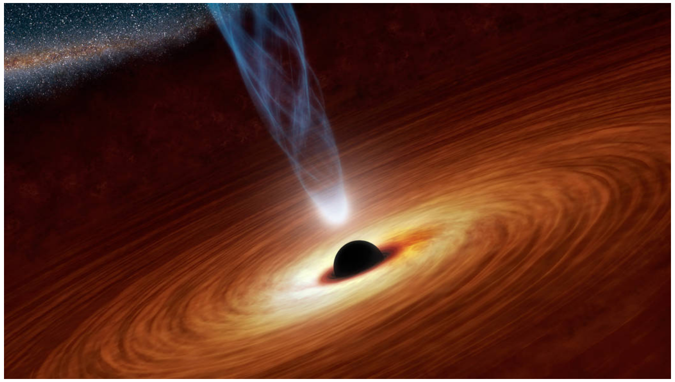

Image Credit:
NASA/JPL-Caltech

Modeling Decade-scale Broad Emission Variability in Active Galactic Nuclei

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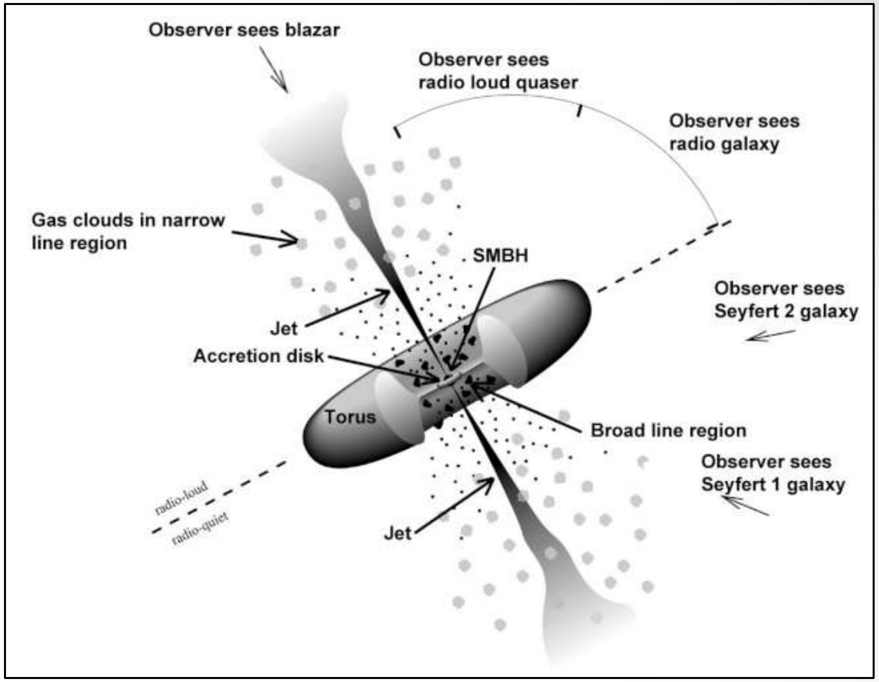
AGN & Variability

- Active Galactic Nuclei (AGN)
  - Supermassive (10^7-$10^9 M_{sun}$) black hole (SMBH)
  - Accretion disk
  - Broad line region (BLR)
    - Gas moving at 1000s of km/s
  - Narrow line region (NLR)
    - Gas moving at 100s of km/s
  - Different viewing angle determines observation of different components
  - e.g. edge-on view BLR is obscured by dust in the torus

- BLR not always detected
  - Naked AGN?
  - Obscured by torus
  - Buried in host galaxy light
  - **Variability**

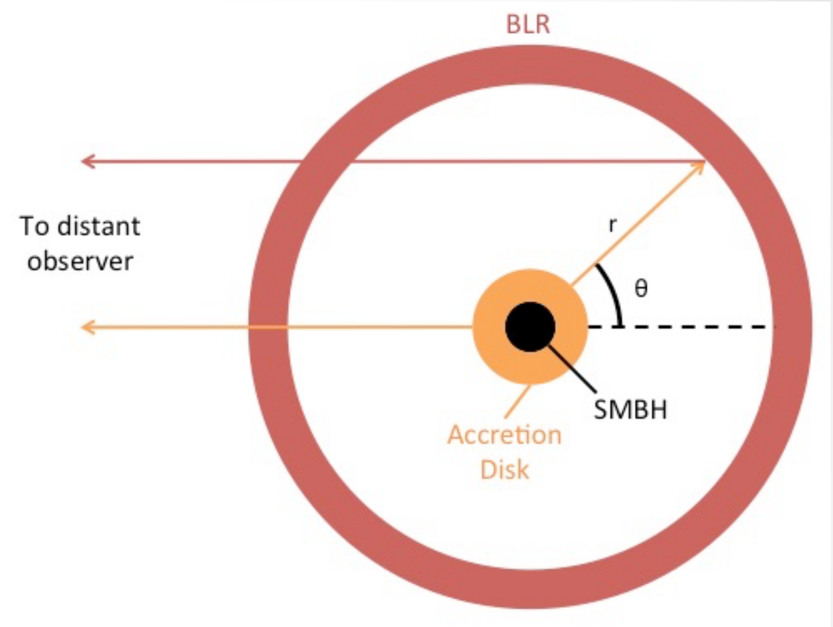


Why study variability?

