AT2021ehb
A Spectacular *X-ray* Tidal Disruption Event

Yuhan Yao (Graduate Student, Caltech)
with Suvi Gezari (STScI), Wenbin Lu (Princeton→UCB)
and many others

yyao@astro.caltech.edu

ZTF Collaboration Meeting, 11 May 2022

Rest-frame g-band

AT2019qiz (64Mpc) 1
AT2019azh (96Mpc) 2
AT2020wey (119Mpc) 3
AT2020vwl (142Mpc) 4
AT2018hyz (202Mpc) 5
AT2018bsi (226Mpc) 6
AT2019dsg (227Mpc) 7
AT2020zso (252Mpc) 8
AT2020pj (306Mpc) 9
AT2020mot (315Mpc) 10
AT2020ocn (318Mpc) 11
AT2018zr (320Mpc) 12
AT2019ehz (334Mpc) 13
AT2020nov (382Mpc) 14
AT2019teq (400Mpc) 15
AT2019vcb (406Mpc) 16

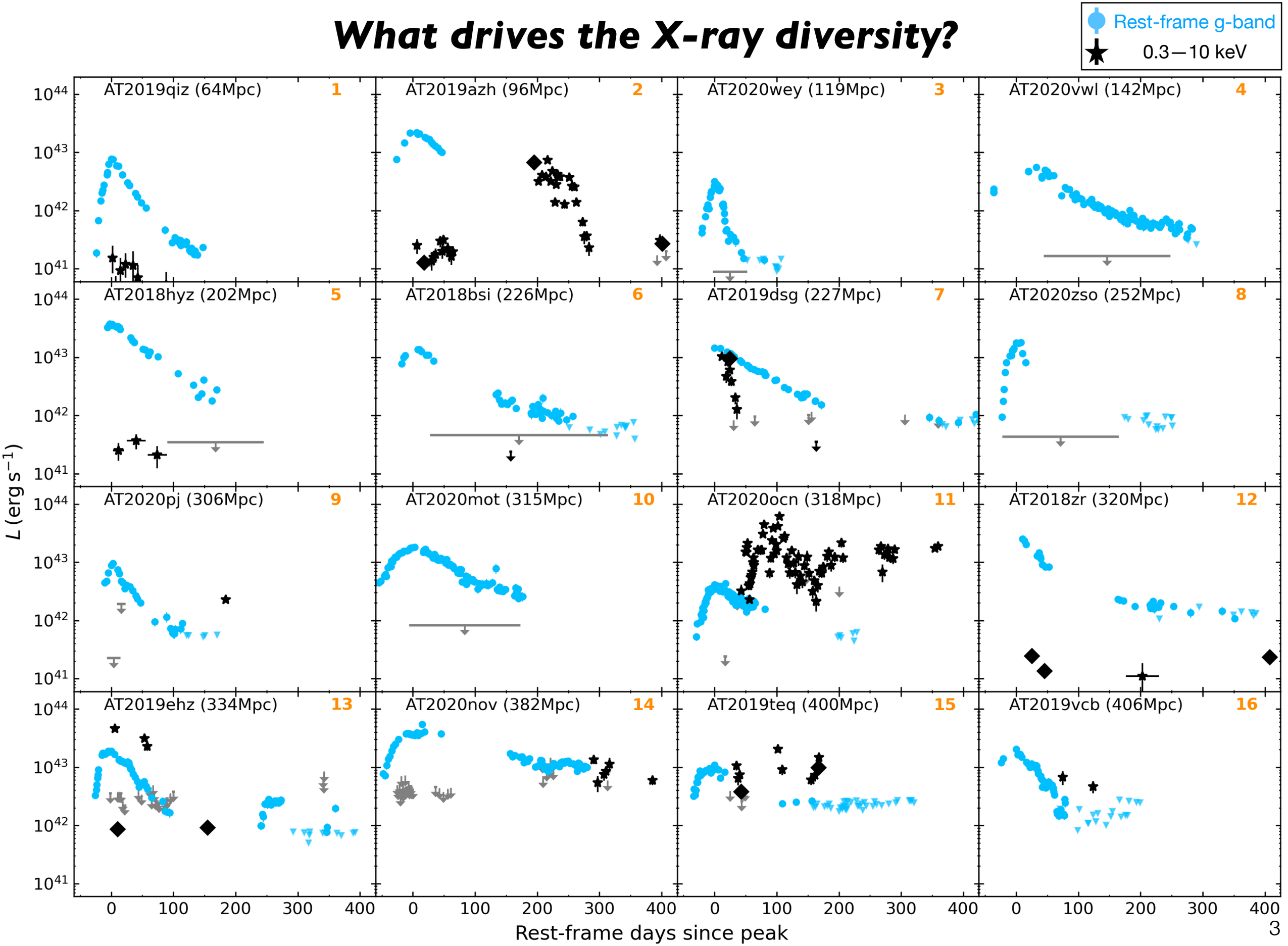
L (erg s^{-1})

10^{44}
10^{43}
10^{42}
10^{41}

0 100 200 300 400

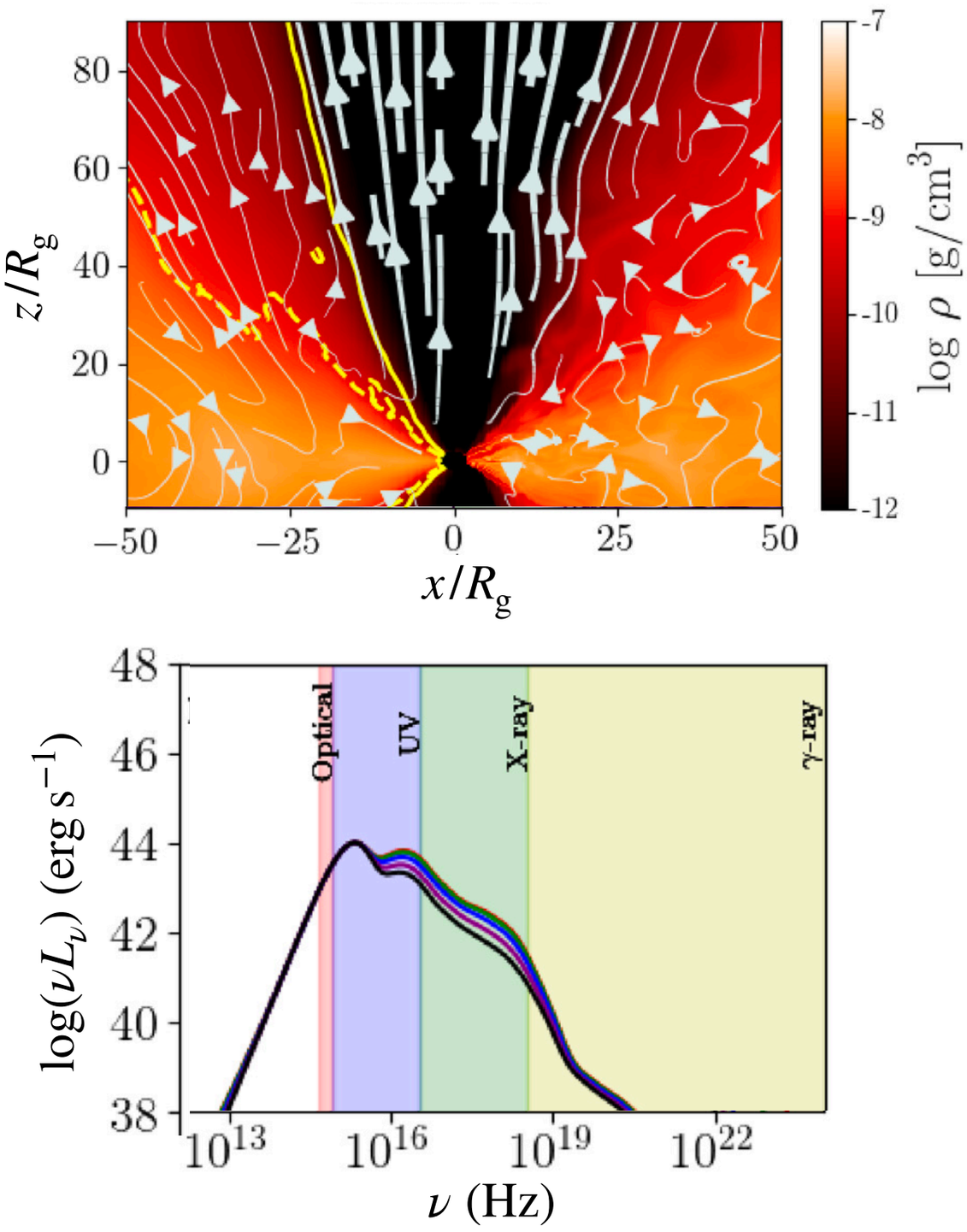
Rest-frame days since peak

What drives the X-ray diversity?



Where does the UV/optical emission come from?

Reprocessing by a <u>radiation-driven wind</u>

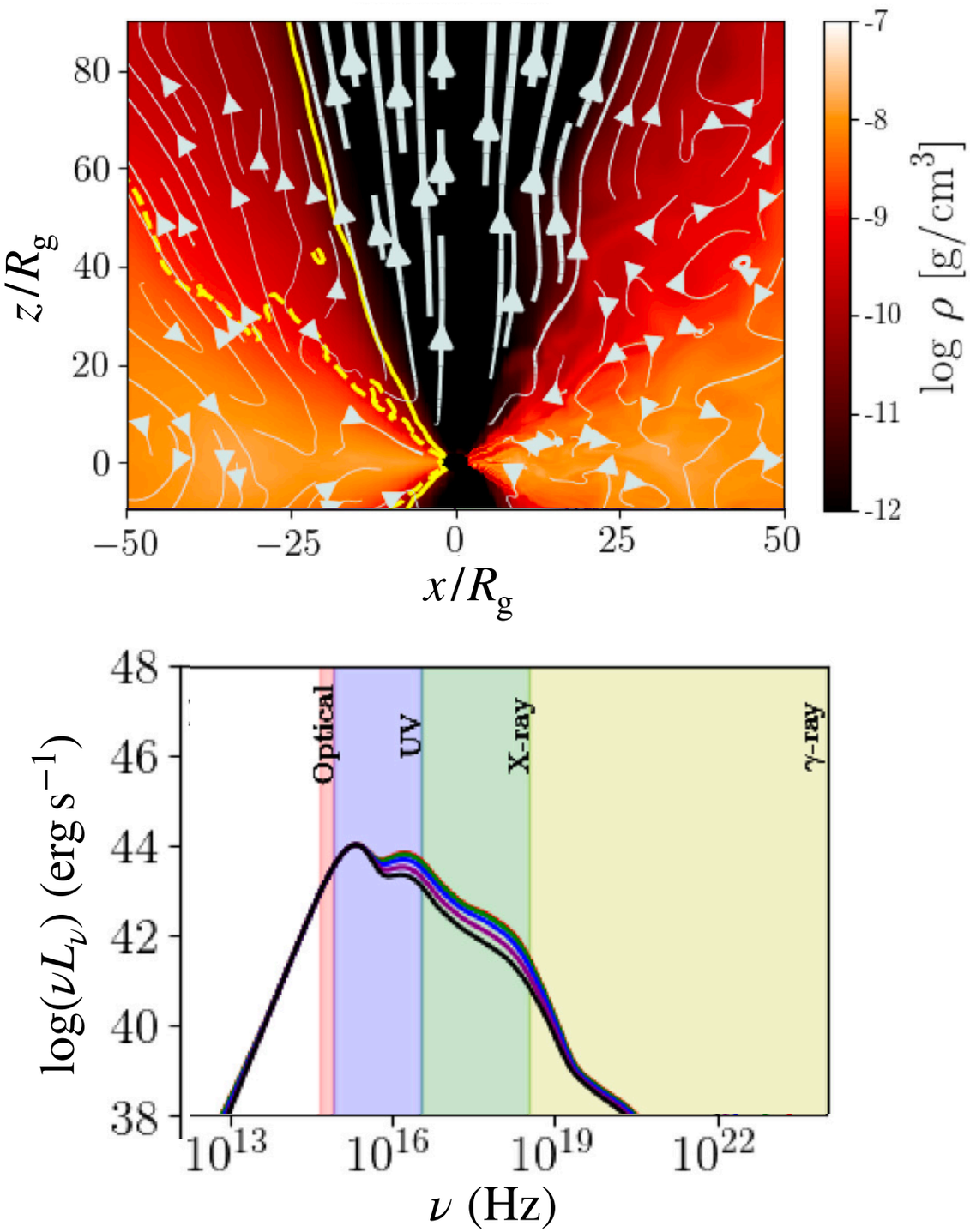


Curd & Narayan 2019

Energy dissipation by a <u>self-collision shock</u>

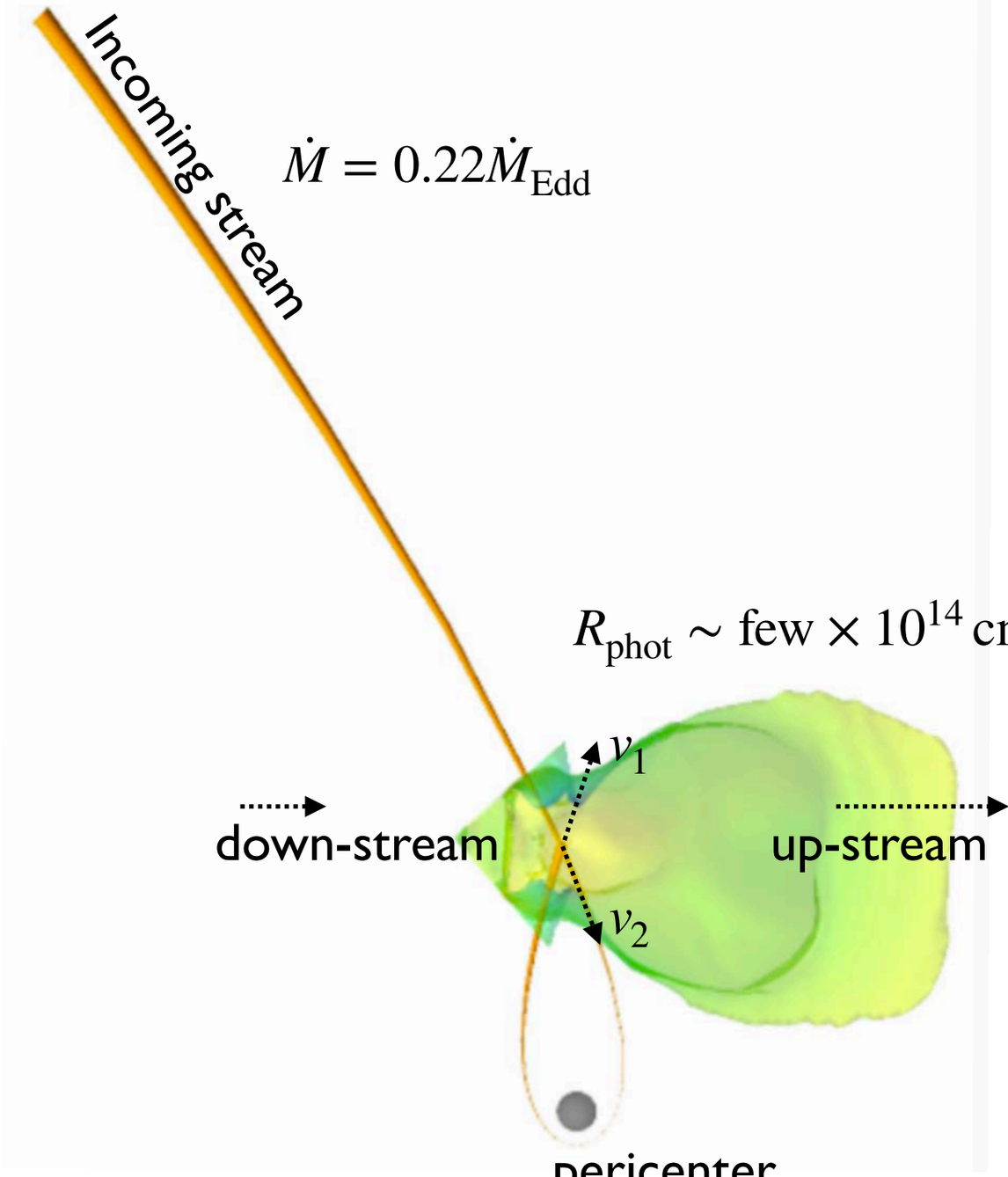
Where does the UV/optical emission come from?

Reprocessing by a <u>radiation-driven wind</u>



Curd & Narayan 2019

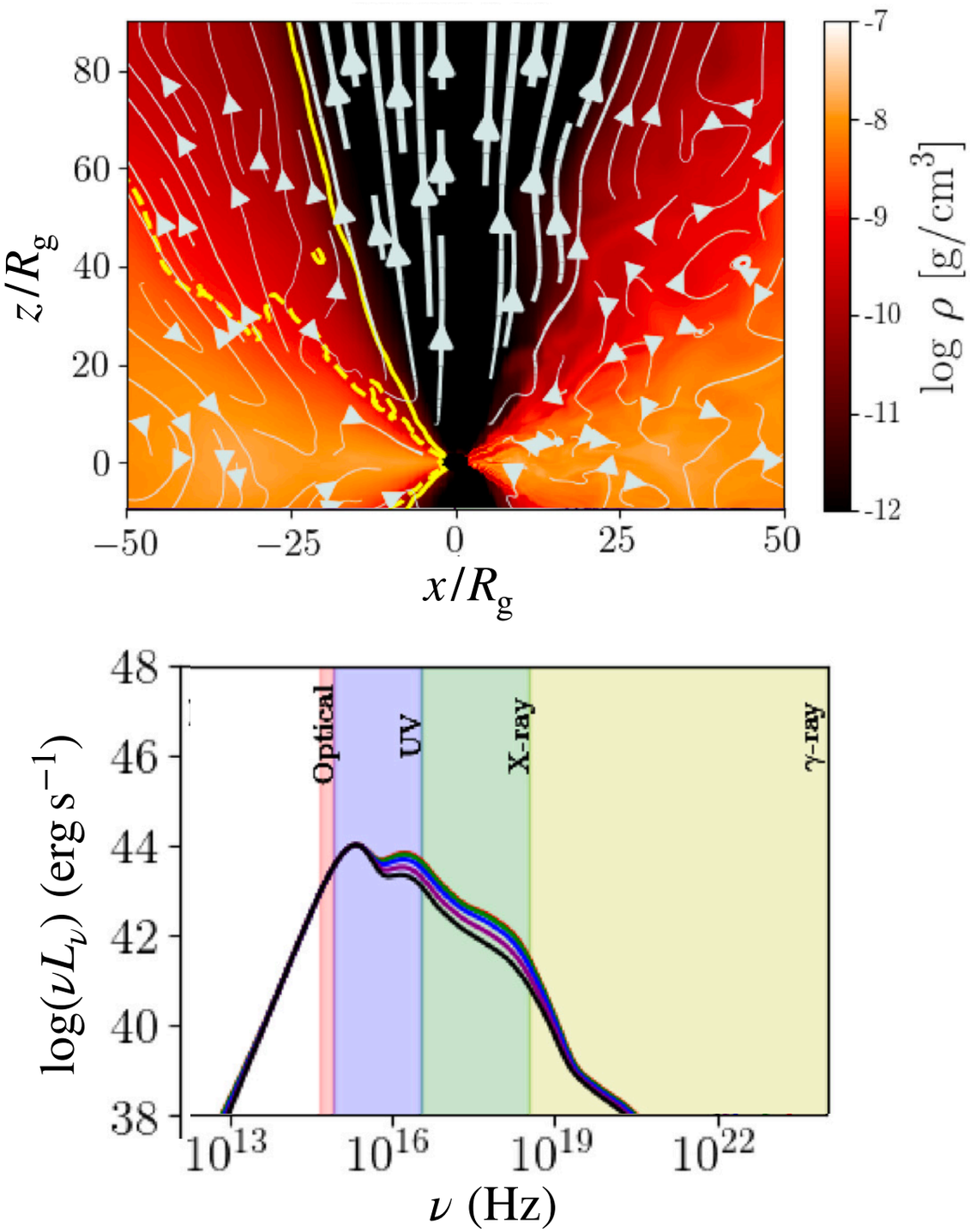
Energy dissipation by a <u>self-collision shock</u>



