Active Galactic Nuclei (AGN)

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41st ISYA, Socorro, July 2018

Lecture 1: taxonomy

- Classification of AGN
- Multifrequency detection of nuclear activity
- Energetics
- Unification

Lecture 2: the role of BHs in AGN, and of AGN in galaxy formation and evolution

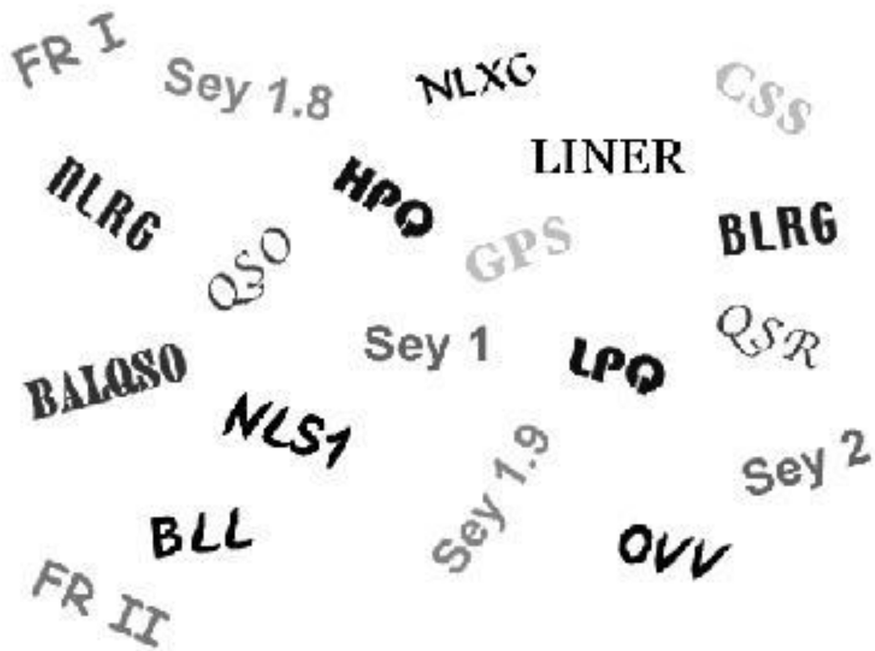
- Basic concepts of the standard model of AGN
- Evidence for BHs in AGN
- Methods to weigh a BH in an AGN
- Demographics of QSOs and BHs
- QSOs in the context of galaxy formation and evolution

AGN taxonomy

“Active” is used to refer to energetic processes that are not related to the normal evolution of stars.

However, the nucleus of a galaxy is defined as an AGN when it has certain optical spectroscopic characteristics. The definition does not address the mechanism responsible for the peculiarities of the spectra.

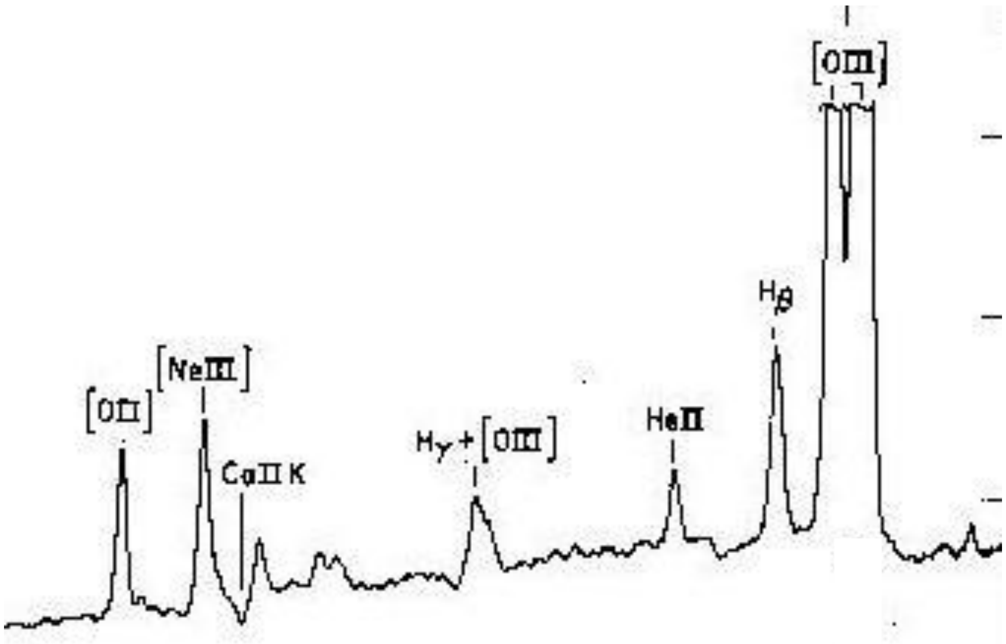
AGN are a very heterogeneous group:

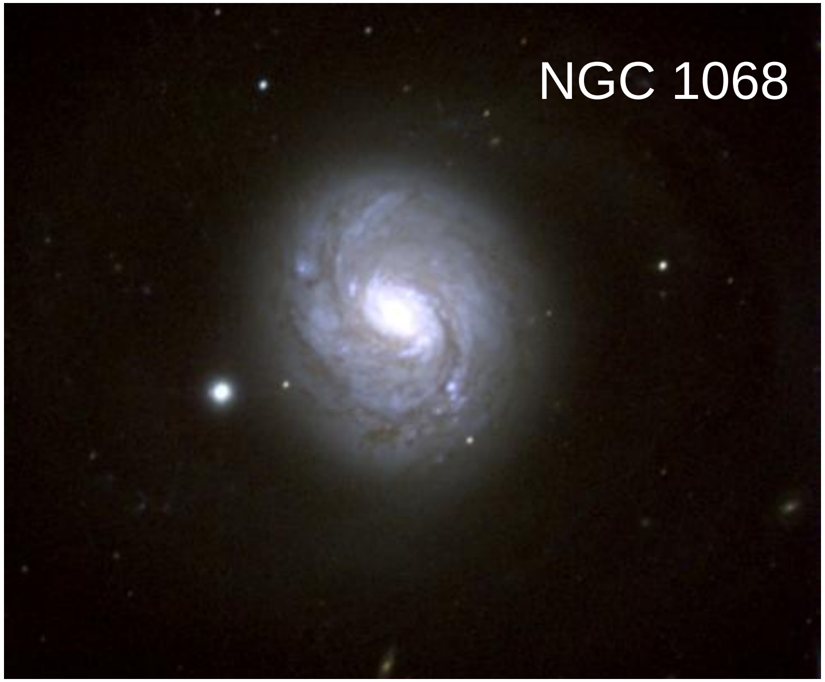


(Goodrich 2001)

AGN taxonomy

Seyfert galaxy: galaxy (usually a spiral) with a high surface brightness nucleus that reveals unusual emission-lines (Seyfert 1943).





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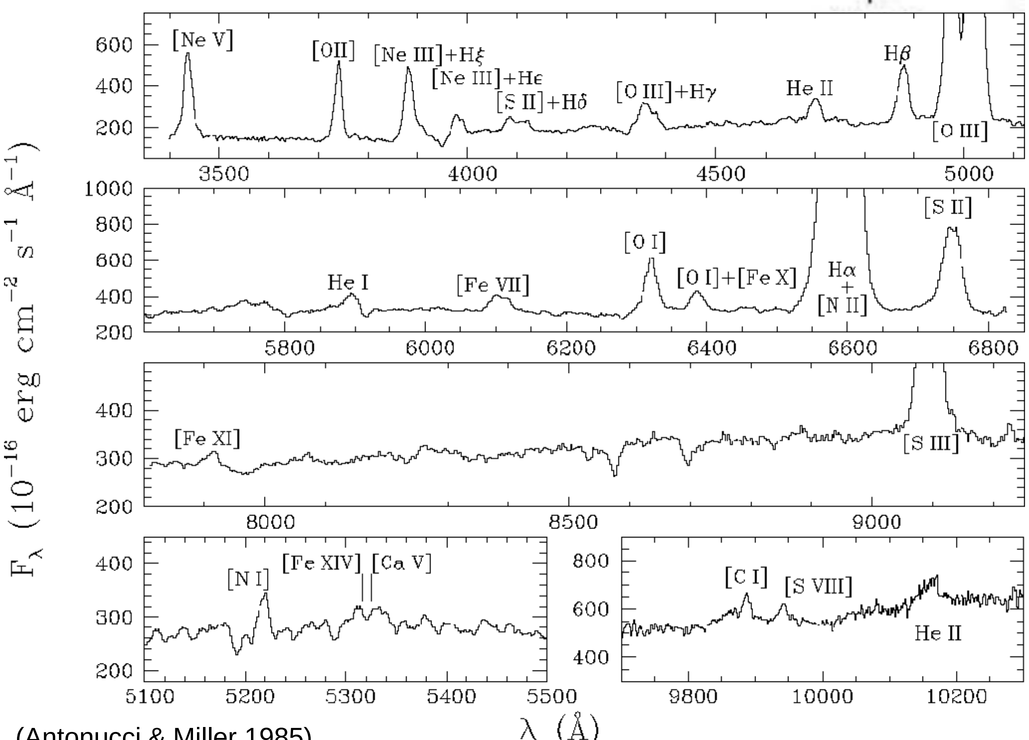
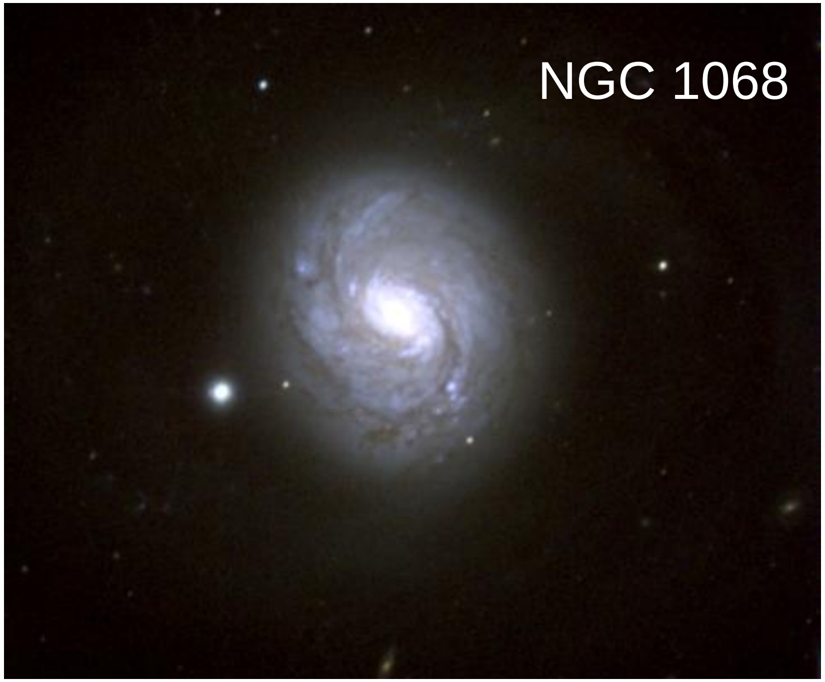
The definition has evolved to underline the presence of strong high-ionization lines, and even coronal lines (although not all AGN have them).

AGN taxonomy

Seyfert galaxy: galaxy (usually a spiral) with a high surface brightness nucleus that reveals unusual emission-lines (Seyfert 1943).

(Paul van der Werf’s web-page, see also Kraemer & Crenshaw 2000)





(Antonucci & Miller 1985)

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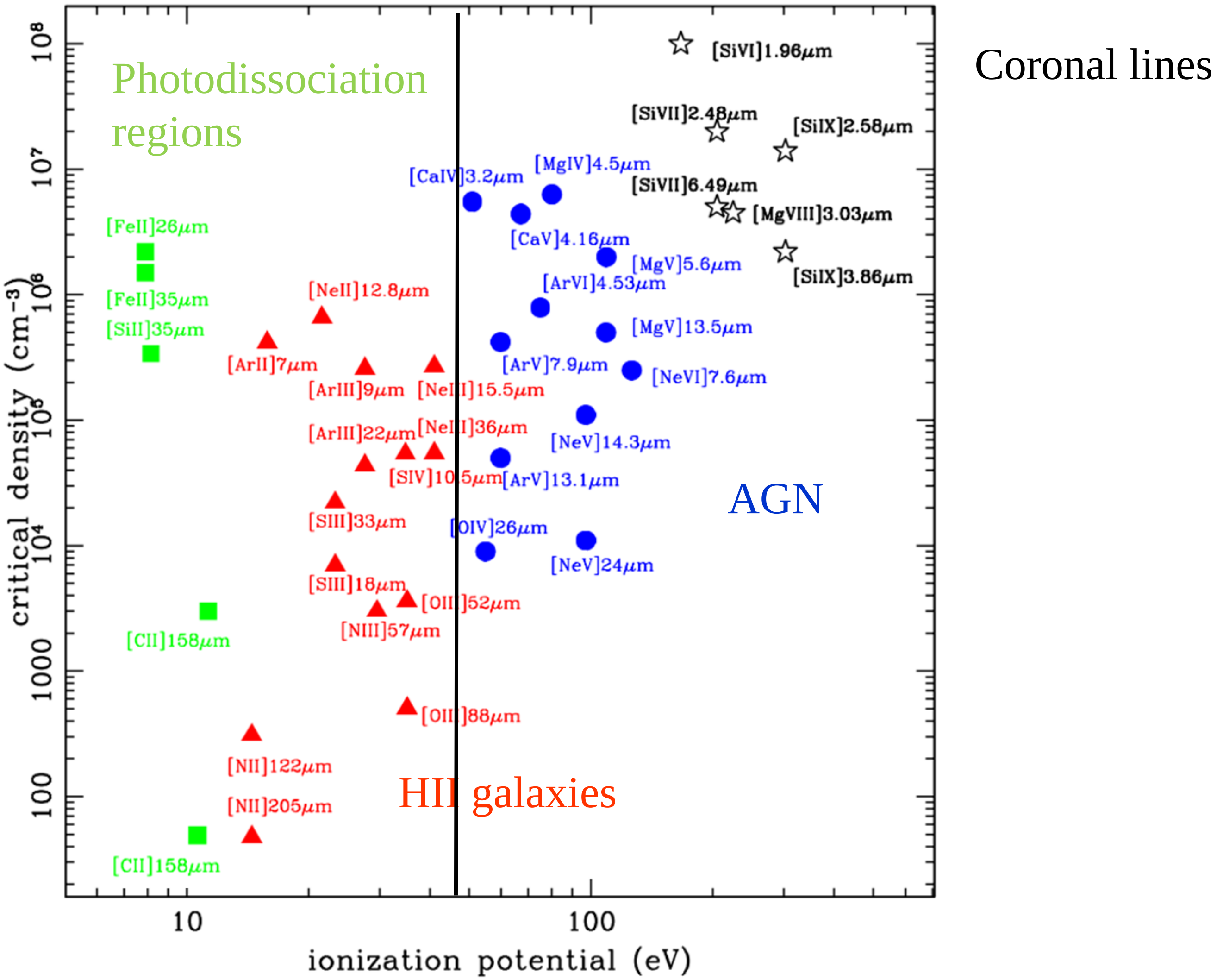
AGN diagnostic diagrams

Presence of high-ionization lines at FIR (rest-frame) wavelengths (Spingolio et al. 2012)

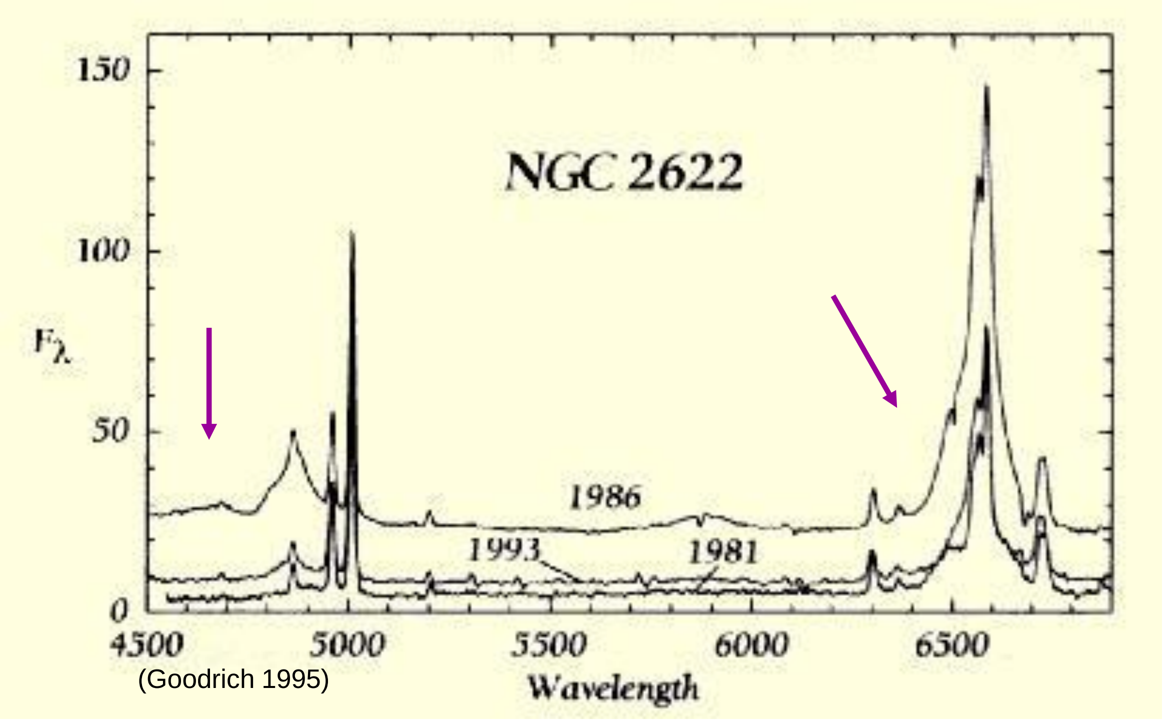


AGN taxonomy: Seyfert galaxies

Seyfert types: depending on the width of the optical emission lines (Khachikian & Weedman 1974, Osterbrock 1981):

- Sy 2: narrow emission lines of FWHM ≤ few x 100 km s^{-1}
- Sy 1: broad permitted emission lines (Hα, He II, ...), of FWHM ≥ 10^3 km s^{-1} that originate in a high-density medium ($n_e \geq 10^9$ cm^{-3}), and narrow-forbidden lines ([O III], [N II], …) that originate in a low-density medium ($n_e \approx 10^3$–10^6 cm^{-3}).
- Sy1.x (1.9, 1.8, ...): they graduate with the width of the Hα and Hβ lines.
- NL Sy1: subclass of Sy 2 with X-ray excess and optical Fe II in emission.

But the classification for a single object can change with time, due to AGN variability!



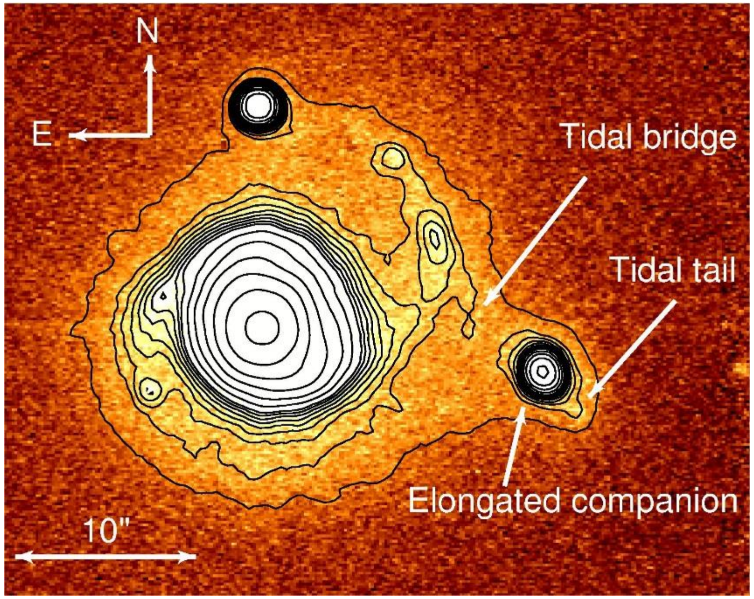
(Goodrich 1995)

AGN taxonomy: NL Sy 1's

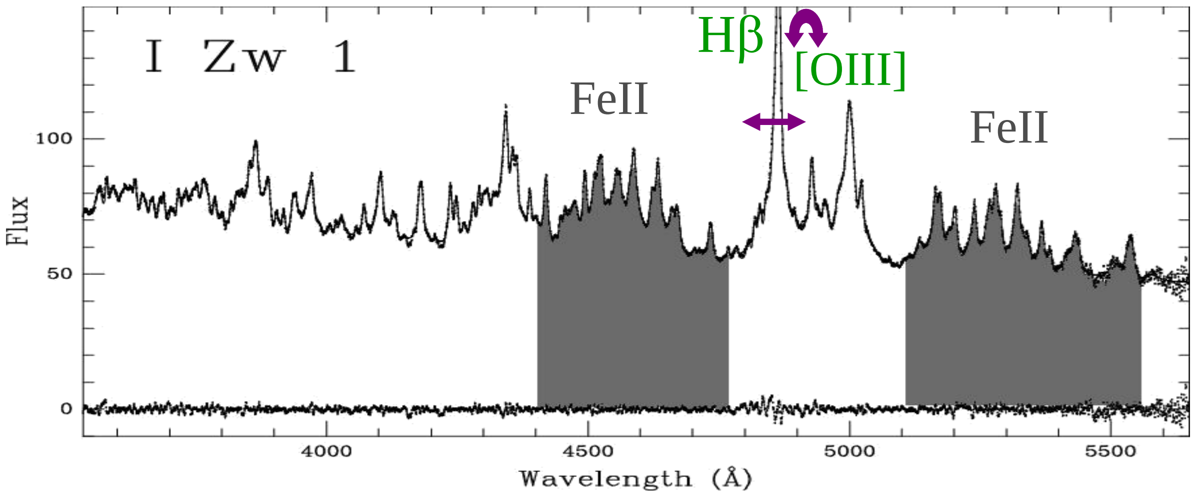
NL Sy1: peculiar subclass of Sy with optical Fe II in emission (Osterbrock & Pogge 1985), and usually X-ray excess:

FWHM (Hβ) < 2000 km/s
[O III] / Hβ < 3
strong Fe II

Extra-soft X-ray selection (Gruppe et al. 2004)



(Scharwächter 2005)



(Komossa et al. 2006)

AGN taxonomy: Quasars and QSOs

Quasar = Quasi Stellar Radio-source , QSO = Quasi-Stellar Object
Scaled-up version of a Seyfert, where the nucleus has a luminosity $M_B < -21.5 + 5 \log h_0$ (Schmidt & Green 1983). The morphology is, most often, star-like. The optical spectra are similar to those of Sy 1 nuclei, with the exception that the narrow lines are generally weaker.

