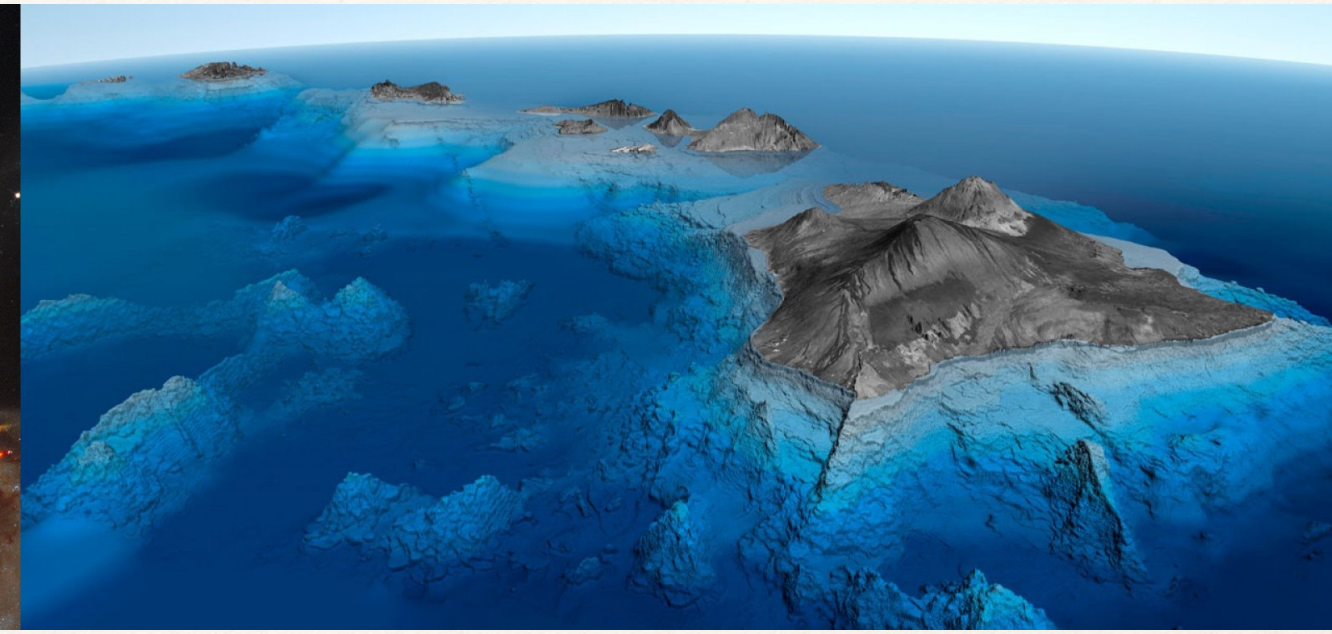


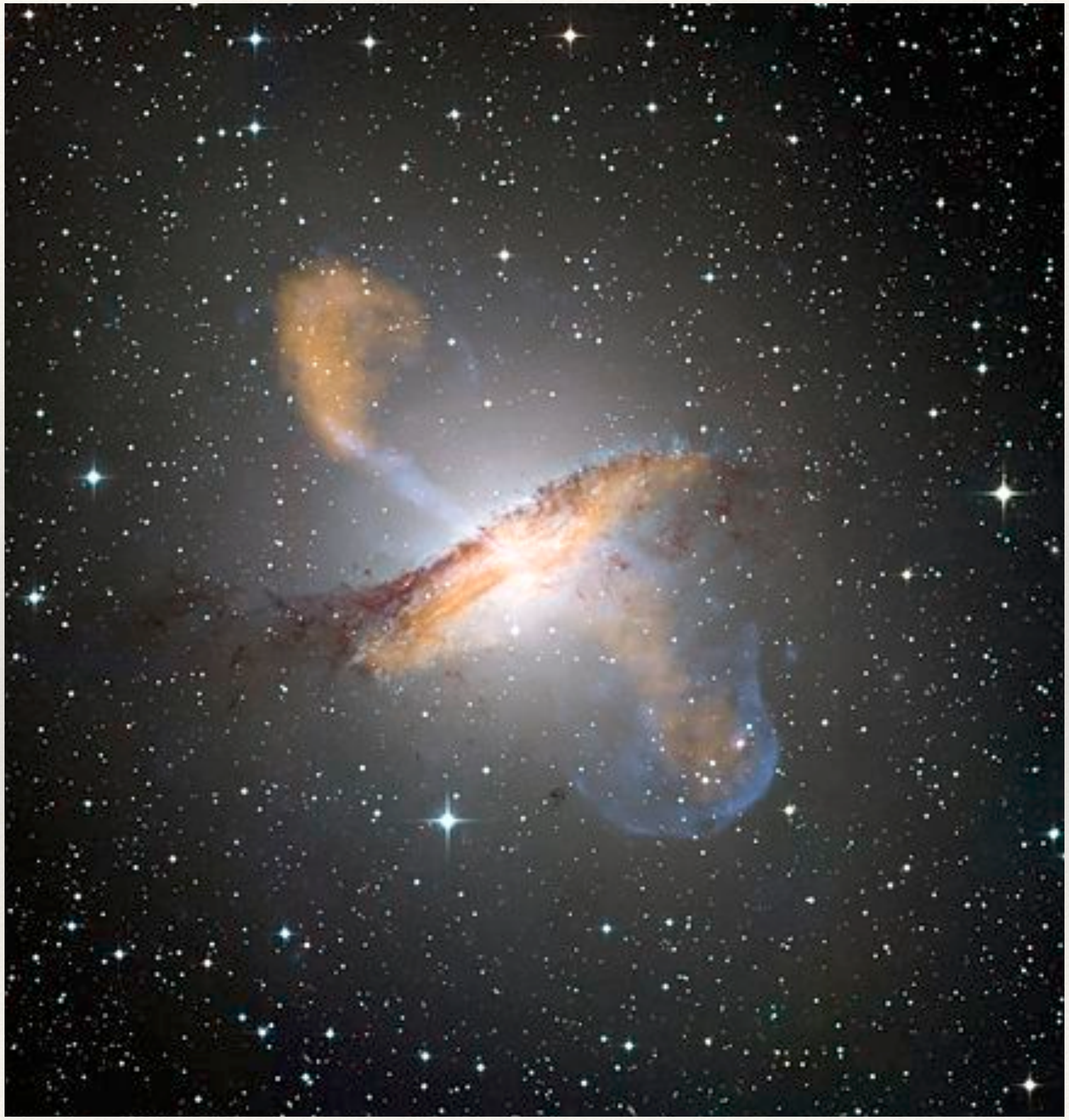
Getting to know the "island universes" out there.

Galaxies I

ASTR 555
Dr. Jon Holtzman

Outline for Today

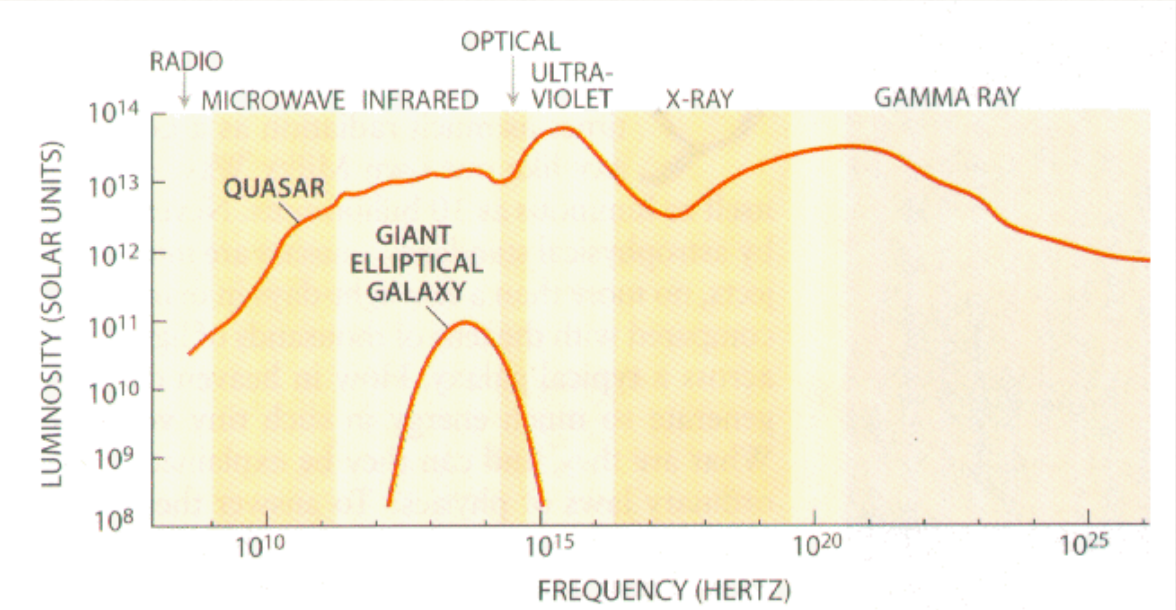
- Building Blocks - Central Black Holes:
  - Signatures
  - Unified Model
  - Masses

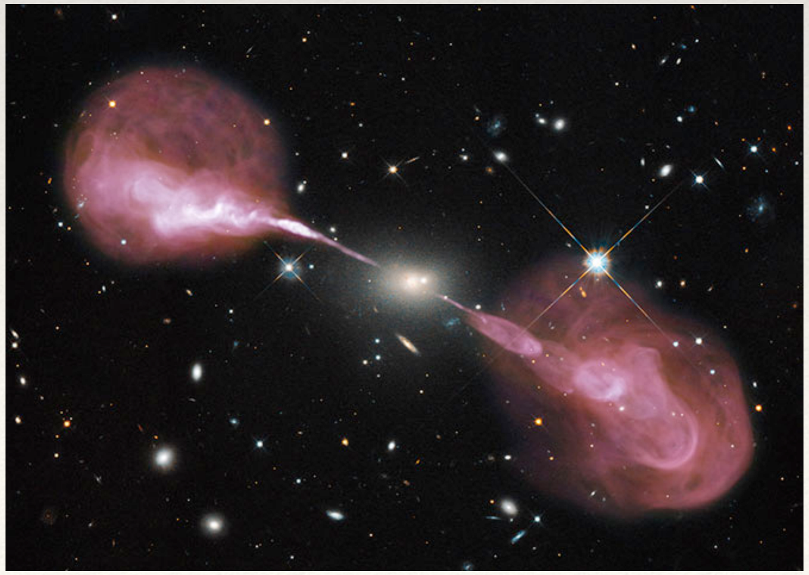


Centaurus A (Credit: ESO/WFI (Optical); MPIfR/ESO/APEX/A.Weiss et al. (Submillimetre); NASA/CXC/CfA/R.Kraft et al. (X-ray))

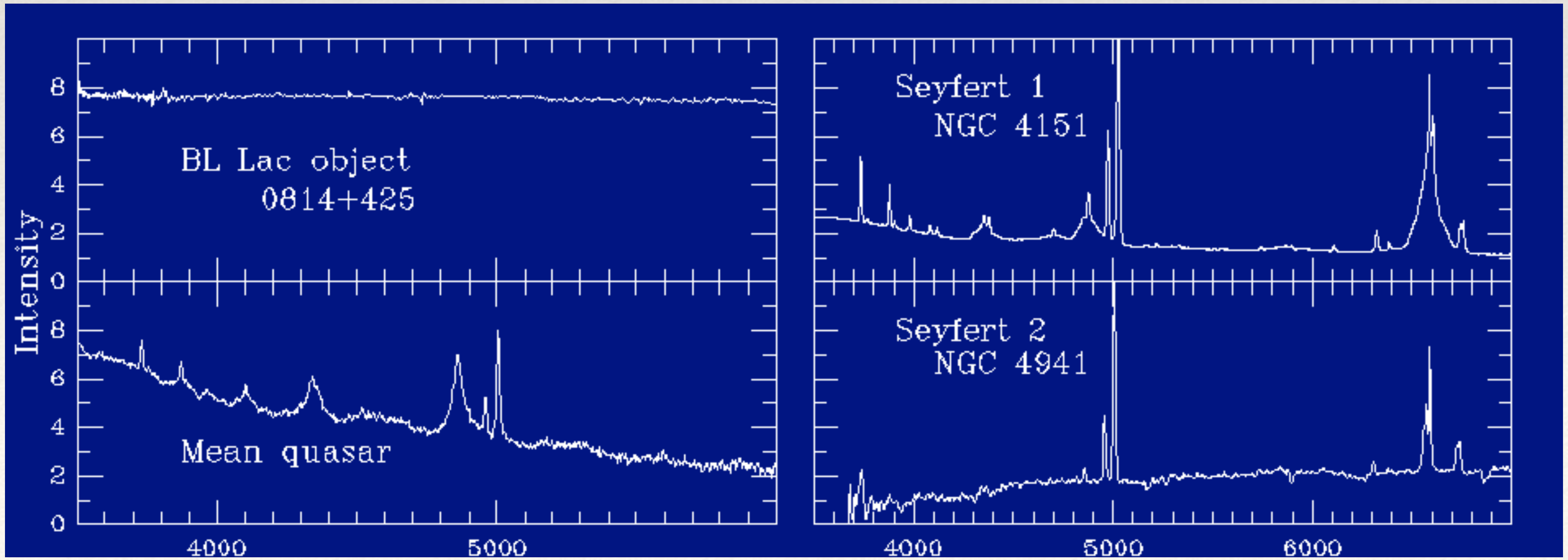
Building Blocks - Central Black Holes

- Nearly all galaxies likely harbor a central supermassive black hole
- Some have "active" galactic nuclei (AGN):
    - luminous, power-law continua
    - broad emission lines or extreme emission line ratios
    - radio sources, often from jets



