The AGN Population in Radio and γ-rays: Theoretical Perspective

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Historical Perspective

EGRET & first IACTs:

~100 FSRQs in GeV, several BL Lacs in TeV;

two γ-detected RGs.

- Efficient γ production exclusive to AGN with superluminal radio jets;
- Broad-band spectra in a general agreement with simple homogeneous one-zone leptonic emission models and a simple prescription for particle acceleration. Well-defined "blazar emission zone" & shock paradigm.

Fermi-LAT & modern IACTs:

~1,000 blazars (FSRQs & BL Lac) in GeV, ~30 blazars (mostly BL Lacs) in TeV;

~30 non-blazar γ-detected AGN of various types.

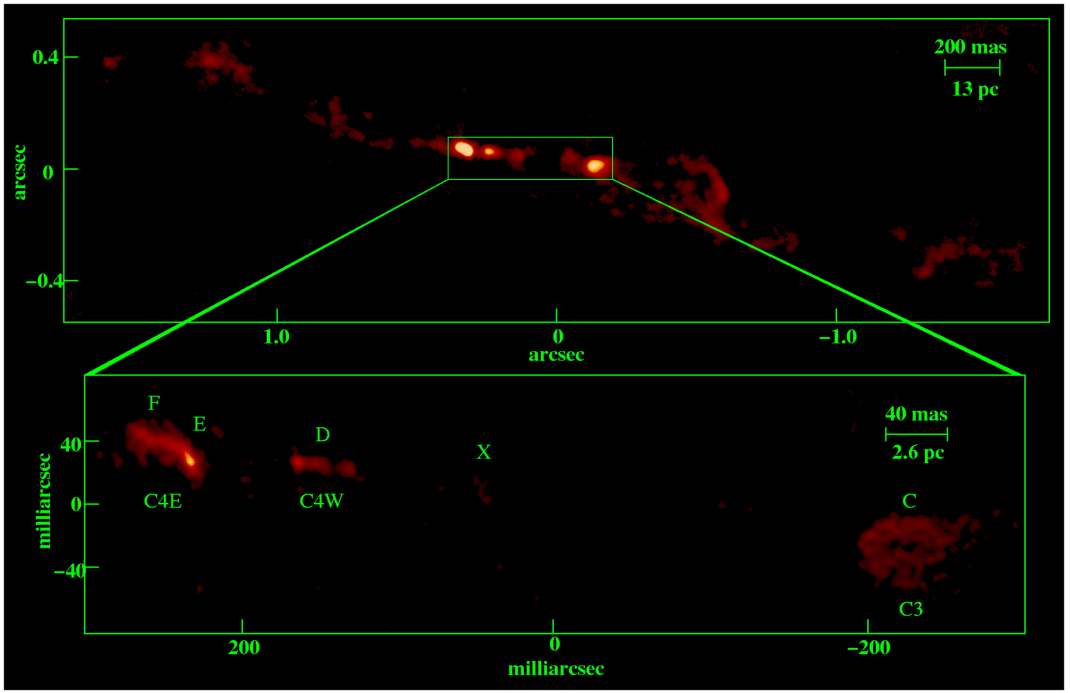
- Relativistic jets dominant but not exclusive sites of the γ production;
- Much larger sample of γ-loud sources and much improved spectral and temporal characterization (thanks to new extensive MWL campaigns) challenged one-zone homogeneous emission models with simple prescription for particle acceleration. We need to revise previous models & paradigms!

Main Questions

1. Are radio loud systems the only AGN loud in γ?
2. Are radio properties of nuclear jets directly related to γ properties?
3. Are nuclear relativistic jets the only relevant γ production sites?

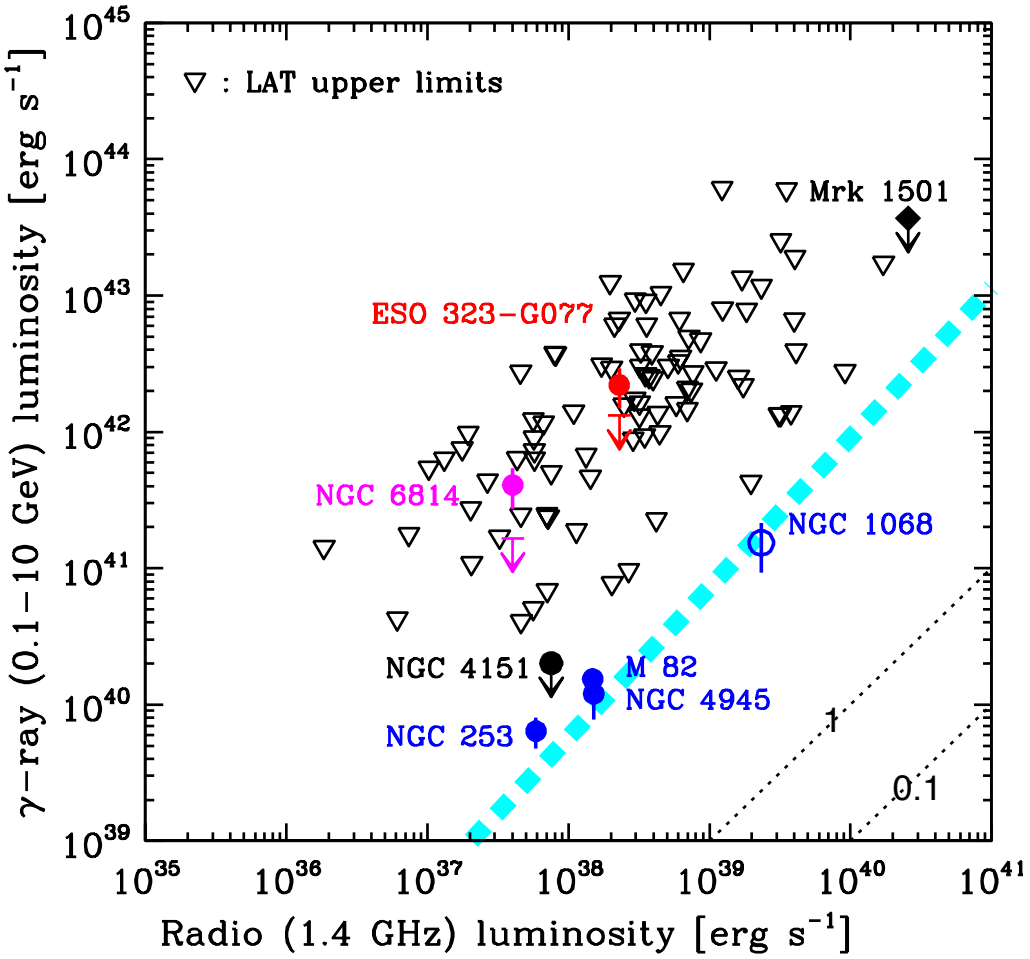
1) Radio Loud = γ Loud ?

Radio jets in “radio quiet” Seyfert galaxies are weak and not relativistic (e.g., NGC 4151; Mundell et al. 2003) .



In addition to blazars and radio galaxies, the only new established class of γ-loud AGN are “radio loud narrow line Seyferts type 1”, for which radio observations reveal signatures of compact relativistic jets (Fermi-LAT 2009)

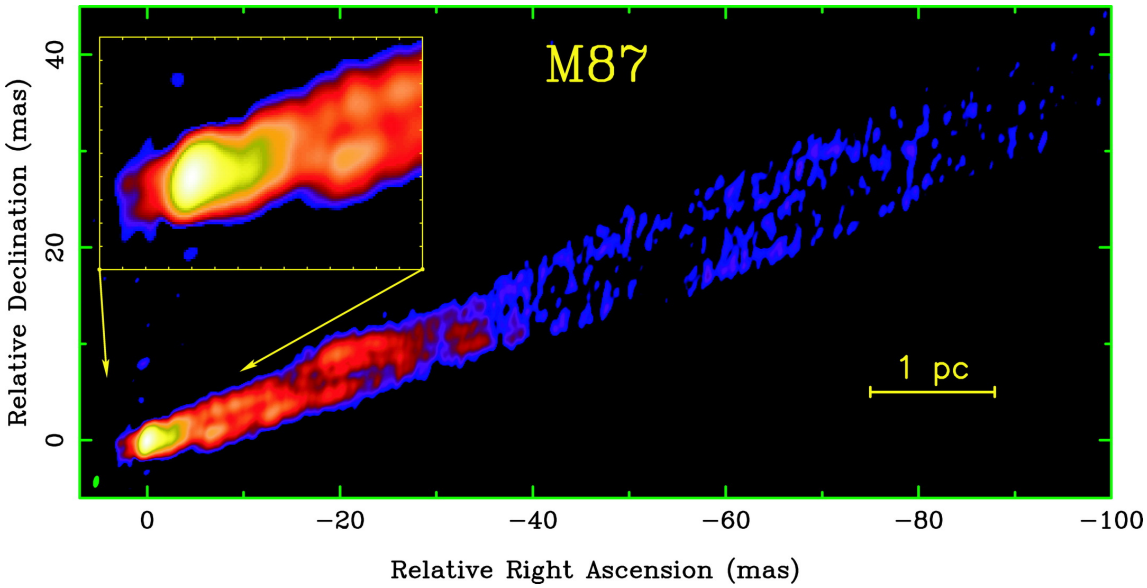
Radio Quiet Seyferts



R quiet Seyferts seem γ quiet as well (Fermi-LAT 2012)

