Modelling the radio - γ-ray emission components of Jetted AGNs

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Introduction

Galaxy is a massive, gravitationally bound system that consists of stars and stellar remnants, an interstellar medium, and dark matter

(def. International Astronomical Union - IAU)

NGC 4414, Credit: NASA/HST

NGC 3923, Credit: NASA/HST

Name → Greek root 'galaxias' = 'milky' (refers to the Milky Way)

Introduction cont'd

Galaxy components: in terms of their content
(in terms of their structure will come later)

- Tens to hundreds of billions of stars (including stellar clusters).

- Stellar remnants (white dwarfs, neutron stars, black holes).

- Interstellar medium (gas and dust).

- Dark matter (still an open question).

Andromeda galaxy (M31)
2.5 million ly away (2.4 x 10^{19} km)

Image credits: David Dayag

Active galactic nuclei (AGNs)

Supermassive black holes (SMBHs) in Galaxies

- SMBHs at centre of almost all known galaxies
- a few percent of these BHs are "active"
- "active" $\rightarrow$ luminous centres — may out-shine entire galaxy

Jets from AGN — Collimated outflows

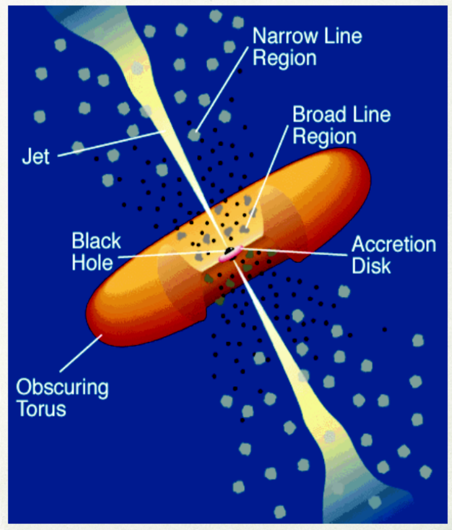
- a few percent of AGN eject radio-emitting jets
- jets with relativistic charged particles

Powering source

- BH & accretion $\rightarrow$ rotation & accretion-disk $\rightarrow$ radiation

Elements of AGNs

- SMBH in the centre $\sim 10^6 - 10^9 M_\odot$
- Accretion disk, large temperature range
- Obscuring torus (dust) may block view on disk
- Broad-line Region (BLR), linewidths $\sim 10^3 - 10^4$ km/s
- Narrow-line Region (NLR), linewidths ~ 500 km/s
- Jets (magnetsied plasma)



Jetted active galactic nuclei

Observational Properties

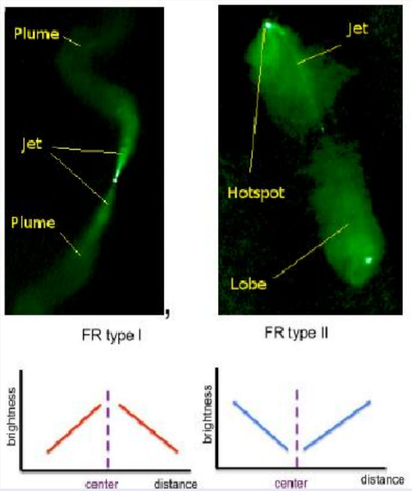
Blazars

- powered by relativistic jets
- rapid and large variation
- high and variable polarization
- superluminal motions
- high energetic GeV/ TeV emissions

Radio galaxies

- powered by relativistic jets
- strong variable polarization
- superluminal motion in their radio jets
- emit radio waves by synchrotron process

Radio Galaxy Classification



- morphology of double structure
- jets, lobes and hotspots
- by Fanaroff & Riley (FR) in 1974
- division on *radio* structures
- FR I: edge-darkened
- FR I e.g. Centaurus A
- FR II: edge-brightened
- RGs seen in VHE seem to be FR I
- Cen A, M 87, NGC 1275, PKS 0625-354, IC 310, Per A

Blazar classification based on synchrotron peak frequency

Blazars are divided into two:

- BL Lacertae Objects (BL Lacs)
- Flat Spectrum Radio Quasars(FSRQs)

BL Lacs:

- Low synchrotron peaked (LSPs)
  $\log \nu_{peak}^{syn} < 14(H_z)$
- Intermediate synchrotron peaked (ISPs)
  $14 < \log \nu_{peak}^{syn} < 15(H_z)$
- High synchrotron peaked (HSPs)
  $\log \nu_{peak}^{syn} > 15(H_z)$

