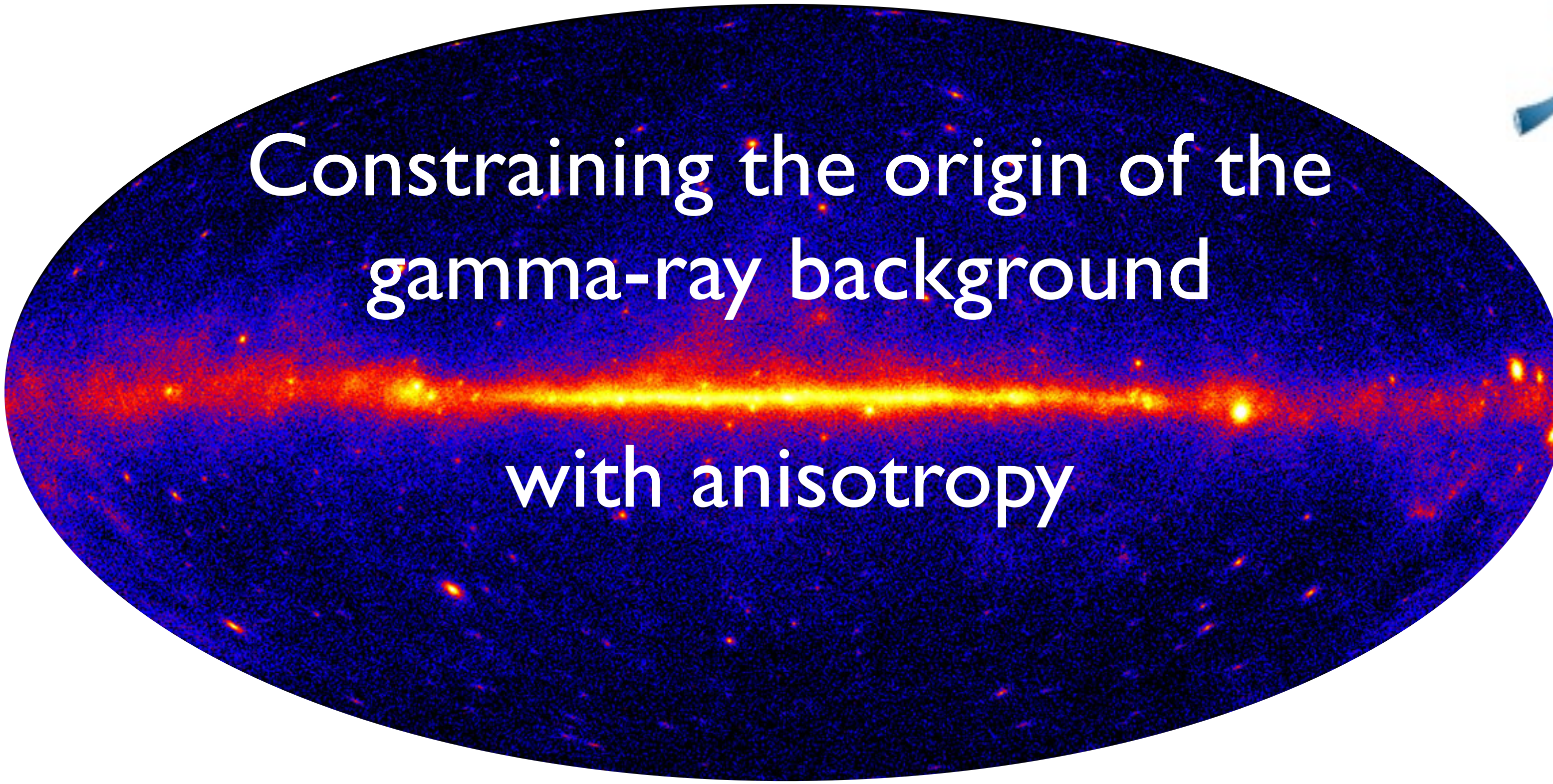
Image Credit: NASA/DOE/International LAT Team

