

EVOLUTION OF QPOS AND SPECTRAL PROPERTIES DURING X-RAY BINARY OUTBURST

31.07.2024 I HOLGER STIELE (JSC) & ALBERT KONG (NTHU)

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Mitglied der Helmholtz-Gemeinschaft

NICER/IXPE WS2024

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 (Ms $\lesssim 1$ M_o, type A,F,G,K,M) through a disc (Rochelobe overflow)
- X-ray emitting region close to event horizon RS
- ₽~200 sources
- ✓~50 black holes





OUTBURST PROPERTIES OF BHXRBS





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NICER VIEW OF THE 2023/24 OUTBURST OF SWIFT J1727.7–1613

- NICER started observing on 2023 August 25
- **SwiftJ1727.7–1613** shows typical evolution from the hard to the soft state
- Here we focus on observations between 25 August and 9 October



- From day 2 to day 42 PDS show two BLN, a QPO and its upper harmonic
- Observe increase in characteristic frequency from about ~0.4 to 1.3 Hz





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Consistent with evolution in LHS & HIMS





RADIUS FROM FUNDAMENTAL QPO

One model to explain type-C QPOs: Lense-Thirring precession of a hot inner flow in a truncated accretion disc (Stella & Vietri 1998; Ingram et al. 2009):

$$v_{\text{prec}} = \frac{5 - 2\zeta}{\pi (1 + 2\zeta)} \frac{a_* \left[1 - (r_i/r_o)^{1/2 + \zeta}\right]}{r_o^{5/2 - \zeta} r_i^{1/2 + \zeta} \left[1 - (r_i/r_o)^{5/2 - \zeta}\right]} \frac{c}{R_g} \approx \nu_c$$

$$\zeta = 0; r_i \sim 2.5 (h/r)^{-4/5} a^{2/5} \text{ with } h/r = 0.2; a = 0.9; M = 10M_{\odot}$$

$$r_o \text{ outer radius of hot flow < inner radius of accretion disc}$$

$$v_c 1.09 \nearrow 1.34 \text{ Hz within } 3.08 \text{ h} \Rightarrow \Delta \text{R} \sim 2.66 \text{ R}_g \text{ or } v \sim 12717 \text{ m/h}$$

$$v_c 1.14 \nearrow 1.41 \text{ Hz in } 10 \text{ day} \Rightarrow v \sim 165 \text{ m/h}$$



COMPARE EVOLUTION OF RADII

- Solution Representation Representatio Representatio Representation Representation Representatio
- Disc radius increase from 370 km to 885 km; decay to a plateau~500 km between days 6 and 16; varies ~216 km days 19 – 24; another plateau ~85 km after day 39





 Similar evolution for the radii obtained by the two methods on days as well as hours timescales
 Supports Lense-Thirring precession



interpretation

NICER VIEW OF THE 2021 OUTBURST OF GX 339-4

- NICER started observing on 2021 January 25
- GX 339-4 shows typical evolution from the hard to the soft state
- Here we focus on observations between 27 and 31 March, when GX 339-4 went from the HIMS to the SIMS



Forschungszentrum

Type-C QPO characteristic frequency evolves from 3 to 6 Hz



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- Then type-B QPO at 5-5.5 Hz appears
- Type-C QPO reappears at 6-6.5 Hz, continuing the increase in frequency before type-B QPO
- Decrease in frequency?



EVOLUTION OF HARDNESS RATIOS

- Hardness ratio: 0.5 2 keV / 2 10 keV
- Red noise and type-B QPOs appear above a HR value of 0.39
- Flat-top noise and type-C QPOs are observed at lower HR values
- Transition between the two states is related to a change in the accretion geometry that shows up in a change of the spectral properties
- Not changes in the spectral shape, but in the contribution of flux in the hard band (Motta et al. 2011)



DISCUSSION

- The results shown here, clearly support the idea that the two different QPO types are caused by two distinct mechanisms
- Fransition from HIMS to SIMS is a gradual process that is intermitted by excursions back to the HIMS → Changes of QPO type is an interplay between two processes
- Similar results found from RXTE data (Motta et al. 2011), however on a much coarser time scale, compared to the scale of hours that is accessible with NICER
- Type-B QPO forms from or disintegrates into a broad feature, sometimes showing a "sub-harmonic" peak before the source transits in or out of the HIMS -> Strong decoherence in the process that causes the type-B QPO
- Simultaneous detection of type-B and C QPOs in one observation of GROJ1655–40 in its ultraluminous state & Presence of a broad feature at frequencies where a type-B QPO forms (Motta et al. 2012)



LENSE-THINNING PRECESSION

- Three components:
 - Hot inner flow that drives type-C QPO
 - Thin accretion disc
 - Transitional region where passive disc is imbedded in outer non-thermal corona
- ν_c anti-correlated to R_{comp}
- Type-C QPO quenched when disc has moved so far inward that hot flow region gets too small to produce detectable QPO; energy spectrum can still show Comptonized emission thanks to transitional region
- Function Temporary increase in $R_{comp} \rightarrow$ reappearance of type-C QPO close to last seen ν_c





DYNAMIC CORONA – DISK SYSTEM

- Based on radiative feedback between a hot e- population in the corona and soft radiation coming from the accretion disc, due to reprocessing of the hard corona radiation (Mastichiadis et al. 2022)
- Type-C QPOs are identified with damped oscillations
- Because of damping oscillations need to be sustained by small fluctuations in the accretion rate
- To quench type-C QPOs, e-need to escape quickly from corona; happens when corona shrinks and outflow becomes continuously narrower as source moves from HIMS to SIMS; increase in soft disc radiation supports suppression of type-C QPO
- Shrinking of corona cannot be uni-directed process and/or fluctuations in the soft disc radiation
- *Can changes in the corona size, soft disc happen on the timescales observed here?*
- Solution Solution Solution ν_c of type-C QPOs after first appearance of type-B
- If increase in accretion rate drives type-C QPOs, this increase may counteract shrinking of corona and explain the reappearance of type-C QPOs



