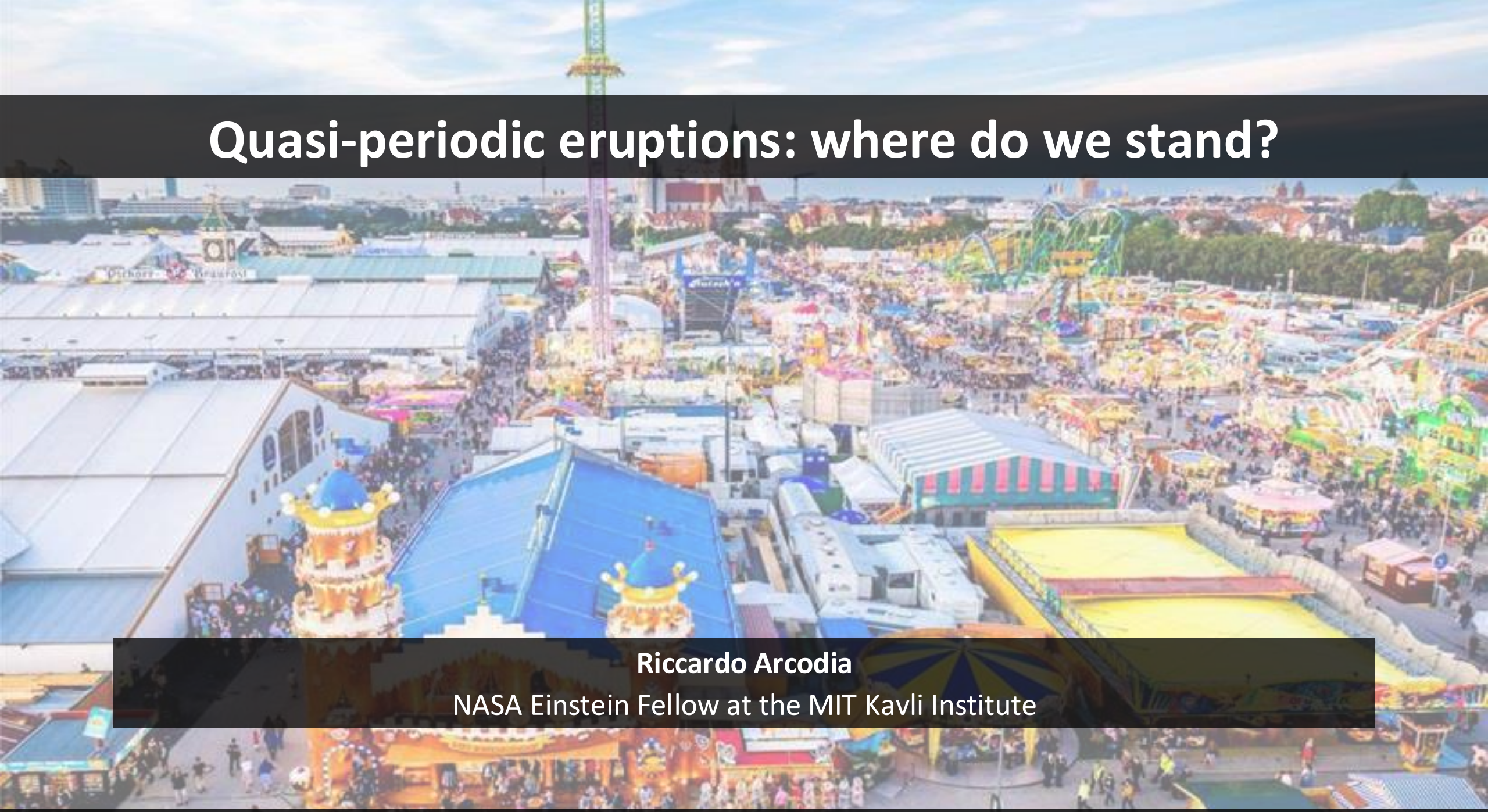
Quasi-periodic eruptions: where do we stand?

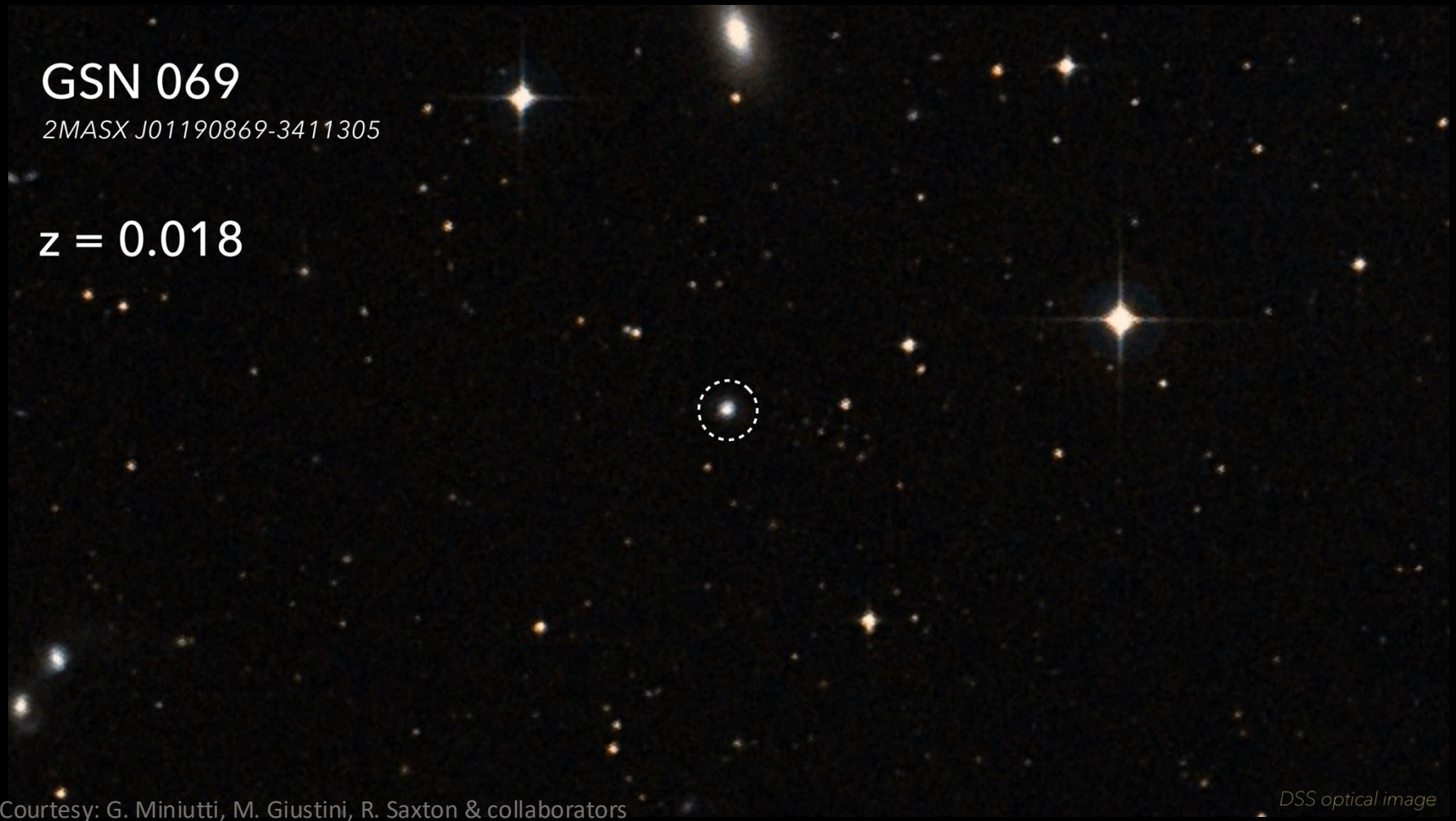


Riccardo Arcodia

NASA Einstein Fellow at the MIT Kavli Institute

Not too long ago in a galaxy not that far away..

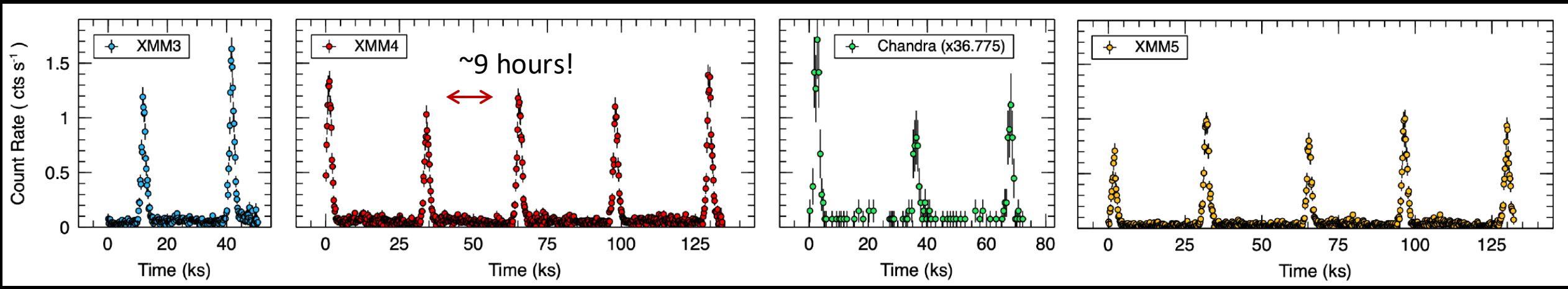
- At the end of 2018 this galaxy was being monitored in X-rays



Courtesy: G. Miniutti, M. Giustini, R. Saxton & collaborators

Quasi-periodic eruptions

- At the end of 2018 this galaxy was being monitored in X-rays



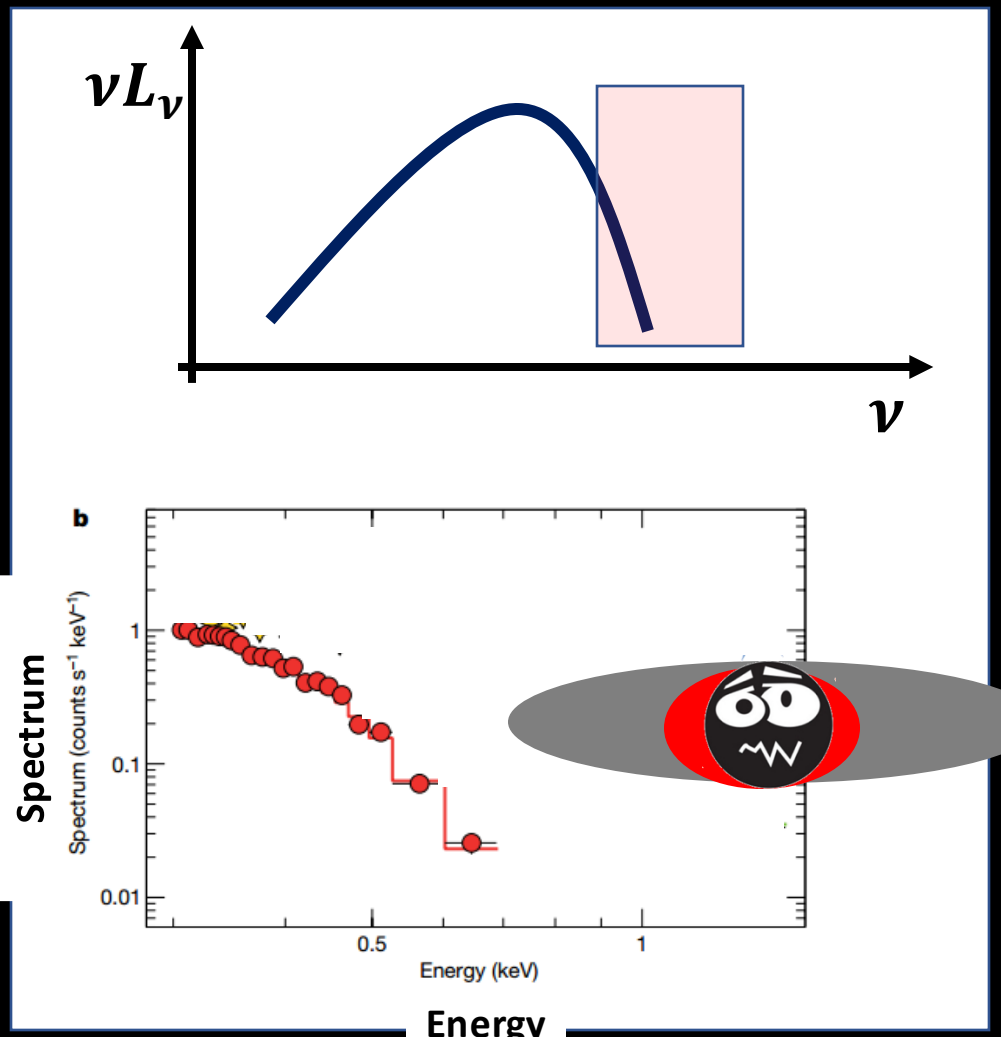
Courtesy: G. Miniutti, M. Giustini, R. Saxton & collaborators

→ This new exotic phenomenon was called “Quasi-Periodic Eruptions (QPEs)”

Observational properties of QPEs

QPEs' basic properties: spectra

- Soft spectra in quiescence

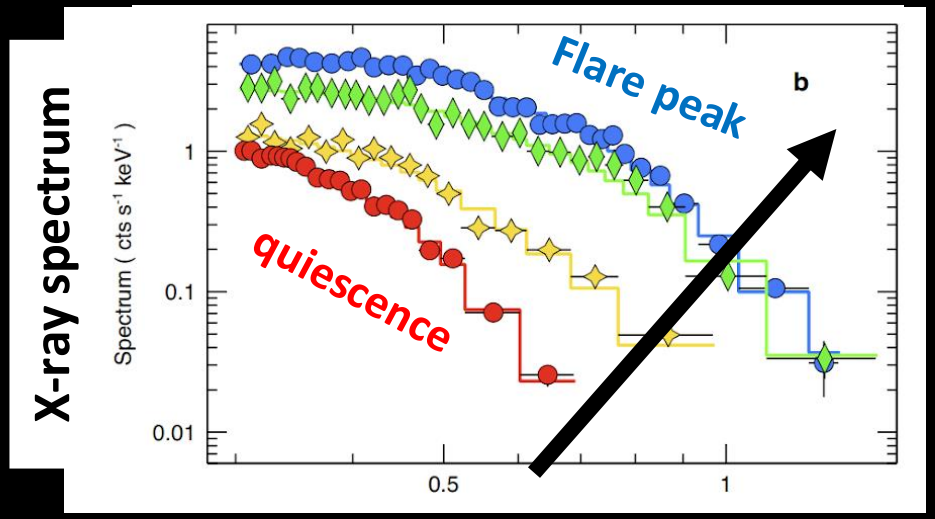


"Quiescent" emission is a radiatively efficient accretion disk!

