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Angular power spectrum of the extragalactic gamma-ray background: **Astrophysical interpretation**

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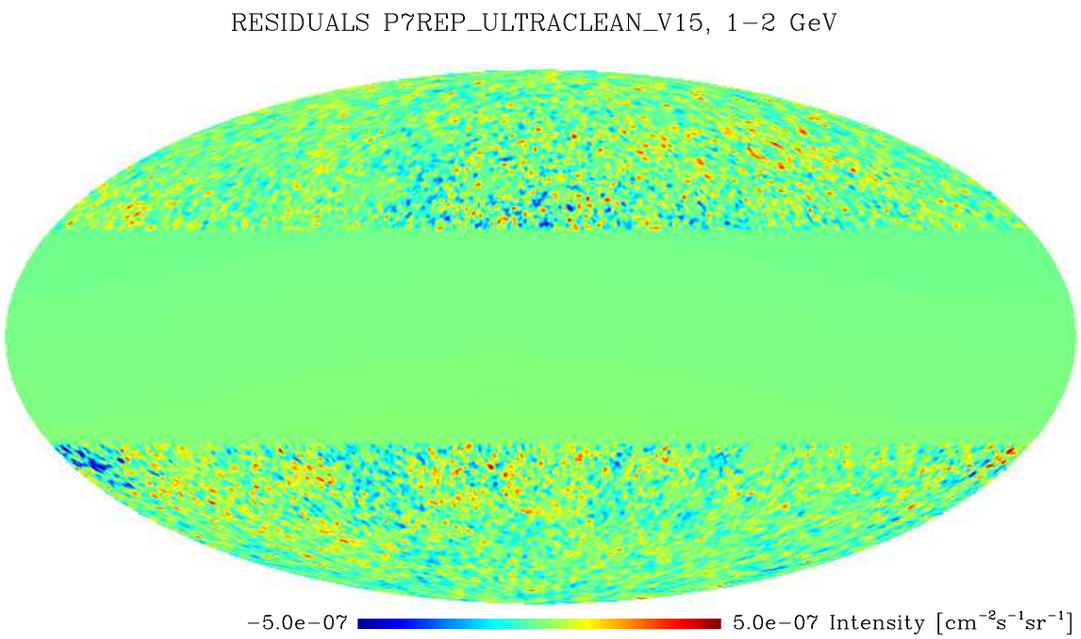
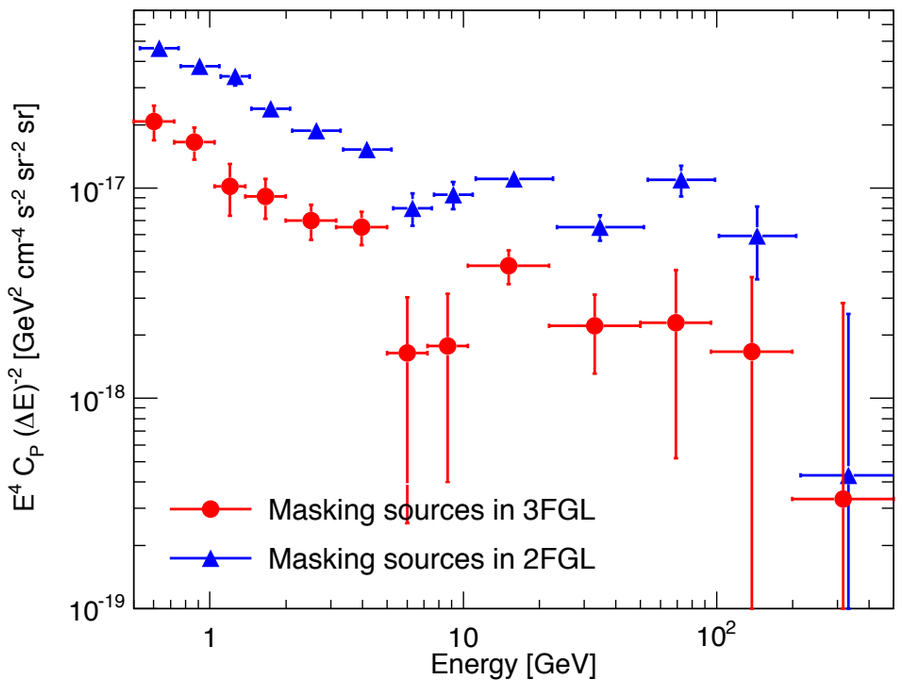
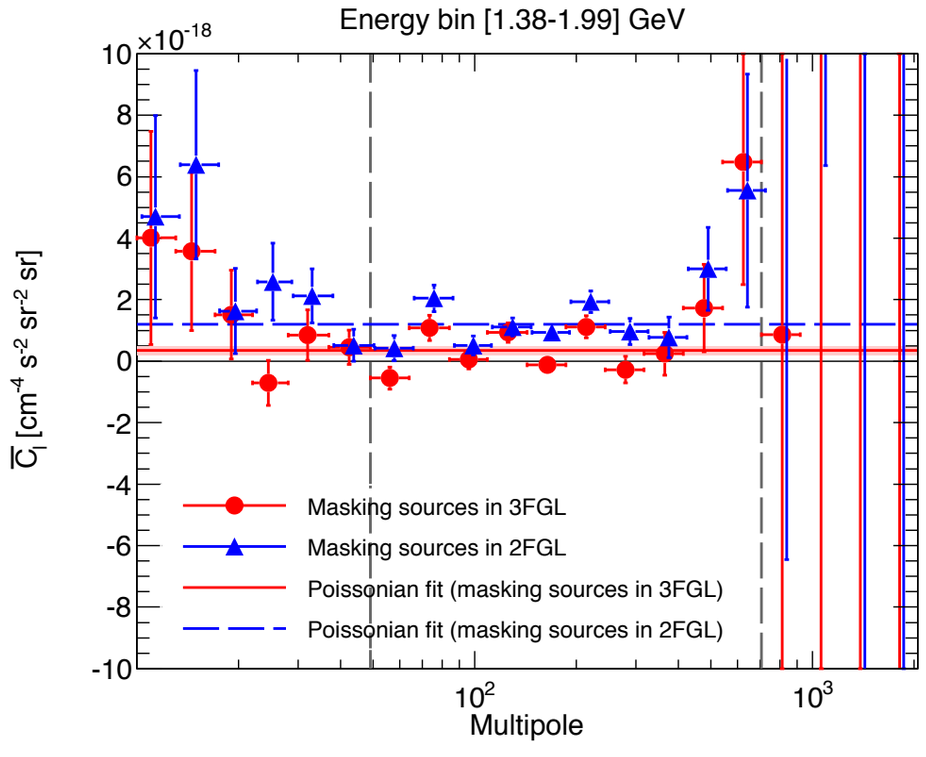
Angular power spectrum of the gamma-ray background



