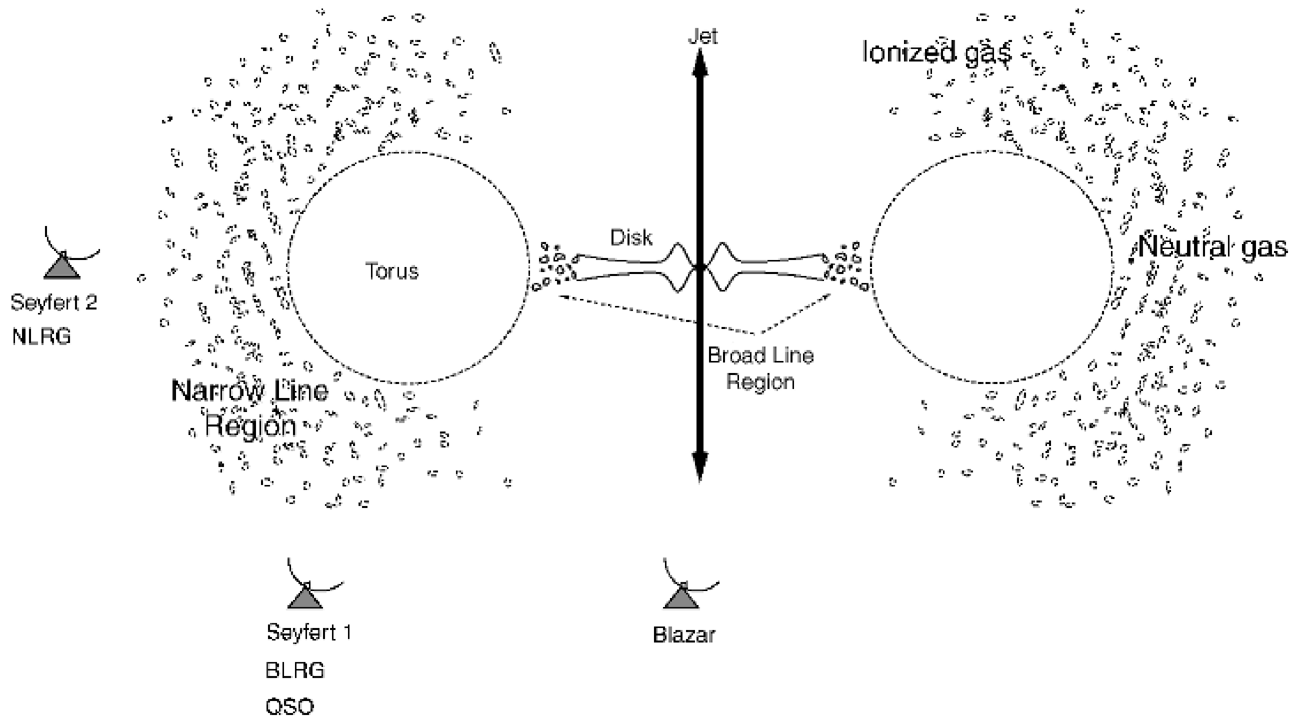
Active Galactic Nuclei

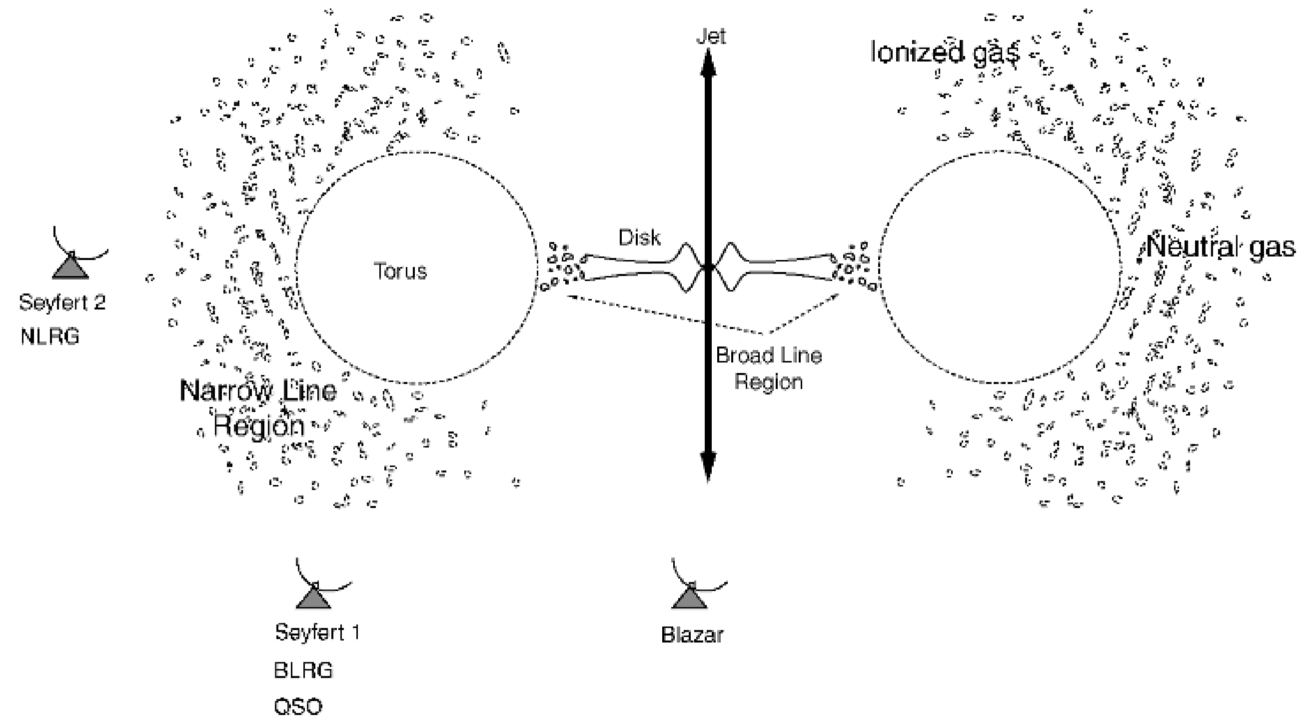
- Geometry: disk, BLR, NLR
- Ionization parameter
- Reverberation mapping
- Jets
- Luminosity function of AGN, K correction
- Absorption lines

Geometry of an AGN



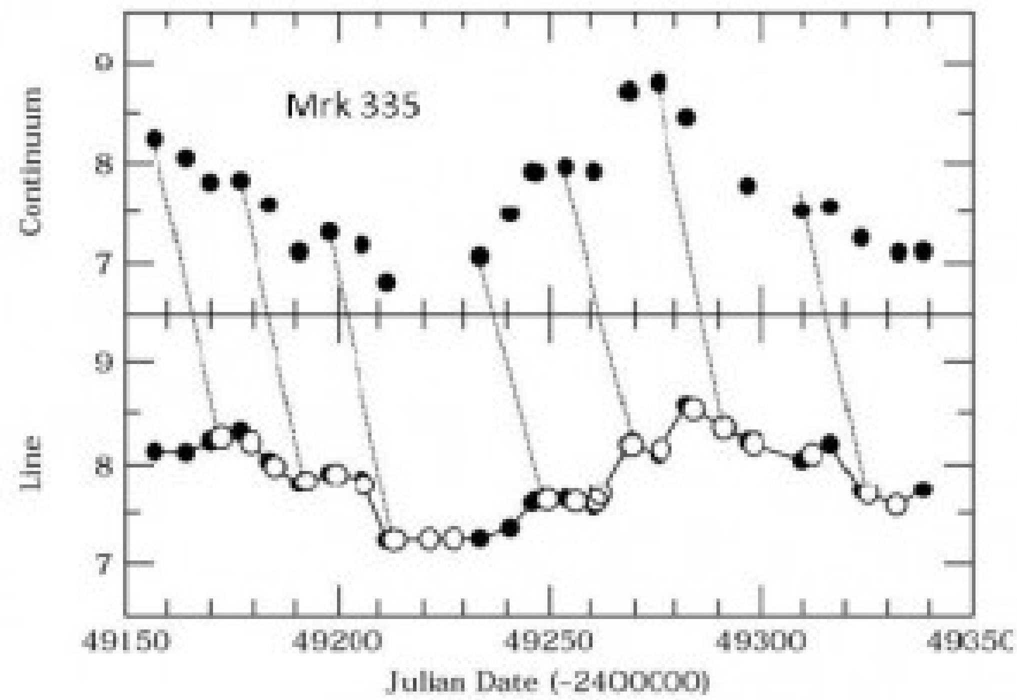
- Black hole at center
- Accretion disk produces thermal emission peaked in the UV - "big blue bump"
  - Big blue bump is not directly detectable due to strong absorption from 13 to 200 eV.
- Accretion also produces X-ray emission with typical spectrum $S_\nu \sim \nu^{-0.7}$.
  - X-rays may arise from a spherical corona above the disk, a thin corona above the disk (either would be powered by magnetic reconnection in the disk) or a separate accretion flow.
- Powerful UV and X-radiation ionized surrounding gas.

