Joint NICER/IXPE workshop 2024 • Washington

2024/07/31

Rapid dimming followed by a **state transition**: a study of the **highly variable** nuclear transient AT 2019avd over 1000 days

Yanan Wang (NAOC)

In collaboration with:
Dheeraj R. Pasham, Diego Altamirano, Andres Gurpide, Noel Castro Segura, Matthew Middleton, Long Ji, Santiago del Palacio, Muryel Guolo, Poshak Gandhi, Shuang-Nan Zhang, Ronald Remillard, Dacheng Lin, Megan Masterson, Ranieri D. Baldi , Francesco Tombesi, Jon M. Miller, Wenda Zhang and Andrea Sanna

State transitions occurring in TDEs

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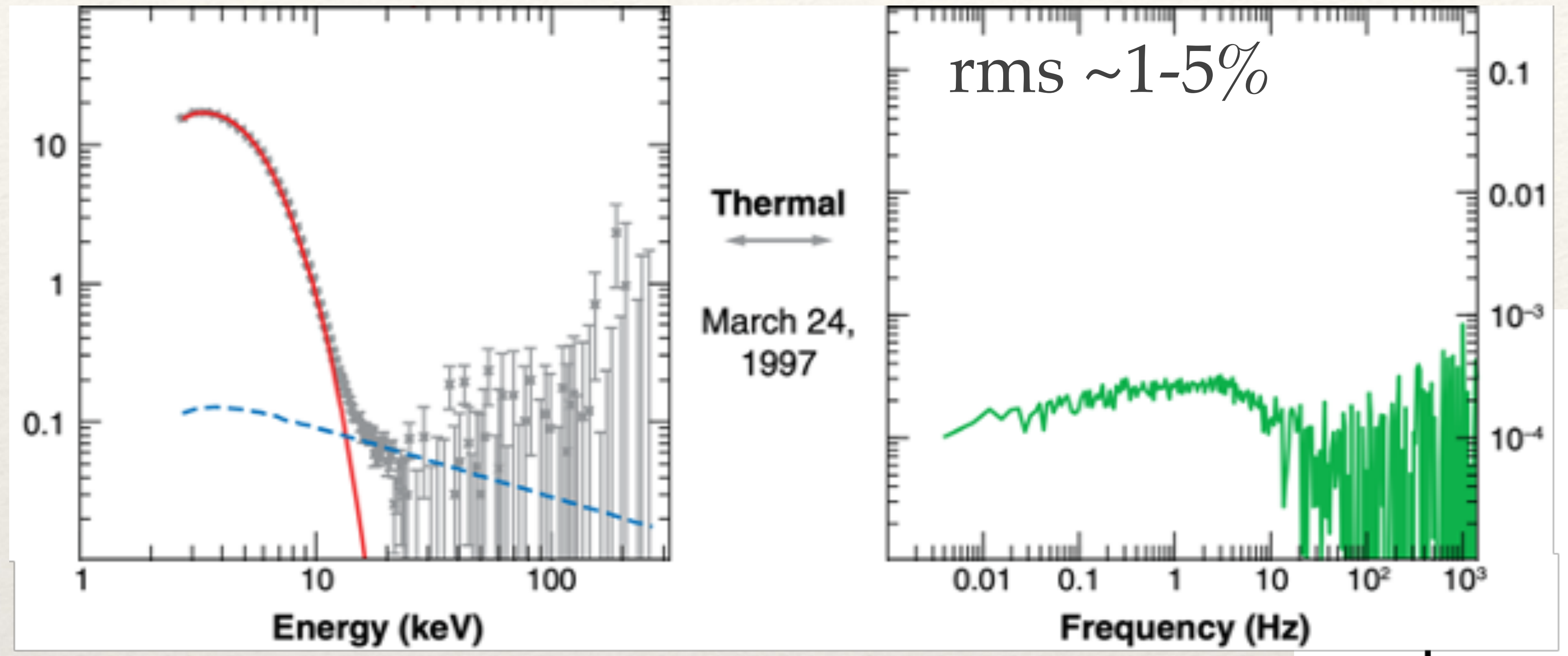
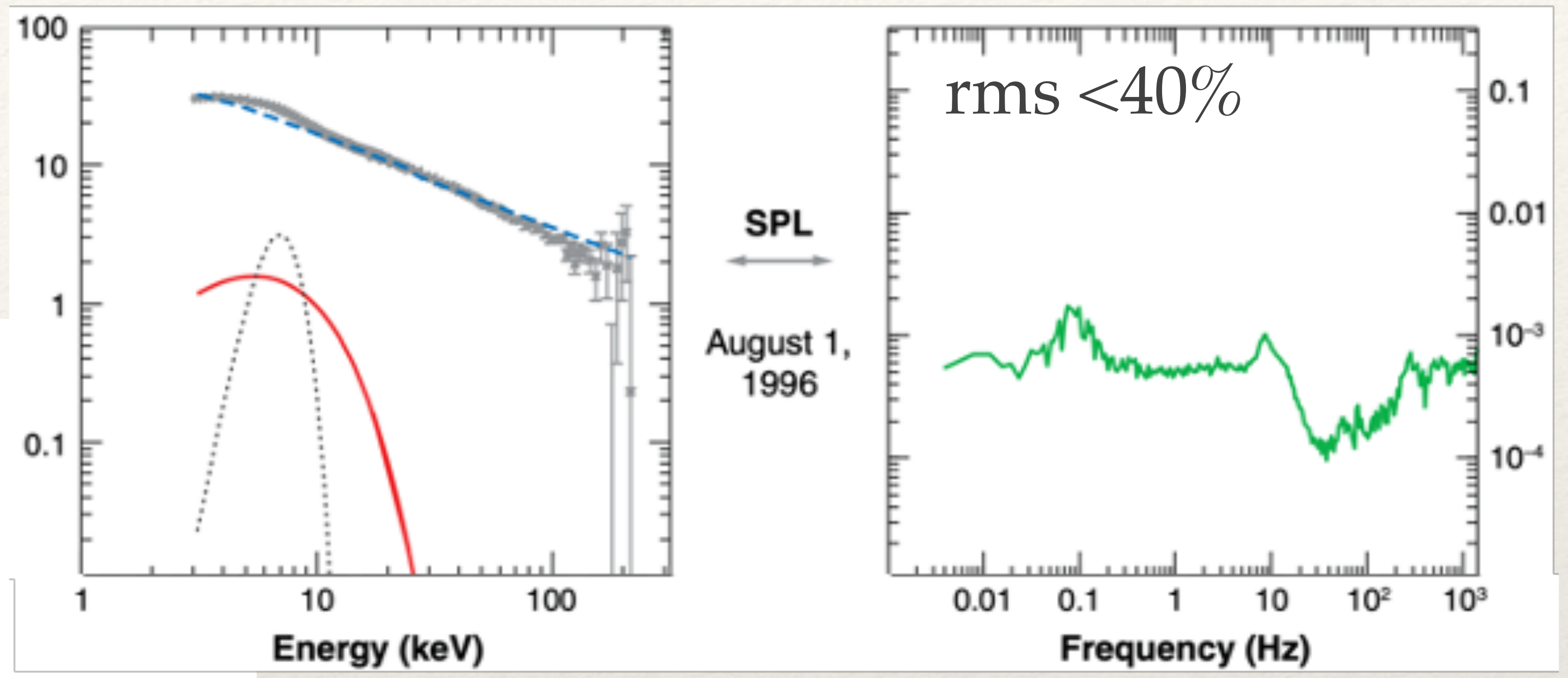
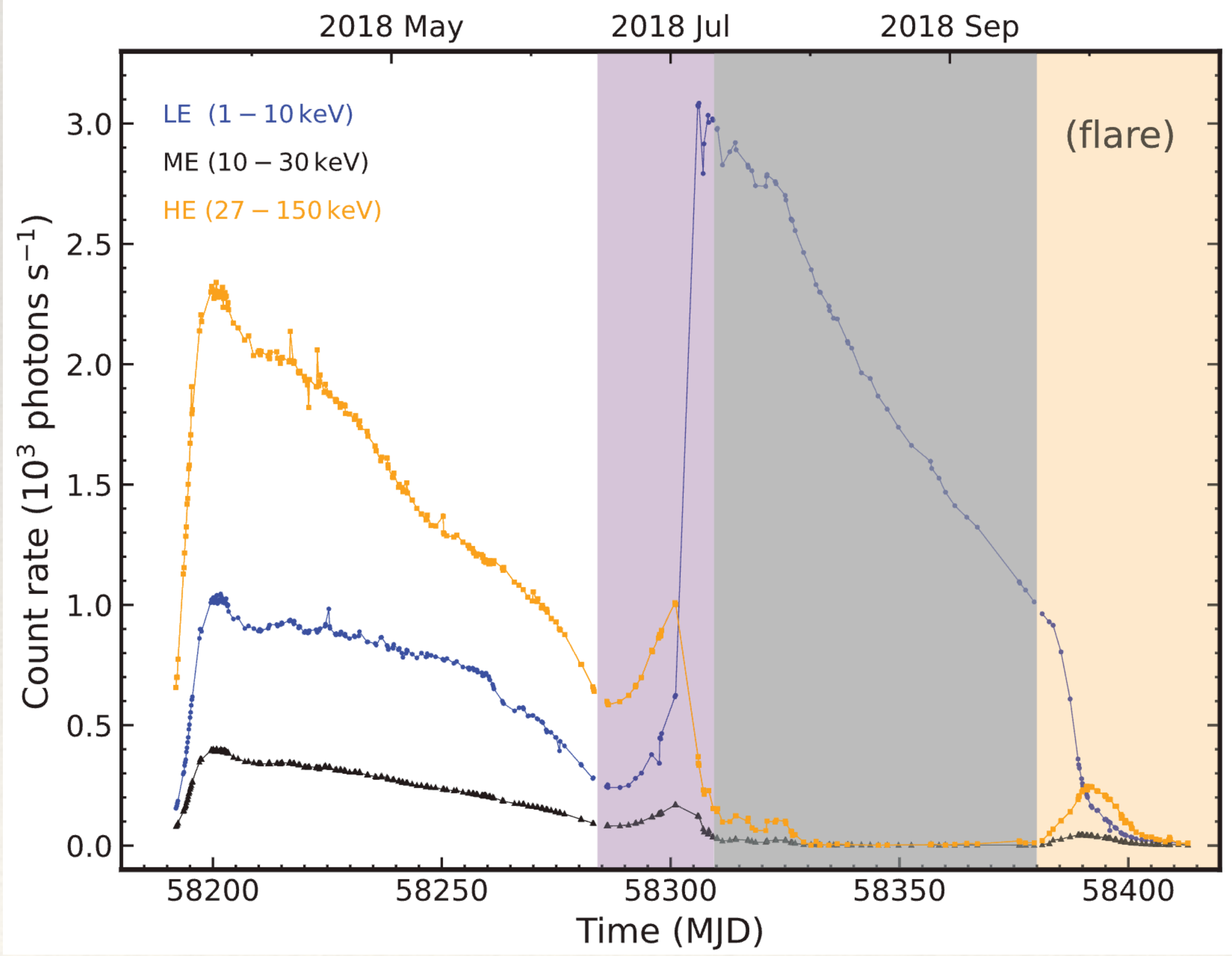
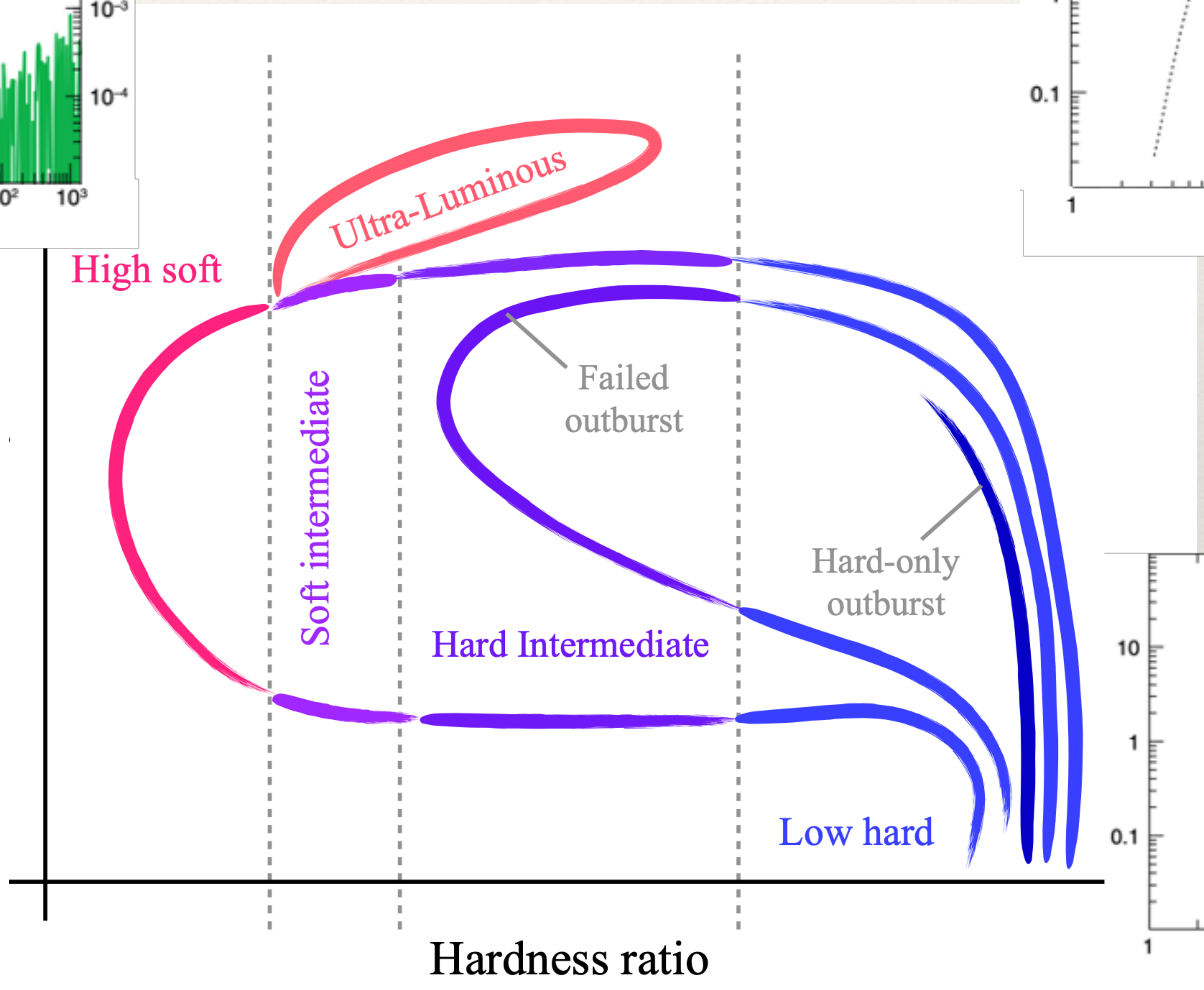
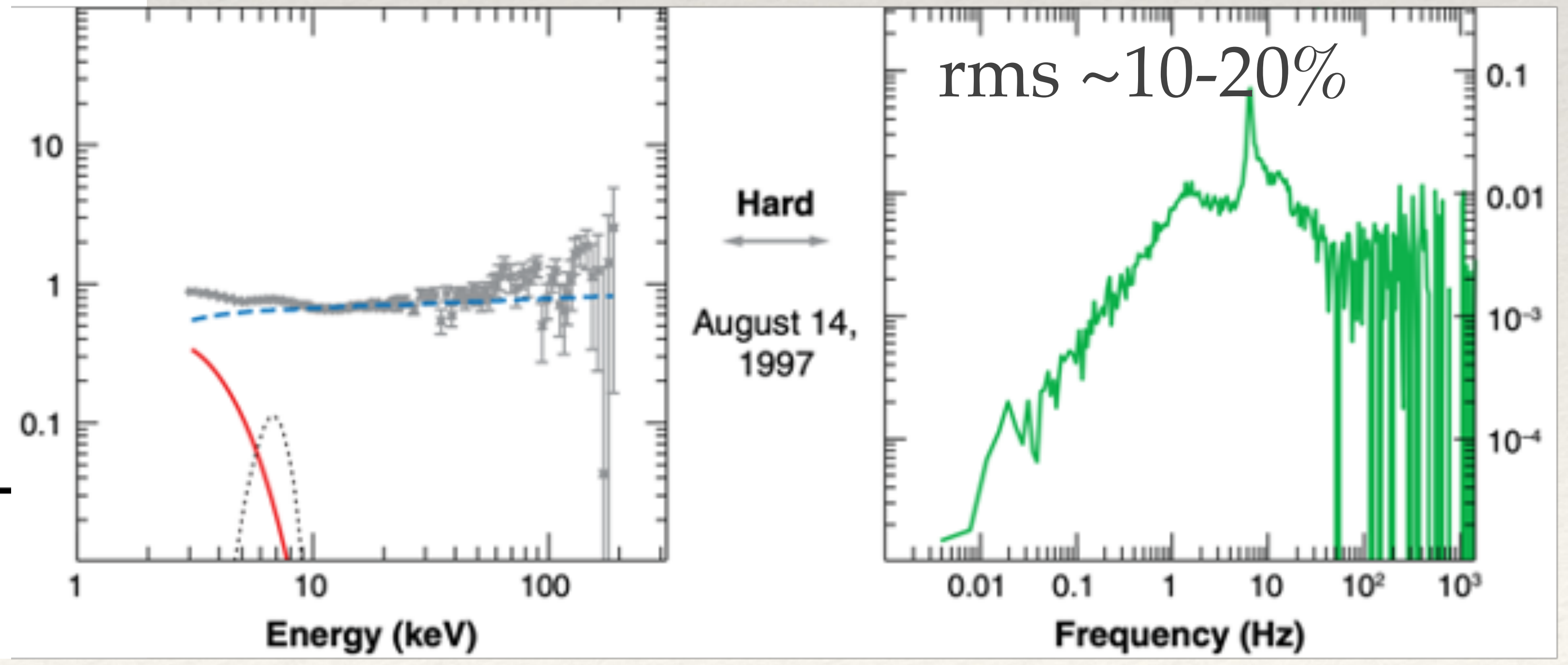
State transitions in BHXRBs











