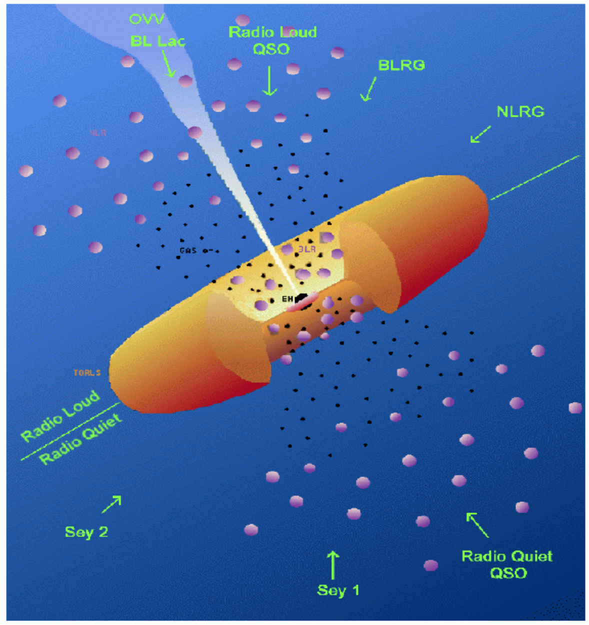
# AGN- Alias **Active** Galactic Nuclei S&G Ch 9.1

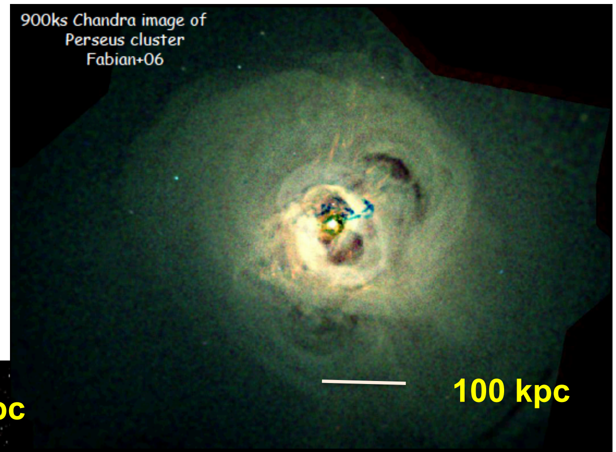
- AGN are **'radiating'** supermassive black holes-
  - Large number of names (Seyert I, Seyfert II, radio galaxies, quasars, Blazars etc etc)
    - The names convey the observational aspects of the objects in the first wavelength band in which they were studied and thus do carry *some* information
  - Are very luminous ($10^{40}$-$10^{48}$ ergs/sec) and seen out to very high redshift (7.5)
- http://nedwww.ipac.caltech.edu/level5/Cambridge/Cambridge_contents.html for an overview OR
- **http://phdcomics.com/comics.php?f=1864**

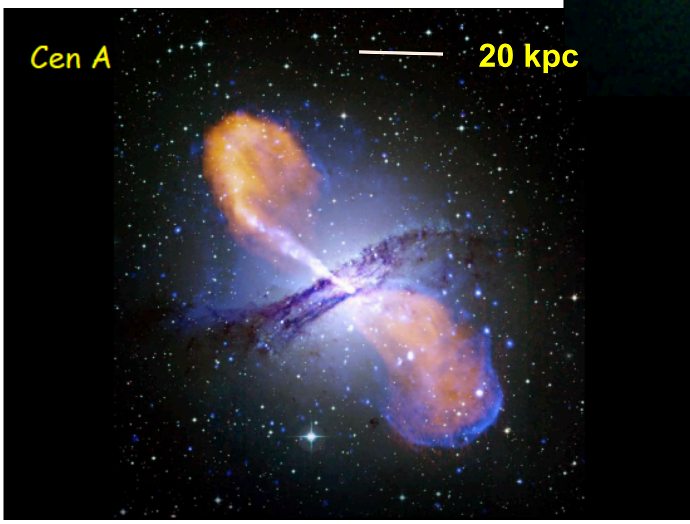



Schemtaic diagram of regions near the SMBH
Urry and Padovani 1995

- http://phdcomics.com/comics.php?f=1864

# AGN- Black Holes can influence their environment on large scales




**It is now believed that almost all massive galaxies have supermassive ($M>10^6 M_\odot$) black holes**

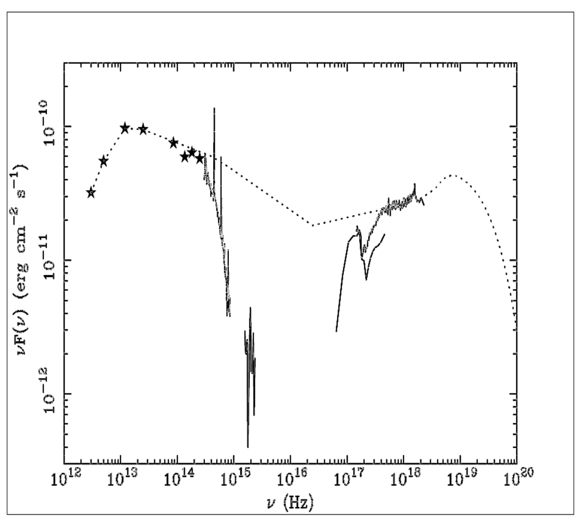
***But at z=0 only ~10% are 'active'***

# What Are Active Galactic Nuclei

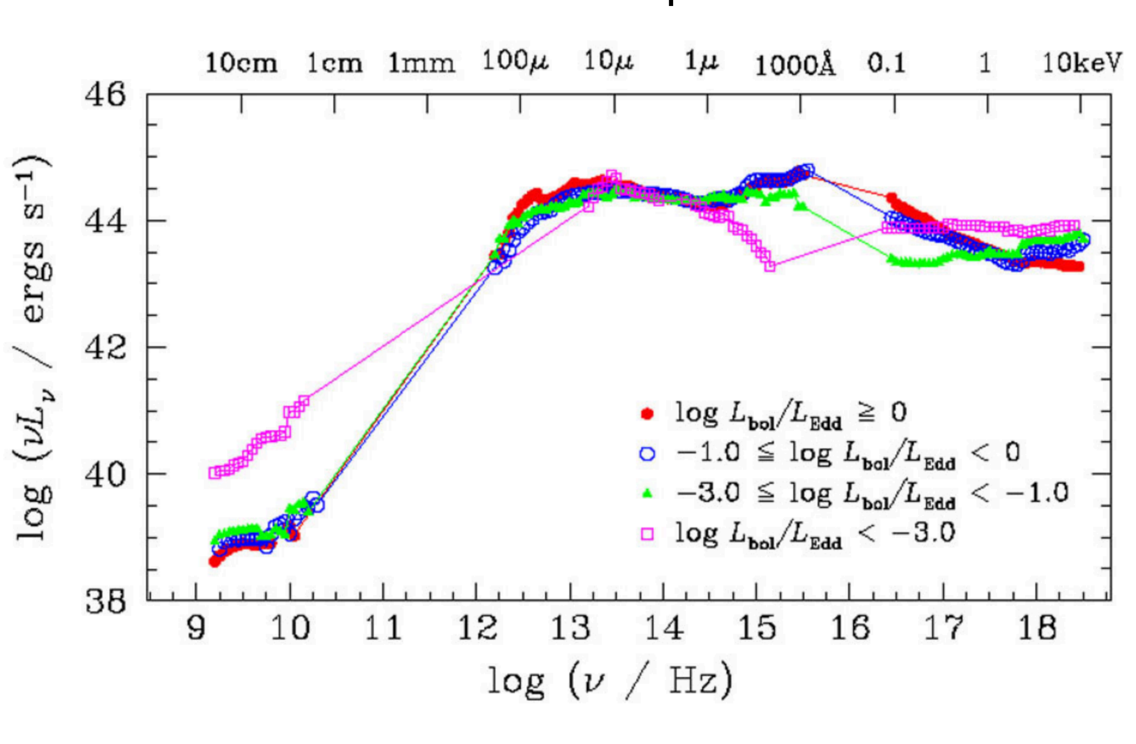
**Radiating** supermassive black holes in the centers of galaxies

