Signs of disc winds in the black hole X-ray binary MAXI J1820+070

Holger Stiele

Albert K. H. Kong

National Tsing Hua University, Hsinchu, Taiwan

Stiele & Kong 2020, ApJ 889, 142

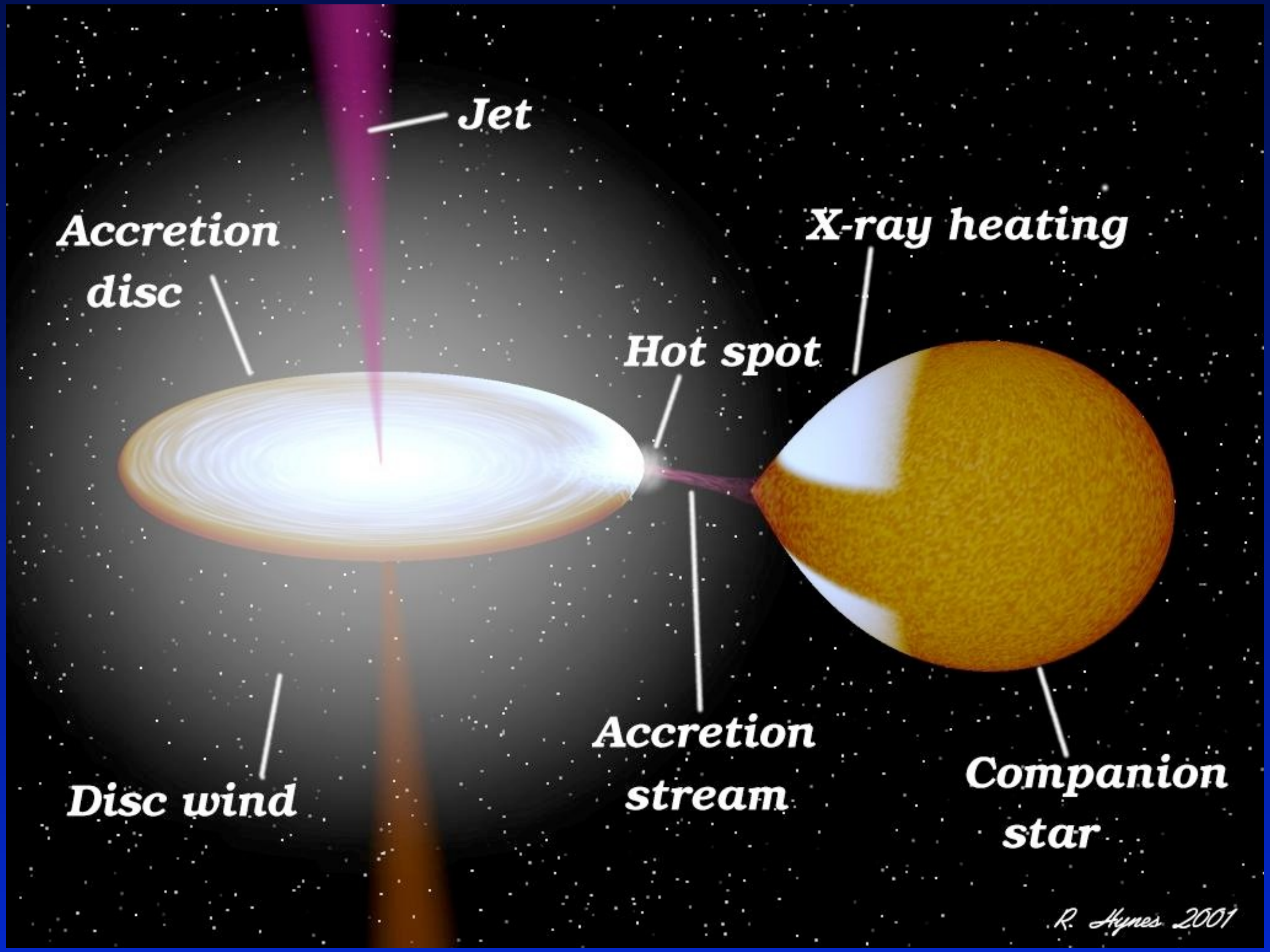
Multiscale Feedback on Galaxy Evolution, NCTS, NTHU, 20. October 2020

Take home points

- MAXI J1820+070, one of the brightest black hole transient ever observed, showed four outbursts in 2018 and 2019: a double outburst and two hard-state-only (reflares)
- Observations of type-C QPOs below 1 Hz during large parts of the outburst
- Source remains during large parts of its outburst in a configuration close to the one typically seen at the beginning of an outburst, when the accretion efficiency is still low
- Presence of disc wind in the hard state (detected in the optical and IR; Muñoz-Darias et al. 2019) can be an explanation why MAXI J1820+070 remained in a state of low accretion efficiency as it hampered the formation of a stable accretion regime

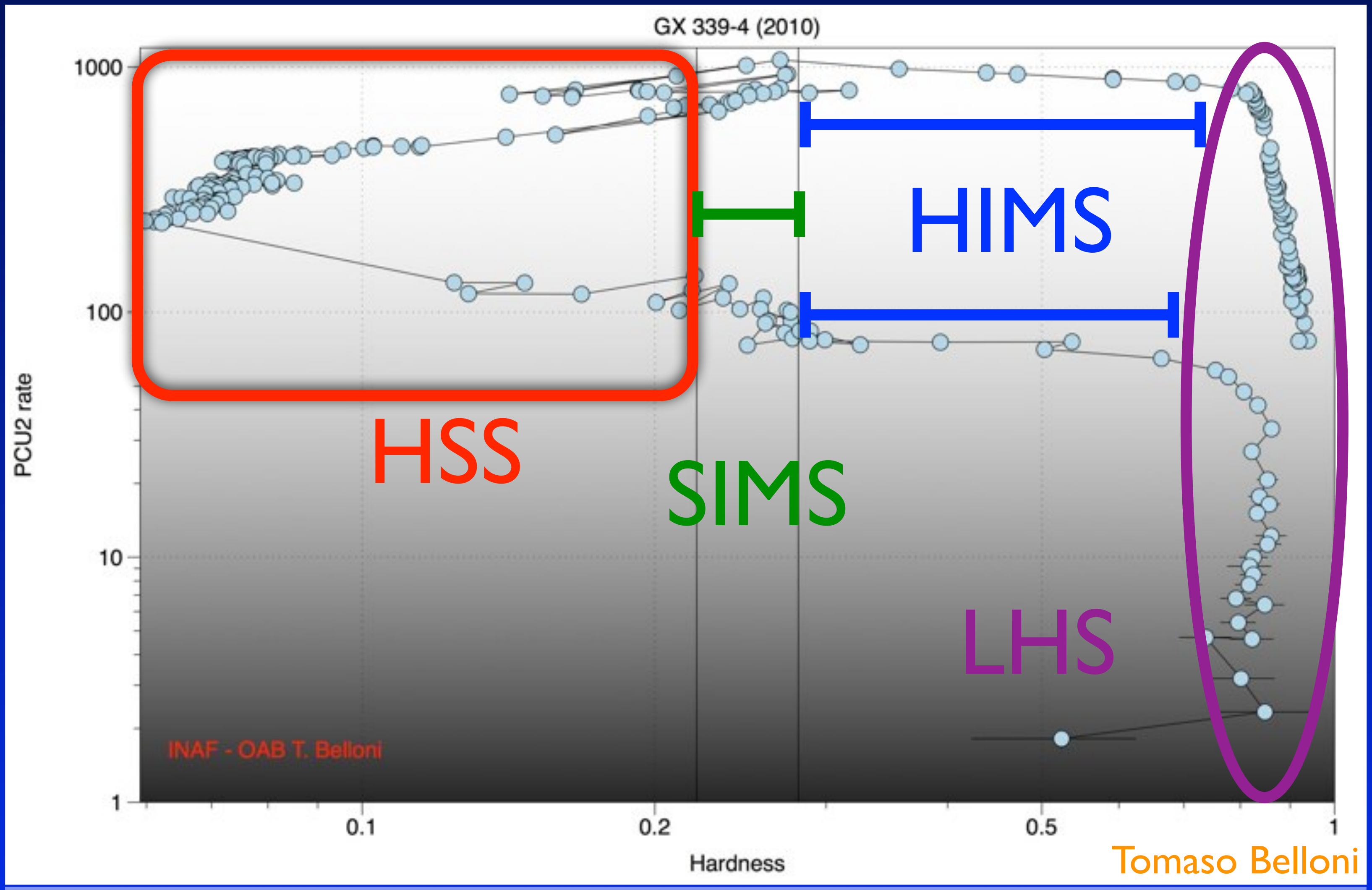
Low mass black hole X-ray binary

- Central object is a stellar mass (3-20 $M_\odot$) black hole
- Accretes matter from its low mass companion star ($M_s \lesssim 1\ M_\odot$, type A,F,G,K,M) through a disc (Roche-lobe overflow)
- X-ray emitting region close to event horizon R_S
- ~200 sources
  ~50 black holes



