# A disk instability model for the quasi-periodic eruptions

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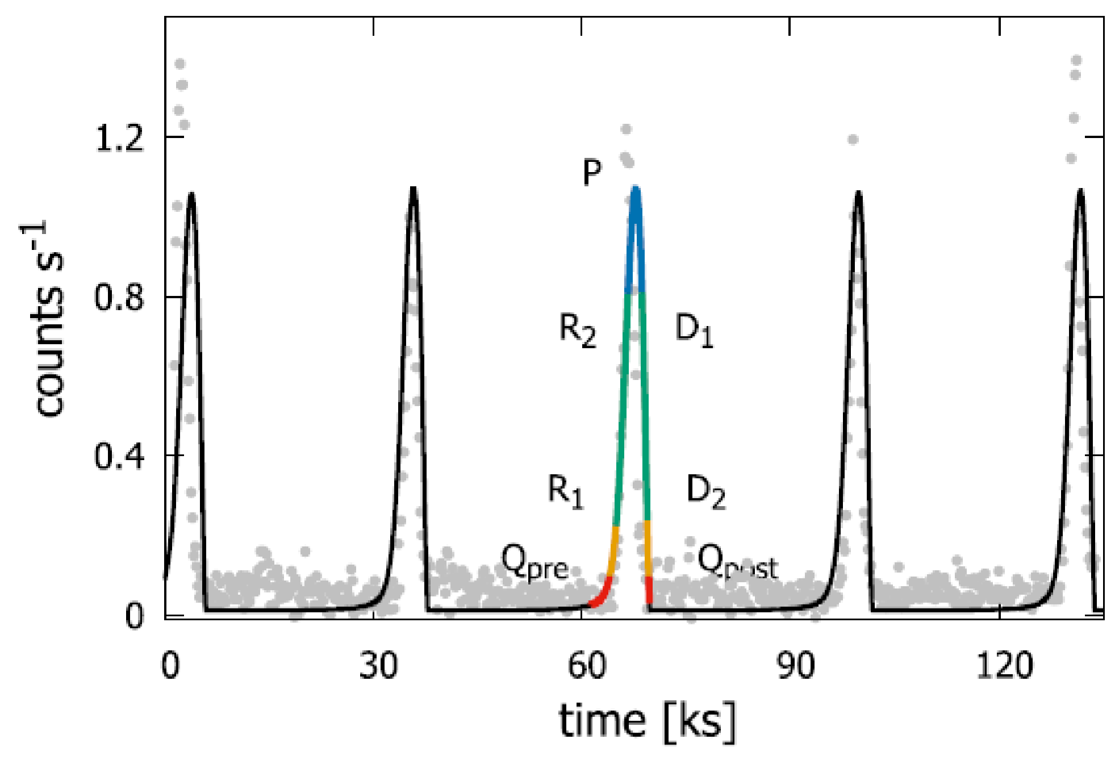
## 1. Introduction

Quasi-periodic eruptions (QPEs) are new phenomena exhibiting quasi-periodic rapid and high-amplitude bursts in soft X-ray that were reported by Miniutti et al. (2019) first in the low-mass Seyfert 2 galaxy GSN 069. The burst duration and period of GSN 069 are about 1 and 9 hr, respectively. In addition to GSN 069, four other QPE sources, i.e., RX J1301.9+2747, 2MASS 02314715-1020112, 2MASX J02344872-4419325, and XMMSL1 J024916.6-041244, have been discovered recently. The primary challenge of this phenomenon is how to construct a physical scenario to produce such a shortly periodic eruptions (several to a dozen of hours).

