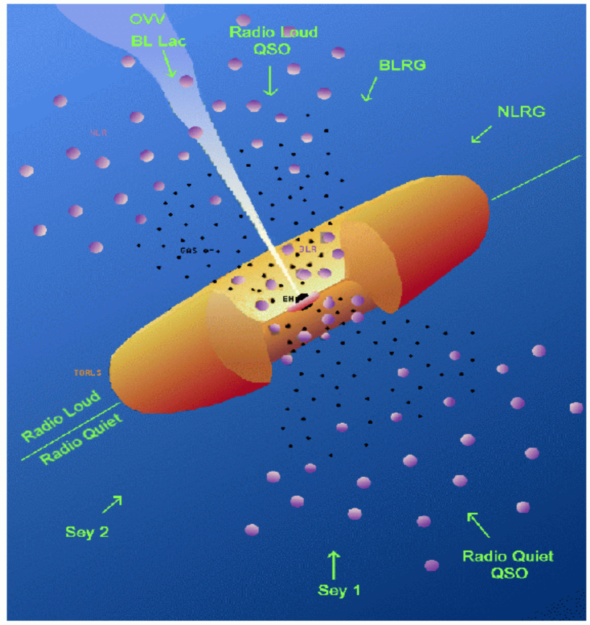
AGN- Alias **Active** Galactic Nuclei

- 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 Ch 14 MBW http://nedwww.ipac.caltech.edu/level5/Cambridge/Cambridge_contents.html for an overview



Schemtaic diagram of regions near the SMBH
Urry and Padovani 1995

What Are Active Galactic Nuclei

Radiating supermassive black holes in the centers of galaxies

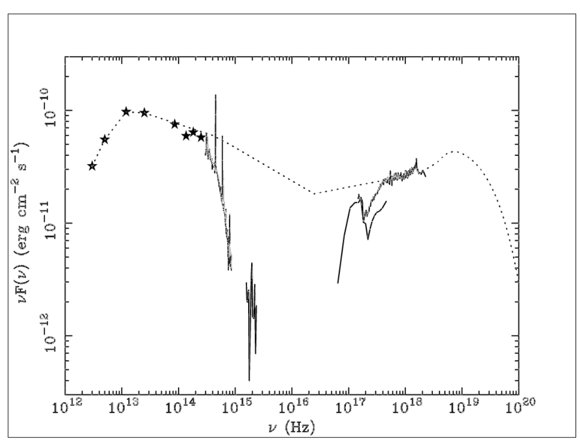
Properties

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

- 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

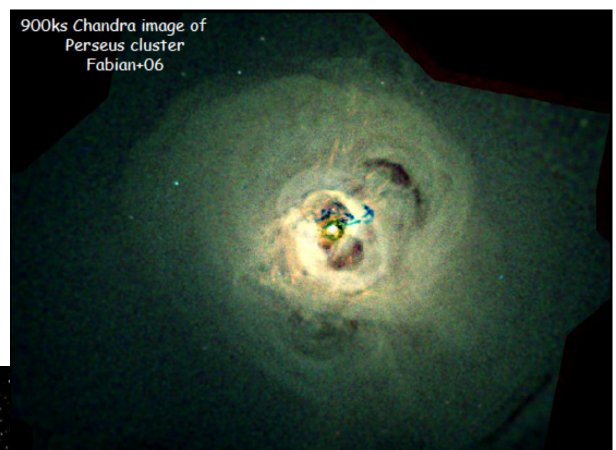
    highly variable

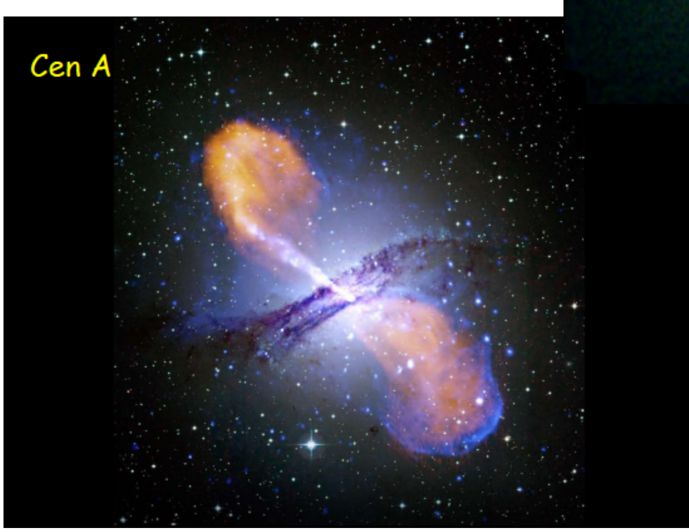


Broad Range of Properties

- Luminosity
  - Range from $<10^{40}$ erg/s to $\sim 10^{48}$ erg/s
  - Fundamental parameters controlling L are **mass and mass accretion rate**
  - Most Powerful objects (quasars)- AGN totally outshines host galaxy
  - Non-thermal broad band spectrum(radio to γ-rays)
- Level of obscuration- how much material is in our line of sight
  - In some objects, can see all of the way down to the SMBH (type I)
  - In other objects, view at some wavelengths is blocked by obscuring material (some objects are blocked at all wavelengths)- type II
  - Level of obscuration connected to **viewing inclination**
- Presence of powerful relativistic (radio) jets
  - Radio-loud AGN : generate powerful jets, seen principally via synchrotron radiation in the radio band
  - Radio-quiet AGN : lack **powerful** jets (often possess weak jets)
  - Fundamental parameter controlling jet production **unknown** **(maybe black hole spin; or magnetic field configuration)**

