Reverberation Mapping the Accretion Disk of NGC5548 with intensive *Swift/HST* monitoring

Could *XMM* do a similar experiment?

R. Edelson, J. Gelbord, K. Horne, I. McHardy, B. Peterson, P. Arevalo, A. Breeveld, G. De Rosa, P. Evans, M. Goad, N. Gehrels, D. Grupe, J. Kennea, M. Siegel, S. Vaughan, T. Dwelly, G. Kriss, I. Papadakis, D. Starkey, P. Uttley, S. Young, A. Barth, M. Bentz, W. N. Brandt, B. Brewer, D. Crenshaw, E. Dalla Bonta, A. De Lorenzo-Caceres Rodriguez, K. Denney, M. Dietrich, J. Ely, M. Fausnaugh, C. Grier, P. Hall, J. Kaastra, B. Kelly, C. Kochanek, K. Korista, P. Lira, S. Mathur, H. Netzer, A. Pancoast, L. Pei, R. Pogge, J. Schimoia, T. Treu, M. Vestergaard, C. Villforth, H. Yan, Y. Zu

ApJ, in press, arXiv:1501.05951

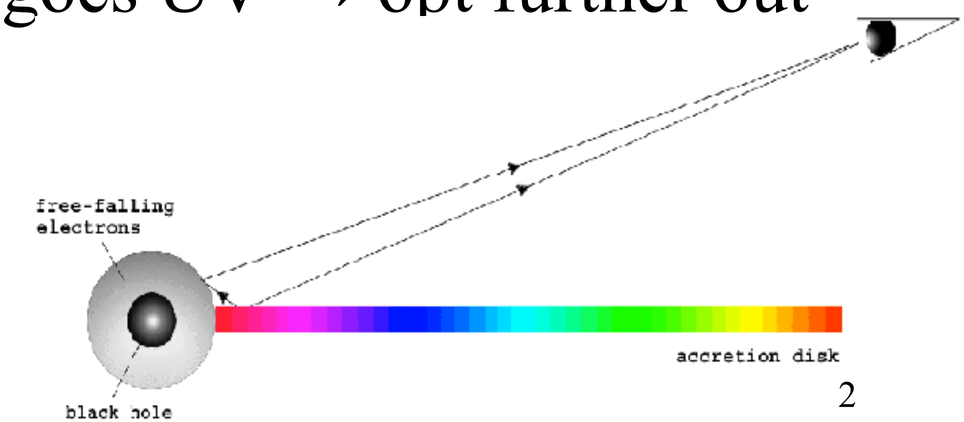
Reverberation Mapping of AGN disks

- AGN RM first proposed by Blandford & McKee (1982)
  - 1989: IUE monitoring of NGC 5548
  - Measure BLR size, structure, orientation, stratification

    Then estimate of AGN central SMBH mass
  - ~50 AGN BLR have now been reverberation mapped
- Can use RM principle to map accretion disk
- Central corona illuminates, heats disk
  - Disk temp ∝ $r^{-3/4}$, peak goes UV → opt further out
  - Search for lags:

