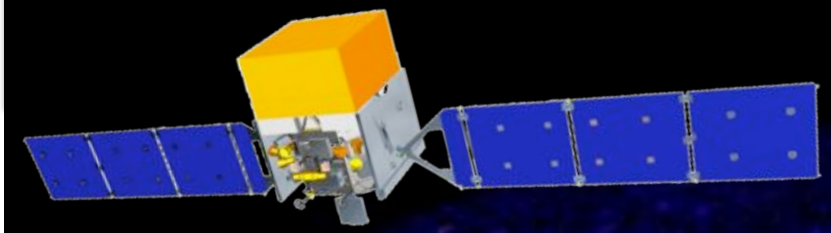


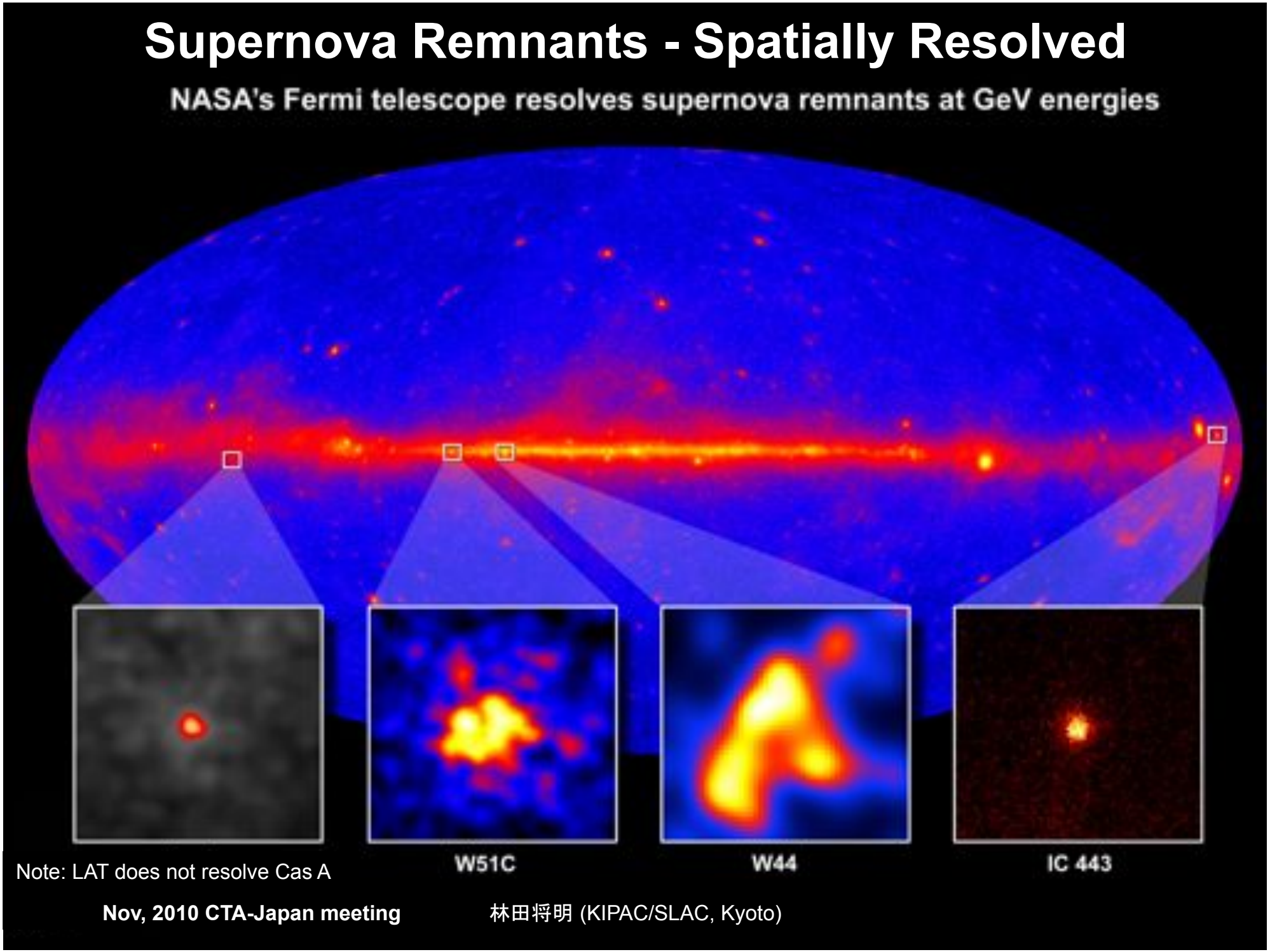
フェルミ衛星による活動銀河核からのガンマ線観測

林田将明

(KIPAC/SLAC, Stanford Univ. & 京都大学)

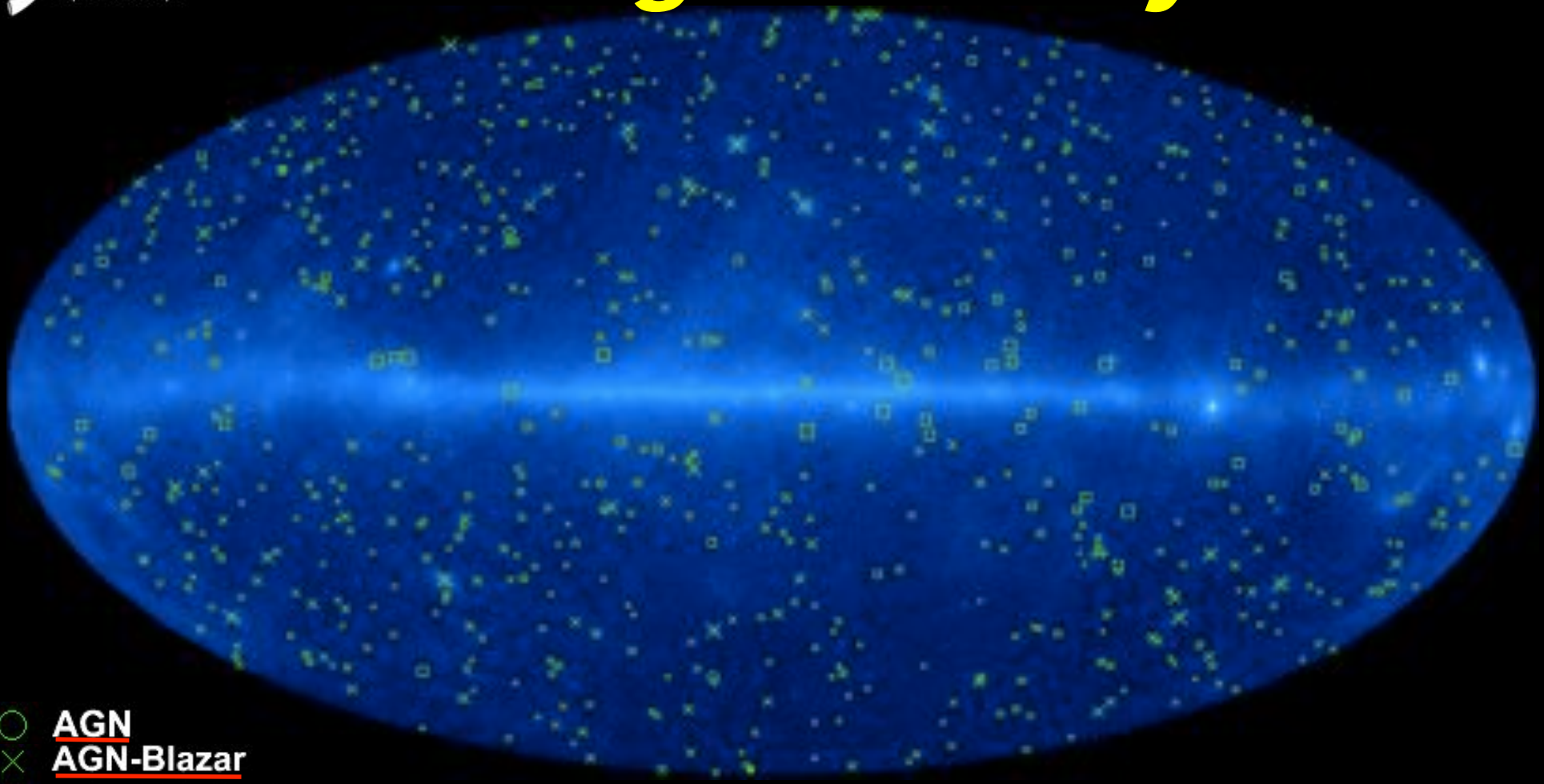
for the *Fermi*-LAT collaboration

Supernova Remnants - Spatially Resolved



Note: LAT does not resolve Cas A

The Fermi LAT 1FGL
Extragalactic Sky



○ AGN
× AGN-Blazar
□ AGN-Non Blazar
⊠ Starburst Galaxy
+ Galaxy

697 extragalactic sources among **1451** source (630 unID)
mostly AGNs, mostly blazar

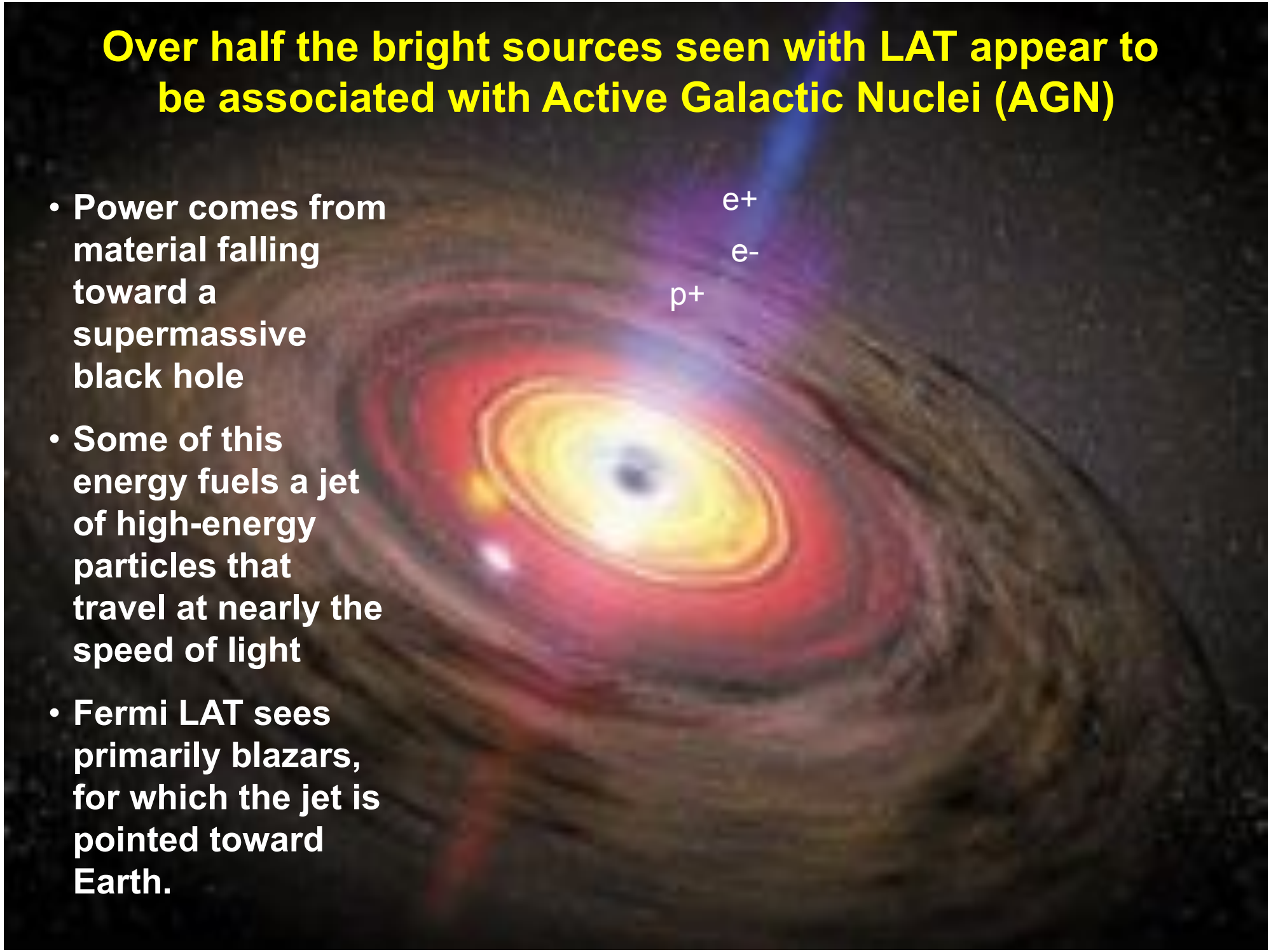
Credit: *Fermi* Large Area Telescope Collaboration

outline

- Blazar
  - Fermi view of blazar
  - jet structure
  - blazar emission model
- radio galaxies (“misaligned” blazar)
  - gamma-ray emission from ~pc to ~100 kpc
- UHECR from AGNs?

