



# The Rhythms of Chaos

## Understanding Quasi-Periodic Eruptions

Erwan QUINTIN

N. Webb, E. Kammoun, S. Guillot, & others

Journées PNHE 2023 - Transitoires S1

# NGC 7793

Optical (DSS):

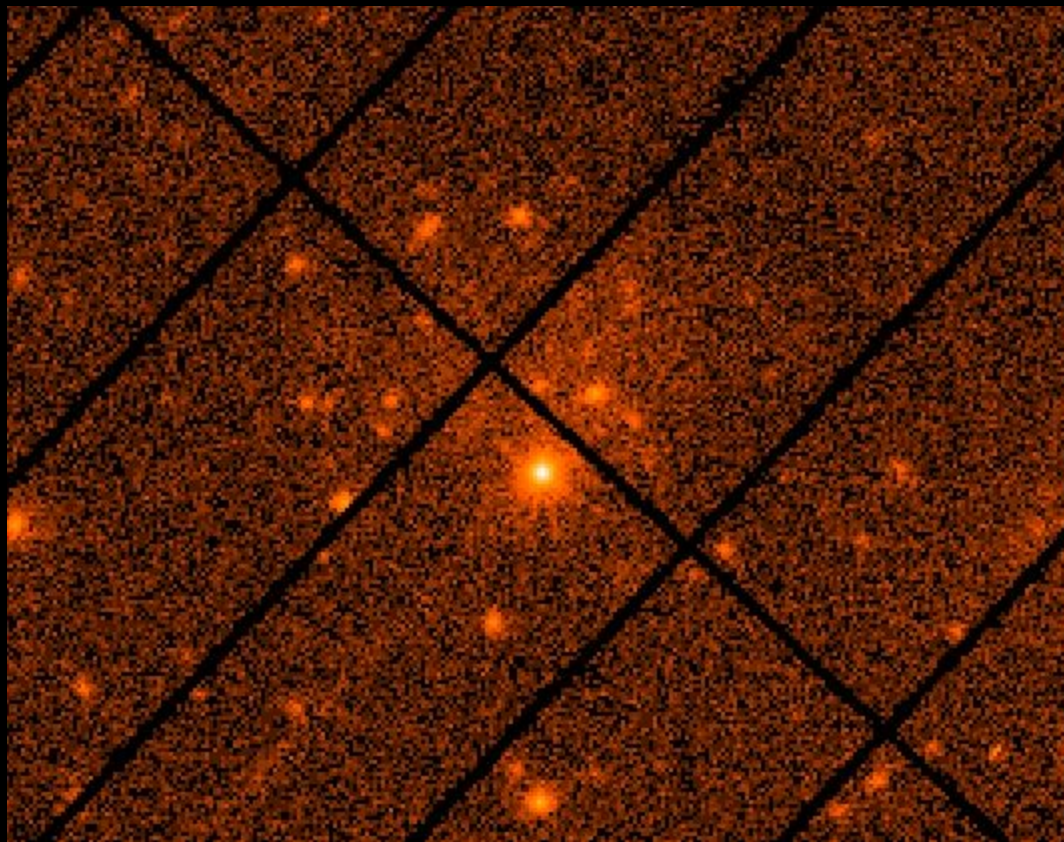
- Gas
- Dust
- AGNs
- Foreground stars



# NGC 7793

X-ray (XMM):

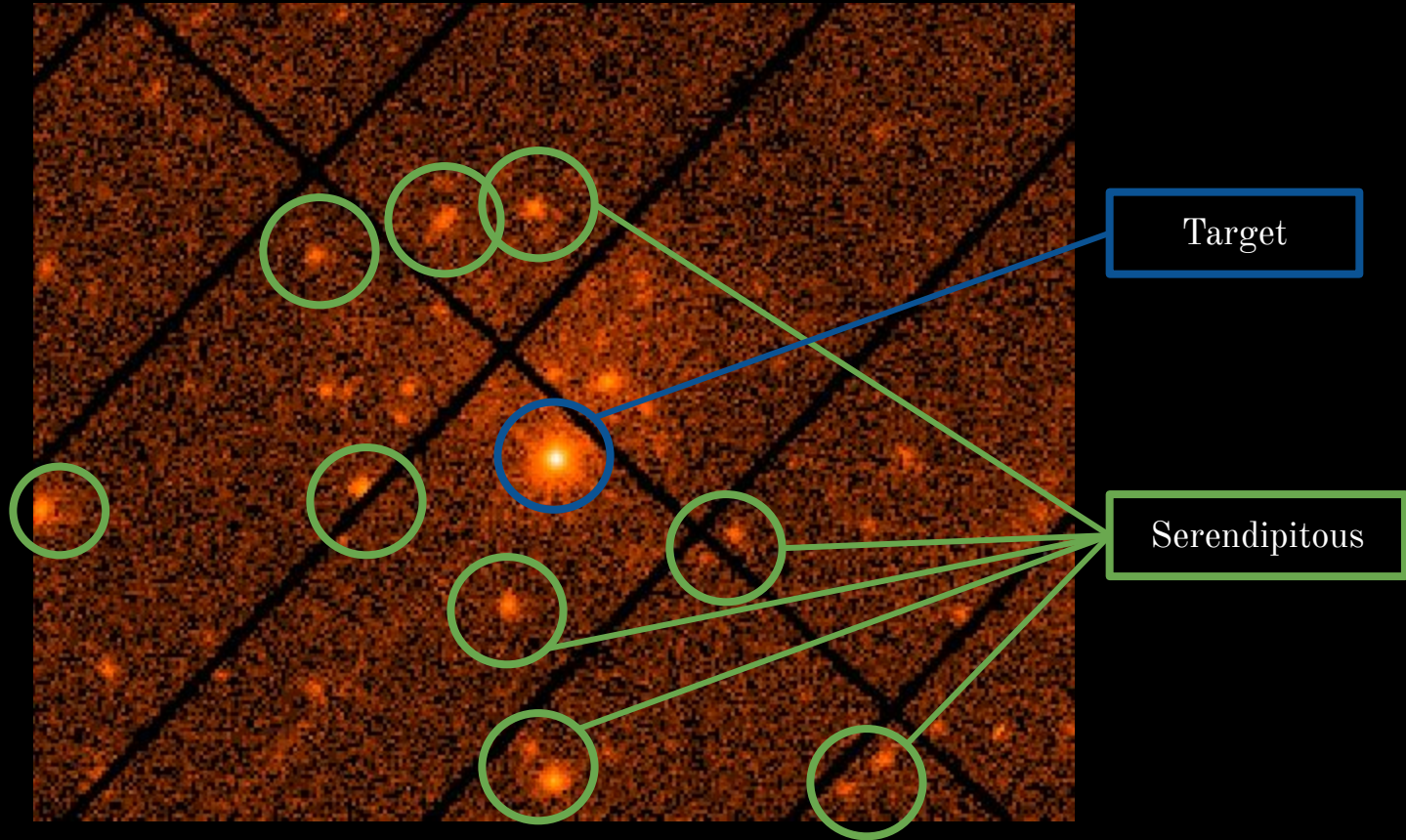
- Binaries
- AGNs
- Some foreground stars



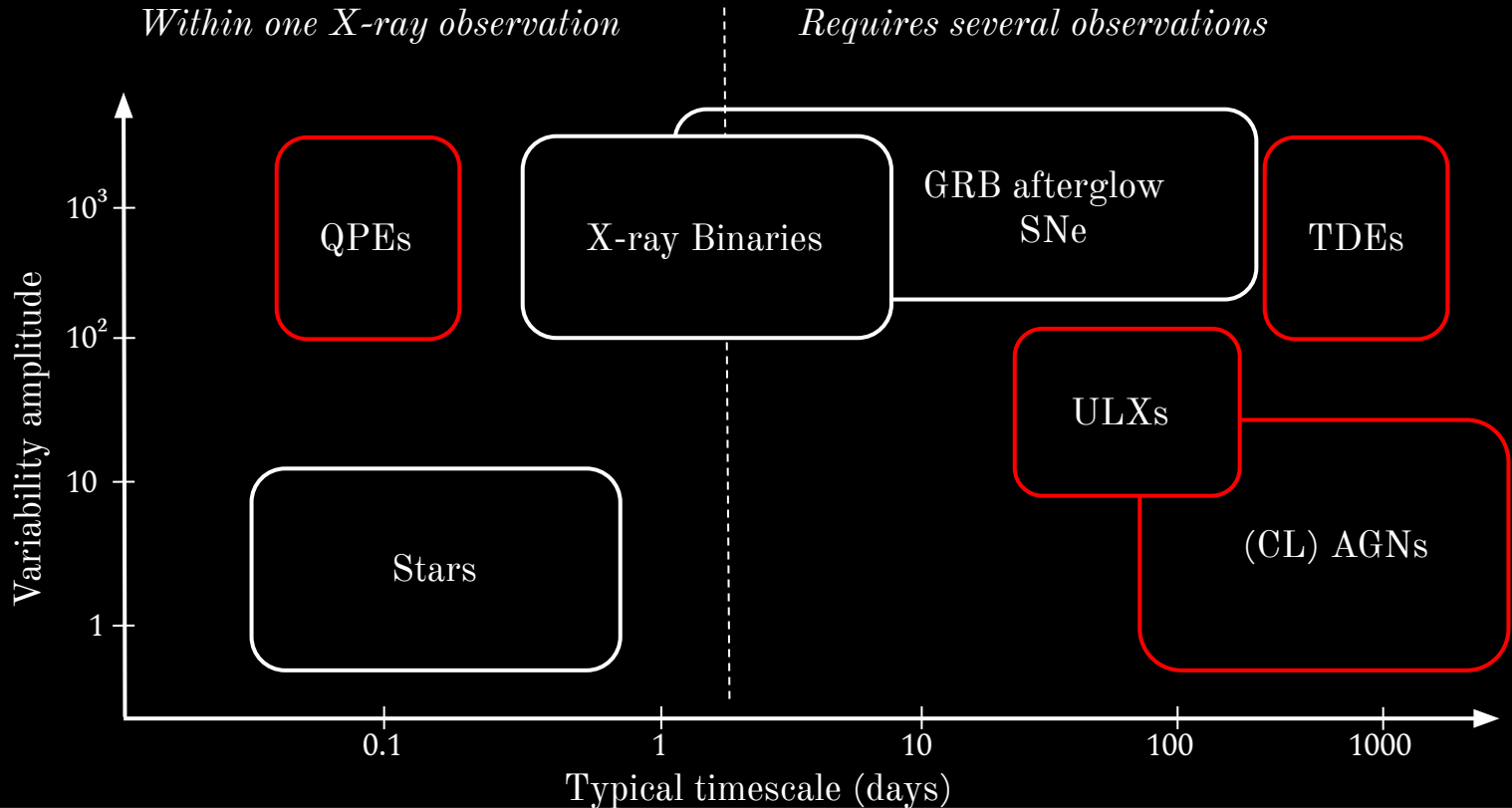
# NGC 7793

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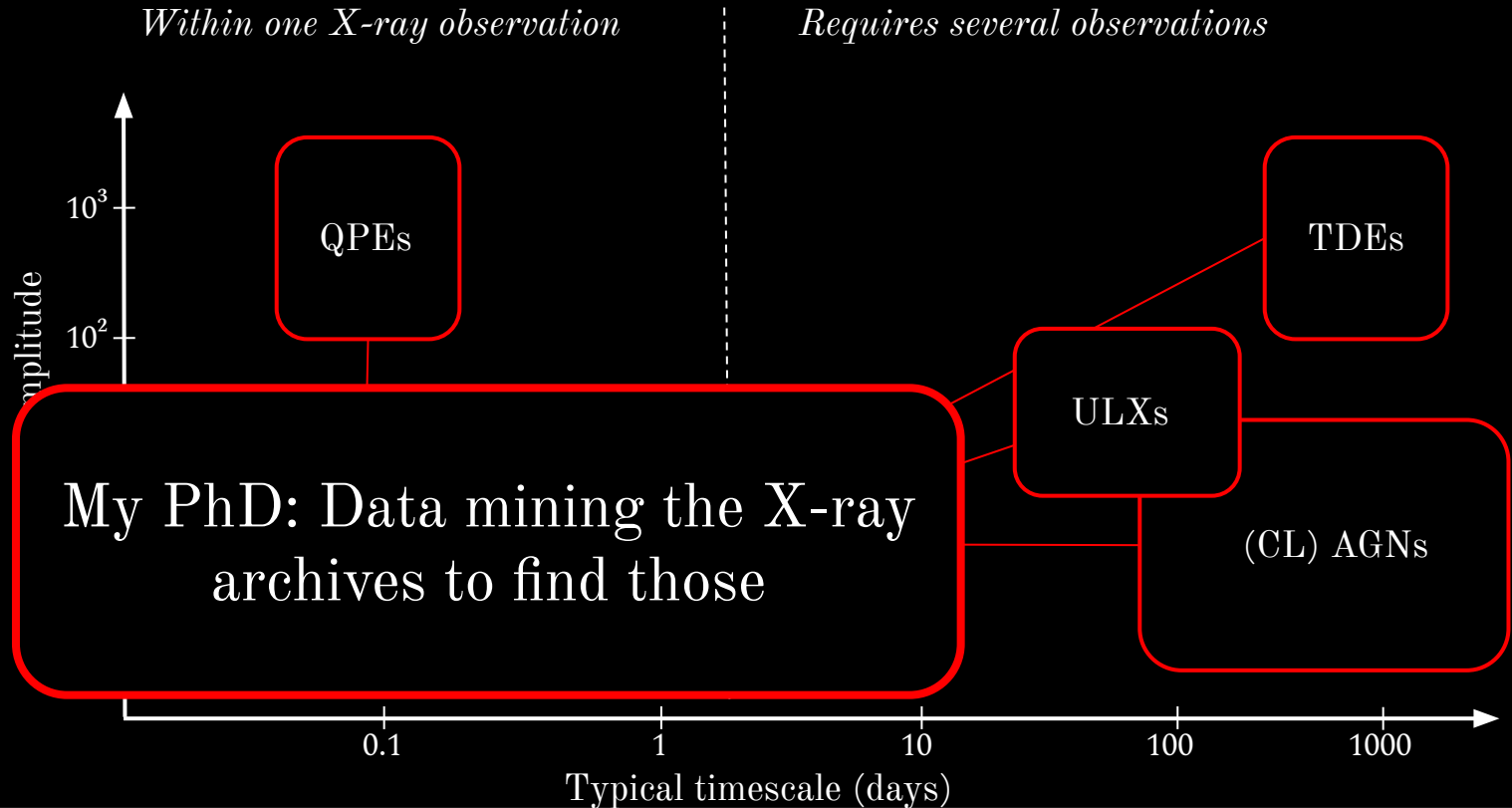
- Binaries
- AGNs
- Some foreground stars



