Active Galactic Nuclei: a brief introduction

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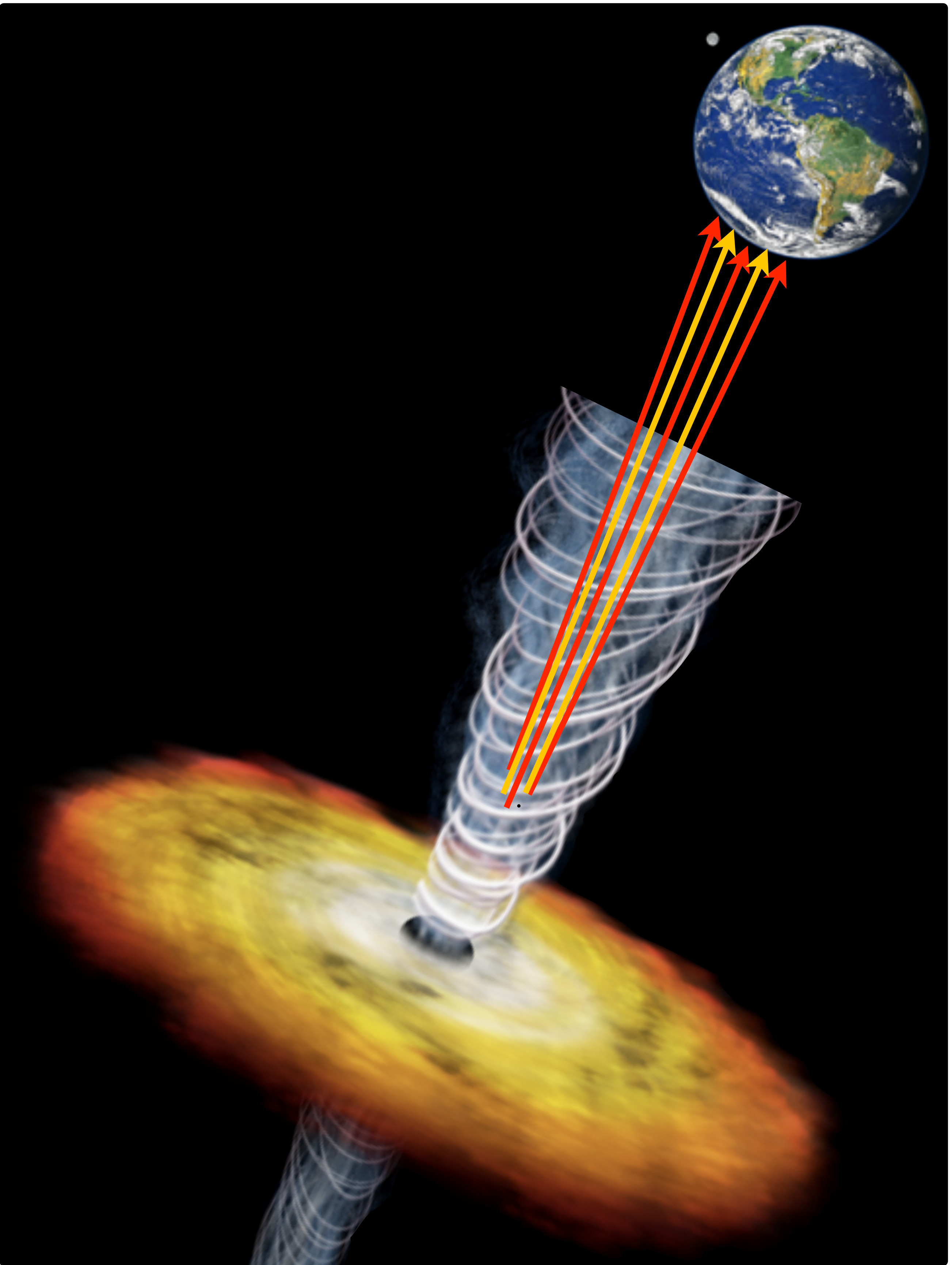
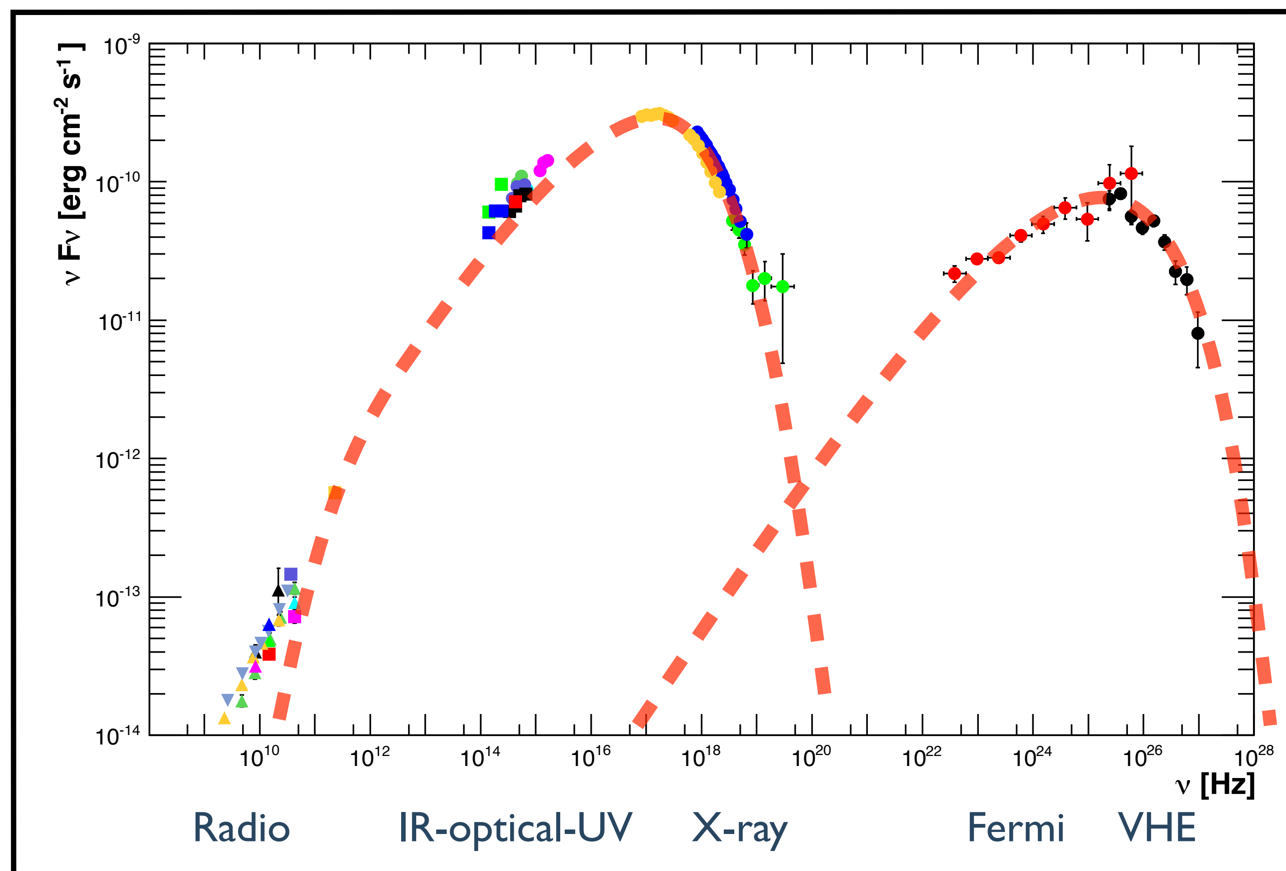
Black Holes and Relativistic jets



- 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.



The power source of AGN

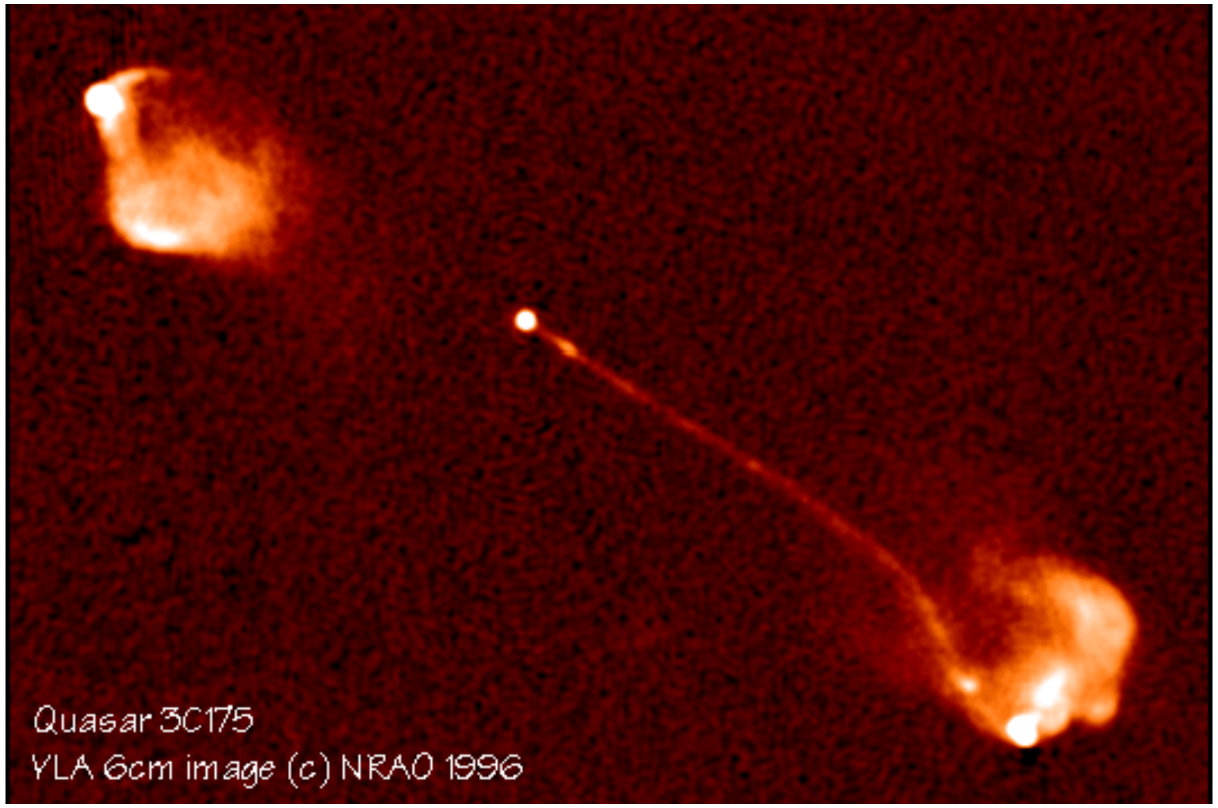
- The luminosity (L) of quasars, i.e. how much power they put out, can be as high as 10^{12} L_{sun} ~ 10^{40} W~ 10^{48} erg/s.
  - Nuclear fusion:

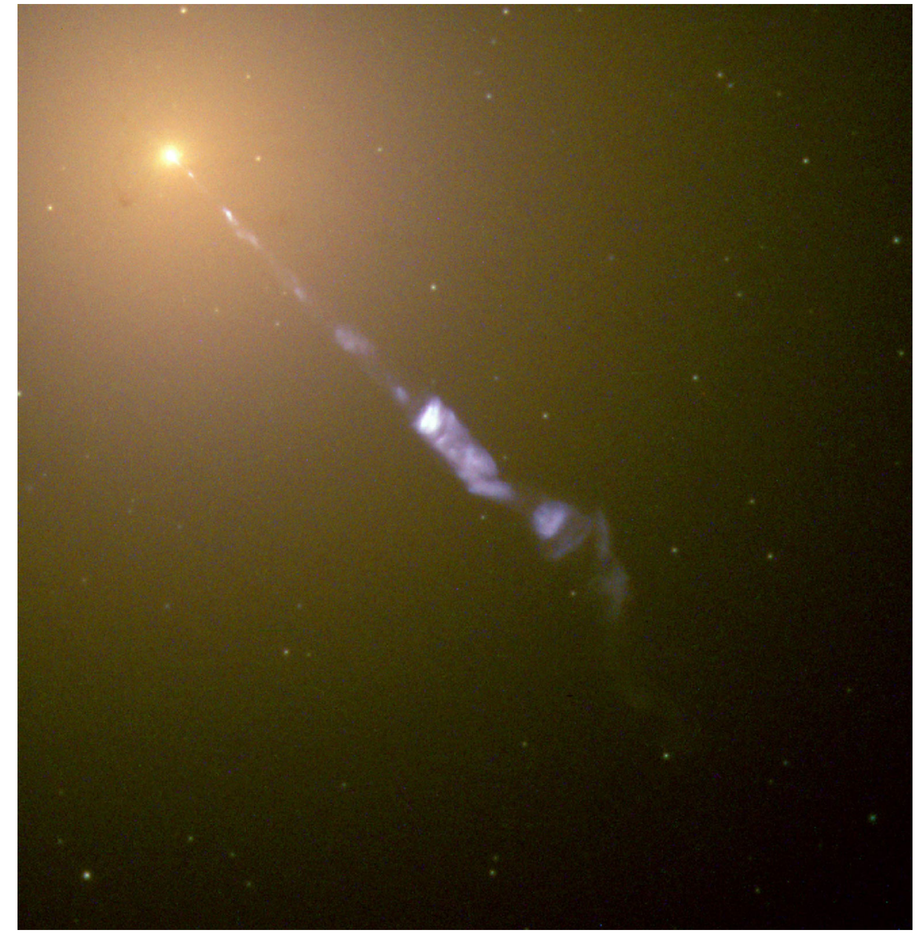
$$E_{\text{nuc}} = 0.007mc^2 \approx 6 \times 10^{18}\,\text{erg g}^{-1}$$

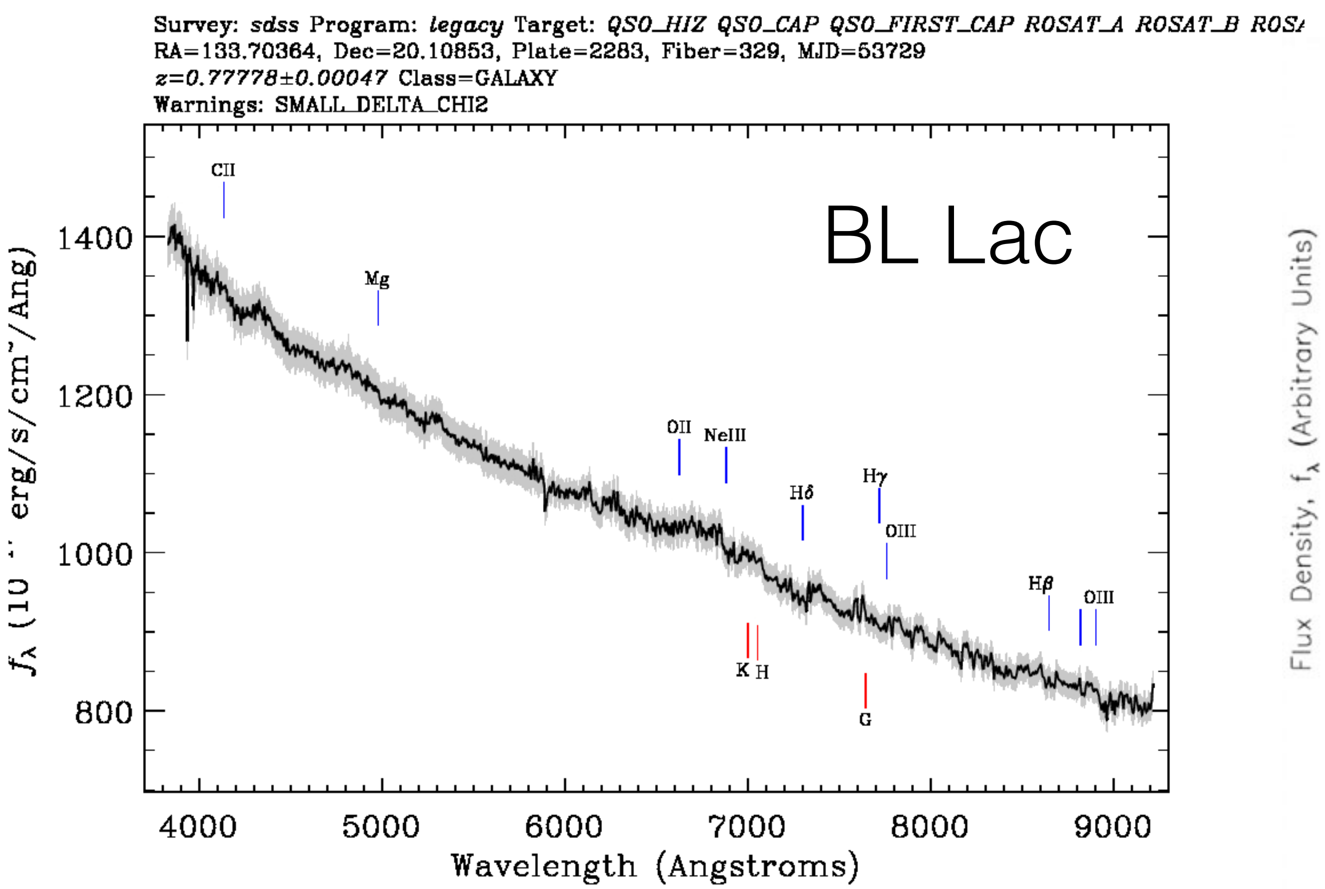
  - Accretion power:

