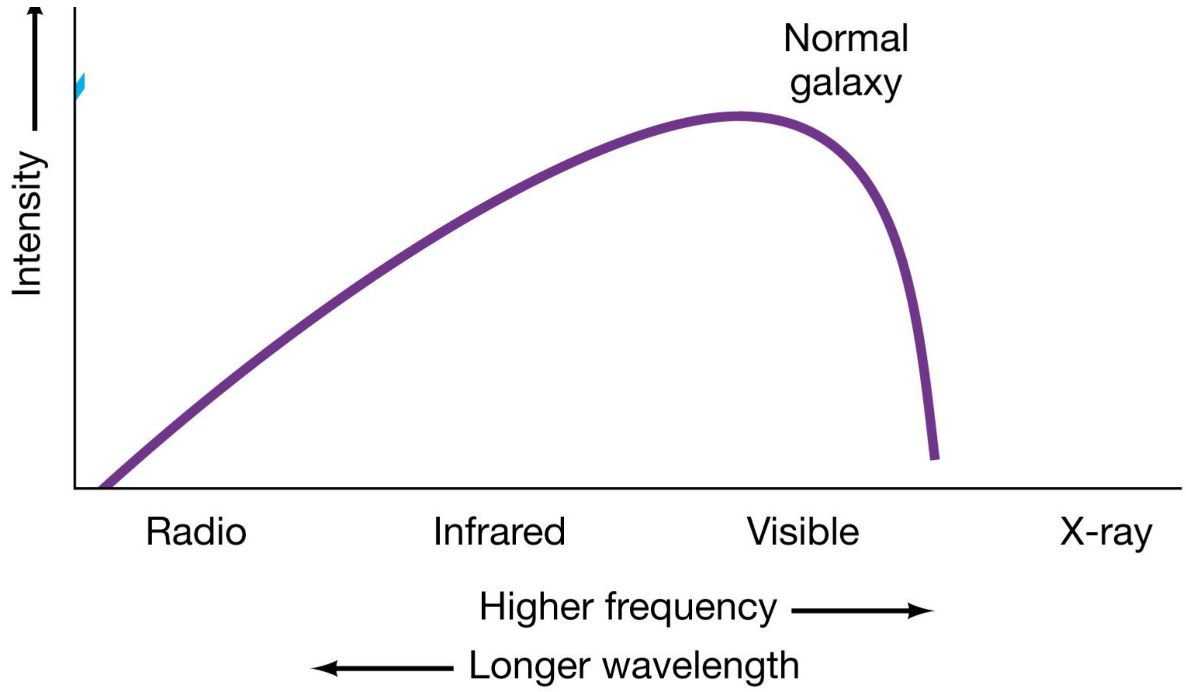
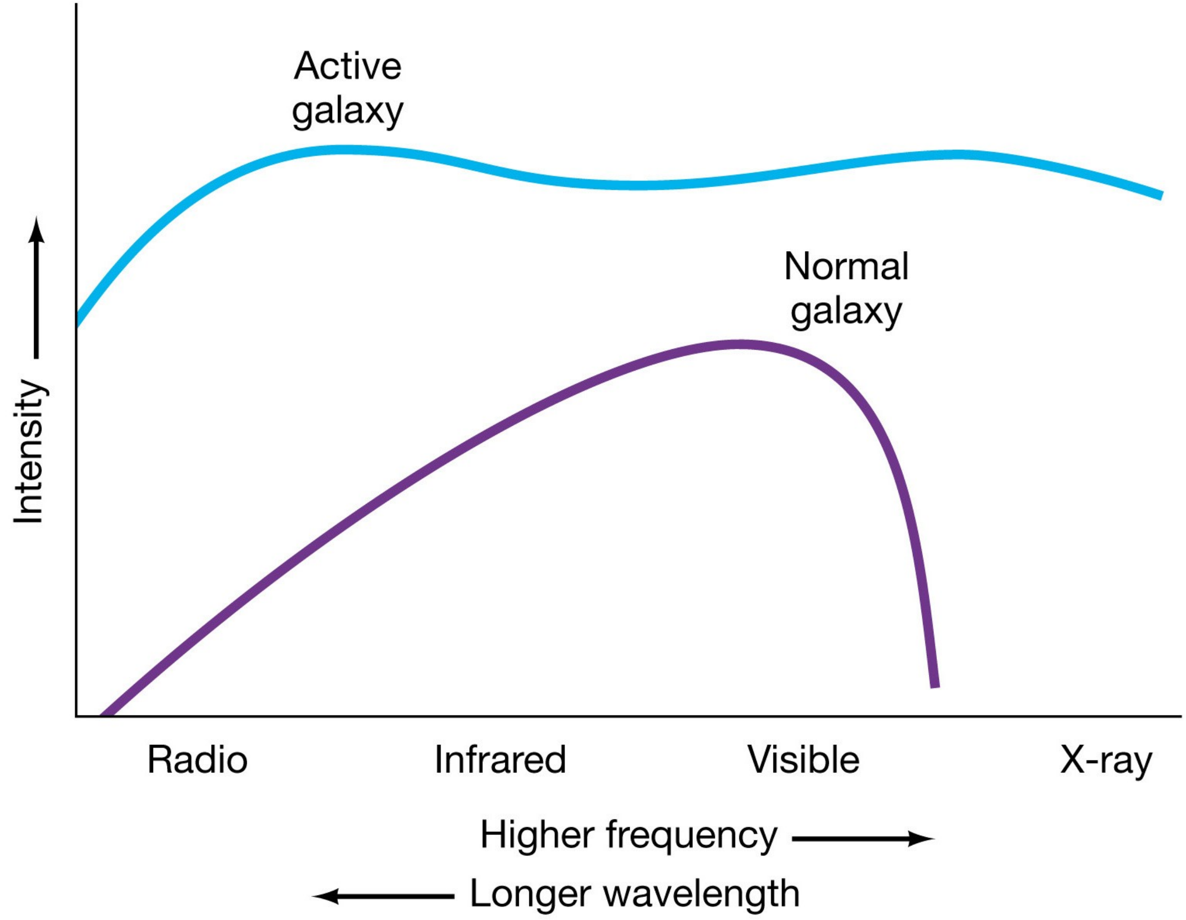
Active Galaxies

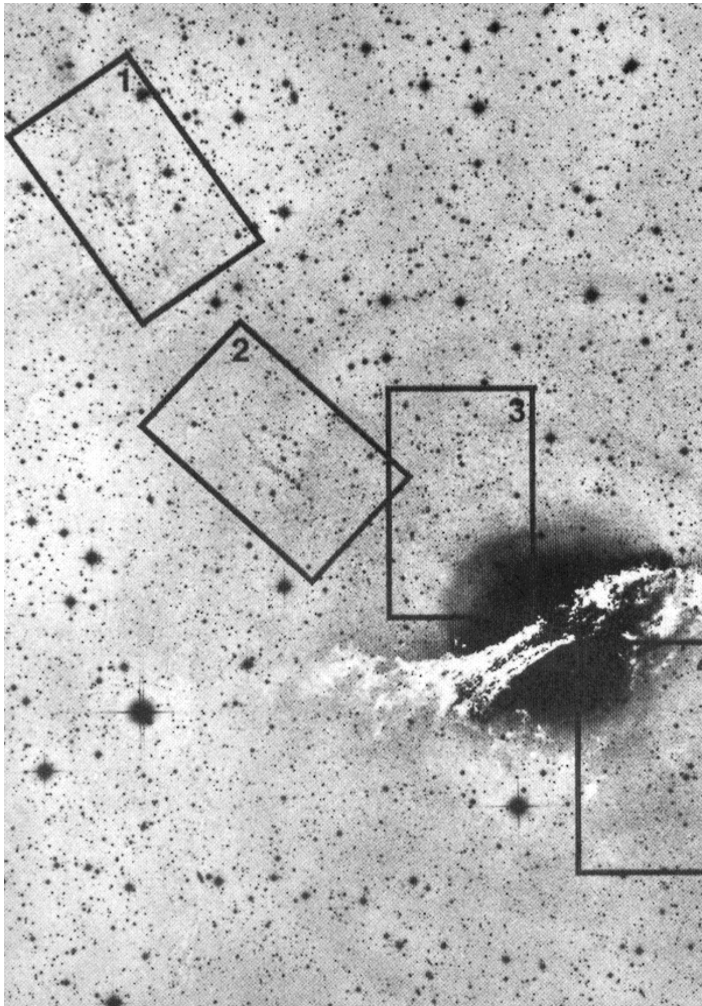
The light from most galaxies is just the sum of light from all of the stars within it, so like starlight, a galaxy's light is brightest at optical wavelengths and fainter at shorter and longer wavelengths.



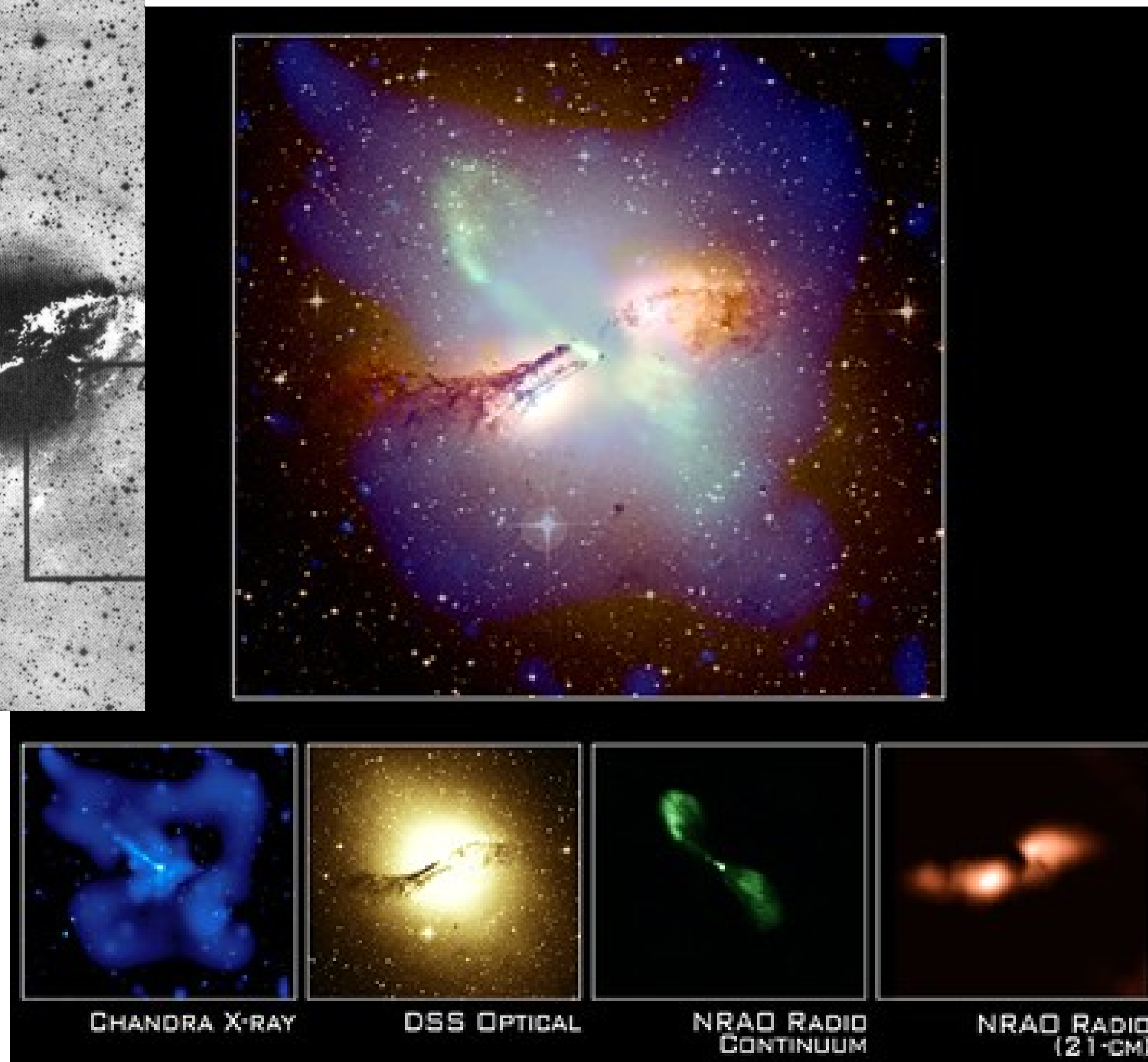
Active Galaxies

But a small fraction of galaxies are different; they are much brighter and produce more long- and short- wavelength emission. They are called active galaxies.