AGN- Black Holes





It is now believed that almost all massive galaxies have supermassive ($M>10^5 M_\odot$) black holes

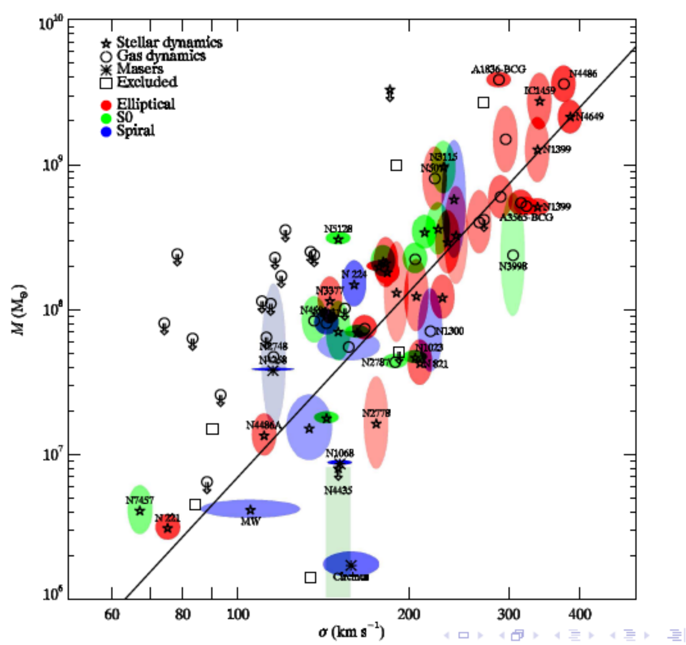
But at z=0 only ~10% are 'active'

Course evaluations are open- Please Respond!

- www.courseevalum.umd.edu
- Why?
  - For the benefit of your peers
  - Because your comments count and we use it to improve our teaching and/or redesign the course
  - Because your opinion is used to evaluate our performance
- Don't put it off till Dec 12th!

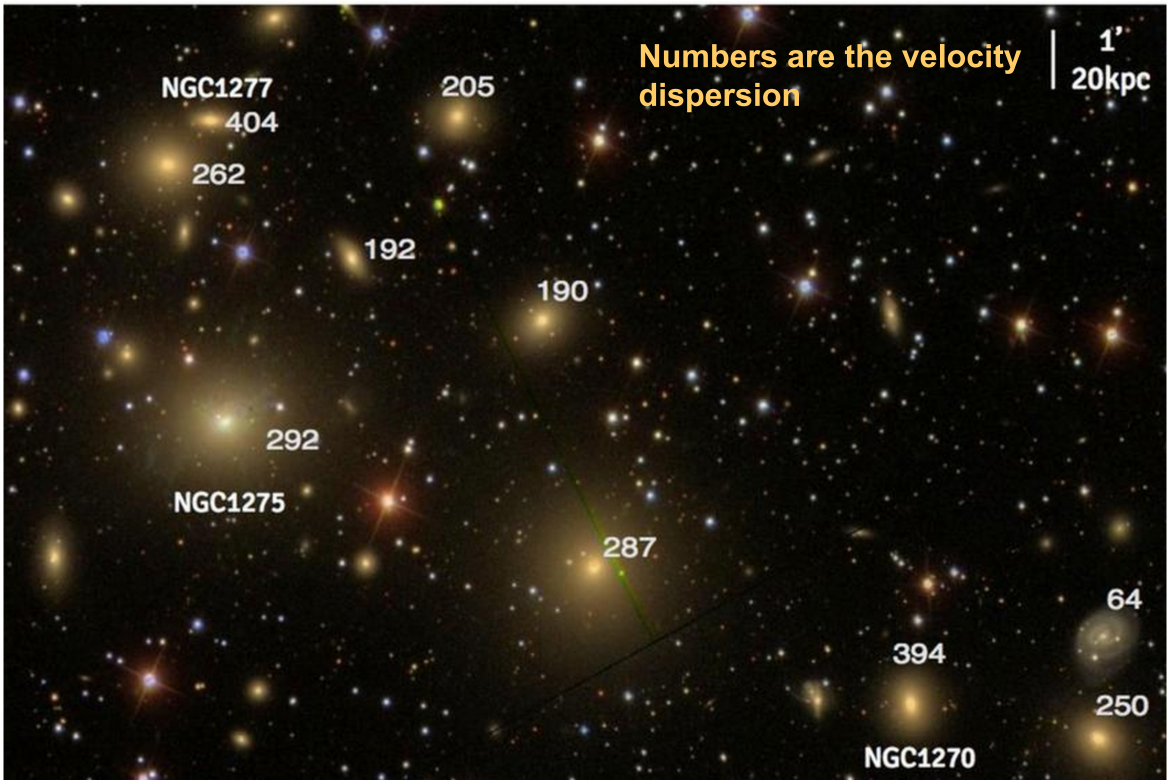
Mass of Black Hole Compared to Velocity Dispersion of Spheroid

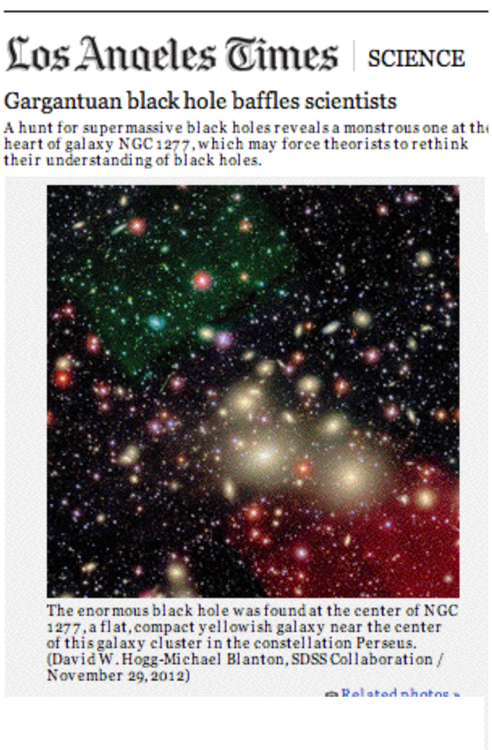
- Sample of non-active galaxies compare mass of black hole (derived later) with velocity dispersion of stars
- Very high detection rate of BHs in 'normal' galaxies- both spheroids and disks.



