Physics of AGN

A Unified View

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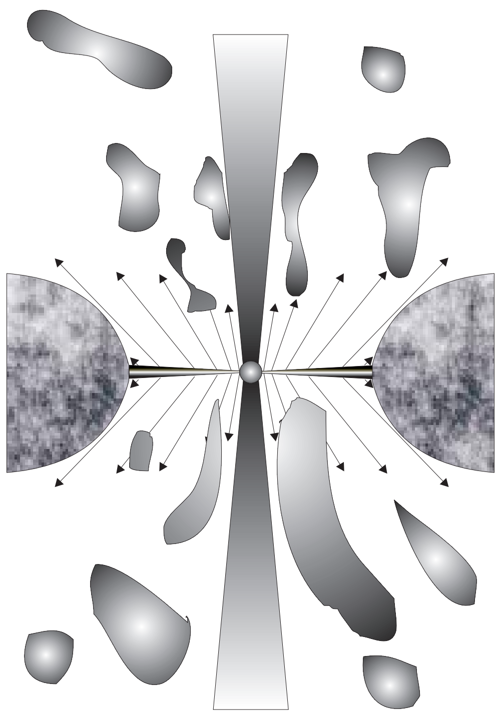


Contents:

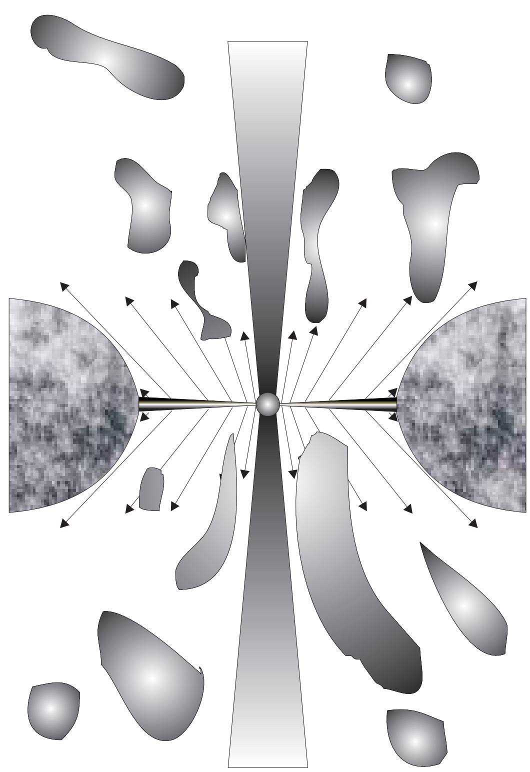
Literature:
"An Introduction to Active Galactic Nuclei", Bradley M. Peterson, Cambridge University Press, Cambridge (Chap. 5, 6, &7)
"Active Galactic Nuclei", Ian Robson, John Wiley & Sons, Chichester (Chap. 9)

AGN

■ Basic Ingredients

An AGN consists of the following basic ingredients:

- Black Hole (power source)
- Accretion Disk (UV/x-rays)
- Jet (radio)
  - Core (compact, flat-spectrum, radio-to-gamma emission)
  - Jet (dissipationless/dissipative)
  - Lobes & Hotspots (extended, steep spectrum)
- Broad-Line Region (BLR)
- Narrow-Line Region (NLR)
- molecular (dusty) “torus” (feeding and obscuration)
- host galaxy (feeding)



BLR

■ Properties

Broad, permitted emission lines (Hα) in the optical spectrum:

- FWHM several thousand km/sec up to 30000 km/sec FWZI (zero intensity)
- derived gas temperatures are several 10^{4-5}, $\Rightarrow c_\mathrm{s} \simeq \sqrt{k_\mathrm{B}T/m_\mathrm{p}} =$ 9 km/sec $(T/10^4\ \mathrm{K})$
- Doppler broadening through bulk motion of gas in gravitational field
- with velocities as high as 0.1c, the distance from the Black Hole can be as close as 100 R_g ($v \propto r^{-1/2}$).
- Comparison of continuum and BLR fluxes indicate that only 10% of the continuum radiation is absorbed by BLR clouds
- The volume filling factor is very low — a few millionths of the central region is occupied by BLR 'clouds'
- The necessary mass in the BLR to produce the observed luminosity is only a few solar masses
- Broad-lines are very smooth — they are either made up of a huge number of small clouds ($R \sim R_\odot,\ N_\mathrm{c} > 10^9$) or represent a coherent structure

