The Changing Face Of UV Emission: Tracing MAXI J1820+070 Across a State Transition

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In collaboration with:
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OVERVIEW

MAXI J1820+070: one of the closest, brightest and least - reddened BHXTs

Unique multi-epoch UV coverage spanning hard, hard - intermediate, and soft states

The UV wavelengths allow us to connect the hot inner flow with the outer disc

Sensitive to X-ray irradiation geometry and intrinsic viscous heating

OBJECTIVES

- Origin of UV emission and accretion geometry
- Testing irradiated disc modelling
- Search of UV wind signatures
- UV variability and QPOs
- Evolutionary history of the binary
- Comparison Across Wavelength Bands

THE LMXB MAXI J1820+070: OBSERVATIONS

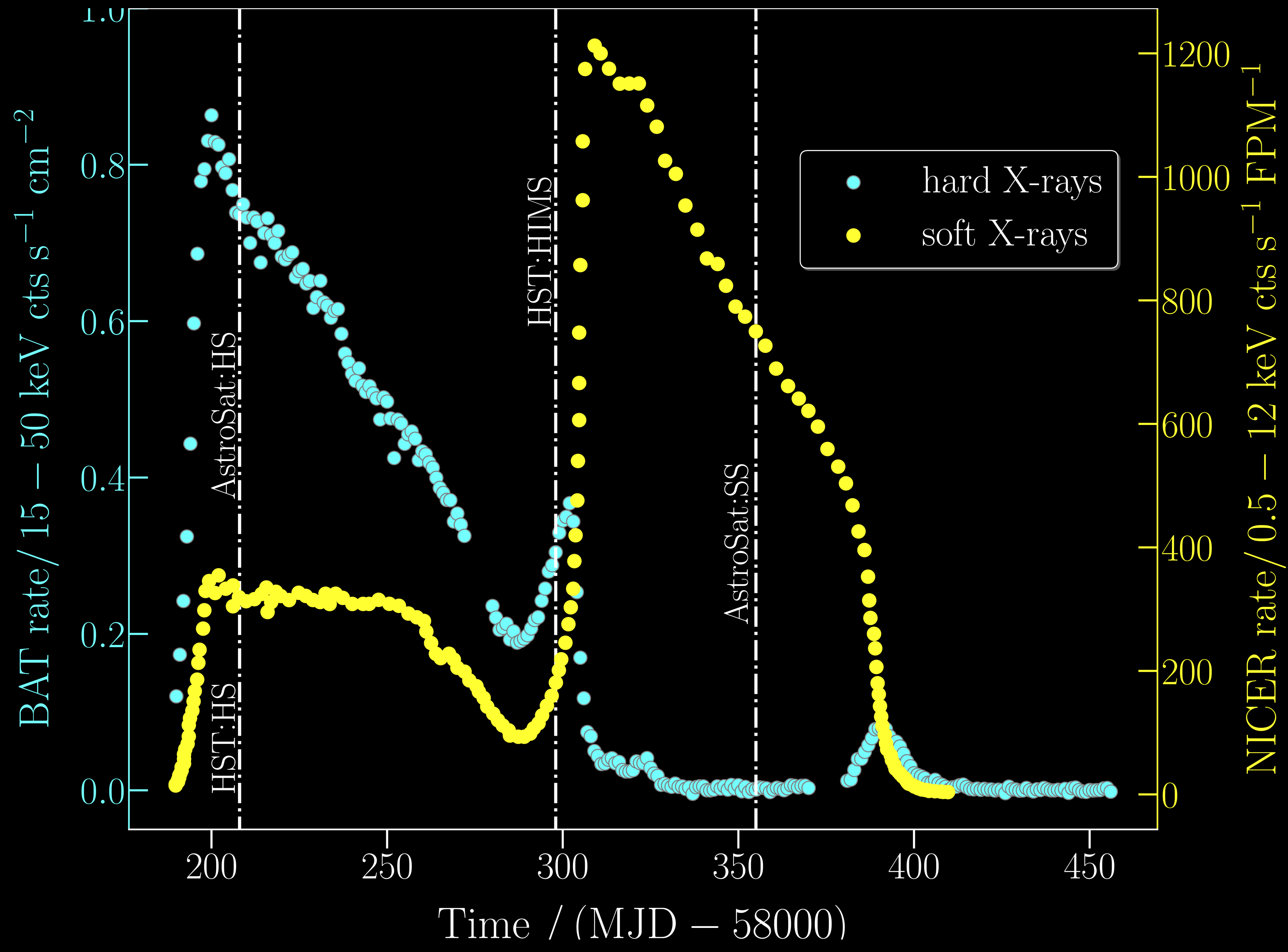
UV STUDY OF THE 2018 OUTBURST

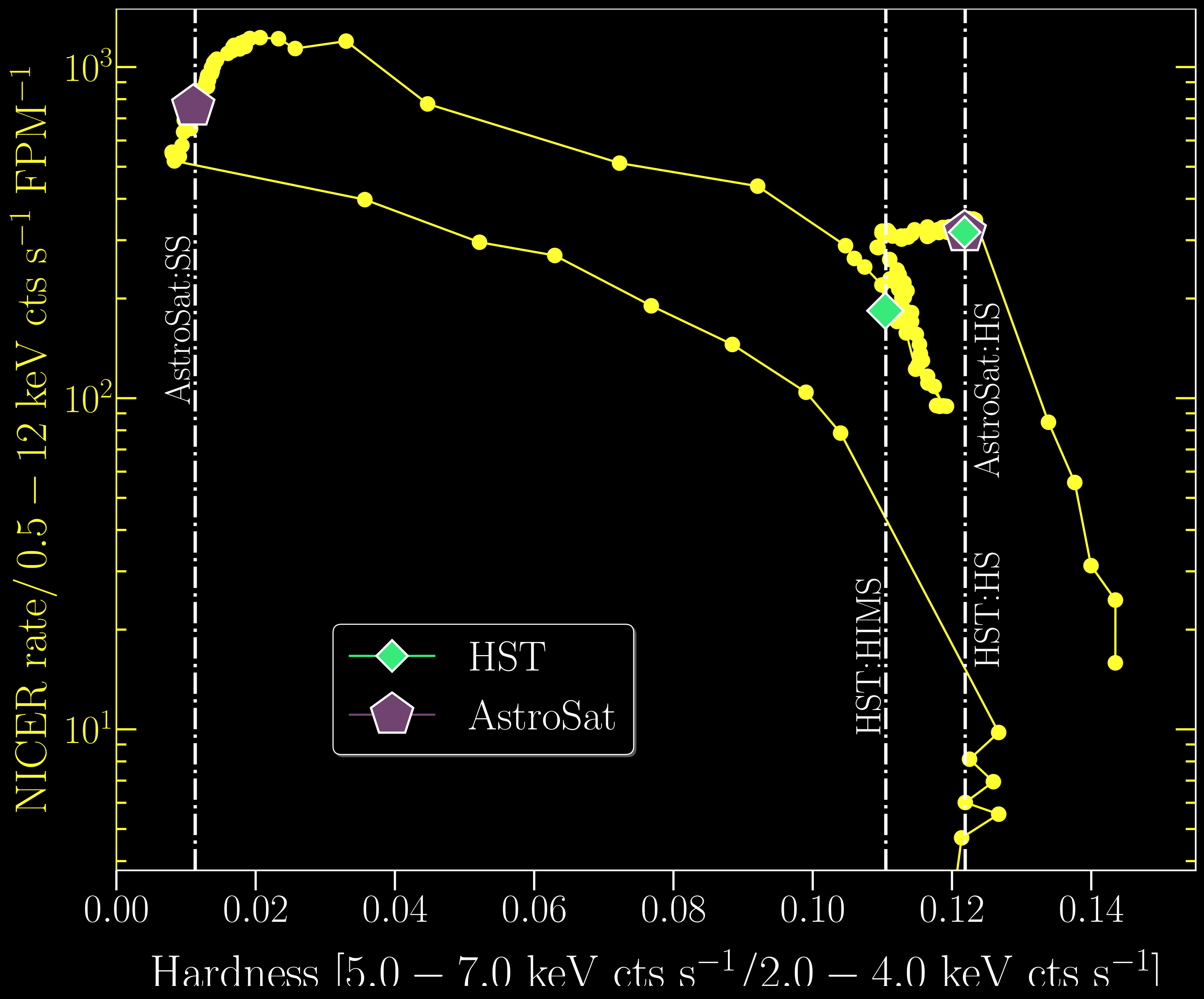
Multi-epoch UV observations covering 3 distinctive epochs

First ever hard state observation of a BHXT

HST/STIS far- and near- UV observations taken when the system was in the hard state

AstroSat/UVIT in the far-UV (1200-1800 A), taken both at the hard and after the transition into the soft state