    between X-ray and UV

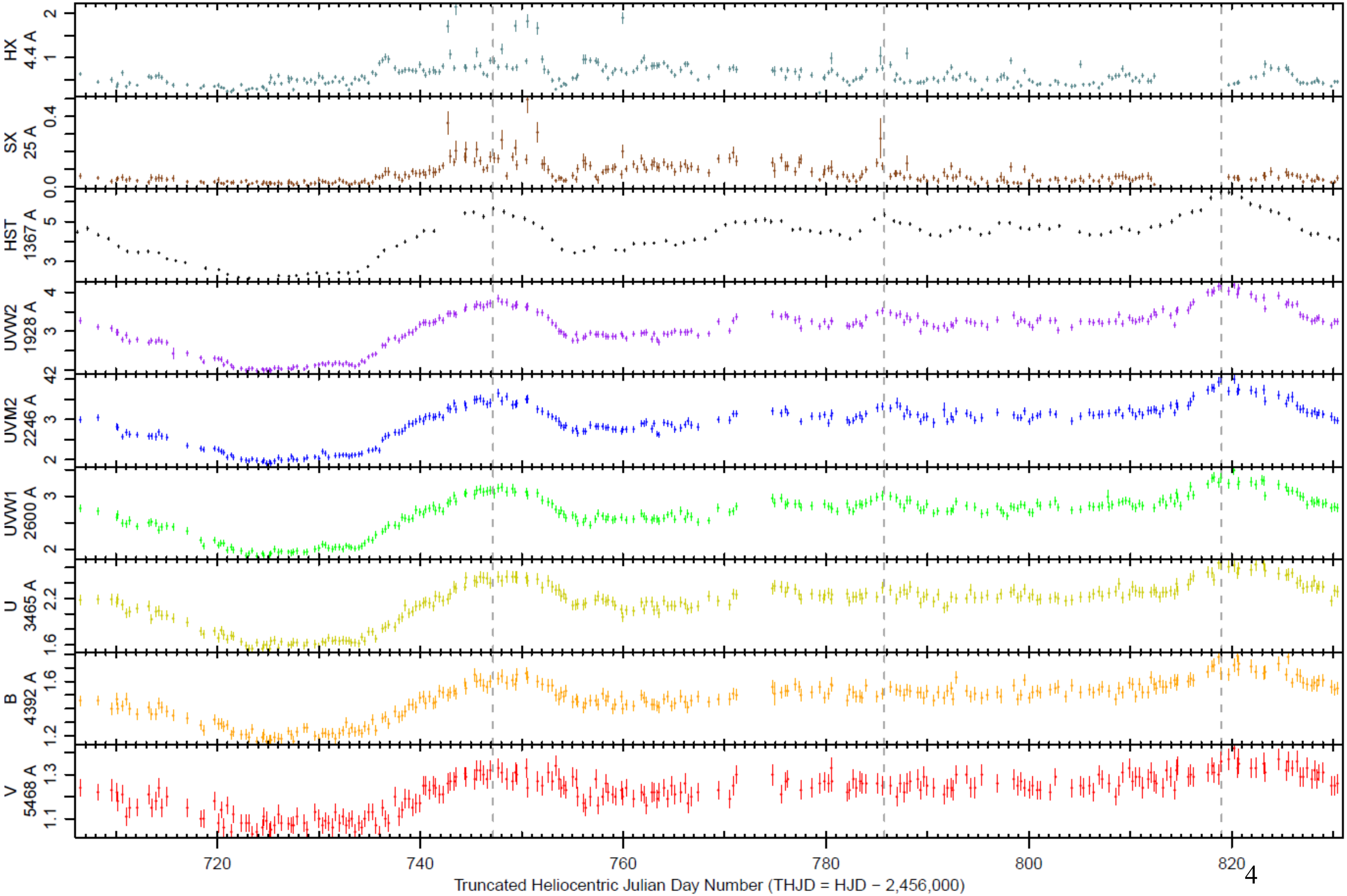
    and within UV/optical



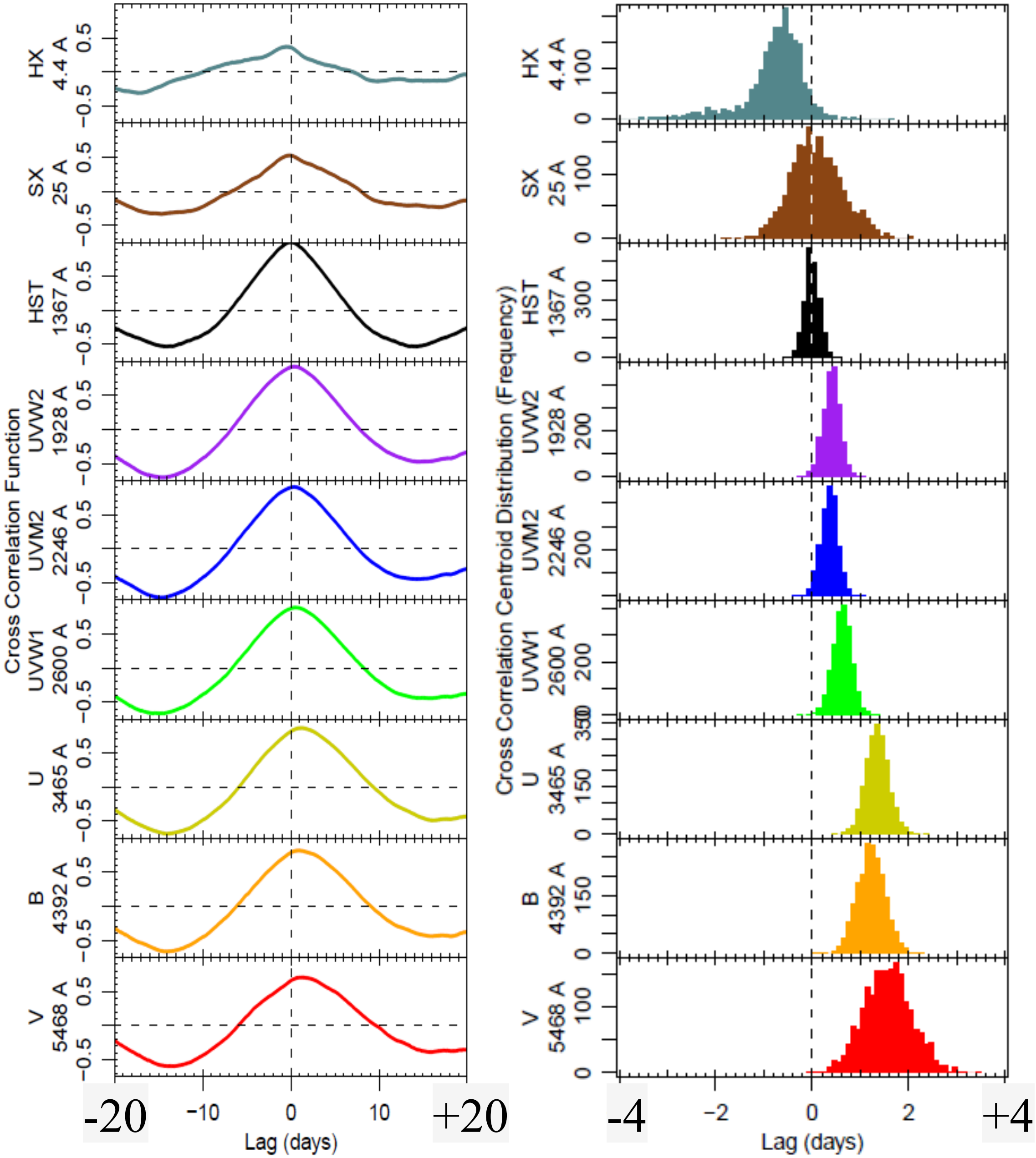
The 2014 NGC5548 *Swift/HST* Campaign

- Previous disk RM results yielded ambiguous results
  - Cadences too long, typically only one UV/opt band
- Solution: intensive multiband monitoring with *Swift*
  - Target: NGC 5548 (everyone's favorite AGN)
  - Sampling: ~0.46 day over 125 days (~280 samples)
  - UVOT 6 bands: UVW2, UVM2, UVW1, U, B, V
  - Also daily HST sampling to get 1367 A continuum
- Also much broader, finer wavelength coverage
  - Seven bands covering 1367-5500 A in optical/UV
  - Two X-ray bands: SX (0.3-0.8 keV), HX (0.8-10 keV)

