Cosmological Aspects of High Energy Astrophysics ~ Day 2 ~

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NTHU Astronomy Winter School @ Online, 2021-01-18-22

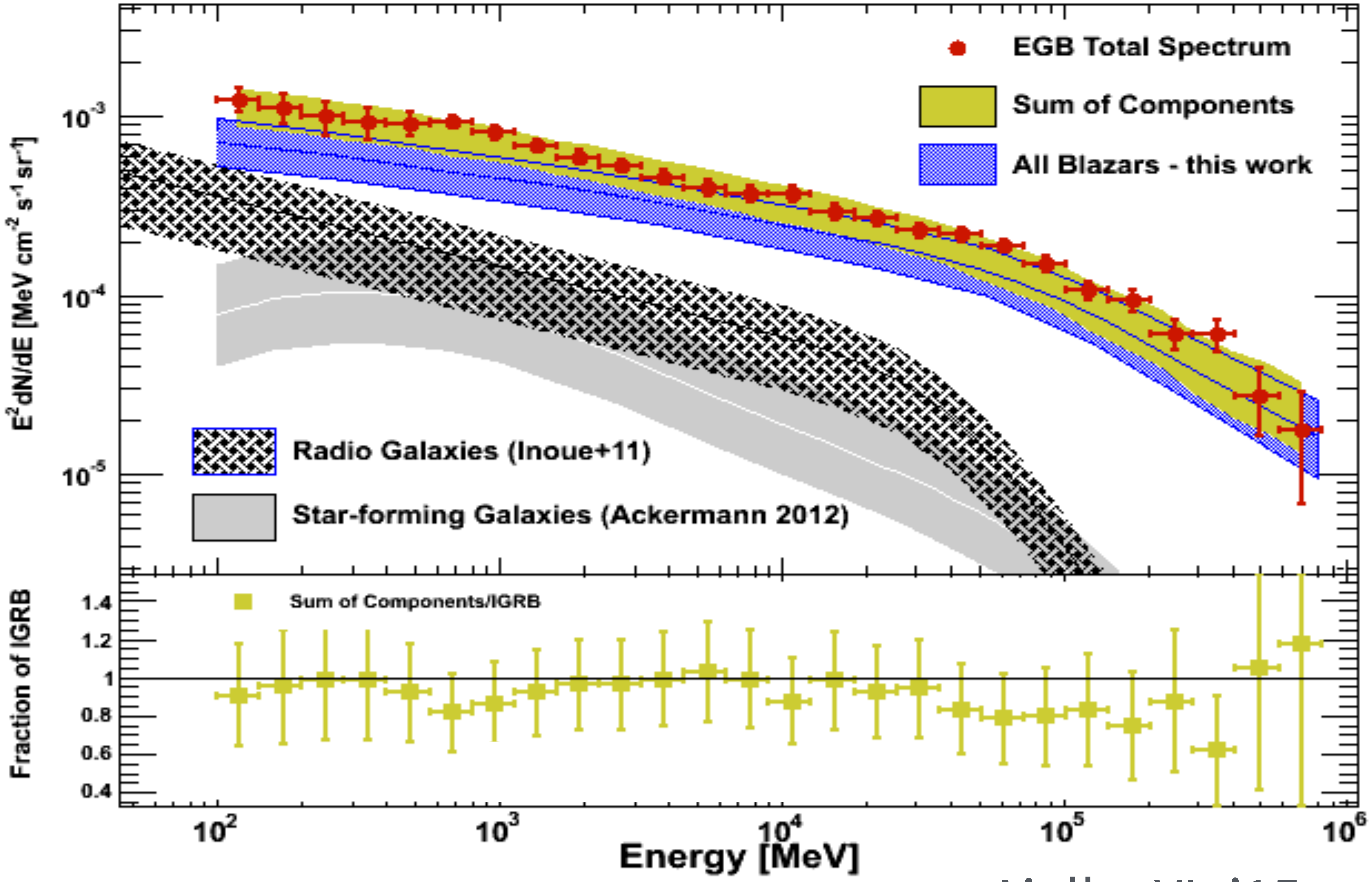
Lecture Schedule

Be careful! It may change!

- ~~Day 1:~~
  - ~~Cosmological Evolution of Gamma-ray Emitting Objects~~
  - ~~Cosmic GeV Gamma-ray Background Radiation Spectrum~~
- Day 2:
  - Cosmic MeV Gamma-ray Background Radiation Spectrum
  - Cosmic Gamma-ray Background Radiation Anisotropy
- Day 3:
  - Gamma-ray Propagation in the Universe
  - Probing Extragalactic Background Light with Gamma-ray Observations
- Day 4:
  - Intergalactic Magnetic Field and Gamma-ray Observations
  - Cosmic Expansion and Gamma-ray Horizon (if possible)

Components of Cosmic Gamma-ray Background

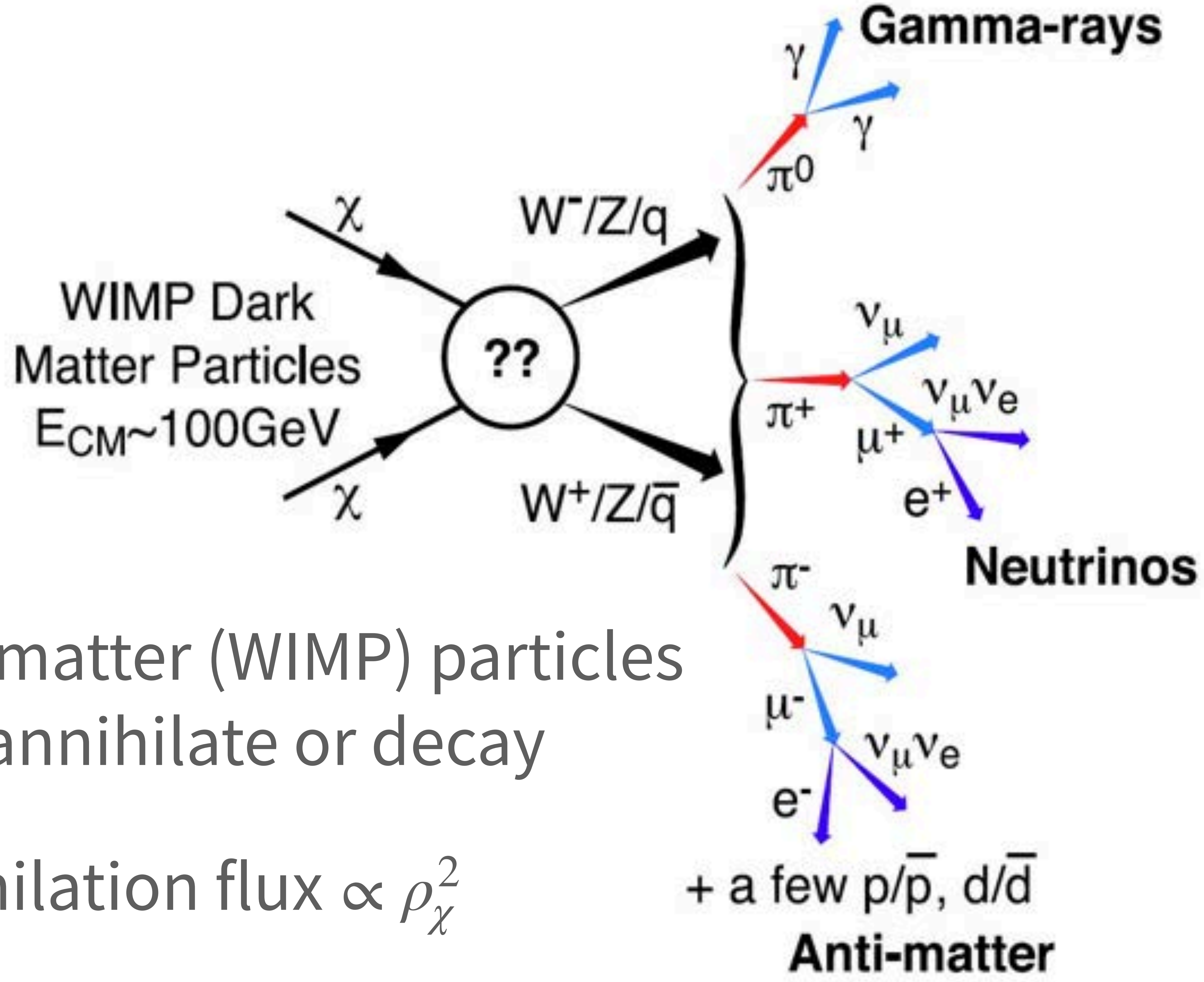
Blazars, Radio galaxies, & Star-forming galaxies



Ajello, YI+'15

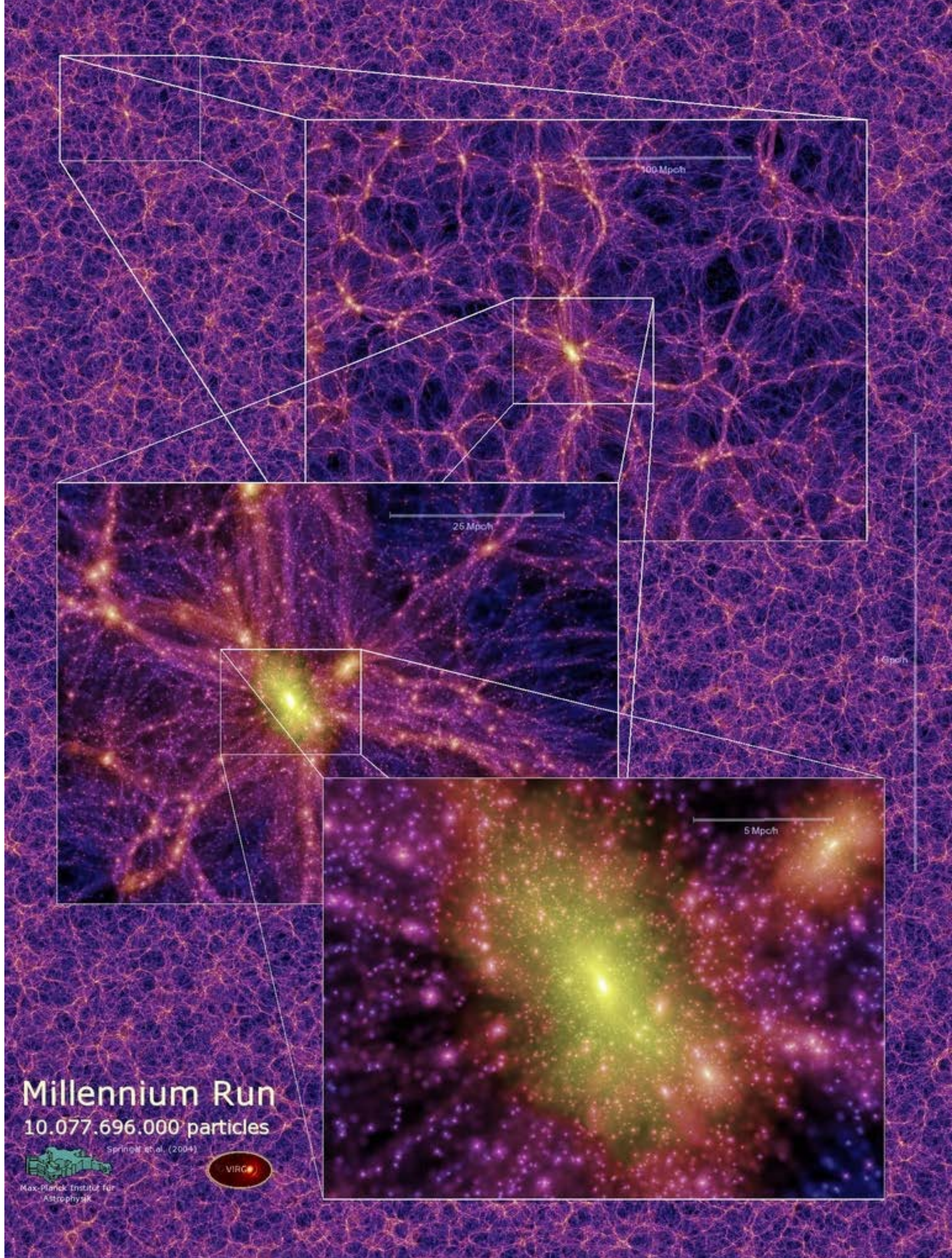
- Blazars: FSRQs (Ajello+'12)
- Blazars: BL Lacs (Ajello+'14)
- Radio galaxies (YI'11)
- Star-forming galaxies (Ackermann+'12)
  - make almost 100% of CGB from 0.1-1000 GeV.

Dark Matter Annihilation / Decay



© Fermi

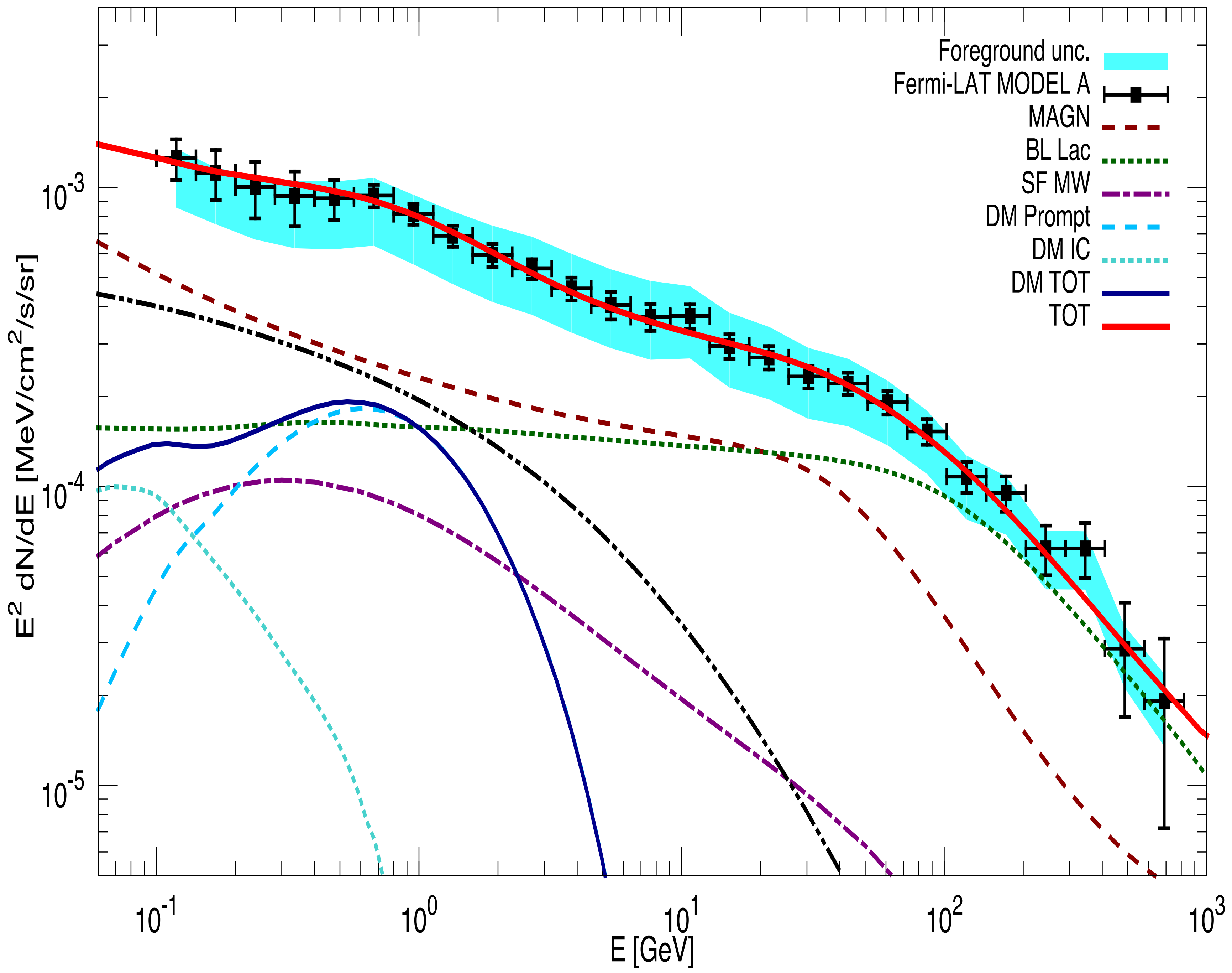
- Dark matter (WIMP) particles may annihilate or decay
- Annihilation flux $\propto \rho_\chi^2$
- Decay flux $\propto \rho_\chi$



