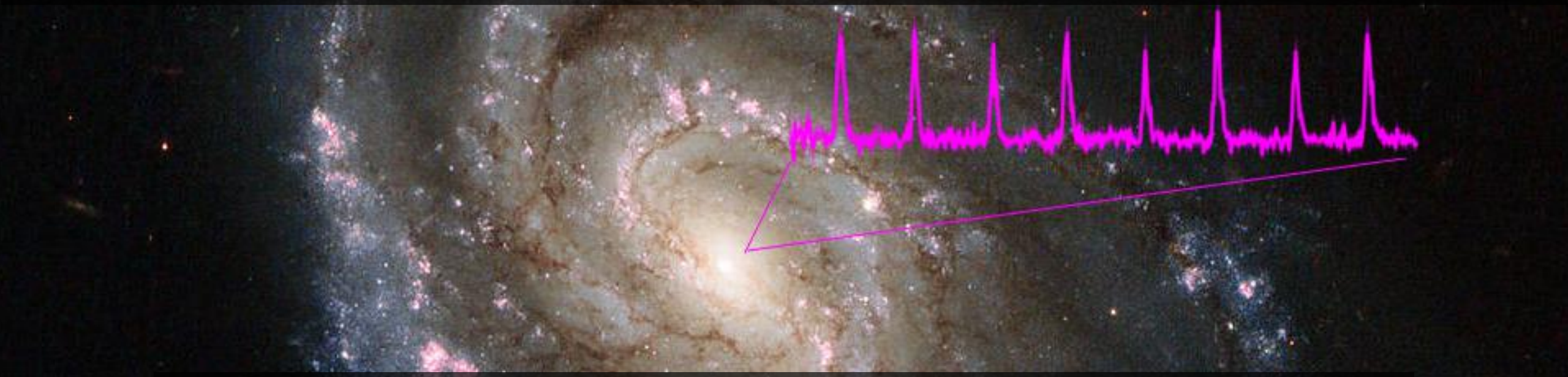
X-ray bursts from two previously quiescent galaxies: massive black holes awakening?

Riccardo Arcodia

(Postdoc @Max-Planck Institute for Extraterrestrial Physics, Garching bei Muenchen)



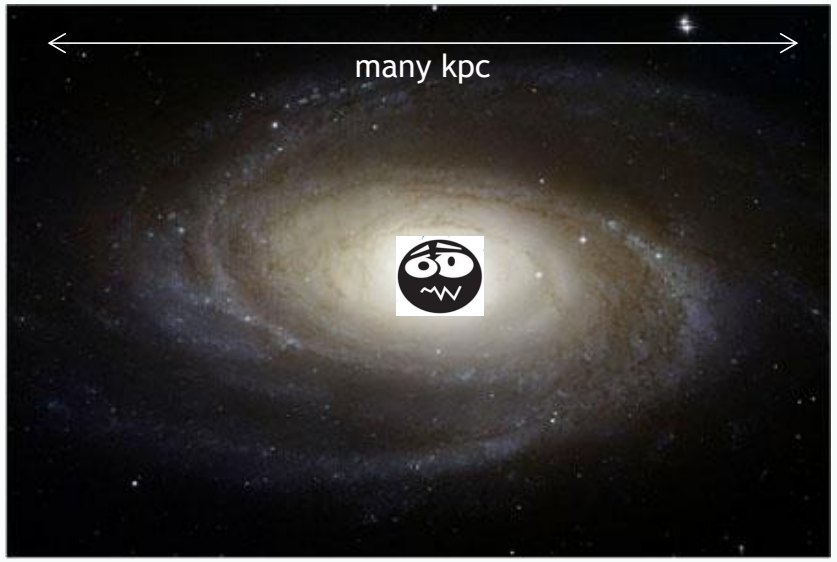
In collaboration with: A.Merloni, K.Nandra, J.Buchner, M.Salvato, J.Comparat, A.Rau, M.E.Ramos-Ceja, J.Wolf, A.Malyali, D.Bogensberger **(MPE)**, E. Kara, D. Pasham, R.Remillard **(MIT)**, G.Lamer, M.Krumpe, A.Schwope **(AIP**), G.Ponti **(INAF-OAB**) D.A.H.Buckley (**SAAO**), Z.Arzoumanian, K.Gendreau **(NASA/GSFC**), M.Gromadzki **(AO Warsaw**), M.Schramm **(Saitama Univ**) & others

@IASF October 27th 2021

Black holes in the nuclei of galaxies

- (almost) all galaxies contain a black hole sitting at their centre

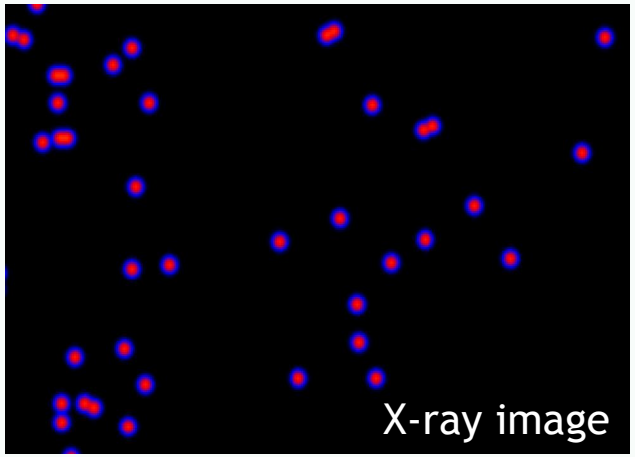
e.g. Kormendy&Ho+13



NASA, ESA and the Hubble Heritage Team (STScI/AURA); S.Gezari

→ Most SMBHs are not active (and faint in X-rays)

e.g. Bongiorno+12; Georgakakis+17; Aird+17



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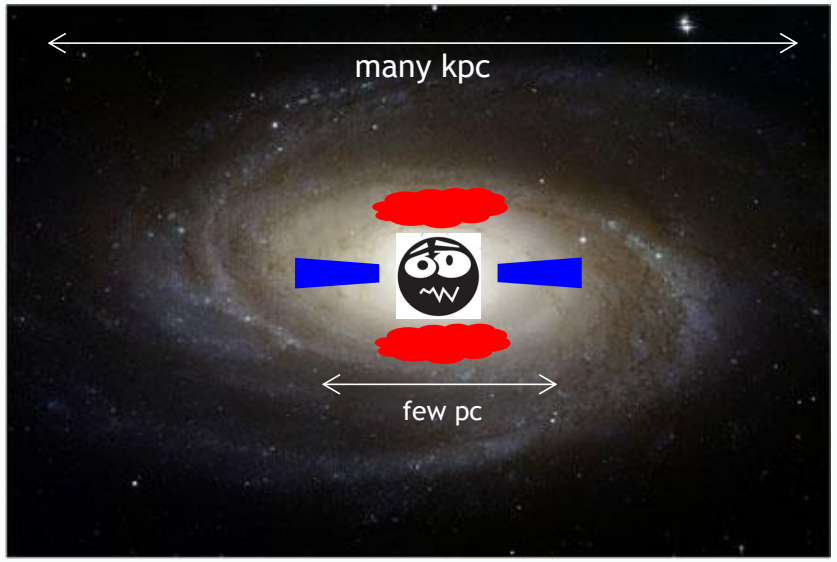
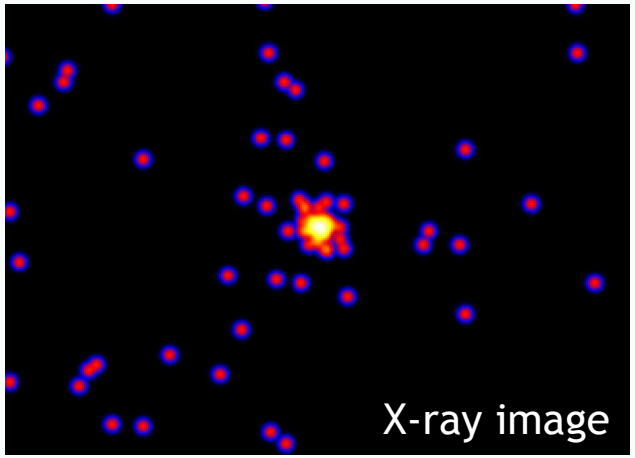


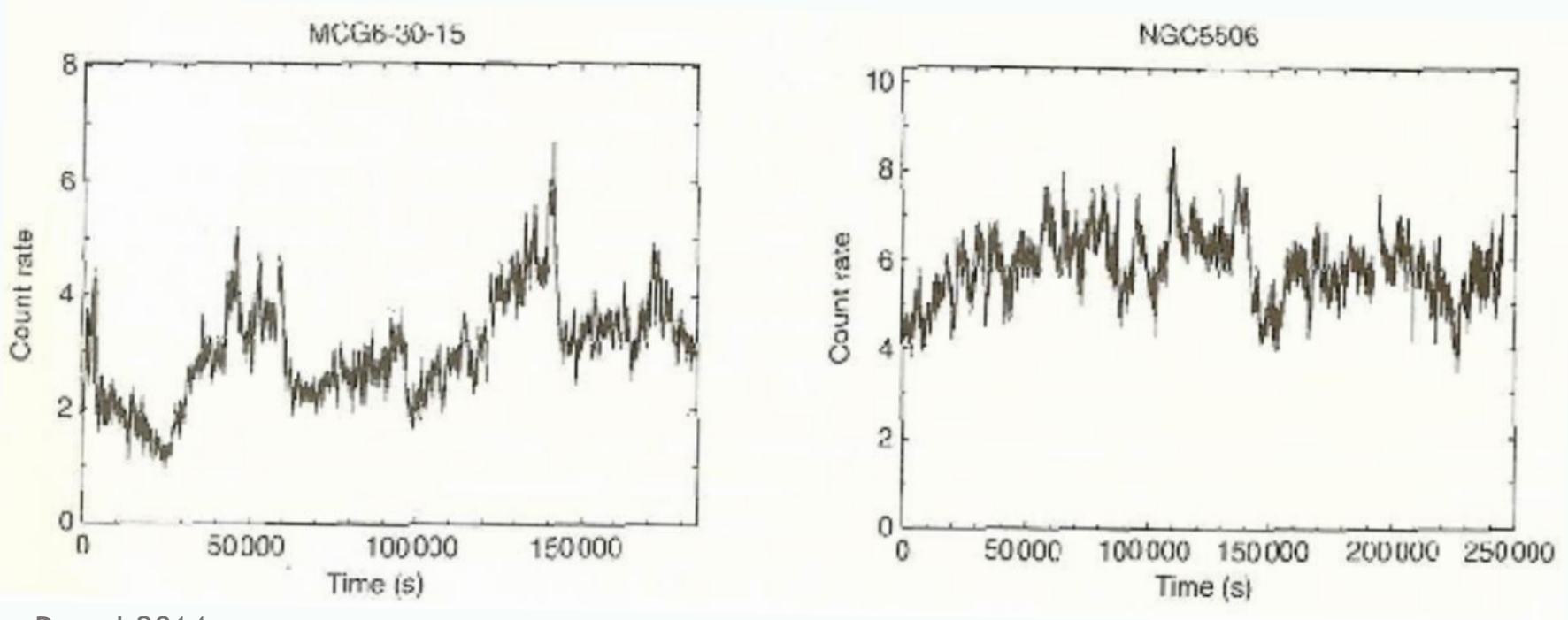
NASA, ESA and the Hubble Heritage Team (STScI/AURA); S.Gezari

→ Some are active: the SMBH emission outshines the whole galaxy



What we are used to seeing in X-rays

- We (think we) know what the X-ray emission of an accreting SMBH looks like



Pounds2014

→ X-ray variability on short timescales was in fact evidence of BHs existence

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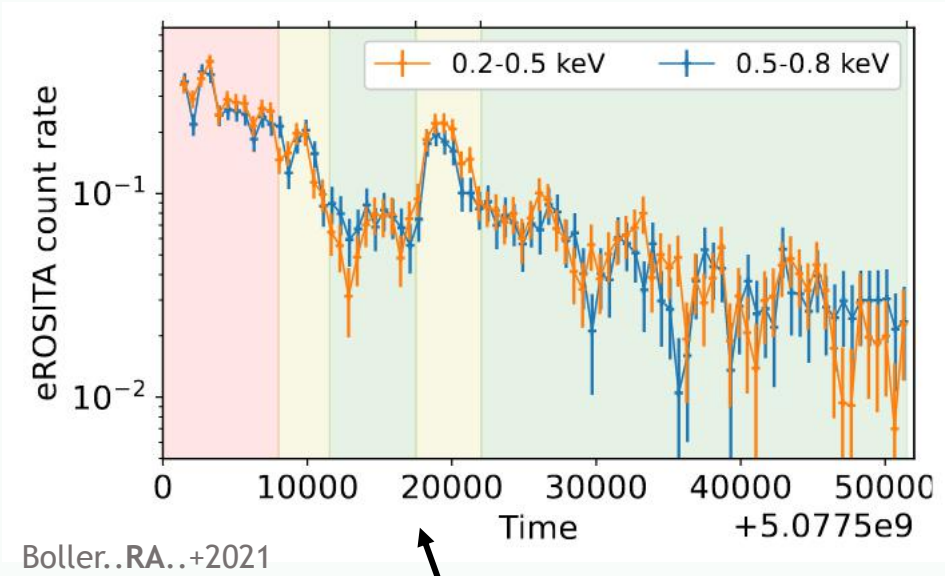
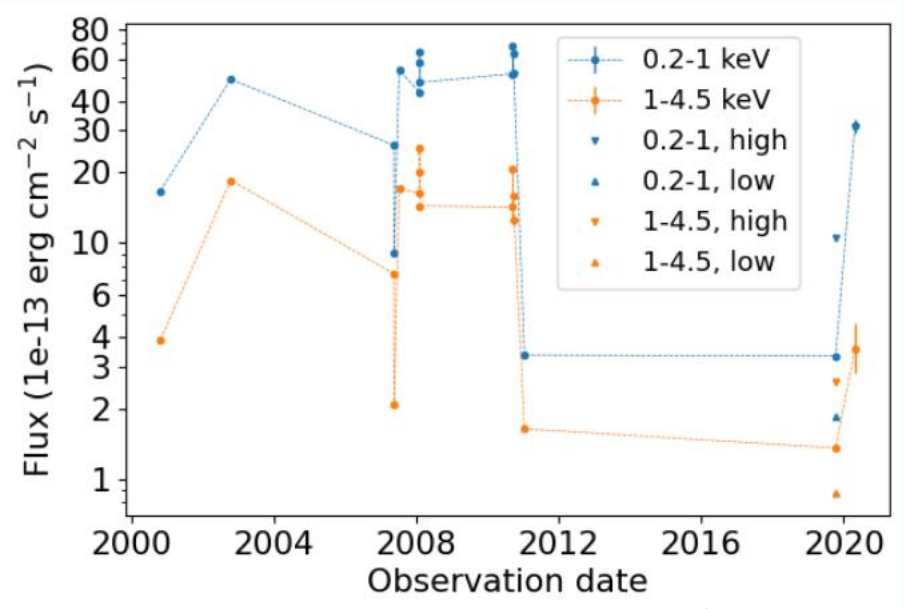


hours



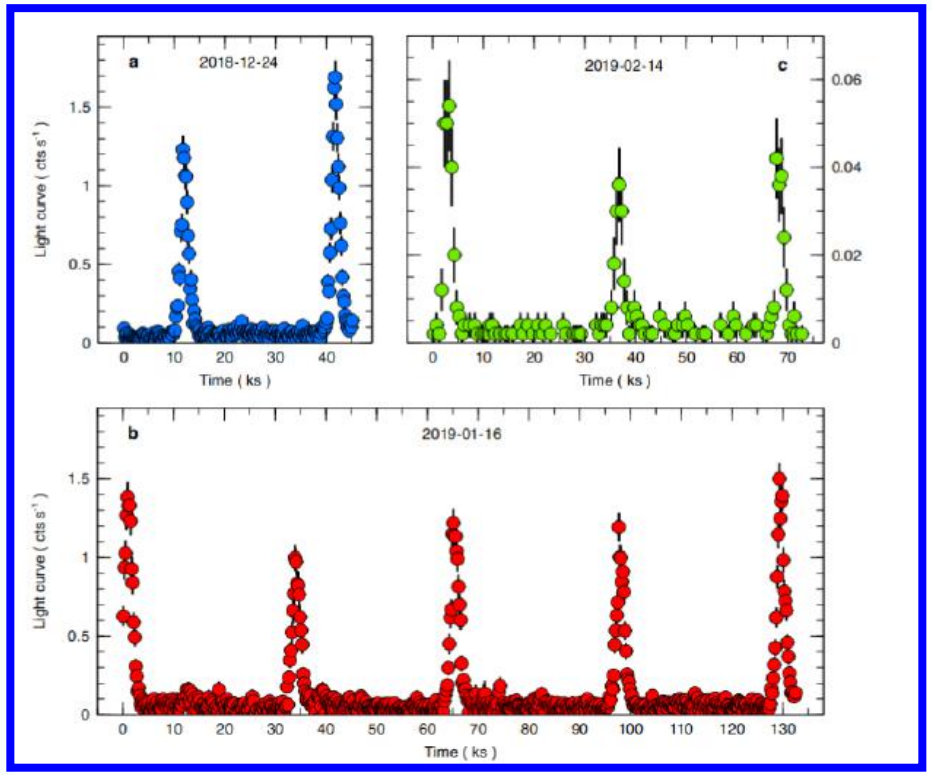
years

factor $\approx 10 - 100$

→ We observe high-amplitude X-ray variability on short and long timescales

What are Quasi-Periodic Eruptions?