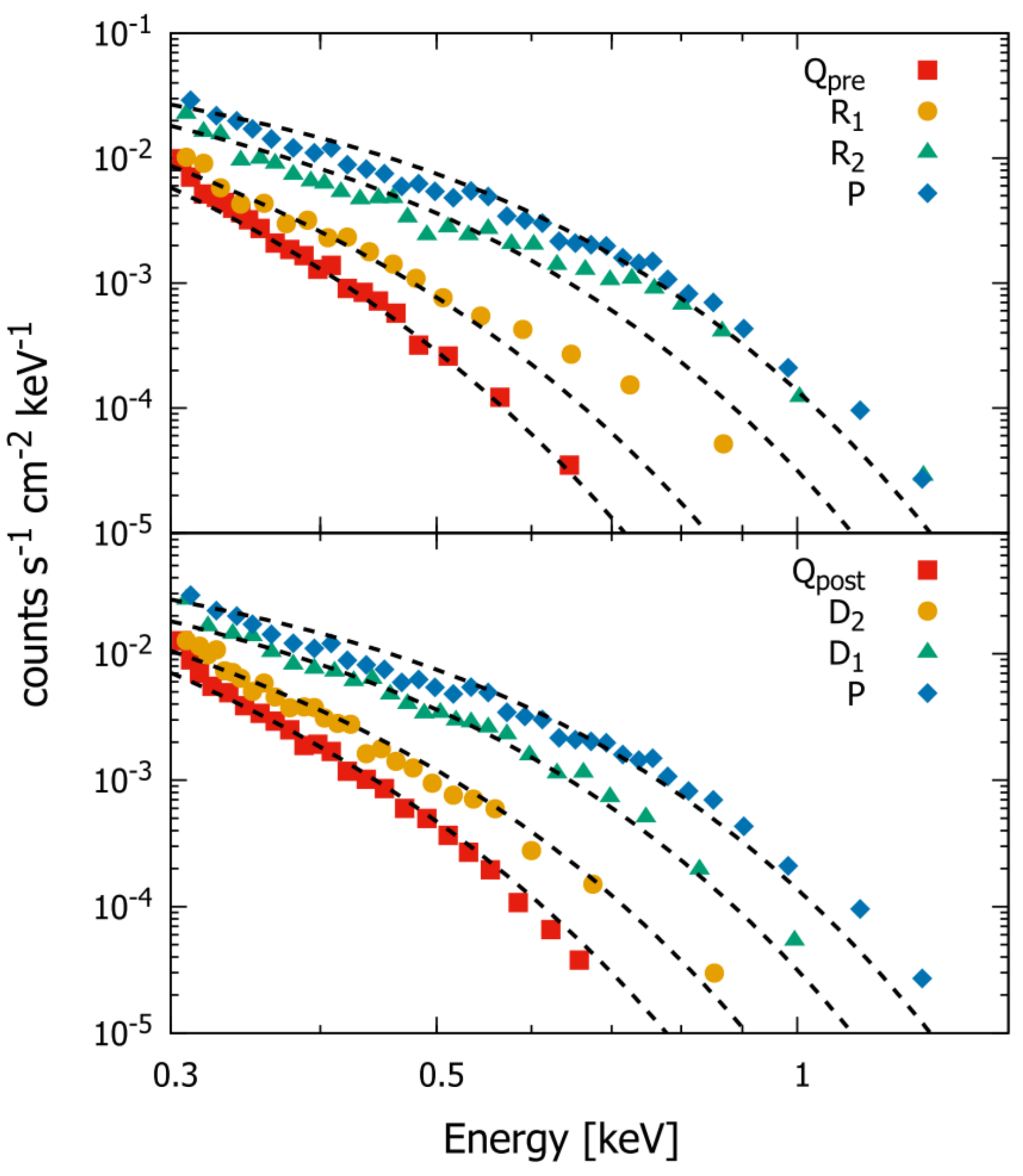
A number of models have been proposed, which can be roughly divided into two categories: while the first one suggests that the periodic outbursts in QPEs originates from the periodic orbital motion of a star captured by the black hole, another one ascribes the periodic behavior to the instability of inner accretion disk dominated by the radiation pressure. Notably, only the model of Pan et al. (2022) is able to fit both the light curves and the phase-resolved X-ray spectrum simultaneously during outbursts in GSN 069.

## 3. GSN 069

### Light curve & spectral evolution



The solid line is the result of our model and the grey dots are the observation data.



The dash lines are the results of our model and the colored dots are the observation data.

### Parameters

| $M$ | $a_*$ | $f$ | $\dot{m}$ | $\alpha$ | $\beta_1$ | $\mu$ |
|---|---|---|---|---|---|---|
| $2\times10^5$ | 0.98 | 0.9 | 0.08 | 0.15 | 38 | 0.27 |

(We did not take the hardening factor into account in this calculation.)

