

Introduction to gamma-ray blazars

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OUTLINE

1. Active galactic nuclei
2. Blazars
3. Models of blazar emission
- 4. The Fermi blazars**
- 5. The TeV blazars**
6. The GeV–TeV Connection
7. The extra-galactic background light
8. Intergalactic magnetic fields
9. Characterising variability

Active galactic nuclei

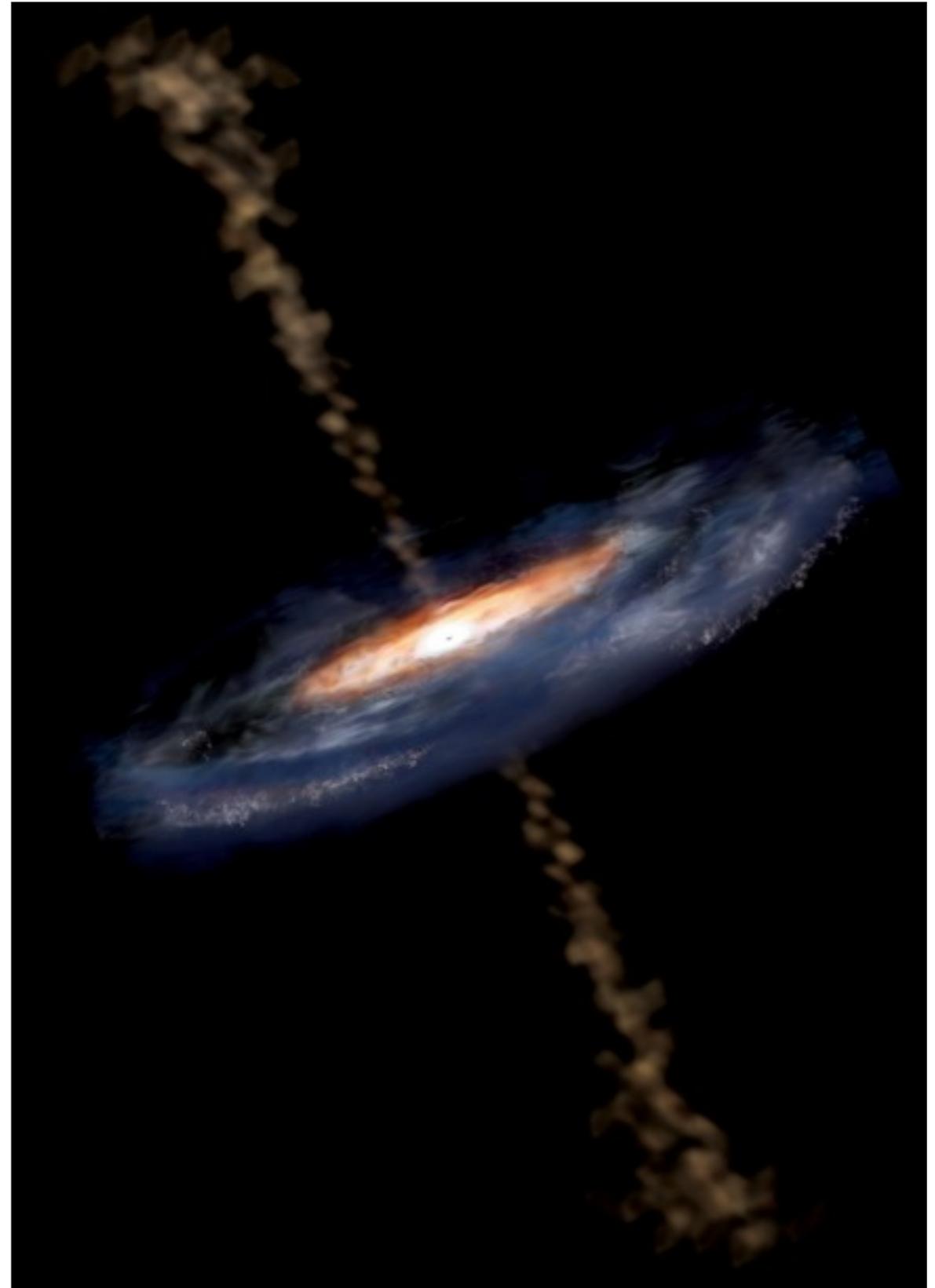
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Active Galactic Nuclei

CHARACTERISTICS

- * **central nucleus outshines the rest of the galaxy**
- high luminosity (normally)
- **emission across entire spectrum ... radio to keV, MeV, TeV**
 - non-thermal
- strong variability
- **radio-loud sources:**
 - relativistic jets ... superluminal motion



Active Galactic Nuclei

TAXONOMY

ACTIVE GALAXIES

What we see depends on how we view it ...

An active galaxy is one in which a tremendous amount of energy is emitted from the nucleus. Active galaxies take many forms; some have exquisitely bright nuclei pouring forth high-energy photons, some have high-energy nuclei but appear to be surrounded by a more-or-less "normal" galaxy, while some have long, narrow jets or beams of matter streaming out from the center. Displayed here is an illustration of an active galaxy that has jets. The nucleus of this galaxy contains a supermassive black hole - the engine that powers the phenomena we see. Following its launch, the Gamma-ray Large Area Space Telescope (GLAST) will see thousands of these types of active galaxies.

All the images are artist's conceptions unless otherwise noted.

Looking In On A Galaxy With Jets



The long view of an active galaxy is dominated by lobes of radio emission caused by highly focused jets of matter streaming out from the galaxy nucleus.

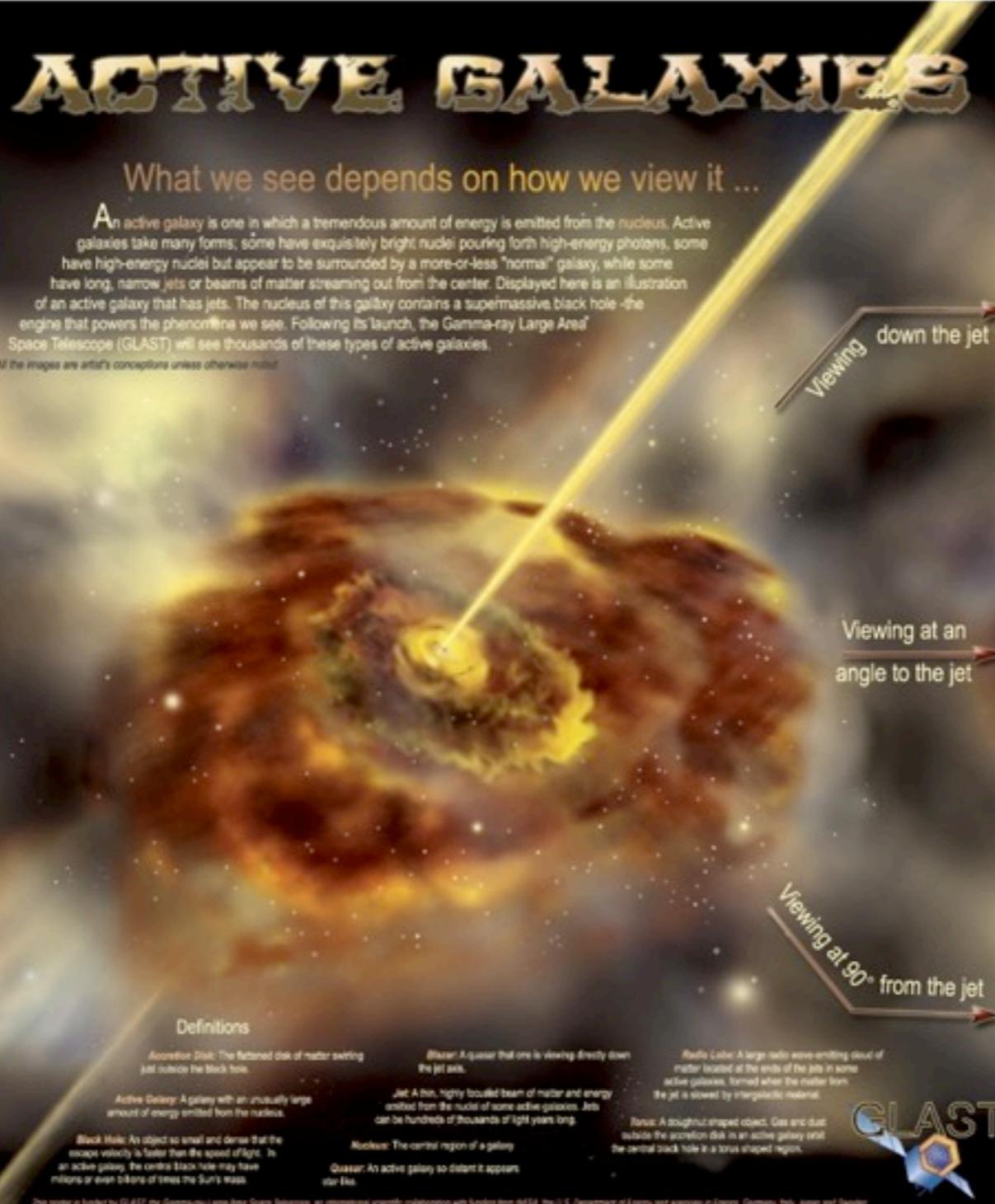


Closer in, a swirl of dust and gas can be seen, swirling outside a faster disk of molting gas.



In an extreme close-up, the black hole in the center is surrounded by a fast accretion disk of rapidly orbiting material. The jets are emitted at right angles from the plane of the disk, driven by physics still not well understood.

<http://glast.sonoma.edu>

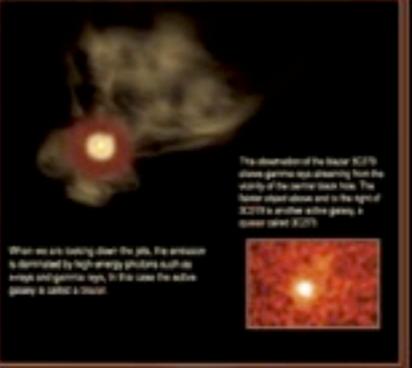


Viewing down the jet

Viewing at an angle to the jet

Viewing at 90° from the jet

Different Angles On A Galaxy With Jets



The observation of the blazar 3C 279 shows gamma rays streaming from the vicinity of the central black hole. The blazar's rapid motion and its light of 3C 279 is another active galaxy, a quasar named 3C 279.

When we are looking down the jets, the emission is dominated by high-energy photons such as x-rays and gamma rays. In this case the active galaxy is called a blazar.



When seen from an angle, the blazar jets are dimmer, and features near the galaxy nucleus are more easily seen. Gamma rays are not detected, although the central source is still bright in x-rays and lower energies down to radio.

The observation of Centaurus A - a nearby active galaxy - is from Centaurus A (Cen A) is striking in its obscurity. It shows a ring from one of the jets, diffuse gas in the galaxy, and numerous point sources near the galaxy center.



When seen from the side, the relatively weak emission from the lobes becomes dominant. The jets powered by the black hole travel "head-on" at thousands of light years before breaking into huge clouds of radio-wave emitting gas.

The observation from the new Large Array shows the radio emission from the lobes of matter in the active galaxy Cygnus A. The central region of the galaxy can be seen as well as jet, with the long and turbulent radio emission double over 300,000 light years from the central black hole.

