Active Galactic Nuclei observed by Fermi-LAT

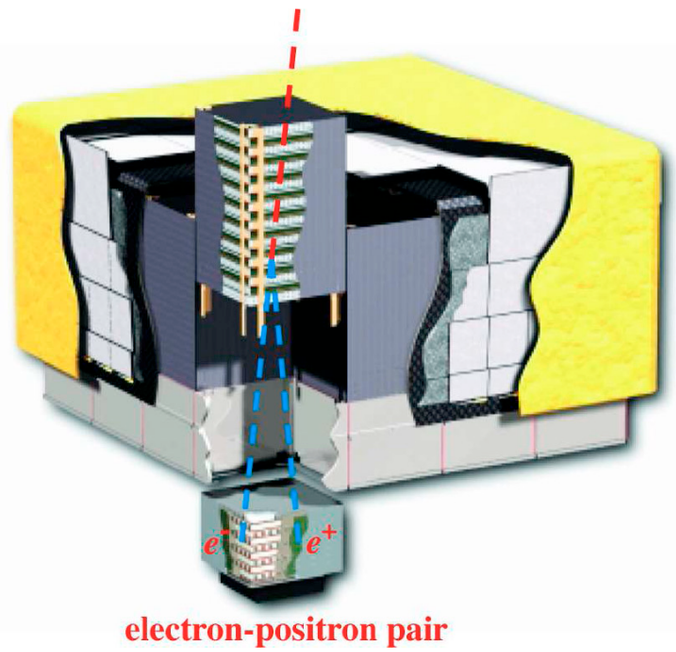
"The extreme Universe viewed in very-high-energy gamma-rays 2015"
2016.1.13-14

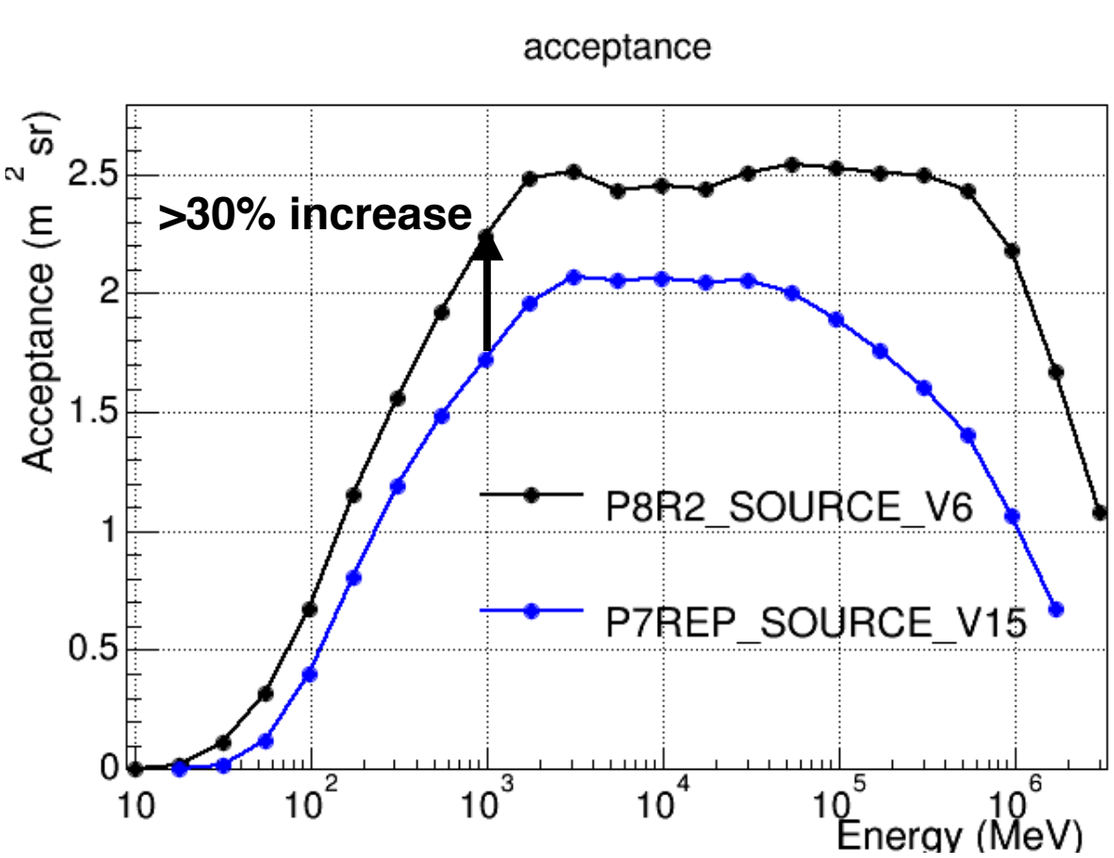
Shinya Saito (Rikkyo Univ.)

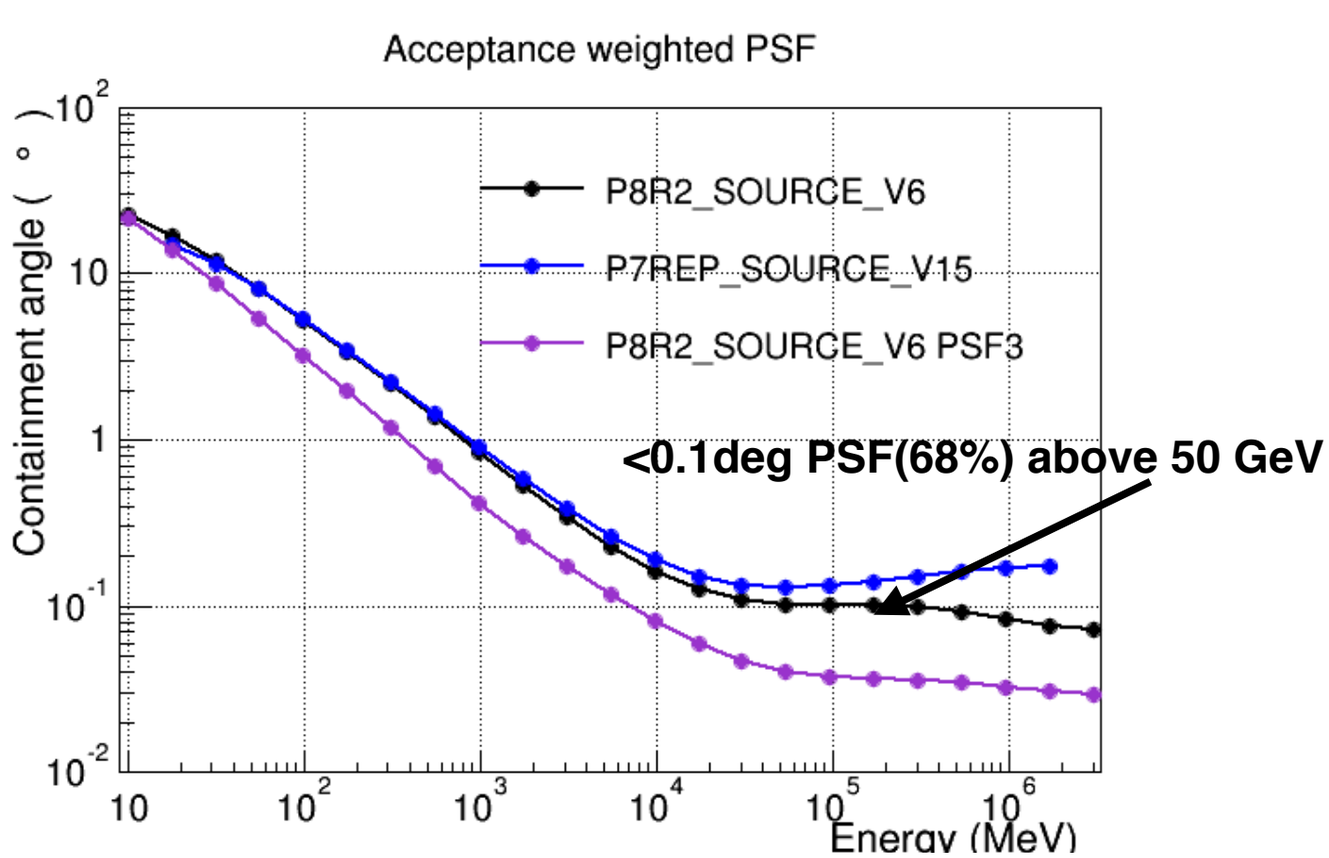
Fermi-LAT updates in 2015

- **Pass8**: Major update on instrument response function.
  Effective area and PSF has been significantly improved.

- All the 7.5-year data has been reprocessed with Pass8 and available now.