You+ (2023)

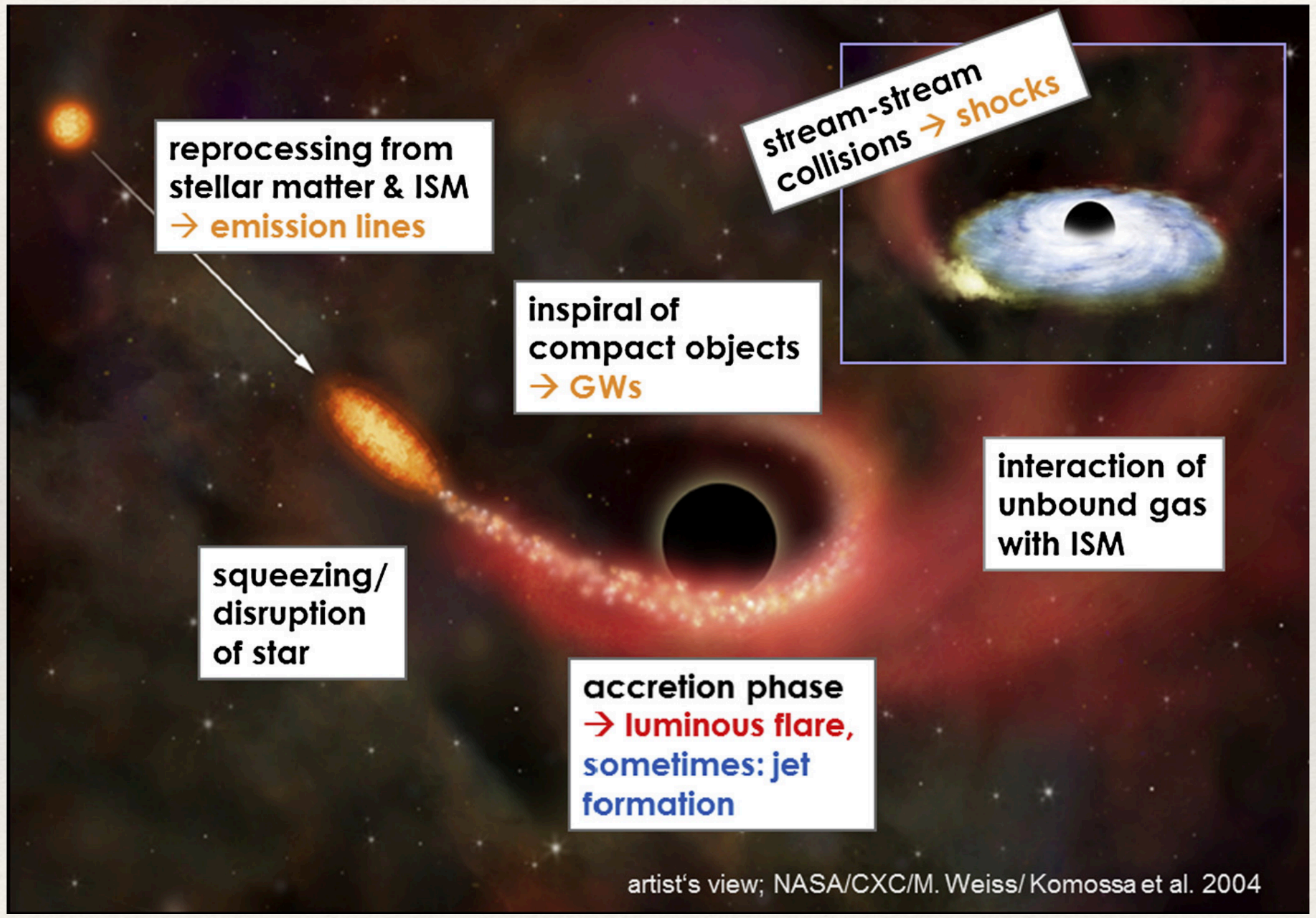
Motta+ (2021)

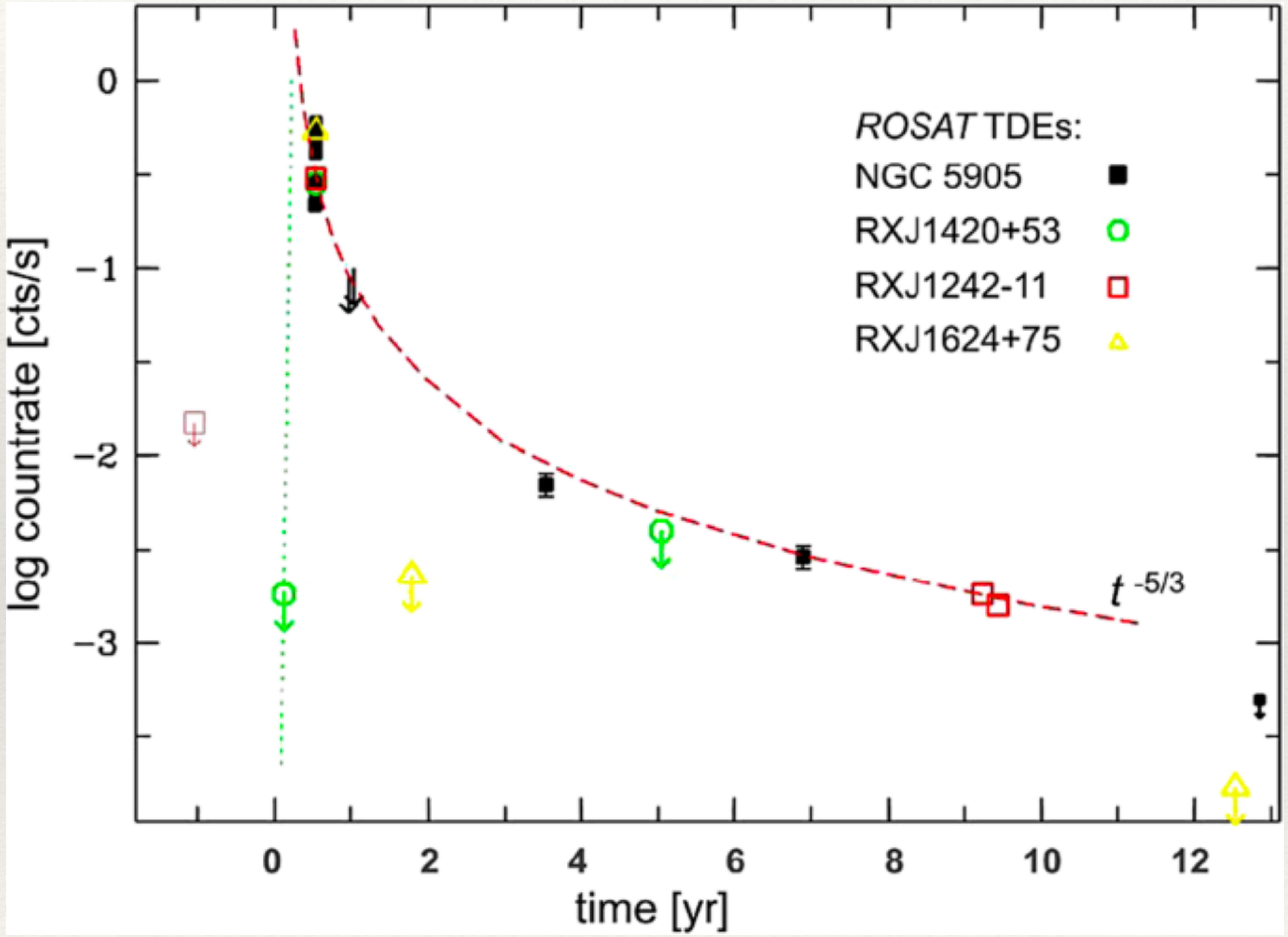
Remillard & McClintock (2006)

Tidal disruption events (TDEs)

Hill (1975); Rees (1988)

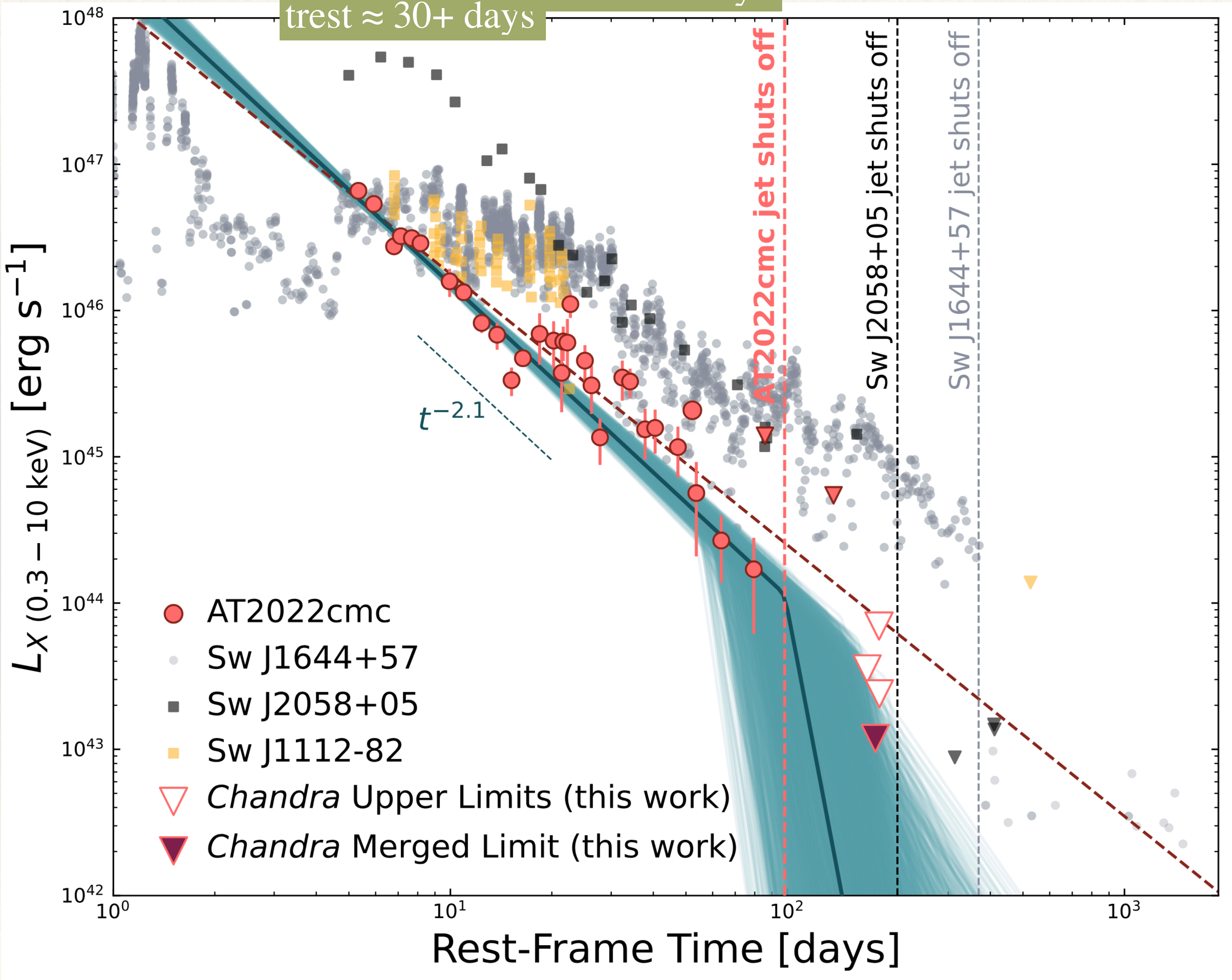
Komossa+ (2004)





State transition in TDEs: Rapid drop-off

trest ≈ 370 days
trest ≈ 200 days
trest ≈ 100 days
trest ≈ 30+ days



AT 2022cmc, Eftekhari+ (submitted)

Swift J1112, $M_{BH} \sim 2-5\times10^6\,M_\odot$, Brown+ (2015)
AT 2022cmc, $M_{BH} < 5\times10^7\,M_\odot$, Yao+ (2024)
SWIFT J2058.4, $M_{BH} \sim 10^{4-6}\,M_\odot$, Pasham+ (2015)
Swift 1644, $M_{BH} \sim 10^{5-6}\,M_\odot$, Burrows+ (2011)

