Quasi-Stars as hypothetical gamma ray sources observed by Fermi

Agnieszka Janiuk

Center for Theoretical Physics, Polish Academy of Sciences

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Collaboration: Bożena Czerny and Marek Sikora

(Copernicus Astronomical Center) , Jean-Pierre Lasota (Institut d'Astrophysique de Paris)

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QUASI-STAR JETS AS UNIDENTIFIED GAMMA-RAY SOURCES

Bozena Czerny[1], Agnieszka Janiuk[2], Marek Sikora[1], and Jean-Pierre Lasota[3,4]
[1] Copernicus Astronomical Center, Polish Academy of Sciences, ul. Bartycka 18, 00-716 Warsaw, Poland; bcz@camk.edu.pl, sikora@camk.edu.pl
[2] Center for Theoretical Physics, Polish Academy of Sciences, Al. Lotnikow 32/46, 02-668 Warsaw, Poland; agnes@cft.edu.pl
[3] Institut d'Astrophysique de Paris, UMR 7095 CNRS, UPMC Univ Paris 06, 98bis Boulevard Arago, F-75014 Paris, France; lasota@iap.fr
[4] Astronomical Observatory, Jagiellonian University, ul. Orla 171, 30-244 Krakow, Poland
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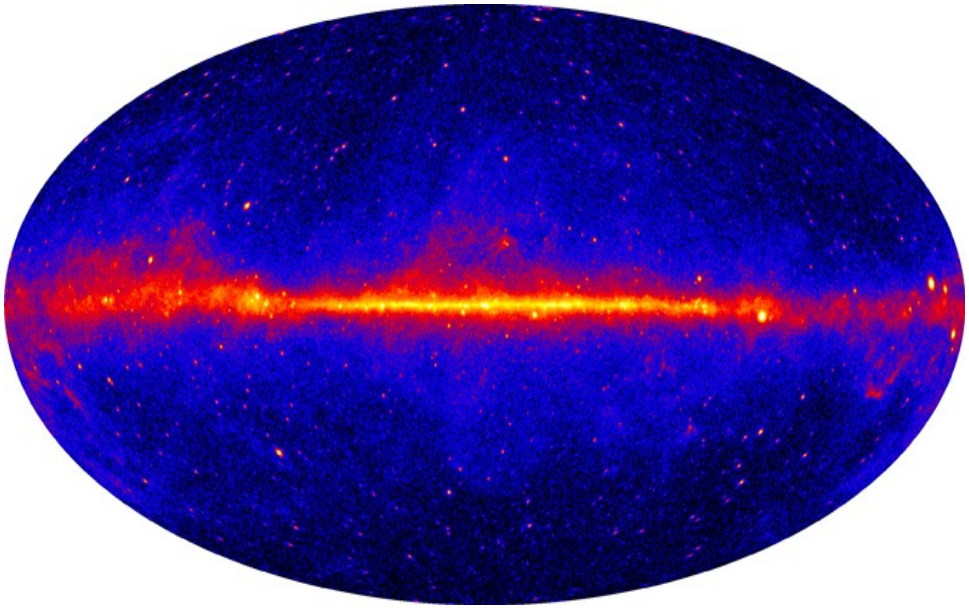
ABSTRACT

Gamma-ray catalogs contain a considerable amount of unidentified sources. Many of these are located out of the Galactic plane and therefore may have extragalactic origin. Here we assume that the formation of massive black holes in galactic nuclei proceeds through a quasi-star stage and consider the possibility of jet production by such objects. Those jets would be the sources of collimated synchrotron and Compton emission, extending from radio to gamma rays. The expected lifetimes of quasi-stars are of the order of million of years while the jet luminosities, somewhat smaller than that of quasar jets, are sufficient to account for the unidentified gamma-ray sources. The jet emission dominates over the thermal emission of a quasi-star in all energy bands, except when the jet is not directed toward an observer. The predicted synchrotron emission peaks in the IR band, with the flux close to the limits of the available IR all sky surveys. The ratio of the gamma-ray flux to the IR flux is found to be very large (~60), much larger than in BL Lac objects but reached by some radio-loud quasars. On the other hand, radio-loud quasars show broad emission lines while no such lines are expected from quasi-stars. Therefore, the differentiation between various scenarios accounting for the unidentified gamma-ray sources will be possible at the basis of the photometry and spectroscopy of the IR/optical counterparts.

