The *Swift* AGN Accretion Disk Reverberation Mapping Survey: Recent Results and Future Prospects

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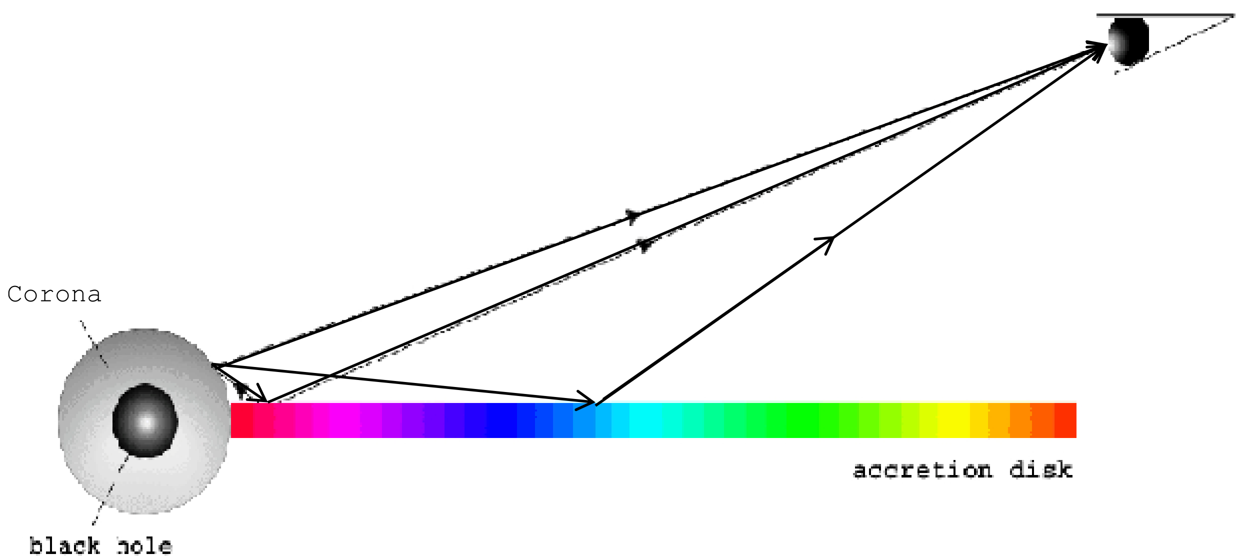
Reverberation mapping the accretion disk

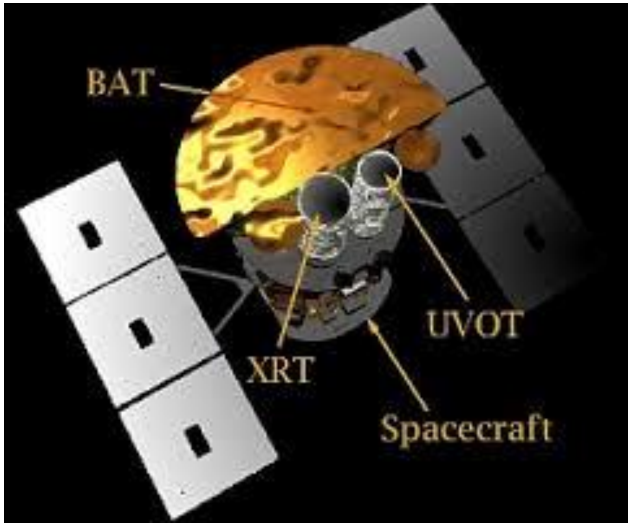
- Can use RM principle to map accretion disk
- Reprocessing: corona illuminates, heats larger disk
  - Thus should expect variability to be correlated, with X-rays leading UV leading optical on day-hours timescale
- Astronomers have been searching for decades for expected lags
  - Model predicts lags go as $\tau = r/c \propto (M\dot{M})^{1/3} T^{-4/3} \propto (M\dot{M})^{1/3} \lambda^{4/3}$



(My modification of an artist's conception of a galactic transient, GRS 1915+105; Rau & Greiner 2013. The physical picture is pretty much the same for AGN.)