Constraining the origin of the gamma-ray background with anisotropy



Jennifer Siegal-Gaskins

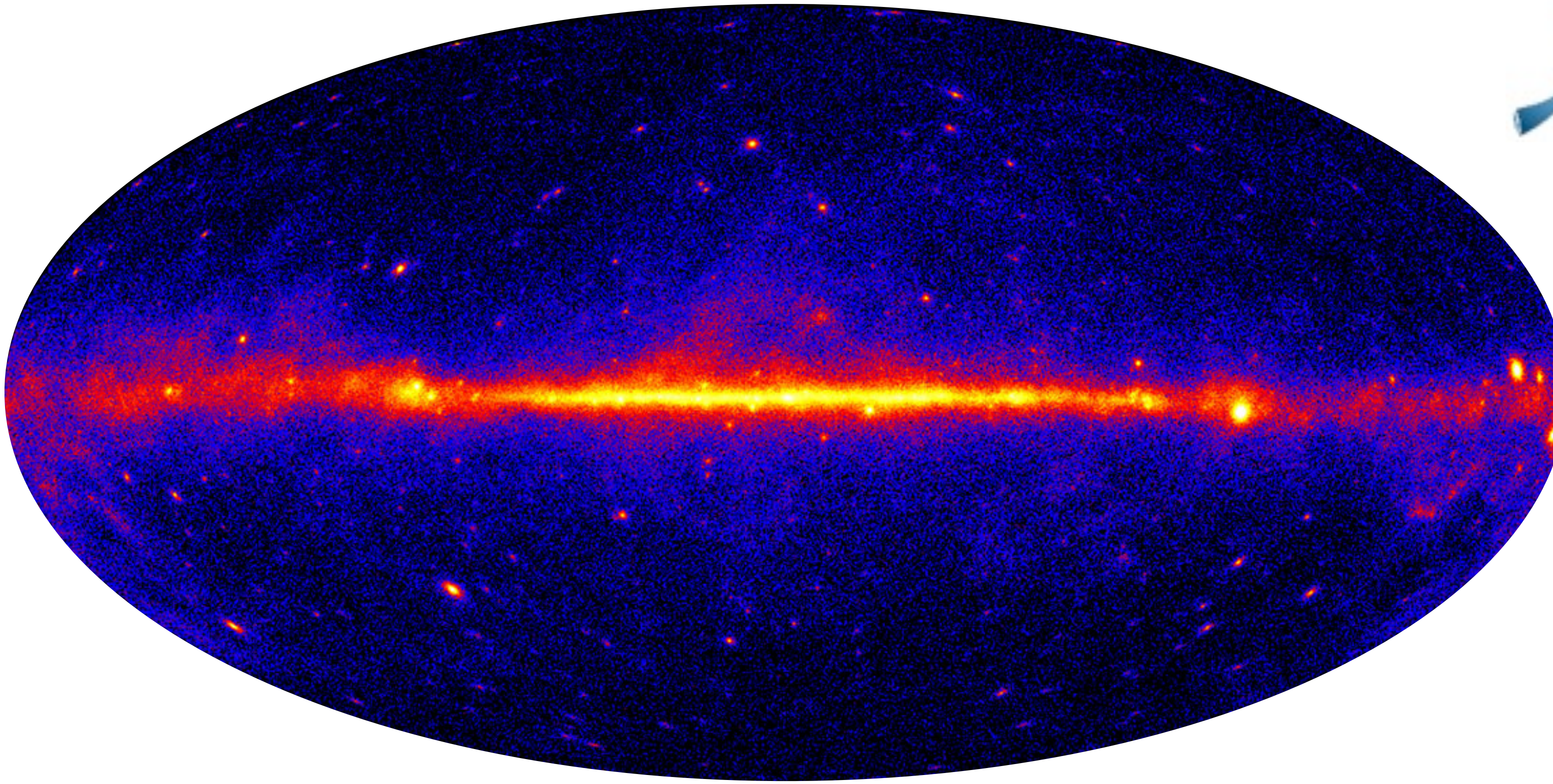
Caltech

Cuoco, Komatsu, and JSG, PRD 86, 063004 (2012), arXiv:1202.5309

Fermi LAT Collaboration + MultiDark Collaboration + Komatsu + Linden, in prep

Lochhaas, JSG, and Ajello, in prep

Image Credit: NASA/DOE/International LAT Team



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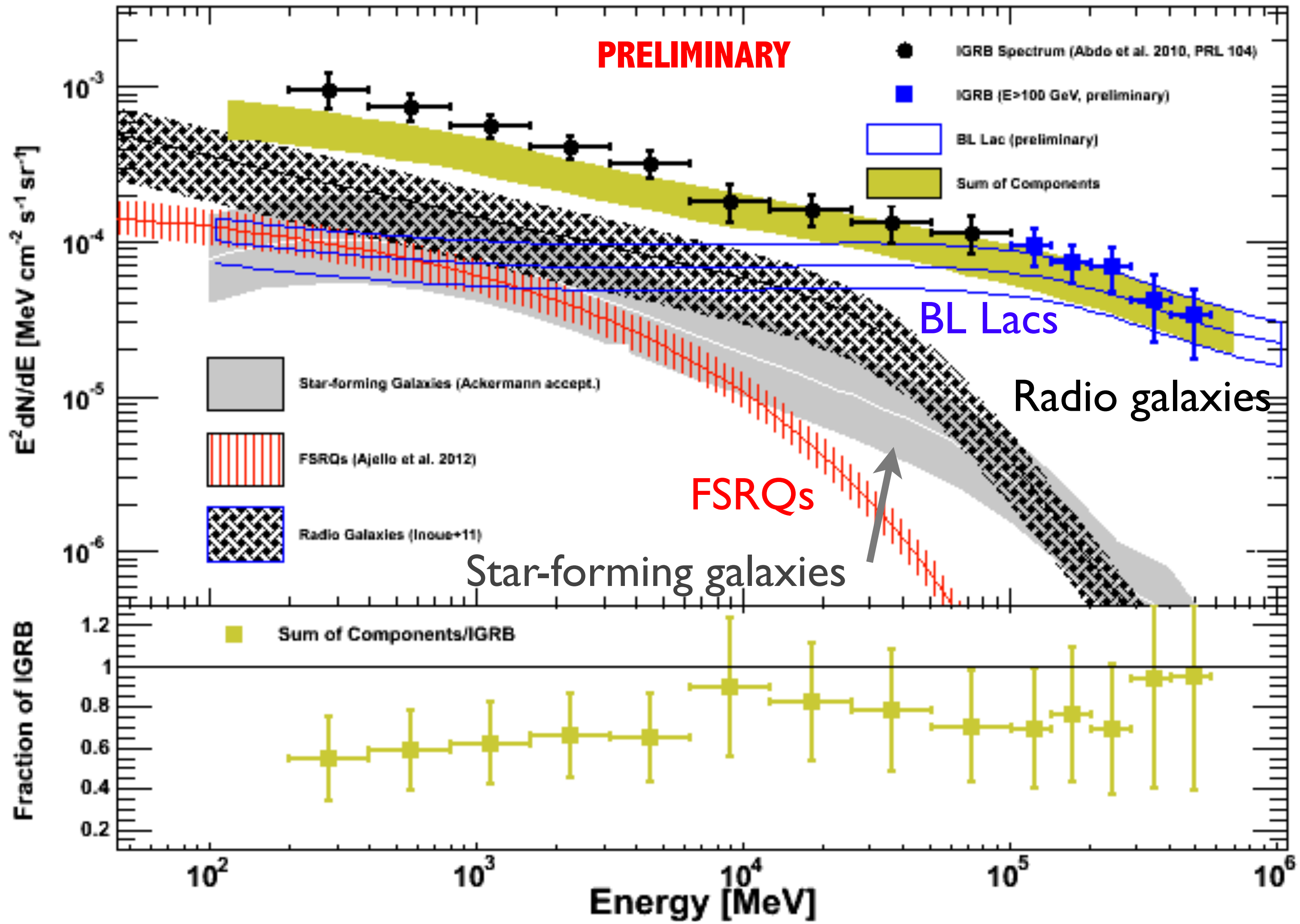
What is making the diffuse gamma-ray background?

Expected contribution of source populations to the *unresolved* IGRB



Sum is ~ 60-100% of IGRB intensity (energy-dependent)

Fermi LAT Collaboration, in prep

The angular power spectrum

$$I(\psi) = \sum_{\ell,m} a_{\ell m} Y_{\ell m}(\psi) \qquad C_\ell = \langle |a_{\ell m}|^2 \rangle$$

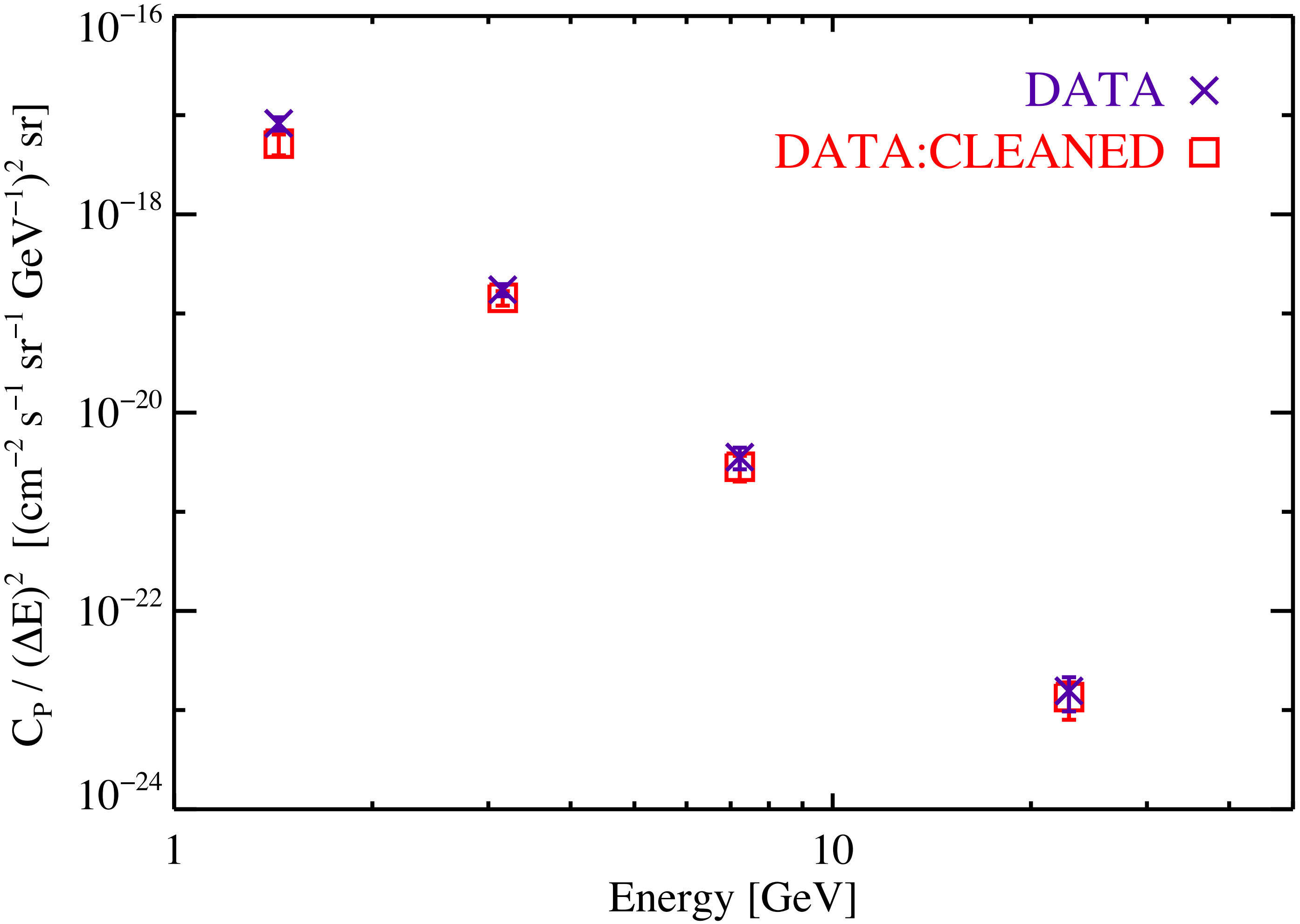
- for unclustered point sources, angular power spectrum takes the same value at all multipoles ("Poisson angular power")
- most gamma-ray source classes look like unclustered point sources

