UV/Optical Band Reverberation Mapping of NGC 5548 with Frequency-Resolved Techniques

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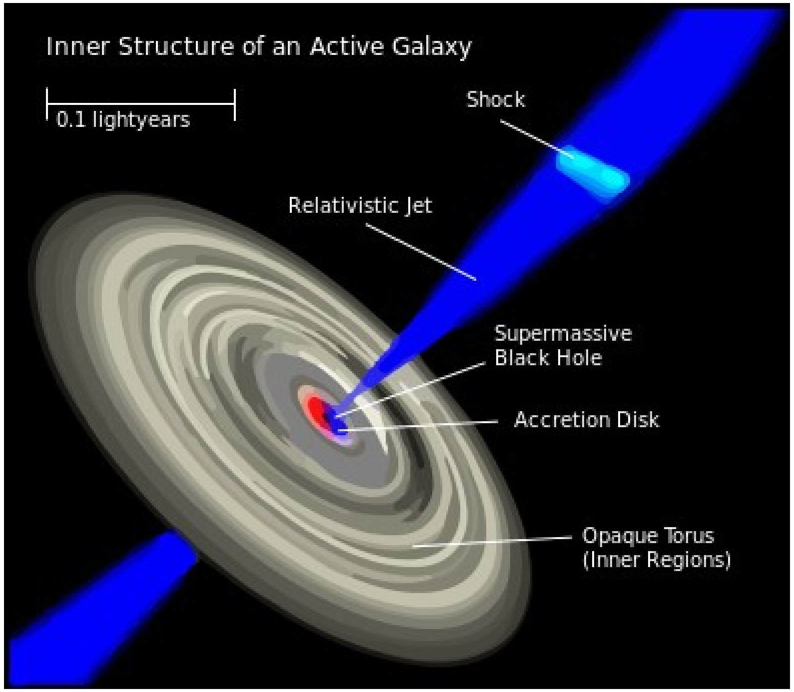
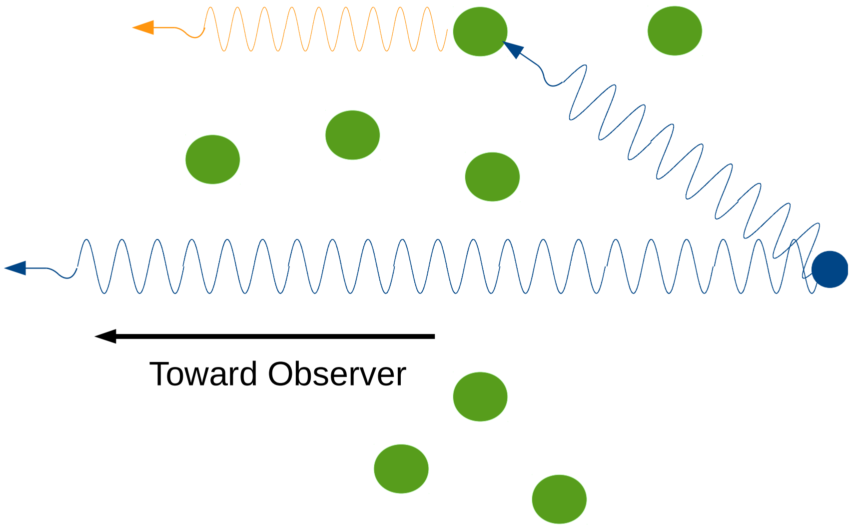
Active Galactic Nuclei

- Systems surrounding supermassive black holes at the center of active galaxies: $10^6 - 10^9$ M_{sun}.
- Some of the most luminous objects in the universe.
- Power is generated by accretion of matter by the central black hole.
- Cannot be resolved directly; geometry is inferred using reverberation mapping.



Reverberation Mapping

- Some photons are reprocessed in gas clouds surrounding the black hole.
- The observer sees these photons as having a time lag and frequency shift.
- A transfer function predicts the time-delay distribution and spectrum for an assumed geometry.