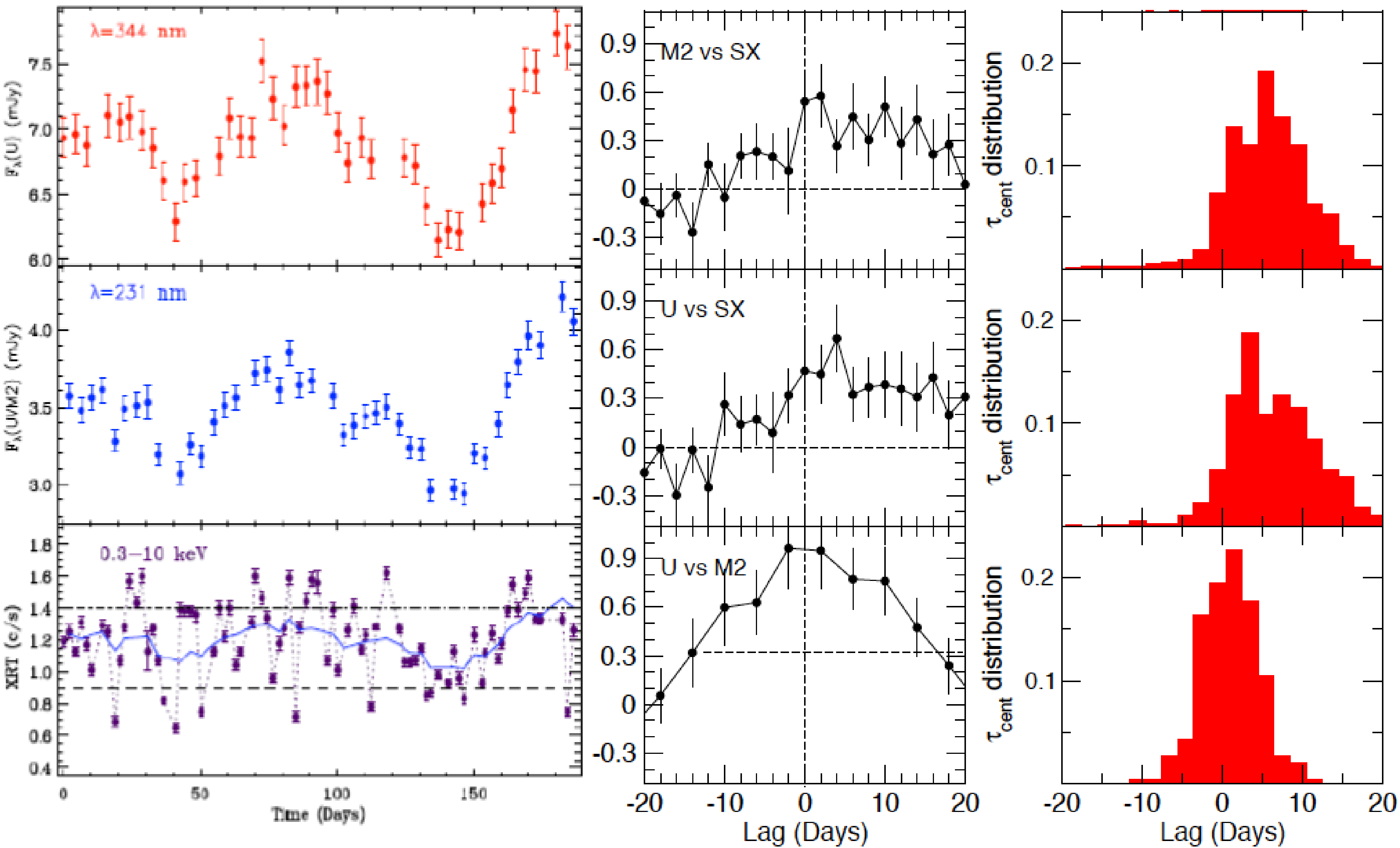
Swift

- Launched in 2004 to study GRBs
  - Large sky coverage, rapid slew
  - Observes ~80 sources/day
  - Broad λ coverage
- UVOT filter wheel has 6 filters covering 1800-5800 A
- XRT covers 0.3-10 keV X-rays
- Mission accomplished long ago, now observes wide range of targets
  - NASA's "time domain observatory"
  - Absolutely ideal for AGN disk RM



Typical early *Swift* AGN disk RM campaign

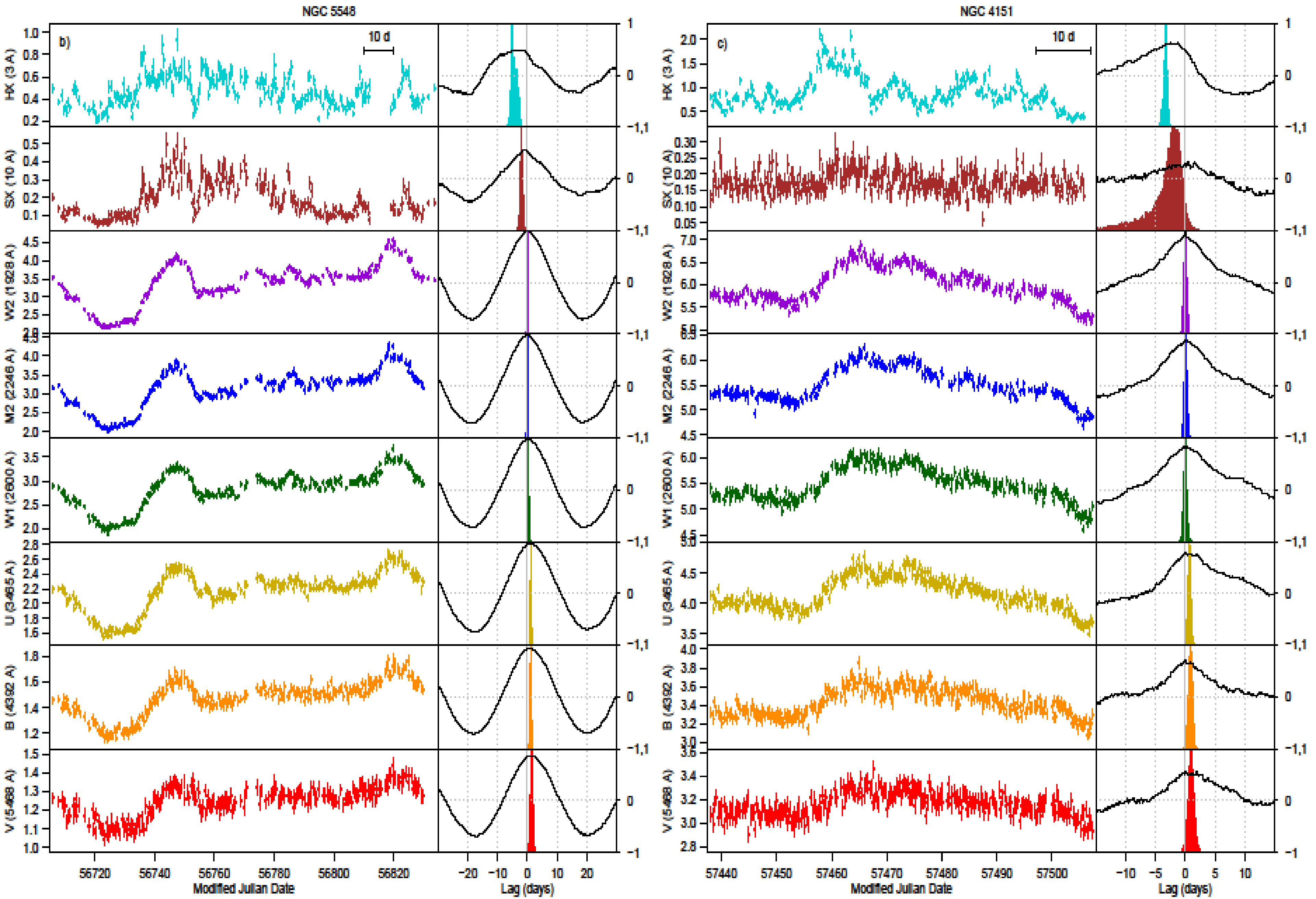
Ark 120 (Gliozzi et al. 2017, MNRAS, 464, 3955)