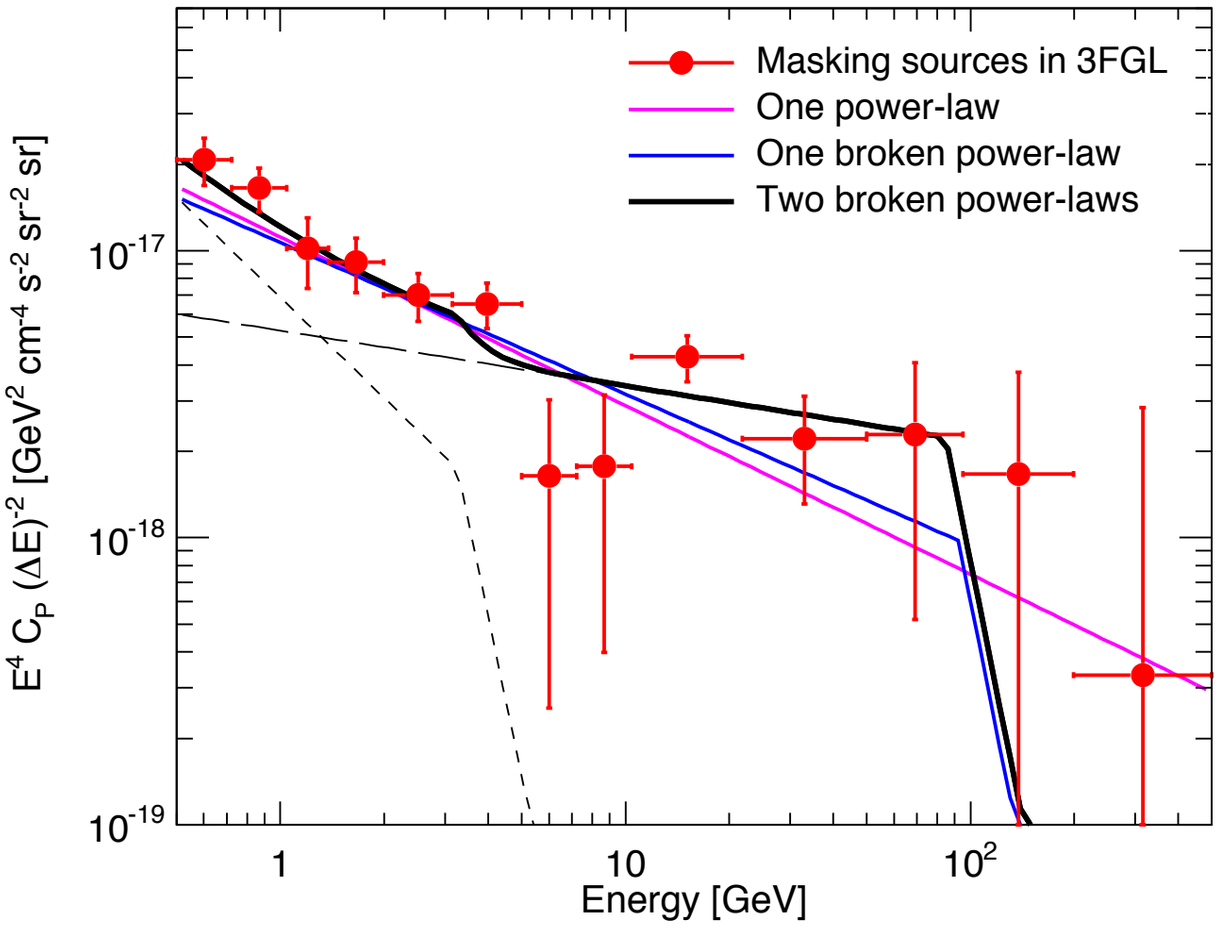




Fornasa et al., arXiv:1608.07289

- Analysis of 81 months of PASS 7 (Reprocessed) data
- Solid detection of APS in 13 energy bins between 0.5 and 500 GeV
- **No multipole-dependence** was found
- Consistent with **unclustered point sources** (***Poisson*** shot noise)

Phenomenological interpretation

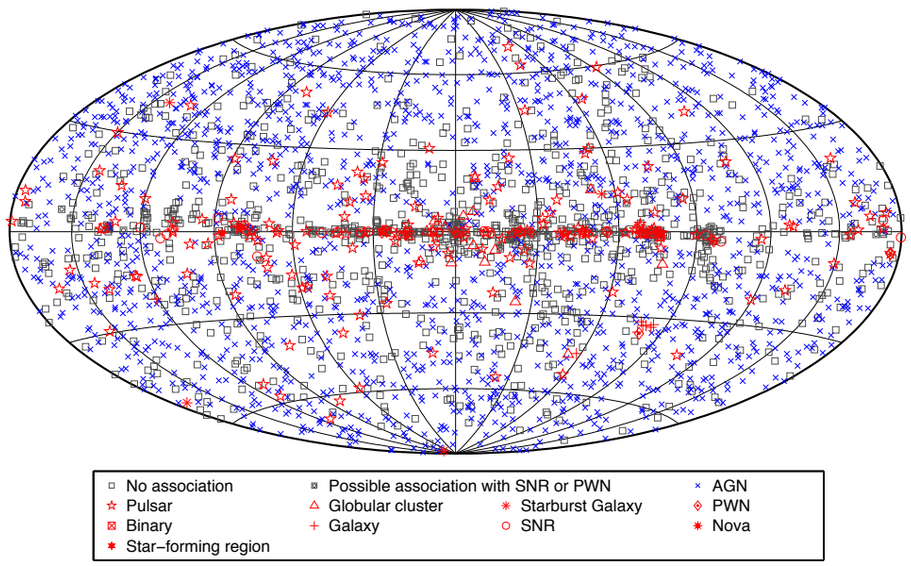


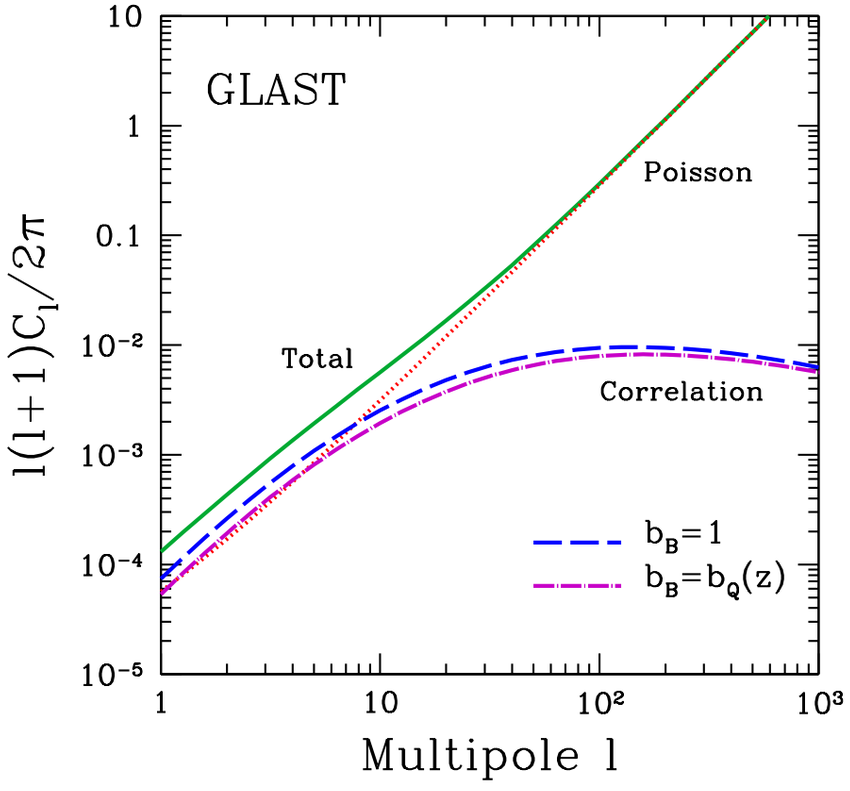
Fornasa et al., arXiv:1608.07289

- One population (one single power-law) model does not fit the data well
- Data prefer two population models (two power laws, with at least one of them broken)
- Transition of power-law slope from 2.7 to 2.1 is seen
- ***What are they?*** **Can the data be entirely explained with the sources that we already know?**

Blazars as a dominant source of APS

Fermi-LAT, *Astrophys. J. Suppl. Ser.* **218**, 23 (2015)





Ando et al., *Phys. Rev. D* **75**, 063519 (2007)

