



Active Galactic Nuclei:
a talk mostly about blazars

Manel Errando

Washington University in St. Louis

The discovery of quasars

3C 273: The first AGN

The discovery of quasars

3C 273: The first AGN

No. 4872 March 16, 1963

NATURE

1037

INVESTIGATION OF THE RADIO SOURCE 3C 273 BY THE METHOD OF
LUNAR OCCULTATIONS

By C. HAZARD, M. B. MACKEY and A. J. SHIMMINS
C.S.I.R.O. Division of Radiophysics, University Grounds, Sydney

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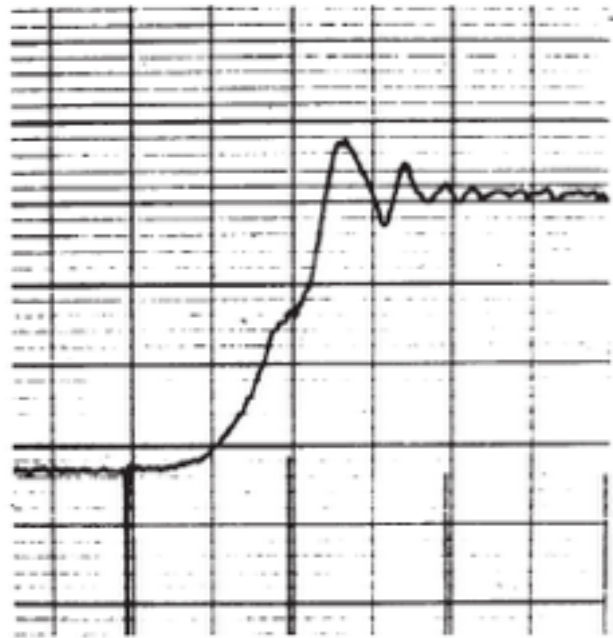
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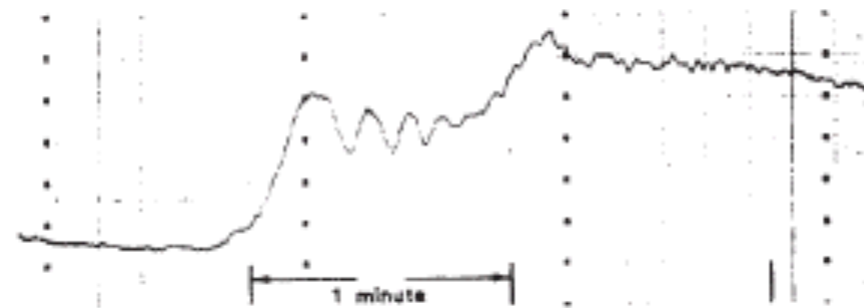
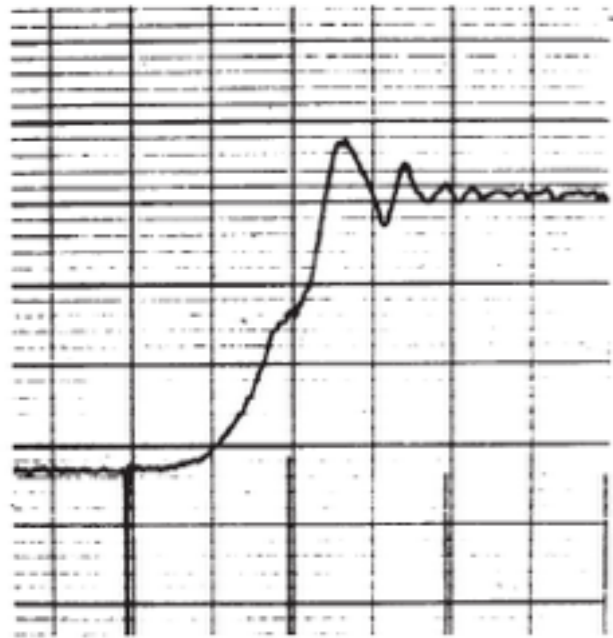
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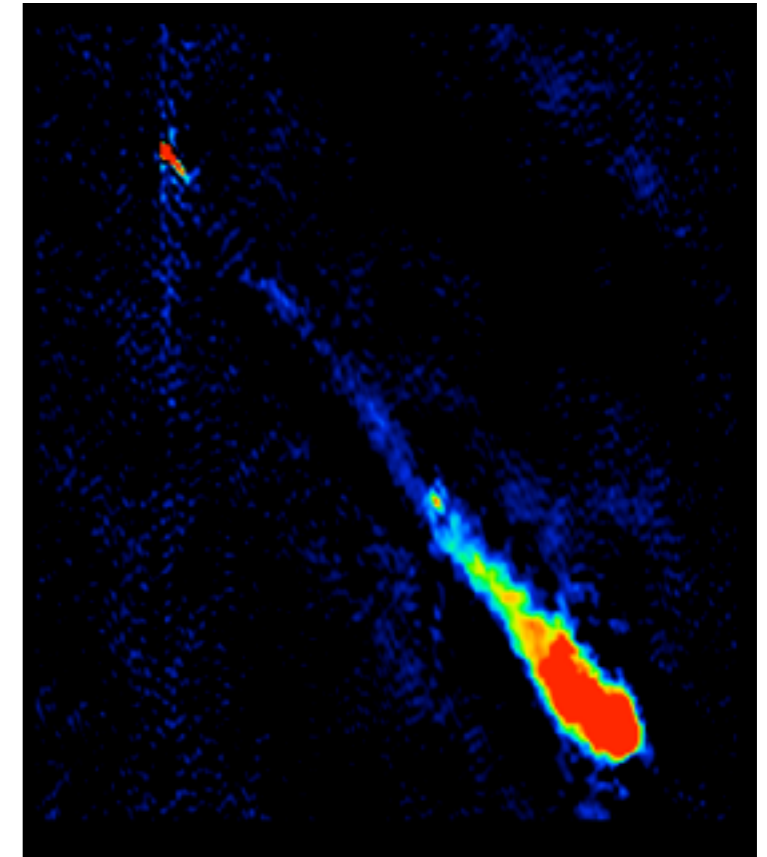
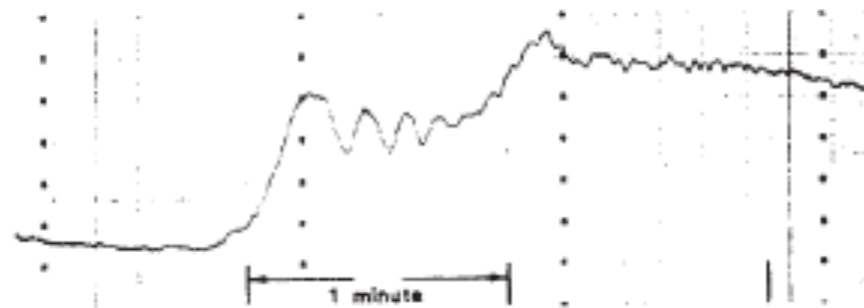
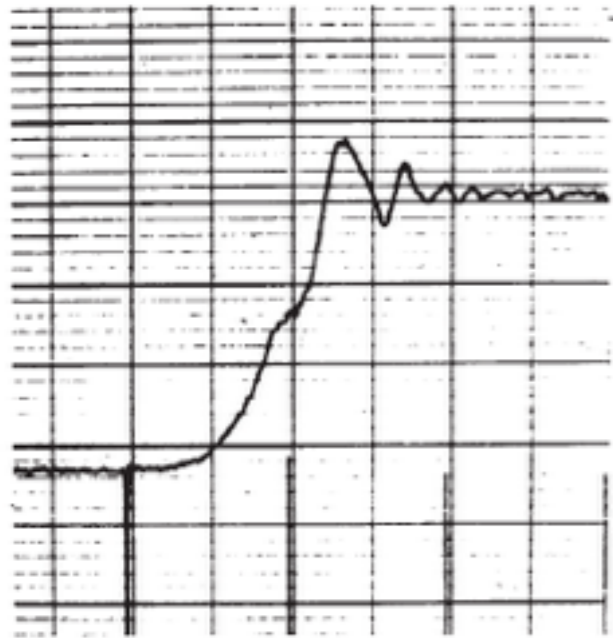
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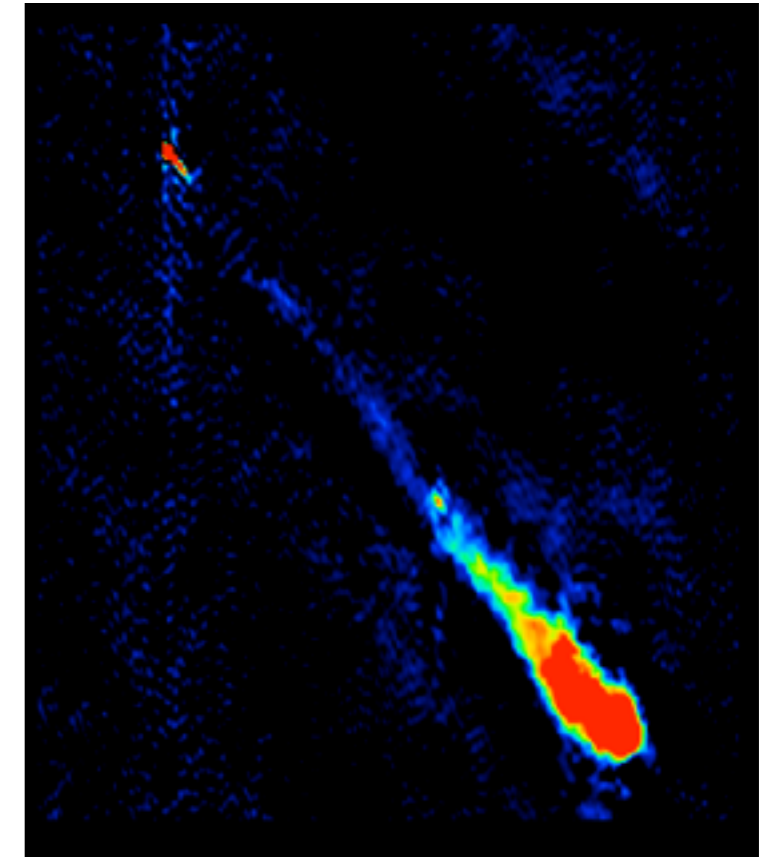
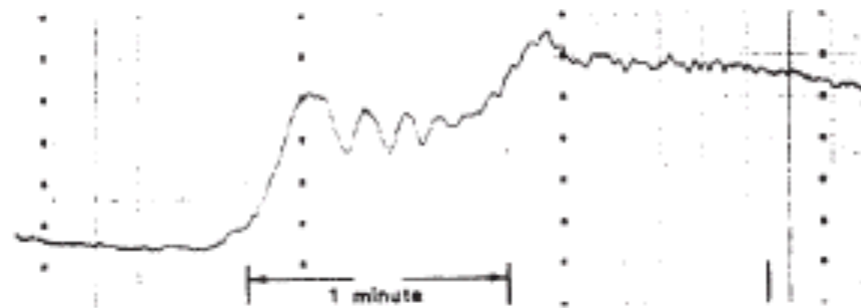
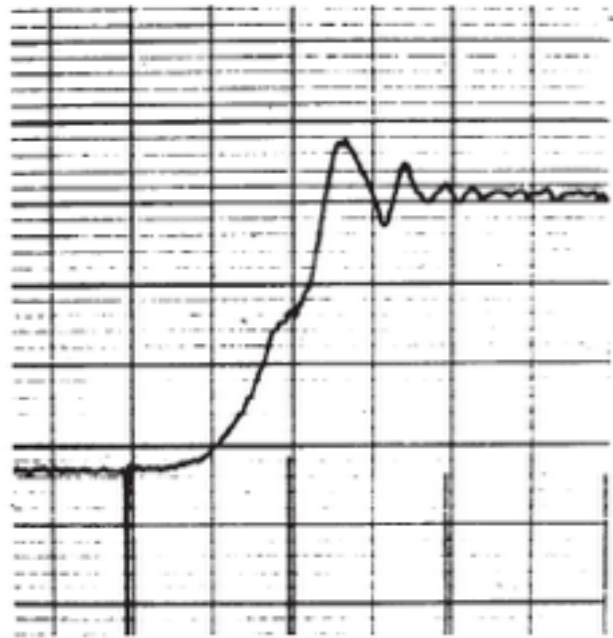
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3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By DR. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

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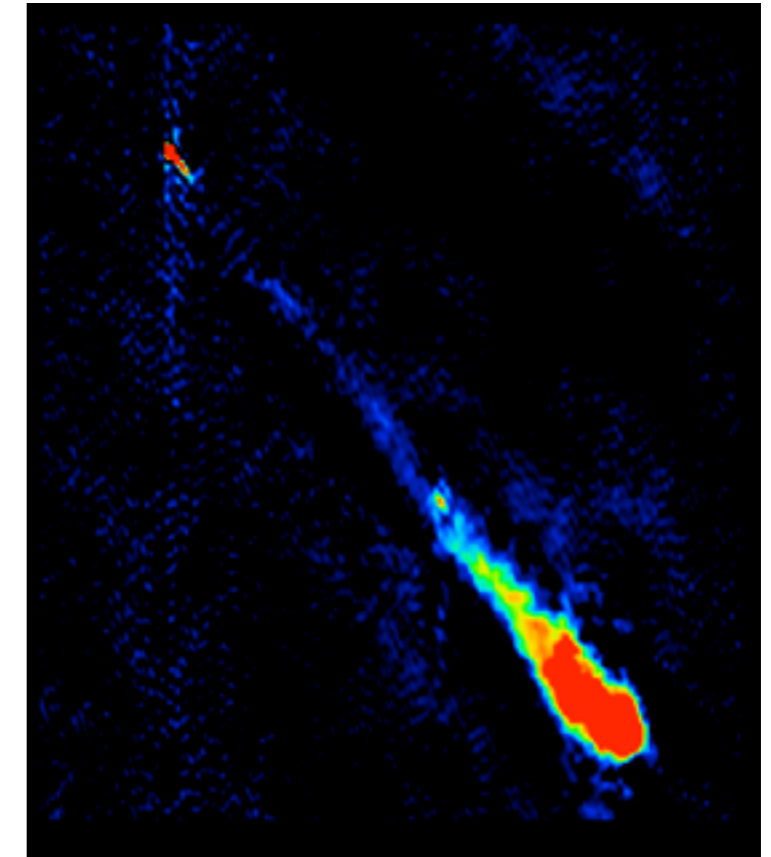
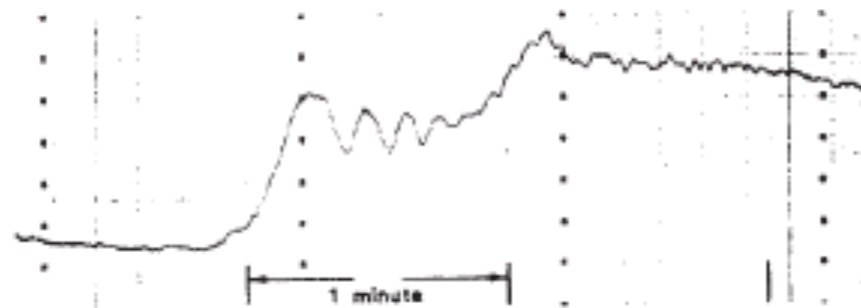
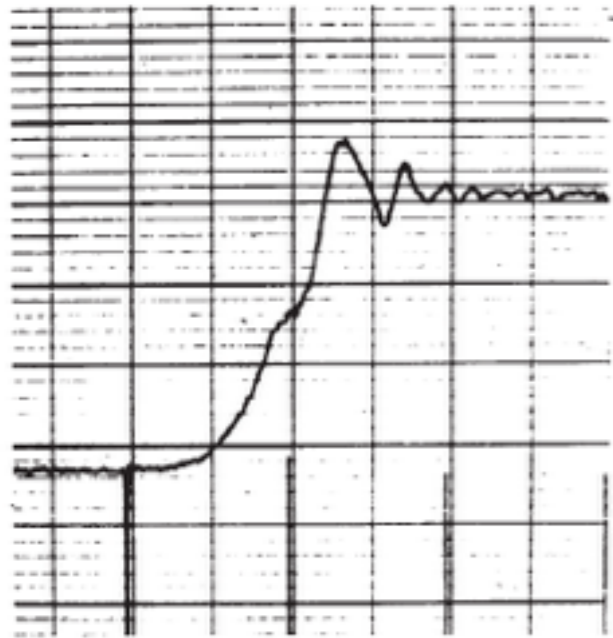
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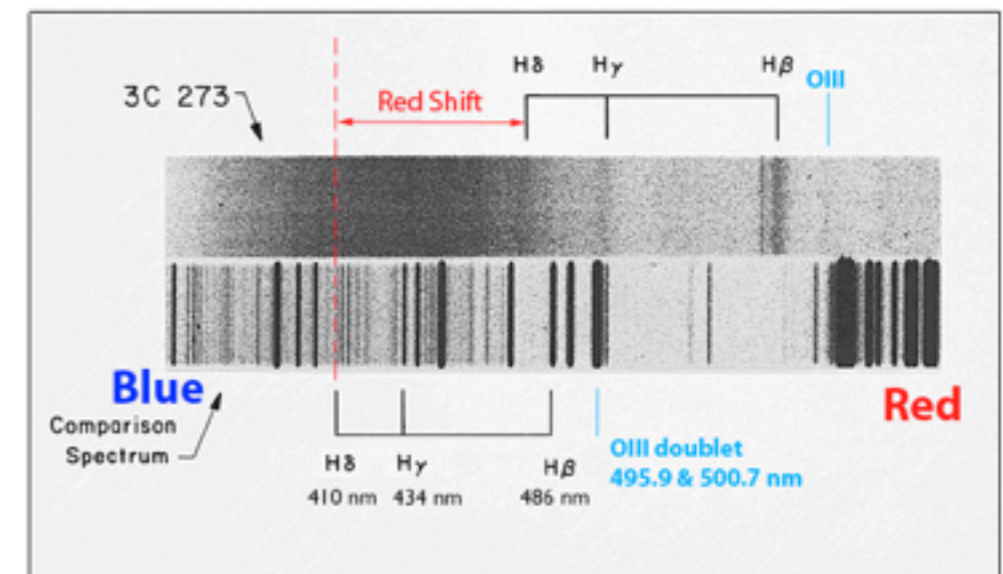
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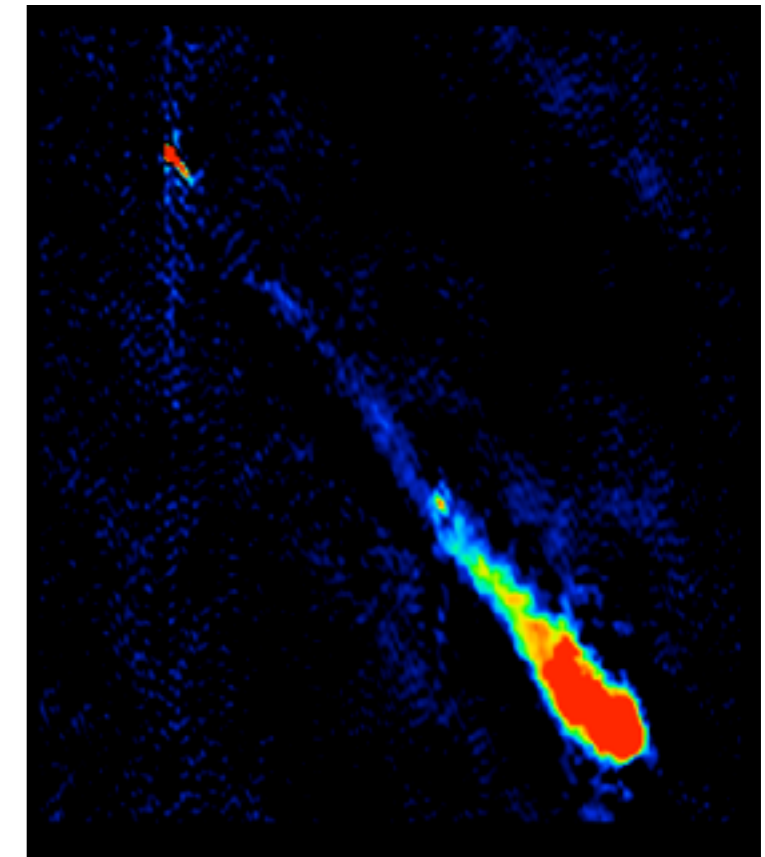
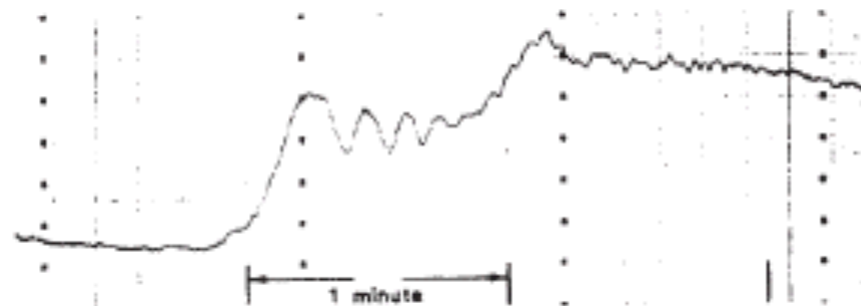
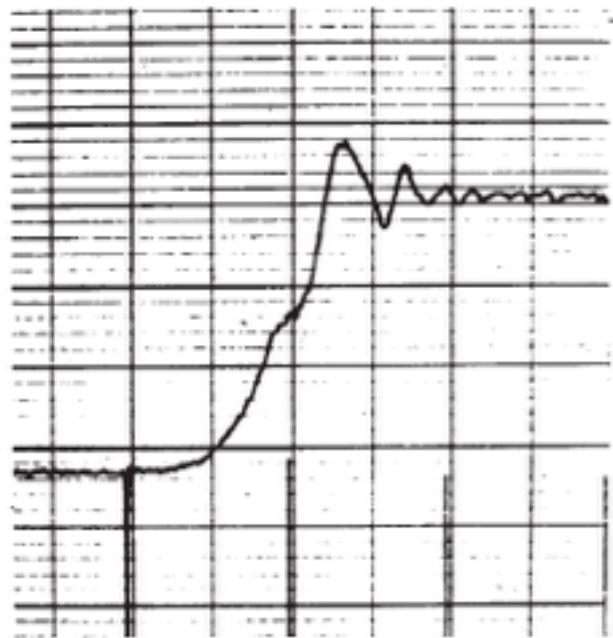
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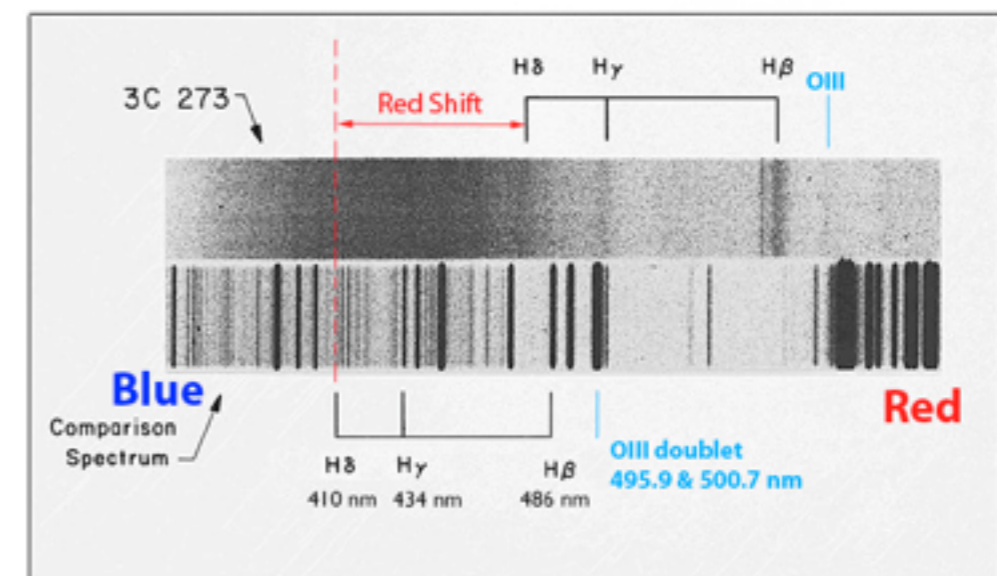
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$$z=0.158$$