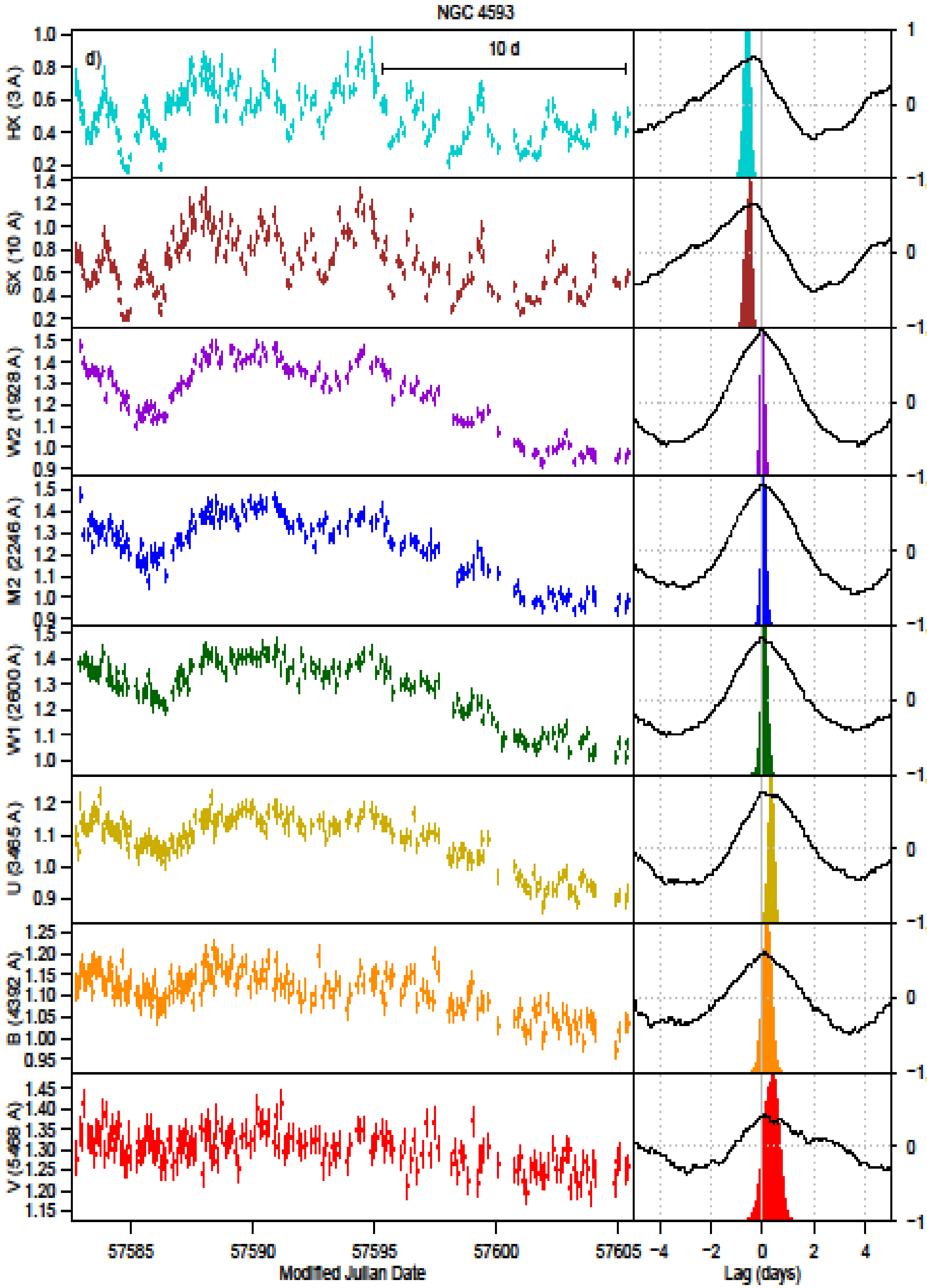
The breakthrough 2012 NGC 5548 campaign

- Early (inconclusive) expts measured X-rays with one instrument (ASCA, RXTE), opt or UV with another (ground-based, HST): highly inefficient and ineffective
- Swift combined these but not optimally used in early years; only 1 or 2 UV/opt bands, low cadence
- Breakthrough: Swift director Gehrels approves TOO, full use of UVOT filter wheel to get 6 bands in opt/UV
  - First target: NGC5548 in association w AGN STORM
  - Next: NGC 4151, NGC 4593, Mrk 509
- This has opened up a new era in AGN monitoring
  - A total of 10 AGN now have IDRM monitoring