Outburst properties of BH XRBs

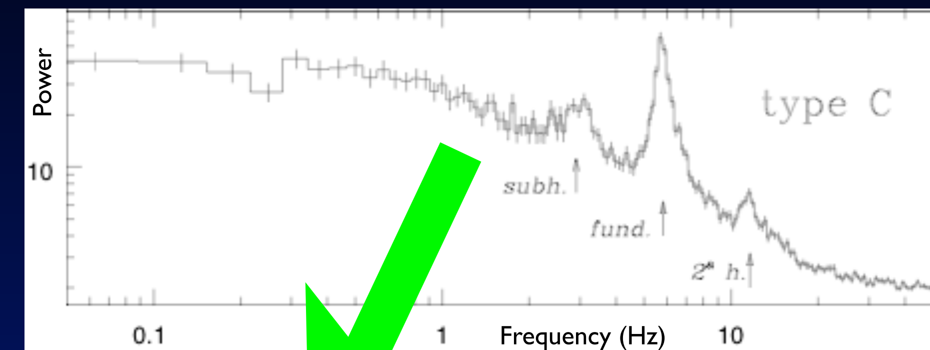
hardness - intensity diagram



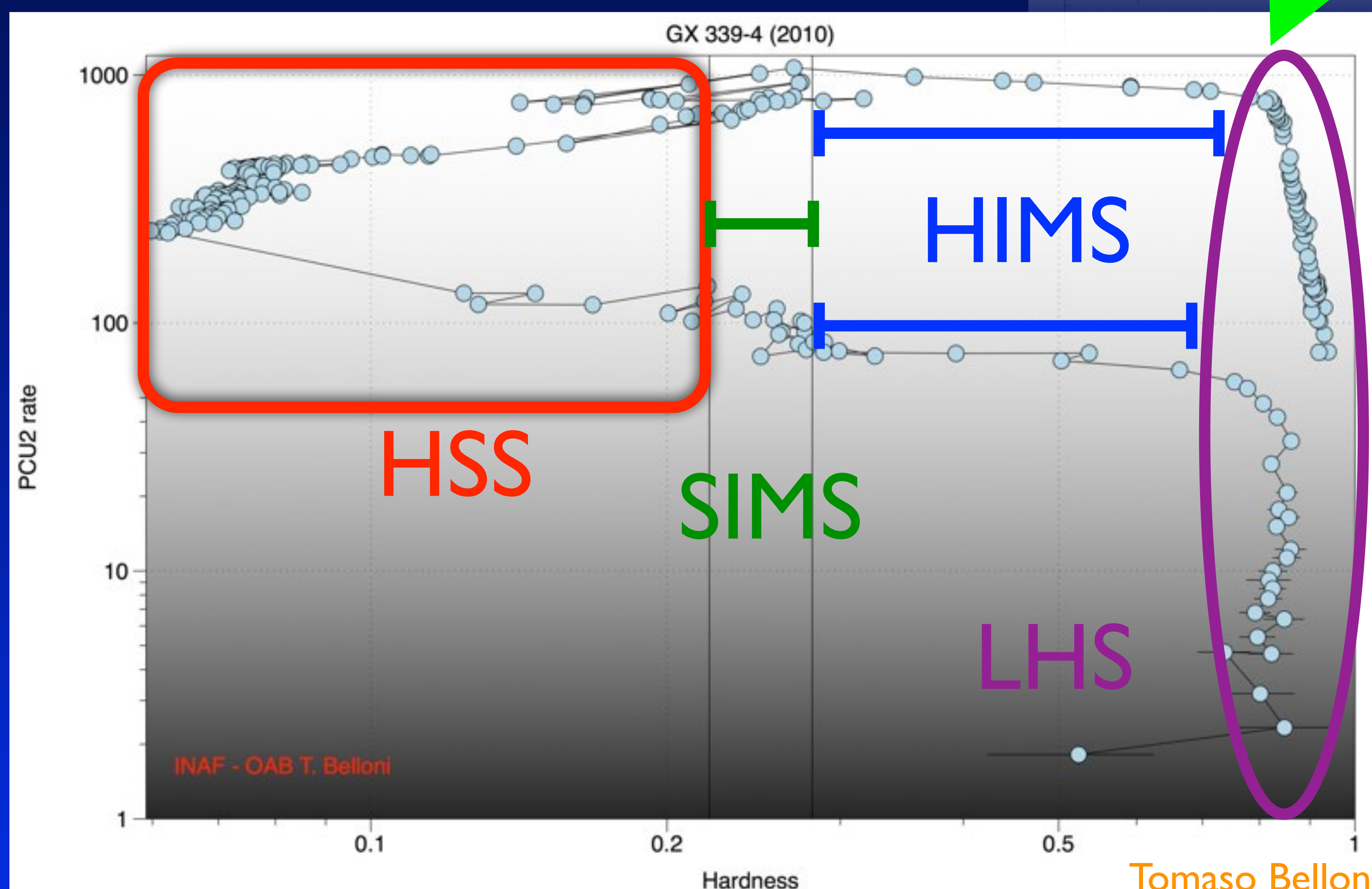
H. Stiele

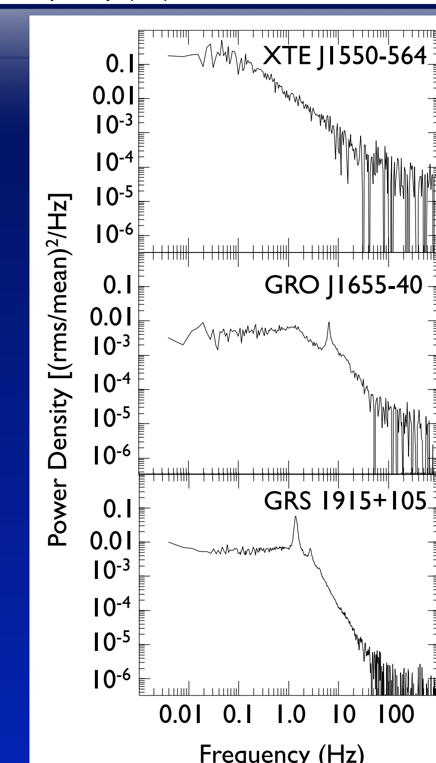
Outburst properties of BH XRBs

Casella et al. 2004, A&A, 426, 587



hardness - intensity diagram



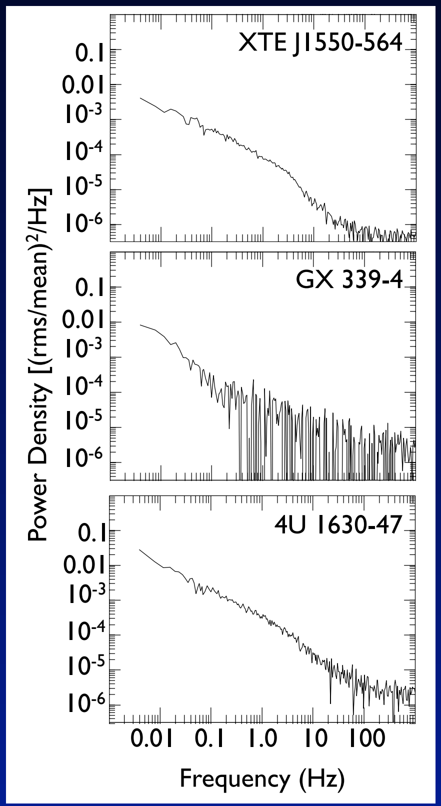


McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

H. Stiele

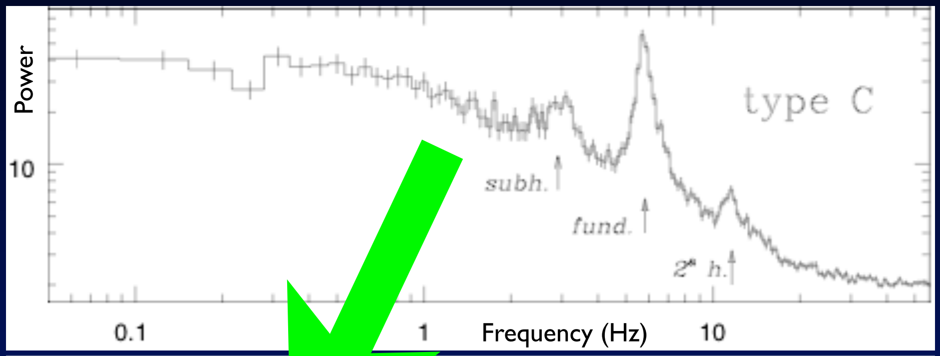
Outburst properties of BH XRBs



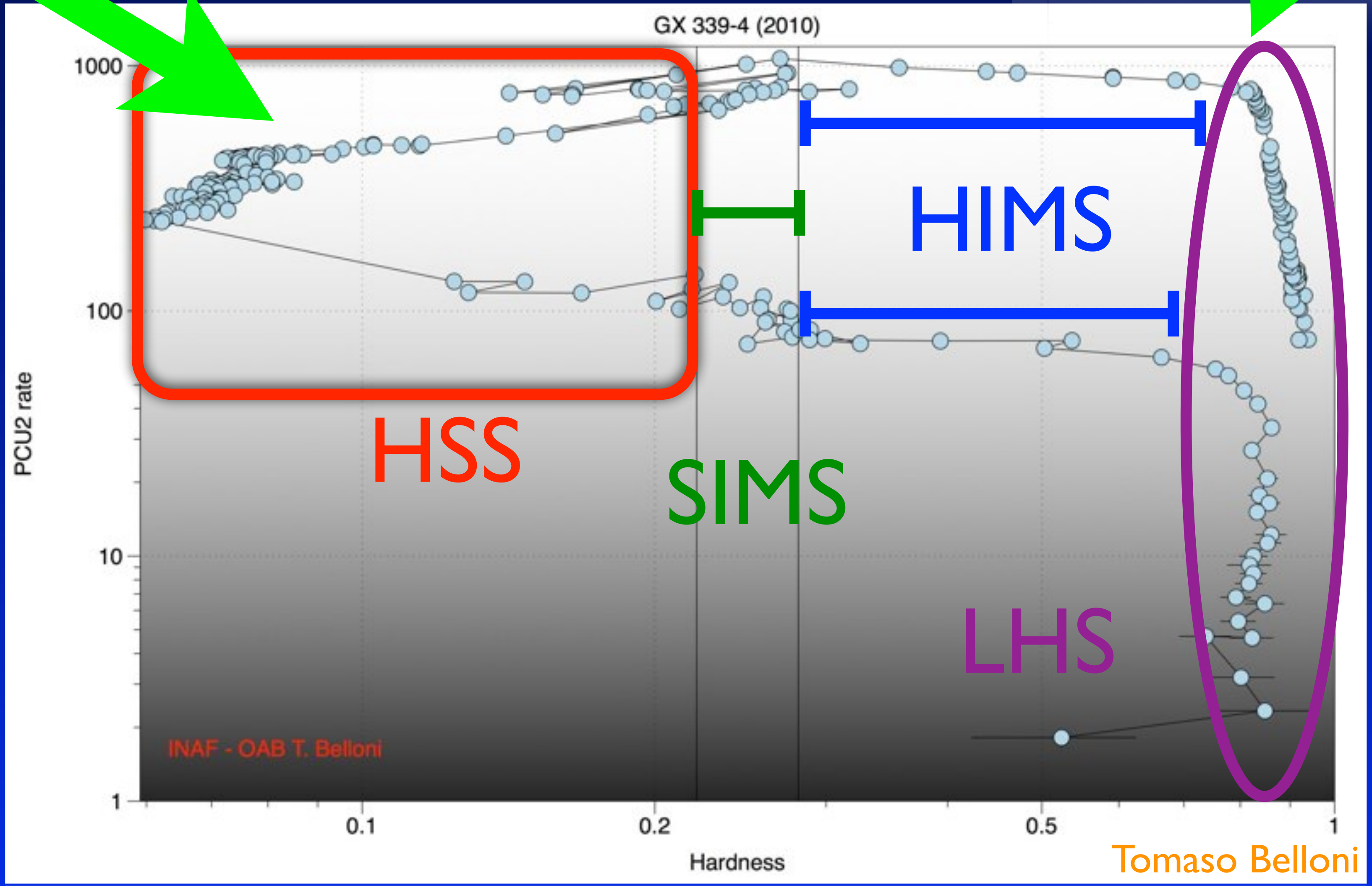
McClintock & Remillard 2006 Black Hole binaries

power law noise

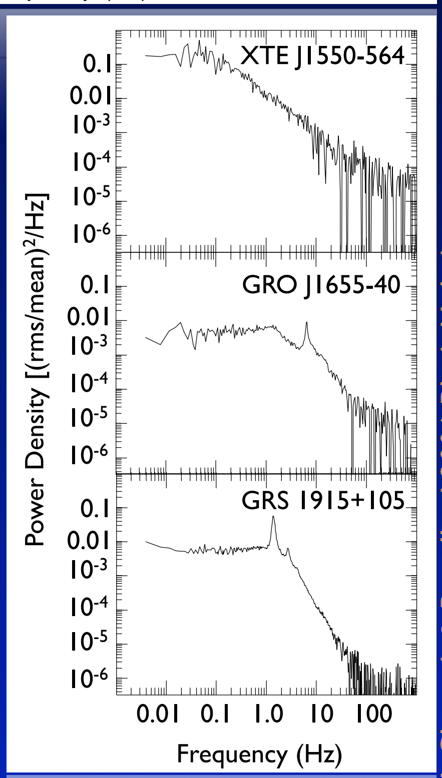
Casella et al. 2004, A&A, 426, 587



hardness - intensity diagram



Tomaso Belloni

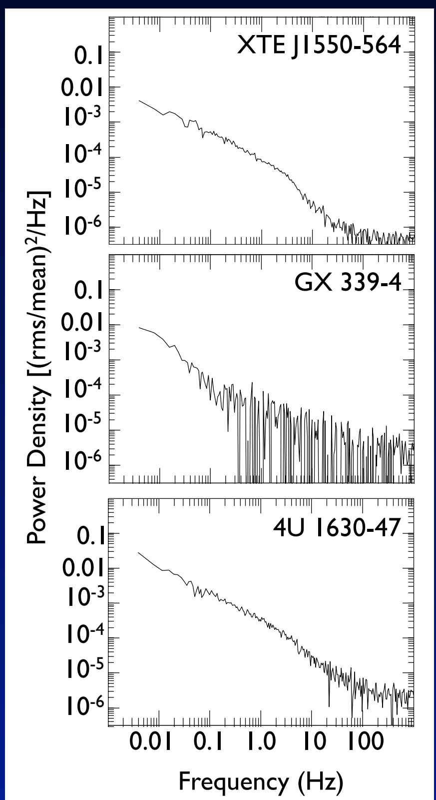


McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

H. Stiele

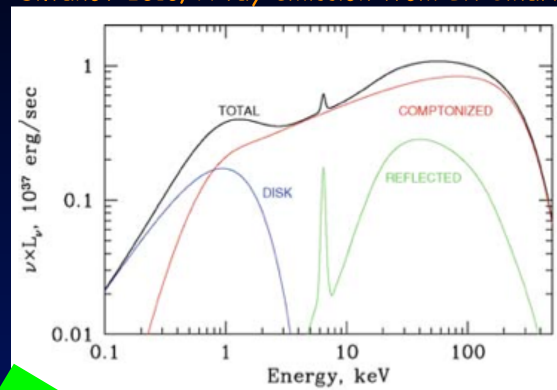
Outburst properties of BH XRBs



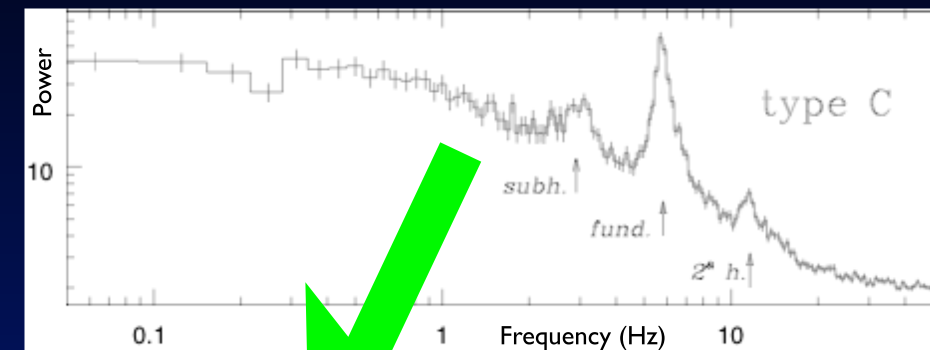
McClintock & Remillard 2006 Black Hole binaries

power law noise

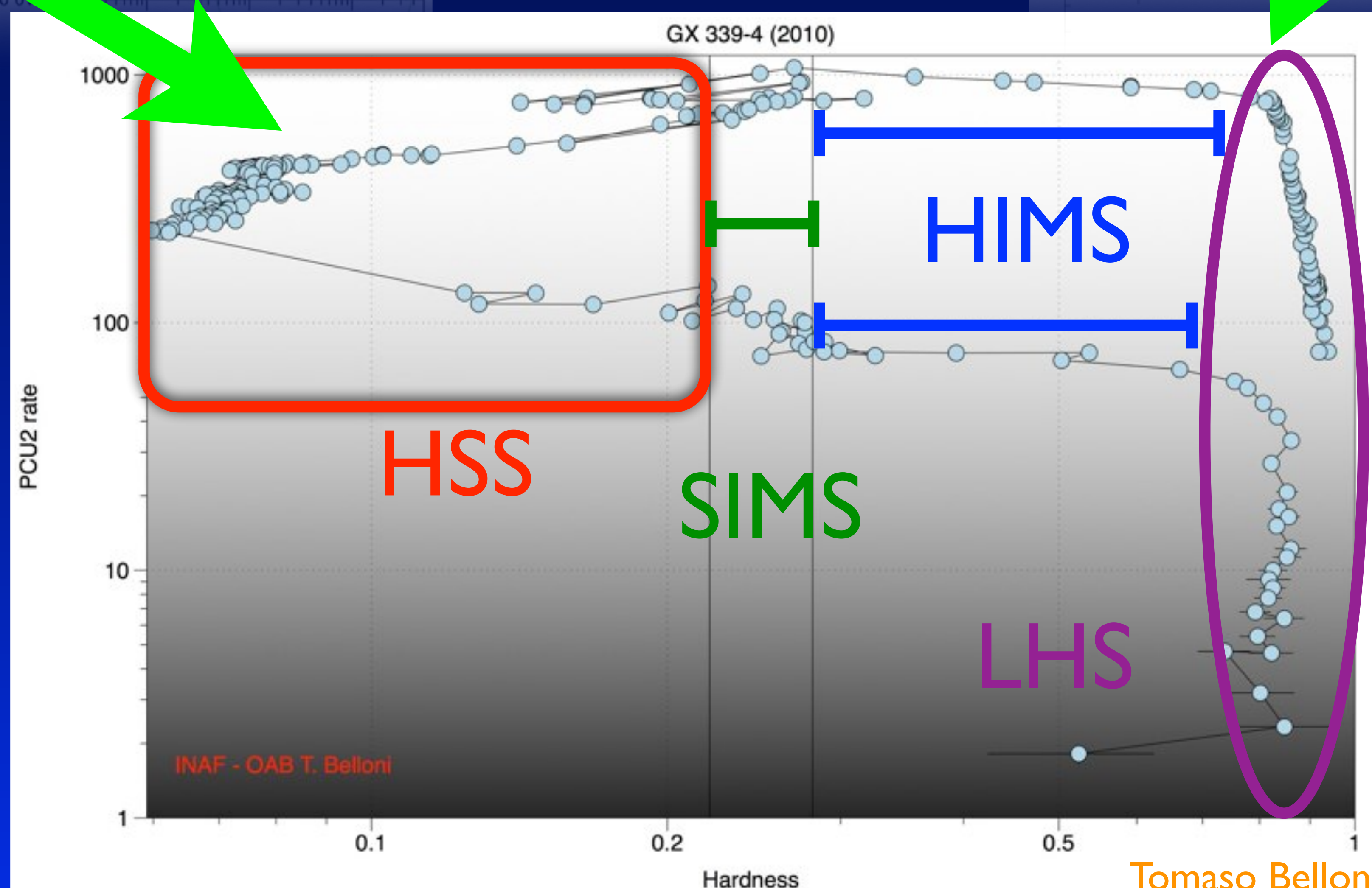
Gilfanov 2010, X-ray emission from BH binaries



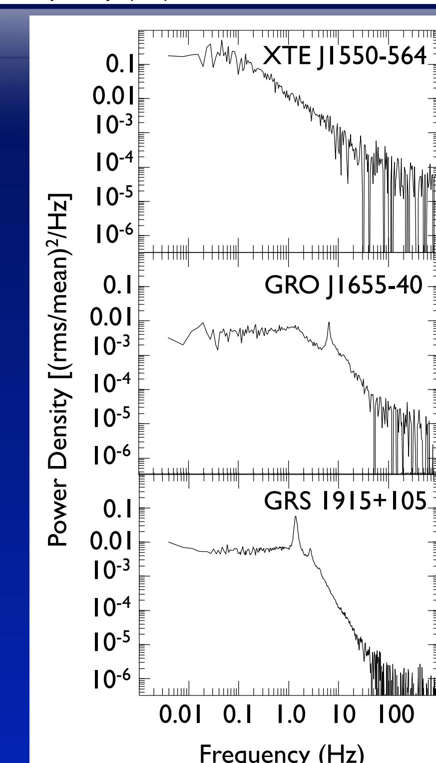
Casella et al. 2004, A&A, 426, 587



hardness - intensity diagram



Tomaso Belloni



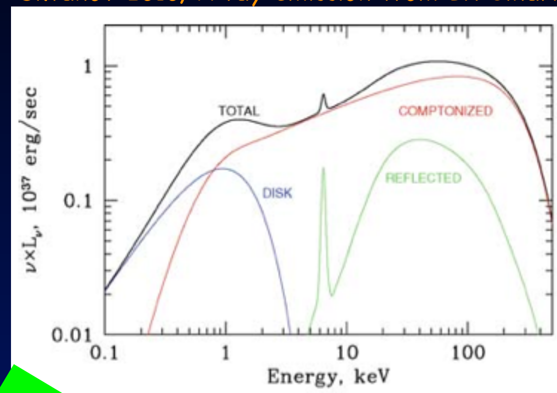
McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

