STORM2 - Variability in the multi-year, multi-wavelength monitoring of Mrk817

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Vasto Accretion meeting – 01/07/25

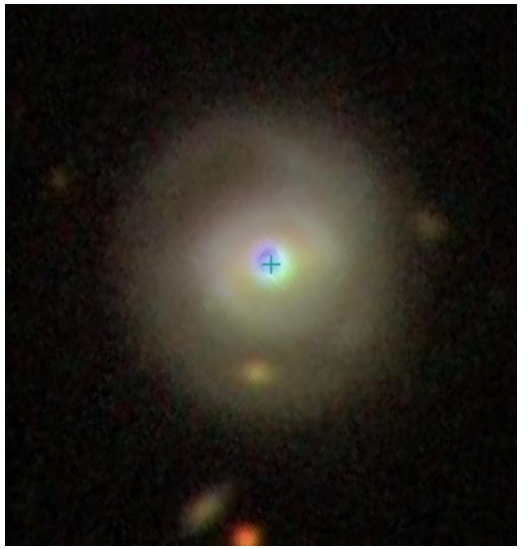
THE STORM2 COLLABORATION



~60 people from 20+ institutes across the US and Europe!

Space **T**elescope and **O**ptical **R**everberation **M**apping program **2**

Multi-year, multi-wavelength monitoring of Mrk817



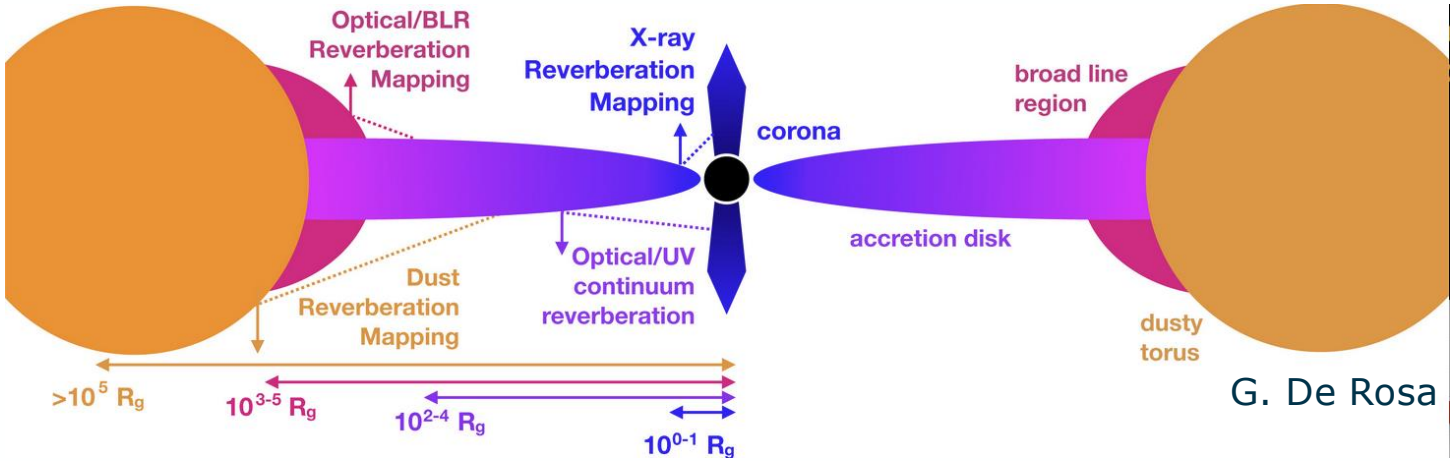
REVERBERATION MAPPING

The ionizing continuum varies rapidly and stochastically

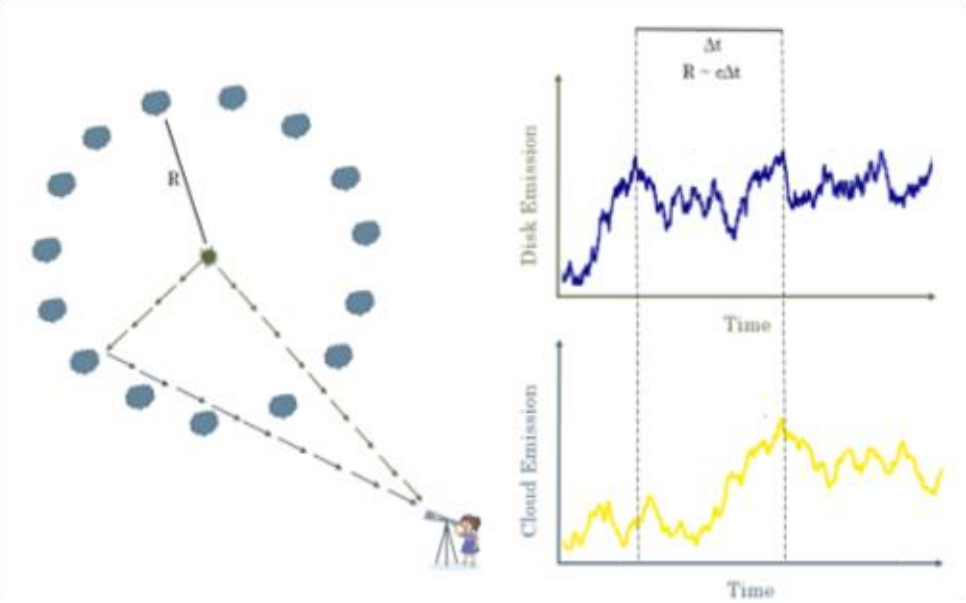
Gas responds to flux variations on a scale t = R/c

We can estimate R from a measurement of the response timescale

Different wavelengths give us information about different regions of the AGN



G. De Rosa



https://jhoormann.github.io/

REVERBERATION MAPPING

We can use RM to

- Test the X-ray corona 'lamp-post' model
- Test the accretion disk size (SS73)
- Measure the size (and shape) of the Broad Line Region
  - Measure SMBH masses $M_{BH} = f\ R\ v^2/G$
- Constrain the dusty torus properties

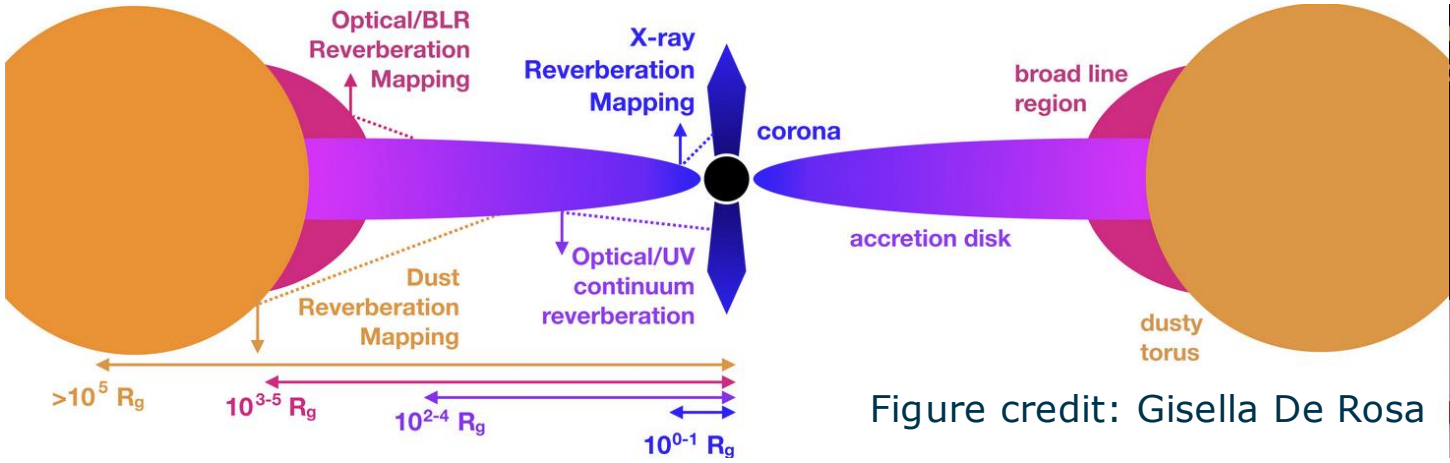
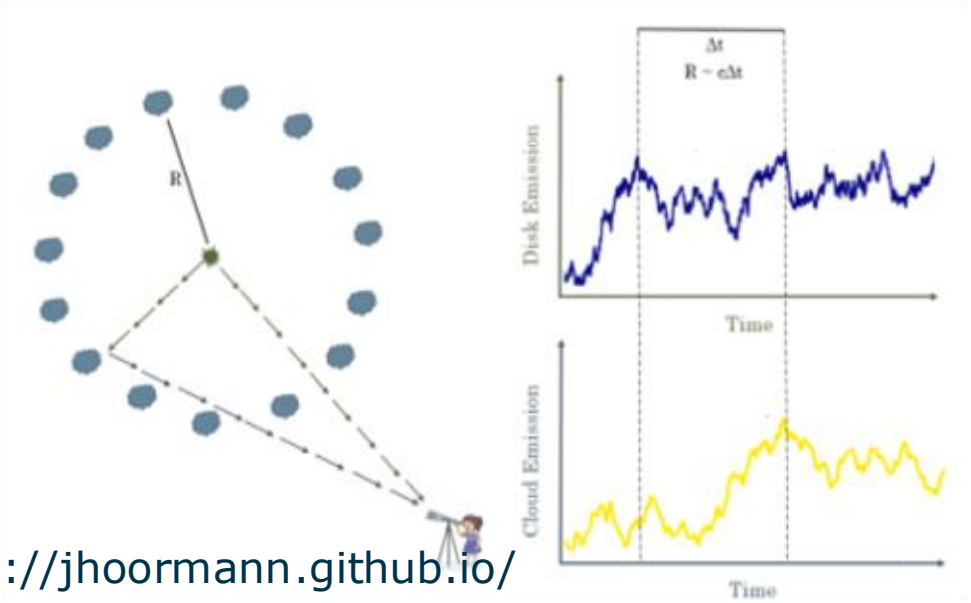


Figure credit: Gisella De Rosa



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REVERBERATION MAPPING

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- Constrain the dusty torus properties

Simultaneous, multi-wavelength analysis is fundamental to get a clear picture of this complex scenario

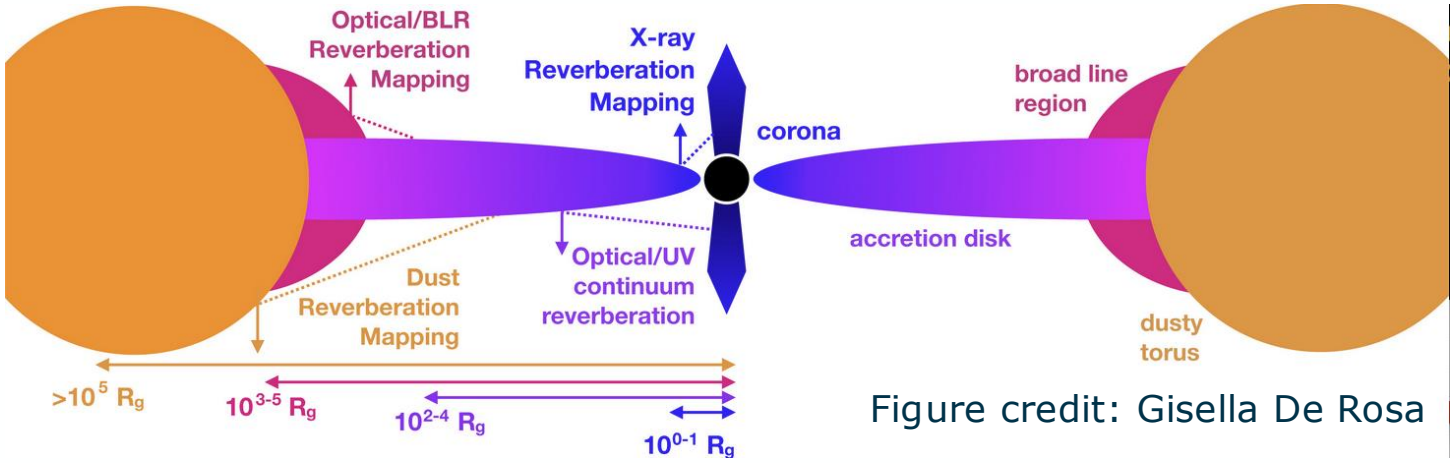
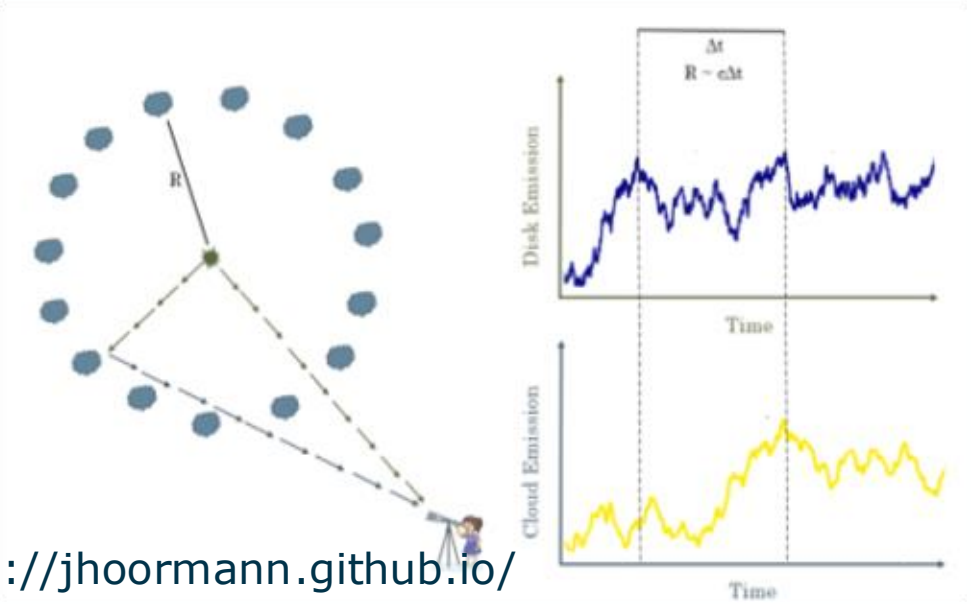


