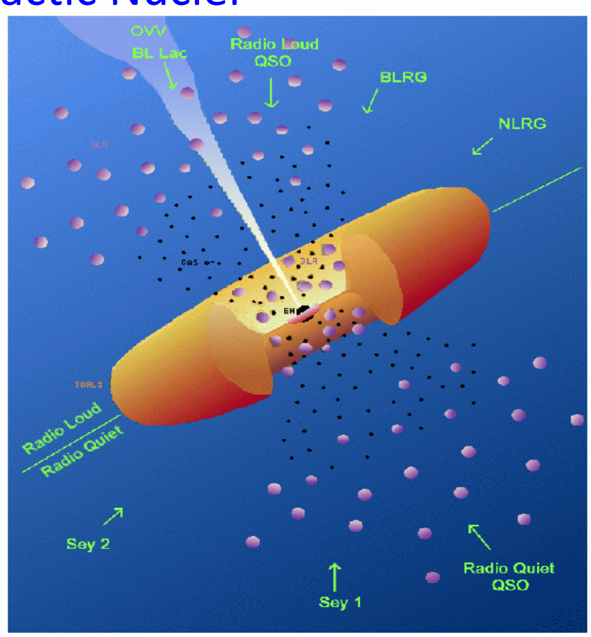
Strong gravity and accreting black holes

- The AGN Zoo
  - AGN Unification
- Black Hole systems
  - The spectrum of accreting black holes

AGN- Alias Active Galactic Nuclei

- AGN are 'radiating' supermassive black holes-
  - They go by a large number of names (Seyert I, Seyfert II, radio galaxies, quasars, Blazars etc etc)
  - The names convey the observational aspects of the objects in the first wavelength band in which they were studied and thus do carry some information
- See http://nedwww.ipac.caltech.edu/level5/Cambridge/Cambridge_contents.htmlfor an overview



Urry and Padovani 1995

AGN in Longair- chapters 18,19,20,21

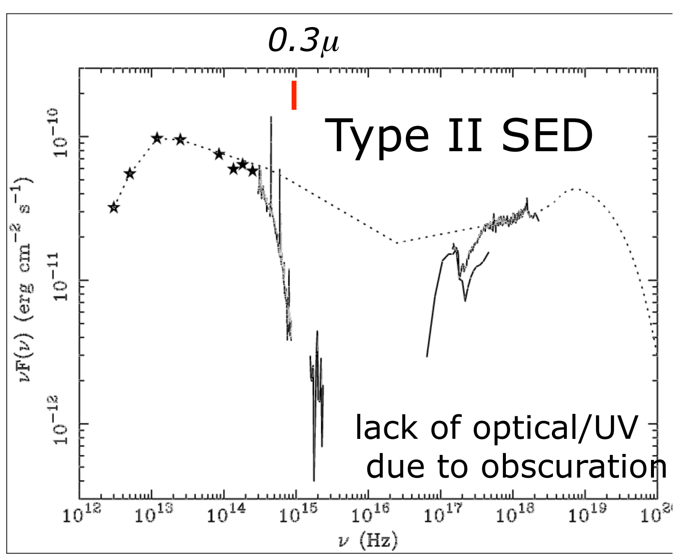
I am covering only a fraction of this material ! (Notice that I have left some sections out entirely)

What Are Active Galactic Nuclei

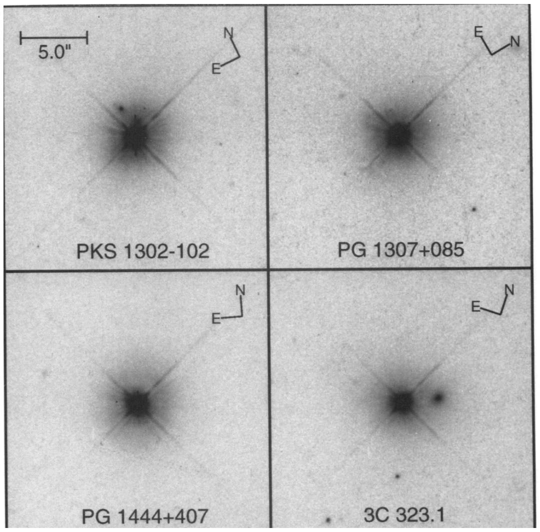
Radiating supermassive black holes in the centers of galaxies

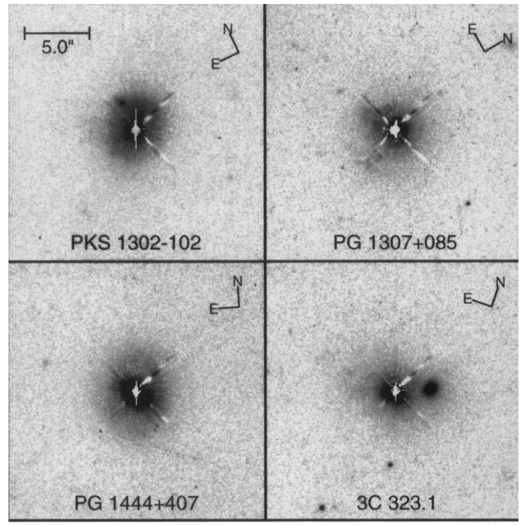
Properties

- 'Point-like'
- luminous **non-stellar broad band spectr**a- very broad range in luminosity log L~ 40-48 ergs/sec
- located in center of *some* galaxies at any one time
  - but SMBHs exist in 'all' massive galaxies



HST Images of 4 Quasars (Bahcall et al 1995





Raw image- spikes are due to diffraction

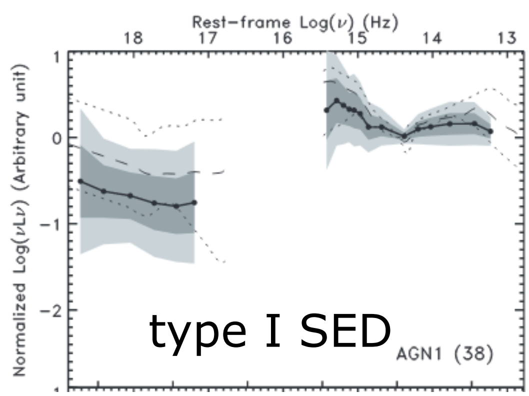
Point source subtractec

Properties

- Optical spectra 3 classes
  - strong broad emission lines (type I)
  - strong narrow emission lines (type II)
  - strong non-thermal continuum (Blazars)
- radio ~10% of AGN show strong radio emission (jets/extended emission) due to synchrotron radiation (Blazars)