2) R vs γ Properties

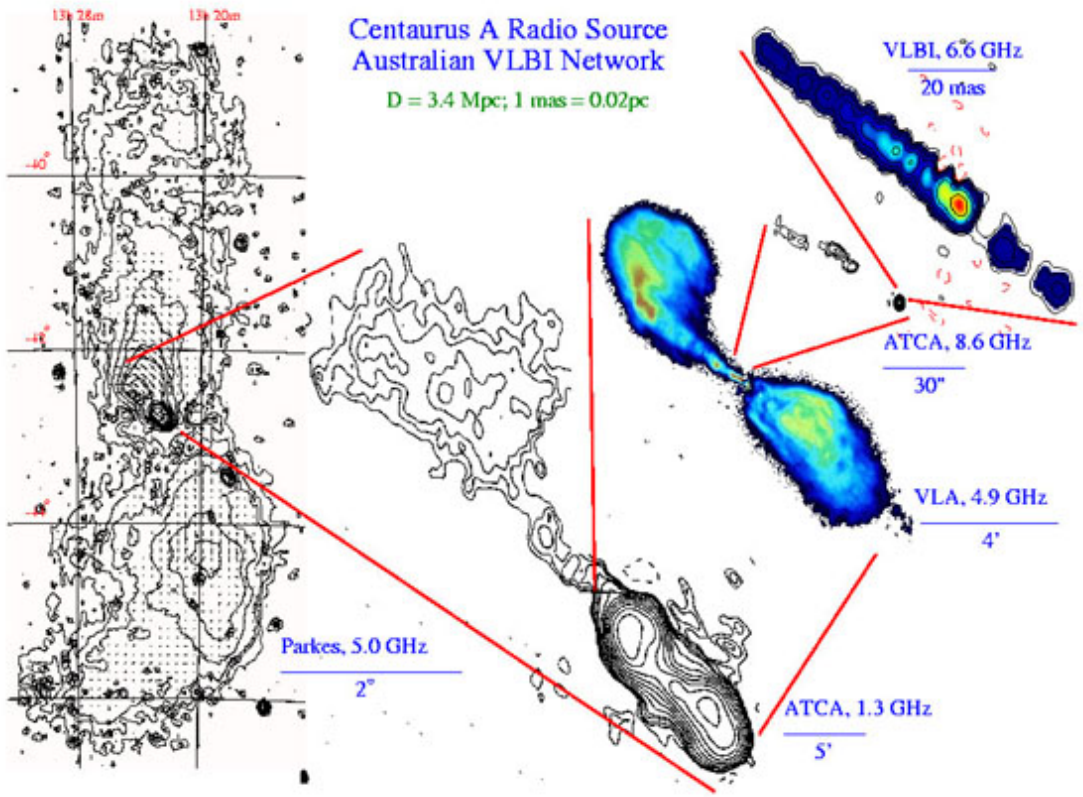
In several nearby R loud AGN we can now probe the jets down to hundreds and tens of gravitational radii of central SMBHs (e.g., M87; Kovalev et al. 2007)



Where is the “blazar emission zone” in this γ-detected “misaligned blazar”?
(more discussion later)

3) Only Nuclear Jets?

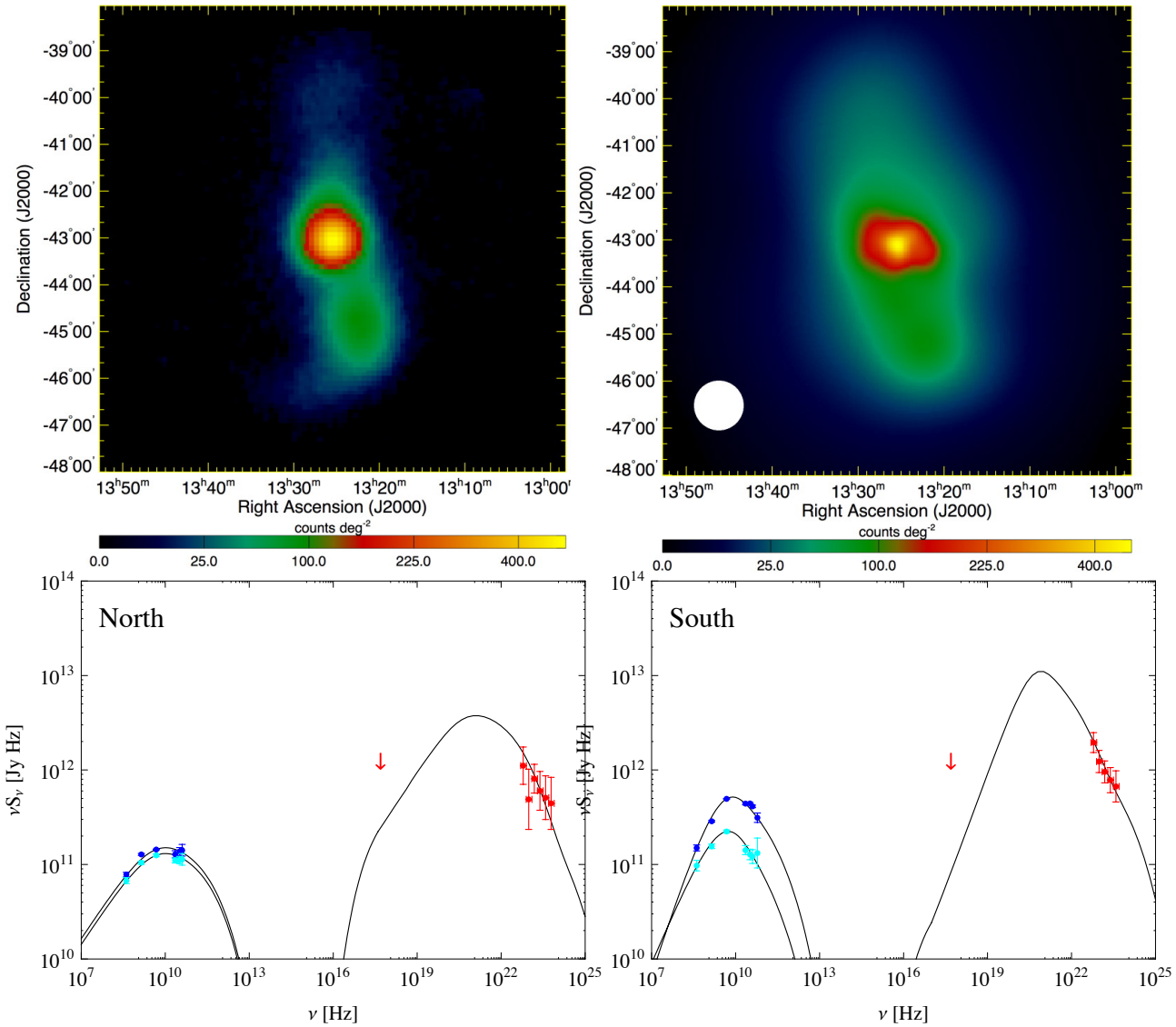
R maps reveal complex multi-component structure and intermittent jet activity in R loud AGN (e.g., Cen A; Morganti 1999)



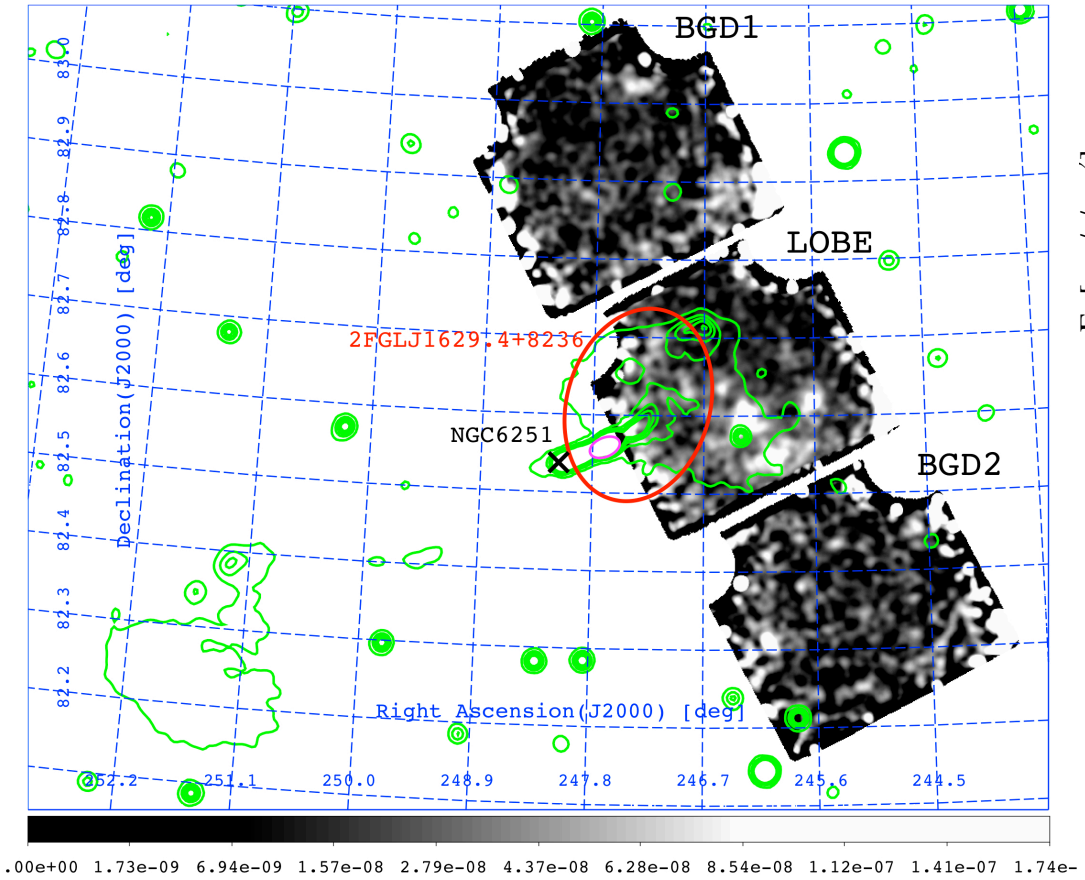
We see high energy X emission produced also in extended lobes and large-scale jets of RL AGN; lobes are now established sources of γ;
R information needed to disentangle contribution of different potential emission components to the observed γ fluxes.