Jiang, Guillochon & Loeb 2016

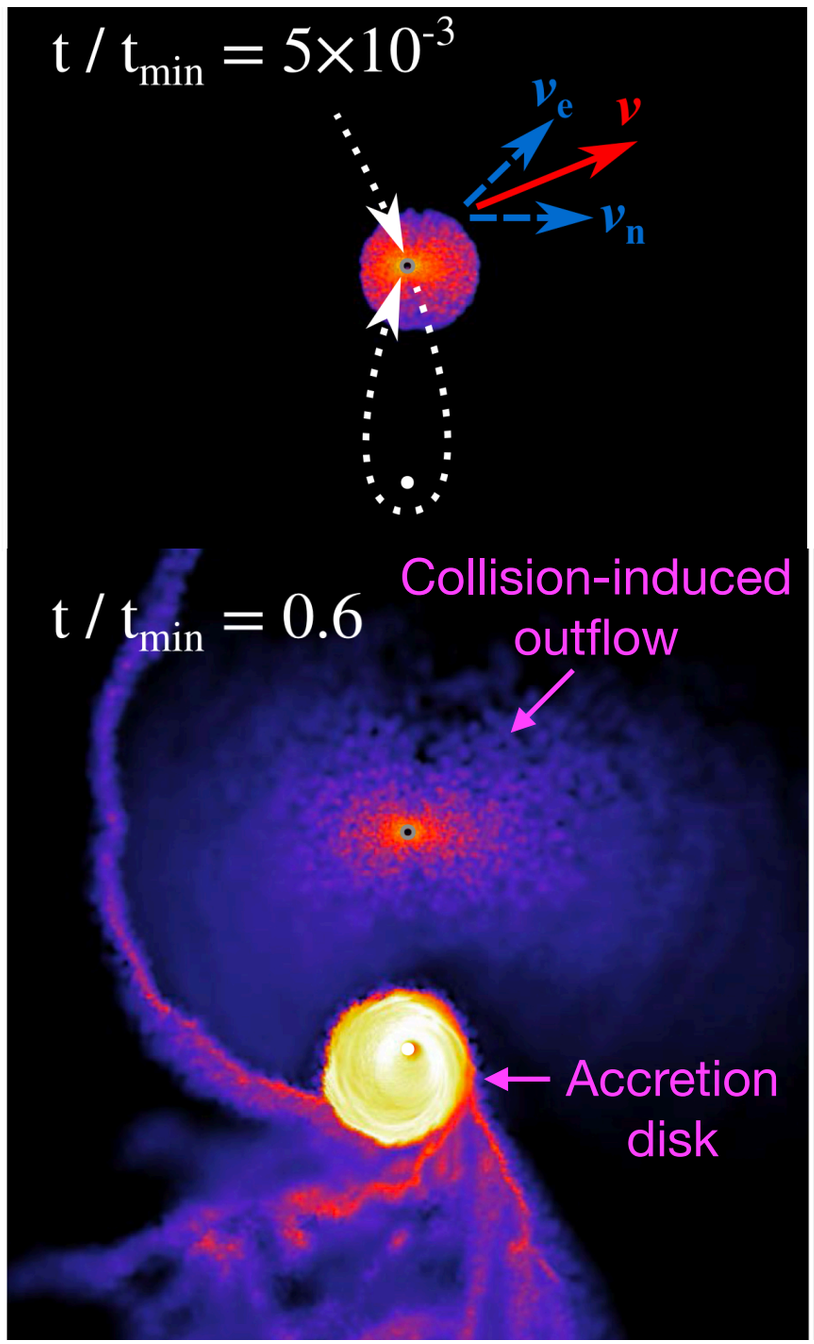
Where does the UV/optical emission come from?

Reprocessing by a <u>radiation-driven wind</u>



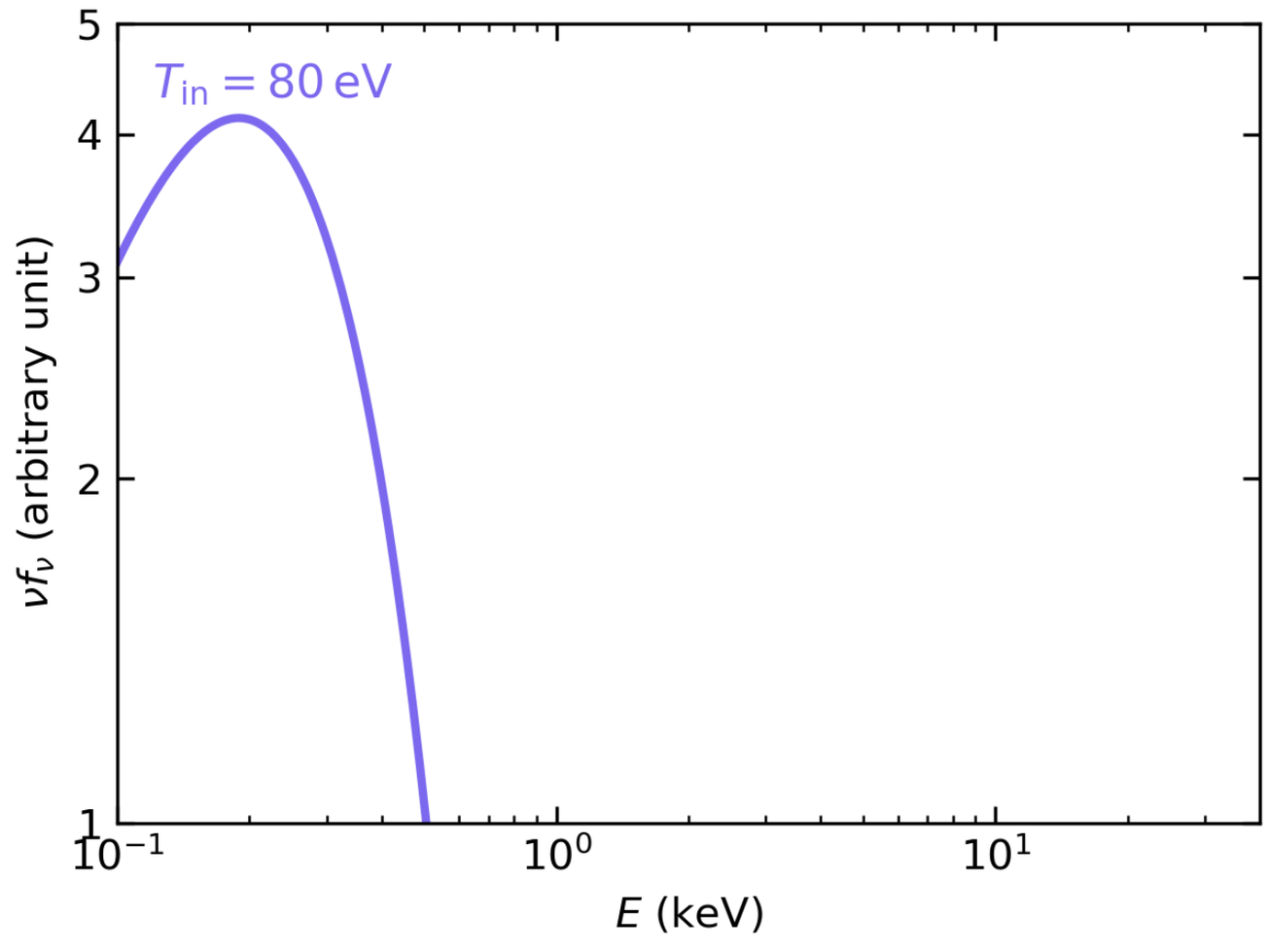
Curd & Narayan 2019

Energy dissipation by a self-collision shock
Or reprocessing by a <u>collision induced outflow</u>



Bonnerot, Lu & Hopkins 2021

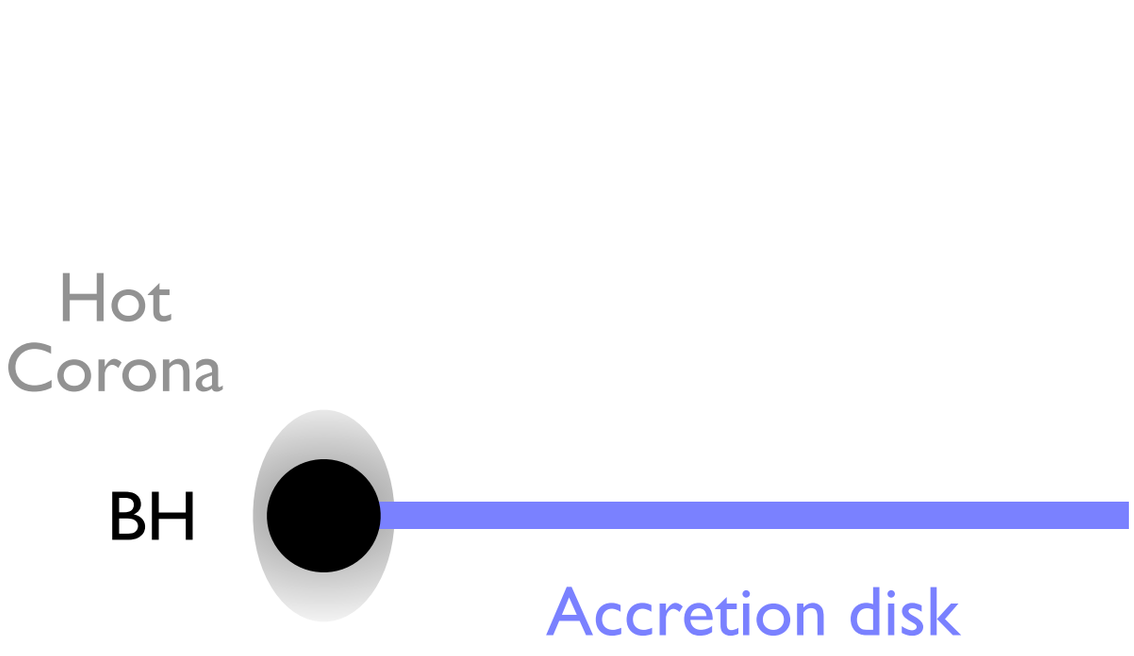
X-rays Probe the Accretion Disk & Corona

