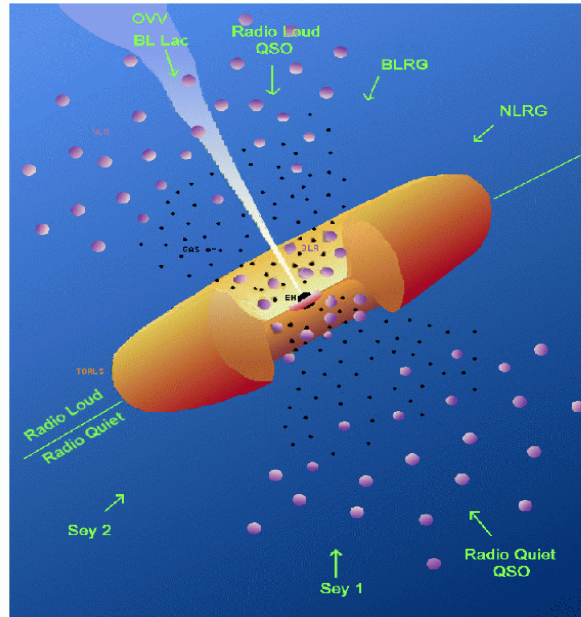


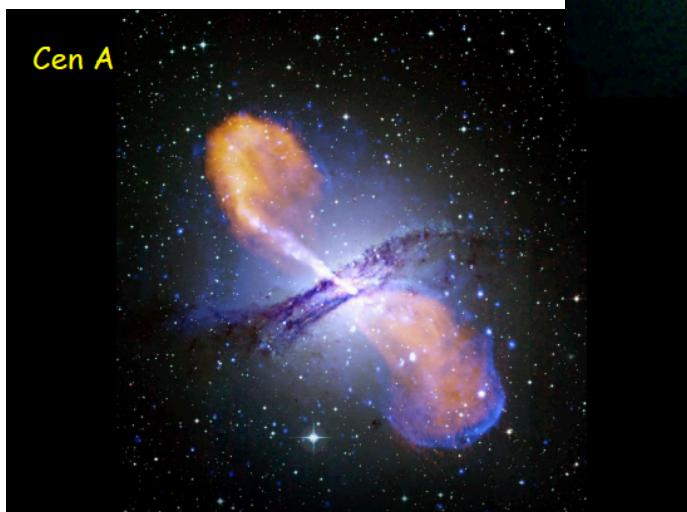
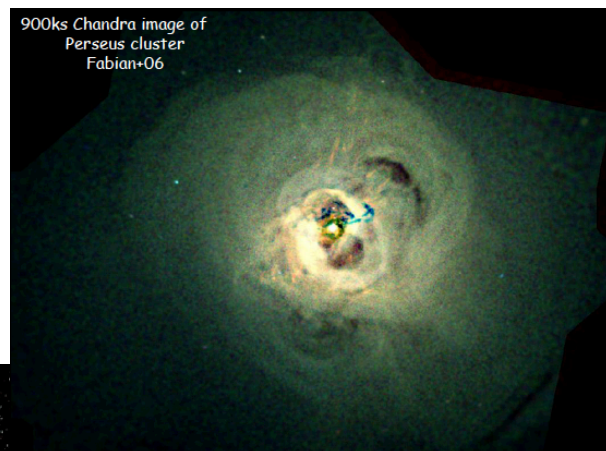
AGN- Alias **Active** Galactic Nuclei

- AGN are '**radiating**' supermassive black holes-
 - They go by a large number of names (Seyfert 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.html for an overview



Schematic diagram of regions near the SMBH
Urry and Padovani 1995

AGN- Black Holes



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

But at $z=0$ only $\sim 10\%$ are 'active'

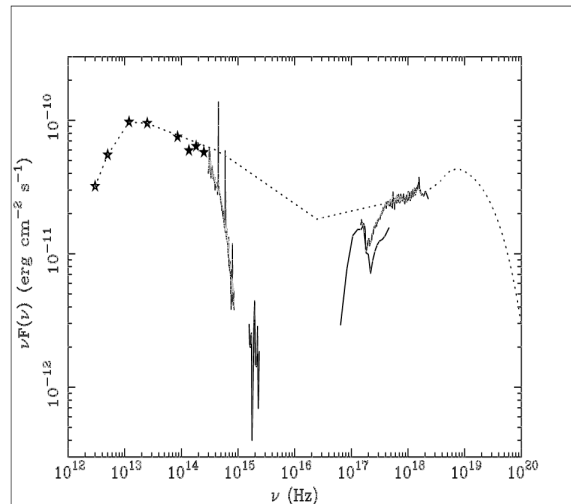
Properties

- 'Point-like'
- luminous non-stellar broad band spectra- very broad range in luminosity $\log L \sim 40-48$ ergs/sec
- located in center of *some* galaxies