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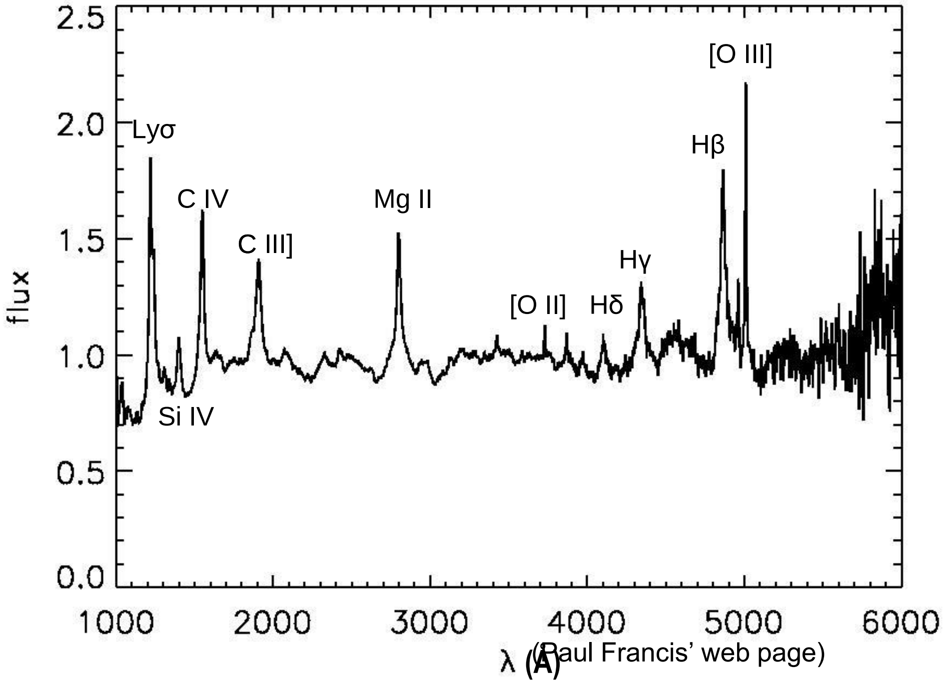
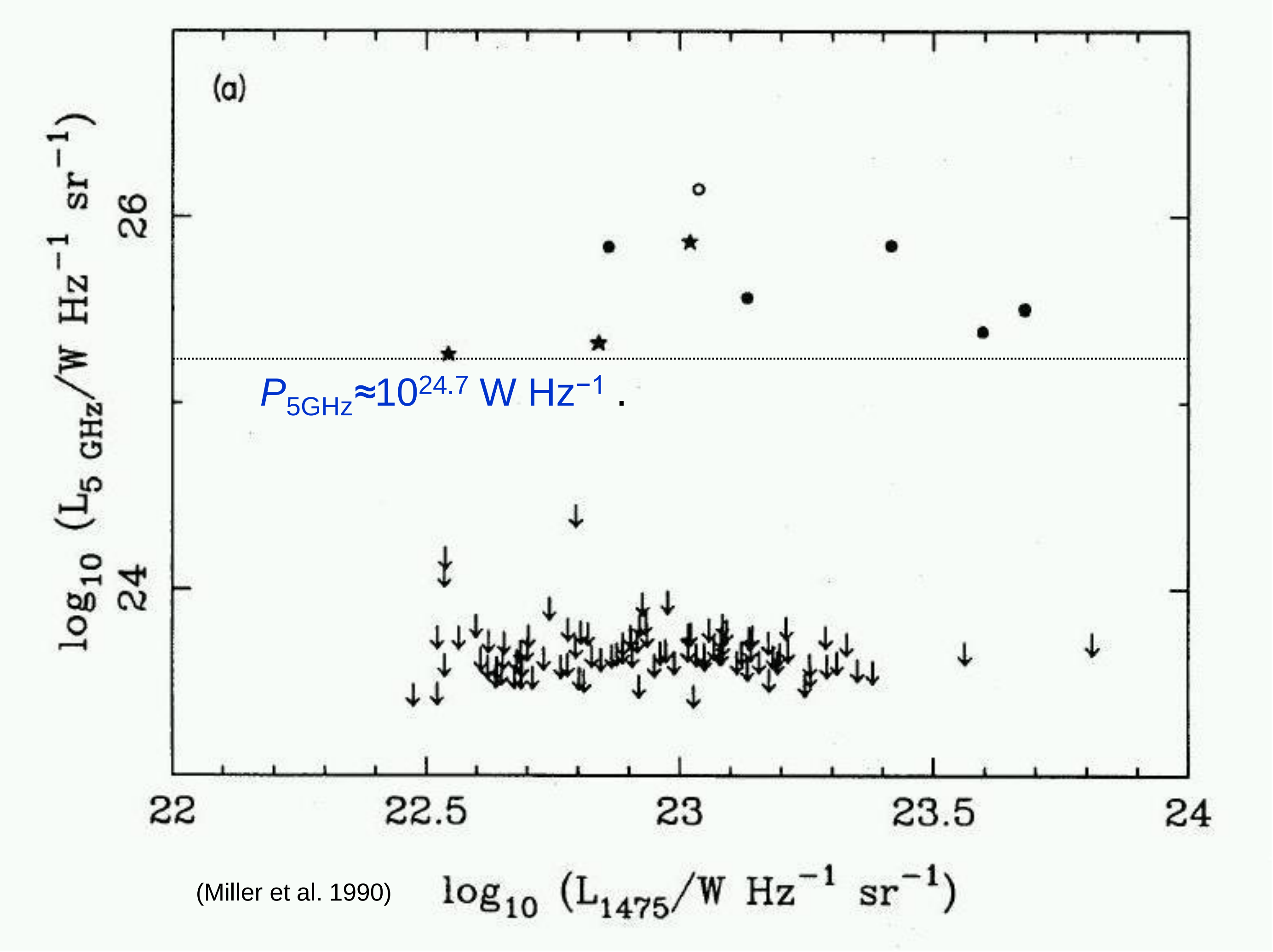


(Paul Francis' web page)

There are two varieties: radio-loud QSOs (quasars or RL QSOs) and radio-quiet QSOs (or RQ QSOs) with a dividing power at $P_{5GHz} \approx 10^{24.7}$ W Hz^{-1} sr^{-1} .
RL QSOs are 5−10% of the total of QSOs.

AGN taxonomy: Quasars and QSOs

There is a big gap in radio power between RL and RQ varieties of QSOs (Kellerman et al. 1989, Miller et al. 1990, Hoper et al. 1995), although some recent samples show a continuity of properties (e.g. Cirasiuolo et al. 2003, Kellermann et al. 2016)



(Miller et al. 1990)

AGN taxonomy: Quasars and QSOs

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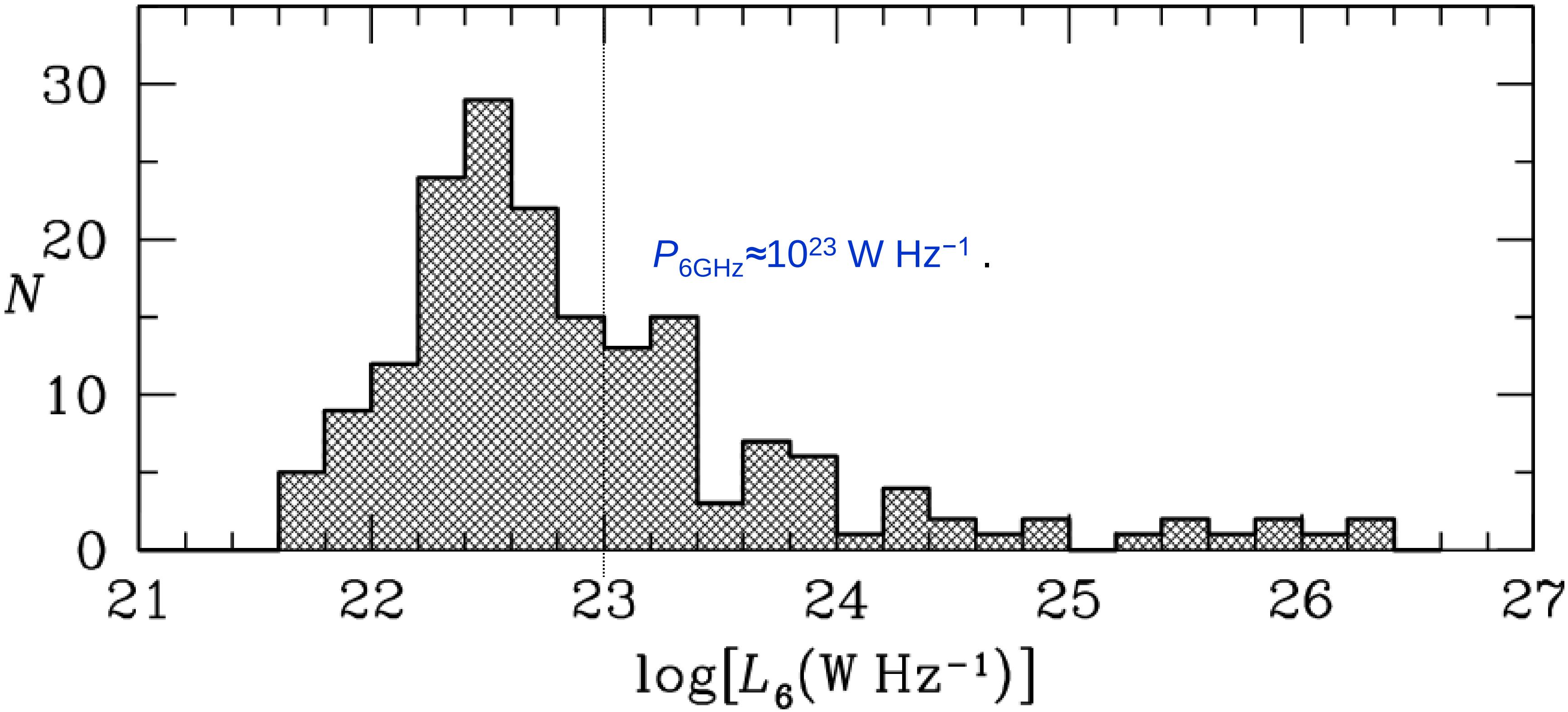


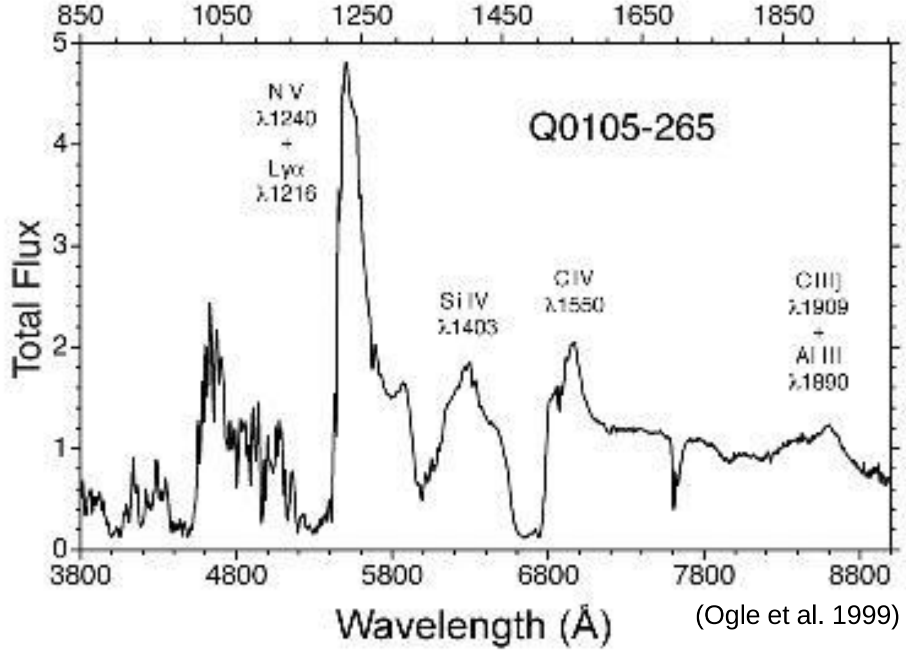
(Kellermann et al. 2016)

AGN taxonomy: BAL QSOs

BAL QSOs = Broad Absorption Line QSOs

Otherwise normal QSOs that show deep blue-shifted absorption lines corresponding to resonance lines of C IV, Si IV, N V.

All of them are at $z \geq 1.5$ because the phenomenon is observed in the rest-frame UV. At these redshifts, they are about 10% of the *observed* population.

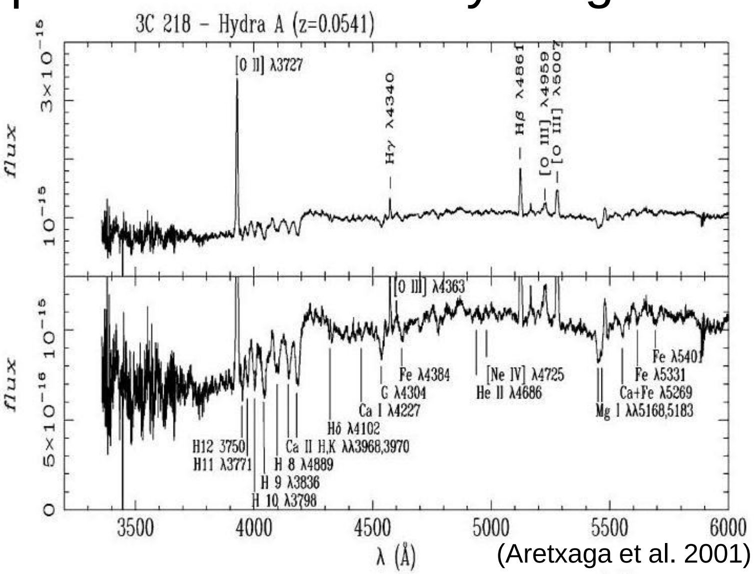


(Ogle et al. 1999)

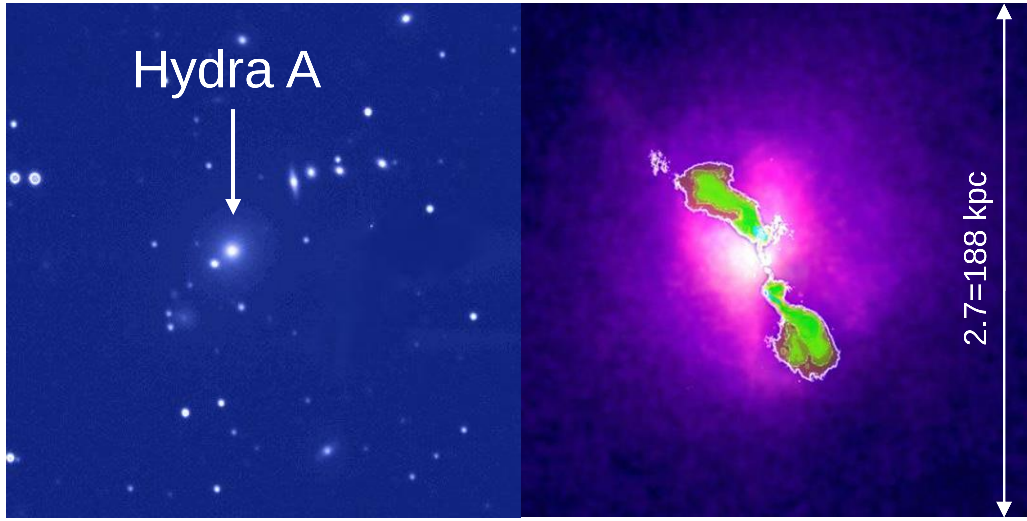
BAL QSOs tend to be more polarized than non-BAL QSOs.

AGN taxonomy: Radio galaxies

Strong radio sources associated with giant elliptical galaxies, with optical spectra similar to Seyfert galaxies.



(Aretxaga et al. 2001)



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Sub-classification according to

♦ optical spectra: NLRG = narrow-line radio galaxy, and BLRG = broad-line radio galaxy, with optical spectra similar to Sy 2 and Sy 1, respectively.

♦ spectral index (α, such that $F_\nu=\nu^\alpha$) at ν=1GHz: steep or flat separated by $\alpha=-0.4$

♦ 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 $R>0.5$

AGN taxonomy: LINERs

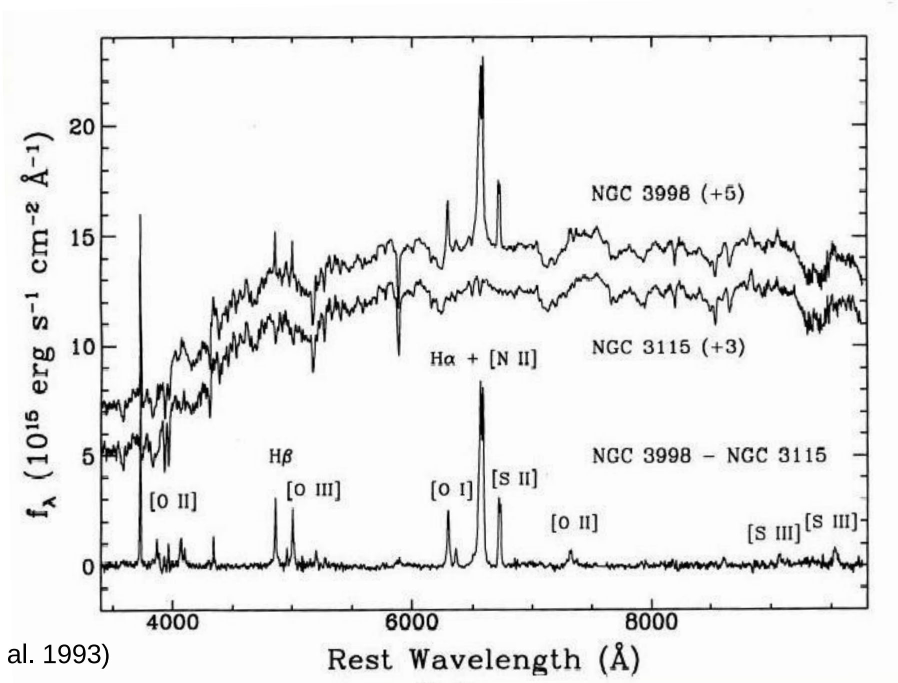
LINER = Low-Ionization Narrow-Line Region

They are characterized by [O II] λ3727Å / [O III] λ5007Å ≥ 1 (Heckman 1980)

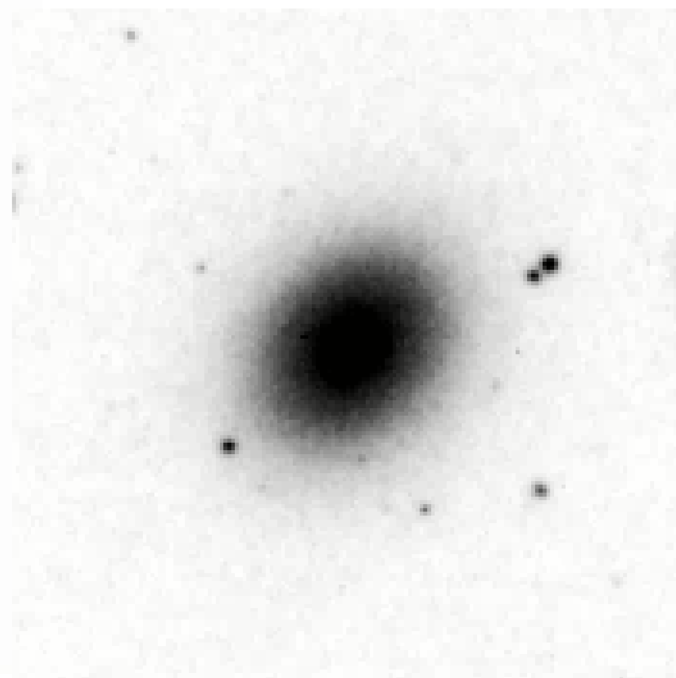
[O I] λ6300Å / [O III] λ5007Å ≥ 1/3

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 (Stauffer 1982, Phillips et al. 1986, Ho, Filippenko & Sargent 1993, …).