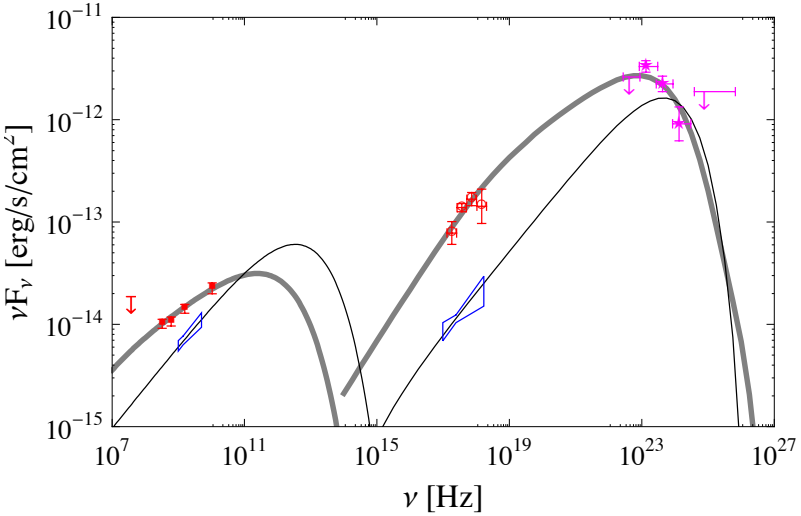
Lobes: Resolved

Giant lobes in Cen A:
$U_e/U_B \sim 4$
(Fermi-LAT 2010)



Lobes: Possibly Resolved



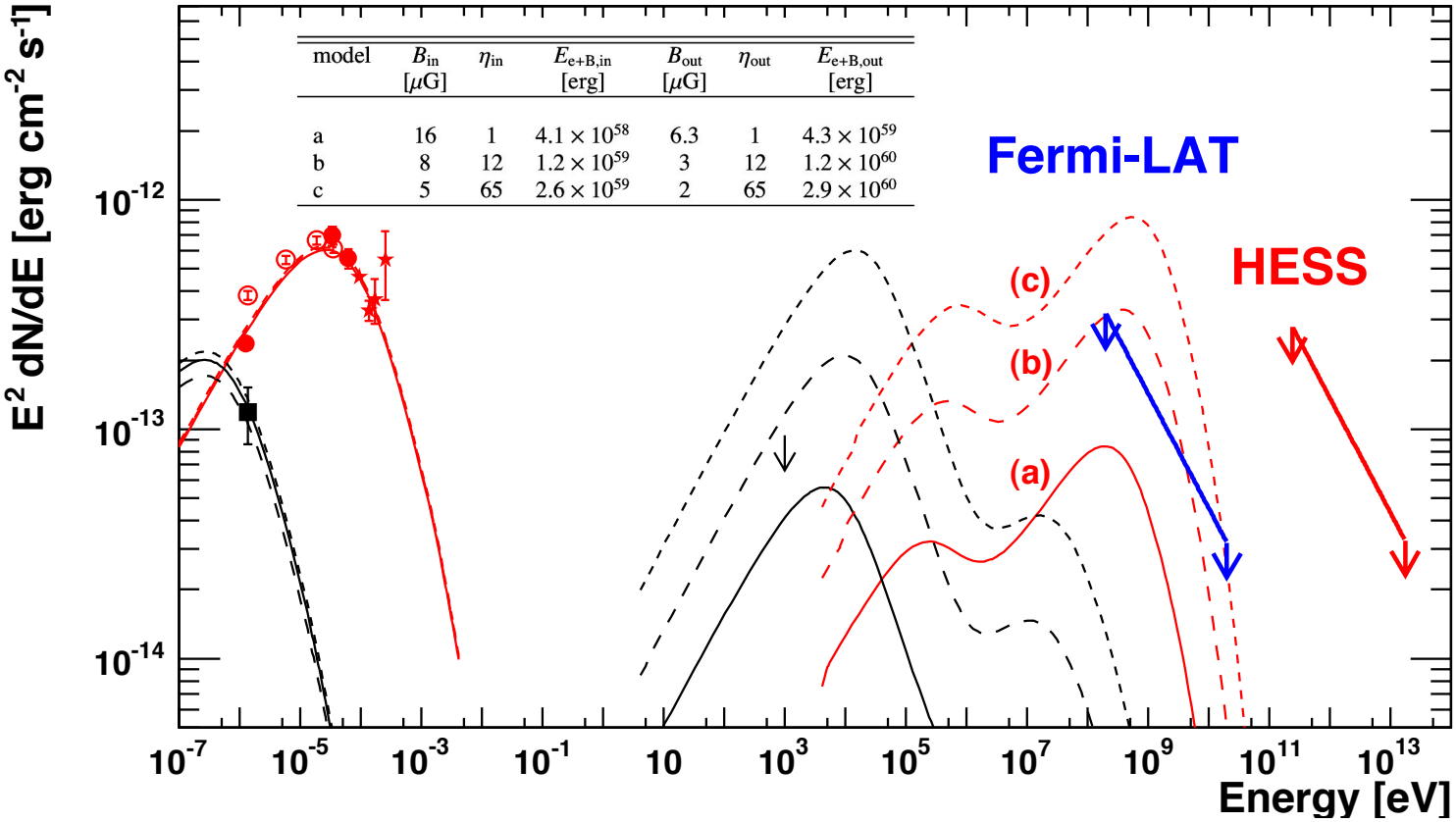


Giant lobe in NGC 6251:

U_e/U_B ~ 45

(Takeuchi et al. 2012)

Lobes: Unresolved



Multiple lobes in Hydra A: $\mathbf{U_e/U_B \sim 1}$ (HESS 2012)

Main Questions

1. Are radio loud systems the only AGN loud in γ? **YES**
2. Are radio properties of nuclear jets directly related to γ properties? **MAYBE**
3. Are nuclear relativistic jets the only relevant γ production sites? **NO**

R/γ Connection

Massive optical and radio surveys of AGN – statistical analysis methods still not fully explored, and several main questioned still open (e.g., radio loudness bimodiality, R/opt correlations). In R/γ we are just starting since only now good (sufficient) quality γ data are available.

- Detailed studies of individual objects: looking at flux, spectral, polarization and morphological changes in both bands

  - requires good-quality data and so bright targets (not many in γ!), continuous monitoring in radio (expensive!), and precludes from making strong general statements on the entire AGN population (the brightest nearby objects may not be representative).

- Statistical studies for well defined classes and subclasses of objects: looking at the flux-flux correlations, spectral and variability characteristics in both bands, etc. ("let's correlate everything with everything"!)

  - allowing to draw general conclusion on the AGN population, but requires complete numerous flux-flux limited samples, and dealing with different observational biases (hard to be recognize and quantify).

Expected Or Not?

- As established by EGRET & first IACTs, γ sources are predominantly beamed RL AGN (blazars), so presence of relativistic nuclear radio jets seems crucial for the efficient γ production.
- But is really the observed R emission of blazar cores directly and tightly related to the observed γ emission?
- Are γ and nuclear R fluxes produced in the same region, by same population of electrons, accelerated by same processes in all the sources?

Not Expected Because...

- **OBSERVATION:**

  $\alpha_R \sim 0$ for unresolved blazar cores, meaning SSA at work and the observed radio flux being produced as a superposition of different jet components, consistently with only low-amplitude slow variability observed; superluminal knots observed on scales >pc and provide only a small fraction of the core luminosity.
- **THEORY:**

  in many acceleration models one expects very different acceleration mechanisms and acceleration sites for low-energy (radio-emitting) and high-energy (γ-emitting) electrons.
- **MODELING:**

  R fluxes rarely included in the model fits assuming blazar emission zone within BLR, which otherwise work quite well, and get recently some support from the observed GeV spectral breaks in FSRQs.

Expected Because…

- **OBSERVATION:**

  L_γ apparently correlated with L_R and β_{app}, while γ flares often accompanied by ejection of superluminal blobs.

