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Statistics of Quasi-periodic Eruptions

Defense of the Bachelor Thesis

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Overview

What are Quasi-periodic eruptions?

Theoretical models

Timing properties

Toy model

What are Quasi-periodic eruptions?

- new category of soft X-ray variability phenomena
- recurrence timescales in tens of minutes, up to tens of days
- present in AGNs or previously active GNs
- peak luminosities in $10^{41}-10^{43}$ erg.s^{-1}
- count rate rises $1-2$ orders of magnitude above the quiescence level

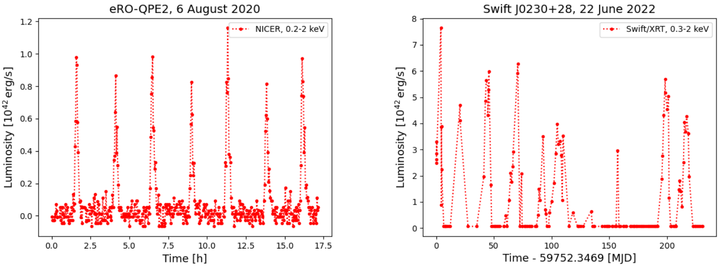


Figure 1: Two very different QPE sources.

- thermal spectra with temperatures kT $\approx$ 50−250 eV
- three sources linked to tidal disruption events (TDEs)
- low-mass host galaxies with $\log M_* = 9-10$

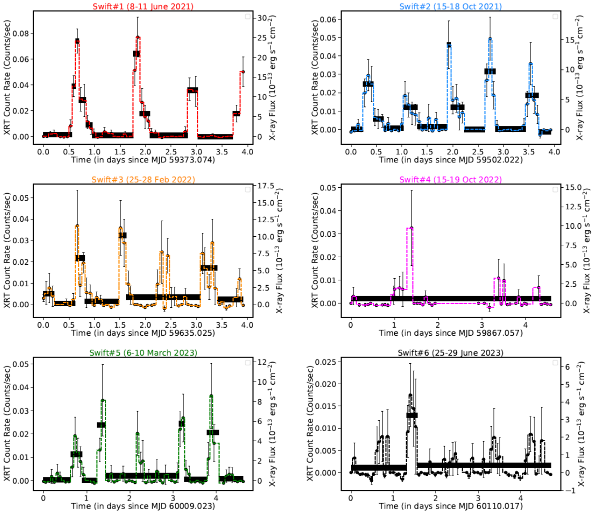


Figure 2: 0.3-1.2 keV light curves of eRO-QPE1. Credit: Pasham et al. [1].

Quasi-periodic oscillations (QPOs)

- X-ray fluxes found mainly in X-ray BHBs, recurrence times in hours
- HFQPOs - unstable with fluxes but constant with frequencies
- important relation between BH mass and QPO frequency

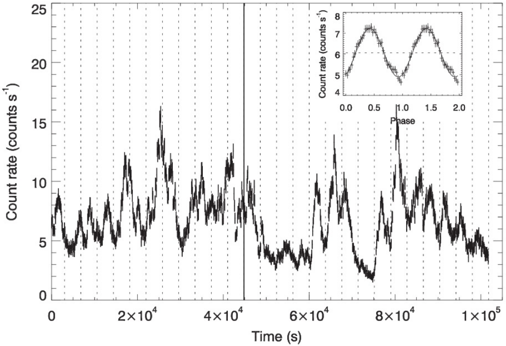


Figure 3: XMM-Newton light curve of 1H 0707−495 in 0.2−10 keV. Upper right: Folded light curve. Credit: Pan et al. [2].

Observations

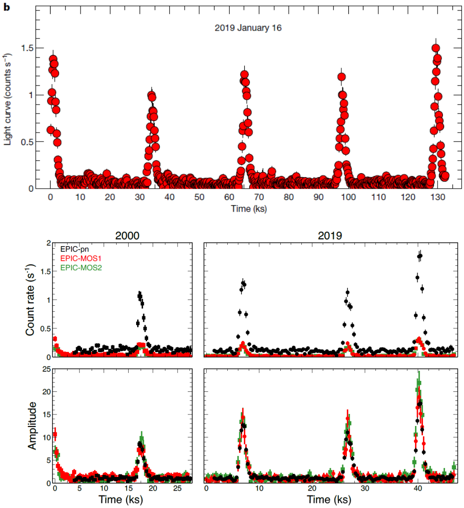


Figure 4: Up: GSN 069, Down: RX J1301.9+2747, Credit: Miniutti et al. [3], Giustini, Miniutti, and Saxton [4].

