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

Image source: http://www.skyandtelescope.com/astronomy-news/watching-a-quasar-shut-down-122614/

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

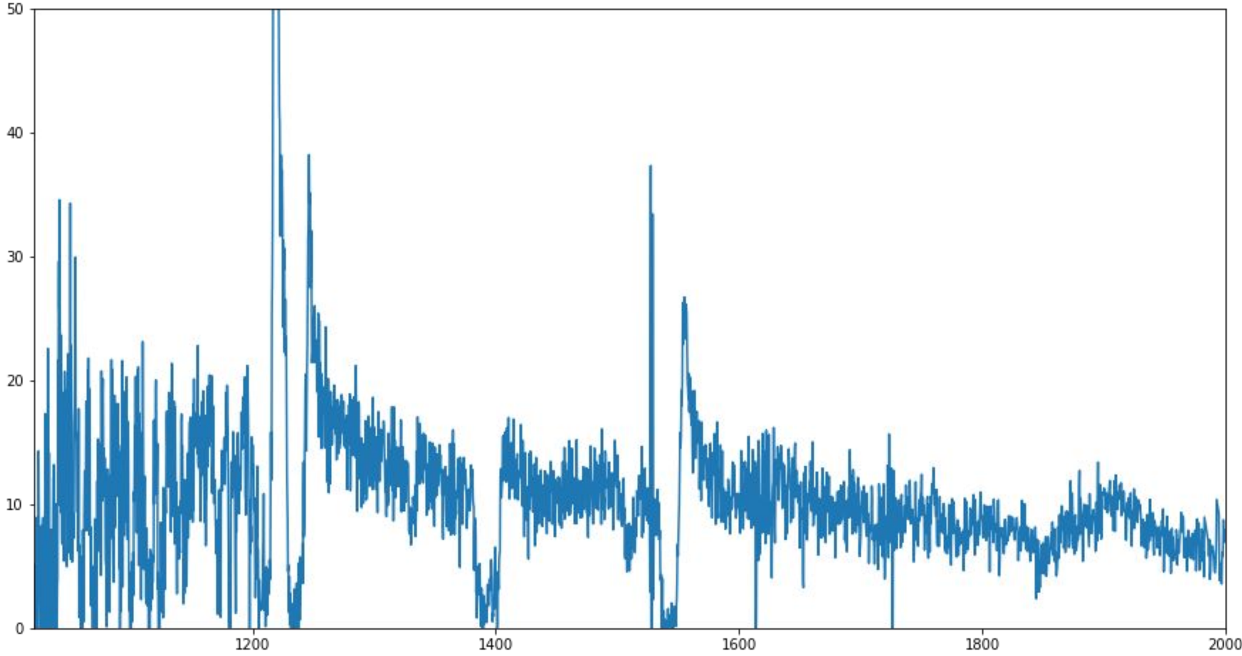
-A photon with a wavelength of 1216 angstoms is needed for the transition of the electron in Hydrogen from n=1 to n=2 (the alpha transition in the Lyman series)

-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

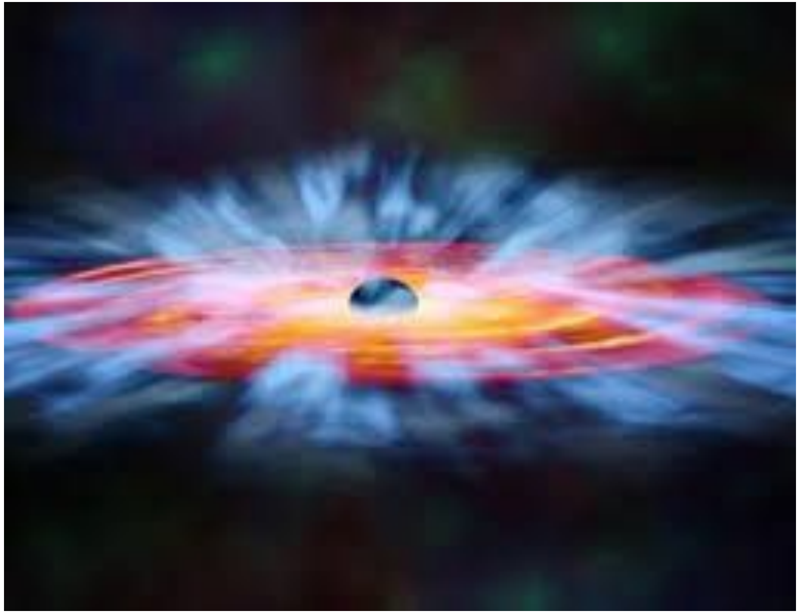


Image source:
https://www.scientificamerican.com/podcast/episode/quasar-winds-clock-in-at-a-fifth-of-light-speed/