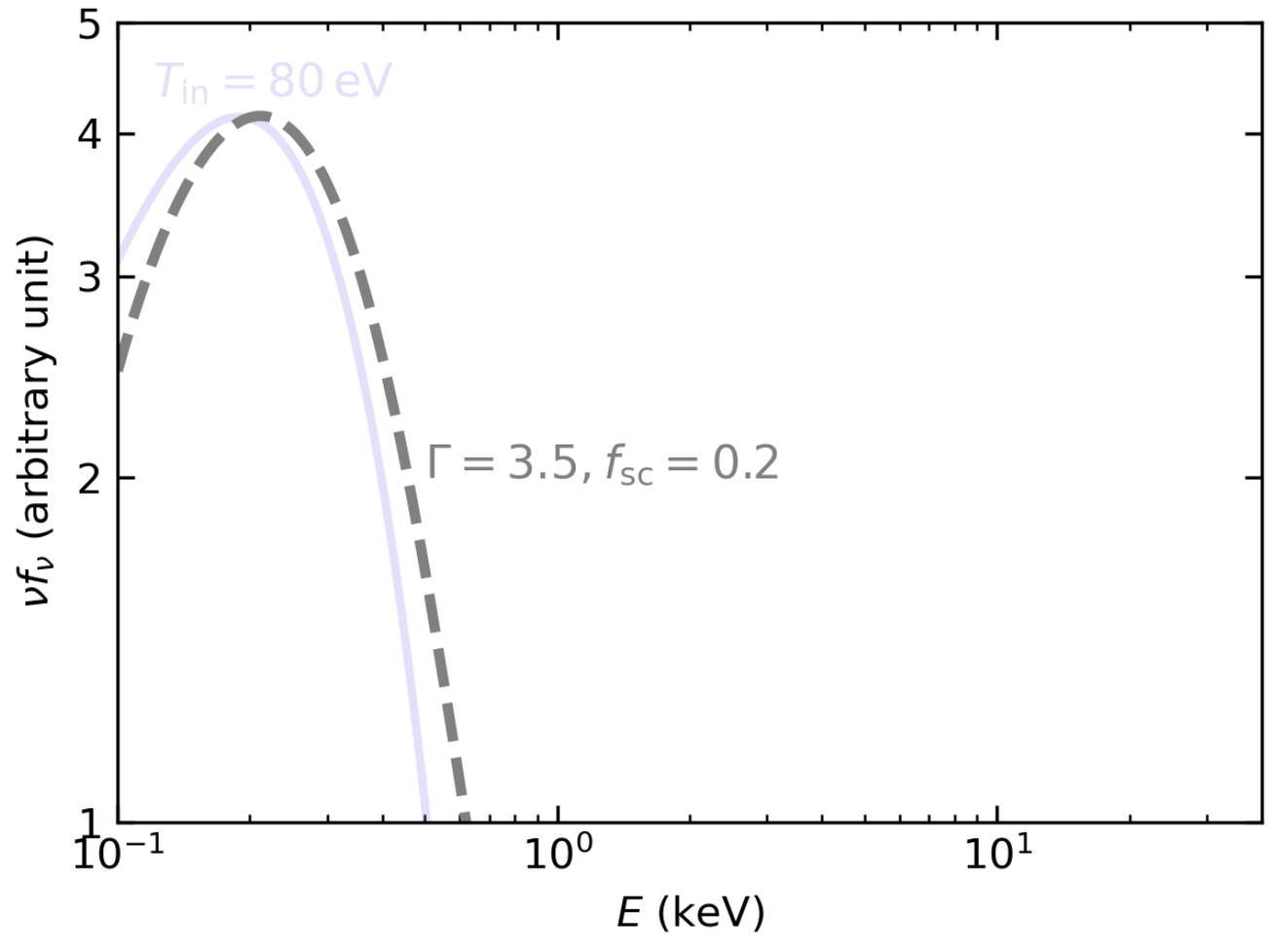


X-rays Probe the Accretion Disk & Corona

Compton up-scattering of a fraction (f_{sc}) of soft photons

Photon energy distribution takes the form $n(E)dE \propto E^{-\Gamma}$

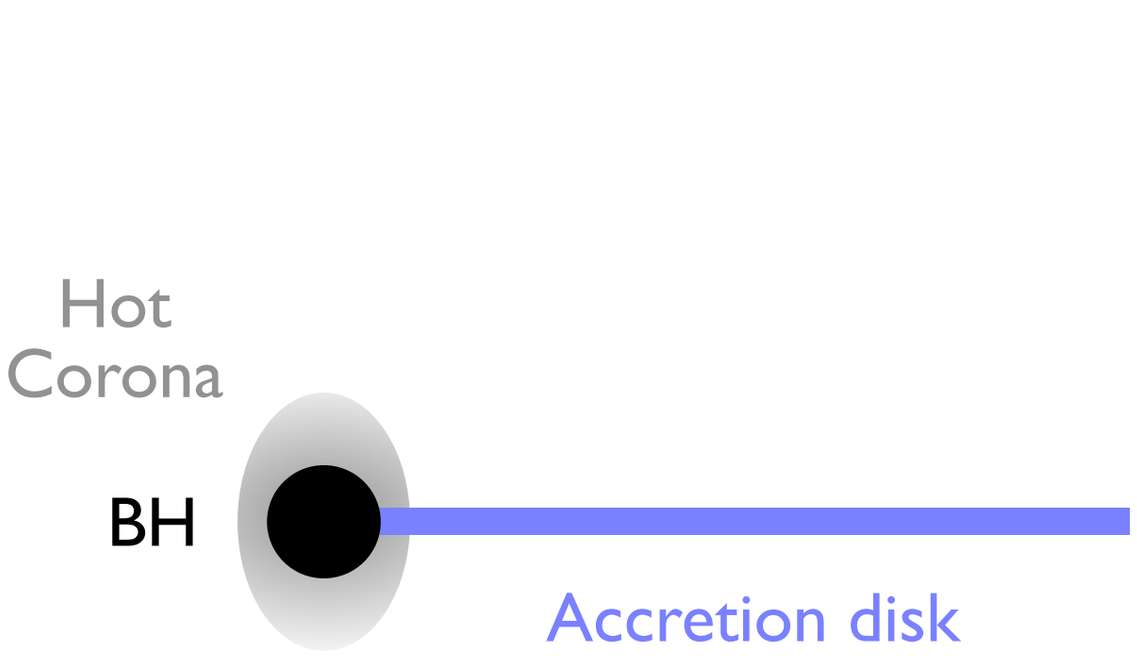


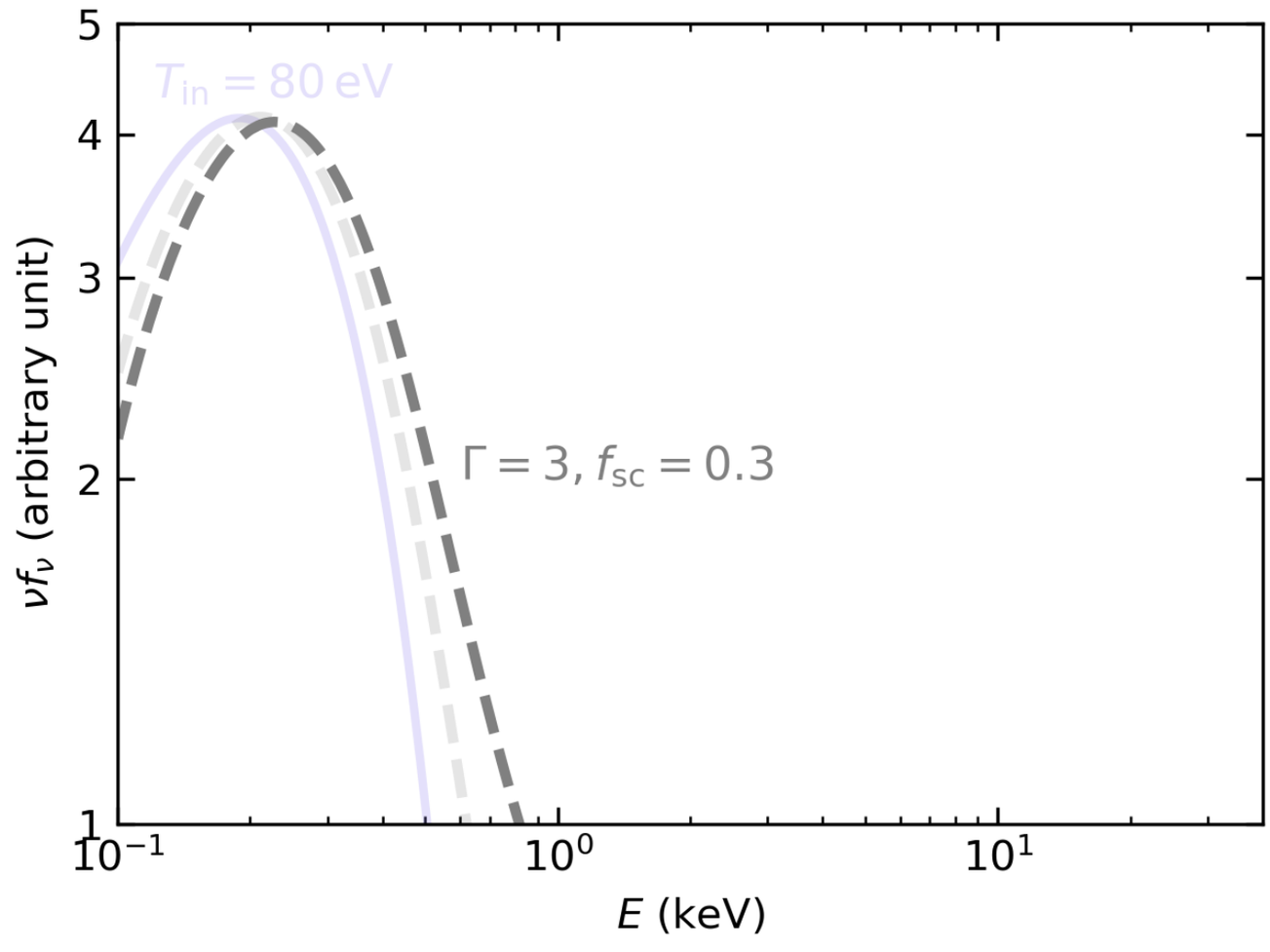


X-rays Probe the Accretion Disk & Corona

Compton up-scattering of a fraction (f_{sc}) of soft photons

Photon energy distribution takes the form $n(E)dE \propto E^{-\Gamma}$

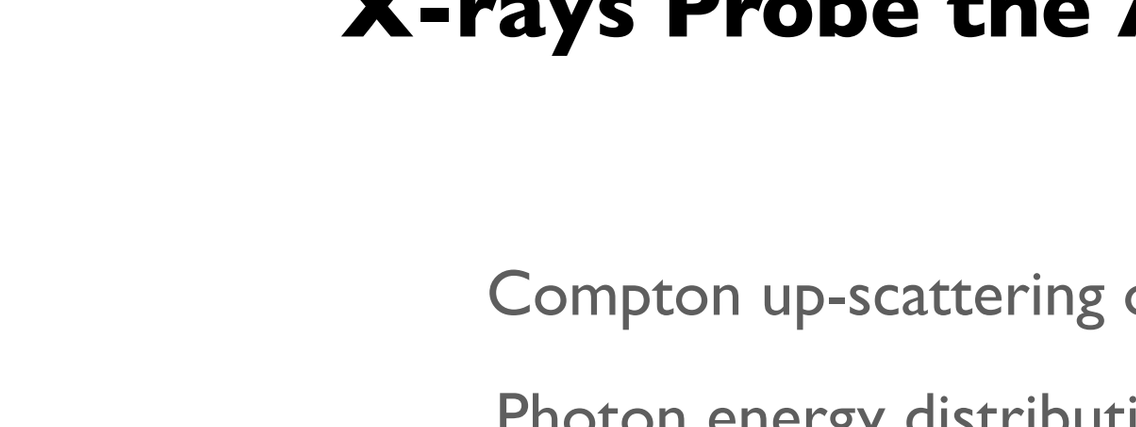


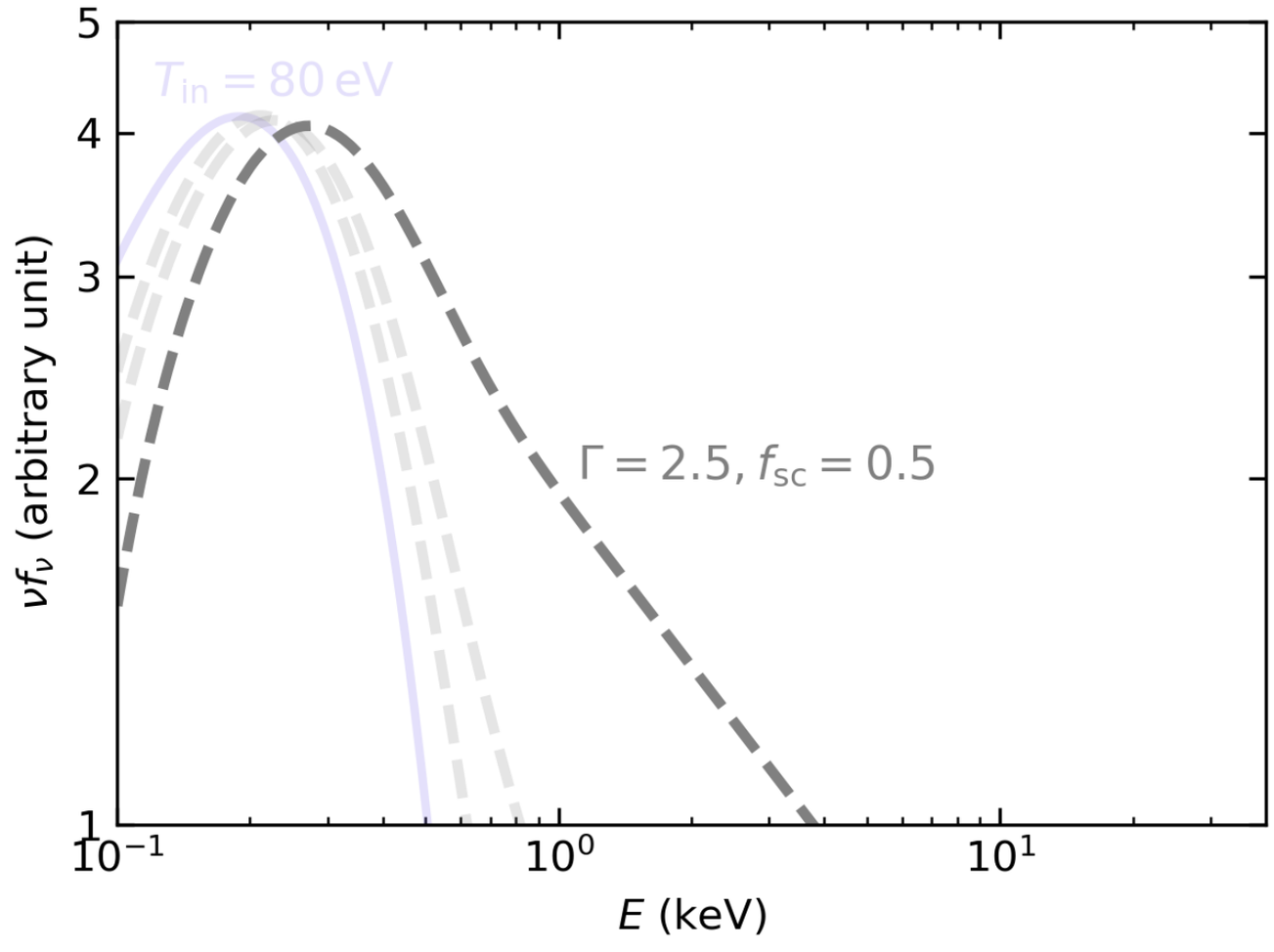


X-rays Probe the Accretion Disk & Corona

Compton up-scattering of a fraction (f_{sc}) of soft photons

Photon energy distribution takes the form $n(E)dE \propto E^{-\Gamma}$

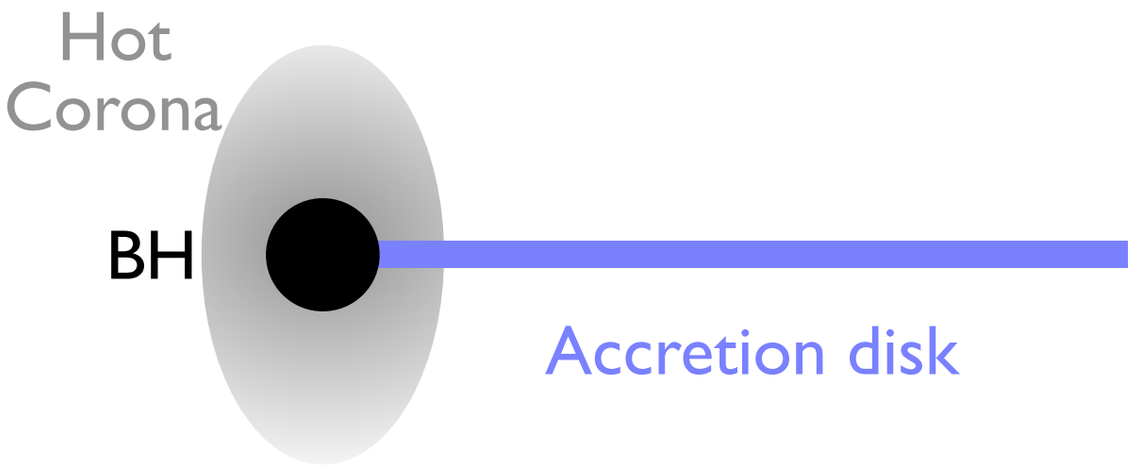


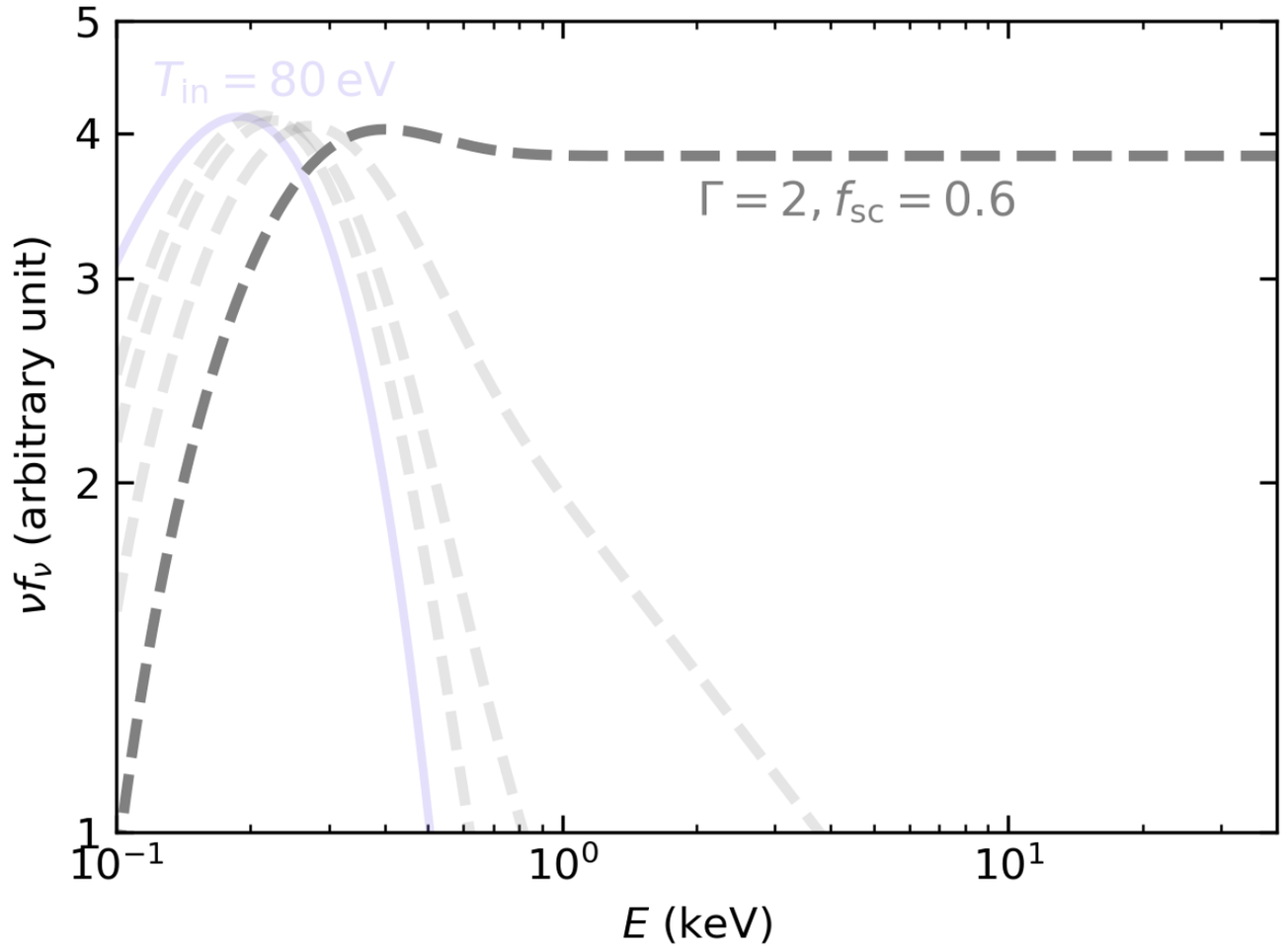


X-rays Probe the Accretion Disk & Corona

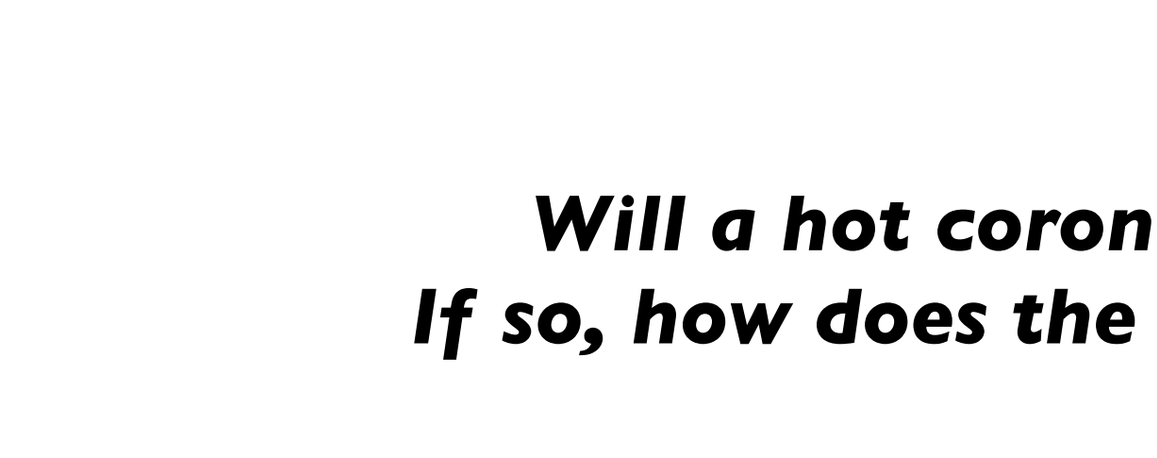
Compton up-scattering of a fraction (f_{sc}) of soft photons

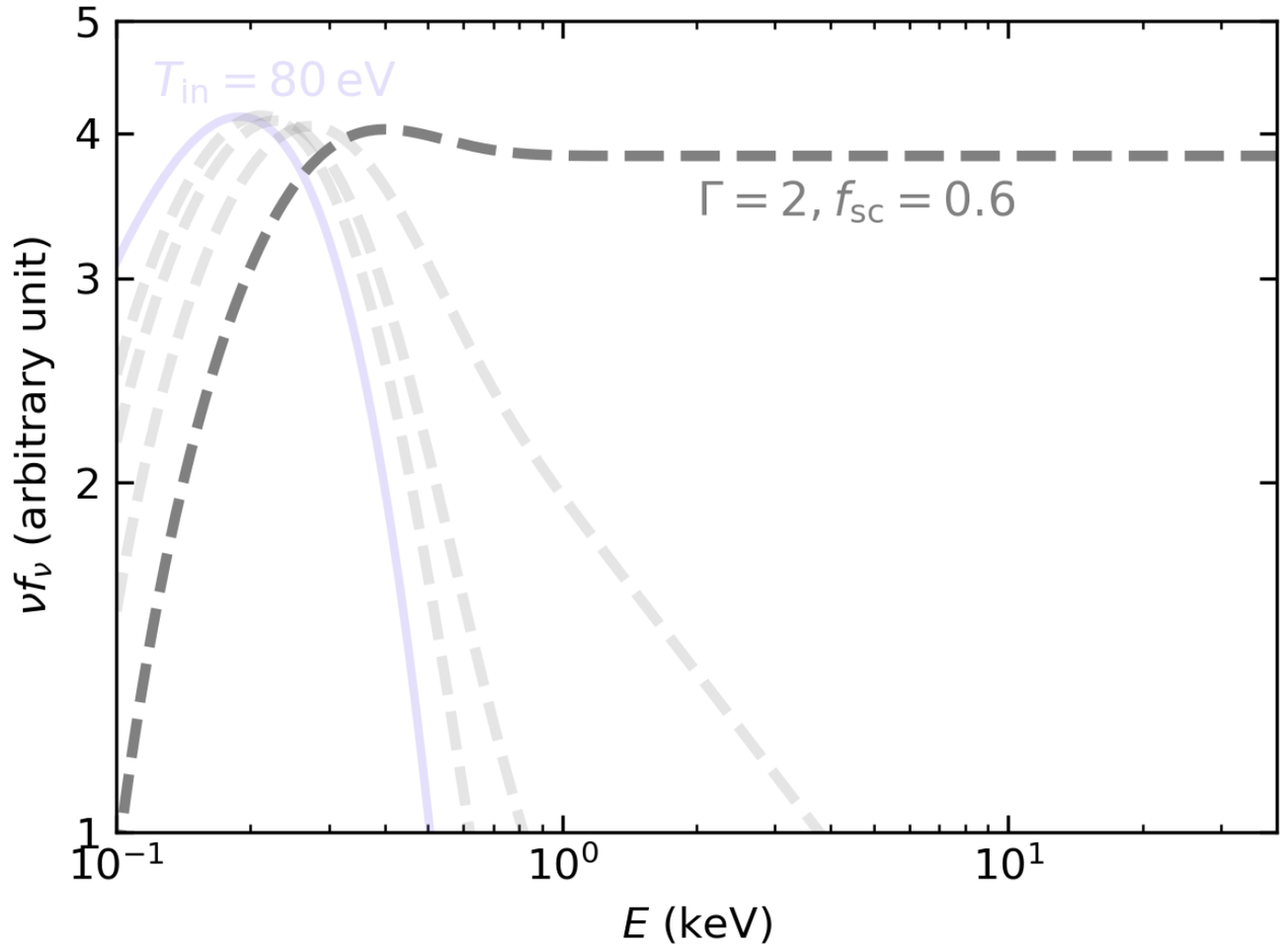
Photon energy distribution takes the form $n(E)dE \propto E^{-\Gamma}$





Will a hot corona form in TDE accretion?
If so, how does the disk—corona system evolve?

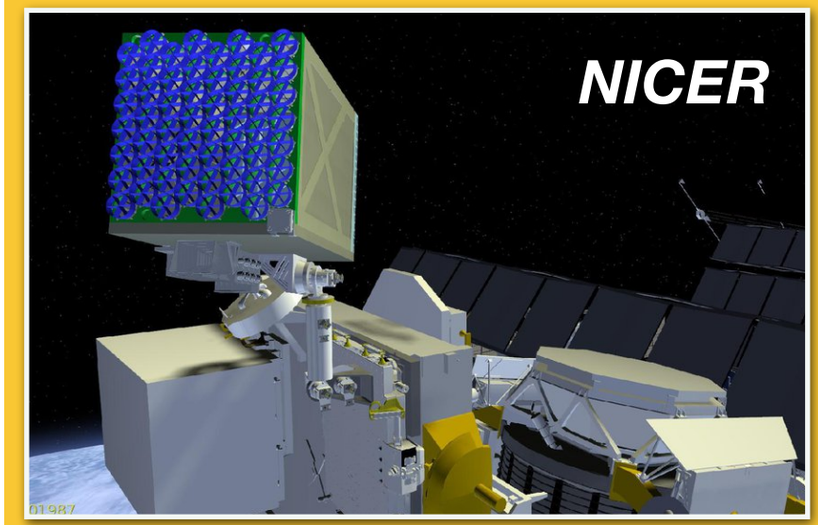


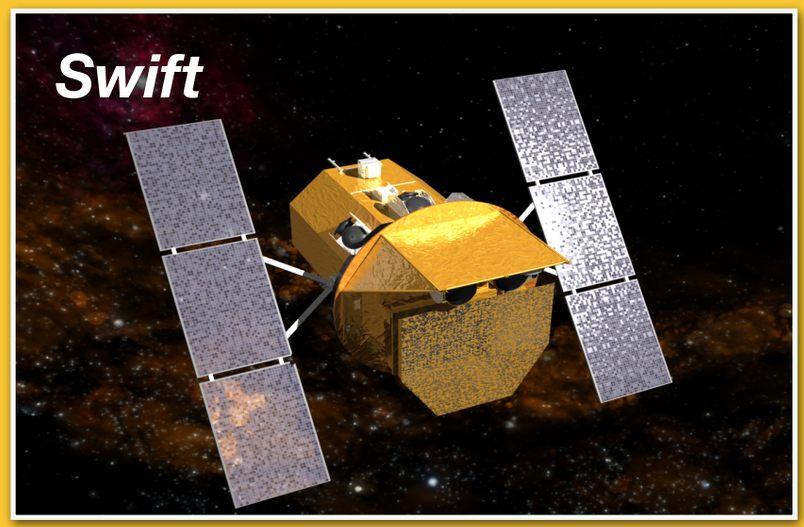


Why is AT2021ehb Exciting?