What are Quasi-periodic eruptions?

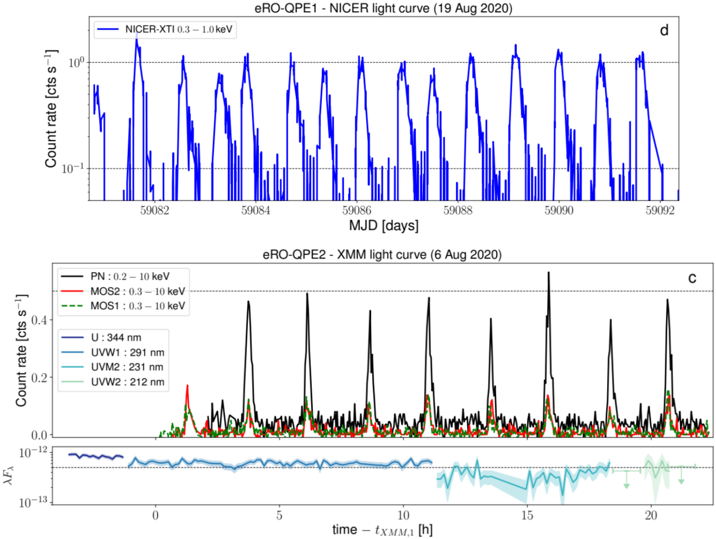


Figure 5: Up: eRO-QPE1, Down: eRO-QPE2, Credit: Arcodia et al. [5].

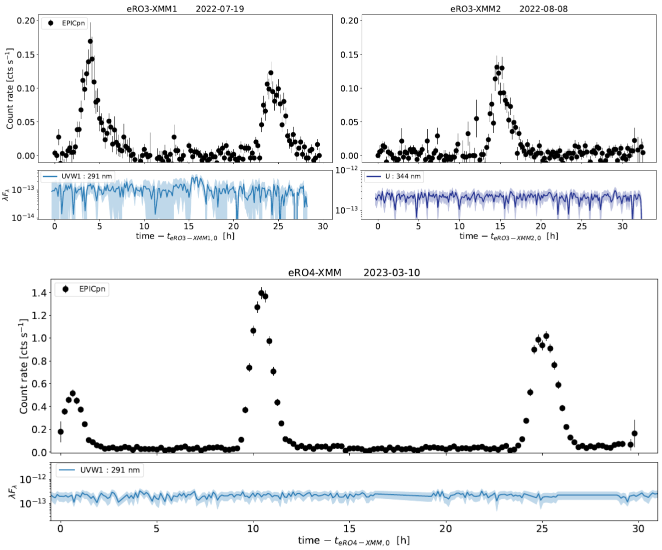


Figure 6: Up: eRO-QPE3, Down: eRO-QPE4, Credit: Arcodia et al. [6].

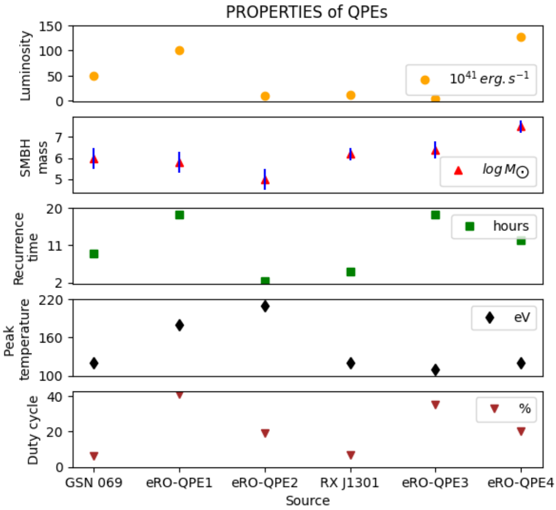


Figure 7: Properties of QPEs

Theoretical models
Disk warping

- Lense-Thirring precession causes warping of the disk $\rightarrow$ breaking into discrete rings, each with its own precession
- variability timescale of the accretion flow - minutes, months, ...