Radiating supermassive black holes in the centers of galaxies

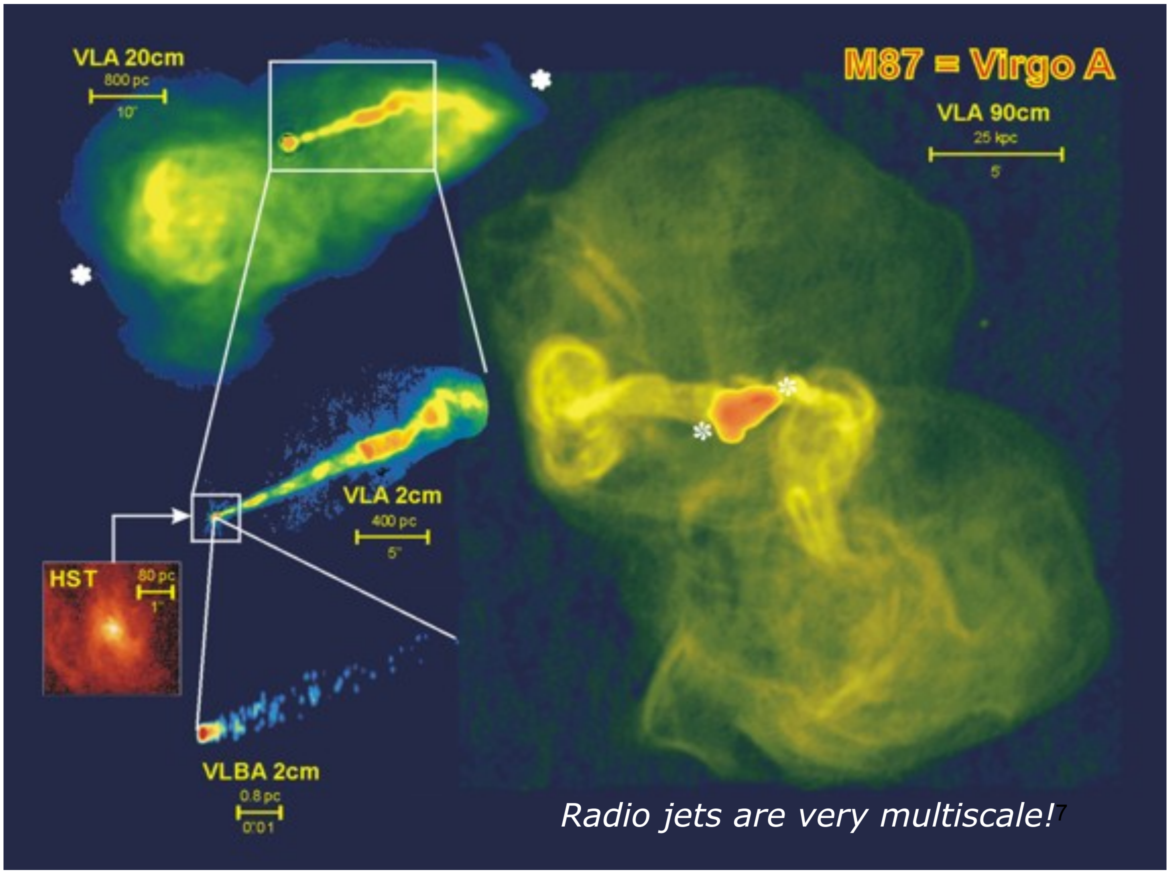
What Are Active Galactic



IR- emission reprocessed from optical-UV-soft x-ray via dust

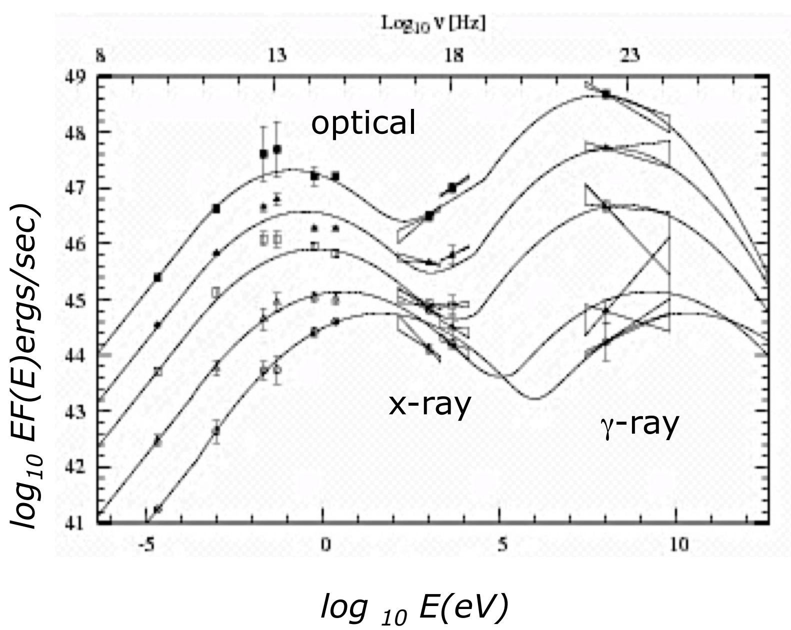
Optical/UV- in most AGN due to accretion disk – variable

X-ray non-thermal power law spectra highly variable

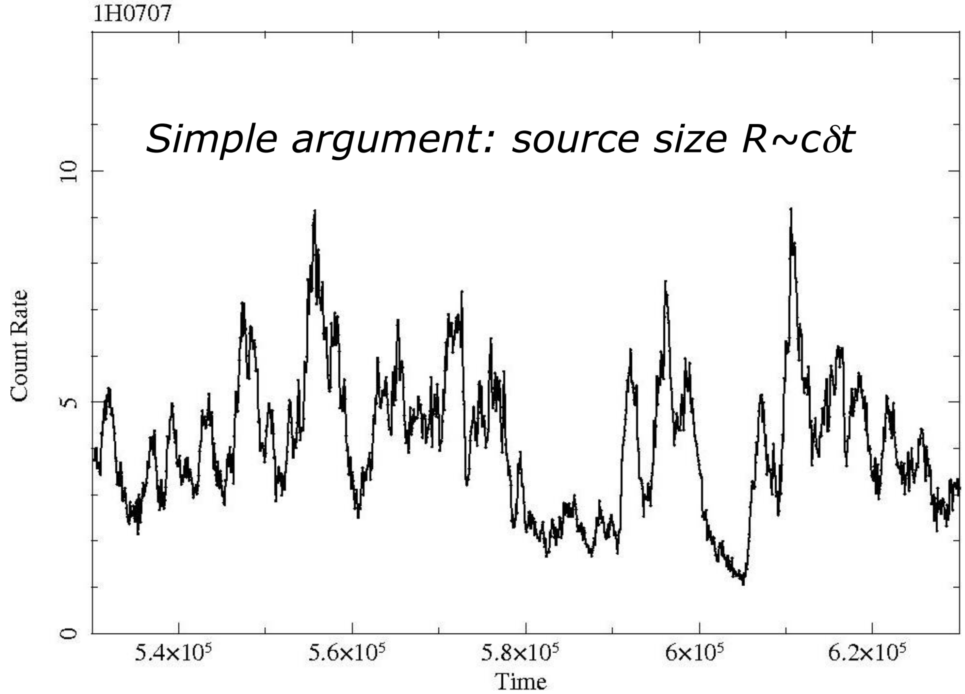


Blazar SED

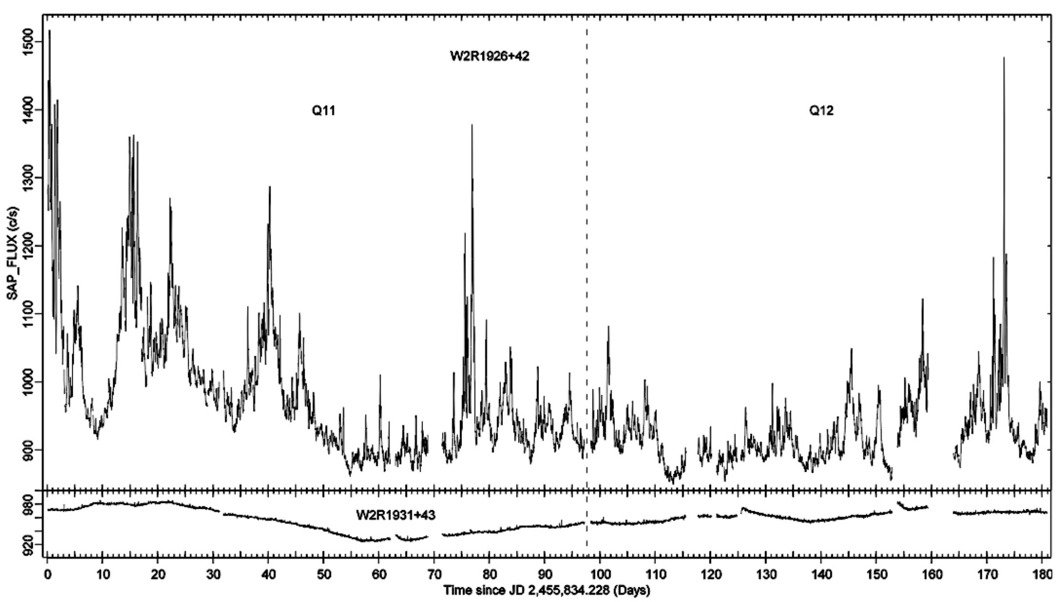
- Very broad, very different from Seyferts/ quasars
- Much of the energy appears in the gamma-ray band



Rapid x-ay variability in AGN luminosity ~5x10^{43} ergs/sec



Kepler optical light curve of a Bl Lac Object (Blazar) W2R1926+42



AGN Zoo

"Radio-loud" objects show jets and enormous lobes of relativistic plasma

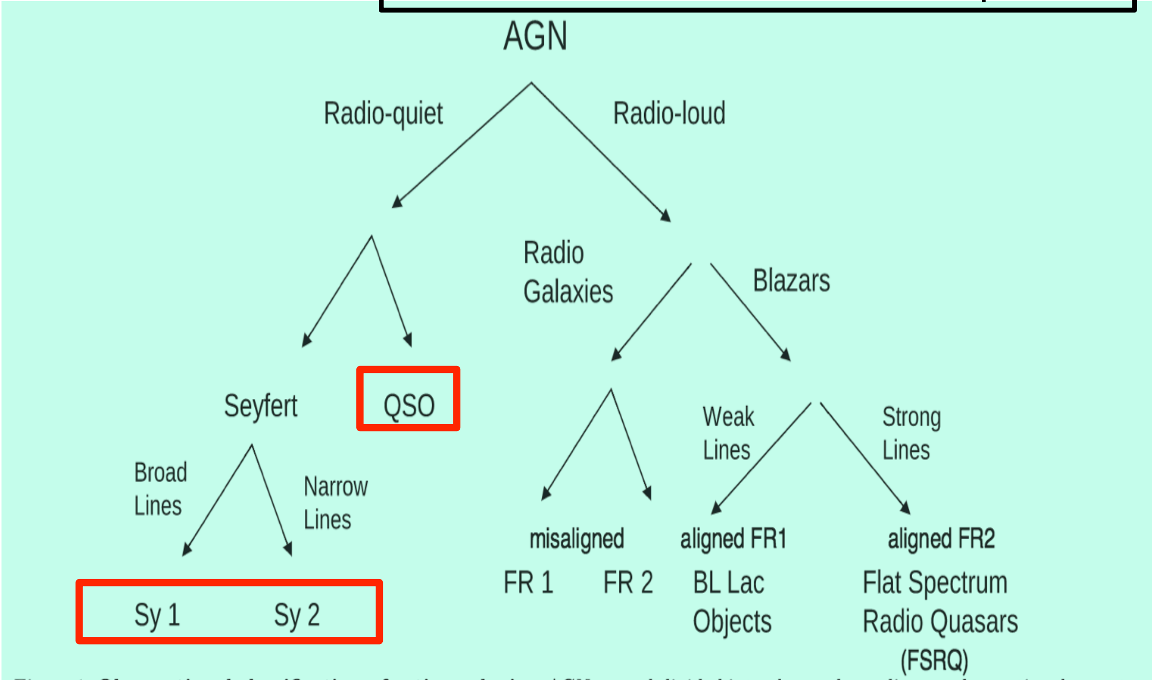


Figure 1. **Observational classification of active galaxies.** AGN are subdivided into classes depending on observational aspects, such as their radio loudness or the presence of optical lines in their spectra. QSO = quasi-stellar objects; Sy1 and Sy2 = Seyfert 1 and 2; FR1 and FR2 = Fanaroff-Riley 1 and 2.