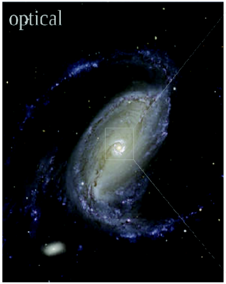
FSRQs

- $\log \nu_{peak}^{syn} < 12(H_z)$

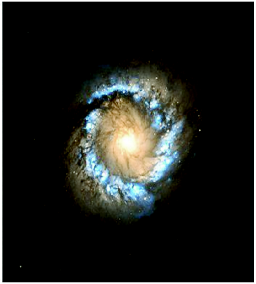
Different from 'normal' galaxies
Tag 1: Bright, unresolved core emission in galaxy

- ***bright, unresolved central emission peak*** (point-like, 'star')
- can be distinguished from surface brightness profile

NGC 1097
redshift : 0.00424
distance : 14.5 Mpc
1 arcsec ≙ 70 pc

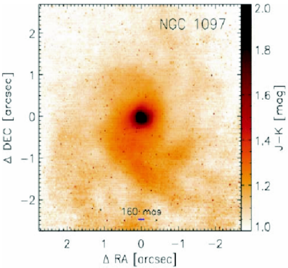


VLT



HST

NIR (adaptive optics)



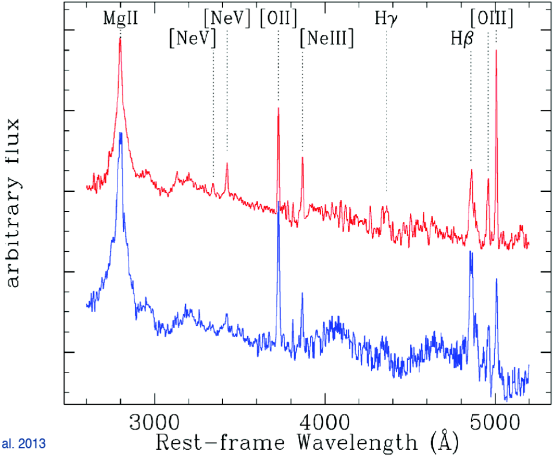
VLT/NACO

[Prieto et al. 2010]

AGN 'tags' and properties cont'd

Tag 3: Strong blue component in spectrum

- spectrum shows lines with ***high ionisation energies*** e.g. NeIII : 41.0 eV; NeV : 97.1 eV
- emission lines 'untypical' for star forming galaxies, e.g. MgII
- unusual line ratios e.g. OIII / Hβ (to be quantified!)

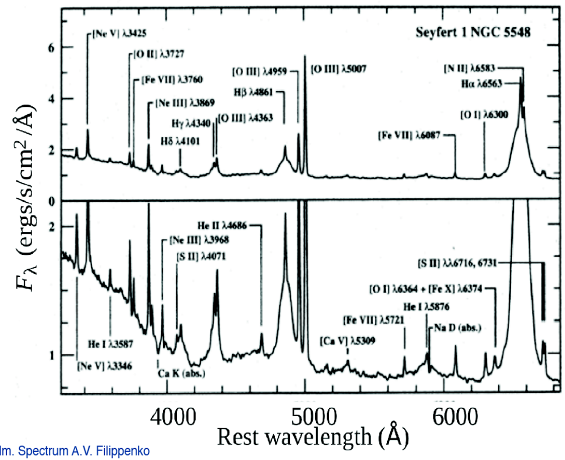


Mignoli et al. 2013

Tag 4: Broad emission lines

- ***broad emission lines*** in the spectrum
  here: Balmer lines
  FWHM ~ 100 Å

- Doppler broadening related to high velocities



ned.ipac.caltech.deu/level5/Glossary/Glossary_S.htlm. Spectrum A.V. Filippenko

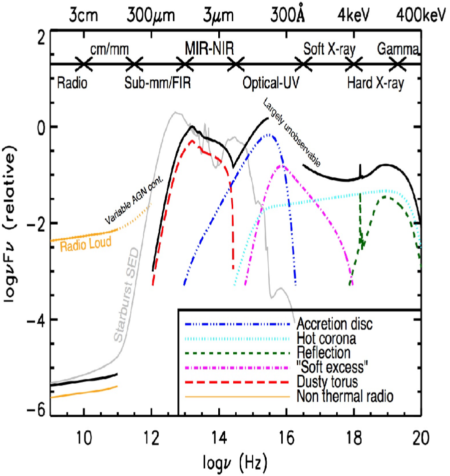
AGN "tags" and classifications cont'd

Tag 5: Broad Spectral Energy Distribution

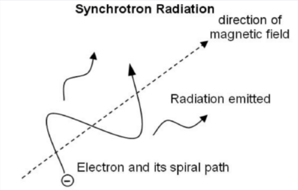
AGNs emissions are

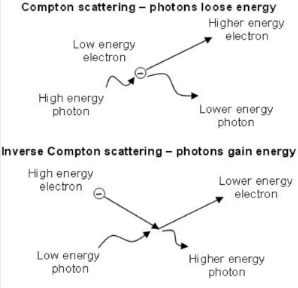
- Thermal/Disk dominated ($\simeq$ 90 %)
- Non-thermal/Jet dominated (less $>$ 10 %)

