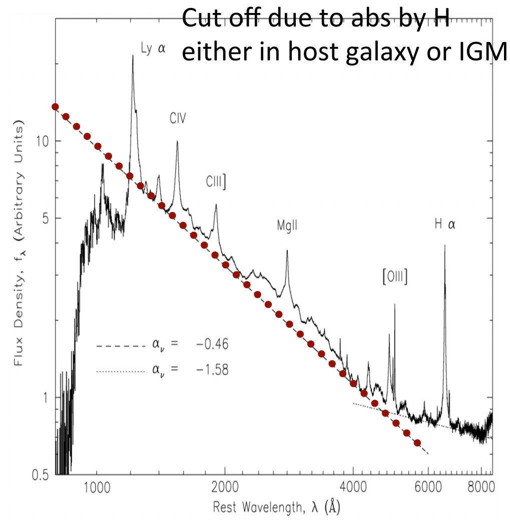
AGN

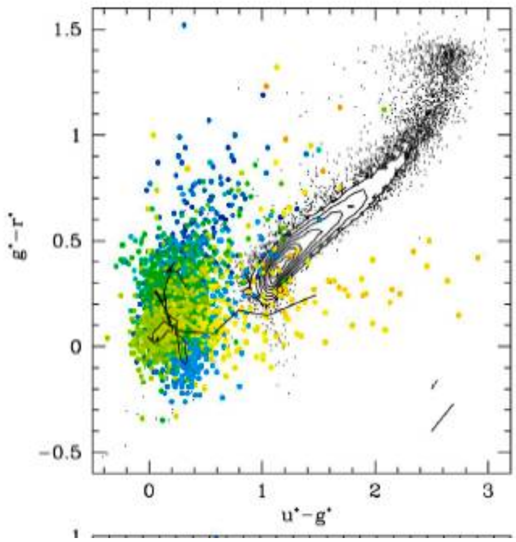
Finding AGN

- Optical: unusual colors, strong lines not like stars, time variability
- Radio: jets, double lobe sources
- X-ray: Luminous point like source in nucleus
- Infra-red: unusual colors

Optical Properties of AGN

- **Strong lines** of hydrogen, carbon, silicon ….



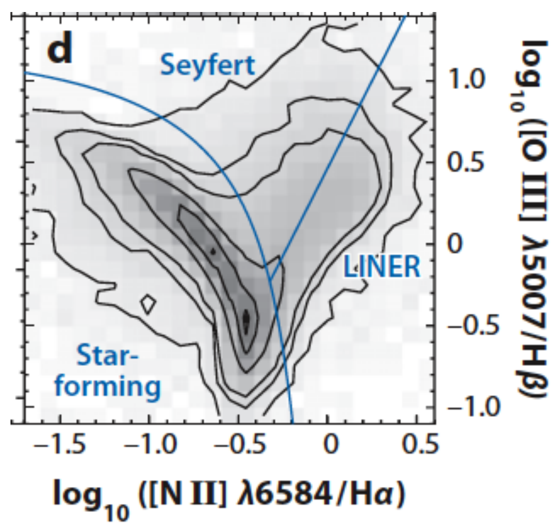


Unusual optical colors (Richards et al SDSS)- quasars in color, stars are black

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

Optical Emission Lines

- Remember that star forming galaxies also can have strong emission lines
- *AGN emission line ratios are different*- indicating ionization by a different type of source ('harder' spectrum- more energy at shorter wavlengths than stars)



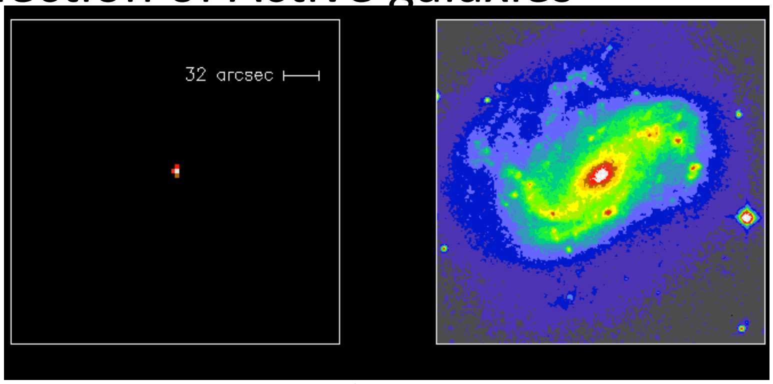
line ratio plot NII/Hα compared to OIII/Hβ−

