Active Galactic Nuclei & Gamma-ray astronomy

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On behalf of Fermi-LAT collaboration

The history of satellite-borne gamma-ray astronomy

The first gamma-ray telescope in **Explorer 11**,picked up fewer than 100 gamma-ray photons coming isotropically from the sky

OSO-3
It detected 621 events attributable to cosmic gamma rays.

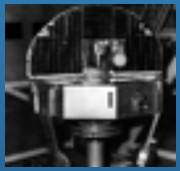
SAS-2 and the **Cos-B** provided for the first time and entire view of gamma rays sky, detected the first gamma-ray sources.

EGRET onboard **CGRO**
it was able to create a detailed map of the "entire high-energy gamma-ray sky. The T 3EG Catalog consists of 271 sources

AGILE
Premio Bruno Rossi 2012 for the detection of the flaring Crab

1961

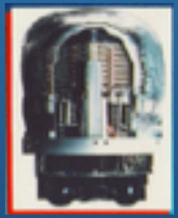
1967



1972

1975

1991

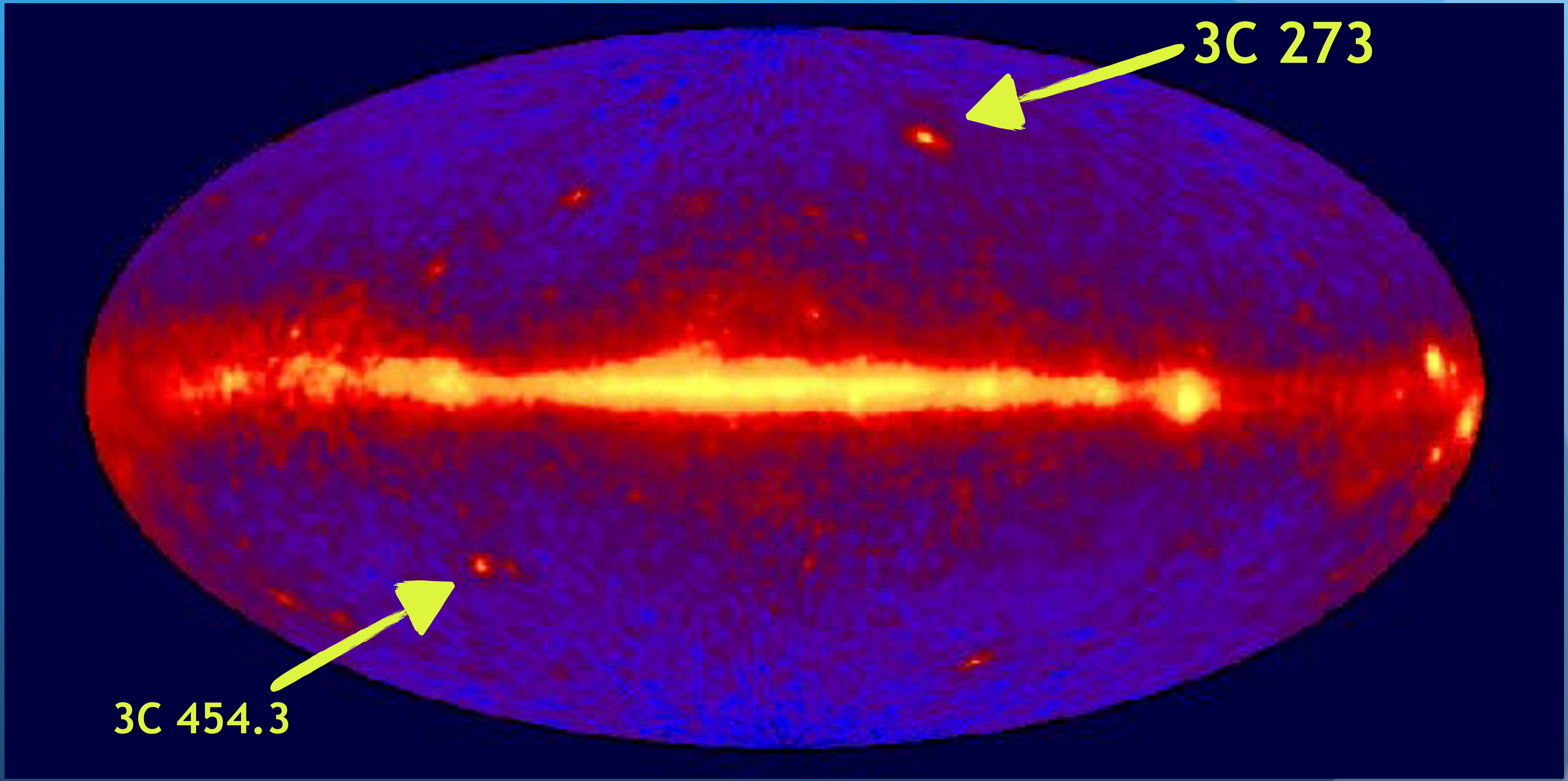


2007

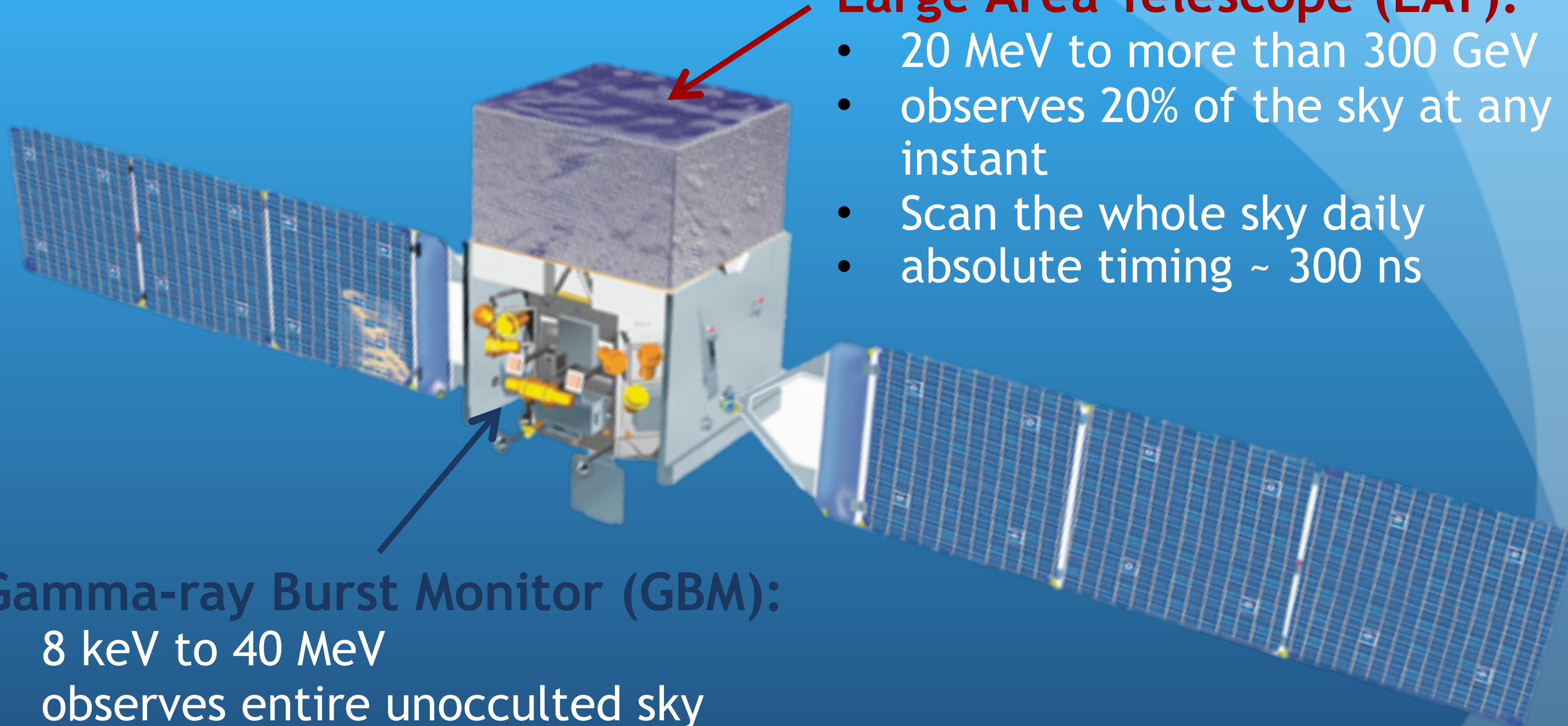
2008 FERMI

First image of gamma-ray sky with EGRET

Third EGRET Catalogue: 27 possible AGN/blazar identifications



The Fermi observatory



Large Area Telescope (LAT):

- 20 MeV to more than 300 GeV
- observes 20% of the sky at any instant
- Scan the whole sky daily
- absolute timing ~ 300 ns

Gamma-ray Burst Monitor (GBM):

- 8 keV to 40 MeV
- observes entire unocculted sky
- absolute timing ~ 2μs
- compute burst location to allow re-orienting Fermi

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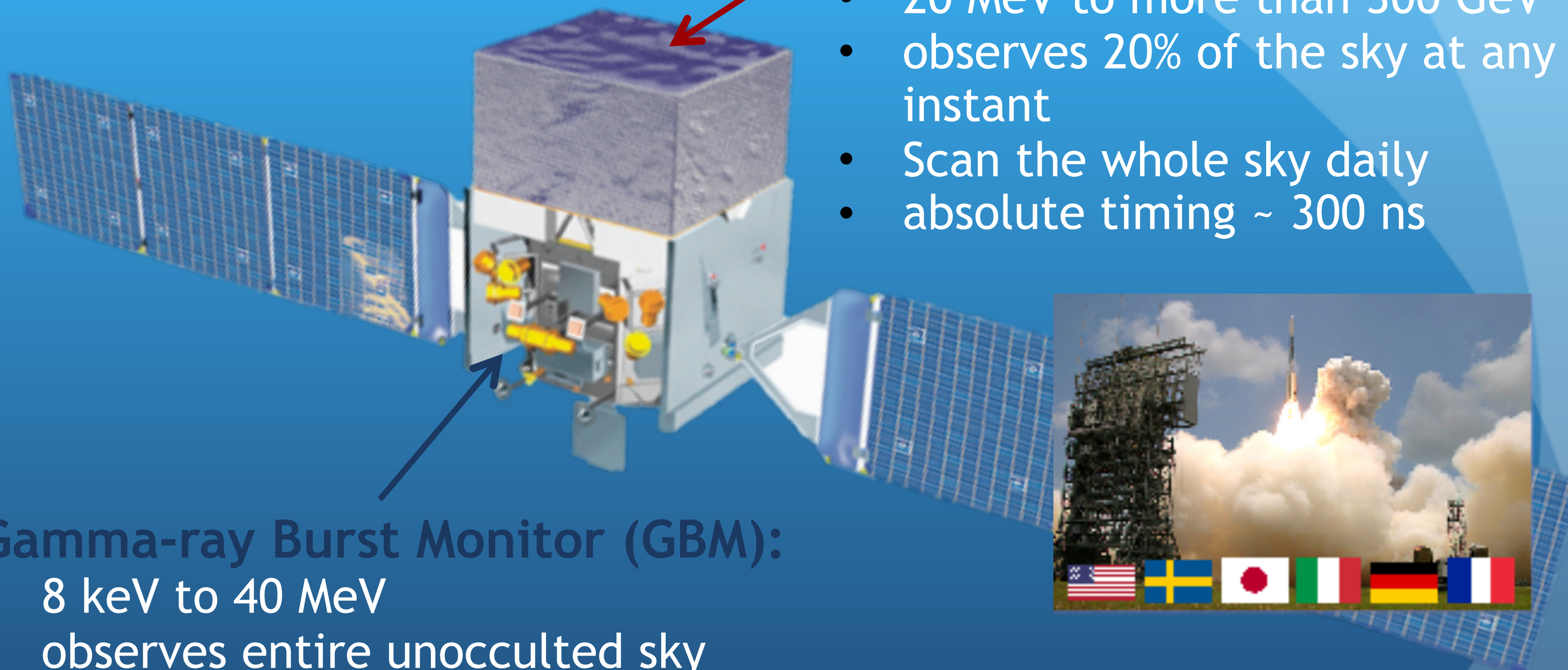

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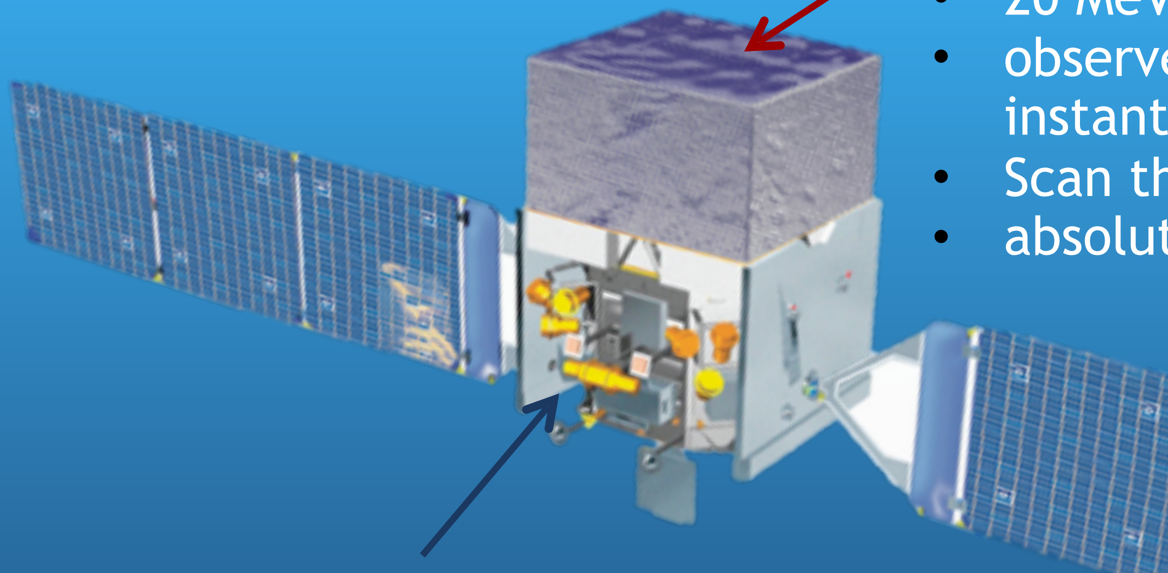

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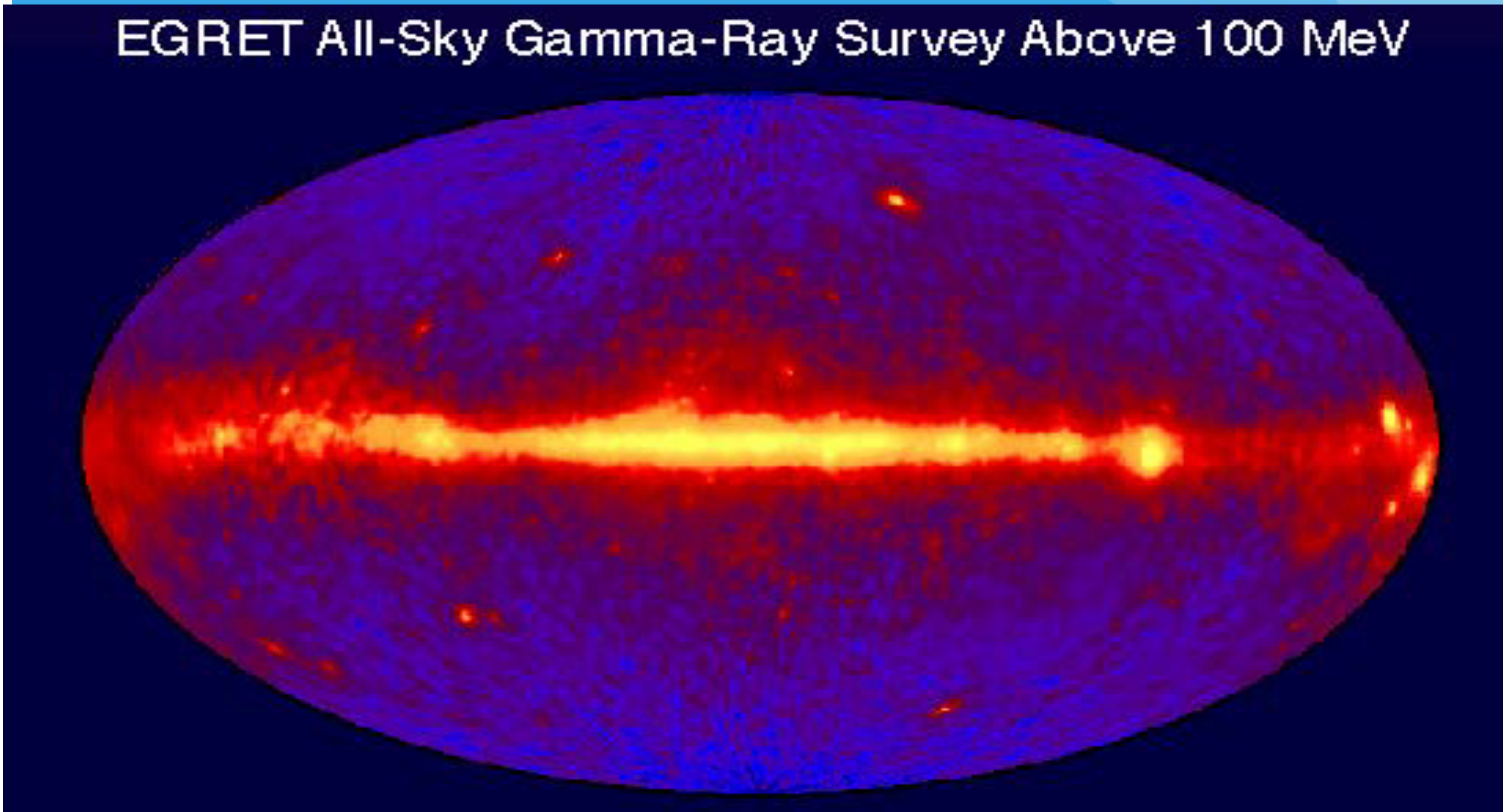
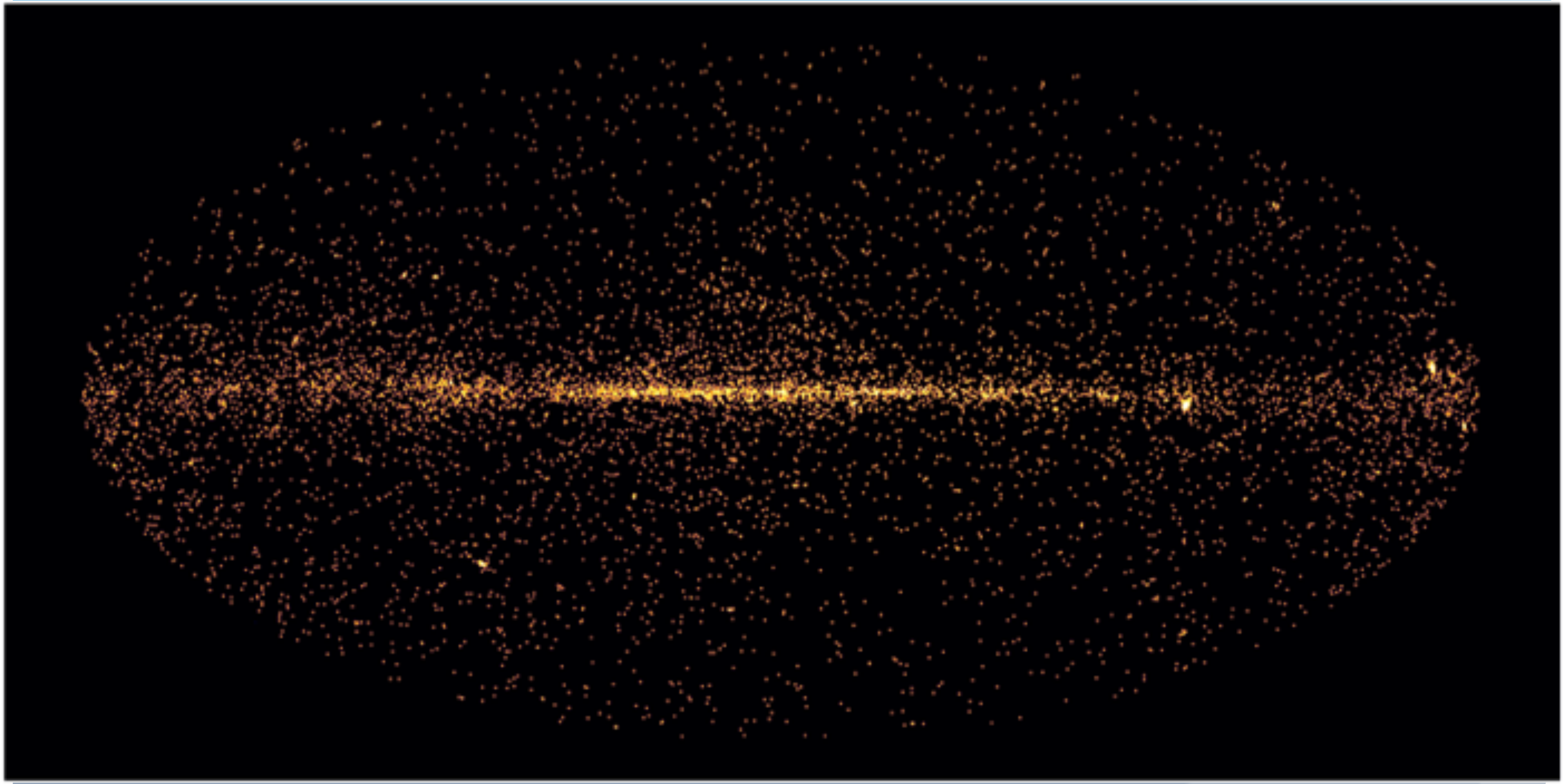
Launch: June 11 2008, NASA

Orbit: circular, 565 km altitude, 25.6° inclination

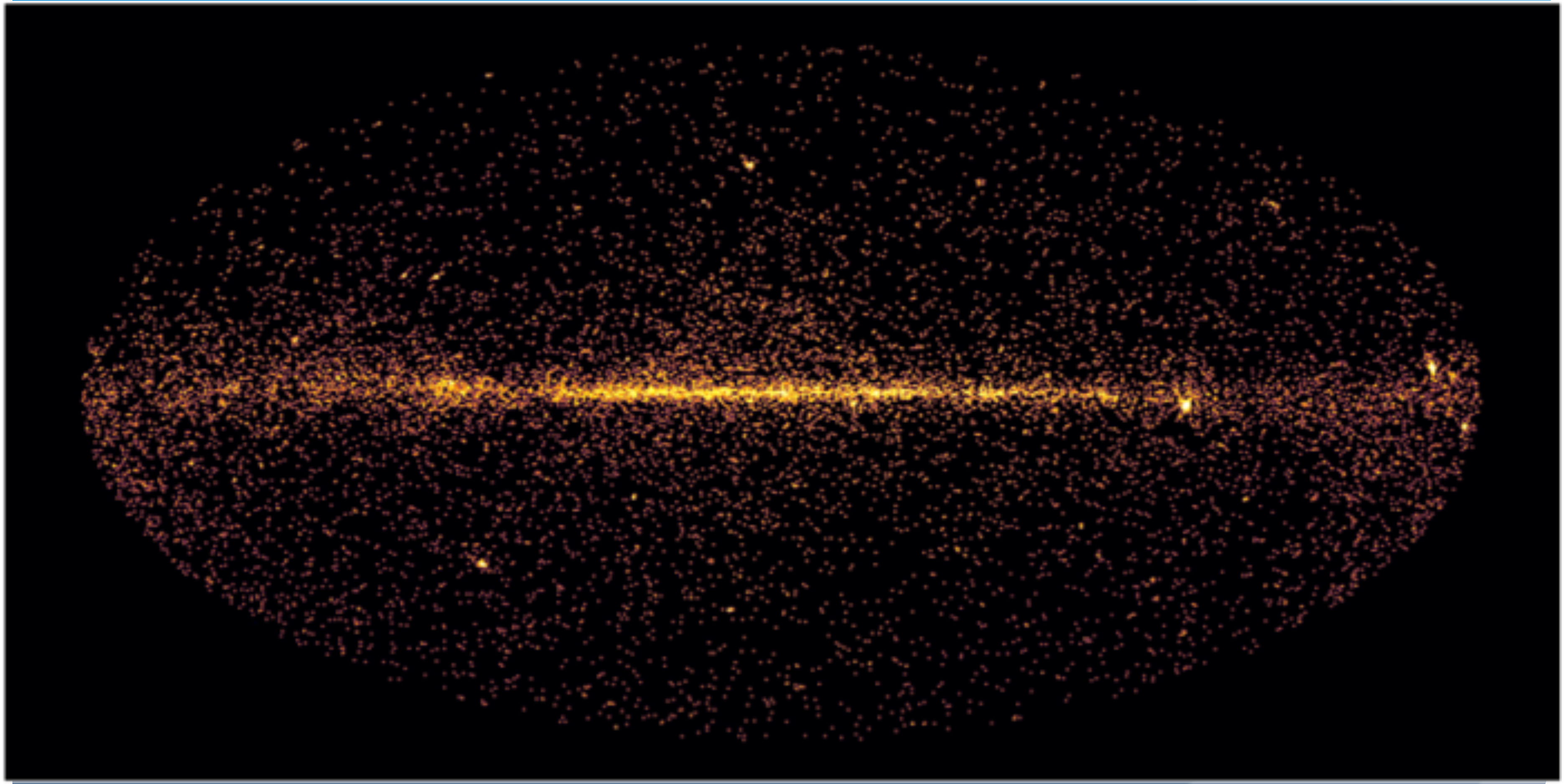
EGRET (5 years mission)