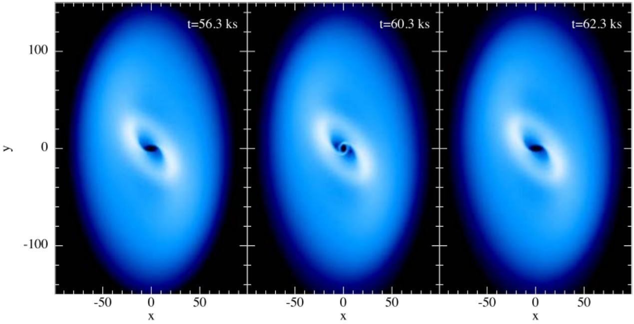


Figure 8: Credit: Raj and Nixon [7].

Theoretical models
EMRIs

- MS star orbits close to a SMBH
- twice per orbit crashes with an accretion disk and ejects gas clouds above and below the midplane
- emission is created by photon production, harder than blackbody temperature
- ablation of the star constraints the lifetime of the system

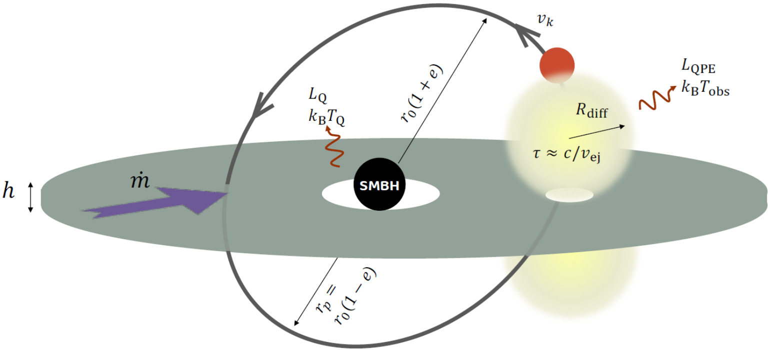


Figure 9: Credit: Linial and Metzger [8].

A stellar mass transfer

- MS star orbits around a SMBH transfering its mass through Roche lobe
- causes relativistic shocks that produce thermal X-ray spectrum

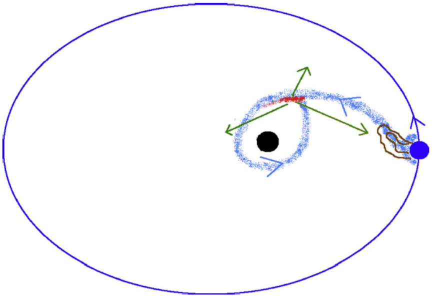


Figure 10: Schematic mass transfer. Credit: Krolik and Linial [9].

Periodicity determination

- we used three algorithms for calculating QPE recurrence times: FFT, Lomb-Scargle, WWZ
- GSN 069 - 9.3 h, 8.9 h, 9.1 h (9 hours inferred from the article Miniutti et al. [3])
- Swift J0230+28 - 25.7 d, 21 d, 19.8 d (values from 15 − 30 days)

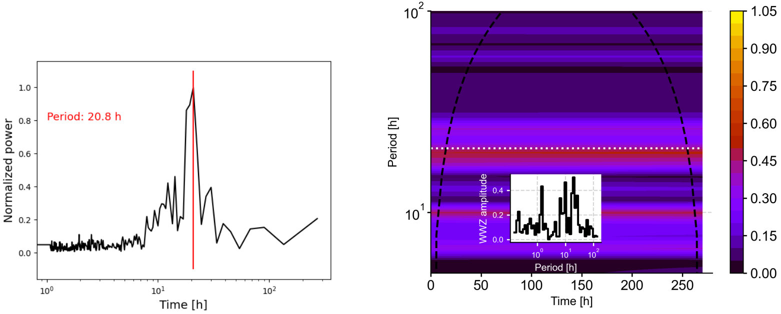


Figure 11: FFT (20.8 h) and WWZ (19.8 h) of eRO-QPE1

Asymmetry of the eruptions

- to analyze the (a)symmetry we fitted a special Gaussian curve to the eruptions
- σ_+/σ_- ratio shows how much is the decay longer than rise
- eRO-QPE1 - 1.29 and GSN 069 - 1.12
- thicker flow in the cold phase than in the hot unstable phase

