Almost regular, always surprising

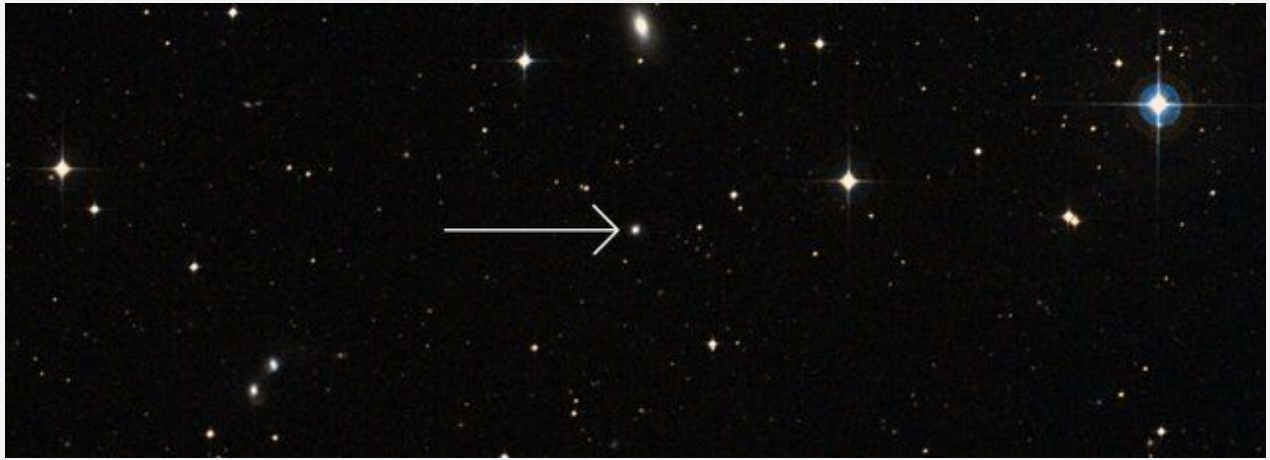
The current state of research on X-ray Quasi-Periodic Eruptions

Erwan QUINTIN
ESA Research Fellow

Introduction: what are QPEs?

Yet another 3-letters acronym

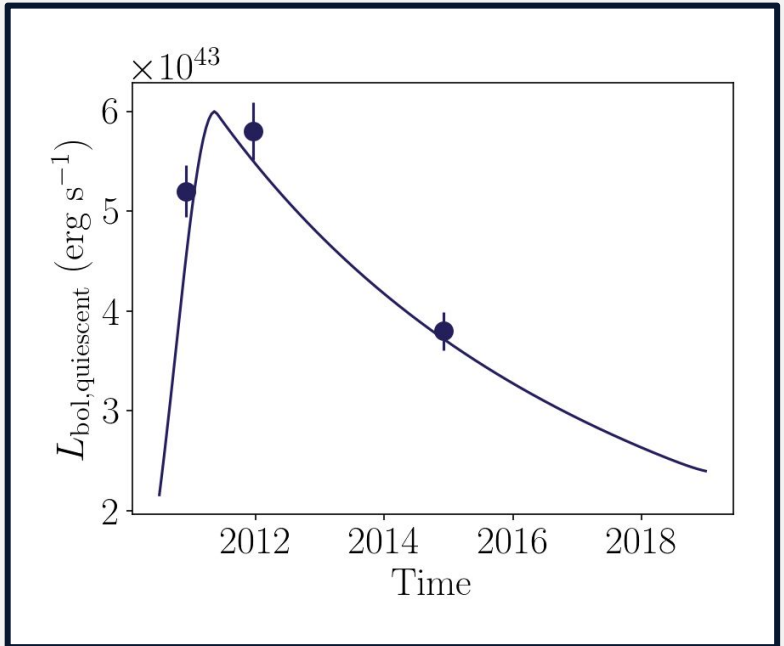
A Christmas story



GSN 069 - Dwarf galaxy

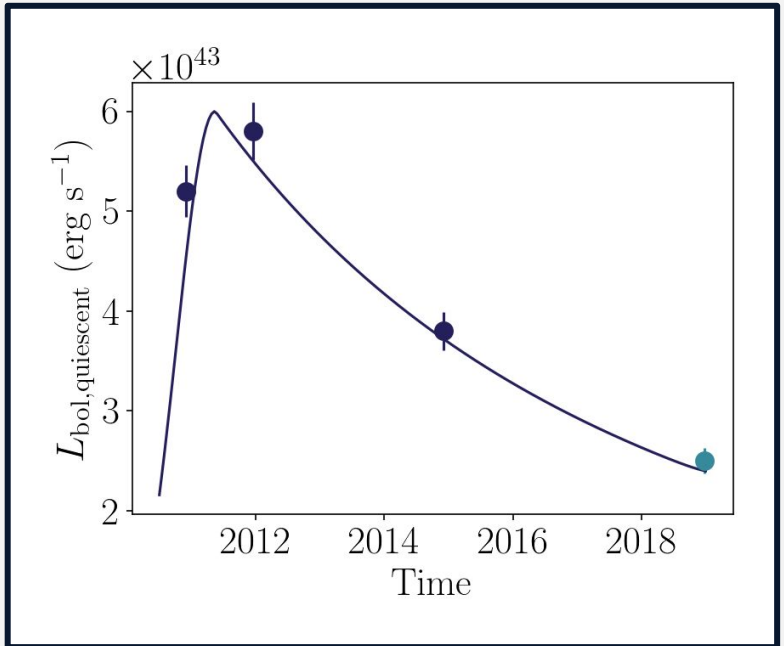
Monitored as a Tidal Disruption Event (TDE) candidate in late 2018

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



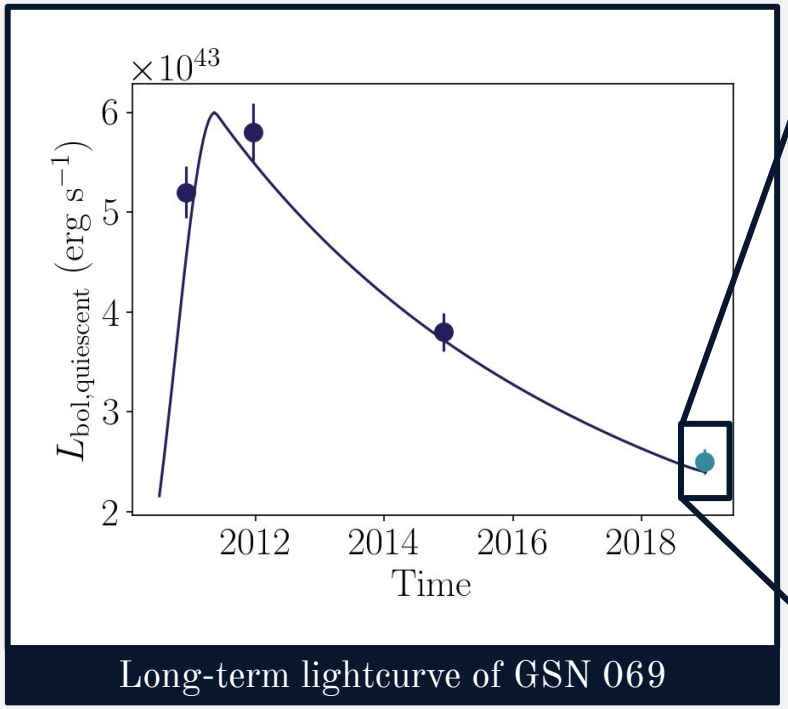
Long-term lightcurve of GSN 069

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



Long-term lightcurve of GSN 069

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



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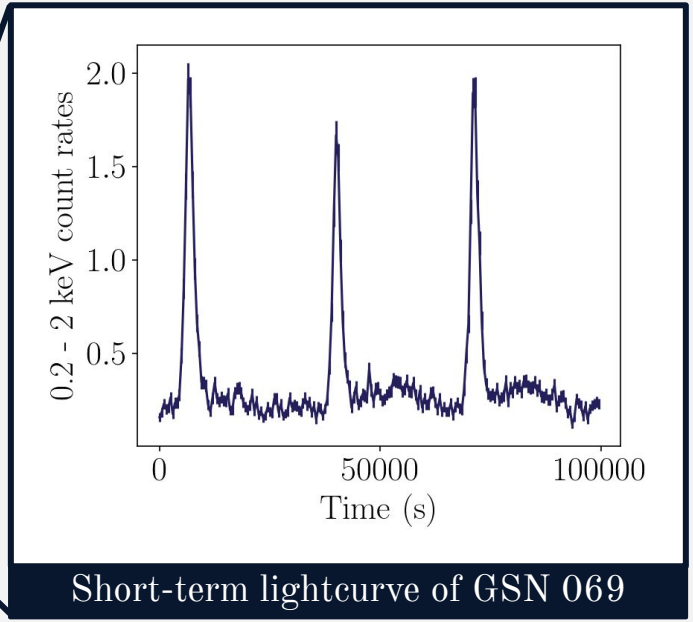
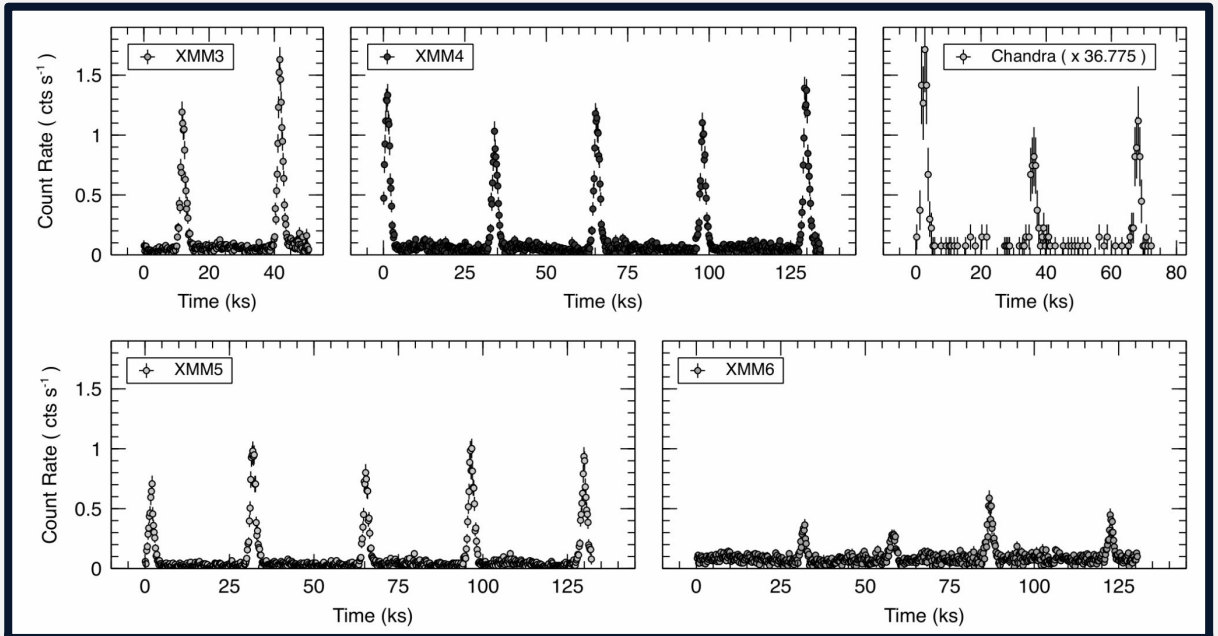