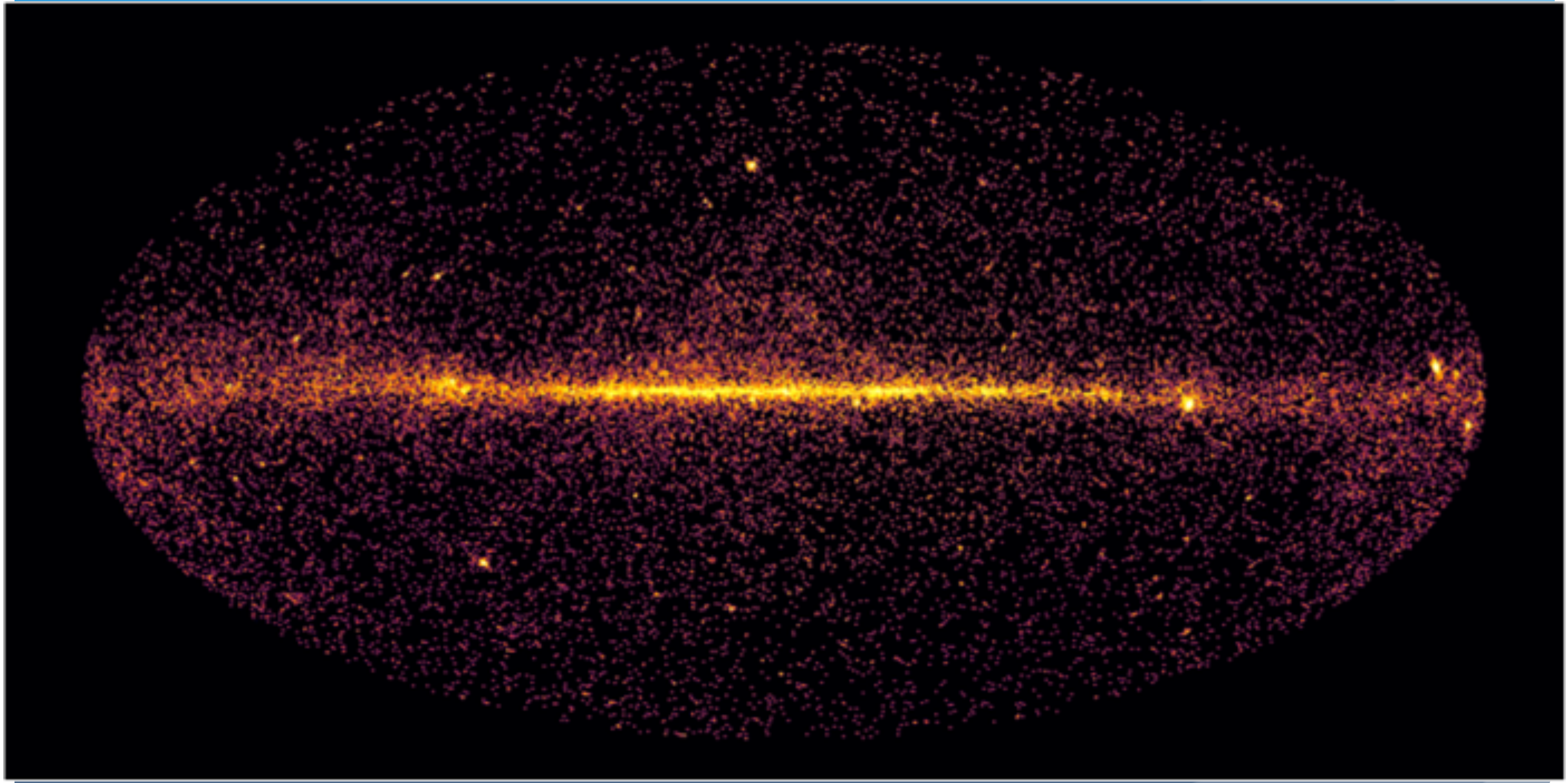
Fermi sky in 30 hours



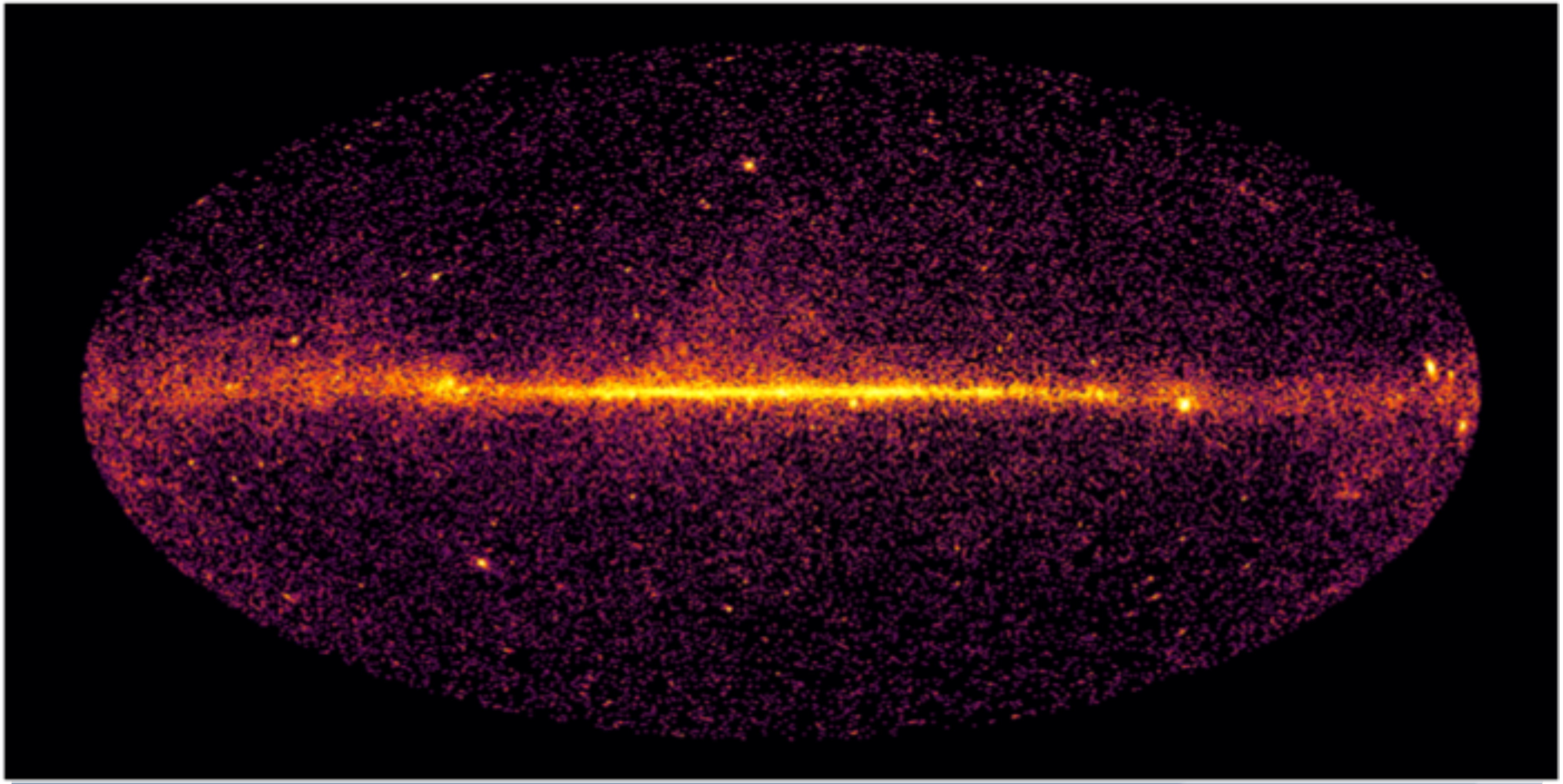
Fermi sky in 60 hours



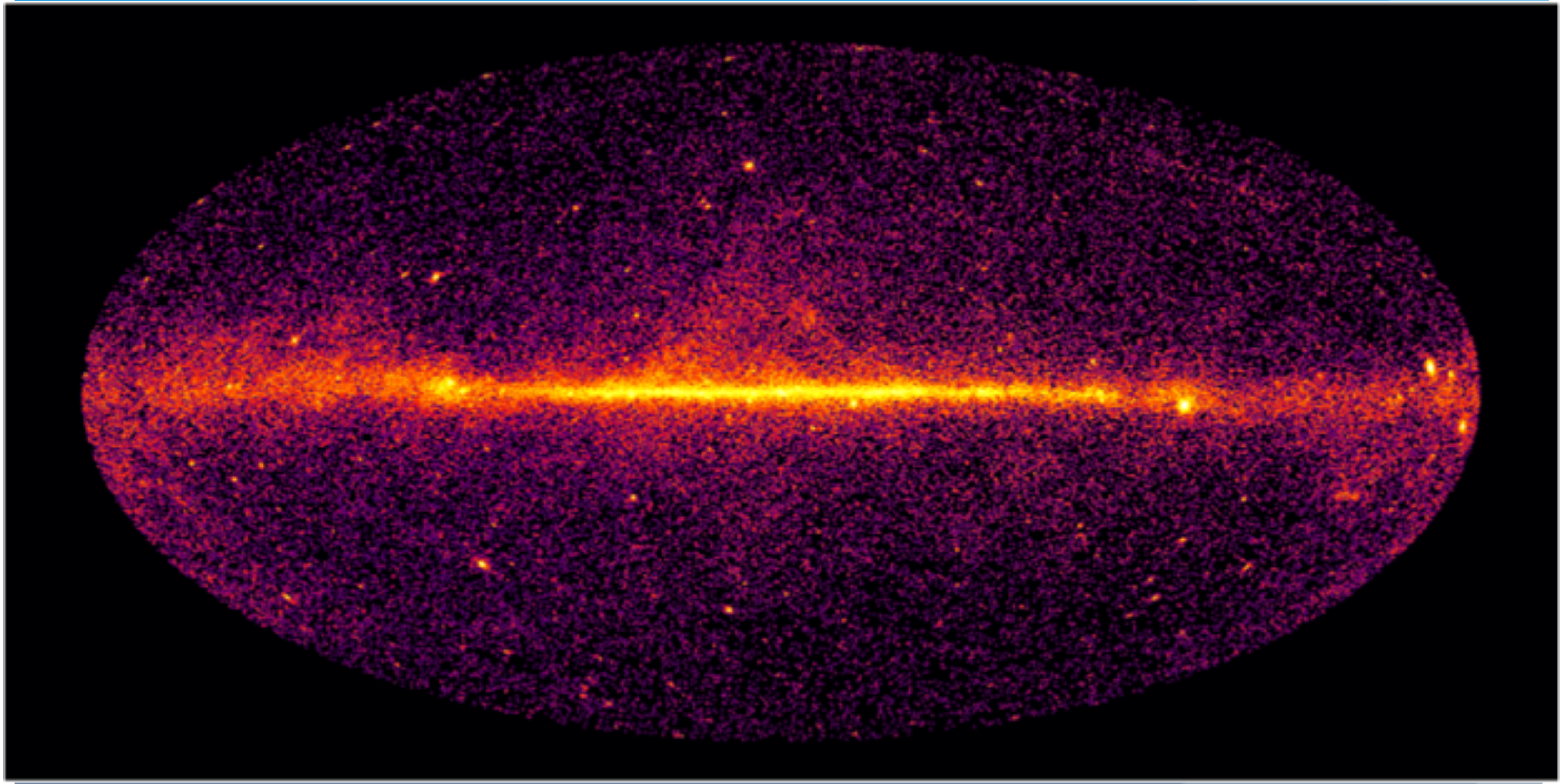
Fermi sky in 5 days



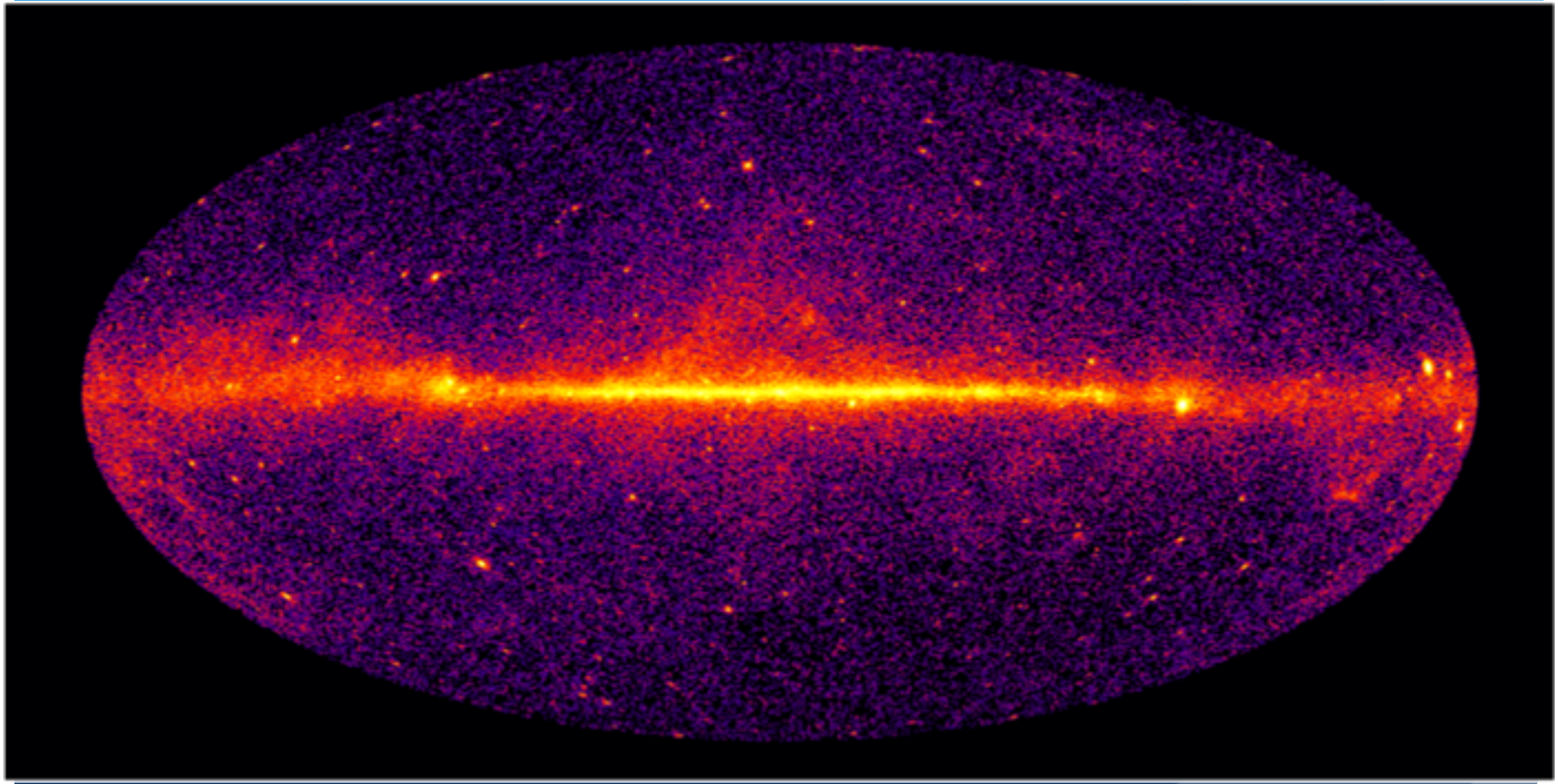
Fermi sky in 10 days



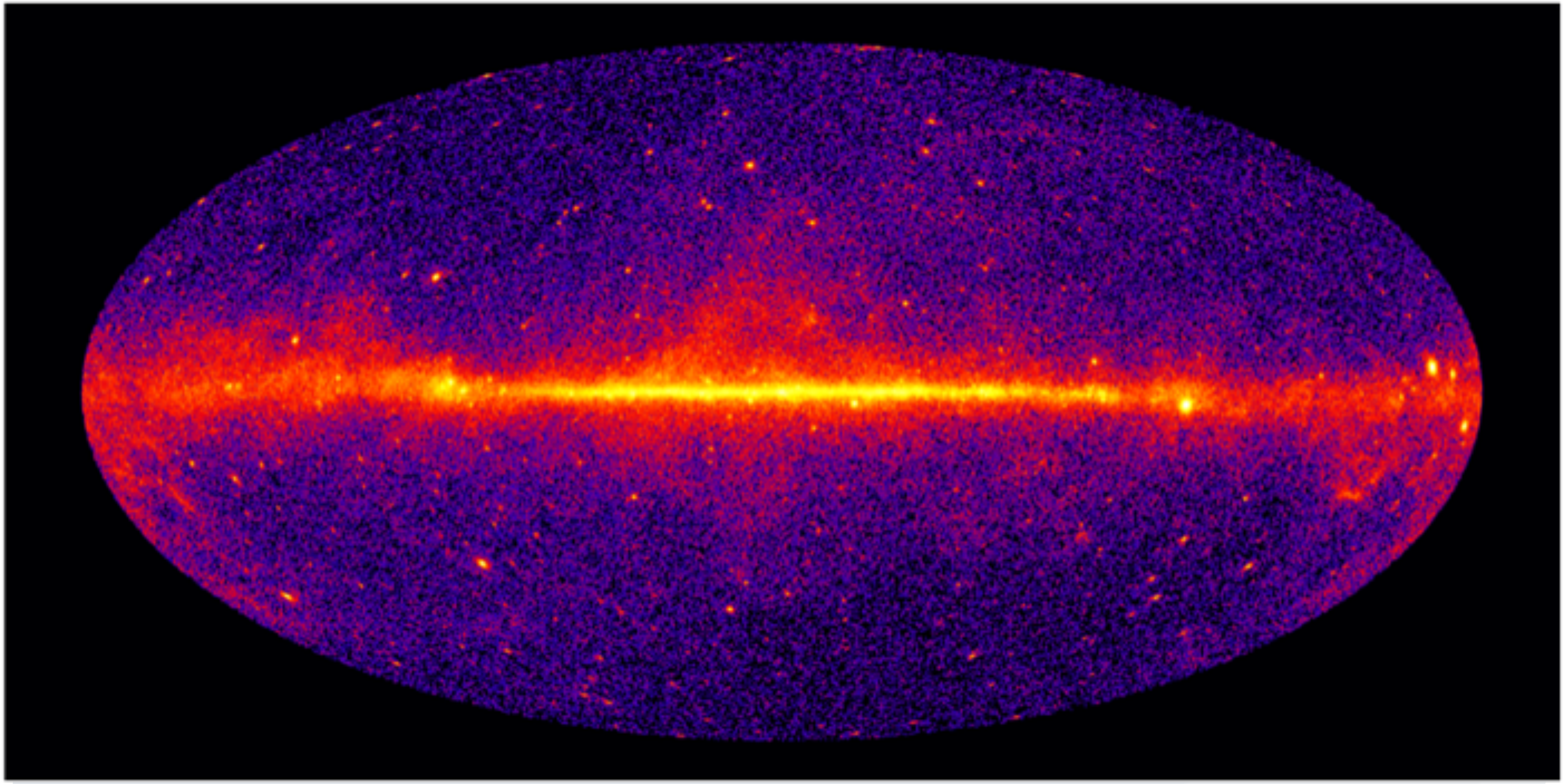
Fermi sky in 20 days



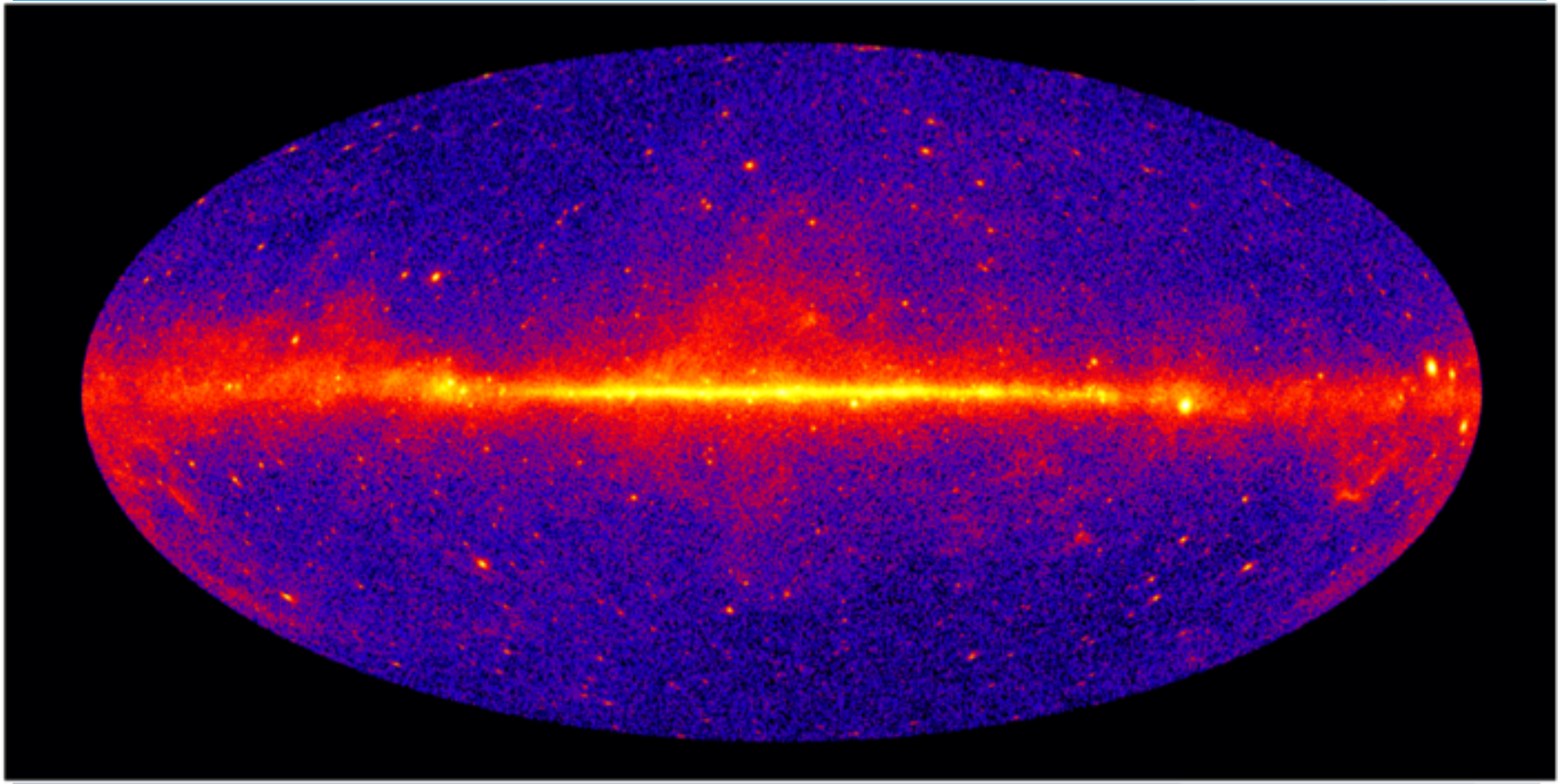
Fermi sky in 40 days



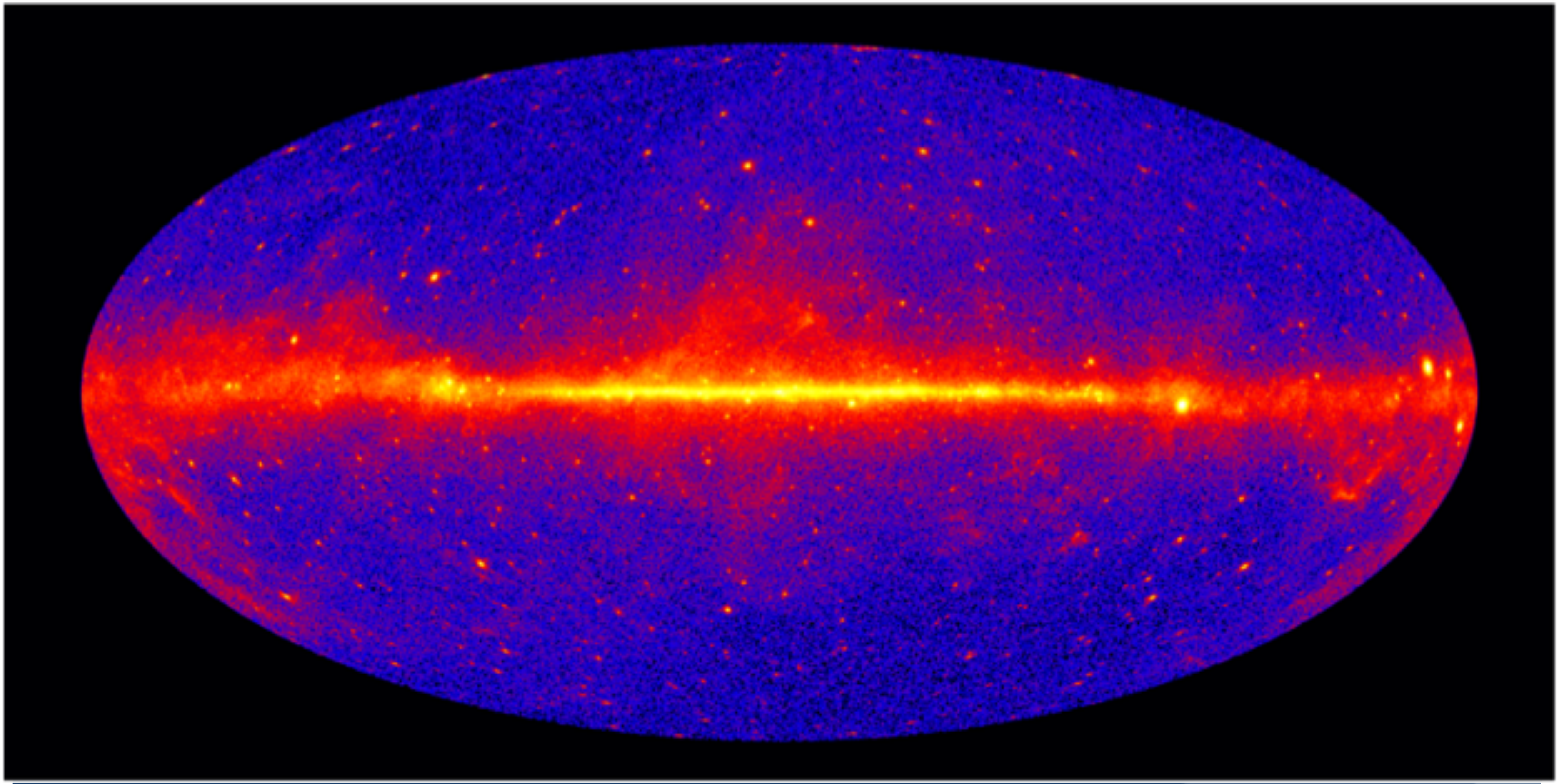
Fermi sky in 80 days



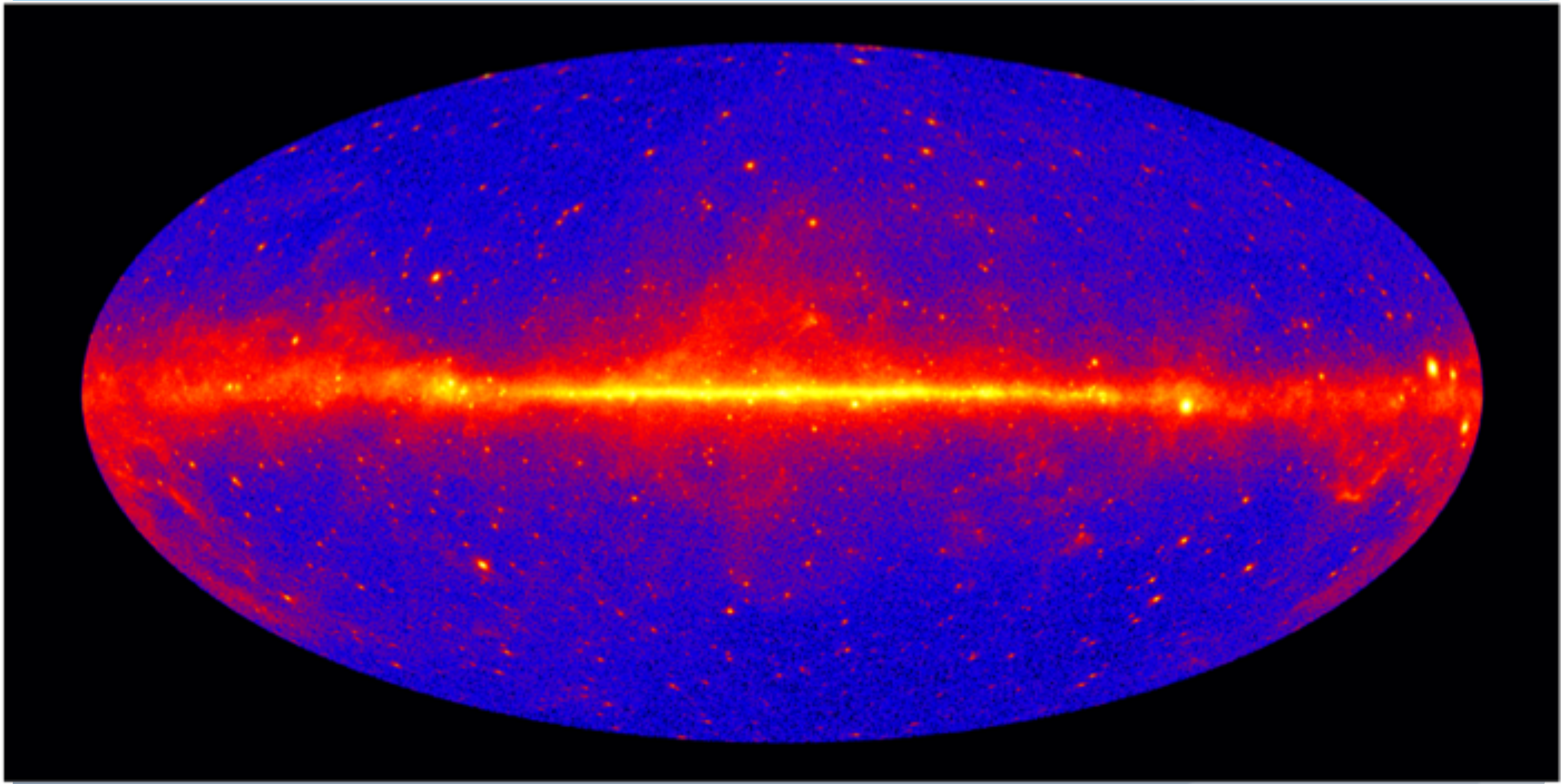
Fermi sky in 160 days



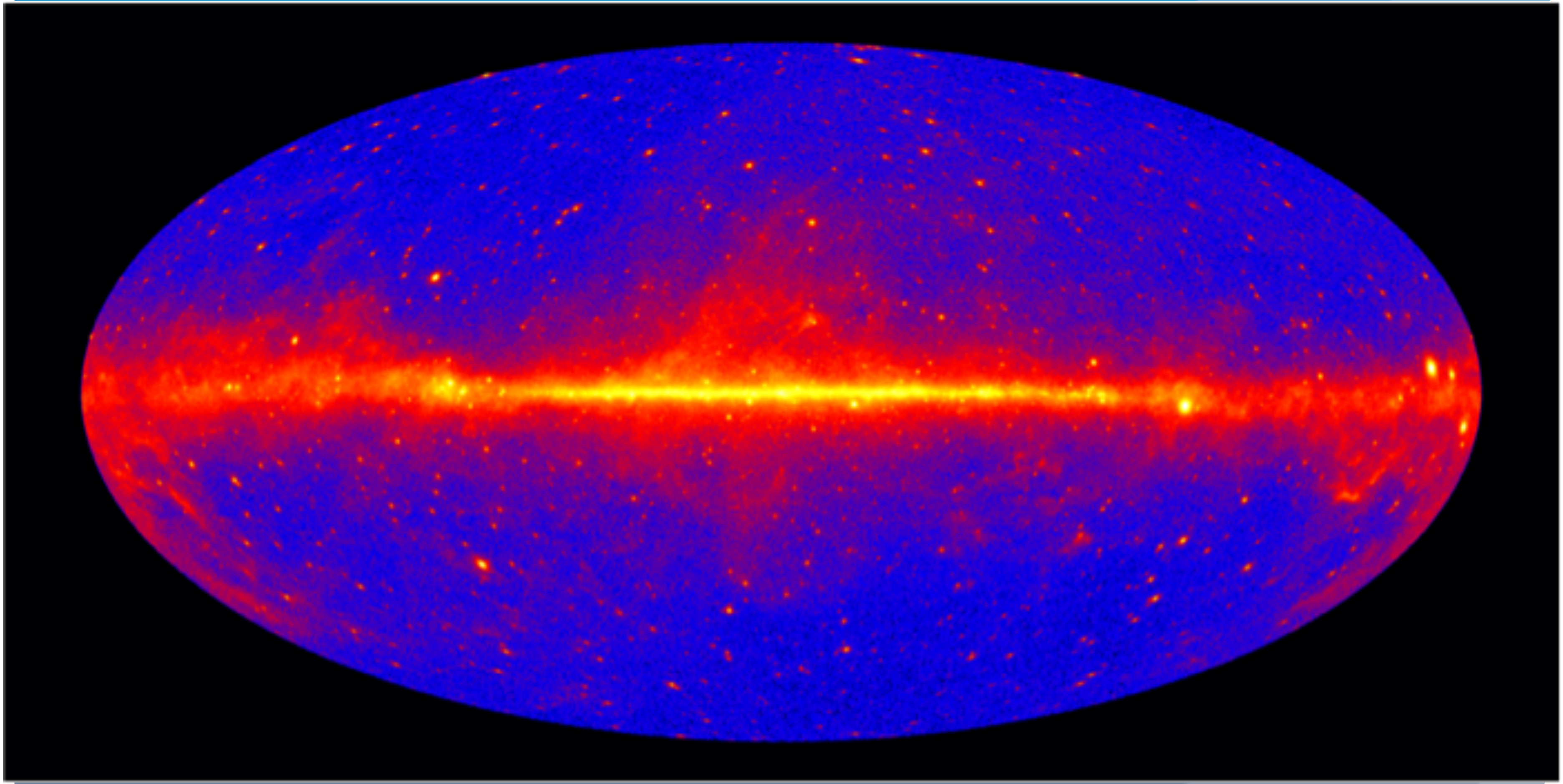
Fermi sky in 320 days



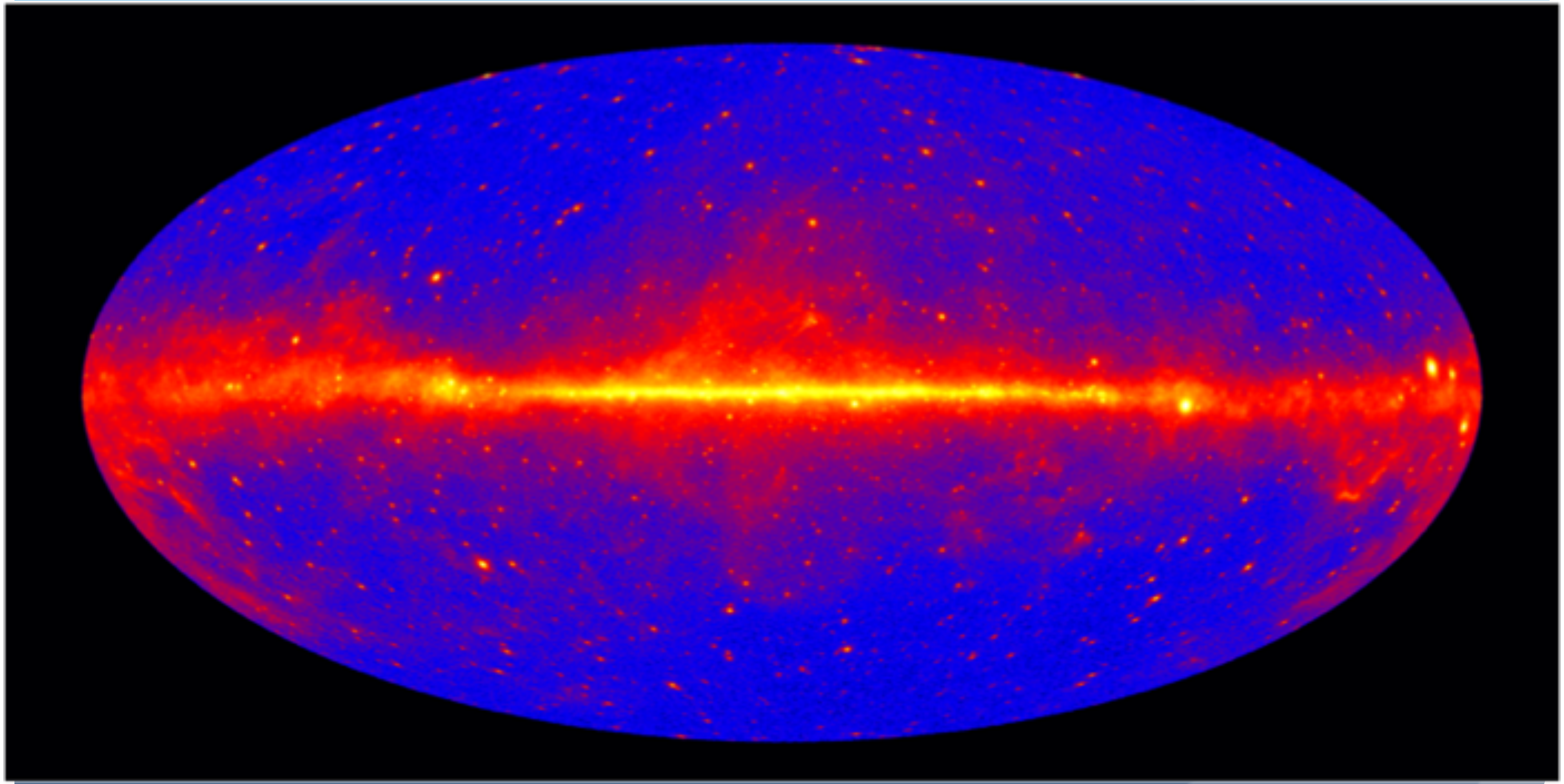
Fermi sky in 640 days



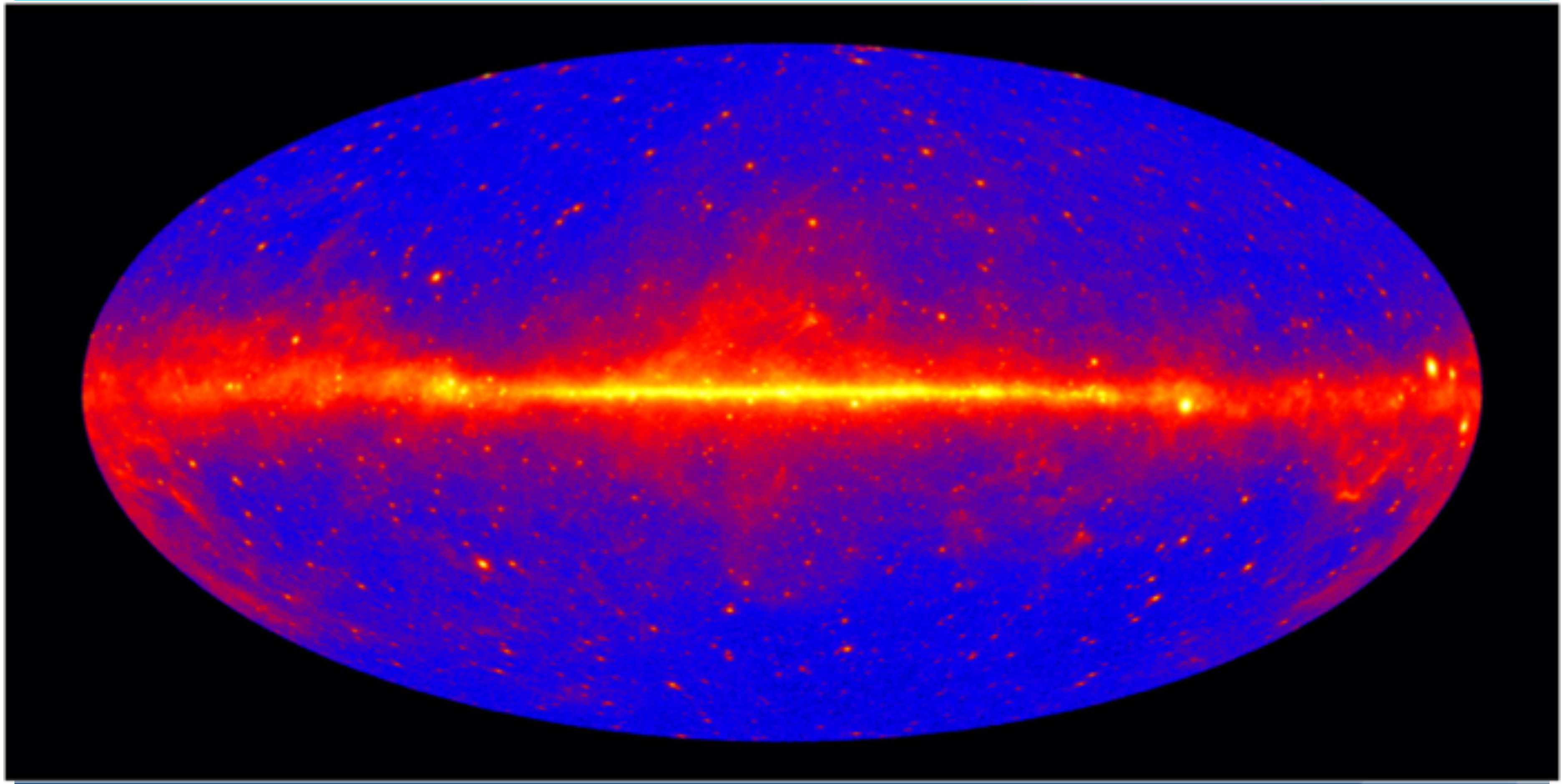
Fermi sky in 1280 days



Fermi sky in 7 years



Composition of Fermi gamma-ray Sky



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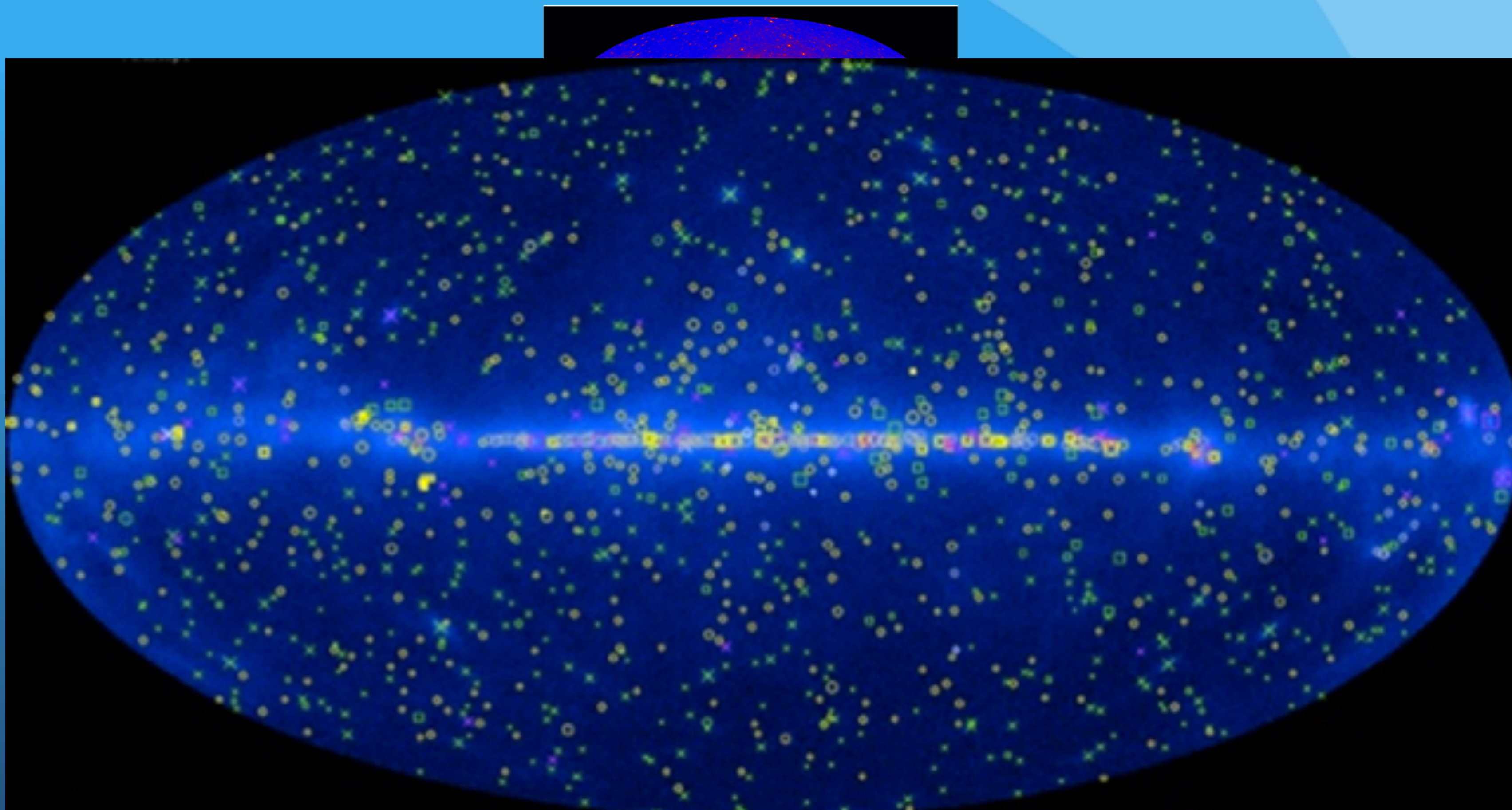