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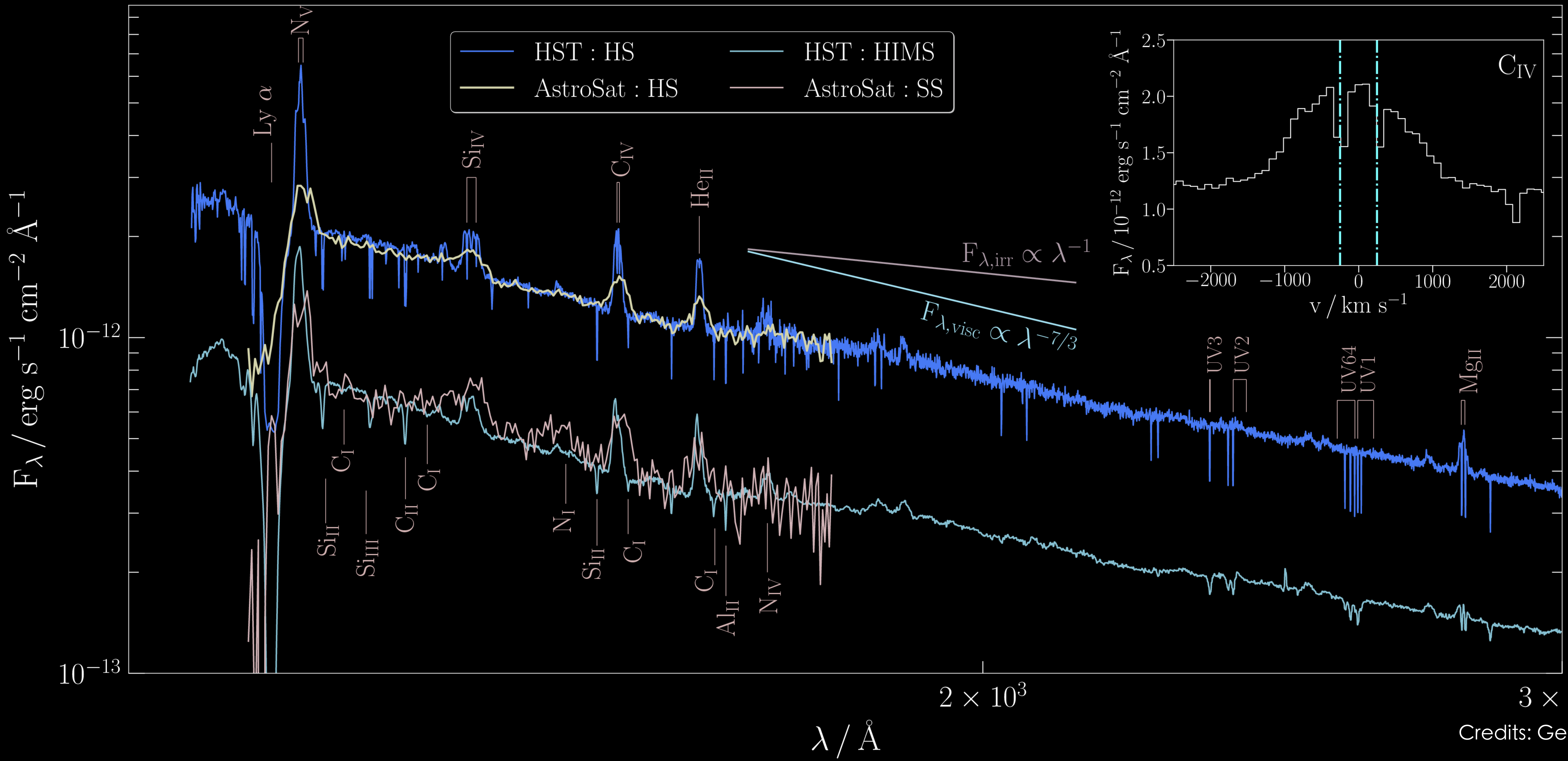
ORIGIN OF UV EMISSION AND ACCRETION GEOMETRY

SPECTRAL EVOLUTION THROUGH THE OUTBURST

How the spectrum evolves between the hard and soft state?



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HIGHLIGHTS

UV continuum
Nearly identical in all three states

Models prediction

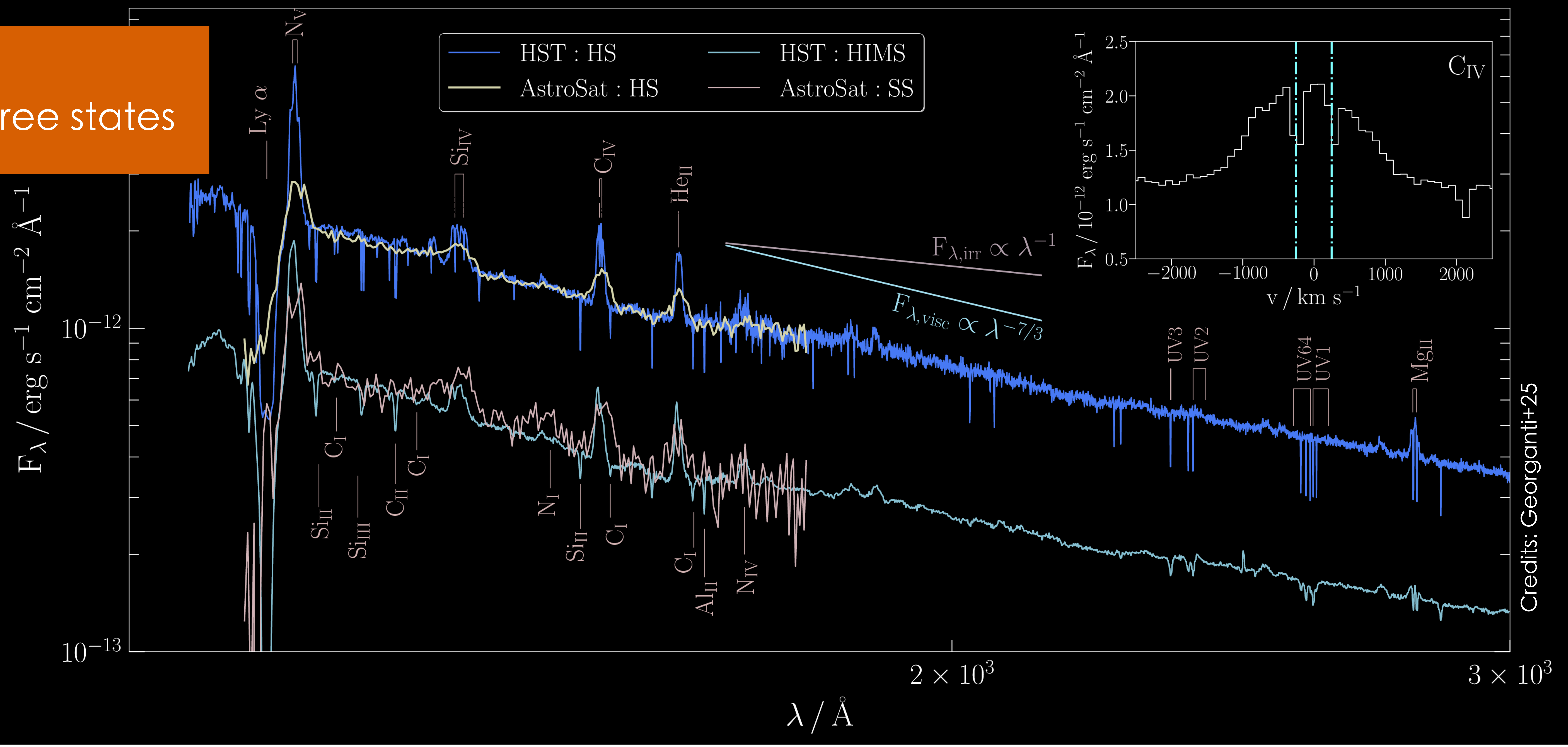
Viscous dissipation

$$F_{\lambda,visc} \propto \lambda^{-7/3}$$

X-ray irradiation

$$F_{\lambda,irr} \propto \lambda^{-1}$$

Extinction estimate
Use of the near-UV 2200 A feature to fit different extinction curves
Fitzpatrick+99: $E_{B-V} = 0.20 \pm 0.05$



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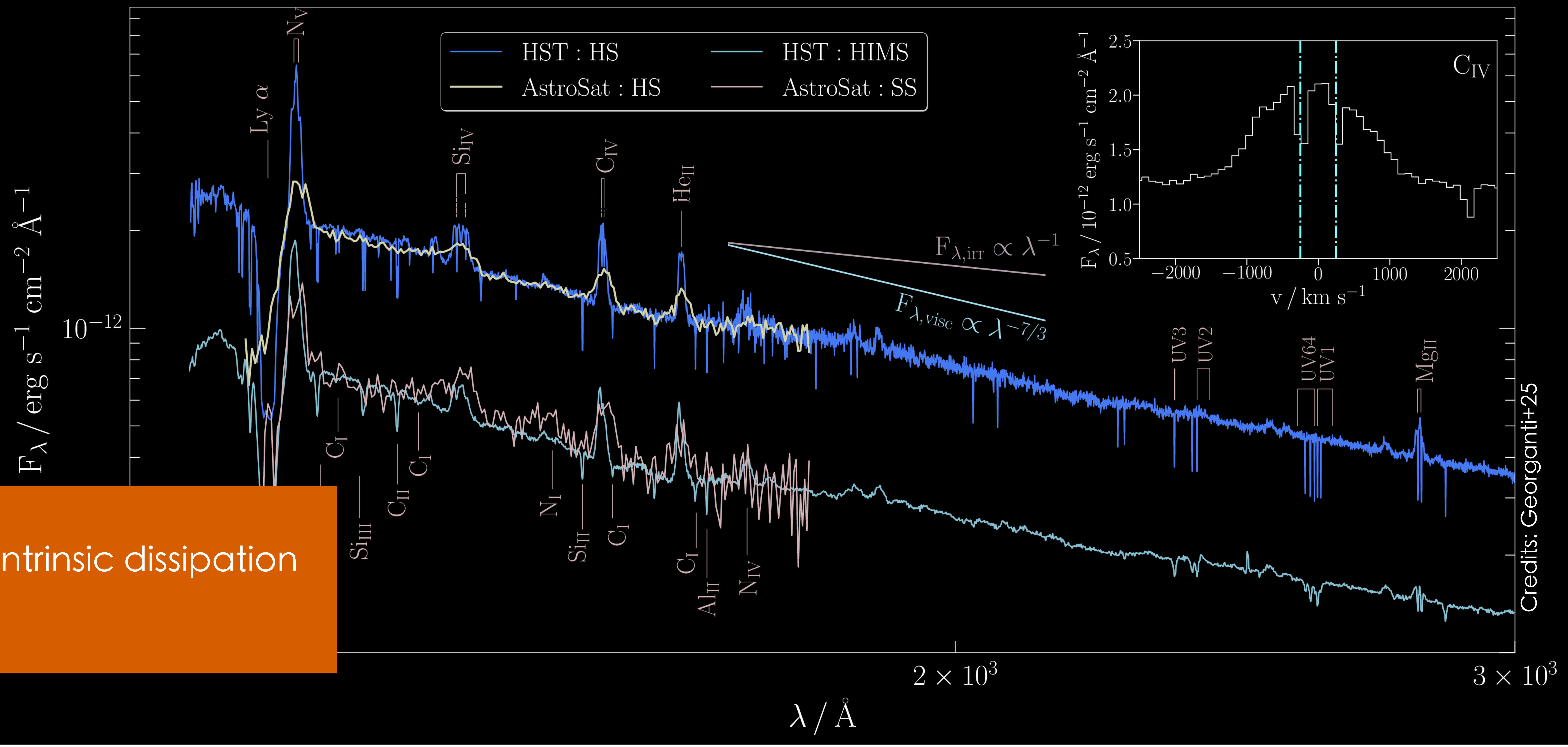

Implication:

UV emission dominated by intrinsic dissipation or shielded from X-rays.