AGN Unification

General comments

- *AGN are diverse… they have a vast range of properties*
- *In general, there are three "axes" to consider…*

I Luminosity

- *Range from <10^{40} erg/s to ~10^{48} erg/s*
- *Fundamental parameters controlling this are **mass** and **mass accretion rate***
- *Powerful objects called quasars (historically, AGN found before host galaxy could be identified)*
- ***But geometry has a major role in observational appearance***

AGN Unification

General comments

II Level of obscuration

- In some objects, can "see" all of the way down to the SMBH (depending on wavelength)

- In other objects, view at some wavelengths is blocked by obscuring material (some objects are blocked at most wavelengths)

- Level of obscuration connected to **viewing angle**

AGN Unification

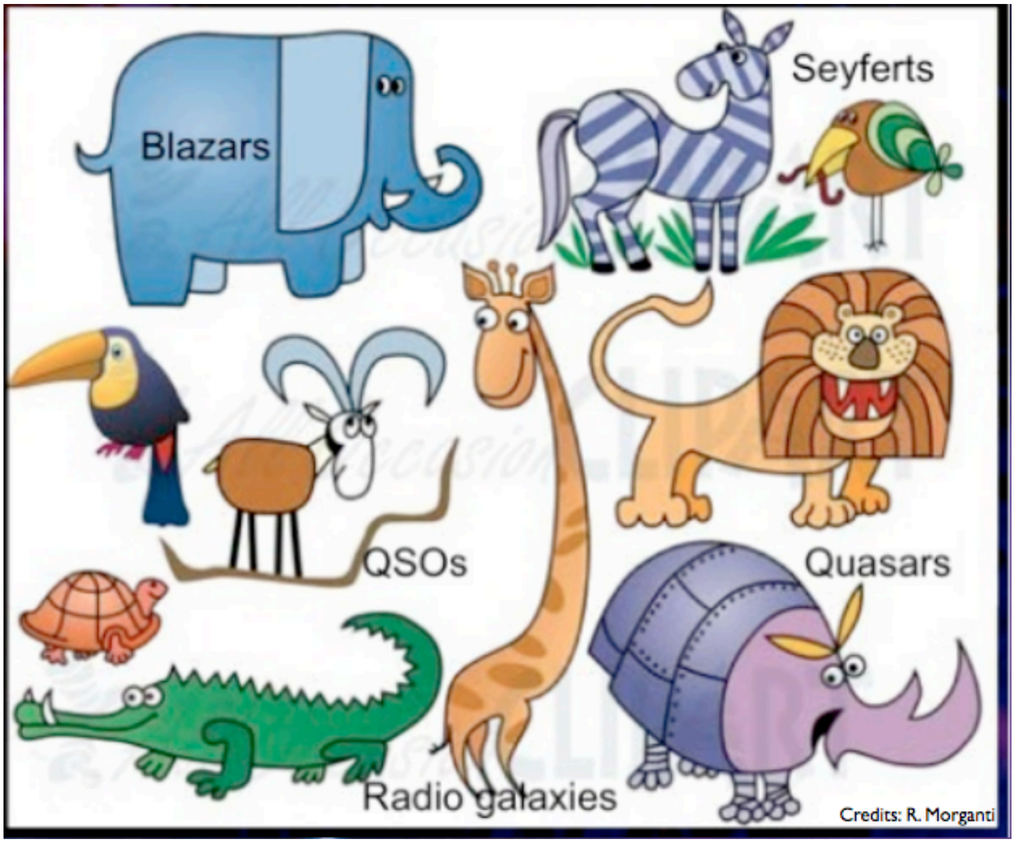
General comments

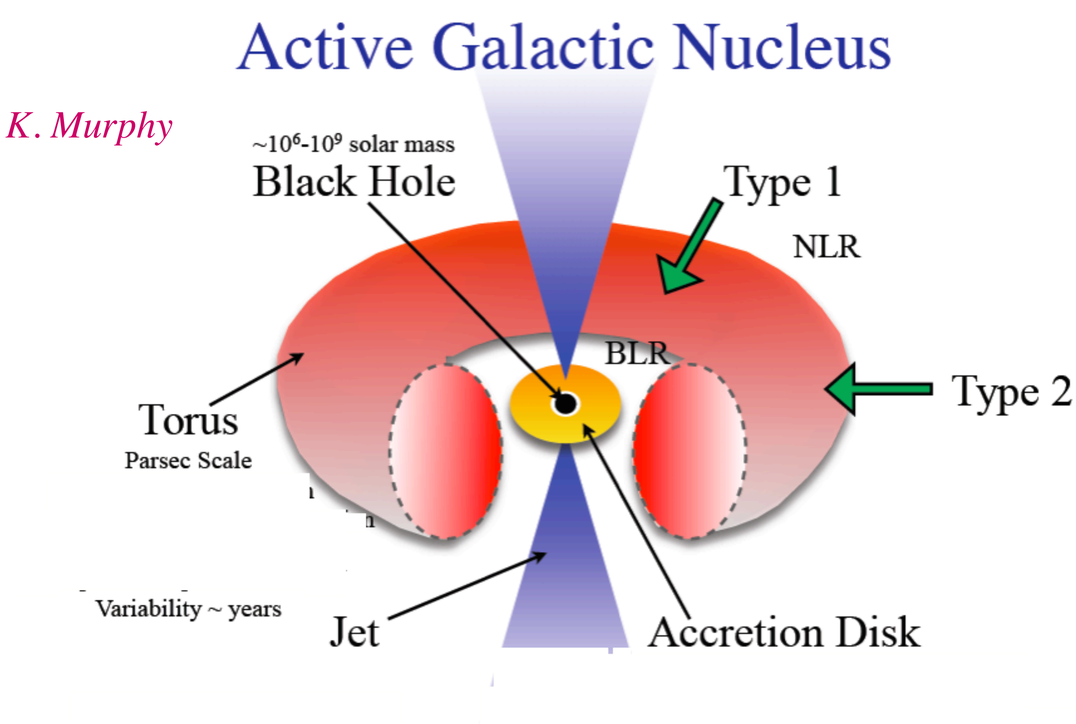
III Presence of powerful relativistic (radio) jets

- Radio-loud AGN : generate powerful jets, seen principally via synchrotron radiation in the radio band
  - also important in x-ray and γ-ray

- Radio-quiet AGN : lack powerful jets (often possess 'weak' jets)

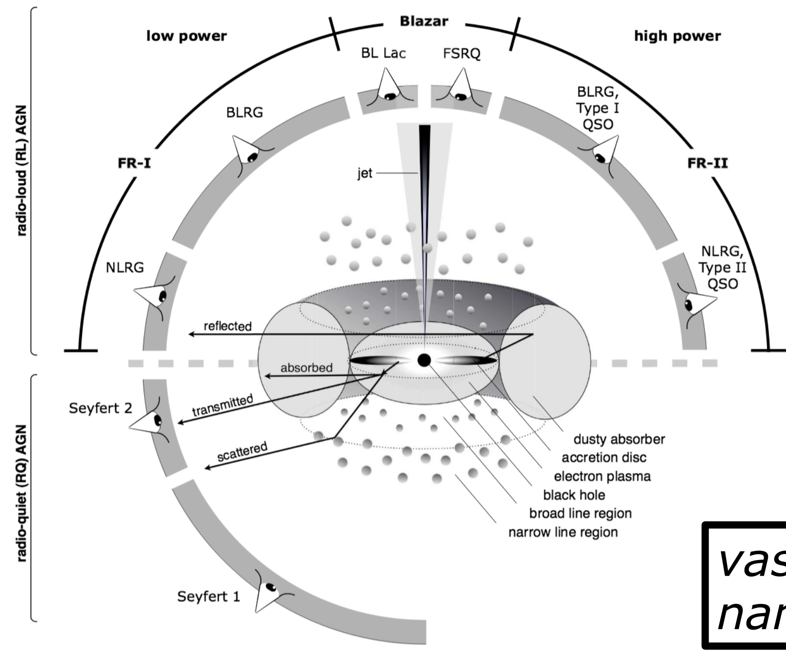
- Fundamental parameter controlling jet production **unknown** **(maybe black hole spin; or magnetic field configuration)**





Not all AGN have visible jets

The Overall Picture (Beckman and Shrader 2013)