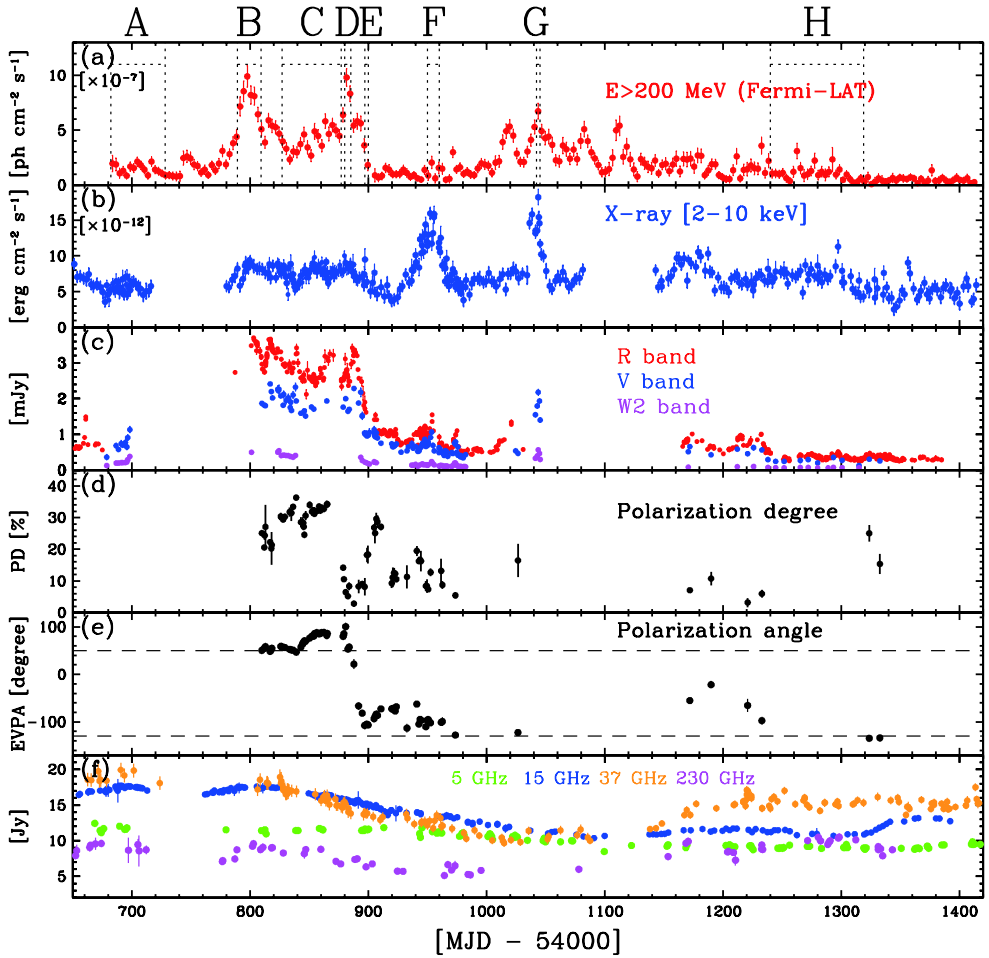
- **THEORY:**

  MHD jet production models predict that AGN jets are launched as Poynting-flux-dominated, and only slowly accelerate and collimate at larger distances from the core; meanwhile, L_γ/L_{syn} ratios in blazars indicate particle dominated emission zones, and highly relativistic well collimated outflows; this seems to imply that the blazar emission region is located further away from the core when the jets are already fully formed.

- **MODELING:**

  Recent modeling results on FSRQs indicate in the opinion of many that the blazar component is produced at ~pc distances (TeV opacity of FSRQs, flat X-ray spectra, some broad-band variability properties with optical PA swings accompanying γ flares, etc.), and this is the scale already probed by radio interferometers.

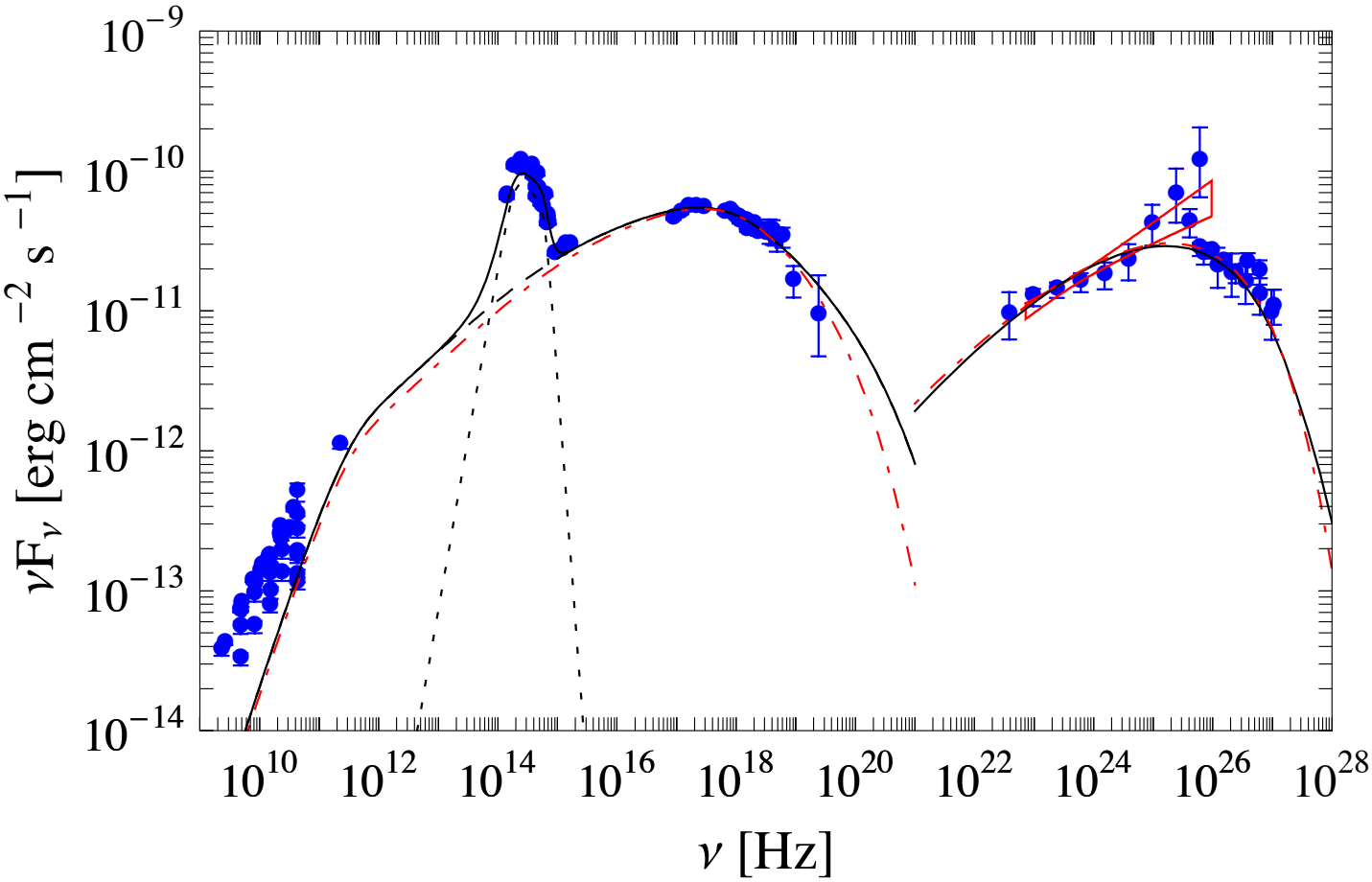
3C 279: Not During Flares!



FSRQs = luminous blazars

Hayashida et al. 2012

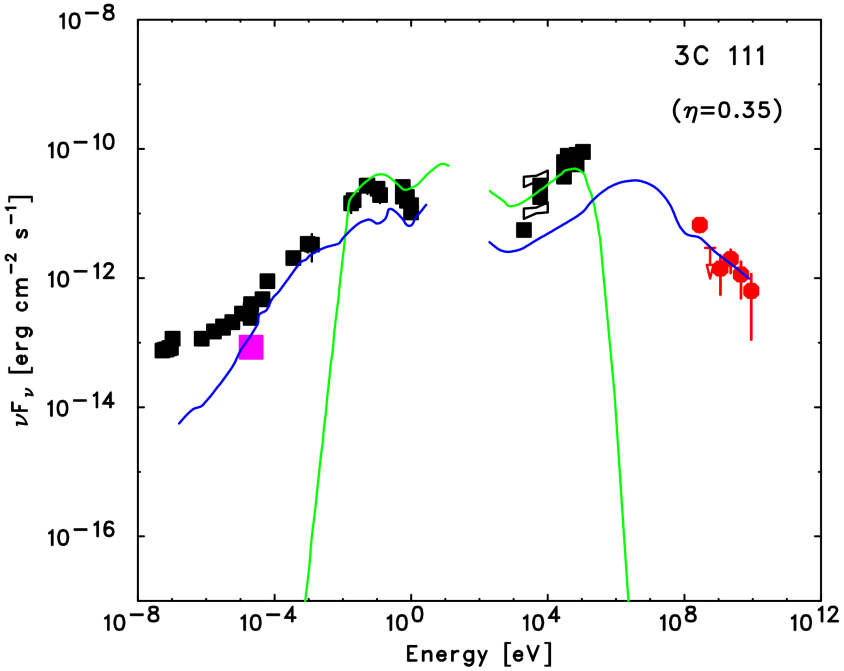
Mrk 501: During Quiescence?