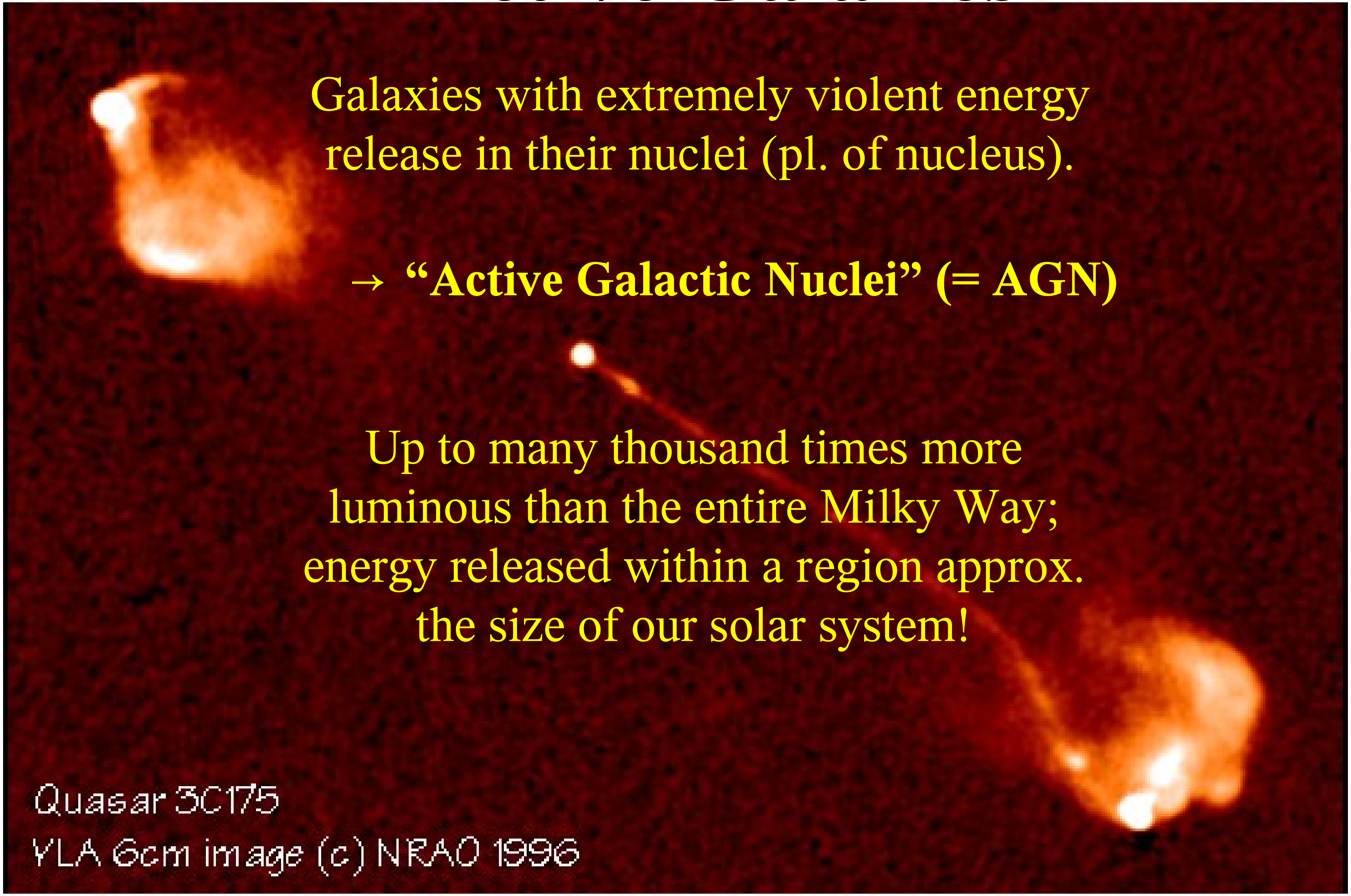




Centaurus A: example of emission in many different wavebands



Active Galaxies



Galaxies with extremely violent energy release in their nuclei (pl. of nucleus).

→ **"Active Galactic Nuclei" (= AGN)**

Up to many thousand times more luminous than the entire Milky Way; energy released within a region approx. the size of our solar system!

What are the Active Galactic Nuclei

Difficult to have an unique definition.

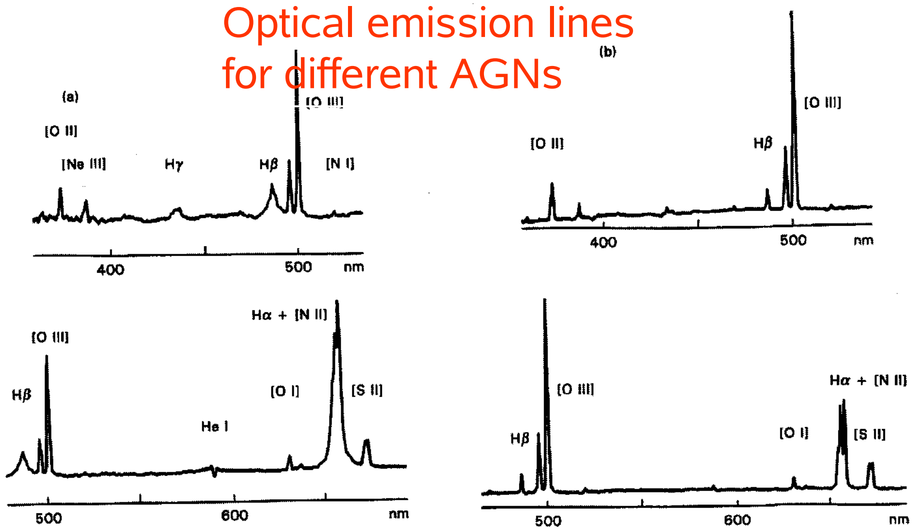
huge amount of energy (up to 10^4 times more than a normal galaxy)
emitted from a tiny region (<1 pc^3)

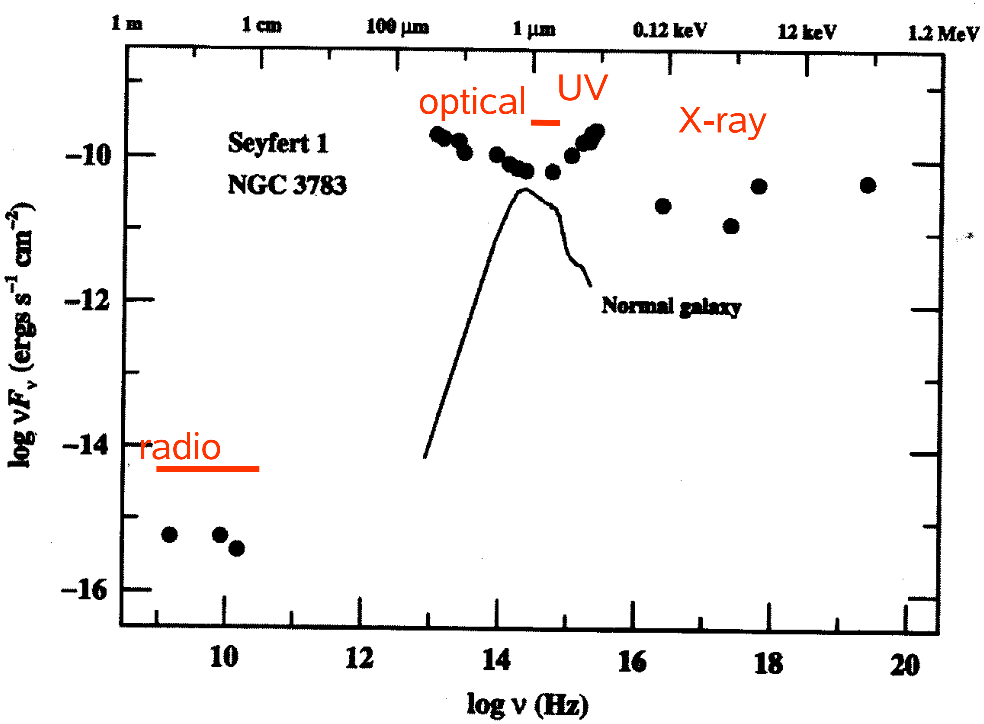
The high energy released by an AGN is believed to originate from a supermassive black-hole (${10^6}$ to 10^9 M_{sun} in <<1pc)

Some characteristics

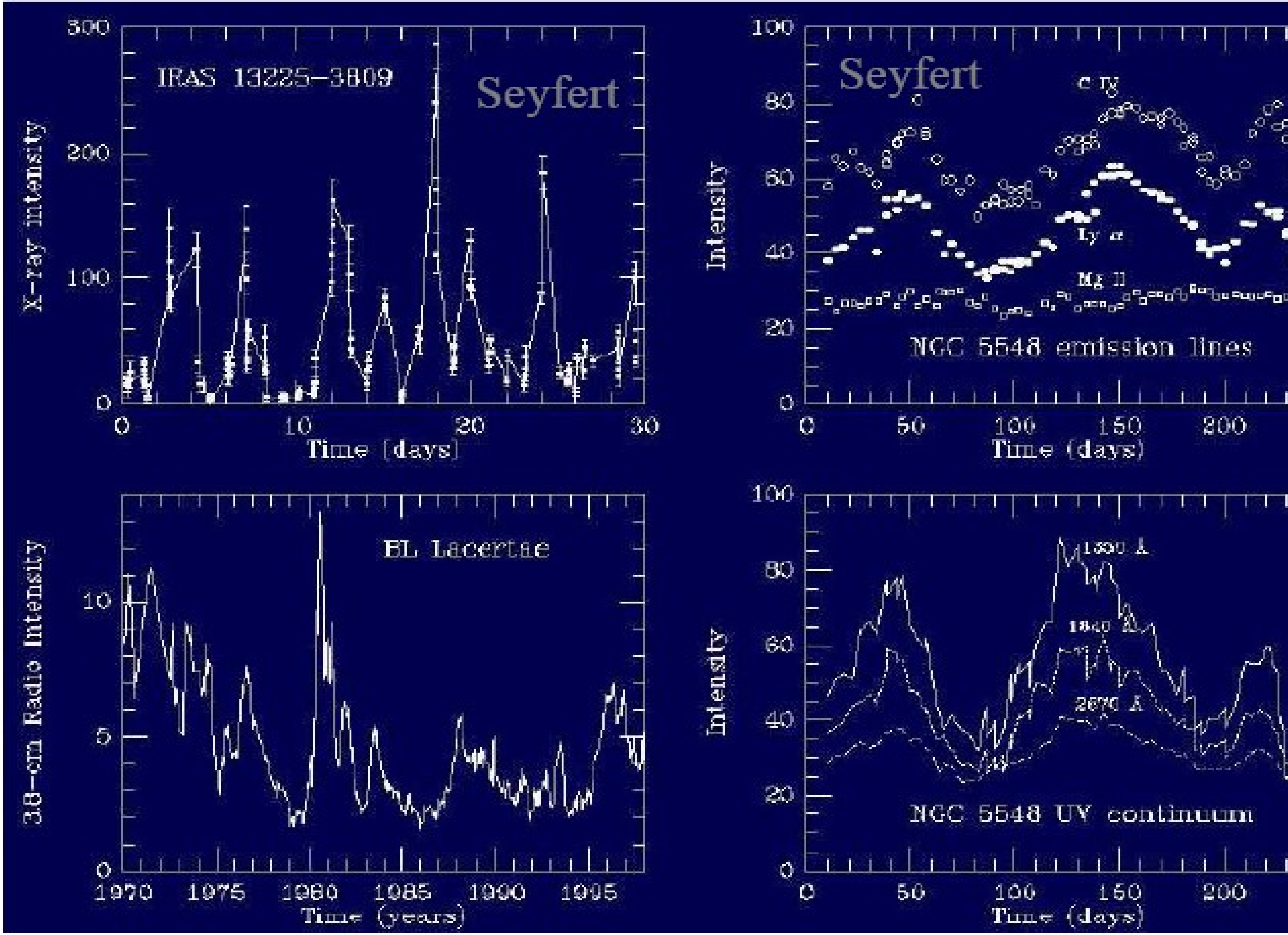
- ✓ High Luminosity
- ✓ continuum emission across ~13 order of magnitude in frequency
- ✓ emission lines