ORIGIN OF UV EMISSION AND ACCRETION GEOMETRY

SPECTRAL EVOLUTION THROUGH THE OUTBURST

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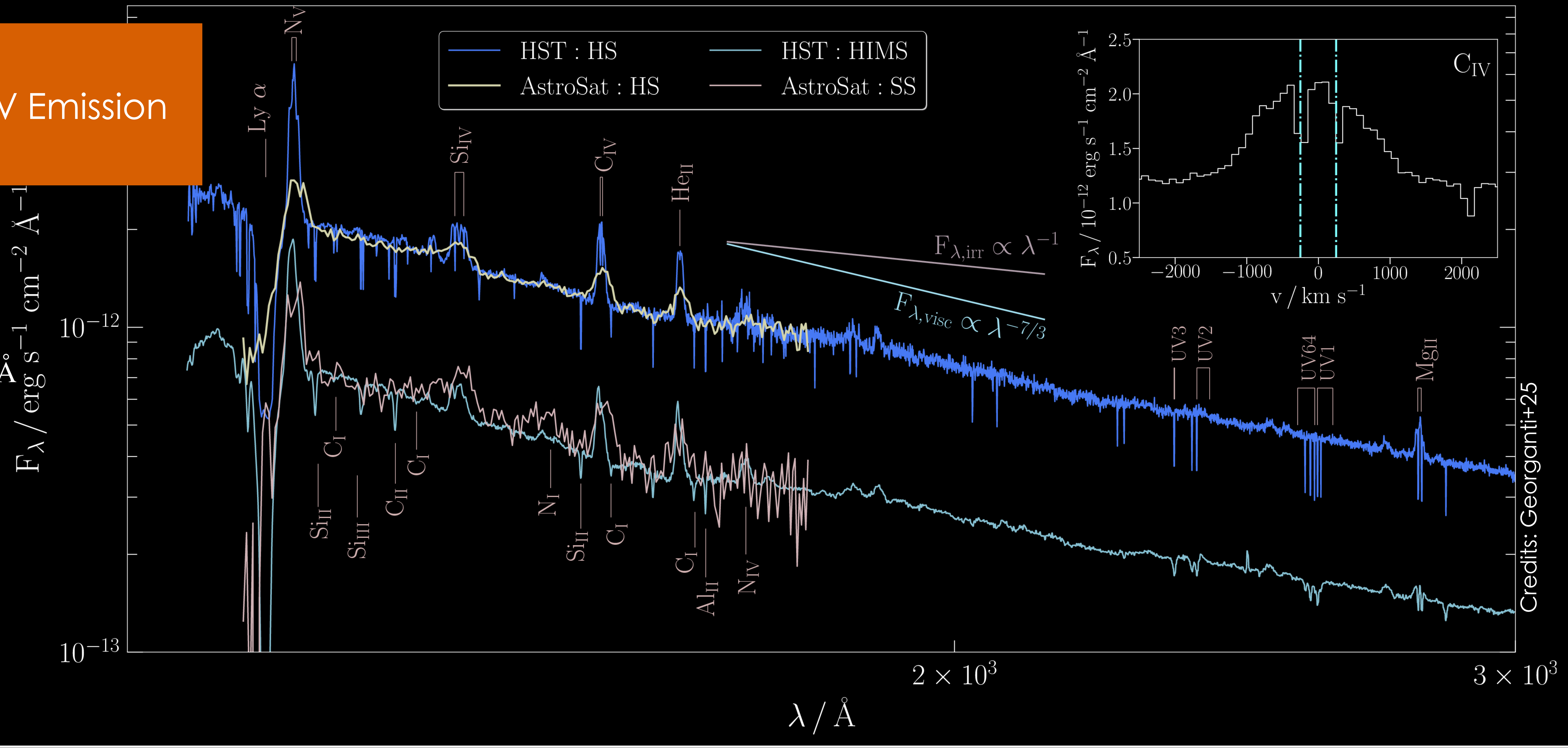
HIGHLIGHTS

Spectral lines
Strong, Double-Peaked UV Emission Lines Detected

UV resonance lines:
N V λ1240Å, Si IV λ1400Å, C IV λ1550Å
He II λ1640Å, Mg II λ2800Å

Seen across all states



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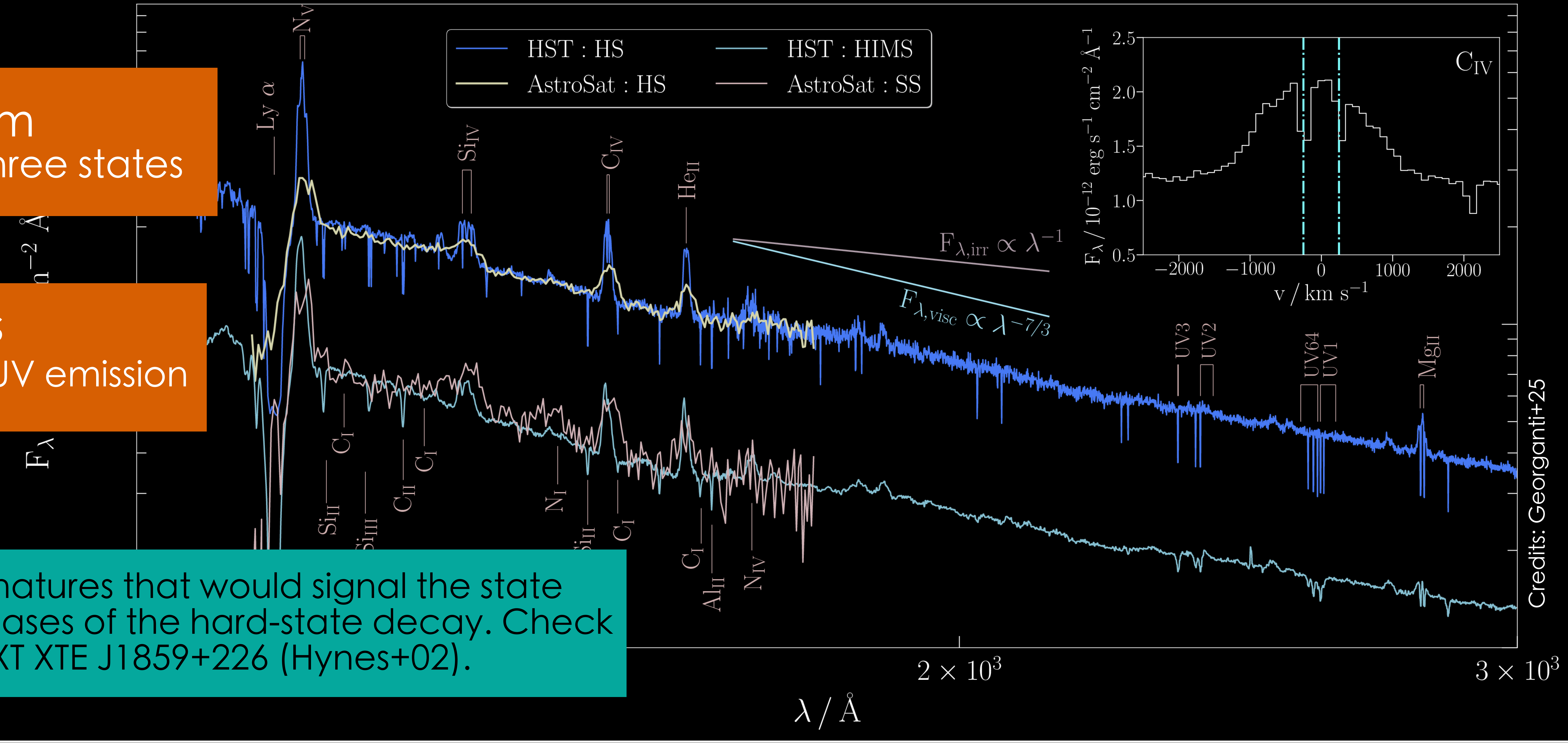

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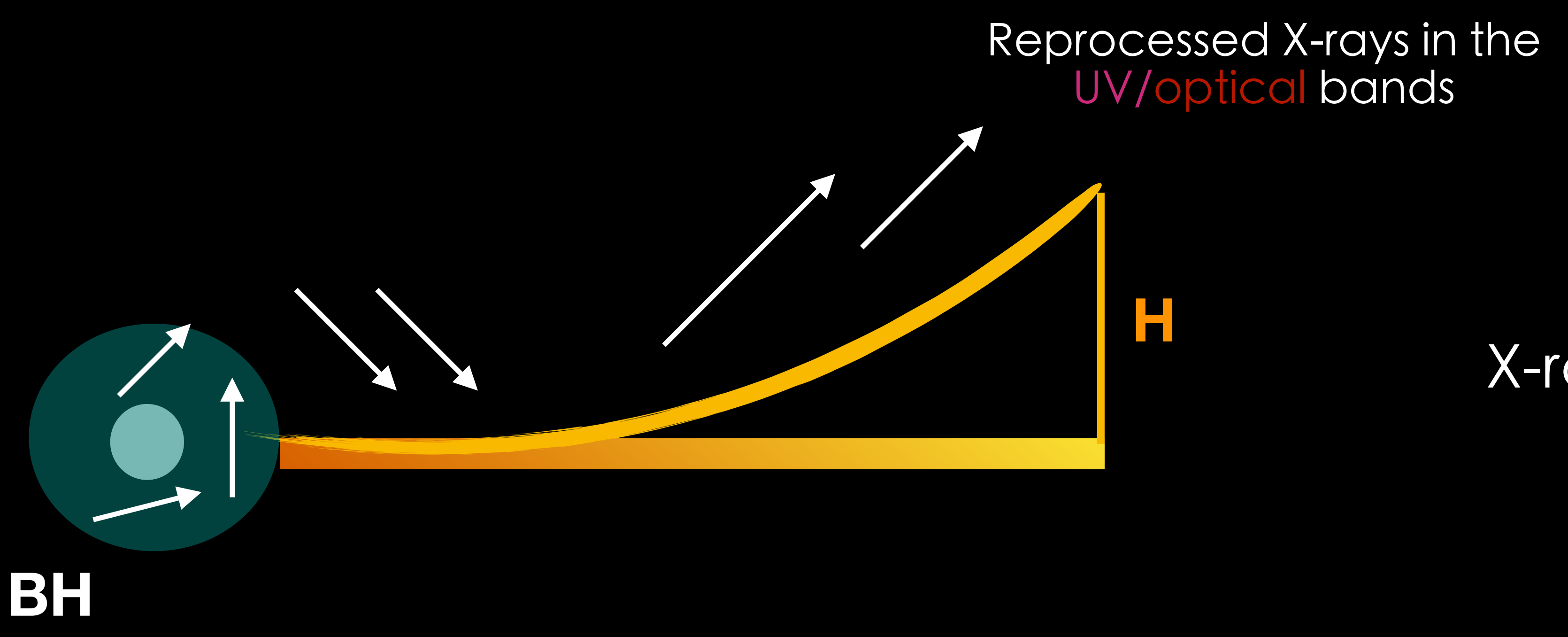
There are no distinct signatures that would signal the state transition or the different phases of the hard-state decay. Check the case of the BHXT XTE J1859+226 (Hynes+02).