The discovery of quasars

3C 273: The first AGN

The First Texas Symposium on Relativistic
Astrophysics - 16-18 December 1963



At the symposium banquet in the Statler-Hilton Hotel, those at the head table included (left to right): Cyril Hazard, University of Sydney, Australia; Rudolph Minkowski, University of California; Thomas Matthews, California Institute of Technology; W. W. Morgan, Yerkes Observatory; P. G. Bergmann, Yeshiva University; Fred Hoyle, Cambridge University, England; Mrs. E. L. Schucking, University of Texas; and J. Robert Oppenheimer, Institute for Advanced Studies, Princeton. Unless otherwise indicated, delegate pictures with this article are by Al Mitchell, director of information, Graduate Research Center of the Southwest.

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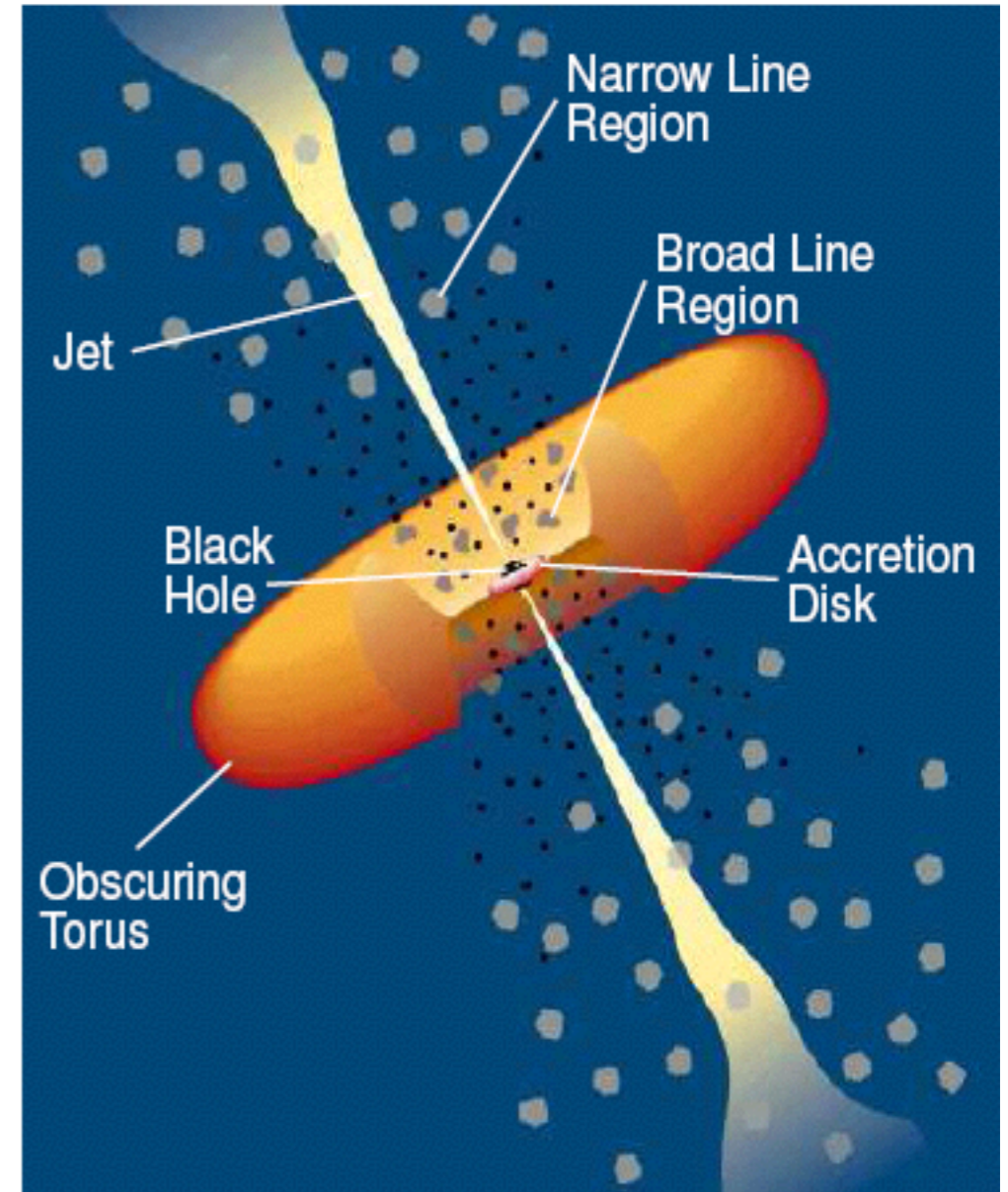


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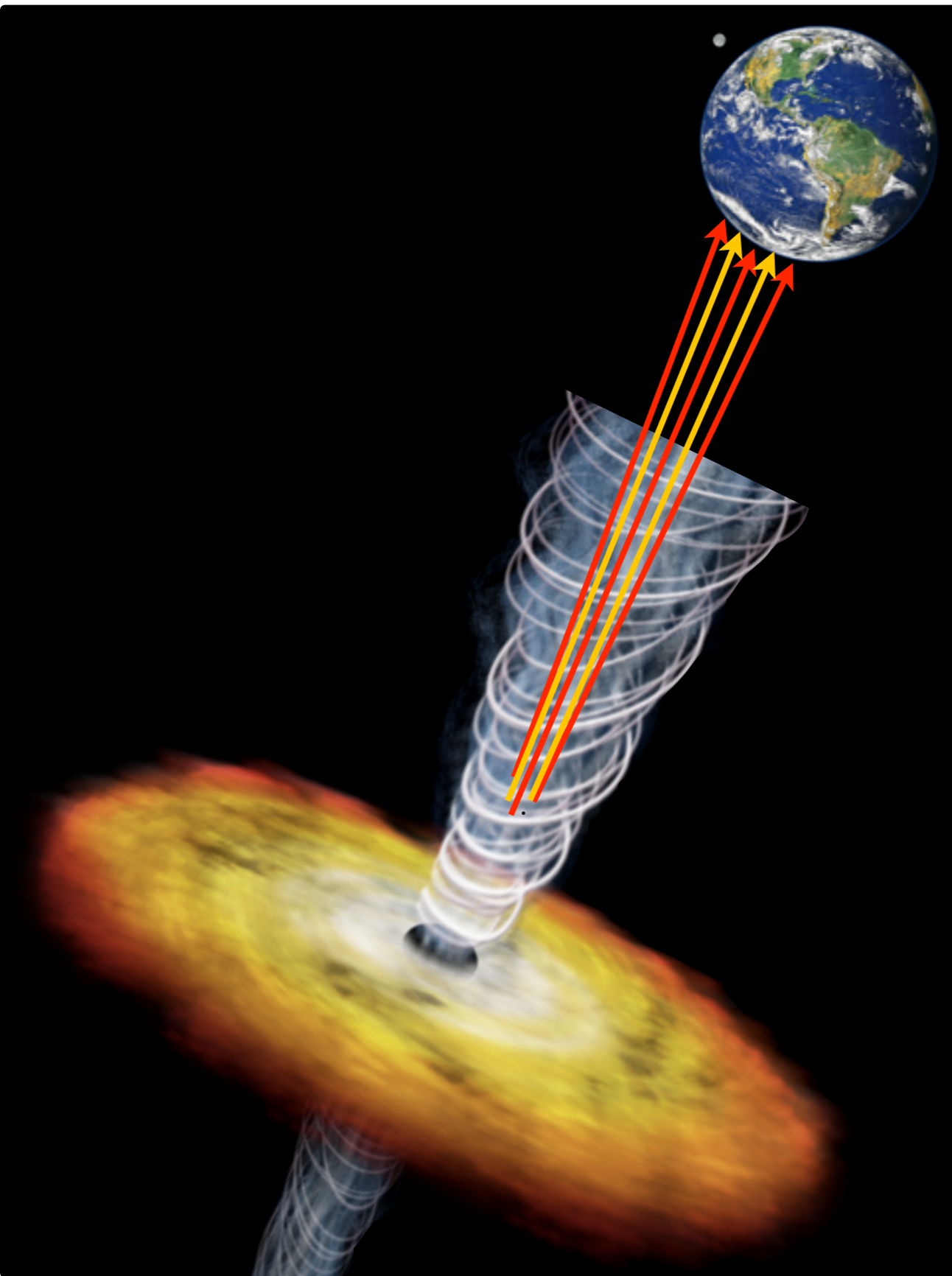


AGN

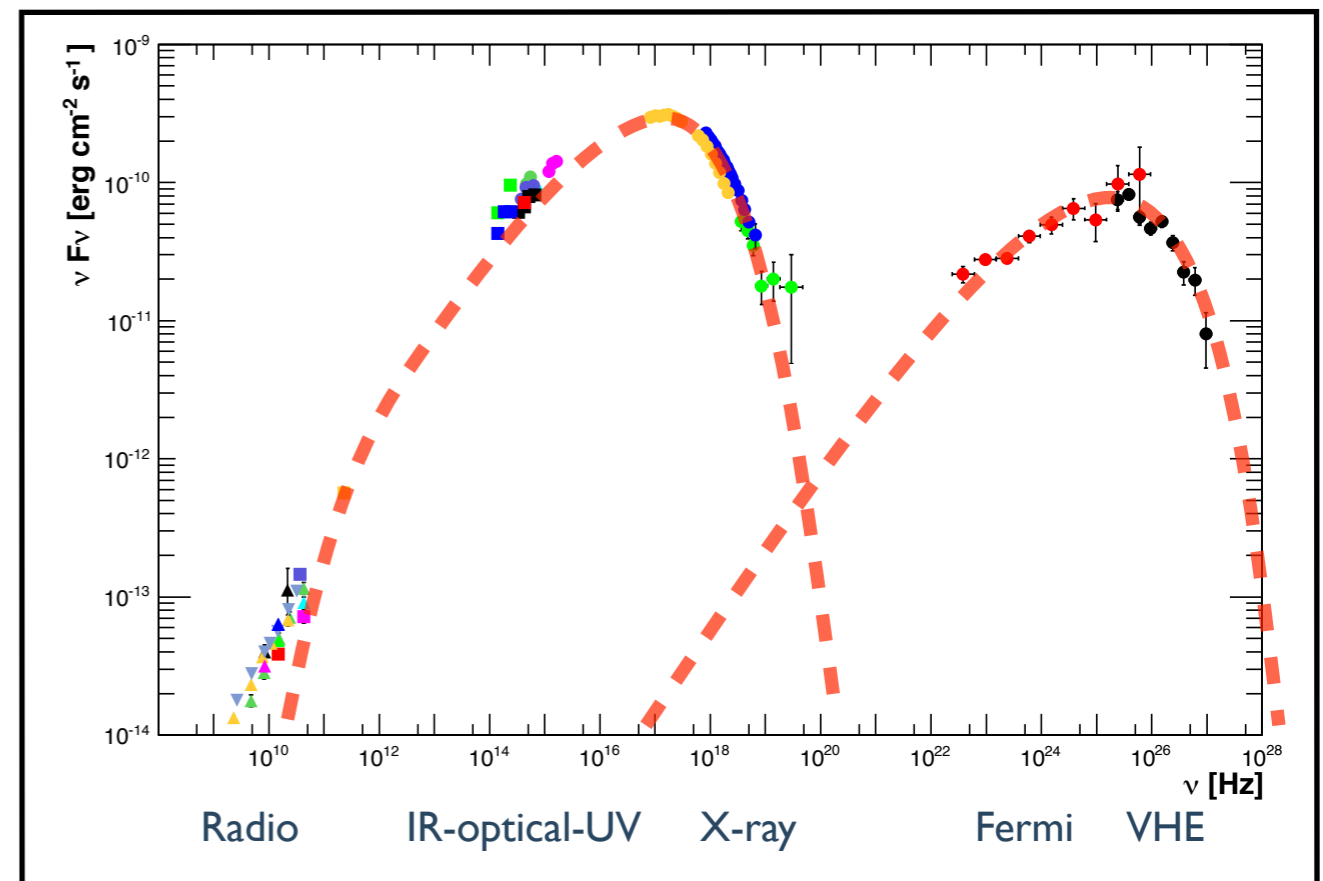
- Characteristics
 - Bright compact nucleus
 - Time variability
- Unified model
 - Supermassive black hole
 - Rotating accretion disk
 - Perspective to observer, accretion rate and BH mass determines the kind of AGN.



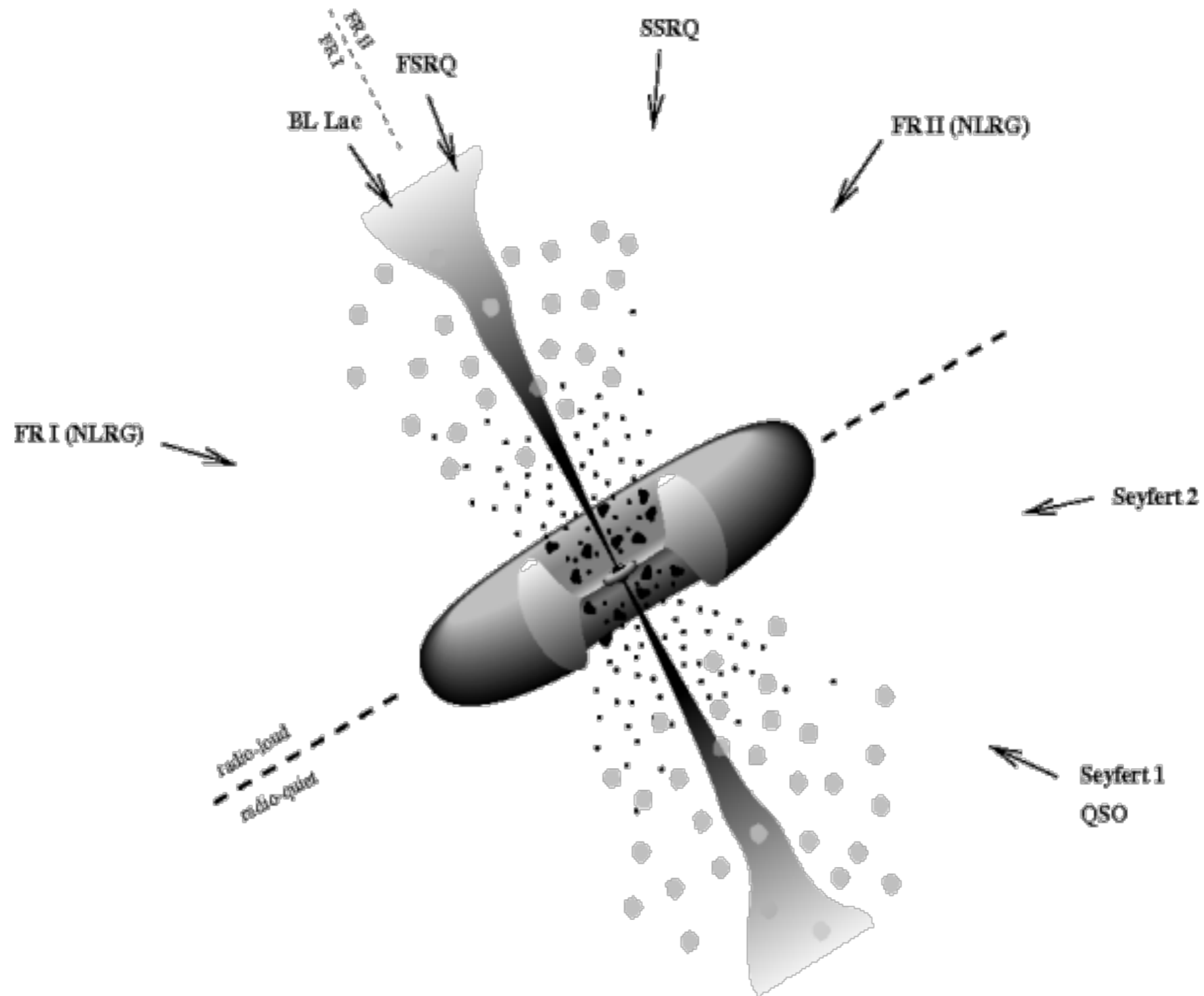
Black Holes and Relativistic jets



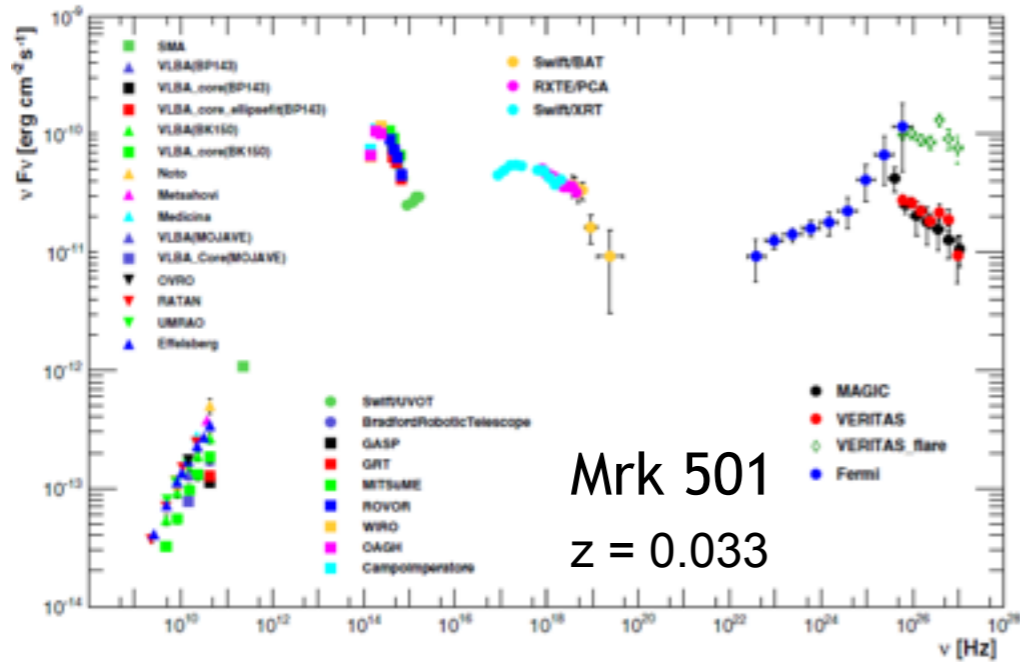
- Supermassive black holes: 10^6 - $10^9 M_{\odot}$
- Active Galactic Nuclei (**AGN**)
- Outflows of particles and radiation: **relativistic jets**.
- Aligned to our line of sight: **Blazars**.
- See them from radio to gamma-ray energies.
- Their emission is highly variable.