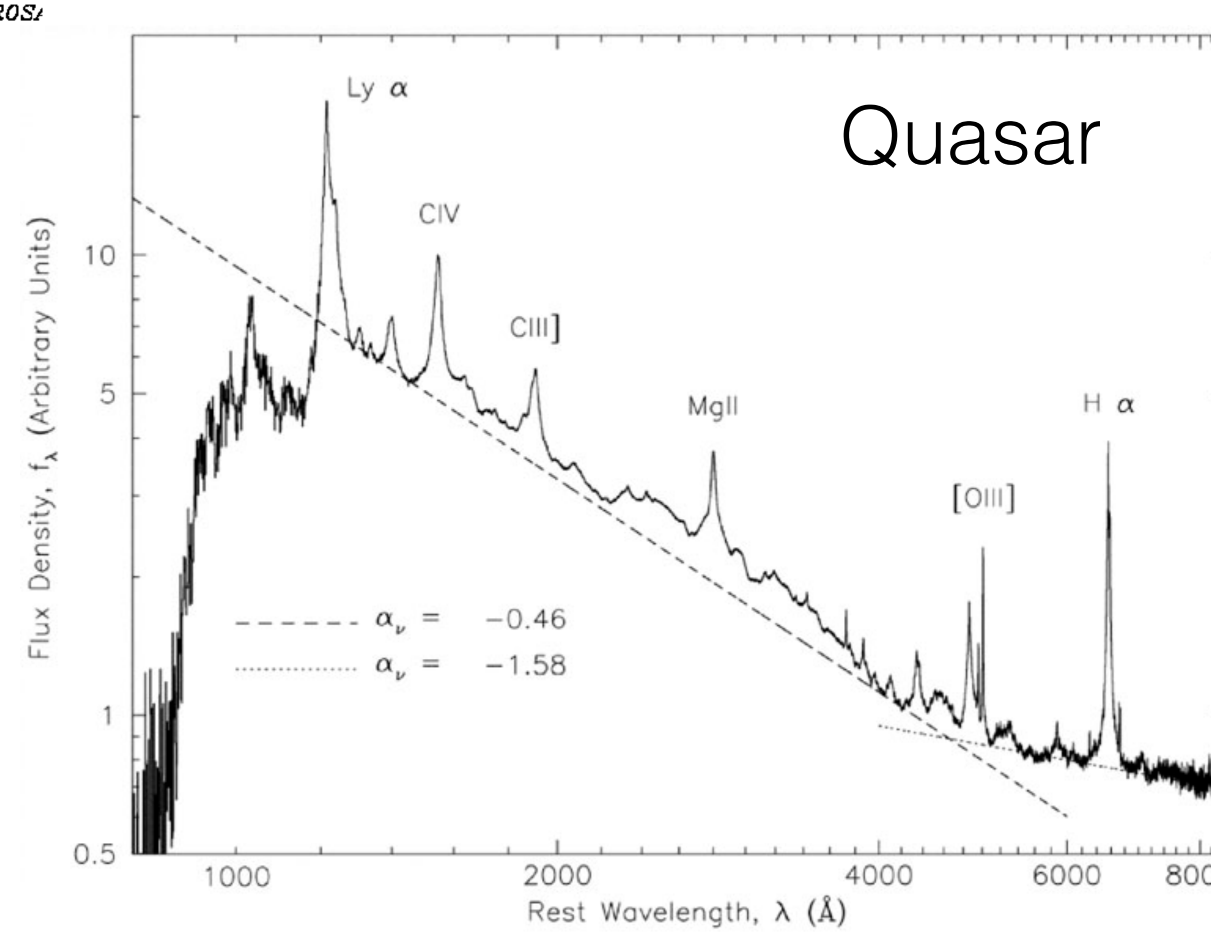
$$E_{\text{acc}} = \frac{GMm}{R} \approx 10^{20}\,\text{erg g}^{-1}$$

Accretion, i.e matter falling onto a black hole is the only energy source that is powerful enough to fuel the very bright luminosity of quasars.


Quasar 3C175
YLA 6cm image (c) NRAO 1996




Survey: sdss Program: legacy Target: QSO_HIZ QSO_CAP QSO_FIRST_CAP ROSAT_A ROSAT_B ROS
RA=133.70364, Dec=20.10853, Plate=2283, Fiber=329, MJD=53729
z=0.77778±0.00047 Class=GALAXY
Warnings: SMALL_DELTA_CHI2
BL Lac
CII
Mg
OII
NeIII
Hδ
Hγ
OIII
Hβ
OIII
K H
G
1400
1200
1000
800
4000
5000
6000
7000
8000
9000
Wavelength (Angstroms)


Quasar
Ly α
CIV
CIII]
MgII
[OIII]
H α
α_ν = −0.46
α_ν = −1.58
Flux Density, f_λ (Arbitrary Units)
10
5
1
0.5
1000
2000
4000
6000
8000
Rest Wavelength, λ (Å)

Slido Question 1

Answer on Slido: https://app.sli.do/event/9bgkzolg/live/polls

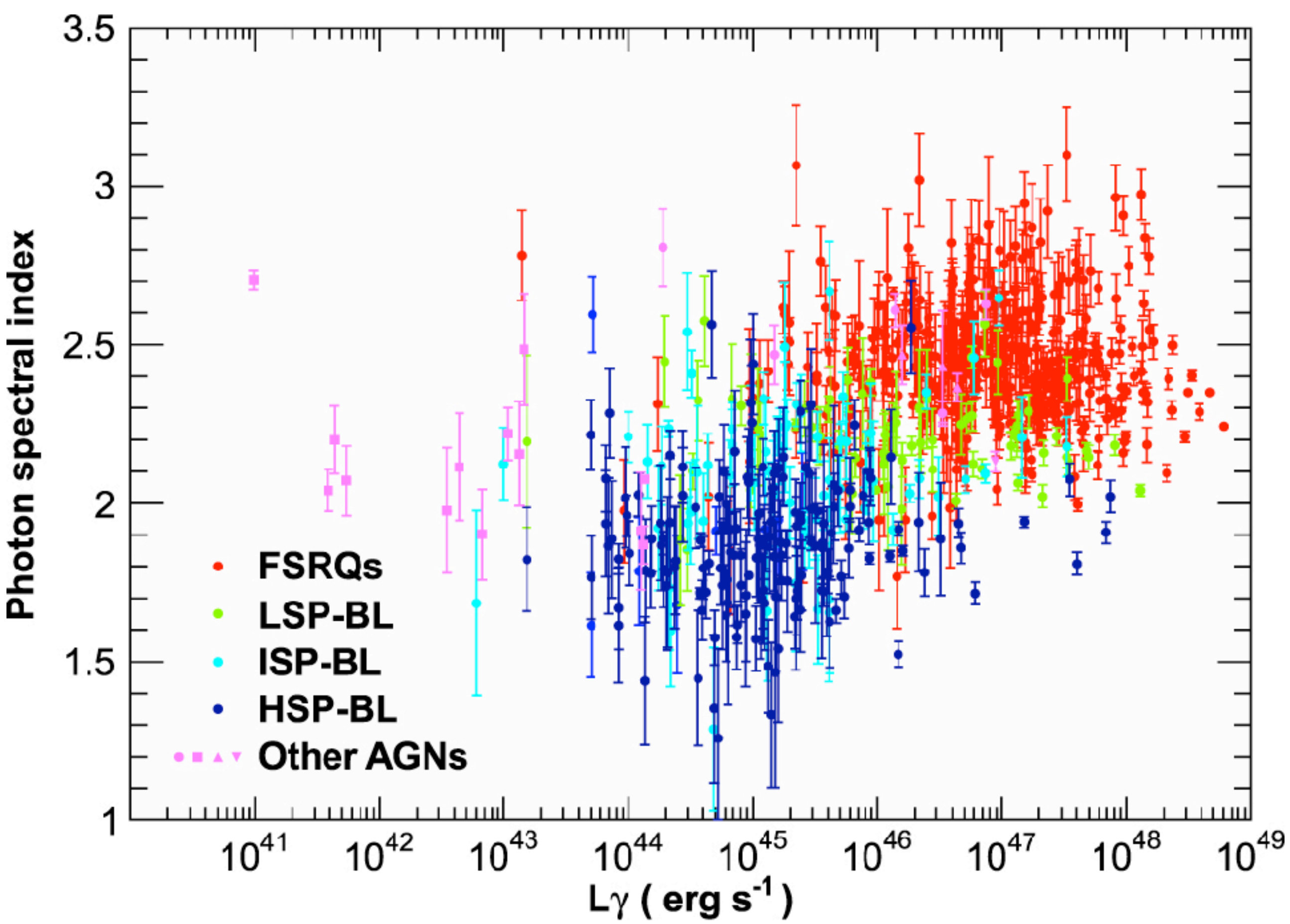
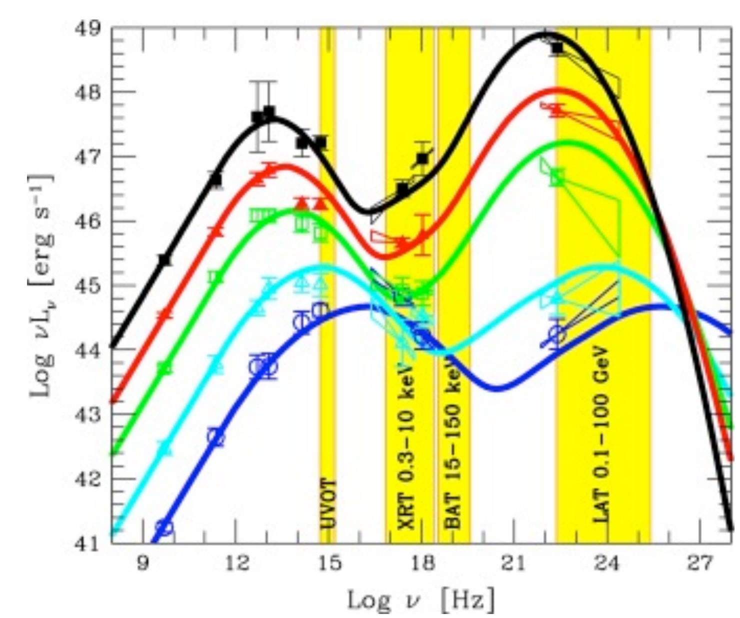
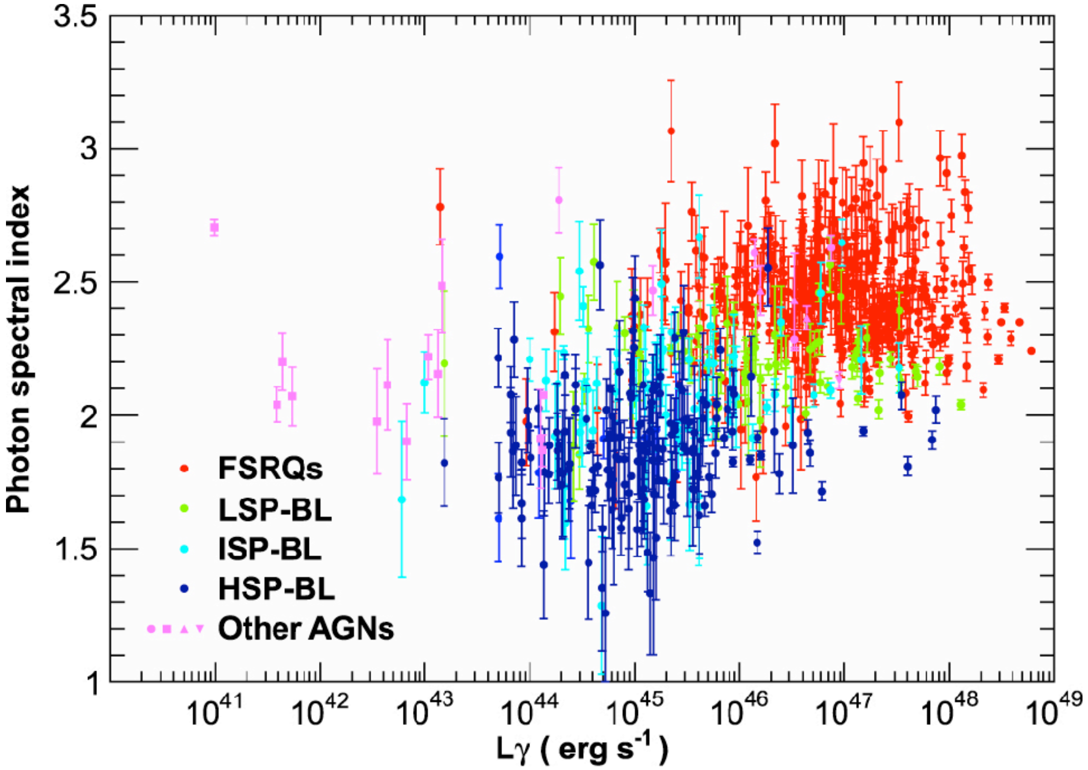


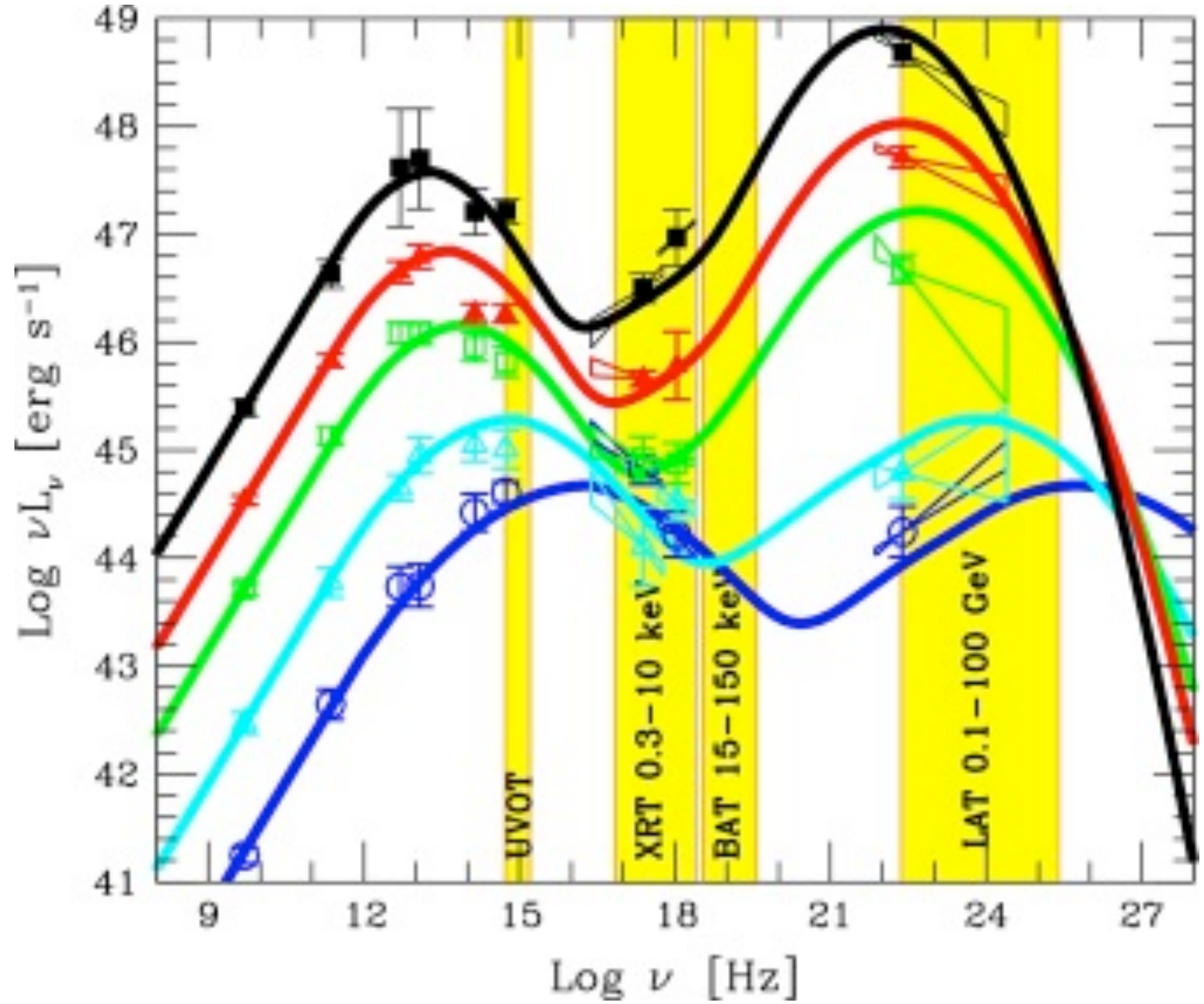
Figure 14: Photon index vs. gamma-ray luminosity. Red: FSRQs; green: LSP-BL Lacs; light blue: ISP-BL Lacs; dark blue: HSP-BL Lacs; magenta: other AGNs (circles: NLSy1s; squares: radio galaxies; up triangles: SSRQs; down triangles: AGNs of other types).