Broad line region



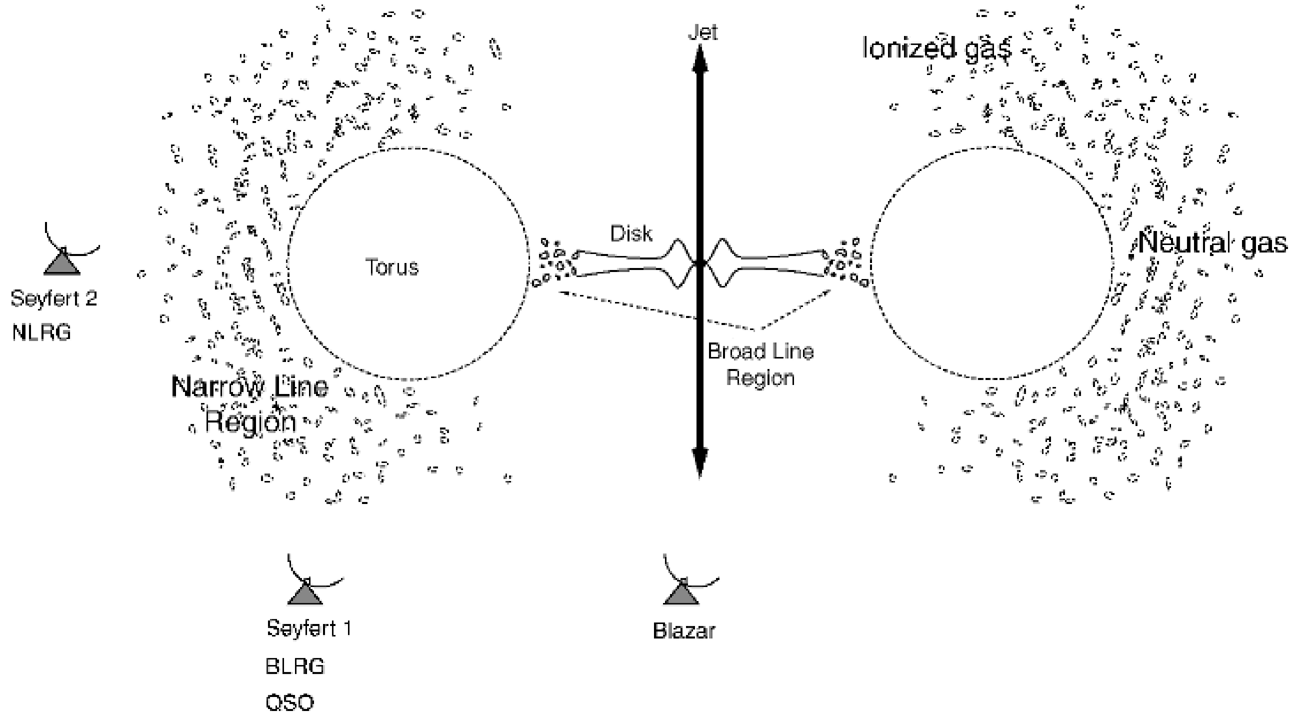
- Emission lines produced when atoms are ionized by X/UV from compact object.
- Ionization parameter $\Xi = L/r^2$, higher closer in, so more highly ionized atoms closer in.
- Line widths indicate speeds up to 10,000 km/s.
- If gravitational, indicated BLR at $r \sim 500\ r_S$.
- From line diagnostics, BLR has $T \sim 20{,}000$ K, density $\sim 10^9$ cm^{-3}, filling factor $\sim 10^{-7}$.

Reverberation mapping



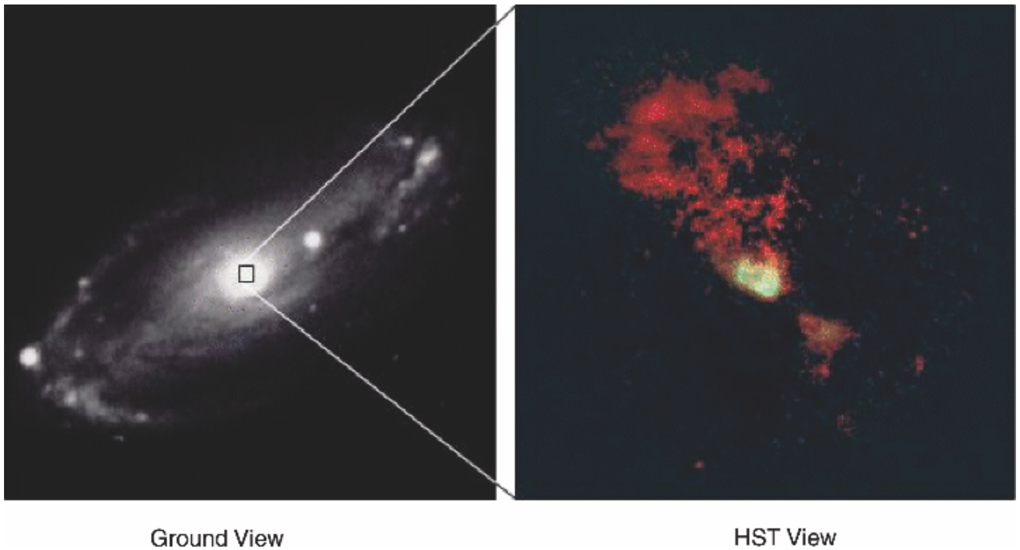
- Variations in X/UV from compact object will produce variations in line strength.
- For line produced at radius r, response will be delayed by $\Delta t \sim r/c$.
- By continually monitoring continuum and line strength, then looking for correlated changes, one can measure Δt and then calculate r.
- Provides constraints on size of BLR.
- Also provides estimate of BH mass, $M \sim r\sigma^2/G$.

