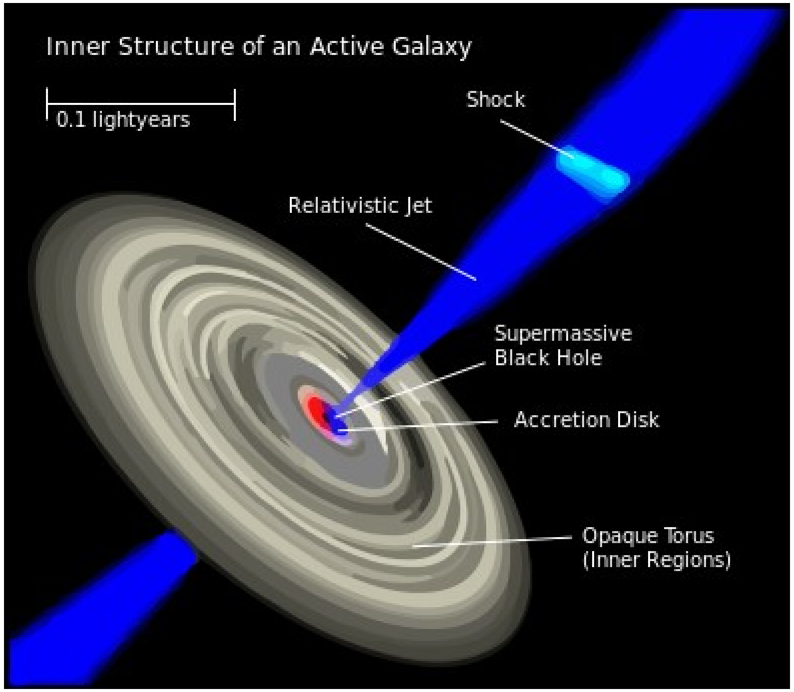
Optical Band Reverberation Mapping of NGC 5548 with Maximum Likelihood

Otho Ulrich[1,2], Edward M. Cackett[2]
[1]Department of Physics, Western Michigan University
[2]Department of Physics and Astronomy, Wayne State University