- If one looks at all the blazars detected by LAT, why would their spectral index be correlated with gamma-ray luminosity?
- Hint:



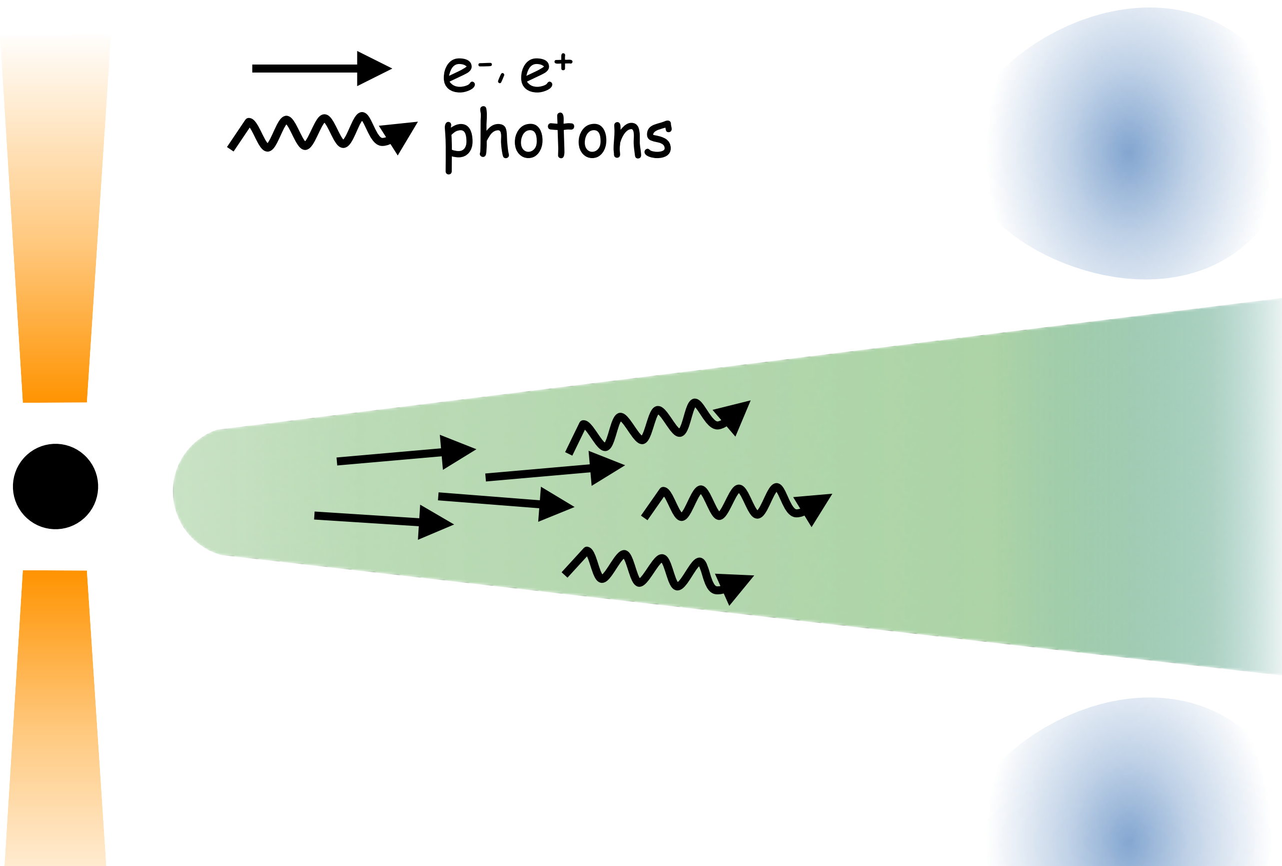
The Third Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope; Ackermann et al. 2015, ApJ, 810, 14

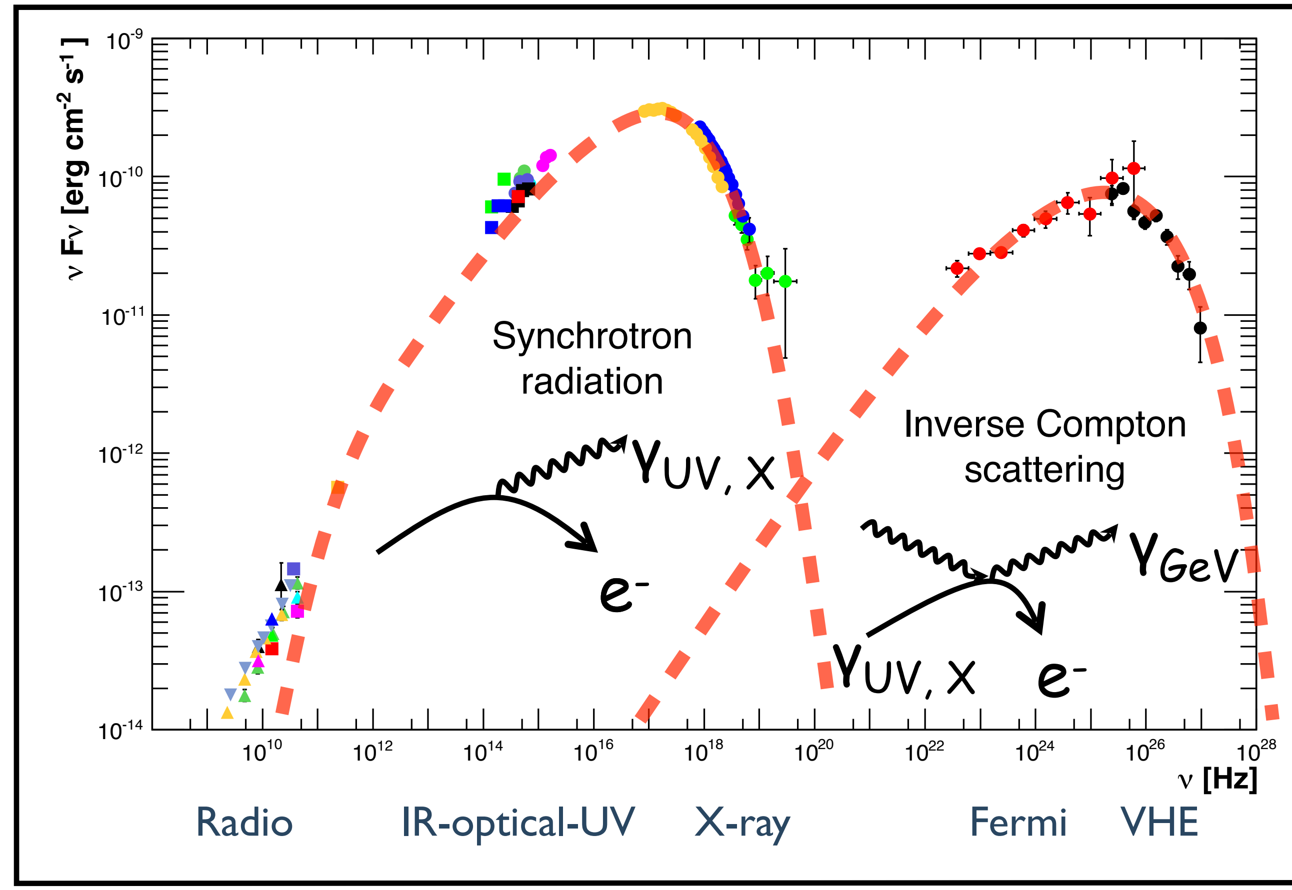




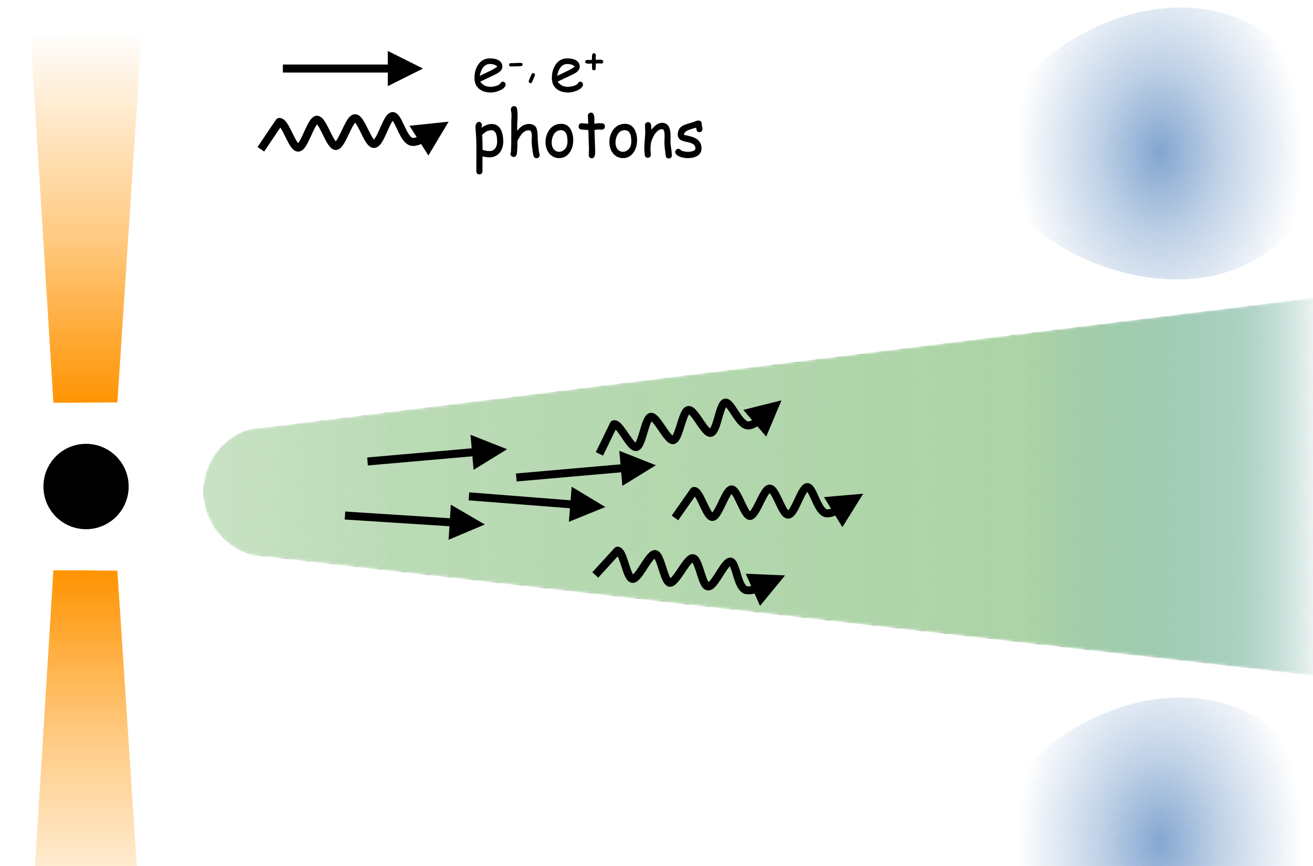
Photon spectral index (Γ), where Γ<2.0 means increasing energy flux with energy.

Luminosity (Lγ): $L_\gamma = 4\pi d^2 F_\gamma$





Low accretion rate (BL Lac)