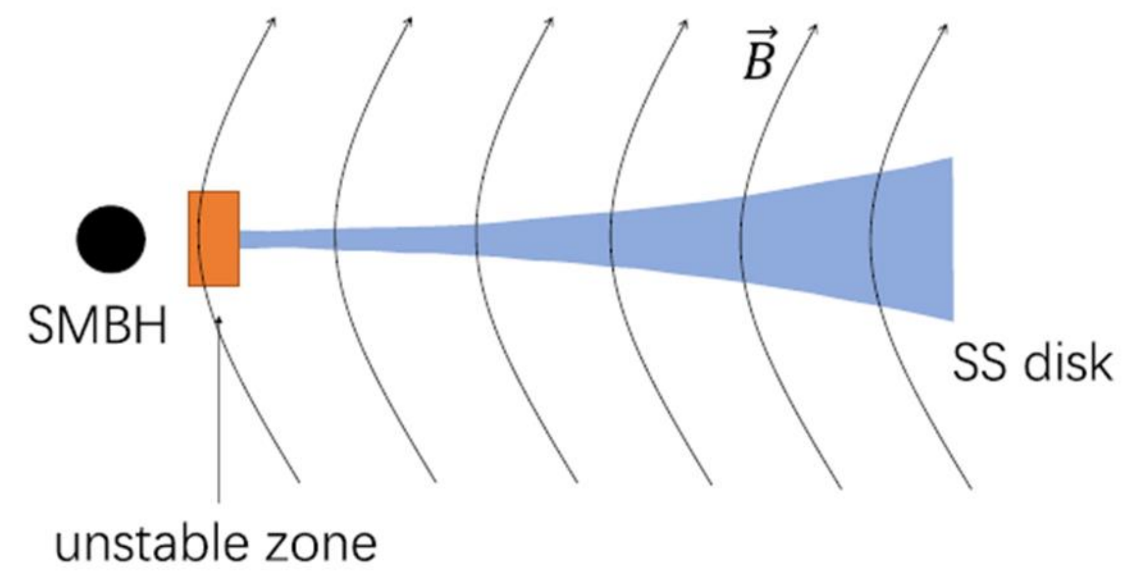
**Ref: A Disk Instability Model for the Quasi-periodic Eruptions of GSN 069**

## 5. Conclusion

- Our model can qualitatively fit the light curves and the phase-resolved X-ray spectrum of GSN 069.
- A hardening factor is applied to adjust the effective temperature of the accretion disk, allowing us to accurately fit the observed X-ray spectra of all other QPEs sources.
- We suggest that the high discovery rate of TDEs in QPEs is due to the ability of TDEs to experience a wide range of accretion rates in a relatively short period, making it easier to meet the parameter space requirements of our model.
- After experiencing a single outburst in 2020, the QPEs phenomenon disappeared in GSN 069. We suggest that if its large-scale magnetic field environment remains relatively stable, it will be able to observe the QPE phenomenon again when the accretion rate decreases to a critical value.
- Some observational details are still problematic for our toy model:
  - the asymmetric eruptions (a faster rise and slower decay is seen in some of the QPE sources).
  - the peak delay at different energy bands (the flux of higher energy bands peak at earlier times).
  - the hard X-ray excess (~1keV) of GSN 069 that is not well reproduced by our model.
  - the alternating long/short and strong/weak QPEs have been observed in GSN 069 and eRO-QPE2.

## 2. Model

### The schematic picture of our model



The outer blue region represents a stable thin disk dominated by gas pressure and the inner orange region is the unstable zone dominated by radiation pressure.

### Two components structure

The observed X-ray spectra at various burst stages in GSN 069 have been successfully reproduced by using a constant disk blackbody plus a variable blackbody component.

**The steady outer disk** can provide a constant disk blackbody emission.
**The inner unstable zone** can be constrained to a narrow belt by applying a large-scale magnetic field ($\beta_1$), and we can then consider the radiation from this small region as a single-temperature blackbody.