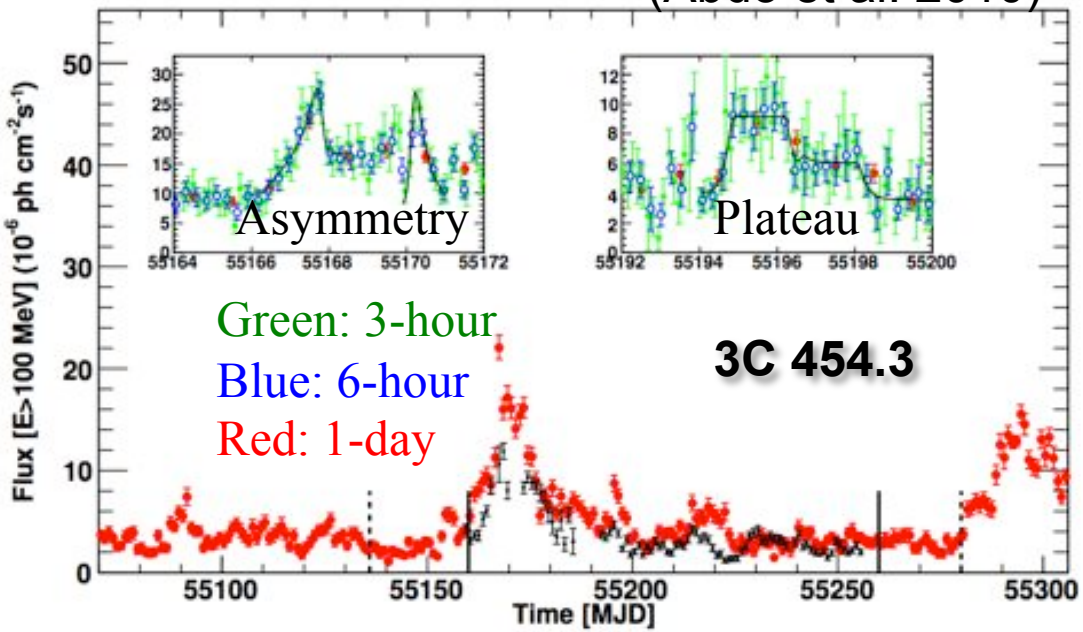
Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)

- Power comes from material falling toward a supermassive black hole
- Some of this energy fuels a jet of high-energy particles that travel at nearly the speed of light
- Fermi LAT sees primarily blazars, for which the jet is pointed toward Earth.

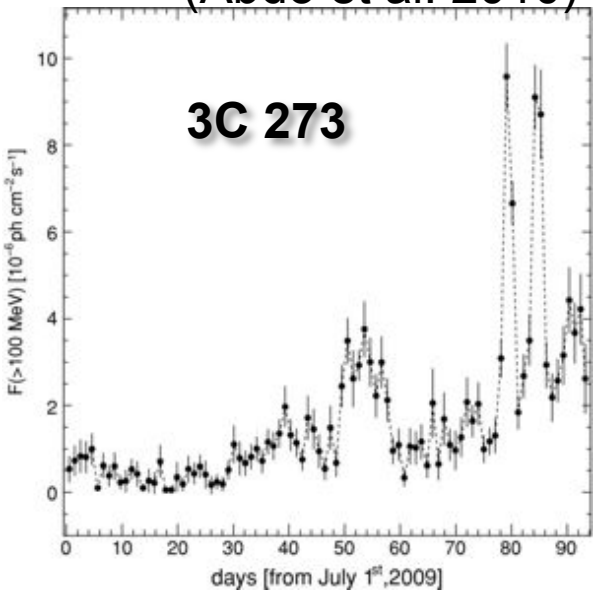


strong variability!!

(Abdo et al. 2010)



(Abdo et al. 2010)



Doubling timescale is ~3 hours

<variability timescale>

$$t_{var} \simeq \frac{(1+z)\,R}{c\,\delta} \cdot$$ **(3 hours)**

From the requirement that γ−γ opacity (e.g., Dondi+95), there should be

relativistic beaming effect!!

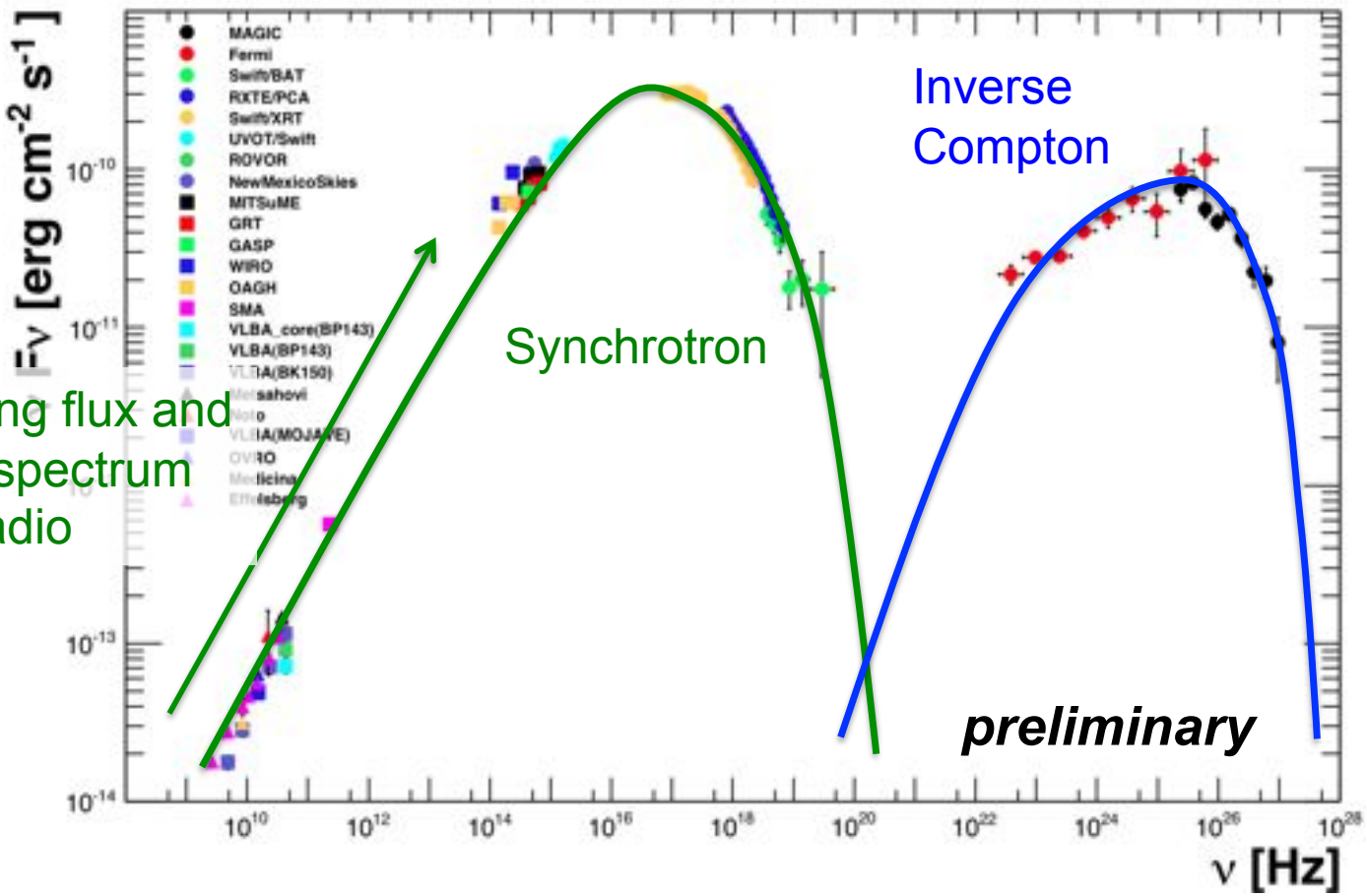
<minimum Doppler factor>

$$\delta_{min} \cong \left[\frac{\sigma_T d_L^2 (1+z)^2 f_{\hat{\epsilon}} \epsilon_1}{4 t_{var} m_e c^4}\right]^{1/6}$$

(> 13)

broad band emission

Mkn 421 (real simultaneous data)



strong flux and flat spectrum in radio

boosting factor : δ

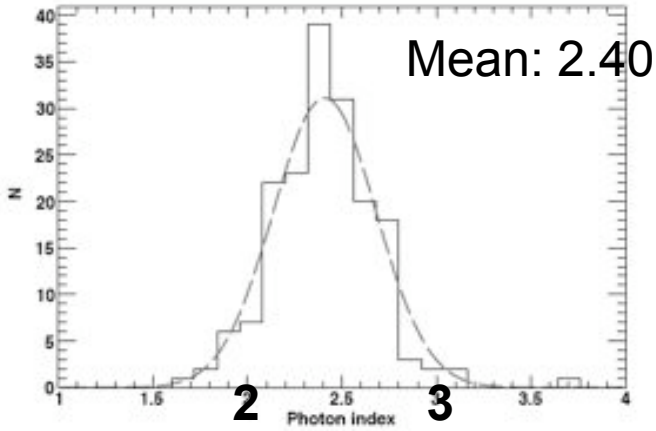
$E = \delta E'$

$L = \delta^{(3+\alpha)} L'$

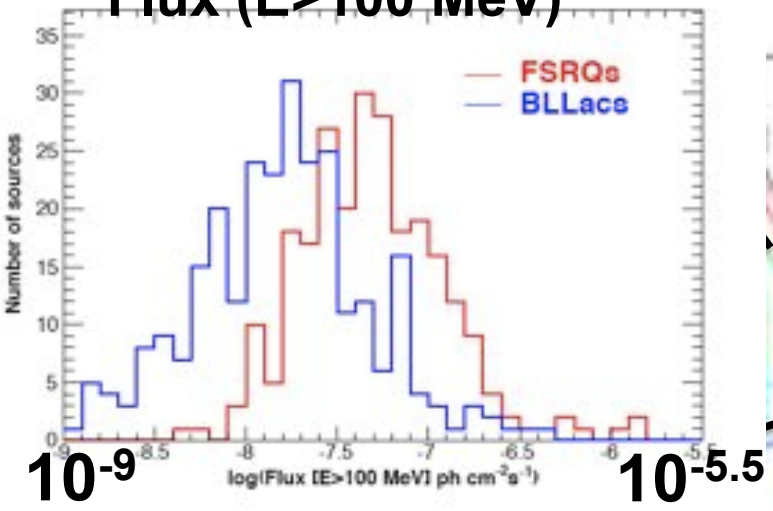
radio → **TeV**

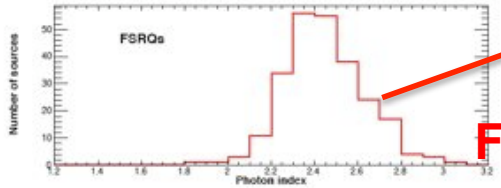
Blazar sequence

photon index

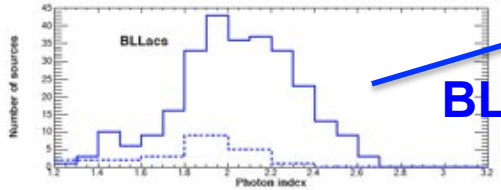


Flux (E>100 MeV)

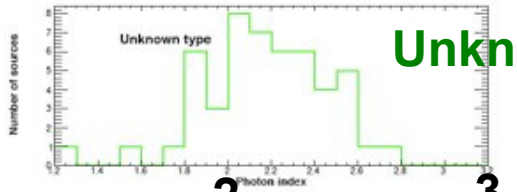




FSRQs

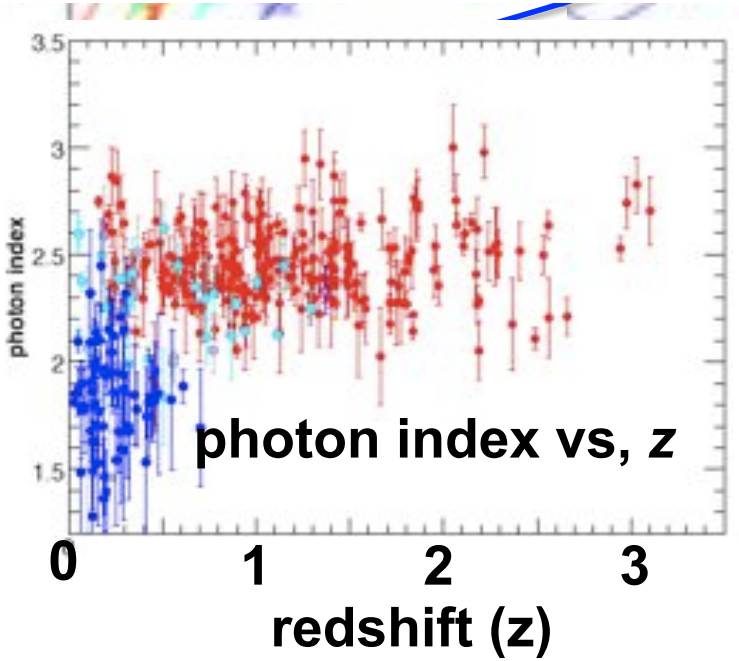


BL Lacs



Unknown type

2 3



photon index vs, *z*

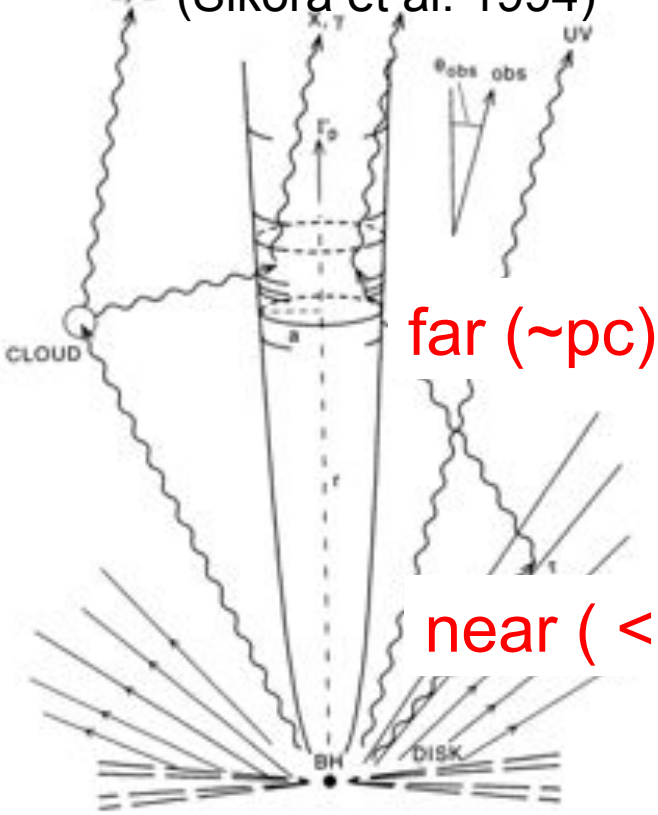
(Abdo et al. 2010, 1LAC)

in the HEAD meeting (in March 2010) by Roger Blandford

Ten Challenges

1. Locate the sites of radio, γ emission
2. Map jet velocity fields
3. Verify the emission mechanism
4.
5.
6.
7.
8.
9.
10.