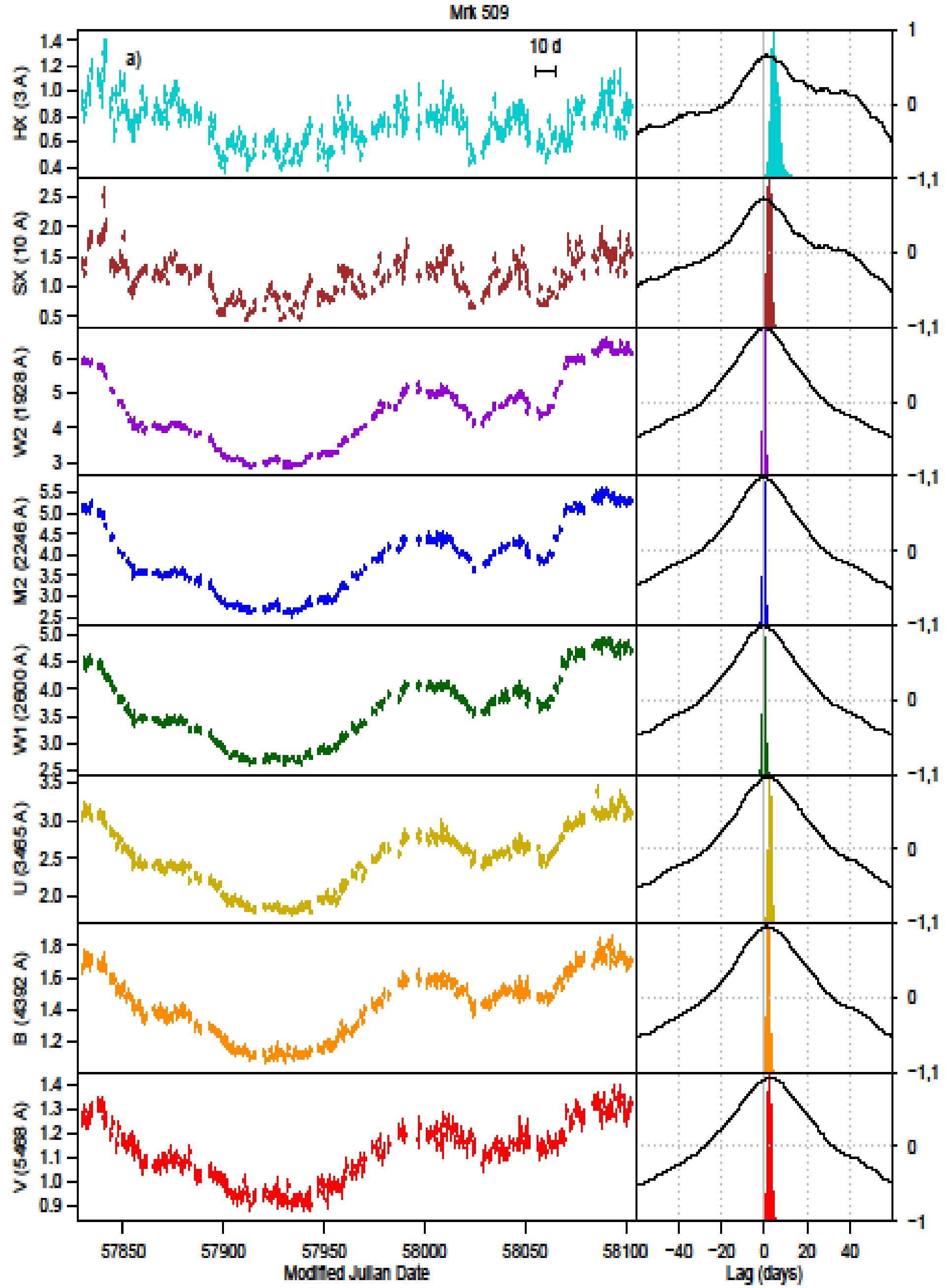
NGC 5548   NGC 4151



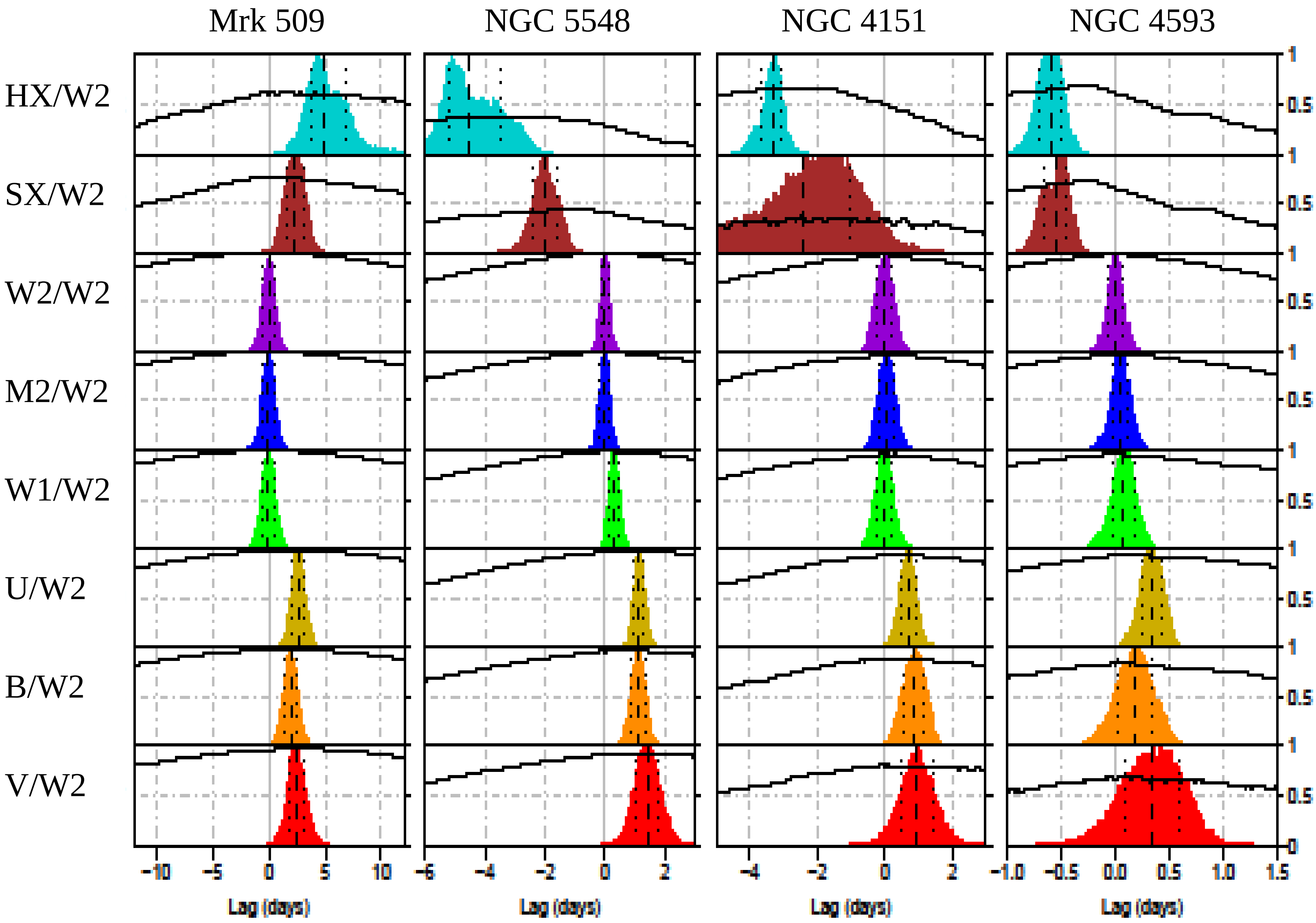
NGC 4593



Mrk 509

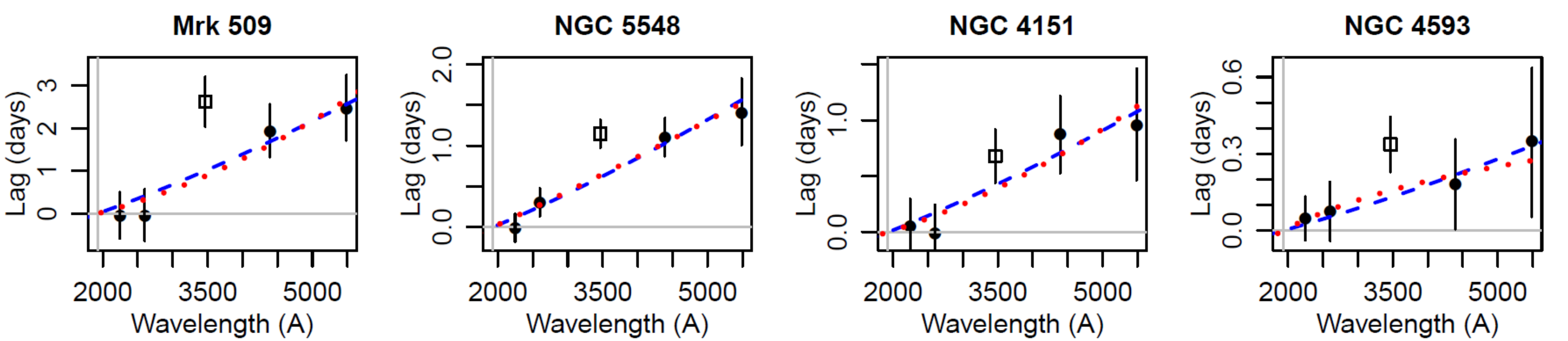


One figure summarizing all Swift AGN IDRM lag results



UV/optical interband lag structure

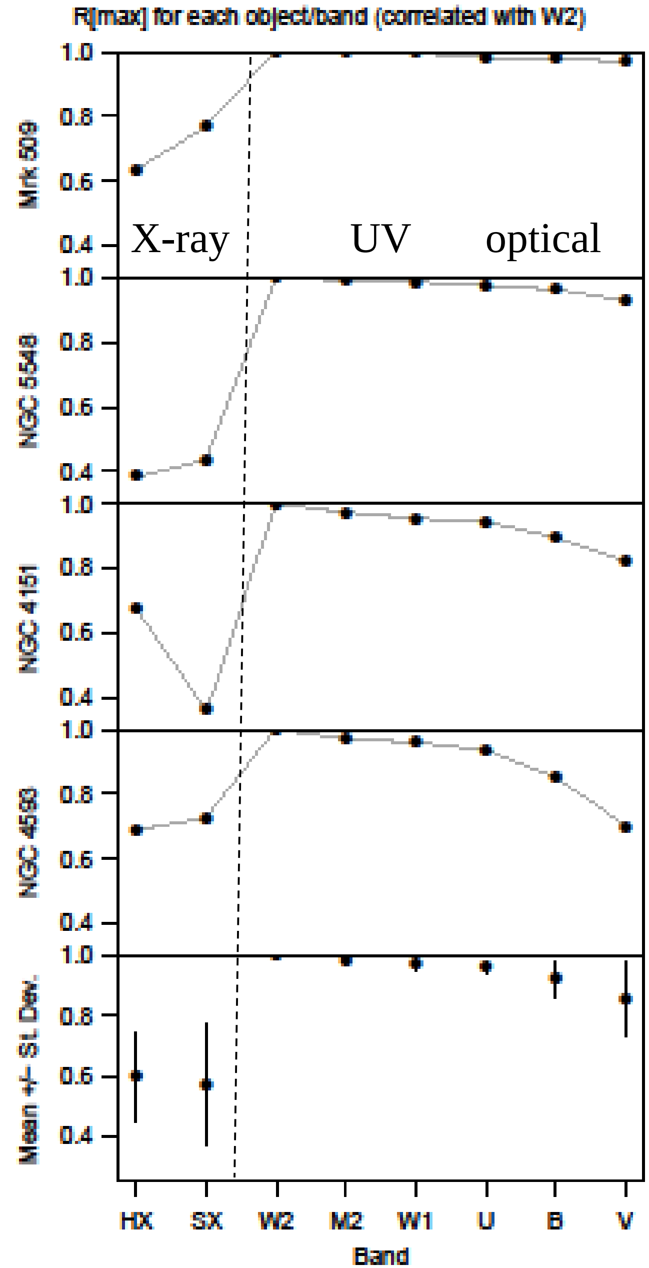
- We can use this small sample of 4 AGN to look for trends by comparing the interband lag behavior
- <u>First finding</u>: all targets show similar behavior within UV/optical:
  - Fitted function (blue dashed line) is $\tau = \tau_0[(\lambda/\lambda_0)^{4/3} - 1]$
  - Excluding U-band (for now), all are well-fitted by $\tau \propto \lambda^{4/3}$
  - Derived disk sizes ($c\tau_0$ at λ_0) appear to scale with L as expected
