Outline

- Go over problem 6.4
- Eddington limit – review “Interacting Binaries” lecture from Fall
- Active galactic nuclei
- Variability
- Spectral energy distribution
- Optical spectra
- Jets

Eddington Luminosity

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

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

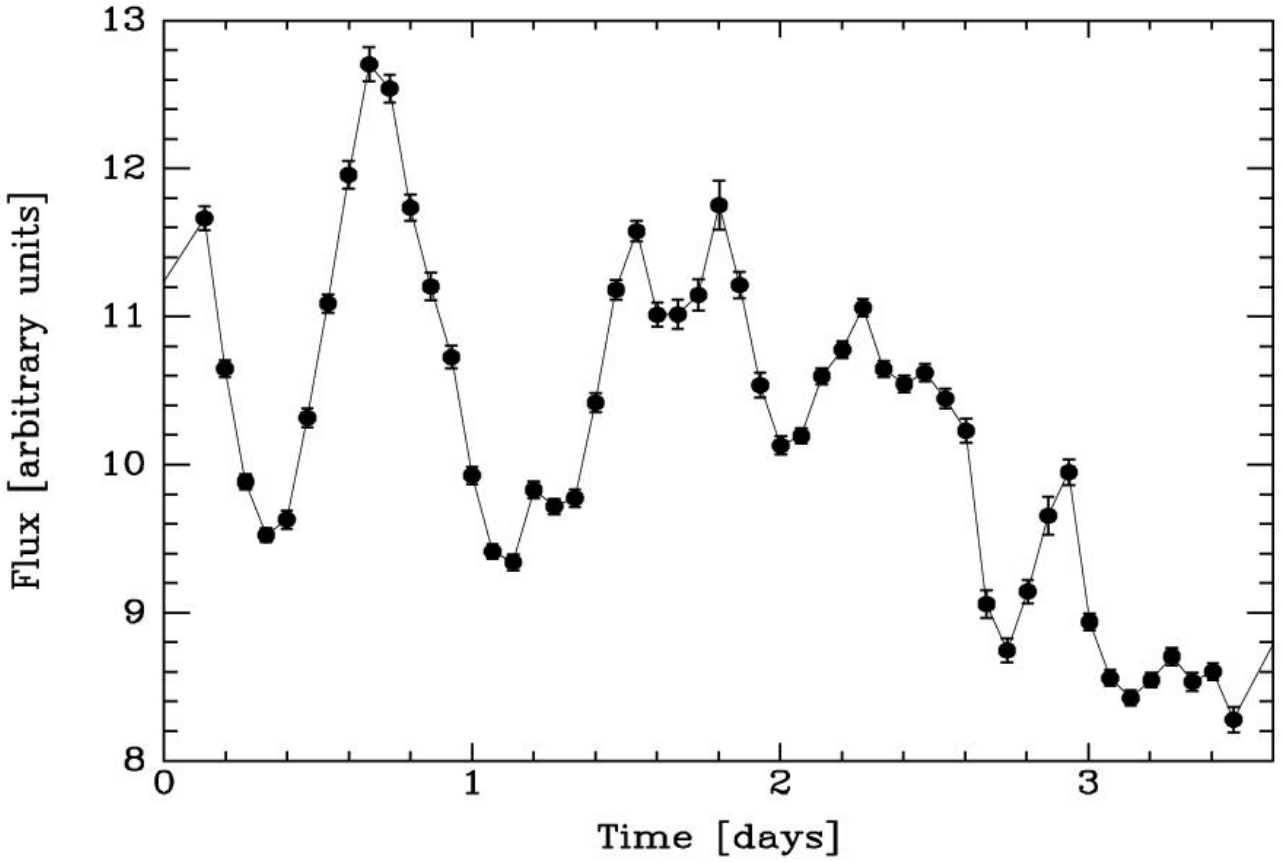
$$L_E = 1.3\times10^{38}\,\mathrm{erg/s}\,\frac{M}{M_{\mathrm{Sun}}} = 3.3\times10^{4}\,L_{\mathrm{Sun}}\,\frac{M}{M_{\mathrm{Sun}}}$$