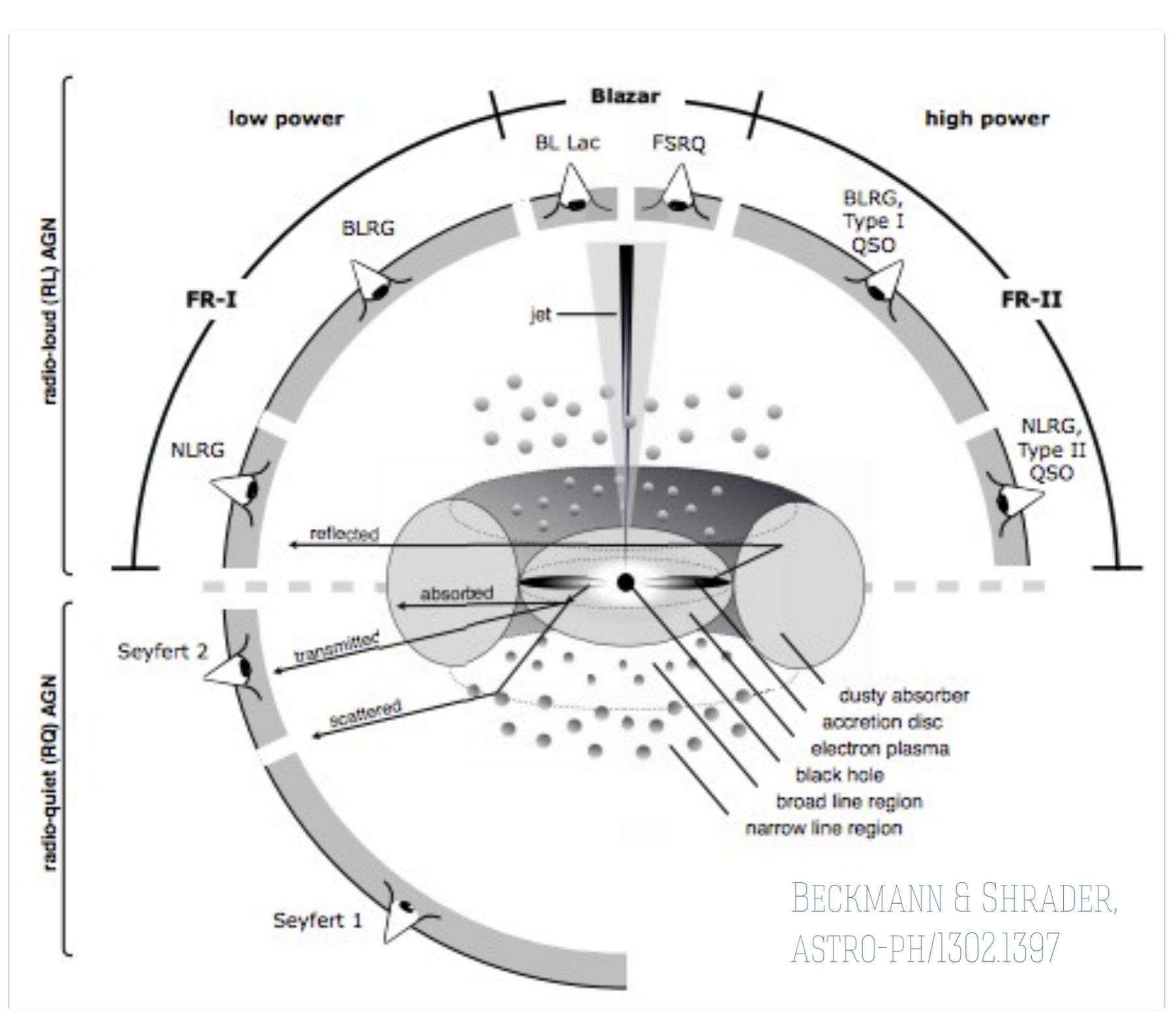
Definitions

<p>Accretion Disk: The flattened disk of matter swirling just outside the black hole.</p> <p>Active Galaxy: A galaxy with an unusually large amount of energy emitted from the nucleus.</p> <p>Black Hole: An object so small and dense that the escape velocity is faster than the speed of light. In an active galaxy, the central black hole may have millions or even billions of times the Sun's mass.</p>	<p>Blazar: A quasar that one is viewing directly down the jet axis.</p> <p>Jet: A thin, highly focused beam of matter and energy emitted from the nuclei of some active galaxies. Jets can be hundreds of thousands of light years long.</p> <p>Quasar: An active galaxy so distant it appears star like.</p>	<p>Radio Lobe: A large radio wave-emitting cloud of matter located at the ends of the jets in some active galaxies, formed when the matter from the jet is slowed by intergalactic material.</p> <p>Ring: A doughnut-shaped object. Gas and dust within the accretion disk in an active galaxy and the central black hole in a broad-shaped region.</p>
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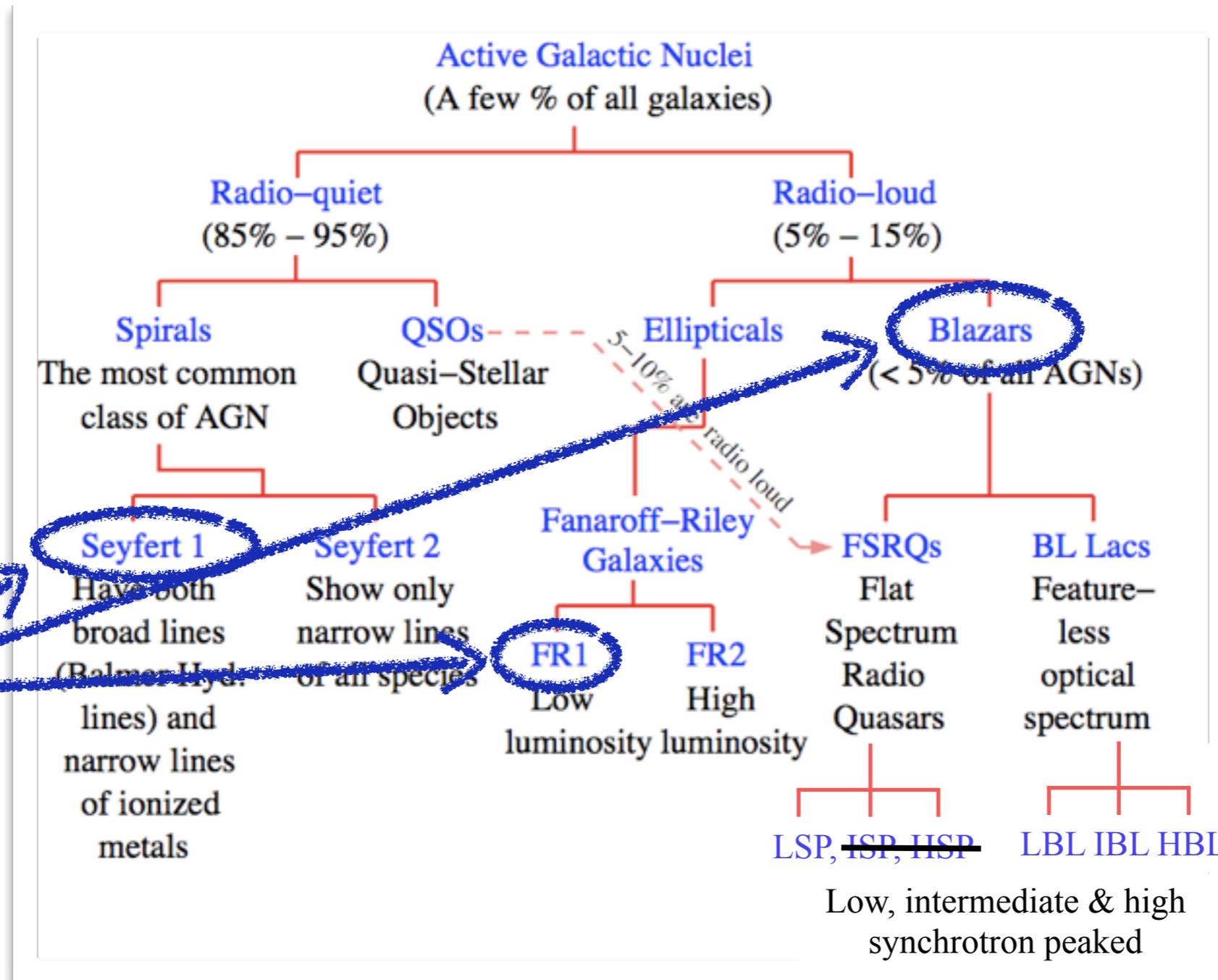
Art Design by Aurore Simonneau, Text by Phil Plait.

Active Galactic Nuclei



Active Galactic Nuclei

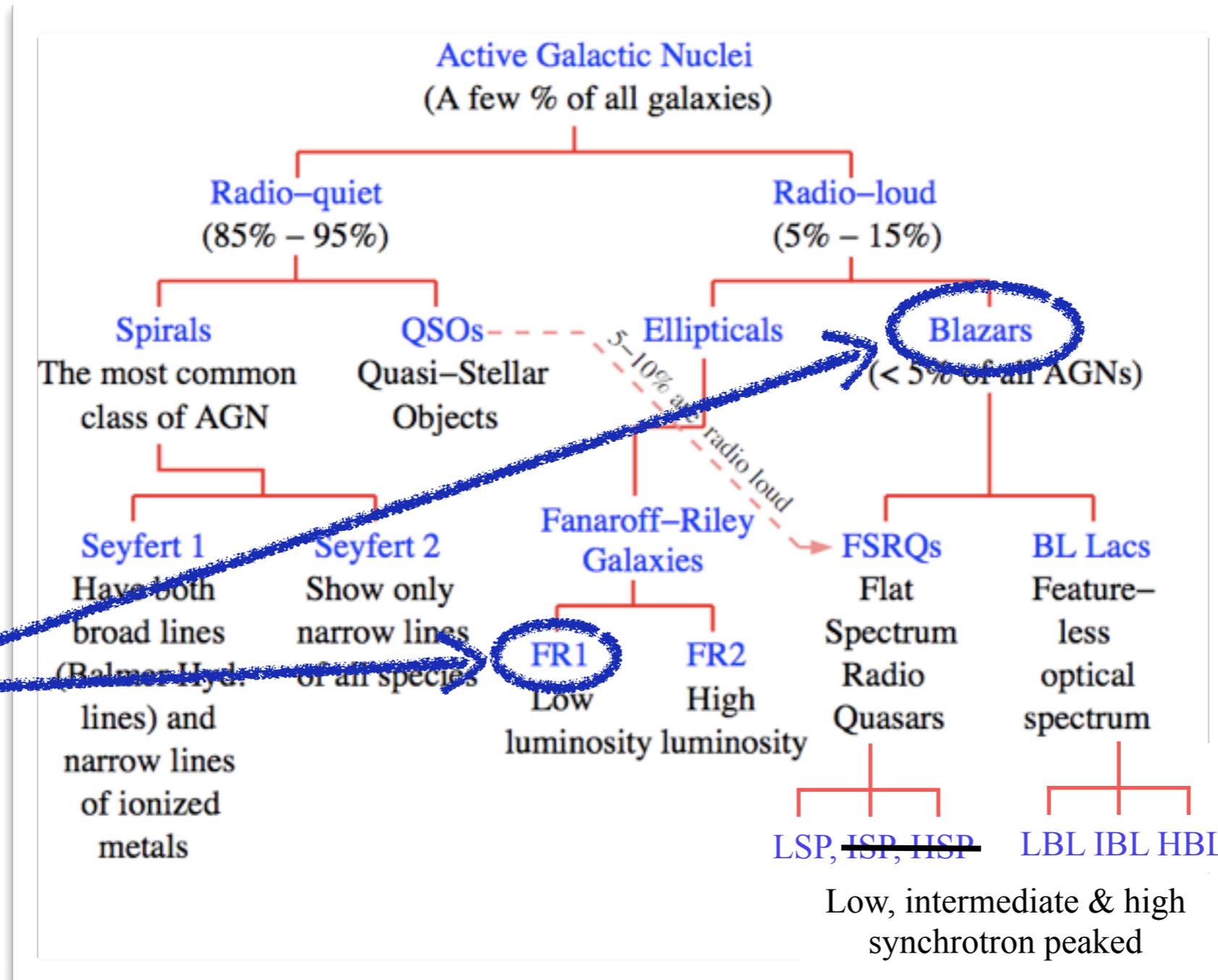
CLASSIFICATION



identified
as Fermi
sources

Active Galactic Nuclei

CLASSIFICATION



Blazars

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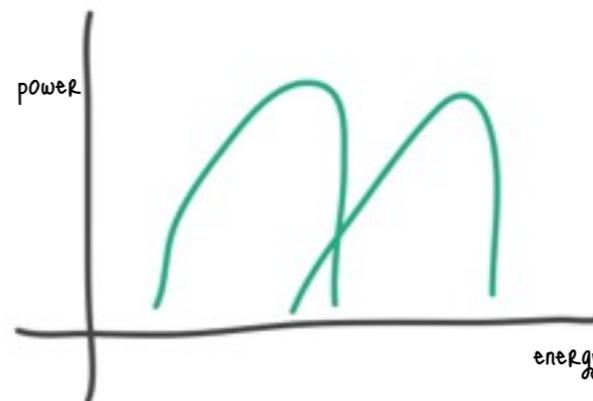


Blazars



CHARACTERISTICS

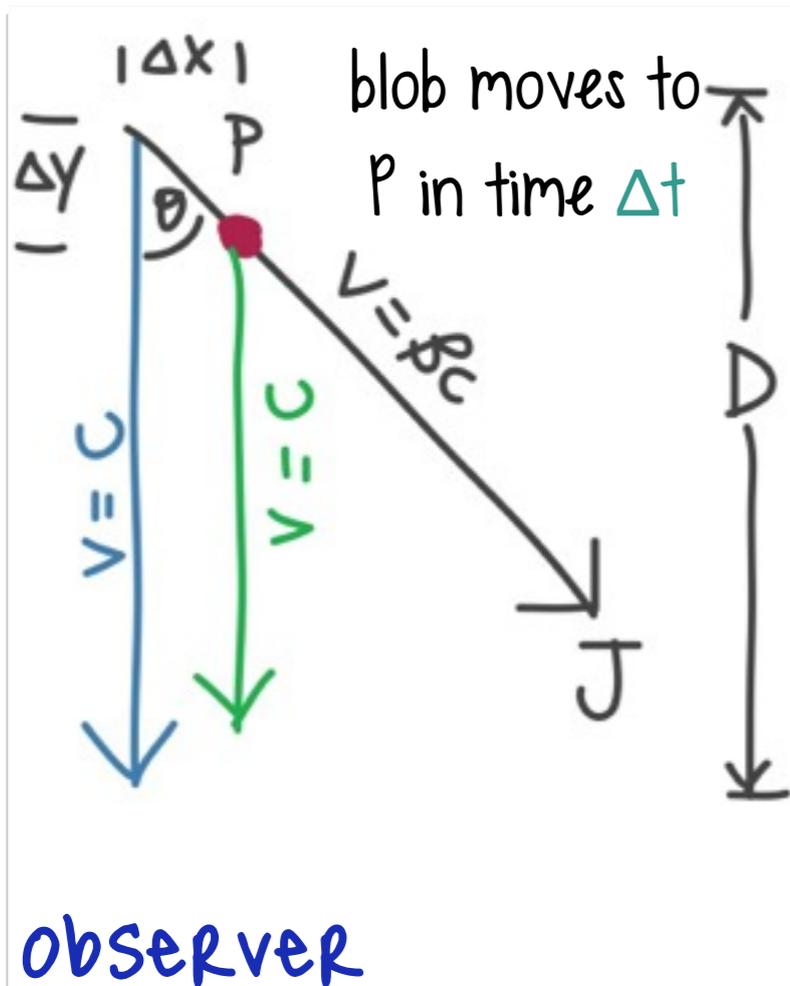
- * <5% of all AGN
- jet points “at” us
- flat radio spectrum
- **radio loud AGN**
- large amplitude variability
- **optical polarisation**
- **spectral energy distribution**



Blazars

Superluminal motion

FIRST PROPOSED BY REES IN 1966 (NATURE, 211, 468) YEARS BEFORE IT WAS FIRST OBSERVED WHEN VLBI TECHNIQUES WERE DEVELOPED



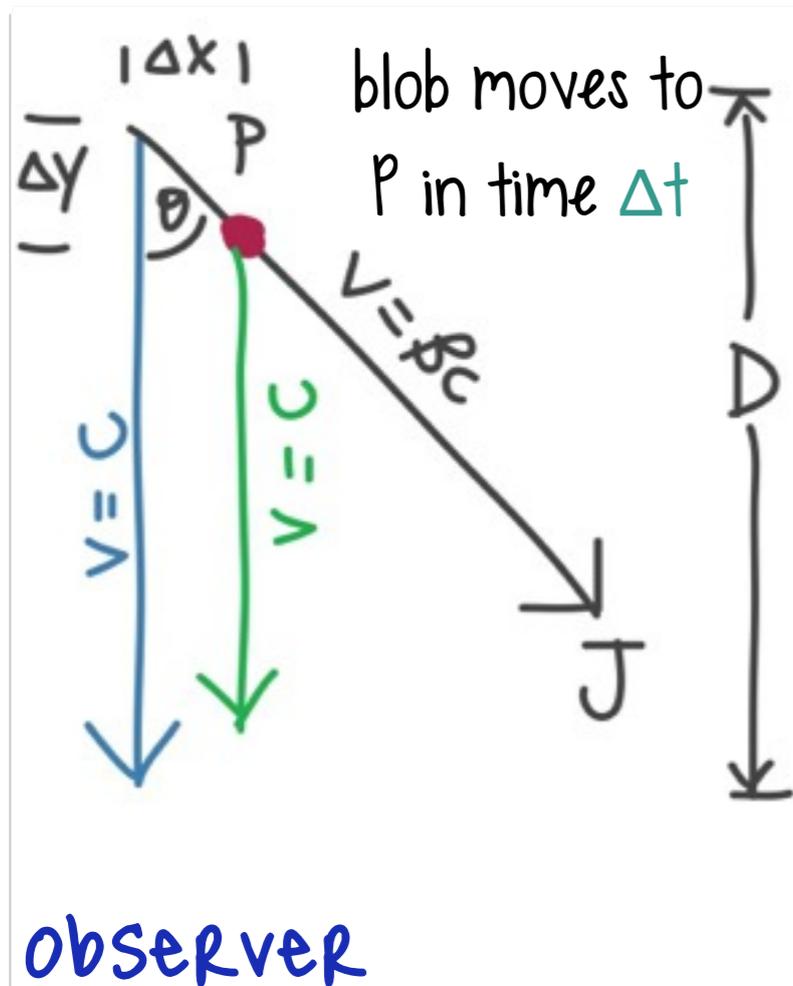
first pulse travels to observer in time D/c ; the second, emitted time Δt later, has a shorter distance to travel: $D - \Delta y$.

Difference in arrival time is:

$$\Delta t_{\text{obs}} = \left[\Delta t + \frac{(D - \Delta y)}{c} \right] - \left[\frac{D}{c} \right]$$

Blazars

Superluminal motion



Difference in arrival time is:

$$\Delta t_{obs} = \left[\Delta t + \frac{(D - \Delta y)}{c} \right] - \left[\frac{D}{c} \right]$$

substitute for Δy & rearrange:

$$\Delta t_{obs} = \Delta t (1 - \beta \cos \theta)$$

measured transverse velocity, v_{obs}

$$v_{obs} = \frac{\Delta x}{\Delta t_{obs}} = \frac{\beta c \sin \theta}{(1 - \beta \cos \theta)}$$

therefore:

$$\beta_{obs} = \frac{\beta \sin \theta}{(1 - \beta \cos \theta)}$$

Blazars

Superluminal motion

So, if the plasma velocity was $0.95c$ and the angle to the observer was 5deg , the apparent velocity would be $1.5c$. The effect is maximised when $\cos\theta = \beta$

$$\beta_{\text{obs}} = \frac{\beta \sin\theta}{(1 - \beta \cos\theta)}$$

Blazars

Relativistic beaming

- Another relativistic effect occurs because the knots of plasma are moving at velocities close to that of light
- When an emitting plasma has a bulk relativistic motion relative to a fixed observer, its emission is beamed in the forward direction in the fixed frame
- The flux density is thus changed by relativistic time dilation so an observer sees much more intense emission than if the plasma were at rest
- The observed emission, S_{obs} is boosted in energy over that emitted in the rest frame, S

Definitions:

The Doppler factor is a measure of the strength of the beaming: $\delta = [\Gamma (1 - \beta \cos \theta)]^{-1}$

The Lorentz factor: $\Gamma = \frac{1}{\sqrt{1 - \beta^2}}$ where $\beta = \frac{v}{c}$

$$S_{\text{obs}} = S [\Gamma (1 - \beta \cos \theta)]^{-3}$$

If plasma velocity is $0.95c$ and θ is 5deg , the boosting factor will be ~ 198

Blazars

Pair-production optical depth

*DONDI & GHISELLINI (1995) MNRAS, 273, 583

**URRY & PADOVANI (1995) PASP, 107, 803

- High energy gamma rays collide with softer radiation to produce e^+e^- pairs
- For gammas to escape from a source, the optical depth for this process τ_e must be sufficiently low
- The cross section for this process is maximized for collisions between gamma rays of energy ...

$$X_\gamma = \frac{h\nu_\gamma}{mc^2} \quad \text{and target photons of energy ...} \quad X_{\text{target}} = \frac{1}{X_\gamma}$$