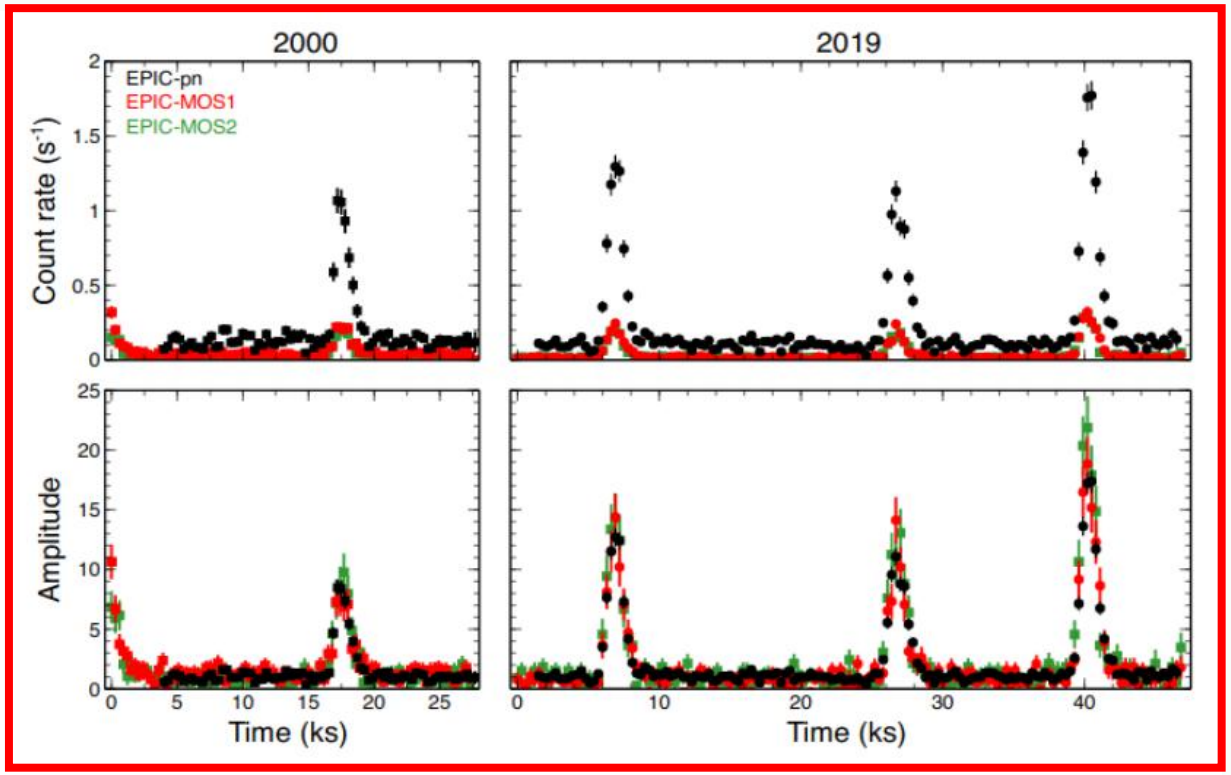
- But this is unusual: very-high-amplitude quasi-periodic soft X-ray bursts from galactic nuclei



Count rate

Miniutti+19

Time (few hours)

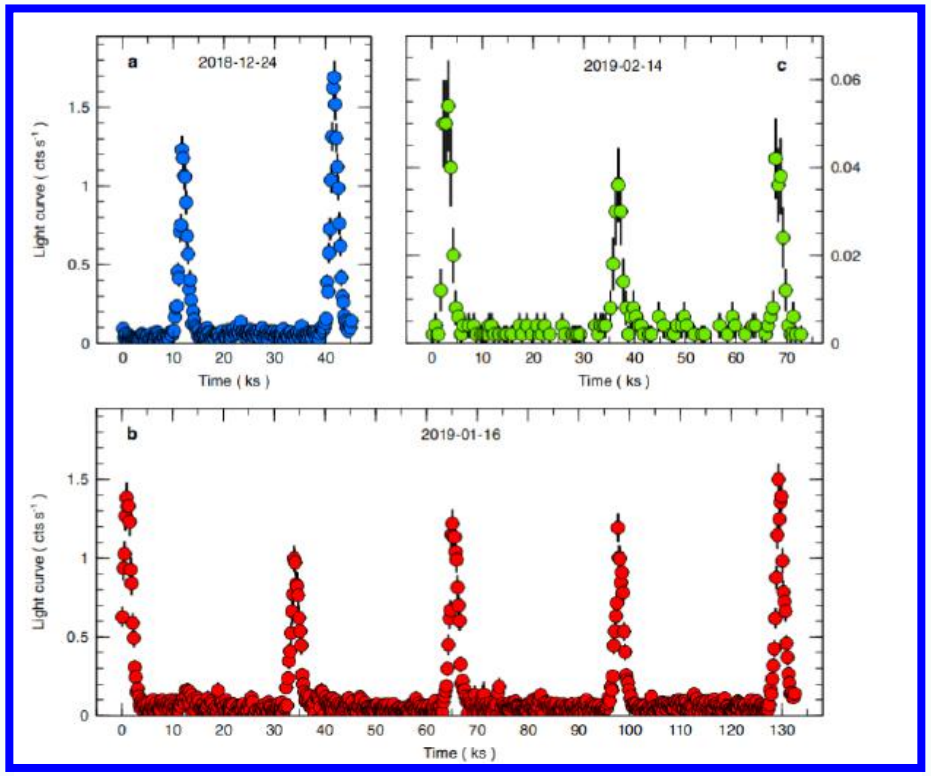


Giustini+20

- Only two sources were first known (Miniutti+19 and Giustini+20), discovered serendipitously or in the archives

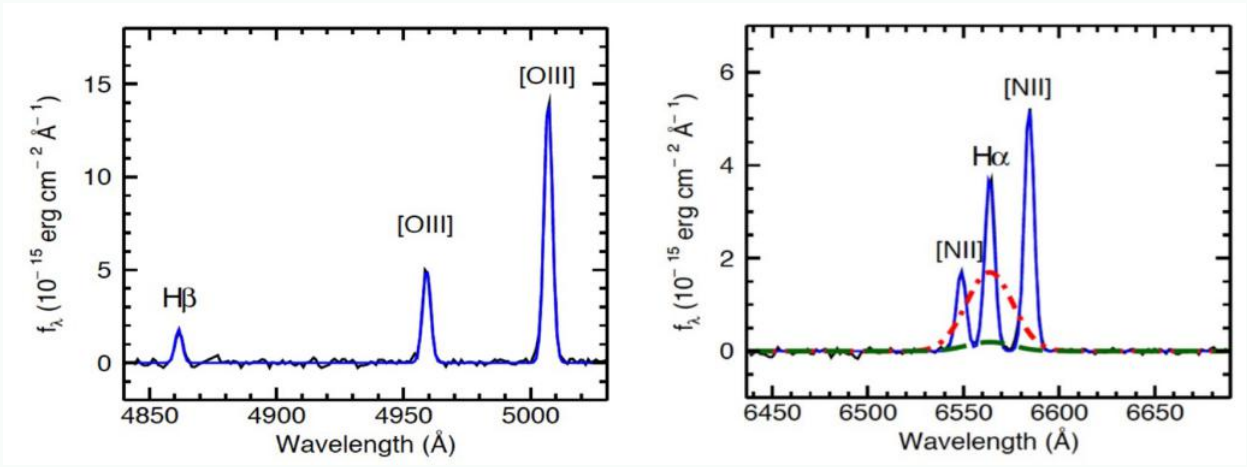
What we knew before eROSITA

- Observational properties based on the first two QPEs



Miniutti+19

→ extragalactic, “**weird” AGN**: no broad lines in optical spectra, no infrared “torus”



Miniutti+13

→ Narrow lines clearly AGN-ionized

Miniutti+13,+19; Sun+13; Shu+17; Giustini+20

AGN: active galactic nuclei

What we knew before eROSITA

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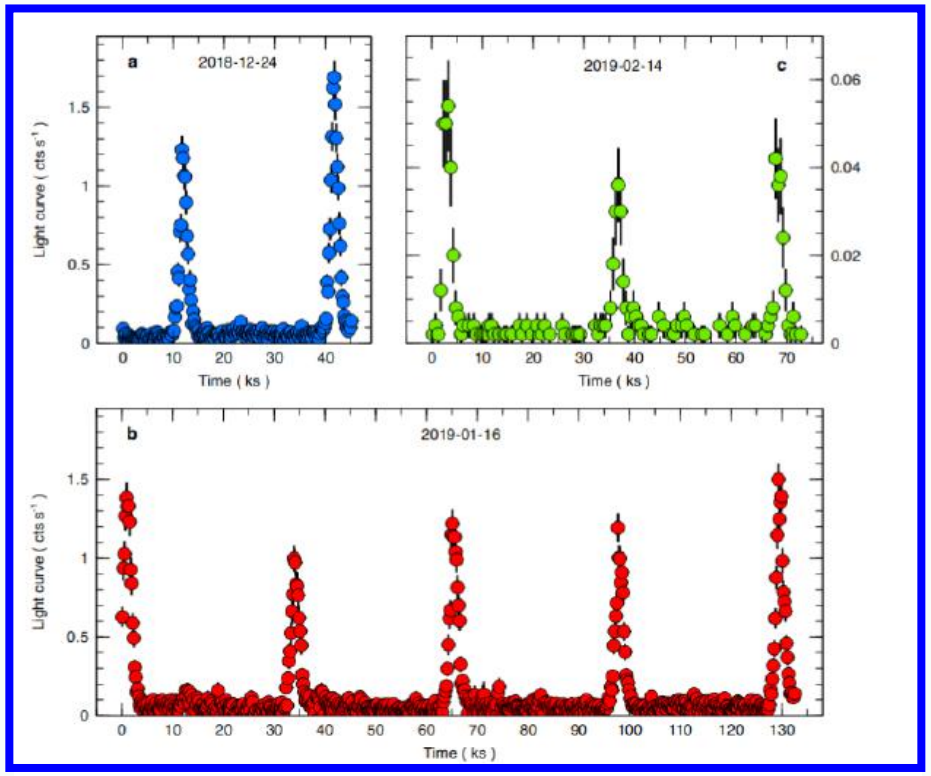
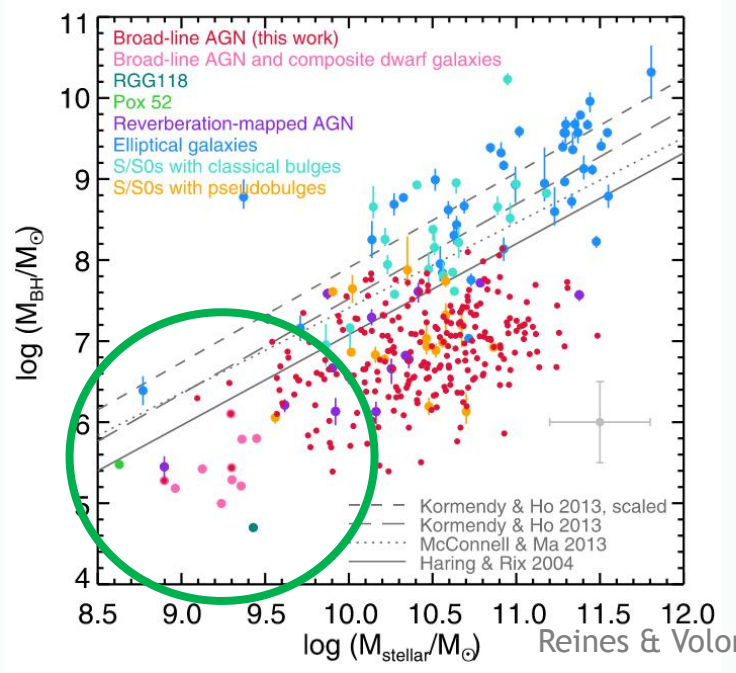


Miniutti+19

→ extragalactic, "**weird" AGN**: no broad lines in optical spectra, no infrared "torus"

→ **low-mass AGN** ($10^5 - 10^7 M_\odot$) in low-mass galaxies

→ Poorly studied mass regime for BH-galaxy co-evolution

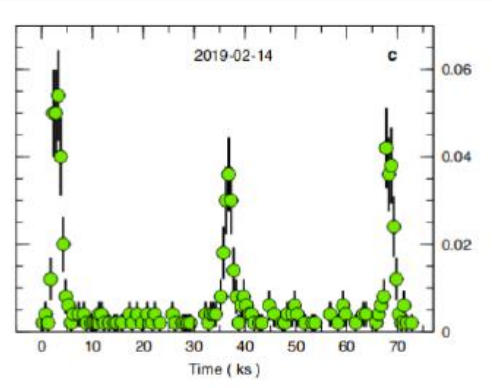


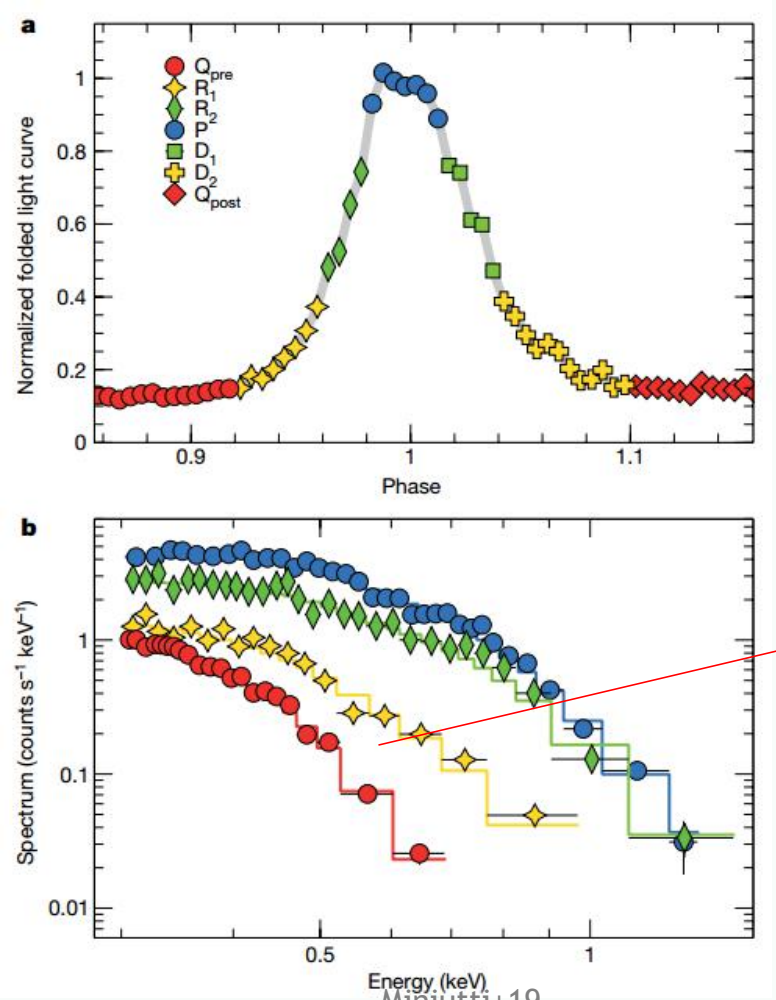
Reines & Volonteri 2015

What we knew before eROSITA

- Observational properties based on the first two QPEs

→ X-ray spectrum is always soft (but hotter during the QPEs)





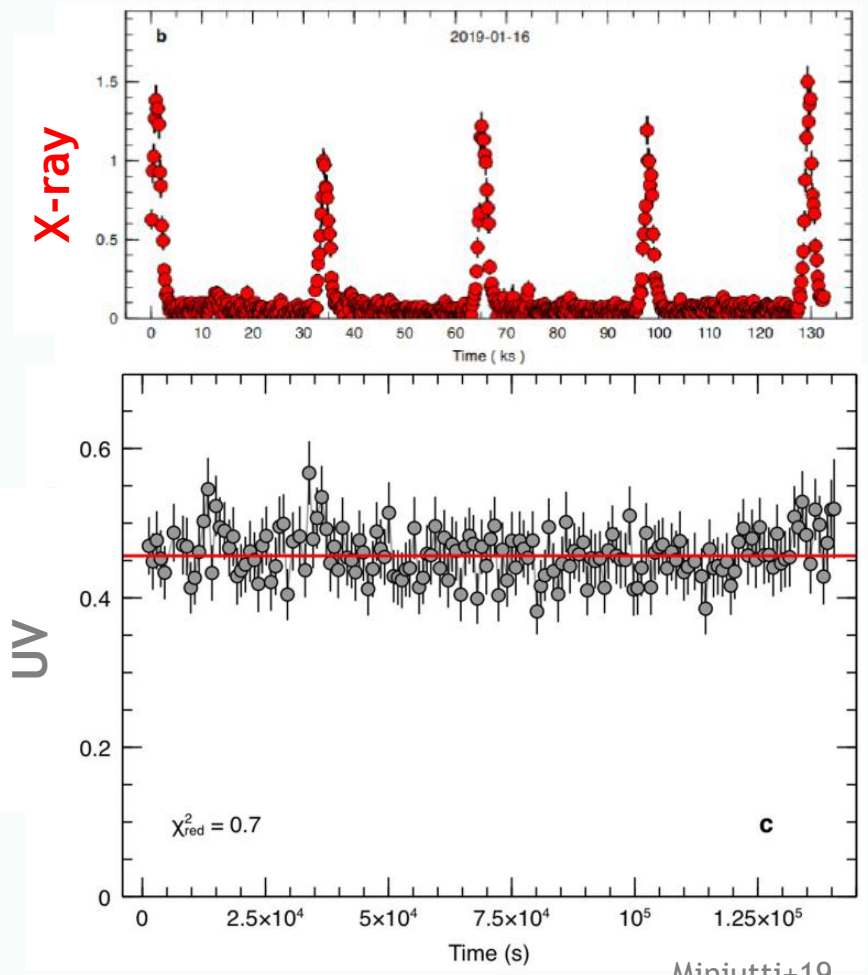
Quiescence is fairly stable: tail of the thermal accretion emission from a low-mass SMBH?