(Sikora et al. 1994)



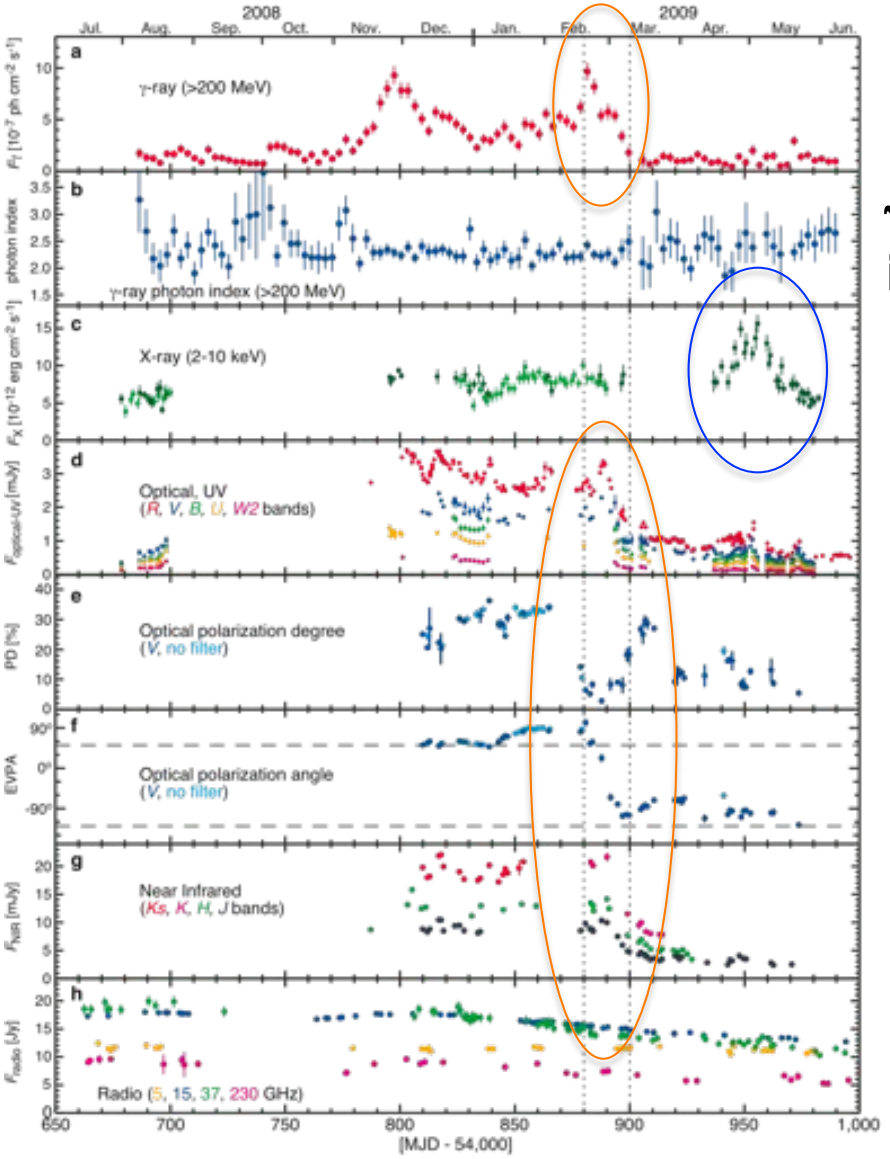
far (~pc) ?

near (< sub-pc) ?

particles (e^+/e^-) are accelerated in the collimated jet (bulk speed: $\Gamma > 10$)

- geometry
  -> one-zone model is still valid?
- What is the seed photon for γ-ray?

3C 279 multi-band observations



γ-ray (LAT)

γ-ray photon index (LAT)

X-ray

optical-UV

光学偏光度 (PD)

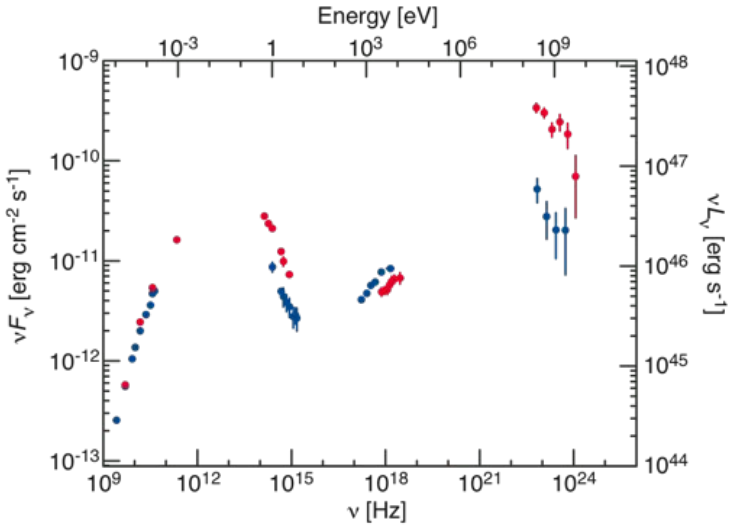
光学偏光角 (EVPA)

Near -Infrared

Radio

3C 279: FSRQ, z=0.536
mass ~ (3-8)x$10^8 M_{solar}$

Light curves between July 2008 to June 2009 (~ 1 year)

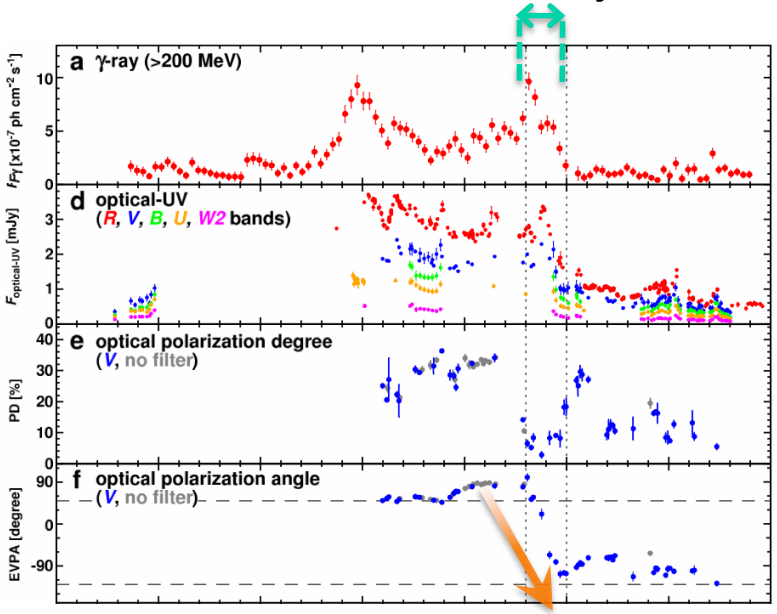


Nature, Abdo et al. (2010) **463**, 919–
Contact authors : **林田将明**, G.Madejski

Complex jet structure

ration of polarization angle lasts 20 days

20 days



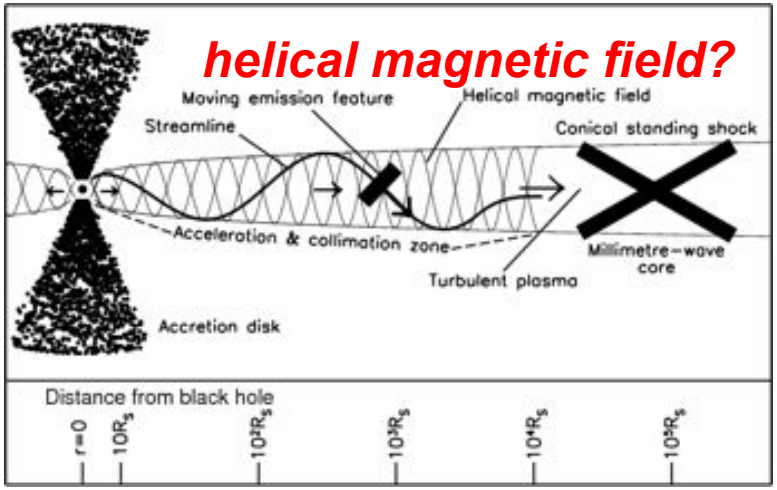
γ

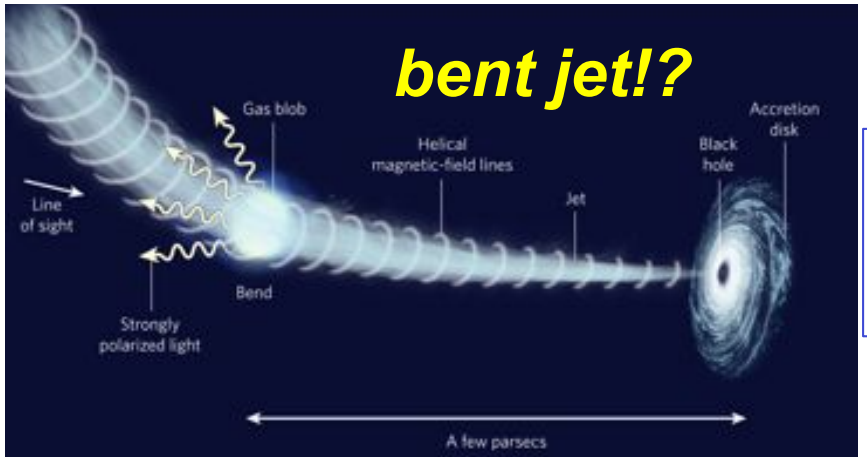
opt.

PD

EVPA

emission zone locates
pc *scale* (~10^5 r_g) from the BH





similar behaviors were observed in
- PKS 1510-089 (Marscher et al. 2010, ApJ)
- 3C 454.3 (Sasada et al., 2010, COSPAR)

emission zone in blazar

- **dominant source of seed photons can be:**

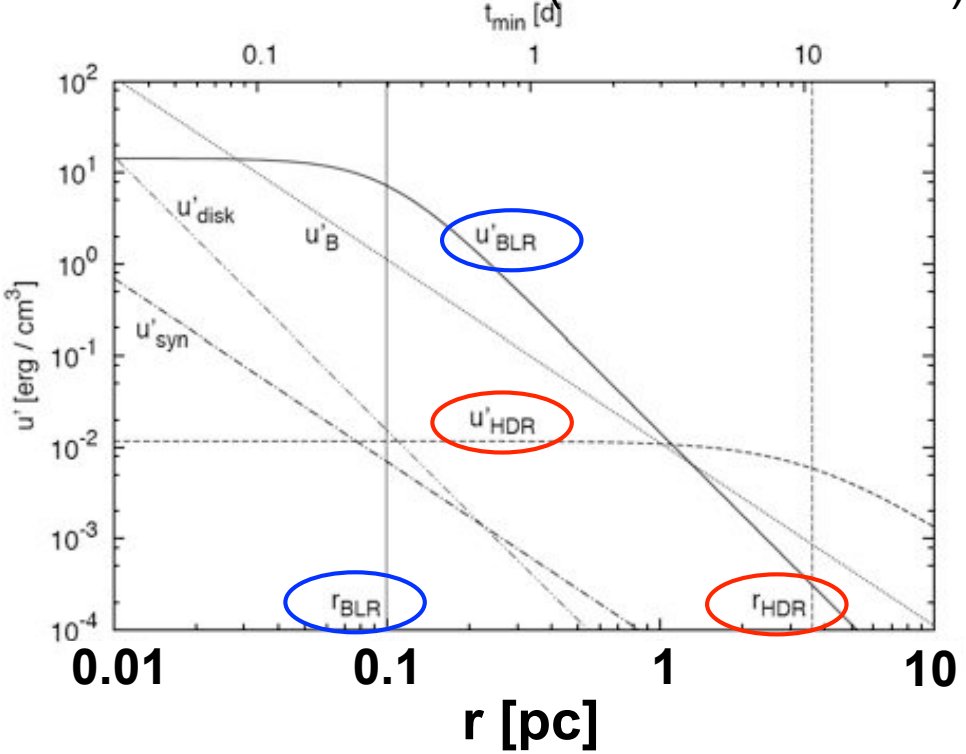
1. **a few pc: IR photon**
   -> hot dust region [HDR]

$$r_{\rm HDR} \simeq 4 \left(\frac{L_{\rm disk}}{10^{46}\ {\rm erg\ s^{-1}}}\right)^{1/2} \left(\frac{T}{10^{3}\ {\rm K}}\right)^{-2.6} {\rm pc}$$

