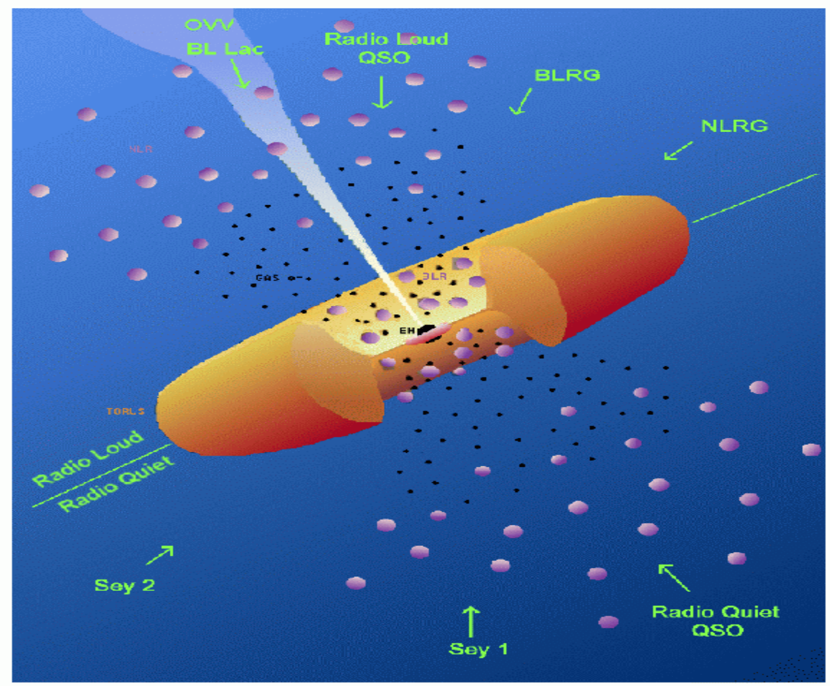
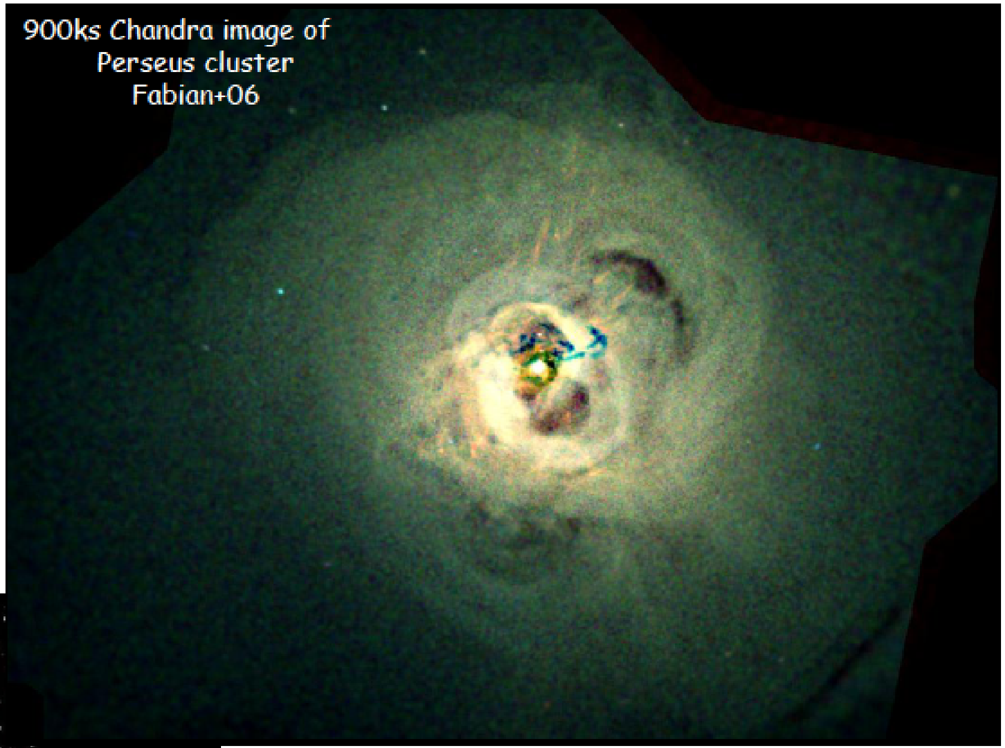
AGN- Alias **Active** Galactic Nuclei

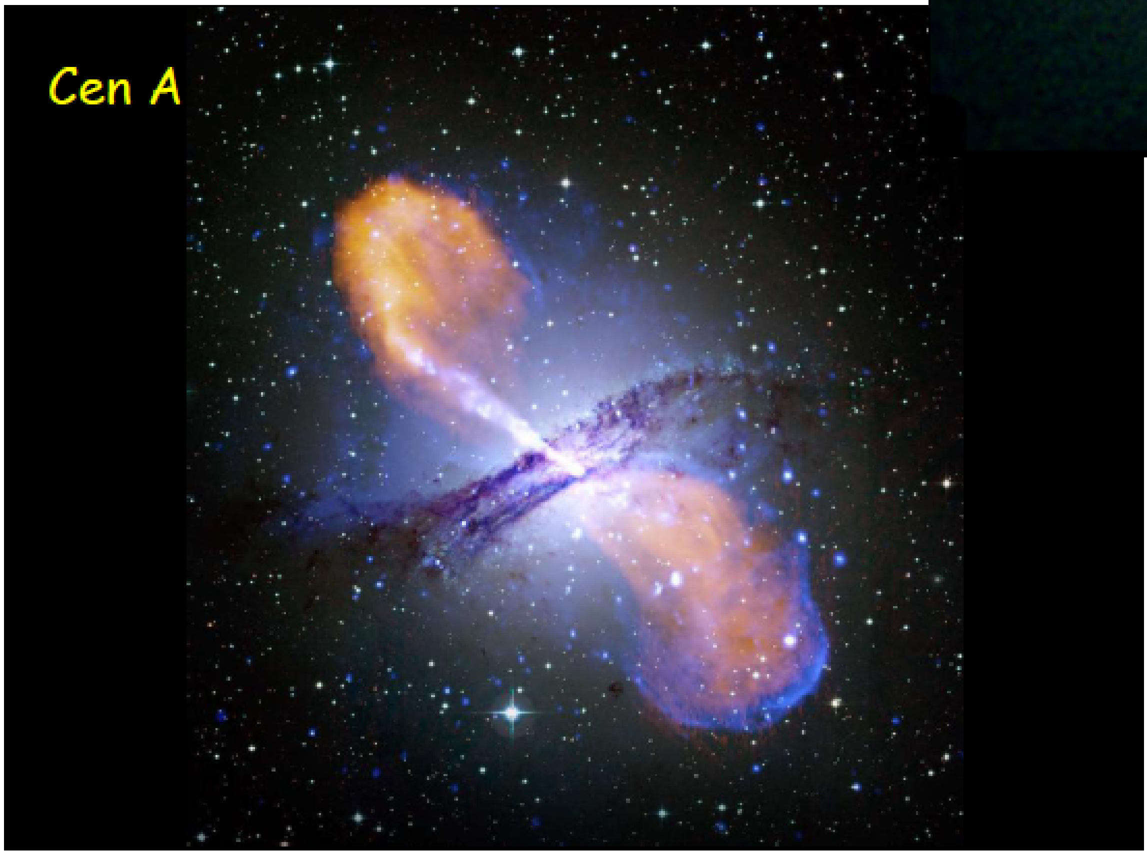
- AGN are **'radiating'** supermassive black holes-
  - They go by a large number of names (Seyert I, Seyfert II, radio galaxies, quasars, Blazars etc etc)
  - The names convey the observational