5000+ γ-ray sources: several source classes, including AGN, PSRs, SNR and more

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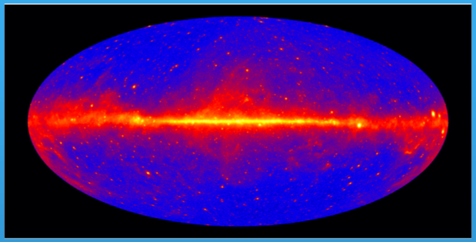

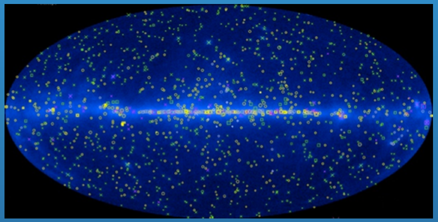

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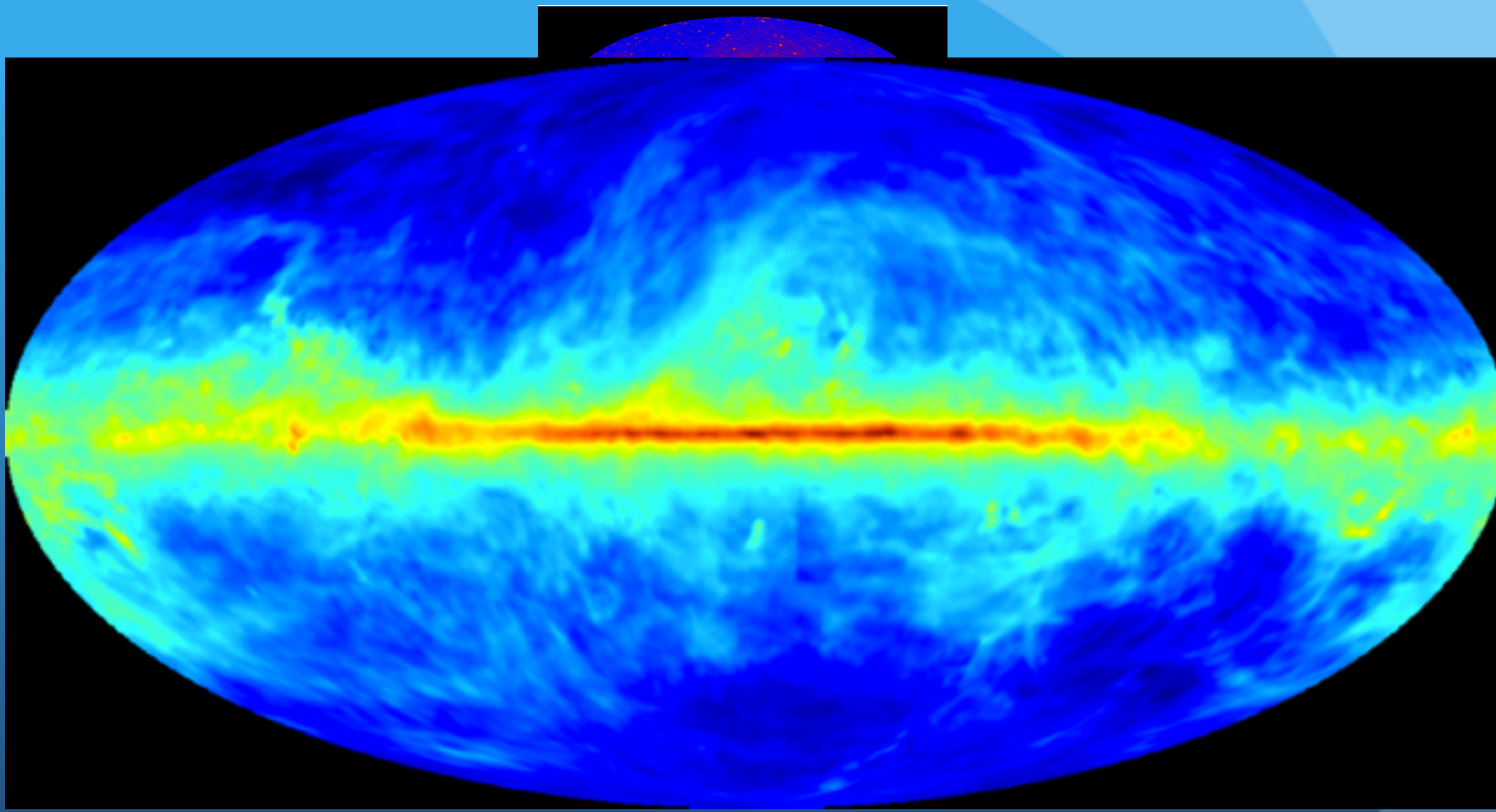

Gamma rays from high-energy **cosmic rays interacting** with dust, gas and radiation fields in the Galaxy

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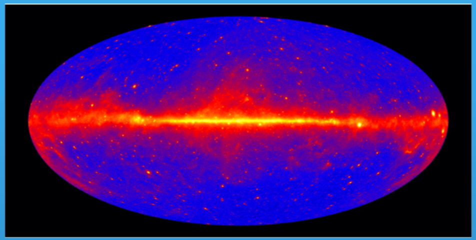

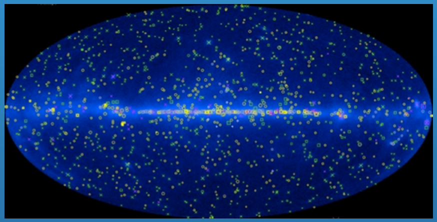

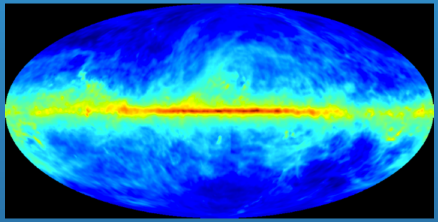

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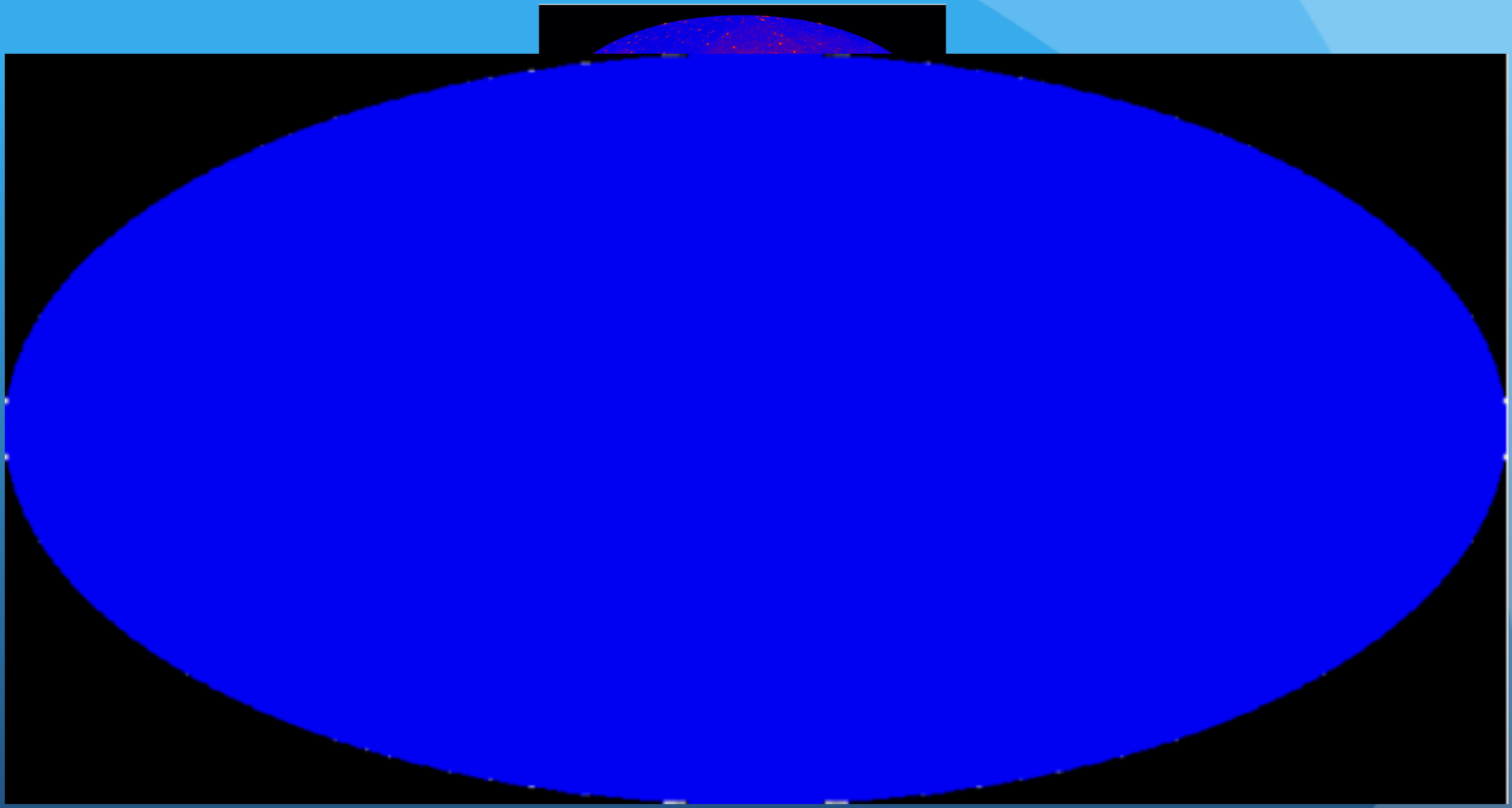

Unresolved emission from extra-Galactic sources, possibly other contributions

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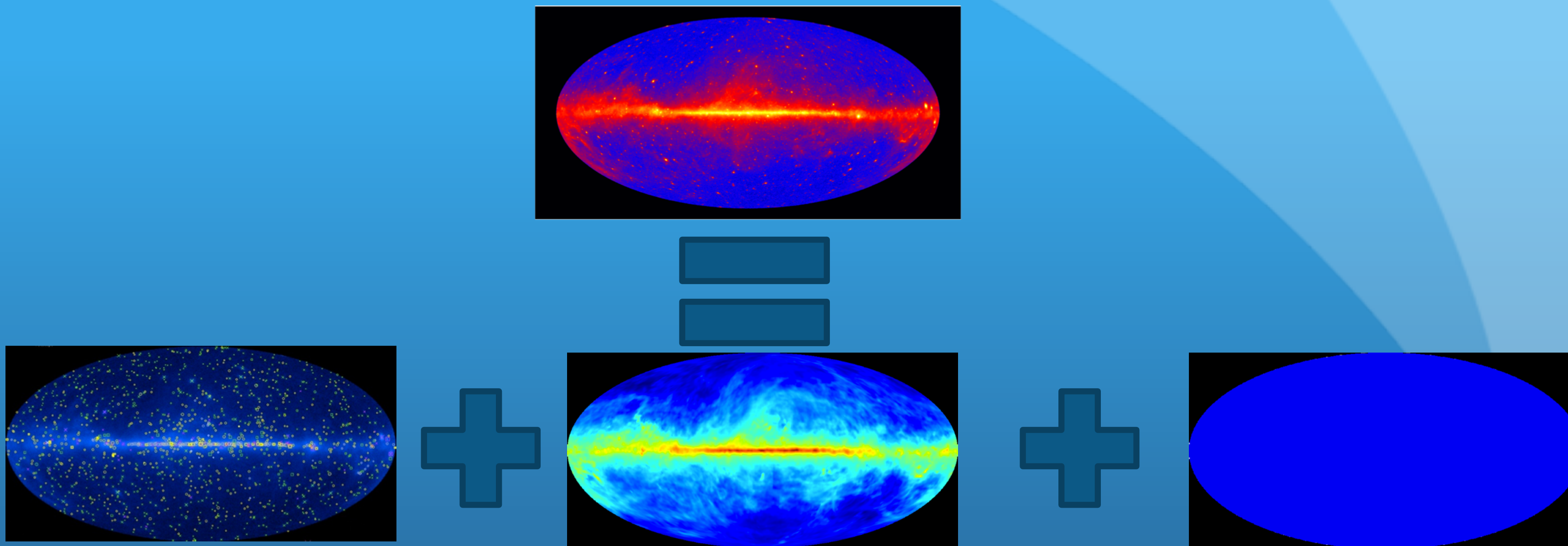

Gamma-ray emitters

Catalogs

***Fermi*-LAT catalog included source not seen before in gamma-ray:**

non-AGN galaxies, globular clusters, high-mass binaries, novae

30% of sources are still unassociated

New type of gamma-ray emitters? Dark matter?

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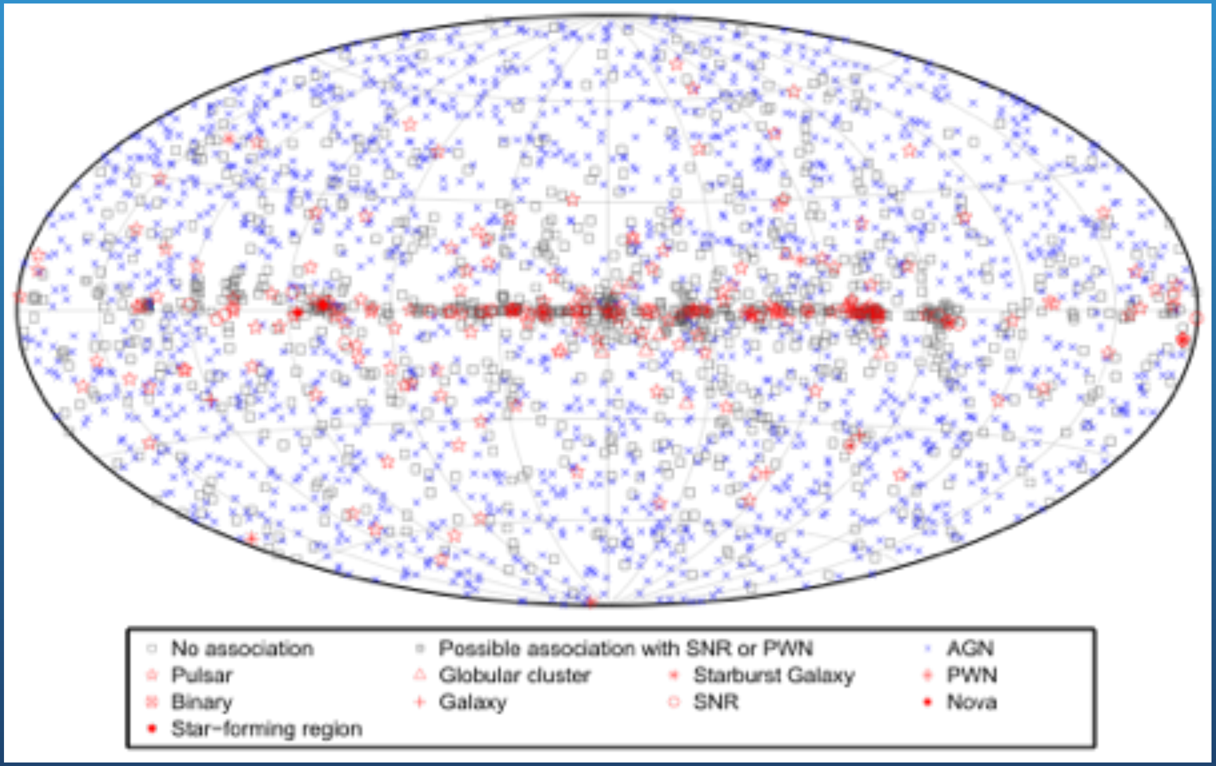

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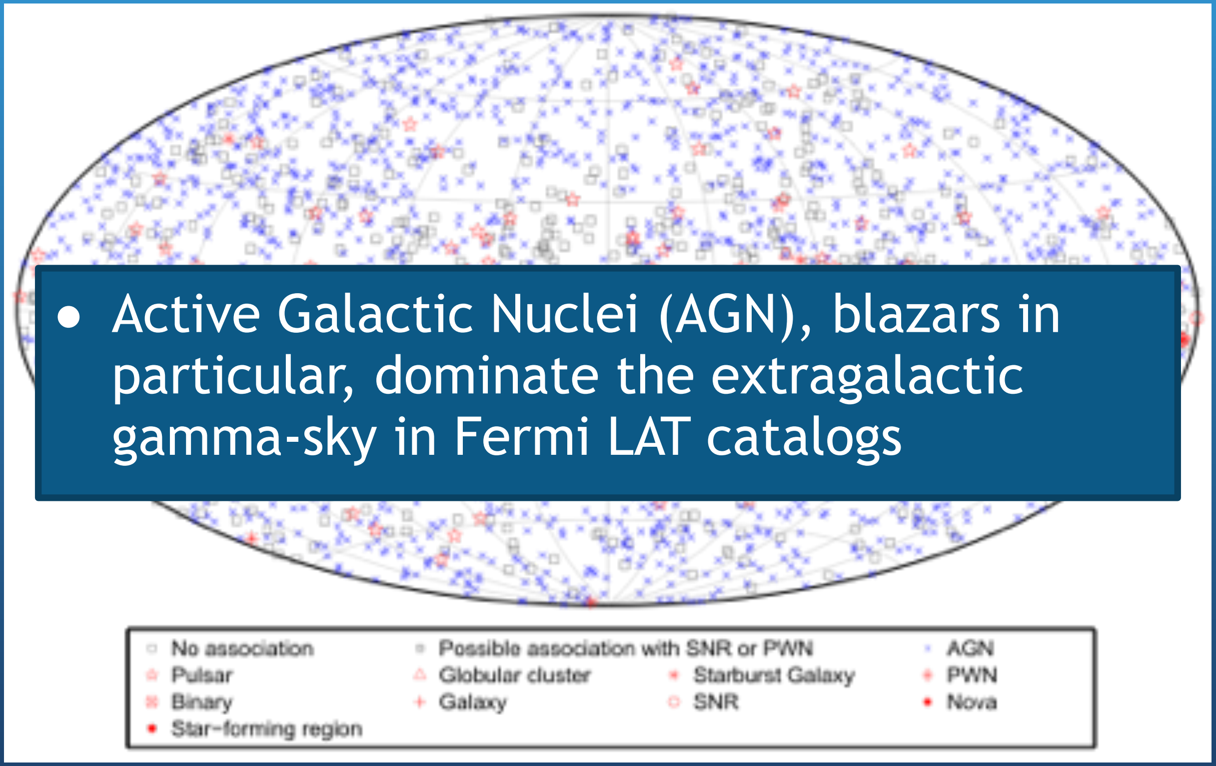

- Active Galactic Nuclei (AGN), blazars in particular, dominate the extragalactic gamma-sky in Fermi LAT catalogs

Active Galactic Nuclei

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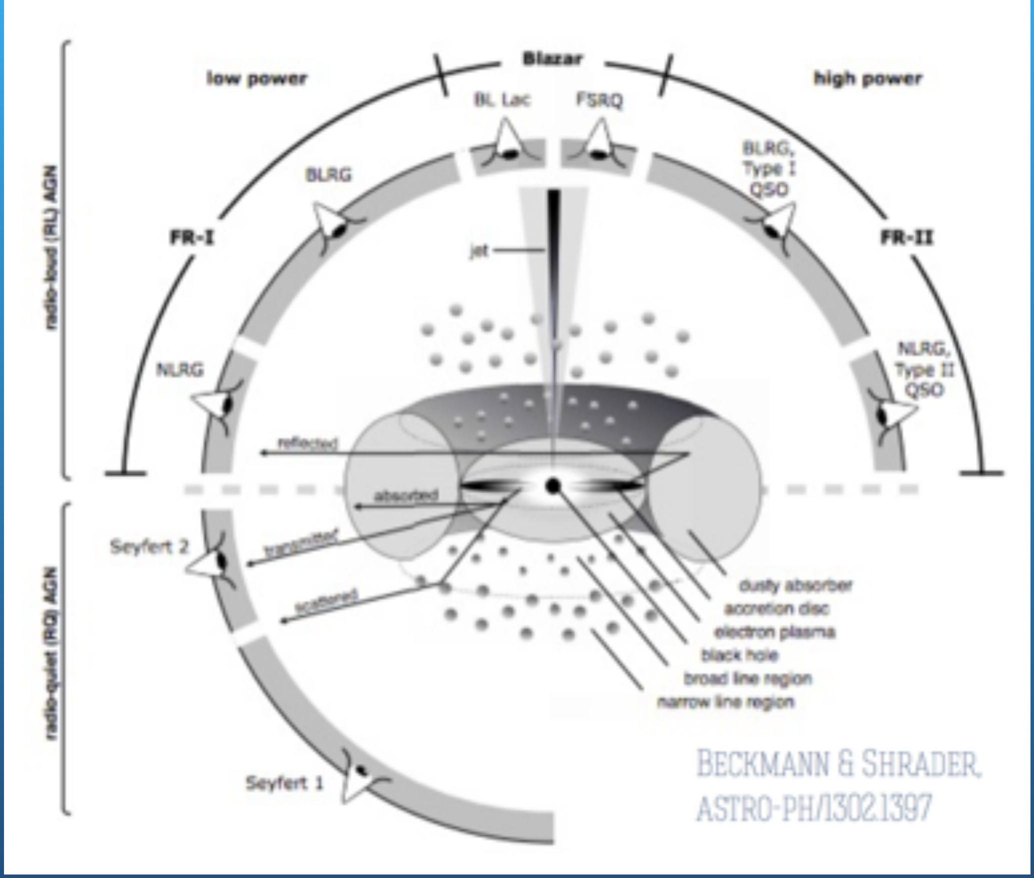
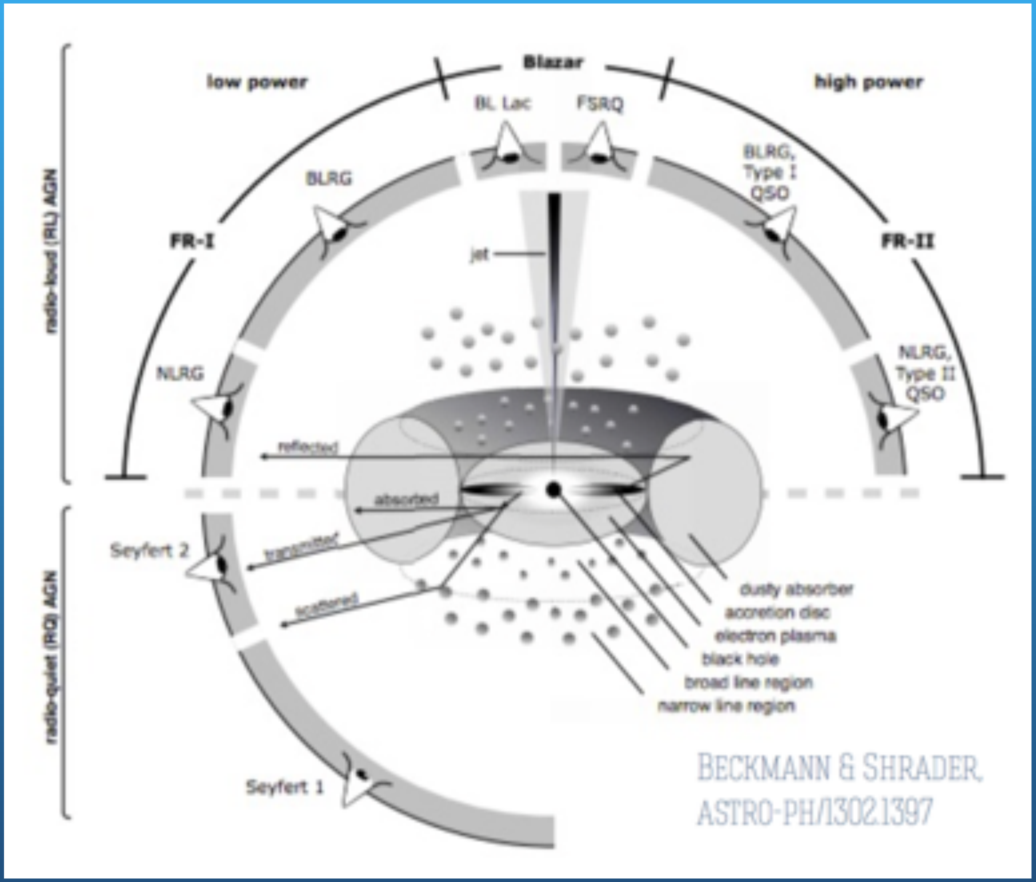
AGN Classes



Blazar
low power
high power
BL Lac
FSRQ
BLRG
BLRG, Type I QSO
FR-I
FR-II
jet
NLRG
NLRG, Type II QSO
radio-loud (RL) AGN
reflected
absorbed
transmitted
scattered
Seyfert 2
radio-quiet (RQ) AGN
dusty absorber
accretion disc
electron plasma
black hole
broad line region
narrow line region
Seyfert 1
BECKMANN & SHRADER, ASTRO-PH/1302.1397

AGN Classes



- Blazars
  - FSRQ
  - BL Lacertae Objects

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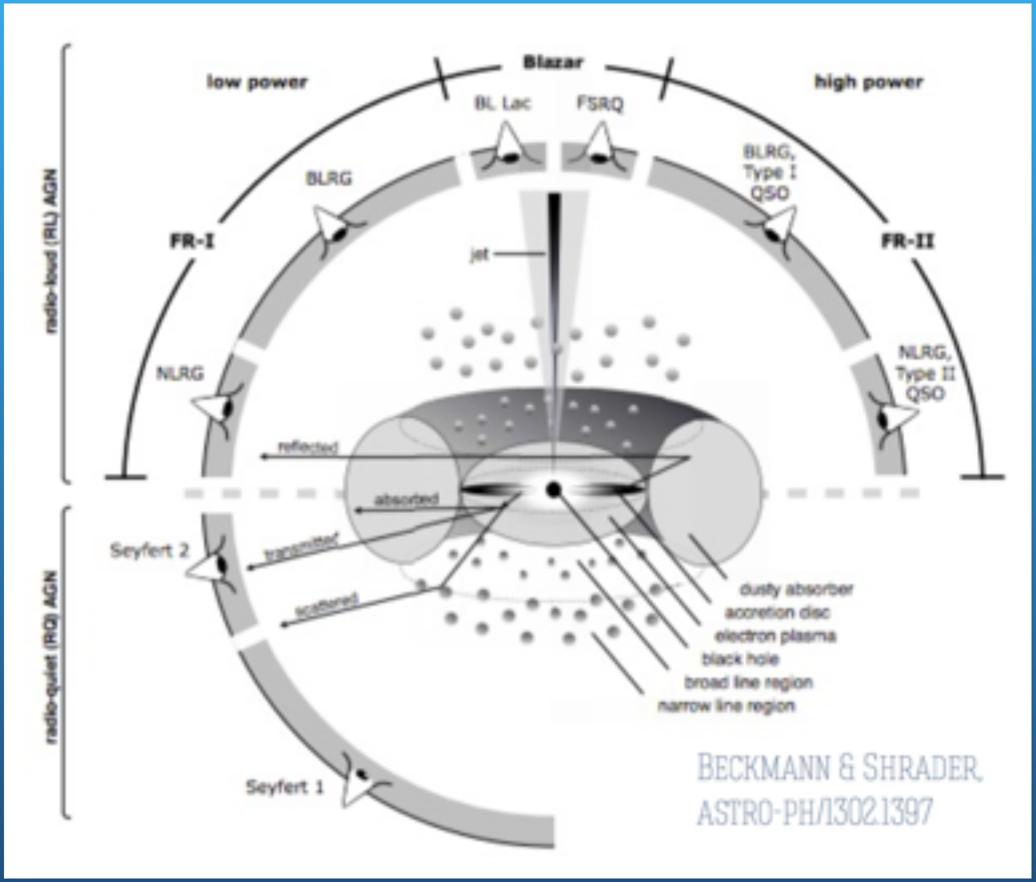

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- Radio Galaxies

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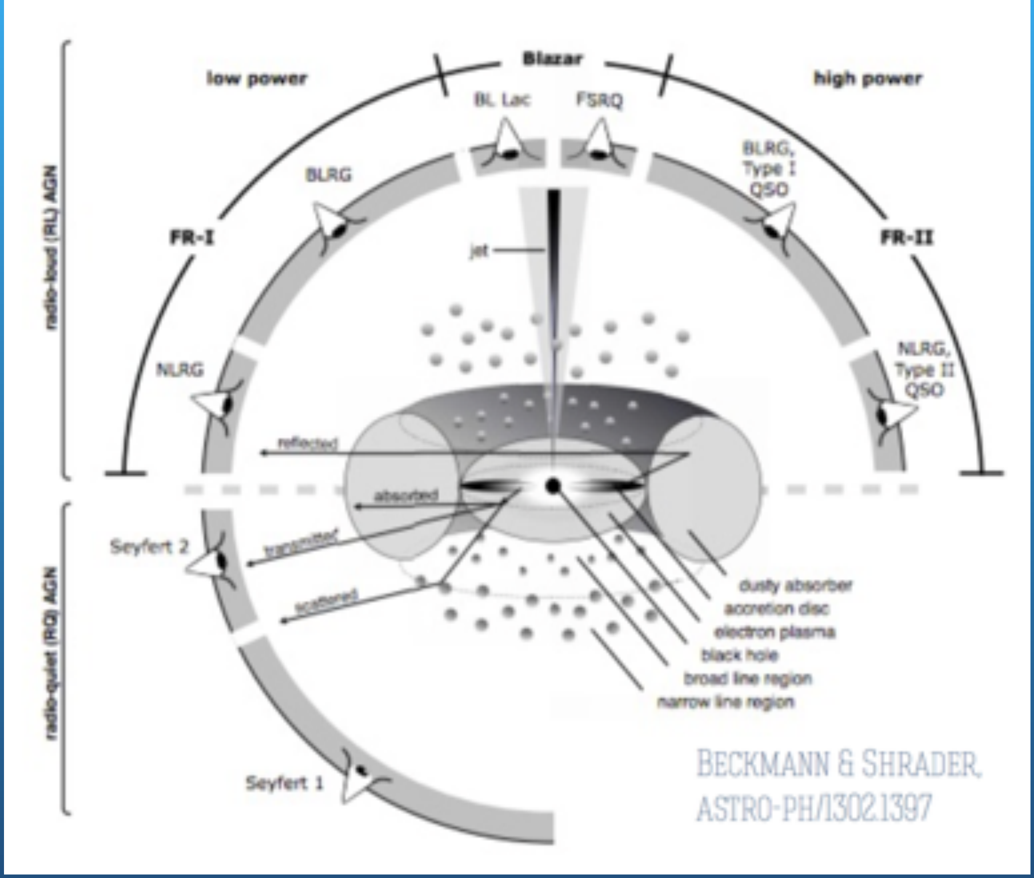

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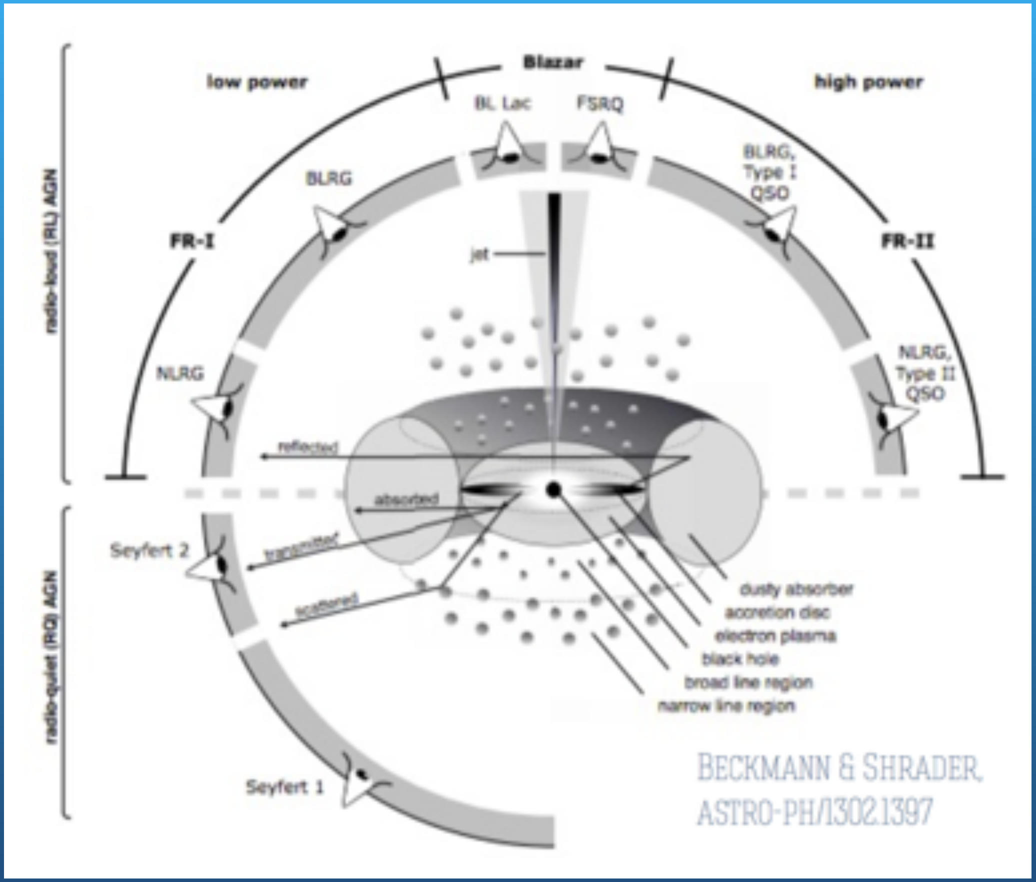