Fermi LAT anisotropy measurement

- 1FGL sources + Galactic plane masked, angular power spectrum measured
- identifying the signal at $155 \leq l \leq 504$ as Poisson angular power C_P, best-fit value of C_P is determined
- significant (>3σ) detection of angular power up to 10 GeV, lower significance power measured at 10-50 GeV
- energy dependence consistent with a source class with power-law spectrum with Γ = -2.40 ± 0.07 (looks like blazars)

intensity angular power spectrum
(Poisson angular power C_P vs E)

DATA:CLEANED = DATA - Galactic diffuse model

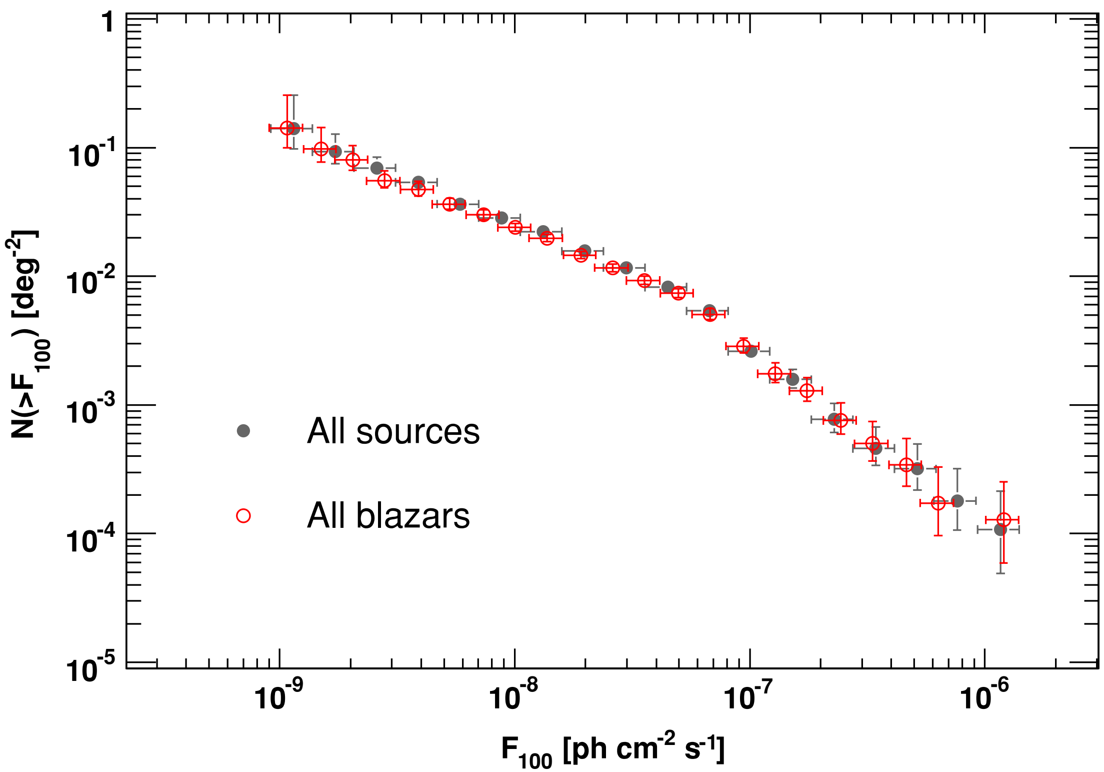


Ackermann et al. [Fermi LAT Collaboration], PRD 85, 083007 (2012)

The source count distribution

the source count distribution ("LogN-LogS") of Fermi-LAT–detected sources is consistent with a broken power law

LogN-LogS of Fermi LAT sources



Abdo et al. (Fermi LAT Collaboration), ApJ 720, 435 (2010)

high (bright-end) spectral index

break flux

$$\frac{dN}{dS} = \begin{cases} A\ S^{-\beta} & S \geq S_b \\ A\ S_b^{-\beta+\alpha} S^{-\alpha} & S < S_b \end{cases}$$

low (faint-end) spectral index

Anisotropy and source counts

the total intensity and Poisson angular power (C_P) from *unresolved* sources can be predicted from the source count distribution

$$I = \int_0^{S_t} \frac{dN}{dS} S dS$$

$$C_\mathrm{P} = \int_0^{S_\mathrm{t}} \frac{dN}{dS} S^2 dS$$

Anisotropy and source counts

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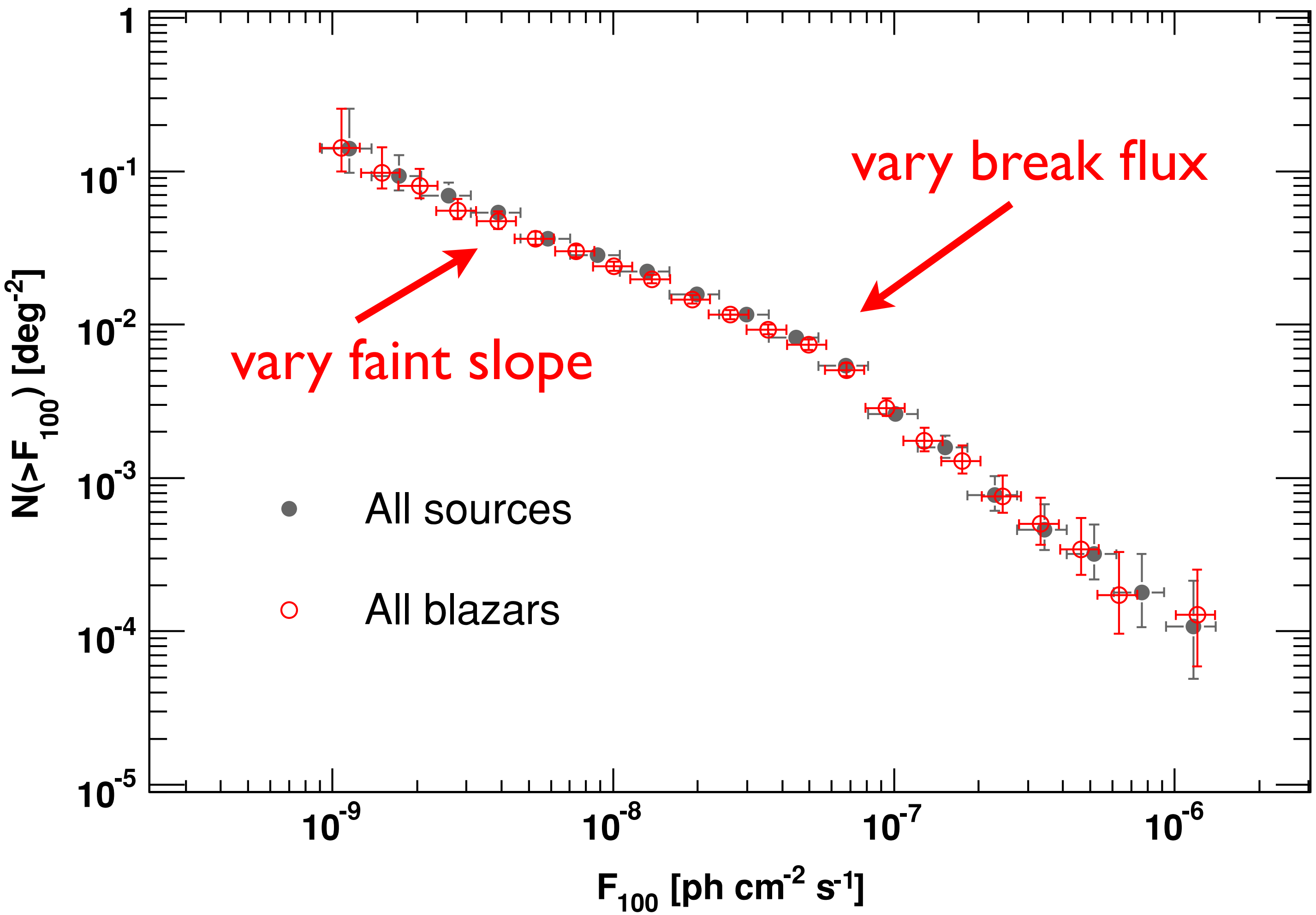
How do the predicted intensity and angular power from unresolved blazars compare to the measured values?