Schemtaic 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

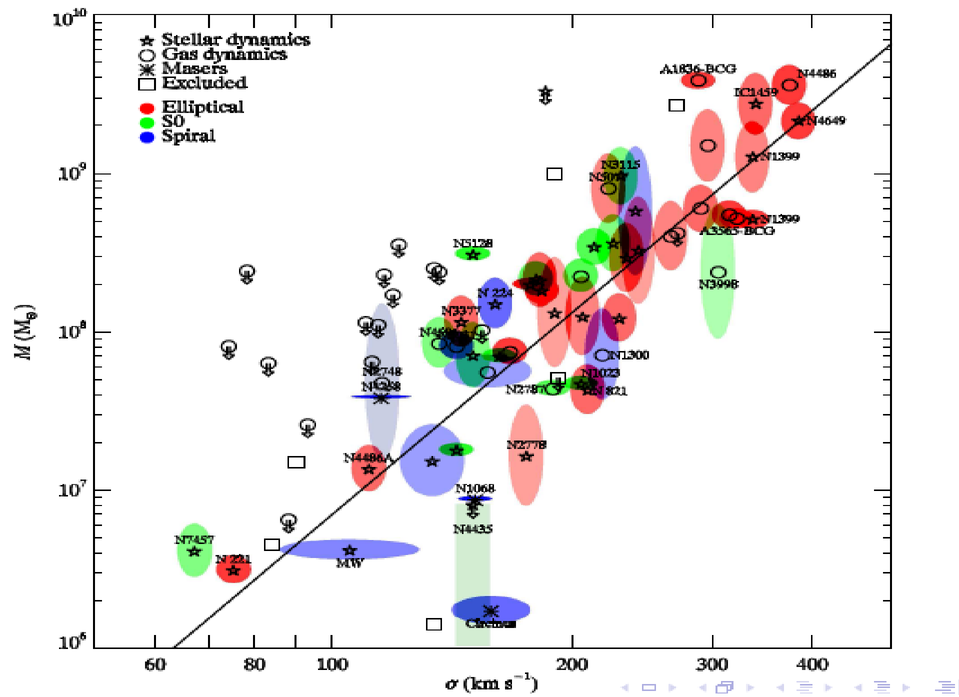
But at z=0 only ~10% are 'active'

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 o black hole (derived later) with velocity dispersion of stars
- Very high detection rate of

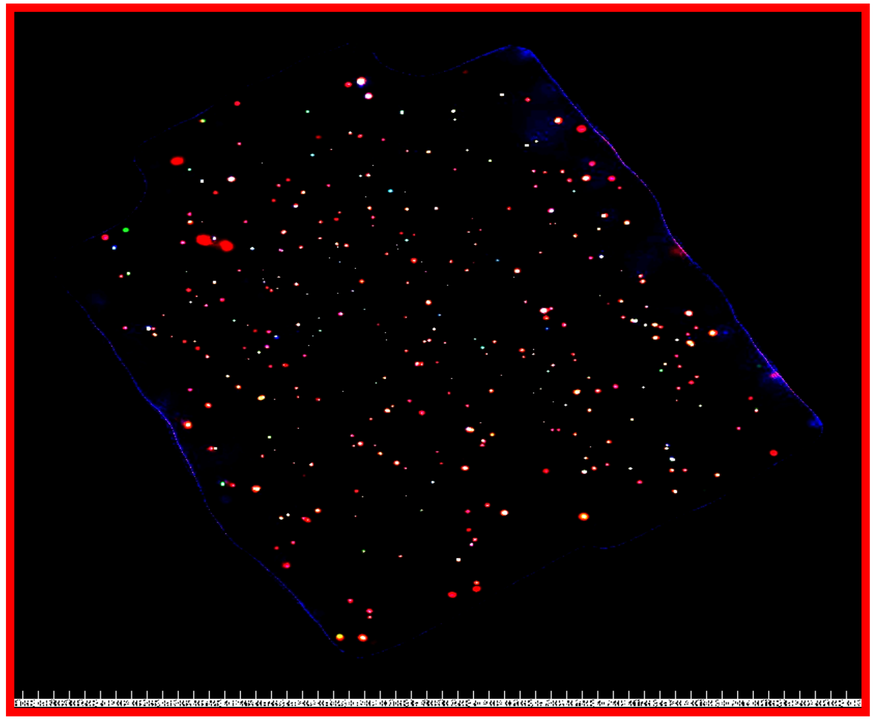


Gultekin 2009

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



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:

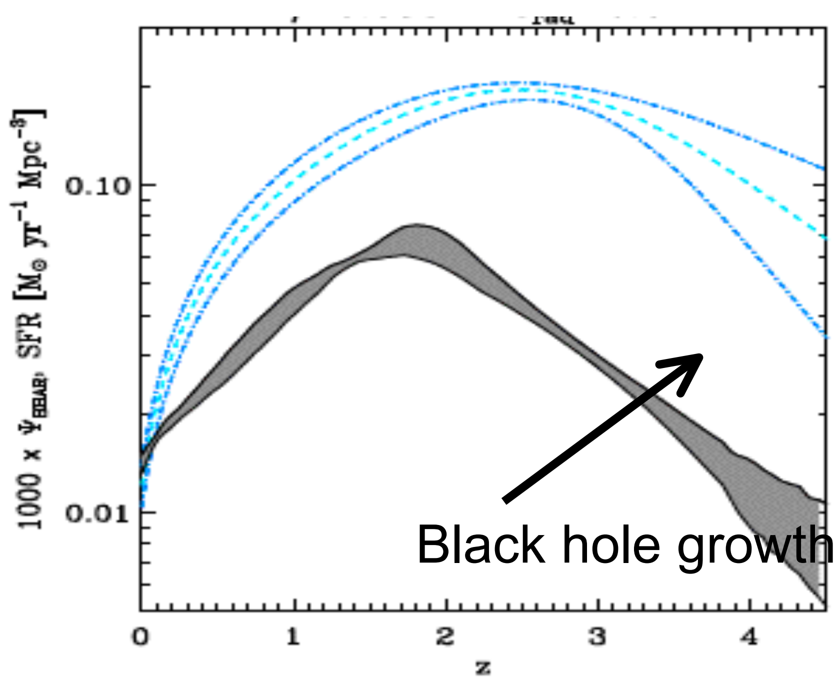
- Solve the cooling flow riddle in clusters of galaxies
- Explain the cluster-scaling relations, e.g. the tilt of the L_x-T relation
- Explain why ellipticals are so gas-poor
- Drive metals into the IGM by quasar-driven winds
- Help to reionize the universe and surpress star formation in small