Gultekin 2009

Which One Does Not Fit? R. van den Bosch





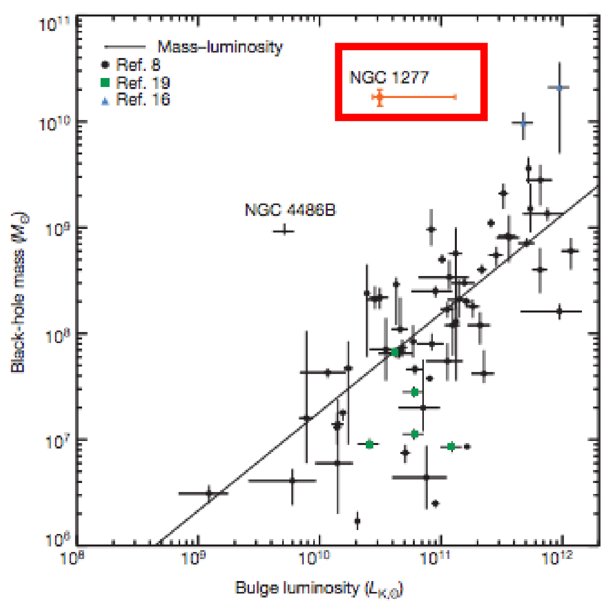
Los Angeles Times | SCIENCE

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 »



- last spring 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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British press awaits standards report

The judge heading an inquiry in to press standards in the UK is to issue his final report after an inquiry prompted by the phone-hacking scandal.

LIVE Reaction to Leveson report | Different ways to regulate press

Nick Robinson: Political headache | Leveson Inquiry: Key moments

Bin Laden doctor 'on hunger strike'

The Pakistani doctor jailed for his part in the US raid that killed Osama Bin Laden is on hunger strike, reports say.

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

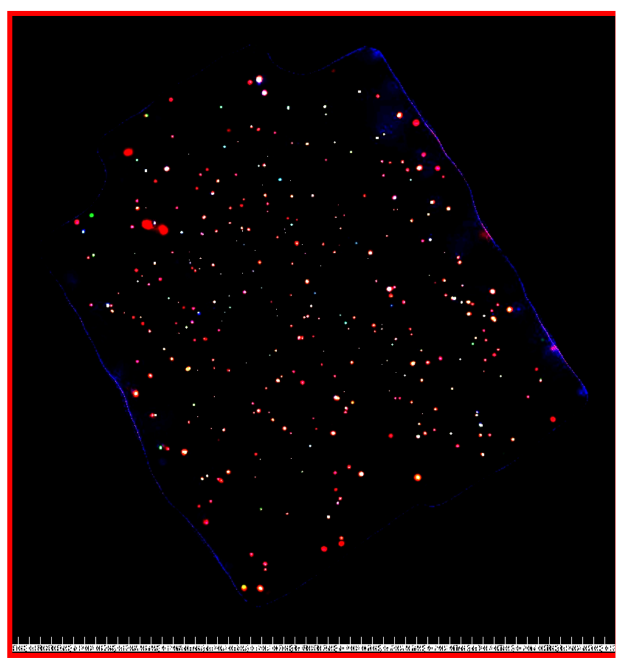
Giant black holes just got bigger

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- CLASXS

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-σ 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)

Feedback by AGN may:

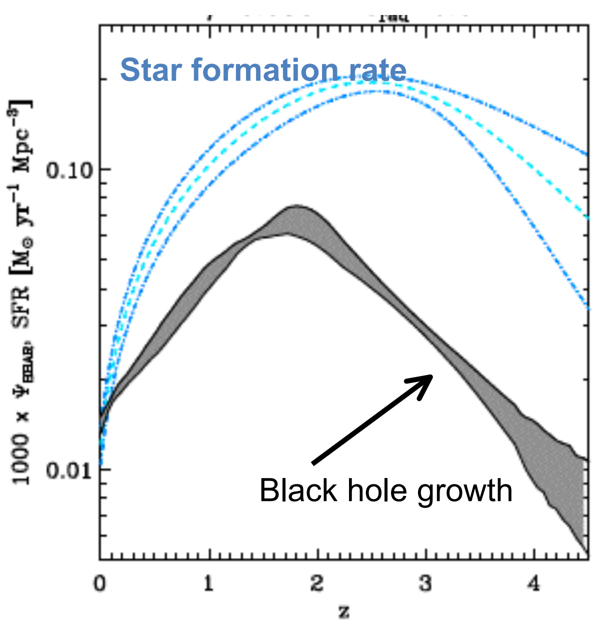
- Solve the cooling flow riddle in clusters of galaxies
- Explain the cluster-scaling relations, e.g. the tilt of the L_x-T relation
- Explain why ellipticals are so gas-poor
- Drive metals into the IGM by quasar-driven winds
- Help to reionize the universe and surpress star formation in small