IRRADIATED DISC MODELLING

X-ray irradiation

outer disc regions absorb and re-emit hard photons at longer wavelengths



Irradiated disc model

X-rays are produced by a point-like, isotropically emitting source at the centre of the disc

The photons will impact the disc and will be reprocessed in UVOIR wavelengths

Additional heating source ⟶ Modification of the temperature profile

OUR MODELLING

Free parameters: $\dot{M}, R_{out}, A$
Fixed parameters: $d, M_{BH}, a_{spin}, E_{B-V}, N_H, R_{in}, i, H/R$

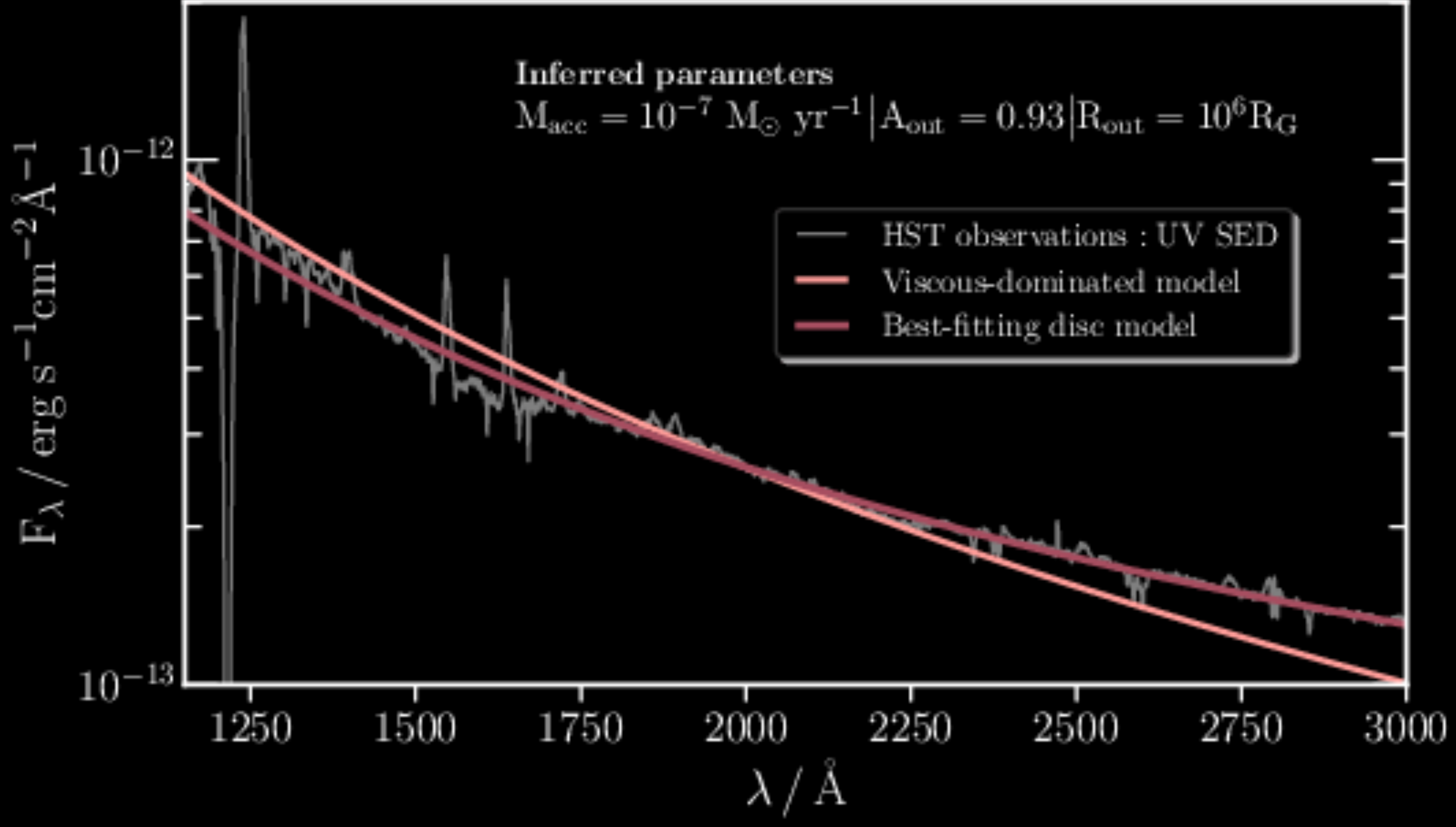
- The (X-ray) related parameters are fixed from literature
- Consideration of surface density change with the radius
- Consideration of spectral hardening factor (Davis+18)

BEST-FIT MODEL

Finding the best-fit model for our far-UV and near-UV SED

Assumptions: the disc radiates as a sum of blackbodies

$R_{in} = R_{ISCO}$



The spectral shape of the far-UV+ near-UV SED is very close to a pure viscously dominated disc with no (or a little) contribution from irradiation

Inferred parameters:

$\dot{M} \simeq 10^{-7}\ M_\odot\ yr^{-1},\ R_{out} \simeq 10^6\ R_g, A = 0.93$

UV Spectrum Resembles Classic Viscous Disc Systems

Similar to Nova Muscae 1991 (Cheng+02), A 0620–00 (Hynes+03)

Take home message: We infer unreasonable values for our parameters, something that it is contradictory of what we know from the observations.

Only unphysical R_out»R_tide or A→1 match UV flux+shape.

Credits: Georganti+25

IRRADIATED DISC MODELLING

Could a number of reasonable parameters reproduce the SED?

Naively thinking, for reasonable values of $\dot{M}, R_{out}, A$, irradiation has to be important.

We employ as reference model the one used by Koljonen+23 for modelling the X-ray-optical SED of MAXI J1820+070 (soft state).

↓

As it can be seen, the model predicts an SED that it is a little too faint at the far-UV region.

We create a small grid for the aforementioned parameters so we can check how sensitive they are ,modelling our spectrum.

Take home message: Even though we try to match the flux level using irradiation, the spectral shape remains too flat.

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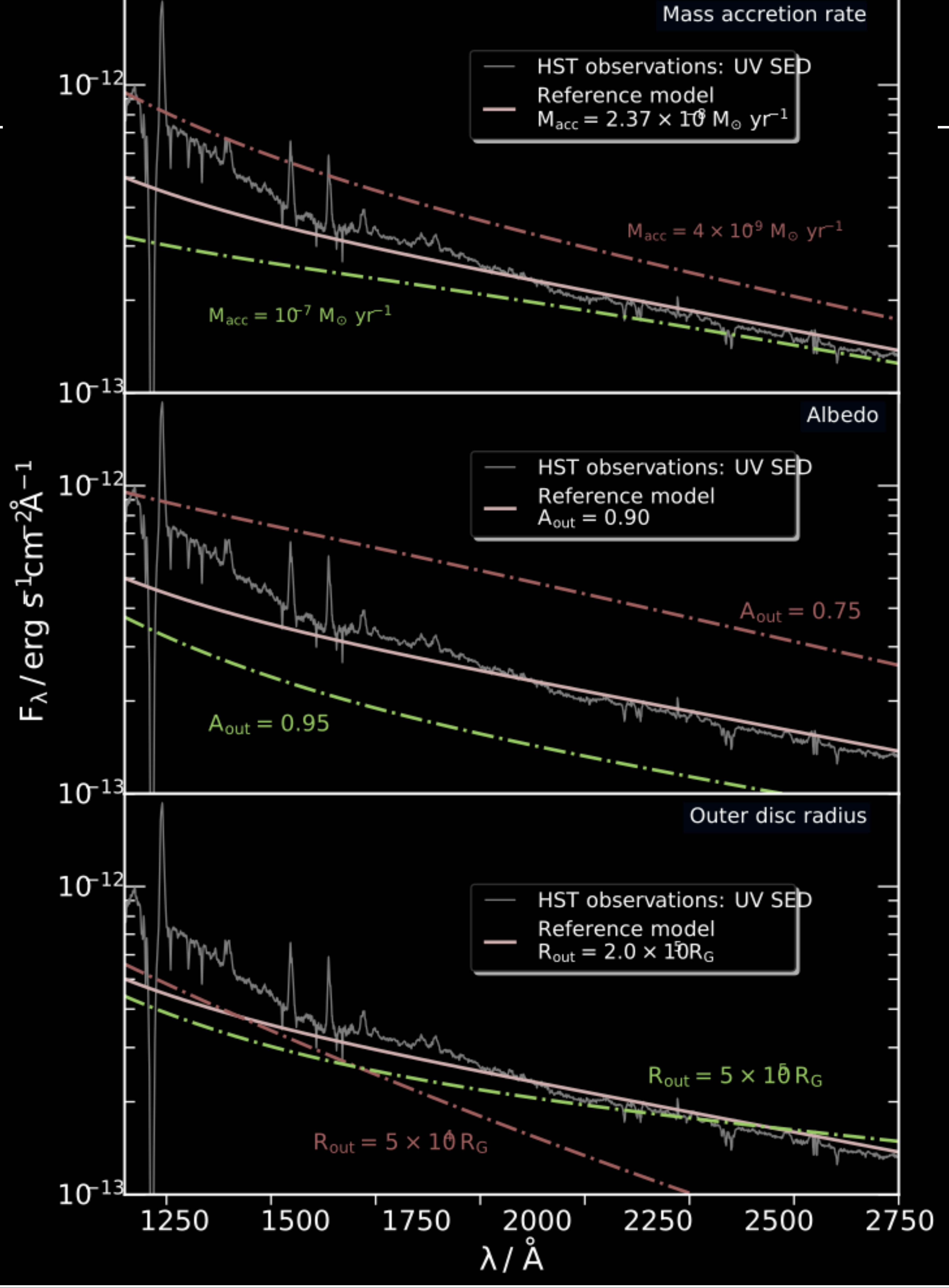
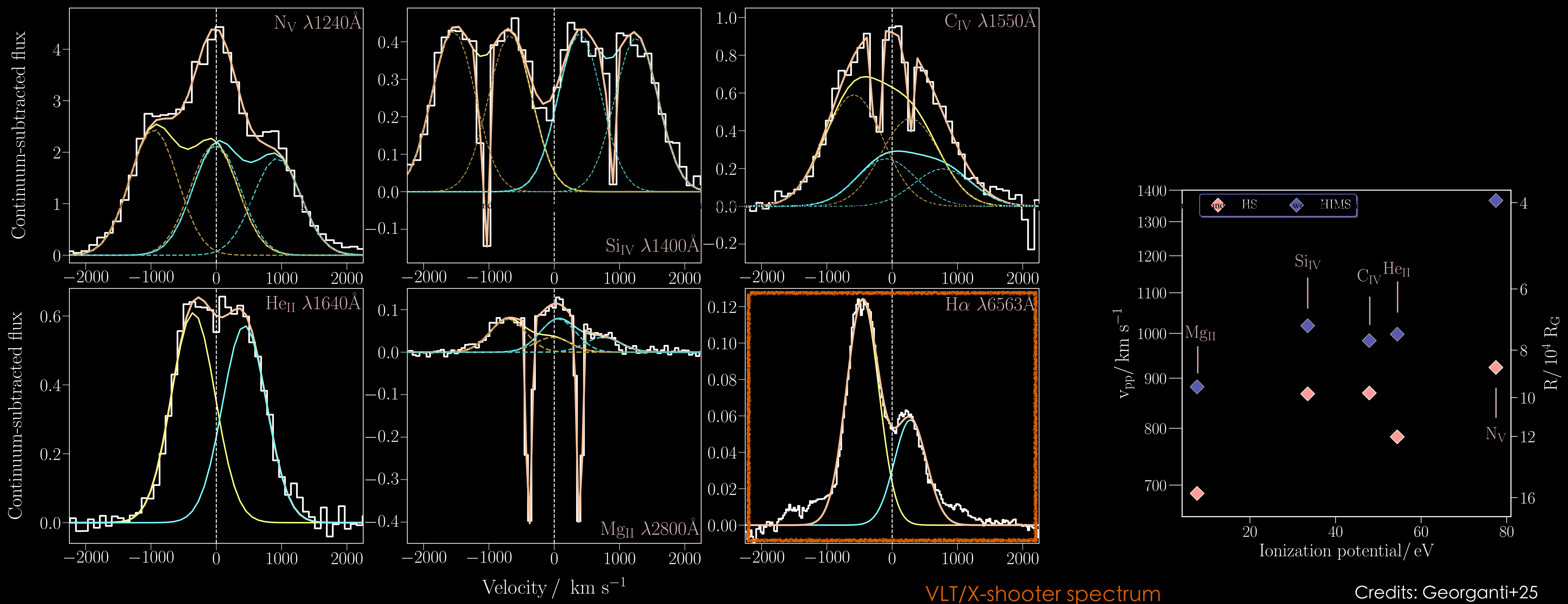