XRT/HST/UVOT Light Curves



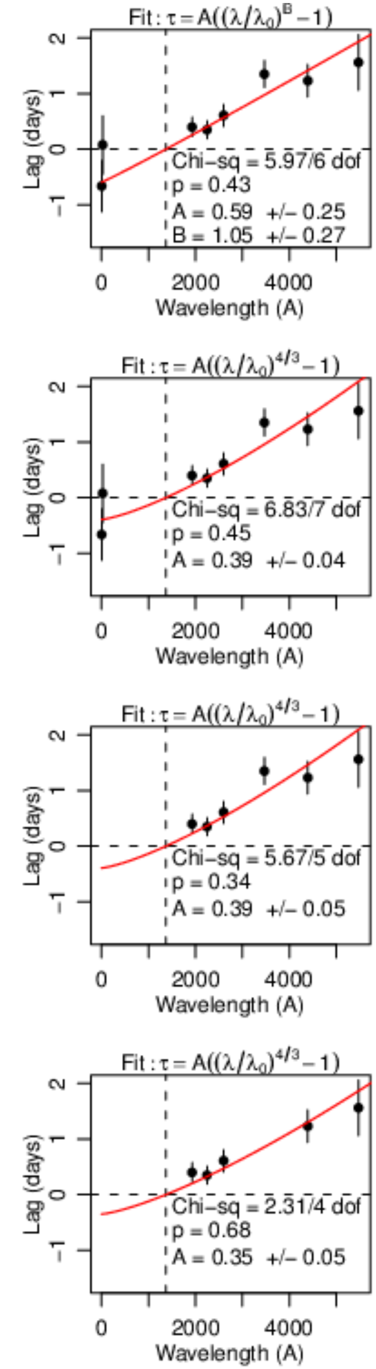
Interband Cross Correlations



- CCF: *left*
  - all relative to HST
  - ICCF (Peterson)
- CCPD: *right*
  Cross Correlation Peak Distribution
  - FR/RSS errors
- Strong correlation within UV/opt
- Lag (τ) increases w/ wavelength (λ)
- Weak w/X-rays