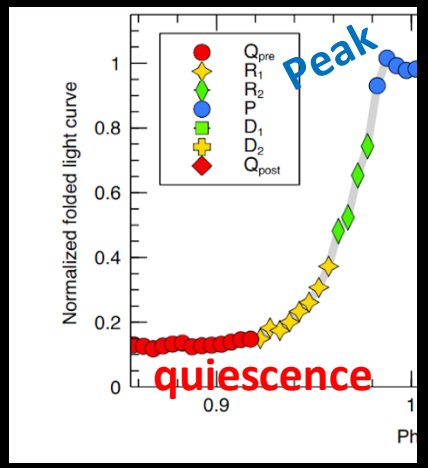
e.g. Miniutti+19

QPEs' basic properties: spectra

- Soft spectra in **quiescence** and **flare**



GSN 069

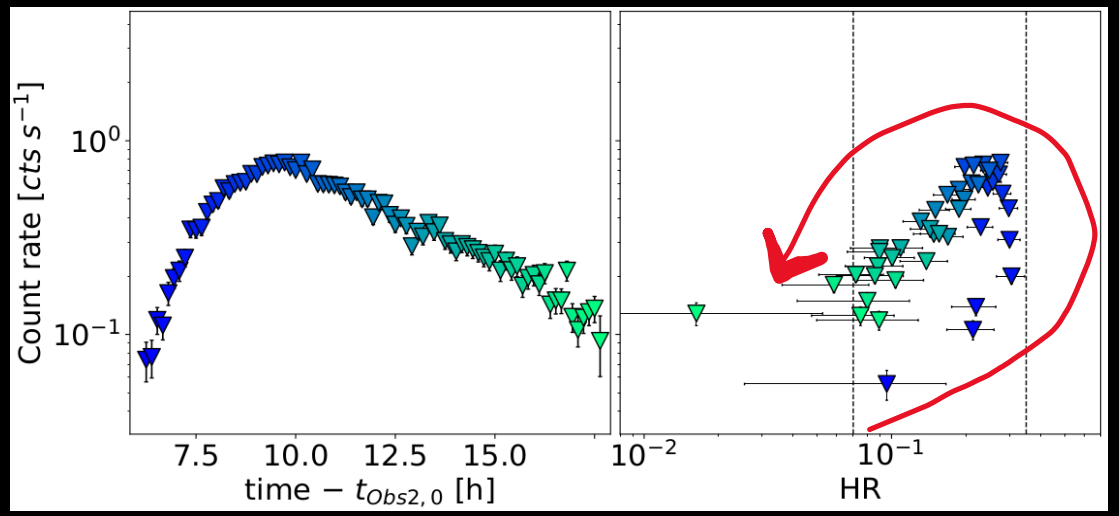


Miniutti+19

Quiescence to flare does not comply with evolution due to accretion

QPEs' basic properties: spectra

- Soft spectra in quiescence and flare, specific behavior (harder rise than decay)

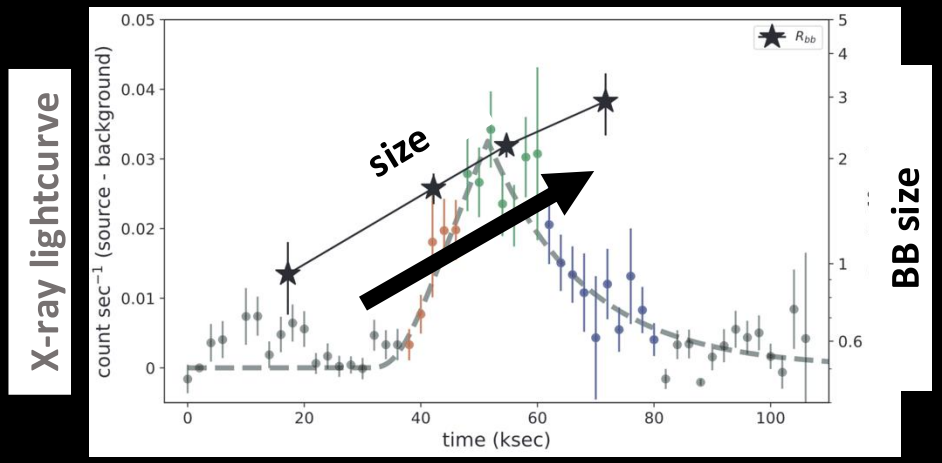


Arcodia+22

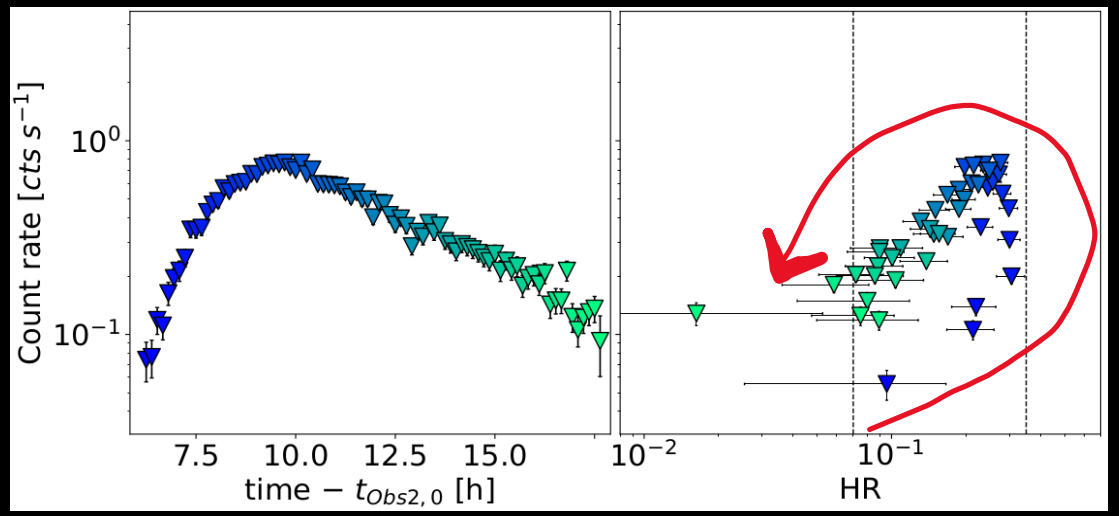
Spectral behavior during the eruptions = physical mechanism driving them

QPEs' basic properties: spectra

- Soft spectra in quiescence and flare, specific behavior (harder rise than decay)



Chakraborty,**RA**+24; see Miniutti+23



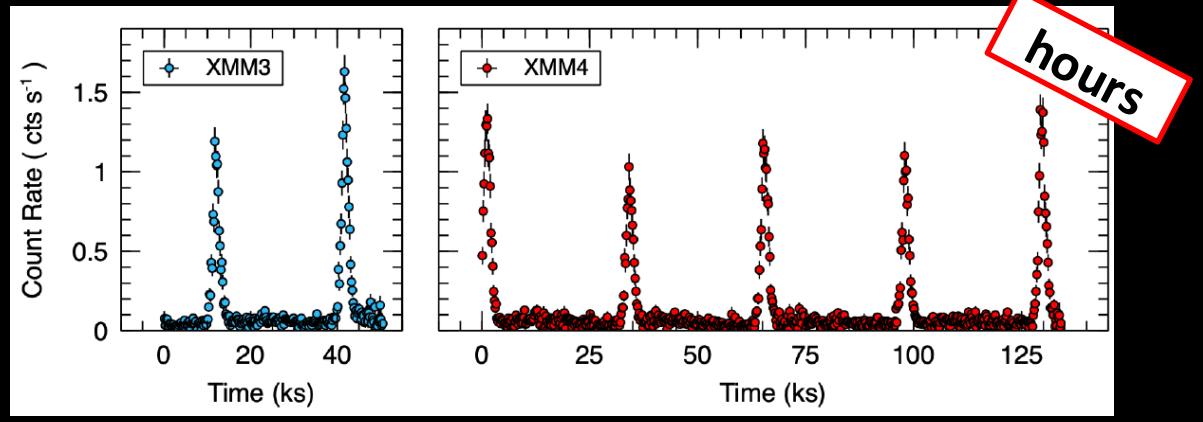
Arcodia+22

If modeled with a black body:
expanding emitting region

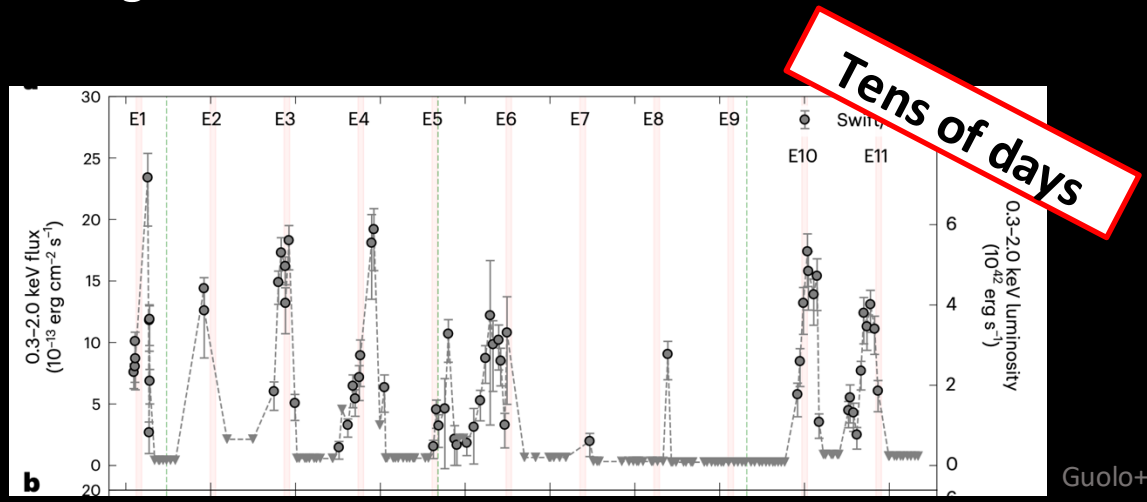
Spectral behavior during the eruptions = physical mechanism driving them

How to define QPEs?

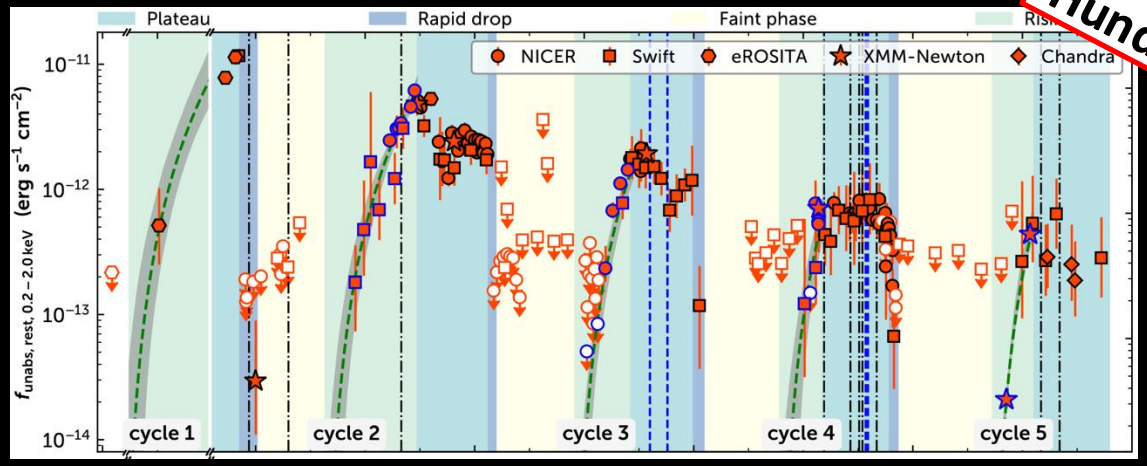
- How to <u>define QPEs</u> within the growing population of repeating nuclear transients?



