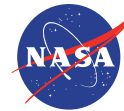




Science with PanChromia: The EM Machine for TDAMM Science

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This document has been reviewed and determined not to contain export controlled technical data.

Workshop Goals this Talk Addresses

1. Discuss potentially driving science cases for future large, strategic astrophysics missions and connect scientific priorities with technological readiness and mission implementation.
2. Provide science cases for the broad discussion of potential instrument architectures

Decadal Recommendation

One of the key visions recommended in the Astro 2020 Decadal survey is “Time Domain Astronomy: A coordinated program to ensure a continuous U.S. presence in space for the study of transient and time-variable phenomena in the universe.” (Astro 2020, P. 399)

Decadal Recommendation

One of the key visions recommended in the Astro 2020 Decadal survey is “Time Domain Astronomy: A coordinated program to ensure a continuous U.S. presence in space for the study of transient and time-variable phenomena in the universe.”

“A future system needs to include the following features: (1) detection capability at X-ray/gamma-ray energies with near 4π sr coverage; (2) prompt event localization at the few arcsecond level or better; (3) rapid-slewing for follow-up imaging and spectroscopy at X-ray, ultraviolet, and IR wavelengths; (4) long-term monitoring in these same bands; and (5) a data system capable of issuing fast alerts to the community with all essential information.” (Astro 2020 P. 414)

Decadal Recommendation

“These could be achievable with a mix of different implementations: either a single probe mission or a suite of medium- and small-size experiments that address some of the requirements. It is essential, however, that all of those capabilities are simultaneously available in space, so coordination in the mission developments and launches is of paramount importance. A competitive selection of the mission architecture based on targeted NASA” (Astro 2020, P415)

Legacy to Build On: Neil Gehrels Swift Observatory

As noted in Astro 2020, the Neil Gehrels Swift Observatory has already shown the advantages of such an observatory:

1. Swift detected GRB 090423, the most distant known spectroscopically confirmed object in the Universe at $z = 8.3$.
2. Swift has measured the metallicity of star-forming regions at high redshift ($z > 5$) using GRBs
3. UVOT and XRT have provided arcsecond positions for short-hard GRBs that have allowed their host galaxies to be identified. This has strengthened the case for the short bursts being due to merging binary neutron stars.
4. Swift has discovered a previously-unknown class of long-soft GRBs that have no associated supernova.
5. XRT has discovered X-ray flares in GRBs and found that in some cases the X-ray afterglow decays very slowly. This suggests that the central engine remains active for minutes to hours after the burst.
6. UVOT has obtained unique ultraviolet light curve for a large number of supernovae of all types.
7. XRT has observed the X-ray flash from the shock breakout of a supernova.
8. BAT has performed the deepest hard X/-ray survey to date finding >400 AGN and absorbed Seyfert 2 galaxies.
9. Swift, in conjunction with XMM-Newton, has found the best evidence for an intermediate mass black hole in the galaxy NGC 5408.
10. Swift, in conjunction with Fermi, discovered two soft gamma-ray repeaters: SGR 0501+4516 and SGR 0415-5729.
11. Swift obtained unique ultraviolet and X-ray data on comets Lulin and 8P/Tuttle, including observing the Deep Impact encounter.

Legacy to Build On: Neil Gehrels Swift Observatory

But since Swift's launch, NASA has flown not only more advanced Gamma-ray, X-ray, and UV/optical telescopes, but also passively cooled and cryocooled infrared telescopes, opening the possibility for an observatory that has capabilities from the Gamma-rays all the way out to the Mid-infrared.

So there is an enormous potential to build on Swift's capabilities!

TDAMM: Time Domain and Multi-Messenger Science

1. Quick detection of transient phenomena (GRB, SN, GW events, ...)
2. Quick follow-up of transient phenomena, whether detected by the telescope itself or not. (GRB, SN, GW events, ...)
3. Monitoring of time variable phenomena (AGN, Variable Stars, Stellar Flares,..)

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With the anticipated demise of the Swift Observatory, a next-generation Swift will undoubtedly build upon the first two science cases noted above.

I will now concentrate on the third science case, where Swift has already made huge advances, but a next-generation Swift can revolutionize some of those fields!

Our Current Understanding of Active Galactic Nuclei (AGN)