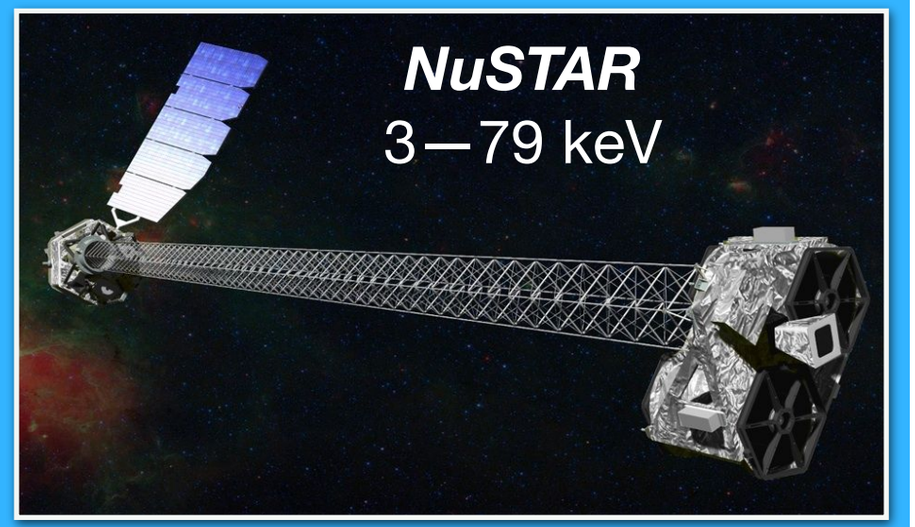
- At z=0.018, it is the 3rd closest TDE discovered in the optical
- Peak X-ray flux = 1 mCrab → brighter than all other non-jetted TDEs!

High-Cadence Monitoring





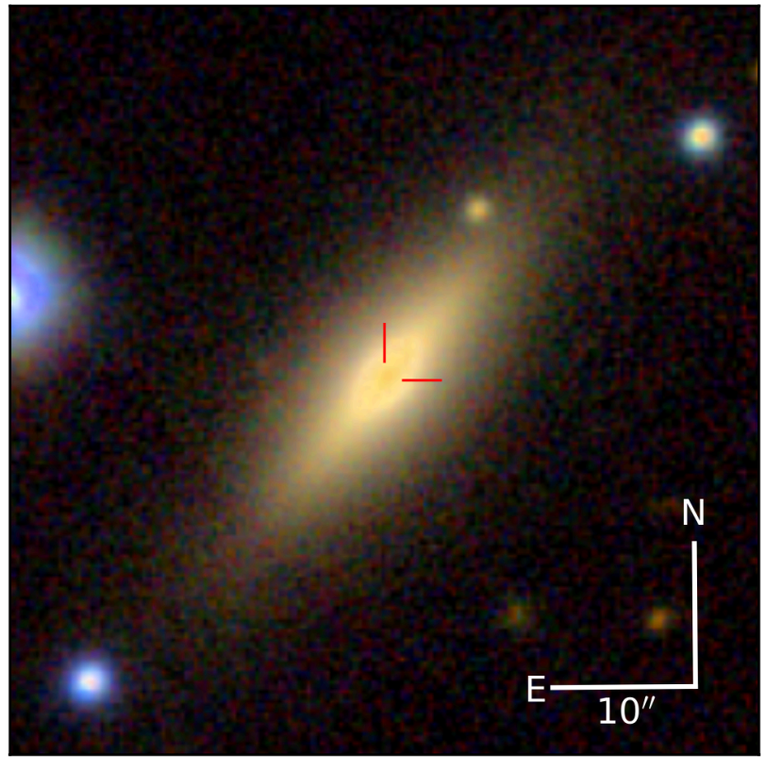
Pointed Observations



Survey Coverage

Host $M_{BH} \sim 10^7\ M_\odot$

- Using the M_{BH}—σ relation:
  $\log(M_{BH}/M_\odot) = 7.03 \pm (0.15 + 0.29)$
- Using the M_{BH}—M_{gal} relation:
  $\log(M_{BH}/M_\odot) = 7.14 \pm (0.10 + 0.79)$

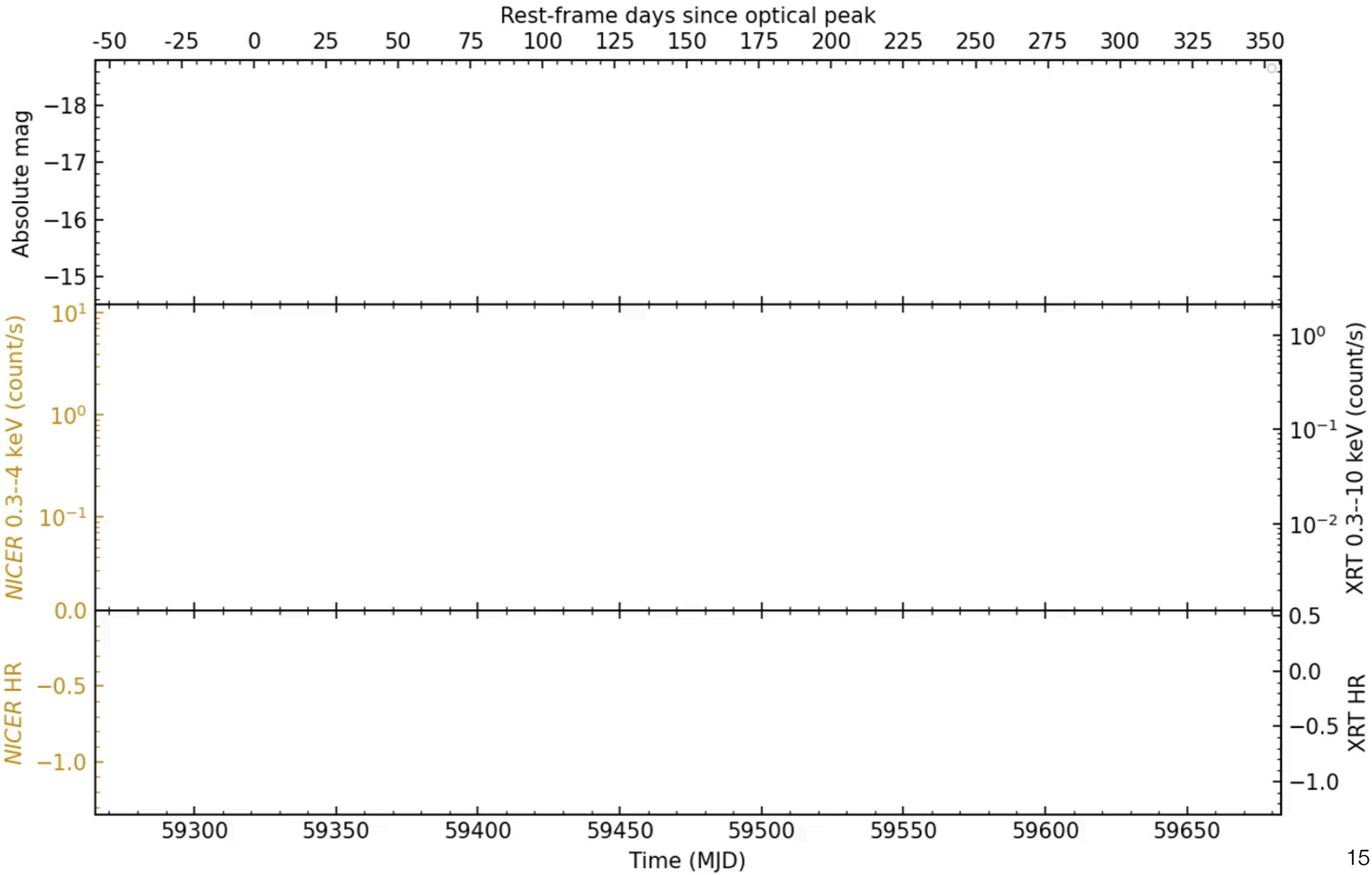


- *On the high end of the M_{BH} distribution of optical selected TDEs*
- *Too heavy to disruption a white dwarf*

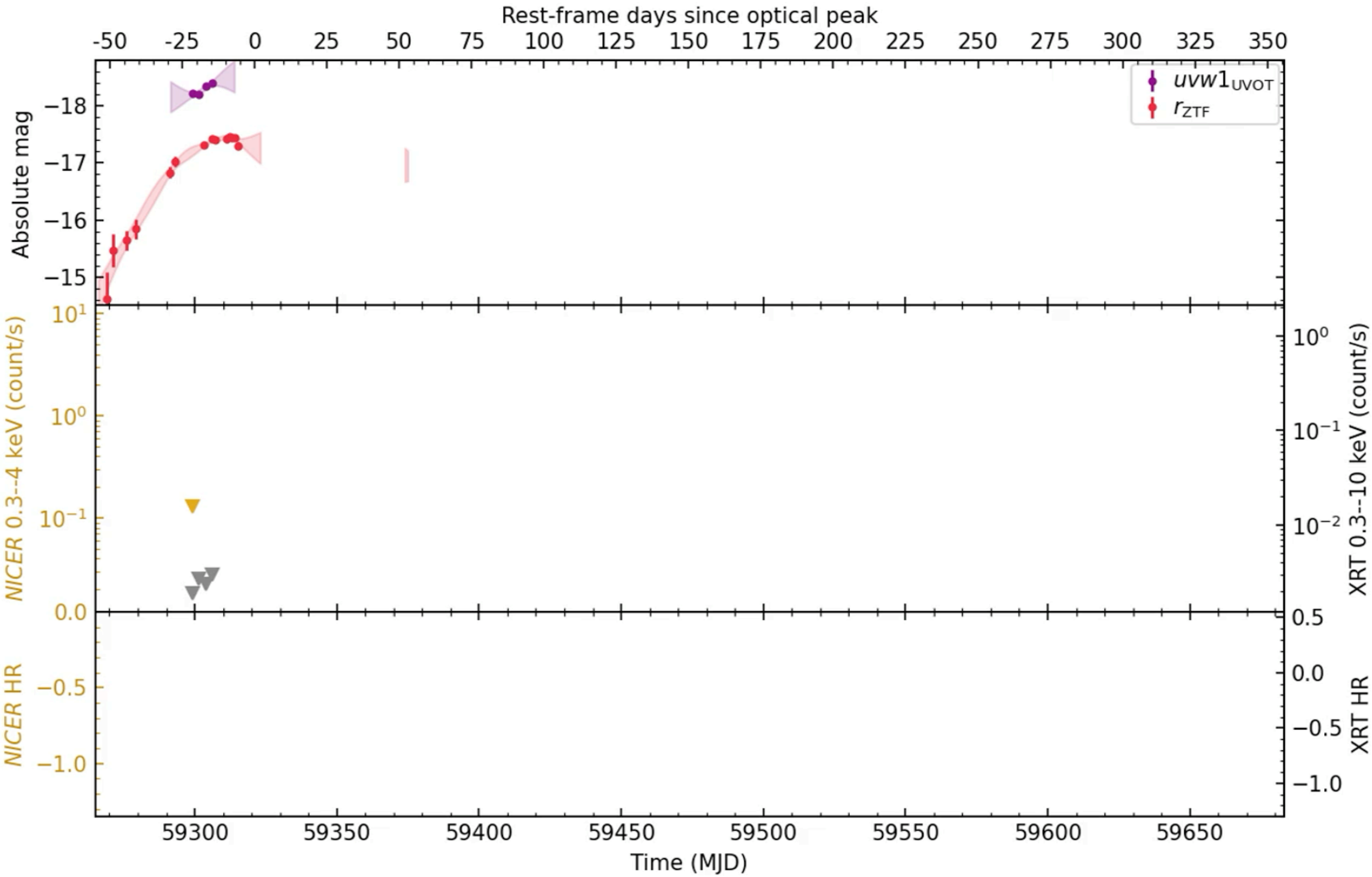
- $L_{Edd} = 4\pi G M_{BH} c/\kappa_{es} \approx 10^{45.1}$ erg/s
- The gravitational radius $R_g = GM_{BH}/c^2 \approx 10^{12.2}$ cm
- For a Sun-like star, the tidal radius $R_T \approx 10^{13.2}$ cm $(M_{BH}/10^7)^{1/3}$

$R_T \sim 10\ R_g$ ⟶ *Strong relativistic apsidal precession expected!*

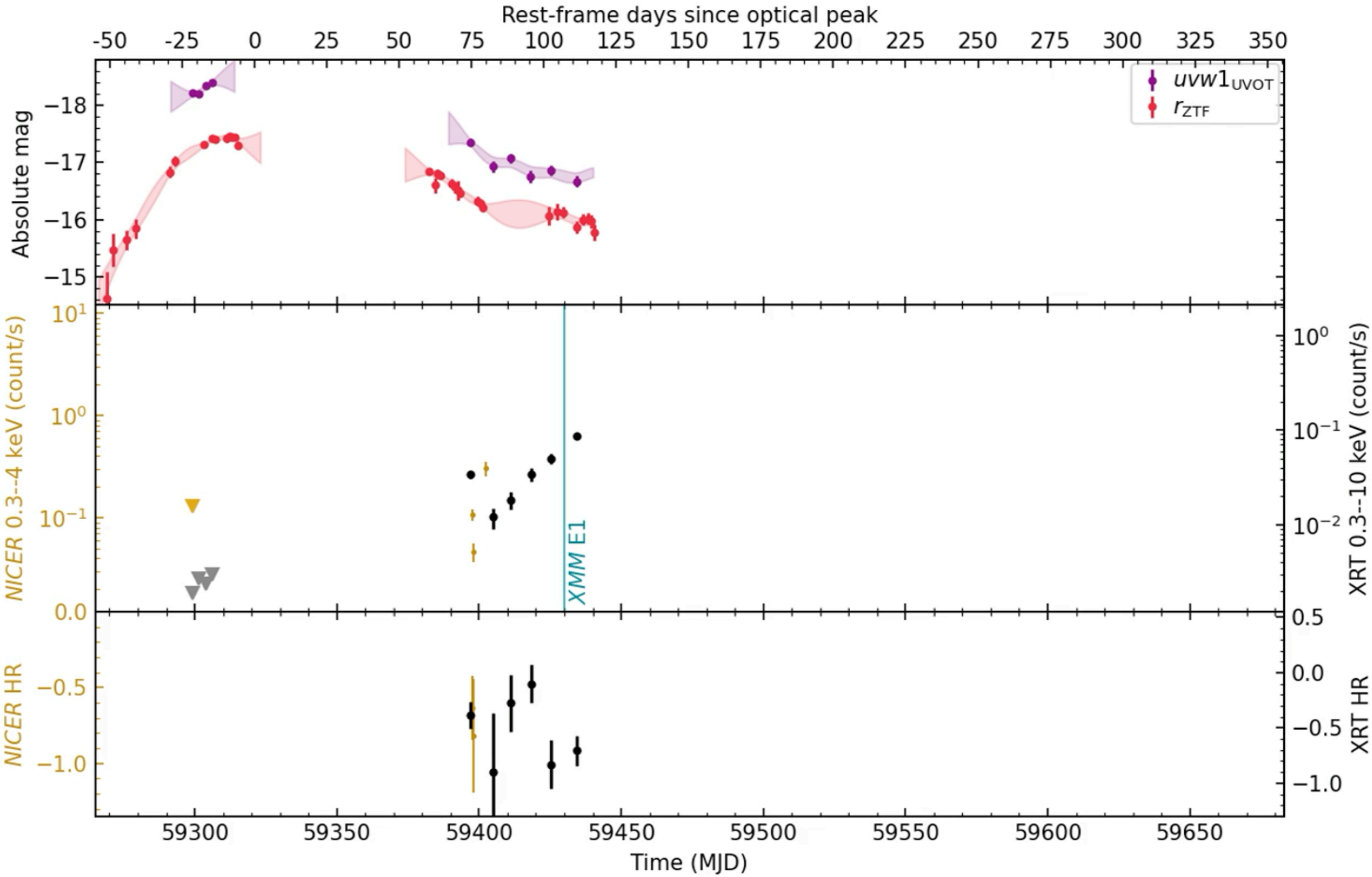
Top: UV/optical light curve
Middle: X-ray light curve
Bottom: X-ray hardness



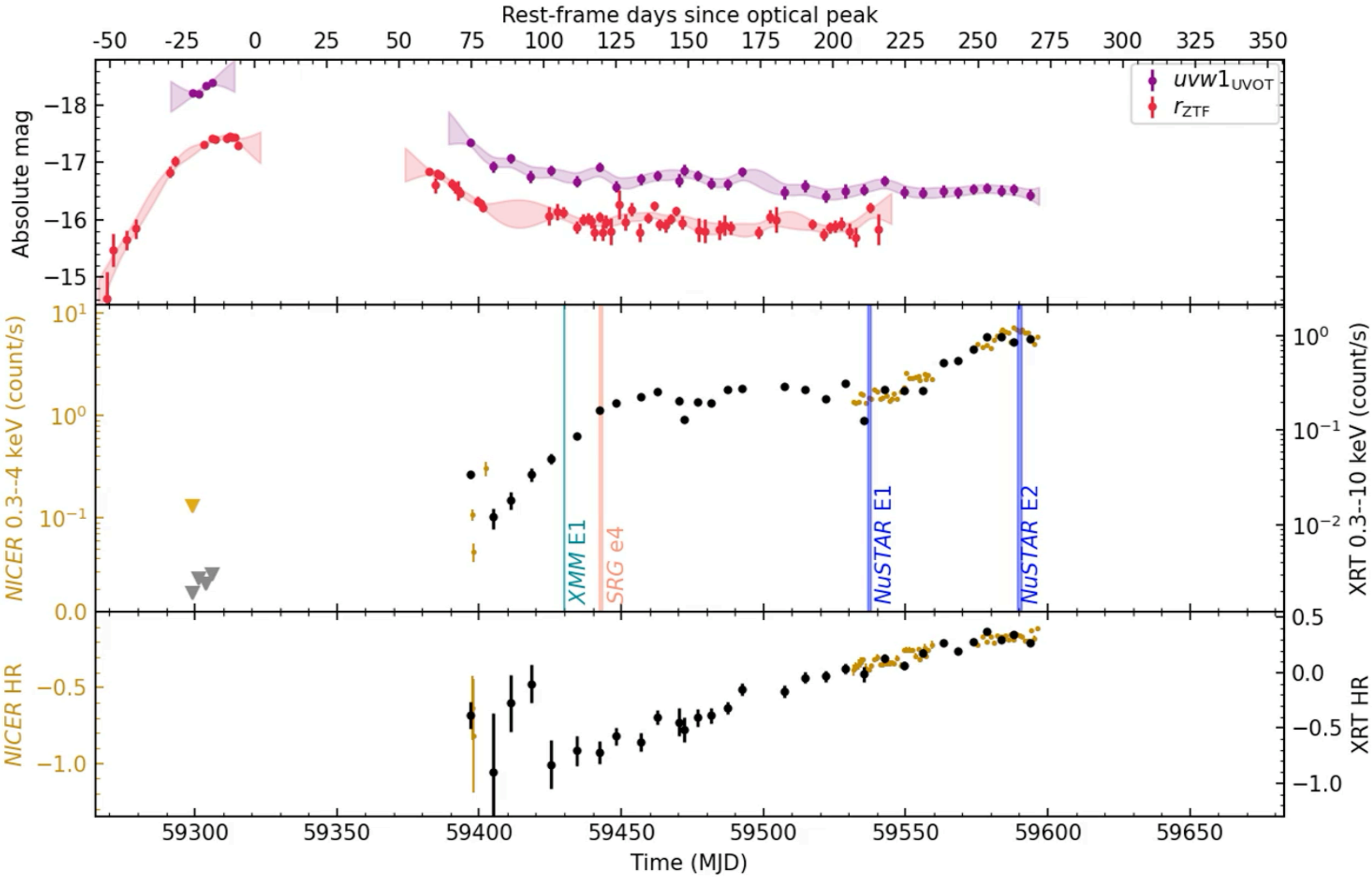
Top: UV/optical light curve
Middle: X-ray light curve
Bottom: X-ray hardness



