X-ray Irradiation Affecting the Unstable Black Hole Accretion Disks

Pulkit Ojha

PhD Candidate, Relativistic Astrophysics Group

Centrum Fizyki Teoretycznej, Polish Academy of Sciences, Warsaw, Poland

Collaborators:

Prof. Agnieszka Janiuk (CFT PAN, Warsaw)

dr. Yuri Cavecchi (Departamento de Astrofísica, Universidad de La Laguna)

dr. Federico Vincentelli (Centre for Fluid and Complex Systems, Coventry University)

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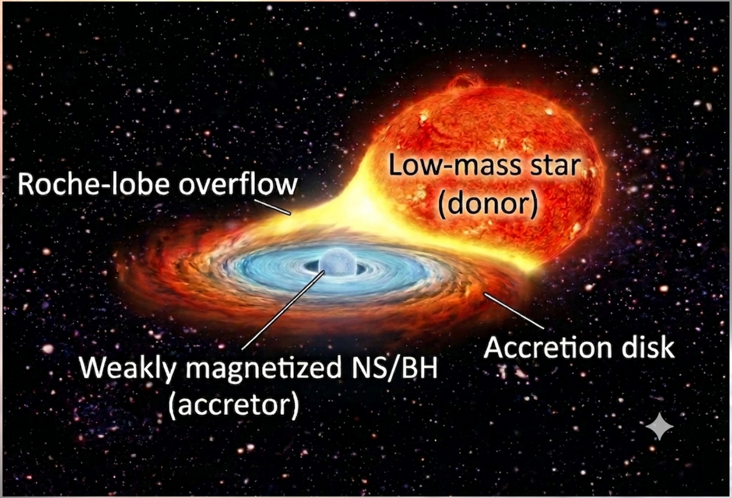
Target Systems: Low Mass X-ray Binaries (LMXB)



Artist's impression of a LMXB, showing accretion onto the compact object through Roche Lobe overflow.

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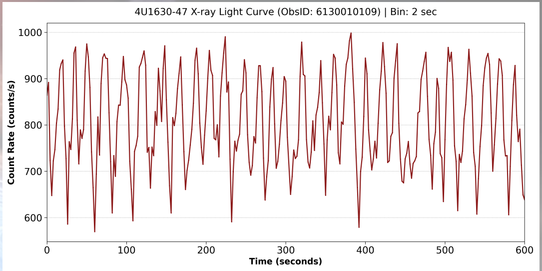

Figure: Quasi-periodic oscillations "heartbeat states" observed by NICER in 4U 1630-47, obsID:6130010109, reported by Fan et al 2025

Methodology: The GLADIS Code

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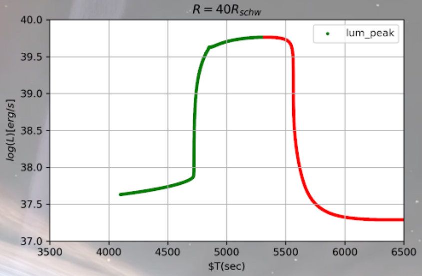
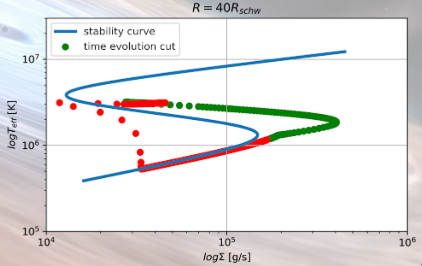
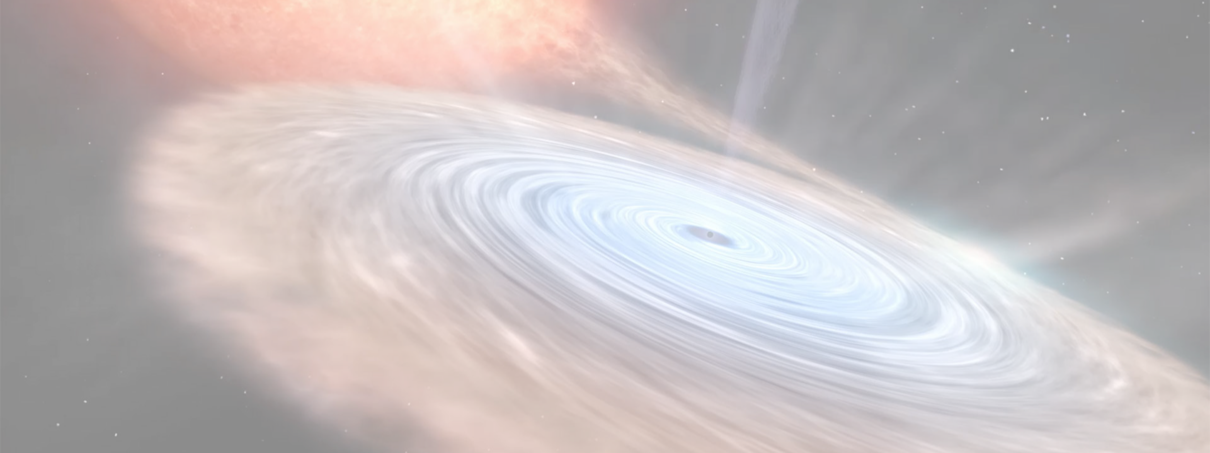
- **Features:** Optionally incorporates disk outflows/winds and mass exchange with a gaseous corona 1D + 1D.
- **Limit-Cycle Behaviour:** Generates local **S-curve diagrams** and **limit-cycle oscillations** in integrated luminosity versus time curves.