### Some modifications

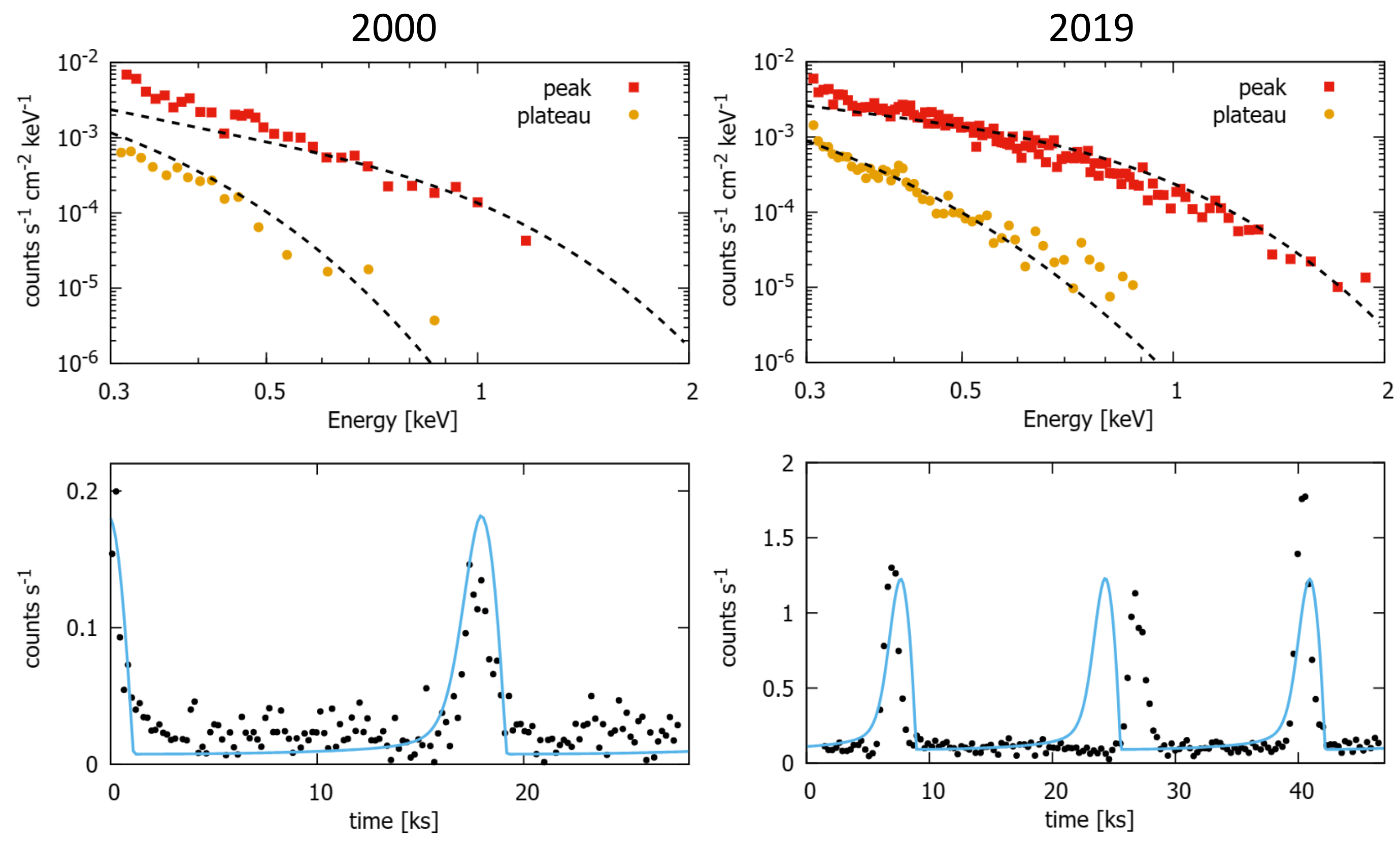
**General relativistic**: Introducing the effect of black hole spin ($a_*$).
**General form for the viscous torque**: Making the accretion disk more stable, further reducing the unstable region ($\mu$).
**Non-zero torque condition at ISCO**: Increasing the temperature of the inner region of the accretion disk ($f$).