Optical emission lines for different AGNs





Comparison of the continuum emission from a Seyfert galaxy and a normal galaxy



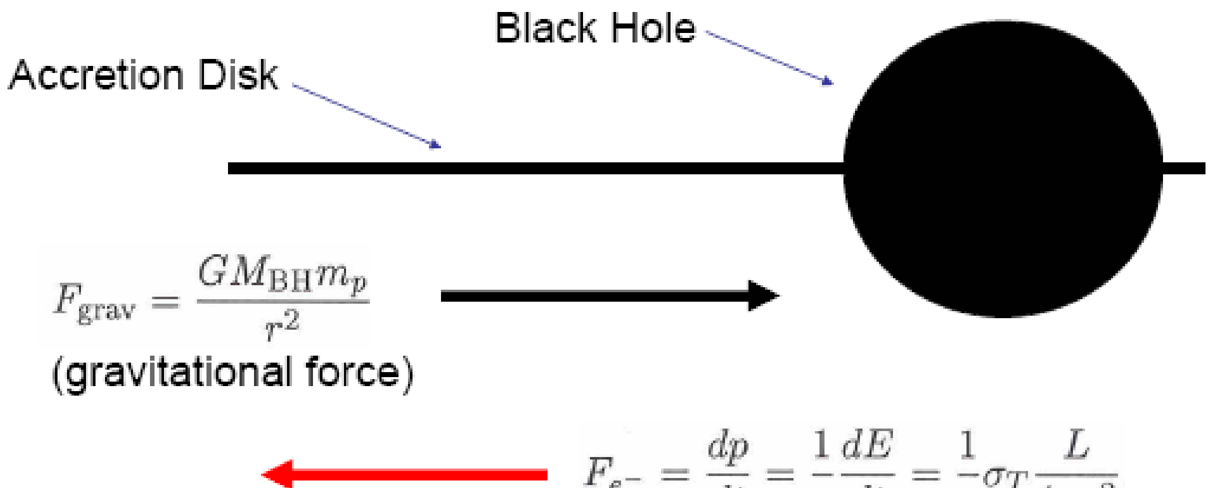
Lightcurves Variability

Observables to classify an object as AGN

Very small angular size	Wavelength/resolution dependent Radio VLBI, HST cores	
High luminosity		
Broad-band continuum	Composite spectrum for AGNs →	
Strong emission lines		
Variability		
Polarization		
Radio emission	Powerful way to detect AGNs, BUT only a minority are strong radio sources and the radio accounts for at m 1% of the total energy output	

Type	Normal Galaxy	Radio Galaxy	Seyfert Galaxy	Quasar	Blazar
Examples	Milky Way	M87, Cygnus A	NGC4151	3C273	BL Lac, 3C279
Galaxy Type	Spiral	Elliptical, irregular	Spiral	Irregular	Elliptical?
Luminosity (Solar units)	$< 10^4$ Central region	$10^6 - 10^8$	$10^8 - 10^{11}$	$10^{11} - 10^{14}$	$10^{11} - 10^{14}$
Central Mass (Solar units)	2.6×10^6	3×10^9	$10^6 - 10^9$	$10^6 - 10^9$	$10^6 - 10^9$
Radio	Faint	Central object + jets +lobes	Only 5% are radio bright	Only 5% are radio bright	Bright, rapidly variable
Optical/IR	Totally obscured	Pop II stars continuum	Broad Emission lines	Broad Emission lines	Spectral line weak or absent
X-rays	Faint	Bright	Bright	Bright	Bright
Gamma Rays	Faint	Faint	Moderate	Bright	Bright
Variability timescale	Unknown	Months - years	Hours – months	Weeks – years	Hours - years

Calculation of Black Hole Mass from the Eddingtion Luminosity



$$F_{\rm grav} = \frac{GM_{\rm BH}m_p}{r^2}$$

(gravitational force)

$$F_{e^-} = \frac{dp}{dt} = \frac{1}{c}\frac{dE}{dt} = \frac{1}{c}\sigma_T\frac{L}{4\pi r^2}$$

(radiative force)

$$F_{rad} < F_{grav}$$

$$\sigma_T \frac{L}{4\pi \ r^2 c} < \frac{GM_\bullet m_p}{r^2}$$

$$L < L_{edd} = \frac{4\pi c G M_\bullet m_p}{\sigma_T} \approx 1.3\times10^{38}\left(\frac{M_\bullet}{M_{sol}}\right) erg/s$$

There are **many different types** of AGNs, depending which characteristic is dominant

- ✓ *radio loud vs radio quiet*
- ✓ *strong optical lines → narrow vs broad*
- ✓ *core dominance*
- ✓ *weird & extremely variable objects*

What kinds of AGN's are out there?

Seyfert Galaxies
- Type 1
- Type 2

Quasars

Blazars
- BL Lacertaes (BL Lacs)
- Optically Violently Variable Quasars (OVV's)

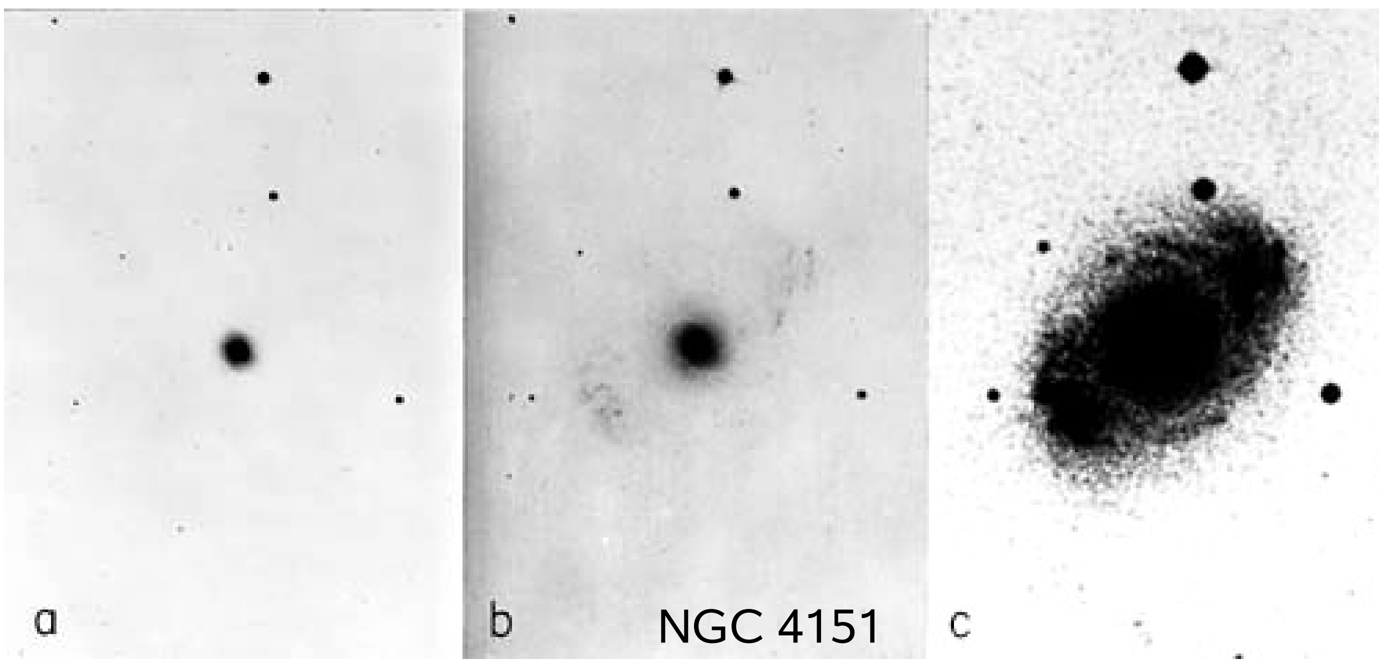
Radio Galaxies
- Narrow Line
- Broad Line

Seyfert galaxies were first identified by Carl Seyfert in 1943.

He defined this class based on observational characteristics:

Almost all the luminosity comes from a **small (unresolved) region** at the center of the galaxy – the galactic nucleus.