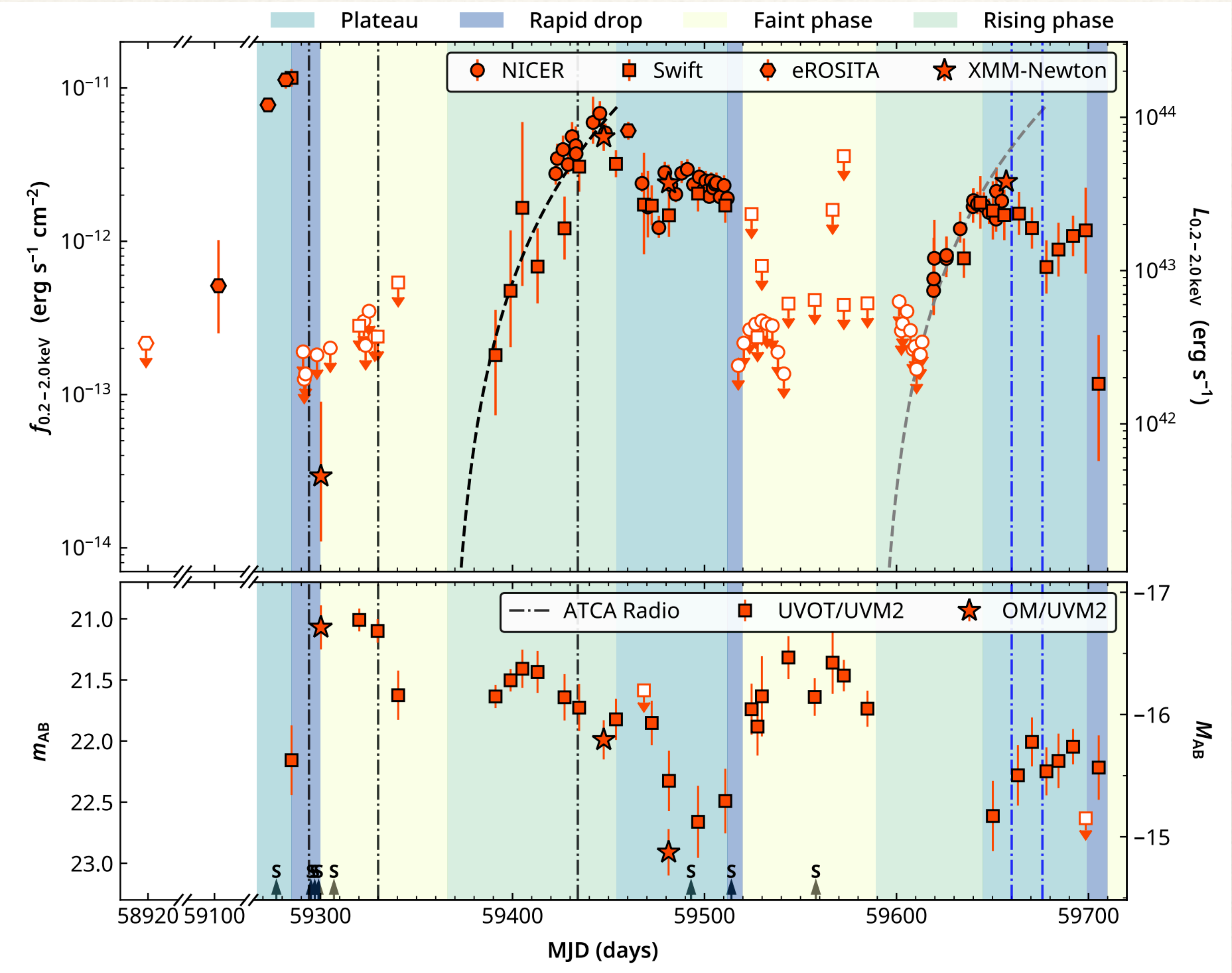
Jetted TDEs

State transition in TDEs: Rapid drop-off

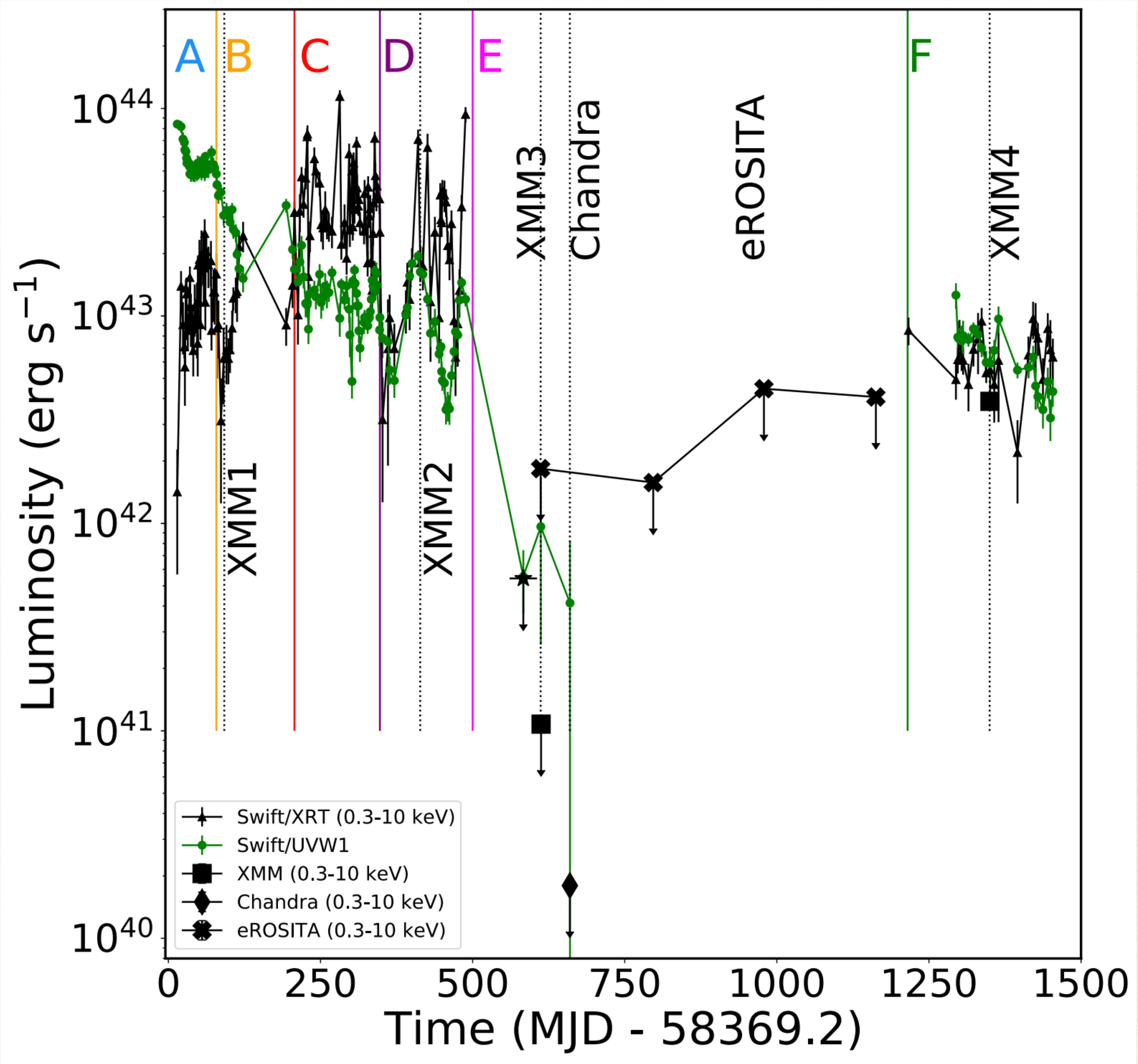
eRASSt J045650.3, $M_{BH} \sim 10^{6-7}\,M_\odot$, Liu+ (2023)

AT 2018fyk, $M_{BH} \sim 10^{7.4\pm0.4}\,M_\odot$, Wevers+ (2021)

trest ≈ 90/150 days



trest ≈ 500 days



Radio emission detected in the plateau phase

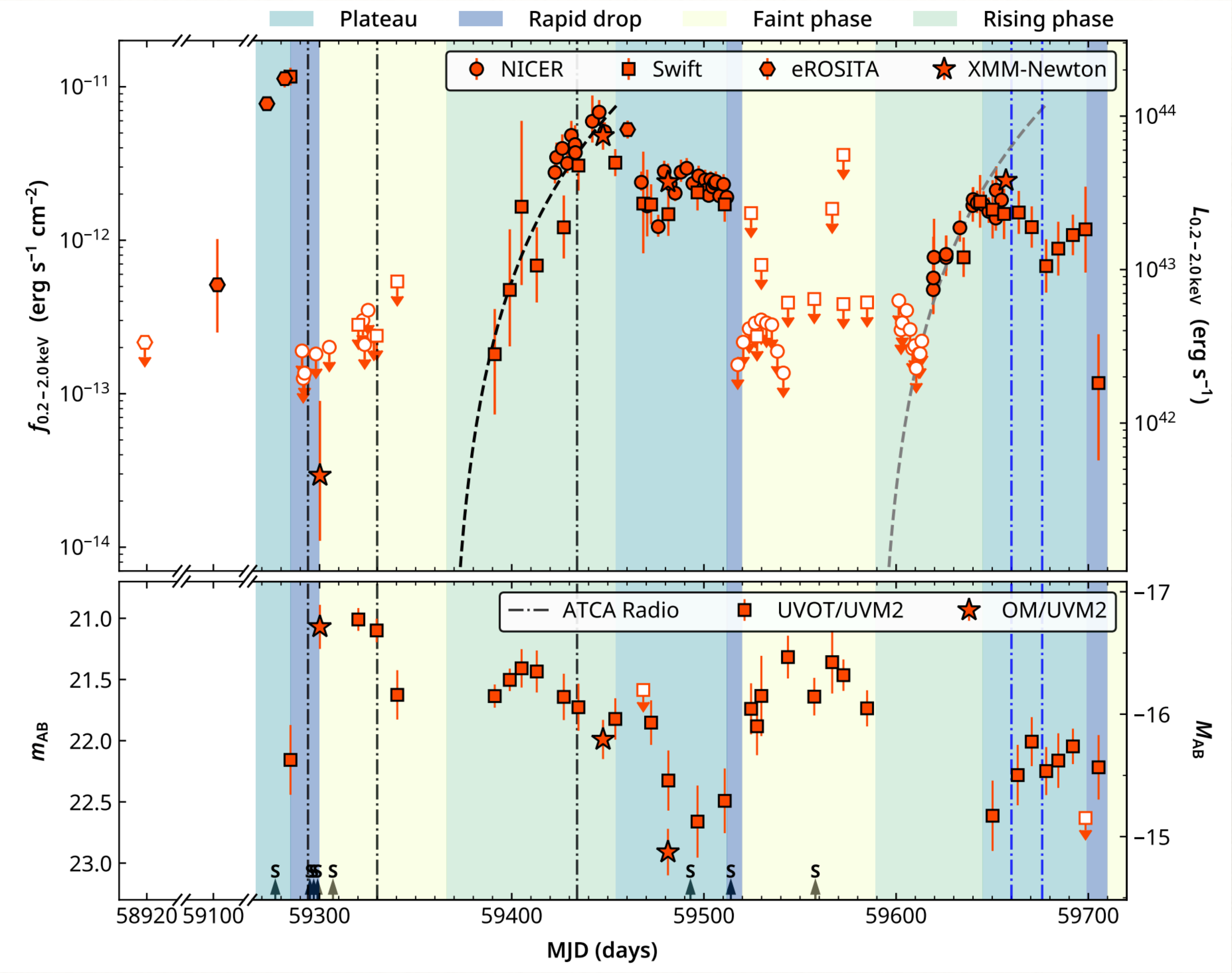
No radio emission detected

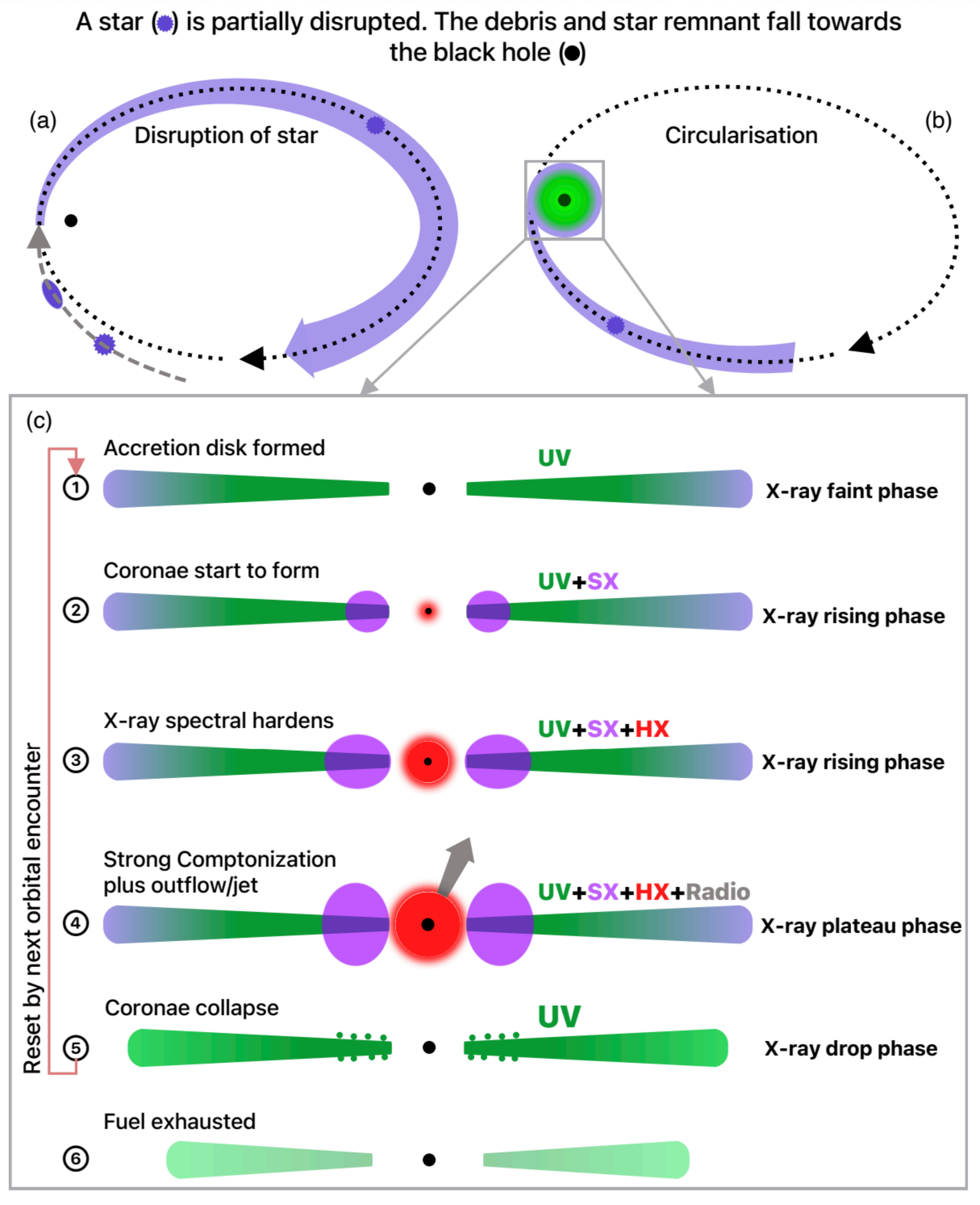
Partial TDEs

State transition in TDEs: Rapid drop-off

eRASSt J045650.3, $M_{BH} \sim 10^{6-7} M_{\odot}$, Liu+ (2023)