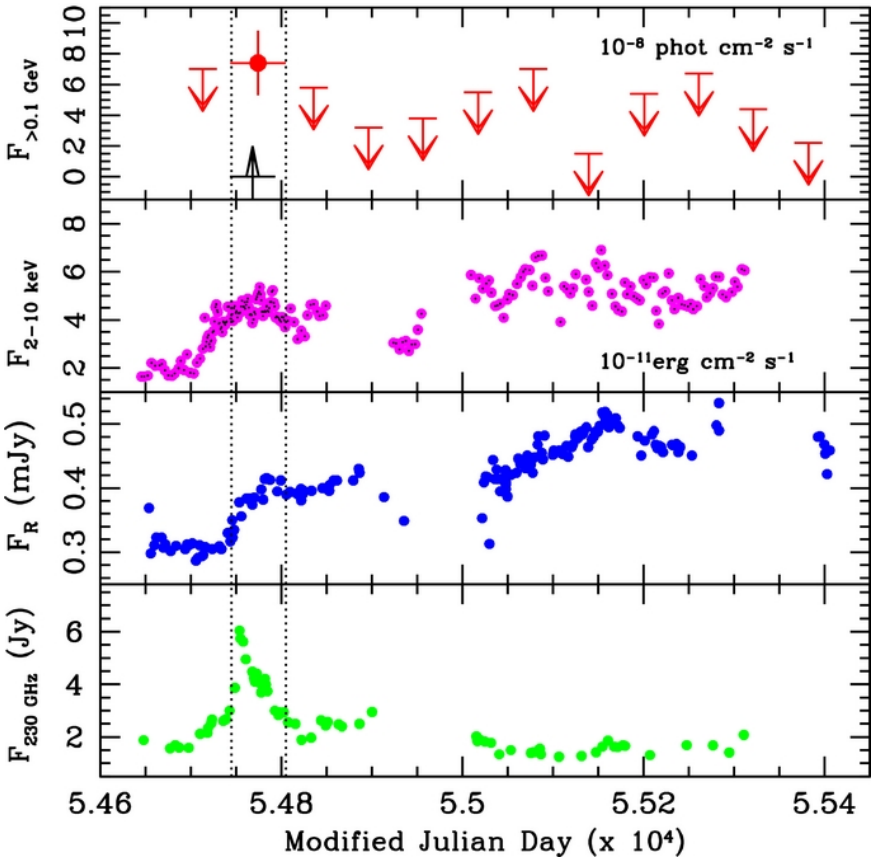


BL Lacs = low-luminosity blazars

Fermi-LAT 2011

3C111: Clear Case

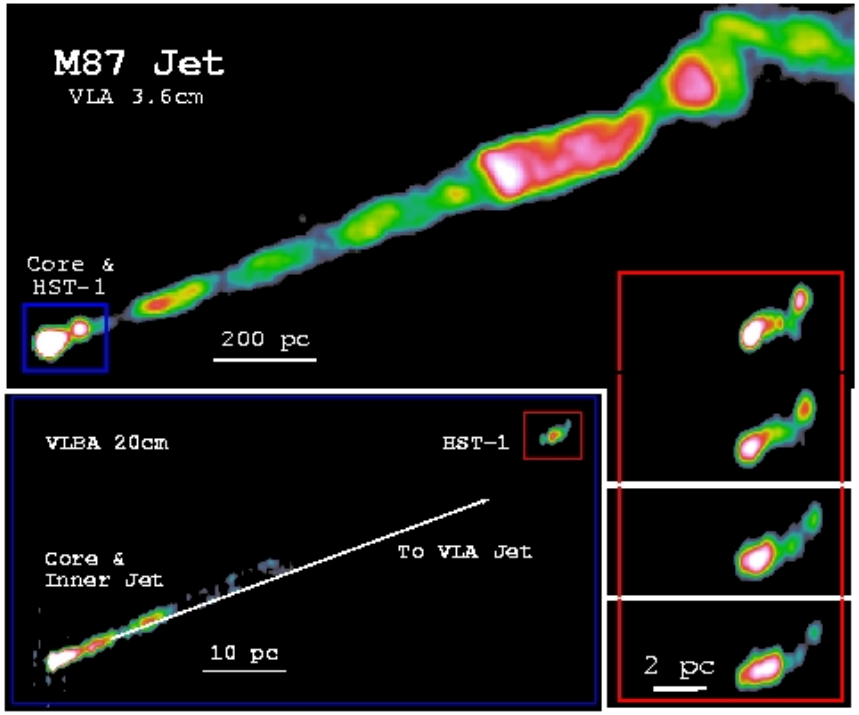




BLRGs = luminous RGs
~ misaligned FSRQs

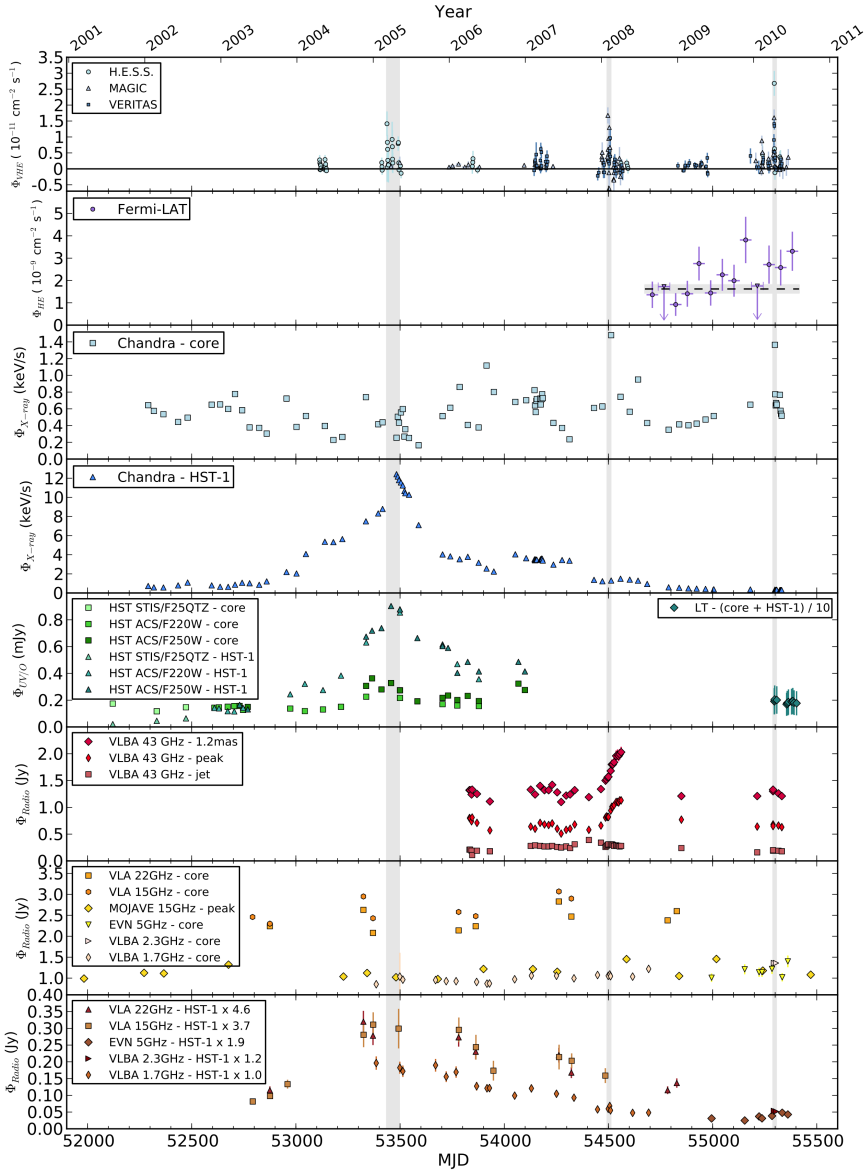
Kataoka et al. 2012
Grandi et al. 2012

M87: Confusing Case...



FR Is = Low-power RGs
~ misaligned BL Lacs

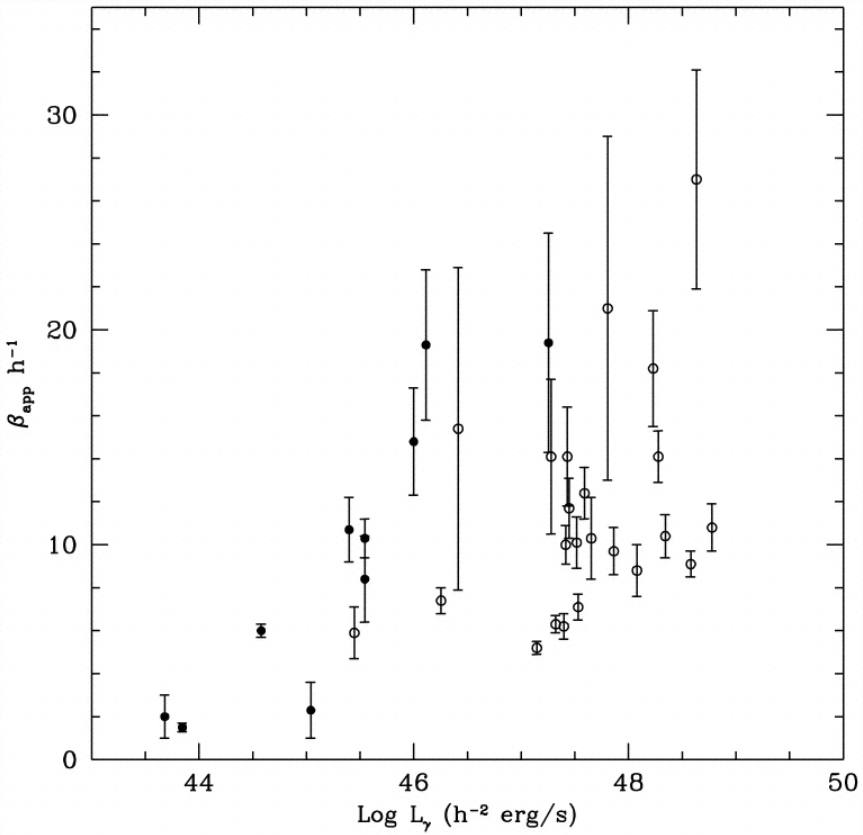
Cheung et al. 2007;
HESS+VERITAS+MAGIC+LAT++ 2012