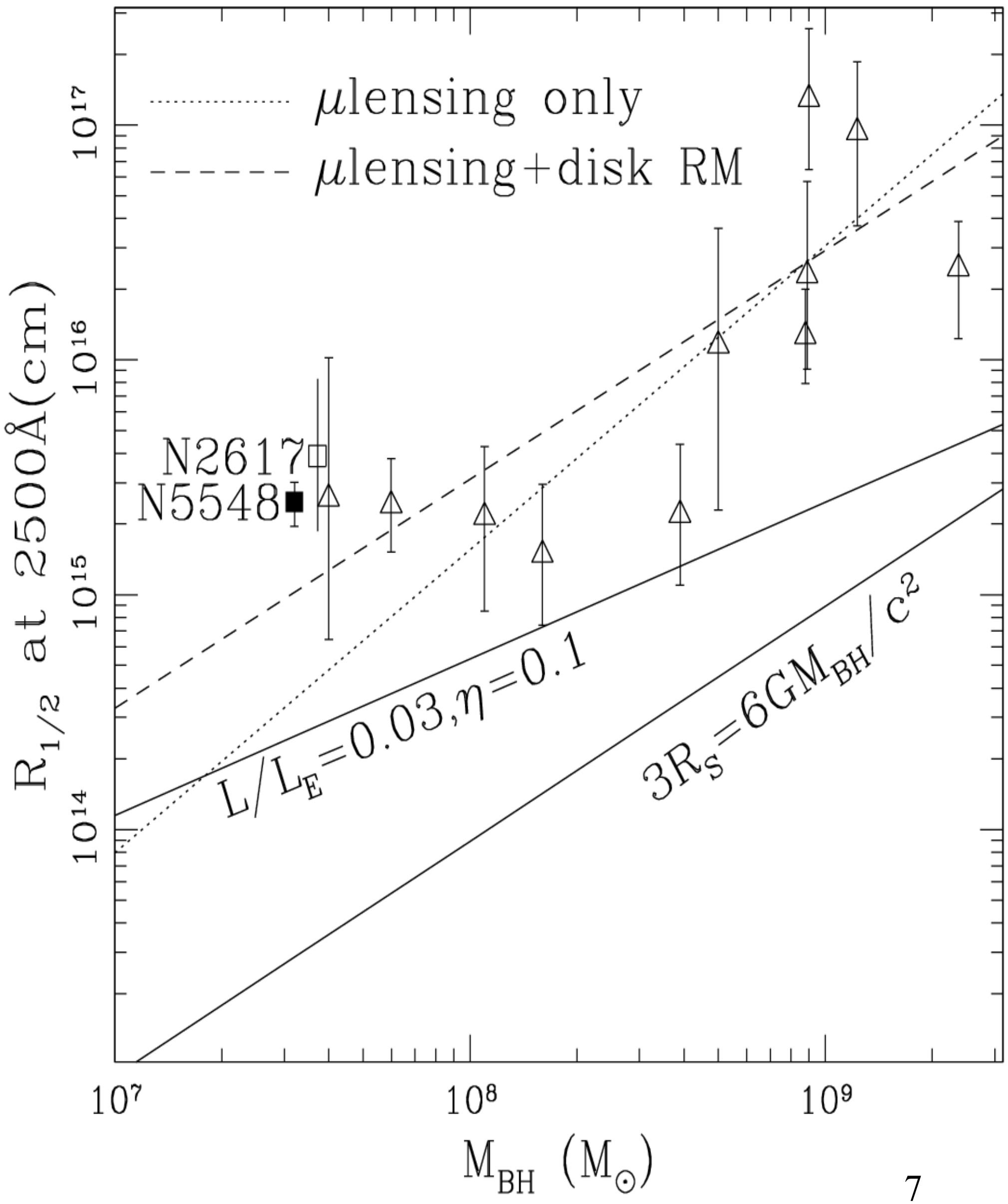
Lag vs. Wavelength

- All relative to HST λ_0=1367 A (dashed line)
- *A*: effectively $\lambda = 0 \rightarrow$ 1367 A interband lag
- Top: Slope (*B*) free = 1.05 ± 0.27
  - barely consistent (1σ) with $\tau \propto \lambda^{4/3}$
  - fit parameter *A* poorly determined
- 2nd: Fix *B* = 4/3 yields very similar χ_ν^2, p
- 3rd: ignoring X-rays has no effect
- 4th: slight improvement by ignoring U-band
  - may be Balmer continuum from BLR
- Final *A* = 0.35 $\rightarrow$ R = 0.35 lt-day @ 1367 A
  - simple face-on disk model, does not account for blackbody



AGN Mass vs. Disk Size Relation

- Combine RM 0.35 lt-day at 1367A w/ grav. microlensing sizes
- Correlate accretion disk size w/ BH mass
- Near linear slope (0.98 w/ large errors) → disk size ∝ mass
- No info < $3 \times 10^7\ M_S$
- Key test at low masses ($\sim 10^6$-$10^7\ M_S$), short timescales (0.01-0.1 d)

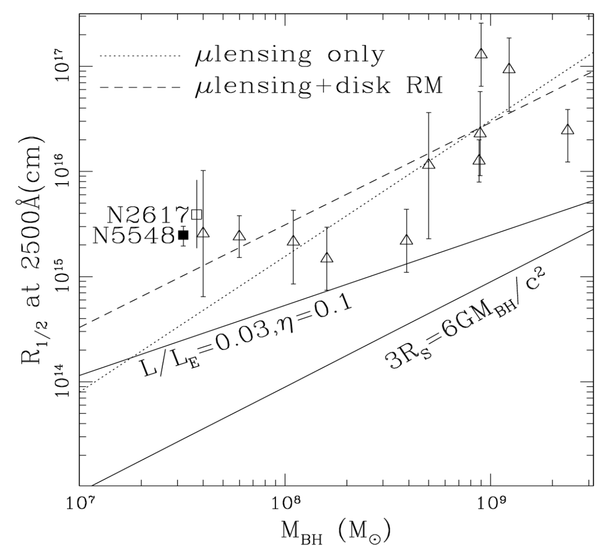


What range of lags/masses can Swift probe?