What Are Active Galactic Nuclei

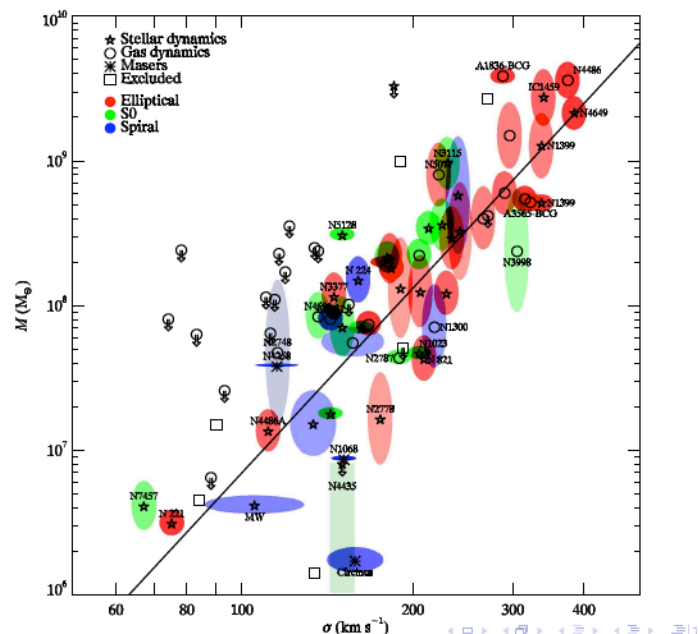
Radiating supermassive black holes in the centers of galaxies

- More details
 - Optical spectra 3 classes
 - strong broad emission lines
 - strong narrow emission lines
 - strong non-thermal continuum
 - radio $\sim 10\%$ 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



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.



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:

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

- ▶ M_B - σ relation
- ▶ Similarity between cosmic SFR history and quasar evolution
- ▶ Blow out of gas in the halo once a critical M_B is reached
Silk & Rees (1998), Wyithe & Loeb (2003)

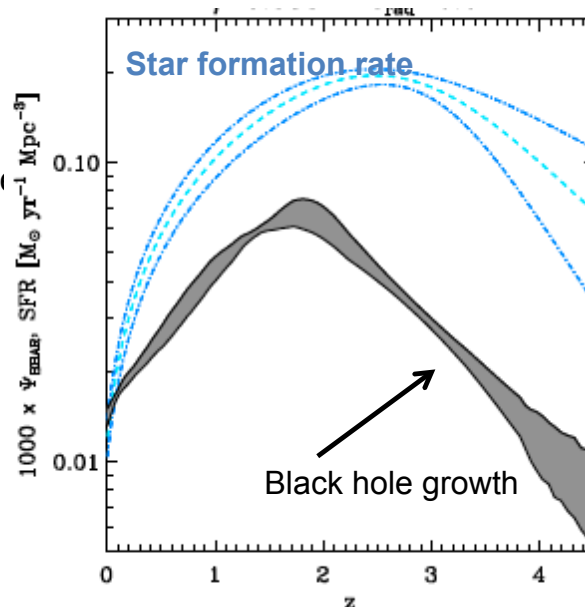
Springel 2004



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

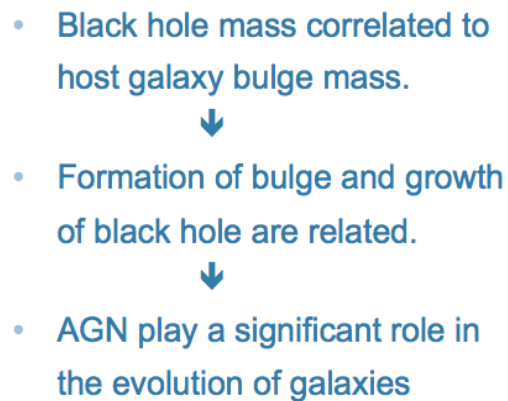
SFR Rate and AGN Growth

- 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
 - Is this cause and effect?



