Active Galactic Nuclei

- Many Galaxies, especially older ones (further away), have extremely bright center (nucleus); can vary over ≈ 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 ($10^{12\text{-}14}$ 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_{var} x 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: (Thompson cross section $6.7 \cdot 10^{-29}$m^2) $F_{r.p.} = \frac{L}{4\pi r^2 c}\sigma_e$
  - …must be < grav. force on proton (attached to e^- in plasma): $F_{grav} = \frac{GMm_p}{r^2}$
  - => yields max. Lumi: $L_E = \frac{4\pi GMm_p c}{\sigma_e} = 3.3 \cdot 10^4 L_{sun} \frac{M}{M_{sun}}$
  - => $M > 3 \cdot 10^8\ M_{sun}$ for $10^{13}\ L_{sun}$
  - Schwarzschild radius $9 \cdot 10^8$ km = 6 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 η = 0.1 on average
- $L = \eta \, \mathrm{d}M/\mathrm{d}t \, c^2$
- => $\mathrm{d}M/\mathrm{d}t = 7 \, M_{sun}$/yr for $L = 10^{13} \, L_{sun}$
- Maybe explains history: after a few10^9 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 $\lambda_{obs}/\lambda_{em}$ = 7.4) => light we see was emitted when Universe was only 2 Gyr old
    - at that time, quasar was 3.7 Gyr·*c* away
    - Now it's 27 Gyr·*c* away
  - Luminosity requires accretion of 200 M_{sun}/yr
  - Do that for 10 Gyr => $2 \cdot 10^{12}$ M_{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