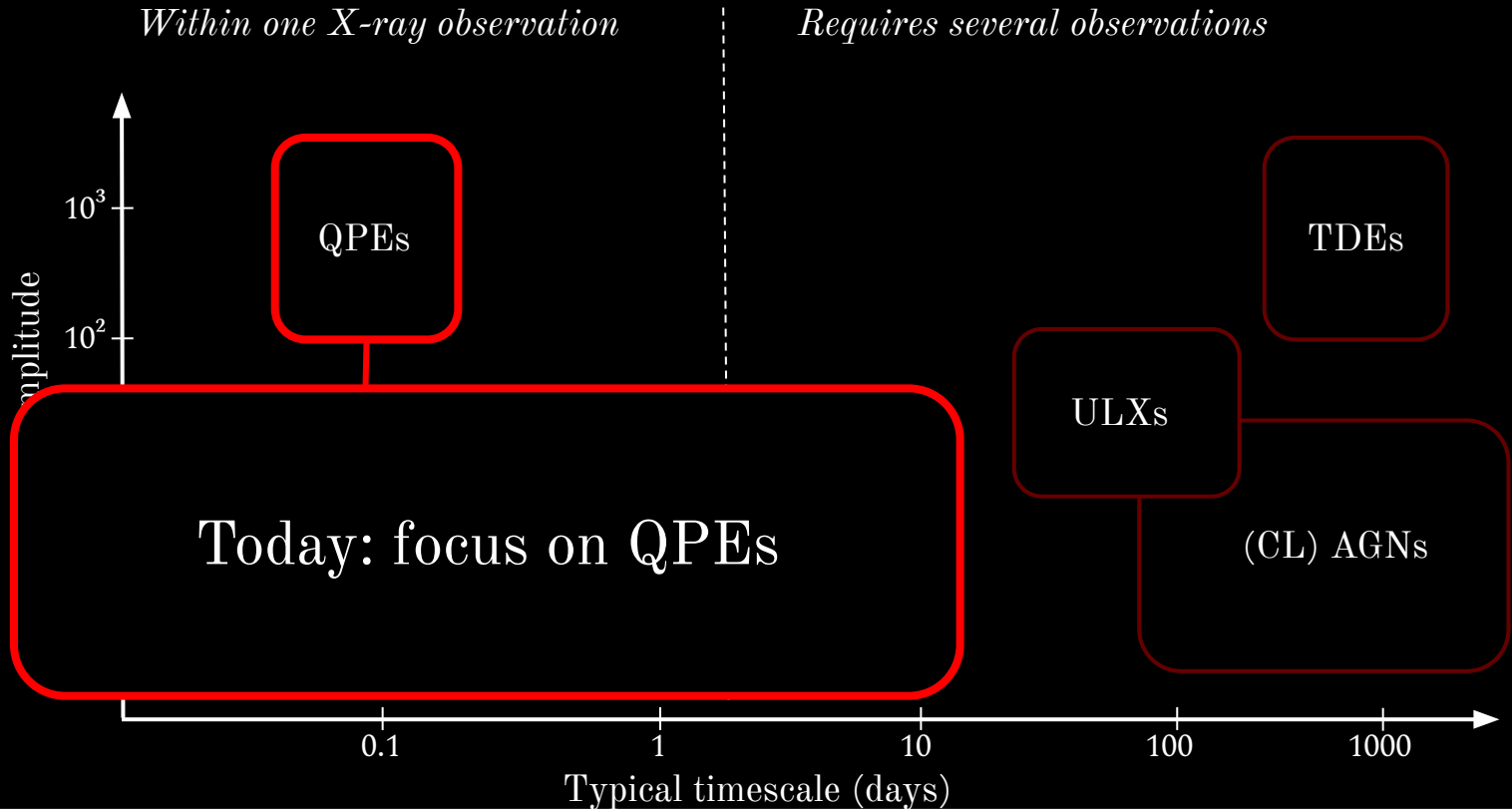
# A quick view of the X-ray transient sky



# A quick view of the X-ray transient sky



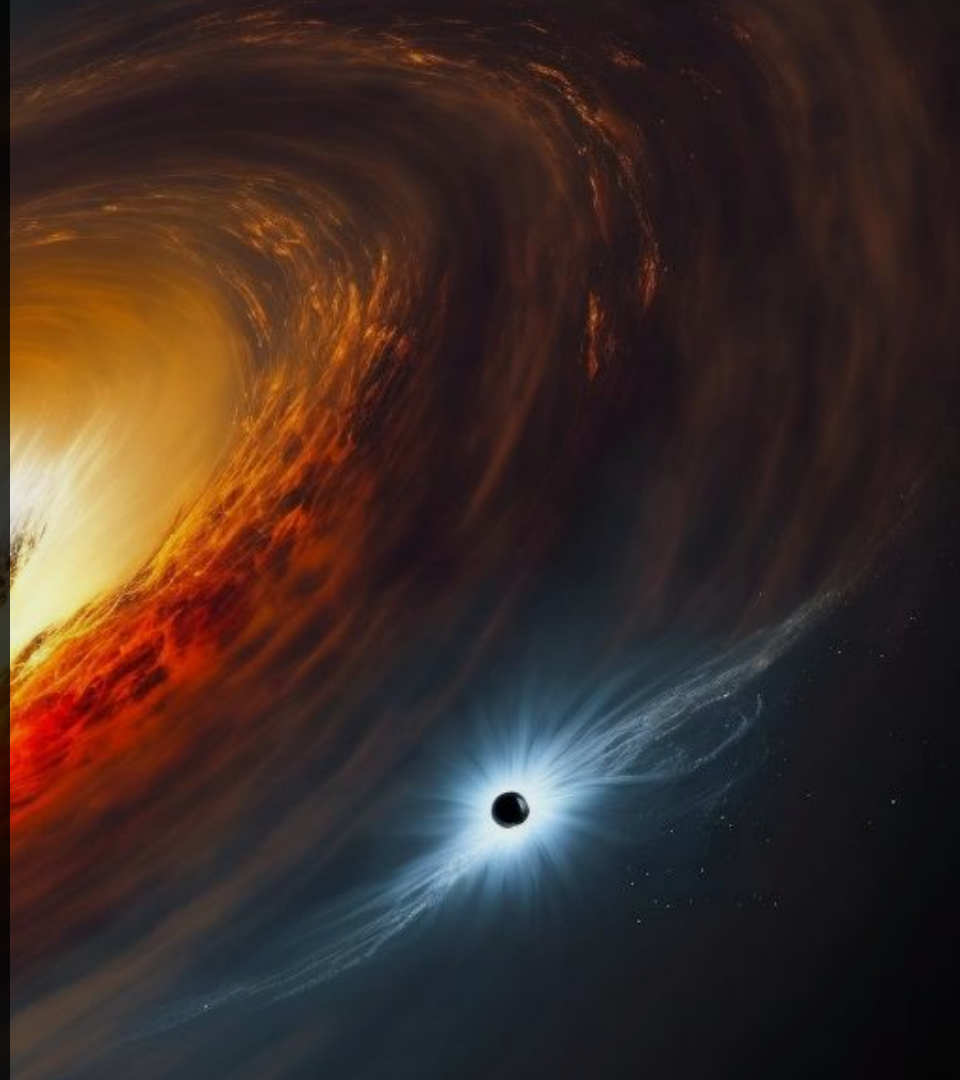
# A quick view of the X-ray transient sky



I – Crash course on QPEs

II – The hunt for new  
archival transients

III – Tormund: a new QPE  
candidate

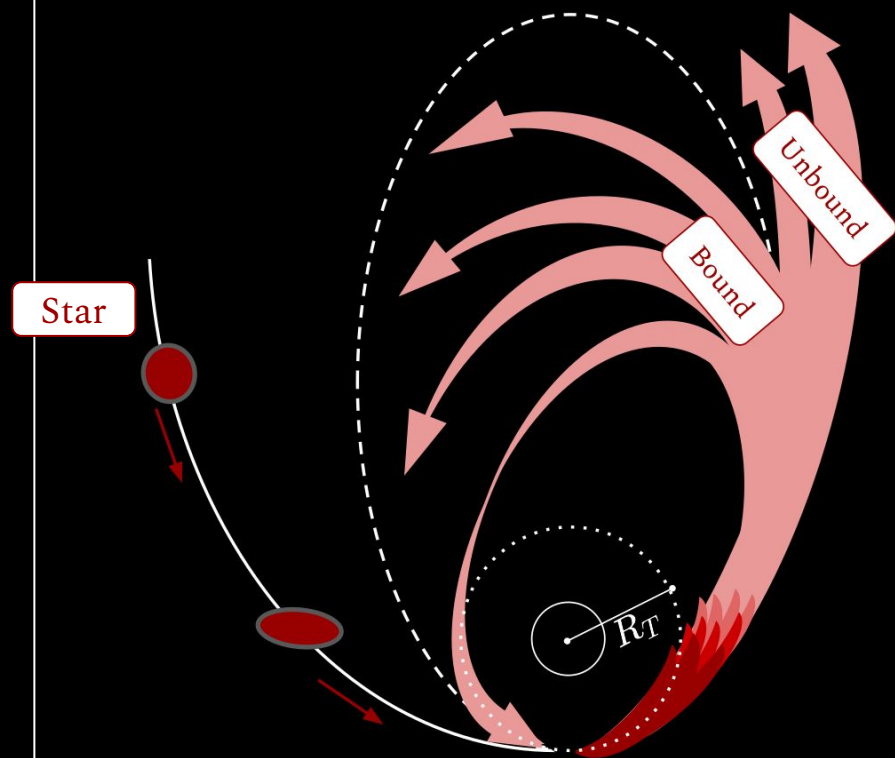




A dramatic astronomical scene featuring a black hole with a glowing accretion disk and a bright star with a blue-white flare. The black hole is positioned in the center, with a large, swirling accretion disk of orange and yellow gas surrounding it. A bright, blue-white star is visible in the lower right, emitting a powerful flare. The background is a dark, starry space.

# I. A crash course on QPEs

# Tidal Disruption Events



# Tidal Disruption Events

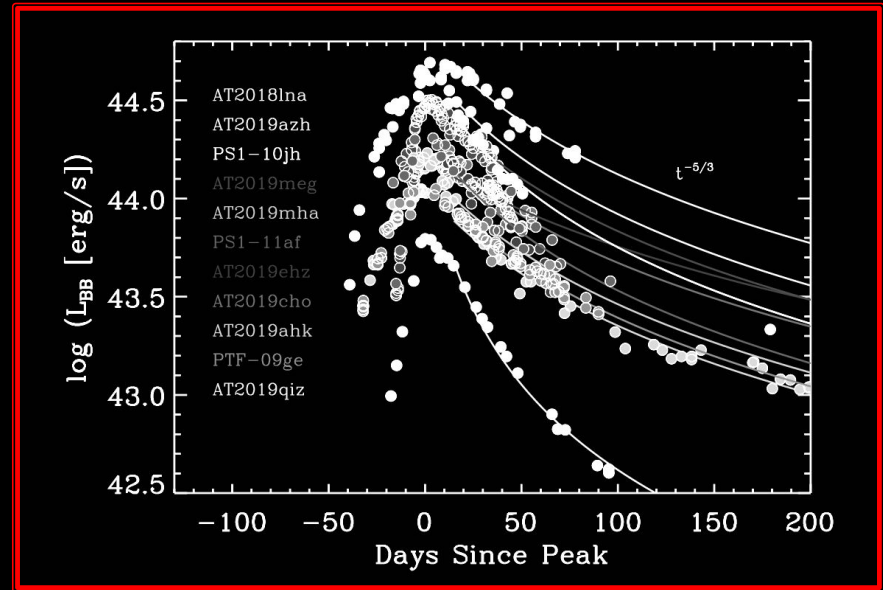
In one wavelength:

- Burst of amplitude 10-100 over a few months
- Temporal evolution :  $F \propto t^{-5/3}$

Multi-wavelength :