trest ≈ 90/150 days





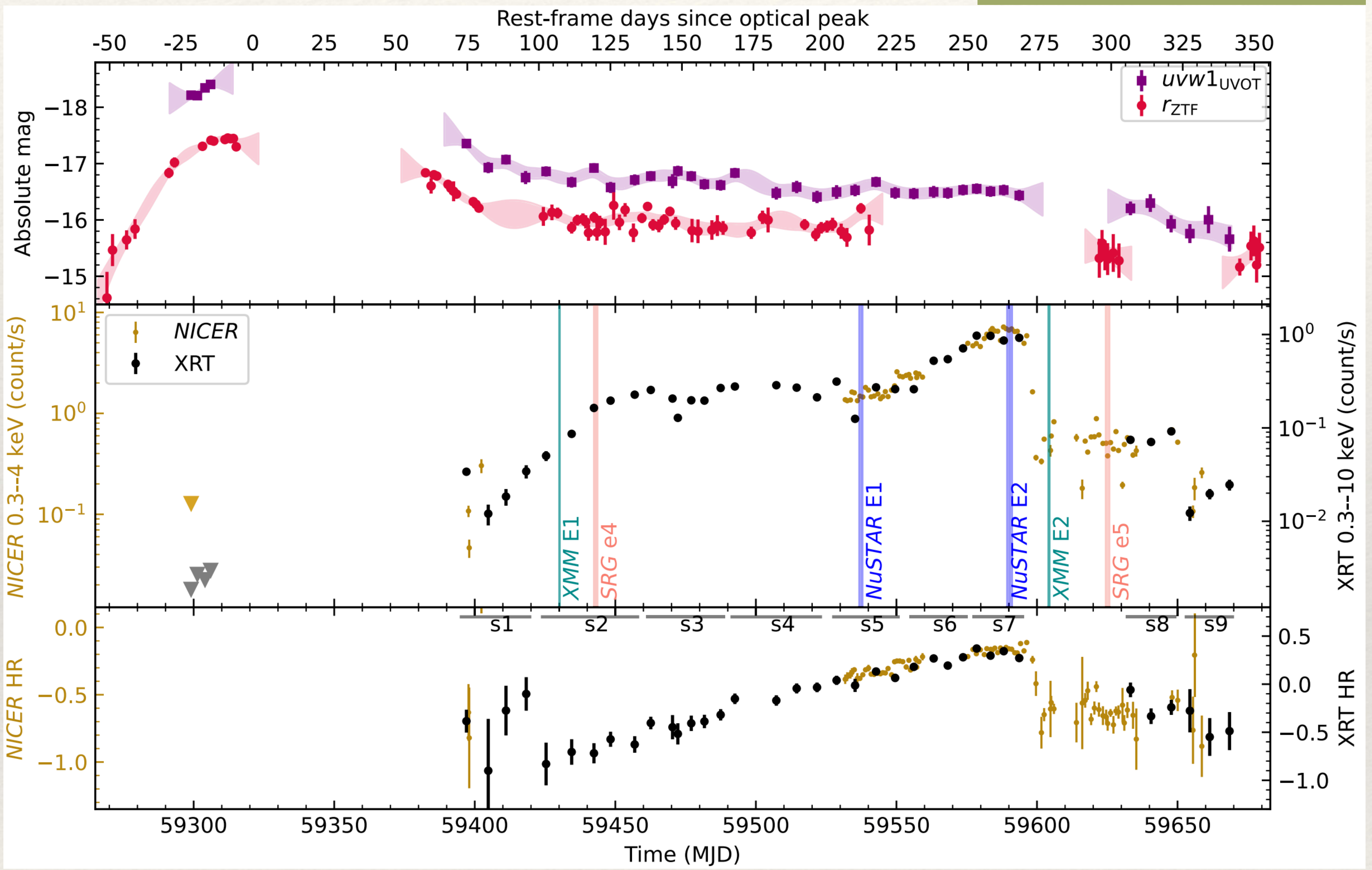
Partial TDEs

Radio emission detected in the plateau phase

State transition in TDEs: Rapid drop-off

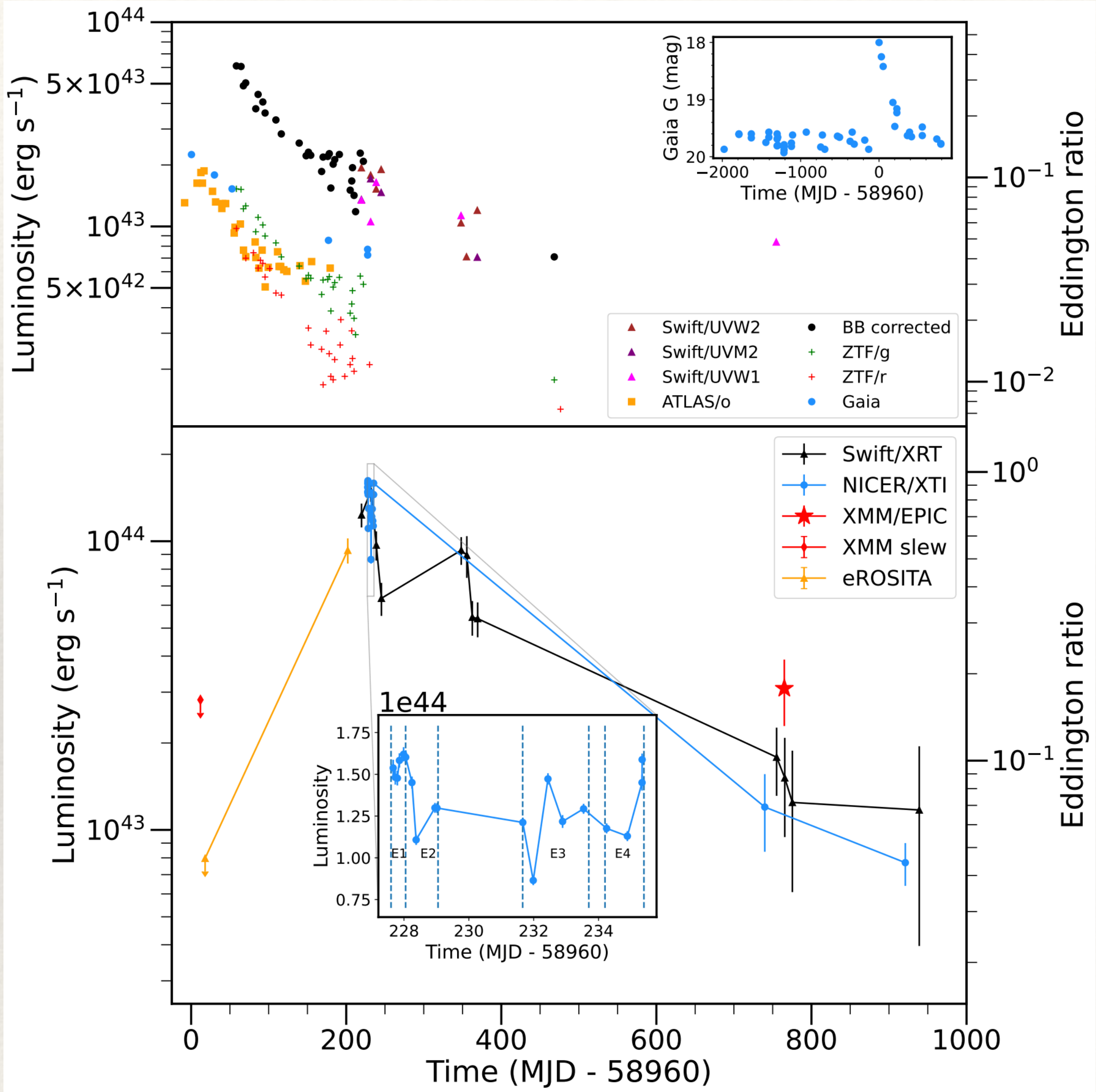
AT 2021ehb, $M_{BH} \sim 10^{7.03\pm0.22}\ M_{\odot}$, Yao+ (2022)

trest ≈ 320/370 days

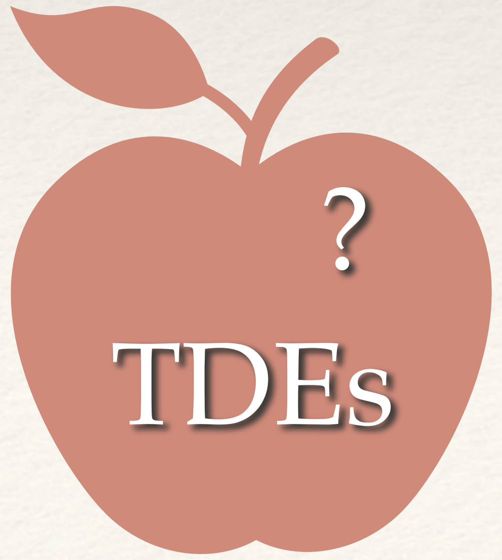


No radio emission detected

AT 2020ksf, $M_{BH} \sim 10^{6.1\pm0.4}\ M_{\odot}$, Wevers+ (2024)

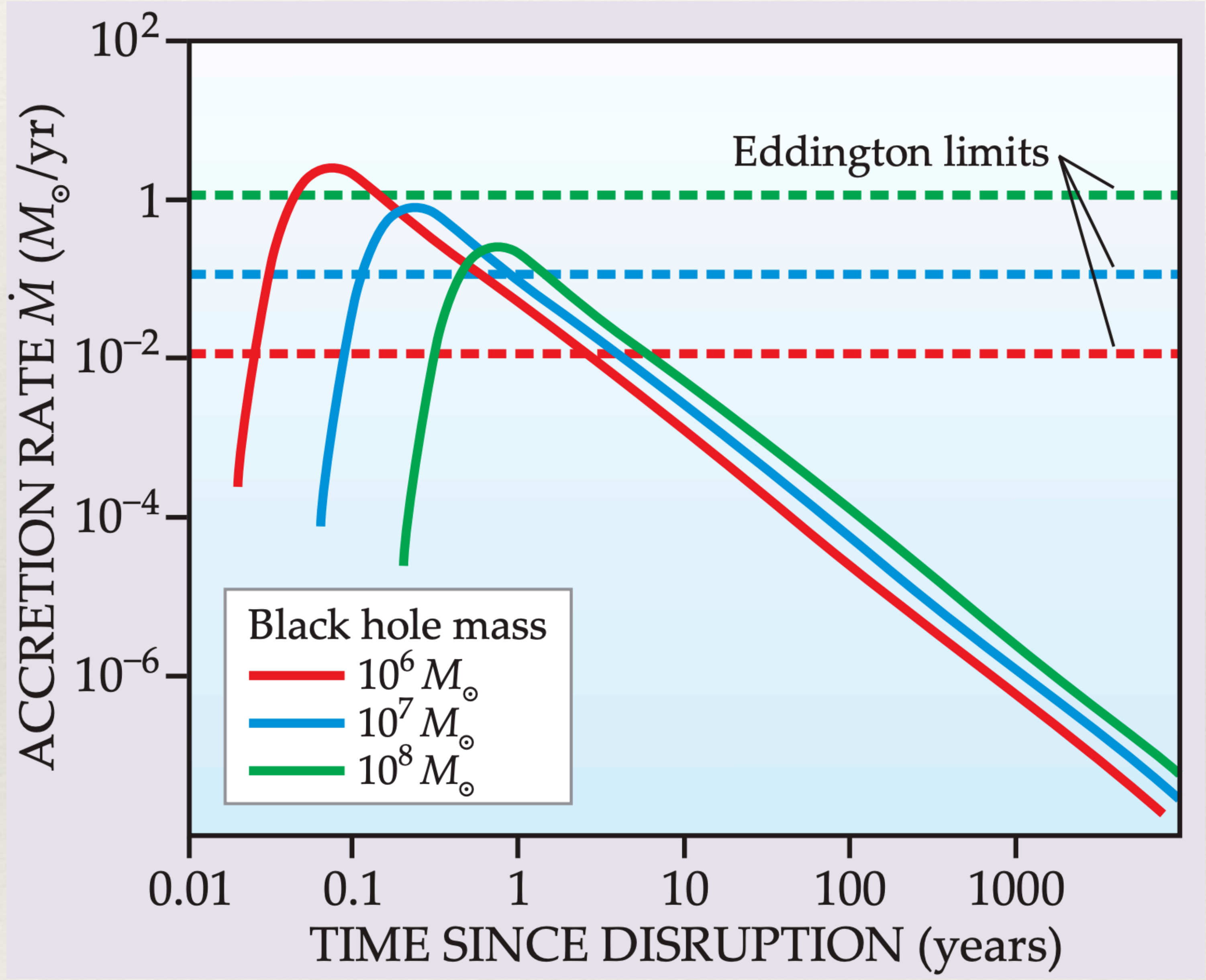


Radio emission detected after 230 days



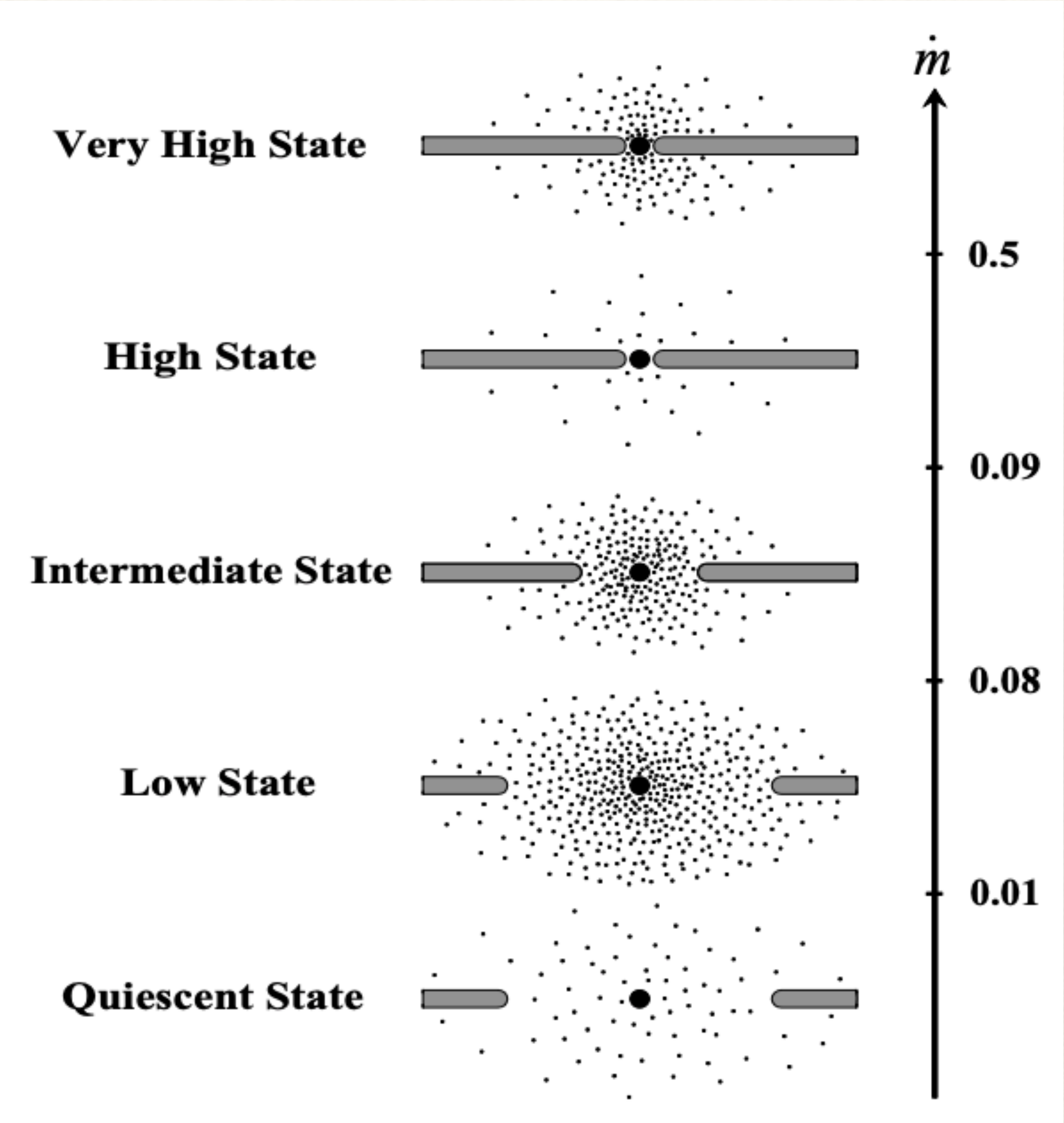
Plausible explanations for the rapid drop-off

super- to sub-critical state



De colle+ (2012); Gezari+ (2014)

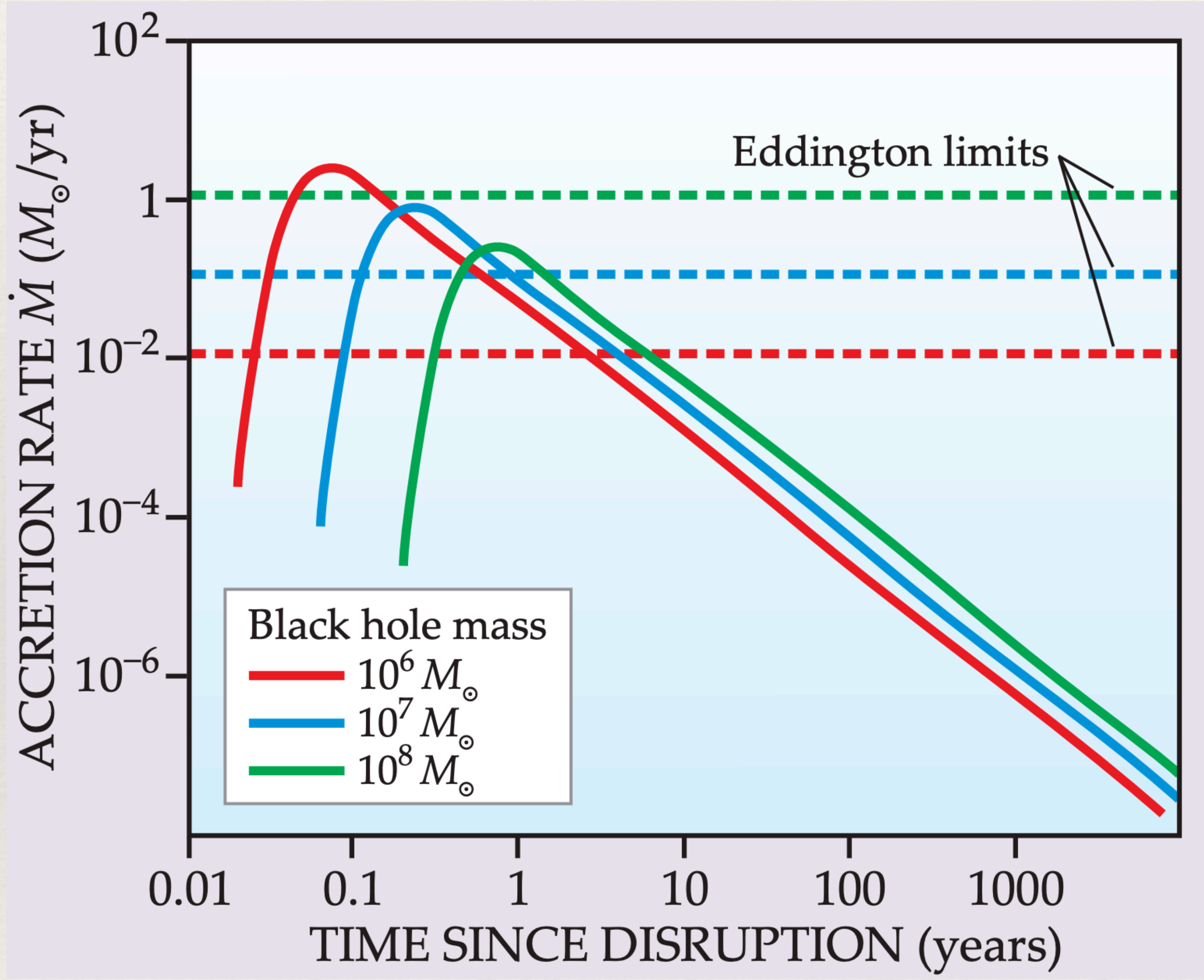
soft to hard state



Esin+ (1997)