Key words: accretion, accretion disks – black hole physics – galaxies: jets – gamma rays: general – infrared: general – stars: massive

Online-only material: color figure

The Fermi-LAT catalogue contains still over 300 of unidentified sources (Abdo et al. 2010)



This all-sky view from Fermi reveals bright emission in the plane of the

Milky Way (center), bright pulsars and super-massive black holes.

Credit: NASA/DOE/International LAT Team

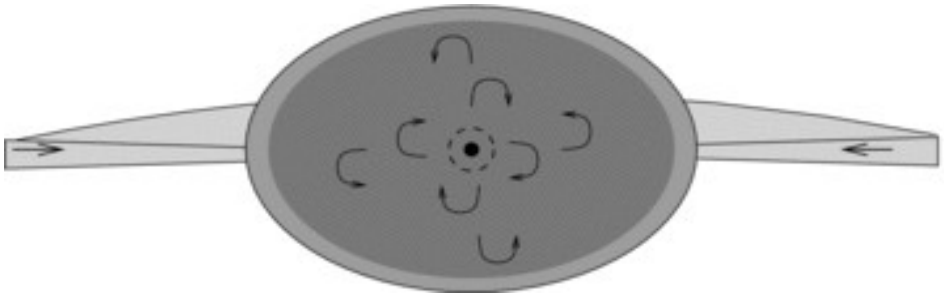
No counterparts in other bands of electromagnetic spectrum.

Located out of the Galactic plane → extragalactic origin

Hypotheses:

- Known active galaxies (Massaro et al. 2012)
- New population of objects?

New population of objects?



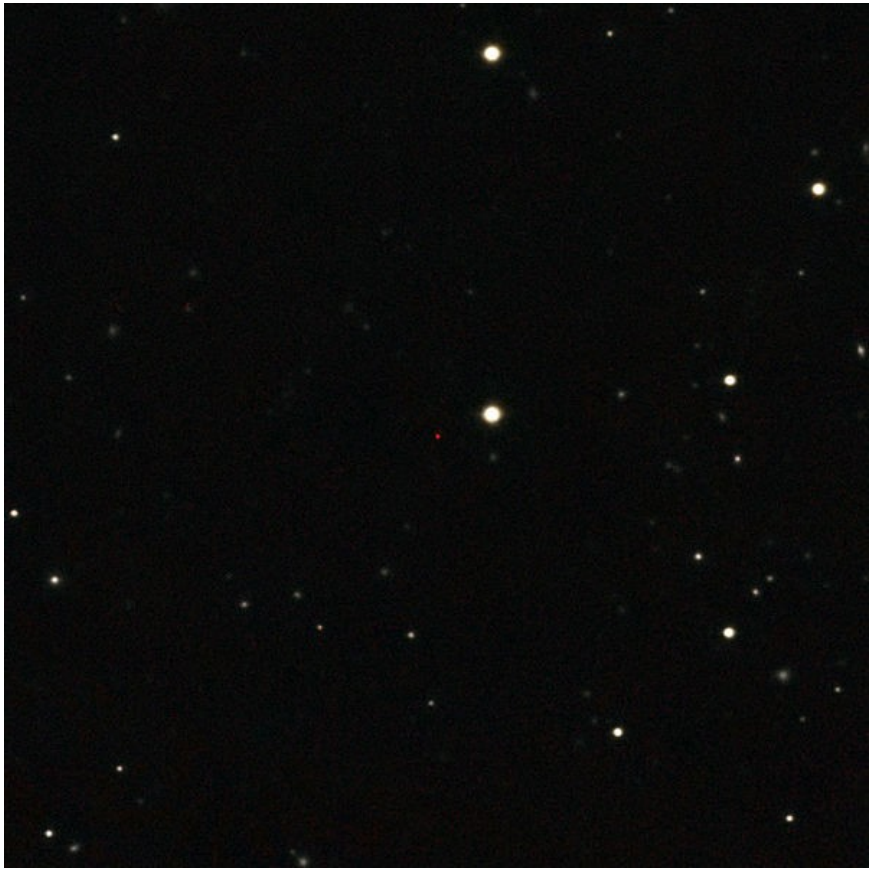
Seed black hole accretes gas from a massive, radiation pressure supported envelope (Begelman, Rossi & Armitage 2008)