TWO COMPTONIZATION REGIONS

- Two Comptonization regions to explain type-B QPOs (García et al. 2021; Peirano et al. 2023; Kylafis et al. 2020)
- Two component corona for type-C QPOs (Karpouzas et al. 2020, 2021)
- Corona and disc size anti-correlated for $\nu_c \gtrsim 2$ Hz, correlated for lower frequencies (Karpouzas et al. 2021)
- Large size of corona at high frequencies makes it challenging to explain "fast" transitions between type-C and B QPOs
- If both type-C and B QPOs are caused by two-component corona -> kind of "oscillation" between the two Comptonization regions



SUMMARY

- Follow hard to soft evolution of SwiftJ1727.7–1613 with NICER
- Consistent evolution of radii obtained from ν_c of type-C QPOs assuming Lense-Thirring precession and radii obtained from diskbb model
- Follow GX 339–4 from the HIMS to the SIMS with NICER; PDS and HR for individual snapshots → evolution
- The results shown here, clearly support the idea that type-C and type-B QPOs are caused by two distinct mechanisms
- In dynamic corona disc system: Can changes in the corona size, soft disc happen on the timescales observed here?
- With two Comptonization regions: Cause of "oscillations" between them?



TOWARDS EXASCALE-READY ASTROPHYSICS

- 3-day workshop on exascale computing for astrophysics and cosmology
- Features a mix of keynote, contributed, and poster presentations, as well as tutorials focusing on astrophysics codes and high-performance computing
- Audience of scientists, code developers, and HPC experts
- Starts on Sept 25th at 9:00 am
- Ends on Sept 27th at 12:30 pm
- Virtual meeting
- No registration fee
- Webpage: <u>https://indico3-jsc.fz-juelich.de/e/tera2024</u>

TERA	
Towards exascale-rea	ady astrophysics
25–27 Sept 2024 Virtual Meeting EuropetBerlin timezone	
Overview Call for Abstracts Agenda Organisers Registration Participant List Contact	Exercise computing represents a transformative tool enabling researchers is better model and analyses compoing systems. Precedy inhancing scientific discourse, With a string emphasis on runnerical simulations is ascongiv first workshop am to present the table diverophemet in a weakas iterhorizy and is applications within the to all attrachysics research. By bringing together scientistis, code developers, and high-performance computing (HPC) qeapert, the workshop am cold docuss current challenges and huter exponting its utilising exacelse computing for astrophysics and cosmology. The associate for the second and analysis of the - Computational astrophysics and cosmology in the exascale entry: challenges and limitations - Exacelse result (green) computing for environmentality austainable astrophysics research - Riflig data astrophysics and cosmology for the viscourd analysis astrophysics research - Riflig data astrophysics and cosmology in the exascale entry challenges and limitations - Exacelse result performance of the second analysis of the science of the second and the string of the optimizer of the second and the science of the second and t
	The workshop will feature a mix of invited, contributed, and poster presentations, as well as interactive totavala focusing on astrophysics isinulation codes, high performance computing, machine lawring, and data analytics. Attendess will have organizations for involvedge harming, discussing involves lease, and lottening collaberati through technical talks, hands-on training sessions, and networking events. We strongly encourage tenake and early career researchers to participate, as their unique perspectives and contributions are invaluable to our discussions.
	Keynoke spoakers (confirmed) - Jenome Befort, mindex al, USA - Geoffrey Leaux, Institute for Planetary Sciences and Astrophysics of Genoble, France - Junición Maldrio, Direfered Networka, Japan - Jason McEvene, University Collega London, UK - Evan Schmeider, University O Pittaburgh, USA - Volker Springel, Max Planck Institute for Astrophysics, Germany
	Al for astrophysiciata • Al for astrophysiciata • AlternaPPF (estrophysical MHD code) • JUPTER (esascale supercomputer) • PLUTO (astrophysical fluid dynamics code) •
	Time and Location
	The workshop will start on September 25 th (9 am) and end on September 27 th (13:00 pm) 2024. It will be held a virtual meeting. There is no registration fee.
	In case of questions, please contact the organisers via tera2024@fz-juelich.de.
	Starts 25 Sept 2024, 09:00 Ends 27 Sept 2024, 13:00 Europe/Berin
	The call for abstracts is open You can submit an abstract for reviewing.



31. July 2024

EVOLUTION OF THE ENERGY SPECTRUM

Background: SCORPEON model

~6.6 keV; iron line

- Source: tbabs (diskbb + nthcomp + gaussian) Wilms et al. (2000) Mitsuda et al. (1984) Życki et al. 1999
- Averaged foreground N_H ~ 2.43x10²¹ cm⁻² similar to that of other Galactic XRBs
- Accretion disc temperature constant ~0.31 keV up until day 16; varies ~0.38 keV days 19 – 23; 0.62–0.85 keV days > 39
- Disc radius increase from 370 km to 885 km; decay to a plateau~500 km between days 6 and 16; varies ~216 km days 19 24; another plateau ~85 km after day 39
- Photon index increases from 1.6 to ~2.3 on day 23; after day 39 $\Gamma \sim 3.0 3.9$

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EVOLUTION OF RMS VALUES

- Regarding rms values:
- No clear distinction between snapshots that show red noise/type-B QPOs and those that show flat-top noise/type-C QPOs.