Figure credit: Gisella De Rosa



https://jhoormann.github.io/

THE STORM1 COLLABORATION

Multi-year, multi-wavelength, multi-epoch monitoring of NGC5548, started in 2014

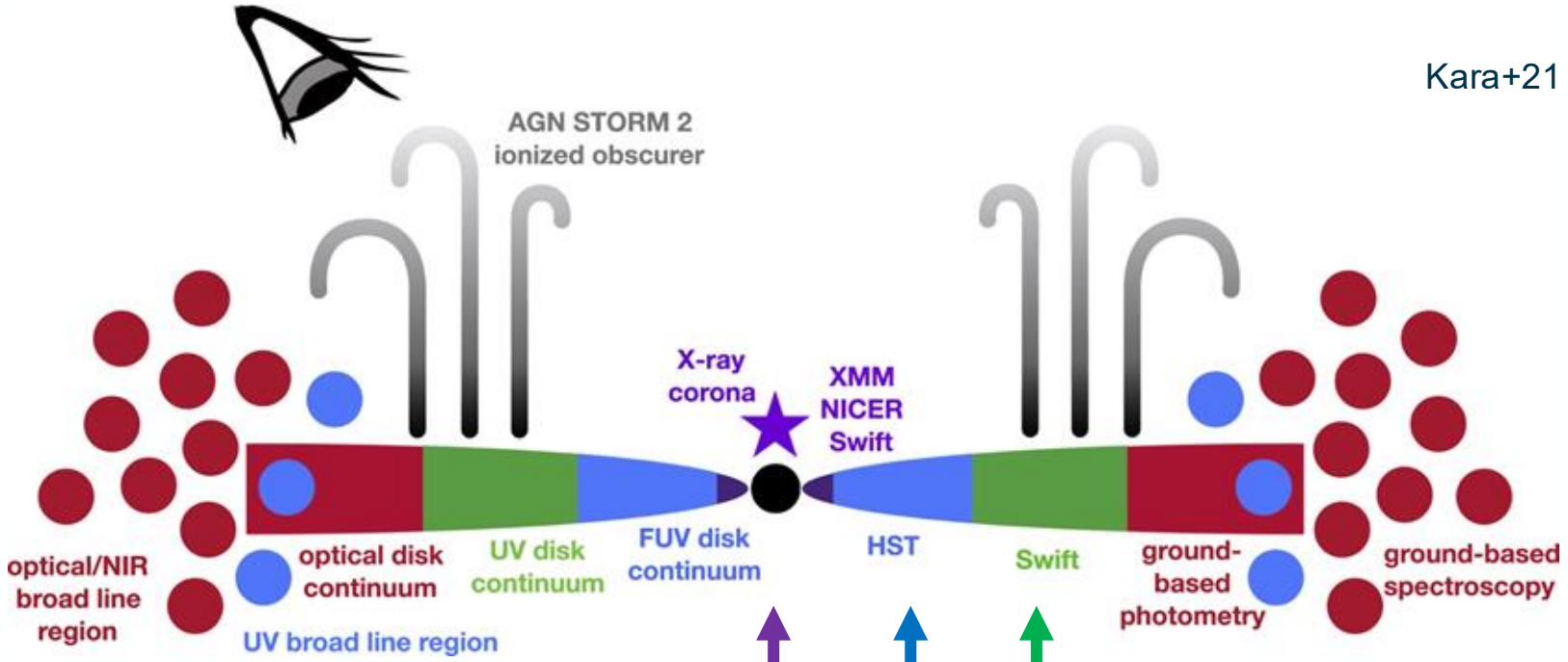
Main results include the discovery of an unexpected obscurer, which complicated lag determination both for the continuum and the emission lines

Mrk817 was chosen for the STORM2 project as

- It has a similar SMBH mass to NGC5548, but higher Eddington ratio
- It is observable year-round from many observatories
- There was no previous history of obscuration



THE STORM2 COLLABORATION



Kara+21

X-ray: XMM+NuSTAR (4 visits)

NICER (every other day) & Swift (daily)

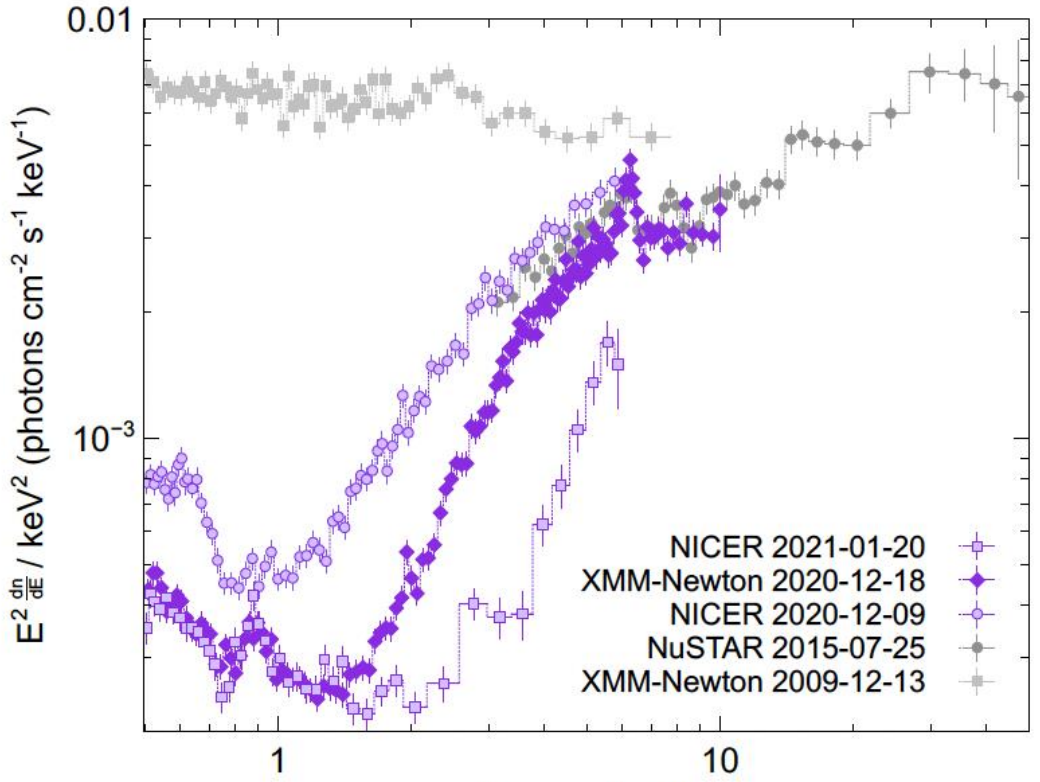
FUV: HST/COS, 2-day cadence, 2020-11-24 to 2022-02-28+ HST/STIS coordinated w/XMM monthly monitoring until June 2024

NUV: Swift daily, HST/STIS (5 visits)

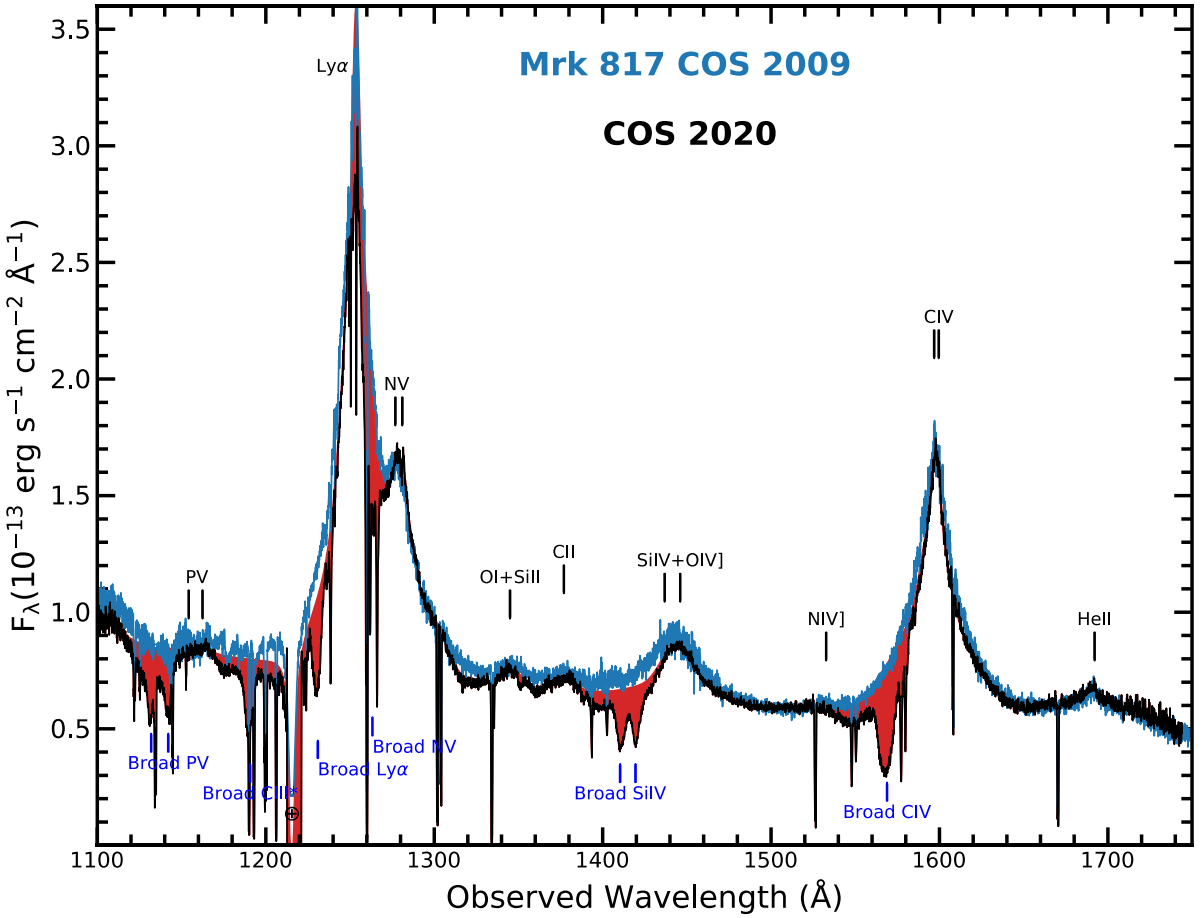
Optical+NIR: Ground-based monitoring using multiple observatories daily + HST/STIS

THE STORM2 COLLABORATION

Unexpected results!
Strong absorptions in the UV + obscured X-ray spectrum... another obscurer!

