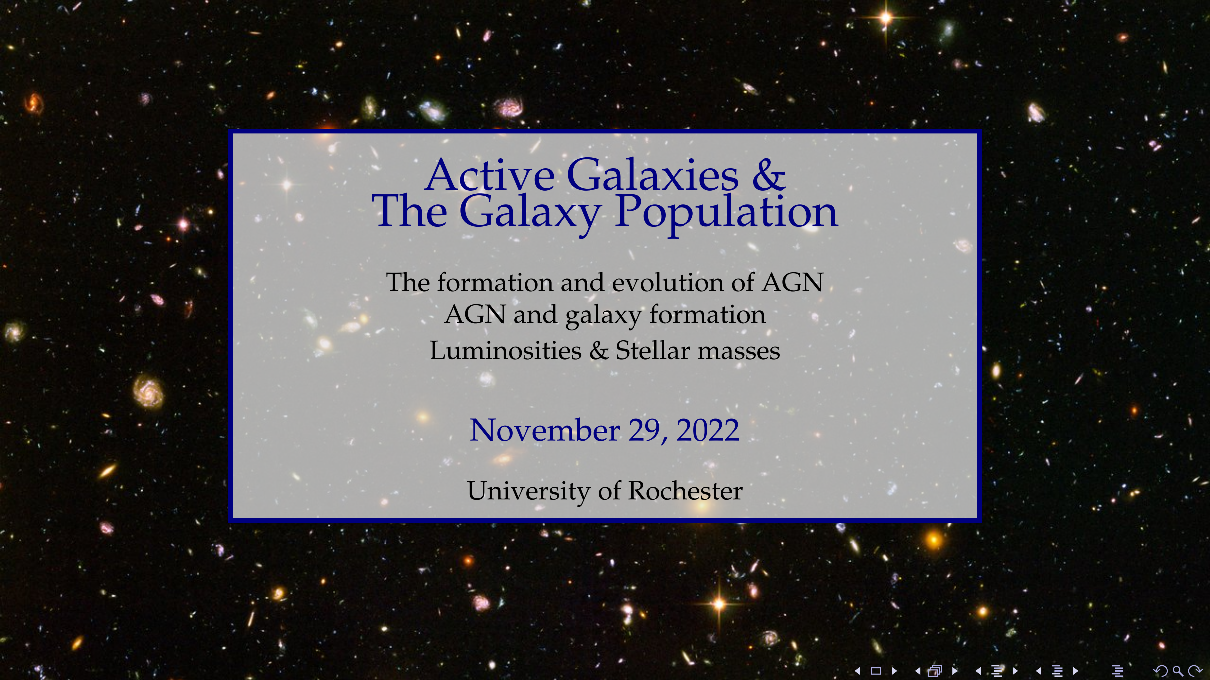

Active Galaxies & The Galaxy Population

The formation and evolution of AGN
AGN and galaxy formation
Luminosities & Stellar masses

November 29, 2022

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Inverse Compton scattering

Relativistic electrons can produce photons with energies up through the X-ray via inverse Compton scattering, where low-energy photons are scattered by the relativistic electrons.

On average, each collision shifts the photon frequency

$$\nu_0 \to \langle \nu \rangle = \frac{4}{3}\gamma^2 \nu_0 \qquad (\gamma \gg 1)$$

If $T_b > 10^{12}$ K, the photons produced by the inverse Compton scattering can themselves be scattered by the relativistic electrons, resulting in catastrophic cooling of the electrons.

This imposes a limit on the size of the region producing the radio emission, as $T_b < 10^{12}$ K for relativistic electrons.