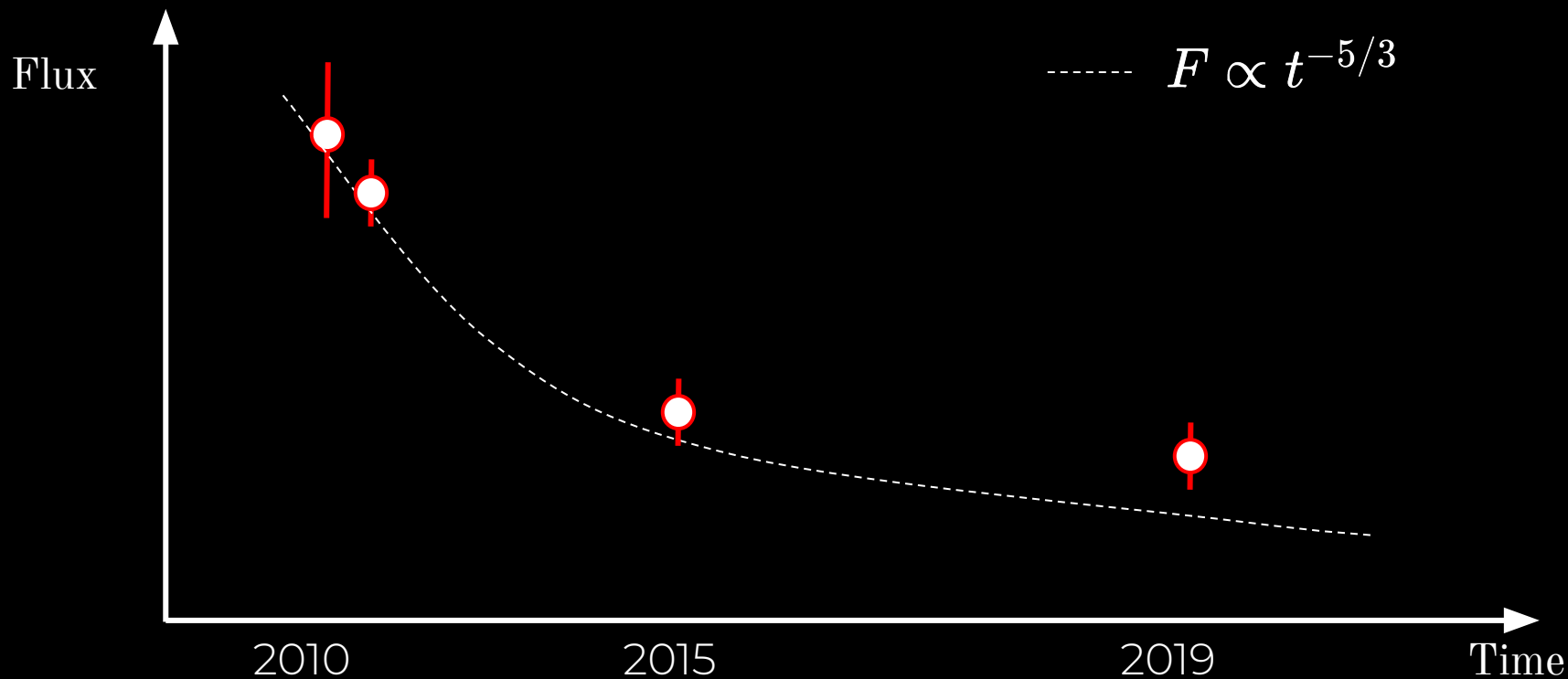
- ?

Few are known (~20 in X & Optical)



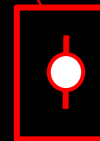
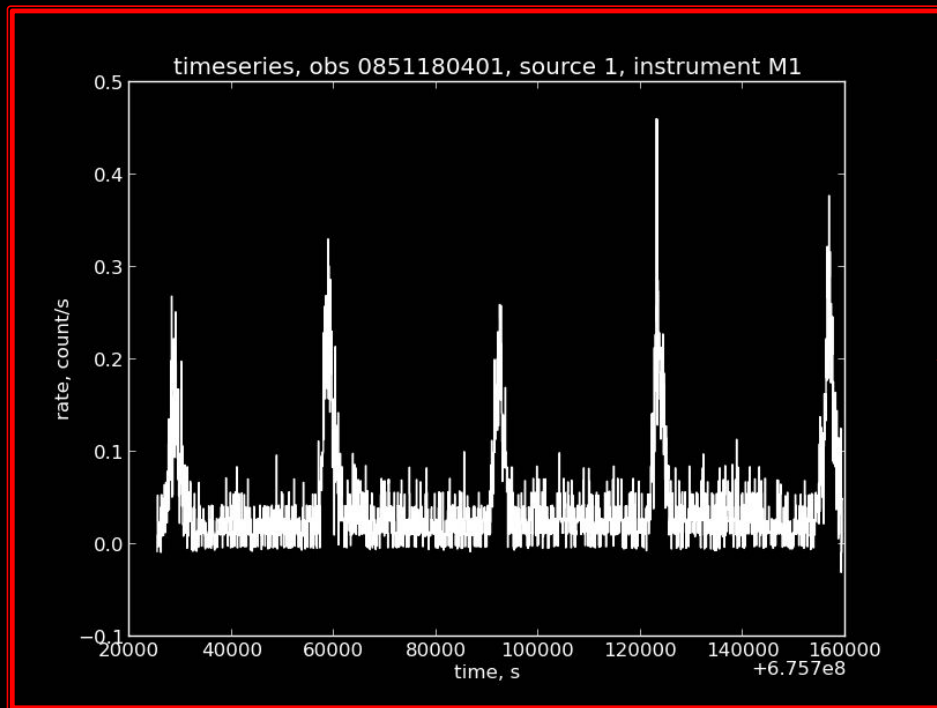
Gezari 21

# GSN 069: your usual X-ray TDE...



# GSN 069: your usual X-ray TDE... and the first QPE

Flux



2010

2015

2019

Time

# Quasi-Periodic Eruptions

## Thermal spectrum

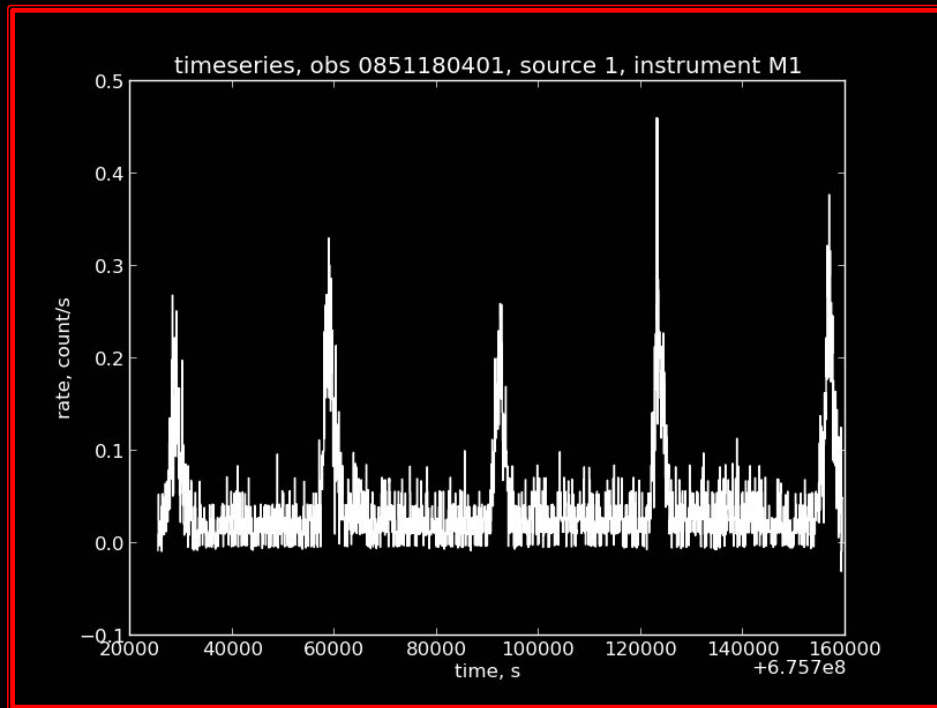
- Temperature:  $\sim 50\text{eV}$  to  $\sim 100\text{eV}$
- Norm  $\sim \times 10$

## Timing

- Duration  $\sim 5\text{ks}$
- Recurrence  $\sim 30\text{ks}$

Alternating strong/weak

Quiescent  $\neq 0$



## Other known QPEs

**GSN 069** (Miniutti+19), found serendipitously

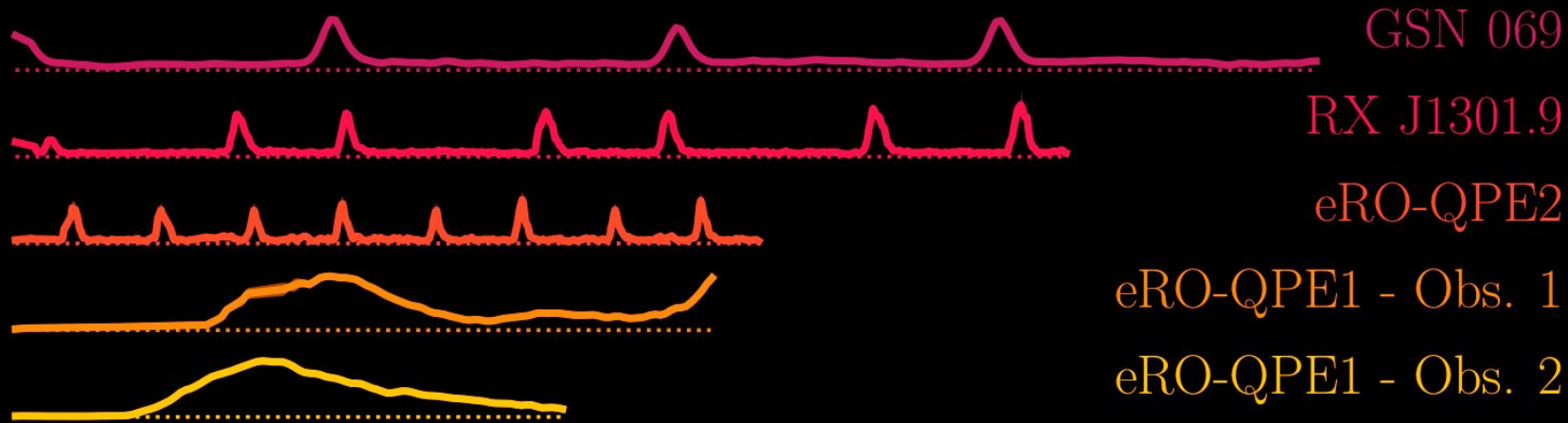
**RX J1301.9+2747** (Giustini+20), found in ROSAT & XMM archives

**eRO-QPE1** & **eRO-QPE2** (Arcodia+21), found in dedicated eROSITA search

**XMMSL1 J0249-0412** (Chakraborty+21), found in XMM archives

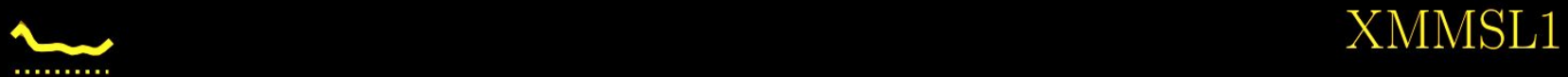
5 QPE sources known to date

# Bona fide



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# Candidates



50 ks



# Overall properties

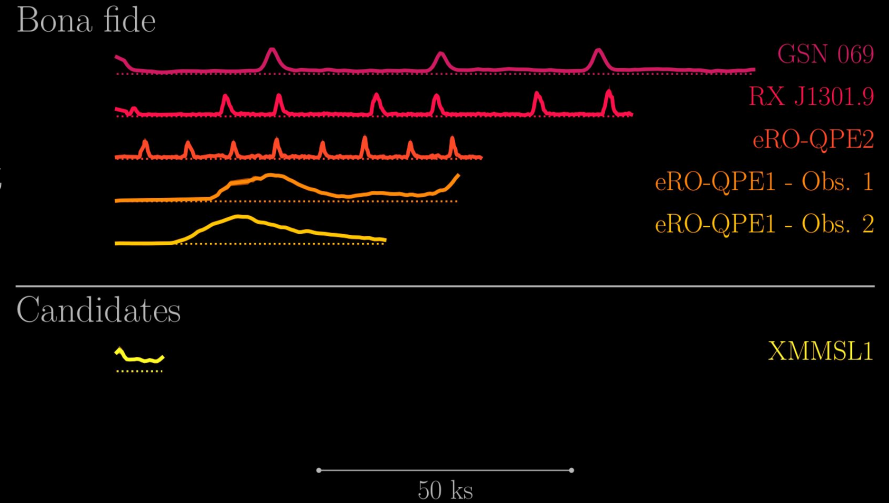
Luminosity:

rising from  $10^{42}$  to  $10^{44}$  erg s $^{-1}$

Timescales:  $\sim 5$ ks peak every  $\sim 30$ ks, except slower eRO-QPE1

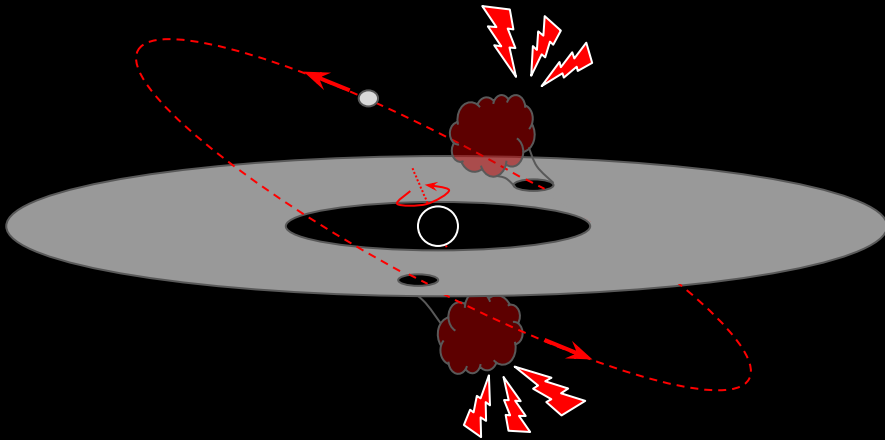
Low-mass SMBH ( $10^5 - 10^6$  Msun)

2 out of 5 are linked to past TDEs



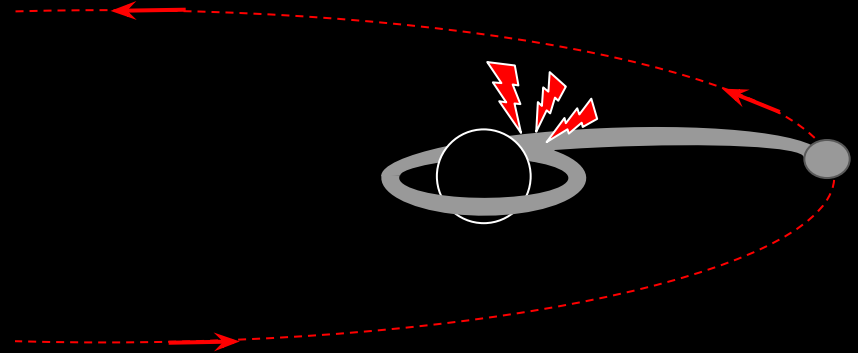
# Two main models: partial TDE, then...