Dark Matter Contribution to the Cosmic Gamma-ray Background

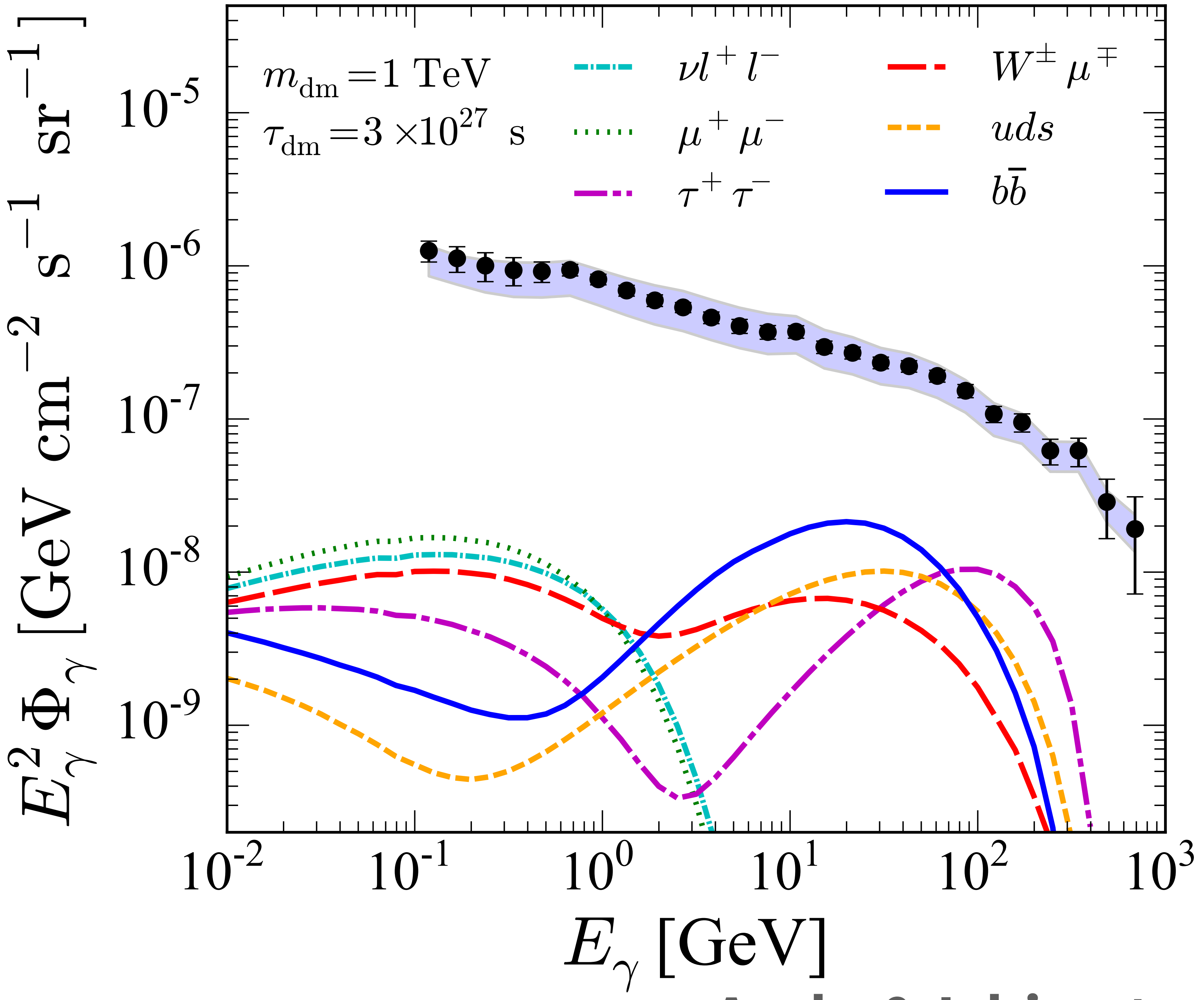
Spectrum

Annihilation



Di Mauro+'15

Decay

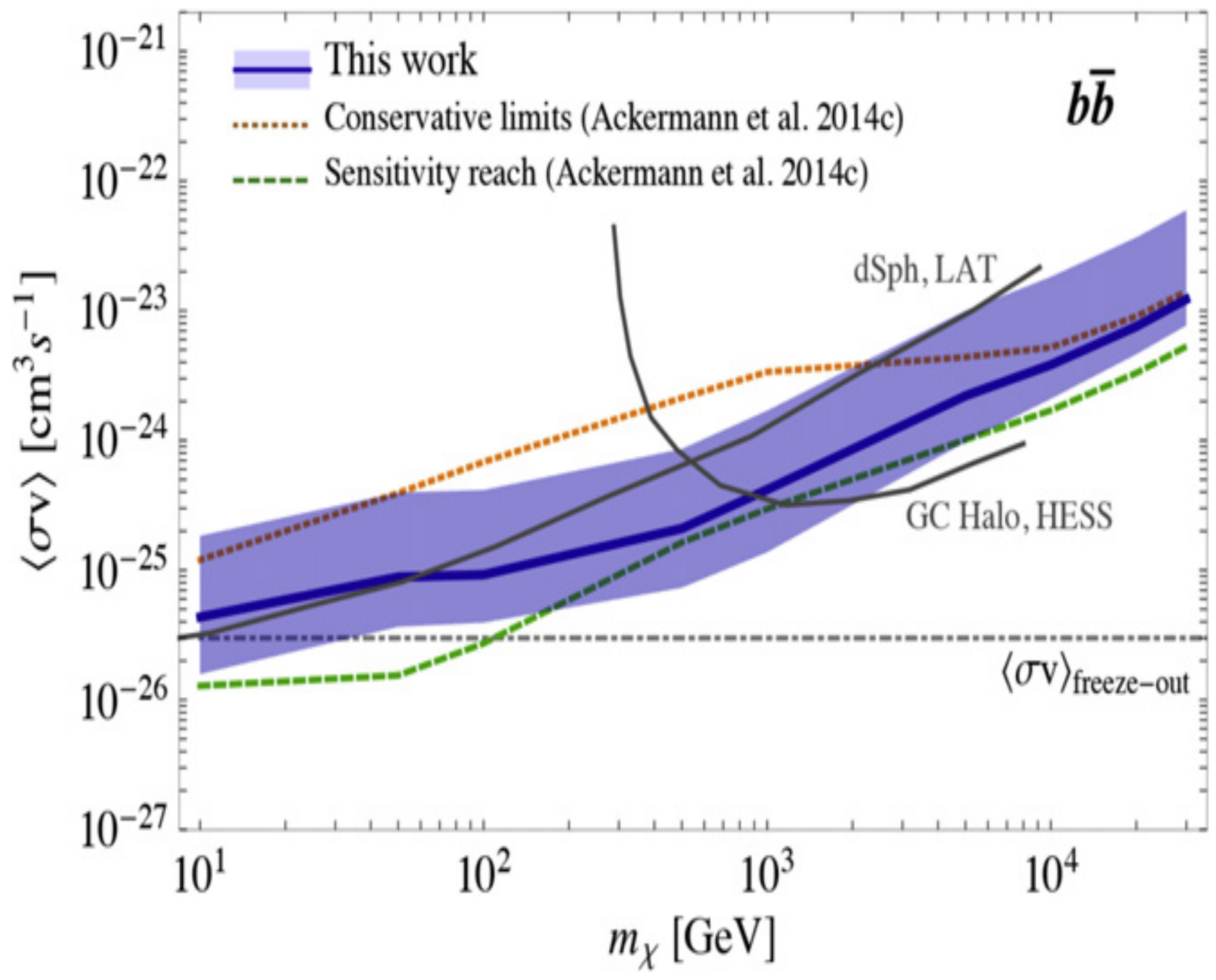


Ando & Ishiwata '15

- DM annihilation / decay create
  - a spectral feature in the spectrum
- Spectral shape of the gamma-ray background is important.

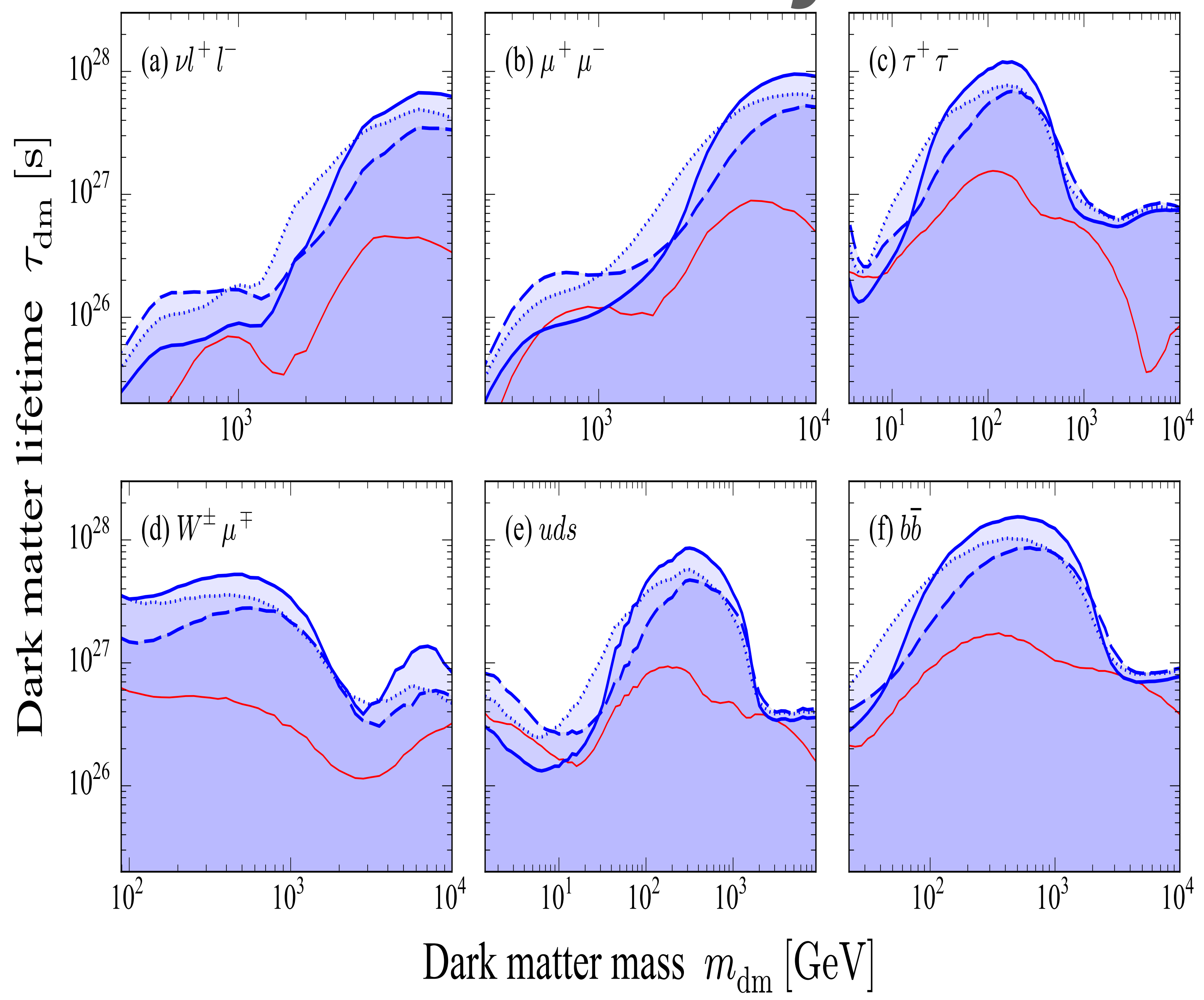
Constraints on Dark Matter Parameters

Annihilation



Ajello, YI+'15

Decay

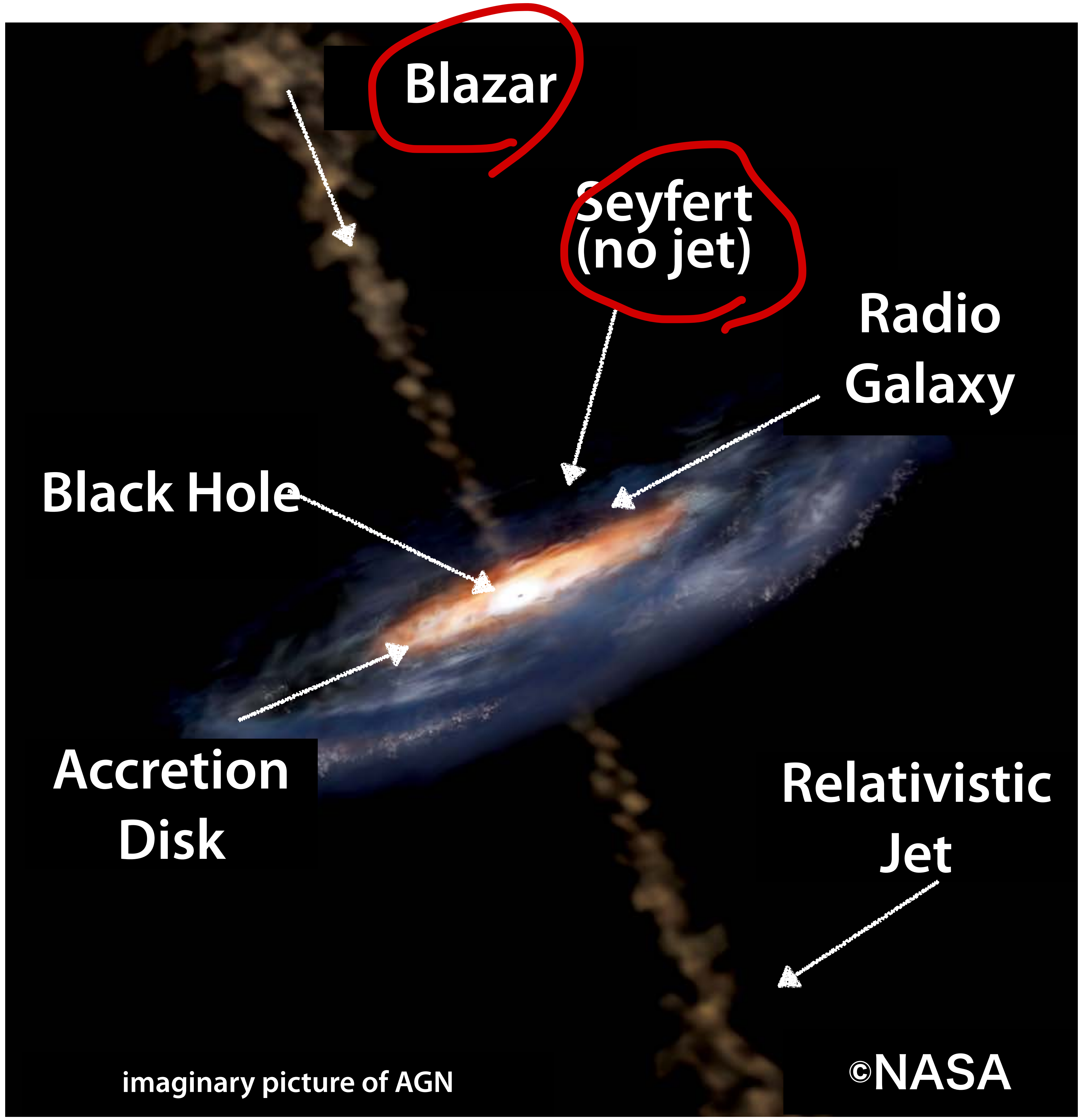


Ando & Ishiwata '15

- comparable to constraints from dwarf galaxies
- Decay timescale is >10^{27} s ($2\text{x}10^9$ t_H)

Cosmic MeV Gamma-ray Background Radiation Spectrum

Active Galactic Nuclei (AGNs)



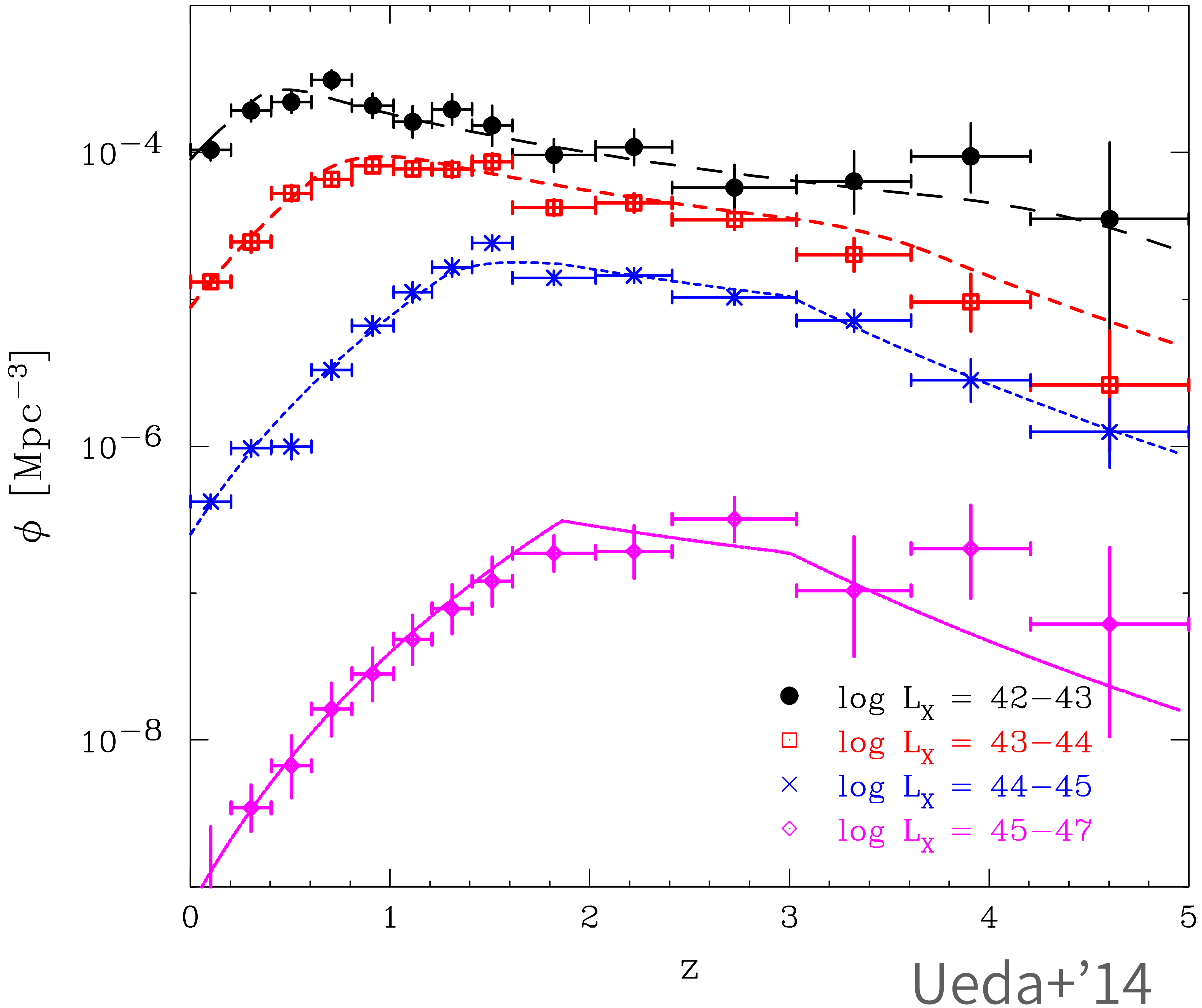
- Gas accretion on to SMBHs

  ➡brighter than the galaxy

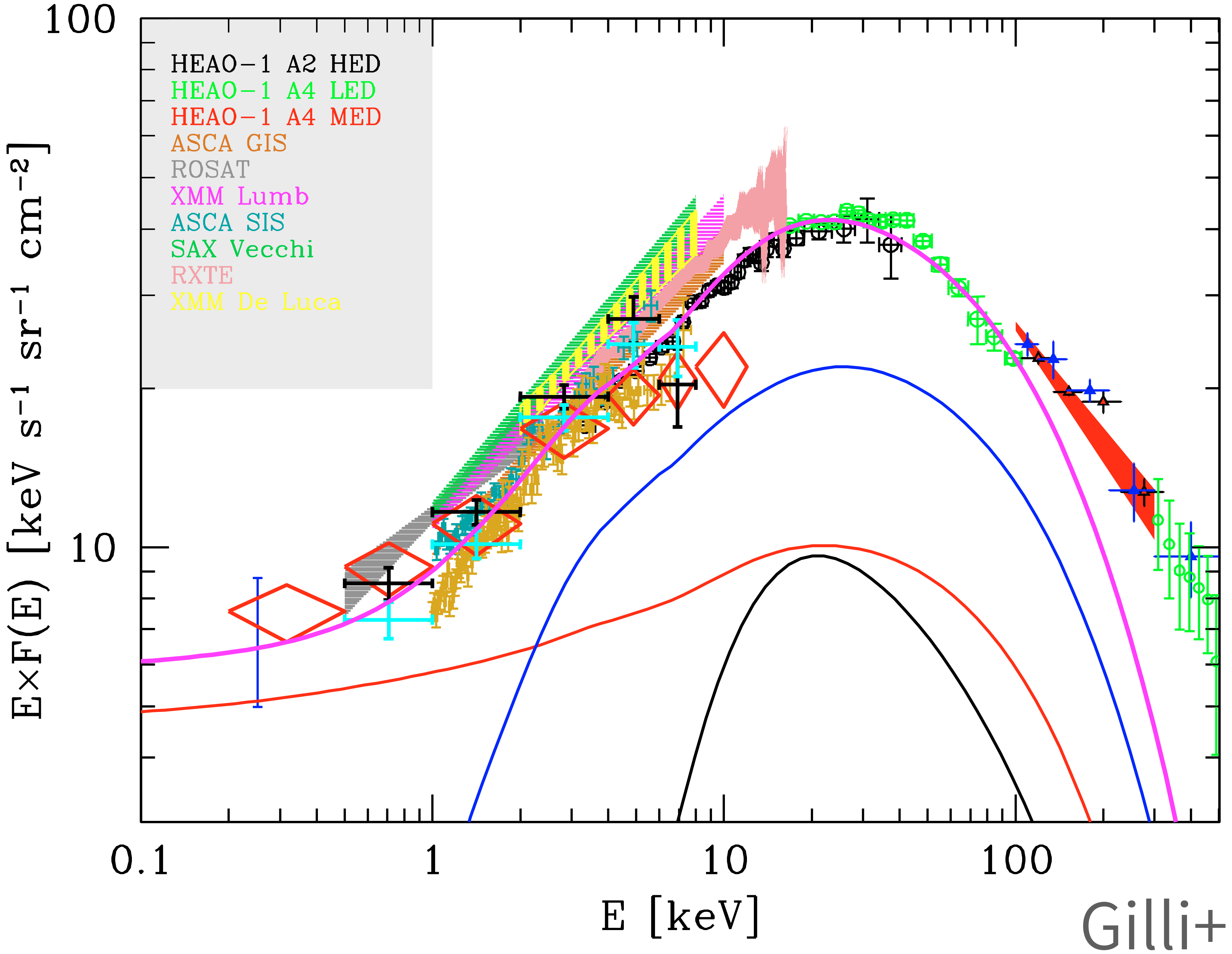
  - Active Galactic Nuclei: AGNs
- Various population
  - Blazar, Radio Galaxy, Seyfert,,,
  - Relativistic jet
    - Feedback / Cosmic rays / Neutrinos

Cosmic X-ray Background Radiation

X-ray emission from AGN disks



Ueda+'14

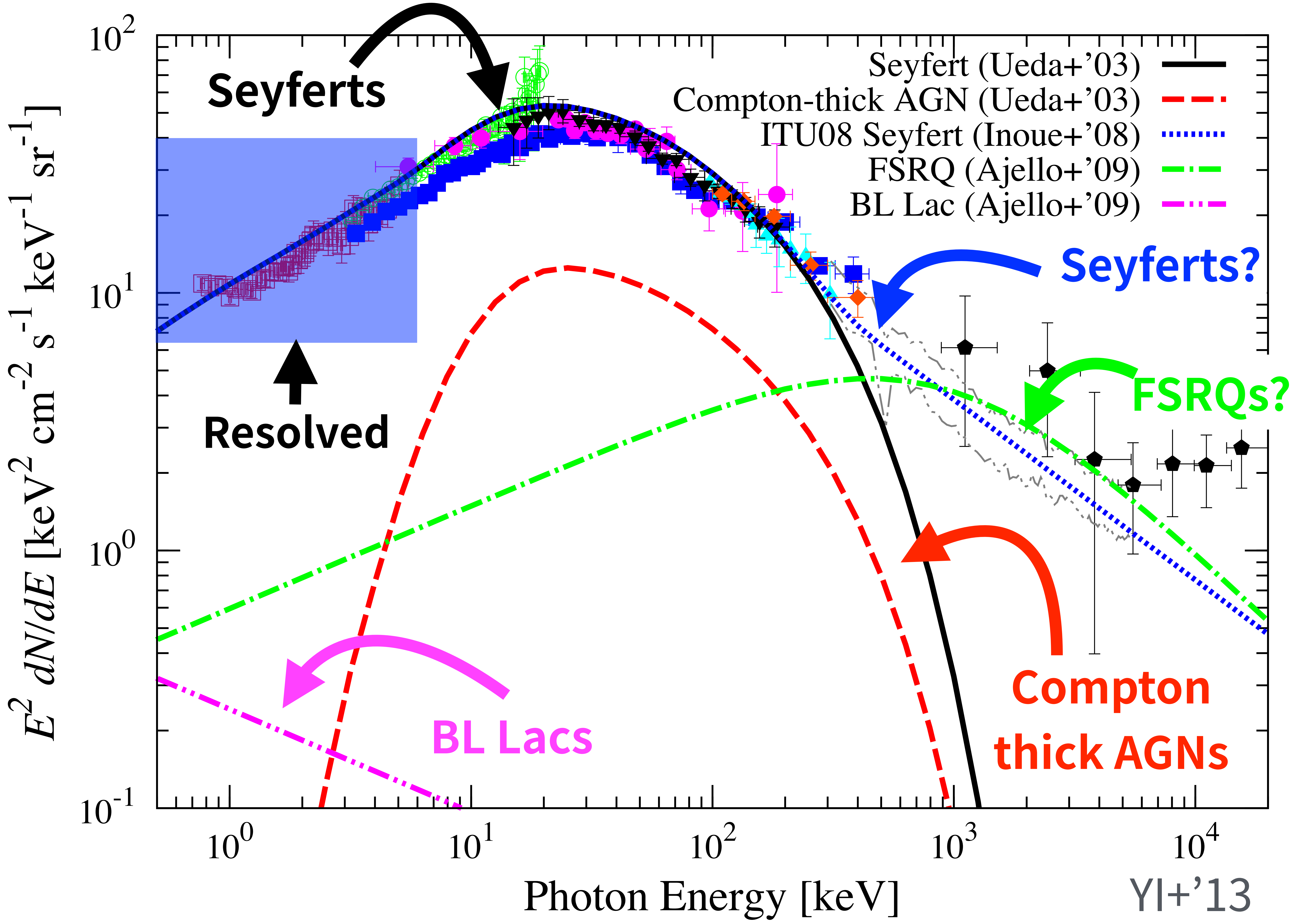


Gilli+'07

- The origin of the X-ray background is AGN disk emission.
  - >90% of CXB at 0.5-10 keV is resolved.