■ Densities

- Suppression of forbidden lines indicates $n_e > 10^9 \mathrm{cm}^{-3}$
  - [OIII] $\lambda\lambda 4363$ is absent in the broad-line region, the critical density for collisional de-excitation of the ${}^1\mathrm{S}_0$ level in O^{++} is $\sim 10^8 \mathrm{cm}^{-3} \Rightarrow$ lower limit
  - broad CIII]$\lambda 1909$ is present, critical density for de-excitation of the ${}^3P_1$ level in C^{++} is $\sim 10^{10} \mathrm{cm}^{-3}$ (upper limit?)
  - reverberation mapping, however, shows this line is further out than Lyα

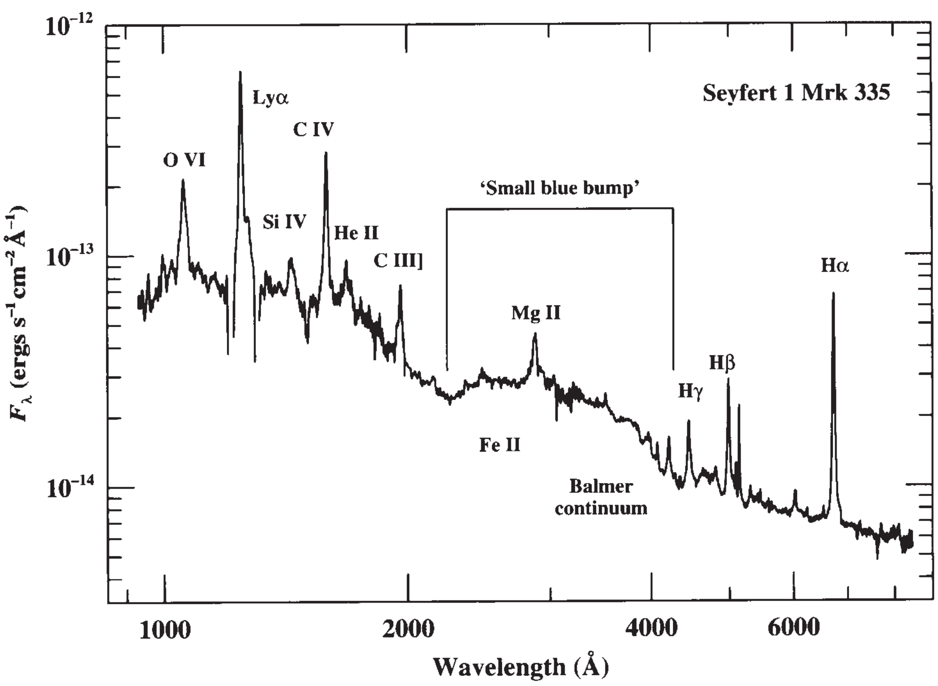


Fig. 5.2. The 'small blue bump', a blend of Balmer continuum and Fe II line emission is prominent in the Seyfert 1 galaxy Mrk 335 (Zheng *et al.* 1995a) and shows up particularly well on a log–log plot. Other strong features are also labeled. Data courtesy of W. Zheng.

■ Reverberation mapping

The size of the BLR can be determined through **reverberation mapping**. If the ionizing continuum in the center varies, the line excitation will change accordingly. The delay between continuum and line-variation will be caused by light-travel time delays and hence are proportional to the distance of the BLR from the (point-like) continuum source. The exact form of the response will also depend on the exact distribution of the ionized gas (hence 'mapping').