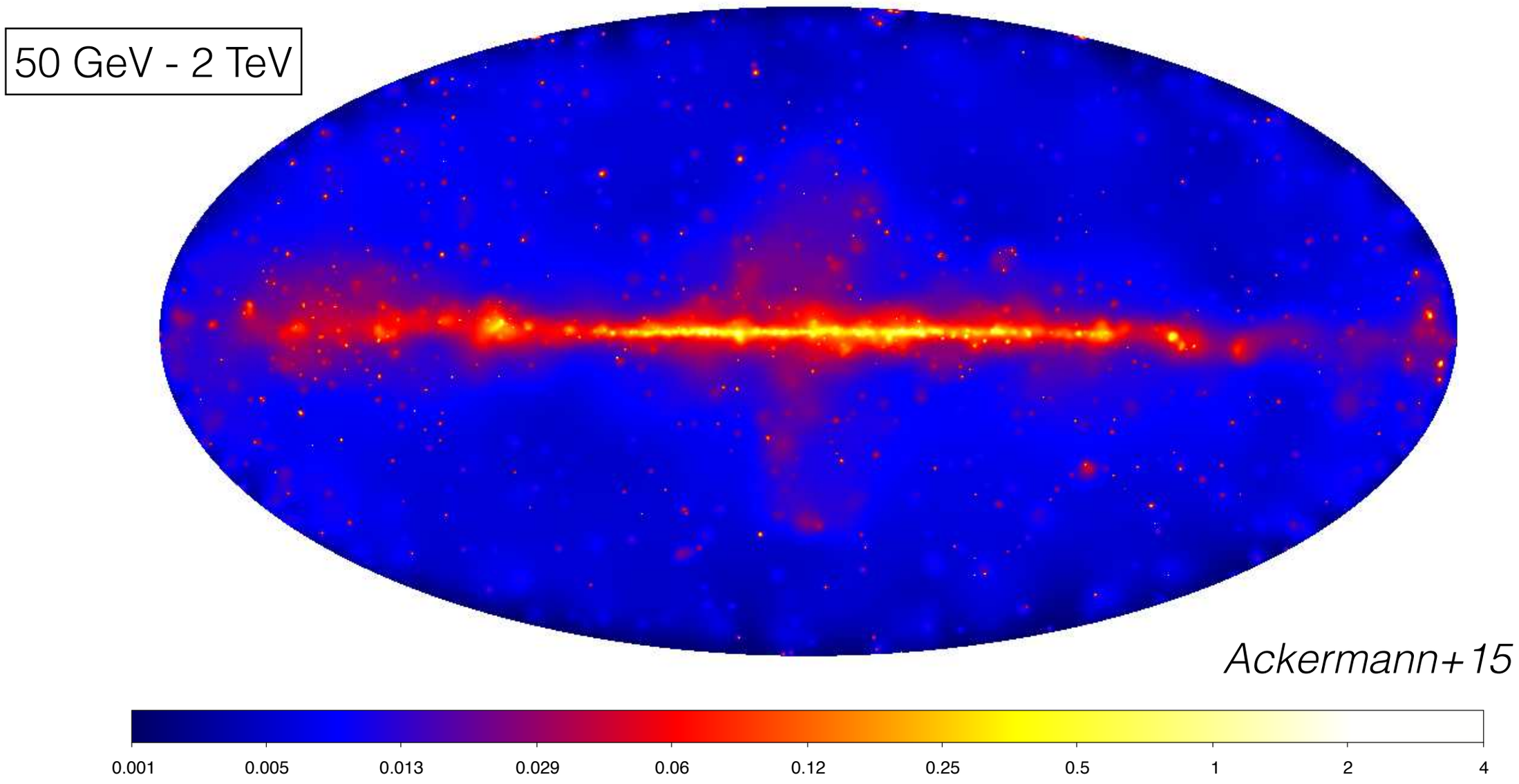




Wood+15

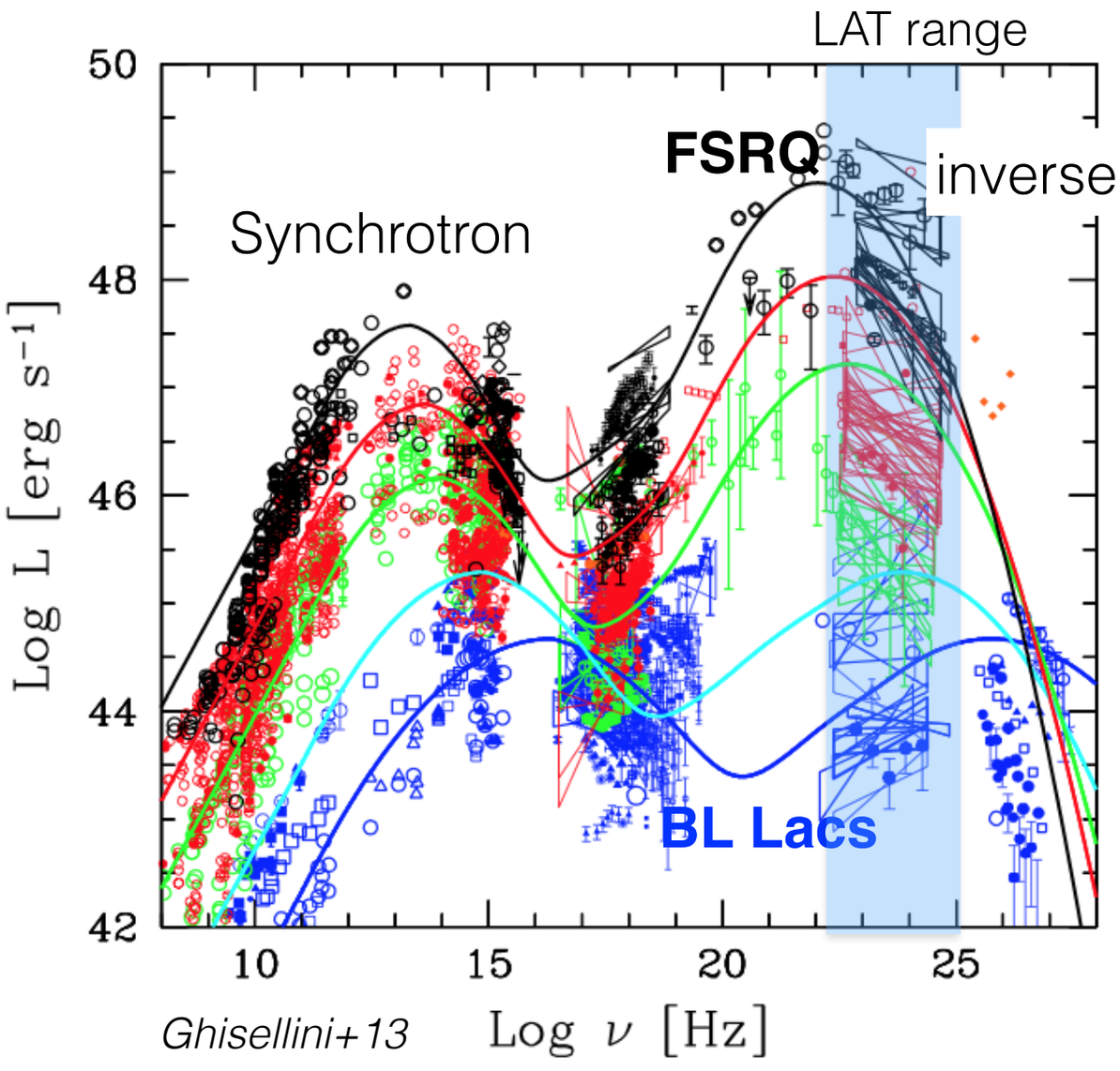
E>50 GeV sky observed by Fermi-LAT

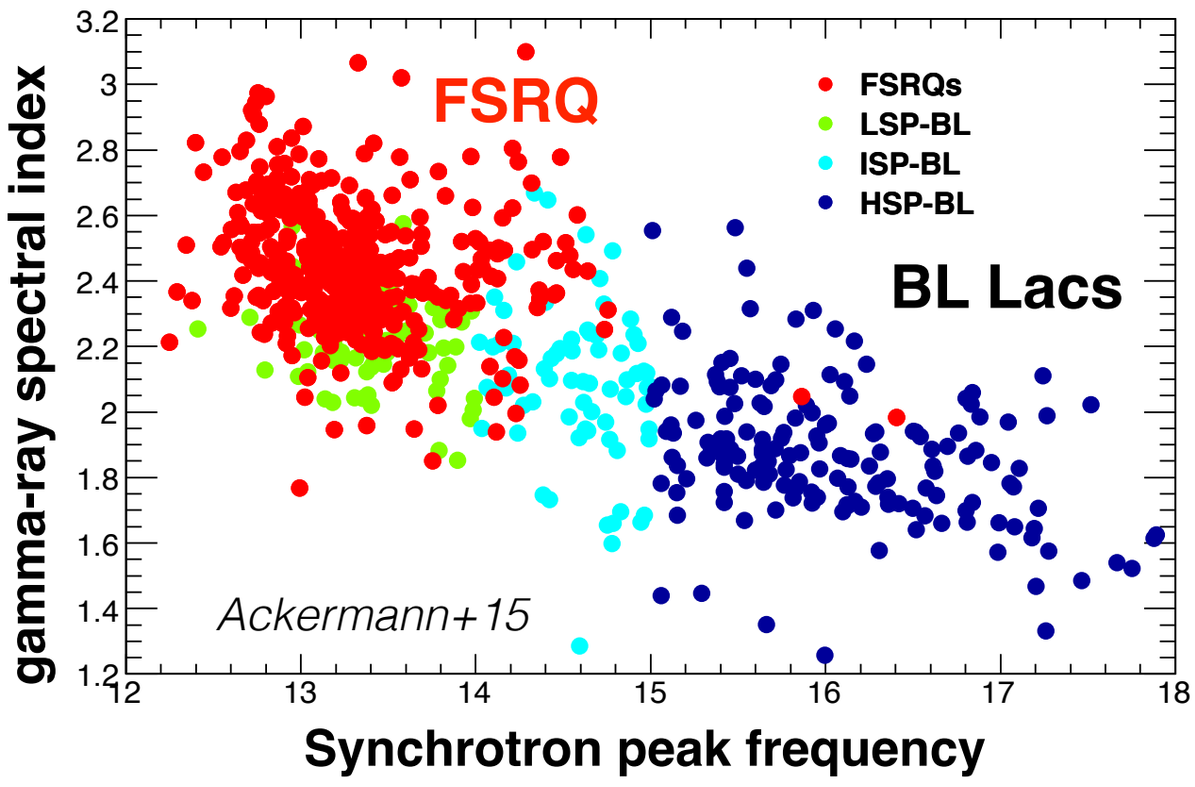
- **2FHL catalog** *(Ackermann+15)* based on Pass8 reprocessed 80-month data.
  61,000 photons in 50 GeV < E < 2 TeV
  360 sources detected
- **90%** of the 2FHL sources (excluding un IDs) are extragalactic sources, and most of them are blazars or blazar candidates.



Blazars

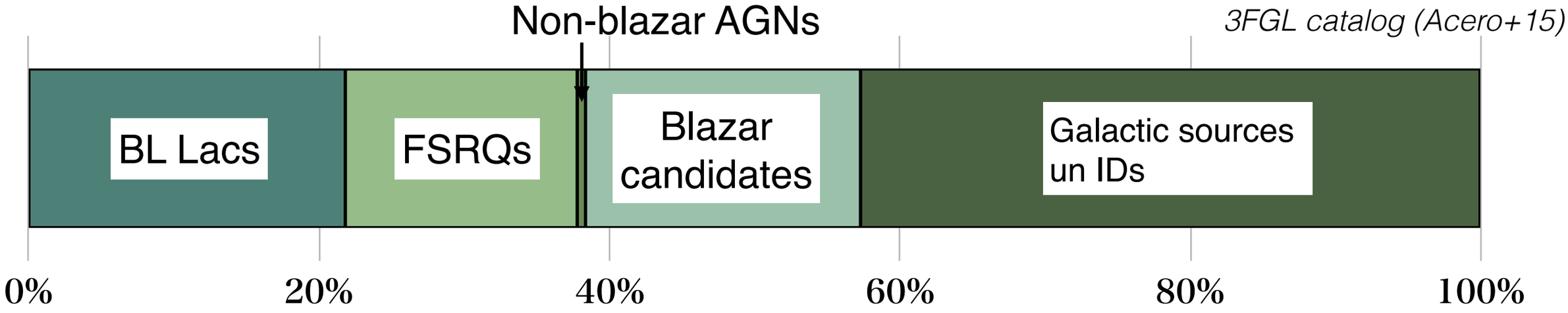
- Blazar : Radio galaxy with a relativistic jet direct toward the earth.
  FSRQs … emission line of EW>5Å, mass accretion rate of >1% Eddington limit
  BL Lacs … no emission line, low mass accretion rate