Inspiration: theory of Mitch Begelman

Pre-quasar epoch in the galaxy evolution: how the supermassive black holes were formed?

The protostar (Pop III) collapsed into BH

Massive envelope absorbs collapse energy and equlibrium quasi-star forms



ULAS J112001+0641
z=7.085;

(Mortlock et al. 2011)

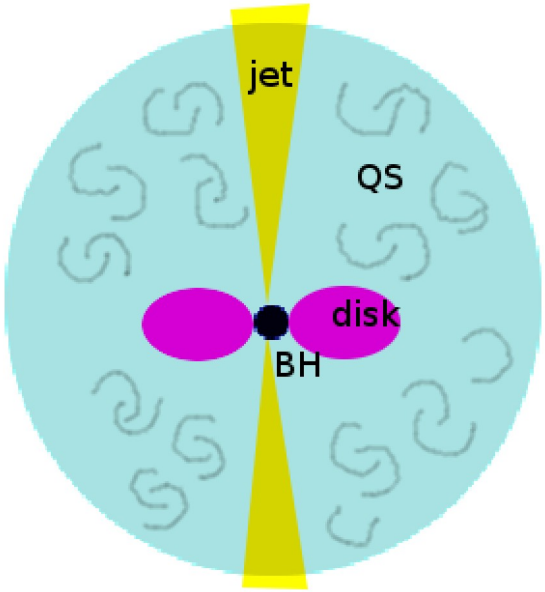
environment is gas-rich after the galaxy mergers

BH growth in quasi star

<< Salpeter time

→

Massive BHs form and quasar activity starts at very large z



But quasi-star must not be spherically symmetric as in Begelman et al. (2010)

The extragalactic sources observed by Fermi satellite may be the signatures of Quasi-Star jets.

- AGN
- GRB
- QS

Gamma rays detectable from cosmological distances due to collimation of radiation

Physical parameters and lifetime

Model of a quasi-star

$$T_{QS} = 5000\, \epsilon_{-1}^{-1/5} M_{BH,4}^{-2/5} M_{QS}^{7/20} [K]$$

Volonteri & Begelman (2010)

Thorne & Zytkow (1977)

mass 10^7 M_{sun};

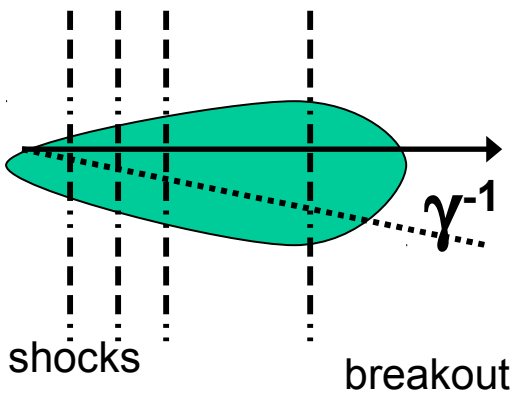
- luminosity of 10^{45} erg/s;
- effective temperature 3000 K (Hayashi limit)
- black hole mass of 10^5 M_{sun},
- accretion rate in disk: 2 M_{sun}/year
- efficiency ~ 0.01 (advective)
- size: 10^{17} cm,

The lifetime is limited by the black hole growth.