## I. Disk Collision



e.g. Xian+21, Linial+23, Franchini+23

## II. Repeated Partial TDEs

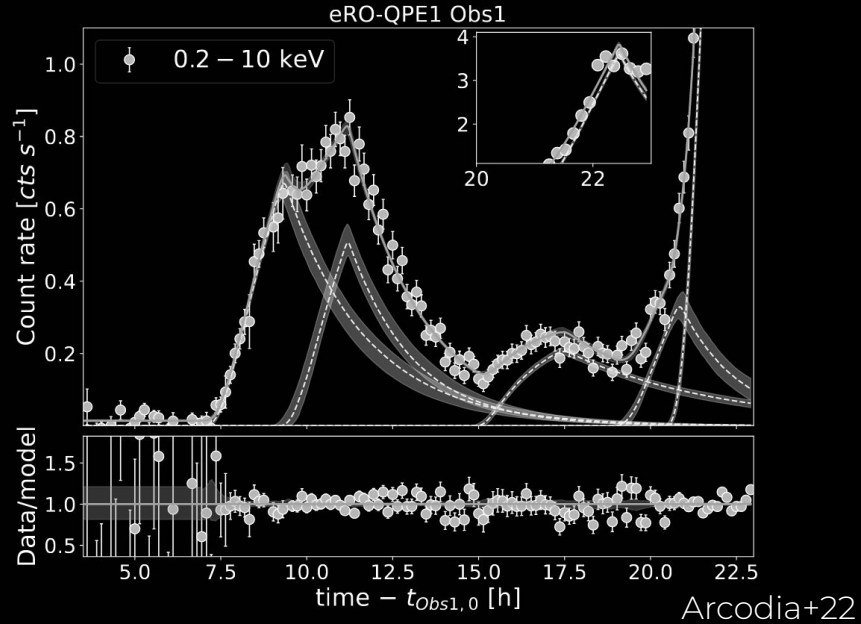


e.g. King 20, 22, Zhao+22, Wang+22, Chen+22

# Most recent advances

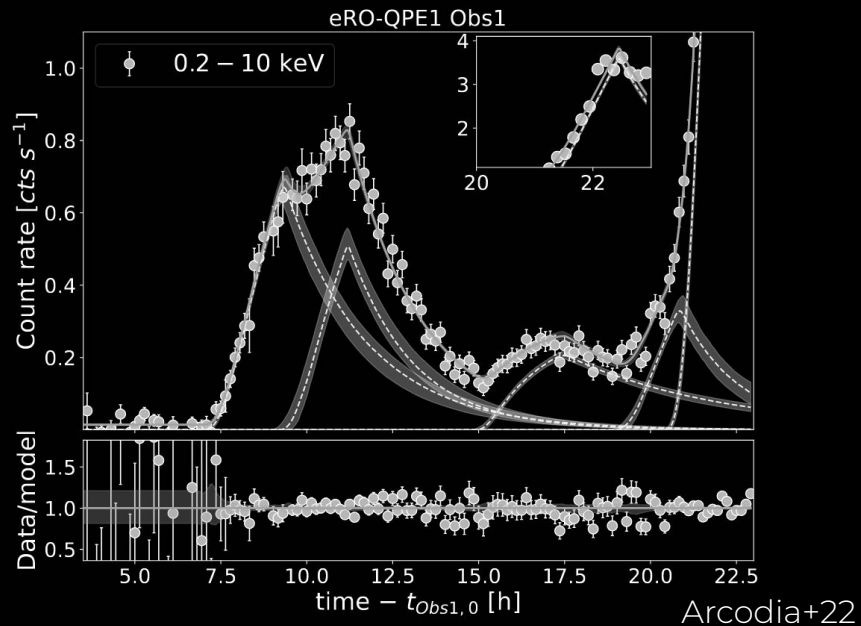
# Most recent advances

## I. Multi-peak profile in eRO-QPE1

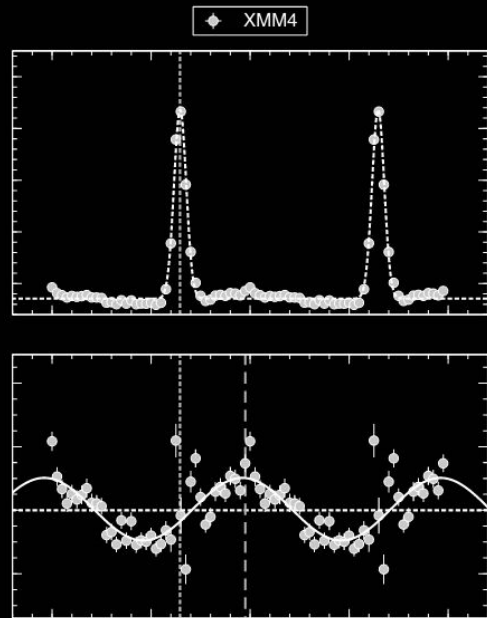


# Most recent advances

## I. Multi-peak profile in eRO-QPE1



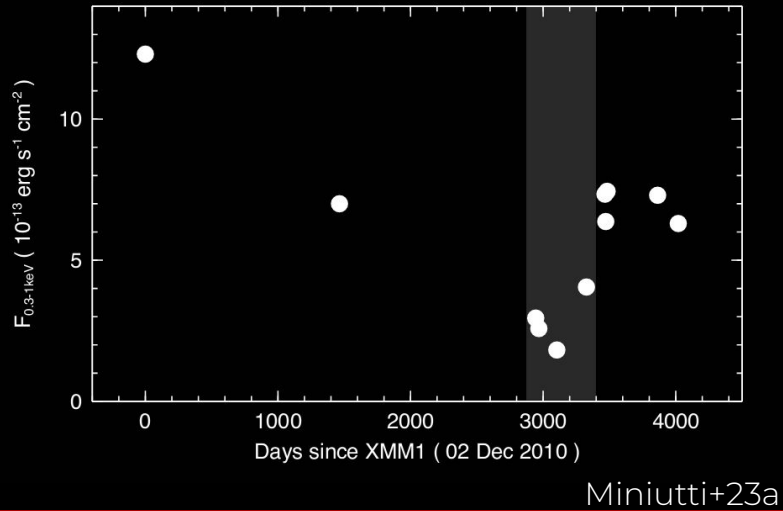
## II. Quasi-Periodic Oscillations of the quiescent state



Miniutti+23a

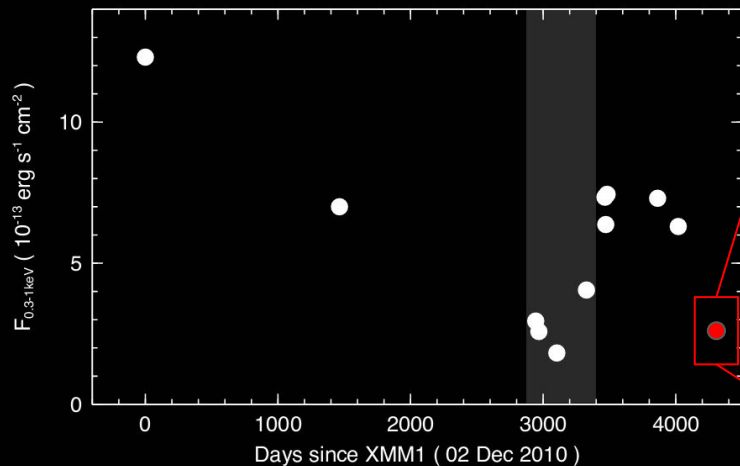
# Most recent advances

## III. Long-term rebrightening of GSN 069 : a second TDE?

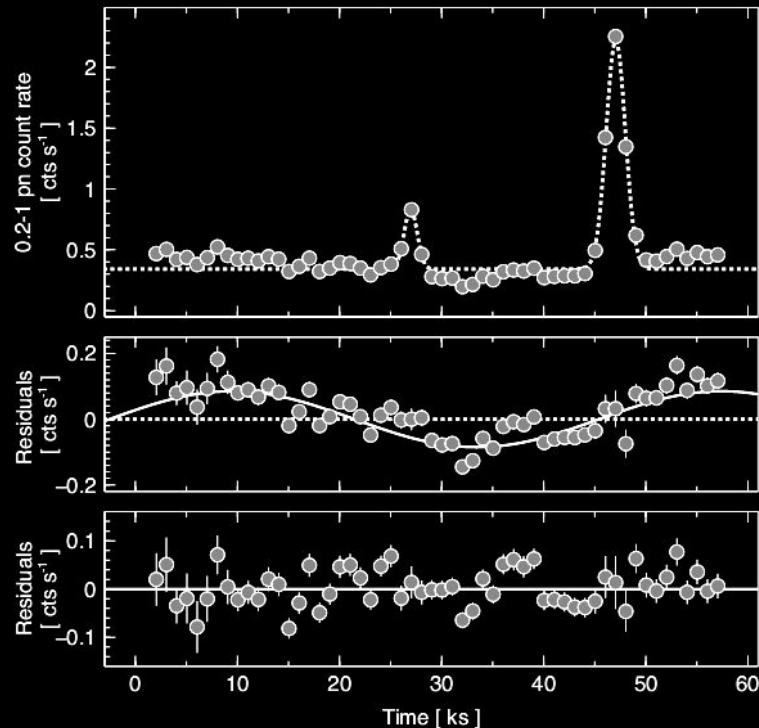


# Most recent advances

## III. Long-term rebrightening of GSN 069 : a second TDE?



Miniutti+23a



Still “Alive & Kicking” ! Miniutti+23b

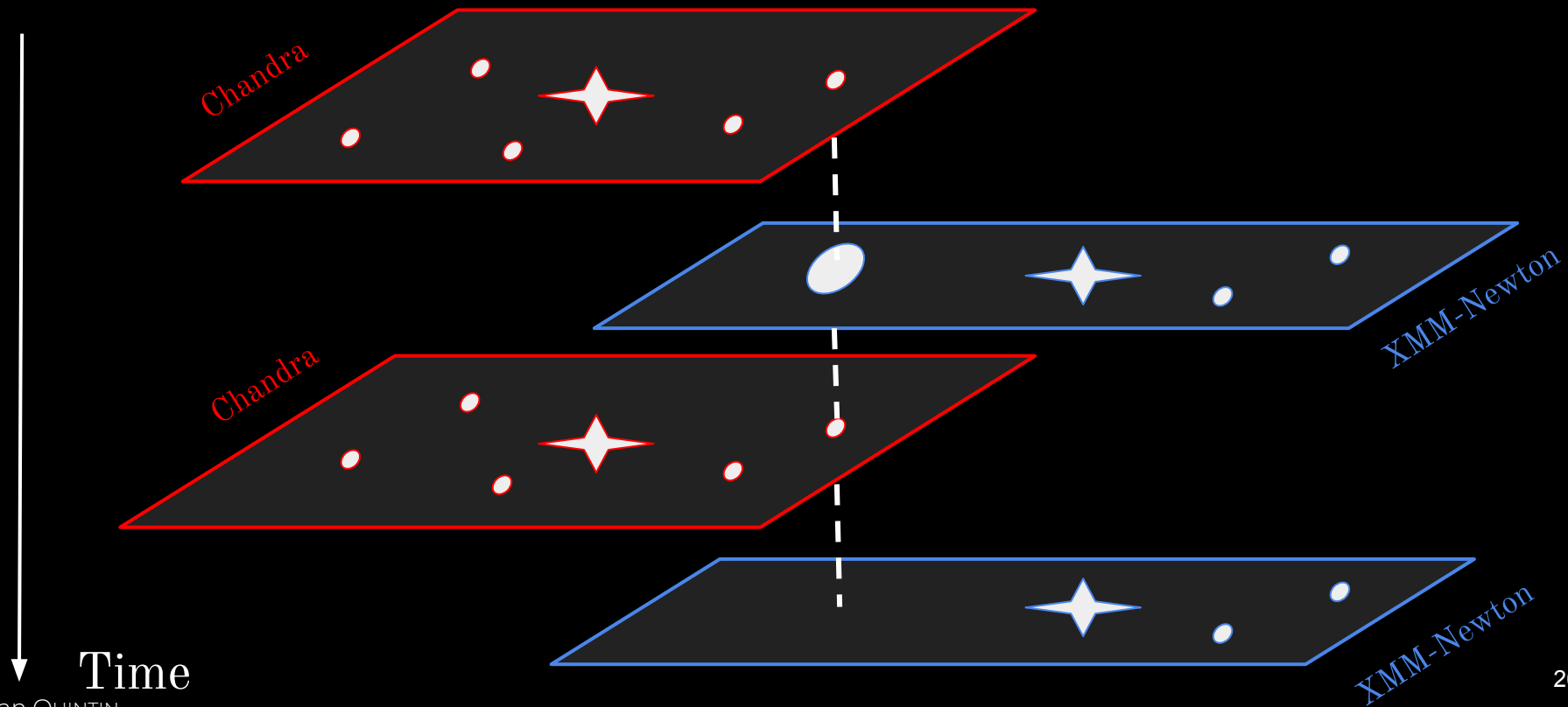
Still quite unclear: we need  
more candidates !