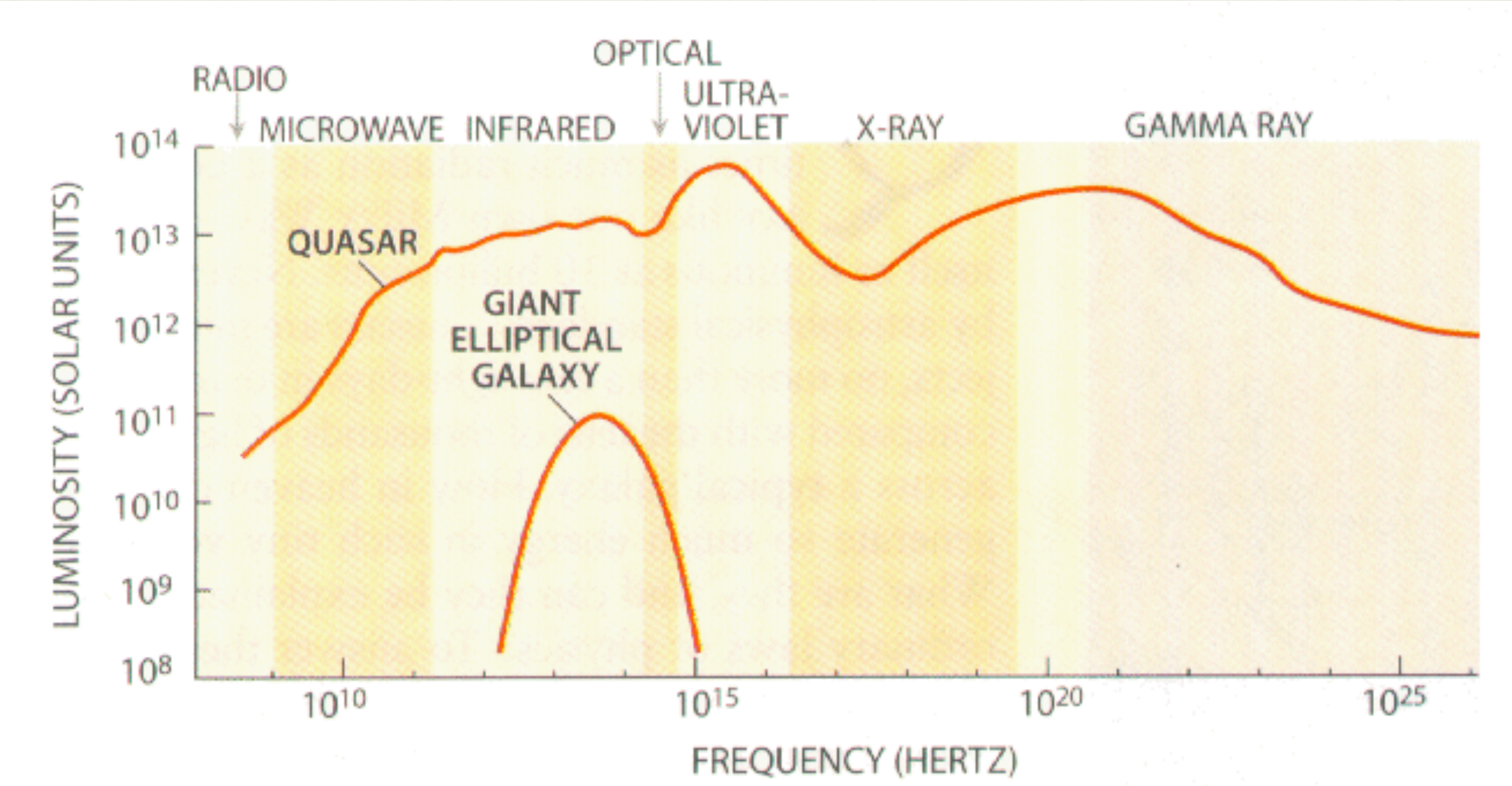


Hercules A (Credit: NASA/ESA)



Central Black Holes

- AGN are generally considered to be powered by accretion onto nuclear black hole. Why do we think so?
  - 1) Continuum: clearly a non-stellar source!

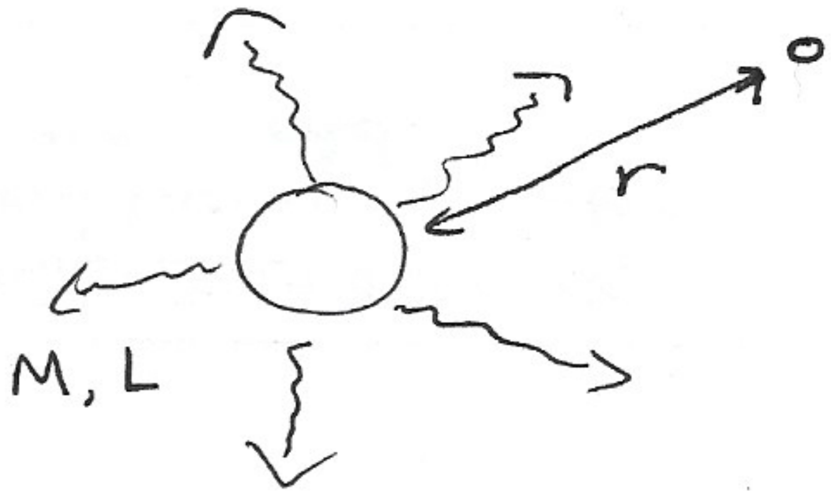


http://abyss.uoregon.edu/~js/ast123/lectures/lec12.html

Central Black Holes

- AGN are generally considered to be powered by accretion onto nuclear black hole. Why do we think so?
  - 2) Eddington Luminosity: AGN are very luminous **(~10^{45-58}** ergs/s**)** so must be very massive, so that radiation pressure doesn't disperse them

Energy Flux: $f = \frac{L}{4\pi r^2}$



Momentum: $p = \frac{E}{c}$ for a photon

Momentum Flux: $f_p = \frac{f}{c} = \frac{L}{c\,4\pi r^2}$

Photons exert force on free e⁻ & protons with e⁻ having much larger <u>cross-section</u> for interaction:

$\Rightarrow \sigma_T$ (Thomson cross-section)

Force on e⁻ from photons:

$F_{rad} = \sigma_T f_p = \sigma_T \frac{L}{c\,4\pi r^2}$

Electrons drags nearest proton with it

Force of gravity on proton (m_p):

$$F_{grav} = \frac{G M m_p}{r^2}$$

Eddington Luminosity is where radiation = gravity

$$\sigma_T \frac{L}{c 4\pi r^2} = \frac{G M m_p}{r^2}$$

$$\boxed{L = \frac{G M m_p c (4\pi)}{\sigma_T}}$$

Central Black Holes

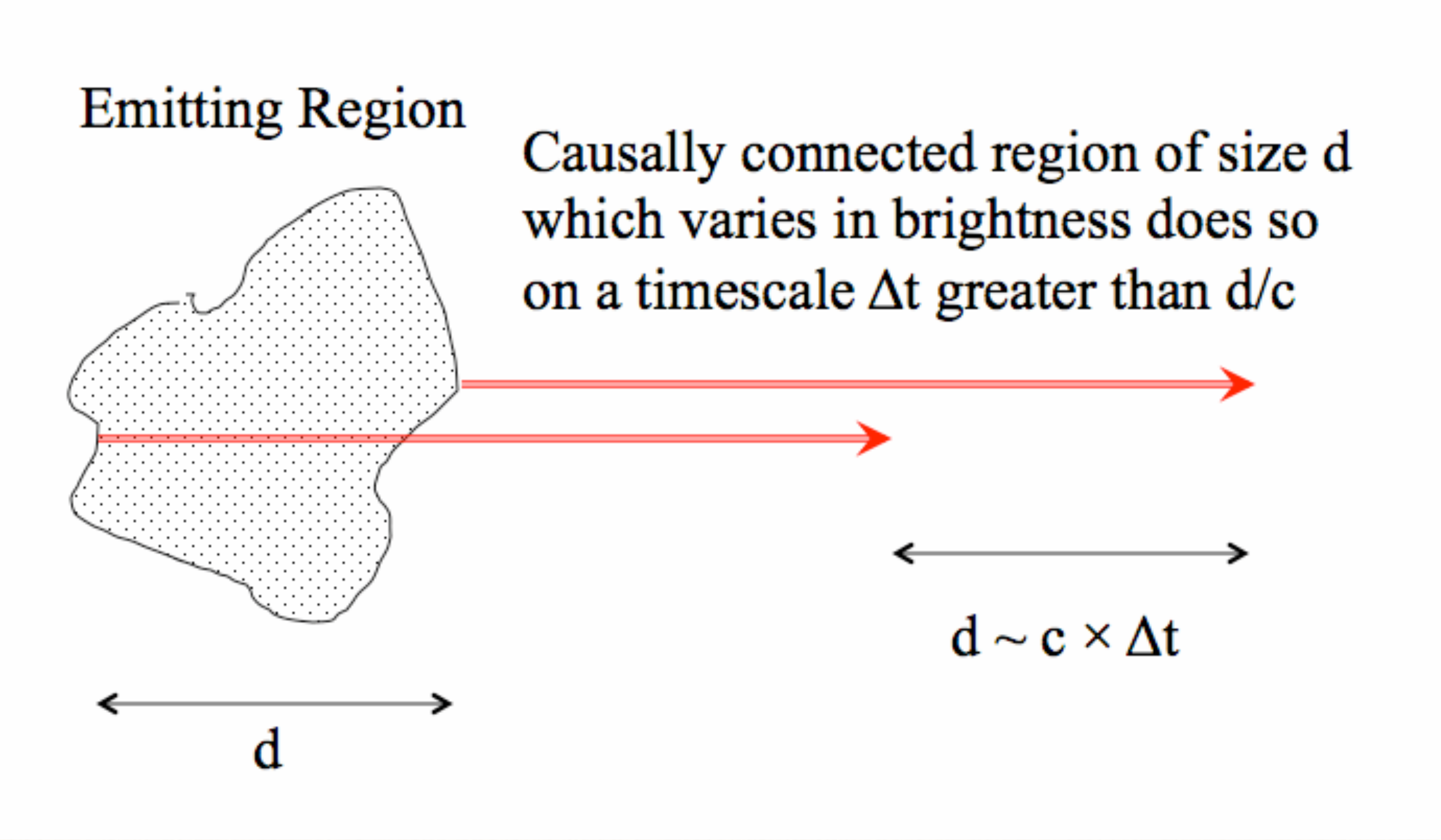
- AGN are generally considered to be powered by accretion onto nuclear black hole. Why do we think so?
  - 2) Eddington Luminosity: very luminous (~$10^{45\text{-}58}$ ergs/s) so must be very massive!

$$L_e = \frac{4\pi G M m_p c}{\sigma_T} = 1.3 \times 10^{46} \frac{M}{10^8 M_{sun}} ergs/s$$

If more luminous than the Eddington Luminosity, an object blows itself apart!