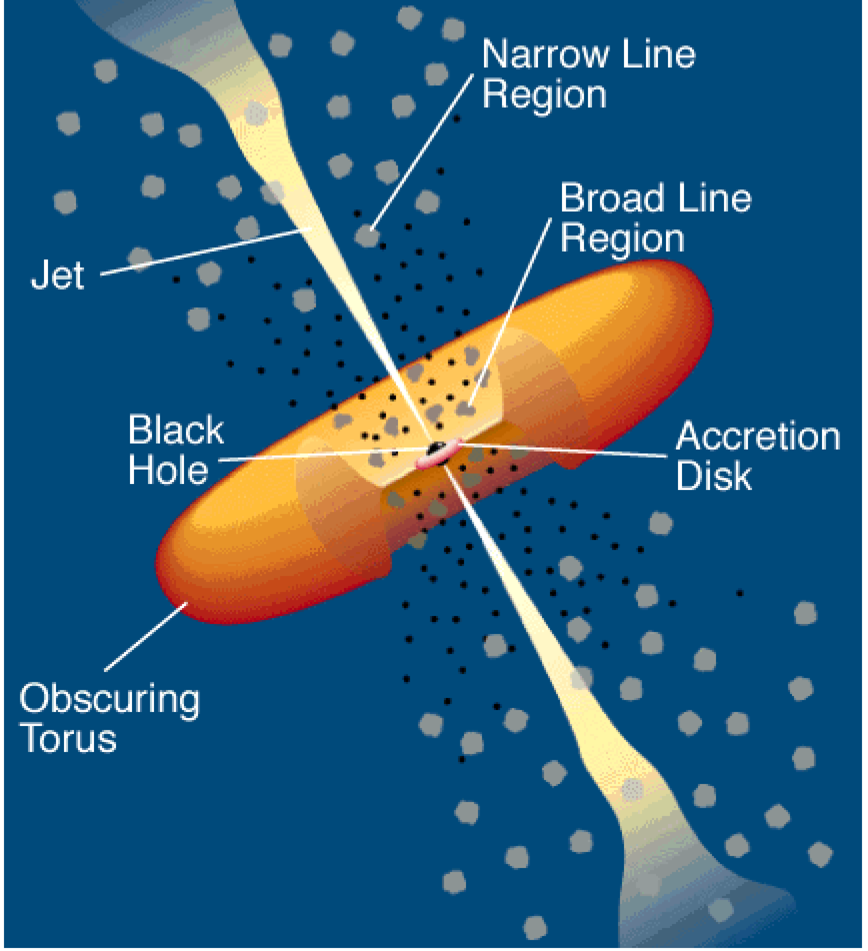
Torus



- To understand the range of AGN, a structure that blocks some lines of sight to the accretion disk is needed.
- The torus contains dust and is geometrically thick.

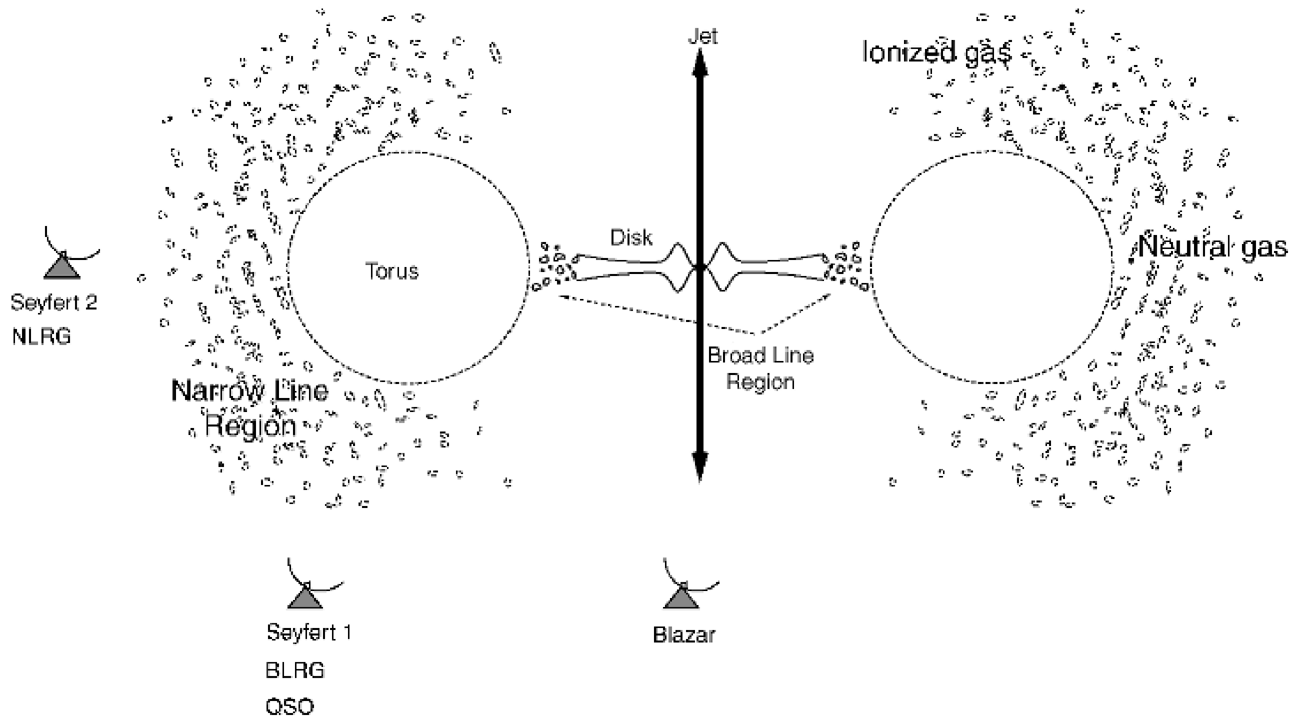
Narrow line region





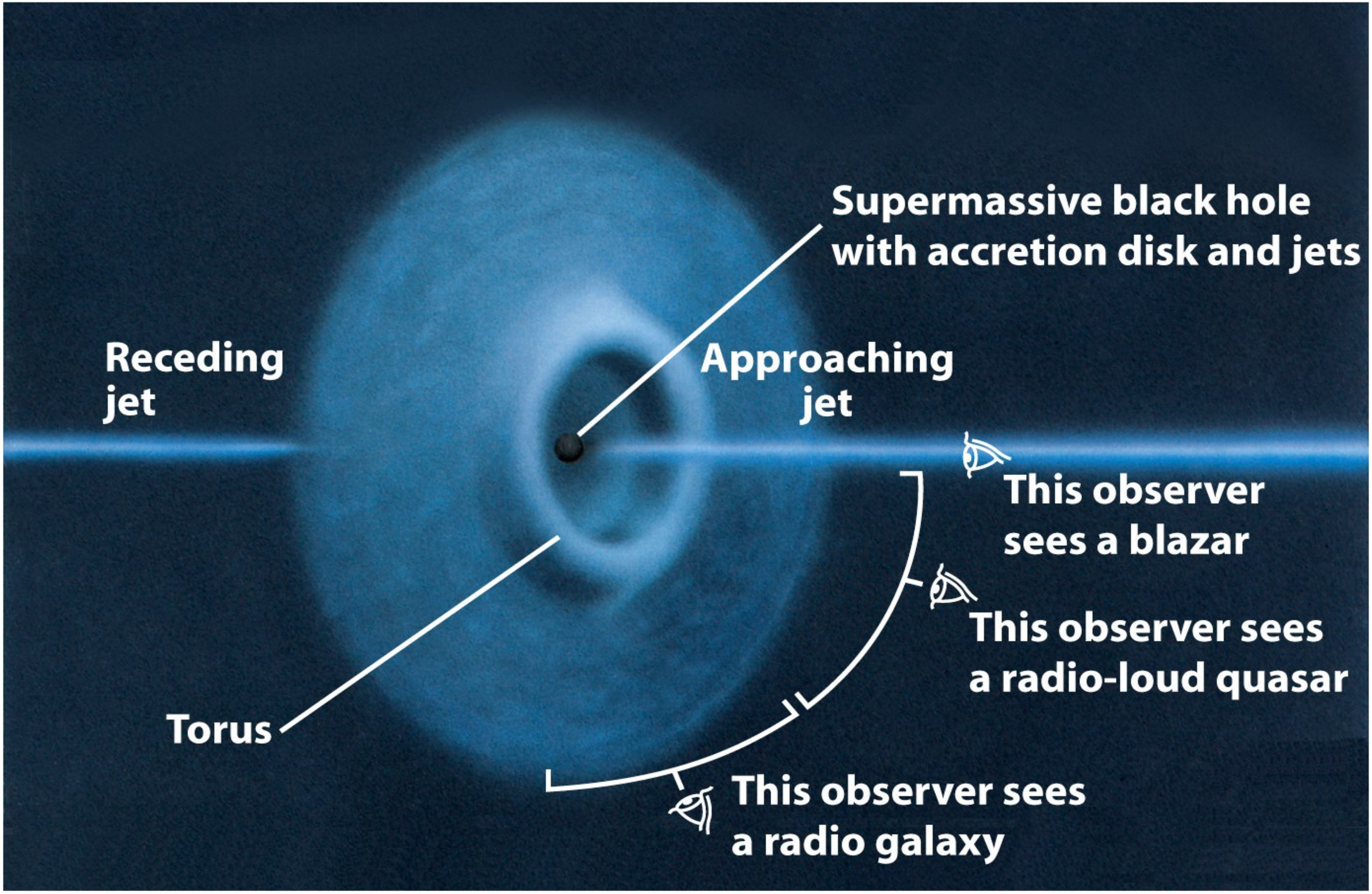
- Narrow line region consists of gas clouds farther away from the BH, thus with lower velocities and lower ionization levels.
- Also ionized by X/UV from accretion disk.
- Distances ~ 100 pc.
- NLR has T ~ 16,000 K, density ~ 10^3 cm^{-3}, and filling factor ~ 0.01.