Short-term lightcurve of GSN 069

Miniutti+19

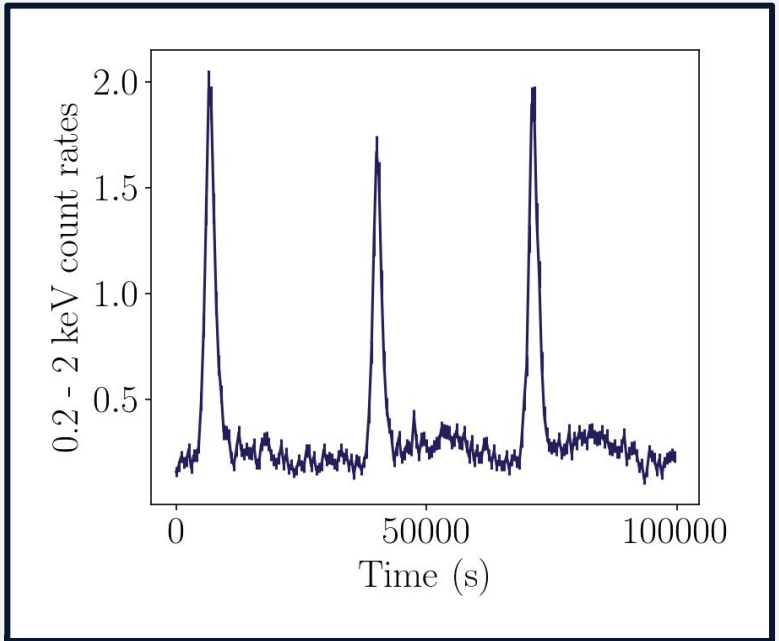
GSN 069: the QPE prototype



Monitoring of GSN 069

Miniutti+23

GSN 069: the QPE prototype



Short-term lightcurve of GSN 069

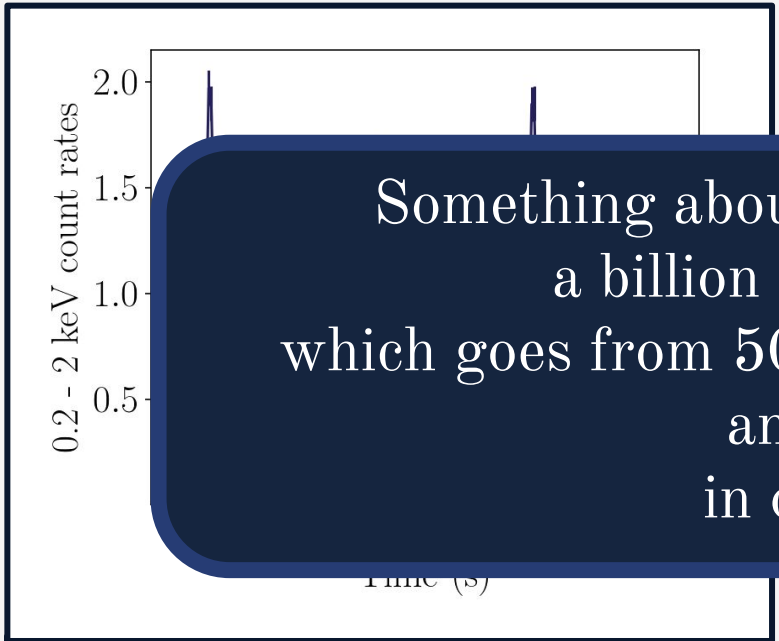
Timing properties

- Duration ~1h
- Recurrence ~9h
- Alternating strong/weak

Spectral properties

- Temperature:
  ~50 eV to ~100 eV
- Luminosity:
  $2x10^{42}$ to 10^{43} erg s^{-1}

GSN 069: the QPE prototype



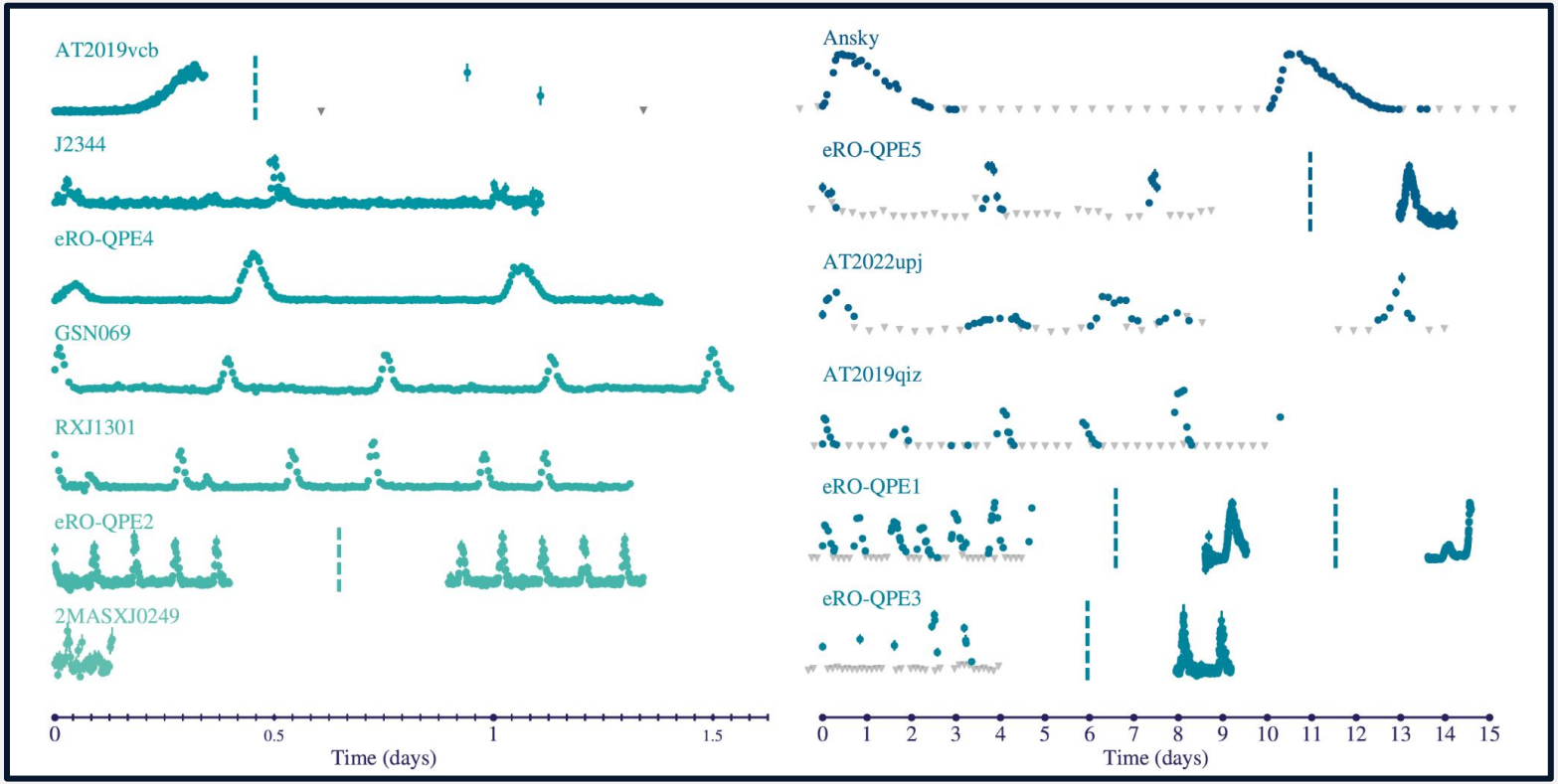
Short-term lightcurve of GSN 069

Something about the size of the sun,
a billion times brighter
which goes from 500 000 K to 1 million K,
and back,
in one hour

Timing properties

- Luminosity:
  $2x10^{42}$ to 10^{43} erg s^{-1}

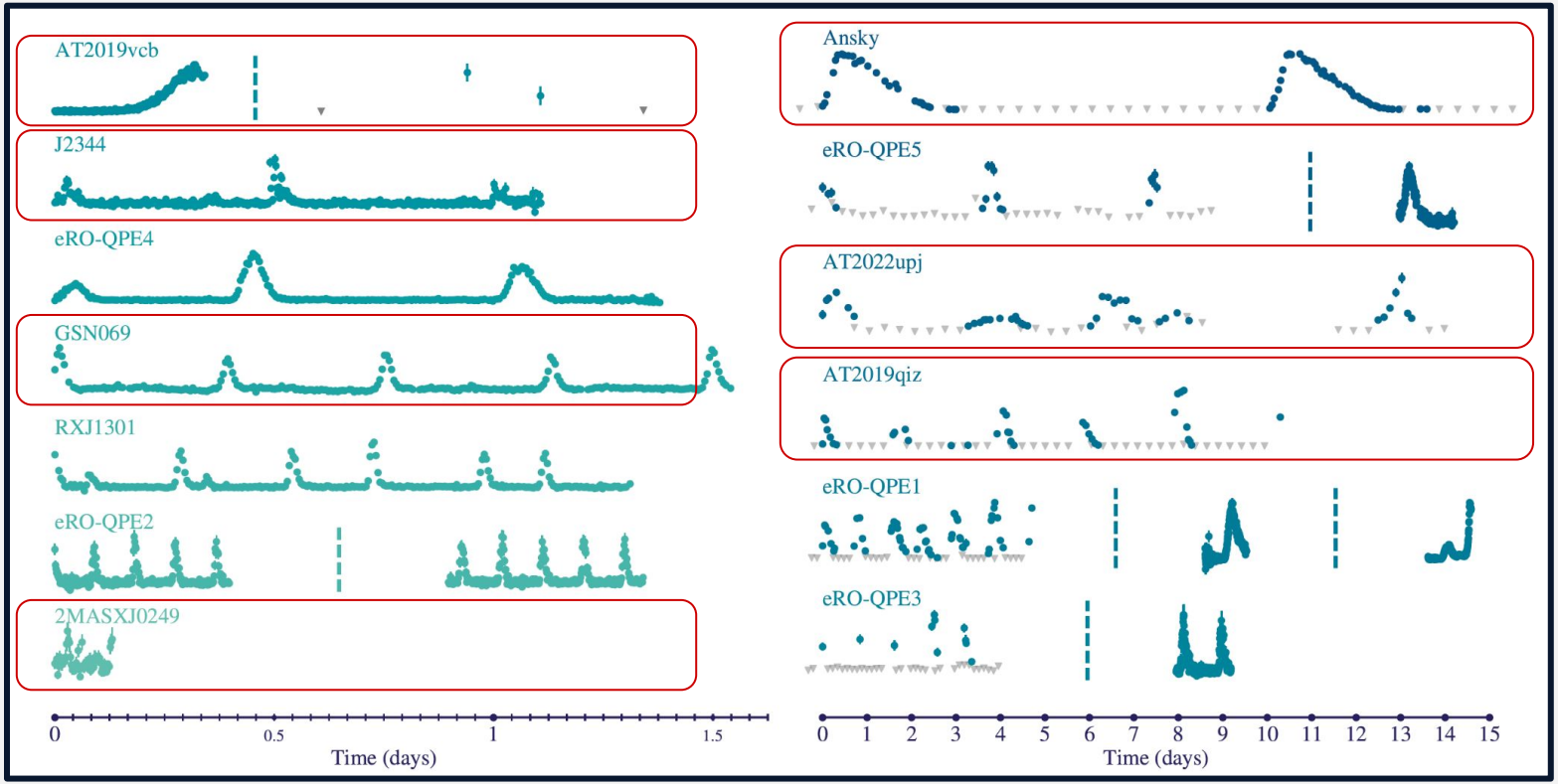
What are Quasi-Periodic Eruptions ?