- Constrain models of accretion (continuous vs. episodes)
- Puts limits on BLR detectability → AGN detection and census
- Constrain models of geometry and properties of the broad line emitting region

Variability in BLR

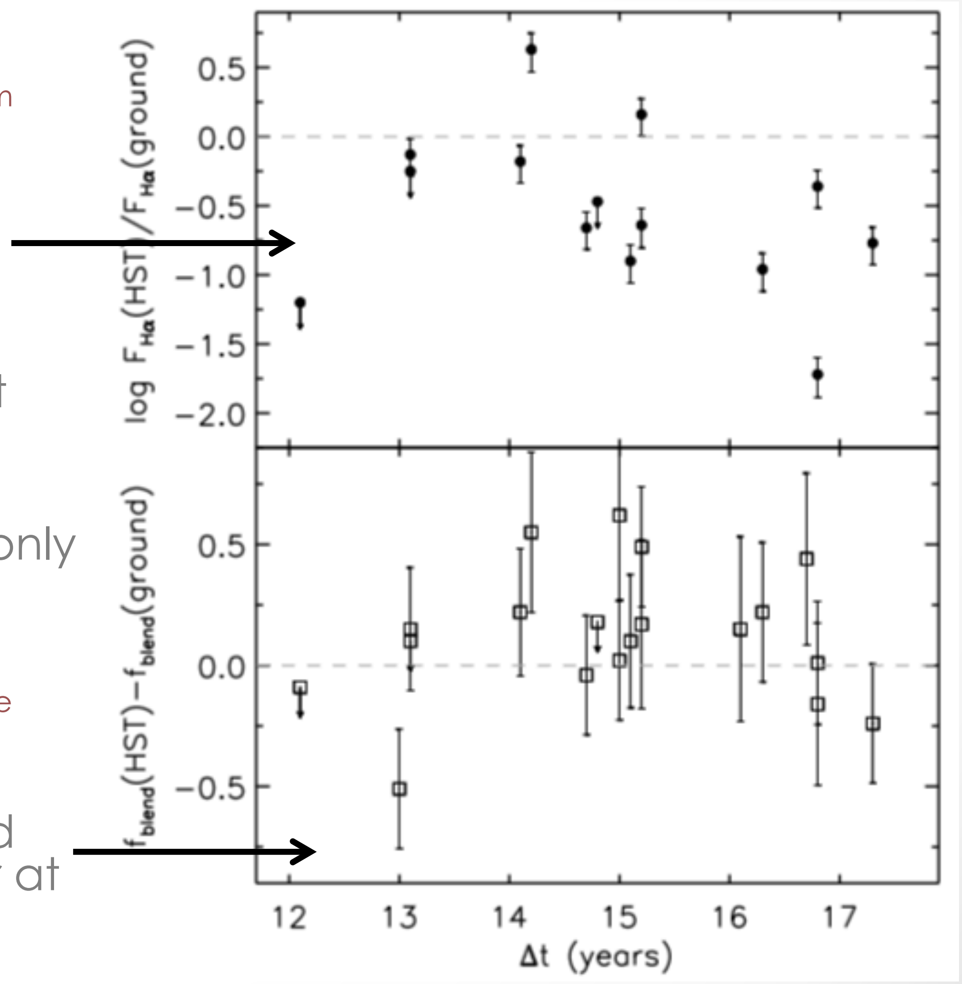
- Short-term variability (time-scales < 1 year)
  - Well studied soon after the discovery of quasars (1963)
  - Relatively easy to gather data
  - Determine size of BLR through reverberation mapping
  - e.g.: AGN Watch (OSU)



- Long-term variability (time-scales > 10 years)
  - Very little to no research
  - Much more difficult to gather data
    - Requires more time and money
  - Recent tantalizing evidence Constantin et al. (2015)
  - Potentially useful for converting the BLR detection rate in one time survey of AGN ➔ true census of actively accreting SMBHs in the universe

Evidence for Decade-scale Variability in BLR?