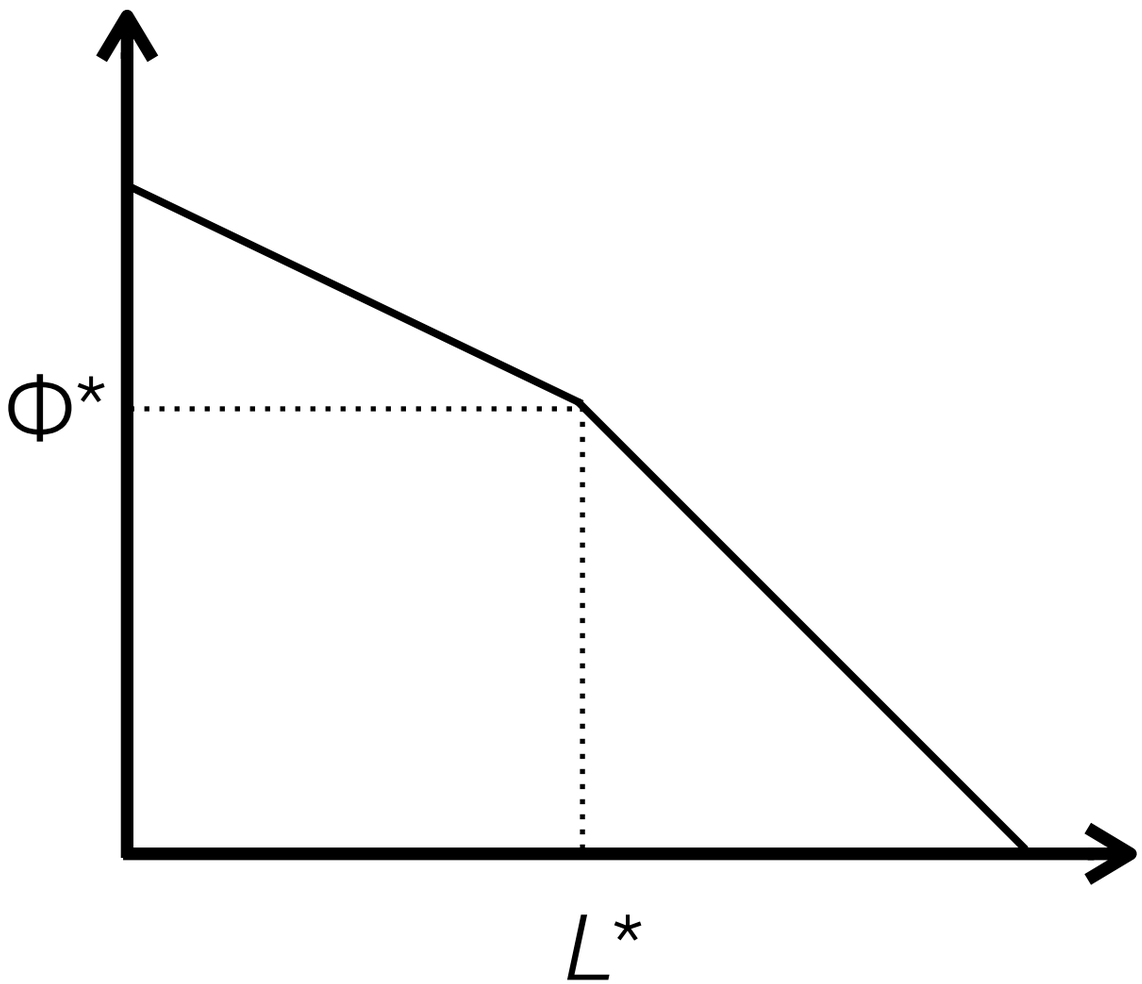
- Rule of thumb: **Poisson APS is dominated by brighter, less abundant sources**

- Blazars are a very bright, low-density gamma-ray source class, which are best studied with Fermi-LAT

- APS measurement in 2012 was well in consistent with blazar model alone (Ando et al. 2007)

- **Is this still the same for the new data? Can we learn blazar parameters?**

Gamma-ray luminosity function



- Gamma-ray luminosity function: number density of a source (i.e., blazar) per unit luminosity range $\Phi = dn/dL$

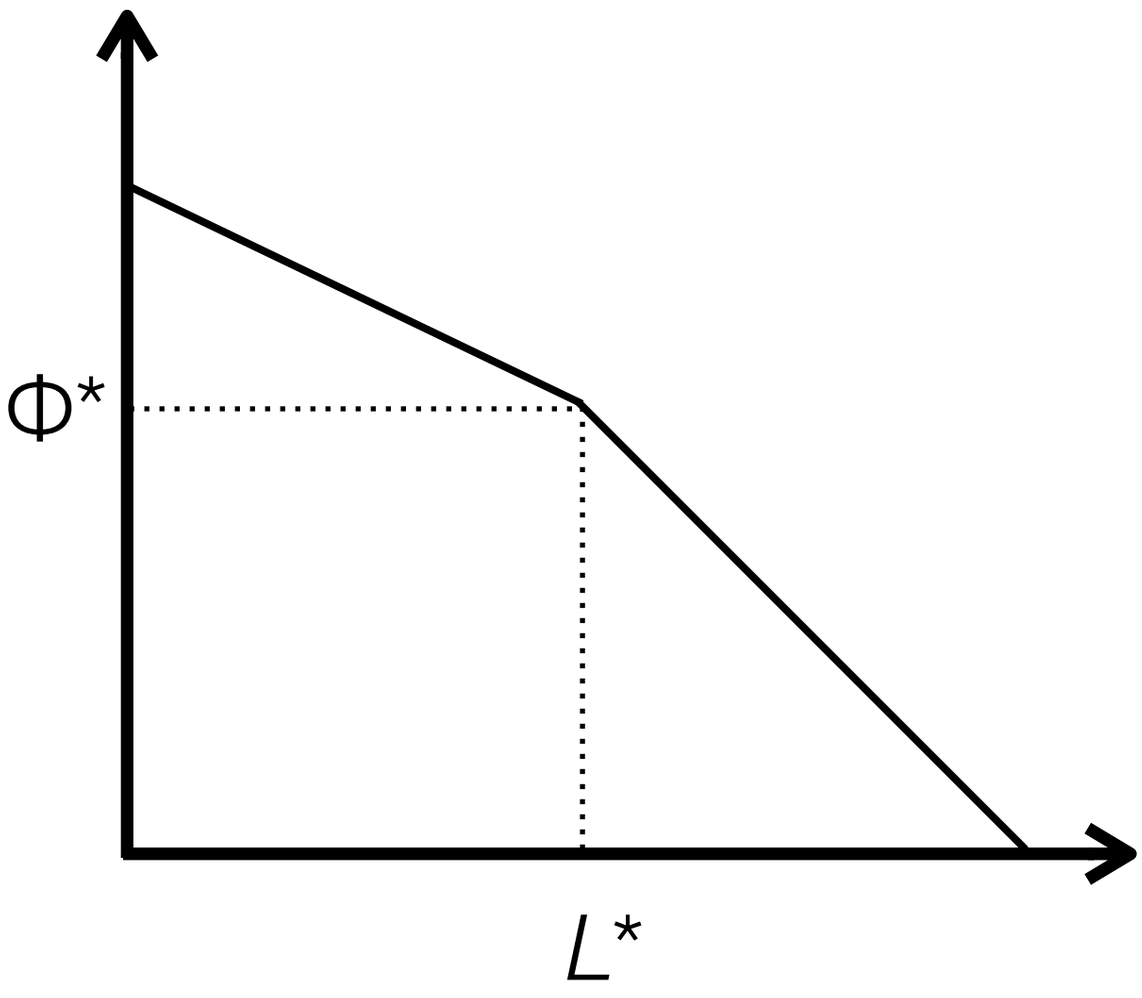
- It is typically modelled as a broken power law

- *Pure luminosity evolution (PLE)*: Only L^* evolves with redshift z

- *Pure density evolution (PDE)*: Only Φ^* evolves with z

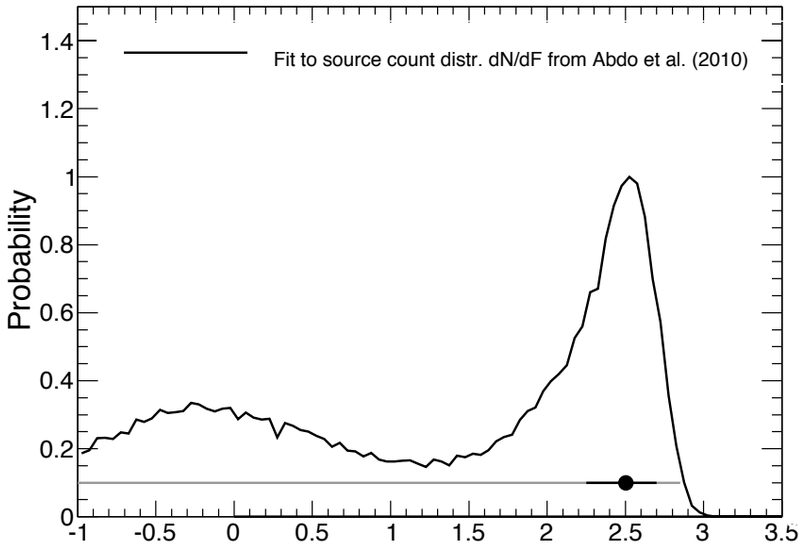
- ***Luminosity-dependent density evolution (LDDE)***: both L^* and Φ^* evolve with z