Springel 2004

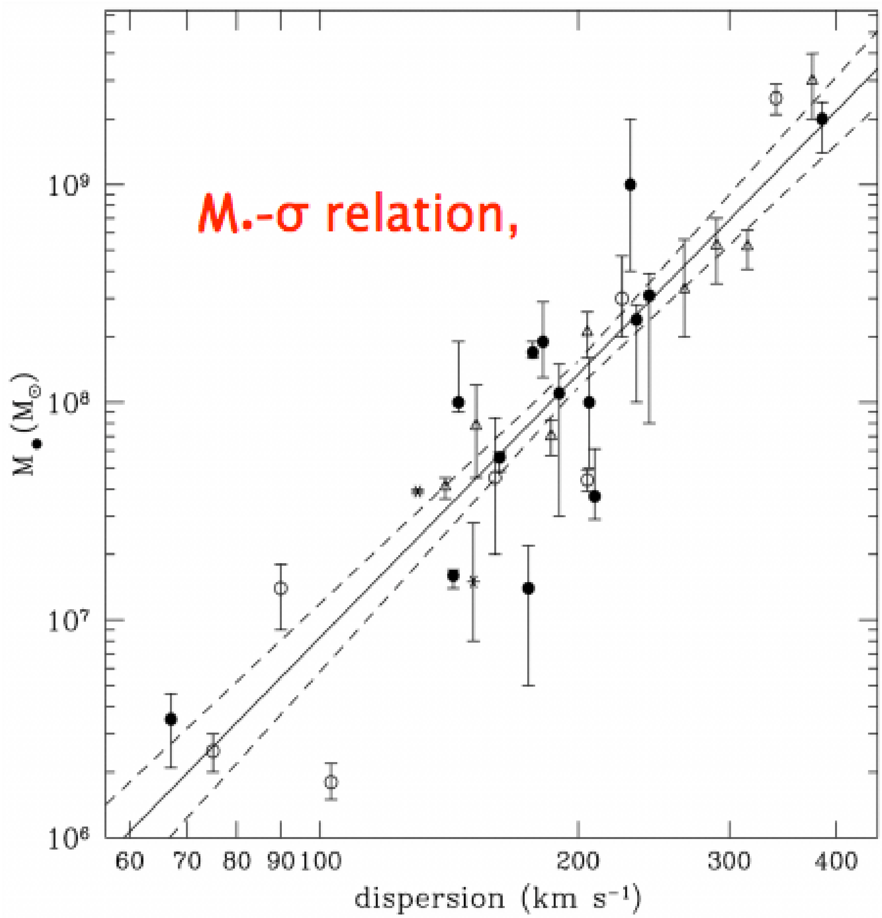
Galaxy formation models need to include the growth and feedback of black holes !

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



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

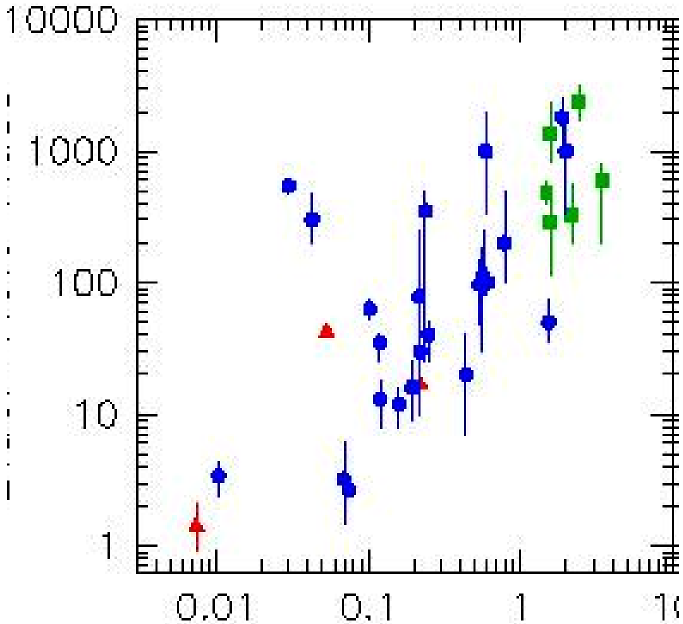
Magorrian et al. 1988; Gebhardt et al. 2000; Ferrarese & Merrit 2000; Tremaine et al. 2002

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

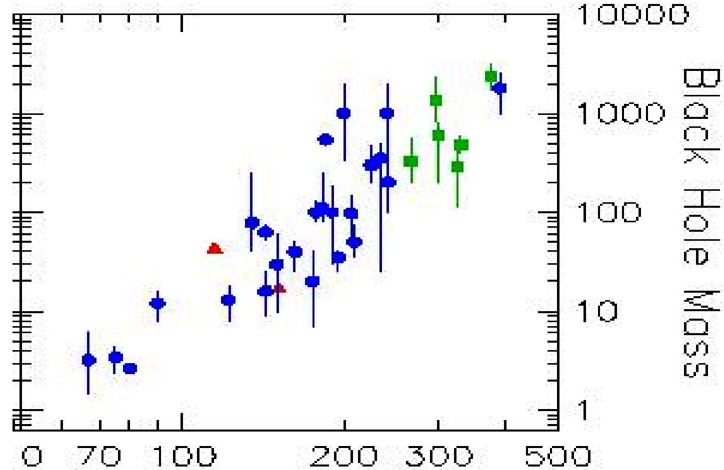
Strong relationship between galaxy and its central massive black hole