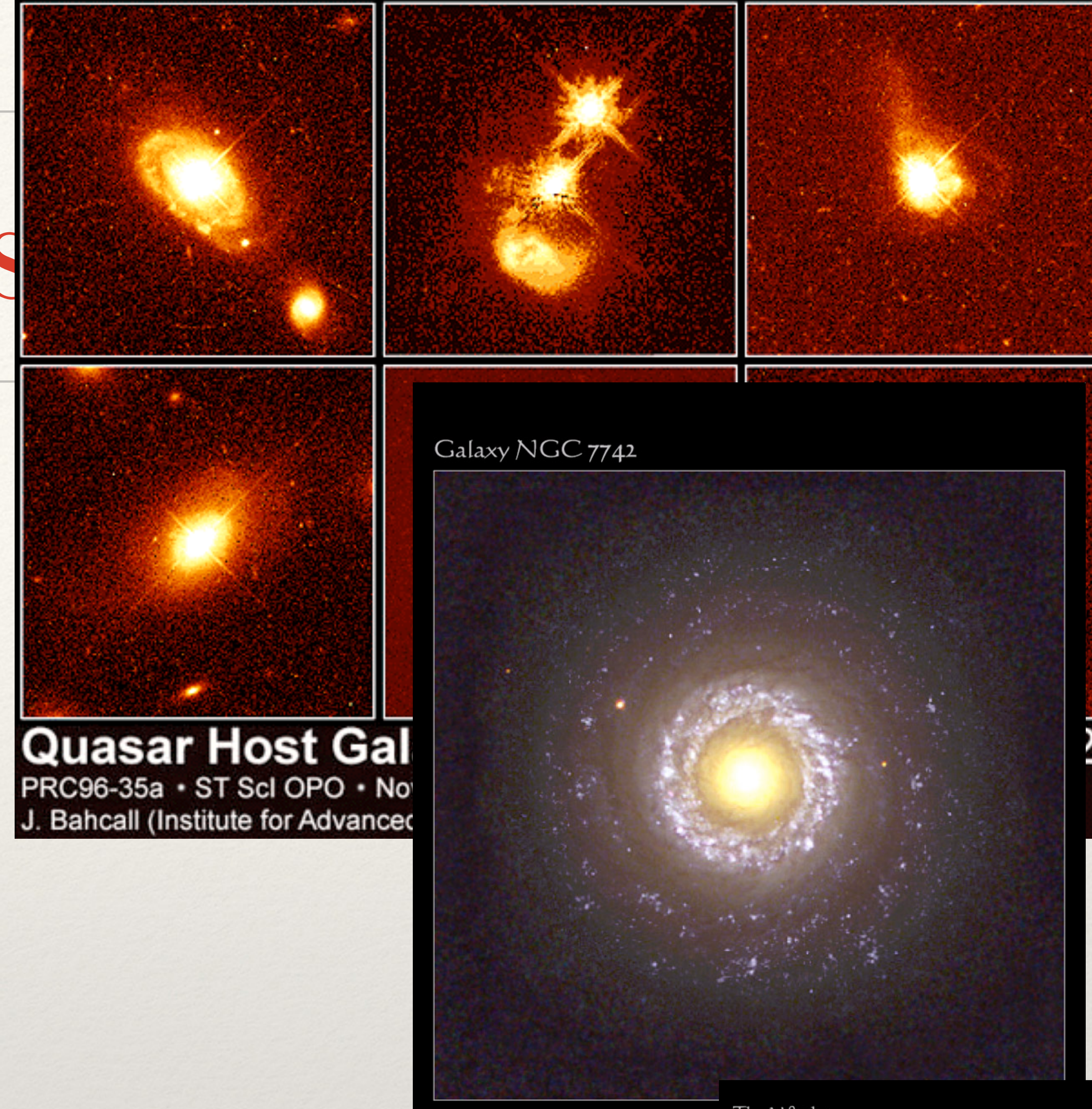
Central Black Holes

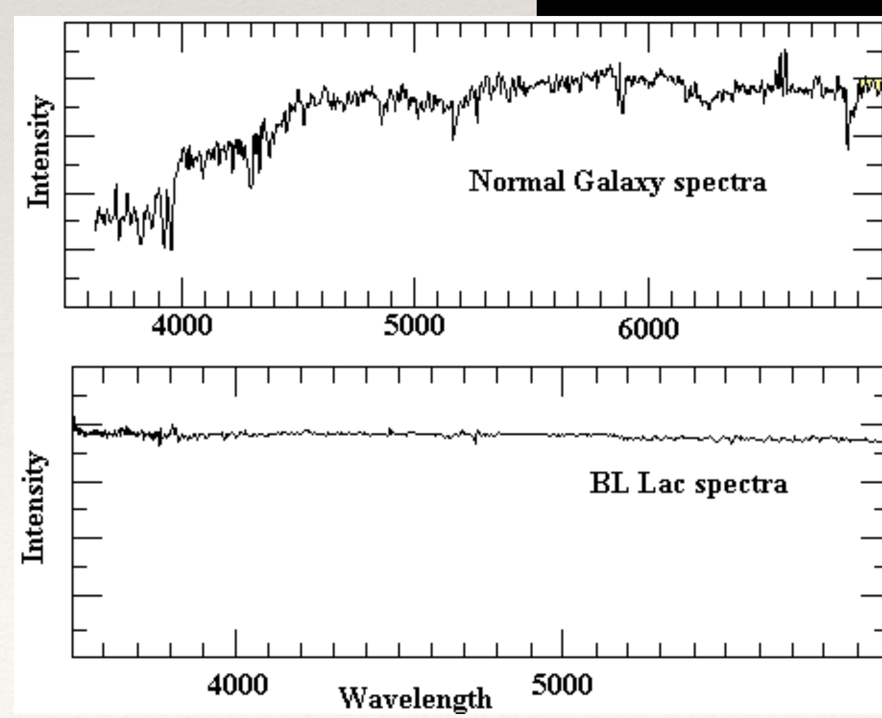
- AGN are generally considered to be powered by accretion onto nuclear black hole. Why do we think so?
  - 3) Timing: rapid variability (hours-days) implies very small region (fraction of a pc)!

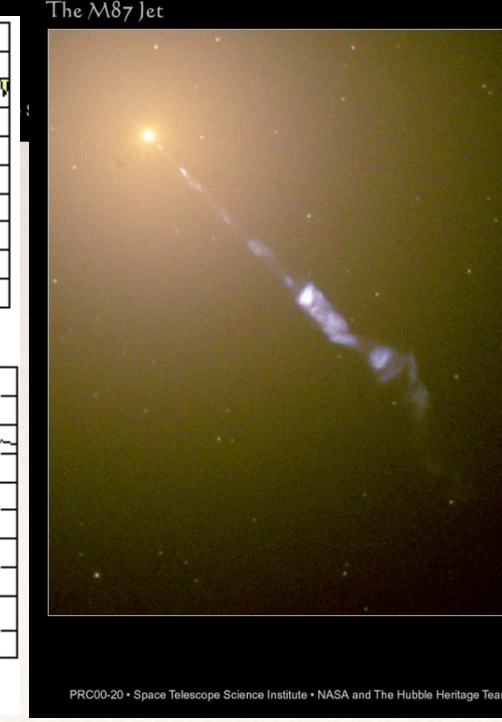


Central Black Holes

- AGN "zoo":
  - **Quasars / QSOs** — near-point sources with $L_{nucleus} \gg L_{galaxy}$
  - **Seyfert galaxies** — galaxies with bright cores, odd emission lines
  - **LI(N)ERs** — "Low Ionization (Nuclear) Emission Regions"
  - **BL Lac objects** — bright, feature-less continua
  - **Radio Galaxies** — radio synchrotron in lobes / jets



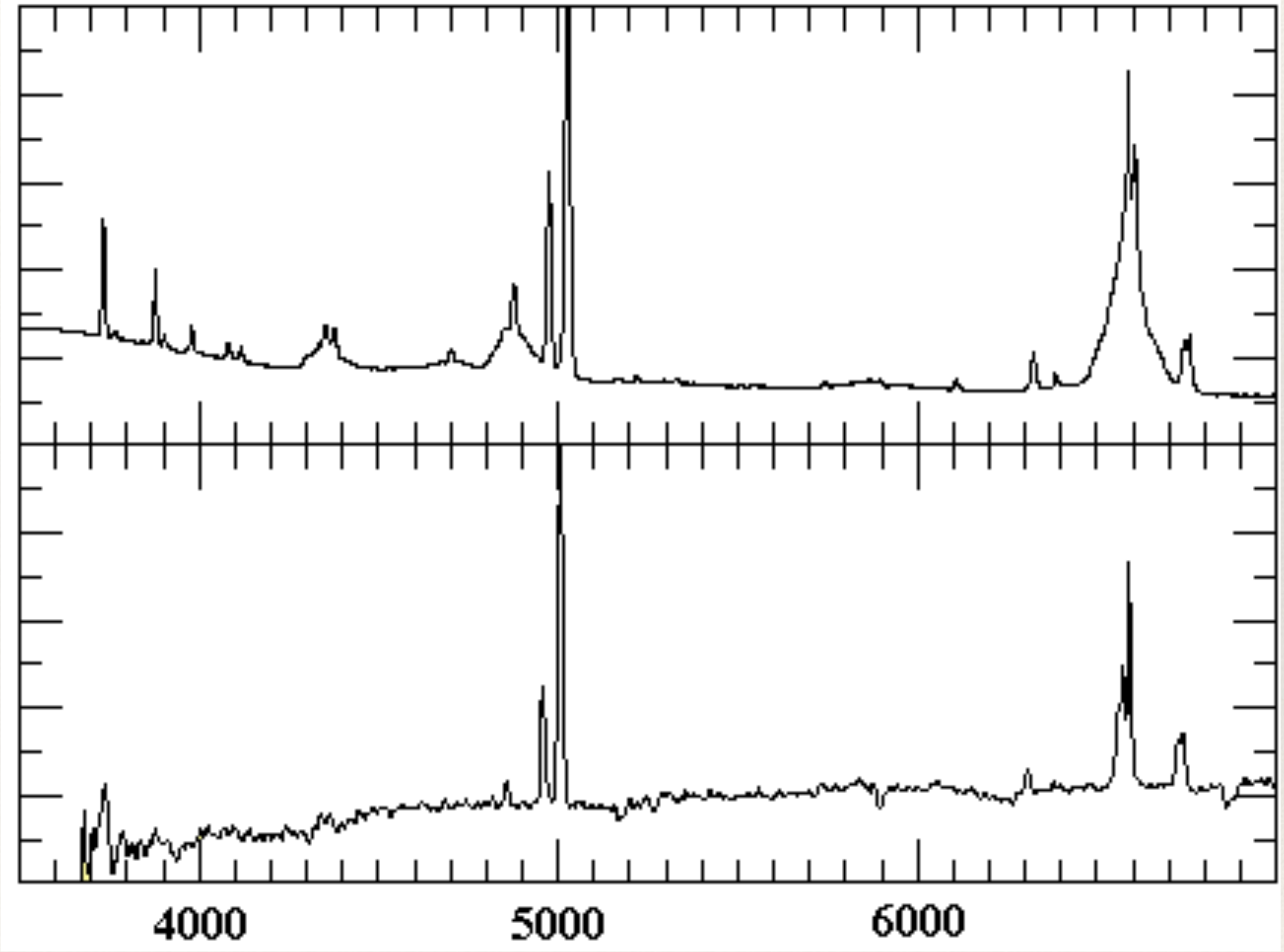




Thought Question

- What emission lines can you identify in these two AGN spectra?
- What differences do you notice?