Miniutti+19

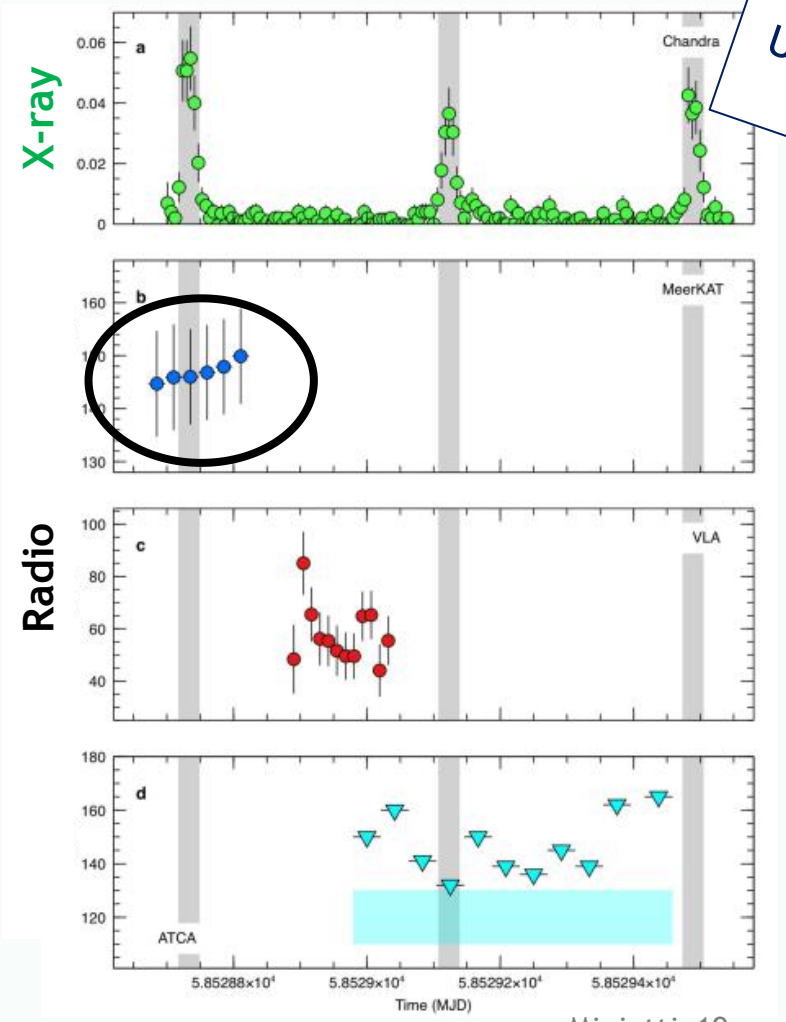
What we knew before eROSITA

- Observational properties based on the first two QPEs

→ no obvious peculiarities at other wavelengths



Miniutti+19

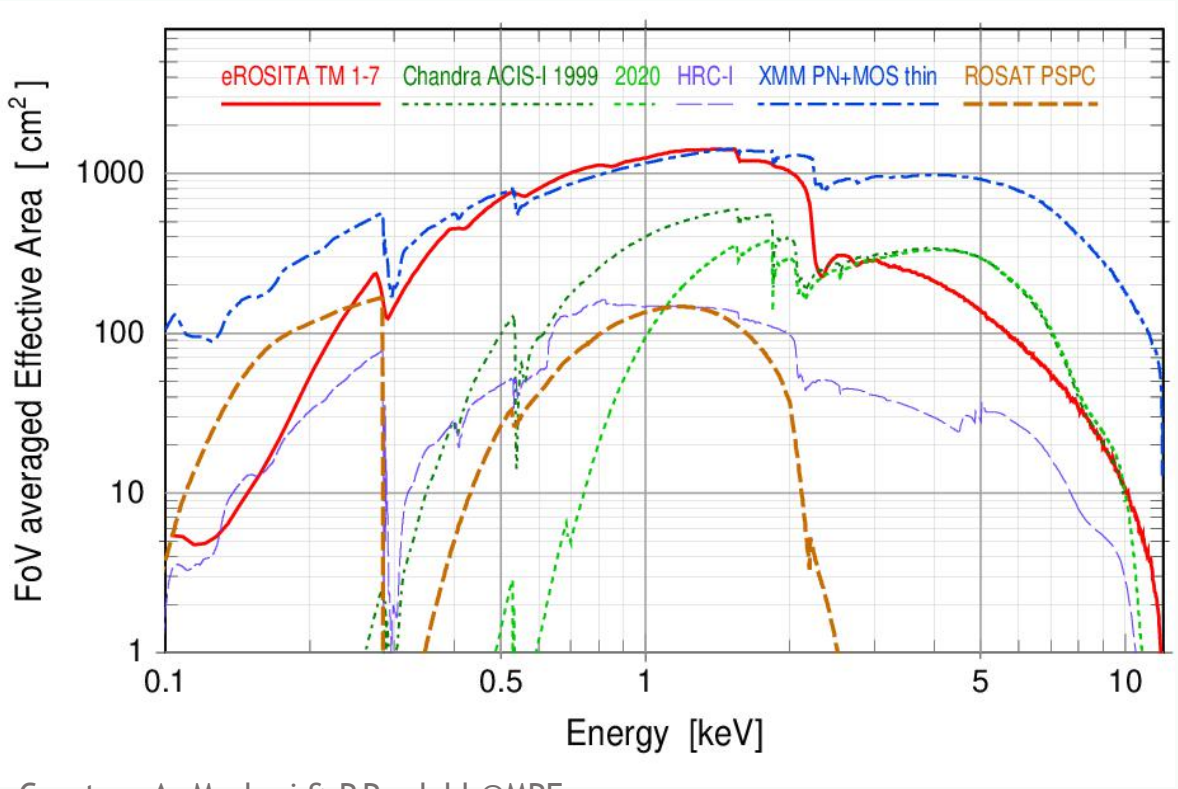


Miniutti+19

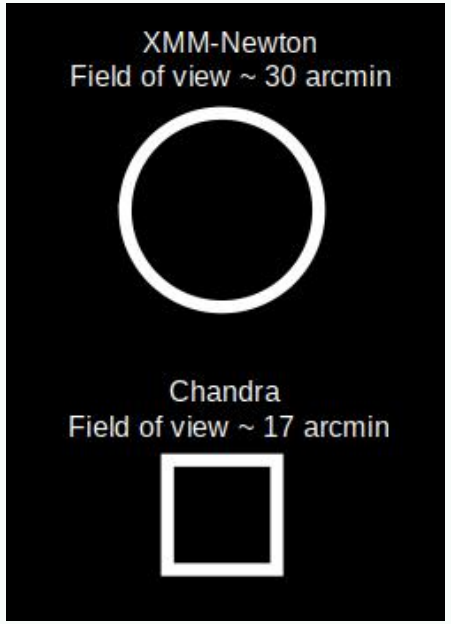
Caveat:
UV, optical, radio probably galaxy-dominated

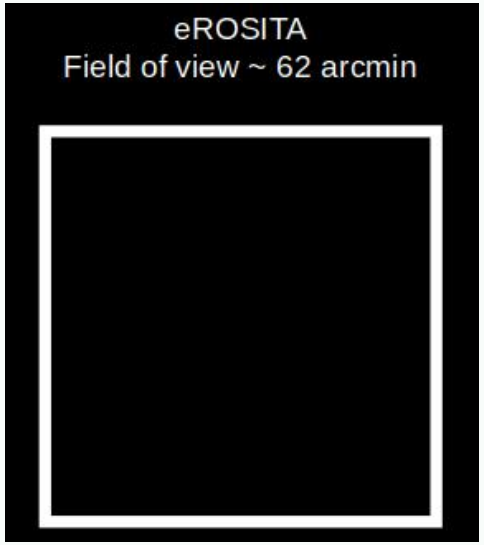
Finding QPEs with eROSITA

- Only detectable via soft X-rays: ideal application for eROSITA!



Courtesy A. Merloni & P.Predehl @MPE





→ Great photons collecting power + large FoV!

Finding QPEs with eROSITA

- It will perform 8 all-sky surveys (eRASS) [3 are already completed]

Courtesy A. Merloni & P.Predehl @MPE

→ Full sky observed in 6 months!

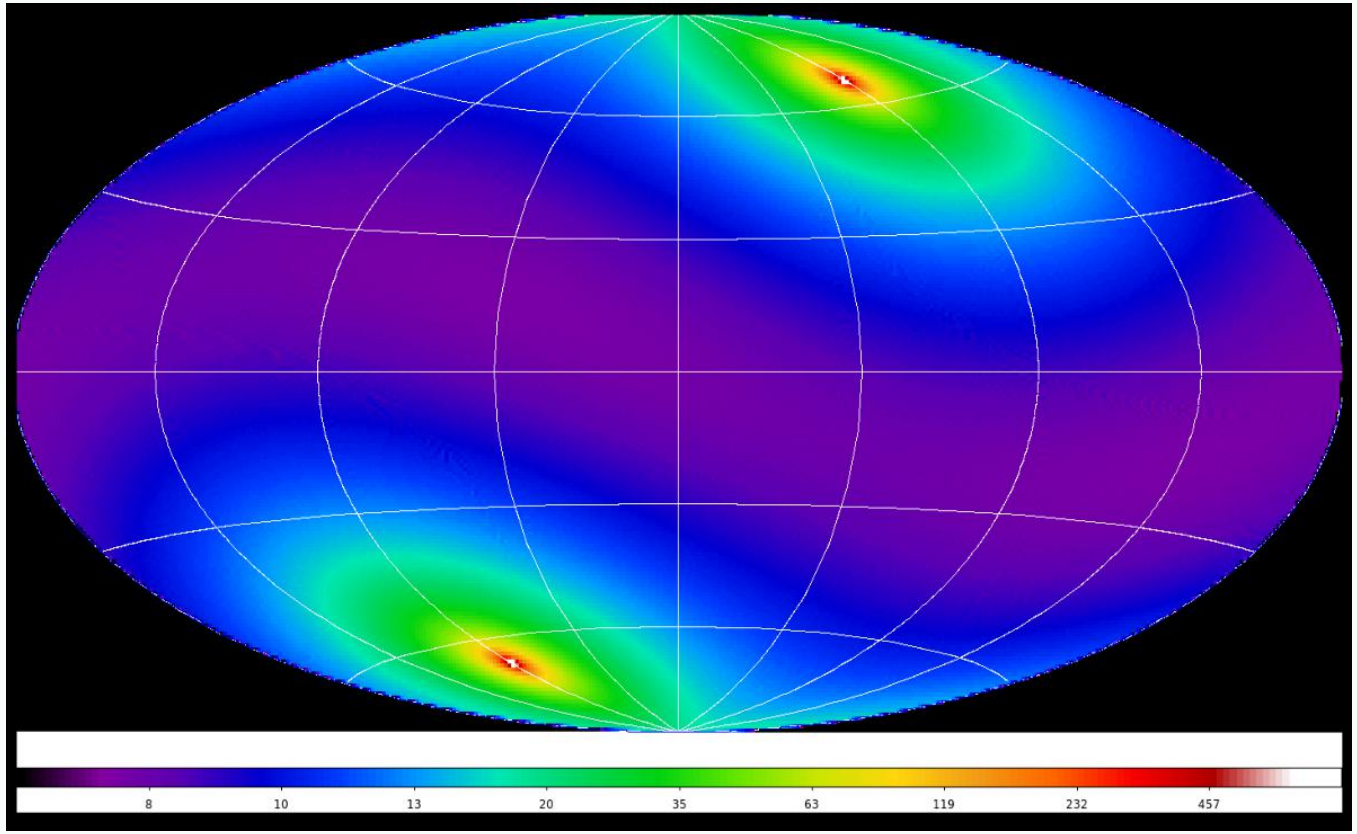
Finding QPEs with eROSITA

- N of times (separated by ~4h) each point is observed in one all-sky survey

Around the ecliptic ~6

A bit above/below ~10-12

~inf at the ecl. poles

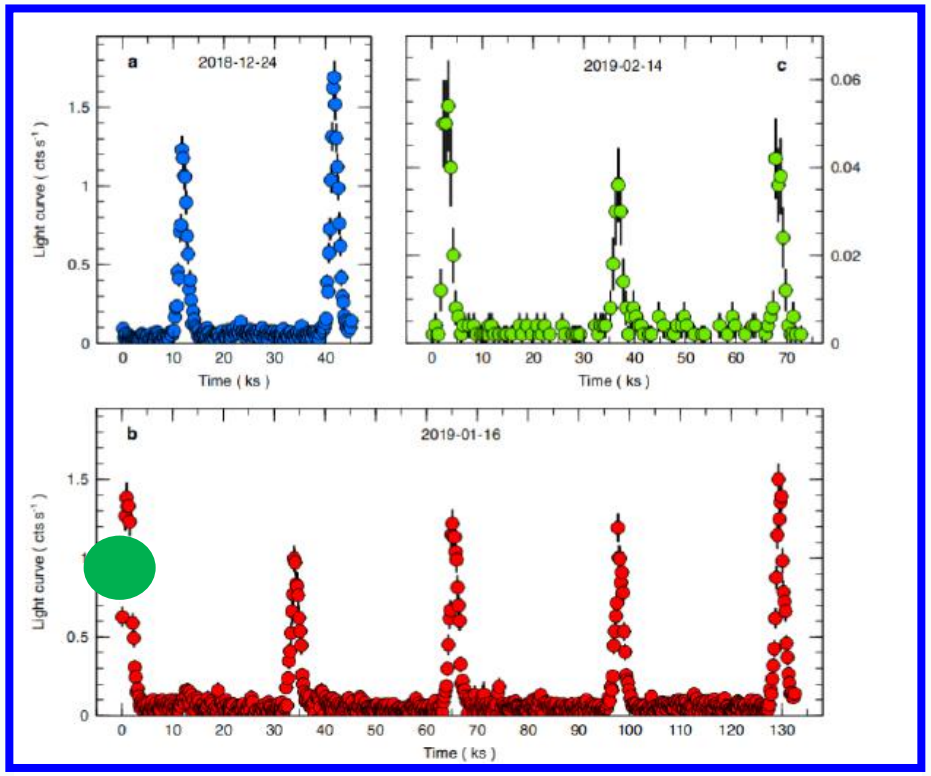


Courtesy A. Merloni & P.Predehl @MPE

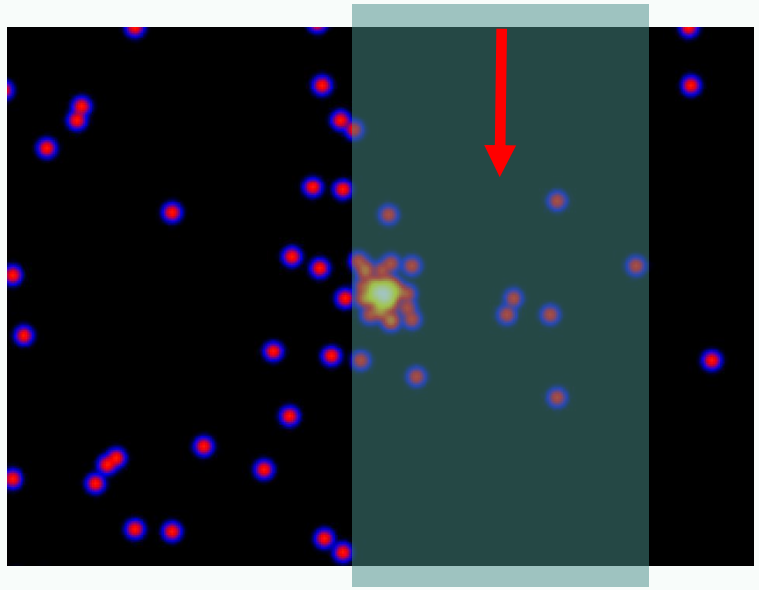
→ Ideal to find sources varying on ~hours timescales!

Finding QPEs with eROSITA

- Assume an ongoing QPE: what does eROSITA see?