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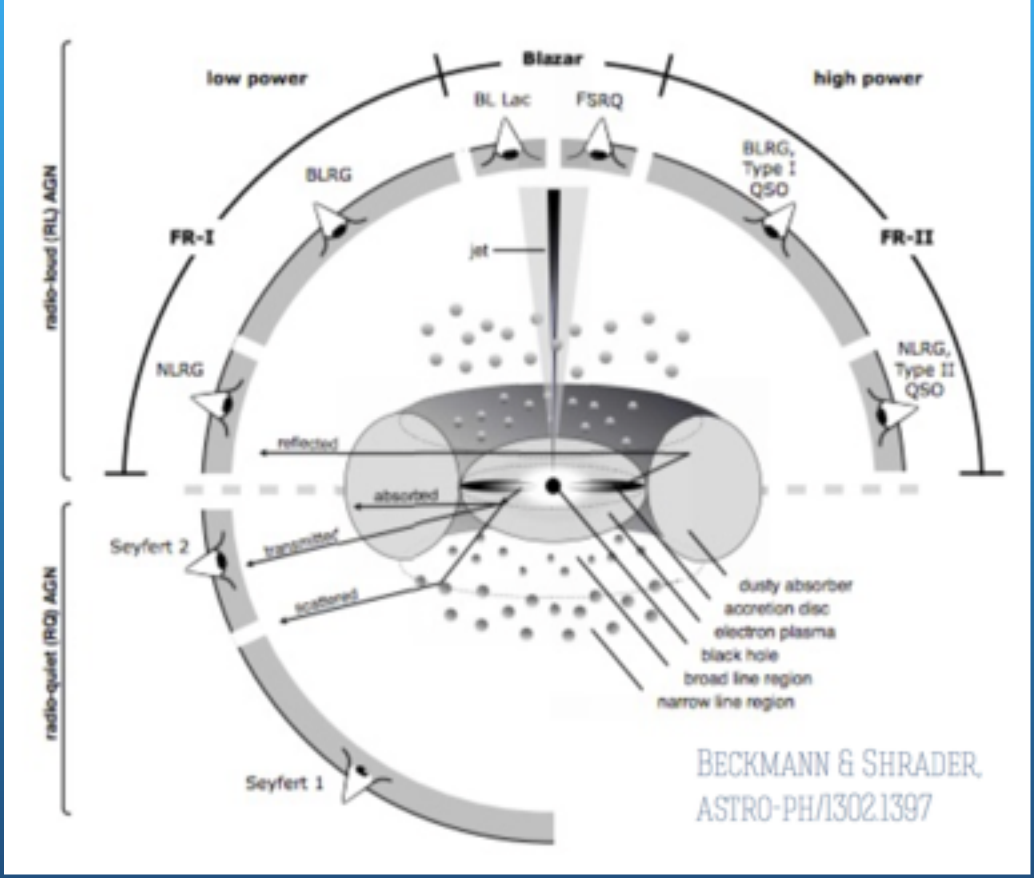

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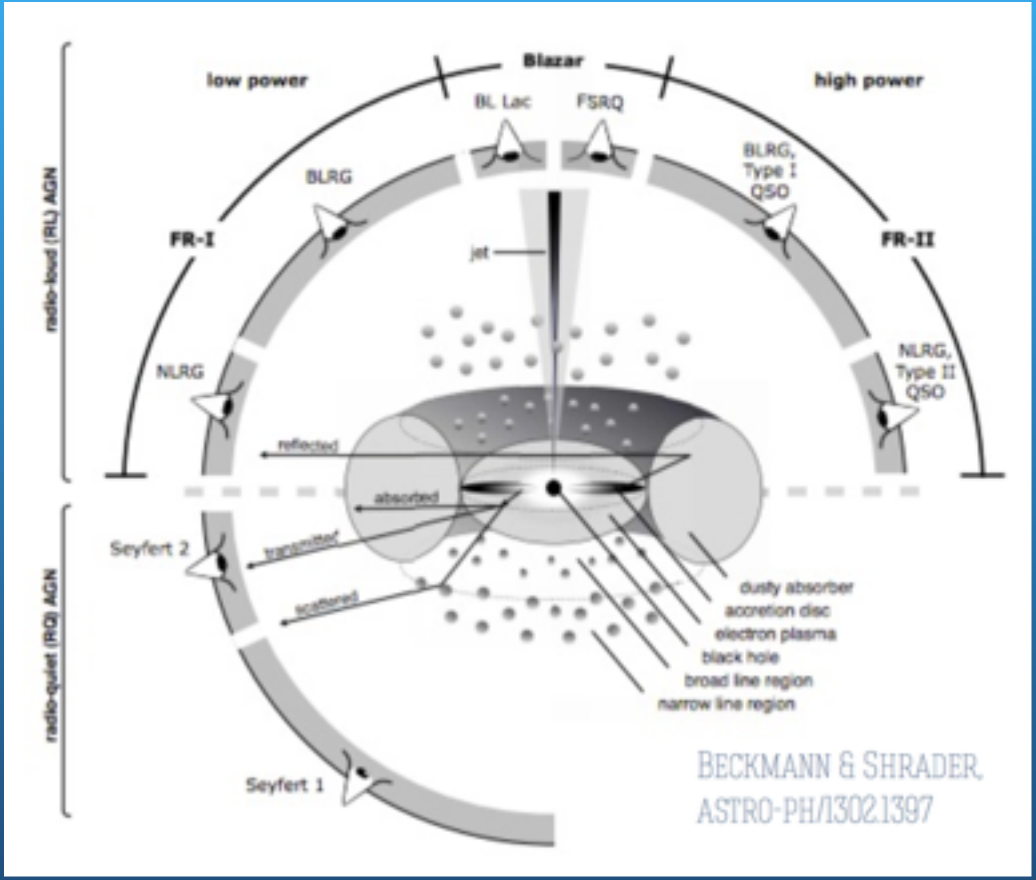

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- Seyfert Galaxies

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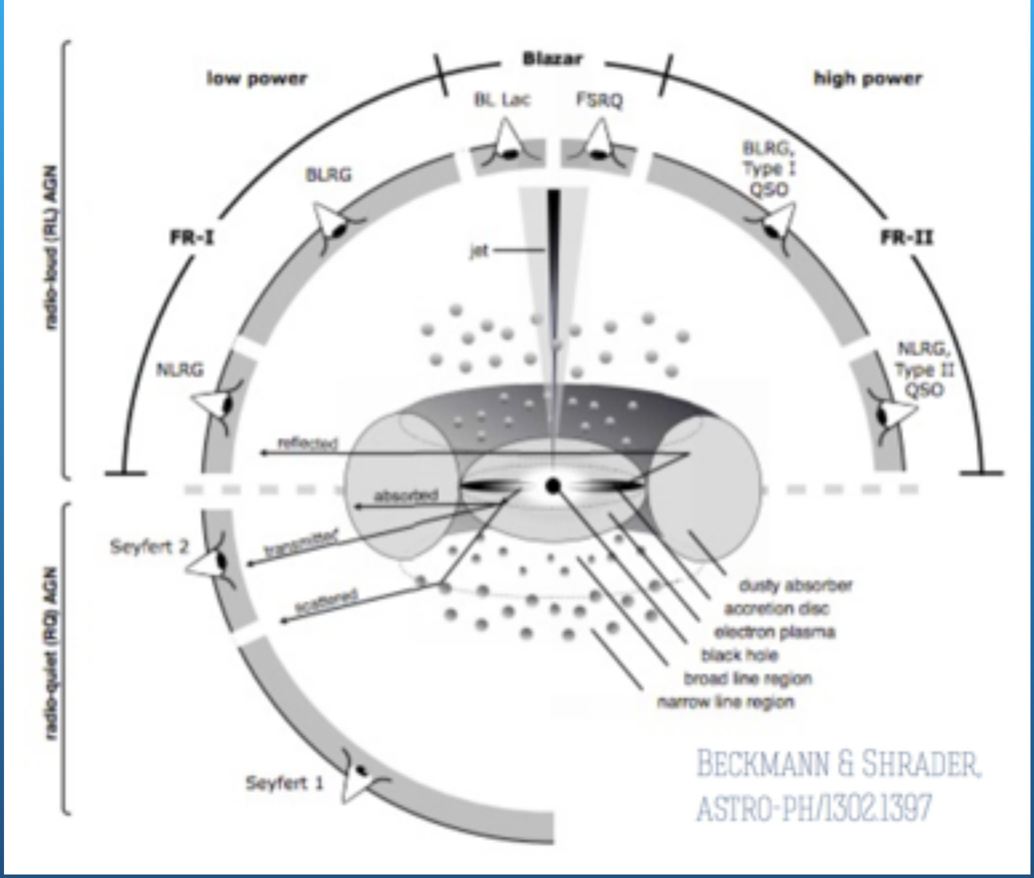

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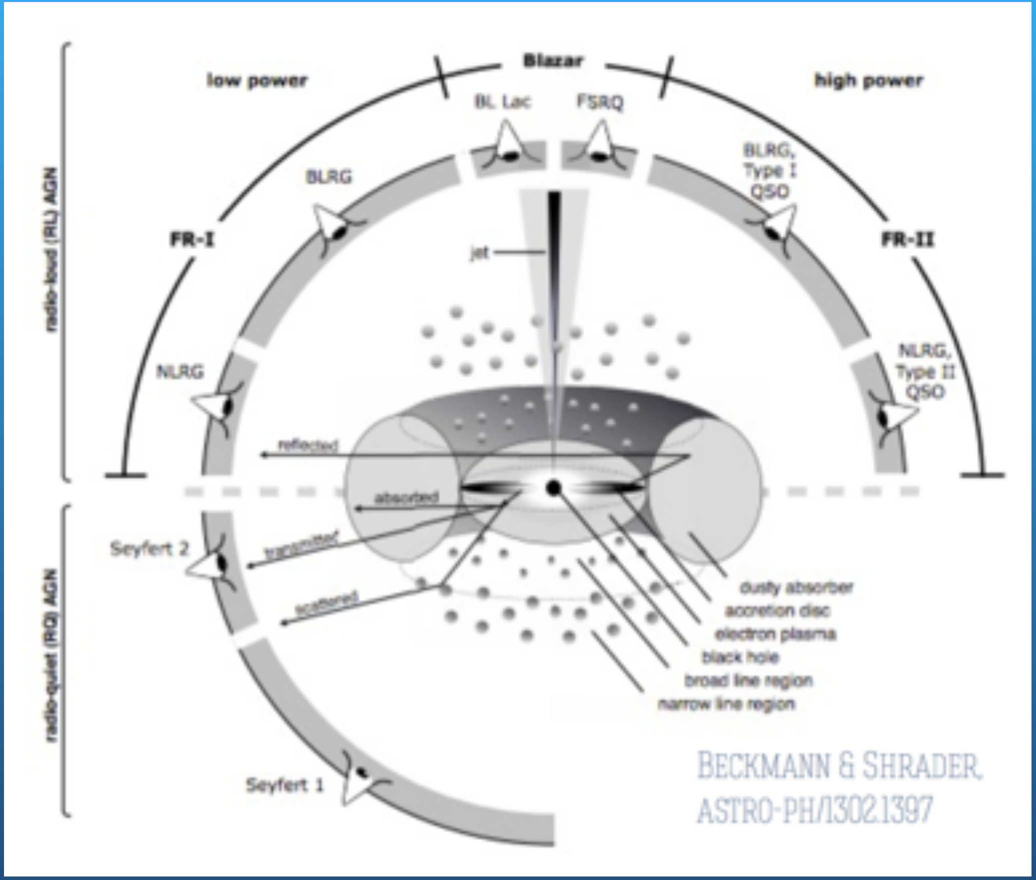

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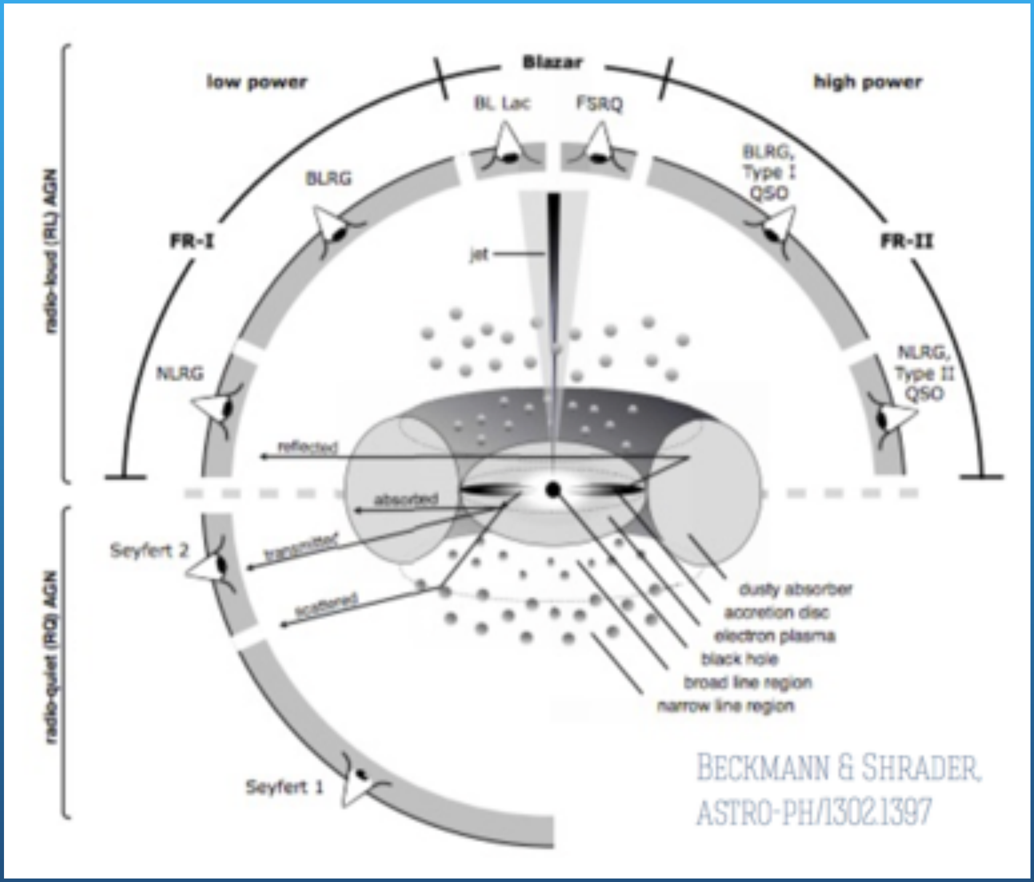

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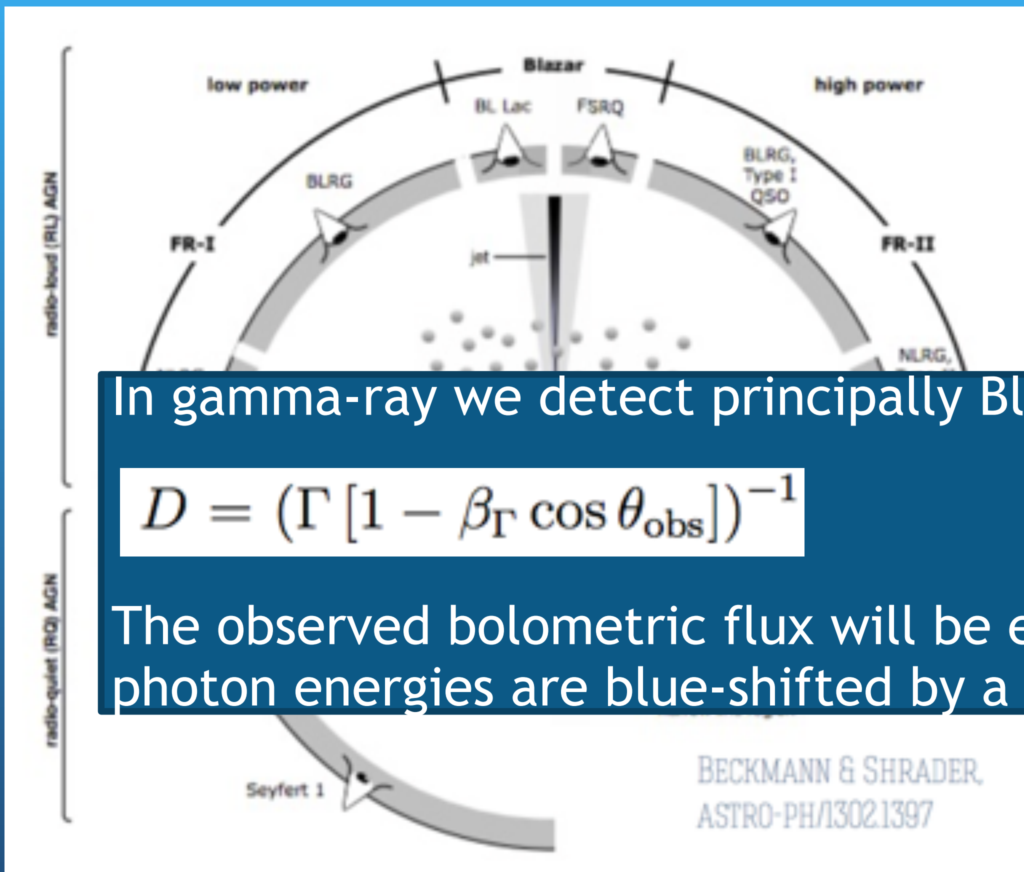

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In gamma-ray we detect principally Blazar—>Doppler boosting D

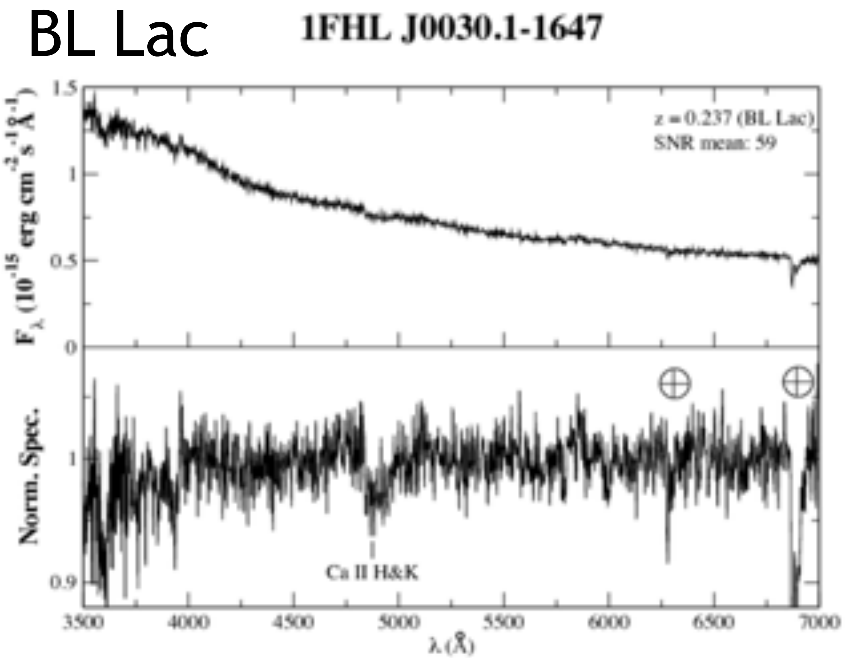
$$D = \left(\Gamma\left[1 - \beta_\Gamma \cos\theta_{\mathrm{obs}}\right]\right)^{-1}$$

The observed bolometric flux will be enhanced by a factor D^4,while photon energies are blue-shifted by a factor D

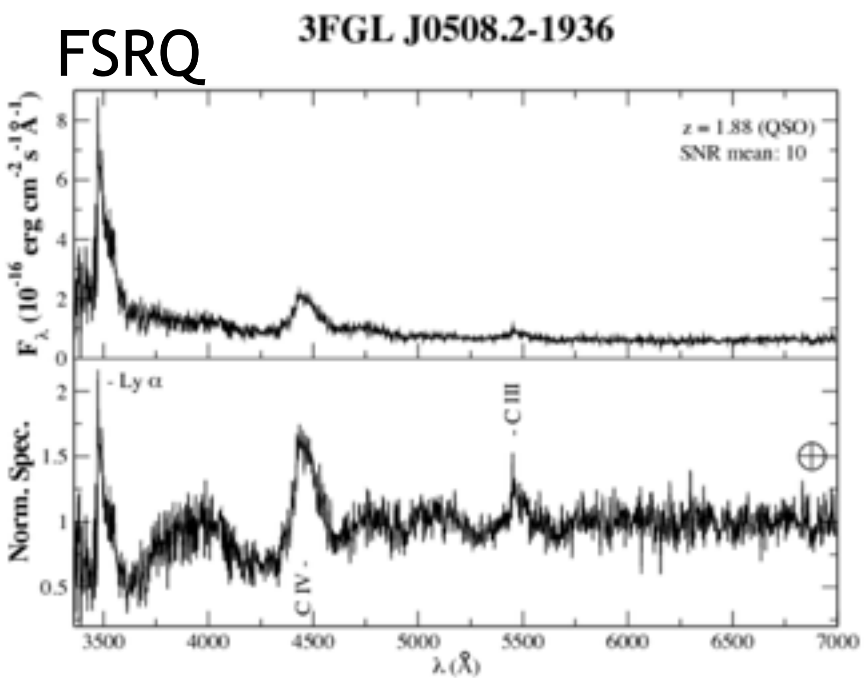
Blazars - First Distinction

- < 5% of all AGN
- BL LACs rest frame EW < 5 A & FSRQs rest frame EW > 5 A (Stickel+ 1991; Stocke+ 1991)
- The classical EW-based classification of blazars between FSRQs and BLLs is not physically motivated

BL Lac



FSRQ



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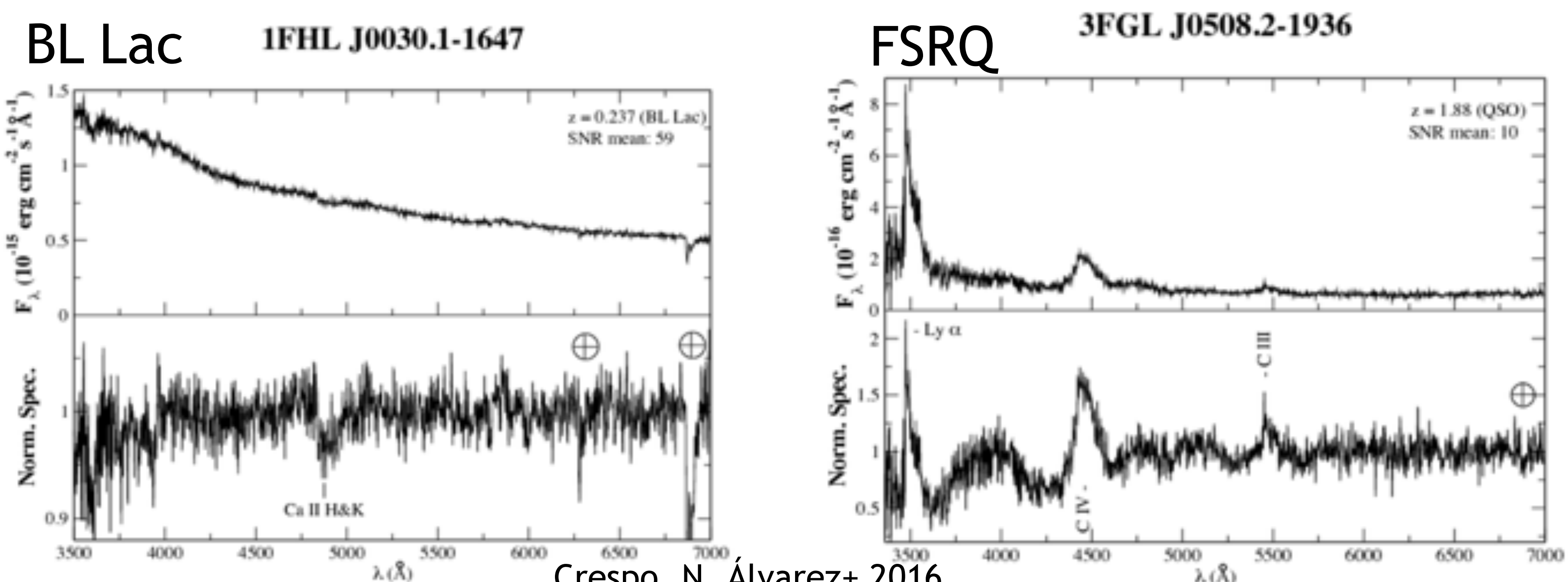


Crespo, N. Álvarez+ 2016

To be, or not to be a BL Lac?

- The physical distinction between FSRQs and BLLs is suspected to stem from the divergent natures of their underlying accretion flows around the central super massive black holes (Ghisellini & Tavecchio 2008)

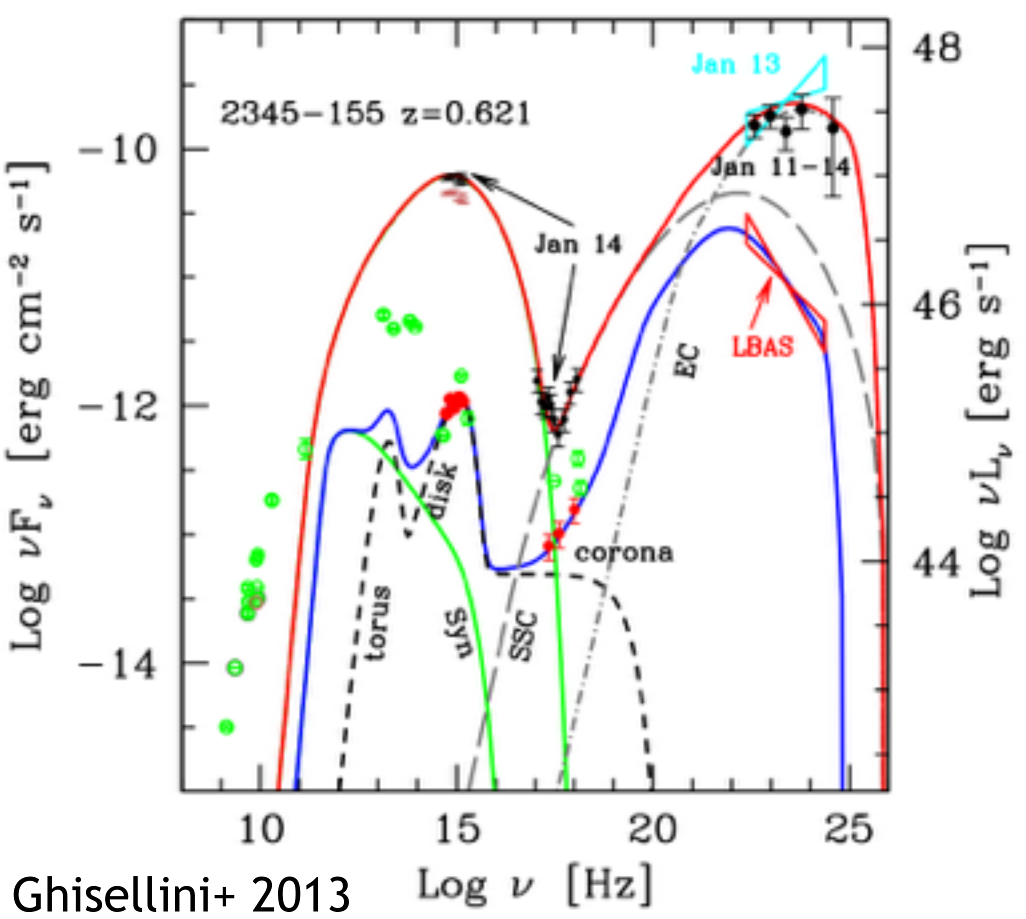
  - FSRQs are believed to harbor geometrically-thin, optically-thick accretion disks that are accreting rapidly

—> Presence of broad emission lines in their optical spectra from high-velocity gas clouds

  - BLLs are thought to have geometrically-thick, optically-thin accretion disks (at least in their inner regions), where the accretion is radiatively inefficient (ADAF)

—> Lack of broad emission lines and dust emission

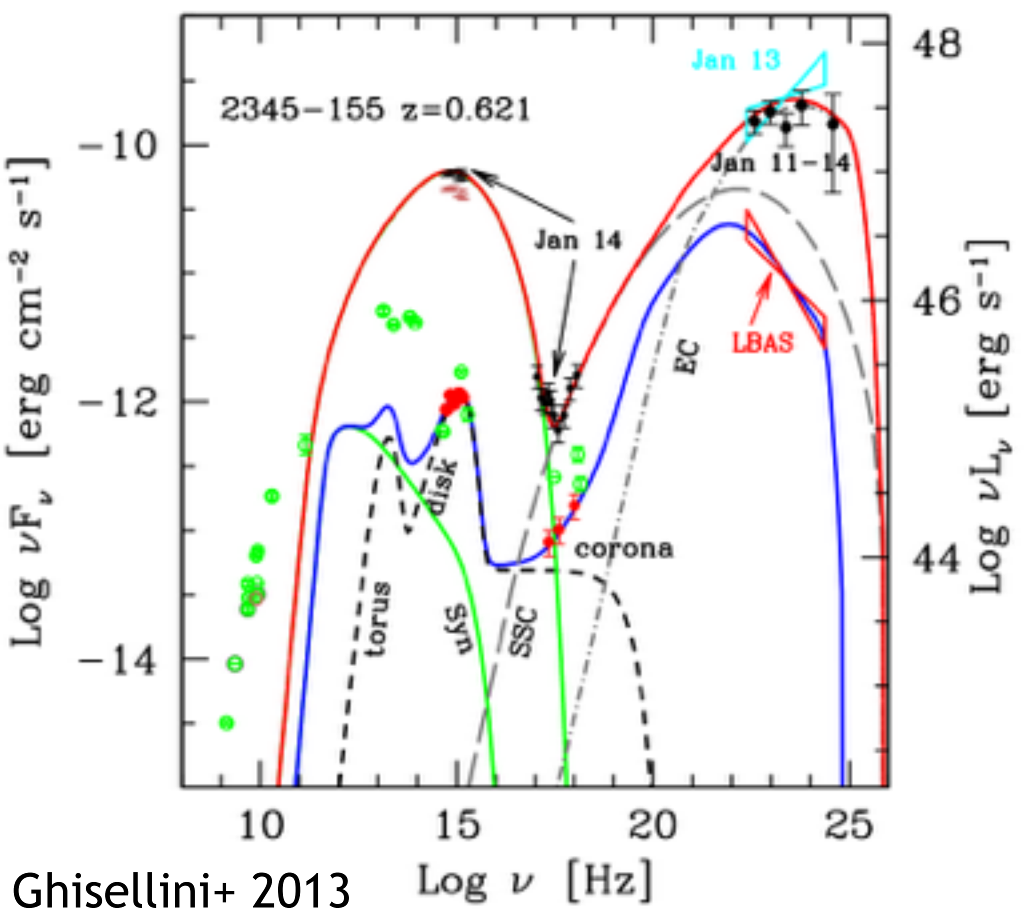
Transitional objects?



Ghisellini+ 2013

- PMN J2345-1555 red blazar become blue

Transitional objects?

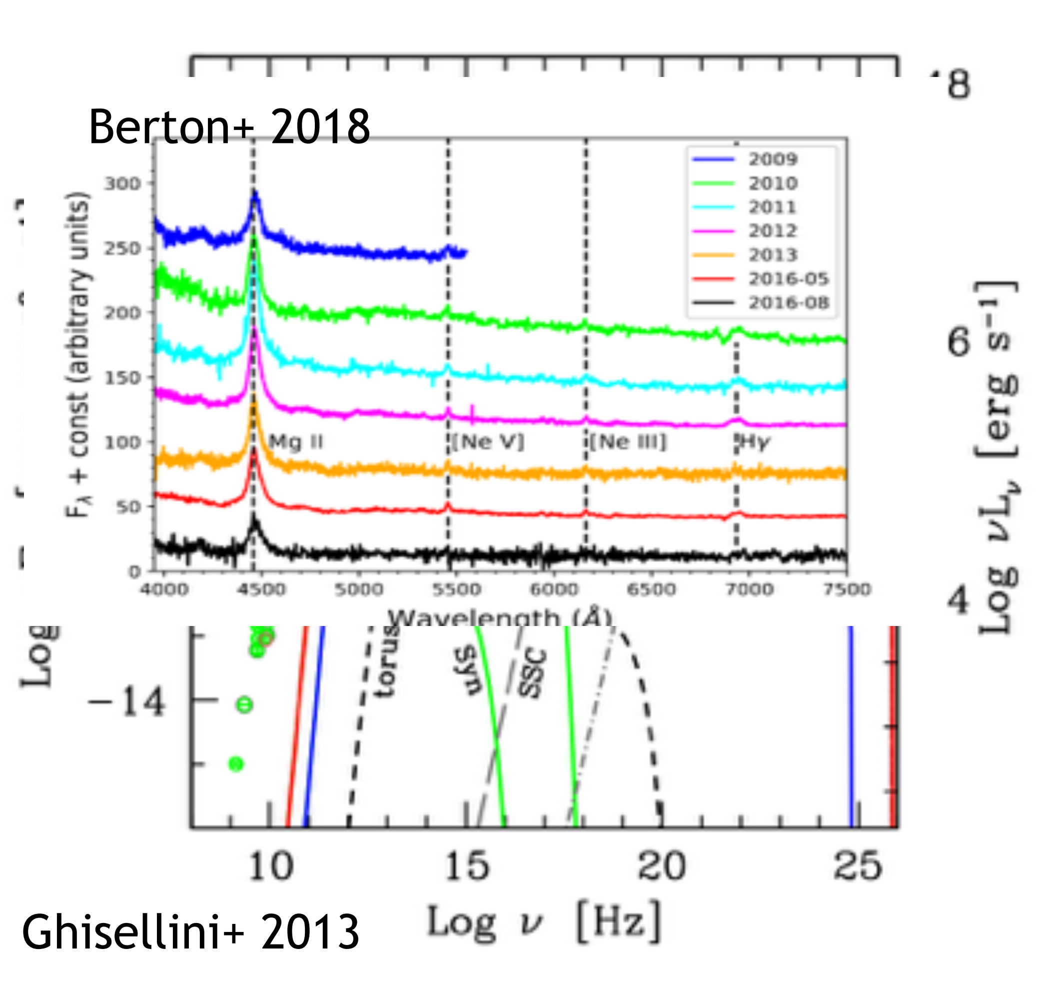


Ghisellini+ 2013

- PMN J2345-1555 red blazar become blue

- 3C 345 change the EW of Mg II line during the gamma-ray flaring state

Transitional objects?