AGN lie in a particular part of this diagram

Darkness of plot is log of the number of objects inside the contour

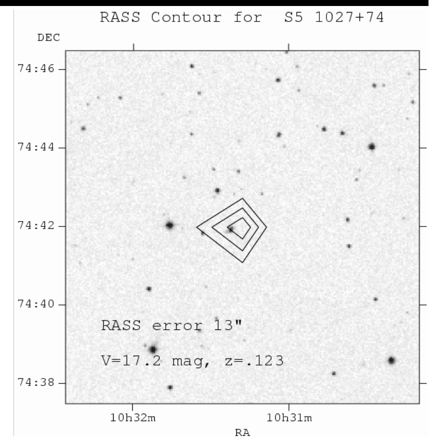
X-ray Selection of Active galaxies

- 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

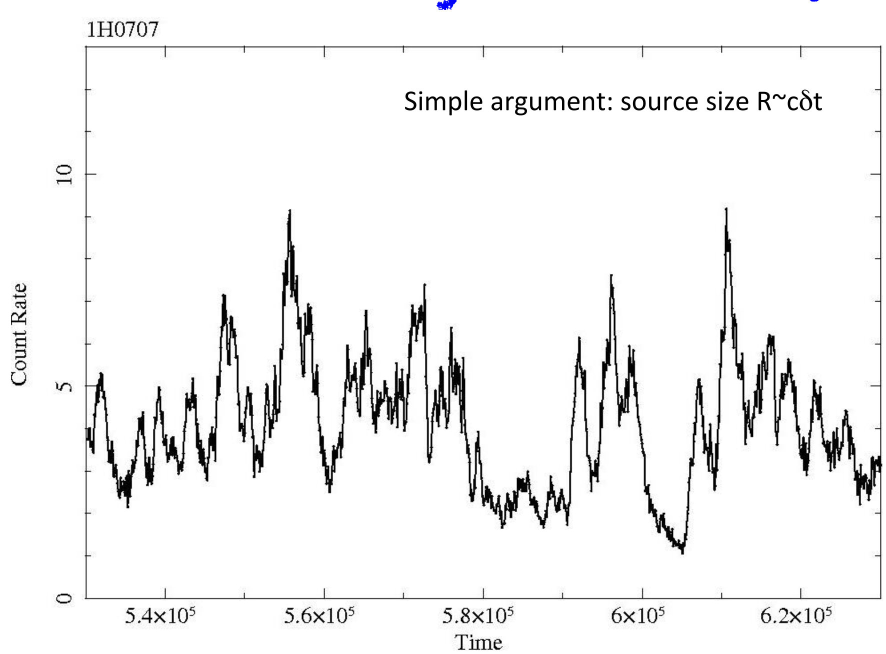


* Find lots of AGN 'hidden' at other wavelengths

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



Rapid variability in AGN
Source luminosity ~5×10^{43} ergs/sec



Rapid High Amplitude Variability

- Strong variability is often detected in the radio, optical, UV and x-ray (NGC5548 Edelson et al 2015

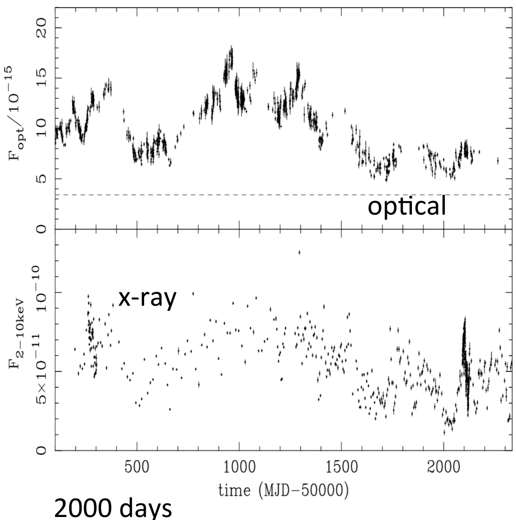
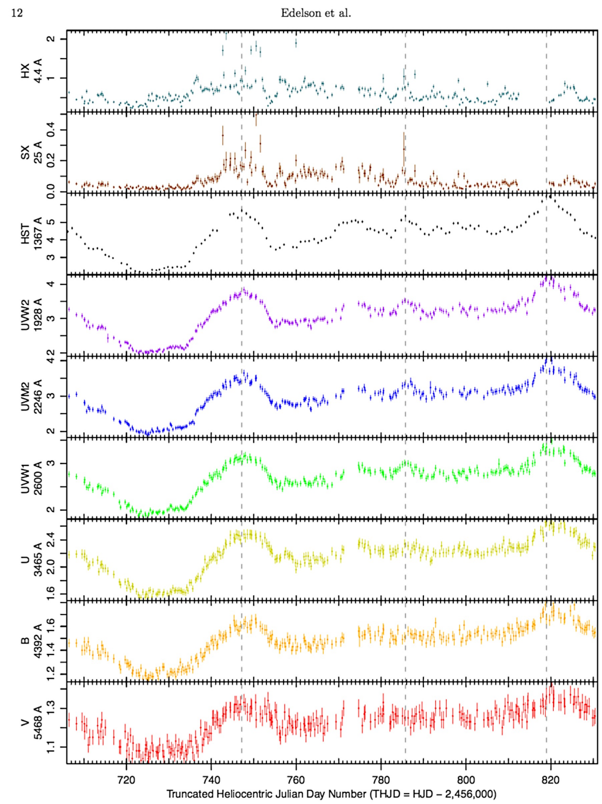
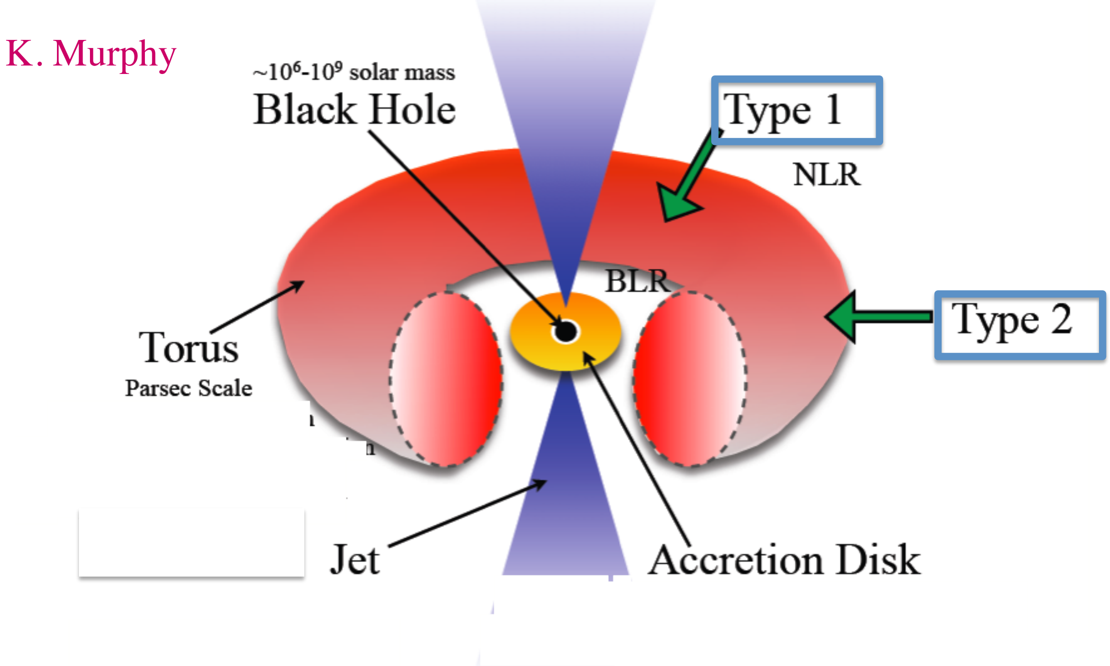


Fig. 1.— Long-term optical 5100Å (top) and X-ray 2-10 keV (bottom) light curves of