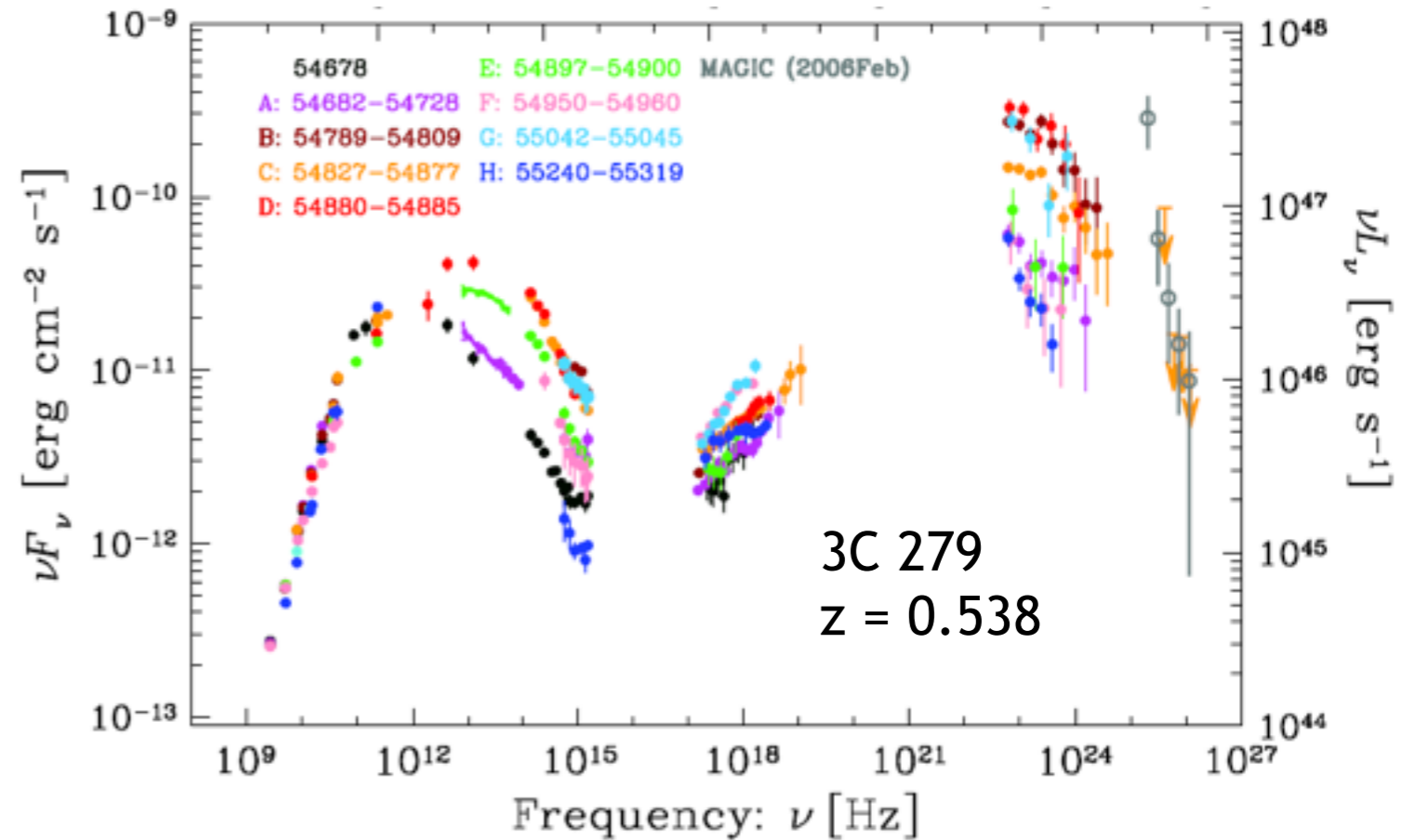
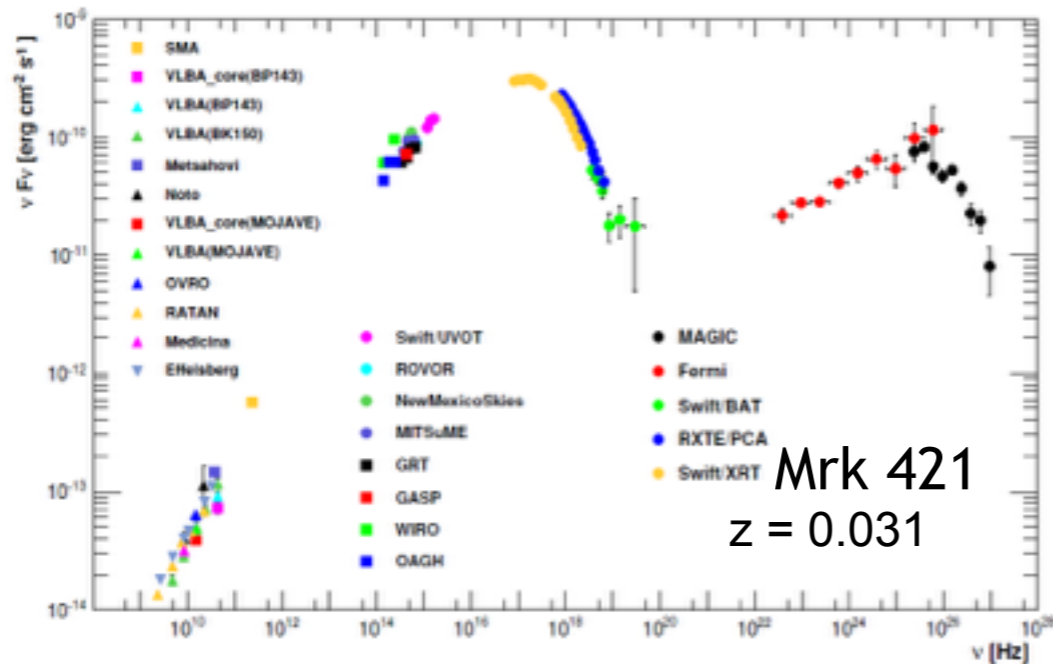
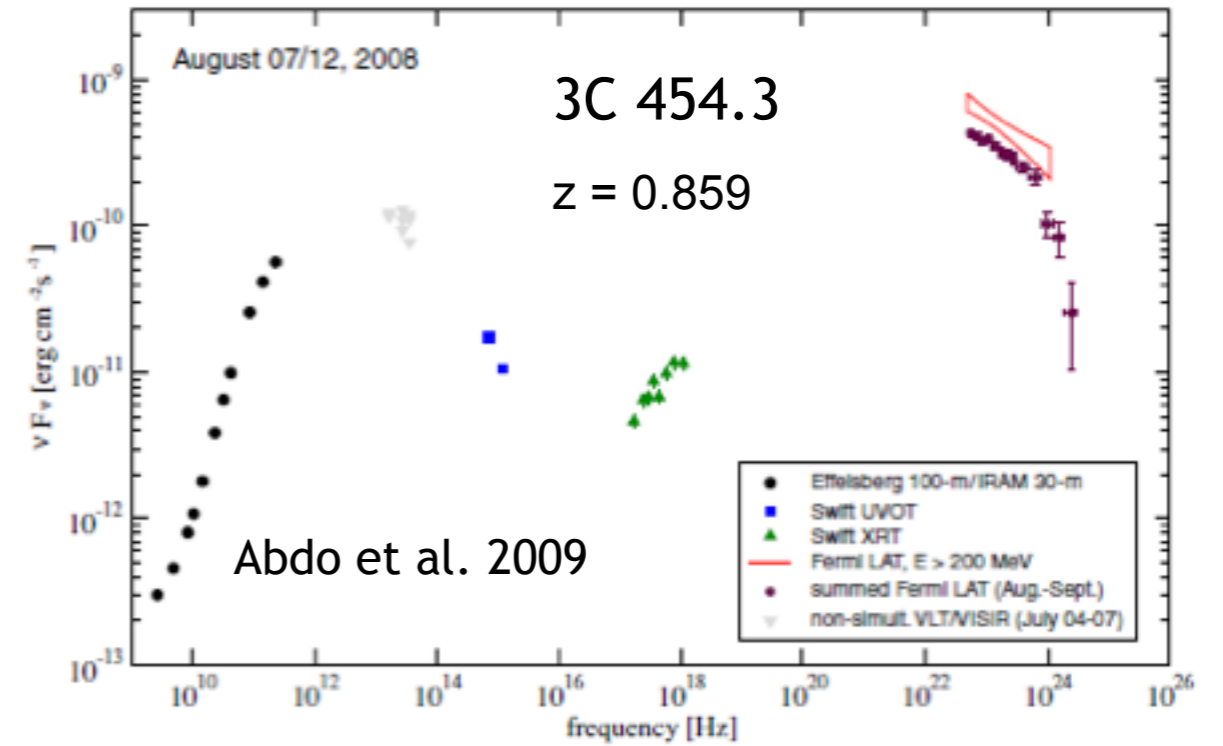
AGN



Blazar Spectral Energy Distributions

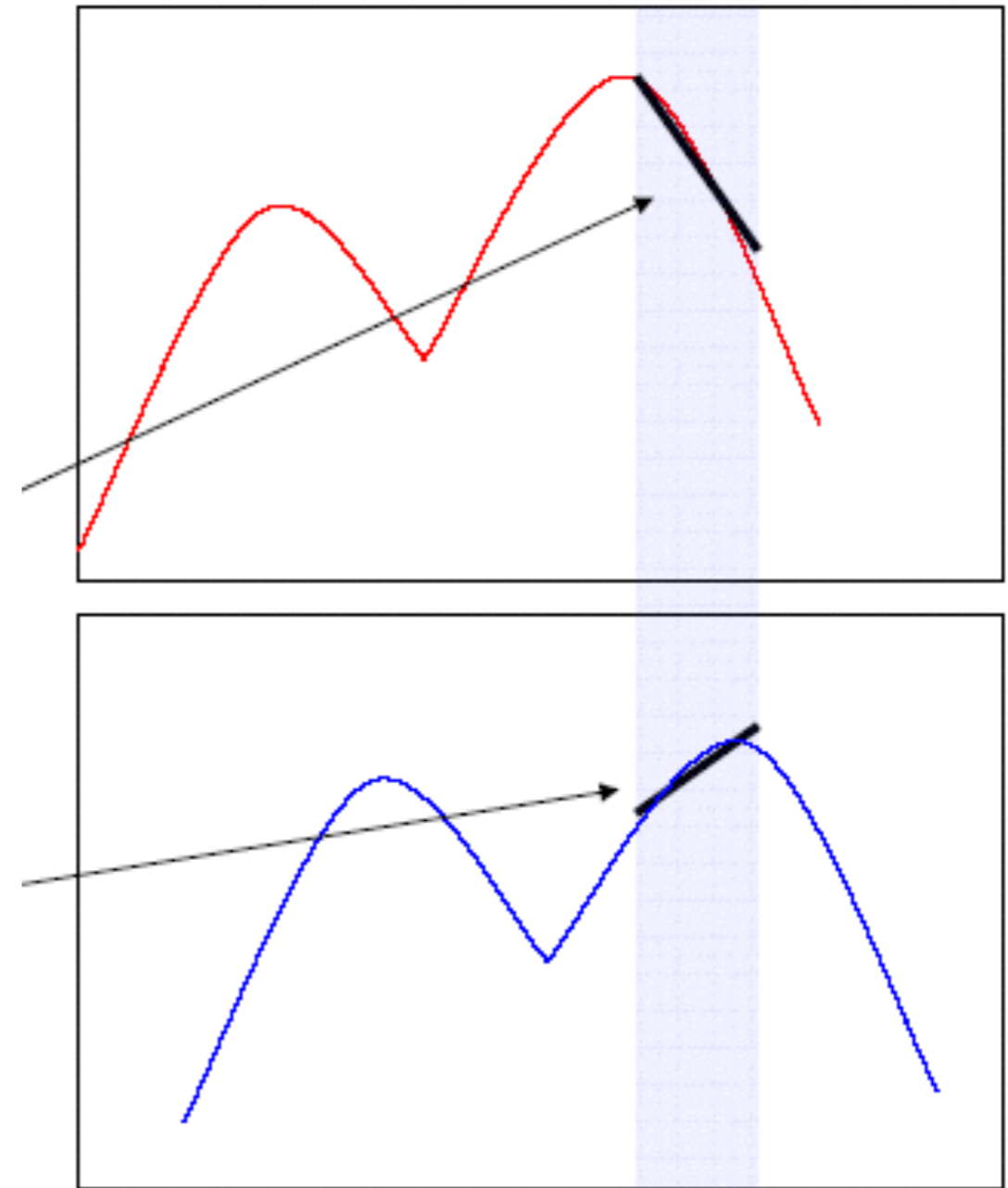
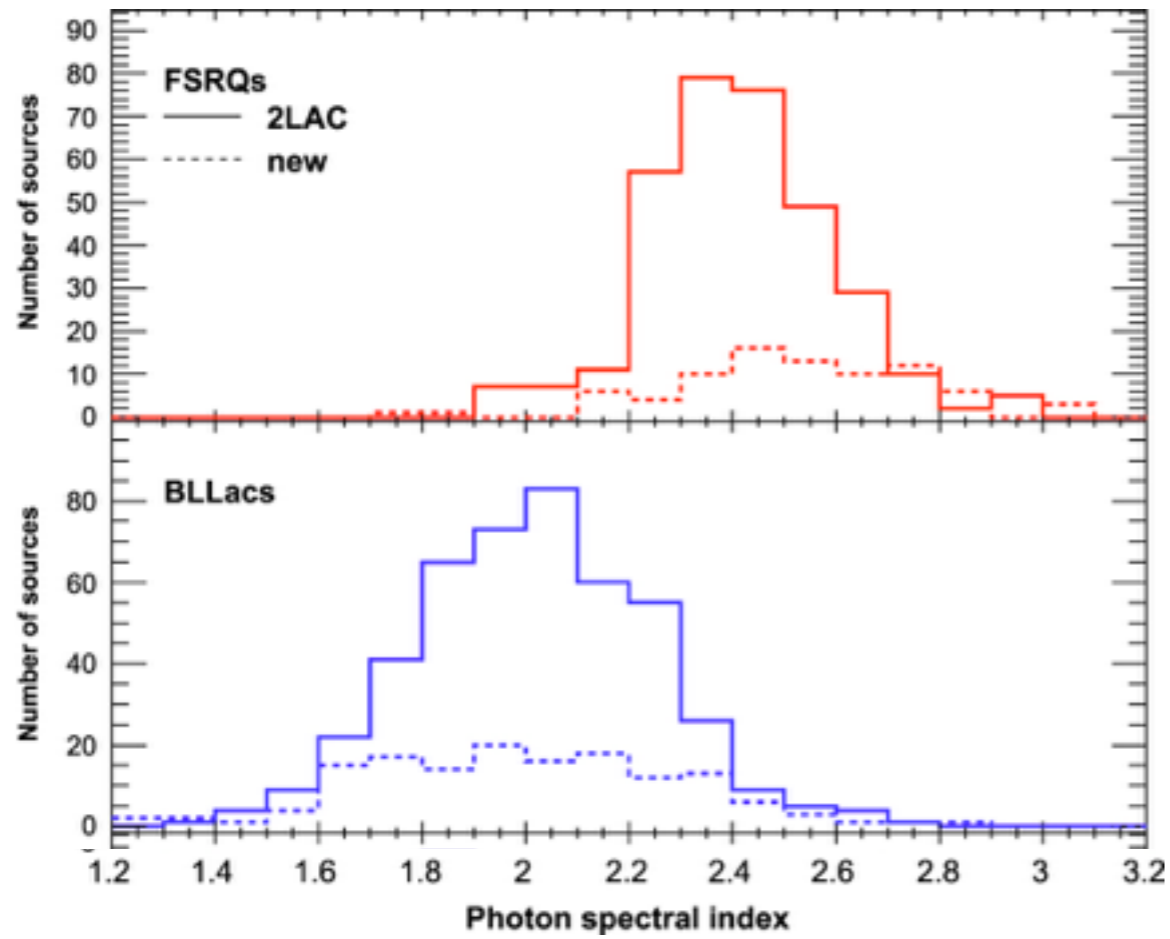


Abdo et al. 2011a



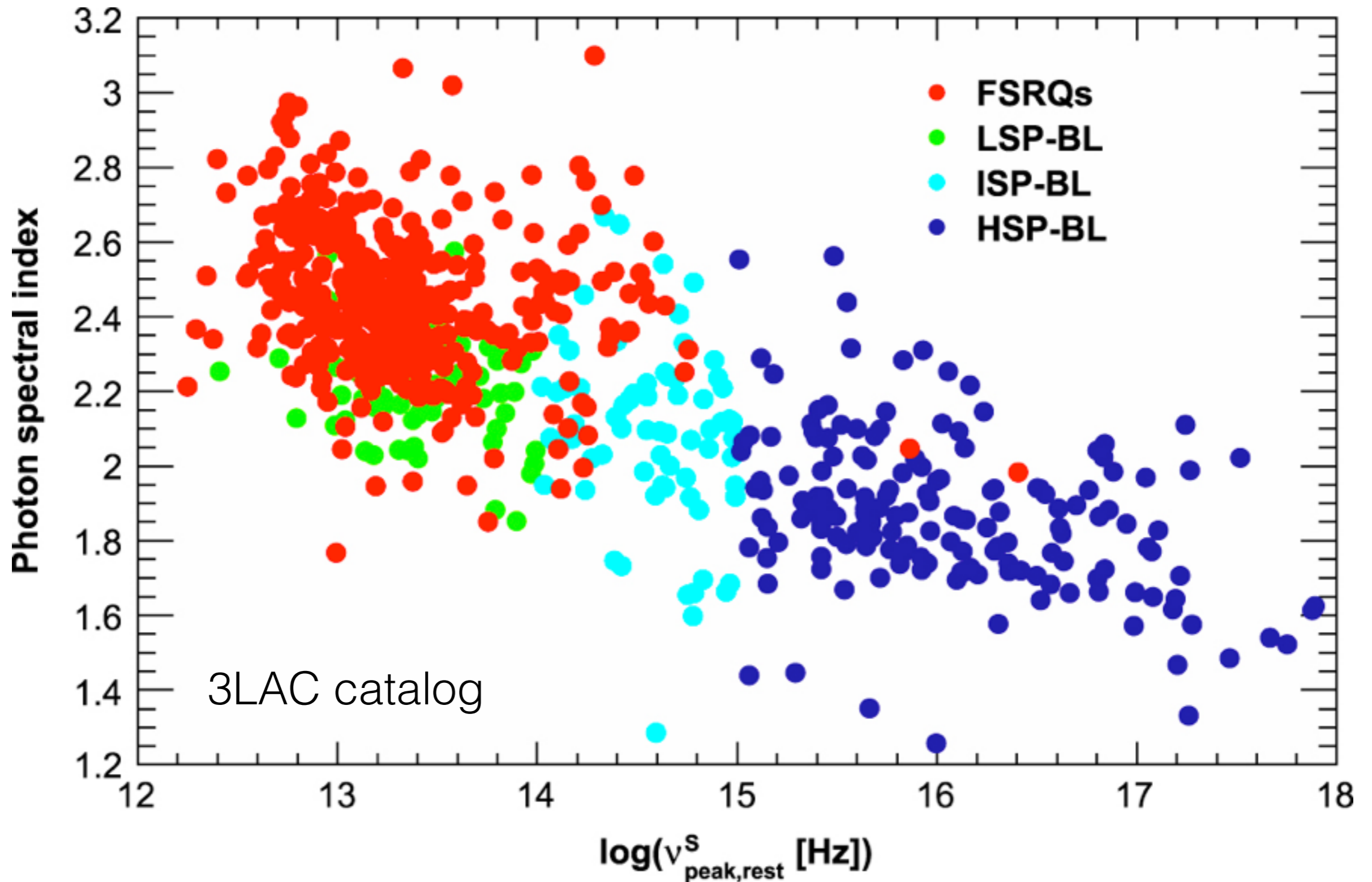
Spectral Energy Distribution and Spectral Index Distribution