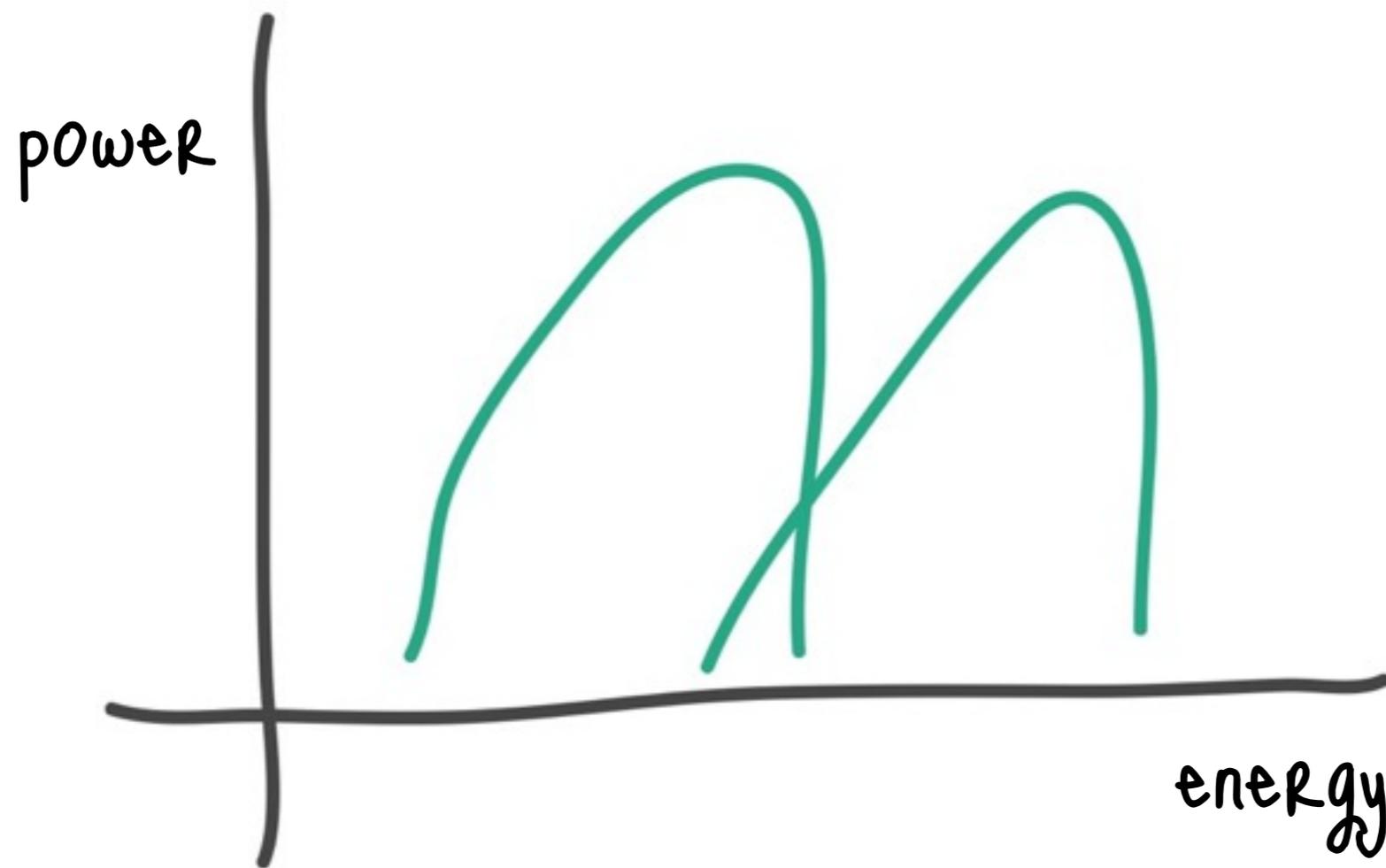
- The optical depth is then defined as: $\tau_{e^\pm} = \frac{\sigma_T}{5} N X_{\text{target}} R$
... where N is the number of soft photons, R is the radius of the plasma "blob" (assumed shape) and σ_T is the Thompson-scattering cross section*
- A useful parameter that can then be derived** is the compactness of the source - it is a direct measure of the importance of the pair-production process

$$l = \frac{L}{R} \frac{\sigma_T}{m_e c^3}$$

- The criterion for gammas to escape from a source is ... $\tau_{e^\pm} \sim \frac{l}{40} \ll 1$

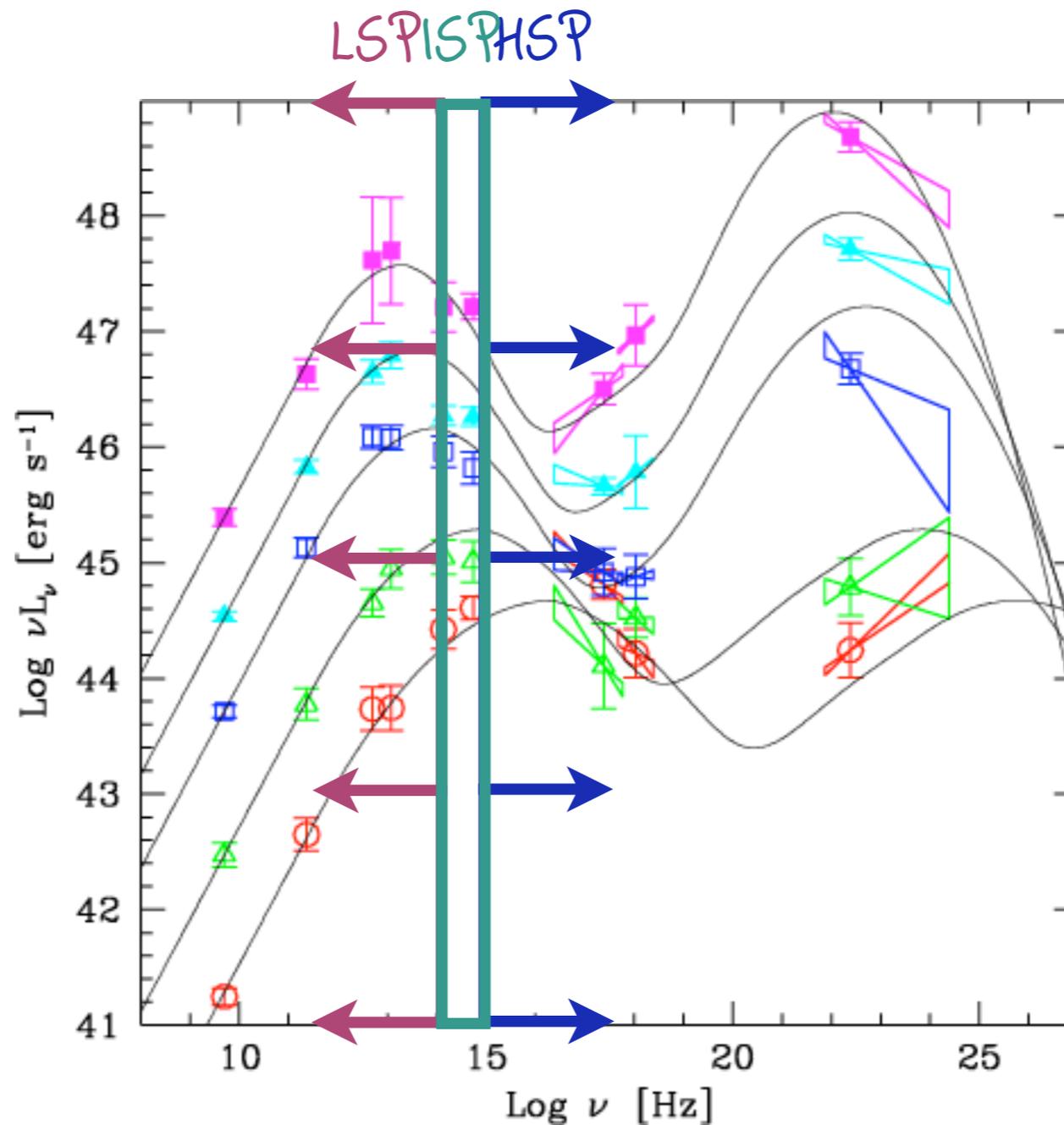
Blazars

SPECTRAL ENERGY DISTRIBUTION



Blazars

SPECTRAL ENERGY DISTRIBUTION



Before, definitions were based on ratio of flux at 5GHz to that at 1 keV

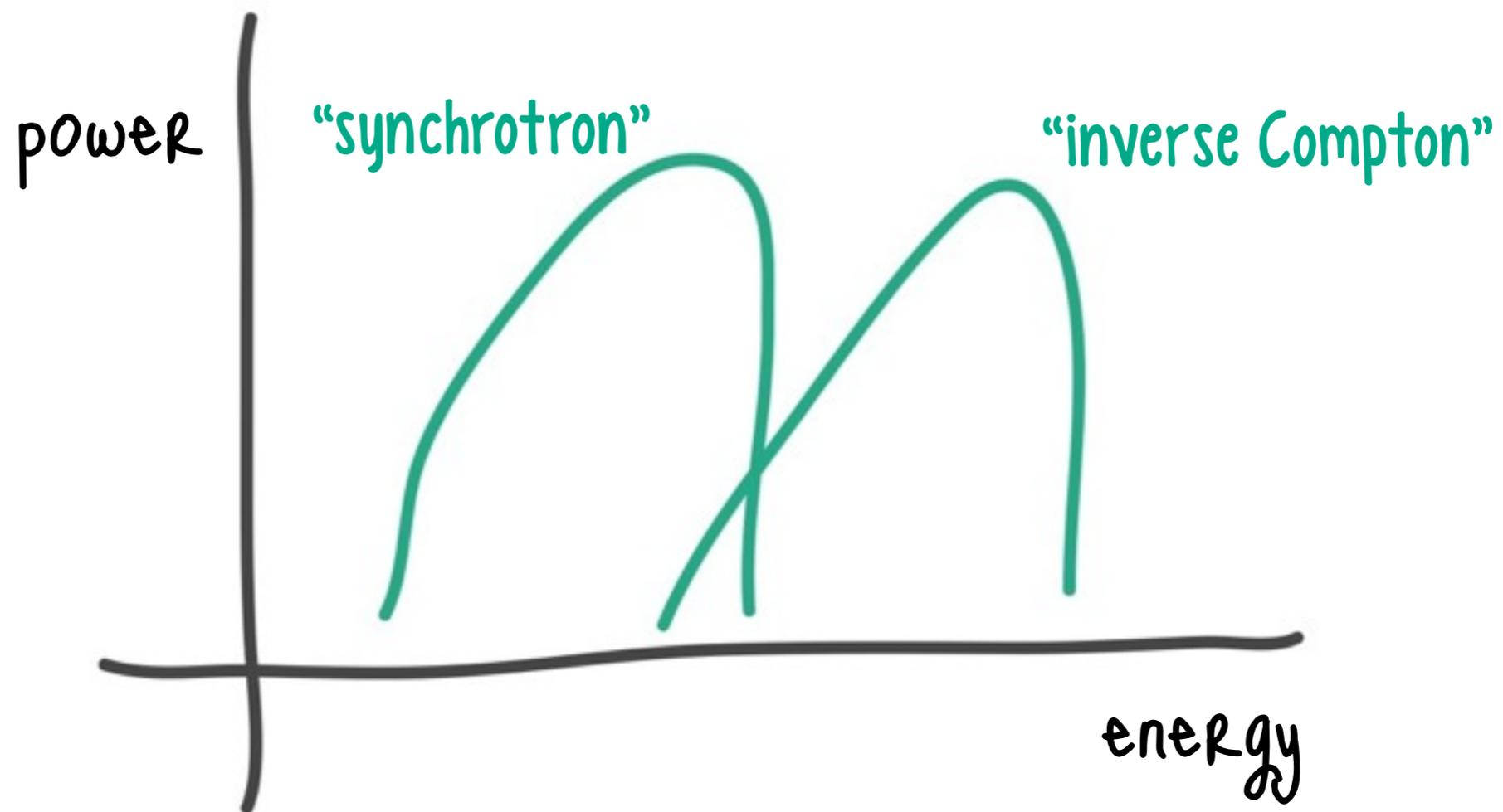
Models of blazar emission

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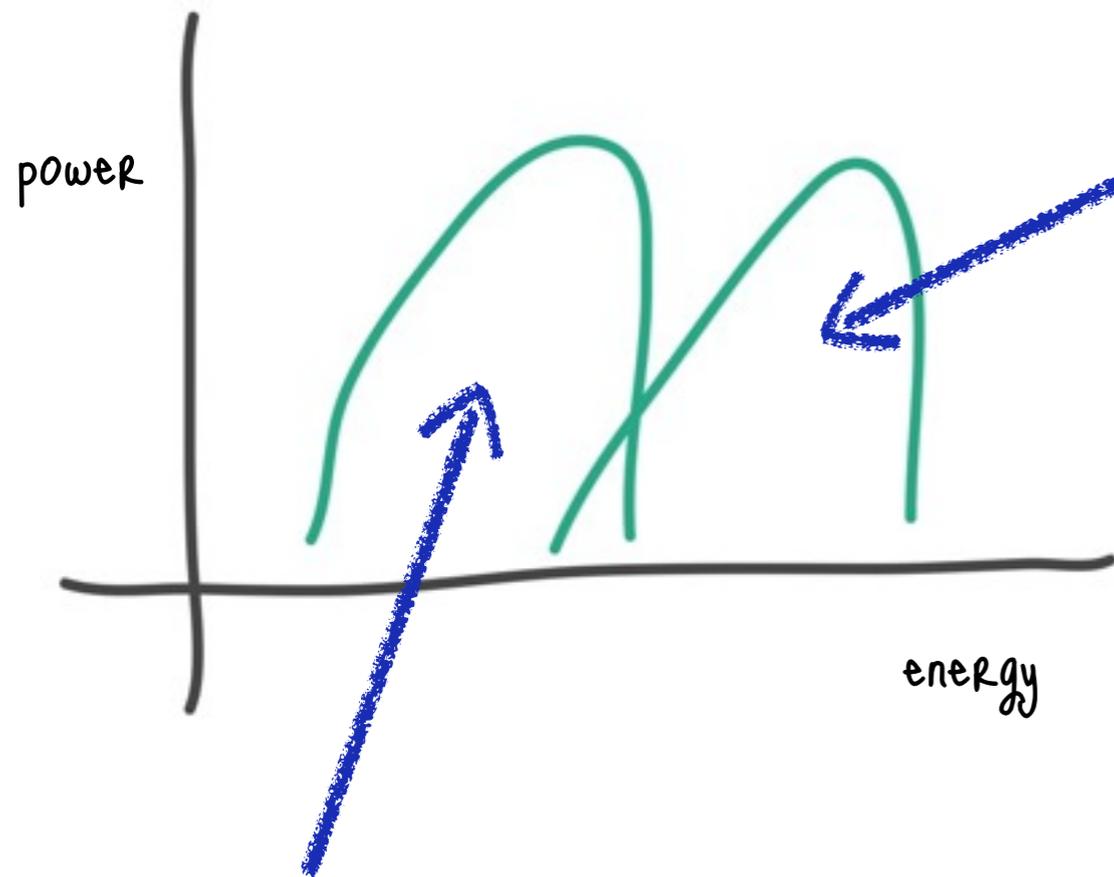