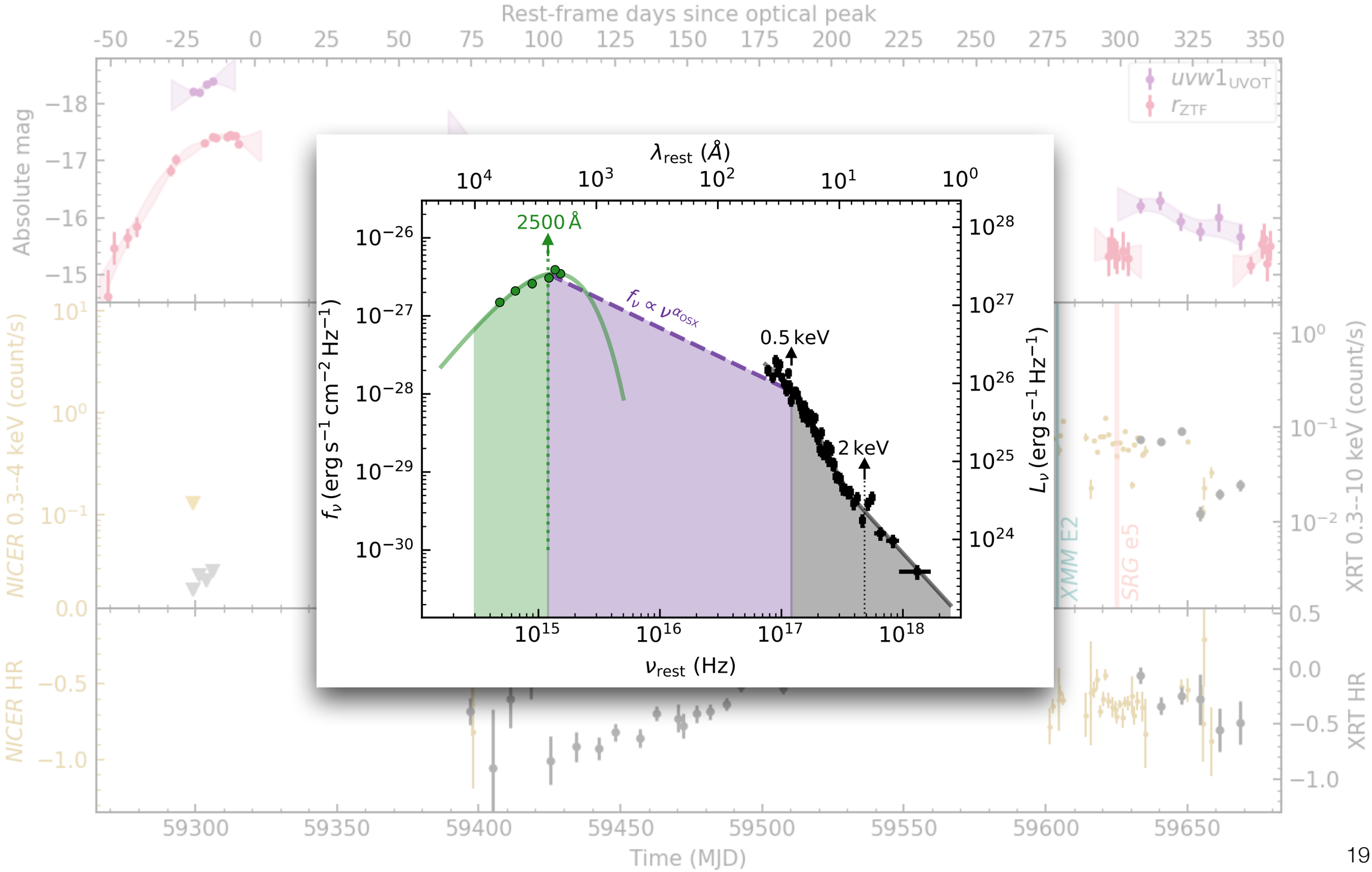
Top: UV/optical light curve
Middle: X-ray light curve
Bottom: X-ray hardness



Top: UV/optical light curve
Middle: X-ray light curve
Bottom: X-ray hardness



Top: UV/optical light curve
Middle: X-ray light curve
Bottom: X-ray hardness

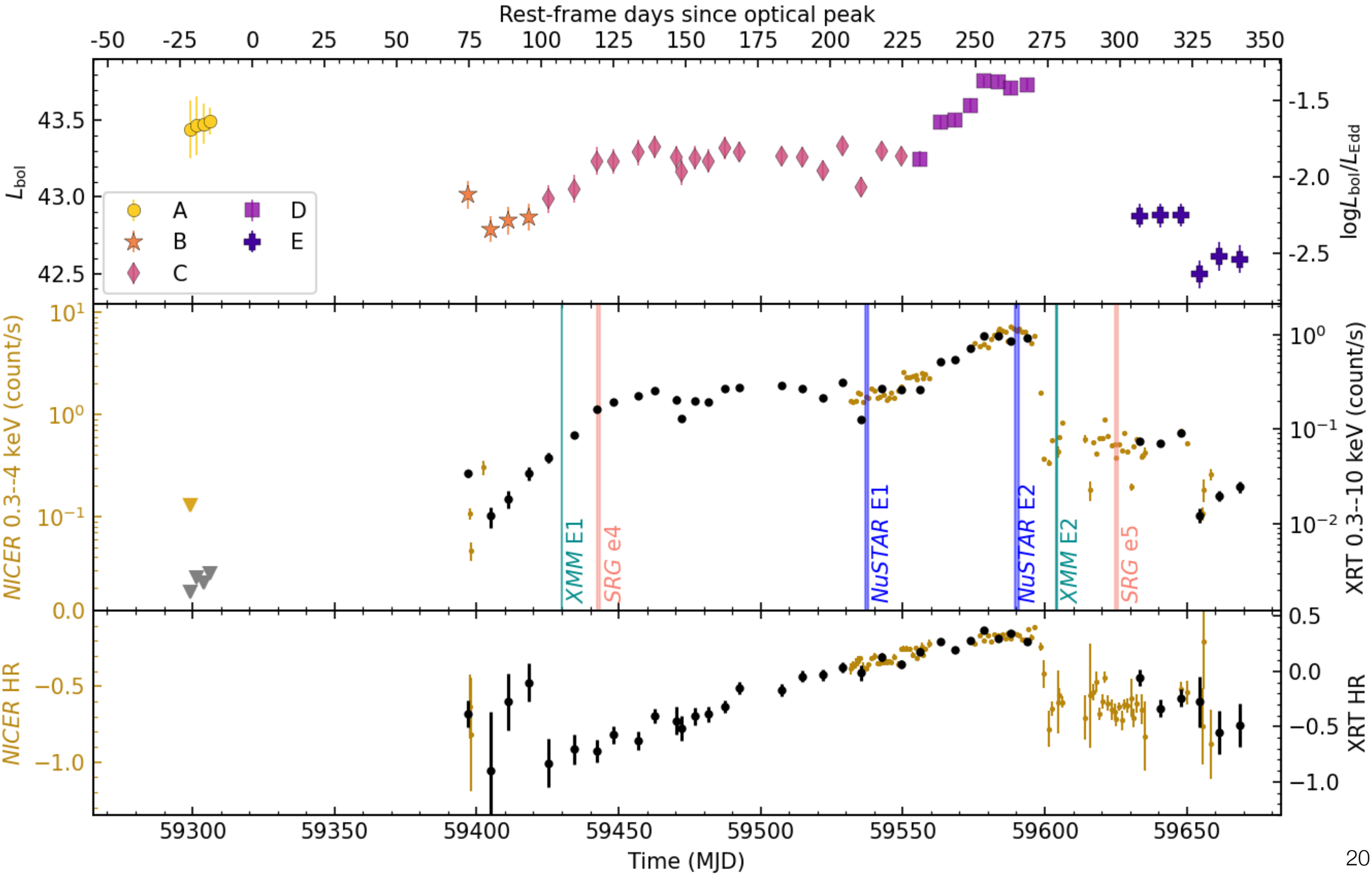


Top: Bolometric light curve

Middle: X-ray light curve

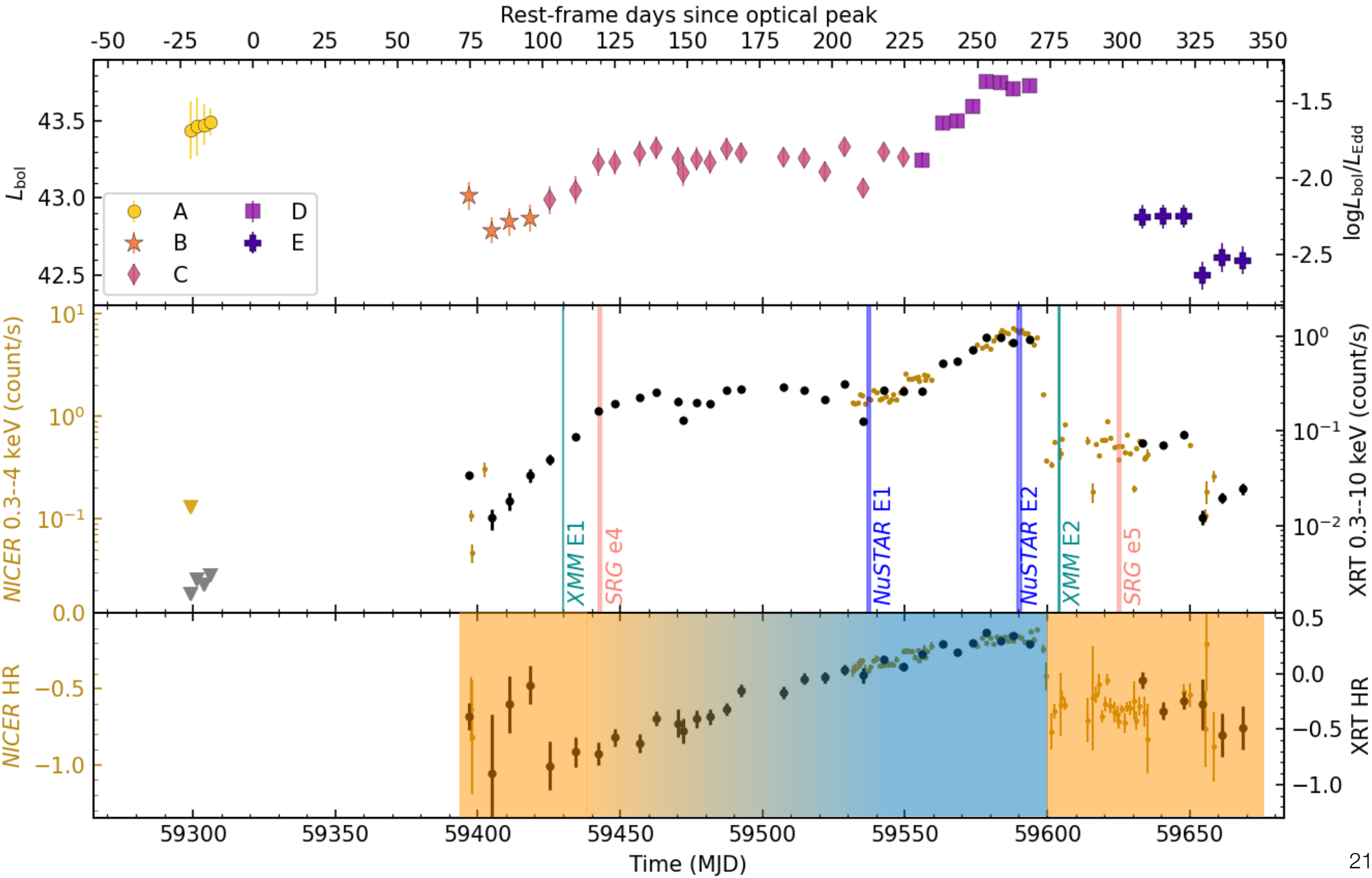
Bottom: X-ray hardness

L_{bol}/L_{Edd} < -1.3 +/- 0.4

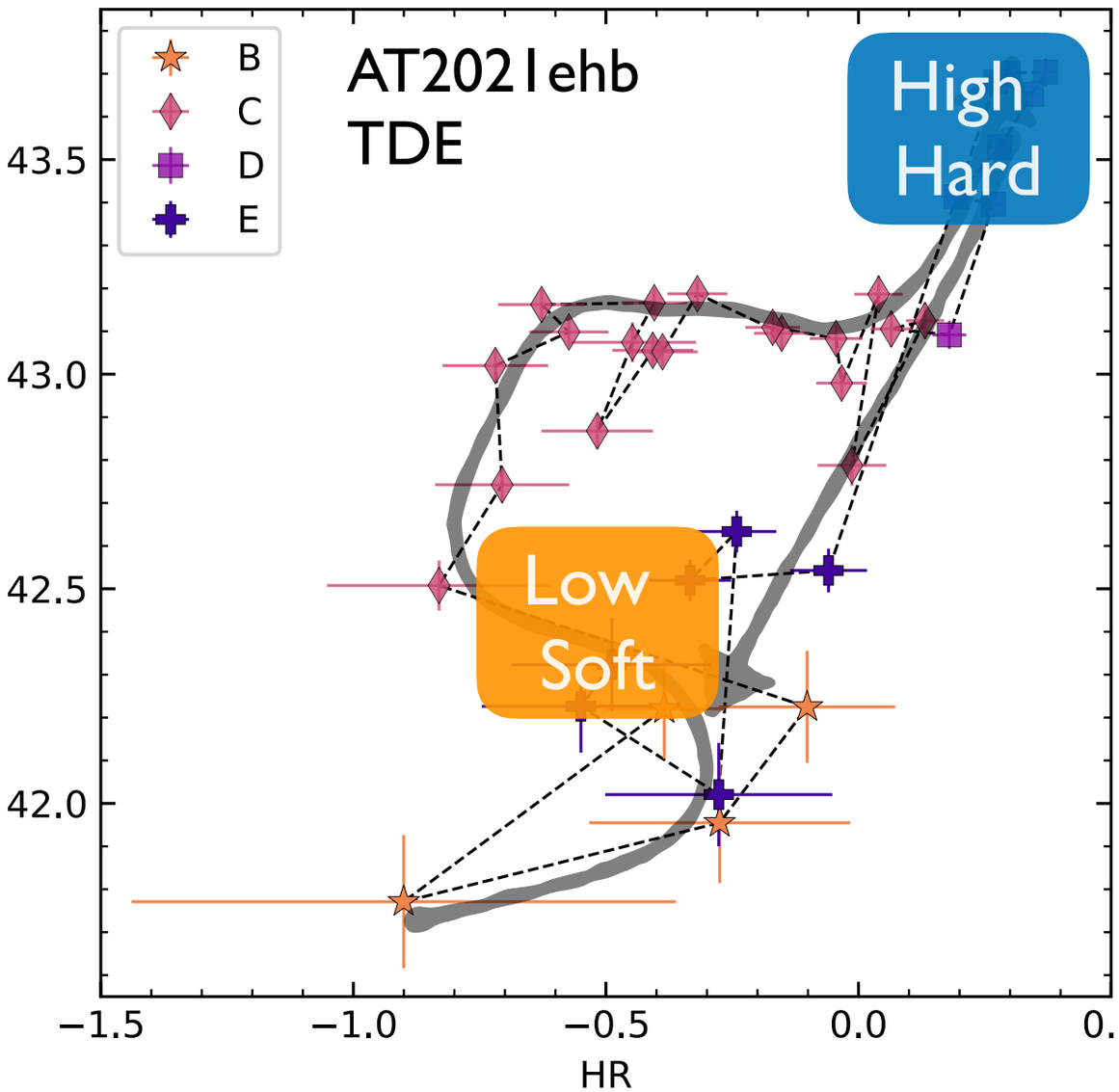


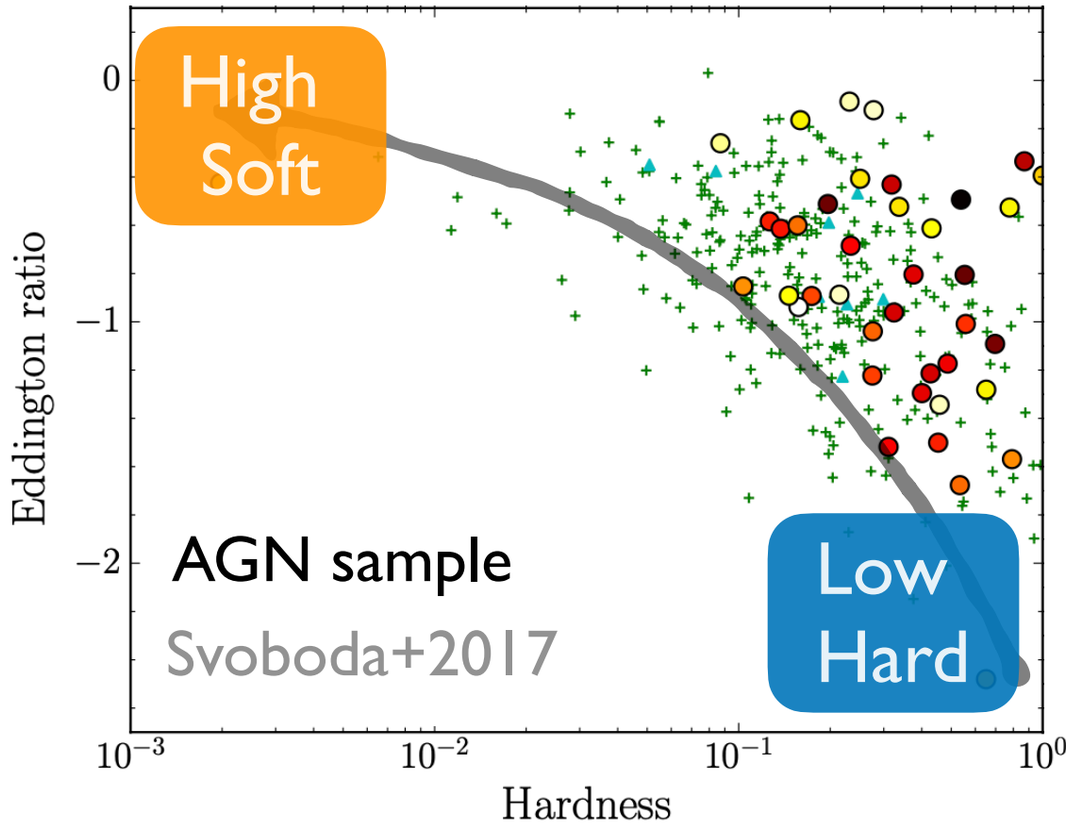
Top: Bolometric light curve
Middle: X-ray light curve
Bottom: X-ray hardness