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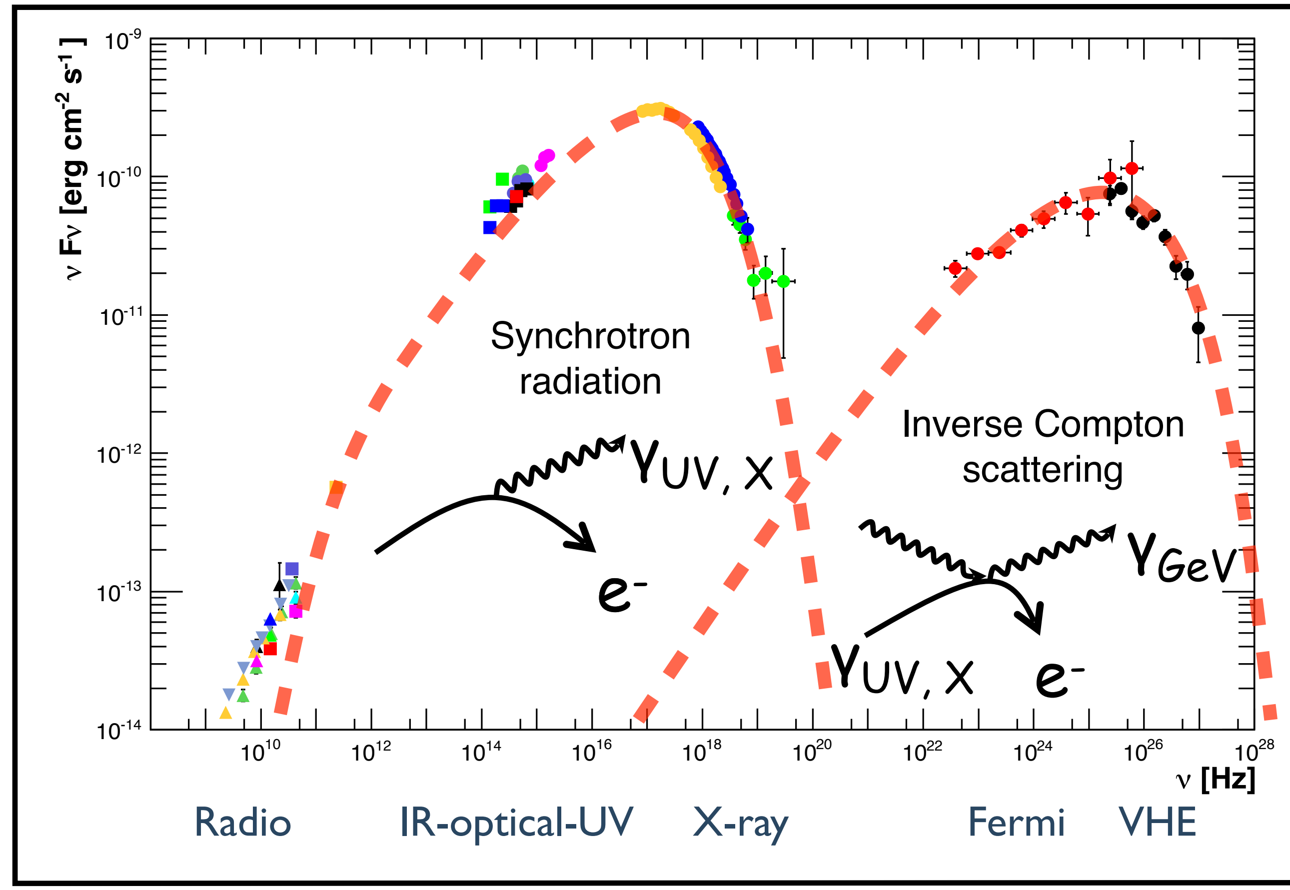
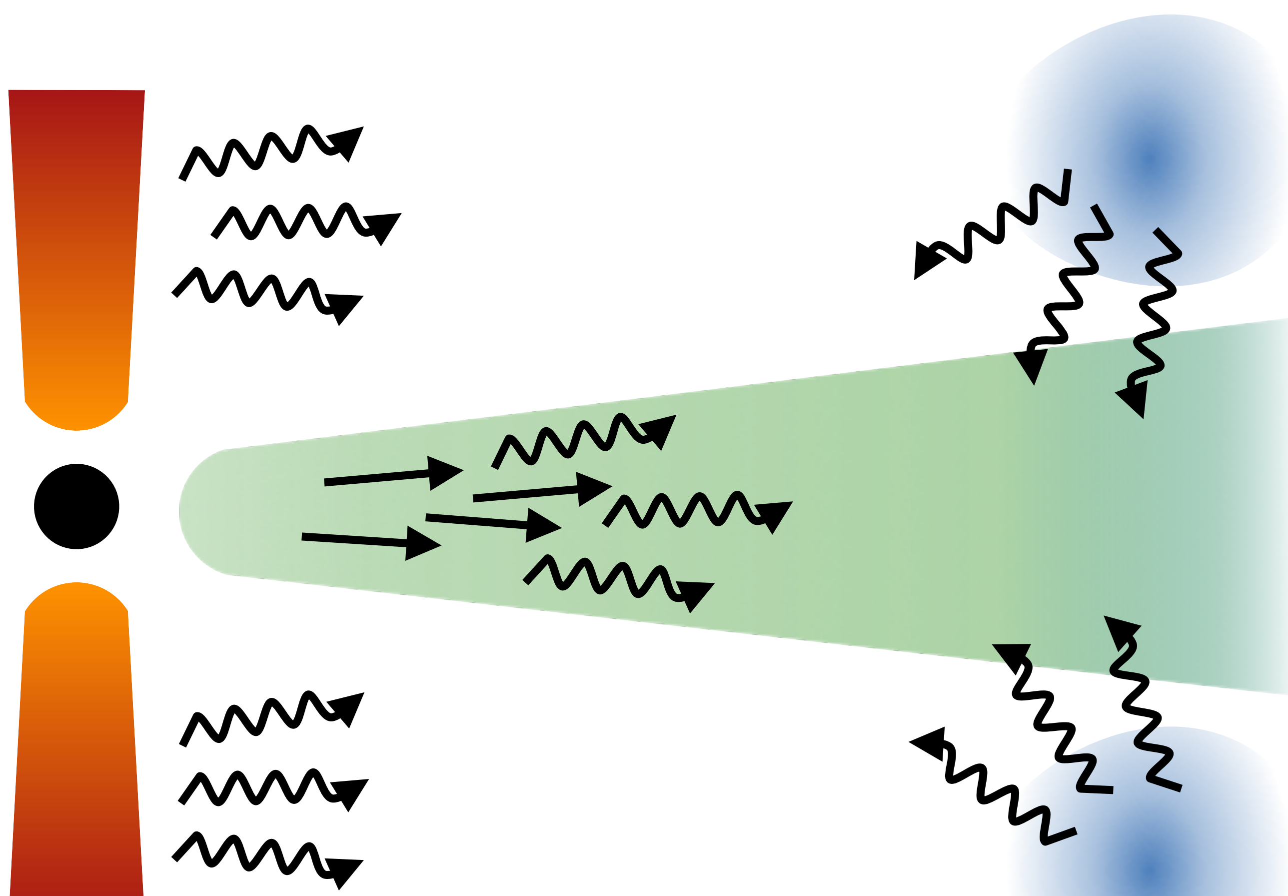
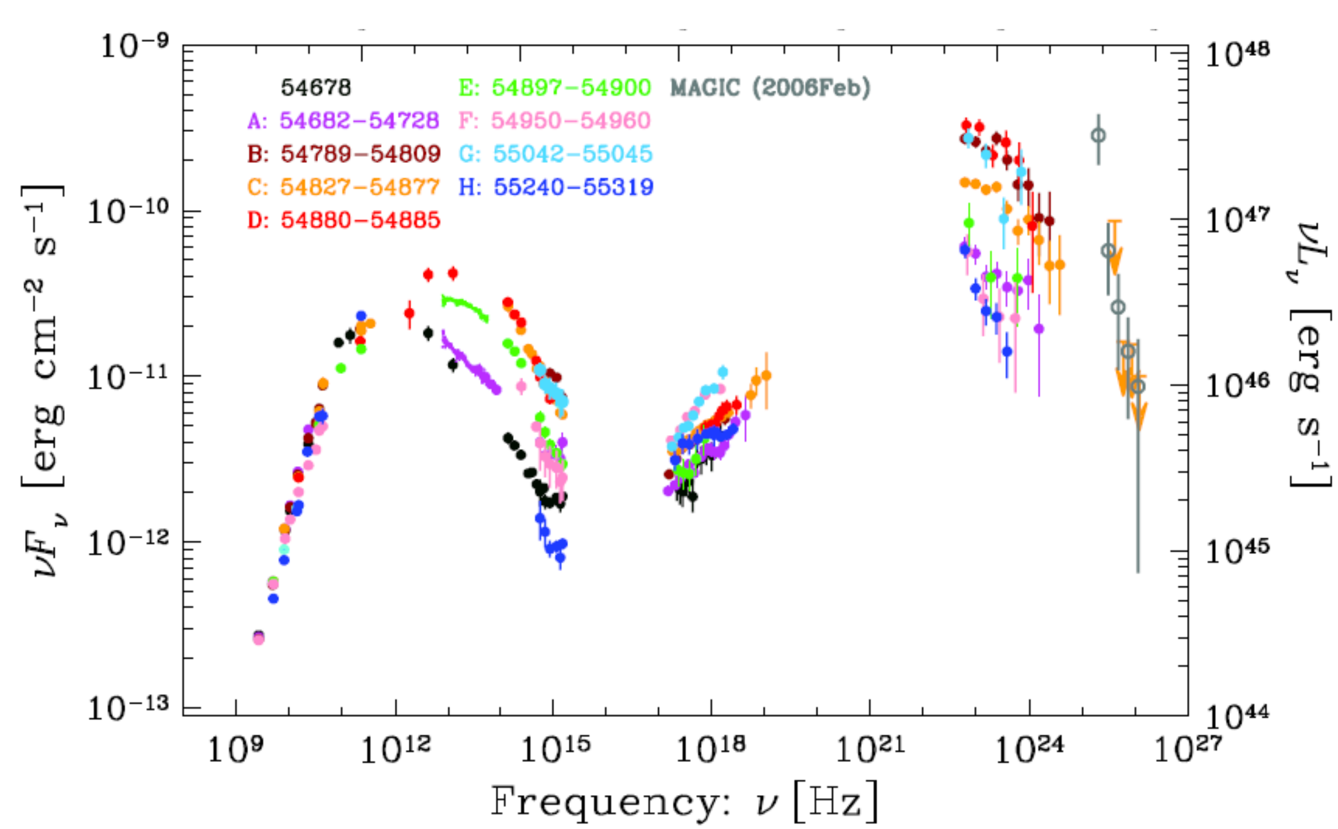
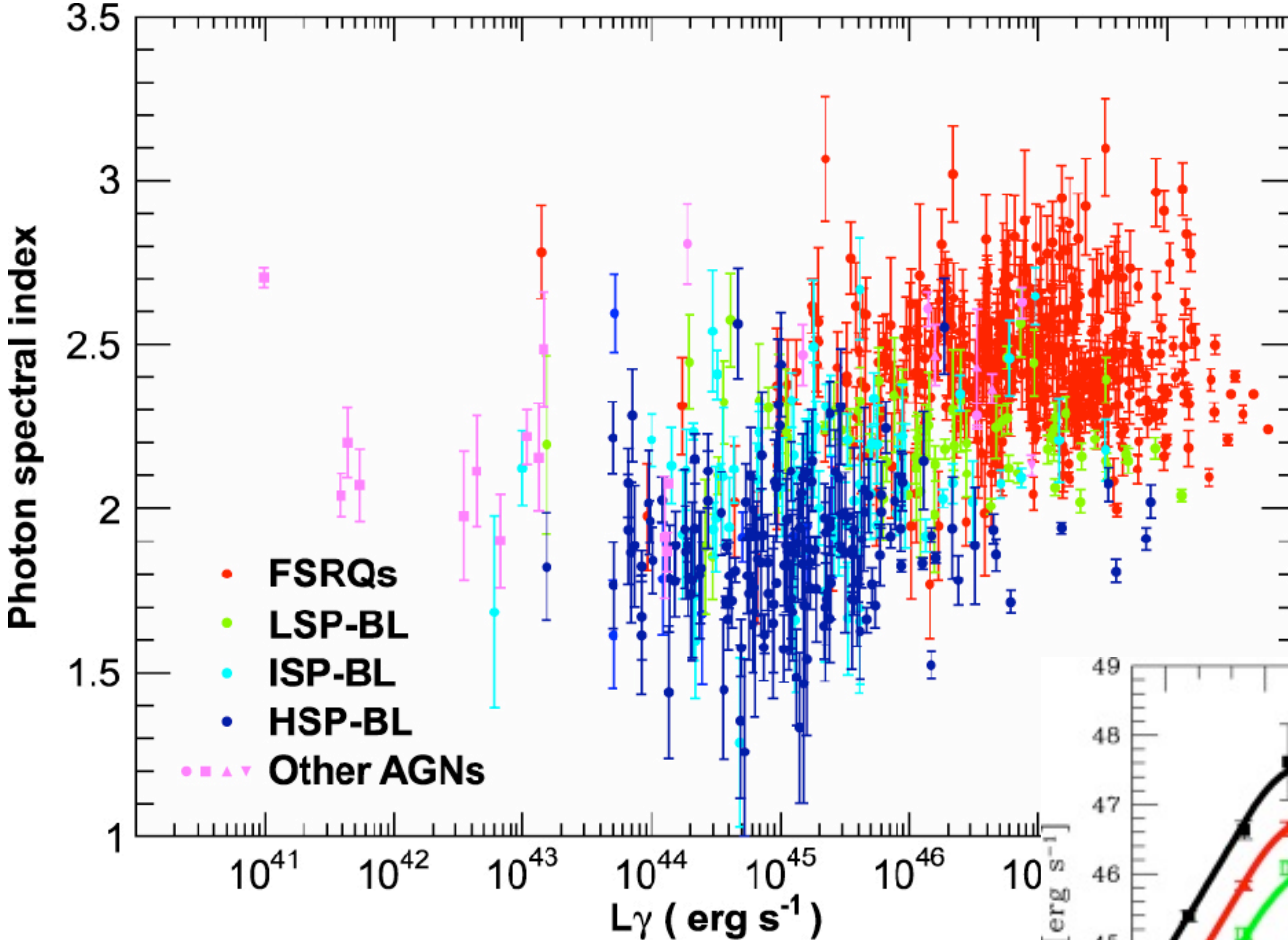
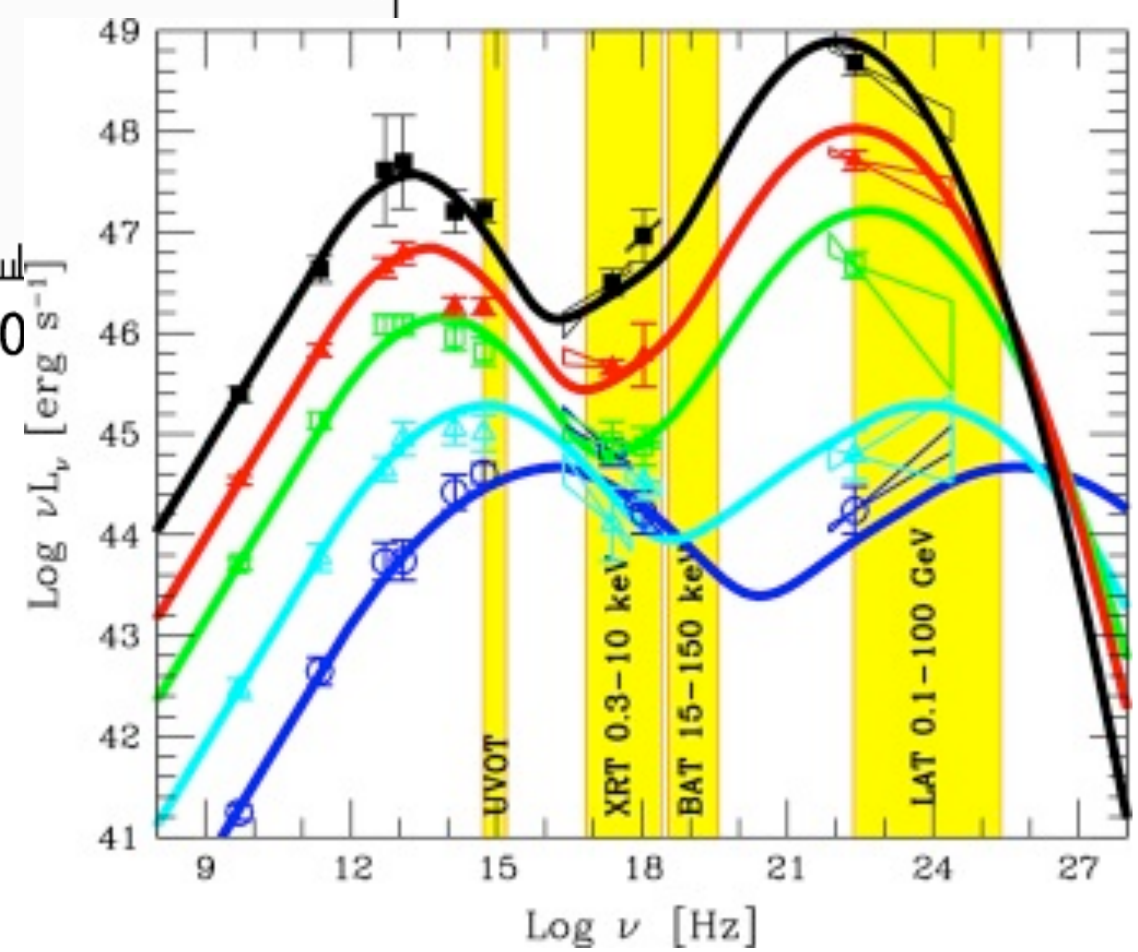




High accretion rate (quasar)







Blazar sequence: powerful AGN ionize nuclear gas, leading to higher Compton cooling rate and relativistic particles with smaller maximum energies.