Exploring the LogN-LogS parameter space

- we fix the high index and normalization of the source count distribution to the measured best-fit values
- we vary the low index and break flux, and calculate the intensity and anisotropy produced by the unresolved sources in the 1-10 GeV band

LogN-LogS of Fermi LAT sources



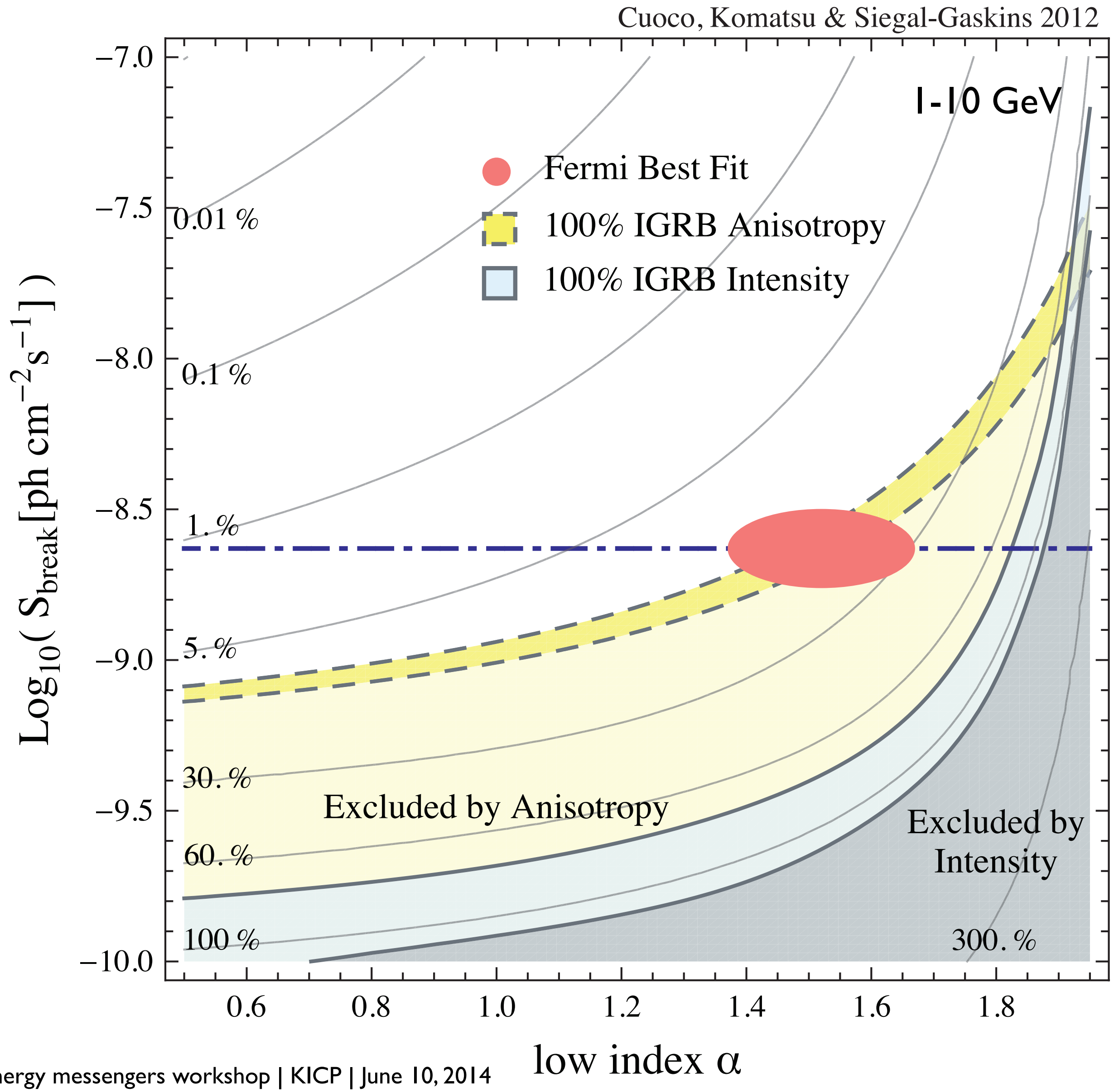
Abdo et al. [Fermi LAT Collaboration], ApJ 720, 435 (2010)

Constraints on unresolved gamma-ray sources

- anisotropy and source count analysis point to blazars contributing ~20% of *unresolved* IGRB intensity and ~100% of IGRB anisotropy at 1-10 GeV
- this result implies that component(s) making ~80% of *unresolved* IGRB intensity have very low level of anisotropy
- anisotropy is a powerful constraint: measured angular power excludes Stecker & Venters 2011 model

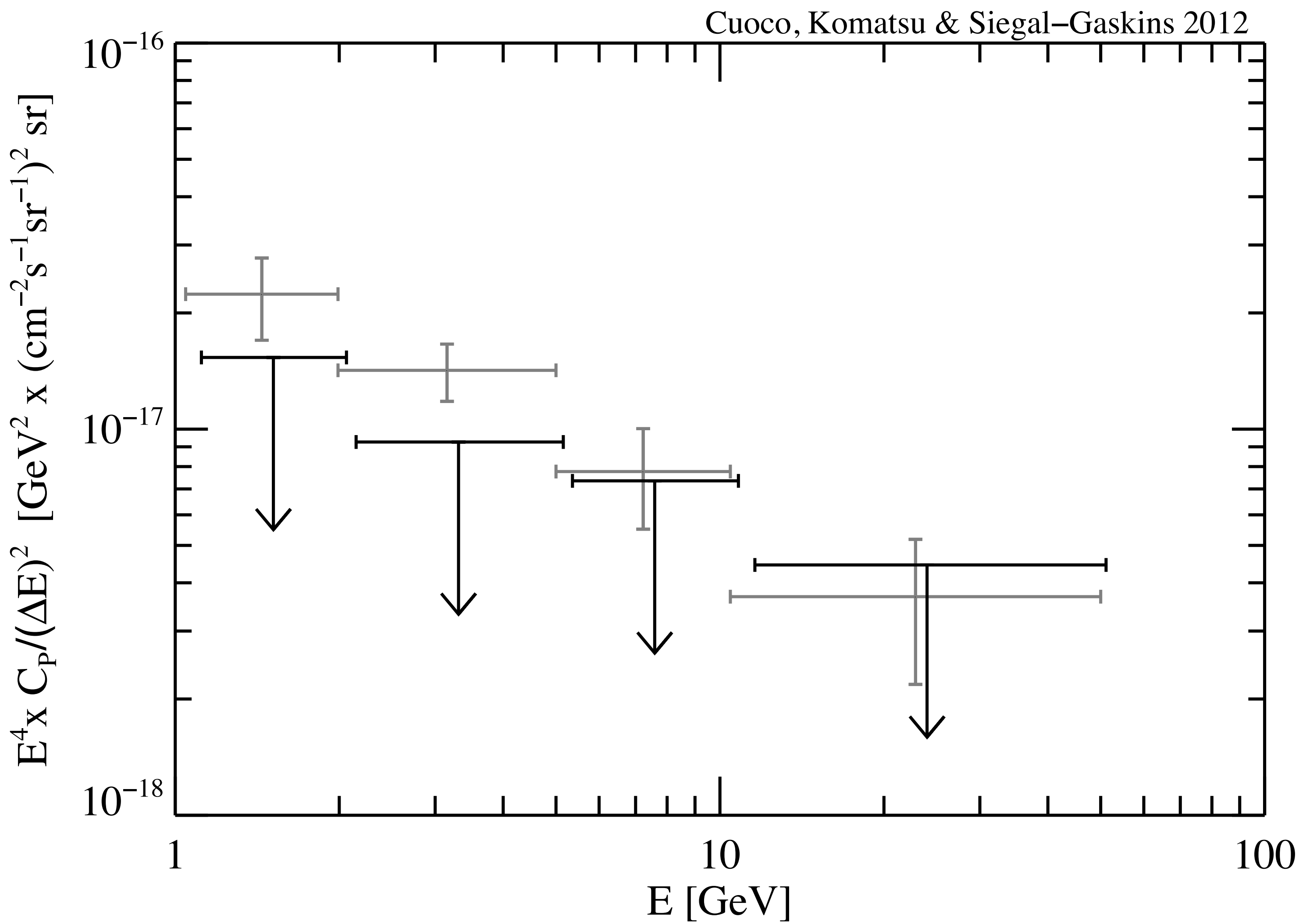
(see also Harding & Abazajian 2012)