  - Sizes are a factor of a few too large, but systematic uncertainties on predicted size are quite large
  - Supports the picture of centrally-illuminated thin disk



X-ray/UV interband correlations

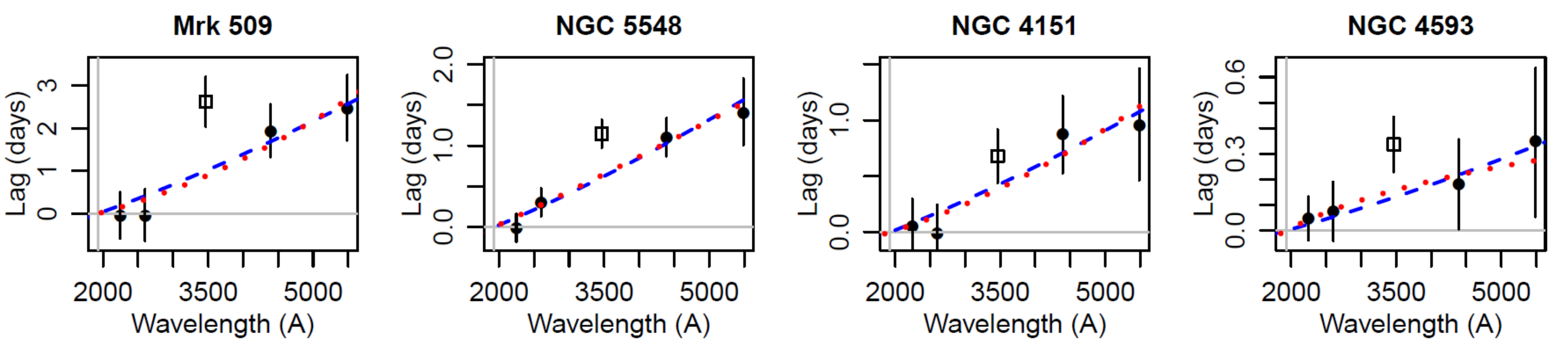
- Plot of measured maximum correlation coefficient (r_{max}) with W2 for 4 AGN
- Bottom panel: mean ± S.D. in each band
- Strong correlations within UV/optical
  - UV/X-ray correlations are **much** weaker
- <u>Second finding</u>: weak/non-existent X/UV correlation not compatible w/ reprocessing
  - Perhaps observed X-rays not the driver

    e.g. due to asymmetry, obscuration
  - Perhaps modified by inward viscous term (e.g., Uttley & Casella 2014)
  - Or perhaps the entire picture is wrong
- Severe challenge to reprocessing picture