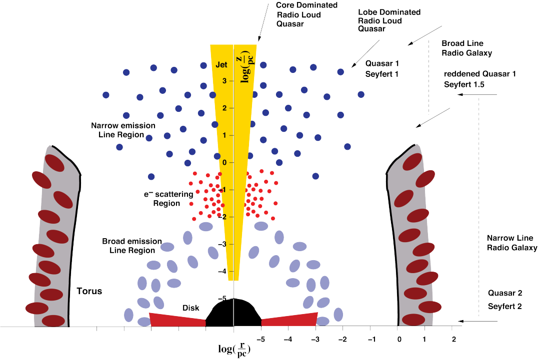
Emission lines: allowed v. forbidden transitions

In general, emission lines can be separated into two classes based on their spontaneous transition probability.

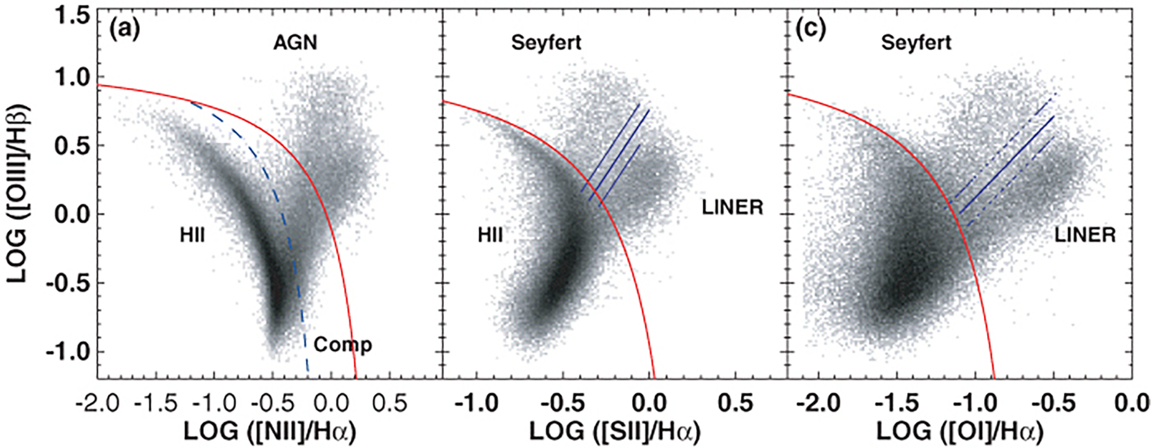
Permitted lines have high transition probabilities (corresponding to short lifetimes). These are the transitions allowed by the electric-dipole selection rules.

Forbidden lines have low transition probabilities (corresponding to long lifetimes) and are denoted by square brackets (e.g. [OIII]). These transitions have a zero dipole component, but non-zero higher-order components.

Semiforbidden lines have intermediate transition probabilities and are denoted by a single square bracket (e.g. CIII]).



Determining the source of ionization



Kewley et al. (2006)

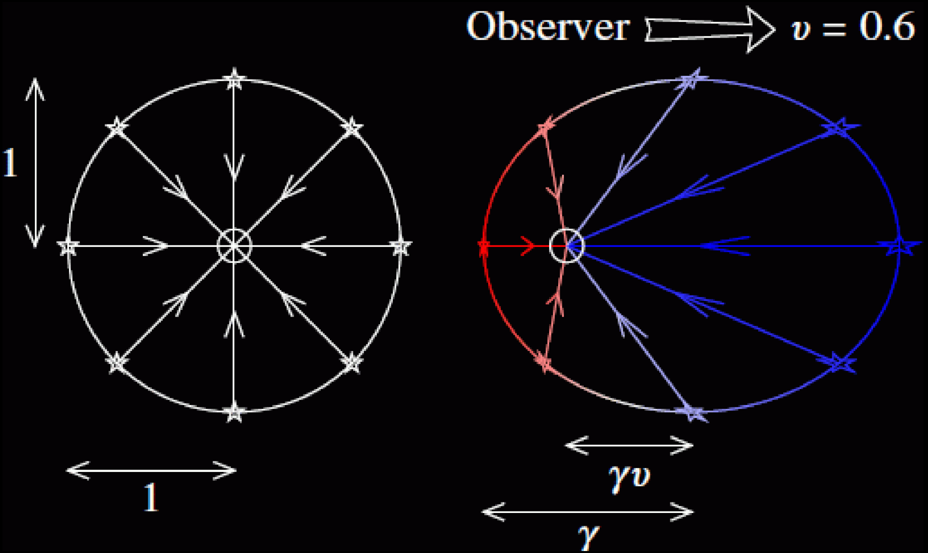
Operation of AGN accretion disks

If the velocity of the relativistic charges takes them into the disk, then they just collide with disk material and lose their energy to heat. If their velocity takes them perpendicular to the disk, they may escape (Blandford & Rees 1975).