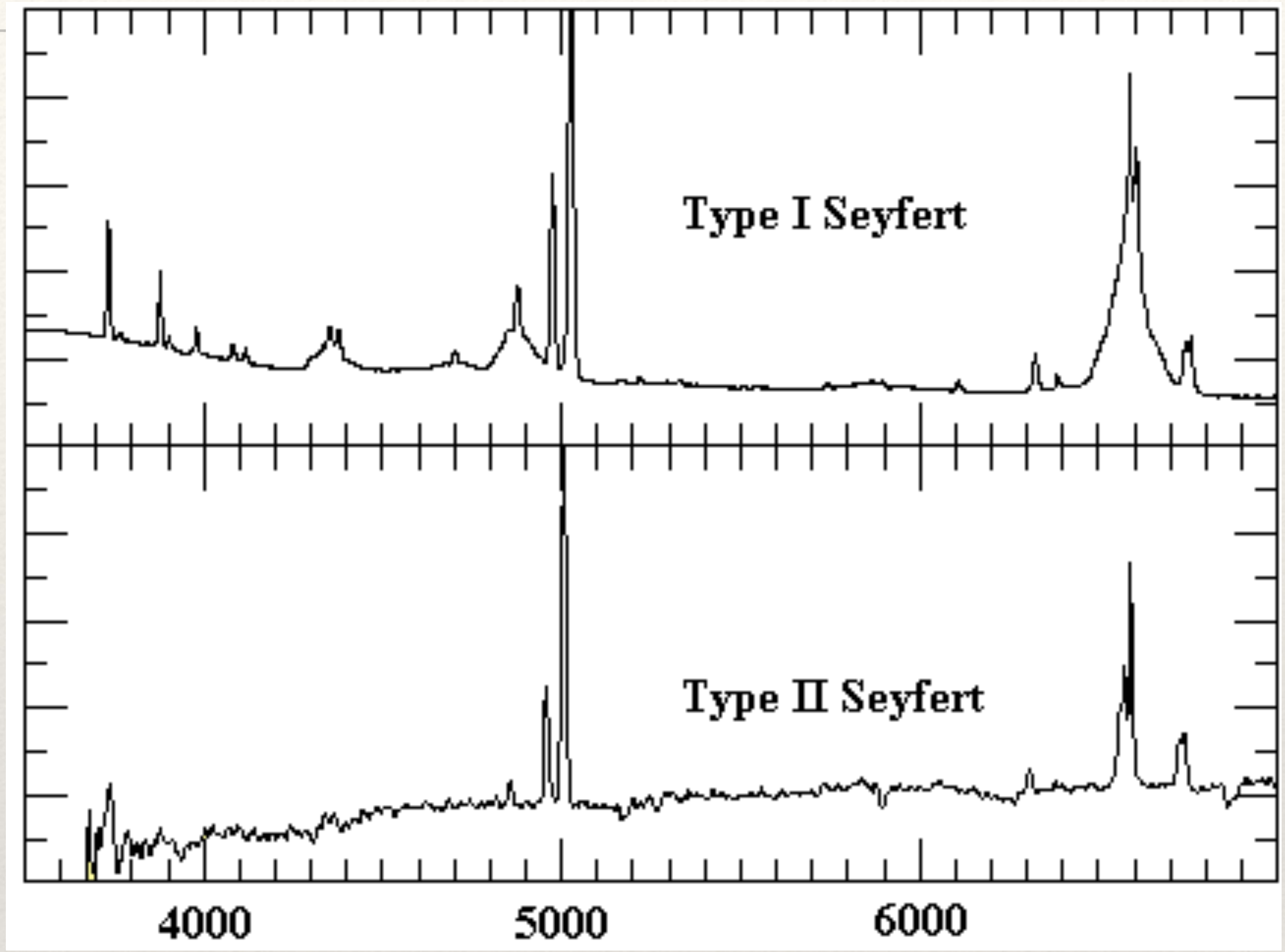
http://gtn.sonoma.edu/images/seyfertspectra.gif



Central Black Holes

- **Two Types of AGN**
  - Type 1:
    - broad emission lines (permitted lines like H I, He I, He II)
    - narrow emission lines (forbidden lines like [O III])
    - luminous blue continuum emission

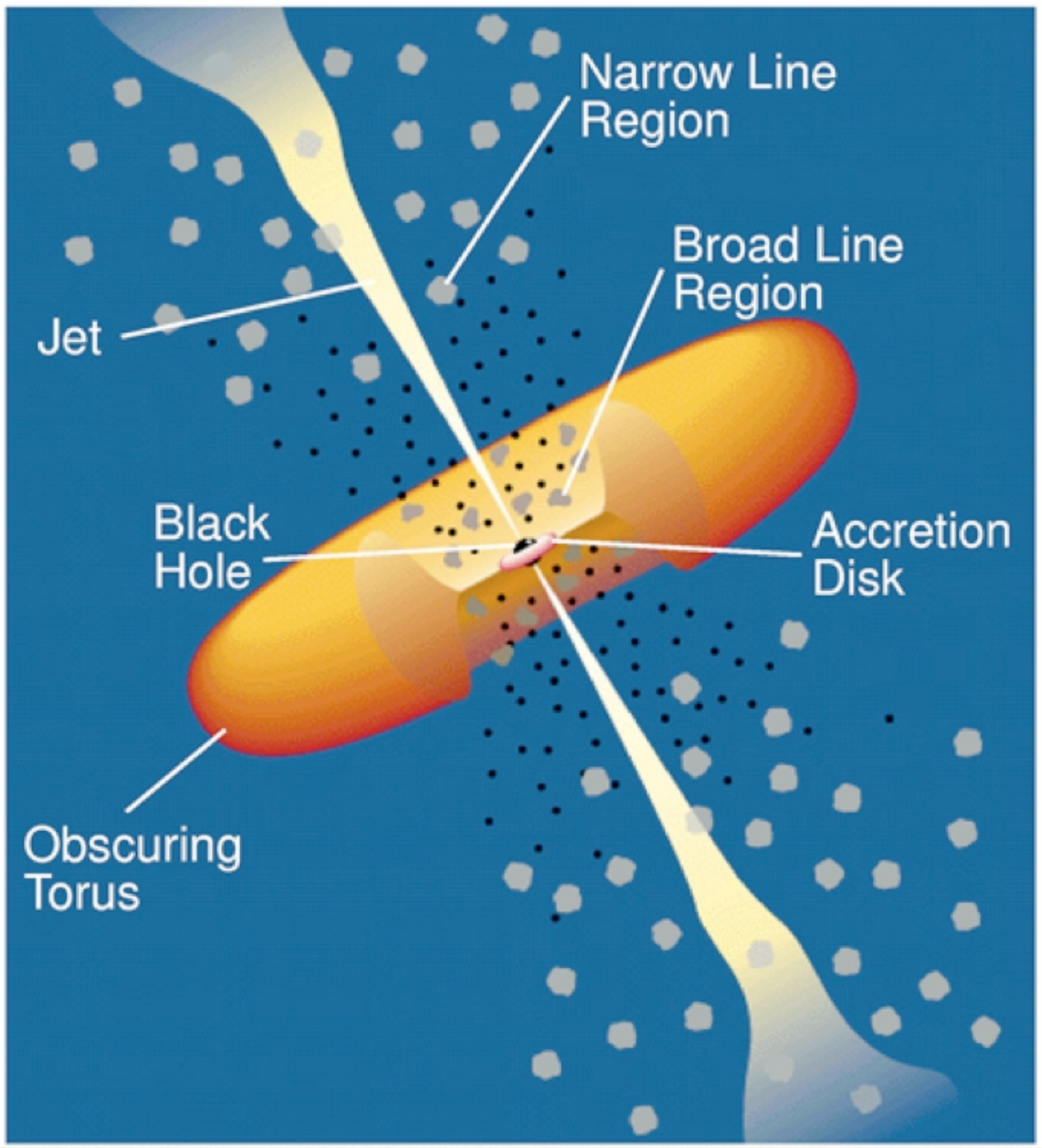
http://gtn.sonoma.edu/images/seyfertspectra.gif



  - Type 2:
    - only narrow lines (permitted and forbidden)
    - redder continuum emission

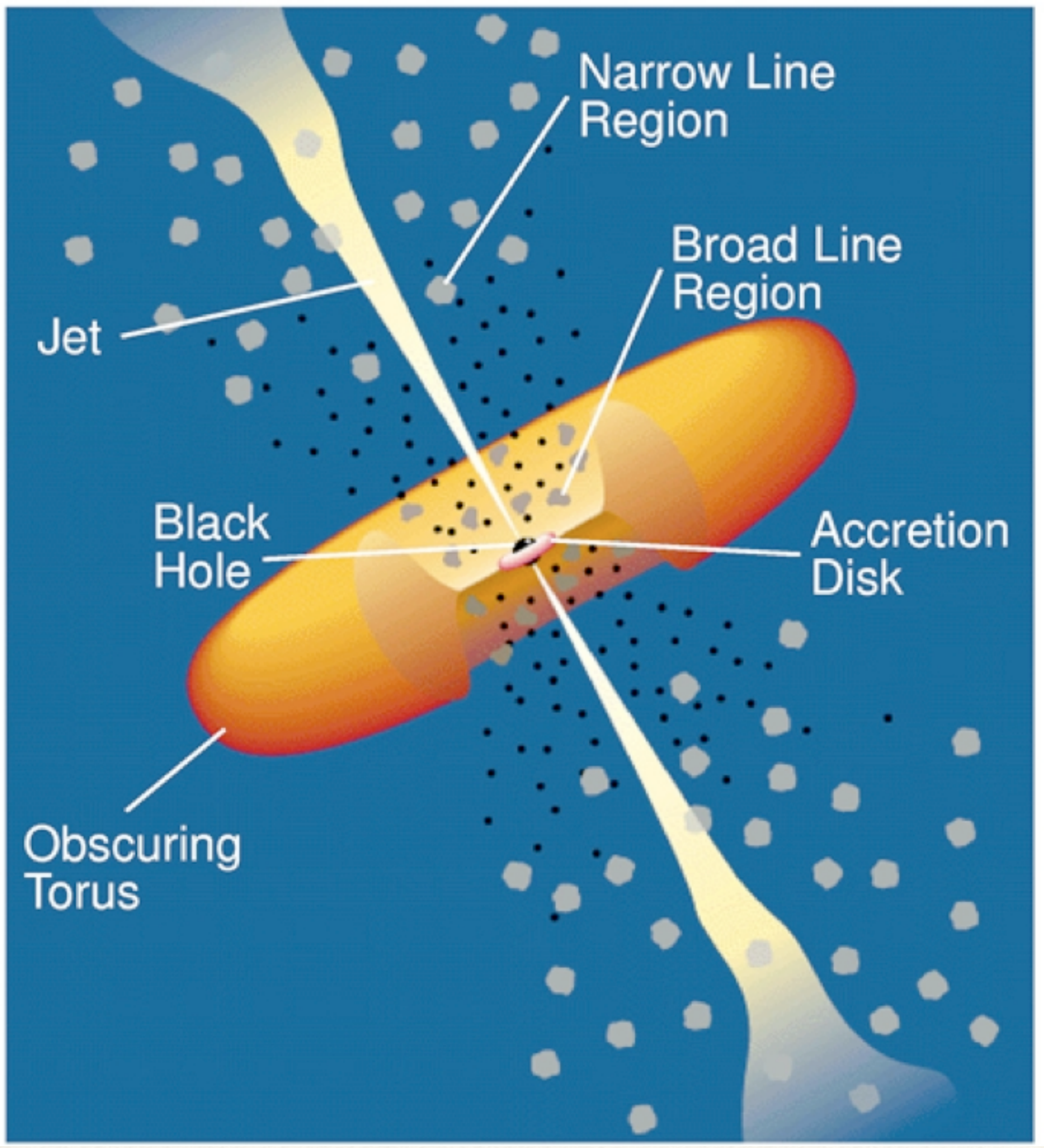
Central Black Holes

- **Unified Model of AGN** — all arise from a common physical scenario:
  - Active galaxies powered by material accreting onto massive central black hole in nuclei of galaxies



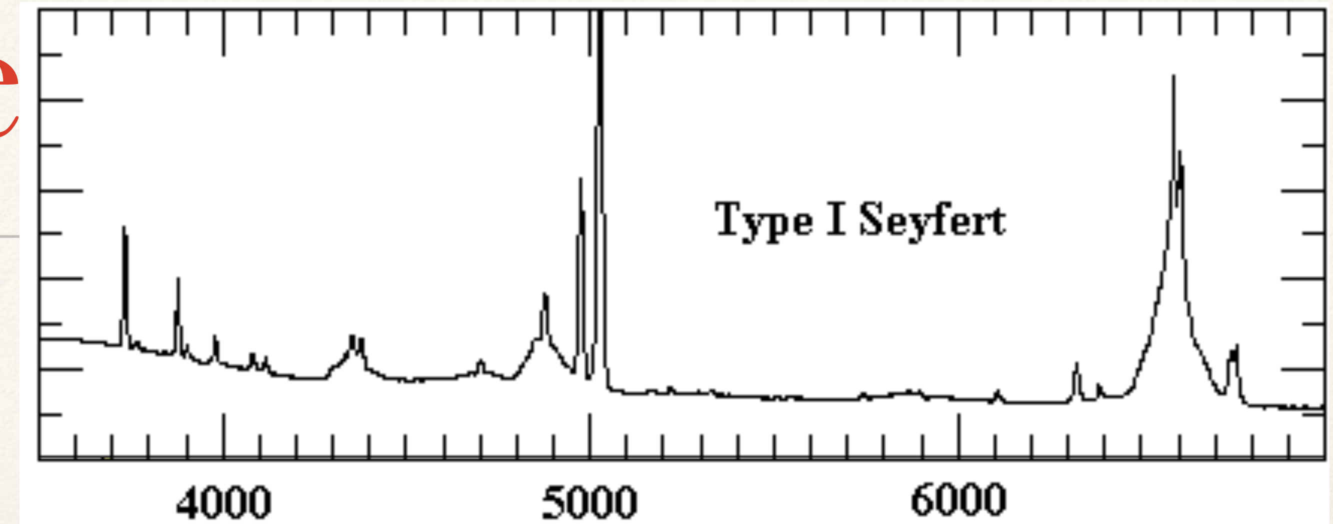
Central Black Holes

- What are we seeing?
  - **Accretion disk**: hot, luminous gas orbiting the black hole
  - **Broad-line Region (BLR)**: gas clouds near accretion disk, turbulent motions at high speed
  - **Narrow-line Region (NLR)**: gas clouds further away from central black hole, moving more slowly
  - **Dusty torus**: obscuring ring of denser gas and dust surrounding nucleus
  - **Jets**: charged particles moving at relativistic speeds out of nucleus