Cosmic MeV Gamma-ray Background Radiation

Huge discovery space behind it?

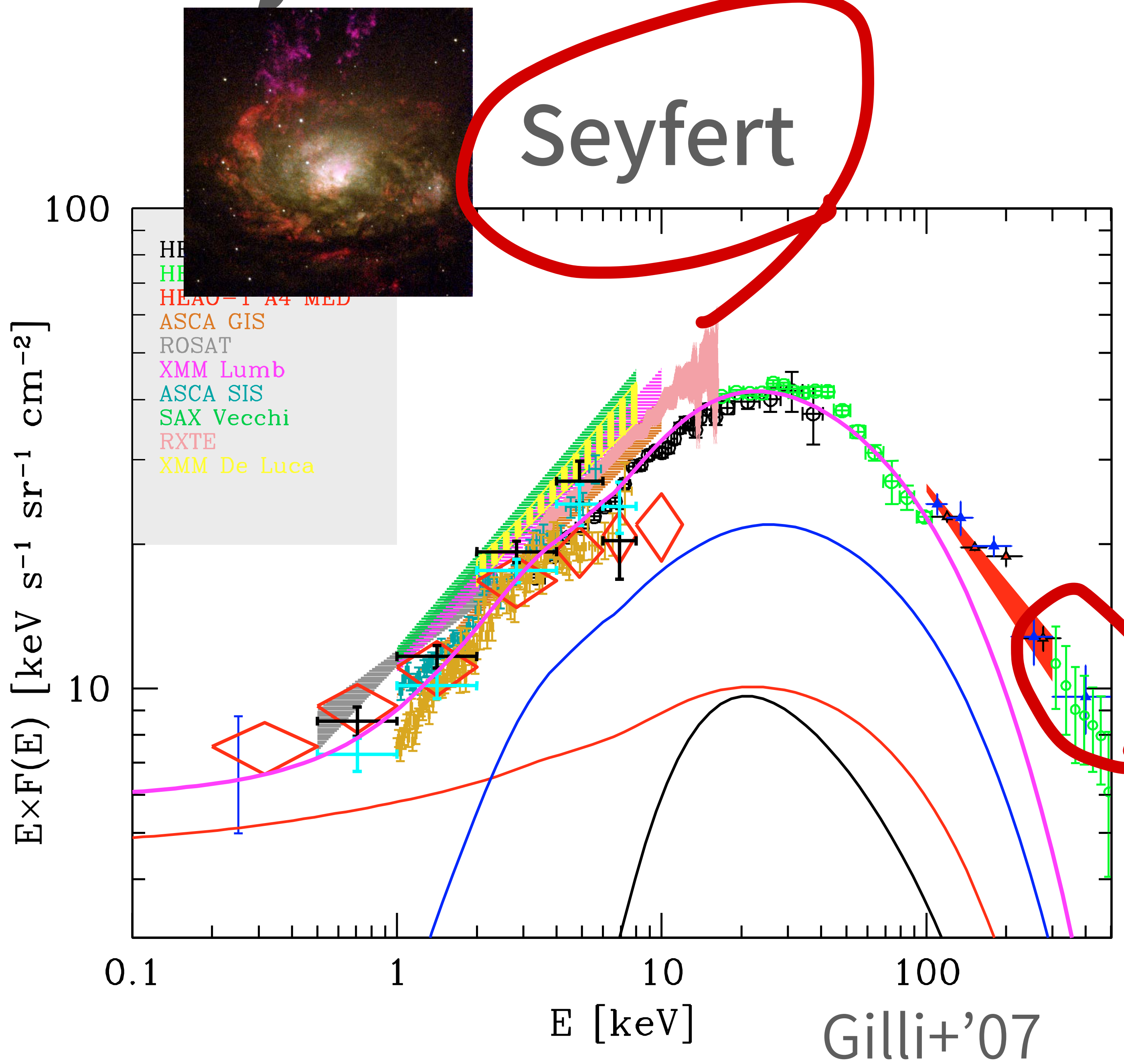


- X-ray background
  - AGN Disk
- GeV background
  - AGN jets + Galaxies
- What about MeV?

What is the origin of the MeV background?

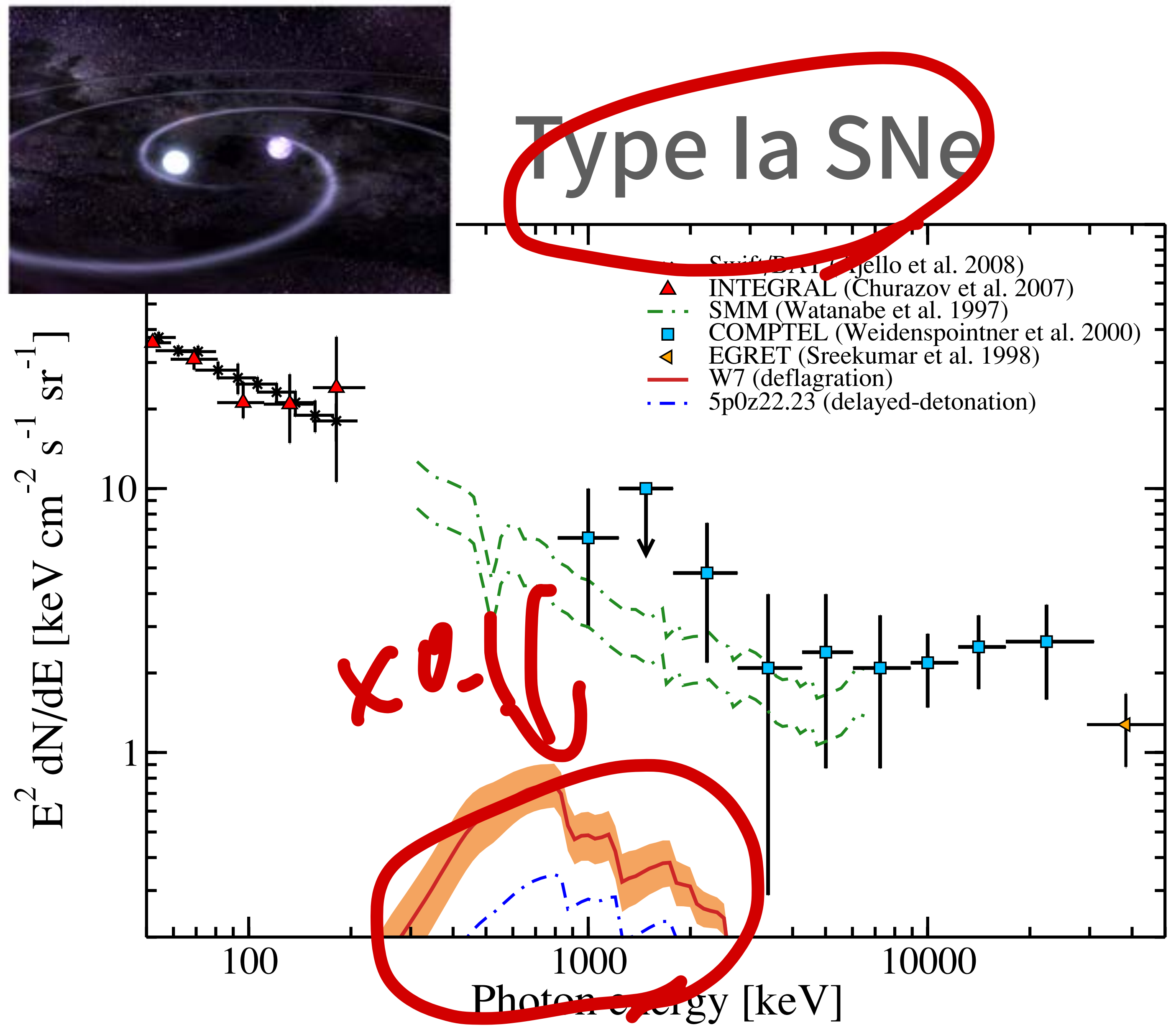
Many candidates = No conclusion…

Seyfert



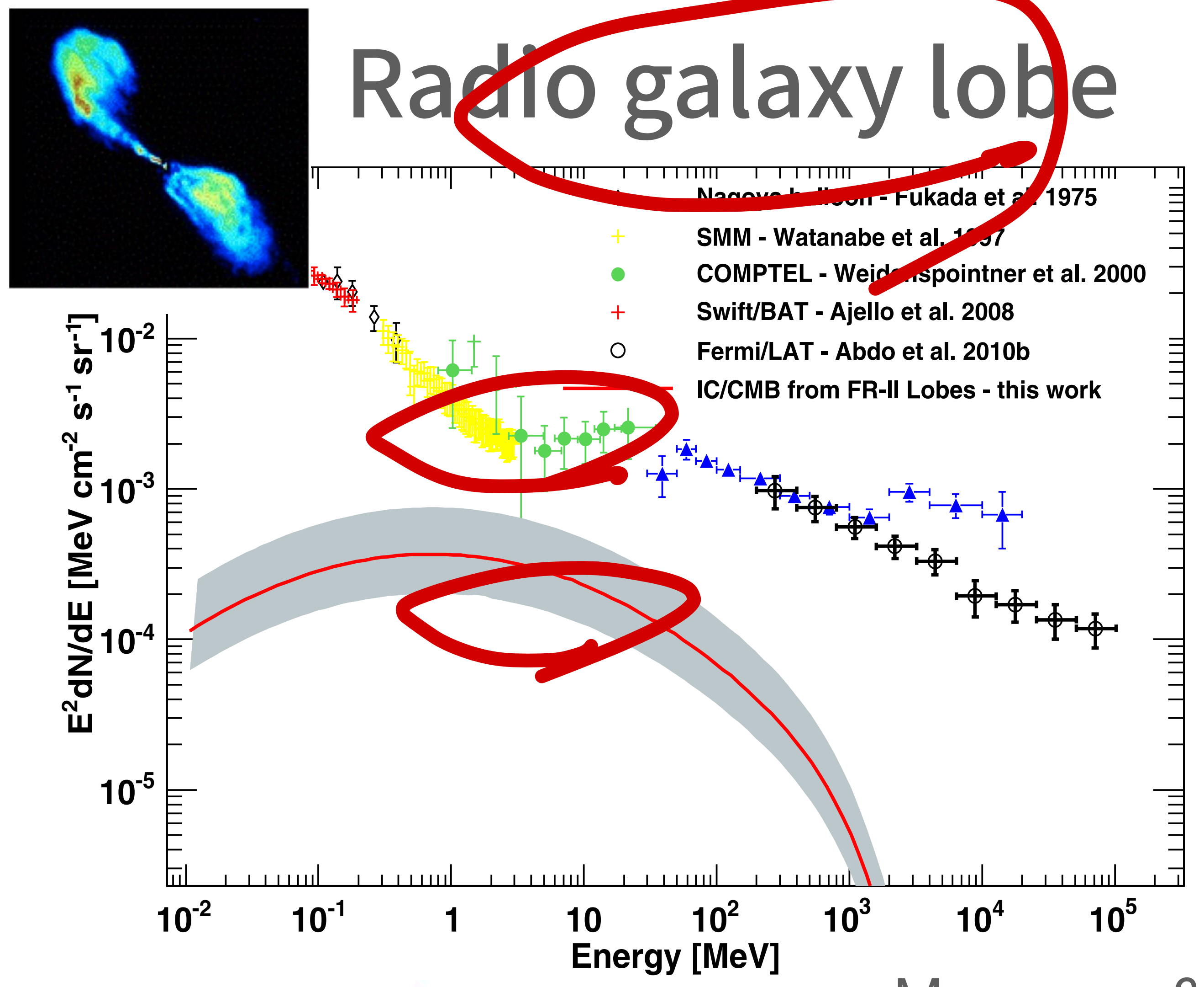
Gilli+'07

Type Ia SNe



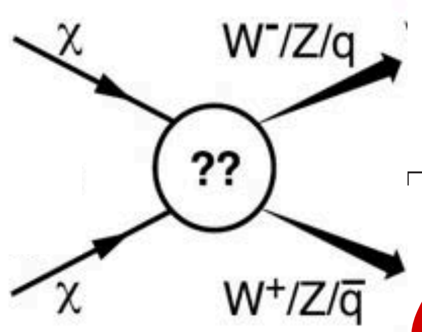
Horiuchi & Beacom +'10

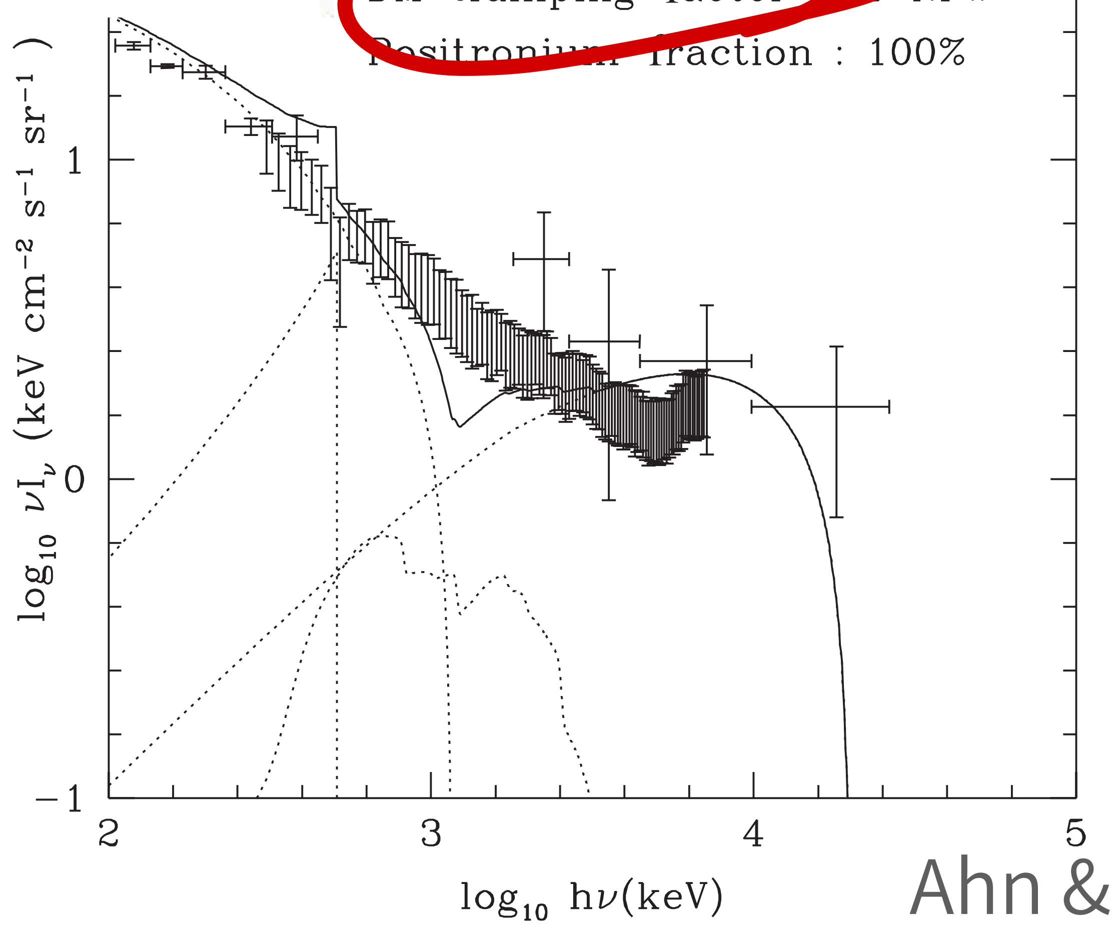
Radio galaxy lobe



Massaro & Ajello '11

Dark Matter





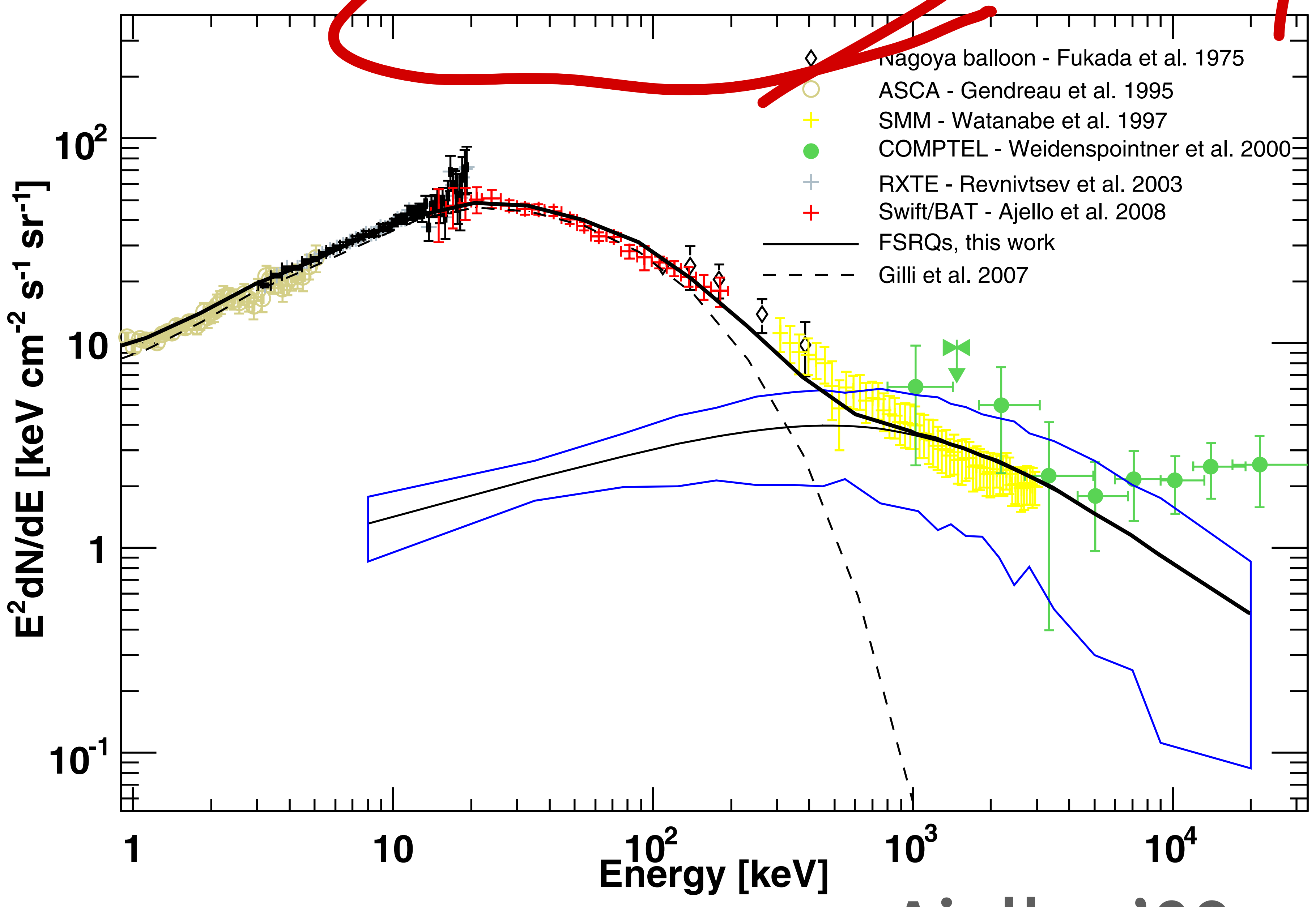
Ahn & Komatsu '05

- Smooth extension from the CXB is not well explained in literature.

