AGN - with the focus on blazars

Astrophysics exam presentation
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University of Siena, PhD cycle XXXVII
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Outline

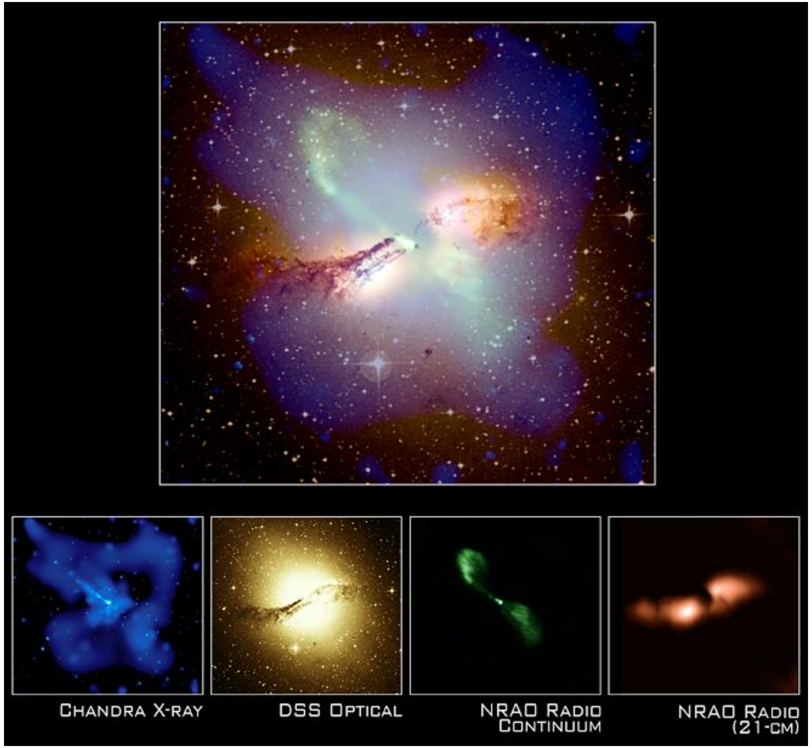
- Definition and basic properties
- AGN classification
- Unification of AGNs
- Extra-galactic accelerators (3FGL -> 4FGL)
- Blazars
- The extragalactic background light
- Blazars MWL studies

Definition and basic properties of AGNs

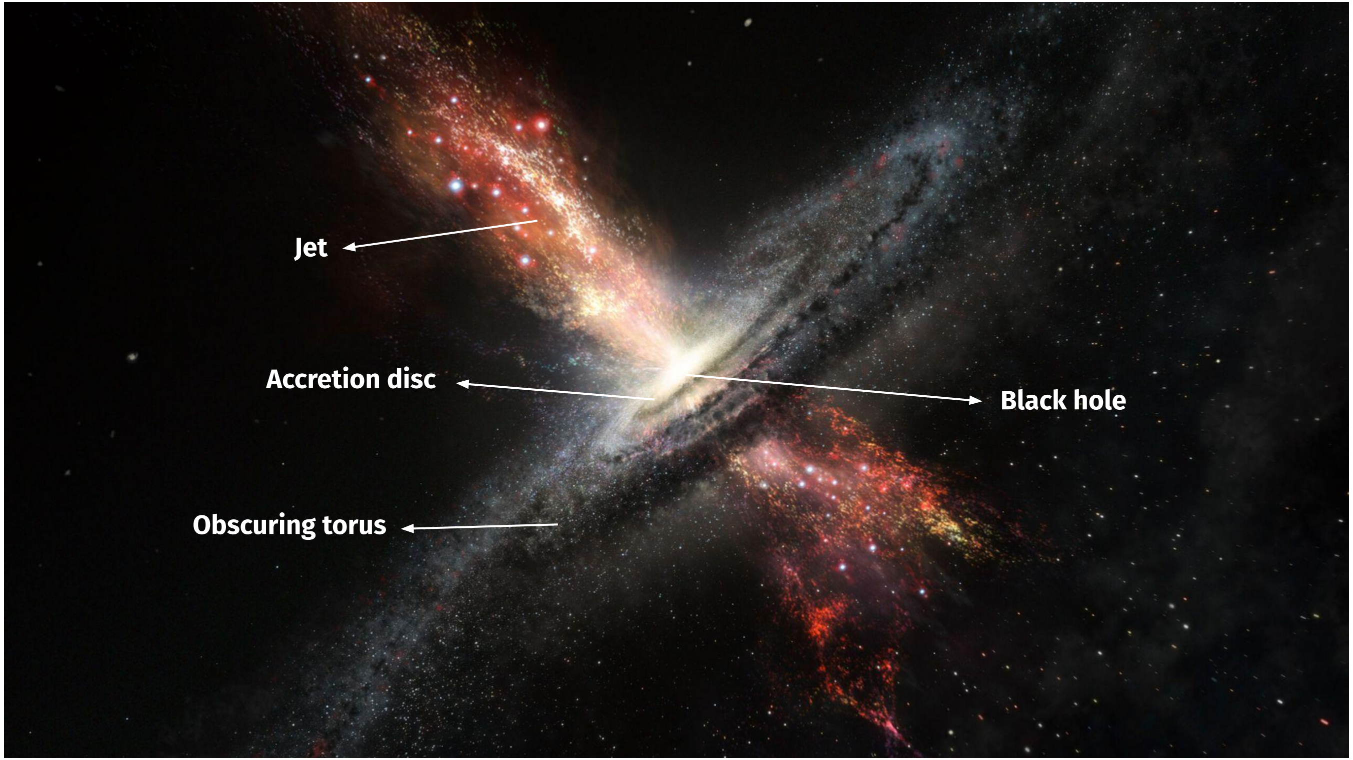
At optical, emission from most galaxies is dominated by starlight.

Observations in other wavebands (radio, IR, UV, X-rays & Gamma-rays) often also reveal emission indicating a variety of non-stellar processes are present.

Active Galactic Nucleus (AGN) indicate existence of highly energetic phenomena in the nucleus or central region of a galaxy not directly attributable to stars



A composite X-ray (blue), radio (pink and green), and optical (orange and yellow) image of the galaxy Centaurus A (image credit CXC)



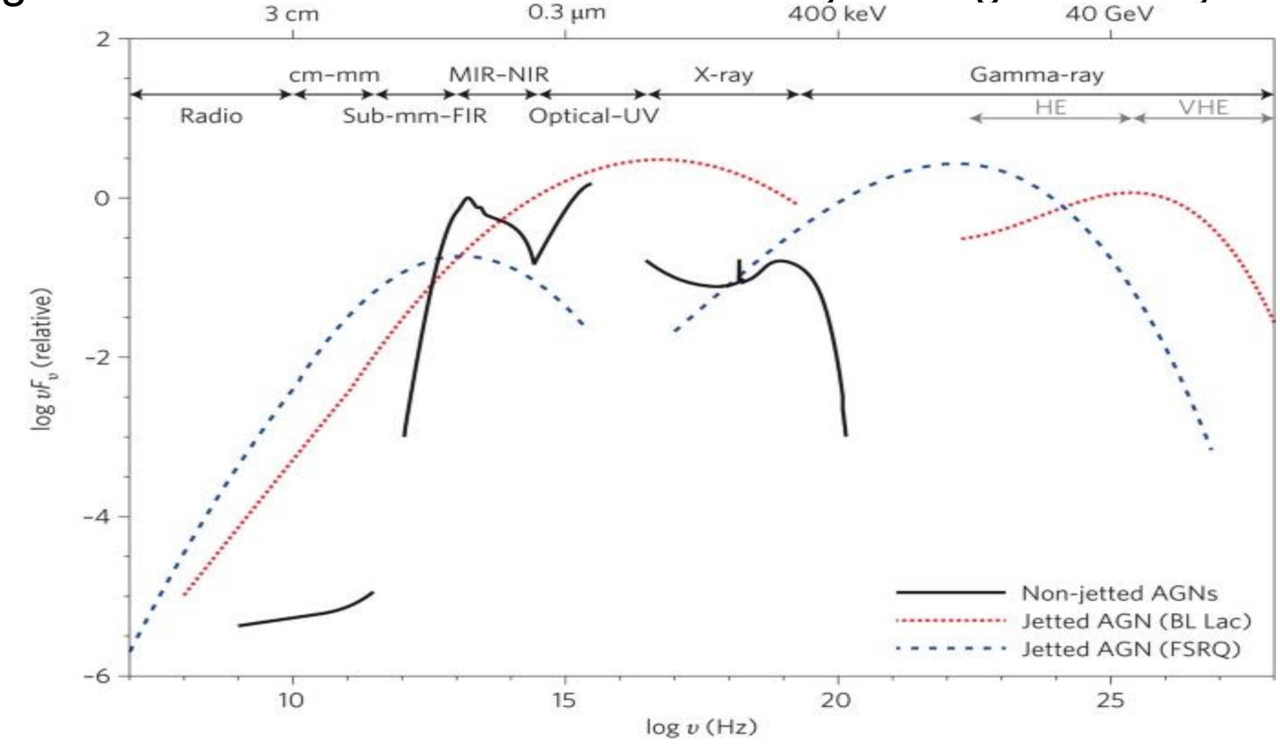
Typical model of an AGN

Physical properties:

- Mass of the black hole
- Rate of accretion onto the black hole
- Presence of a jet
- Angle at which the galaxy is viewed