Slido Question 2

Answer on Slido: https://app.sli.do/event/zjenm0zr

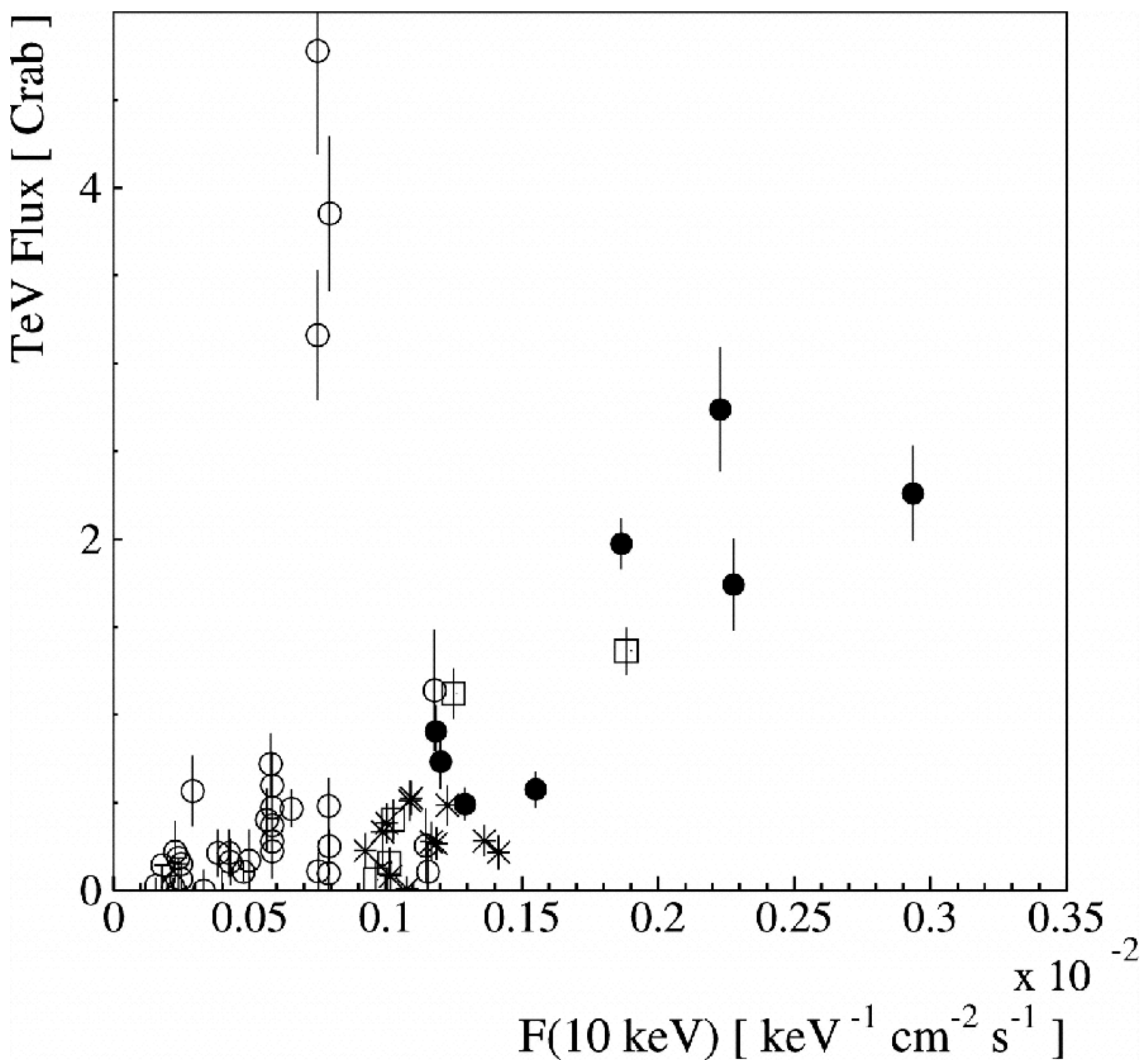
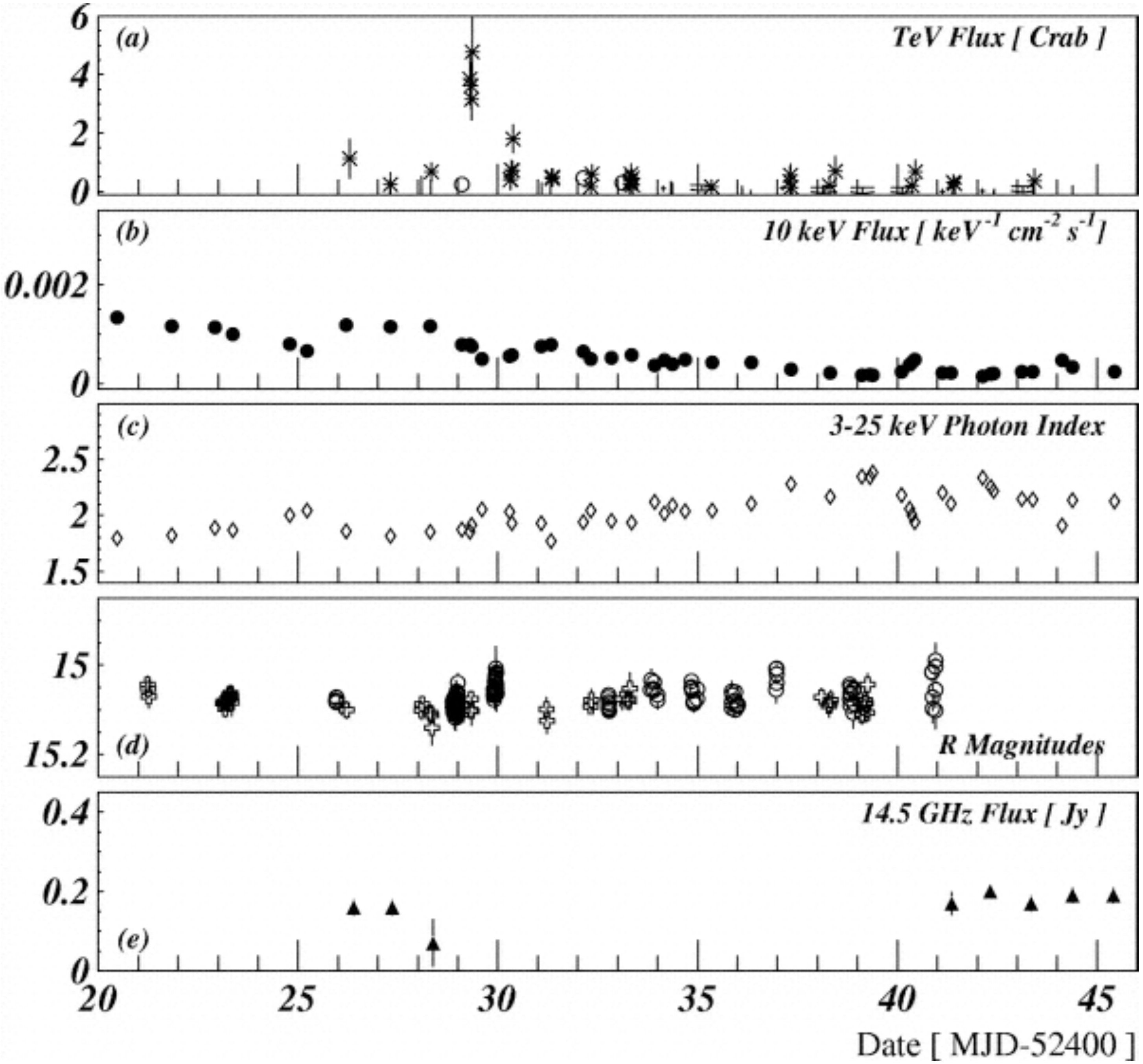


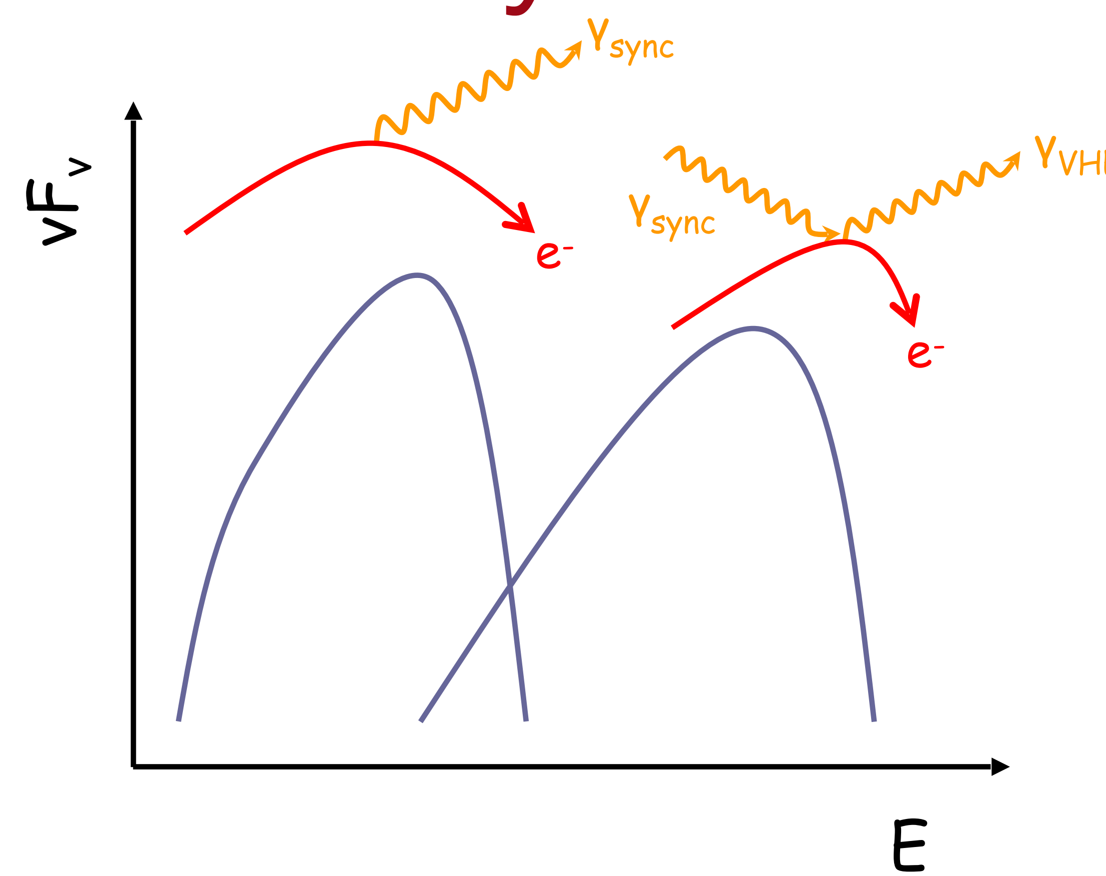
Fig. 8: Correlation between the X−ray flux and the Whipple and HEGRA γ−ray fluxes: epochs 1 (*filled circles*), 2 (*open circles*), 3 (*squares*), and 4 (*asterisks*). Only points with a direct overlap of the γ−ray and X−ray observations have been included.

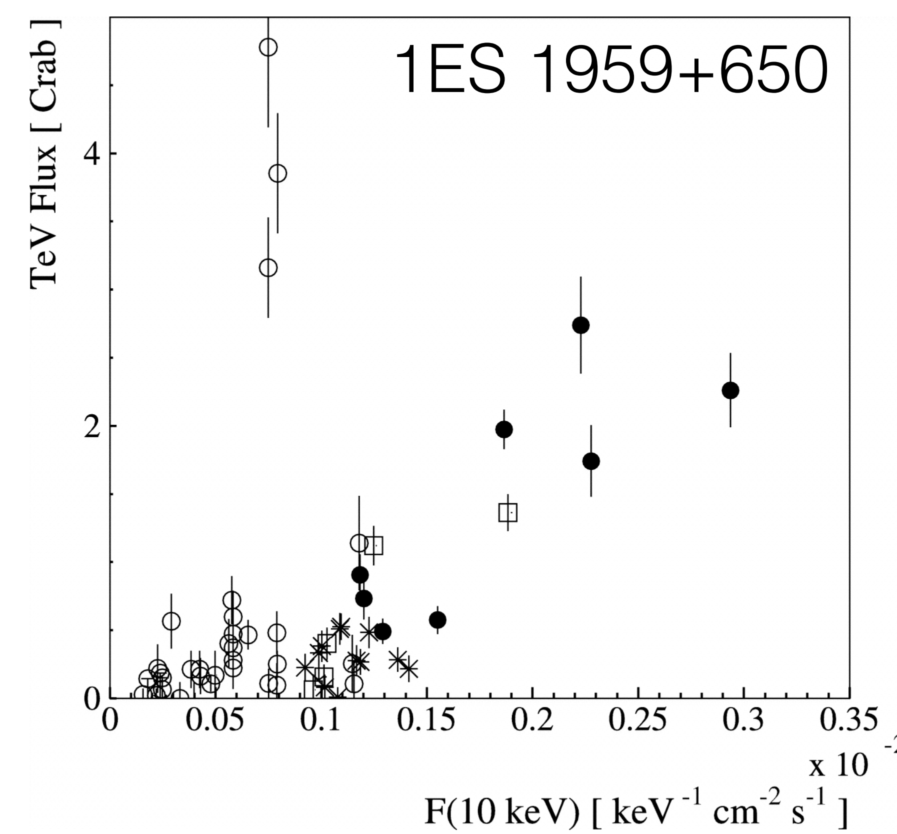
- This figure plots the gamma-ray flux of a blazar vs its X-ray flux. Why would we expect the fluxes to be correlated, and what happens when they are not?

Multiwavelength Observations of Strong Flares from the TeV Blazar 1ES 1959+650; Krawczynski et al. 2004, ApJ, 601, 151