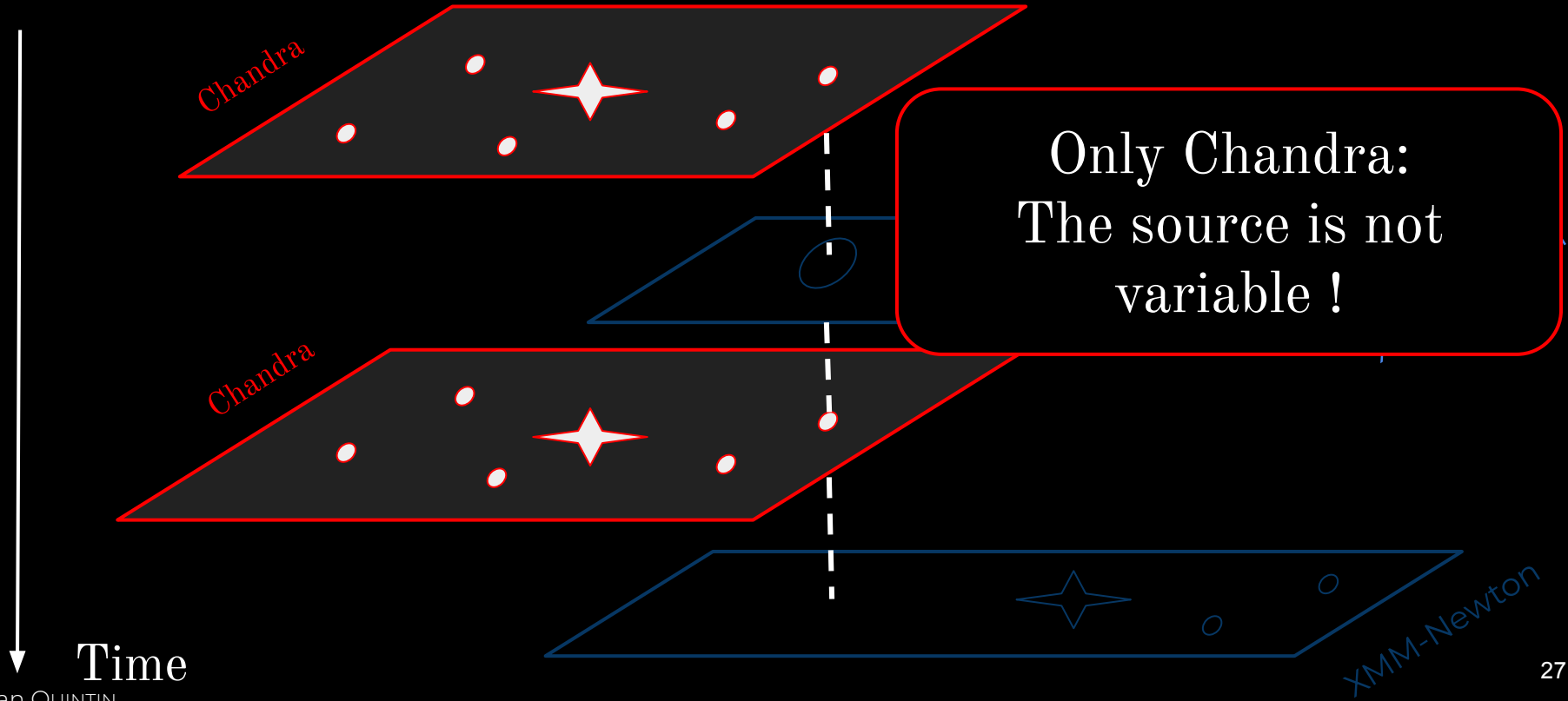


## II. The search for new archival transients

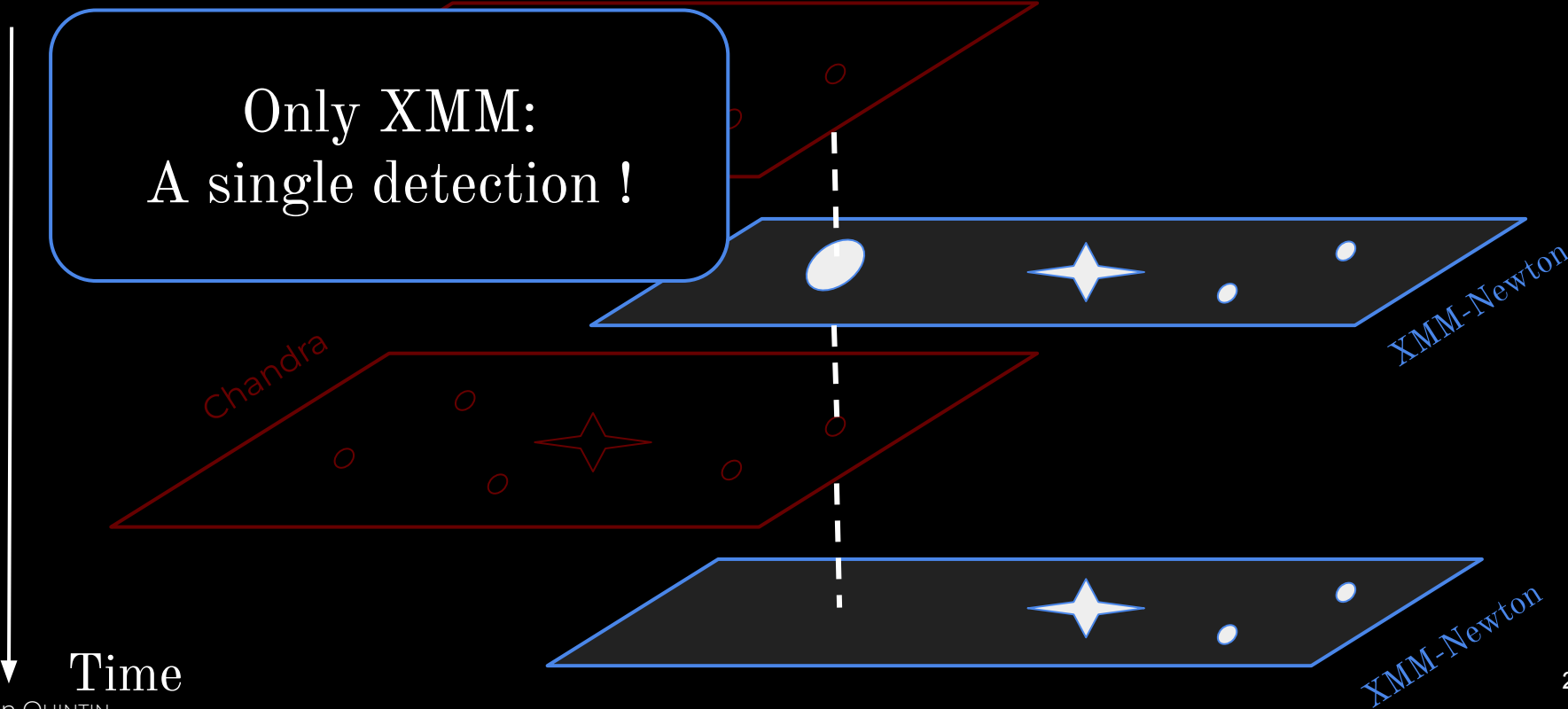
# Several observations by X-ray telescopes



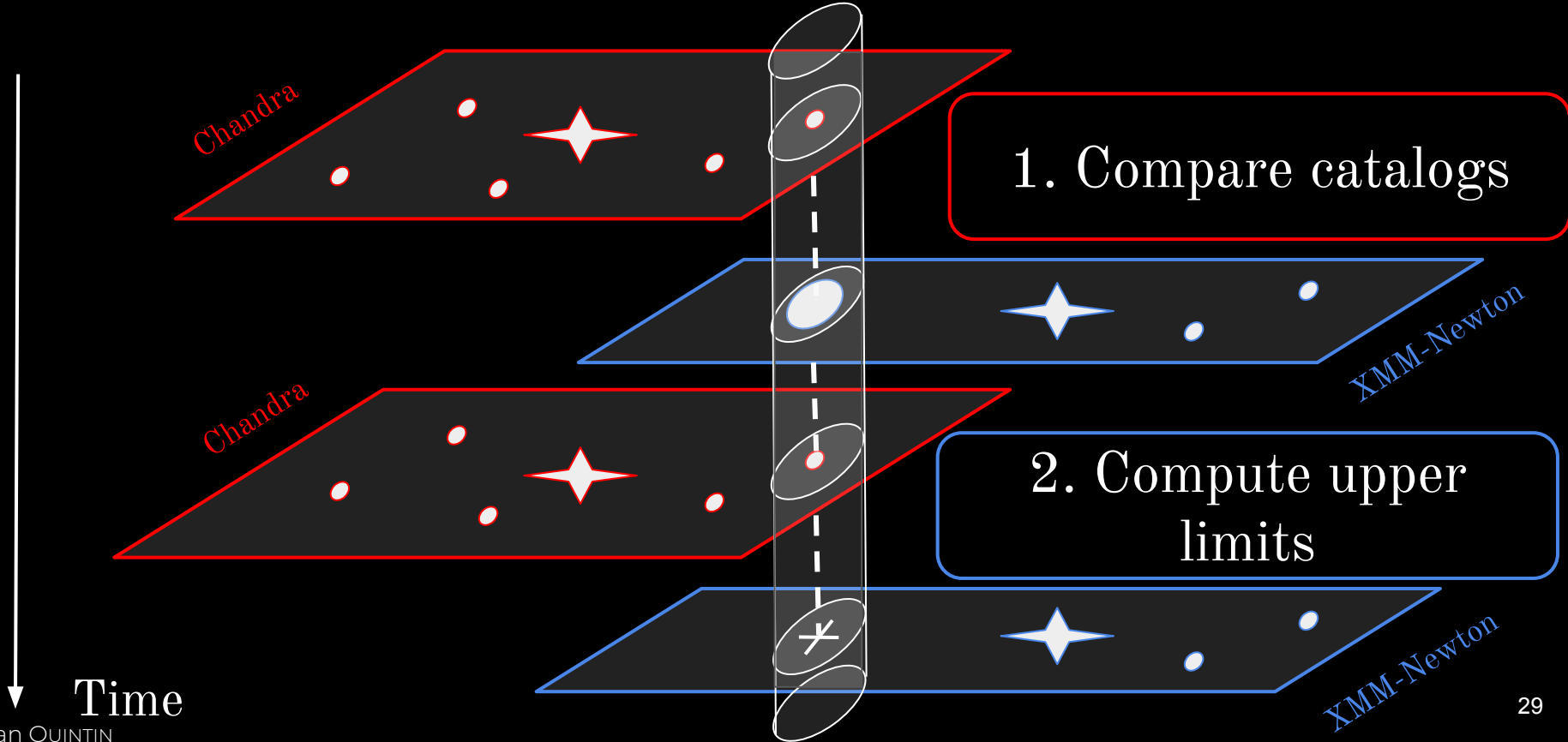
# Several observations by X-ray telescopes



# Several observations by X-ray telescopes



# Several observations by X-ray telescopes



A multi-instrument  
archival X-ray catalog  
~1M sources

First Application:

Compare it to new detections:  
transient alert system

STONKS - Quintin et al. to be  
sub.



Second Application:

Archival data mining for past  
transients

The image is a composite astronomical visualization. It features a central black hole or neutron star surrounded by a glowing, multi-colored accretion disk. The disk transitions from blue and white at the inner edge to yellow, orange, and red towards the outer edge. A bright, blue-white jet of light is shown emanating from the top of the central object. The background is a dark space filled with stars and a faint, blueish nebula or galaxy structure.