FSRQs and the MeV Background

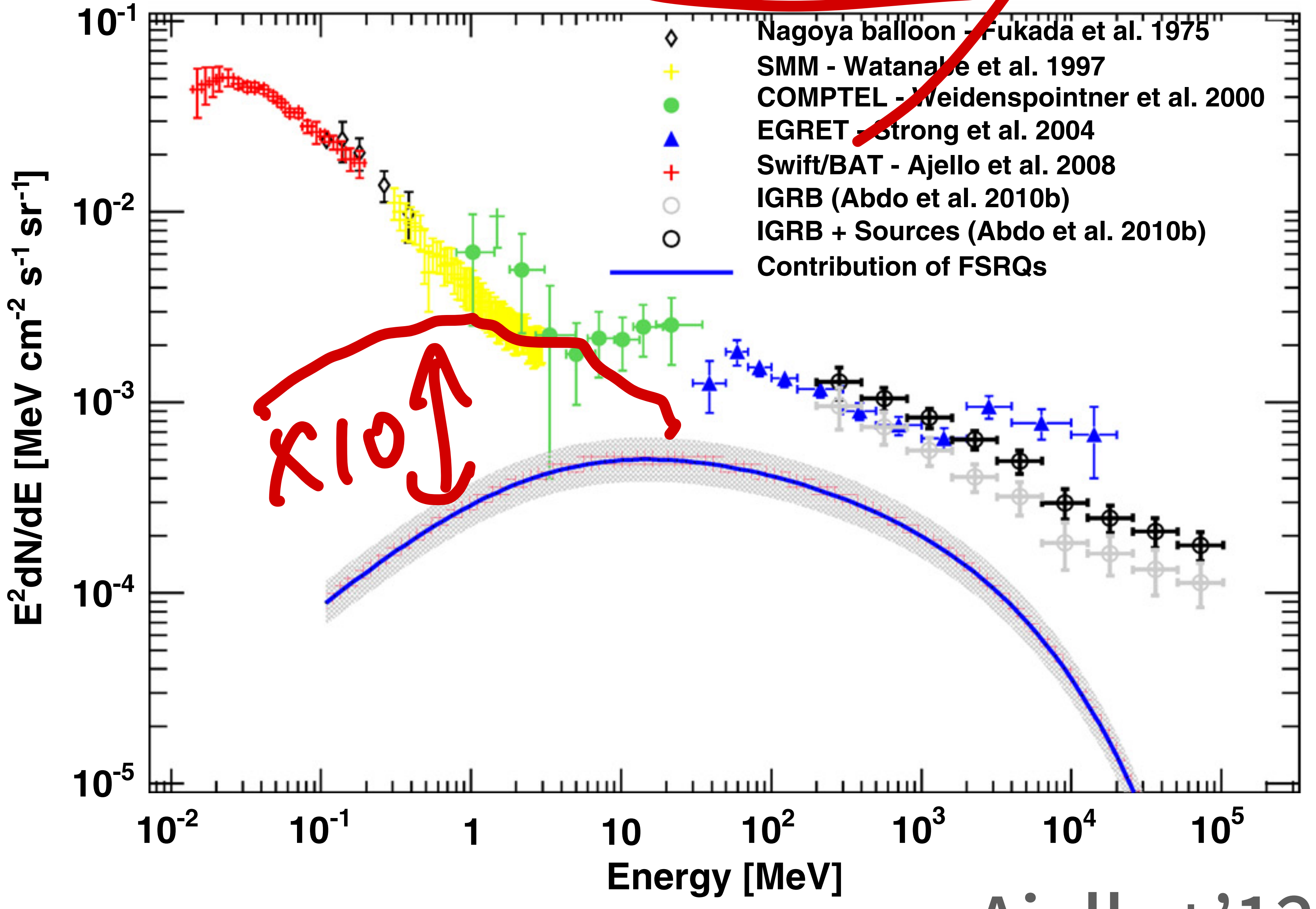
What happens between X-ray and GeV?

Based on Swift-BAT ~ 2yr



Ajello+'09

Based on Fermi-LAT



Ajello+'12

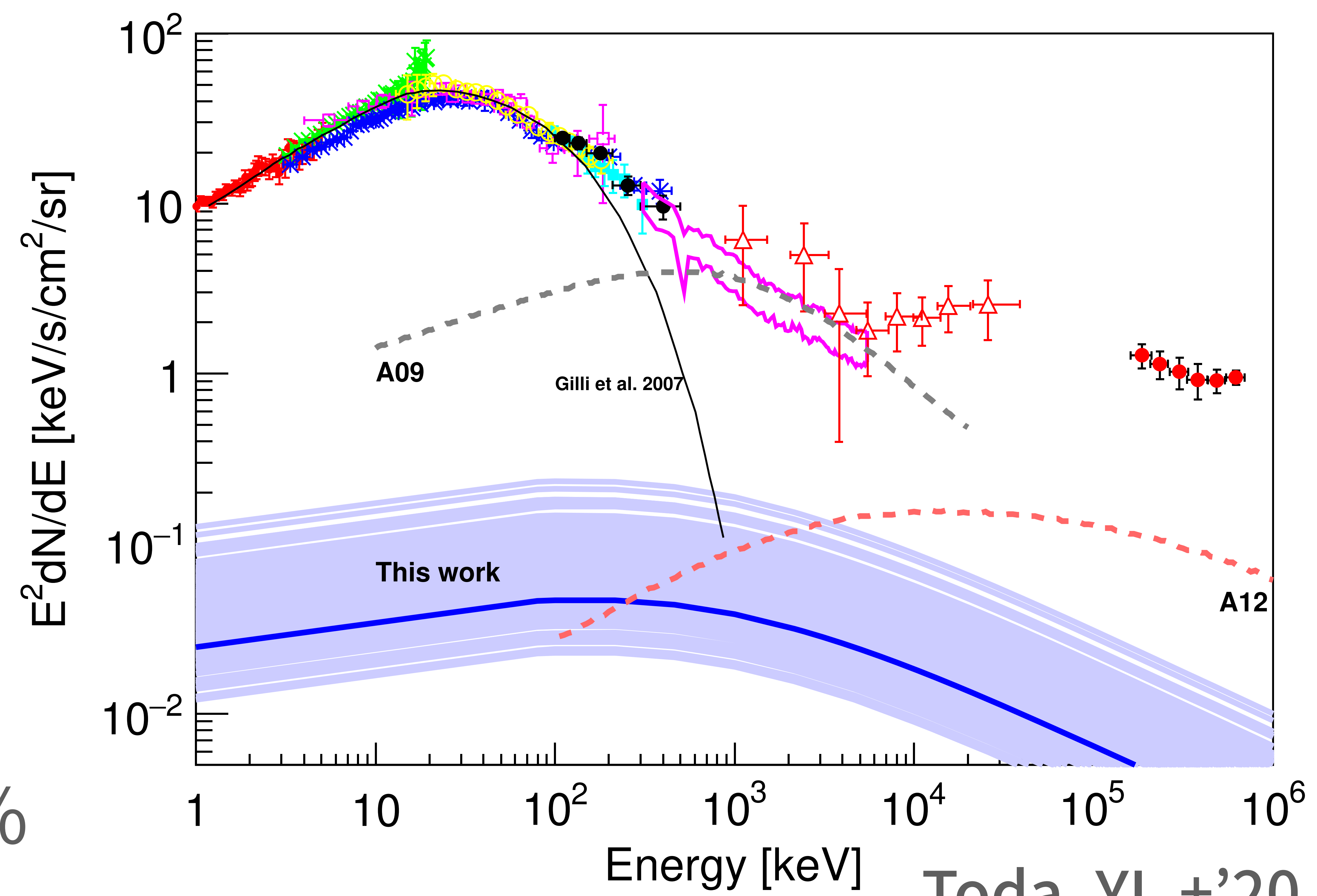
- FSRQs can explain the whole MeV background

FSRQs contribute to the GeV background with a peak at ~100 MeV

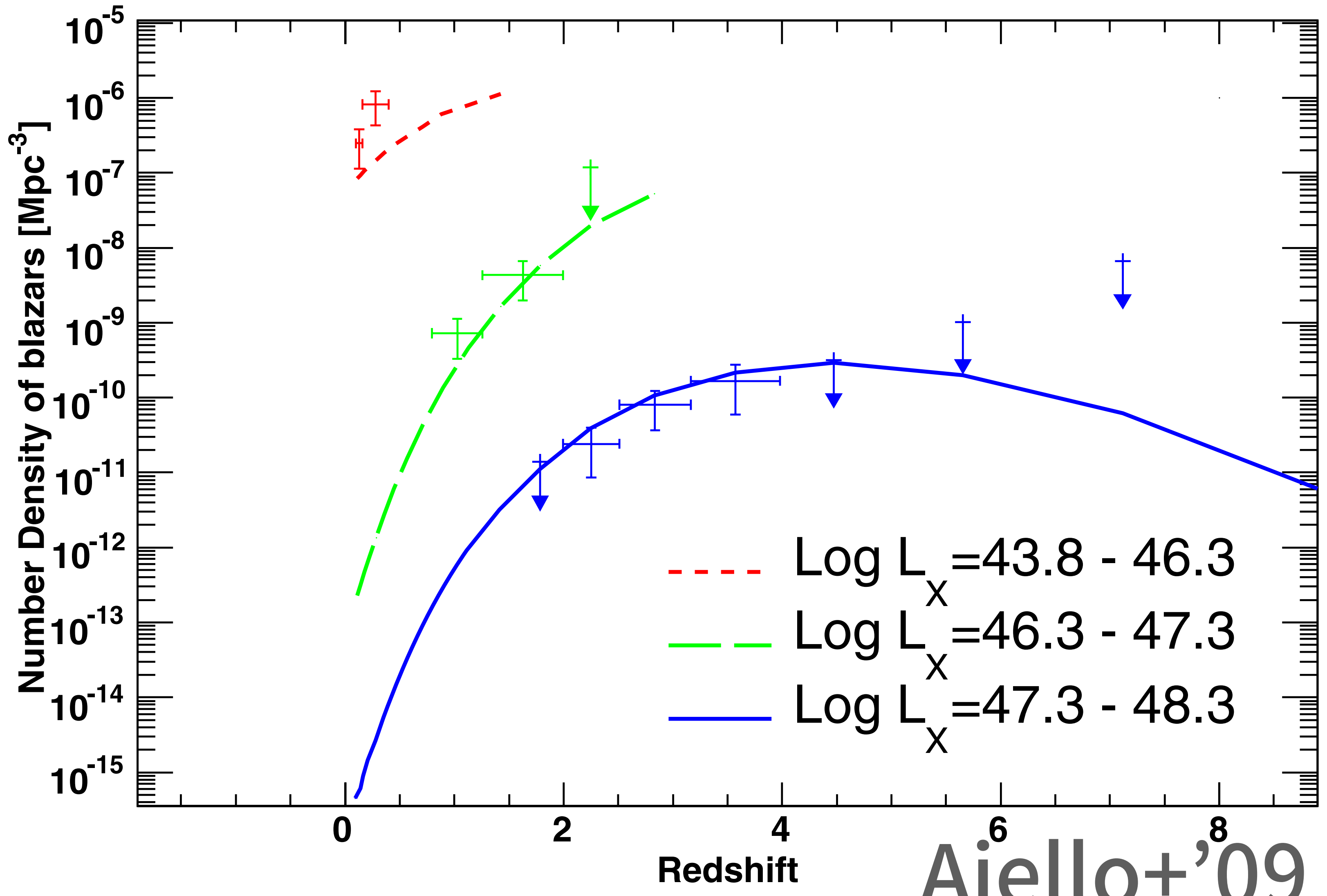
Revisiting FSRQ Evolution

Based on 105-month BAT catalog (Oh+'18)

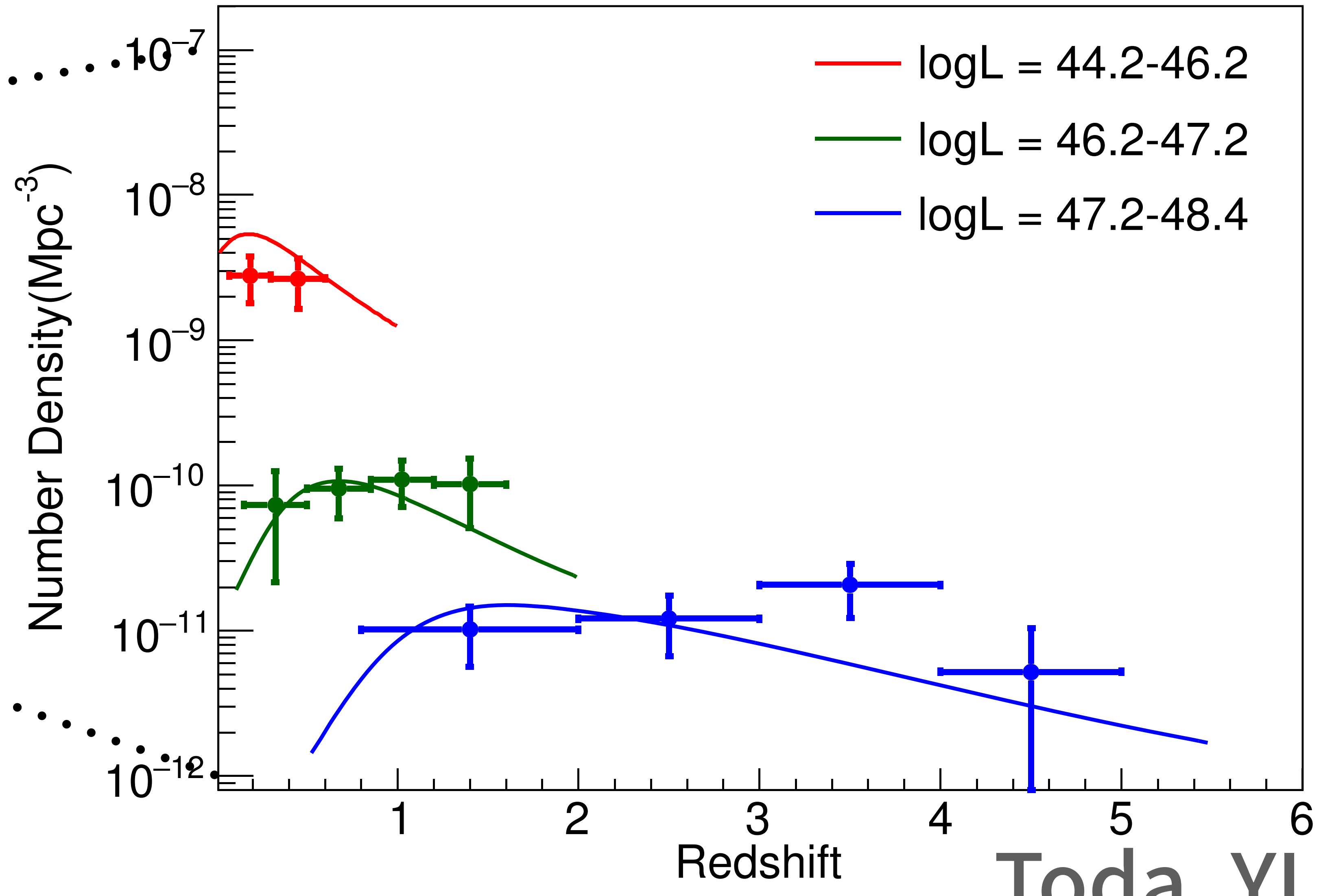
- 26 (Ajello+'09) → 53 FSRQs (Toda+'20)
- $z_{\mathrm{peak}} \sim 4 \rightarrow \sim 2$
- MeV background contribution: 100% → 3%