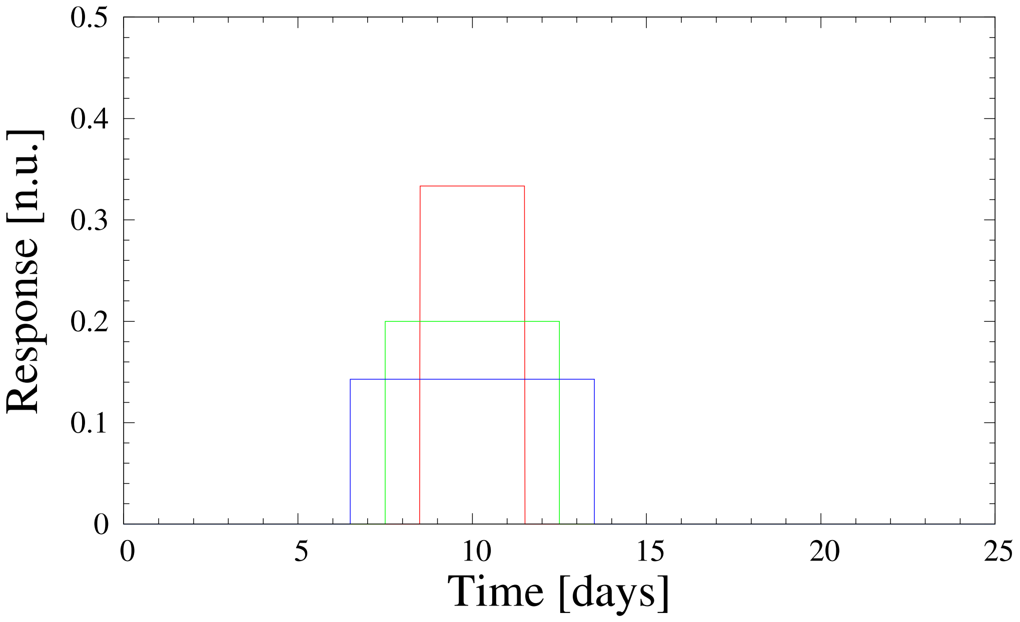


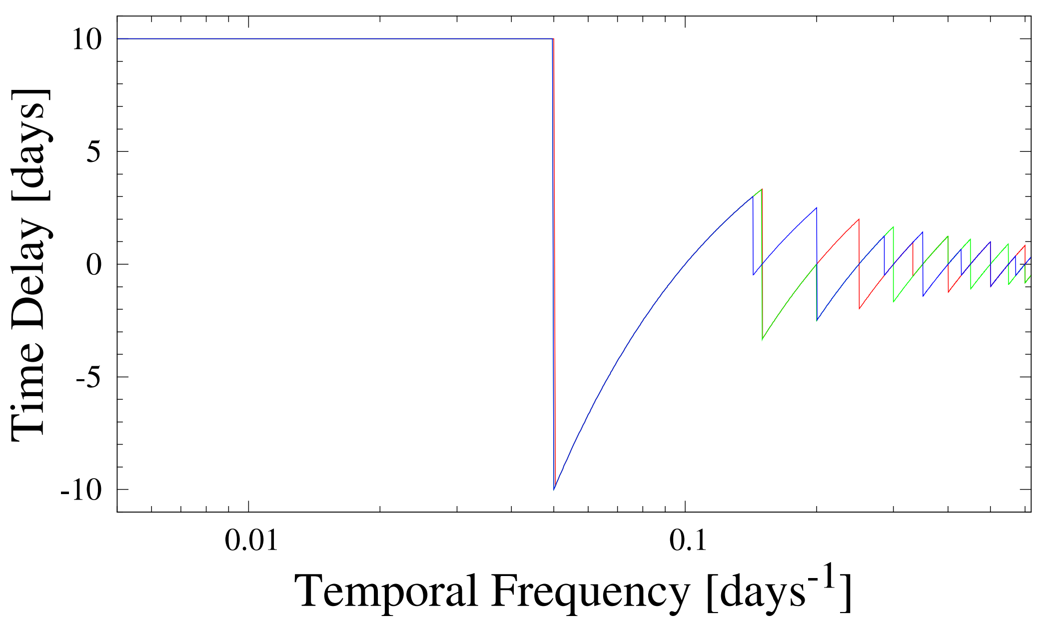
Particles scatter photons in the surrounding matter

Recovering the Transfer Function

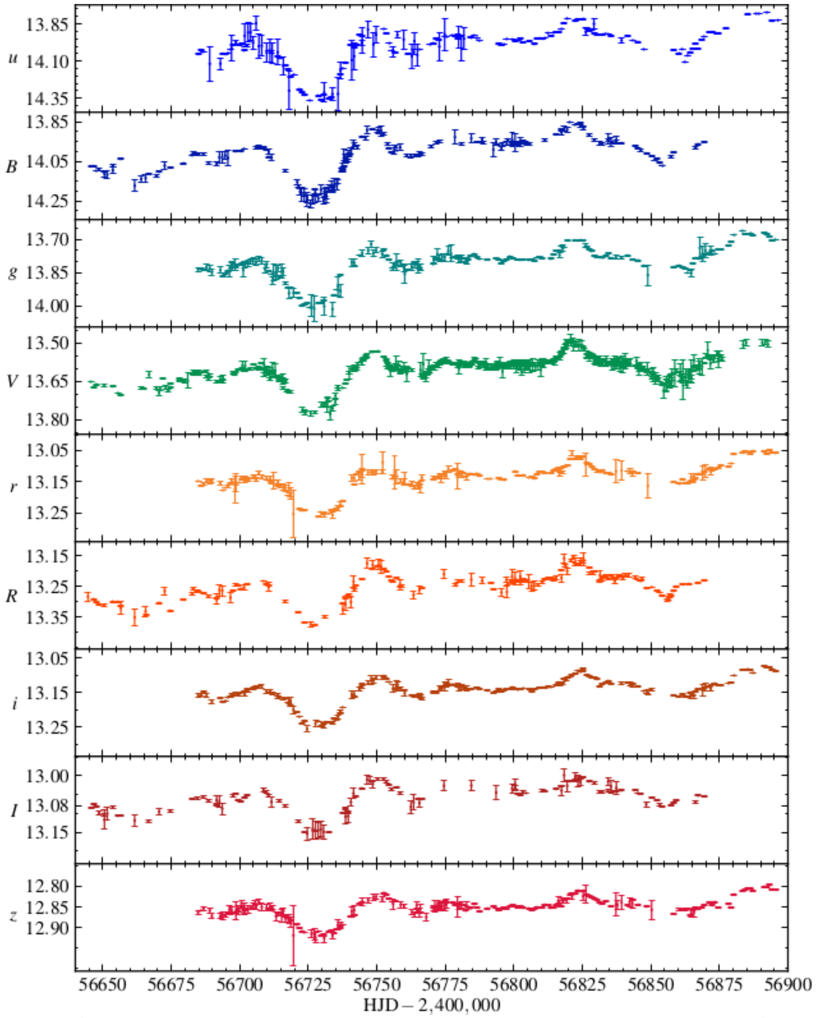
$$y(t)=\int_{-\infty}^{\infty} g(\tau)\,x(t-\tau)\,d\tau$$