Diffuse continuum emission from the BLR

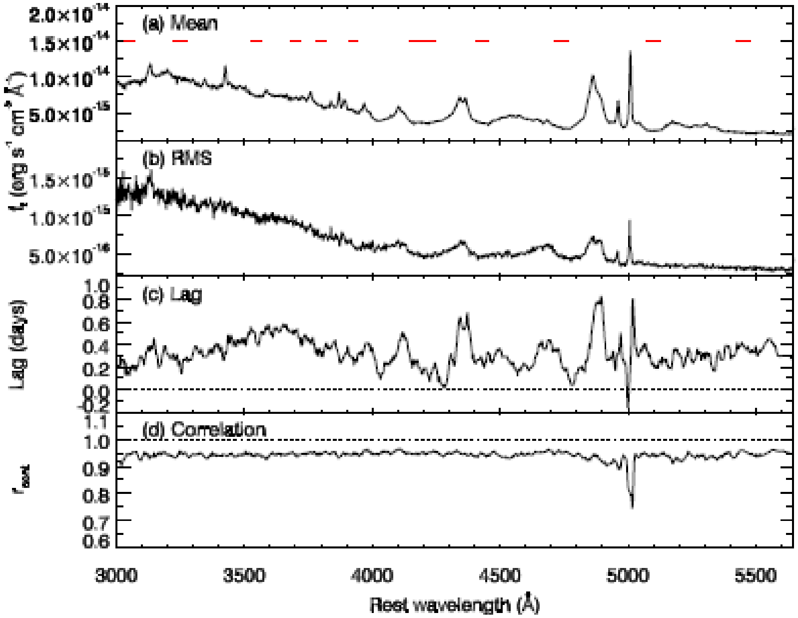
- Why do UV/opt fits show strong U band excess lags?
  - Korista & Goad (2001) noticed hints of this excess in an earlier ground-based campaign on NGC 5548, suggested it was due to diffuse continuum emission (DC) from the BLR
  - Strongest DC feature is the Balmer break (in U band)
- <u>Third finding</u>: DC from BLR strongly contaminates interband lag structure, complicating interpretation
  - DC likely responsible for part (but not all) of the apparent disk sizes being larger than expected, so we need to understand/ remove DC contribution to make further progress on the disk

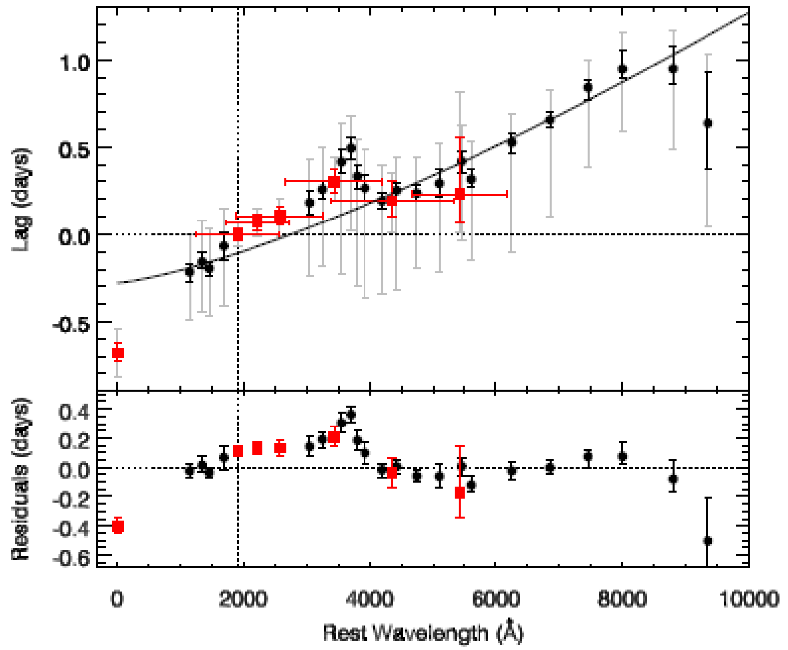


Swift/HST lag spectra of NGC 4593

- Simultaneous Swift/low-resolution HST spectra of one: NGC 4593
  – Cackett et al. 2018, ApJ, 857, 53
- Another synergy: *Swift* provides high time resolution, *HST* spectral resolution
- Lag spectrum: large lags in lines due to BLR being larger than disk
- Also clear, broad excess around 3646 A (Balmer jump) – in U filter
  – A "smoking gun" that BLR emission complicates interband lag interpret.
  – Lawther et al (2018, MNRAS, 481, 533) predicts BLR contamination across entire optical/UV