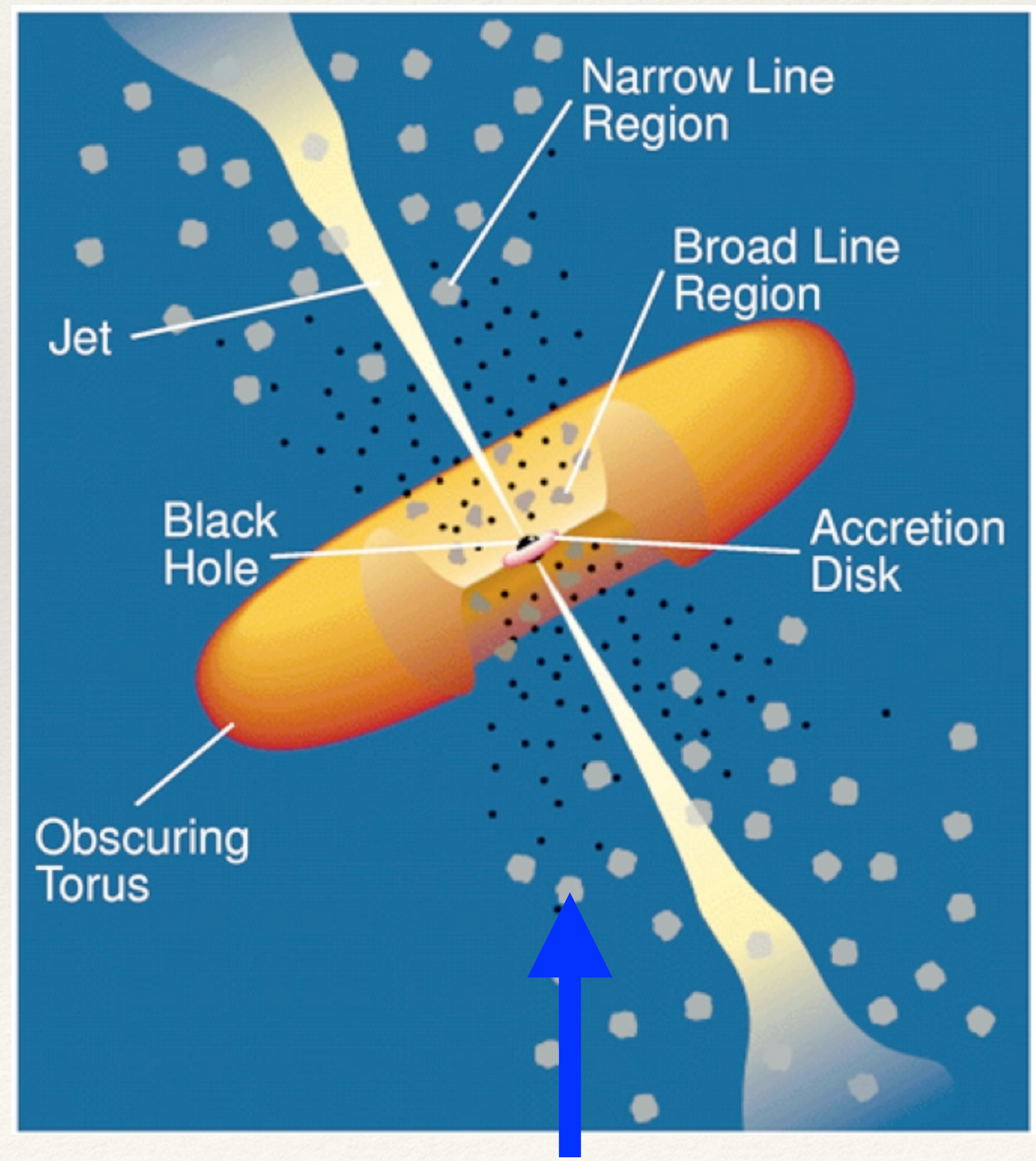


Central Black Hole

http://gtn.sonoma.edu/images/seyfertspectra.gif



- What are we seeing?
  - **Type 1** if viewed from to bottom:
    - broad lines
    - narrow lines
    - bright continuum from central engine
  - **Type 2** if viewed from e t right:
    - no broad lines (obscured by torus)
    - narrow lines
    - less of the bright continuum from central source



Central Black Hole

- What are we seeing?
  - Type 1 if viewed from bottom:
    - broad lines
    - narrow lines
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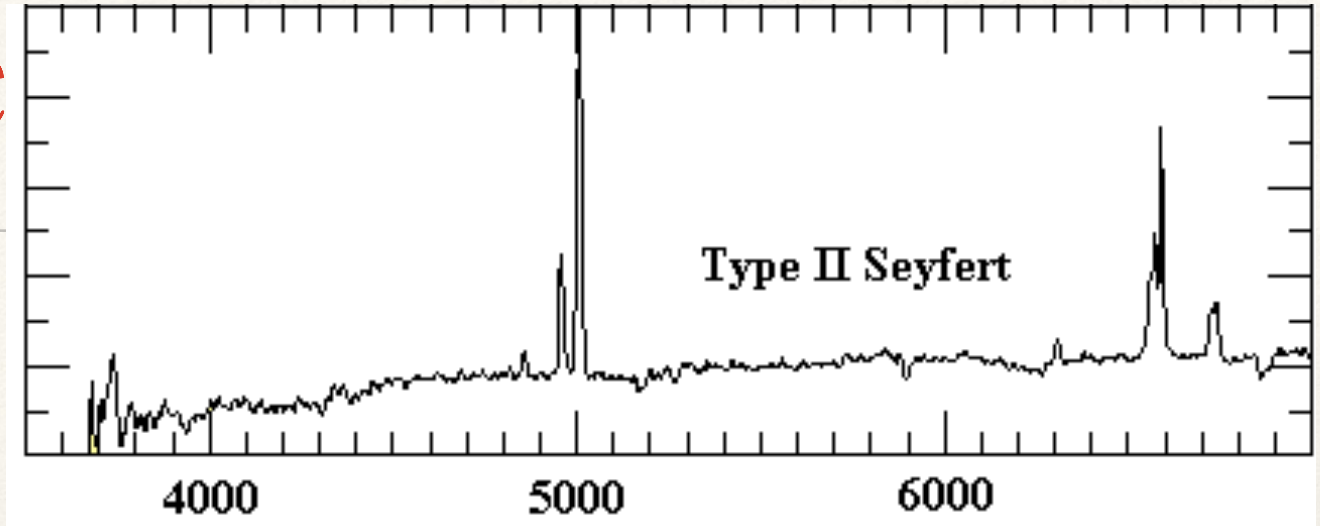
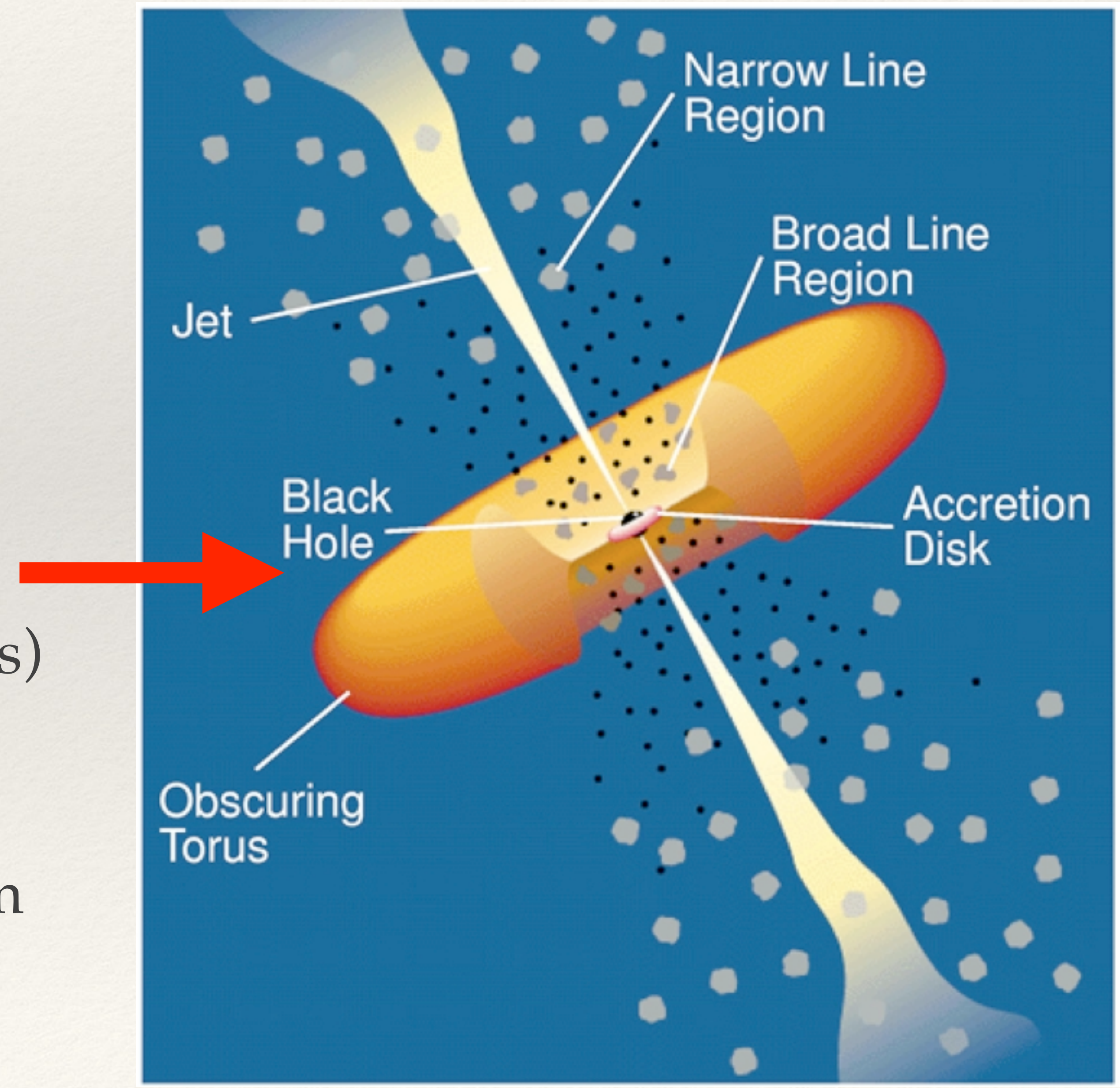
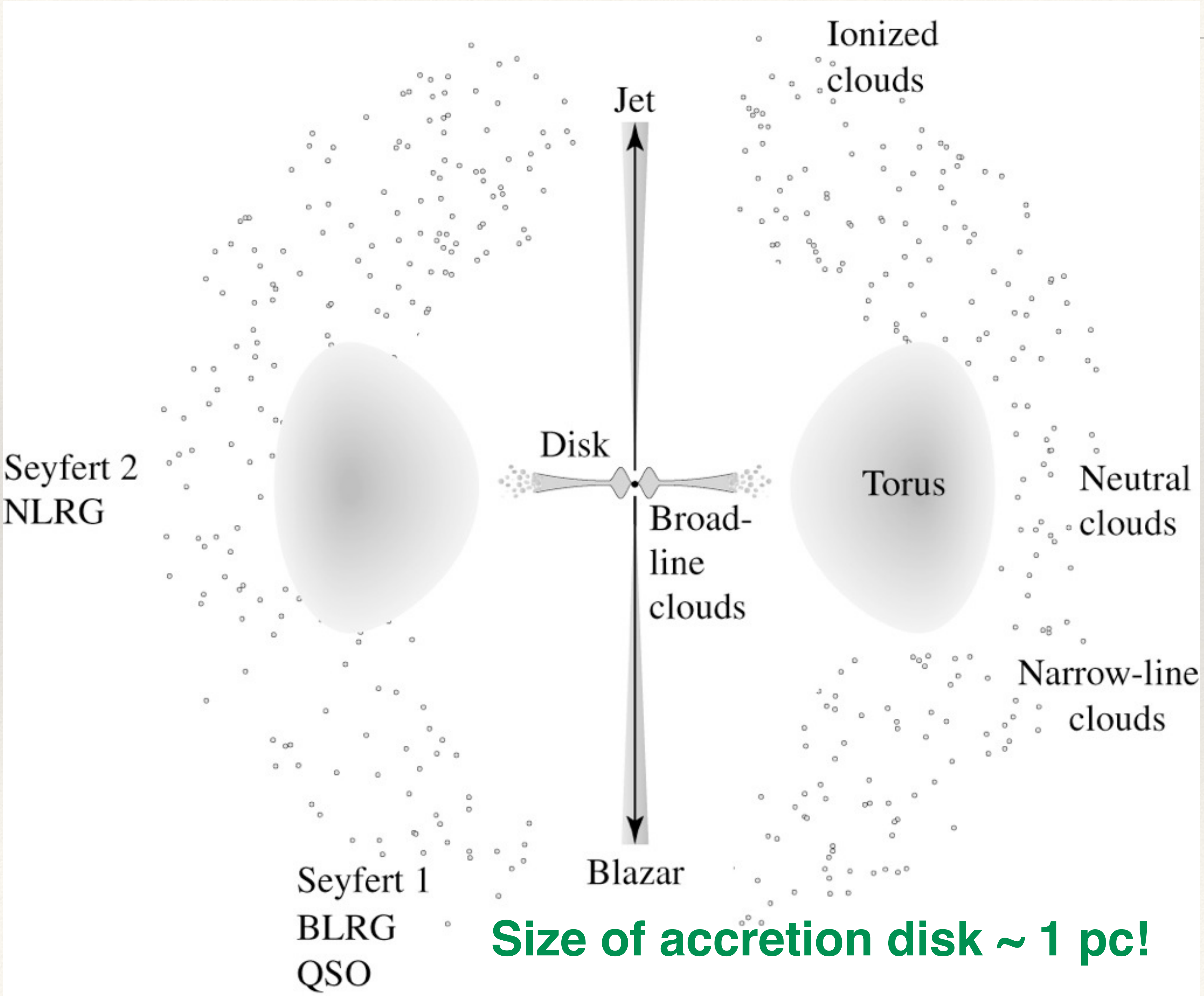
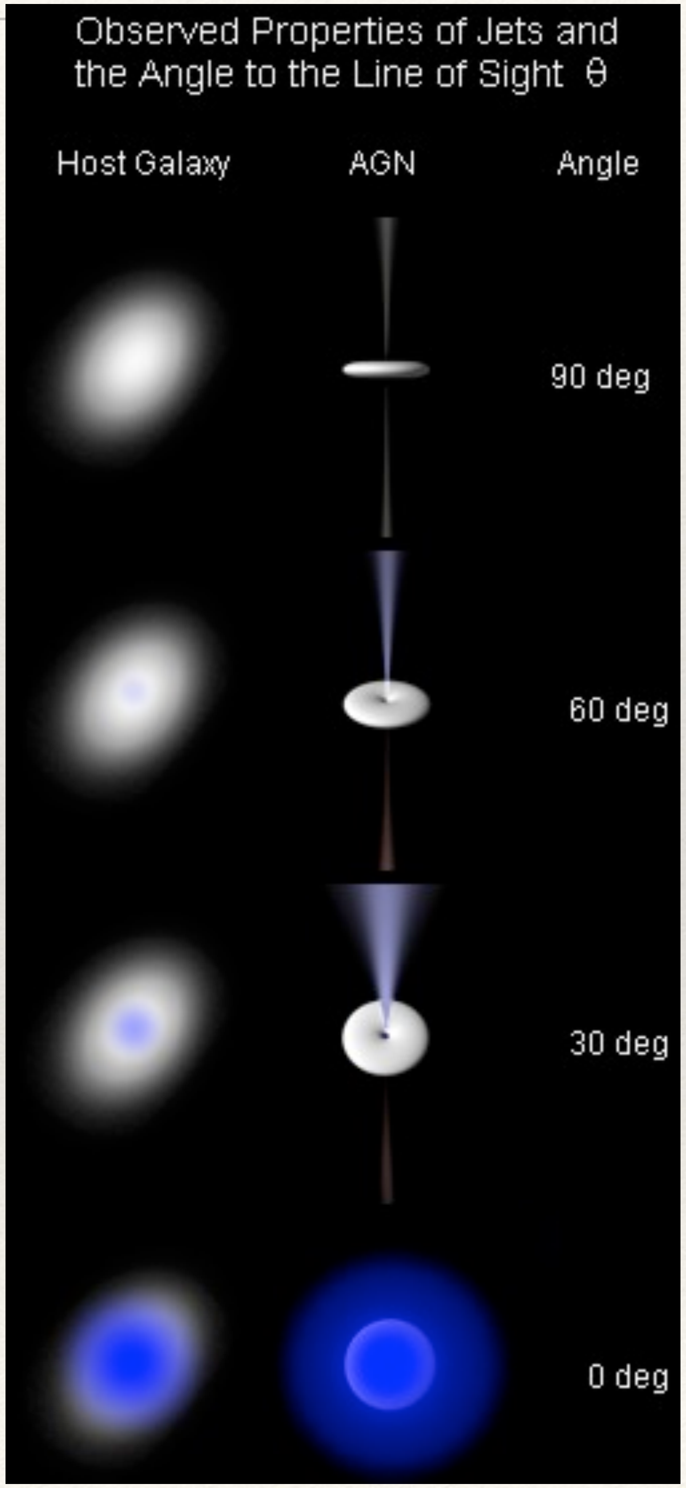