EMISSION LINE SHAPES AND FLUXES

All UV lines are double-peaked → Keplerian disc origin

Disc Mapping: Ionisation stratification confirms Keplerian velocities ↔ emission radius.



VLT/X-shooter spectrum

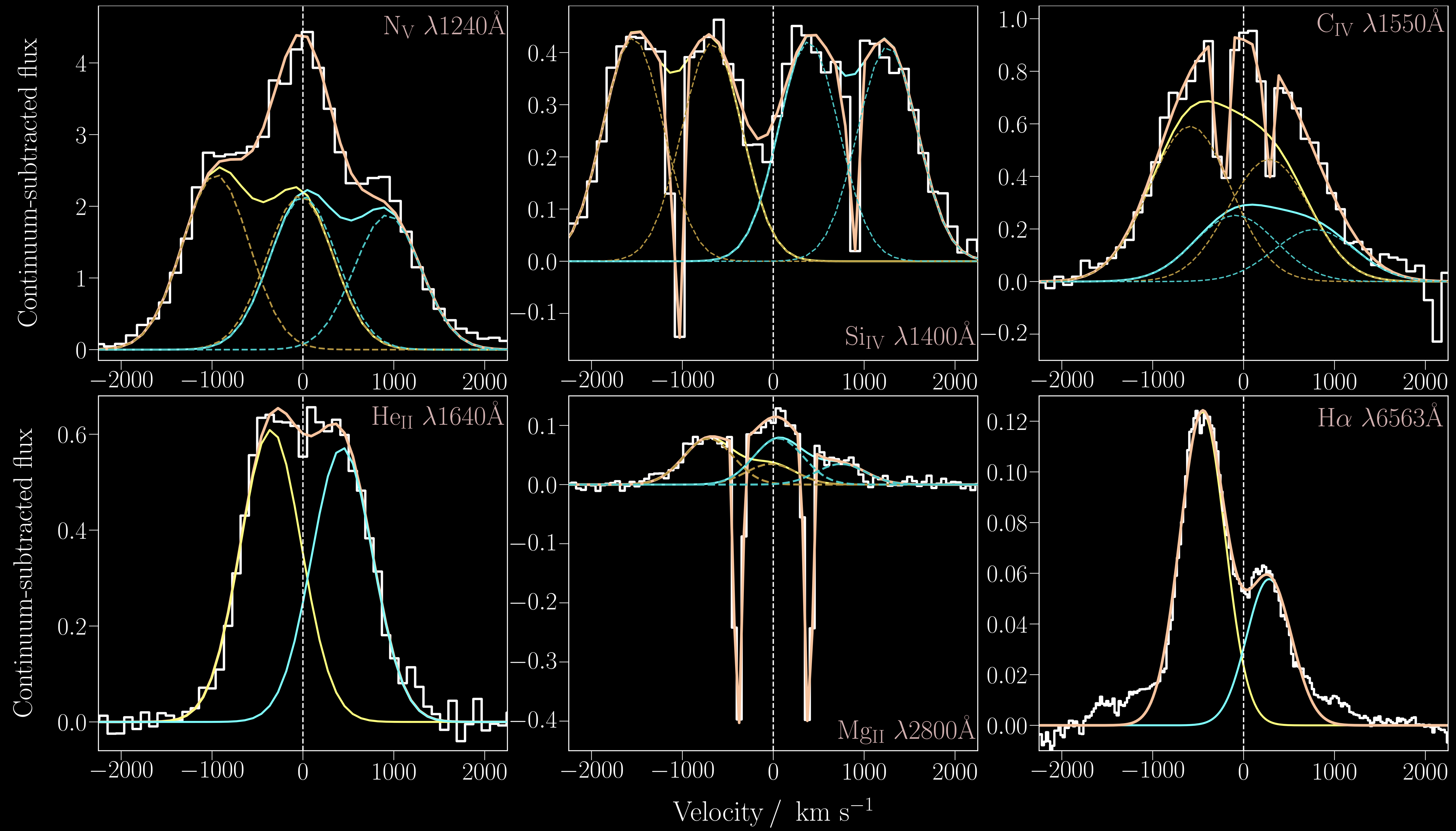
Credits: Georganti+25

EMISSION LINE SHAPES AND FLUXES

Search of UV wind signatures

Expectation: UV resonance lines show blue-shifted absorption/P-Cygni profiles if winds present.

Clear UV signatures: Swift J1858.6-0814 (Castro Segura+22), UW CrB (Fijma+23)



MAXI J1820+070

No identification of wind signatures in the hard state

Contrast with optical/NIR : no detection of wind features in hard state (Munoz-Darias+19, Sánchez-Sierras & Muñoz-Darias+20)

Possible explanations:

i) Wind too highly ionised → no UV resonance opacit

ii) Clumpy/low covering fraction; geometry misaligned

iii) Transient phenomena with our limited observation window

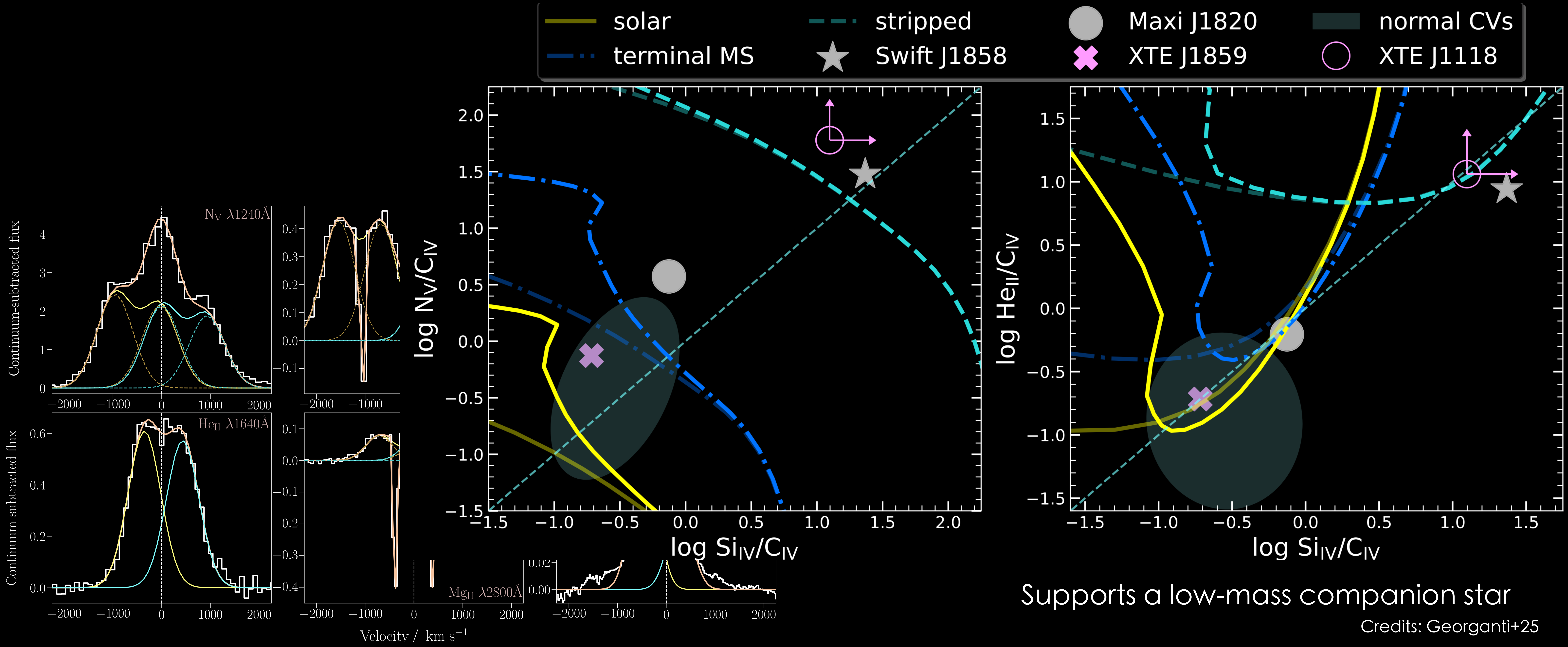
Credits: Georganti+25

EMISSION LINE SHAPES AND FLUXES

Evolutionary history of the binary

(e.g. Mauche+97, Gansicke+03, Castro Segura+24)

Line ratios: strong dependence of the degree of CNO processing the accreting material has been subjected to