What BALs Tell Us

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

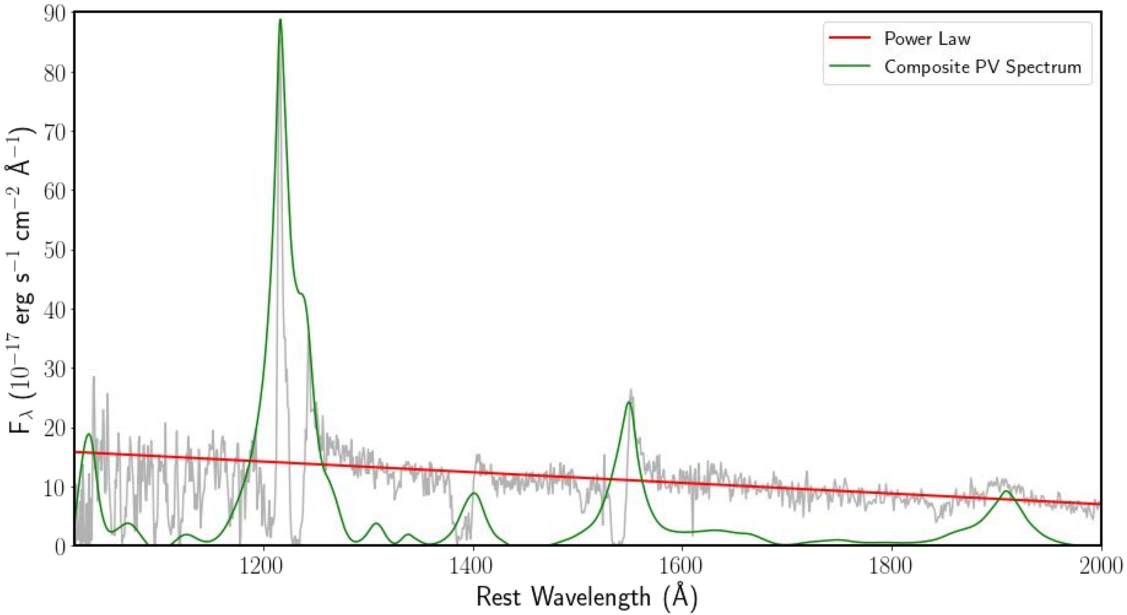
-It's thought that high velocity outflows affect feedback in galaxy evolution and can change supermassive black hole growth and star formation rates

-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

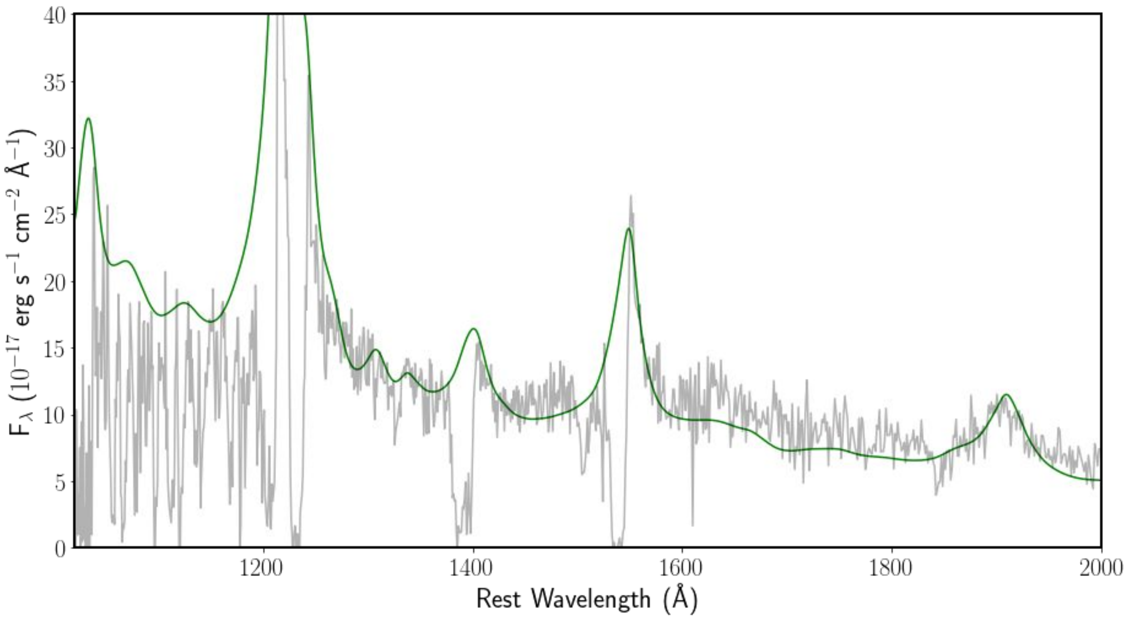


- Accretion Disk Continuum is modeled by a Power Law.