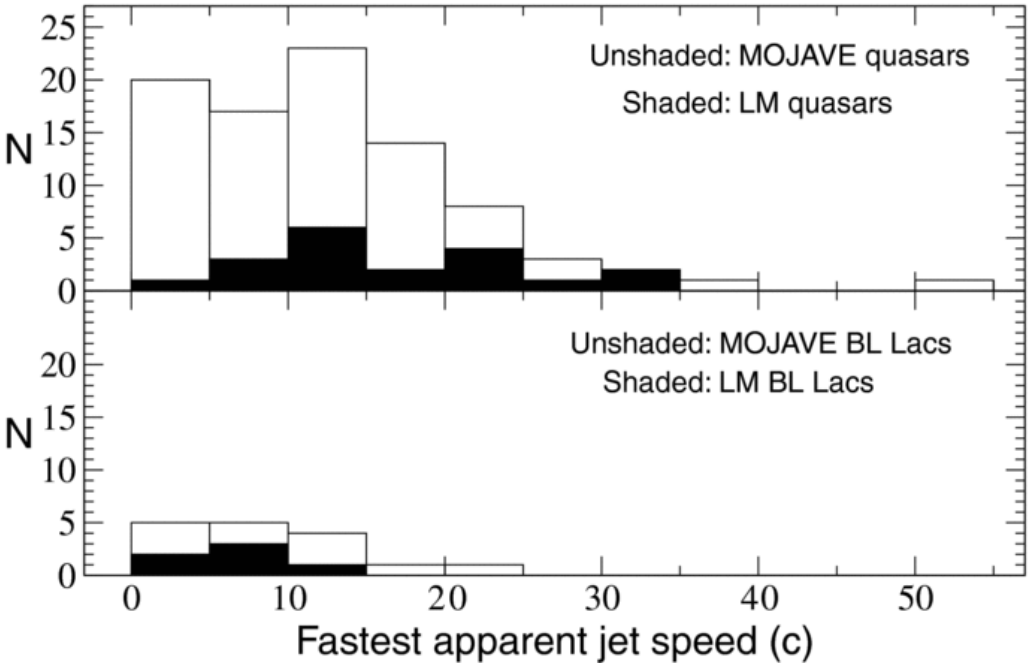


Correlations: Questions

- Are there any correlations or not?
- If yes, are they real or not?
- If yes, do they imply that R and γ fluxes produced co-spatially?

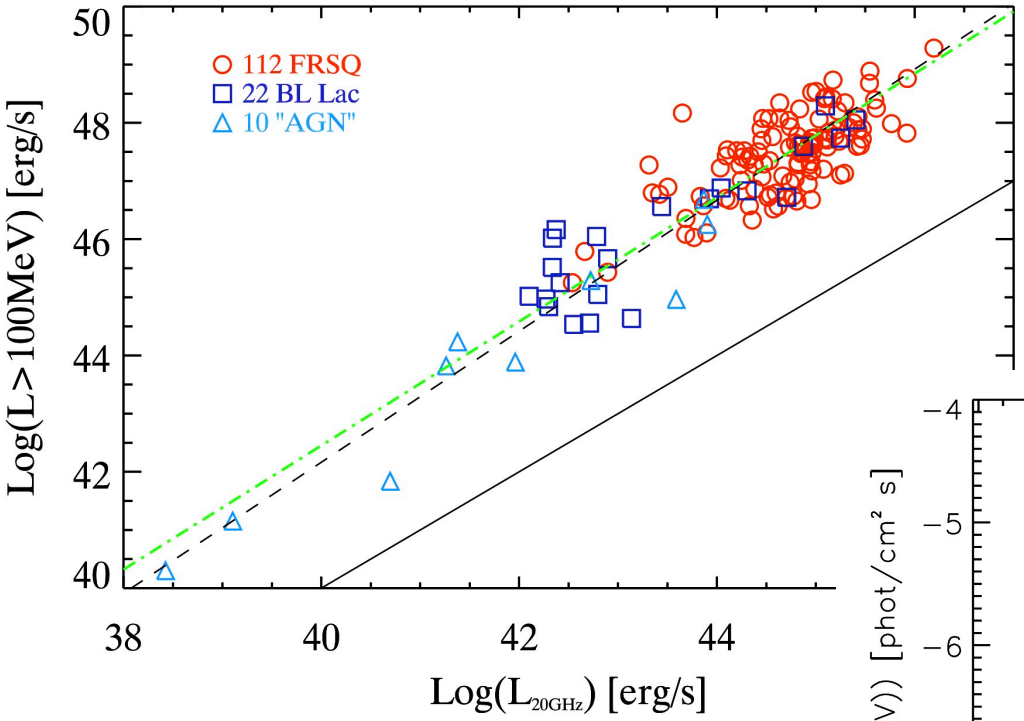
Faster?



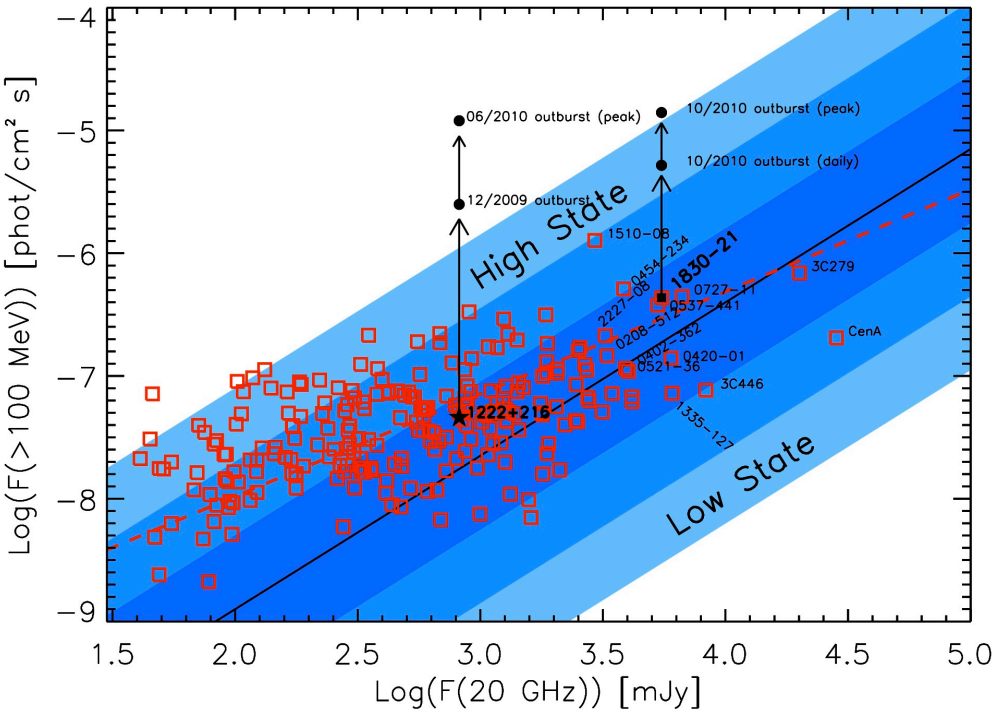


γ-detected blazars seem faster
(Jorstad et al. 2001, Lister et al. 2009)

Lum-Lum Correlation



Positive R/γ correlations seem to be present both in flux-flux and also lum-lum distributions (e.g., Ghirlanda et al. 2011)



Real Or Not?

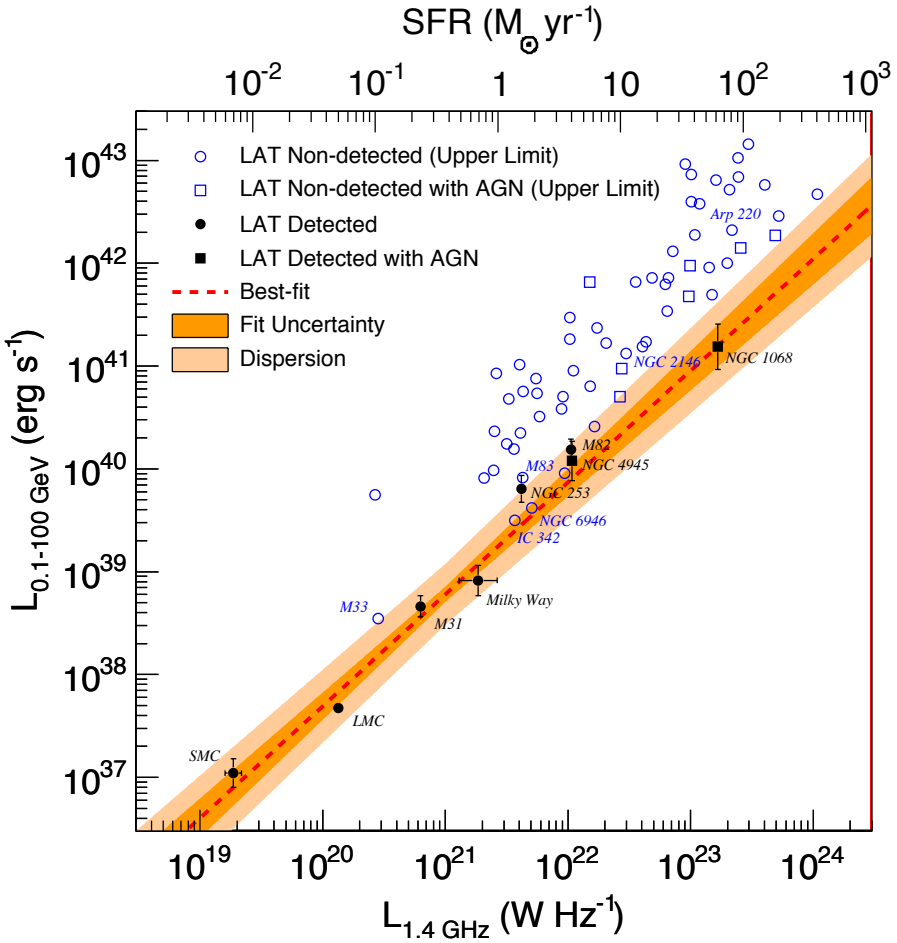
A) In flux-flux limited samples artificial lum-lum correlations $L_i \sim L_j^a$ with a~1 are expected; recognizing and removing such artificial correlations requires sophisticated statistical analysis methods, and numerous samples with upper limits included.