Miniutti+19



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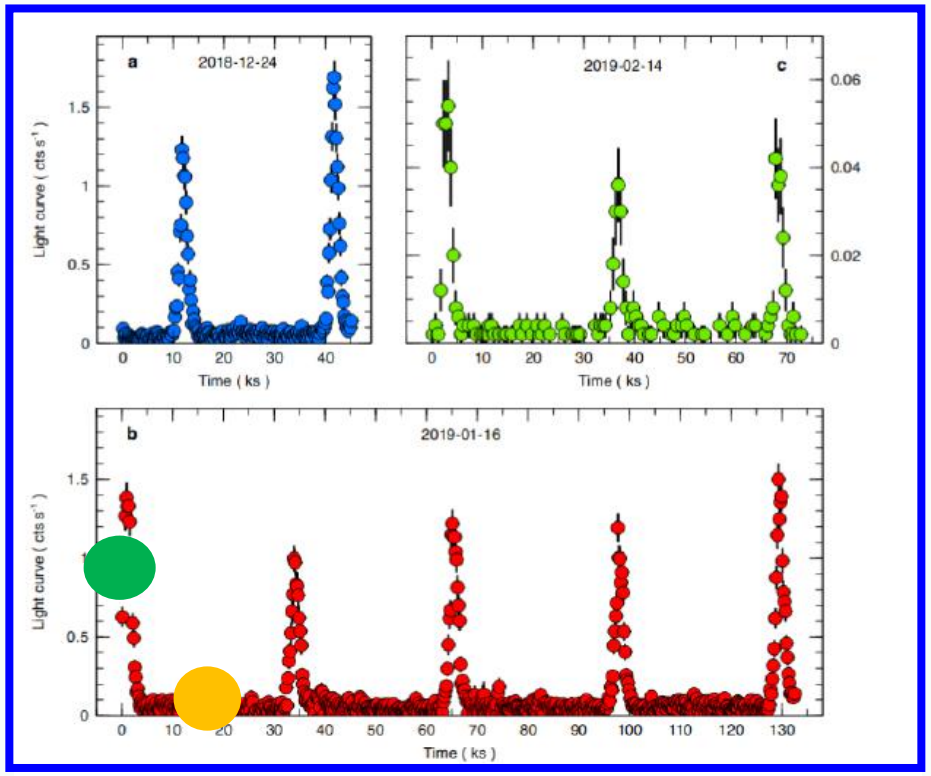

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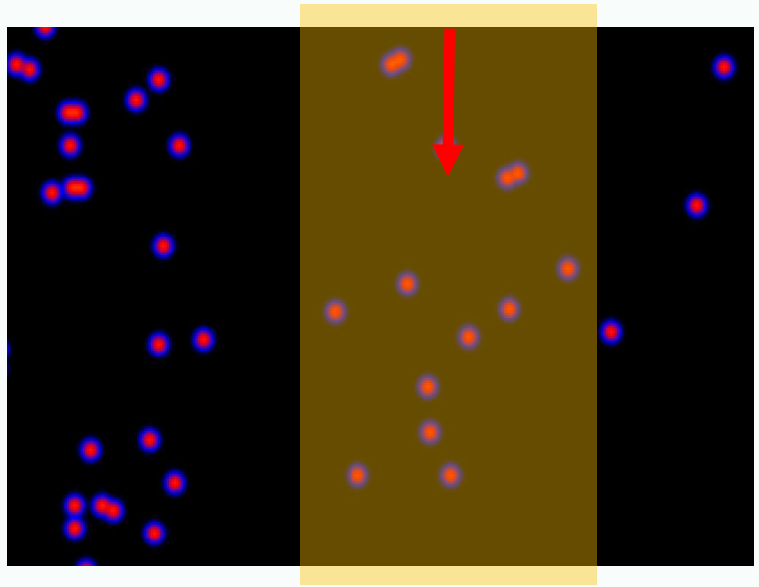

4h later

Finding QPEs with eROSITA

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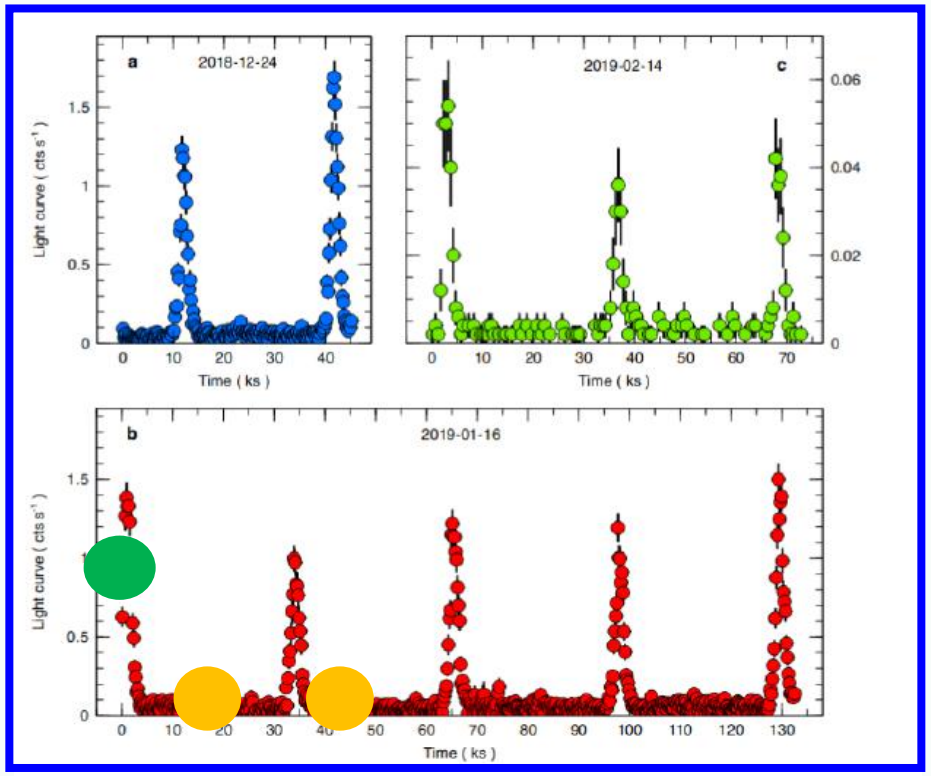
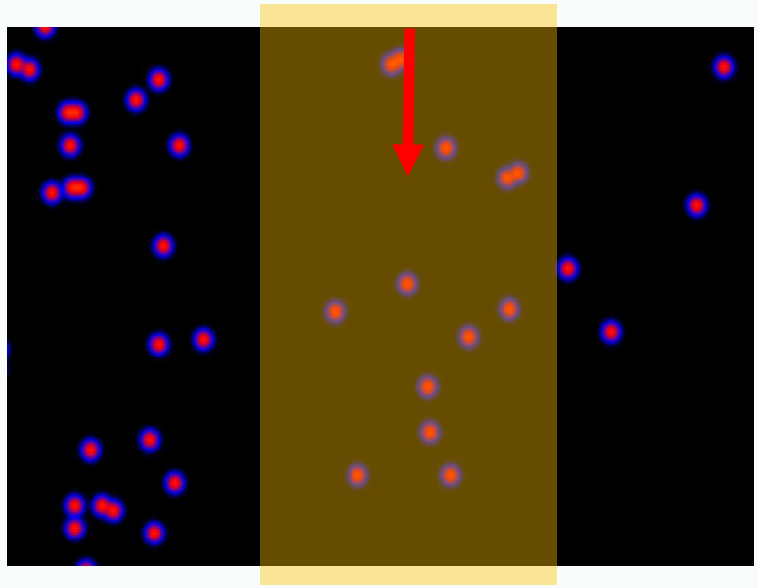


Miniutti+19



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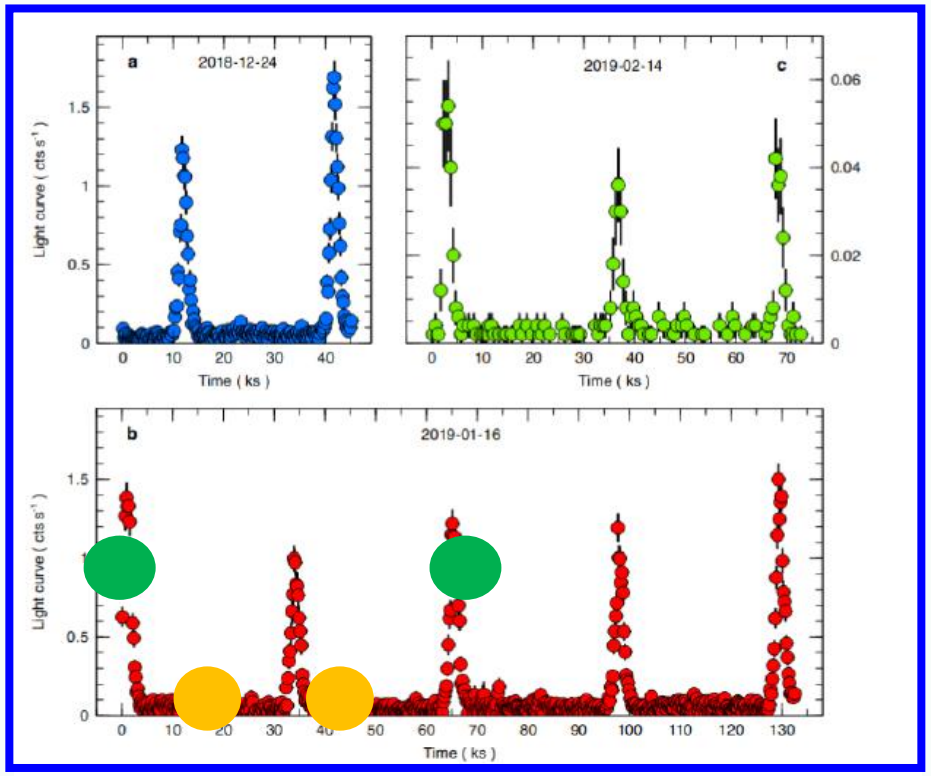
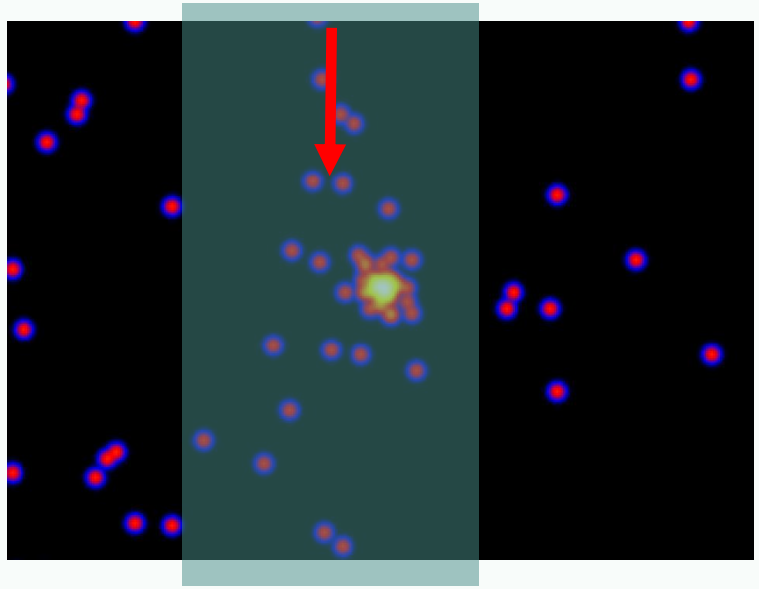


Miniutti+19



4h later

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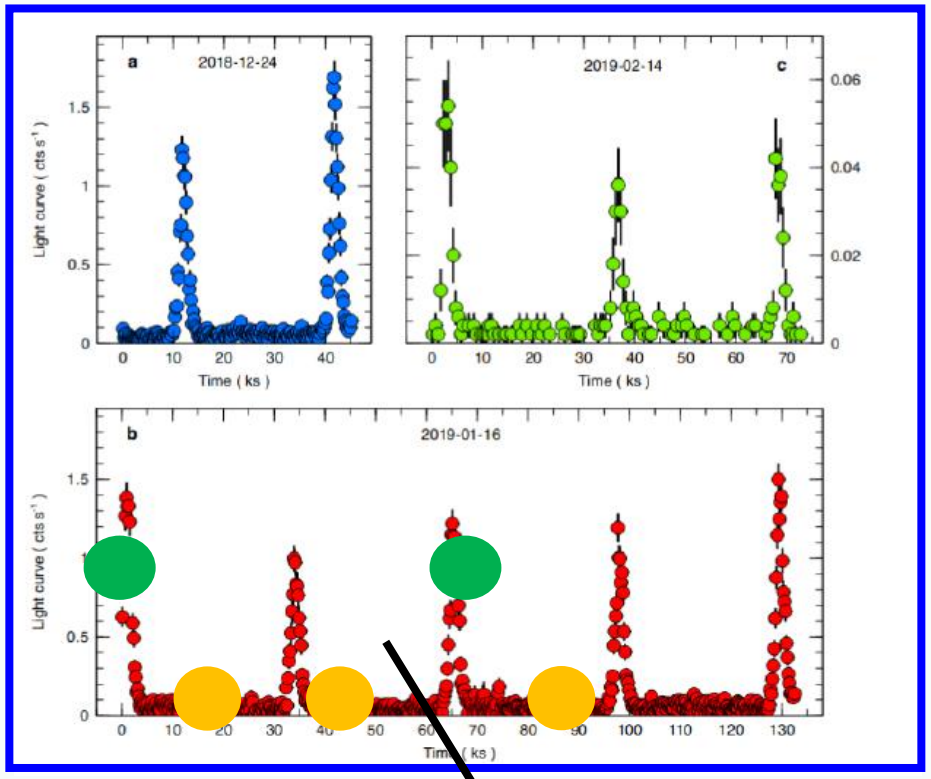

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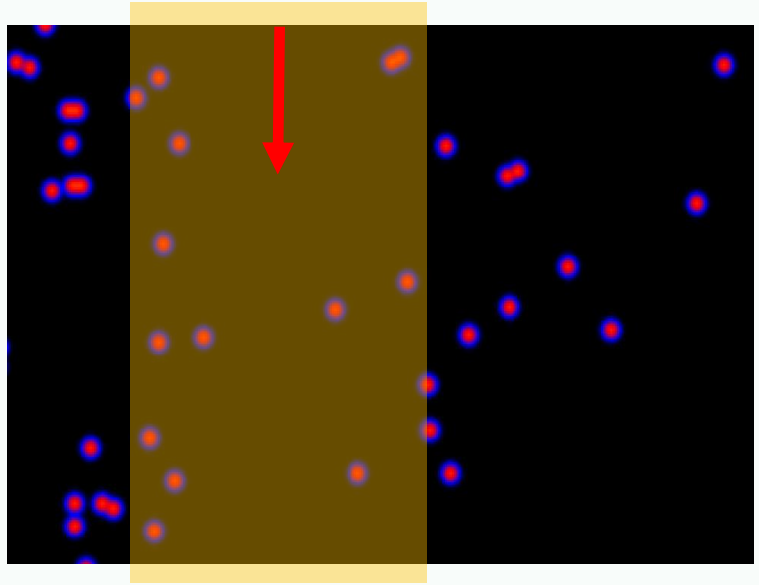
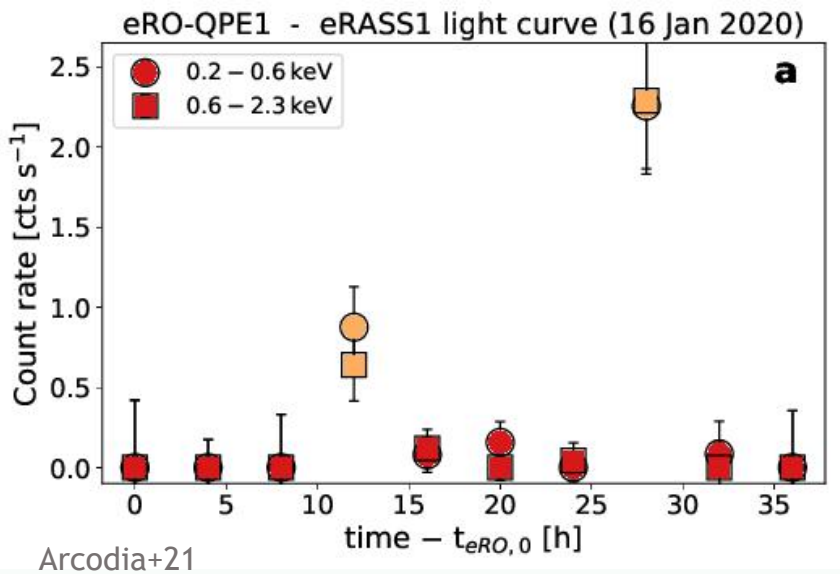