Properties

- 'Point-like', variable in intensity
- luminous **non-stellar broad band spectra**- very broad range in luminosity log L~ 40-48 ergs/sec ($10^7$-$10^{15}$x suns luminosity)
- located in center of *some* galaxies (~10% at z~0, higher fraction at higher z)
- More details
  - Optical spectra 3 classes
    - strong broad emission lines
    - strong narrow emission lines
    - strong non-thermal continuum
  - radio ~10% of AGN show strong radio emission (jets/extended emission) due to synchrotron radiation
  - IR- emission reprocessed from optical-UV-soft x-ray
  - X-ray non-thermal power law spectra highly variable



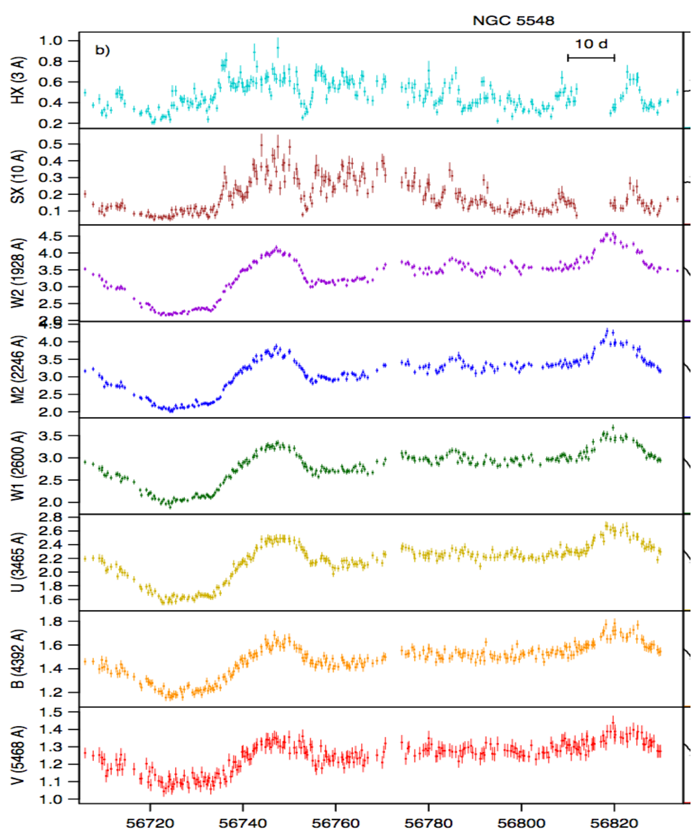
# AGN Broad band Spectrum



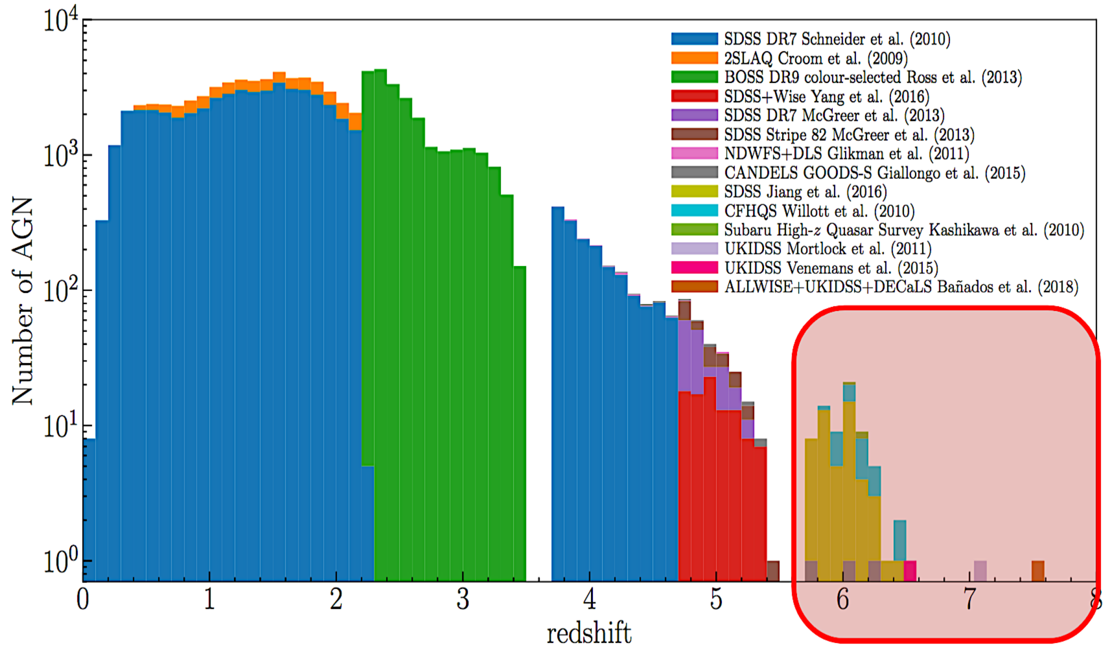

- https://ned.ipac.caltech.edu/level5/March08/Ho/Ho5.html

## AGN Variability

- AGN are variable across the entire EM spectrum with large amplitude. (Edelson et al 2018)
- Notice for NGC 5548 a factor of 5 change in a few days in the x-ray intensity