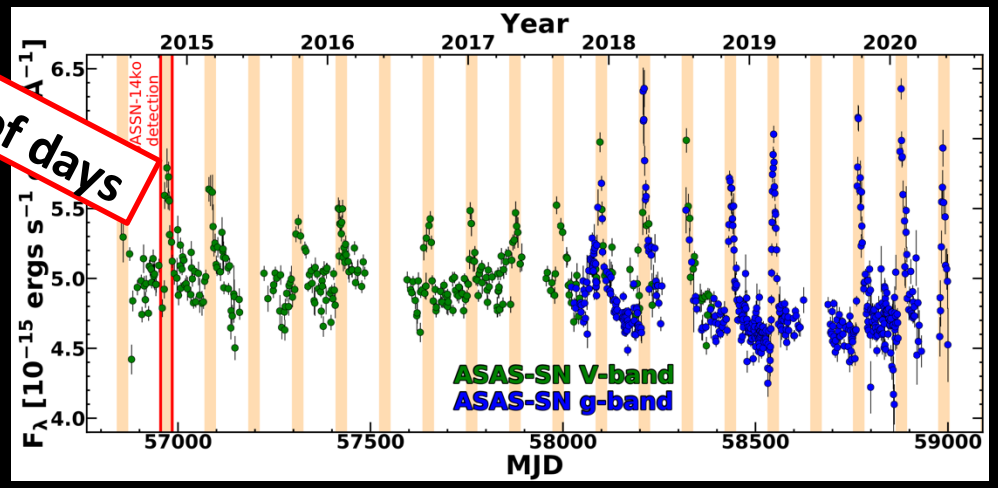
Miniutti+19



Guolo+24



Liu+24



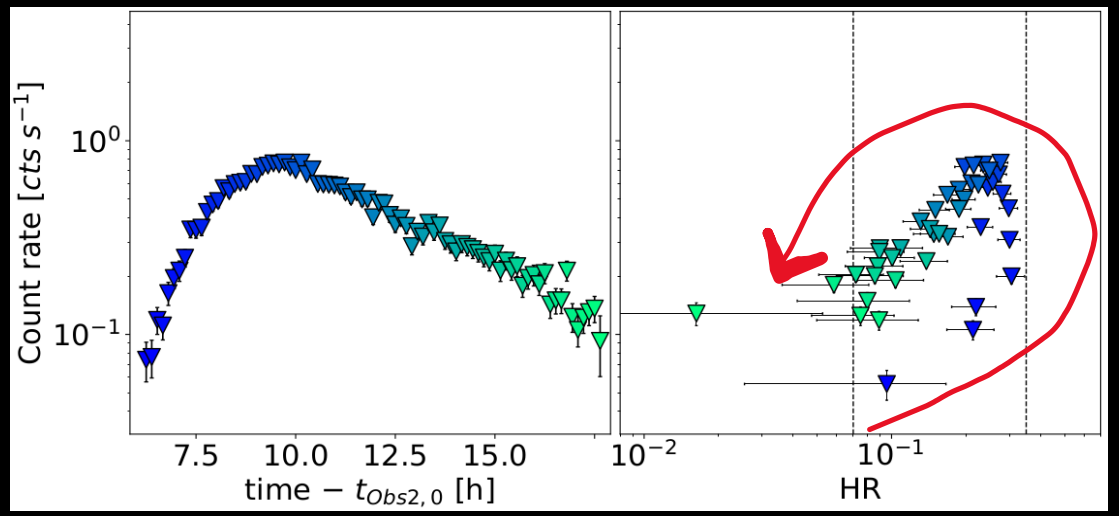
Payne+21

QPEs' basic properties: spectra

- Soft spectra in quiescence and flare, specific behavior (harder rise than decay)

Seen in 7 public sources to date
(GSN069, RXJ1301, eRO-QPE1-4; AT2019qiz)
+1-3 others in prep

Miniutti+19; Giustini+20; **Arcodia+21;24a**
Nicholl+24

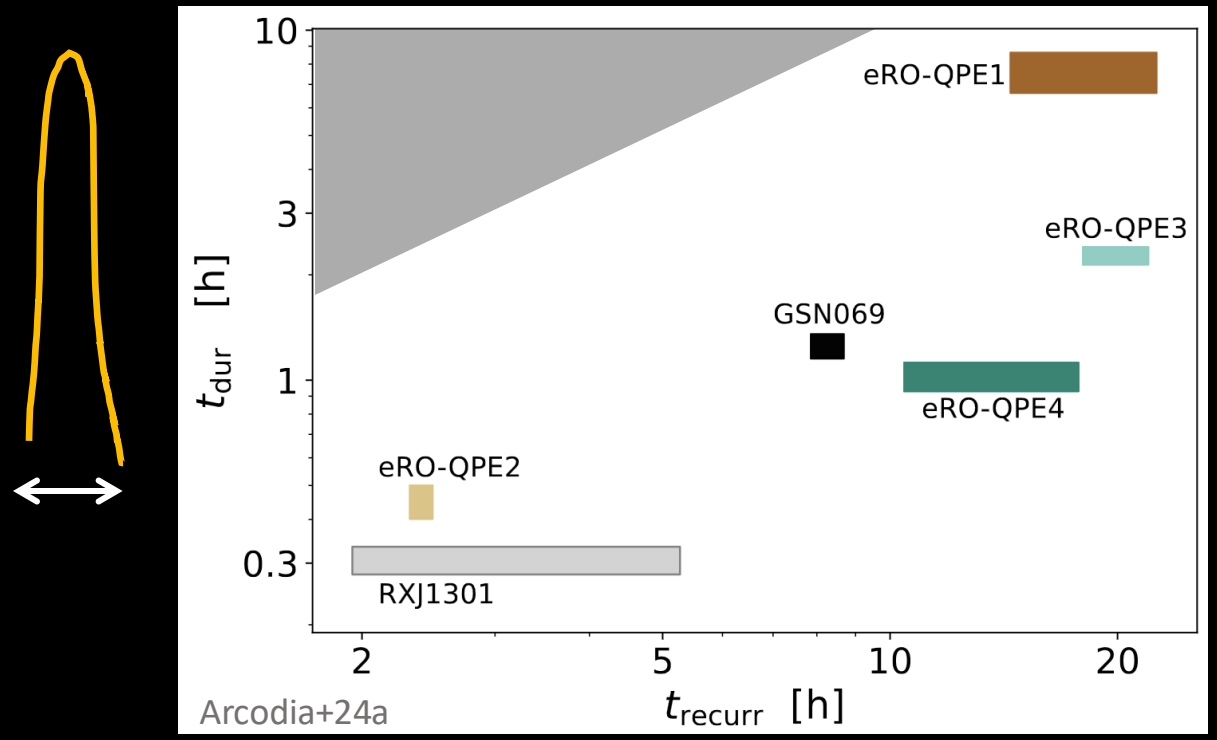


Arcodia+22

Spectral behavior during the eruptions = physical mechanism driving them

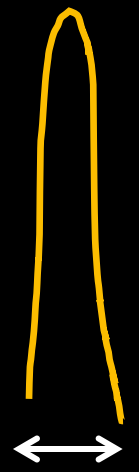
QPEs' basic properties: timing

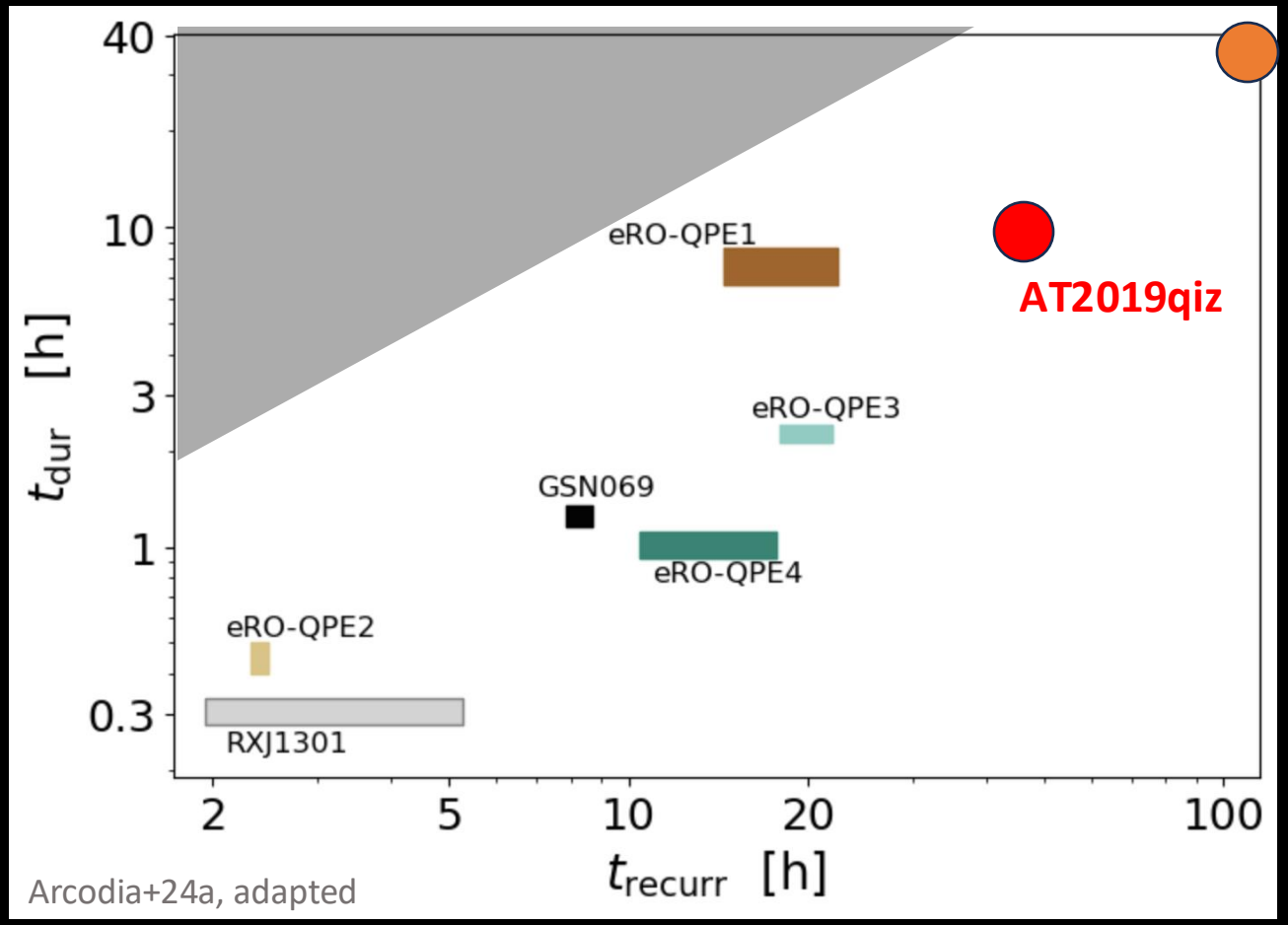
- X-ray flares lasting few-several hours, recurring every several hours-days



QPEs' basic properties: timing

- X-ray flares lasting few-several hours, recurring every several hours-days





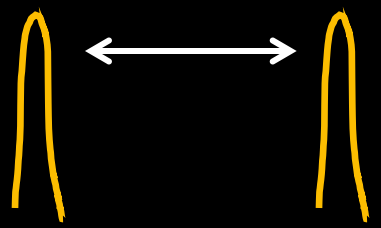
Arcodia+24a, adapted

ZTF19acnskyy

Hernandez-Garcia+in prep.