Unified model

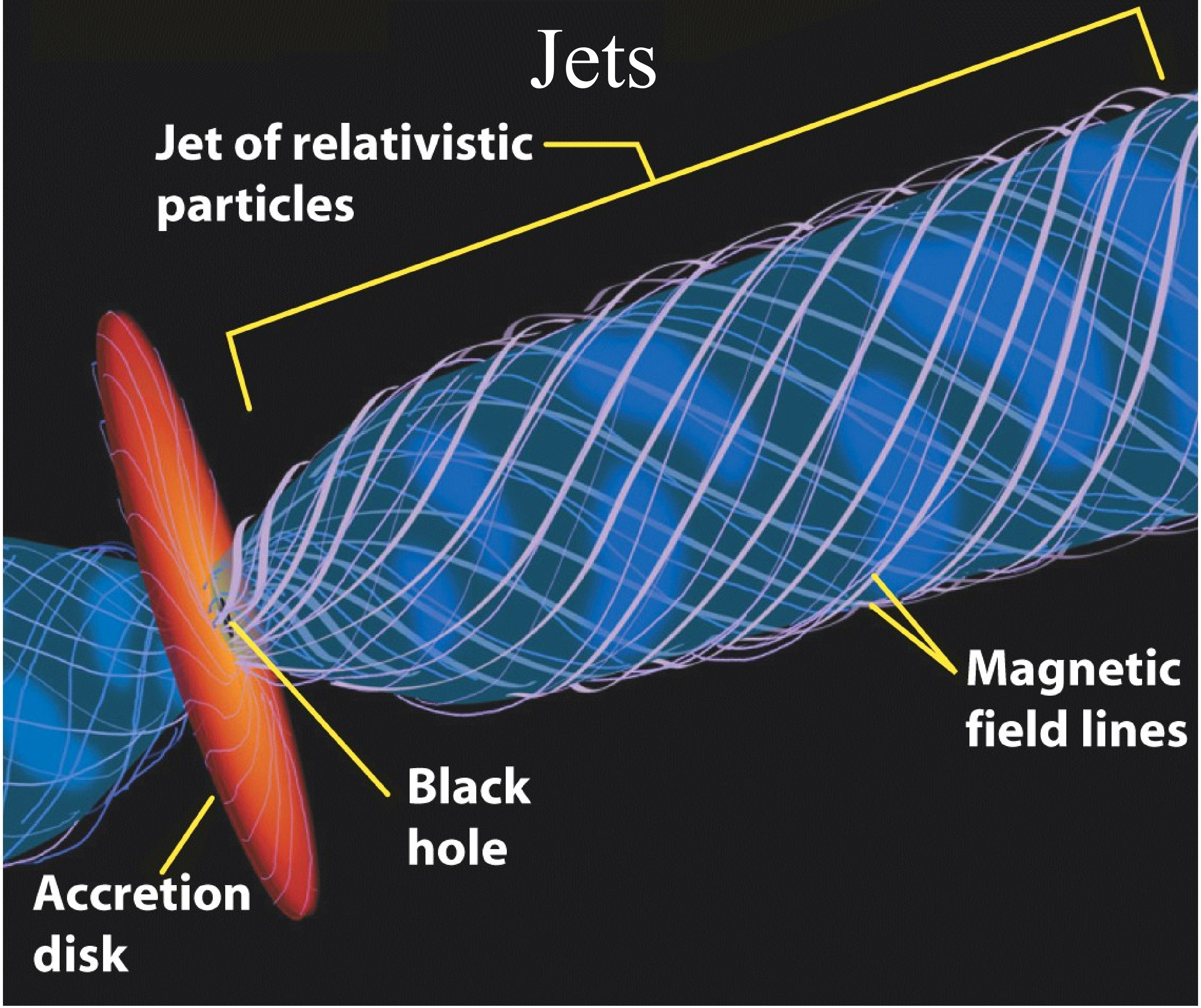


- Differing properties of different types of AGN can be understood as a viewing angle effect.
- For blazars, our line of sight is close to the jet axis and the radiation we see is dominated by the jet.
- For Seyfert 1's, we the disk, BLR, NLR
- For Seyfert 2's, the disk and BLR are blocked by the torus.
- NGC 1068 is a Seyfert 2, but shows BLR in polarized = scattered light