- The mass of stars in the galaxy is strongly correlated

Black Hole Mass

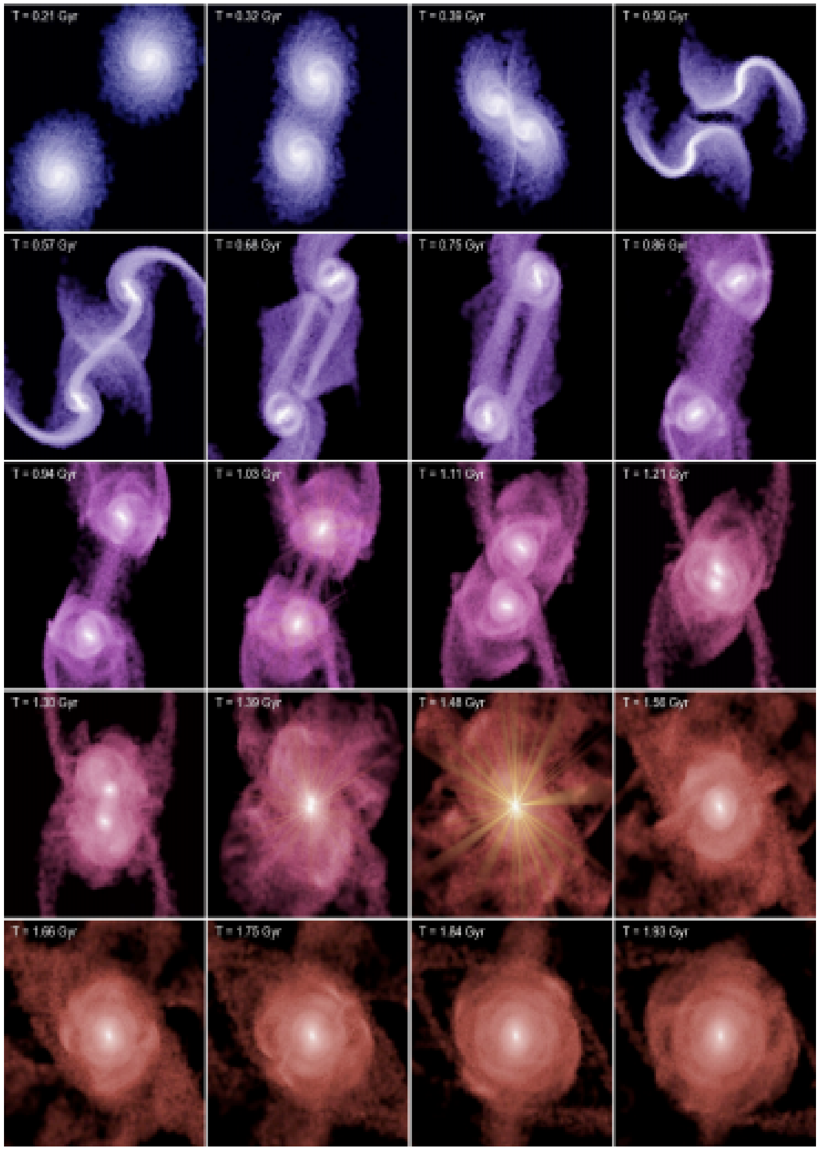


Light in stars



(Mass in stars)$^{1/2}$

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)

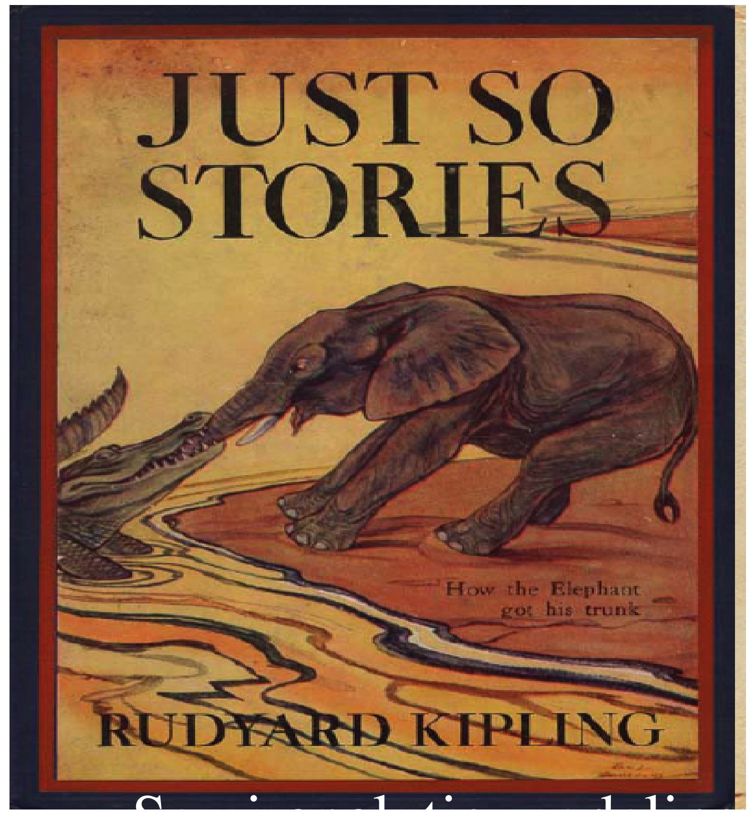
Problems with the Formation of the Universe

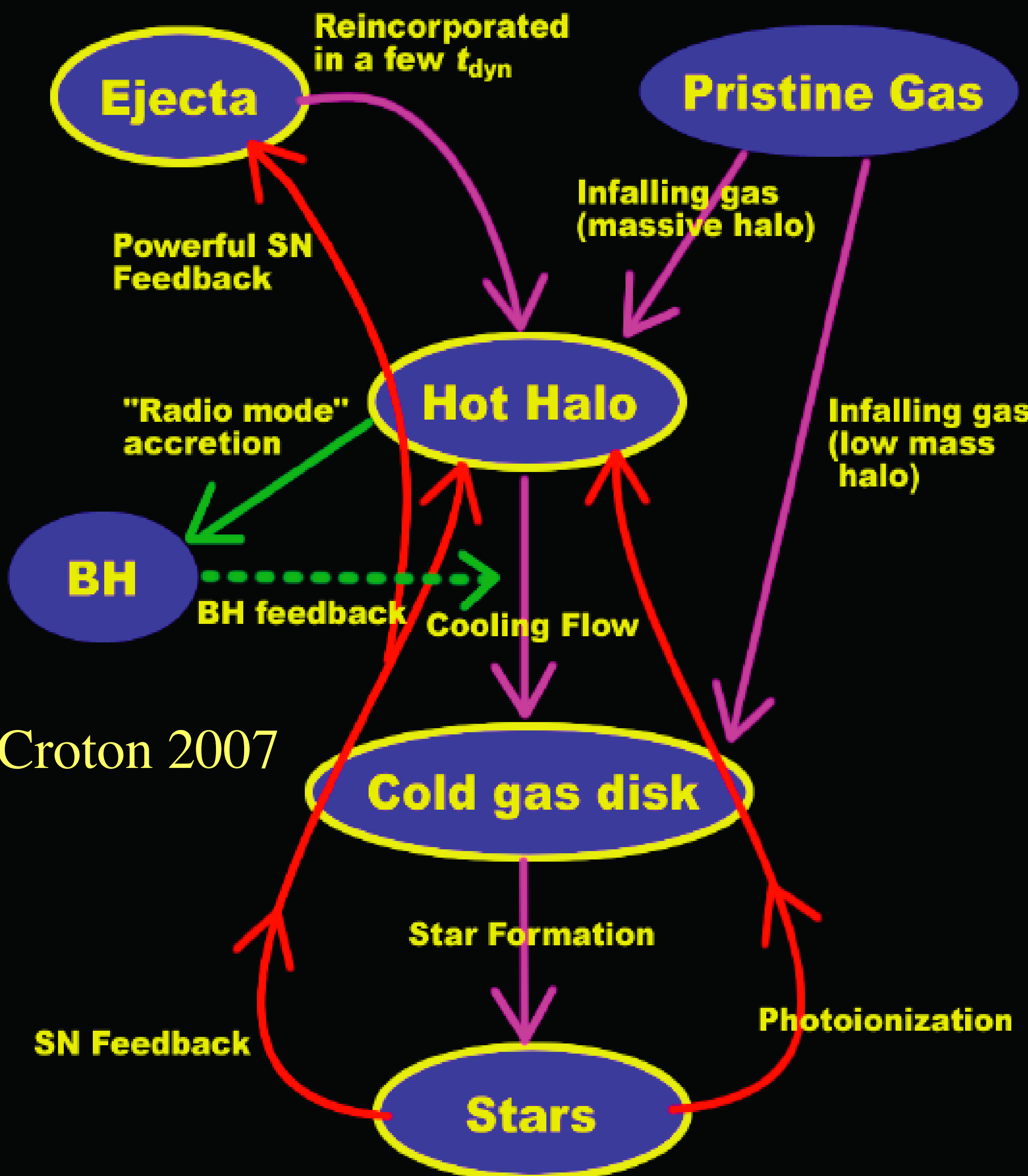
- How did the universe come to look like it does?
- Detailed numerical simulations show that gravity+ hydrodynamics does not produce the universe we see - many things are wrong e.g. galaxies are too big, too bright too blue, form at wrong time, wrong place
- What else is required?
  - FEEDBACK-The influence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