Models of blazar emission

SPECTRAL ENERGY DISTRIBUTION



Models of blazar emission

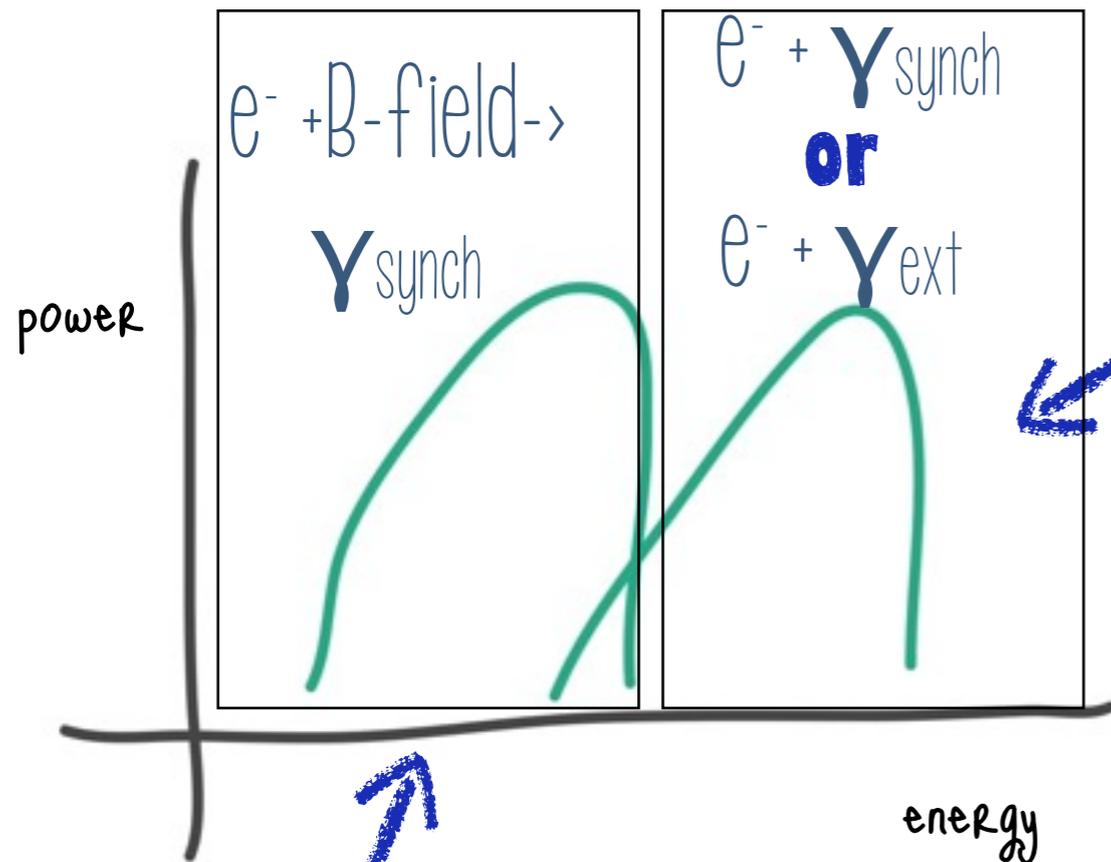


Two fundamentally different approaches to explain the higher energy emission

- Leptonic & Hadronic

Lower energy emission due to synchrotron emission from relativistic e^- s in the jet

Models of blazar emission



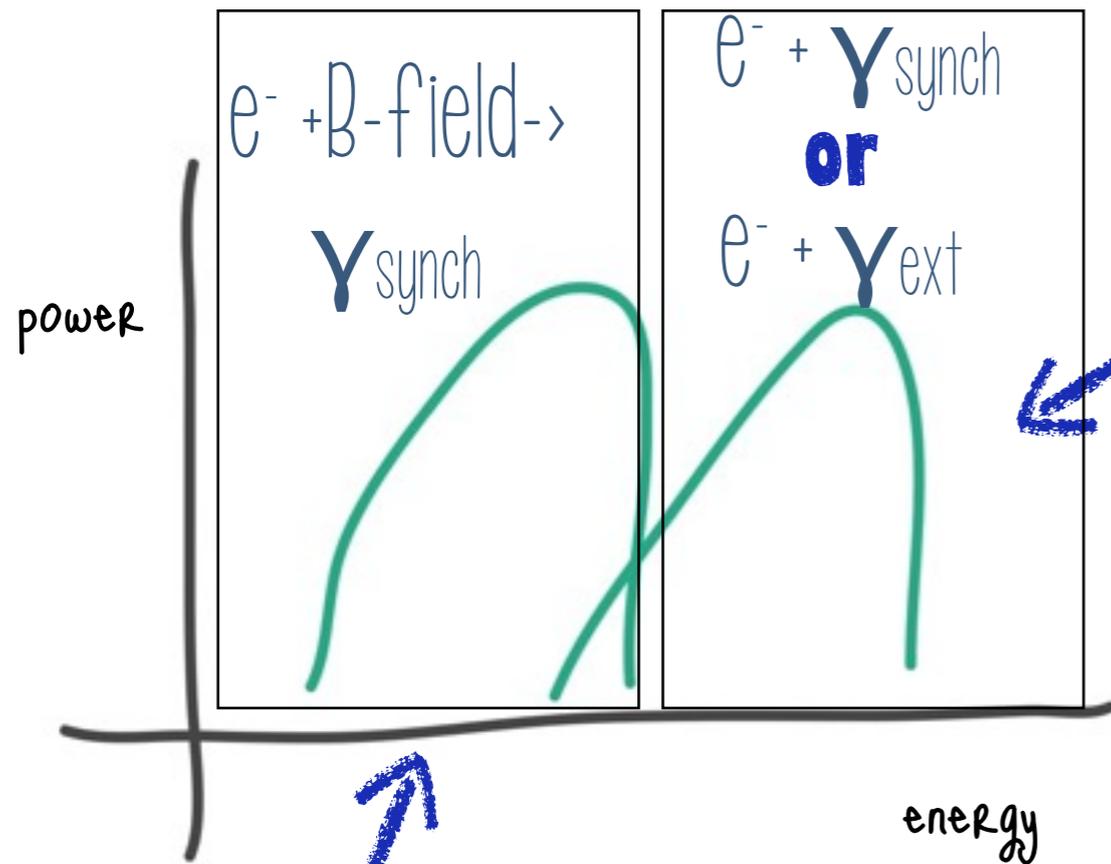
Two fundamentally different approaches to explain the higher energy emission

• Leptonic & Hadronic

- radiative output dominated by e^-/e^+
- high-energy photons most likely the result of inverse Compton scattering by the same e^- s that produced the synch
 - upscatter the low-energy photons responsible for first bump
 - synchrotron self-Compton
 - upscatter photons from the broad-line region, disc, torus ...
 - external Compton

Lower energy emission due to synchrotron emission from relativistic e^- s in the jet

Models of blazar emission



Two fundamentally different approaches to explain the higher energy emission

• Leptonic & Hadronic

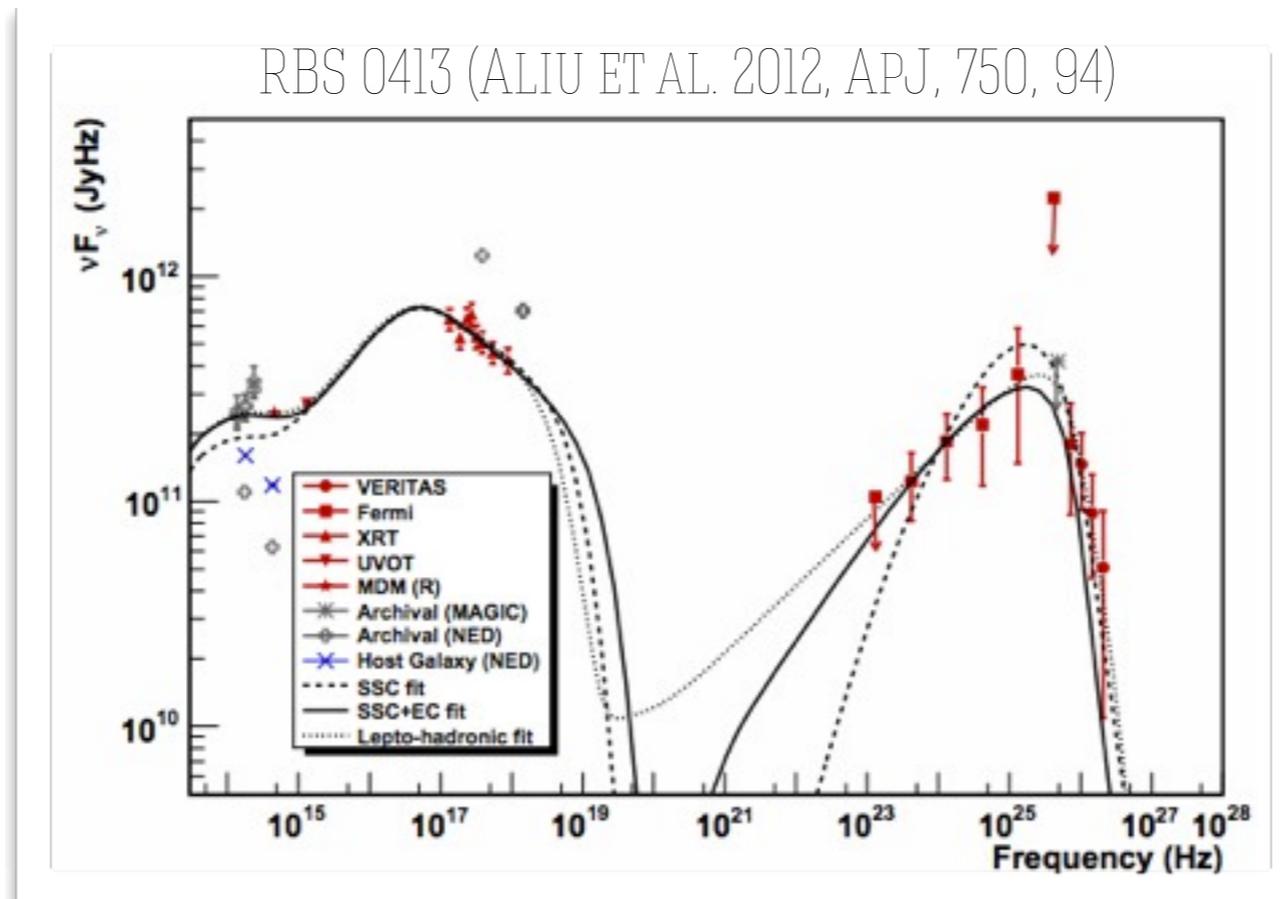
- both e^-/e^+ and p accelerated to ultra-relativistic energies
- p 's exceed threshold for $p\gamma$ photo-pion production on soft photon field in emission region
- high energy emission dominated by
 - proton synchrotron
 - π^0 decay products
 - synchrotron and Compton emission from secondary products of charged pions
 - external Compton

Lower energy emission due to synchrotron emission from relativistic e^- s in the jet

BOETTCHER, M. (2012) FERMI & JANSKY, ASTRO-PH/1205.0539
BOETTCHER M. (2013), APJ (IN PRESS), ASTRO-PH/1304.0605

Models of blazar emission

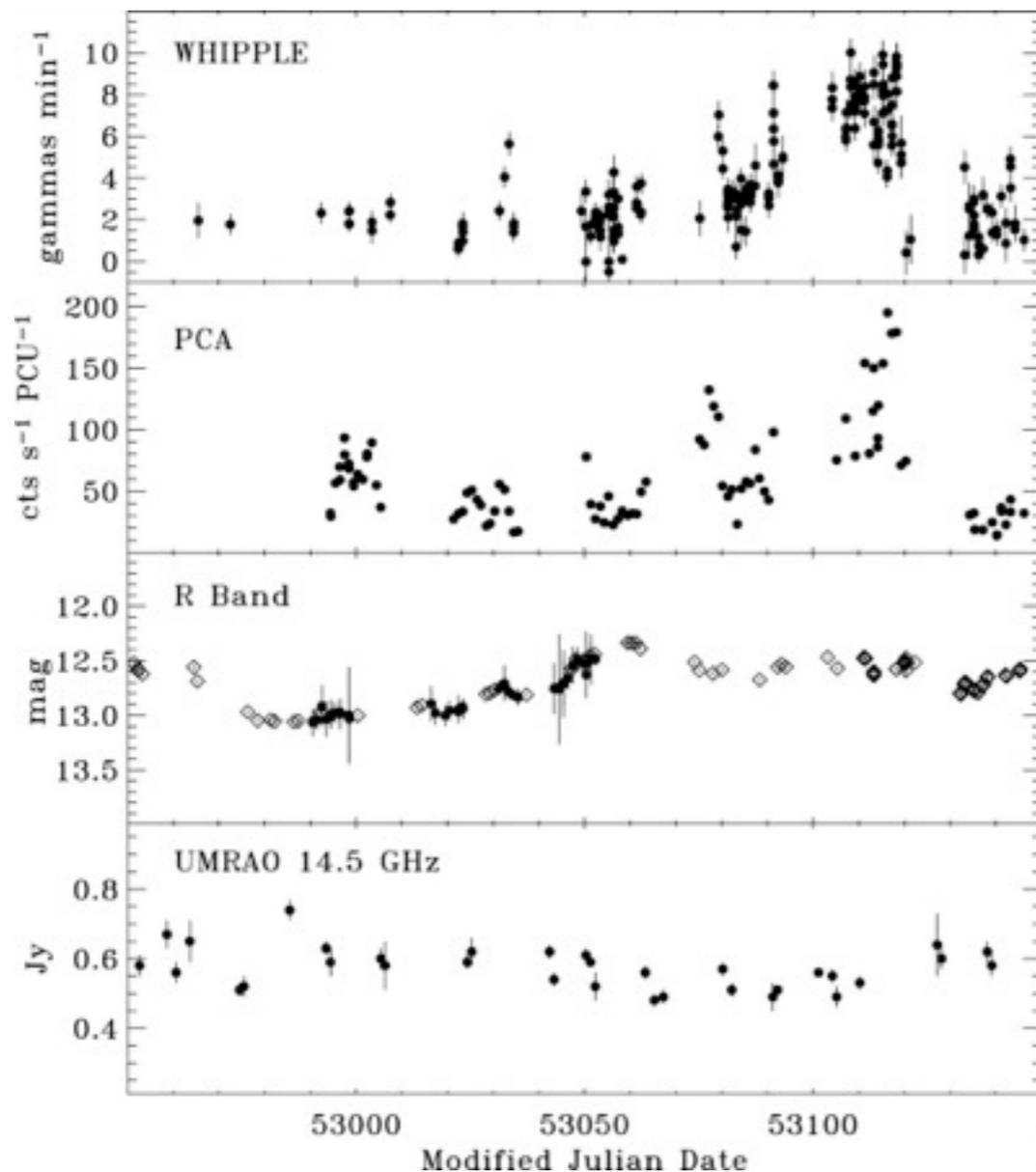
- leptonic models provide good fits to many blazars



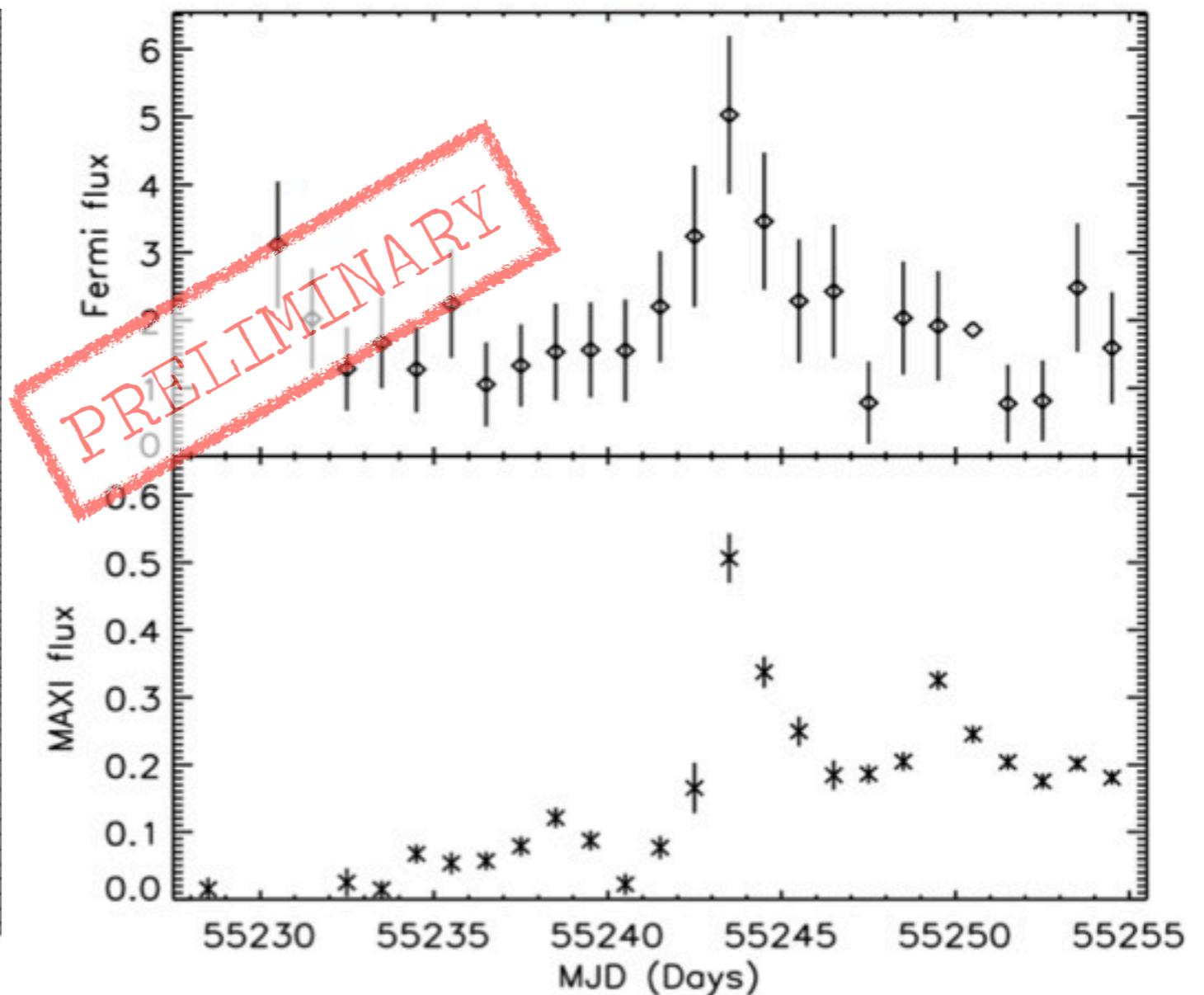
Models of blazar emission

- leptonic models provide good fits to many blazars
- **X-ray and gamma-ray emission often correlated - a fact naturally explained by SSC models**