# AGN in the first billion years

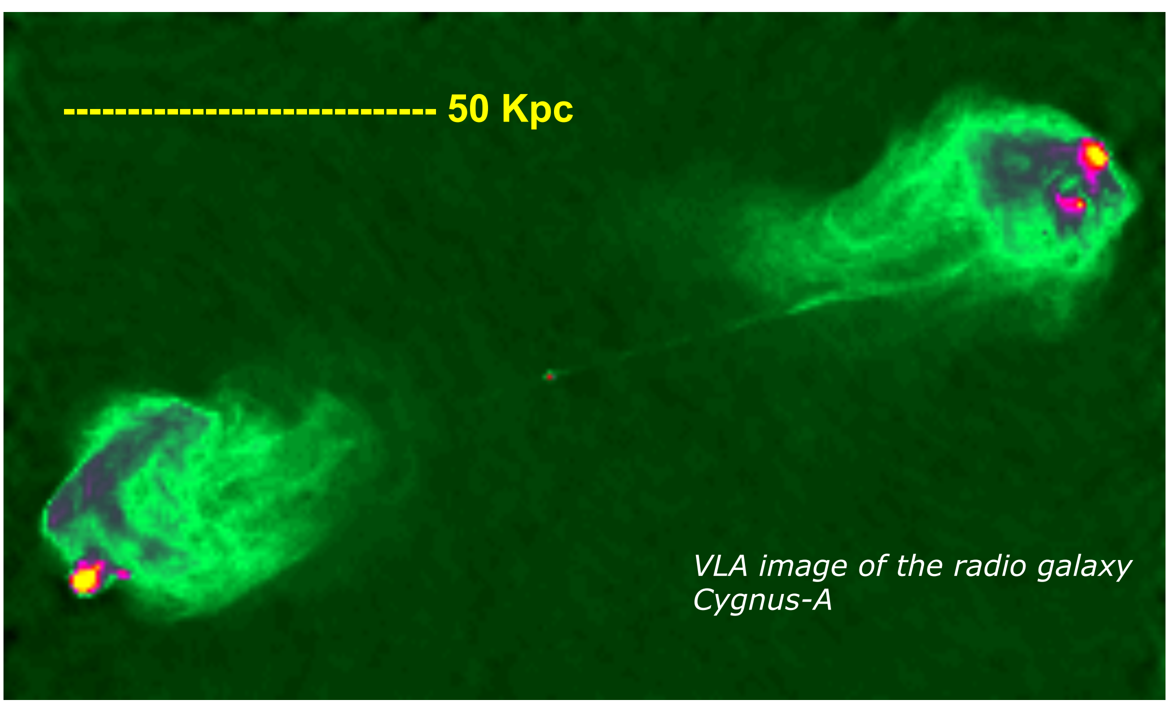


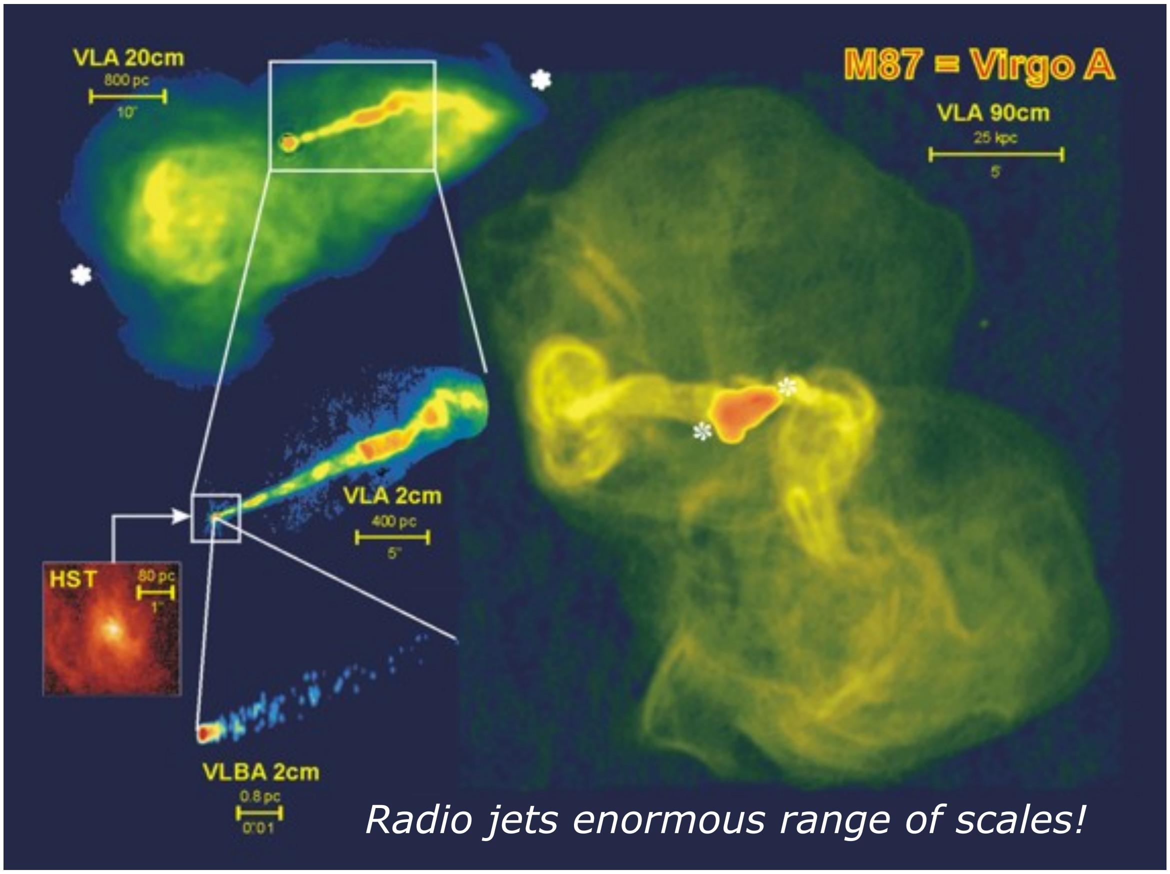

Kulkarni+ 2018

**$8 \times 10^8 M_{sun}$ black hole**
**690 Myrafter Big Bang!**

Eduardo Bañados

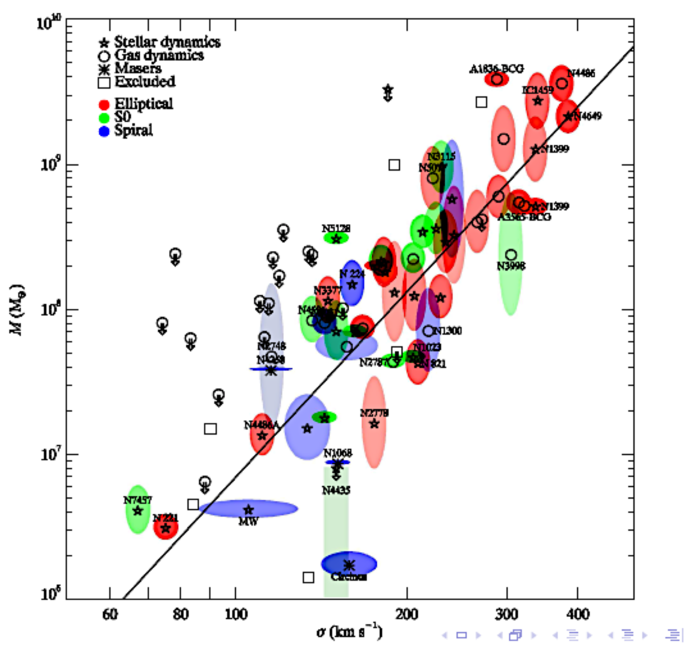
# AGN 'Types' The Radio-loud/Radio-quiet dichotomy






# Mass of Black Hole Compared to Velocity Dispersion of Spheroid

- Sample of non-active galaxies compare mass of black hole (derived later) with velocity dispersion of stars
- Very high detection rate of BHs in 'normal' galaxies- both spheroids and disks
  - only small number of galaxies with interesting upper limits on mass of central black hole (M33).