Physics & Geometry of X-ray Irradiation

- **Heating Source:** Central irradiation (hot corona for BHs, boundary layer for NSs) alters disk temperature profile & instability cycles.



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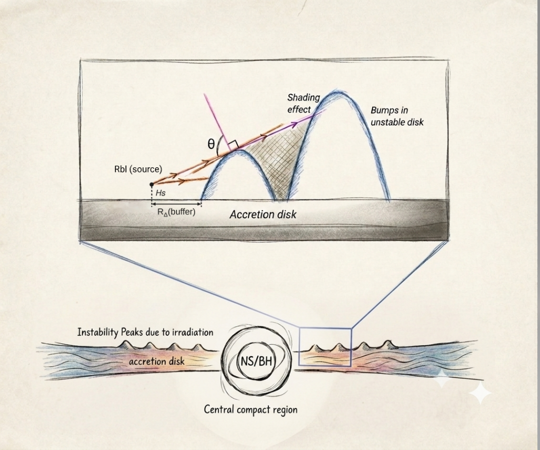
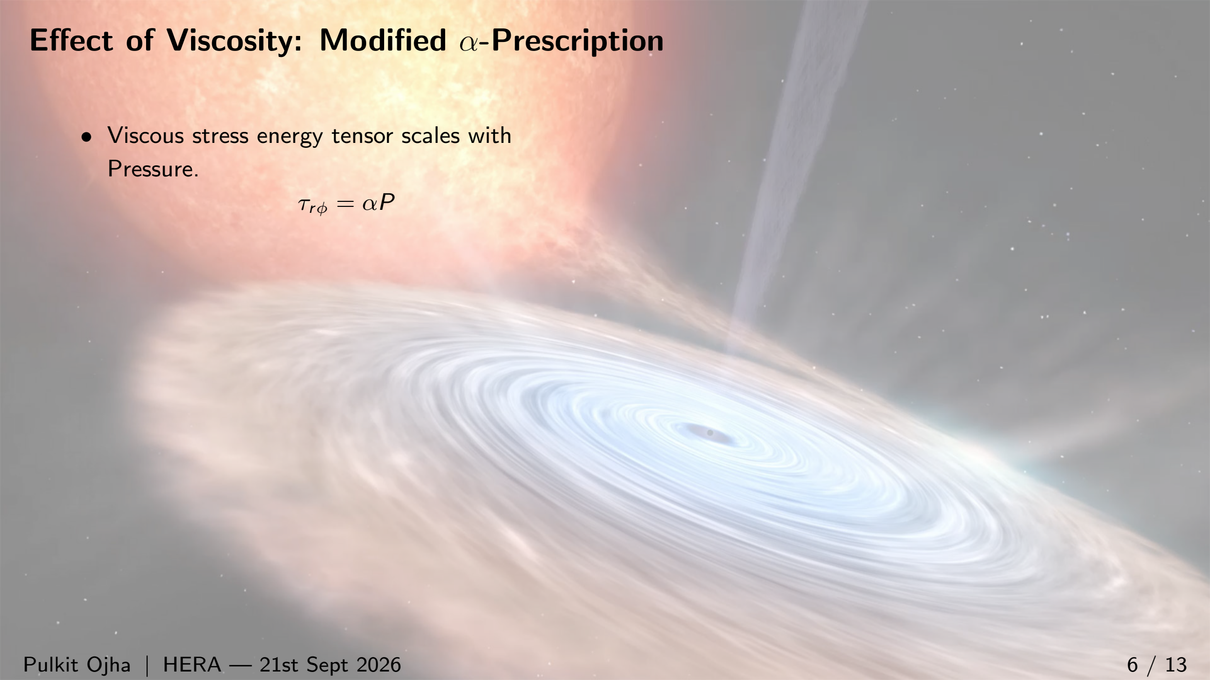
- We consider the irradiating source at some additional height to control the illumination.