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:



(Ho et al. 1993)



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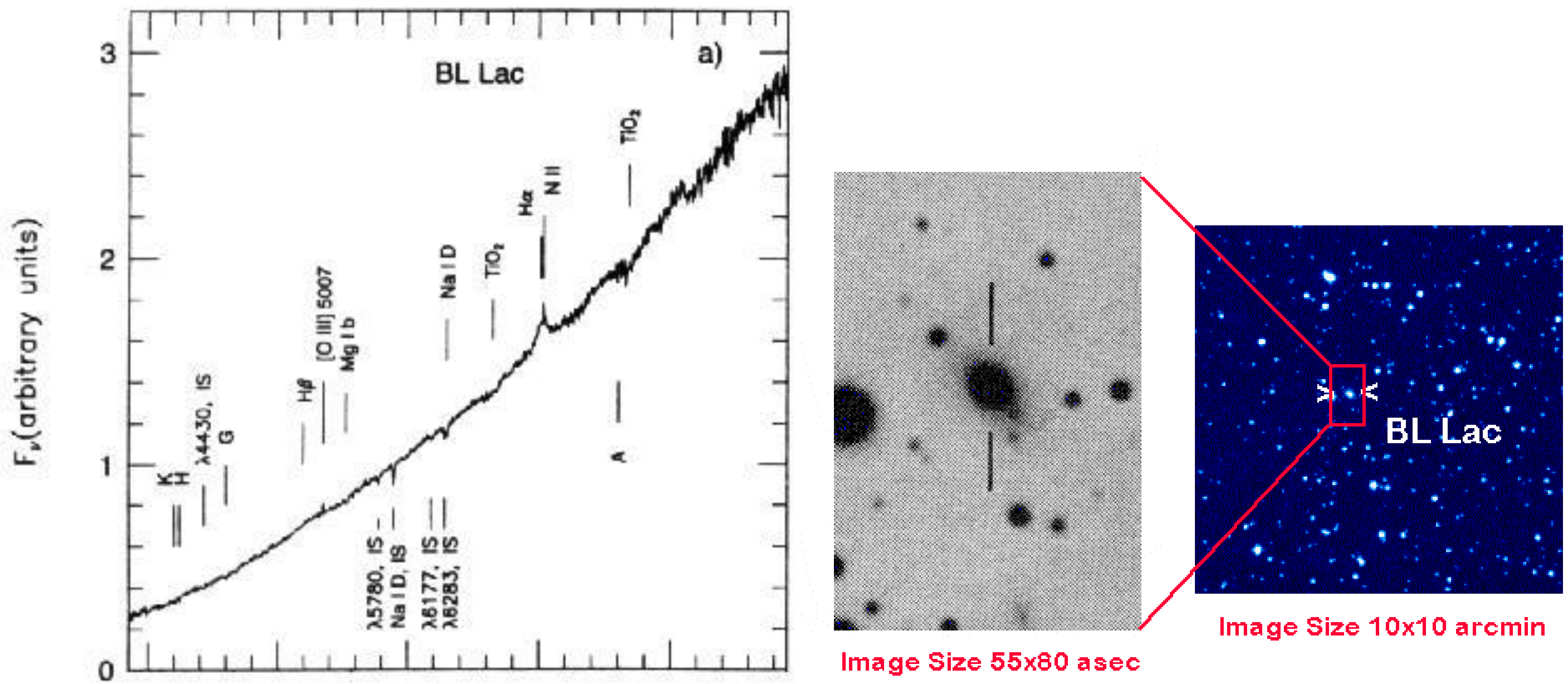
AGN taxonomy: BL Lacs

BL Lac is the prototype of its class, an object, stellar in appearance, with very weak emission lines and variable, intense and highly polarized continuum. The weak lines often just appear in the most quiescent stages. Blazars encompass BL Lacs and optically violent-variable (OVV) QSOs. These are believed to be objects with a strong relativistically beamed jet in the line of sight.



(Vermeulen et al. 1994)

AGN history of events (Shields 1999)

1909 Fath: First spectroscopy of spiral nebulae, inc. NGC1068, he detected nebular emission lines and was awarded his PhD.

1943 Seyfert: Systematic study of galaxies with emission lines, and focused on those with high excitation nuclear emission lines.

1944 Reber: Detection at 160MHz of Cyg-A (actually 2nd brightest source in the sky), confirmed by Bolton & Stanley (1948) as a discrete source (arcmin FWHMs). With interferometry, double radio structure was apparent (Hanbury et al. 1952).

1951 Smith: Accurate position for Cyg-A, optically identified by Baade & Minkowski (1954), who also IDed VirA (M87).

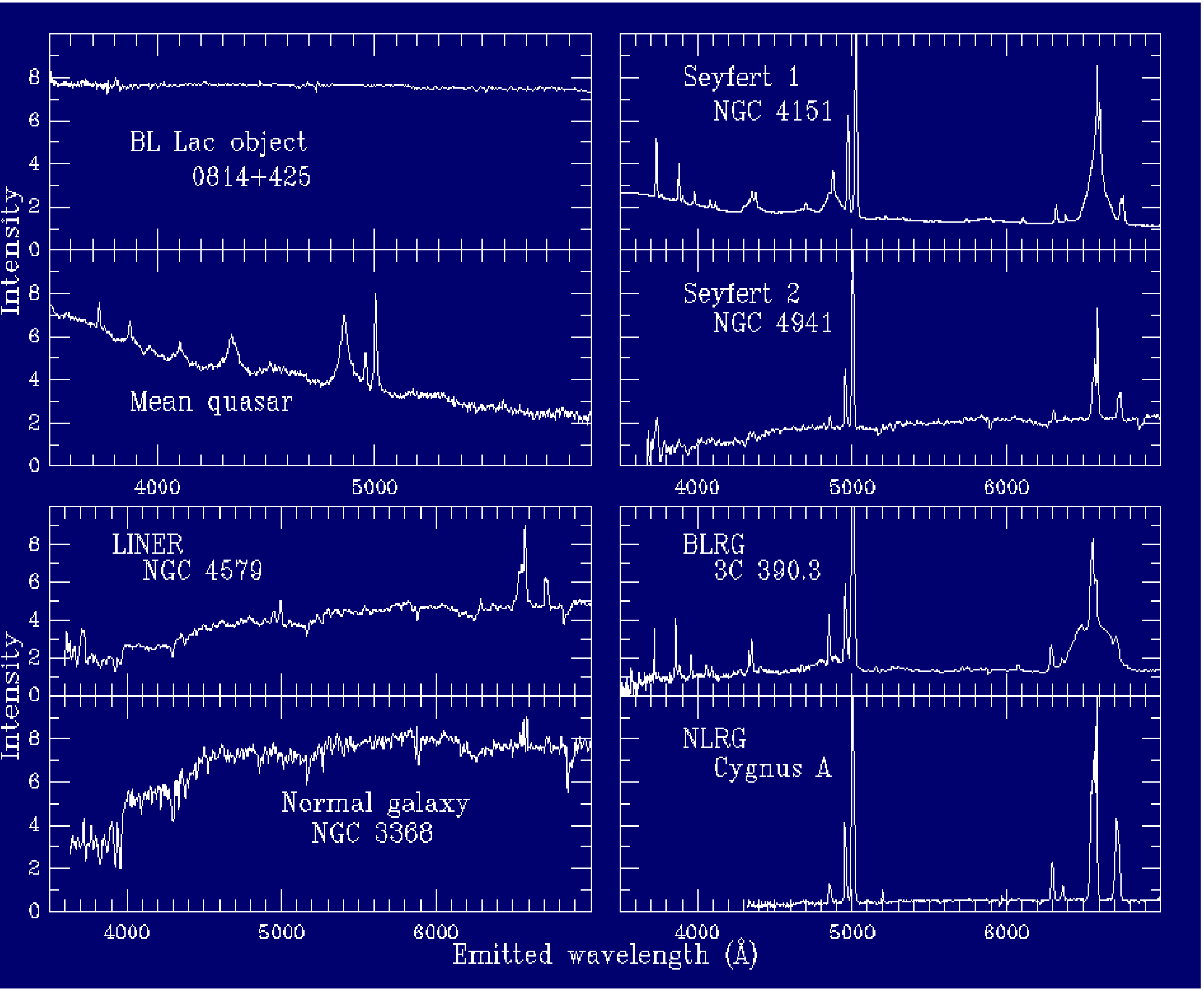
1950-60's: Radio catalogs by Cambridge (*e.g.* 3C, Edge et al. 1959, Bennett et al. 1962) and Parkes (Bolton et al. 1964) teams.

1963 Schmidt: 3C 273 optical spectrum at z=0.158 from a lunar occultation accurate position (Hazard et al. 1963).

1965 Sandage: finds that most quasars are radio-quiet (blue-colour selected)…

1964-65: First extensive Seyfert galaxy searches through compactness (Zwicky) or UV excess (Markarian)

AGN gallery and densities



(Bill Keel´s web page)

Space densities in the local Universe

(Wotjer 1990, Peterson 1997)

Radio-quiet

Sy 2: 8 x 10^5 h_0^3 Gpc^{-3}

Sy 1: 3 x 10^5 h_0^3 Gpc^{-3}

QSOs: 800 h_0^3 Gpc^{-3}

Radio-loud

FR I: 2 x 10^4 h_0^3 Gpc^{-3}

BL Lac: 600 h_0^3 Gpc^{-3}

FR II: 80 h_0^3 Gpc^{-3}

Quasars: 20 h_0^3 Gpc^{-3}

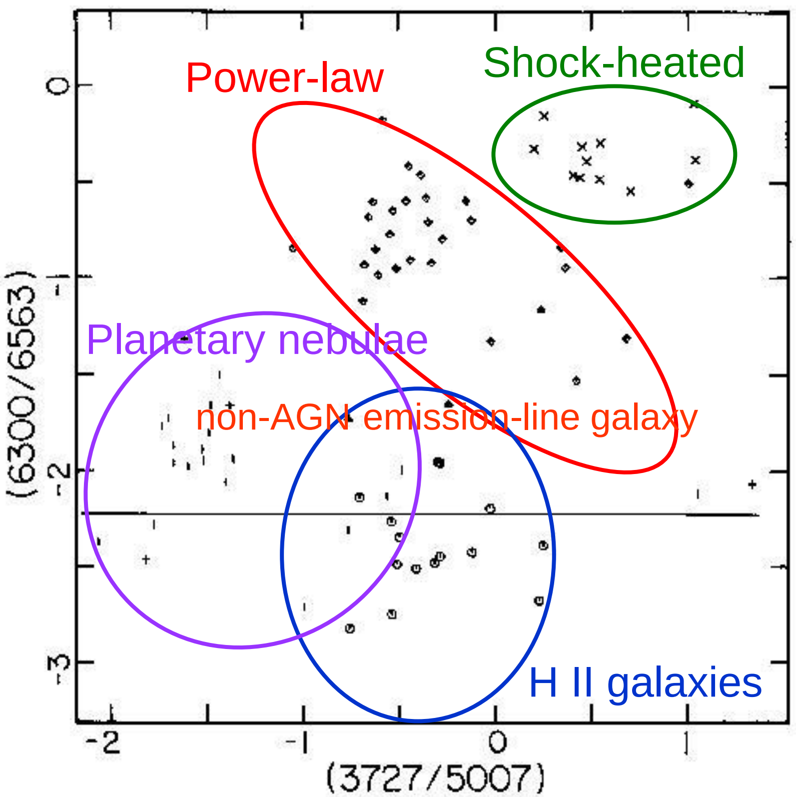
All galaxies

S: 1.5 x 10^7 h_0^3 Gpc^{-3}

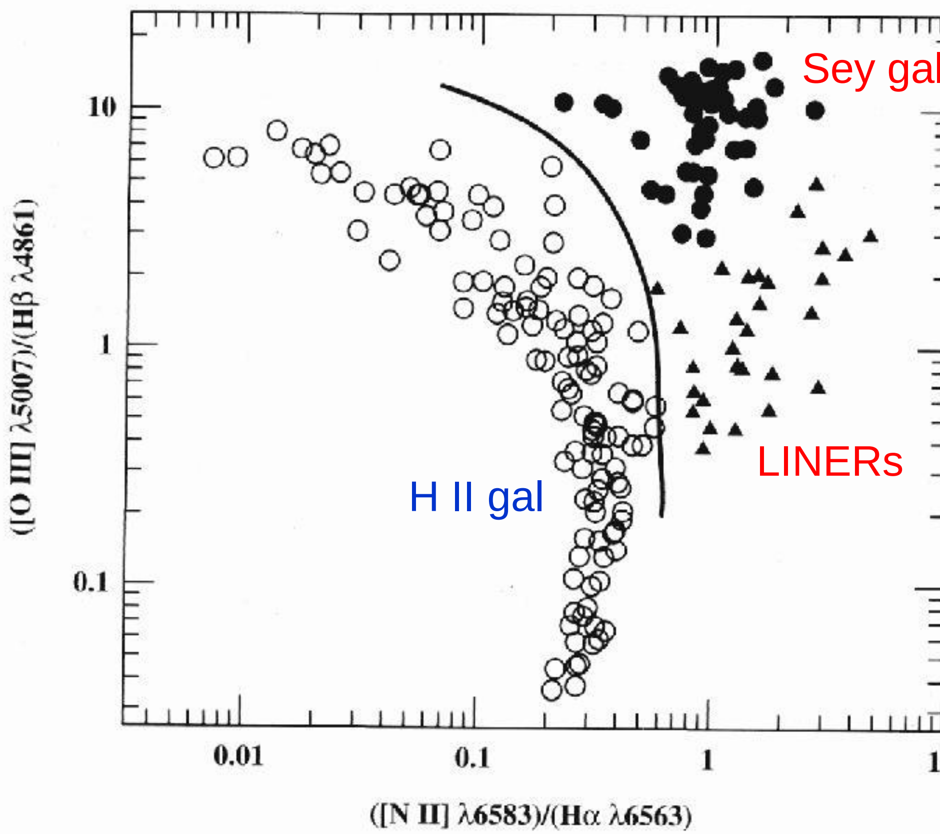
E: 1.0 x 10^7 h_0^3 Gpc^{-3}

AGN diagnostic diagrams

The BPT diagrams are used in narrow-line emission systems, to distinguish between hard and soft radiation (Balwin, Phillips & Terlevich 1981, Veilleux & Ostrebrock 1987), which is usually ascribed to non-stellar and stellar activity, respectively.



(BPT 1981)



(Peterson 1997)

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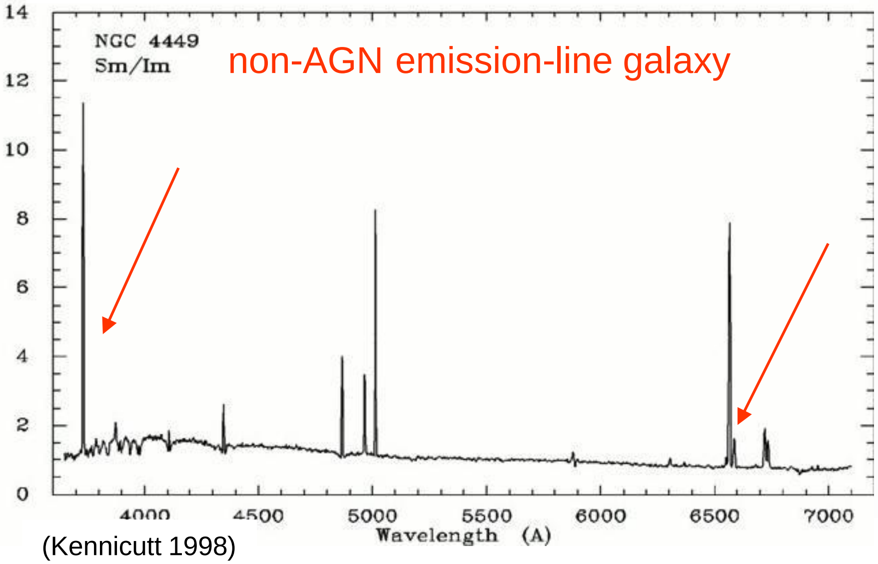
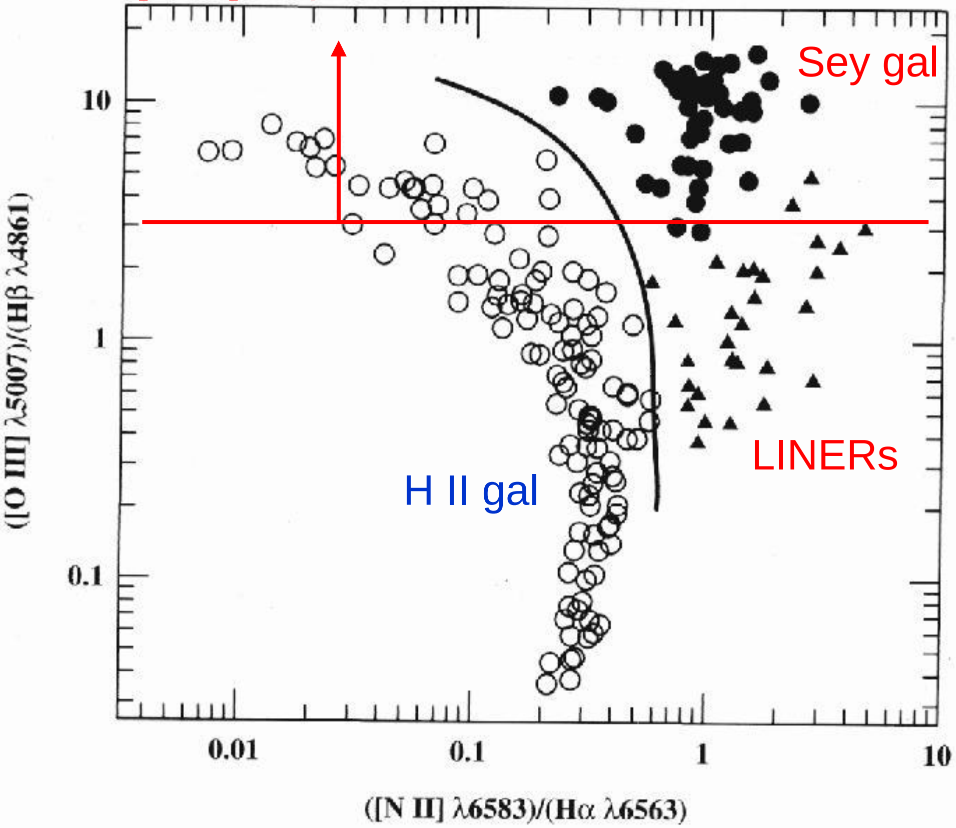


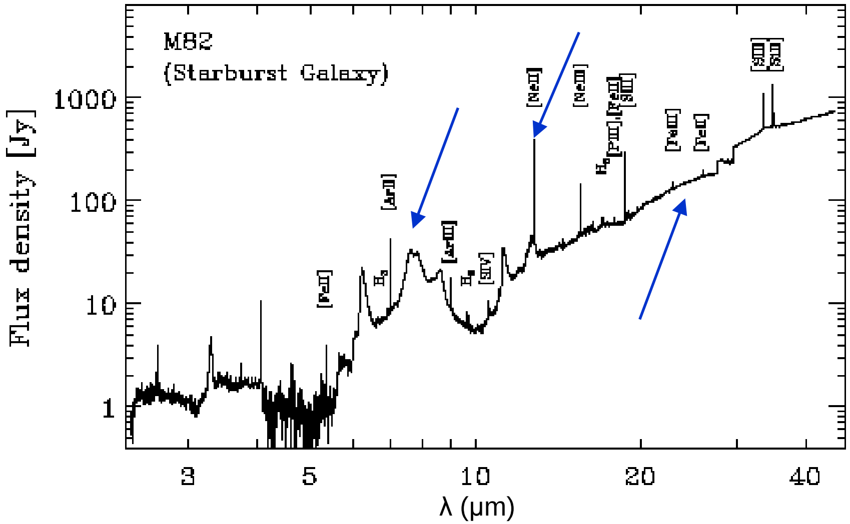
(Kennicutt 1998)

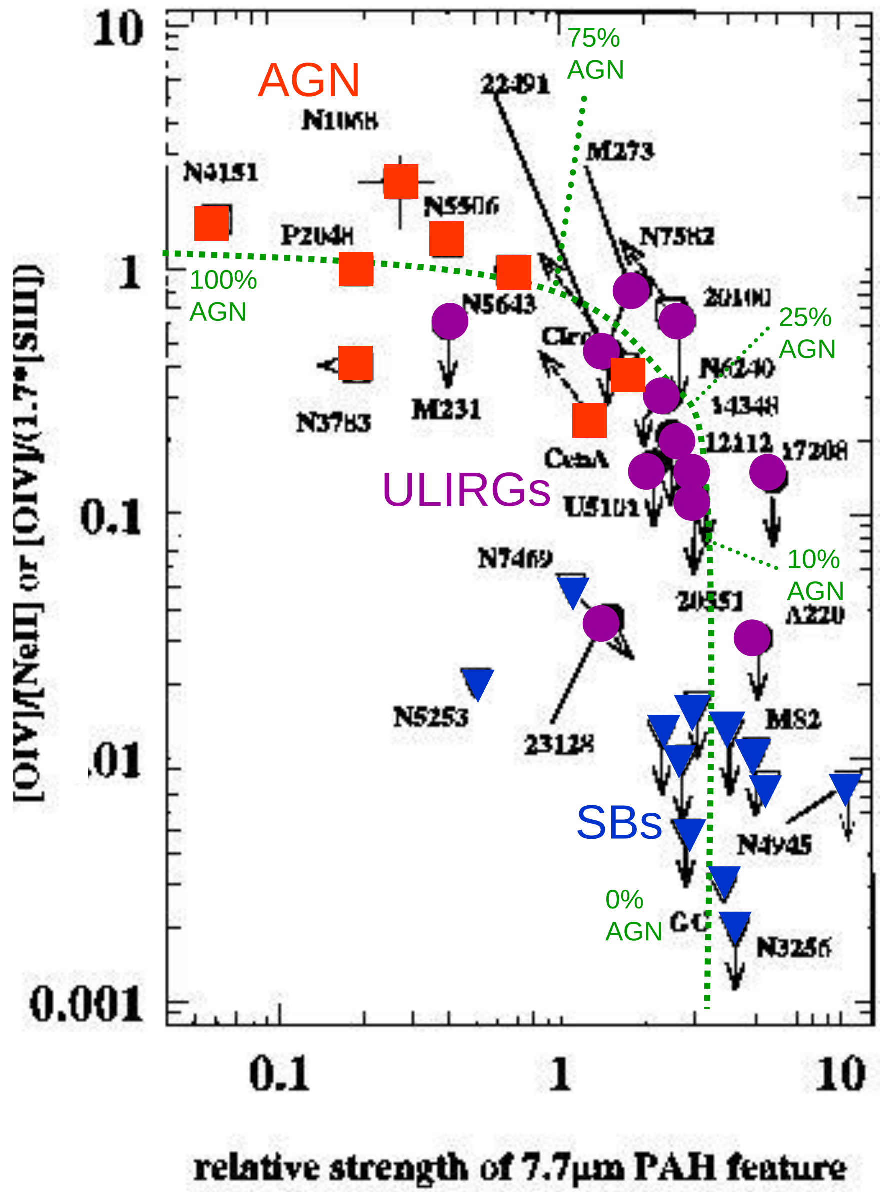
Some people erronously take [O III] / Hβ > 3 as the criterium for AGN



(Peterson 1997)