- No rigorous way to answer "what range of interband lags could we have detected," so this will be a bit qualitative
- We probably could go ~1.5 shorter or ~10 longer
- We also can change Swift sampling to cover instead a factor ~3 shorter or factor of ~2 longer
- So scale *A* = 0.35 day factor of ~5 shorter, ~20 longer:
  - Swift can be used to measure lags A = 0.07 – 7 day
- Scale NGC 5548 BH mass linearly Swift sensitive to $6 \times 10^{6}\ M_S$ – $6 \times 10^{8}\ M_S$
- Most important to go to lower masses, where disk size-BH mass scaling cannot be probed with Swift

Can XMM probe these low masses?

- Assume 1 revolution. Start with long timescale limit:
  - Scale (1.5/125) * 0.35 day *10 = 0.04 day (maximum)
  - Factor of 17.5 shorter; scale mass linearly with lag: $M_{BH} = 3.2\text{x}10^7\ M_S / 18 = 4\text{x}10^6\ M_S$
- Short TS limit function of cadence
  - Assume 800 sec → 160 cycles
    → dynamic range is 15*160/280
    → range is factor of = 8
    → limit is 0.005 day
    or $0.5\text{x}10^6\ M_S$



Swift →

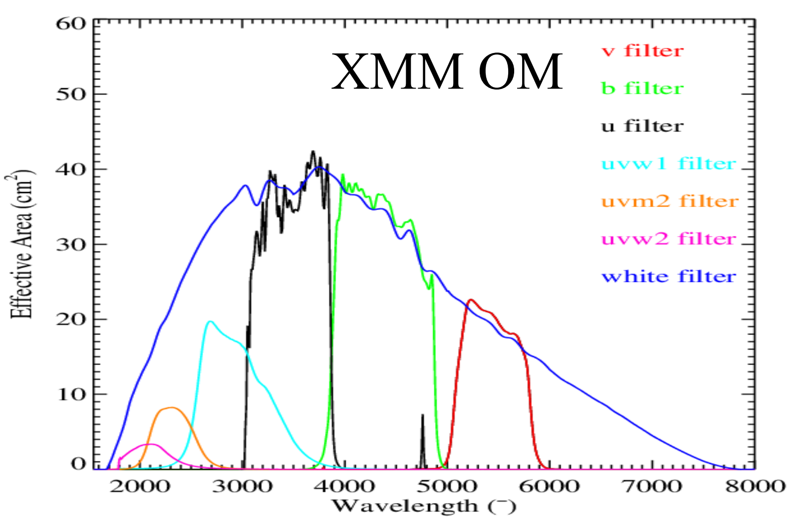
XMM →

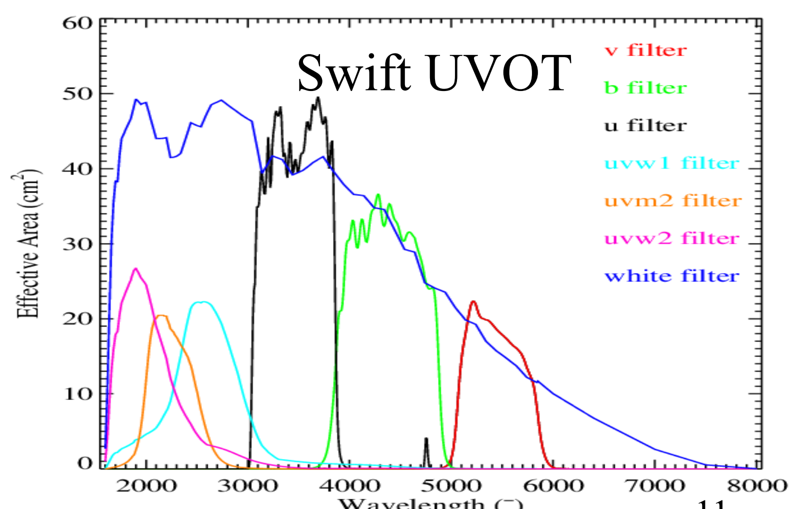
Baseline Experiment

- OM cycles through UVW1/U/B/V for 1 full revolution
  - 200 sec in each filter → 800 sec sampling rate
  - total 160 cycles in 130 ks (NGC 5548 Swift got ~280)
- XMM cover key short and low masses that Swift cannot!
- Good candidates in range, e.g NGC 4051 (~2 x10^6 M_S)
- But can this be done?

Is OM technically able to do this experiment?

- XMM OM nearly the same as Swift UVOT
  - identical design, built by same group (MSSL)
- One difference: OM has weaker UV response than UVOT
  - only UVW1, U, B, V are viable for the XMM OM
  - this will affect the power of the test
- Effective area curves below have the same scale





This would violate OM rules

- RPS users manual (5.2.4.5): filter wheel exposure sequence must have increasing position numbers

  → no more than one cycle per visit

  – Goal is safety: minimize number of filter wheel moves
- Is this necessary? XMM OM has done approximately ~50,000 filter moves, Swift UVOT ~500,000 moves

  – UVOT has made ~10x as many moves as the OM!
- There is also a minimum 800 sec integration time