Wevers et al. in prep.

What are Quasi-Periodic Eruptions ?

in Tidal Disruption Events



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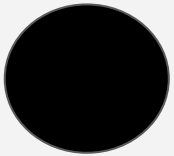
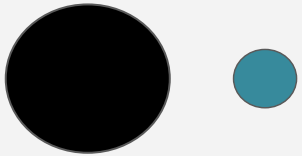
Two flavor of models



\+ accretion stream (likely from TDE)



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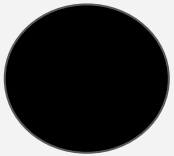

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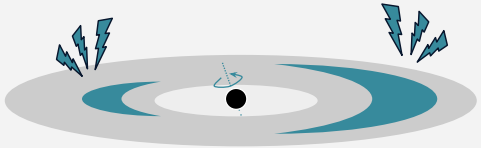
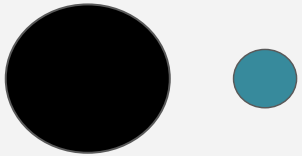
Disk Instabilities



Disk Tearing

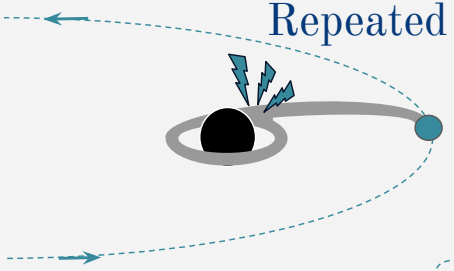
Lensing

Raj & Nixon 2021; Pan et al. 2021a, 2022, 2023; Kaur et al. 2023; Sniegowska et al. 2020, 2023; Middleton et al. 2025

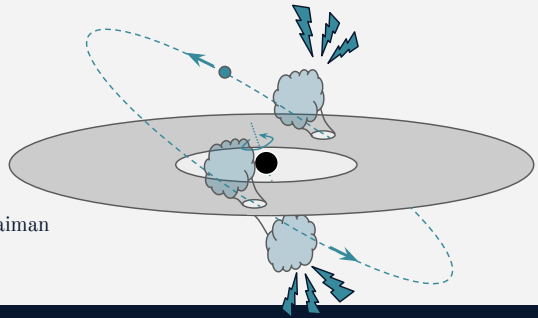


\+ accretion stream (likely from TDE)

Repeated disruptions



Disk collision



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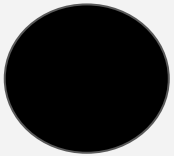

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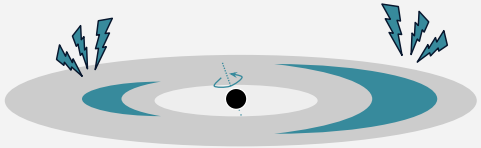

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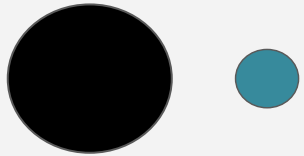

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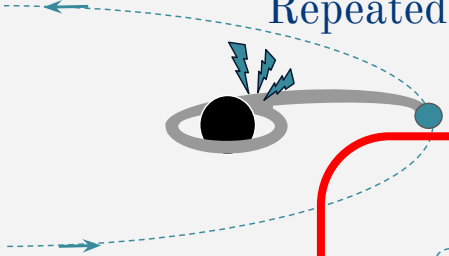

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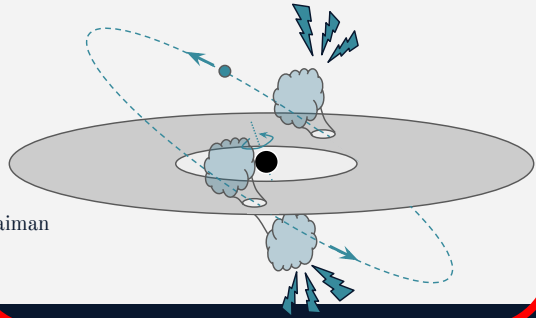

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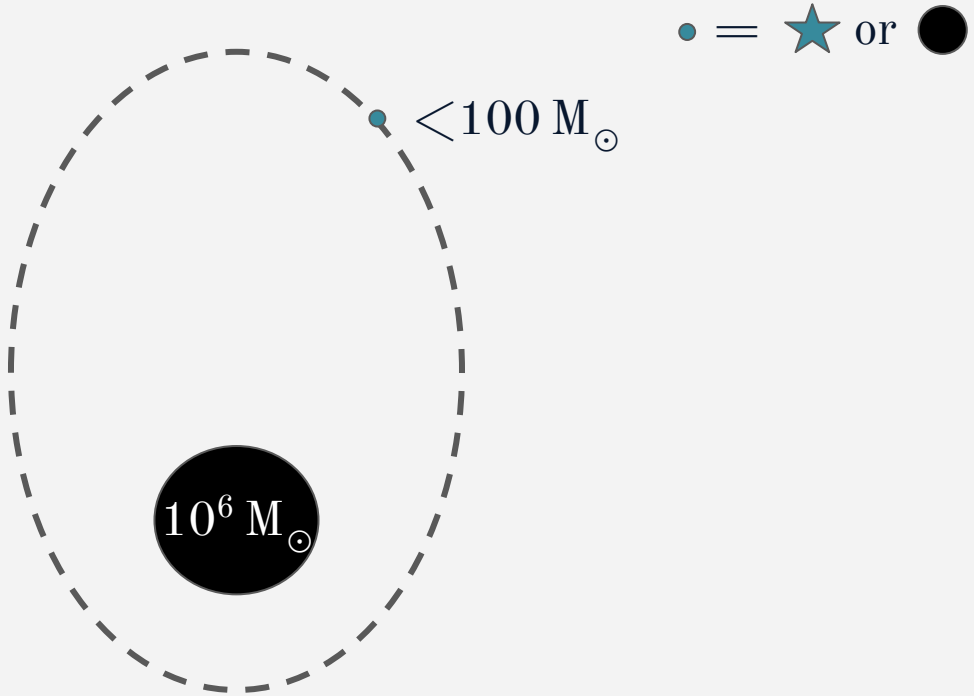
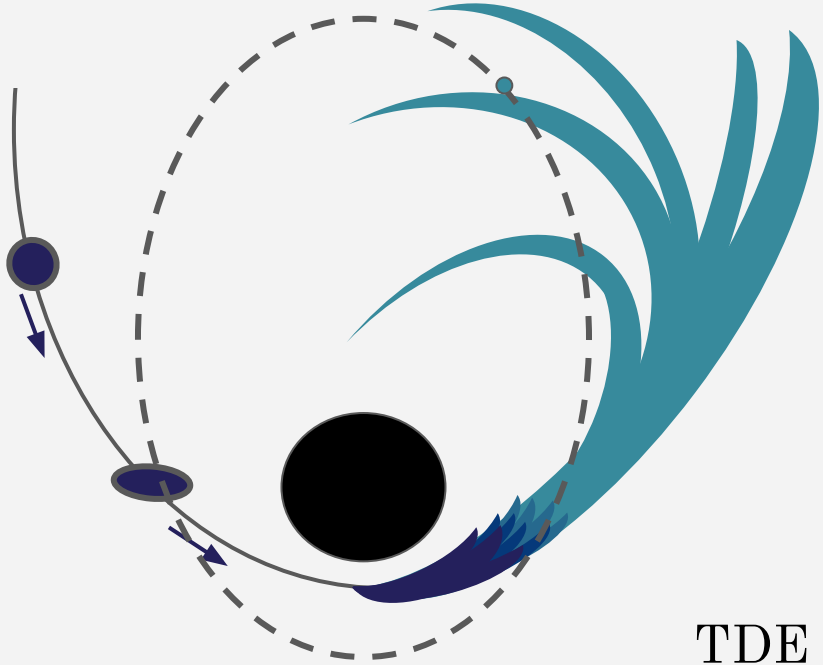
Currently favored model