Nuclei have $M_B > -23$ (arbitrary dividing line between quasars/seyferts)

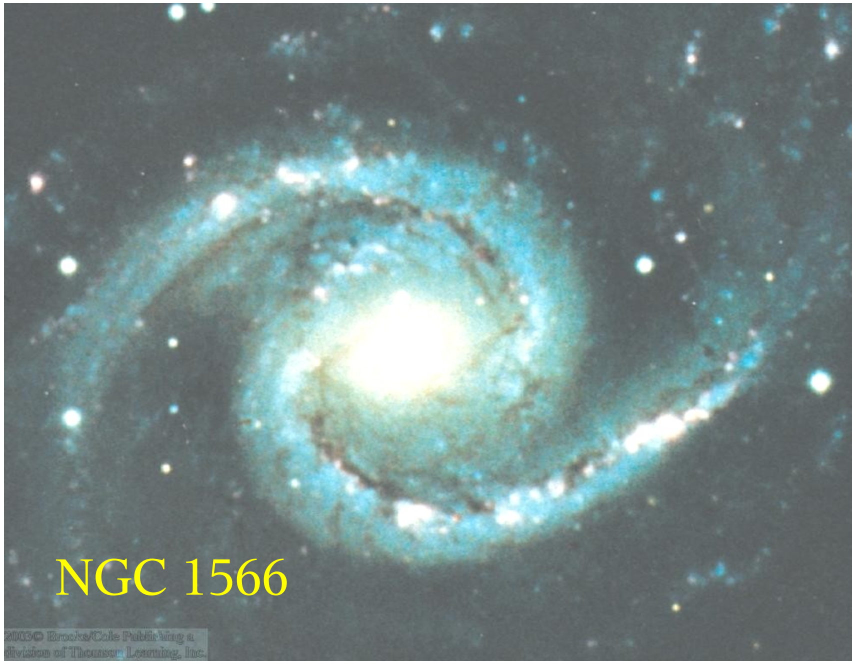


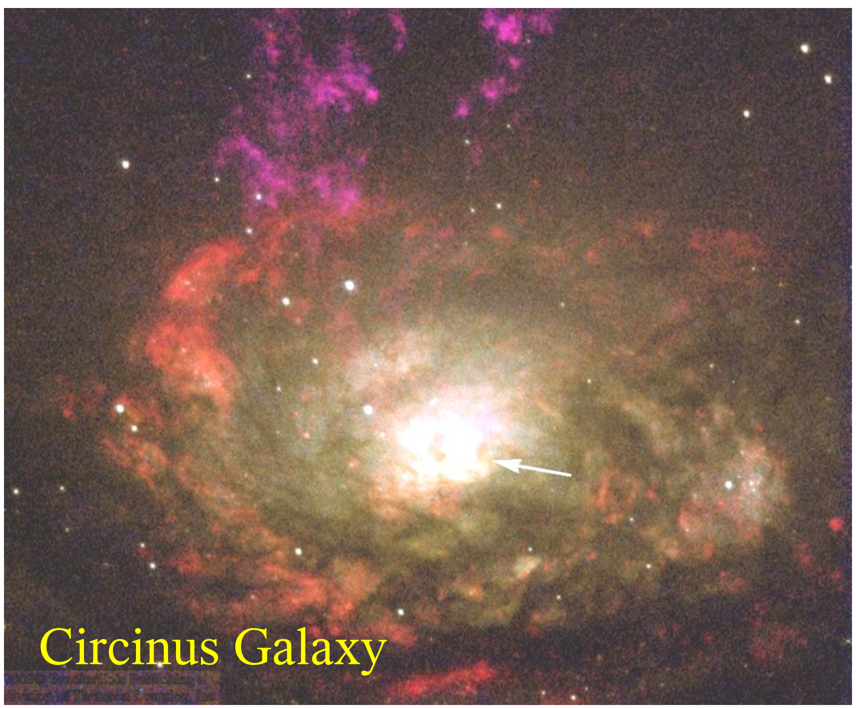
short exposure

long exposure

10000 times brighter than our galactic nucleus!

Seyfert Galaxies





Unusual spiral galaxies:

- Very bright cores
- Emission line spectra.
- Variability: ~ 50 % in a few months

Most likely power source:

Accretion onto a supermassive black hole ($\sim 10^7 - 10^8\ M_{sun}$)

– **Seyfert Galaxies are broken into two sub classes, Type 1 and Type 2, based on the emission lines appearing in their spectra.**

Type 1:

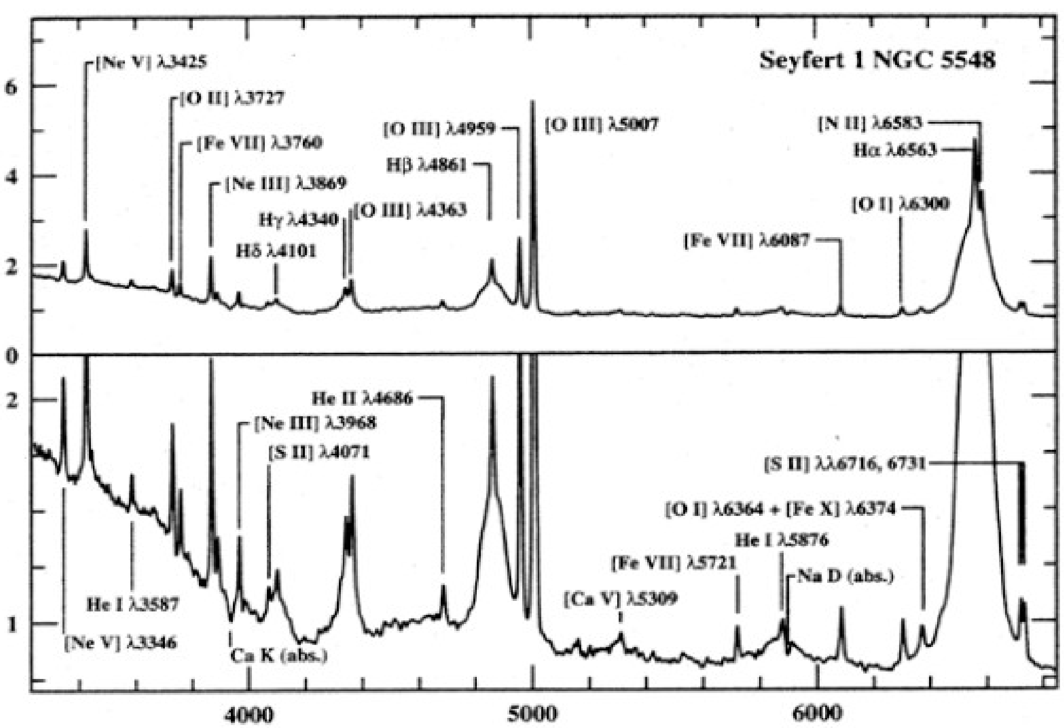
These have both narrow line <u>and</u> broad line peaks in their spectrum.

Emission Lines :

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

X-axis: Wavelength (Angstroms) from the AGN's frame of reference.

Y-axis: Intensity of flux (no units)



Broad-Line region (BLR)

- Above the accretion disk
- heavy ionized clouds
  - Become noticable with very broad lines

Movement 1.000-10.000 km/s

Narrow-Line region (NLR)

- Beyond the BLR
- heavy ionized clouds

-Emissionlines in the spectrum less intensely dispread

Slower movement (ca. 100 km/s)

Broad emission line : v=10000 km/sec

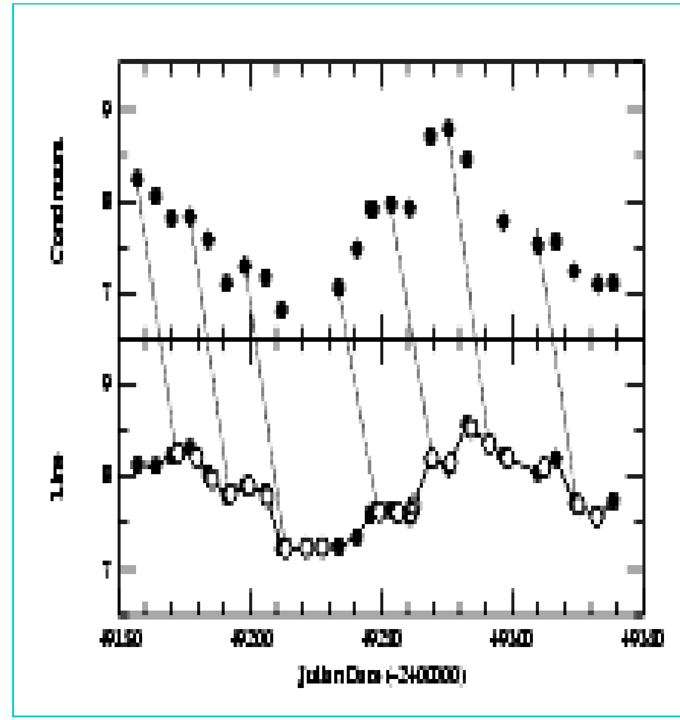
$$v_{rot} \approx \sqrt{\frac{GM_\bullet}{r}} = \frac{c}{\sqrt{2}}\left(\frac{r}{r_s}\right)^{-1/2}$$

für v~c/30

$$\Rightarrow \left(\frac{r}{r_s}\right) \approx 500$$

Reverberation mapping from optical variability

Peterson (1997)



Broad emission line region: 0.01 - 1pc; Illuminated by the AGN's photoionizing continuum radiation and reprocess it into emission lines

R_{BLR} estimated by the time delay that corresponds to the light travel time between the continuum source and the line-emitting gas: $R_{BLR} = c\,\Delta t$

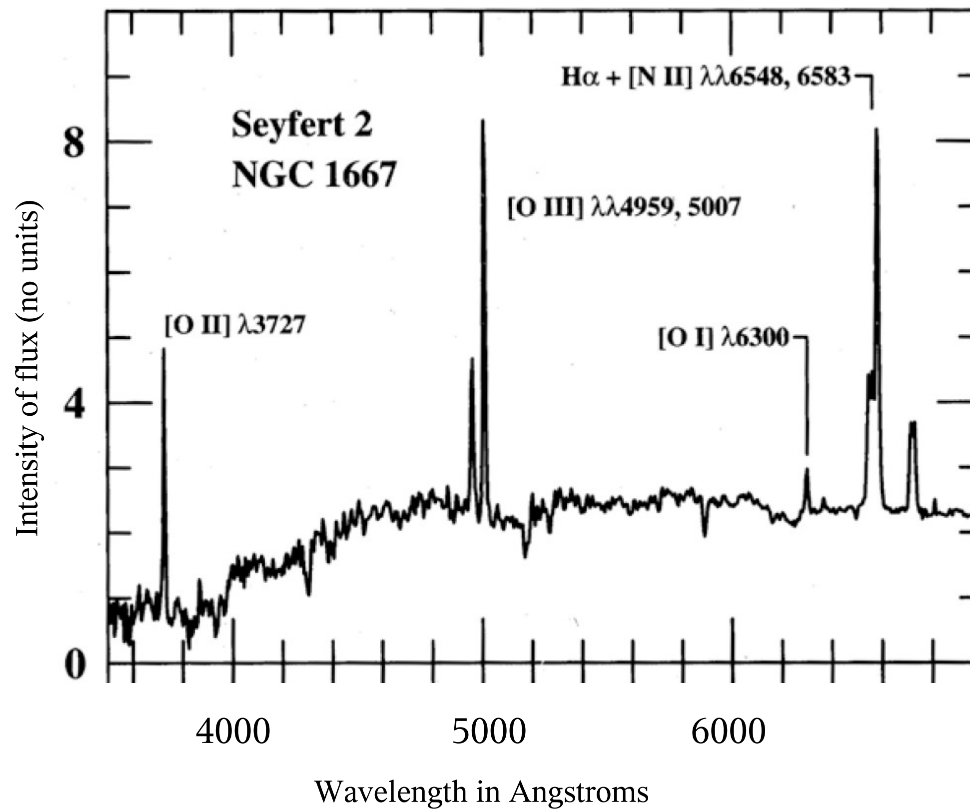
***V* estimated by the FWHM of broad emission line**

$V = f \times \mathrm{FWHM(H}\beta), \; f = \sqrt{3}/2$ for random distribution of BLR clouds