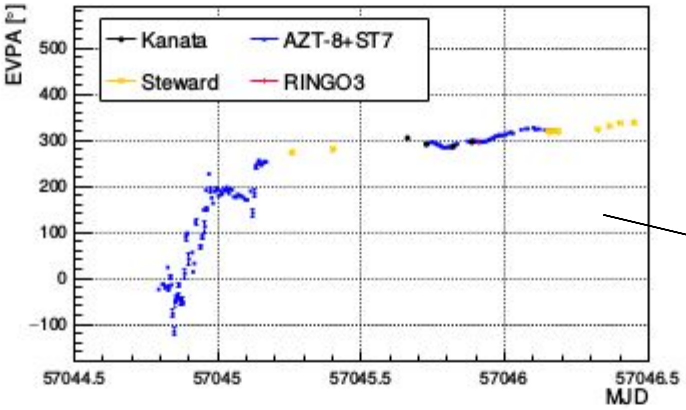
- Highly luminous: L_{bol}~10^{42} - 10^{48} ergs s^{-1} (10^9-10^{15} L_{sun})
- Compact: size << 1 pc
- Broad-band emission:

dL/dlog n = const. From radio and IR to X-rays and gamma-rays

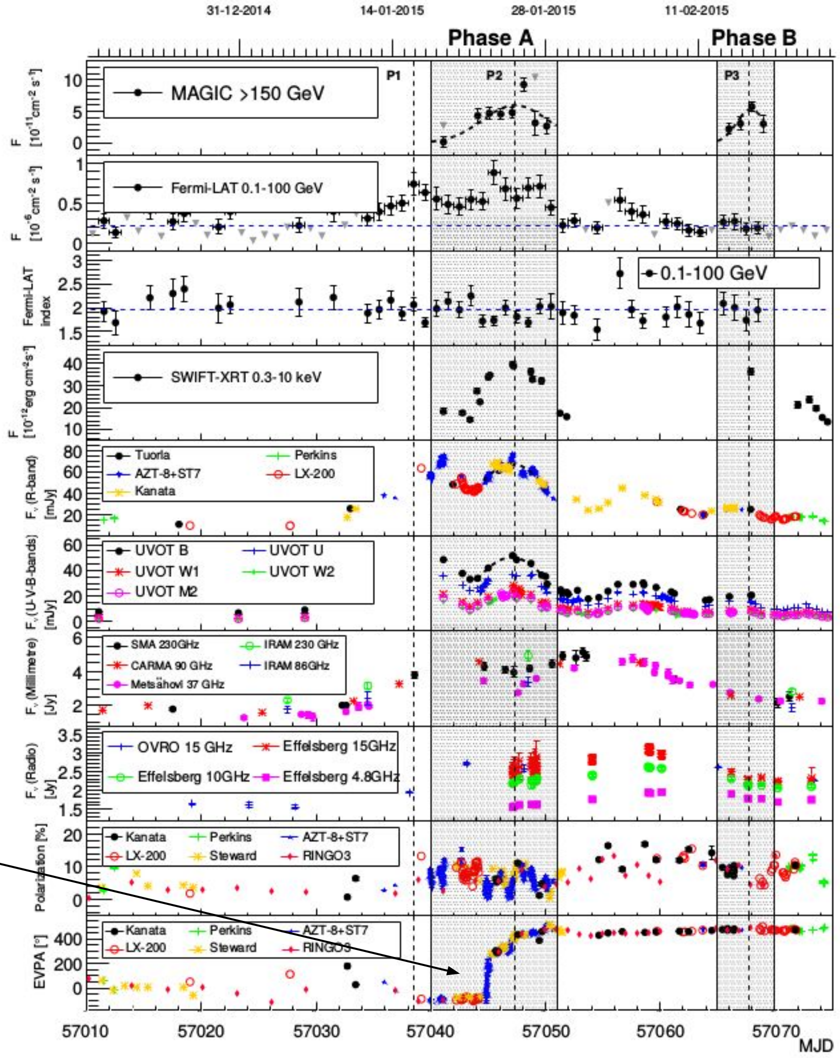


Padovani, P. On the two main classes of active galactic nuclei. *Nat Astron* **1**, 0194 (2017).

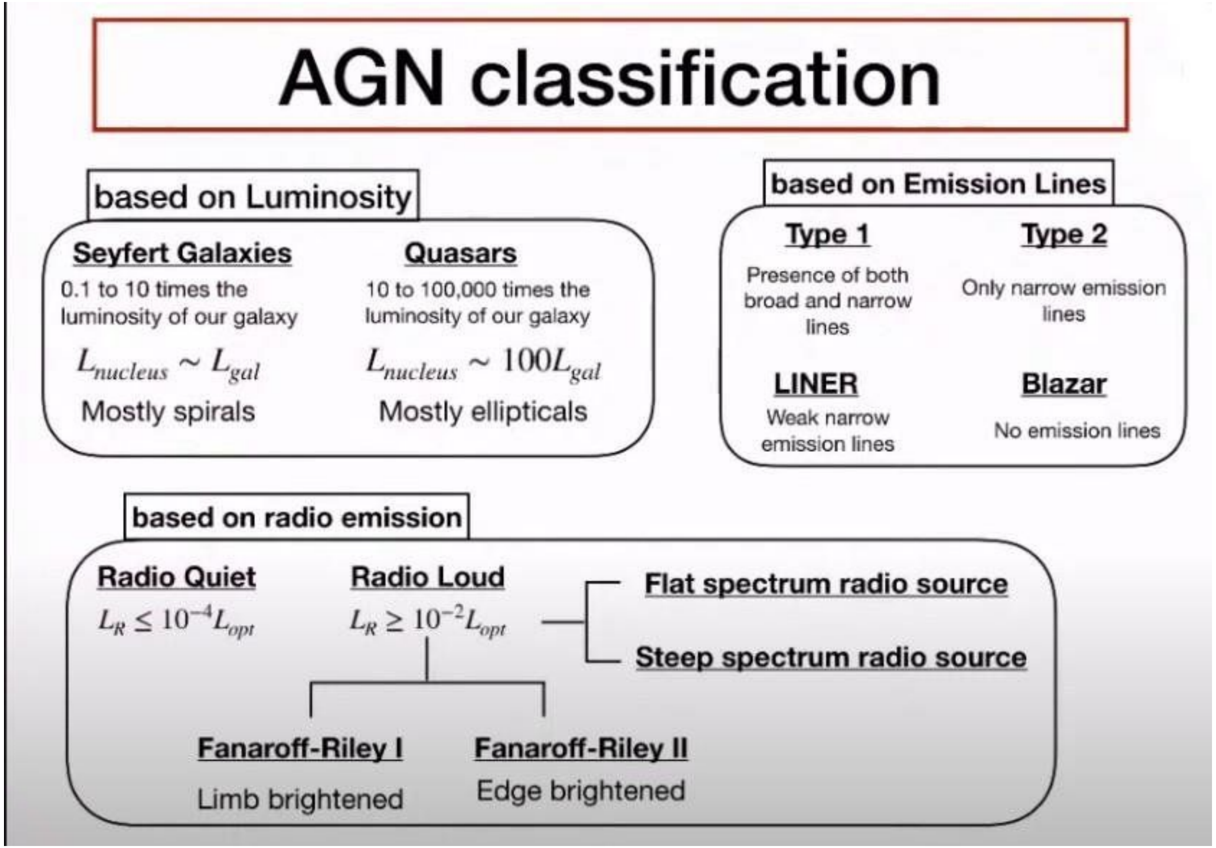
- Variable: on different times scales. Variable across all energy bands
- Strong Radio emitters: in some sources extended, jets are present
- Polarized



A&A 619, A45 (2018)



AGN classification



AGN: The Energetic Centres of Galaxies, Astronomy and Astrophysics Newsletter, 2(4), 3, 2021.

Seyfert galaxies

Characteristics of both Type 1 and Type 2 Seyfert Galaxies:

- Their emissions are moderate in gamma rays and bright in X-rays
- Their host galaxies are often spiral or irregularly shaped galaxies.
- Seyferts are actually fairly common. (There is thought to be a Seyfert AGN at the center of about 1% of spiral galaxies.)
- Seyfert Galaxies are broken into two subclasses, Type 1 and Type 2, based on the emission lines appearing in their spectra.

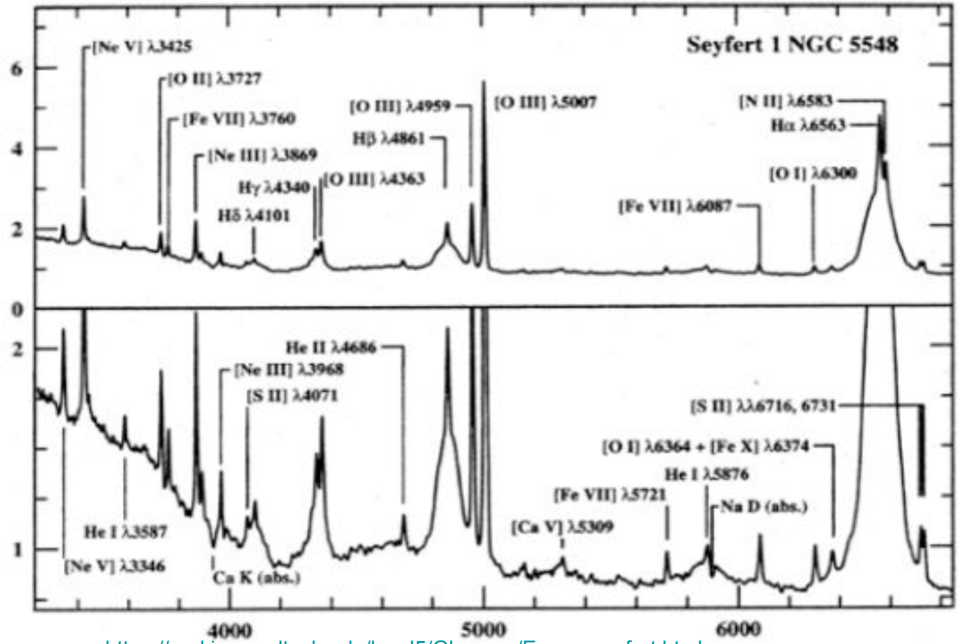
Seyfert galaxies

- Type 1:

  These have both narrow line AND broad line peaks in their spectrum

Emission Lines (Type 1):

Top graph shows full peaks, bottom zooms in along y axis to better show the difference between peak widths.