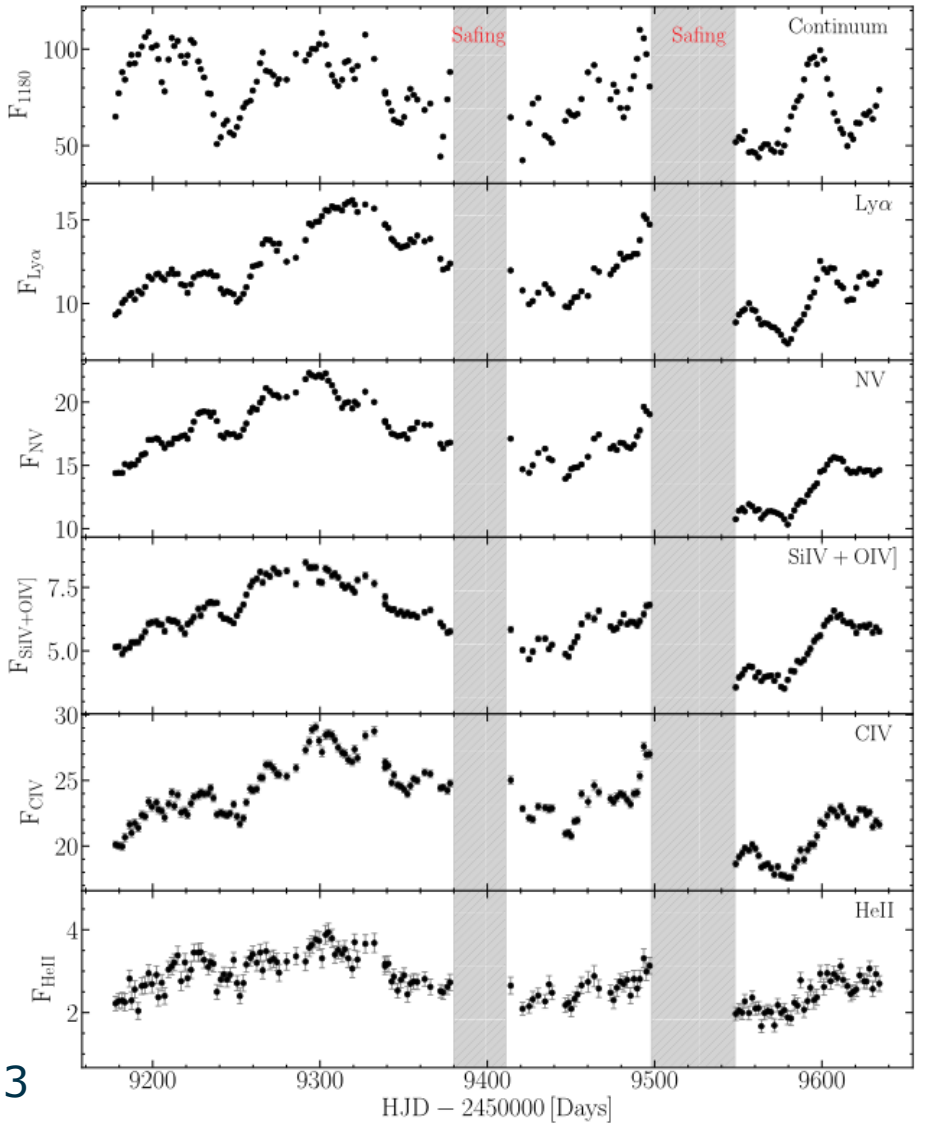


Kara+21



THE BROAD LINE REGION

- UV emission lines show **periods of disconnection** from the continuum ("BLR holiday") → suggest obscured view of the ionizing continuum (Kara+21, Homayouni+23,24).

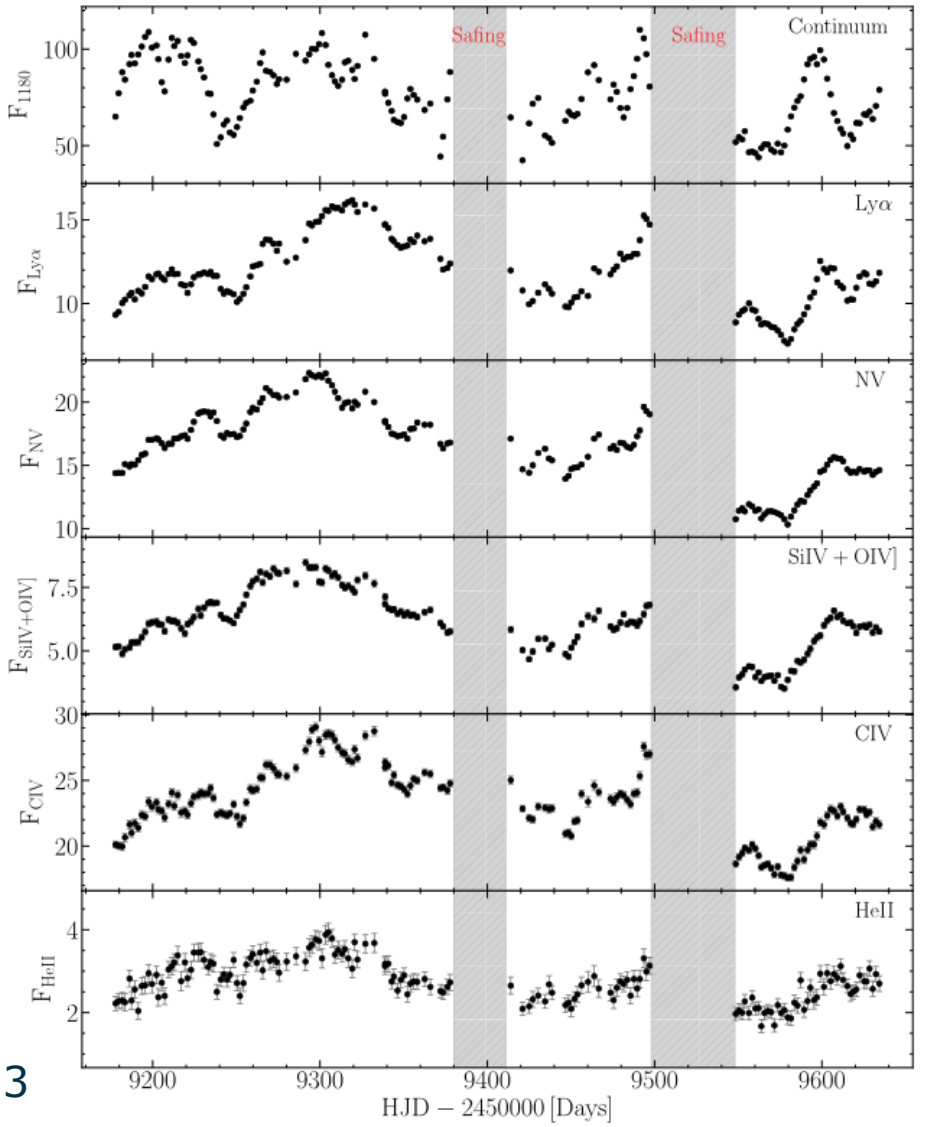


Homayouni+23

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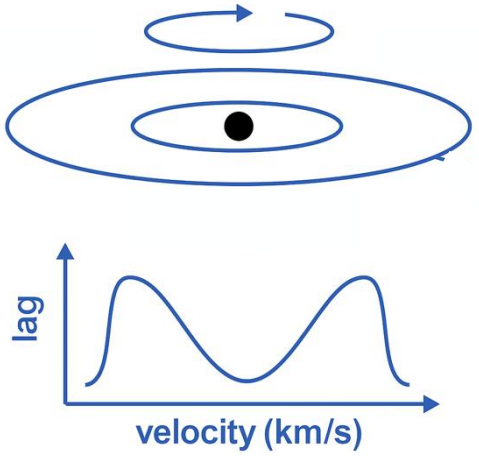
- Interpretation: BLR is not always seeing the same SED as we do, there is a transient obscurer inside the BLR that creates the disconnection

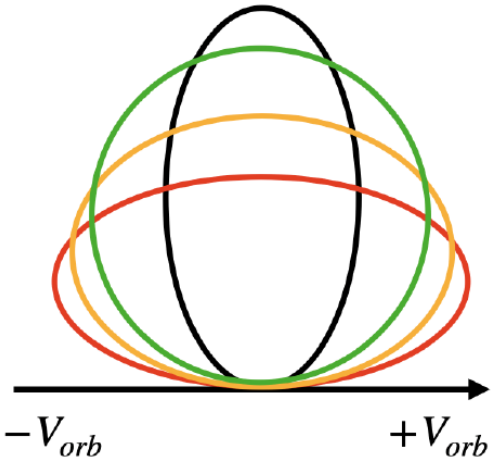


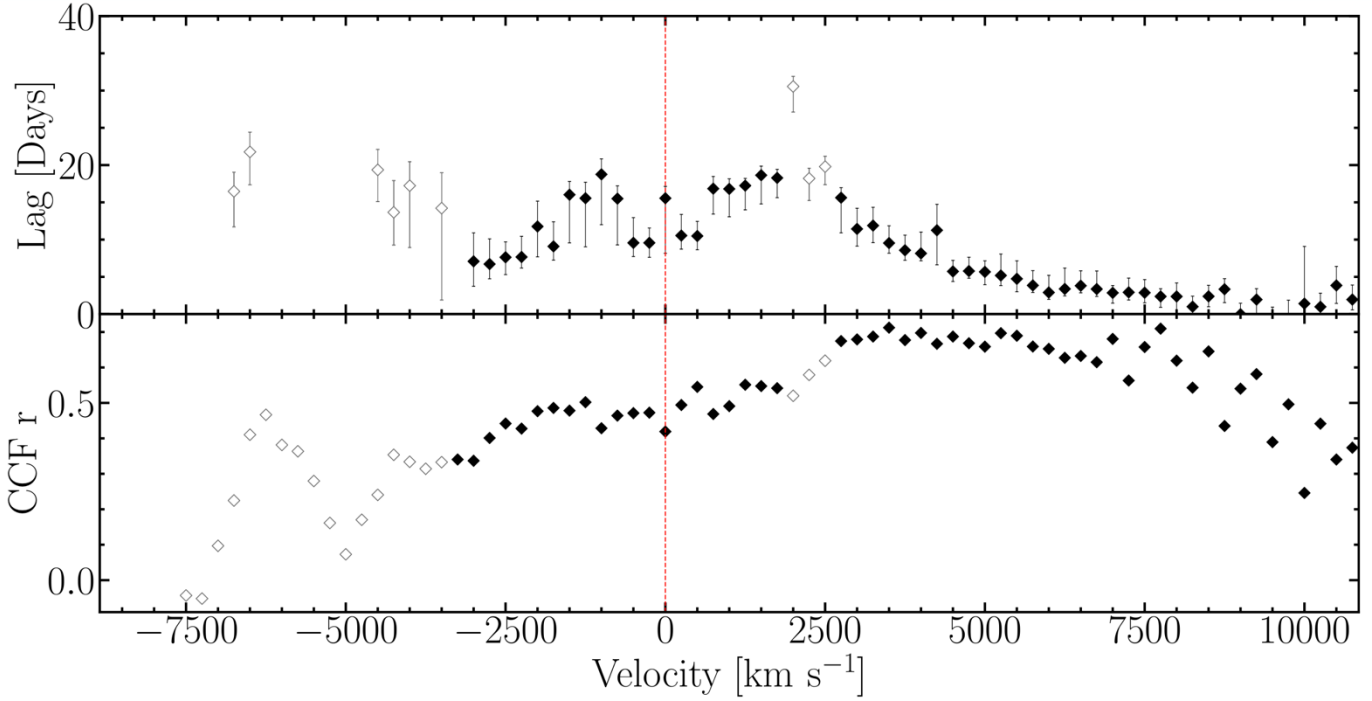
Homayouni+23

THE BROAD LINE REGION

- Velocity-resolved lags: we see the 'M' shape corresponding to a rotating, virialized disk
- The 'weird' BLR behaviour likely comes from obscuration, not geometry







Homayouni+23

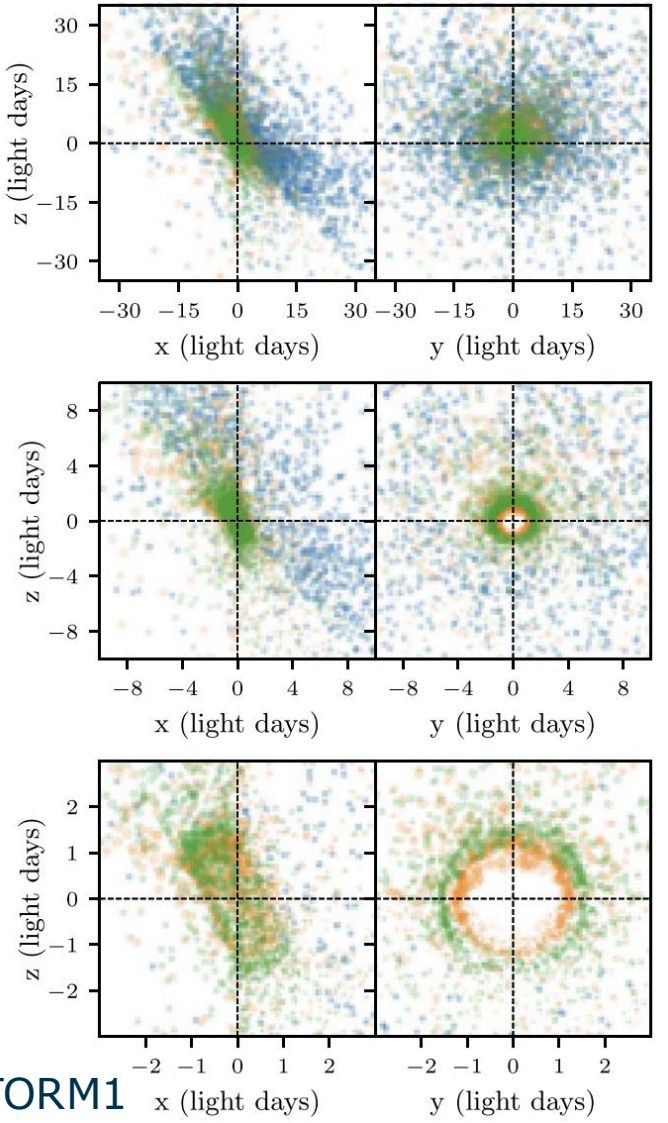
THE BROAD LINE REGION

Work-in-progress:

Dynamical modeling of the BLR with CARAMEL

- The BLR is modelled as a collection of 'clouds' that re-process continuum emission
- The MBH, the geometry and the kinematics of the BLR are all free parameters

- We are currently testing which portions of the lightcurve can be used, as the model assumes no obscuration!