AGN diagnostic diagrams

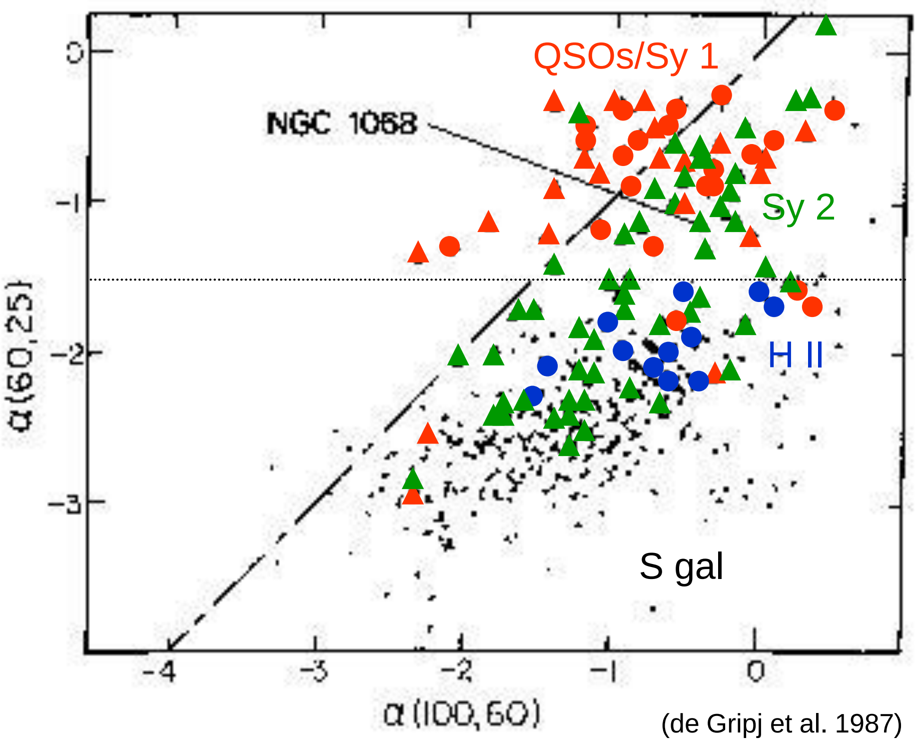




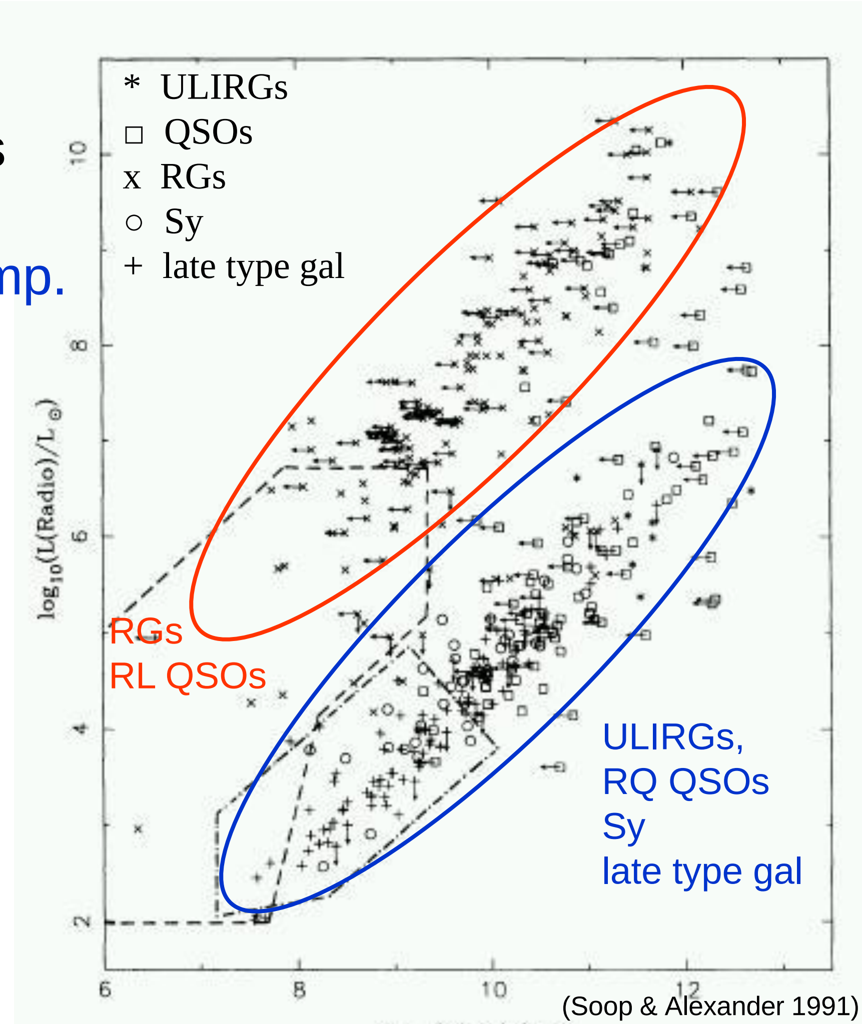
Policyclic aromatic hidrocarbons (PAHs), create bumps in the MIR spectrum, which easily identify soft-UV radiation fields that irradiate hot dust. They get destroyed by hard radiation. ULIRGs have radiation fields closer to starburst galaxies than to AGN. From this diagnostic diagram, it is estimated that 70-80% of the MIR radiation is powered by obscured starbursts and 20-30% by AGN (Genzel et al. 1998).

AGN diagnostic diagrams

Photometric selection at FIR (de Grijp et al. 1985, 1987) or FIR/radio bands has also been proposed as a way to identify AGN, however, spectroscopic confirmation is required since there is overlap with other populations at some degree. The overlap in the FIR/radio diagram of the radio-quiet AGN population with star forming galaxies (Soop & Alexander 1991), points towards stellar heating being the origin of most of the radiation emitted in the IR bump.



(de Gripj et al. 1987)



(Soop & Alexander 1991)

AGN diagnostics: X-ray selection

Accretion is an effective hard-X radiative process (2 - 8keV).

♦ 3-20% of energy radiated in the classical X-ray bands.

♦ High area density (400 deg^{-2})

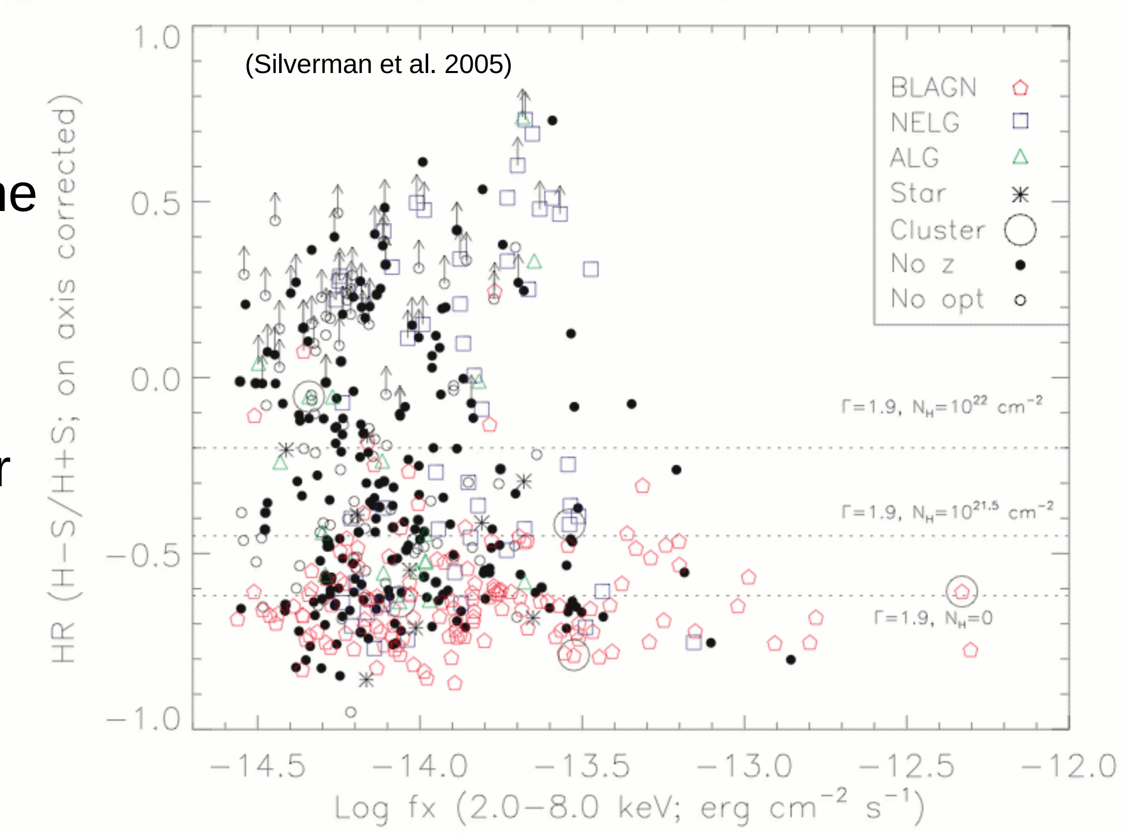
♦ Large amplitude variability

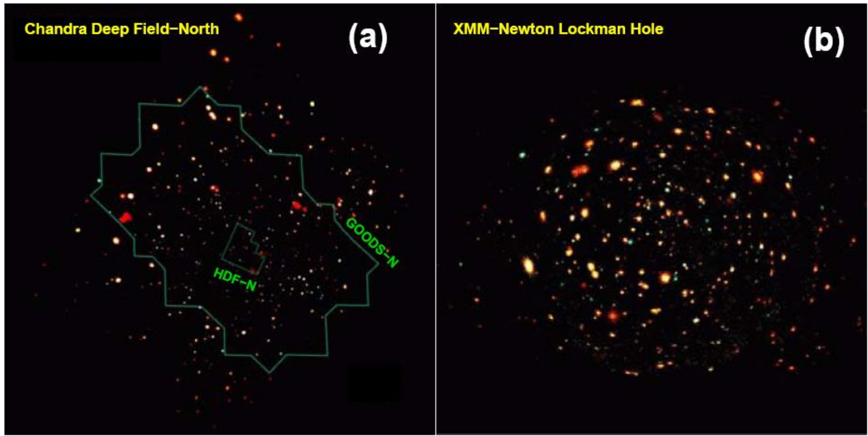
♦ Little contamination from other objects

Spectroscopic confirmation is required

But there are reasons for incompleteness:

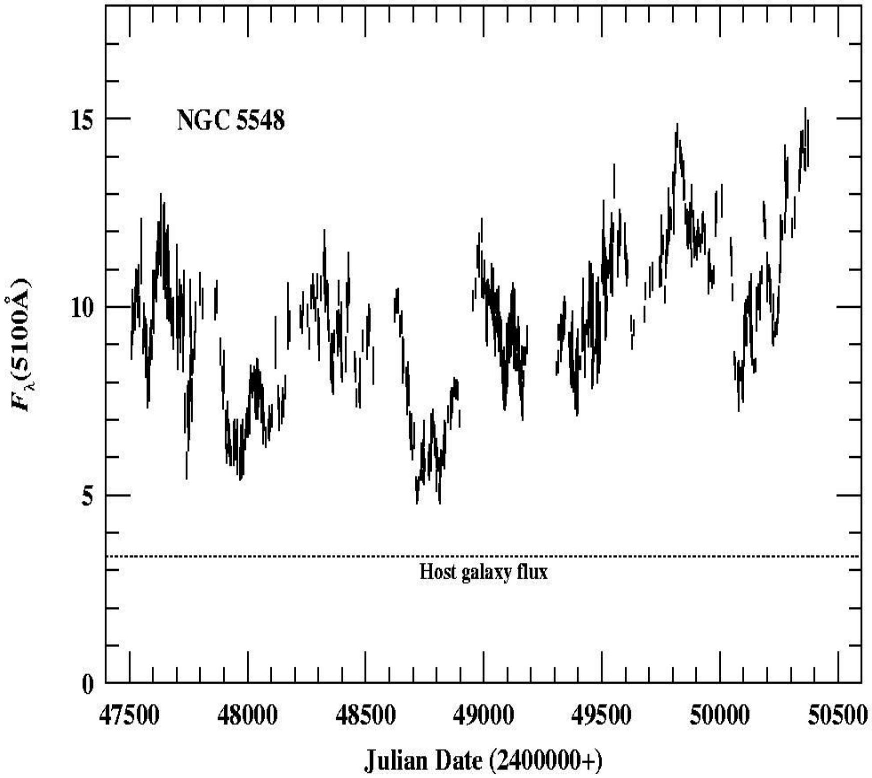
- Compton thick AGN
- Not all AGN are X-ray luminous

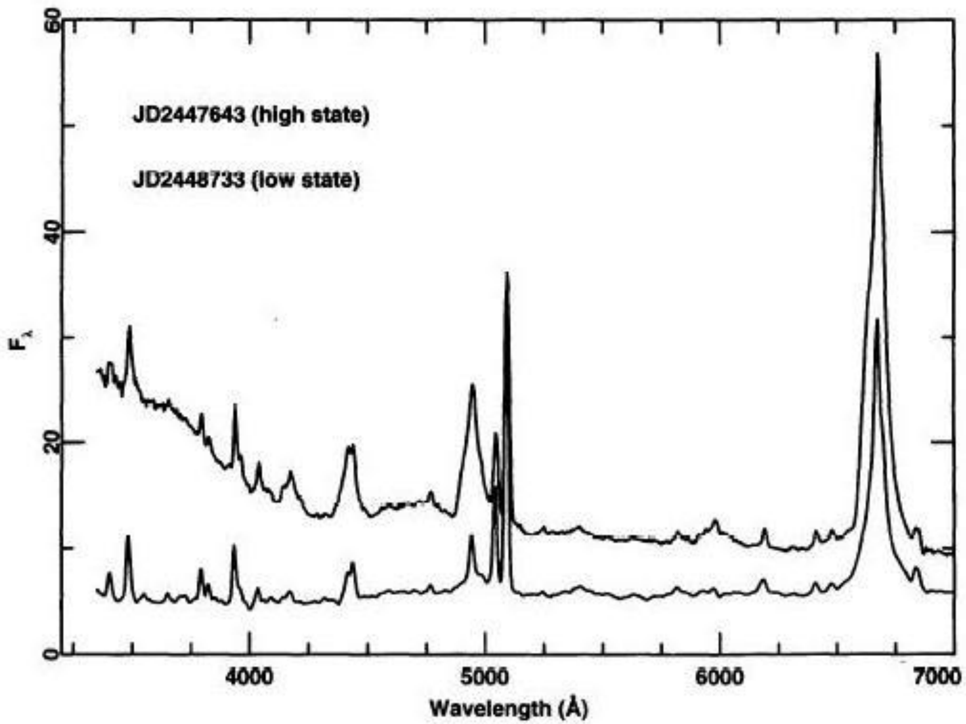




Phenomenology of AGN: variability

Broad-line varieties (Sy 1s, QSOs, BLRGs) are usually variable, where as narrow-line varieties (Sy 2s, LINERs, NLRGs) are usually quiescent.



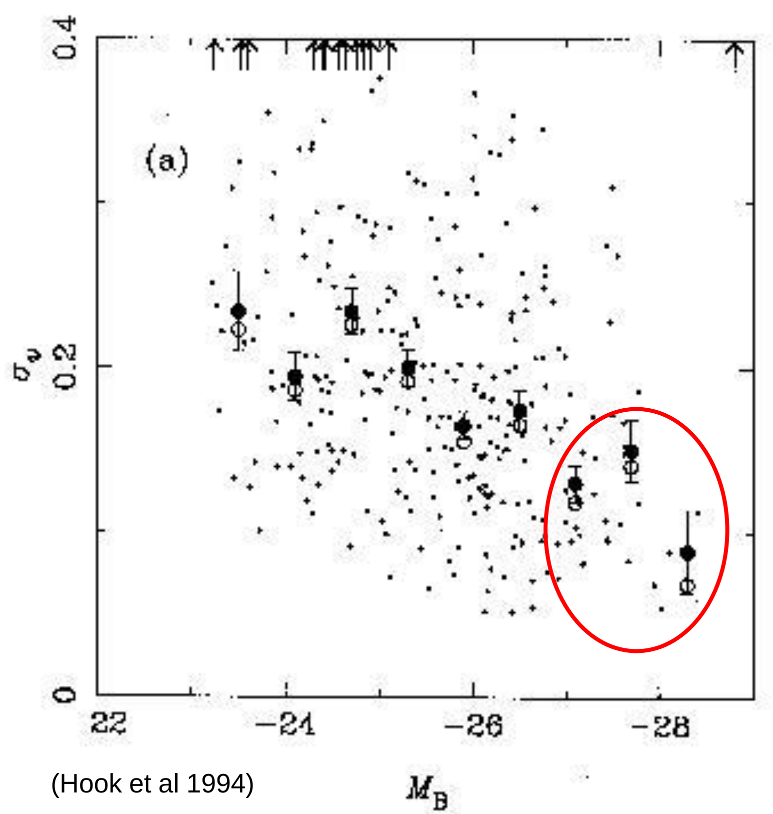


(Peterson et al. 1994, Peterson 2001)

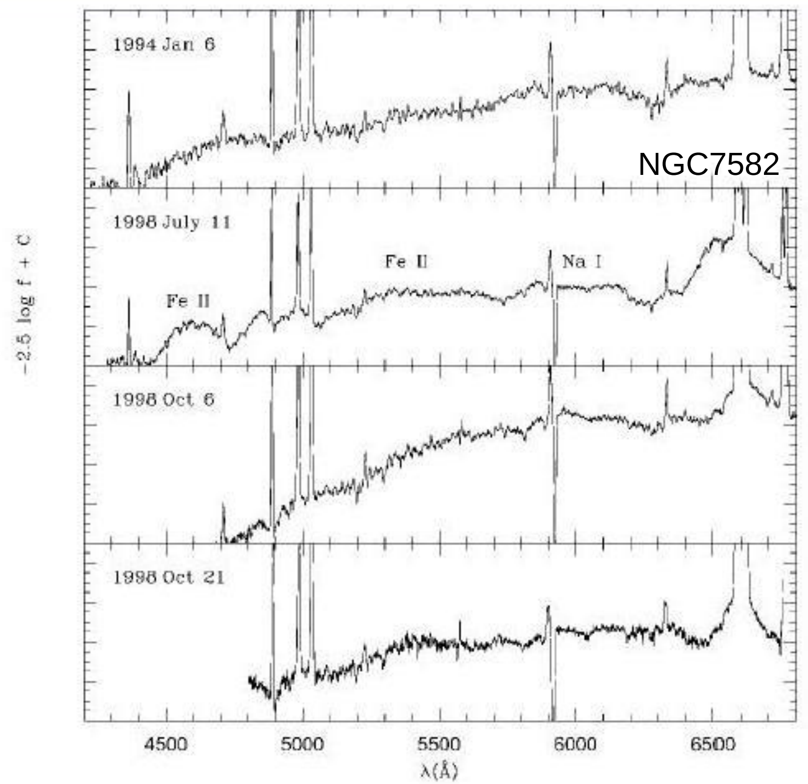
But there are outstanding exceptions....

Phenomenology of AGN: variability

Exceptions to the rule of thumb that “broad” varies, “narrow” stays still:



(Hook et al 1994)

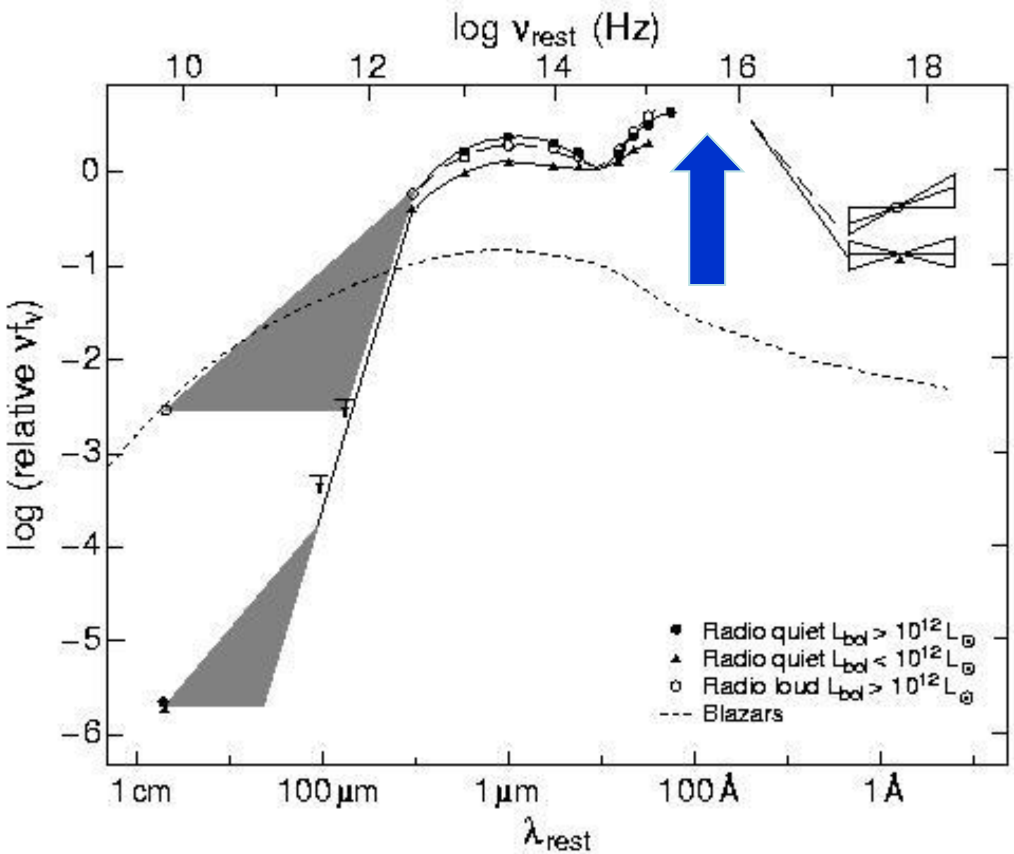


(Aretxaga et al. 1999)

The most luminous radio-quiet QSOs vary little (Hook et al. 1994, Cristiani et al. 1996)

A handful of Sy 2s and LINERs have suddenly developed broad emission lines (NGC1566, Alloin et al. 1986; NGC 1097, Storchi-Bergmann et al.; NGC7582, Aretxaga et al. 1999;...)

Phenomenology of AGN: energetics



(Sanders & Mirabel 1996)

Most of the energy emitted by QSOs is associated with the big blue bump. One needs to understand the emission mechanism in this region to understand what makes AGN unique.