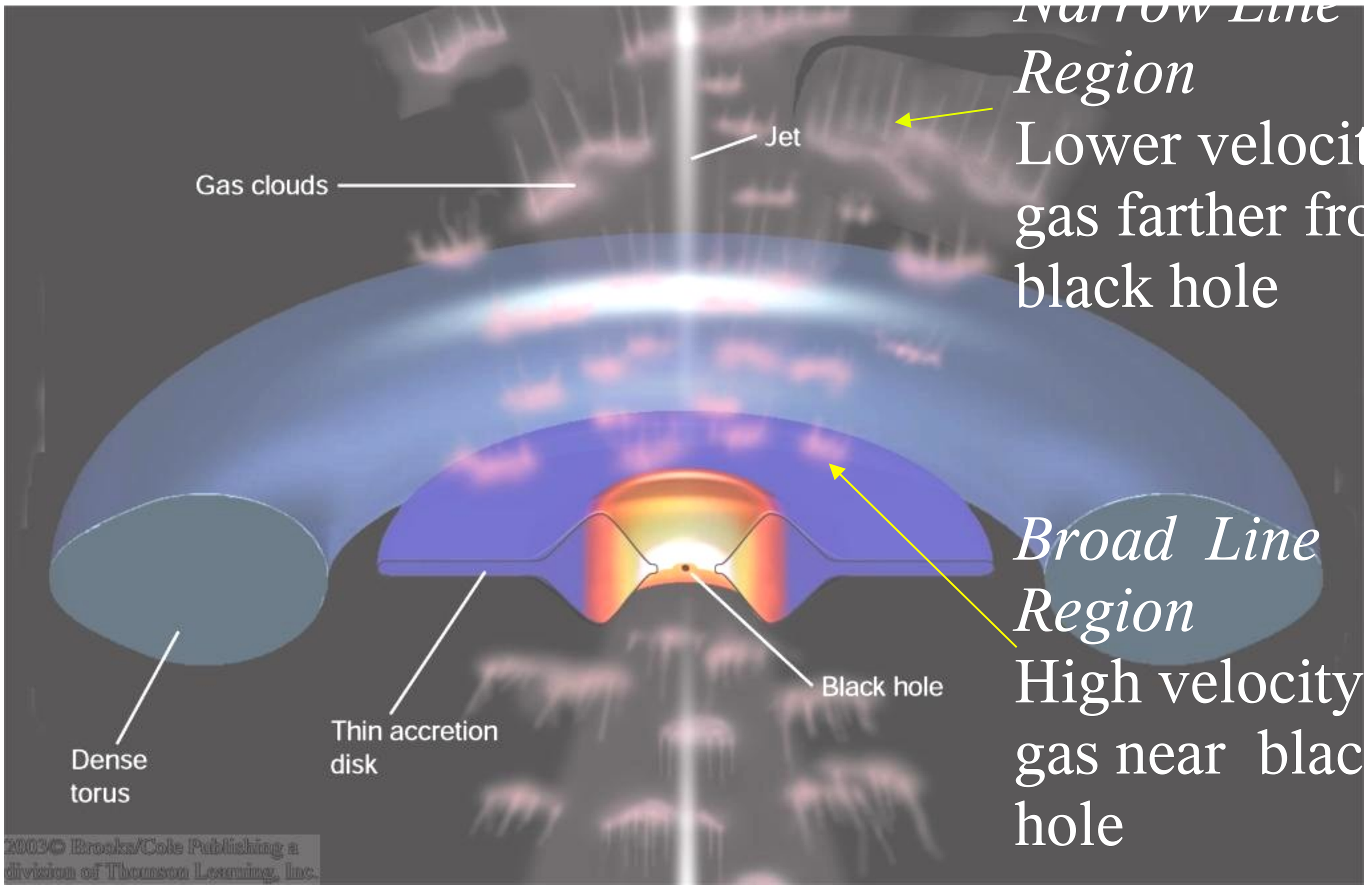
$$\longrightarrow \quad M = \eta \frac{V^2 R_{BLR}}{G}$$

Seyfert Galaxies – Continued

- Type 2:
  - These have only narrow emission lines visible in their spectrum.



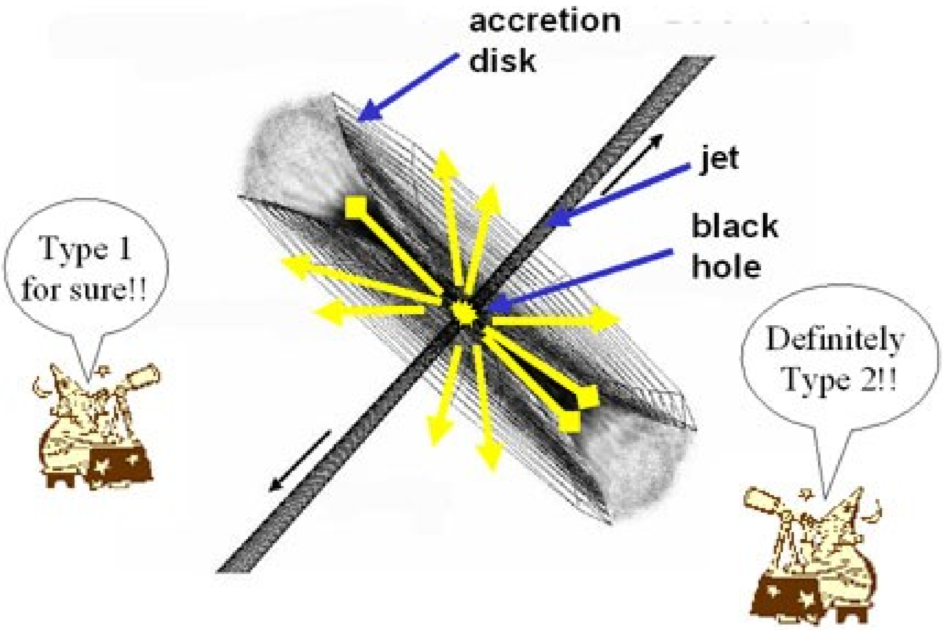
Model for Seyfert Galaxies



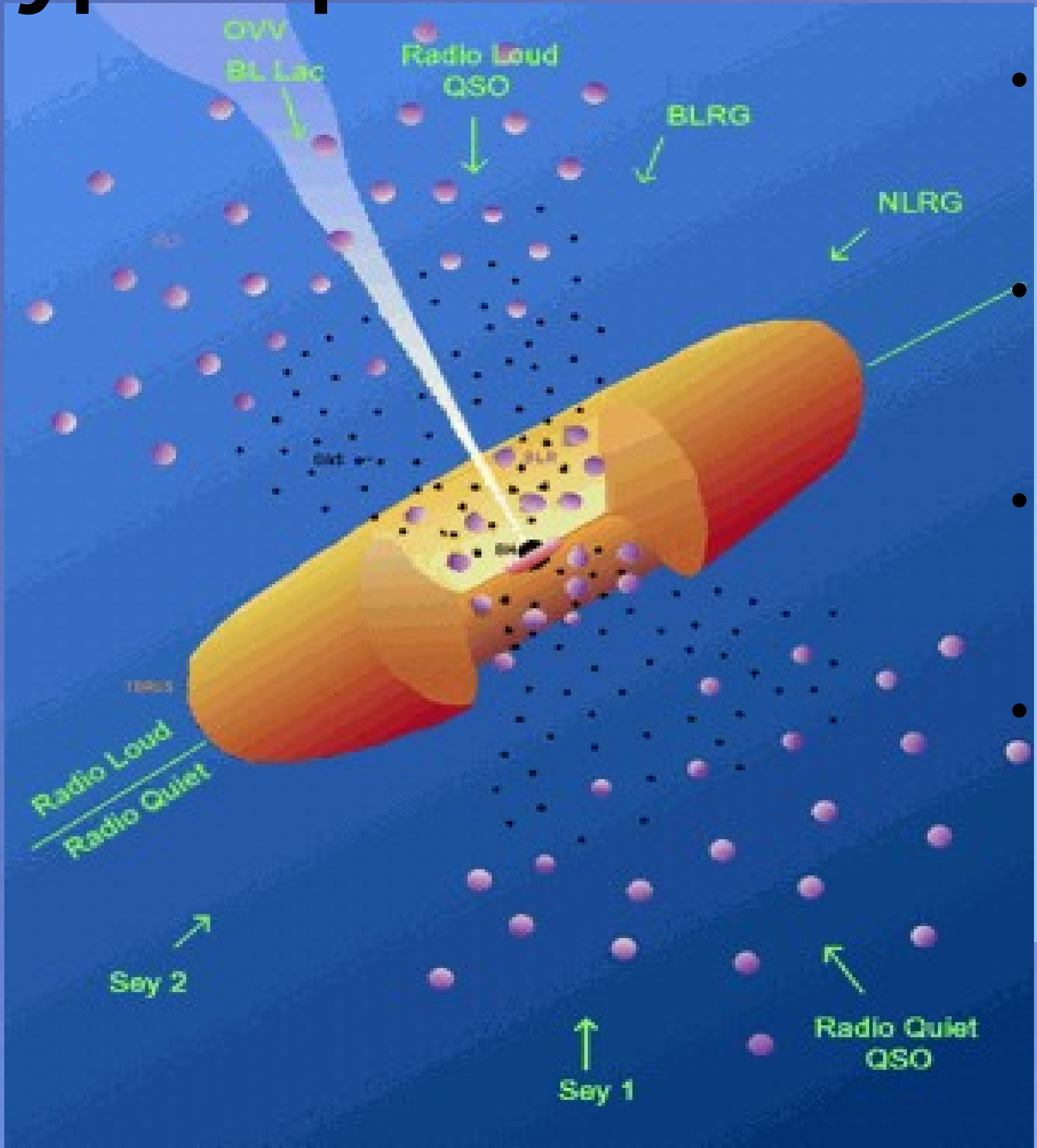
Classes of AGN's

Seyfert AGN's were theorized to be similar objects.

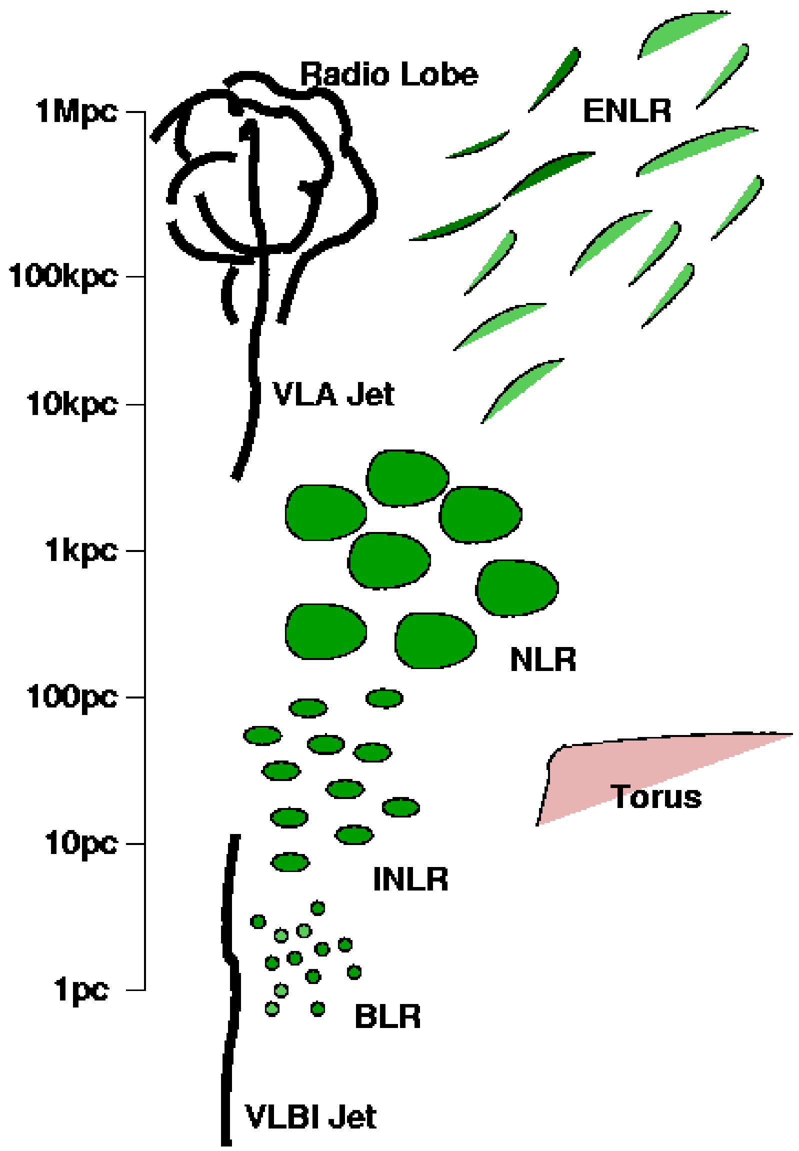
If the observer (Earth) had and un-obscured view of the active nucleus it then it appeared as a Type 1 (with both narrow and broad lines still visible) however if the observers view is obscured by an accretion disk the broad line emissions and low energy X-rays would be blocked and it would appear as a Type 2.