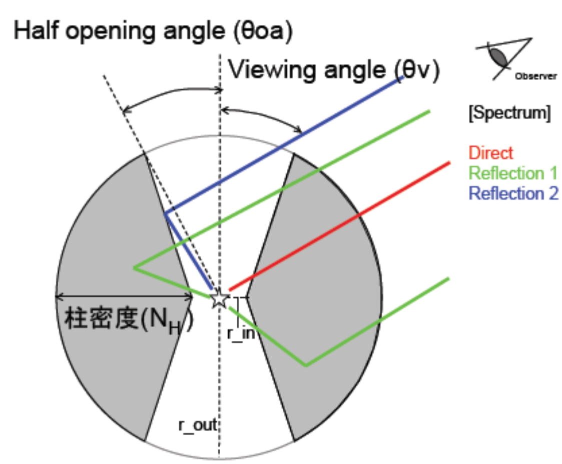
vast array of names

: 1: Schematic representation of our understanding of the AGN phenomenon in the unified scheme
ie type of object we see depends on the viewing angle, whether or not the AGN produces a significant
ission, and how powerful the central engine is. Note that radio loud objects are generally thought to

AGN Zoo

In a simple unification scenario

- broad-lined (Type 1) AGN are viewed face-on
- narrow-lined (Type 2) AGN
  - the broad emission line region (BELR)
  - the soft X-rays
  - optical/UV emission from the AD
- are all "hidden" by dust and high columns of gas and viewed edge-on
- However there are other complications like jets and a range in the geometry



Radio Loudness	Optical Emission Line Properties		
	Type 2 (Narrow Line)	**Type 1** (Broad Line)	**Type 0** (Unusual)
Radio-quiet:	Seyfert 2	Seyfert 1 QSO	
Radio-loud:	NLRG { FR I / FR II	BLRG SSRQ FSRQ	Blazars { BL Lacs / (FSRQ)
	decreasing angle to line of sight ->		

Table 1: AGN Taxonomy: A Simplified Scheme.

Radio Loudness	*Optical Properties*		*No Lines*
Radio quiet (weak or no jet)	Type II (narrow forbidden lines) Seyfert 2	Type I (broad permitted lines) Seyfert 1 QSO	
Radio Loud (strong jet)	FR I NLRG FR II	BLRG	Bl Lac Blazars FSRQ
X-ray Properties	Highly Absorbed-strong narrow Fe K line, strong low E emission lines	Not absorbed- or ionized absorber often broad Fe K line-low energy spectrum with absorption lines	Featureless continuum-highly variable γ-ray sources

table 27-2 Properties of Active Galactic Nuclei (AGNs)

Object	Found in which type of galaxy	Strength of radio emission	Type of emission lines in spectrum	Luminosity (watts)	Luminosity (Milky Way Galaxy = 1)
Blazar	Elliptical	Strong	Weak (compared to synchrotron emission)	10^{38} to 10^{42}	10 to 10^5
Radio-loud quasar	Elliptical	Strong	Broad	10^{38} to 10^{42}	10 to 10^5
Radio galaxy	Elliptical	Strong	Narrow	10^{36} to 10^{38}	0.1 to 10
Radio-quiet quasar	Spiral or elliptical	Weak	Broad	10^{38} to 10^{42}	10 to 10^5
Seyfert 1	Spiral	Weak	Broad	10^{36} to 10^{38}	0.1 to 10
Seyfert 2	Spiral	Weak	Narrow	10^{36} to 10^{38}	0.1 to 10

- Some of different classes of AGN are truly different 'beasts' - (e.g. radio loud vs radio quiet) but
- Much of the apparent differences are due to geometry/inclination effects- this is called the Unified Model for AGN (e.g. type I vs Type I radio quiet objects, blazars - radio loud objects observed down the jet)

(adapted from T. Treu)

table 27-2 Properties of Active Galactic Nuclei (AGNs)

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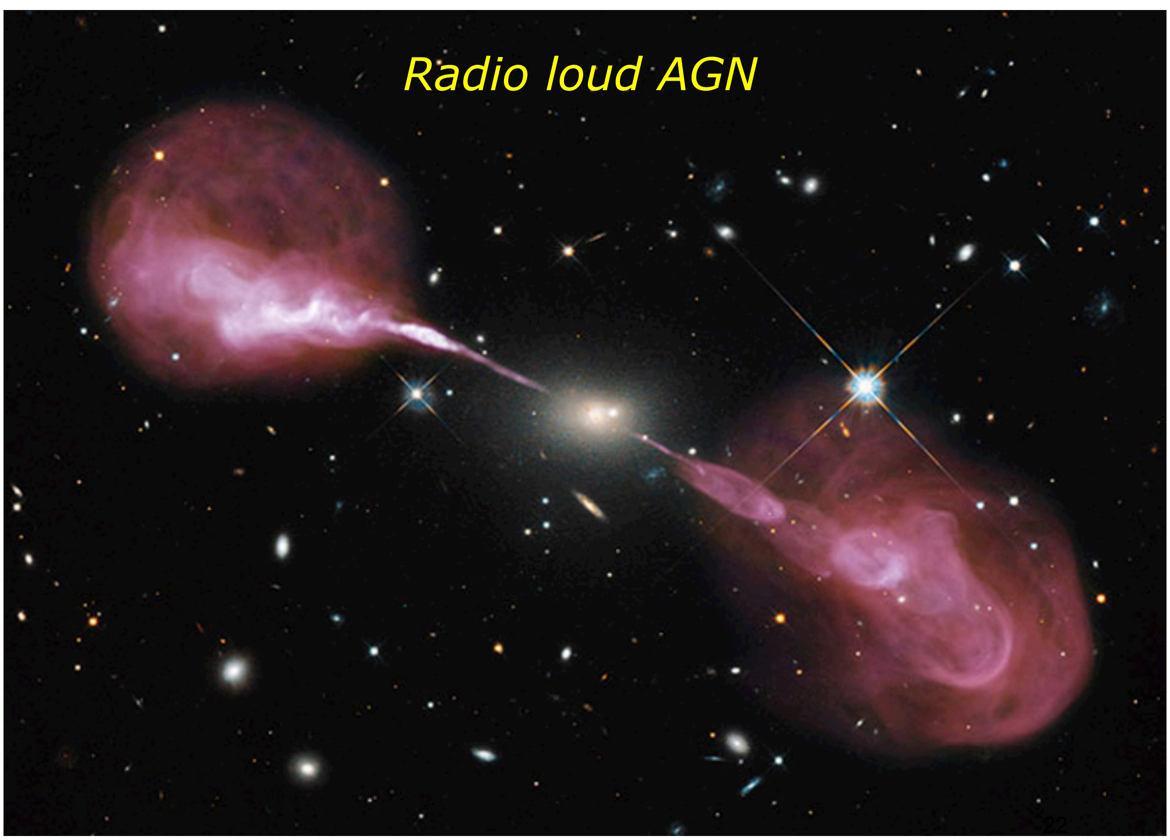
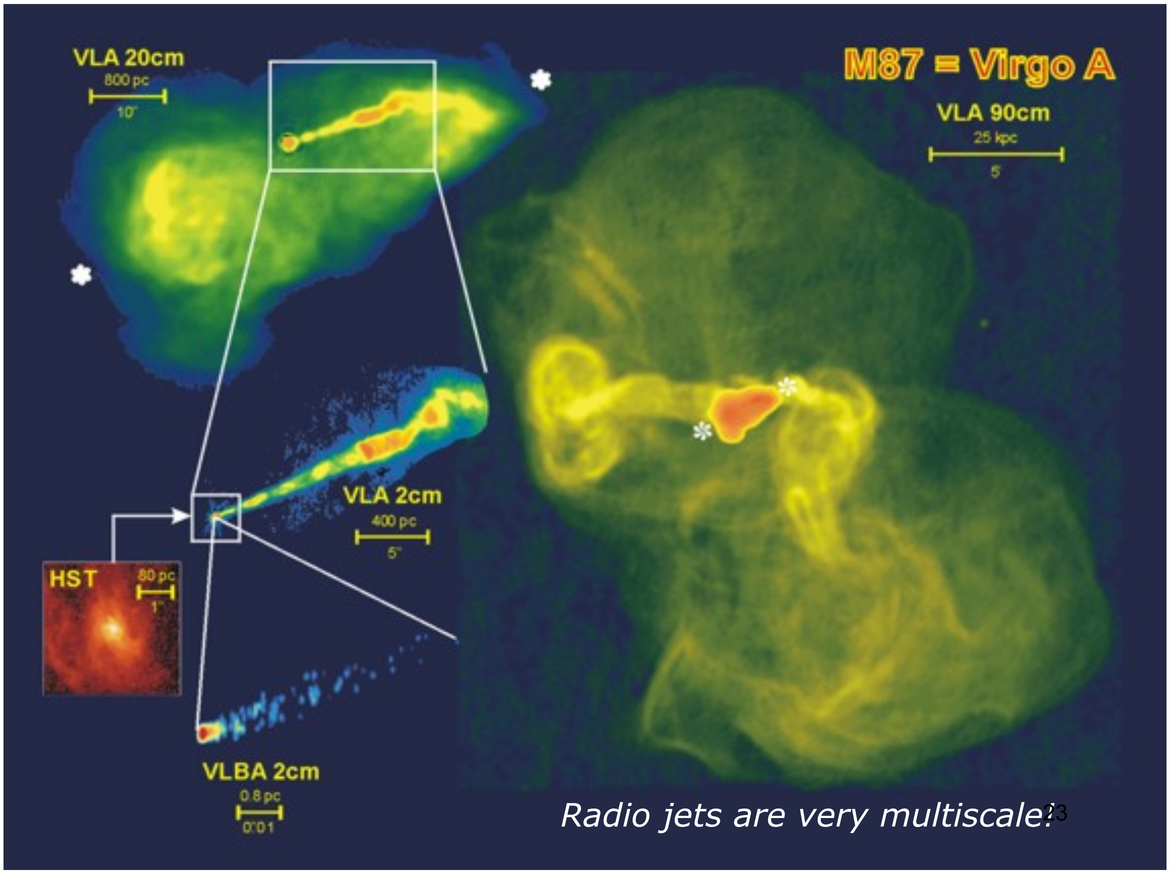
Seyfert 1	Spiral	Weak	Broad	10^{36} to 10^{38}	0.1 to 10
Seyfert 2	Spiral	Weak	Narrow	10^{36} to 10^{38}	0.1 to 10