Constraints on source count distribution (logN-logS) parameter space



Constraints on IGRB anisotropy from non-blazar sources

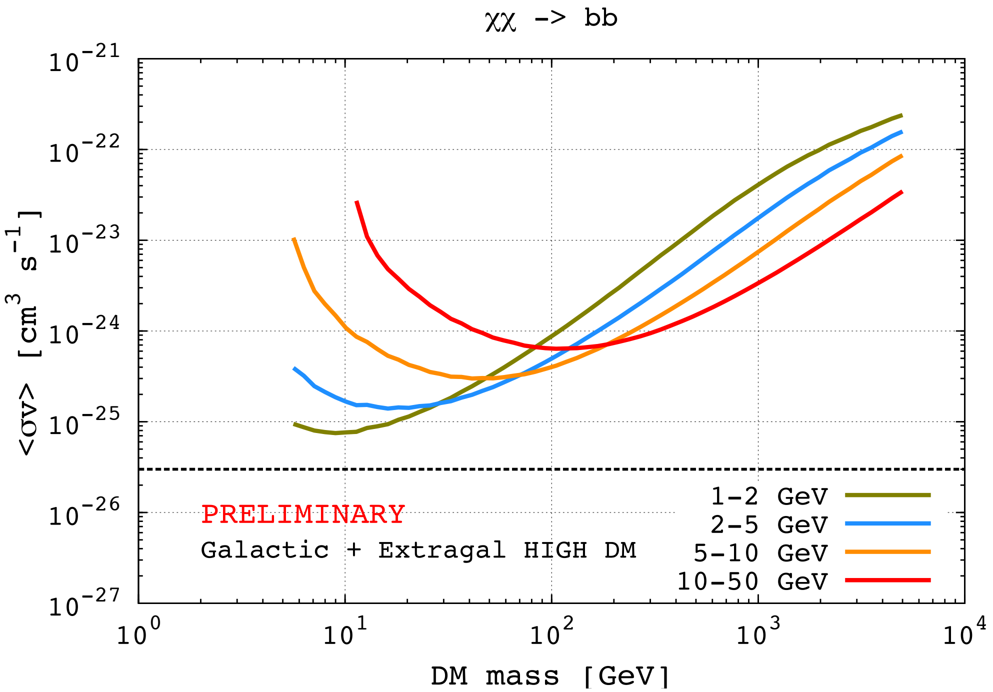
Total measured angular power with 1-sigma uncertainties and 2-sigma upper limits on non-blazar anisotropy



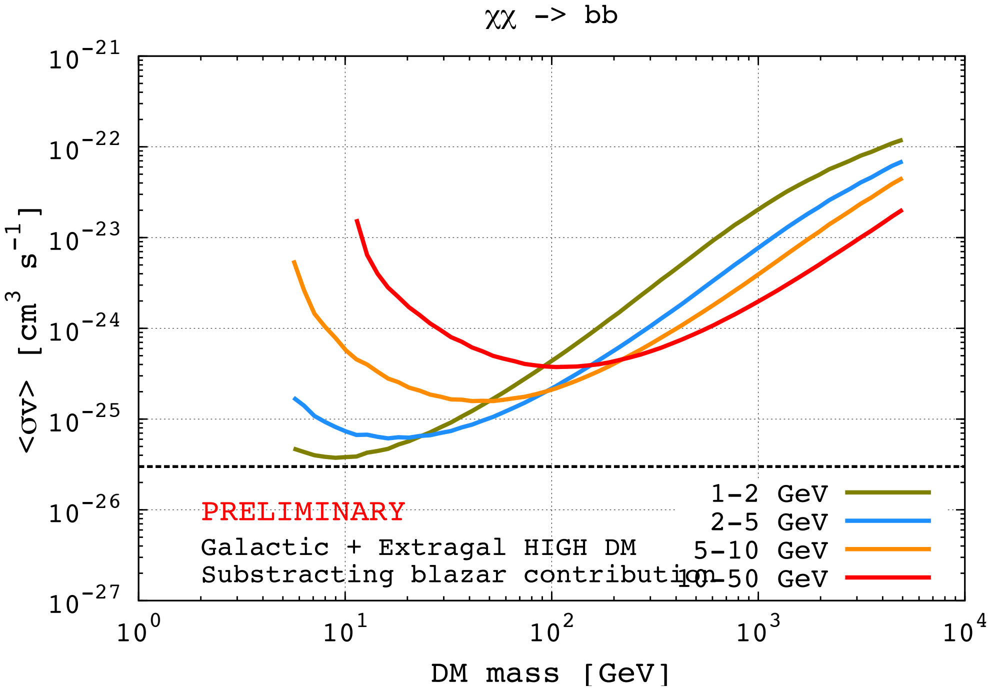
(calculated assuming blazar anisotropy given by best-fit source count parameters)