4h later

eROSITA can provide candidates, follow-up is needed

First discoveries with eROSITA

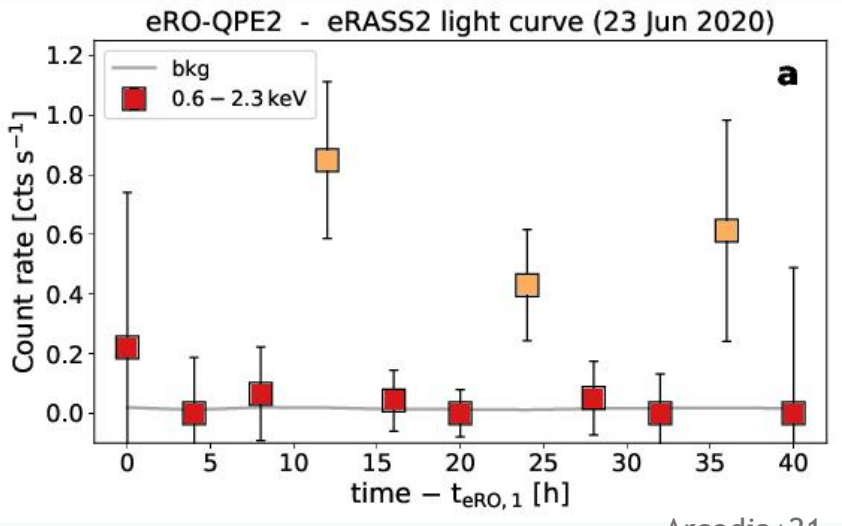
- 2 new confirmed QPEs discovered in the first year of eROSITA operations (Arcodia+2021, Nature)



Arcodia+21

(eRO-)QPE1

QPE2



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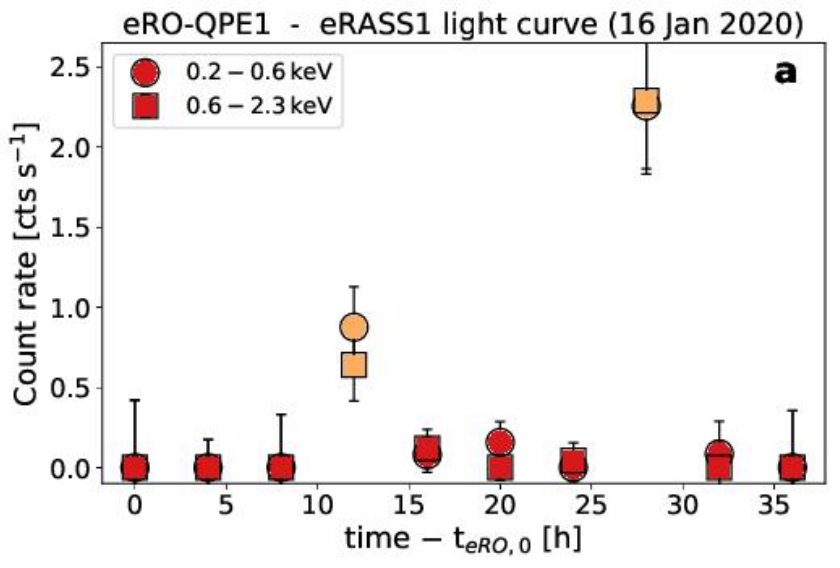
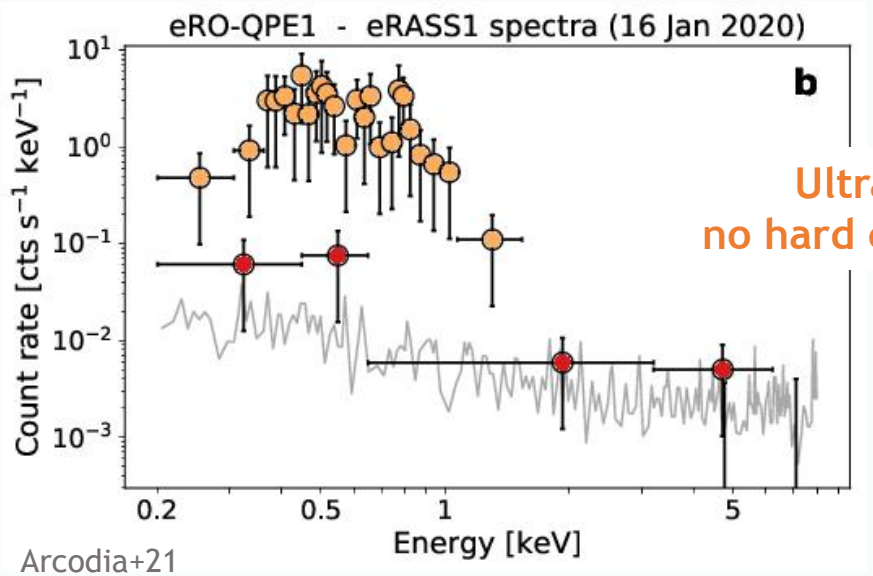
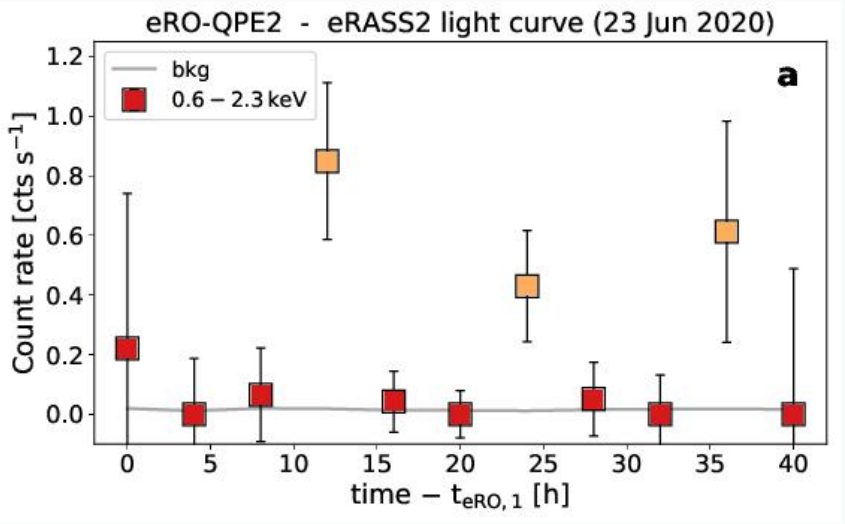


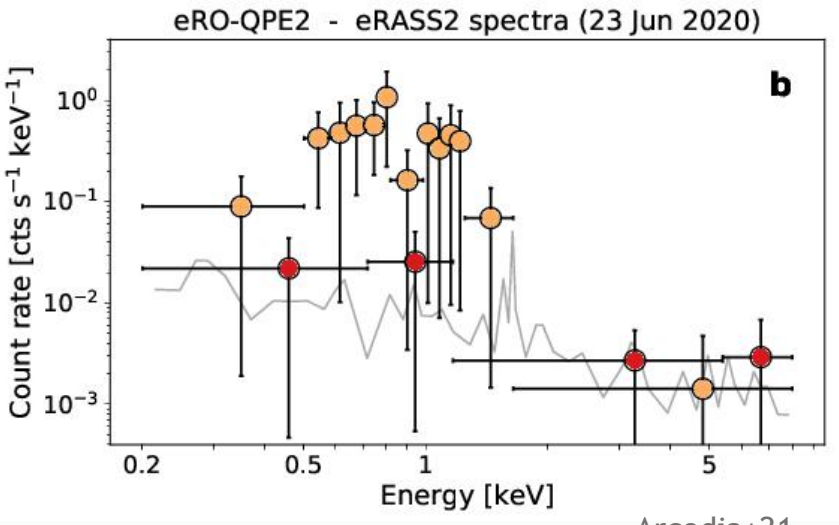


Ultra-soft,
no hard component

Arcodia+21

(eRO-)QPE1 | **QPE2**





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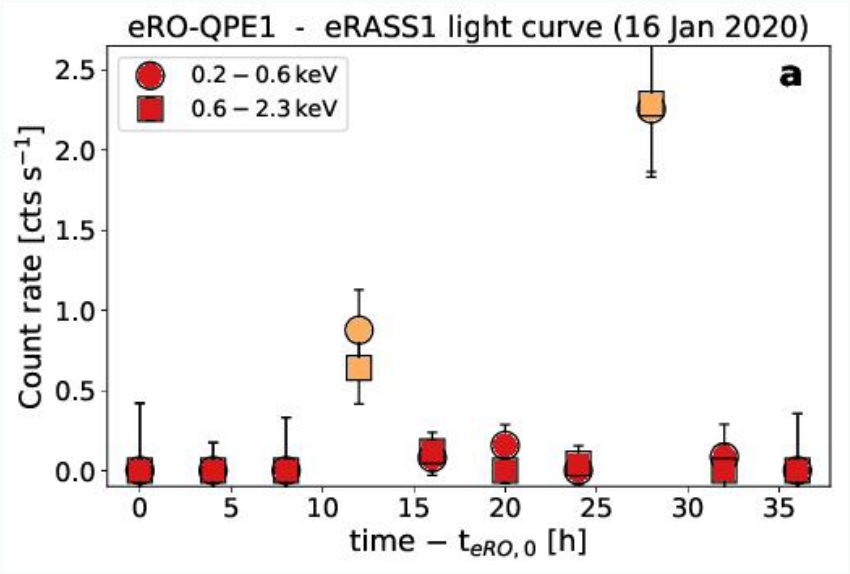
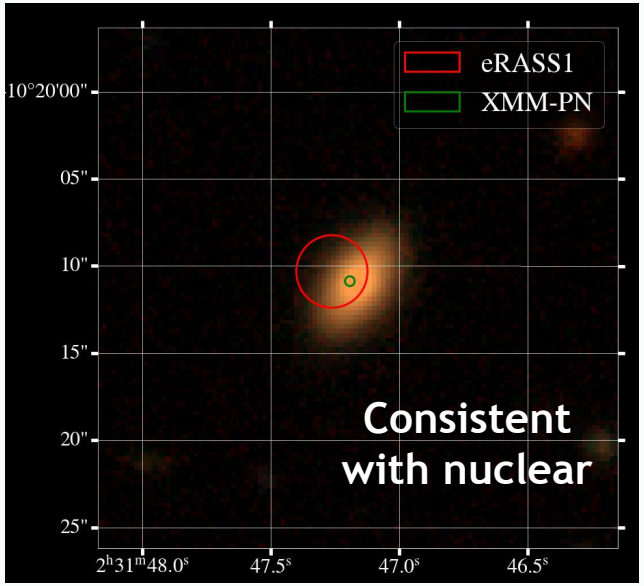
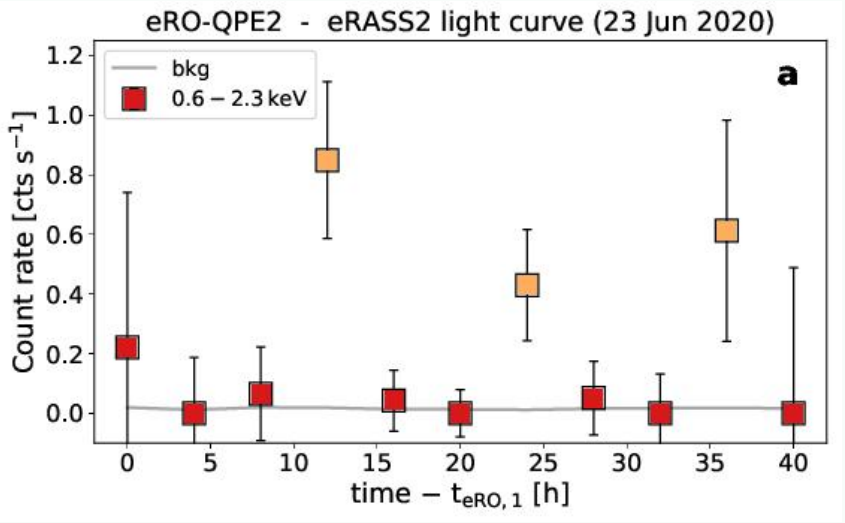


(eRO-)QPE1

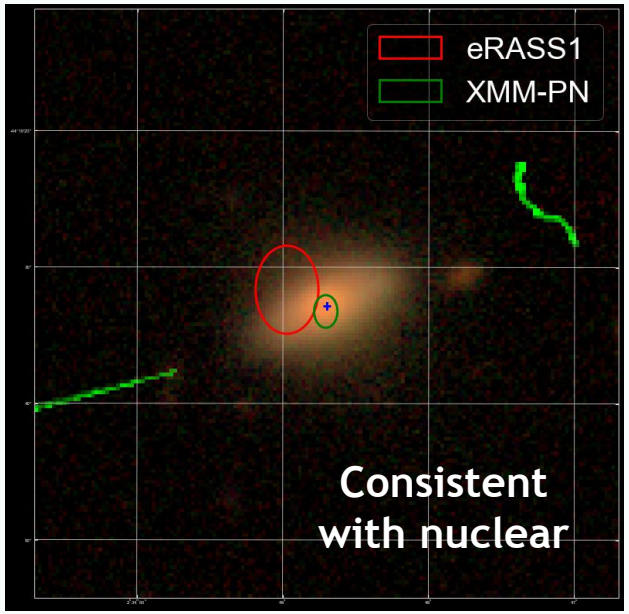
Arcodia+21



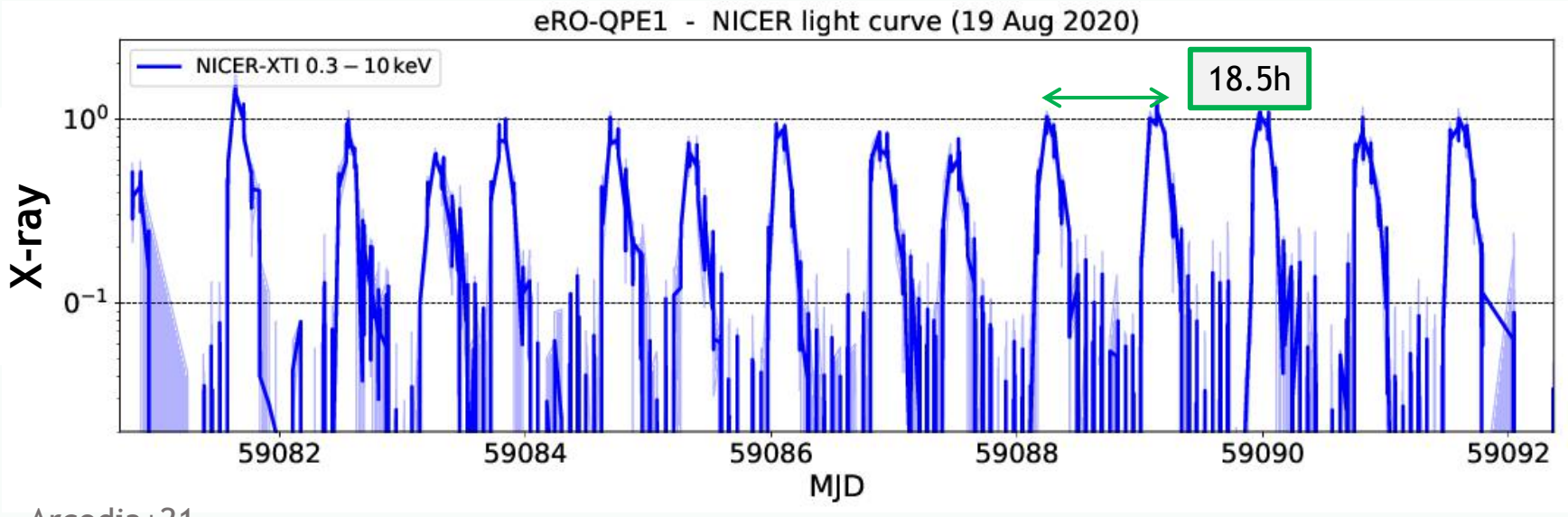
QPE2



Arcodia+21



First discoveries with eROSITA



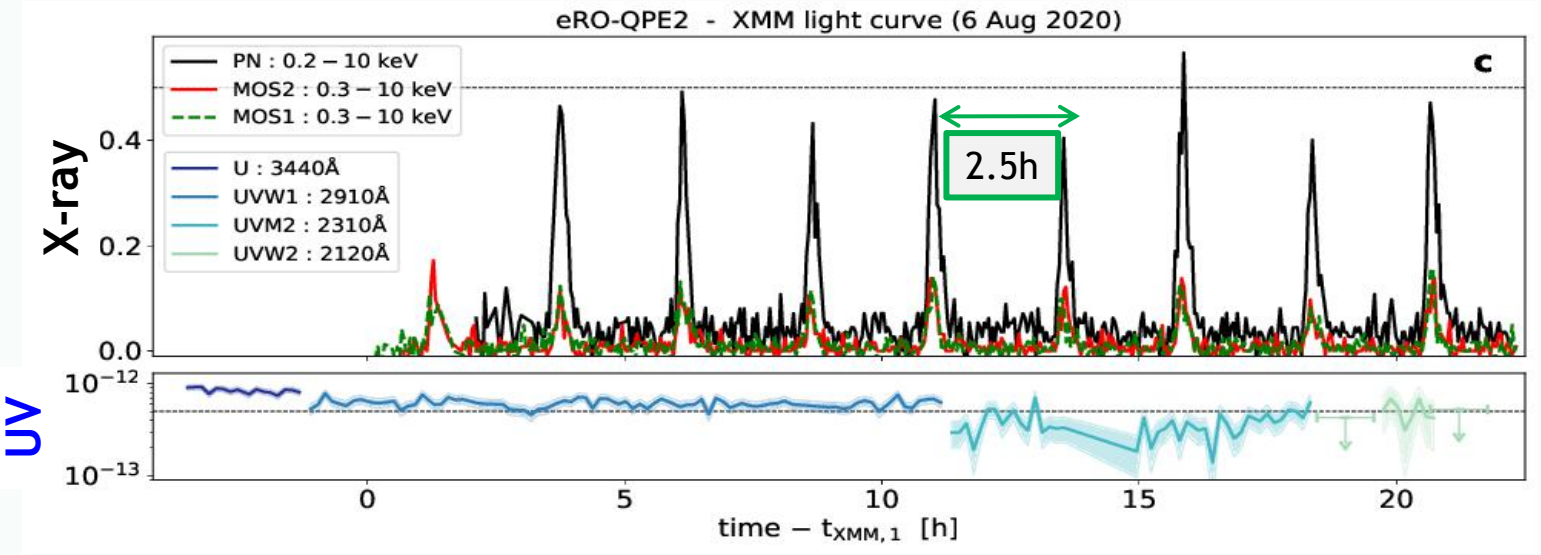
Arcodia+21

QPE1

followed-up with XMM+NICER

$Lx^{peak}_{0.5-2keV} \approx 1e43\ erg\ s^{-1}$

11 days!