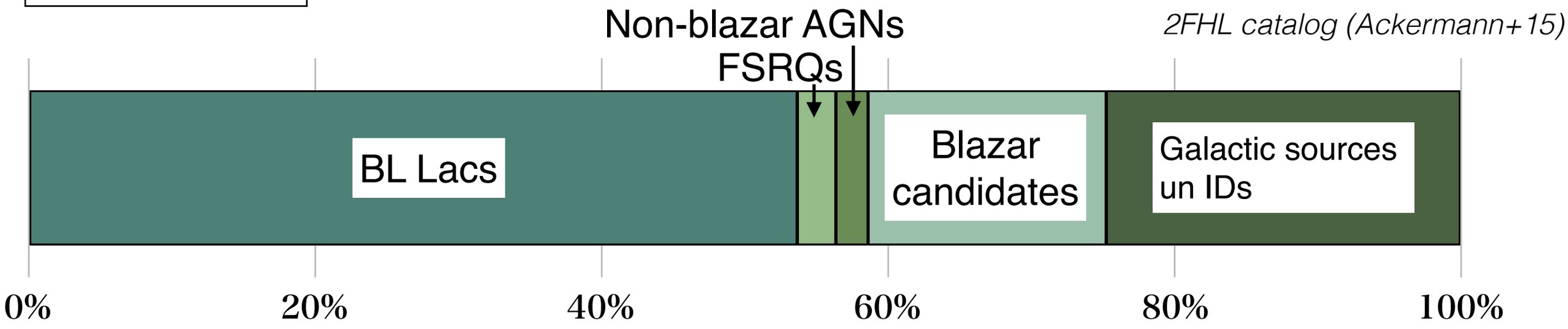


Source population

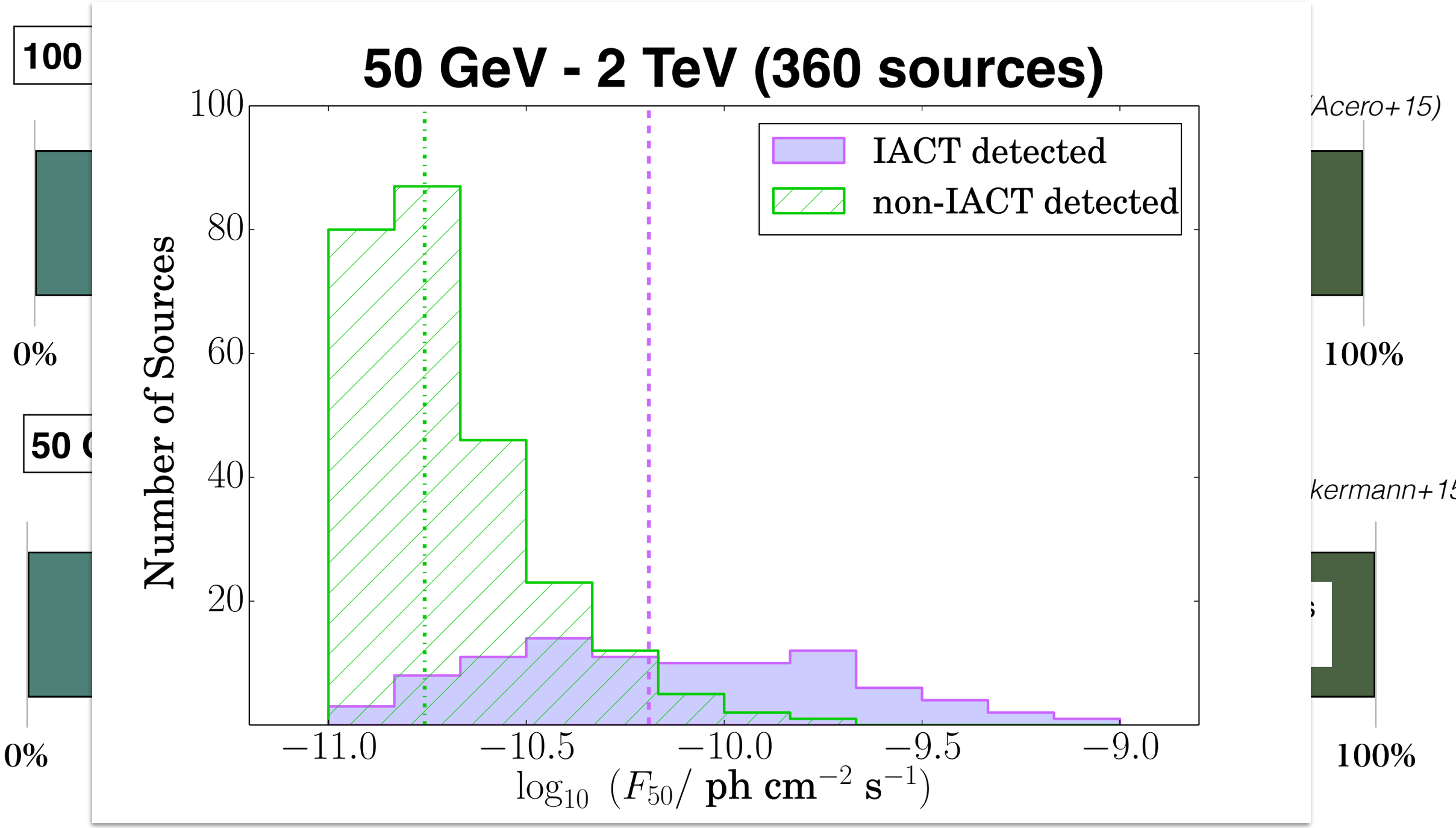
100 MeV - 300 GeV **3033 sources**



50 GeV - 2 TeV **360 sources**



Source population



- **282 (78%) of 2FHL sources have not been detected yet with IACTs.**
  → promising targets for CTA.

What can we infer from gamma-ray observations of AGNs?

Recent works with Fermi-LAT

Physics of AGN jets

- **Locating blazar zone and inferring underlying particle acceleration in relativistic AGN jets.**
  — Simultaneous broadband observations (e.g. 3C279; Hayahida+15)
  — Time-dependent modelling of flares (Asano+15, Saito+15)
  — Gamma-ray / VLBA observation of a radio galaxy (3C120; Tanaka+15, Casadio+15)

Cosmological measurements

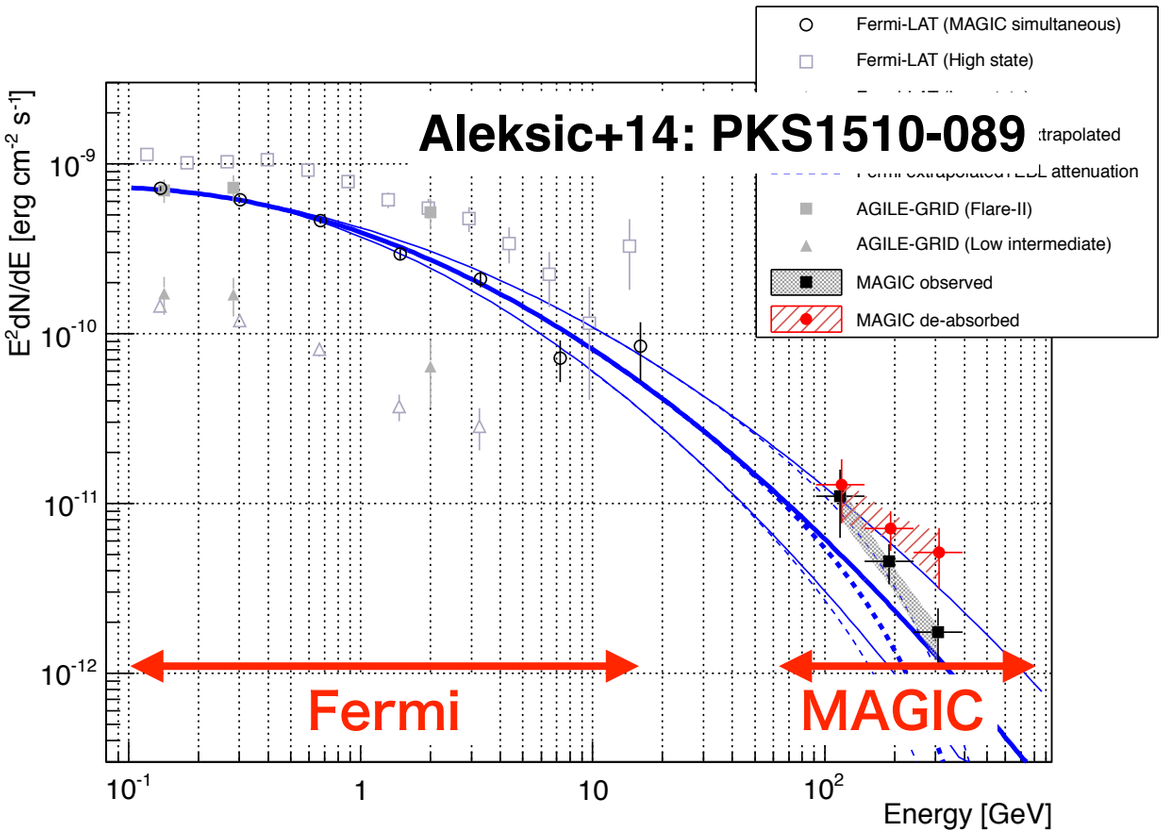
- **Extragalactic gamma-ray background (EGB)**
  — Resolving EGB into individual components (Ajello+15)
  — Constraints on cross section of dark matter annihilation (Ajello+15)
  — Constraints on TeV gamma-ray background (Inoue+15)