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 <u>additional physics</u> (beyond gravity and

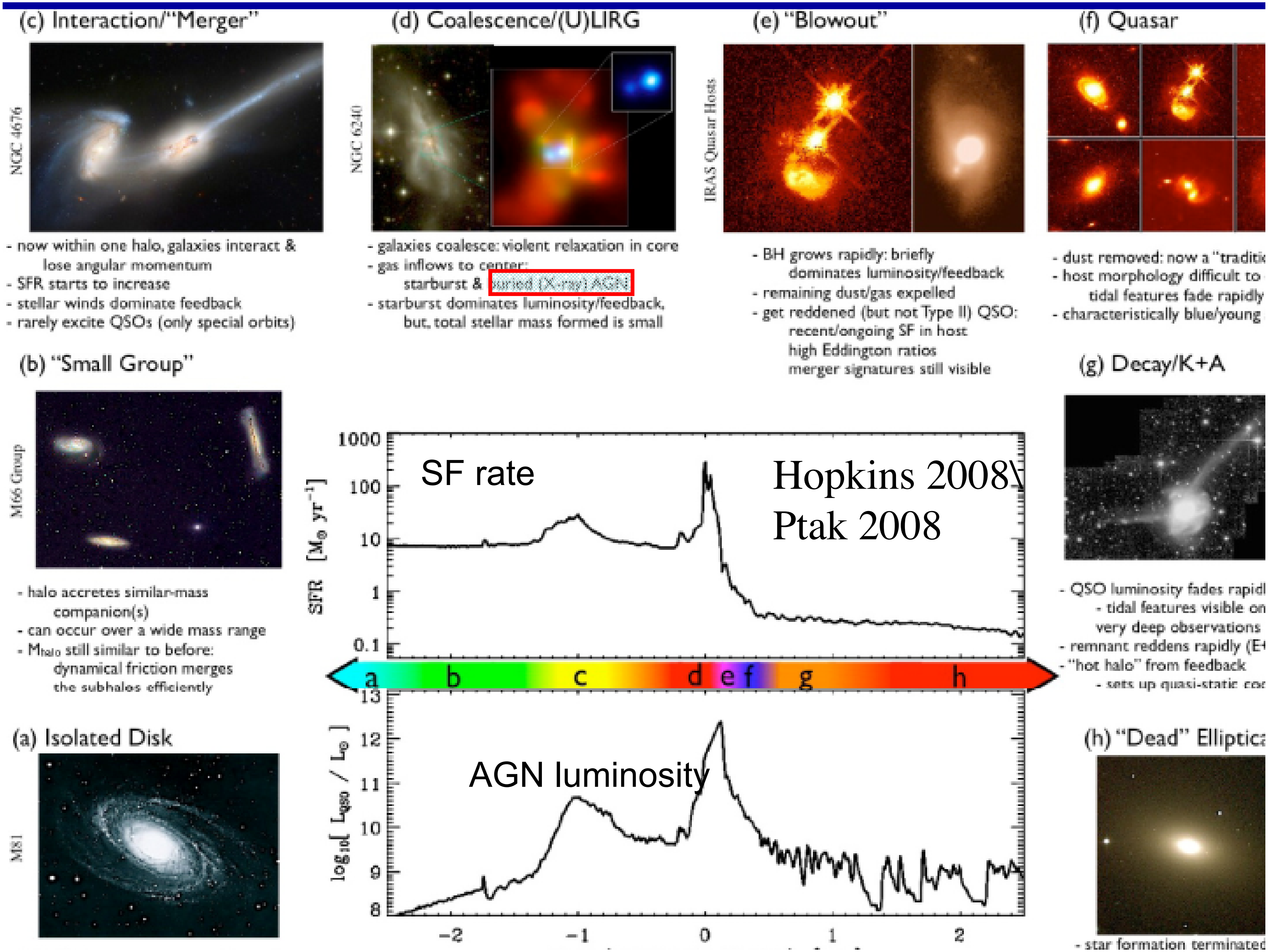




D. Croton 2007

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



(c) Interaction/"Merger"
NGC 4676
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)
(d) Coalescence/(U)LIRG
NGC 6240
- galaxies coalesce: violent relaxation in core
- gas inflows to center:
starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback,
but, total stellar mass formed is small
(e) "Blowout"
IRAS Quasar Hosts
- BH grows rapidly: briefly
dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO:
recent/ongoing SF in host
high Eddington ratios
merger signatures still visible
(f) Quasar
- dust removed: now a "traditi
- host morphology difficult to
tidal features fade rapidly
- characteristically blue/young
(b) "Small Group"
M66 Group
- halo accretes similar-mass
companion(s)
- can occur over a wide mass range
- Mhalo still similar to before:
dynamical friction merges
the subhalos efficiently
(g) Decay/K+A
- QSO luminosity fades rapidl
- tidal features visible on
very deep observations
- remnant reddens rapidly (E+
- "hot halo" from feedback
(a) Isolated Disk
M81
(h) "Dead" Elliptica
- star formation terminated
SF rate
Hopkins 2008\
Ptak 2008
SFR [M⊙ yr⁻¹]
1000
100
10
1
0.1
a
b
c
d
e
f
g
h
AGN luminosity
log10[Lbol / L⊙]
13
12
11
10
9
8
−2
−1
0
1
2

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

The Bottom Line..