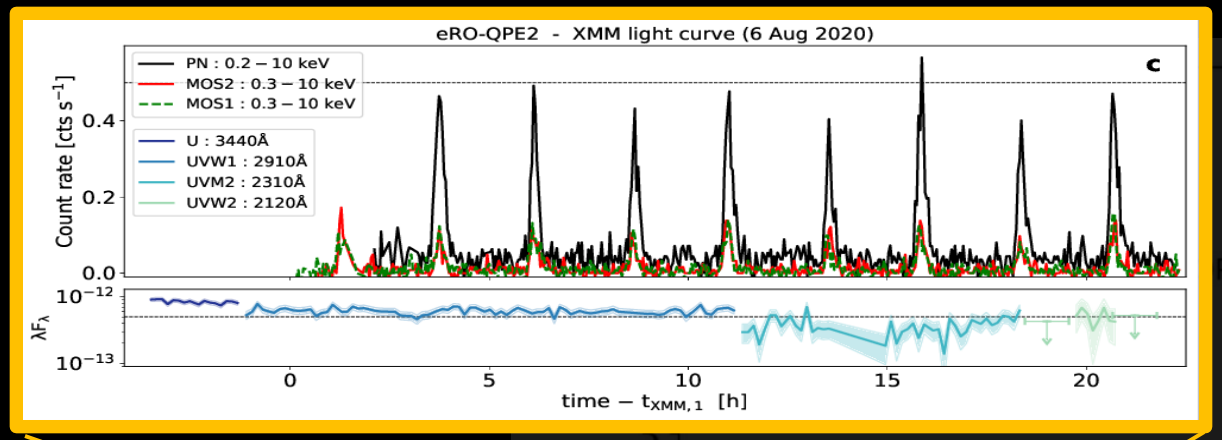
AT2019qiz

Nicholl+24

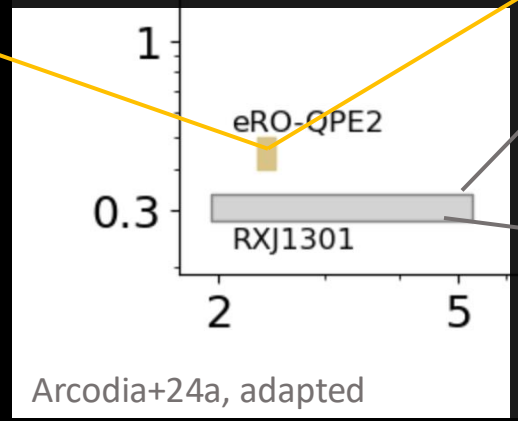


QPEs' basic properties: timing

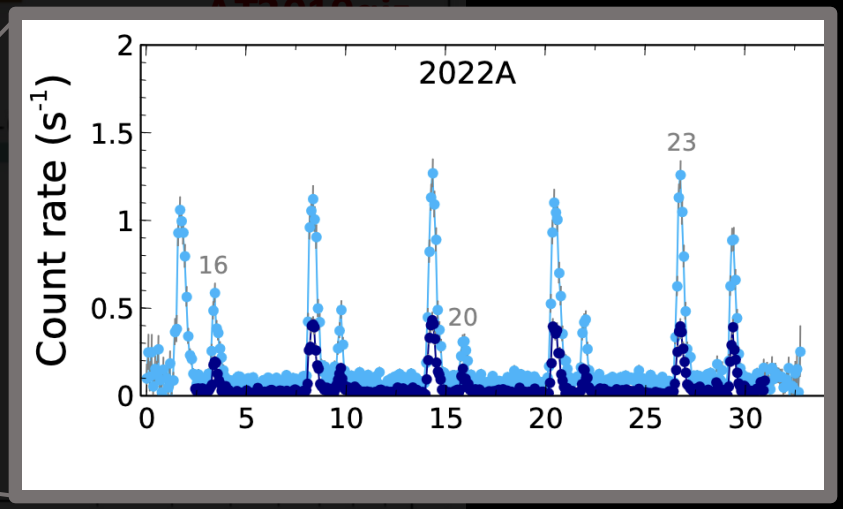
- X-ray flares lasting few-several hours, recurring every several hours-days



Arcodia+21



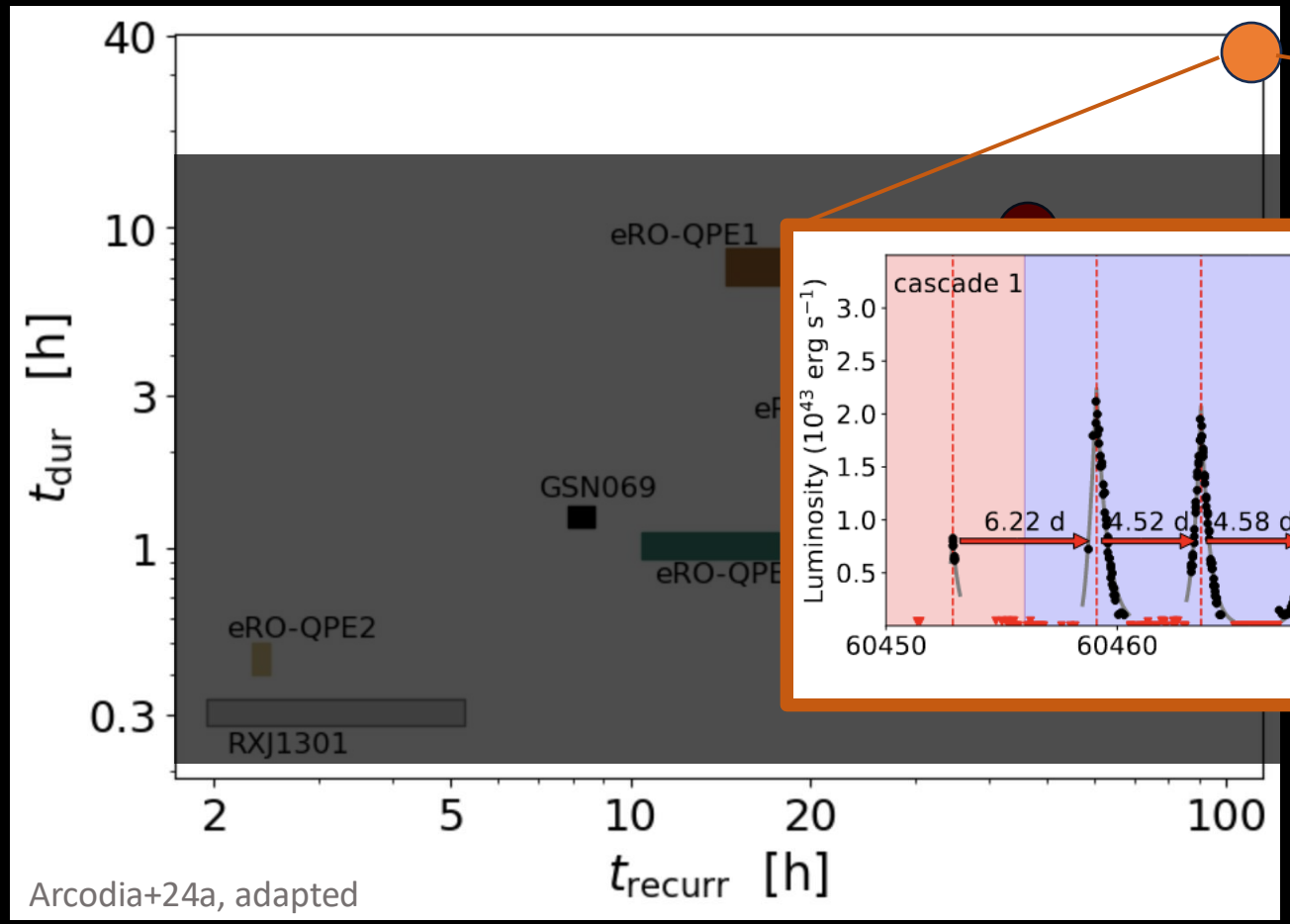
Arcodia+24a, adapted



Giustini..RA+24

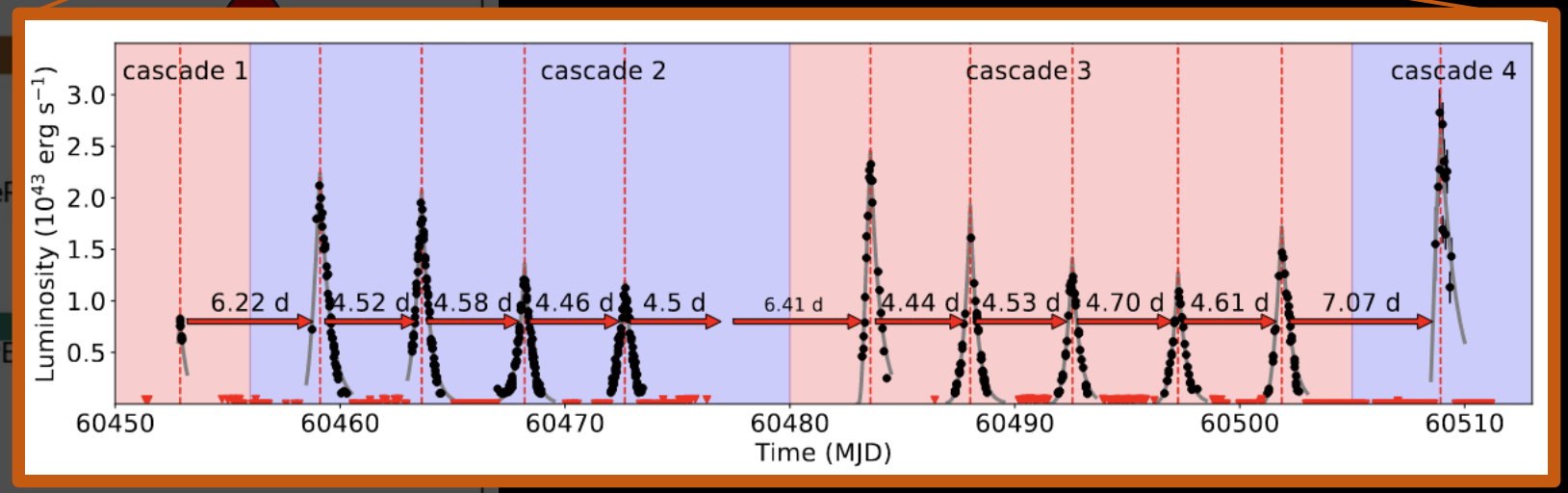
QPEs' basic properties: timing

- X-ray flares lasting few-several hours, recurring every several hours-days



Arcodia+24a, adapted

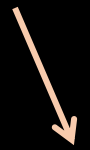
ZTF19acnskyy (Hernandez-Garcia+in prep.)



Courtesy P. Sanchez-Saez; J. Chakraborty

QPEs' basic properties: precursor

- Observational connection with TDEs in some/most cases

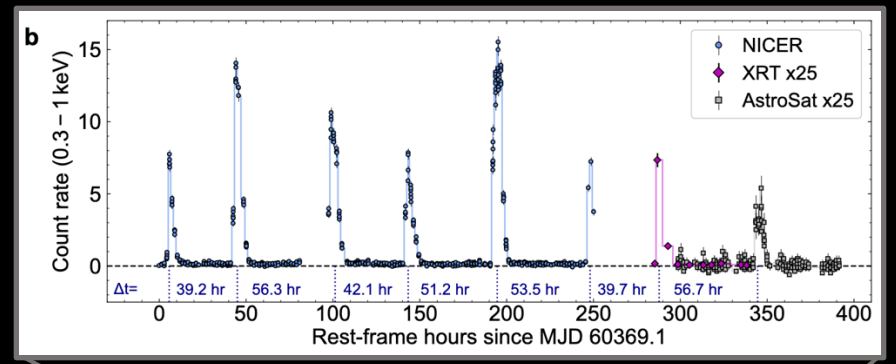


  - TDE-like spectrum in quiescence
  - TDE-like decays before QPEs
  - TDE-like host galaxies and MBHs
  - TDE-like lines in UV spectrum

e.g. Sheng+21; Chakraborty+21; Quintin+23; Arcodia+21; 24a; Wevers+22;24

QPEs' basic properties: precursor

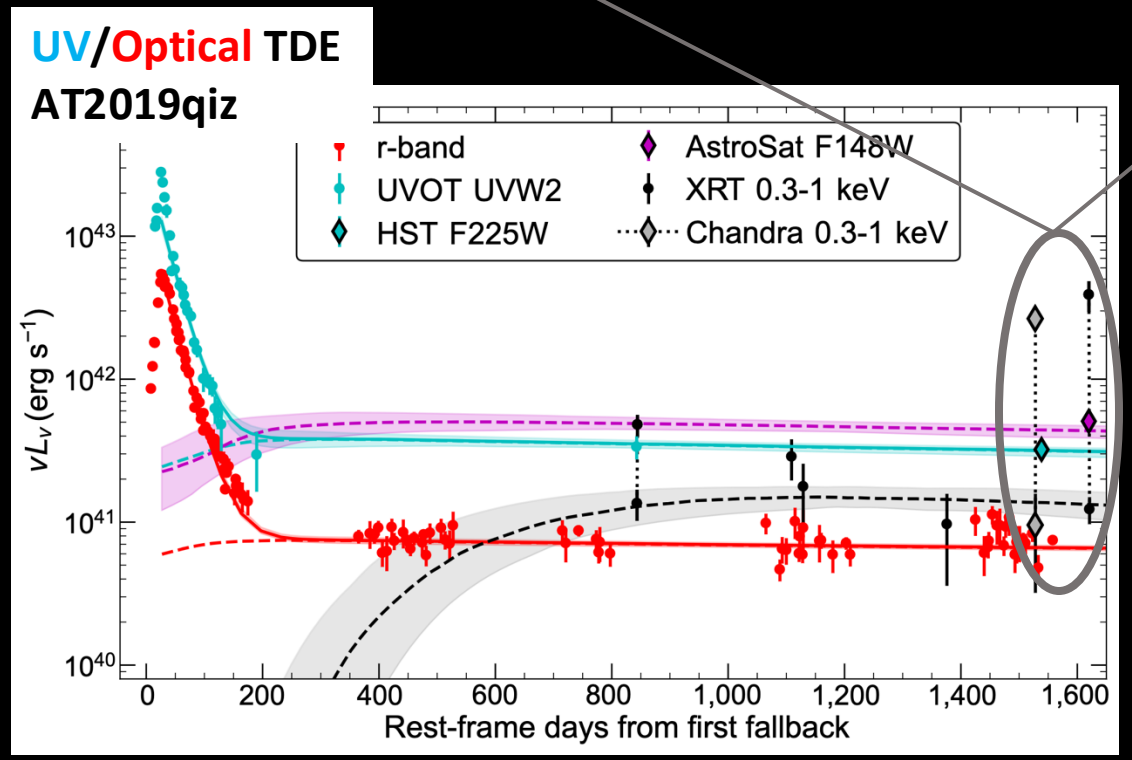
- Observational connection with TDEs in some/most cases



- TDE-like spectrum in quiescence
- TDE-like decays before QPEs
- TDE-like host galaxies and MBHs
- TDE-like lines in UV spectrum

e.g. Sheng+21; Chakraborty+21; Quintin+23; Arcodia+21; 24a; Wevers+22;24

QPEs after an optical TDE!

