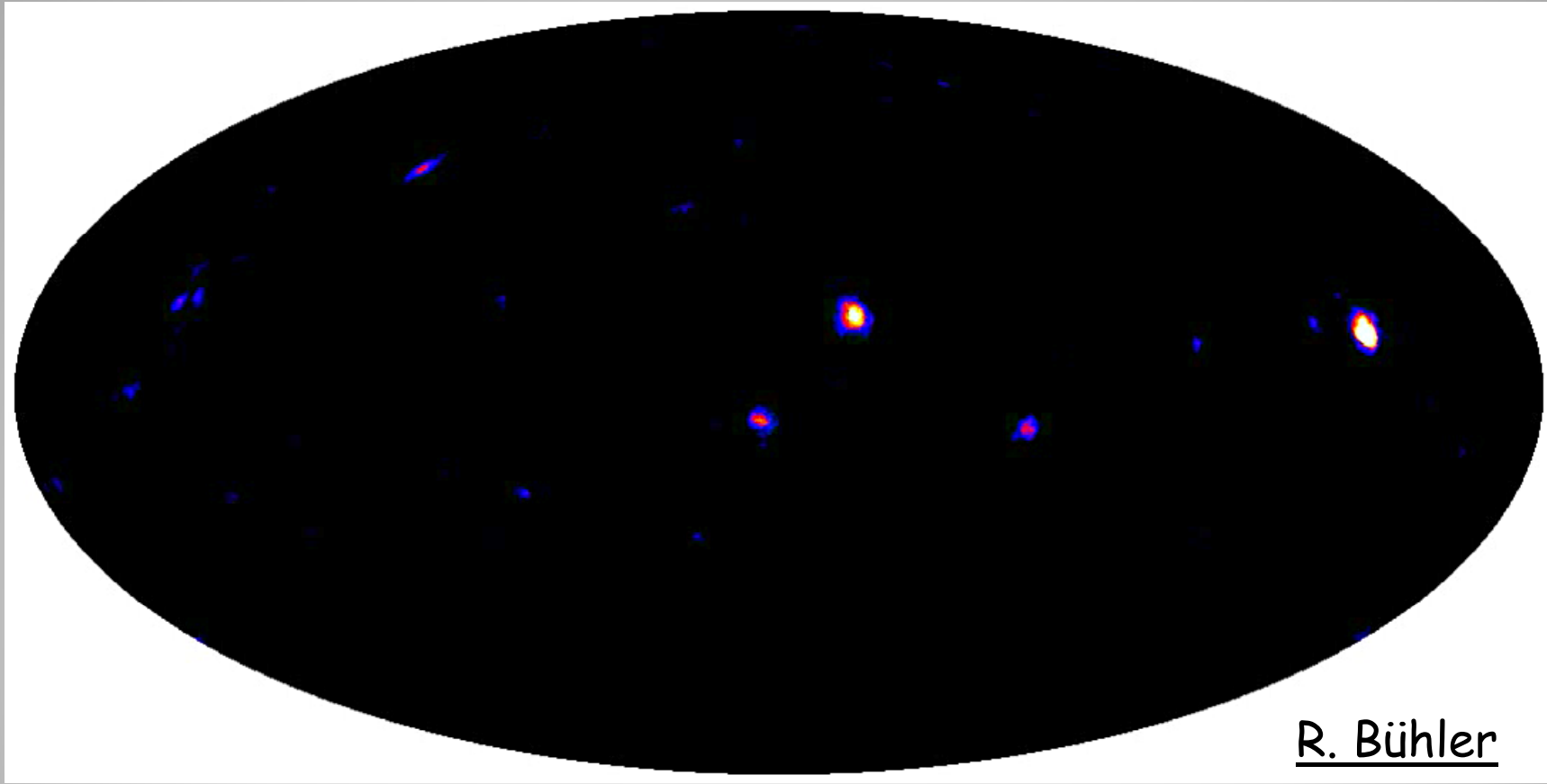
F.A.V.A

R. Bühler, M. Ajello, S. Funk

- **Fermi All-sky Variability Analysis:**
  - Systematic search for gamma-ray transients at any energy or time-scale (and position in the sky)
  - Simple Idea: subtract steady emission at each position in the sky !! → Leaves only flaring sources
- **Detect and Identify flaring sources is easier**
  - Look for flaring high-redshift AGN
- **Look for new class of sources**
  - Are there Galactic plane flaring sources ?
- **What else can we learn ?**
  - Do AGN flare and vary all the same way ?

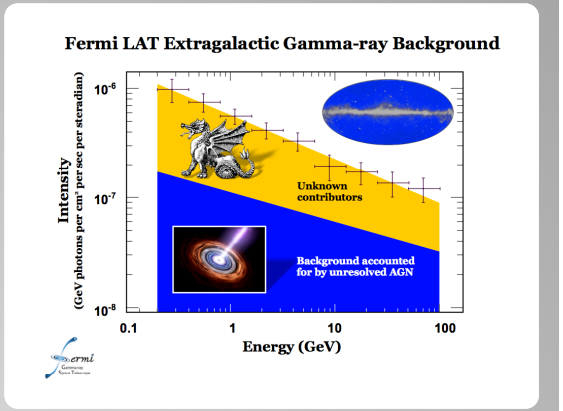
FAVA unleashed

(First public appearance)



Conclusion

- *Fermi* measured the new spectrum of the Extragalactic Gamma-ray Background after careful modeling of all other components
  - → It has lower intensity than the one measured by EGRET and it is featureless (it has no bumps)



- *Fermi* determined that only <30% of the Extragalactic Gamma-ray Background is made up by blazars
  - 70% of the EGB is produced by unknown source classes or can be truly diffuse (e.g. Intergalactic shocks, Dark Matter, etc.)
- The most distant blazars ?
  - The hunt is open
- FAVA: expected to yield many discoveries…..

The End