### III. Tormund - a new QPE candidate

# Archival search for QPEs

## Criteria:

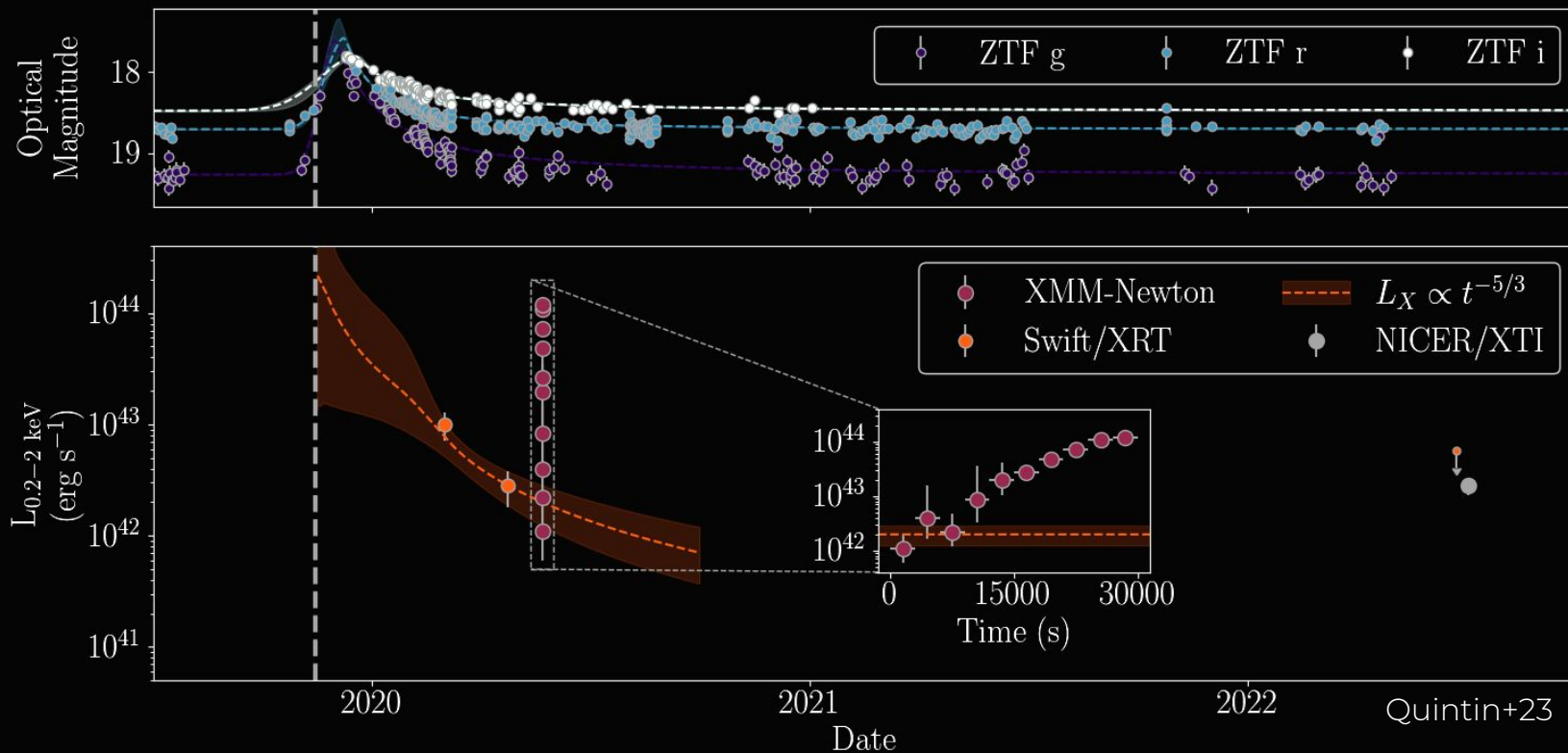
- Match a galaxy
- Soft
- Short term variable

We retrieve known QPEs + AT2019vcb

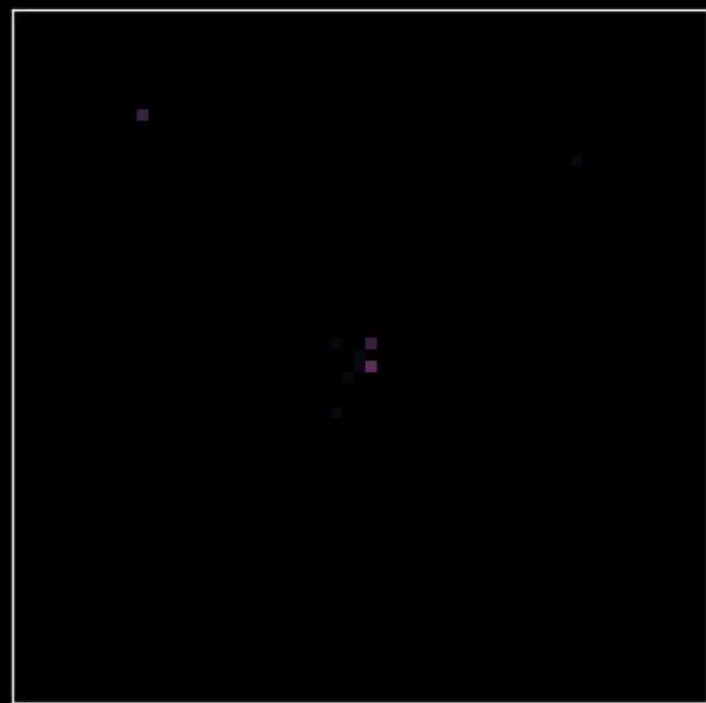


# AT2019vcb

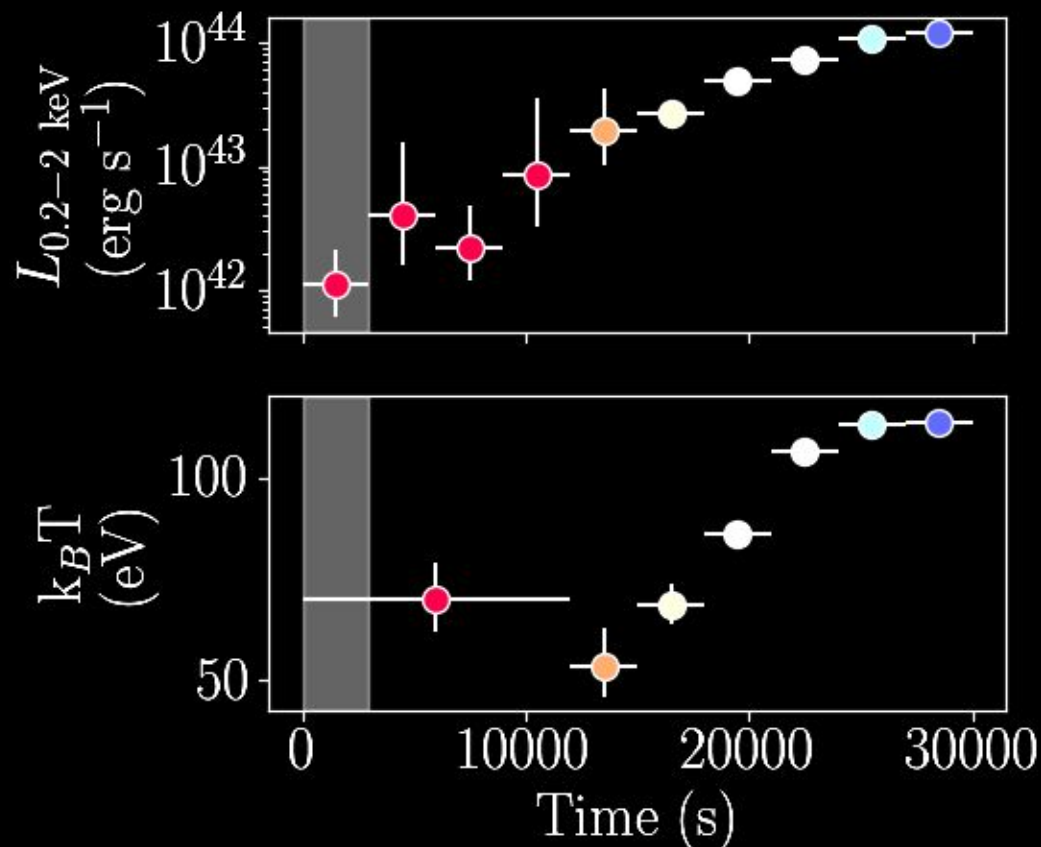
Detected as a TDE by ZTF, nicknamed “Tormund”



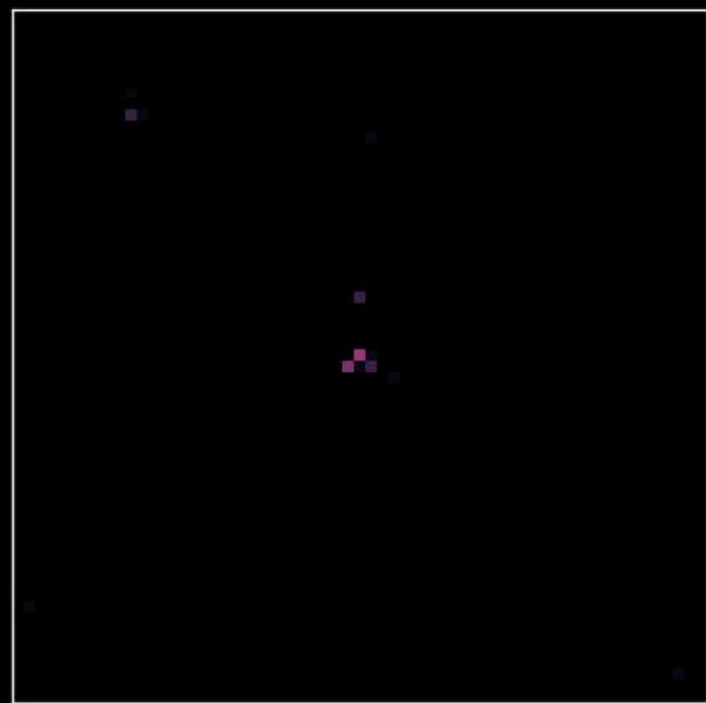
# Tormund's return: QPE features from a recent optical TDE