Merloni 2010

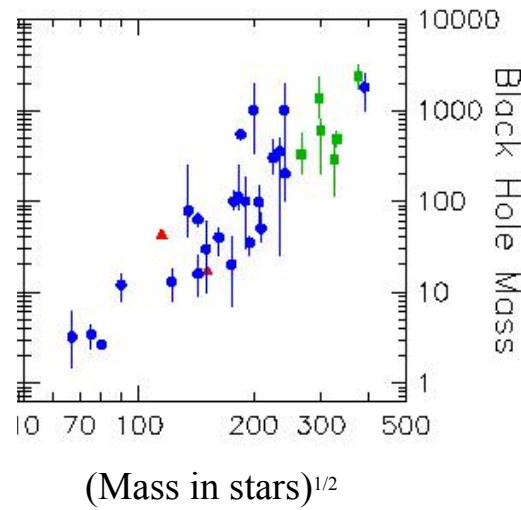
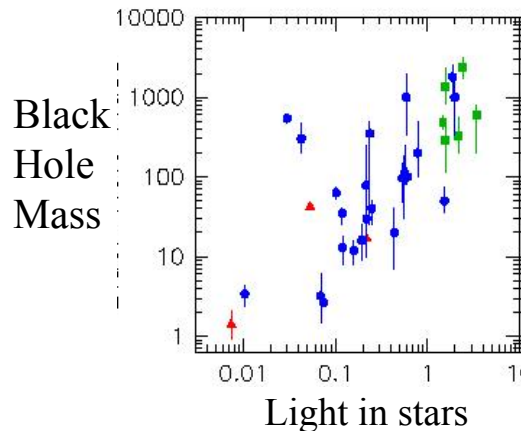
- Sample of non-active galaxies
 - mass of black hole (derived later) compared with the with **velocity dispersion of stars**



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

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 evolution



Scaling relations that allows estimate of BH mass in distant galaxies

Problems with the Formation of the Universe

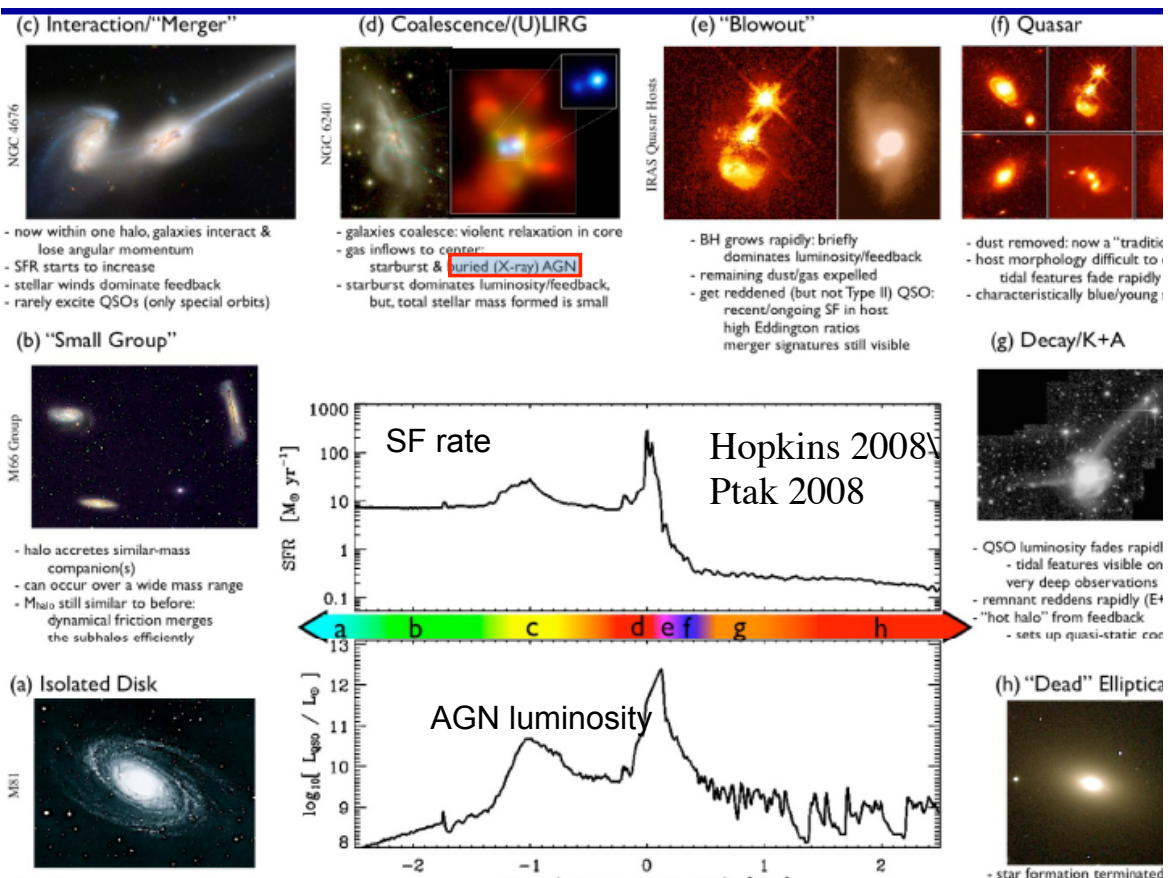
- How did the universe come to look like it does?
- Detailed numerical simulations show that gravity+ hydrodynamics does not produce the universe we see - many things are wrong e.g. galaxies are too big, too bright too blue, form at wrong time, wrong place (previous lecture)
- What else is required?
 - **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