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

Active Galactic Nuclei

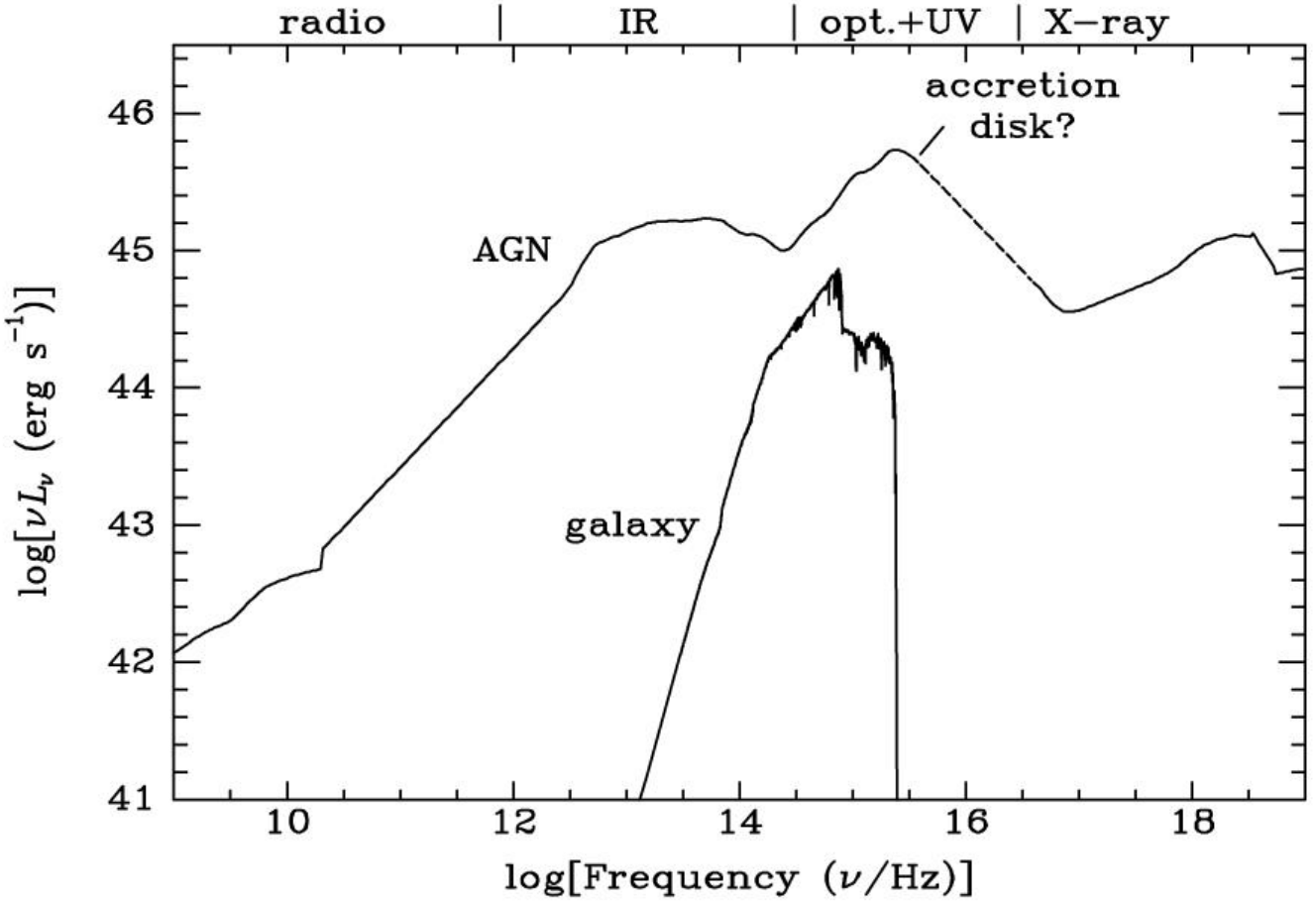
- Defined as galaxies with significant non-stellar light
- Evidence for non-stellar origin:
  - Rapid variability
  - Spectral energy distribution
  - Optical spectrum
  - Relativistic jets

Rapid Variability



- Places upper bound on the size of emitting region, $R < c\Delta t$.
- From X-ray light curve of NGC 3516 in 2-10 keV band, see variability on $\Delta t \sim 0.25$ days.
- Size $R < 0.2$ light-days = 40 A.U. = really small.

