Outline

- Go over problem 6.7
- Soltan argument
- Nukers
- M-σ relation

Eddington Luminosity

- Maximum accretion rate and maximum luminosity occurs when radiation pressure exactly balances gravity. This is the "Eddington luminosity"

$$L_E = \frac{4\pi c G M m_p}{\sigma_T}$$

$$L_E = 1.3\times10^{38}\,\mathrm{erg/s}\,\frac{M}{M_{\mathrm{Sun}}} = 3.3\times10^{4}\,L_{\mathrm{Sun}}\,\frac{M}{M_{\mathrm{Sun}}}$$

- For $M = 4\times10^6\, M_{\mathrm{Sun}}$, have $\mathrm{L} = 1.3\times10^{11}\, L_{\mathrm{sun}}$
- For comparison, luminosity of Milky Way is $\mathrm{L} = 2\times10^{10}\, L_{\mathrm{sun}}$
- Central black hole would outshine whole galaxy if radiating near the Eddington limit.

Accretion Disks

- Radiative efficiency is fraction of rest mass energy of accreted matter that is radiated

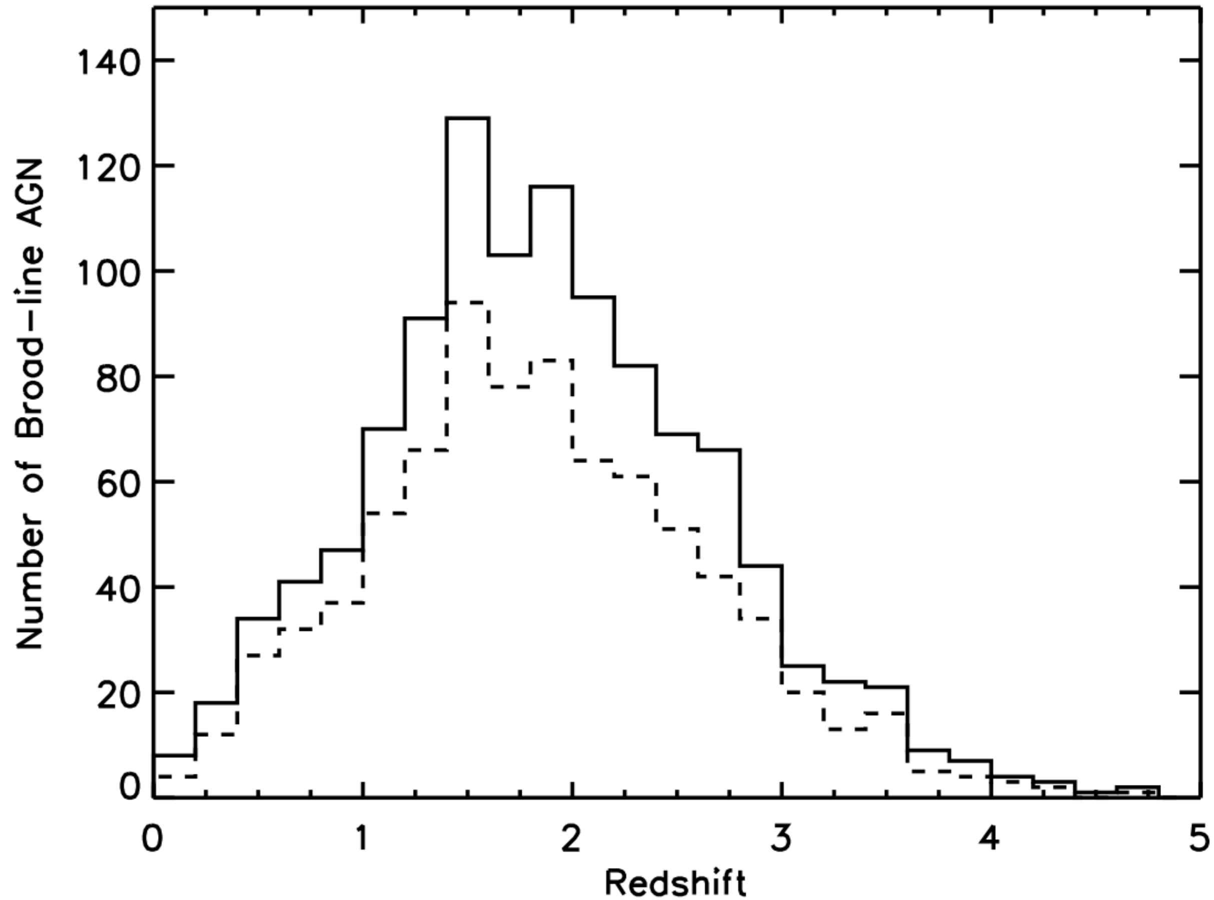
$$\eta = \frac{L}{\dot{M} c^2} = \frac{1}{2}\frac{GM}{r_{\rm in} c^2}$$