The ingredients are:

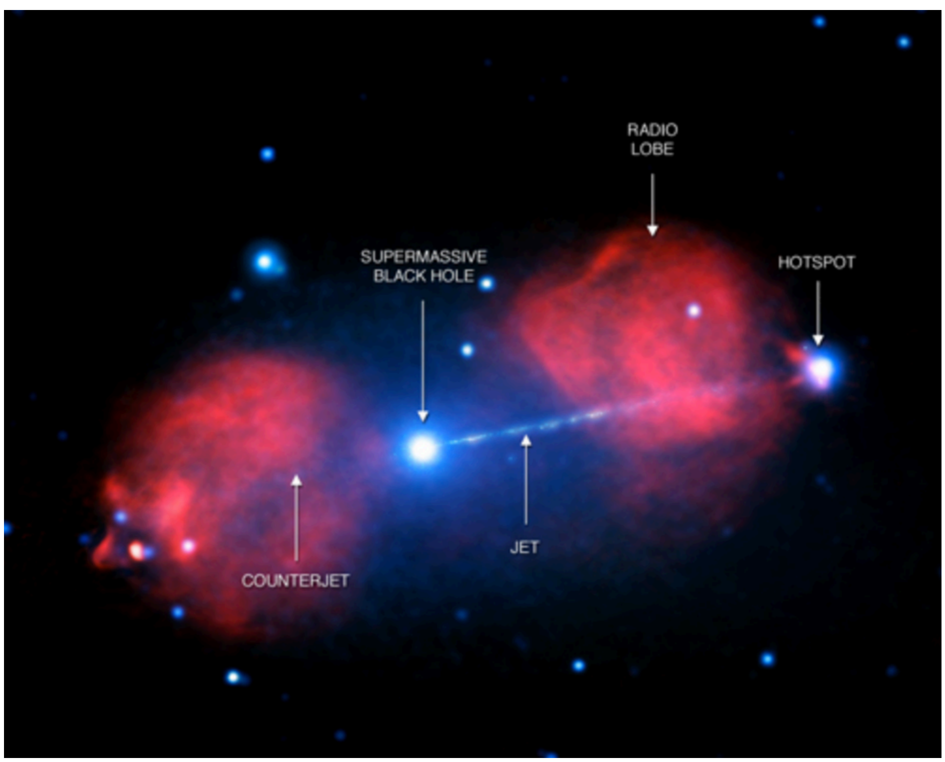
- the black hole,
- accretion disk,
- the jet,
- some orbiting dense clouds of gas close in (the broad line region),
- plus a dusty torus that surrounds the inner disk
- some less dense clouds of gas further out (the narrow line region) (adapted from T. Treu)



Hercules-A



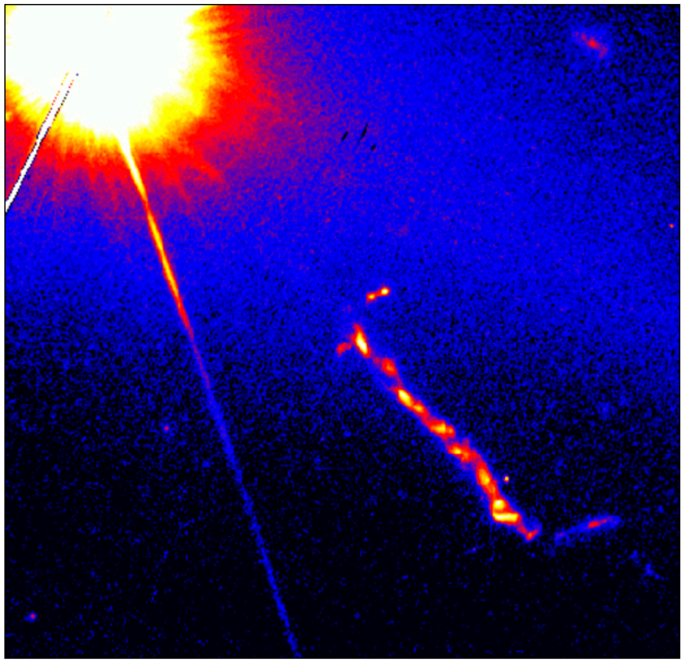
Radio jets are very multiscale!



Pictor A: X-ray in blue, radio in red

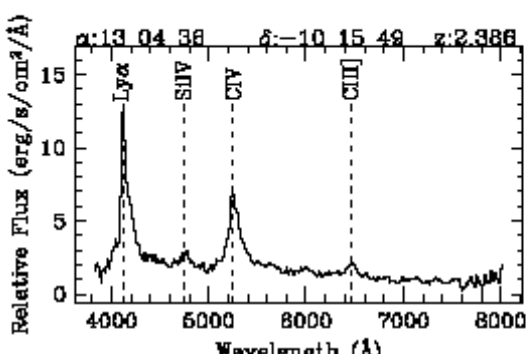
Examples:
Powerful quasar 3C273

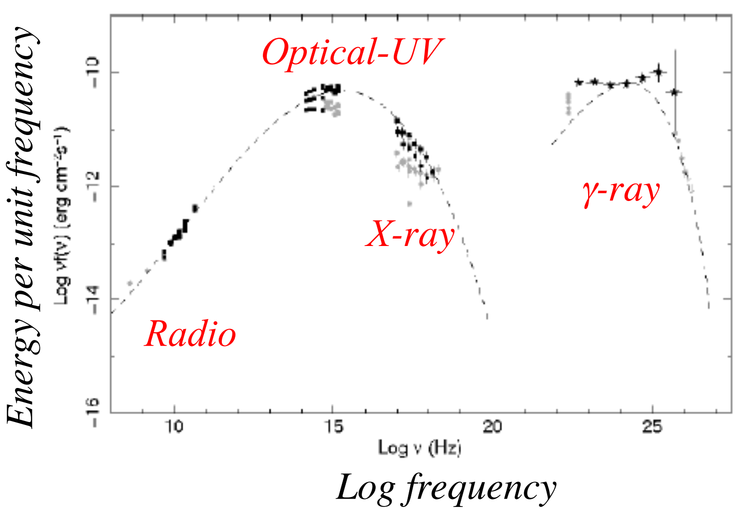
HST



Broad Band Properties of AGN

- **Broad band continuum- very different from stars or galaxies**
- **Strong UV lines not seen in stars**
- Can be very variable





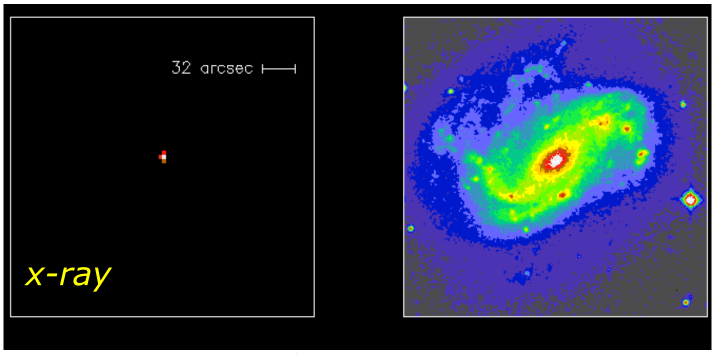
Broad band spectral energy distribution (SED) of a 'blazar' (an active galaxy whose observed radiation is dominated by a relativistic jet 'coming at' us

A large fraction of the total observed energy appears in the γ-ray band (due to relativistic beaming)

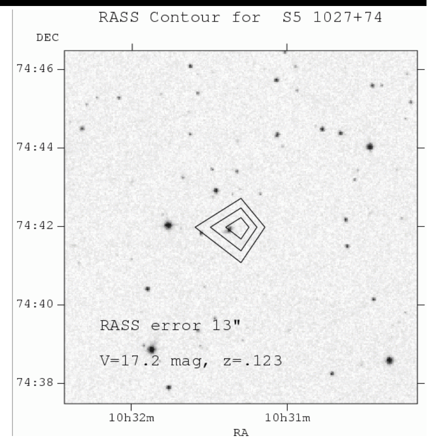
X-ray Selection of Active galaxies

- X-ray and optical image of a nearby AGN NGC4051-
- Note the very high contrast in the x-ray image
- Find x-ray AGN via
  - luminous* pointlike x-ray source in nucleus of galaxy
  - hard x-ray spectrum
  - frequently variable