$$Y(\nu)=G(\nu)\,X(\nu)$$





NGC 5548 Light Curves from STORM III

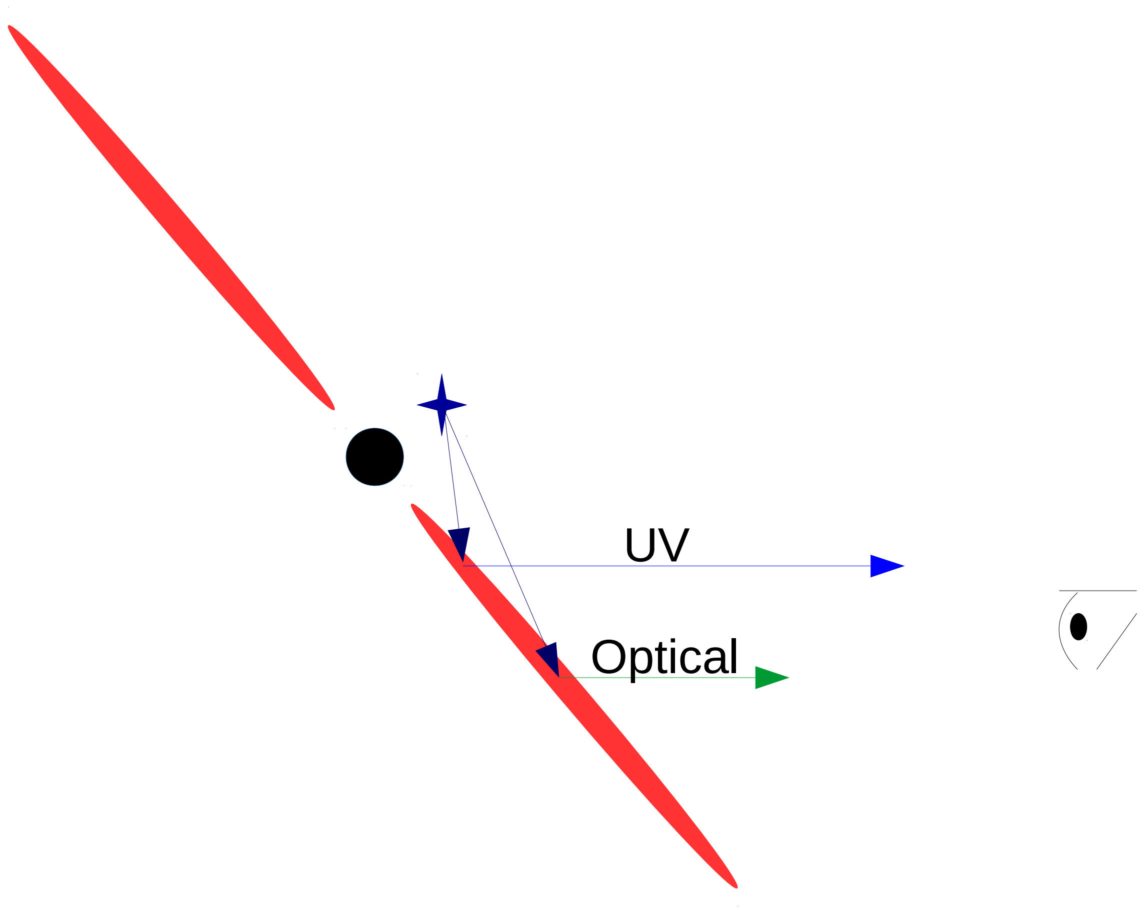


Flux

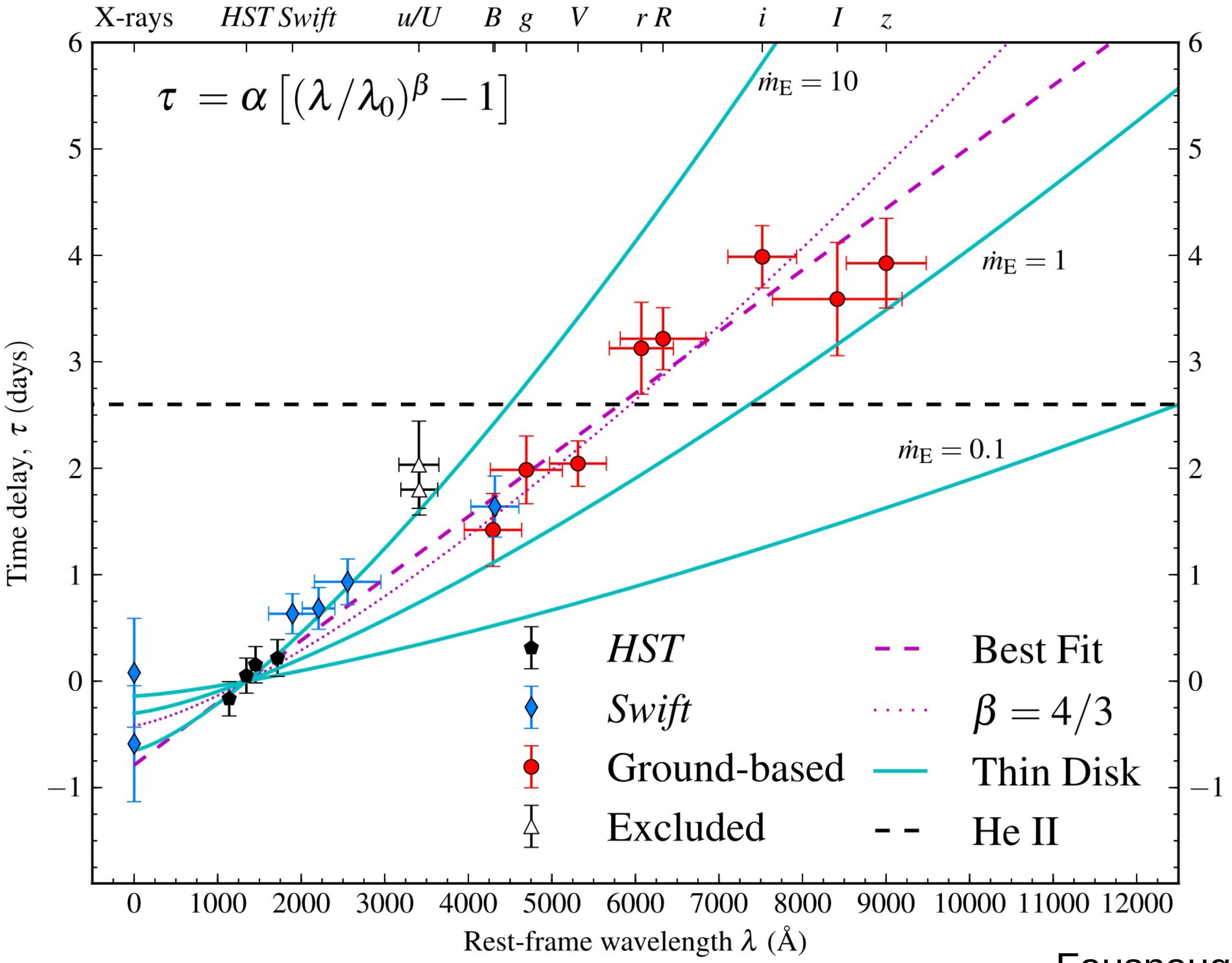
260 Days

Fausnaugh et al. (2016)

Reverberation Geometry



Time-Domain Delay Analysis from STORM III



Fausnaugh et al. (2016)

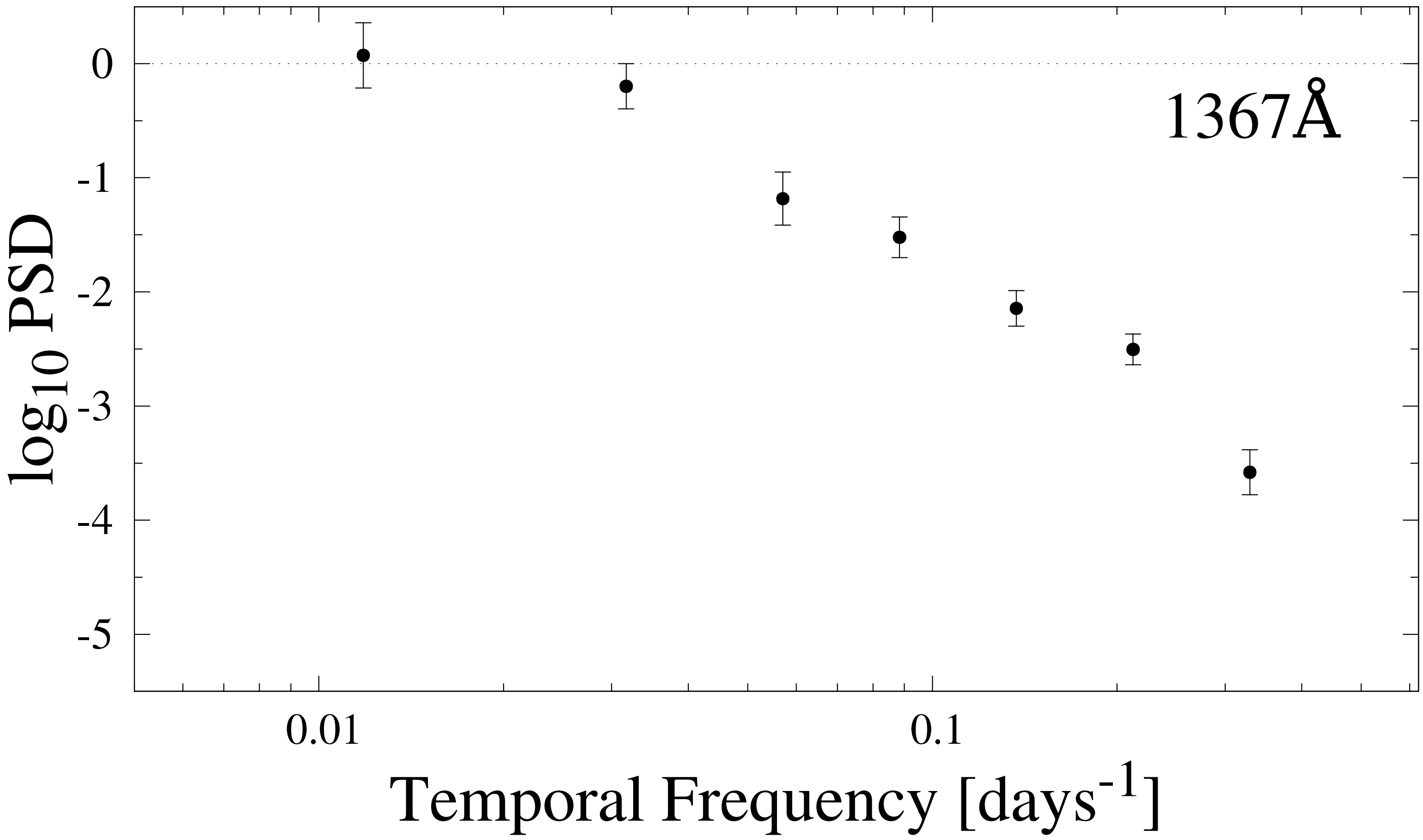
Motivation

- Optical Band Reverberation Mapping has thus-far involved time-domain techniques that reveal only average time lags.
- More information is retained using frequency-domain analyses.
- X-ray reverberation mapping has developed a technique to extract frequency-domain information from unevenly sampled data.