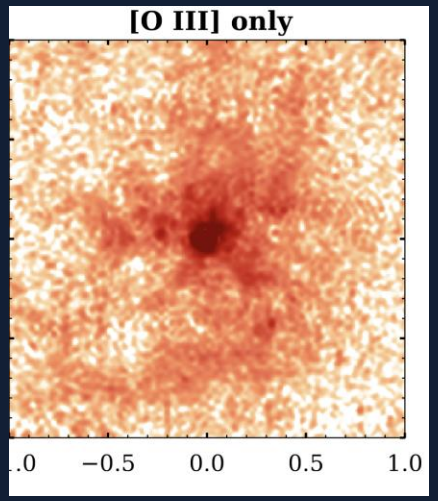


X-ray QPEs

Nicholl+24

QPEs' basic properties: precursor

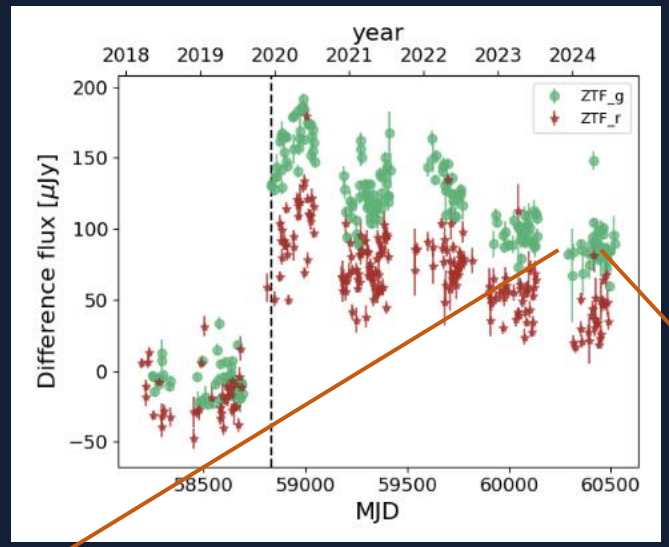
- Relatively newborn/short lived accretion flow (of whatever origin!)



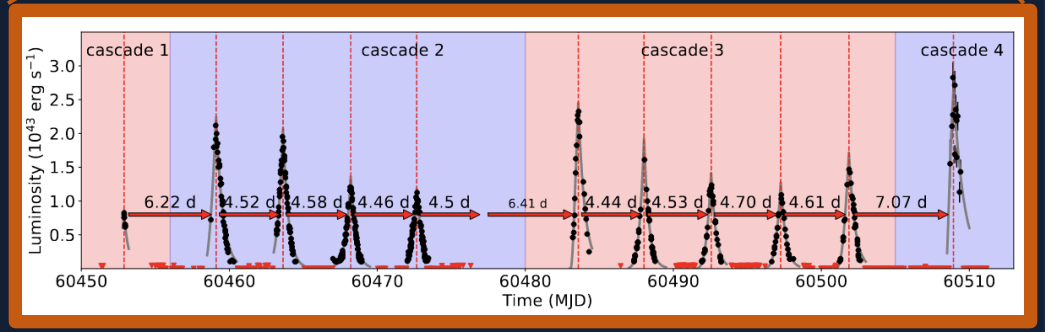
Patra+24

HST finds compact [OIII] emission aging the accretion system of GSN069 to <10-100y

QPEs found in a newborn compact AGN



(Hernandez-Garcia+in prep.)



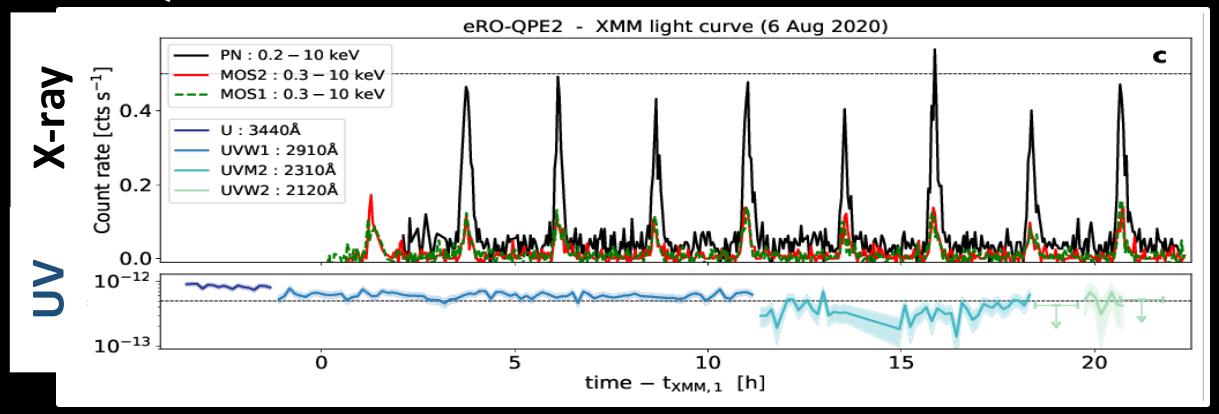
Courtesy P. Sanchez-Saez; J. Chakraborty

QPEs' basic properties: flare counterparts?

- No flaring counterpart (optical/UV/IR/radio) to the X-ray eruptions

X-ray only!

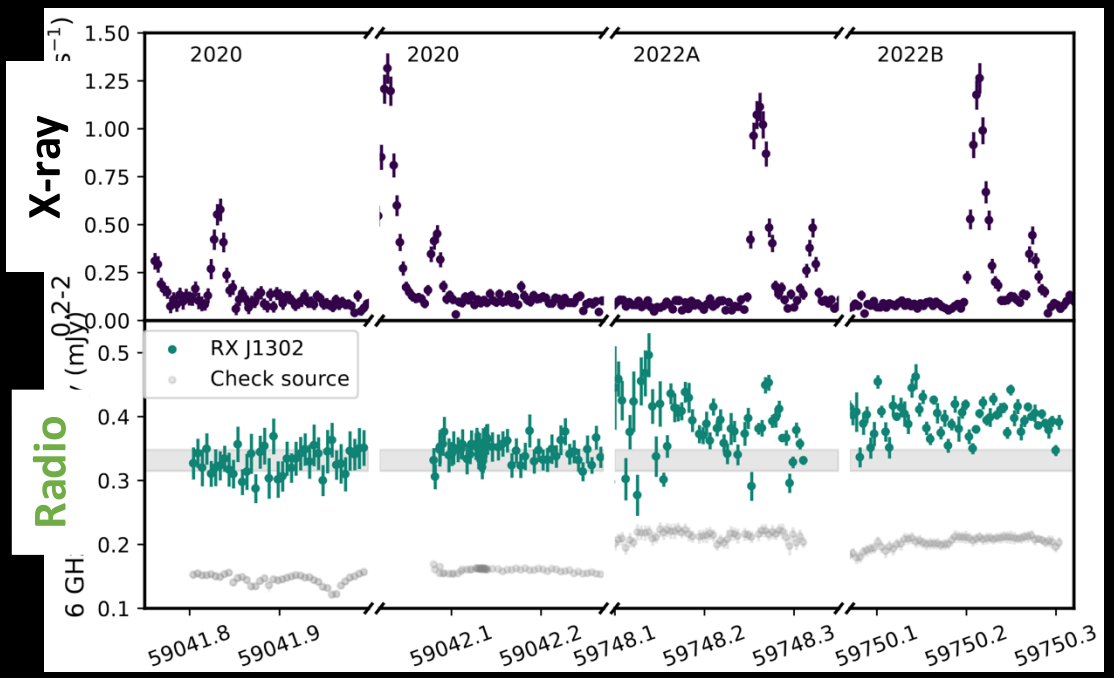
eRO-QPE2



Arcodia+21

RX J1301.9+2747

Giustini..**RA**..+24



QPEs' basic properties: quiescence counterparts

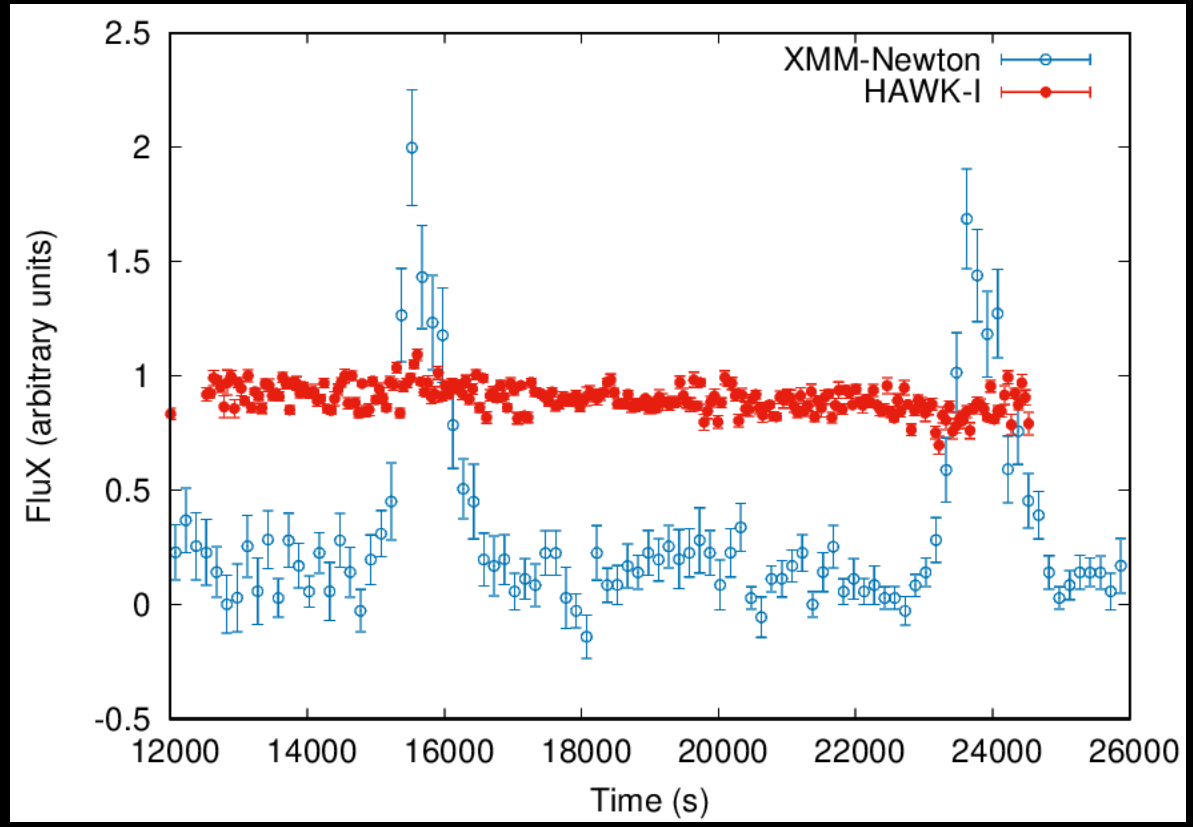
UV

Accretion disk i.e. the "quiescence"

Thomas's talk – HSTxXMM!

IR

Galaxy?



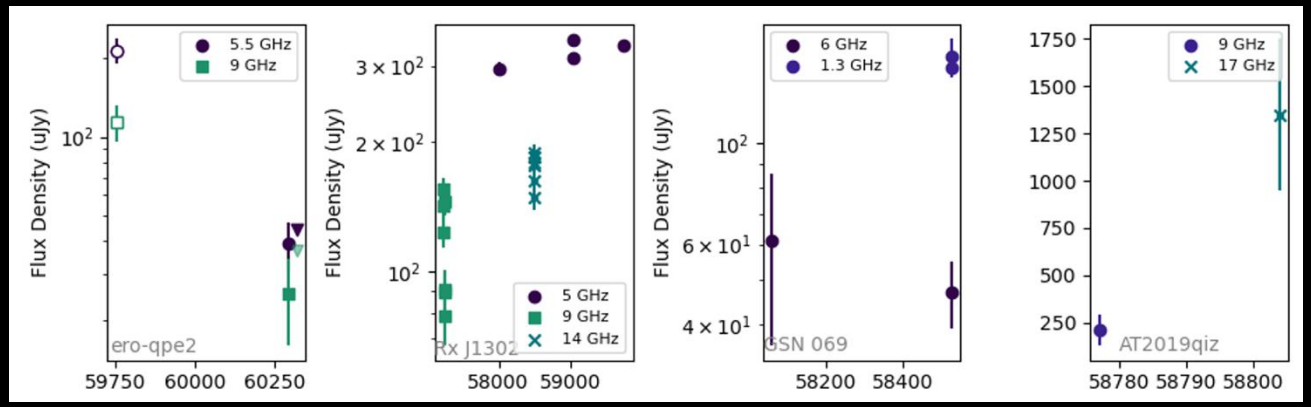
Vincentelli,RA+in prep.

QPEs' basic properties: counterparts

UV Accretion disk i.e. the "quiescence" Wevers+ in prep.