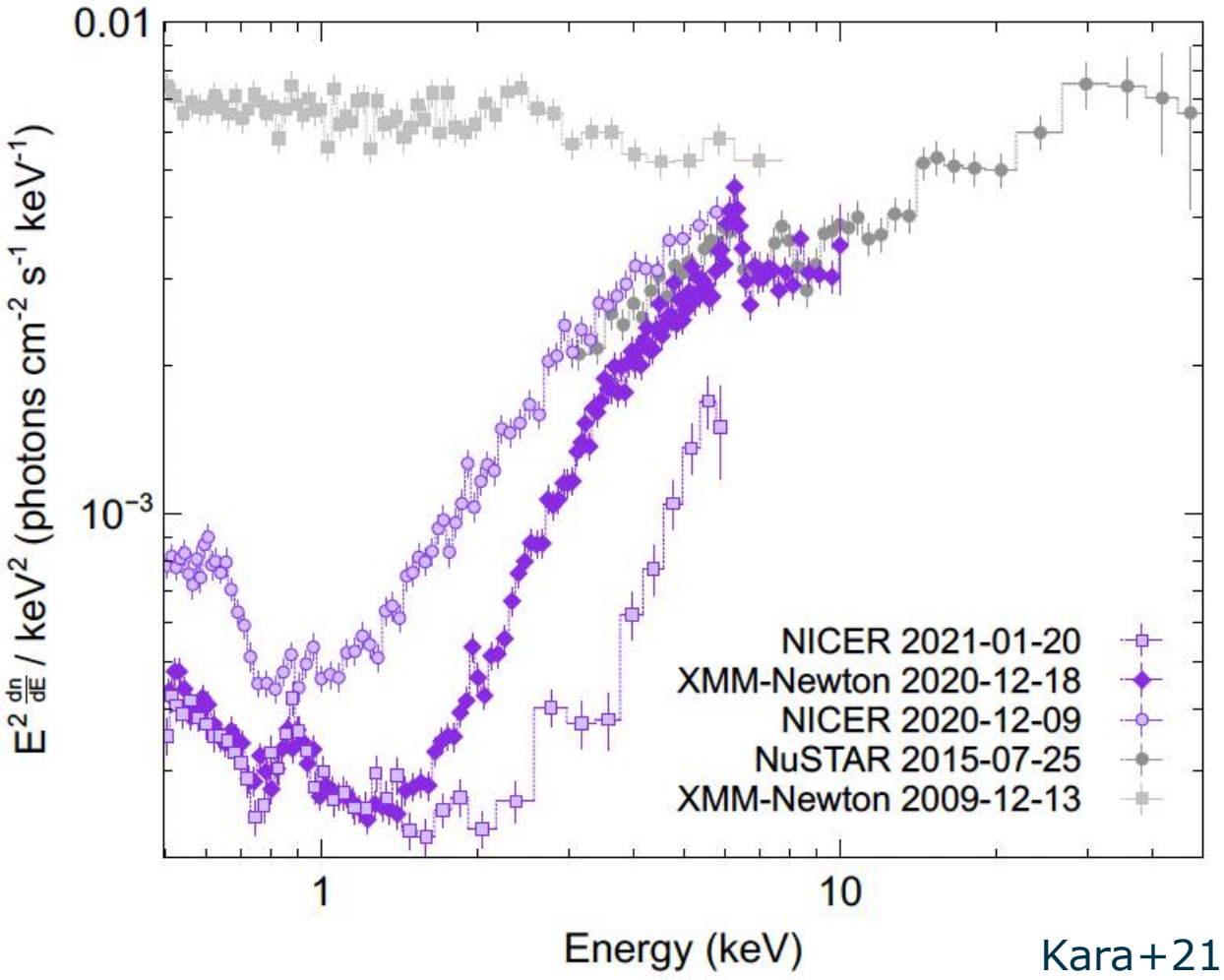


Williams+20 STORM1

THE X-RAY EMISSION AND REVERBERATION

NICER+Swift monitoring

- Mrk817 is fainter than historically throughout the campaign
- The flux varies across the campaign, most of variation is in the soft energies

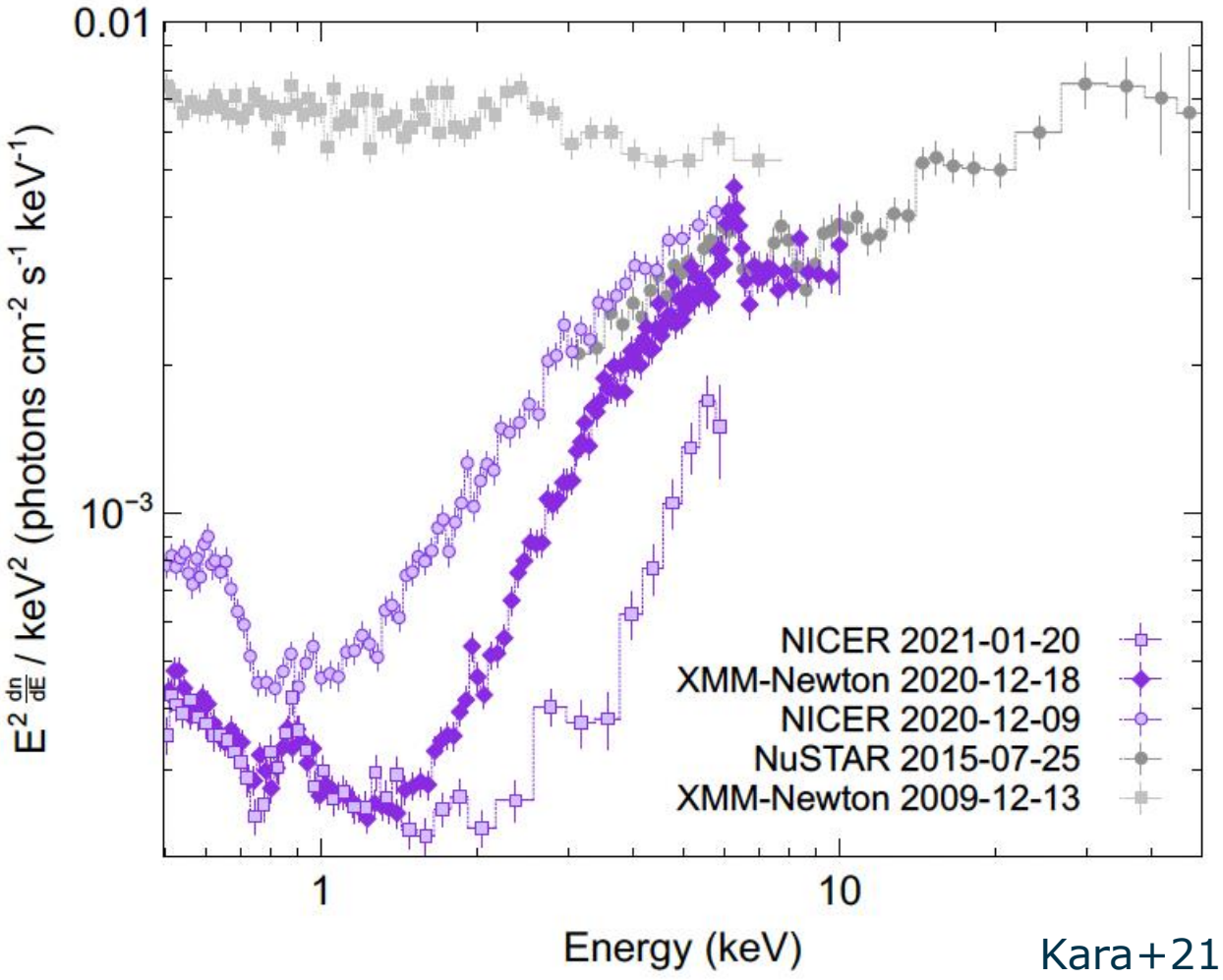


Kara+21

THE X-RAY EMISSION AND REVERBERATION

NICER+Swift monitoring

- Mrk817 is fainter than historically throughout the campaign
- The flux varies across the campaign, most of variation is in the soft energies
- The column density NH varies from $5*10^{22}$ cm^{-2} to $2*10^{23} cm^{-2}$ and the covering factor between 0.83 to 0.96 (Partington+23)
- Changes are very rapid, which suggests a clumpy obscurer

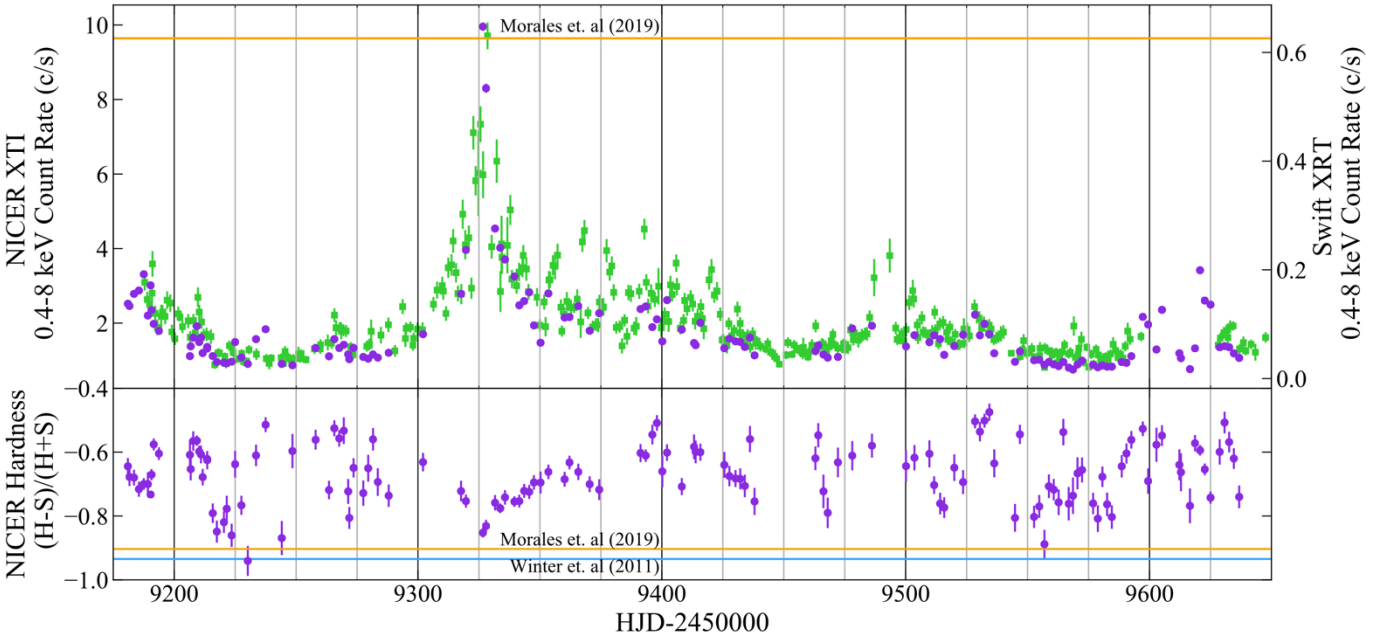


Kara+21

THE X-RAY EMISSION AND REVERBERATION

NICER+Swift monitoring

- There is one ‘flare’ moment where the flux goes back to the ‘historical’ values