- Configuration unstable when M_{BH} > 10% M_* -> about 10^5 years

Jet velocity determined in the comoving frame is supersonic (e.g. Waxman & Meszaros 2003).

Breakout condition $t_{QS} >> r_{QS}/v_{head}$ is satisfied



Particles accelerated via magnetic mirrors (1st order Fermi process; e.g. Niemiec & Ostrowski 2004)

Jets

- Efficiency of accretion energy conversion 0.1
- Power 10^{46} erg/s
- Γ ~15
- Isotropic luminosity 10^{48} erg/s
- Radiative efficiency 0.1
- $L_{j,\,iso} = 850\ L_{QS}$
- Gamma rays produced in reconfinement shocks at 100 – 1000 r_g, which is at 0.01 – 1 R_* (10^{15} – 10^{17} cm)

Radiative properties

$$\frac{F_{ERC}}{F_{syn}} = \frac{L_{ERC}}{L_{syn}} \approx 77 \left[\epsilon_{d,-2} \tau \left(\Gamma / 15 \right)^2 \frac{\left(\Theta_j \Gamma \right)^2}{\sigma_{B,-1} \eta_{j,-1}} \right]$$

τ - opt. depth of external radiation

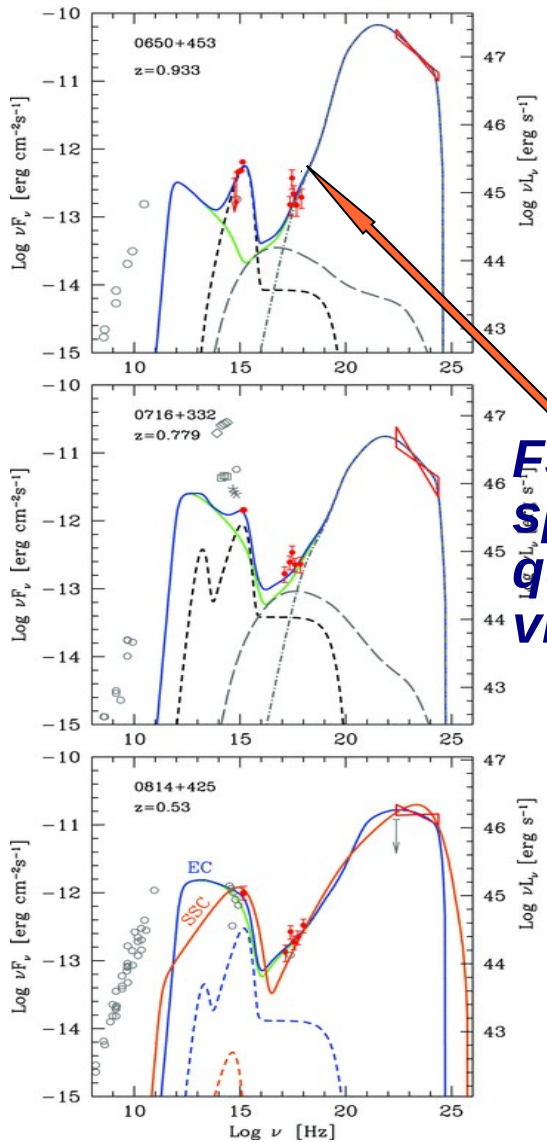
$\sigma_B = L_B / L_K$

- Dominant processes: synchrotron, SSC, ERC.
- $L_{syn} >> L_{SSC}$

$$h \nu_{ERC} \approx 100 \left(\Gamma / 15 \right)^2 \left(r_{QS} / r \right)^{1/2} \tau^{1/4} [\, MeV \,]$$