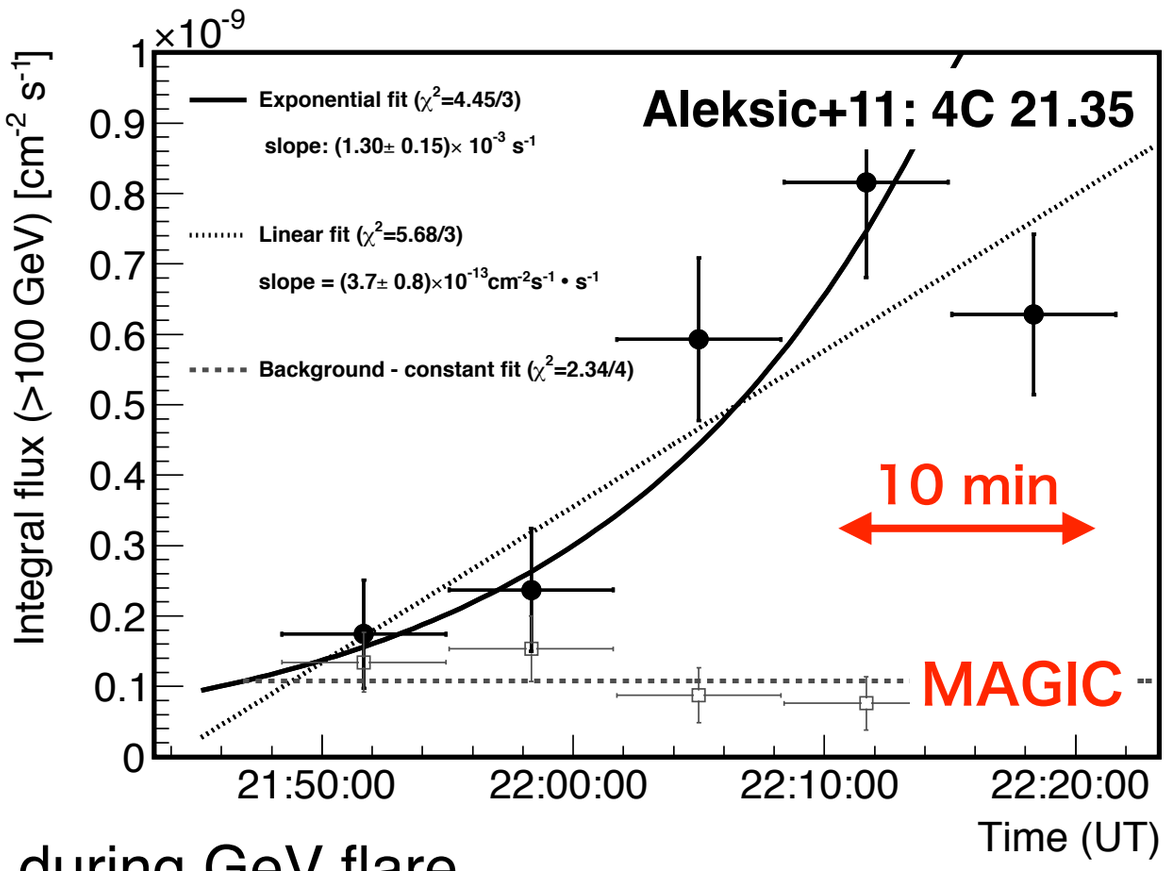
- **EBL / intergalactic conditions**
  — Testing EBL models (Atwood+13, Ackermann+15)
  — Constraints on inter galactic magnetic field (IGMF) (Finke+15)

Constraining emission zone in AGN jets

Location of Emission Zone in Blazars

- Kinetic luminosity of FSRQs is comparable to accretion power during flares.
- **The site and structure of the emission region is controversial.**
- Variability of a few hours is observed with Fermi-LAT. (Foschini+11, Saito+13, Brown +13, Rani+13, Hayashida+15)
  → Location of emission site: $R < c\delta\Gamma\Delta t/(1+z) \fallingdotseq$ **10^{16} cm ~ 100 R_G** (Δt=2hours, Γ=10)





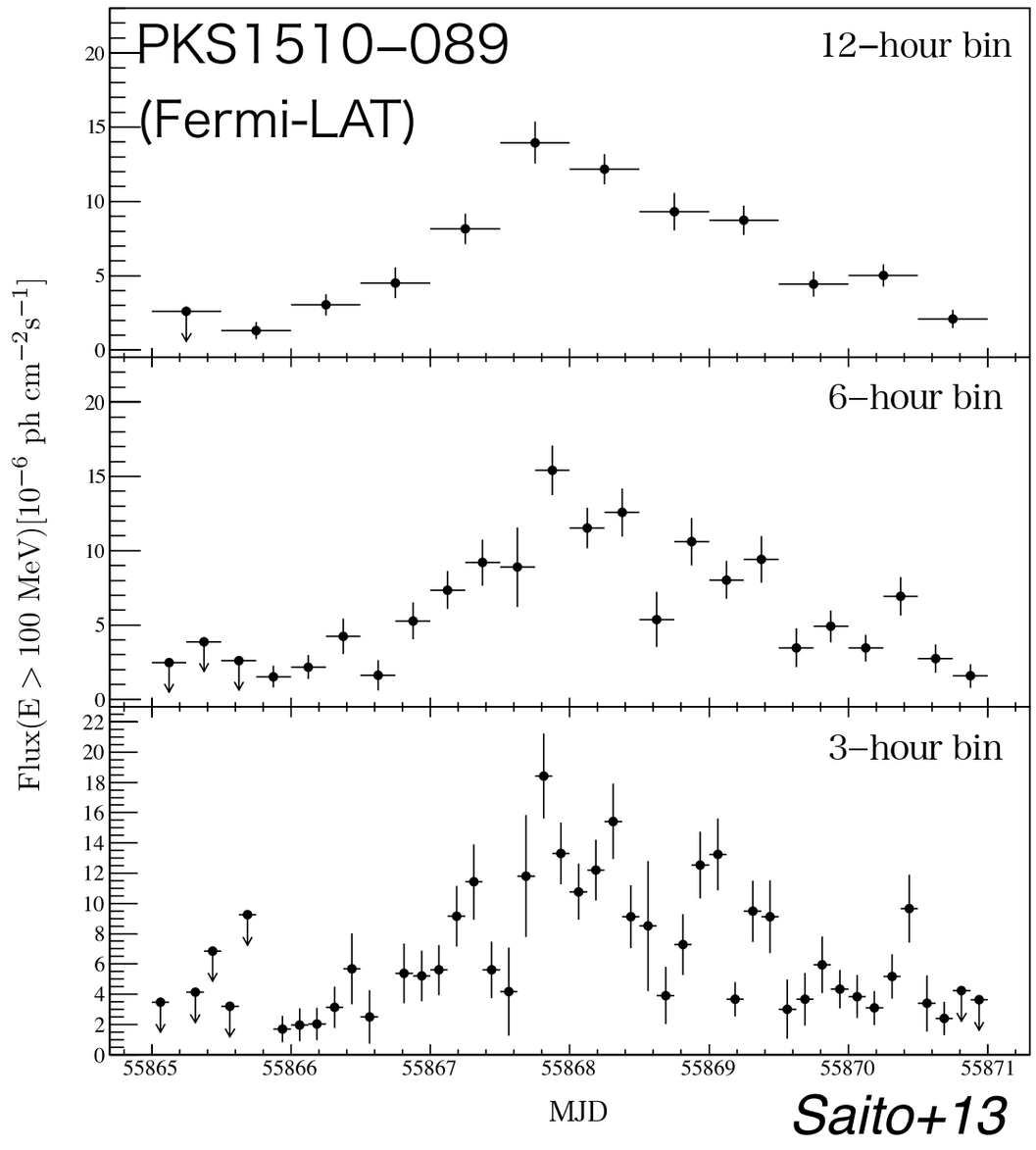
- Smooth connection of GeV and TeV spectra during GeV flare.
  →Suggesting co-spatiality of GeV/TeV emission zone locating outside BLR; **>10^{17} cm**, since VHE photon is absorbed in BLR due to $\gamma\gamma \rightarrow e^+e^-$.

- Variability of several minutes in TeV range

Time-dependent modeling of FSRQ flares

Constraining emission zone of FSRQs by modeling time evolution of SEDs during flares and fitting the simulated GeV gamma-ray light curves to observed ones.
(Saito+15)

• “Finer time resolution” is required to the data since an apparently coherent flare would be resolved into superposition of sub-flares with better resolution.

