

Active Galactic Nuclei

- Many Galaxies, especially older ones (further away), have extremely bright center (nucleus); can vary over \approx days
 - Seyfert Galaxies:
 - Broad lines, continuum spectrum (radio loud/quiet - UV, Xray) from extremely hot center
 - Radio Galaxies:
 - Emission mostly at 10 cm; have jets and “radio lobes”
 - Example: Cygnus A (240 Mpc) brighter in radio spectrum than all but sun and 1 nearby supernova remnant ($5 \cdot 10^{37}$ W = 10^{11} suns!)
 - Quasars (quasi-Stellar radio sourceS)
 - Very far away (100-1000 Mpc), ultra-bright (10^{12-14} suns) objects (appear star-like in telescope since nuclei outshine whole galaxy by huge factor)
- Radiation from accretion disc, surrounding dust, synchrotron motion of free electrons etc.

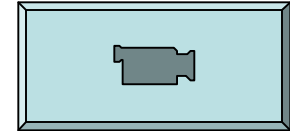
Engine for all these AGNs: Supermassive Black Holes

- Size:
 - Cannot be much larger than $t_{\text{var}} \times c$ (illuminated sphere) => 1 hr implies 7 AU
- Mass: Eddington limit
 - Energy flux density: $F = \frac{L}{4\pi r^2}$ Momentum Flux: $F_p = \frac{L/c}{4\pi r^2}$
 - Radiation Force on electrons: $F_{r.p.} = \frac{L}{4\pi r^2 c} \sigma_e$
(Thompson cross section $6.7 \cdot 10^{-29} \text{m}^2$)
 - ...must be < grav. force on proton (attached to e^- in plasma): $F_{\text{grav}} = \frac{GMm_p}{r^2}$
 - => yields max. Lumi: $L_E = \frac{4\pi GMm_p c}{\sigma_e} = 3.3 \cdot 10^4 L_{\text{sun}} \frac{M}{M_{\text{sun}}}$
 - => $M > 3 \cdot 10^8 M_{\text{sun}}$ for $10^{13} L_{\text{sun}}$
 - Schwarzschild radius $9 \cdot 10^8 \text{ km} = 6 \text{ A.U.}$ => Consistent!

Luminosity via Accretion

- Straight-line infall - mass-energy disappears and simply makes black hole bigger
- Accretion disk (rotating) - lots of gas, “friction” => most of gravitational energy change converted into heat => luminosity
- Non-rotating BH -> smallest orbit = $3R_S$, expect grav. binding energy = $1/6 mc^2$ but in fact only 5.7% available (= efficiency)
- Rotating BH -> can get up to 42%
- Assume efficiency $\eta = 0.1$ on average
- $L = \eta dM/dt c^2$
- => $dM/dt = 7 M_{\text{sun}}/\text{yr}$ for $L = 10^{13} L_{\text{sun}}$
- Maybe explains history: after a few 10^9 yrs, BH creates maximum L ; later it runs out of fuel - see later...

Galactic Evolution



- Looking at far-away galaxies we see young galaxies (as they were a long time ago)
 - Example: Quasar with redshift $z = 6.4$ (meaning $\lambda_{\text{obs}}/\lambda_{\text{em}} = 7.4$) => light we see was emitted when Universe was only 2 Gyr old
 - at that time, quasar was $3.7 \text{ Gyr} \cdot c$ away
 - Now it's $27 \text{ Gyr} \cdot c$ away
 - Luminosity requires accretion of $200 M_{\text{sun}}/\text{yr}$
 - Do that for 10 Gyr => $2 \cdot 10^{12} M_{\text{sun}}$! No black holes that larger have ever been seen (plus where should that mass come from?)
 - Back then, 1 in 1000 galaxies was a quasar
 - Today: 1 in 10^6 galaxies is a quasar
 - 2 possible reasons:
 - fuel is all gobbled up, BHs still around but “hibernating”
 - Much more food around in the past: colliding galaxies (higher density) - see later