Broad Absorption Line Quasars
Quasars

-The brightest objects in the universe: powerful quasars are estimated to convert matter into energy with an efficiency of $0.1mc^2$ (compared to fusion, $0.007mc^2$)

-Energy source: accretion disk around a supermassive black hole (converts potential energy to light) - evidence: extreme x-ray variability and motion of objects near center of galaxy
Black Holes

- Objects so massive and compact that the escape velocity is the speed of light ($c$)

- Schwarzschild radius is $(2GM)/c^2$, sets scale for whole system

- The black holes we’re looking at have masses on the scale of $10^8$-$10^{10}$ solar masses
Photoionization

-Photons can transfer energy to electrons in atoms to excite them or knock them off the atom, creating ions

-Specific wavelengths of photons are known to be the right energy level to create certain ions (ex: 13.6 eV is the energy necessary to turn neutral hydrogen into H\(^+\) and the wavelength for that photon would be 911 angstroms)
The Lyman Alpha Forest

- A photon with a wavelength of 1216 angstroms is needed for the transition of the electron in Hydrogen from n=1 to n=2 (the alpha transition in the Lyman series)

- As light travels long distances through space it becomes redshifted, so photons with a shorter wavelength than 1216 angstroms can photoionize hydrogen after being redshifted a certain amount, leading to a “Lyman alpha forest” in the short wavelength range of the spectra that looks like noise

- We sometimes remove small areas from the spectra and another method of dealing with this is currently being worked on
Example Spectrum

Spectra of quasar J102744
The Quasars We’re Looking At

- Quasars that have broad absorption lines (BALs)
- BALs are associated with high velocity outflows (narrow absorption lines are thought to be able to originate in a greater variety of places)
- The absorption we see comes from one or several clouds of gas that the light passes through before it reaches us
What BALs Tell Us

- We can analyze spectra to get the mass of the black hole

- It’s thought that high velocity outflows affect feedback in galaxy evolution and can change supermassive black hole growth and star formation rates

- Right now high velocity outflows are not very well understood but specific types of absorption lines in quasars can give us more information (ex: $P_V$ tells us column density because of known ratio of $P_V$ to $C_{IV}$)
Creating a Spectrum Model

The benefits of using simbal
Modeling the Continuum

- Accretion Disk Continuum is modeled by a Power Law.
  \[ F_\lambda = \alpha(Wavelength) + \text{PL}_{\text{Norm}} \]
- A sample of PV-spectra is used to create a composite emission spectrum.
- Weighted EMPCA creates Eigenvectors to remove variance.
- Reddening due to the Interstellar Medium must be accounted for.
- Emission lines are broadened by a convolution with a gaussian.
Modeling Absorption

Describing the Outflow:

- Ionization
- Gas Density
- Column Density
- Velocity Offset
- Absorption Line Width
- Covering Fraction
**Ionization and Column Density**

**Ionization:**
- Affected by the amount of photoionization in the outflow.

**Column Density:**
\[ \log N_H - \log U \]
- A measurement of column density with respect to the hydrogen ionization front.

Grey region is where photons greater than 13.6 eV will ionize.
Partial Covering

- Represents how much of the accretion disk is covered by an absorber.
- The physical meaning of this is not well understood.

http://chandra.harvard.edu/resources/illustrations/quasar.html
Modeling a single component

A decent model for most absorption lines.

However, the model is a poor fit for the red region.

This indicates a possible second component.
Complex Outflows

Two components create a more effective model

A good starting point to begin statistical analysis
Statistical Comparison of Models

Analyzing Best-Fit Models of Quasar Spectra
Spectra
Chi Squared and Bayes’ Theorem

\[ \chi^2 = \sum_{i=1}^{N} \frac{(x_i - m_i)^2}{\sigma^2} \]

\[
p(B \mid A) = \frac{p(A \mid B) p(B)}{p(A)}
\]
Chi Squared and Bayes’ Theorem

Chi squared = 531

Chi squared = 84
Markov Chain Monte Carlo

- Choose start position in parameter space
- Calculate likelihood (from Bayes’ Theorem)
- Take a “random step” in parameter space (methods vary)
- Calculate new likelihood
- Choose to accept or reject new point
- Repeat for a number of simulations
Emcee

Markov Chain Monte Carlo method

Uses a number of “walkers” (300)

Affine Invariant: walkers influence each other
Results
Results
Results