BLAZEJOWSKI, M. ET AL. 2005, APJ, 630, 130

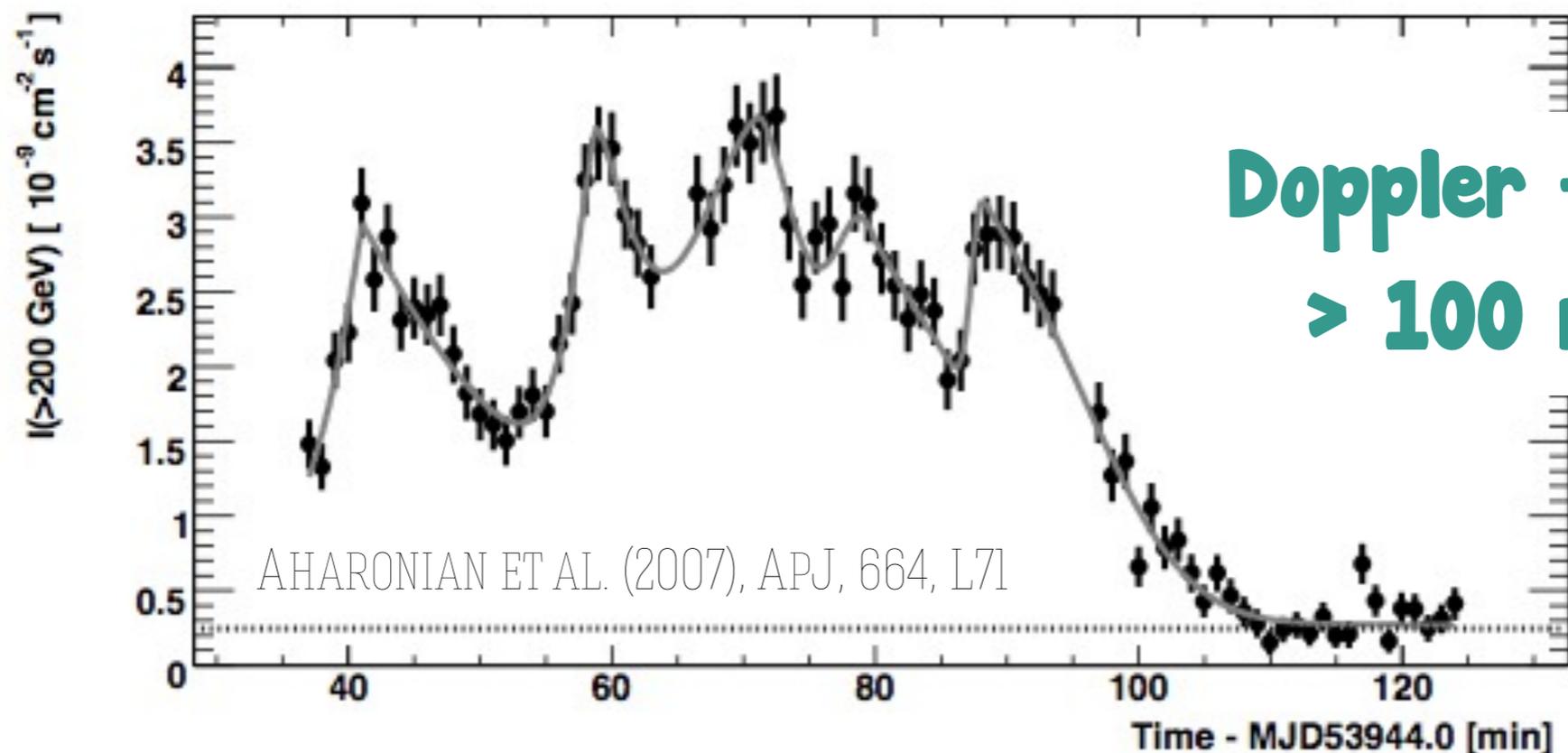


FORTSON ET AL. (2012) GAMMA 2012



Models of blazar emission

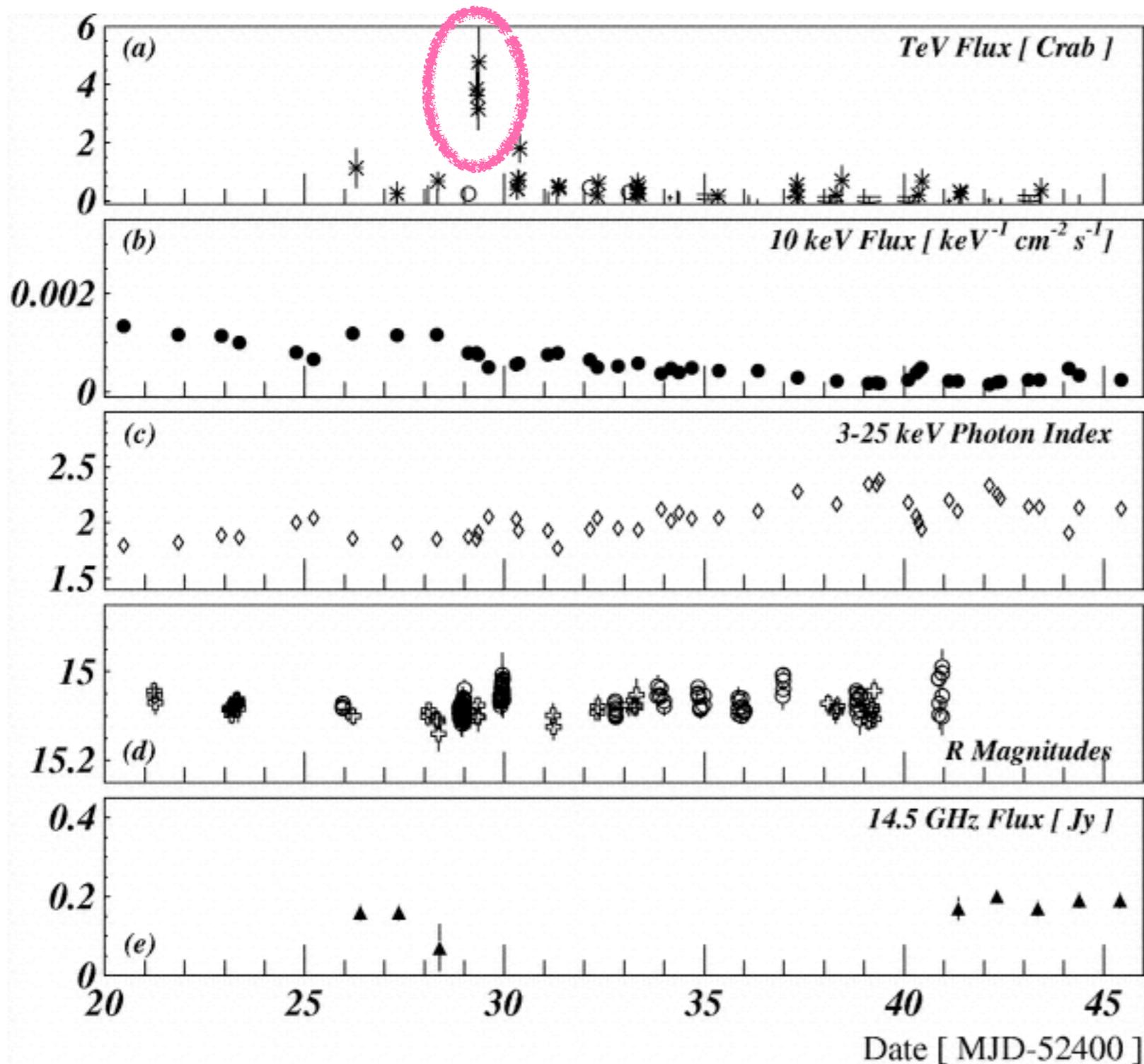
- leptonic models provide good fits to many blazars
- **X-ray and gamma-ray emission often correlated - a fact naturally explained by SSC models**
- in hadronic models, the cooling times are longer, which makes it more difficult to explain the rapid variability often seen in blazars
 - proton synchrotron can produce rapid variability with very high energy protons in extremely magnetised, compact regions HOLDER, J. (2012), ASTROPART. PHYS., 39, 61



**Doppler factors of
> 100 required**

Models of blazar emission

KRAWCZYNSKI ET AL. (2004), APJ 601, 151



“orphan” flare
from TeV blazar,
1ES 1959+650

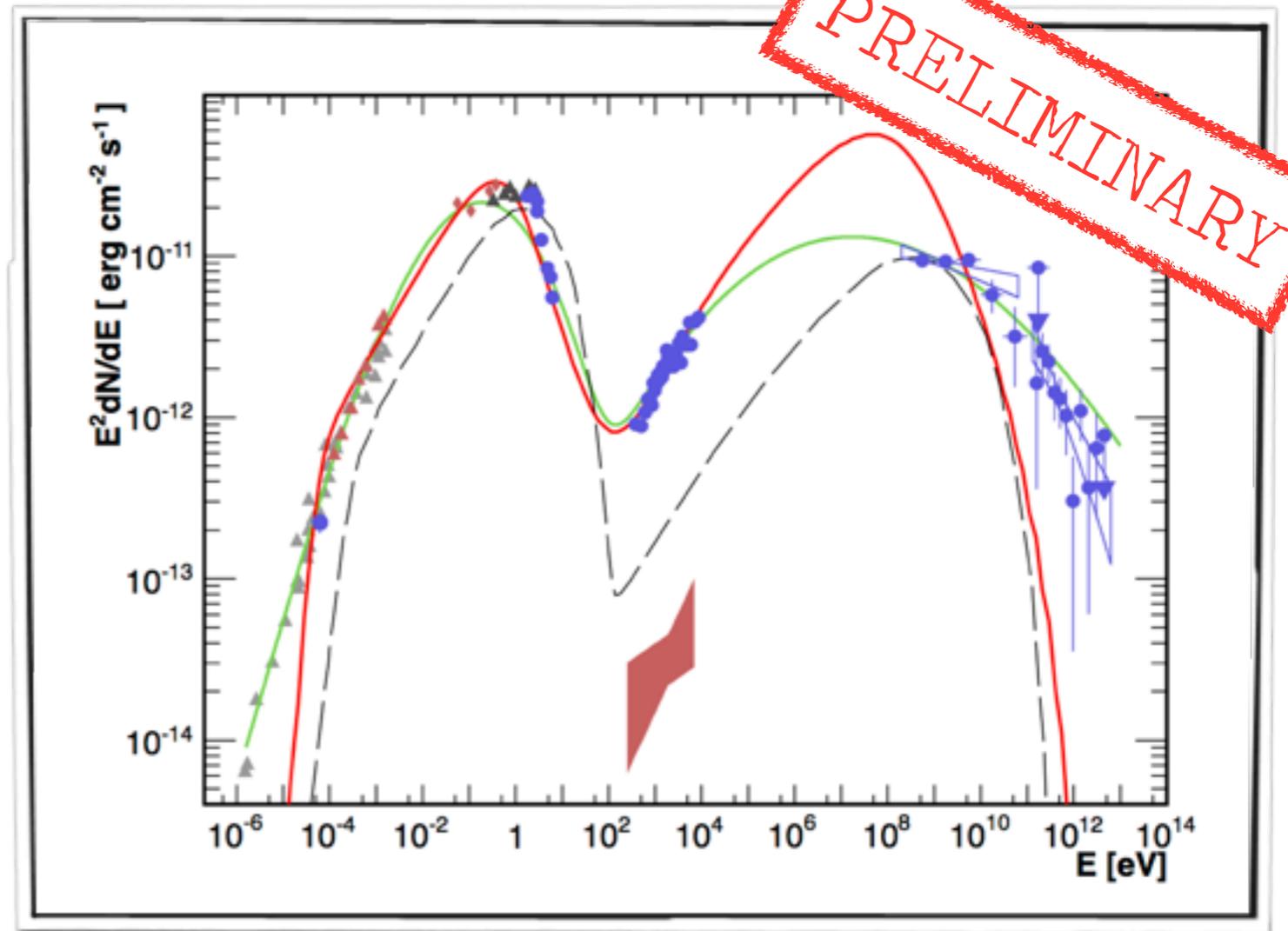
hadronic models have
been invoked to
explain this behaviour