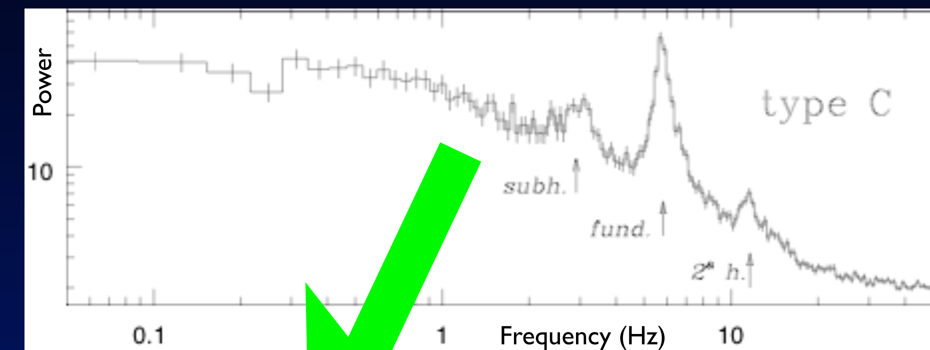
H. Stiele

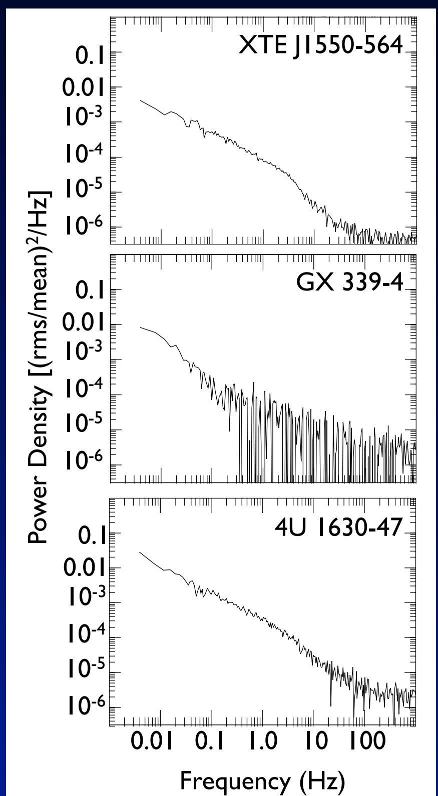
Outburst properties of BH XRBs

Gilfanov 2010, X-ray emission from BH binaries



Casella et al. 2004, A&A, 426, 587

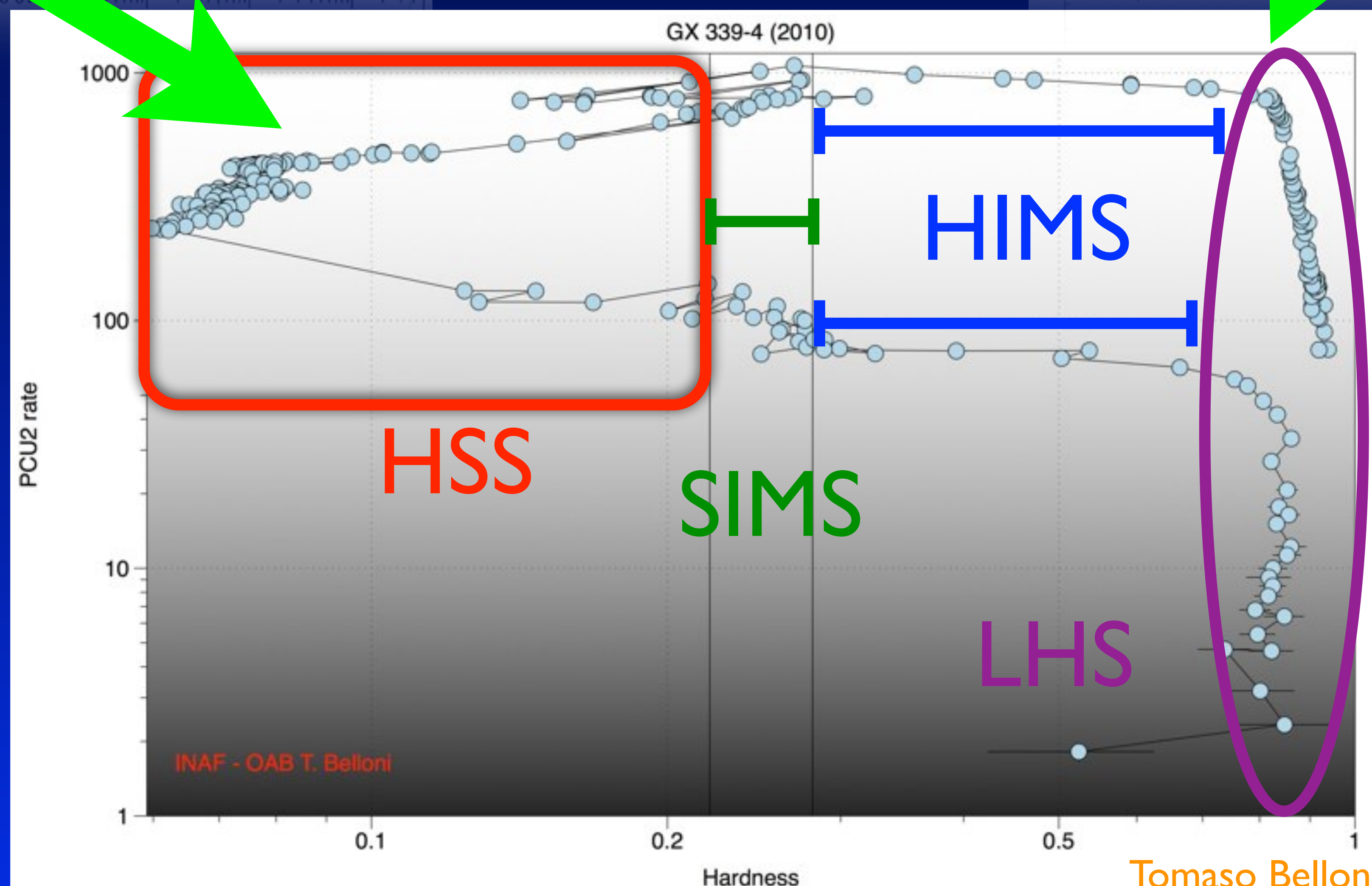




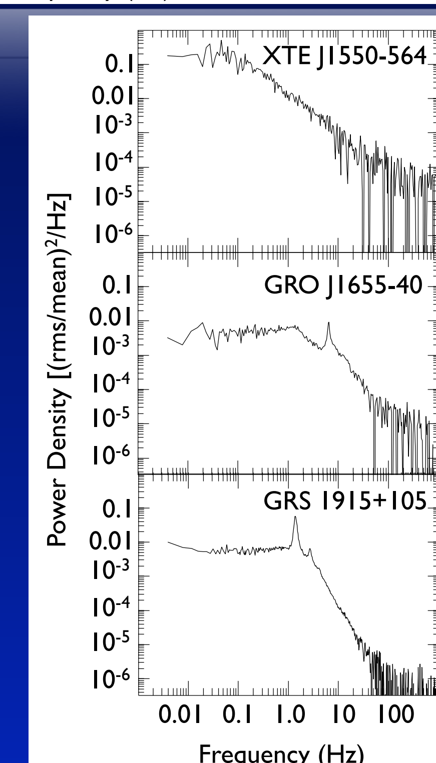
McClintock & Remillard 2006 Black Hole binaries

power law noise

hardness - intensity diagram



Tomaso Belloni



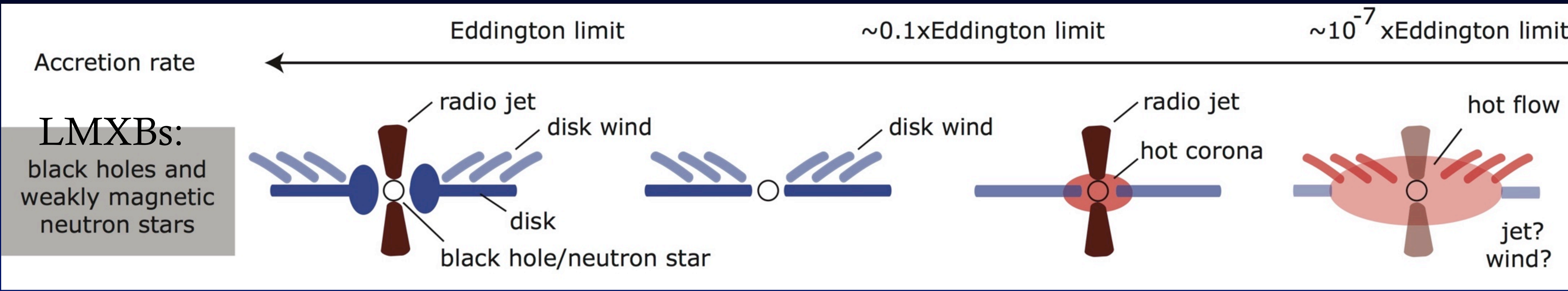
McClintock & Remillard 2006 Black Hole binaries

band limited noise and QPO

about 40% of sources remain in hard state Tetarenko et al. 2016, ApJS, 222, 15

H. Stiele

Outflows



highly ionised (hot) wind

Near/super Eddington → Relatively rare

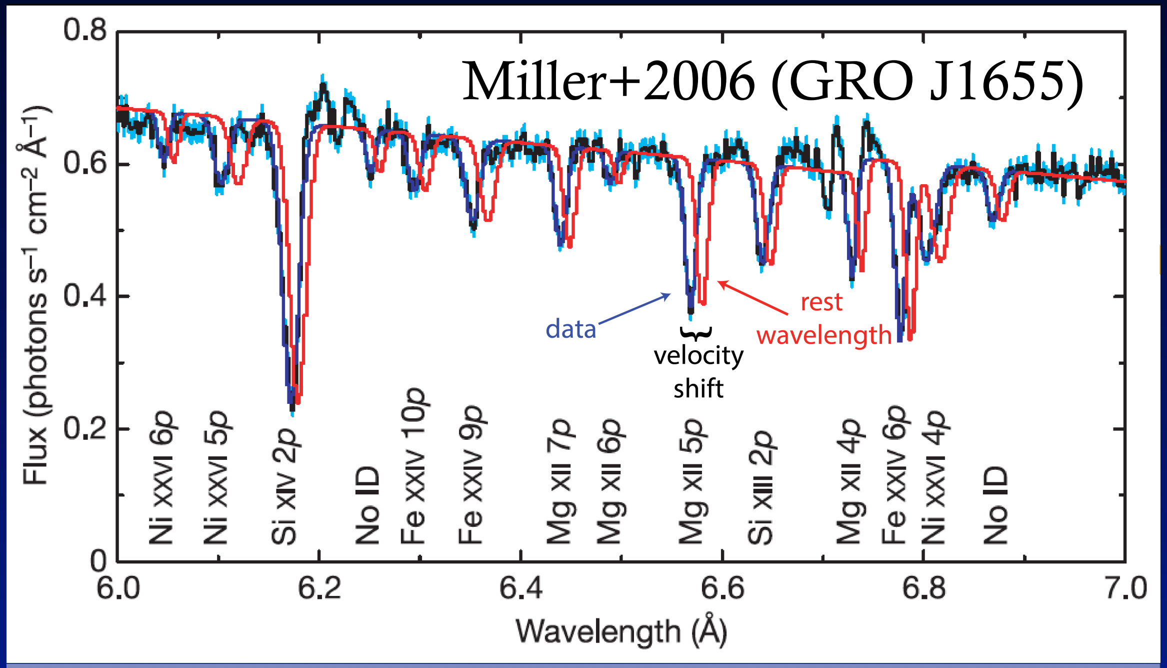
Soft state / **Hard state** → Most easily studied

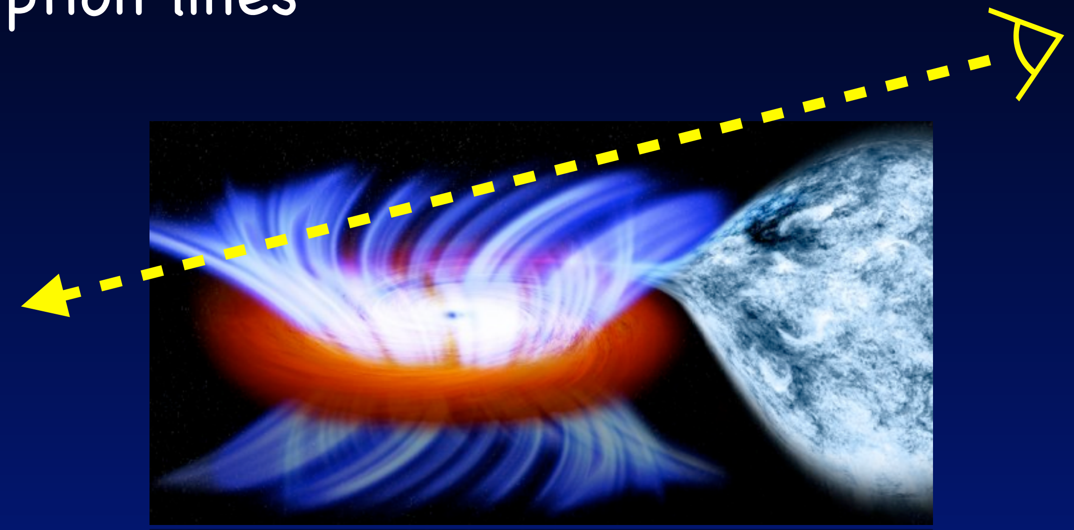
Quiescence → Common but difficult to study

- Wide range of accretion rates possible
- Accretion geometry & outflows change with accretion rate
- Details of wind-launching mechanism, photoionisation instabilities and over-ionisation of the ejecta (e.g. Chakravorty et al. 2013; Bianchi et al. 2017; Gatuzz et al. 2019)

Observing (hot) disc winds

- Detected through blue-shifted absorption lines





Observables

- line species
- line shift
- line width
- line depth

Physical information

- velocity of the plasma
- ionisation state
- (column) density
- launch radius

Díaz Trigo & Boirin 2016; Ponti et al. 2016

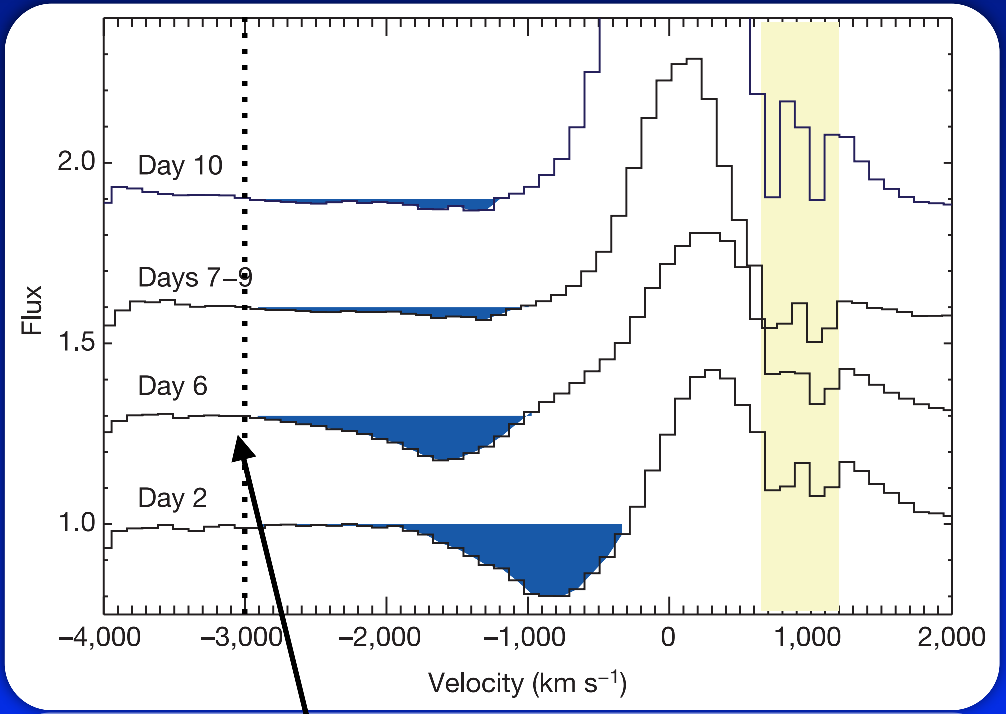
H. Stiele

Low ionisation disc winds

- Low ionisation (cold) disc winds observed in optical/infrared observations of luminous and violent outbursts of V404 Cyg (Muñoz-Darias et al. 2016; Muñoz-Darias et al. 2017; Rahoui et al. 2017; Mata Sánchez et al. 2018; see also Casares et al. 1991) and V4641 Sgr (Chaty et al. 2003; Lindstrøm et al. 2005; Muñoz-Darias et al. 2018).