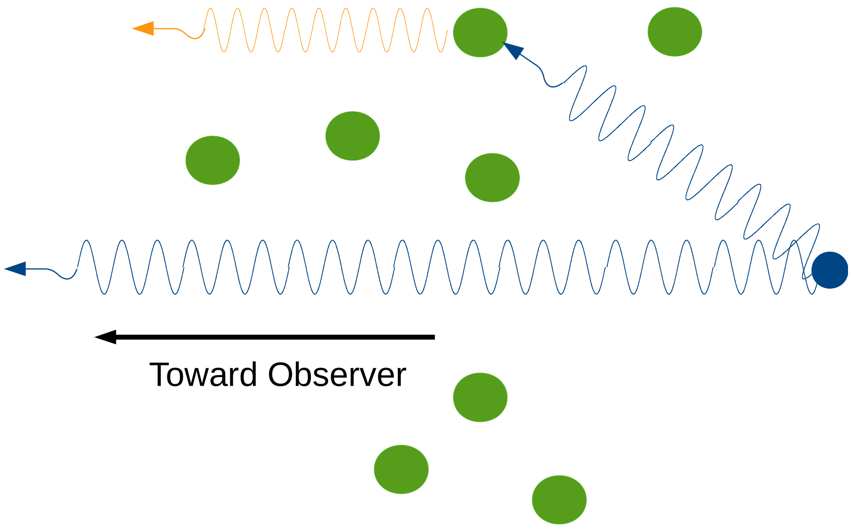
Active Galactic Nuclei

- 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

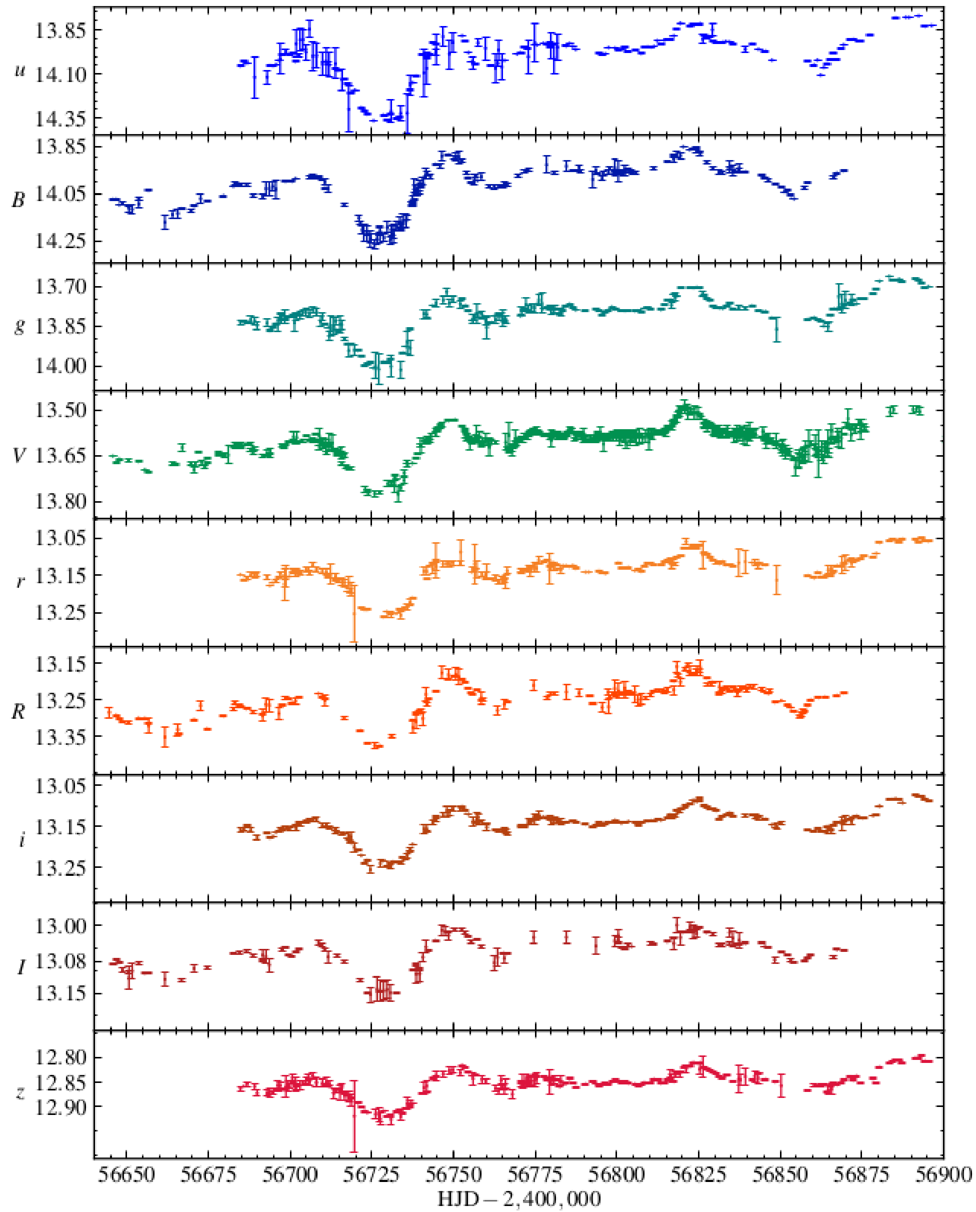
Recovering the Transfer Function

Transfer Equation

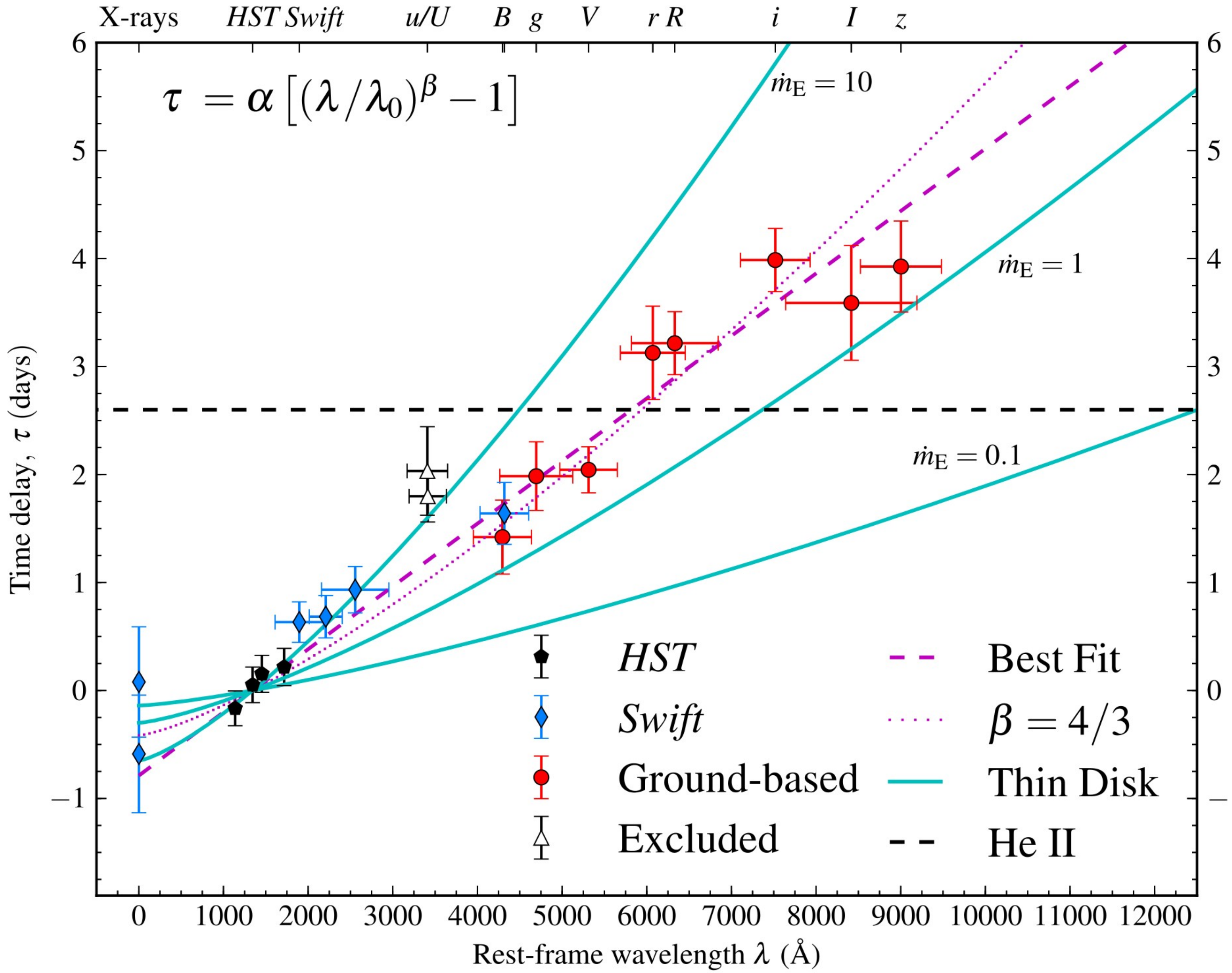
Top hat in Time Domain

Top hat in Frequency Domain from FFT

NGC 5548 Light Curves from STORM III



Frequency-Dependent Time Delay Analysis from STORM III



Motivation

- Optical Band Reverberation Mapping has thus-far involved time-domain techniques.
- More information is available through 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.