Correlated variability







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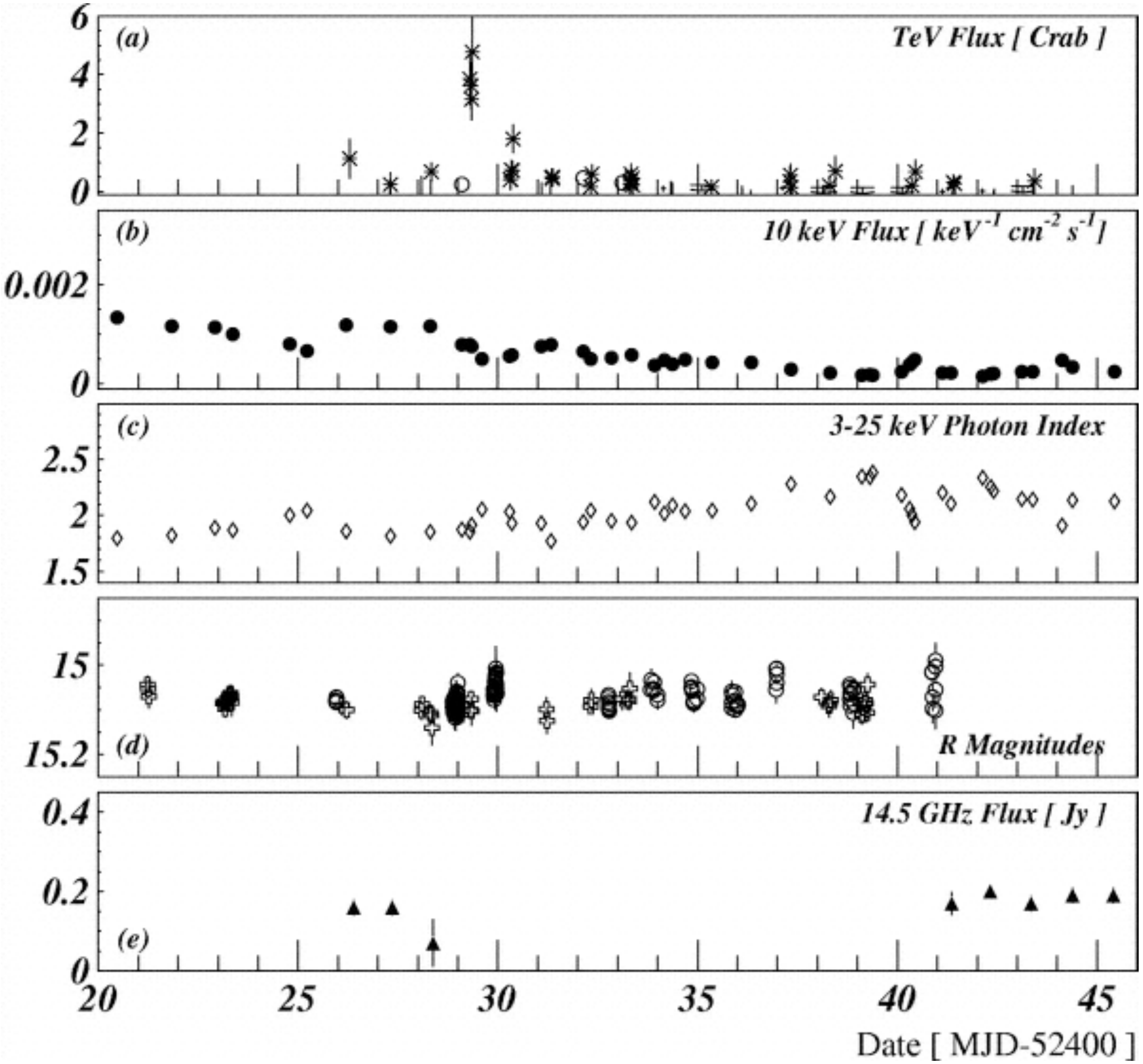
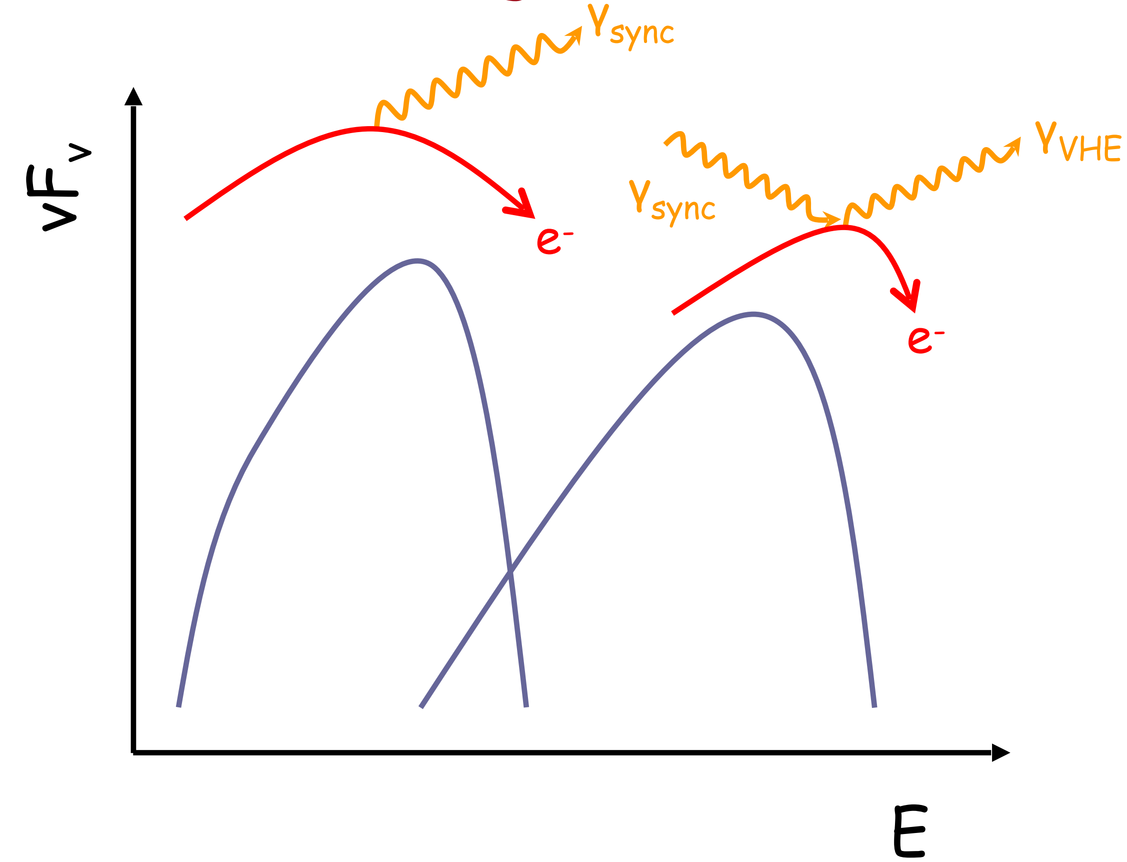
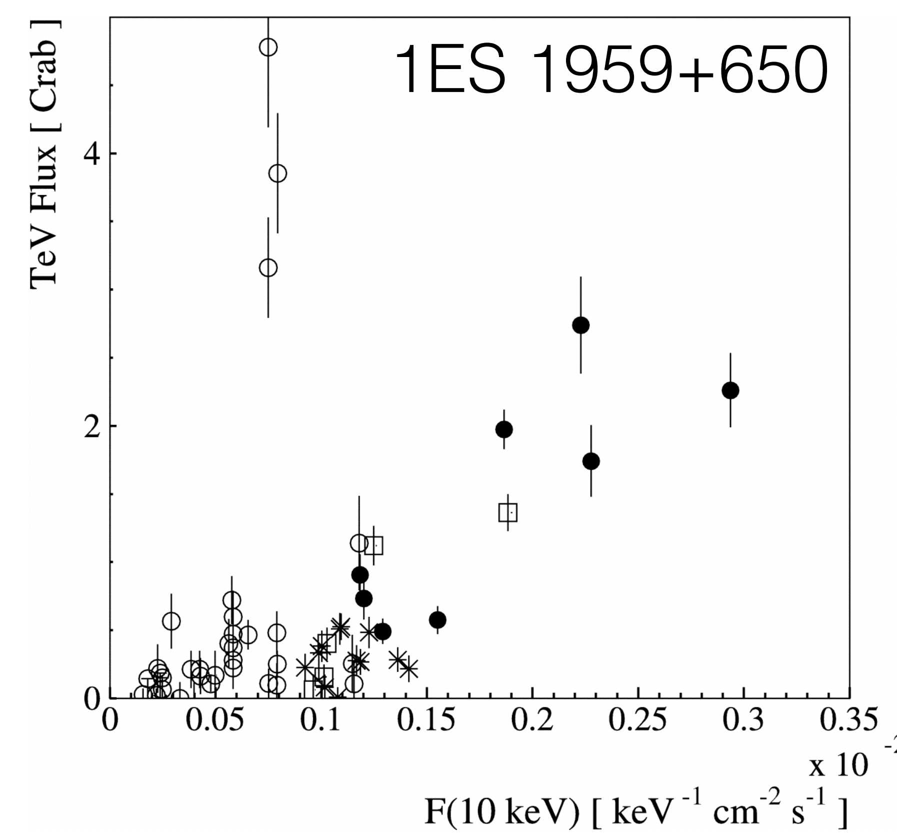


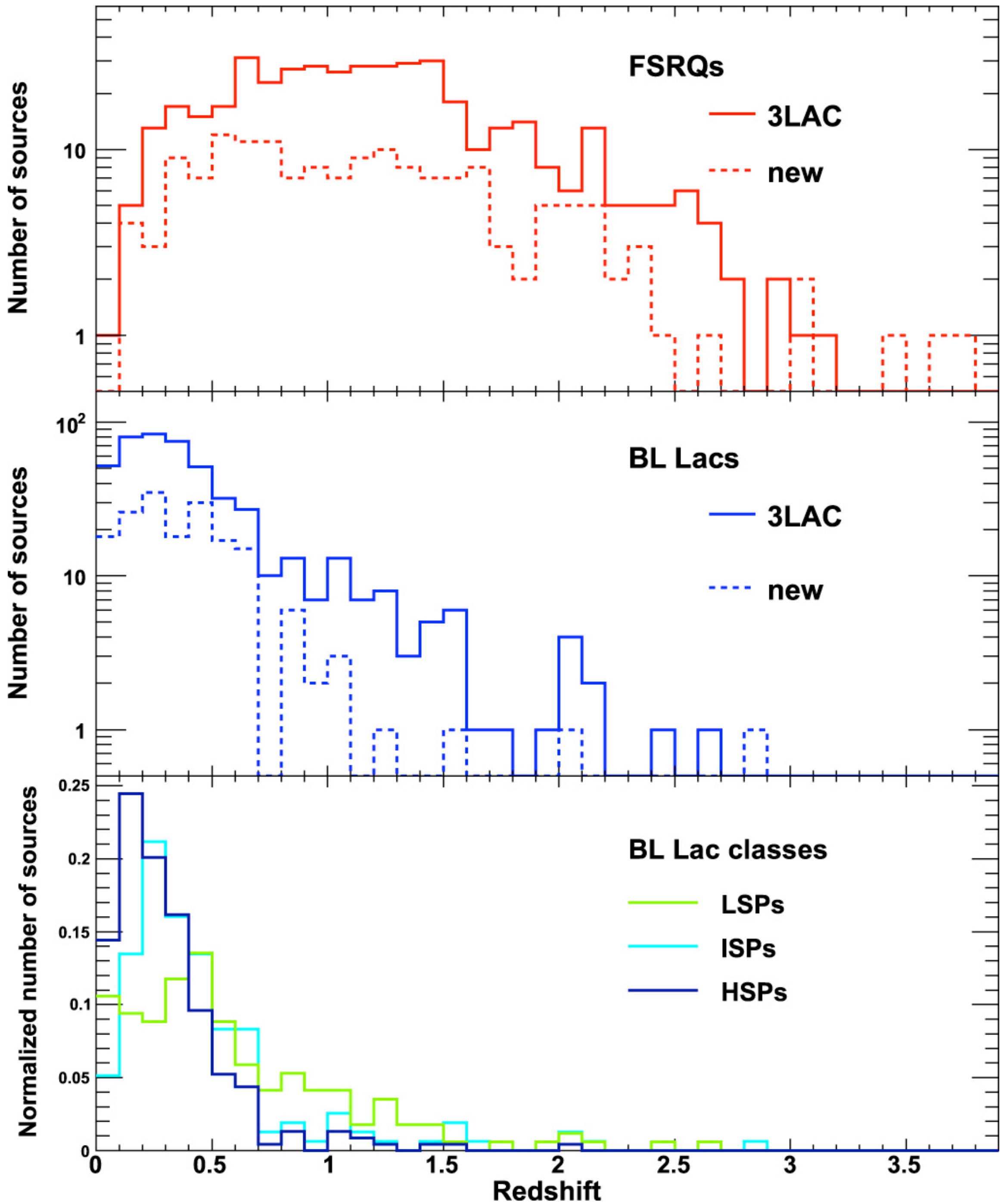




Simple emission models predict synchrotron and gamma-ray components to be correlated

Multiwavelength Observations of Strong Flares from the TeV Blazar 1ES 1959+650; Krawczynski et al. 2004, ApJ, 601, 151

Extra question



The Third Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope; Ackermann et al. 2015, ApJ, 810, 14

Quasars are typically found at higher redshifts than BL Lacs. How do we explain that?

Galaxy evolution in a nutshell

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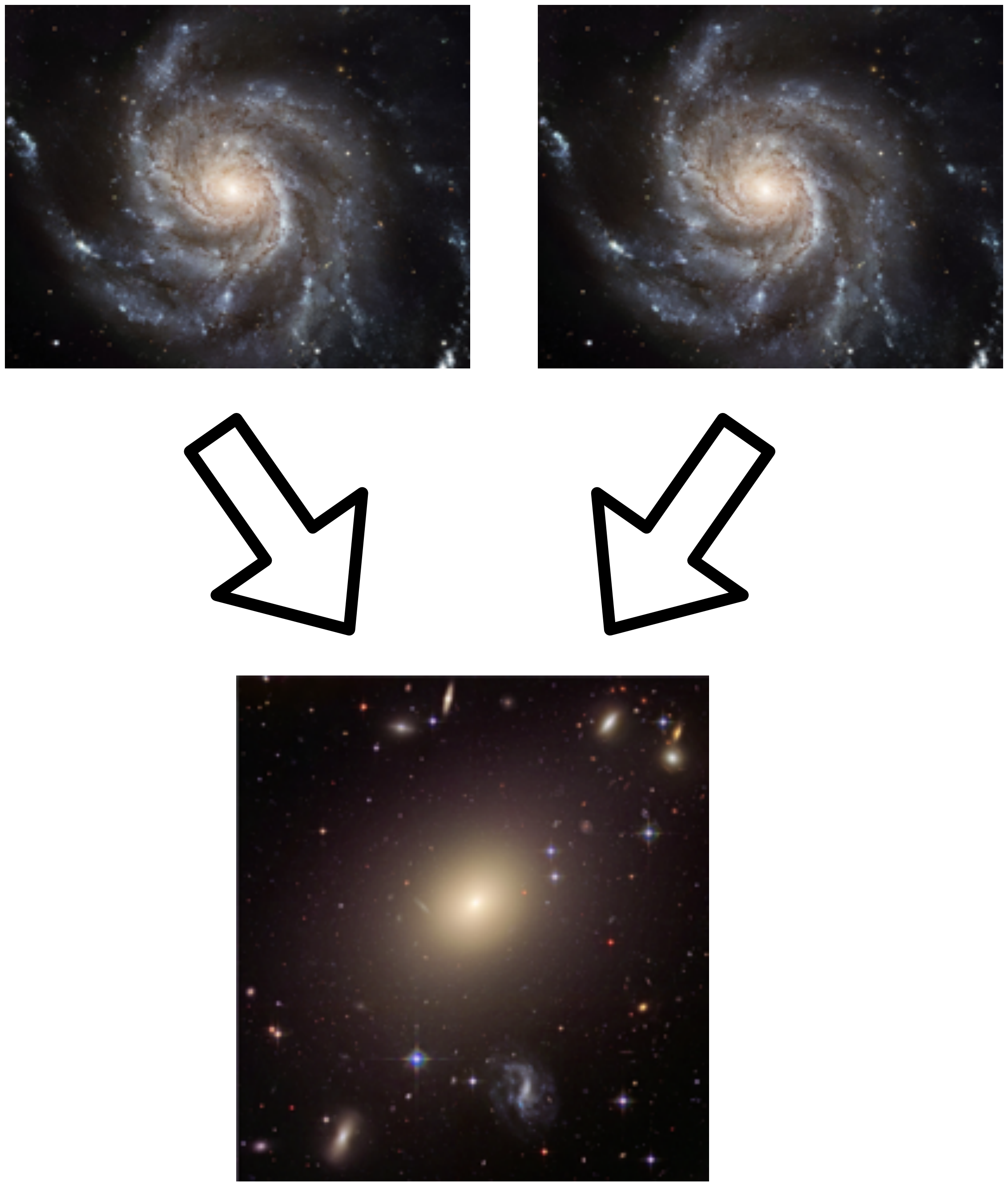

Galaxy evolution in a nutshell

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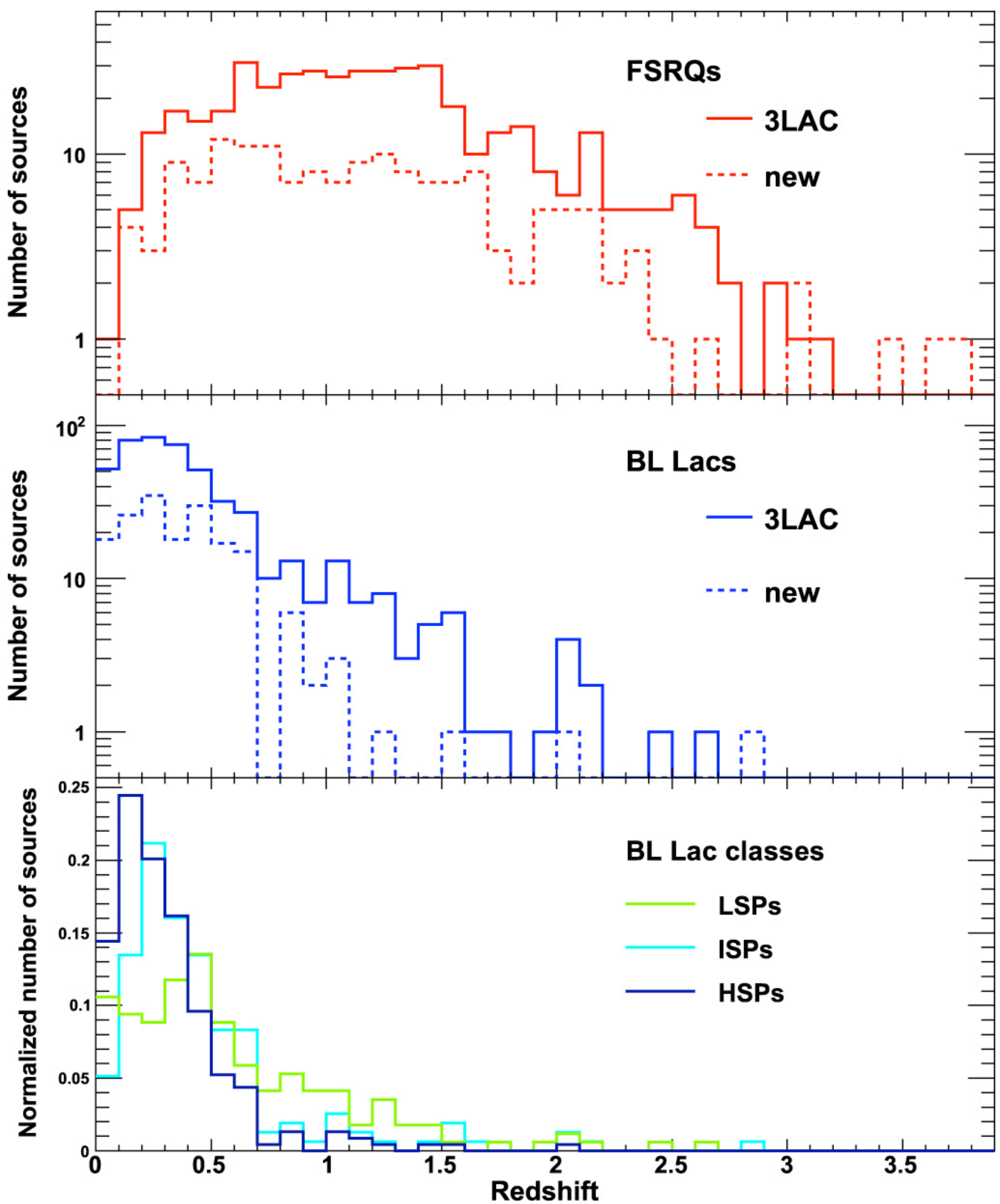
Galaxy merger