  – may be software limit, I'm just not sure
- ***Question: should OM be allowed to exceed these limits under rare, specifically justified circumstances?***

Revised Experiment

- Go from say 1 → 3 revolutions, still use UVW1/U/B/V
  - Typically get 1.5 days per 2 days
  - 800 sec in each filter → 3.2 ksec sampling rate
    → 40 cycles per revolution
  - Add Swift every orbit in the ~12 hr gaps (8 more)
  - (40+8)*3= 144 samples (not quite even) / 6 days
- Add 90 HST orbits (15/day for 6 days) to get mid-UV
  - 4 times the duration → 4 times the mass of 1 rev expt.
  - We can study (about) 2×10^6 - 2×10^7 M_S
  - This is the sweet spot we want to study

OM Productivity (Risk/Reward)

- XMM has 5,100 papers in database as of 23 May 2015
  - Of these 3,186 list one instrument (EPIC, RGS, OM)
    Others have either none (1,347) or 2+ (567) listed
- EPIC leads with 3,000 (exactly), RGS has 149 papers
- OM has 37 papers (1.2% of total)
  - Conservative operation means we can only take a snapshot in time (or do Ian's single-band experiment)
  - Important science can be done if we can make a movie
- No other telescope can reach the high time resolution and optical/UV wavelength coverage of the XMM OM

Still photo vs movie?

- Currently OM can only take a "color picture"
  - One image in each filter, then monitor in last filter
  - This cannot observe the propagation of signal outward in the accretion disk
- We need to get a "color movie"
  - We can watch an impulse move out from hot, inner disk to cool, outer disk
  - This requires cycling through multiple filters
- Is the risk worth the reward?

Conclusions

- Swift has now demonstrated that we can do disk RM
- We are finding larger disks than expected, consistent with lensing sizes yielding roughly linear scaling.
  - Next: M. Fausnaugh et al., D. Starkey et al., in prep.
- Swift can probe BH masses down to ~ $6x10^6$ M_S
- XMM could probe smaller masses (up to $2x10^7$ M_S)
  - would extend the disk size-mass relation much further
  - continue ground-breaking science in XMM's 2nd decade
- Would also require new rules for OM filter movements
  - This decision can only be made by project team, based on technical feasibility/risk assessment