Springel 2004

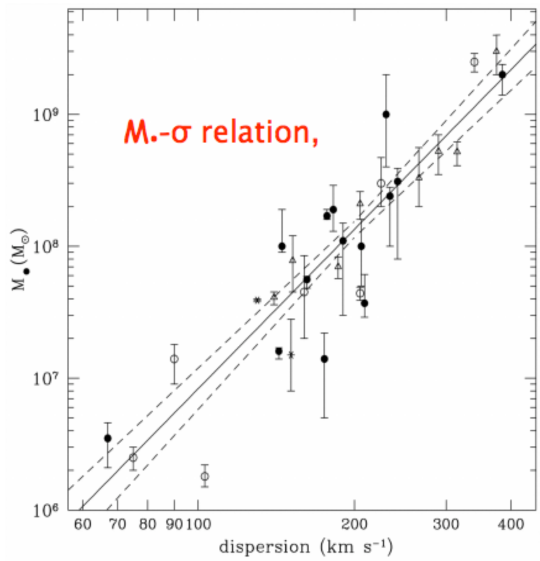
Galaxy formation models need to include the growth and feedback of black holes !

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



- Black hole mass correlated to host galaxy bulge mass.

↓

- Formation of bulge and growth of black hole are related.

↓

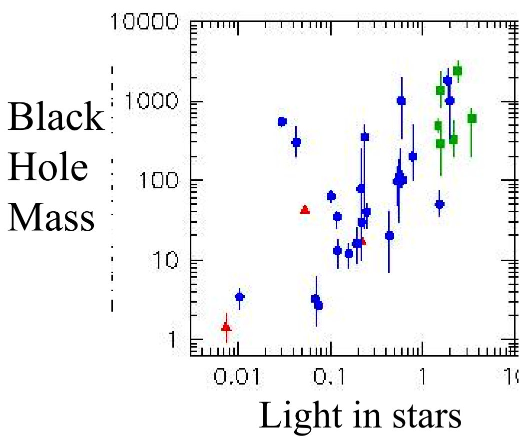
- AGN play a significant role in the evolution of galaxies

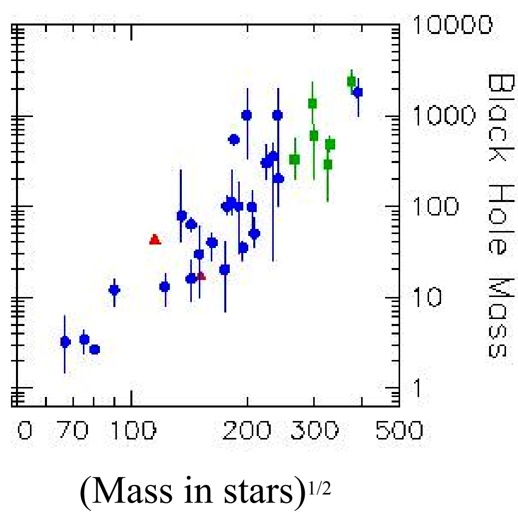
Magorrian et al. 1988; Gebhardt et al. 2000; Ferrarese & Merrit 2000; Tremaine et al. 2002

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

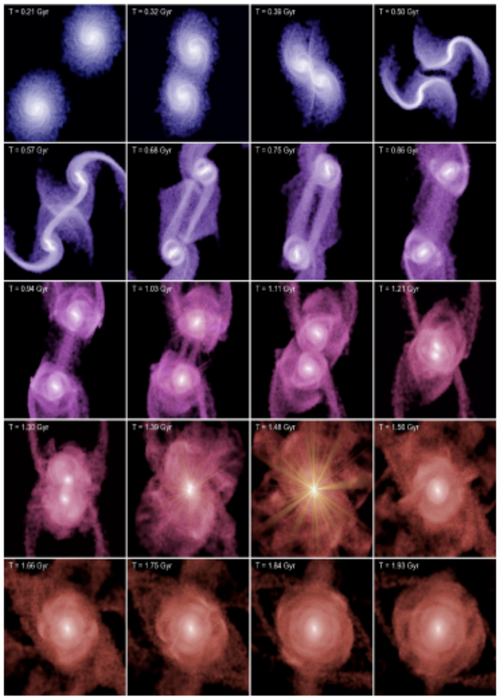
Strong relationship between galaxy and its central massive black hole

- 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 vv





Scaling relations that allows estimate o BH mass in distant galaxies



Stills from last weeks movie

- 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)

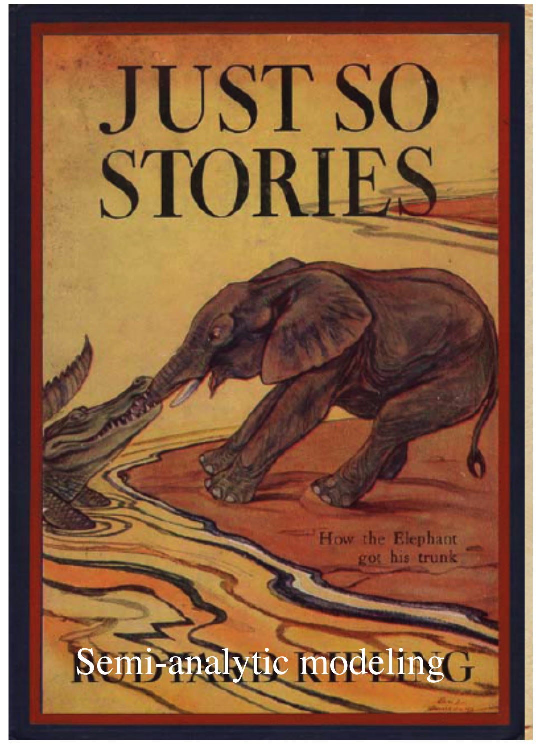
Problems with the Formation of the Universe