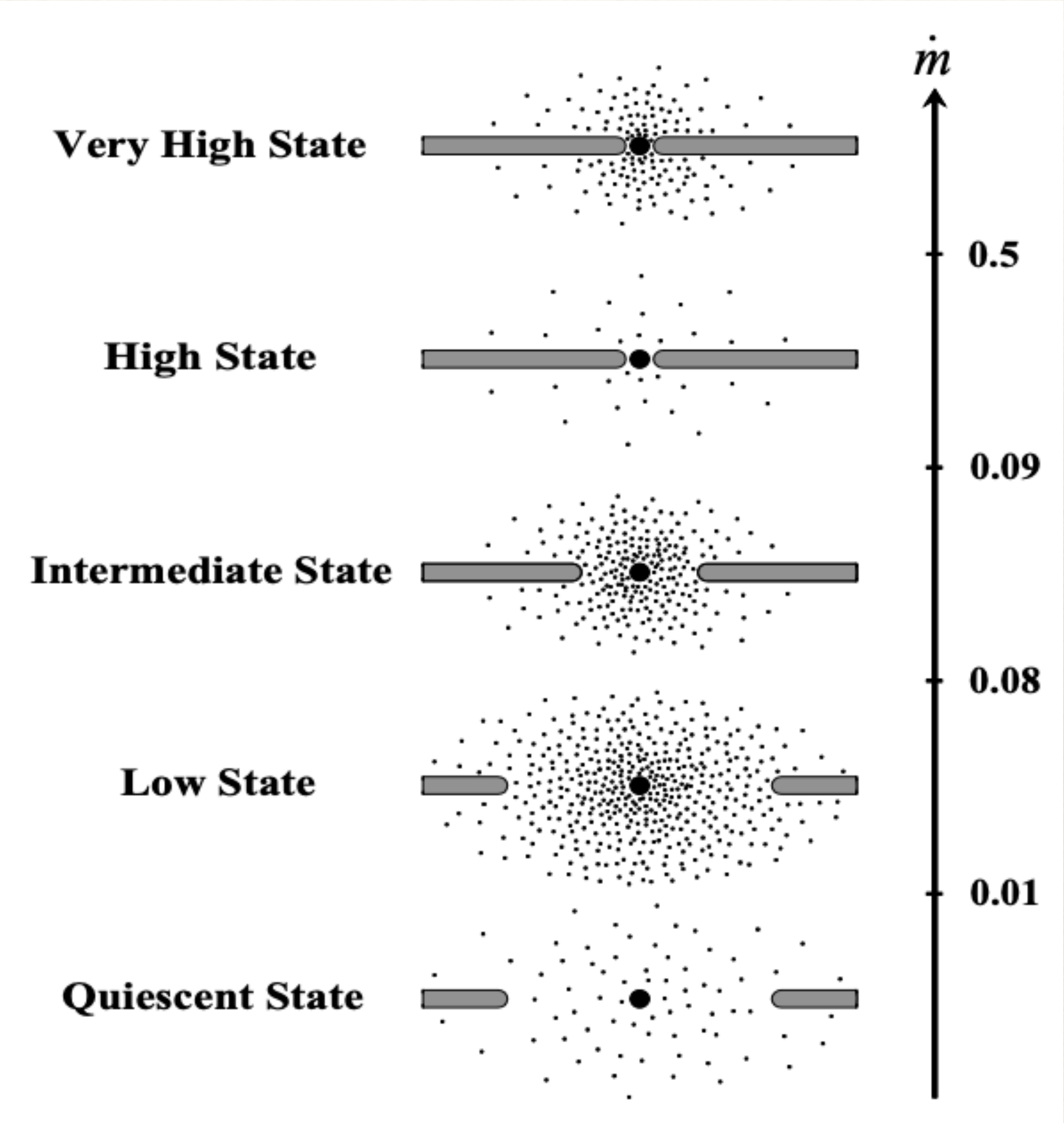
Plausible explanations for the rapid drop-off

super- to sub-critical state



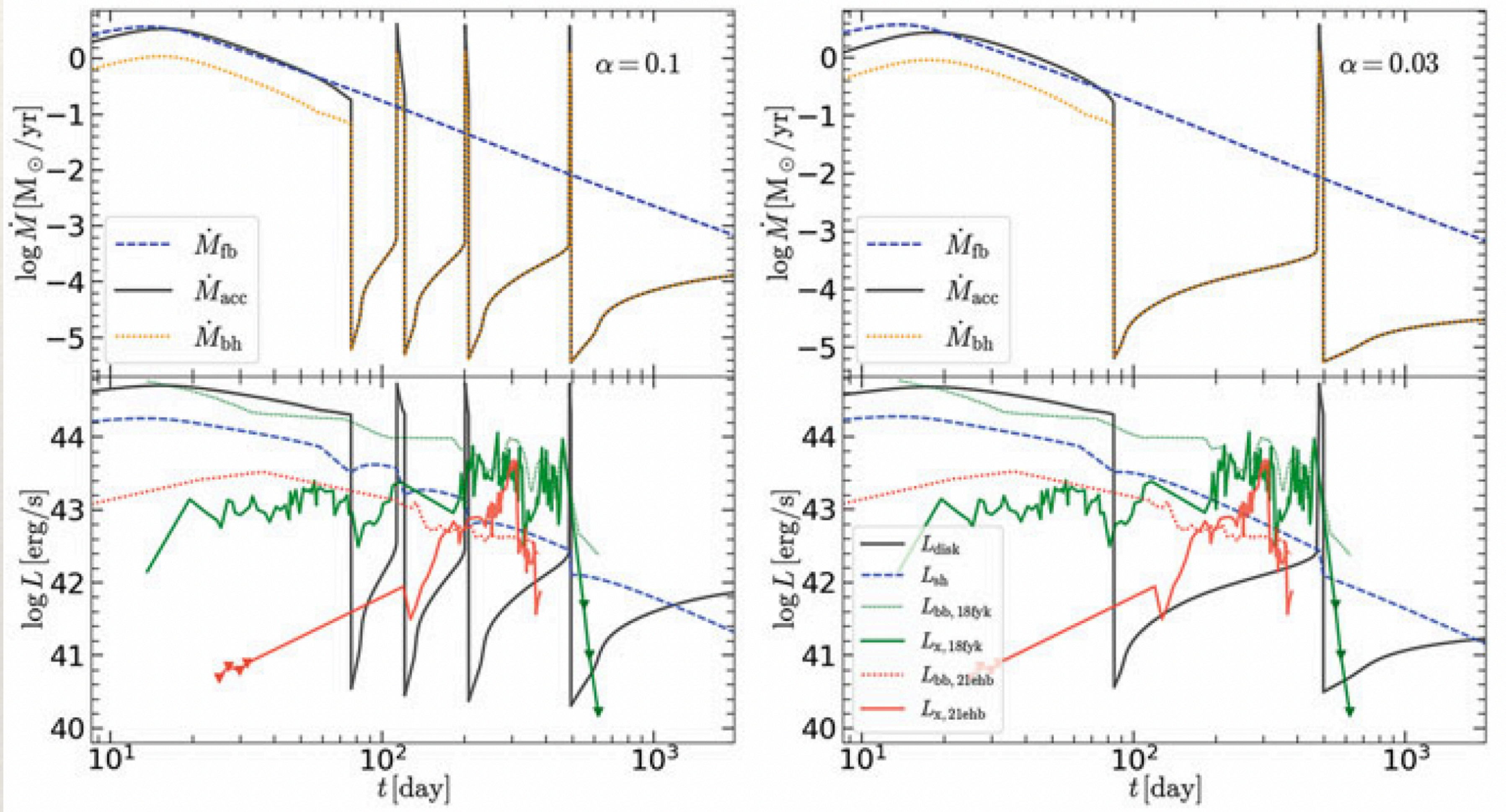
De colle+ (2012); Gezari+ (2014)

soft to hard state



Esin+ (1997)

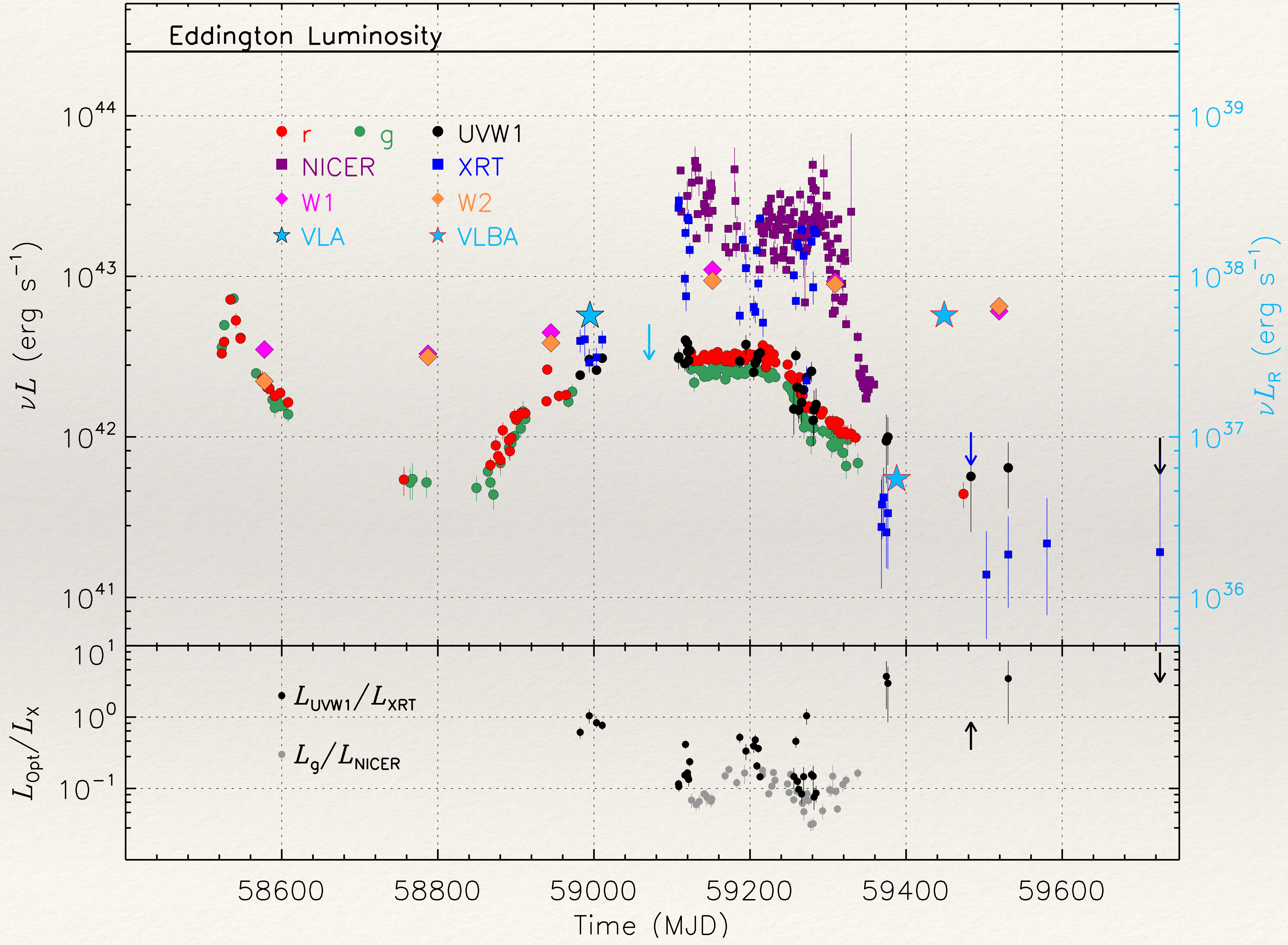
super-critical state:
radiation pressure instabilities



Lu (2023)

AT 2019avd: Multi-wavelength emission

AT 2019avd, $M_{BH} \sim 10^{6.3\pm0.3} M_{\odot}$, Wang Y.+ (2023)

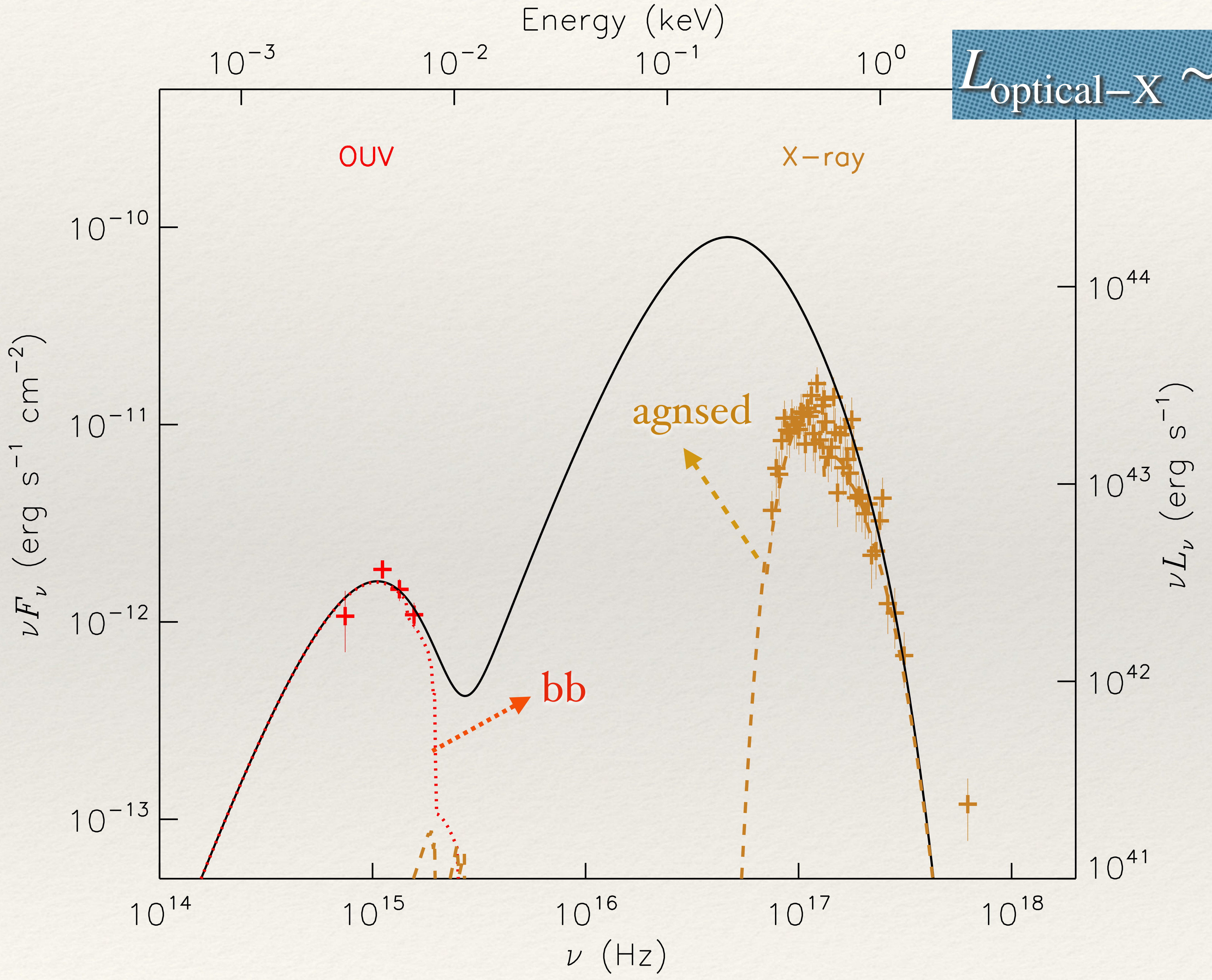


Including **seven** telescopes from radio to soft X-ray:

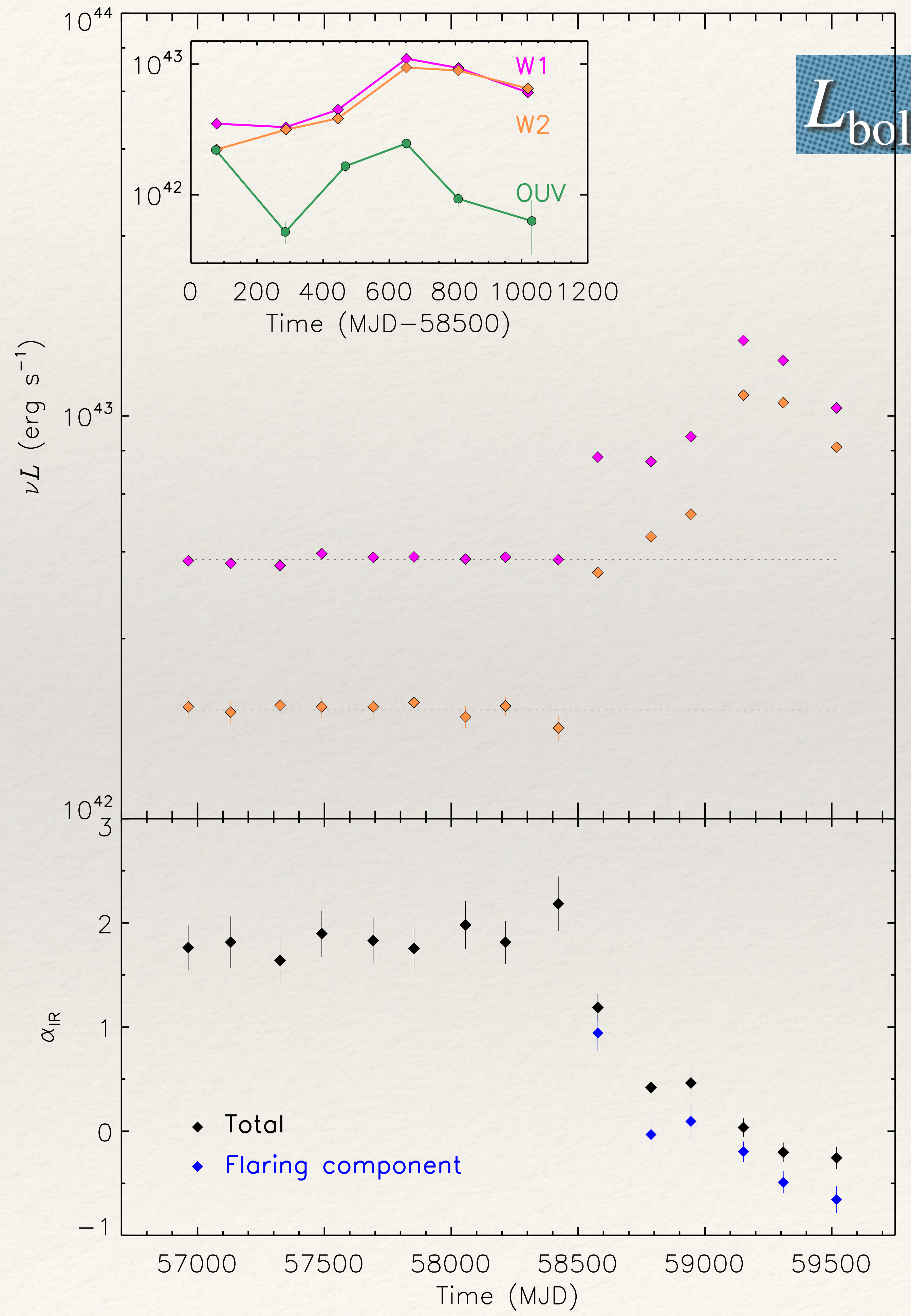
- Radio: VLA & VLBA;
- Infrared: WISE;
- Optical/UV: ZTF & UVOT;
- X-ray: NICER/XRT/Chandra.

AT 2019avd: Super-Eddington luminosity

$L_{\text{optical-X}} \sim 6.7\, L_{\text{Edd}}$



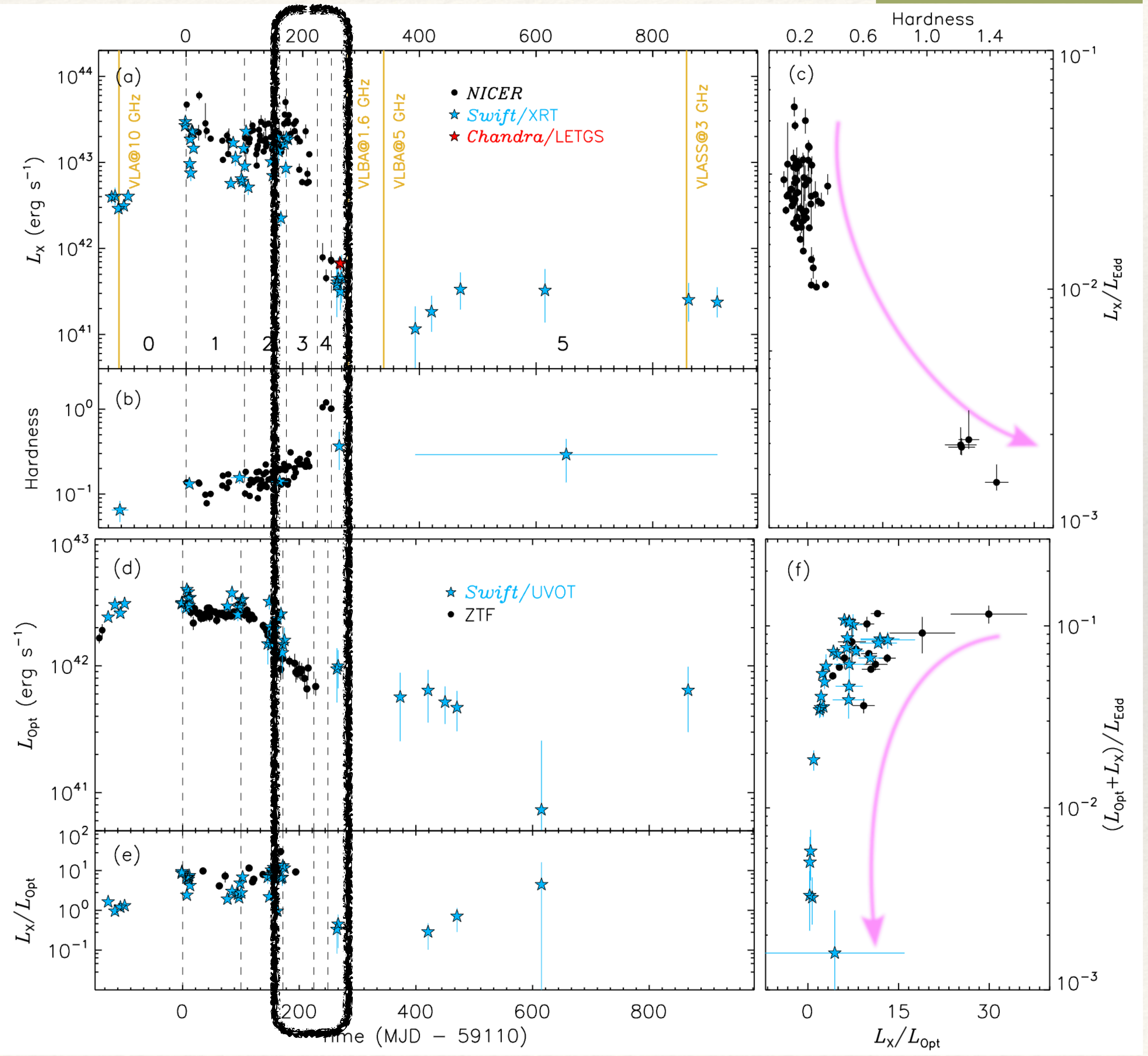
$L_{\text{bol}} \sim 0.94\, L_{\text{Edd}}$

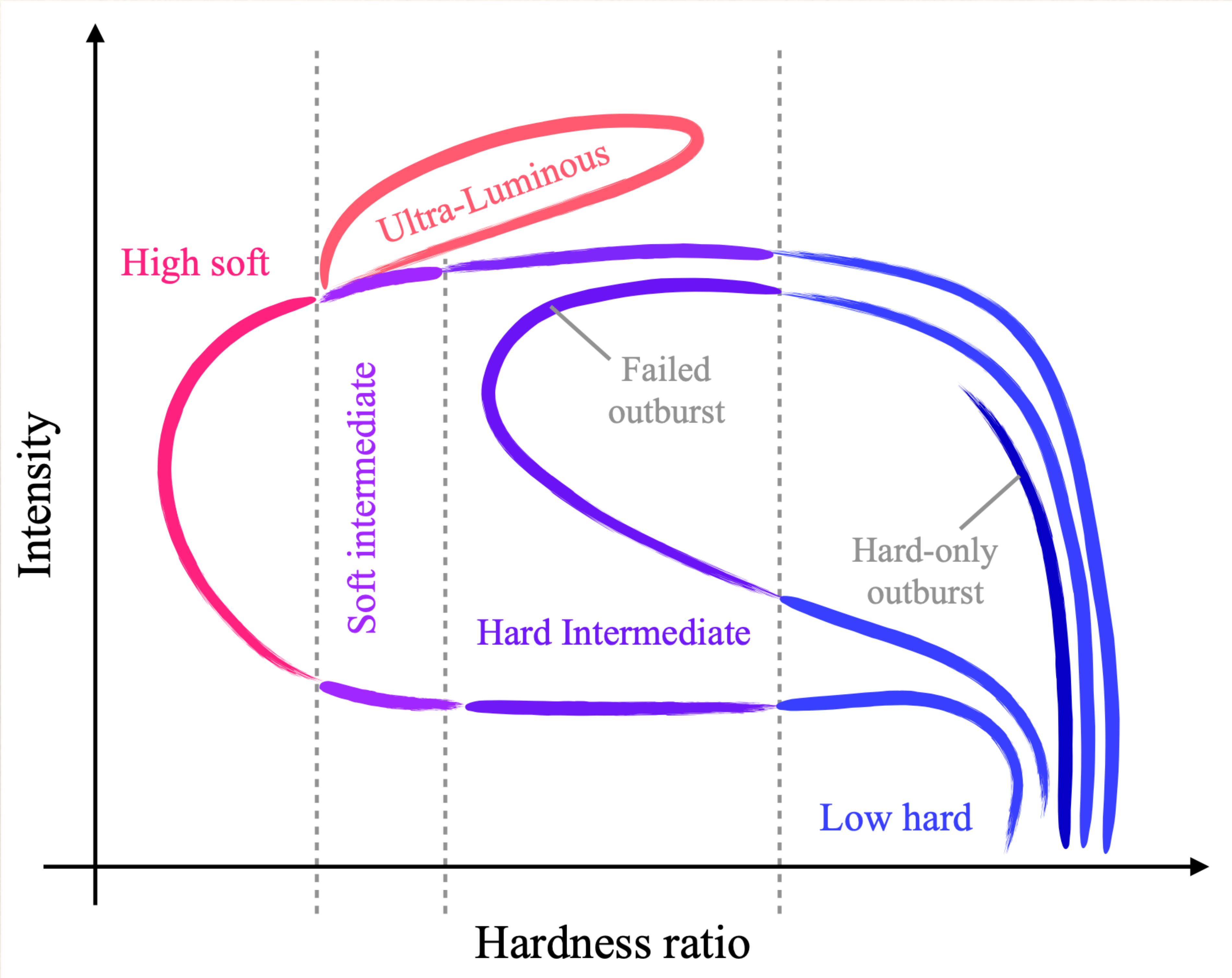


Wang Y.+ (2023)

AT 2019avd: Rapid X-ray dimming and spectral hardening

trest ≈ 225 days



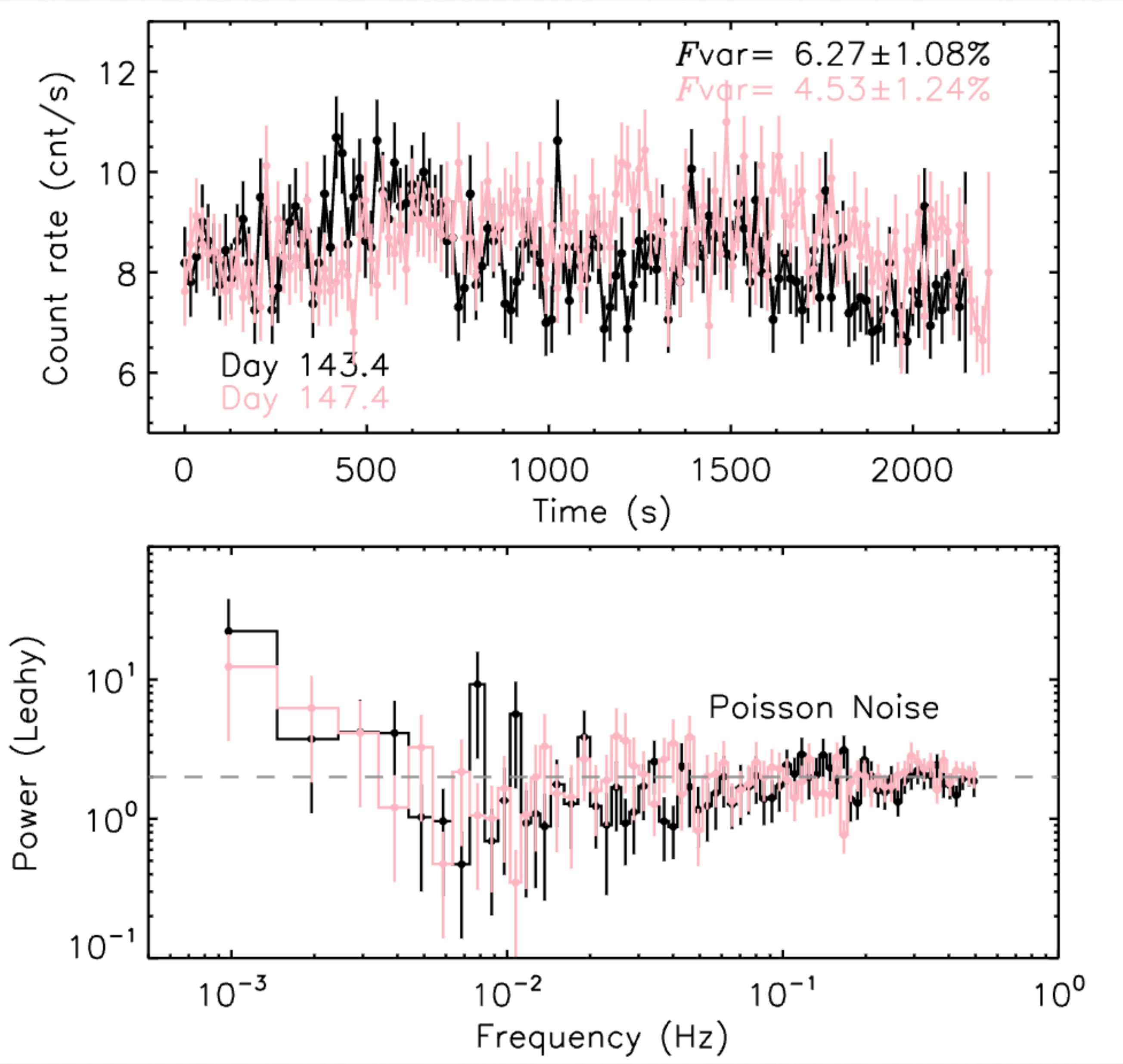


Motta+ (2021)