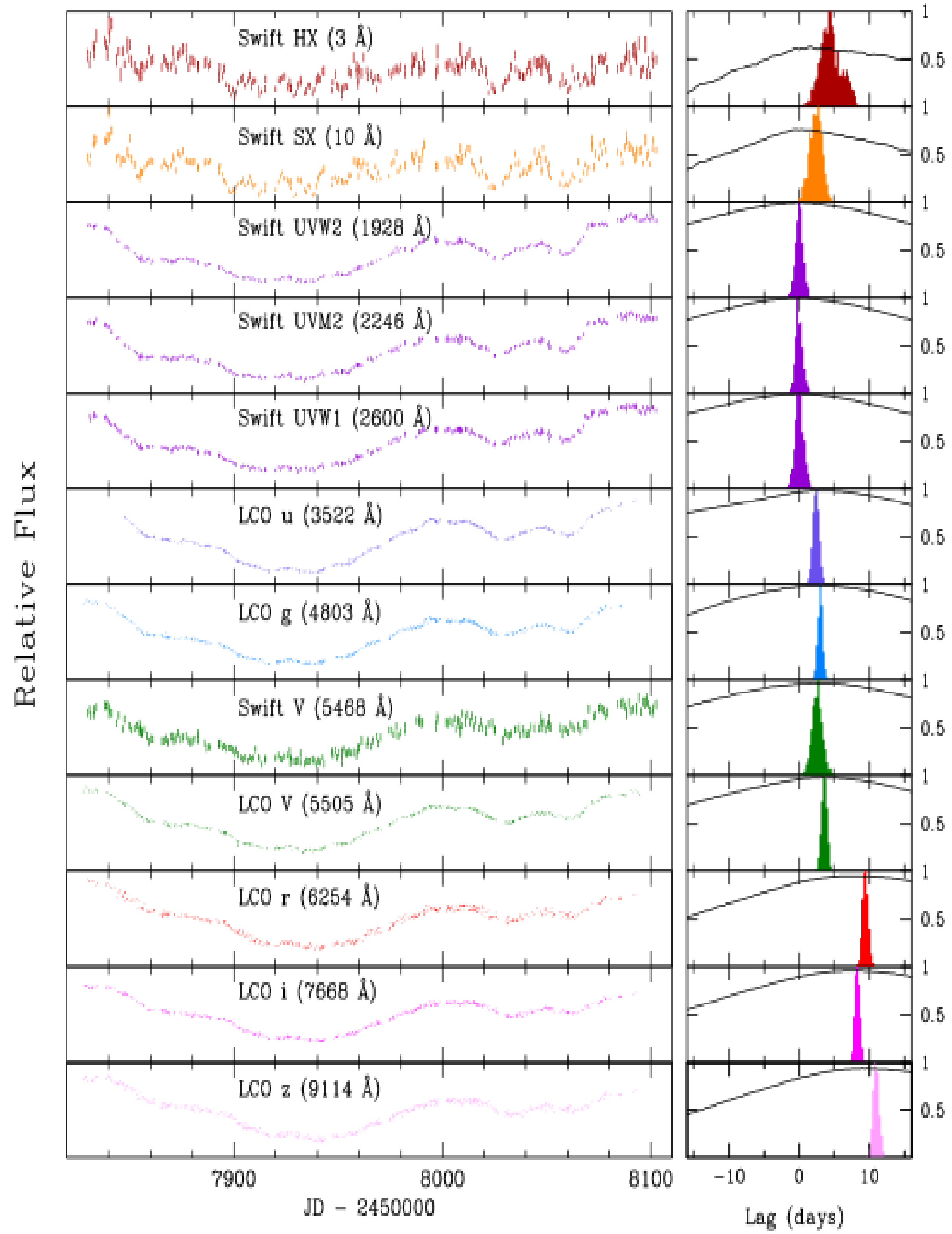
➢We **need** to understand DC emission





Swift's ground-based complement: *LCO*

- *Las Cumbres Observatory*:
  - Network of telescopes at 6 sites around the globe
- Plot shows Mrk 509 Swift and *LCO* data
  - Barth et al. (2019 in prep)
  - Note very clear lag vs wavelength trend over extended wavelength range
- *Swift* & *LCO* have great synergy, large sky coverage needed for AGN IDRM



Intensive disk reverberation mapping (IDRM)

- This is the technique that is allowing a revolution in our studies of AGN central engines
- Three key aspects:

1. Full coverage with Swift XRT, 6-filter UVOT
2. Intensive sampling: minimum 200 visits (even more is even better), scaled with MBH to cover shortest relevant timescales
3. Ground-based griz data at similar/higher cadence
   - LCO is ideal for this

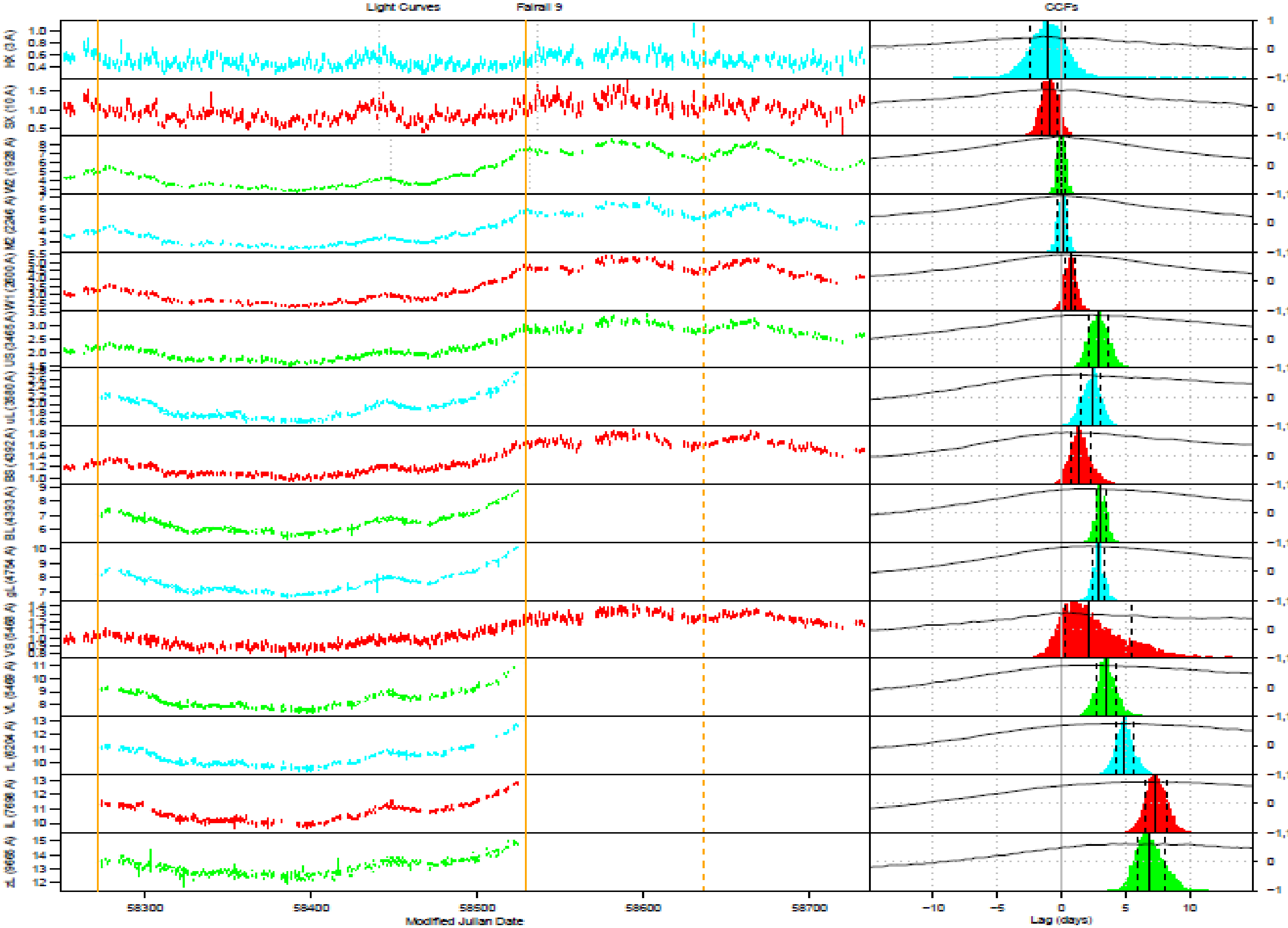
- I am skeptical of approaches that don’t have this level of time/wavelength coverage