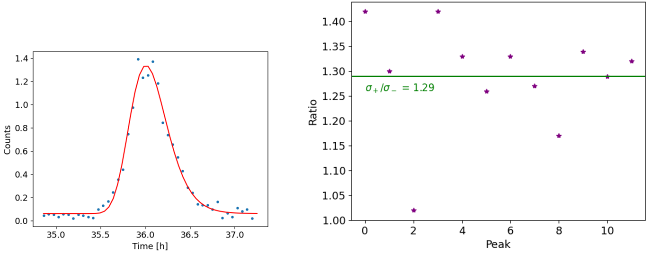


Figure 12: Left: Example of the Gaussian fit, Right: Average value of σ_+/σ_-

Correlations

- comparison of QPE properties (BHM, peak temperature, count-rate, duty cycle, recurrence time) with Pearson and Spearman correlation coefficients
- positive correlation of the MBH and the peak temperature can be traced from the $T(R)$ dependence of the Shakura-Sunayev description

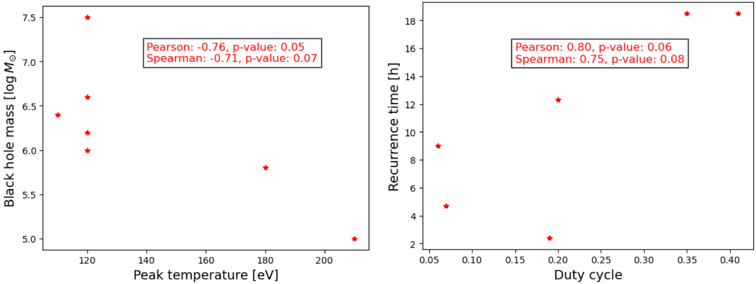


Figure 13: Correlation coefficients

Long-term evolution

- from Pasham et al. [1] epochs of eRO-QPE1 are collected from 2021−2023
- long-term linear fit of peak count rates and periods
- according to our presumption, eRO-QPE1 will not be detectable by June 2025

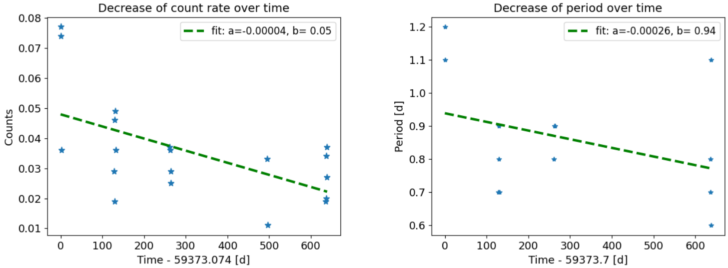


Figure 14: Data collected from 6 observations

Toy model

- Franchini, Alessia et al. [10] tries to explain the mechanism of QPE creation
- BH of 100 $M_\odot$ is orbiting around a MBH on an inclined orbit with almost circular trajectory (Keplerian) – EMRI
- model of accretion disk comes from the α−description
- each time it gets close it crashes with an accretion disk and punches out two hot clouds (with radius R_{inf} of the BH)
- the hot cloud is material with a post-shock temperature, after the crash it adiabatically expands and emits blackbody radiation
- effects causing the quasi-periodicity: EMRI orbital precession, Lense-Thirring precession, accretion disk precession