Toda, YI, +'20



Ajello+'09

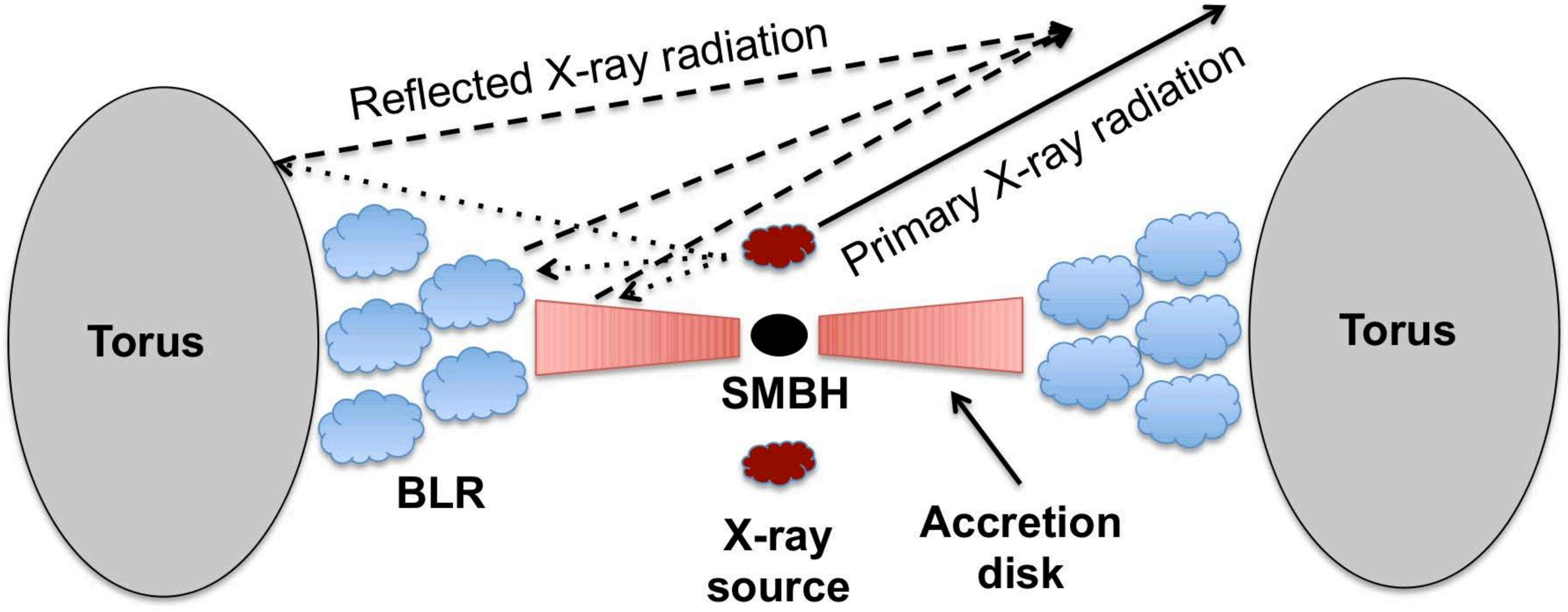


Toda, YI, +'20

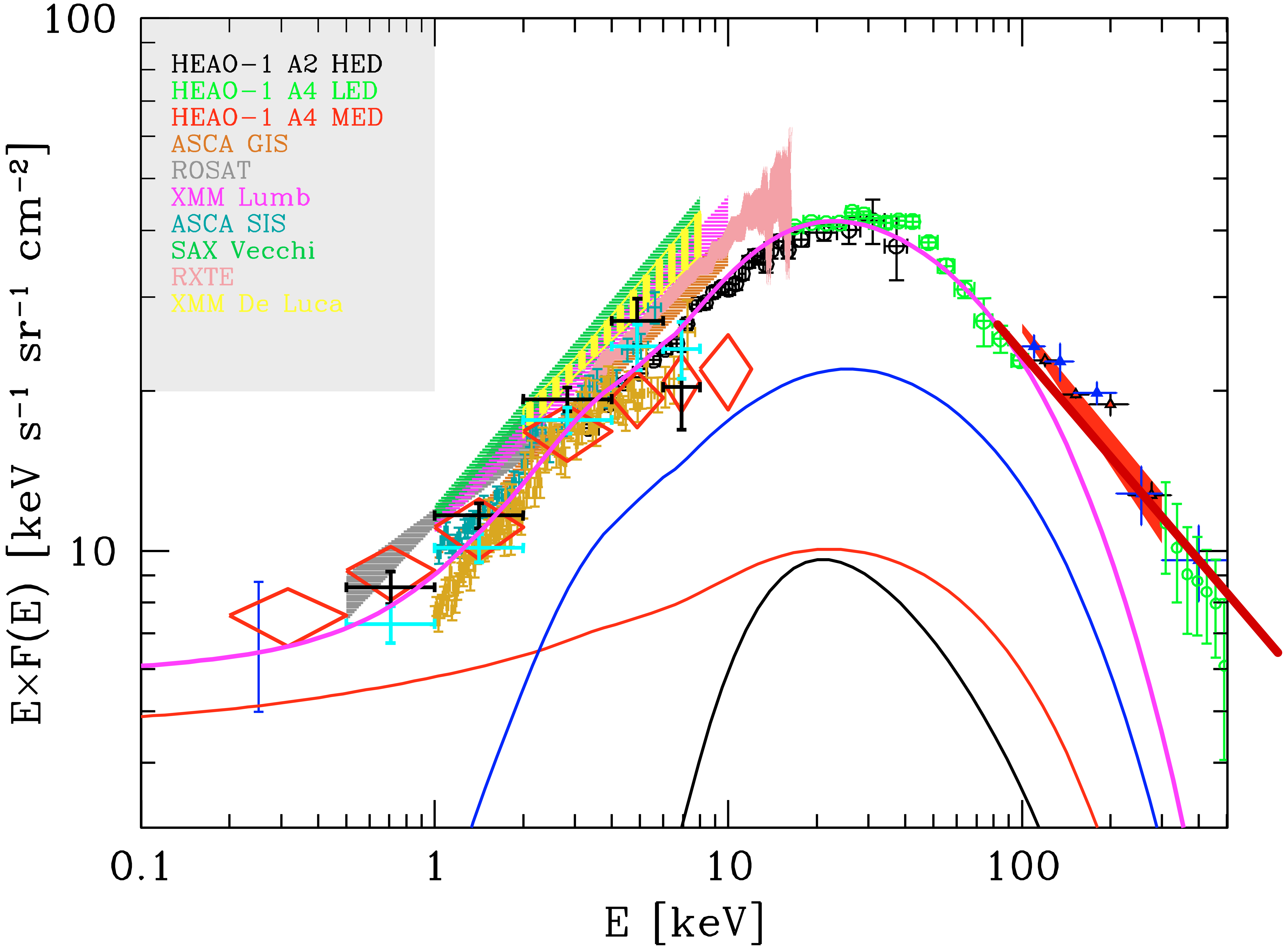
Seyferts and the MeV Background

Extension from X-ray background?

- X-ray emission of Seyferts comes from **thermal** hot disk corona
- If there are **non-thermal** particles, we can have a power-law tail from the X-ray background.

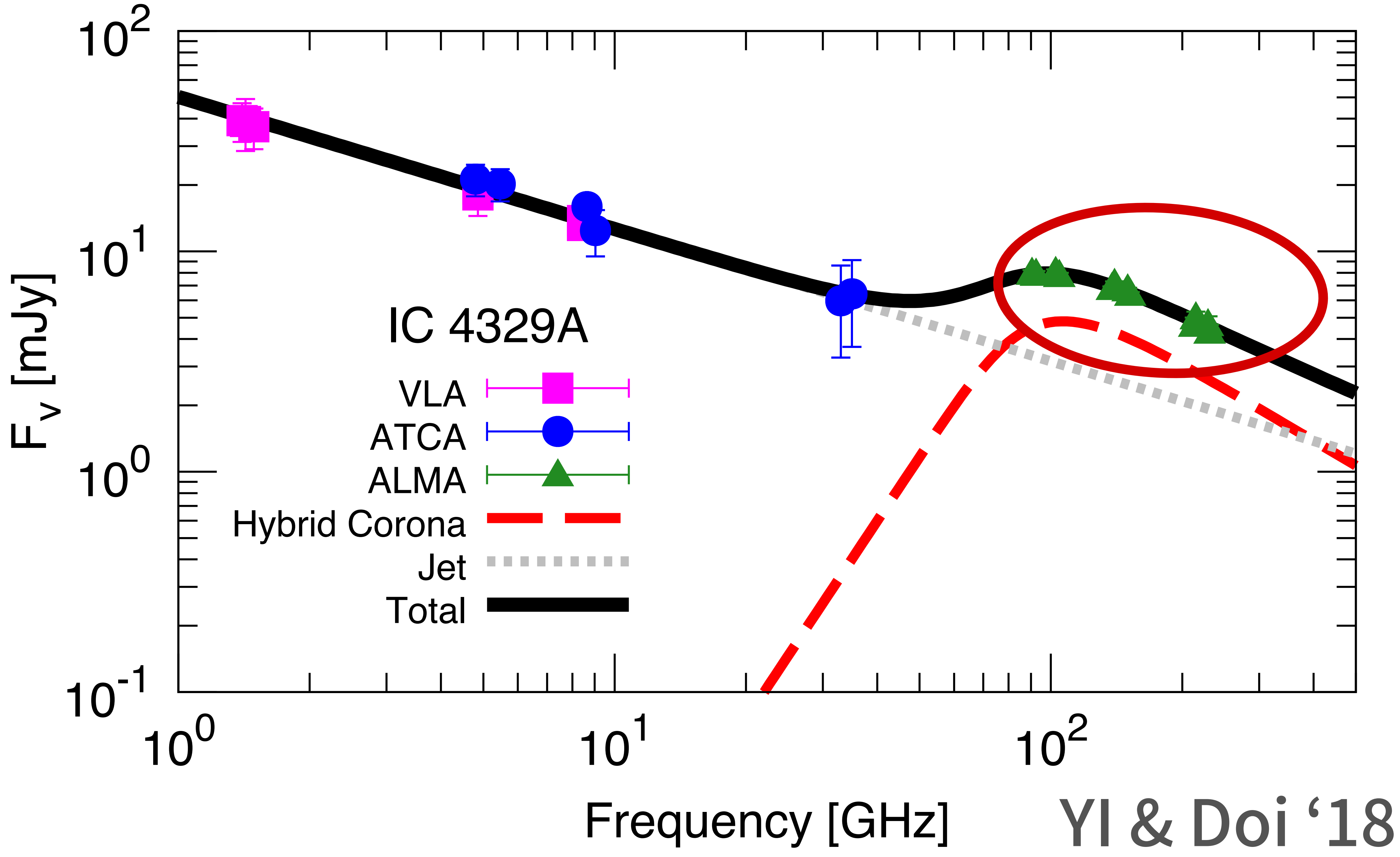


©Ricci

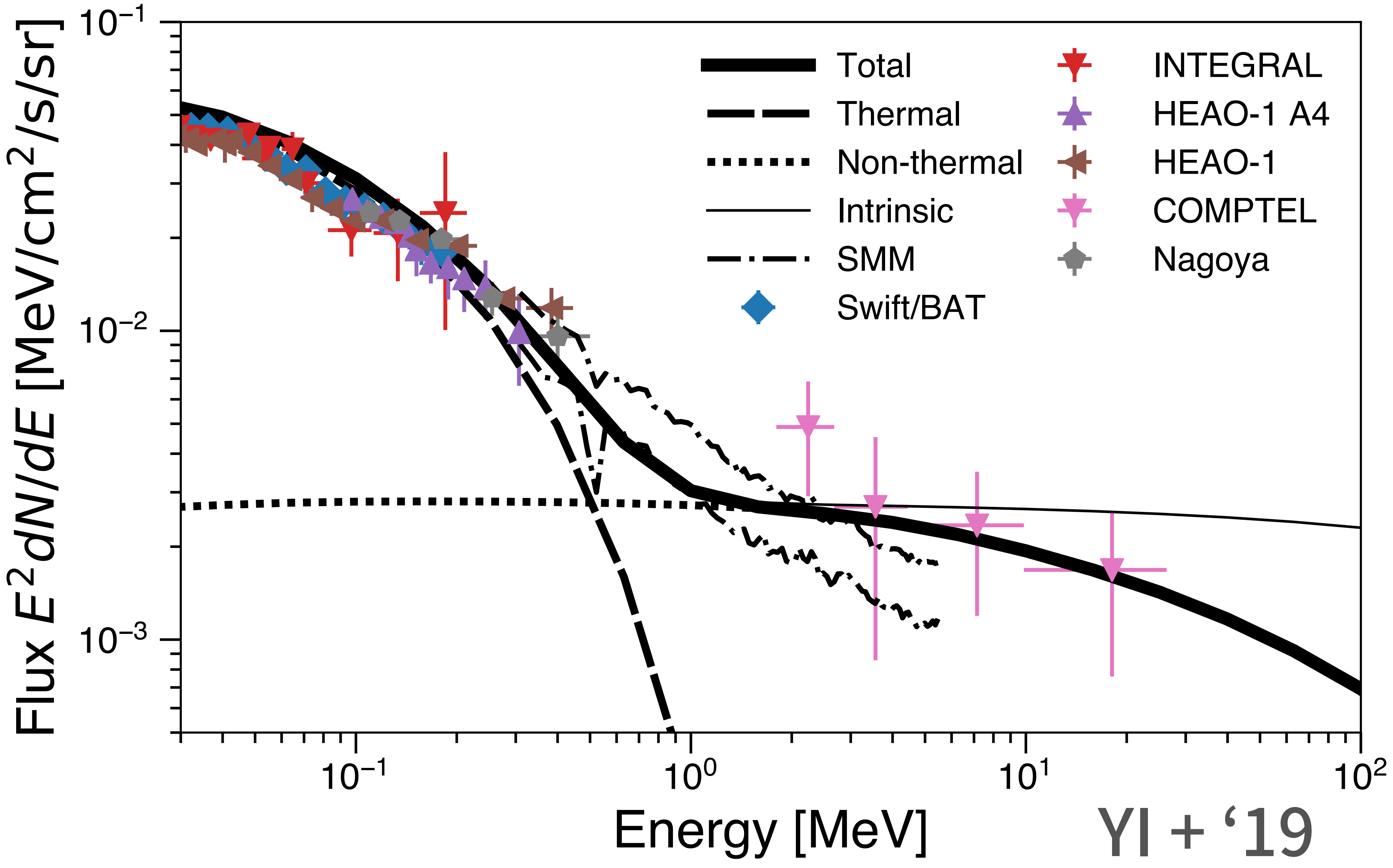


Gilli+'07

Non-thermal electrons exist in the coronae



YI & Doi '18

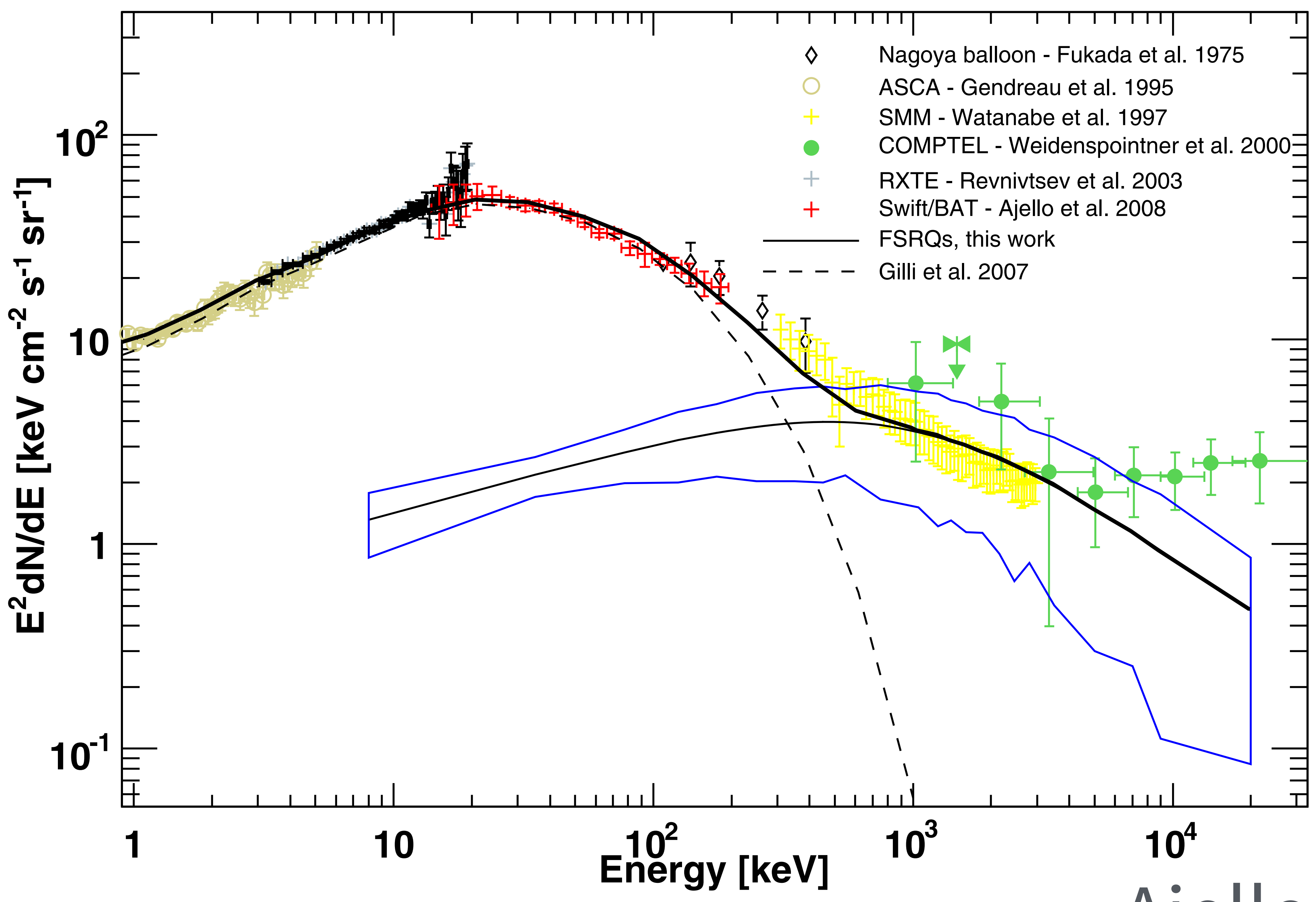


YI + '19

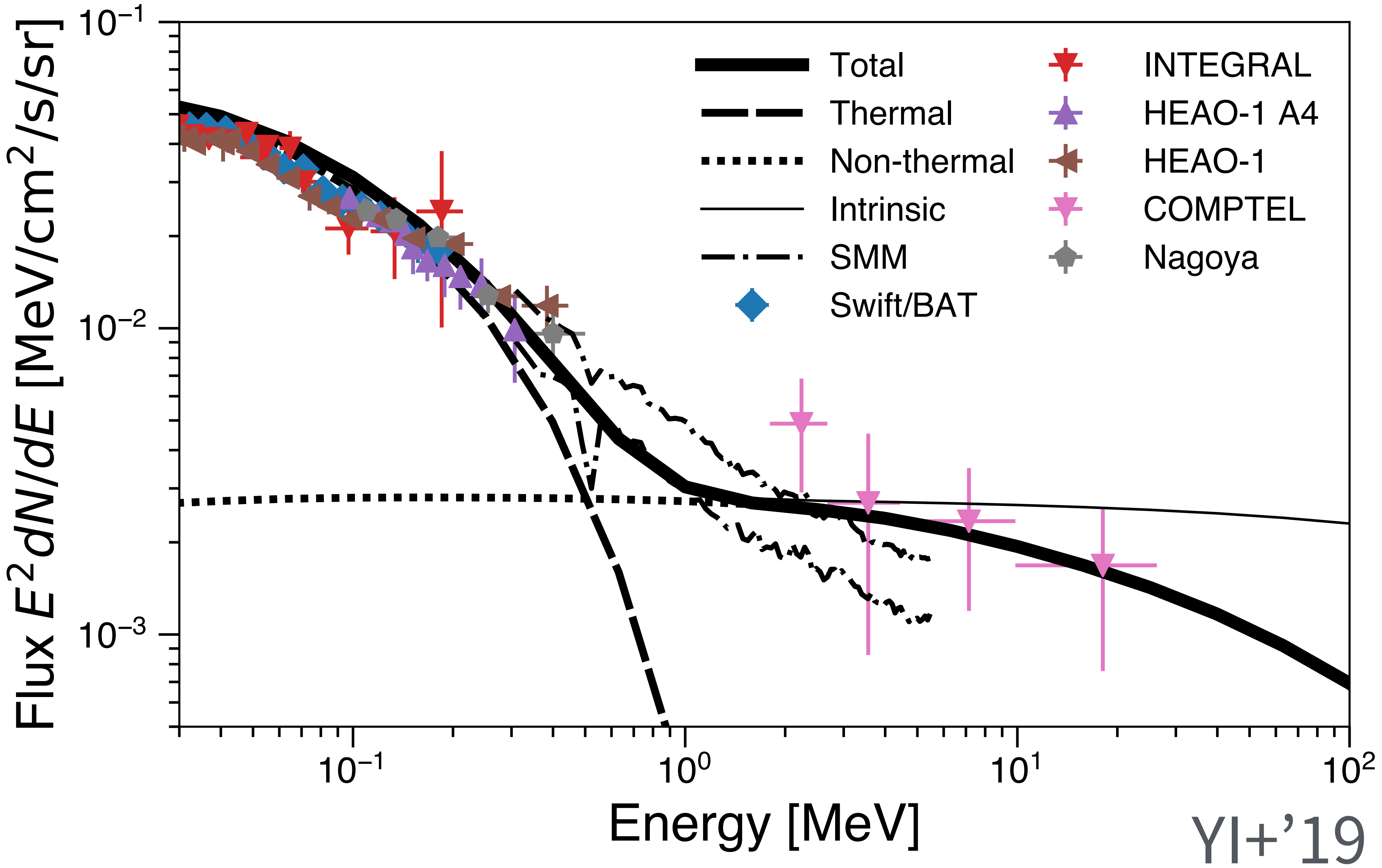
- Coronal synchrotron emission is found by ALMA (YI+'18)
- Non-thermal MeV tail in Seyferts can explain the MeV background radiation (YI+'08; YI+'19)

(Possible) Origins of the MeV Background

FSRQs (jet) ? Seyferts (disk)?