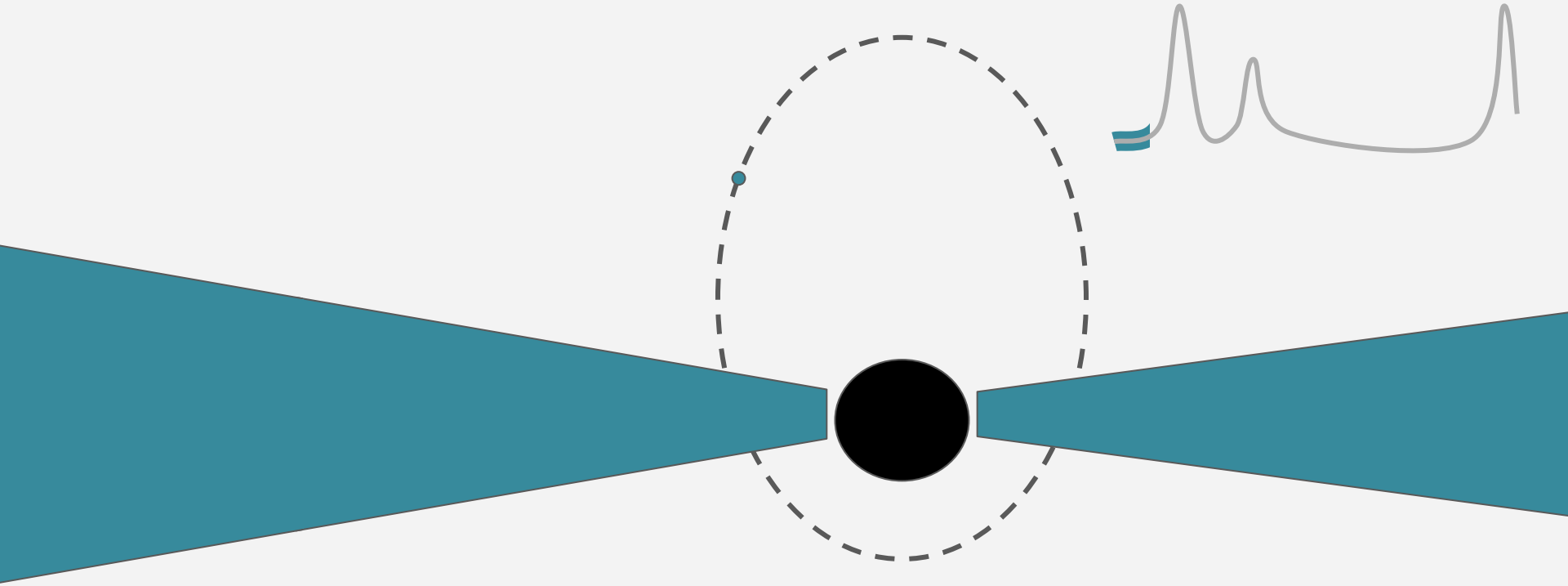
Pre-existing (stellar?) Extreme Mass Ratio Inspiral (EMRI)

Currently favored model



TDE of other star

Currently favored model



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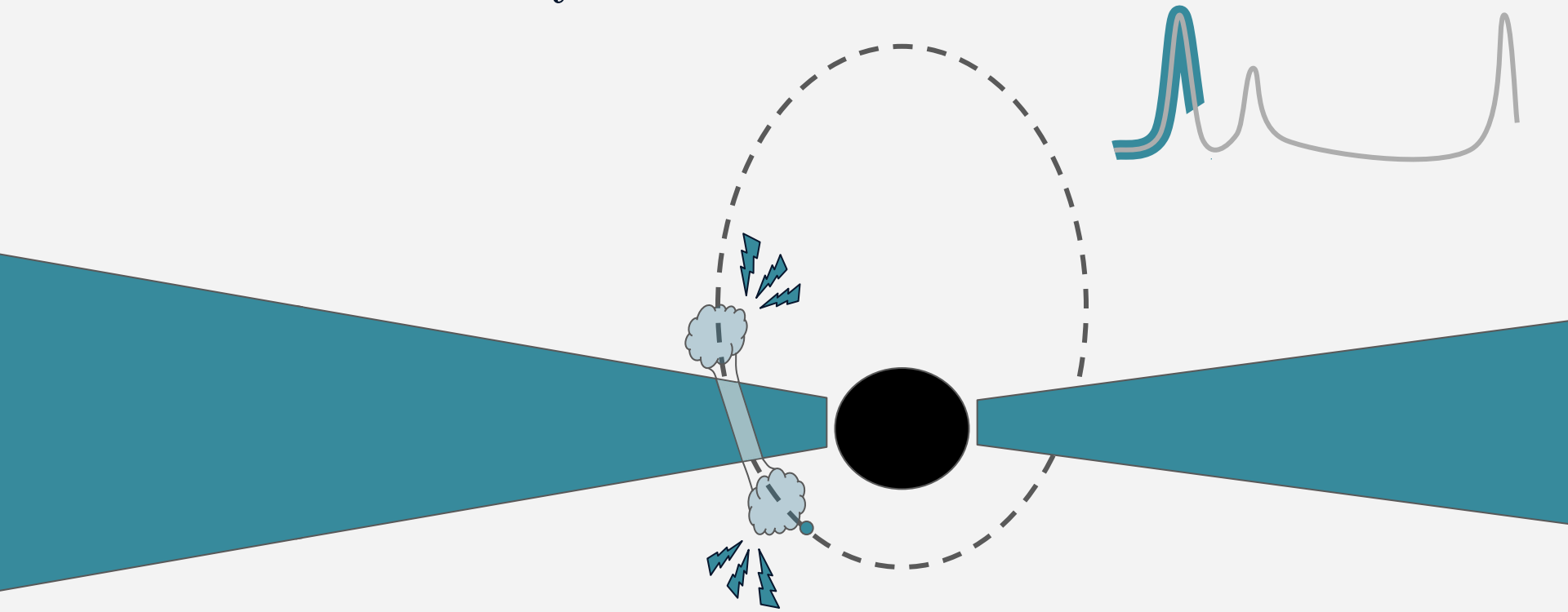

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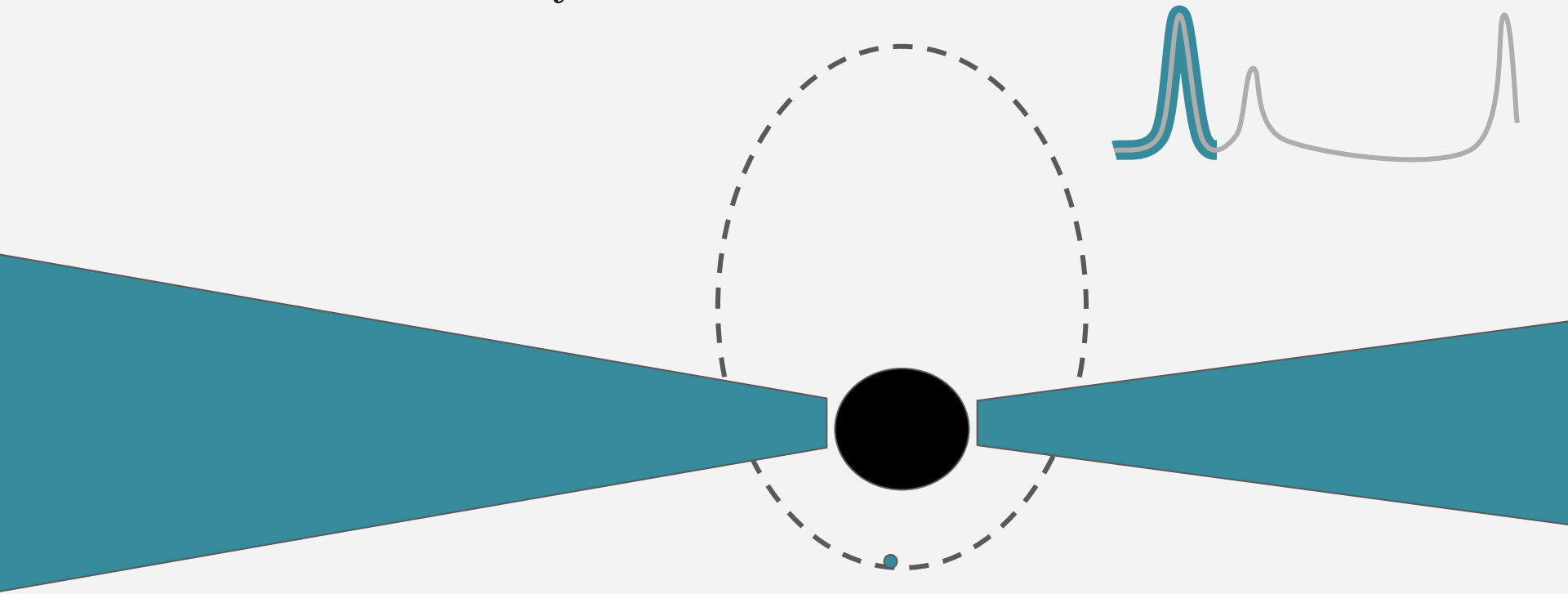

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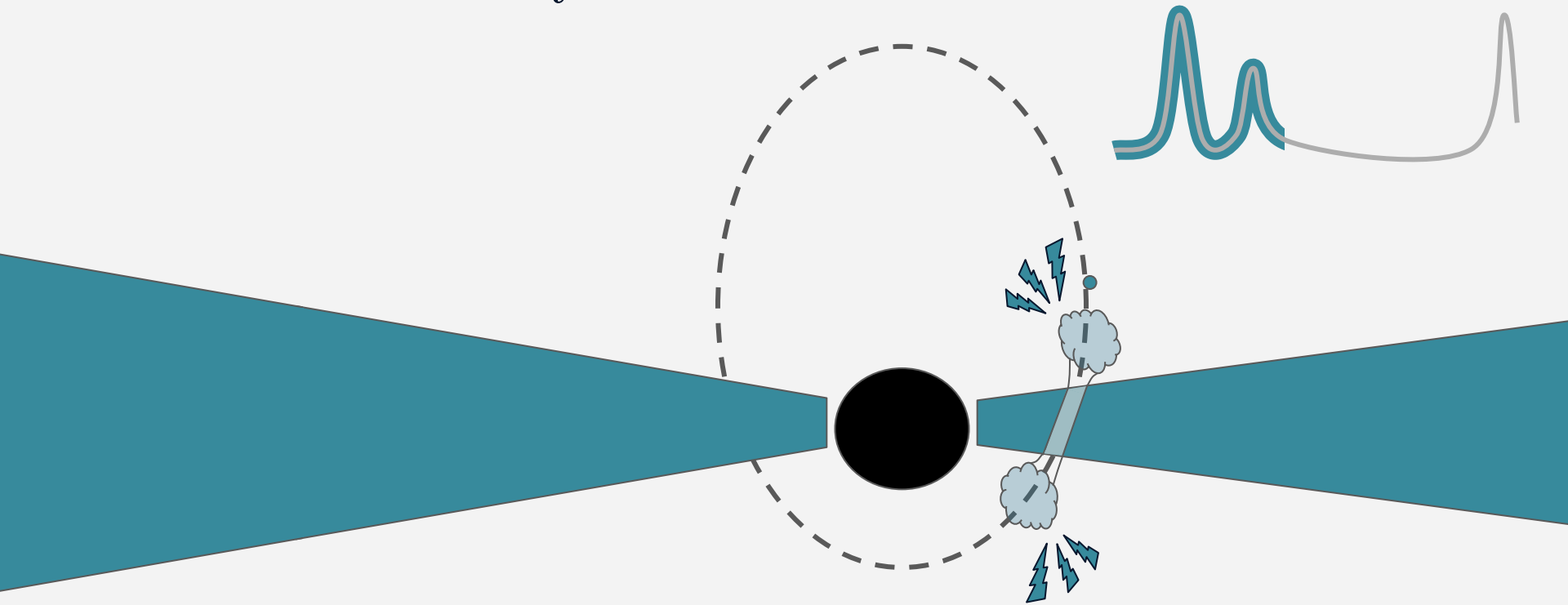