$$F_\lambda = \alpha(\text{Wavelength}) + PL_{Norm}$$

- 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.

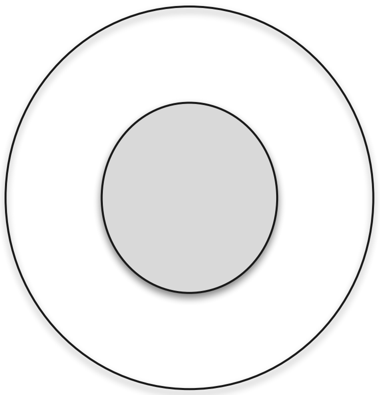
Modeling Absorption



Describing the Outflow:

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

Ionization and Column Density



Grey region is where photons greater than 13.6 eV will ionize

Ionization:

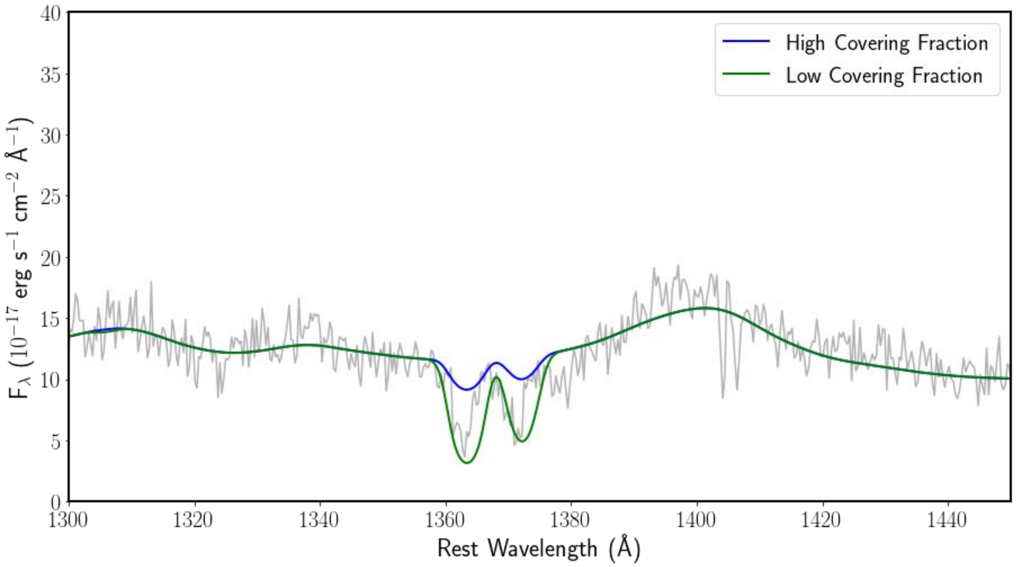
- Affected by the amount of photoionization in the outflow.

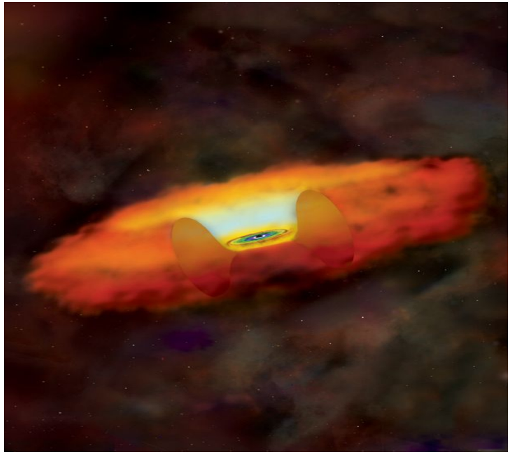
Column Density:

$$\log N_H - \log U$$

- A measurement of column density with respect to the hydrogen ionization front.