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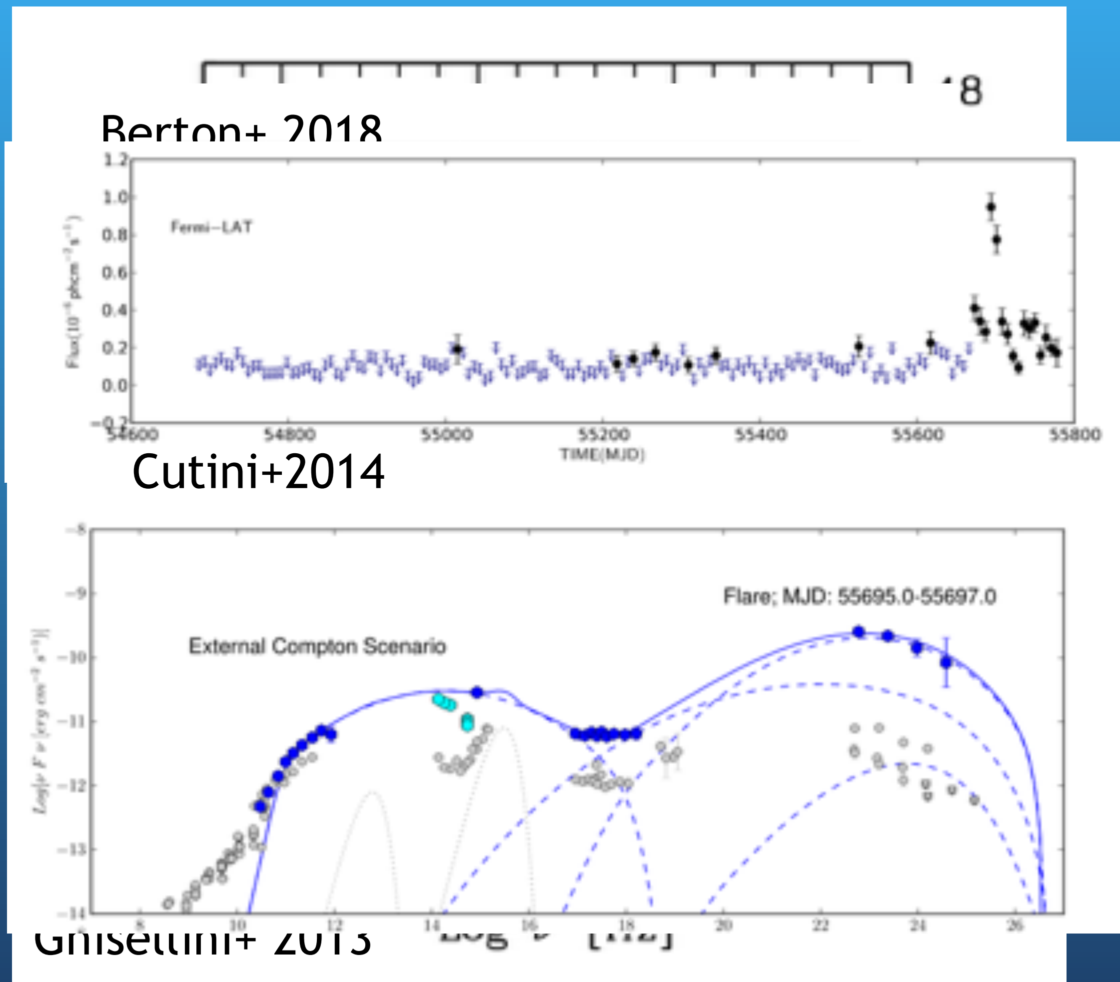

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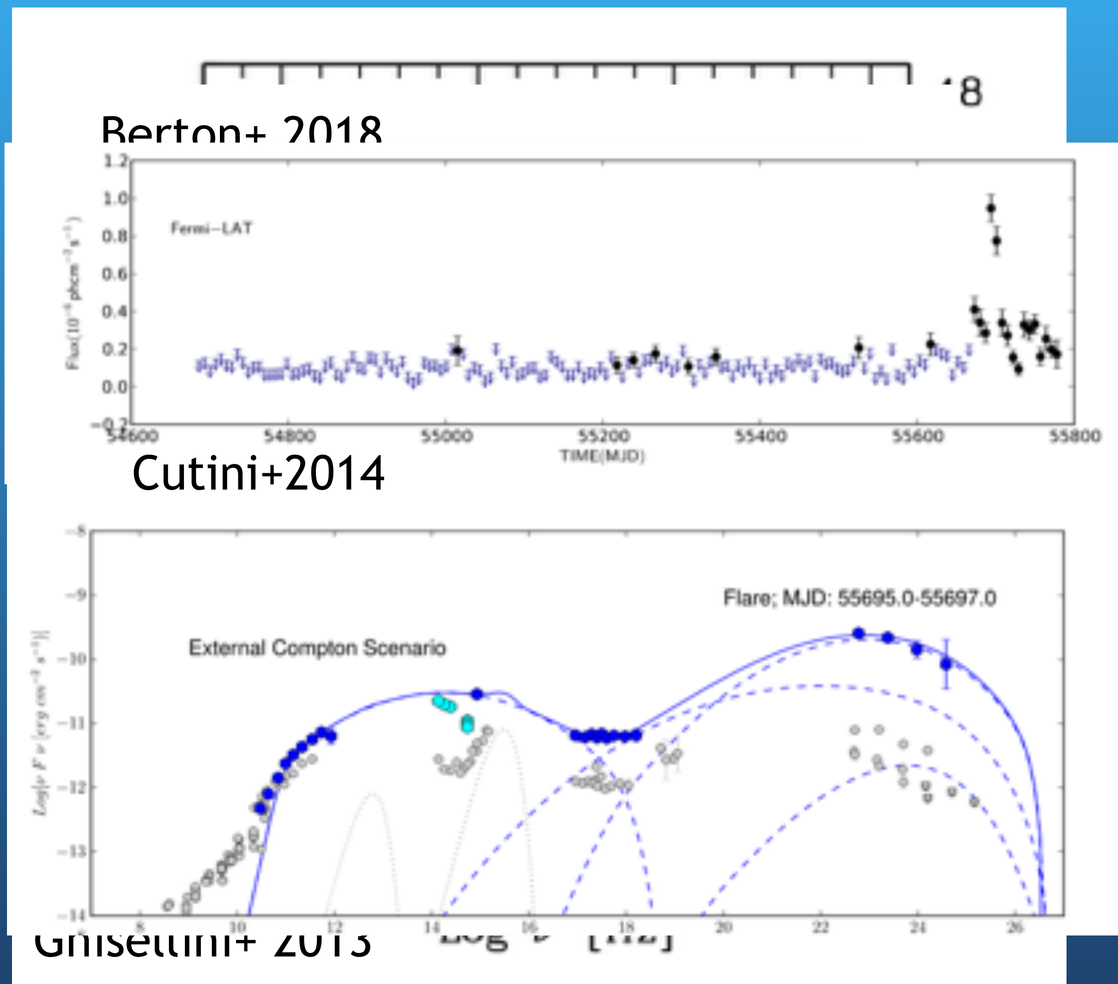


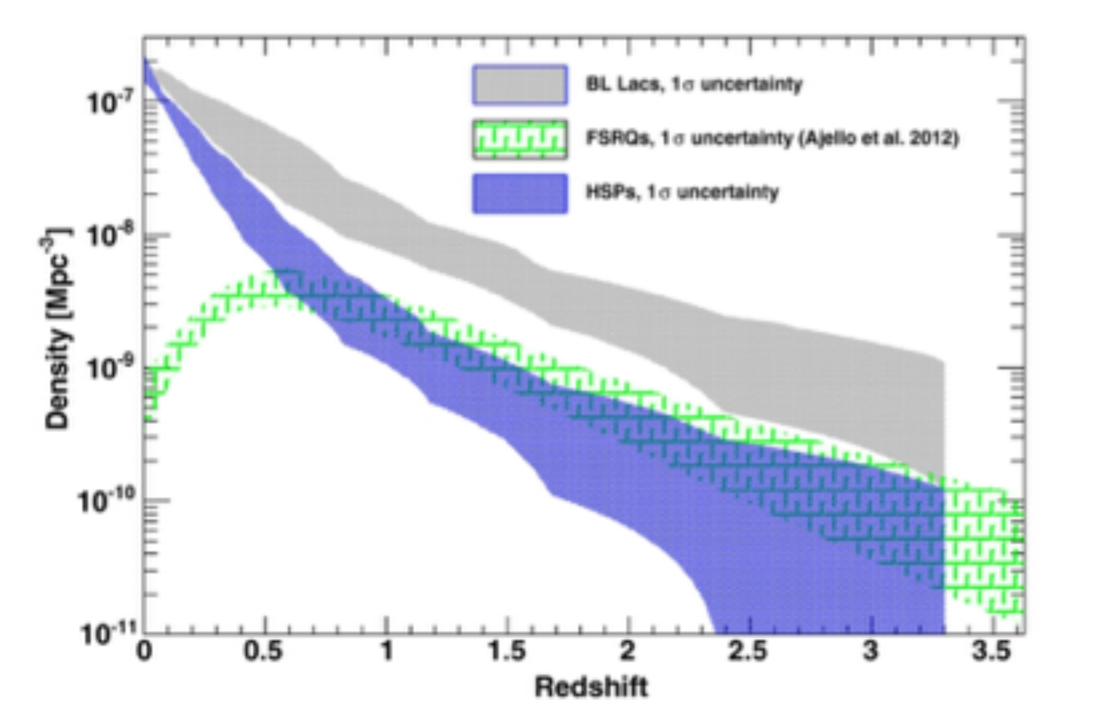
- PMN J2345-1555 red blazar become blue

- 3C 345 change the EW of Mg II line during the gamma-ray flaring state

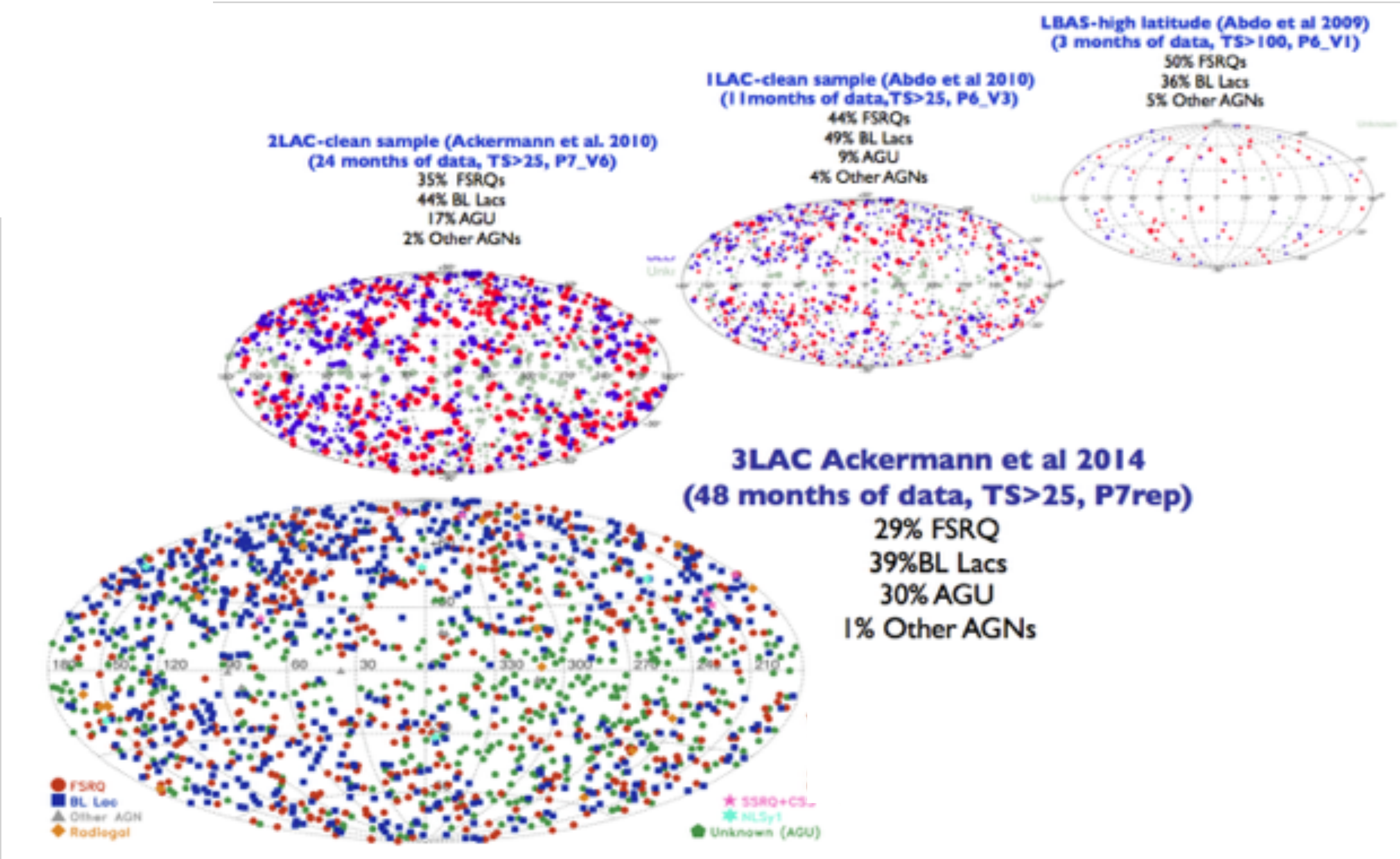
- 4C+49.22 from gamma-ray quite to gamma-ray active —> EW diluted by the not-thermal component ~20 times

Starving FSRQs become BL Lacs?

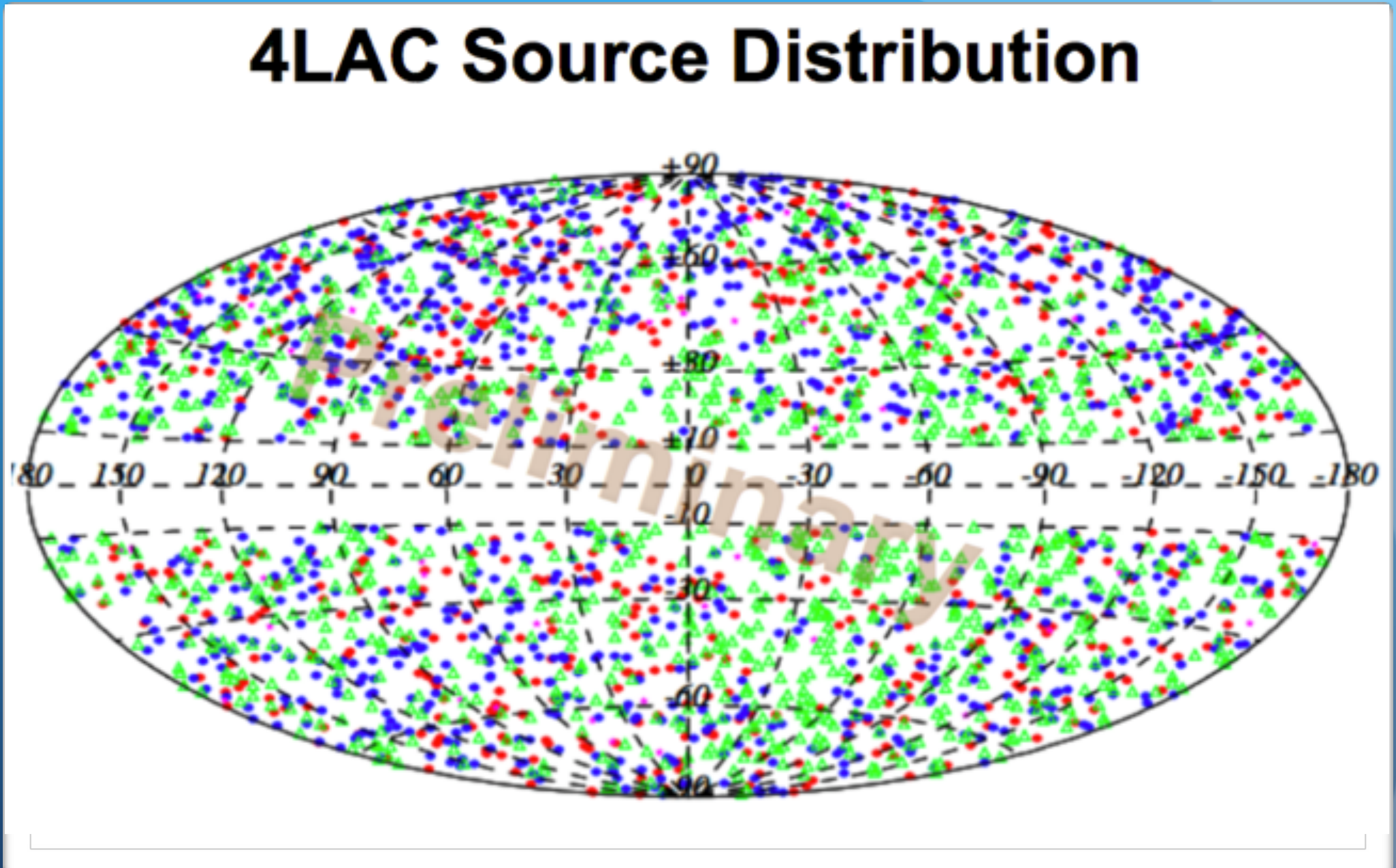
- Low-luminosity, high-synchrotron-peaked (HSP) BL Lac objects showed strong negative evolution
- Number density increasing for z <~ 0.5. Since this rise corresponds to a drop-off in the density of flat-spectrum radio quasars (FSRQs), —> possible interpretation is that these HSPs represent an accretion-starved end state of an earlier merger-driven gas-rich phase.