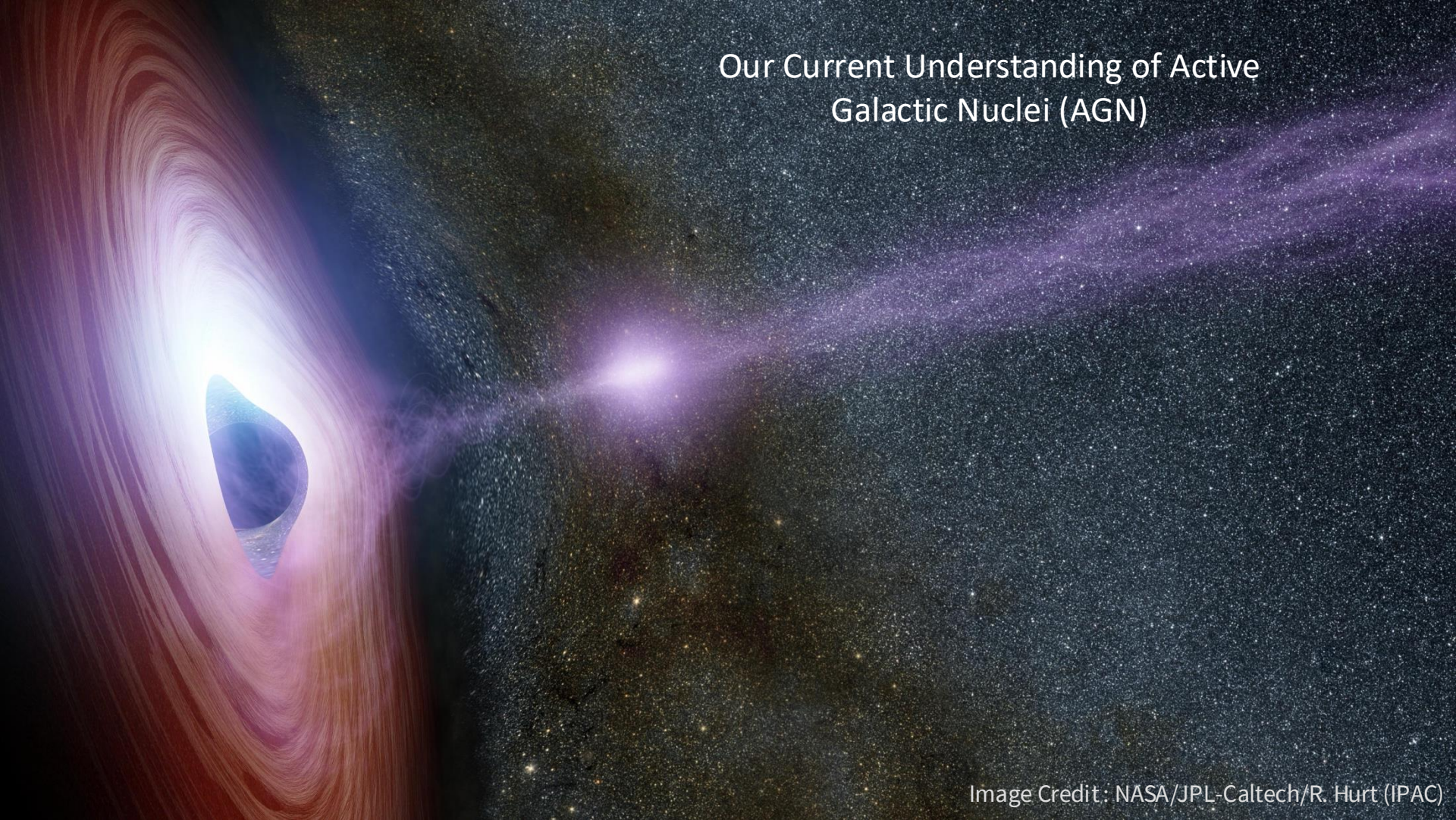
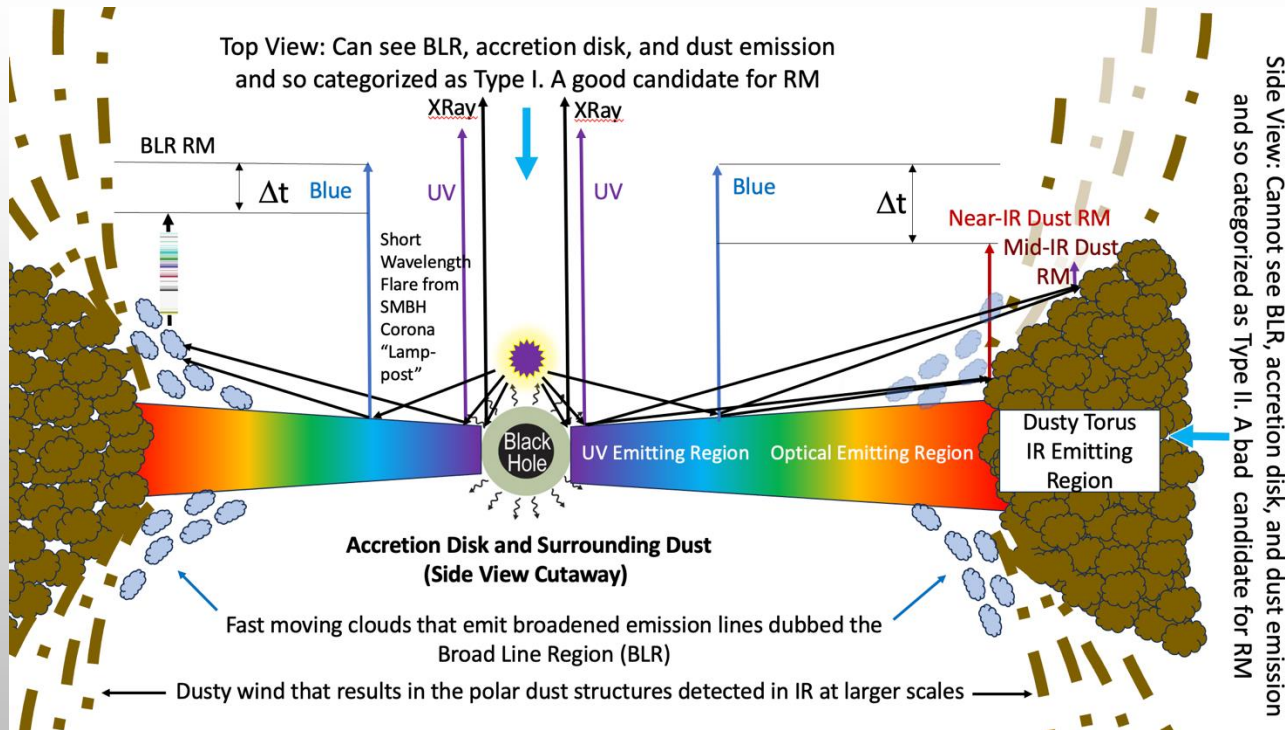
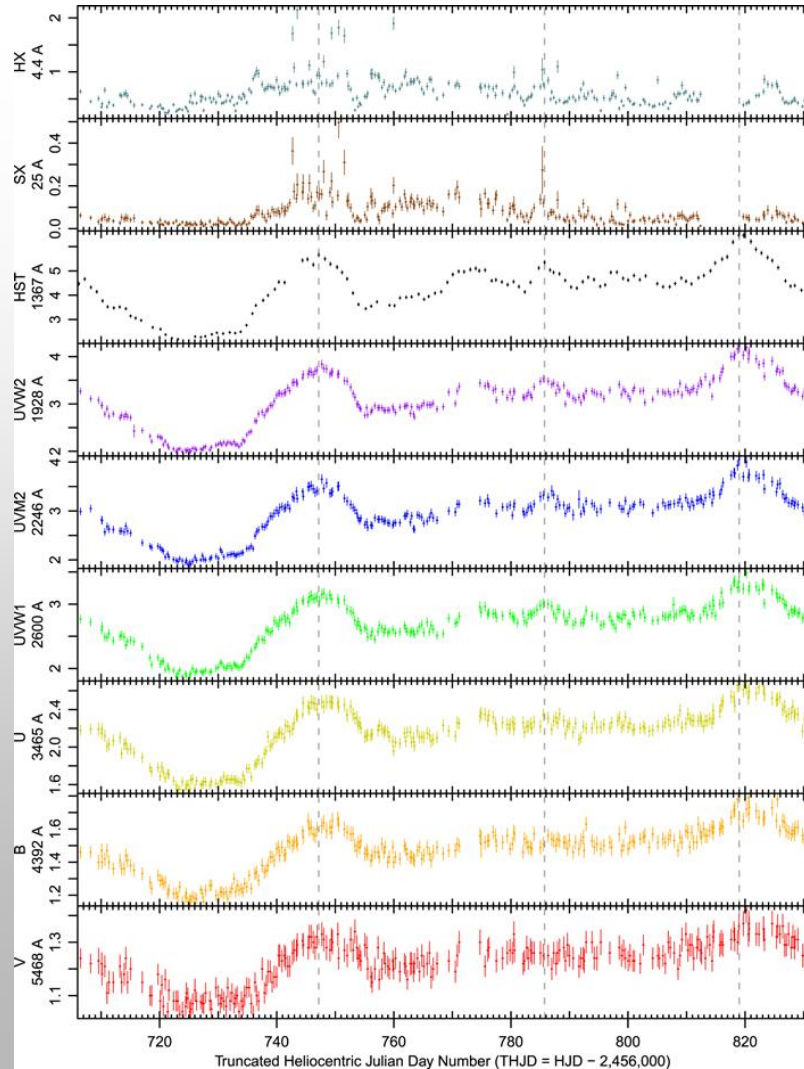


