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.


![Schematic diagram of regions near the SMBH](image)

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'.
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
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.

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:

- $M_B-\sigma$ relation
- Similarity between cosmic SFR history and quasar evolution
- Blow out of gas in the halo once a critical $M_B$ is reached

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

- Help to reionize the universe and suppress star formation in small galaxies
- Explain the cluster scaling relations, e.g. the $L_X-T$ relation
- Explain why ellipticals are so gas poor
- Drive metals into the ICM by quasar-driven winds

Feedback by AGN may:

- Solve the cooling flow riddle in clusters of galaxies

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

- 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. 1998; Gebhardt et al. 2000; Ferrarese & Merrit 2000; Tremaine et al. 2002
Strong relationship between galaxy and its central massive black hole

- The mass of stars in the galaxy is strongly correlated

Scaling relations that allows estimate of BH mass in distant galaxies
- 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?
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
Calculations from first principles are extremely complex and difficult.
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

- 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

- dust removed: now a "traditio"l host morphology difficult to tidal features fade rapidly
- characteristically blue/young

- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- $M_{\text{halo}}$ still similar to before: dynamical friction merges the subhalos efficiently

- QSO luminosity fades rapidly
- tidal features visible on very deep observations
- remnant reddens rapidly (E)
- "hot halo" from feedback
- sets up quasi-static cor

- star formation terminated
Why AGN?

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

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

- mass density of SN $\rho_{\text{SN}} \sim 4 \times 10^7 M_{\odot} \text{Mpc}^{-3}$ over life of galaxy* $(1/MW/100\text{yrs})$
- mass density of AGN $\rho_{\text{AGN}} \sim 4 \times 10^5 M_{\odot} \text{Mpc}^{-3}$ at $z=0$
The Bottom Line..

- Since mass of black holes scales linearly

\[ E_{\text{BlackHole}} > 30 \times E_{\text{Galaxy}} \]

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
- Boyle et al 2002 optical survey
- Sharp Peak at z~2.5

Energy density of quasar light

New
- 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.

Mortlock et al. 2011, Nature, 474, 616

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

M~$10^9 M_\odot$
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
Total Lifetime of active BHs

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

- \( M_{\text{BH}} \) e-fold time (Salpeter's):
  - To grow a BH
    - SEVERAL \( t_{\text{Salp}} \) needed:
      - \( 7 \ t_{\text{Salp}} \ 10^3 \Rightarrow 10^6 \ M_\odot \)
      - \( 14 \ t_{\text{Salp}} \ 10^3 \Rightarrow 10^9 \ M_\odot \)

- \( t_{\text{BH}} \) independent of \( M_{\text{BH}} \) longer \( t_{\text{BH}} \) at
  - \( t_{\text{BH}} \sim 2 \times 10^8 \text{ yr} \ (>10^9 \ M_\odot) \)
  - \( t_{\text{BH}} \sim 7 \times 10^8 \text{ yr} \ (<10^8 \ M_\odot) \)

\( \varepsilon = \) efficiency

\( \lambda = \) Eddington ratio
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 $10^6$-$1\,M_\odot$ 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 $\log L \sim 40-48$ 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