https://ned.ipac.caltech.edu/level5/Glossary/Essay_seyfert.html

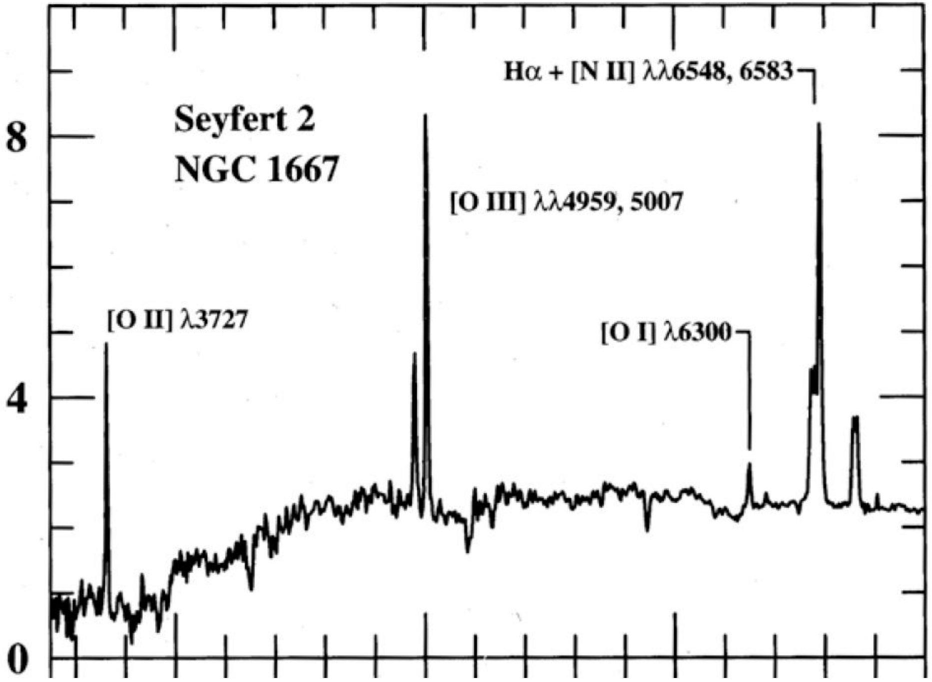
Seyfert galaxies

- Type 2:

  These have only narrow emission lines visible in their spectrum

Emission Lines (Type 2):

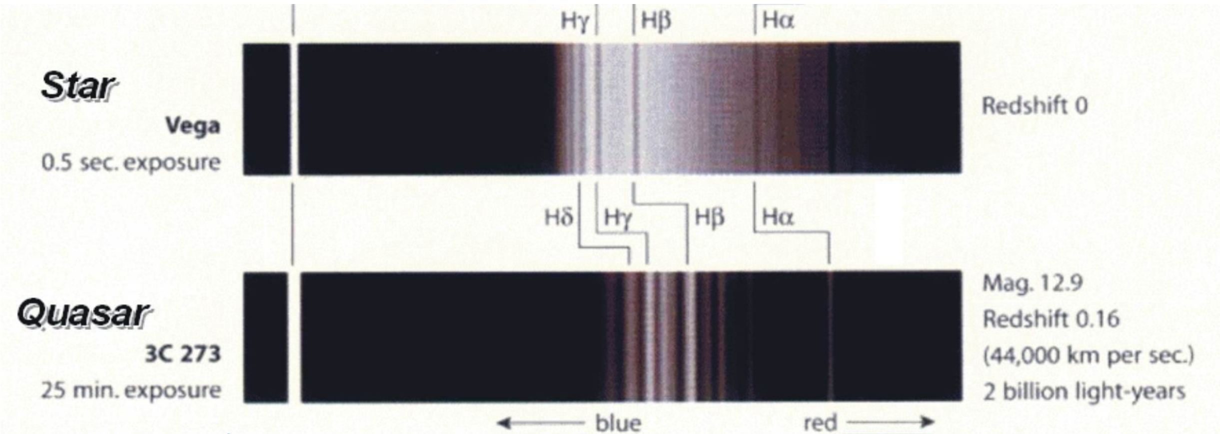
Only narrow peaks are present.



https://ned.ipac.caltech.edu/level5/Glossary/Essay_seyfert.html

Quasars

- Quasars are the most luminous out of all the AGNs: $M_B < -21.5 + 5 \log h_0$
- Quasars are similar to Seyfert galaxies except that the nuclear source is brighter than the combined brightness of all the stars by a factor of 100 or more
- Jets emitted can be more prominent than the host galaxy

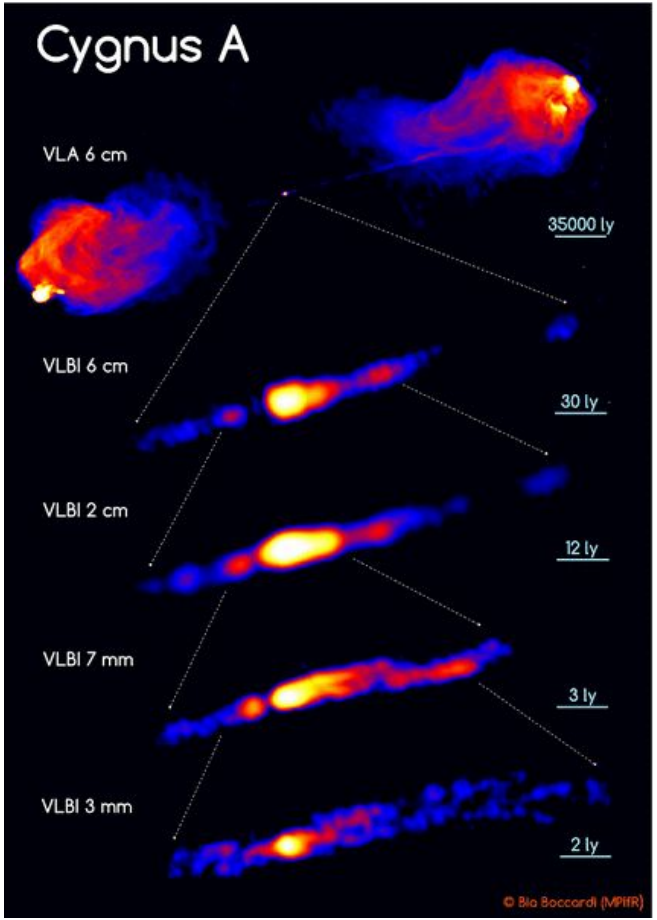


http://quasar.square7.ch/fqm/1226+023.html

Radio galaxies

- Radio Galaxies are usually elliptical galaxies in which the emission is more prominent in the radio wavelengths.
- These emissions are often accompanied by single or twin radio lobes that are in the order of Mpc.
- Radio galaxy's emission is non-thermal because it is a Synchrotron emission produced by fast-moving electrons spiralling around magnetic fields.
- Radio morphology: Fanaroff & Riley (1974): measured by the ratio of the distance between the two brightest spots and the overall size of the radio image.