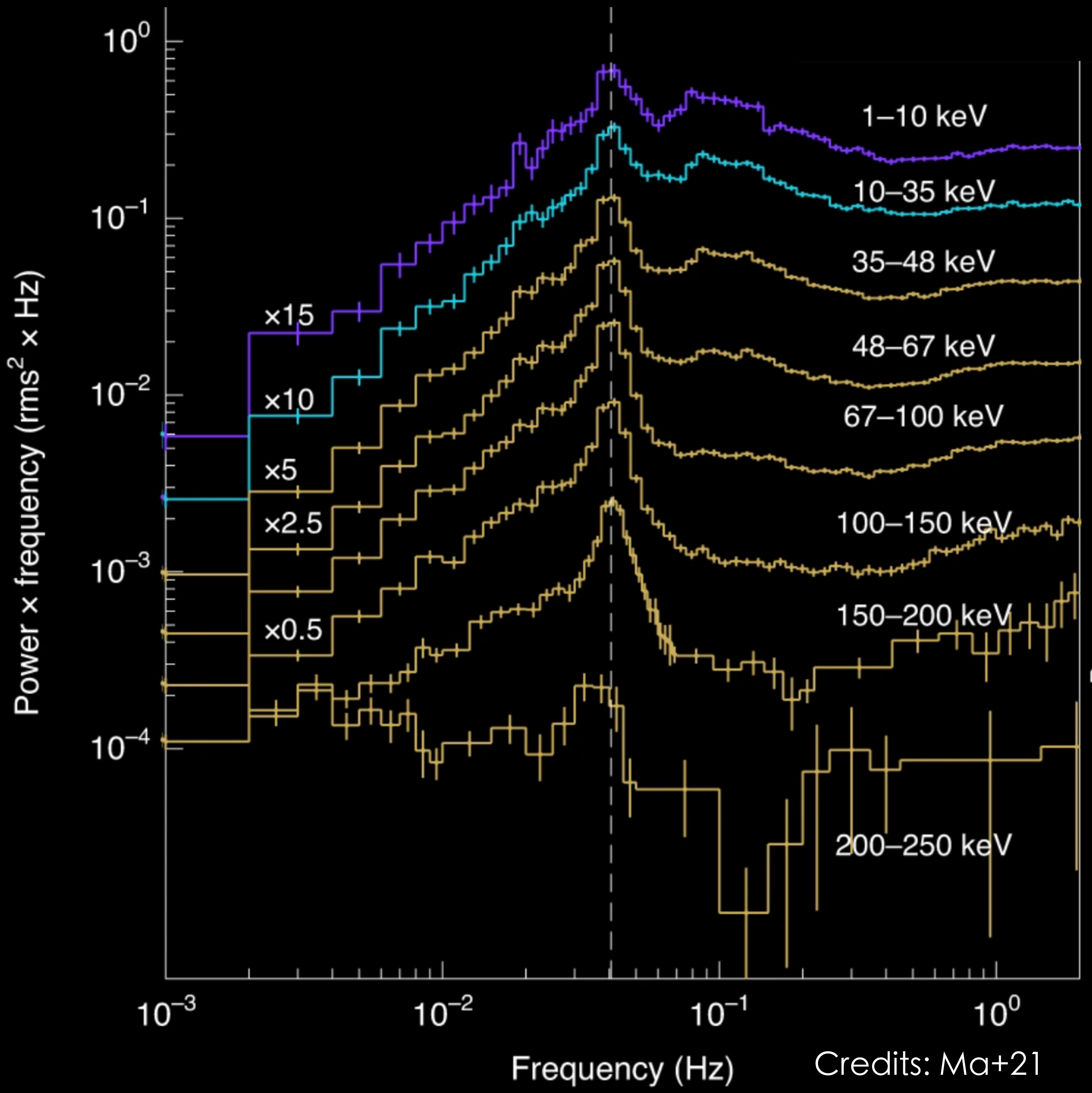
Supports a low-mass companion star

Credits: Georganti+25

UV VARIABILITY AND DETECTION OF QPOs

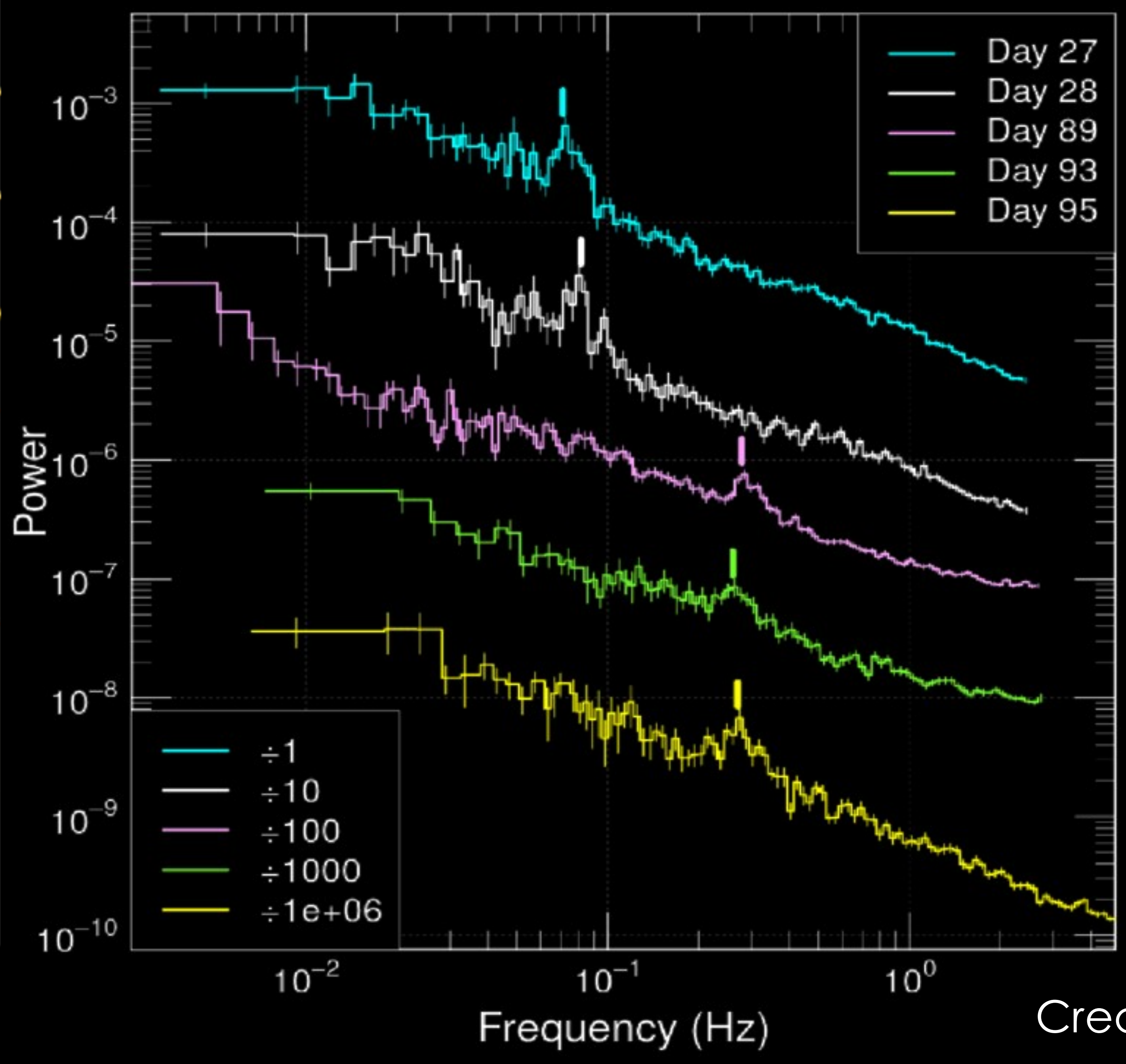
Multi-band low-frequency disc variability ⟶ connected to the state of the source

Timing observations of BHXTs indicate the presence of broadband noise and the appearance of QPOs across the span of their outbursts



Credits: Ma+21

MAXI J1820+070, Hard state



Credits: Thomas+22

X-rays

Origin: Lense-Thirring precession (e.g. Ingram & Motta+19), disc instabilities (e.g. Tagger & Pelat+99), corona variability (e.g. Titarchuk&Fiorito+04)

Optical

Origin: thermal reprocessing (e.g.Valedina&Poutanen+15), jet-synchrotron emission (e.g. Gandhi+17)

Recent studies by Ma+21, Mao+22, Thomas+22 provide crucial context for comparing our UV observations with near-simultaneous optical and X-ray data

What happens in the UV?