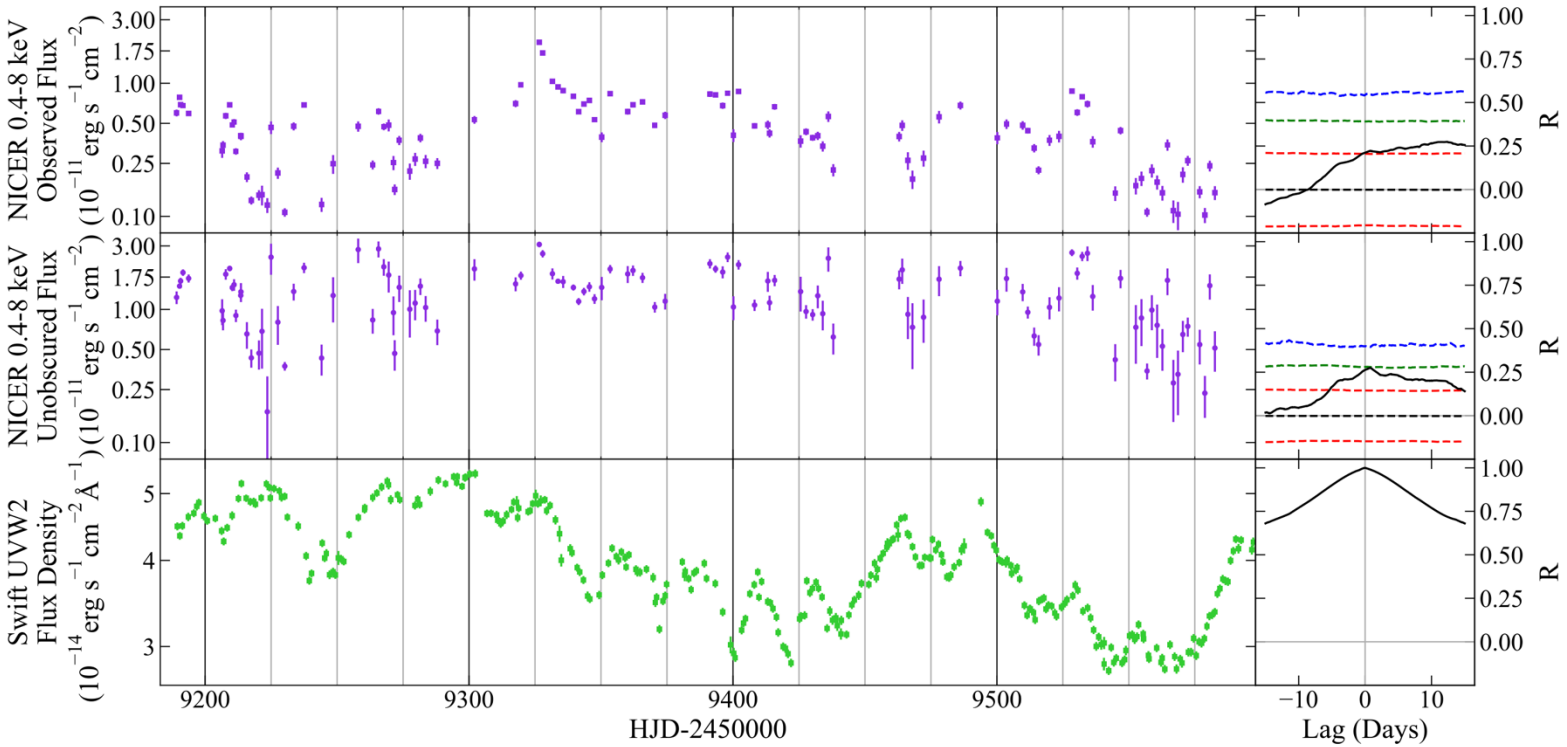


Partington+23

THE X-RAY EMISSION AND REVERBERATION

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- No correlation between the X-ray and the continuum light curves!

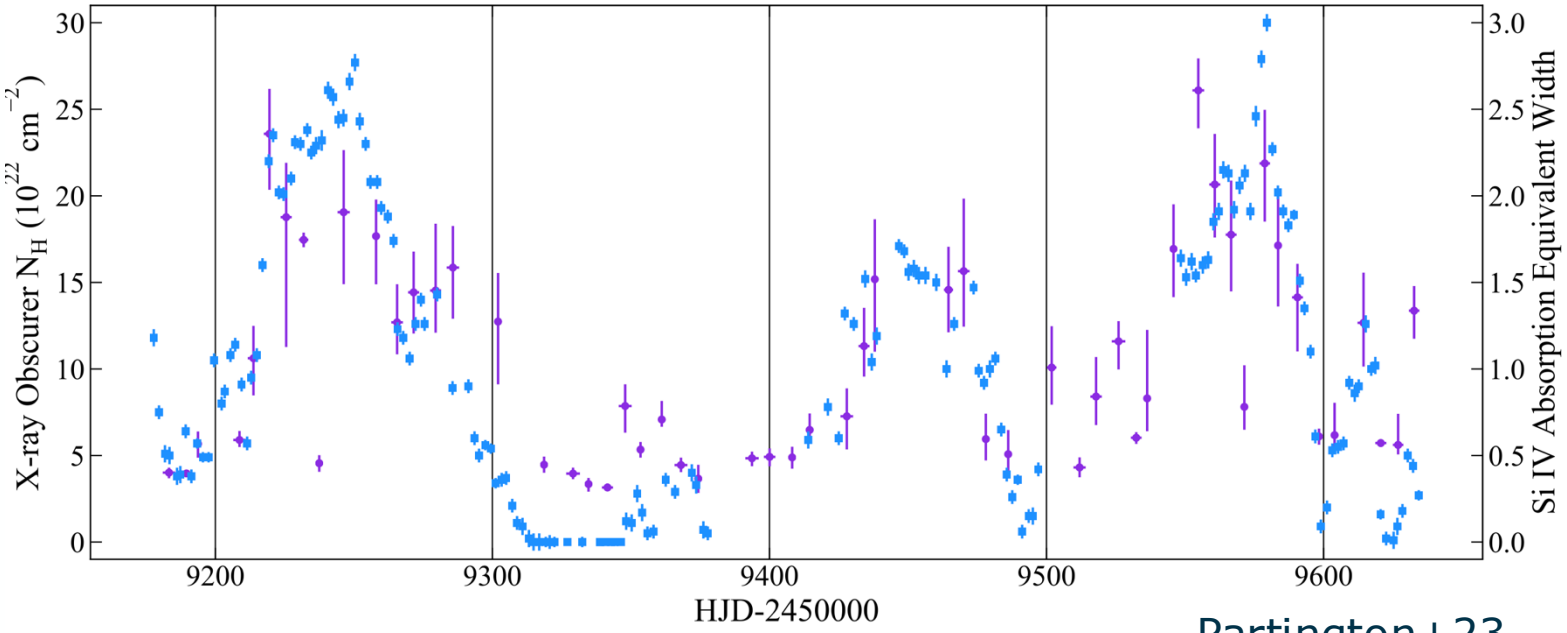


Partington+23

THE X-RAY EMISSION AND REVERBERATION

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- No correlation between the X-ray and the continuum light curves!
- BUT: strong correlation between the obscurer NH and the equivalent width of the broad Si IV absorption troughs in the COS spectra

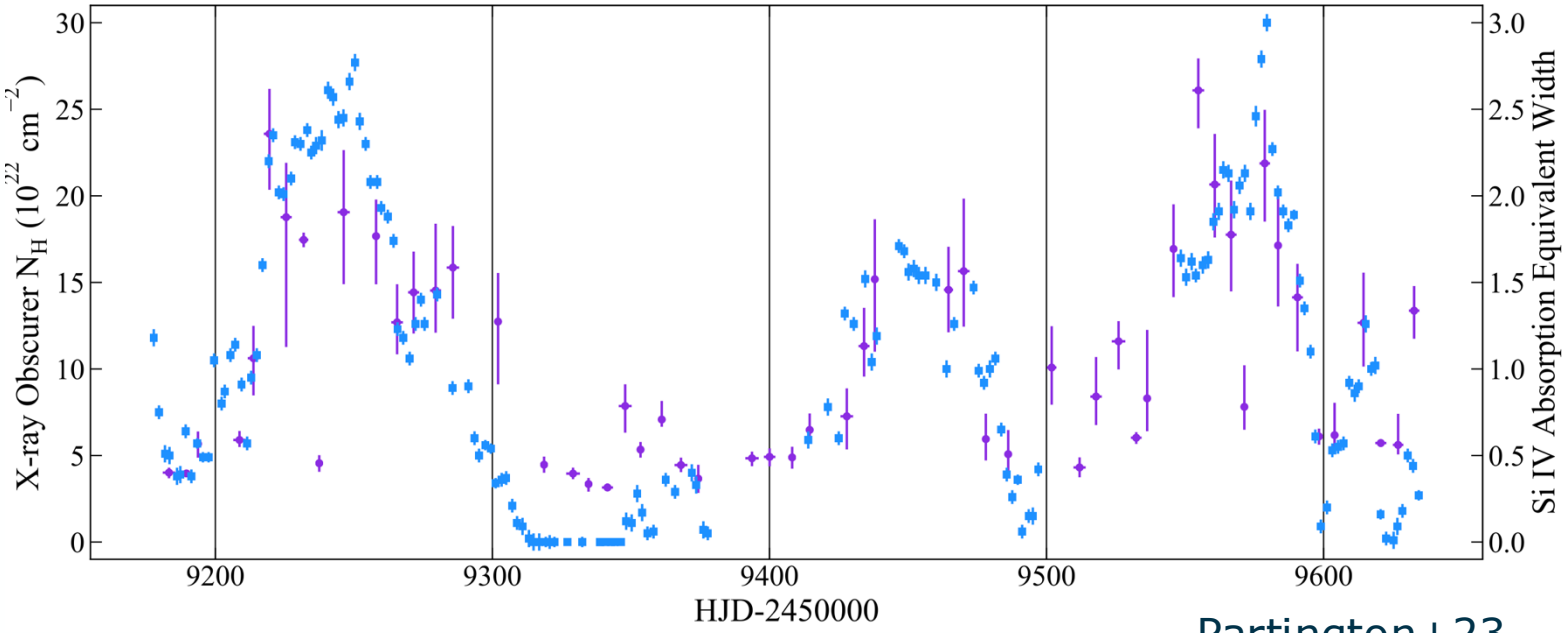


Partington+23

THE X-RAY EMISSION AND REVERBERATION

NICER+Swift monitoring

- No correlation between the X-ray and the continuum light curves!
- BUT: strong correlation between the obscurer NH and the equivalent width of the broad Si IV absorption troughs in the COS spectra
- Evidence that the X-ray and UV continuum are affected by the same obscuring gas