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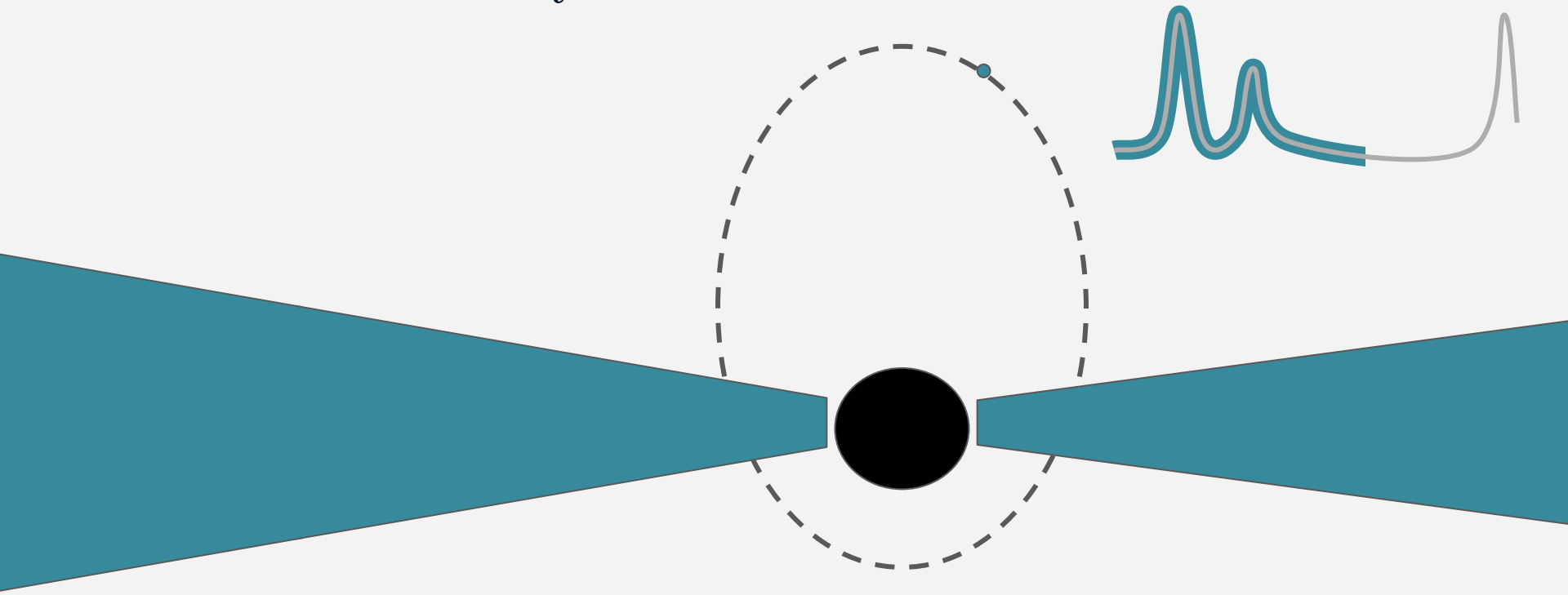

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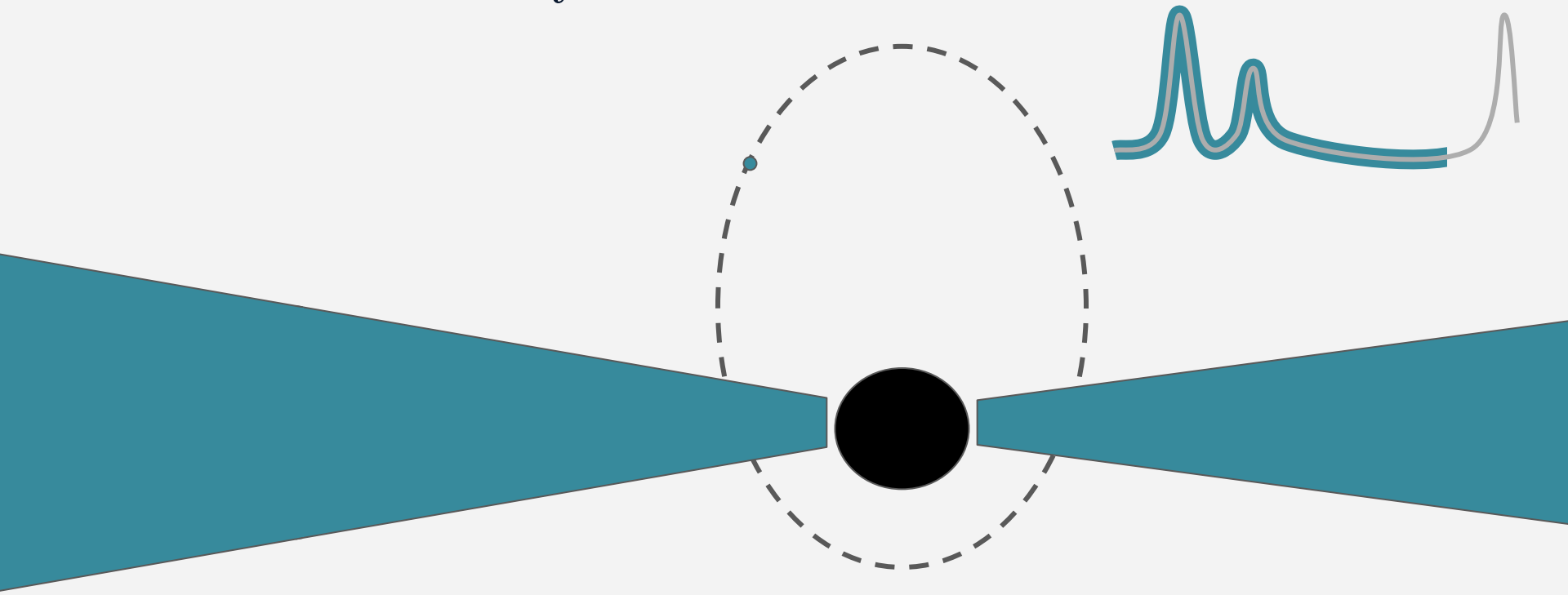

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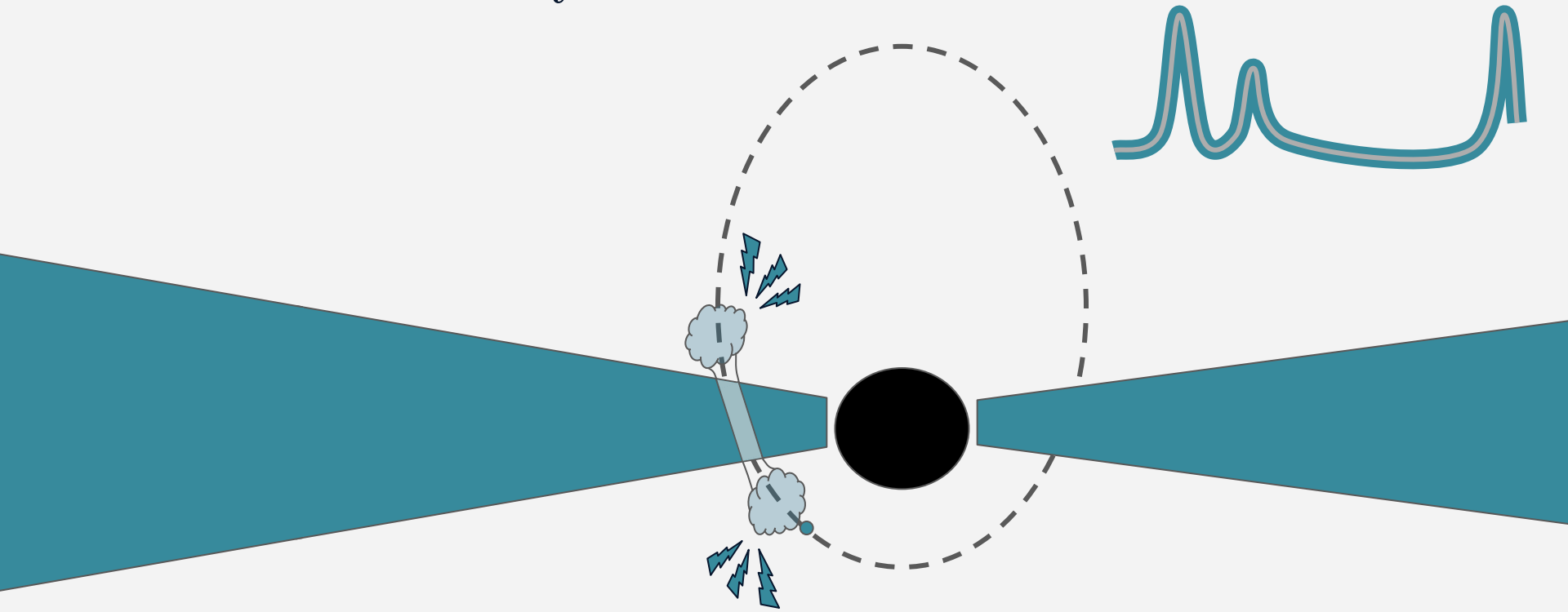