**Gultekin 2009**

## Galaxy formation and accretion on supermassive black holes appear to be closely related

Black holes play an important role in galaxy formation theories

Observational evidence suggests a link between BH growth and galaxy formation:

- $M_B$-$\sigma$ relation
- Similarity between cosmic SFR history and quasar evolution

Theoretical models often assume that BH growth is self-regulated by **strong** feedback:

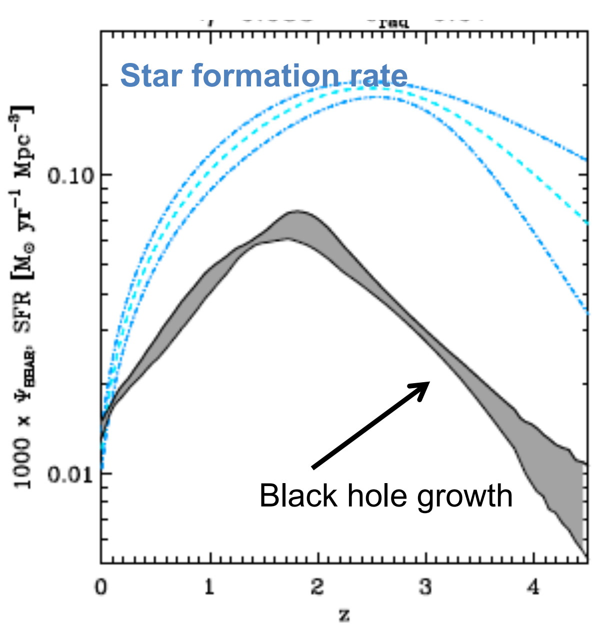
- Blow out of gas in the halo once a crtitical $M_B$ is reached
  Silk & Rees (1998), Wyithe & Loeb (2003)

Springel 2004

***Galaxy formation models need to include the growth and feedback of black holes !***

## SFR Rate and AGN Growth

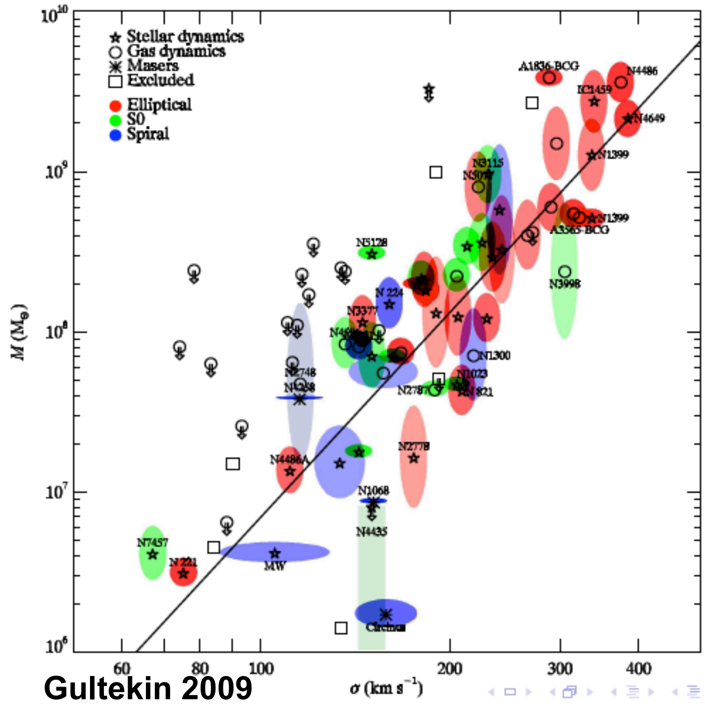
- To first order the growth of supermassive black holes (as traced by their luminosity converted to accretion rate) and the star formation rate are very similar
  - showing similar rises and falls
  - It this cause and effect?



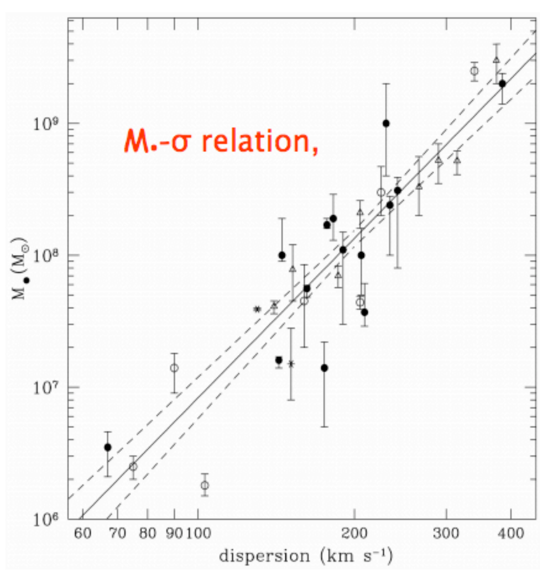

Merloni 2010

# Mass of Black Hole Compared to Velocity Dispersion of Spheroid

- Sample of non-active galaxies
  - mass of black hole (derived later) compared with the with **velocity dispersion of stars**
  - **BH 'knows' about the galaxy and vice versa**
- Very high detection rate of BHs in 'normal' galaxies- both spheroids and disks.




Gultekin 2009



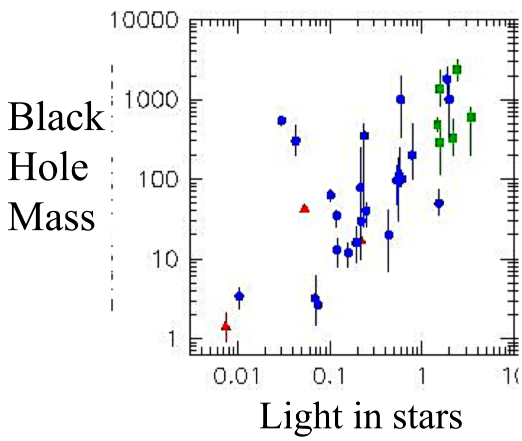

- Black hole mass correlated to host galaxy bulge mass.
- Formation of bulge and growth of black hole are related.
- AGN play a significant role in the evolution of galaxies