Image Credit: NASA/JPL-Caltech/R. Hurt (IPAC)

A Brief AGN Reverberation Tutorial



Short wavelength radiation originating from near the black hole acts as a lamp-post and irradiates its surroundings. That radiation is absorbed by the accretion disk, the broad line region (BLR) clouds, and the dust and re-emitted. The difference between the arrival times of the different wavelengths, Δt , gauges the distance, $c\Delta t$, from the black hole to each region of the disk, BLR, and dust. NOT TO SCALE

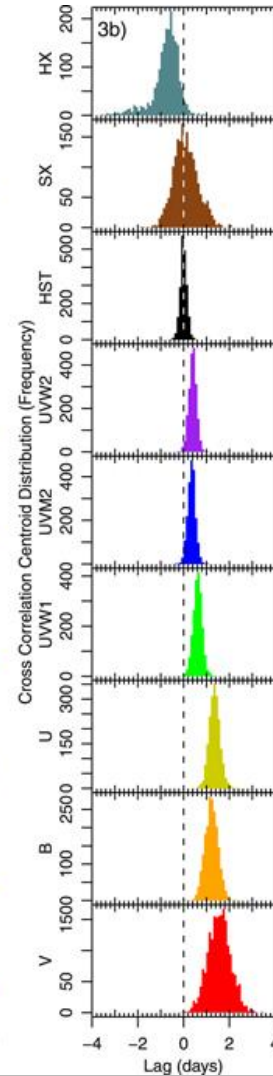
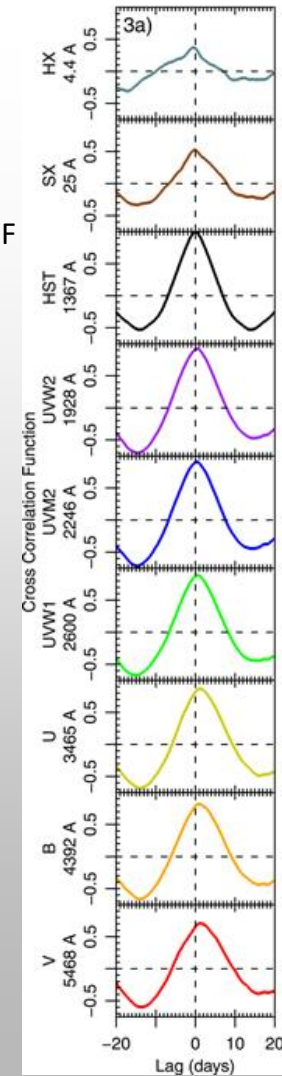