- For non-rotating black hole, stable orbits are not possible inside of the "innermost stable circular orbit" at $r_{\rm in} = 3r_{\rm s} = 6GM/c^2$ and $\eta = 0.057$.
- Means that 94% of matter is accreted, increasing black hole mass.
- Can calculate ratio between emitted light and change in mass

$$\dot{M}_{\rm BH} = (1-\eta)\dot{M} = \frac{1-\eta}{\eta c^2} L$$

$$\Delta M_{\rm BH} = \int \dot{M}_{\rm BH} dt = \frac{1-\eta}{\eta c^2}\int L\, dt$$

Active Galactic Nuclei



- Contain accreting super-massive black holes
  - Found preferentially at higher redshifts
- Accretion leads to increase in black hole mass
- Therefore, even if the black holes are no longer accreting today, there should be massive black holes at the nuclei of nearby galaxies
- Can we figure out how many?

Soltan Argument

- Consider a "co-moving volume" in the universe.
- Measure the luminosity function of AGN inside that volume.
- Integrate the luminosity function to find the total light (need to apply Bolometric corrections since lots of AGN light is outside optical band).
- Integrate over time and space to find the total luminosity emitted by AGN in that volume over the lifetime of the universe.
- This enables one to calculate the total mass in supermassive black holes inside that volume (neglecting their initial masses).