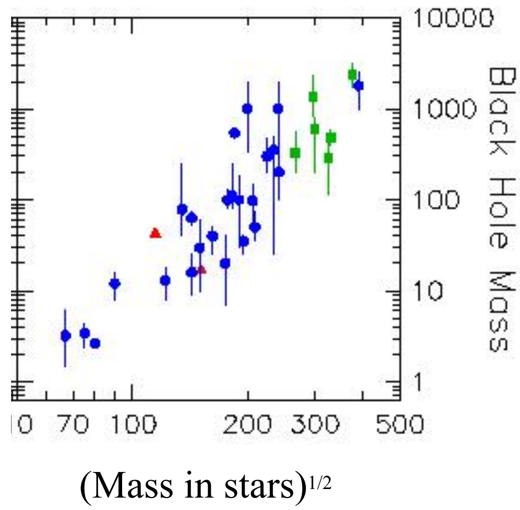
Magorrian et al. 1988; Gebhardt et al. 2000; Ferrarese & Merrit 2000; Tremaine et al. 2002

- Relation of mass of central black ($M_{BH}$) hole to the velocity dispersion of the stars in the bulge ($\sigma$)

# Strong relationship between galaxy and its central massive black hole

- The mass of stars in the galaxy is strongly correlated with the mass of the central black hole
- Black holes have had a strong influence on galaxy formation and vv




Scaling relations that allows estimate of BH mass in distant galaxies

# Problems with the Formation of the Universe

- How did the universe come to look like it does?
- Detailed numerical simulations show that gravity+ hydrodynamics does not produce the universe we see - many things are wrong e.g. galaxies are too big, too bright too blue, form at wrong time, wrong place (previous lecture)
- What else is required?
  - FEEDBACK-The influence of objects on the universe (stars and AGN)
  - Stars don't have enough energy
  - So it has to be AGN
    - How ?
    - Where ?
    - When ?
- lots of reasons to believe in feedback

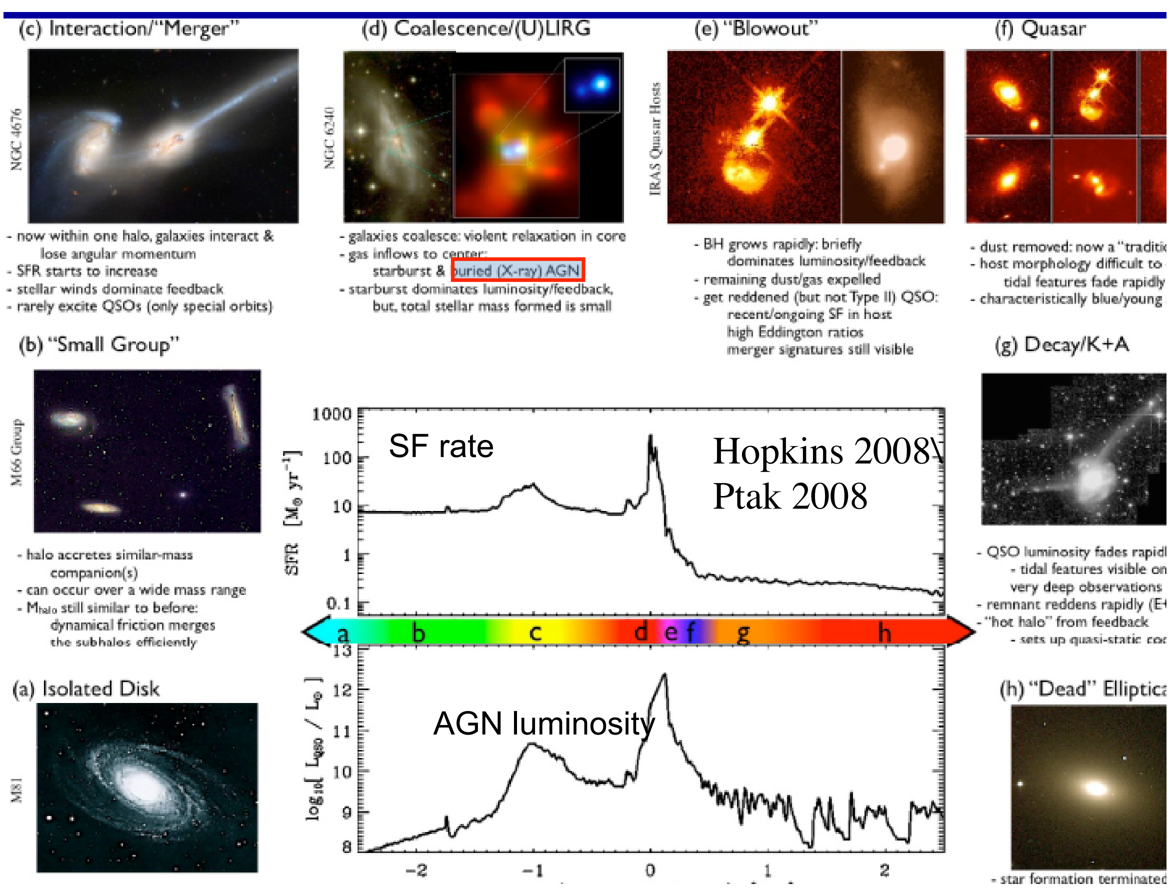
Paradiso Canto 31

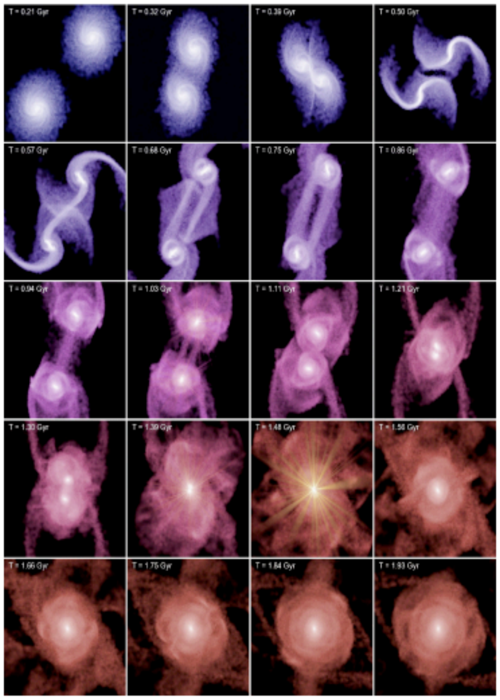
# *How the Observable Universe Came to Be*

- Dark matter evolution in the universe now understood
  - **it is not well understood how 'baryonic structures' (galaxies, groups, clusters) form.**

- For models to fit the data <u>additional physics</u> (beyond gravity and hydrodynamics) is required (heating, cooling, mass and metal injection, gas motions etc)

- AGN seem to be a critical component in this story.





- Gas rich major merger
- Inflows trigger BH accretion & starbursts
- Dust/gas clouds obscure AGN
- AGN wind sweeps away gas, quenching SF and BH accretion.