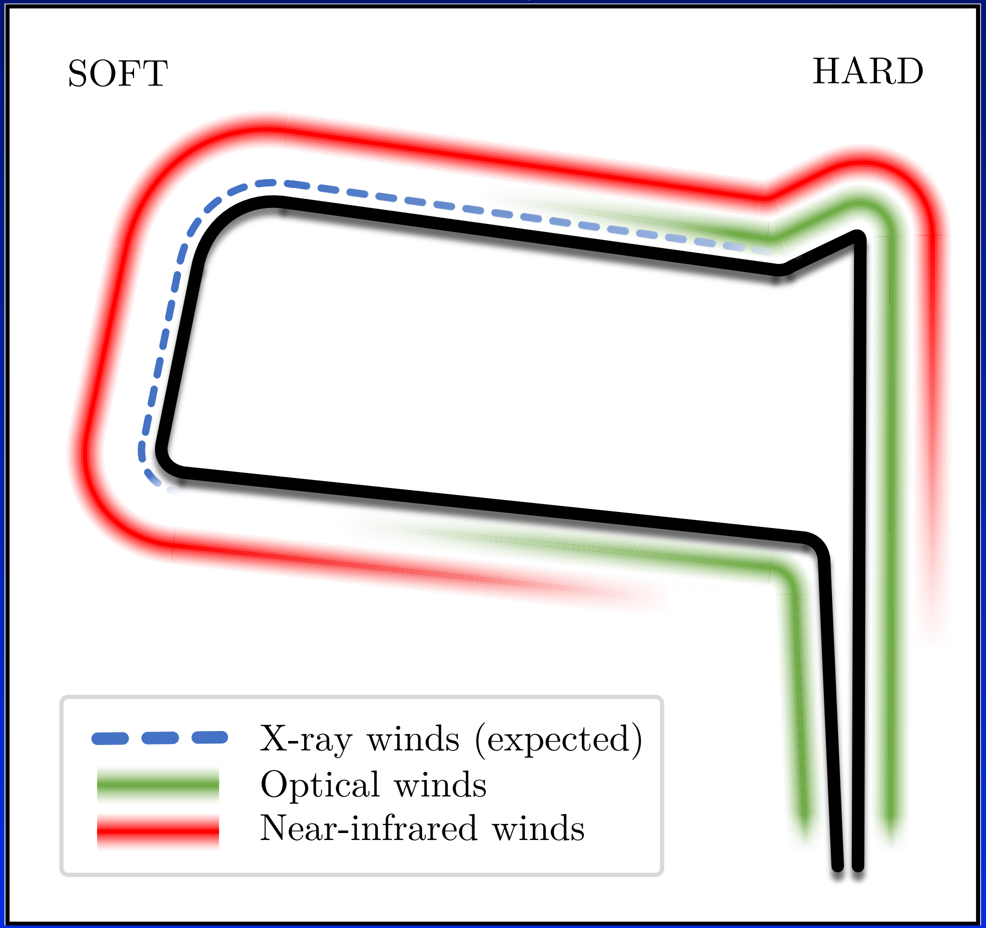
- P-Cygni profiles

Muñoz-Darias et al. 2016



Wind terminal velocity

Sánchez-Sierras & Muñoz-Darias et al. 2020



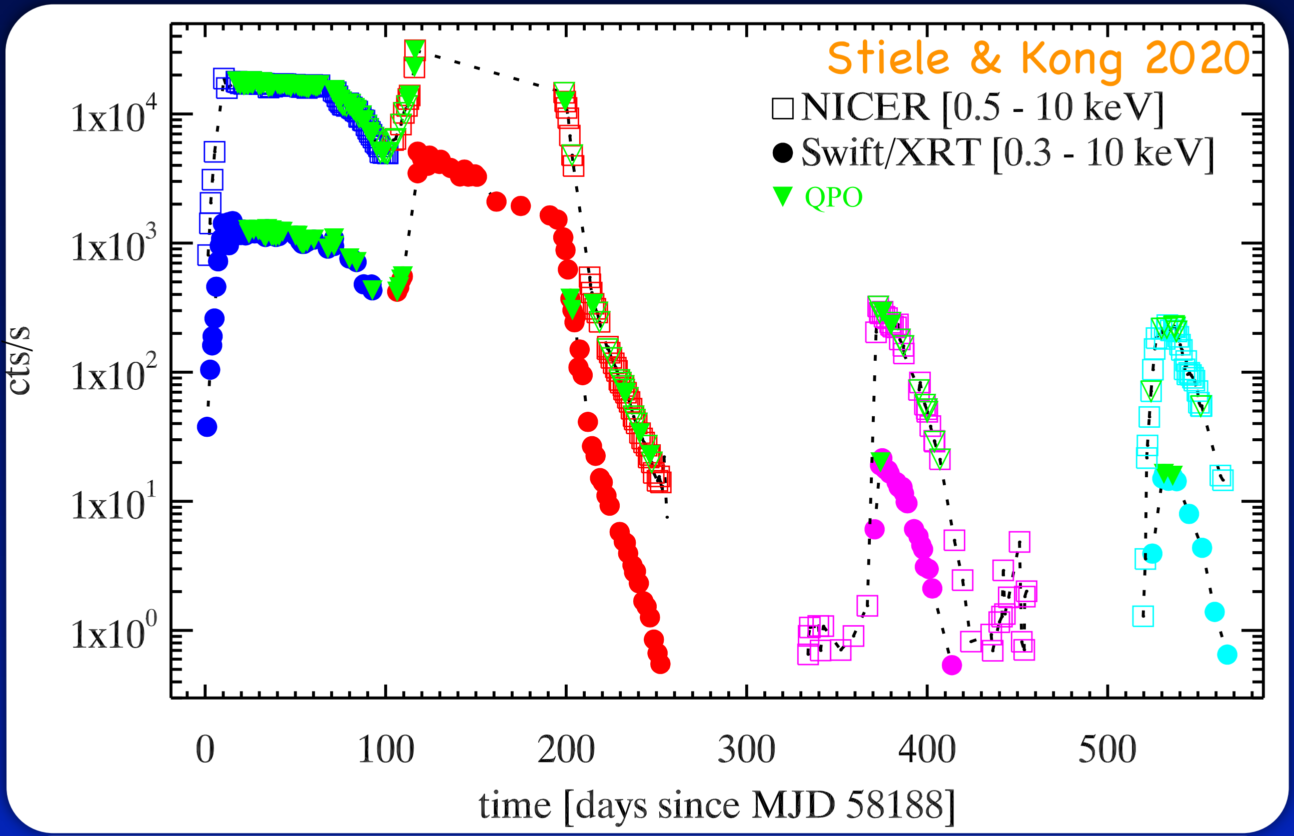
H. Stiele

MAXI J1820+070

- MAXI J1820+070 detected in MAXI/GSC and Swift/BAT monitoring observations on 2018 March 11th (Kawamuro al. 2018, ATel #11399; Kennea et al. 2018, ATel #11403)
- We analyse all Swift/XRT timing mode data between 2018 March 11th and 2019 Sep. 28th
- NICER observed between 2018 March 12th and 2019 Oct. 25th

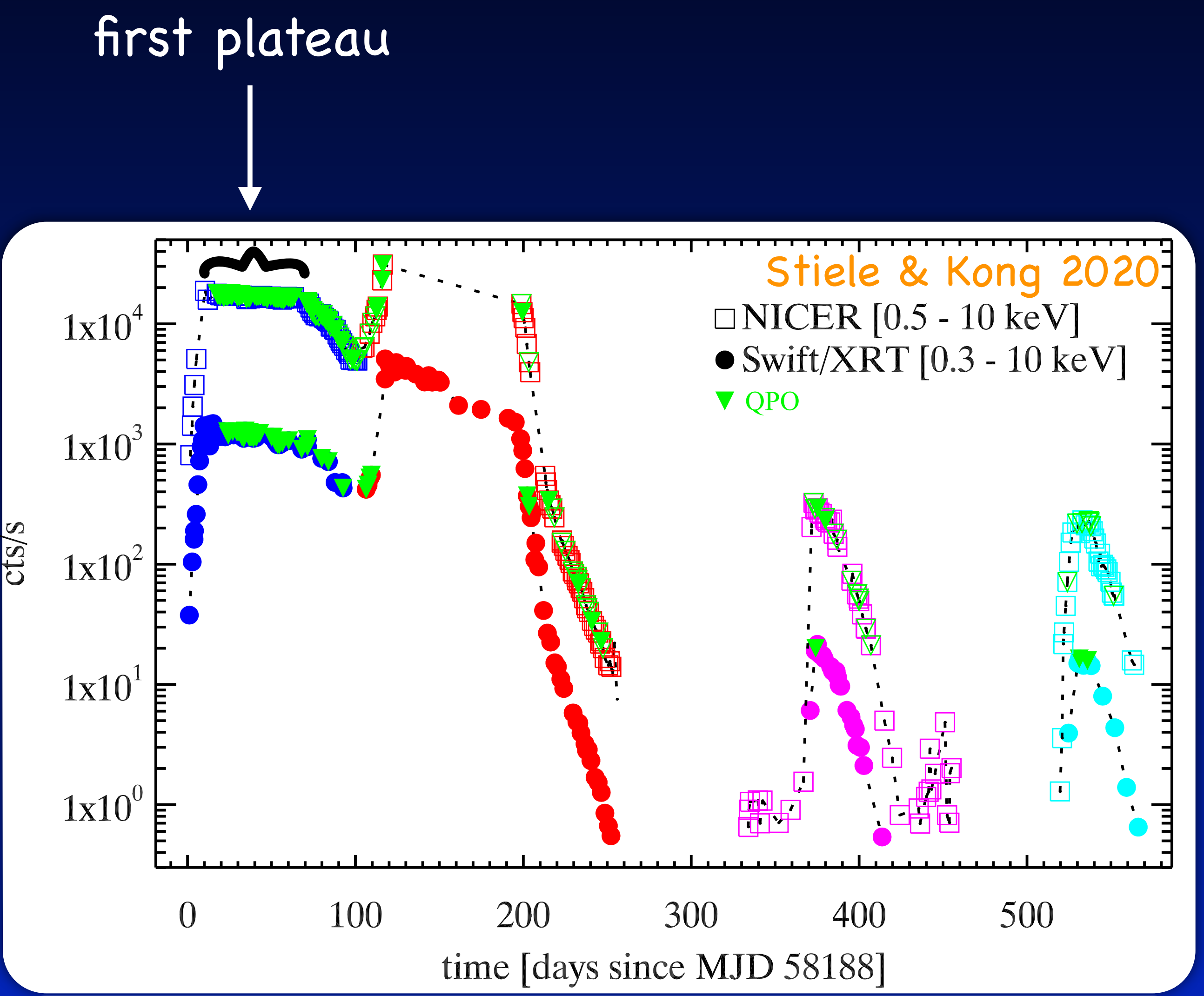
Light curves

- Swift/XRT and NICER light curves show that MAXI J1820+070 underwent four outbursts. The source remained in the hard state during its first outburst, while the rise of the second outburst corresponds with the transition to the soft state.
- This double outburst (similar to the 2004 one of GX 339−4; Joinet et al. 2007, ApJ, 657, 400; Plant et al. 2014, MNRAS, 442, 1767) is followed by two fainter, hard-state only outbursts (reflares).
- Outburst peaks at ~4 Crab (~9.6×10^{-8} erg cm^{-2} s^{-1}); among the brightest black hole transients ever observed



Light curves

- Swift/XRT and NICER light curves show that MAXI J1820+070 underwent four outbursts. The source remained in the hard state during its first outburst, while the rise of the second outburst corresponds with the transition to the soft state.
- This double outburst (similar to the 2004 one of GX 339−4; Joinet et al. 2007, ApJ, 657, 400; Plant et al. 2014, MNRAS, 442, 1767) is followed by two fainter, hard-state only outbursts (reflares).
- Outburst peaks at ~4 Crab (~9.6×10^{-8} erg cm^{-2} s^{-1}); among the brightest black hole transients ever observed

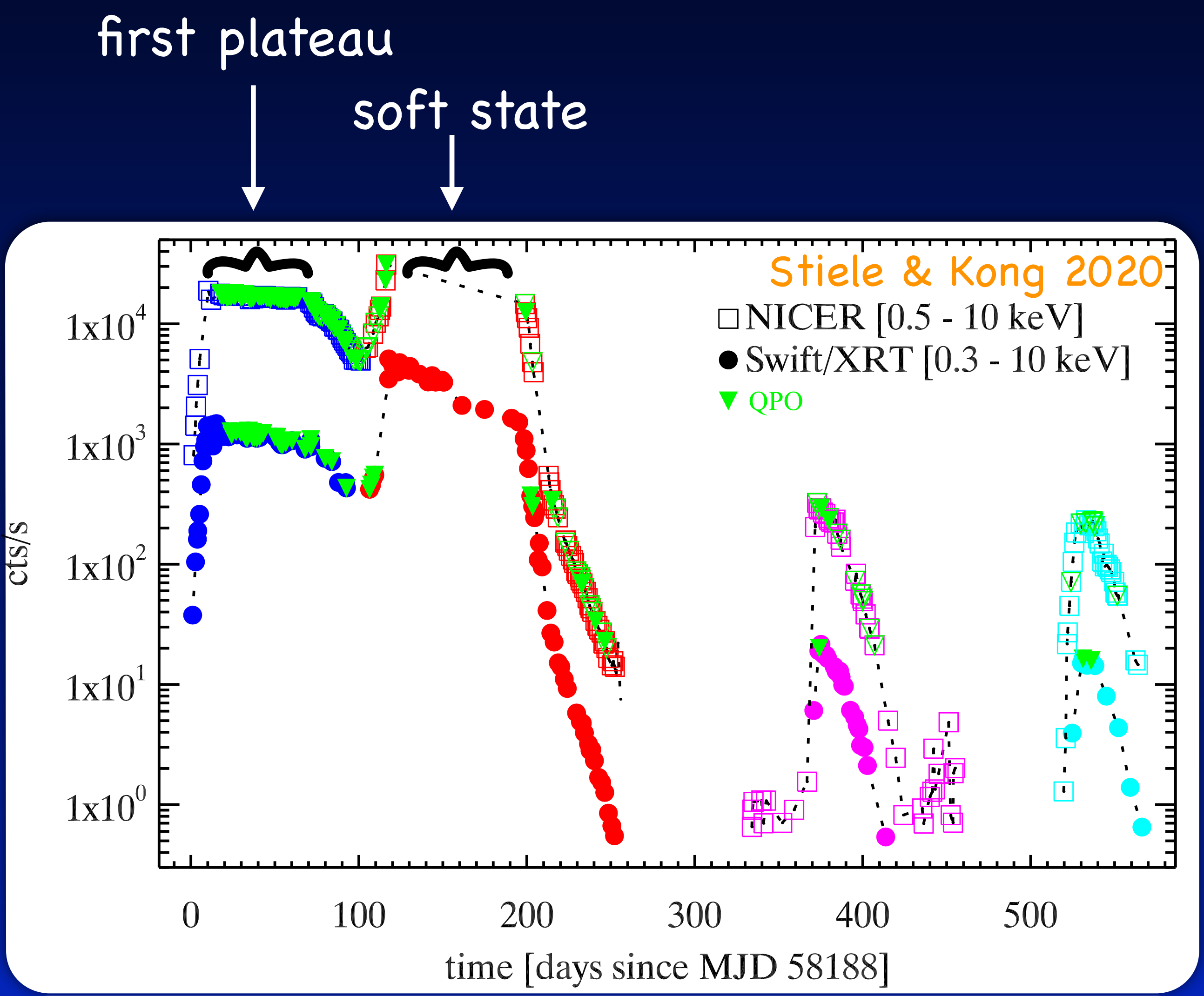


Light curves

- Swift/XRT and NICER light curves show that MAXI J1820+070 underwent four outbursts. The source remained in the hard state during its first outburst, while the rise of the second outburst corresponds with the transition to the soft state.