E.G., BOETTCHER (2005), APJ, 621, 176
SAHU ET AL. (2013), PHYS. REV. D
... (IN PRESS) ASTRO-PH/1305.4985

Models of blazar emission

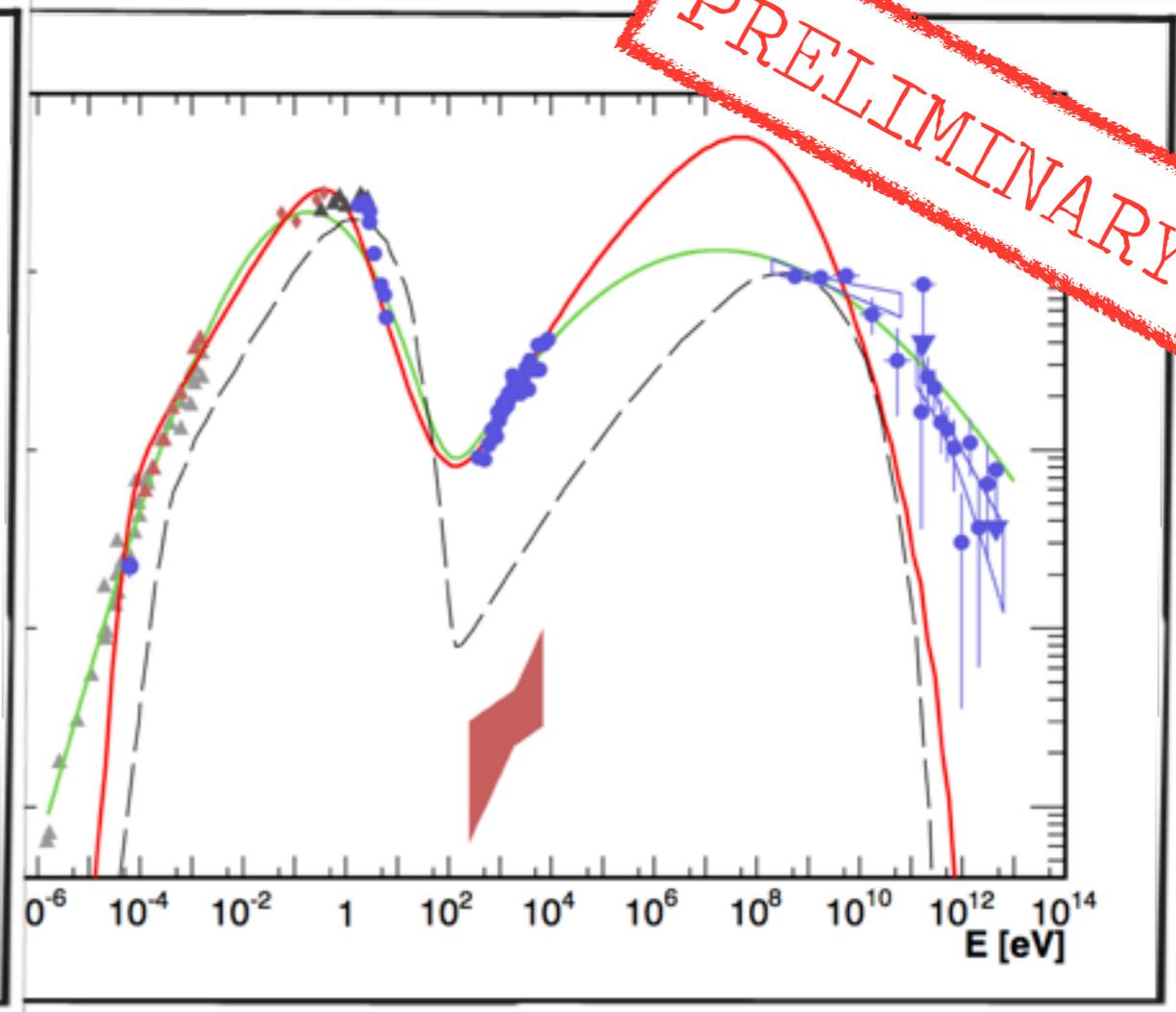
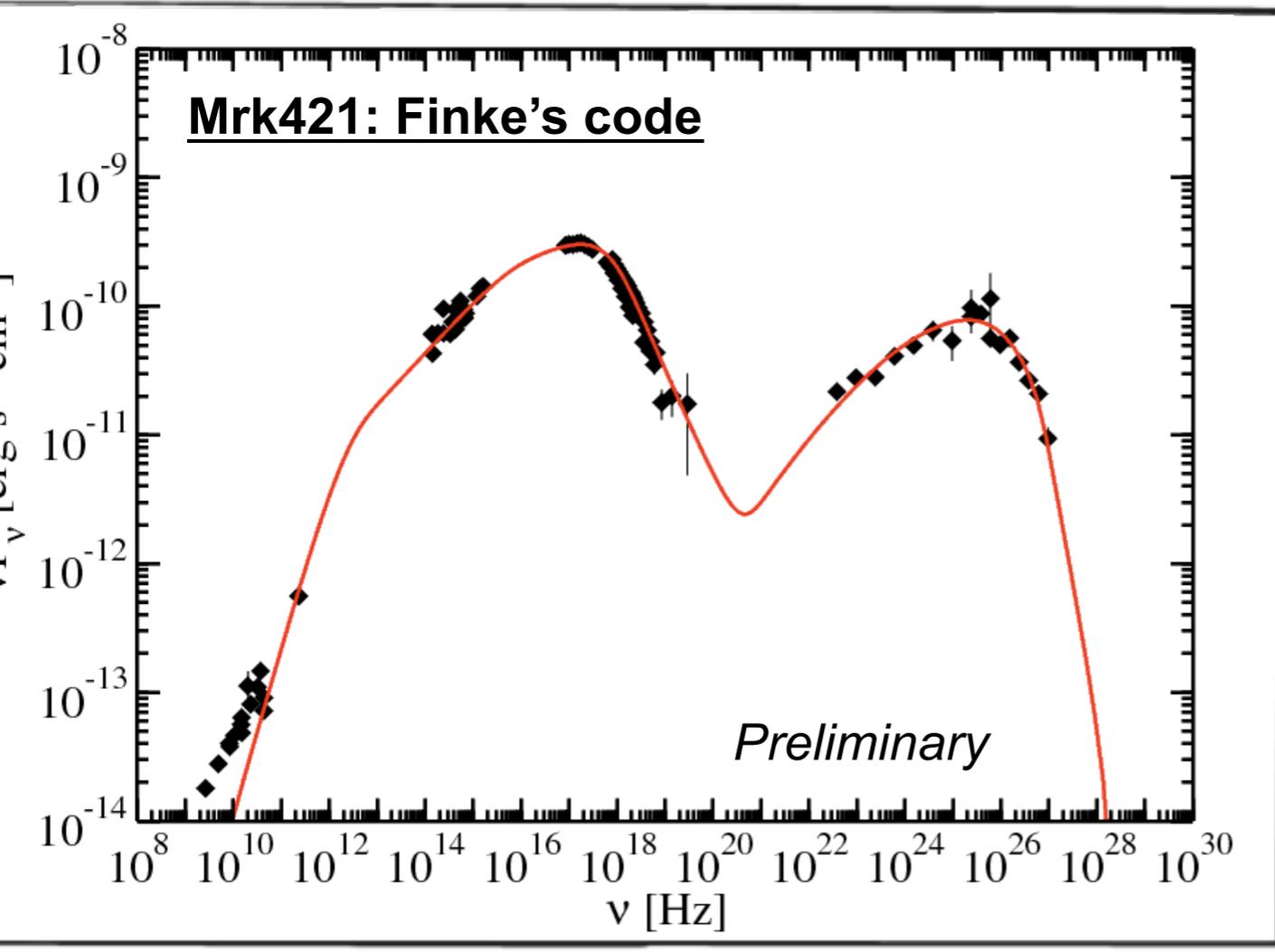
H.E.S.S. COLLABORATION ET AL. (2013 - IN PRESS) DAVID SANCHEZ & PASCAL FORTIN

- VHE emission discovered by H.E.S.S. (ATel July 2010)
- Hard Fermi spectrum (2.1) and nearby ($z=0.049$)
 - ➔ excellent candidate for TeV emission
- X-ray observations taken simultaneously with VHE reveal onset of HE component at unusually low energies for a TeV BL Lac



Models of blazar emission

H.E.S.S. COLLABORATION ET AL. (2013 - IN PRESS) DAVID SANCHEZ & PASCAL FORTIN

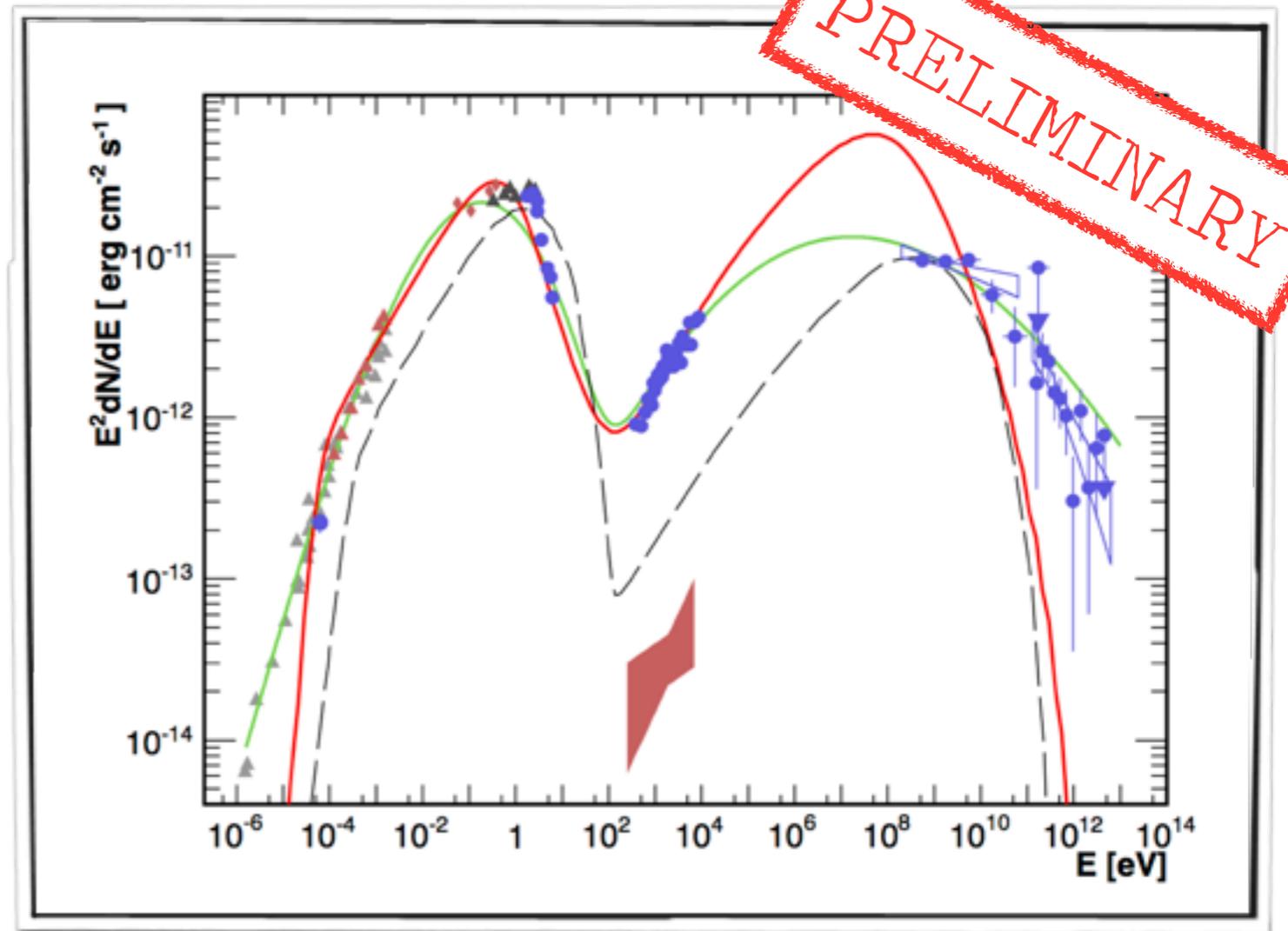


at unusually low energies for a TeV BL Lac

Models of blazar emission

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 - ➔ excellent candidate for TeV emission
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Difficult to model with a single zone homogeneous SSC model due to the unprecedented width of the HE component compared to the LE component

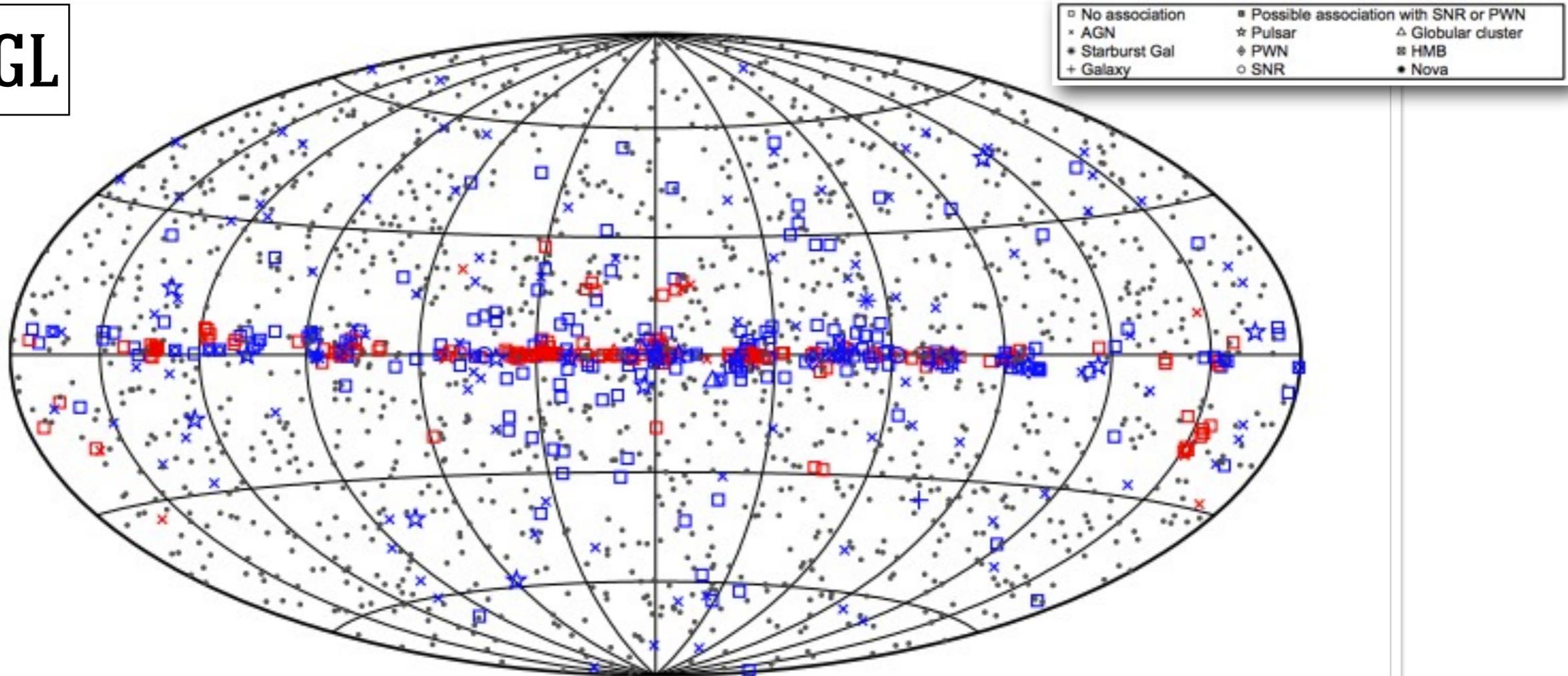
The Fermi blazars

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The Fermi blazars

2FGL



NOLAN ET AL. (2012), APJS, 199, 31



1873 SOURCES
1298 IDENTIFIED/ASSOCIATED

84%
AGN*

*74%
 blazars

The Fermi blazars

1 **LBAS** (Abdo et. al 2009, ApJ 700, 597)

Based on OGL, 3 months data, $\sim 10\sigma$

106 high-confidence blazars

2 **1LAC** (Abdo et. al 2010, ApJ 715, 429)

Based on 1FGL, 11 months data, $\sim 5\sigma$

523 (blazars) / 599 (total) in clean sample

3 **2LAC** (Ackermann et. al 2011, ApJ 743, 171)