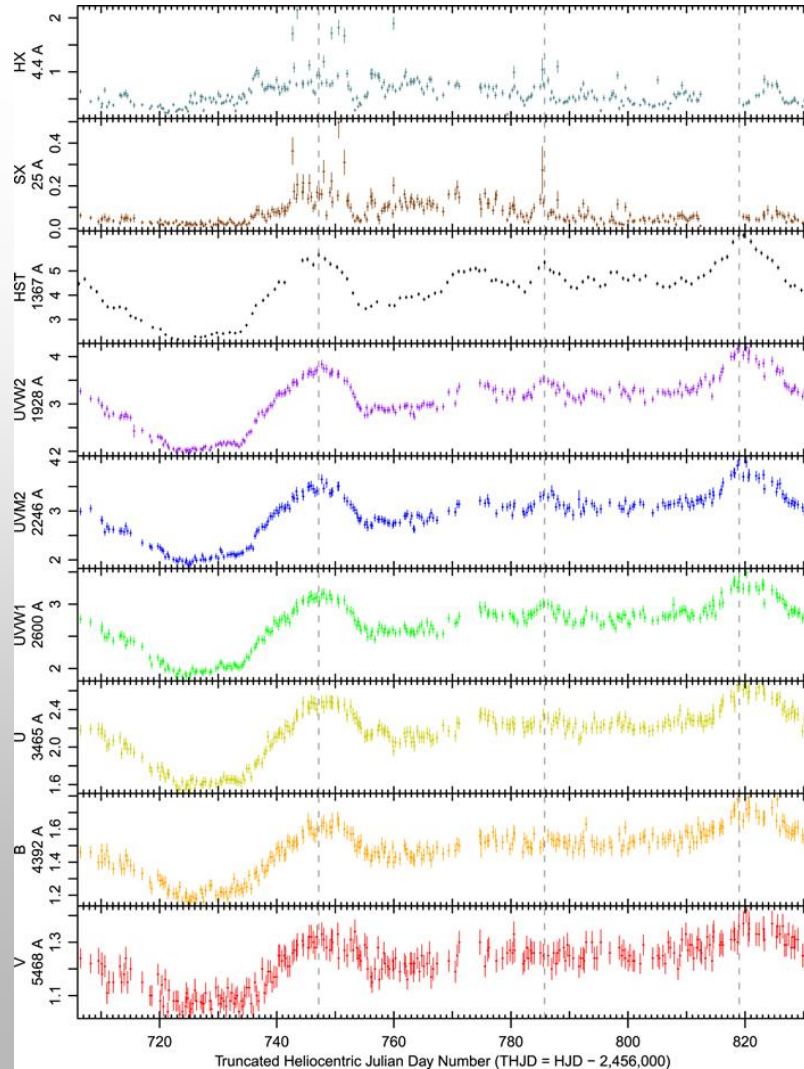
SWIFT AND *HST* REVERBERATION MAPPING OF THE ACCRETION DISK OF NGC 5548

Edelson et al 2015

By the

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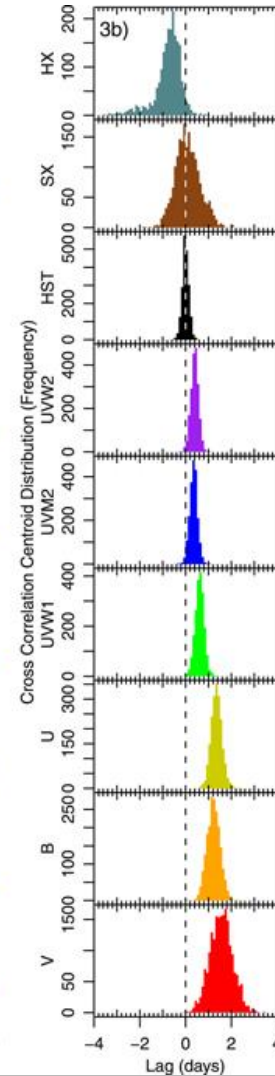
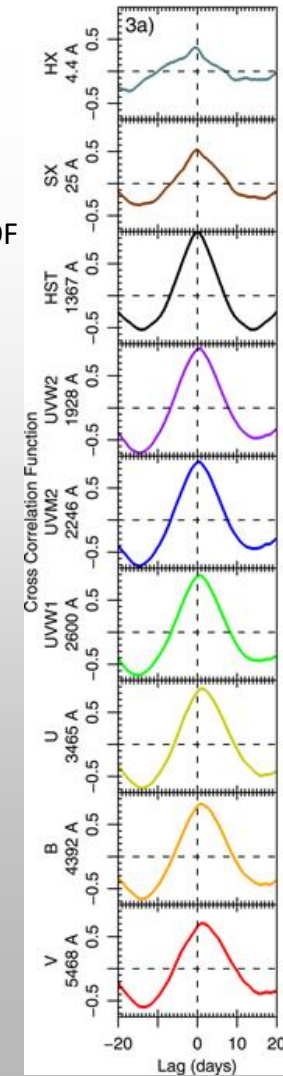


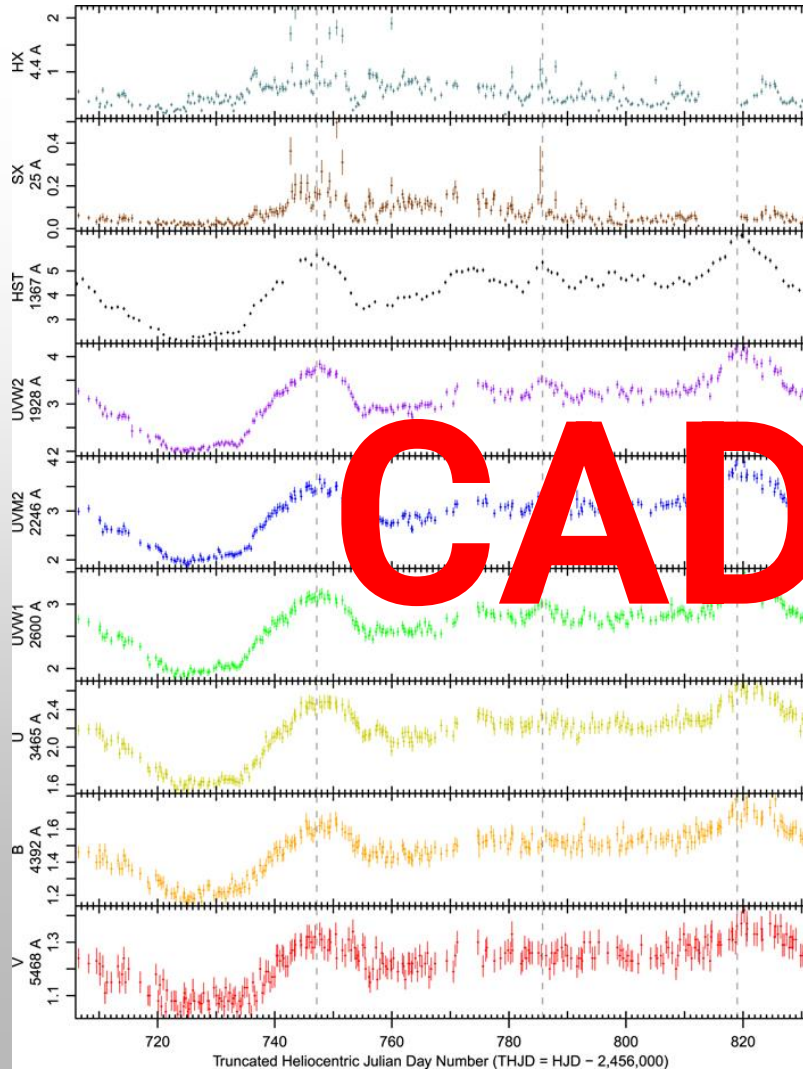
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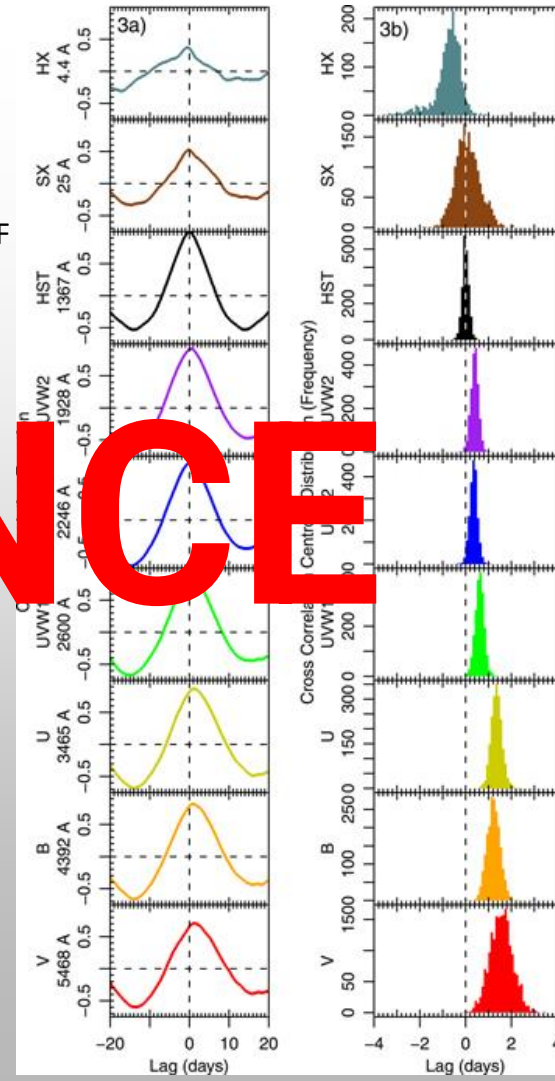