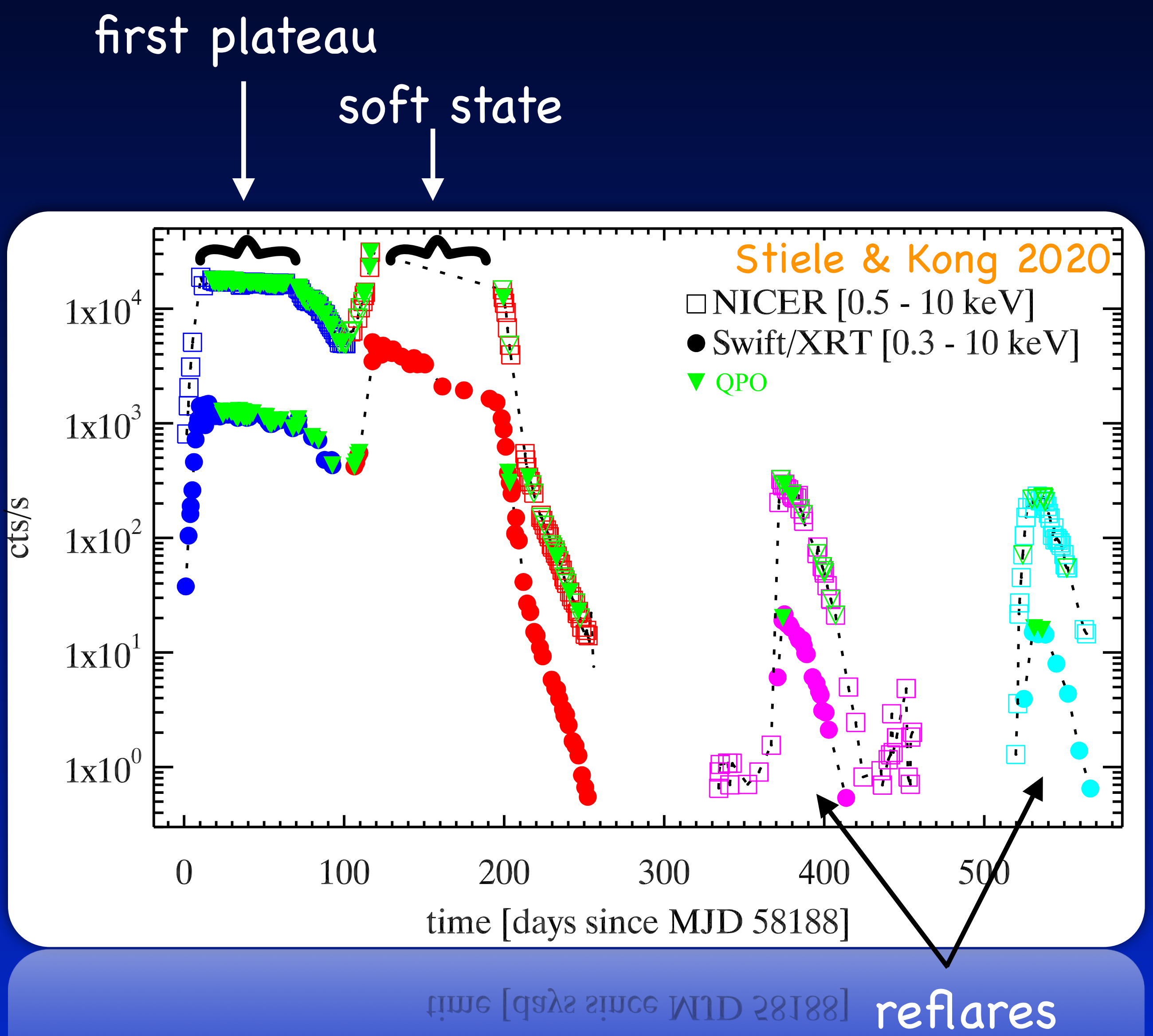
- This double outburst (similar to the 2004 one of GX 339−4; Joinet et al. 2007, ApJ, 657, 400; Plant et al. 2014, MNRAS, 442, 1767) is followed by two fainter, hard-state only outbursts (reflares).

- Outburst peaks at ~4 Crab (~9.6×10^{-8} erg cm^{-2} s^{-1}); among the brightest black hole transients ever observed



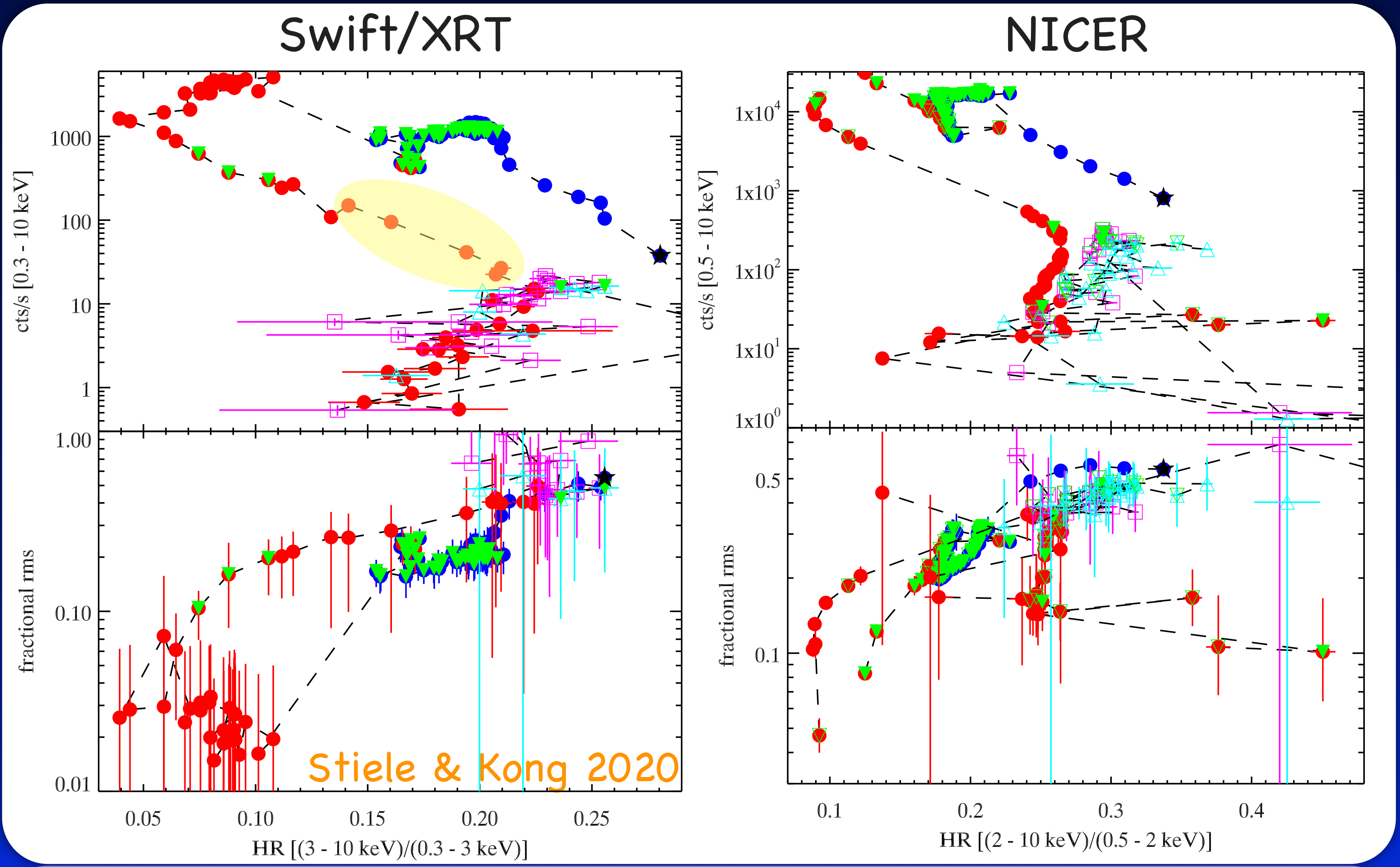
Light curves

- Swift/XRT and NICER light curves show that MAXI J1820+070 underwent four outbursts. The source remained in the hard state during its first outburst, while the rise of the second outburst corresponds with the transition to the soft state.
- This double outburst (similar to the 2004 one of GX 339−4; Joinet et al. 2007, ApJ, 657, 400; Plant et al. 2014, MNRAS, 442, 1767) is followed by two fainter, hard-state only outbursts (reflares).
- Outburst peaks at ~4 Crab (~9.6×10^{-8} erg cm^{-2} s^{-1}); among the brightest black hole transients ever observed



Hardness-Intensity and hardness-rms diagrams

- HR decreases during first plateau
- Second plateau corresponds to soft state
- Hardening during steep decay; then softening again
- 3rd outburst: HR > decay; but < start of 1st outburst
- 4th outburst HR little bit harder than 3rd outburst

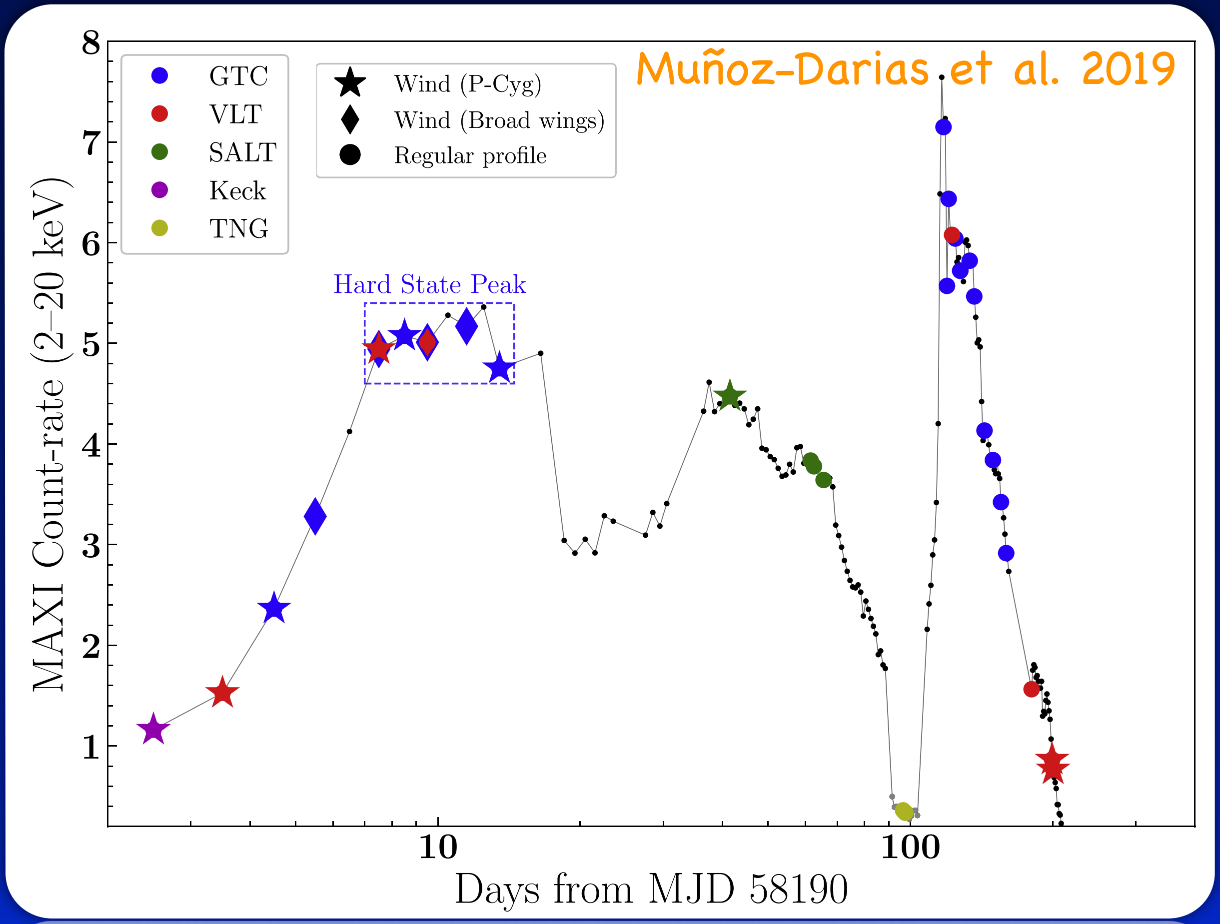


H. Stiele

Optical and IR data

- GTC: Gran Telescopio Canarias
- VLT: Very Large Telescope
- SALT: Southern African Large Telescope
- TNG: Telescopio Nazionale Galileo

- Optical spectra rich in emission lines, including Balmer series, He I and He II transitions.
- NIR spectra: Hα, He I and Paschen lines
- Strong line asymmetries, shallow P-Cyg profiles, and broad, non-Gaussian emission line wings are observed

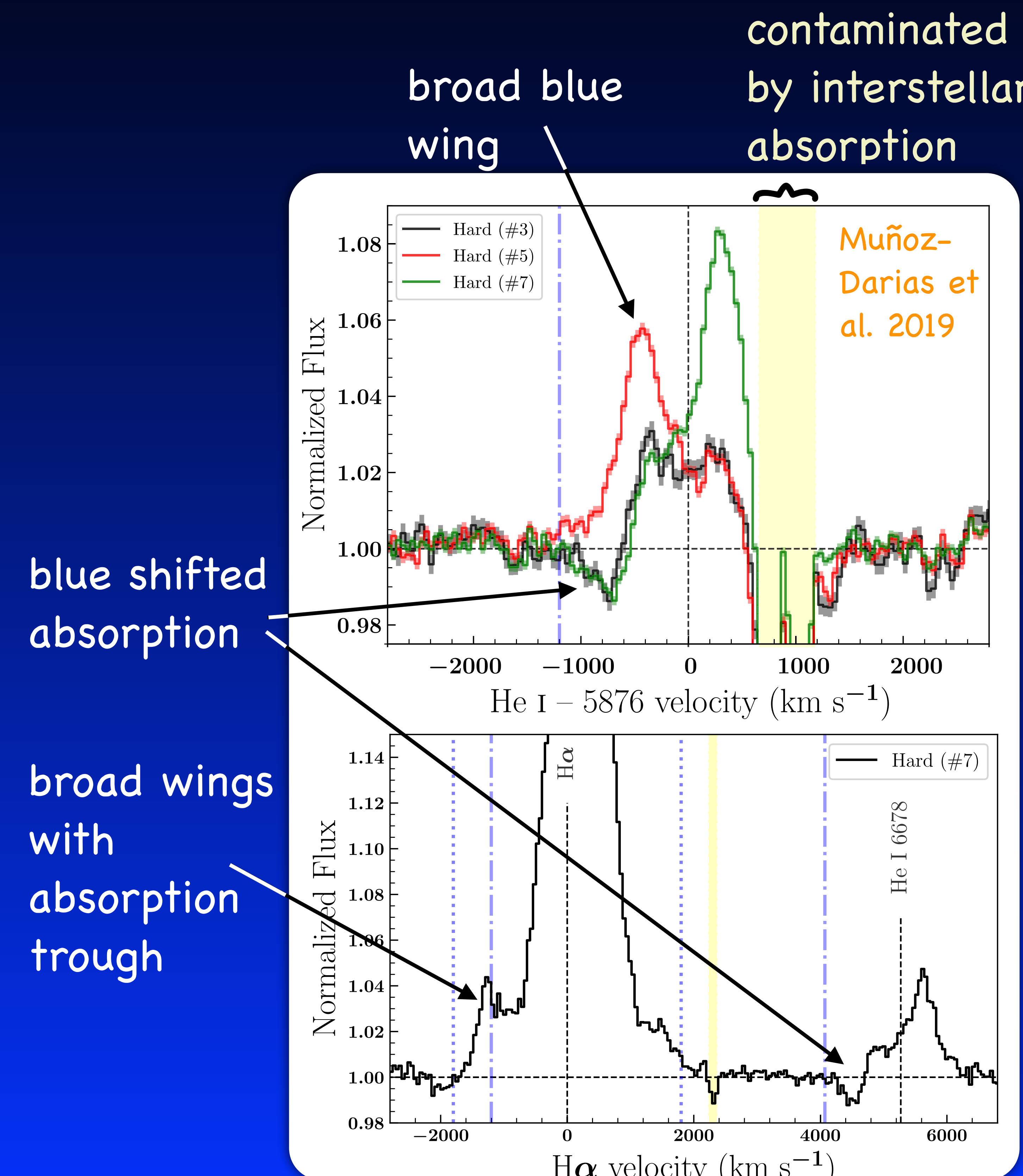


P-Cygni profiles

- P-Cyg profile ➜ evidence for outflow
- In X-ray binaries strong emission lines are produced in the accretion discs