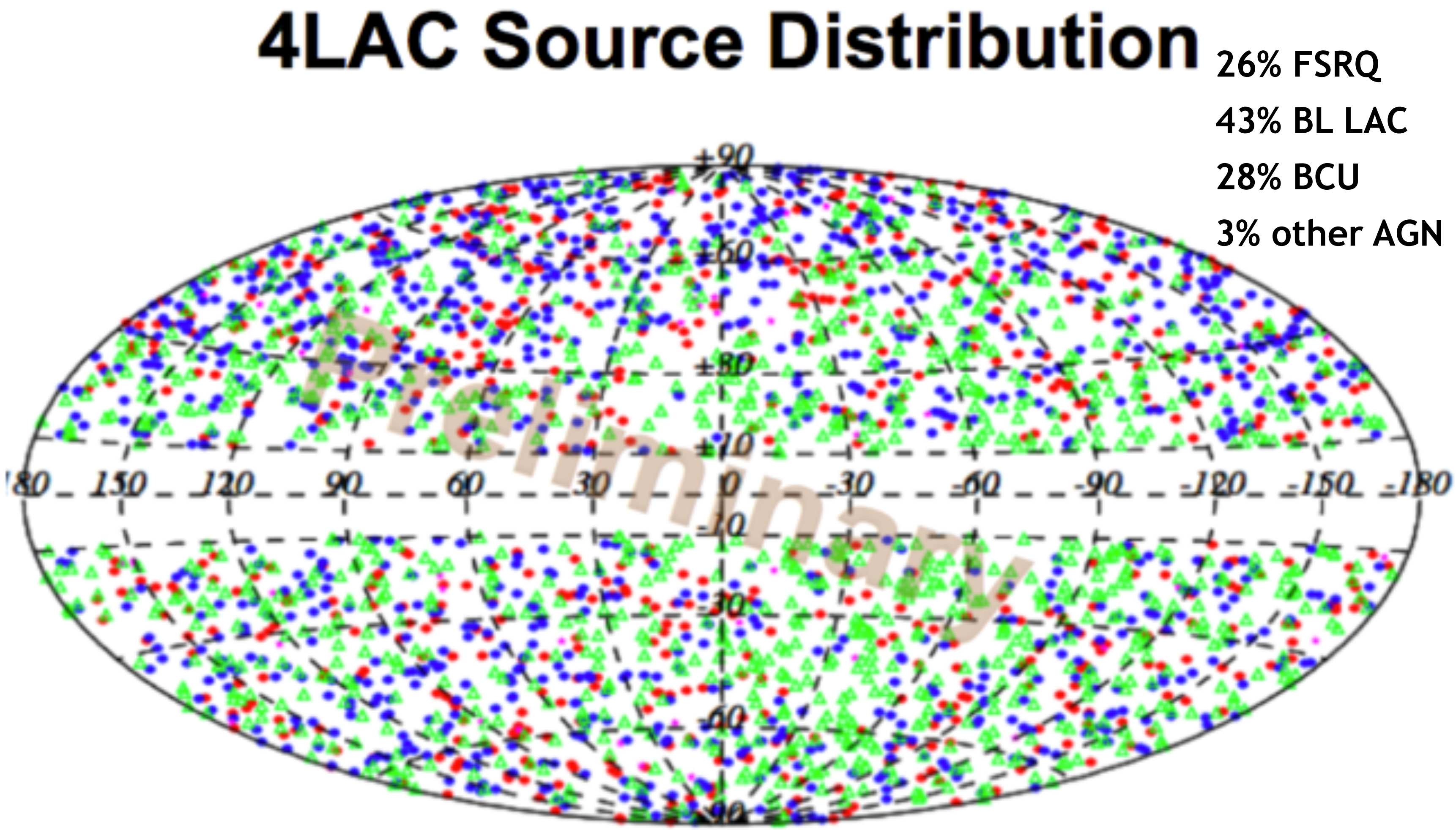
AGN catalogs



AGN catalogs



AGN catalogs



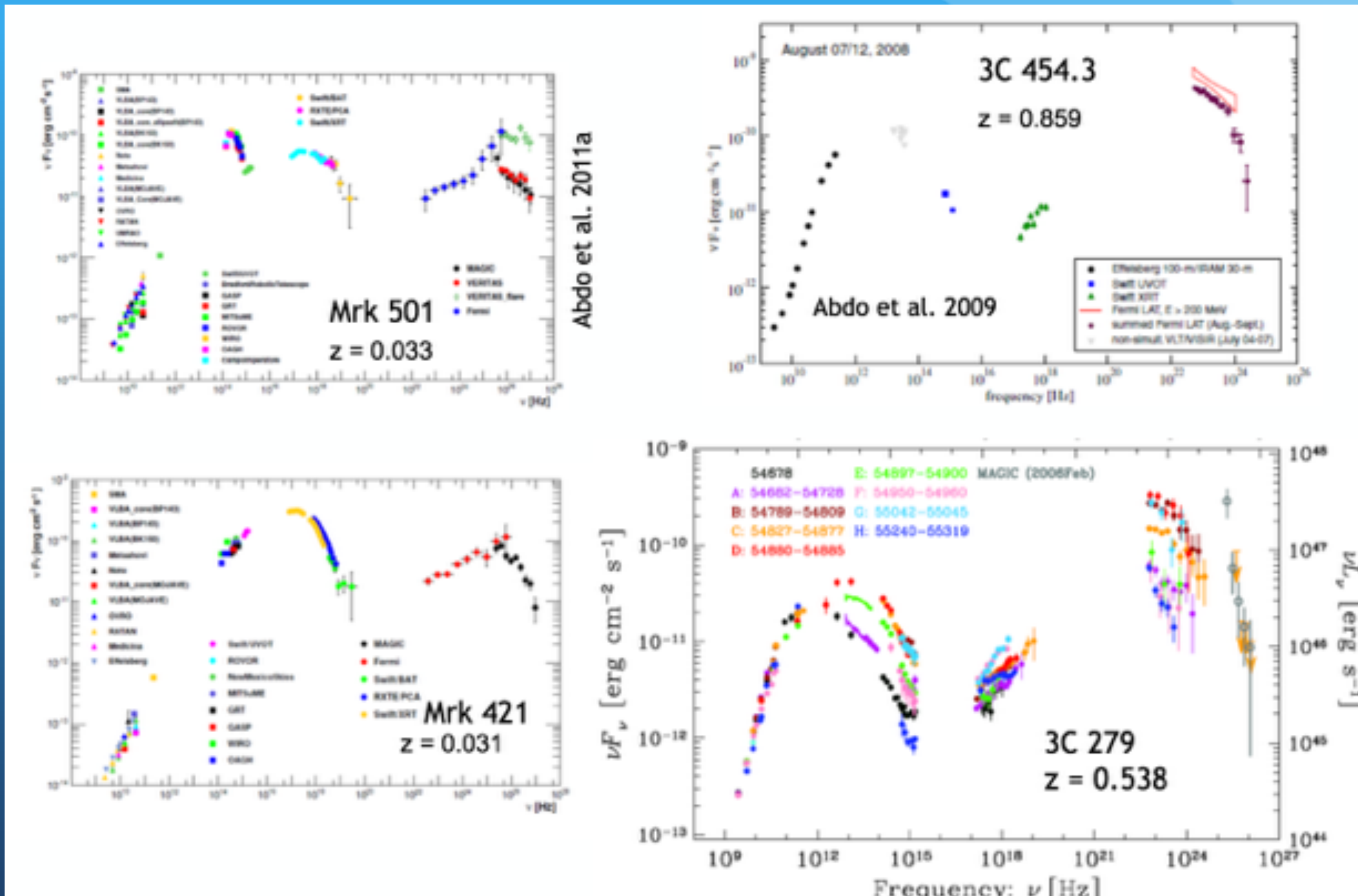
26% FSRQ

43% BL LAC

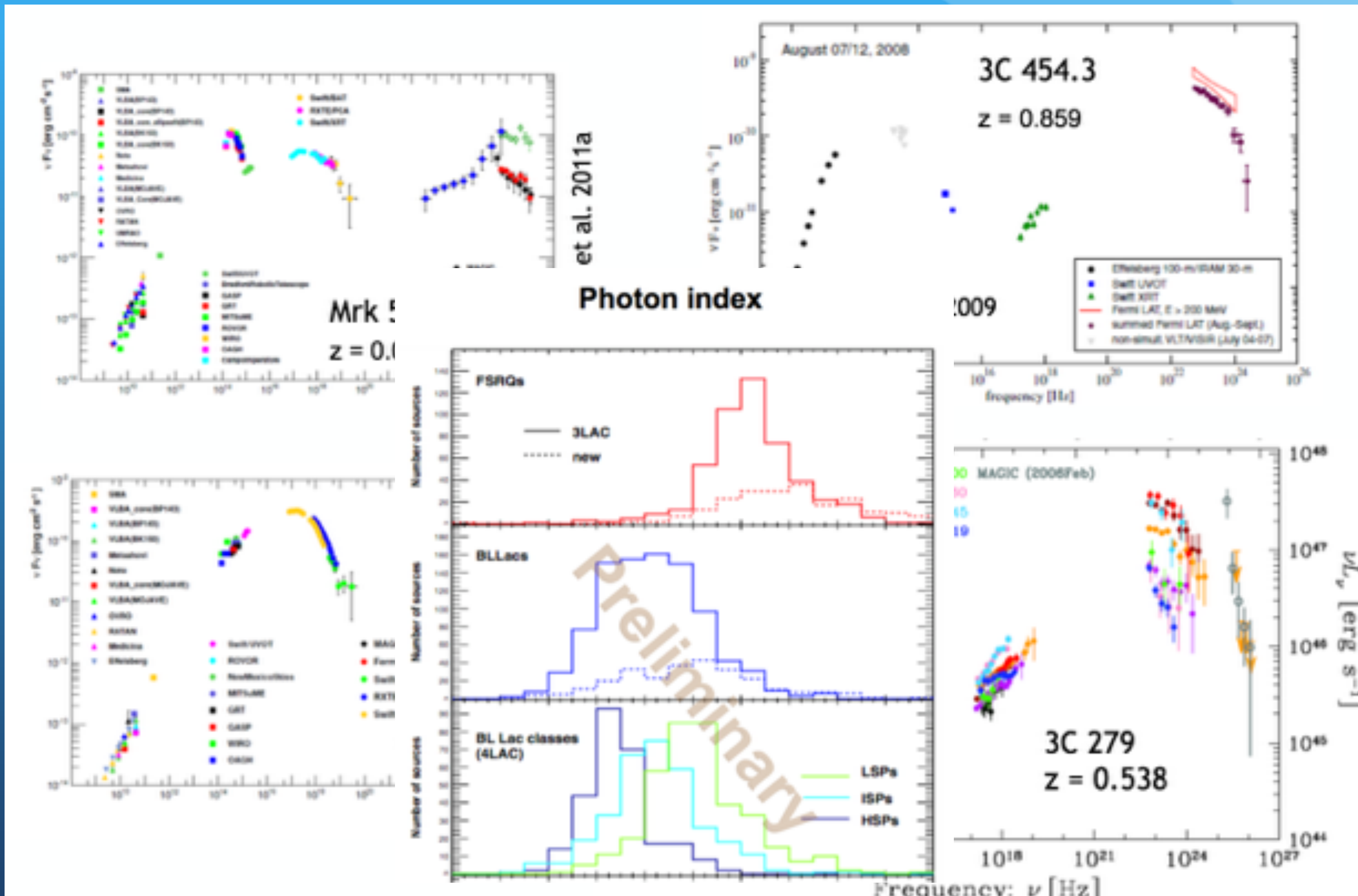
28% BCU

3% other AGN

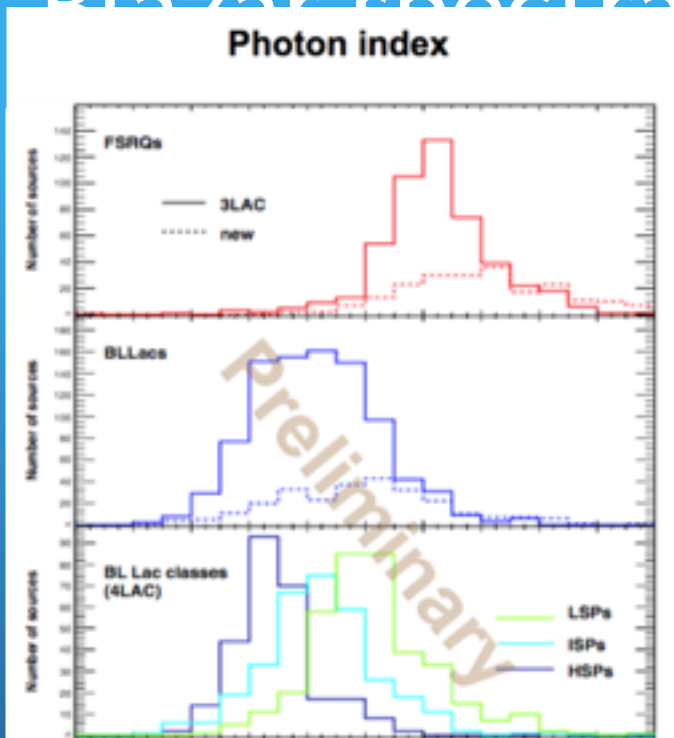
Blazar spectral energy distribution



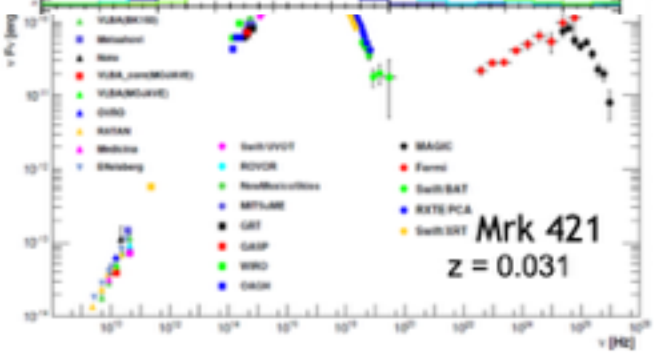
Blazar spectral energy distribution

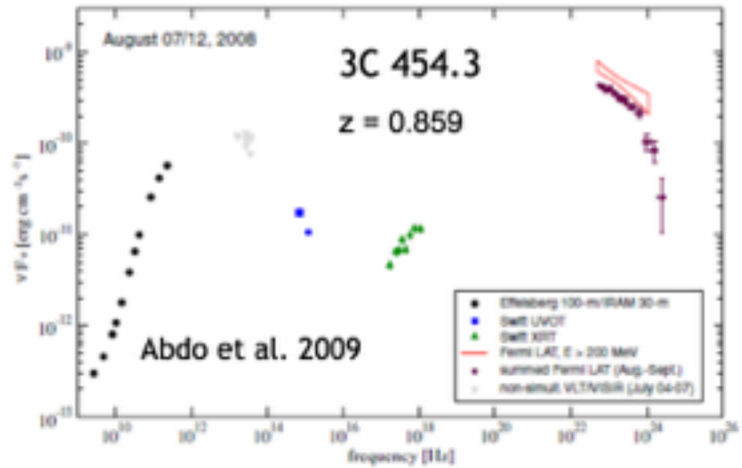


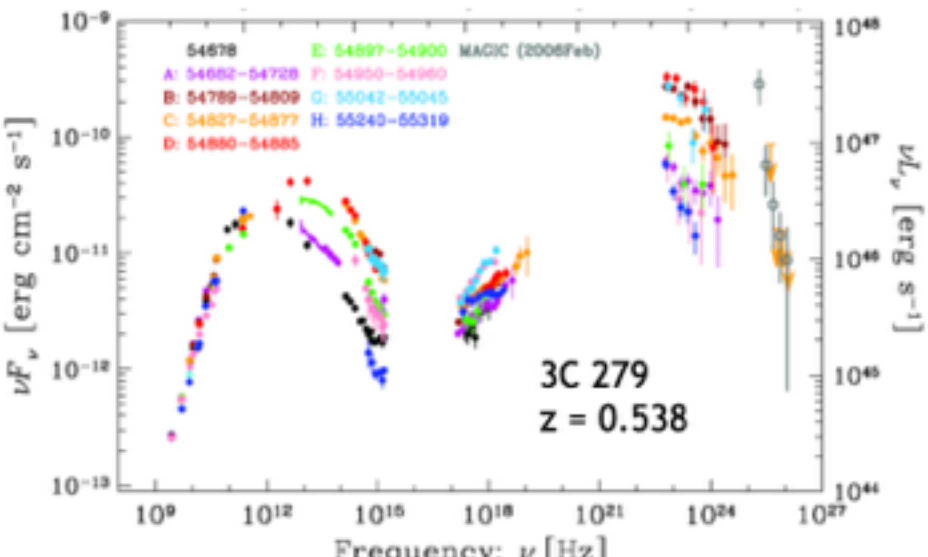
Blazar spectral energy distribution



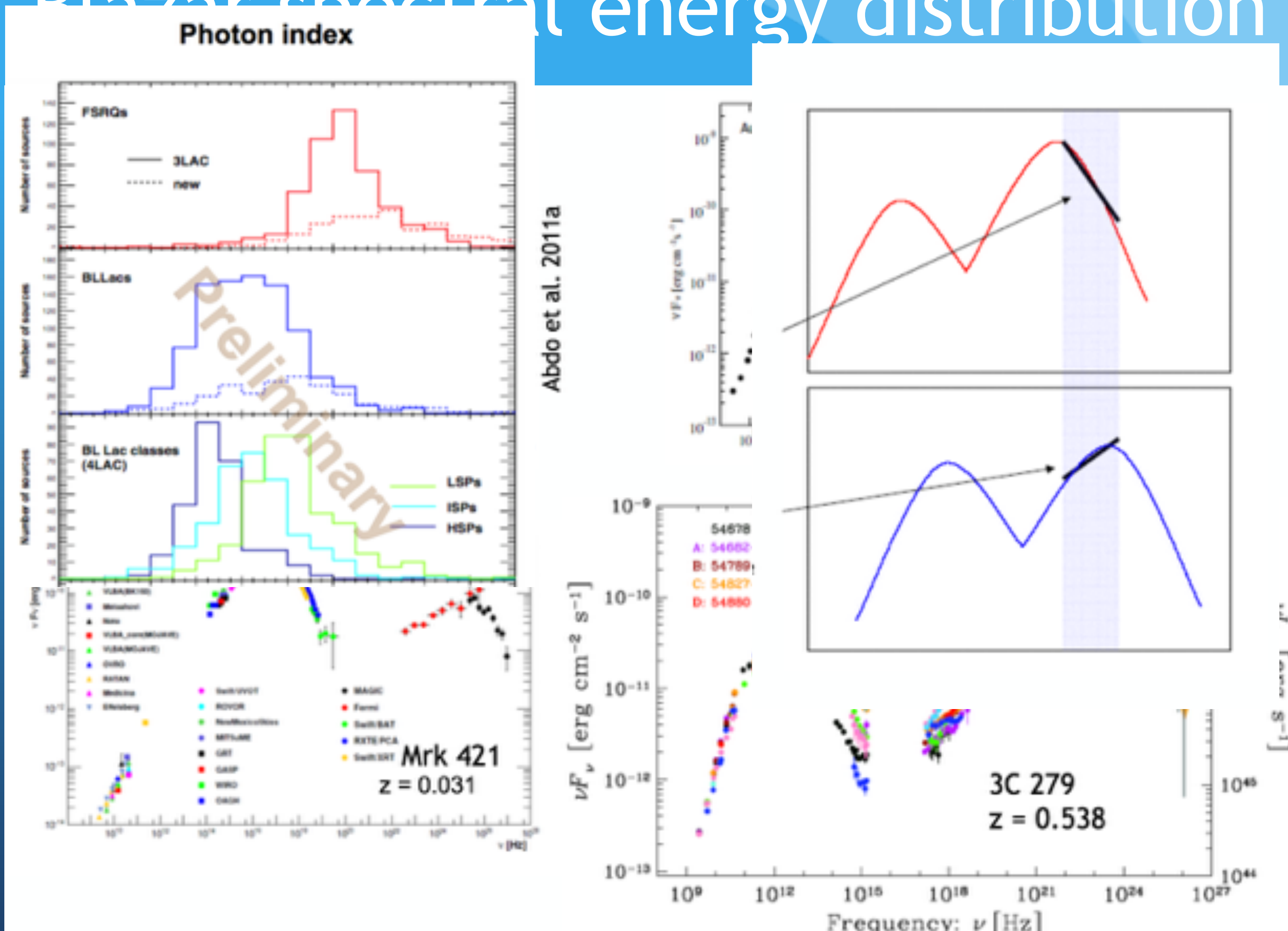
Abdo et al. 2011a



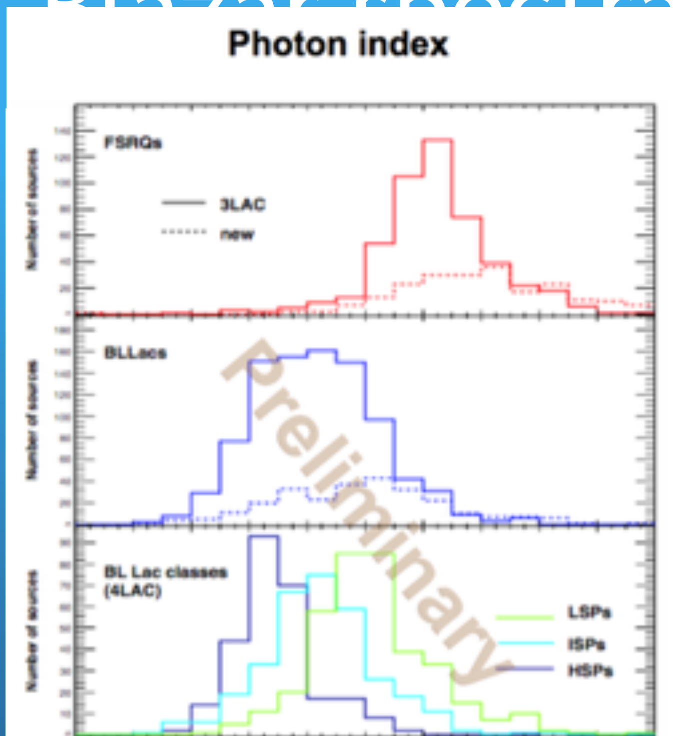


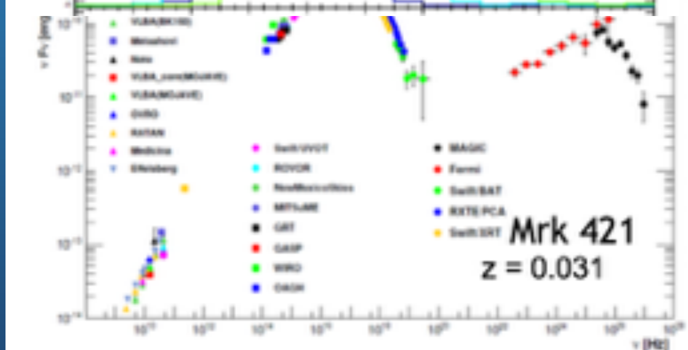


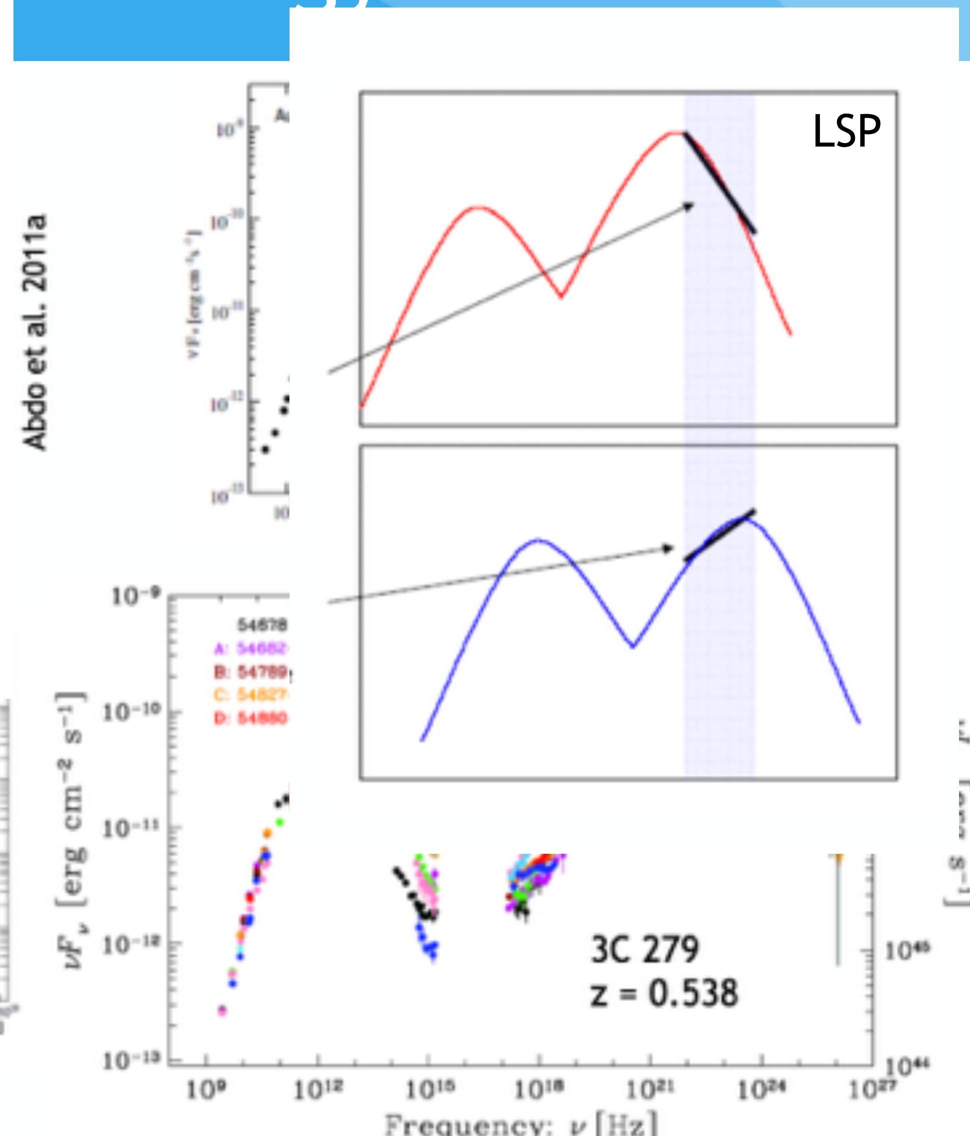
Blazar spectral energy distribution



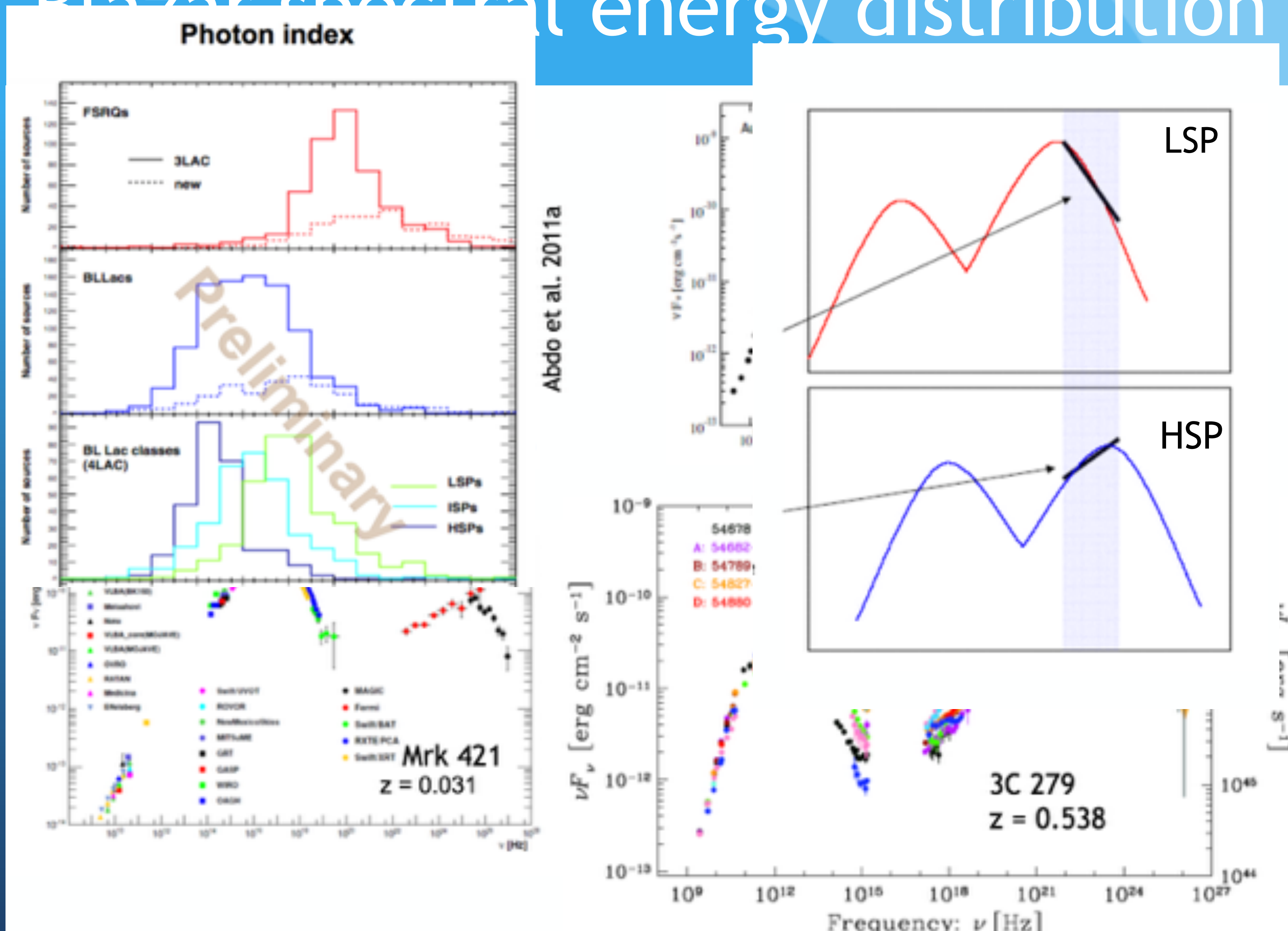
Blazar spectral energy distribution



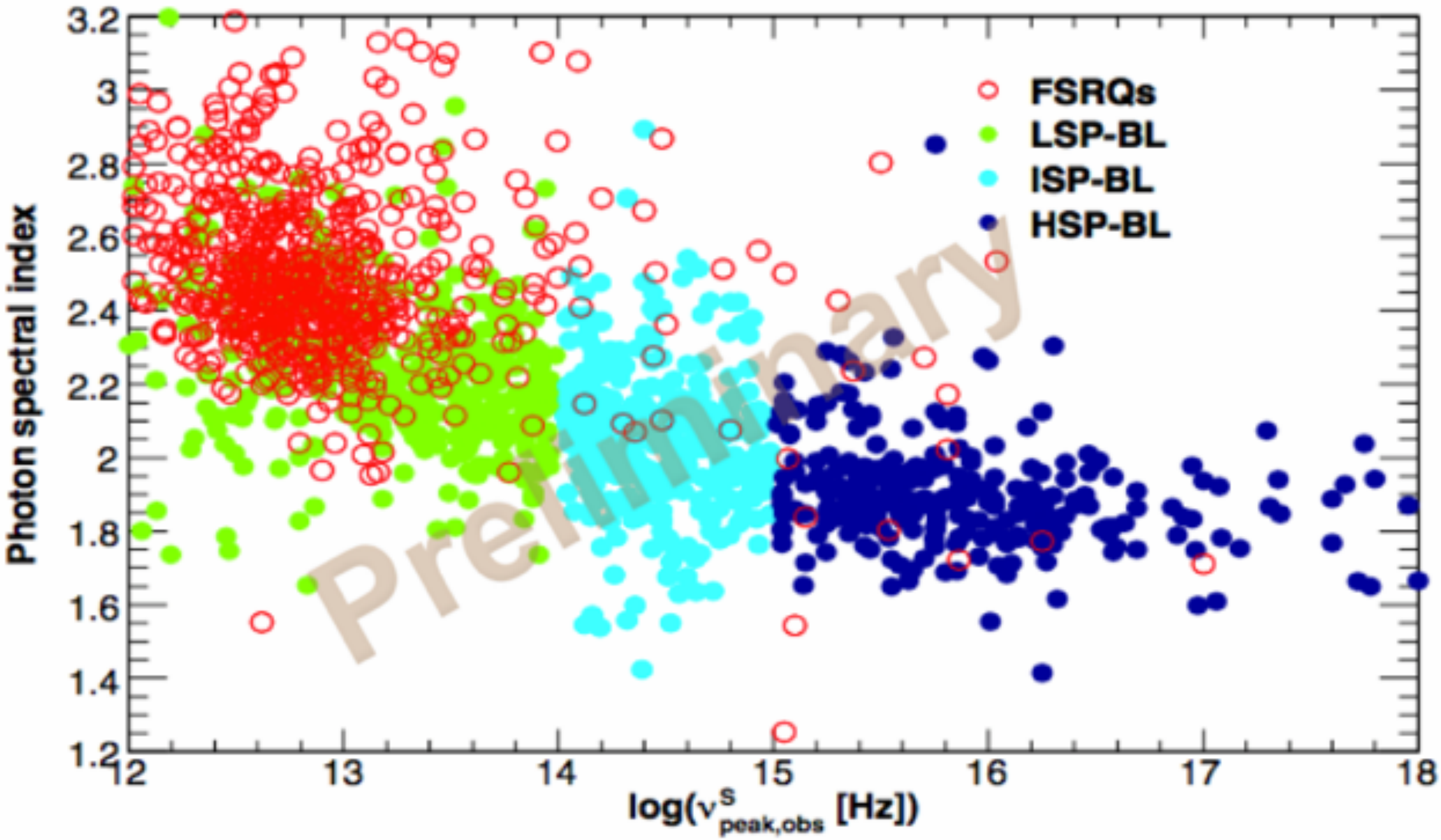




Blazar spectral energy distribution

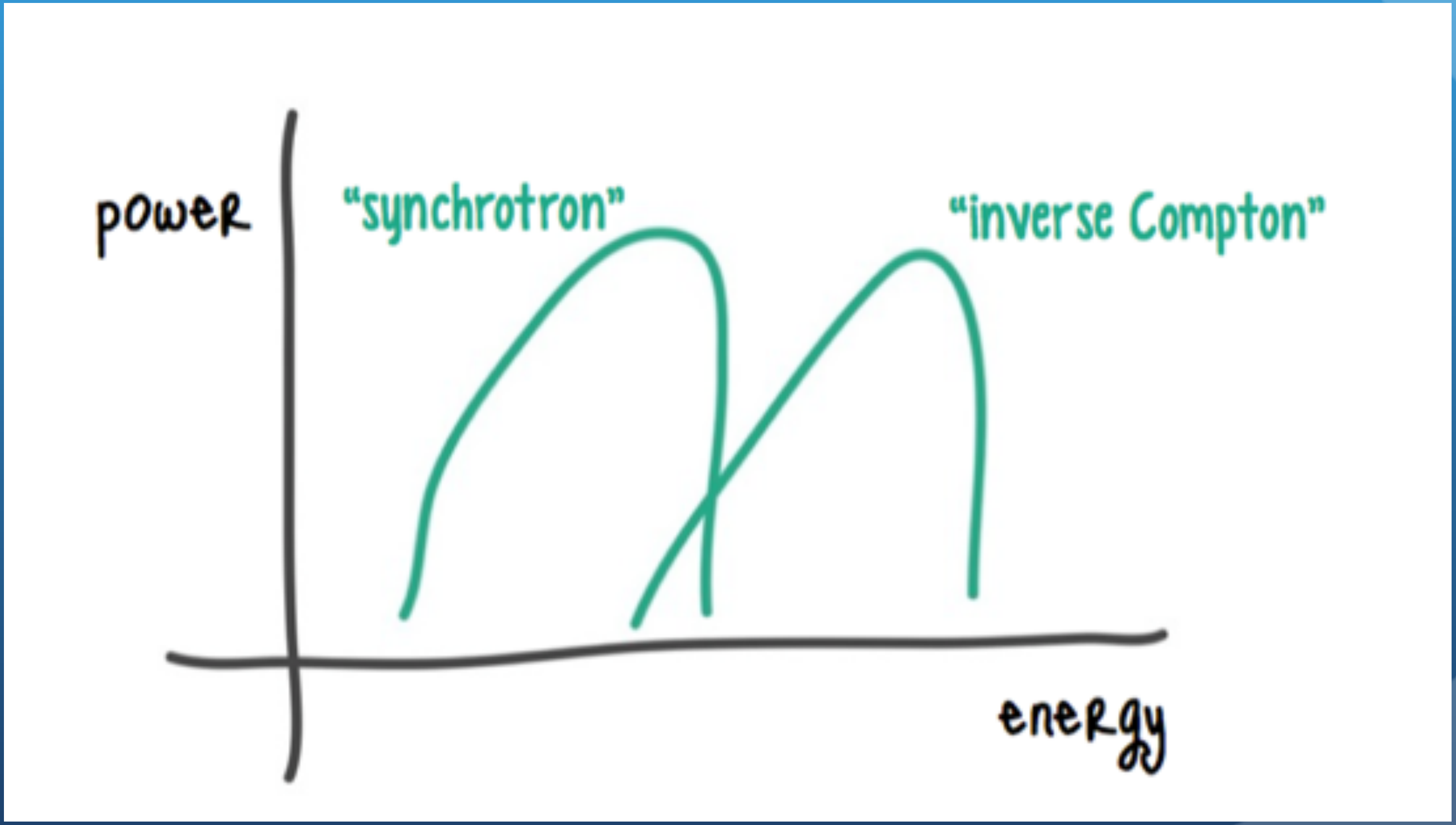


Synchrotron peak vs Photon index



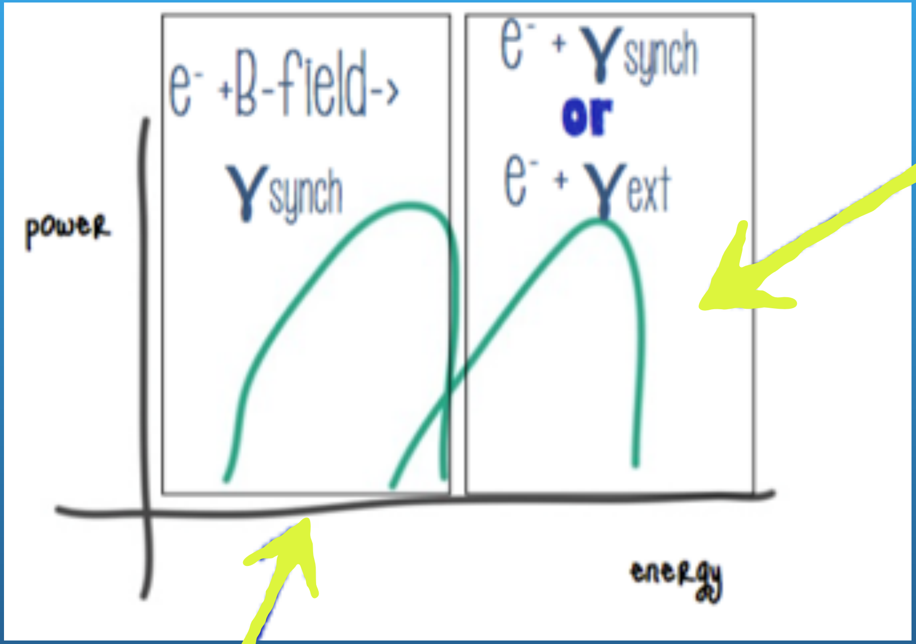
Model of blazar emission

- Classyfing blazars from SED shape
  - LSP: log(nu_peak_syn) <14Hz
  - ISP: 14Hz<log(nu_peak_syn) <15Hz
  - HSP: log(nu_peak_syn) >15Hz



Model of blazar emission

Leptonic



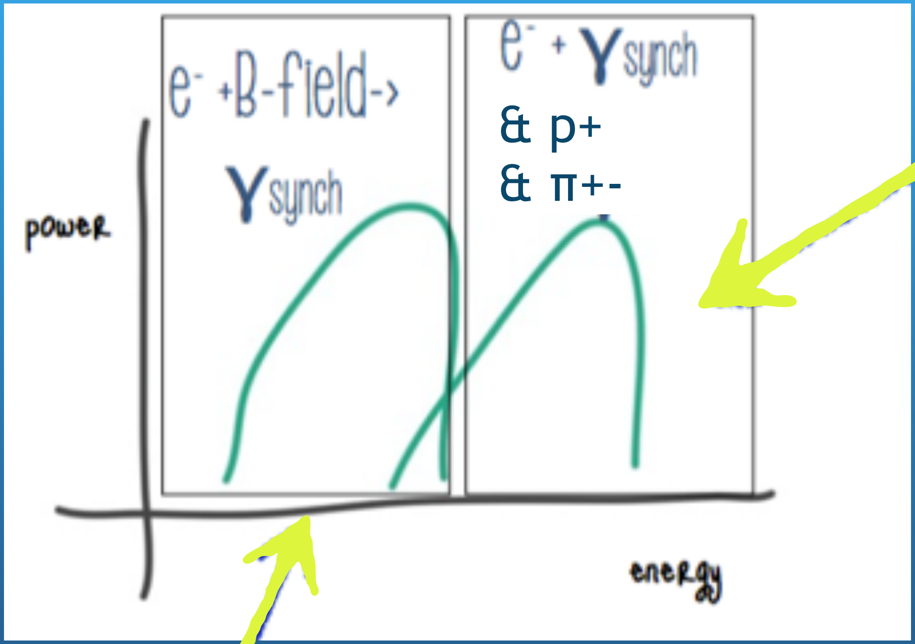
High-energy photons most likely the result of inverse Compton scattering by the same population that produced the synchrotron

- Upscatter the low energy photons responsible of the first bump —> SSC
- upscatter photons from the broad-line region, disc, torus —> EC

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

Model of blazar emission

Hardonic



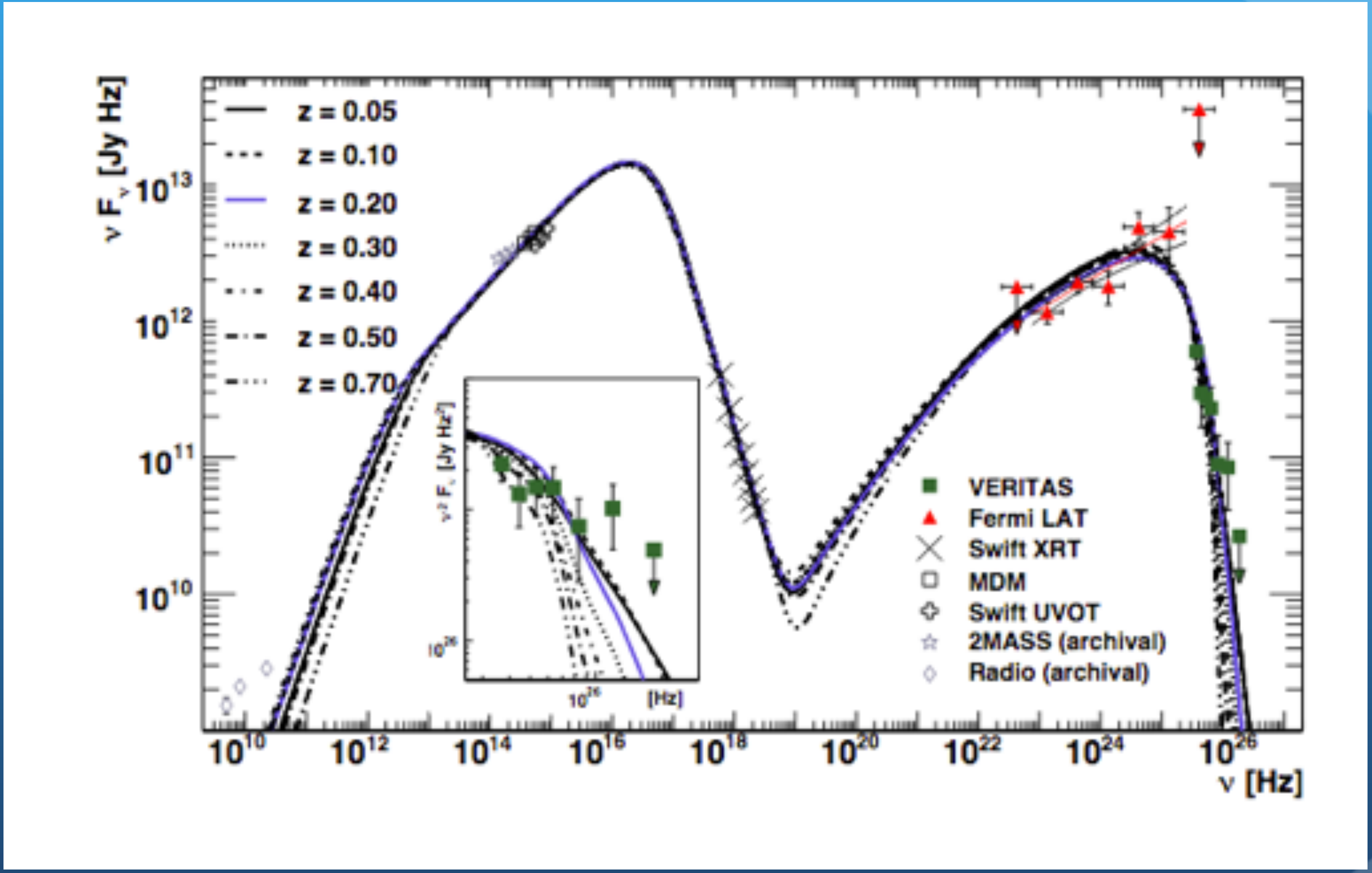
Both e-s and p accelerated to ultra relativistic energies

high energy emission dominated by
—> proton synchrotron
—>π0 decay products
—>synchrotron and Compton emission from secondary products of charged pions

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

Blazars SED - BL Lac

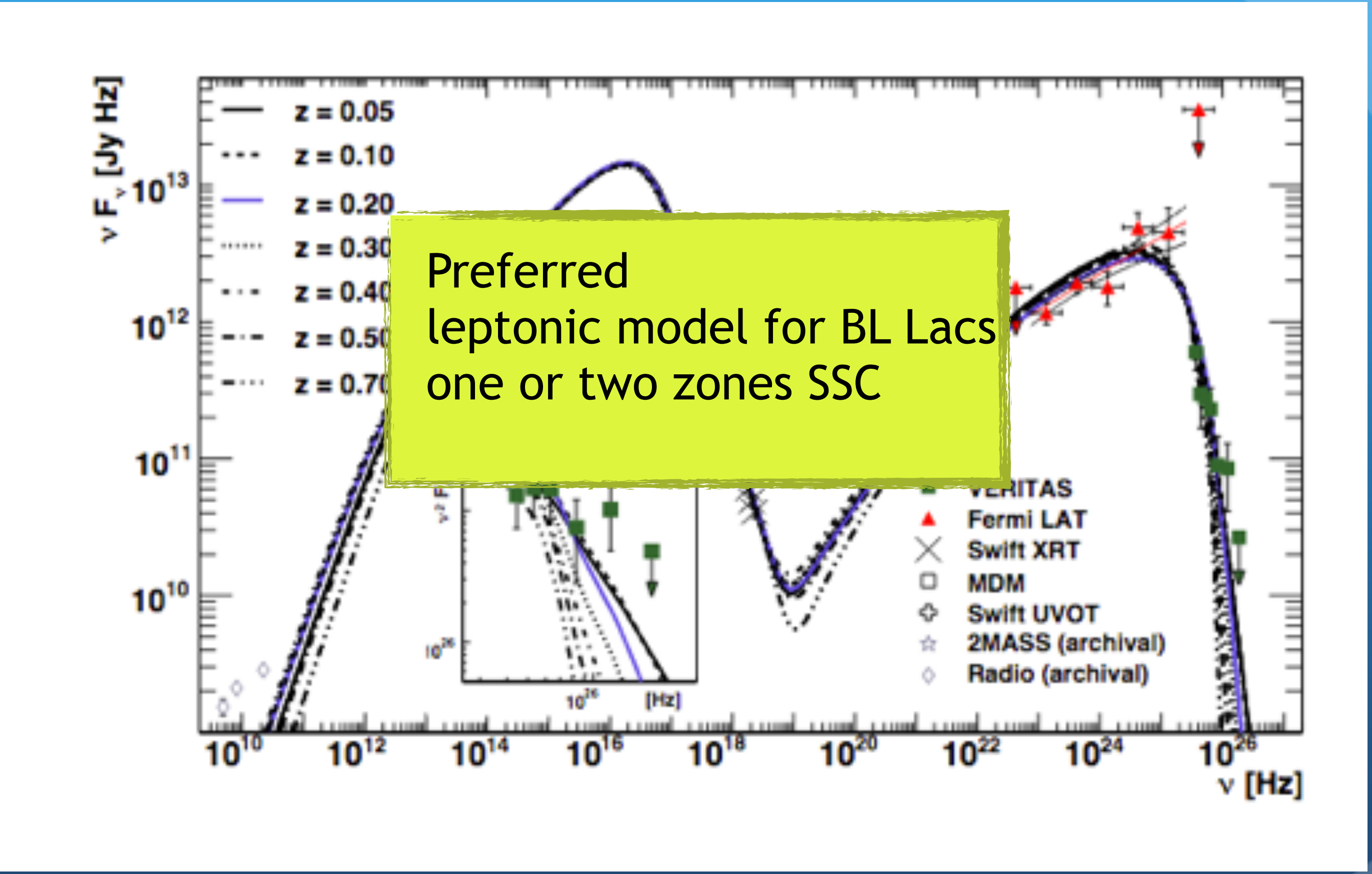
- Leptonic model provide a good fits to many blazars



Acciari+ 2010 - BL Lac - PKS 1424+240

Blazars SED - BL Lac

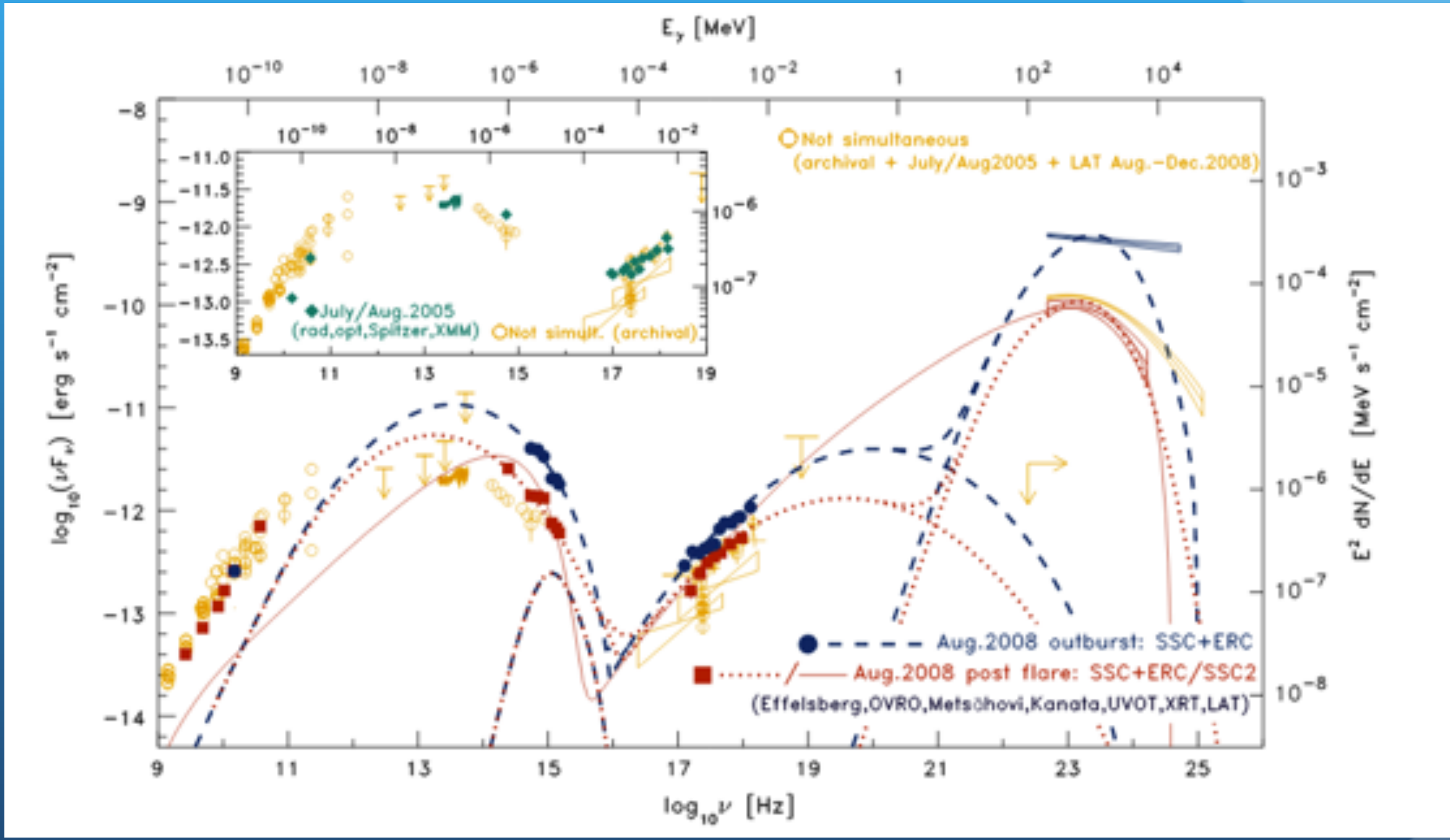
- Leptonic model provide a good fits to many blazars