100 days

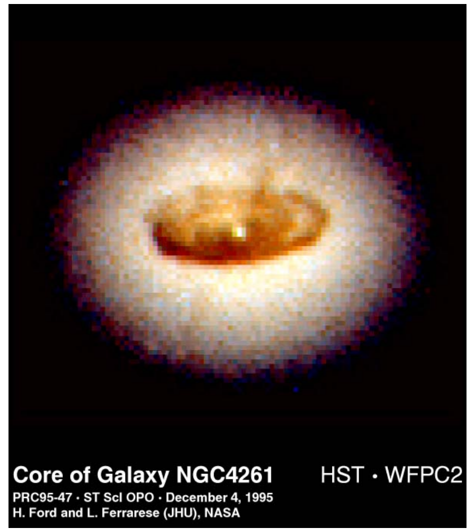
Active Galactic Nucleus

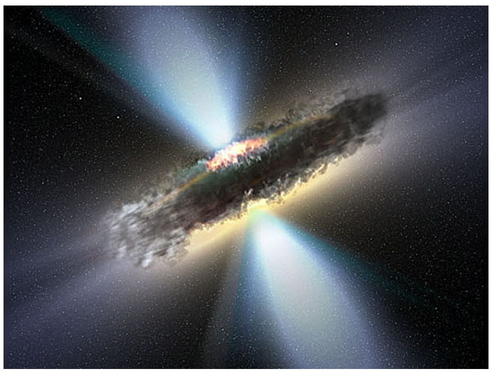


The Dark Side of AGN

- ***Many AGN are obscured***- obscuring material is of several types
  - Located in the ISM of the host galaxy
  - A wind associated with the AGN
  - An ‘obscuring torus’

Lack of uniform sample not sensitive to absorption or emission from this structure has limited knowledge of true distribution of properties



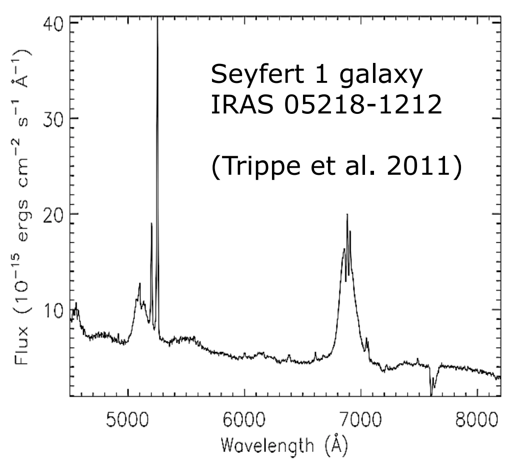


physical conditions in obscuring regions are not the same from object to object - can be complex with large and unpredictable effects on the spectrum

AGN Types

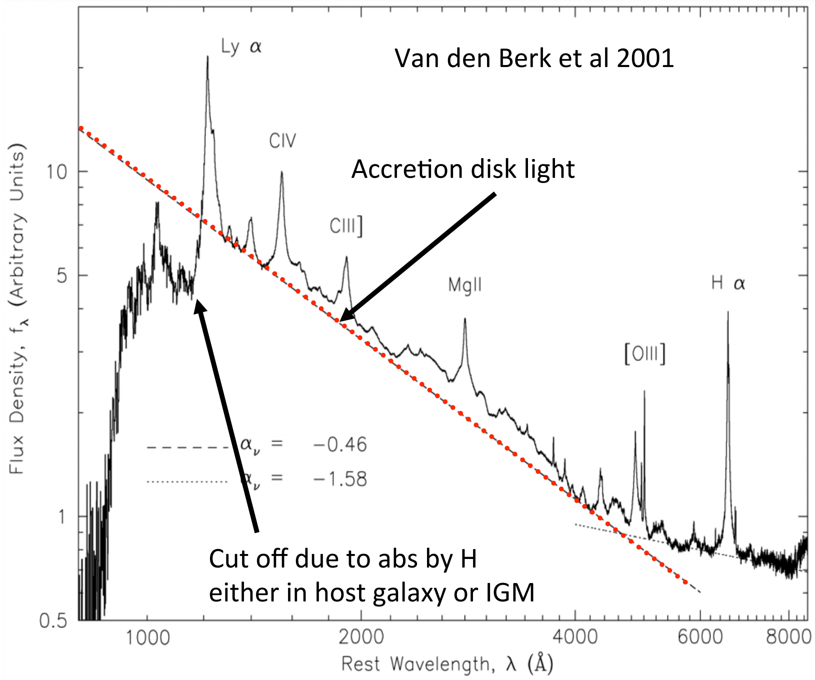
Optical Broad line (type-1) objects

- 'Blue' optical/UV continuum
- Broad optical/UV lines
  - Emission lines from permitted (not forbidden) transitions
  - Photoionized matter $n>10^9 cm^{-3}$
  - FWHM~2000-20,000 km/s
- Narrow optical/UV lines
  - Emission lines from both permitted and forbidden transitions
  - FWHM~500km/s
  - Spatially resolved 0.1-1kpc



Hβ, [OIII], [NII],Hα

- 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
- 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



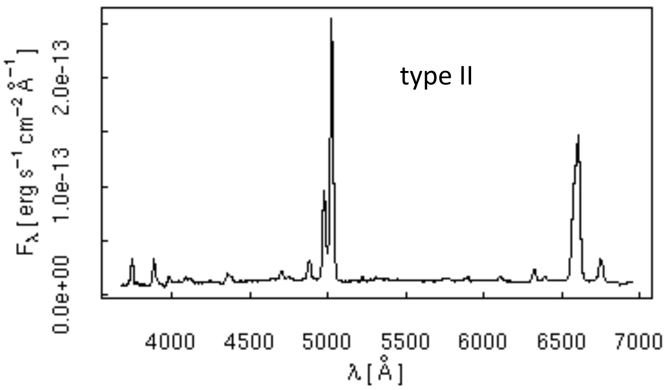
Origin of λ>4000Å continuum not known

AGN Types
Narrow line (type-2) objects

- Very little optical light from nucleus
- Optical Emission line spectrum
  - "Full light" spectrum only shows narrow (~500km/sec) optical/UV lines
    - Broad optical/UV lines seen in *polarized* light… shows that there is a hidden broad line region seen via scattering (Antonucci & Miller 1985)
- **X-ray spectrum usually reveals highly absorbed nucleus (N_H>10^{22}cm^{-2})**