Jets: high-speed particles escaping perpendicular to the disk, observed in radio and visible images of radio galaxies and quasars.

Accelerated by gravity and by radiation pressure — and perhaps even magnetic effects — the escaping material is expected to be relativistic, just as we actually observe in jets.

Relativistic beaming



Origins of the central SMBH

Clearly, the SMBH must be quite different in origin from the stellar-mass black holes produced at the end of the lifetimes of massive stars. Since stars do not form larger than about $100M_\odot$, SMBHs could not have arisen via a stellar collapse.

In fact, the origin of supermassive black holes is not well understood.

- Leading models include primordial black holes, or black holes formed from ultra-dense dark matter cores in proto-galaxy nuclei.

A black hole's mass grows at a rate

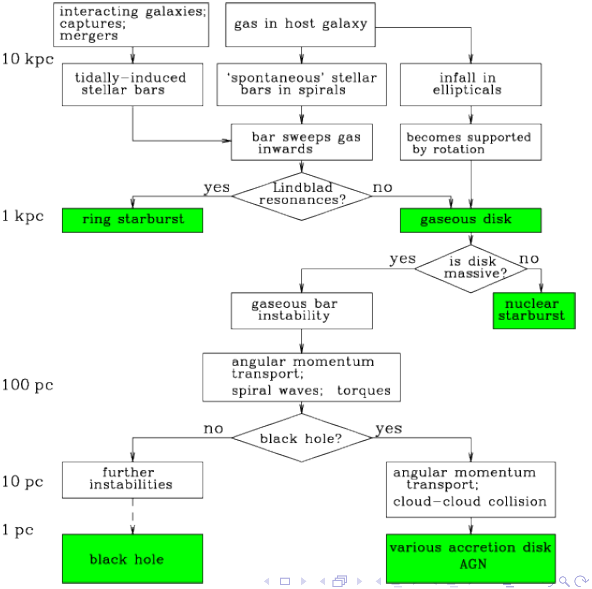
$$M_{BH}(t) = M_{BH,0}e^{t/t_{BH}}$$

where

$$t_{BH} = \left(\frac{L}{L_E}\right)^{-1} \varepsilon t_E \approx 4.4 \times 10^7\ \mathrm{yr}\ \left(\frac{\varepsilon}{0.1}\right)\left(\frac{L}{L_E}\right)^{-1}$$

Fueling the central SMBH

In order for the central SMBH to be an AGN, it must be actively accreting material. Therefore, no matter the formation scenerio for the SMBH, a process must exist to funnel gas to the galactic center in order to fuel the SMBH.



Observational signatures of merger source

If galaxy mergers are the source of AGN, then we should observe a surplus of mergers with AGN signatures relative to the number of non-merging galaxies containing AGN.

The hierarchical formation scenerio predicts a higher rate of merging galaxies at high redshifts. In addition, these galaxies would be more gas-rich.

We should then expect to observe the number density of AGN increase with time, peak, and then fall back off. And, we would expect today's early-type galaxies to host more AGN than late-type galaxies.