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CADENCE



A Brief Reverberation Tutorial

- The disk structure is modeled by relating the temperature (T) to the radius (R) of the accretion disk that are related by

$$T \propto R^{-\beta}$$

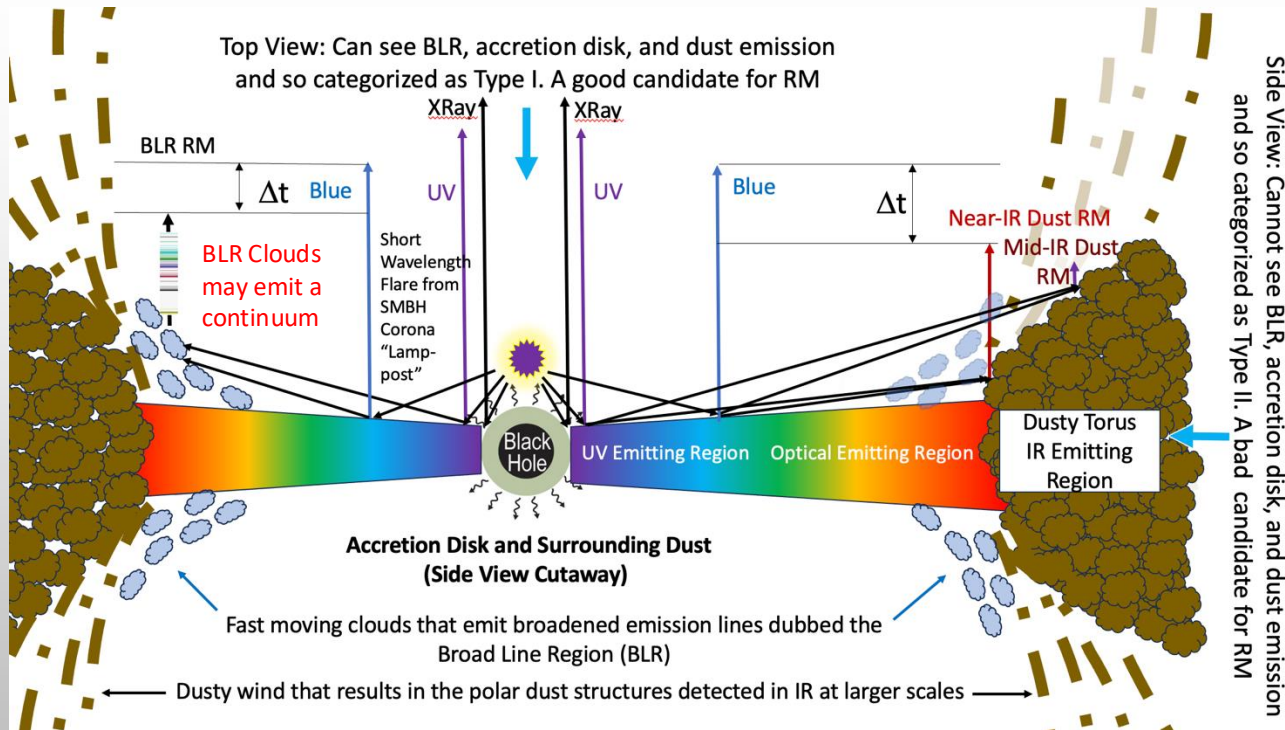
A Brief Reverberation Tutorial

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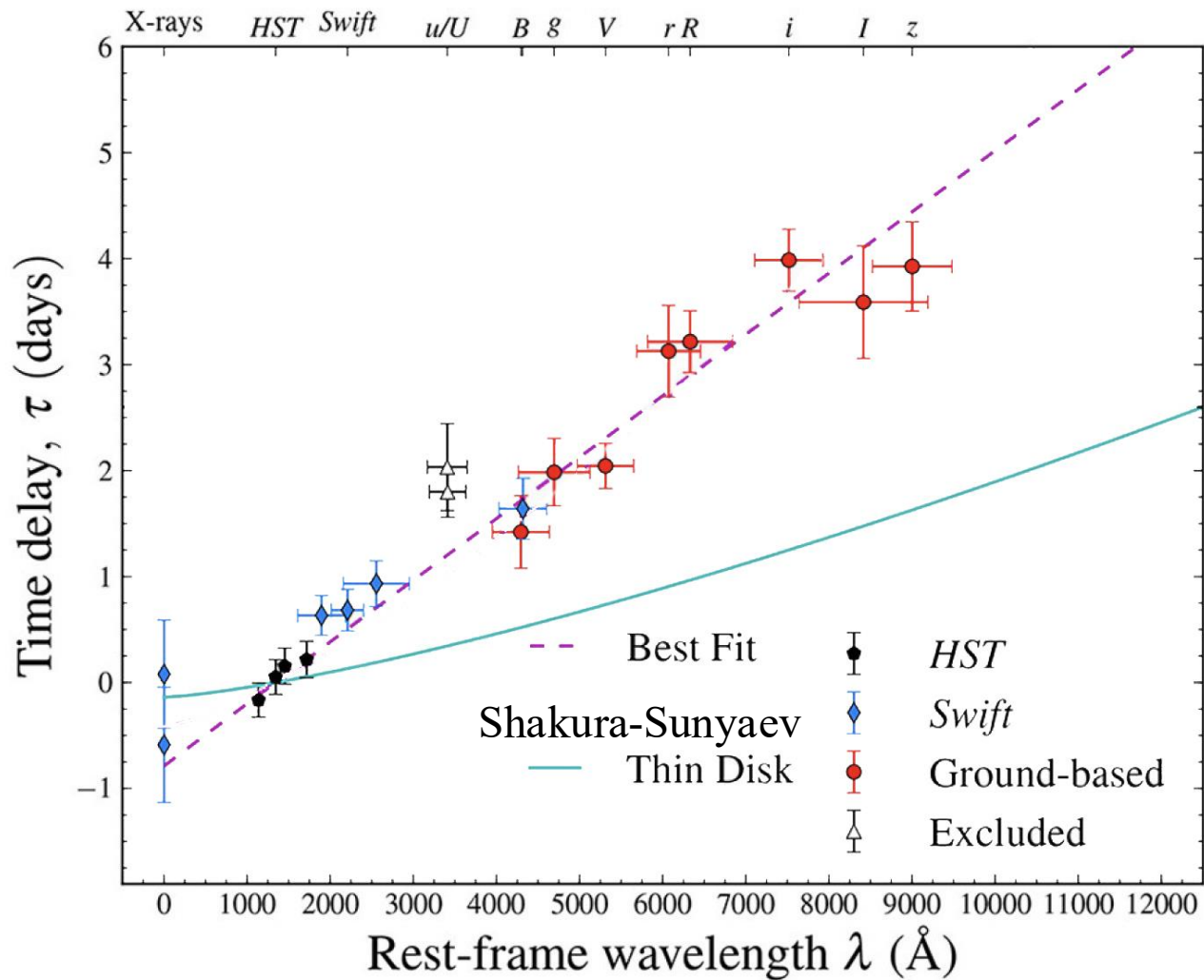
$$T \propto R^{-\beta}$$

- Observationally this results in a relation between wavelength (λ) $\rightarrow (\lambda \propto T^{-1})$ and the time delay between wavelengths (τ) $\rightarrow (\tau c = R)$
- And so determining β with high precision is the ultimate goal