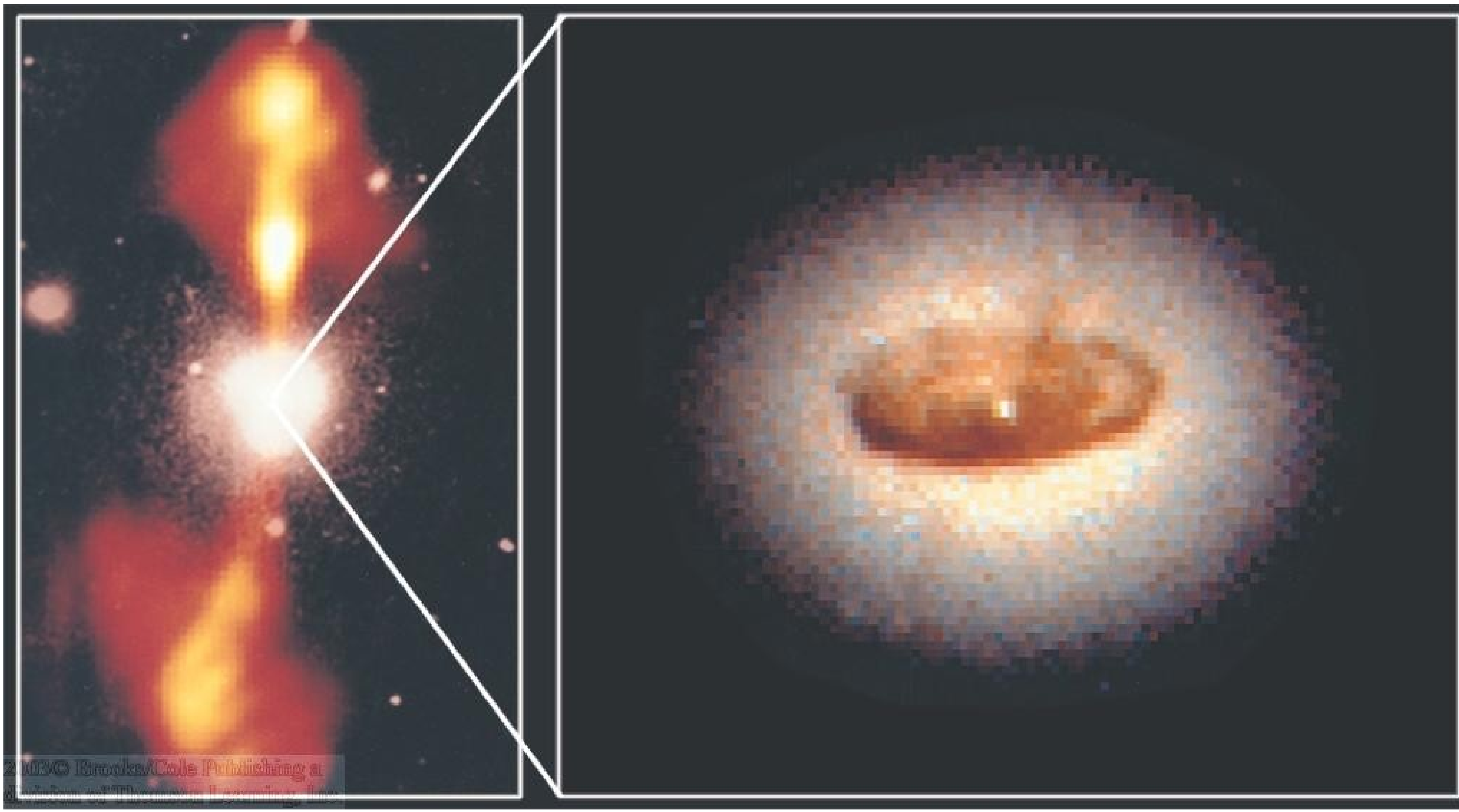
Type dependent on observing angle



- Blazars
  - BL Lacs
  - OVV
- Quasars
  - Radio Loud
  - Radio Quiet
- Radio Galaxy
  - Narrow Line
  - Broad Line
- Seyfert
  - Type 1
  - Type 2


Radio Lobe
1Mpc
ENLR
100kpc
10kpc
VLA Jet
1kpc
NLR
100pc
Torus
10pc
INLR
1pc
BLR
VLBI Jet

The Dust Torus in NGC 4261



In some Type 2 Seyfert galaxies, the broad component can be observed in polarized light

years ago (Khachikian & Weedman 1974), a classification scheme that has served astronomers well in attempting to determine the nature of these galaxies. The original classification into two types was based almost entirely on the relative widths of the strong emission lines. In the Seyfert 1 galaxies, the permitted lines have strong components with widths on the order of 10,000 km s^{-1}; they also may have weaker components with widths on the order of 500 km s^{-1}, as do the forbidden emission lines (such as [O III]). Both permitted and forbidden lines have similar widths of 500 km s^{-1} in Seyfert 2 galaxies. Intermediate Seyfert classifications ranging from 1.2 to 1.9 have been proposed over the years based on the relative strengths of the broad and narrow components of the permitted lines (e.g., Osterbrock & Koski 1976; Osterbrock 1981; Cohen 1983). Some Seyfert galaxies have changed their classifications on time scales of weeks t months, usually within the various intermediate Seyfert clas sifications (e.g., Cohen *et al.* 1986).

It was long believed that the nuclei of Seyfert 2 galaxie have radio sources that are systematically more powerful an larger than those in Seyfert 1 galaxies, with Seyfert 1. through 1.9 galaxies being intermediate in radio propertie (de Bruyn & Wilson 1978; Meurs 1982; Meurs & Wilso 1984; Ulvestad & Wilson 1984a, b; Ulvestad 1986). Edelso

nuclear and disk radio emission. Ulvestad & Wilson (1989) showed that the apparently higher nuclear radio luminosity and size of the Seyfert 2 galaxies might be accounted for by selection effects; when the weaker Seyferts (mostly Seyfert 2 galaxies) found in surveys of nearby galaxies are included and radio-source sizes are compared at equivalent dynamic ranges, the differences in radio powers and sizes are no longer statistically significant. A contemporaneous study by Giuricin *et al.* (1990), based on a sample of bright, spectroscopically selected Seyferts, also concluded that the radio sources in the different Seyfert types are not significantly different. A recent summary of the radio properties of Seyfert galaxies can be found in Wilson (1991).

Antonucci (1983) noted that the Seyfert 1 galaxies tend to have optical continuum polarization parallel to their radio

larization. This has been interpreted as a difference between thin and thick scattering disks (Antonucci 1984). However, the remarkable result that NGC 1068, the archetypal Seyfert 2 galaxy, shows very broad permitted line emission in polarized light (Antonucci & Miller 1985) indicates that at least some of the difference between Seyfert 1 and Seyfert 2 galaxies might be merely an orientation effect; a similar suggestion, based on x-ray properties of the galaxies, was made by

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- Antonucci & Miller (1985) discovered the polarized broad lines in NGC1068 .

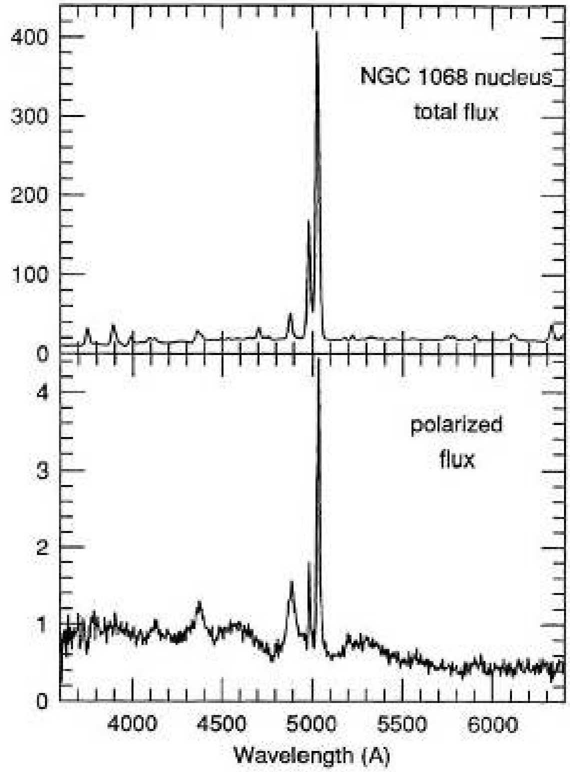
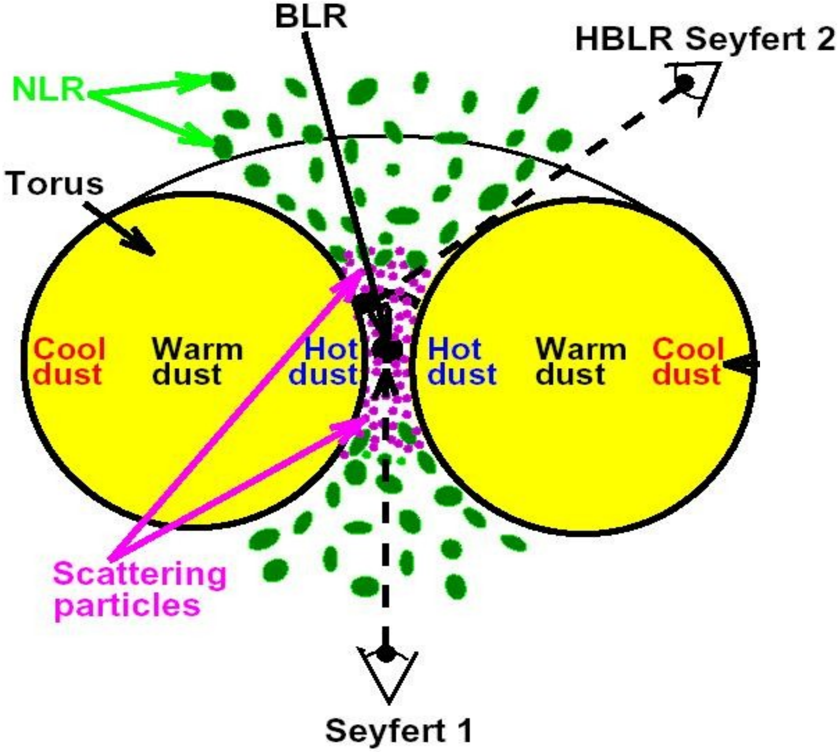


Figure 2 Spectropolarimetry of NGC 1068 by Miller et al 1991. The flux spectrum (*top*) indicates a Type 2 classification, while the polarized flux (*bottom*) is indistinguishable from the flux spectra of Type 1 Seyferts.