2. **a few x 0.01 pc: UV photon**
   -> broad line region [BLR]
   (or direct accretion disk)

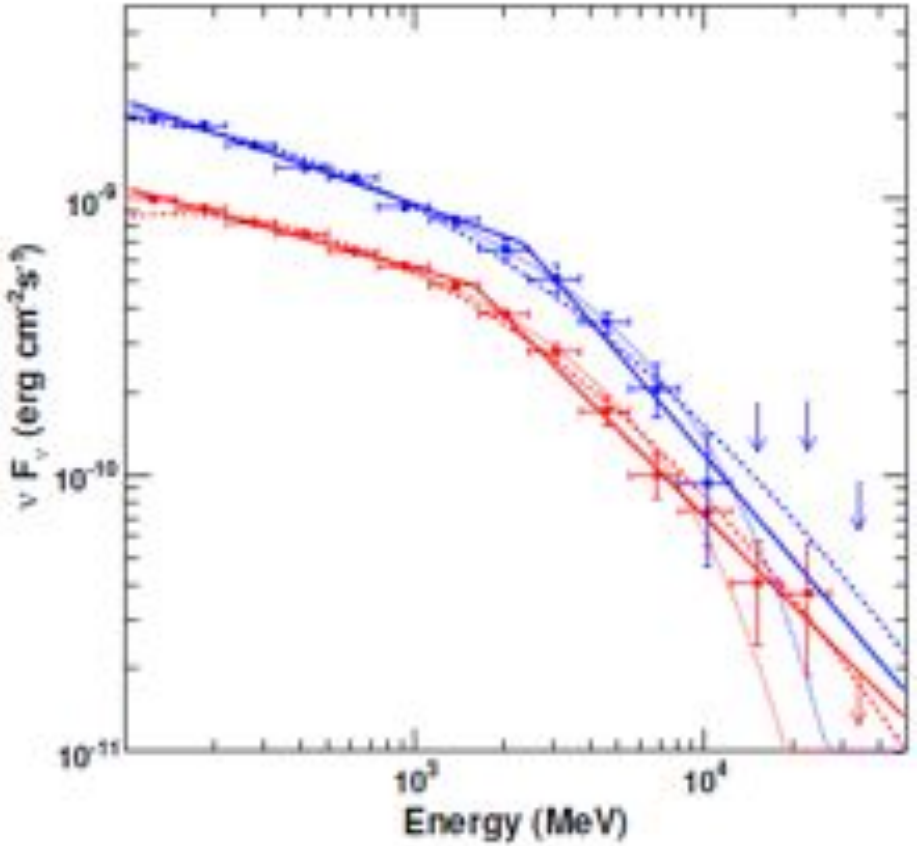
$$r_{\rm BLR} \simeq 0.1 \left(\frac{L_{\rm disk}}{10^{46}\ {\rm erg\ s^{-1}}}\right)^{1/2} {\rm pc}$$

Energy densities as function of distance from BH (Sikora et al. 2009)



(model: Γ=20, $L_{disk}=10^{46}$ erg/s, $L_{syc}=10^{47}$ erg/s, magnetic flux $L_B=10^{46}$ erg/s, $M_{BH}=10^9 M_{solar}$)

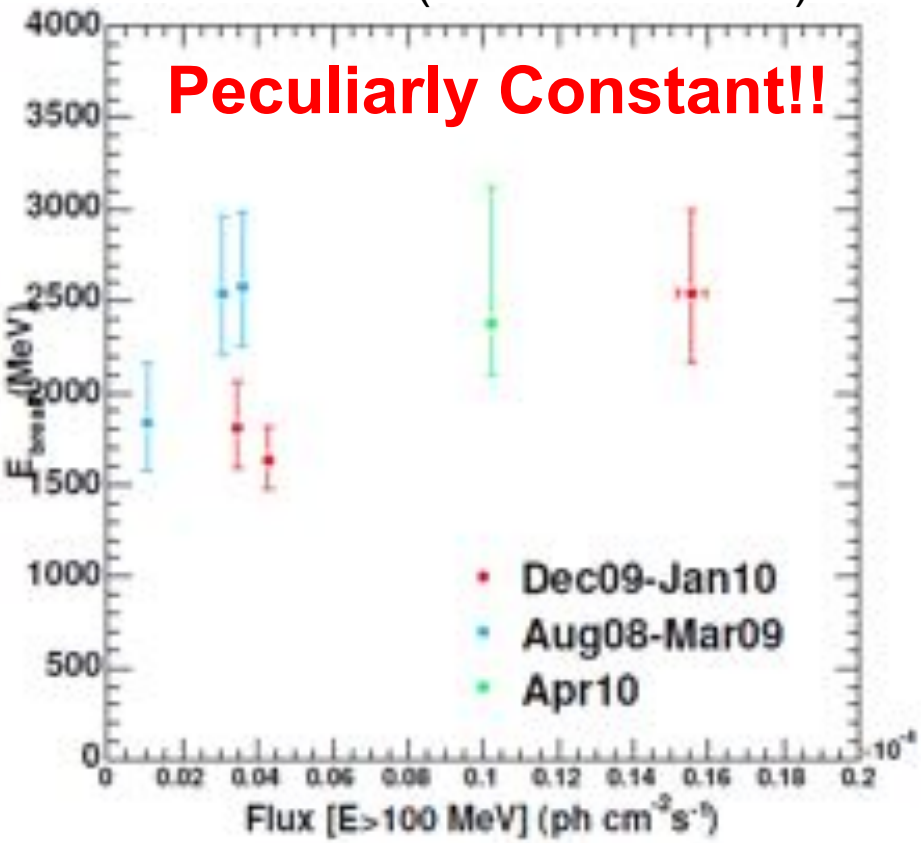
The GeV Spectral Break in 3C 454.3



νF_ν for ● MJD=55152-55261
● MJD=55280-55300

Fit : BPL, LogPar, Expcutoff

(Abdo et al. 2010)

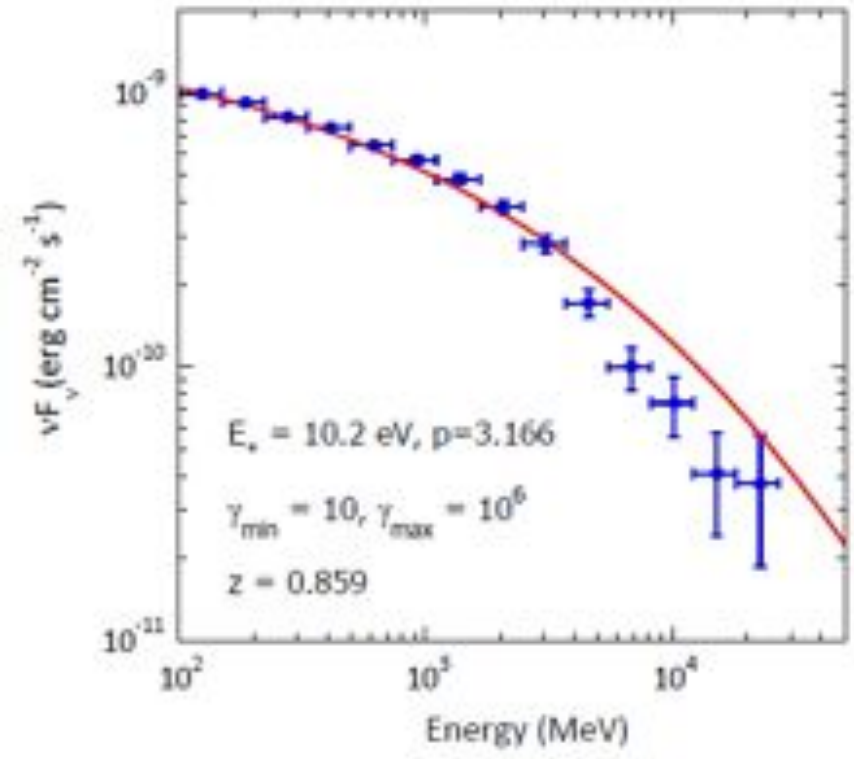


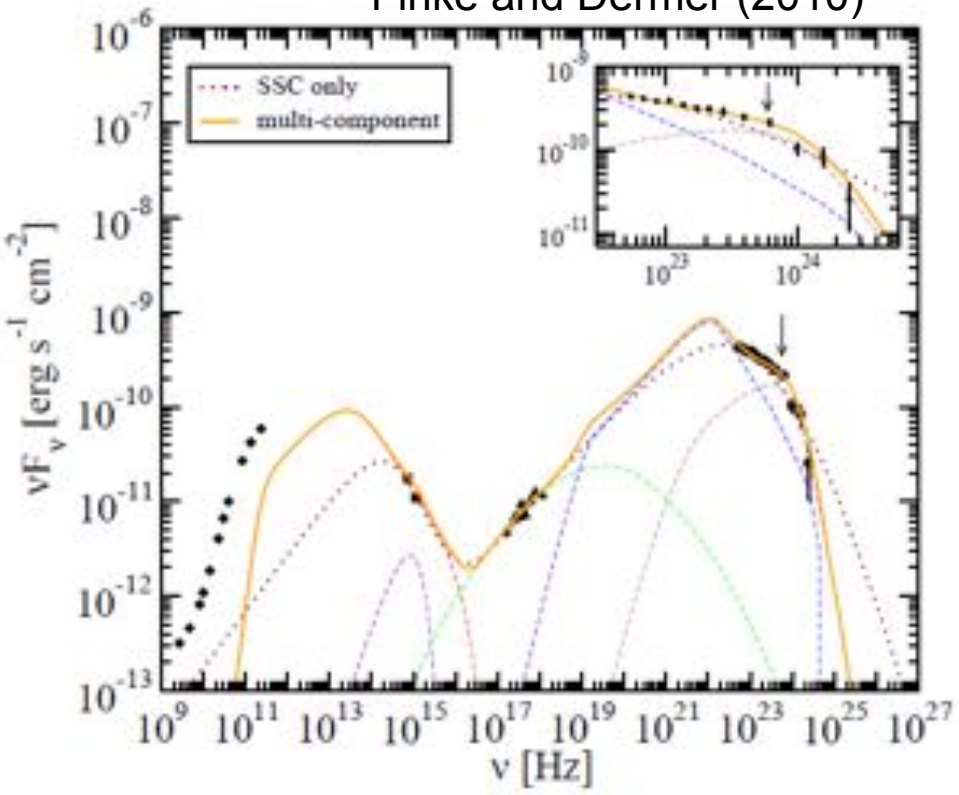
No strong evolution of E_b is found

$\Delta\Gamma$ > 0.5 -> should not be a simple cooling break

Model for spectral break

Finke and Dermer (2010)





KN effect due to Compton-Scattered Ly α Radiation?
-> unlikely,,

Intrinsic electron spectral break
with both disk and broad line region radiation

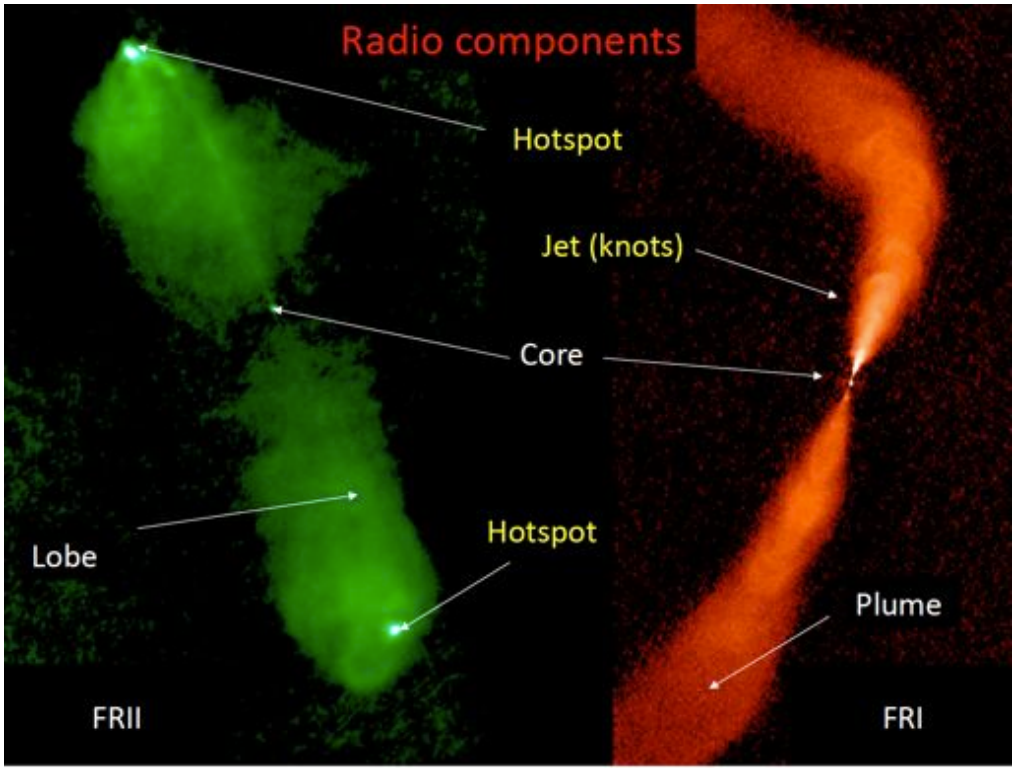
AGN are not all pointing toward us…

Centaurus A – AGN, Radio Galaxy
Composite image with Chandra (blue, X-rays),
APEX (Radio, red), ESO/WFI (true)