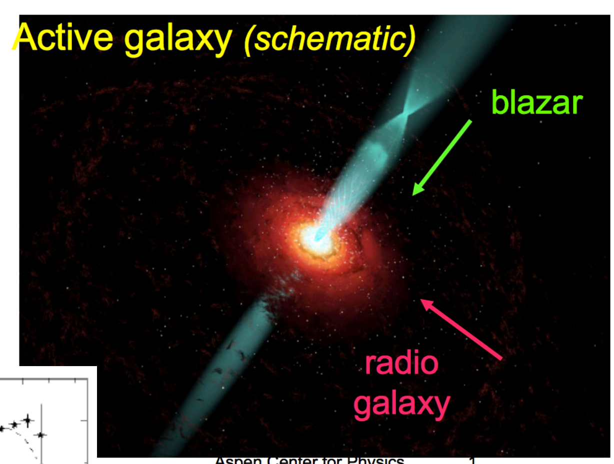
Objects without a Strong Continuum-e.g type II

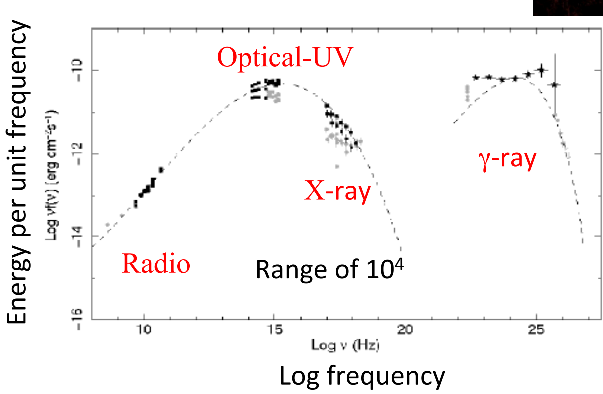
- type II do not have broad lines and have a weak or absent 'non-stellar' continuum
- Strong absorption in x-ray band **N_H>10^{22}cm-2**
- Depending on the type of survey and luminosity range ~50% of all AGN are of type II



- Featureless (no lines) broad band continuum radio-gamma rays
- Thought to be due to emission from jet in our line of sight
- Can be very luminous – most luminous γ-ray emitters

AGN types Blazar





AGN Zoo

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

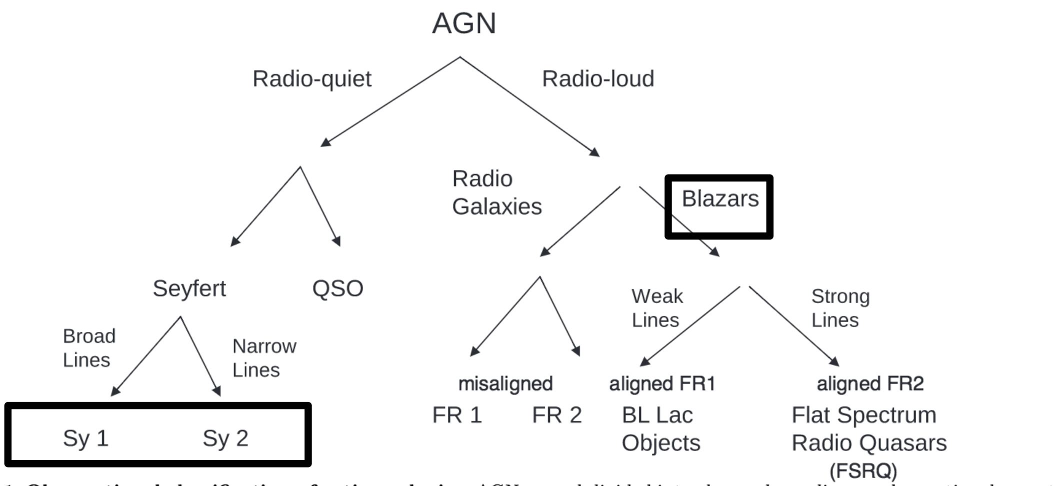
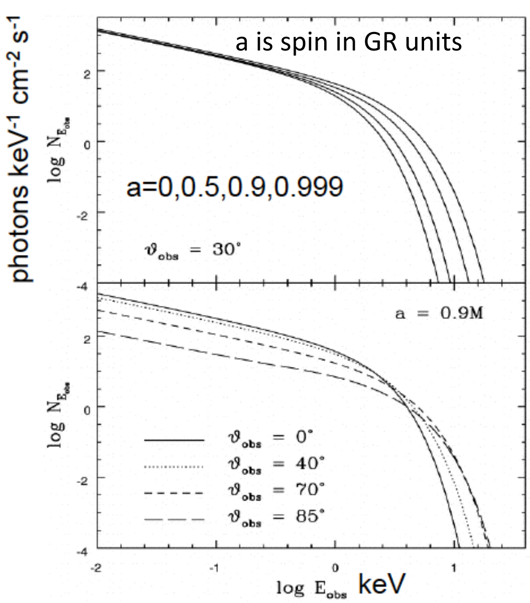
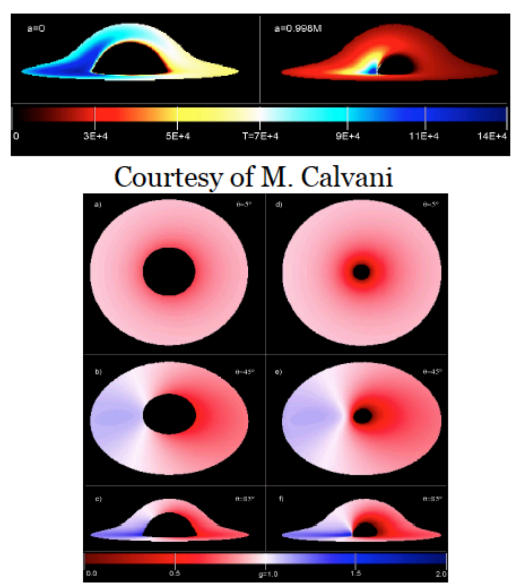