➡ Only blue-shifted absorption unaltered and unambiguous wind signature

- Wind terminal velocity $V_t \sim 1200$ km s^{-1}



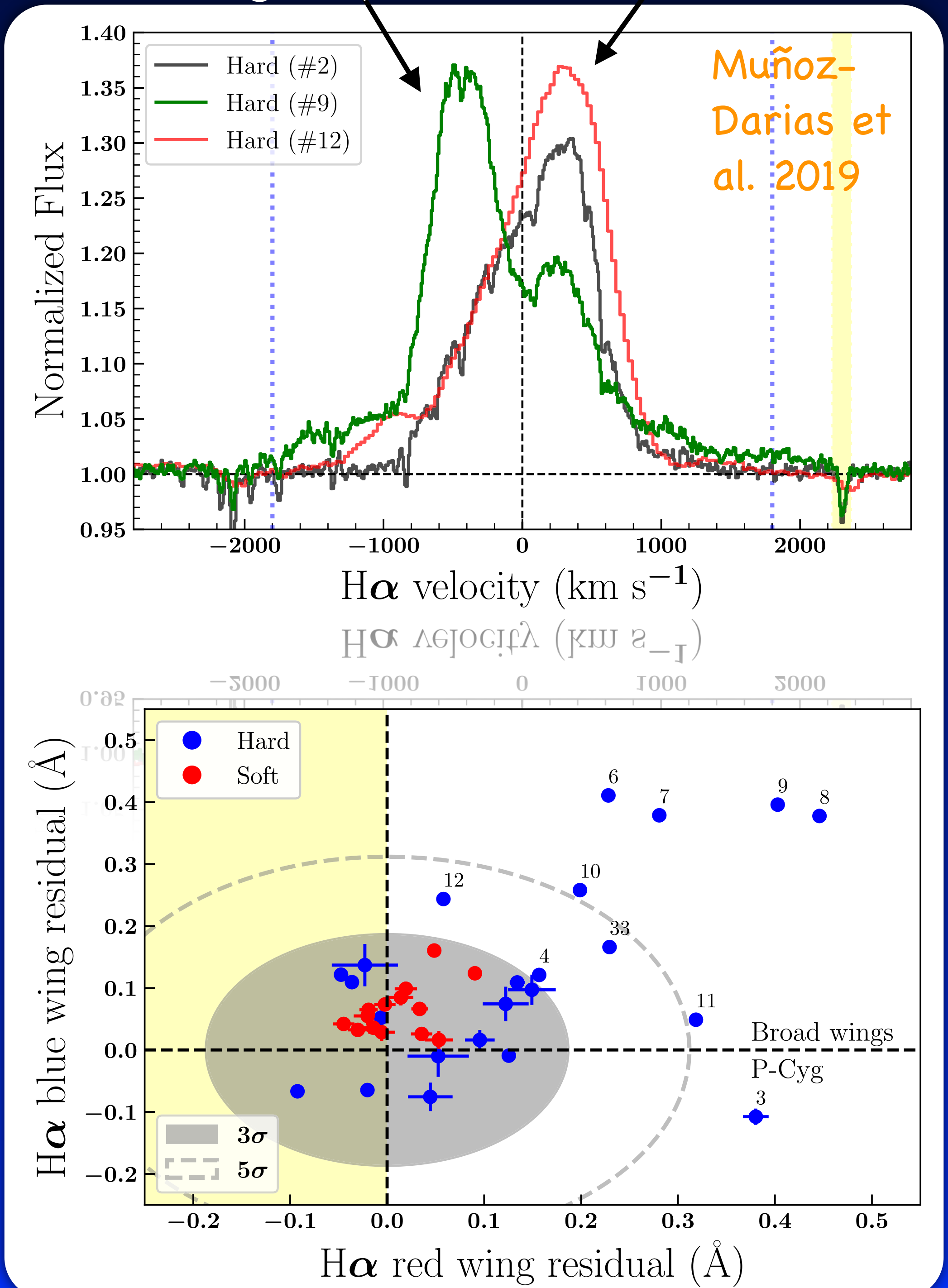
H. Stiele

The H α spectral region

- Broad H α wings and strong line asymmetries
- Wind terminal velocity V_t~1800 km s^{-1}
- Systematic search for wind features using diagnostic diagram developed by Mata Sánchez et al. (2018)
- Gaussian fit to line profile; plot equivalent width (EW) of residuals in the blue and red emission line wings
- Observations exceeding 3 σ level quoted as wind detections

broad blue wing

asymmetric lines

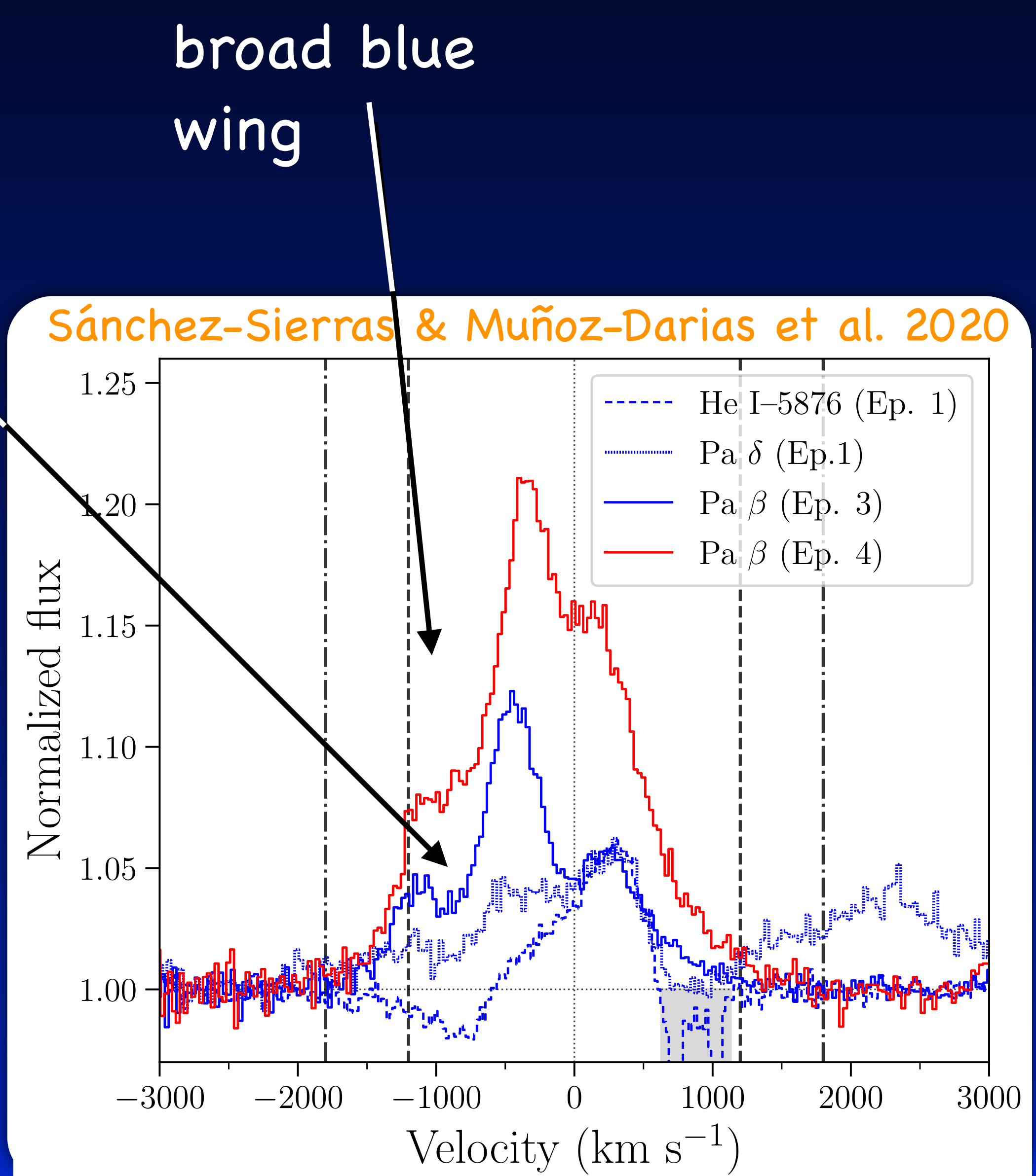


H. Stiele

NIR Paschen lines

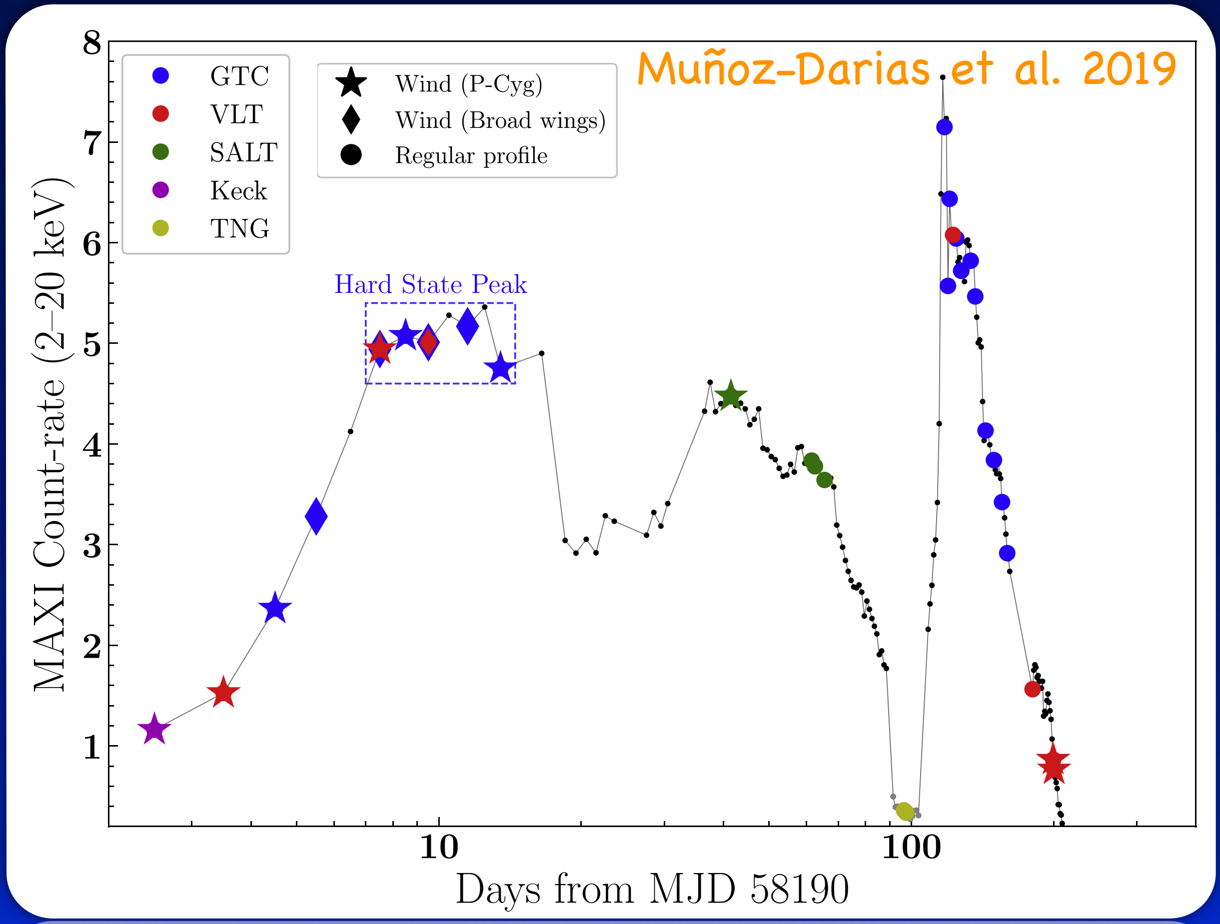
- Paschen lines are asymmetric, Pa δ displays a blue emission line wing, shows hint of an absorption trough