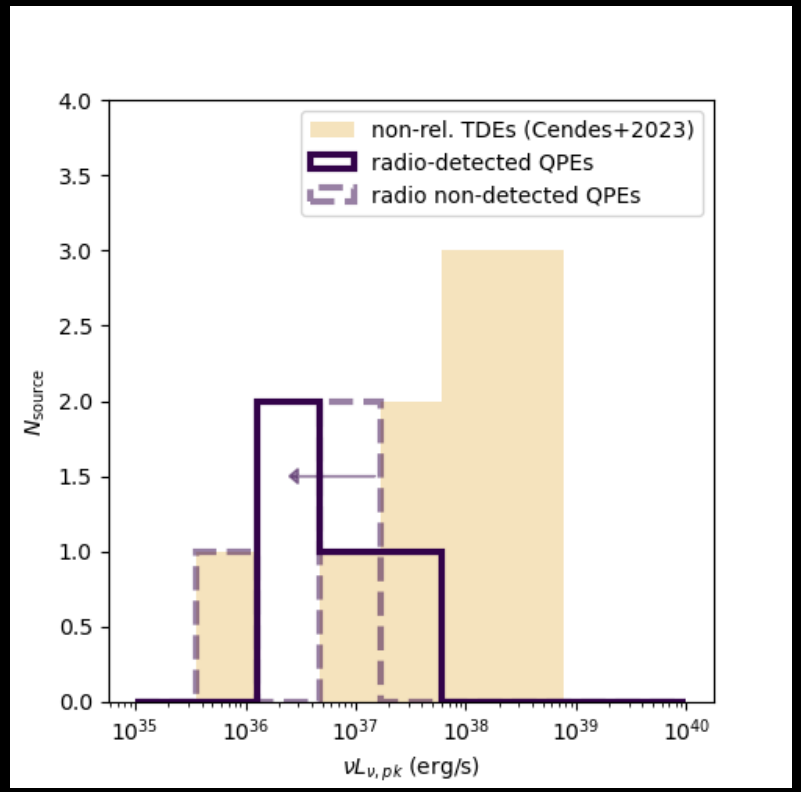
IR Galaxy? Vincentelli+ in prep

Radio Accretion outflows/Galaxy?



Goodwin+ in prep.

Only 4 QPEs detected in radio, only 2 variable
(less luminous and less variable than TDEs)

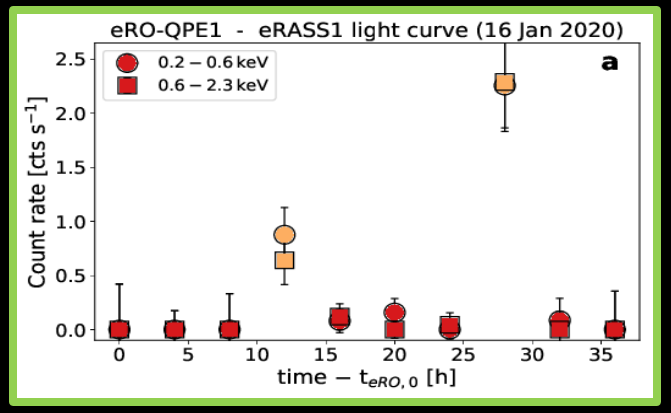


QPEs' basic properties: discoveries

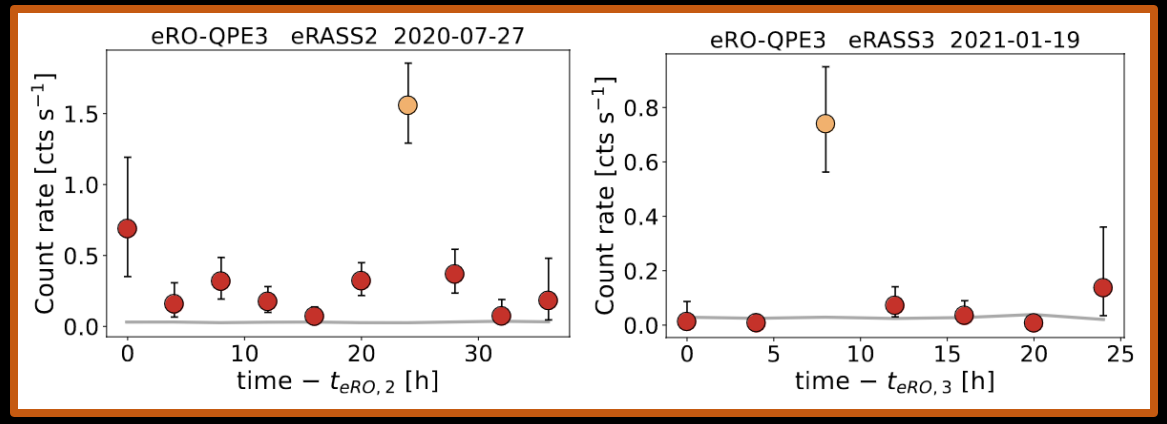
- How did we find them so far?

→ Serendipity + archival searches (~50%) Miniutti+19; Giustini+20; Nicholl+24 + others in prep

→ Systematic X-ray blind searches (~50%, with eROSITA + follow-up) **Arcodia+21;24**



eRO-QPE1



eRO-QPE3

QPEs' basic properties: discoveries

- What's next? sensitive wide-area discovery machine missing..

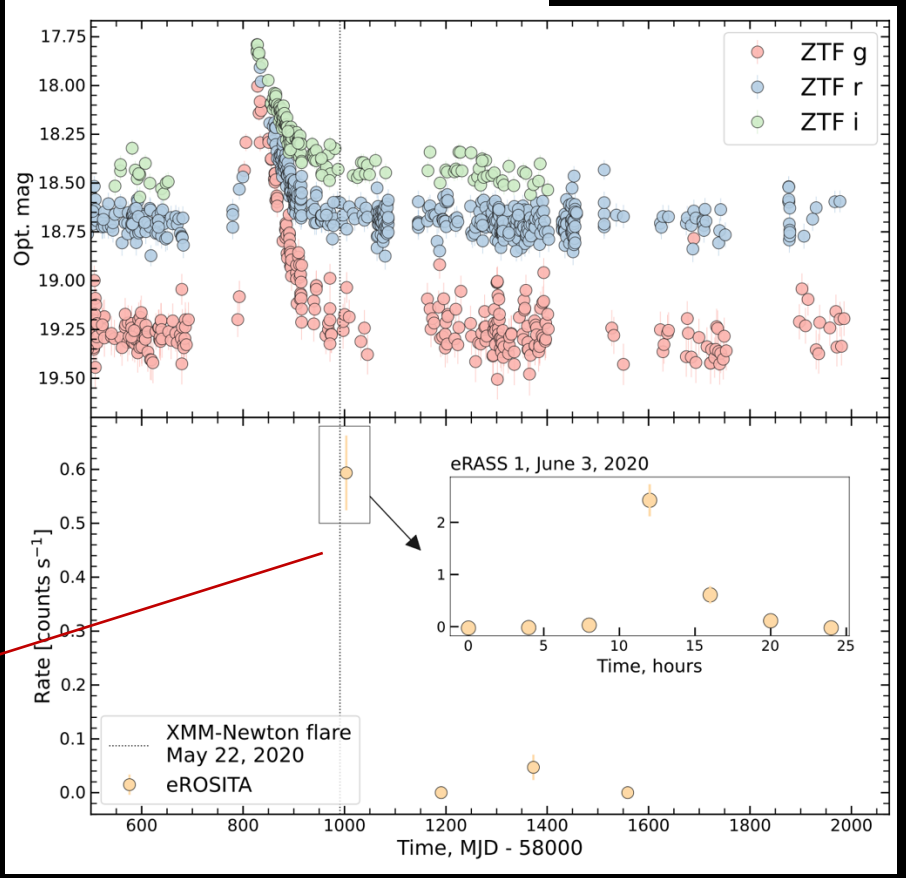
↘ X-rays post optical flares? e.g. Nicholl+24 + others in prep

QPEs' basic properties: discoveries

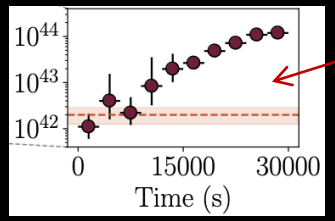
- What's next? sensitive wide-area discovery machine missing..

X-rays post optical flares? e.g. Nicholl+24 + others in prep

TDE AT2019vcb "Tormund"



Part of eruption?



Quintin+23

eRASS1 eruption 13d the partial

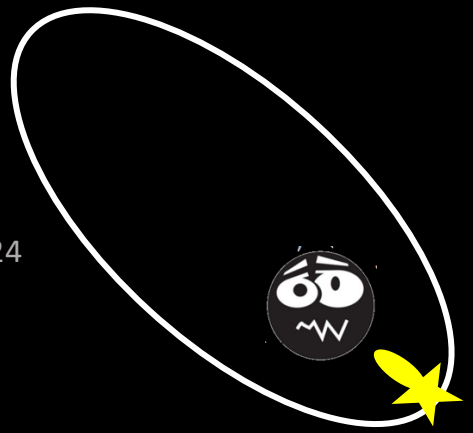
Bykov+ in prep. (eROSITA-RU)

What are they?

Proposed QPE models

- QPEs = pTDEs

  e.g. King20,22; Zhao+22, Metzger+22, Xian+22, Wang+22; Lu&Quataert23; Linial&Sari23; Wang24 (but see Cufari+23)

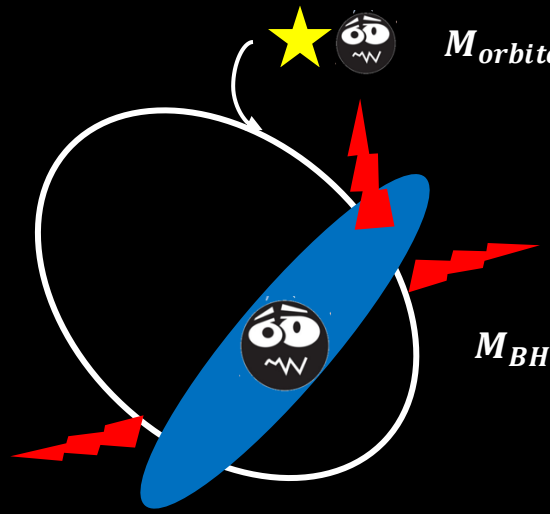


- QPEs = disk instabilities/tearing

  e.g. Sniegowska+20,23; Pan+21,23; Kaur+23; Raj&Nixon+21

- QPEs = EMRIs (collisions)

  Xian+21; Sukova+21; Linial&Metzger23; Franchini,Bonetti+23; Tagawa&Haiman23; Zhou+24



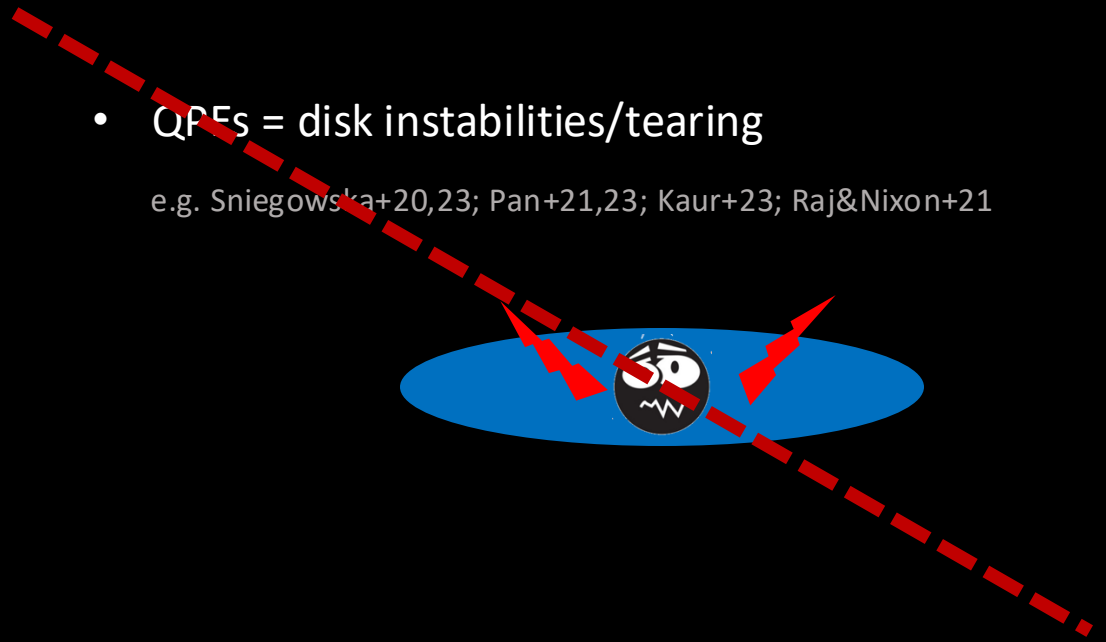
Proposed QPE models

- QPEs = pTDEs

  e.g. King20,22; Zhao+22, Metzger+22, Xian+22, Wang+22; Lu&Quataert23; Linial&Sari23, Wang24 (but see Cufari+23)