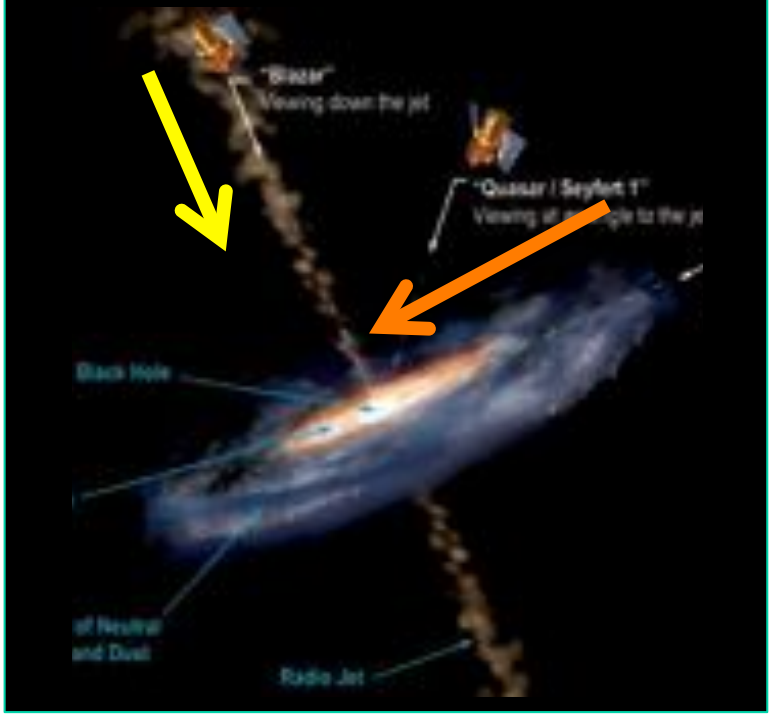
Radio galaxies (RG)

FR-II :
bright hotspot
higher power

FR-I :
Core dominant
Lower power



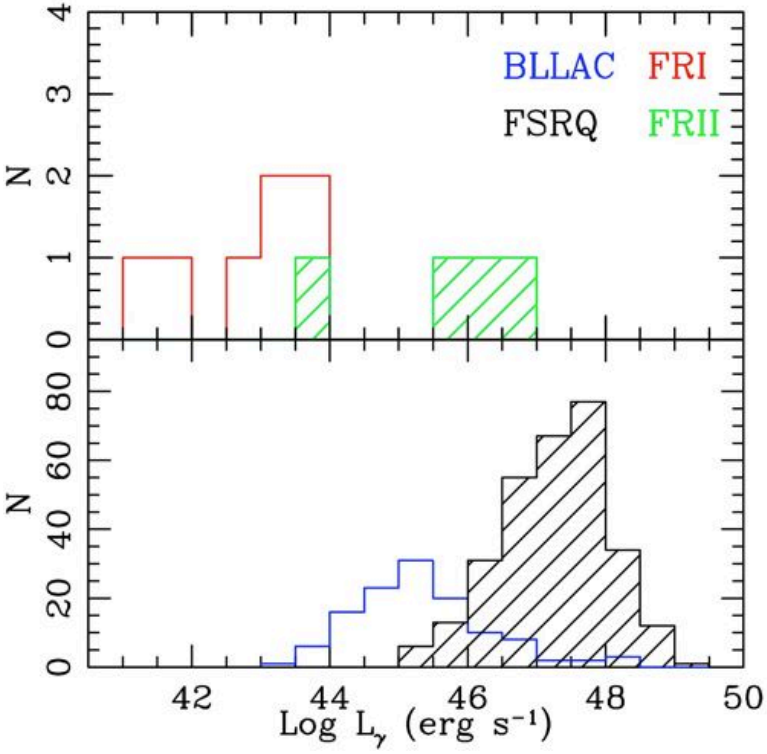
Unified model:
Blazar: FSRQ --- BL Lac
RG: FR II --- FR I



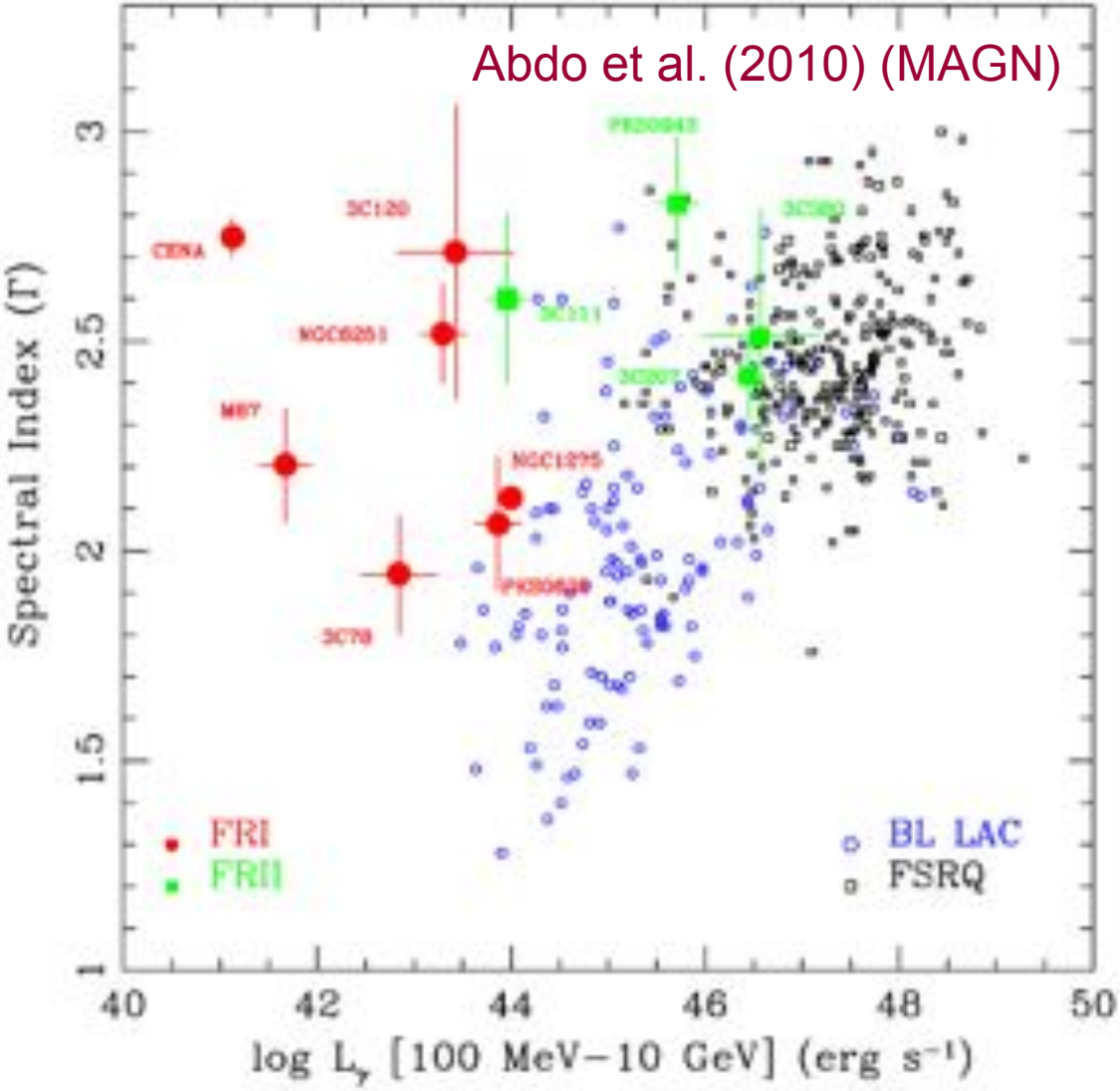
difference only in the relativistic beaming effect ?

Radio galaxies as “misaligned” blazar?

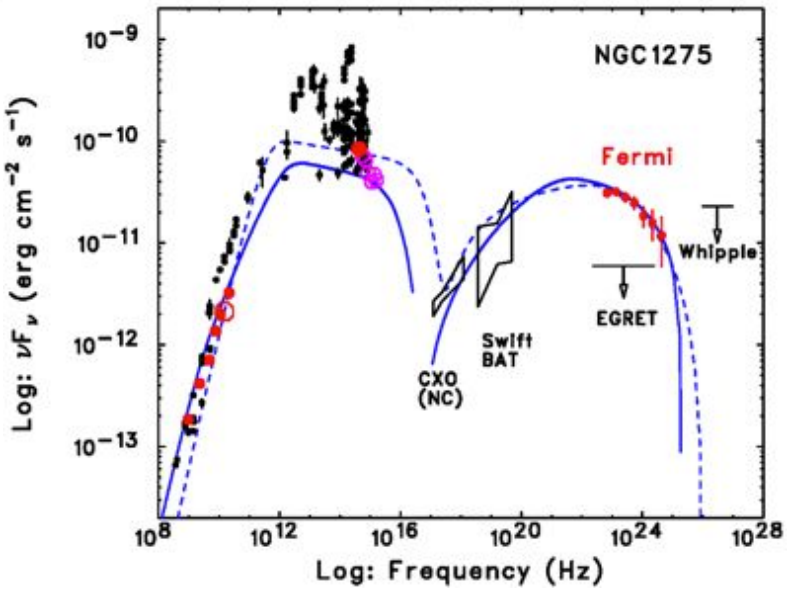
7 FR I and 4 FR II



Abdo et al. (2010) (MAGN)

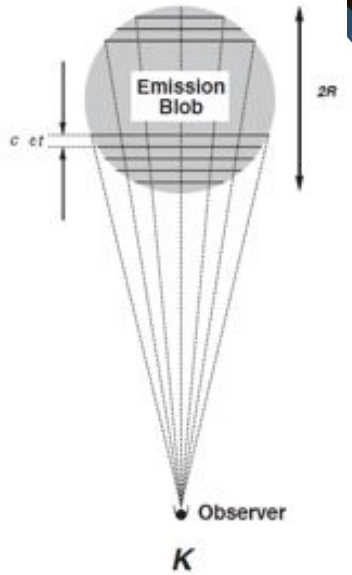


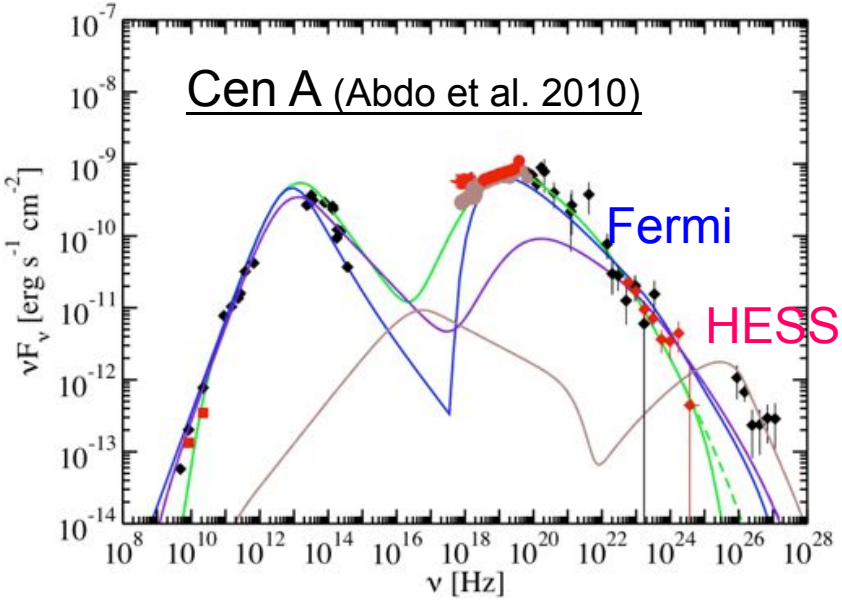
emission from core



NGC1275 (Abdo et al. 2009)