The extreme luminosities emitted by AGN

bolometric $L_{Sy} \approx 10^{44}$ erg s^{-1}

$L_{QSO} \approx 10^{46}$ erg s^{-1}

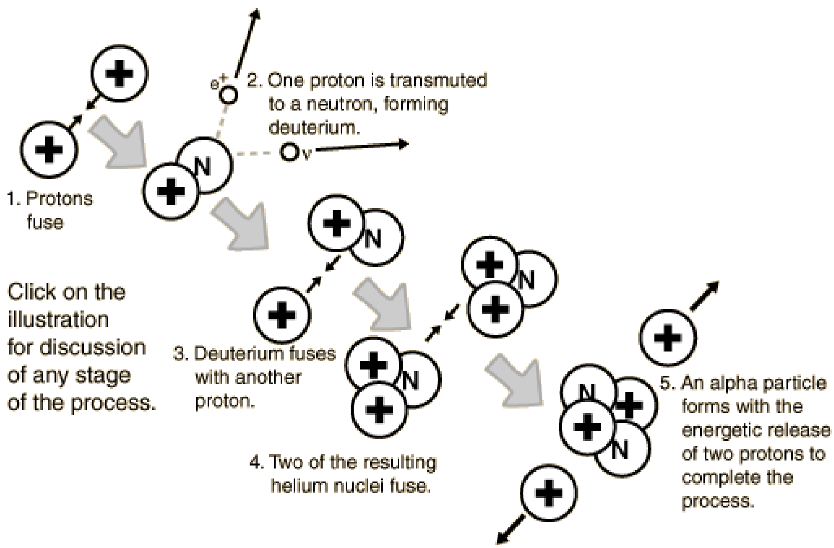
made it clear that the easiest way to explain them was through the release of gravitational energy. In the mid-60s the concept of a supermassive black hole (**SMBH**) surrounded by a viscous disk of accreting matter gained popularity (Zeldovich & Novikov 1964, Lynden-Bell 1969), and become the standard model for AGN ever since.

The standard model of AGN: SMBHs

Nuclear Fusion

Main sequence He production

$4H \rightarrow {}^{4}He + \Delta mc^2$



liberates ~6 x 10^8 erg g^{-1}

$\Delta E_{nuc} \sim 0.007\, m_p c^2$

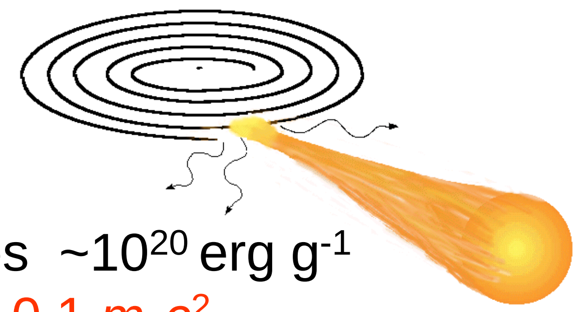
Gravitation

Potential energy from accreting a mass m from ∞ to R_S

$\Delta E_{acc} = GM_{BH}m/R_S$, where

$R_S = 2GM_{BH}/c^2$

$\rightarrow \Delta E_{acc} = mc^2/2$

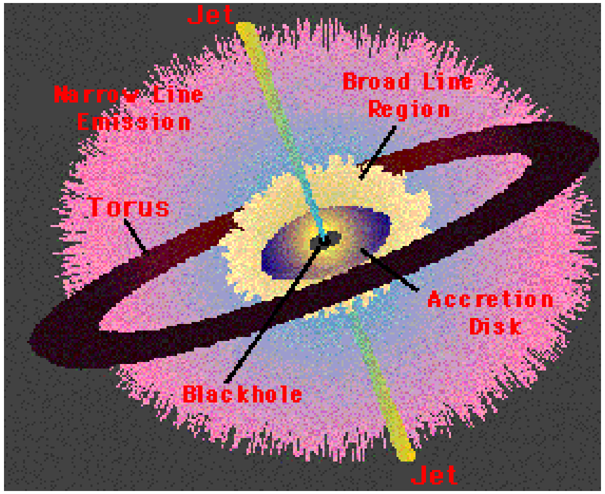


liberates ~10^{20} erg g^{-1}

$\Delta E_{acc} \sim 0.1\, m_p c^2$

Hence accretion of material is the most efficient astrophysical energy source

The standard model of AGN: components



Black hole: $M_{BH} \sim 10^6$-10^9 $M_\odot$

accretion disk: $r \sim 10^{-3}$ pc $n \sim 10^{15}$ cm^{-3}

$v \sim 0.3$c

Broad Line Region (BLR):

$r \sim 0.01 - 0.1$ pc $n \sim 10^{10}$ cm^{-3}

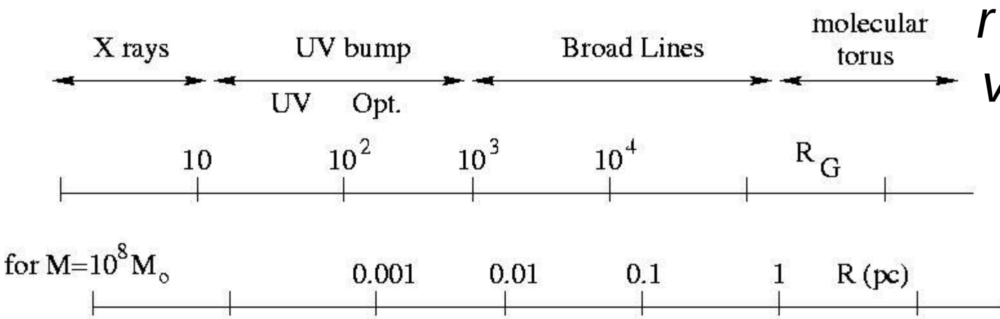
$v \sim$ few x 10^3 km s^{-1}

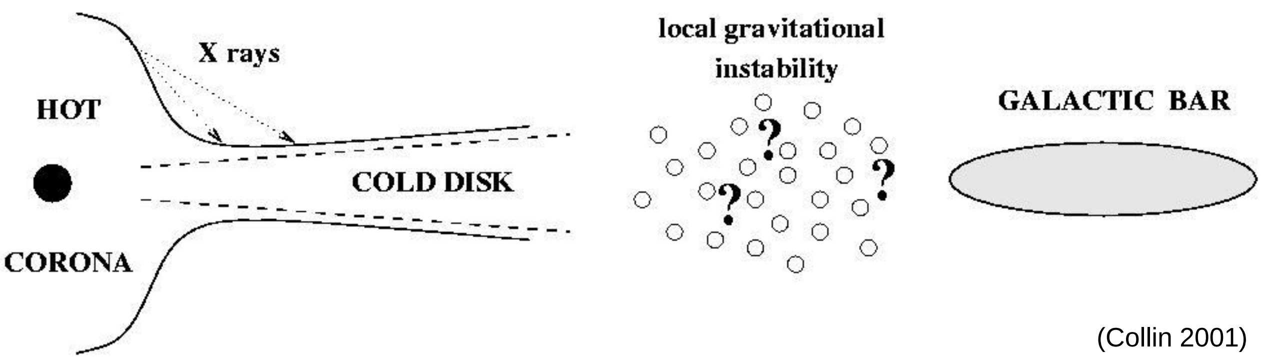
torus: $r \sim 1 - 100$ pc $n \sim 10^3 - 10^6$ cm^{-3}

Narrow Line Region (NLR):

$r \sim 100-1000$ pc $n \sim 10^3 - 10^6$ cm^{-3}

$v \sim$ few x 100 km s^{-1}





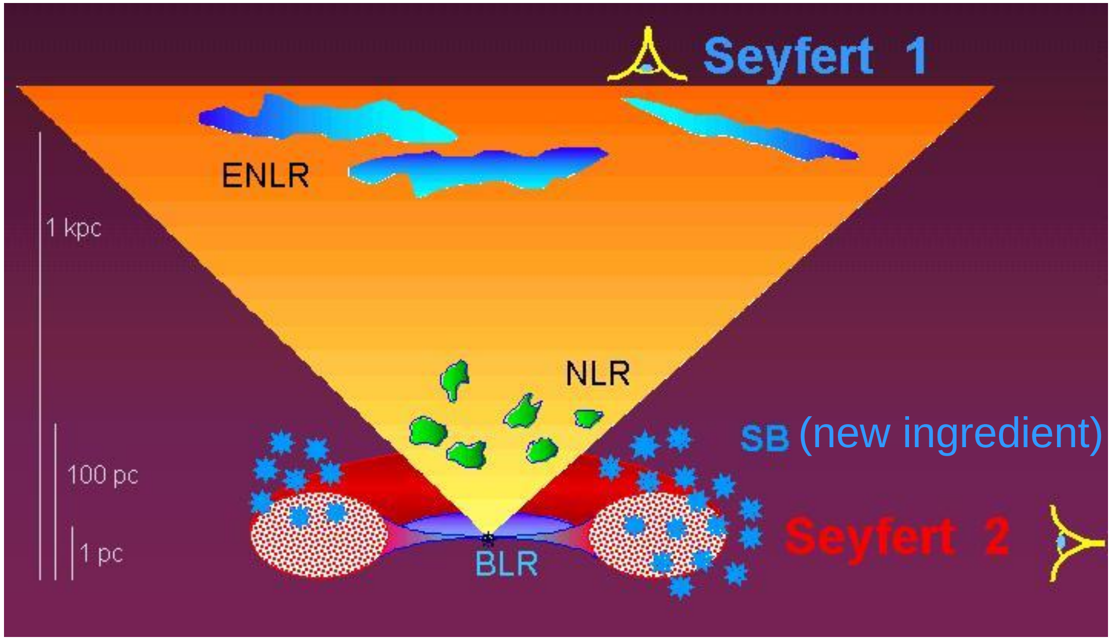
(Collin 2001)

Unification in AGN

All AGN are the same type of object but looked at from a different point of view

	Face-on	Edge-on
Radio-quiet	Sy 1	Sy 2
	QSO	FIR gal?
Radio-loud	BL Lac	FR I
	BLRG	NLRG
	quasar	FR II

This idea dates back to, at least, Rowan-Robinson (1977), and became popular in the mid-80s (reviews by Lawrence 1987, Antonucci 1993, Urry & Padovani 1997, Goodrich 2001).

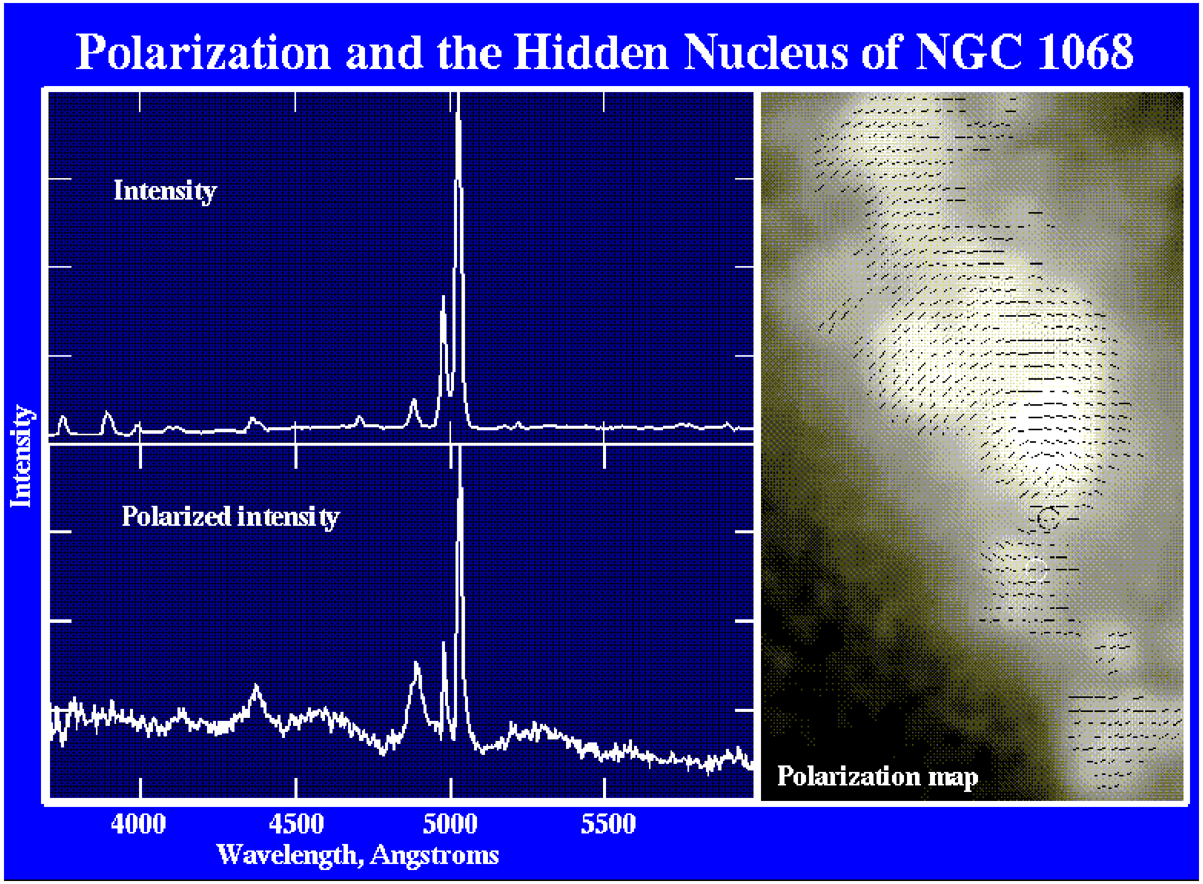


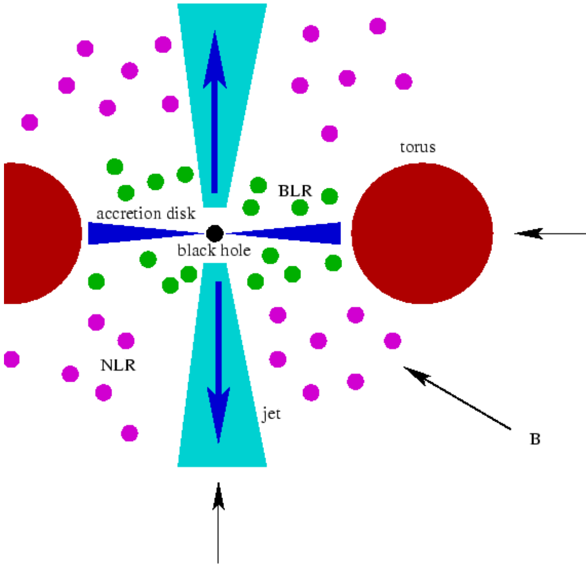
(Rosa González-Delgado´s web page)

Support for unification: hidden emission lines

Some Sy 2s show broad lines in polarized light (Antonucci & Miller 1995, Goodrich & Miller 1990, ...): the fraction is still unclear since the observed samples are biased towards high-*P* broad-band continuum objects.

The polarization level of the continuum flux is roughly constant up to λ1500Å (Code et al. 1993), which implies that hot electrons are the scattering source near the nucleus, but dust dominates the outskirts.





(Bill Keel´s web page with data from Miller, Goodrich & Mathews 1991, Capetti et al. 1995)

Support for unification: ionization cones

A number of Sy 2s also show clear anisotropy in the highly ionized emission lines (like [O III]) which, often, resemble a cone (Pogge 1988): the ionization cone is “collimated” by the obscuring torus.

One can readily assess that the radiation field is anisotropic (Neugebauer et al. 1980, Wilson et al. 1988, Storchi-Bergmann et al. 1992):

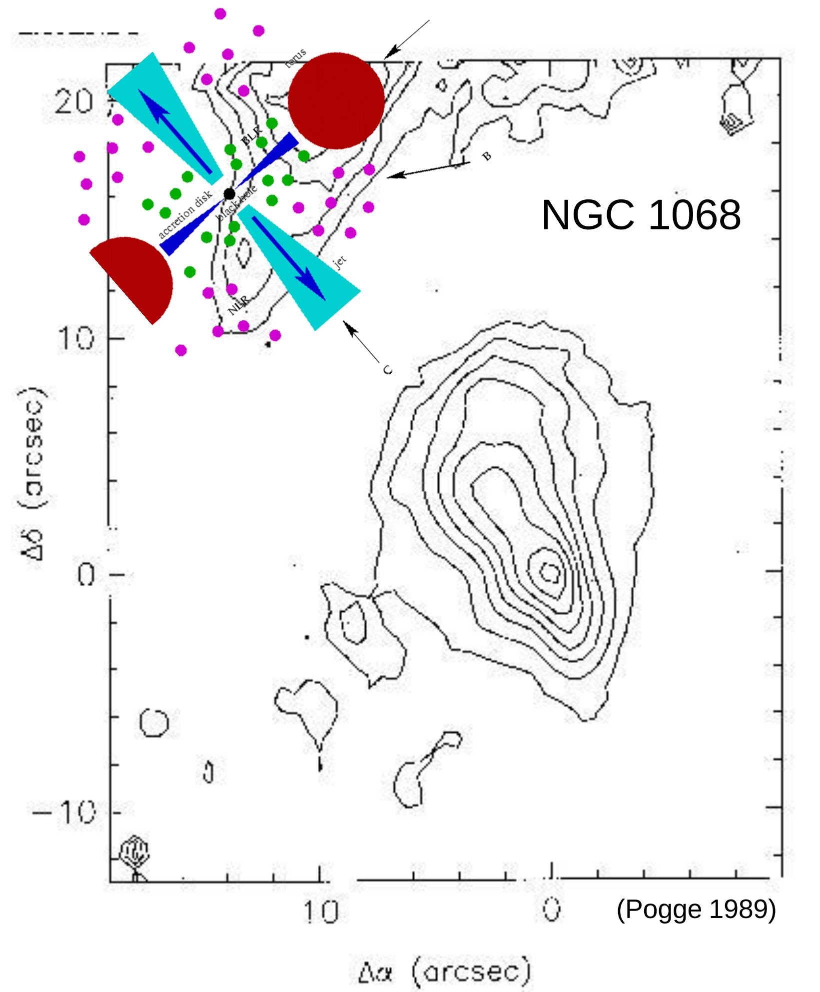
The number of ionizing photons to produce Hβ:

$$N_m(\mathrm{H}) = \frac{L(\mathrm{H}\beta)}{h\nu_{\mathrm{H}\beta}} \frac{\alpha_B}{\alpha^{\mathrm{eff}}_{\mathrm{H}\beta}} \approx 2.1\times 10^{52} L_{40}(\mathrm{H}\beta) \quad \text{photons s}^{-1}$$

This can be compared with the ionizing production rate inferred from the continuum:

$$N_i(\mathrm{H}) = 4\pi d^2 \int_{\nu_1}^{\nu_2} \frac{F_\nu d\nu}{h\nu}$$

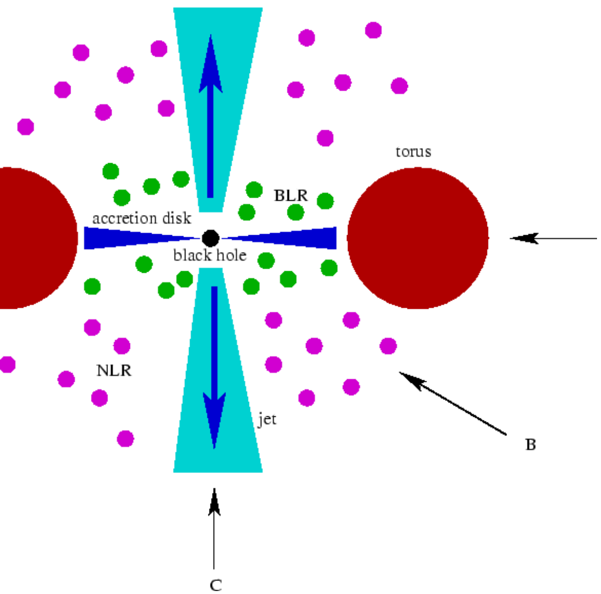
which yields $N_m(\mathrm{H})/N_i(\mathrm{H}) > 1$, and suggests that the ionization cone sees a more luminous continuum than we do.

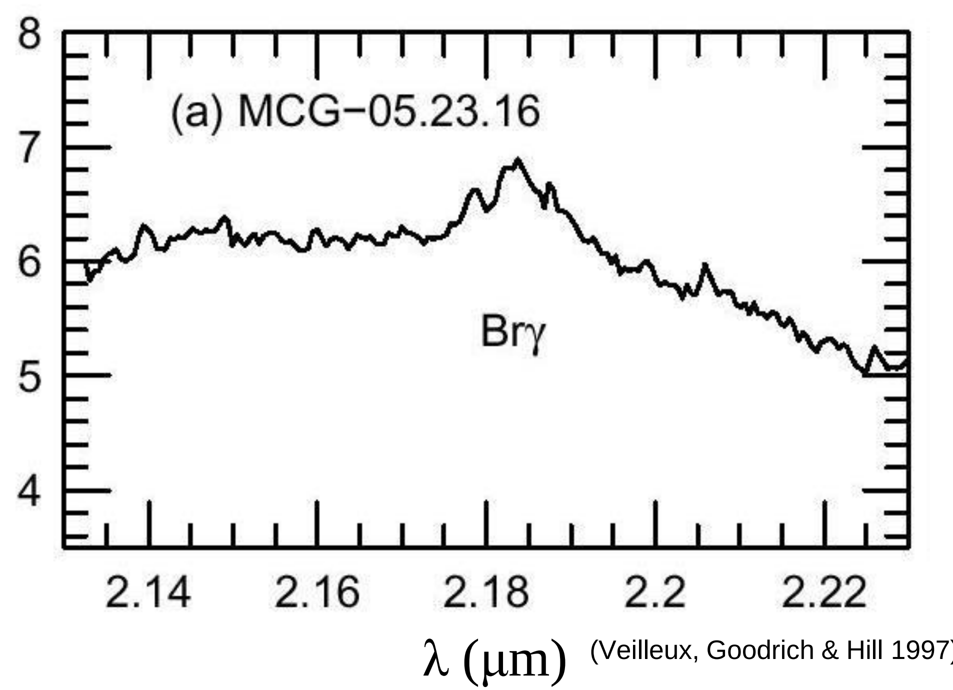


(Pogge 1989)

Support for unification: broad IR lines

There are searches for broad-recombination lines in the near-IR spectrum of Sy 2s, where the extinction affects the emitted spectrum less. They will be detectable if $A_V \leq 11$ mag for Paβ, $A_V \leq 26$ mag for Brγ and $A_V \leq 68$ mag for Brα. These searches have had moderate success: 25% of Sy 2s show some broad component in the IR (Goodrich et al. 1994).