FR I with R<0.5 and FR II with R>0.5



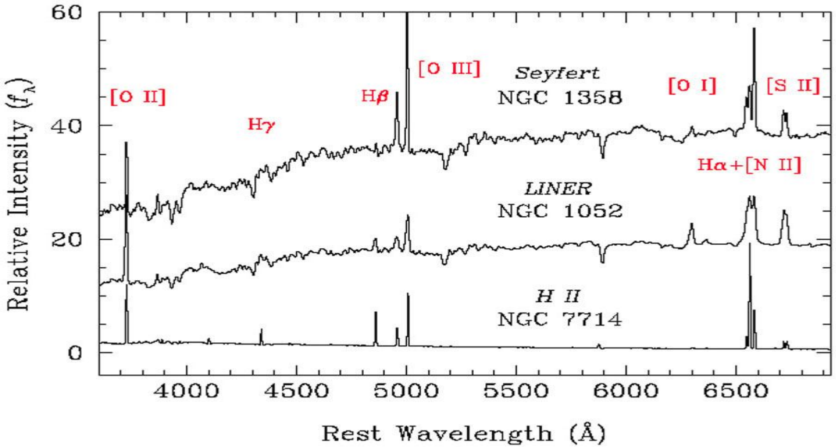
LINERS

LINER = Low-Ionization Narrow-Line Region

They are characterized by [O II] λ3727Å / [O III] λ5007Å ≥ 1

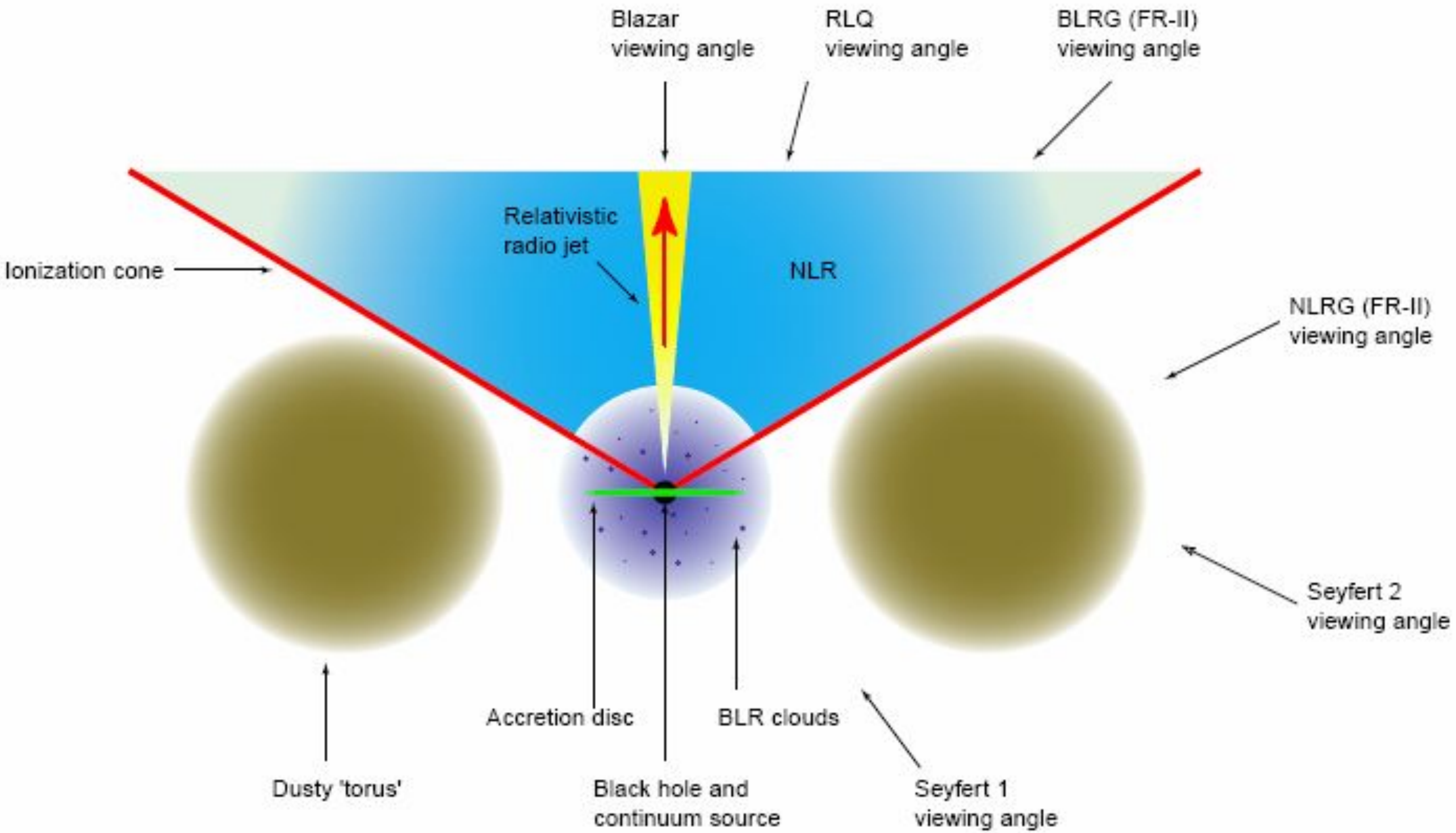
[O I] λ6300Å / [O III] λ5007Å ≥ ⅓

- Most of the nuclei of nearby galaxies are LINERs.
- A census of the brightest 250 galaxies in the nearby
- Universe shows that 50–75% of giant galaxies have some weak LINER activity
- They are the weakest form of activity in the AGN zoo.
- One has to dig into the bulge spectrum sometimes to get the characteristic emission lines.

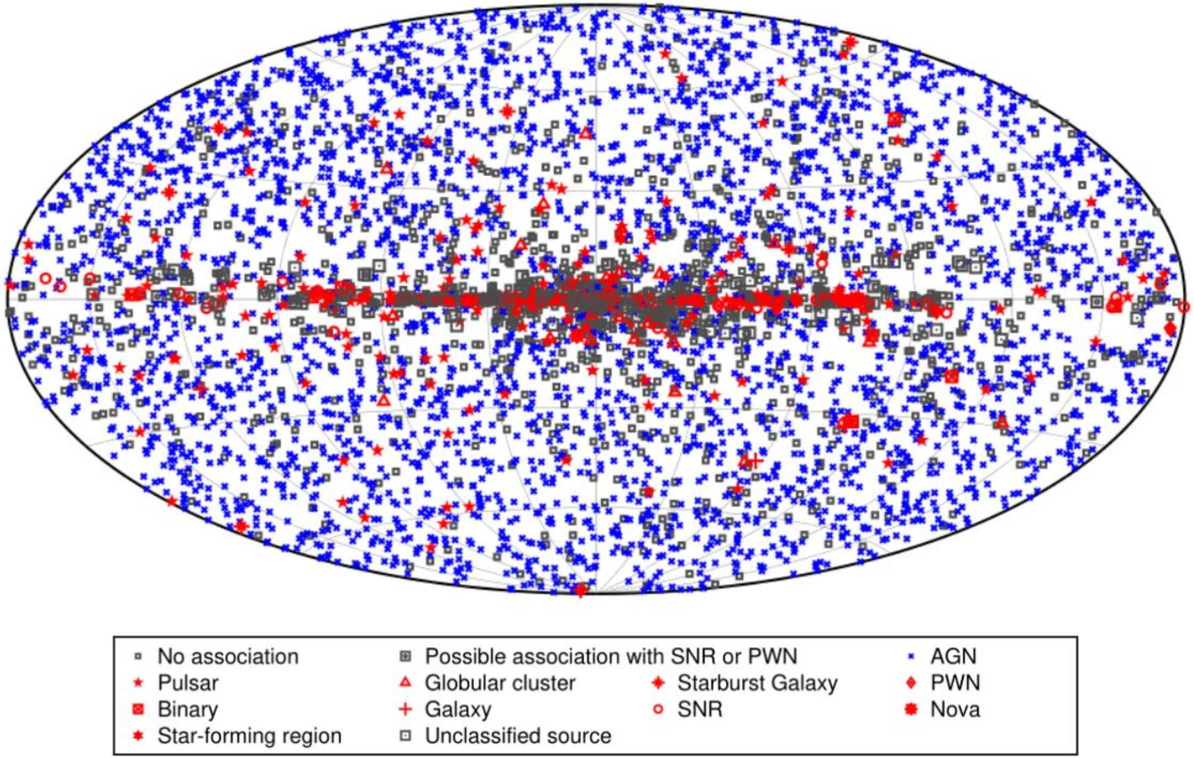


Astronomy and Astrophysics, Vol. 87, P. 152, 1980

Unification of AGNs



Extra-galactic accelerators - 4FGL



https://arxiv.org/abs/1902.10045

Extra-galactic accelerators - 4FGL

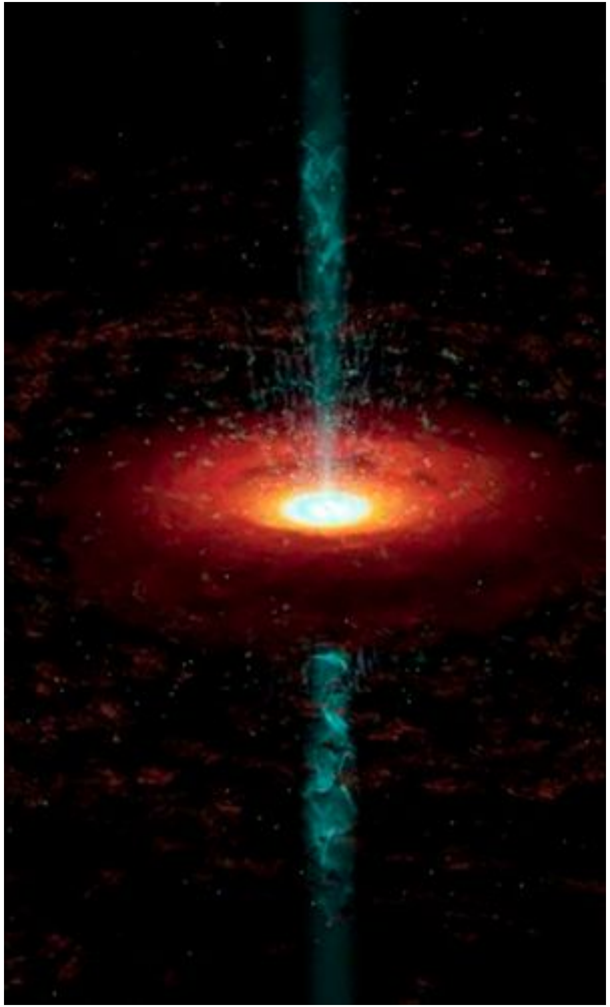
Acronym	IRFs/Diffuse model	Energy range/Duration	Sources	Analysis/Reference
1FGL	P6_V3_DIFFUSE	0.1 – 100 GeV	1451 (P)	Unbinned, F/B
	gll_iem_v02	11 months		Abdo et al. (2010a)
2FGL	P7SOURCE_V6	0.1 – 100 GeV	1873 (P)	Binned, F/B
	gal_2yearp7v6_v0	2 years		Nolan et al. (2012)
3FGL	P7REP_SOURCE_V15	0.1 – 300 GeV	3033 (P)	Binned, F/B
	gll_iem_v06	4 years		Acero et al. (2015)
FGES	P8R2_SOURCE_V6	10 GeV – 2 TeV	46 (E)	Binned, PSF, $\|b\| < 7°$
	gll_iem_v06	6 years		Ackermann et al. (2017b)
3FHL	P8R2_SOURCE_V6	10 GeV – 2 TeV	1556 (P)	Unbinned, PSF
	gll_iem_v06	7 years		Ajello et al. (2017)
FHES	P8R2_SOURCE_V6	1 GeV – 1 TeV	24 (E)	Binned, PSF, $\|b\| > 5°$
	gll_iem_v06	7.5 years		Ackermann et al. (2018)
4FGL	P8R3_SOURCE_V2	0.05 GeV – 1 TeV	5064 (P)	Binned, PSF
	gll_iem_v07 (§ 2.4.1)	8 years		this work