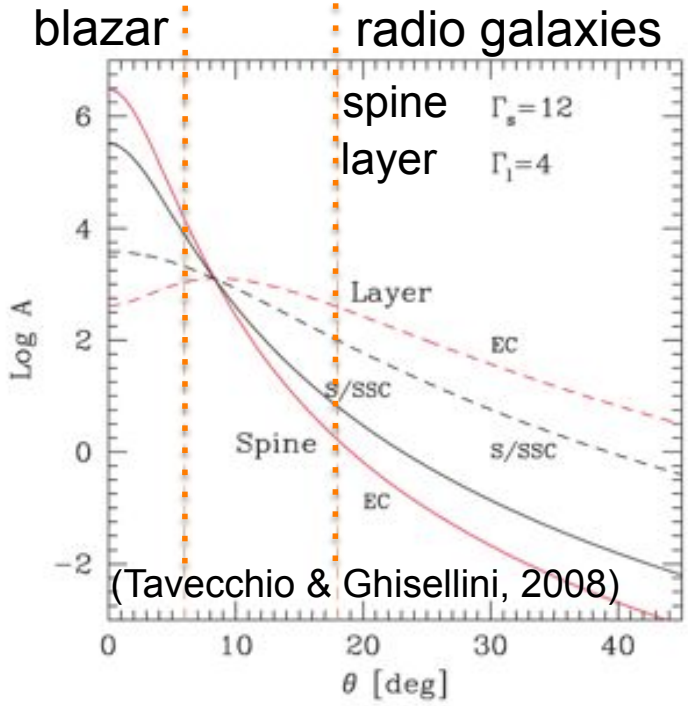
One-zone SSC model works, but with small bulk speed jet (Γ = 1.8)





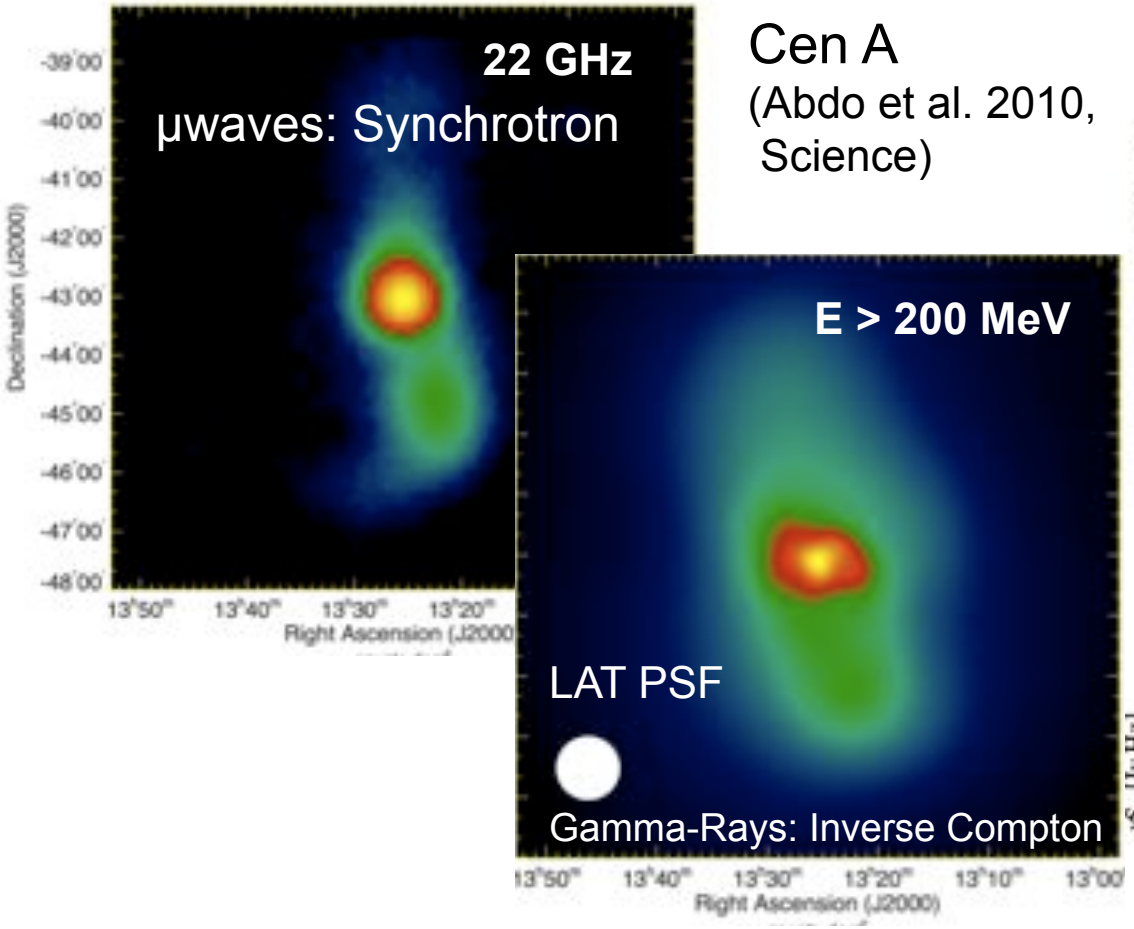
di

blazar radio galaxies

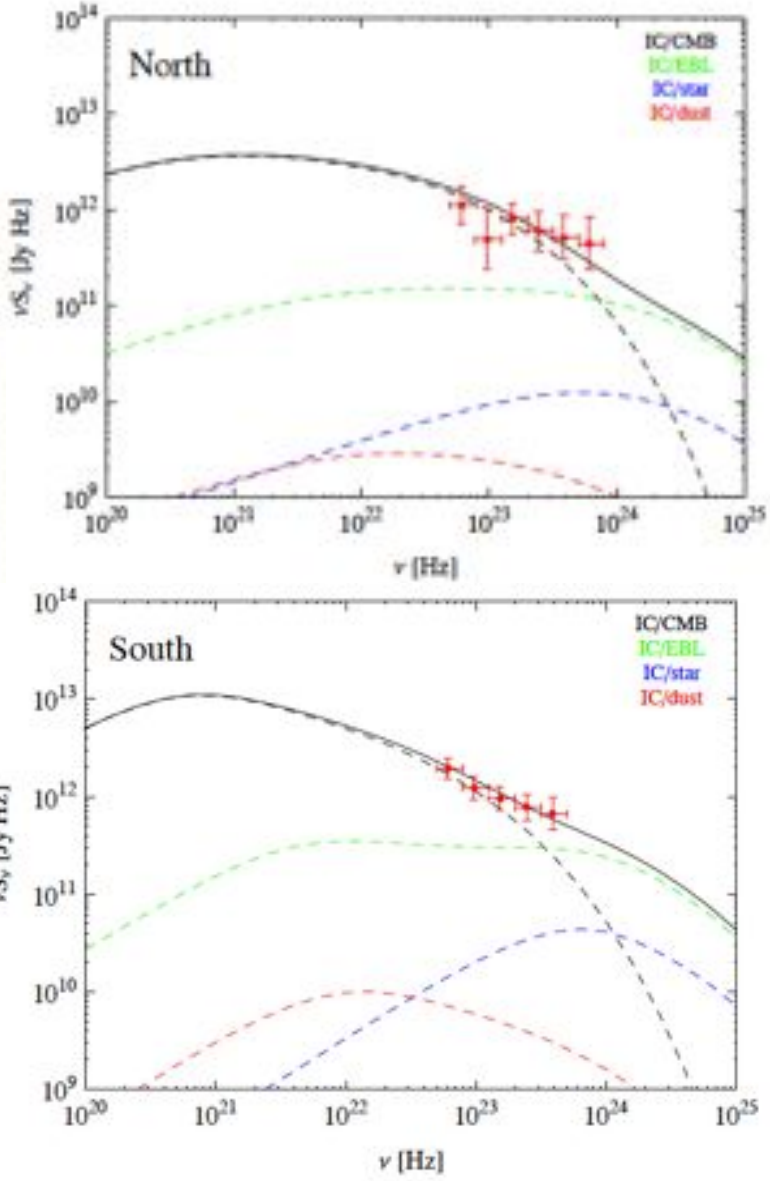


(Tavecchio & Ghisellini, 2008)

Resolving Giant Lobes with LAT



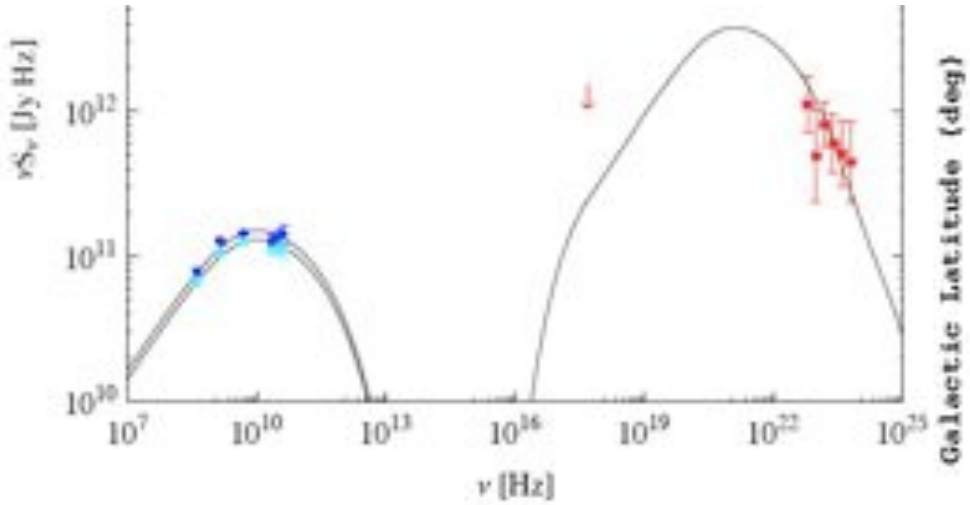
Cen A
(Abdo et al. 2010, Science)



extended ~ 10 deg

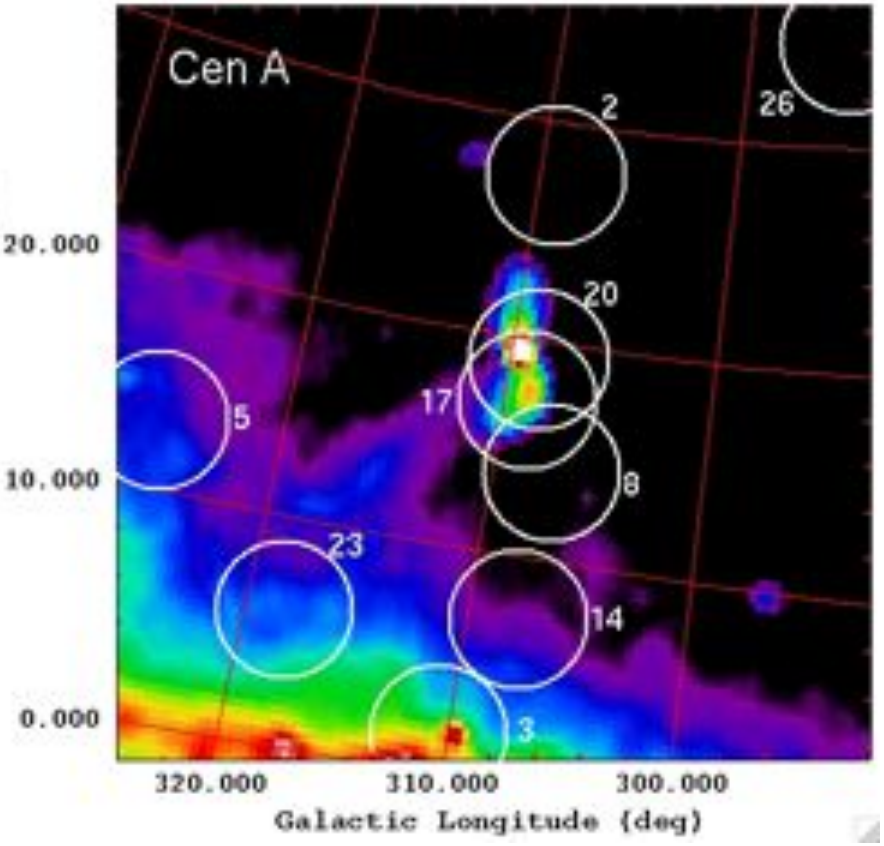
particle acceleration in 100's kpc scale

- **LAT detected γ-ray emission requires 0.1-1 TeV electron in 100's kpc-scale lobes.**



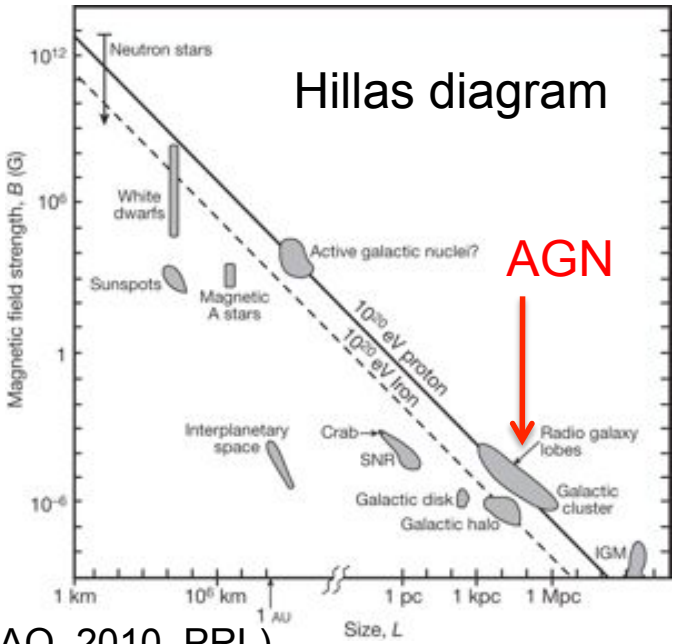
high-energy particle acceleration in very large scale!! (2nd order "Fermi"?)