Orientation

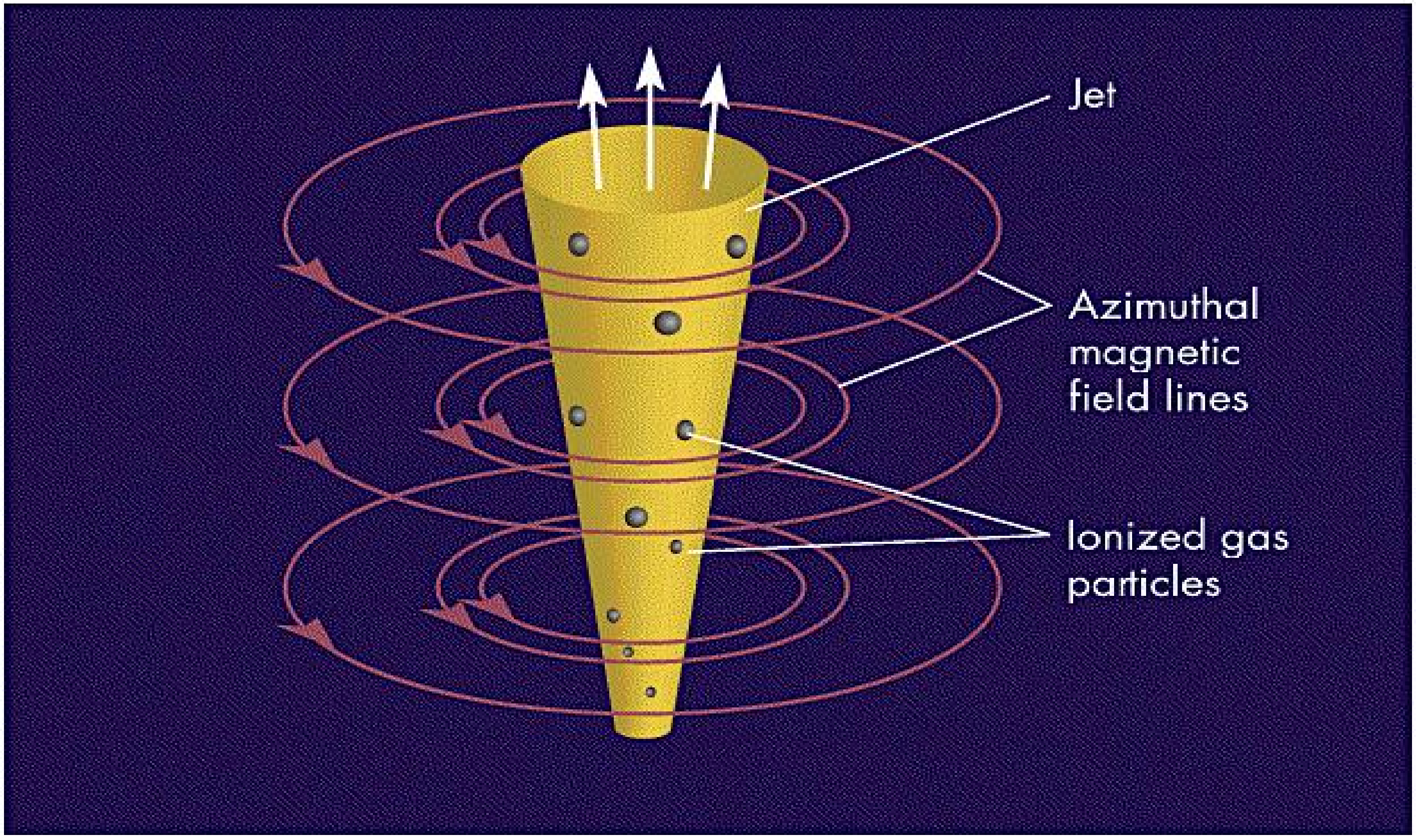


Jets



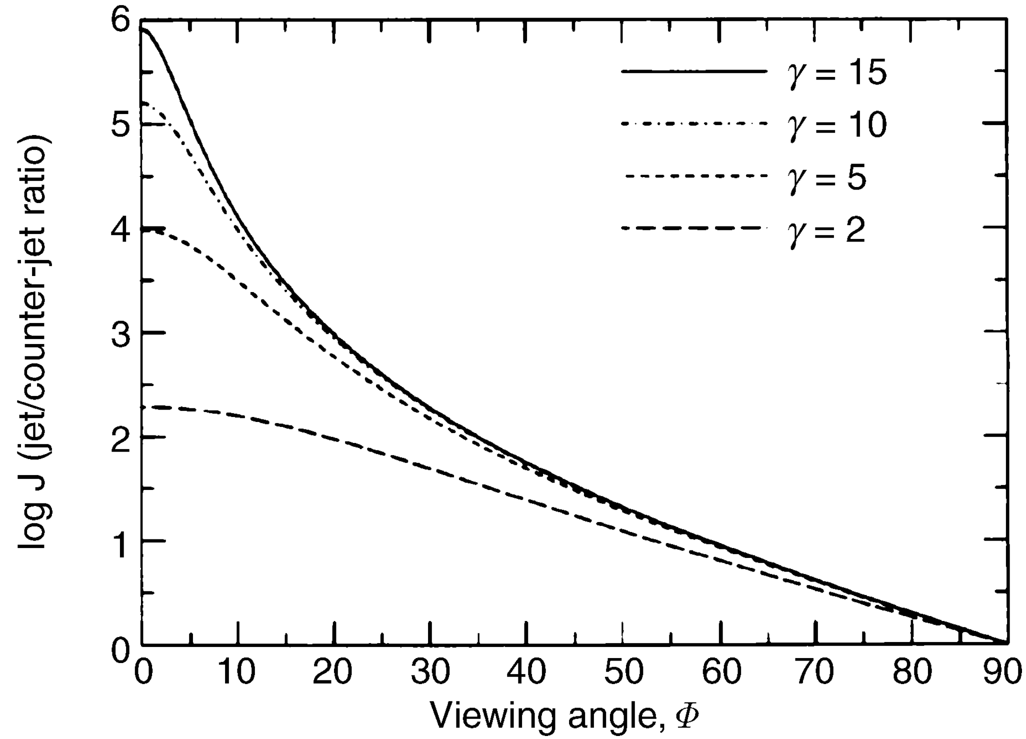
Jet of relativistic particles
Magnetic field lines
Black hole
Accretion disk

Collimation of a jet



Production of jets is not well understood and is a major topic in current research.

Relativistic beaming

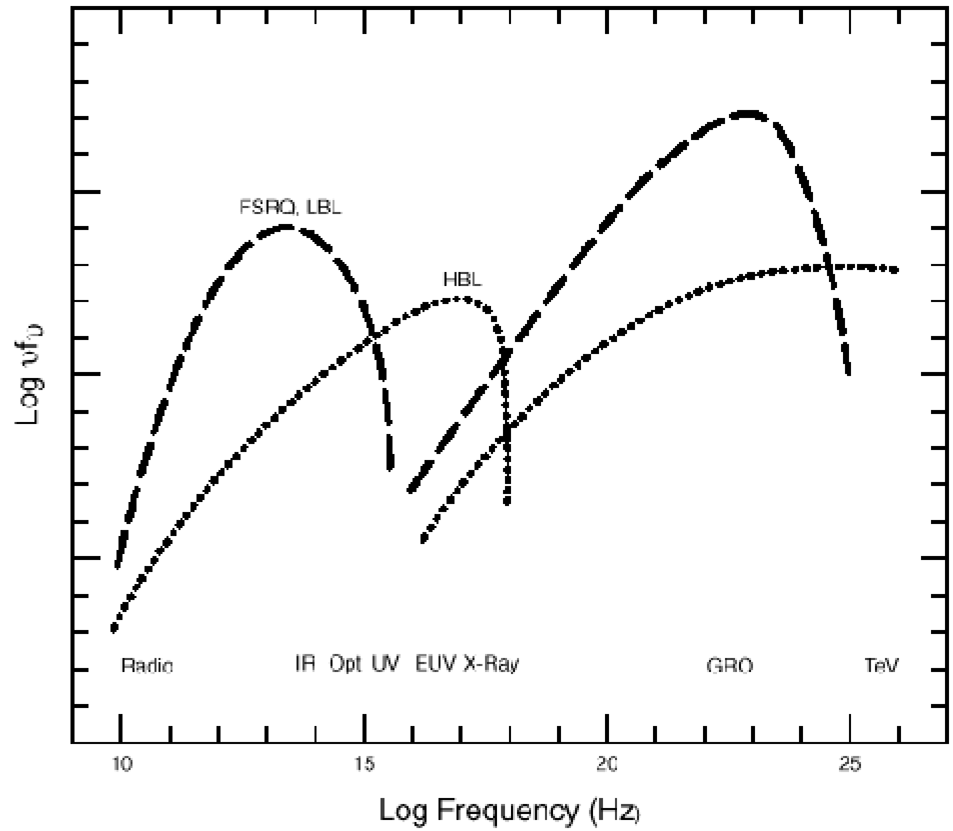


Doppler boost for approaching jet: $$D_a = \left(\frac{1}{\gamma(1-\beta\cos\varphi)} \right)^{2+\alpha}$$

Note that the boost depends on the spectral slope since the observed wavelength is Doppler shifted relative to the emitted wavelength.

Doppler boosting makes approaching jet (often) much brighter than receding jet.