Arcodia+21

QPE2

followed-up with XMM-Newton

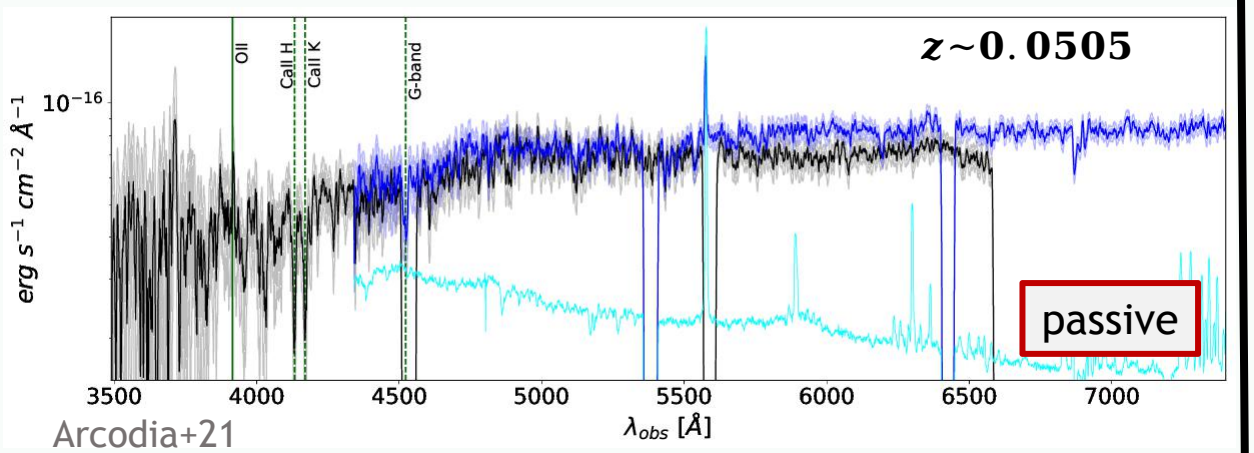
$Lx^{peak}_{0.5-2keV} \approx 1e42\ erg\ s^{-1}$

1 day!

Massive black holes awakening?

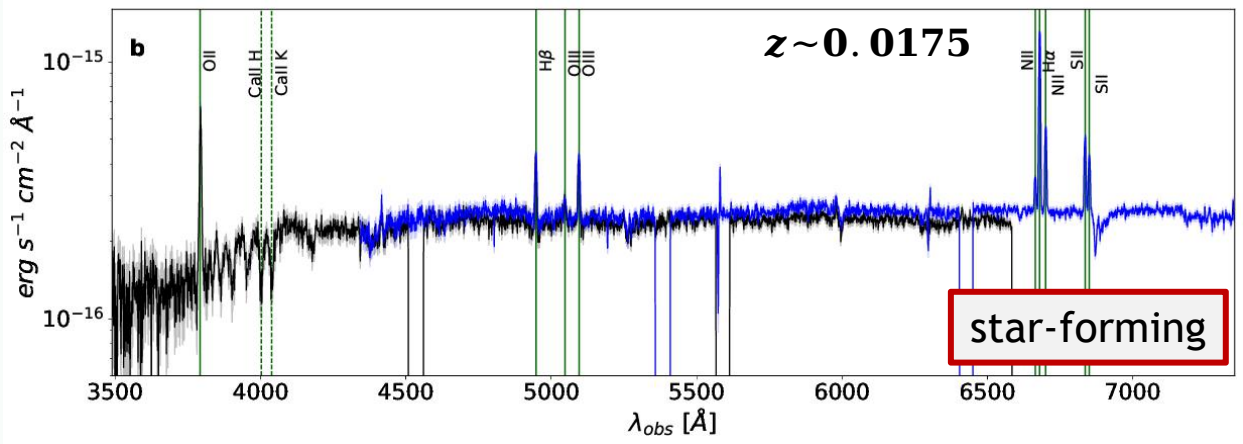
- Optical spectroscopy indicates inactive nuclei!

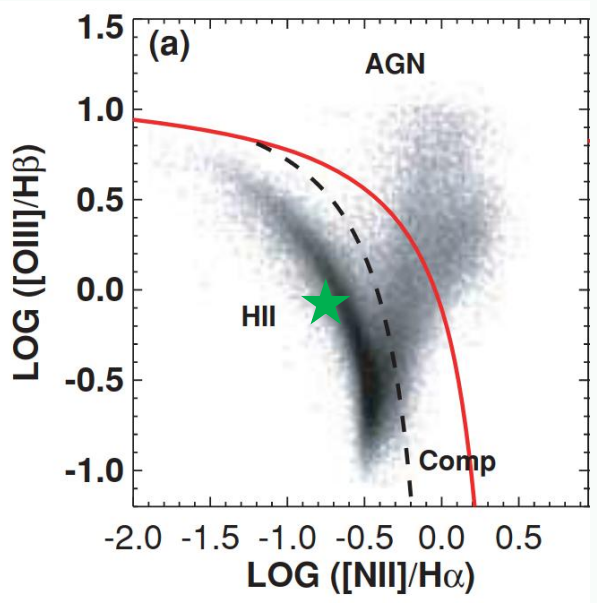
QPE1



Arcodia+21

QPE2



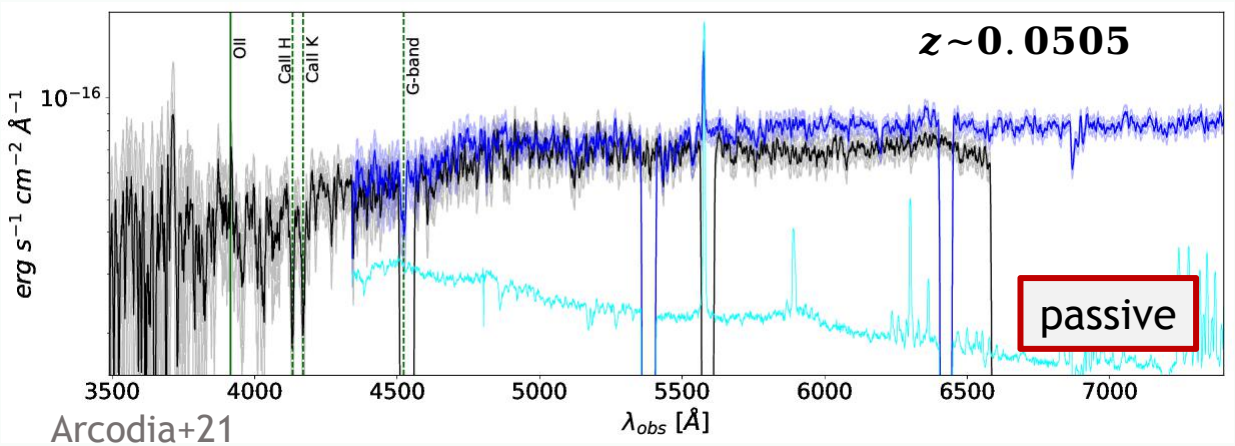


Kewley+06

Massive black holes awakening?

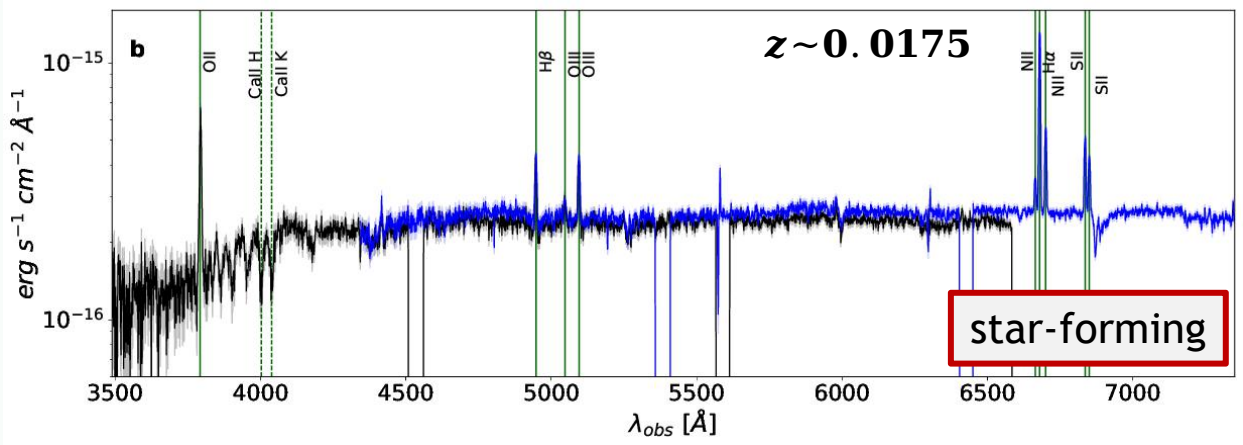
- Optical spectroscopy indicates inactive nuclei!

QPE1



Arcodia+21

QPE2



→ eROSITA's search is blind in terms of their host galaxies

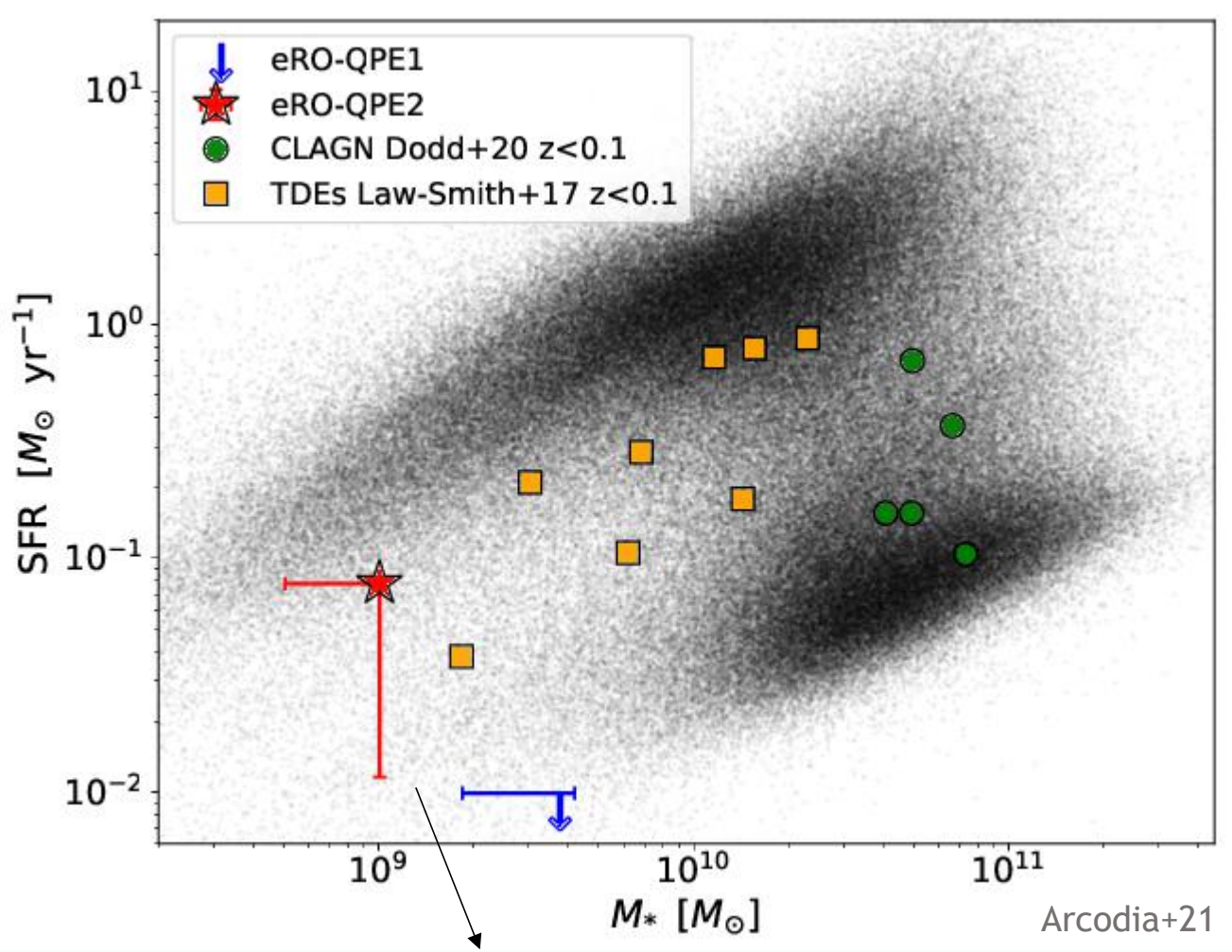
→ QPEs might not need a pre-existing AGN flow, probably just a (low-mass) SMBH

+ inefficient flow?

credits for the BH cartoon: Suvi Gezari

A poorly explored range of BH-galaxy evolution

- QPEs seem to be found in low-mass galaxies

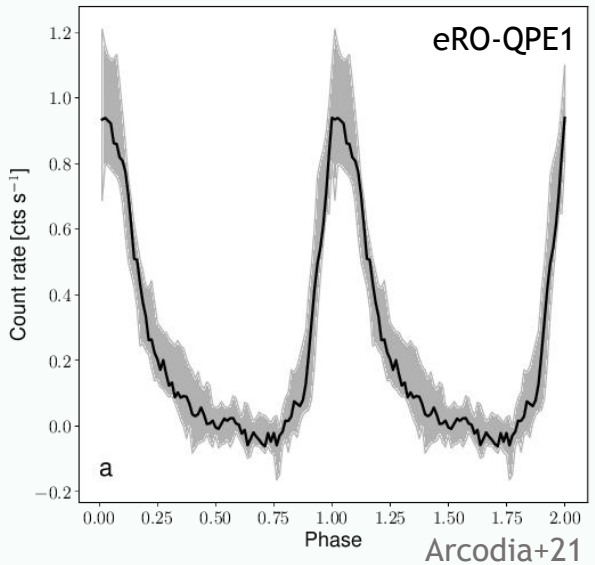


Poorly studied regime

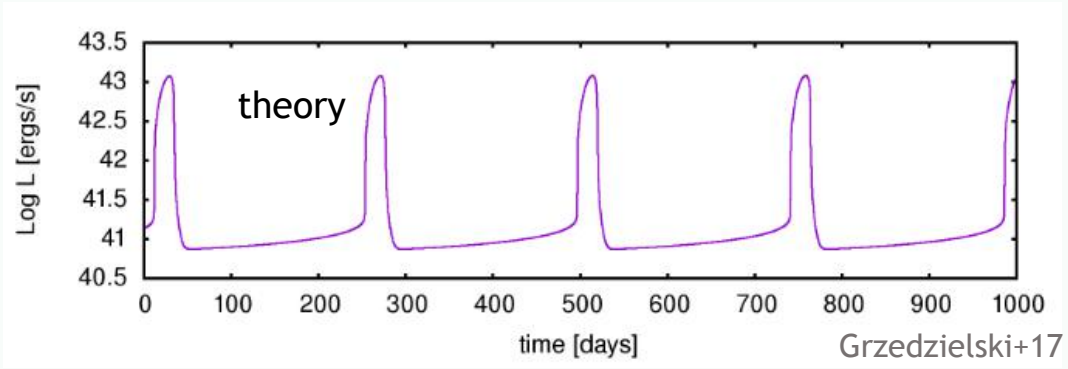
New insights: disk instabilities?