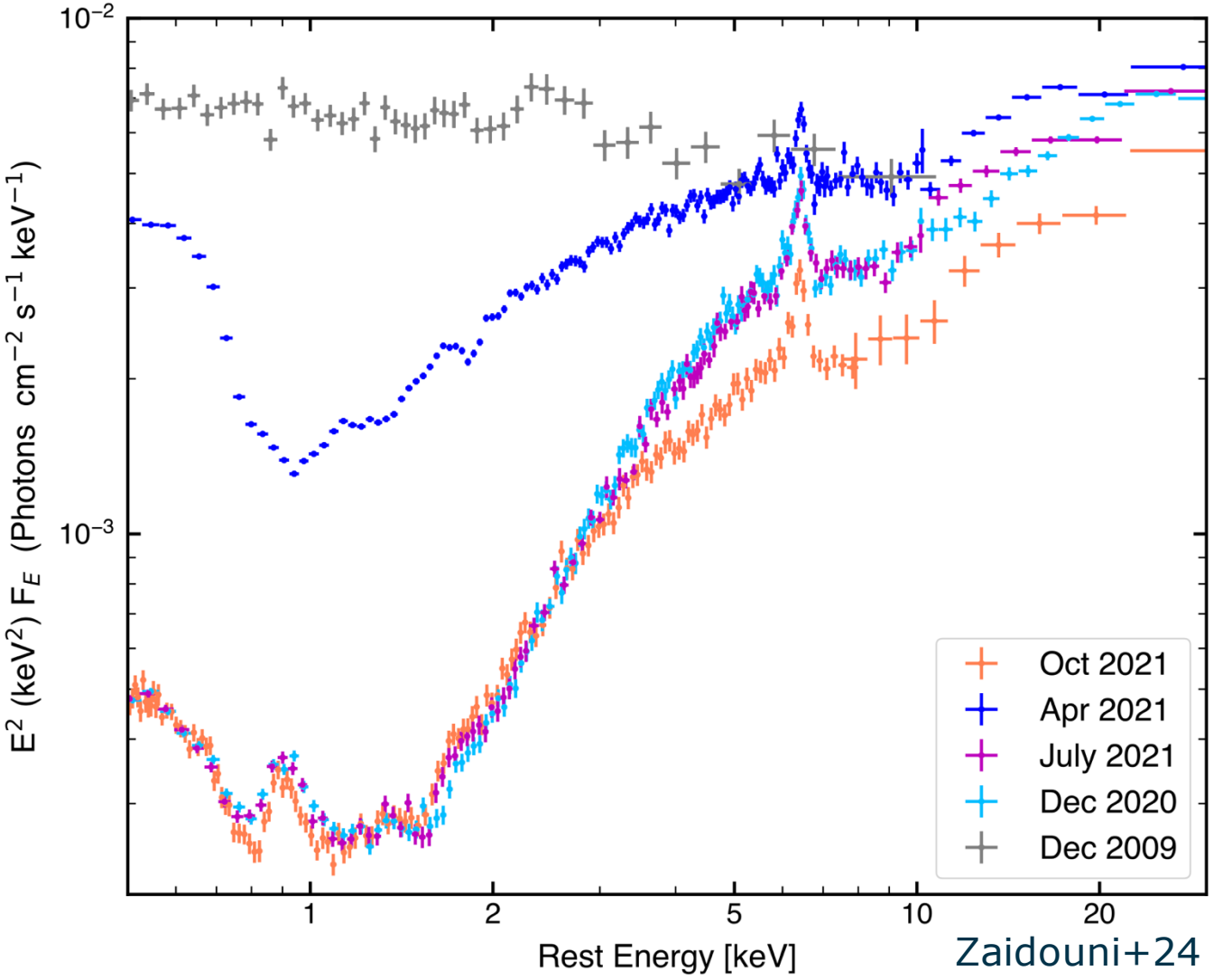


Partington+23

THE X-RAY EMISSION AND REVERBERATION

XMM-Newton

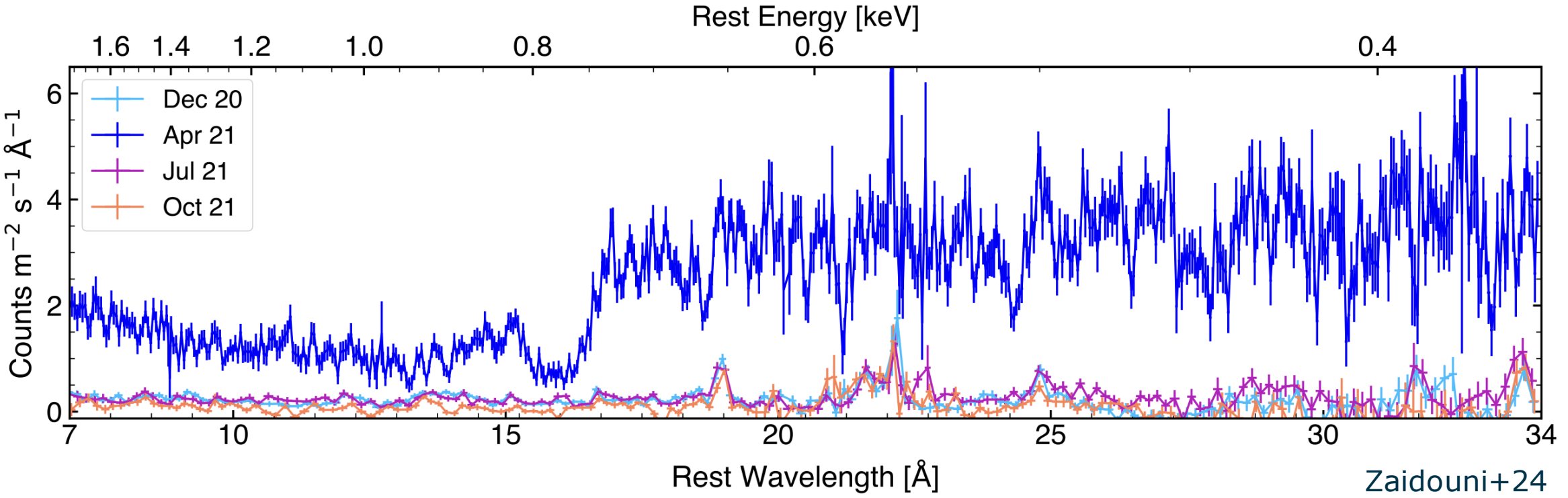
- 4 observations, one happened during the flare



THE X-RAY EMISSION AND REVERBERATION

XMM-Newton - RGS

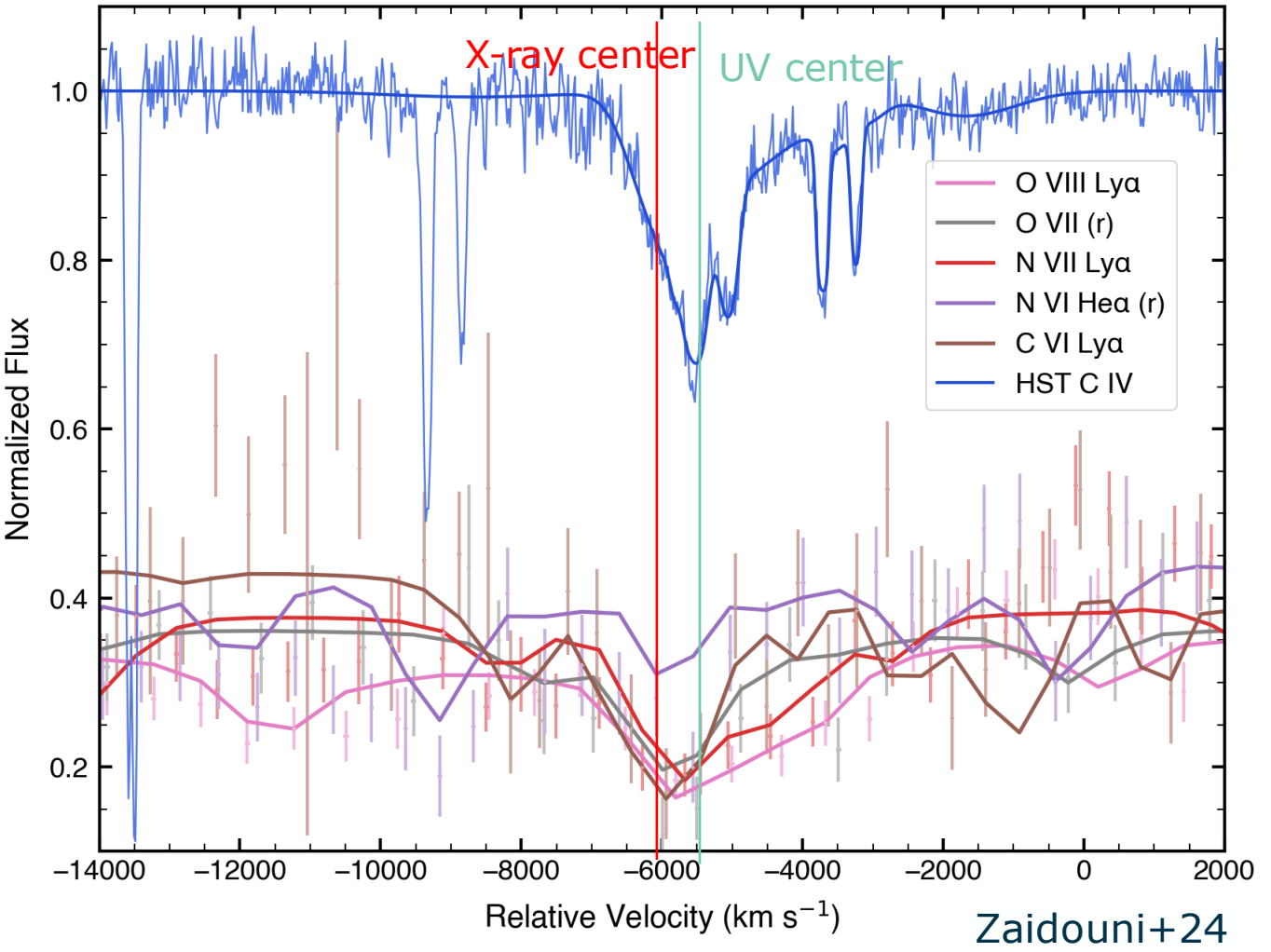
- 4 observations, one happened during the flare -> it has enough counts for us to study absorption troughs



THE X-RAY EMISSION AND REVERBERATION

XMM-Newton - RGS

- 4 observations, one happened during the flare -> it has enough counts for us to study absorption troughs
- Same velocity as UV absorption line profiles from the HST/COS spectrum taken 1 day prior!