Partial Covering

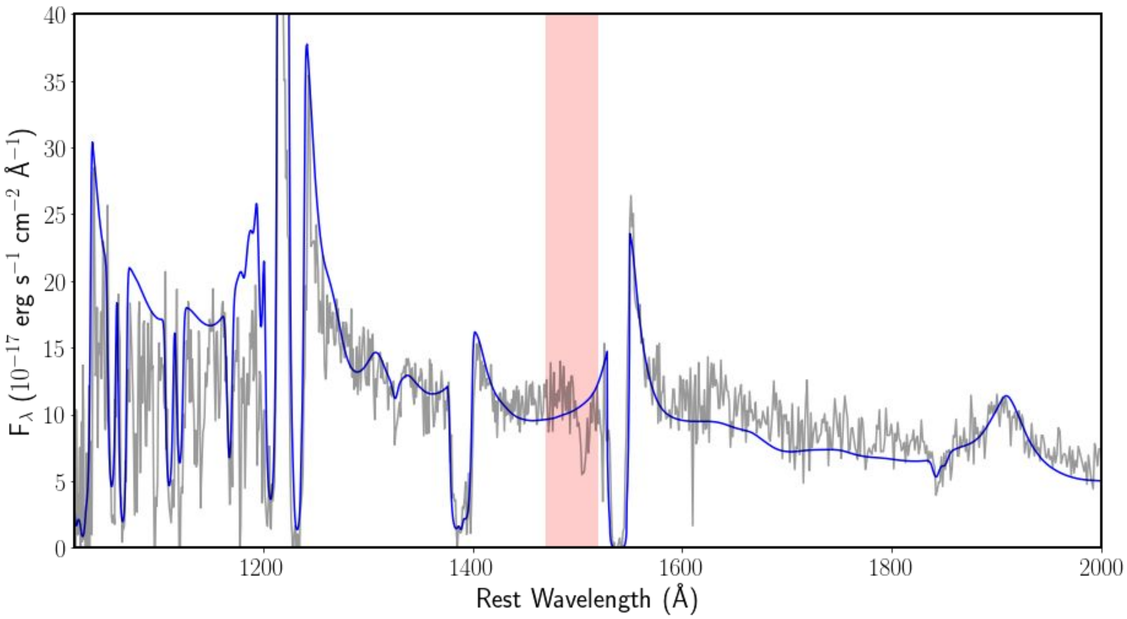




http://chandra.harvard.edu/resources/illustrations/quasar.html

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

Modeling a single component

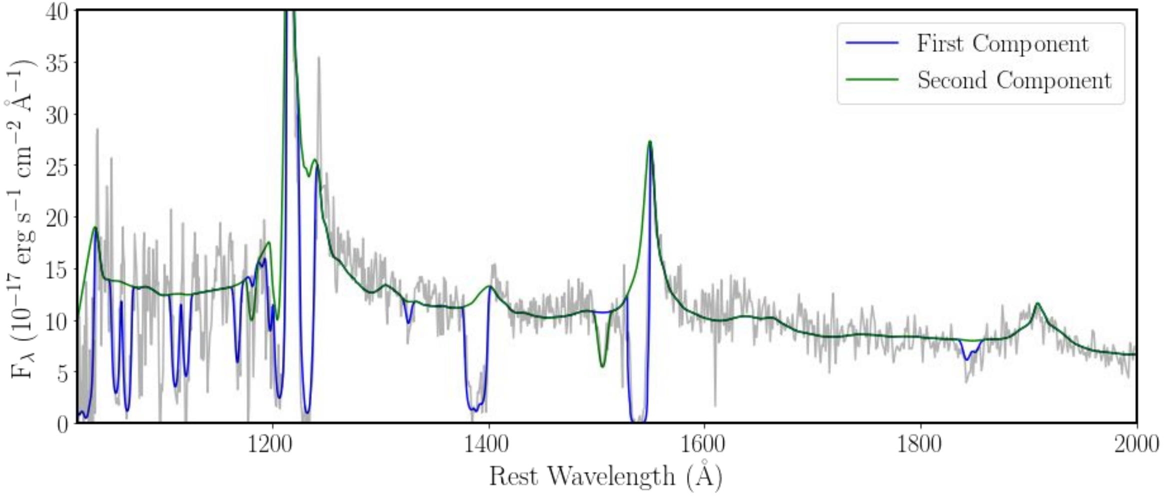


A decent model for most absorption lines.

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

This indicates a possible second component.