Toy model

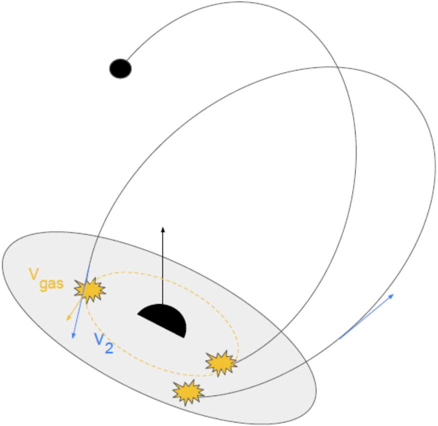


Figure 15: Scheme picture from Franchini, Alessia et al. [10]

Results from the Toy model - Ep. 1

- different results than in the original EMRI model
- GSN 069 is almost periodic (χ = 0.1, e = 0.1, i = 10º, $M_{BH} = 10^6$ M$_\odot$, P = 18 h); M_2 changed to 70 M$_\odot$

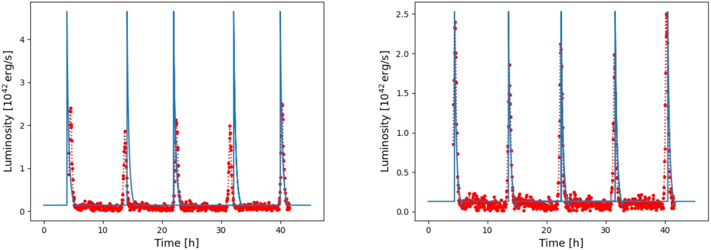


Figure 16: Left: Artificial light curves with parameters from Franchini, Alessia et al. [10], Right: Modified

Results from the Toy model - Ep. 2

- eRO-QPE1 quiescent level estimated to be below 1.6×10^{41} erg.s^{-1}, χ = 0.65, e = 0.05, i = 20°, $M_{\mathrm{BH}} = 10^{5.8}\,\mathrm{M}_\odot$, P = 40 h; M_2 changed to 600 $\mathrm{M}_\odot$
- resulting fit is two orders of magnitude lower from the article

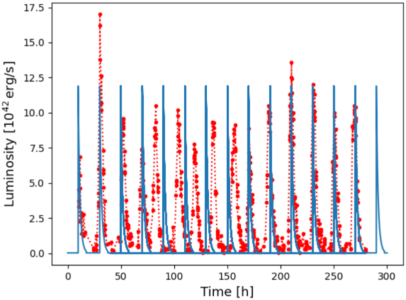
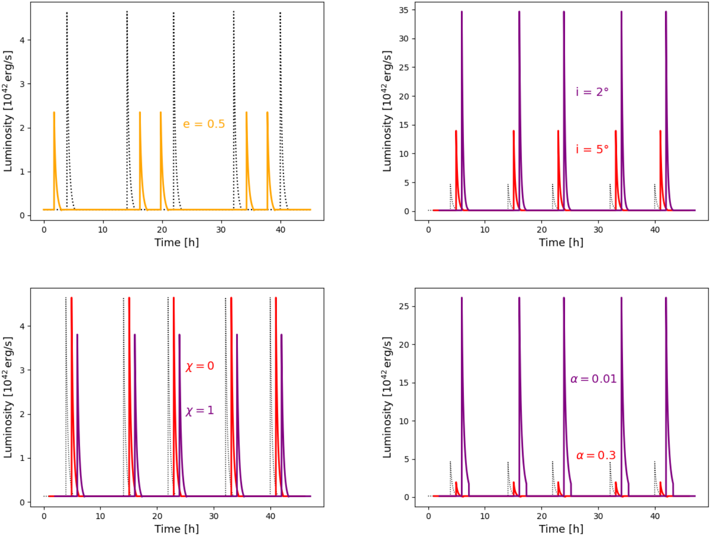


Figure 17: Light curves with modified parameter M_2

Parameter modifications



Discussion

Asymmetry

GSN 069, eRO-QPE1 and eRO-QPE2 have faster rise than decay.

Correlations

With greater MBH comes smaller peak temperature of the eruption. With bigger recurrence time comes bigger duty cycle.

Longevity

In 2 years eRO-QPE1 may stop being detectable. Lifetime of QPEs can be estimated.

Parameters

Extreme values of α-parameter and inclination have immense impact on the outlook of the light curves.

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