Schematic Geometry: Central source illuminating inner instability waves ($R_{\rm BL}, H_{\rm BL}$). Modulated geometry dictates local $\cos\theta$ intercept.

Effect of Viscosity: Modified α-Prescription



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Impact on Disk States: Disk spends significantly **more time** in the hot/outburst state vs. quiescent cold state.

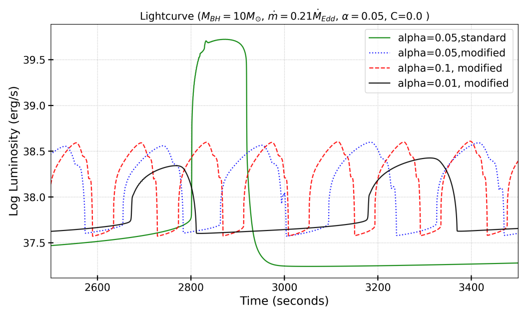
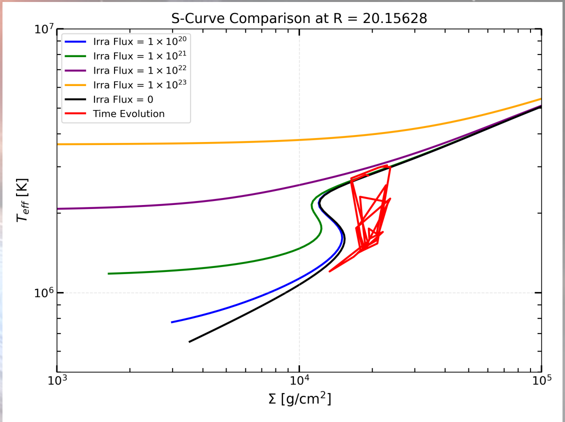


Figure: Oscillations of the disk shown for a typical case of standard and modified viscosity, without irradiation flux.

Effect of Irradiation on Light Curves & S-Curves

- **S-Curve Shift:** Higher flux elevates the overall disk ($T_{\rm eff}$), completely changing the limit-cycle oscillations.



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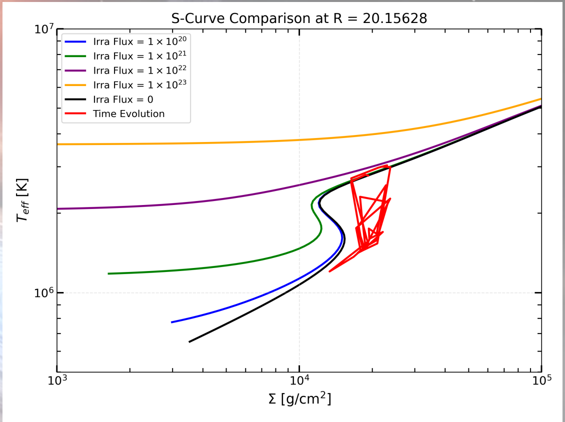