B) Even the observed lum-lum correlation is not due to flux-flux truncation in the dataset, it may arise for uncorrelated (intrinsically) bands if the sources in question undergo positive luminosity evolution.

Co-spatial?

i) In starforming galaxies L_γ ~ SFR, and also L_R ~ SFR; hence L_γ ~ L_R even though R and γ are produced by very different particles.

ii) Also R/opt correlation observed for quasar sources, where optical flux is dominated by the accretion disks; similarly, FIR/X correlation discussed recently for AGN may be real even though FIR and X fluxes are produced in very different regions by very different processes.

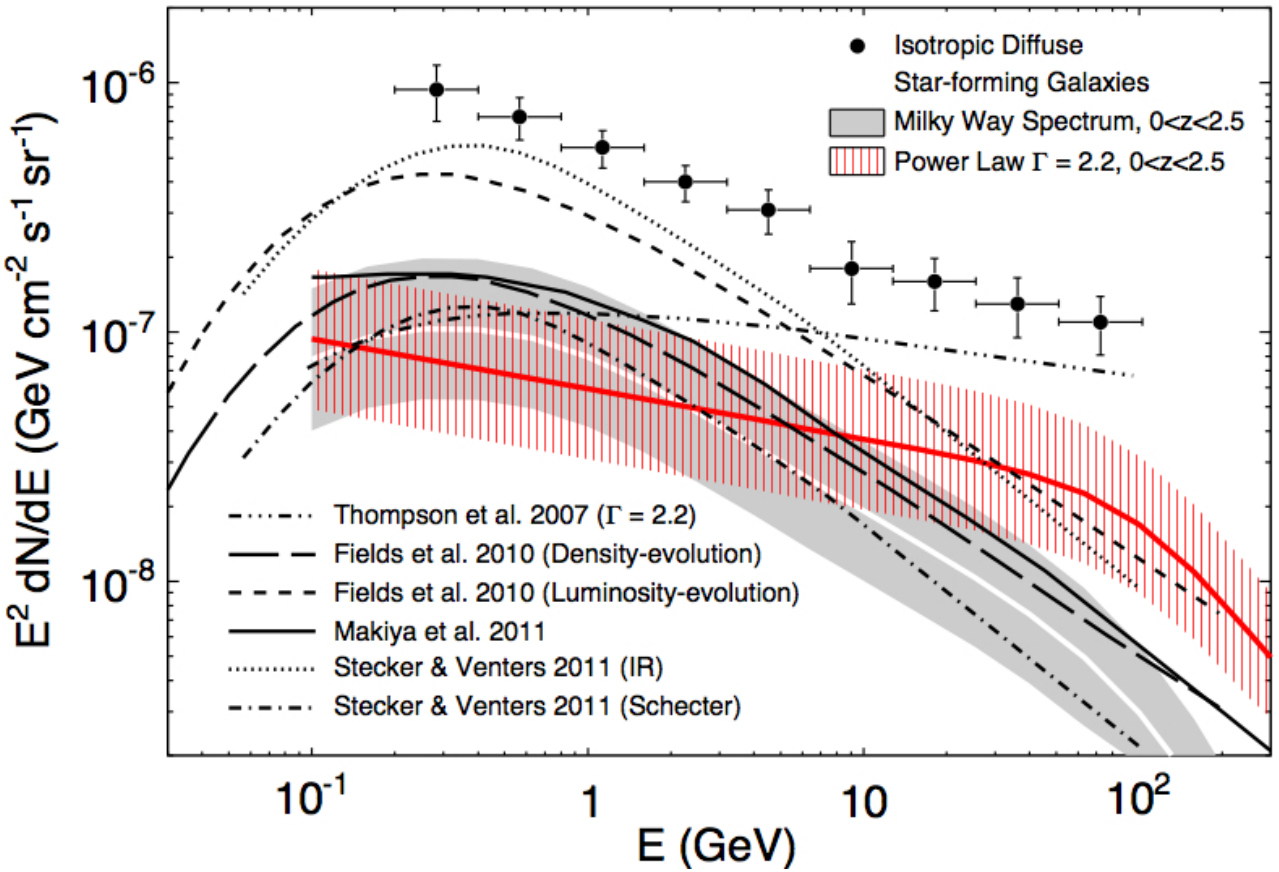


Fermi-LAT 2012

Correlations: Questions

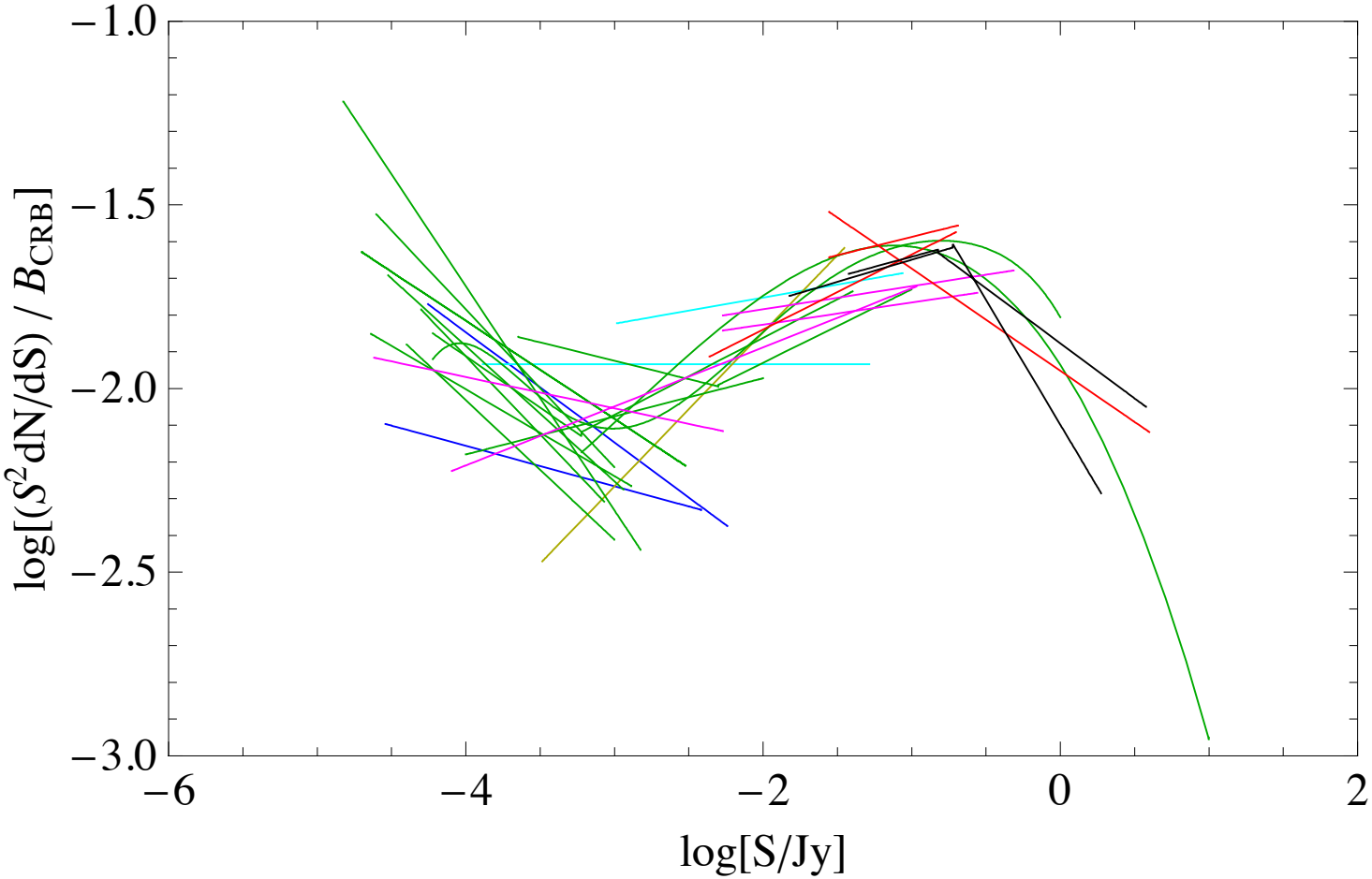
- Are there any correlations or not? **YES**
- If yes, are they real or not? **MAYBE**
- If yes, do they imply that R and γ are produced co-spatially? **NO**