Non-thermal emissions occur at all wavebands



AGNs Radiative Processes





Various ways of producing photons

- focus: non-thermal processes
- all types of bremsstrahlung not discussed
- synchrotron radiation
- Compton: photon looses energy
- inverse-Compton: photon gains
- Synchrotron Self-Compton (SSC)
- external-Compton (EC)
- leptonic (electron-based) models
- other models: hadronic (proton-based), lepto-hadronic

Modelling of Emission spectrum

Jetted AGNs emission processes

- Low energy (radio to X-ray) component - Synchrotron process by electrons in the relativistic jet.

High energy (X-ray to γ-ray component)

- Leptonic model
- Hadronic model

High energy radiation is produced via inverse Compton scattering that can be either SSC or EC

Methodology and Basic Asssumption

Proxy parameters known as *synchrotron spectrum* (SS), *Inverse − Compton spectrum* (IC) and *Compton spectrum* (CS)

Synchrotron spectrum

$$= -\frac{log(\frac{L_r}{L_x}.K)}{log\,\frac{v_r}{v_x}} \tag{1}$$

Compton spectrum

$$= -\frac{log(\frac{L_x}{L_\gamma}.K)}{log\,\frac{v_x}{v_\gamma}} \tag{2}$$

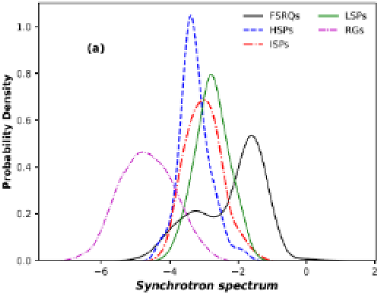
Inverse compton spectrum

$$= -\frac{log(\frac{L_r}{L_\gamma}.K)}{log\,\frac{v_r}{v_\gamma}} \tag{3}$$

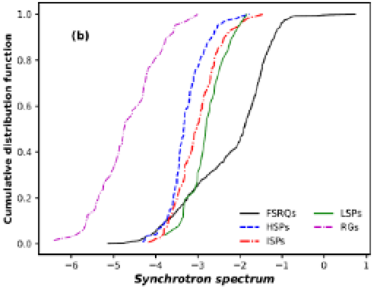
L is the luminosities of the objects in radio, X-ray and γ-ray while ν and K are the observed frequency and the total k-correction factor respectively

Results

Distribution of Synchrotron Spectrum



(a) Density distribution of synchrotron spectrum

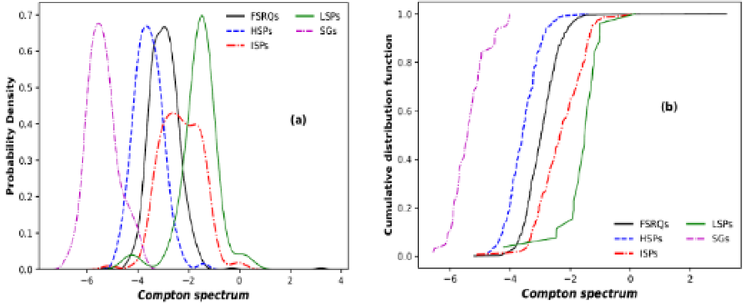


(b) Cumulative distribution function synchrotron spectrum

Parameter	*Subsamples*	*n*	*d*	*p*
synchrotron spectrum	RGs – HSPs	64 – 138	0.39	0.000864
synchrotron spectrum	RGs – LSPs	64 – 133	0.66	0.0003569
synchrotron spectrum	RGs – ISPs	64 – 130	0.71	0.00087534
synchrotron spectrum	RGs – FSRQs	64 – 279	0.87	0.0002344

Results cont'd

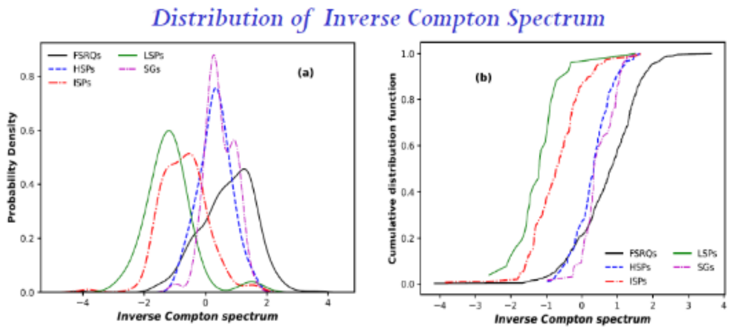
Distribution of Compton Spectrum



(a) *Density distribution of Compton spectrum* (b) *Cumulative distribution function Compton spectrum*