Sánchez-Sierras & Muñoz-Darias et al. 2020

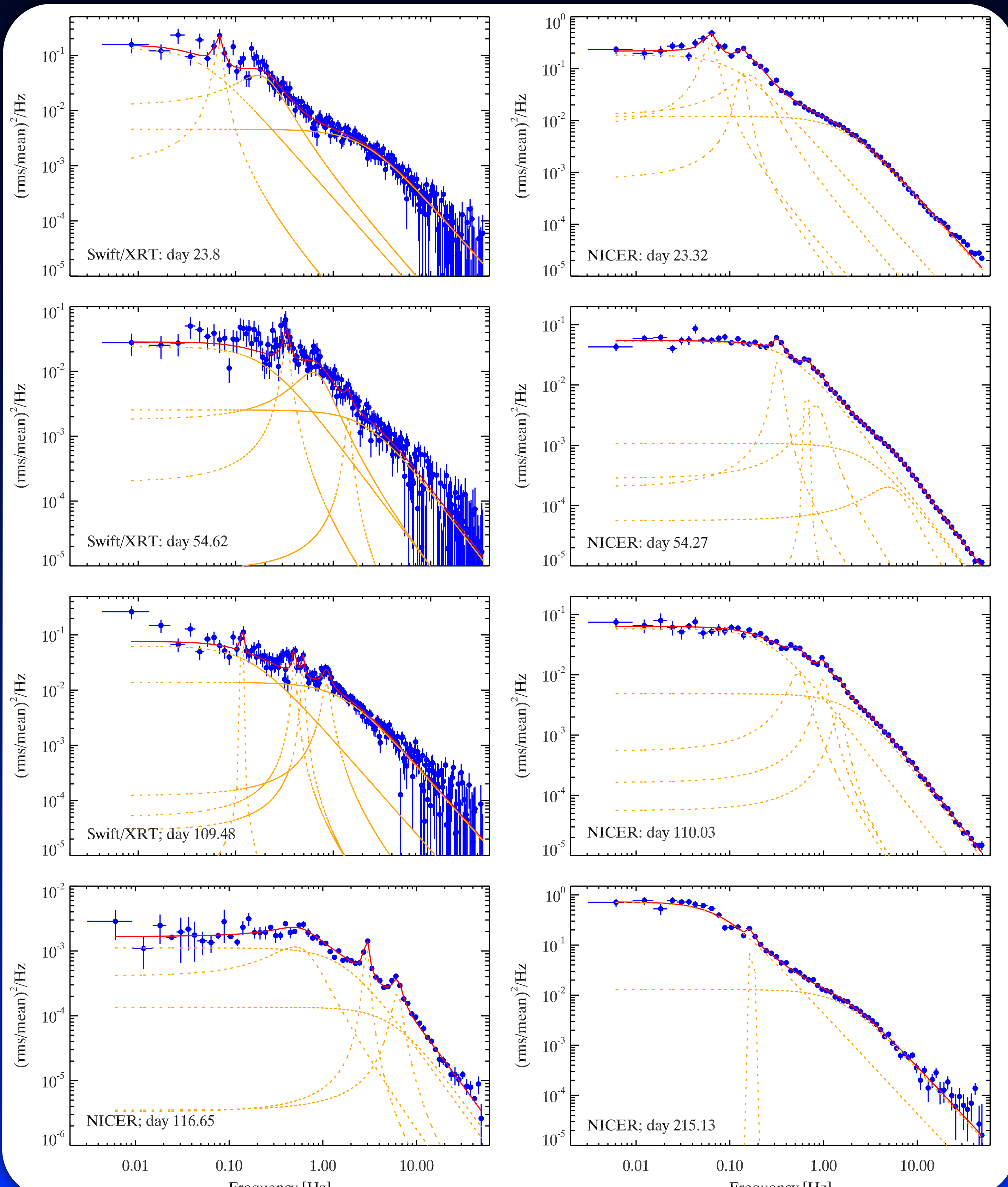


Optical and NIR summary

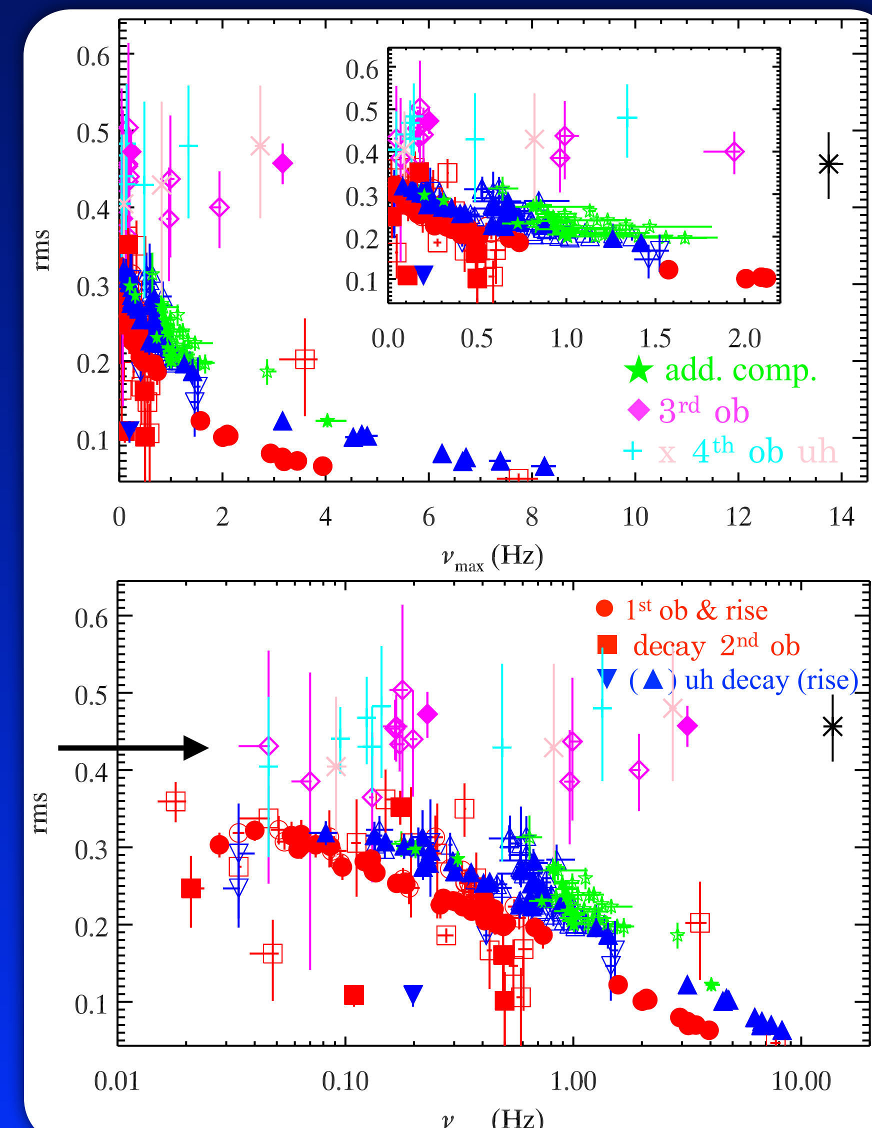
- Wind signatures in MAXI J1820+070 significantly shallower than those observed in V404 Cyg and V4641 Sgr
- Detection possible thanks to exceptional brightness of source and systematic monitoring at very high signal-to-noise
- Wind detections during hard state; especially around peak of the optical outburst
- Two characteristic wind velocities ➜ complex wind structure; different launching mechanisms?
- Similar to V_t derived from optical and X-ray winds in other systems



Quasi-periodic oscillations



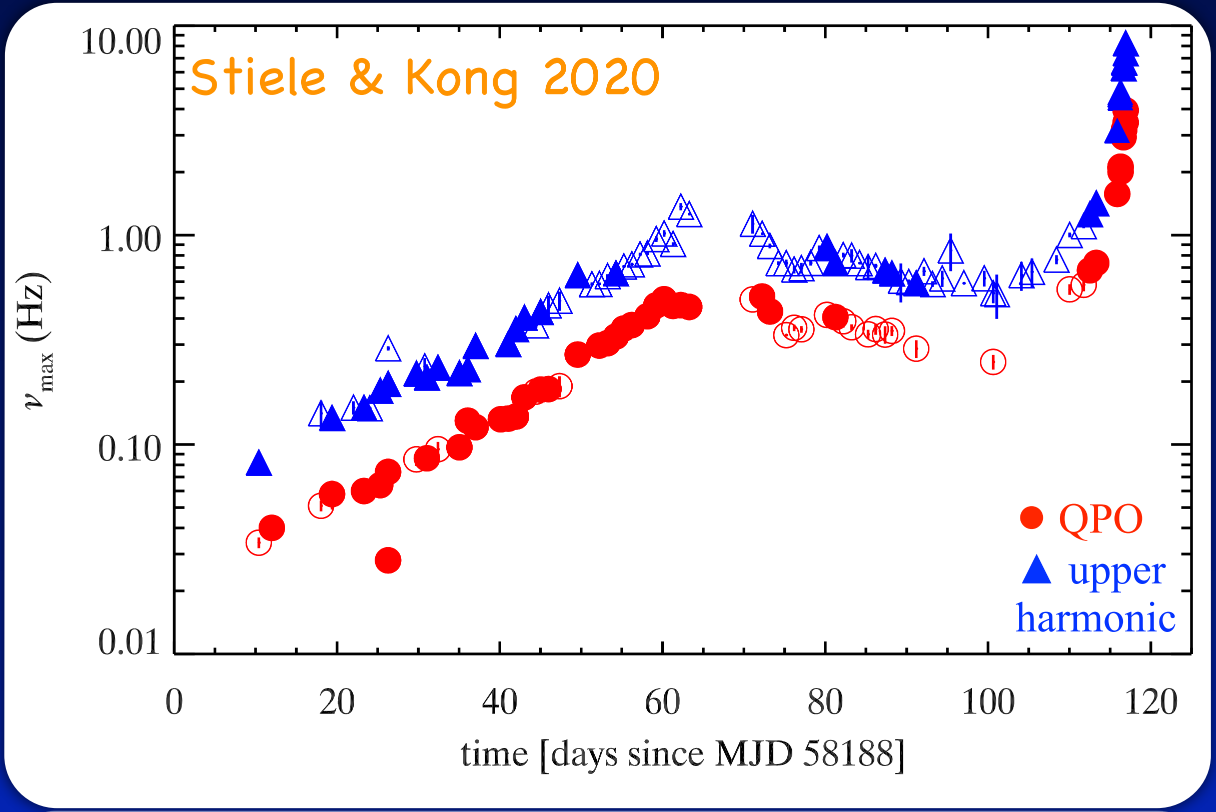
- Anti-correlation between total fractional rms and ν_{char} ➜ **QPOs are of type-C**
- QPOs of 3[rd] and 4[th] outburst show a flat correlation at ~43% rms



H. Stiele

QPO frequencies

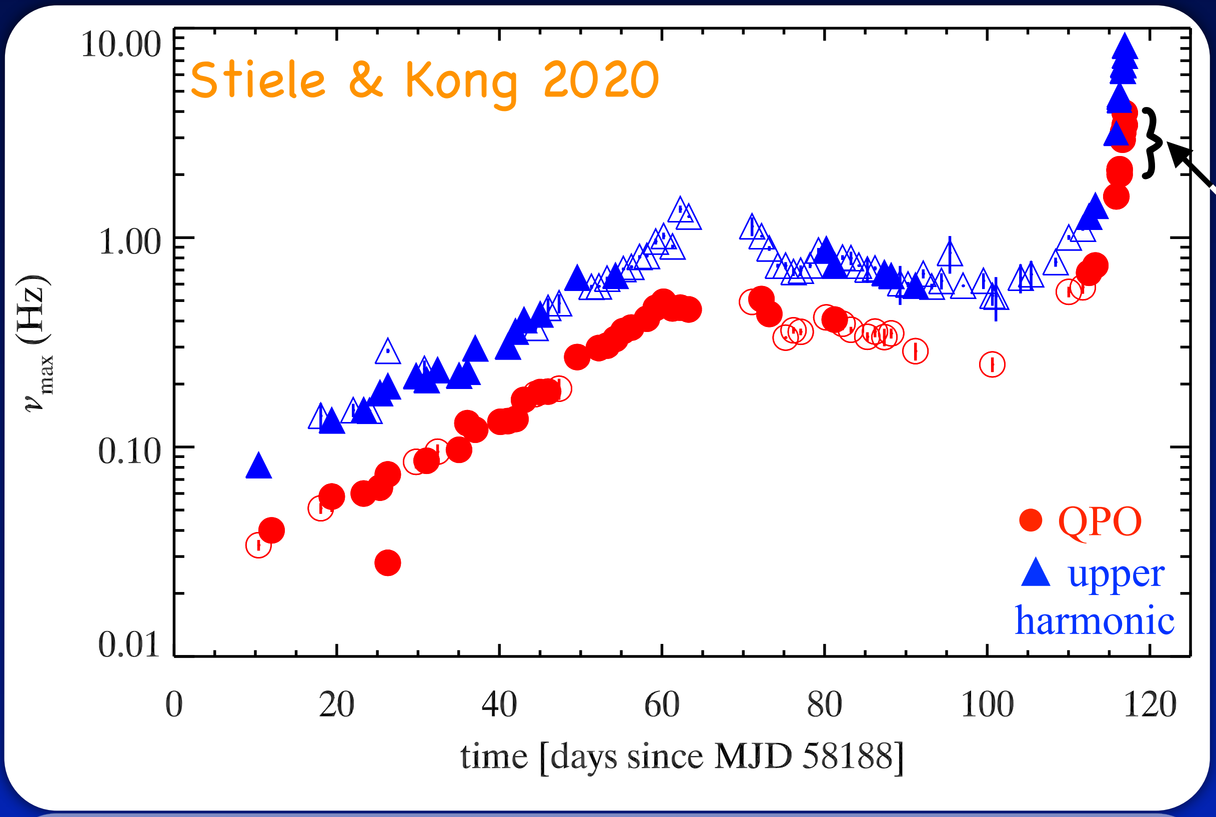
- Most NICER observations between day 10 and 116 show a QPO and an upper harmonic with frequency increasing from 0.03 to 1.57 Hz and Q ~ 3 – 10



H. Stiele

QPO frequencies

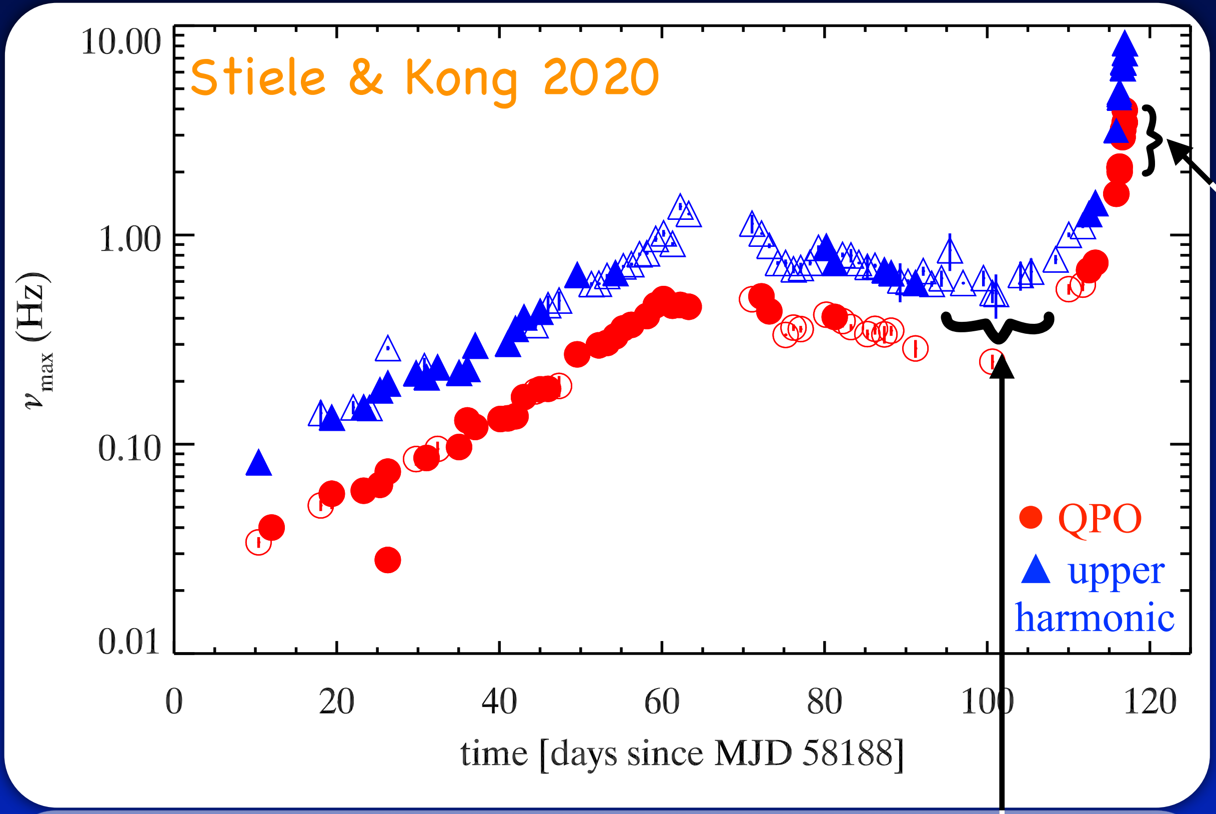
- Most NICER observations between day 10 and 116 show a QPO and an upper harmonic with frequency increasing from 0.03 to 1.57 Hz and Q ~ 3 – 10



- On day 116 ν_{char} increases from 2 to 4 Hz

QPO frequencies

- Most NICER observations between day 10 and 116 show a QPO and an upper harmonic with frequency increasing from 0.03 to 1.57 Hz and Q ~ 3 – 10



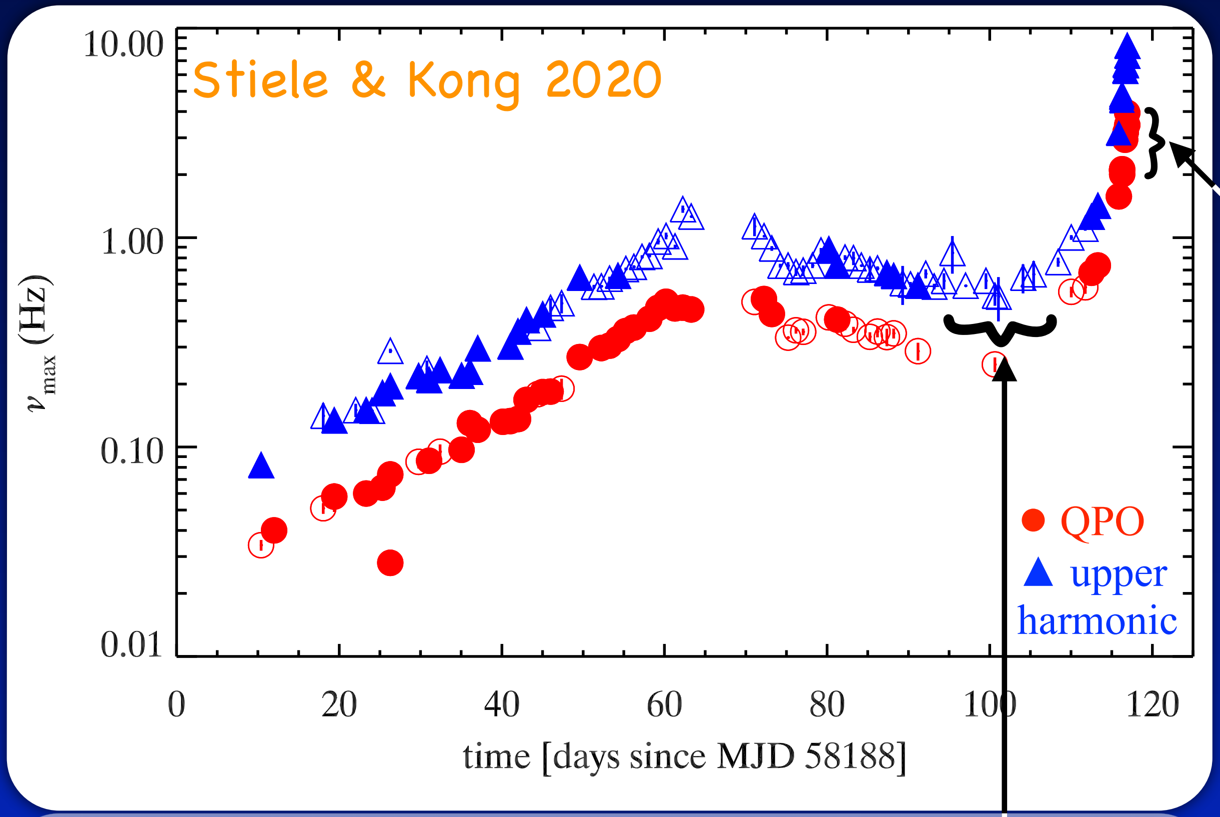
- On day 116 ν_{char} increases from 2 to 4 Hz