Complex Outflows



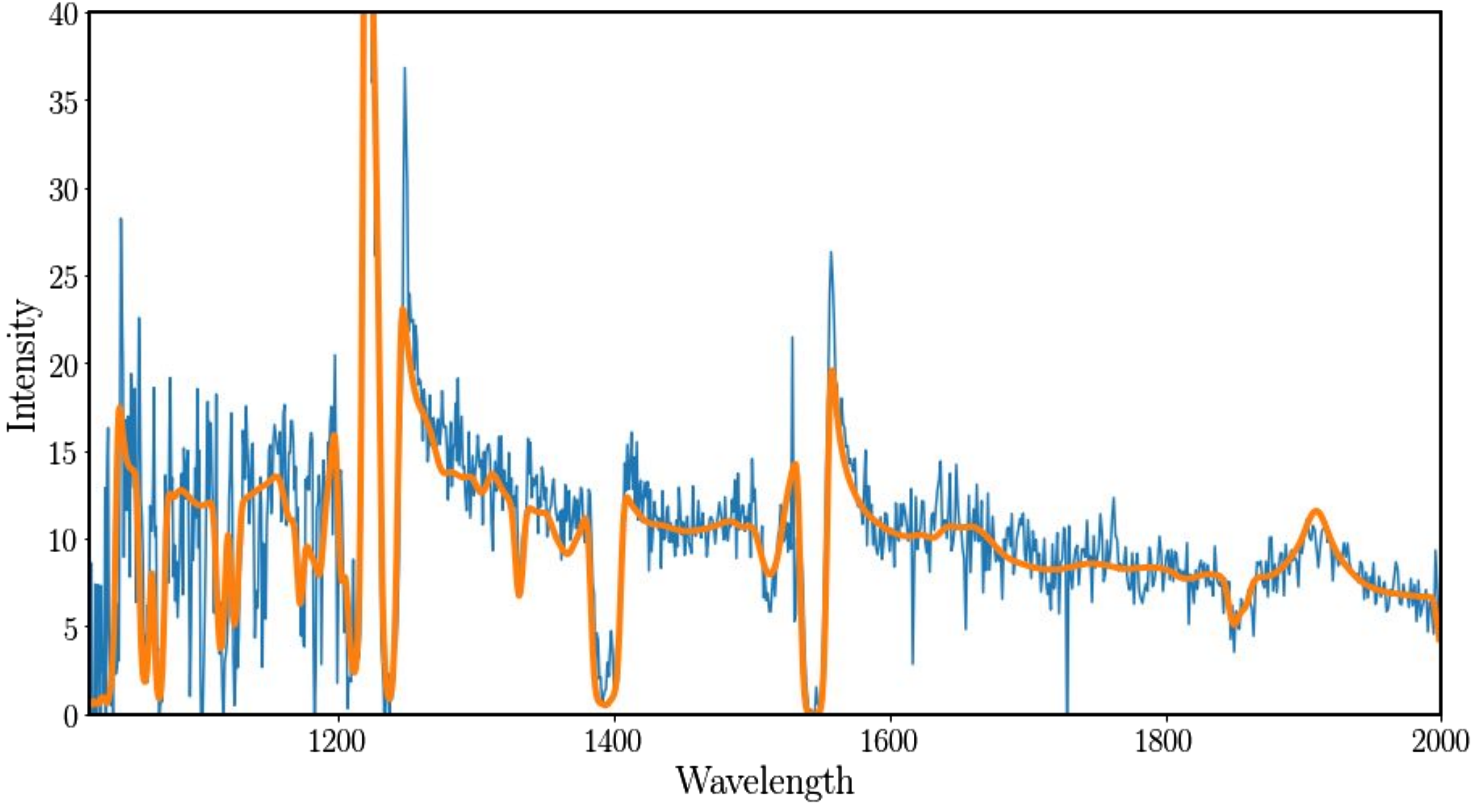
Two components create a more effective model