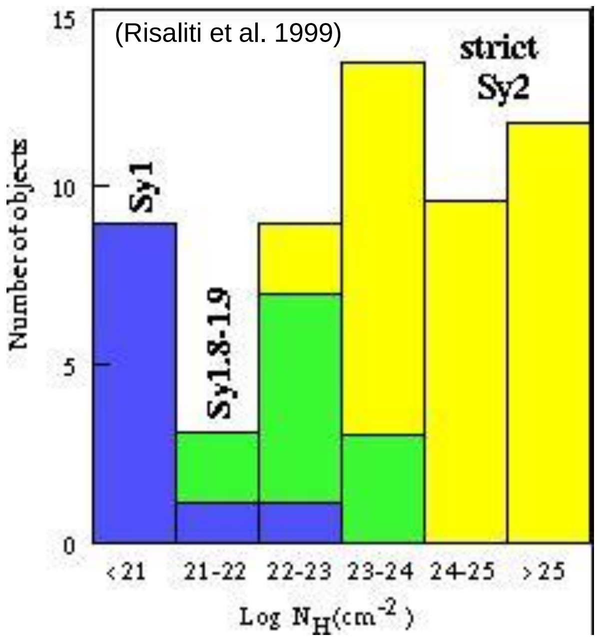




(Veilleux, Goodrich & Hill 1997)

Support for unification: IR and N_H excess

One can measure the column of neutral H that absorbs the soft X-rays emitted by the nucleus. The gas is associated with the dust in the molecular torus, and thus provides a rough estimate of the dust content and the attenuation this provides.

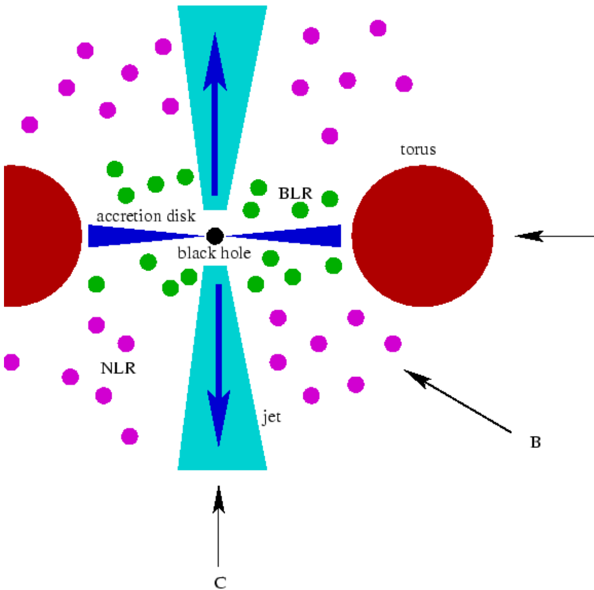


Sy 2s have the largest absorption columns, many of which imply the medium is Compton thick, so that X-rays are suppressed below 10 keV (Mushotzky 1982, Risaliti et al. 1999, Bassani et al. 1999).

Sy 2s also have colder IR colours than Sy 1s, as inferred from a sample of 10 Seyfert galaxies with ISO colours (Pérez-García et al. 1998):

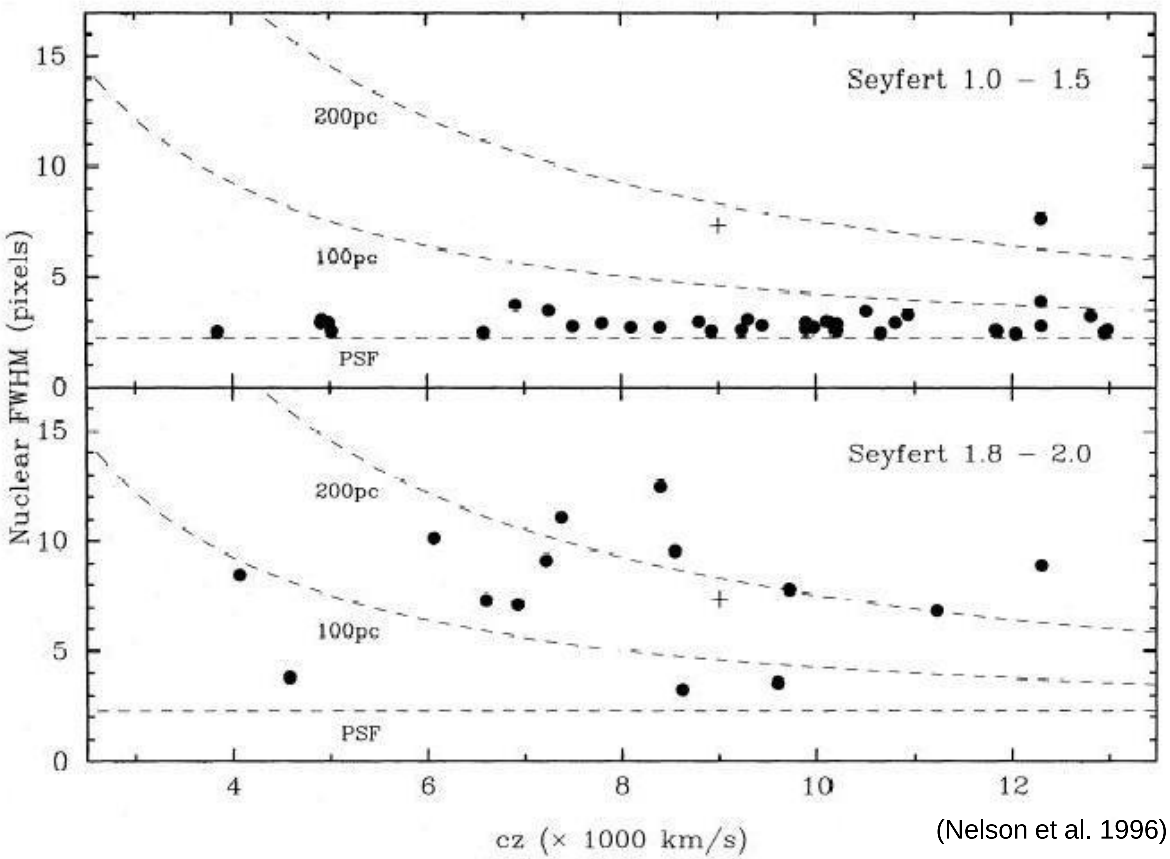
T_{Sy2}=112 – 136 K $\qquad$ $T_{Sy1}\approx$ 150 K

which can be explained if the torus is partially thick at mid-IR wavelengths.

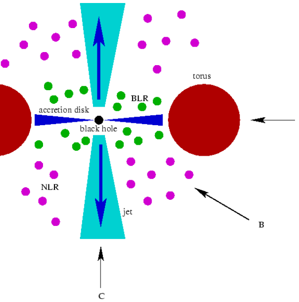


Support for unification: other statistical tests

- The continuum is stronger in Sy 1s than in Sy 2s (Lawrence 1987)
- All Seyfet galaxies have a NLR with very similar properties (Cohen 1993)
- Variability differs between different types (Lawrence 1987)
- The size of the Sy 1 continuum emitting regions are smaller than those of Sy 2s in HST images (Nelson et al. 1996)

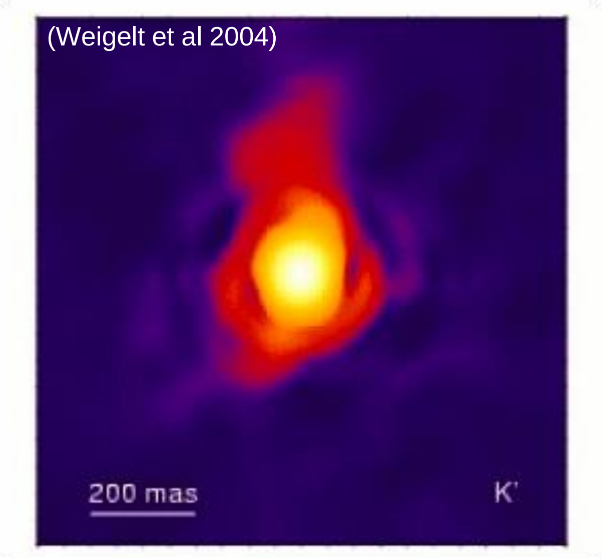


(Nelson et al. 1996)



Support for unification: direct detection of tori

- NGC1068: 2μm speckel imaging, R ~ 1 pc (Weigelt et al 2004),
  10μm interferometry, R ~ 2 pc, T~320 K (Jaffe et al 2004)
- Cen A: 2μm, R < 0.5 pc (Prieto et al 04)
  9,10μm, R ~ 1.5 pc (Karovska et al 03)
- Circinus: 2μm, R ~ 1pc (Prieto et al 04)
  10μm interferometry, R ~ 2 pc (Tristram et al 07)
- ~30 Sy1/Sy2: 10μm interf., R ~ 1-10 pc , T~300K (Tristram et al 09, Kishimoto et al. 2011)



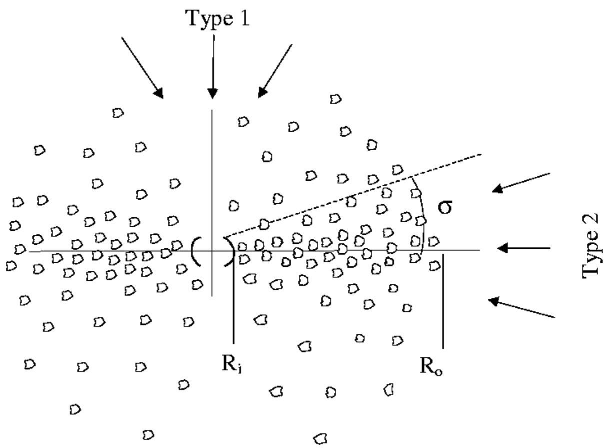
Clumping solves the compact emission problem (Elitzur):
e.g. for NGC1068, $L_{bol} = 2 \times 10^{45}$ erg s^{-1} = 2×10^{38} W (Mason et al 2006)

$T(r = 2\text{ pc}) = 960$ K

$r(T = 320\text{ K}) = 26$ pc

$r(T = 226\text{ K}) = 57$ pc

If the medium is clumpy, different T's at same r



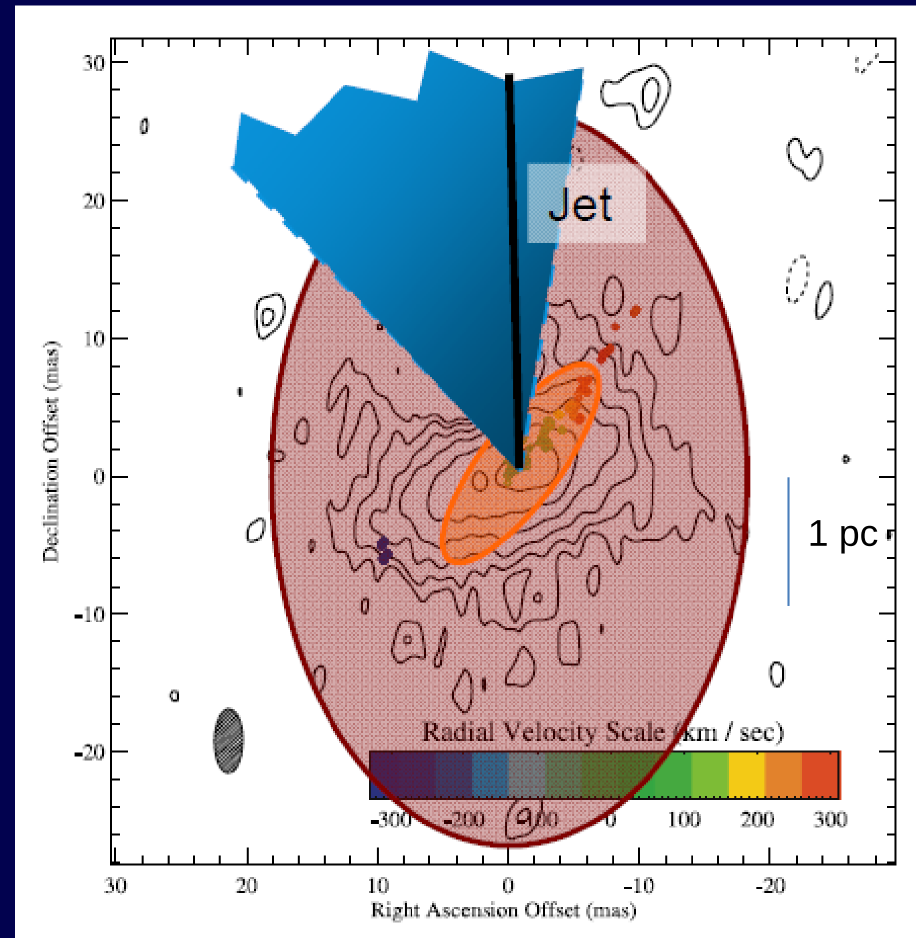
For an homogeneous grey body: r(pc) ~ $L_{39}^{1/2}\, T_3^{-(4+\beta)}$

Support for unification: direct detection of tori

NGC1068

Two Blackbody Gaussians:

FWHM major:	Δ_1 =	20±3 mas
FWHM minor:	δ_1 =	6±1 mas
Position angle	α_1 =	42±2°
Silicate depth:	τ_1 =	1.9±0.5
Temperature:	T_1 =	800±150 K
Covering factor:	f_1 =	0.25±0.07
FWHM major:	Δ_2 =	56±5 mas
FWHM minor:	δ_2 =	42±5 mas
Position angle:	α_2 =	0±50°
Silicate depth:	τ_2 =	0.42±0.2
Temperature:	T_2 =	290±10 K
Covering factor:	f_2 =	0.64±0.15



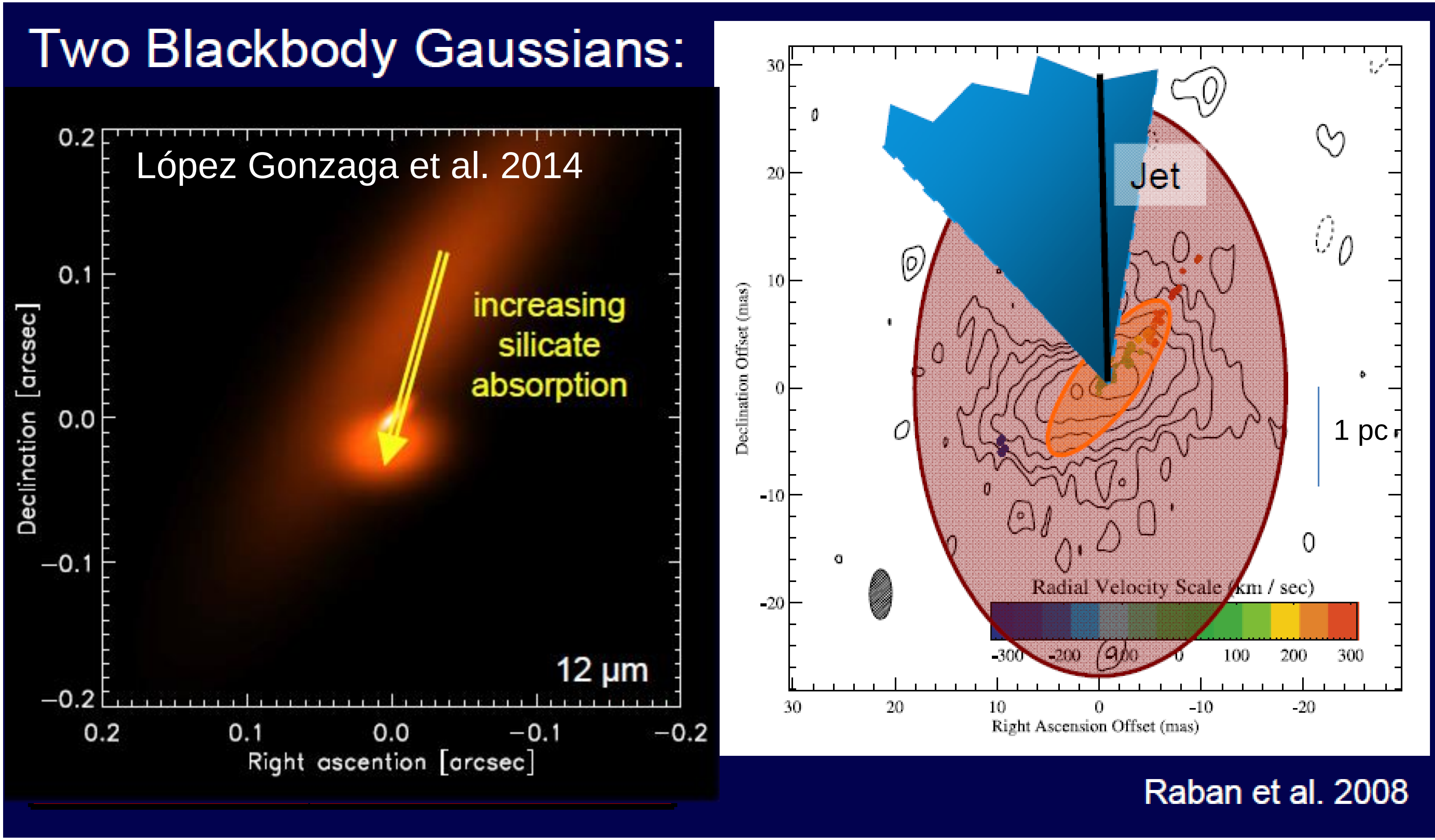
Raban et al. 2008

- NGC 1068, the prototypical Seyfert 2

(from K. Tristram’s presentation lib.)

Support for unification: direct detection of tori

NGC1068

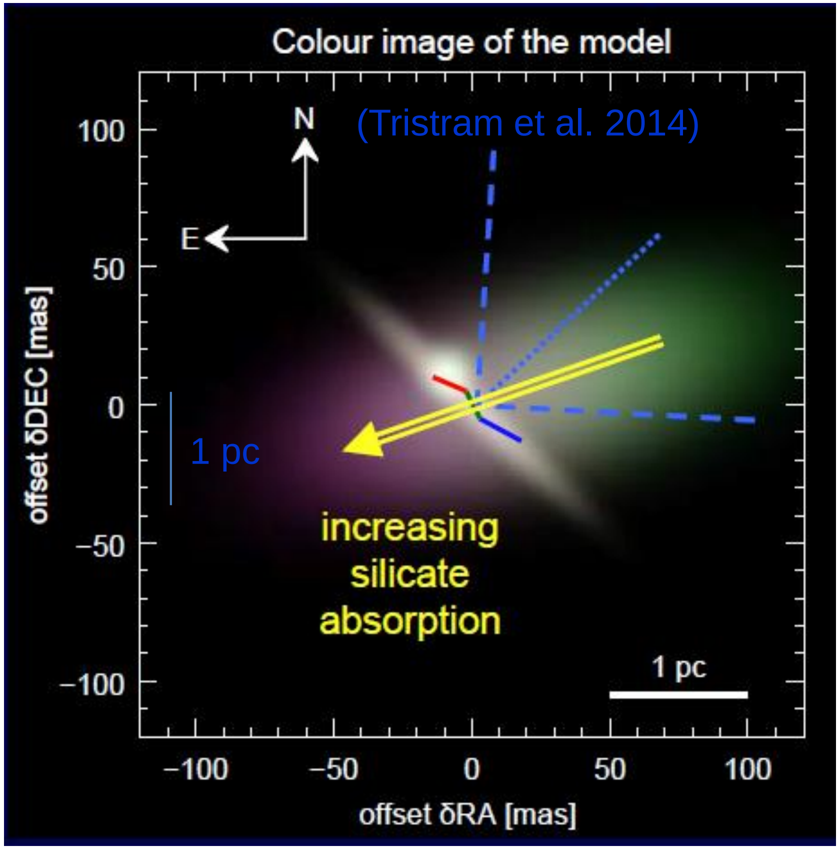


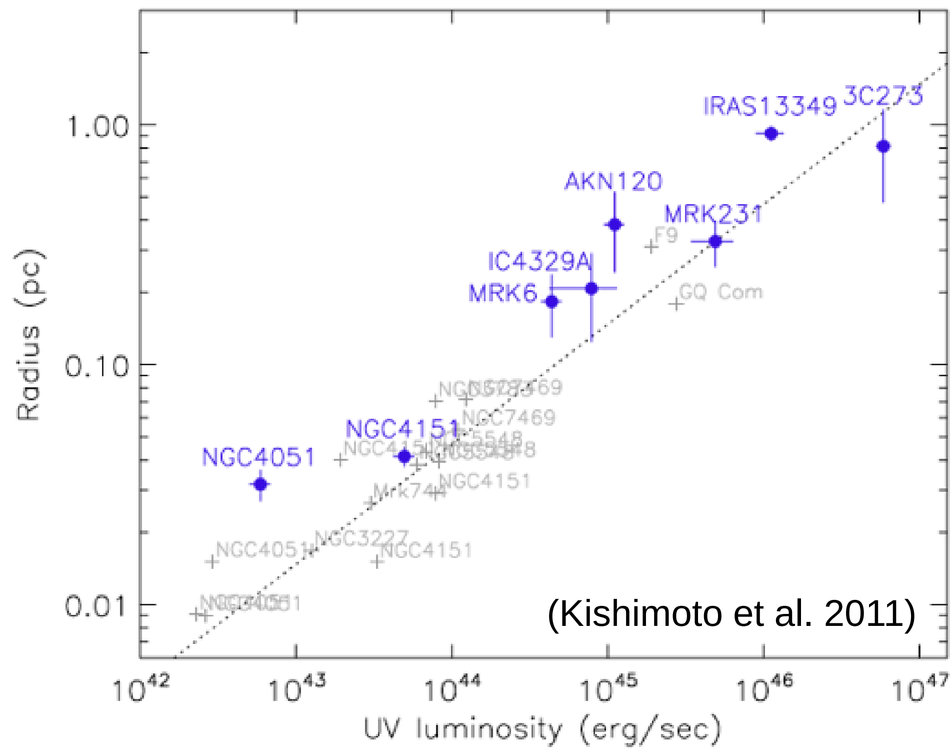
- NGC 1068, the prototypical Seyfert 2

(from K. Tristram's presentation lib.)