Ajello+'09



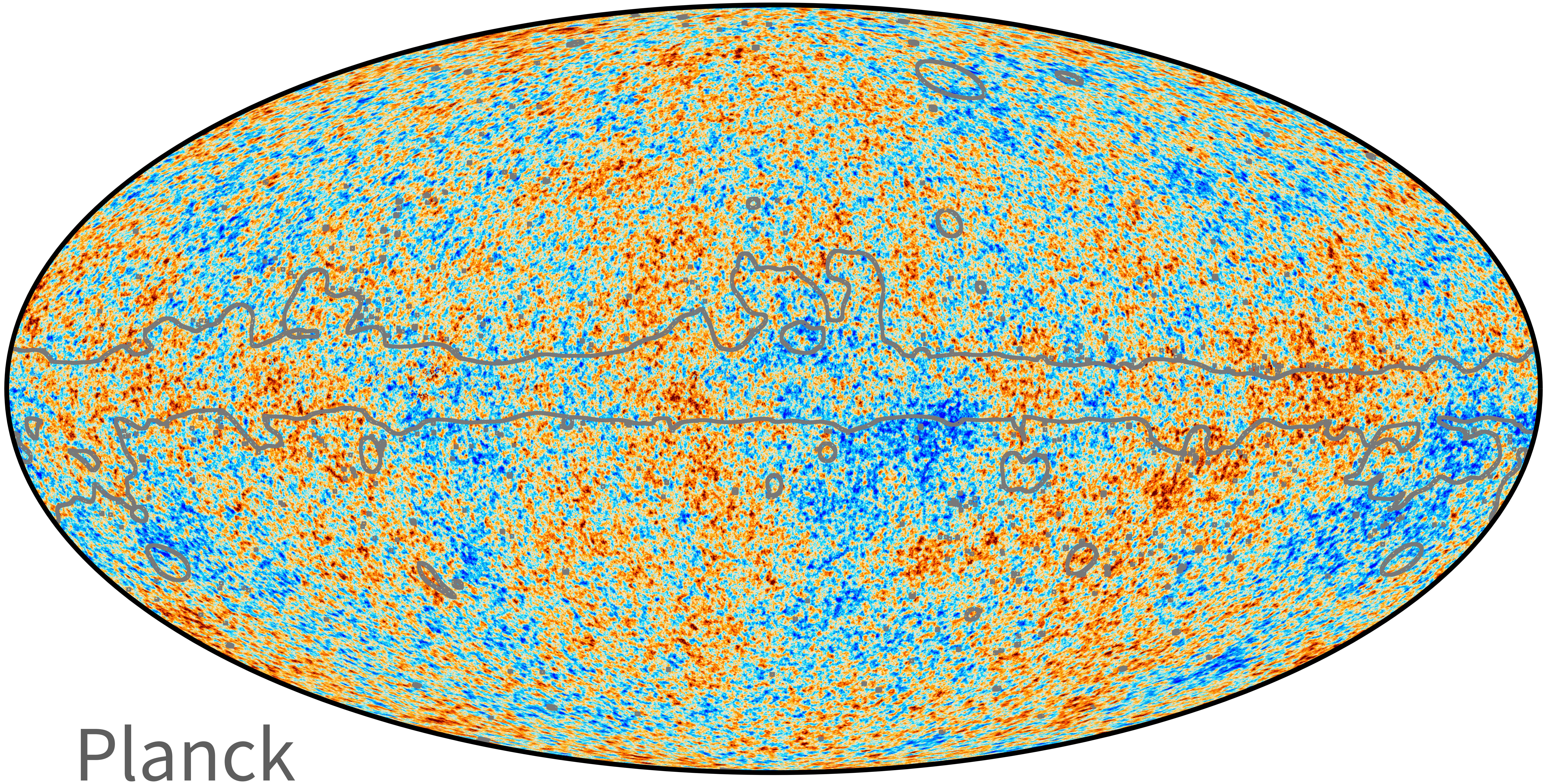
YI+'19

- FSRQs may explain (Ajello+'09)
  - Contradicts with evolution seen in GeV
  - Recent FSRQ XLF shows it is ~3%
- Seyferts may explain (YI+'08; YI+'19)
  - No MeV emission has been detected from Seyferts.
  - Synchrotron counterpart is detected by ALMA

Cosmic Gamma-ray Background Radiation Anisotropy

Anisotropy of the Cosmic Microwave Background

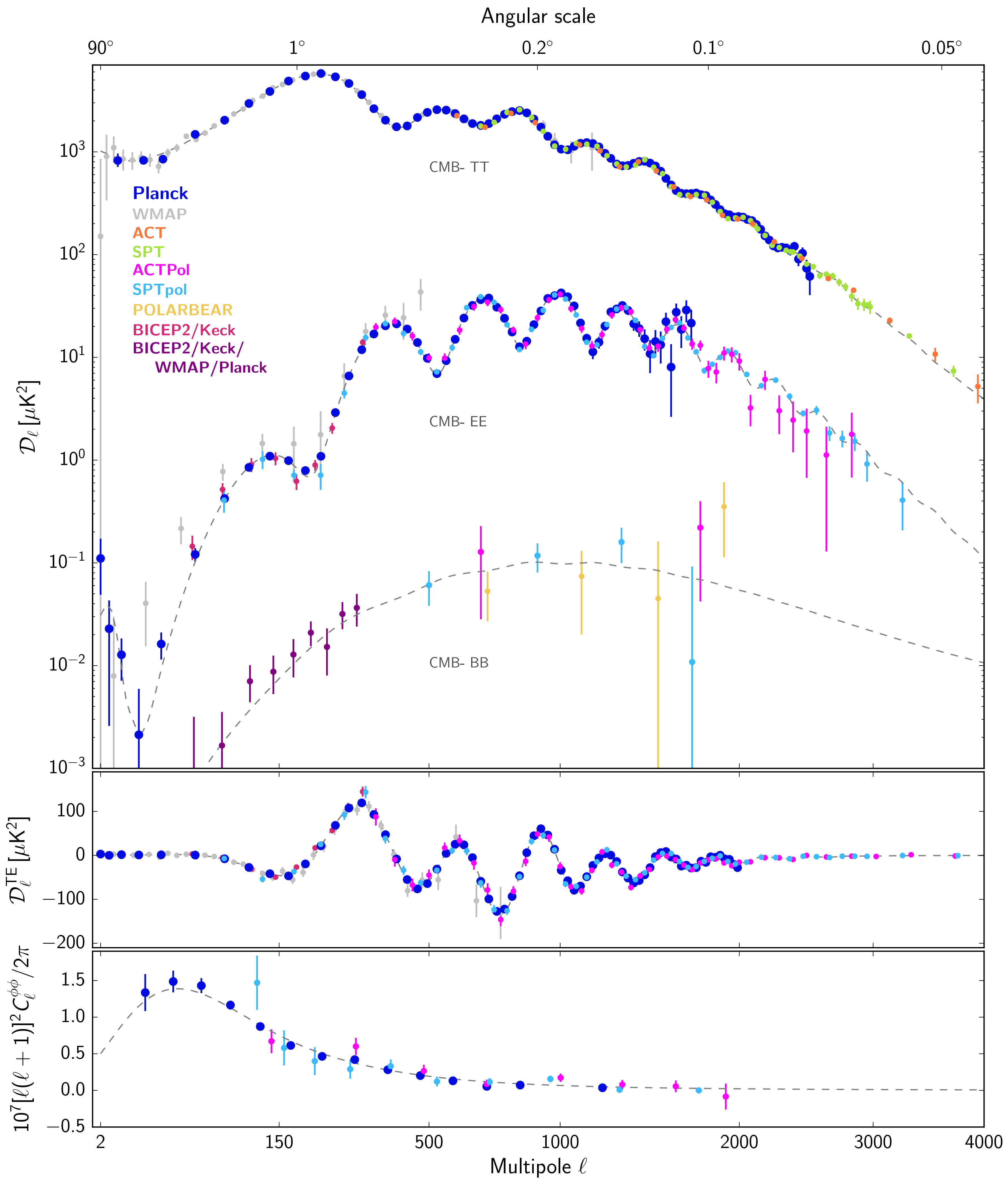
Clues for Big Bang Cosmology.

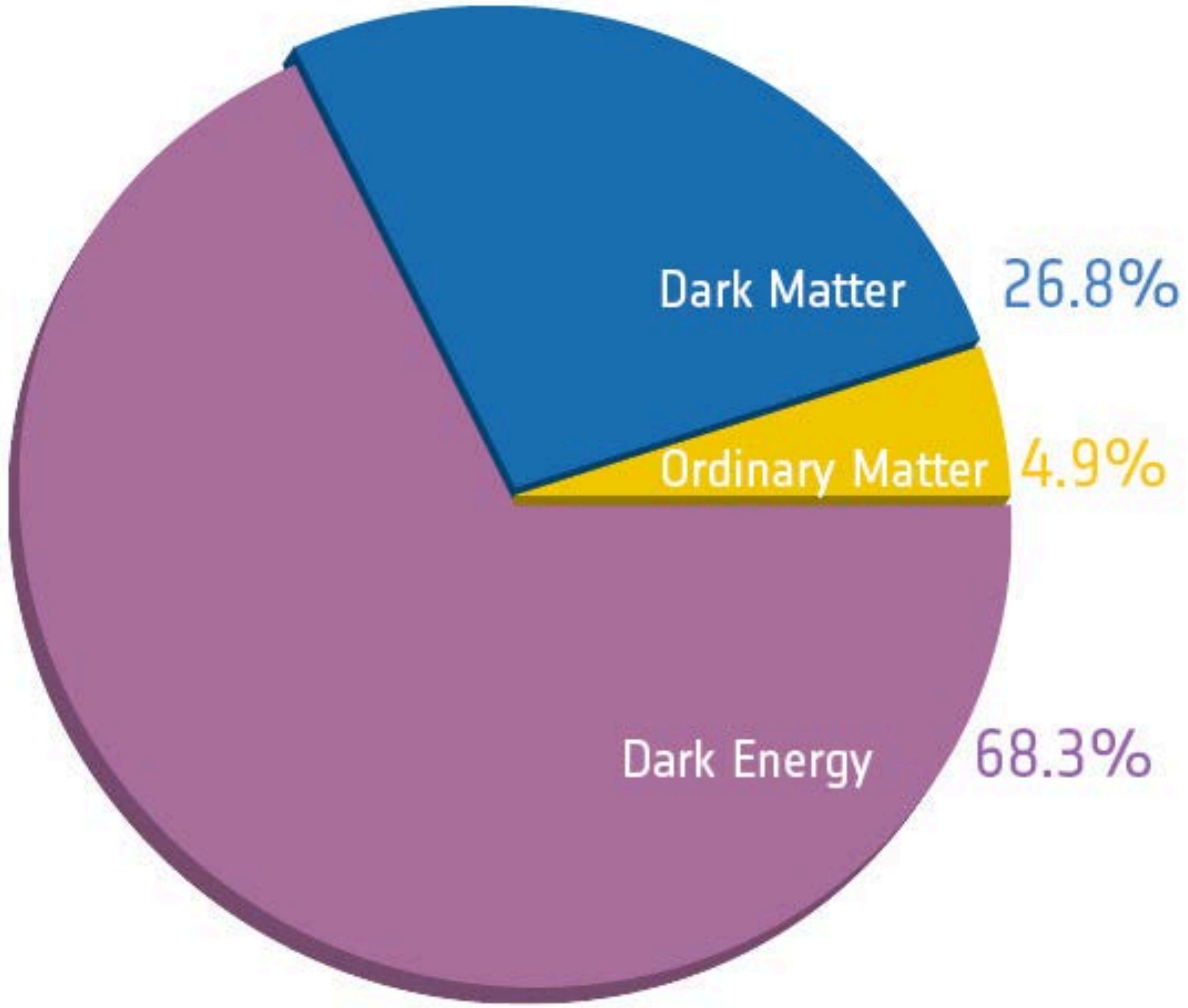


Planck

Anisotropy of the Cosmic Microwave Background

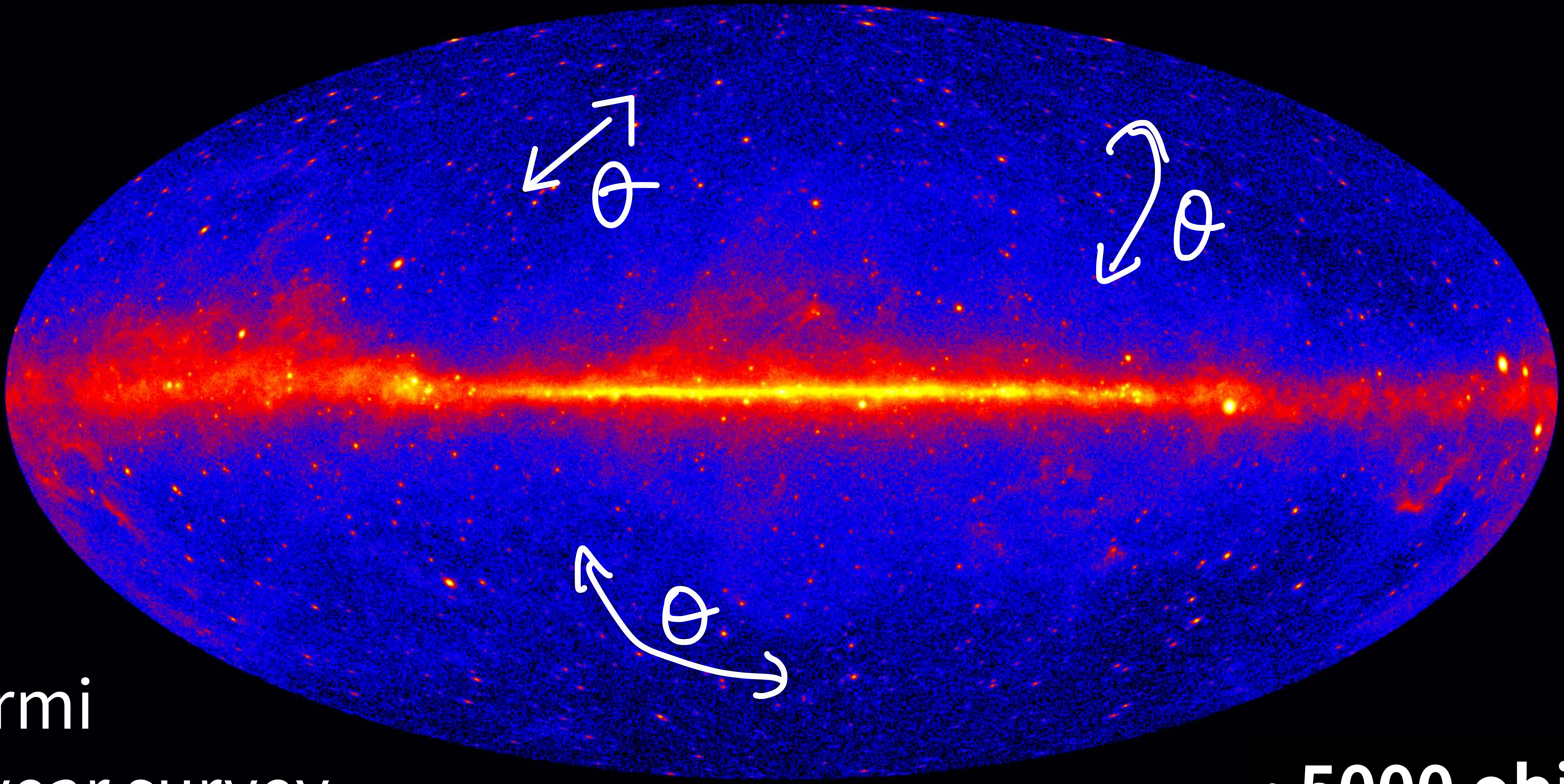
Converting the map to the angular power spectrum