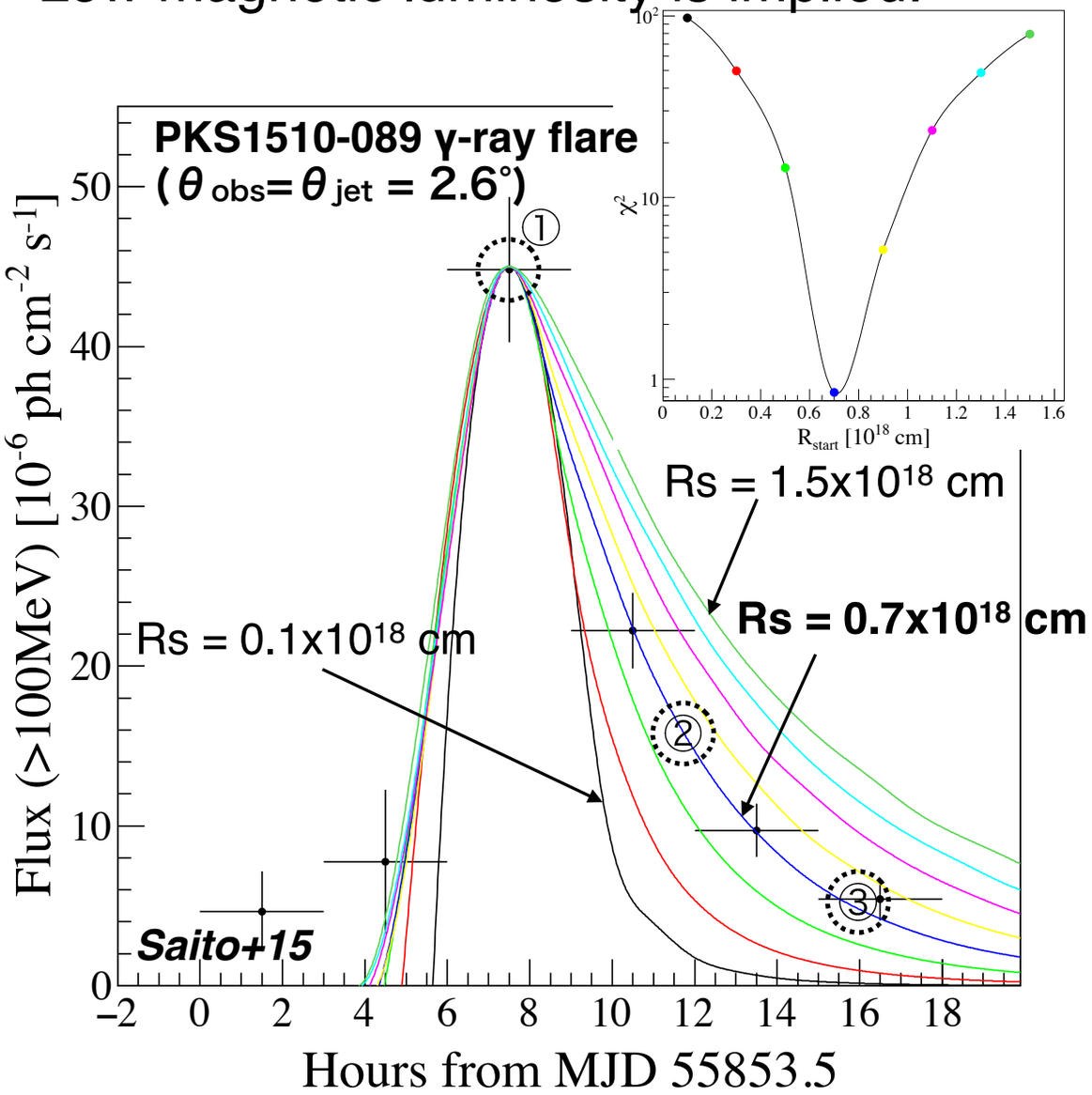


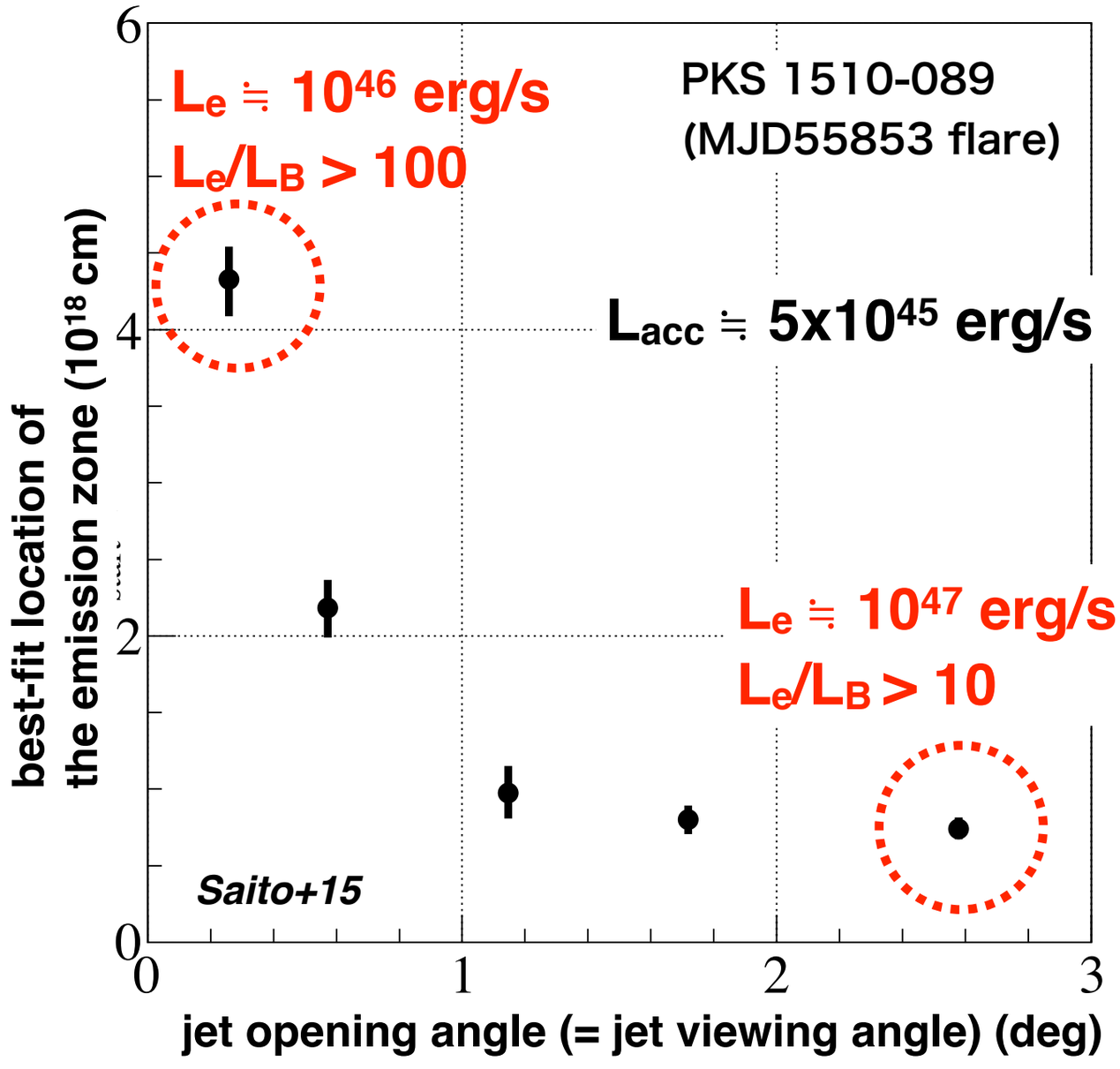
Constraints on the geometry of emission zone

- Time dependent single-zone model with given electron injection spectra.

- Distance of gamma-ray emission zone from the SMBH:
  0.7×10^{18} cm (0.2pc) ; $\Gamma\theta_{jet} = 1$
  4.5×10^{18} cm (1.5pc) ; $\Gamma\theta_{jet} = 0.1$ (*e.g. Jorstad+05, Clausen-Brown+13)*

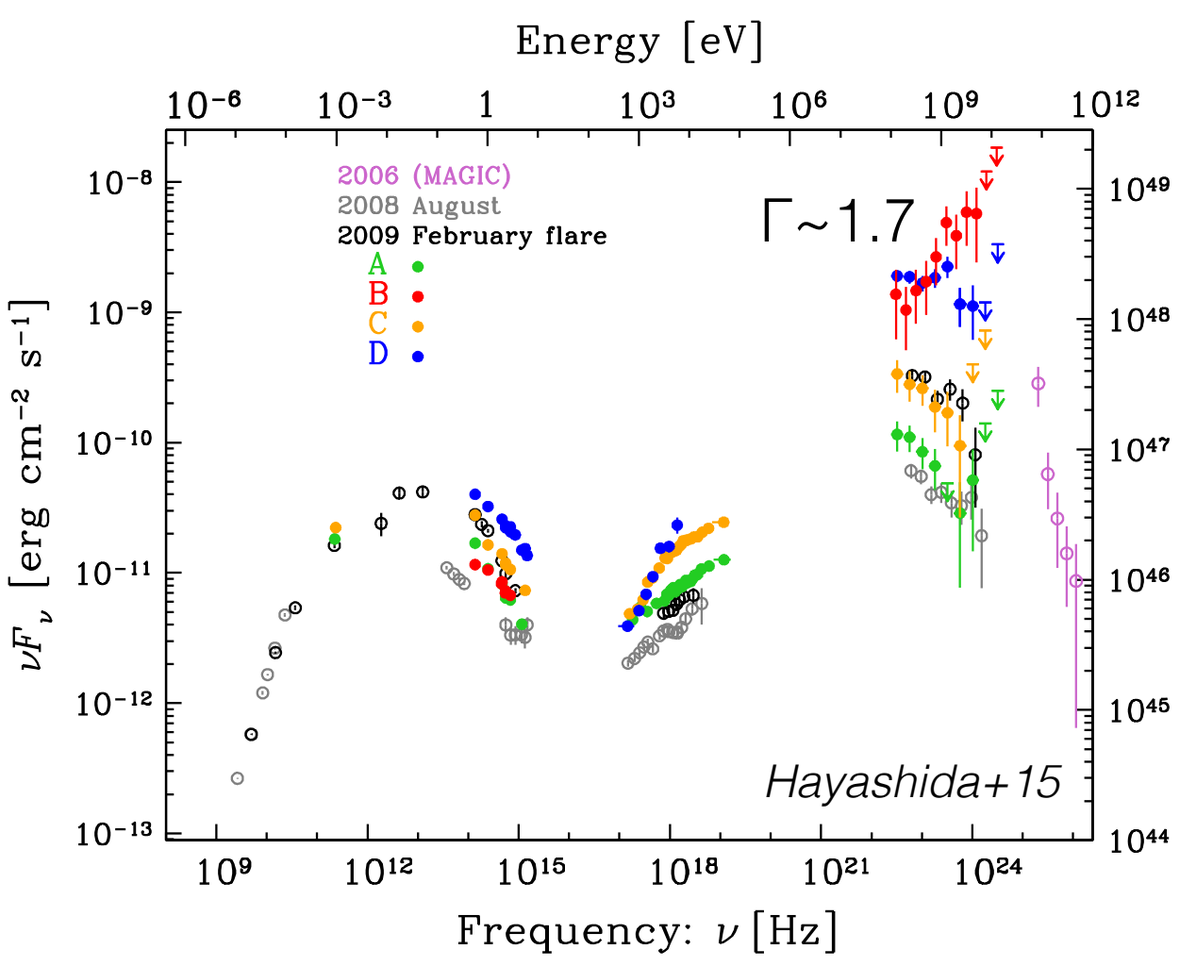
- Low magnetic luminosity is implied.