Central Black Holes

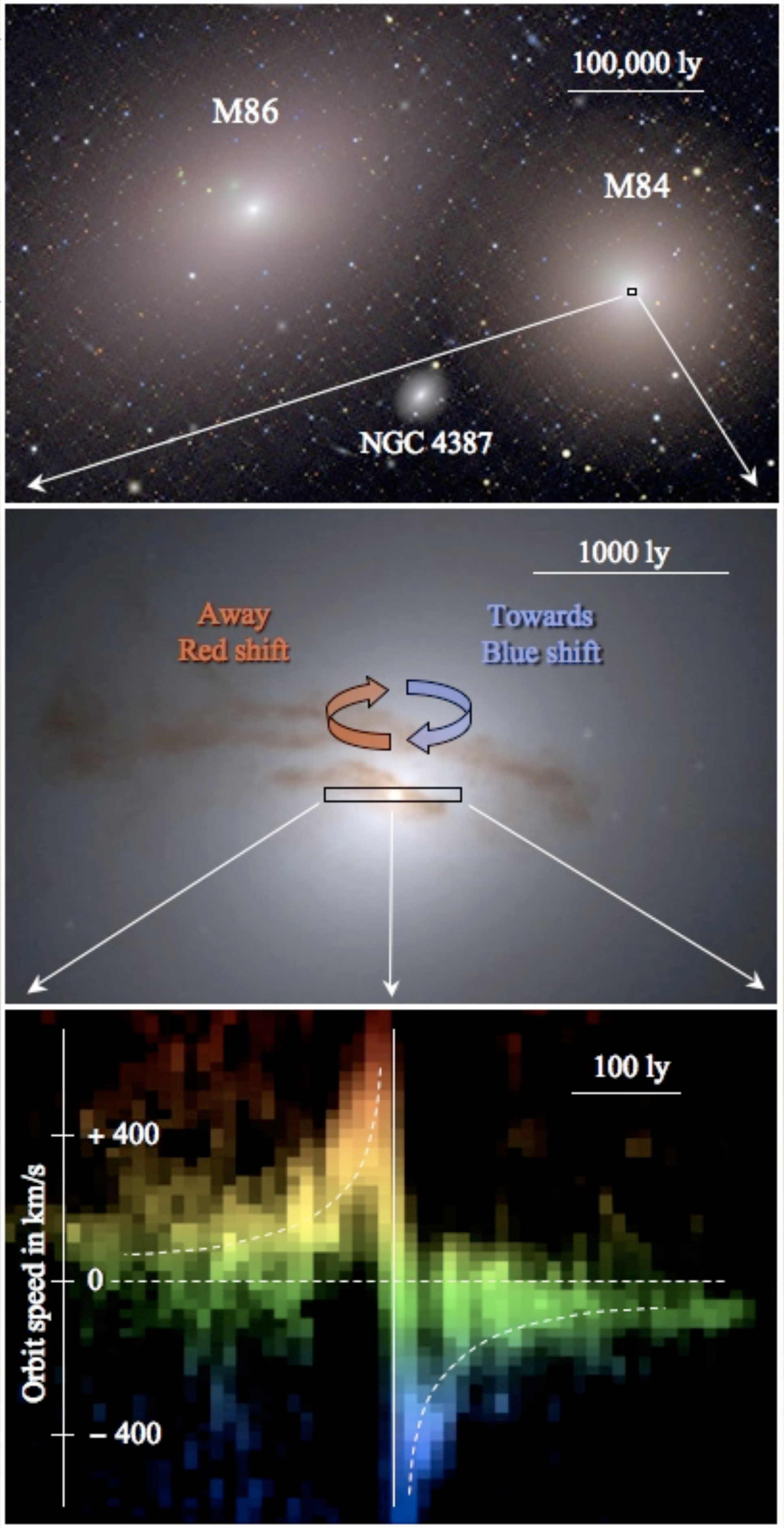


Size of accretion disk ~ 1 pc!



Central Black Holes

- Black holes in non-active galaxies
  - seems like most galaxies have BHs
  - hard to detect, because "sphere of influence", where gravity from BH dominates that of galaxy, is small



Thought questions

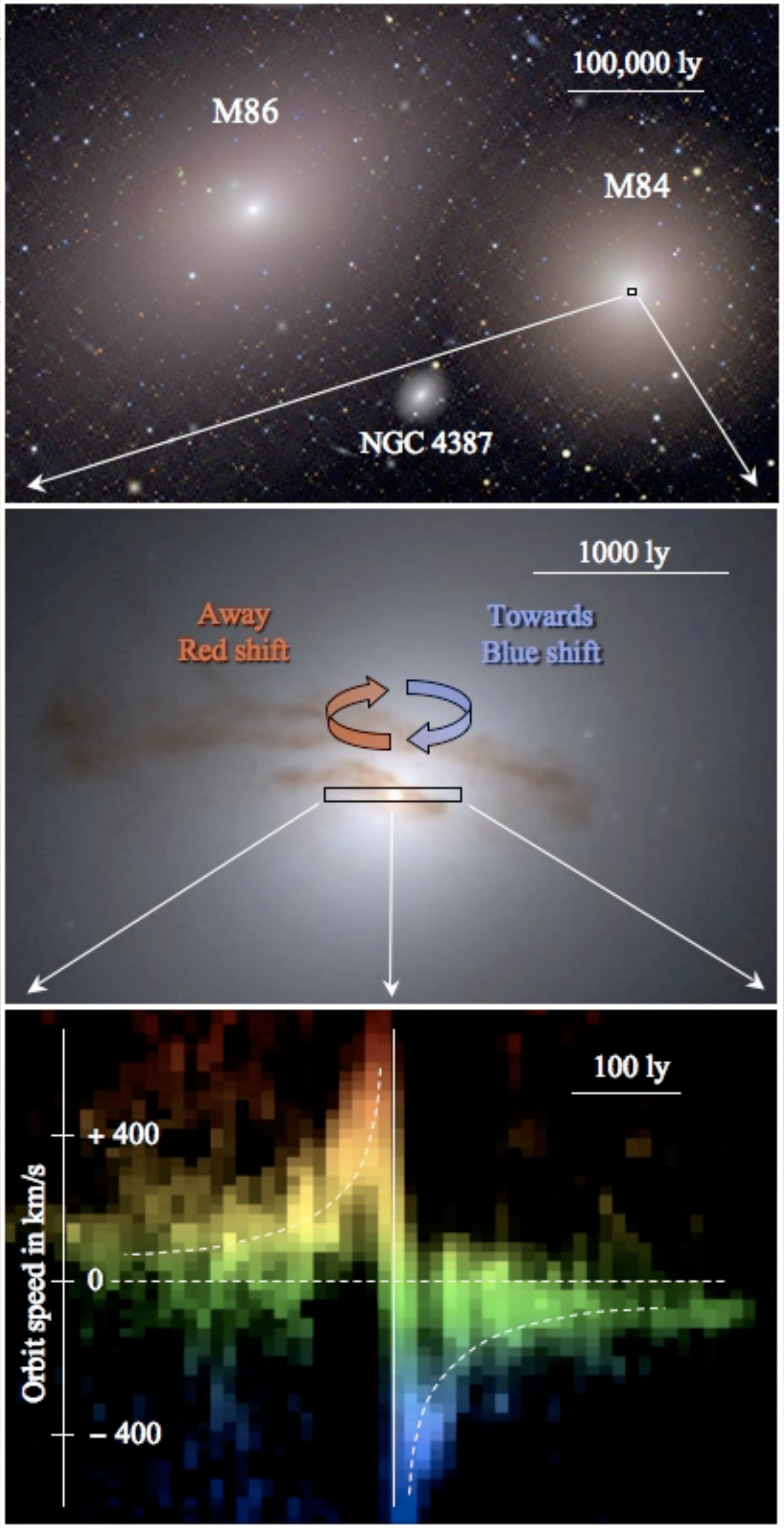
- How will a central black hole affect stellar velocities?
- How are typical velocities in centers of galaxies characterized in the absence of a black hole?
- In what region will velocities from a black hole dominate?