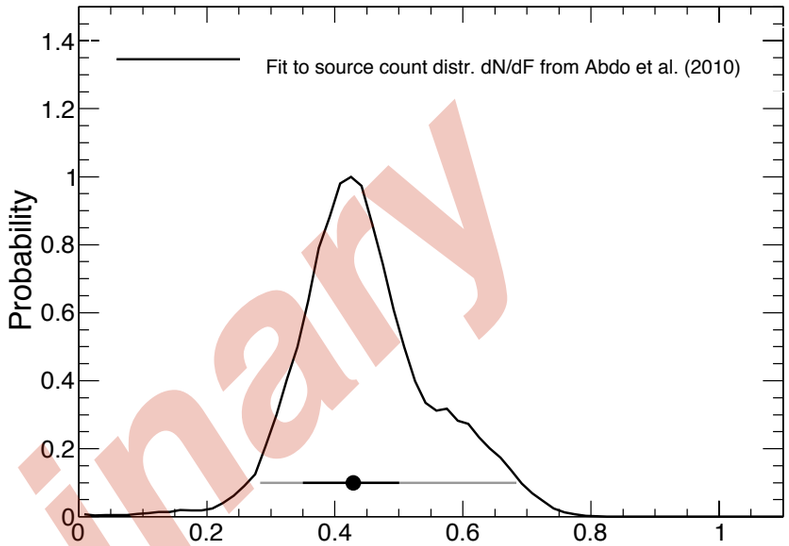
Procedure: Parameters to constrain

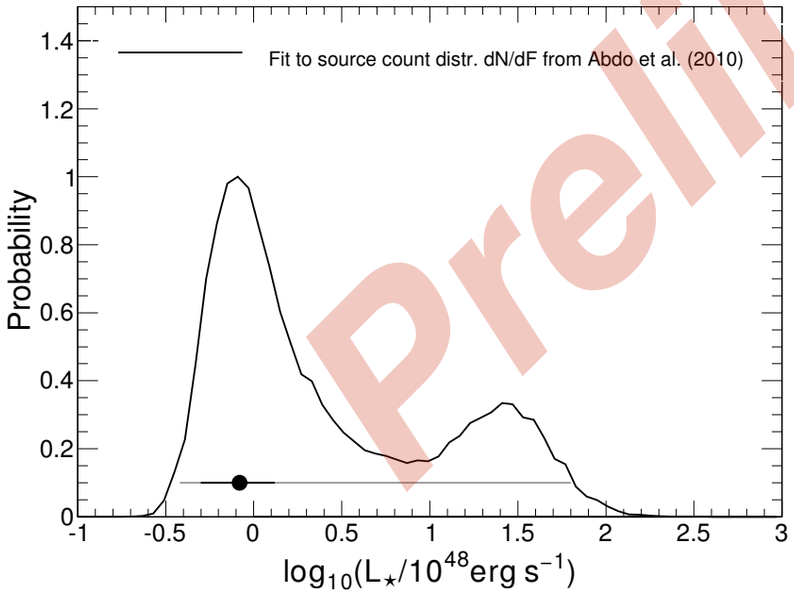


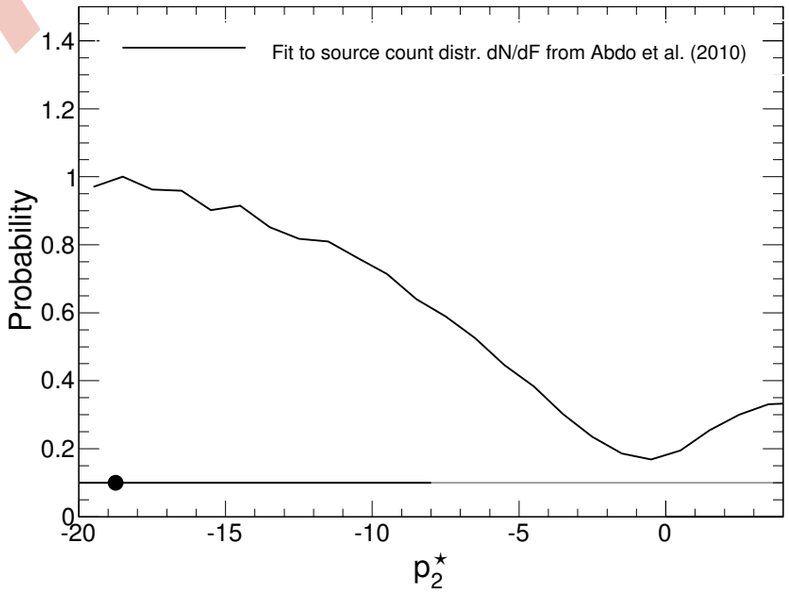
- Four free parameters (as from Ajello et al. 2015):
  - Overall normalization ***A***
  - Low-luminosity power-law slope γ_1
  - Break luminosity ***L**** at $z = 0$
  - High-redshift power-law slope p_2^*
- Everything else is fixed to median of Ajello et al. (2015)
- Energy spectrum depends on luminosity (the less luminous, the harder); taking into account both FSRQs and BL Lacs