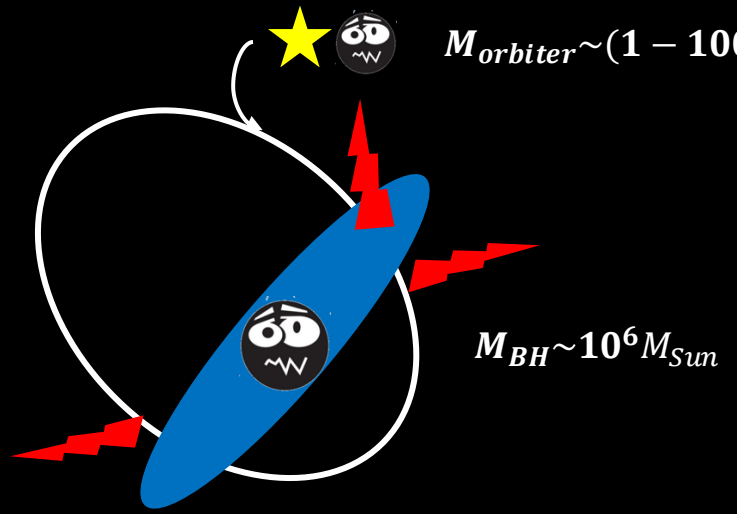
- QPEs = disk instabilities/tearing

  e.g. Sniegowska+20,23; Pan+21,23; Kaur+23; Raj&Nixon+21



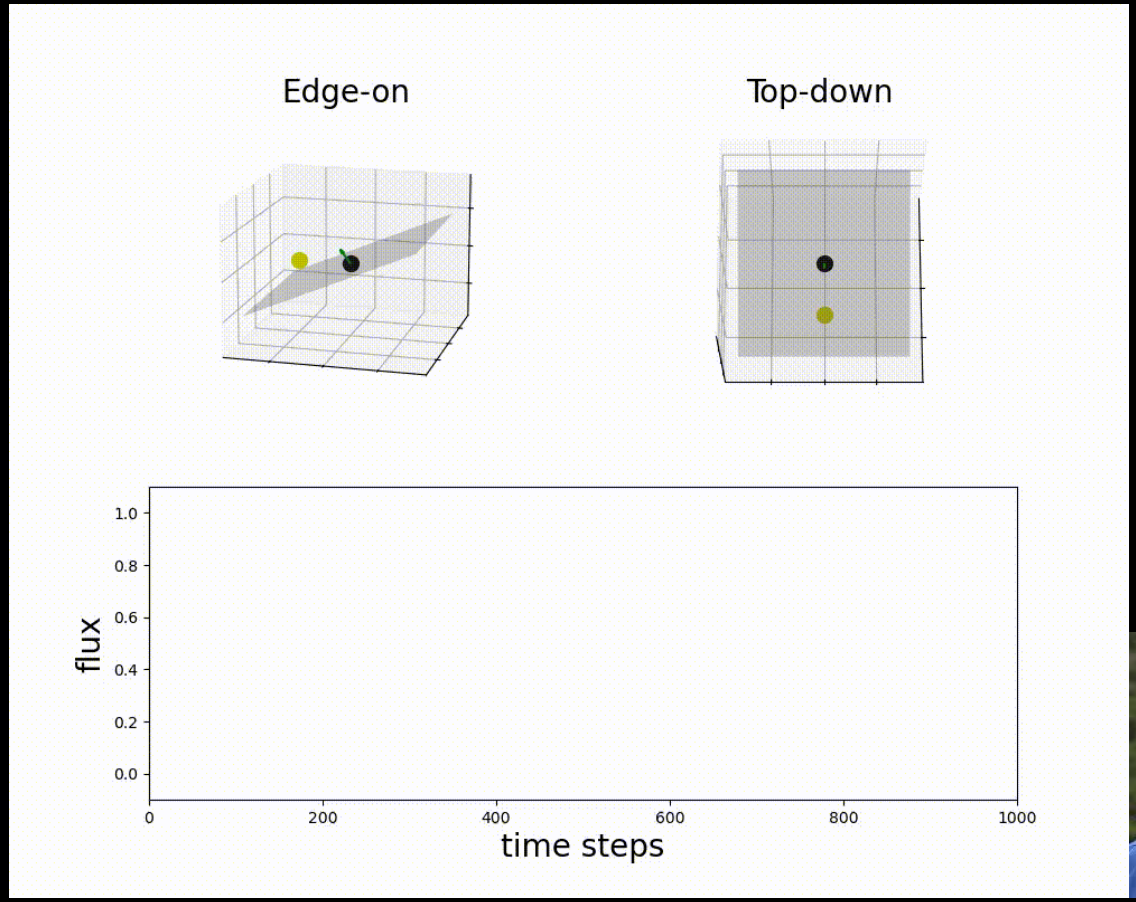
- QPEs = EMRIs (collisions)

  Xian+21; Sukova+21; Linial&Metzger23; Franchini,Bonetti+23; Tagawa&Haiman23; Zhou+24



Testing orbital models

- In absence of eccentricity, and precession:

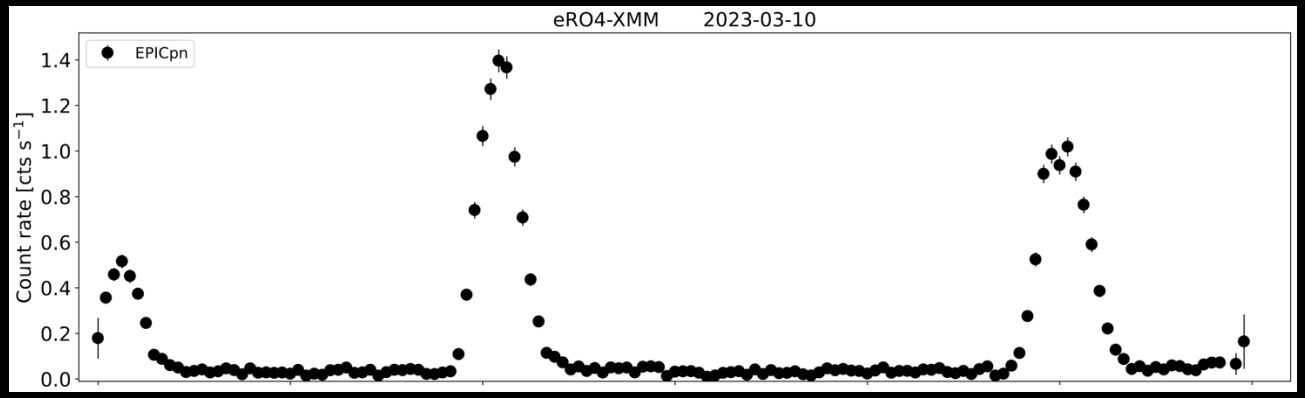


Joheen Chakraborty, MIT

Testing orbital models

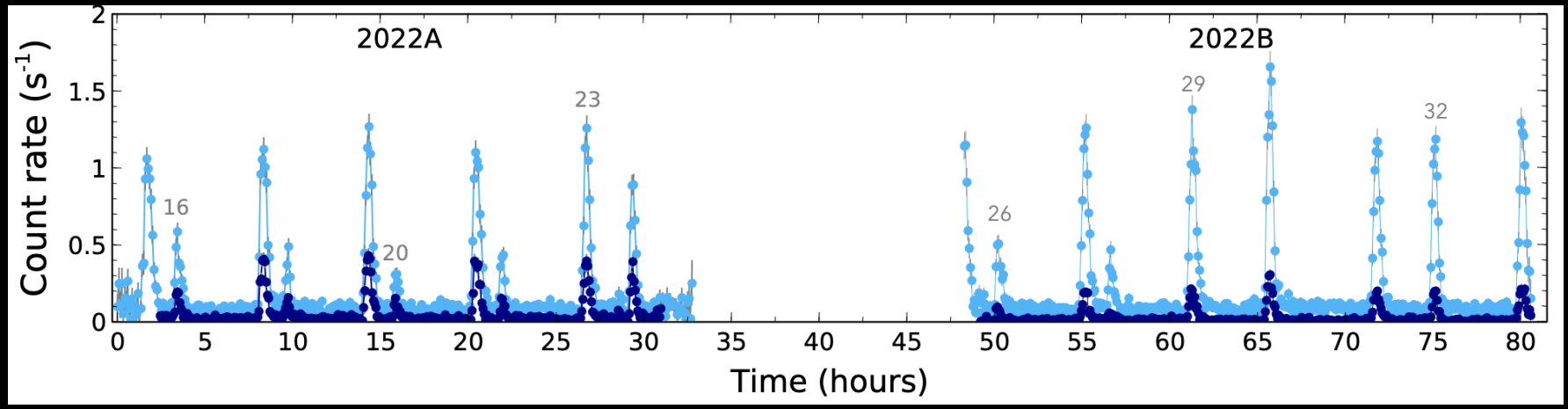
- In absence of eccentricity, and precession: not quite what we see

eRO-QPE4



Arcodia+24a

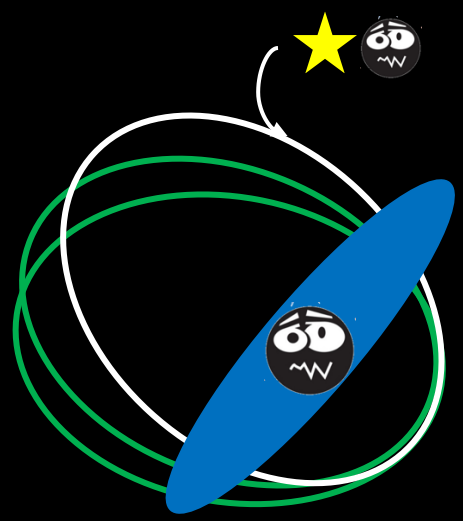
RX J1301.9+2747



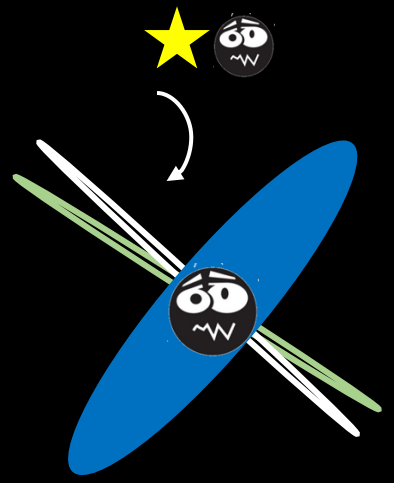
Giustini+(**RA**)24

Testing orbital models

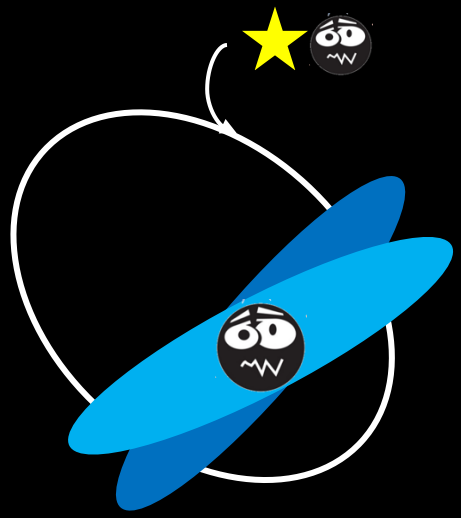
- What effects do we expect to be at play? e.g. Linial&Metzger23;Franchini+(**RA**)23



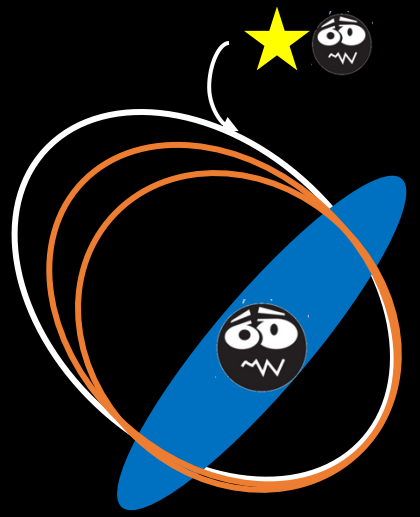
EMRI apsidal
(tens of days)



EMRI nodal
(~1-few years)



Disk nodal
(?? days to years ??)