https://arxiv.org/abs/1902.10045

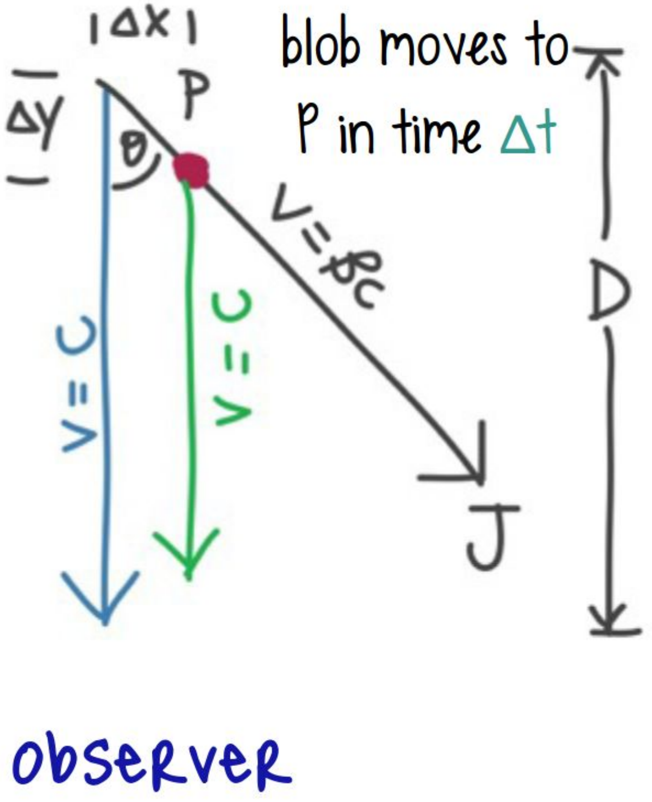
Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	232	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	7
Pulsar wind nebula	PWN	11	pwn	6
Supernova remnant	SNR	24	snr	16
Supernova remnant / Pulsar wind nebula	SPP	0	spp	78
Globular cluster	GLC	0	glc	30
Star-forming region	SFR	3	sfr	0
High-mass binary	HMB	5	hmb	3
Low-mass binary	LMB	1	lmb	1
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
BL Lac type of blazar	BLL	22	bll	1109
FSRQ type of blazar	FSRQ	43	fsrq	651
Radio galaxy	RDG	6	rdg	36
Non-blazar active galaxy	AGN	1	agn	10
Steep spectrum radio quasar	SSRQ	0	ssrq	2
Compact Steep Spectrum radio source	CSS	0	css	5
Blazar candidate of uncertain type	BCU	2	bcu	1310
Narrow-line Seyfert 1	NLSY1	4	nlsy1	5
Seyfert galaxy	SEY	0	sey	1
Starburst galaxy	SBG	0	sbg	7
Normal galaxy (or part)	GAL	2	gal	1
Unknown	UNK	0	unk	92
Total	...	358	...	3370
Unassociated	...	...	...	1336

Blazars

- Jet pointed to the observer
- Generally divided in two subclasses:
  Bl Lac type blazars
  FSRQ type of blazars
- Difference between two subclasses is in the presence of emission lines in their spectra
- Large amplitude variability
- Optical polarization



Blazars - superluminal motion



Superluminal motion occurs as a special case of a more general phenomenon arising from the difference between the apparent speed of distant objects moving across the sky and their actual speed as measured at the source

Blazars - relativistic beaming

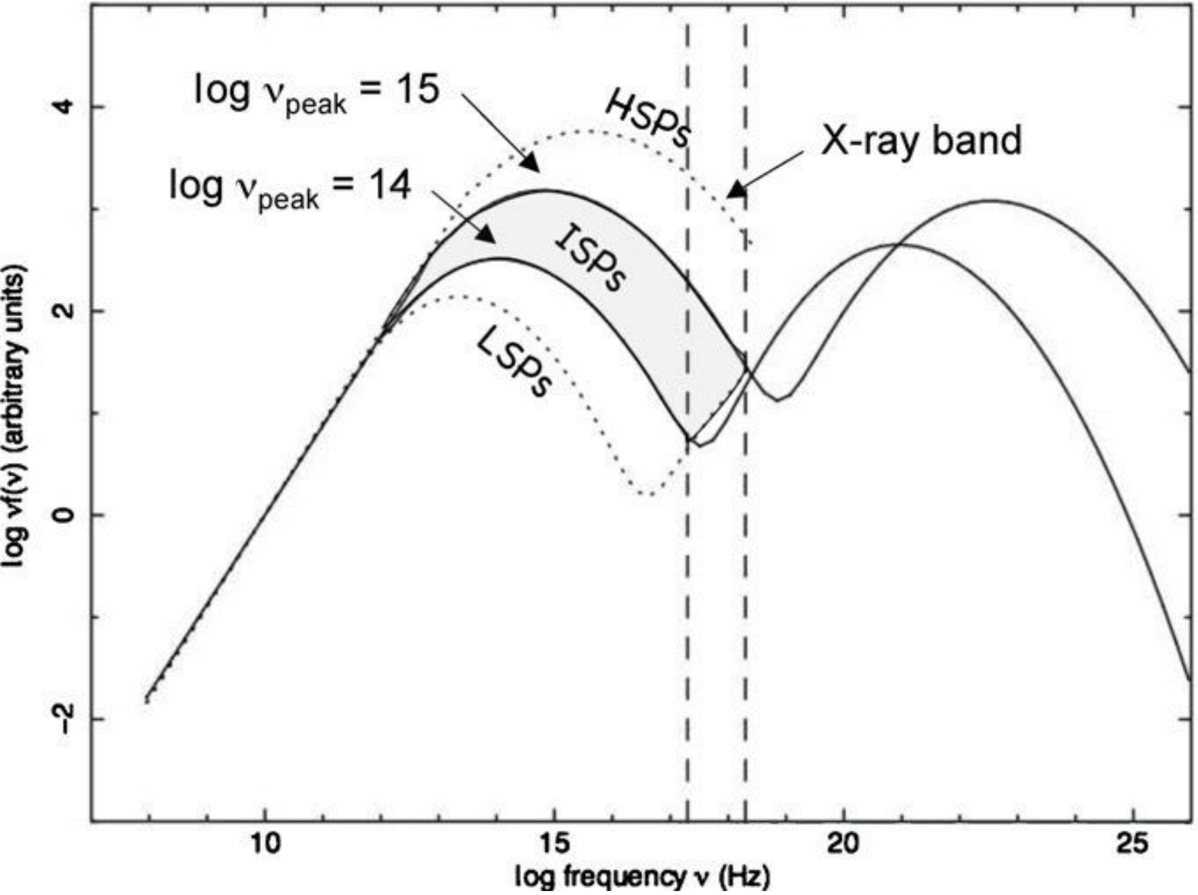
- Another relativistic effect occurs because the knots of plasma are moving at velocities close to that of light
- When emitting plasma has a bulk relativistic motion relative to a fixed observer, its emission is beamed in the forward direction in the fixed frame
- The flux density is thus changed by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

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

Blazars - pair production optical depth

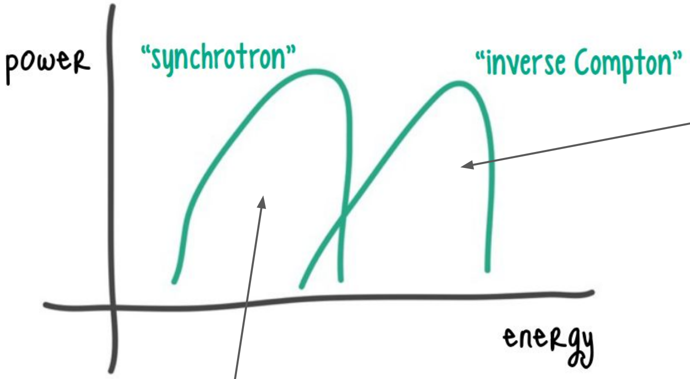
- High energy gamma rays collide with softer radiation to produce e^+e^- pairs
- For gammas to escape from source the optical depth for this process τ_e must be sufficiently low
- The cross section for this process is maximized for collisions between gamma rays of energy $x_{gamma}=hu_{gamma}/mc^2$ and target photon energy $x_{target}=1/x_{gamma}$
- The optical depth is then defined as: $\tau_e= (\sigma_t Nx_{target}R)/S$ where N is the number of photons, R is the radius of the plasma blob 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 : $l = L\sigma_t / Rm_ec^3$
- The criterion for gammas to escape from the source is $\tau_e \sim l / 40 << 1$

Blazars - spectral energy distribution



LBL Log ν (Hz)	IBL Log ν (Hz)	HBL Log ν (Hz)	Ref
< 15		> 15	Padovani & Giommi, 1996
< 14.5	14.5 ~ 16.5	> 16.5	Nieppola et al. 2006
<14	14 ~ 15	> 15	Abdo et al. 2010

Blazars - emission models

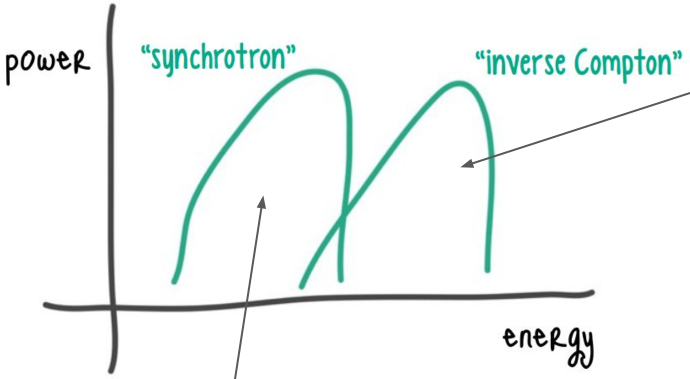


Two fundamentally different approaches to explain the higher energy emission

Leptonic & Hadronic

Lower energy emission due to synchrotron emission from relativistic electrons in the jet

Blazars - emission models



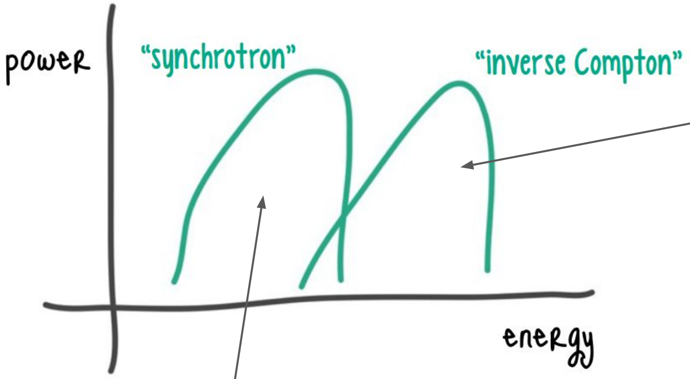
Lower energy emission due to synchrotron emission from relativistic electrons in the jet