Extragalactic γ Background



Starforming galaxies may account for ~ 25% of extragalactic γ background as measured by LAT; blazars are expected to contribute another ~25% (Fermi-LAT 2012)

Extragalactic R Background



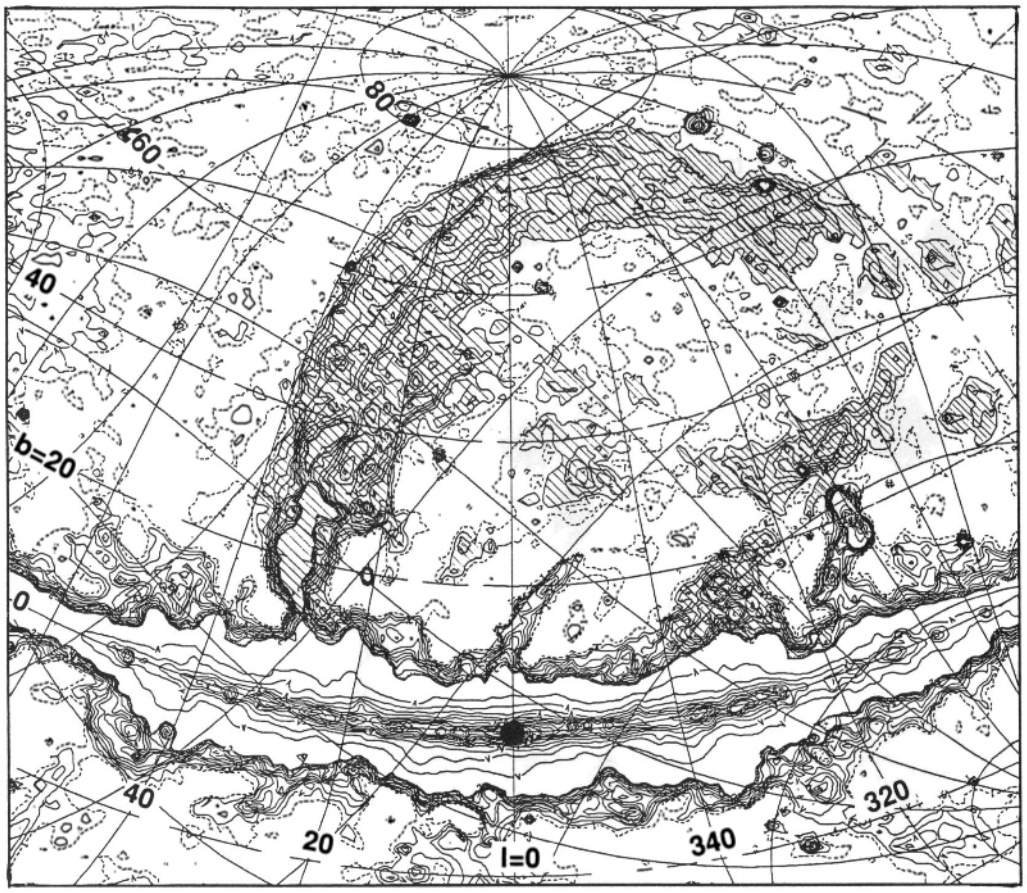
Known types of AGN & starforming galaxies may account for ~25% of extragalactic radio background as claimed by ARCADE (Singal et al. 2010)

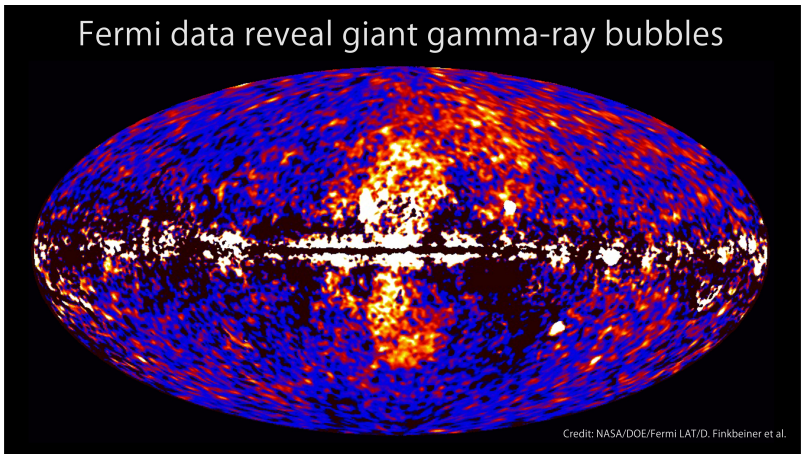
AGN Population in R and γ

- IR-to-X band best suited for investigating accretion-related radiative output of AGN
- R and γ bands best suited for investigating jet-related radiative output of AGN

  (not contaminated by accretion-related components, providing complementary information on jet parameters, structure, and particle acceleration processes)
- Starformation & AGN activity in R/γ

Fermi Bubble

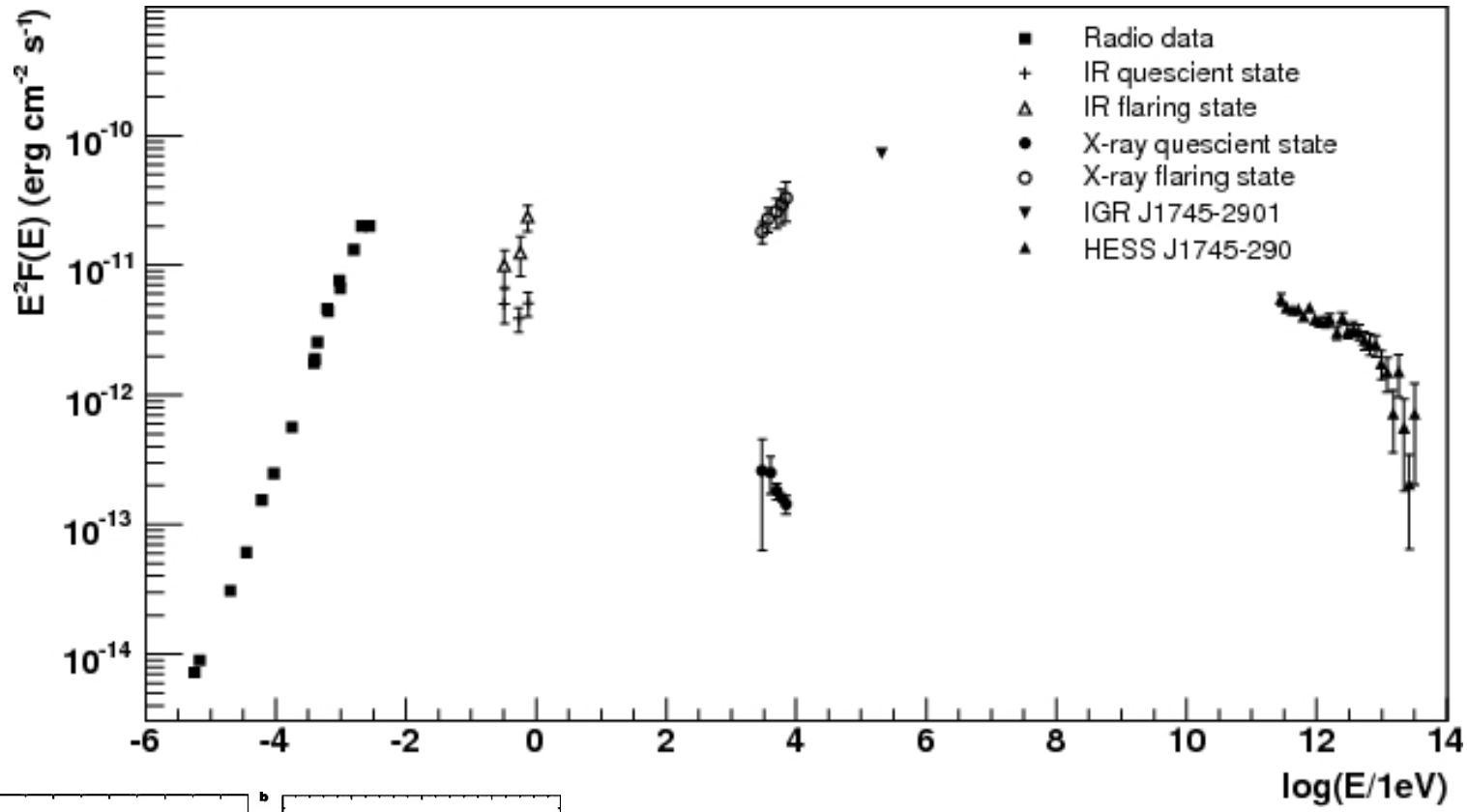


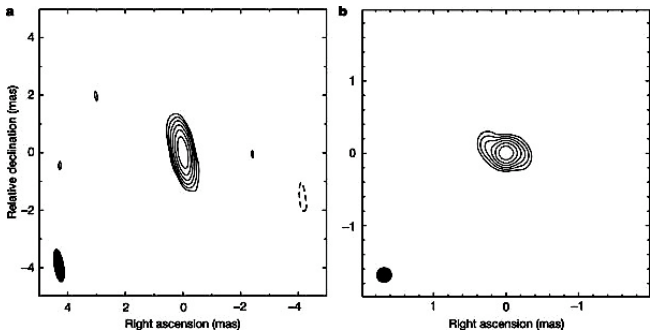


…, Sofue 1994, Su et al 2010, …

Starburst or jet activity
in the Galactic Center?

Sgr A*





…, Shen et al. 2004, HESS 2004-2009, …

γ production site: jet or accretion flow or something else?