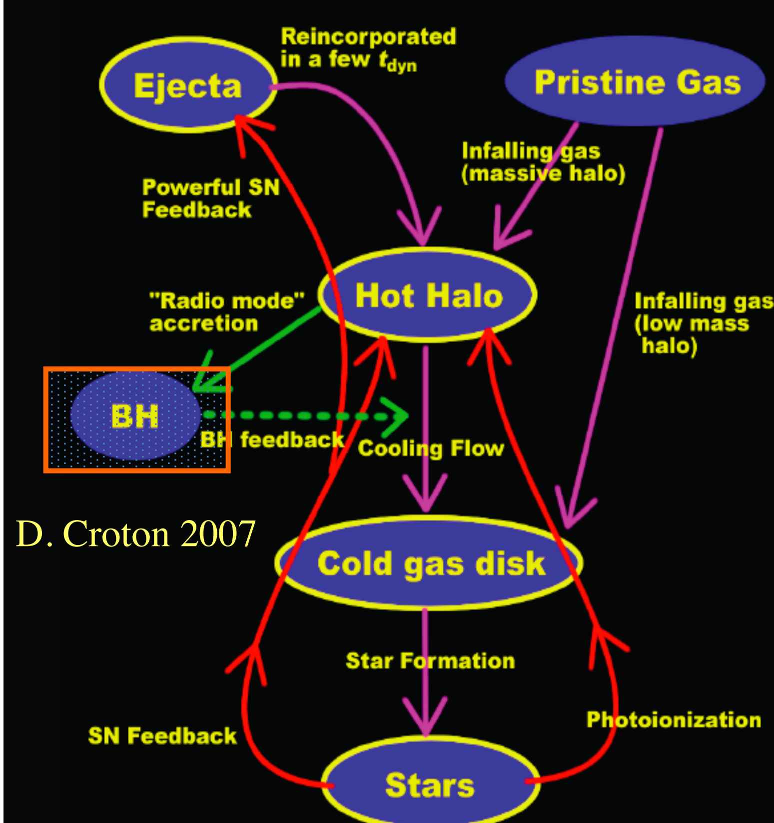
- How did the universe come to look like it does?
- Detailed numerical simulations show that gravity+ hydrodynamics does not produce the universe we see -many things are wrong e.g. galaxies are too big, too bright too blue, form at wrong time, wrong place
- What else is required?
  - FEEDBACK-The influence of objects on the universe (stars and AGN)
  - Stars don't have enough energy
  - So it has to be AGN
    - How ?
    - Where ?
    - When ?
- reasons to believe in feedback
  - baryon fraction in galaxies,
  - IGM absorption in metal lines at moderate z
  - Entropy in groups
  - Detection of effects of radio sources on gas in galaxies and clusters

Paradiso Canto 31

How the Observable Universe Came to Be

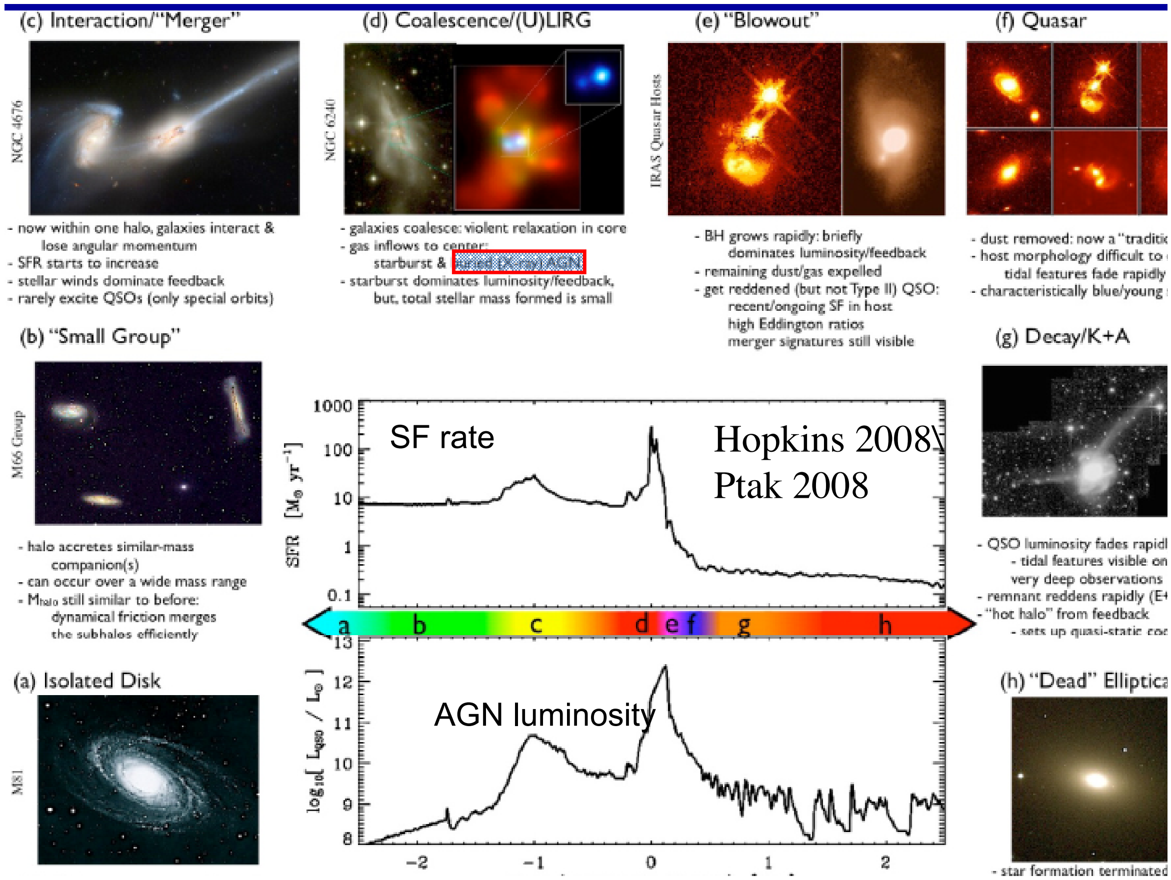
- Dark matter evolution in the universe now understood
  - **it is not at all understood how ‘baryonic structures’ (galaxies, groups, clusters) form.**
- For models to fit the data additional physics (beyond gravity and hydrodynamics) is required (heating, cooling, mass and metal injection, gas motions etc)
- Up until now this has been parameterized in ‘semi-analytic’ models -
- ***The critical problem is to put physics into these stories***