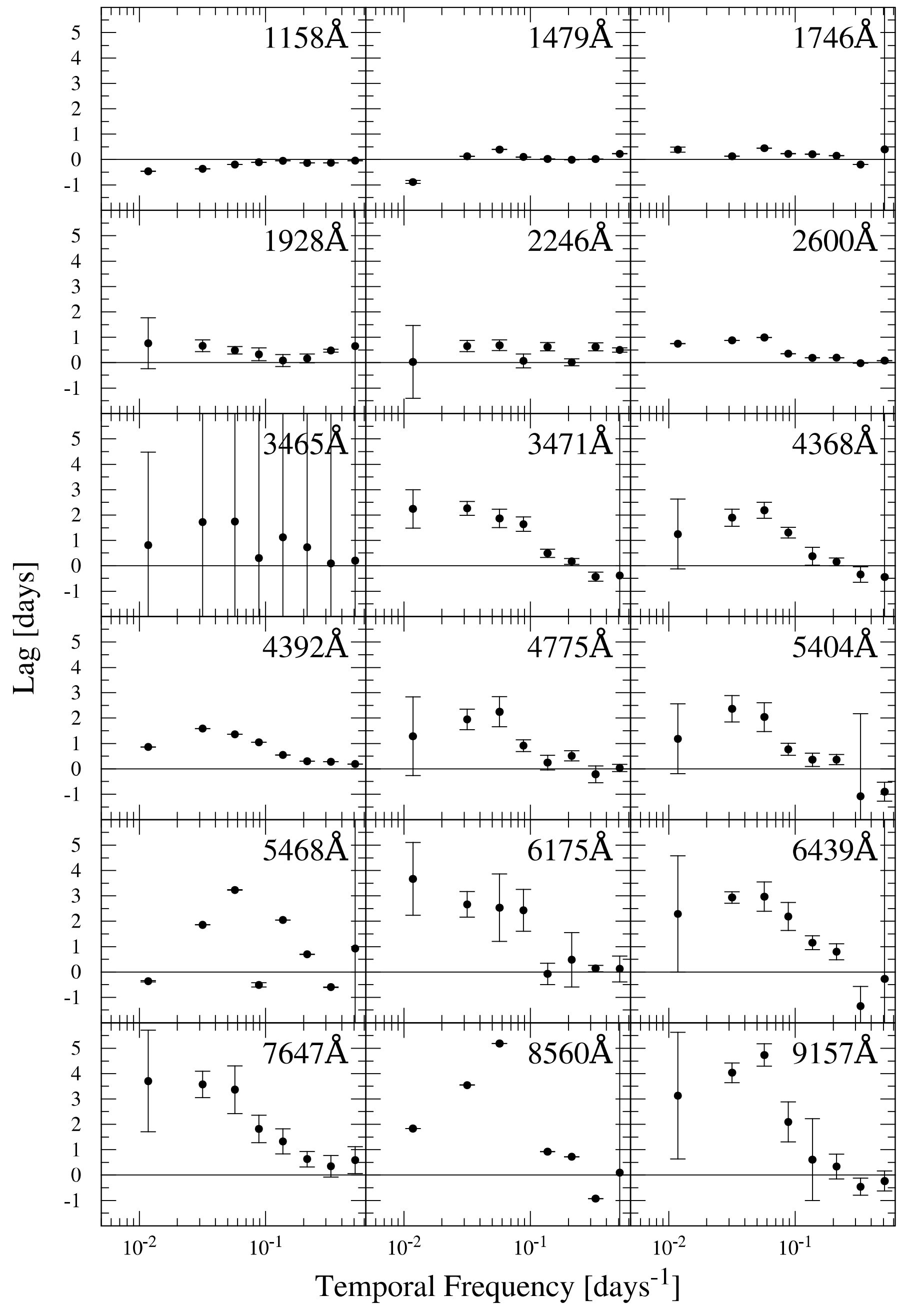
Power Spectral Density

PSD of reference band 1367Å