Support for unification: direct detection of tori

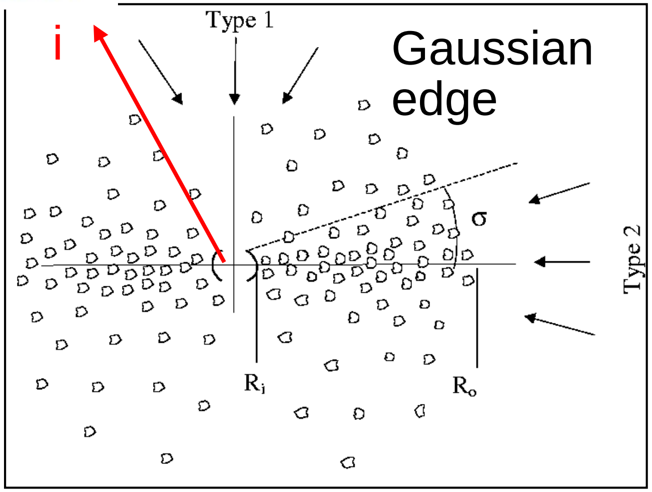
Circinus





- NGC1068 & Circinus first objects to get interferometric MIR imaging, now samples of few x 10s
- Inner radius of torus scales with $L^{1/2}$ (as expected from dust)
- brightness and colour temperatures ~ 1500 K (as expected from dust)
- Sizes in accordance clumpy tori

Clumpy tori of Nenkova et al. (2008)



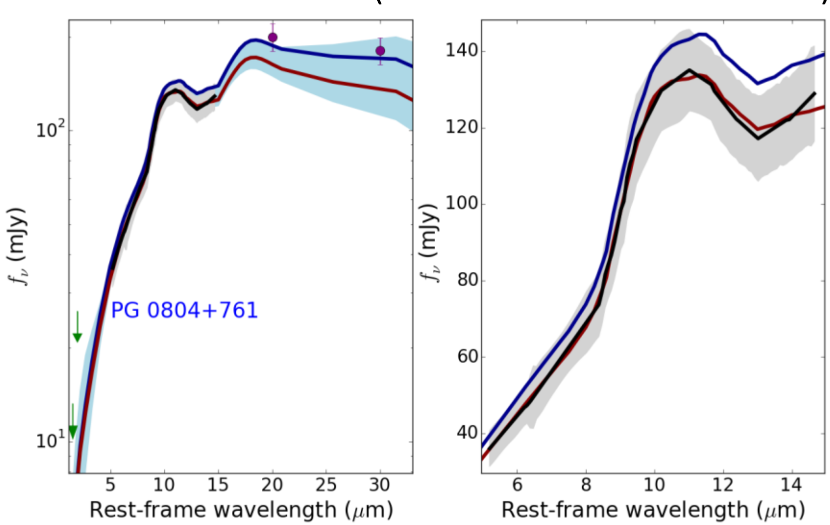
Successful modeling

- sub-Kepler rotating geometrically thick accretion flows dM/dt ~ 10 $M_\odot$/yr
- quasi-stable clouds of M~50 $M_\odot$, N~10^4 clouds
- optically thick individually

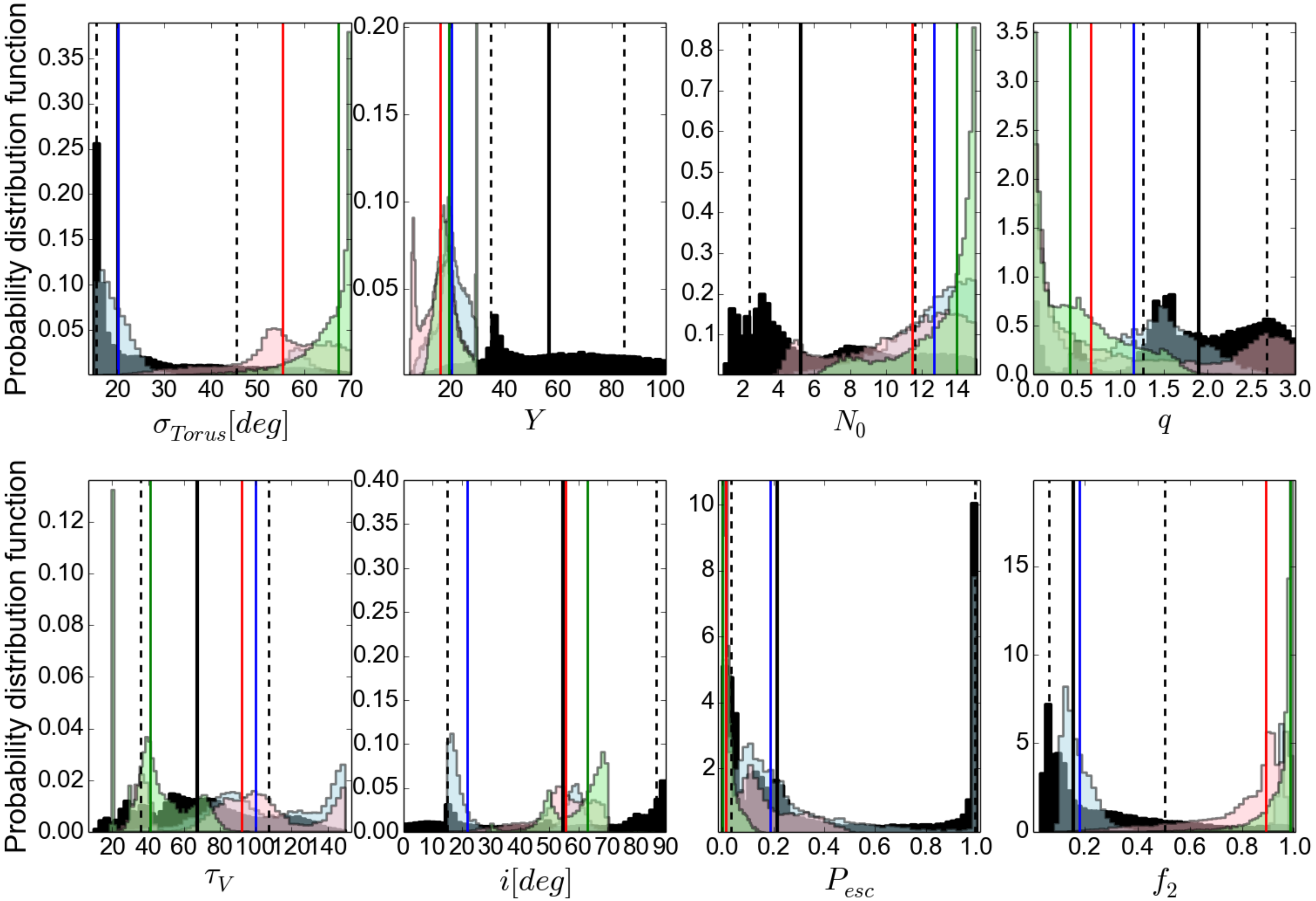
Viewing angle: i
Size of the torus: Y=Ro/Ri, Ro is the outer radius
Width of the angular distribution of clouds: σ
Optical depth of the clouds: τ_V
Distribution of clouds: q, r^q
Number of clouds along the equator: N_0

Clumpliness implies that type 1/type 2 is a probabilistic effect! Modelling the MIR light shows differences in the intrinsic parameters.

(Martínez-Paredes et al. 2016)



The tori of QSOs are different from those of Sy1/2s
And also between hidden and unhidden BL Sy2s



(Ichikawa et al. 2015, Martínez-Paredes et al. 2017)

Problems for unification: polarization levels

• The continuum is seen in direct light, while the broad lines are just seen in polarized light for Sy 2s

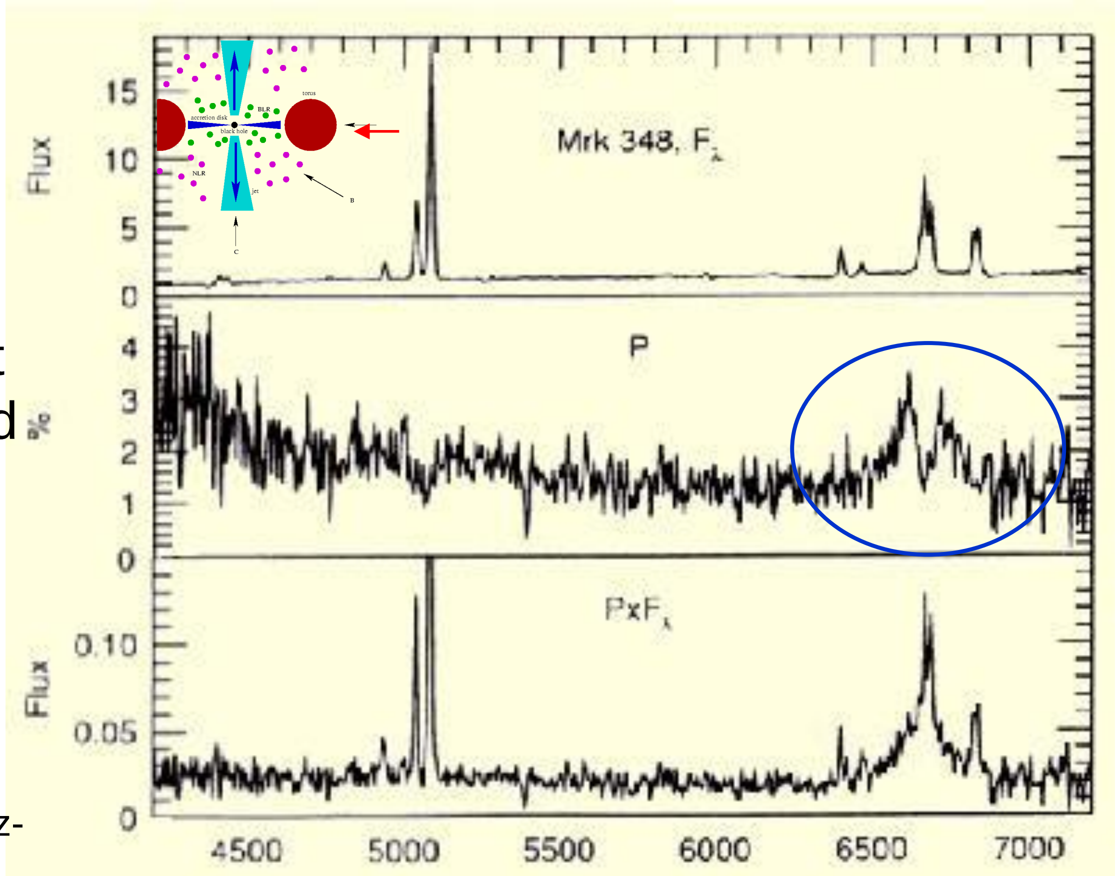
• The continuum is polarized at a lower level than the broad lines in most Sy 2s (Goodrich & Miller 1990, Miller & Goodrich 1990, Tran 1995) .

• The UV slopes of Sy 1 and 2s are very similar (Kinney et al. 1991)

In order to fix the problem, a second featureless continuum FC2 (Tran 1995) is introduced:

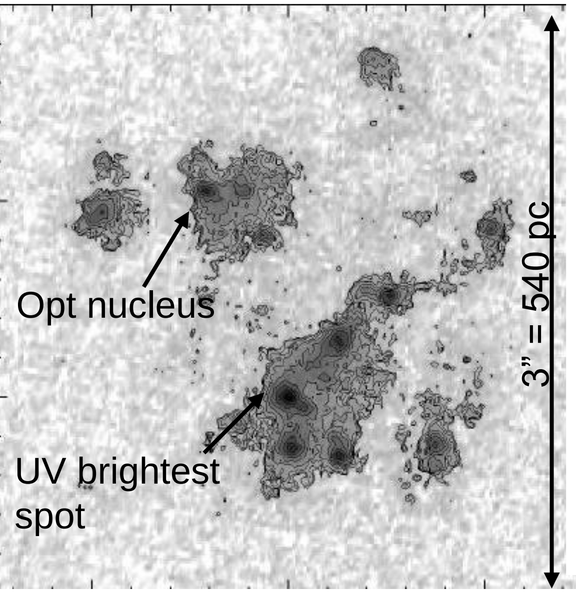
• free-free emission from the scattering electrons (Tran 1995), but this would also create very broad emission lines.

• atmospheres of hot stars in a starburst surrounding the torus (Goodrich 1989, Cid Fernandes & Terlevich 1995), which has been found in some UV bright Sy 2s (e.g. González-Delgado et al. 1999, Aretxaga et al. 2001)



(Miller & Goodrich 1990)

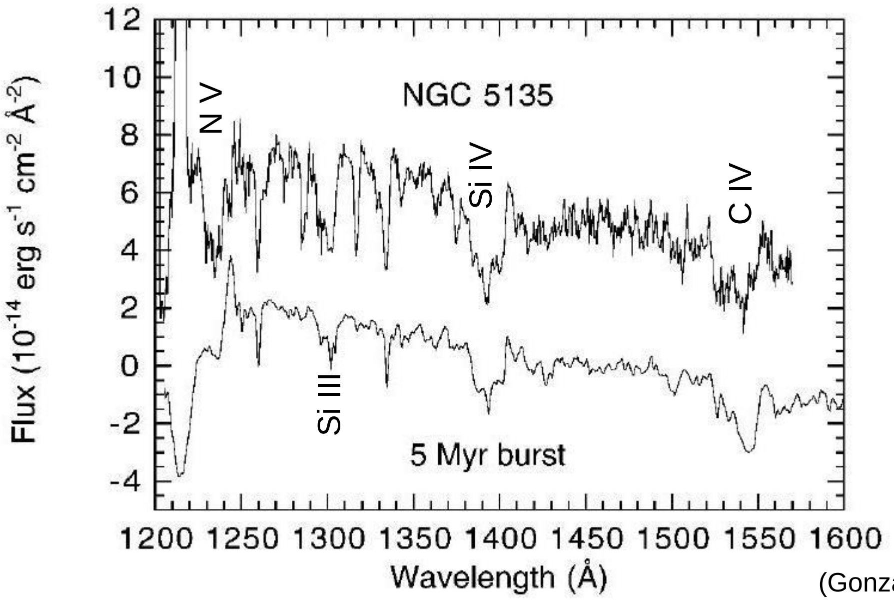
Stars in type-2 AGN: OB stars in Sy 2s

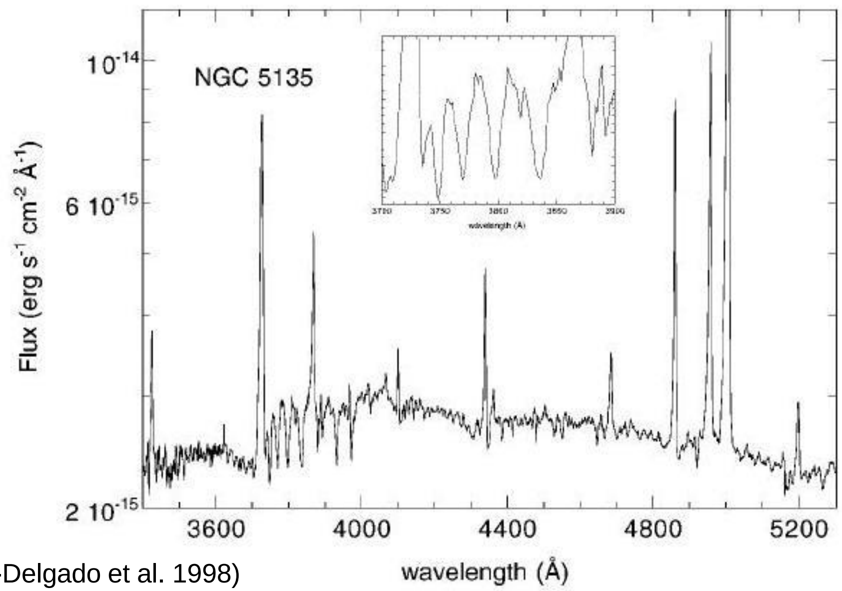


HST UV imaging and spectroscopy of 4 Sy 2s selected for being strong [O III] and 1.4GHz emitters (i.e. AGN properties) show resolved knots that are dominated by starburst features (Heckman et al. 1997, González-Delgado et al. 1998), with characteristic:

$L_{SB} \approx 10^{10} - 10^{11} L_\odot$
$M_{SB} \approx 5 \times 10^6 - 5 \times 10^7 M_\odot$
age ≈ 3 − 6 Myr
$Z \geq Z_\odot$
size ≈ 100 pc

as luminous as the hidden nucleus, which can be inferred from the N V emission lines.

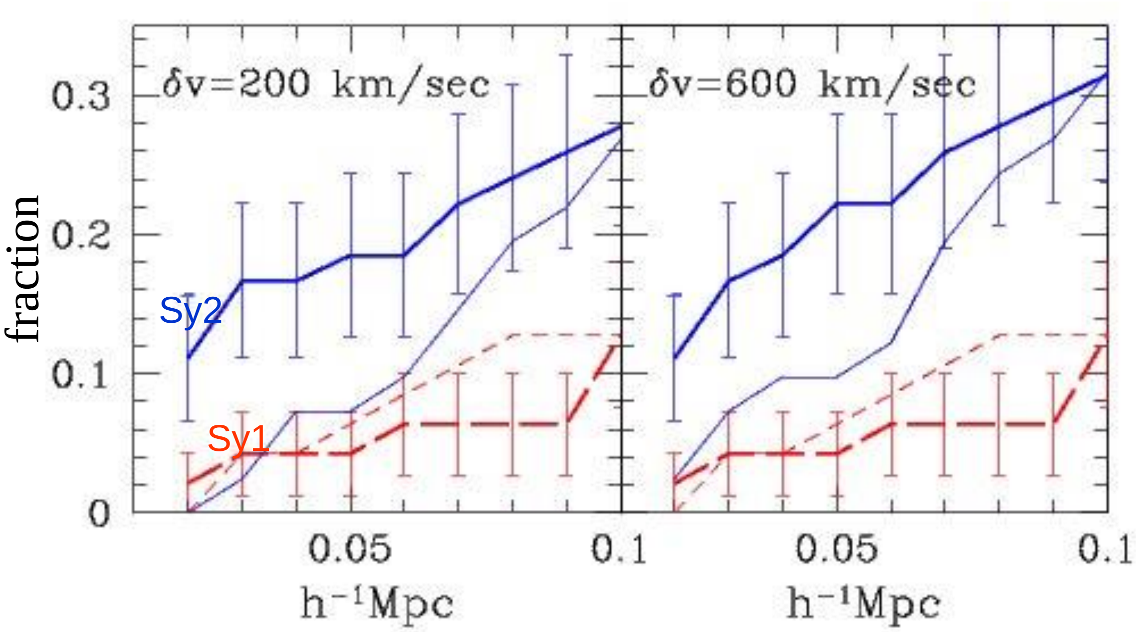




(González-Delgado et al. 1998)

Problems for unification: environments

In detailed statistical studies of companions, there is evidence for an excess of galaxies with diameters $D_C \geq$ 10kpc within the 100 kpc around Seyfert 2 galaxies, that is not present in the Seyfert 1s (Dultzin-Hacyan et al. 1999, Koulouridis et al. 2006).

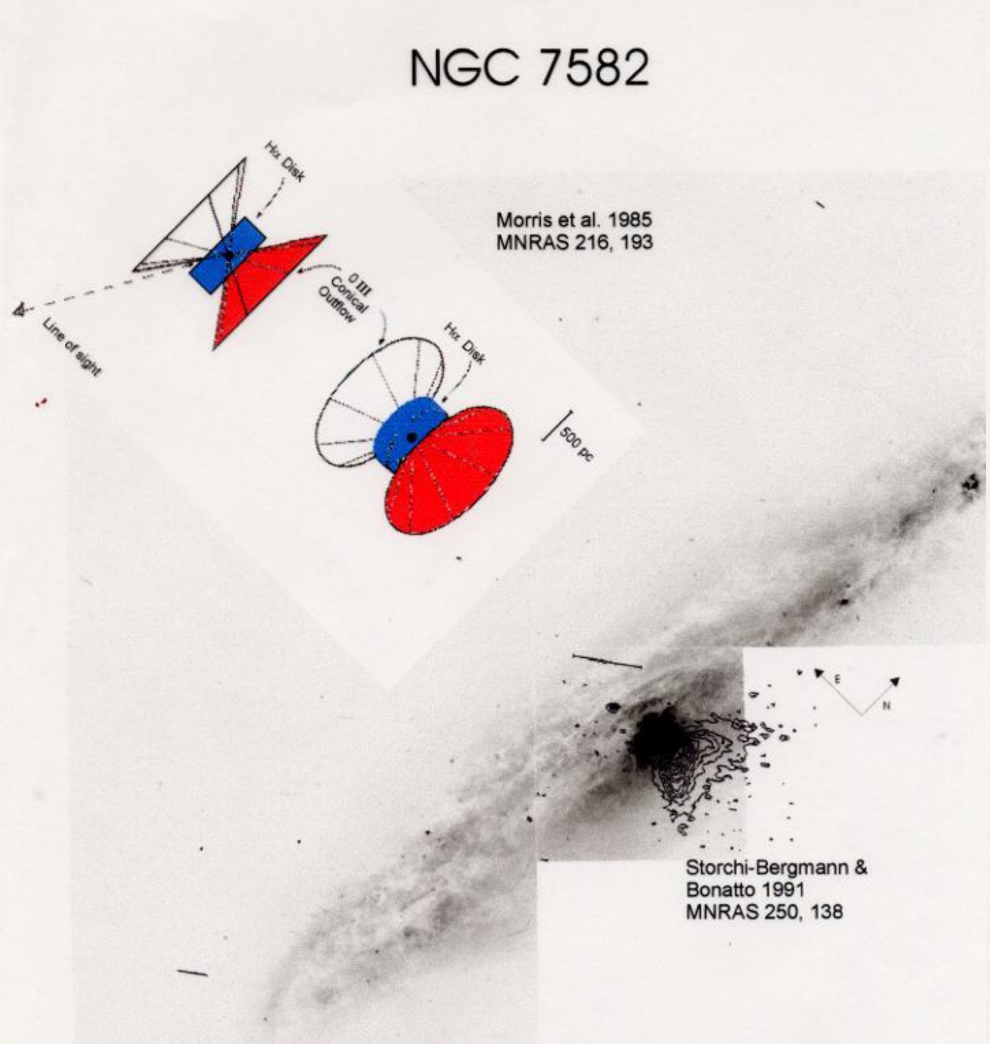


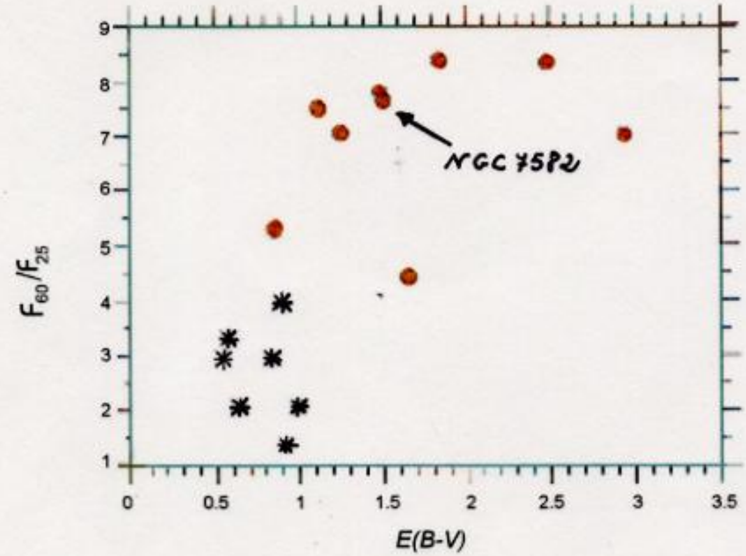
(Koulouridis et al. 2006)

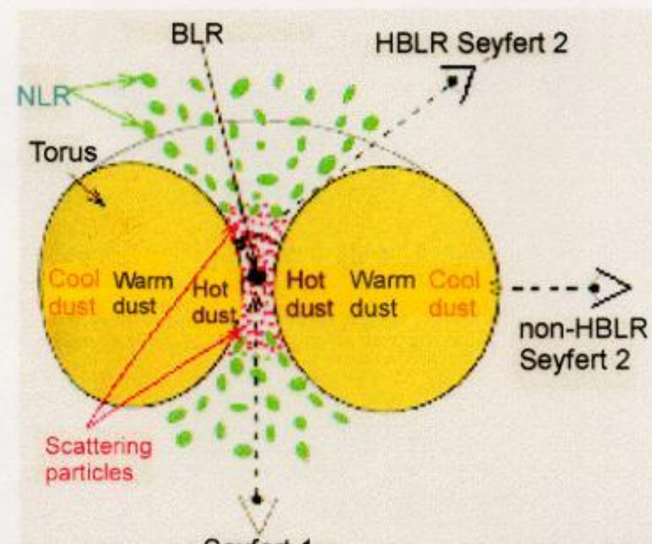
1/3 of Sy 2s have these close companions, not all.