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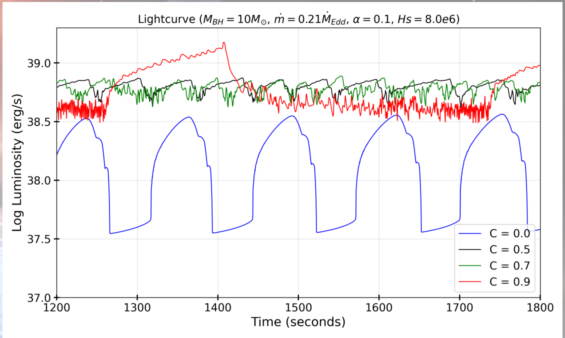

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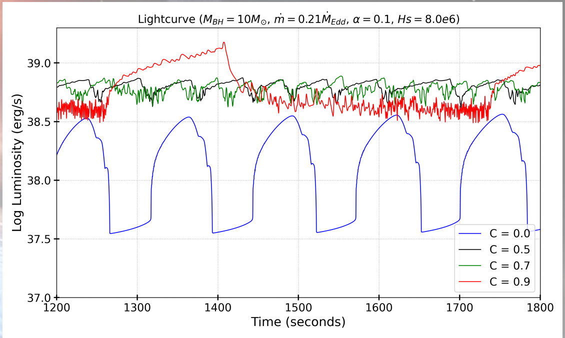
  - Are we getting "heartbeat" states?



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High Irradiation Regime: Heartbeat State

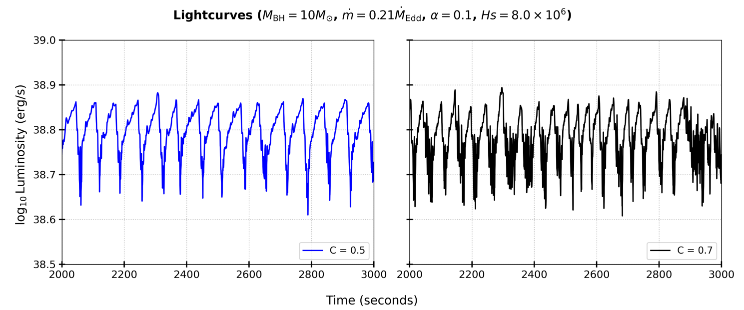

Figure 1: Simulated lightcurves for $M_{\mathrm{BH}} = 10M_\odot$ at $\dot{m} = 0.21\dot{M}_{\mathrm{Edd}}$, comparing moderate ($C = 0.5$, left) vs. high ($C = 0.7$, right) irradiation regimes.

- Yes! We are (at least A/Q the observation guy in our team :), depending upon *the source height* and *irradiation strength*).

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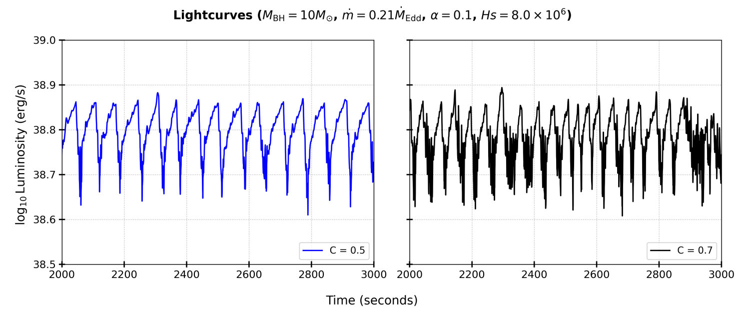

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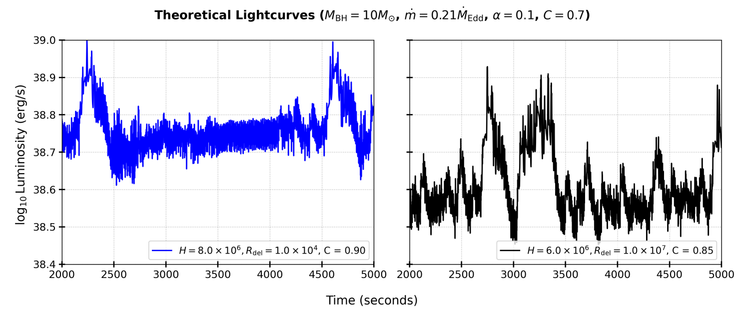

Figure 2: Lightcurve showing random stochastic oscillations with suppressed heartbeat patterns at extreme parameters.