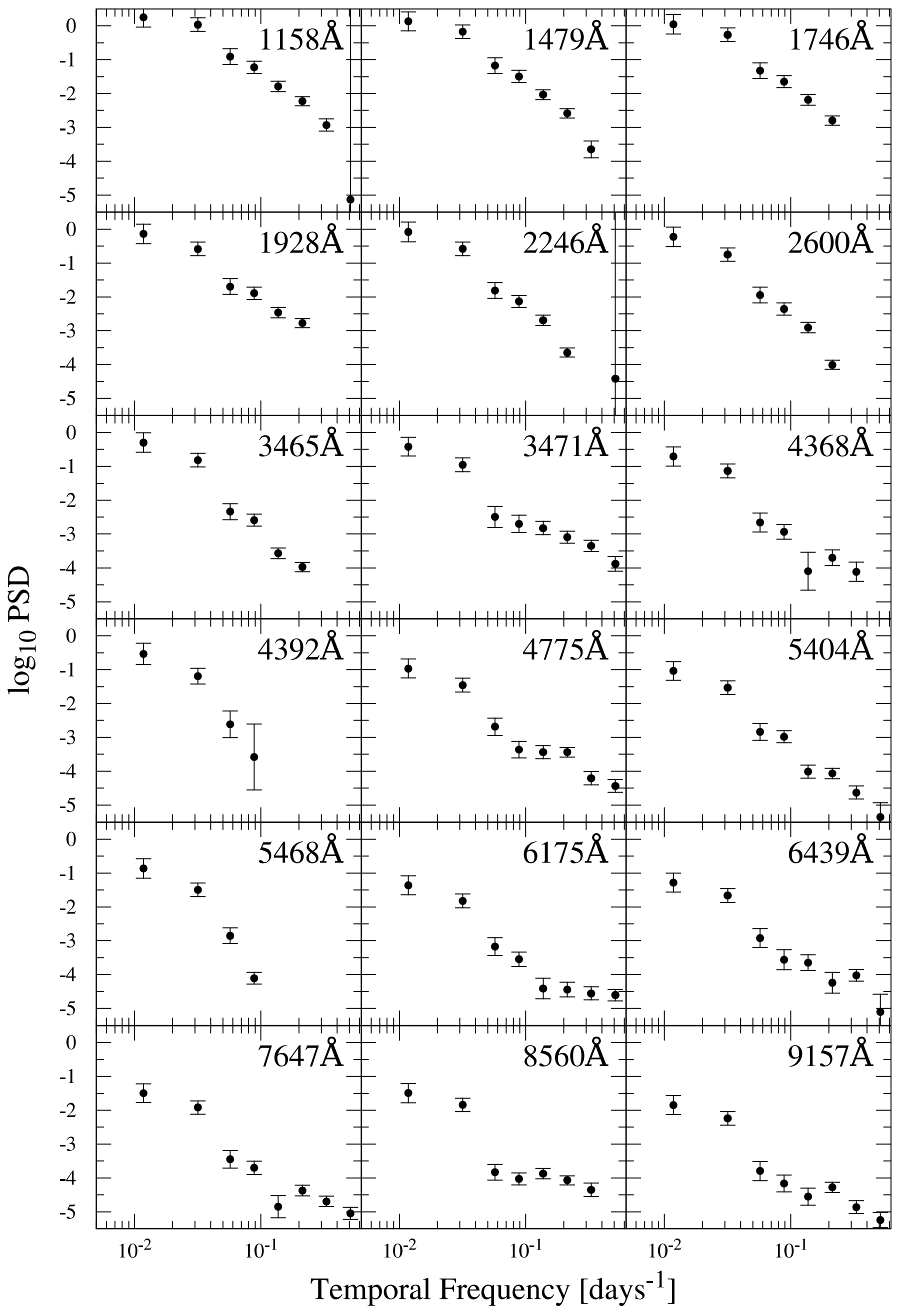
Frequency-Dependent Time Delay

Time Delay for a band, probably 4368Å.