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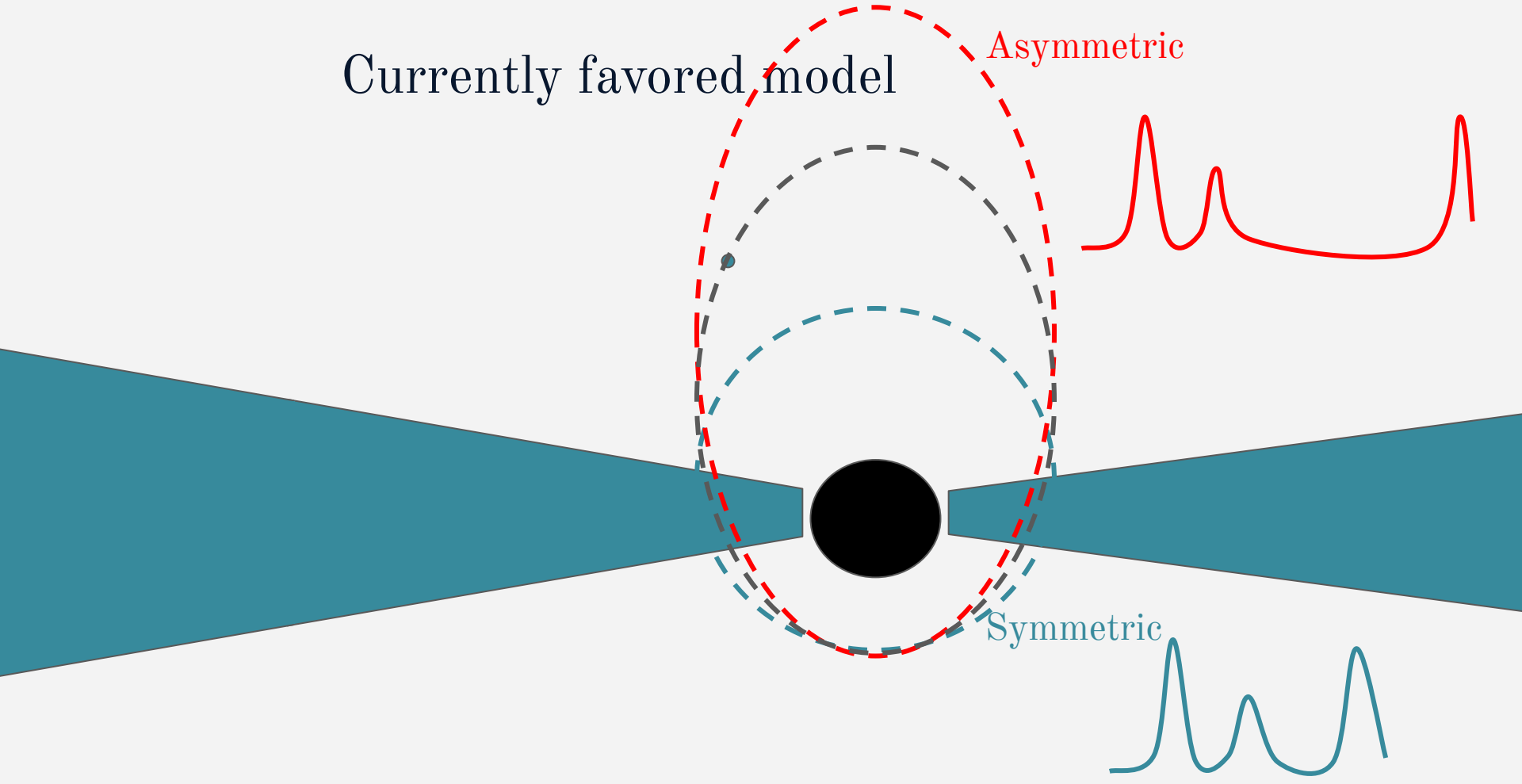
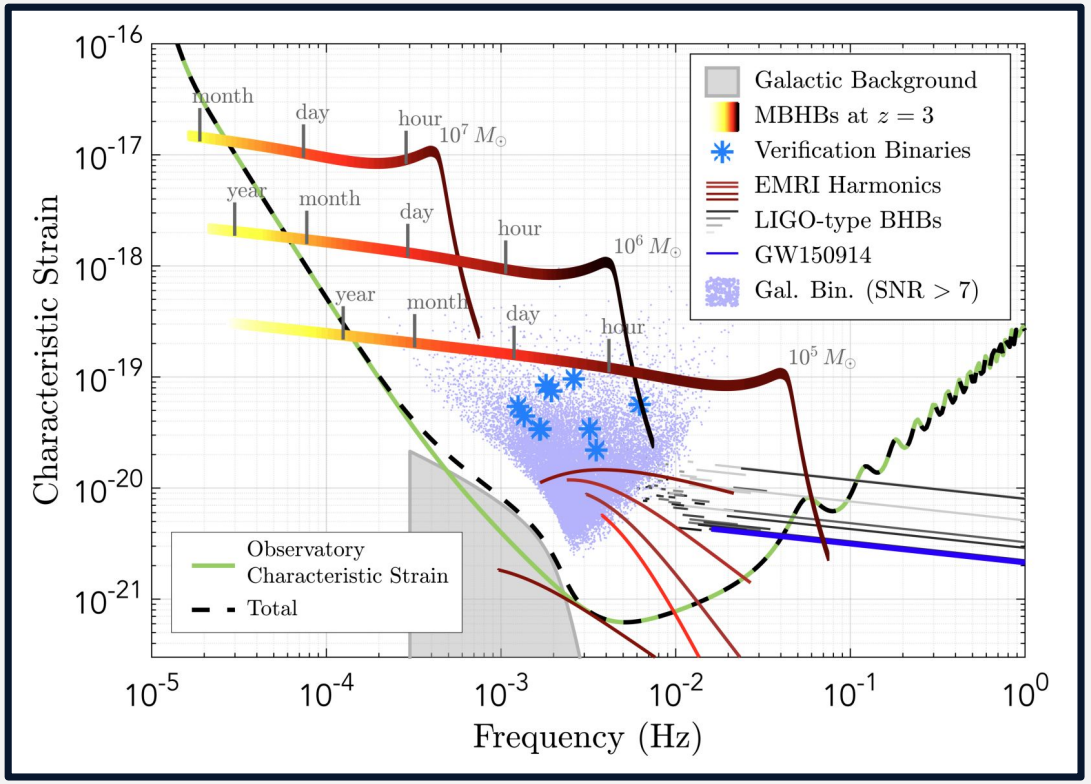


QPEs as EMRIs

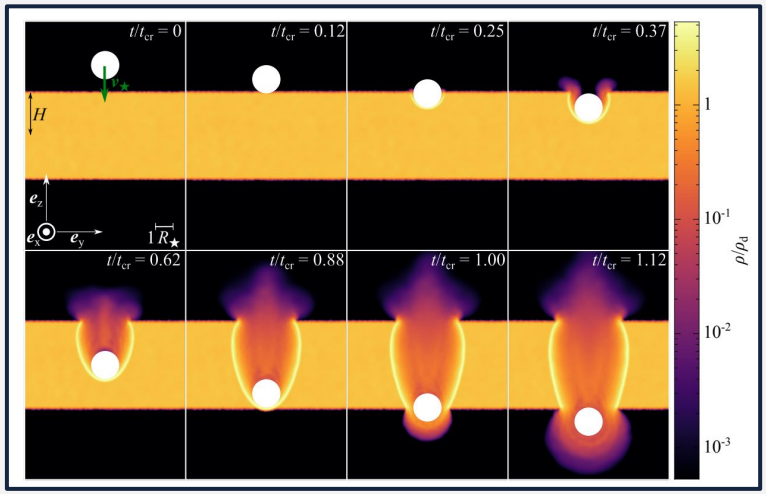


EMRIs emit ~mHz GW

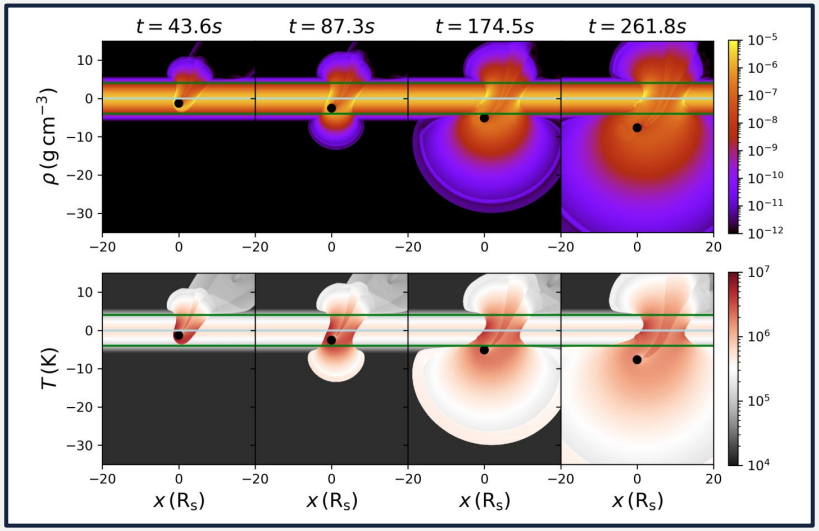
No other EM counterparts (after formation)