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 the IC scattering by the same e^- that produced the SC
- Upscatter the low energy photons responsible for the first bump
  - SSC
- Upscatter photons from the broad-line region, disc, torus…
  - external Compton

Blazars - emission models



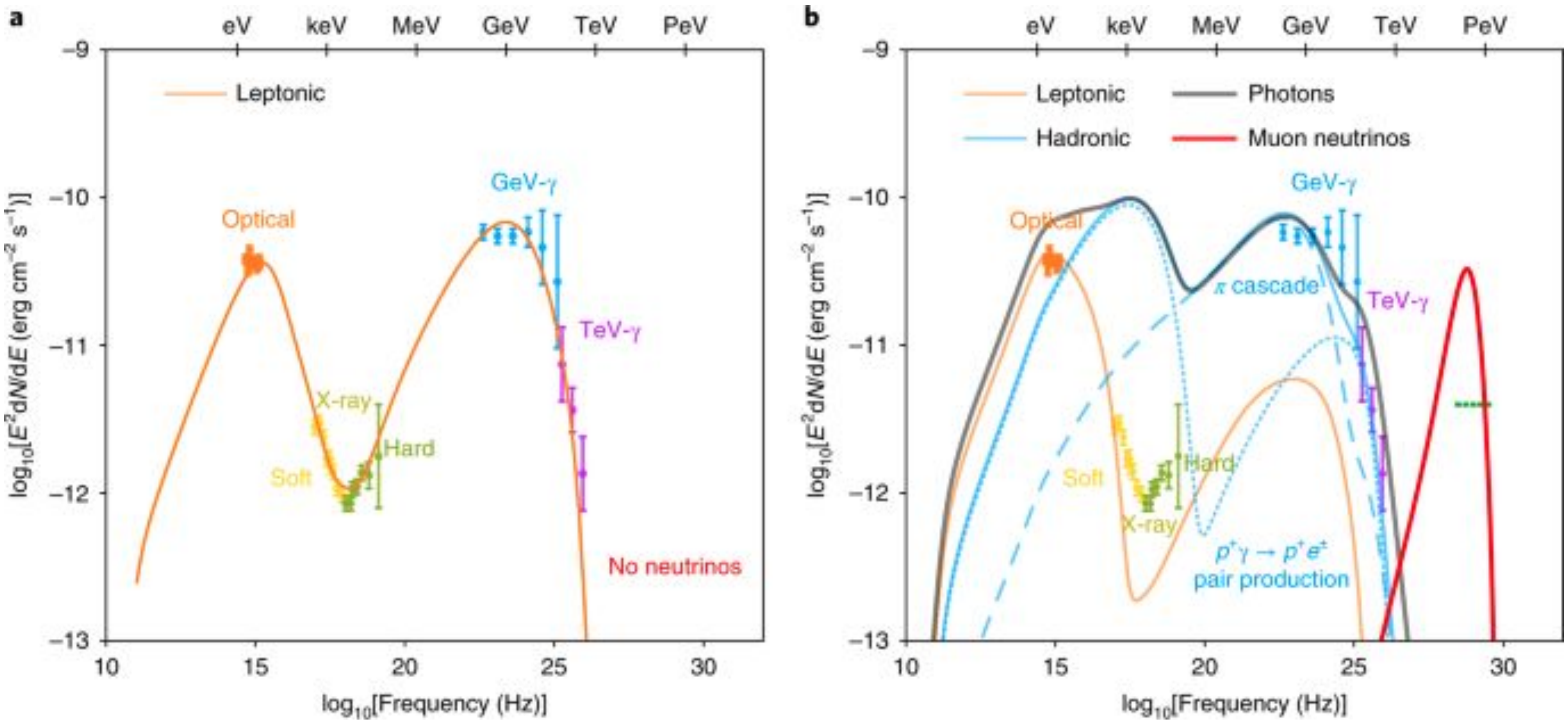
Two fundamentally different approaches to explain the higher energy emission

Leptonic & Hadronic

Lower energy emission due to synchrotron emission from relativistic electrons in the jet

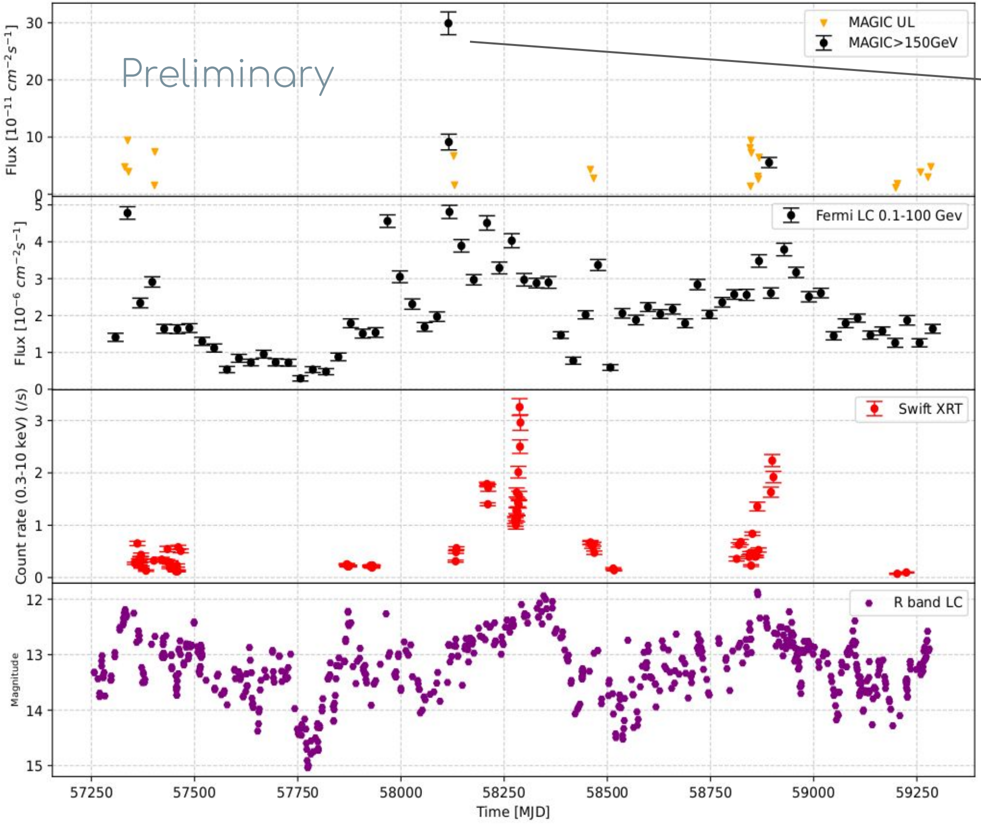
- Both e^+/e^- and p accelerated to ultra relativistic energies
- p's exceed thresholds for photo-pion production on soft photon field emission region
- High energy emission dominated by
  - proton synchrotron
  - neutral pion decays
  - synchrotron and Compton emission from secondary products of charged pions
    - external Compton