- Between day 92 and 109 only upper harmonic is detected

H. Stiele

QPO frequencies

- Most NICER observations between day 10 and 116 show a QPO and an upper harmonic with frequency increasing from 0.03 to 1.57 Hz and Q ~ 3 – 10



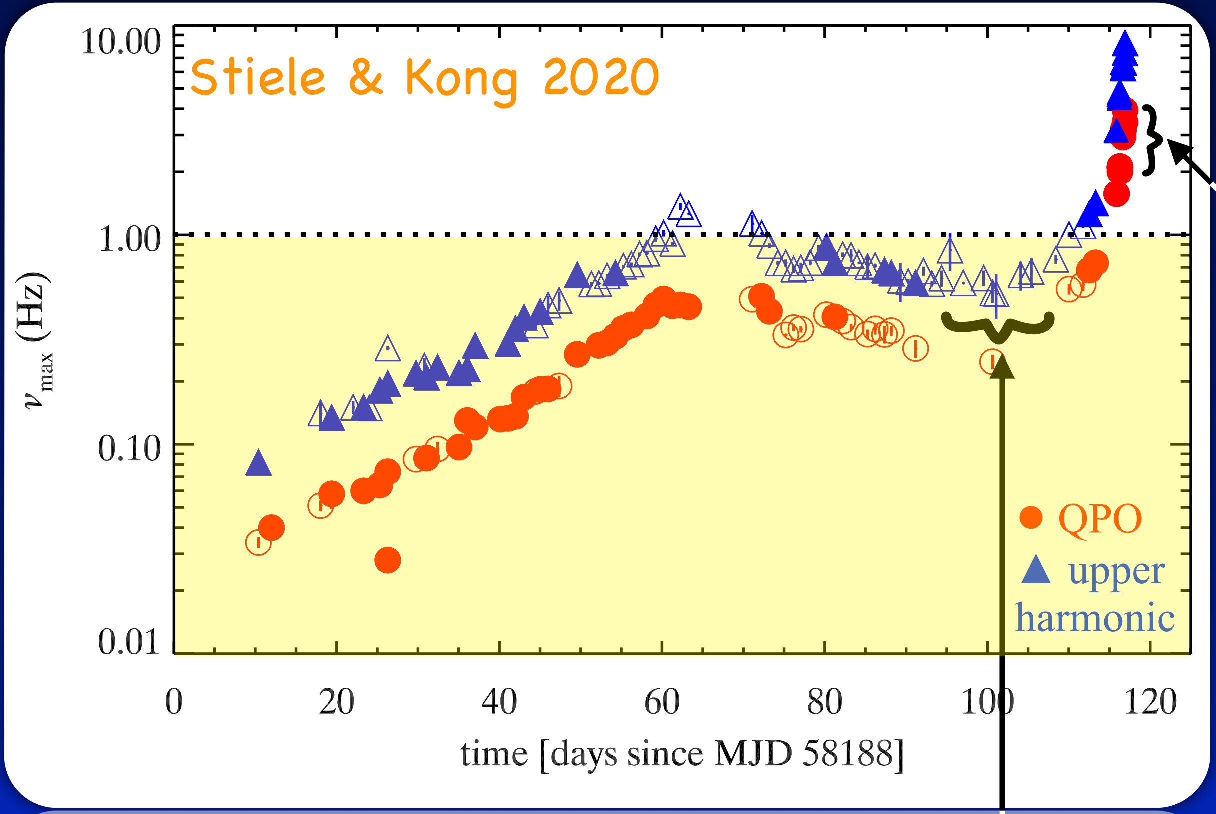
- On day 116 ν_{char} increases from 2 to 4 Hz

- Between day 92 and 109 only upper harmonic is detected

- Few QPOs detected during decay with $0.02 < \nu_{char} < 0.50$ Hz
- Some more QPOs are detected during the 3rd and 4th outburst

QPO frequencies

- Most NICER observations between day 10 and 116 show a QPO and an upper harmonic with frequency increasing from 0.03 to 1.57 Hz and Q ~ 3 – 10



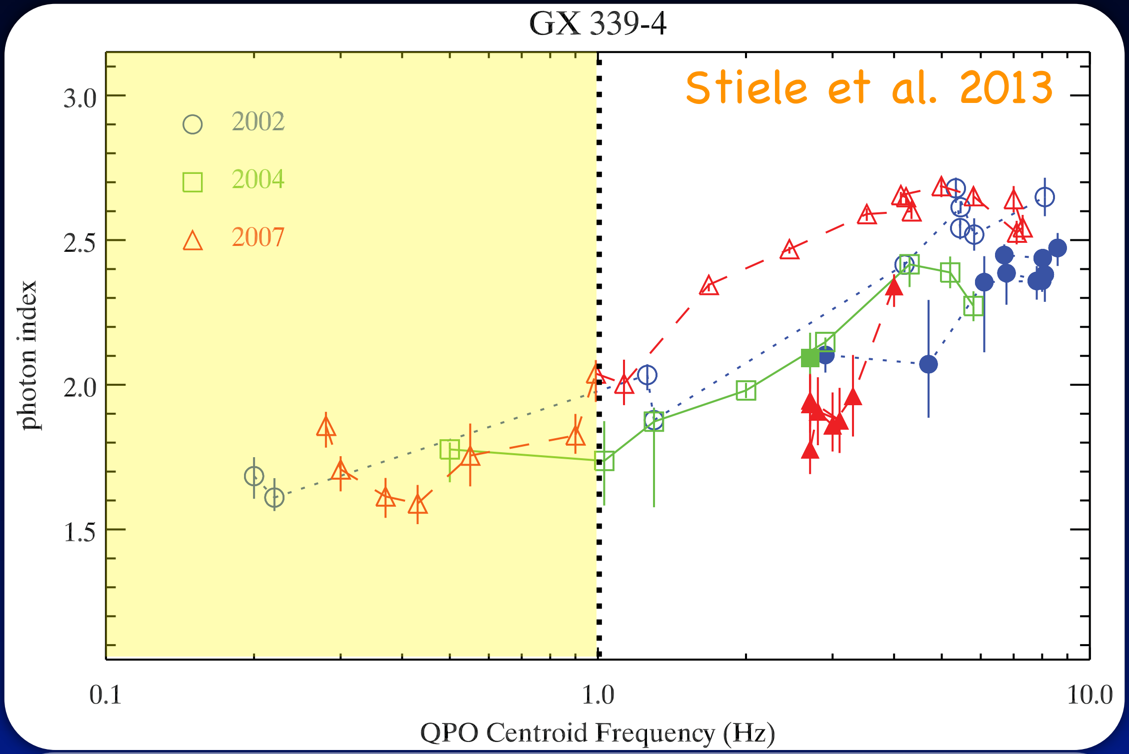
- On day 116 ν_{char} increases from 2 to 4 Hz

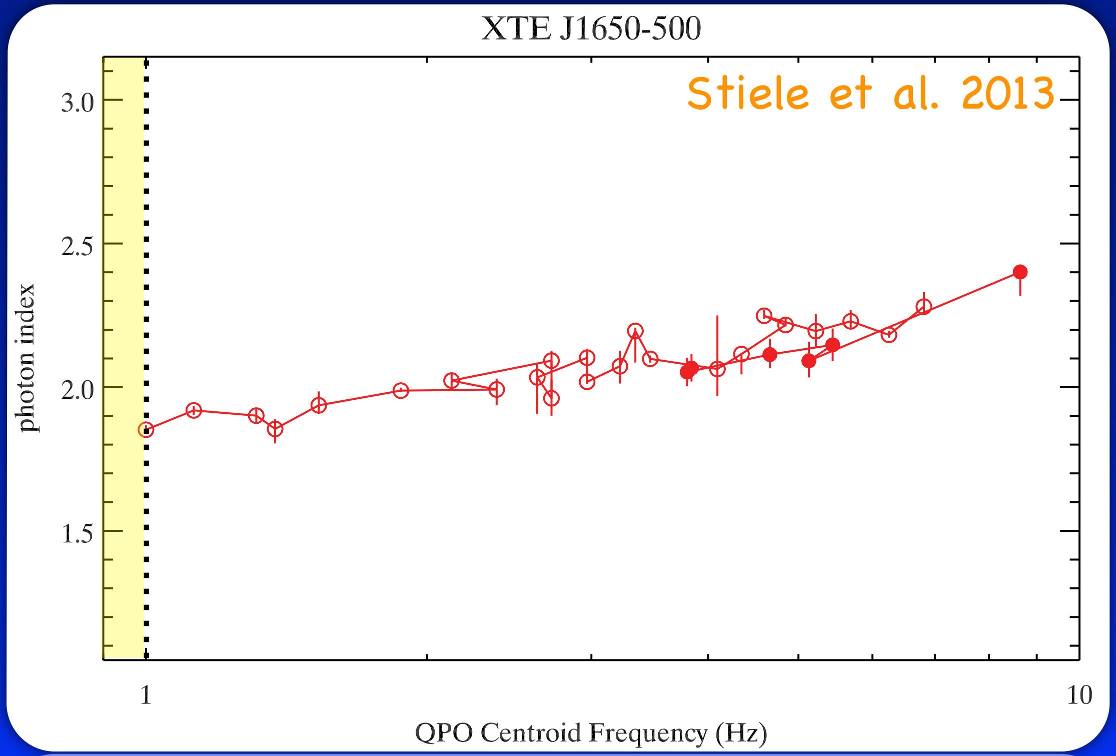
- Between day 92 and 109 only upper harmonic is detected

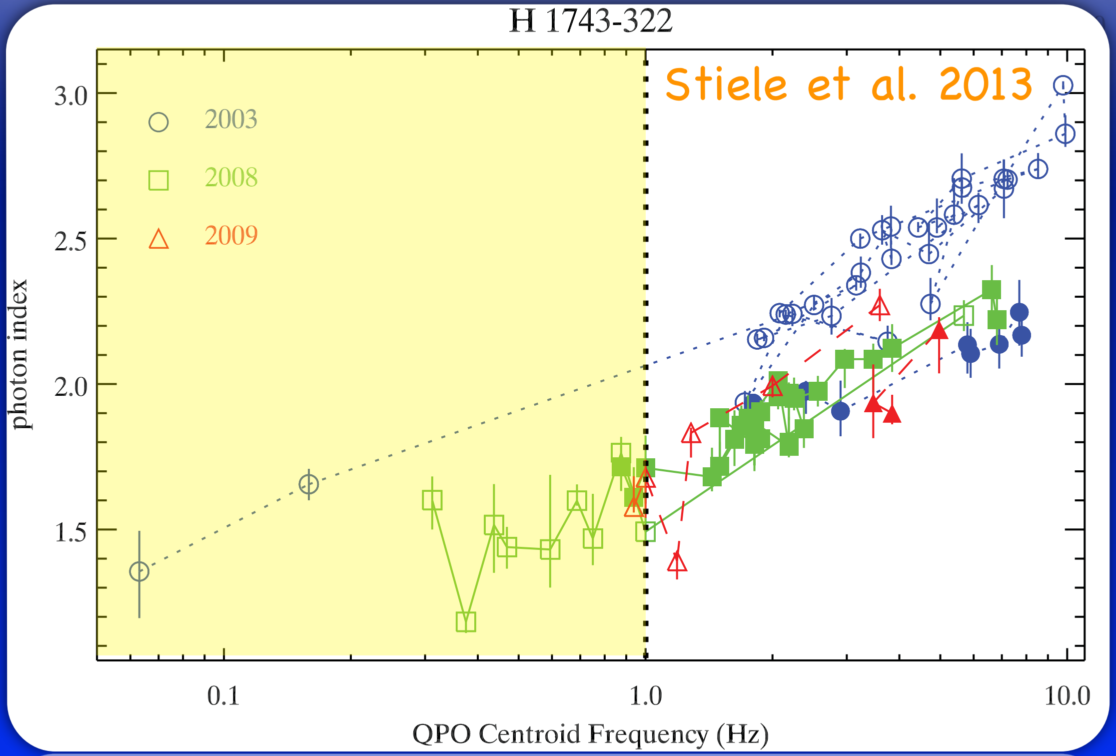
- Few QPOs detected during decay with $0.02 < \nu_{char} < 0.50$ Hz
- Some more QPOs are detected during the 3rd and 4th outburst

QPO frequencies in other systems

- Outbursts of GX 339-4, H1743-322, and XTE J1650-500
- Many QPOs detected at frequencies above 1 Hz







H. Stiele

Discussion

- Four outbursts monitored by Swift/XRT and NICER in 2018 and 2019
- HID shows typical q-shape observed in black hole X-ray binaries; 1^{st} outburst in hard state, 2^{nd} transition to soft state, 3^{rd} + 4^{th} hard state only
- Many observations during outburst rise show QPOs. Frequency range, Q factors and anti-correlation between rms and ν_{char} ➜ type-C QPOs
- Apart from last two NICER observations before the soft state ν_{char} below 1 Hz
- Observations of type-C QPOs below 1 Hz during large parts of an outburst is exceptional.
- Low ν_{char} during large parts of the outburst ➜ source remains in a configuration close to the one typically seen at the beginning of an outburst, when the accretion efficiency is still low

Discussion II

- In Lense-Thirring precession model (Stella & Vietri 1998, ApJ, 492, L59; Ingram et al. 2009, MNRAS, 397, L101) low QPO frequencies correspond to an accretion disc truncated at several R_g
- Low QPO frequencies imply disc truncated far away from the black hole and not much evolution of the truncation radius during outburst
- Consistent with results of Kara et al. (2019, Nature, 565, 198) based on X-ray reverberation lags
- Detection of a disc wind in the optical, IR during the hard state (Muñoz-Darias et al. 2019, ApJ, 879, L4) thanks to the detection of P-Cyg profiles, broad line wings, and strong line asymmetries
- **Presence of disc wind in the hard state can be an explanation why MAXI J1820+070 remained in a state of low accretion efficiency as it hampered the formation of a stable accretion regime**

V404 Cygni

- QPOs at ν_{char} below 1 Hz observed in X-ray observations (Swift/XRT and Chandra) of the 2015 outburst of V404 Cyg

Huppenkothen et al. 2017

MJD	Instrument	QPO frequency	q-factor	QPO fractional rms amplitude
57195.47033	*Swift*/XRT	18 mHz	~ 4.5	0.18 ± 0.02
57195.47033	*Fermi*/GBM	18 mHz	~ 4.5	0.03 ± 0.01
57195.66909	*Chandra*/ACIS	73 mHz	~ 6.0	0.27 ± 0.03
57195.66909	*Chandra*/ACIS	1.03 Hz	9.0	0.46 ± 0.02
57195.47244	*Swift*/XRT	136 mHz	~ 5.8	0.08 ± 0.02

Summary

- MAXI J1820+070, one of the brightest black hole transient ever observed, showed four outbursts in 2018 and 2019: a double outburst and two hard-state-only (reflares)
- Observations of type-C QPOs below 1 Hz during large parts of the outburst
- Source remains during large parts of its outburst in a configuration close to the one typically seen at the beginning of an outburst, when the accretion efficiency is still low
- Presence of disc wind in the hard state (detected in the optical and IR; Muñoz-Darias et al. 2019) can be an explanation why MAXI J1820+070 remained in a state of low accretion efficiency as it hampered the formation of a stable accretion regime

type-C QPOs with $\nu_{char} \lesssim 1$ Hz ⟷ ? ⟷ **cold disc winds**

Thanks for your attention

谢 谢