Hernquist (1989)
Springel et al. (2005)
Hopkins et al. (2006)

One scenario for how AGN influence their host galaxy

## The Bottom Line..

- Since mass of black holes scales linearly with mass of bulge can scale energy required to form a BH with the mass of the galaxy

$$E_{BlackHole} > 30 \times E_{Galaxy}$$

Energy released by growth of Black Hole

Gravitational Binding Energy of Host Galaxy

**If the energy is in the right form and available at the right time AGN can have a strong influence on the baryons in the galaxy**

## Some Details

- **AGN have more energy than supernova voer the life of the galaxy**
  - for a given galaxy (take M87) $M_{BH}$~$6x10^9$; $E=\varepsilon M_{BH}c^2$--- $E$~$10^{-1}M_{BH}c^2$~$10^{63}$ ergs;
    - Characteristic time to radiate at the maximum allowed (Eddington limit) ~40Myr
- binding energy of galaxy $E_{bind}$~$GM_{baryon}M_{DM}/R_{galaxy}$ ~$10^{62}$ ergs

  Average over universe

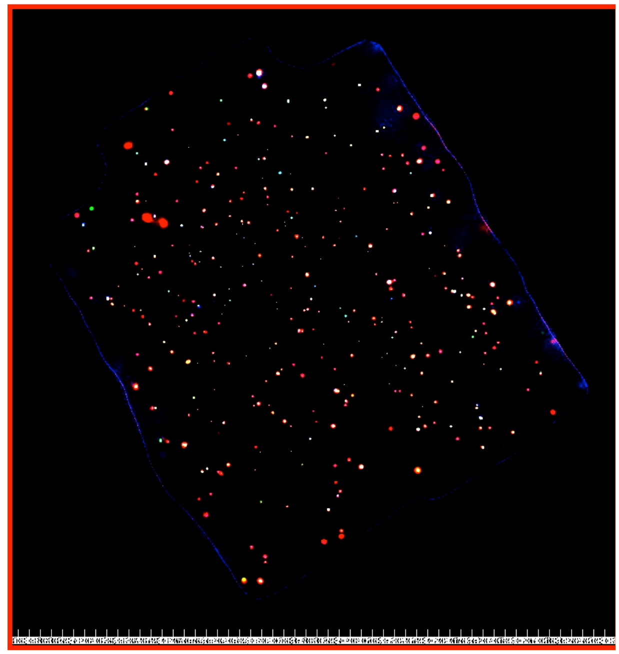
  $E_{SN}$~$10^{-4}M_{star}c^2$ $E_{AGN}$~$10^{-1}M_{BH}c^2$
  - mass density of SN $\rho_{SN}$~$4x10^{7}\ M_{\odot}\ Mpc^{-3}$ over life of galaxy* (1/MW/100yrs)
  - mass density of AGN $\rho_{AGN}$~$4x10^5\ M_{\odot}\ Mpc^{-3}$ at z=0
  - total energy $E_{SN}$~$10^3M_{\odot r}c^2$
  - $E_{AGN}$~$4x10^4M_{\odot}c^2$
  - AGN have 10x more total energy than SN !

## Some Details

- Do they have enough energy to do the trick ?
  - convert energy to motion : take total mass of baryons in galaxy and dump the SN or AGN luminosity into it
  - $\varepsilon_{bh}/\rho_{baryons}$~$(750km/s)^2$ $\varepsilon_{SN}/\rho_{baryons}$~$(100\text{-}250km/s)^2$
  - since potential depth of galaxies like MW ~500km/sec AGN can expel the gas !!

# The History of Active Galaxies

- Active Galaxies (AKA quasars, Seyfert galaxies etc) are radiating massive black holes with $L \sim 10^8 - 10^{14} L_{sun}$
- The change in the luminosity and number of AGN with time are fundamental to understanding the origin and nature of massive black holes and the creation and evolution of galaxies
- ~20% of all energy radiated over the life of the universe comes from AGN- a strong influence on the formation of all structure.

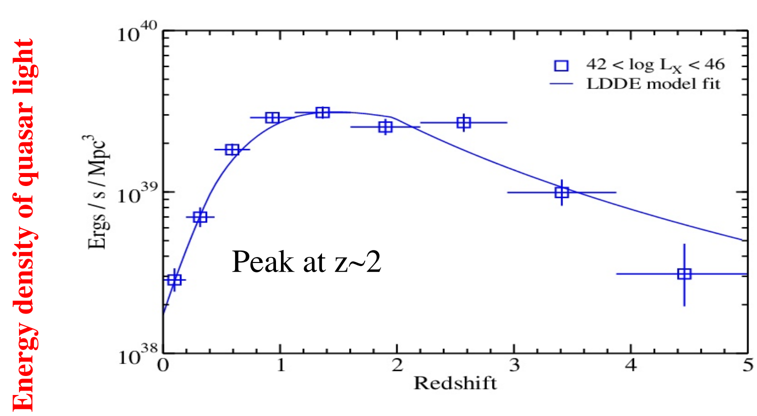


X-ray Color Image (1deg) of the Chandra Large Area X-ray Survey-all of the 'dots' are x-ray detected AGN- except 2 red blobs which are clusters

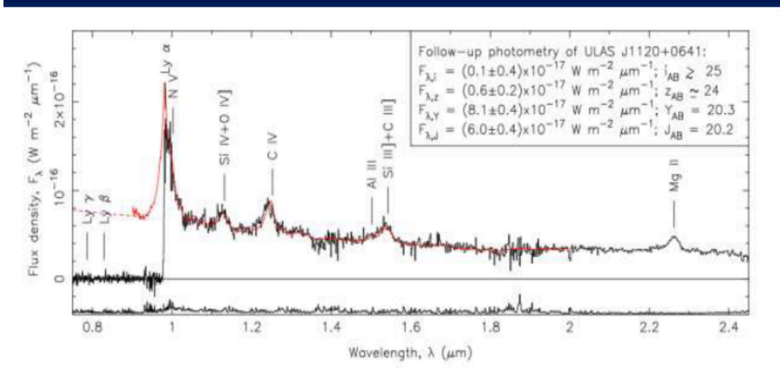
# AGN Evolution

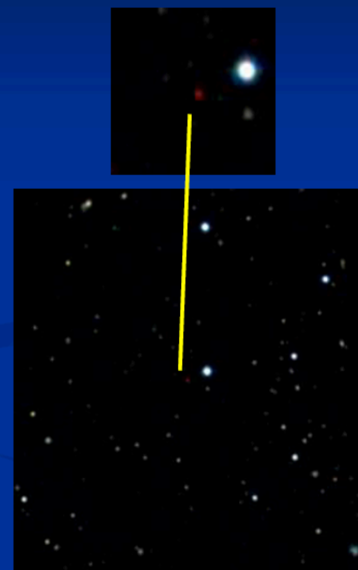
AGN evolve rapidly in low z universe- reach peak at z~1 and decline rapidly at z>2.5

- Highest z QSO ~7 (universe 780Myrs old)
- most of the AGN in the universe are obscured- strong effect on optical/UV surveys