- Inconsistent with current models of radiation pressure disk instabilities

see Sniegowska+20 as well



Arcodia+21



Grzedzielski+17

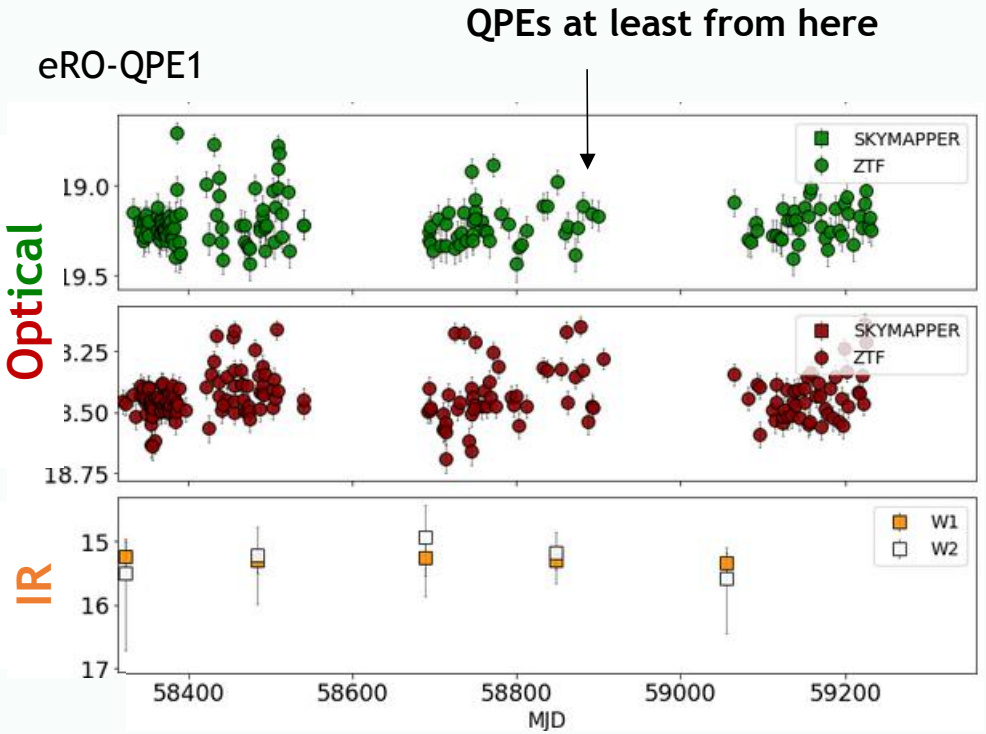
→ Periodicity, amplitude and shape are inconsistent!

New insights: binary?

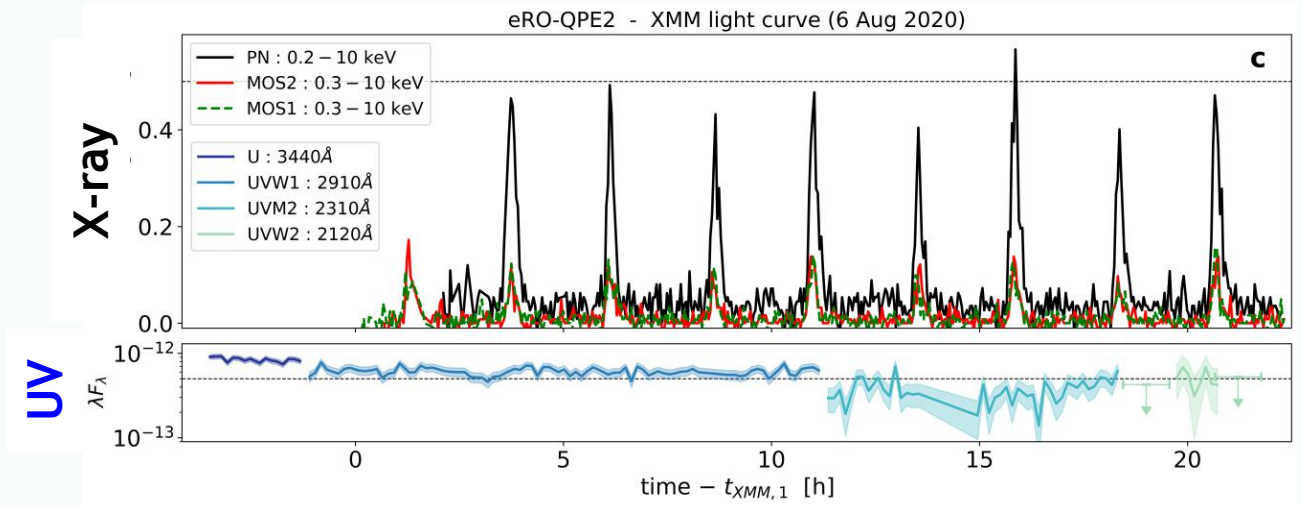
- BH binary with mass-ratio ~1 unlikely

→ No sign of sinusoidal/periodic variability in opt-UV-IR

eRO-QPE1



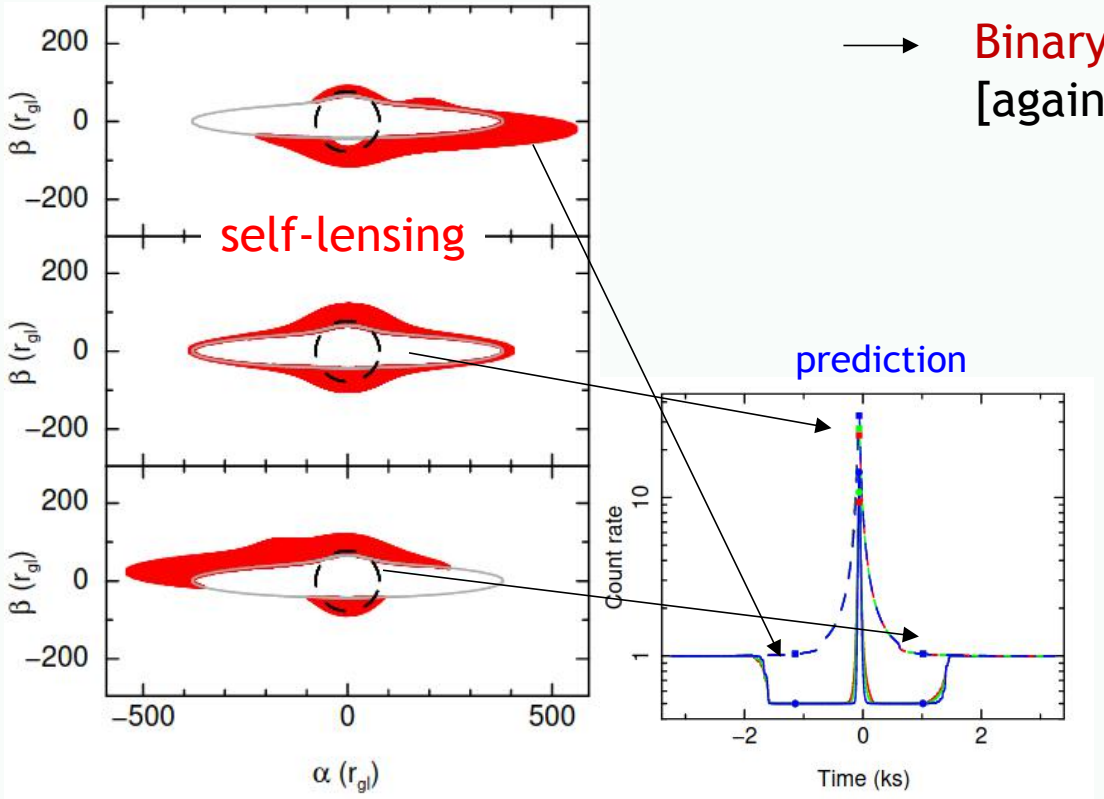
eRO-QPE2



Arcodia+21

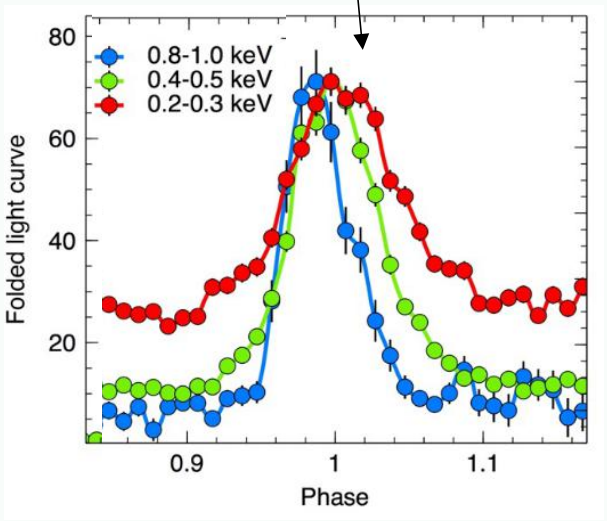
New insights: binary?

- BH binary with mass-ratio ~1 unlikely



Ingram+21

→ Binary self-lensing could produce sharp bursts, but achromatic
[against strong energy dependence in QPEs]

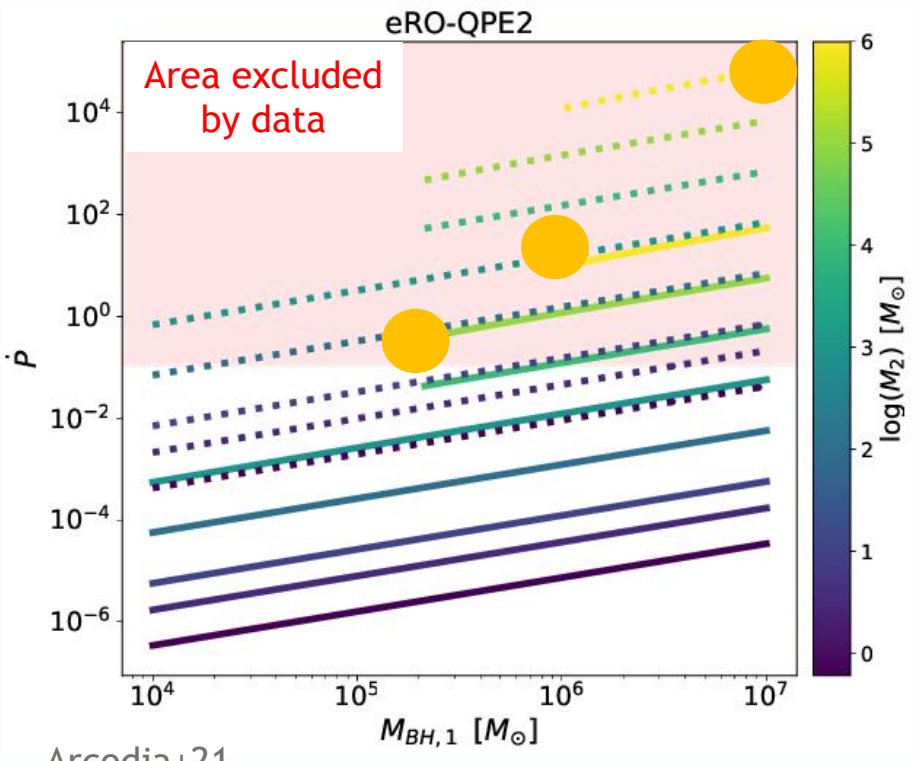


Miniutti+19

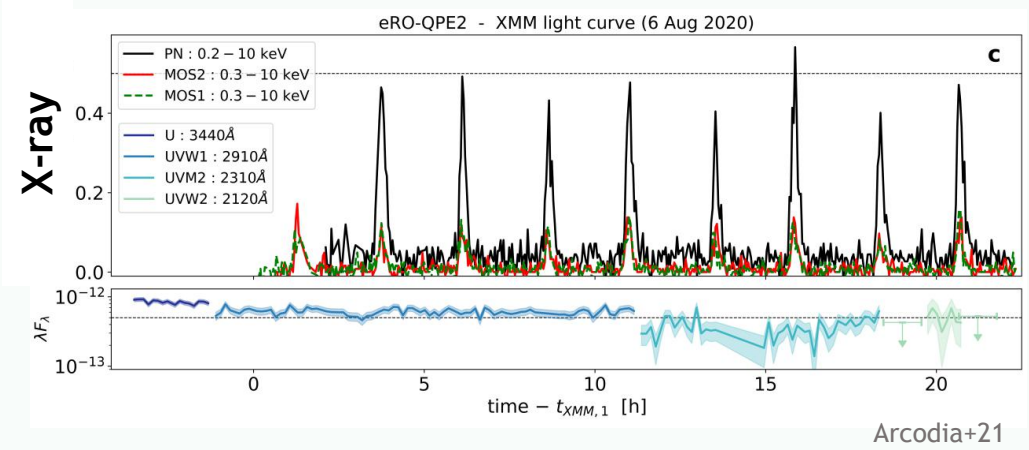
New insights: binary?

- BH binary with mass-ratio ~1 unlikely

→ we'd have observed a strong $\dot{P}$ already and they would be very close to merger



Arcodia+21

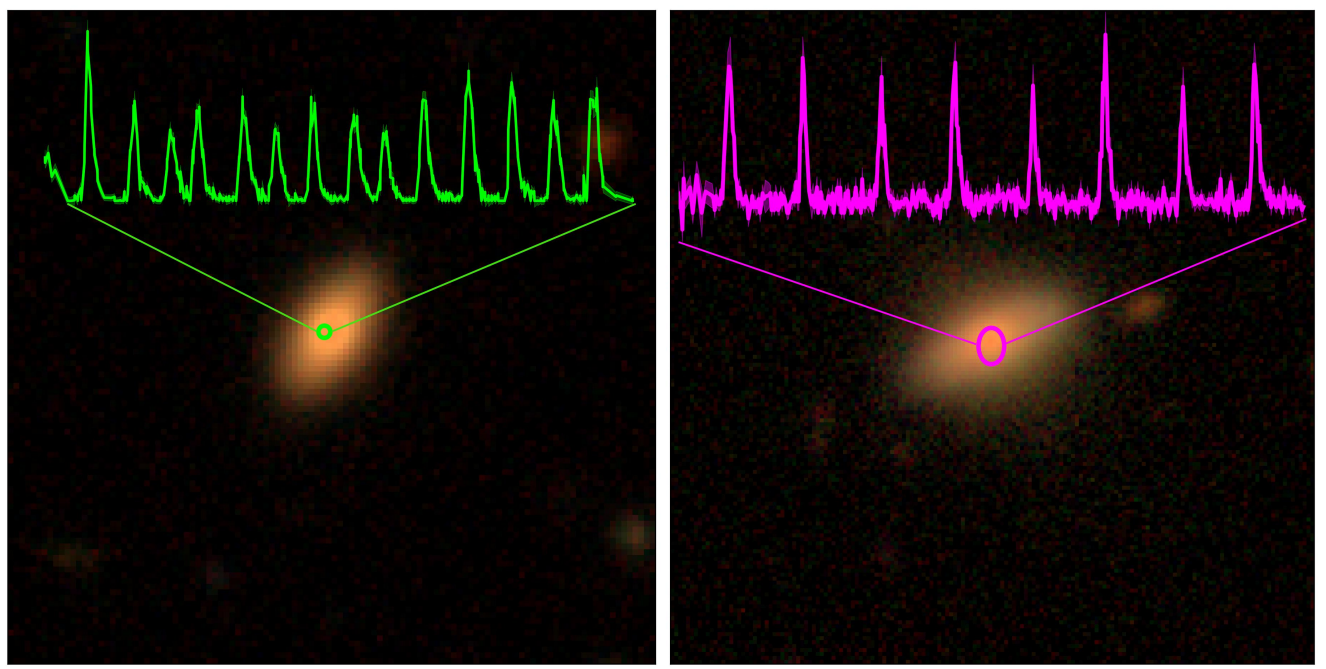


Arcodia+21

New insights: extreme mass-ratio inspirals?

- High mass-ratio binaries? i.e. low-mass SMBH and stellar-mass object (e.g. King2020, Zhao+2021)

→ TDEs ballpark? consistent with the two eROSITA QPEs (found in previously quiescent galaxies)



Full credits: https://www.mpe.mpg.de/7587547/news20210429

→ **low-mass SMBH** ($10^5 - 10^7 M_\odot$) in low-mass galaxies

→ soft thermal-like X-ray spectra

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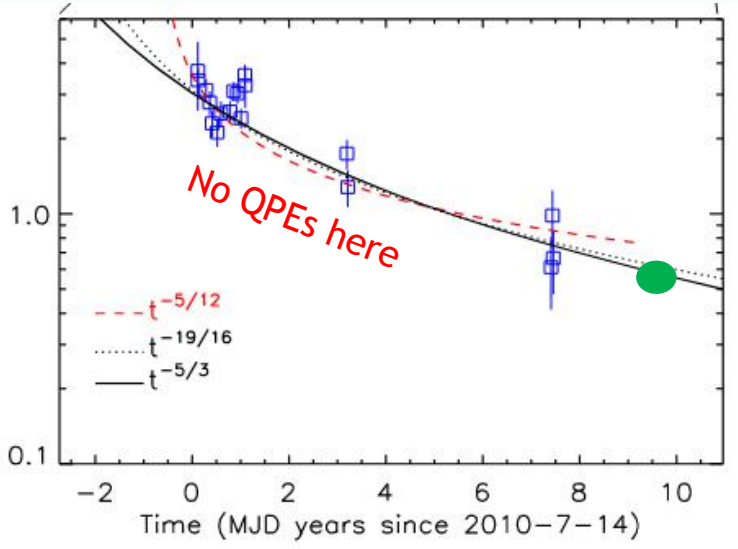
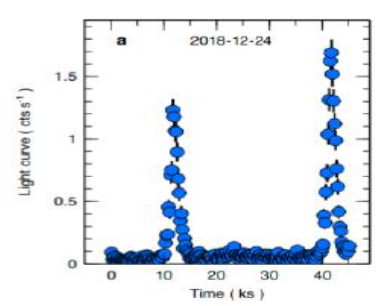
→ TDEs ballpark? consistent with GSN069 (the discovery QPE) (Miniutti+19)

(Shu+18; Miniutti+19)



first QPEs

TDE from envelope, QPEs from remnant? (King20; Sheng+21)



(Miniutti+19)

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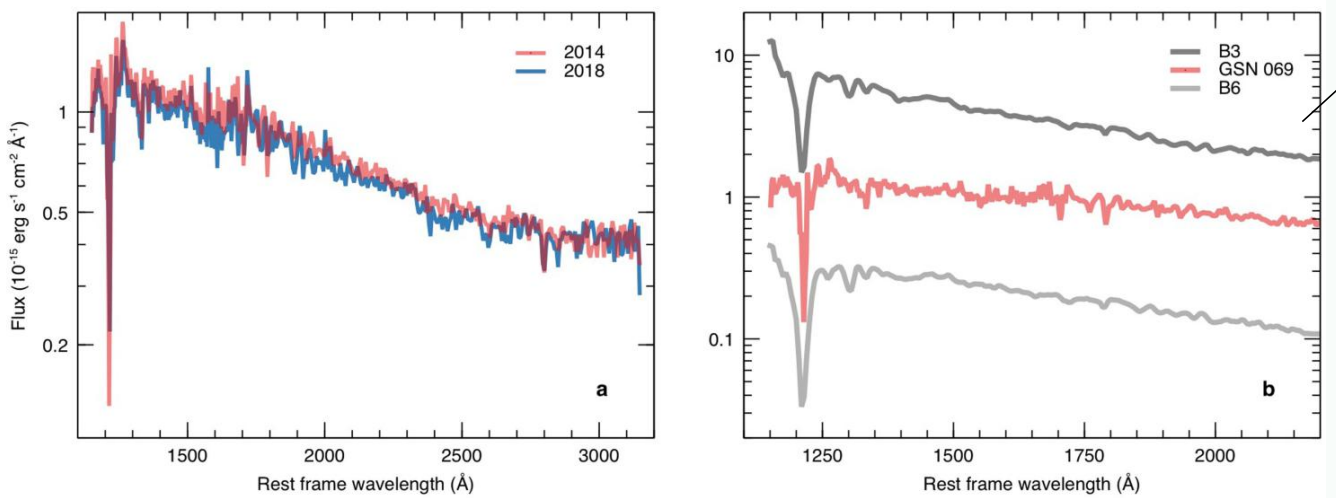
→ TDEs ballpark? consistent with GSN069 (the discovery QPE) (Miniutti+19)

presence of nuclear star cluster?