- Galaxies observed 12-17 years apart showed different strengths in broad Hα
  - Later observations had higher contrast between emission features and continuum
- Later observations consistently show weaker broad Hα
- Higher contrast in later observation ➔ easier to detect weaker emission
- Later observed broad flux not only tends to be different, but also lower
  - Earlier observations had less contrast and could only detect broad emission near the maximum in variability cycle
- Fraction of Hα flux in the broad component tends to be higher at later observation



Constantin et al. 2015, ApJ, 814, 149

Model Design: Simulating a Survey of 10^5 AGNs

- C++ code
- Optical spectra λ 6500Å – λ 6650Å
  - Covers the Hα and [NII] doublet region
- Monte Carlo methods to build parameter space defining each spectrum
- Distribution of each parameter is modeled by a uniform distribution
- Ranges of parameters match measurements from AGN surveys

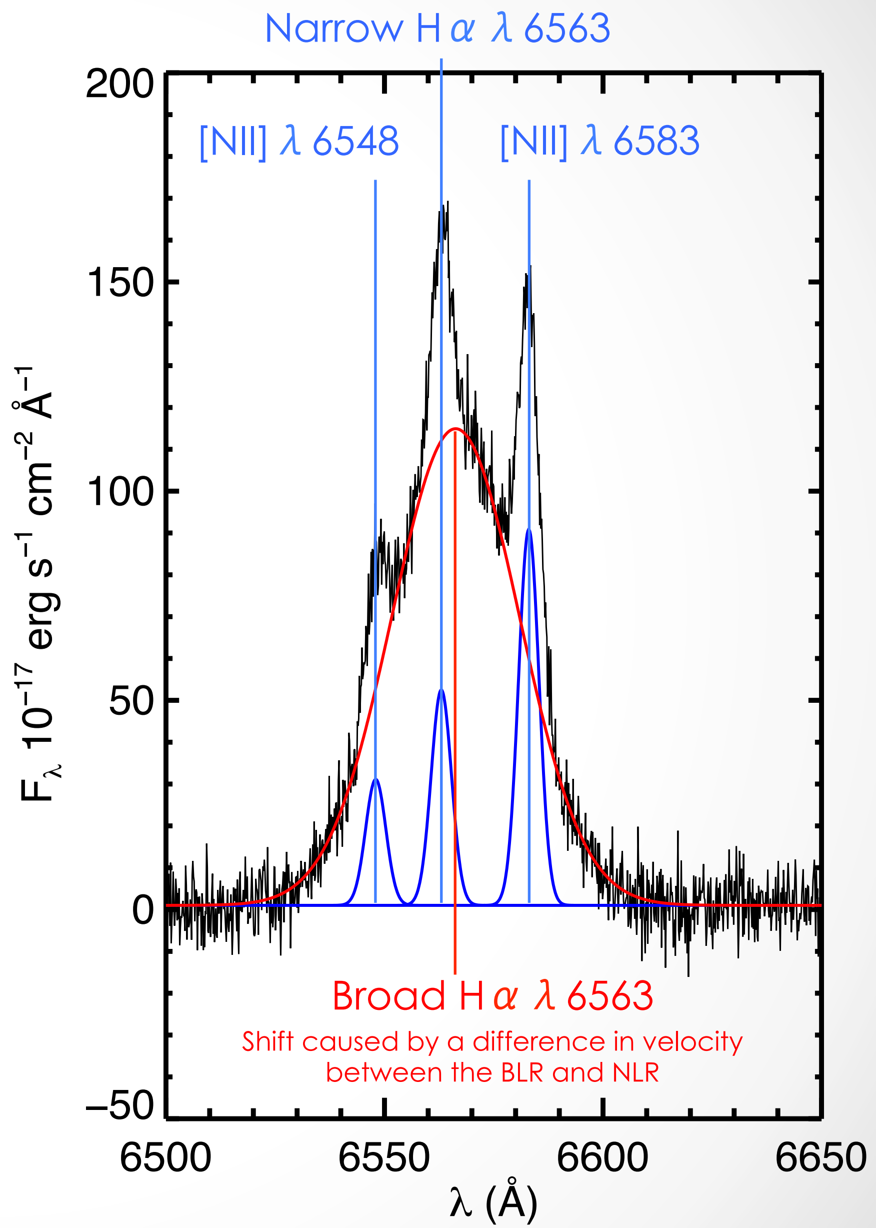
A Spectrum

Emission lines

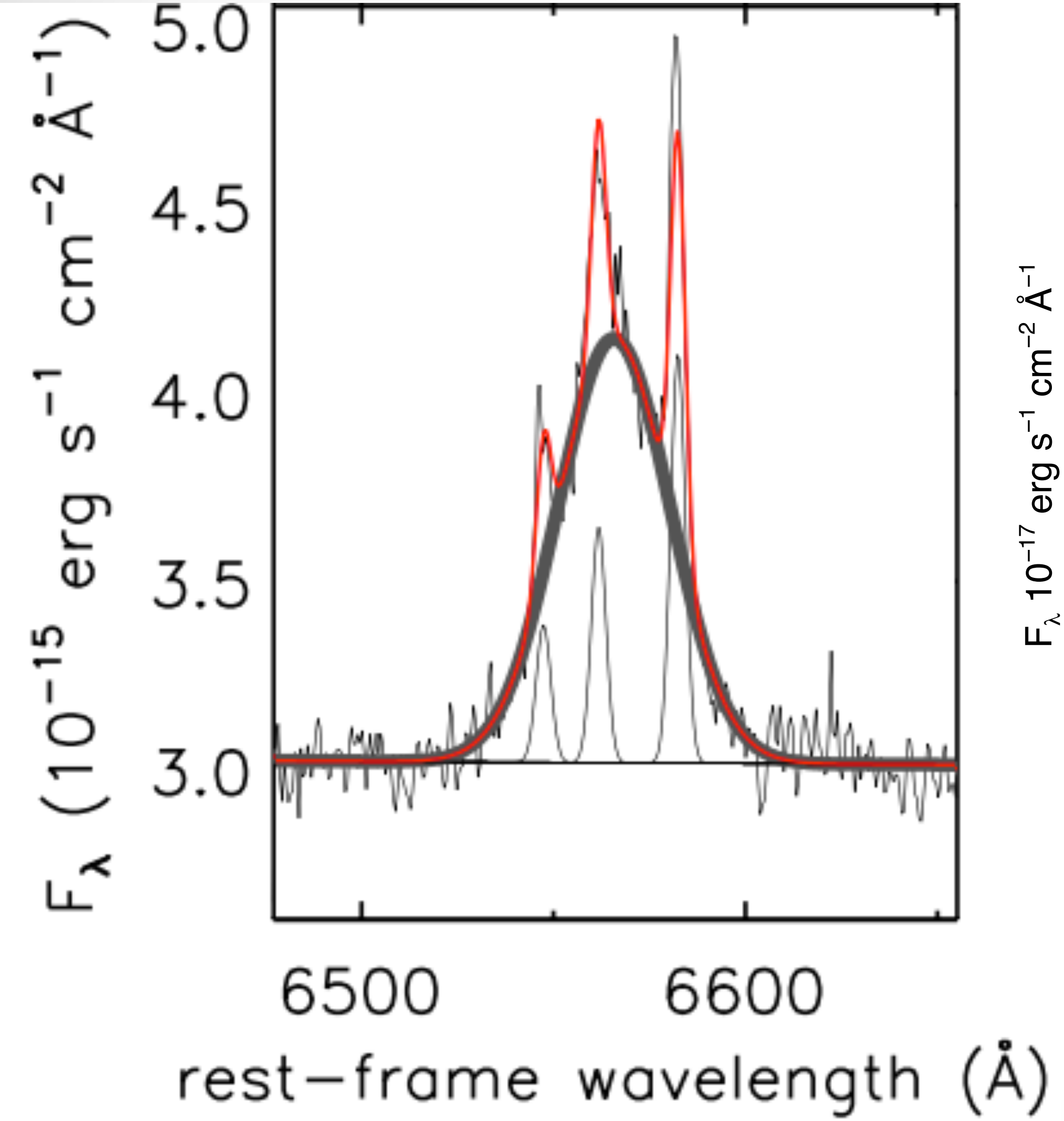
- Modeled as a Gaussian distribution
  - Center
  - FWHM (width of the line in km/s)
  - Total Flux
- Narrow Hα at 6563Å
- [NII] doublet (also originating from NLR)
  - [NII] λ 6548 is 1/3 flux of [NII] λ 6583
- Broad Hα