Acciari+ 2010 - BL Lac - PKS 1424+240

Blazars SED -FSRQ

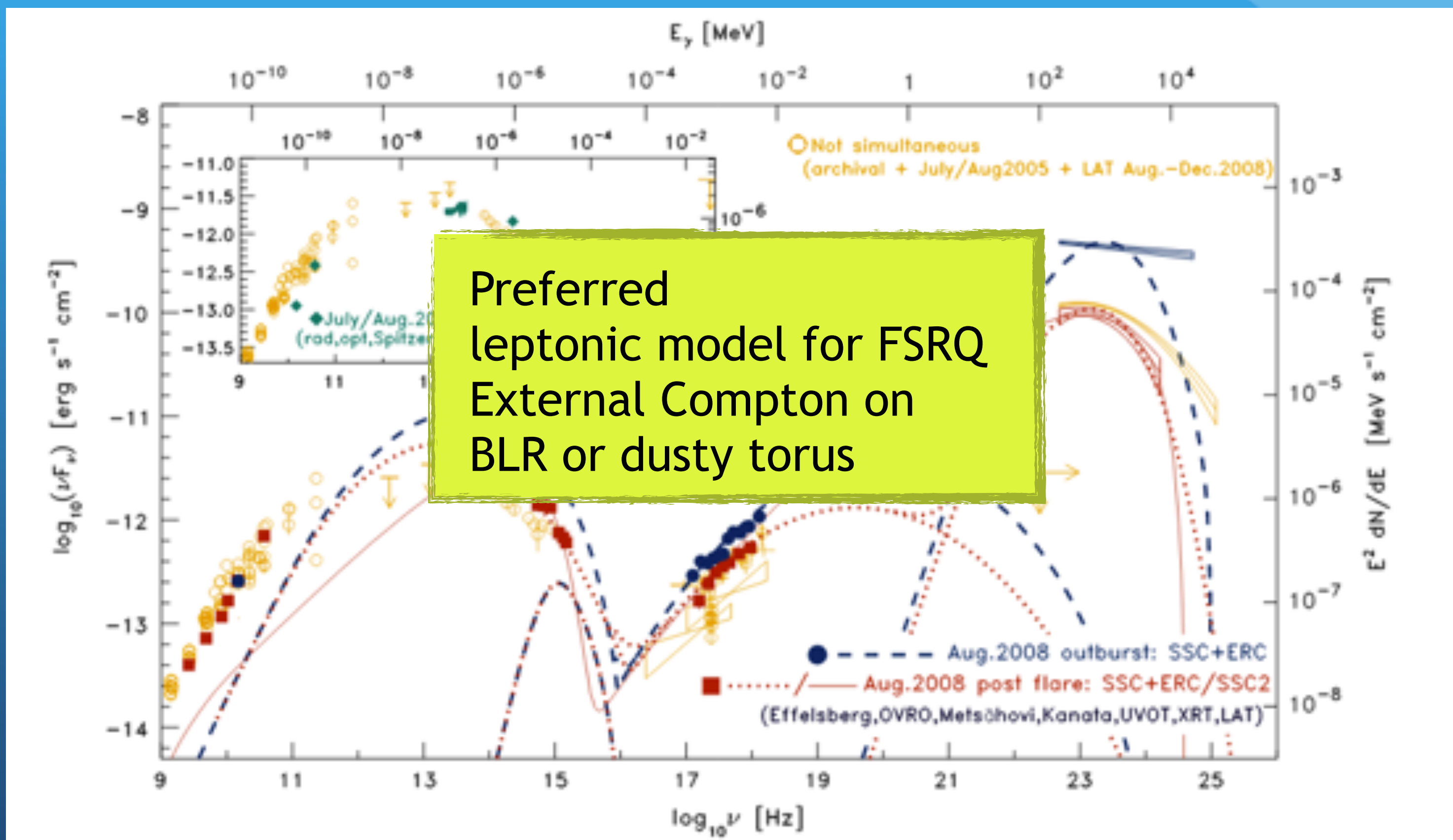
- Leptonic model provide a good fits to many blazars



Abdo+ 2010 - FSRQ - PKS 1502+106

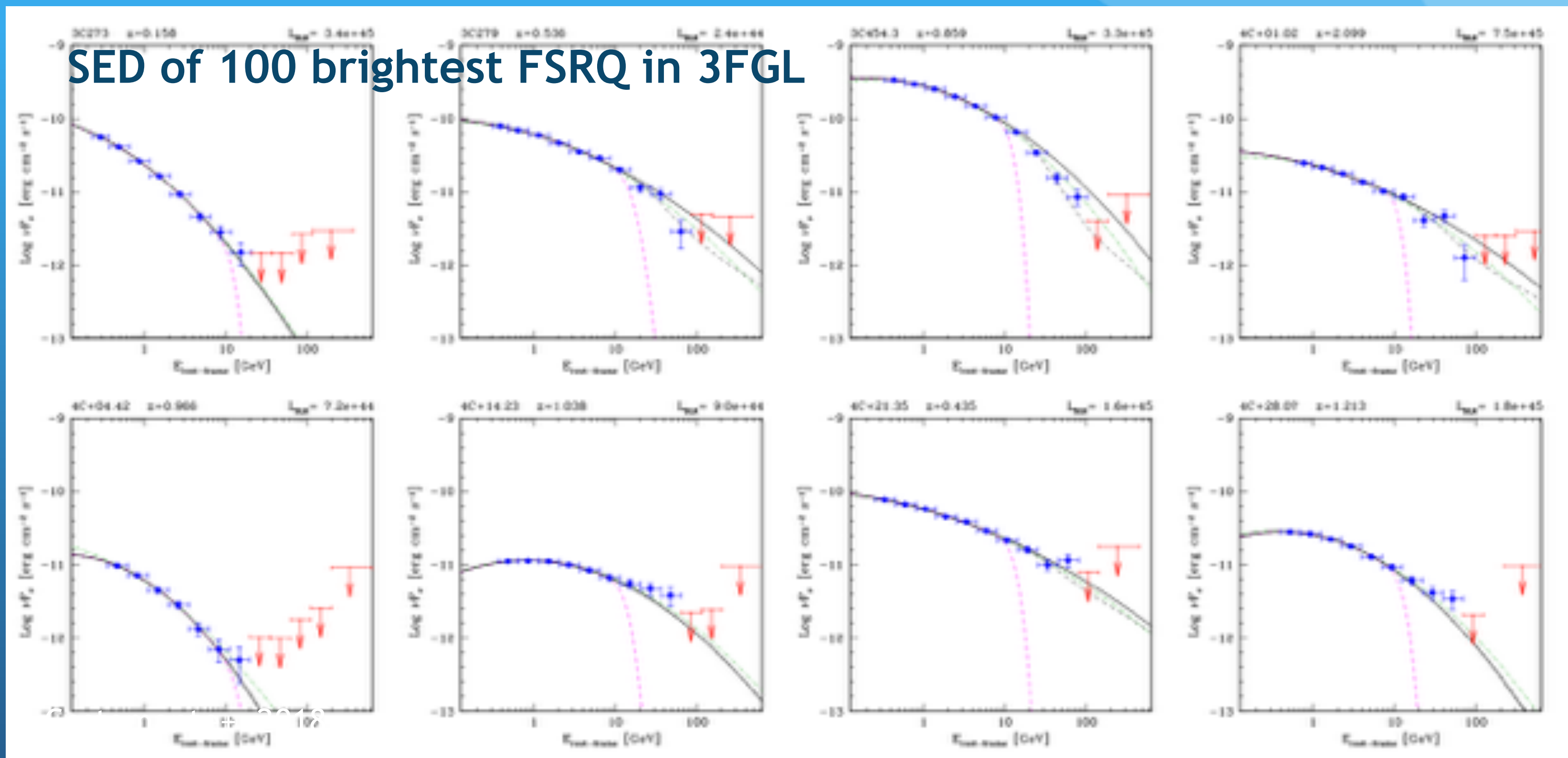
Blazars SED -FSRQ

- Leptonic model provide a good fits to many blazars



Abdo+ 2010 - FSRQ - PKS 1502+106

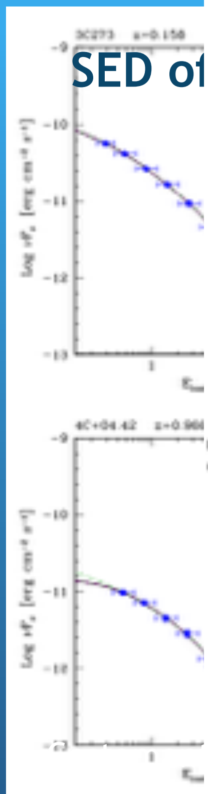
Blazar zone: inside or outside the BLR?

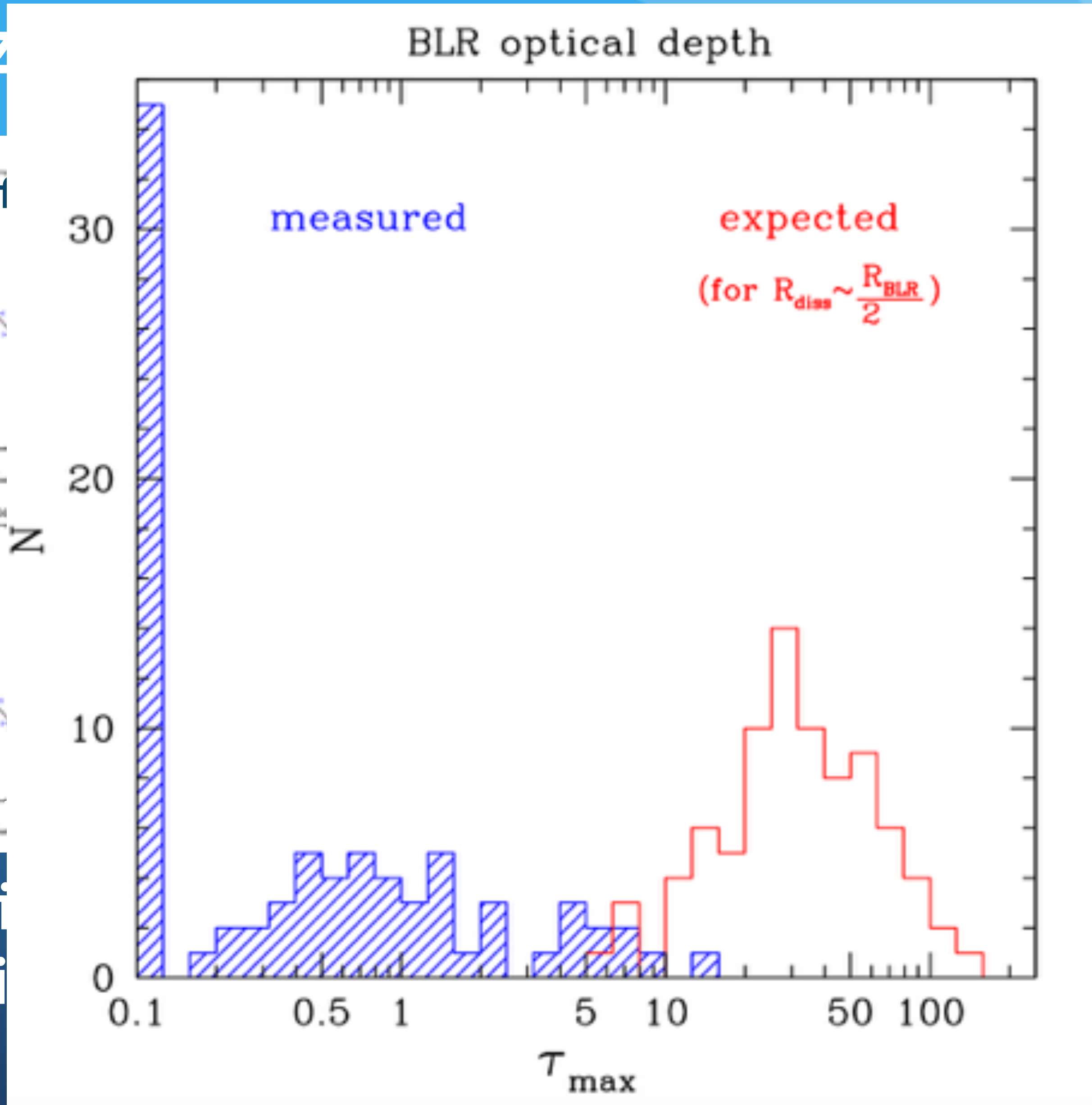


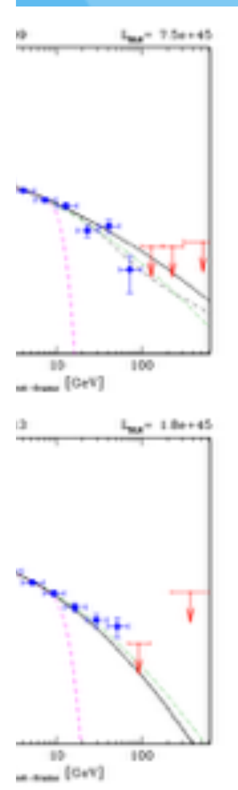
No evidence of Broad Line region absorption—> emission region is outside of BLR

Blaz… e BLR?

SED of



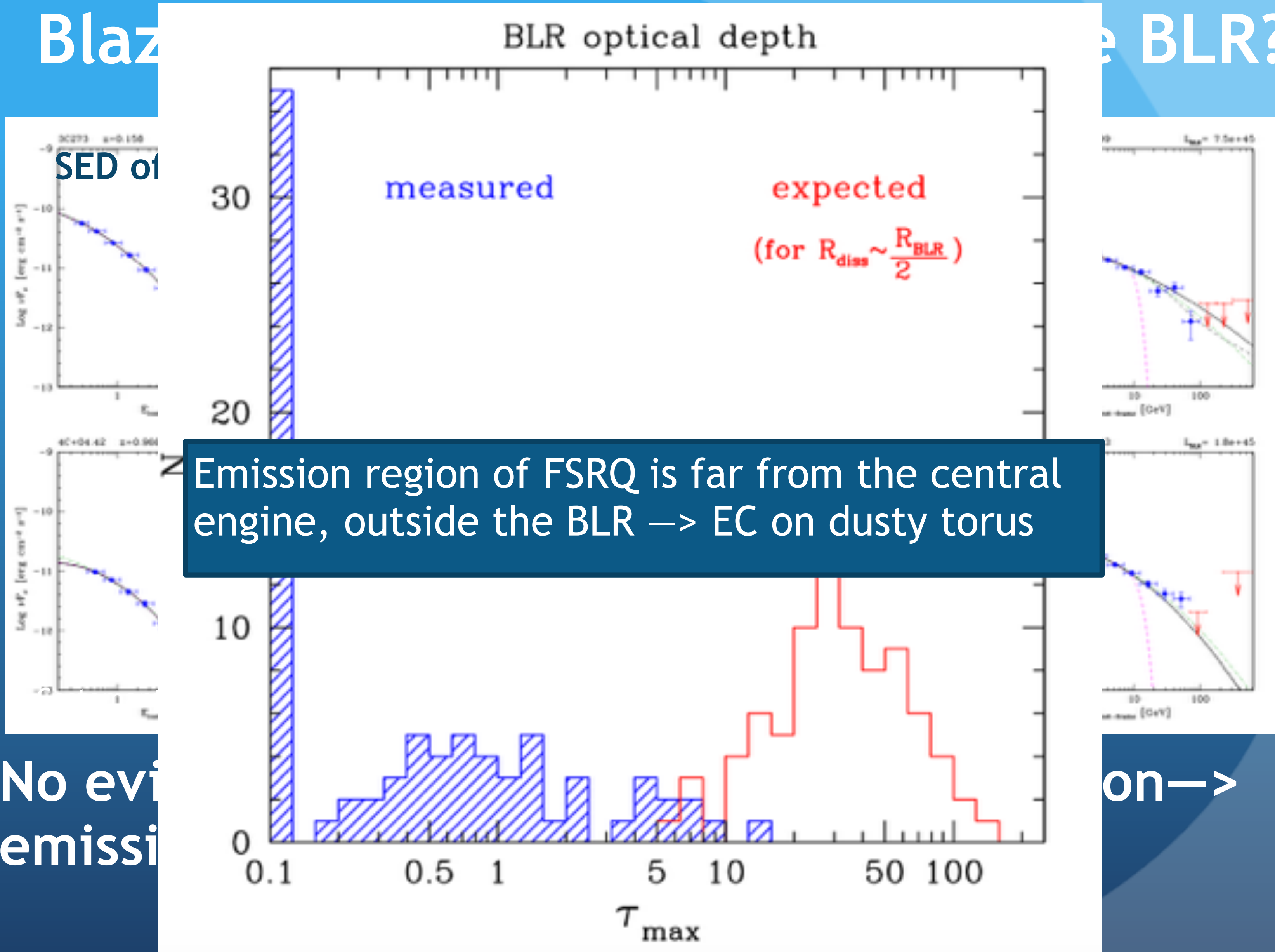




No evi… on—>
emissi…

Blaz… e BLR?

SED of

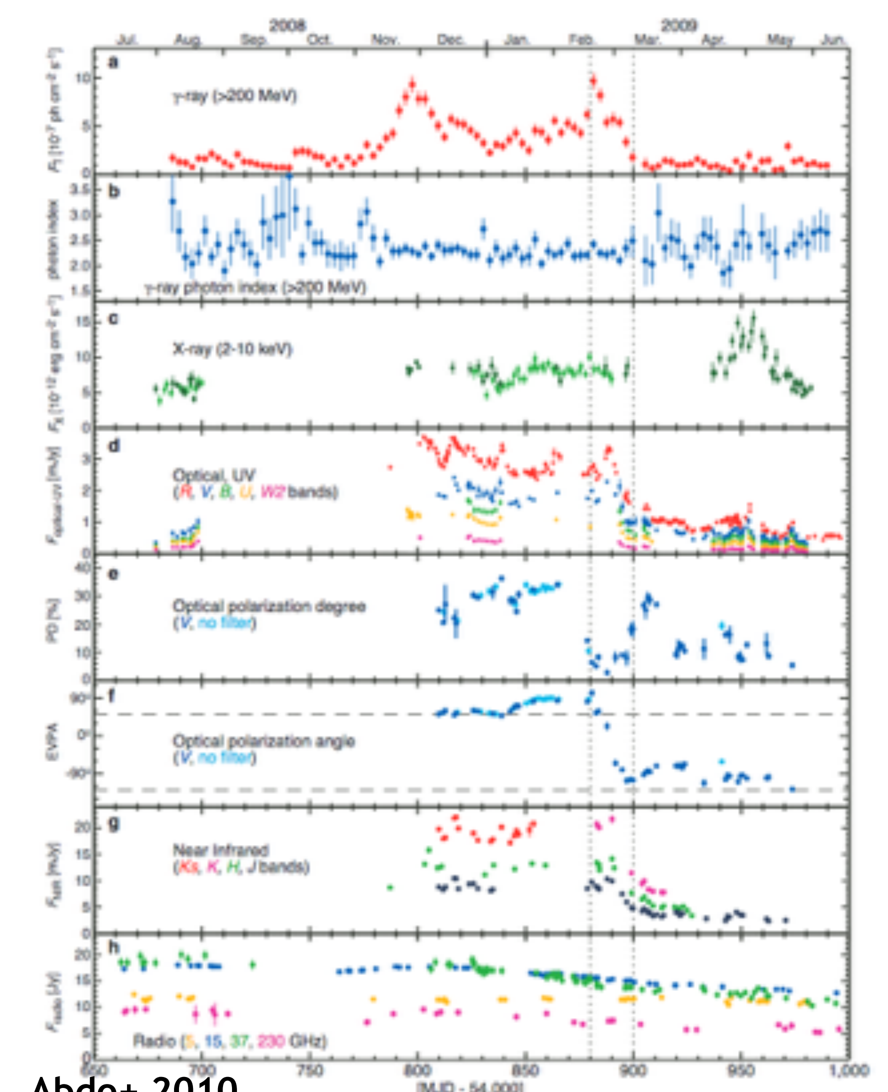


Emission region of FSRQ is far from the central engine, outside the BLR —> EC on dusty torus

No evi… on—>
emissi…

Some peculiar cases

3C 279 - 2009 outburst



Abdo+ 2010

Strong gamma-ray flare in Feb. 2009 with associated a dramatic change of the polarization angle:

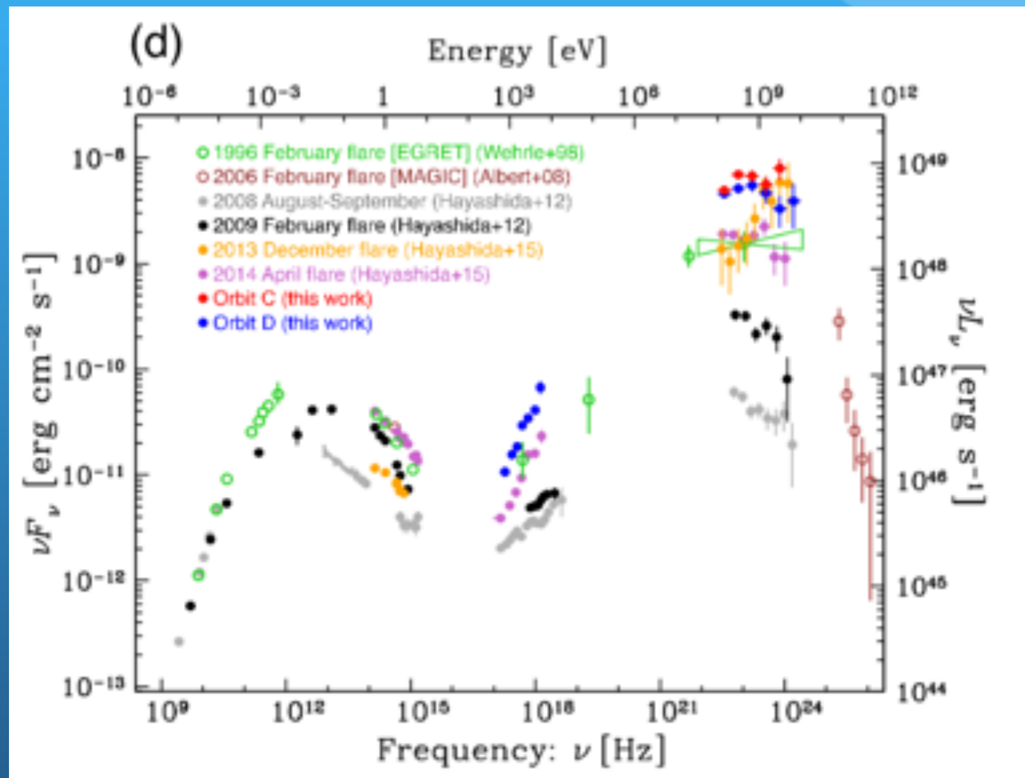
→co-spatiality of the optical and gamma-ray emission zone

→highly ordered jet magnetic field

→emission region distant from the BH

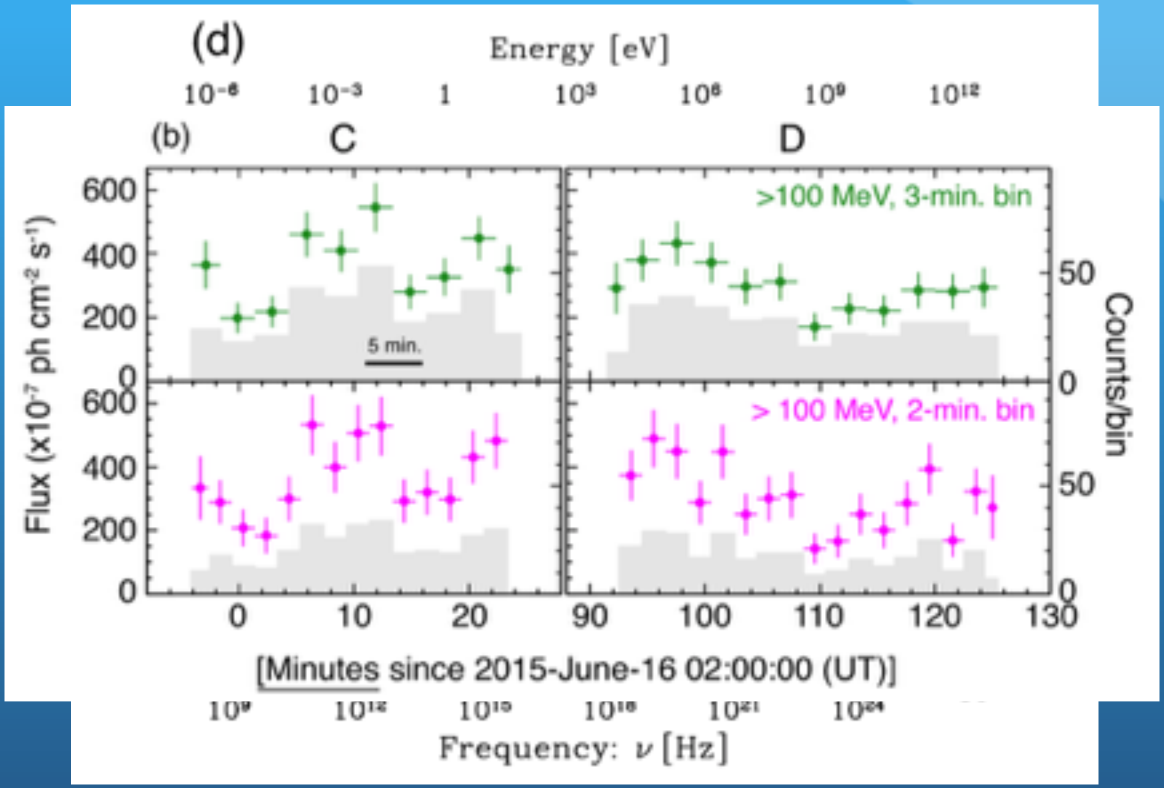
→Possibility of a bend jet scenario

3C 279 - 2015 outburst



- **3C 279:** One of the brightest powerful blazars had a flare in 2015 June (red and blue points) (Ackermann+2016)

3C 279 - 2015 outburst



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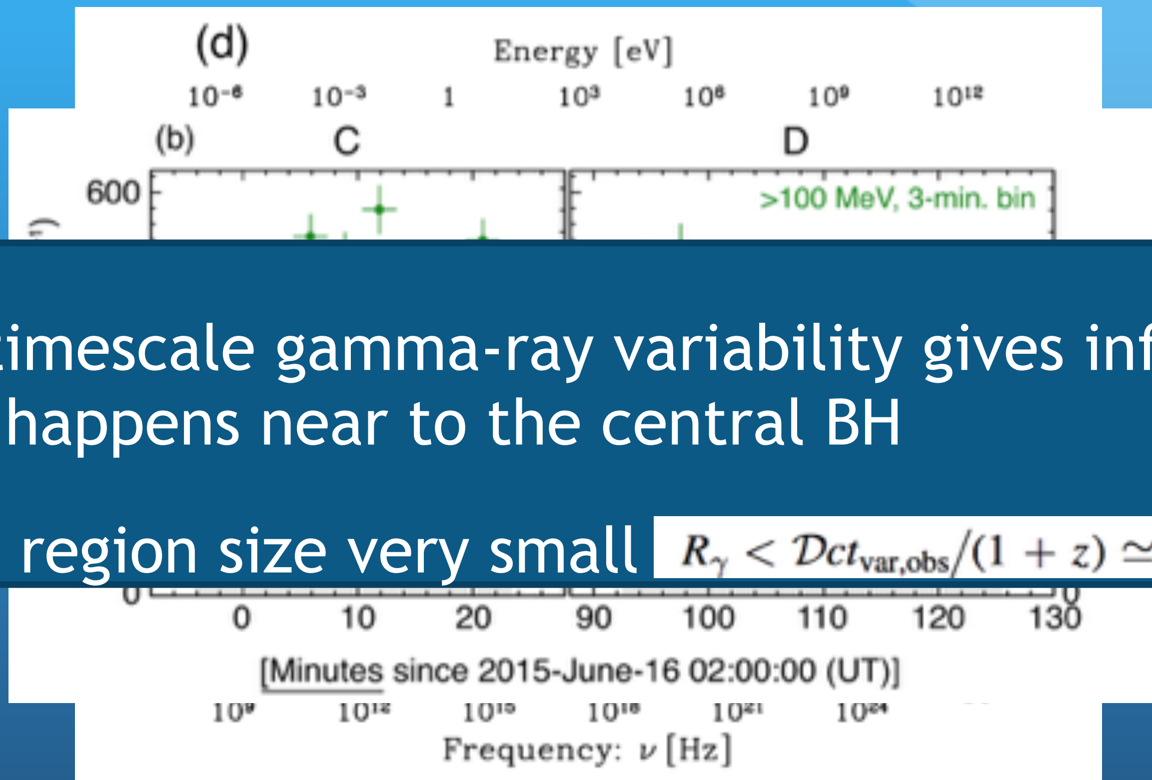


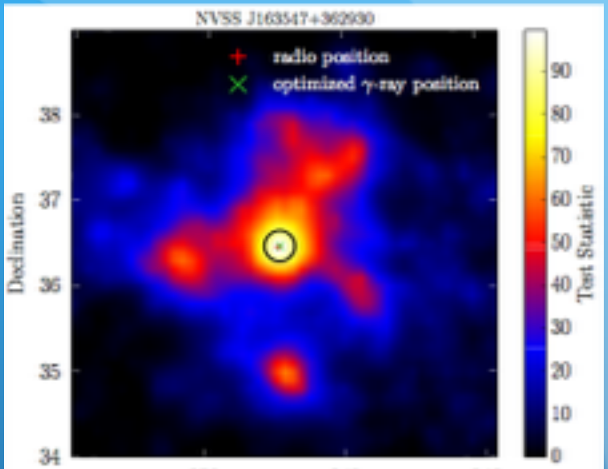
Minute timescale gamma-ray variability gives information on what happens near to the central BH

Emission region size very small $R_\gamma < \mathcal{D} c t_{\rm var,obs}/(1+z) \simeq 10^{-4}(\mathcal{D}/50)\mathrm{pc}$

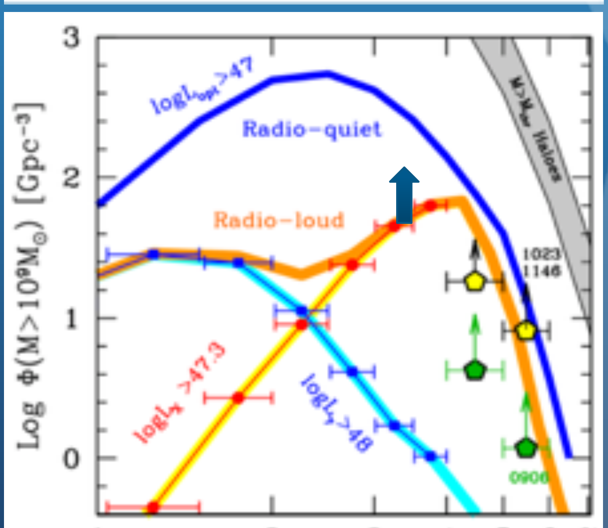
- **3C 279:** One of the brightest powerful blazars had a flare in 2015 June (red and blue points) (Ackermann+2016)

Blazars at the dawn of Universe

- Found 5 sources with a significative detection by Fermi-LAT with $3.3 < Z < 4.31$ (Ackermann+ 2017)
- These are placed within the first two billion years since the Big Bang
- Mass : $8.5 < \text{Log}\ M_{BH} < 9.8\ M_{\odot}$ (2 over 9 $M_{\odot}$)
- This has increased the space density of billion solar mass black holes in radio-loud sources to 68 Gpc^{-3}, compared to ~50 Gpc^{-3} known earlier



Ackermann+ 2017



Sbarrato+2012

Blazars at the dawn of Universe

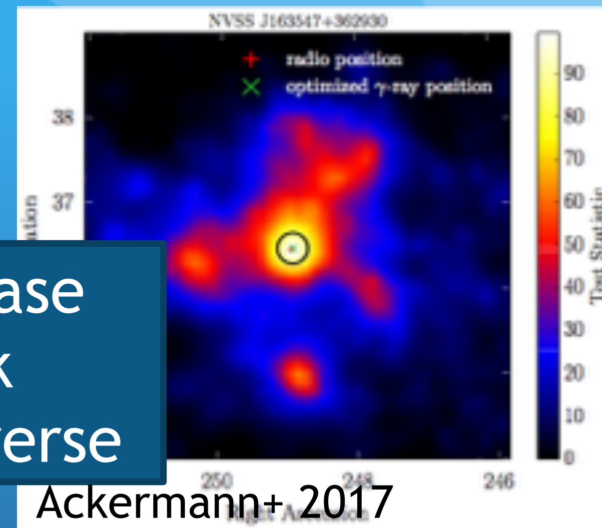
- Found 5 sources with a significative detection by Fermi-LAT with 3.3 < Z < 4.31

This implies that the radio-loud phase may be a key ingredient for a quick black hole growth in the early Universe

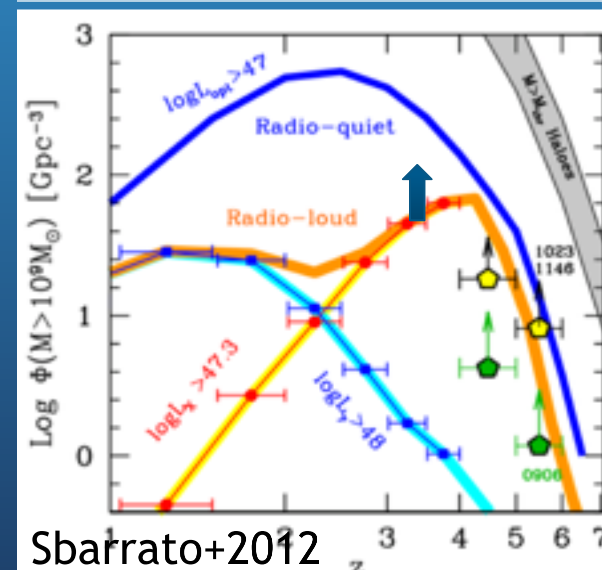
Bang

- Mass : $8.5 < \text{Log } M_{BH} < 9.8\ M_\odot$ (2 over 9 $M_\odot$)

- This has increased the space density of billion solar mass black holes in radio-loud sources to 68 Gpc^{-3}, compared to ~50 Gpc^{-3} known earlier