Latest progress

More detailed numerical simulations



Jankovič+26



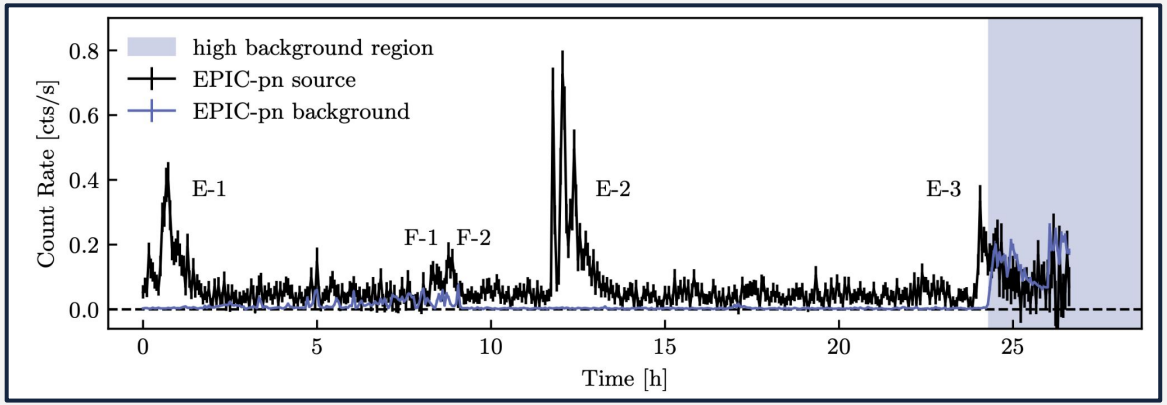
Huang+26

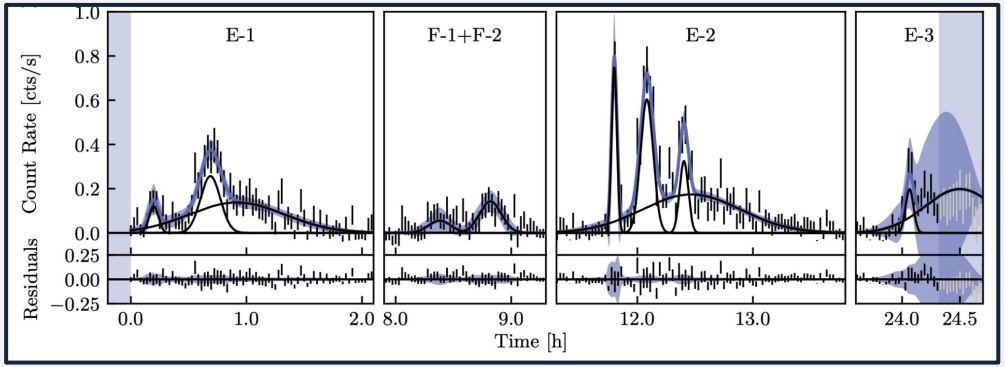
Quite complex to do

Mechanisms ~okay

but details (e.g. back-prop) to improve

A new member to the family: J2344





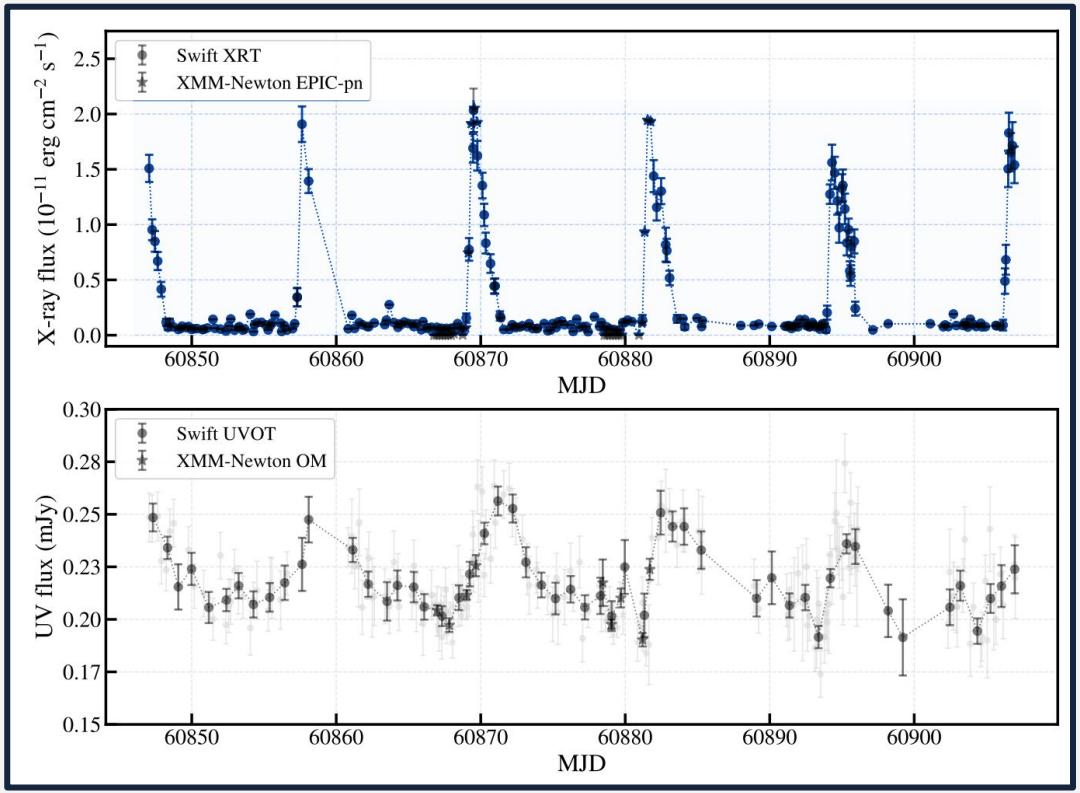
Baldini+26

Found by eROSITA

Confirmed by EP

Monitored with XMM

The first multi–wavelength counterpart



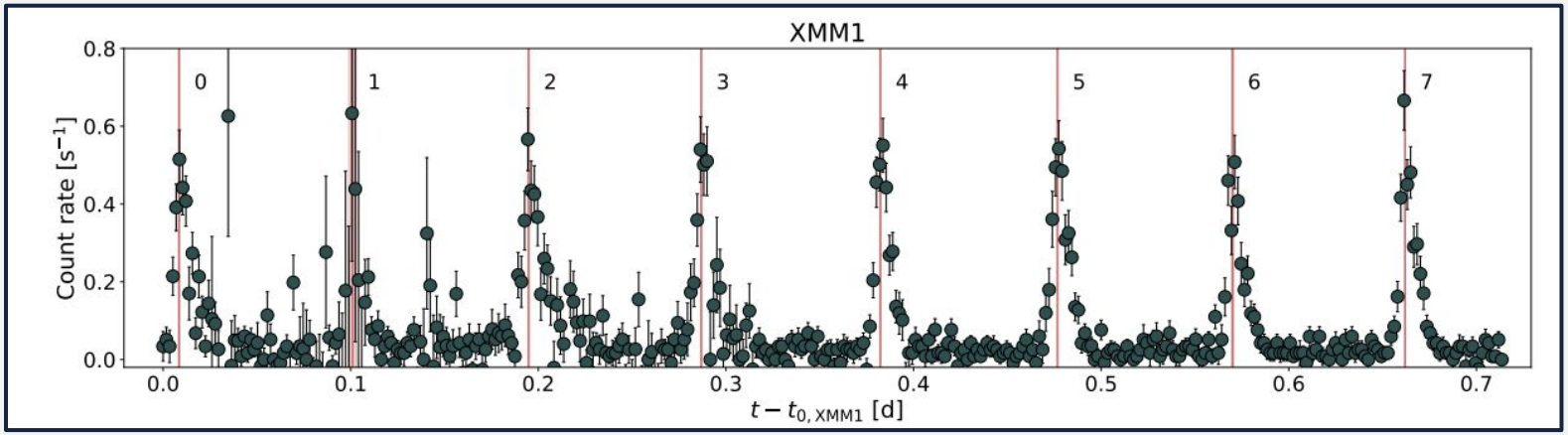
Guo+26

Delayed UV eruptions in the brightest X-ray QPE

Origin unknown

This source: recurrence time from 11d to 22d to ~33d

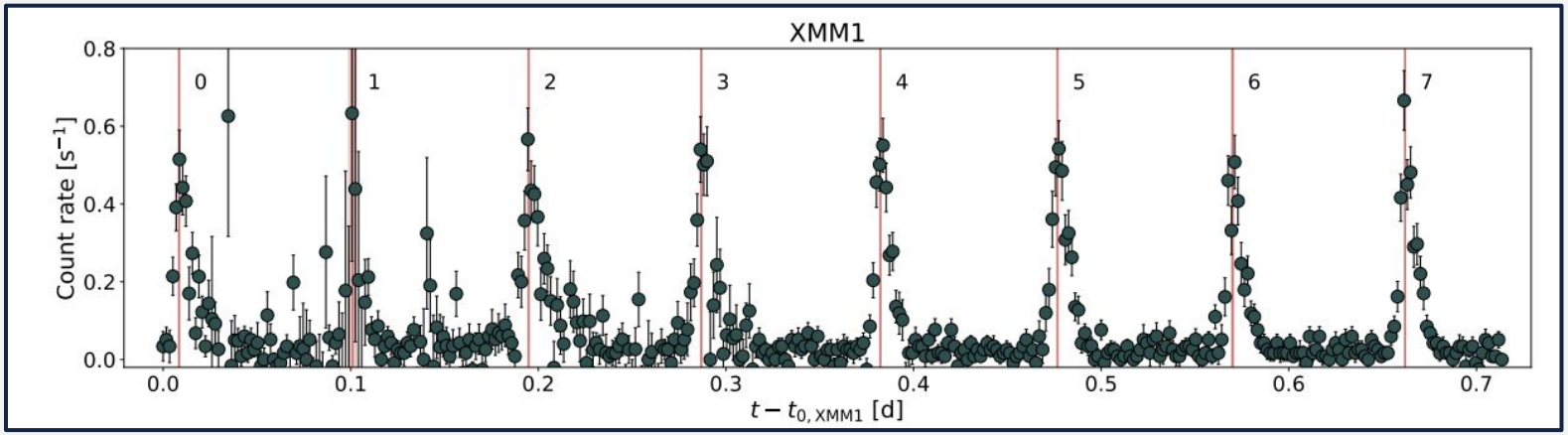
Current challenges to the EMRI model



Arcodia+26

Study in detail the delays in eruptions - model it with an orbiter

Current challenges to the EMRI model



Arcodia+26

Study in detail the delays in eruptions - model it with an orbiter

- In GSN069: inconsistent with simple precession Miniutti+25

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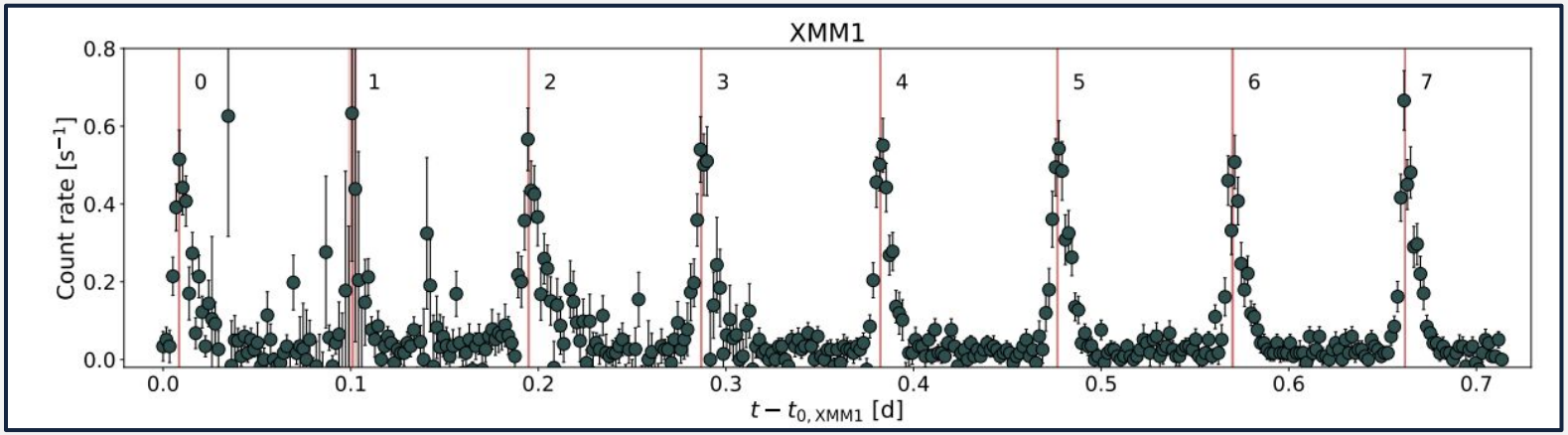


Arcodia+26

Study in detail the delays in eruptions - model it with an orbiter

- In GSN069: inconsistent with simple precession Miniutti+25
- In eRO-QPE2: excludes two bursts per orbit - ~OK with precession Arcodia+26

The (immediate) future for QPEs

What model is correct ?