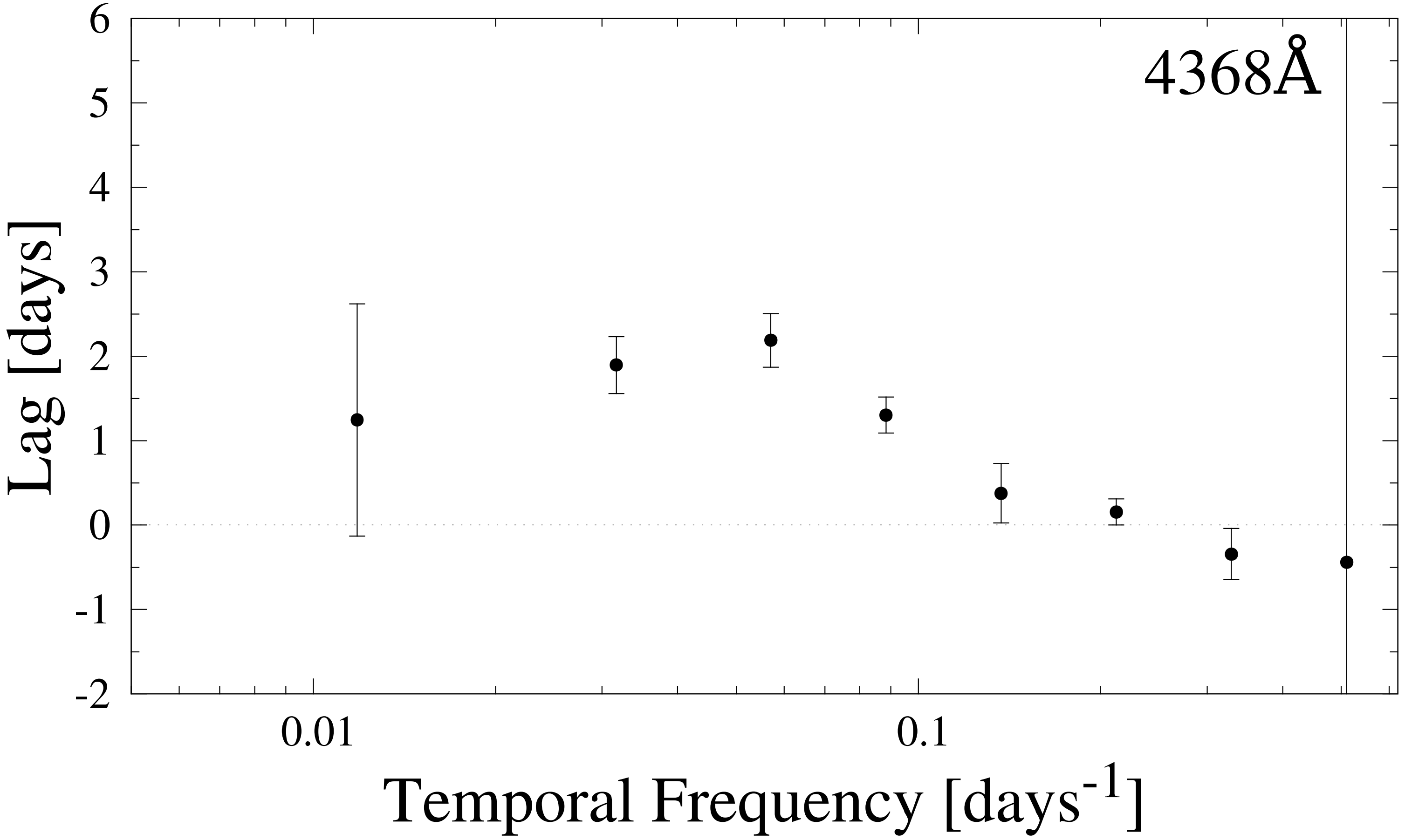
Project Goals

- Use maximum likelihood method to compute temporal frequency-dependent power spectral densities and time lags from STORM III light curves.
- Recover transfer function for NGC 5548's continuum emission.