Test run: Fitting the flux distribution *dN/dF*



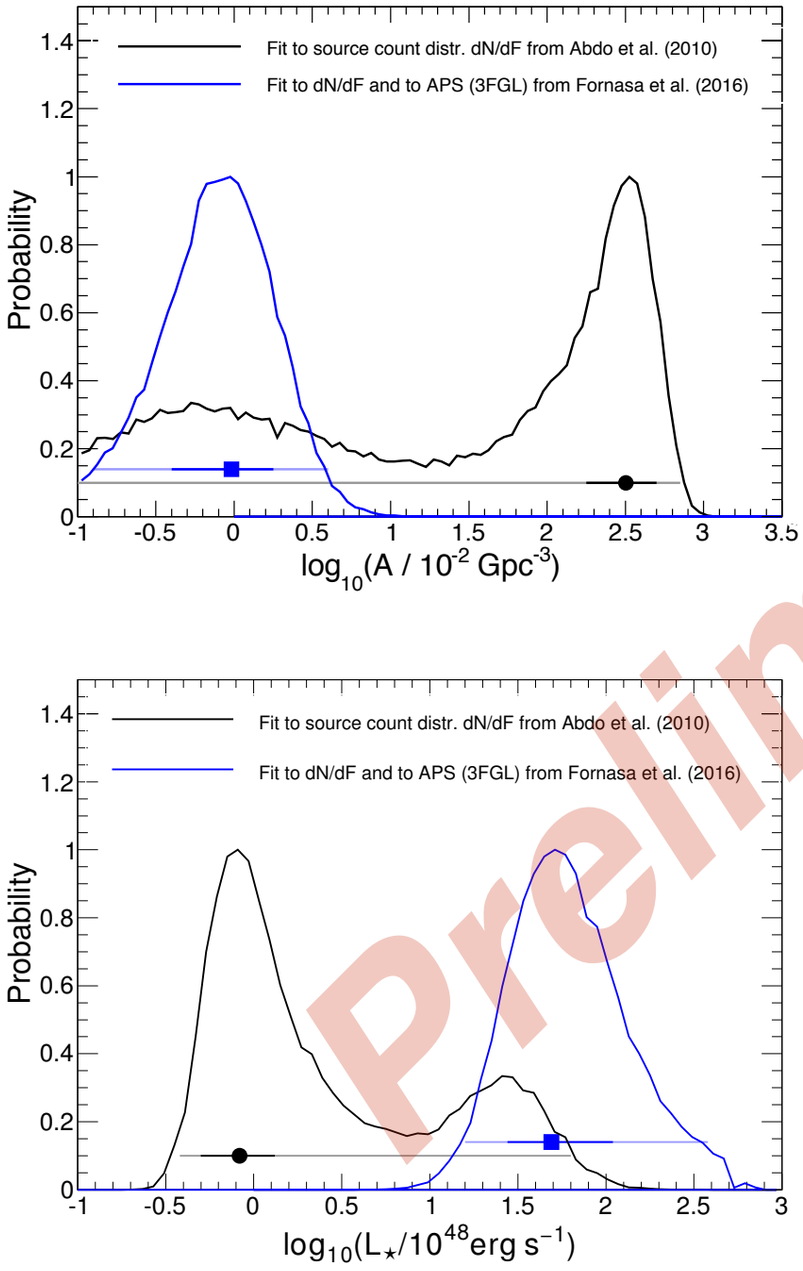


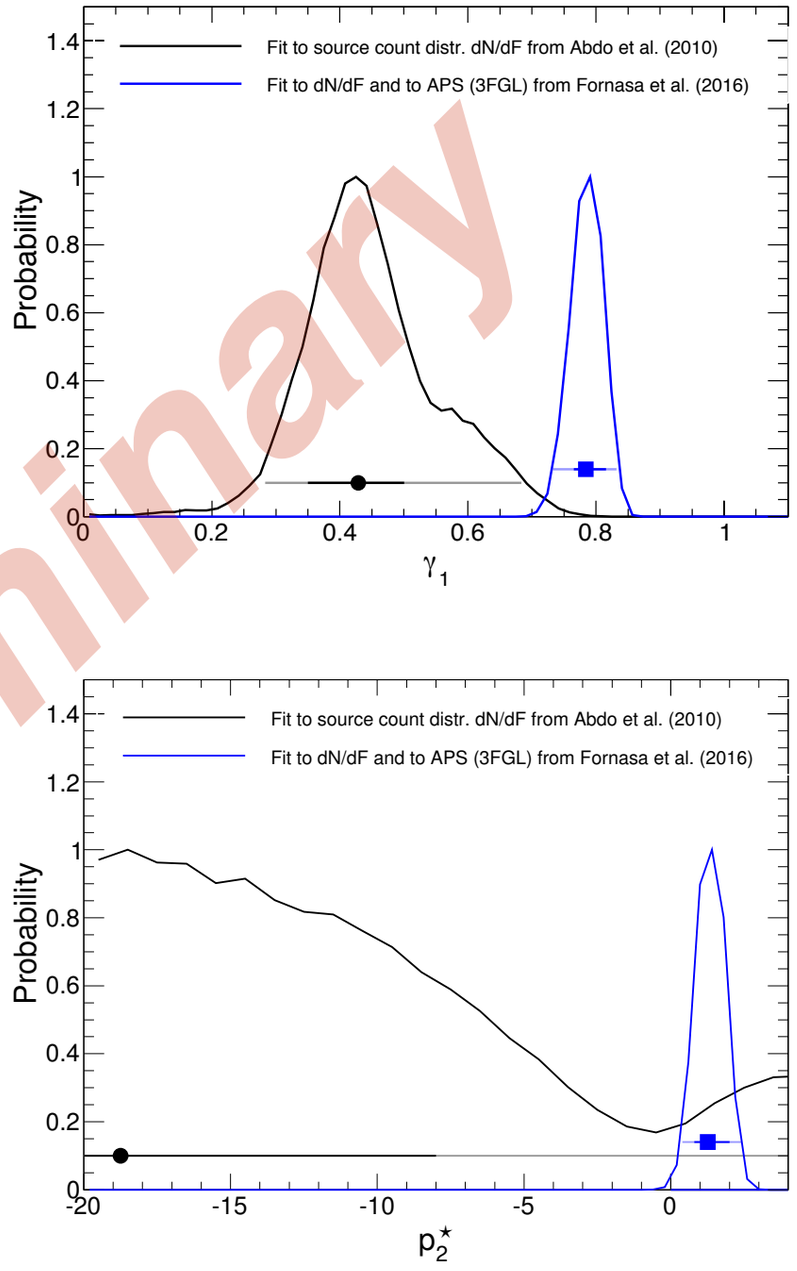




- Fitting 24 data points on *dN/dF* of all *detected* blazars in 1FGL
- Consistent with results by Ajello et al. (2015)
  - But they are weaker, as Ajello et al. (2015) fit both luminosity and redshift distributions
- Weak constraint on $p_2^\star$
  - Cannot exclude positive evolution at high-z ($z > 1$)