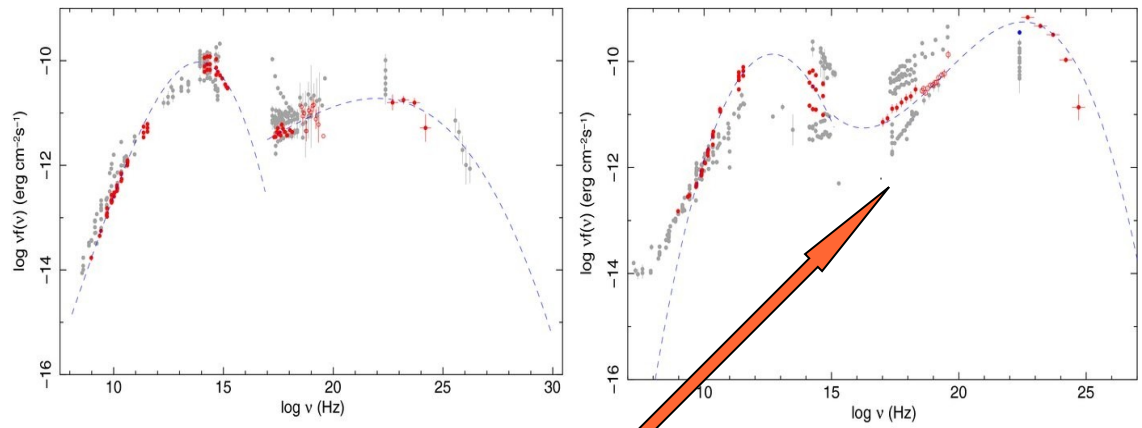
$$\nu_{syn} \approx 2 \times 10^{14} \frac{\left(\Gamma / 15 \right) \kappa^2 \sigma_{B,-1}^{1/2} \left(r_{QS} / r \right) \eta_{j,-1}^{1/2}}{\theta_j \Gamma \epsilon_{d,-2}^{1/2}} [\, Hz \,]$$

Identified Fermi sources



Ghisellini G et al. MNRAS 2010;402:497-518

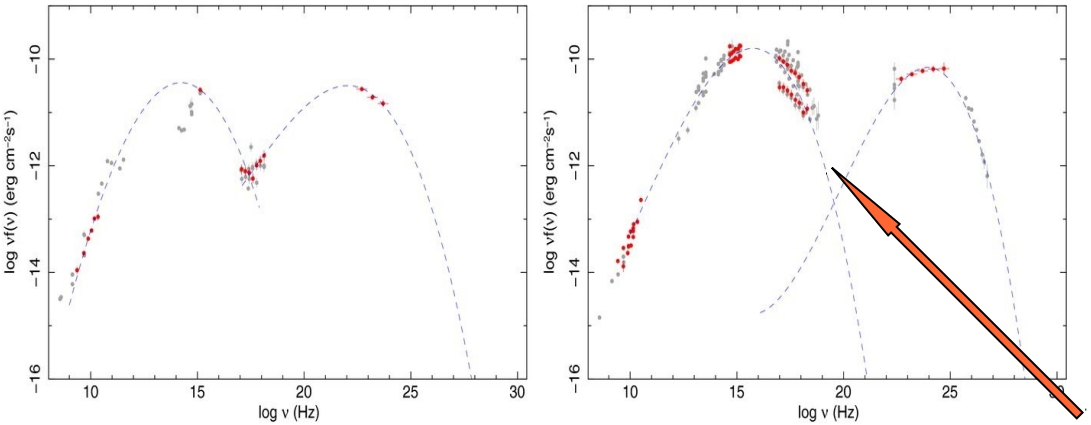
FSRQ (flat spectrum radio quasar) with visible disk