Anisotropy constraints on dark matter models

Constraints using 2-sigma upper limit on total measured anisotropy



Constraints using 2-sigma upper limits on non-blazar anisotropy



Fermi LAT collaboration + MultiDark + Komatsu + Linden, in prep

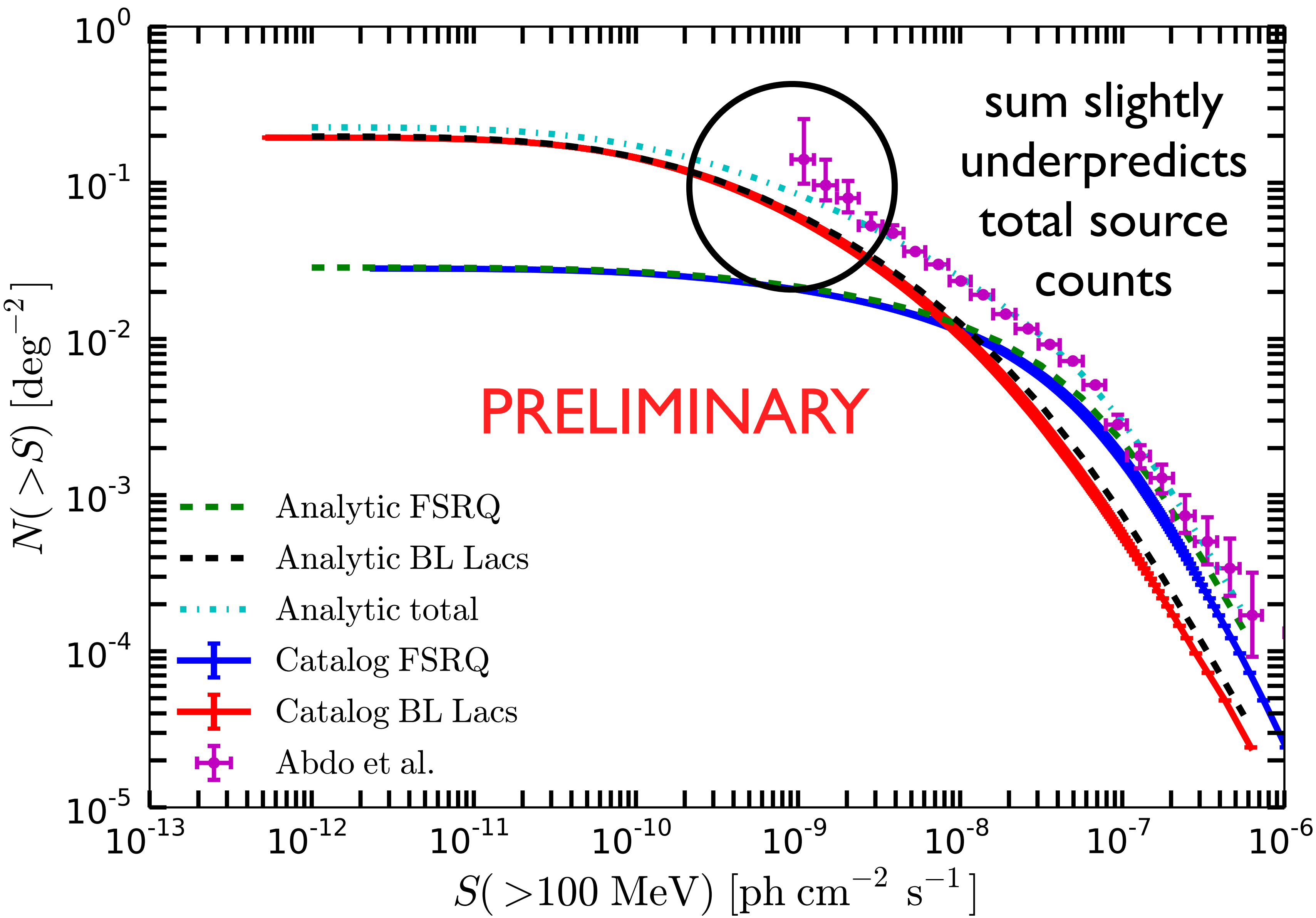
- preliminary dark matter constraints from published anisotropy measurement
- updated measurement should yield improved sensitivity due to more energy bins and improved statistics

Refine the calculation: new blazar models

- use blazar luminosity functions to derive energy-dependent intensity and anisotropy contribution to IGRB
- adopt LDDE model with following params:
  - FSRQs from Ajello et al., ApJ 751, 108 (2012)
  - BL Lacs from Ajello et al., ApJ 780, 73 (2014)
- implement detailed spectral model:
  - FSRQs: broken power law + cutoff
  - BL Lacs: broken power law
- cross-check analytic results with catalog approach