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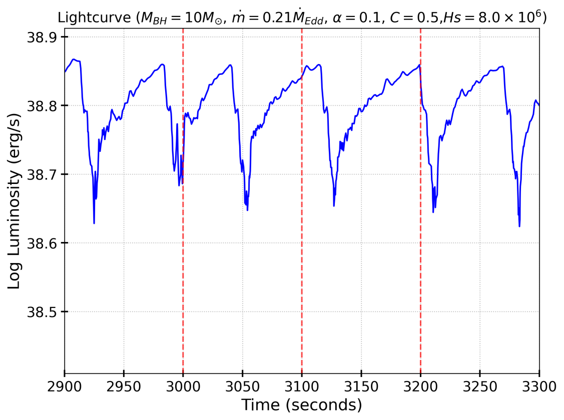
High Irradiation Regime: Physical Picture

- Let's mark different phases of the lightcurve, rise, peak and decay.



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High Irradiation Regime: Physical Picture

- Let's mark different phases of the lightcurve,rise, peak and decay and see the physics.
- RPI waves are way higher due to irradiation flux, from the irradiated cells towards the outer radii.
- Radiation feedback creates multiple peaks, possible reason for the stochastic oscillations present in the lightcurve.
- Small instability peaks present in the outer zones, not understood properly yet :(

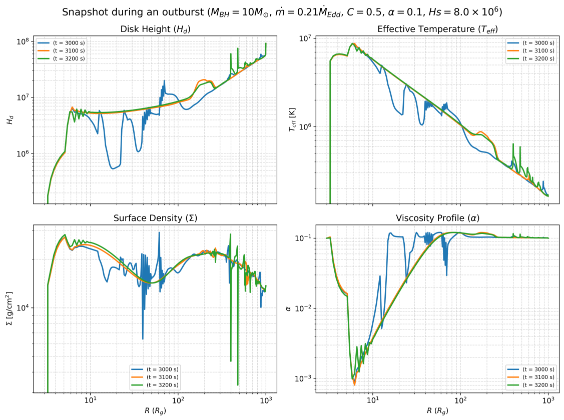
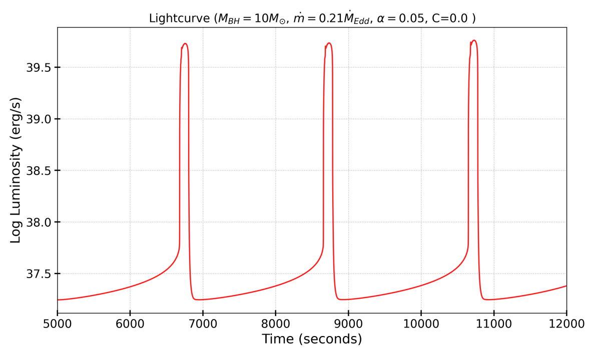


Figure 2: Physical picture showing radial profiles and instability waves at different accretion phases.

Model Progression: From RPI to Outflow Dynamics

1. RPI Instability Waves

* Each physical process builds upon the baseline model to regulate disk limit-cycle oscillations.



Step 1: Unstable limit-cycle oscillations driven purely by radiation pressure instability (RPI).

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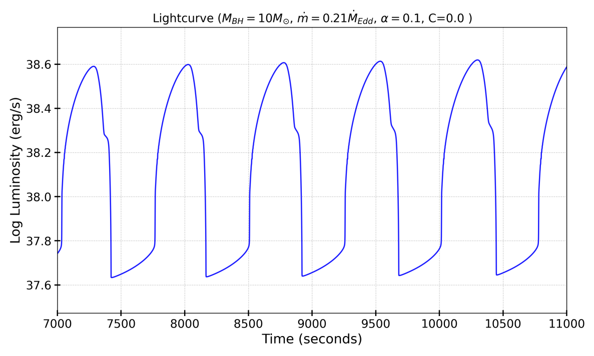

Step 2: Impact of pressure ratio-dependent α-viscosity on baseline duty cycles.