Blazar spectra

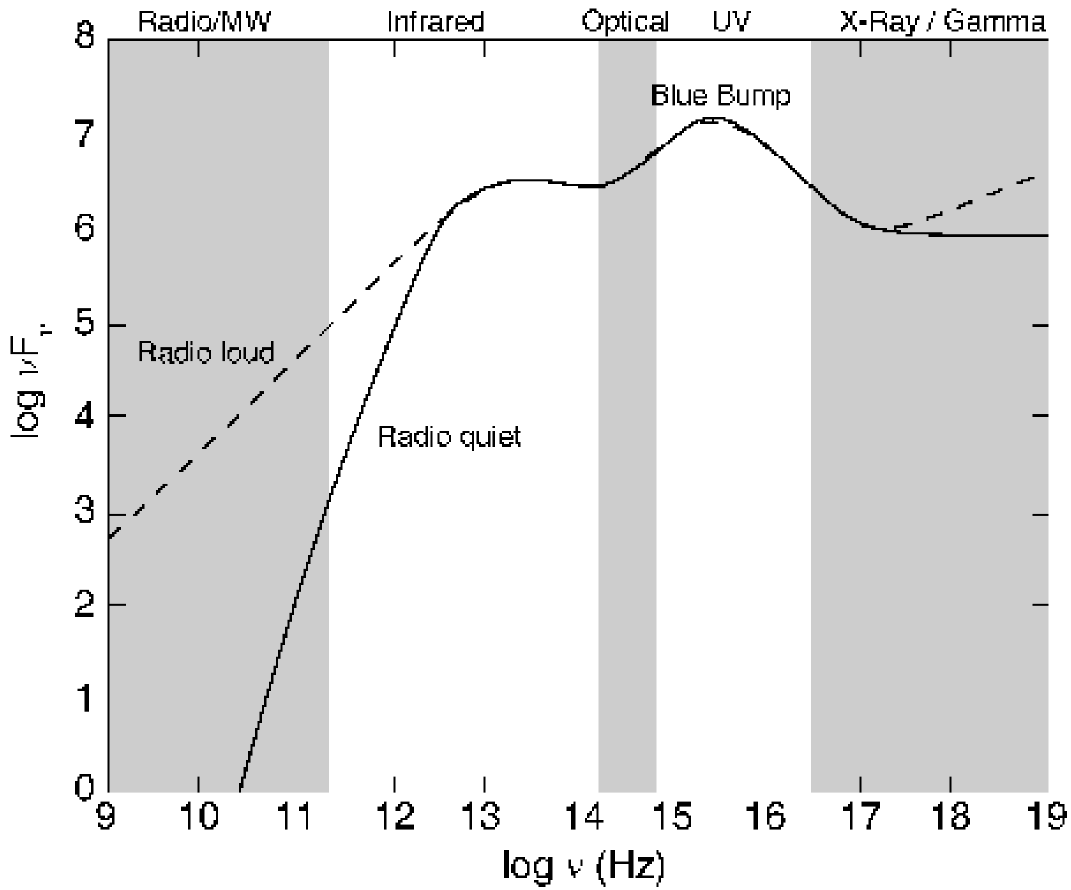


- Low frequency peak is due to synchrotron emission from relativistic electrons.

- High frequency peak is due to inverse-Compton scattering of photons by the same electrons.

- Photons can come from external sources (accretion disk, BLR, torus) thus “external Compton” or from the synchrotron emission “synchrotron self Compton”.

AGN spectra



- Low frequency emission is synchrotron emission from relativistic electrons in the jet.
- High frequency emission is inverse-Compton on relativistic electrons in the jet.
- X-rays can come from jet or accretion flow.
- Blue bump is accretion disk emission.
- IR bump is from dust – the torus.

K correction

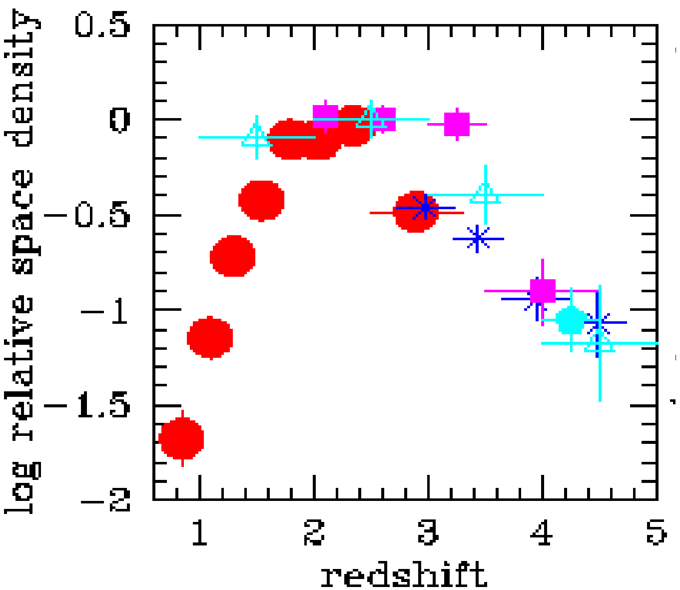
- When viewing AGN at cosmological distances, one must correct for effect of redshift on spectrum – the K correction. This is particularly important if one is observing only in one wavelength band.
- Relation of flux density S_ν measured at frequency and luminosity density $L_{\nu'}$ emitted at rest frame frequency $\nu = \nu' (1+z)$ is

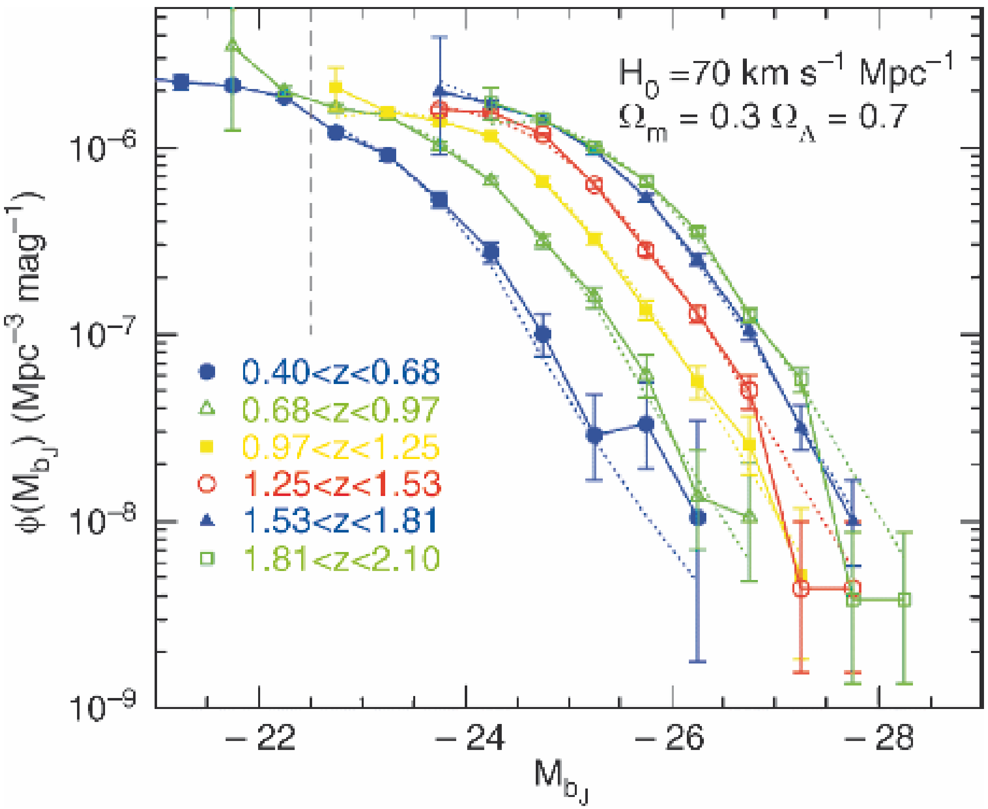
$$s_\nu = \frac{(1+z) L_{\nu'}}{4\pi D_L^2} = \frac{L_\nu}{4\pi D_L^2}\left[\frac{L_{\nu'}}{L_\nu}(1+z)\right]$$