Based on 2FGL, 24 months data, $\sim 5\sigma$

862 (blazars) / 886 (total) in clean sample

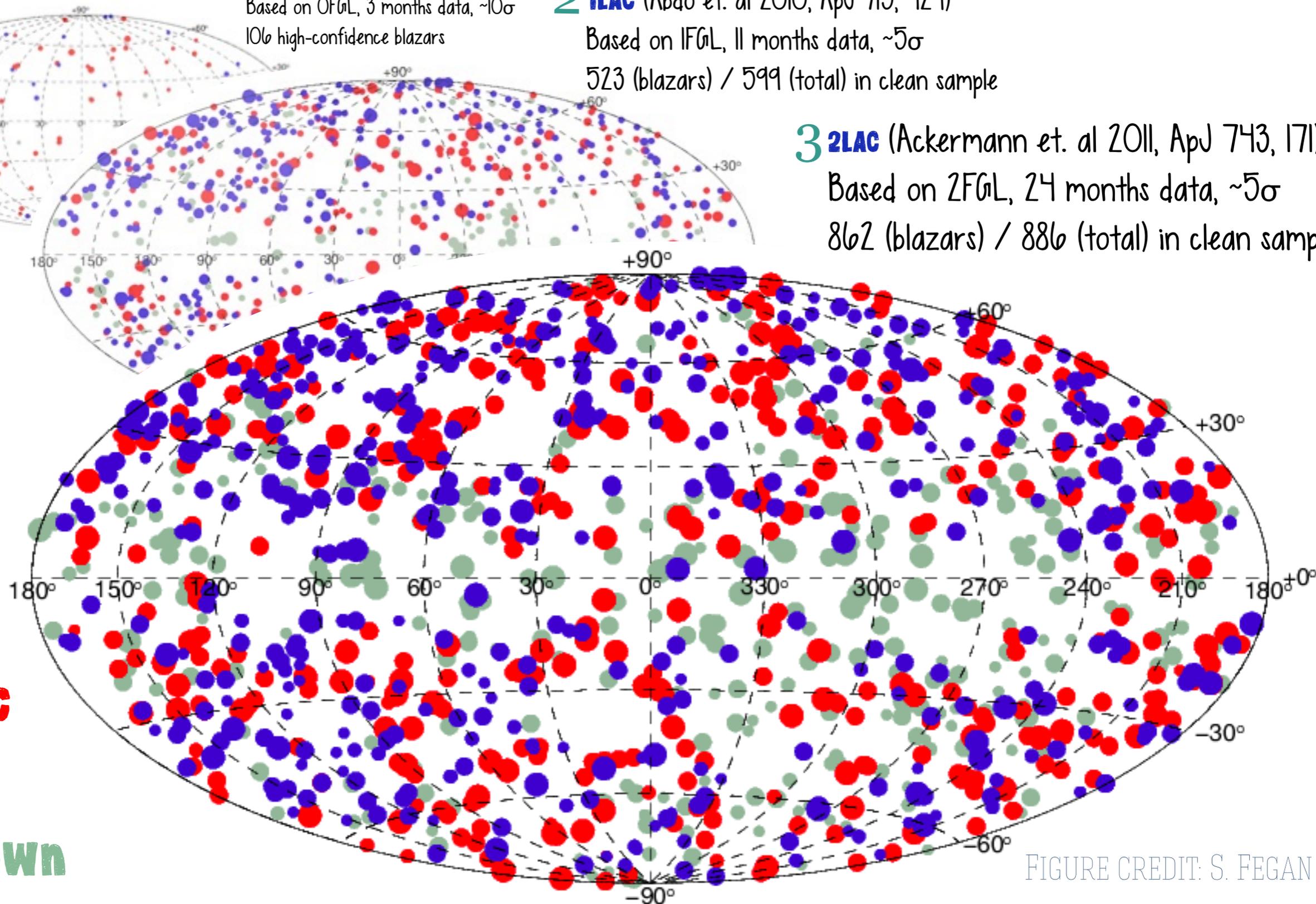
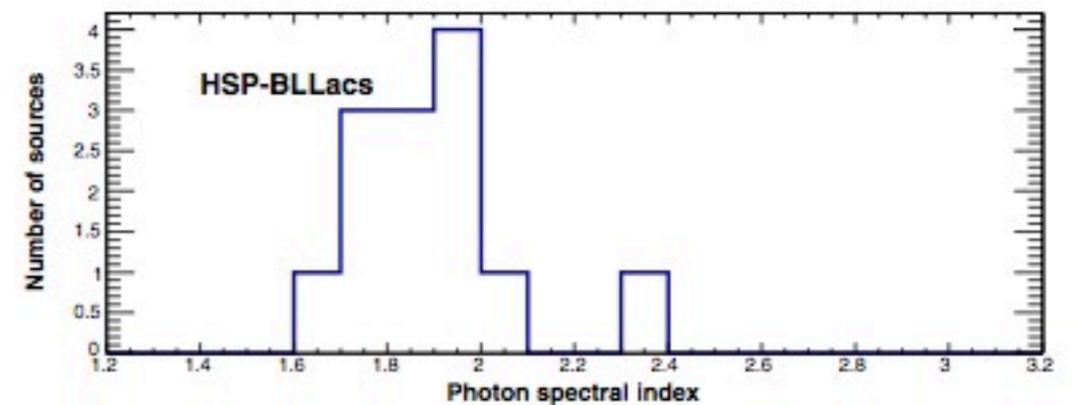
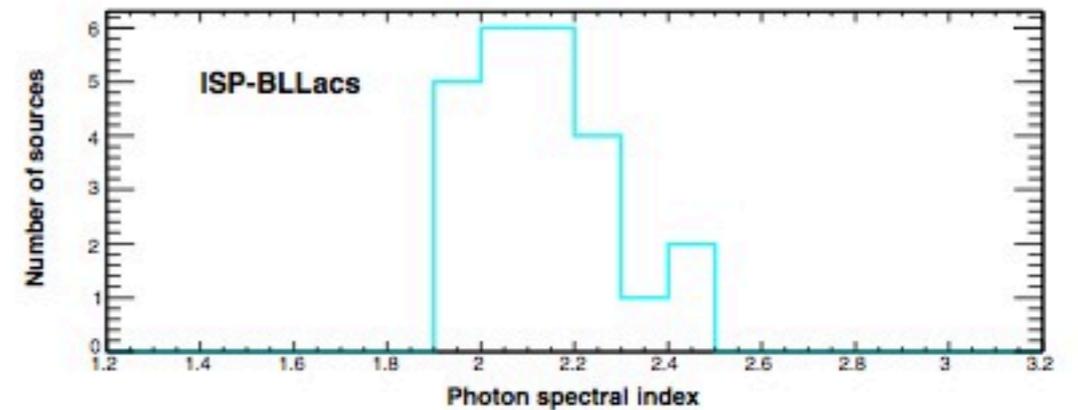
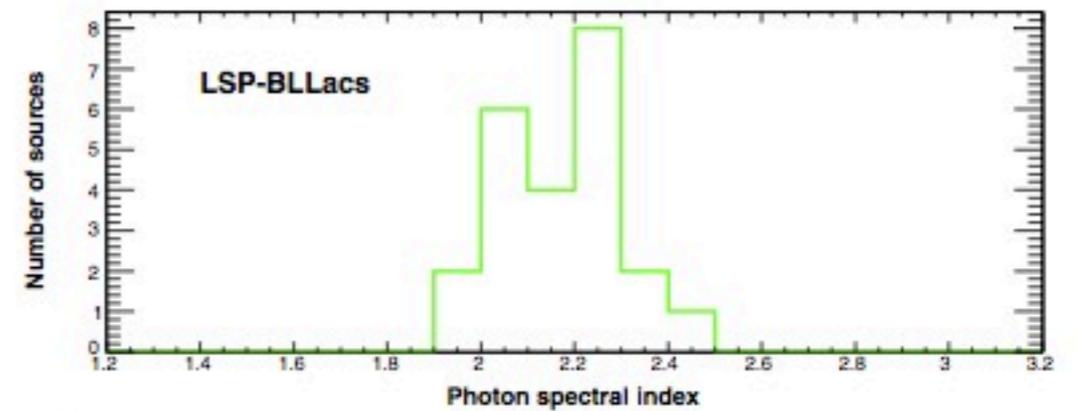
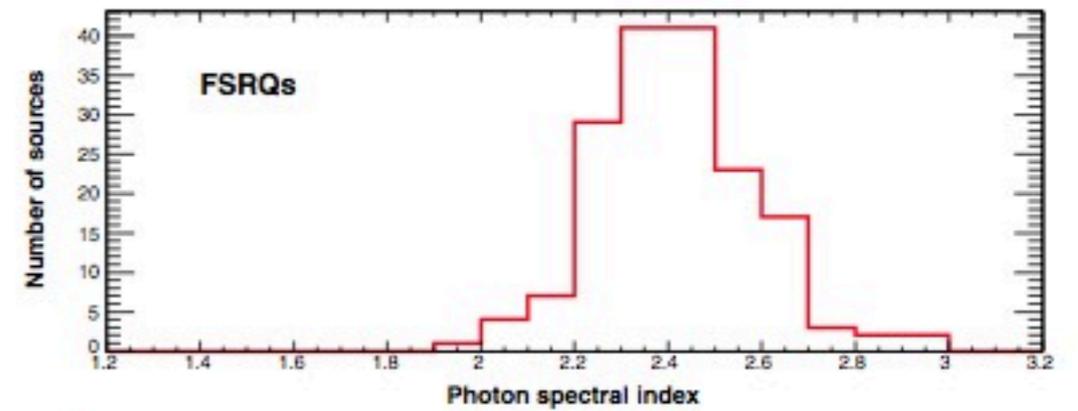
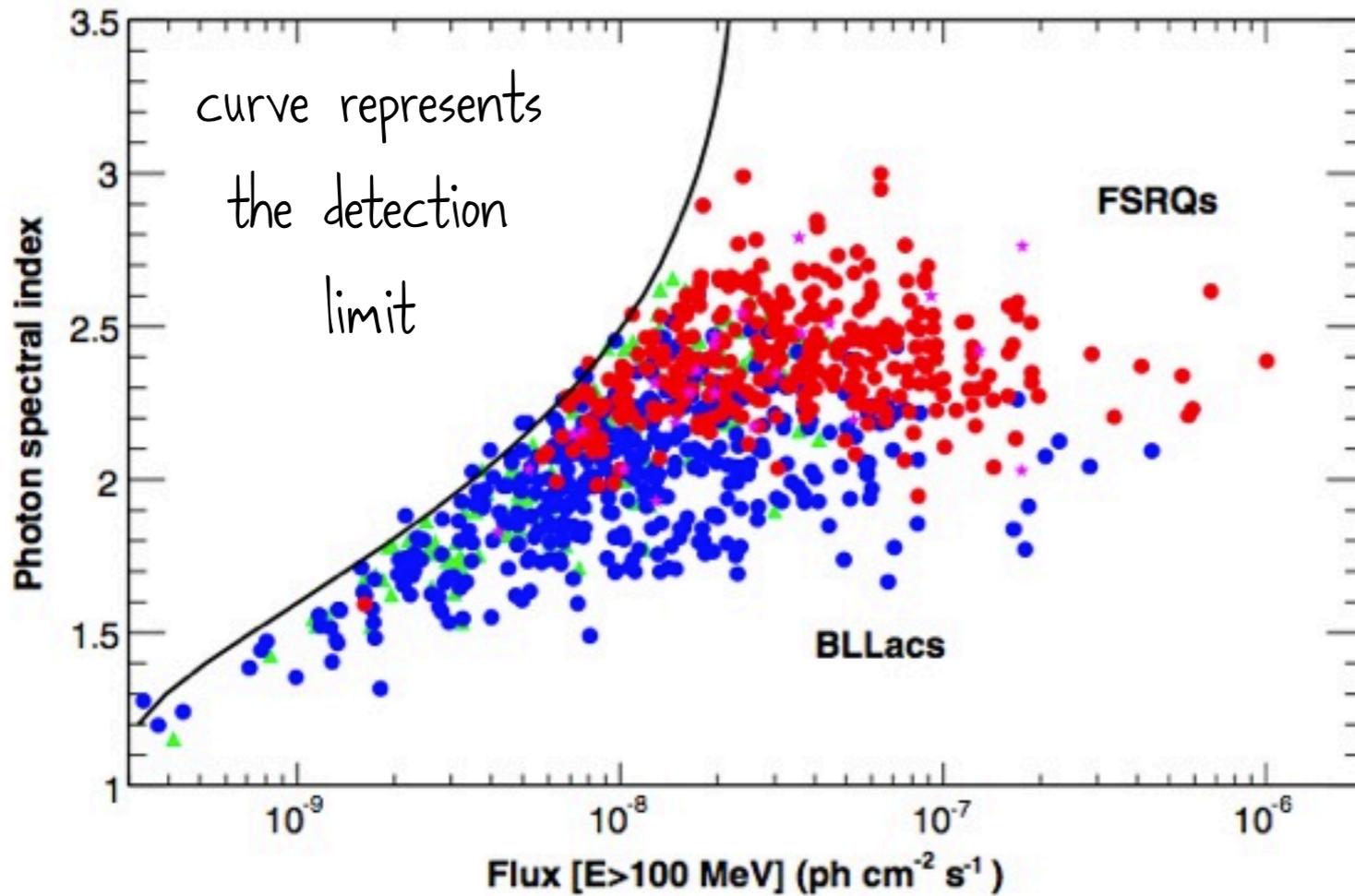


FIGURE CREDIT: S. FEGAN

The Fermi blazars



ACKERMANN ET. AL 2011, APJ 743, 171

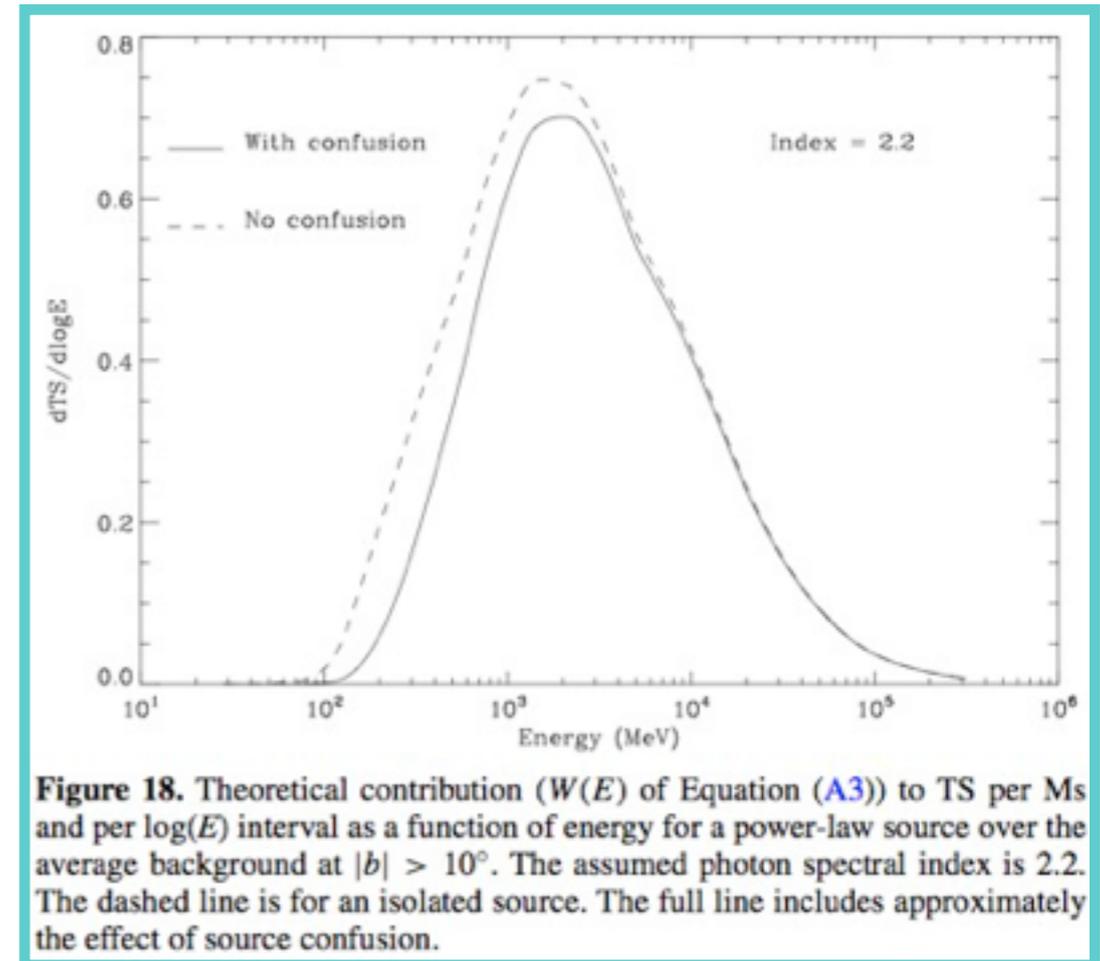
The Fermi blazars

Table 5
Census of Sources

AGN Type	Entire 2LAC	2LAC Clean Sample ^a	Low-lat Sample
All	1017	886	104
FSRQ	360	310	19
LSP	246	221	7
ISP	4	3	2
HSP	2	0	0
No classification	108	86	10
BL Lac	423	395	16
LSP	65	61	3
ISP	82	81	3
HSP	174	160	5
No classification	102	93	5
Blazar of unknown type	204	157	67
LSP	24	19	10
ISP	13	11	3
HSP	65	53	13
No classification	102	74	41
Other AGNs	30	24	2

Note. ^a Sources with single counterparts and without analysis flags. See Section 5 for the definitions of this sample.