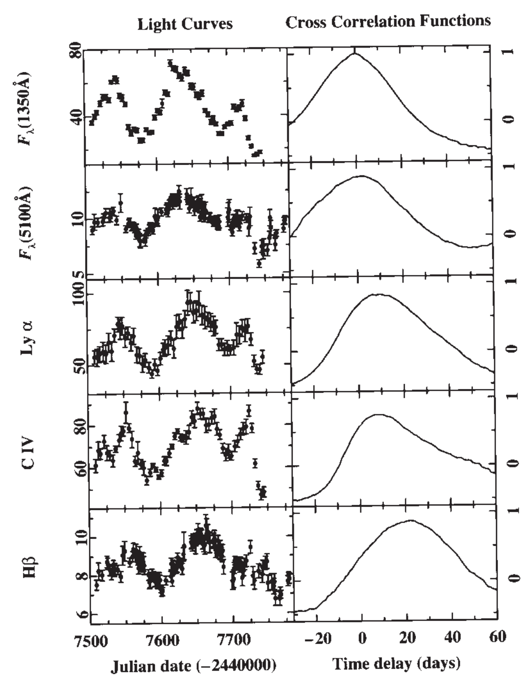


Fig. 5.6. The left-hand column shows continuum and emission-line light curves for the Seyfert 1 galaxy NGC 5548 that were obtained in 1988–89 (Clavel *et al.* 1991, Peterson *et al.* 1991). The ultraviolet (1350 Å) and optical (5100 Å) fluxes (in units of 10^{-15} ergs s^{-1} cm^{-2} Å^{-1}) appear to vary in phase. The variations of the strong emission lines (Lyα λ1216, C IV λ1549, and Hβ, in units of 10^{-13} ergs s^{-1} cm^{-2}) show the same general pattern of variations, but with a time delay due to light travel-time effects in the BLR. The time delay is calculated by cross-correlation of each light curve with the 1350 Å light curve. The cross-correlation functions are shown in the right-hand column for each light curve. The panel to the right of the 1350 Å shows the autocorrelation function, i.e., the result of cross-correlating the 1350 Å continuum with itself.

- Lines from highly ionized gas (He II $\lambda 1640$, C IV $\lambda 1549$) respond faster than lines from lower ionization levels (e.g. Balmer lines) $\Rightarrow$ ionization structure in BLR
- The size of the BLR is a function of luminosity $r \propto L^{1/2}$

$$r = 10 \text{ lightdays} \left[\frac{L_\lambda(CIV)}{10^{40} \text{ergs sec}^{-1}, \text{AA}^{-1}} \right]^{1/2}$$

NLR

■ Narrow-Line Region

- FWHM of typically 400-500 km/sec
- forbidden-lines, low densities 10^{2-4}
- total mass in NLR can be several million solar masses
- size $\gtrsim$ 100 pc - resolved in many Seyfert galaxies
- excess blue-ward flux $\Rightarrow$ radial (outflow) plus attenuation (of back side) through dust?