- Since mass of black holes scales linearly

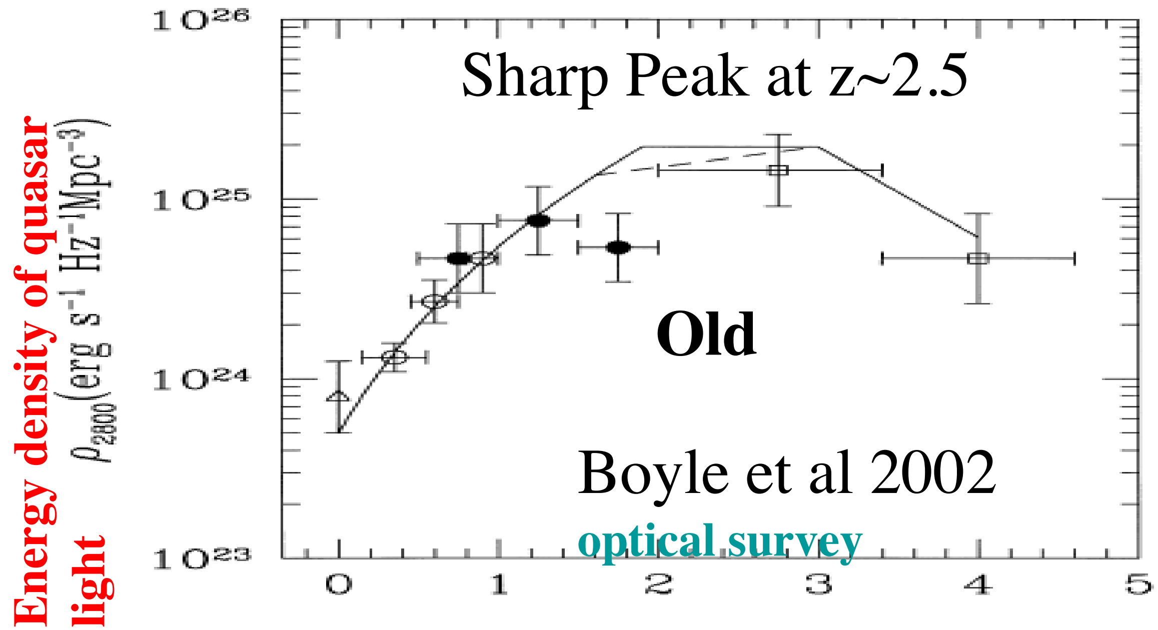
$$E_{BlackHole} > 30 \times E_{Galaxy}$$

Energy released by growth of Black Hole

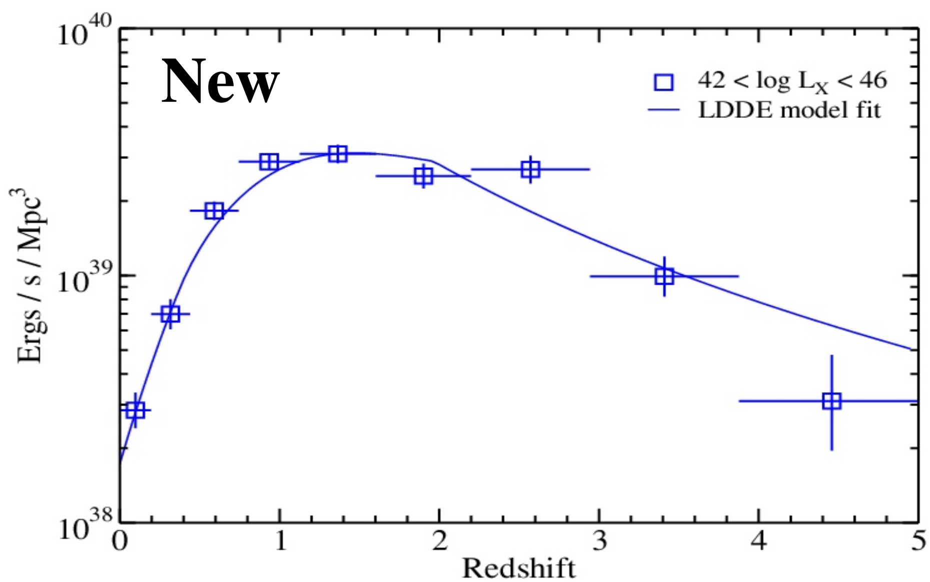
Gravitational Binding Energy of Host Galaxy

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 Evolutio

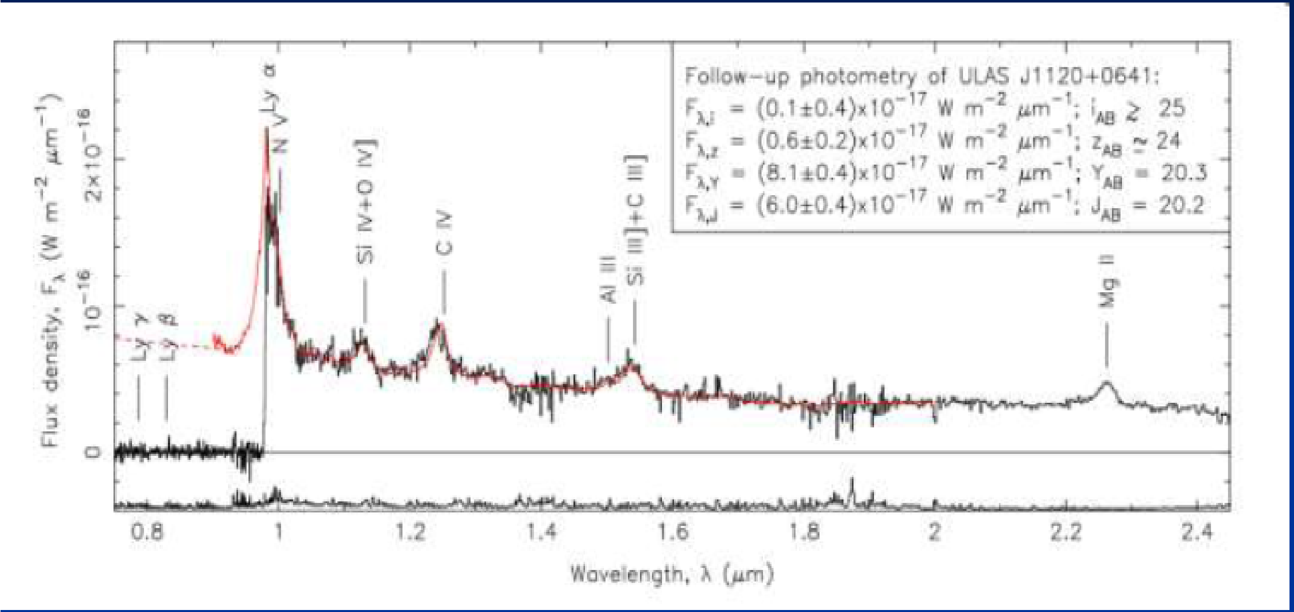


- AGN evolve rapidly in low z universe- reach peak at z~1 and decline rapidly at z>2.5