Elliptical galaxy with quasar

Gas runs out: BL Lac

Extra question



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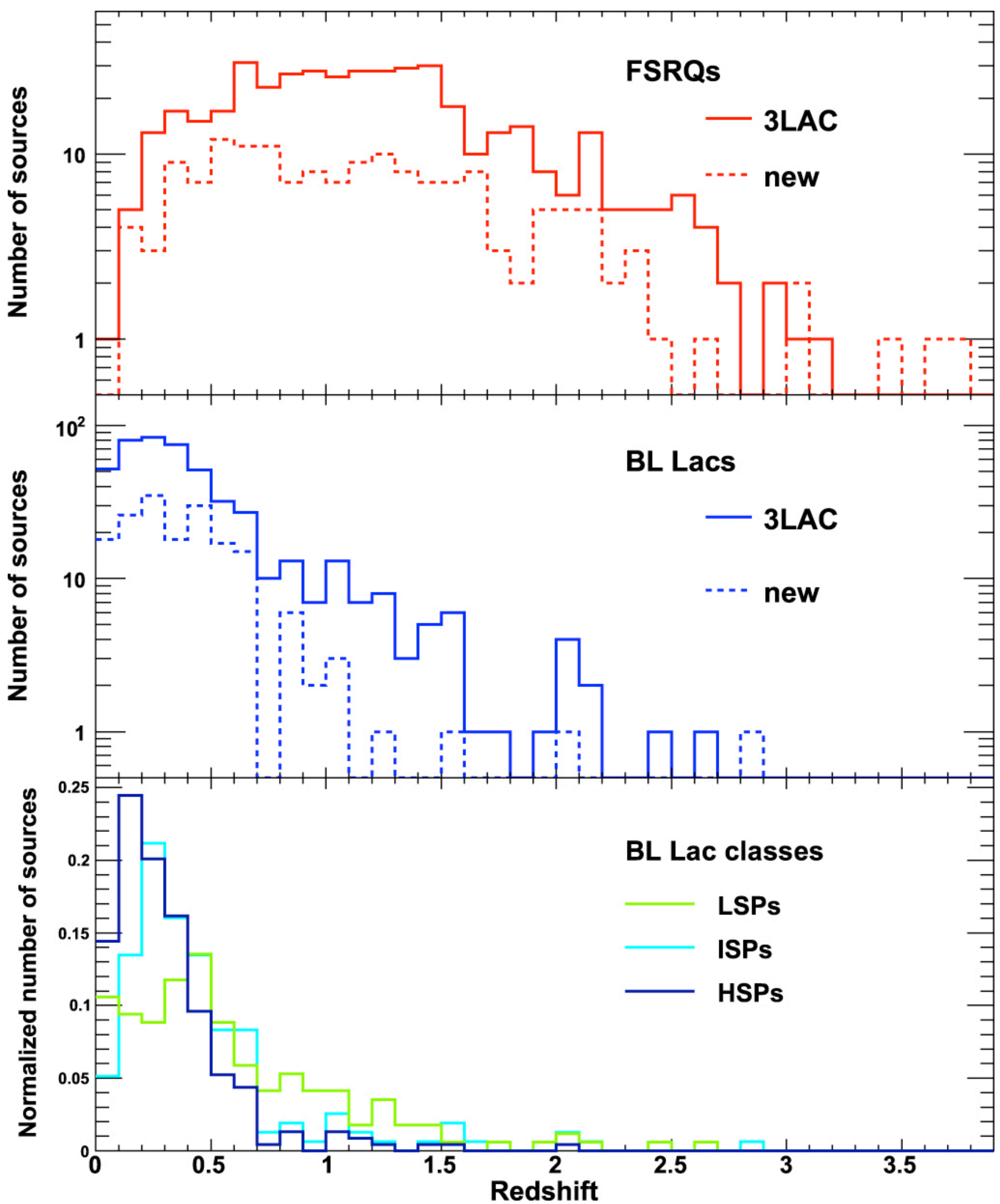


The Third Catalog of Active Galactic Nuclei Detected by the Fermi Large Area Telescope; Ackermann et al. 2015, ApJ, 810, 14

Quasars are typically found at higher redshifts than BL Lacs. How do we explain that?

Quasars are the first evolutionary stage of AGN. When gas runs out, they turn into a BL Lac stage.

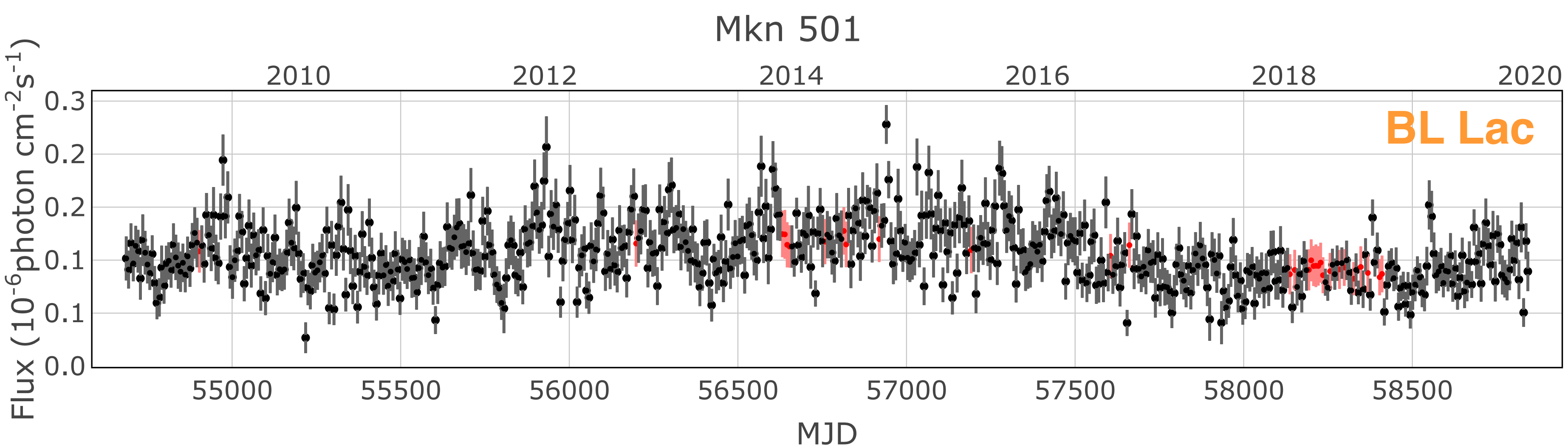
Summary

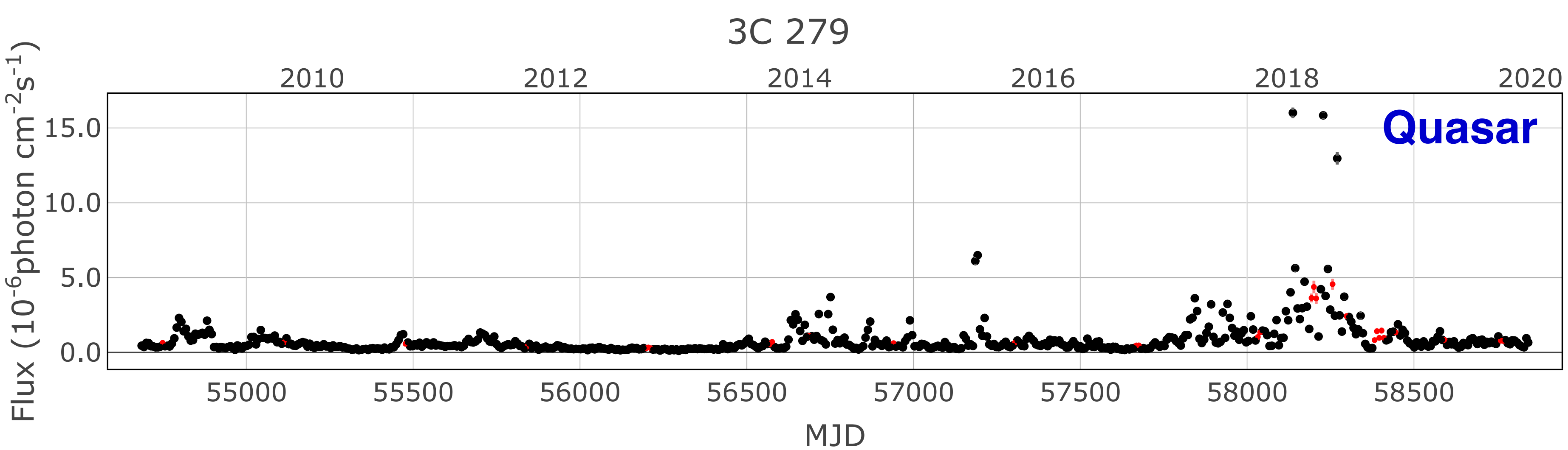
- There is a lot we don't yet know about how supermassive black holes grow, and how they shape star formation in their host galaxies.
- Radiation from accreting supermassive black holes (AGN) is the best tracer we have of black hole evolution.
- Basic models exist that explain the radiation we observe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

New tools: flux variability

How can we characterize the differences between blazar classes in the time domain?

Stationary process: random process where the mean and the variance do not change over time.





Errando & Groebe, submitted

Solution: Autoregressive fractionally integrated moving average ARFIMA (1,d,0)

$$(1 - \phi B)(1 - B)^d (y_t - \mu) = \epsilon_t$$

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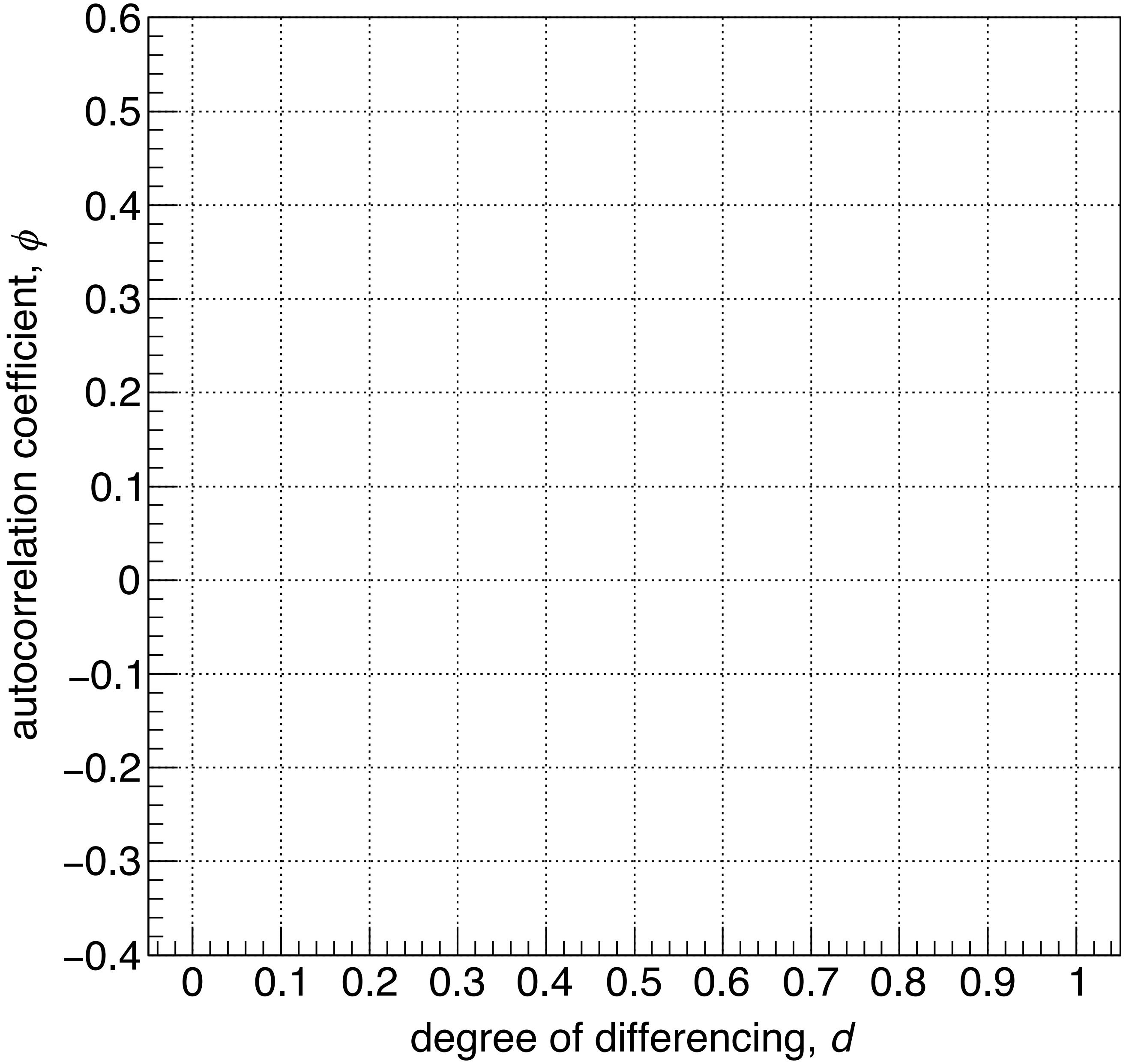

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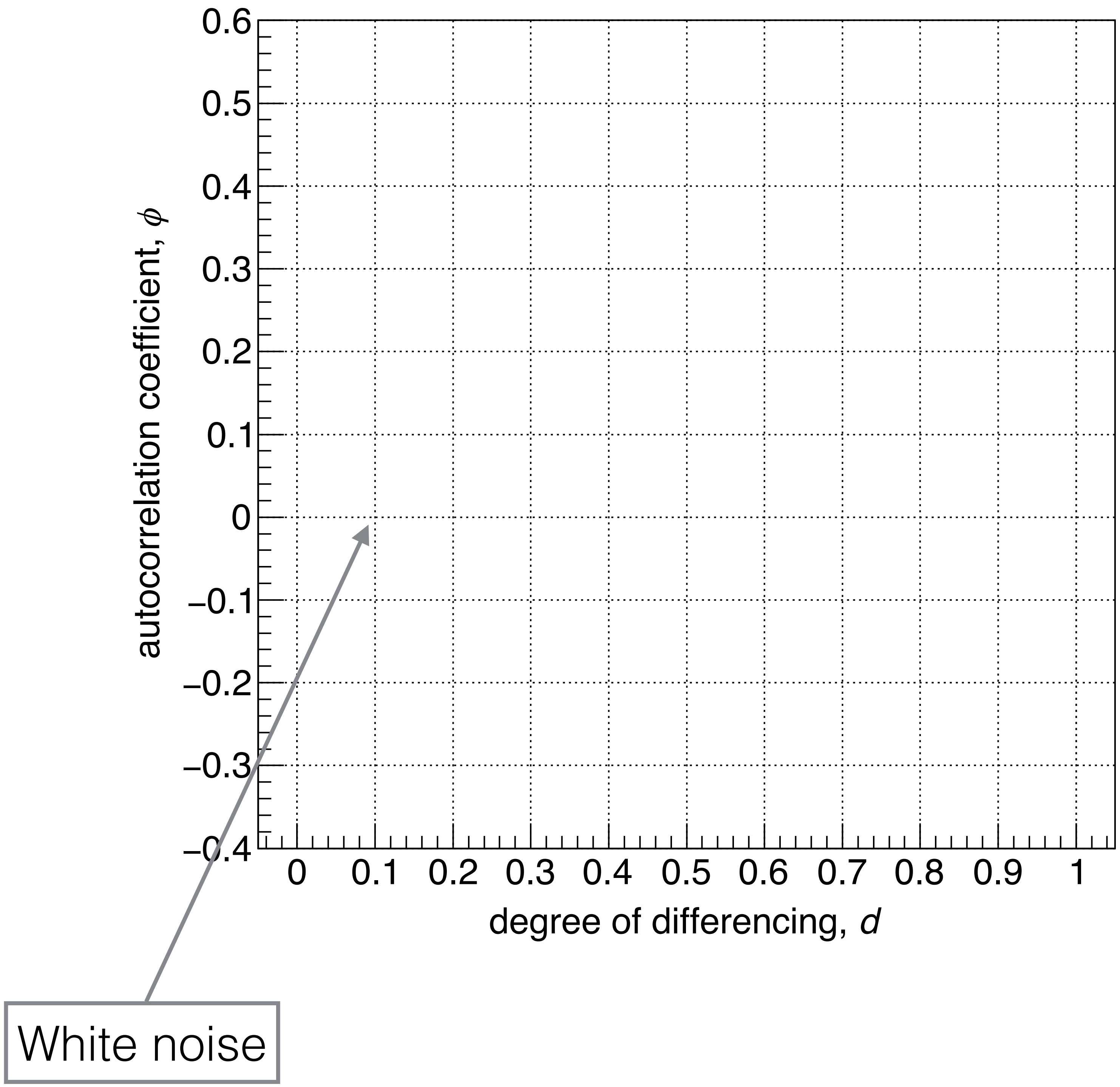
$$(1-\phi B)(1-B)^d(y_t-\mu)=\epsilon_t$$