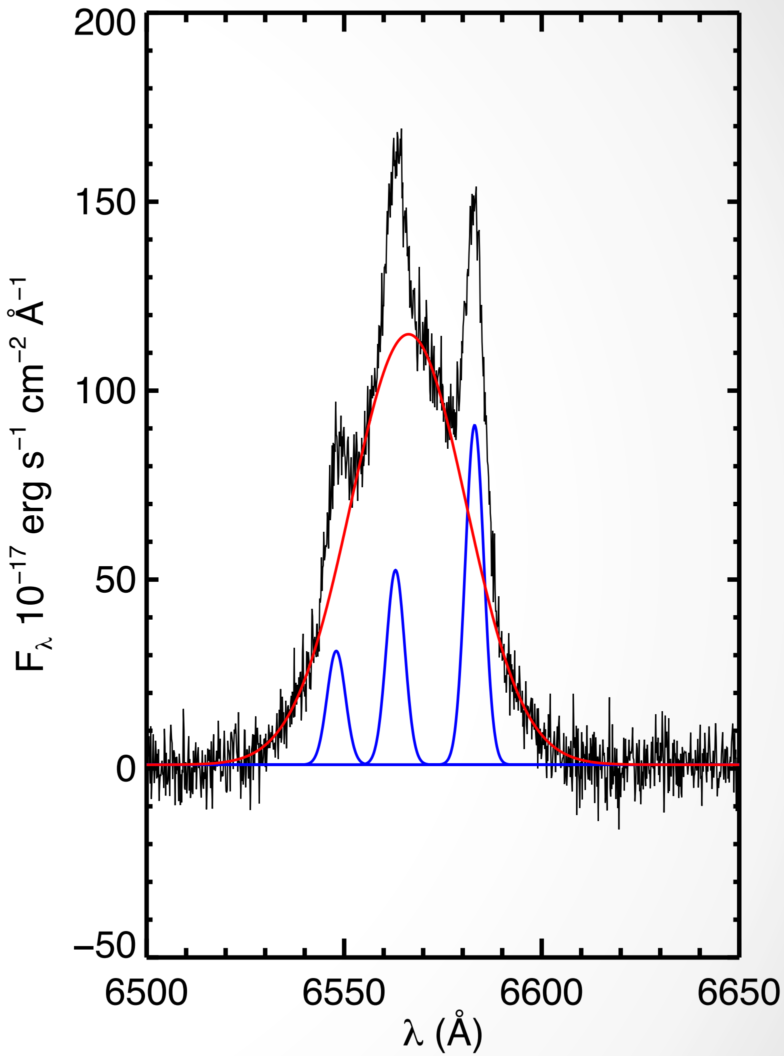
Other components

- Continuum
  - Modeled with line: y=1
  - (subtracted off in real data)
- Noise
  - Modeled with random numbers



Matching a Spectrum





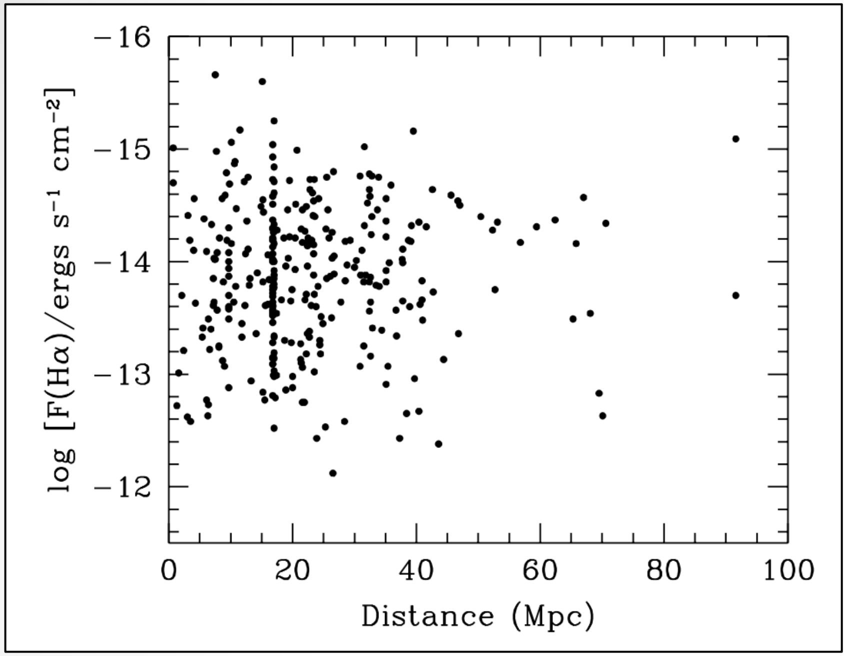
7 Model Parameters

Parameter	Minimum	Maximum
$\log[F_{H\alpha\_narrow} / 10^{-17}\ \mathrm{erg\ s^{-1}\ cm^{-2}}]$	1	5
$[NII]\lambda 6583$ / $H\alpha$	0.316	5.6
$\log[F_{H\alpha\_broad} / 10^{-17}\ \mathrm{erg\ s^{-1}\ cm^{-2}}]$	1	5
FWHM(NLR) in km/s	100	800
FWHM(BLR; $H\alpha$) in km/s	1000	7000
Δv (broad relative to systemic) in km/s	-50	1300
Signal-to-noise Ratio	1	20

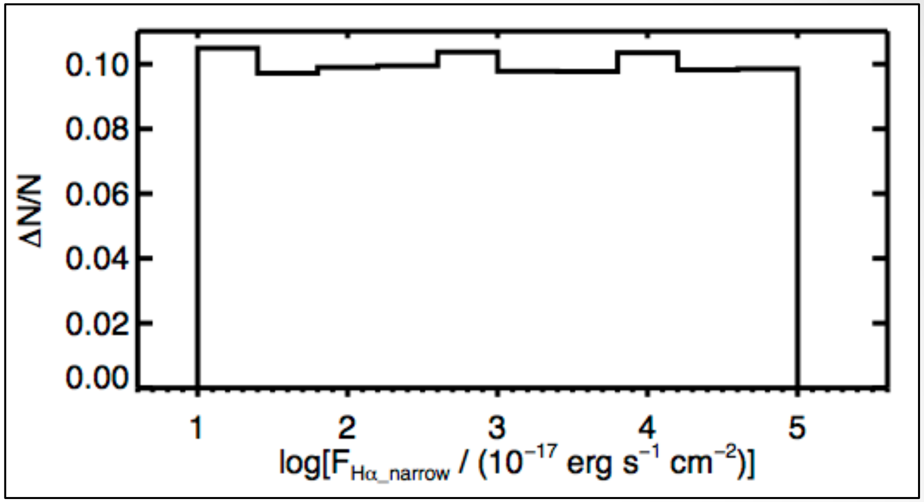
- These 7 parameters completely defines a given object's spectrum
- (to begin with) All parameters are modeled with uniform distributions