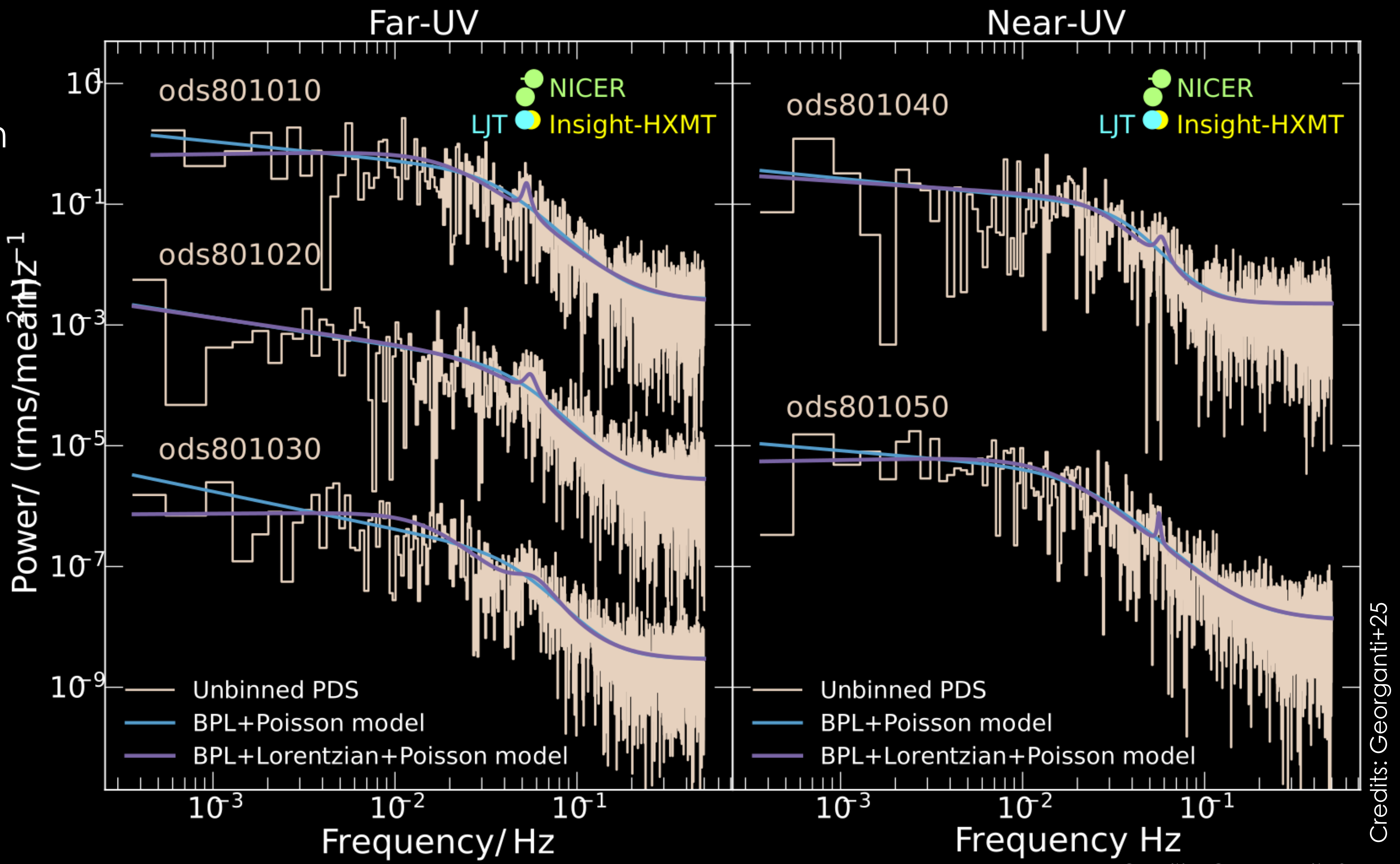
UV VARIABILITY AND DETECTION OF QPOs

It is still unclear, though, whether the X-ray and longer-wavelength signals are physically associated and how the latter are actually produced

Hard state

Time-resolved HST UV data shows broken power-law variability

Our modelling suggests a tentative detection (2-3σ) nearly at the same frequency that has been seen in optical and X-rays



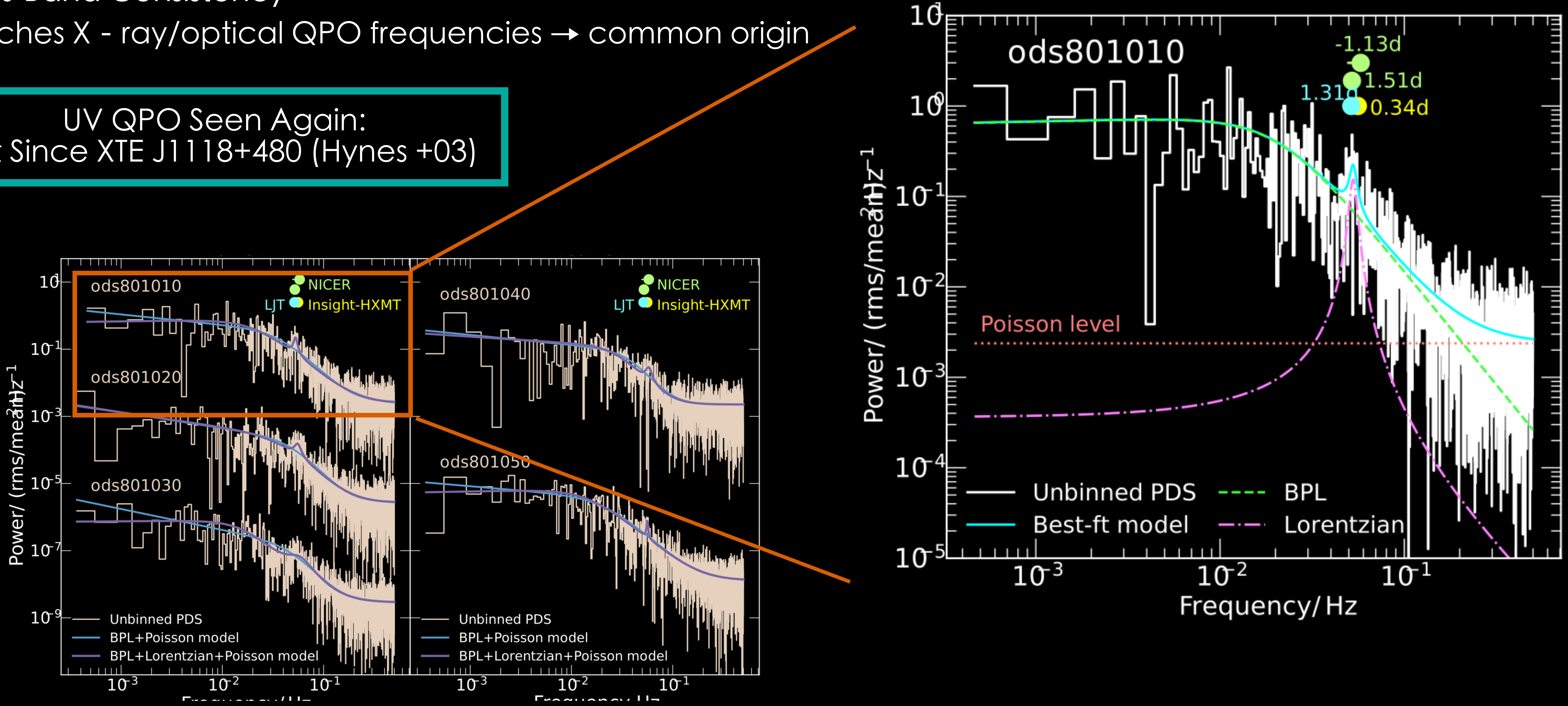
Credits: Georganti+25

UV VARIABILITY AND DETECTION OF QPOs

Cross-Band Consistency:

Matches X - ray/optical QPO frequencies → common origin

UV QPO Seen Again:
First Since XTE J1118+480 (Hynes +03)



Credits: Georganti+25

CONCLUSIONS AND FUTURE WORK

MAXI J1820+070 $\longrightarrow$ an unprecedented UV view of black hole accretion

The continuum spectral shape and emission lines remain virtually unchanged across various stages of the outburst

UV continuum remains viscous - like ↔ suppressed/hidden irradiation

Double - peaked UV lines map radial ionisation structure

No detection of UV outflows in the hard state in contrast of what it is seen in other bands

The inferred line ratios are consistent with a low-mass donor, $M_2 \leq 1.5 M_{\odot}$

Tentative evidence for a low-frequency UV QPO during the luminous hard state. The candidate QPO frequencies align with those seen in near-simultaneous X-ray and optical observations of MAXI J1820+070. If confirmed, it would likely arise from reprocessing

FUTURE WORK

UV wavelengths can suffer significant extinction

Urgency to expand our sample of BHXTs (but in general, LMXBs), observed in different states of outburst.

Future multi-wavelength, time-resolved campaigns essential

Back to basics: limitations in our understanding of X-ray irradiation and the implementation of the current irradiated disc models — introducing realistic conditions, i.e. different shapes and properties of the corona

Complementary slides

THE BHXT MAXI J1820+070

WIND SIGNATURES

Hot winds

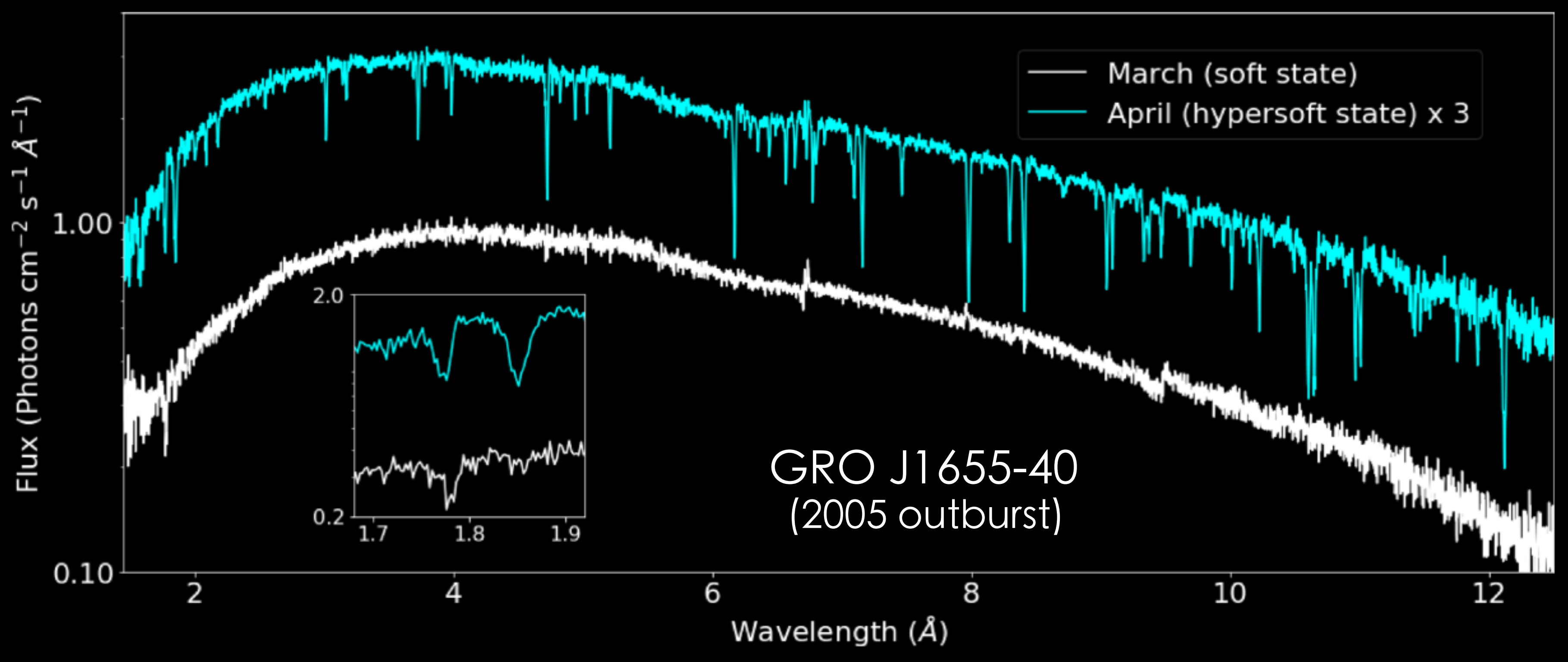
X-ray winds - apparent in the soft state