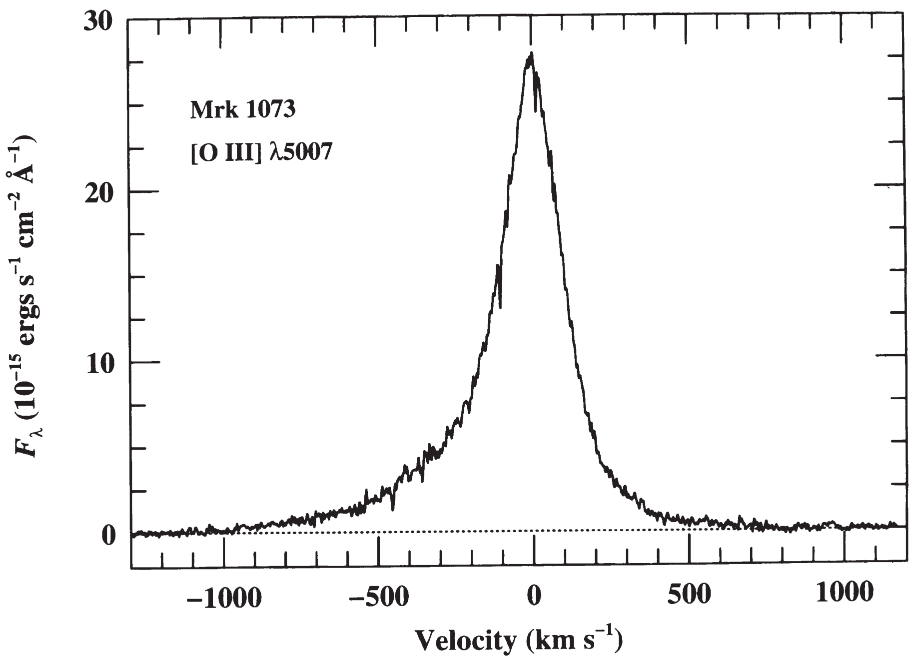


Fig. 6.5. The [O III] λ5007 emission-line profile in the Seyfert 2 galaxy Markarian 1073 (Veilleux 1991) at a resolution of $10\,\mathrm{km\,s^{-1}}$. The line is asymmetric about the peak (which is defined to be $v = 0$), with more flux shortward than longward of line center. Data courtesy of S. Veilleux.

- in many cases HST sees a highly structured NLR with signs of significant jet impact

Unified Scheme

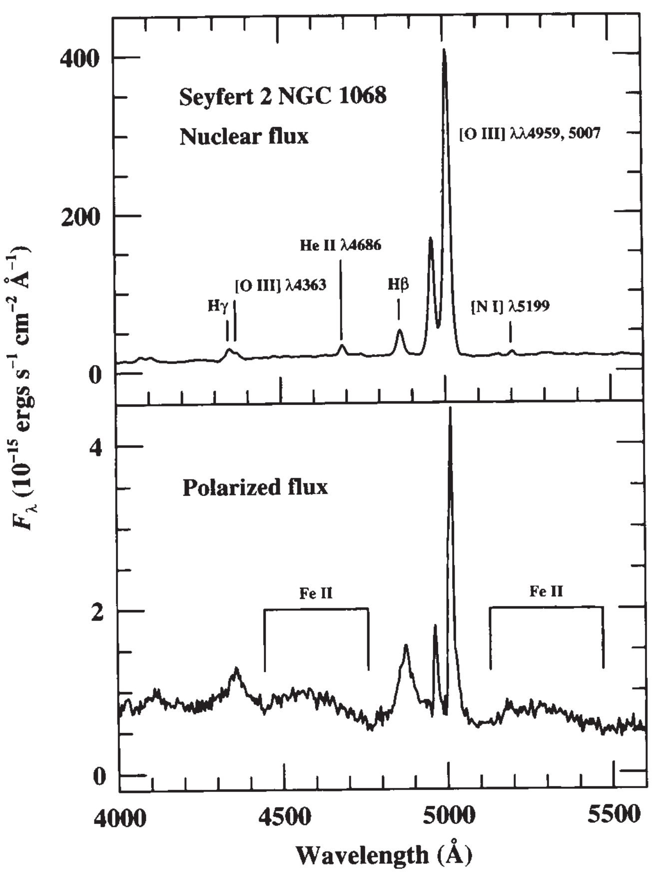
■ Seyfert 1s & 2s

There are two types of Seyferts:

- Seyfert 1: broad & narrow lines
- Seyfert 2: only narrow lines

Question: Are they fundamentally different?
Answer: Probably not!

Antonucci & Miller (1983) found that the prototypical Seyfert 2 galaxy NGC1068 suddenly showed broad-lines when viewed in polarized light.



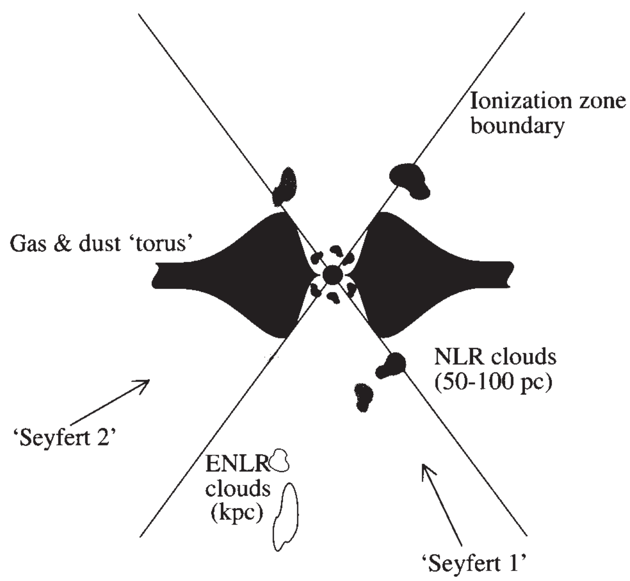
Explanation: The light is polarized because it is scattered into our line of sight (mirror). Apparently is the radiation from the BLR hidden from our direct view and becomes visible only after it is scattered into our direction.