PSD for Bands in Storm III



Delays in Bands from STORM III



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

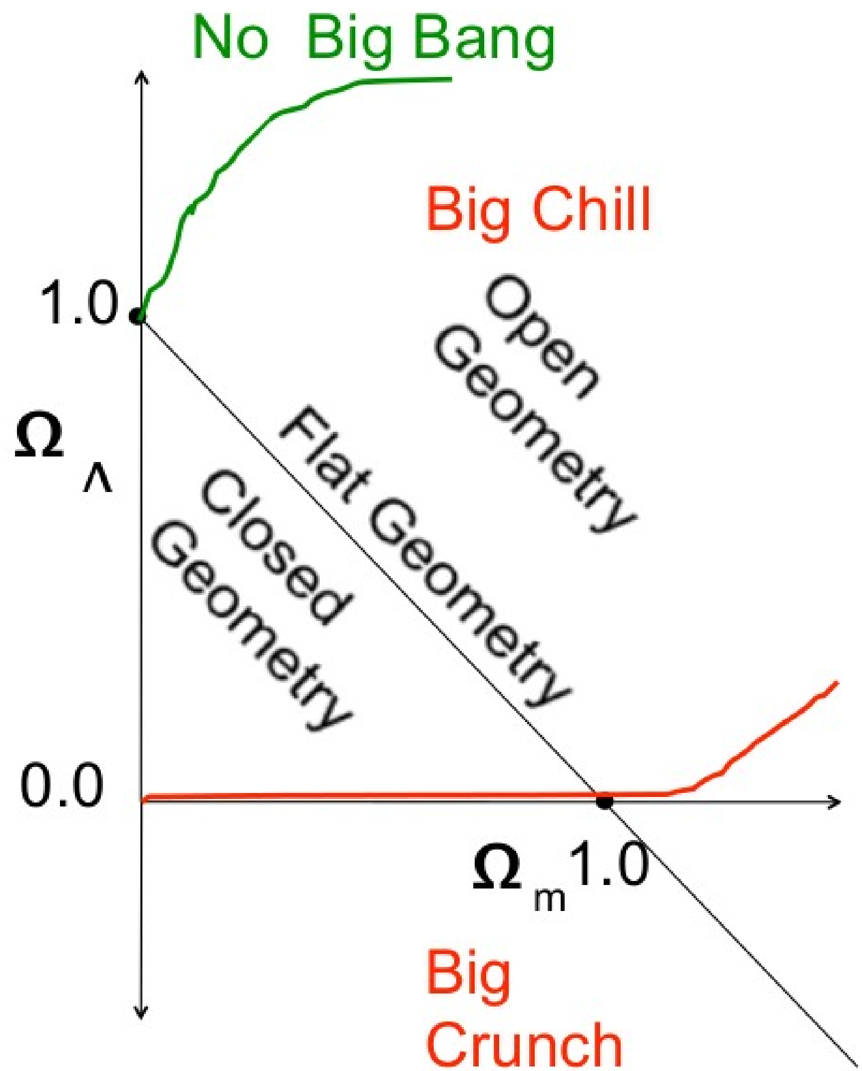
- Fourier analysis provides time-delay distribution as a function of frequency.
- Standard techniques are restricted to evenly distributed data.
- Zoghbi et al. (2013), with Dr. Cackett, developed a maximum likelihood method to predict time lags across light curve gaps.
- Technique should apply nicely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