- One needs to know the spectral shape in order to do the correction. The K-correction is usually written in terms of magnitudes

$$K(z) = -2.5\log\left[\frac{L_{\nu'}}{L_\nu}(1+z)\right]$$

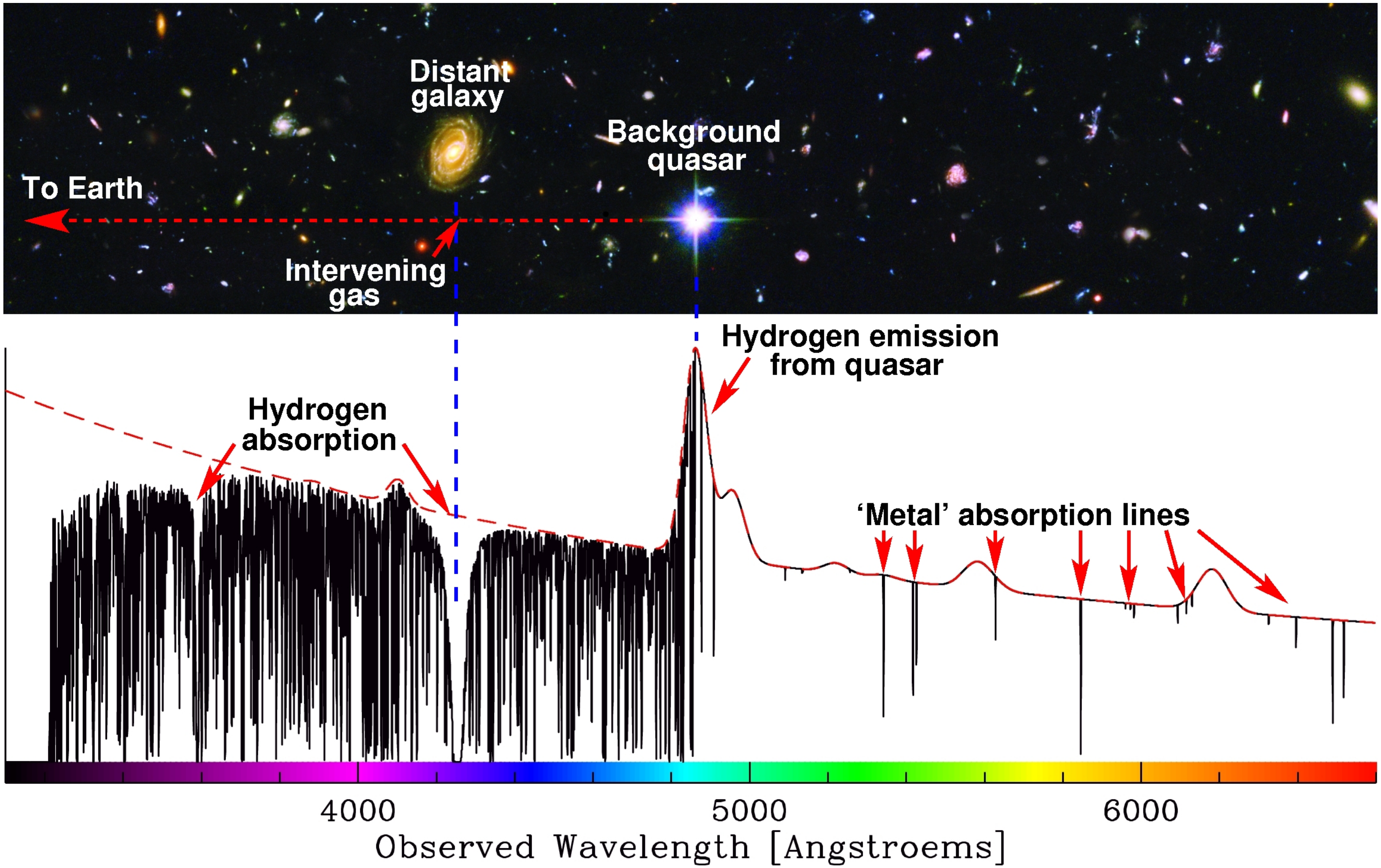
QSO luminosity functions





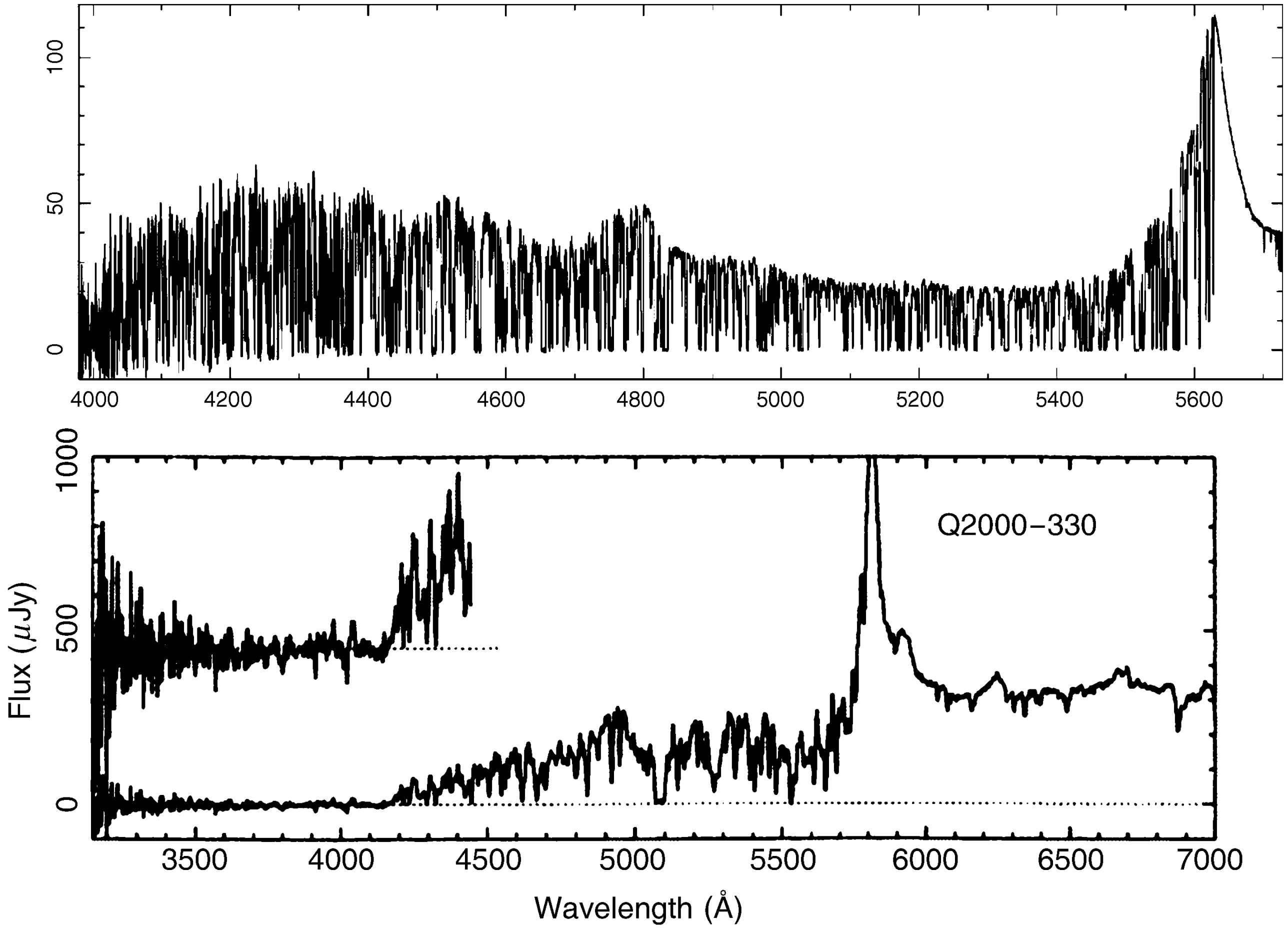
- QSO luminosity function is often described with a double power-law in $L/L^*(z)$ where $L^*(z)$ is the characteristic luminosity versus redshift.
- Luminosity evolves strongly with redshift, $L^*(z) \sim (1+z)^k$ with $k \sim 3.5$ for $z < 2$.
- Space density of QSOs also evolves with a peak around 2-3, the 'quasar epoch'.