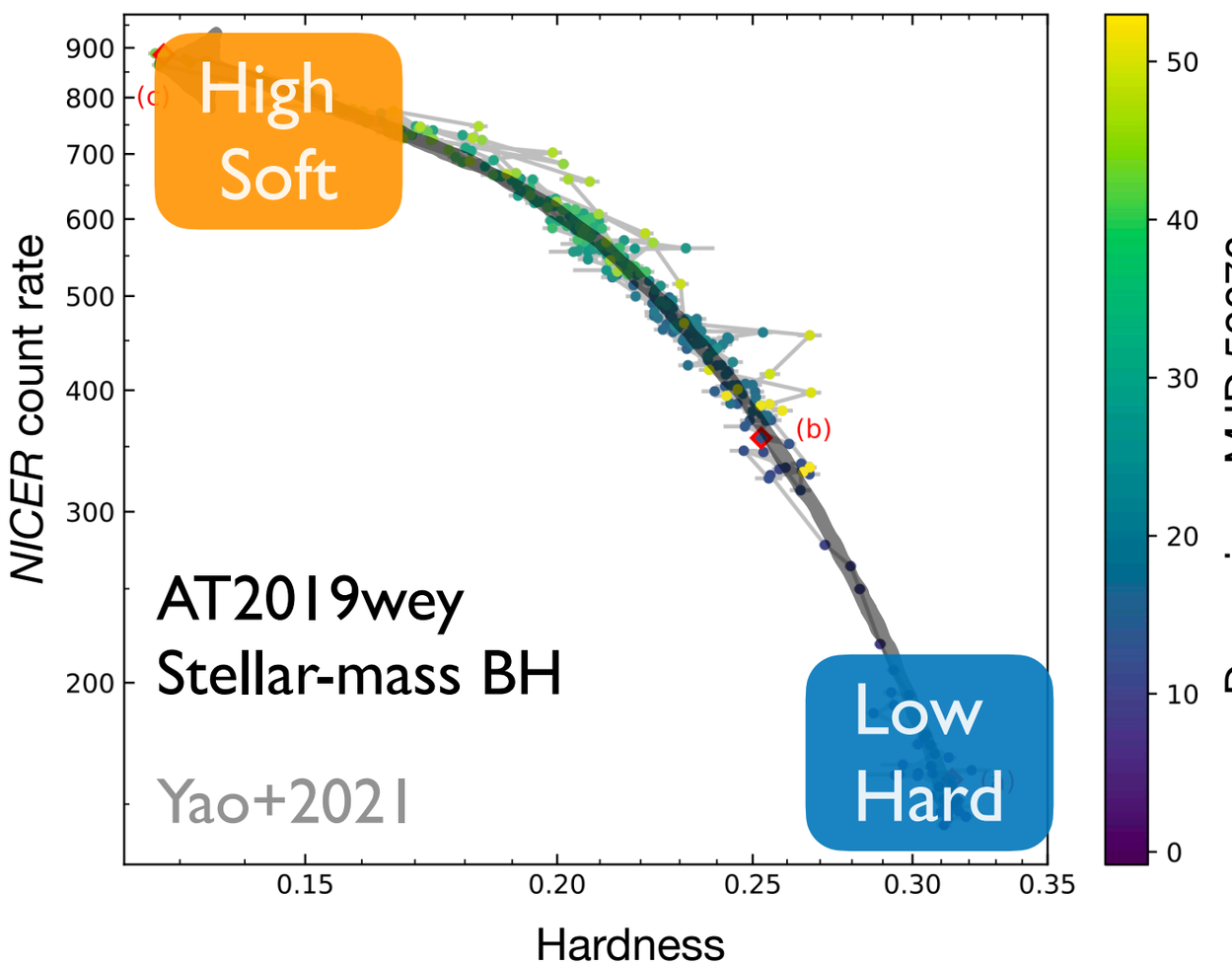
Soft → Hard → Soft Spectral Transition



Comparison with Other Accreting Systems



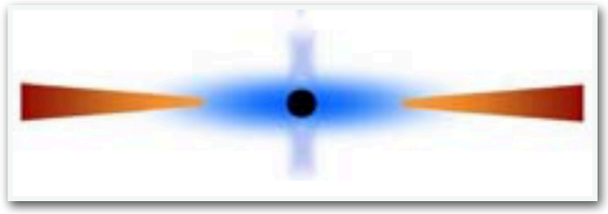




Disk—Corona Evolution

Standard Picture: Done 2007

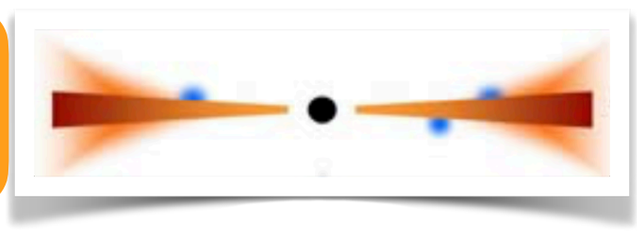
Low Hard



R_{in} *moves inwards*

Hot inner flow (corona) collapses into a thin disk

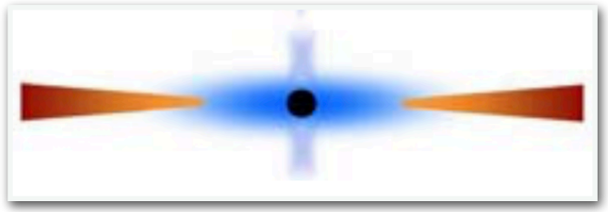
High Soft



Disk—Corona Evolution

Standard Picture: Done 2007

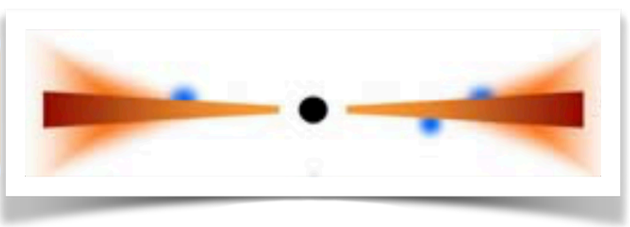
Low Hard



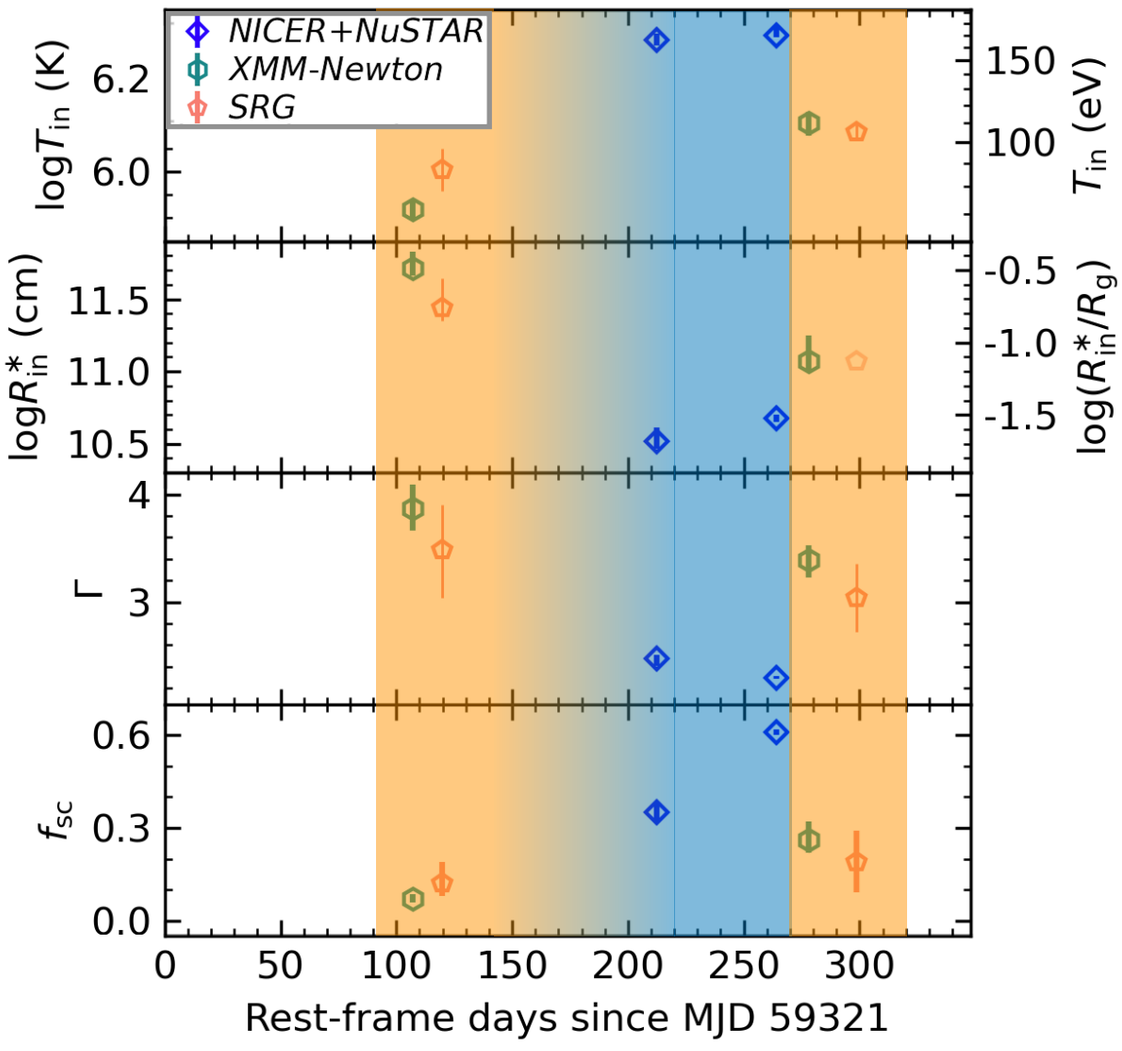
R_{in} *moves inwards*

Hot inner flow (corona) collapses into a thin disk

High Soft

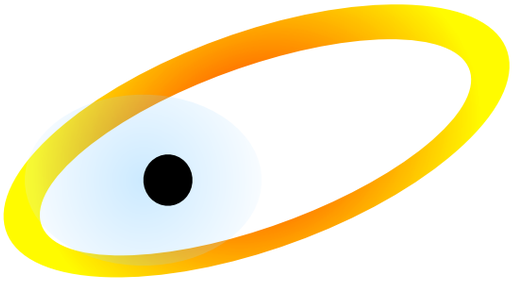


AT2021ehb:



Low Soft

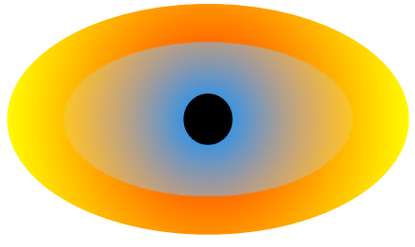
debris circularize from "ring" to "disk"



Corona grows
R_{in} *moves inwards*

High Hard

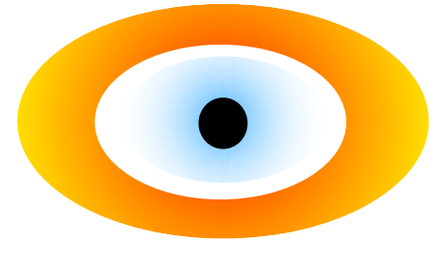
$\dot{M}_{acc}$ at maximum
Circularize to thin disk



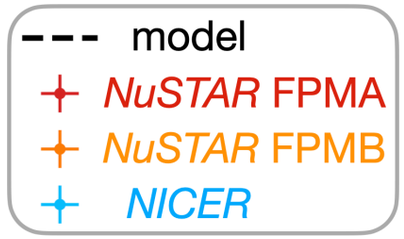
Corona collapse?
R_{in} *moves outwards*

Low Soft

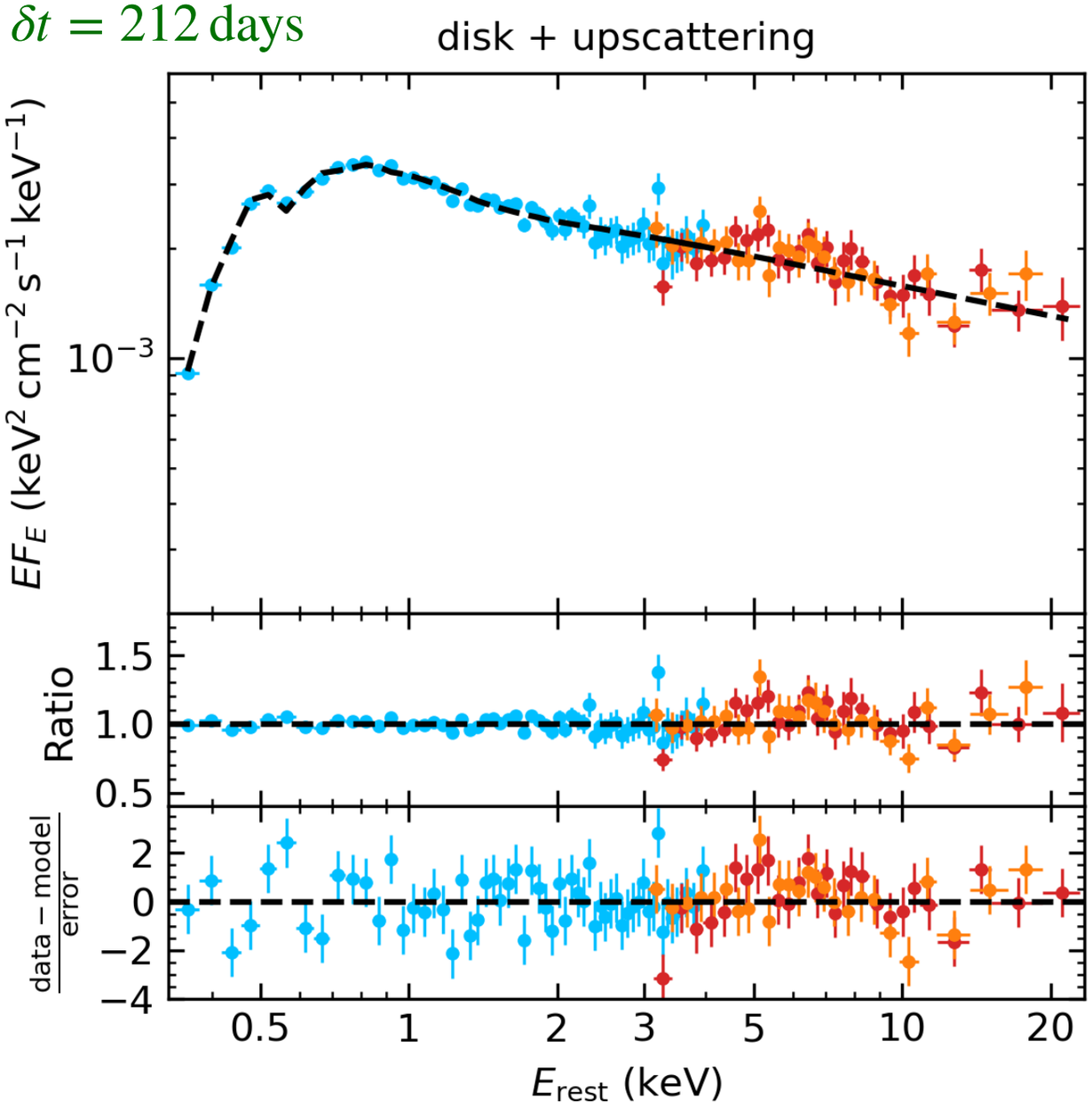
$\dot{M}_{acc}<0.01\dot{M}_{Edd}$
Hot ADAF disk?