Lochhaas, JSG, & Ajello, in prep

New models: source count distribution

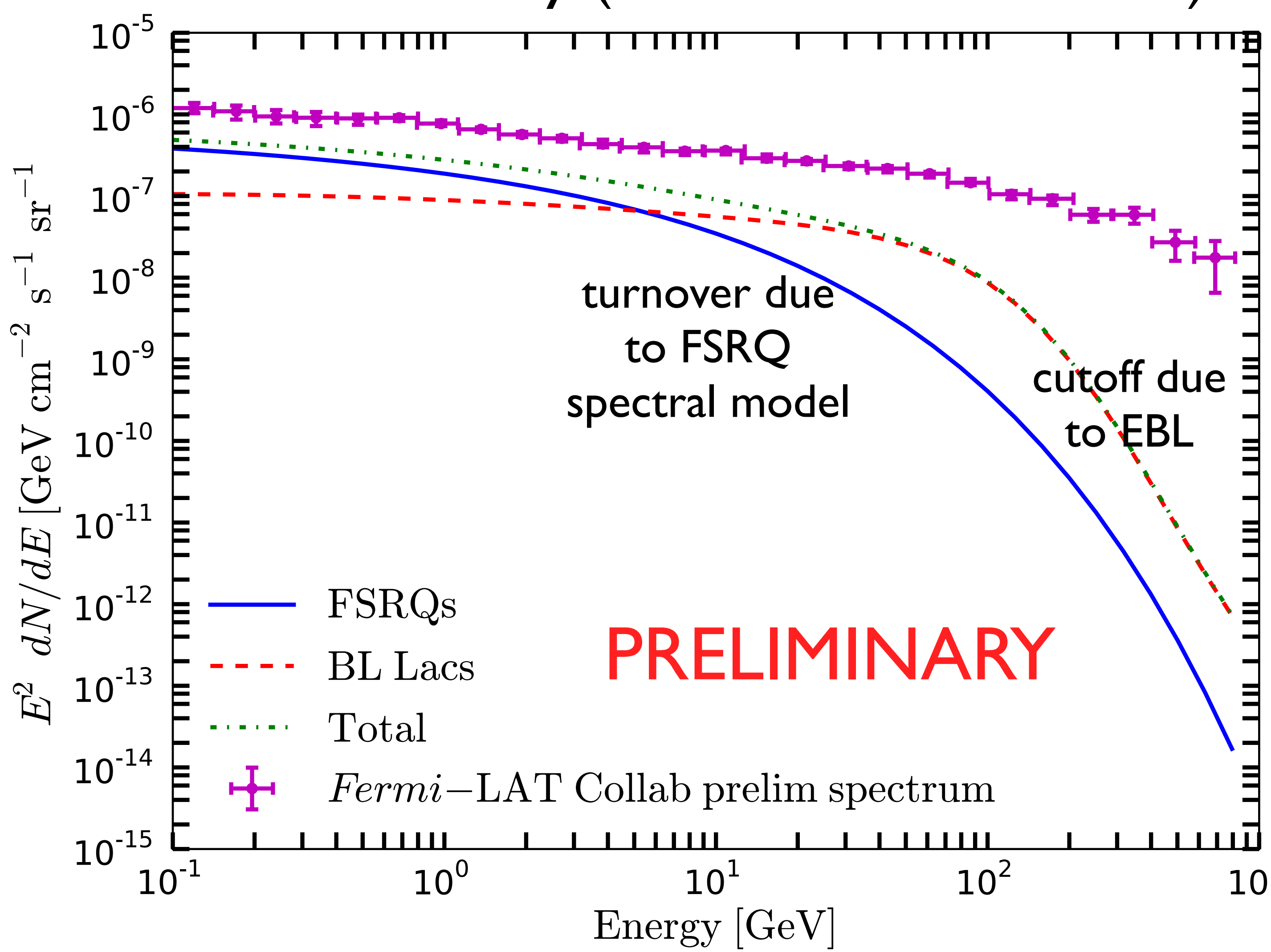


Lochhaas, JSG, & Ajello, in prep

IGRB intensity from blazars

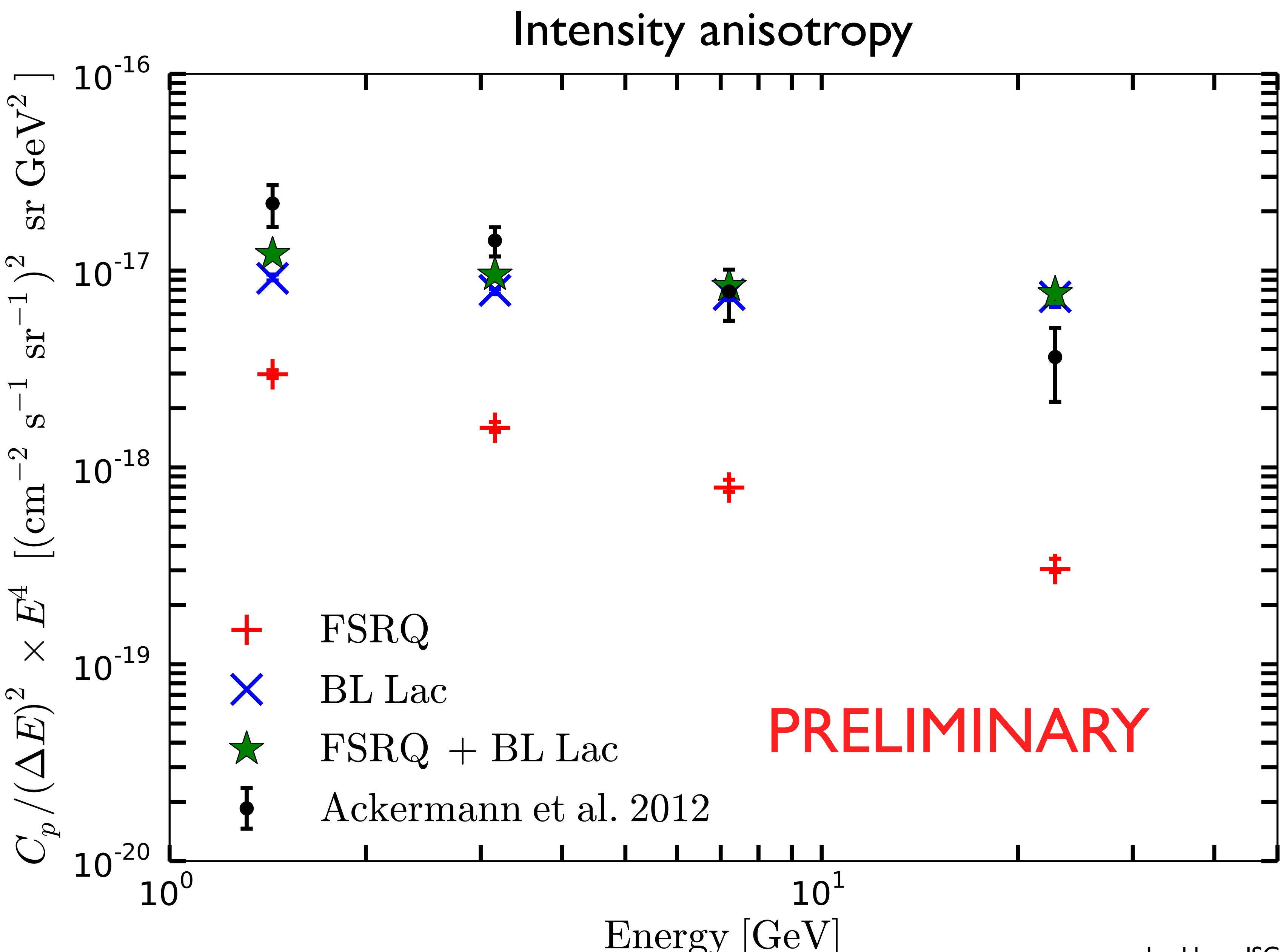
- blazars contribute up to ~50-60% of *total* IGRB intensity at 100 MeV, less at higher energies (but see also Marco's talk)
- FSRQs dominate blazar contribution below a few GeV, BL Lacs above
- EBL model of Finke, Razzaque, & Dermer 2010

Total intensity (resolved + unresolved)