Model Progression: From RPI to Outflow Dynamics

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3. X-ray Irradiation

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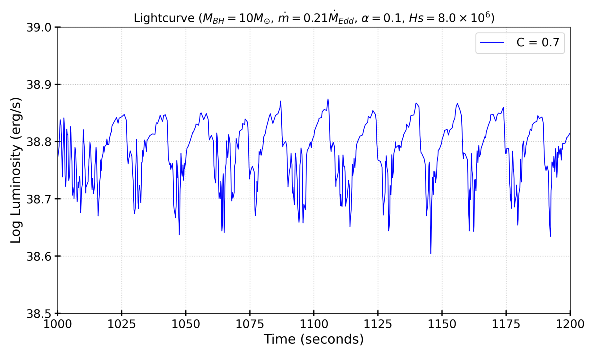


Step 3: Irradiation flux elevates cold-branch baseline and introduces stochastic oscillations.

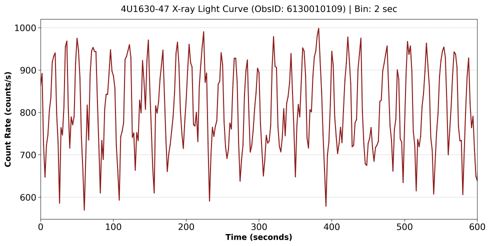
Observational Properties: QPOs in 4U 1630-47

Observed Low-Frequency QPOs

ObsID	Period (s)	Frac. RMS (%)
6130010109	21.28	10.25 ± 1.28
4130010115[a]	17.86	7.03 ± 1.75
4130010115[b]	13.70	8.77 ± 0.75
8130010113*	10.20	4.60 ± 0.37

QPOs and QRM($*$) in 4U1630-47

- **Variability Morphology:** Prominent quasi-periodic oscillations (heartbeat-like state) and quasi-regulated modulations (QRMs) observed in this source.
- **Observed Window:** Oscillations span between **10.20** s and **21.28** s.



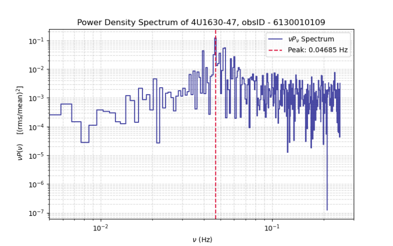


Figure: X-ray light curve (top) and corresponding PDS showing the QPO peak at 0.04685 Hz for ObsID 6130010109 (bottom).

Obtaining Observation Periods

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α	C	**Period (s)**
0.4	0.5	**19.96**
0.4	0.7	**17.16**
0.1	0.5	73.51
0.1	0.7	49.22
0.1	0.9	125.00

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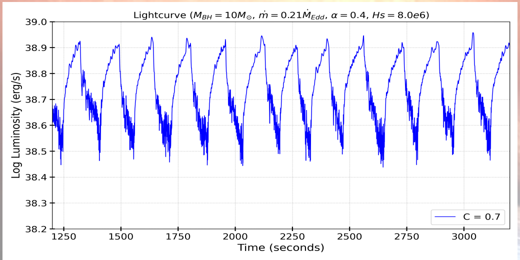
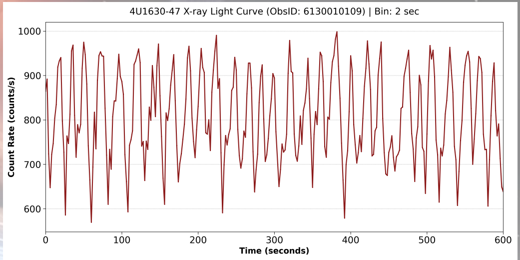
Conclusively,

- Viscosity coefficient α and irradiation strength C, Hs determine the periods for these heartbeat oscillations.
- Irradiation produces "heartbeat" states for selected parameters, which needs to be explored further, too much irradiation or too much shading can lead to random peaks full of stochastic oscillations.

Summary





We incorporated **irradiation effects** with a **modified viscosity prescription** into our disk-instability model, finding that irradiated accretion disks produce short-timescale, highly **stochastic outbursts** that closely resemble the **low-frequency QPO** observed in XRB 4U1630-47.

*T*HANK YOU!!!