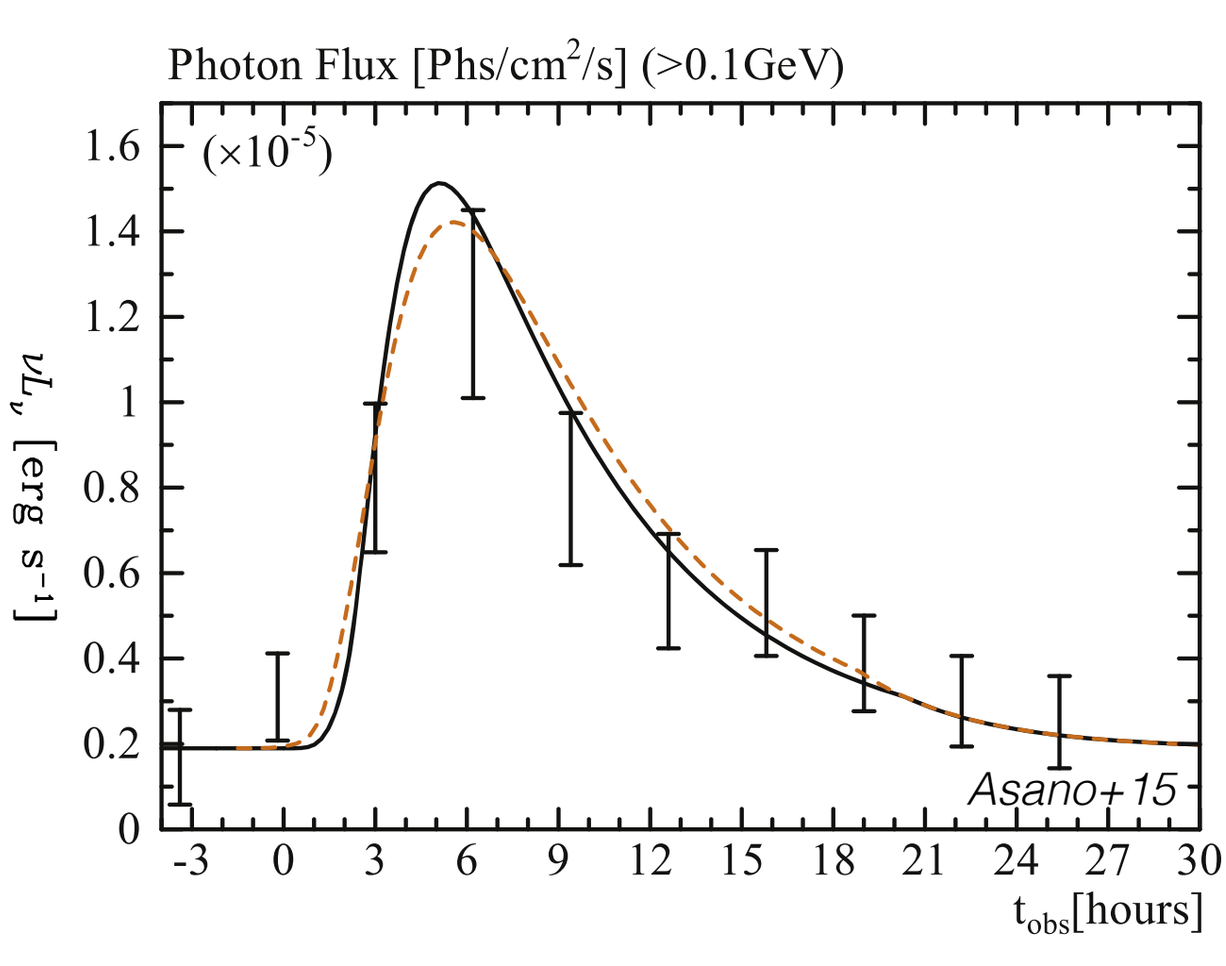




MWL observation of 3C279 huge flare

- Prominent gamma-ray flare with Γ~1.7 and fine variability profile. (Hayashida+15)
- One zone model could not explain X-ray spectrum.
- Low jet magnetisation; $L_B/L_j<10^{-4}$
- Acceleration by turbulence with varying magnetic field could explain time evolution of broadband SED during the flare. (Asano+15)

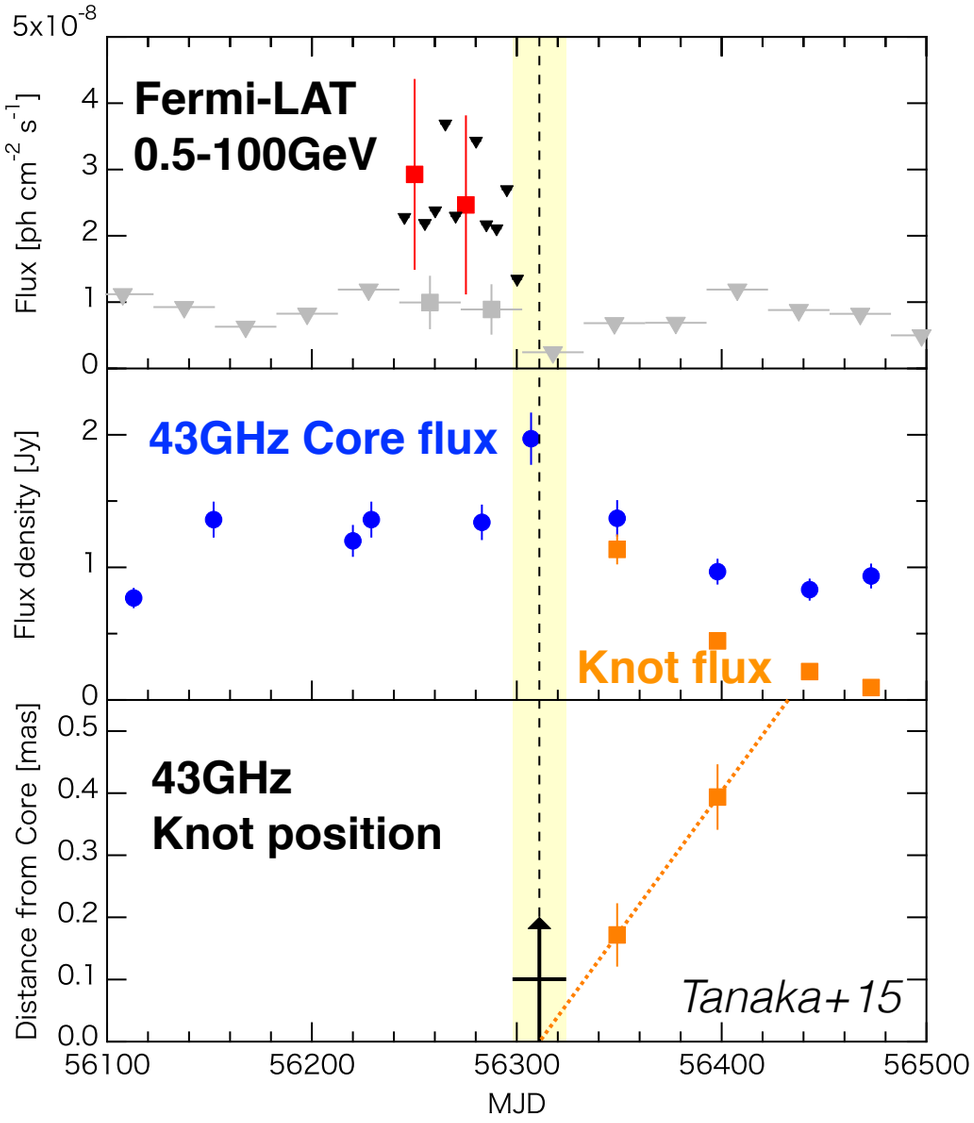


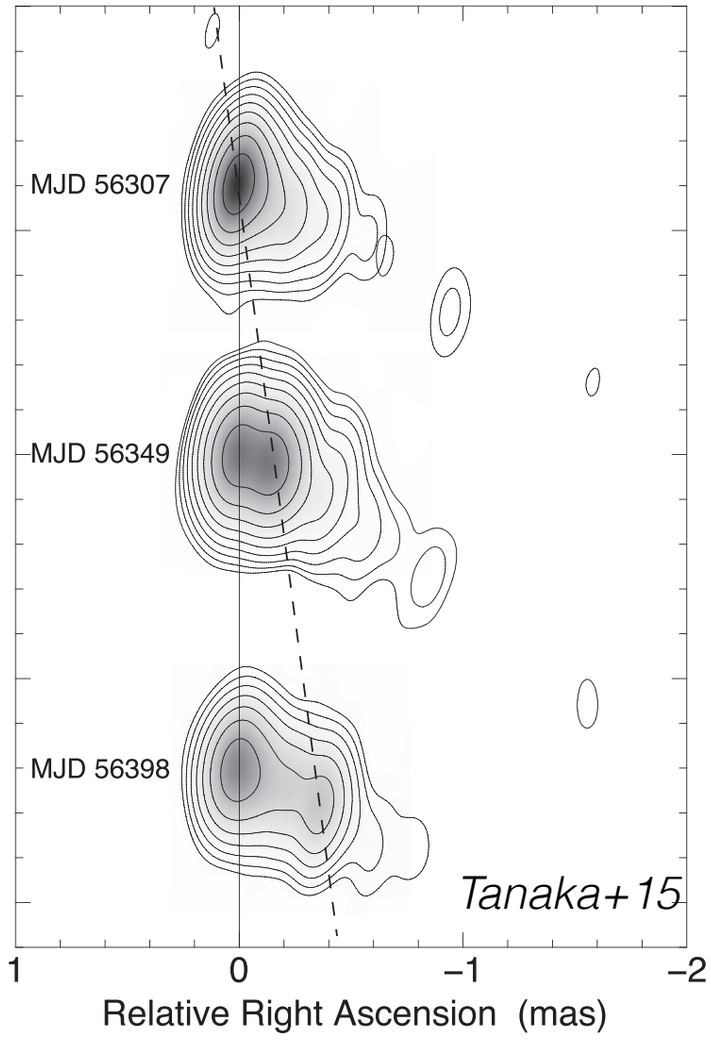


Radio galaxies

• ~15 radio galaxies has been detected by Fermi-LAT, which realize complementary study of AGN jets. (e.g. propagation of radio knots, monitoring physical change in jet and disk)

• Gamma-ray/radio observation of FR1 radio galaxy 3C120 (Tanaka+15, Casadio+15)
• Radio knot emerged 60 days after the gamma-ray brightening. Based on the time lag, gamma-ray emission site is estimated around ~0.1-0.3 pc from the central BH.