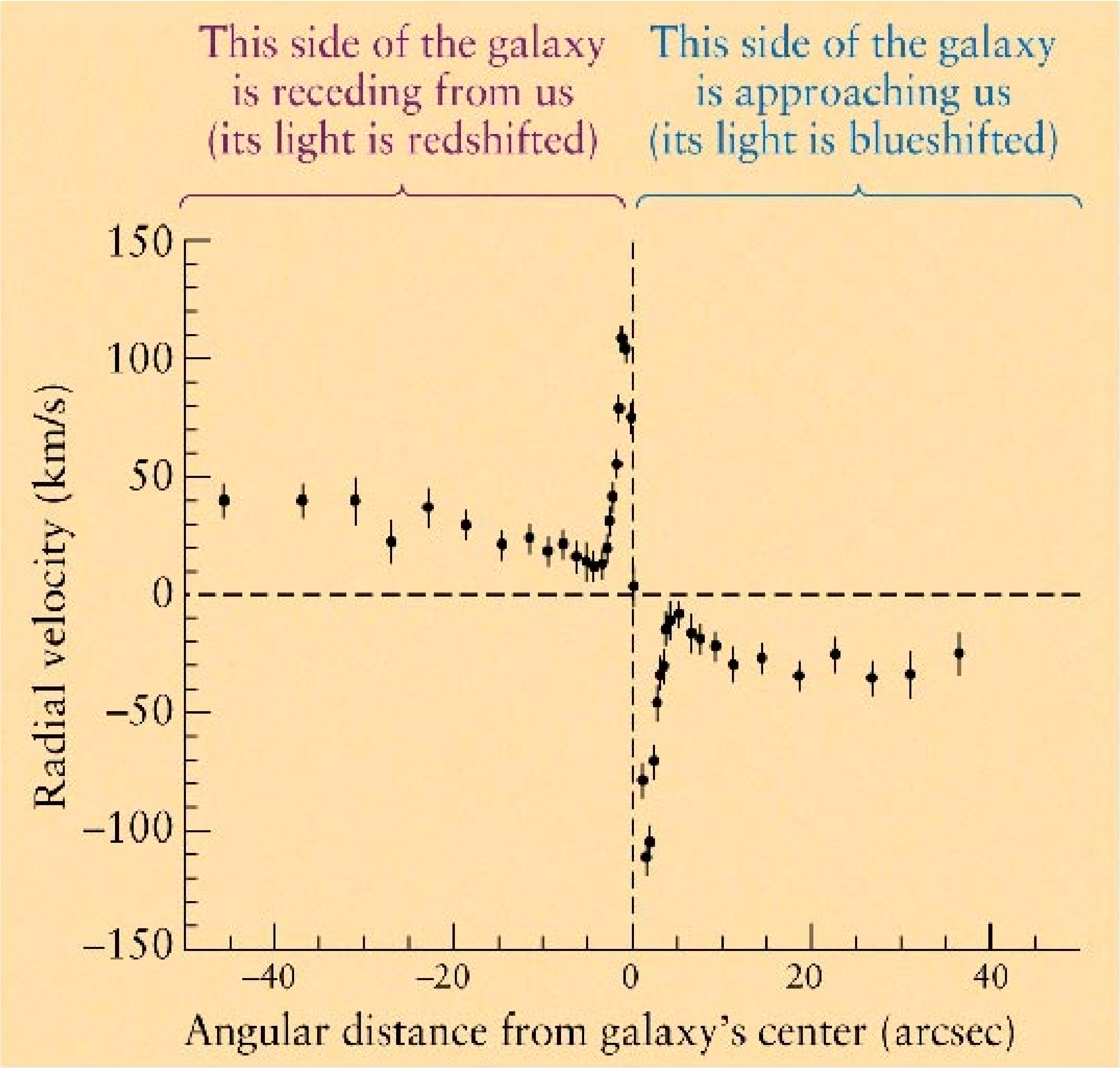
$$M = \sum_{i \in V} m_i = \frac{1}{\eta c^2} \int \int L \, dt \, dV$$

- Find mass density = $5 \times 10^4 \, M_{\mathrm{Sun}} \, \mathrm{Mpc}^{-3}$.
- Using X-ray background gives values up to $9 \times 10^5 \, M_{\mathrm{Sun}} \, \mathrm{Mpc}^{-3}$.
- Recall, one L* galaxy per 100 Mpc^3, so $10^6 - 10^8 \, M_{\mathrm{Sun}}$ per L* galaxy.