Anisotropy of the sky

Trace the matter distribution in the universe

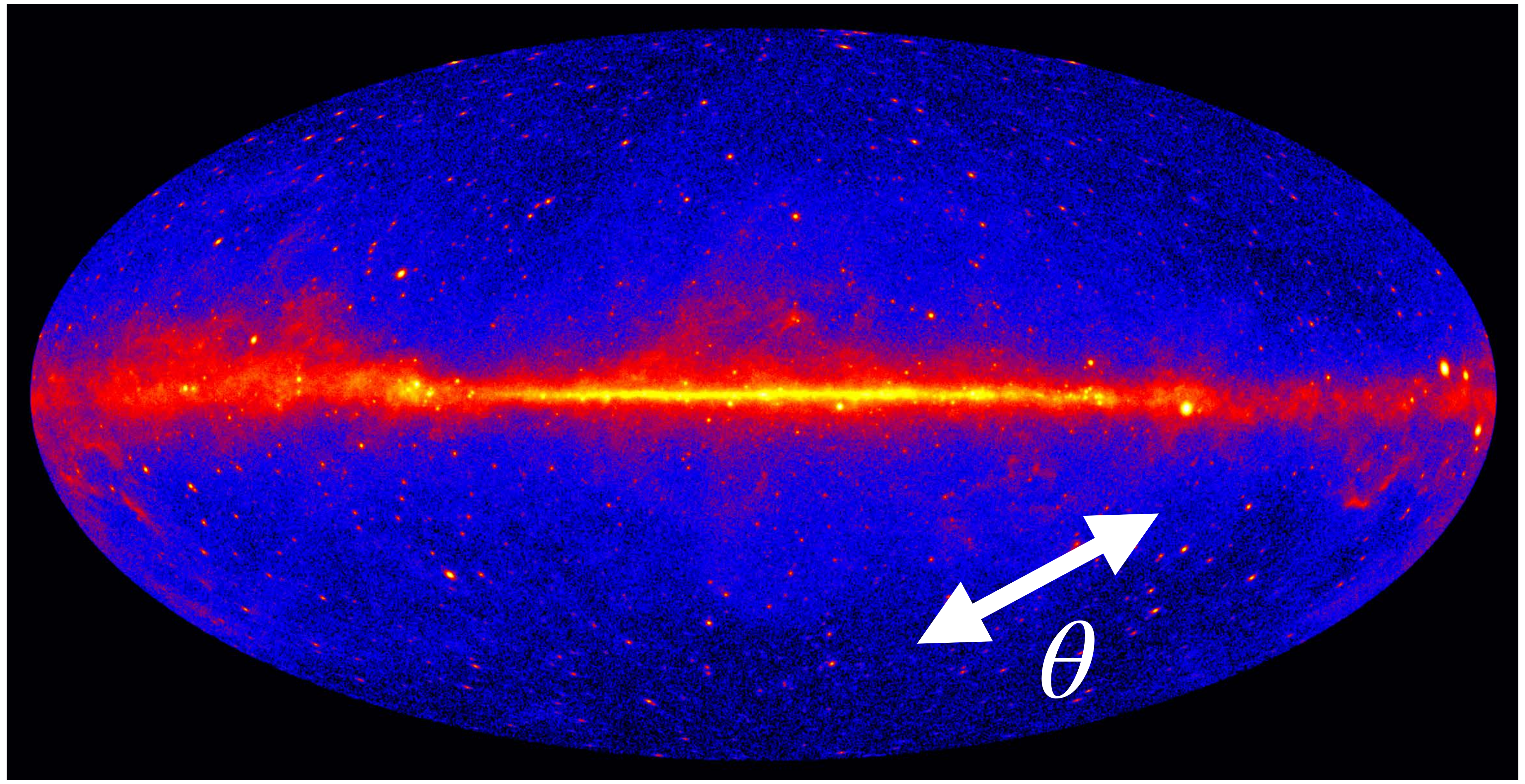


Fermi
5-year survey

~5000 objects

Anisotropy of the CGB

Proposed by Ando & Komatsu 2006

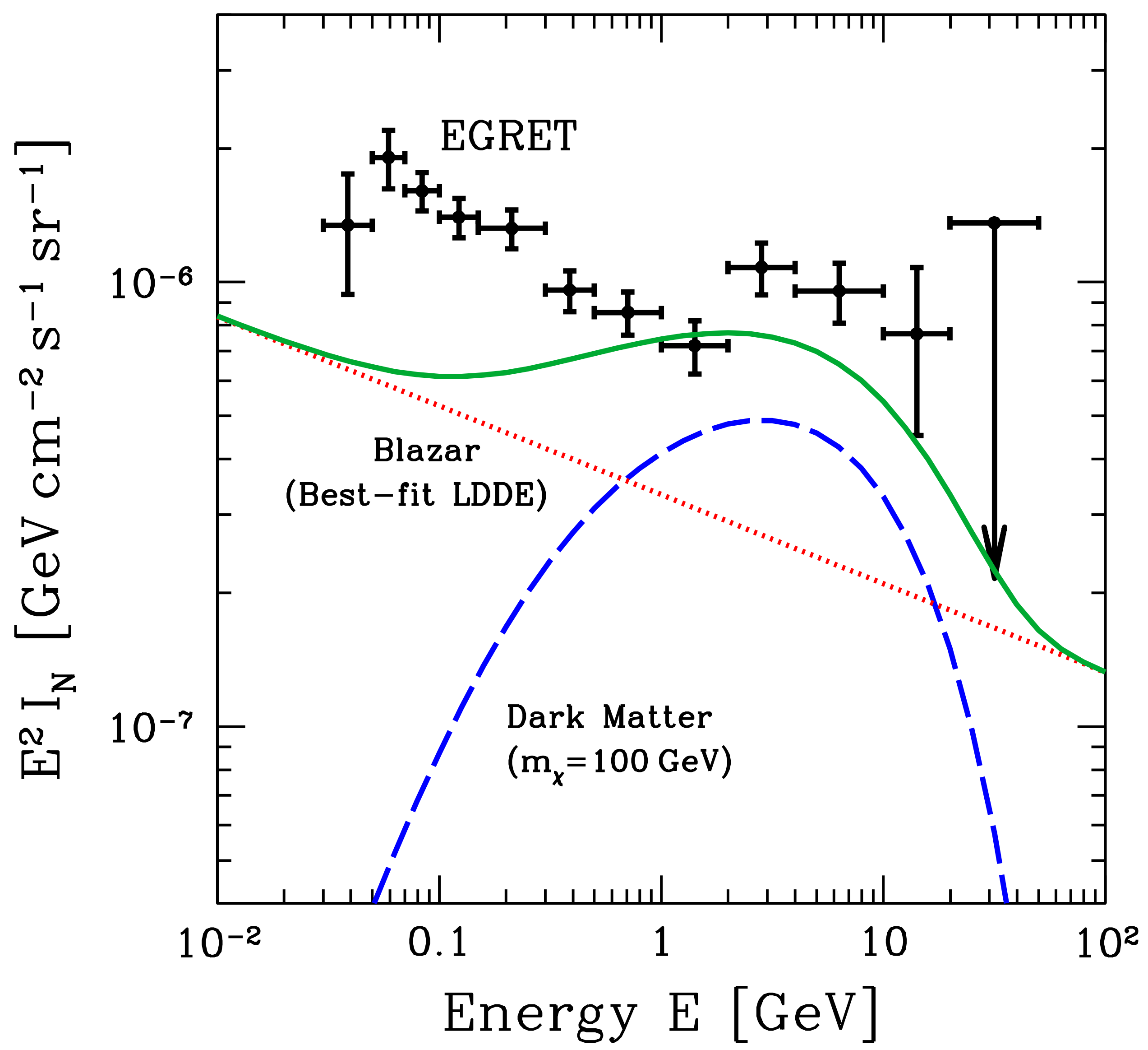


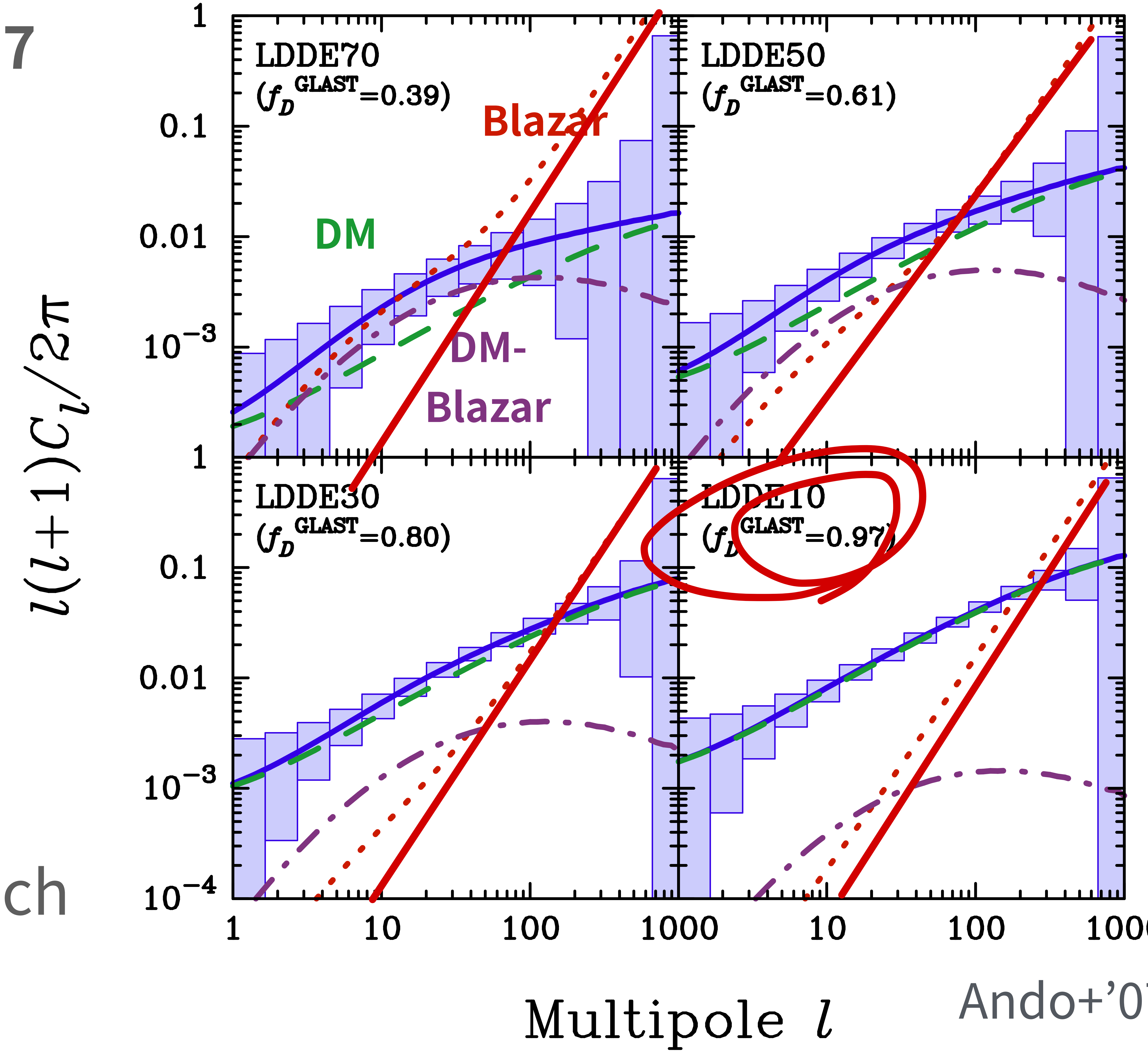
- Angular power spectrum: $C(\theta) = \langle \delta I(\hat{r}_1) \delta I(\hat{r}_2) \rangle$
- Poisson term: $C_l^P \equiv C(\theta = 0)$
  - i.e., Shot noise $C_l^P = \int_0^{S_0} dS\ S^2 \frac{dN}{dS}$ ← flux
- Correlation term: $C_l^C \equiv \int_{\theta \neq 0} d^2\theta e^{-il\cdot\theta} C(\theta)$
  - includes structure information.
- Note: multipole $l \simeq 180/\theta$ ← [deg]

$l \nearrow \ \theta \searrow$

Angular Power Spectrum of the CGB

Ando & Komatsu 2006; Ando et al. 2007



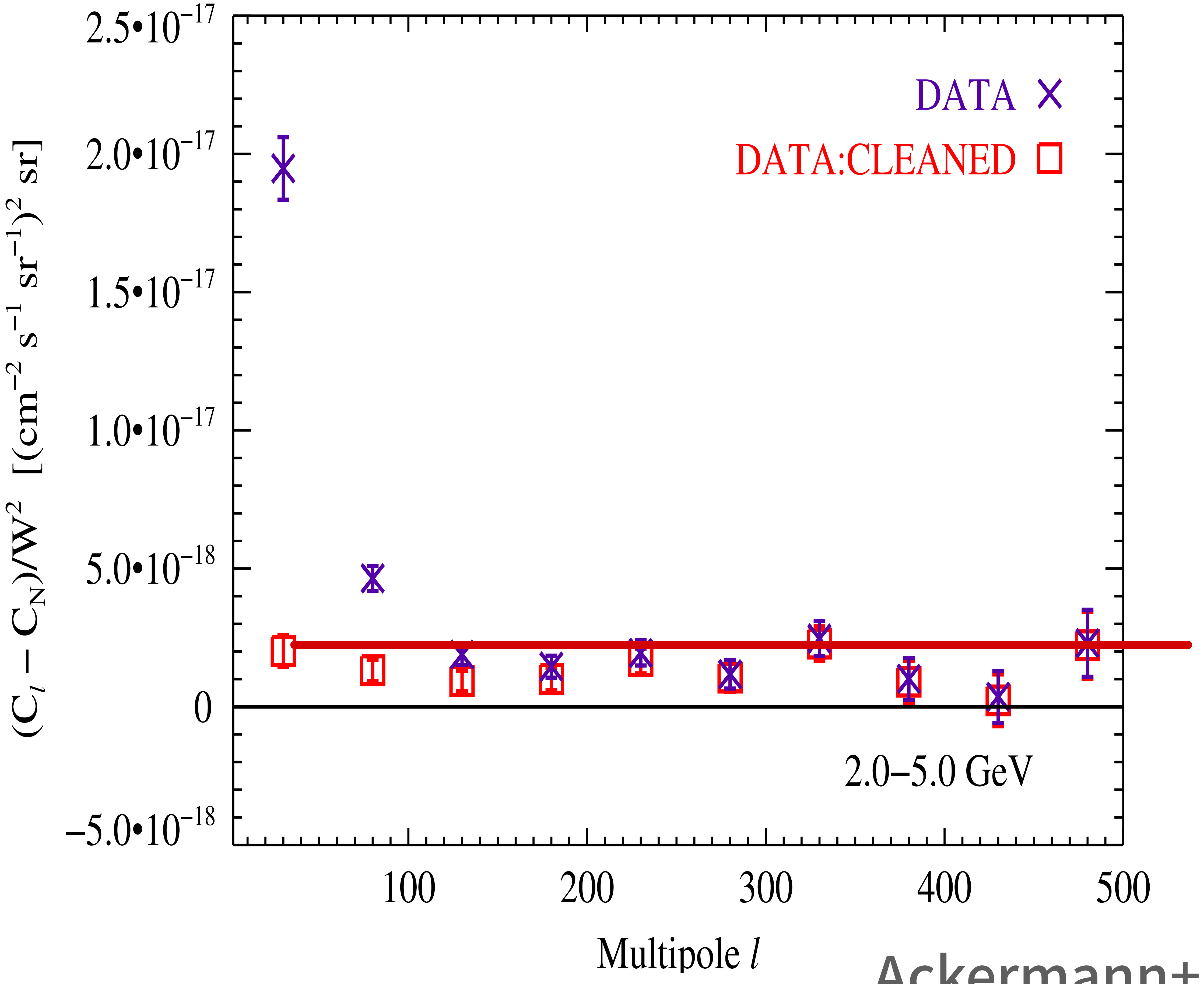


Ando+'07

- Note: this work was before the launch of Fermi.

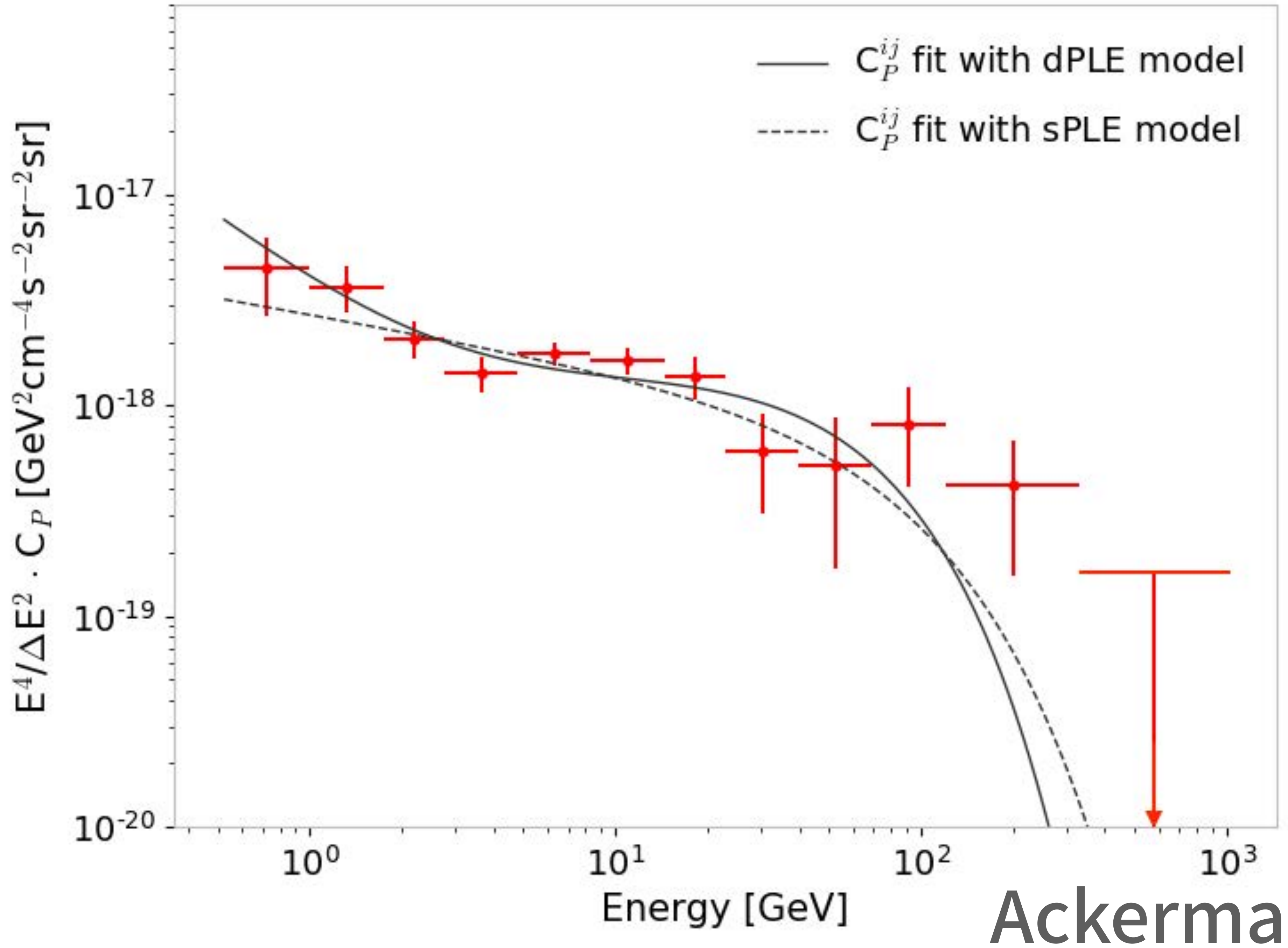
Anisotropy Measurement of the CGB

Fermi measured it.



Ackermann+'12

- Constant excess at 100 < l < 500
  - Poisson term
- >1 populations are required.