Figure 1. **Observational classification of active galaxies.** AGN are subdivided into classes depending on observational aspects, such as their radio loudness or the presence of optical lines in their spectra. QSO = quasi-stellar objects; Sy1 and Sy2 = Seyfert 1 and 2; FR1 and FR2 = Fanaroff-Riley 1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

Effects of Strong Gravity (Spin), Inclination Angle on Spectrum of Disk (Merloni 2010)





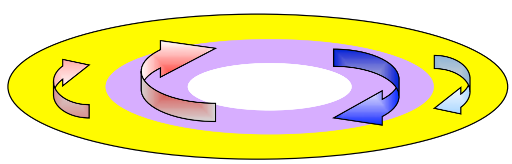
Zheng et al. 1997; Li et al. 2005; Shafee et al. 2006; McClintock et al. 2006; Nowak et al. 2008; Steiner et al. 2010; Kubota et al. 2010

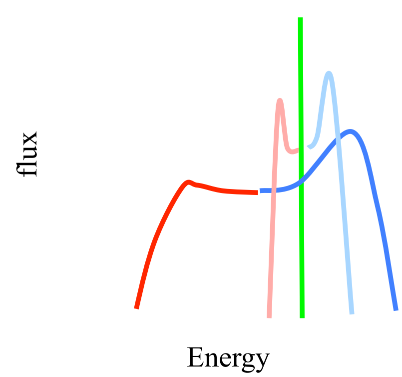
How Does Accretion Work

- Because of conservation of angular momentum, as the material falls in, it produces an accretion disk (fig 9.3)
- The accretion disk is hotter in the center and has a relatively simple temperature and emissivity profile
  - but as the gas spirals into the black hole special and general relativistic effects become large, strongly effecting the emergent spectrum

Relativistic effects- C. Done

- Relativistic effects (special and general) affect all emission (Cunningham 1975)
- Fe Kα line from irradiated disc – broad and skewed! (Fabian et al 1989)
- Broadening gives an independent measure of R_{in} – so spin if ISO (Laor 1991)





Radio Loudness	Names and 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)- **ONLY in ELLIPTICAL Galaxies**	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

Evolution of AGN Over Cosmic Time

The number of and luminosity of AGN varies greatly over cosmic time

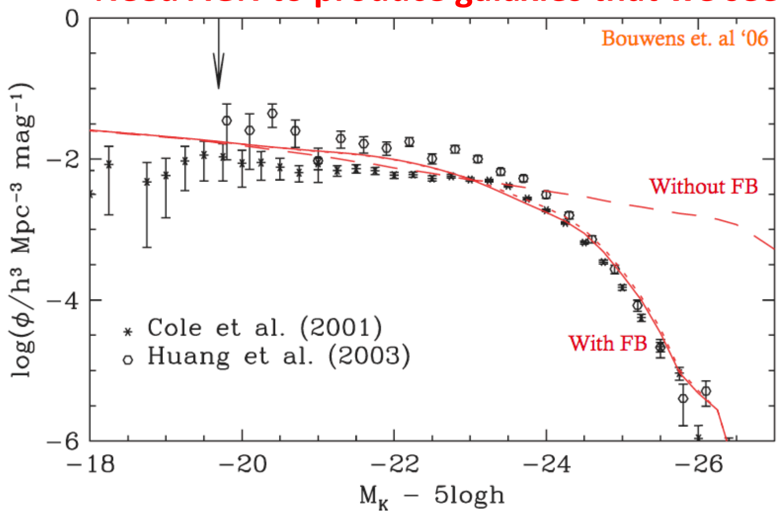
AGN where much more numerous and more luminous (on average) out to z~2
At z>2 the evolution reverses with AGN becoming much rarer at higher redshifts.

This evolution in number and luminosity can be 'inverted' under certain assumptions to derive the growth of black holes over cosmic time

Major questions still remain:
does the relationship of the black hole to its host galaxy change of $\sim 10^{10}$years
How does black hole spin change
What is the relative importance to growth of accretion vs mergers?
How often are black holes 'on' (e.g. radiating) e.g. duty cycle of activity

AGN Feedback

Need AGN to produce galaxies that we see today



Luminosity function of galaxies in the local universe

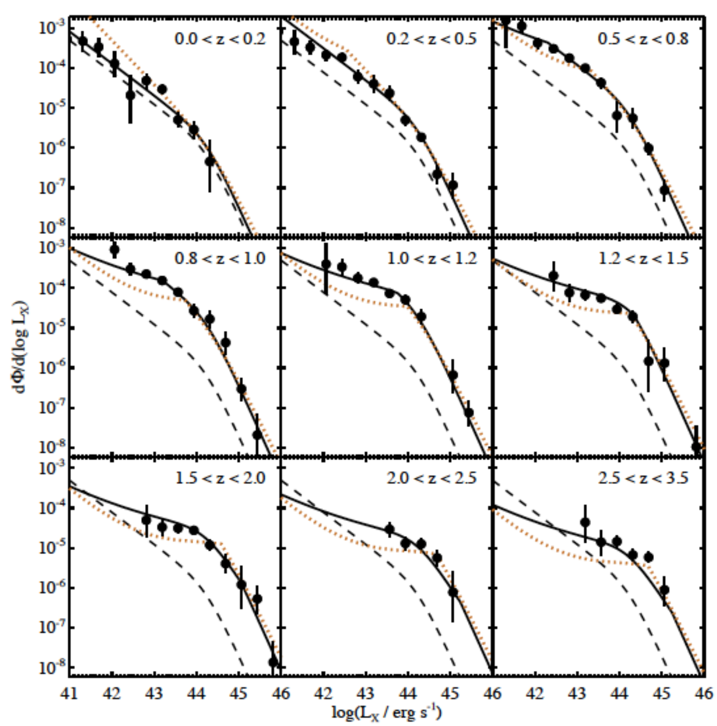
Without AGN Models:

- overpredict luminosities of massive galaxies by ~2 mags
- predict a number of massive blue galaxies much higher than observed
- get galaxy evolution wrong