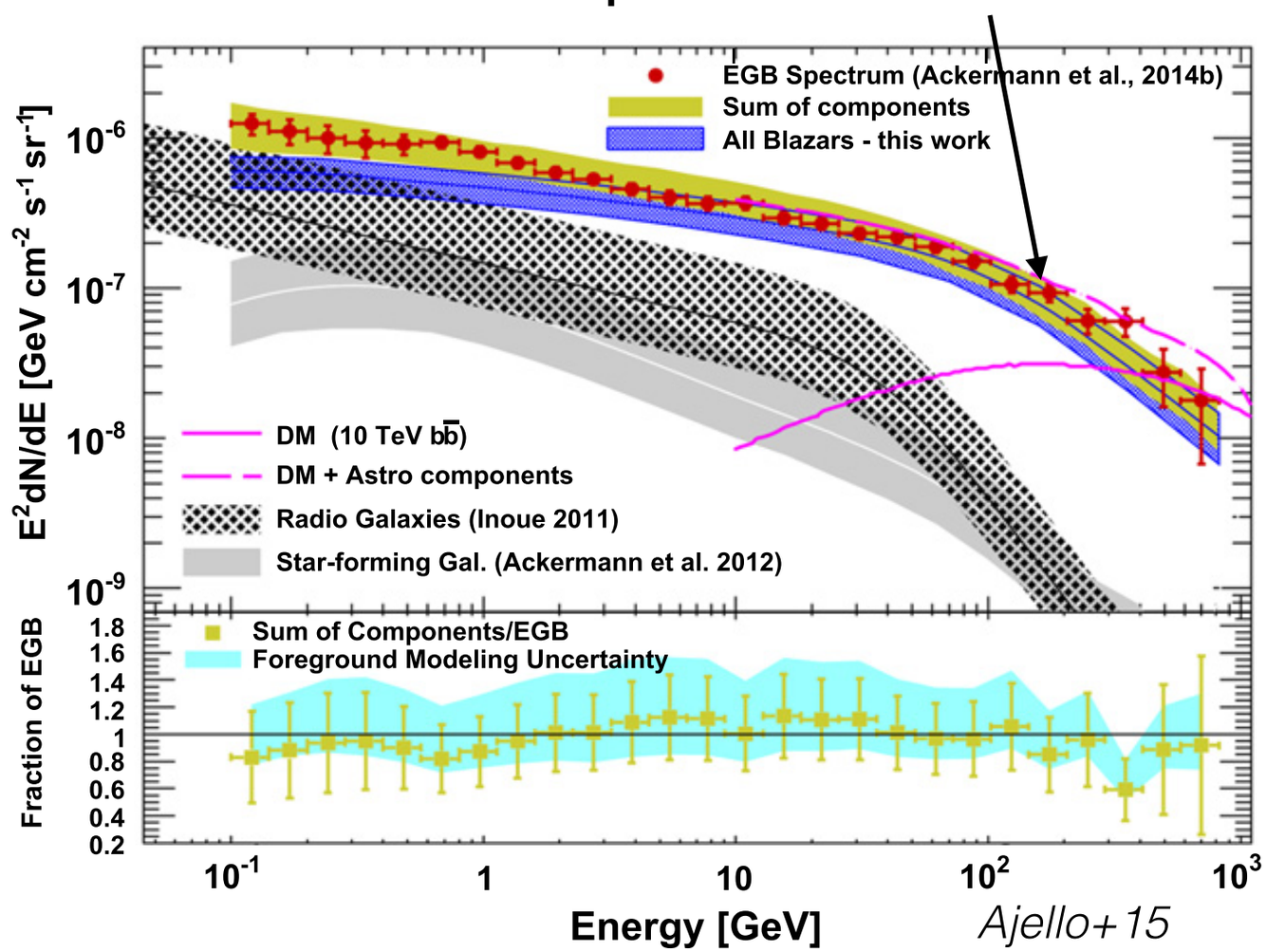


Blazars as a probe for cosmological measurements

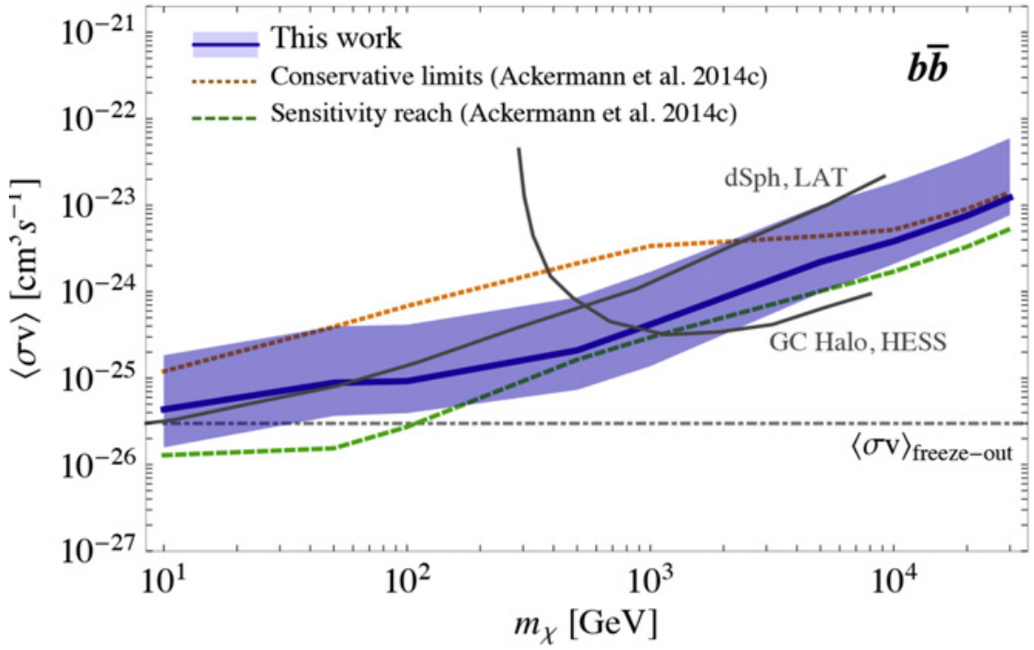
Extragalactic gamma-ray background

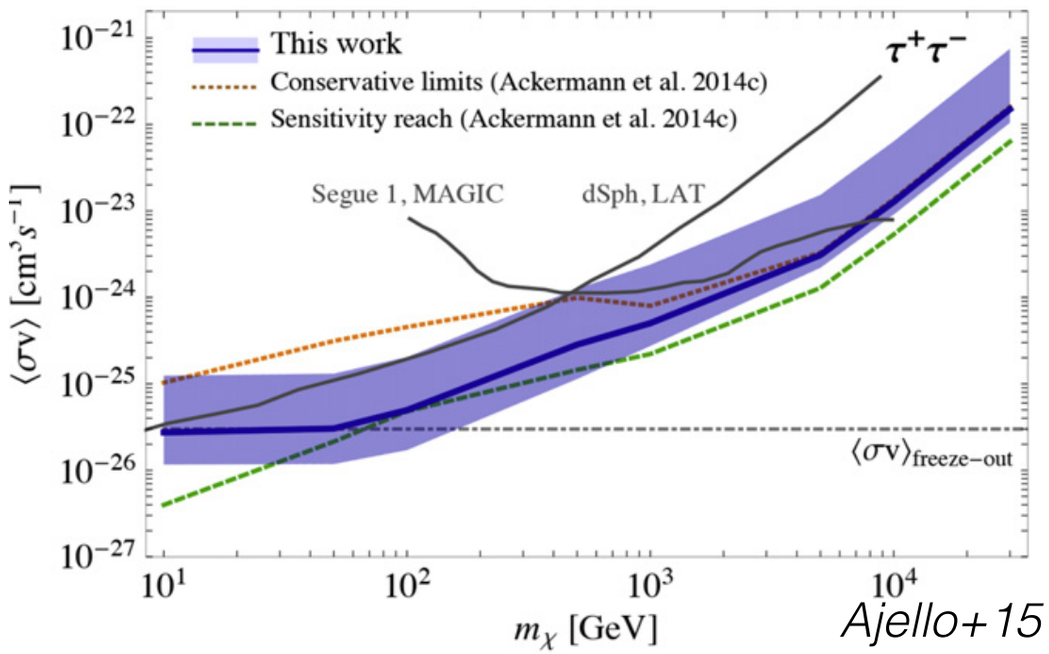
- Blazars constitute ~50% of extragalactic gamma-ray background (EGB) above 100 MeV.
- TeV background was constrained by Fermi-LAT/ VHE data (Inoue+15, Inoue+12)
- Dark matter annihilation cross section could be constrained within unresolved EGB and uncertainty of EGB estimation. (Ajello+15)

EBL attenuation of VHE photons from BL Lacs



Ajello+15





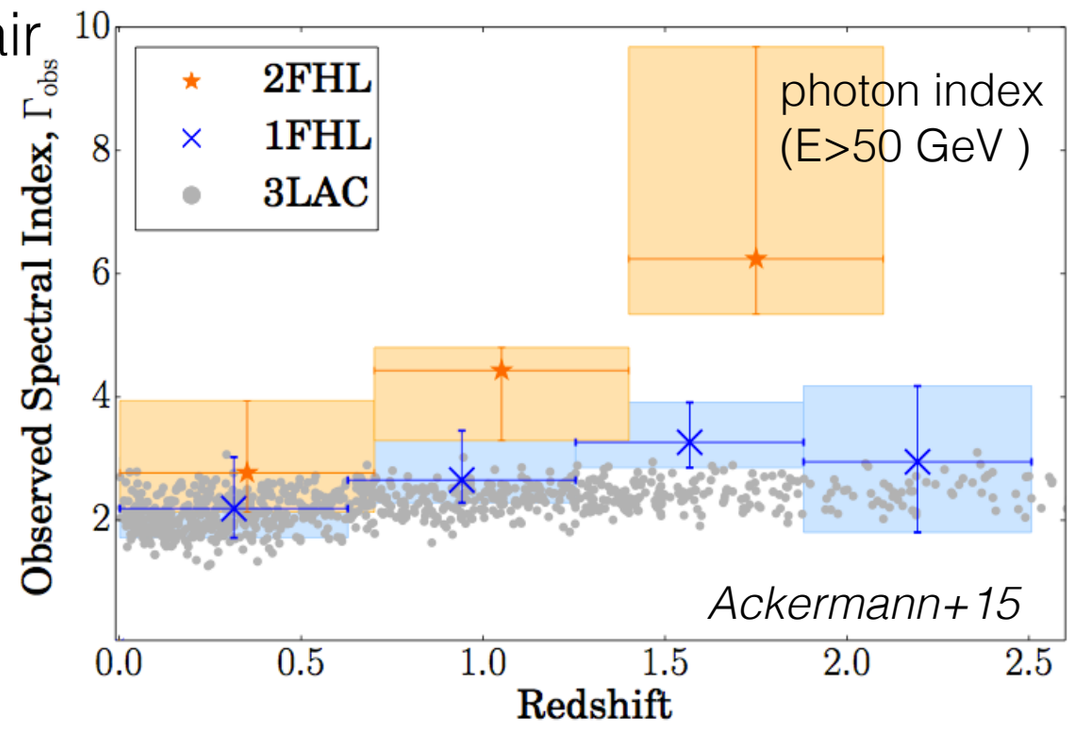
Ajello+15

Testing EBL models through high-z blazars

- VHE photons interact with EBL photons through pair production.
→Softer VHE spectral index at higher redshifts.