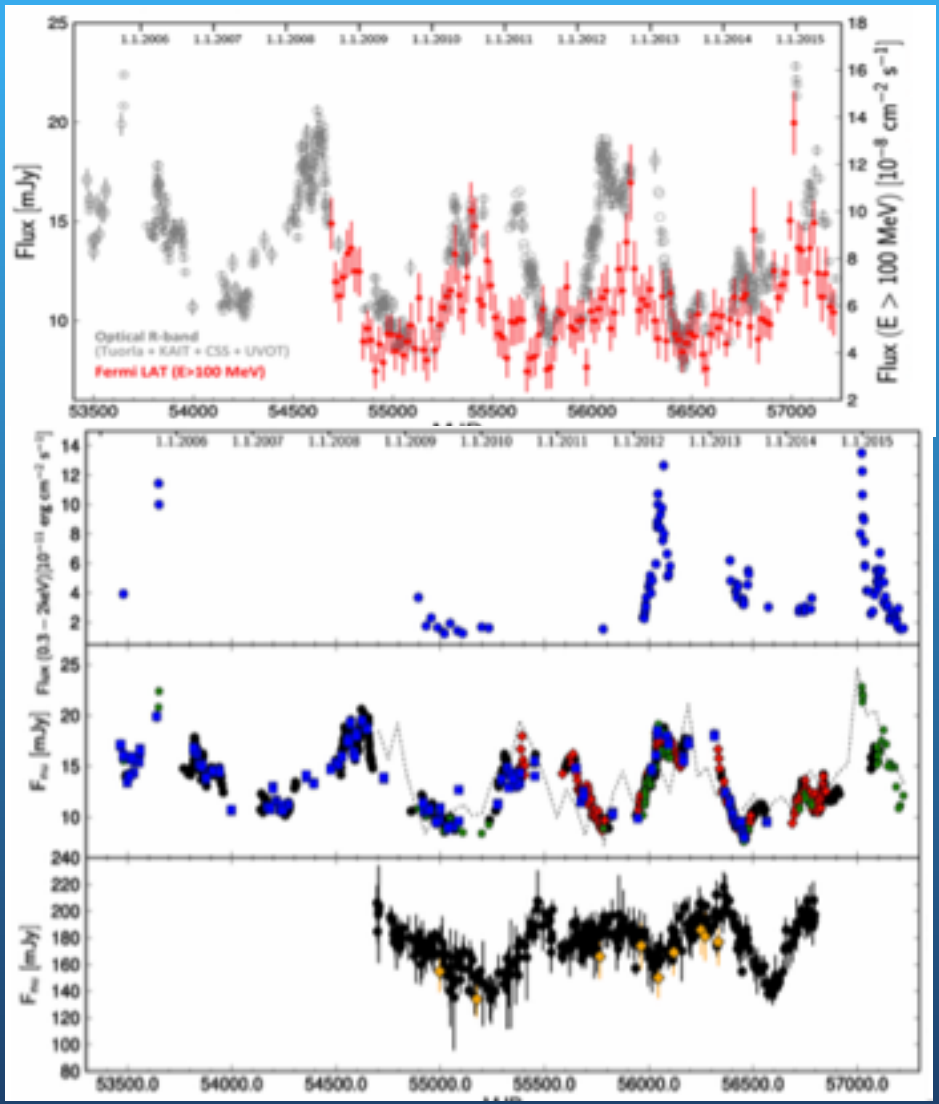


Ackermann+ 2017



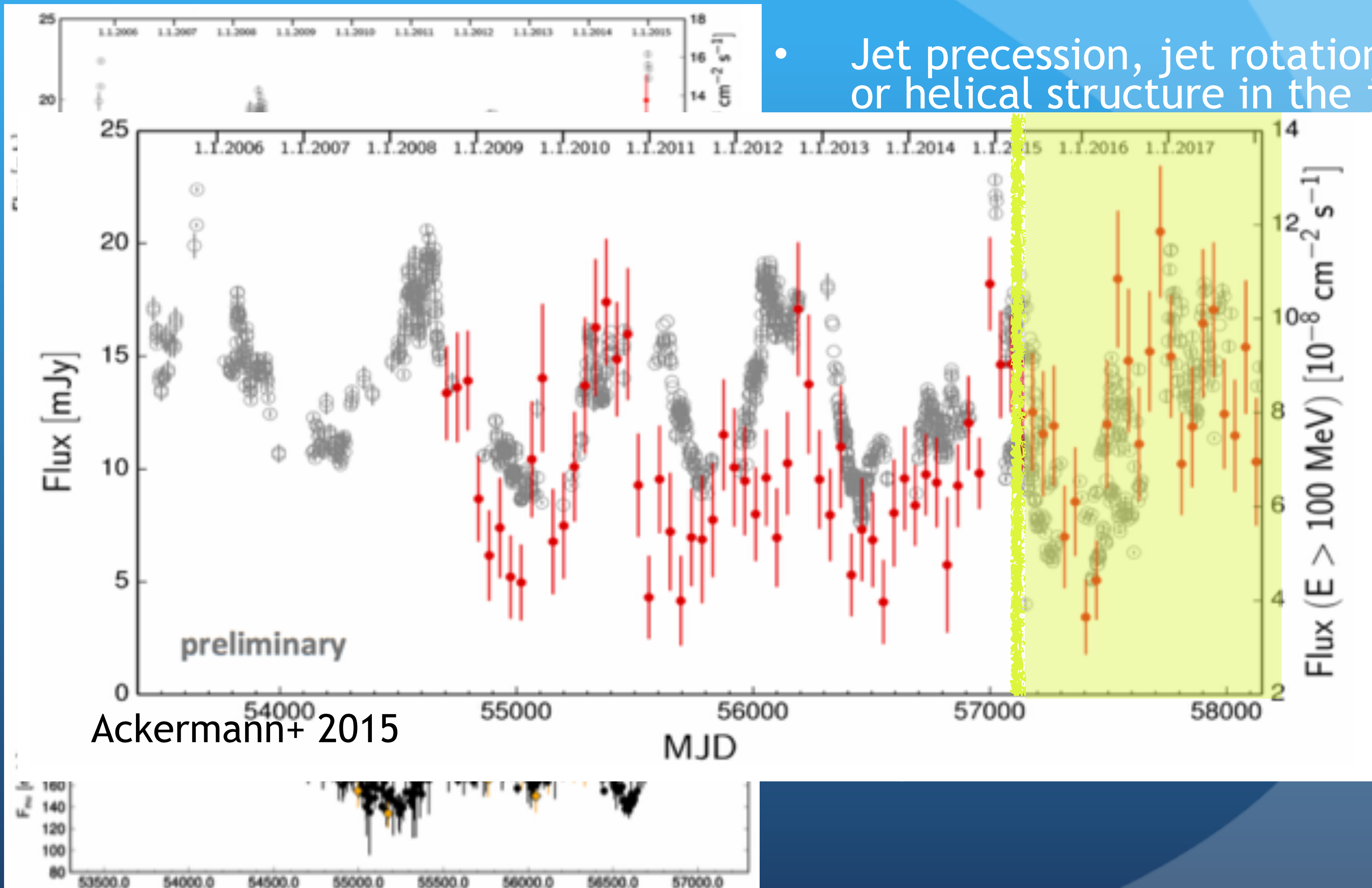
Sbarrato+2012

Periodicity in blazars: double BH?



- Jet precession, jet rotation, or helical structure in the jet
- Mechanism similar low-frequency QPO from Galactic high-mass binaries (Lense-Thirring precession)
- Binary, gravitationally bound, SMBH system (total mass of 1.6×10^8 Msun, milliparsec separation, early inspiral gravitational-wave driven regime.

Periodicity in blazars: double BH?



Ackermann+ 2015

- Jet precession, jet rotation, or helical structure in the jet

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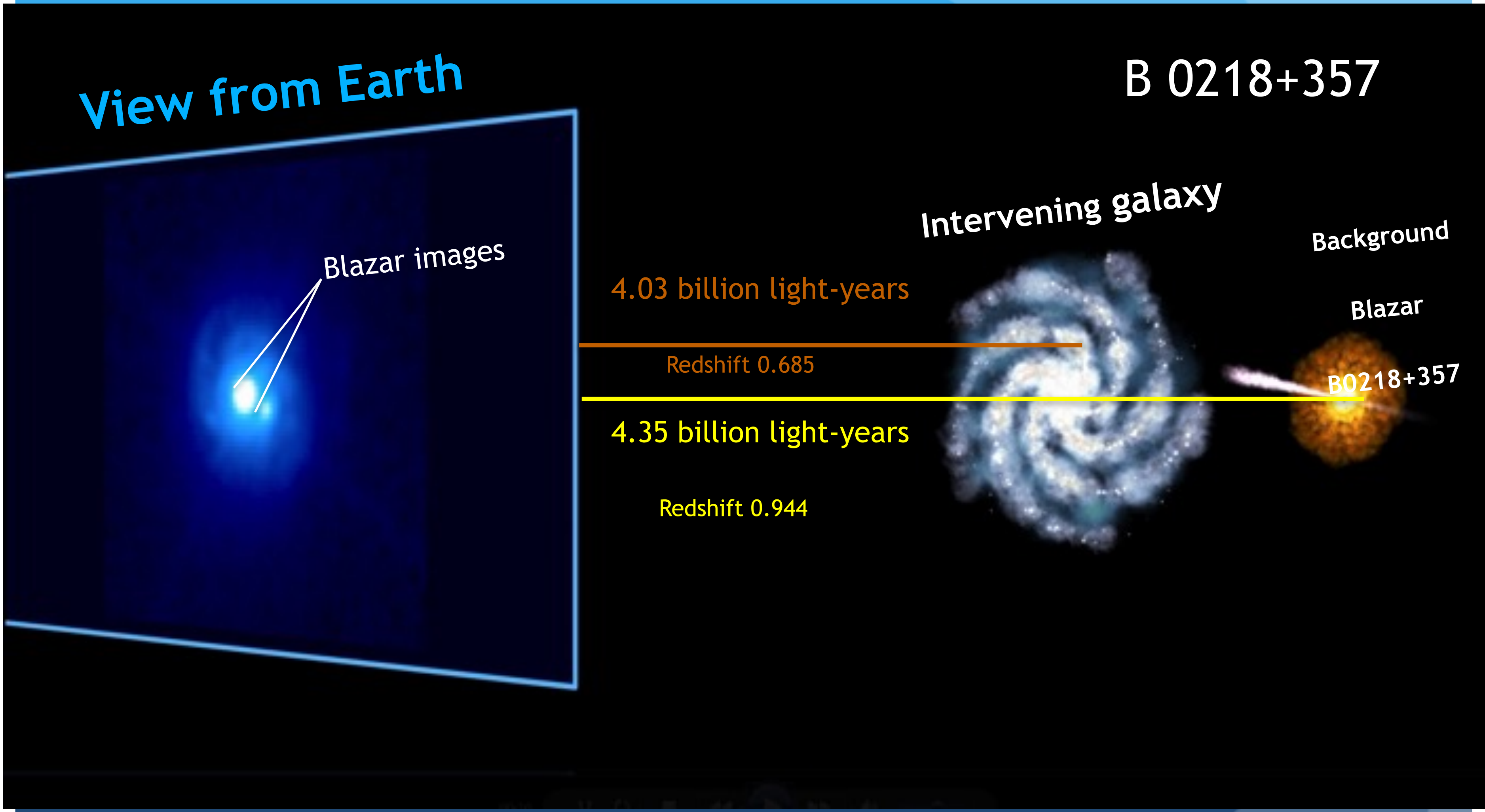
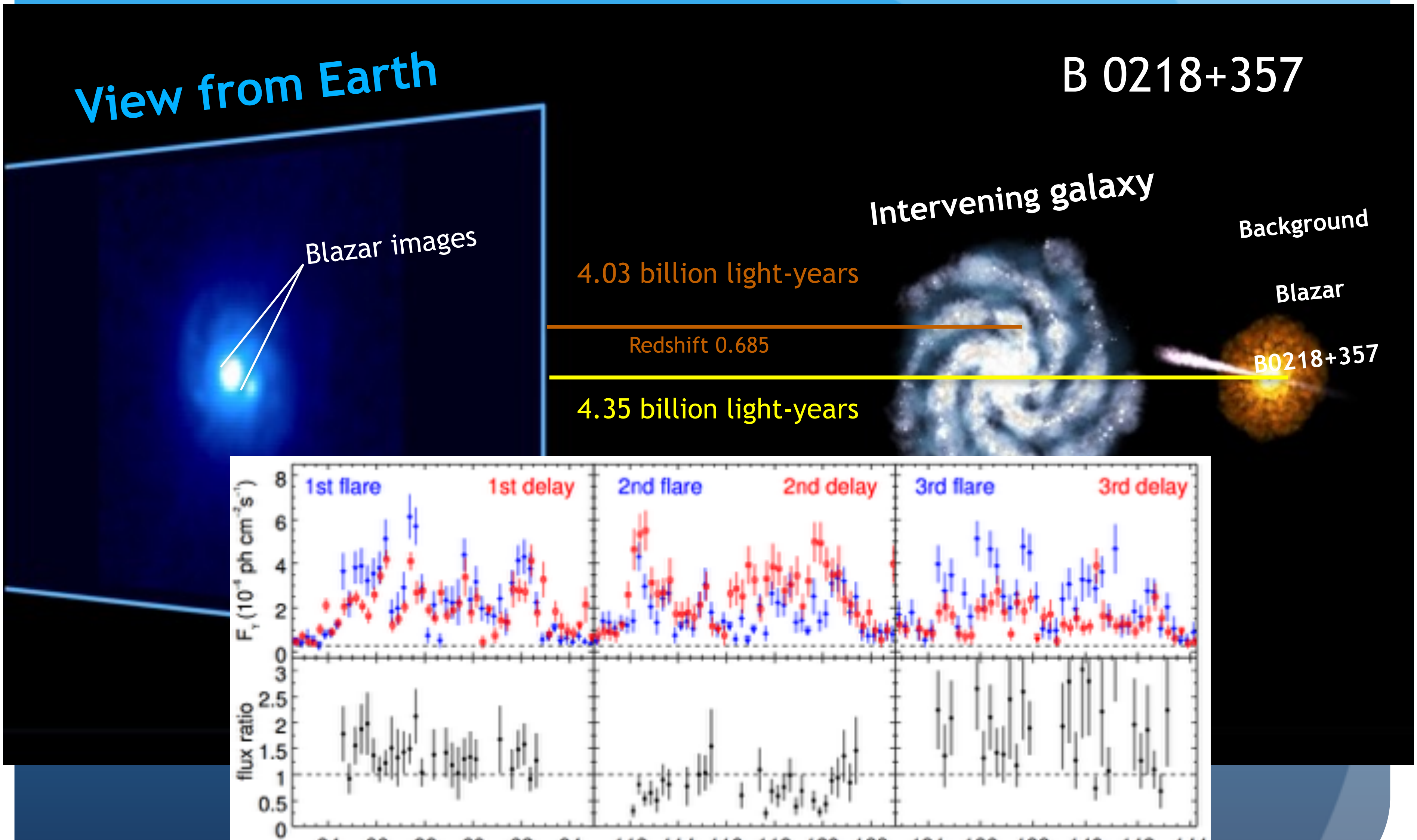
Detection of delay in gravitational lensed source



Cheung+ 2014

Detection of delay in gravitational lensed source



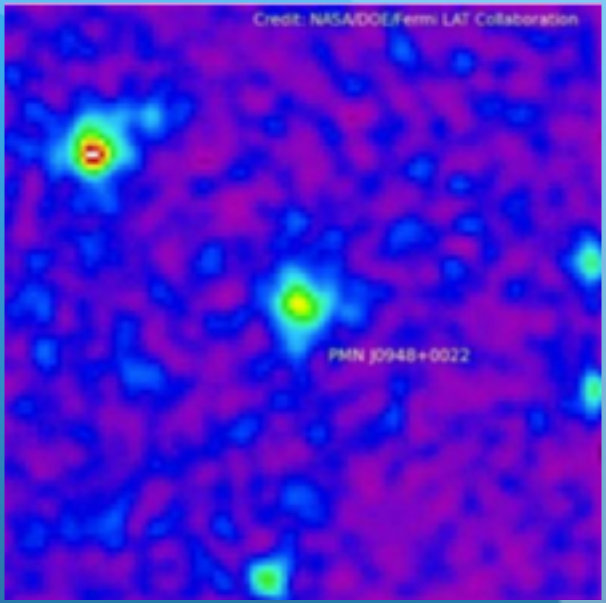
Cheung+ 2014

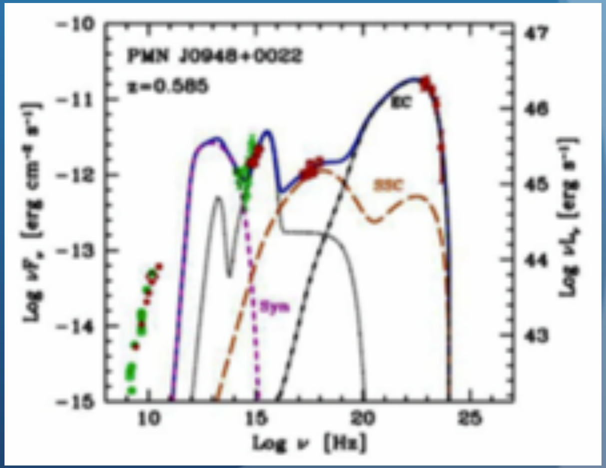
Not only blazars: RdG and NLSy1

- Centaurus A – one of the nearest radio galaxies
  - Lobes are 10 degrees across (600 kpc)
  - Purple glow is a resolved detection from Fermi-LAT (Su+ 2016)
  - leptonic emission model
    - lower energies → synchrotron
    - higher energies → external Compton scattering (IC/CMB & IC/EBL)
- Interesting results also from Fornax A lobes:
  - An excess of GeV emission may require hadronic emission

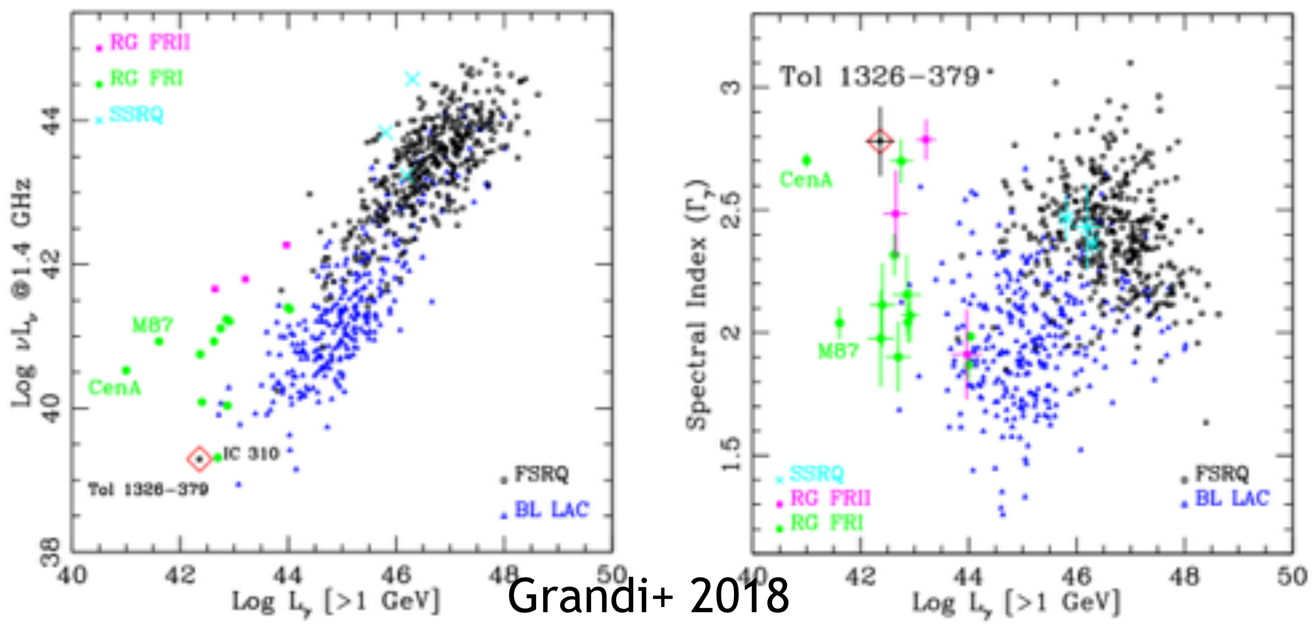
Not only blazars: RdG and NLSy1

- Discover of a new class of gamma-ray emitter: Narrow Line Seyfert 1 (Abdo+ 2009 and many more)
  - Now there are about 10 of these sources
  - They have some blazar-like properties (for example at parsec scale a core-jet radio structure was observed)
  - Seyfert galaxies in general have lower mass BHs (about 10^7 Msun) and NLSy1s have high accretion rate.





FR0: new class of gamma-ray emitters

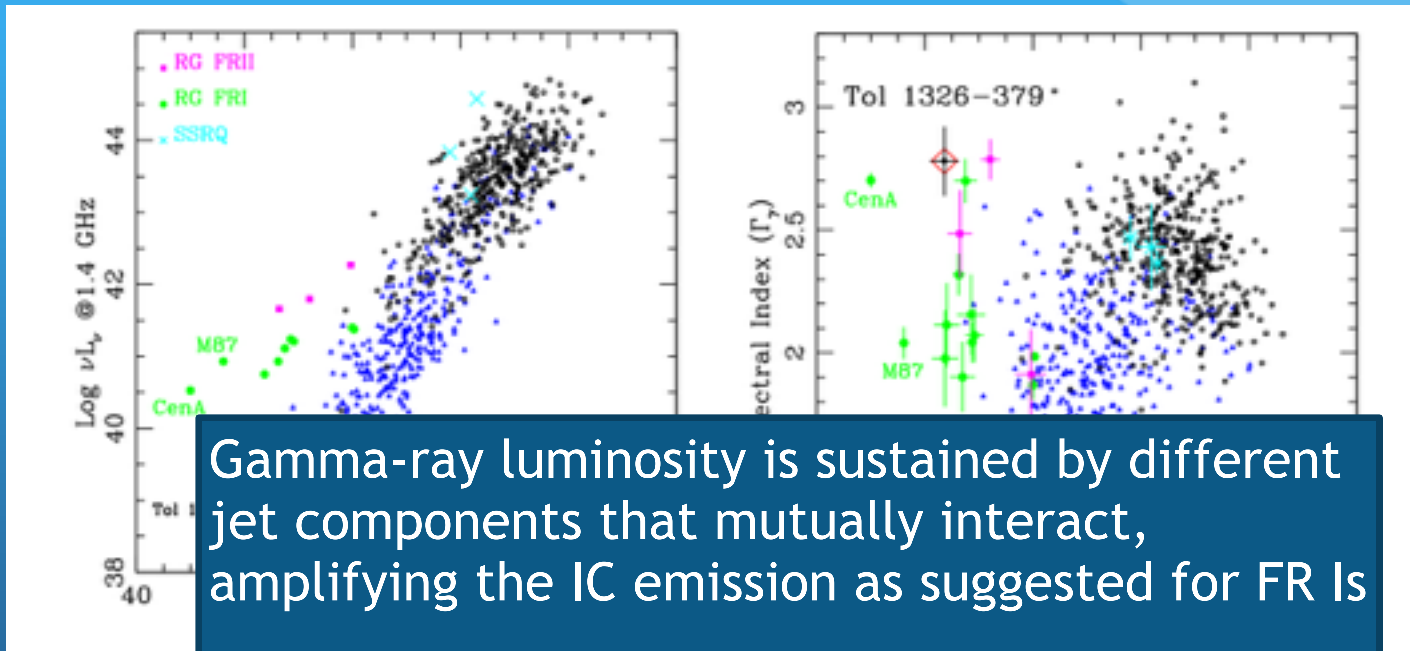


Grandi+ 2018

FR 0s represent the majority of the local population of radio-loud active galactic nuclei but their nature is still unclear

low-excitation galaxies - high radio core dominance

FR0: new class of gamma-ray emitters



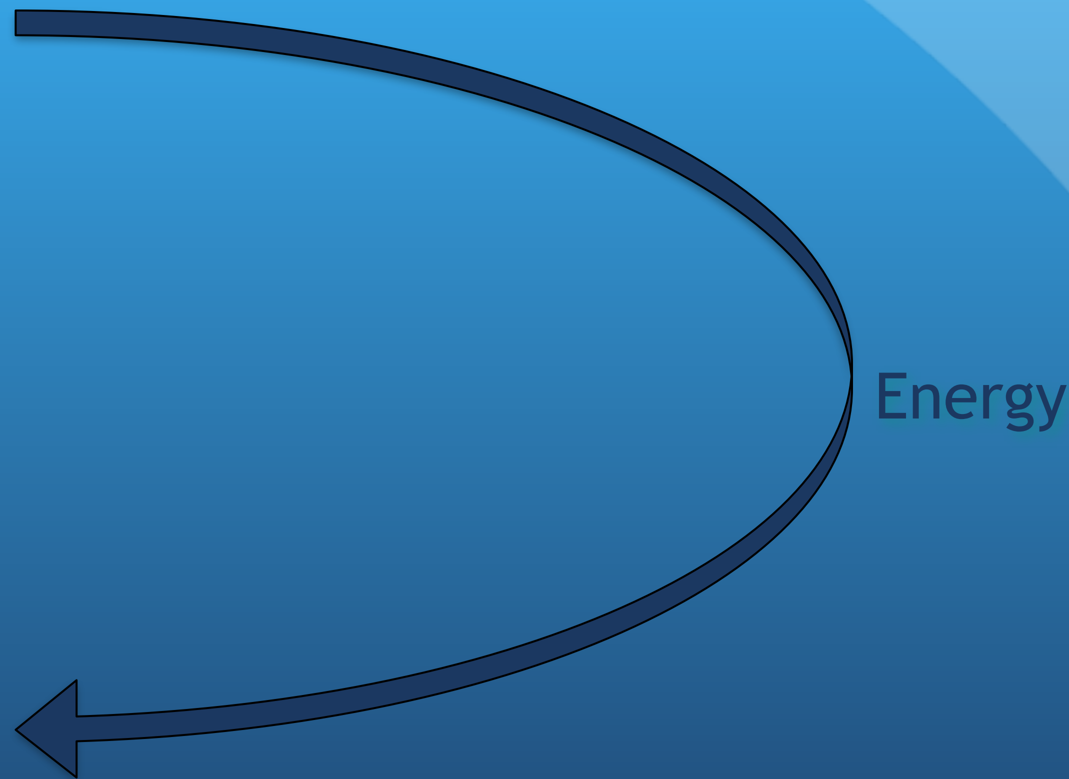
Gamma-ray luminosity is sustained by different jet components that mutually interact, amplifying the IC emission as suggested for FR Is

FR 0s represent the majority of the local population of radio-loud active galactic nuclei but their nature is still unclear

low-excitation galaxies - high radio core dominance

Synergy with other instruments

Synergy with other instruments



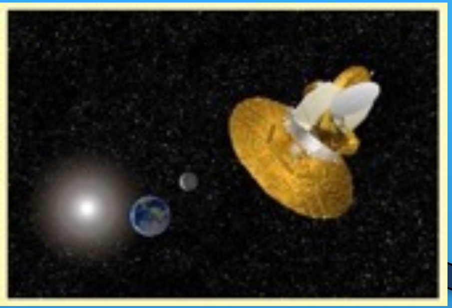
Synergy with other instruments

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…

Energy

Synergy with other instruments

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…

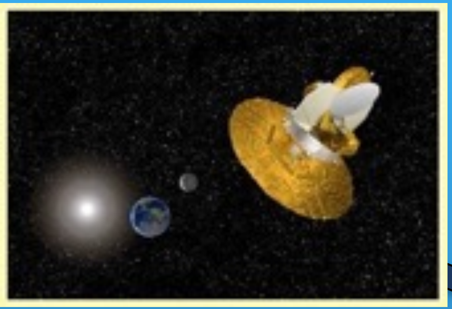


Microwave: diffuse maps & morphology, host galaxy characteristic

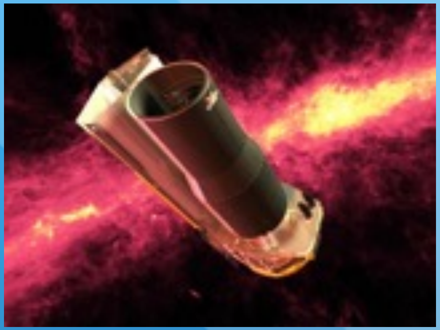
Energy

Synergy with other instruments

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…



Microwave: diffuse maps & morphology, host galaxy characteristic

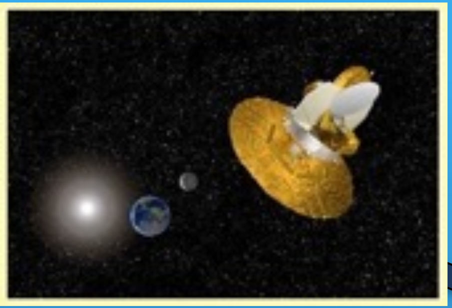


IR: gas/ dust maps, host galaxy characteristics

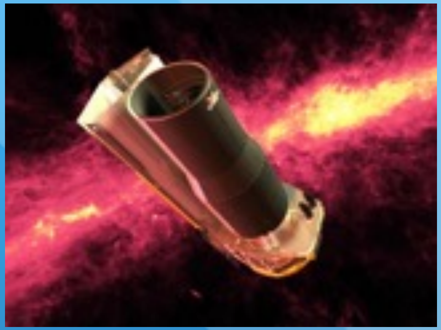
Energy

Synergy with other instruments

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…



Microwave: diffuse maps & morphology, host galaxy characteristic



IR: gas/ dust maps, host galaxy characteristics

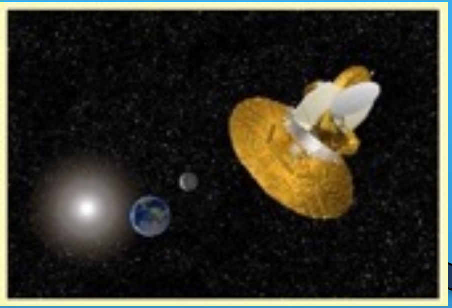
Energy

Optical:

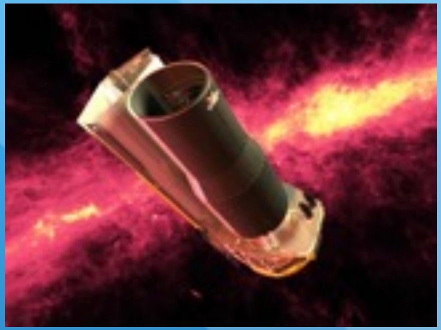
GRB afterglows, AGN/ GRB redshift

Synergy with other instruments

Radio: pulsations, synchrotron emission, gas / dust maps, high resolution imaging of host galaxies…



Microwave: diffuse maps & morphology, host galaxy characteristic



IR: gas/ dust maps, host galaxy characteristics

Energy

X-ray:

GRB afterglows, Galactic source morphology & pulsar association

Optical:

GRB afterglows, AGN/ GRB redshift

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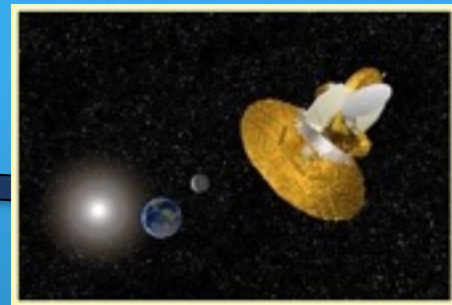

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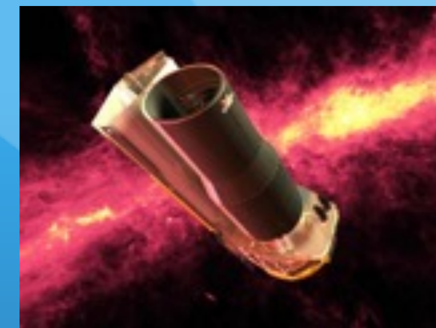

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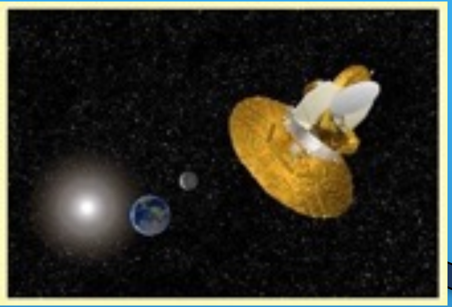

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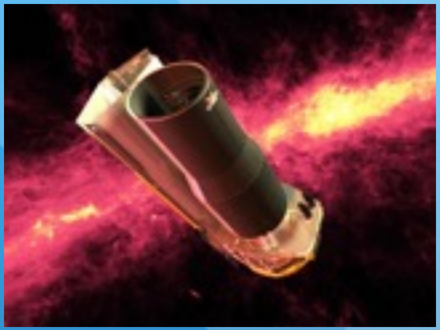

IR: gas/ dust maps, host galaxy characteristics

- LAT source location better than 0.1° —> easy follow up

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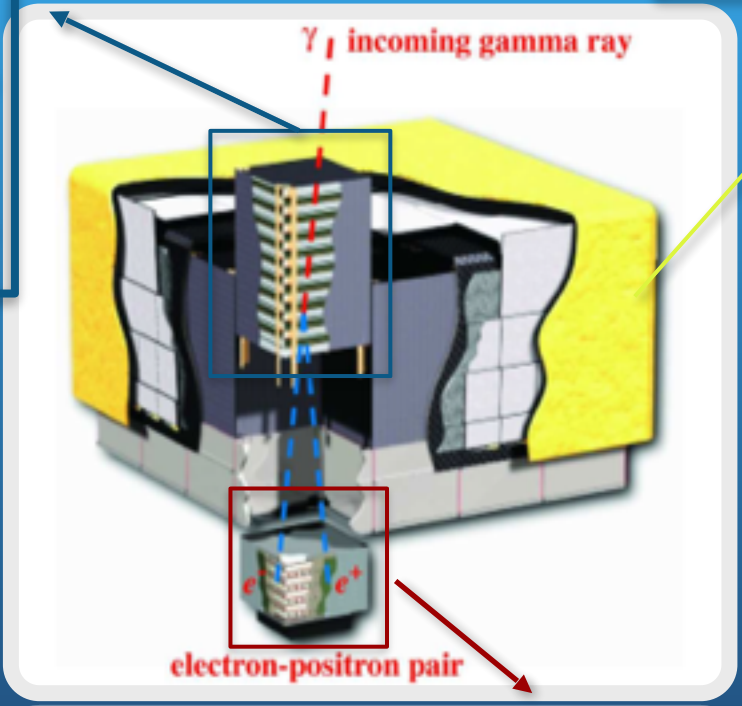
Thanks for the attention!

spares

The Fermi-LAT detector

TRACKER-CONVERTER
- Incoming particle direction
- 18 x,y tracking planes: SSD
- 16 planes of tungsten
  - “FRONT” --> first 12 “thin” layers of 3% radiation length tungsten converters
  - “BACK” --> next 4 “thick” layers of 18% radiation length tungsten converters

ANTICOINCIDENCE DETECTOR
- Charged particle bkg rejection
- Plastic Scintillator, WLS Fibers
- Segmented tiles



Calorimeter
- Energy deposition
- Shower development Imaging
- Segmented 96 CsI(Tl) crystals

Pass8 = complete revamp of event reconstruction algorithms (2015)

Improved performances and IRF
Retroactively updated entire data archive
Open new discovery space