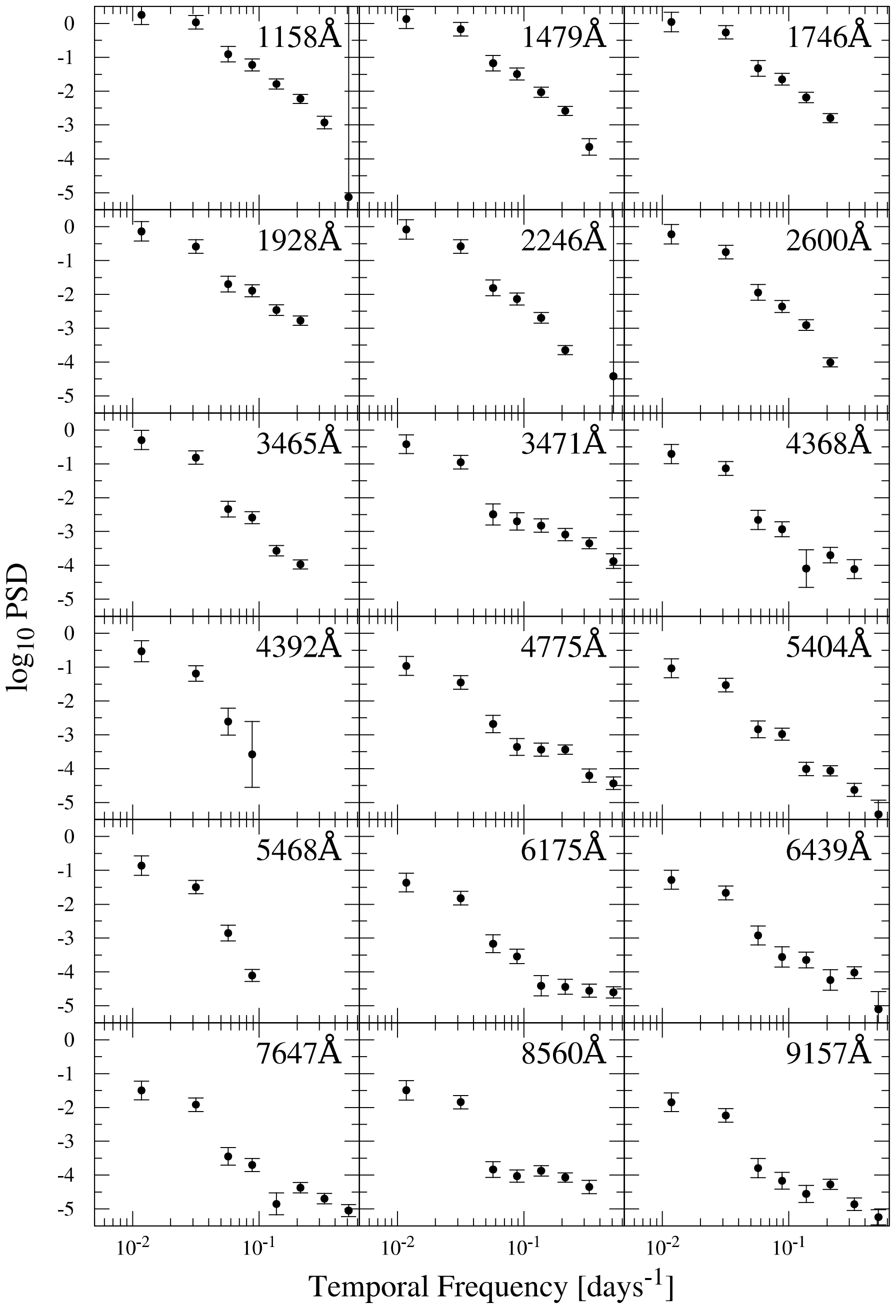
Power Spectral Density



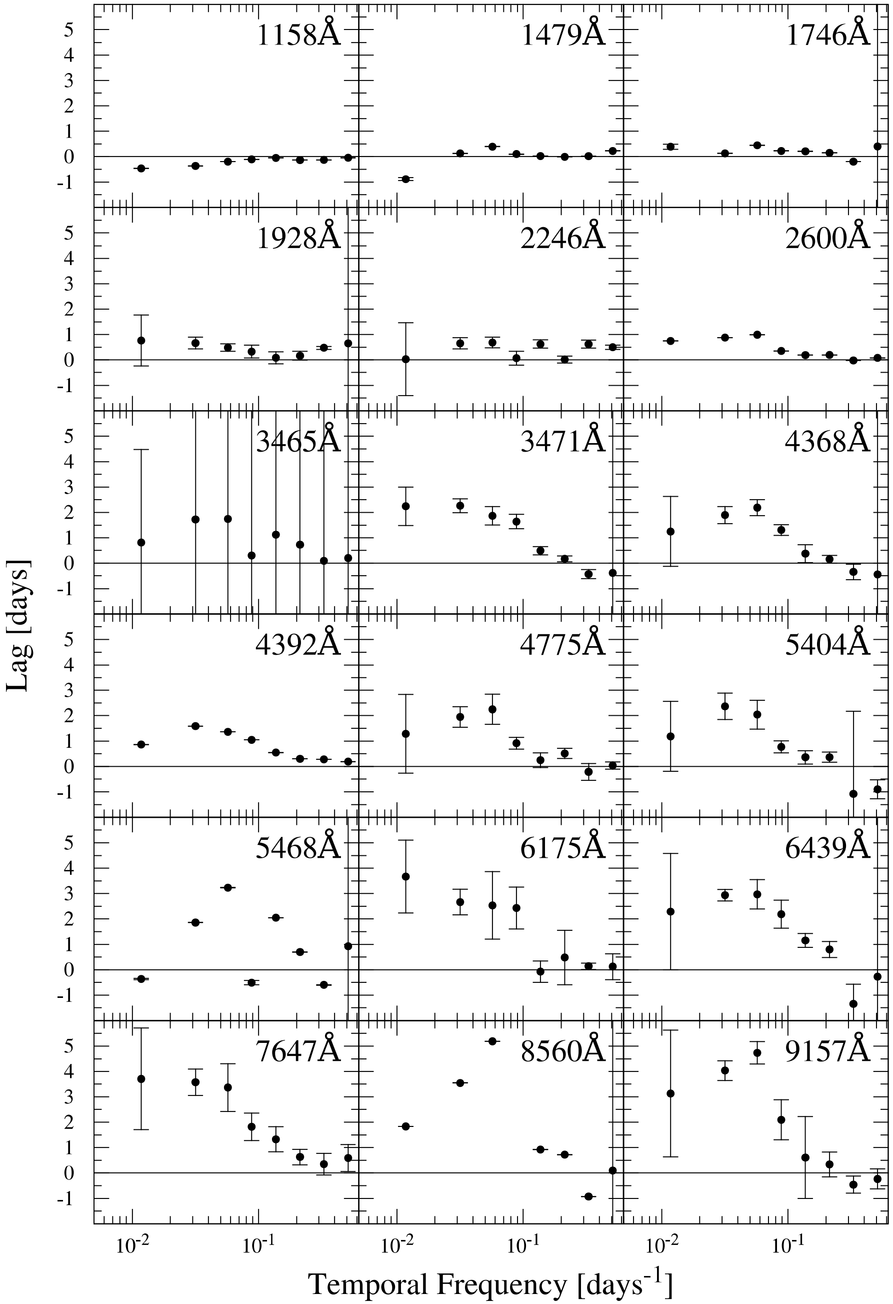
Frequency-Dependent Time Delay



PSD for Bands in STORM III



Time Delays for Bands in STORM III



Conclusions

- Method works with quality of optical AGN data available.
- PSD is wavelength dependent.
- Time lags show frequency dependence; average lag follows trend shown by time-domain analysis.

Next Steps

- Improve error analysis using Monte Carlo or Likelihood Function.
- Fit top hat and log-Gaussian transfer functions to time lags.
- Confirm average time lags reported in STORM III.

Acknowledgements

- Dr. Cackett – The best, thank you many times
- Dr. Zoghbi
- Fausnaugh et al.
- Dr. Cinabro and Dr. Petrov
- Dept. of Physics, Wayne State University
- NSF

Thank You

Questions

Additional Slides

Fourier Techniques

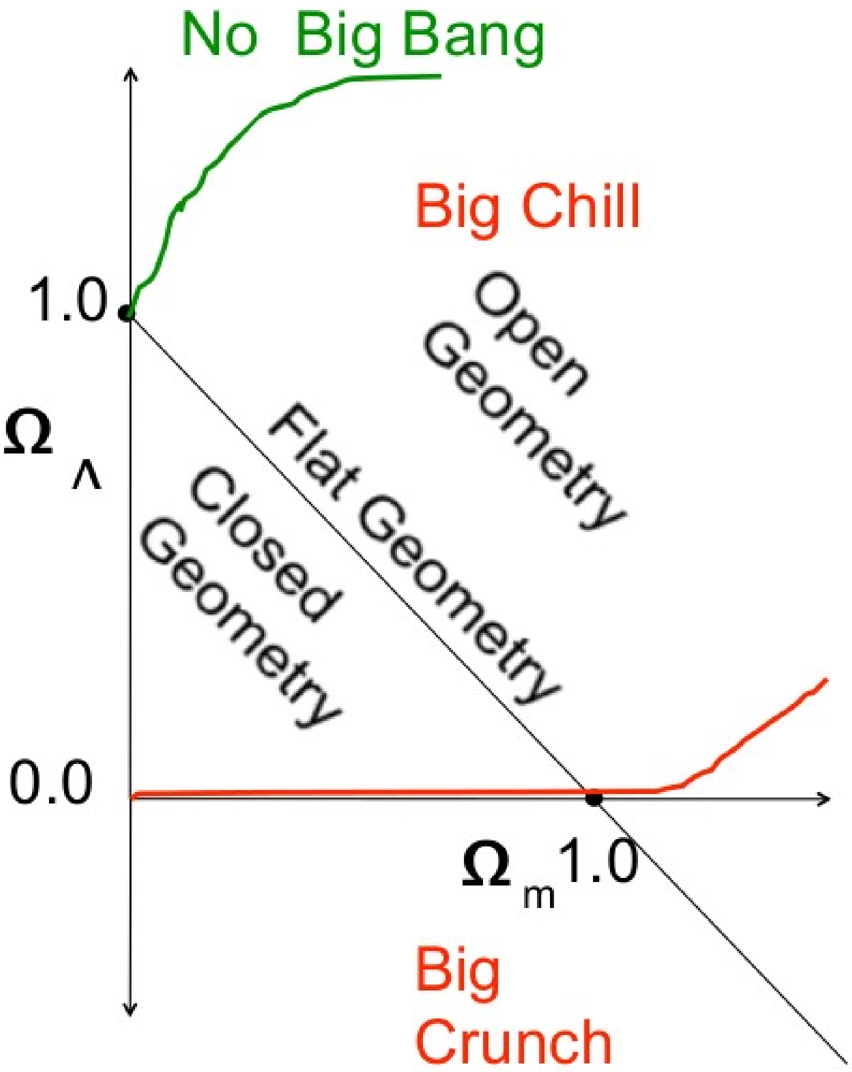
- Fourier analysis provides time-delay distribution as a function of frequency.
- Standard techniques are restricted to evenly distributed data.
- Zoghbi et al. (2013), with Dr. Cackett, developed a maximum likelihood method to predict time lags across light curve gaps.
- Technique should apply nicely to optical data that exhibit gaps.

AGN as Cosmological Probe

- AGN can be used as a standard candle and cosmological probe.
  - Collier et al. (1999), and later Cackett et al. (2007), have calculated Hubble's constant using this standard, but issues remain.
  - Cackett et al. (2007) also indicates promise for constraining cosmological parameters Ω_Λ and Ω_m .
- Optical Band Reverberation Mapping has thus-far involved cross-correlation analysis in the time domain.
  - Requires data that are evenly distributed in time, but many data in the optical bands are not.
  - Provides only the average time lag.
- X-Ray Reverberation Mapping has developed a technique to deal with unevenly distributed data.