Fermi 3LAC catalog

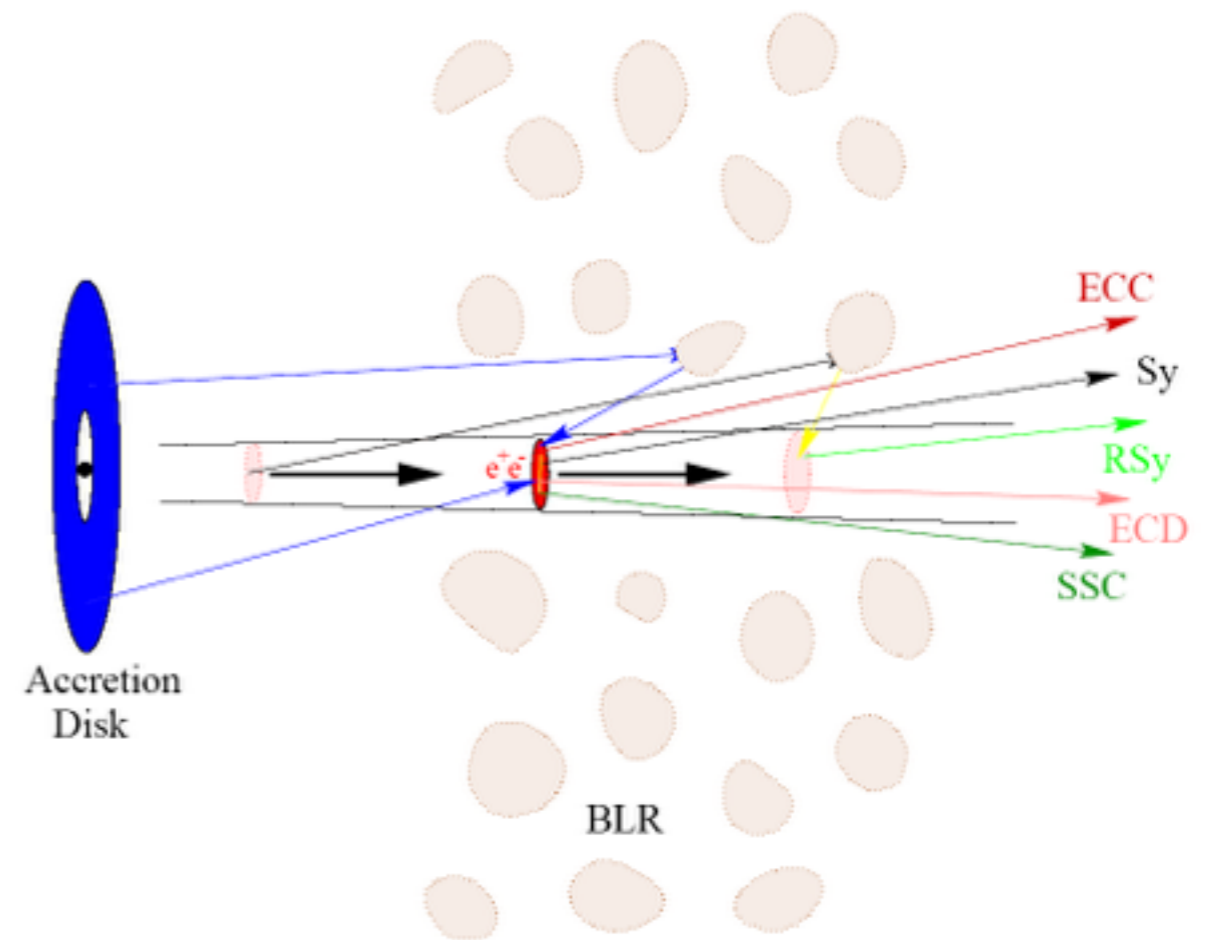
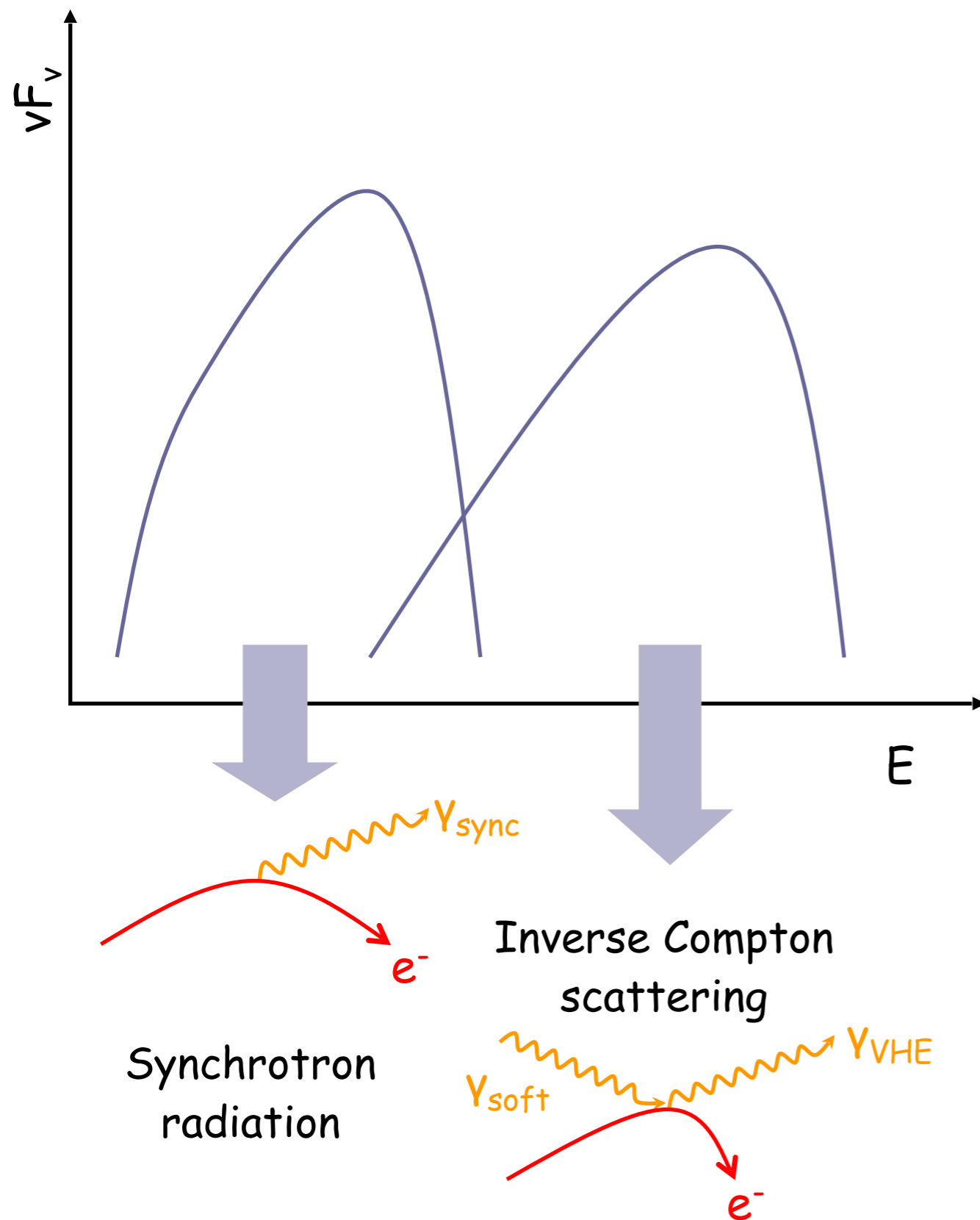


Spectral Index vs. Peak Synchrotron Frequency

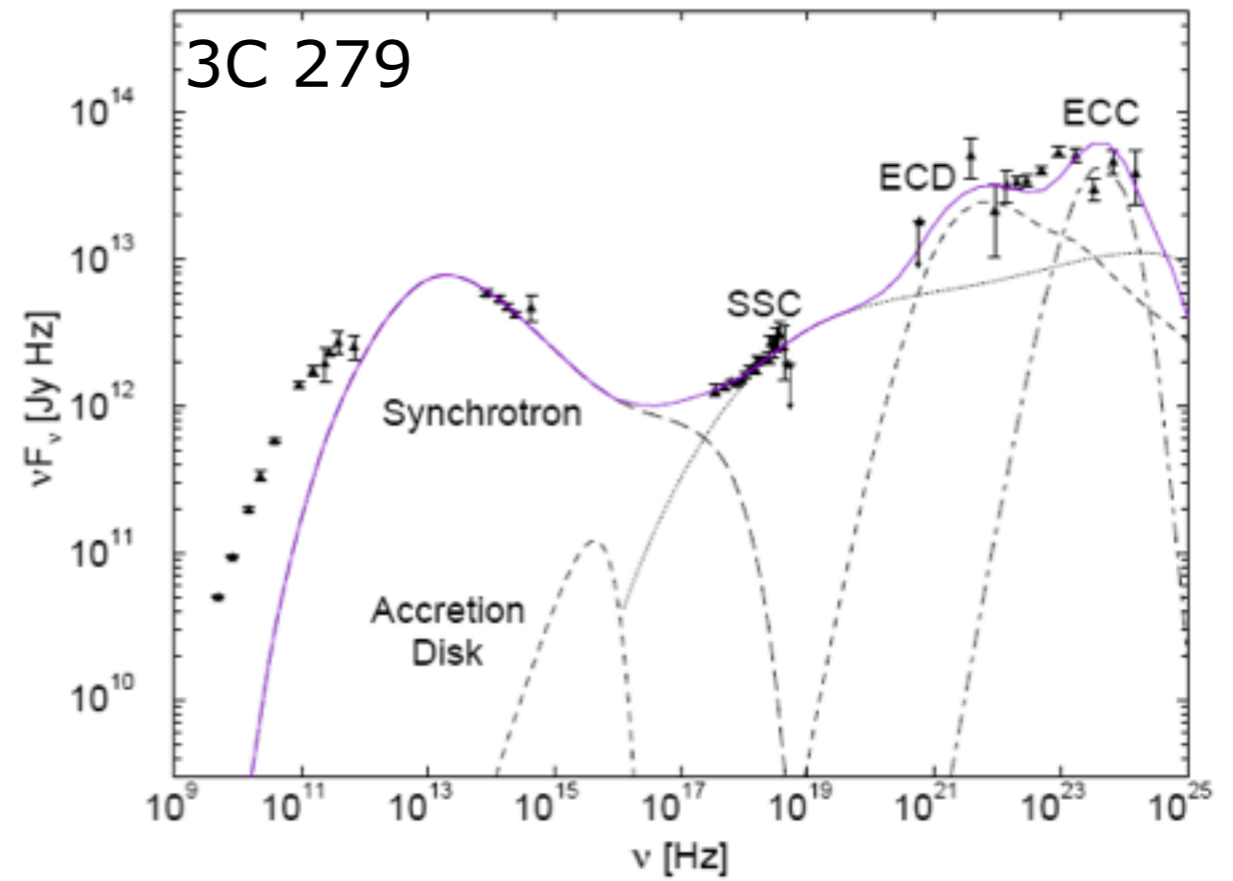
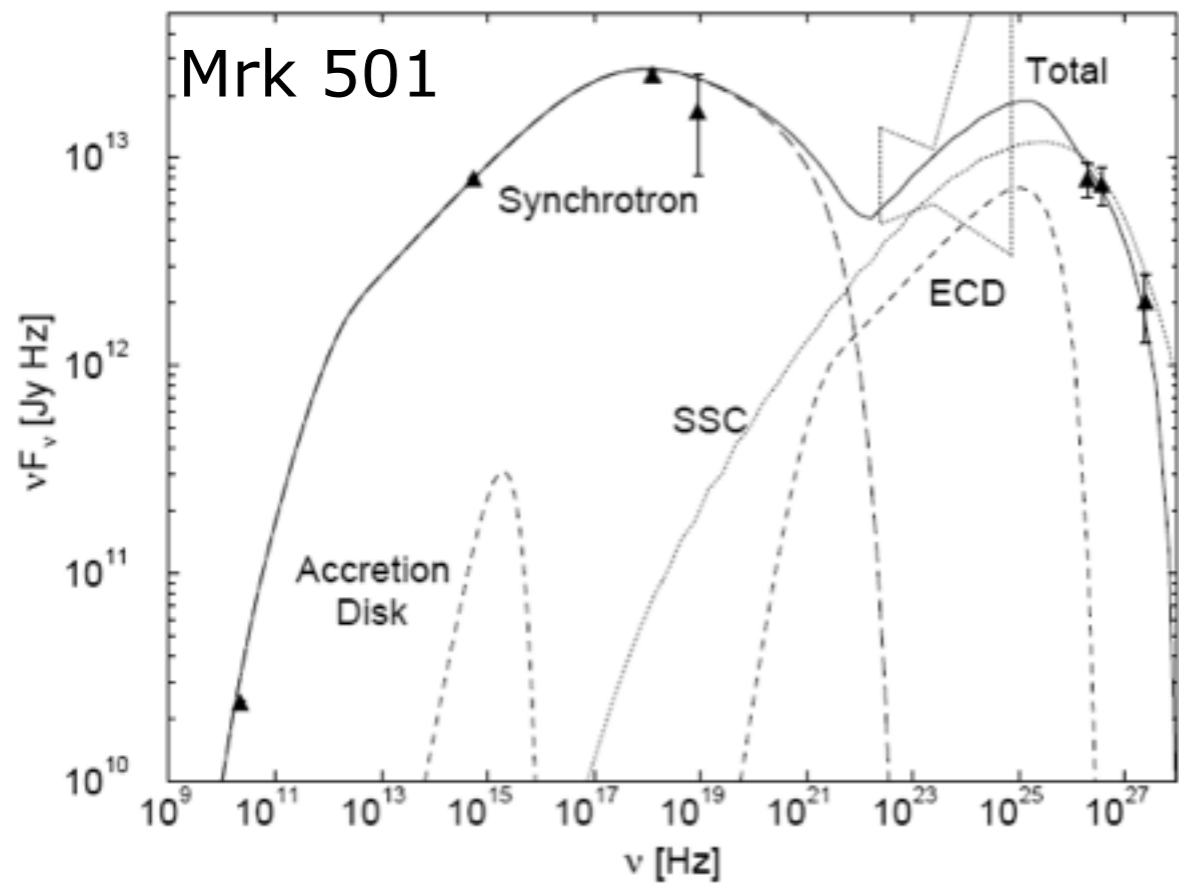
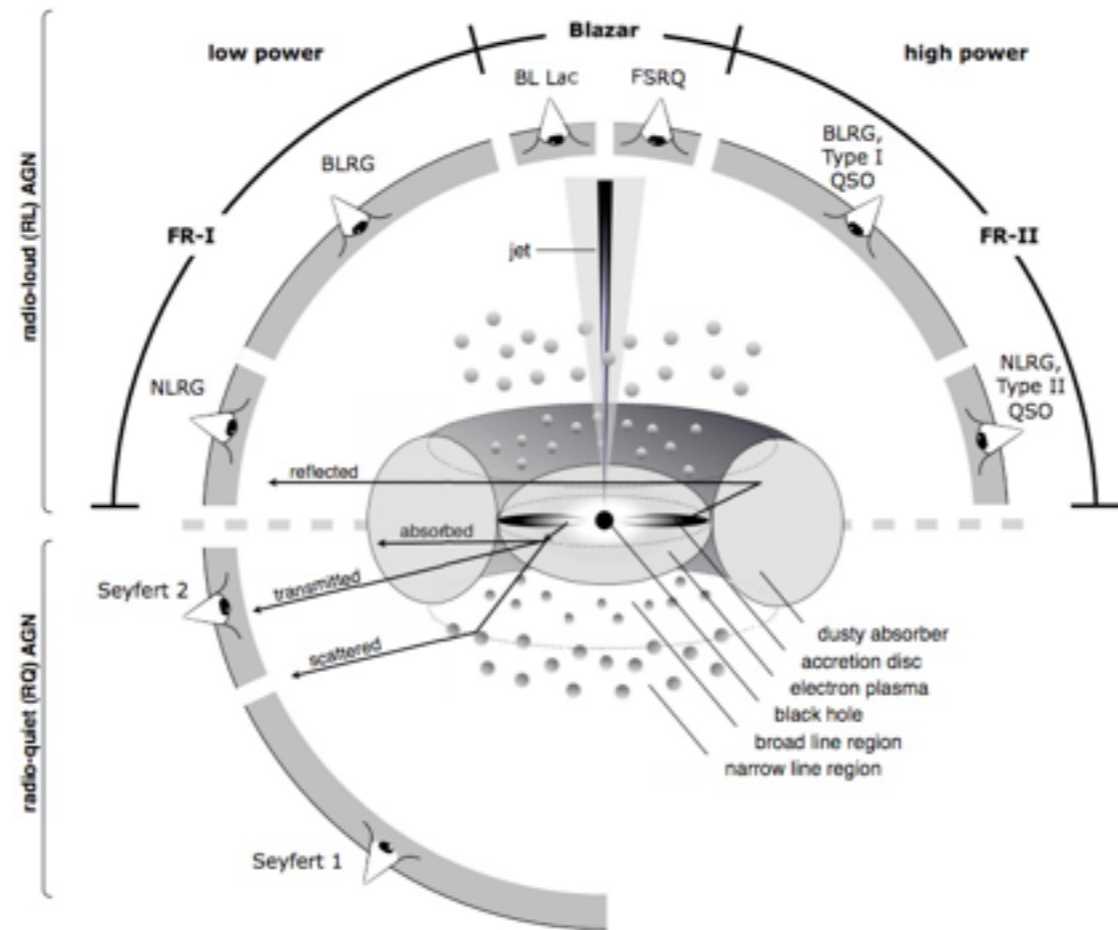
> 100 MeV γ -ray photon index vs. peak synchrotron frequency