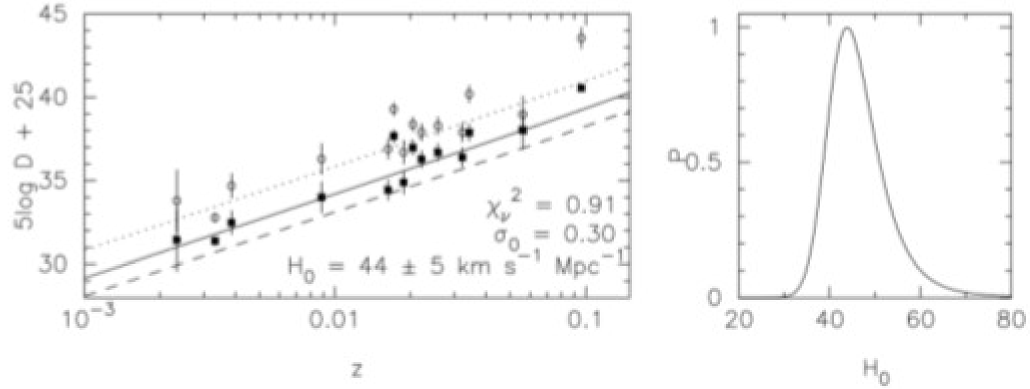


Figure 11. Left-hand panel: Hubble diagram for 14 AGN from the Sergeev et al. sample. Distance modulus is plotted versus redshift. The solid line is the best-fitting model (fit to the filled circles), where as the dashed line indicates $H_0 = 72\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The filled squares are 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.

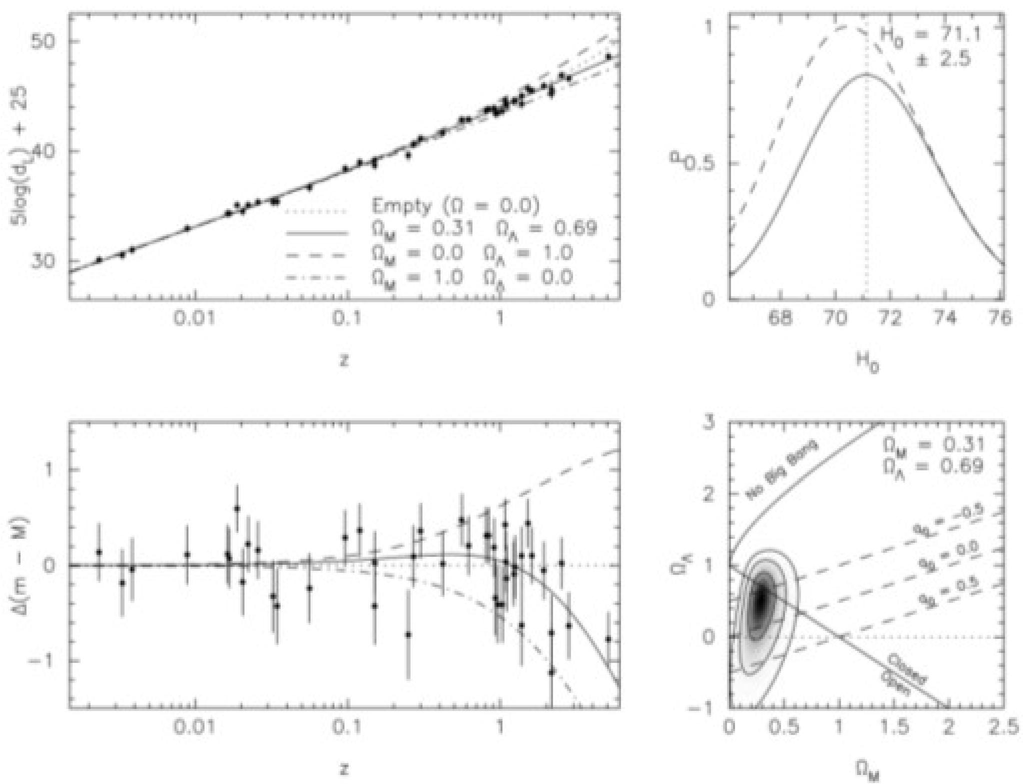


Figure 13. Simulation of constraints on H_0, Ω_M and Ω_Λ from 44 AGN. Top left-hand panel: distance modulus versus redshift for the 44 AGN. Various cosmological models are shown, with the solid line indicating the best-fitting flat cosmology. Bottom left-hand panel: magnitude difference between the distance 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 Ω_{tot}. Bottom right-hand panel: probability distribution for Ω_M and Ω_Λ. Contours indicate 1, 2 and 3σ confidence limits.

Local Group Active Galaxy Caught in Action