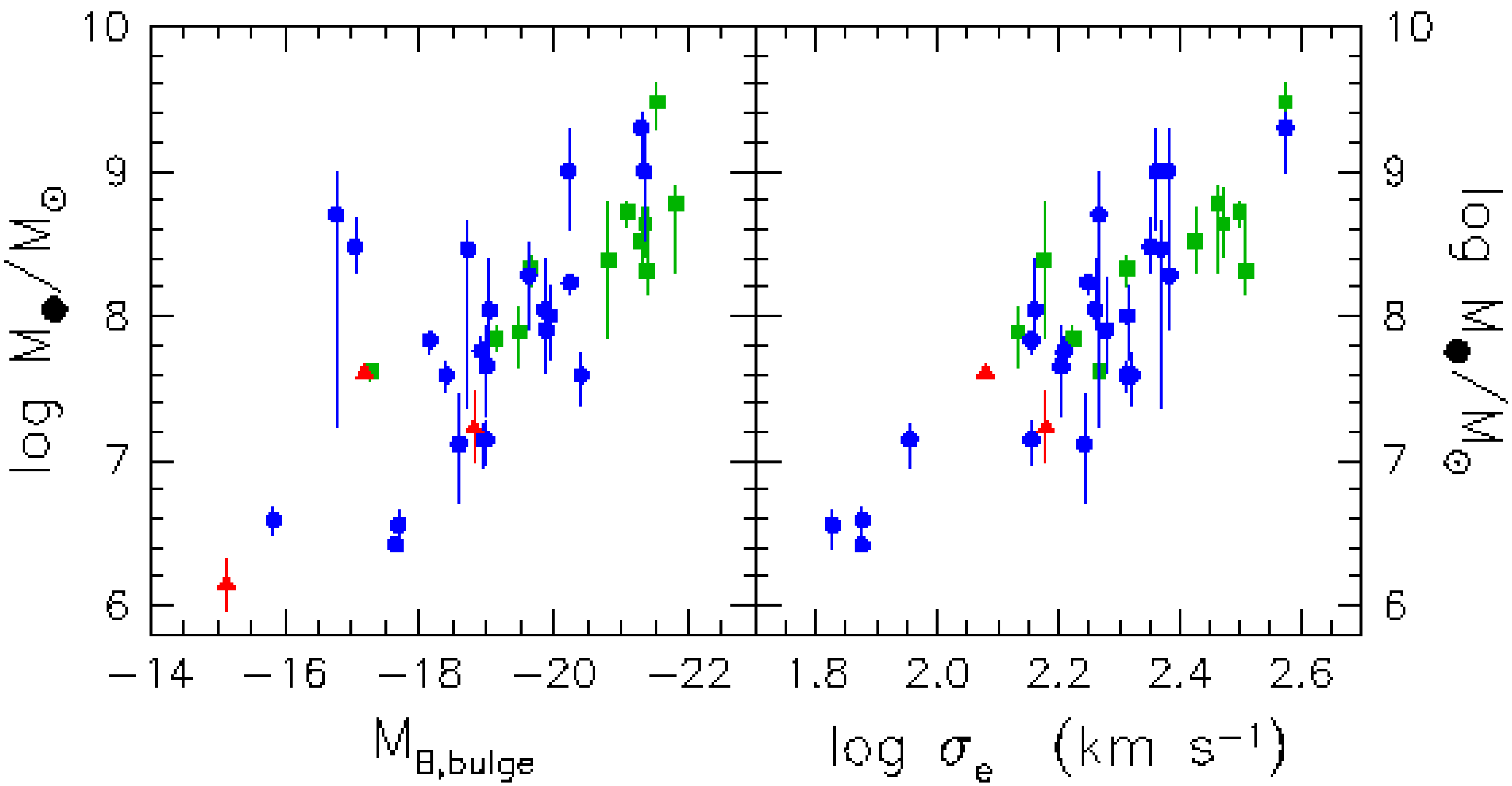
How to look for non-active black holes

- Look at motions of stars near nucleus. Influenced by
  - gravity of black hole
  - gravity of all other matter
- Most stars near the nucleus are in the bulge
  - Bluge has velocity dispersion = σ
- Define "sphere of influence" where orbital velocity due to BH ≥ σ
  - Derive $r_h = GM_{BH}/\sigma^2$.
- For $M_{BH} = 10^7\, M_{Sun}$ and $\sigma = 100$ km/s, $r_h = 4$ pc.
- For a galaxy at 10 Mpc, need $\Delta\theta < r_h/D = 0.1$ arcsec, need HST.
- "Nukers" was group formed to use HST to measure central object masses in nearby galaxies.

How to look for non-active black holes



Mass-dispersion relation (M-σ)



- Found that BH mass is correlated with properties of the bulge: mass and σ.
  - $M_{BH} \propto \sigma^{\beta}$ with β = 4.2 ± 0.4 (Gultekin et al. 2009).
- **Implies that BH formation and bulge formation are linked.**

Homework

For next class: AGN growth problem

A supermassive black hole at the nucleus of a galaxy accretes at the Eddington luminosity with the efficiency of a maximally rotating black hole, $\eta = 0.42$. Find an expression for the mass of the black hole as a function of time – note that the Eddington luminosity changes as the black hole mass changes. How much time is needed to grow a 10^9 solar mass black if one starts with a 10 solar mass black hole?

Why would the black hole be (near) maximally rotating?