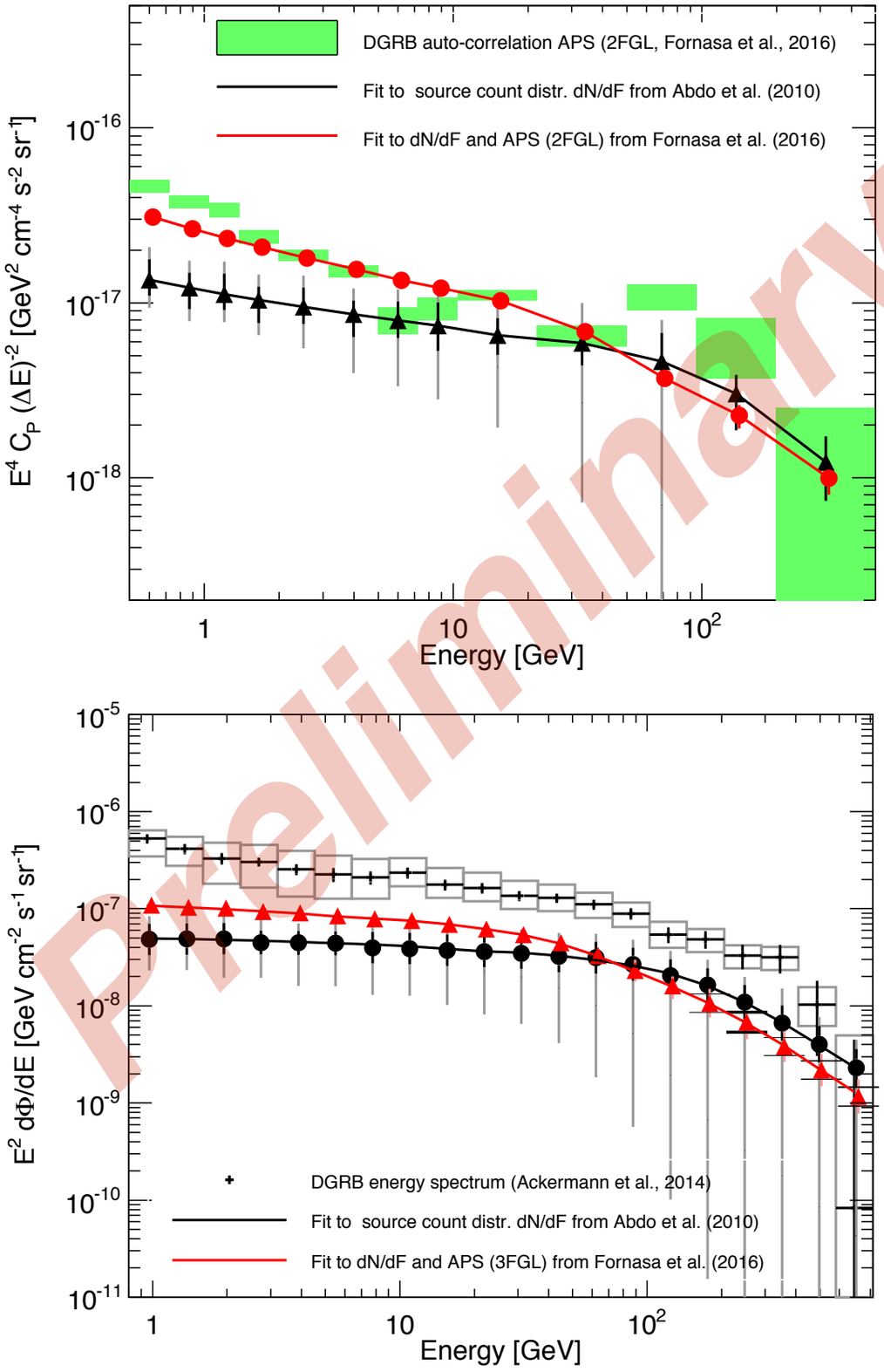
Fitting both *dN/dF* and C_P





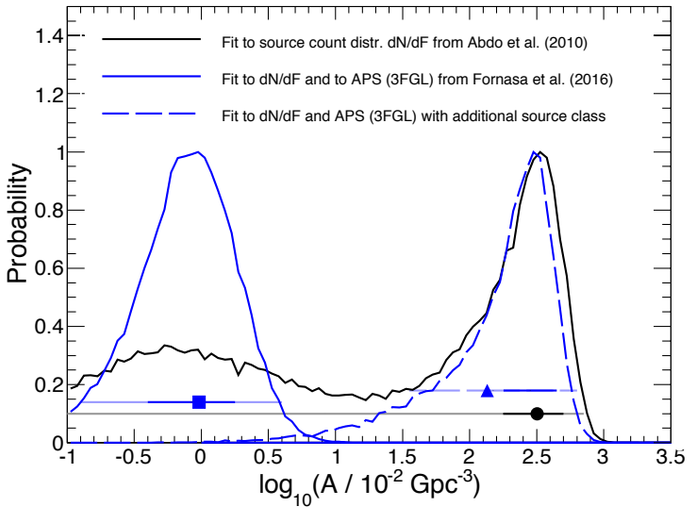
- Additional 91 data points of C_P:
  - Both auto- and cross-correlations among maps at 13 energy bins [13*(13+1)/2 = 91]
- All the parameters are shifted quite significantly
  - Implication: *dN/dF* and C_P data are incompatible under blazar-only interpretation
- $p_2^\star$ is clearly preferred to be positive!! (in tension with redshift distribution of blazars)

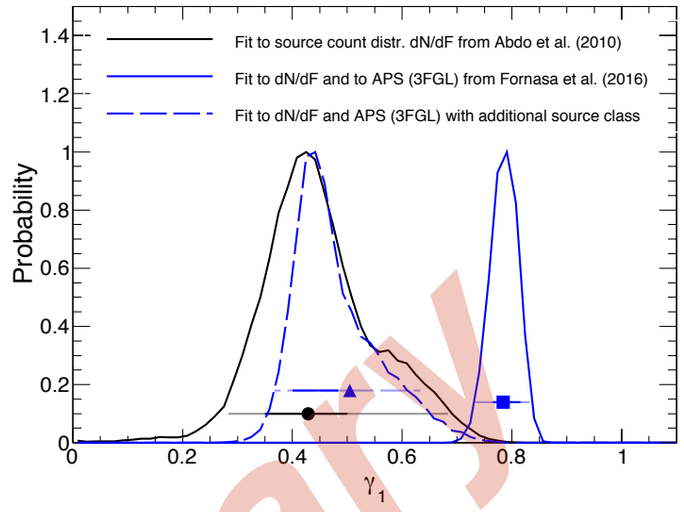
Resulting C_P and EGRB spectrum

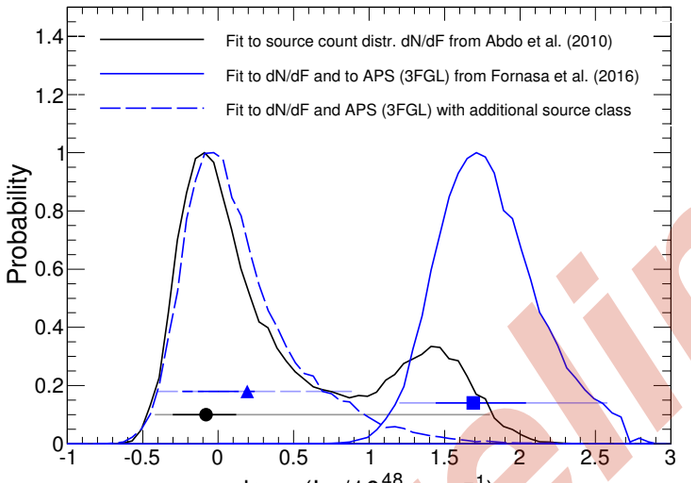


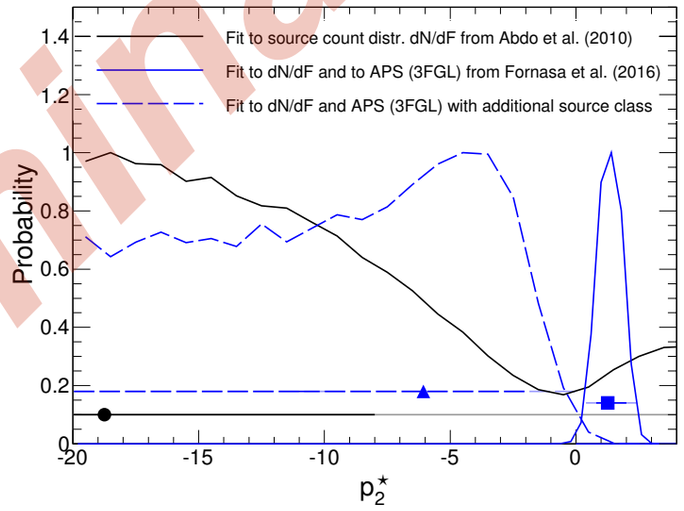
- Even the best-fit model of both *dN/dF* and C_P data does not provide good fit to C_P spectrum
  - χ^2/dof = 166.25/111
  - It clearly under-predicts data below 1 GeV
- Predicted blazar contribution to the EGRB spectrum is always subdominant
- ***This suggests a missing component at low-energy region (NEW!!)***