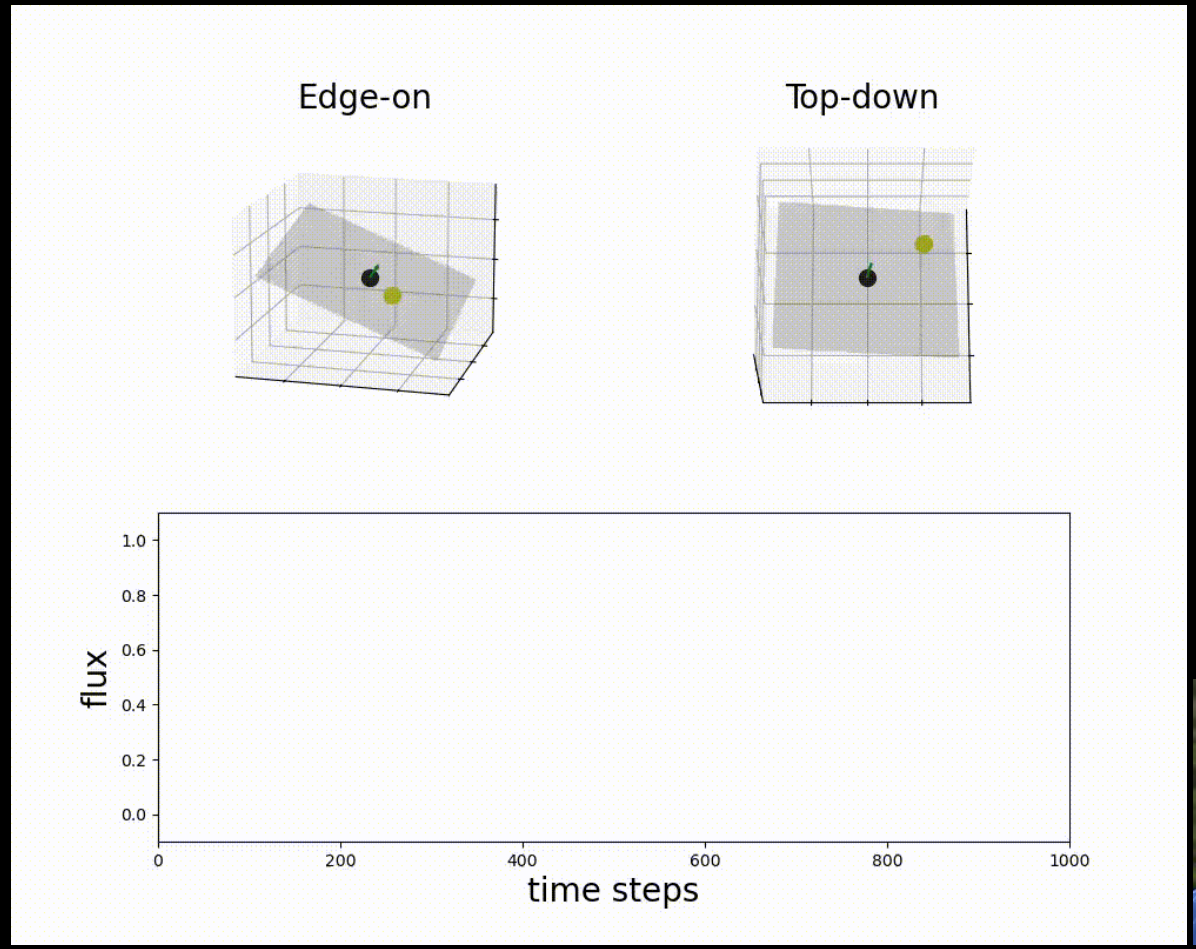


GW
(<<1s - <1s per year)

Hydro-drag
(10-100s seconds per year)

Testing orbital models

- What effects do we expect to be at play? e.g. Linial&Metzger23;Franchini+(**RA**)23



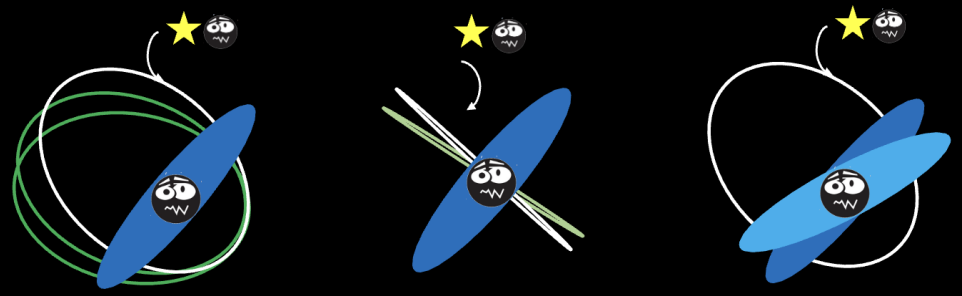
Joheen Chakraborty, MIT

Testing orbital models

- What can we do now? Per-epoch constraints; model-dependent assumptions to fill the gaps

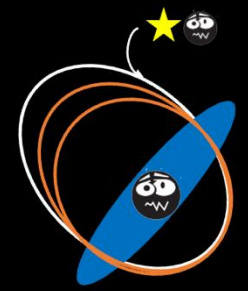
e.g. Xian+21; Franchini+23; Zhou+24a,b

↘ Test short-term and long-term super-orbital modulation



Chakraborty, **RA**+24; **Arcodi**a+24c; Miniutti+ in prep. & others

↘ Plan campaigns to test for orbital decay



Arcodia+ in prep

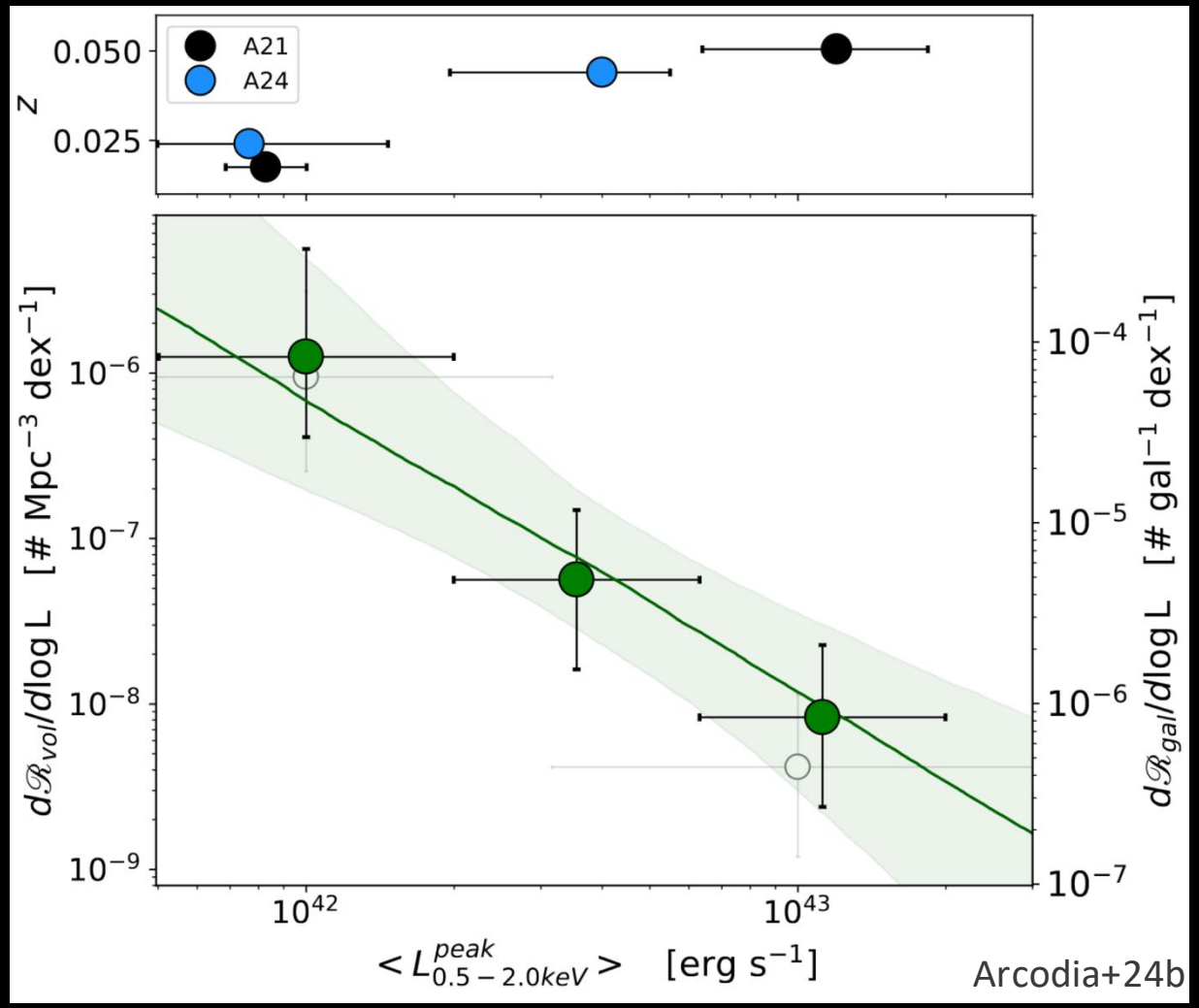
Rates of QPEs

A probe for LISA EMRI rates?

Intrinsic rates

- QPEs luminosity function, corrected for detection efficiency

Number density of QPEs



Assuming gal $\sim 10^{8.5-10.5} M_*$

Abundance rate:

$\approx 10^{-6}$ Mpc^{-3}

$\approx$ 1 every 10^4 gal is emitting QPEs

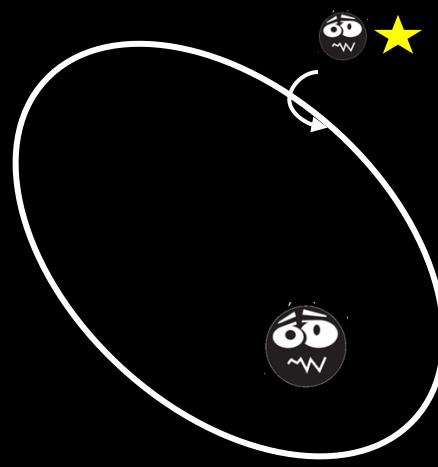
($log \mathrm{L}_X > 41.7$)

Summary

- QPEs approaching N~10, now also found after optical TDE/ignition events

  → How common are they in TDEs?

- The QPE=EMRI connection is being tested

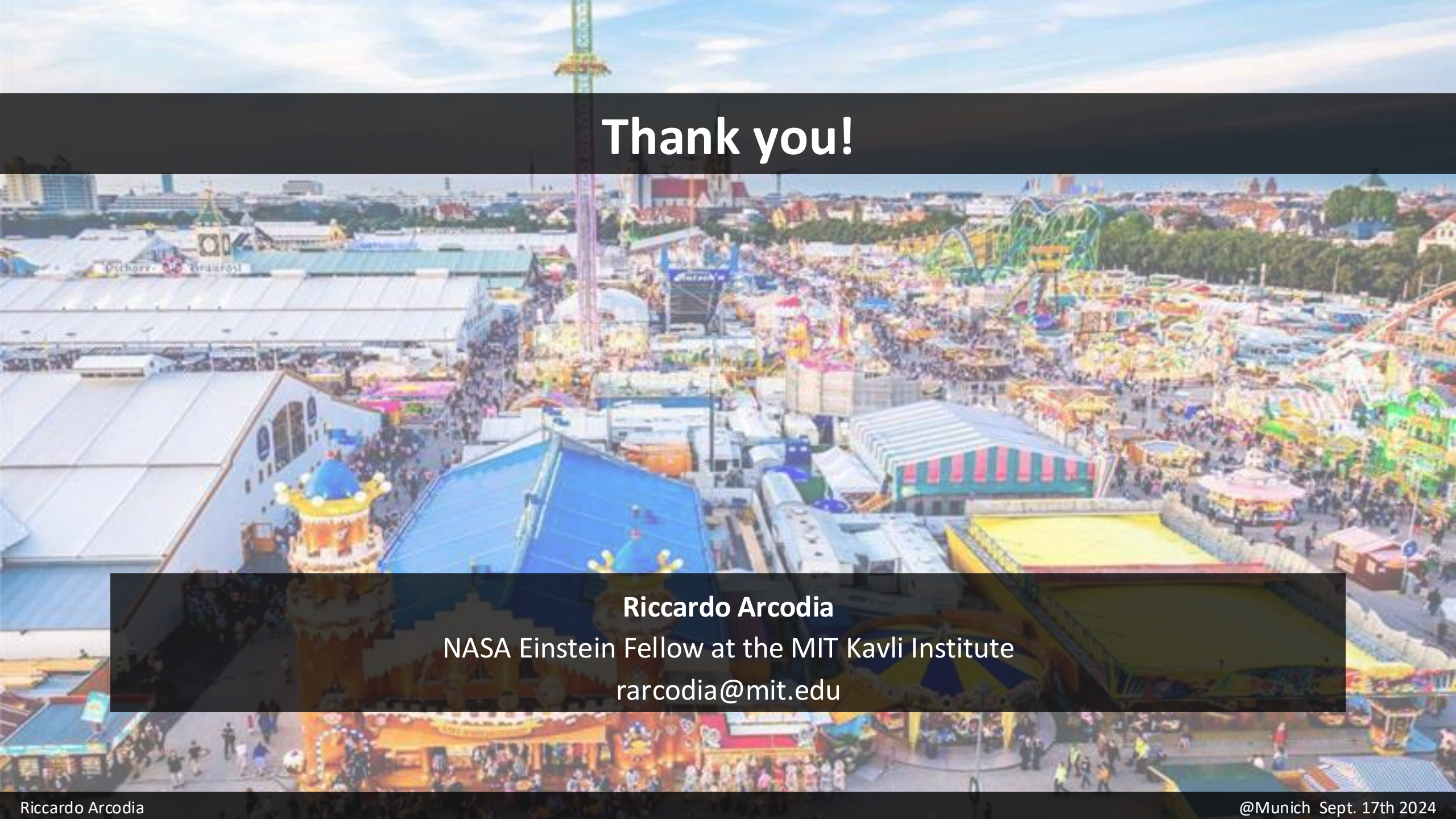


  → Conclusive test needed, stay tuned!

  → If confirmed, massive consequences for the future of multi-messenger astronomy

- $1/10^4$ galaxies emit QPEs at any time: LISA EMRI rates? Future X-ray missions?

Thank you!



Riccardo Arcodia
NASA Einstein Fellow at the MIT Kavli Institute
rarcodia@mit.edu