Describing the Universe

- How Astronomers describe the Universe on the cosmological scale.
- Repulsive cosmological constant(Λ) versus attractive mass(m).
- > 1.0: Enough attractive to force Big Crunch.



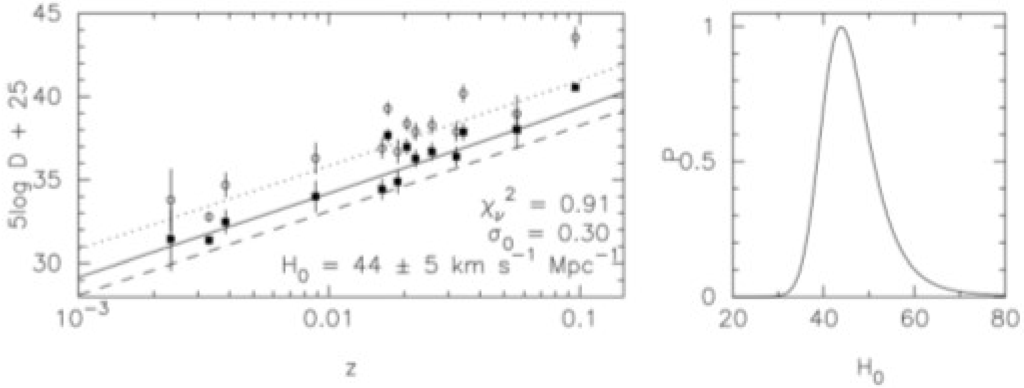


Figure 11. Left-hand panel: Hubble diagram for 14 AGN from the Sergeev et al. sample. Distance modulus is plotted versus redshift. The solid line is the best-fitting model (fit to the filled circles), where as the dashed line indicates $H_0 = 72\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The filled squares are for the distances determined when the B-band galaxy flux is =0, and the open circles are for when the B-band galaxy is set to the maximum possible. The dotted line is the best fit to the open circles. Right-hand panel: probability distribution for H_0.

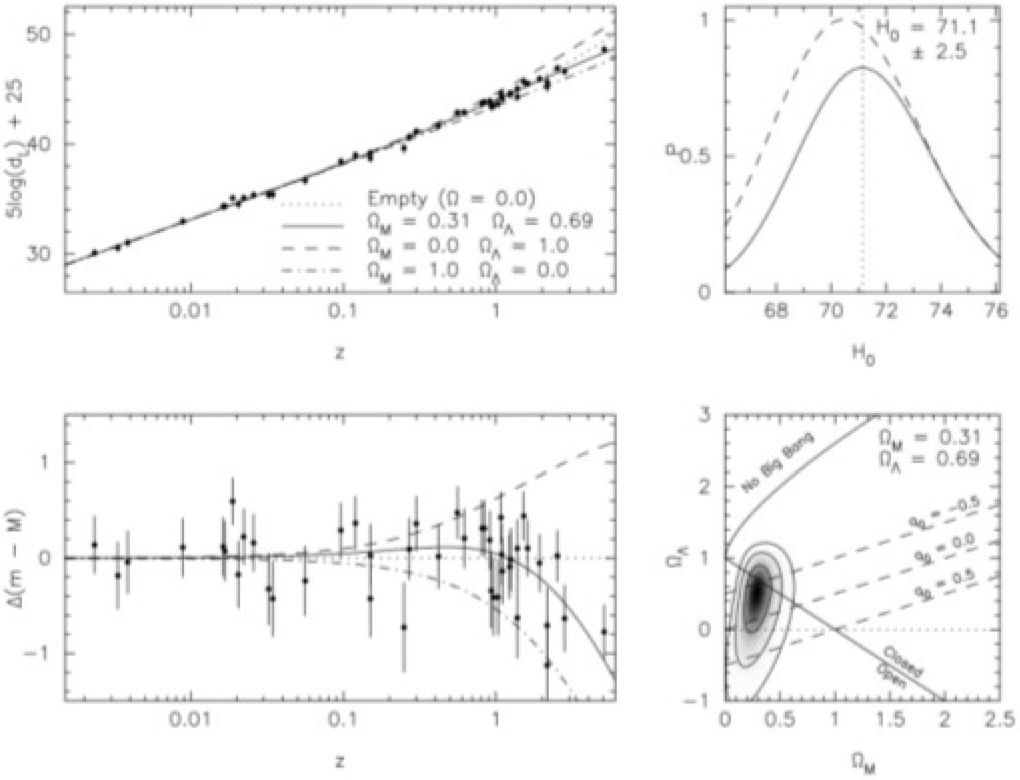


Figure 13. Simulation of constraints on H_0, $\Omega_{\rm M}$ and Ω_Λ from 44 AGN. Top left-hand panel: distance modulus versus redshift for the 44 AGN. Various cosmological models are shown, with the solid line indicating the best-fitting flat cosmology. Bottom left-hand panel: magnitude difference between the distance modulus and an empty universe. Top right-hand panel: probability distribution for H_0. The solid line indicates the probability distribution when a flat cosmology is assumed, and the dashed line shows the distribution with no constraint on $\Omega_{\rm tot}$. Bottom right-hand panel: probability distribution for $\Omega_{\rm M}$ and Ω_Λ. Contours indicate 1, 2 and 3σ confidence limits.

Local Group Active Galaxy Caught in Action