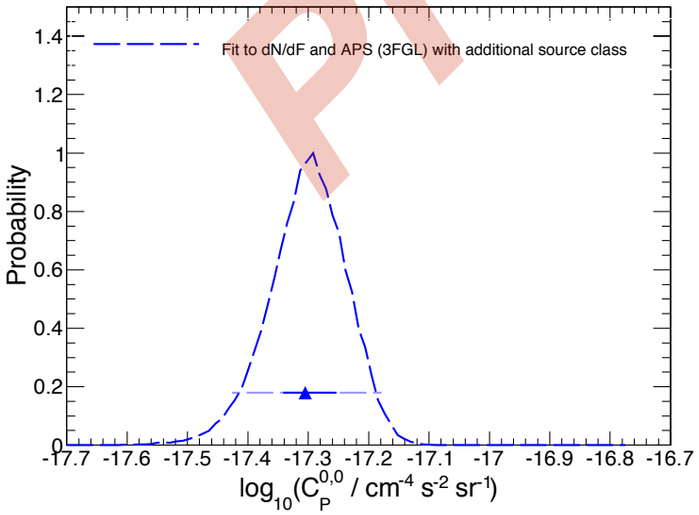
Adding a new source population

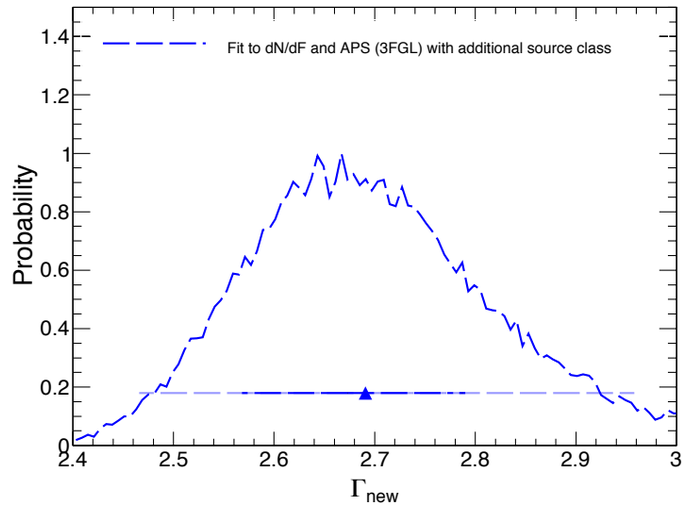






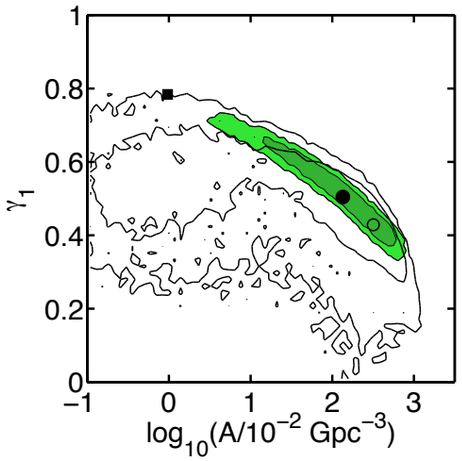


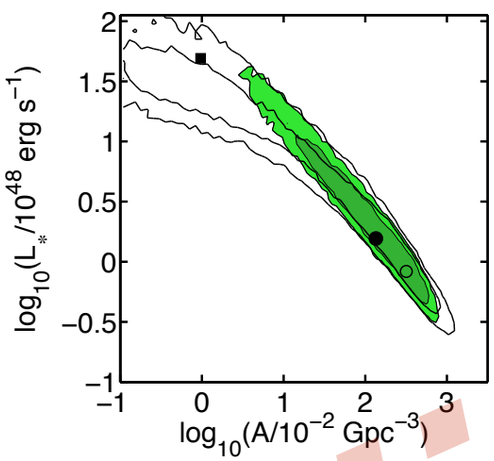


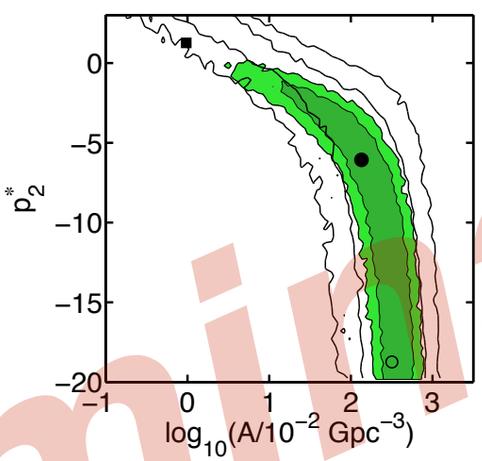


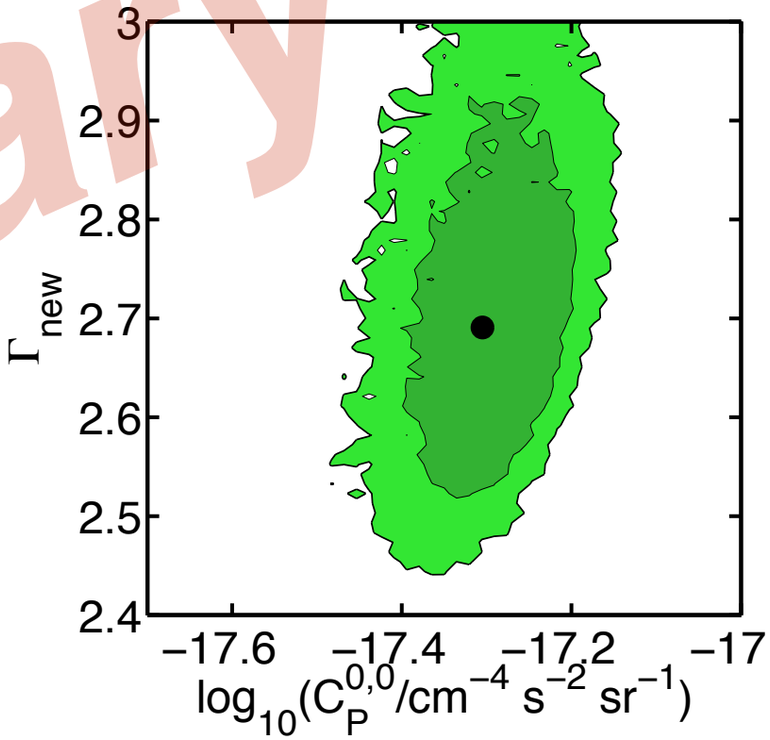
- Assume a single-power law energy spectrum
- Two additional free parameters:
  - Normalisation of C_P at the lowest energy bin
  - Spectral index Γ_{new}
- This recovers original parameters of Ajello et al. (2015), strengthening the constraints
- The new source has to be soft: $\Gamma_{new} \sim 2.7$
- Fits improve to χ^2/dof = 121.33/109 = 1.11 (*p*-value: 0.14)