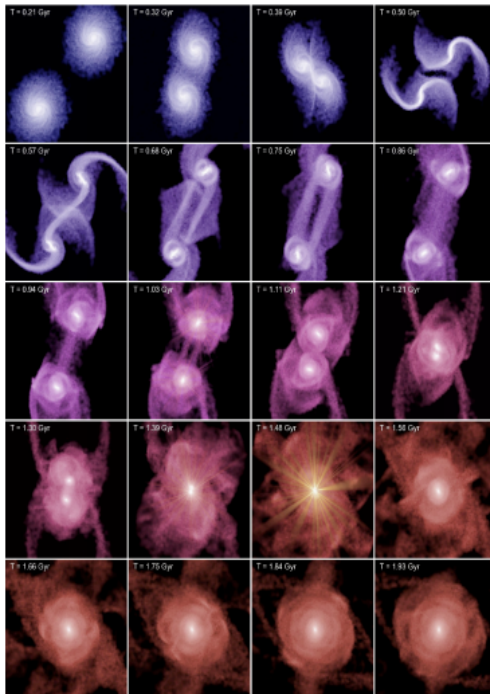


Paradiso Canto 31

How the Observable Universe Came to Be

- Dark matter evolution in the universe now understood
 - it is not at all understood how ‘baryonic structures’ (galaxies, groups, clusters) form.
- For models to fit the data additional physics (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 are triggered

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**

- for a given galaxy (take M87) $M_{\text{BH}} \sim 6 \times 10^9$; $E = 10^{-1} M_{\text{BH}} c^2 \sim 10^{63}$ ergs; binding energy of galaxy $E_{\text{bind}} \sim G M_{\text{baryon}} M_{\text{DM}} / R_{\text{galaxy}} \sim 10^{62}$ ergs
- Characteristic time to radiate at the maximum allowed (Eddington limit) $\sim 40 \text{ Myr}$

Average over universe

$$E_{\text{SN}} \sim 10^{-4} M_{\text{star}} c^2 \quad E_{\text{AGN}} \sim 10^{-1} M_{\text{BH}} c^2$$