Central Black Holes

- Black holes in non-active galaxies
  - seems like most galaxies have BHs
  - hard to detect, because "sphere of influence", where gravity from BH dominates that of galaxy, is small:

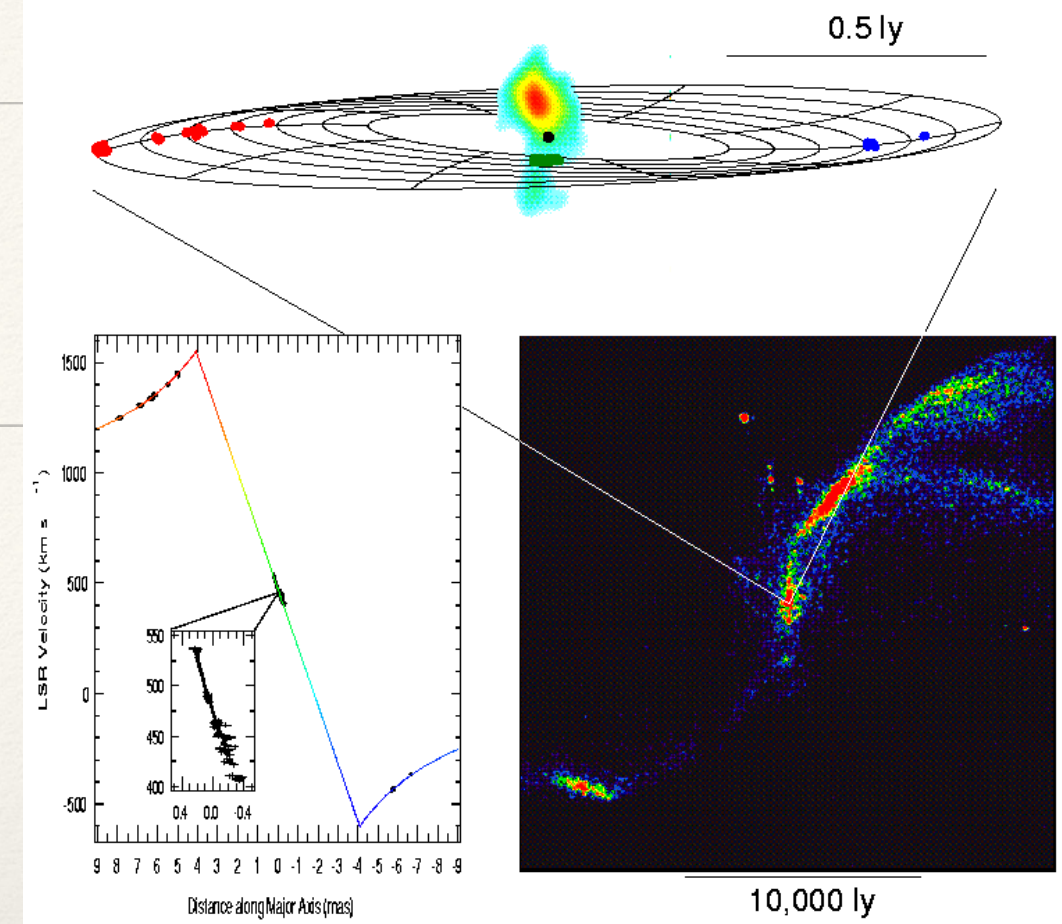
$$r_h \sim \frac{GM_{bh}}{\sigma^2} \sim 11.2 \frac{M_{bh}}{10^8 M_{sun}} \left(\frac{\sigma}{200 km/s} \right)^{-2} pc$$

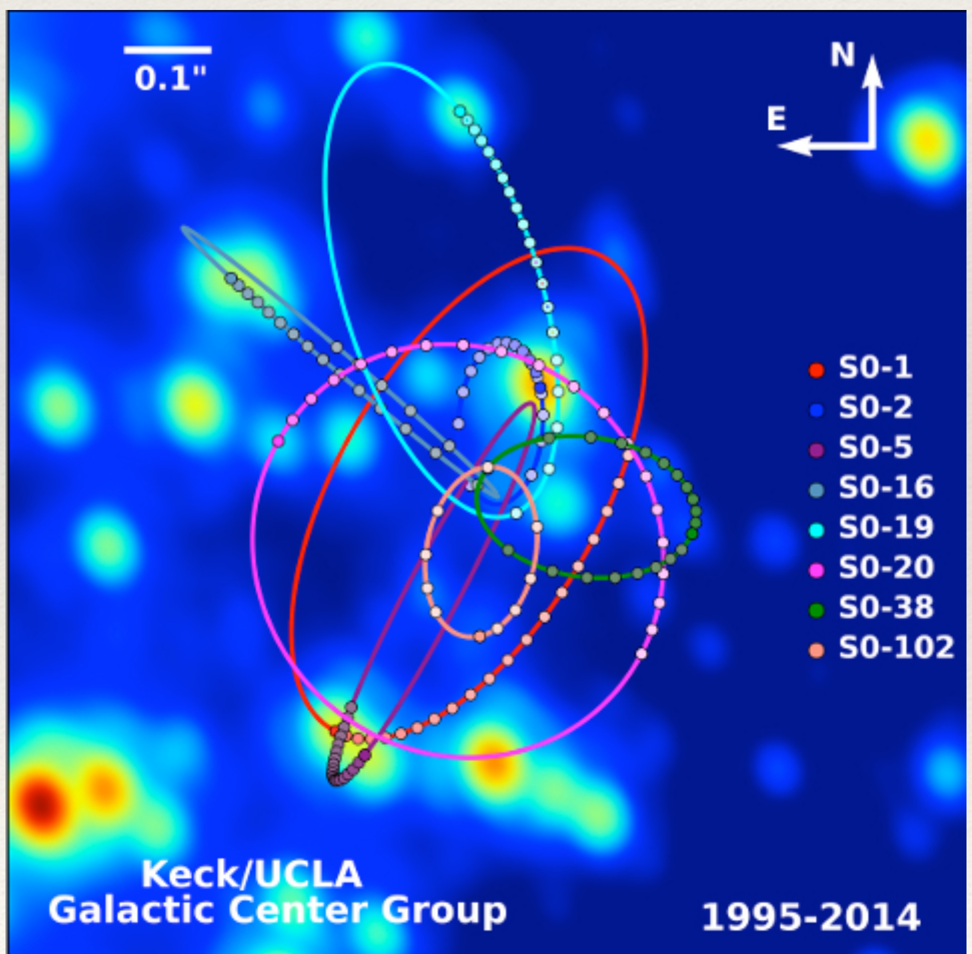
- HST enabled detections of rapidly rotating disks in cores of nearby galaxies
- Event Horizon telescope detects BHs in Milky Way and M87 "directly"!

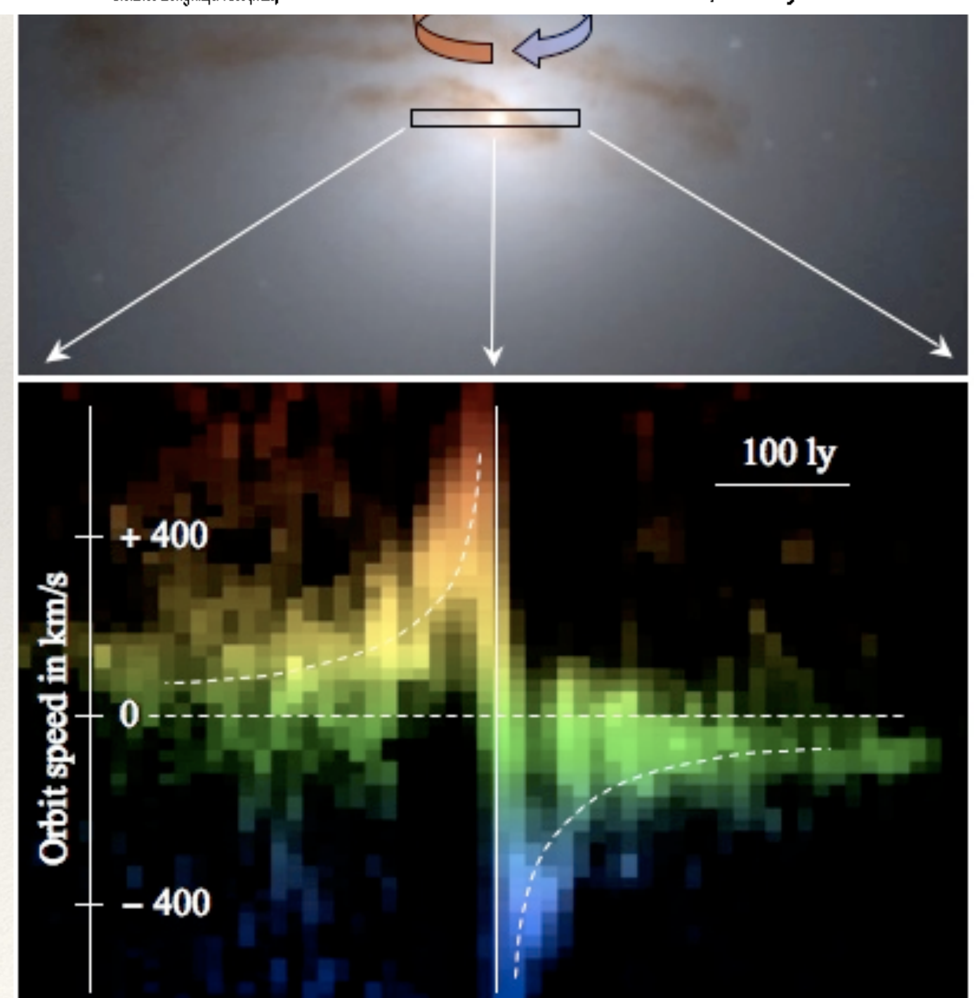


Central Black Holes

- Measuring Black Hole Masses
  - Motion of stars and gas around black hole
  - Milky Way proper motions
  - NGC 4258 maser