Current/future IDRM campaigns

- Now 10 IDRM campaigns in various stages of completion.
  - Amazing when you think IDRM only started in 2012!
- Four published campaigns (Swift Survey, Edelson et al. 2019):
  - NGC 5548, NGC 4151, NGC 4593, Mrk 509
- Three completed campaigns :
  - Mrk 142 (Cackett), discussed at this meeting
  - Mrk 110 (McHardy, Pahari), discussed here
  - Mrk 1220 (Edelson) simul w Kepler – turned out to be a dud
- Three current/upcoming campaigns
  - Mrk 876 (Gelbord): 1 Jun 2019 - 12 Jul 2020, simul with TESS
  - Mrk 335 (Kara): 14 Oct 2019 - 22 Jan 2020, will include XMM
  - Fairall 9 (Edelson): 13 May 2019 - 21 Feb 2020

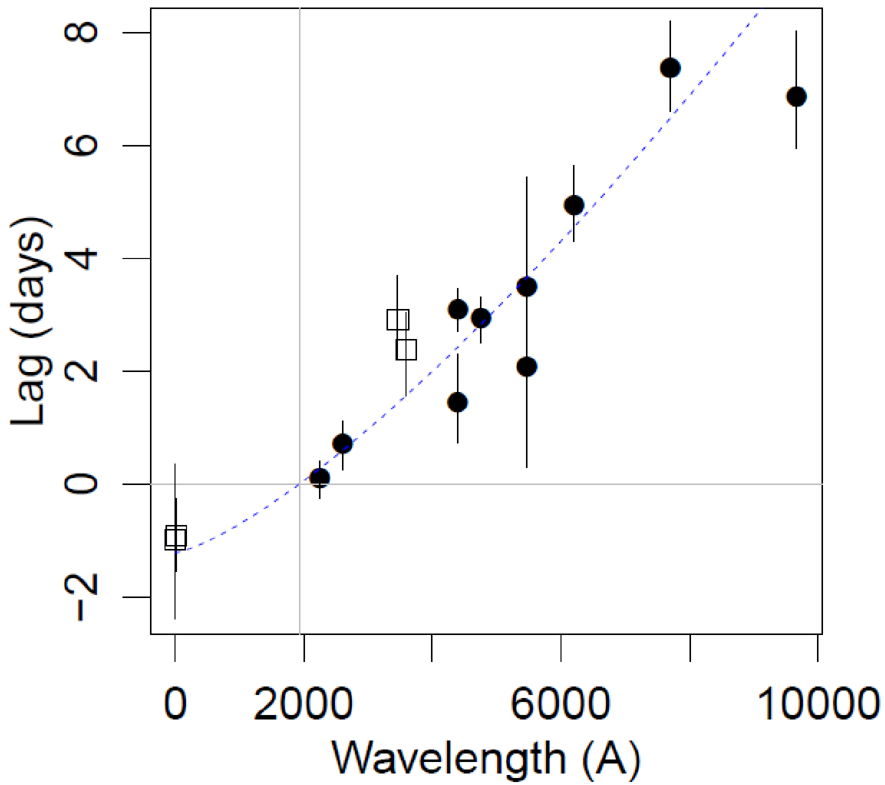
    Will talk more about this fantastic target…

Fairall 9


Light Curves
Fairall 9
CCFs
HX (3 A)
SX (10 A)
W2 (1928 A)
M2 (2246 A)
W1 (2600 A)
US (3465 A)
uL (3580 A)
BB (4392 A)
BL (4393 A)
gL (4794 A)
VS (5468 A)
VL (5469 A)
rL (6204 A)
iL (7698 A)
zL (9665 A)
58300
58400
58500
58600
58700
Modified Julian Date
−10
−5
0
5
10
Lag (days)

Fairall 9

- My current favorite target, being observed for 1.7 yr
  – Swift (1x/day), LCO (3x/day), NICER (as possible)
- "Bare" AGN suggested by Chris Done
- Also high ecliptic latitude: always visible to Swift
- Fit to $\tau = \tau_0[(\lambda/\lambda_0)^{4/3} - 1]$ (first year) yields $\tau_0 = 1.21$ +/- 0.07 days
- Consistent with SS disk
- Strong U band excess
- Weaker X/UV correlation, eye picks out problematic "events."



Current/future IDRM campaigns

- My personal goal is to extend F9 data campaign to get daily coverage w Swift, 3x daily w LCO, for 4+ years
  - This will allow us to study how the disk size changes with flux
  - Best data set to sort out the X/UV relation
- Also important to keep pushing to high L/L_{edd}
  - Right now we only have 1 or 2 such AGN
- Finally we really need to sort out the DE contribution
  - Observationally, this requires HST, which is a problem
  - Also need to make theoretical progress

Summary/Conclusions

- Findings based on 4 earliest IDRM AGN Swift data:
  1. UV/optical well-fitted by extension of standard SS thin disk model, perhaps a bit too large
  2. UV/X-ray correlations not as expected, rules out the simplest reprocessing model
     - Does a more complex model work? Maybe
  3. DC emission from BLR important contaminant
     - We really need to get a handle on this
- We now have 10 IDRM AGN at various stages
  – We have already learned a lot, and I expect we will learn a great deal more with this technique