Parameter	*Subsamples*	*n*	*d*	*p*
Compton spectrum	RGs – HSPs	64 – 138	0.34	1.21×10^{-08}
Compton spectrum	RGs – LSPs	64 – 133	0.62	6.34×10^{-05}
Compton spectrum	RGs – ISPs	64 – 130	0.68	8.98×10^{-07}
Compton spectrum	RGs – FSRQs	64 – 279	0.82	3.45×10^{-06}

Results cont'd



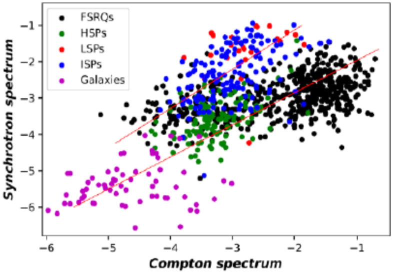
(a) Density distribution of Compton spectrum

(b) Cumulative distribution function Compton spectrum

Parameter	Subsamples	n	d	p
Inverse Compton spectrum	RGs – HSPs	64 – 138	0.63	4.21×10^{-06}
Inverse Compton spectrum	RGs – LSPs	64 – 133	0.56	3.07×10^{-04}
Inverse Compton spectrum	RGs – ISPs	64 – 130	0.48	1.08×10^{-05}
Inverse Compton spectrum	RGs – FSRQs	64 – 279	0.53	2.98×10^{-07}

Results cont'd

Correlations among the continuous spectra



Scatter plot of SS against CS

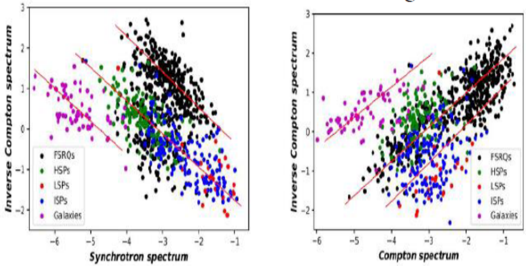
Two Groups of objects:

- radio galaxies - FSRQs
- BL Lacs
- radio galaxies and FSRQs are aligned

Results of linear regression fitting given as $y = (\kappa \pm \Delta\kappa)\,x + (\kappa_0 \pm \Delta\kappa_0)$

plots	Sample	k	Δk	k_0	Δk_0	r	p
SS – CS	Whole sample	0.96	0.24	-6.22	0.40	0.62	1.91×10^{-6}
SS – CS	radio galaxies – FSRQs	0.82	0.20	-5.03	0.20	0.71	2.03×10^{-6}
SS – CS	BL Lacs	0.74	0.18	-5.20	0.30	0.57	3.26×10^{-6}

Correlations among the continuous spectra



Three Groups of objects:

- Radio galaxies – lowest in *SS*, *CS*
- FSRQs – highest in *IS*
- BL Lacs –highest in *SS*

Fig. 7: IC – CS and *IC – CS* plot against Compton spectrum for FSRQs, Seyfert galaxies and BL Lacs

plots	Sample	k	Δk	k_0	Δk_0	r	p
$IC-SS$	*Whole sample*	*-0.93*	*0.31*	*2.17*	*0.08*	*-0.65*	10^{-6}
$IC-SS$	*Seyfert galaxies*	*-0.75*	*0.26*	*1.08*	*0.06*	*-0.52*	10^{-6}
$IC-SS$	*BL Lacs*	*-0.56*	*0.23*	*2.90*	*0.10*	*-0.62*	10^{-6}
$IC-SS$	*FSRQs*	*-0.56*	*0.32*	*2.90*	*0.10*	*-0.68*	10^{-6}

plots	Sample	k	Δk	k_0	Δk_0	r	p
$IC-CS$	*Whole sample*	*1.14*	*0.34*	*0.72*	*0.38*	*0.57*	10^{-7}
$IC-CS$	*Seyfert galaxies*	*2.03*	*0.20*	*0.22*	*0.26*	*0.56*	10^{-7}
$IC-CS$	*BL Lac subclasses*	*1.25*	*0.23*	*-4.32*	*0.30*	*0.58*	10^{-7}
$IC-CS$	*FSRQs*	*1.30*	*0.16*	*-5.01*	*0.20*	*0.61*	10^{-7}

Conclusion

- Modeled parameters of blazars and radio galaxies used to quantitatively test the emission components of the sources
- From the comparison of the distributions of SS, CS and IC, it is observed that FSRQs could be the extreme version of radio galaxy populations
- This indicates that an AGN may start off as a radio galaxy and grow in different emission spectra through BL Lacs to FSRQs
- Signifying that radio galaxies are the youngest subclasses of the jetted AGNs

Questions/Comments/Suggestions

Me

You

Thanks for Listening