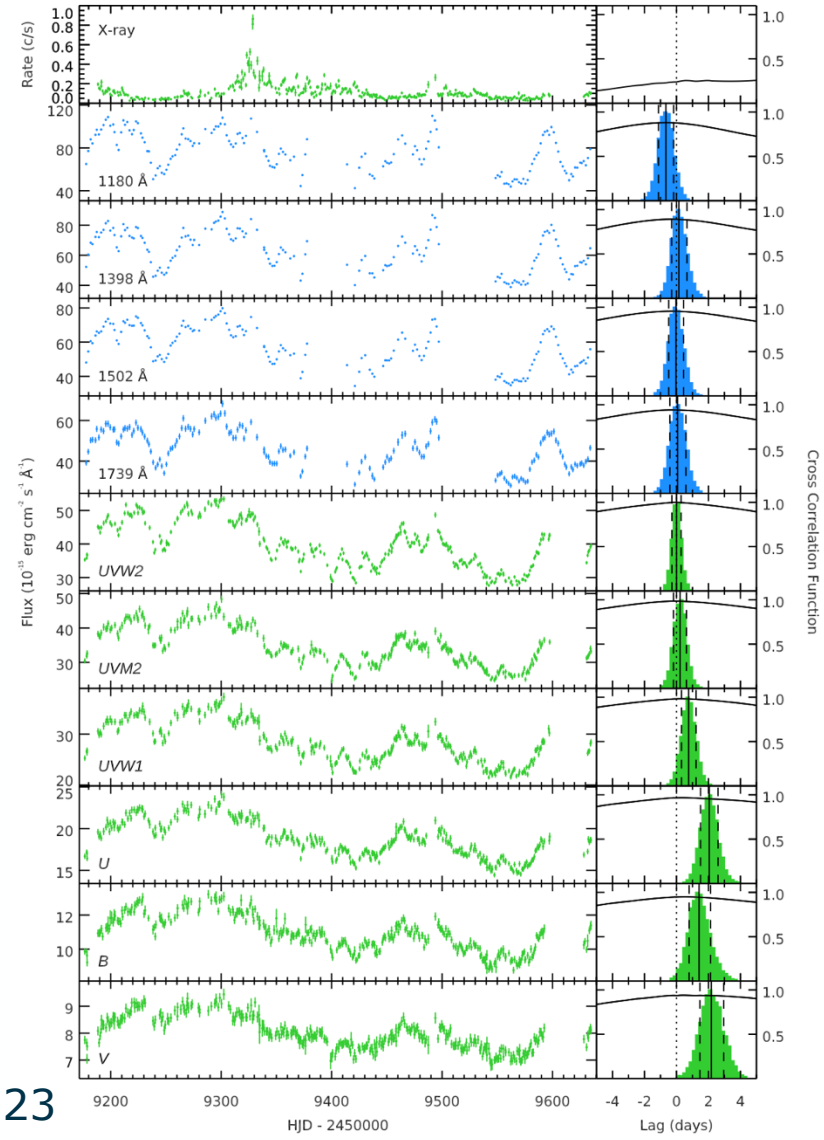


Zaidouni+24

DISK REVERBERATION

Swift monitoring

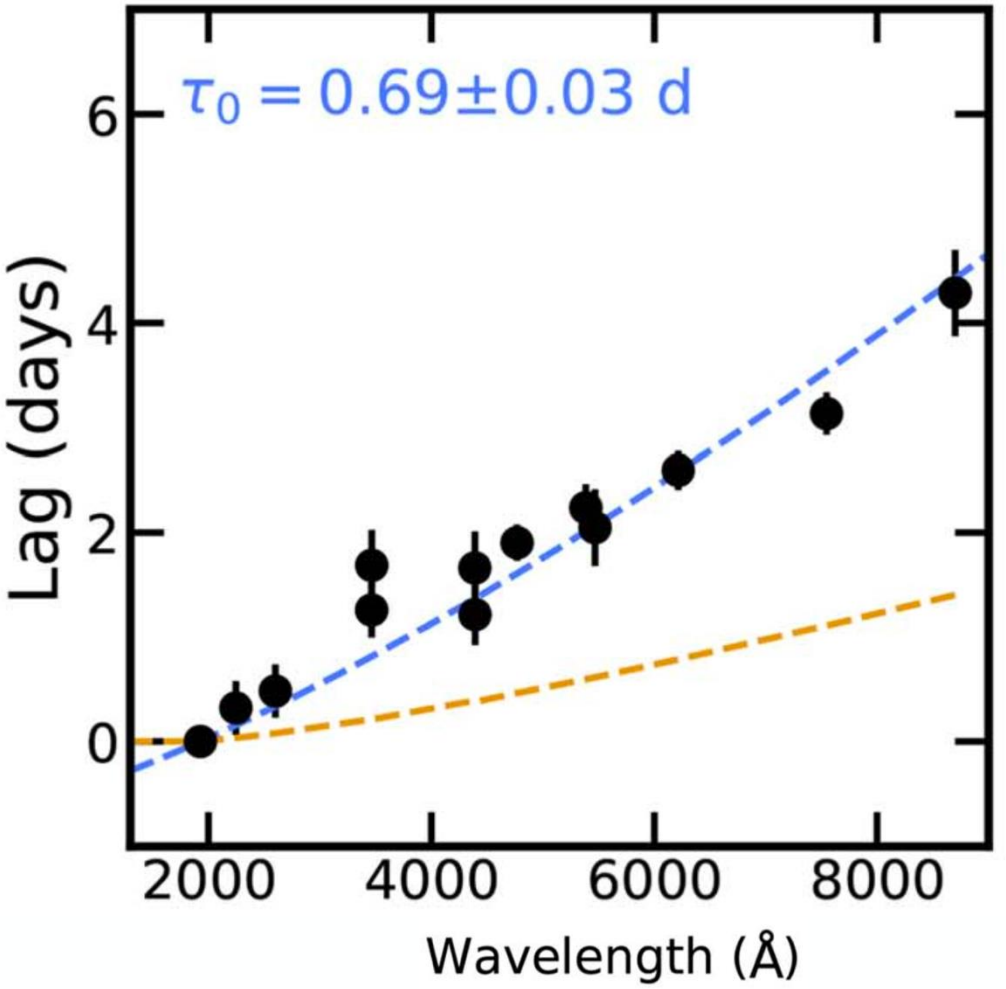
- Contrarily to the X-ray, the disc emission is unchanged from the historical values
- No correlation with the X-rays
- We see the expected increase of lag going at higher wavelengths with $\tau \propto \lambda^{4/3}$



Cackett+23

DISK REVERBERATION

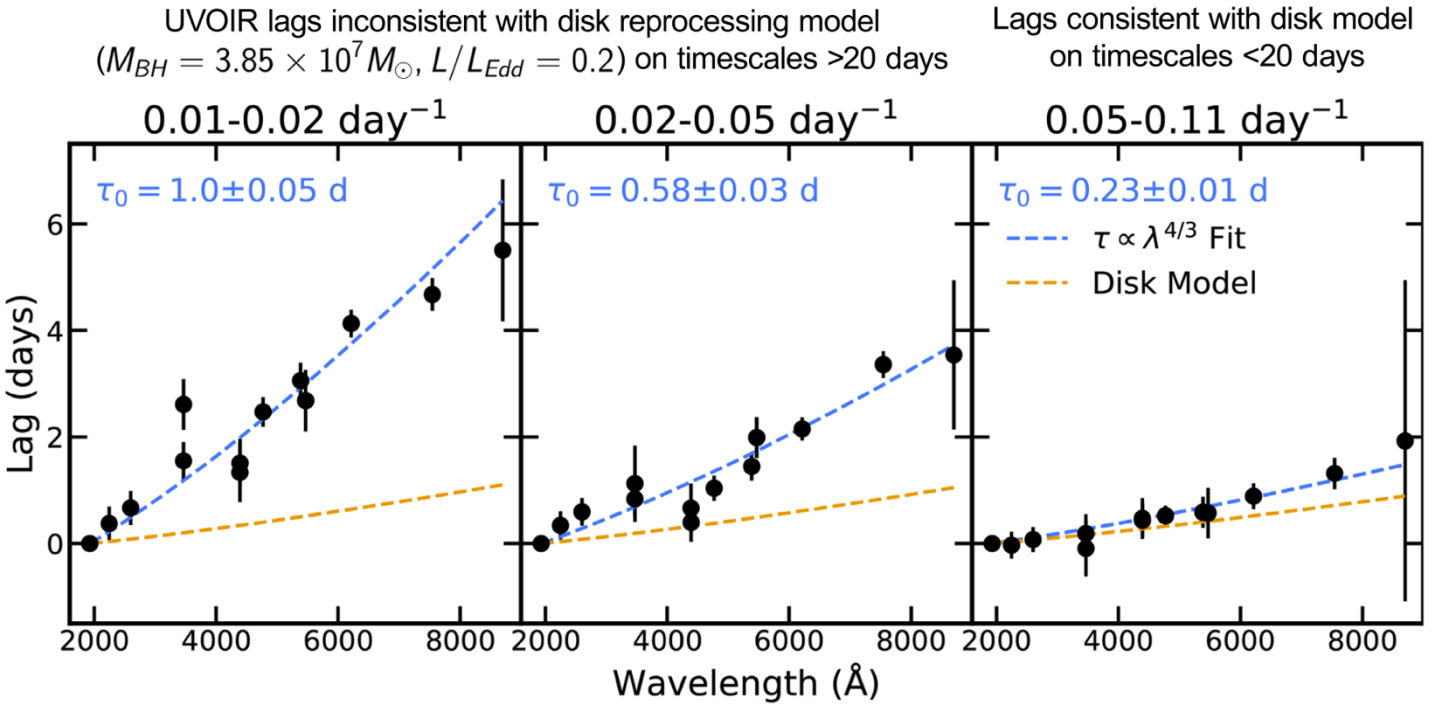
- As in other campaigns, the continuum lags show the expected $\tau \propto \lambda^{4/3}$ trend, but with size 2-3 times bigger than the SS73 prediction



Lewin+24

DISK REVERBERATION

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- Lags can be studied in the frequency regime: lags are consistent with the disc model on timescales <20 days

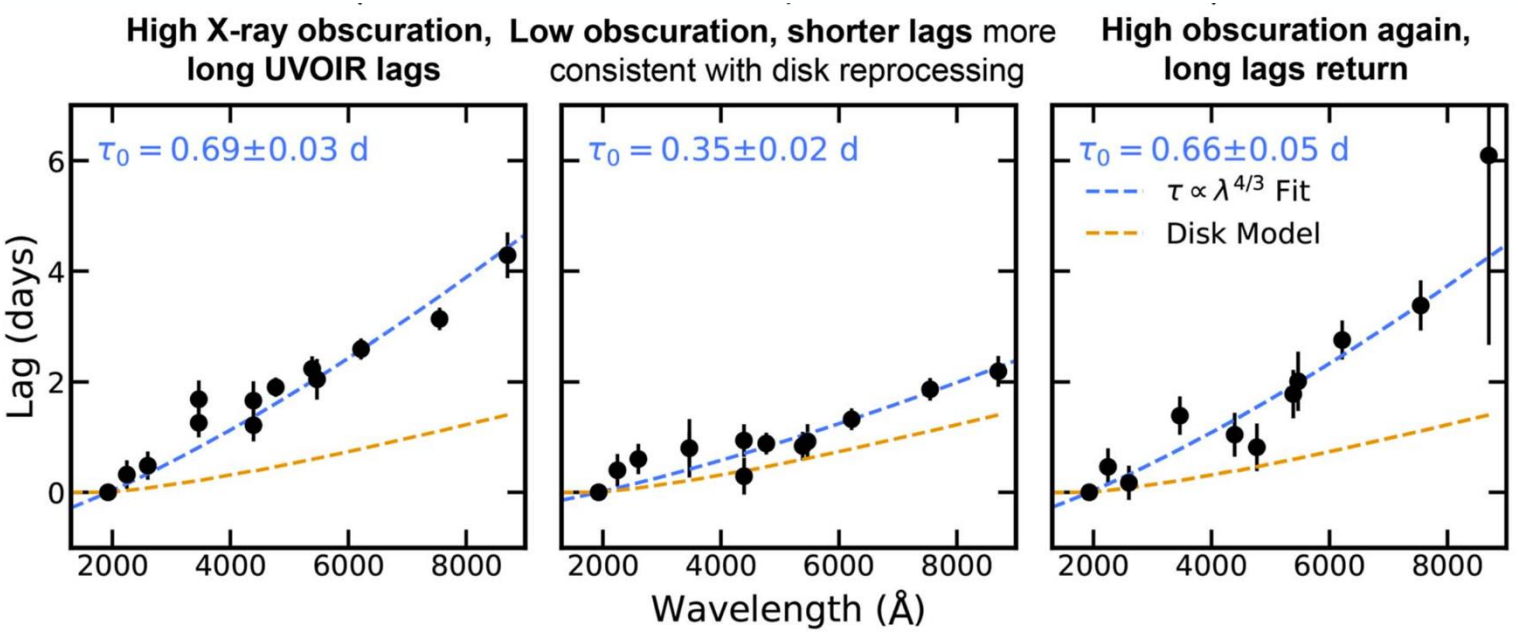


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- Dividing the lightcurve in time bins, we see lags more consistent with the disc model when obscuration is low

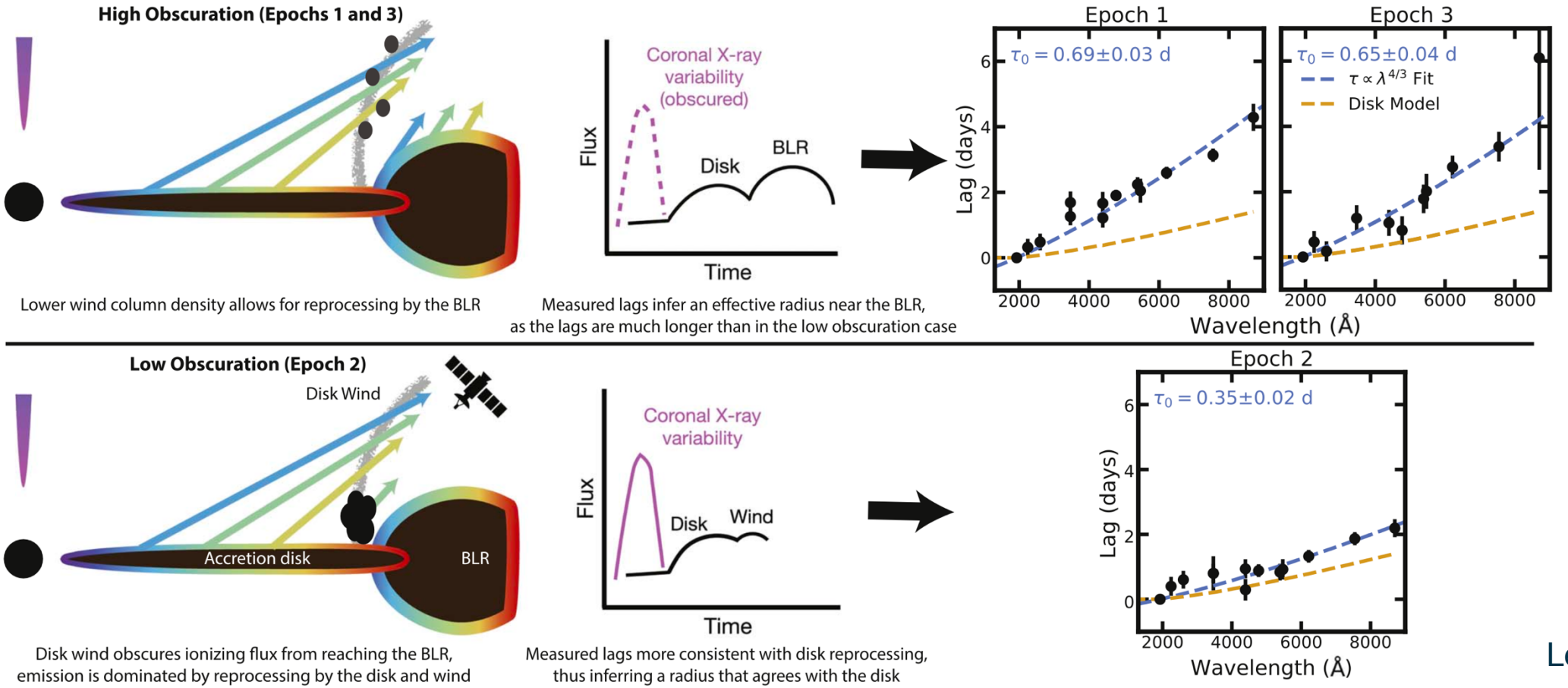
The BLR reprocessing is likely 'elongating' the lags