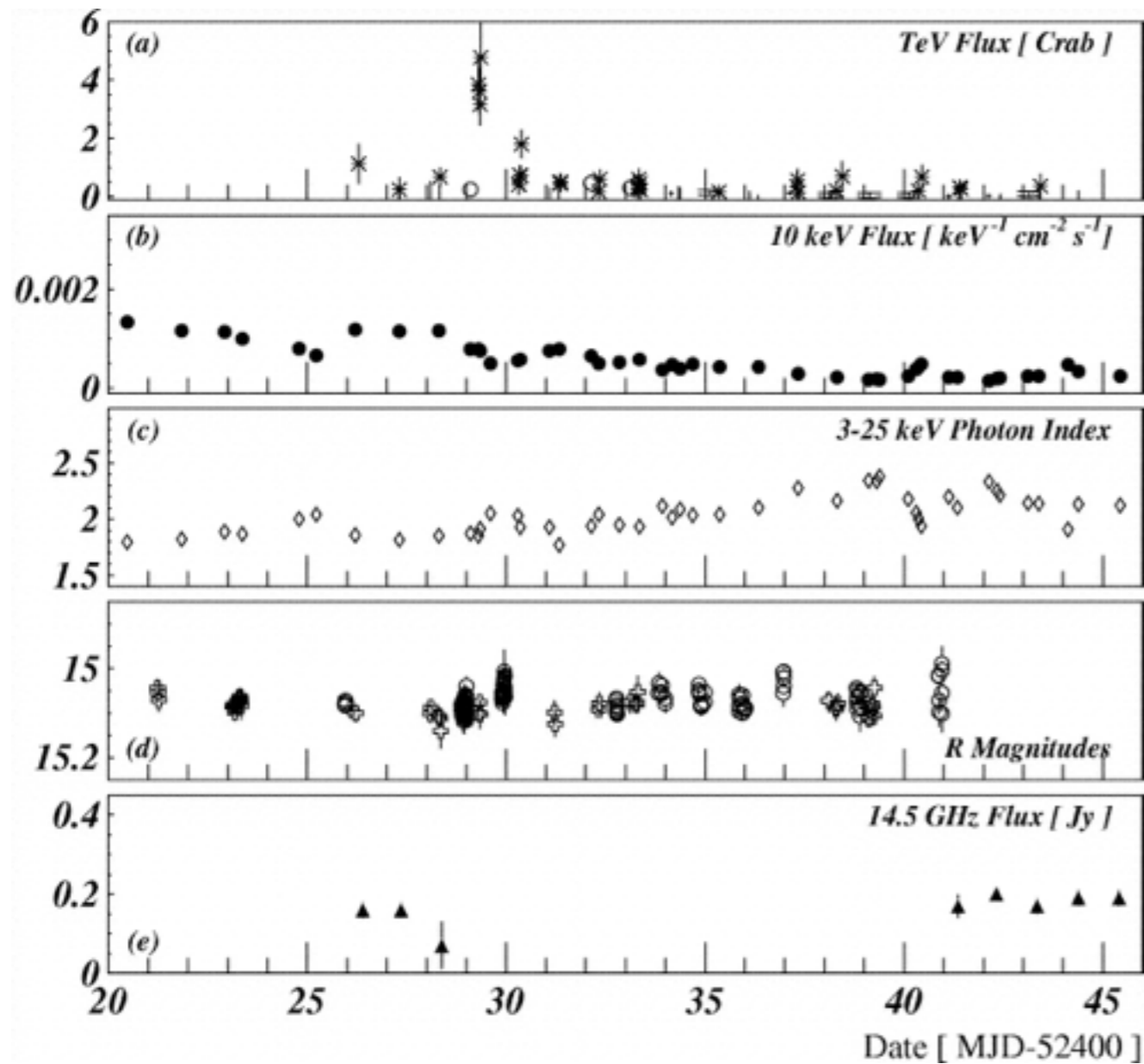
Leptonic models



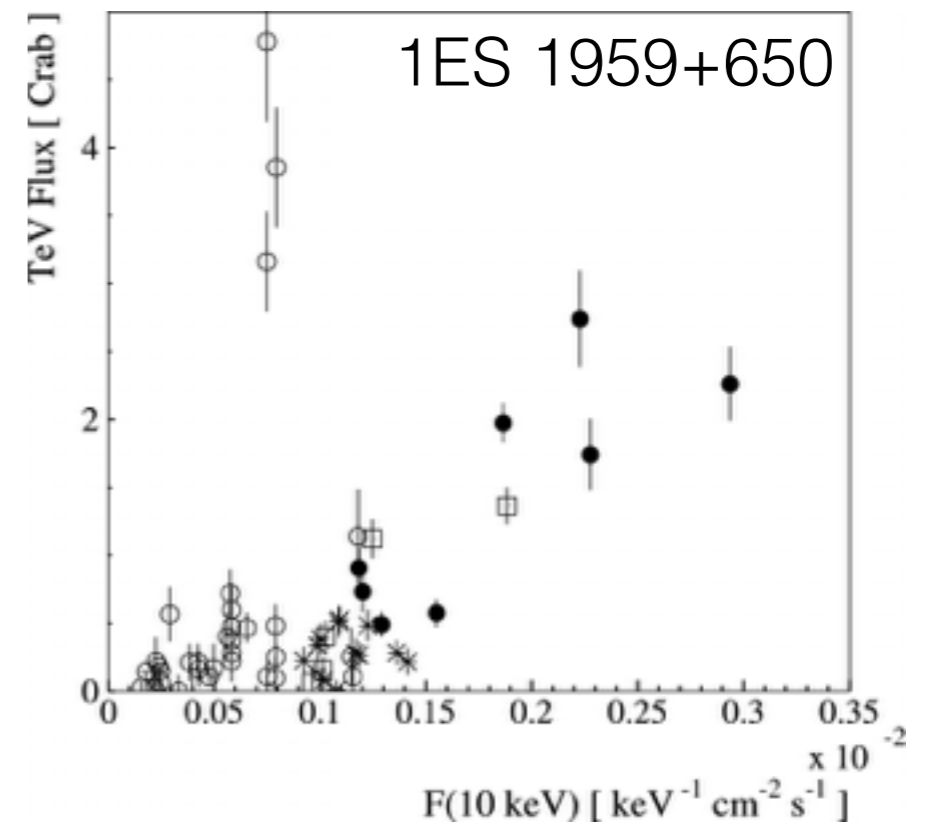
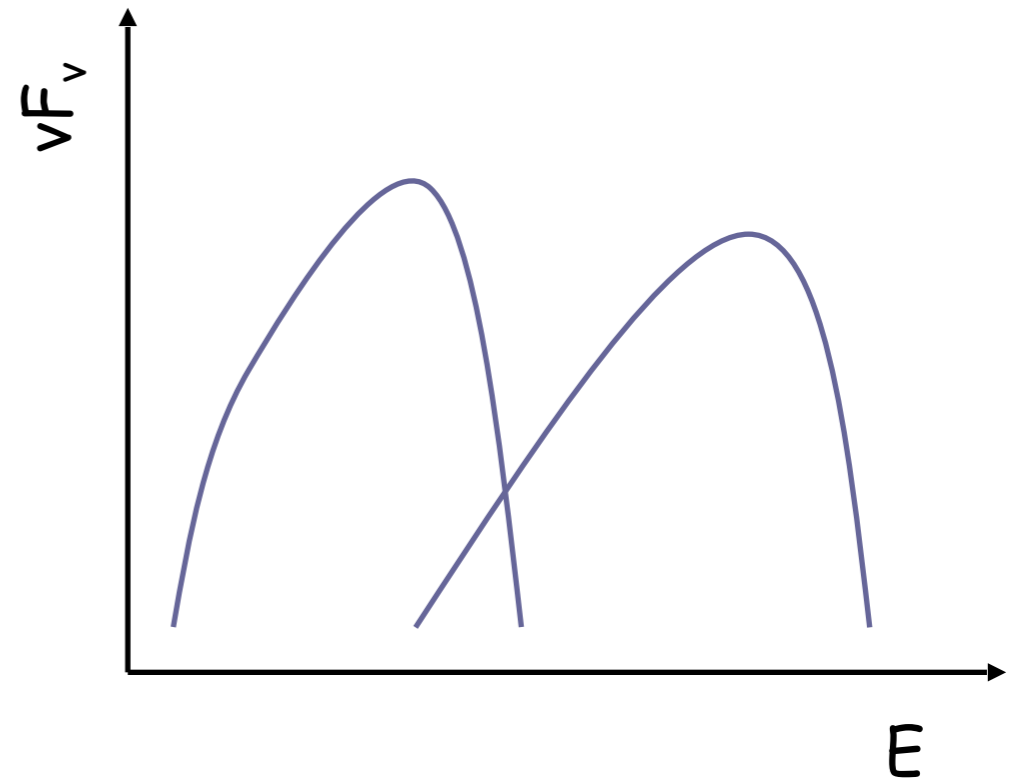
- Soft photon population:
 - SSC: synchrotron photons
 - Emission from the disk
 - Broad Line Region
 - Reprocessed emission from the dust torus



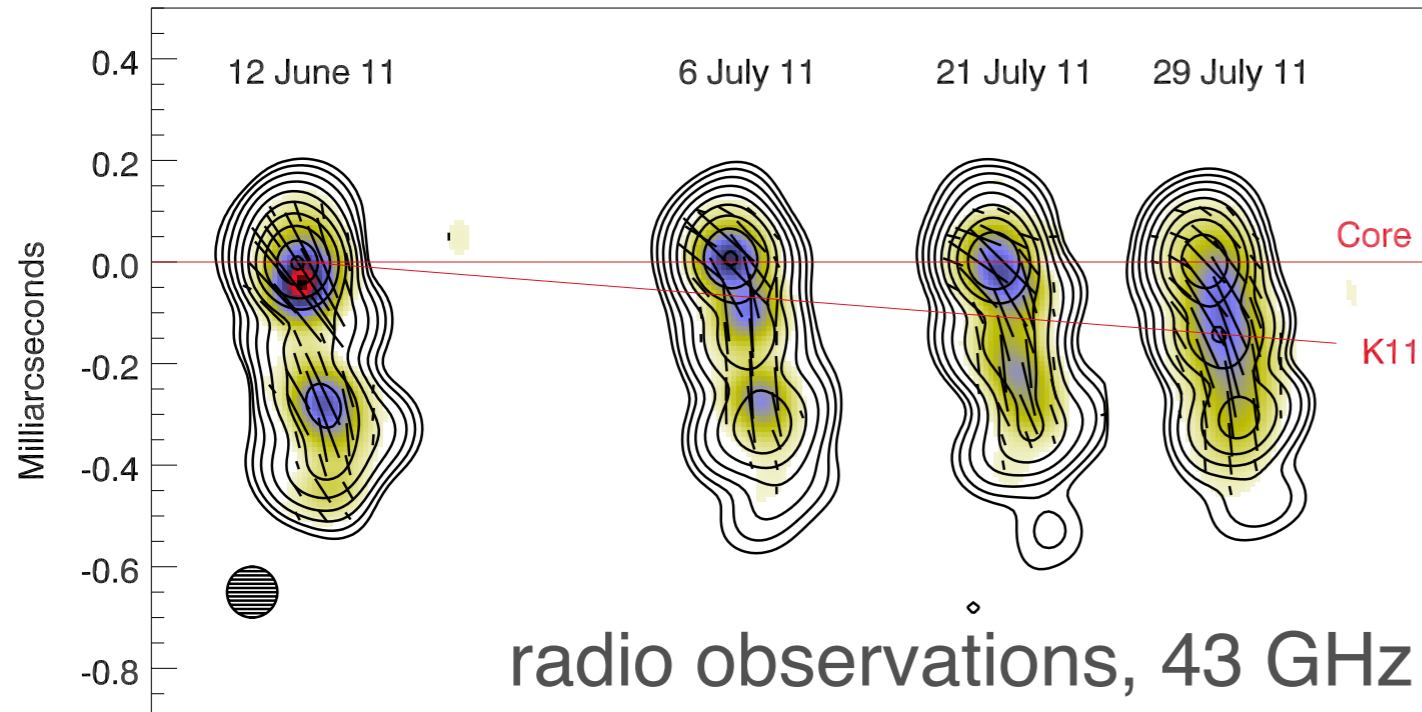
Correlated variability



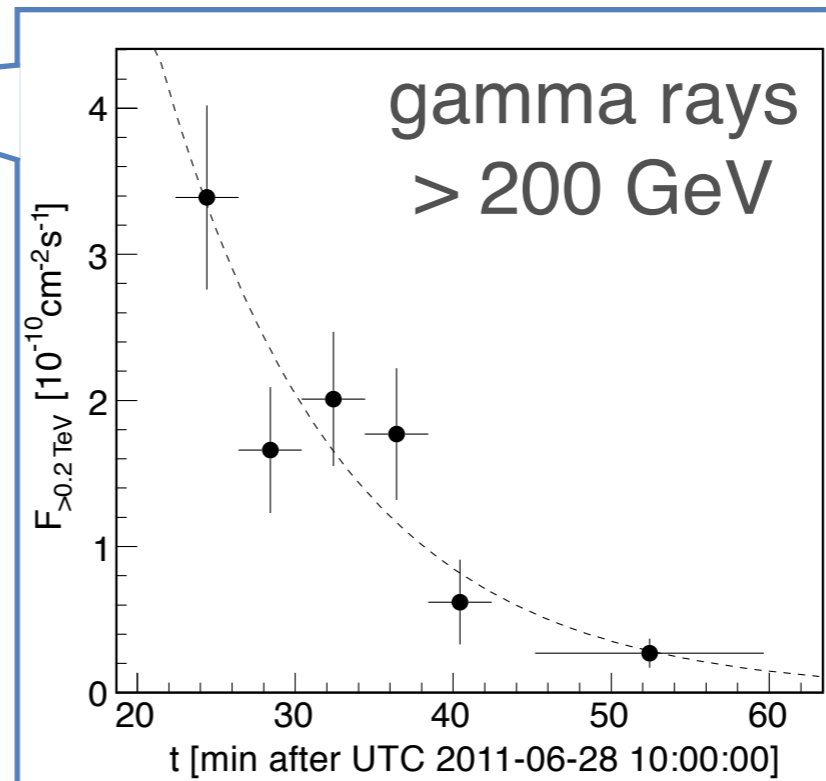
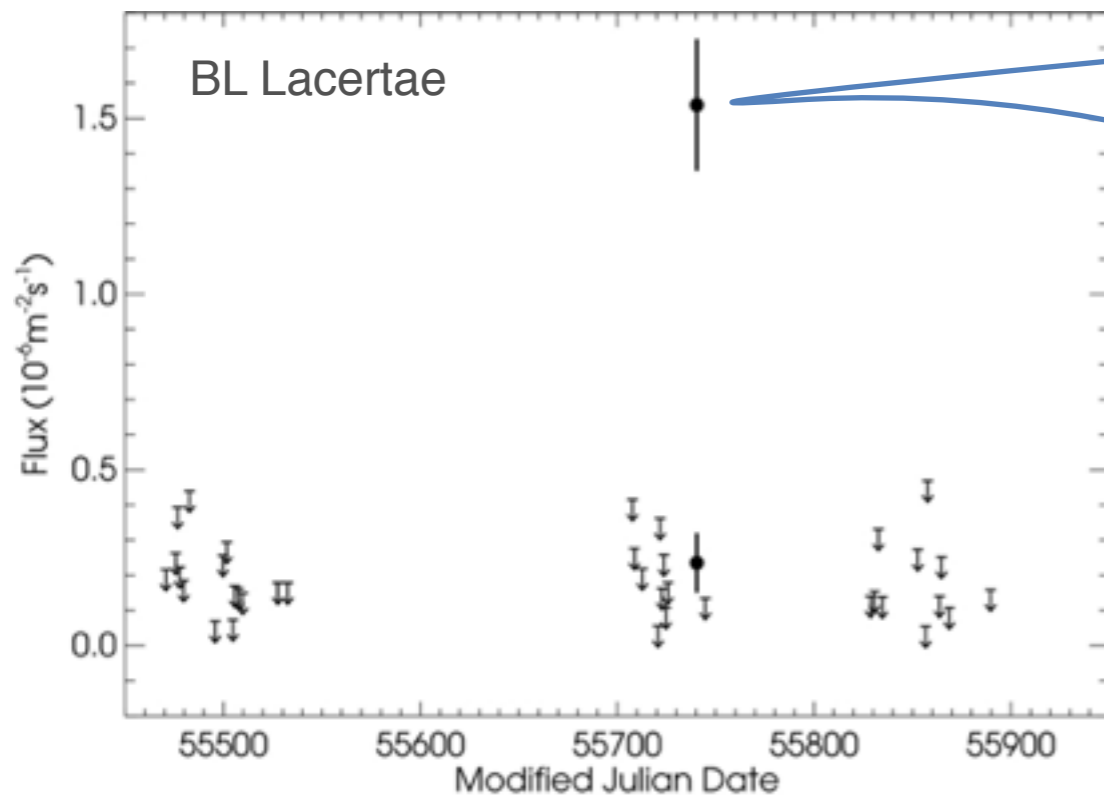
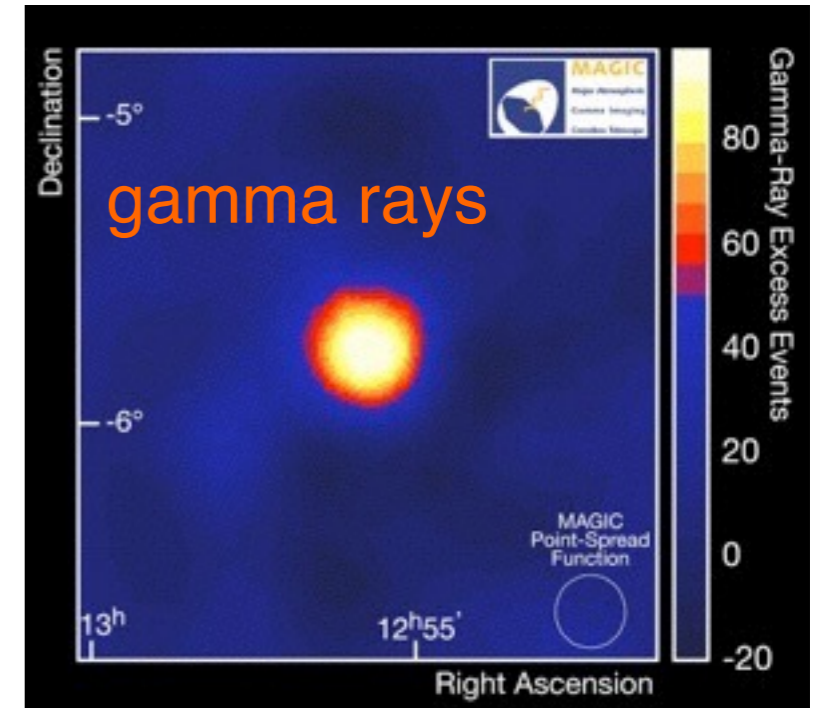
Krawczynski et al. 2004



Location of the gamma-ray emission



0.5 mas
 1 deg
 x10⁸ zoom

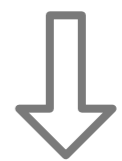


$$R < ct_{var} \delta$$

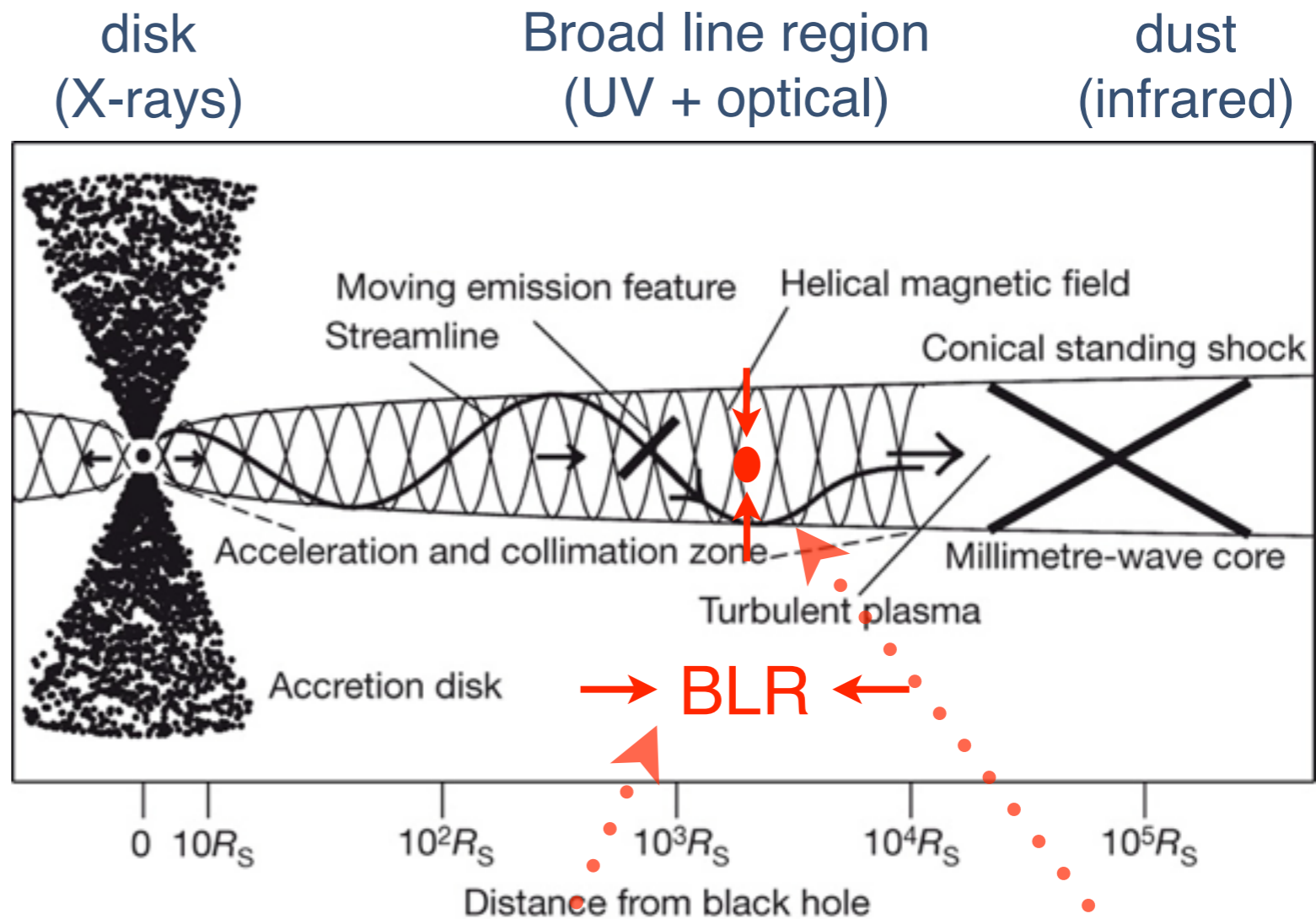
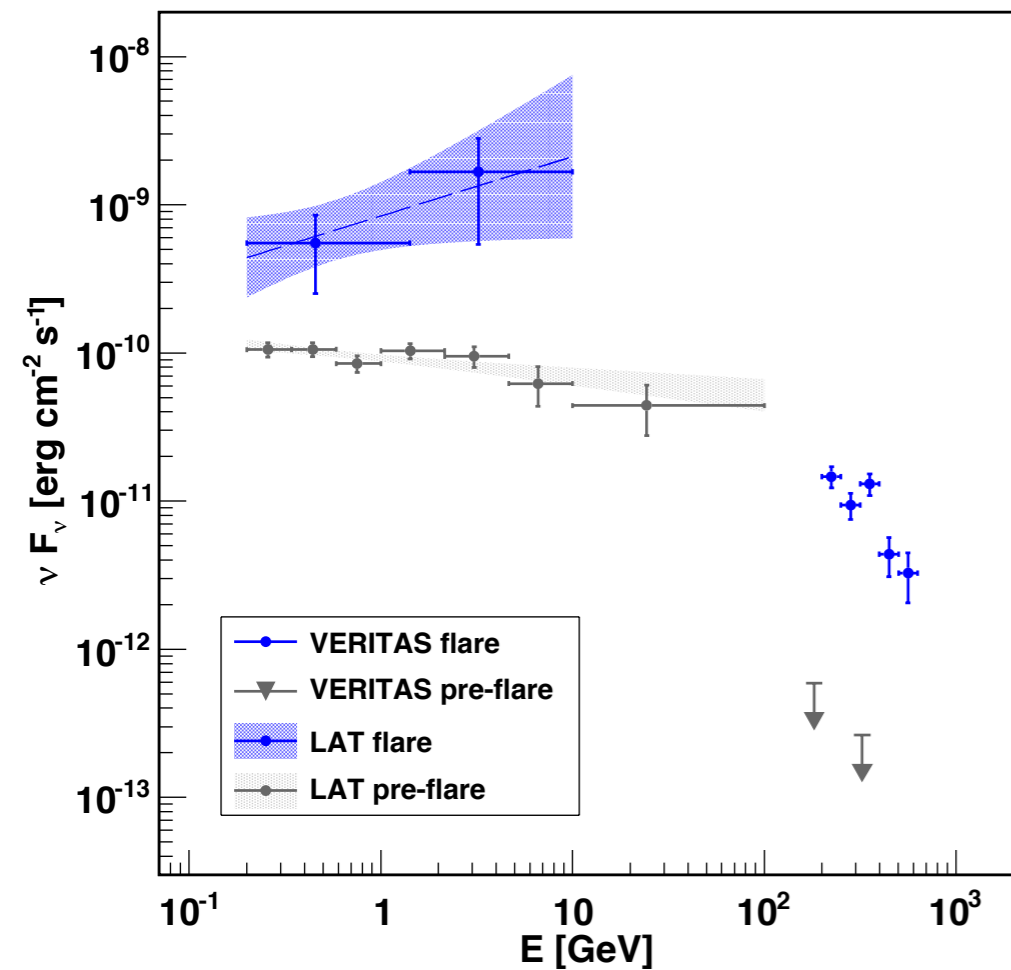
$$t_{var} = 13 \text{ min}$$

$$\delta \sim 10$$

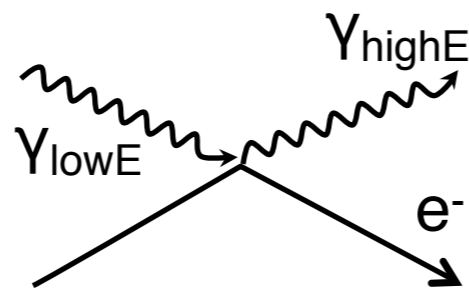
$$R < 3 \times 10^{12} \text{ m}$$



10 a.u. !