FSRQ (flat spectrum radio quasar), unseen disk – 3C 454.3

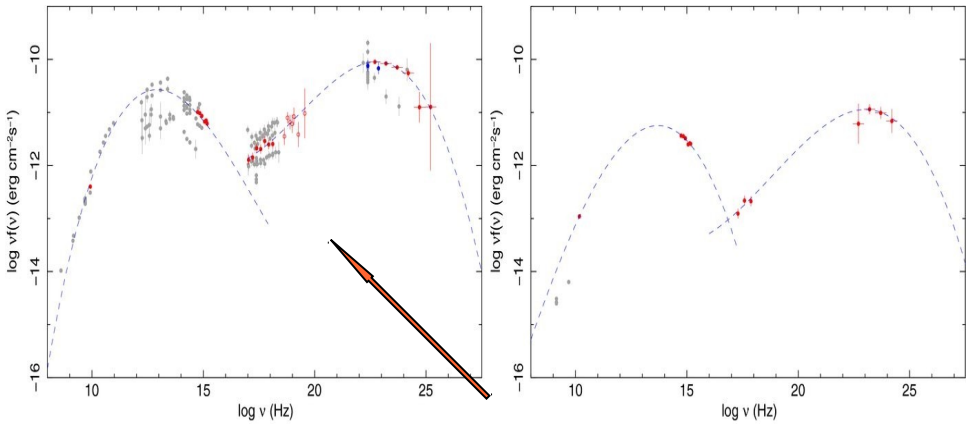
Figure 23 from The Spectral Energy Distribution of Fermi Bright Blazars
A. A. Abdo et al. 2010 ApJ 716 30 doi:10.1088/0004-637X/716/1/30

Figure 22 from The Spectral Energy Distribution of Fermi Bright Blazars
A. A. Abdo et al. 2010 ApJ 716 30 doi:10.1088/0004-637X/716/1/30



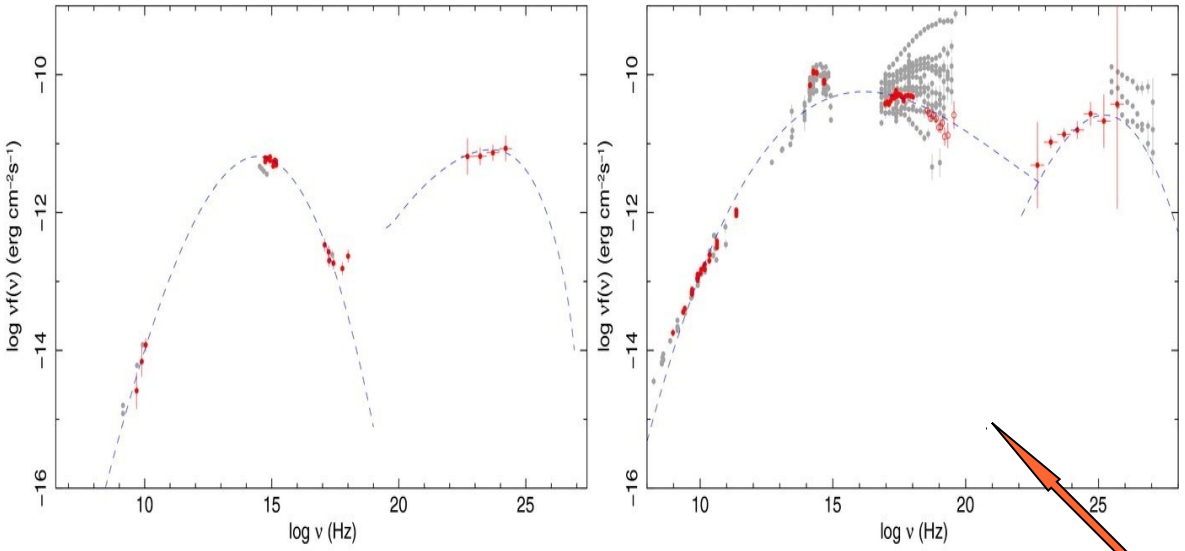
HBL (high energy peak BL Lac) – PKS 2155

Figure 9 from The Spectral Energy Distribution of Fermi Bright Blazars
A. A. Abdo et al. 2010 ApJ 716 30 doi:10.1088/0004-637X/716/1/30