* Have to distinguish from x-ray binaries located near nucleus

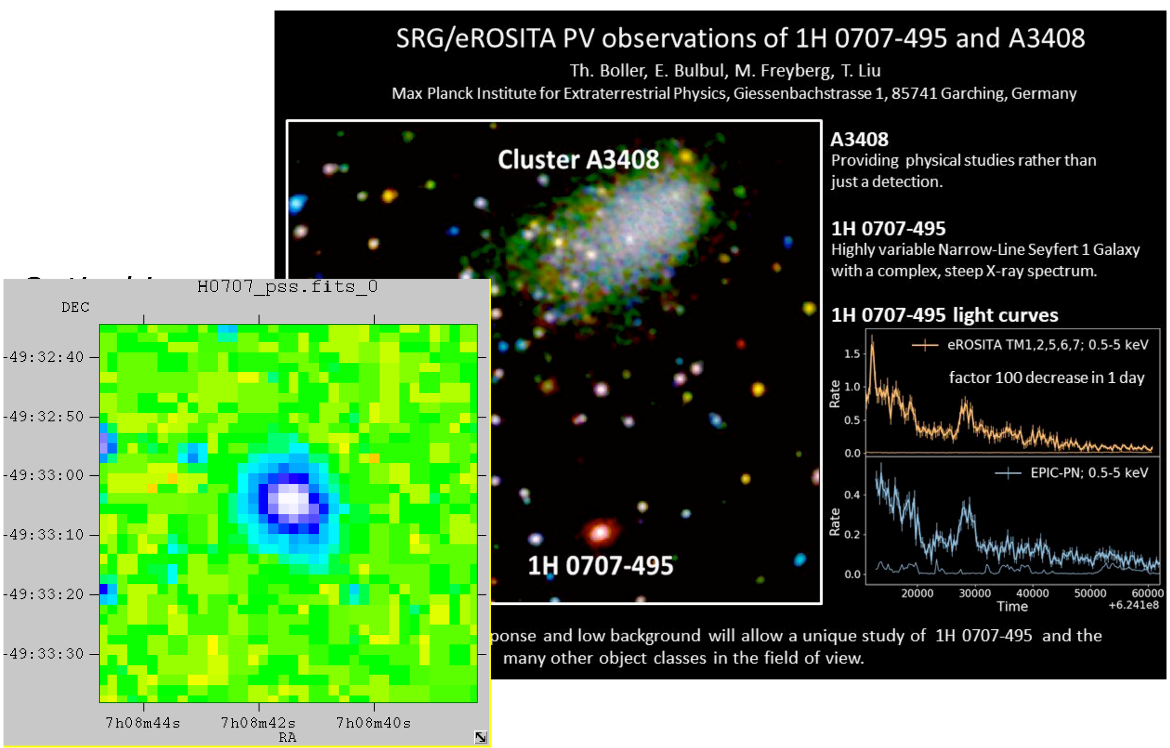


Rosat x-ray all sky survey image overlaid on sky survey image



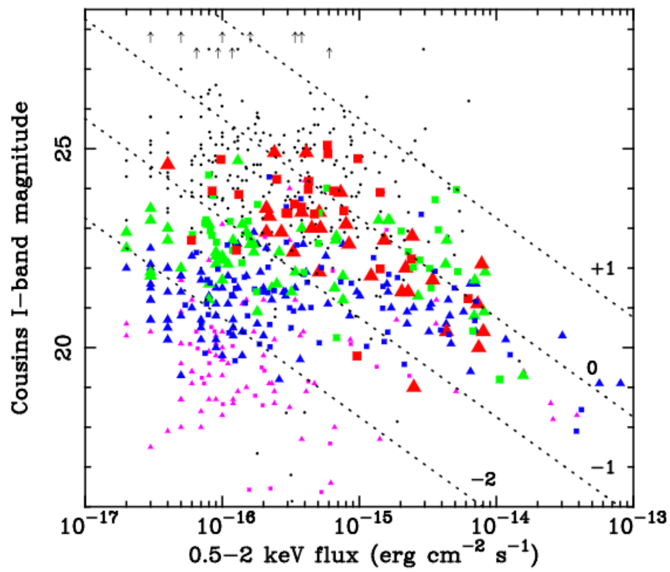
X-ray Selection of Active galaxies

- eRosita X-ray image of a nearby AGN H0707



X-ray Selection of AGN

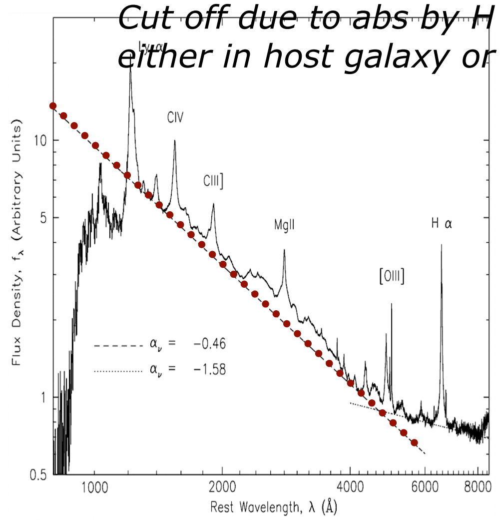
- Comparison of x-ray luminosity of AGN vs the total galaxy luminosity in a 'blind' x-ray survey
- AGN have log L(x)~L(opt)



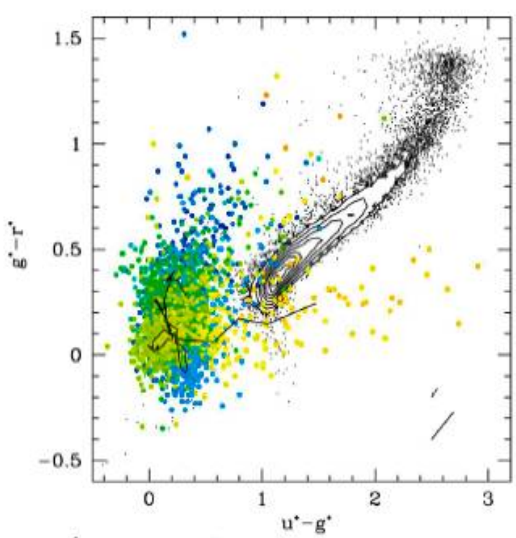
Hasinger and Brandt ARAA 2005
color code is which observation the data were obtained from- **lines represent log of ratio of x-ray to optical flux**

Optical Properties of AGN

- **Strong lines** of hydrogen, carbon, oxygen from highly ionized species ….



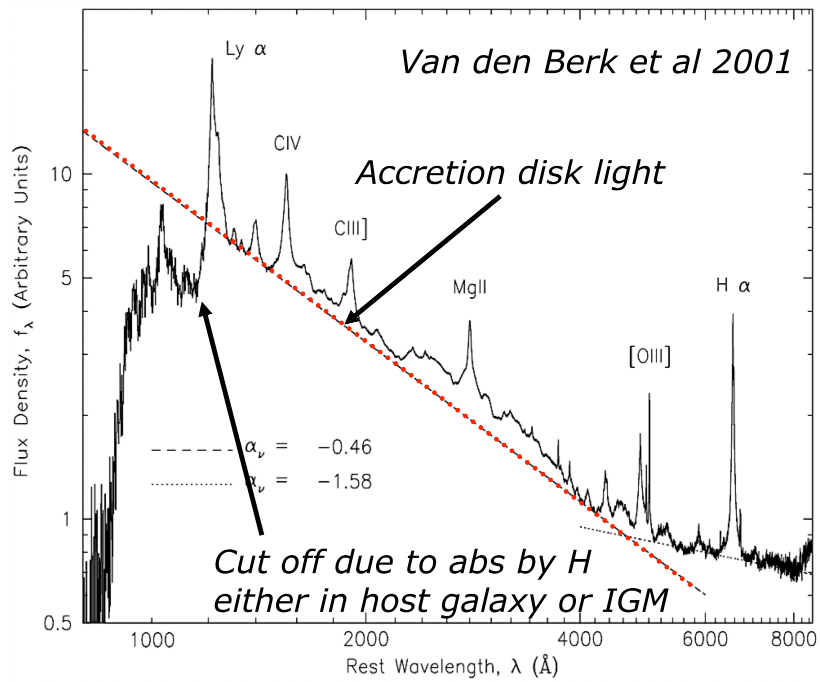
Cut off due to abs by H either in host galaxy or IGM



<u>Unusual optical colors</u> (Richards et al SDSS)- quasars in color, stars are black

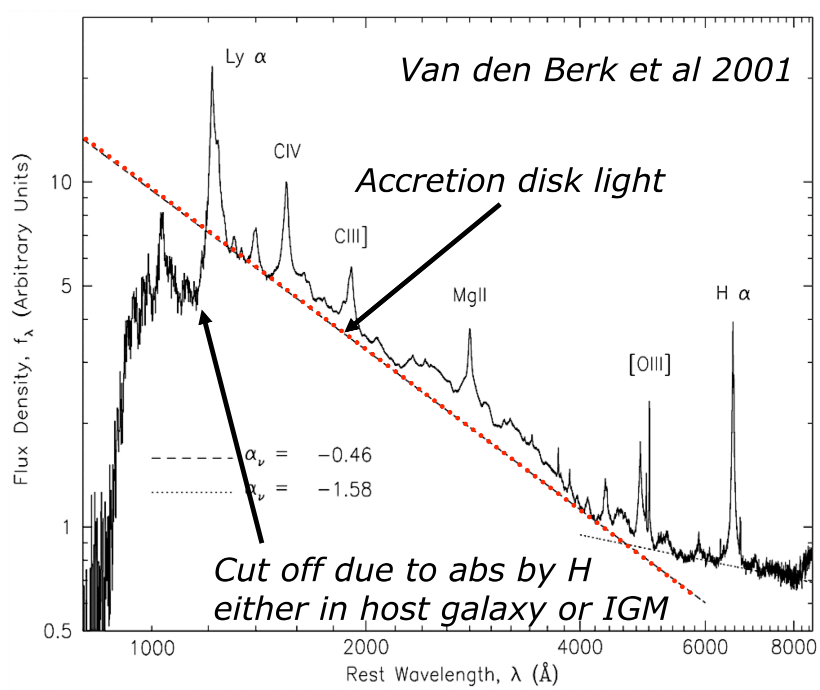
UV-Optical Continuum is thought to arise via thermal emission in an accretion disk