A Brief AGN Reverberation Tutorial

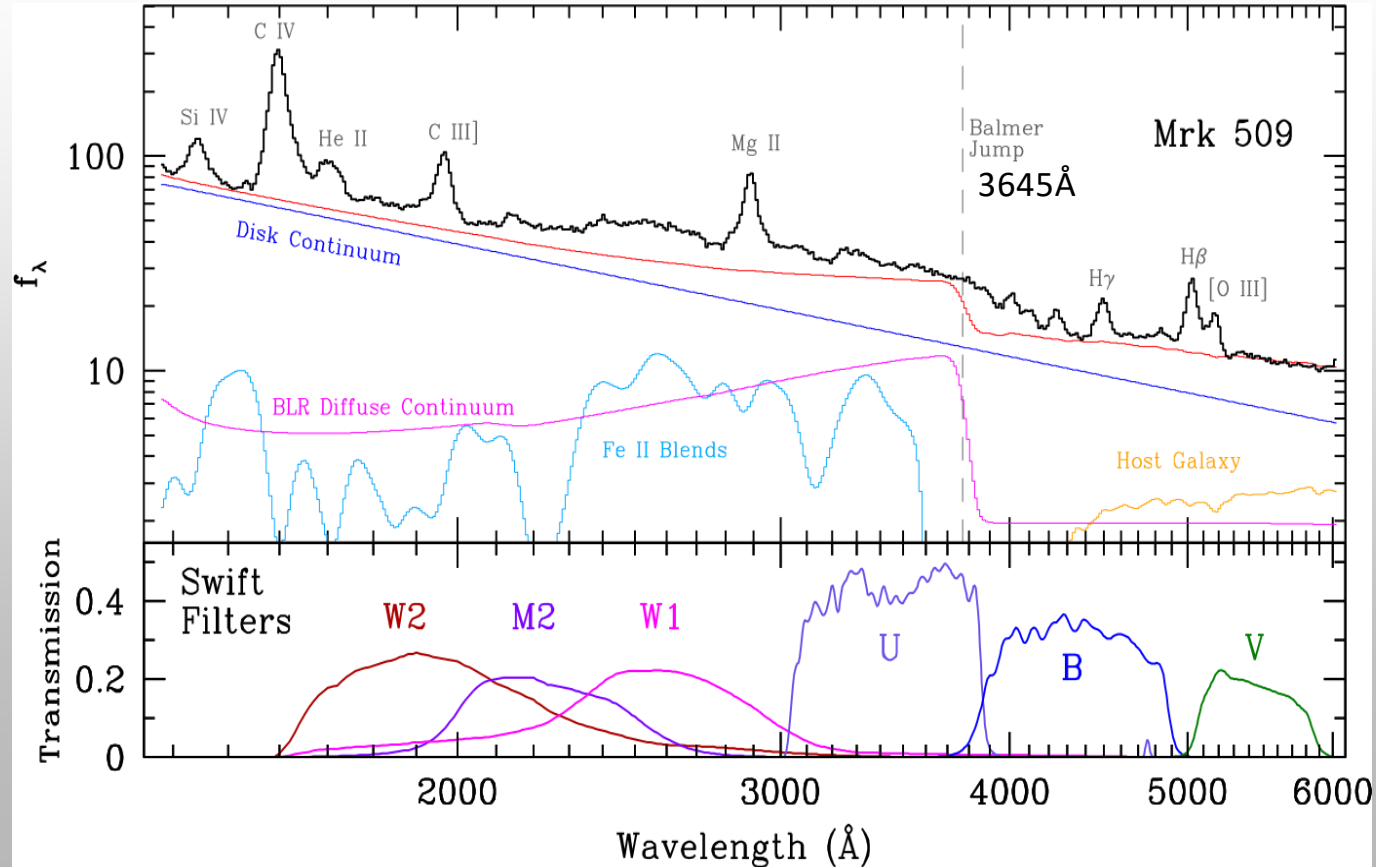


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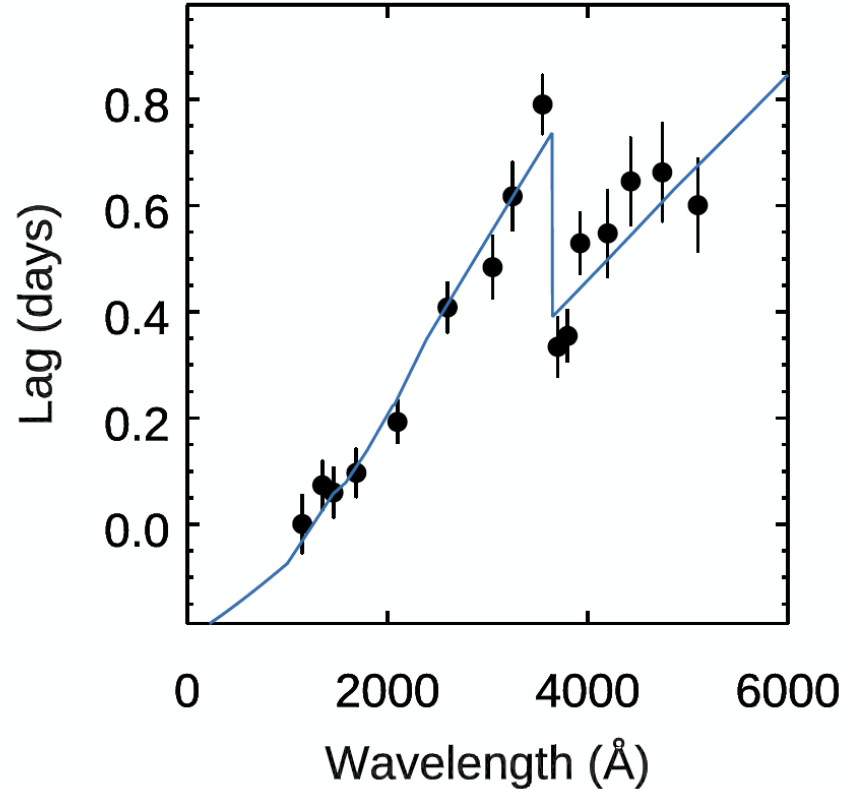
NGC 5548 adapted
from Fausnaugh et al 2018
AGN STORM