LBL (low energy peak BL Lac) – PKS 0537

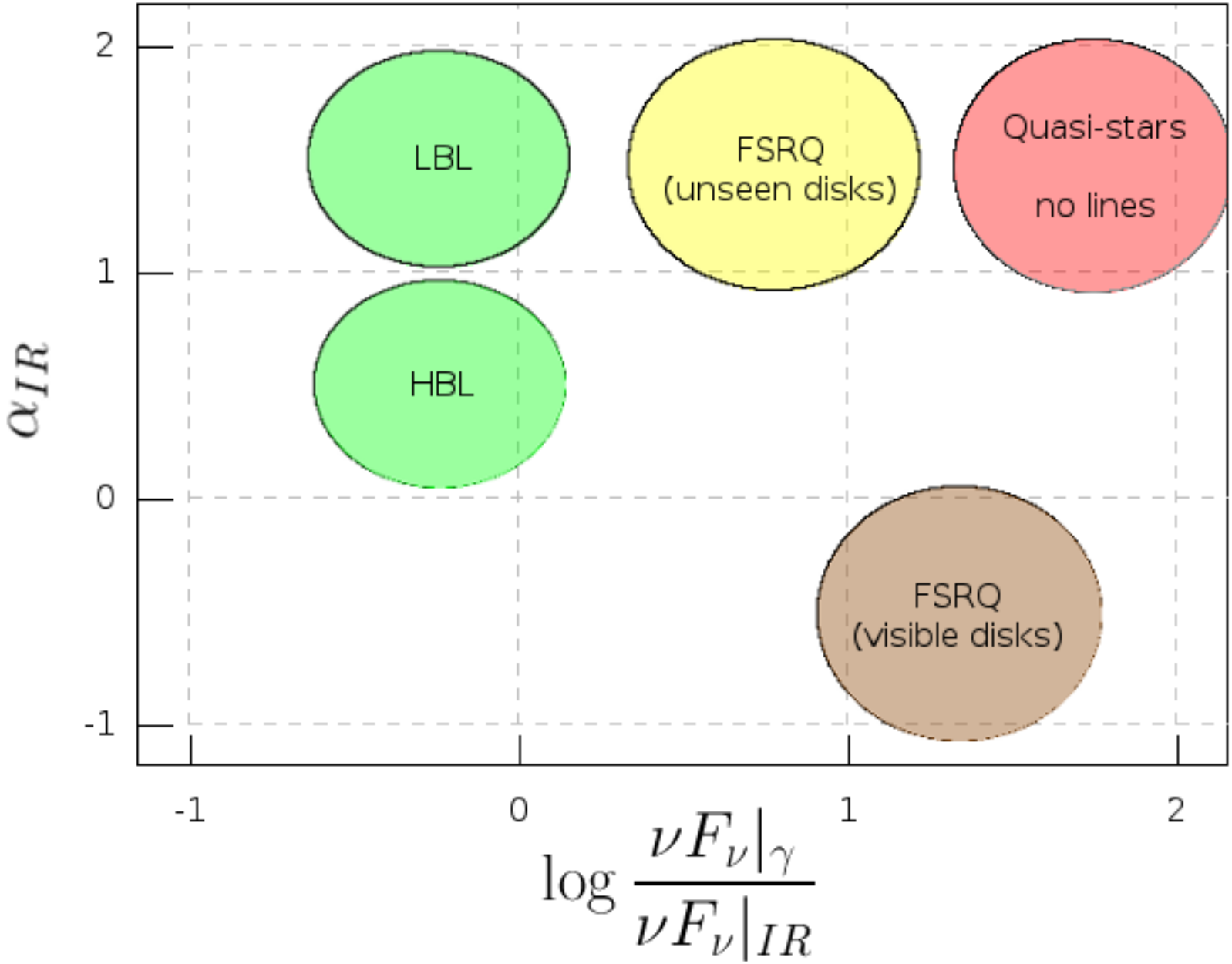
Figure 19 from The Spectral Energy Distribution of Fermi Bright Blazars
A. A. Abdo et al. 2010 ApJ 716 30 doi:10.1088/0004-637X/716/1/30