Calculations from first principles are extremely complex and difficult

- Schmidt law star formation
- SFR dependent SN winds
- satellite gas stripping
- morphological transformation
- assembly through mergers
- starbursts through mergers
- Magorrian relation BH growth
- jet & bubble AGN feedback



Why AGN ?

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

Average over universe

E_{SN}~$10^{-4}M_{star}c^2$; E_{AGN}~$10^{-1}M_{BH}c^2$

- mass density of SN ρ_{SN}~$4x10^{7}$ $M_\odot$ Mpc^{-3} over life of galaxy* (1/MW/100yrs)
- mass density of AGN ρ_{AGN}~$4x10^5$ $M_\odot$ Mpc^{-3} at z=0

- total energy E_{SN}~$10^3 M_{\odot r}c^2$
- E_{AGN}~$4x10^4 M_\odot c^2$

- AGN have 10x more total energy than SN

- 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

Why AGN -MBW pg 649

- Can feedback from AGN have significant impact on galaxy formation and evolution
- Compare total energy output from an AGN with the binding energy of its host galaxy. (ε is the mean efficiency of accretion)
- According to the virial theorem, the gravitational binding energy is roughly

$W \sim M_{gal}\sigma^2$. Then $E/|W| \sim \varepsilon M_{BH}/M_{gal}(c/\sigma)^2$

Observationally $M_{BH}/M_{gal} \sim 10^{-3}$.

Thus, for a massive galaxy with $\sigma \sim 300$km/s the ratio $E/|W|$ is about 10^3 indicating that the AGN energy can easily surpass the total binding energy of the host galaxy.

It is therefore very well possible that the energy feedback from AGN plays an important role in the formation and evolution of galaxies.

see MBW sec 14.4 for how feedback may work

The Bottom Line..

- Since mass of black holes scales linearly with mass of bulge

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

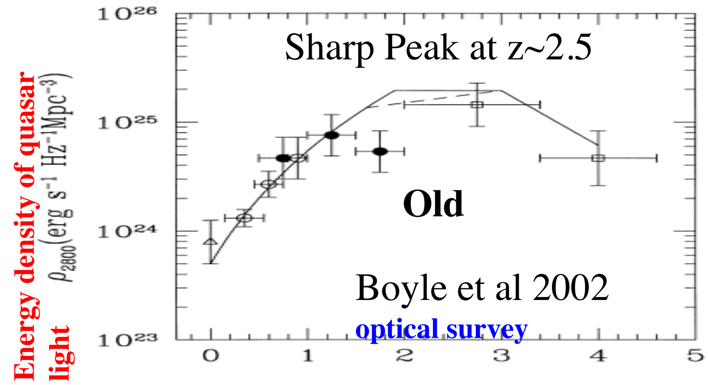
Energy released by growth of Black Hole

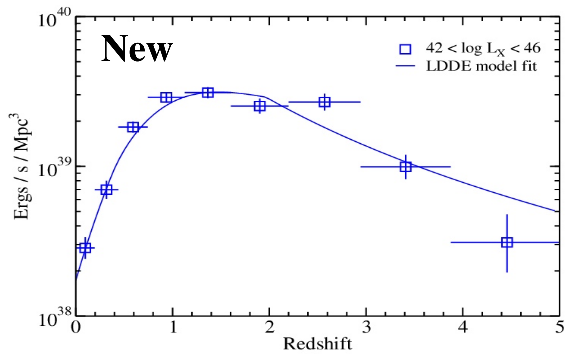
Gravitational Binding Energy of Host Galaxy

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

AGN Evolution

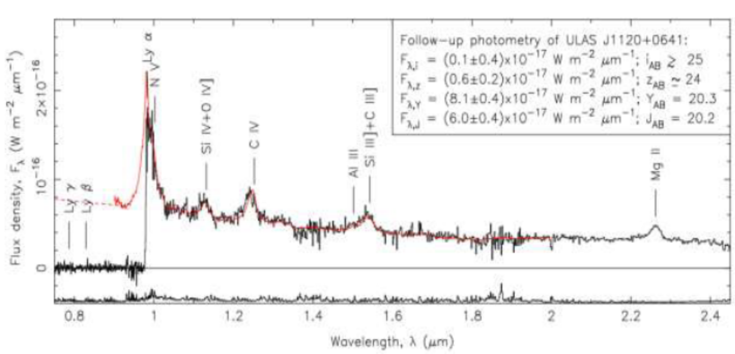
- AGN evolve rapidly in low z universe- reach peak at z~1 and decline rapidly at z>2.5
- Highest z QSO ~7 (universe 780Myrs old)
- most of the AGN in the universe are obscured- strong effect on optical/UV surveys