inverse Compton scattering

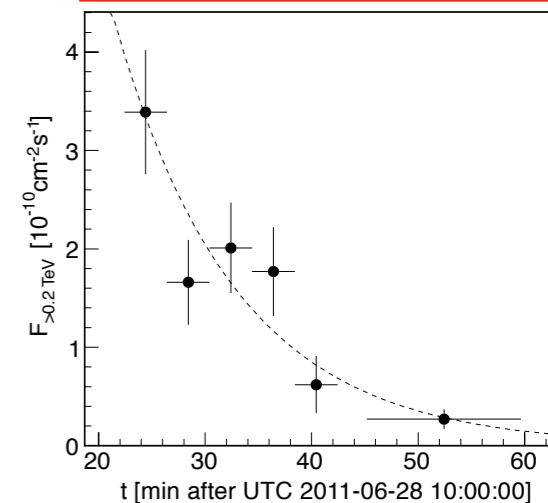


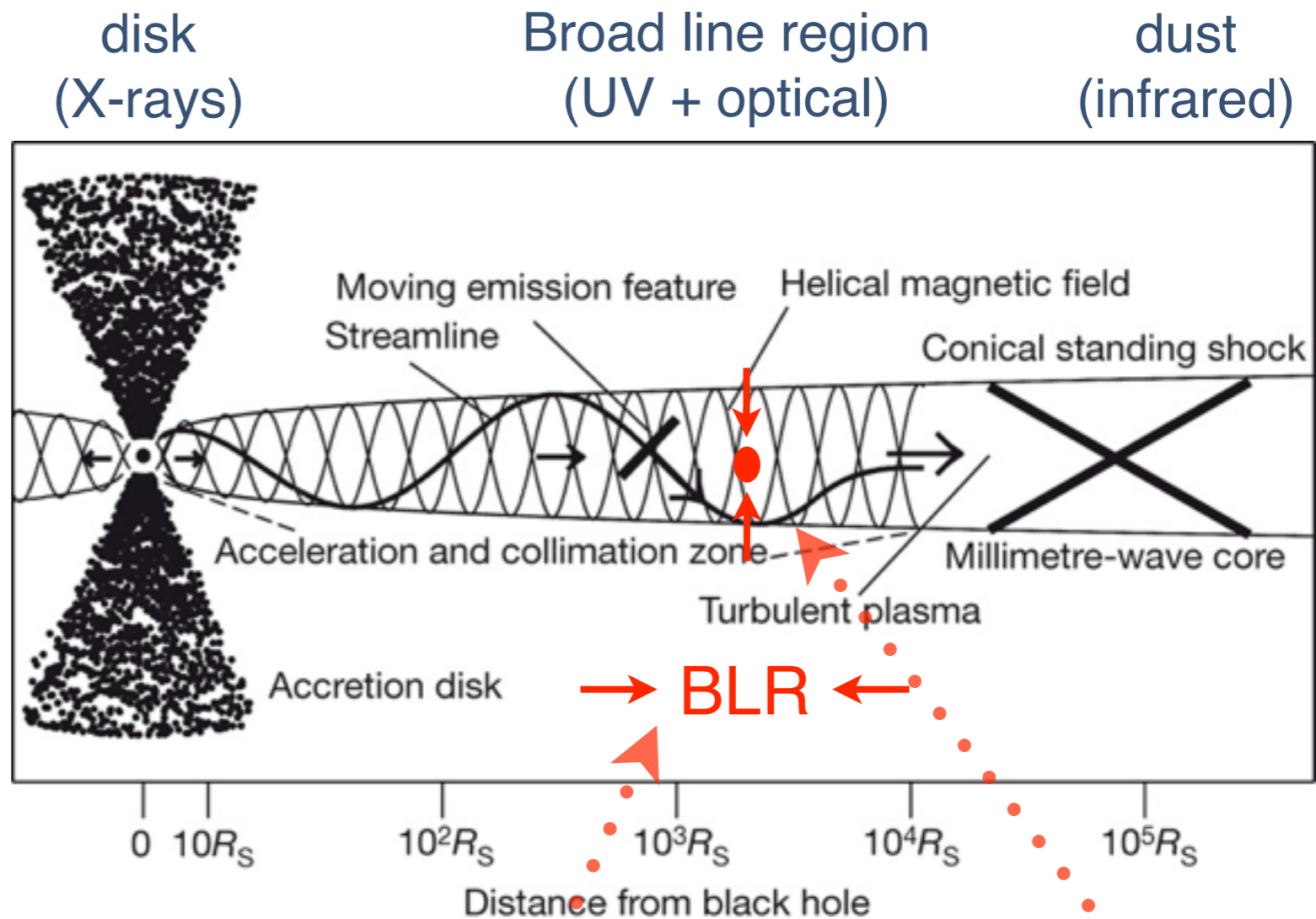
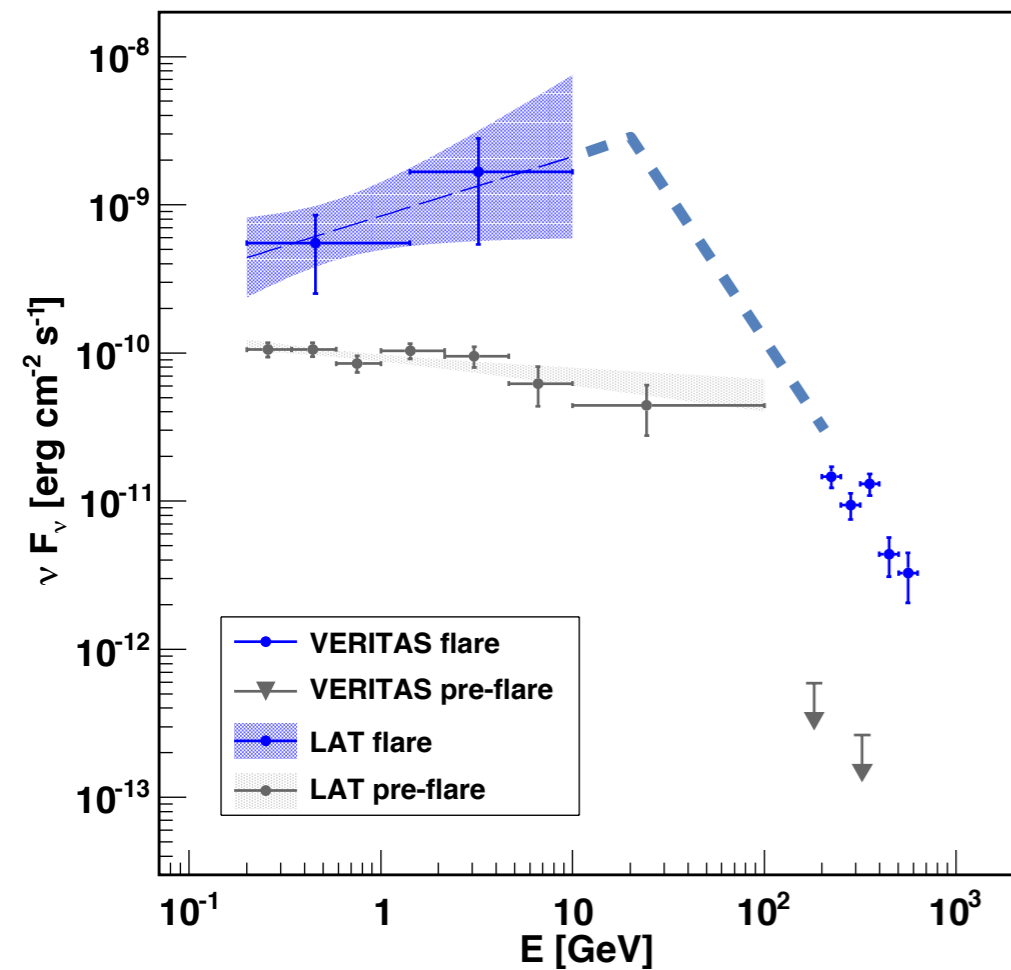
- Transition from Thompson to Klein-Nishina regime

Spectral break at ~ 10 GeV
electrons cooling on ~ 10 eV photons

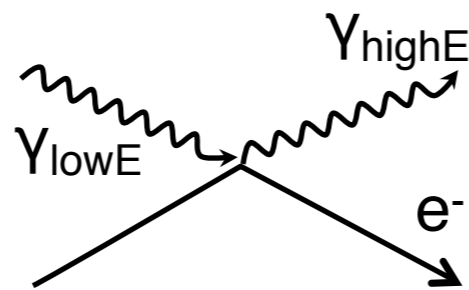
Turbulence

Rapid variability





inverse Compton scattering

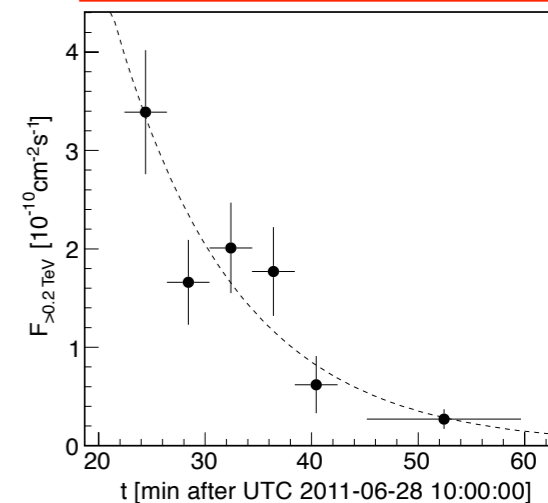


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Spectral break at ~ 10 GeV
electrons cooling on ~ 10 eV photons

Turbulence

Rapid variability



Hadronic models

$$p \gamma \rightarrow p \pi^0$$

$$\hookrightarrow 2\gamma$$

$$p \gamma \rightarrow n \pi^+$$

$$\hookrightarrow \mu \nu$$

$$\hookrightarrow e 2\nu$$

$$p \gamma \rightarrow p \pi^+ \pi^-$$

$$\hookrightarrow 2\mu 2\nu$$

$$\hookrightarrow 2e 2\nu$$

$$p p \rightarrow p p \pi^0$$

$$\hookrightarrow 2\gamma$$

$$p p \rightarrow p n \pi^+$$

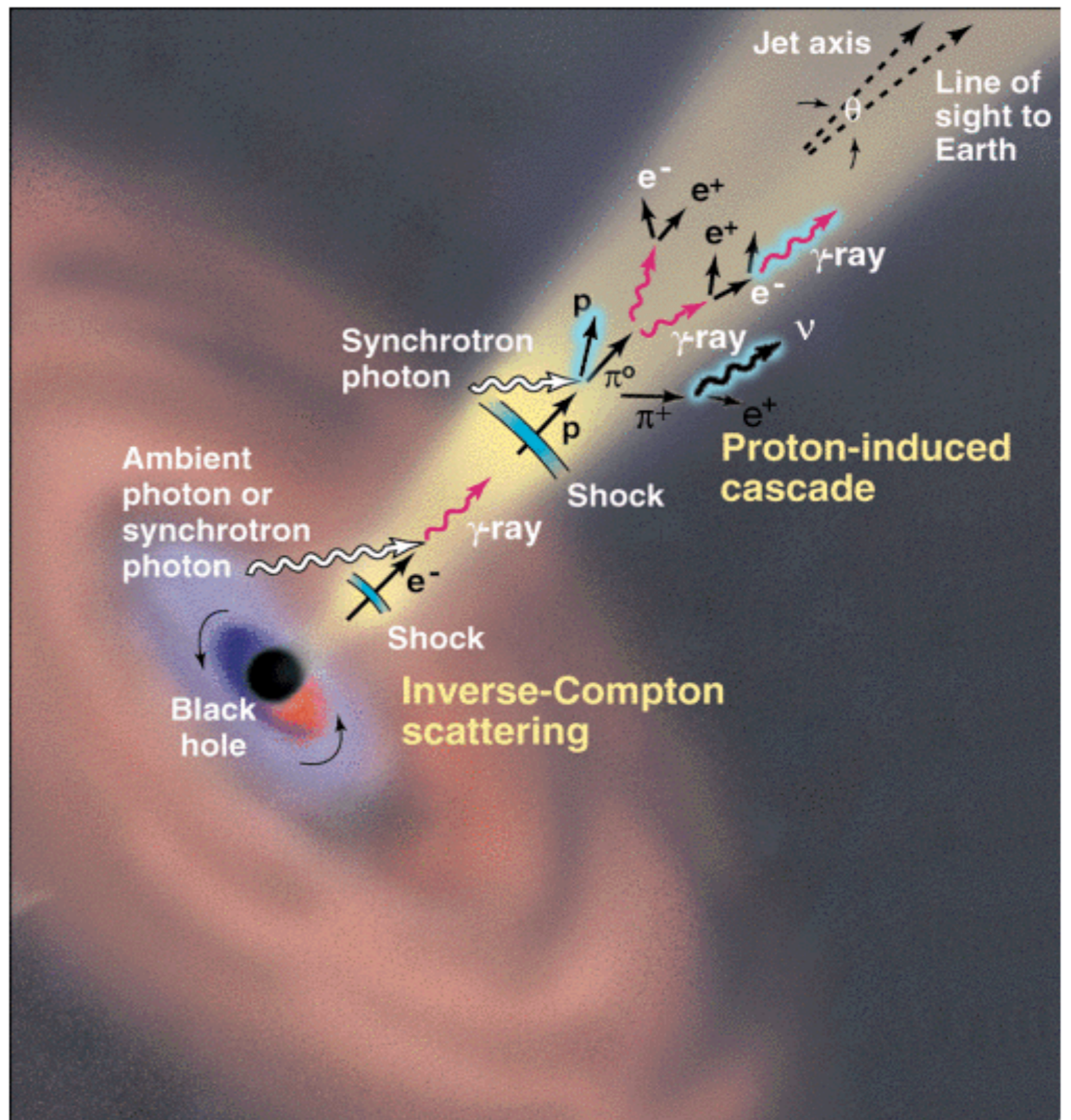
$$\hookrightarrow \mu \nu$$

$$\hookrightarrow e 2\nu$$

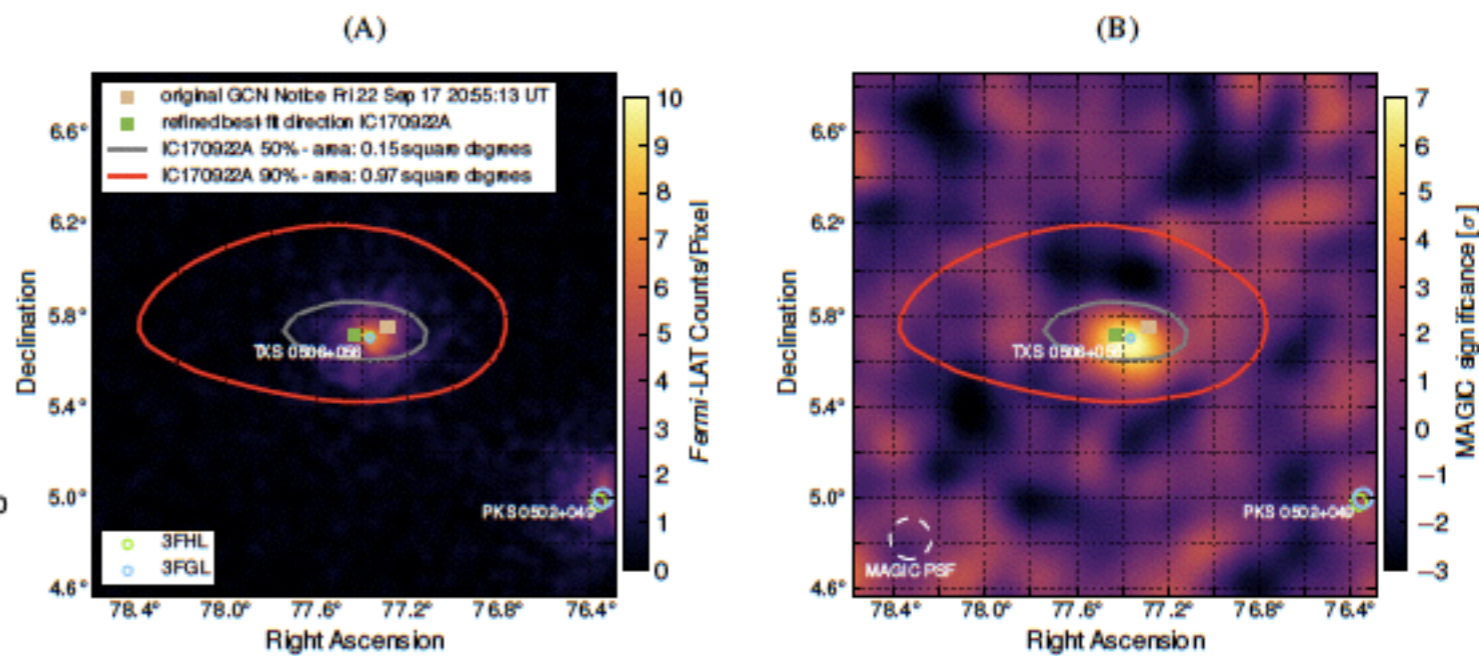
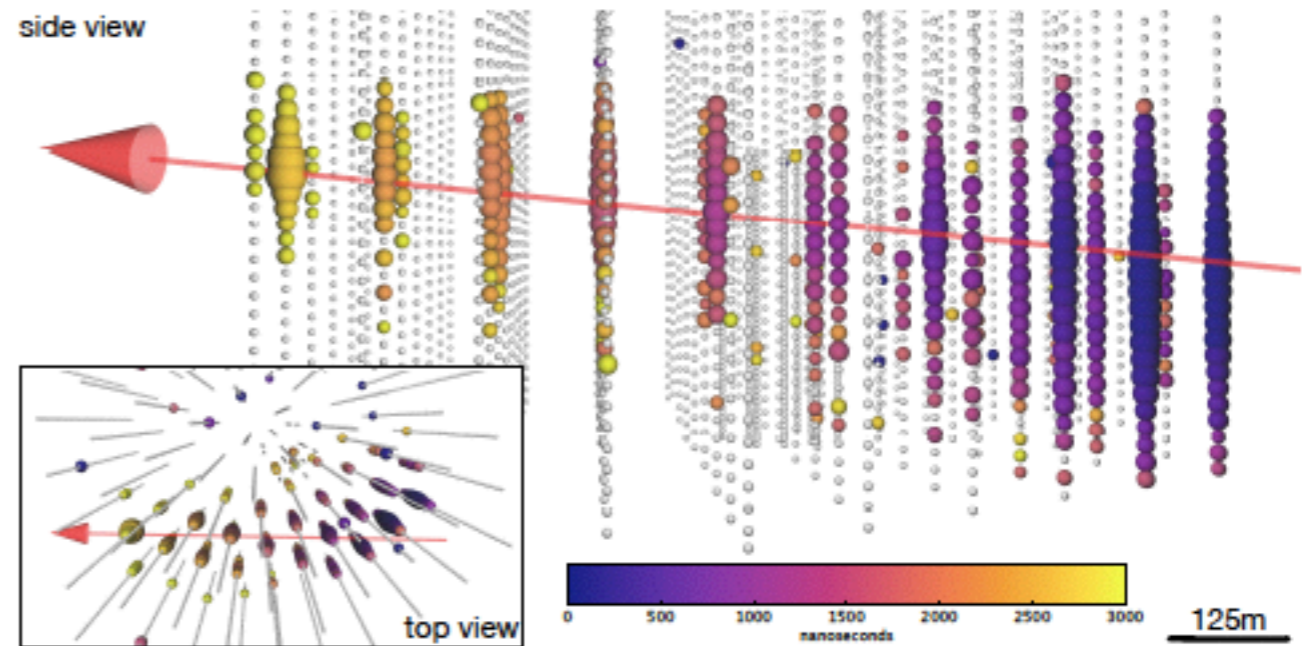
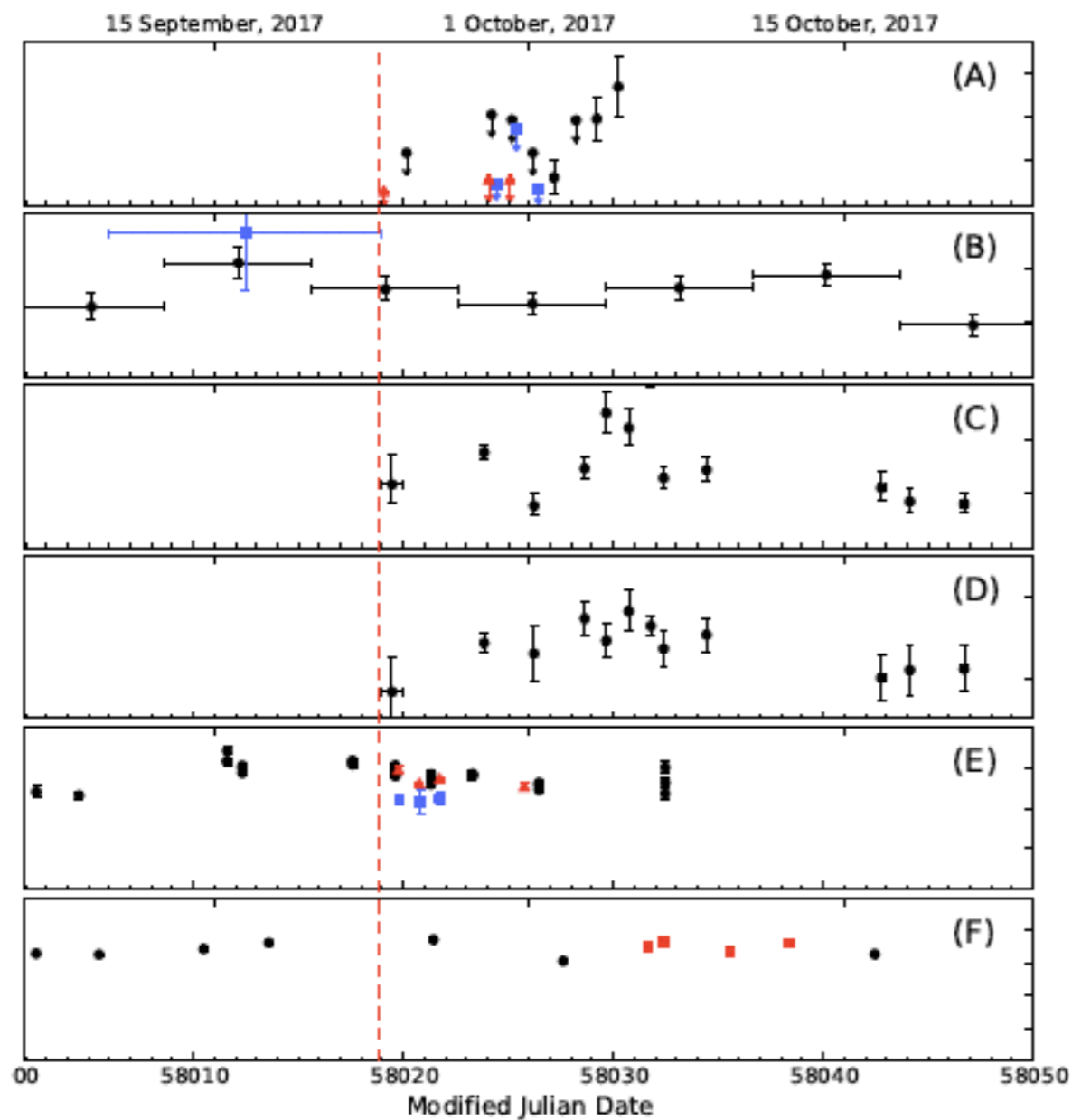
$$p p \rightarrow n n 2\pi^+$$