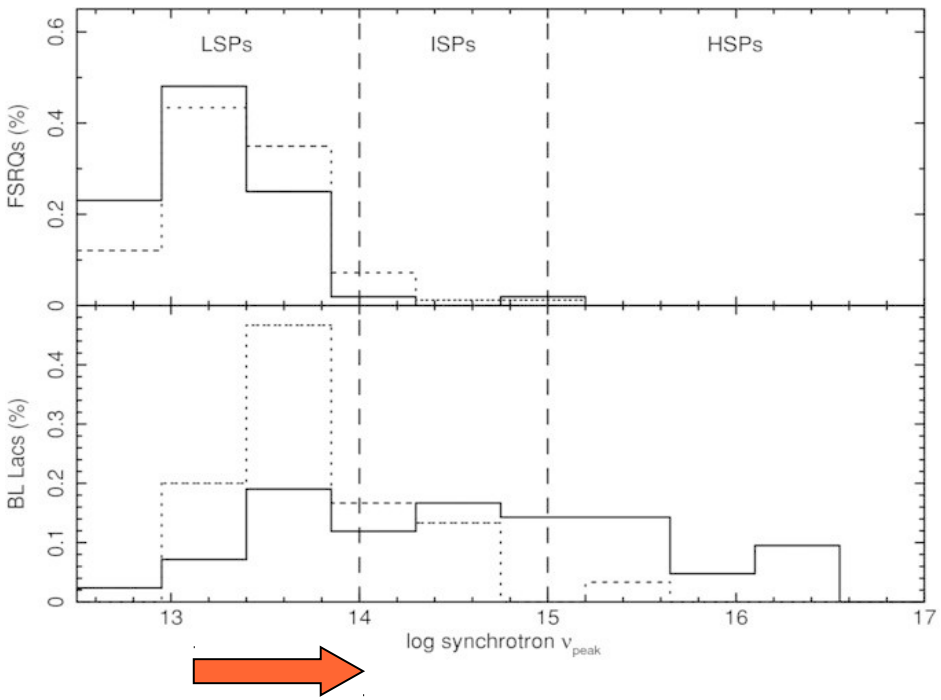
Very faint BLac (dominated by host galaxy starlight) – Mrk 501

How to find quasi stars?

Predictive power of our theory



(Figure: Bartek Kamiński)



Predicted IR/Optical magnitudes of Quasi stars:

17-18 mag (K band)

20-21 mag (R band)

→ at the border of WISE detection

Distribution of blazar peaks

Top: quasars

Bottom: BL Lacs

WISE band: 1.14 e13 Hz – 0.88e14 Hz

Figure 31 from The Spectral Energy Distribution of Fermi Bright Blazars
A. A. Abdo et al. 2010 ApJ 716 30

- Contrary to blazars, our objects will have no broad emission lines.
- The optical brightness of about 20–21 mag may help identify the sources in other surveys, e.g. Sloan Digital Sky Survey

Are the quasi stars comparable in number with the Fermi sources?

Postdictive power of our theory

$$N_{QS} \approx 400 \left(\theta / 4^{\circ}\right)^{2} M_{QS,7}^{-1/8} \epsilon_{d,-2}^{1/2}$$

- The number of quasi-stars forming between z=2-4: is about 0.01 per Mpc^3 (estimated by V&B10) → total number of 10^{10}.
- Observed currently number of such objects is much lower due to short lifetime → 3×10^5
- It depends also on the jet's collimation angle.
- Number of sources ~ 400: in agreement with the unidentified Fermi sources.

Conclusions

- The number of observable quasi stars would be about 400, in agreement with the unidentified Fermi sources (post-diction).
- The ratio of gamma to infrared luminosities would be about several tens, much different from BL Lac objects (prediction).
- Contrary to blazars, our objects will have no broad emission lines (fact).
- The optical brightness of about 20-21 mag may help identify these sources in other surveys, e.g. Sloan Digital Sky Survey or WISE (further test).

Thank you