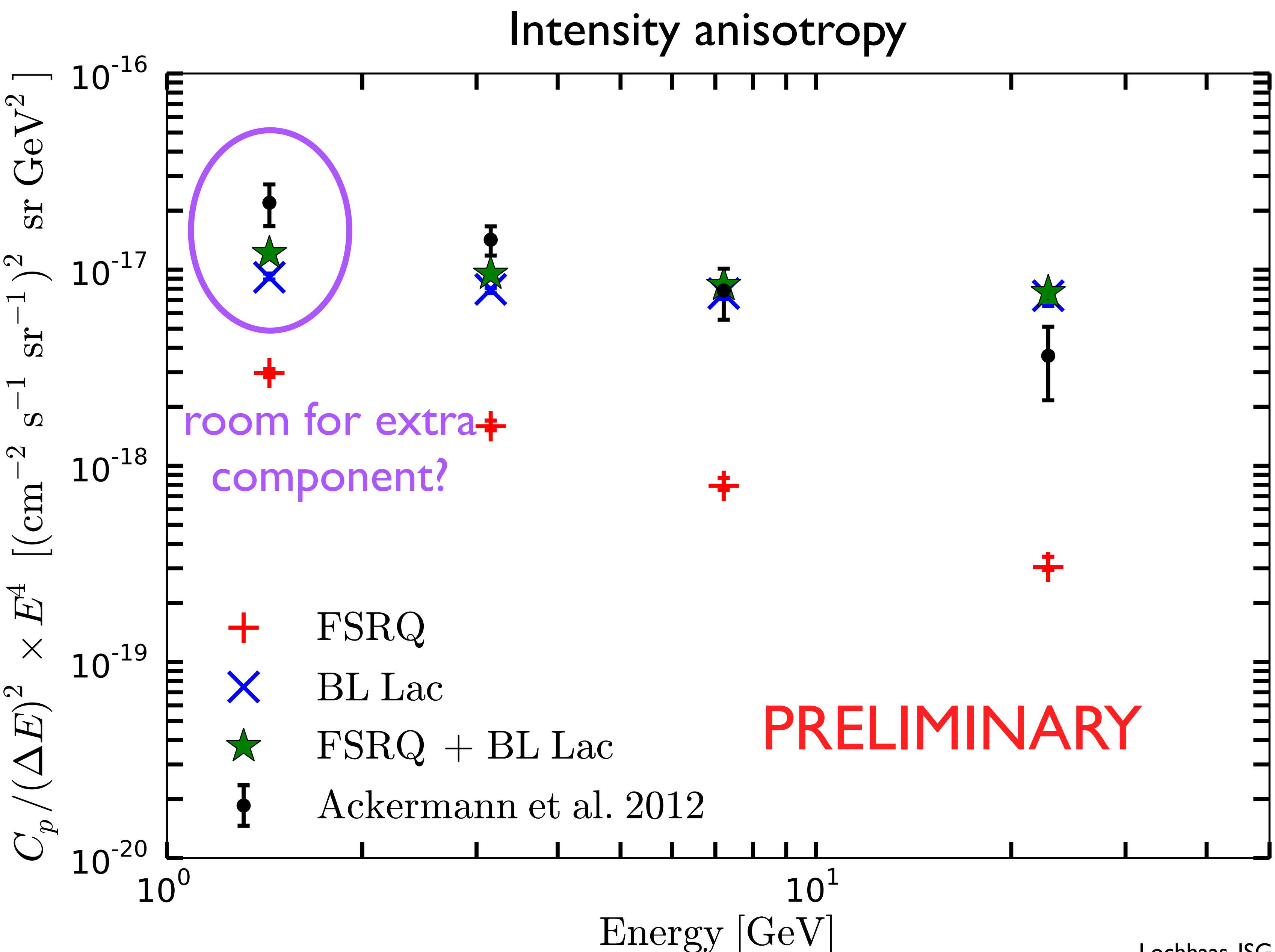
Lochhaas, JSG, & Ajello, in prep

IGRB anisotropy from blazars



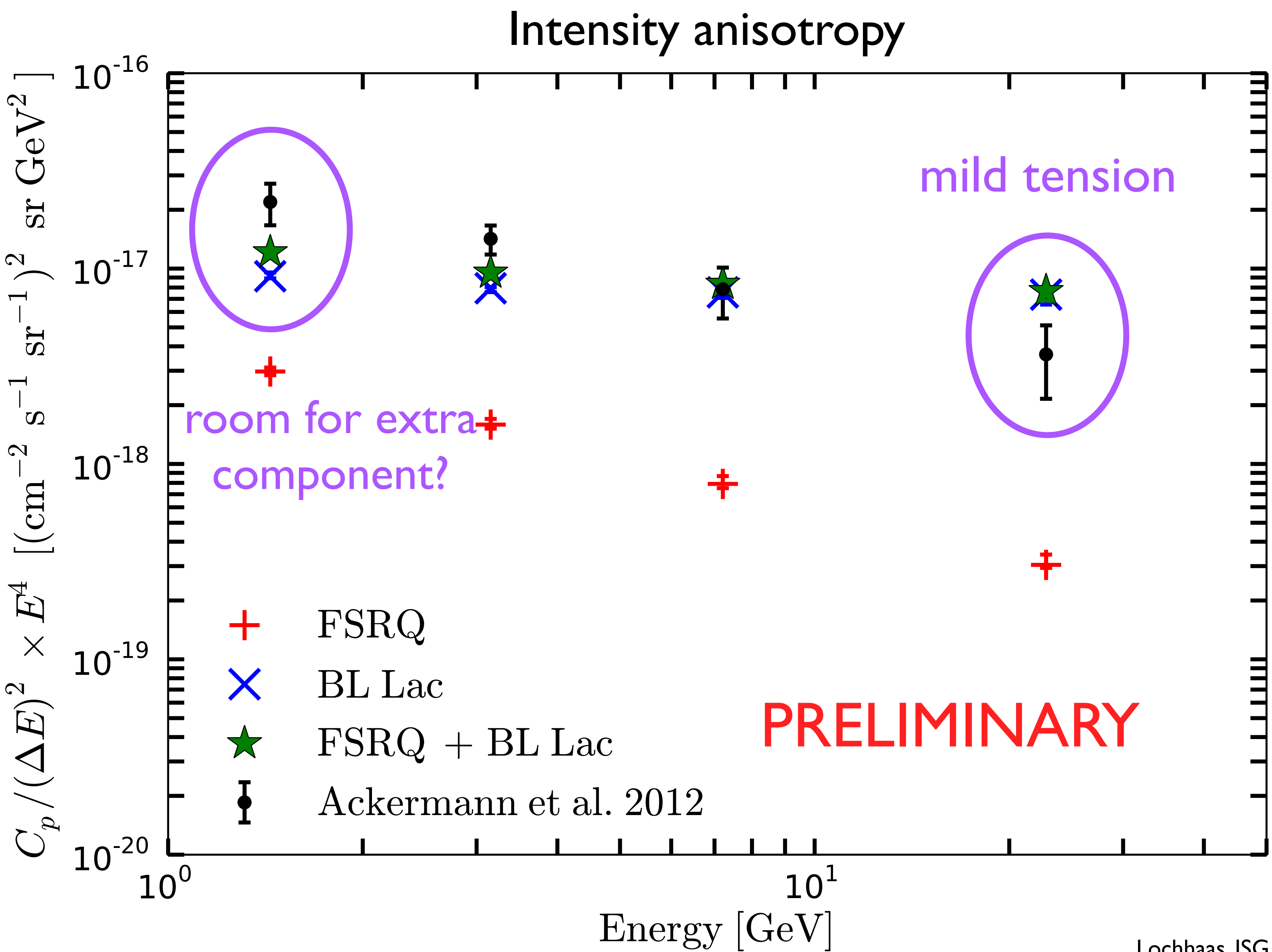
Lochhaas, JSG, & Ajello, in prep

IGRB anisotropy from blazars



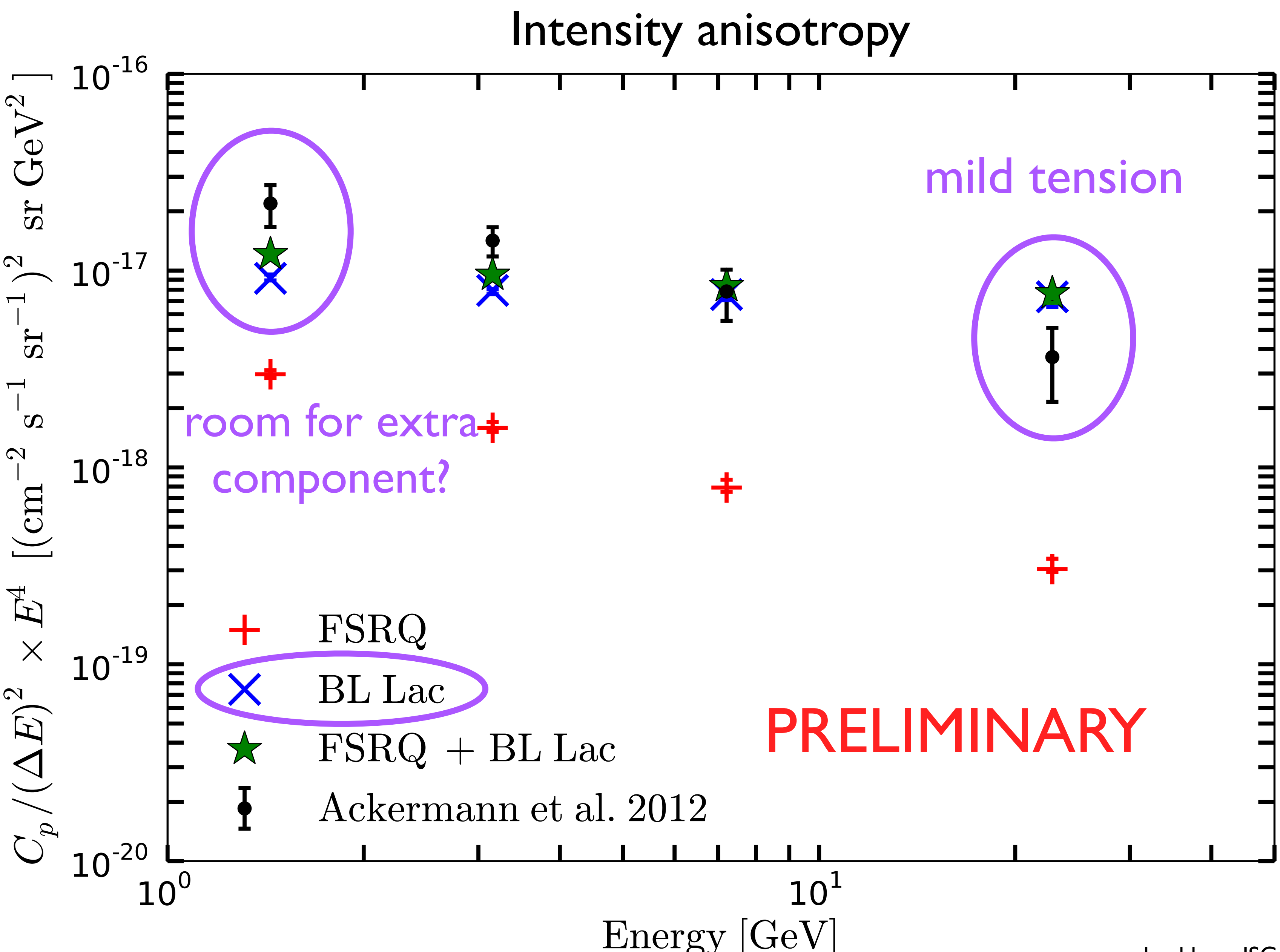
Lochhaas, JSG, & Ajello, in prep

IGRB anisotropy from blazars



Lochhaas, JSG, & Ajello, in prep

IGRB anisotropy from blazars



Lochhaas, JSG, & Ajello, in prep

Summary

- source count analysis and anisotropy measurements point to blazars contributing ~100% of the anisotropy but only less than ~20% of the *unresolved* intensity of the IGRB at 1-10 GeV
- refined blazar anisotropy analysis (in prep):
    - blazars contribute ~ 50% to *total* IGRB intensity from 1-50 GeV
    - BL Lacs dominate the blazar contribution to the anisotropy, can mostly account for measured anisotropy at 1-50 GeV
    - may allow for additional contribution at a few GeV, mild tension with measurement at 10-50 GeV
- pinning down contributions of known source classes important to constrain and characterize possible exotic contributions