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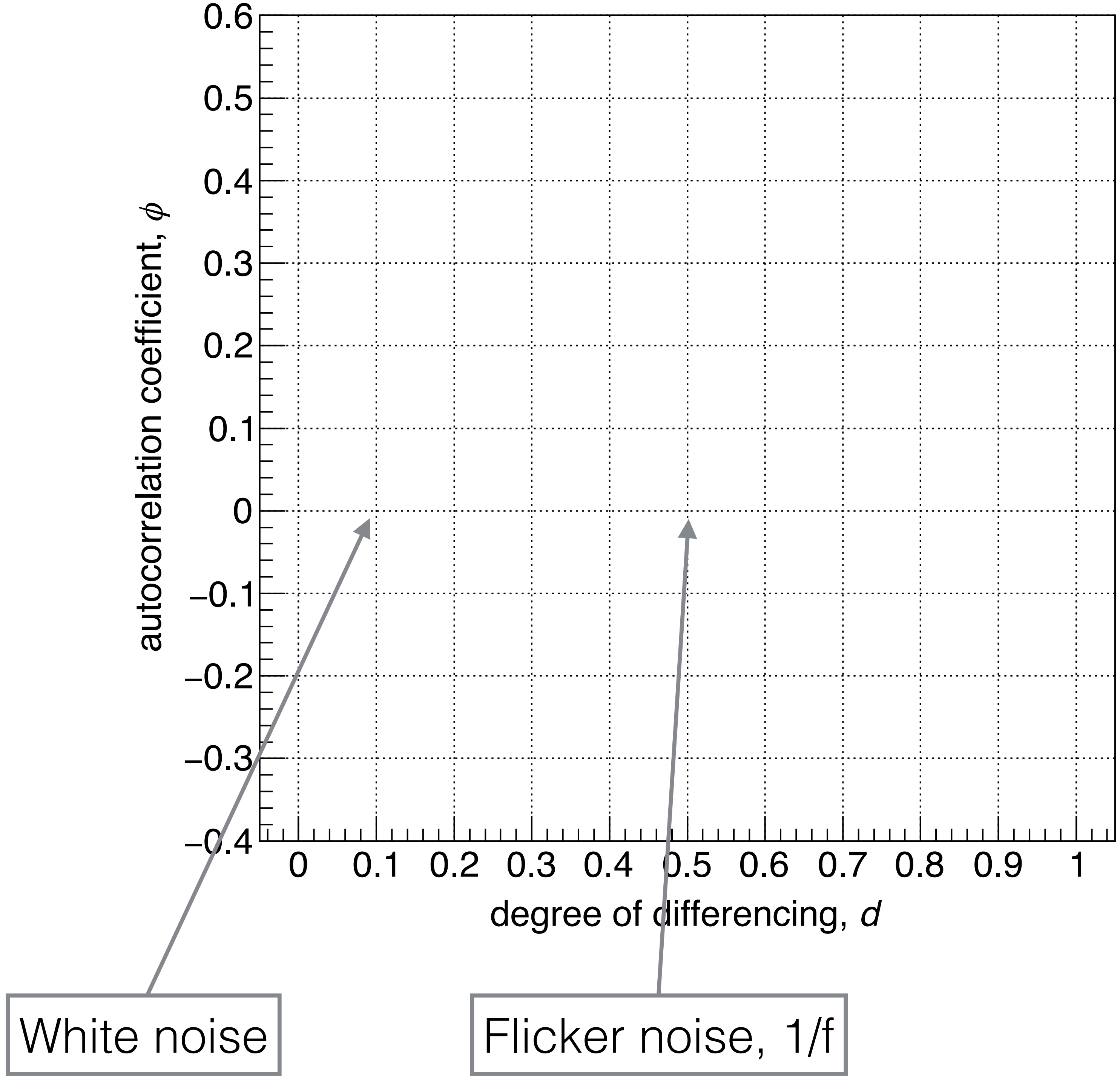

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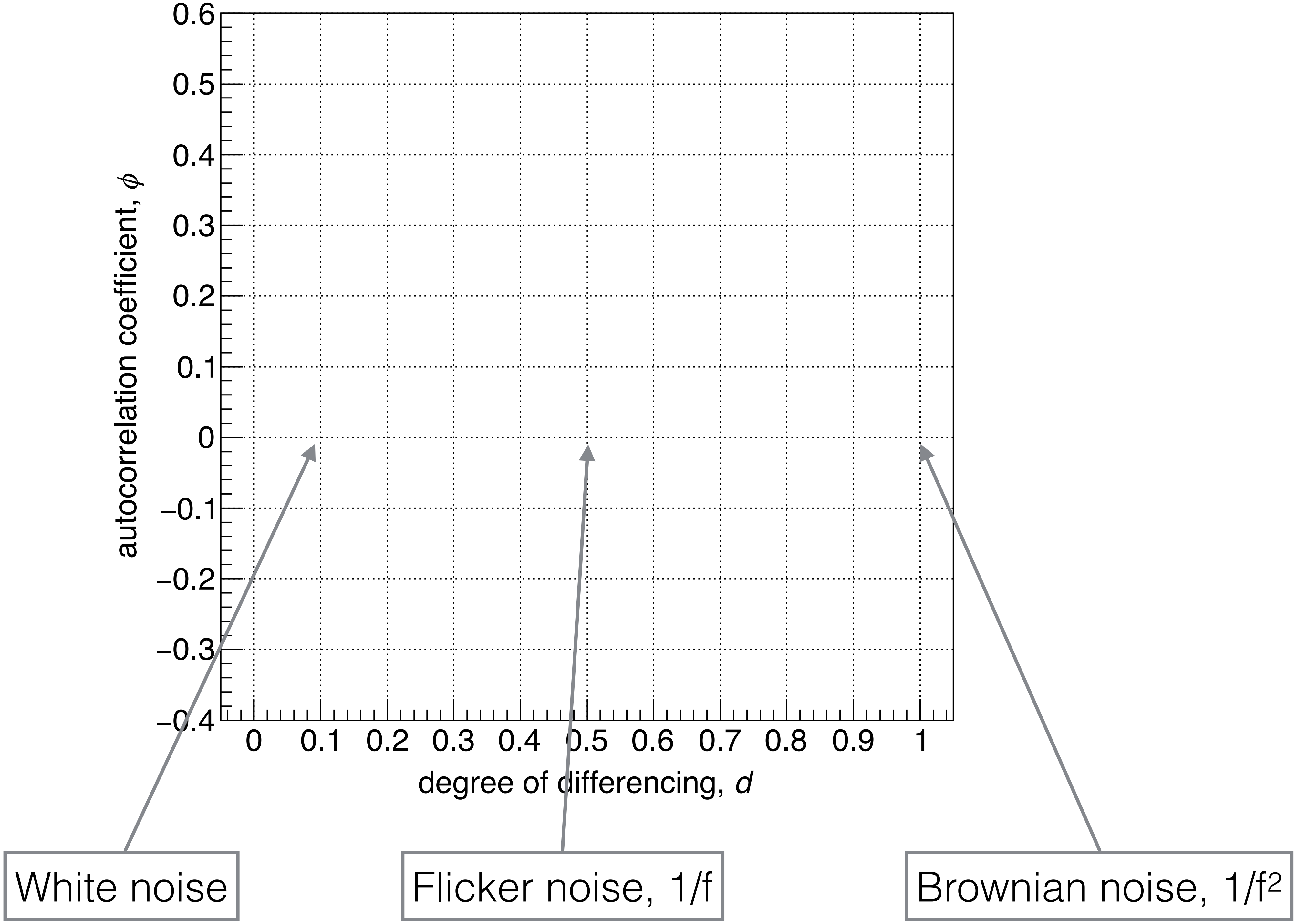

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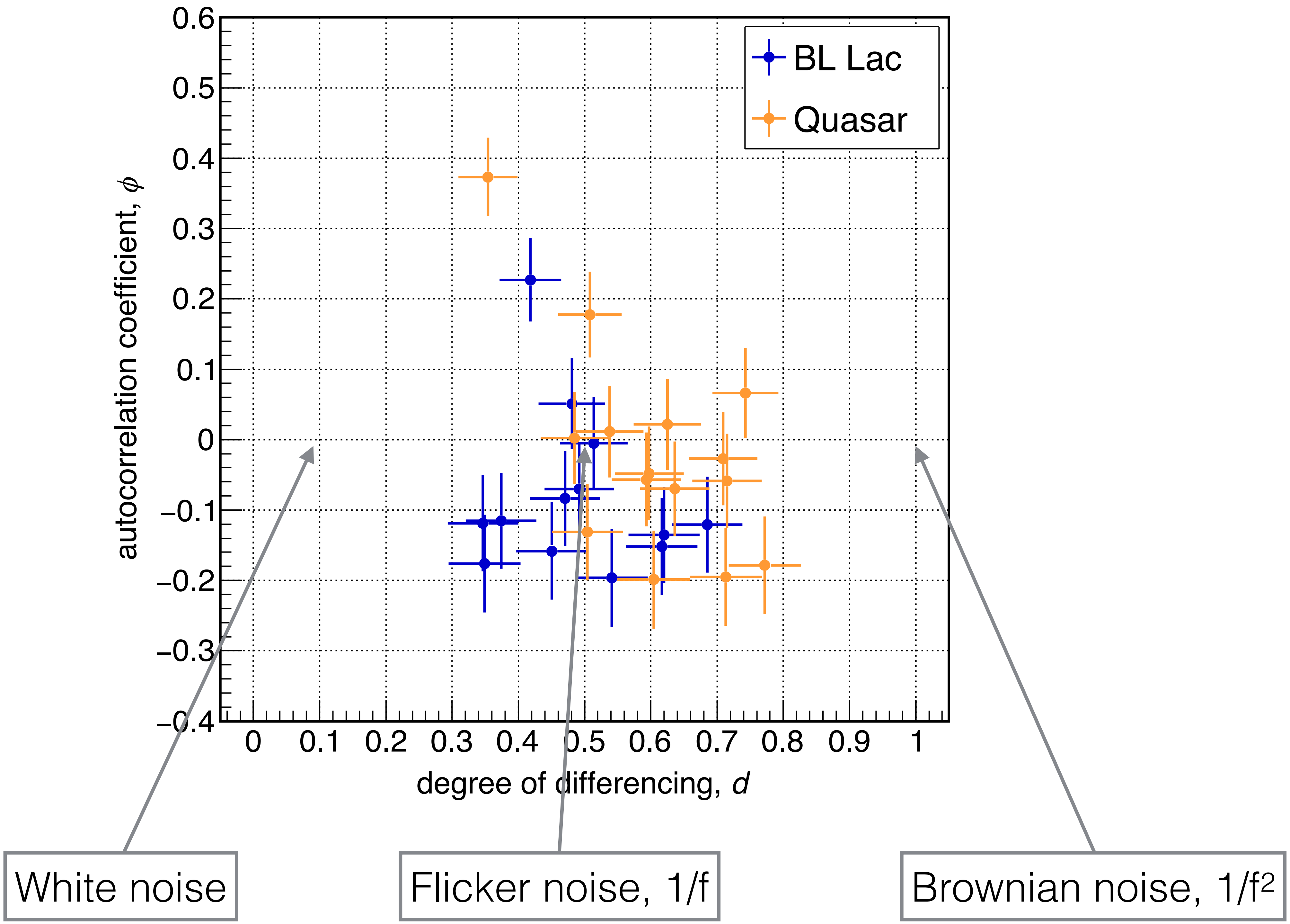

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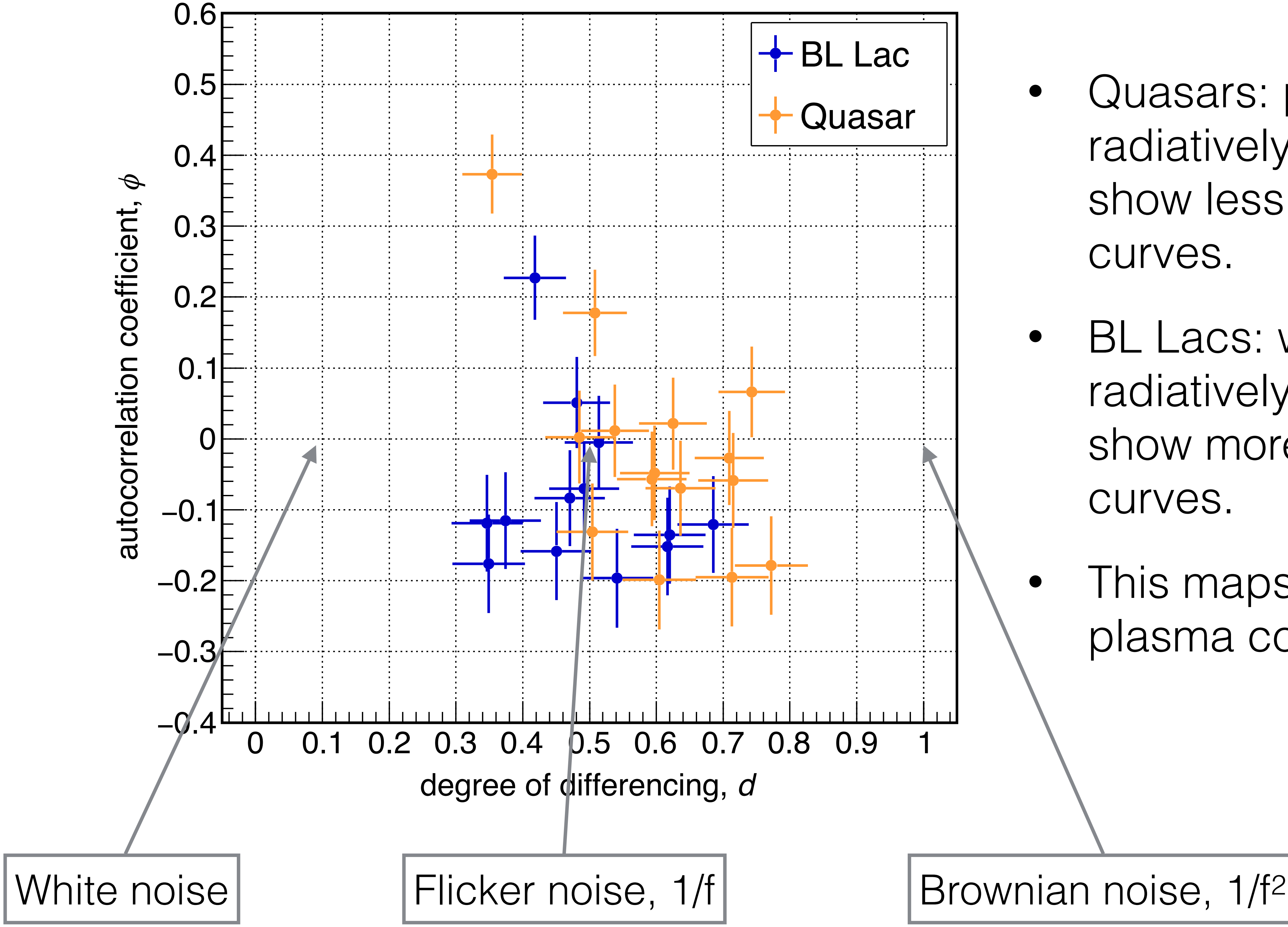

- Quasars: powerful jets, radiatively efficient disks, show less stationary light curves.
- BL Lacs: weak jets, radiatively inefficient disks, show more flicker-type light curves.
- This maps differences in jet plasma cooling.

References

- Complete up-to-date review of relativistic jets in AGN: Blandford, Maier, Redhead 2019, ARAA, 57, 467
- Flux variability in gamma rays: Begelman, Fabian & Rees 2008, MNRAS, 384, 19
- Properties of AGN at all wavelengths: Active Galactic Nuclei, Robson 1996, Wiley
- Accretion power in astrophysics, Frank, King & Raine 2002, Cambridge
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Email me if you have further questions:
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