### Hardening factor

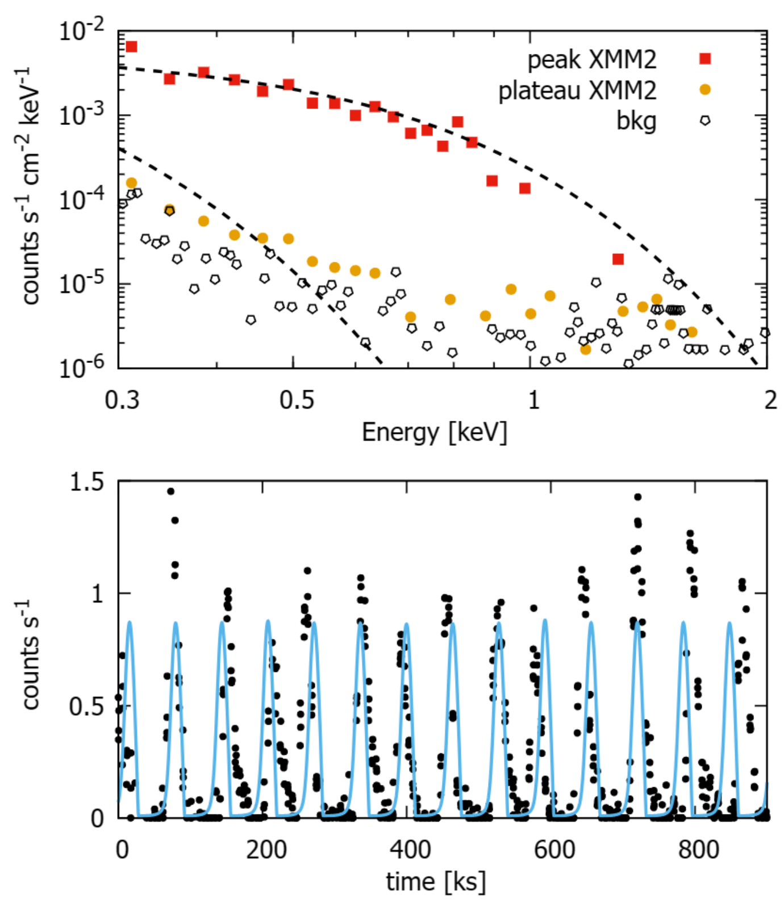
We correct the deviation of the local radiation spectrum of the accretion disk from the blackbody by introducing a hardening factor $f_{\rm cor}$.