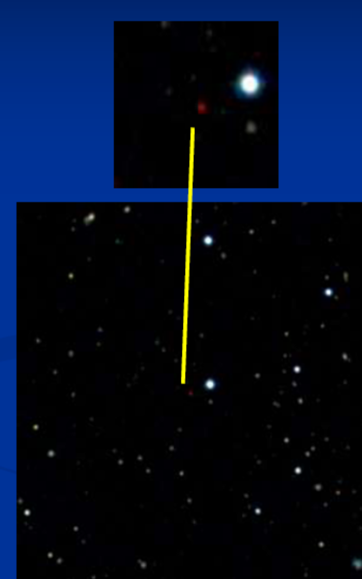




Yencho et al 2009- xray survey

Gemini Quasar at z=7.1





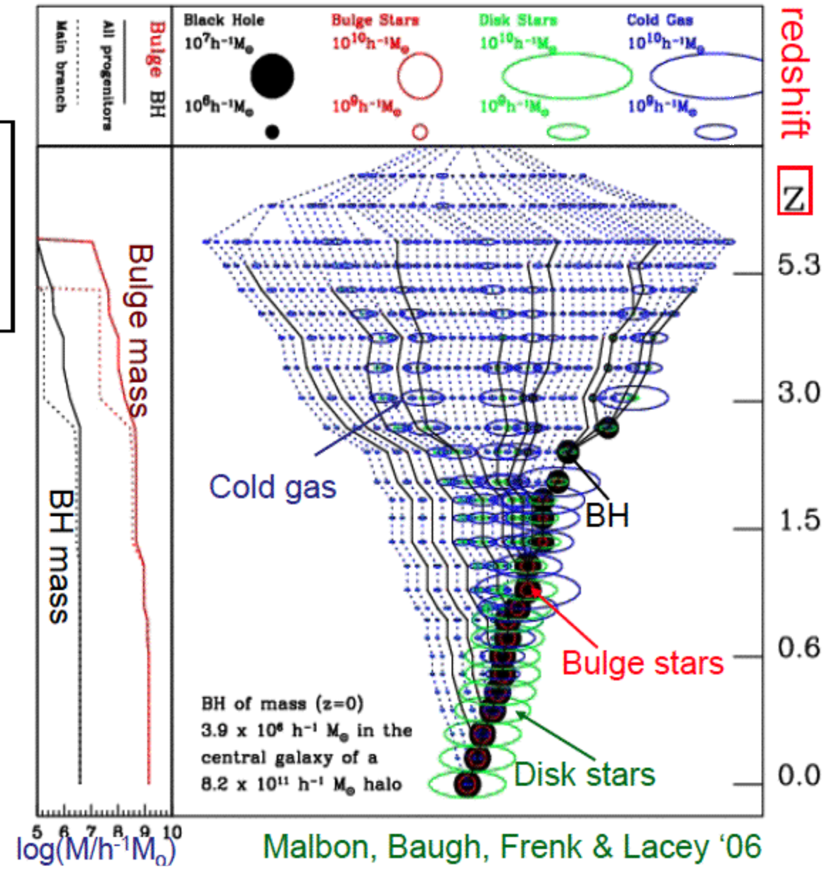
- GNIRS + VLT spectrum of most distant QSO yet discovered. Massive black holes existed when universe was 750 MY old. IR-optimized Gemini was key to this discovery.

$M \sim 10^9 M_\odot$

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)



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

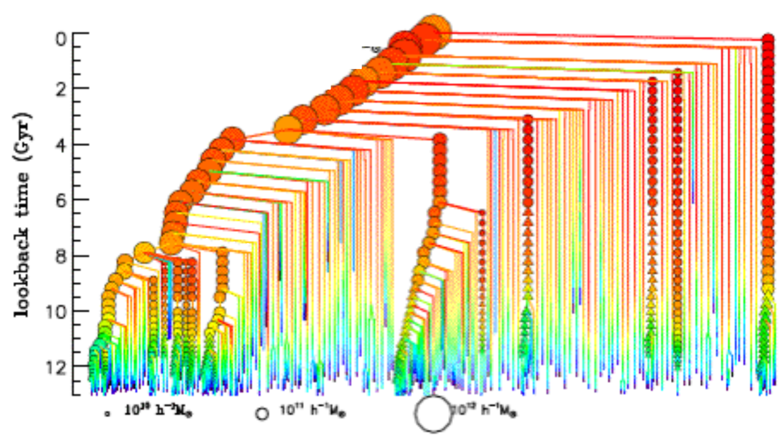
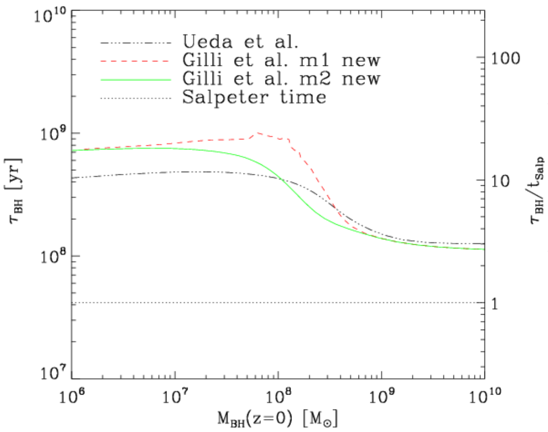