Luminosity function of QSOs

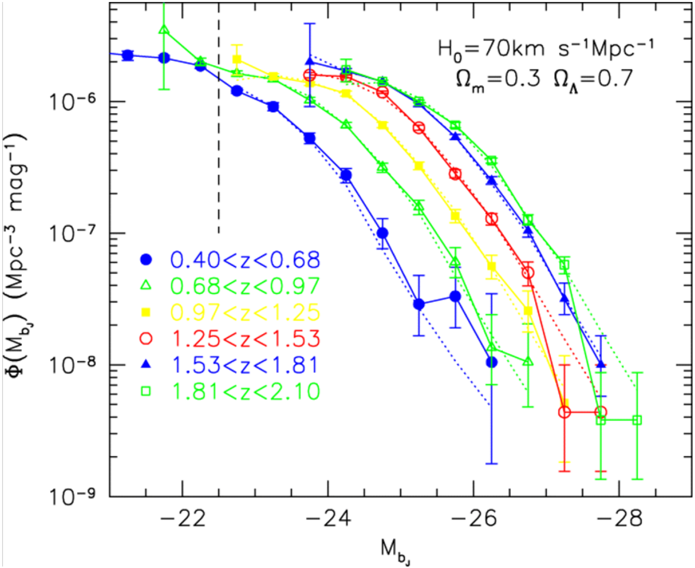
The luminosity function of QSOs is well-described by

$$\phi(L,z)\,dL = \phi^*(z)\left[\left(\frac{L}{L^*(z)}\right)^{\beta_1} + \left(\frac{L}{L^*(z)}\right)^{\beta_2}\right]^{-1} \frac{dL}{L^*(z)}$$

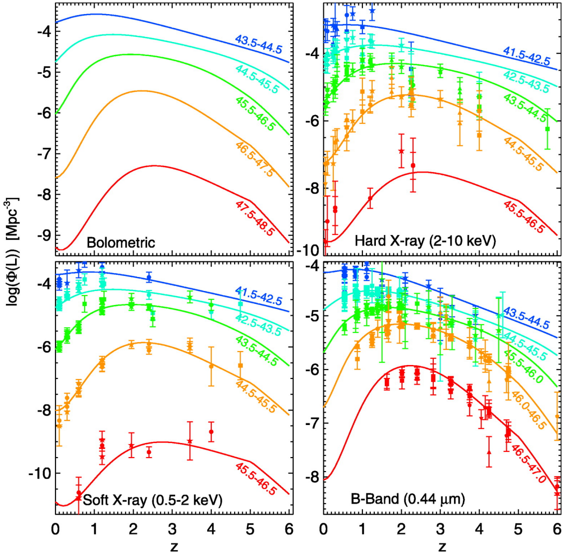
where

ϕ^* is independent of z

$L^*(z)$ $\propto L^*(0)(1+z)^k$ with $k \sim 3.45$



Number density evolution of QSOs



Implications for AGN formation

If AGN are hosted by massive dark matter halos, then we would expect to see a steady increase in the number of halos hosting AGN with decreasing redshift.

If AGN activity is triggered by mergers, then we would expect a decrease in AGN activity below $z \lesssim 3$, since

- There are fewer galaxies to merge.
- Galaxies are less gas-rich.
- AGN feedback is more effective.
- The galaxies capable of hosting AGN are in environments which are too hot.

AGN v. galaxy

How does the energy output of an AGN compare to the binding energy of a galaxy?

The total power output of the AGN is

$$\frac{dE}{dt} = \varepsilon \frac{dm}{dt} c^2$$

By integrating, we find that the total energy produced by the AGN over its lifetime is

$$E = \bar{\varepsilon} M_{BH} c^2$$

Assuming that the galaxy is in virial equilibrium, its gravitational binding energy is

$$U \sim -M_{\text{gal}} \sigma^2$$

AGN v. galaxy

The ratio of these energies is then

$$\frac{E}{|U|} \sim \frac{\bar{\varepsilon} c^2}{\sigma^2} \frac{M_{BH}}{M_{\rm gal}}$$

Observations show us that $M_{BH}/M_{\rm gal} \sim 10^{-3}$.

For a massive galaxy ($\sigma \sim 300$ km/s), $E/|U| \sim 10^3 \bar{\varepsilon}$.