A good starting point to begin statistical analysis

Statistical Comparison of Models

Analyzing Best-Fit Models of Quasar Spectra

Spectra



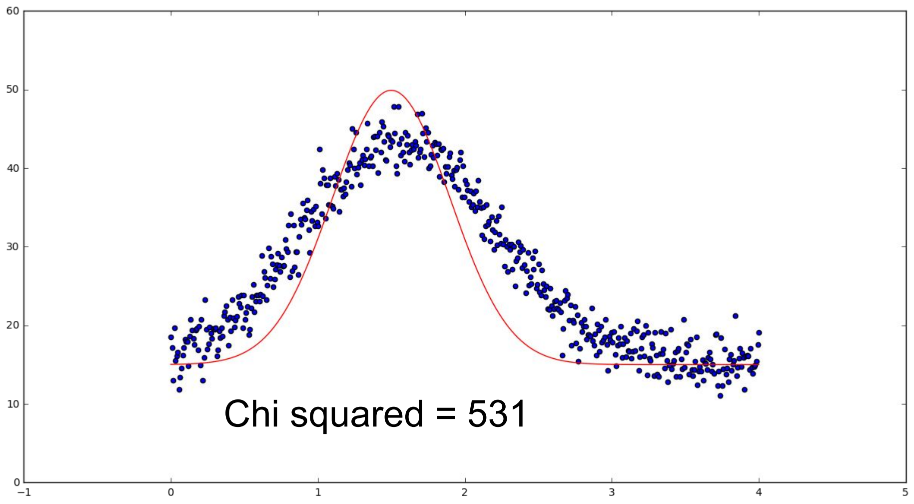
Intensity
40
35
30
25
20
15
10
5
0
1200
1400
1600
1800
2000
Wavelength