Figure 1. BCG merger tree. Symbols are colour-coded as a function of B - V colour and their area scales with the stellar mass. Only progenitors more massive than 10^{10} M$_\odot$ h^{-1} are shown with symbols. Circles are used for galaxies that reside in the FOF group inhabited by the main branch. Triangles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

Total Lifetime of active BHs

ε= efficiency
λ= Eddington ratio



t_{BH}~2 $\times 10^8$ yr (>10^9 $M_\odot$)
t_{BH}~7 $\times 10^8$ yr (<10^8 $M_\odot$)

- M_{BH} e-fold time (Salpeter's):

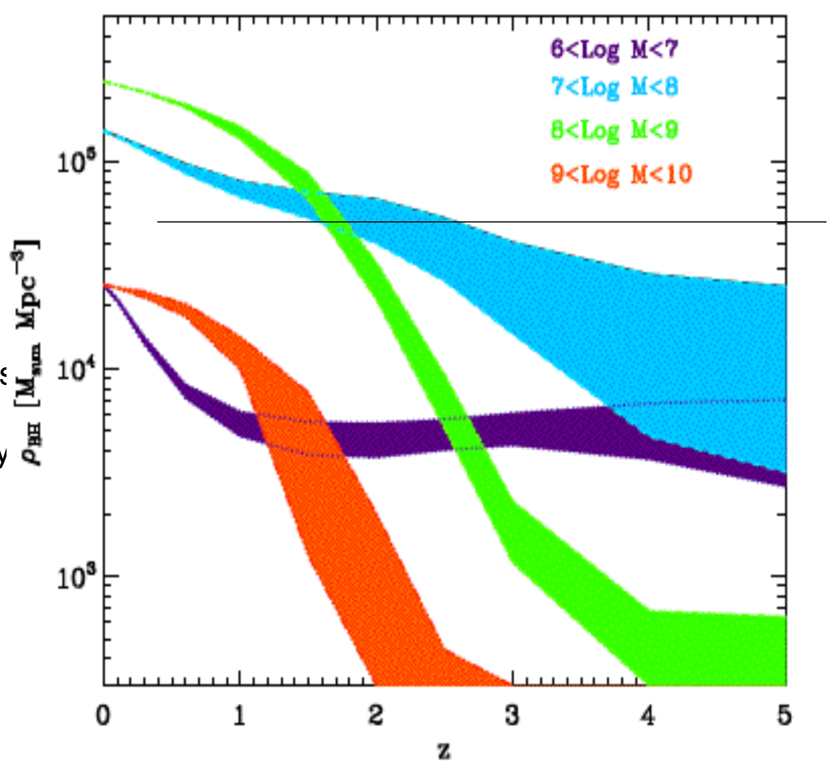
$$t_{Salp} = \frac{\varepsilon t_E}{(1-\varepsilon)\lambda} = 4.2\times 10^7\, yr \left[\frac{(1-\varepsilon)}{9\varepsilon}\right]^{-1} \lambda^{-1}$$

- To grow a BH 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}, longer t_{BH} at lower M_{BH} indicates a more difficult growth of smaller BHs (feedback?).
- Estimated AGN lifetimes range from 10^6 to 10^8 yr (AGNs from SDSS imply lifetimes > 10^8 yr; Miller et al. 2003).

How Black holes grow

Merloni 2009

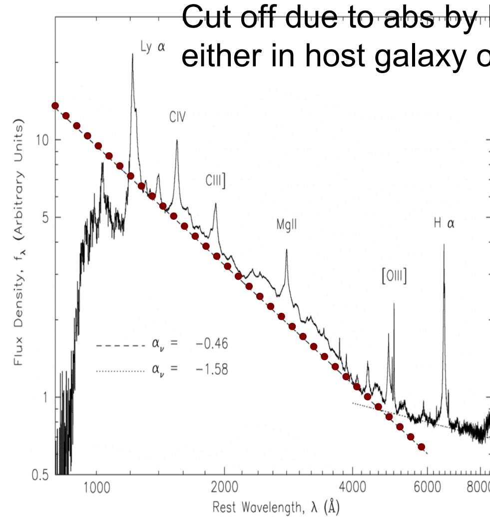
- Most of the mass in BHs today is in the 10^8-10^9 $M_\odot$ range
- BH in mass range 10^6-10^7 $M_\odot$ are growing rapidly today- like spiral galxies
- Massive >109M BHs grew fast in early universe, slow today (like elliptical galaxies)

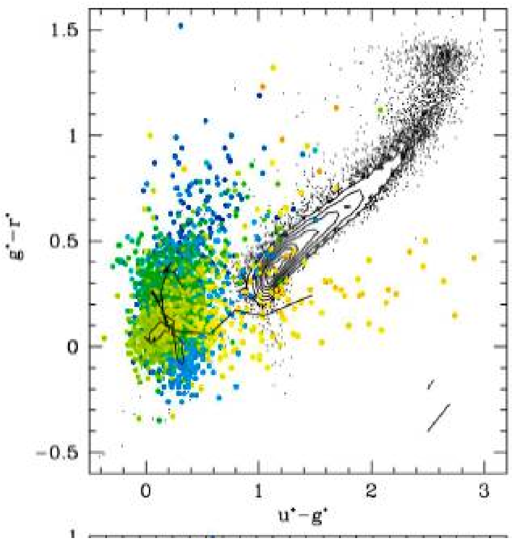


Optical Properties of AGN

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

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





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