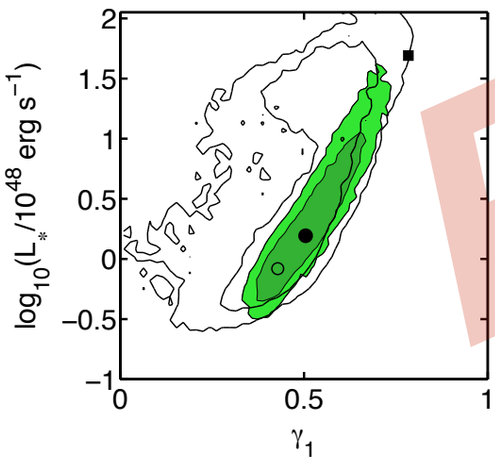
Two-dimensional contours

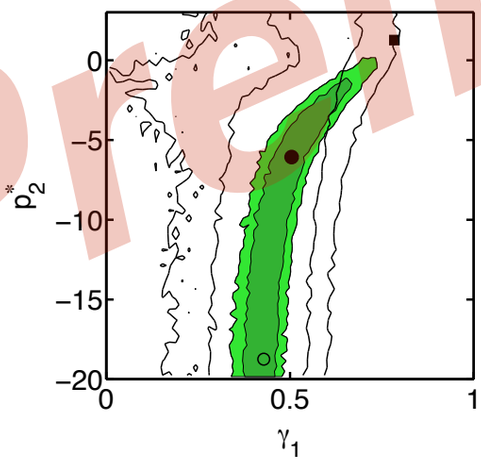


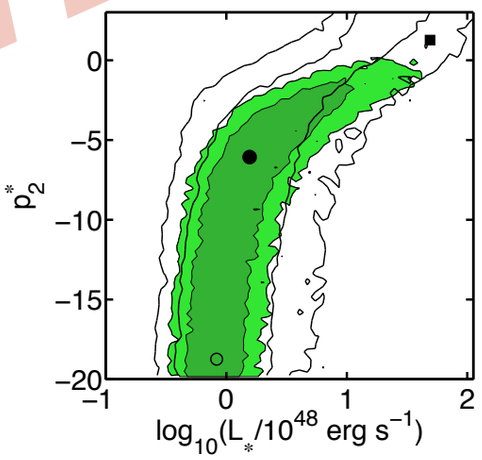








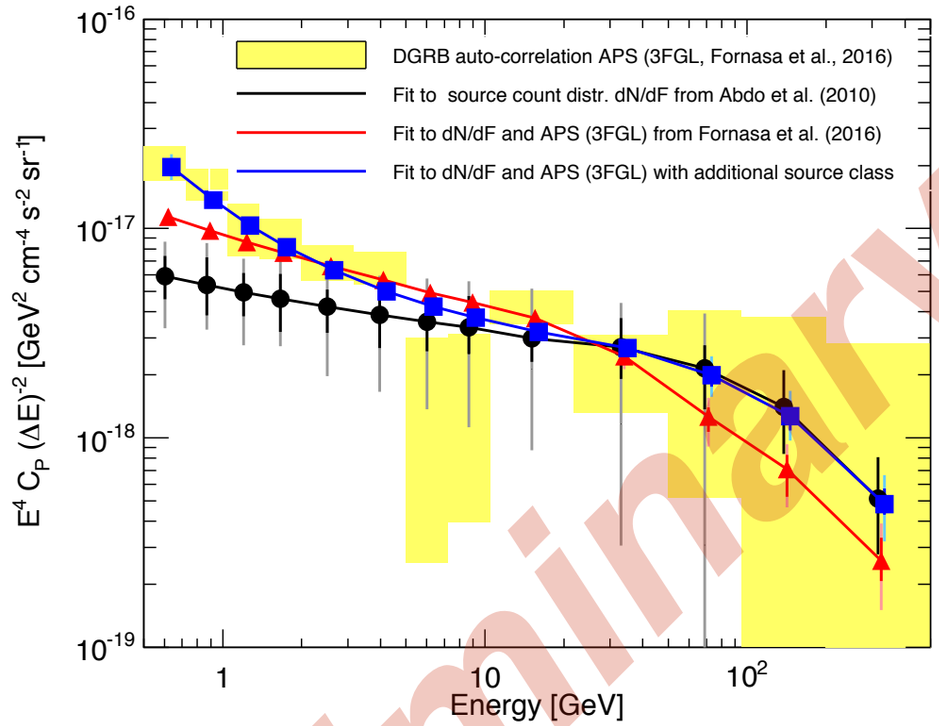


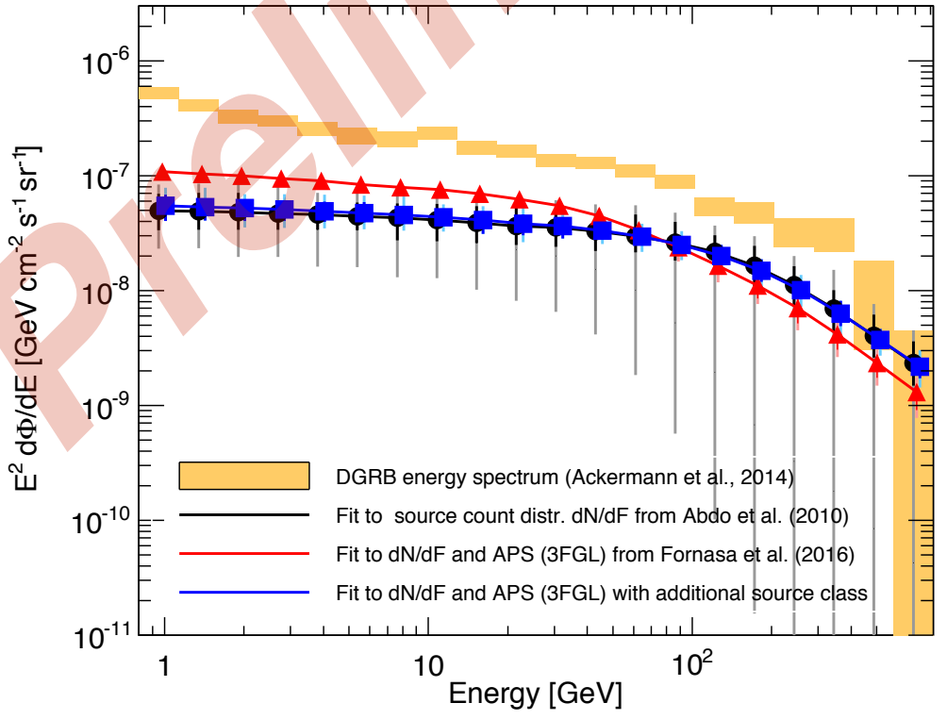


Open: *dN/dF* for blazars only

Filled: *dN/dF* and C_P for blazars and a new source population

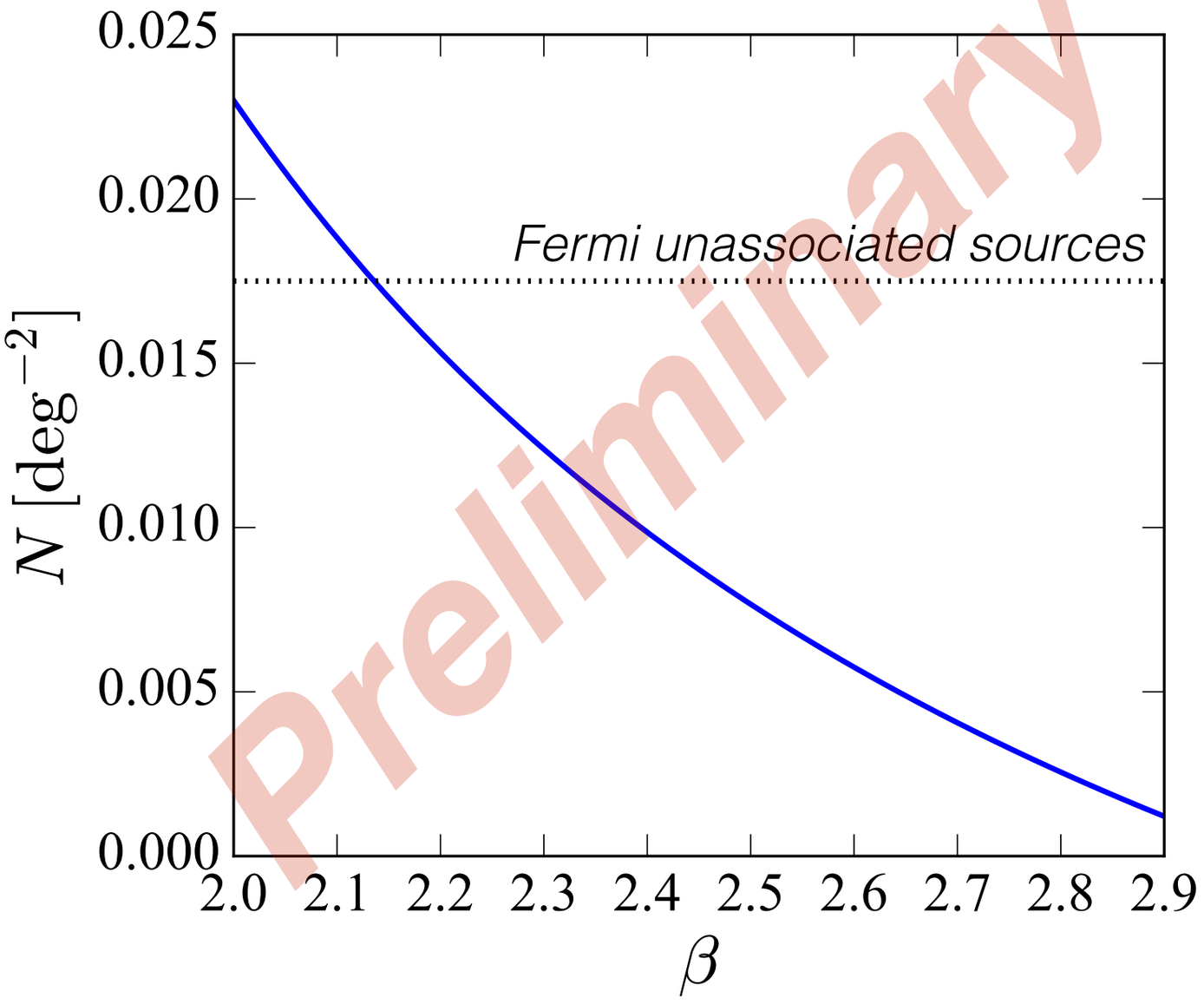
What are the sources? Star-forming galaxies?





- There are other known populations that contribute to EGRB
  - Star-forming galaxies
  - Radio galaxies (misaligned AGNs)
- Soft spectrum ($E^{-2.7}$) suggests towards the former
- But C_P must be significantly smaller (by about 3 orders of magnitude; e.g., Ando & Pavlidou 2009, Tamborra et al. 2014)

What are the sources? Fermi unassociated sources



- About 1000 sources detected with Fermi-LAT are *unassociated*
  - They satisfy the rule of thumb: **bright and rare**
- As long as the flux distribution of the source is softer than $F^{-2.1}$, the number density is below that of unassociated sources
- EGRB contribution can still be subdominant even at low energies

Conclusions

- Blazars are believed to be the dominant source in the gamma-ray anisotropies

- Our study, however, shows that the **blazars alone cannot explain both the latest APS and flux distribution** at the same time

- It appears to call for **another source population with a relatively soft energy spectrum, $E^{-2.7}$**

- Star-forming galaxies are just too many; **it might be related to a fraction of Fermi unassociated sources**

- Consistent answers are obtained for 3FGL and 2FGL maskings

- **All results are preliminary yet**; further checks under way