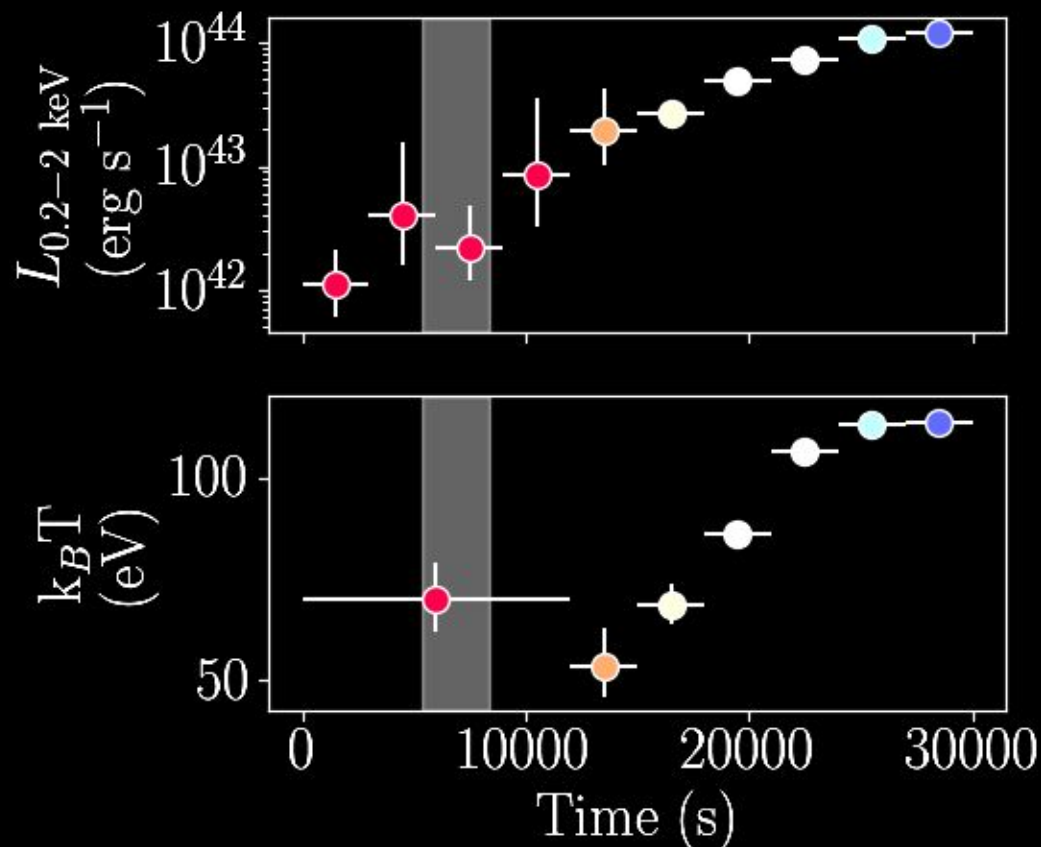
0.3-0.9 keV EPIC-pn Image



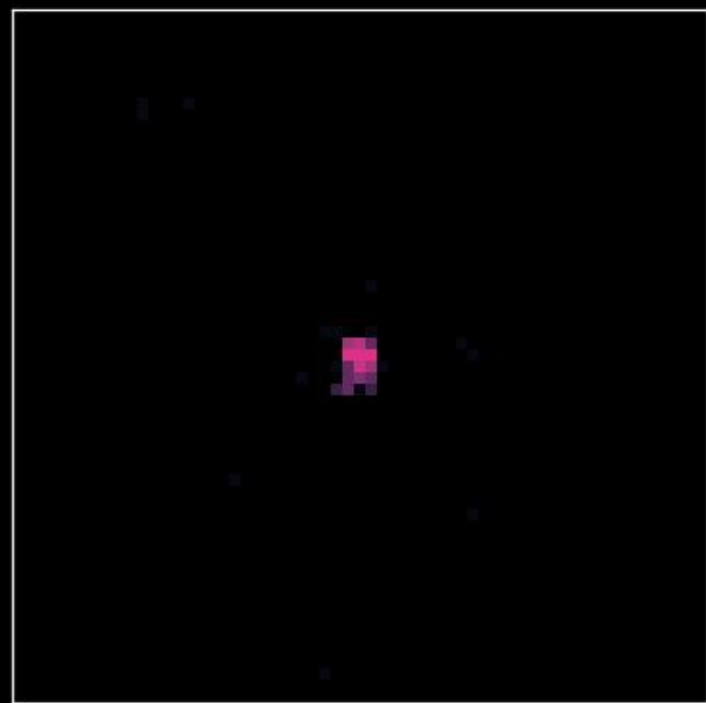
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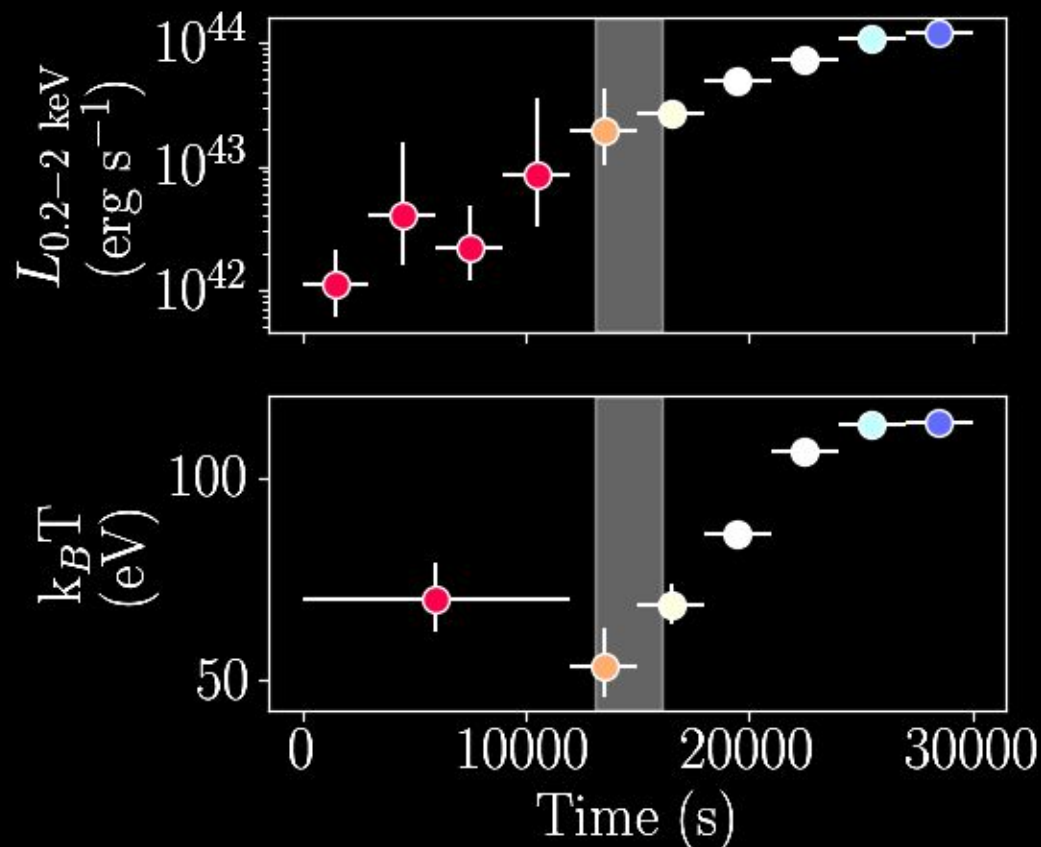
0.3-0.9 keV EPIC-pn Image



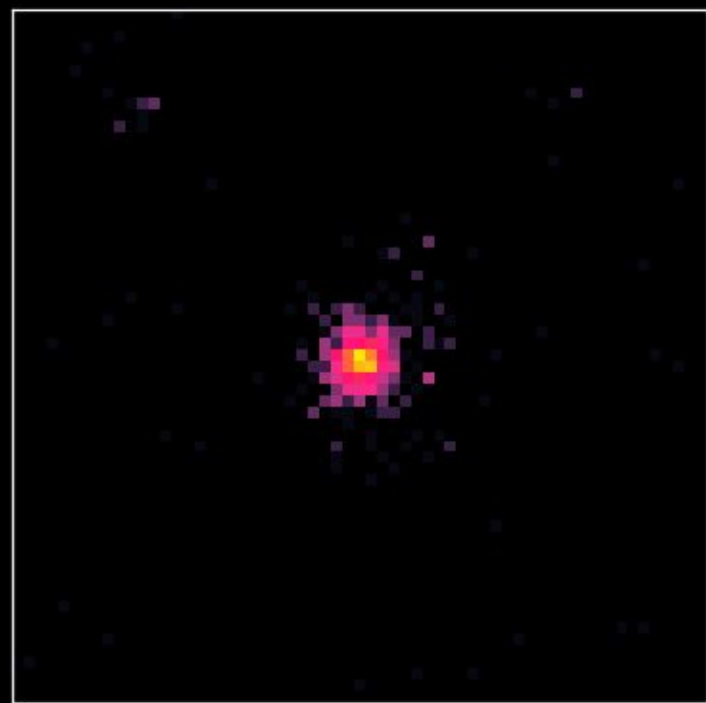
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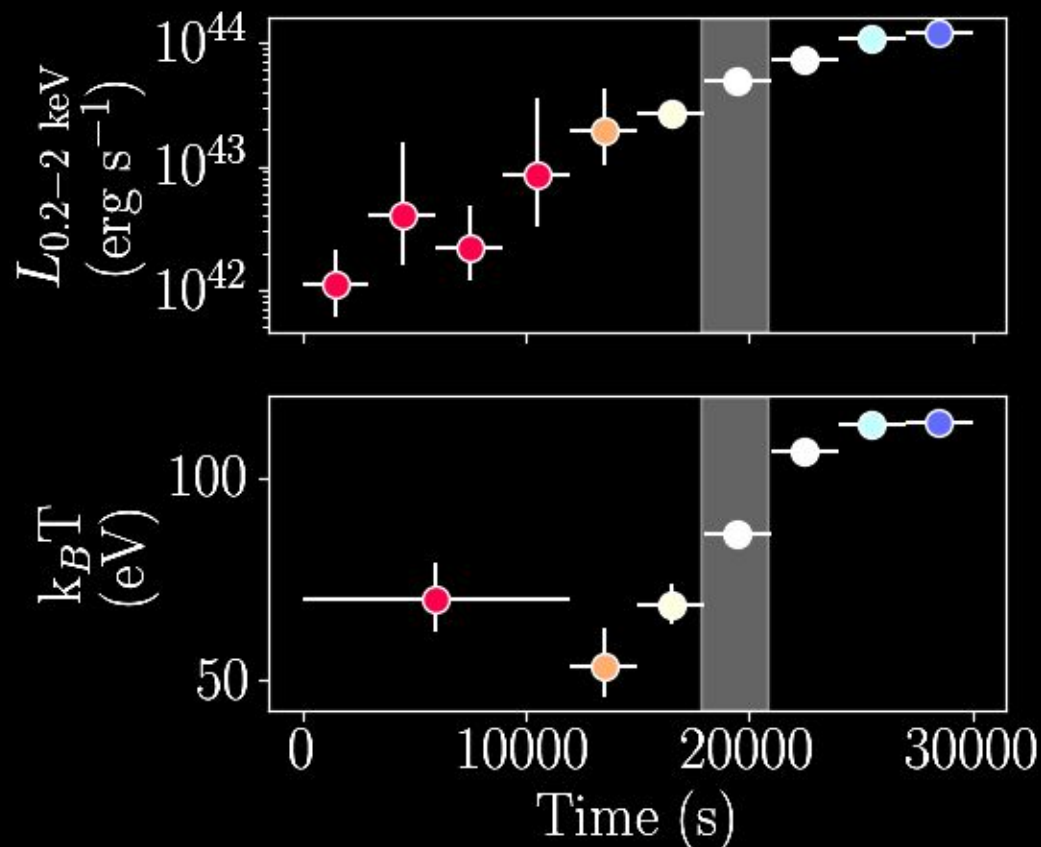
0.3-0.9 keV EPIC-pn Image



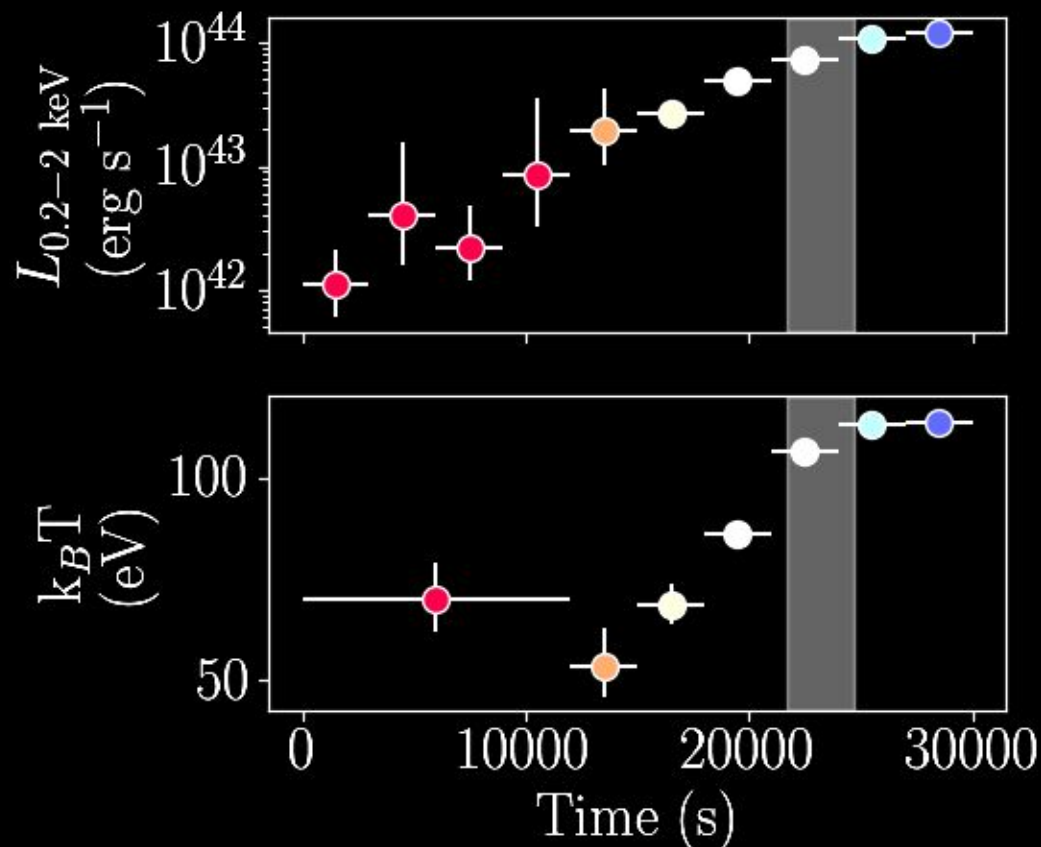
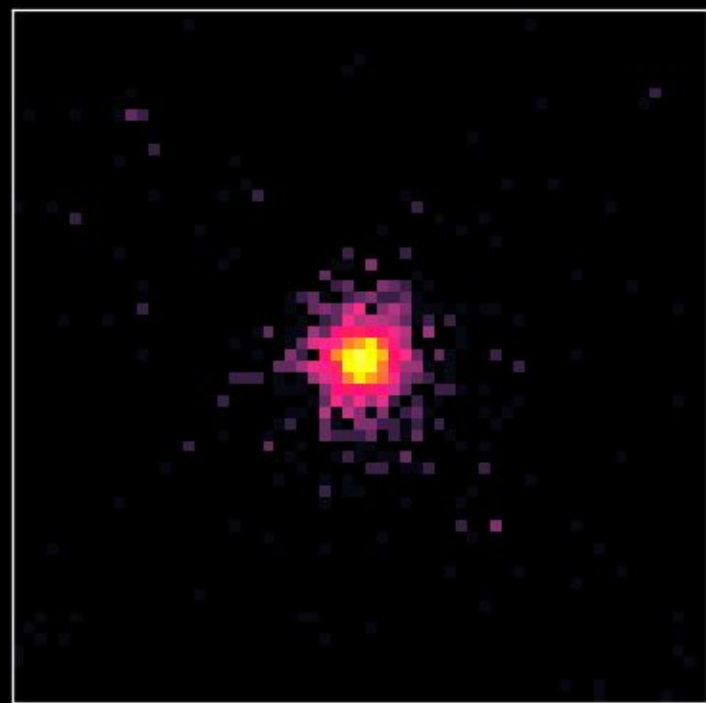
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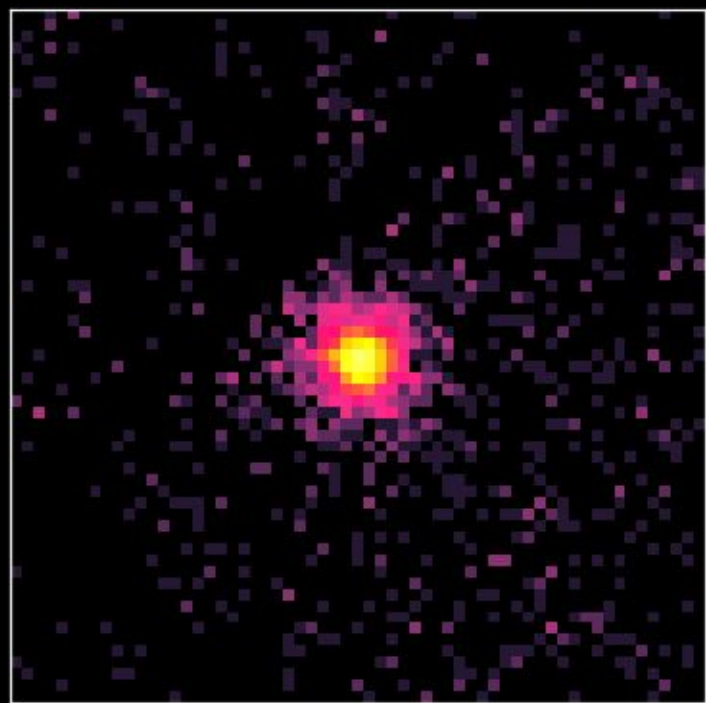
0.3-0.9 keV EPIC-pn Image