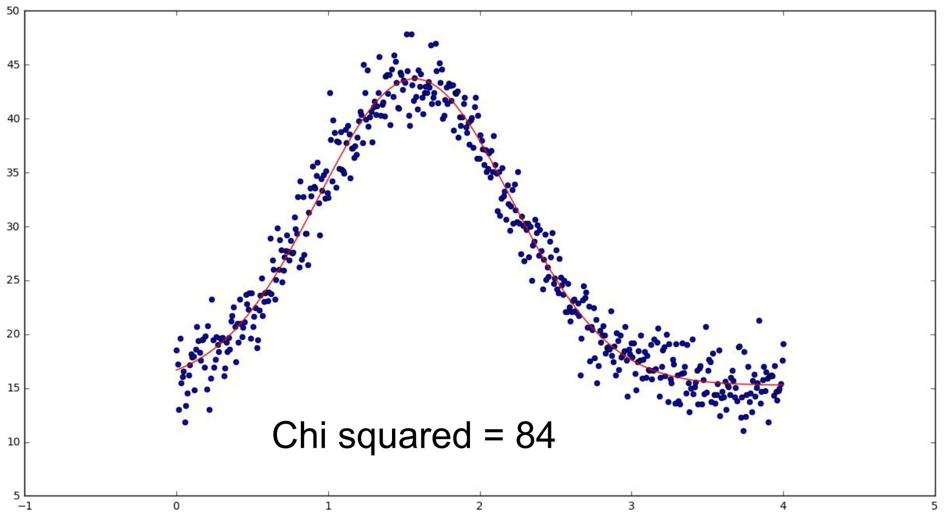
Chi Squared and Bayes' Theorem

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

$$p(B \mid A) = \frac{p(A \mid B)\, p(B)}{p(A)}$$

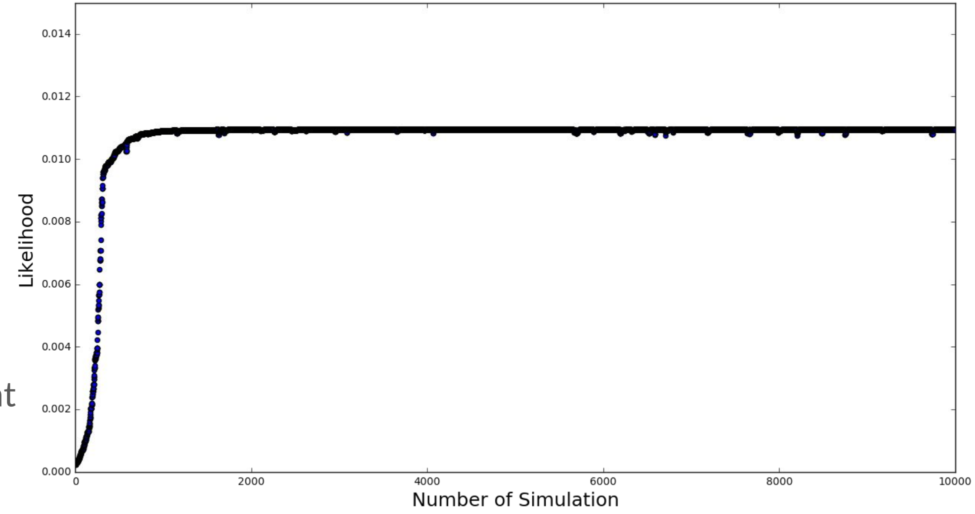
Chi Squared and Bayes' Theorem





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

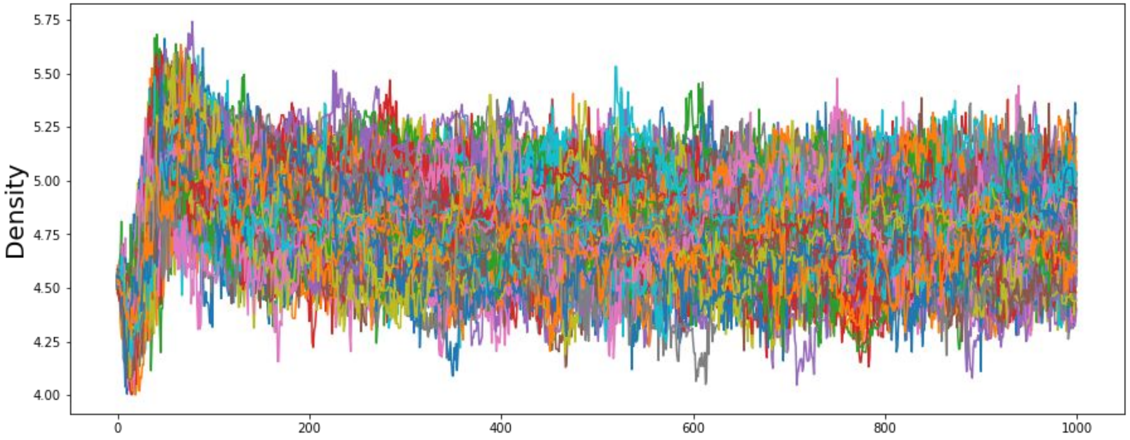


Emcee

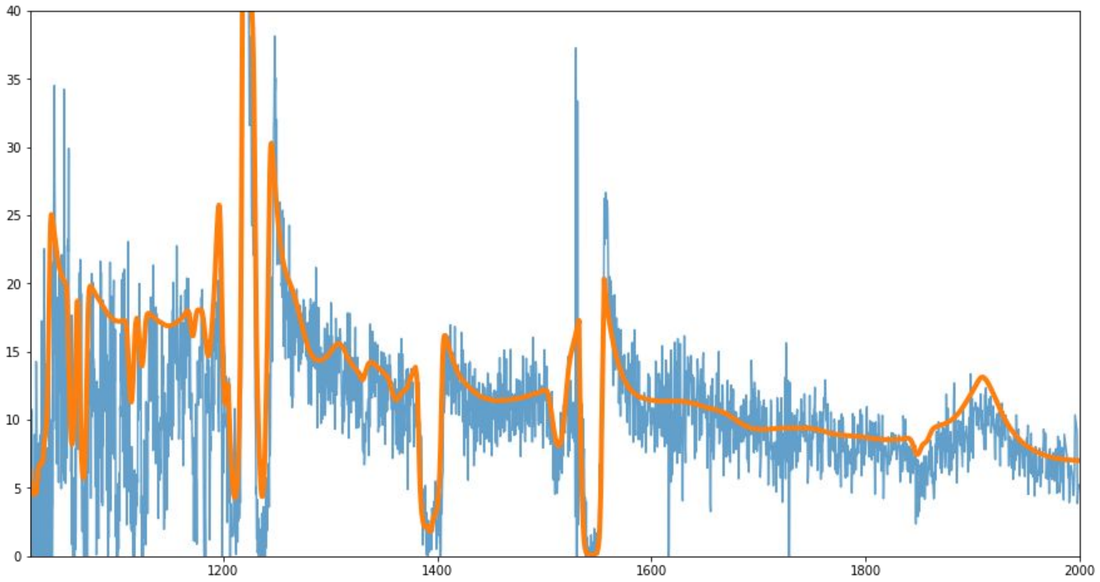
Markov Chain Monte Carlo method

Uses a number of “walkers” (300)