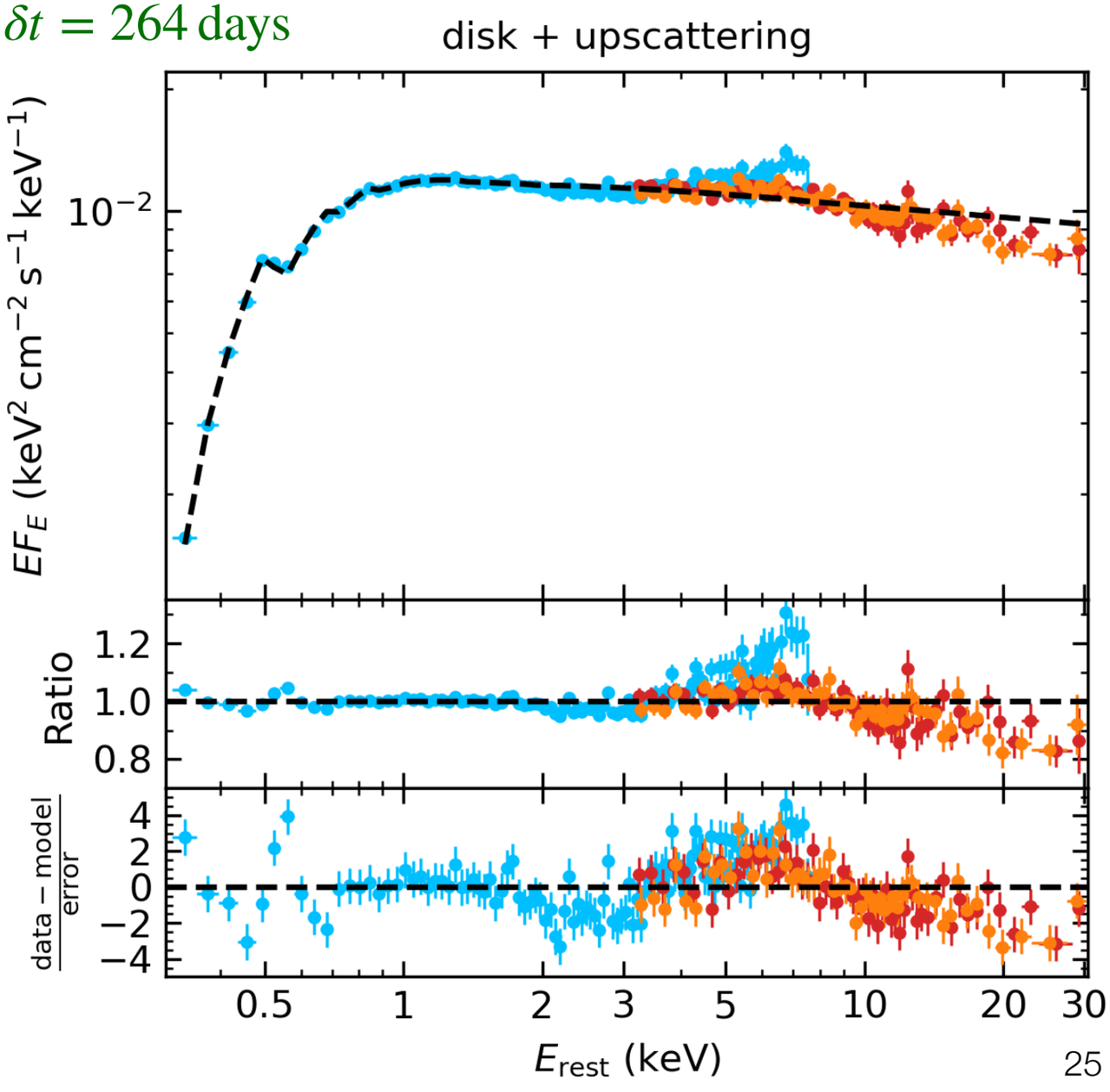
Hard-state Joint Spectral Modeling



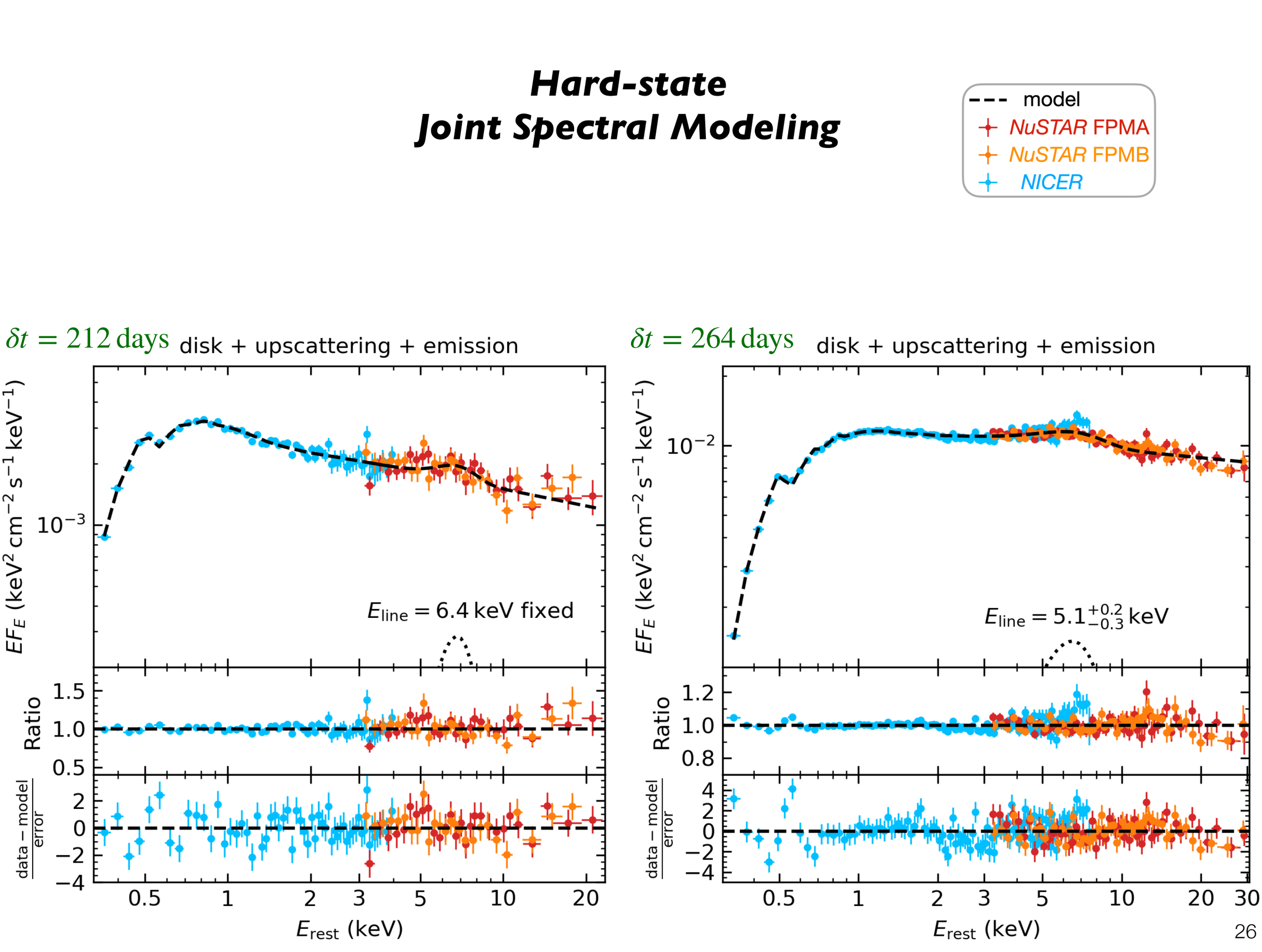
$\delta t = 212$ days



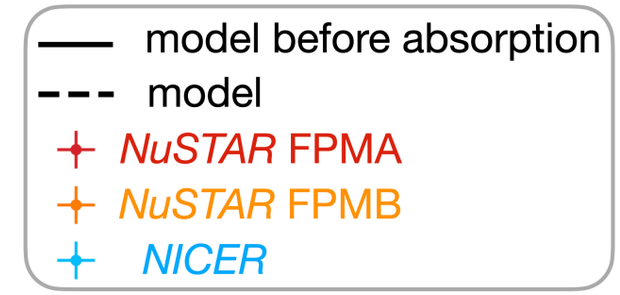
$\delta t = 264$ days



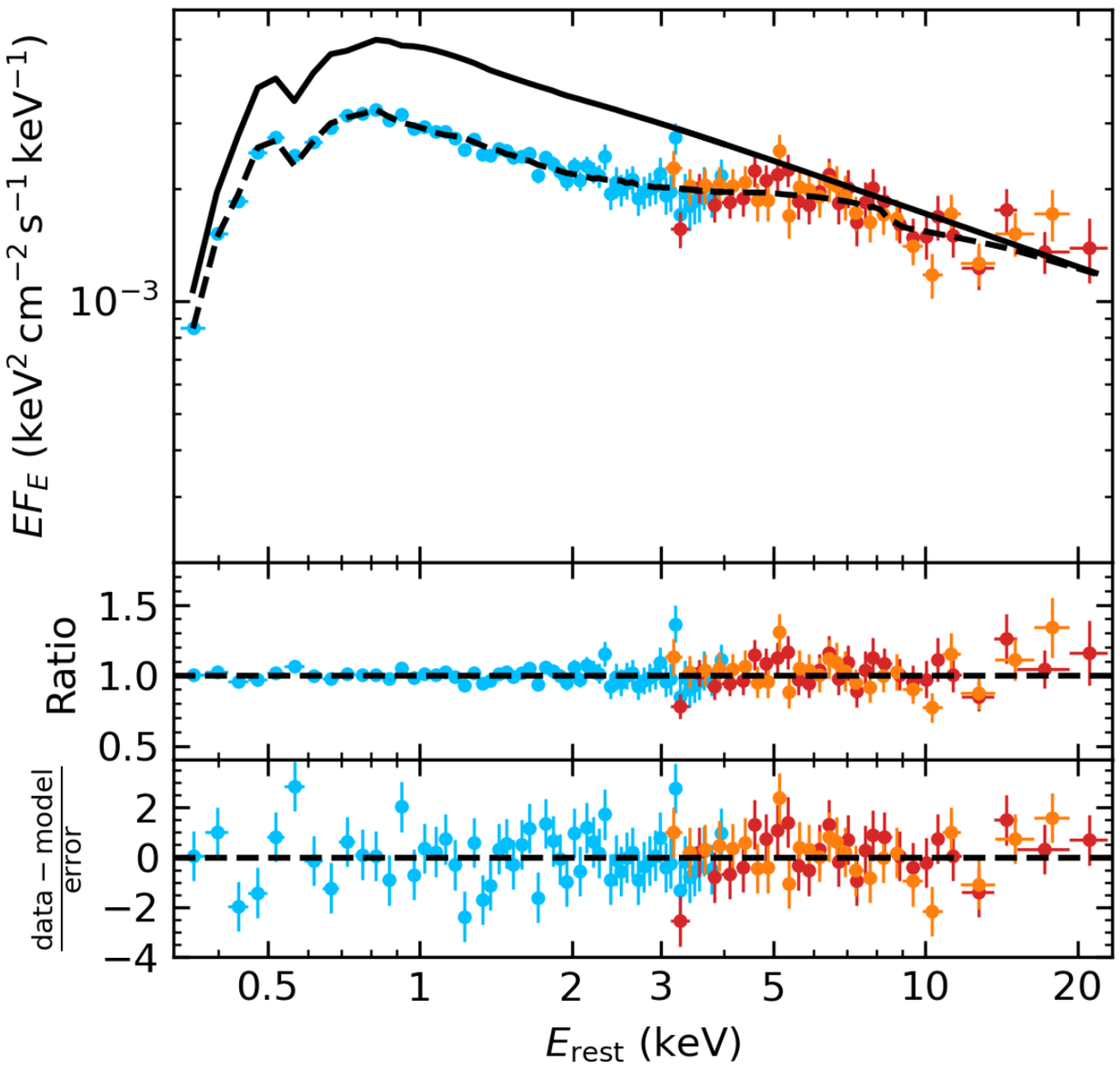
Hard-state Joint Spectral Modeling



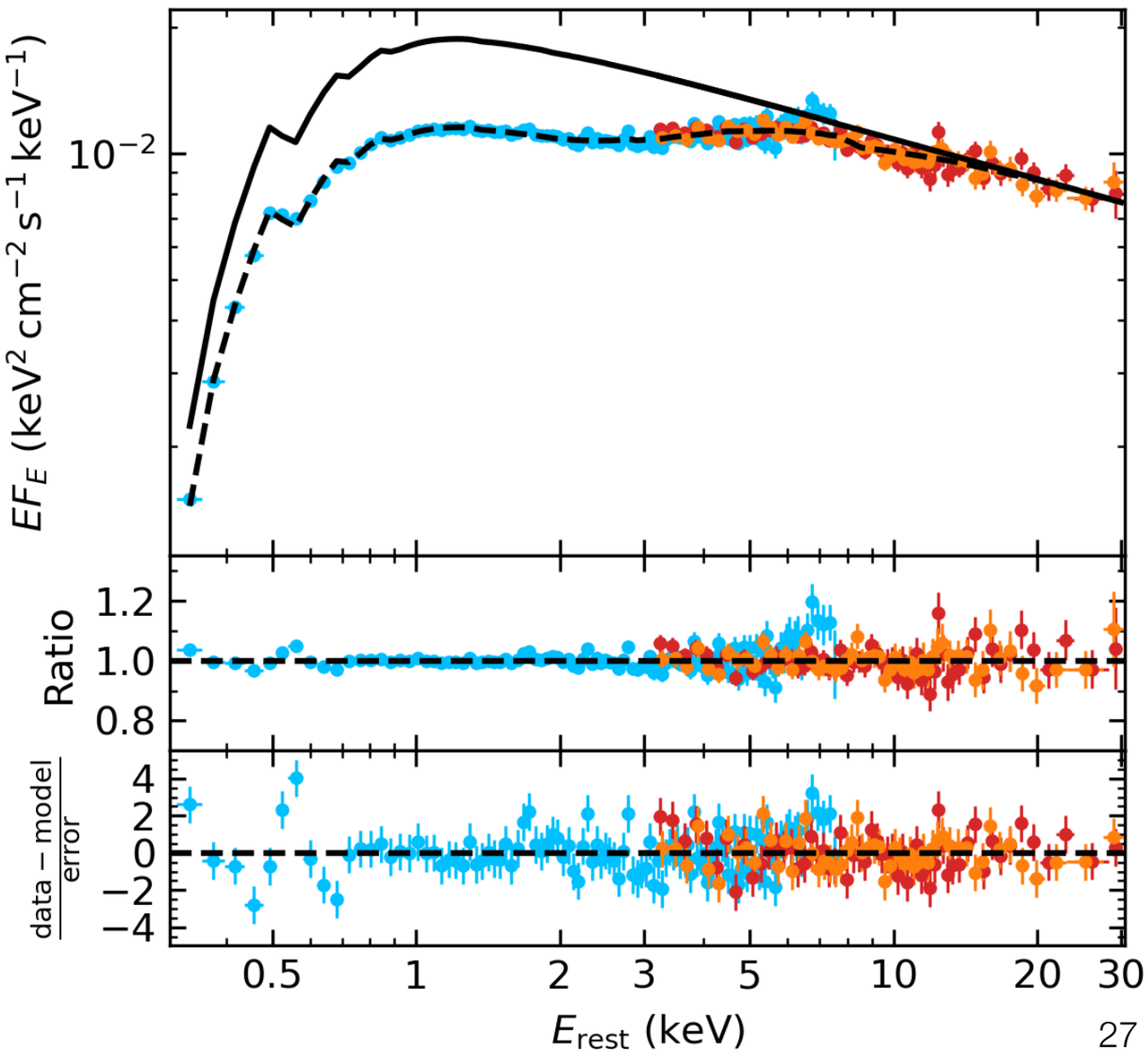
Hard-state Joint Spectral Modeling



$\delta t = 212$ days (disk + upscattering) * outflow



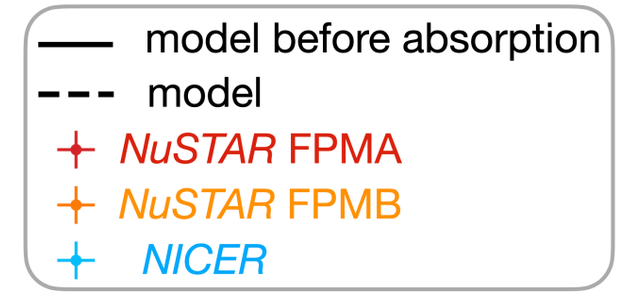
$\delta t = 264$ days (disk + upscattering) * outflow



Evidence of a Sub-relativistic Outflow

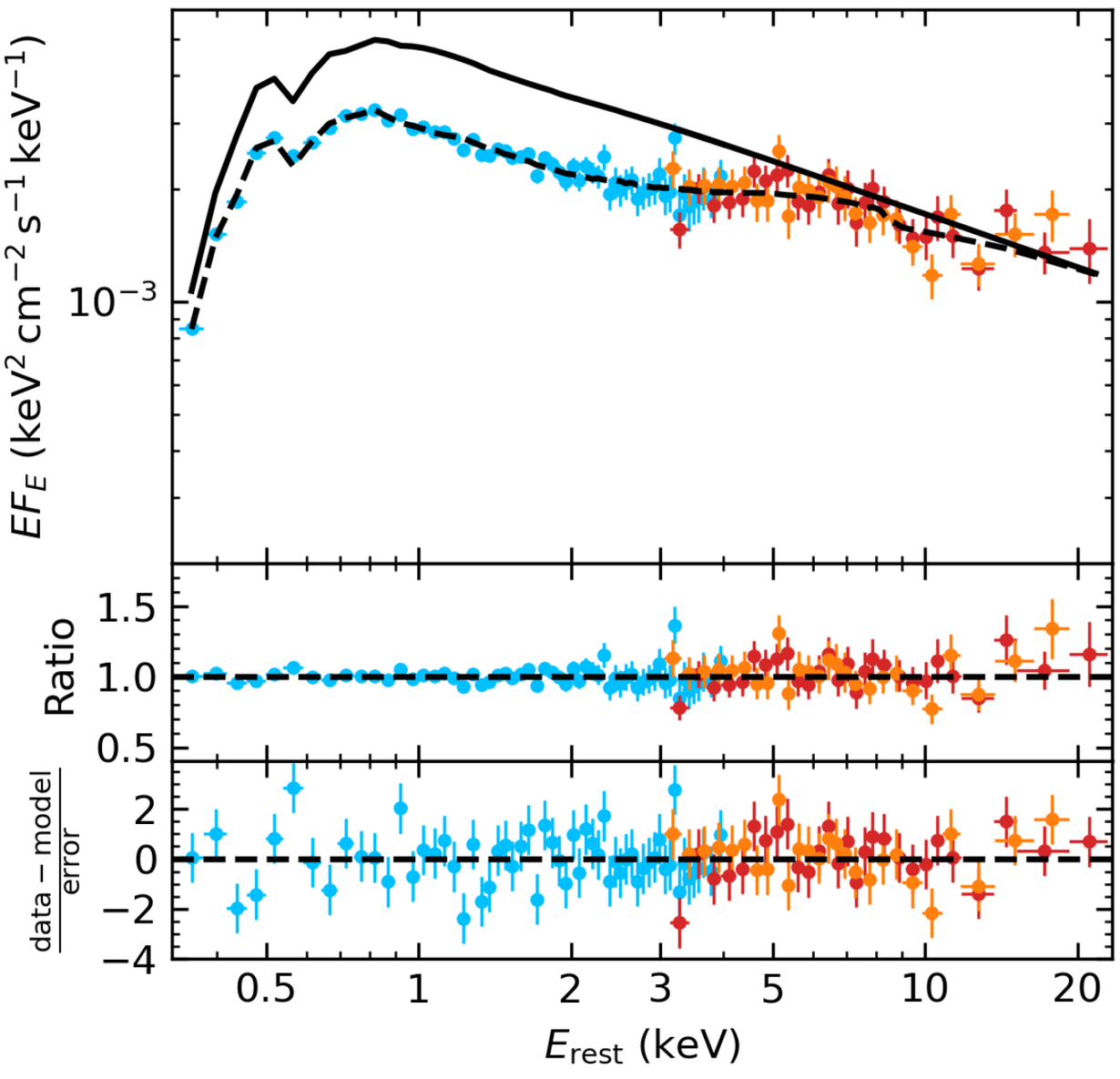
Outflow parameters consistent with results from Chandra/LETG (grating spectroscopy)