Advantages of Spectra Over Photometry



BHAGERA: Wavelength Coverage

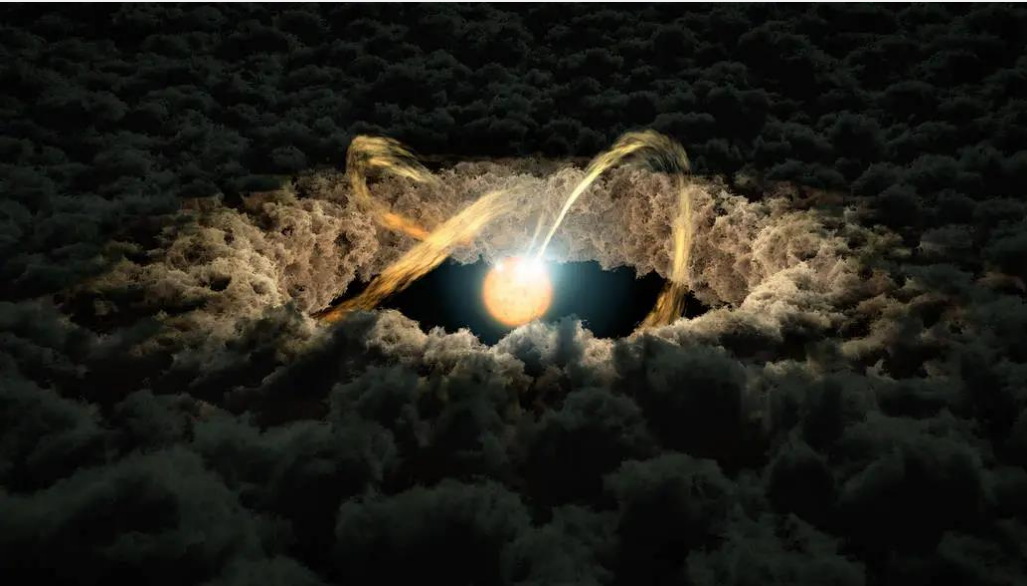
Model of multiwavelength variability of NGC 4593. With wavelength coverage from 1400 to 5000 and 1% photometric accuracy we recover $\beta = 0.752 \pm 0.01$ and disk size to 12%



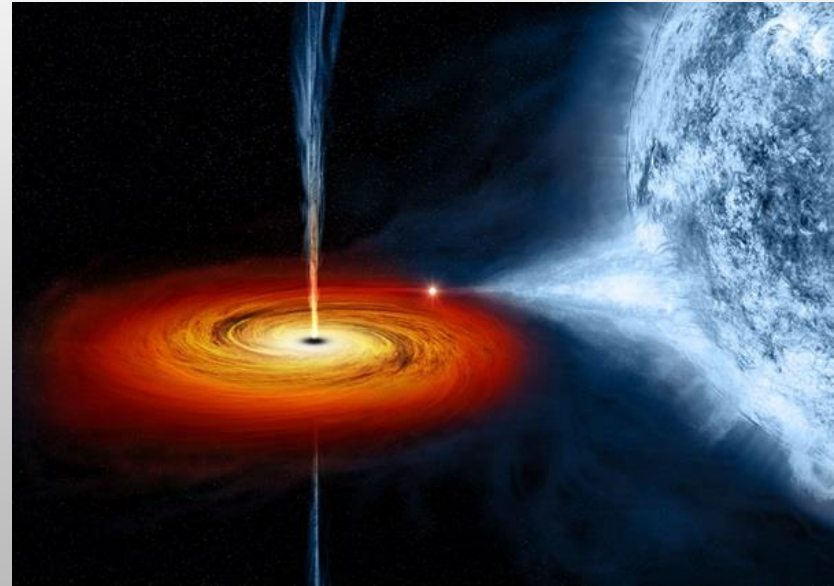
Other disks can also be studied

Other disks can also be studied

Protoplanetary Disks

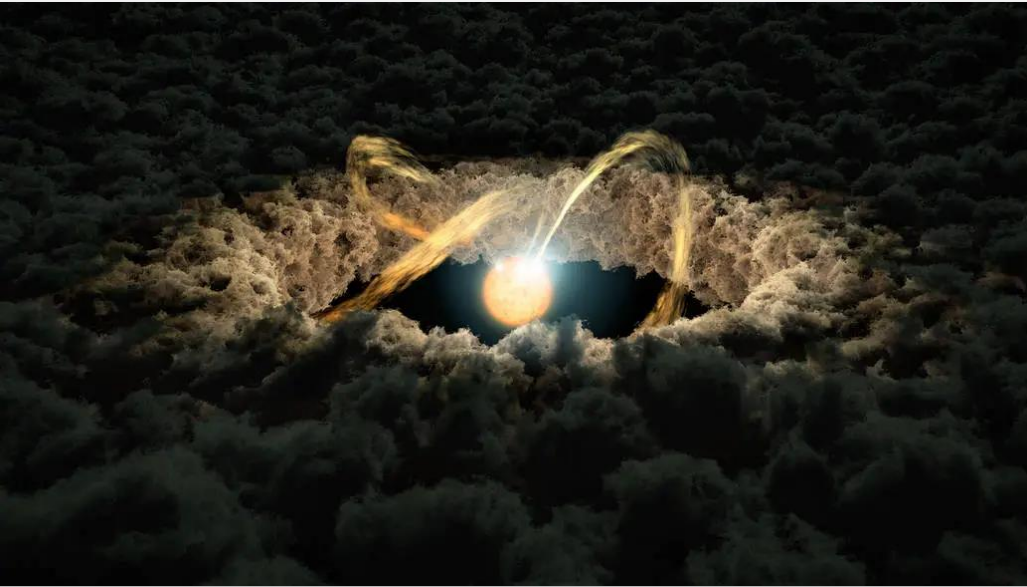


X-ray Binaries

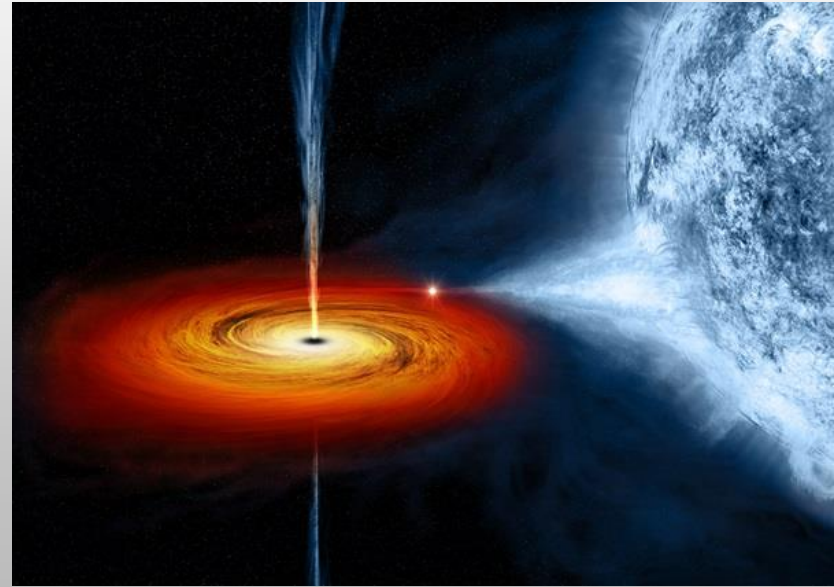


Other disks can also be studied with a large enough aperture to do reverberation on shorter timescales