QSO absorption lines



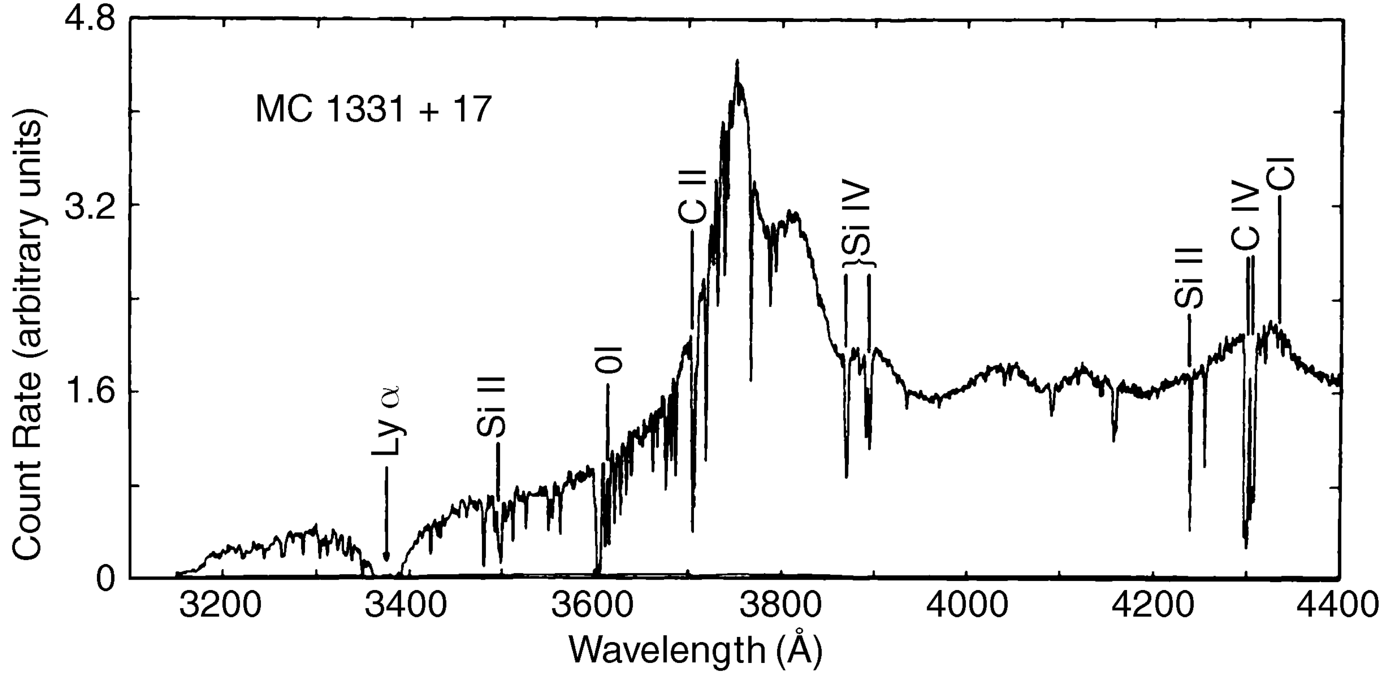
• Gas within quasars or in gas clouds or galaxies between us the and quasar can produce absorption lines.

Lyman α



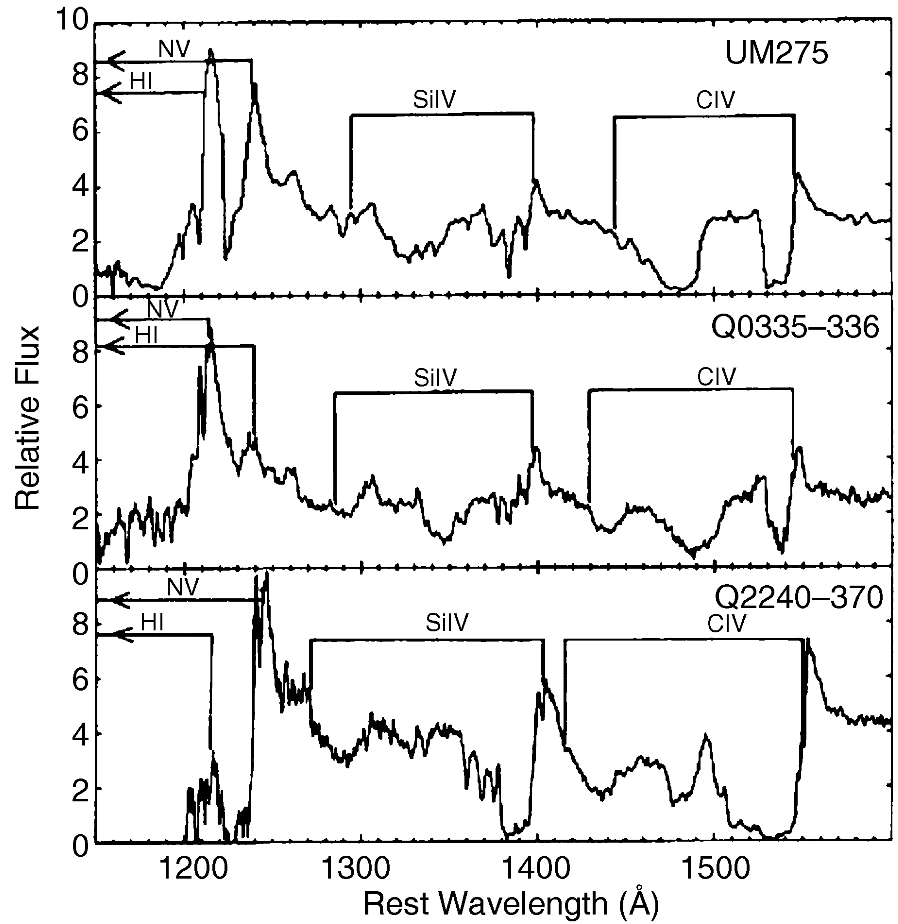
- Lyman α is the n=2 to n=1 transition. For H it is at 1216 Å and Lyman limit is 912 Å.
- Ly α forest arises from low density clouds, $N_H < 10^{17}$ cm^{-2}.
- Ly α limit systems, $N_H > 10^{17}$ cm^{-2}, completely block light shortward of 912 Å.
- Damped Ly α systems, $N_H > 10^{20}$ cm^{-2}, block light over broad bands around 1216 Å.

Metal systems



- Ly α absorption arises from primordial gas or gas associated with galaxies.
- Metal absorption lines indicate nuclear fusion, so stars and usually a nearby galaxy.
- Typically need $N_H > 10^{17}$ cm^{-2}.
- Note damped Ly α line and at 3400 Å, corresponding Lyman limit would be at 2550 Å.
- Most common metal lines are Mg II and C IV.

Broad absorption line QSOs



- Some QSOs show broad absorption lines blueward of their emission lines.
- Caused by neutral (or lower ionization level) atoms in outflowing gas.
- Gas is coming towards us, thus blue shifted.
- These are broad absorption line (BAL) quasars.
- Similar lines, but narrower = lower speeds, are seen from stars with winds.

For next class

- Read 6.1-6.3.
- For Wednesday 10/3, write project proposal talk
  - title, authors, paper reference with title (if using one)
  - background – introduce the class to the subject
  - motivation - what question does it answer? why is that important?
  - analysis and results – what data will you look at and how?
  - conclusions – what do you hope to learn in terms of specific results?
- Each group will have 8 minutes with 4 minutes for questions (asked by anyone in the class at any point during/after each talk)