- AGN (type I) optical and UV spectra consist of a 'feature less continuum' with strong 'broad' lines superimposed
- Typical velocity widths (σ, the Gaussian dispersion) are ~2000-5000km/sec



Origin of λ>4000Å continuum not know

- The broad range of ionization is due to the 'photoionzation' of the gas- the gas is **not** in collisional equilibrium
- At short wavelengths the continuum is thought to be due to the accretion disk



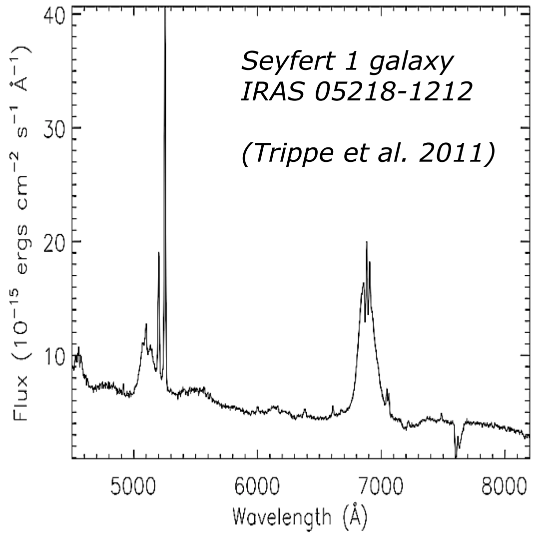
Origin of λ>5000Å continuum is complex

AGN Unification

Broad line (type-1) objects

- **Blue optical/UV continuum**
- **Broad** optical/UV lines
  - Emission lines from permitted (not forbidden) transitions
  - Photoionized matter $n>10^9 cm^{-3}$
  - BLR lines FWHM~2000-20000 km/s
- **Narrow** optical/UV lines
  - Emission lines from both permitted and forbidden transitions
  - FWHM~500km/s
  - Sometimes spatially resolved 0.1-1kpc

- ***Overall spectrum reveals unabsorbed/unreddened nucleus***



Seyfert I Composite Spectra (SDSS)

- Pol& Wadadekar 2016

UV-N

TABLE 2
MEASURED EMISSION LINES

Line Identification	Wavelength (Å)
Lyα	1216
C IV	1548, 1550
He II₁	1640
C III]	1908
C II]	2326
[Ne IV]	2424
Mg II	2796, 2803
[Ne V]	3426
[O II]₁	3726, 3729
[Ne III]	3869
Hγ	4340
[O III]₁	4363
He II₂	4686
Hβ	4861
[O III]₂	5007
He I	5876
[O I]	6300
[N II]	6584
Hα	6563
[S II]₁	6717
[S II]₂	6731
[Ar III]	7135
[O II]₂	7319, 7330
[S III]₁	9069
[S III]₂	9532

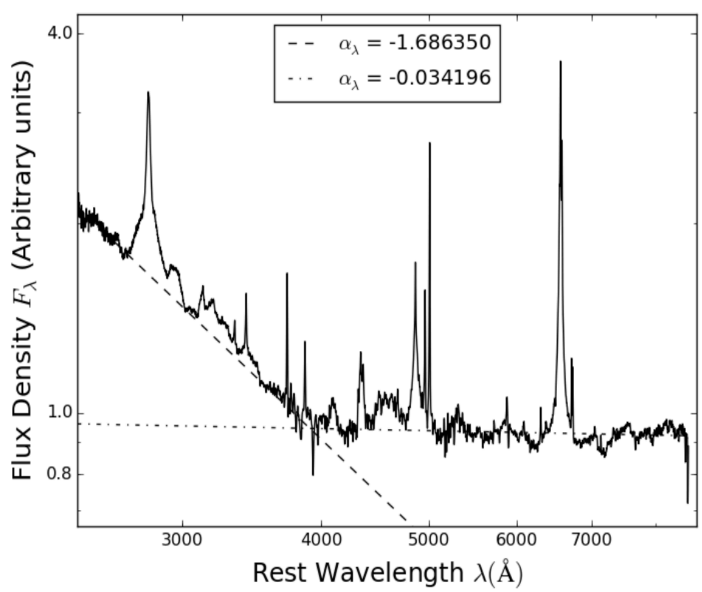


Figure 4. Seyfert 1 composite spectrum generated using m

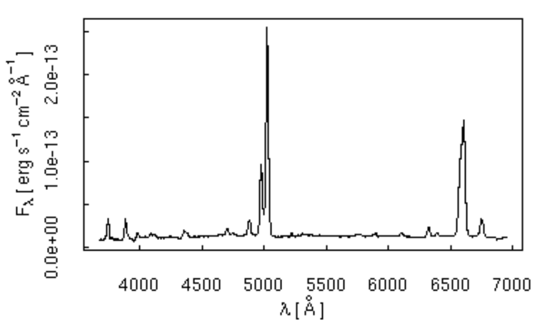
- Notice wide range of ionization of lines OI- NeV
- Permitted and forbidden [..] lines

MEASURED EMISSION LINES

Line Identification	Wavelength (Å)
Lyα	1216
C IV	1548, 1550
He II$_1$	1640
C III]	1908
C II]	2326
[Ne IV]	2424
Mg II	2796, 2803
[Ne V]	3426
[O II]$_1$	3726, 3729
[Ne III]	3869
Hγ	4340
[O III]$_1$	4363
He II$_2$	4686
Hβ	4861
[O III]$_2$	5007
He I	5876
[O I]	6300
[N II]	6584
Hα	6563
[S II]$_1$	6717
[S II]$_2$	6731
[Ar III]	7135
[O II]$_2$	7319, 7330
[S III]$_1$	9069
[S III]$_2$	9532

AGN Unification Narrow line (type-2) objects

- Reddened Optical/UV continuum
- Emission line spectrum
  - "Full light" spectrum only shows narrow optical/UV lines
  - Broad optical/UV lines seen in polarized light… shows that there is a hidden broad line region **seen in scattered light** (Antonucci & Miller 1985)
- **X-ray spectrum usually reveals highly absorbed nucleus (NH>10^{22}cm-2)**