Yencho et al 2009- xray survey

Gemini Quasar at z=7.1



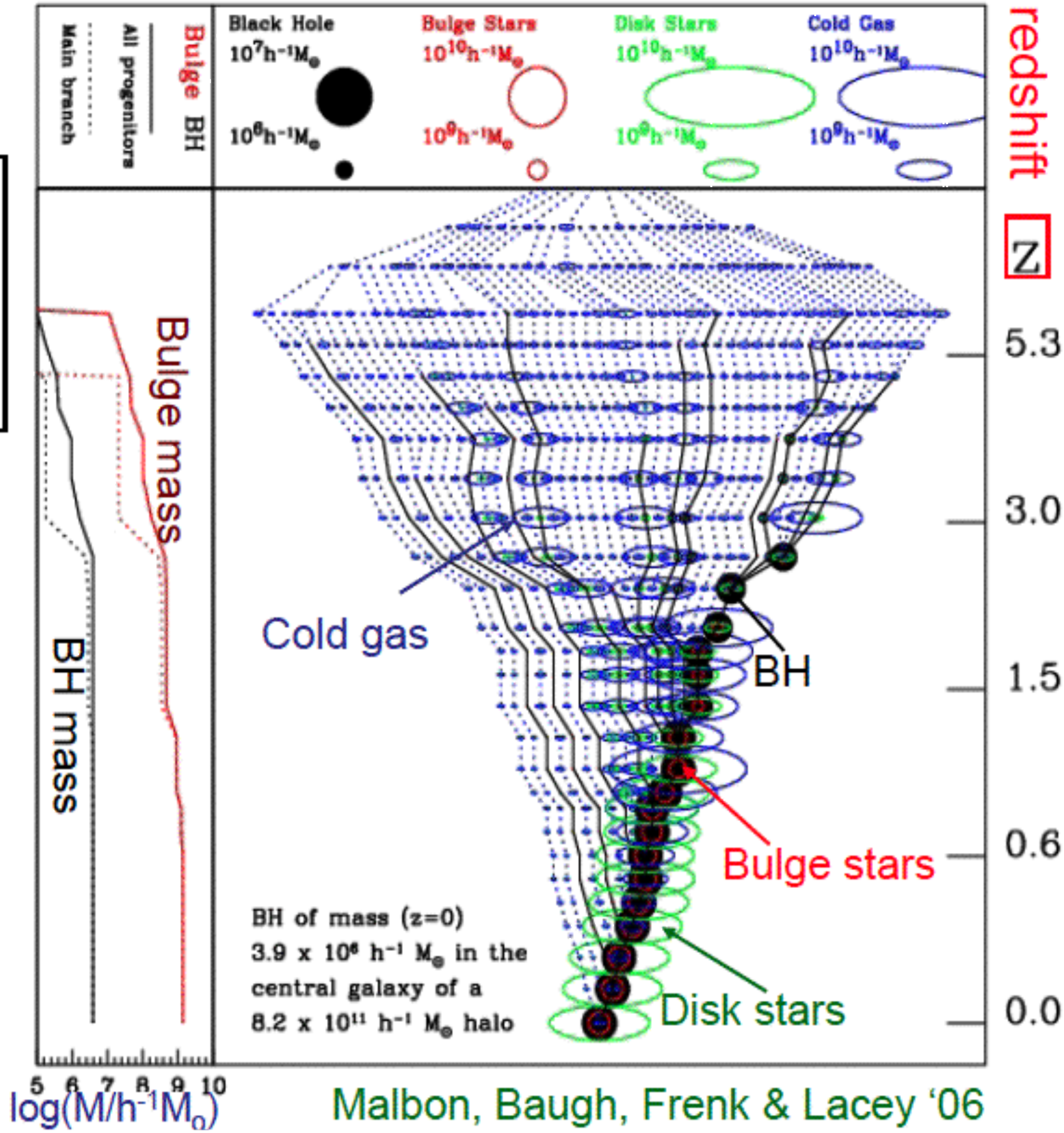
- GNIRS + VLT spectrum of most distant QSO yet discovered. Massive black holes existed when universe was 750 MY old. IR-optimized Gemini was key to this discovery.

$M\sim10^9 M_\odot$

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

Why Backward??

- Cold Dark Matter (CDM) theory of structure forma... ys that
  - sma... s form first
  - mer...
- Expec... the un...