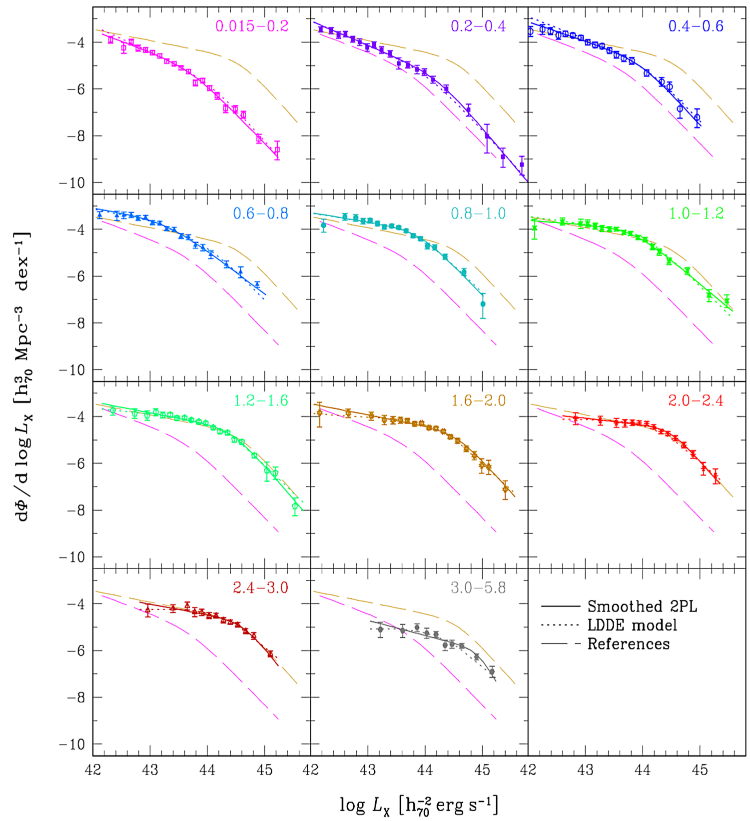
- The Evolution in the Luminosity Function of BH vs cosmic time
- #/Volume/luminosity
- In each plot the dotted grey line is the z=0 function
- Notice that the number of and luminosity of AGN increases up to z~2 and then declines.

Luminosity function vs z

Aird et al 2009

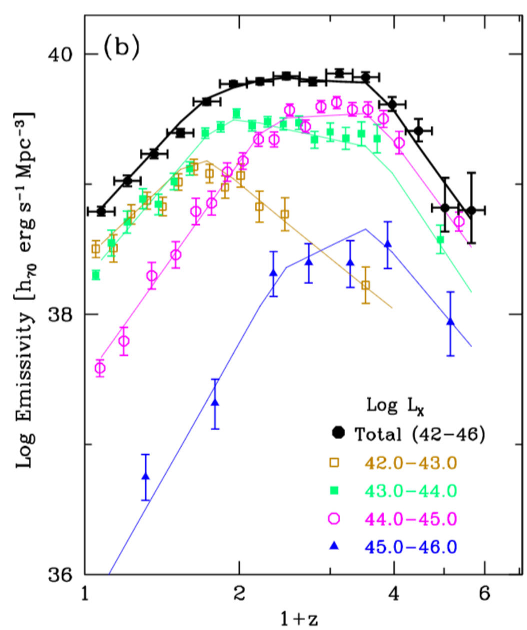


- Miyaji et al 2015



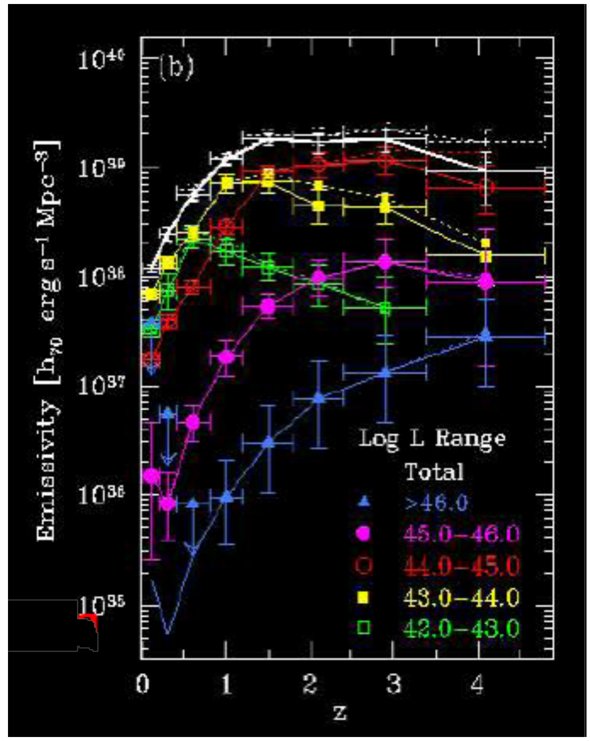
How the AGN Luminosity Function Evolves with Cosmic Time

- ~3200 unique X-ray AGNs from
- a combination of wide to deep samples covering the redshifts of 0.015< z <5.8 and six orders of magnitude in flux (Miyaji 2015)



Transform Luminosity Function to Energy Emissivity

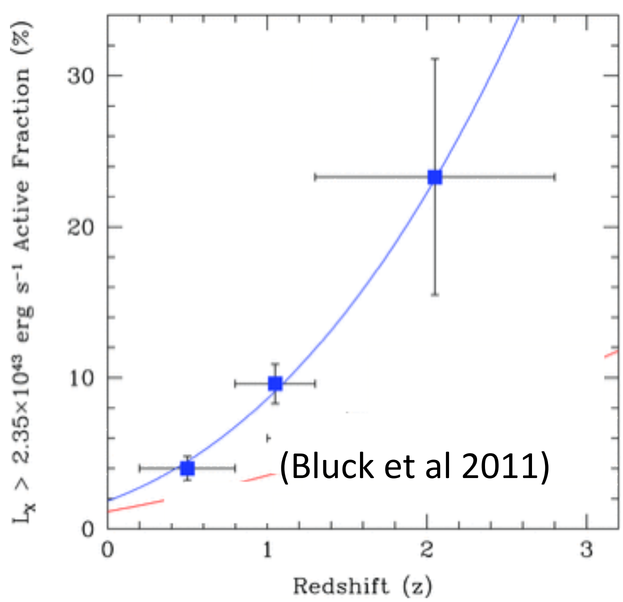
- Integrate the luminosity function in redshift shells
- Notice downsizing more luminous objects are more dominant at high redshift and that the evolution is a function of luminosity
- E_{AGN}~1.4 +/- 0.25 x10^{61} erg per galaxy since z = 3.