- evidence of the existence of a geometrically and optically thick “torus”.

The torus is (1) face-on : Seyfert 1.
(2) edge-on : Seyfert 2.



NGC 3147: a 'true' type 2 Seyfert galaxy without the broad-line region
Bianchi et al. 2008

„We report on simultaneous optical and X-ray observations of the Seyfert galaxy, NGC 3147. The XMM–Newton spectrum shows that the source is unabsorbed in the X-rays (NH < 5 × 1020 cm−2) . On the other hand, no broad lines are present in the optical spectrum. The origin of this optical/X-rays misclassification (with respect to the Unification Model) cannot be attributed to variability, since the observations in the two bands are simultaneous. Moreover, a Compton-thick nature of the object can be rejected on the basis of the low-equivalent width of the iron Kα line (≃130 eV) and the large ratio between the 2–10 keV and the [O iii] fluxes. **It seems therefore inescapable to conclude that NGC 3147 intrinsically lacks the Broad-Line Region, making it the first 'true' type 2 Seyfert galaxy.**

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Lawrence & Elvis (1982). Since the original discovery in NGC 1068, a number of other Seyfert 2 galaxies also have been shown to display broad permitted lines in polarized light (Miller & Goodrich 1990), supporting the intrinsic similarity of Seyfert 1 and Seyfert 2 galaxies.

Yet another class of Seyfert galaxies was proposed by Osterbrock & Pogge (1985), the "narrow-lined Seyfert 1 galaxies" (hereafter referred to as NLS1 galaxies). These objects have permitted linewidths much smaller than typical Seyfert 1 galaxies, on the order of 1,000 km s^{-1}. However, they differ from Seyfert 2 galaxies in that their optical spectra show several characteristics normally associated with Seyfert 1 galaxies, such as [O III]/Hβ ratios of less than 3, permitted lines somewhat broader than the forbidden lines, and either blends of Fe II emission or very high excitation emission lines such as [Fe VII] or [Fe X]. Most significant of these characteristics is the low [O III]/Hβ ratio, despite generally high ionization of the narrow lines. It indicates the

We have made new Very Large Array (VLA)[2] observations of a number of NLS1 galaxies in an effort to relate them to the other types of Seyfert galaxies and provide additional data for determining whether their properties are determined largely by orientation or by intrinsic differences from other Seyferts. Of particular interest are the typical sizes of the radio sources, which might be expected to be quite small if the disks are viewed in a polar direction, and the relation between the radio axes and the optical polarization position angles. Goodrich (1989) reports optical polarization position angles nearly perpendicular to the radio major axes in two NLS1 galaxies, and more such examples have been sought with the additional VLA observations. This paper reports the results of the new VLA observations and briefly compares the radio properties of the NLS1 galaxies to other Seyfert galaxies.

2. OBSERVATIONS AND DATA REDUCTION

Another subclass:

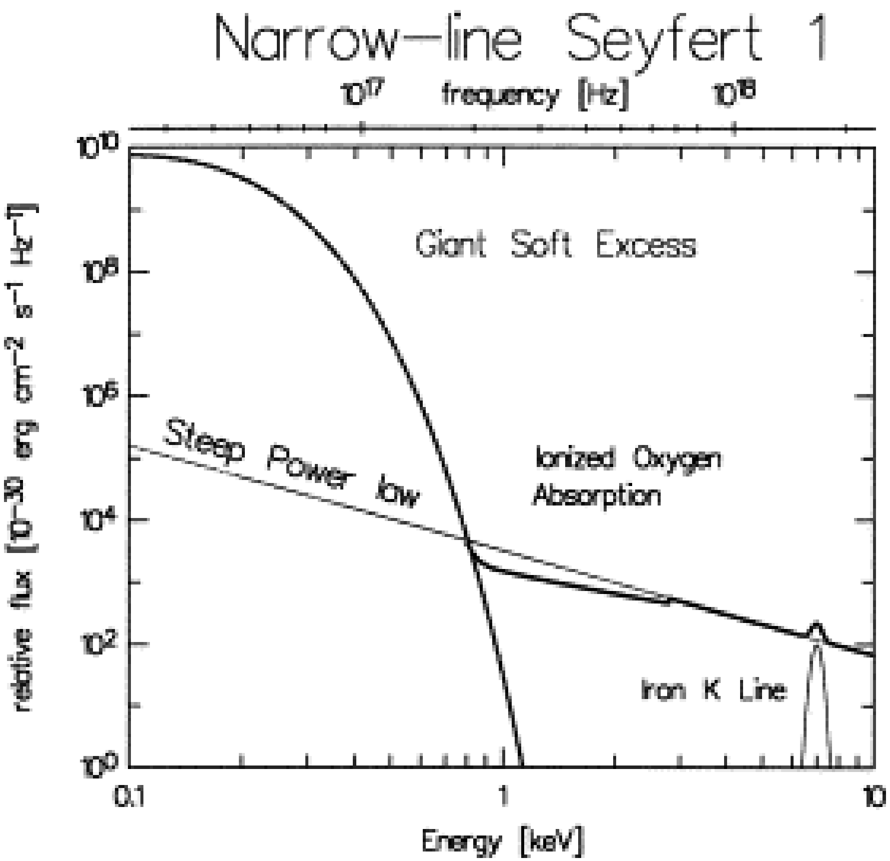
Narrow-line
Seyfert I

X-ray Spectra of AGN

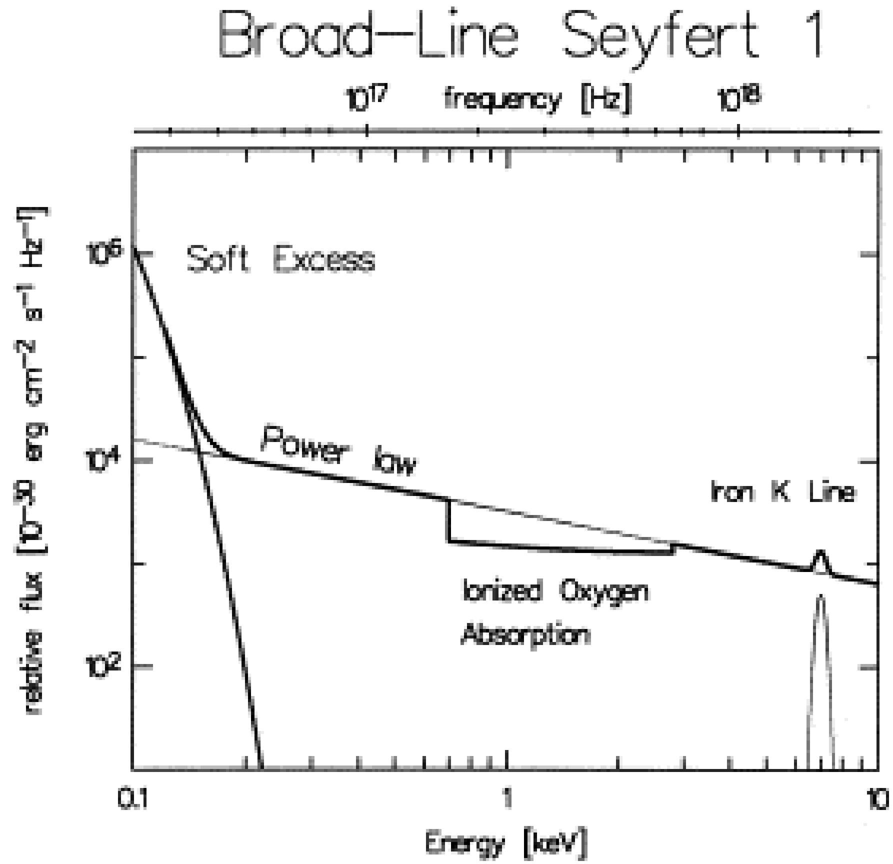
Seyfert I

Excess emission below 2 keV

- ROSAT has shown that the narrow line Seyfert I galaxies (NLS1) have generally strong soft excess components compared to Sy1 with broader optical permitted lines. **When simple power law models are fit to the data, photon values reach values up to about 5, much higher than the photon index of around 2 seen in Sy1**
- A clear anticorrelation is found between the ROSAT spectral softness and the line width of the optical permitted lines



Narrow-line Seyfert 1
frequency [Hz]
10^{17}
10^{18}
Giant Soft Excess
Steep Power law
Ionized Oxygen Absorption
Iron K Line
relative flux [10^{-30} erg cm^{-2} s^{-1} Hz^{-1}]
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
0.1
1
10
Energy [keV]

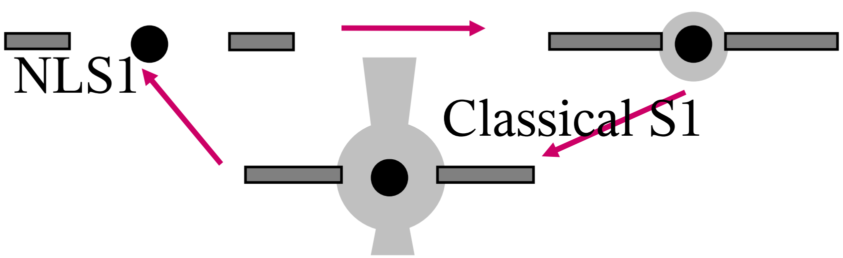


Broad-Line Seyfert 1
frequency [Hz]
10^{17}
10^{18}
Soft Excess
Power law
Iron K Line
Ionized Oxygen Absorption
relative flux [10^{-30} erg cm^{-2} s^{-1} Hz^{-1}]
10^{6}
10^{4}
10^{2}
0.1
1
10
Energy [keV]

Thick & Thin Disks In AGN

Oscillatory Nature of Classical Seyfert 1s And Narrow-Lined Seyfert 1s (NLS1s) ?