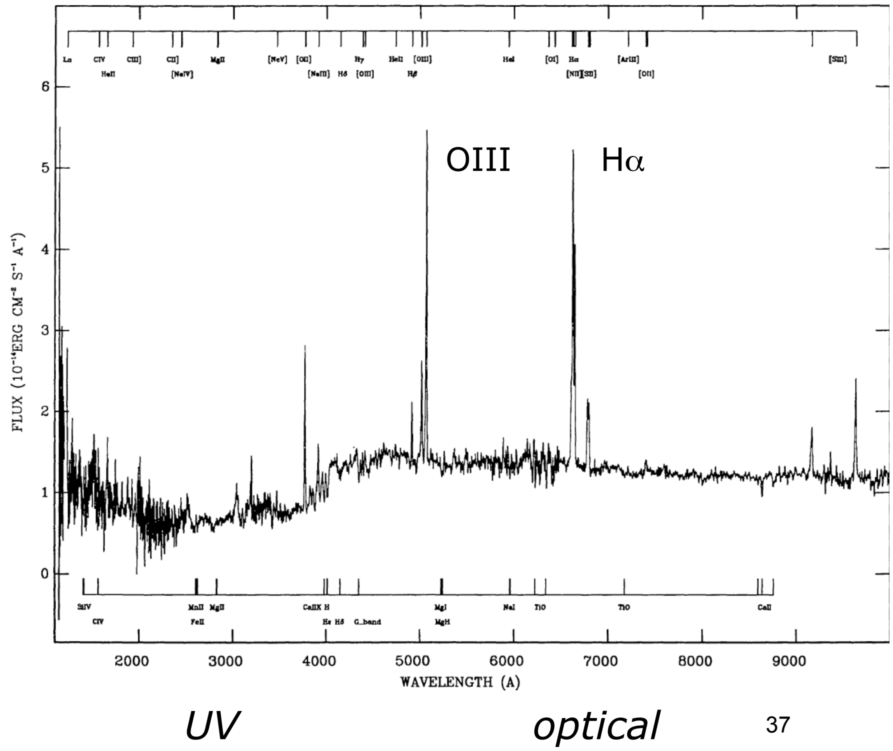


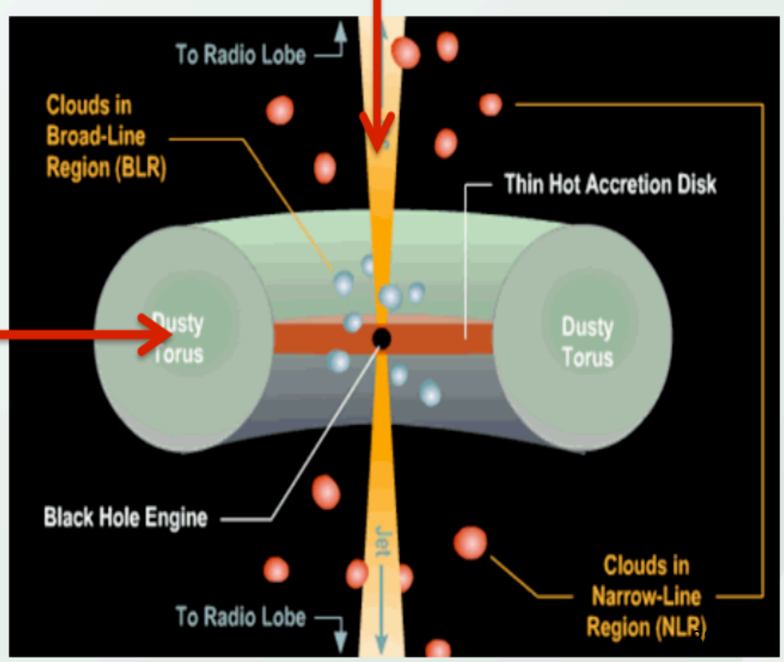
*type II **do not have broad lines and have a weak or absent 'non-stellar' continuum***

Depending on the type of survey and luminosity range ~50% of all AGN are of type II

Seyfert II Optical/UV spectrum

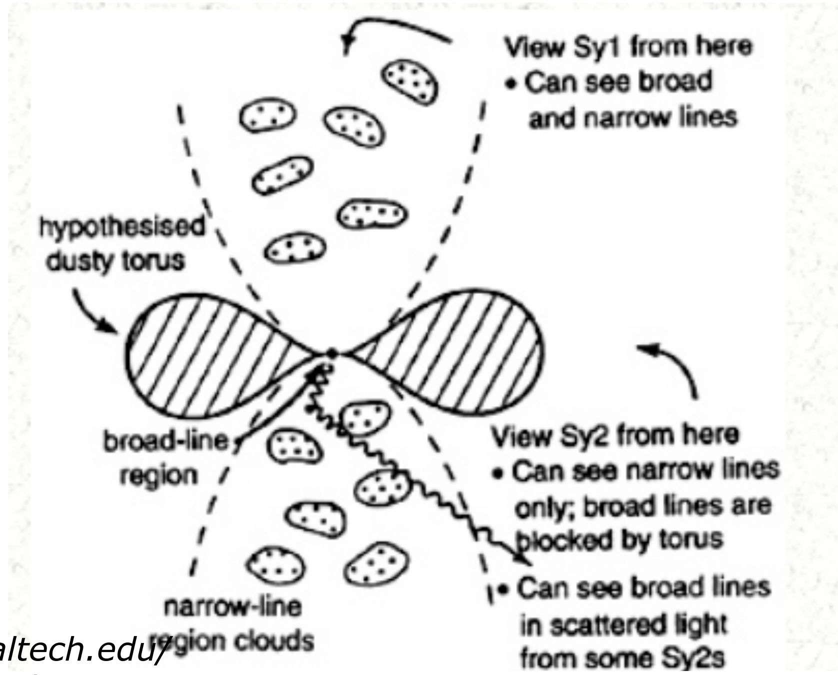
- Only narrow lines , weak UV spectrum





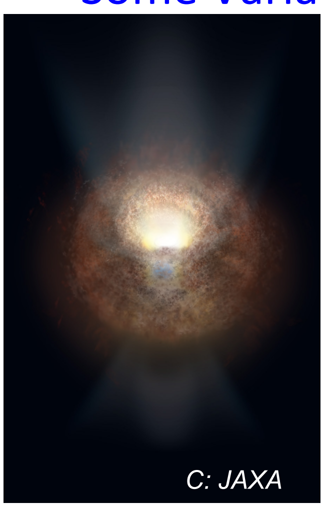
- Anna Feltre

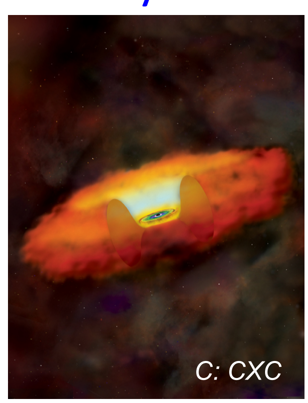
"See" Into Central Regions via Scattering

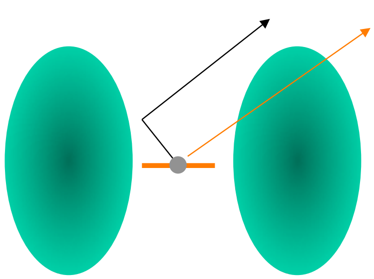


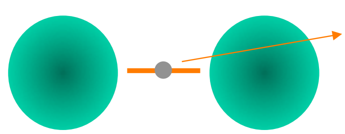
https://ned.ipac.caltech.edu/level5/March02/Roy/Roy_contents.html

Some Variation in Geometry


C: JAXA

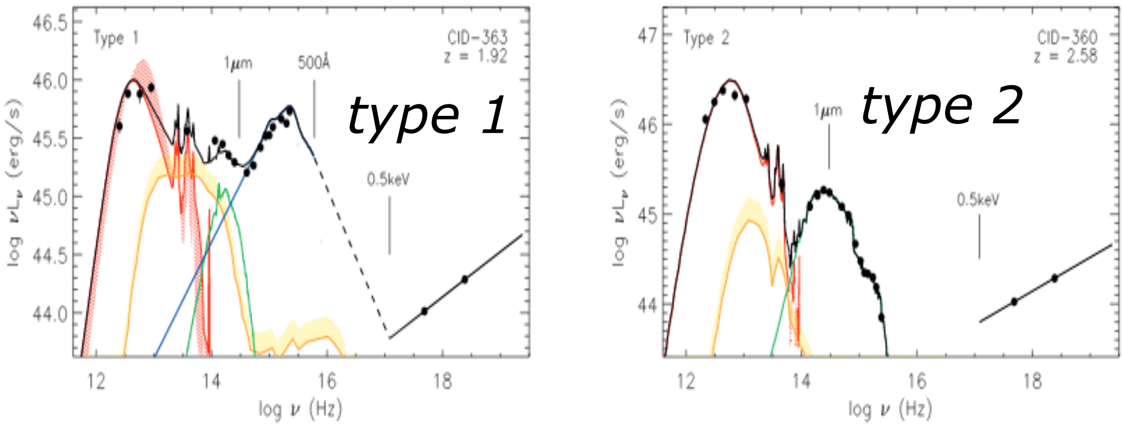

C: CXC





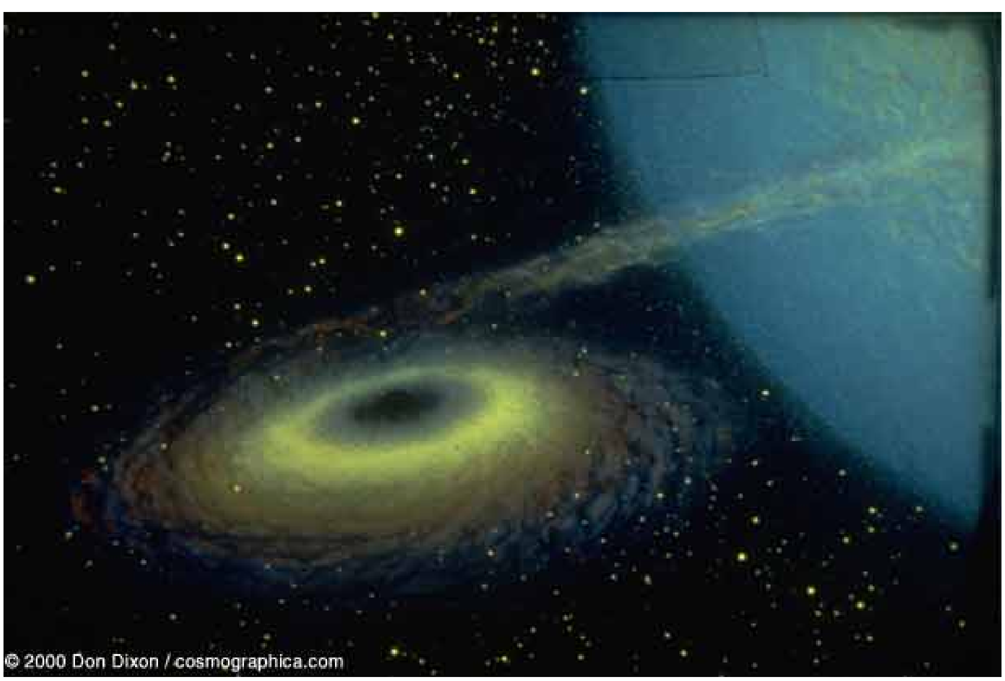
- Effects of geometry can be seen in the spectra

Total Emission-Galaxy+AGN



- Red is dust emission from star formation
- Green is starlight, **yellow AGN driven dust emission**, blue accretion disk (Suh et al 2018)

Spectra of accreting black holes



How are the Masses of SMBHs Determined