Protoplanetary Disks

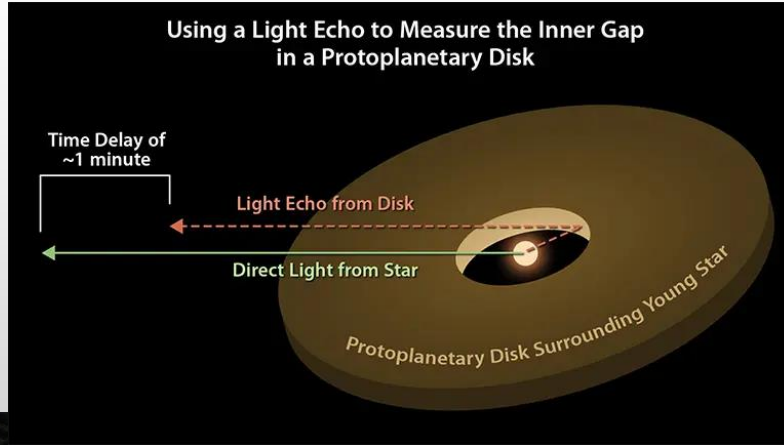


X-ray Binaries



Other disks can also be studied

YLW 16B in the ρ Ophiuchi star-forming region



4.5 μm emission lagged K (2.2 μm) emission by 74.5 ± 3.2 s. Considering the nearly edge-on geometry of the disk, the inner rim should be 0.084 au from the protostar on average, with an error of order 0.01 au.

Meng et al. 2016

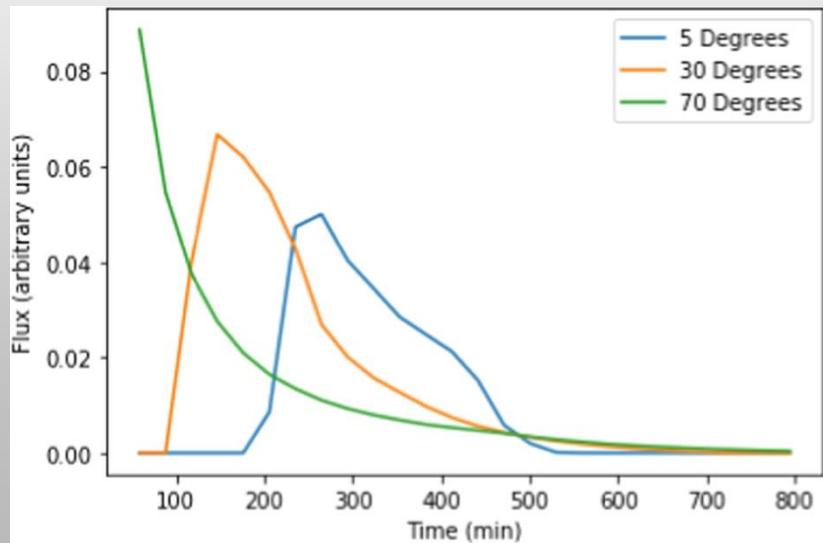


Other disks can also be studied ... like debris disks

Seeking Echoes of Circumstellar Disks in Kepler Light Curves

Benjamin C. Bromley *et al* 2021 *AJ* **162** 98

“With increased sensitivity, echo detection will let time-domain astronomy complement spectroscopic and direct-imaging studies in mapping how, when, and where planets form.”



Simulated echo light curves produced by an extended disk, showing the effect of the inclination of the disk relative to the observer. The light curves were calculated for a disk of inner radius 30 au, outer radius 60 au, mass of $0.5 M_{\oplus}$, and g and v factors for the Draine function of 0.429 and 0.114, respectively (see Draine [2003](#)).

Other disks (and planets) can also be studied

A Framework for Planet Detection with Faint Light-curve Echoes

Chris Mann *et al* 2018 *AJ* **156** 200

“This technique is most sensitive to giant planets within 0.1 au of active flare stars and offers new opportunities for planet discovery in orientations and configurations that are inaccessible with other planet search methods.”

The Direct Detection and Characterization of M-dwarf Planets Using Light Echoes

William B. Sparks *et al* 2018 *ApJ* **854** 134

“Scattered light can reveal the albedo spectrum of the planet to within a size scale factor, and is likely to be polarized. Intrinsic emission mechanisms include fluorescent pumping of multiple molecular hydrogen and neutral oxygen lines by intense Ly α and Ly β flare emission, recombination radiation of ionized and photodissociated species, and atmospheric processes such as terrestrial upper atmosphere airglow and near-infrared hydroxyl emission.”

Other disks can also be studied

1. Since the scales of the disks are so much smaller, much shorter cadence on the order of seconds to minutes is required.
2. BUT to achieve a reliable measurement of reverberation, a high signal to noise is required (SNR ~ 100).
3. The above two requirements lead to an architecture that needs high sensitivity detectors as well as a large aperture...
4. In terms of detector development, this sets a need for fast readout capabilities to achieve these short timescale measurements

Workshop Goals this Talk Addresses

1. Discuss potentially driving science cases for future large, strategic astrophysics missions and connect scientific priorities with technological readiness and mission implementation.
 - A. Transient Follow-up of GRBs, Gravitational Wave progenitors, and SN
 - B. Reverberation on both large and small disks will allow for studies of a crucial component of astrophysics
 - C. General astrophysical monitoring like for comets in our solar system
2. Provide science cases for the broad discussion of potential instrument architectures
 - A. High sensitivity detectors would be needed for best spectroscopic signal to noise
 - B. Fast-readout detectors will be necessary to achieve the time resolution needed to study small scale disks

Workshop Goals this Talk Addresses

3. Distribution of Wavelengths to Multiple Spacecraft: One Potential Scenario
 - A. Gamma Ray and X-ray wavelengths can be one spacecraft
 - B. UV/Optical wavelengths can be one spacecraft
 - C. Near and Mid-Infrared wavelength with passive and/or active cooling can be one spacecraft



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BHAGERA: Wavelength Coverage

Note that the science objective CANNOT be achieved from the ground by observing high z quasars where the UV is redshifted into the optical.

Redshifting the 1400 Å continuum to 4000 Å, requires a $z=1.85$.

The time dilation would be a factor of $1+z= 2.85$. That would mean that to capture the variations that we can see in 3 - 6 months of observations from nearby Seyferts would require nearly 9 - 18 continuous months for a high z quasar.

Furthermore, all variations will inherently be slower because quasars are more luminous and have larger disks and so would need even longer continuous observations. On the longer wavelength end, the 6000 Å light will be shifted to the near-infrared at 17,100 Å.