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

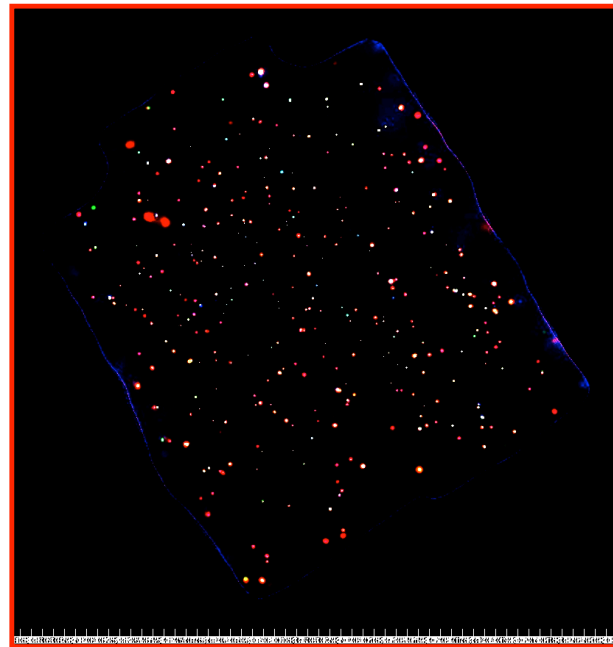
Some Details

- **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
- $\epsilon_{\text{bh}} / \rho_{\text{baryons}} \sim (750 \text{ km/s})^2 \quad \epsilon_{\text{SN}} / \rho_{\text{baryons}} \sim (100-250 \text{ km/s})^2$
- since potential depth of galaxies like MW $\sim 500 \text{ km/sec}$ AGN can expel the gas !!

The History of Active Galaxies

- Active Galaxies (AKA quasars, Seyfert galaxies etc) are **radiating massive black holes** with $L \sim 10^8 - 10^{14} L_{\text{sun}}$
- 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.



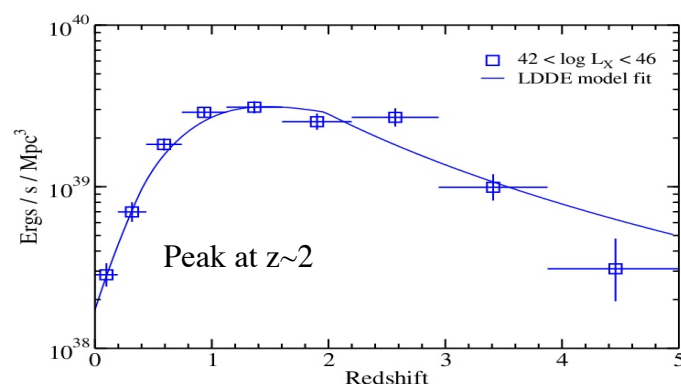
X-ray Color Image (1deg)
of the Chandra Large Area X-ray Survey-all of the 'dots' are x-ray detected AGN- except 2 red blobs which are clusters

AGN Evolution

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

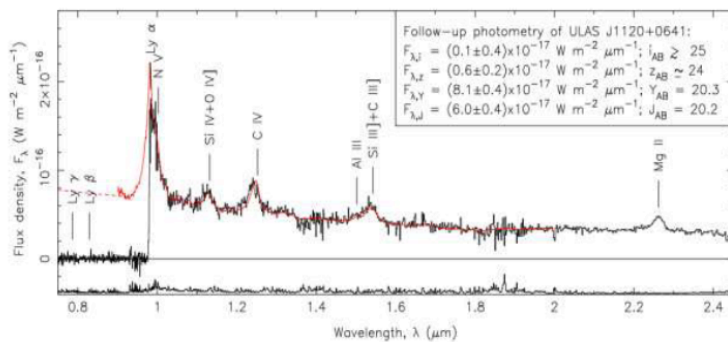
- Highest z QSO ~ 7 (universe 780 Myrs old)
- most of the AGN in the universe are obscured- strong effect on optical/UV surveys

Energy density of quasar light





Gemini Quasar at $z=7.1$

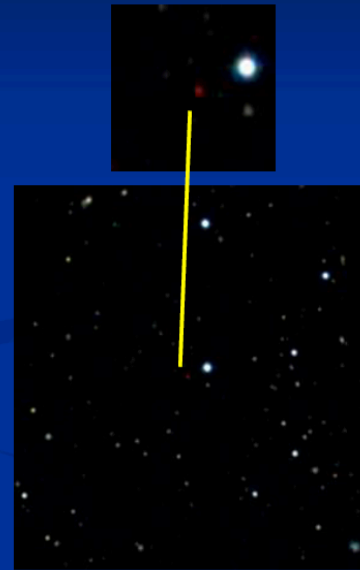


- GNIRS + VLT spectrum of most distant QSO yet discovered. Massive black holes existed when universe was 750 MY old. IR-optimized Gemini was key to this discovery.