$$\gamma_{TeV} + \gamma_{eV} \rightarrow e^+ + e^-$$

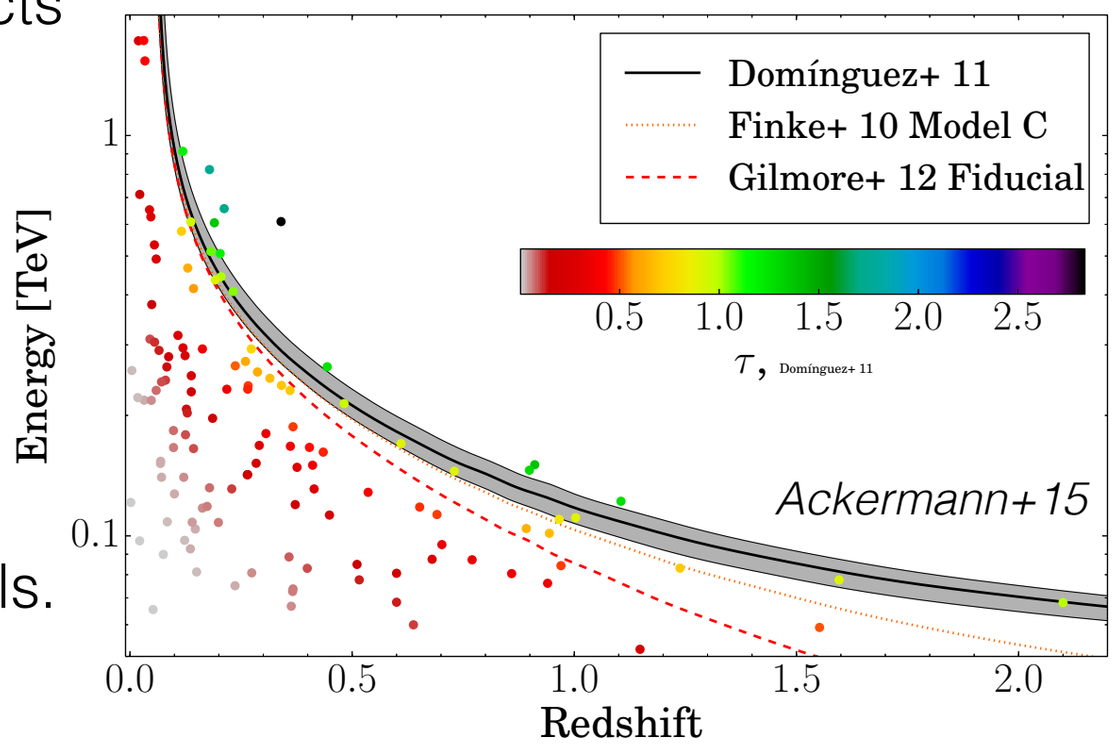
Photon index distribution vs redshift



- Detection of VHE photons from high redshift objects gives a test for current EBL models.

<u>E>100GeV photons from high-z blazars</u>
e.g.)
PKS0426+380(z=1.1) Tanaka+13
PKS1441+25 (z=0.94) Ahnen+15(MAGIC)

CTA will provide a more extensive test of EBL models.



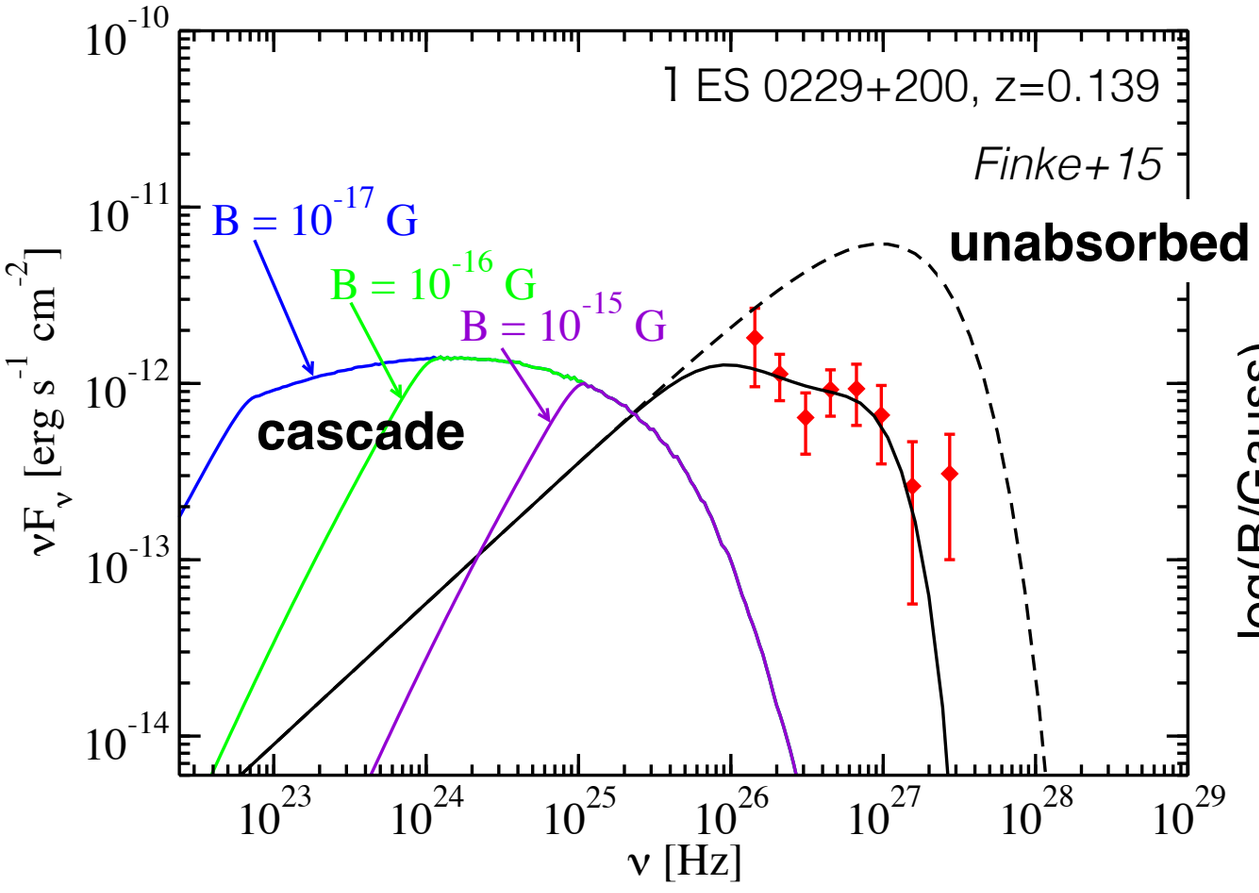
Constraints on intergalactic magnetic field

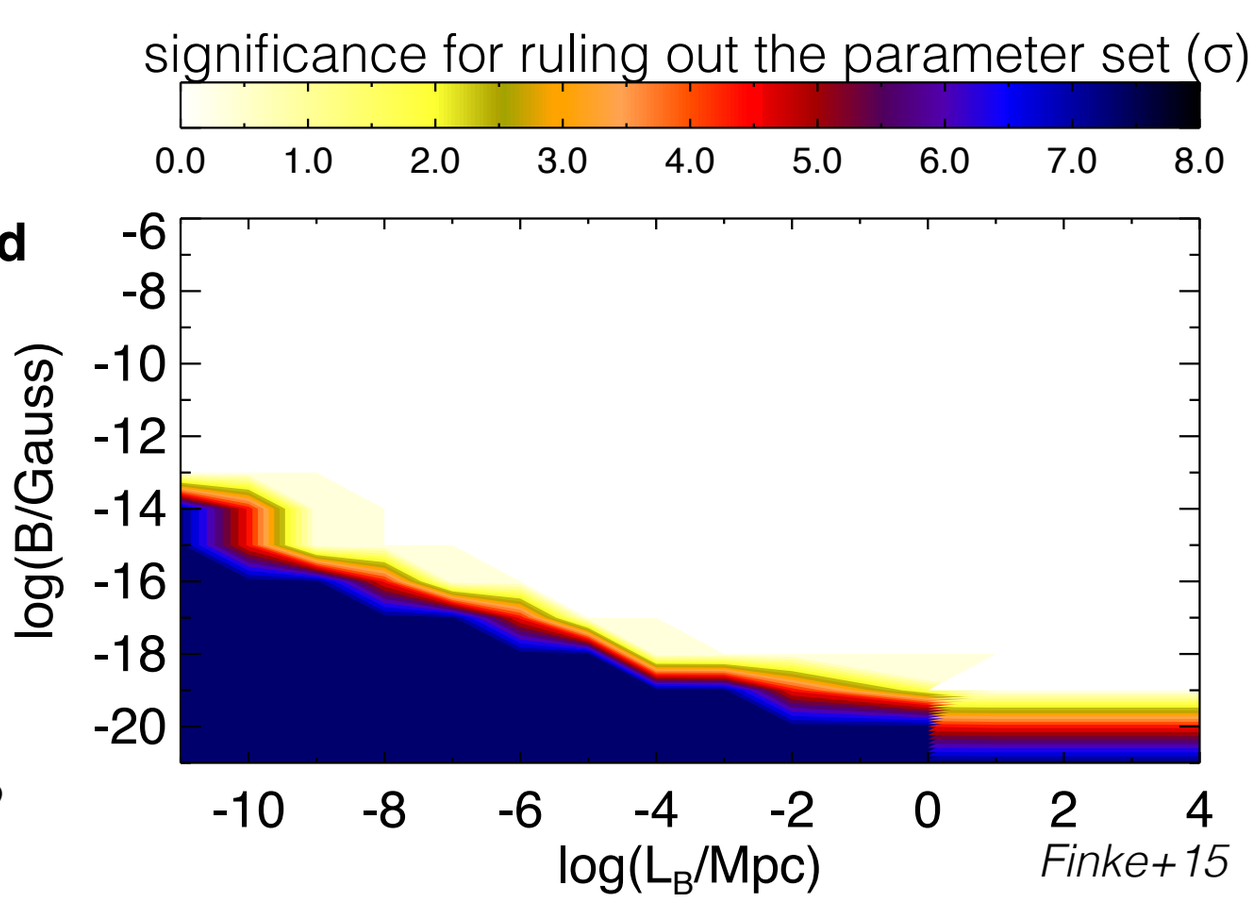
- Cascade emission

$$\gamma_{TeV} + \gamma_{EBL} \rightarrow e^+ + e^-$$
$$e^{+/-} + \gamma_{CMB} \rightarrow \gamma_{GeV}$$

- Intergalactic magnetic field (IGMF) deflects e+/e- pairs and suppress the cascade emission component.

- HE/VHE observations of BL Lacs at known redshifts constrain IGMF strength and coherence length since the expected cascade should be below the observed GeV flux.
- B $<10^{-19}$ G is ruled out for various EBL models. (Finke+15)





Summary

- Fermi-LAT detects 360 sources above 50 GeV, where ~80% of them has not been detected yet by any IACTs. The number of the Fermi-LAT samples will gradually increase as statistics increases. Catalogs like 2FHL will provide a promising target list for future CTA observations.

- Emission zone in AGN jets has been a long lasting problem, while recent studies with different approaches (e.g. time dependet modelling, MWL fitting) suggests blazar zone be locating at sub-pc distance from the SMBH. Future MWL observations including CTA with excellent photon statistics would remove degeneracy of jet models.

- Extragalactic gamma-ray background from 0.1GeV to ~ 1TeV is mostly resolved into blazars, radio galaxies, and star forming galaxies. Small room of unresolved EGB and uncertainty of the EGB estimation gives a tight constraint for annihilation cross section of the dark matter.

- CTA can test various EBL models through observations of high-z blazars.