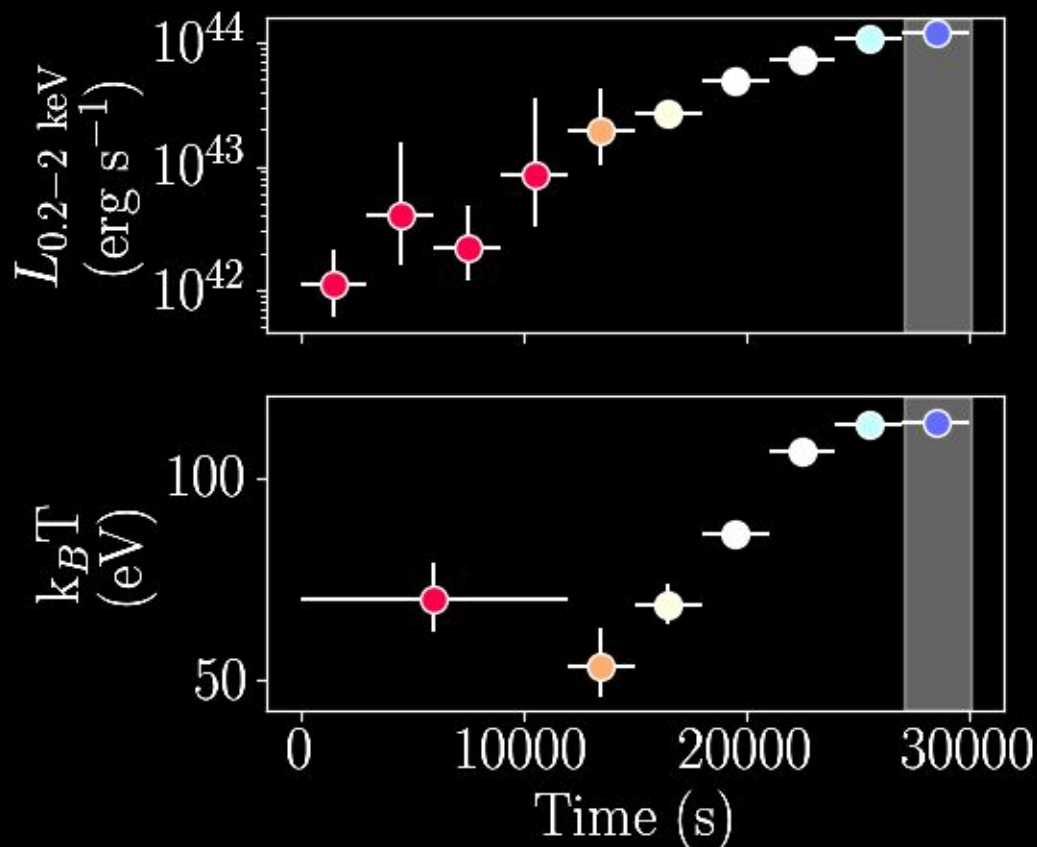
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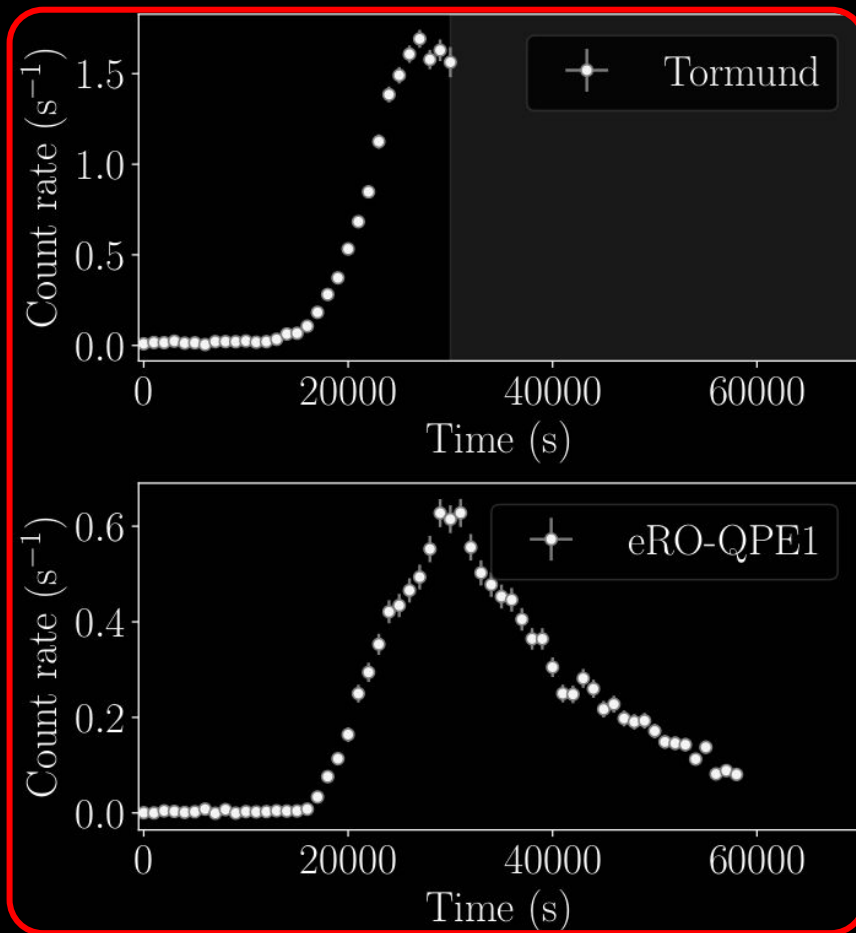
0.3-0.9 keV EPIC-pn Image



# Is it a QPE ?

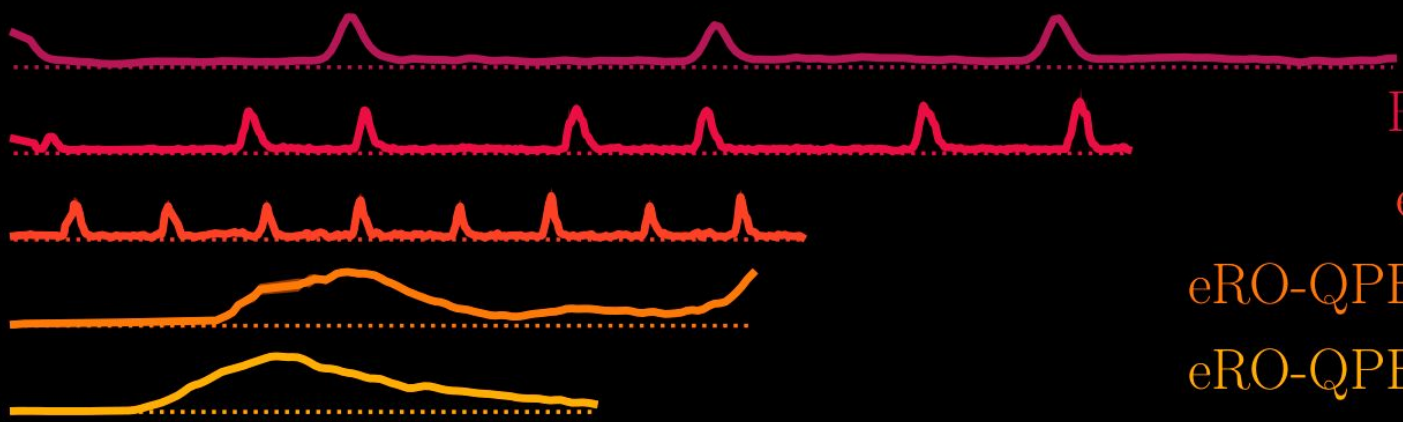
Only one rise detected, BUT:

- Other interpretations struggle (late TDE, AGN)
- Similar to eRO-QPE1





# Bona fide



GSN 069

RX J1301.9

eRO-QPE2

eRO-QPE1 - Obs. 1

eRO-QPE1 - Obs. 2

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# Candidates



XMMSL1

Tormund



# What this source tells us

- Strengthens the link **QPE / TDE** (now 3 out of 6)
- First with optically detected TDE: constrains **formation time  $< 6$  months**
- Brightest in peak and quiescence & largest BH & largest timescale:  
**BH mass scaling ?**

# What's next

## Observations :

- Find new **QPEs** in **eROSITA** and in **follow-ups of TDEs**
- Find very faint repeated soft bursts in **XMM archives**  
(EXOD - M. Gupta)

## Theory :

- Find a model **consistent with transitions** (maybe combination ?)
- May well be the key to **understand the TDE emission mechanisms**



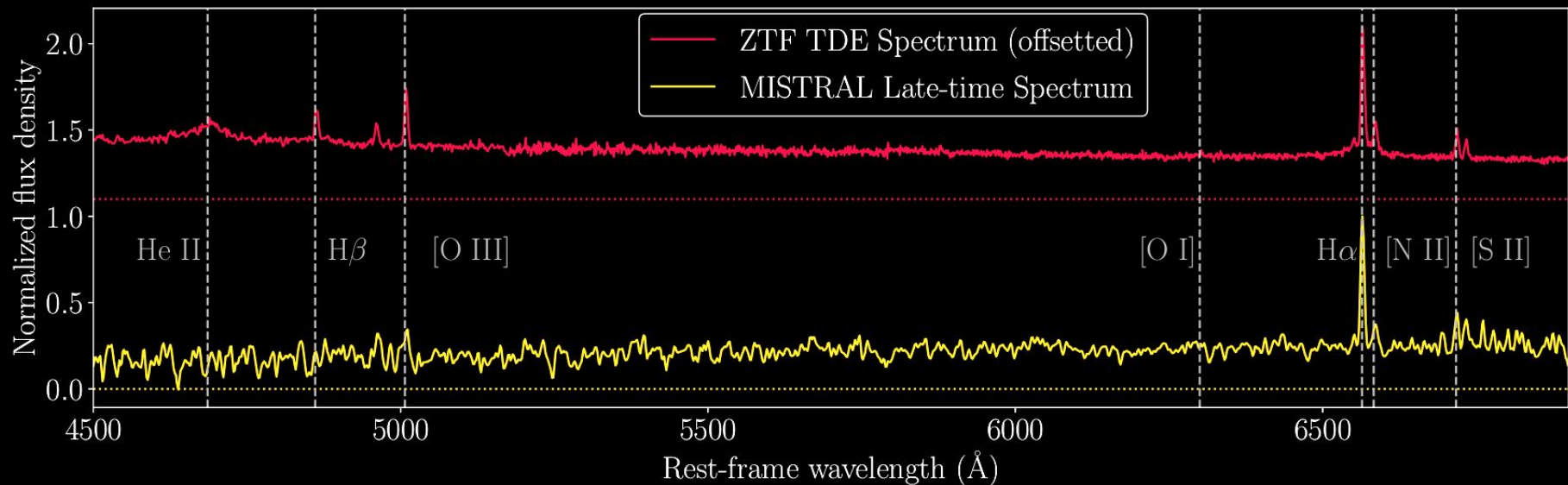
Thanks for your  
attention !

More details in the paper  
Quintin et al. 2023

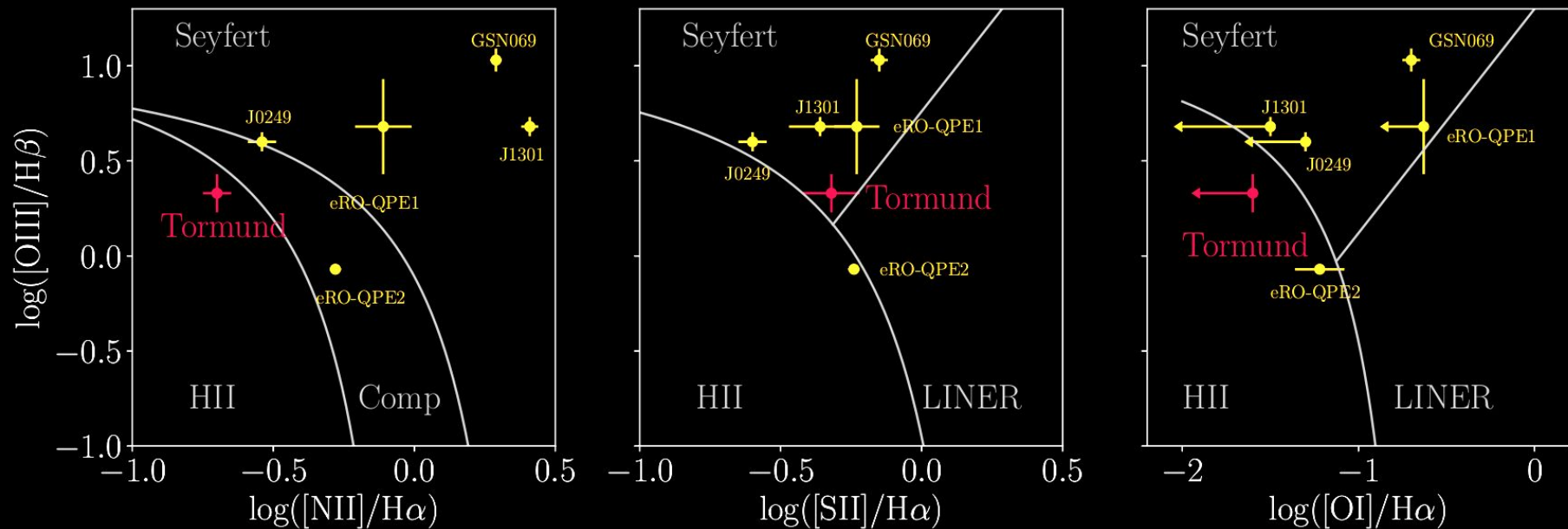
& XMM transient alert system soon !



# Optical Spectrum follow-up



# Optical Spectrum follow-up



# STONKS workflow