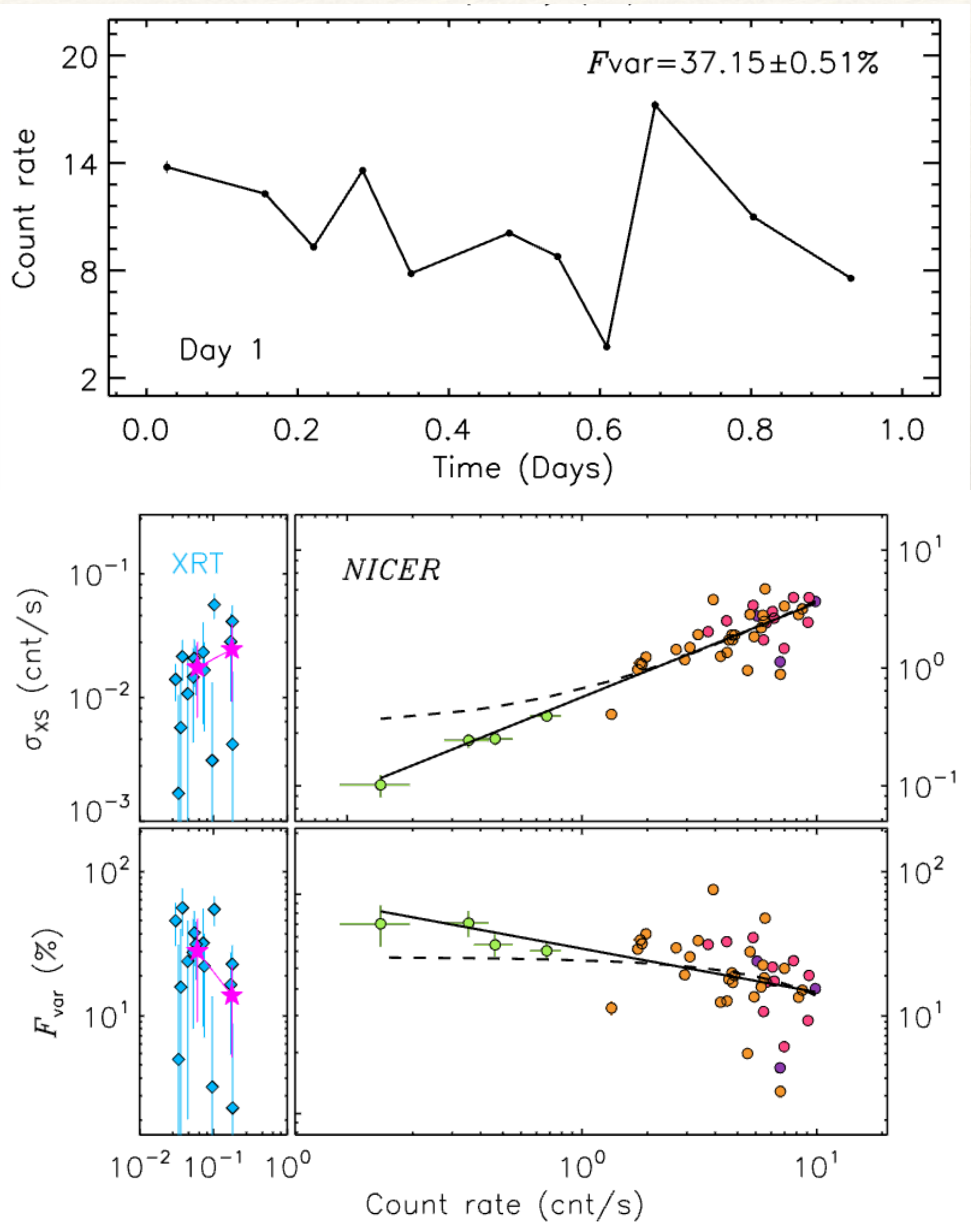
Wang Y.+ (2024)

AT 2019avd: X-ray variability across different timescales

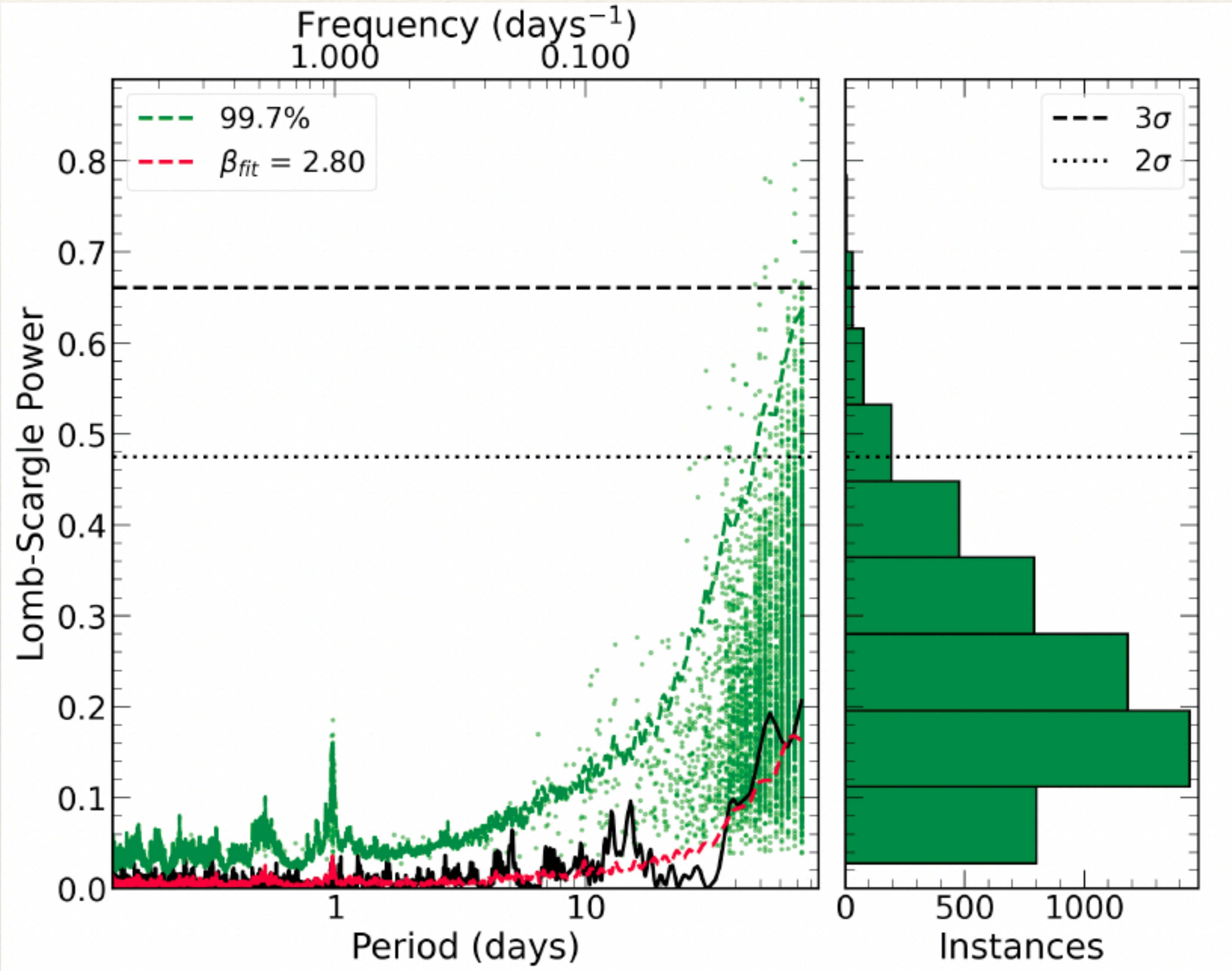
~minutes



~hours



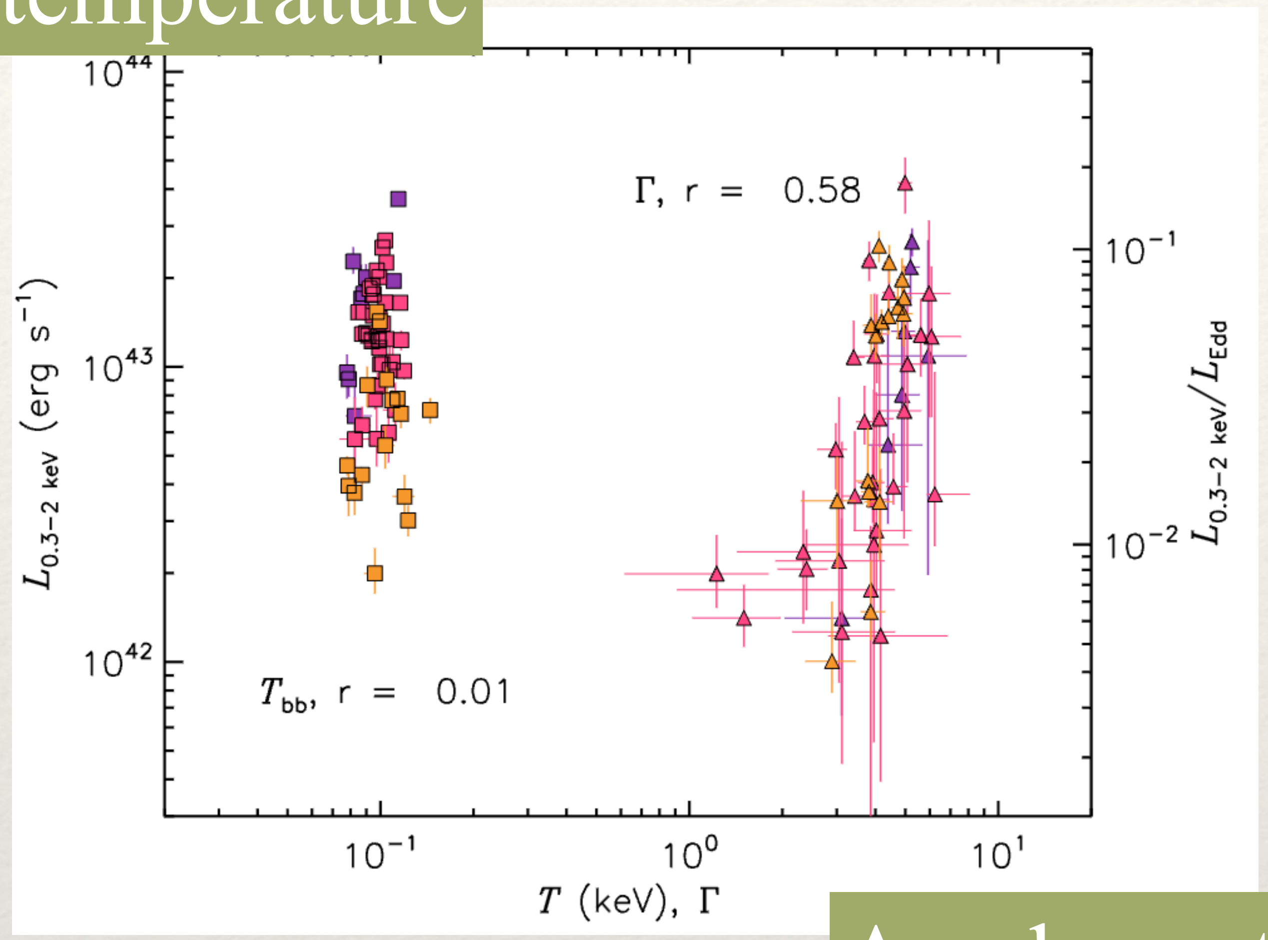
~days



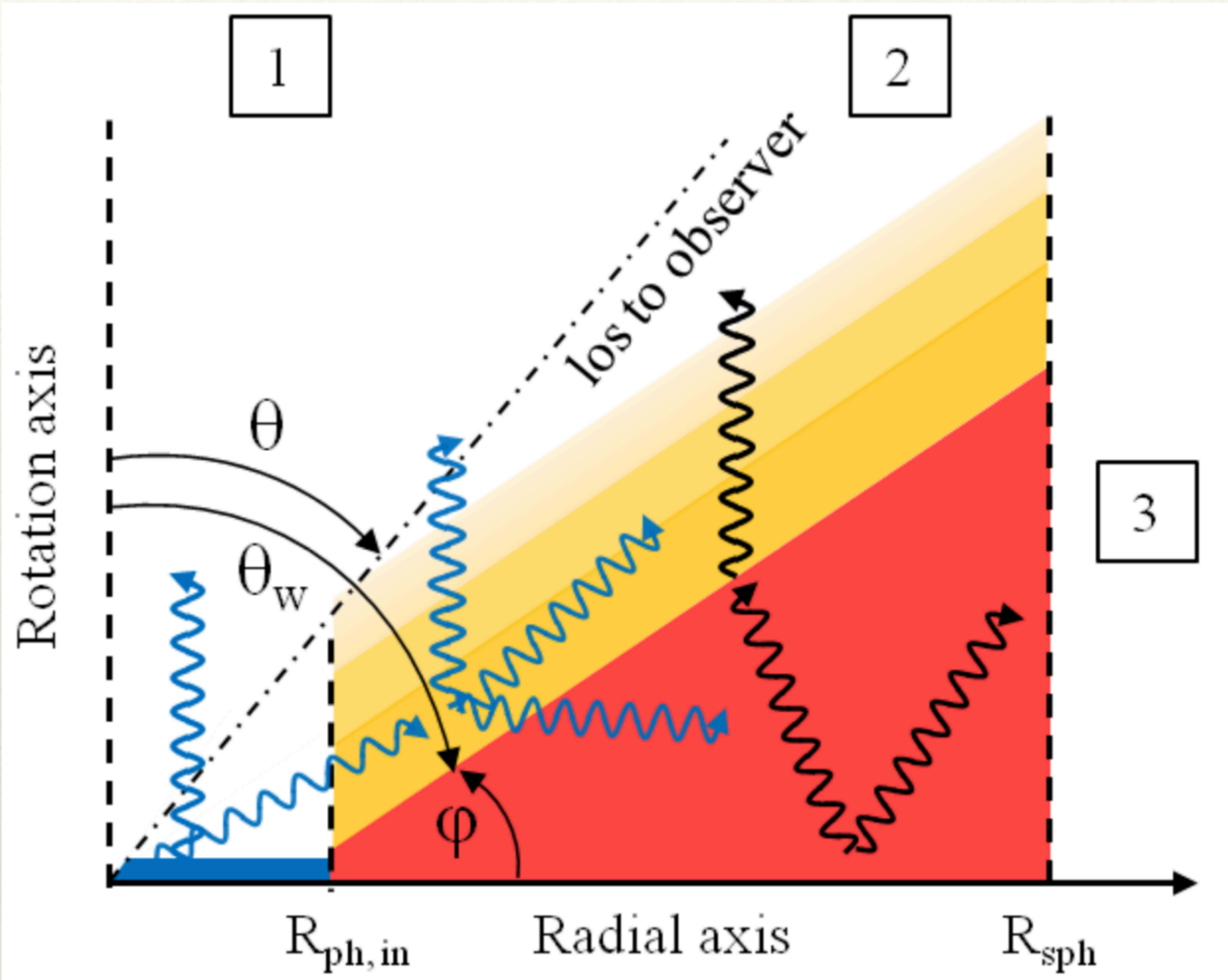
Wang Y.+ (2024)

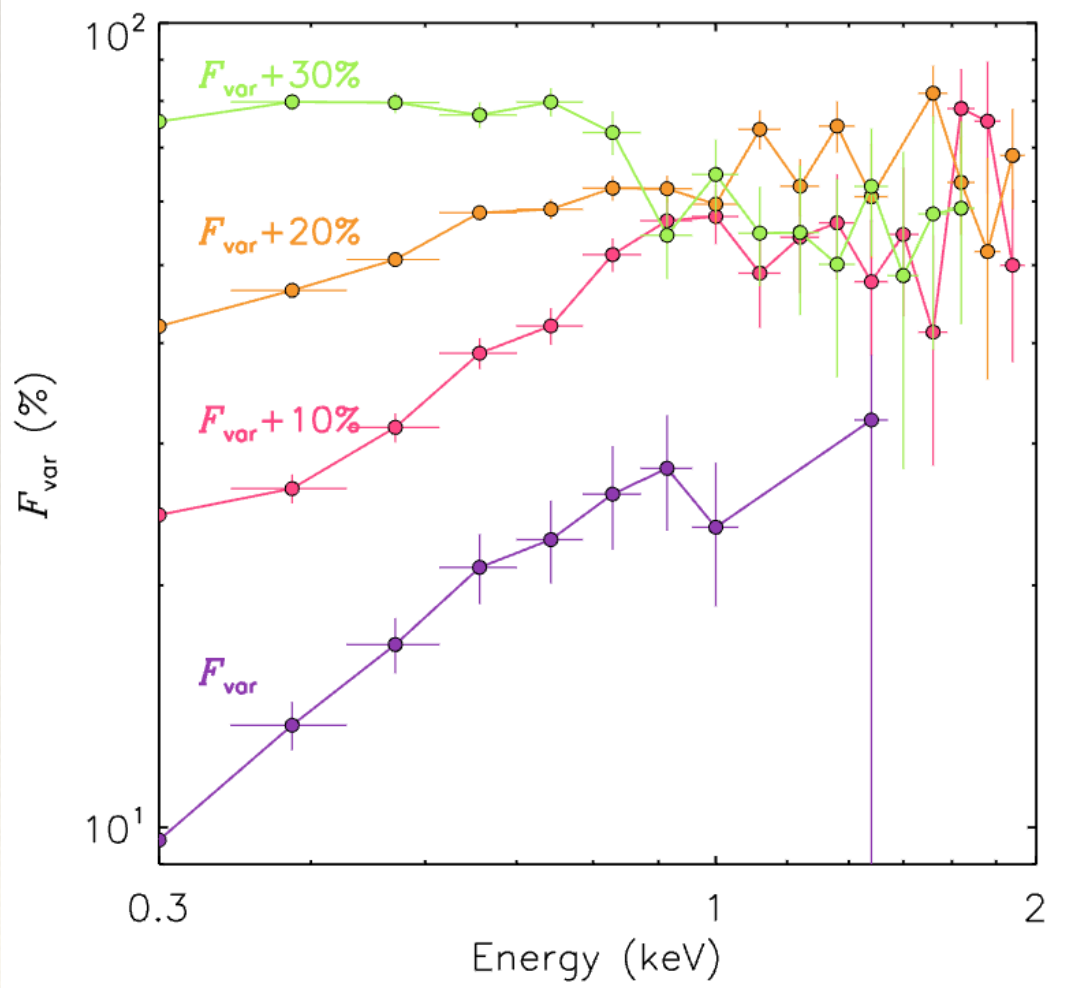
AT 2019avd: a plausible explanation for the high variability