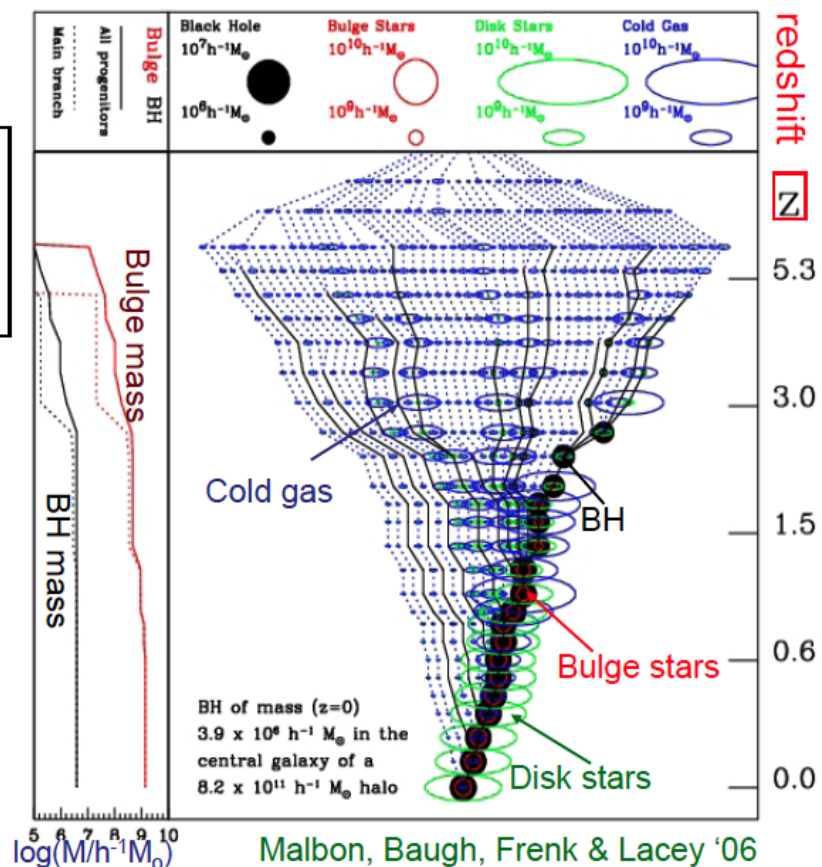
Mortlock et al. 2011, Nature, 474, 616

$M \sim 10^9 M_\odot$

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



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



Total Lifetime of active BHs

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

$$t_{\text{Salp}} = \frac{\epsilon t_E}{(1 - \epsilon)\lambda} = 4.2 \times 10^7 \text{ yr} \left[\frac{(1 - \epsilon)}{9\epsilon} \right]^{-1} \lambda^{-1}$$

M_{BH} e-fold time (t_{Salp} , Salpeter's e-folding 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:

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

$$14 t_{\text{Salp}} 10^3 \Rightarrow 10^9 M_{\odot}$$

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

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

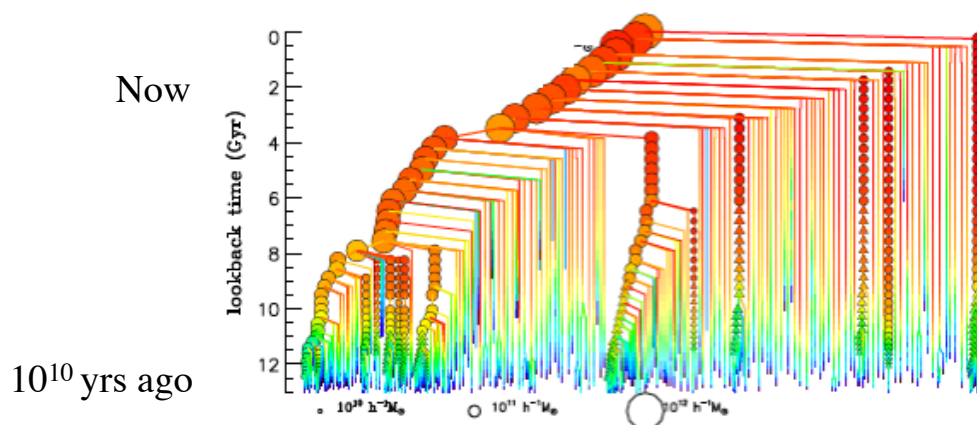
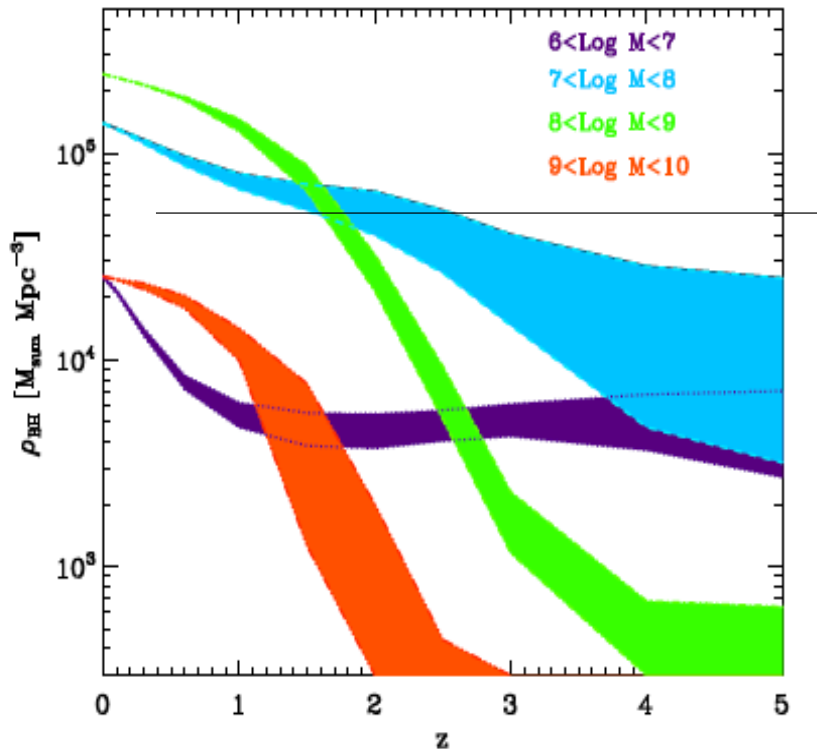


Figure 1. BCG merger tree. Symbols are colour-coded as a function of B - V colour and their area scales with the stellar mass. Only progenitors more massive than $10^{10} M_{\odot} h^{-1}$ are shown with symbols. Circles are used for galaxies that reside in the FOF group inhabited by the main branch.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

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 galaxies
- Massive $>10^9 M_\odot$ BHs grew fast in early universe, slowly today (like elliptical galaxies) tend to live in massive elliptical galaxies



Los Angeles Times | SCIENCE

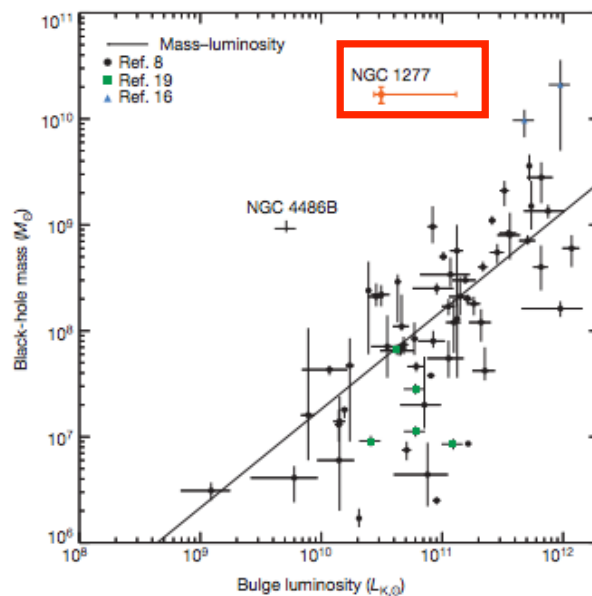
Gargantuan black hole baffles scientists

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)

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."


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Bin Laden doctor 'on hunger strike'

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[Q&A: Shakil Afridi speaks out](#) [Was 'Bin Laden doctor' a pawn?](#)



Giant black hole found in tiny galaxy

Astronomers spot the second-largest black hole ever seen, but in a tiny galaxy just a quarter the size of the Milky Way.

[Milky Way's black hole set to feed](#)

[Giant black holes just got bigger](#)