$$\hookrightarrow 2\mu 2\nu$$

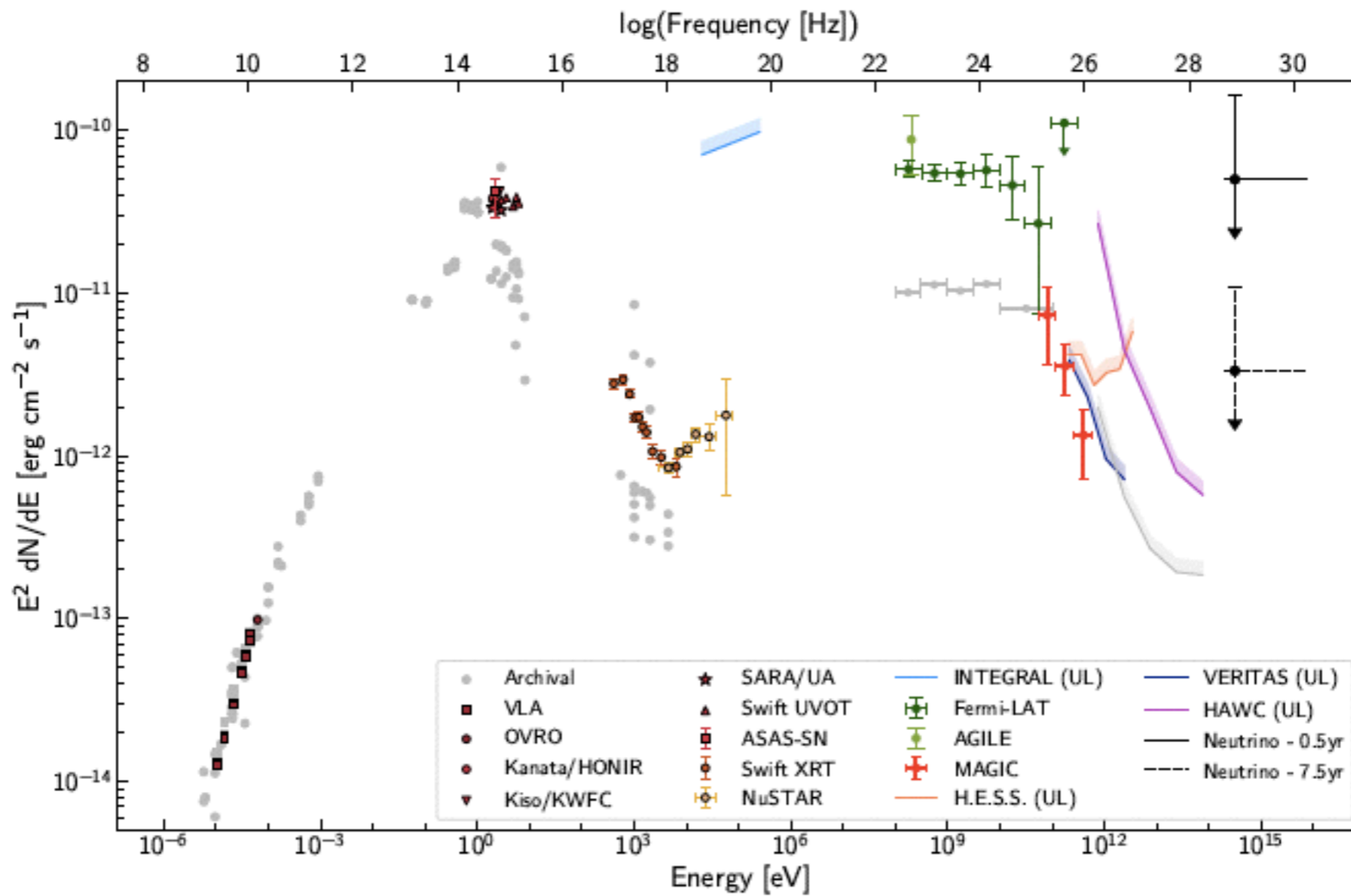
$$\hookrightarrow 2e 2\nu$$



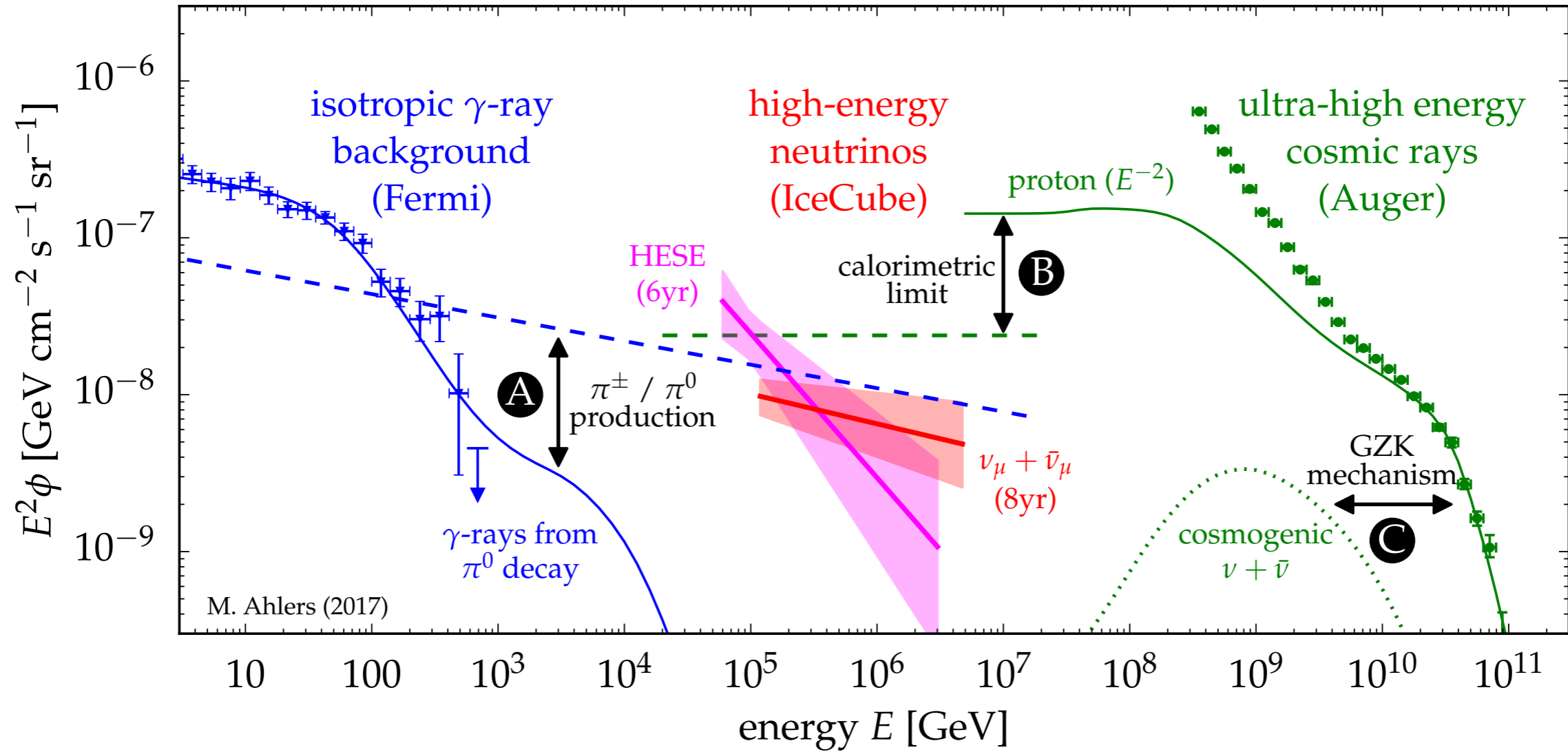
TXS 0506+056



TXS 0506+056



Hadronic models

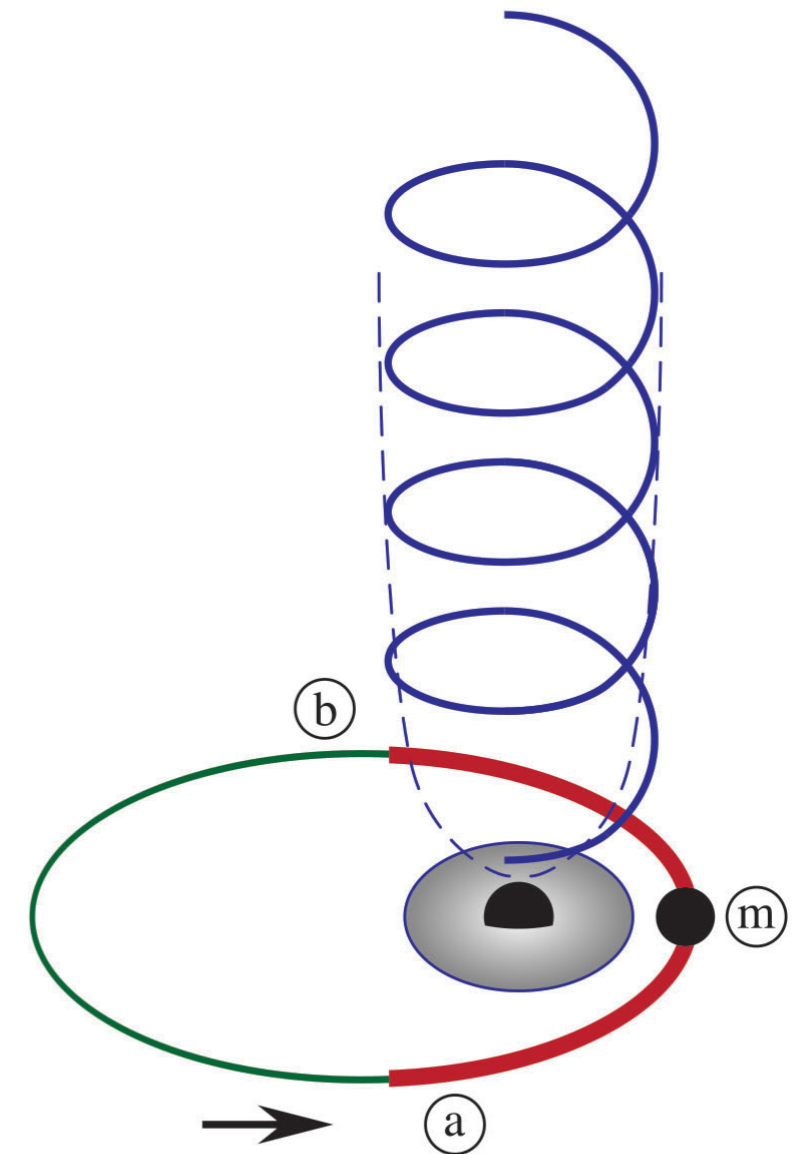
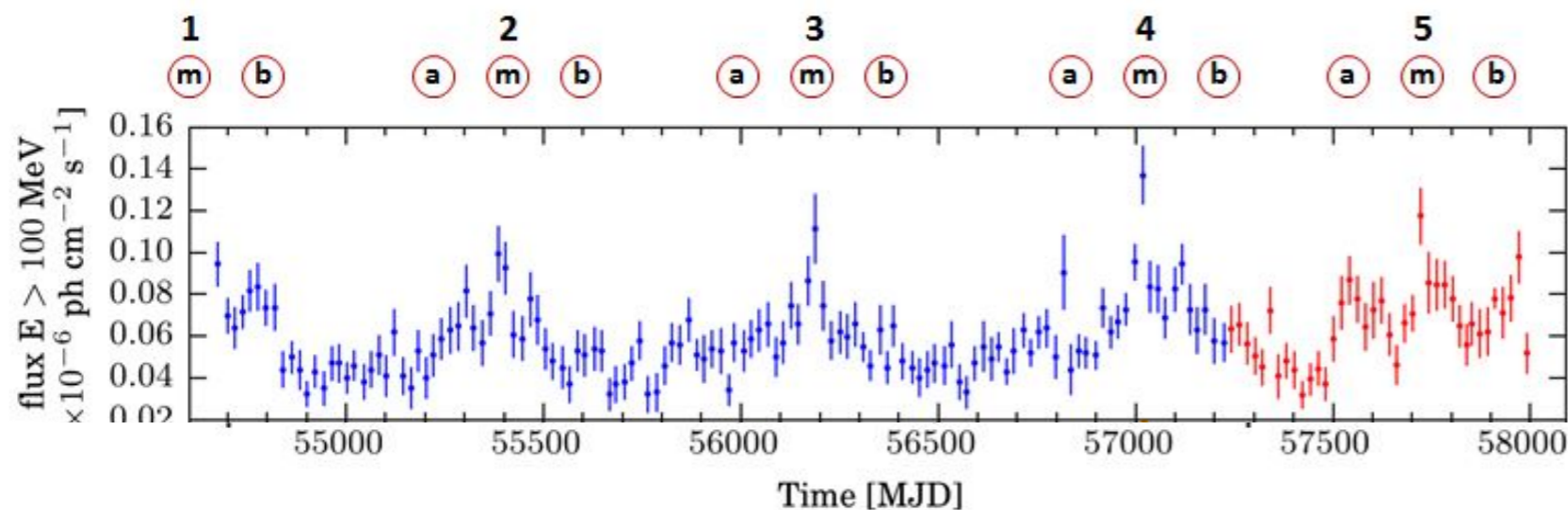


Ahlers & Halzen (2018)

Periodic emission from AGN jets

In the last three years, there have been about a dozen claims for periodic behavior in the light curves of blazars in the GeV band.