A constant disk temperature

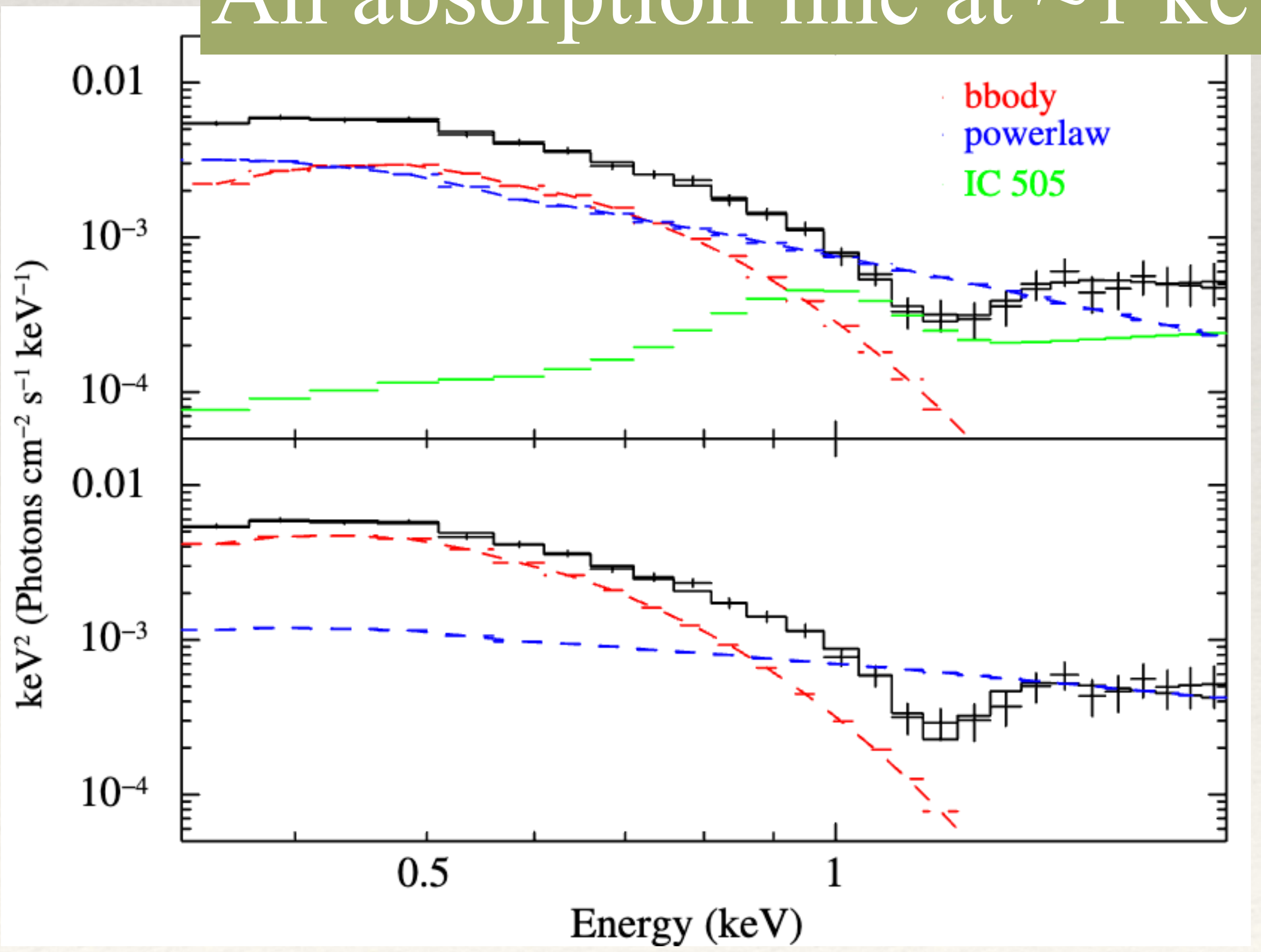


Middleton+ (2015)





An absorption line at ~1 keV



- Intrinsic variability via propagated fluctuations
- Extrinsic variability via obscuration and scattering by winds

rms increasing with energy

Wang Y.+ (2024)

Summary

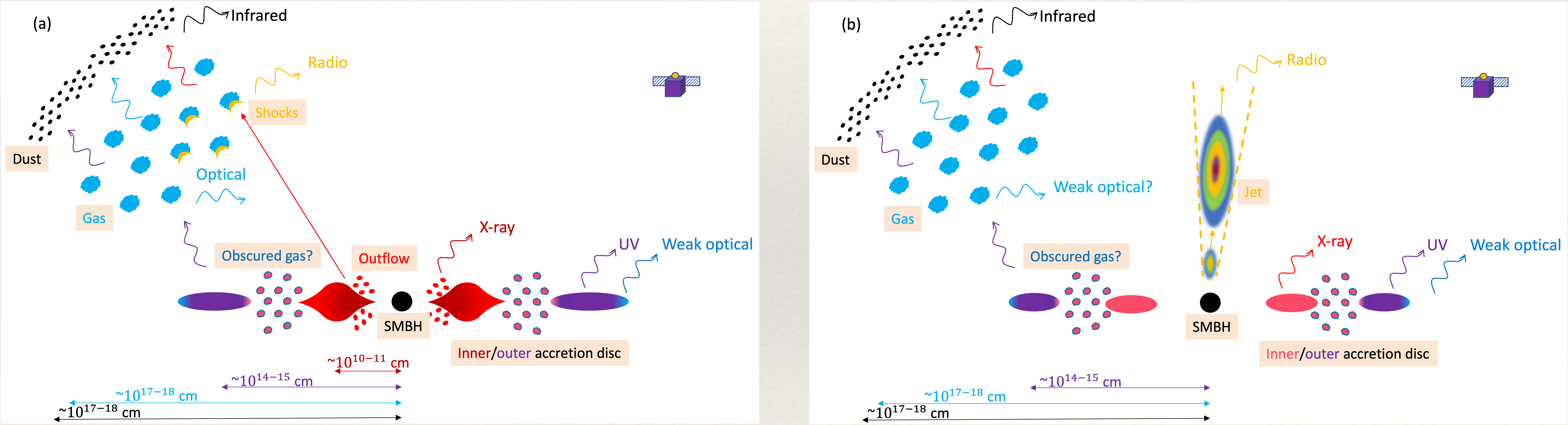
- A rapid drop in X-rays occurs ~225 days after the peak of the flare, followed by a soft-to-hard transition when the luminosity decreases down to 0.01 L_{Edd}, and by the possible ejection of a optically-thick radio outflow;
- The softer-when-brighter relation has been observed throughout the flare: the spectrum hardens as the luminosity decreases;
- The fractional rms amplitude is high with an average of 43% and its evolution is related to spectral state; The variability may be attributed to some clumpy outflows intercepting with the X-ray emission from the accretion disk;
- A soft excess has been detected at least in the relatively soft state, whose temperature remains more or less constant while the luminosity decreases by over one order of magnitude.

State transition in TDEs: soft-to-hard or super- to sub-critical?

Wang Y.+ (2024)

AT 2019avd: Super- to sub-Eddington accretion regimes

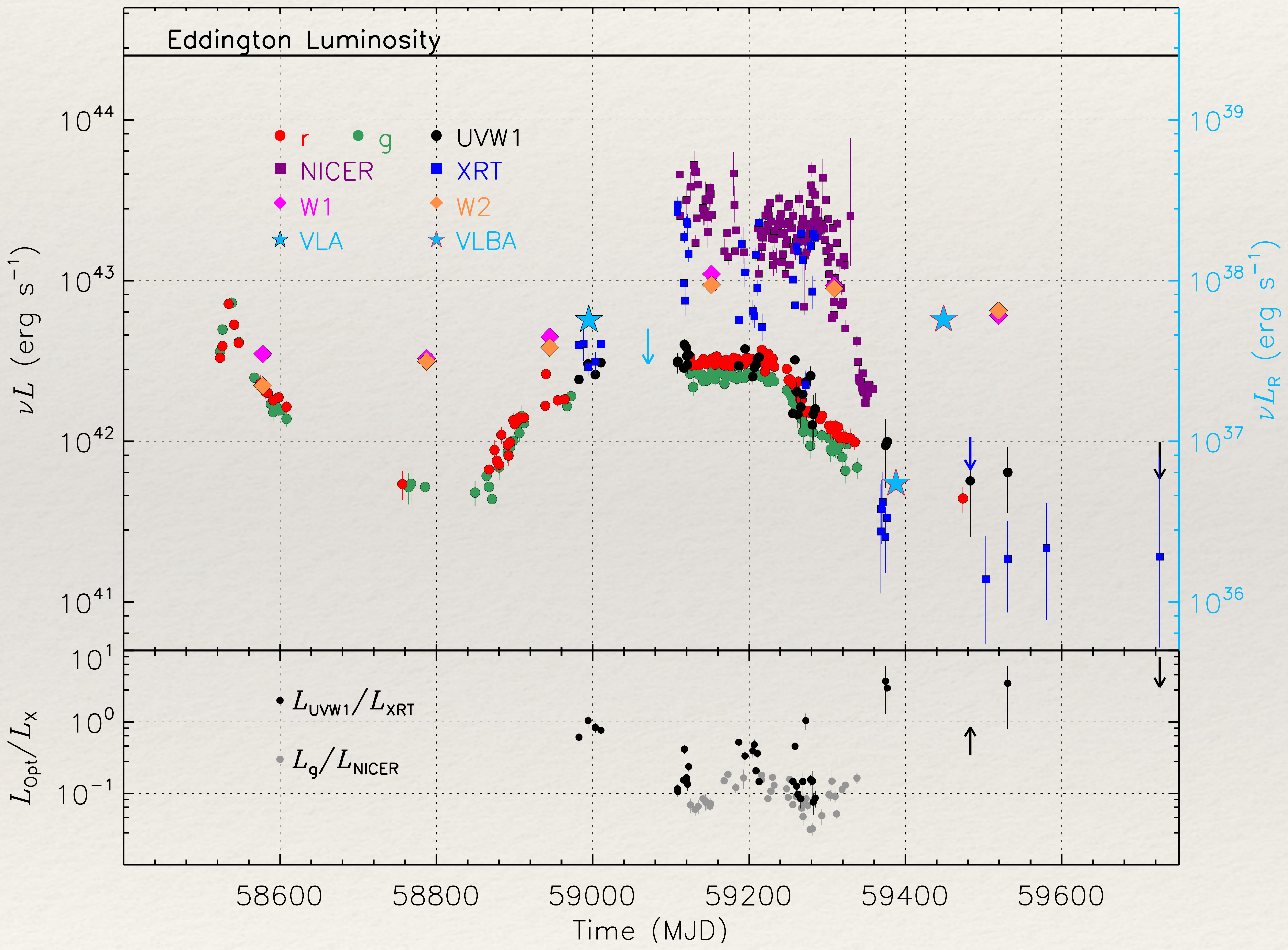
The properties of AT 2019avd offer a unique window into both super- and sub-Eddington accretion processes around SMBHs and offer compelling evidence for the mass-scale invariance of accretion around black holes.

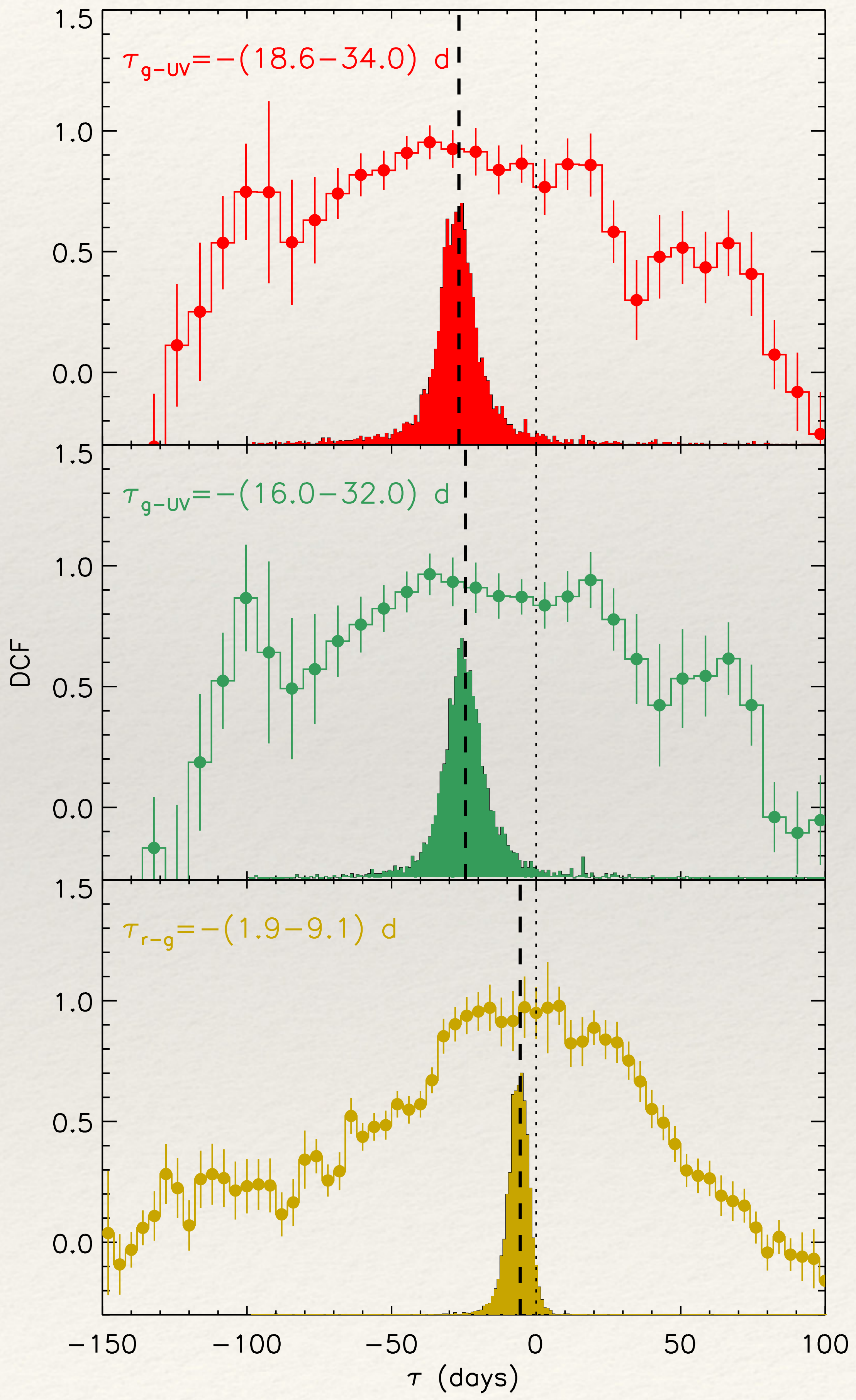


Wang Y.+ (2023)

AT 2019avd: Gaseous environments

The optical emission likely comes from UV reprocessing by a gas at a distance of 0.01–0.03 pc





Time lags:
discrete correlation function plus bootstrapping technique.

Considering only the light-travel time, the timescale of τ_{r-UV} or τ_{g-UV} corresponds to a distance of $4.4-8.7\times10^{17}$ cm, which is more than four orders of magnitude larger than the circularized debris disc.

Wang Y.+ (2023)