- Seyferts are generally believed to be accreting near the Eddington limit
  - Should be in the Unstable Very High State
  - Oscillation times of ~ 2 yr ($M/10^6$ M)



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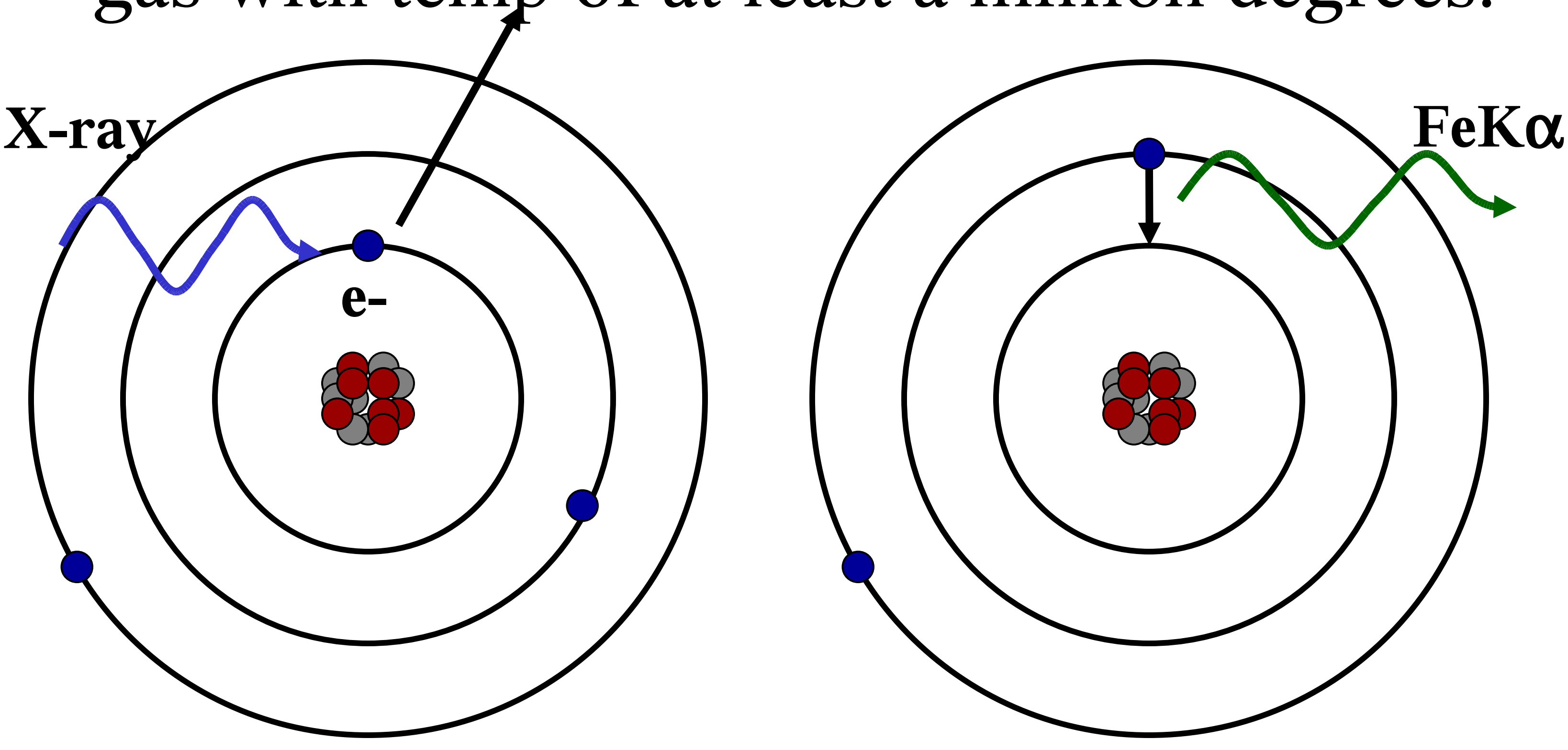
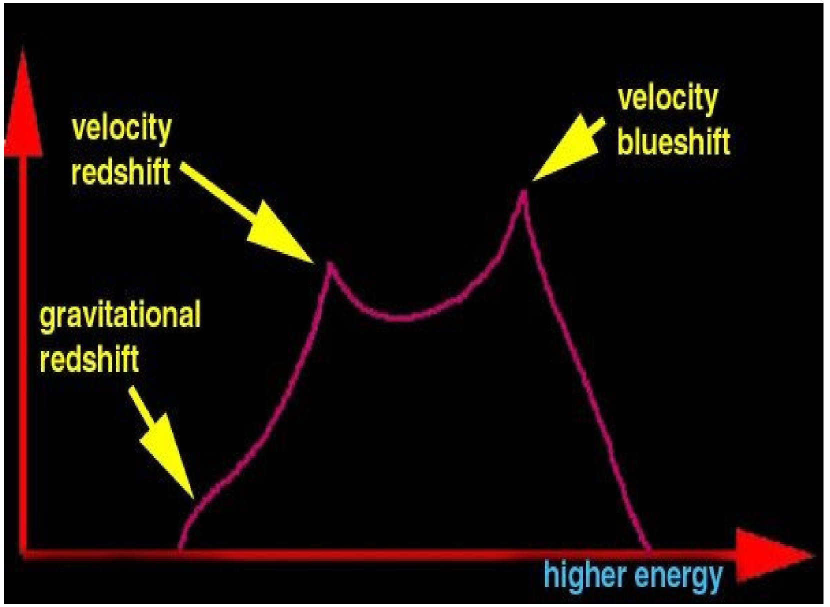
X-ray lines: Fe Kα Line

Fluorescence line observed in Seyferts – from gas with temp of at least a million degrees.





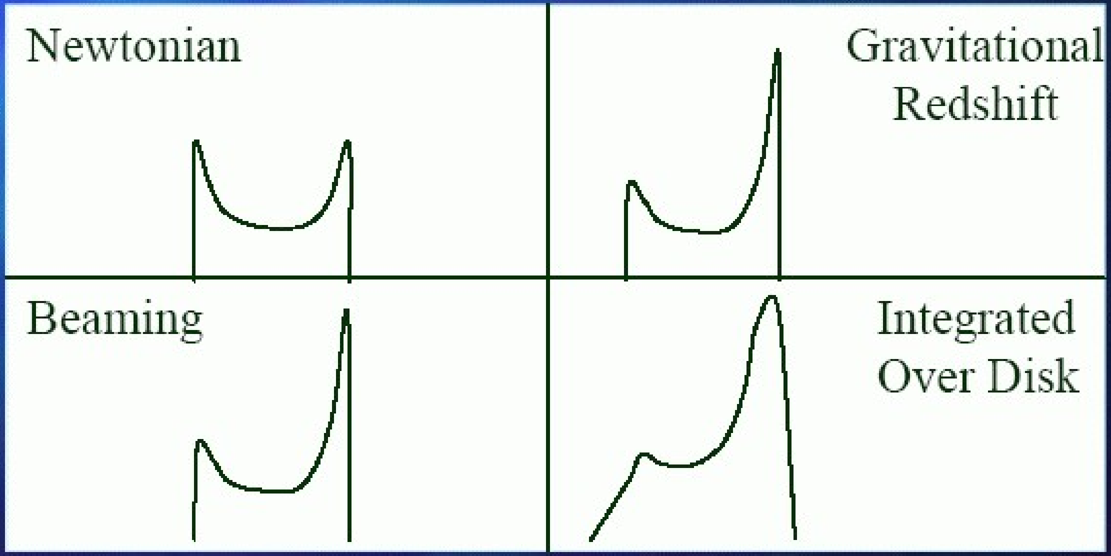
X-ray emissions from hot iron atoms swirling around a black hole make a characteristic double-horn pattern predicted from Einstein's relativity theory

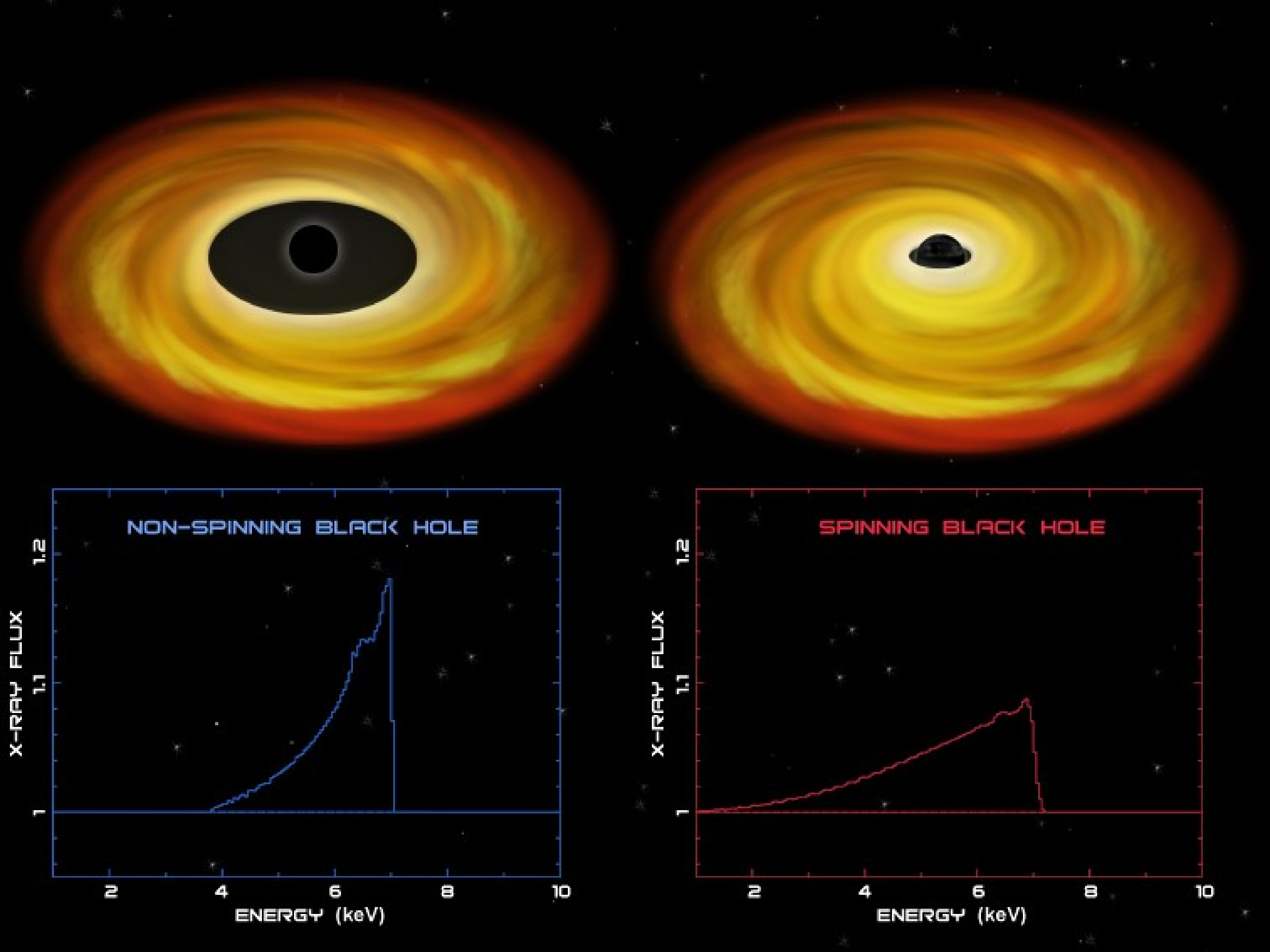
double peak.
The presence of such a feature is a clear sign of inner disk emission influenced by gravitational and Doppler effects.

Broad Fe-Lines in AGNs II

Line Profile:

- Fe Kα line is intrinsically narrow.
- Broadening can be attributed to the disk dynamics (Doppler shifts) and gravitational redshifting. ⇒ <u>Characteristic broad, skewed line</u>
- "Blue" End: Inclination angle – "Red" End: Inner Radius




NON-SPINNING BLACK HOLE
SPINNING BLACK HOLE
X-RAY FLUX
ENERGY (keV)
1
1.1
1.2
2
4
6
8
10

Seyfert I

Fe K emission lines

The 6.4 keV Fe emission line due to fluorescence of cold material is present on most Seyfert I galaxies

The distribution of EW is quite broad 50<EW<350 eV

The Fe K line and “hard tail” features are most probably due to the reprocessing (or reflection) of primary X-rays in optically thick material subtending a substantial solid angle to the X-ray source, possibly the accretion disk

LINER Low-Ionization Nuclear Emission-line Regions

subclass of low-luminosity AGNs (LLAGNs)

A low-ionization nuclear emission-line region (LINER) is a type of galactic nucleus that is defined by its spectral line emission.

The spectra typically include **line emission from weakly ionized** or neutral atoms, such as O, O+, N+, and S+. Conversely, the spectral line emission from strongly ionized atoms, such as O++, Ne++, and He+, is relatively weak.