Brandt and Hasinger 2005 ARAA

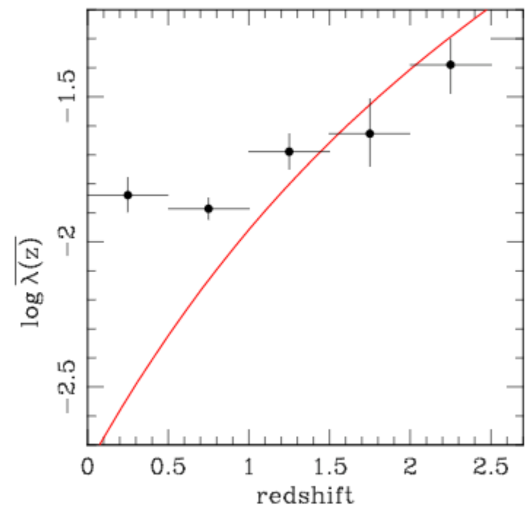
Larger Fraction of Galaxies Active in the past

- The evolution seen in luminosity and number is reflected in the fact that the fraction of 'normal' galaxies that host AGN increases at higher redshifts e.g.galaxies were on average more "active" in the past.
- Extrapolating to z>3 indicates that most galaxies host AGN (!!)



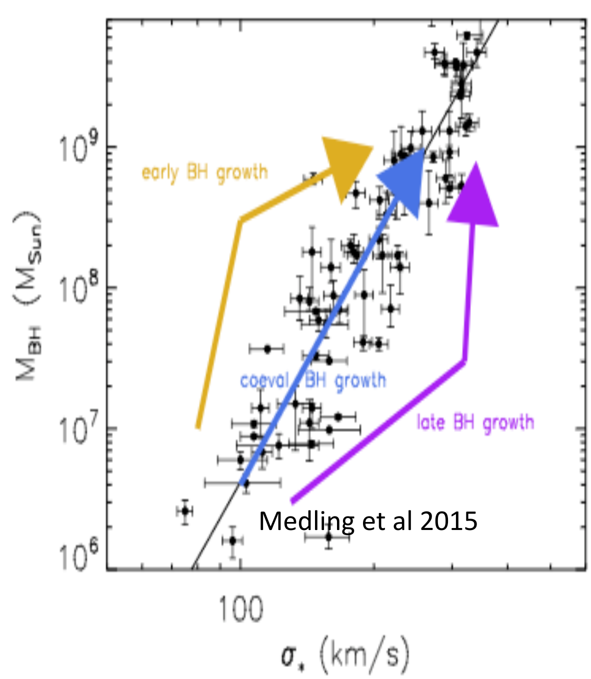
On Average Higher Eddington Ratio

- At higher redshift Eddington ratio increases (ratio of observed luminosity to maximum possible luminosity) Georgakakis et al.2017

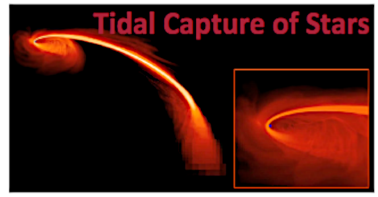


How and When Do Black Holes Grow

Evolution of BH accretion rate and star formation rate have similar
trends - physical mechanisms driving star formation in galaxies and black hole growth are linked



How Do Black Holes Grow?



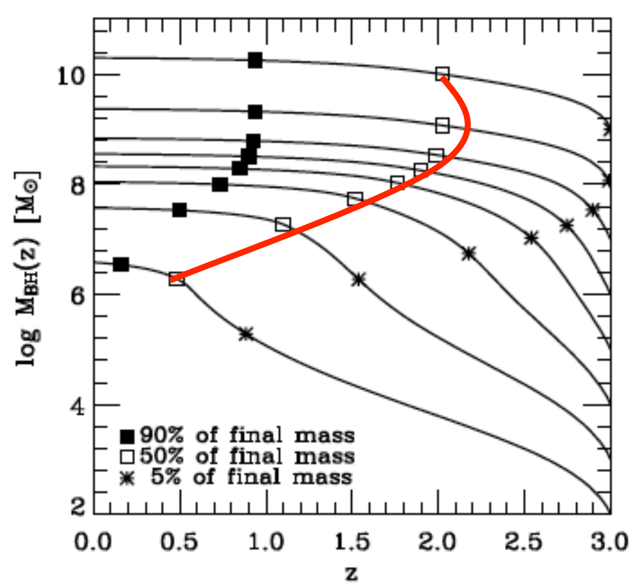
Efficiency of these channels depends on:

Aykutalp 2016 .

- black hole seed masses and cosmic time
- occurrence of merger events
- properties of the central region and of the host galaxy
- larger scale environment of the host dark matter halo
- stellar and black hole feedback processes

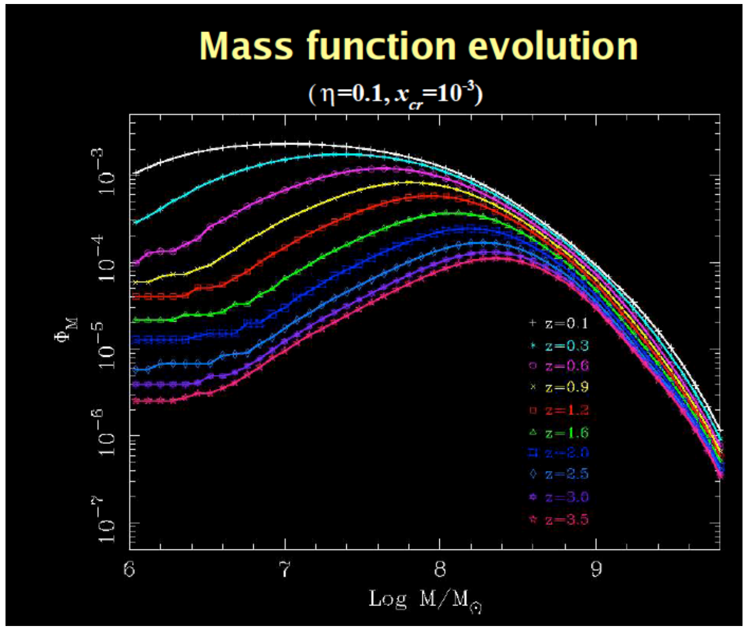
One realization of BH growth

- Big BHs form in deeper potential wells ⇨ they form first.
- Smaller BHs form in shallower potential wells ⇨ they form later and take more time to grow.
  - Marconi 2003, Merloni 2004