# Gemini Quasar at z=7.1



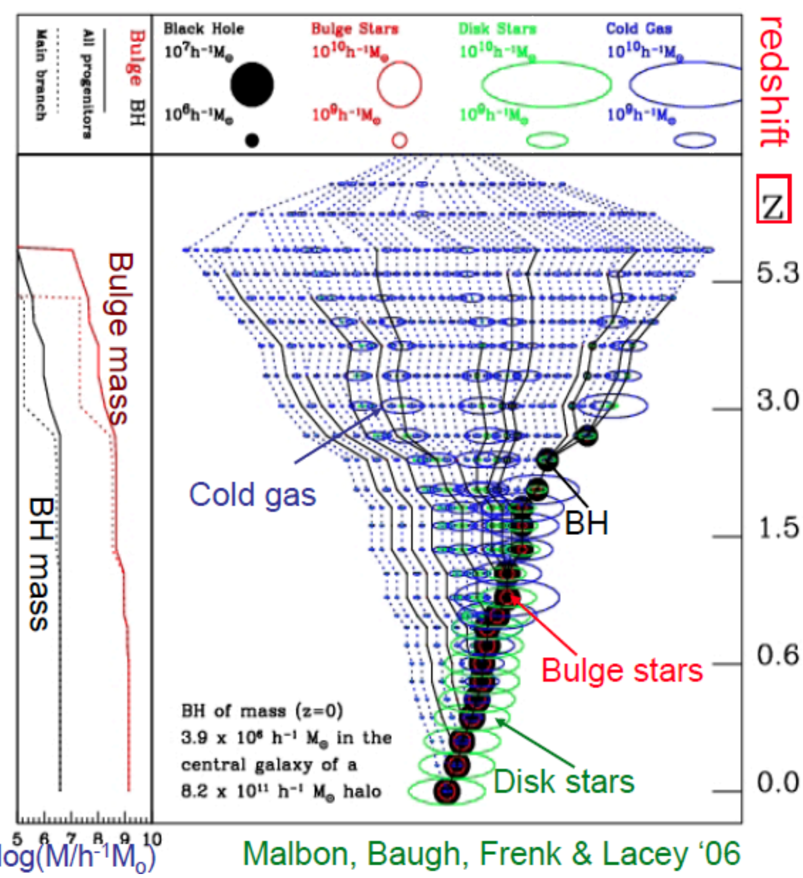
- GNIRS + VLT spectrum of most distant QSO yet discovered. Massive black holes existed when universe was 750 MY old. IR-optimized Gemini was key to this discovery.

$M \sim 10^9 M_\odot$

QSO is the red object in the center of the frame.

Mortlock et al. 2011, Nature, 474, 616

Joint growth of BH and galaxy (bulge stars, disk stars, cold gas)




Malbon, Baugh, Frenk & Lacey '06

# Total Lifetime of active BHs

**ε= efficiency of converting mass to energy**
**λ= Eddington ratio**

$$t_{Salp} = \frac{\varepsilon\, t_E}{(1-\varepsilon)\lambda} = 4.2\times10^7\, yr\left[\frac{(1-\varepsilon)}{9\varepsilon}\right]^{-1}\lambda^{-1}$$

$M_{BH}$ e-fold time ($t_{Sap}$, Salpeter's e-foldimg timescale):

Idea is that matter falls into the black hole at a some rate (which we normalize to the maximum rate) and the some of the matter is converted into energy before disappearing beyond the event horizon

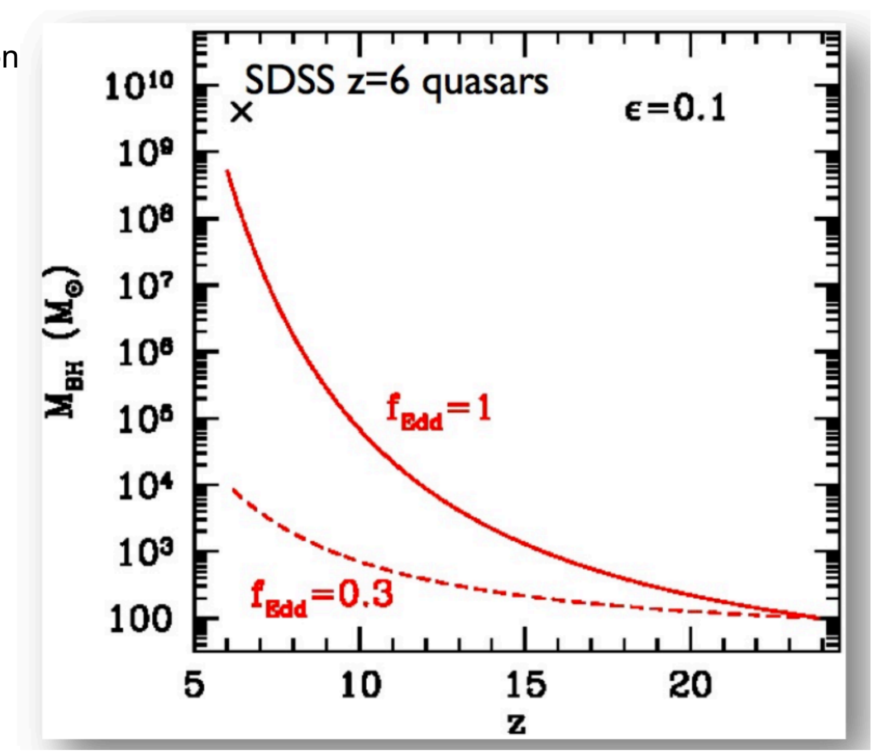
- To grow a mass BH from a small seed SEVERAL $t_{Salp}$ needed:

  7 $t_{Salp}$ $10^3$ ⇨ $10^6$ $M_\odot$

  14 $t_{Salp}$ $10^3$ ⇨ $10^9$ $M_\odot$
- $t_{Salp}$ independent of $M_{BH}$.
- Eddington ratio is the ratio of the observed luminosity to the maximum possible if radiation balances gravity $L_{Edd}=1.3\times10^{38} M_{sun}$ ergs/sec

# How Fast Can Black Holes Grow??

Set by the Eddington limit



## How Black holes grow

Merloni 2009

- Most of the mass in BHs today is in the $10^8$-$10^9$ $M_\odot$ range
- BH in mass range $10^6$-$10^7$ $M_\odot$ are growing rapidly today- like spiral galxies
- Massive $>10^9$M BHs grew fast in early universe, slowly today *(like elliptical galaxies*) and tend to live in massive elliptical galaxies