PG 1553+113, $P \sim 2.2$ years
Fermi-LAT data over 9 years

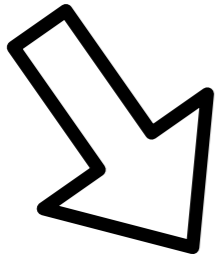


Tavani et al. (2018)

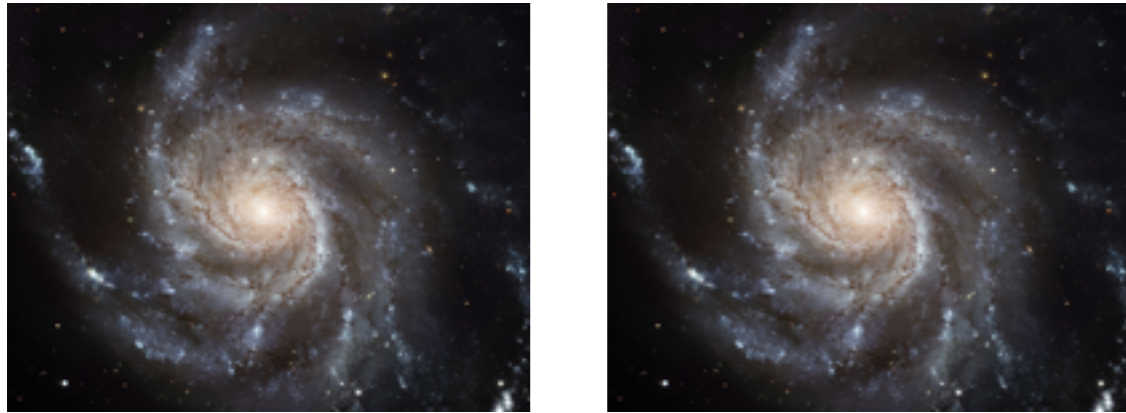
Galaxy evolution in a nutshell



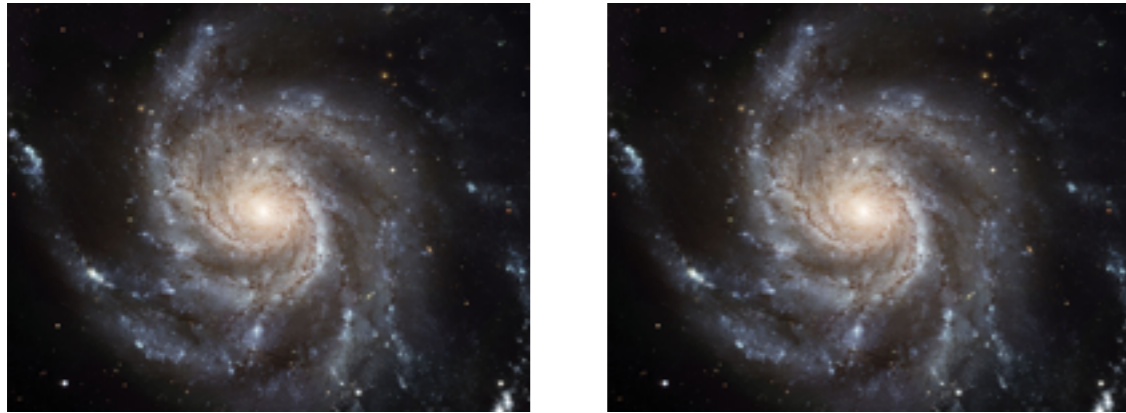
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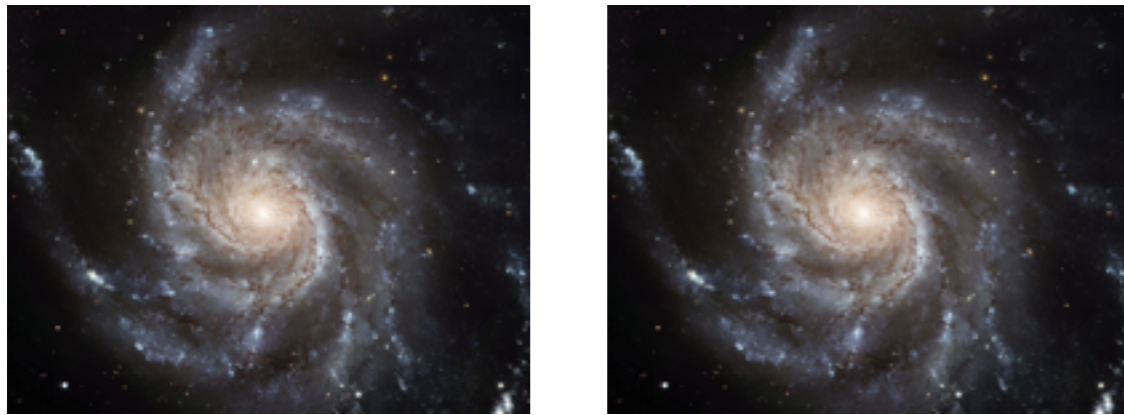
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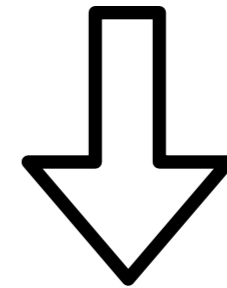
Galaxy evolution in a nutshell



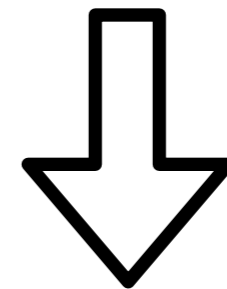
Galaxy evolution in a nutshell



supermassive BH +
supermassive BH

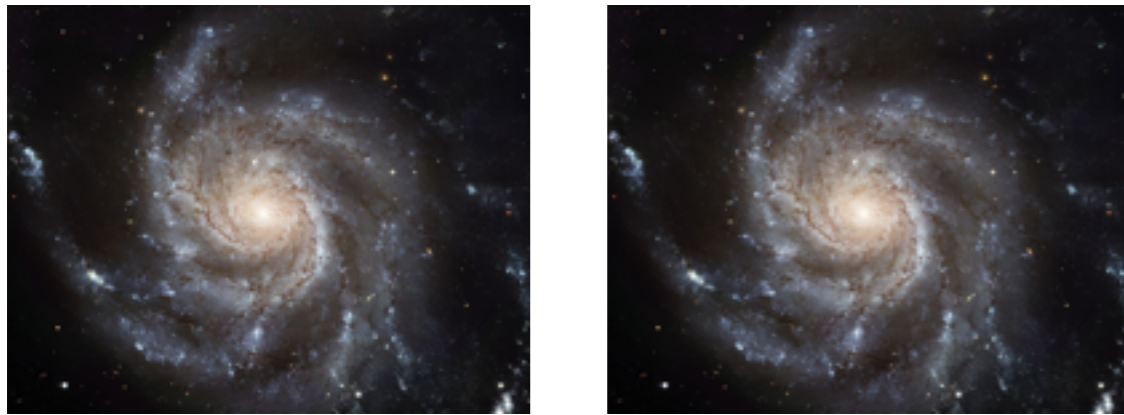


supermassive BH
binary

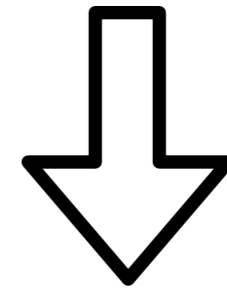


supermassive BH
merger

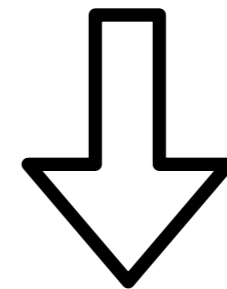
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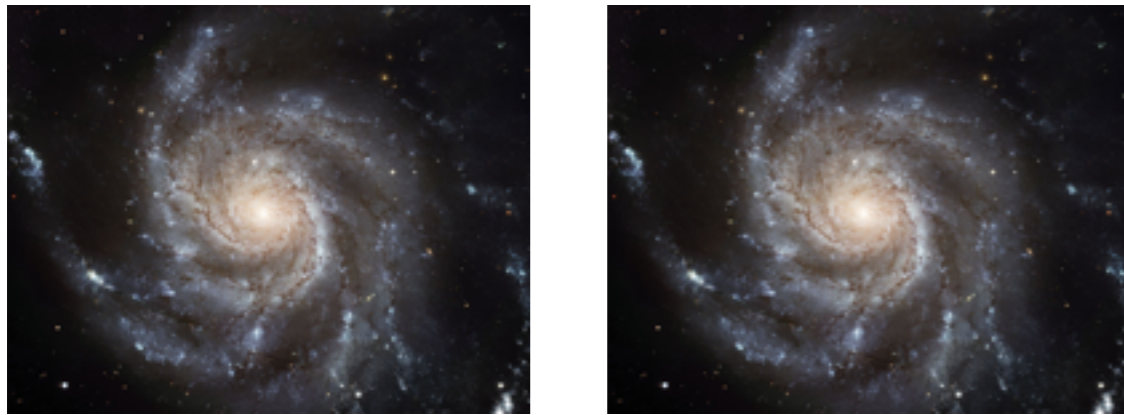
supermassive BH
binary



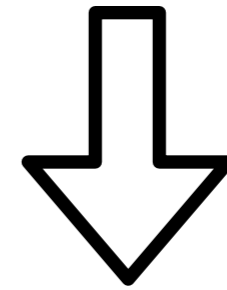
supermassive BH
merger

- $t_{\text{BH merger}}$ depends on the spin speed and alignment of the seed BHs.

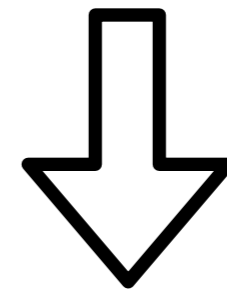
Galaxy evolution in a nutshell



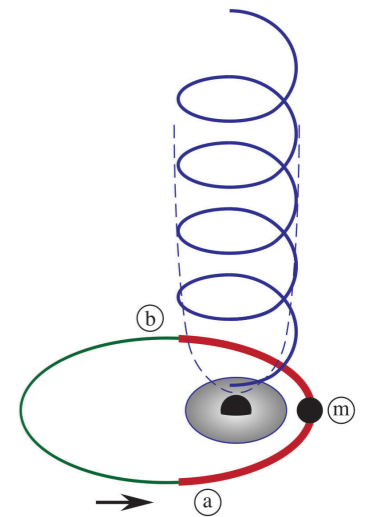
supermassive BH +
supermassive BH



supermassive BH
binary

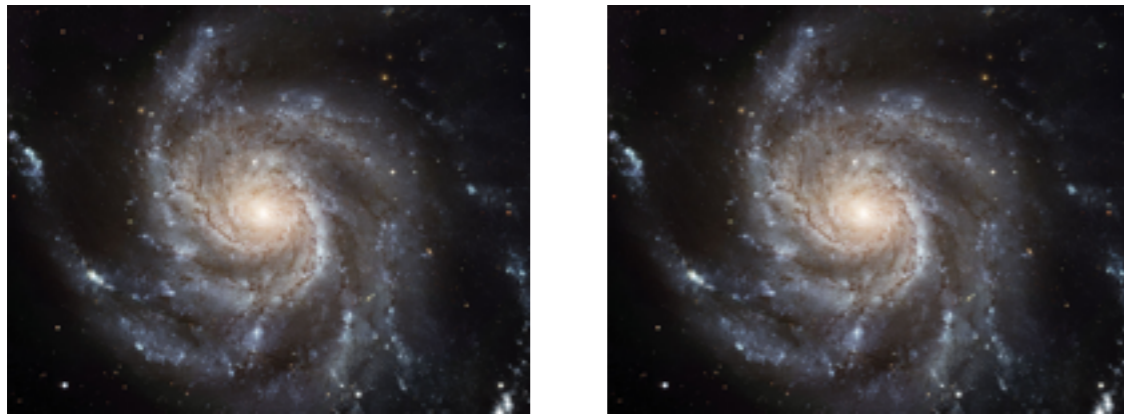


supermassive BH
merger

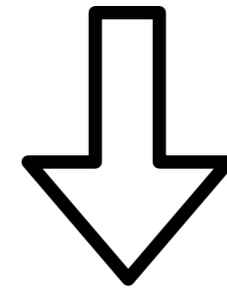


- $t_{\text{BH merger}}$ depends on the spin speed and alignment of the seed BHs.

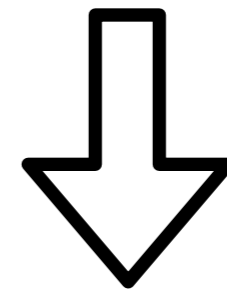
Galaxy evolution in a nutshell



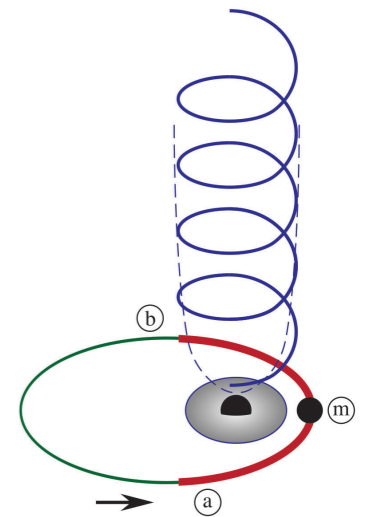
supermassive BH +
supermassive BH



supermassive BH
binary

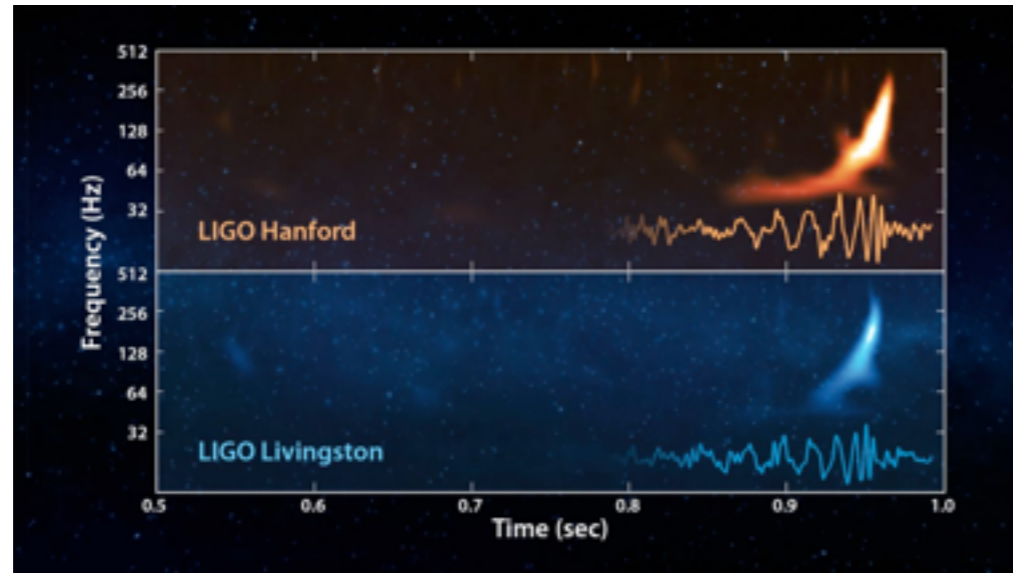


supermassive BH
merger

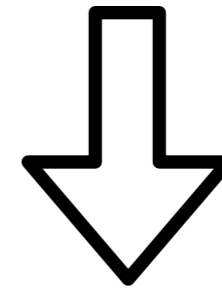


- $t_{\text{BH merger}}$ depends on the spin speed and alignment of the seed BHs.
- if $t_{\text{galaxy merger}} < t_{\text{BH merger}}$ we have a 3 BH problem \rightarrow BH recoil kick.

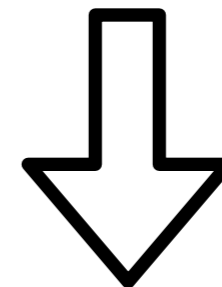
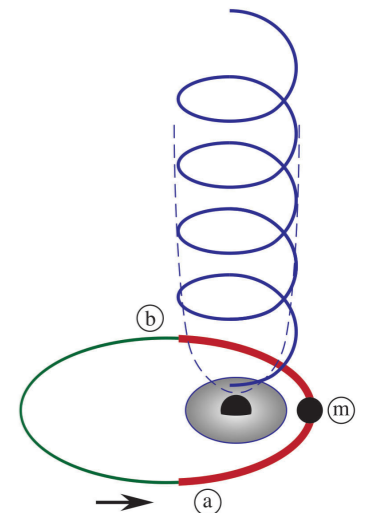
Galaxy evolution in a nutshell



supermassive BH +
supermassive BH

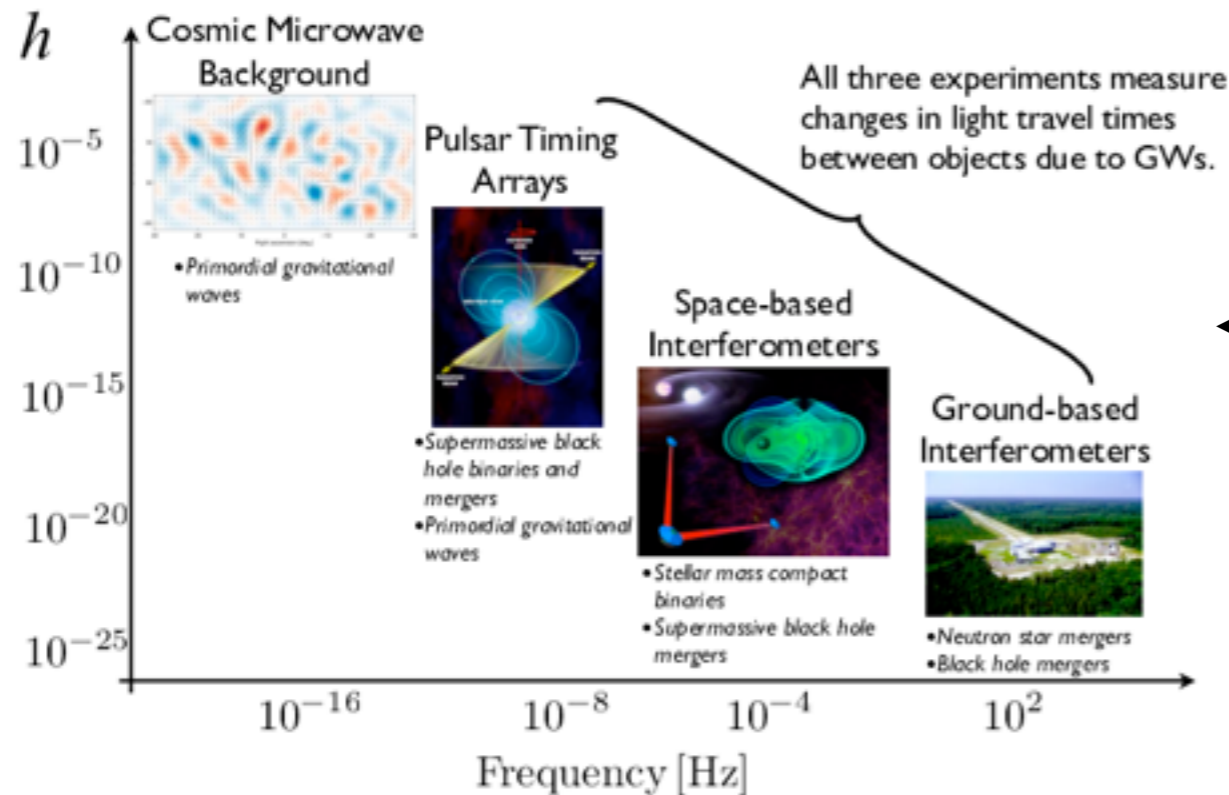


supermassive BH
binary

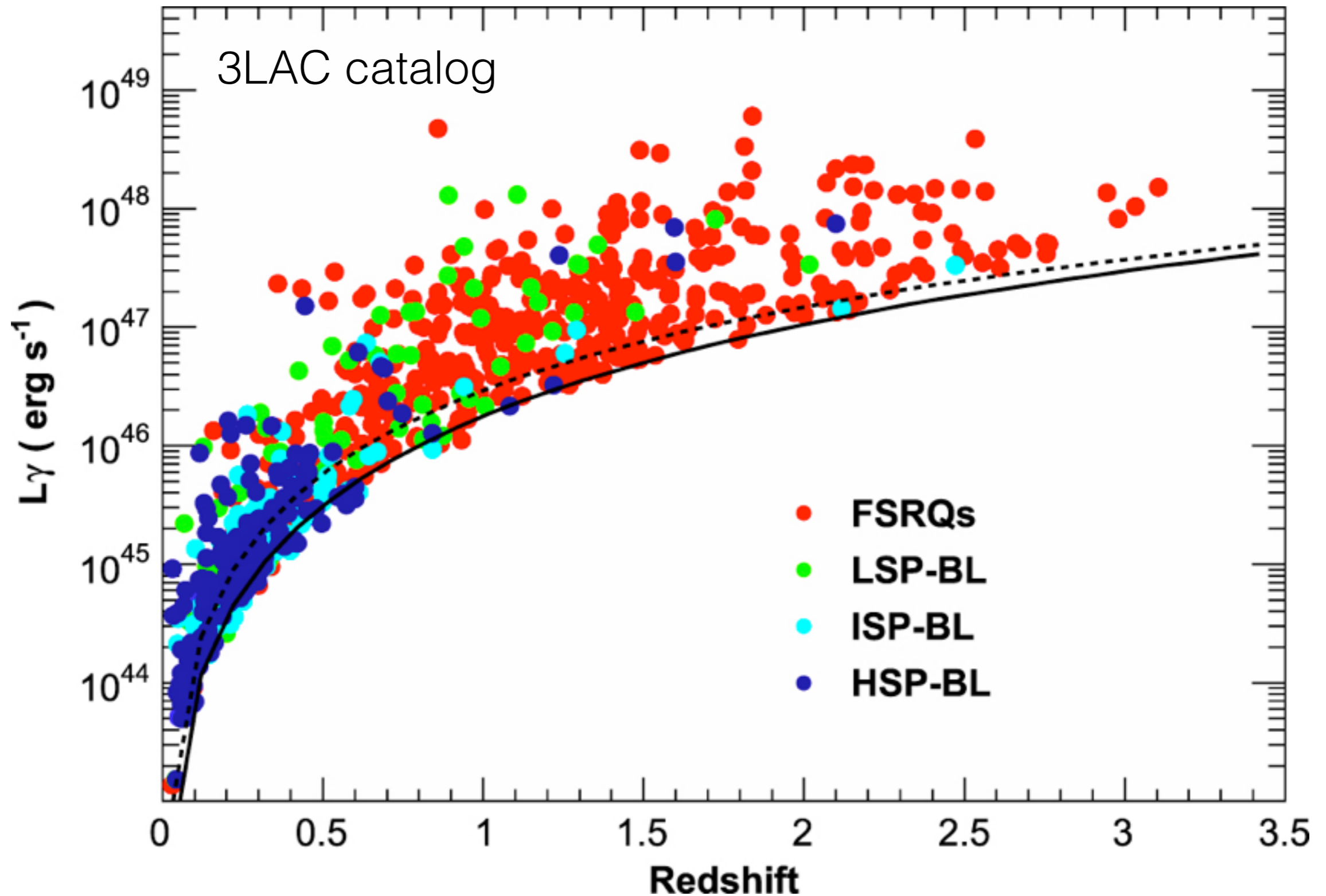


supermassive BH
merger

The spectrum of gravitational wave astronomy



AGN evolution



Summary

- There is a lot we don't yet know about how supermassive black holes grow, and how they shape star formation in their host galaxies.
- Radiation from accreting supermassive black holes (AGN) is the best tracer we have of black hole evolution.
- Basic models exist that explain the radiation we observe from relativistic jets.
- Most models break down when observational data becomes more abundant and more detailed.