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

Could $XMM$ do a similar experiment?


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 $\propto r^{-3/4}$, peak goes UV $\rightarrow$ opt further out
  – Search for lags:
    between X-ray and UV
    and within UV/optical
The 2014 NGC5548 \textit{Swift/HST} Campaign

- Previous disk RM results yielded ambiguous results
  - Cadences too long, typically only one UV/opt band
- Solution: intensive multiband monitoring with \textit{Swift}
  - Target: NGC 5548 (everyone's favorite AGN)
  - Sampling: \approx 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 $\lambda_0 = 1367$ A (dashed line)
- $A$: effectively $\lambda = 0 \rightarrow 1367$ A interband lag
- Top: Slope ($B$) free = $1.05 \pm 0.27$
  - barely consistent ($1\sigma$) with $\tau \propto \lambda^{4/3}$
  - fit parameter $A$ poorly determined
- 2nd: Fix $B = 4/3$ yields very similar $\chi^2$, $p$
- 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 $\propto$ mass
- No info < 3x10$^7$ 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 $6 \times 10^6 M_\odot – 6 \times 10^8 M_\odot$

• 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 \((1.5/125) \times 0.35 \text{ day} \times 10 = 0.04 \text{ day}\) (maximum)
  – Factor of 17.5 shorter; scale mass linearly with lag:
    \(M_{\text{BH}} = 3.2 \times 10^7 \text{ M}_\odot / 18 = 4 \times 10^6 \text{ M}_\odot\)

• Short TS limit function of cadence
  – Assume 800 sec → 160 cycles
    → dynamic range is \(15 \times 160 / 280\)
    → range is factor of = 8
    → limit is 0.005 day
    or \(0.5 \times 10^6 \text{ M}_\odot\)

\[\text{Swift} \rightarrow \quad \text{XMM} \rightarrow\]
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_☉)

• 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) $2 \times 10^6 - 2 \times 10^7 \text{M}_\odot$
  – 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 $\sim 6 \times 10^6 M_\odot$
• XMM could probe smaller masses (up to $2 \times 10^7 M_\odot$)
  – 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