Spectral Energy Distribution



- Stars produce thermal spectral with temperatures of 10^3-10^5 K.
- AGN is bright at radio, IR, optical/UV, X-rays (sometimes gamma-rays).
- Radio and gamma-rays are from jets.
- “UV bump” is from accretion disk – find accretion disk temperature.

Accretion Disks

- Temperature versus radius in accretion disk

$$T(r) = \left(\frac{GM\dot{M}}{8\pi\sigma} \right)^{1/4} r^{-3/4}$$

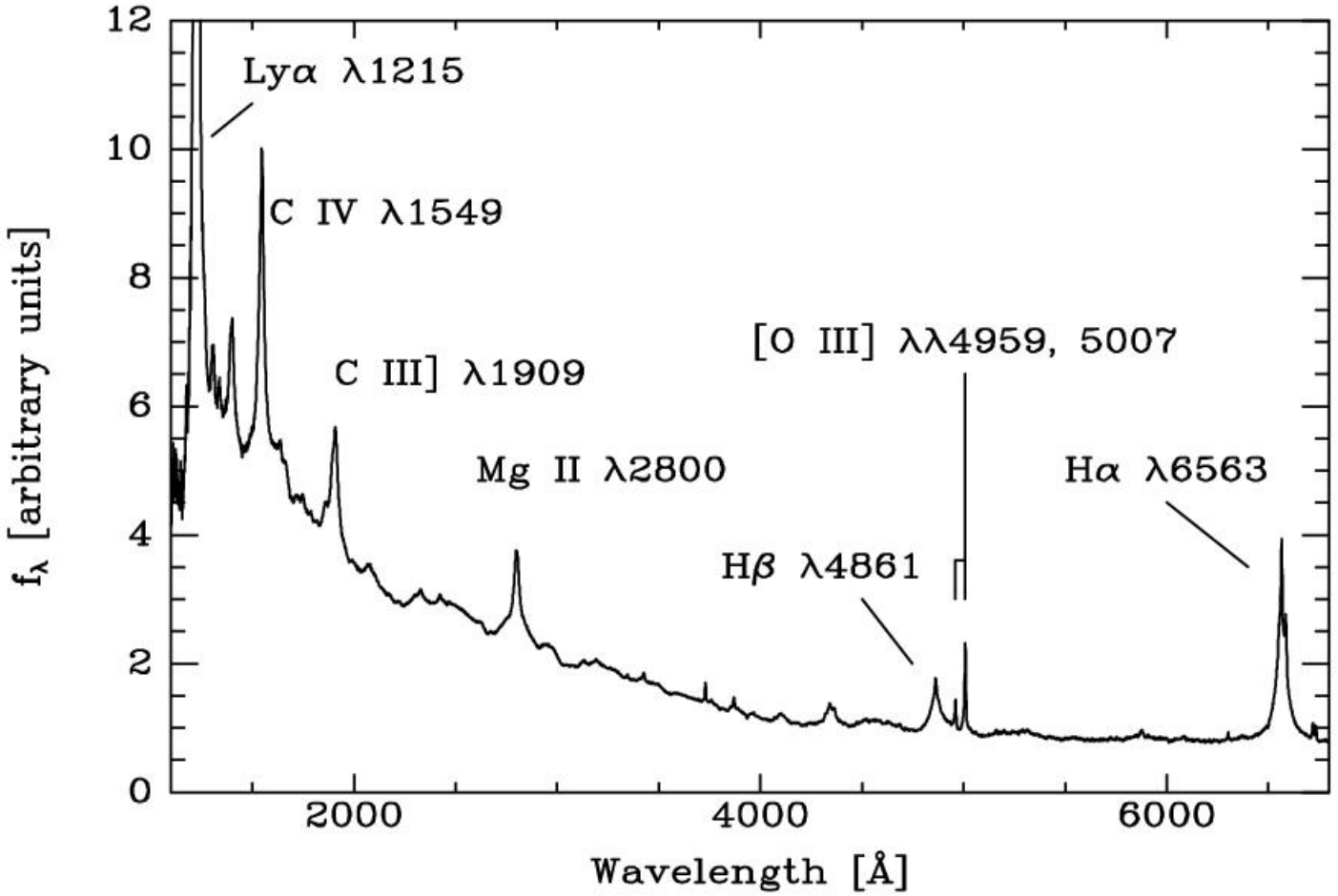
- Radiative efficiency is fraction of rest mass energy of accreted matter that is radiated

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

- 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 $\eta = 0.057$.