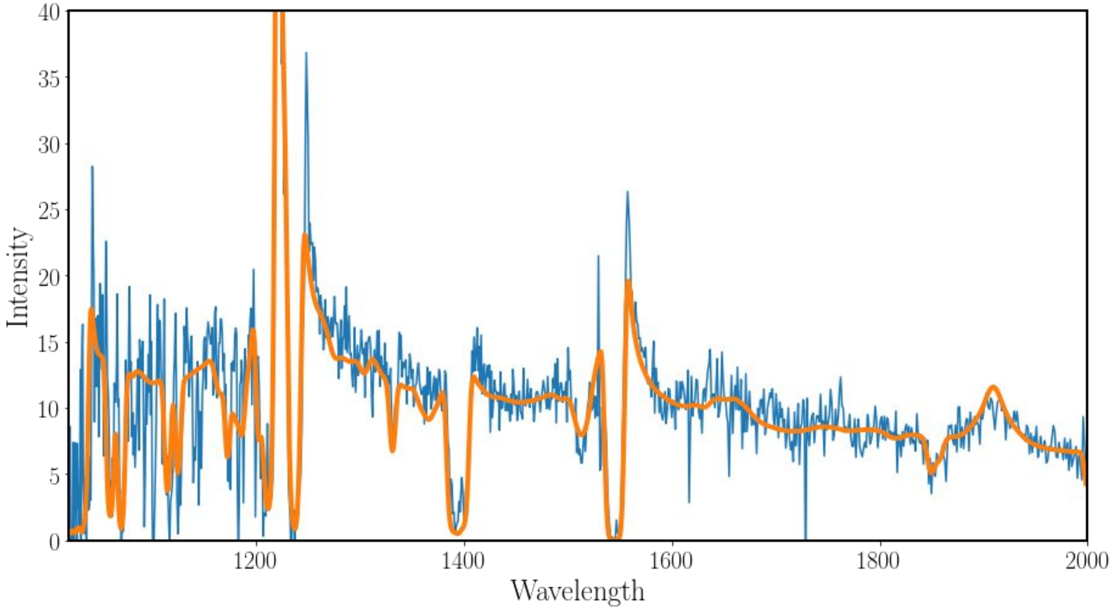
Affine Invariant: walkers influence each other



Results



Results



40
35
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Intensity
1200
1400
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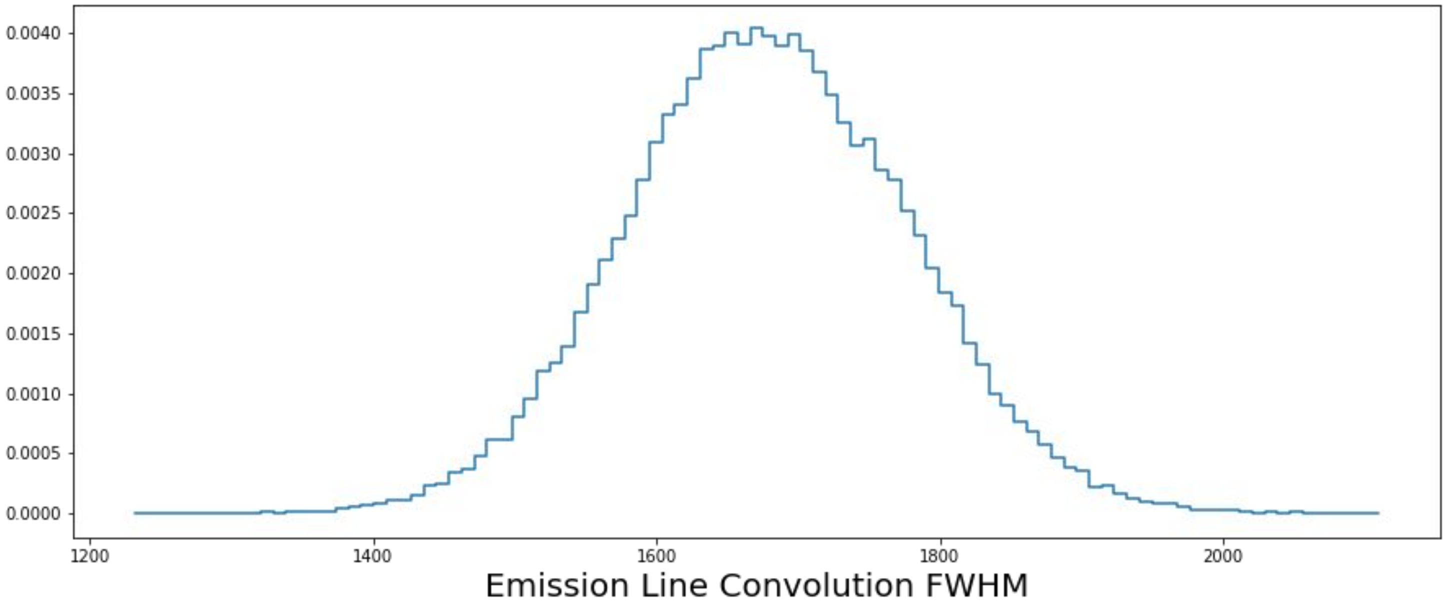
Wavelength

Results


0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
1200
1400
1600
1800
2000
Emission Line Convolution FWHM

Results