Lewin+24

THE DISK WIND

This is compatible with a disc wind launched from the outer disc, which respectively blocks the BLR or us from seeing the continuum at different times



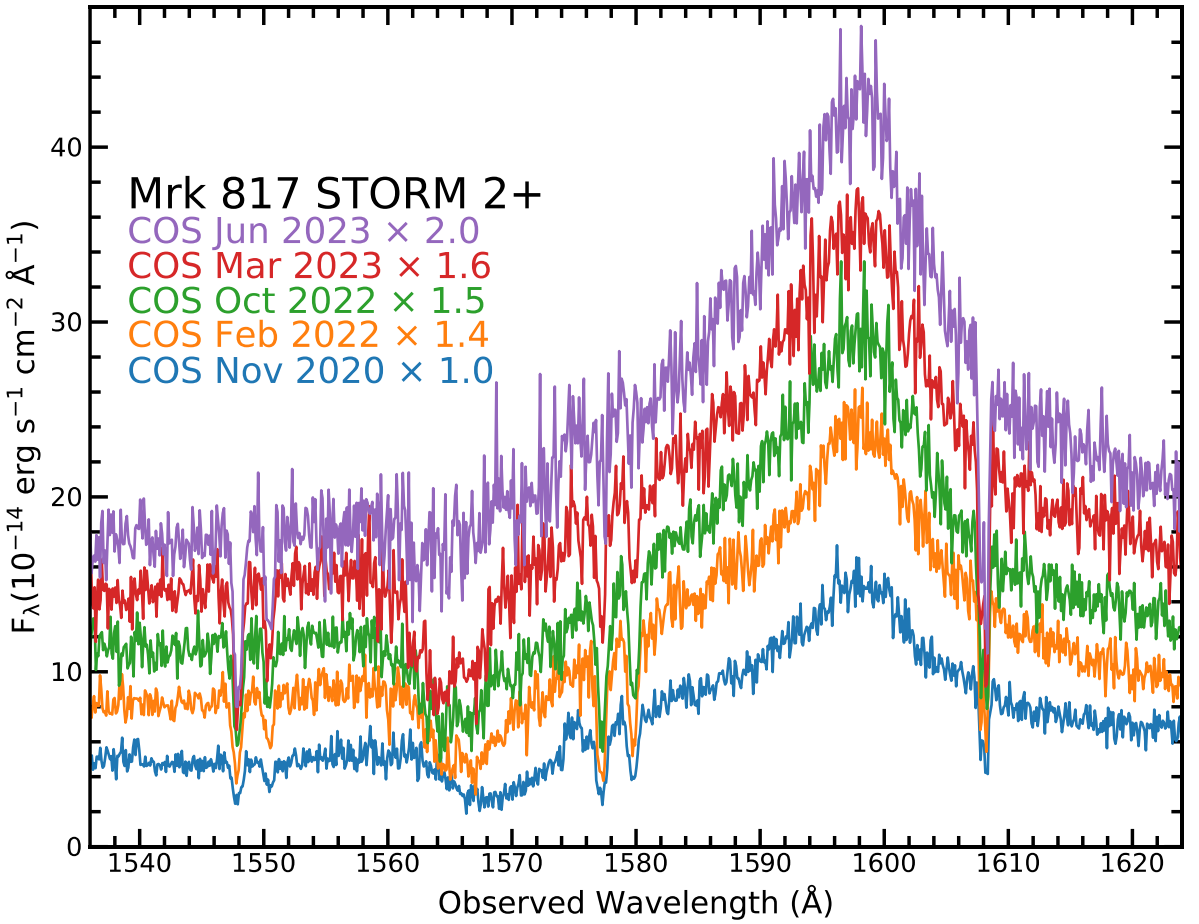
Lewin+24

THE DISK WIND

A disk wind launched from the internal BLR can explain

- The UVOIR lags
- The X-ray obscuration properties
- The UV absorption line properties
- Emission lines responsitivity
- The timescales of the variation of observed quantities that we see

- The weakening + increase in velocity of the obscuring troughs



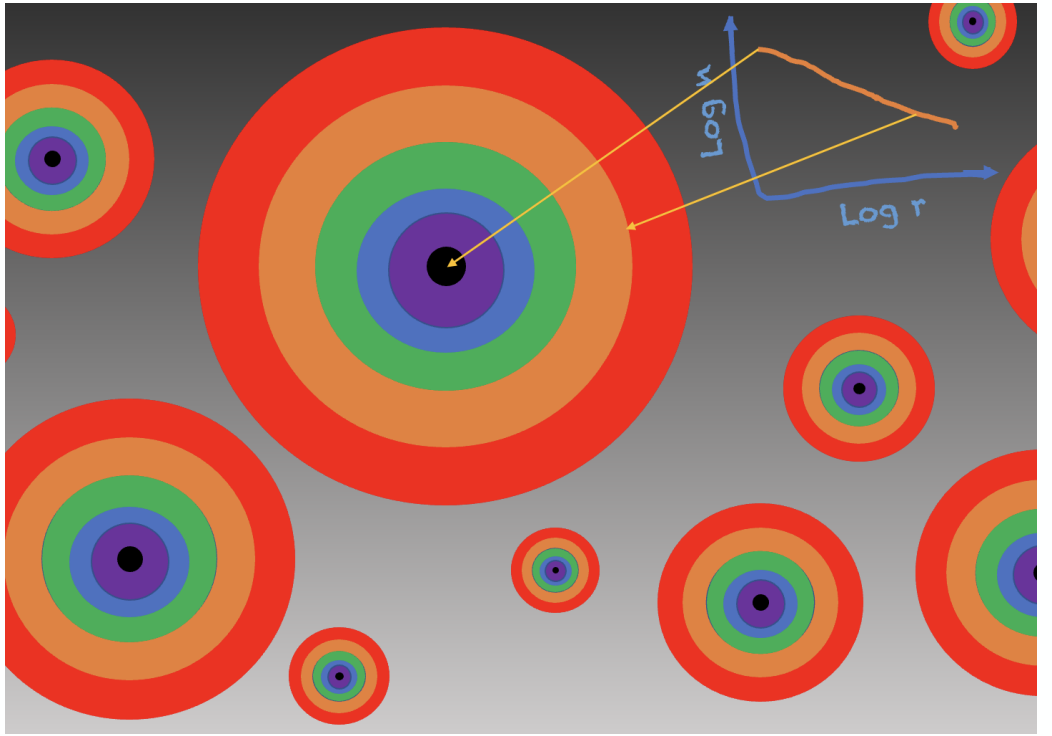
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- The wind needs to be a multi-phase medium with high-density clumps in a more massive and more highly ionized outflow

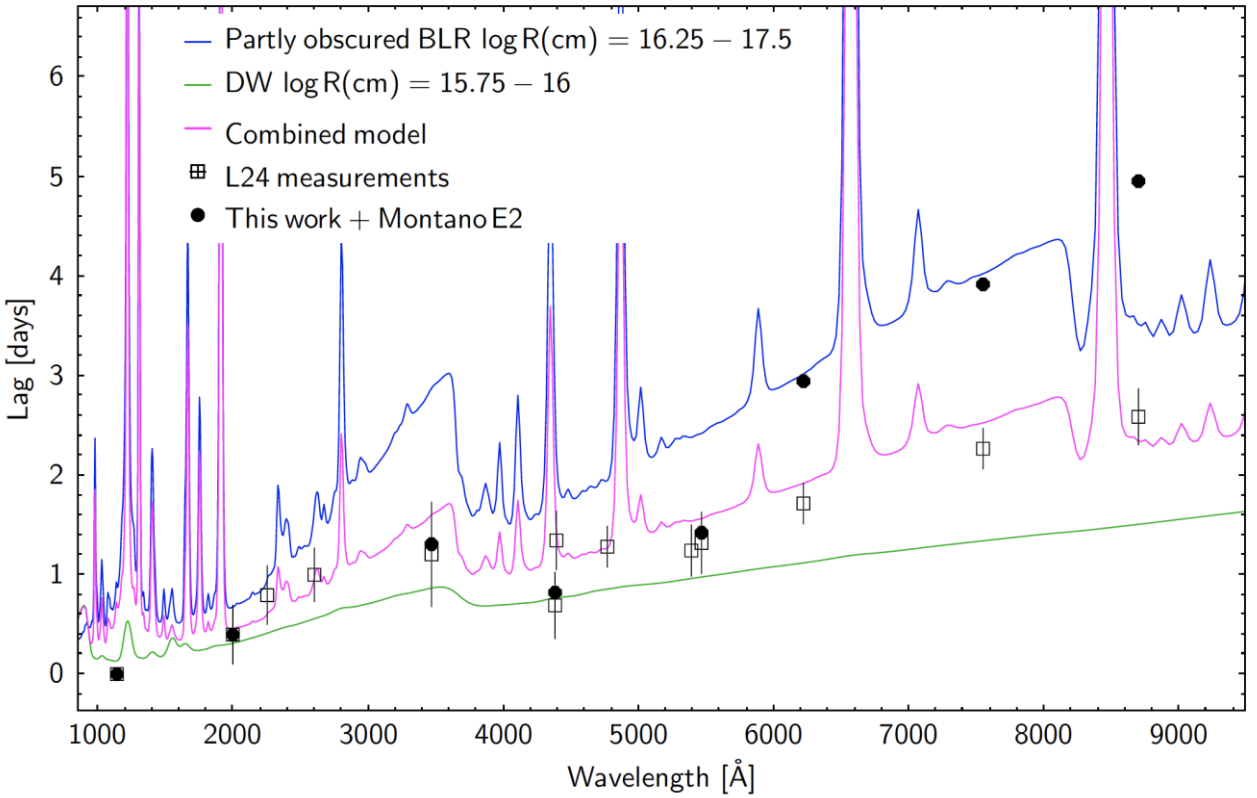


THE DISK WIND

Disk semi-analytical modeling (Netzer+24)

- The mass outflow rate has a peak at ~50 gravitational radii (Rg)
- The wind is launched within a range of radii (20–200 Rg)
- The outflow rate evolves with time on a characteristic timescale of ~100 days

- The wind leads to large changes in the ionizing photon output — up to a factor of ~5 — while leaving the optical luminosity unchanged
- The effective reprocessing region shifts outward



CONCLUSIONS

- Multi-year multi-wavelength monitoring is important to understand the complex interplay between different AGN components
- The presence of disk winds is more common that we thought (and/or we have been unlucky)
- For Mrk817, a transient disk wind launched from the outer disk/inner BLR can put together what we see at different wavelengths
- Similar obscuration could explain puzzling results in other campaigns, like BLR not responding to the continuum or the 'bigger than expected' disk sizes
- In reverberation mapping campaigns, things do not always go as planned, but there is still a lot that we can learn from them!

CONCLUSIONS

- **Kara+21** - Reverberation Mapping of the Accretion Disk, Broad-line Region, and Dust Torus in Mrk 817 with Swift, HST, and Ground-based Telescopes
- **Homayouni+23** - Ultraviolet Observations of Mrk 817 with the Cosmic Origins Spectrograph on the Hubble Space Telescope
- **Partington+23** - A NICER View of the Variable X-Ray Obscurer in Mrk 817
- **Cackett+23** - Swift X-Ray and Ultraviolet/Optical Monitoring of Mrk 817
- **Homayouni+24** - Anomalous Behavior of the C IV Light Curve of Mrk 817
- **Neustadt+24** - Mapping Temperature Fluctuations in the Accretion Disk of Mrk 817
- **Lewin+24** - A Frequency-resolved Map of the Accretion Disk in Mrk 817: Simultaneous X-Ray Reverberation and UVOIR Disk Reprocessing Time Lags
- **Dehghanian+24** - Investigating the Narrow Absorption Lines in Mrk 817 Using HST-COS Observations
- **Zaidouni+24** - Studying the Dynamics of the Ionized Obscurer in Mrk 817 with High-resolution X-Ray Spectroscopy
- **Netzer+24** - The Origin of the Interband Continuum Delays in Mrk 817

In prep:

- Landt+ - Spectroscopic reverberation mapping of the hot dust in Mrk 817, tbs
- Signorini+ - Broad Line Region dynamical modeling
- Hu+ - Optical spectroscopy
- Montano+ - Ground based photometric reverberation mapping
- Kriss+ - UV spectra modeling
- …

Thank you!