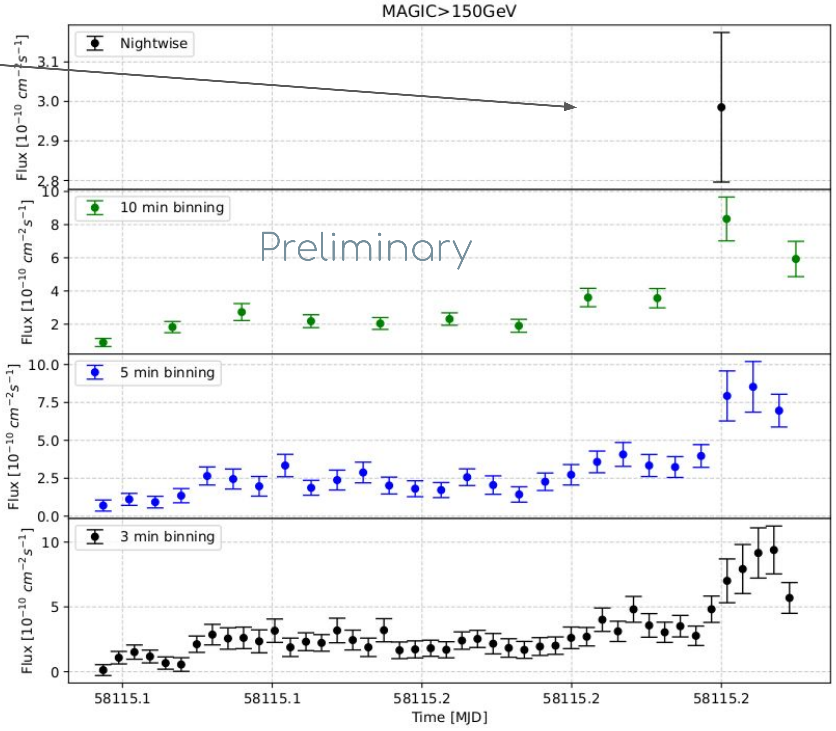
Blazars - emission models



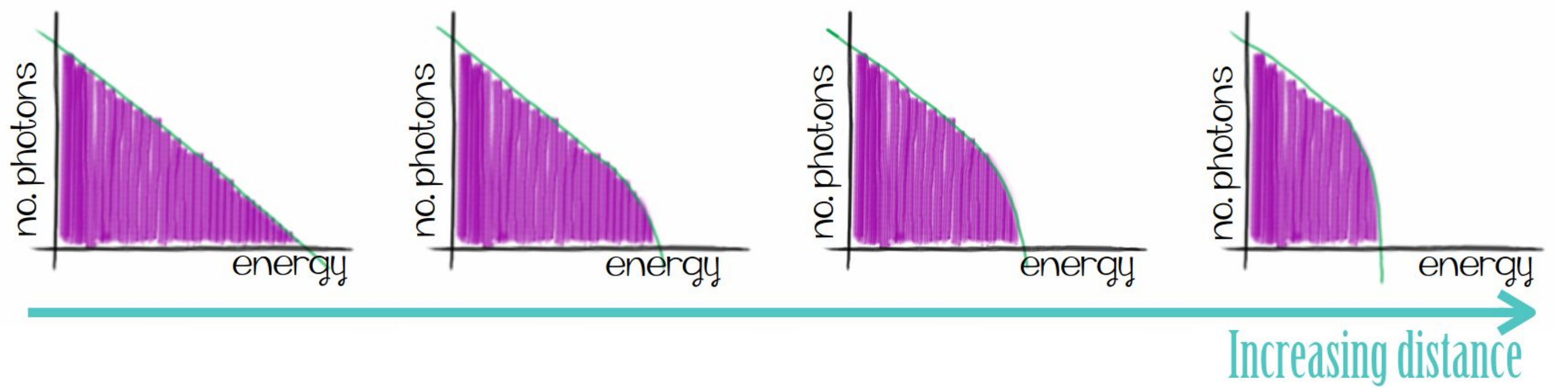
Gao, S., Fedynitch, A., Winter, W. *et al.* Modelling the coincident observation of a high-energy neutrino and a bright blazar flare. *Nat Astron* **3**, 88–92 (2019).
https://doi.org/10.1038/s41550-018-0610-1

Blazars - very high energy variability

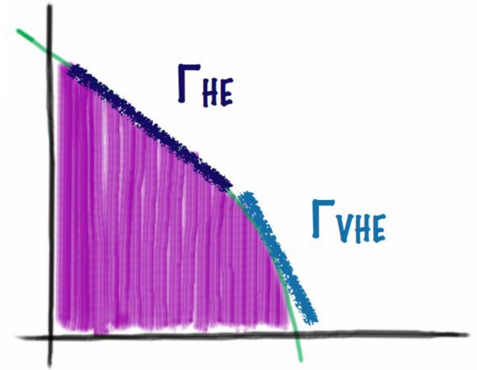


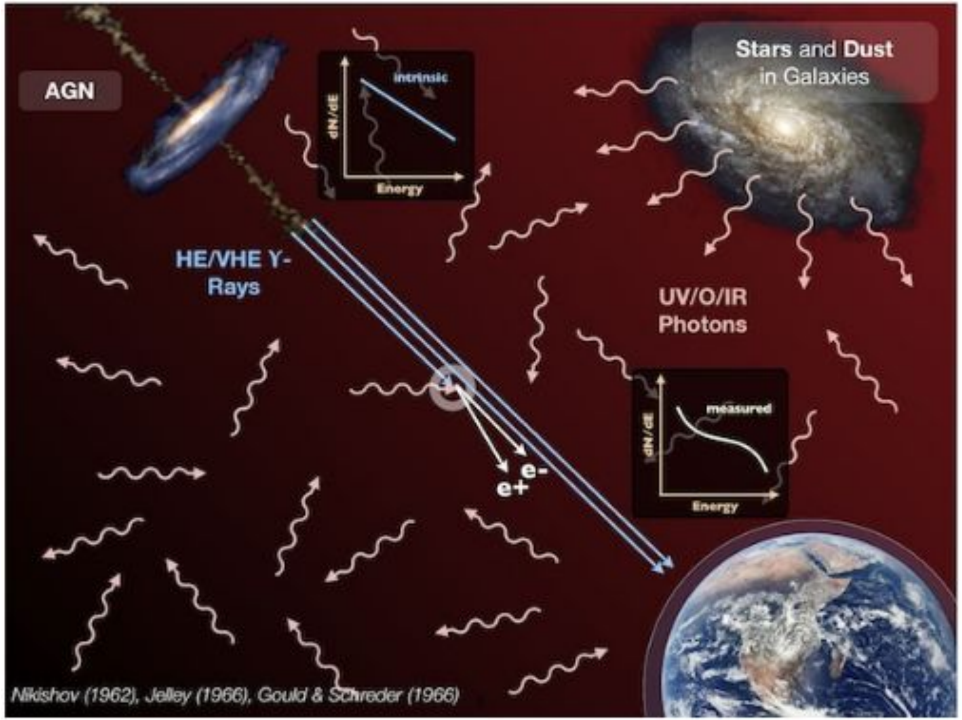


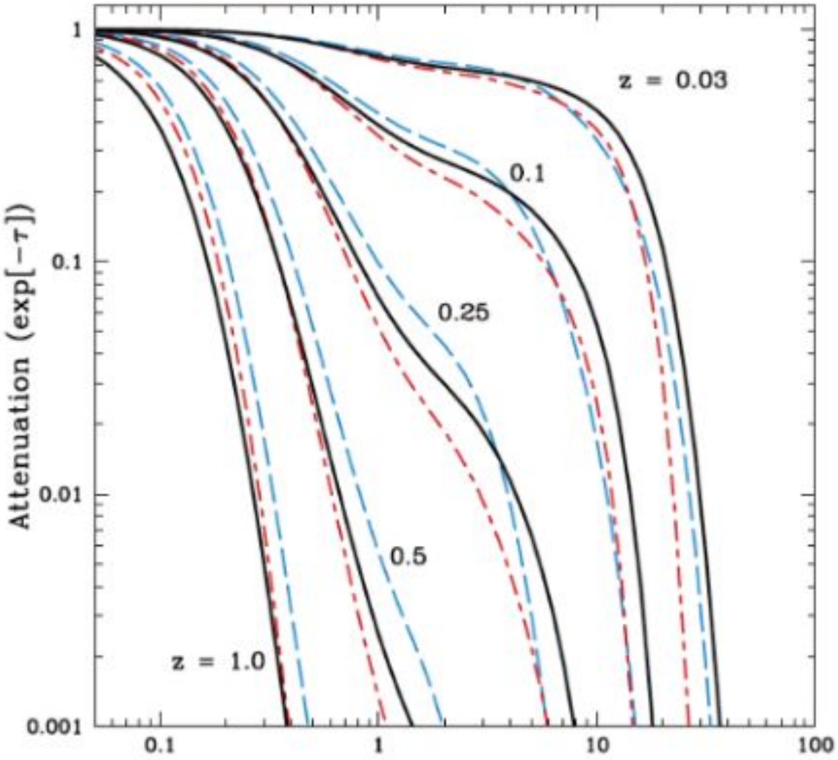
The extragalactic background light



The further away the object we detect, the more its TeV photons are absorbed by the EBL - this results in a break in the spectrum





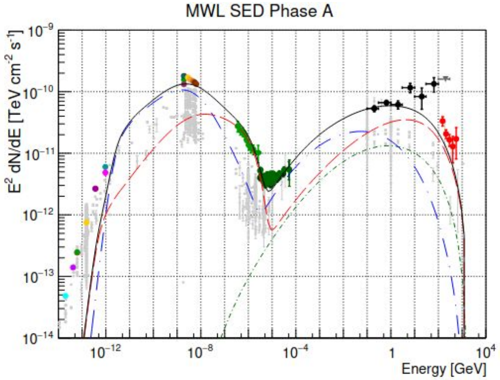


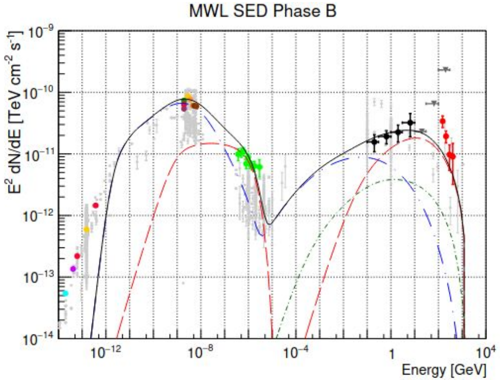
https://arxiv.org/pdf/1107.2566.pdf

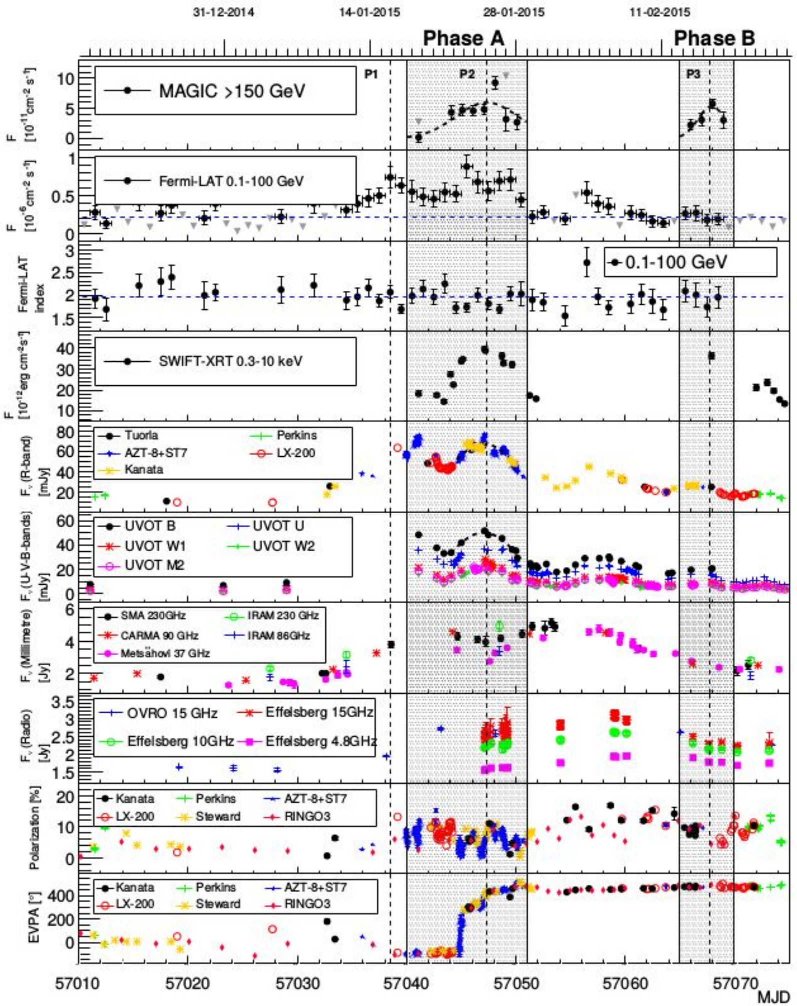
Blazar MWL studies

- Blazars multi-wavelength light-curves and spectral energy distribution are the essential parameters to constrain the models proposed for their emission
- Long term simultaneous data across the electromagnetic spectrum are required to generate high quality light-curves
- spectral energy distributions are required to understand the origin of these photons