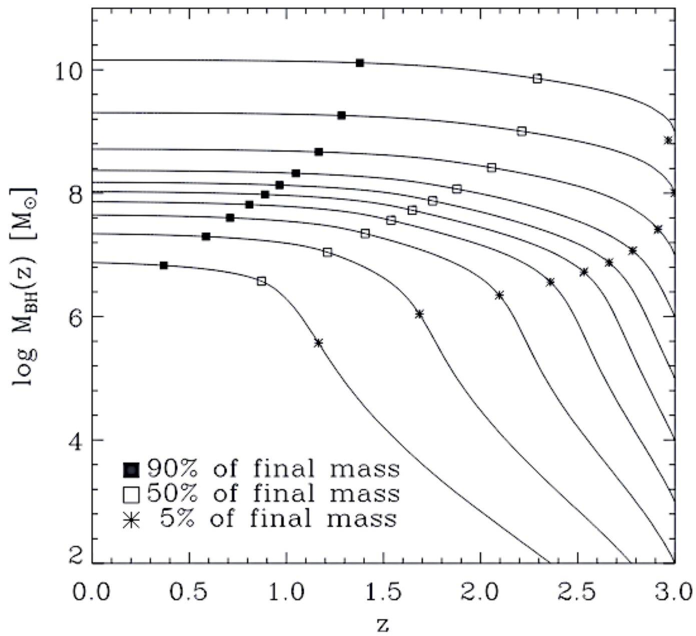



**Fig. 2.** Average growth history of SMBHs as computed by Marconi et al. (16) using X-ray AGN luminosity

## Why Backward??

- Cold Dark Matter (CDM) theory of structure formation says that
  - small things form first
  - merge together over time to form big things
- Expect massive (luminous)BHs to appear later in the universe than smaller mass BHs

Now

$10^{10}$ yrs ago

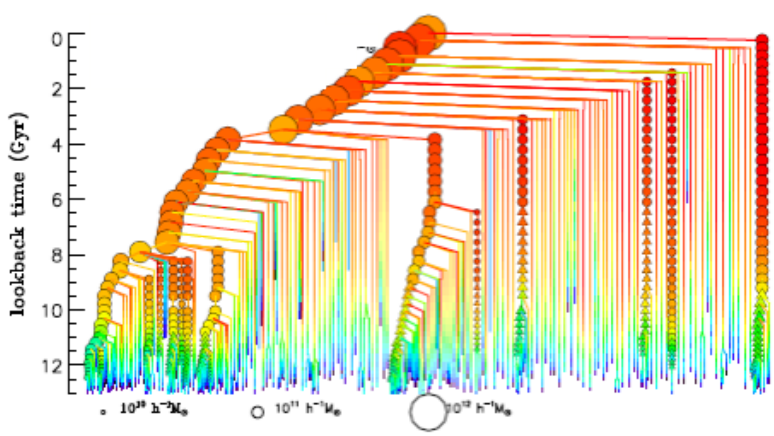
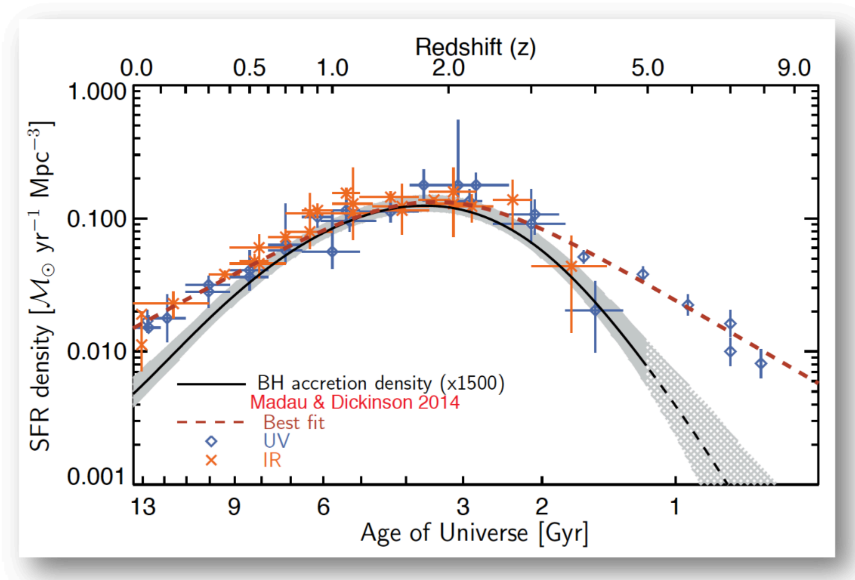



**Figure 1.** BCG merger tree. Symbols are colour-coded as a function of B - V colour and their area scales with the stellar mass. Only progenitors more massive than $10^{10}$ $M_\odot$ $h^{-1}$ are shown with symbols. Circles are used for galaxies that reside in the FOF group inhabited by the main branch. Triangles show galaxies that have not yet joined this FOF group.

# Black Holes Growth vs Star Formation

- Very similar functional form over wide redshift range

BH accretion density versus star-formation density




Aird et al. (2015)

Los Angeles Times | SCIENCE

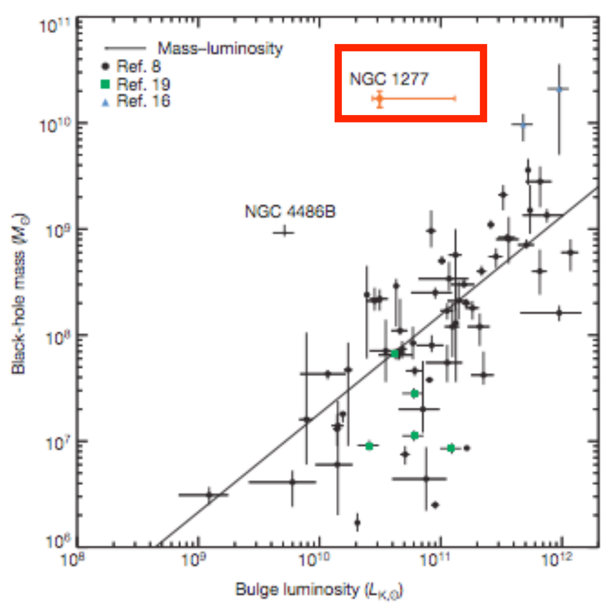
Gargantuan black hole baffles scientists

A hunt for supermassive black holes reveals a monstrous one at the heart of galaxy NGC 1277, which may force theorists to rethink their understanding of black holes.

The enormous black hole was found at the center of NGC 1277, a flat, compact yellowish galaxy near the center of this galaxy cluster in the constellation Perseus. (David W. Hogg-Michael Blanton, SDSS Collaboration / November 29, 2012)

Related photos »

# Not everything fits




- Yesterday In Nature the object with the highest ratio of BH mass to total galaxy mass 2:3 was discovered.
- \

- But NGC 1277 is stranger still, and could help advance our theories of how black holes evolve in the first place.

- "This galaxy seems to be very old," Dr Van den Bosch said. "So somehow this black hole grew very quickly a long time ago, but since then that galaxy has been sitting there not forming any new stars or anything else.


Please Read Chapter 9 of S&G Active galactic nuclei

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Have you been challenged and learned new things? Have I been effective, responsive, respectful, engaging, etc?-or dull,boring, stodgy, unprepared?
Your responses are strictly anonymous. I only see the statistics.
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