Unified Scheme

■ Obscuring Torus

The favorite model to explain the obscuration is the **obscuring torus'**.

Prediction: There is a thick, obscuring 'torus' around the central engine—larger than the BLR, smaller than the NLR—which for certain aspect angles, absorbs all radiation from the nucleus. Therefore, the ionizing radiation will escape anisotropically from the AGN—large parts of the ISM are shadowed from the UV radiation by this torus.



Other results, strongly supporting this picture

- Soft x-rays seem to be heavily absorbed in Seyfert 2s
- Excitation maps (divide a high-excitation line map by a low-excitation line map to find regions of high excitation) of the NLR reveal fan-shaped excitation regions—the so called excitation cones expected when an isotropic radiation source is shadowed by a torus.
- Scattering is wavelengths independent and thus caused by electrons (in the jet?), the polarization vector is perpendicular to the radio axis.

■ Quasars and Radio Galaxies

The same principal has been applied to radio loud quasars.

- Powerful radio galaxies and radio loud quasars share the same extended radio structure: flat-spectrum core, jet, extended lobes, and hotspots
- Quasars have a BLR and a UV-bump, radio galaxies don't.
- cores and jets are less prominent in radio-galaxies than in quasars

Unified Scheme 1: Radio galaxies and quasars are the same objects seen under different aspect angles. In radio galaxies our view into the central engine is blocked by an obscuring torus with rotation axis aligned with the jet axis.

Unified Scheme 2: Steep-Spectrum quasars and flat-spectrum quasars are the same objects, only that flat-spectrum quasars are almost seen face on, so that the flat-spectrum core is relativistically boosted.

This can explain all differences between the three classes simply as being due to different inclination angles.

⇒ With a simple boosting model one can then reproduce the relative numbers of radio galaxies, steep-spectrum quasars, and flat-spectrum quasars.

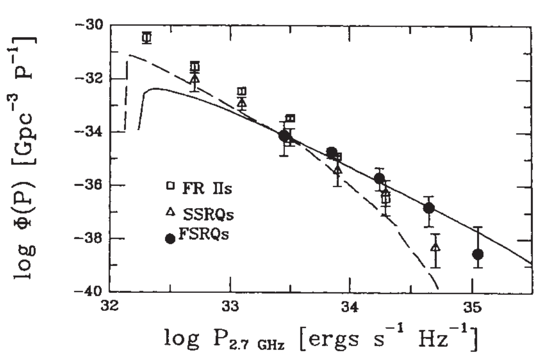
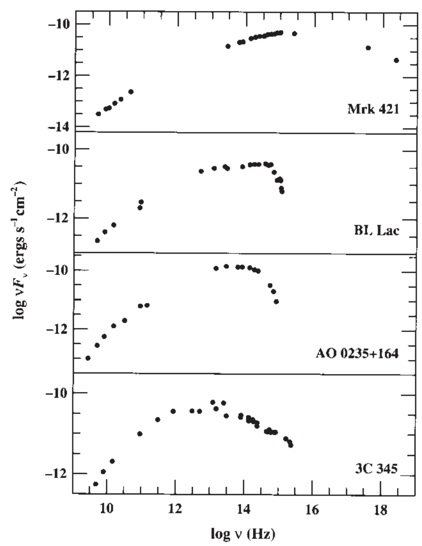


Fig. 2. Local luminosity functions for radio sources: filled circles represent flat spectrum radio quasars, open triangles represent steep spectrum radio quasars, while open squares represent FR II galaxies. The predictions of a beaming model are shown for flat spectrum radio quasars (solid line) and steep spectrum radio quasars (dashed line). The error bars have been derived by summing in quadrature the Poisson errors and the variations of the number density associated with a 1σ change in the evolutionary parameter τ (see *Padovani & Urry* [1] for details).