Blazar MWL studies
- S50716+714

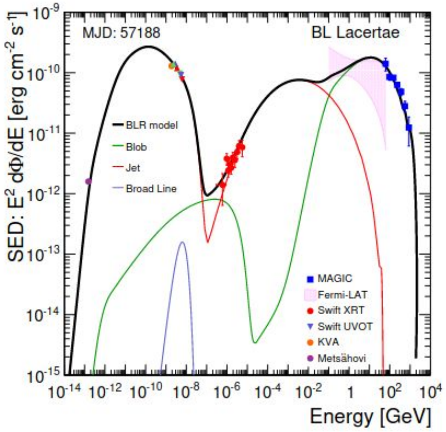


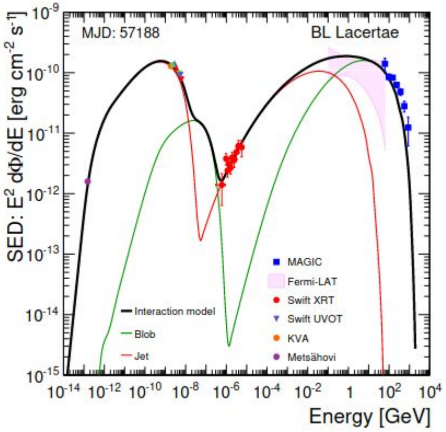


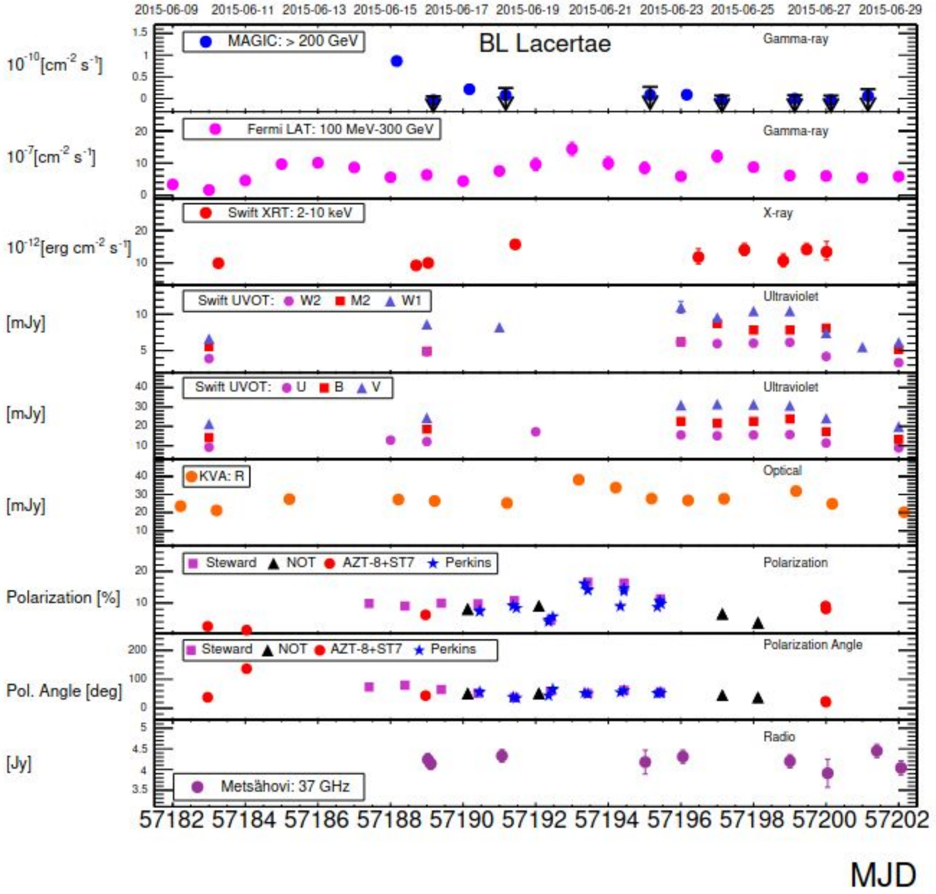


A&A 619, A45 (2018)

Blazar MWL studies
- Bl Lac

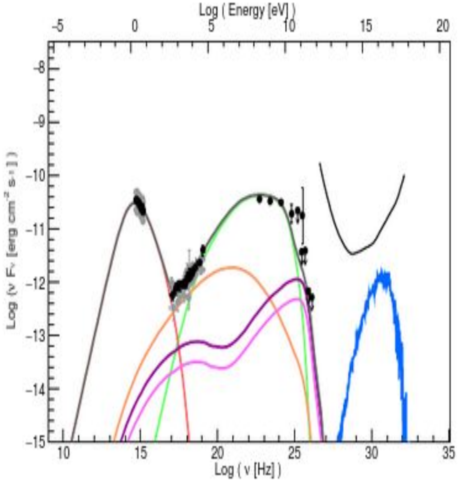


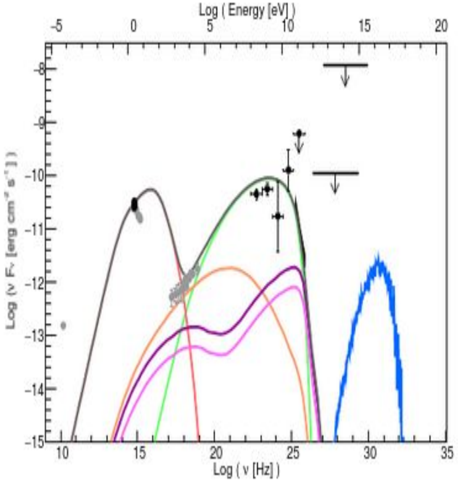


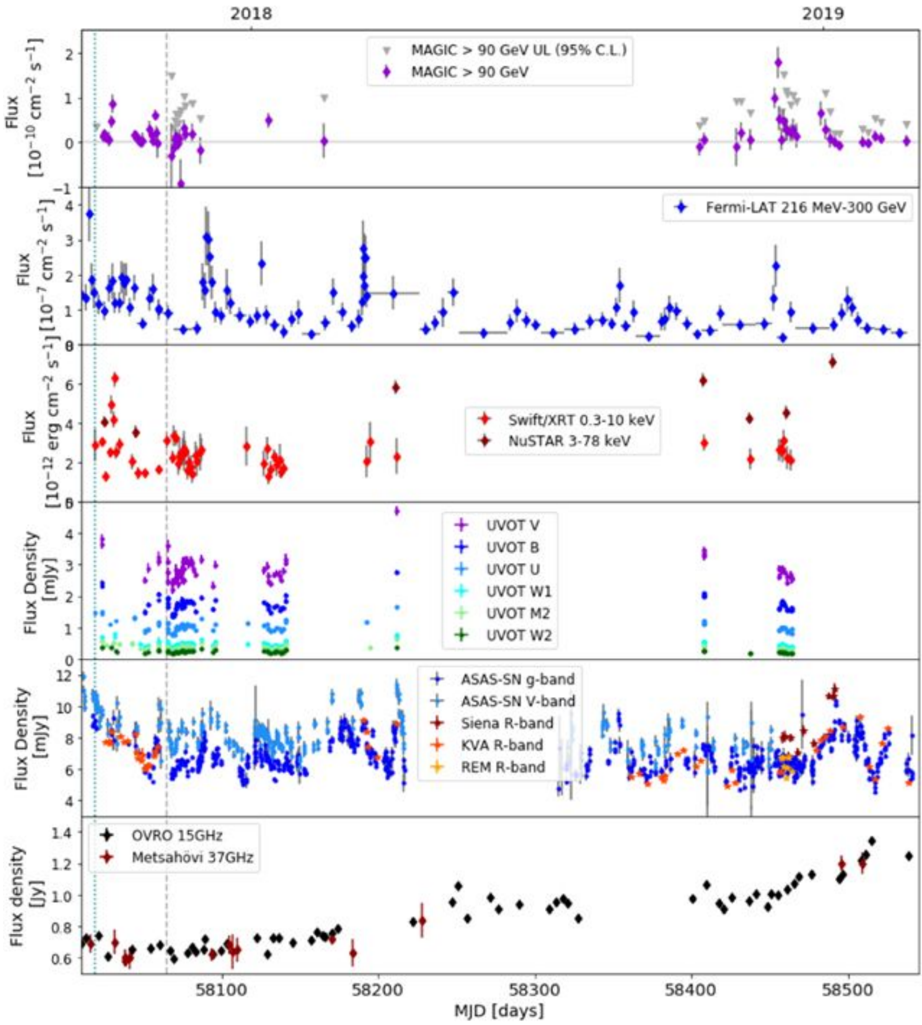


A&A 623, A175 (2019)

Blazar MWL studies
- TXS 0506+056







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Summary

- AGN’s - powerful engines in the galaxies emitting across all EM spectrum
- AGN unification based on view angle
- Blazars are class of AGN’s which have jet pointed to observer
- Understanding emission models of blazars
- Very variabile objects even in VHE in a short time scales
- EBL absorption cuts off some portion of emission spectrum
- Importance of the MWL studies and emission modeling