- Final goal: to implement more realistic distributions, based on real measurements

Building the Parameter Distributions: e.g., F(Hα)



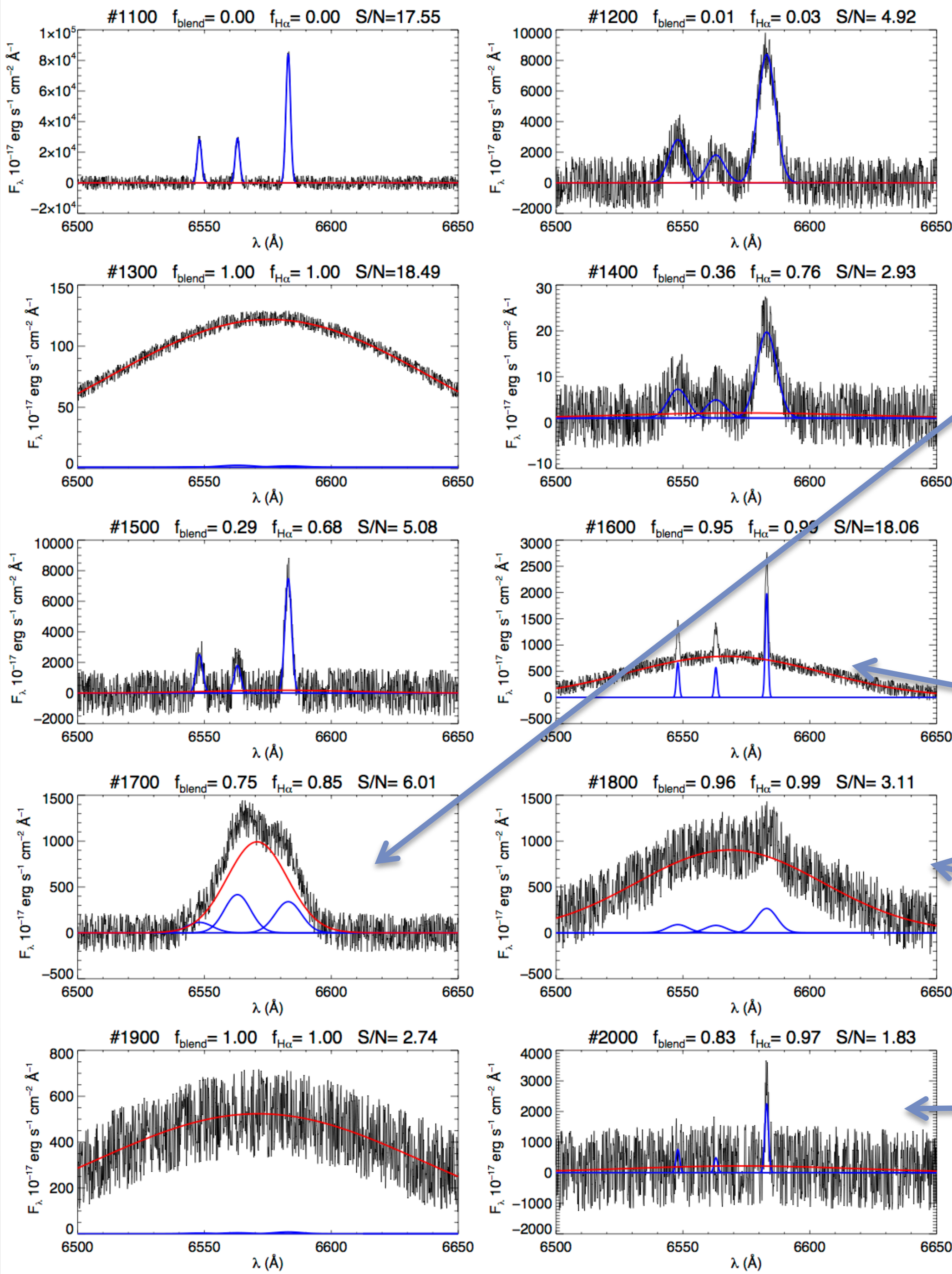
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJS, 112, 315



Distribution used in Model

- Distribution for H α narrow line flux found in Ho et al. (1997a)
- The minimum and maximum values are matched with available data, then used to build uniform distributions
  - $10^{-12} - 10^{-16}$
  - Use units of 10^{-17} erg s^{-1} cm^{-2}
  - In log-space our range is (-16 – -12) + 17 = (1 – 5)

Simulated Survey



Large broad Hα flux,
moderate FWHM
Moderate narrow Hα flux
Moderate signal-to-noise

Large broad Hα flux
Large FWHM
Small narrow FWHM
Large velocity shift (Δv)
High signal-to-noise