■ BL Lac objects & FR Is

BL Lacs are dominated by a single non-thermal spectrum throughout. They have very weak or no emission lines and can produce extremely high photon energies (up to TeV).



BL Lacs are best explained as being dominated by emission from a relativistic jet seen face on. It was suggested that their host population are FR I radio galaxies which also have very weak emission lines.

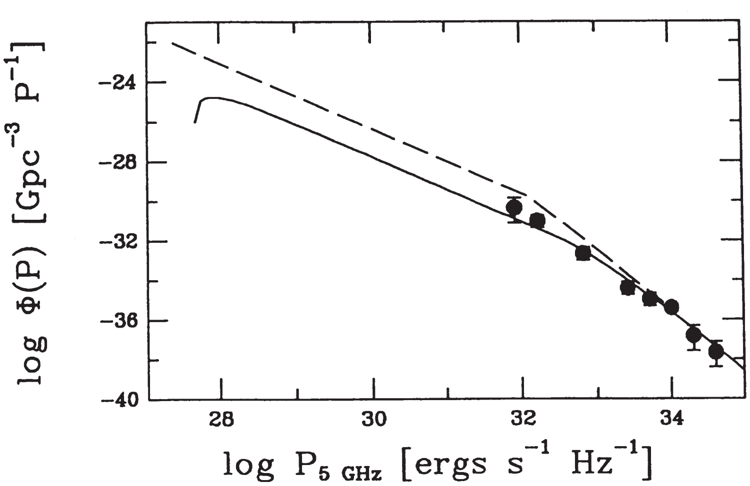


Fig. 1. The differential luminosity function of BL Lacertae objects (solid line) as predicted by our beaming model compared to the observational estimates (filled points) from *Stickel et al.* [9]. The differential luminosity function of FR I galaxies is also shown (dashed line)

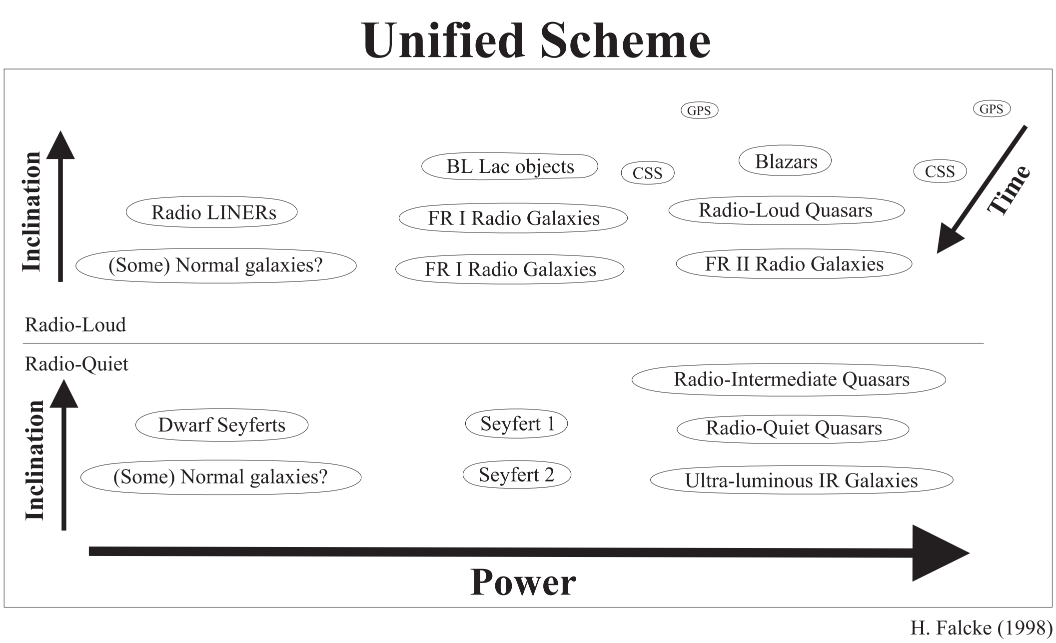
Unified Scheme

■ The big picture

It is not possible to unify all sources into one picture by just changing one parameter. At least the following factors have to be considered:

- Inclination
- Power
- Time (Age)
- Radio-Loudness (binary?)
- Black Hole mass (disk structure?)
- Host galaxy (jet/ISM interaction)

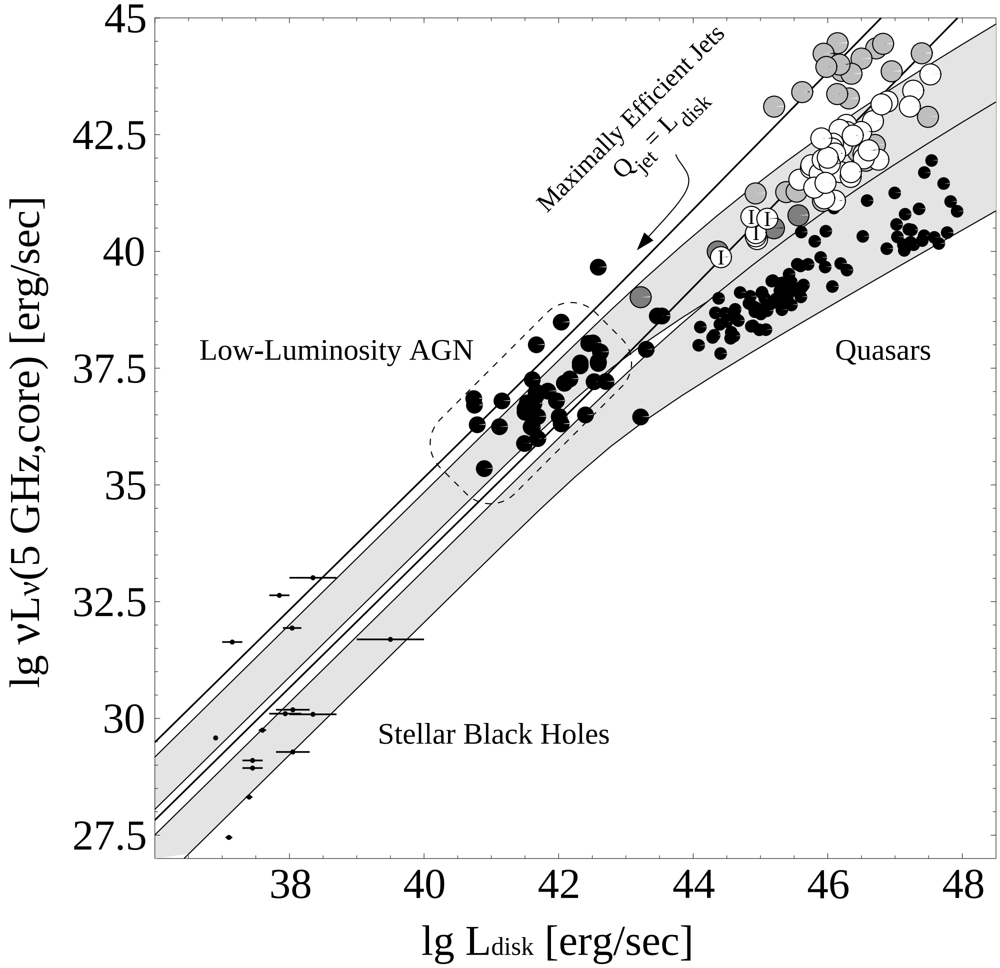
Most of the objects can be unified in the following scheme:



■ The big picture

Another way of unifying a large number of active systems in one diagram is the radio core vs. accretion disk plot (radio vs. optical/UV/X-ray) plot.

The lines are predictions for a coupled jet/disk-system, for radio-loud and radio-quiet jets respectively, with inclination angle ranging from 0° to 90°.



(big gray circles are blazars, (I)s are FR I radio galaxies assumed to be 30 times more luminous)