ACKERMANN ET. AL 2011, APJ 743, 171

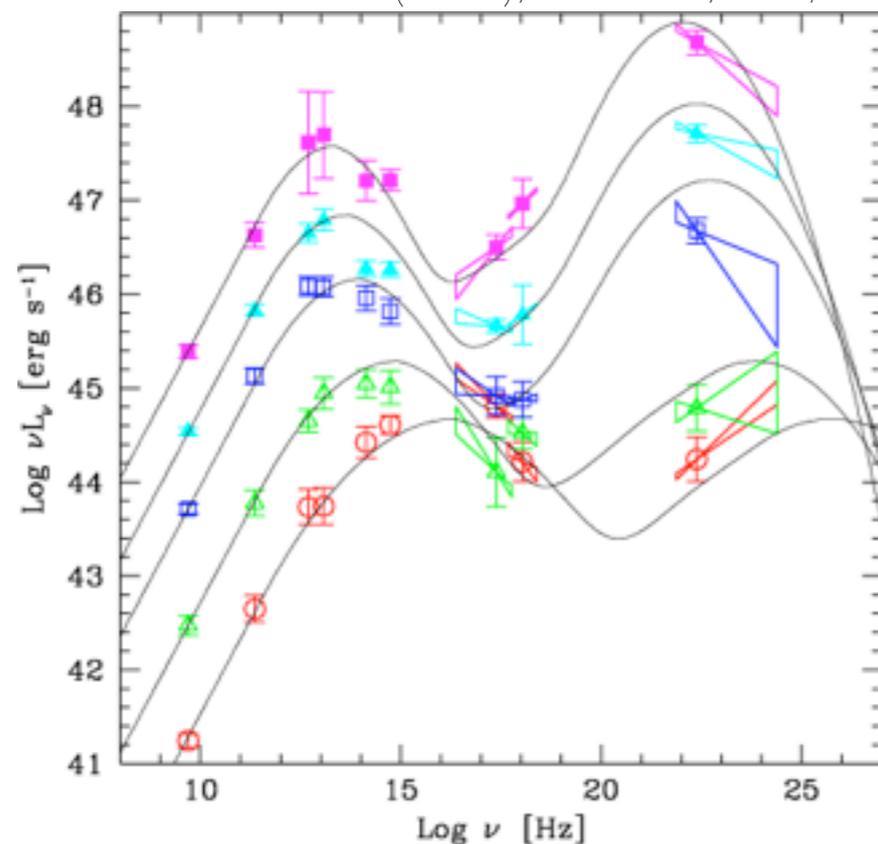


ABDO ET. AL 2010, APJS 188, 405

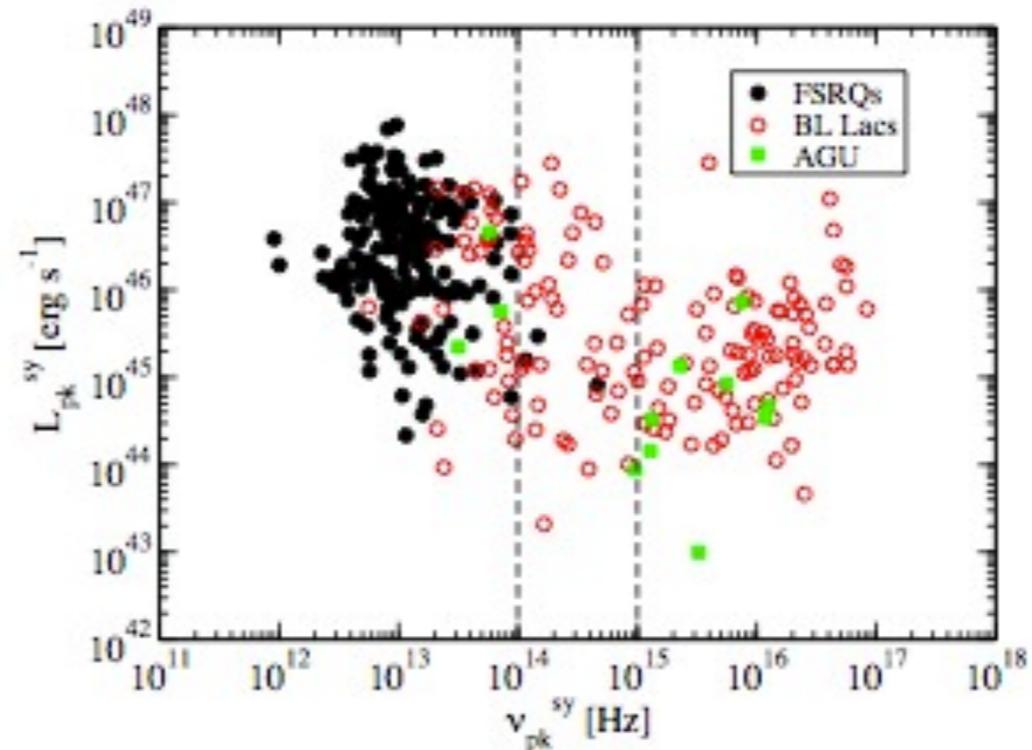
***8 misaligned blazars**
4 NLSy1s
10 AGN of other type
2 starbursts

The Fermi blazars

FOSSATI ET AL. (1998), MNRAS, 299, 433

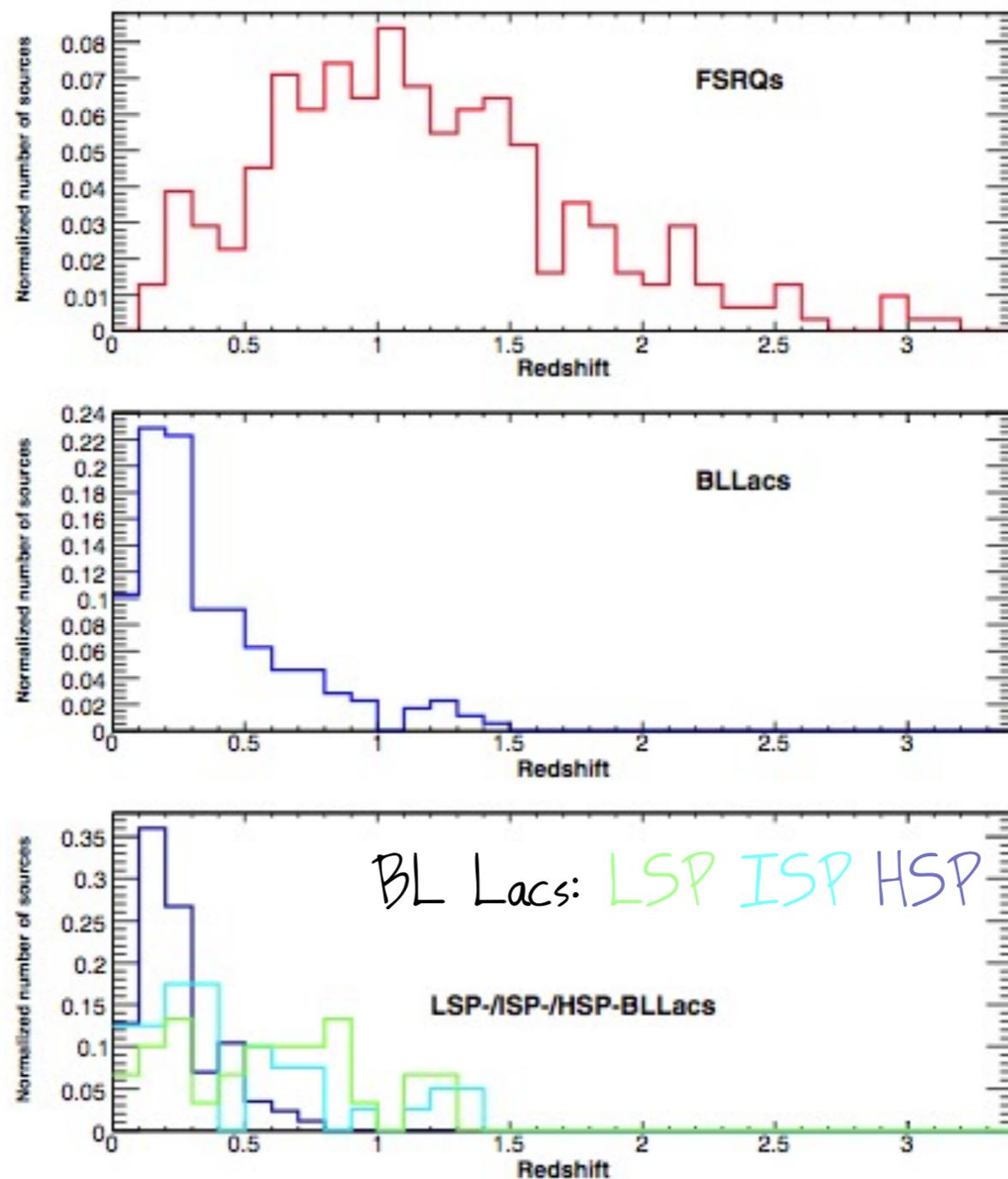


FINKE, J. (2012), FERMI-JANSKY (ASTRO-PH/1301.6081)



"If the seed photon source for external Compton scattering is the broad line region (BLR), and the BLR strength is correlated with the power injected into electrons in the jet, one would expect that more luminous jets have stronger broad emission lines and greater Compton cooling, and thus a lower ν_{sy} . As the power injected in electrons is reduced, the broad line luminosity decreases, there are fewer seed photons for Compton scattering, and consequently the peak synchrotron frequency moves to higher frequencies. This is also reflected in the lower luminosity of the Compton-scattered component relative to the synchrotron component as ν_{sy} moves to higher frequencies." FINKE, J. (2012), FERMI-JANSKY (ASTRO-PH/1301.6081)

The Fermi blazars



ACKERMANN ET. AL 2011, APJ 743, 171

The Fermi blazars

The Hard Source List - a catalog above 10 GeV

D. PANEQUE, FERMI SYMPOSIUM (2012)

- Work is underway to publish the 1st Fermi-LAT catalog of sources > 10 GeV
- Shape of the spectrum at > 10 GeV might not be well characterized if we use a single fit in the energy range 0.1 GeV - 100 GeV

→ Lower energies

- The variability at lowest energies, which

SEE LAMB & MACOMB (1997), 488, L872

which may radiate from the same/different location

from that at the emission of particles

→ Are sources more variable at HE than at LE ? or the other way around ?

- Understand better the population of sources emitting above 10 GeV

→ What are the sources dominating the highest LAT energies?

- **IDENTIFY PROMISING CANDIDATES FOR IACTS ... NEW VHE DISCOVERIES**

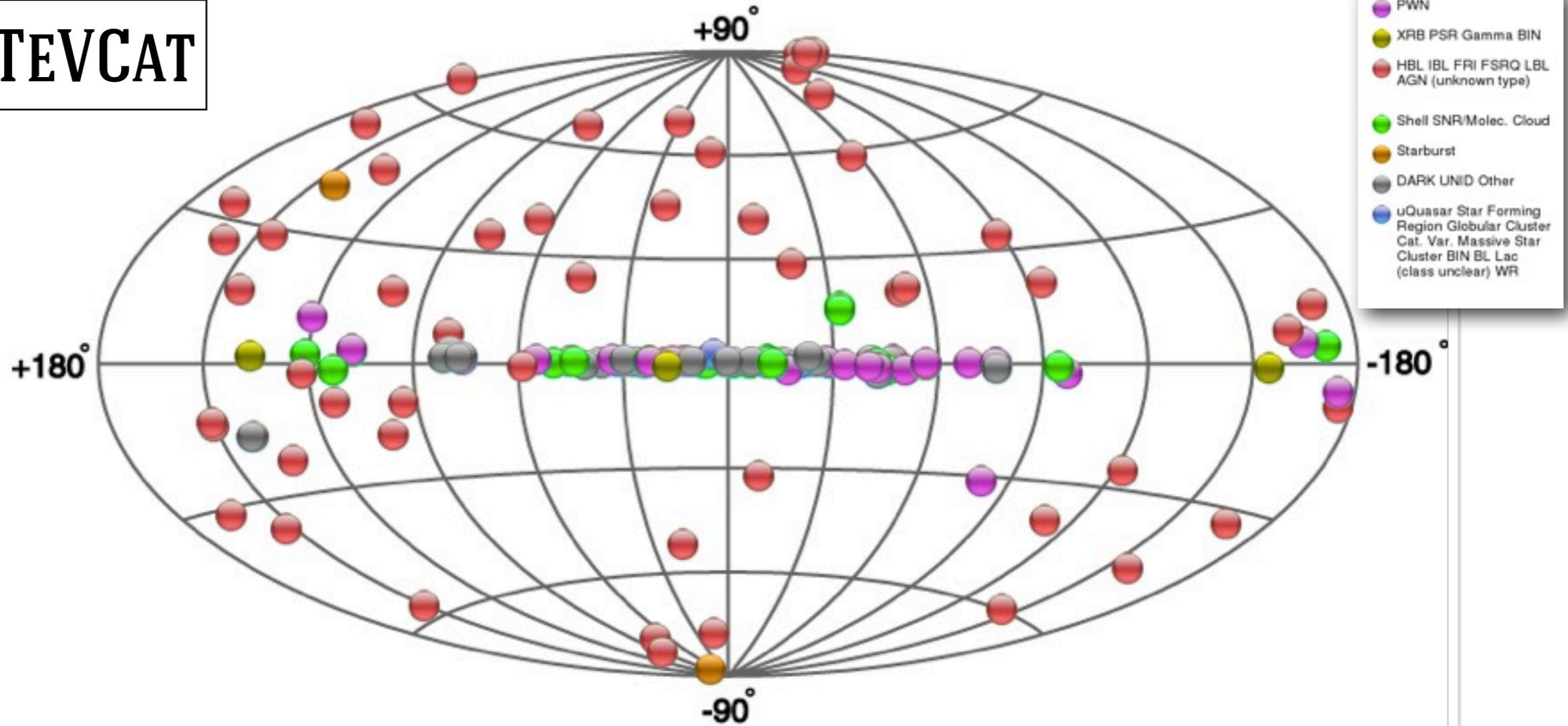
The TeV blazars

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The TeV blazars

TEVCAT



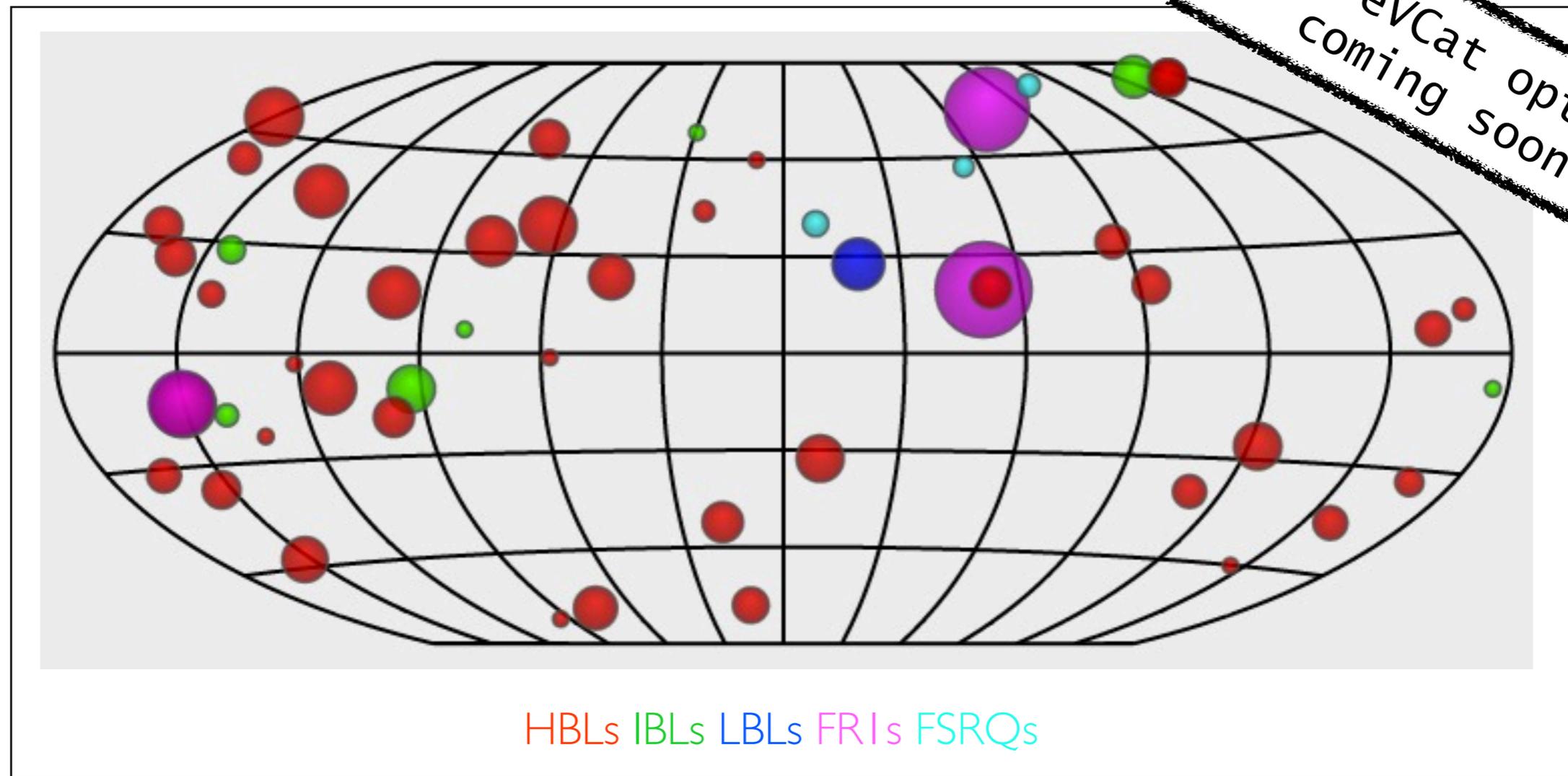
145 sources
114 identified/associated

84%
AGN*

*95%
blazars

The TeV blazars

As of writing this talk, there are 145 sources in TeVCat - 57 Extragalactic



The TeV blazars

As of writing this talk, there are 145 sources in TeVCat - 57 Extragalactic