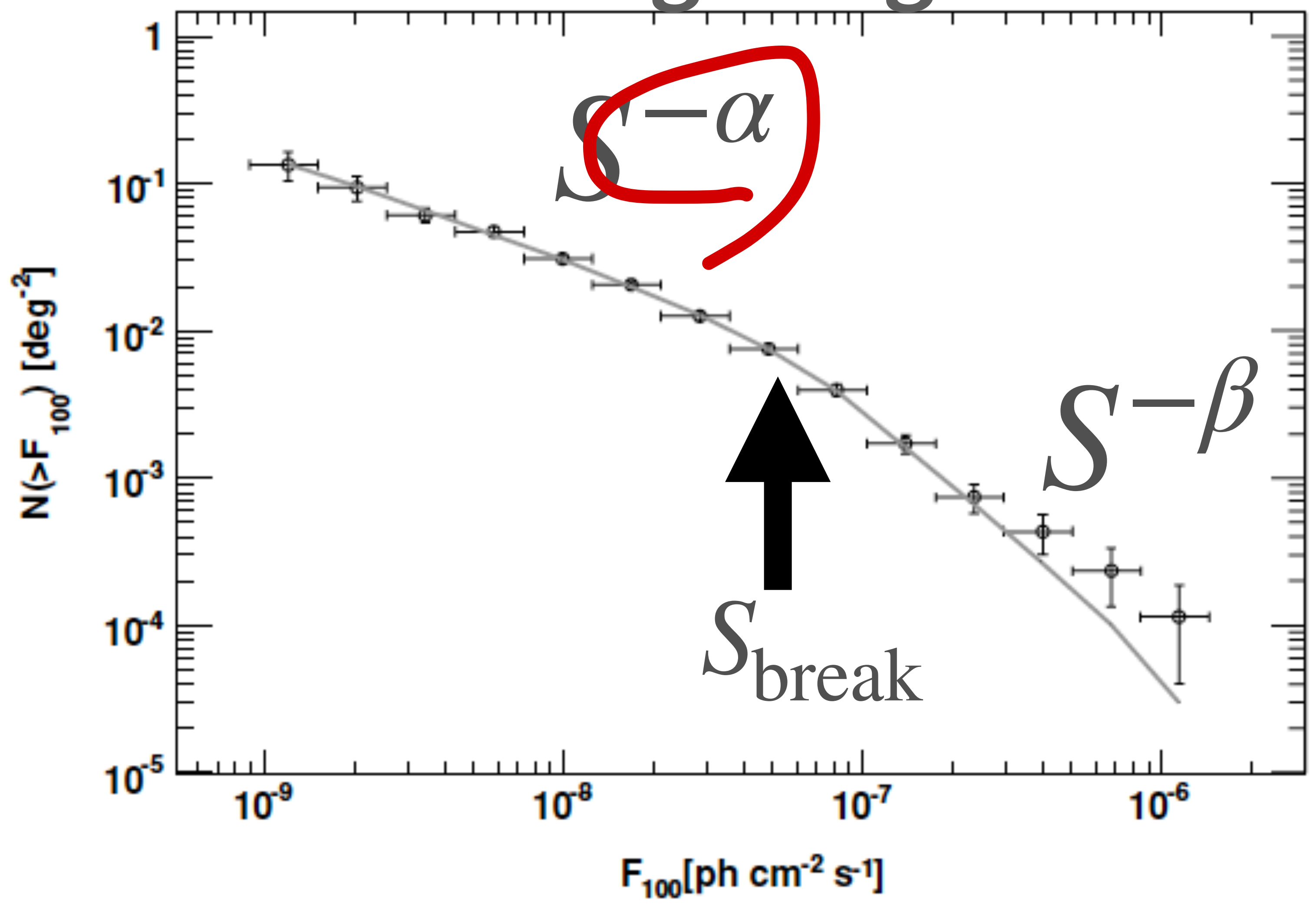
Ackermann+'19

$C_l^P = \int ds\, s^2 dN/ds$

Anisotropy Constraints on Blazar models

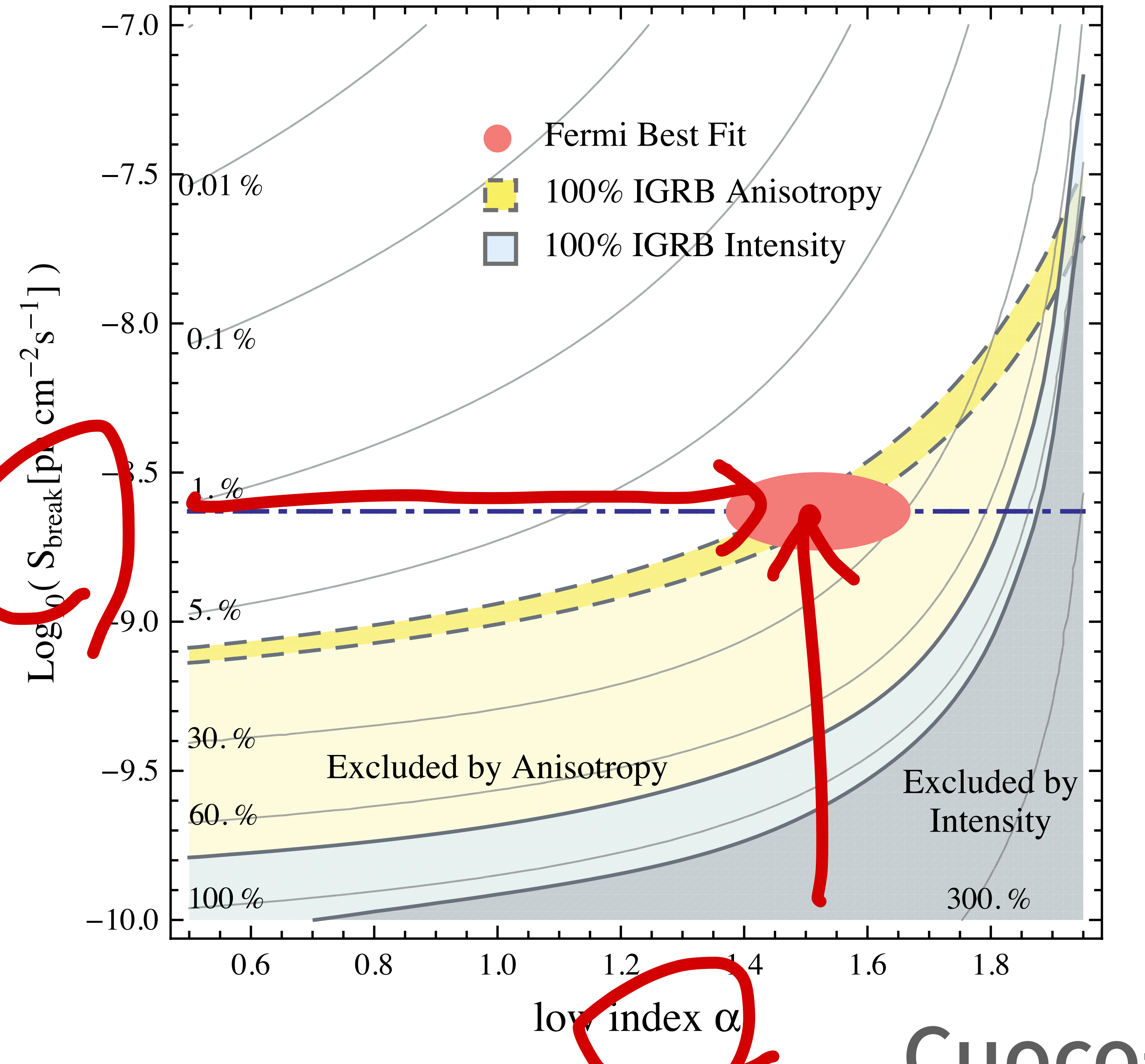
Independent test of blazar evolution

logN-logS



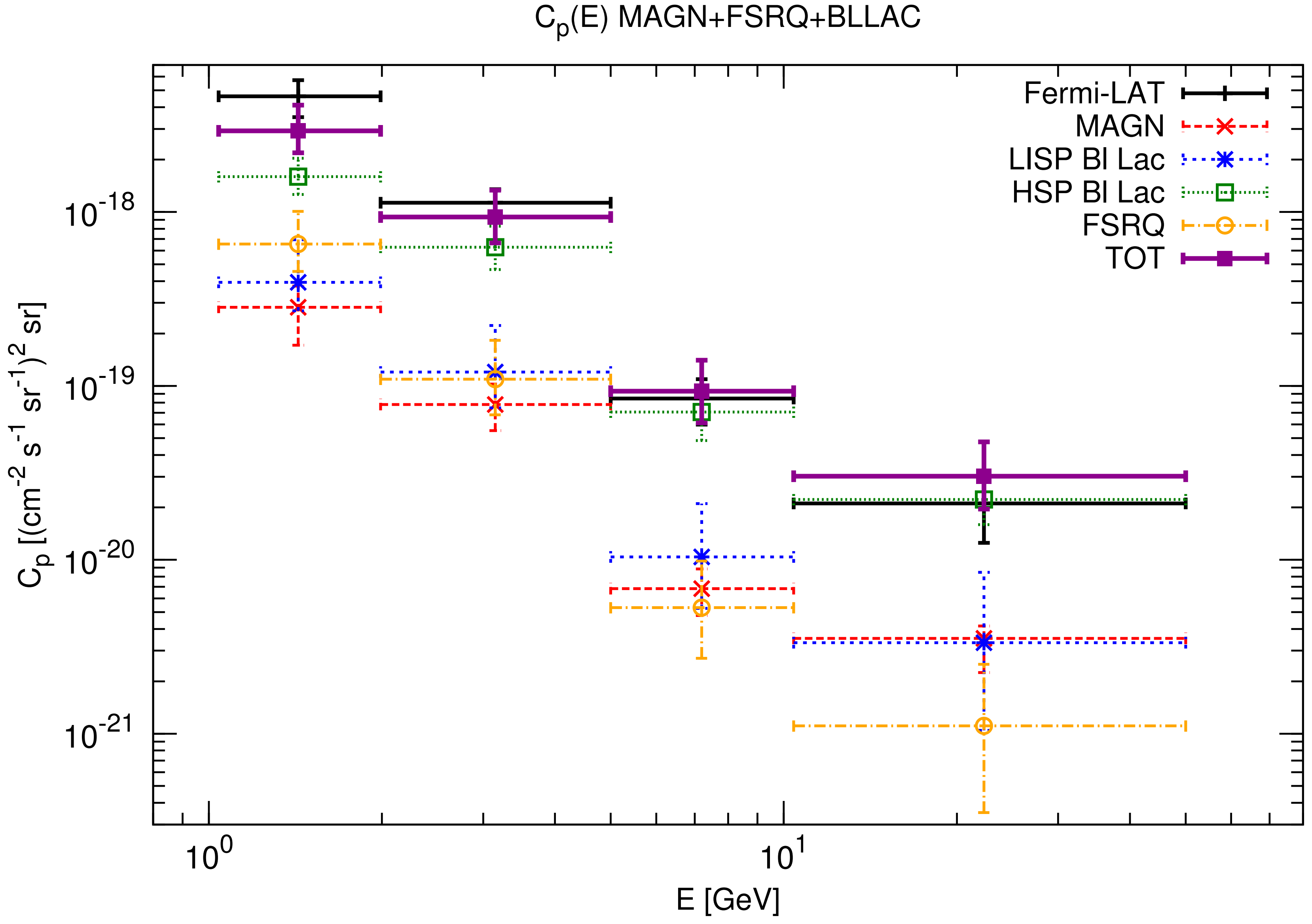
Abdo+'10

Joint constraint



Cuoco+'12

Energy dependent C_l^P

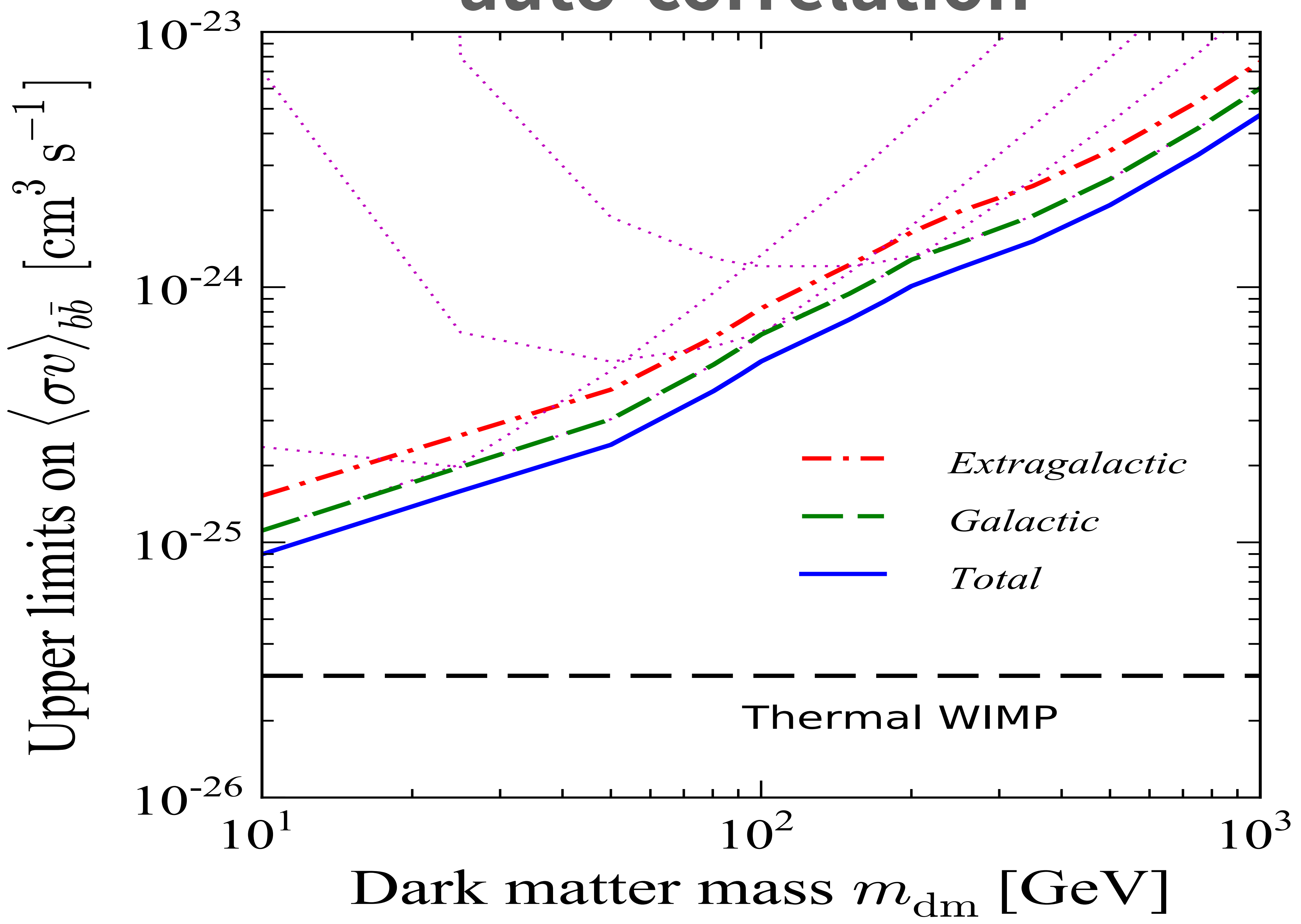


Di Mauro+'14

- We can estimate C_l^P
  - Anisotory & source count constrain the evolution models (Cuoco+'12; Harding & Abazajian '13)
- Anisotropy is well explained by blazars and radio galaxies (Di Mauro+'14)

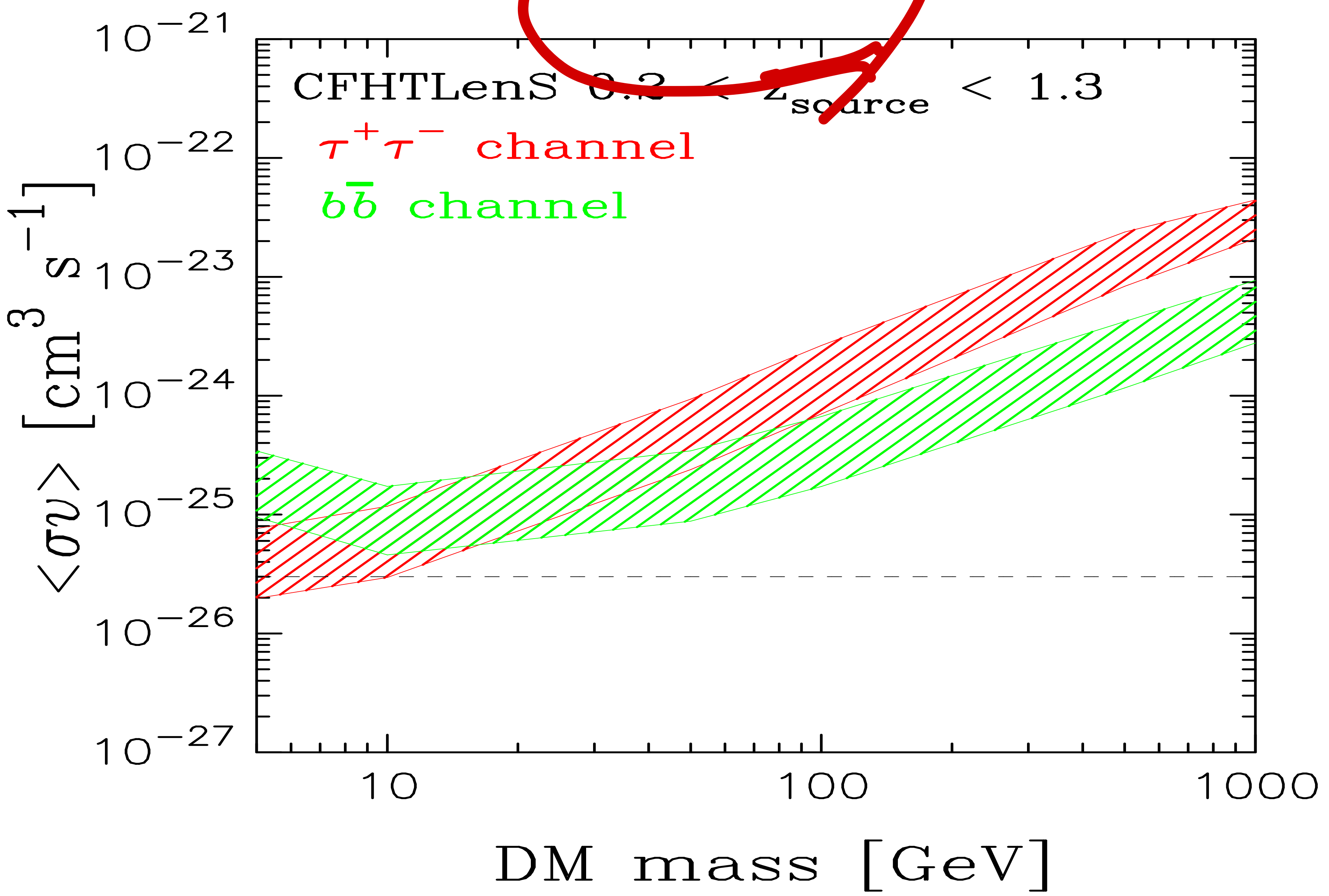
Anisotropy Constraints on Dark Matter Parameters

auto-correlation



Ando&Komatsu ‘13

cross-correlation

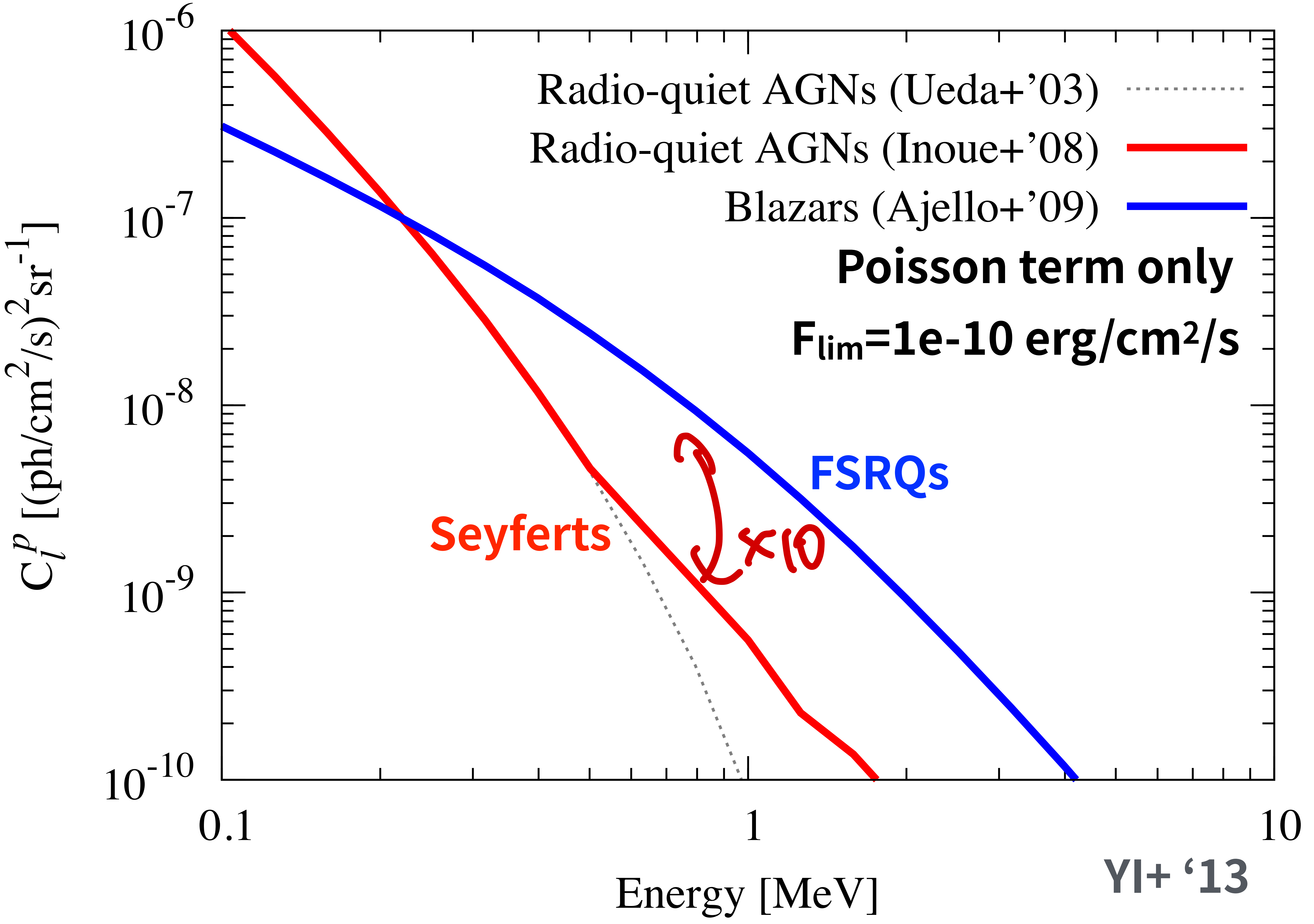


Shirasaki+’14

- Angular power spectra of CGB is a powerful tool to constrain the DM properties (e.g. Ando & Komatsu ’06, ’13).
- Cross-correlation between cosmic shear and CGB will be a new powerful tool (e.g. Camera+’13, Shirasaki+’14).

Anisotropy of the MeV Background

Can be achieved by coming balloon missions



YI+ '13

- FSRQs are bright but rare

  ➡High C_l^P ↗

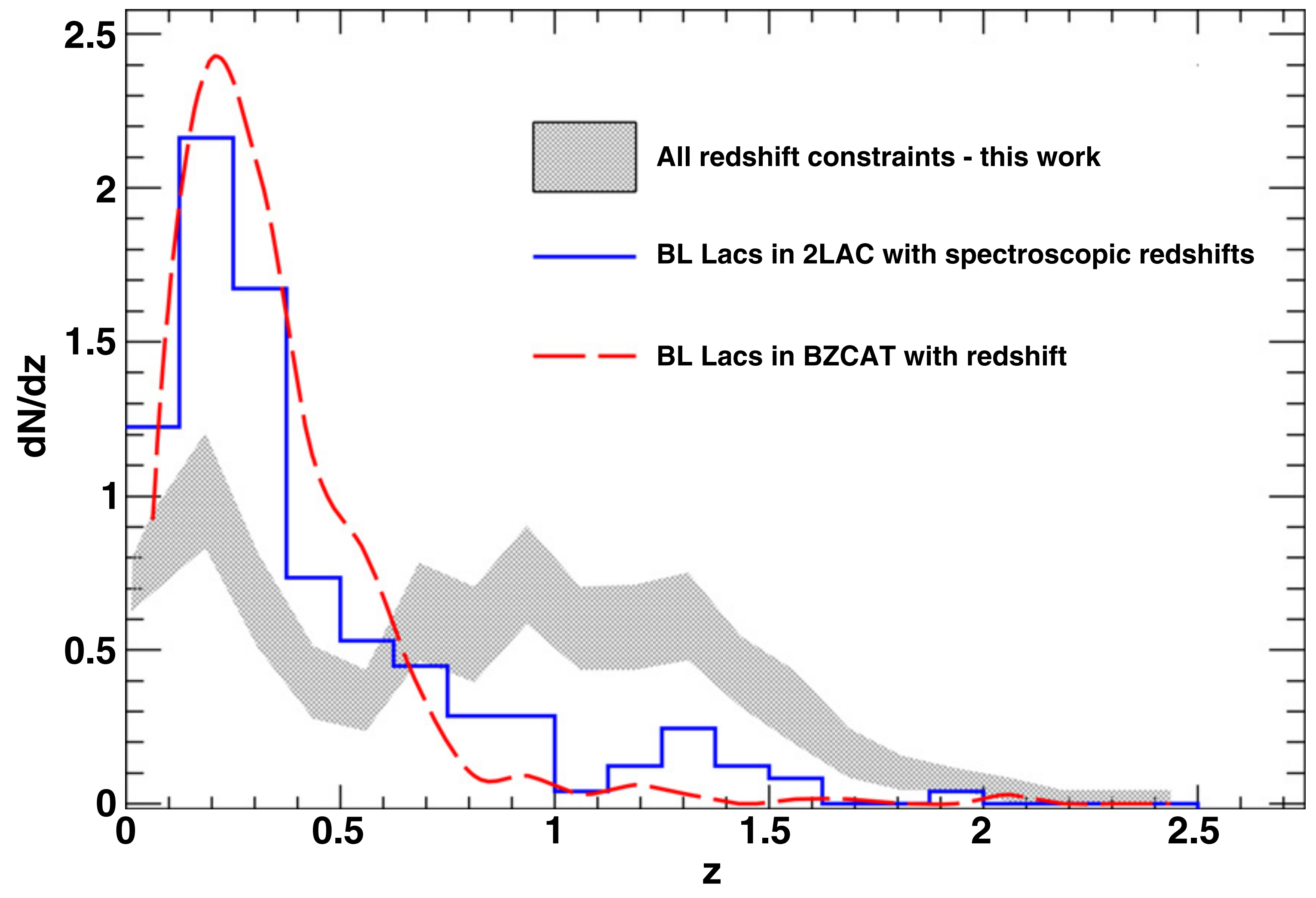
- Seyferts are faint but numerous

  ➡Low C_l^P ↘

- Future missions can unveil the MeV background through anisotropy.

More topics in cosmic evolution studies

- Connection to Neutrinos & Cosmic-ray backgrounds
- Evolution of blazars
  - Redshift measurements of BL Lacs
- TeV background radiation



Ajello+'14

Day 2 Summary

- Origin of the cosmic MeV gamma-ray background is still under debate.
  - Seyferts?
    - But, no MeV emission is confirmed.
  - FSRQs?
    - But, evolution is inconsistent with GeV data.
- Anisotropy of the cosmic gamma-ray background is a powerful tool.
  - Fermi has measured the Poisson term.
  - >1 populations are required for the GeV background.