Now

10^{10} yrs ago

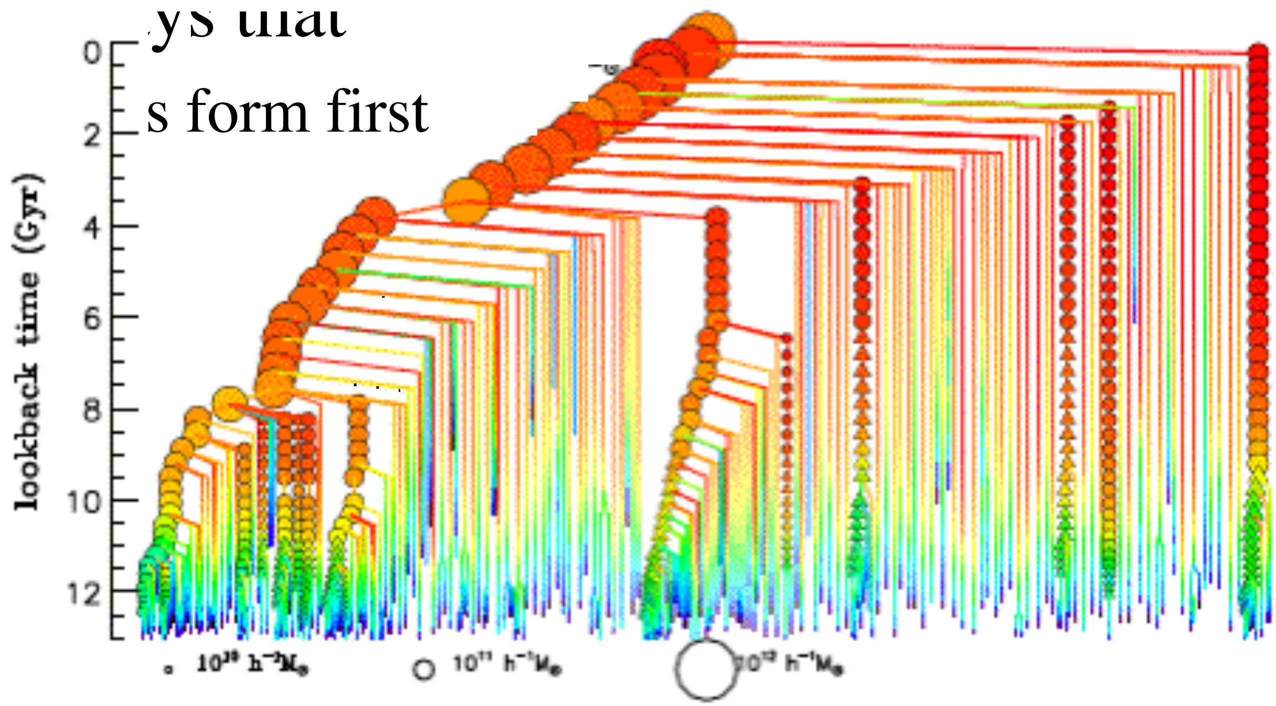


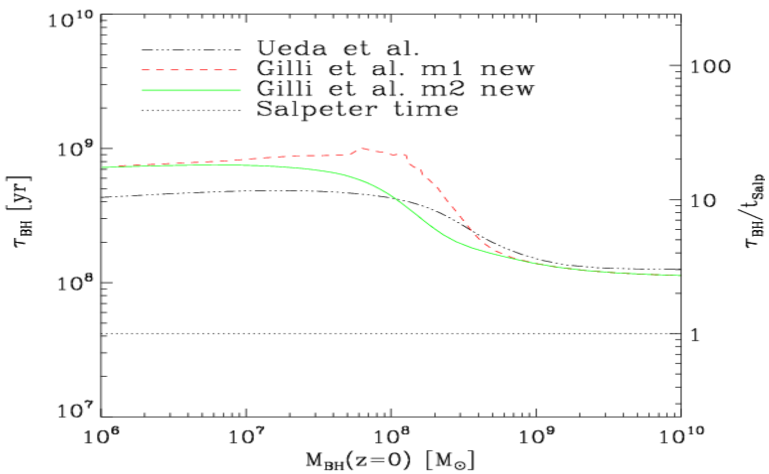
Figure 1. BCG merger tree. Symbols are colour-coded as a function of B - V colour and their area scales with the stellar mass. Only progenitors more massive than 10^{10} $M_\odot$ h^{-1} are shown with symbols. Circles are used for galaxies that reside in the FOF group inhabited by the main branch. Triangles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

Total Lifetime of active BHs

ε= efficiency
λ= Eddington ratio

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

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

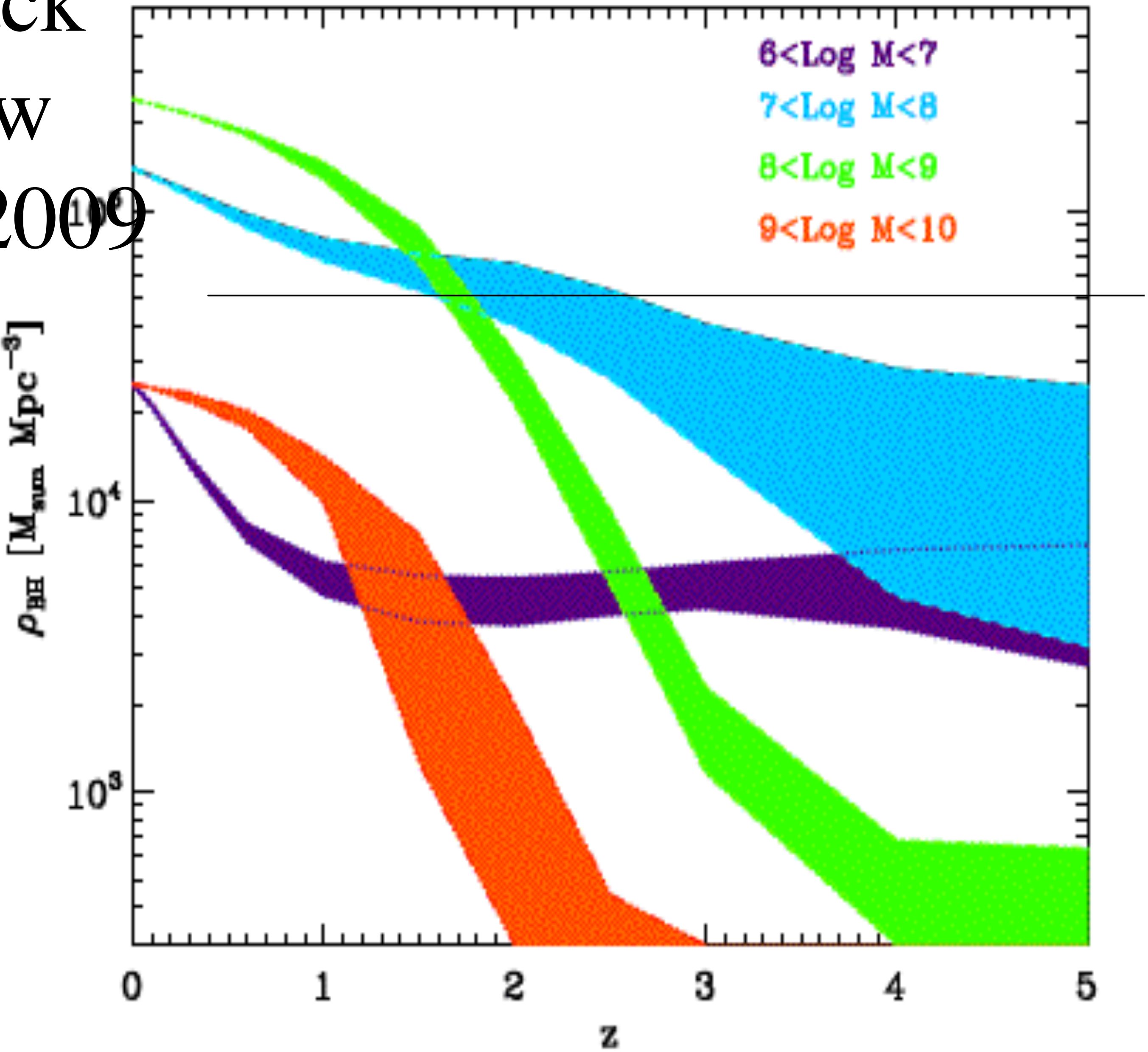


- To grow a BH SEVERAL t_{Salp} needed: 7 t_{Salp} 10^3 ⇨ 10^6 $M_\odot$
  14 t_{Salp} 10^3 ⇨ 10^9 $M_\odot$
- t_{Salp} independent of M... longer t... at

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

How Black holes grow Merloni 2009

- Most of the mass in BH today is in the 10^8-10^9 $M_\odot$ range
- BH in mass range 10^6-1 $M_\odot$ are growing rapidly today- like

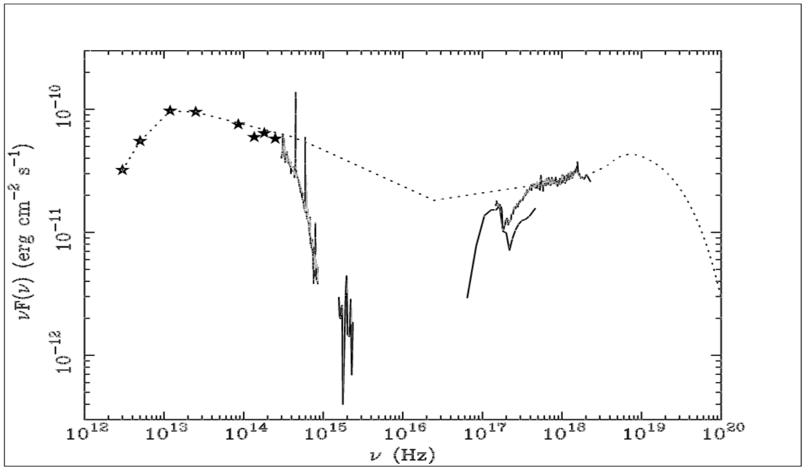


What Are Active Galactic Nuclei

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