Large broad FWHM
Average signal-to-noise

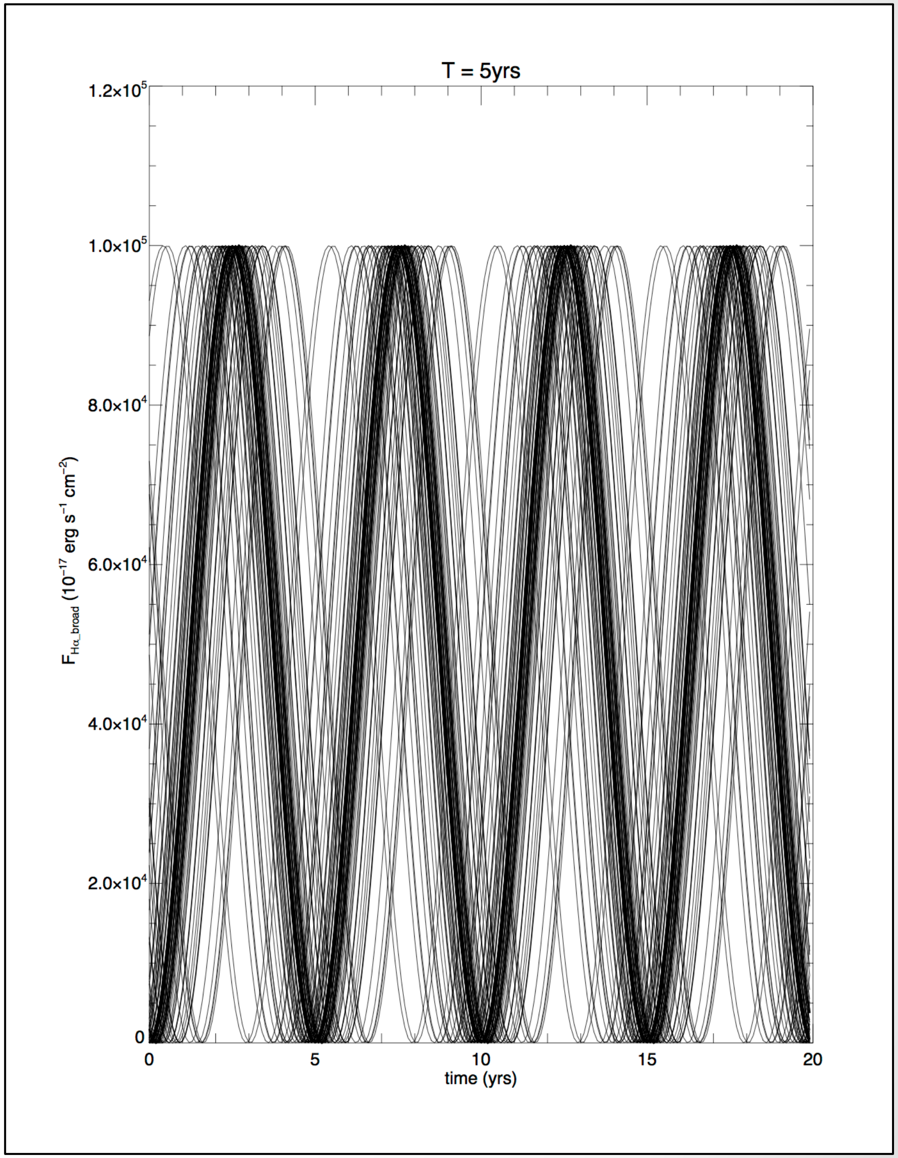
Large broad Hα flux
Small narrow line fluxes
Low signal-to-noise

Modeling the Hα Broad Flux Variability

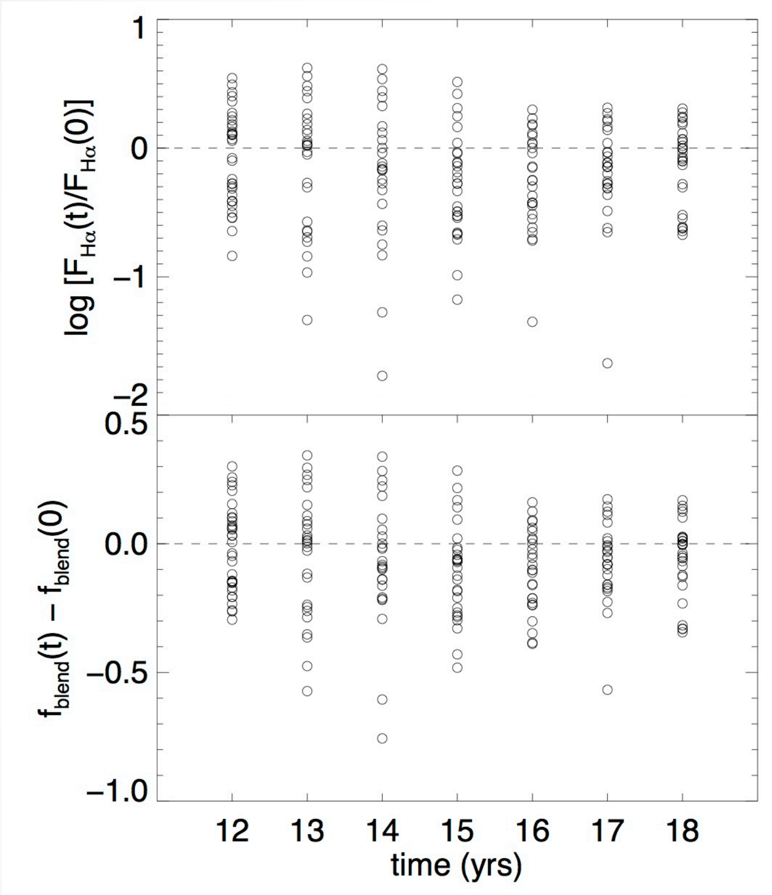
- Assume simple sinusoidal variability in broad flux F(t)
  - Model/build distribution of initial broad flux (at first observation)
  - Range of broad flux is the range of variation (to match data)