What drives the delays ?

If EMRI, what is the nature of the orbiter?

What governs the long-term evolution ?

Many open questions

What are their rates ?

What are their contributions to LISA signal ?

What is their lifetime ?

The main current directions

Simulations

- Understand details

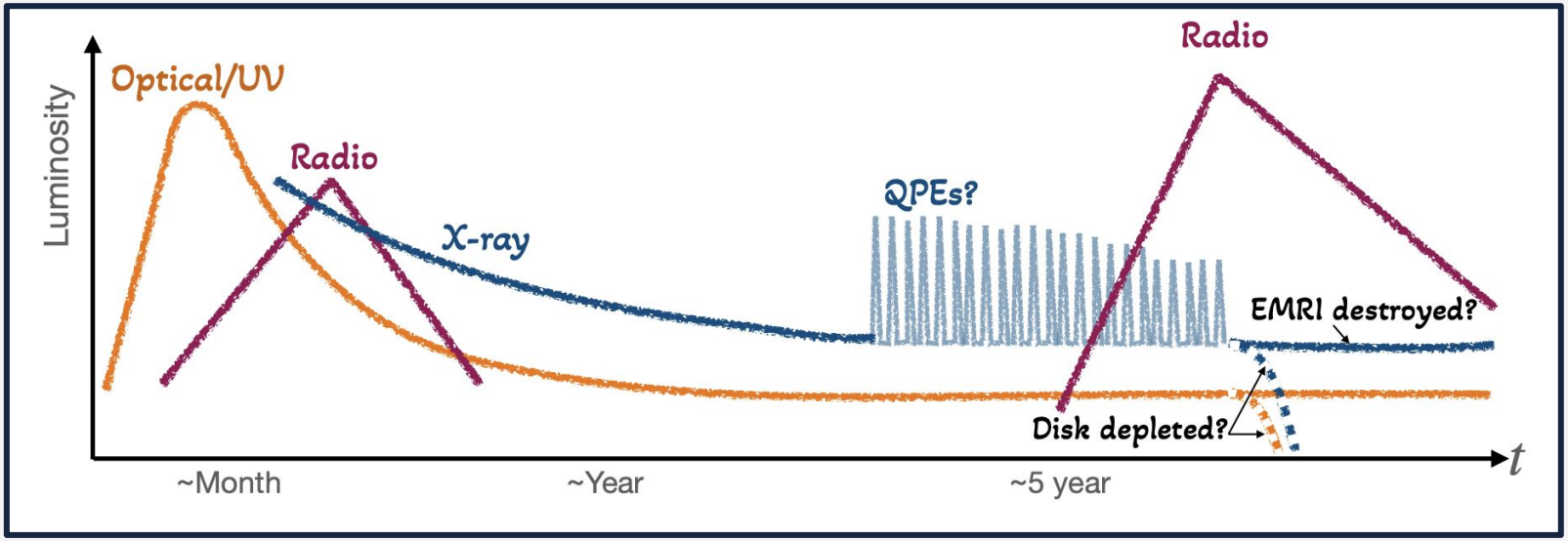
Modelling

- Understand issues in delays
  - Warped disk?
  - Issues timing of eruptions ?

Observations

- Find new ones
- Monitor the ones we have

How to find new QPEs ?

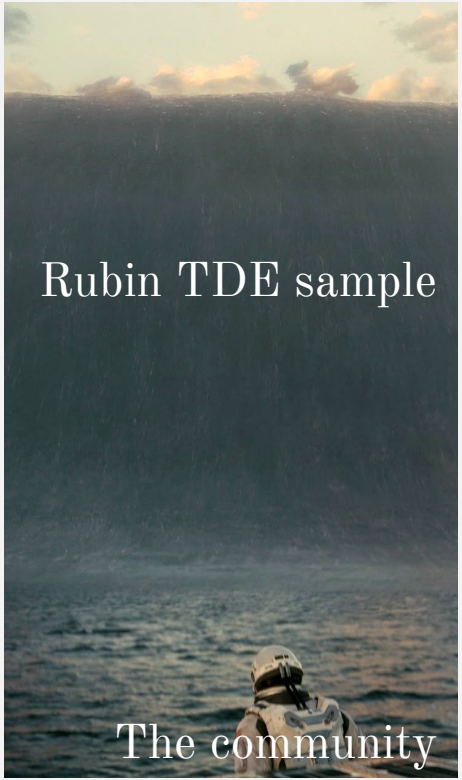


Linial+26

Follow up at late times on TDEs

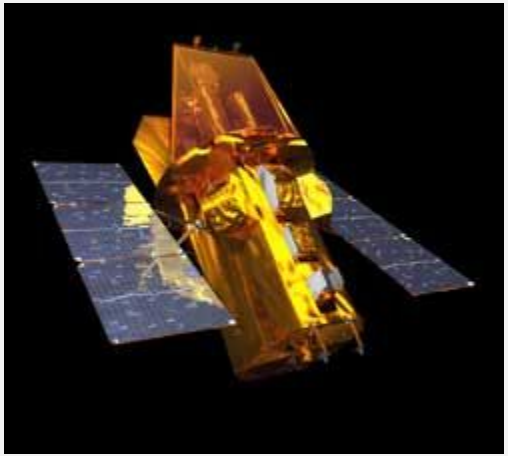
How to find new QPEs ?

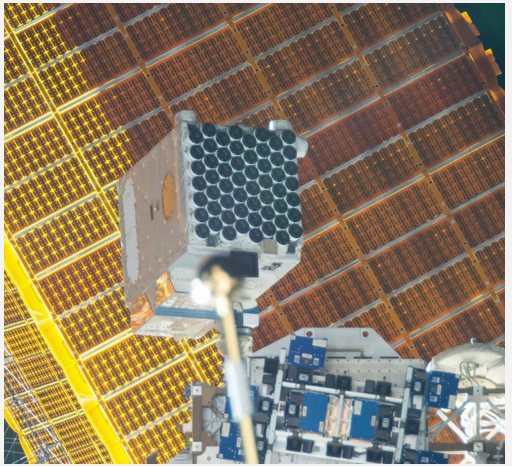
- Detect new TDEs (e.g. optical with Rubin)



How to find new QPEs ?

- Detect new TDEs (e.g. optical with Rubin)
- Monitor them in X-rays
- Follow-up with more intensive campaigns if detected





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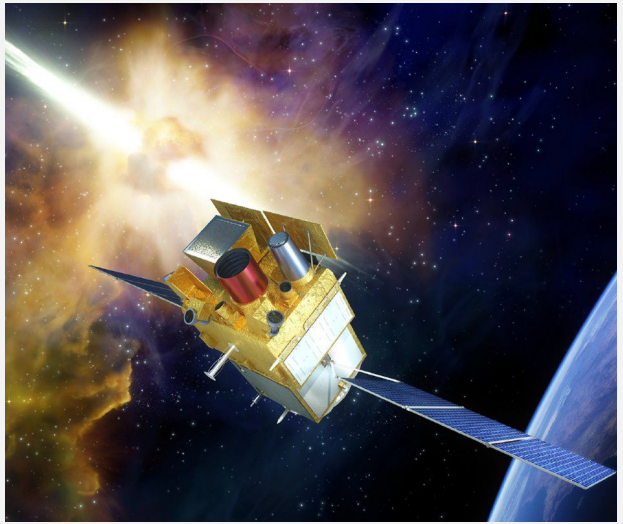


Long term: NewAthena

- **With X-IFU:**
  Detailed time-resolved study of the outflows (~0.15c)

- **With WFI:**
  Survey possibilities to detect serendipitous new TDEs/QPEs

see the special issue !

Conclusions

QPEs are still puzzling

Some recent progress

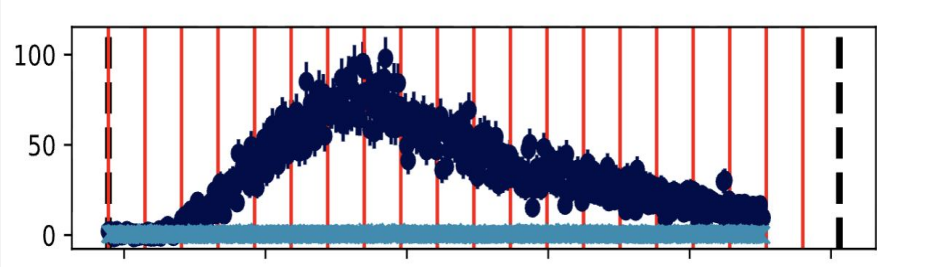
- Current model: EMRI+TDE
- But some issues
- Observing them is challenging

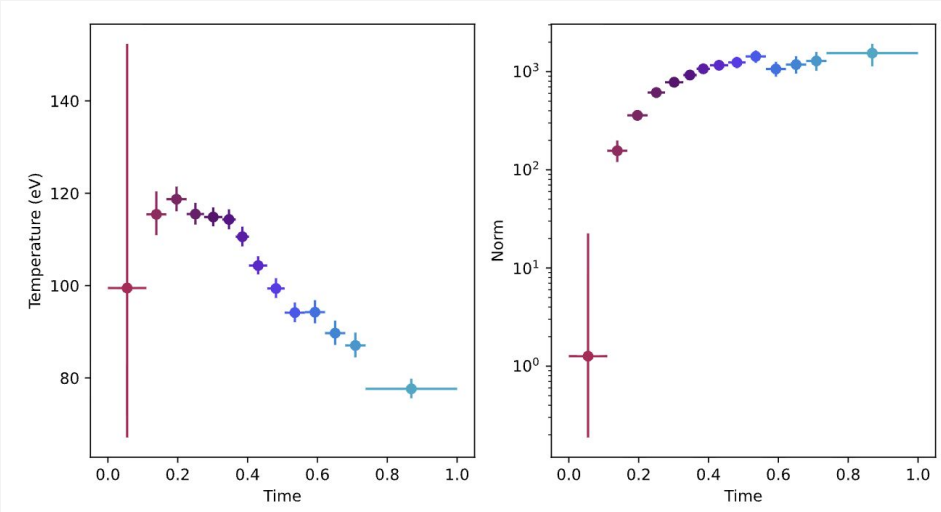
If model is true: they can help understand EMRIs & their GWs

Questions ?

erwan.quintin@esa.int

Is the way we time eruptions the right one ?





For now, timing done as peak of the lightcurves

Observed counts = function of Temperature and Radius

Peak luminosity depends on the temperature evolution

Better estimate: extrapolate radius for size 0

Jaxspec (Dupourqué+24)