They propose an evolutionary scenario where Sy 2s are obscured Sy 1s because they are suffering a close interaction with a giant galaxy that is bringing gas to the nucleus and obscures the BLR in a process that involves star formation near the nucleus, but hosts are also different.

Problems for unification: variability of Sy 2s



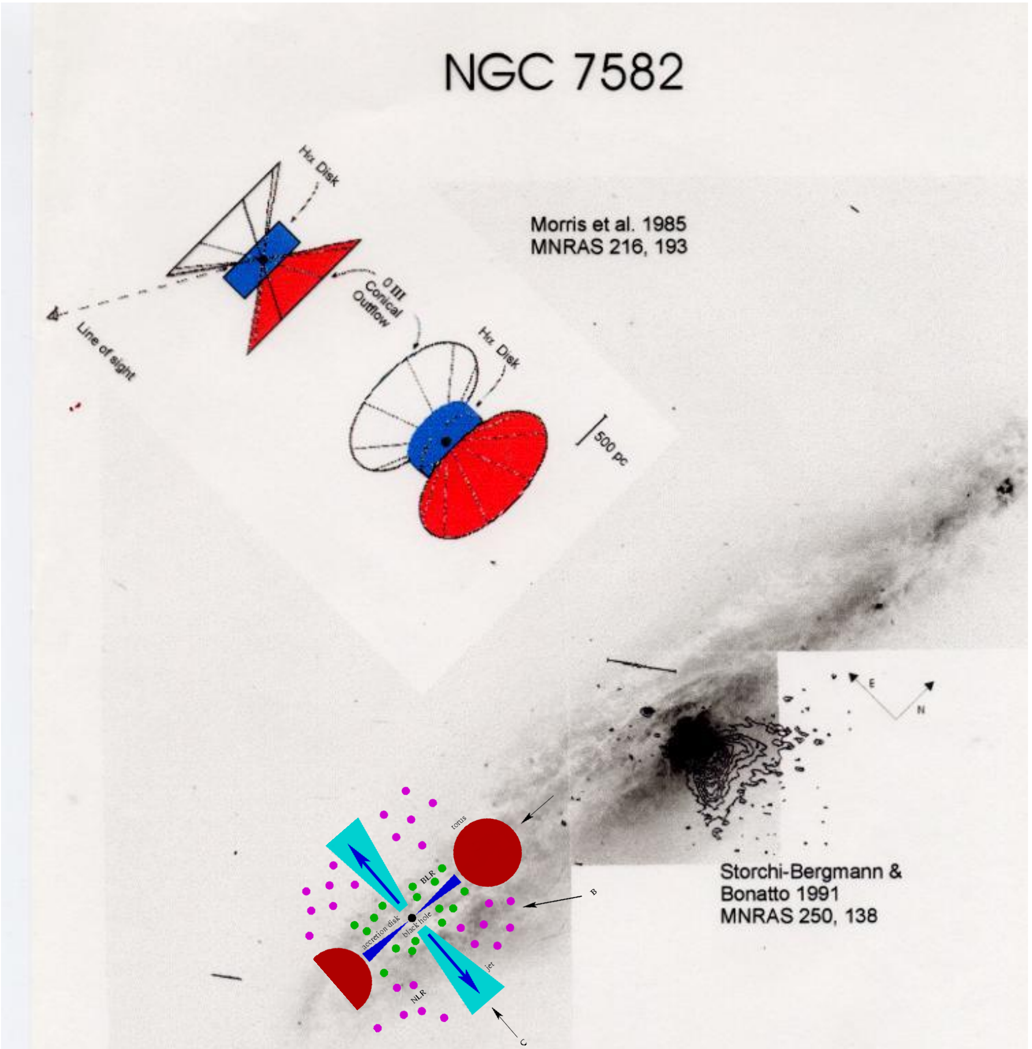


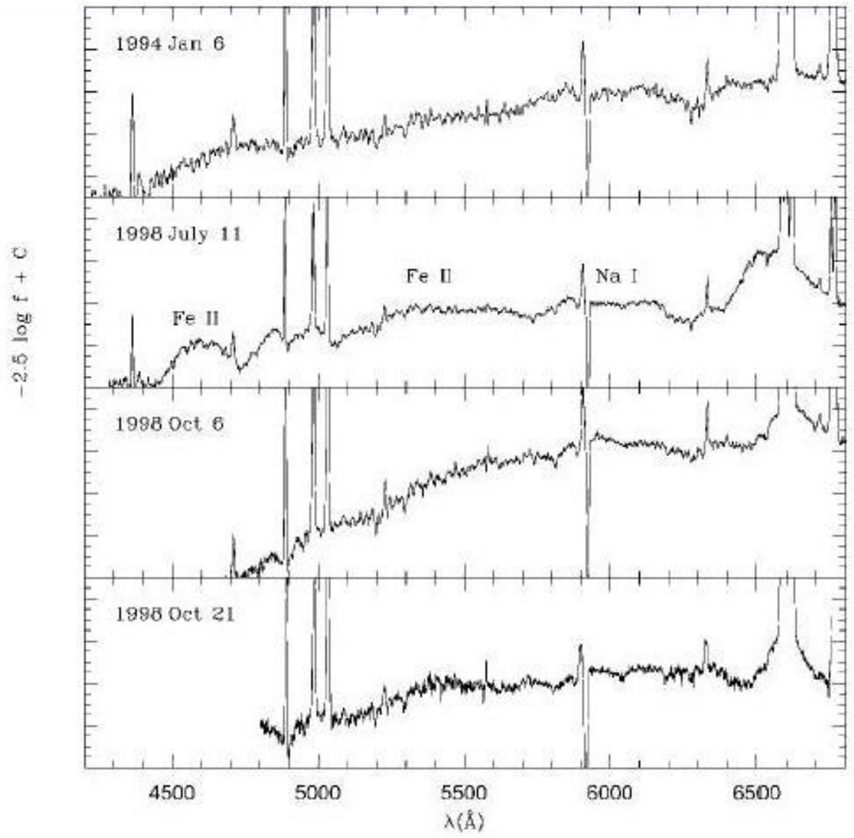


(Heisler, Stuart & Bailey 1997)

NGC 7582 was a prototype Sy 2, that fit all criteria to be a hidden Sy 1 seen edge on...

Problems for unification: variability of Sy 2





Starburst activity or hole in the torus? (Aretxaga et al. 1999)

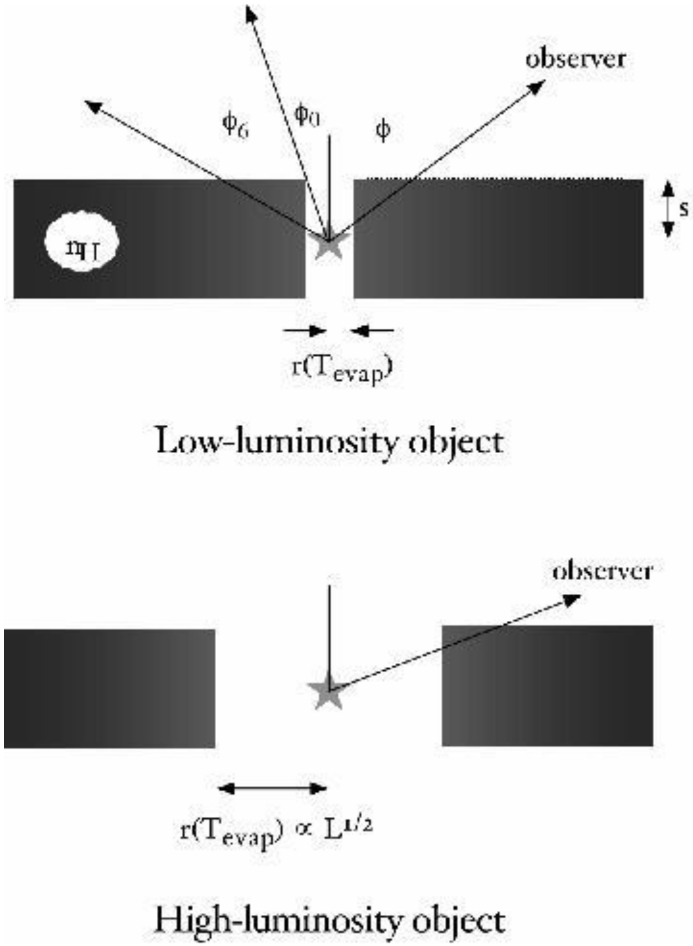
NGC 7582 was a prototype Sy 2, that fit all criteria to be a hidden Sy 1 seen edge on... until it became a true Sy 1!

Problems for unification: type-2 QSOs

While Sy 2s are ubiquitous in the nearby Universe, we don´t know of many narrow-line QSOs.

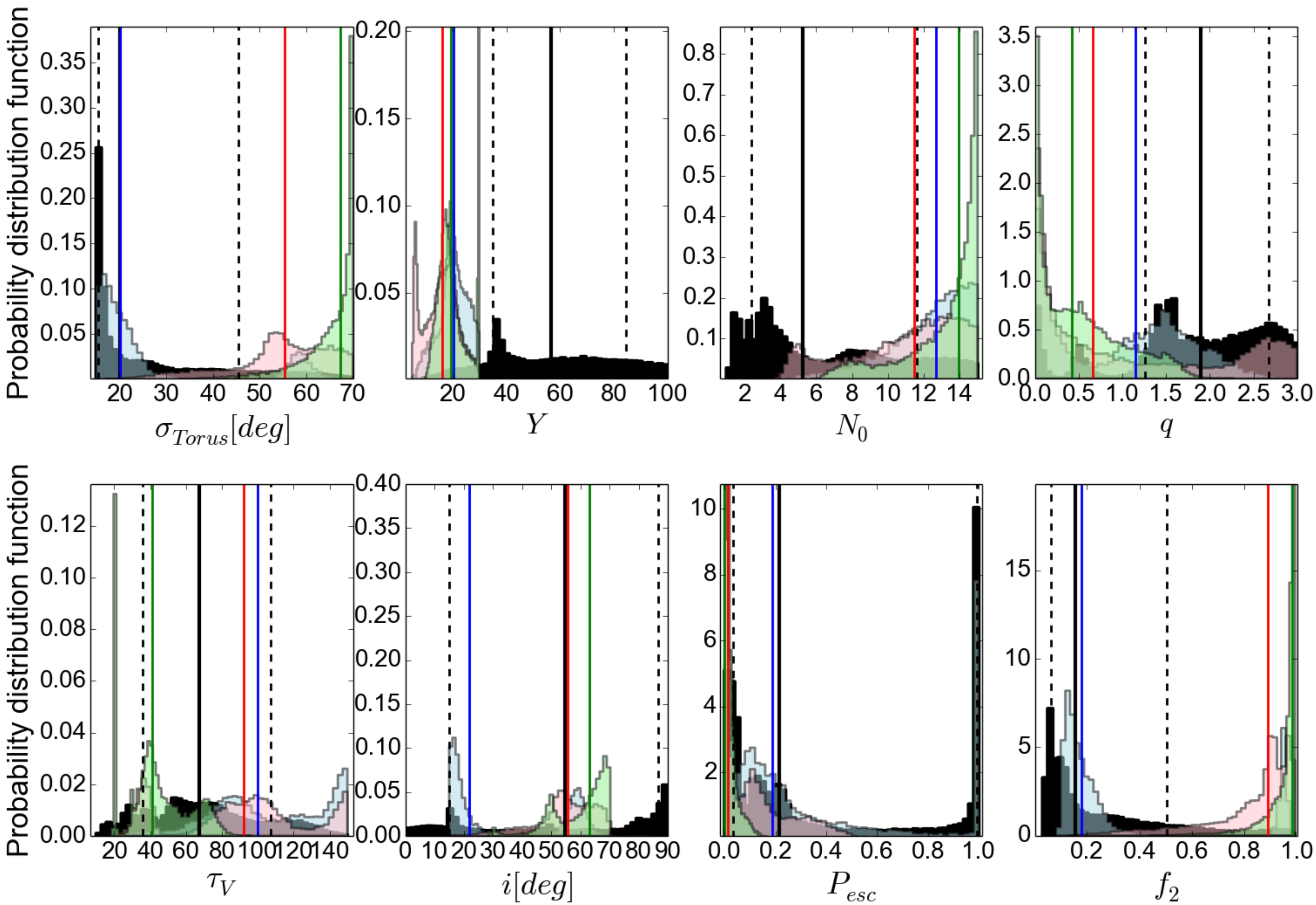
One possibility is that ULIRGs and sub-mm galaxies are related to the AGN phenomenon, but only ~10% of these show X-ray emission and it is not yet clear they have Sy2-equivalent properties (e.g. Ridway et al. 2007).

The absence of type-2 QSOs could also be explained by a recceeding torus model, where the luminous engine sublimates a dust ring which has increasingly larger radius with the luminosity of the central AGN (Hill et al. 1995). The central sublimated area thus offers less lines of sight to obscure the BLR.



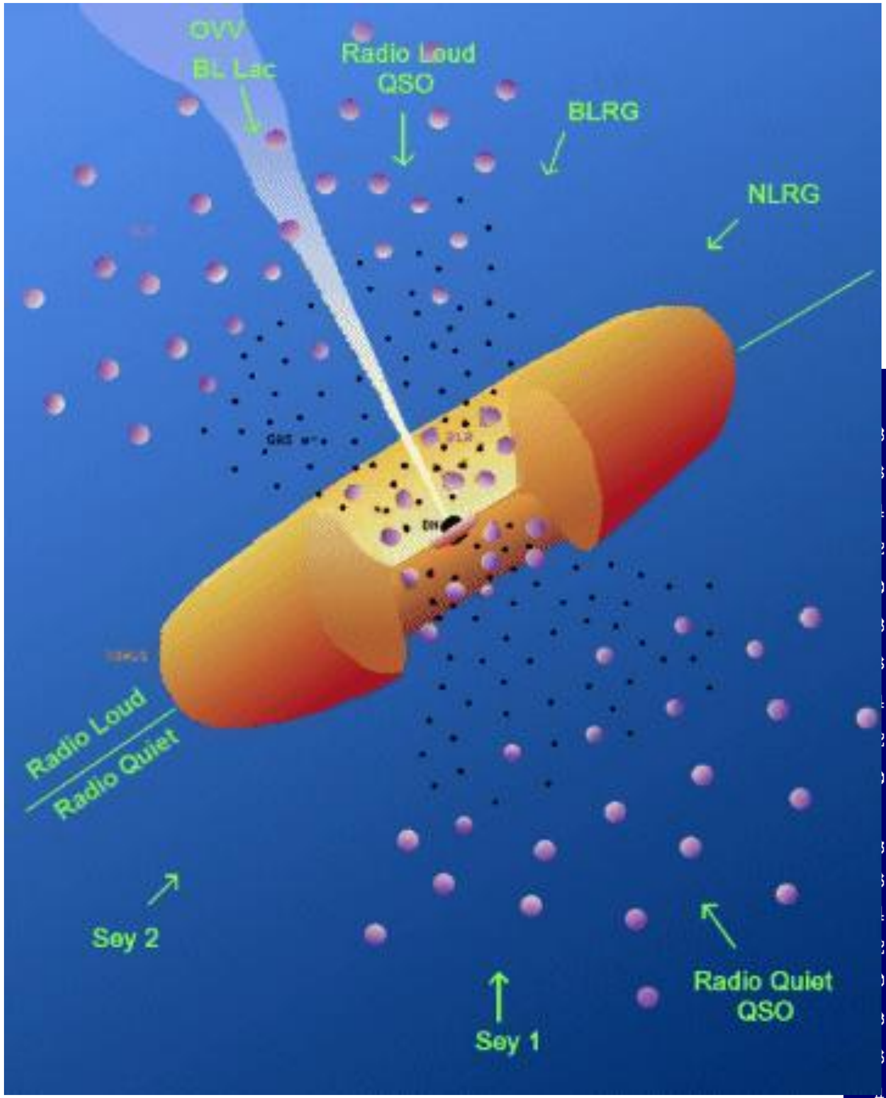
(Hill et al 1995)

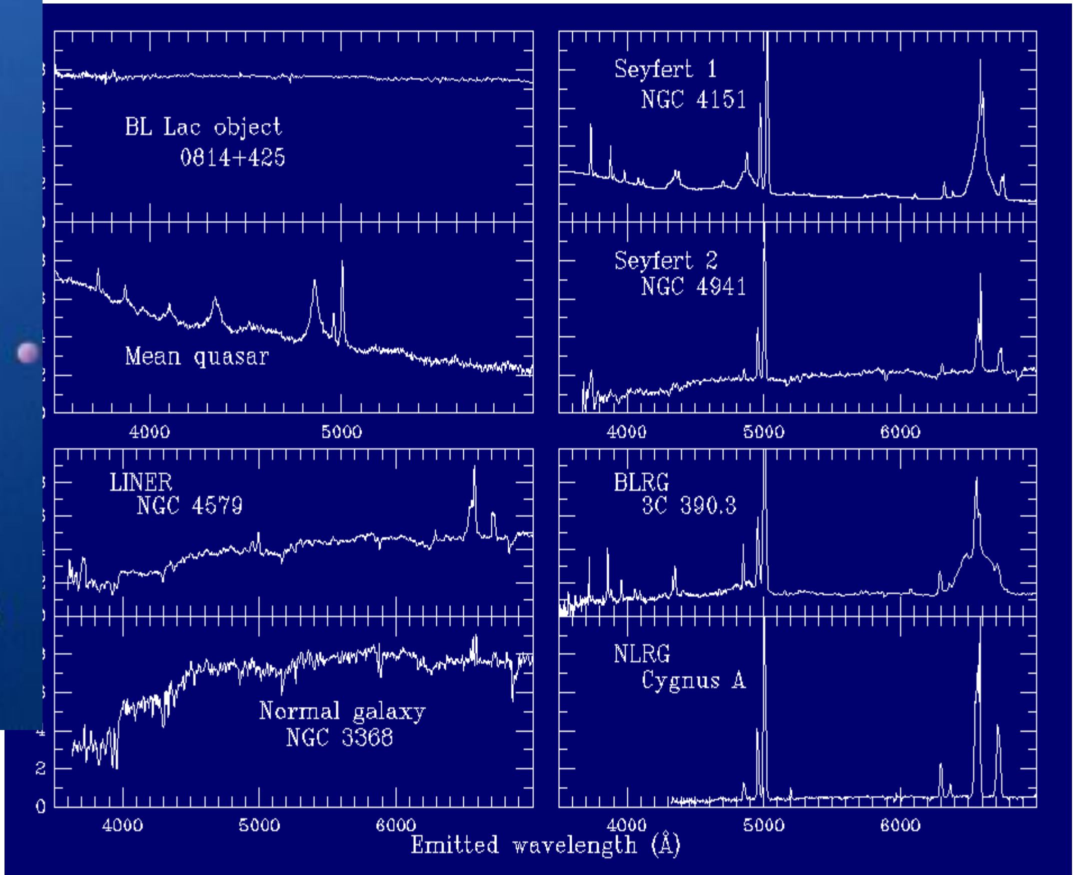
The tori of QSOs are different from those of Sy1/2s



(Martínez-Paredes et al. 2016)

Unification: a useful classifying idea at least!





Active Galactic Nuclei

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• "The Physics and Evolution of AGN", H. Netzer, 2013, CUP
• "Advanced Lectures on the Starburst−AGN Connection", 2001, Eds. I. Aretxaga, D. Kunth & R. Mújica, Word Scientific. Includes reviews by B.P. Peterson, R. Goodrich, H. Netzer, S. Collin, F. Combes, R.J. Terlevich & B.J. Boyle.
• the papers can be found in ADS or arXiv lists
• a compilation of useful reviews can be found at Level 5 @ IPAC

• A recent unification review paper: Netzer H., 2015, ARAA, 53, 365
Revisiting the Unification Model of Active Galactic Nuclei