$$F(t) = A\sin(\omega t + \varphi) \rightarrow F(t) = A\sin\left(\frac{2\pi}{T}t + \varphi\right) + F_{\min} + A$$

- The amplitude (A) is half the range $A = (F_{max} - F_{min})/2$
- The additional terms raise the flux F(t) from being periodic between –A and A to be periodic between F_{min} and F_{max}
- The initial phase (φ) is modeled to match the initial distribution of broad Hα fluxes
- Test varying periods of variation (T = 5, 10, 15 years)



Results (Preliminary)



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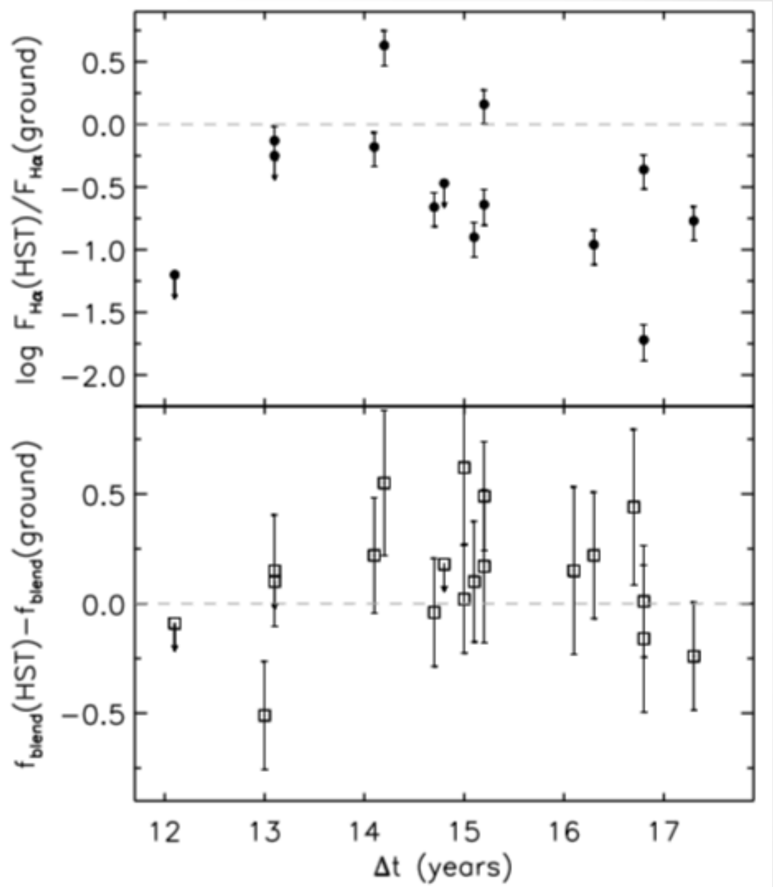

- Condition for BLR detection in initial observation: $f_{H\alpha} > 0.6$; i.e., Only strong broad Hα is detected
- Condition for BLR detection in later observation: $f_{H\alpha} > 0.3$ (weaker broad Halpha becomes detectable with better constrast)
- Period of variability tested: T = 10 years
- Plot shows 1% of all modeled objects (random selection of 100/10000 total simulated spectra)

Further Directions

- Use distributions that more closely match those found from surveys
  - Instead of modeling as uniform
- Couple the parameters used in modeling H α broad and narrow fluxes
- Use a distribution of periods for the sample of objects
- Use a distribution for amplitudes (not all AGNs varying to the same degree)
- Develop and test model for narrow line variability (while matching observational data)
- Add stellar continuum of various strengths (instead of assuming it has been completely subtracted out) ➔ very useful for accounting for the lack of BLR in weak AGNs.
  - Test new range of parameters for detection thresholds
- Based on this analysis we will be able to place new strong constraints on AGN census ➔ accurate census of SMBHs in the universe