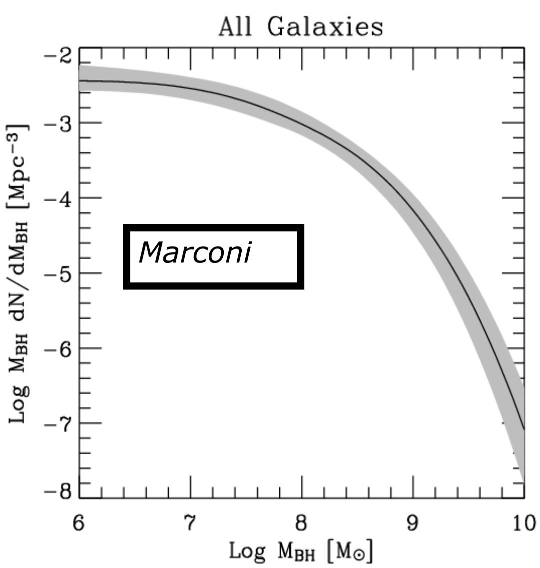


Transform to Mass Growth

- Take accretion rate and some model of initial BH mass distribution and watch them grow (Merloni et al 2006)
- Notice 'down sizing' big black holes grow first and small black holes later



The local Black Hole Mass Function



Marconi et al. 2004

- Convolve Galaxy Luminosity functions with M_{BH}-L_{bul} and M_{BH}-σ to obtain the local BH mass function.
  - M_{BH}-L_{bul} and M_{BH}-σ provide consistent BH mass functions provided that dispersions are taken in to account (shaded area indicates uncertainties)

$\rho_{BH} \sim 4.1^{+1.9}_{-1.4} \times 10^5\ M_\odot\ \mathrm{Mpc}^{-3}$

(cf. Merritt & Ferrarese 2001, Ferrarese 2002, Shankar et al. 2004)

- In summary: 3-5 $\times 10^5\ M_\odot\ \mathrm{Mpc}^{-3}$ (see Ferrarese & Ford 2005 for a review)

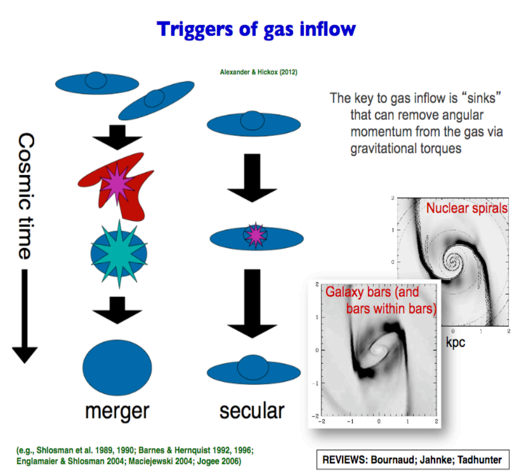
Sizes and Time Variability (see Begelman, Fabian and Rees 2008, Fabian and Rees 1979)

- Assume each emitting region has a size ℓ' in its co-moving frame and is causally connected over a time $\Delta t'$ -- implying $\ell' < c\,\Delta t'$
- In the laboratory frame the time scale is dilated to $\Gamma\Delta t'$ ($\Gamma=1/\mathrm{sqrt}(1-\beta^2)$; $\beta=v/c$
- From an observers point of view the duration is reduced by $1/(1-\beta\cos\theta)$- in the limit $\beta\sim1$ and $\theta<1/\Gamma$ this is $\sim2\Gamma^2$
- Thus a observed time scale $\ell'<c\,t_{var}\Gamma$

- Generalized Efficiency argument (similar to the Eddington limit)
- the mass required to produce a total amount of energy $E=\Delta L\Delta t=\varepsilon Mc^2$ (ε is the efficiency of converting matter to energy)
- This is related to the optical depth τ by $M=4R^2\tau m_p/\sigma$ and the emitted photons emerge on a time scale $\Delta t=R/c(1+\tau)$ − then minimize Δt for a given mass M

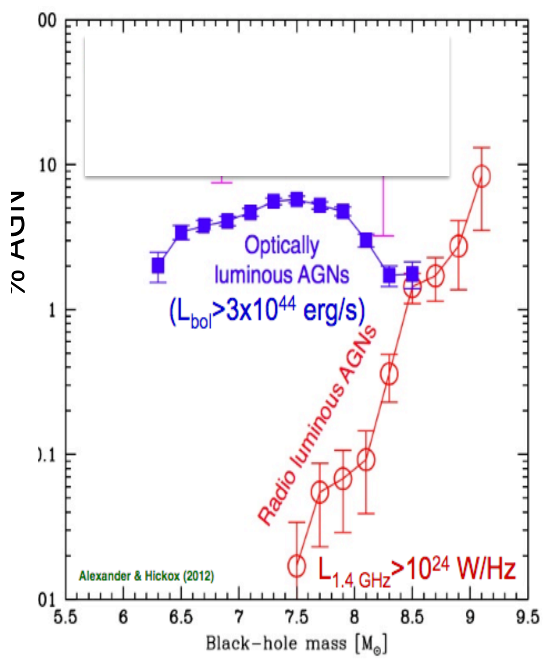
  giving $\Delta L<\varepsilon c^2\,\Delta t m_p/\sigma$
- which for the Thompson cross section and 10% efficiency gives
- $\Delta L<2\mathrm{x}10^{41}\varepsilon_{0.1}\Delta t$ ergs/sec

How Do Black Holes Grow



- Relative importance of mergers vs gas accretion

Local AGN Fraction



Black hole mass

D.Alexander 2014