(Moskalenko et al. 2009)



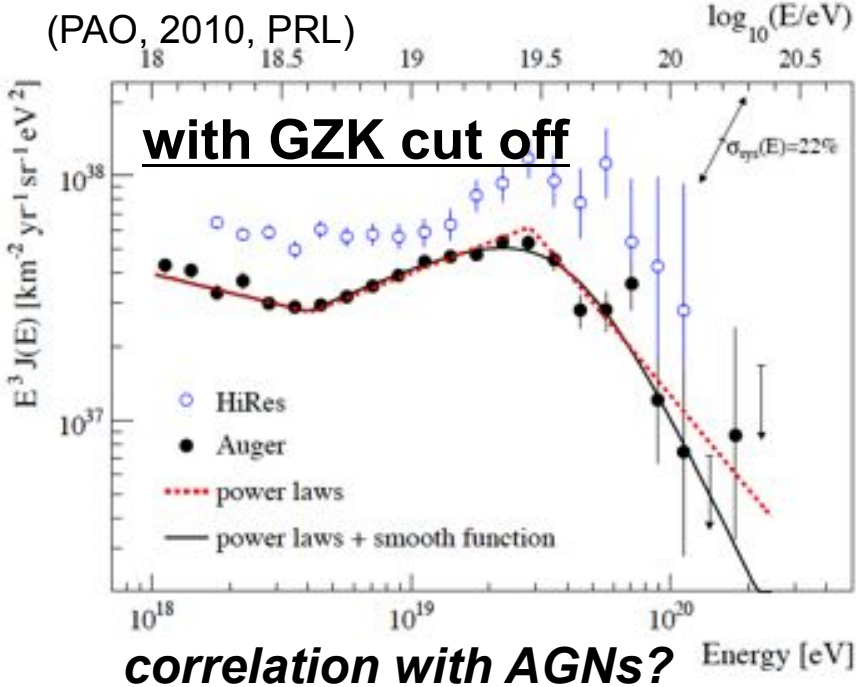
35°x35° of 408 MHz image with directions of **Auger UHECR events (E > 57 EeV)** indicated (r=3.2d)

Ultra-high energy cosmic-ray from AGNs ?

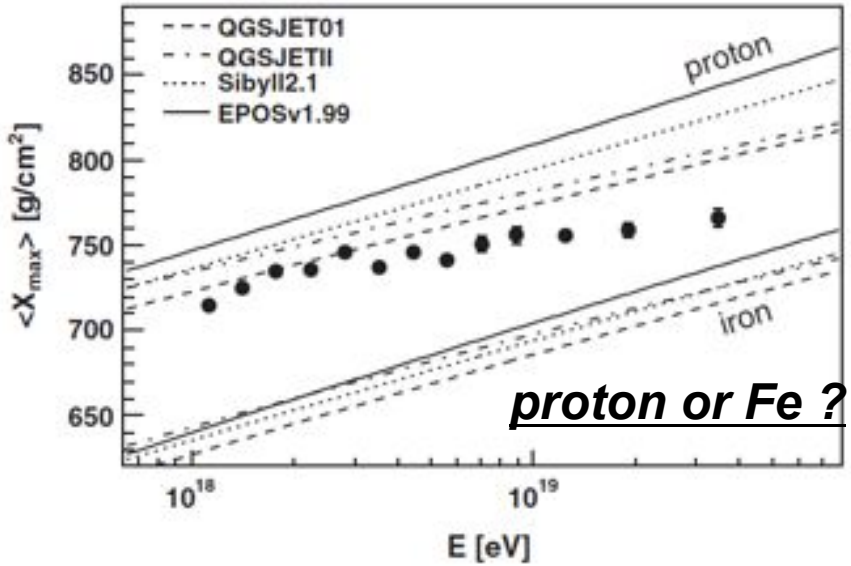


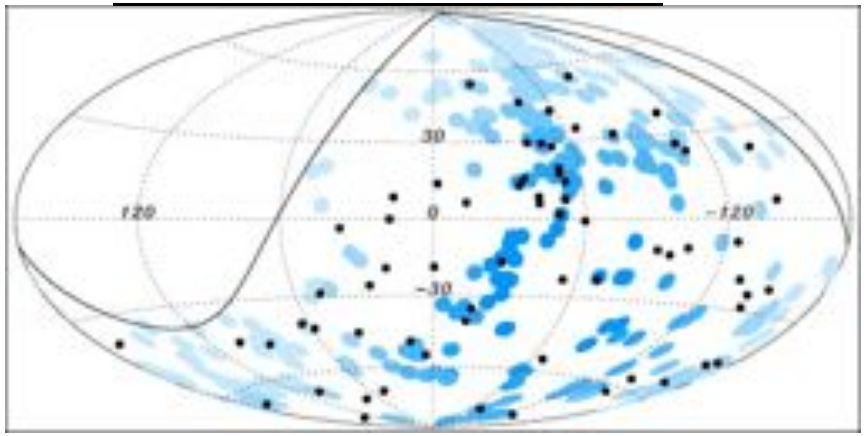
(PAO, 2010, PRL)

(PAO, 2010, PRL)



correlation with AGNs?





(PAO, 2010, APh)

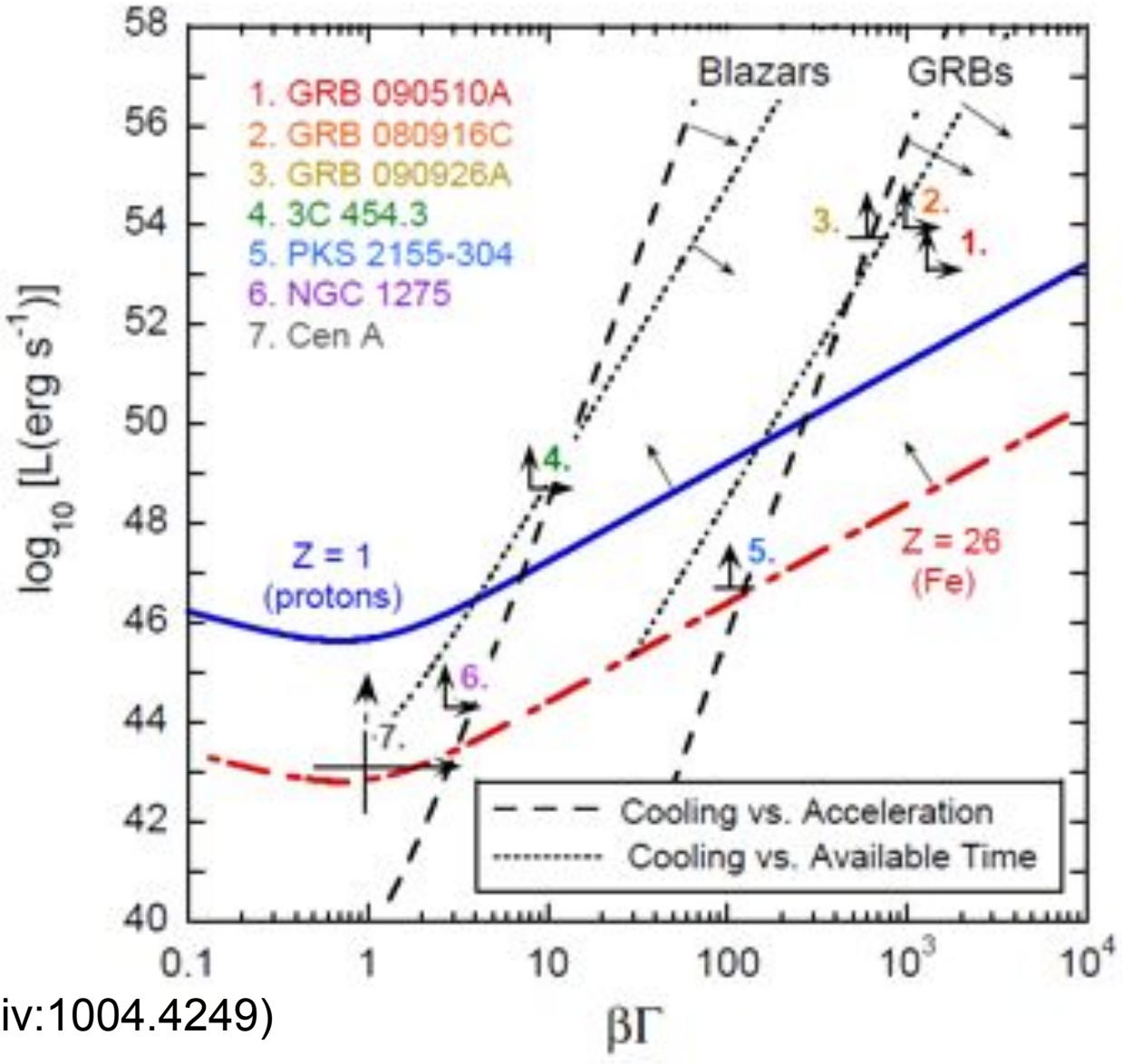
black dot: E > 55 EeV

Blue : AGNs < 75 Mpc (VVC)

L - Γ diagram

- **Sources with jet Lorentz factor Γ must have jet power L exceeding heavy solid and dot-dashed curves to accelerate p and Fe respectively, to E = 10^{20} eV.**

- **Upper limits to L vs. Γ defined by competition between synchrotron losses and acceleration time (dashed lines), and synchrotron losses and available time (dotted lines).**



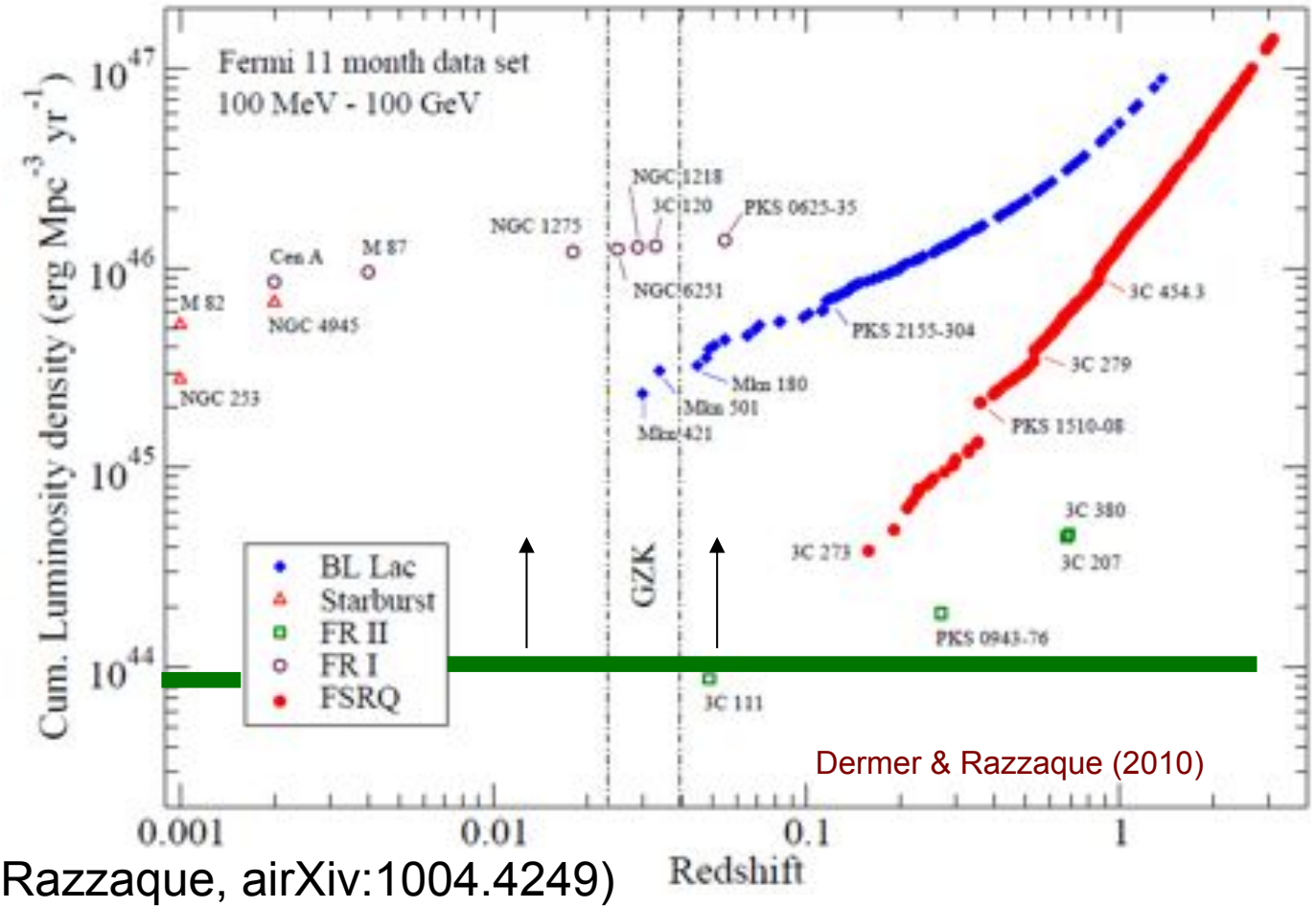
(Dermer & Razzaque, airXiv:1004.4249)