high inclination systems

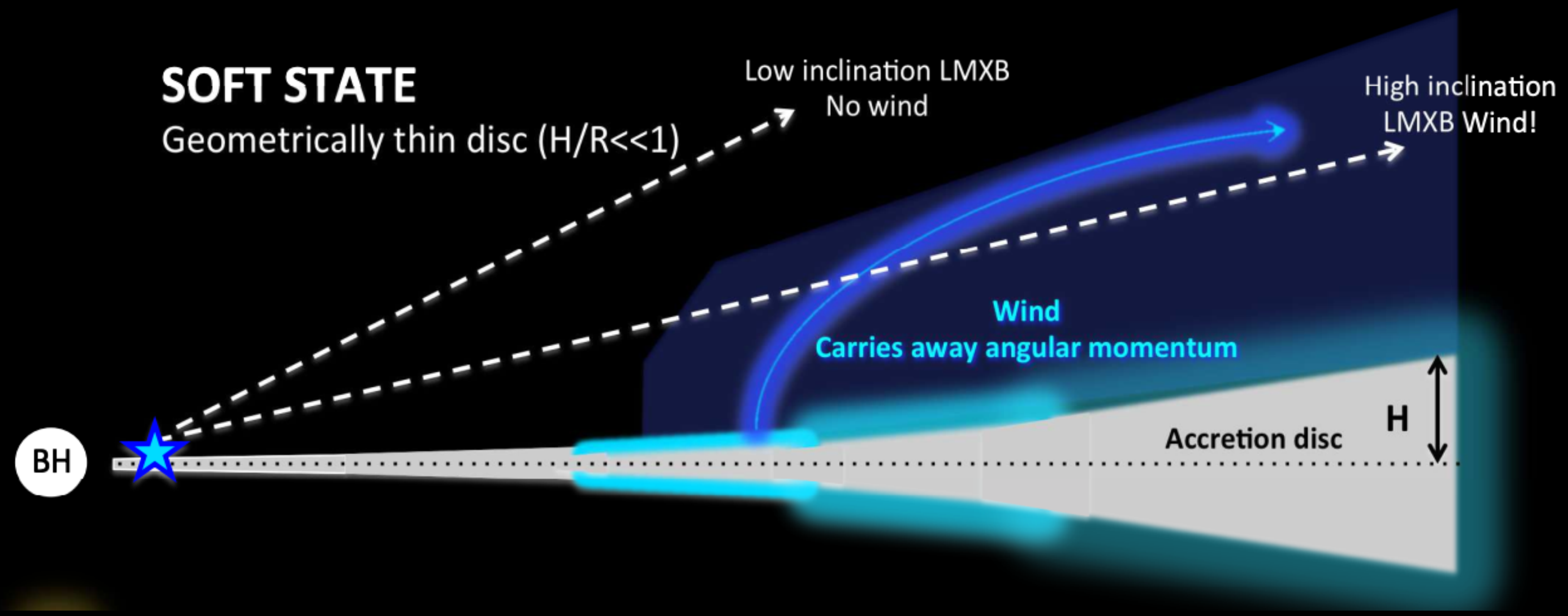
Cold winds

Optical/near-IR winds - seen in the hard state

different outflows or the same outflows at different phases?

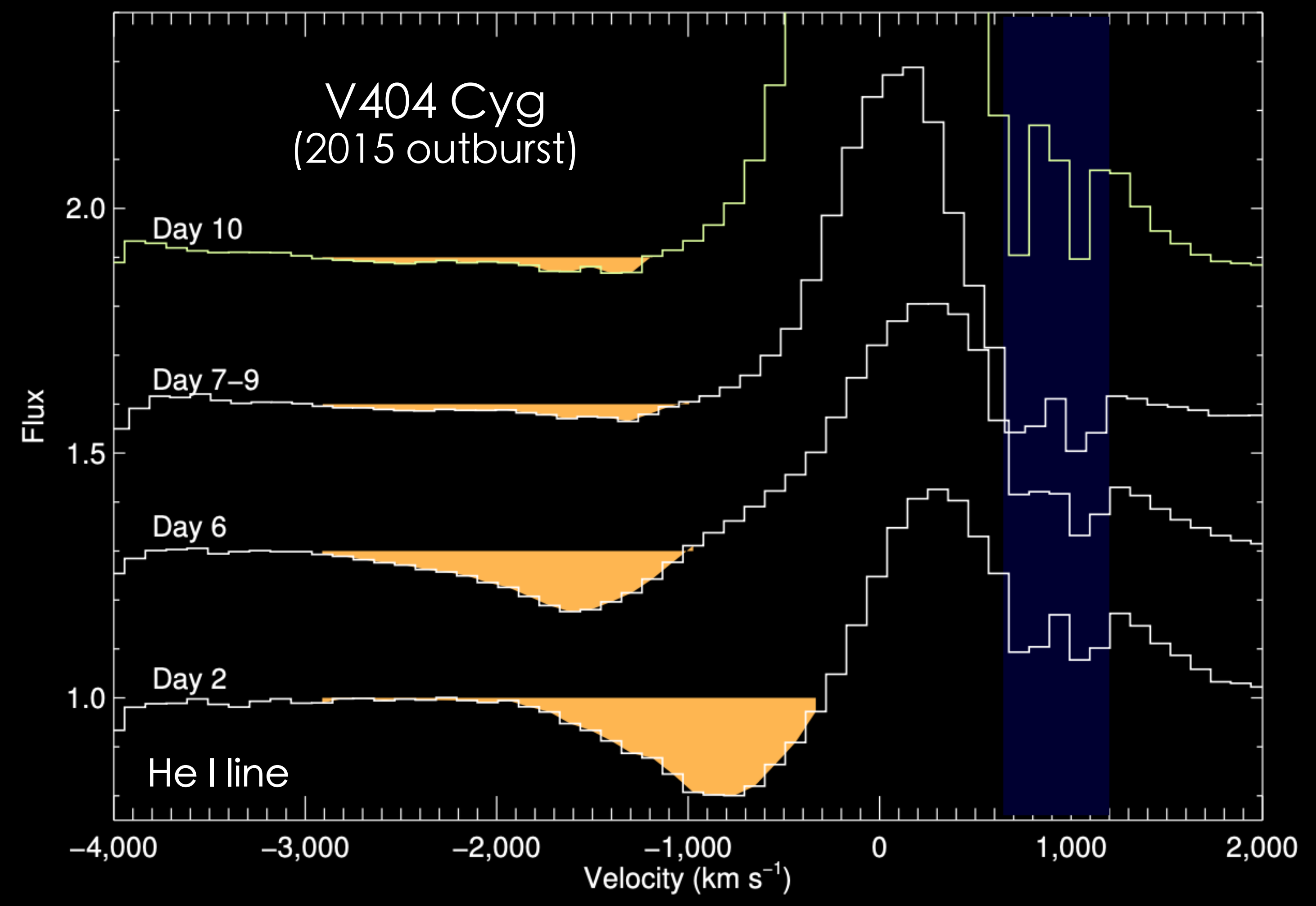


Credits: Higginbottom+18

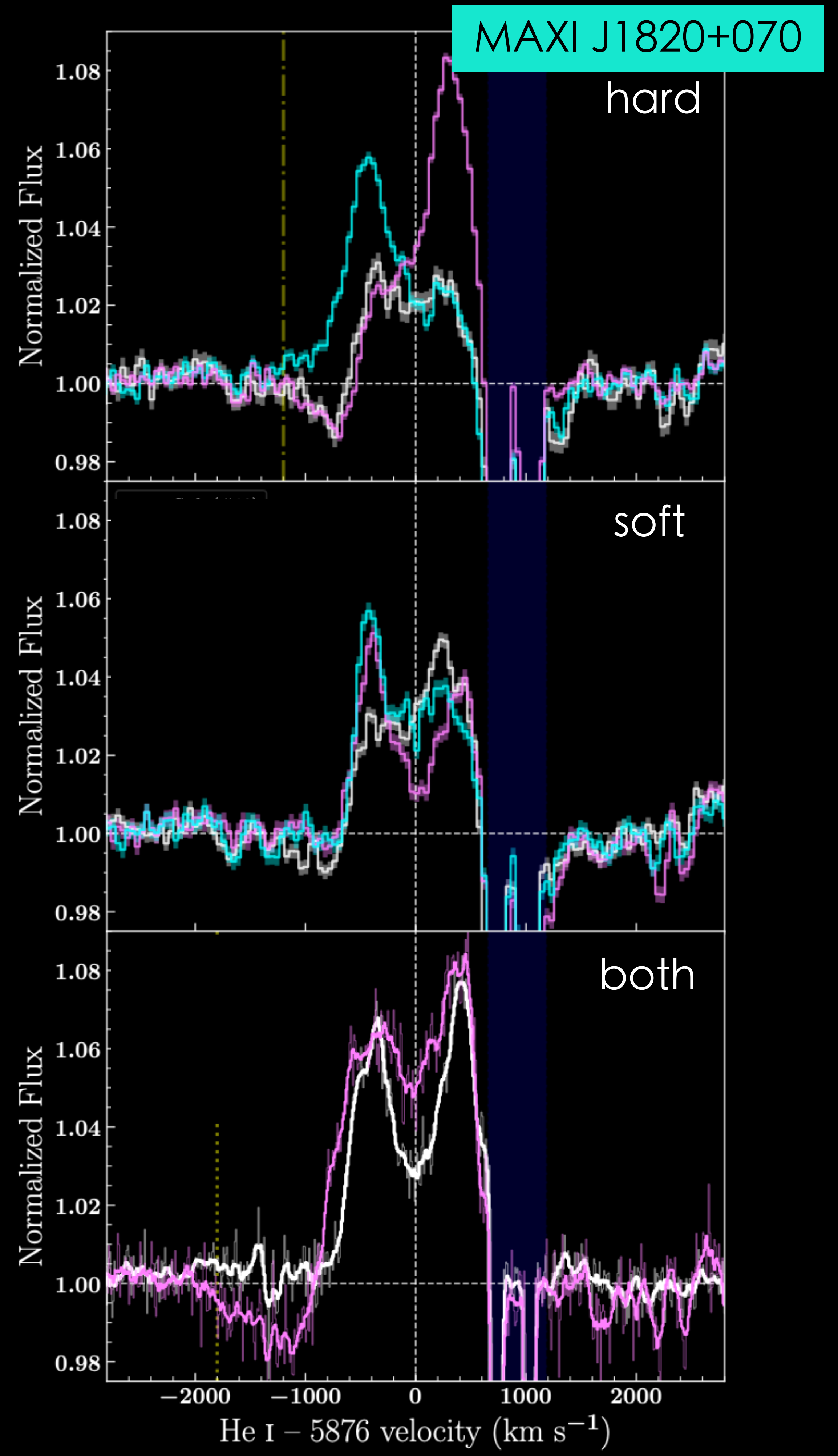


Credits: Ponti+12

First detection!!!



Credits: Muñoz-Darias+16



Credits: Muñoz-Darias+19