## 4. Other sources

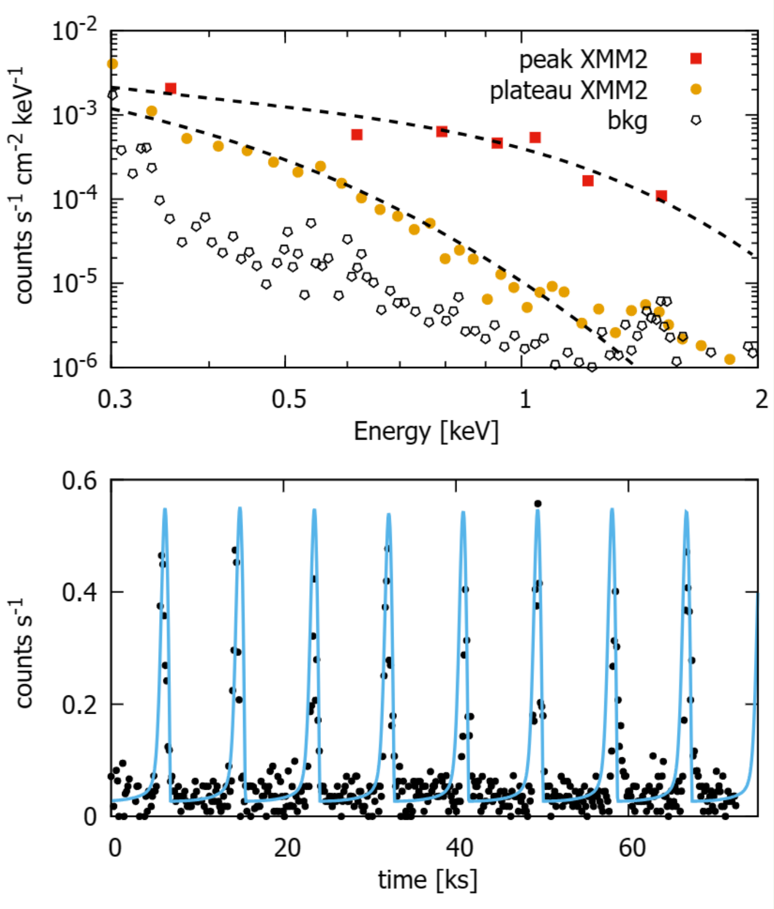
### RX J1301.9+2747



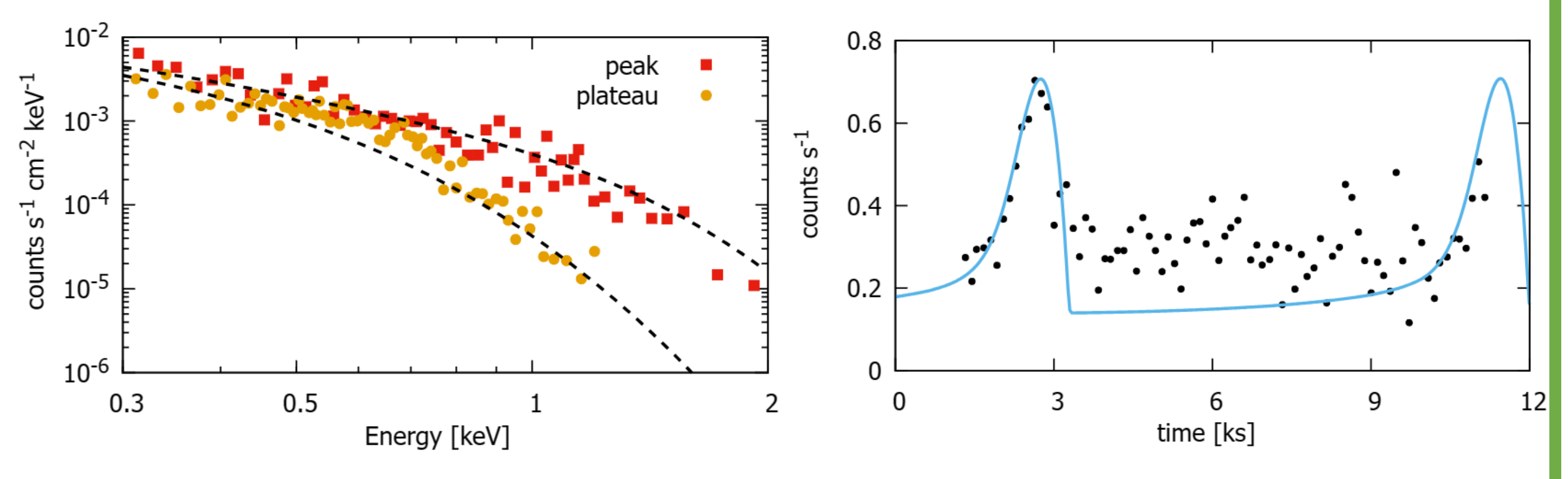
### eRO-QPE1



### eRO-QPE2



### XMMSL1 J024916.6-041244



### Parameters

| Source | $M(\times10^5 M_\odot)$ | $\dot{m}(\dot{M}_{\rm Edd})$ | $\alpha$ | $\beta_1$ | $\mu$ | $n_{\rm H}(\times10^{20}{\rm cm}^{-2})$ | $\Delta R(R_s)$ | $f_{\rm cor,in}$ |
|---|---|---|---|---|---|---|---|---|
| RX J1301.9+2747 (2000) | 3 | 0.15 | 0.15 | 5.5 | 0.1 | 0.4 | 0.088 | 2.37 |
| RX J1301.9+2747 (2019) | 3 | 0.15 | 0.15 | 5 | 0.1 | 0.4 | 0.083 | 2.41 |
| eRO-QPE1 | 10 | 0.15 | 0.1 | 8 | 0.15 | 2 | 0.048 | 2.51 |
| eRO-QPE2 | 1 | 0.19 | 0.1 | 10.5 | 0.1 | 10 | 0.119 | 2.24 |
| XMMSL1 J024916.6-041244 | 0.7 | 0.08 | 0.15 | 24.5 | 0.22 | 6 | 0.099 | 2.19 |

We set $a_* = 0.98$ and $f = 0.9$ for all the calculations.

**Ref: Application of the disk instability model to all Quasi-Periodic Eruptions**

## Author

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