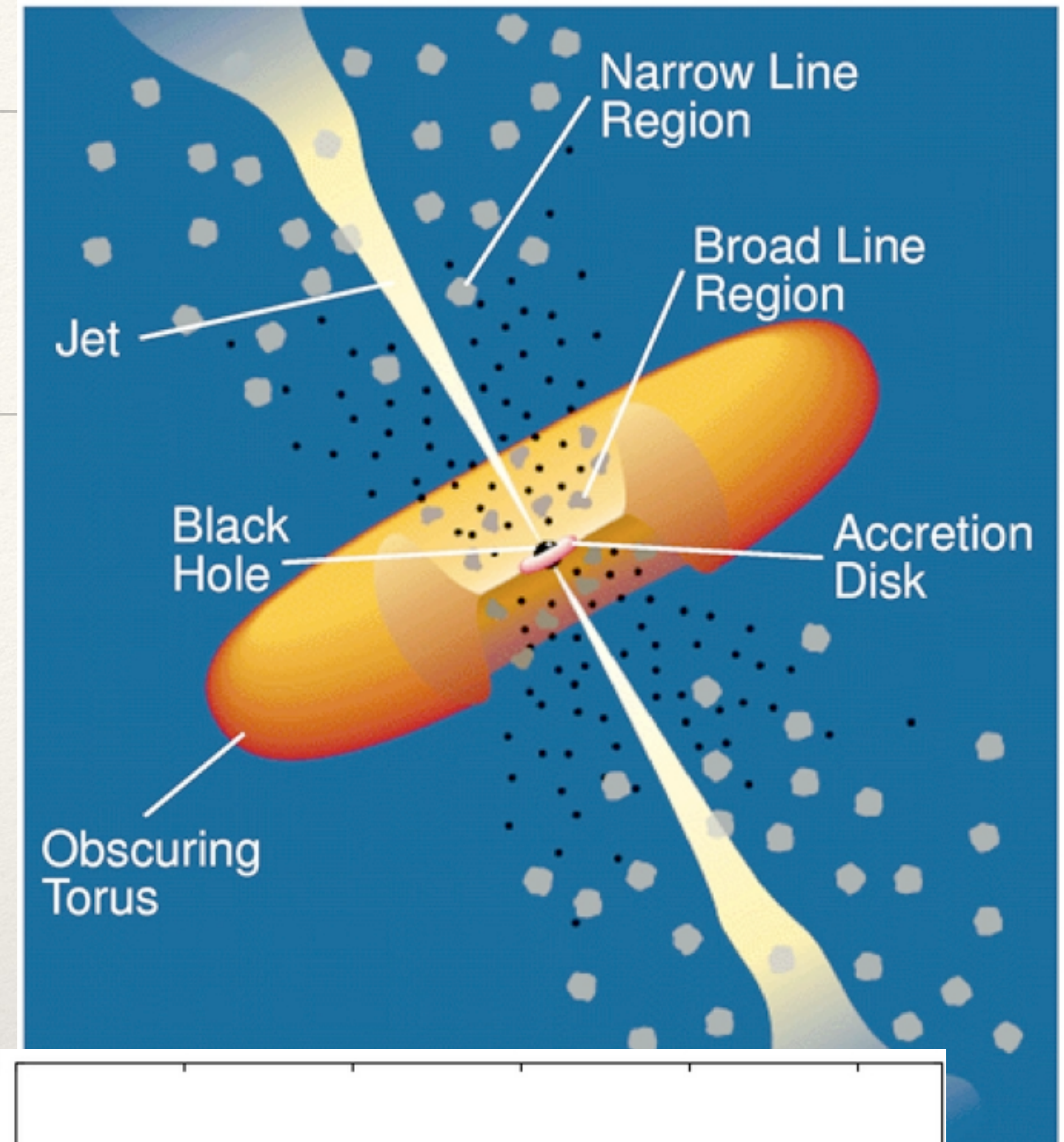






see https://galacticcenter.astro.ucla.edu/animations.html

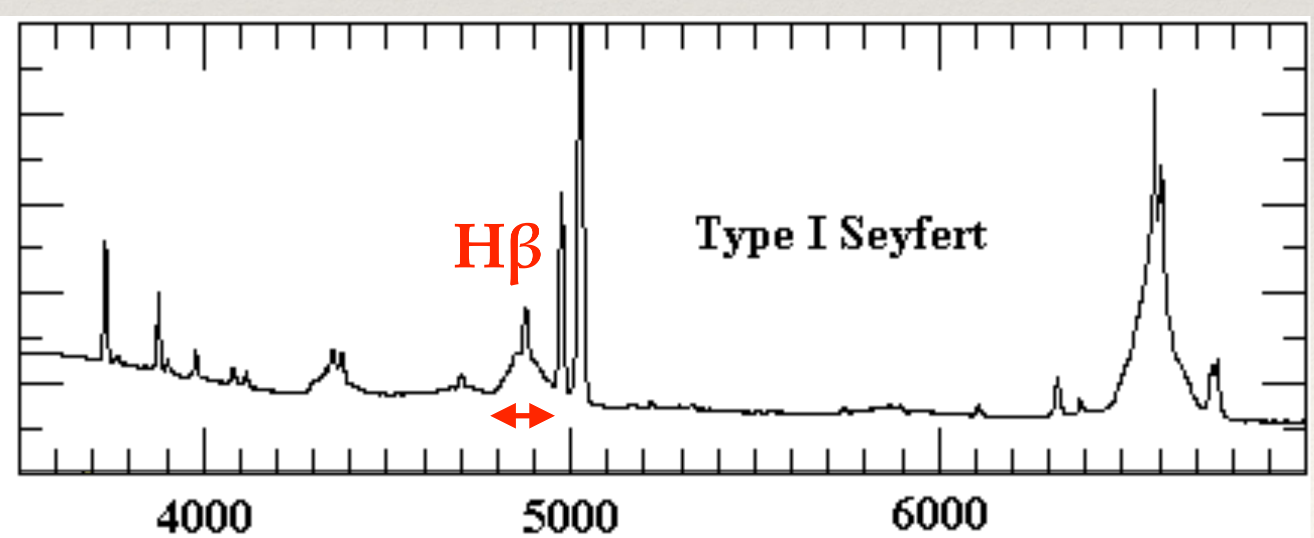
Central Black Holes

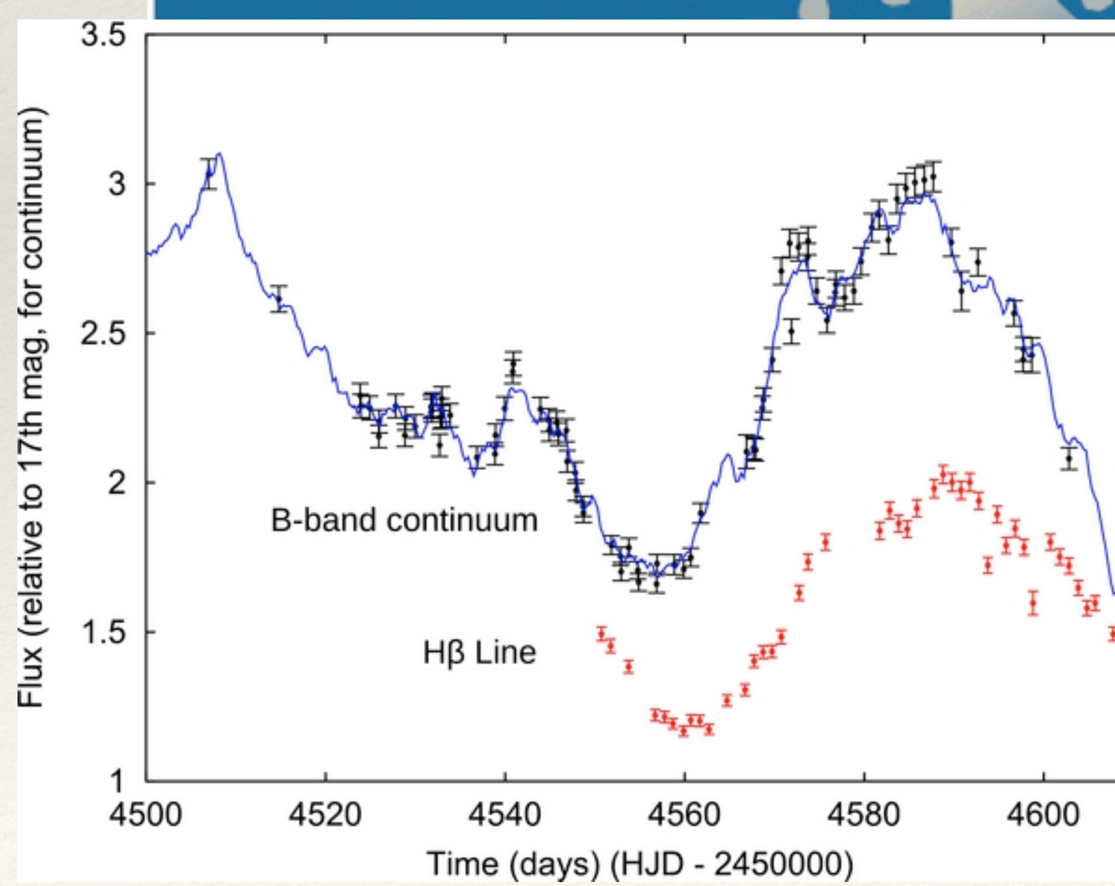


- Measuring Black Hole Masses
  - Reverberation mapping — BLR response time + velocity widths scale with black hole mass

$$v^2 \propto \frac{GM}{R}$$

  - get v from width of broad lines
  - estimate R from time lag of line variation from continuum variation

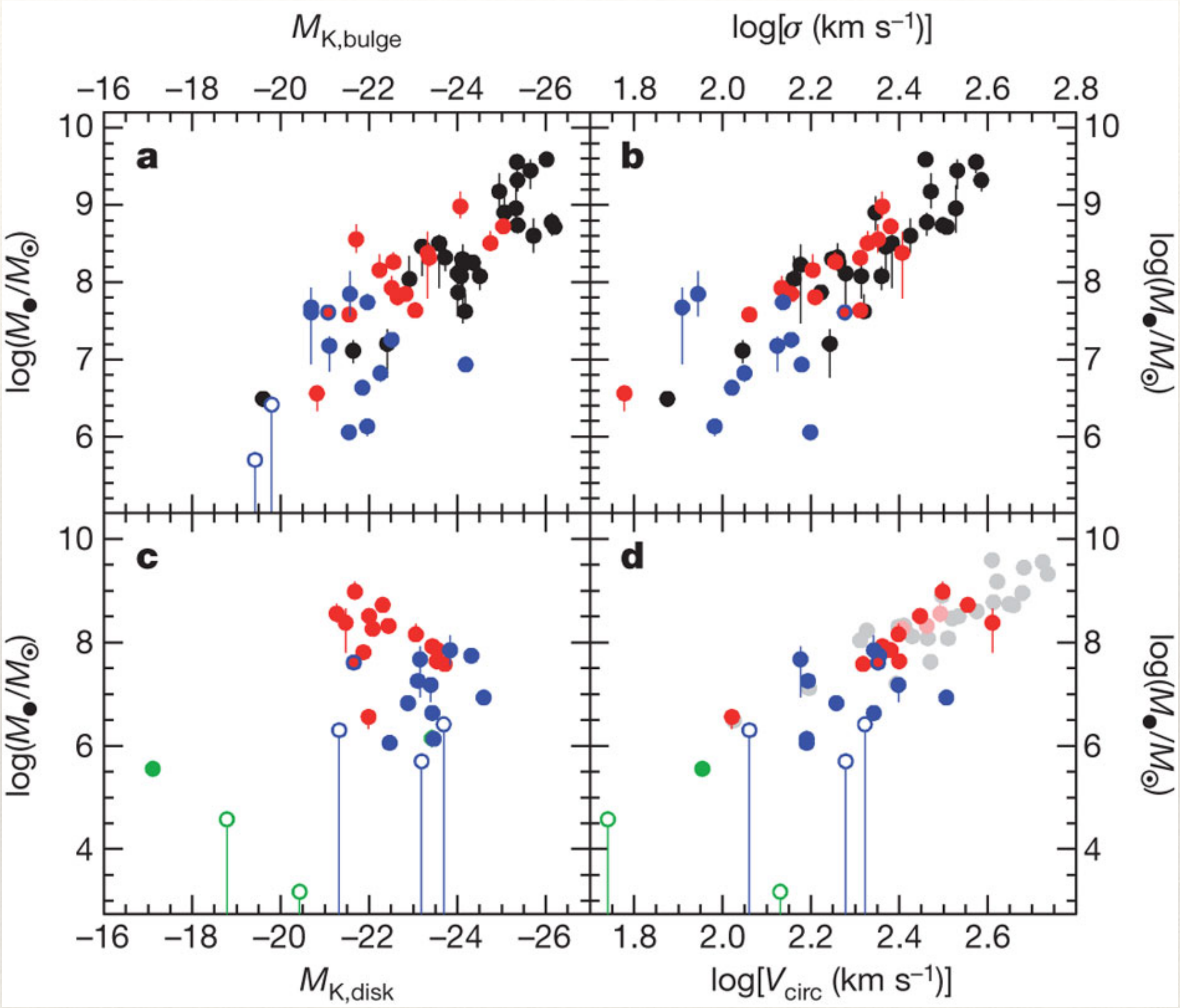




http://gtn.sonoma.edu/images/seyfertspectra.gif

Central Black Holes

- Measuring Black Hole Masses
  - find correlation between BH masses and bulge luminosity, or even tighter correlationwith central velocity dispersion
  - BHs may be fundamental in galaxy evolution! merger related?
- Why aren't all galaxies active? gas supply? duty cycle?



Kormendy & Bender 2011

a, Black-hole mass, M[circle 50 percent shaded], versus the K-band absolute magnitude of the host galaxy bulge, MK,bulge, with disk light removed. b, M[circle 50 percent shaded] versus the velocity dispersion, σ, of the host bulge averaged inside the radius that contains one-half of the bulge light. Elliptical galaxies are plotted in black, classical bulges are plotted in red and pseudobulges are plotted in blue.