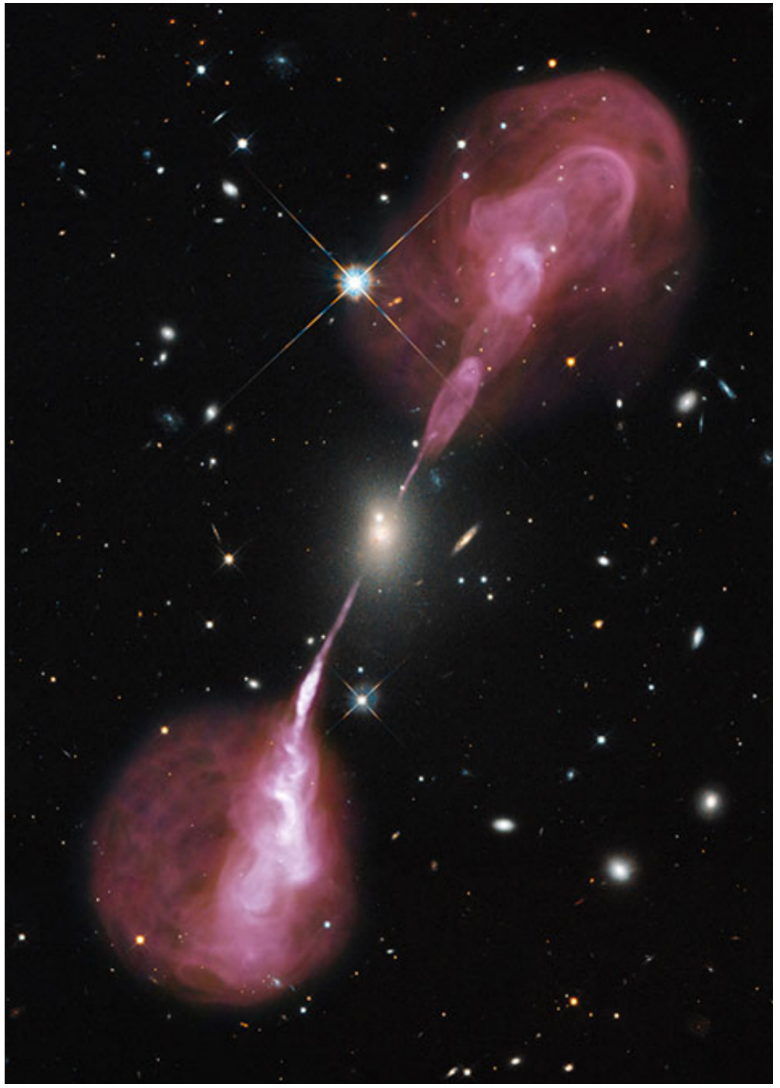
- Find mass accretion rate for 10^9 solar mass BH at Eddington luminosity and the corresponding disk temperature and frequency of peak.

Optical Spectrum



- UV/X-ray flux from accretion disk photoionizes surrounding gas.
- Optical spectra show strong emission lines.
- Emission lines are broad – indicating speeds of 10^3-10^4 km/s due to motion around black hole.

Relativistic jets



- Jet of Hercules A, $R = 10^6$ light years.
- Luminosity of jet, $L = 10^{45}$ erg/s.
- Power source active for $\tau > R/s$, where s = speed of jet = $0.1c$ to c, $\tau \sim 10^7$ years.
- η = efficiency for conversion of mass to energy, $E = \eta mc^2 = L\tau$.
  - $\eta = 0.007$ for stellar nuclear burning
  - $\eta = 0.057$ for non-rotating BH
  - $\eta = 0.42$ for maximally-rotating BH

- Calculate mass needed to produce jet

Homework

- For next class:
  - Problem 6-7 (MOND)