Miller ATel 15179



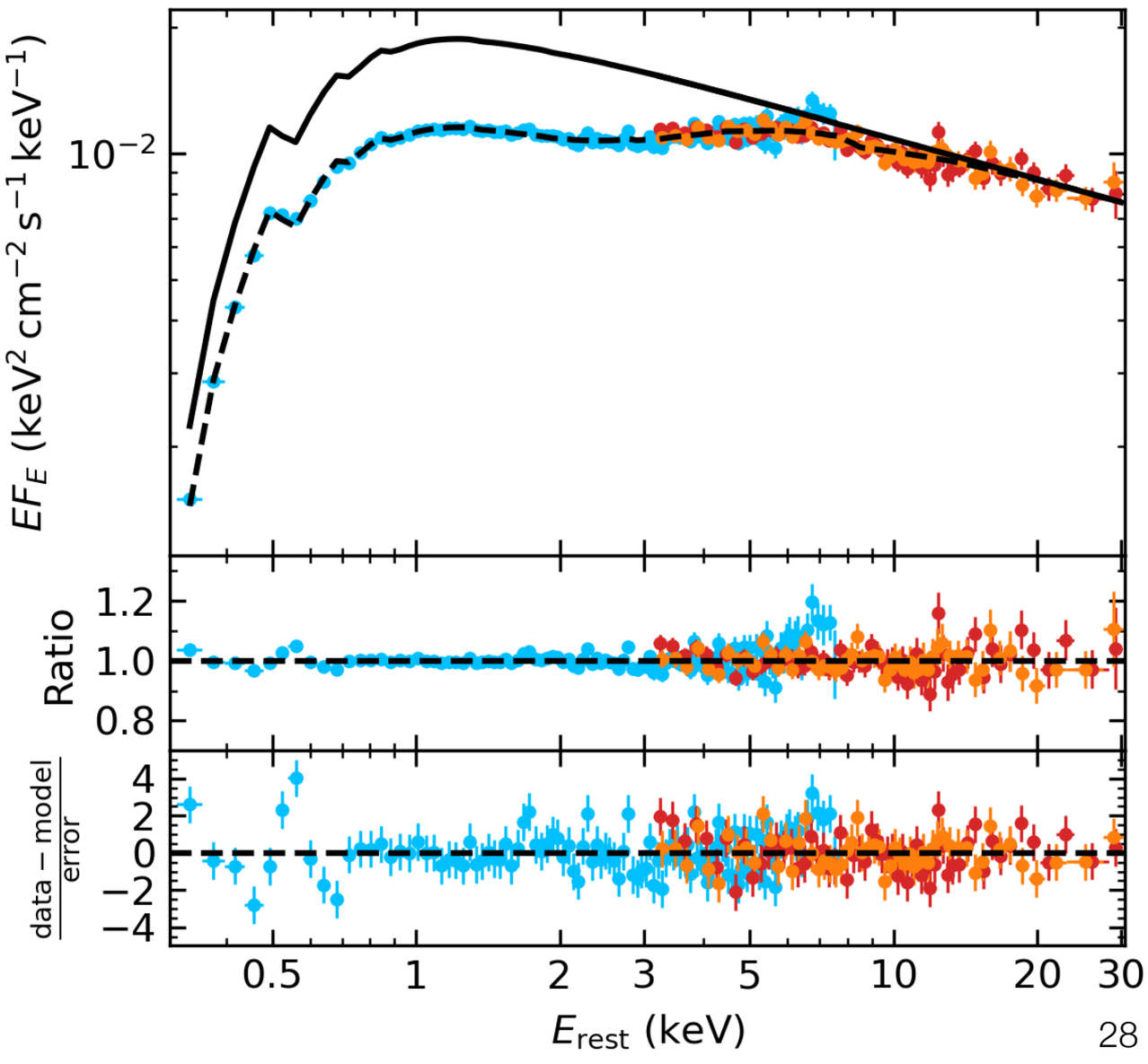
Velocity ~ 0.17c

$\delta t = 212$ days (disk + upscattering) * outflow



Velocity ~ 0.1c

$\delta t = 264$ days (disk + upscattering) * outflow

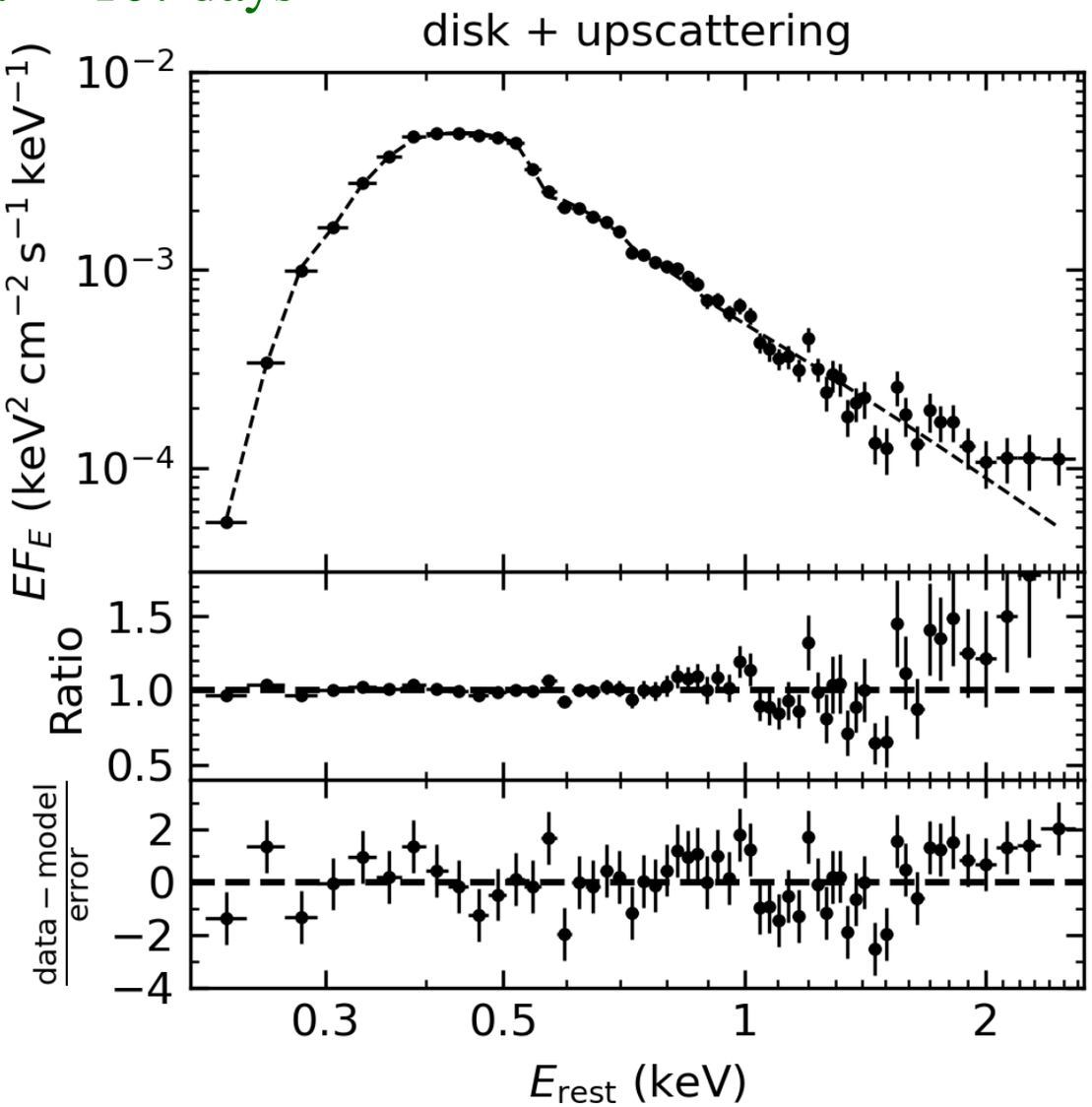


Evidence of a Sub-relativistic Outflow

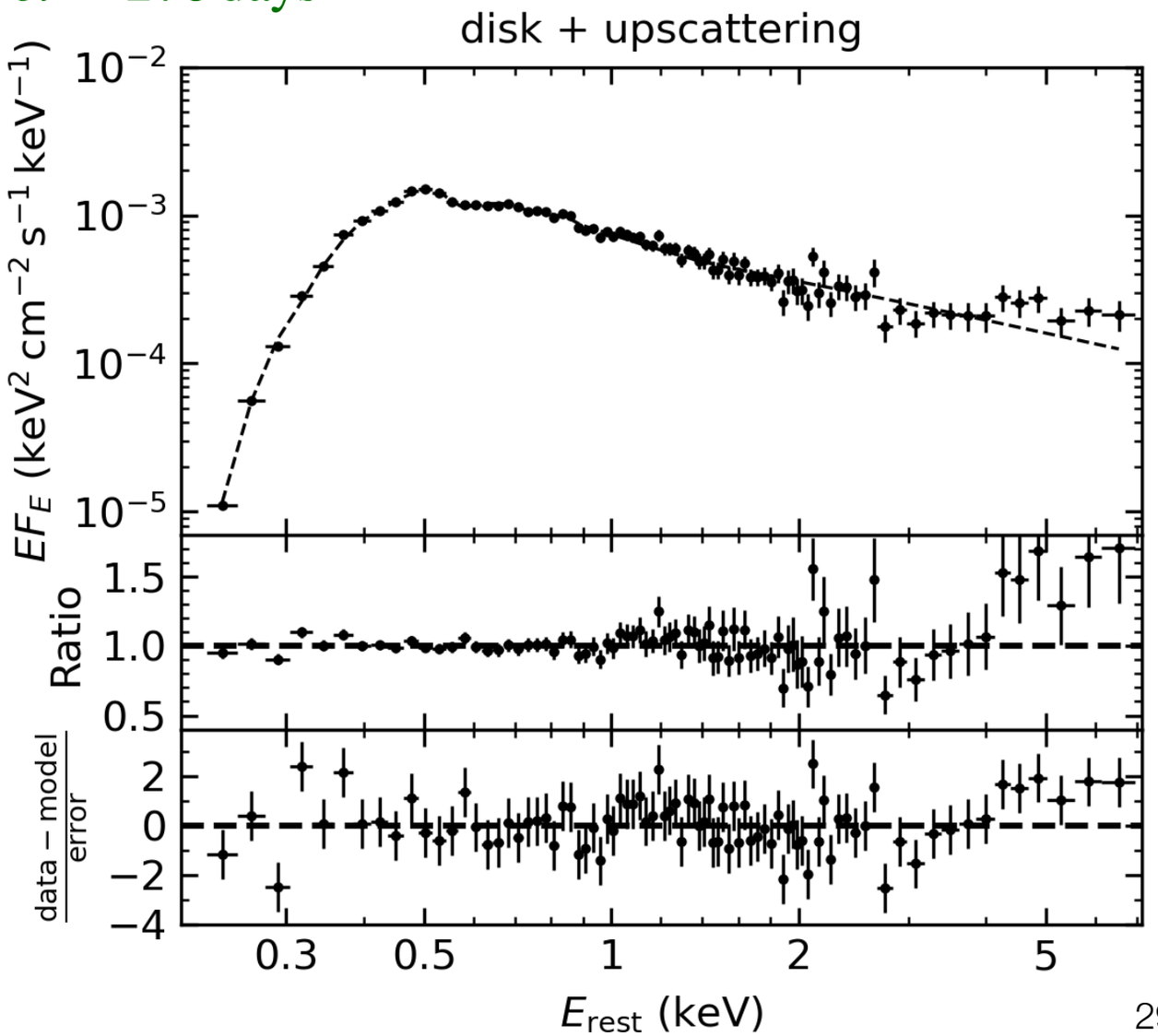
Early-time Soft state

Late-time Soft state

$\delta t = 107$ days



$\delta t = 278$ days

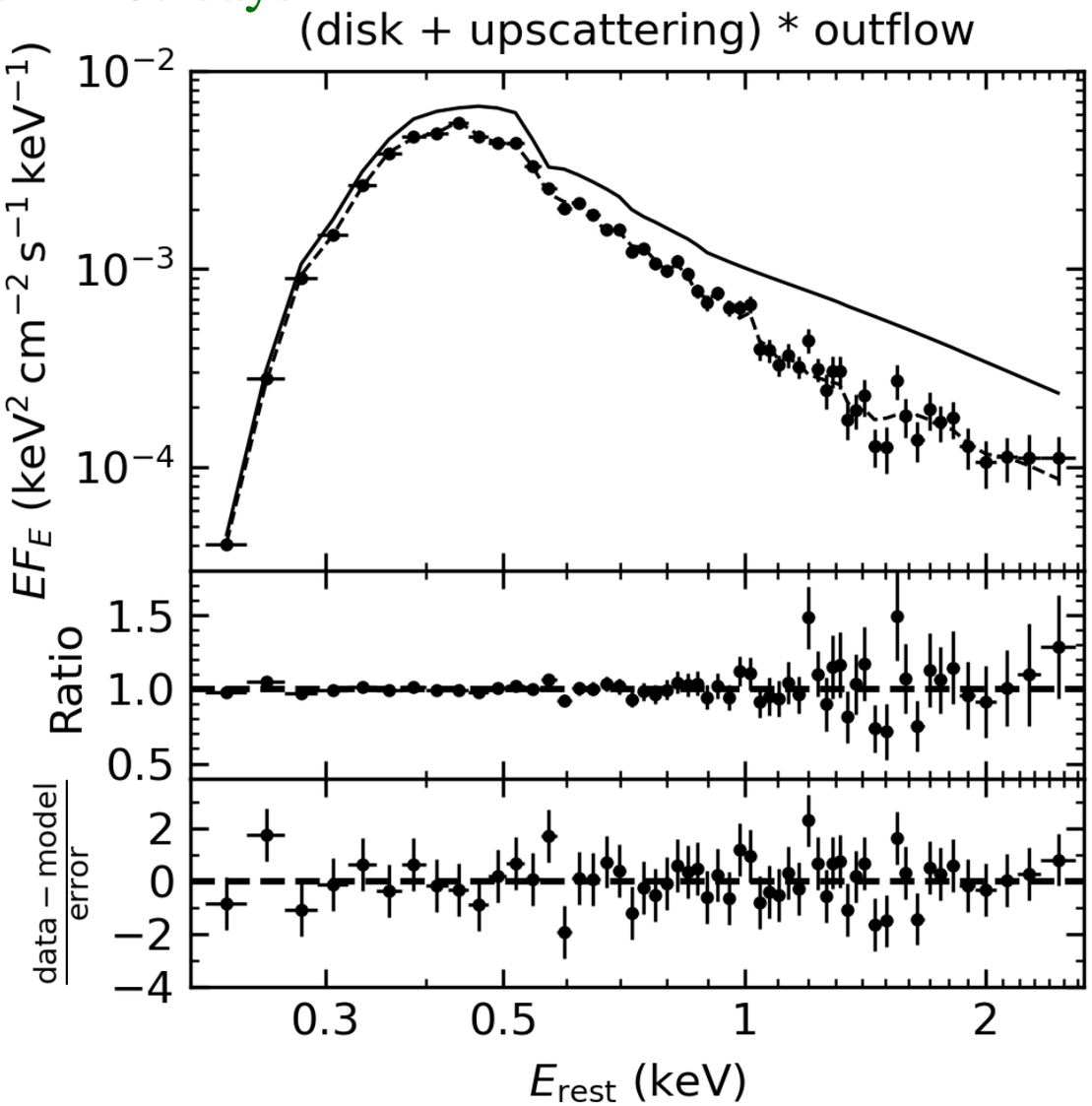


Evidence of a Sub-relativistic Outflow

Early-time Soft state

Velocity ~ 0.29c

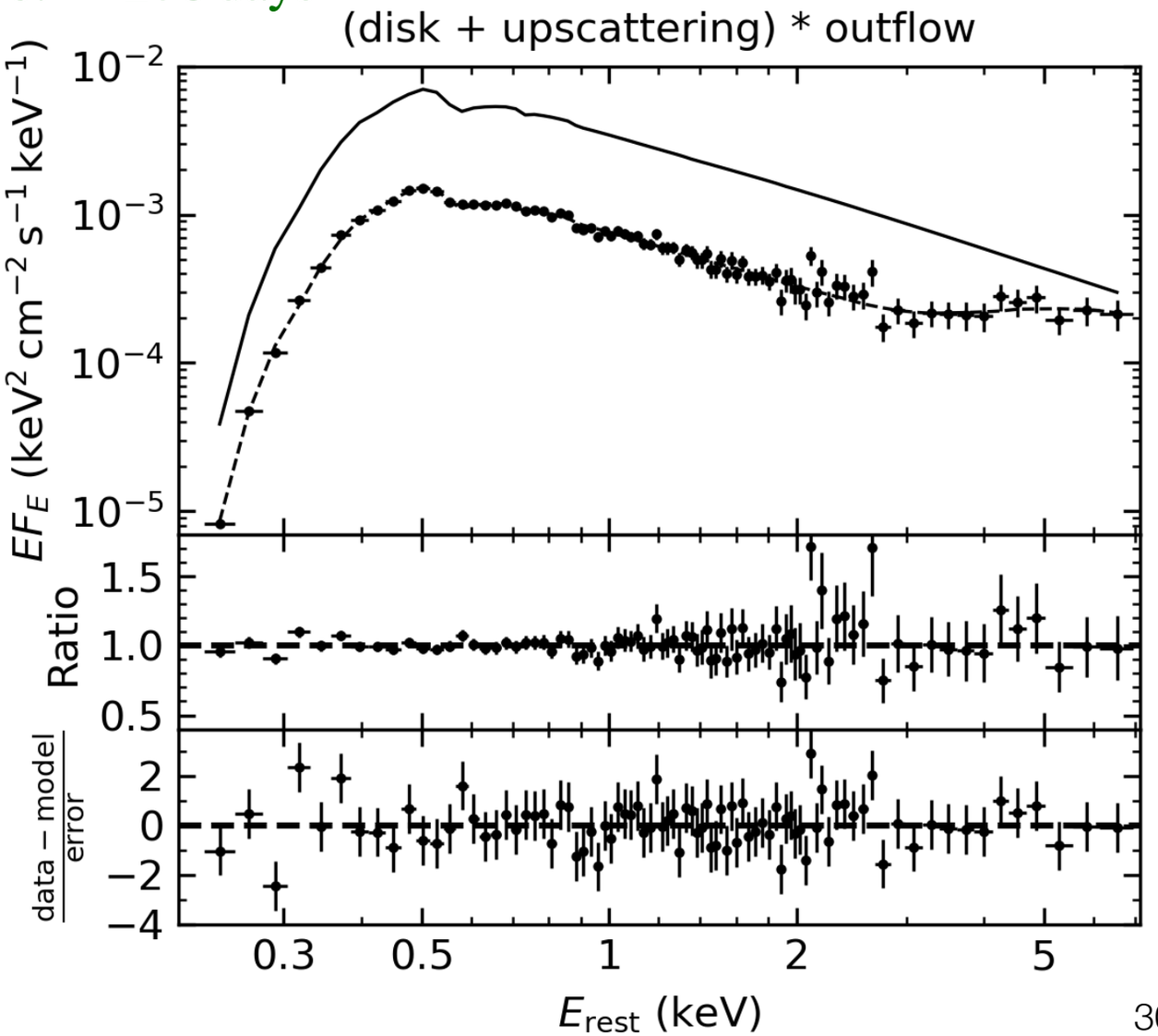
$\delta t = 107$ days



Late-time Soft state

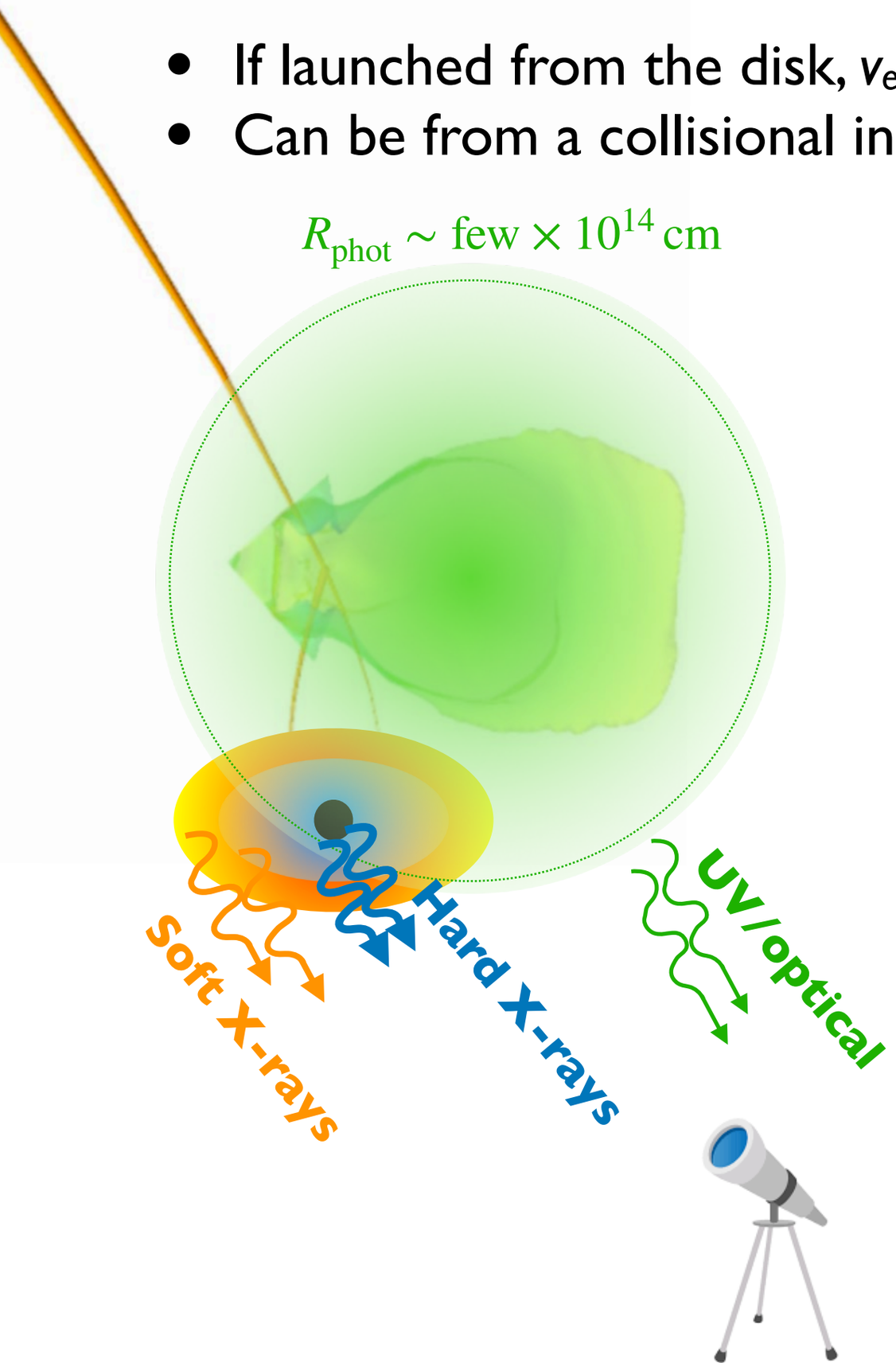
Velocity not well constrained
(Strong degeneracy with N_H)

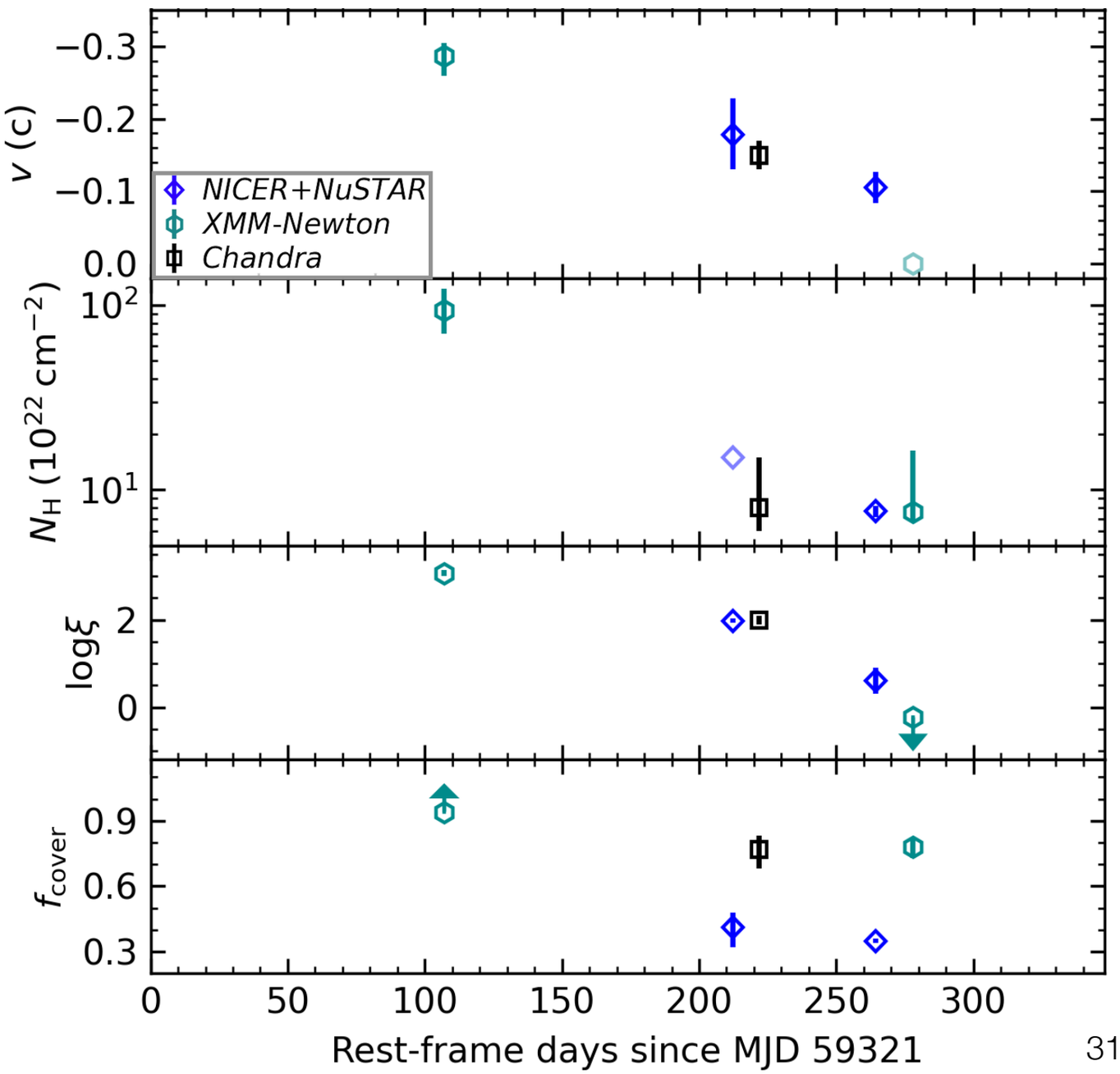
$\delta t = 278$ days



The Ultra-fast Outflow (UFO)

- If launched from the disk, $v_{es} \sim 0.1c \sim 2GM_{BH}/R_{launch}$; $R_{launch} \sim 200R_g \sim 20R_T$
- Can be from a collisional induced outflow





Take-home Message

- AT2021ehb is the brightest non-jetted TDE in the X-ray band;
  The first non-jetted TDE with detected X-ray photons at 30 keV;
  $M_{BH} \sim 10^7 M_\odot$

- The initial Soft→Hard spectral transition signatures outside-in formation of an accretion disk

- The later Hard→Soft spectral transition can be triggered by the formation of an advection dominated inner accretion flow (expected ~ $0.01 L_{Edd}$)

- The first TDE that show signatures of an ultra-fast outflow (UFO) in ***multiple*** X-ray observations

- The UFO may come from the stream-stream collision shock

yyao@astro.caltech.edu