Luminosity Density of γ-ray Galaxies from Fermi Data

- **1LAC AGNs**
  - **FSRQs**
  - **BL Lac**
  - **Misaligned Radio Galaxies**
  - **Starburst (and Star-forming)**

- Need adequate luminosity density and number of sources within GZK radius

- Fermi data favors *high-Z ion* acceleration by BL Lacs/FR1 radio galaxies



(Dermer & Razzaque, airXiv:1004.4249)

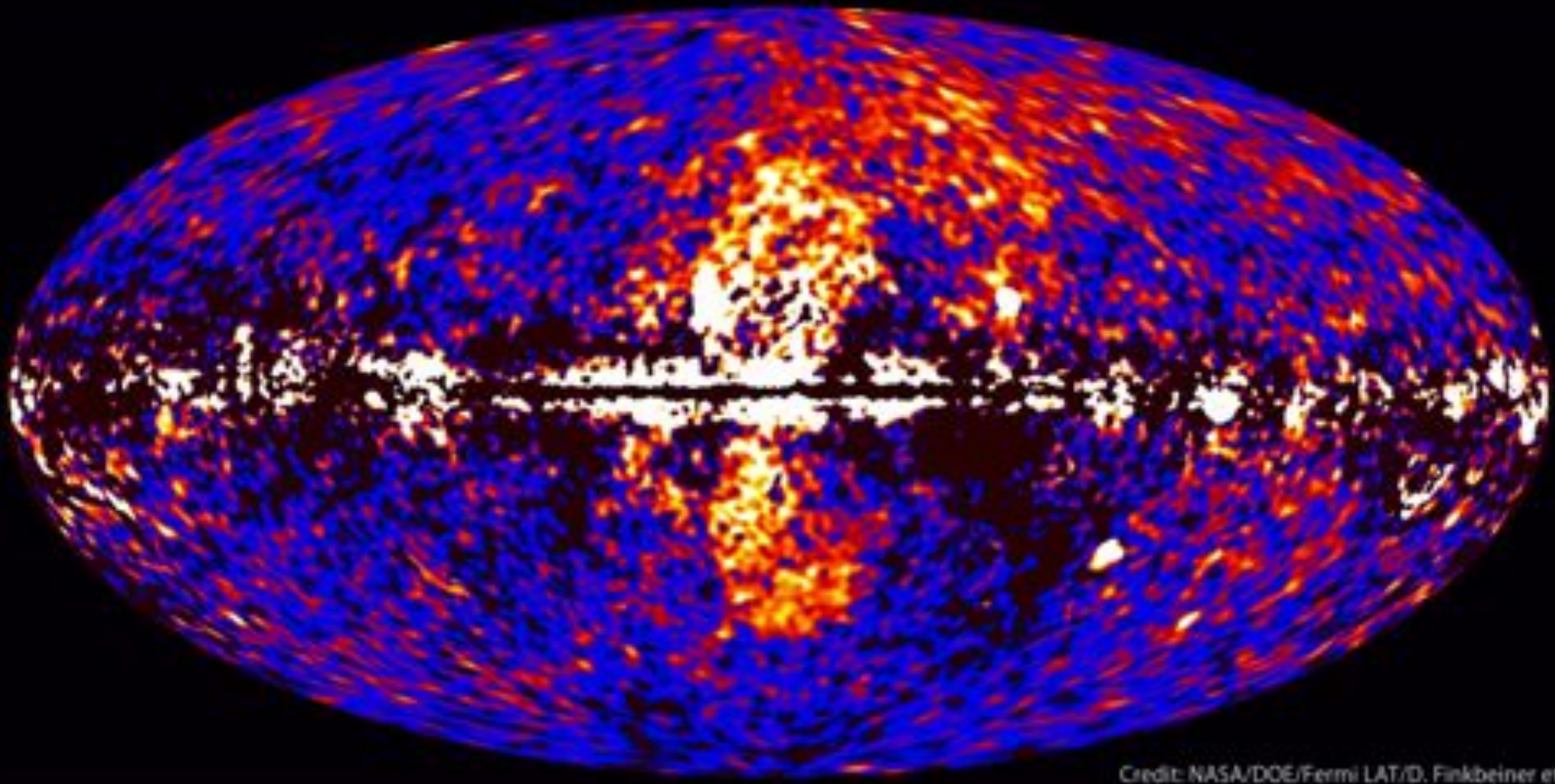
Summary of AGNs

- Fermi-LAT detect 682 AGNs in the 1st catalog
  - blazar sequence looks OK!
- Location of γ-ray emission :
  - blazar : not only at sub-pc, but also at pc scale
  - Radio Galaxies : not only at core (pc), but also at lobe (Mpc)

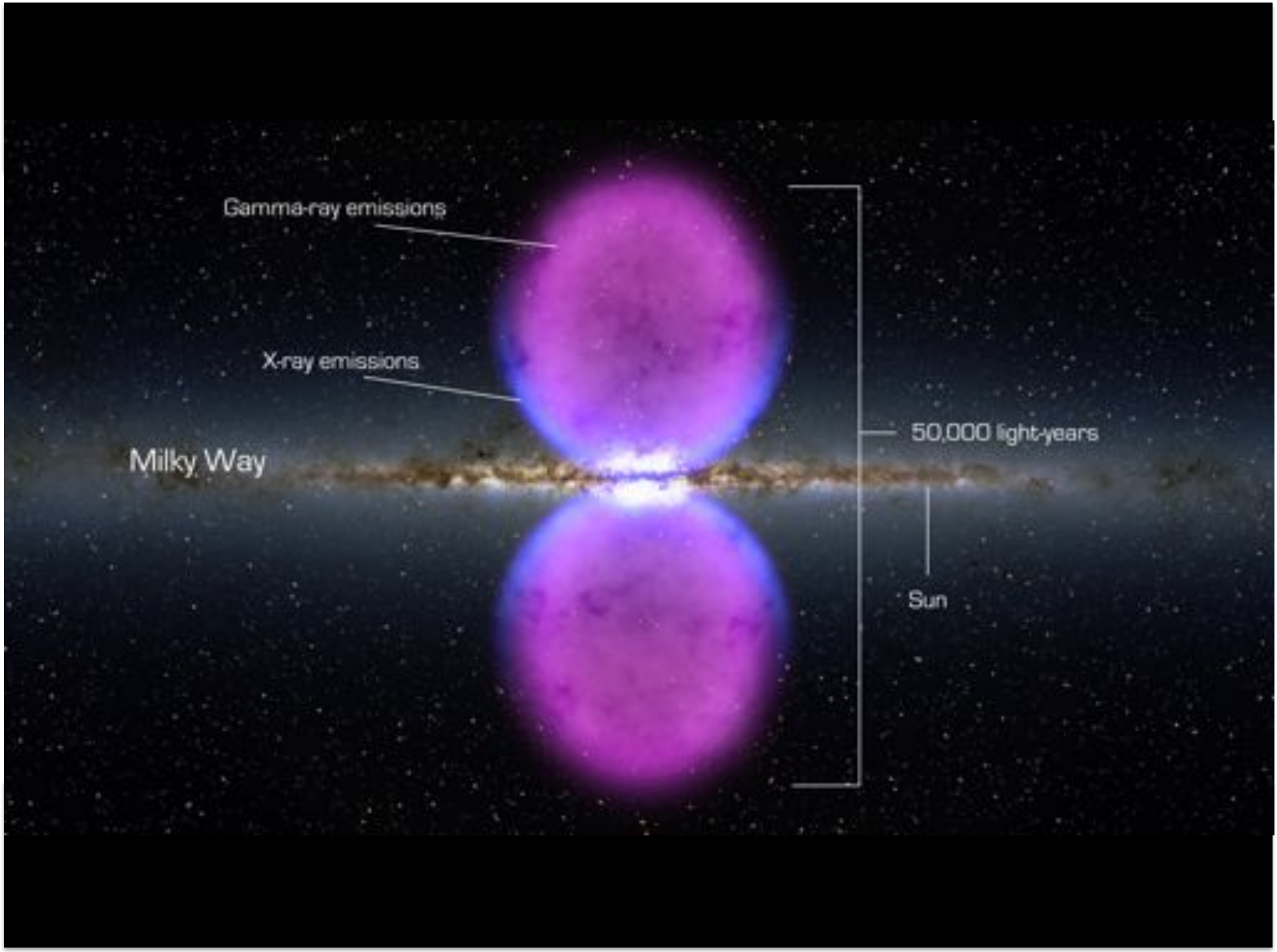
Gamma-ray can also be generated far from BH !!

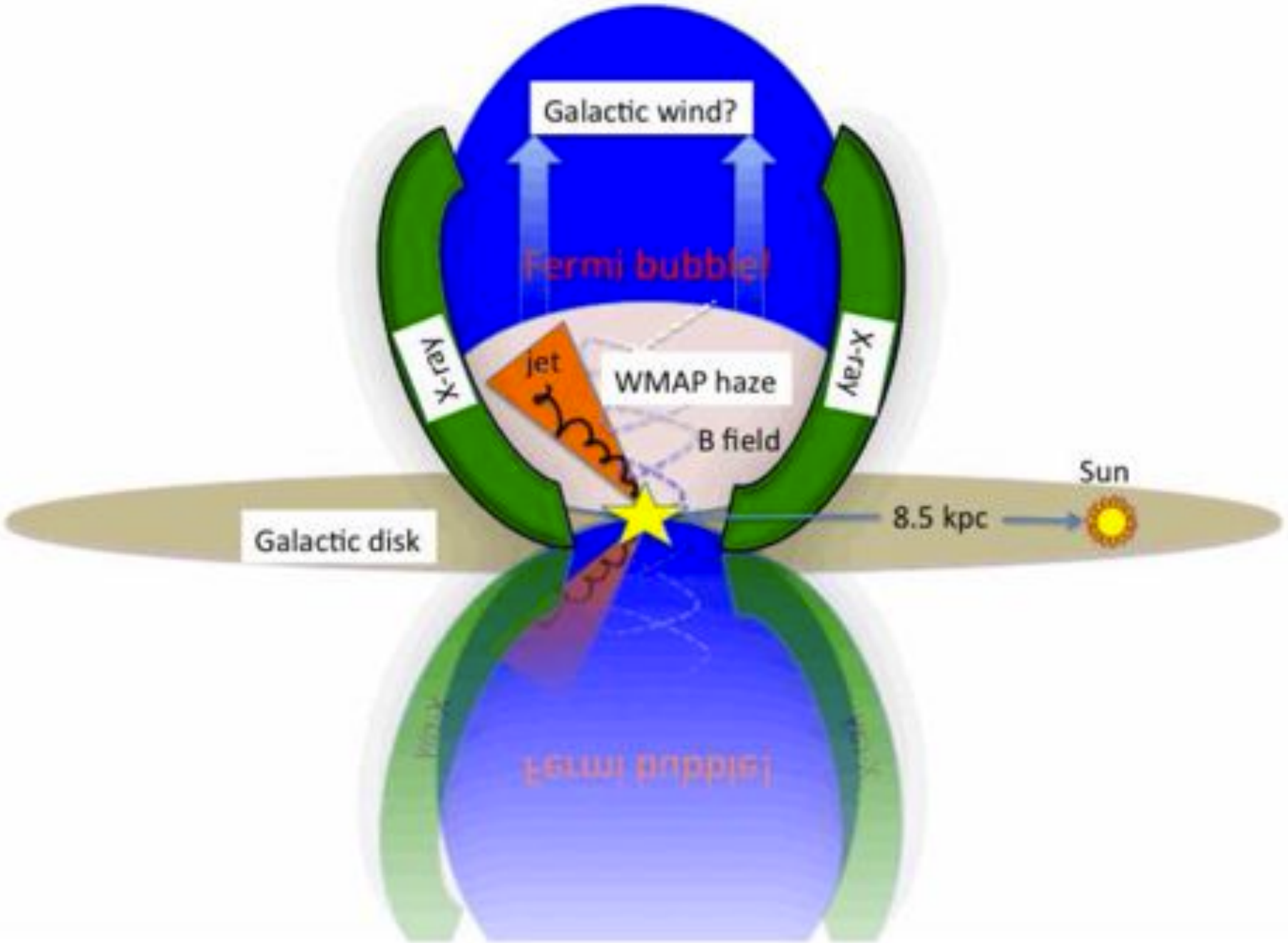
- Geometry :
  - complex jet structure (bent jet? helical magnetic field?)
  - classical one-zone model is too simple!!
  - multi-zone? (spine and layer?)
- Gamma-ray emission mechanism :
  - Inverse-Compton with either UV or IR photons depending on the location of emission region

Fermi data reveal giant gamma-ray bubbles



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.


Gamma-ray emissions
X-ray emissions
Milky Way
50,000 light-years
Sun


Galactic wind?
Fermi bubble!
X-ray
X-ray
jet
WMAP haze
B field
Sun
8.5 kpc
Galactic disk


Thank you