(Miniutti+19; Sheng+21)

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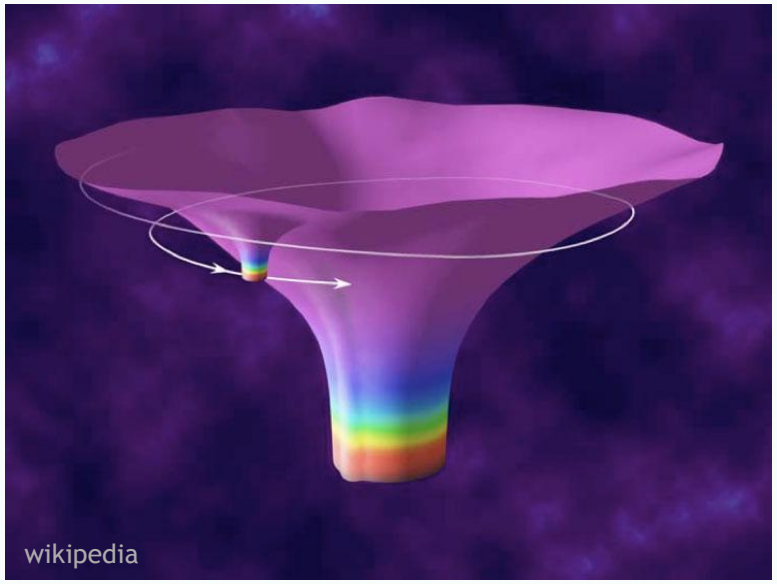
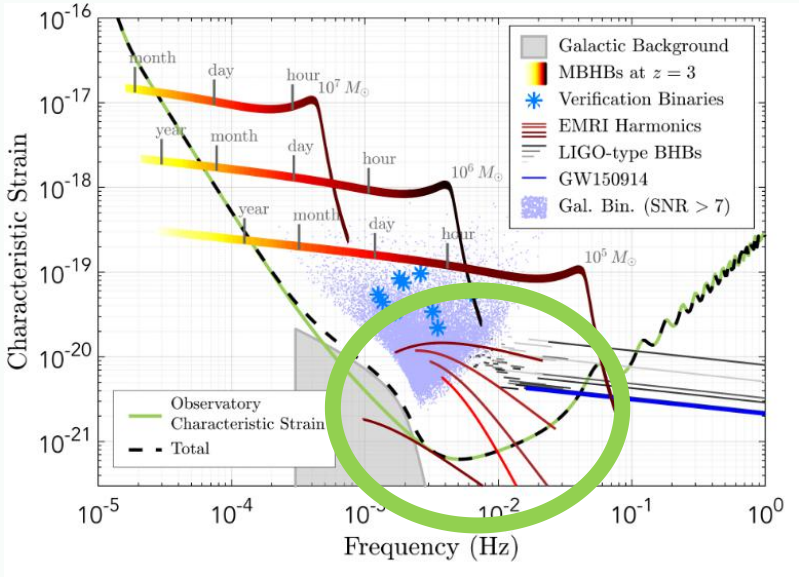


→ EM counterpart of extreme mass-ratio inspirals, detectable by LISA! (Zhao+2021)



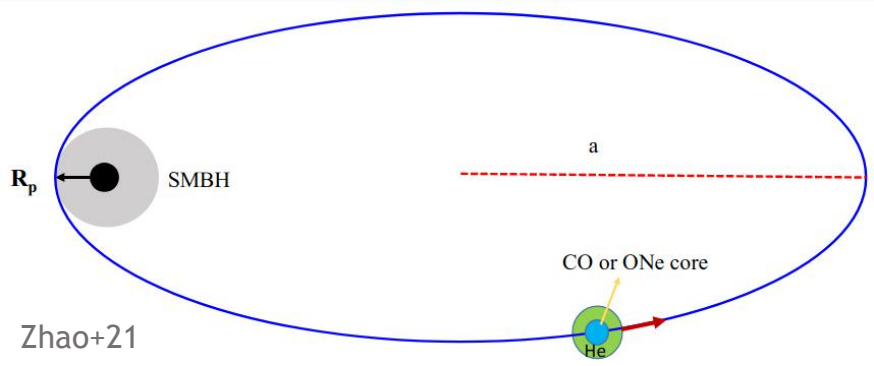
Amaro-Seoane+17

New insights: extreme mass-ratio inspirals?

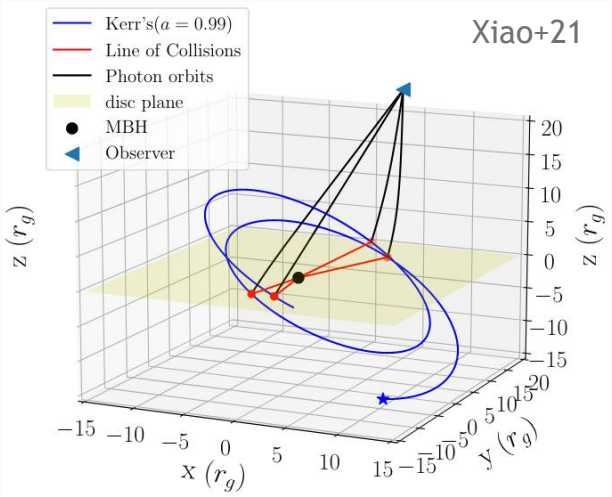
- High mass-ratio binaries? i.e. low-mass SMBH and stellar-mass object (e.g. King2020, Zhao+2021)

→ This scenario is the one which is being tested the most (e.g. King20, Sukova+21; Zhao+21, Metgzer+21, Xiao+21)

e.g. He-envelope star partially stripped



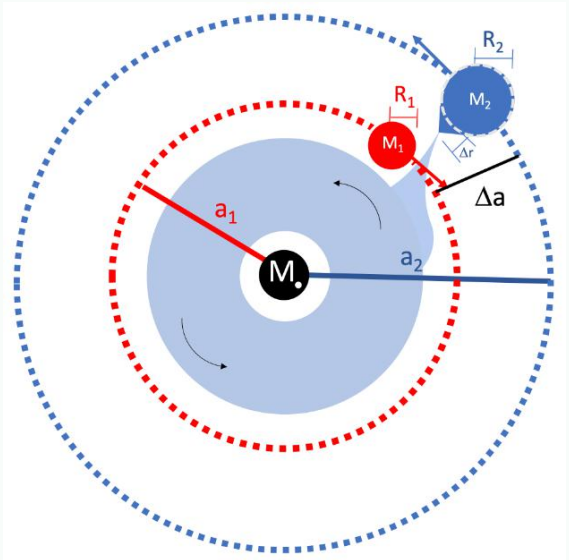
Zhao+21



Xiao+21

e.g. star-disk collisions

e.g. two co-planar counter-orbiting stellar EMRIs



Metzger+21

What's next?

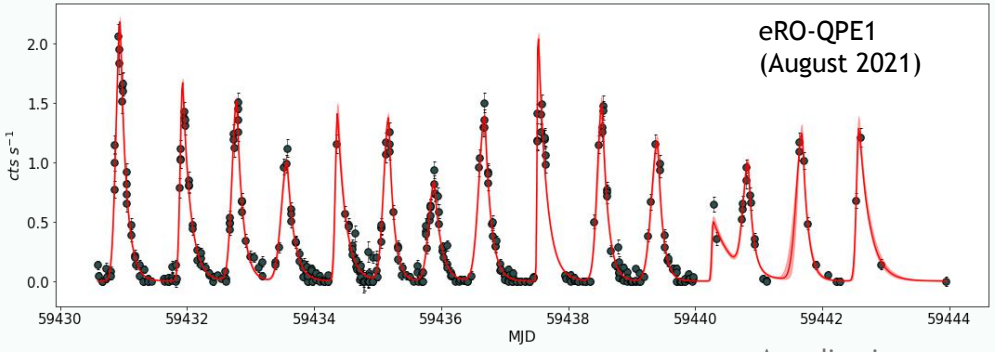
- eROSITA data are being continuously monitored for new QPEs

  → expected ~1-2 per year

- Perform further follow-up of the known QPEs

  → X-rays

  → Radio?



Arcodia+ in prep.

- Use current+future data to study/constrain the bursts' physics and origin

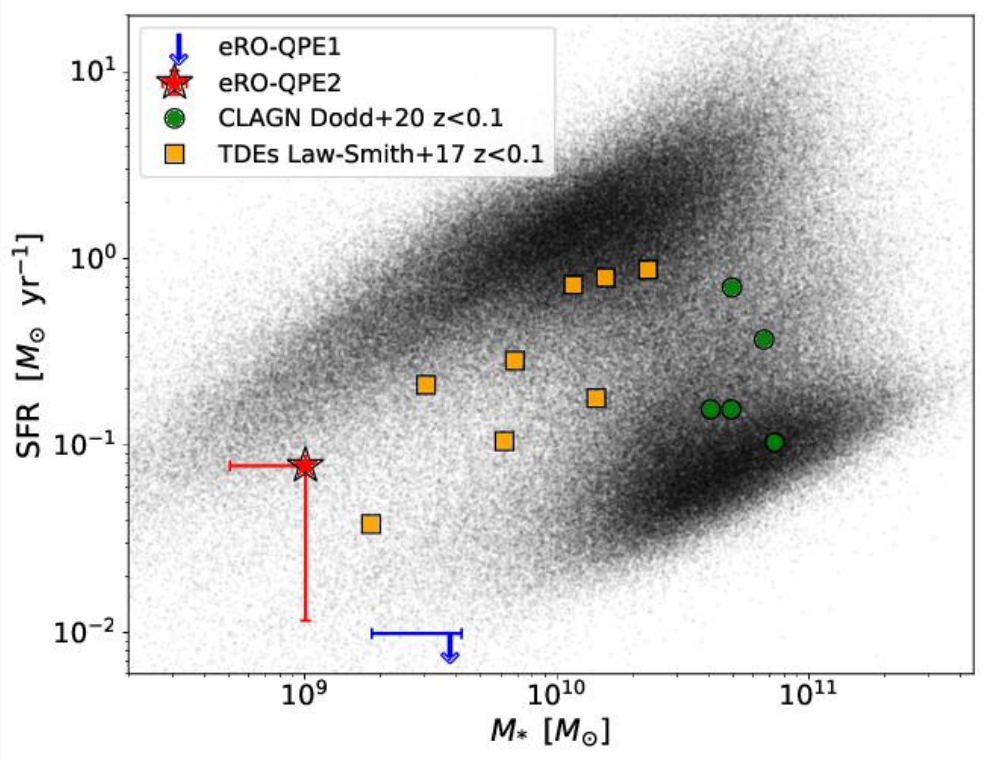
  → A lot to do: what causes these bursts?

  see, e.g., King20; Sukova+21, Metzger+21; Zhao+21; Xian+21

Summary

- QPEs are a new type of exotic X-ray phenomena related to BH accretion

→ Low-mass SMBHs in low-mass galaxies: poorly studied mass regime for their co-evolution

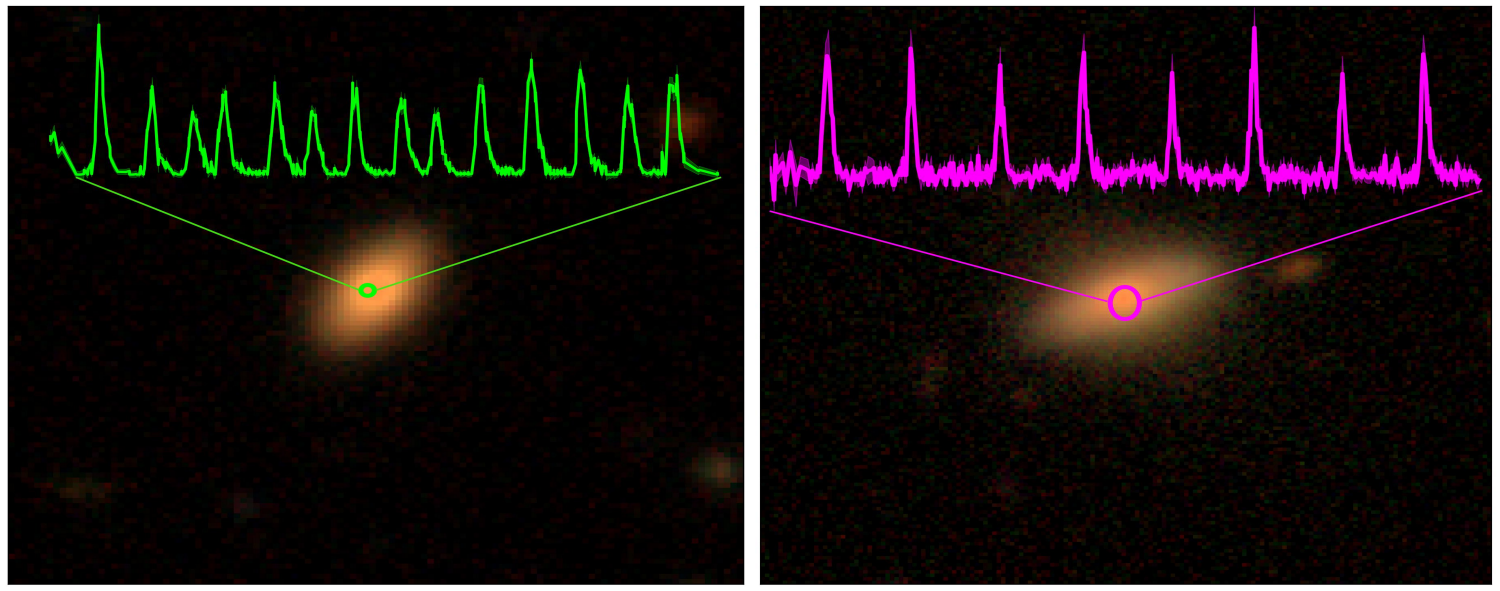


Summary

- QPEs are a new type of exotic X-ray phenomena related to BH accretion

→ Low-mass SMBHs in low-mass galaxies: poorly studied mass regime for their co-evolution

- We have found 2 with eROSITA, doubling the sample!
- Now found also in inactive galaxies (one needs “only” a low-mass SMBH)



Summary

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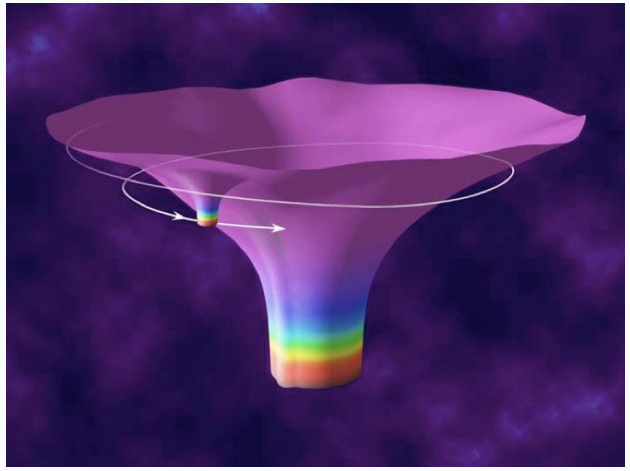
→ Low-mass SMBHs in low-mass galaxies: poorly studied mass regime for their co-evolution

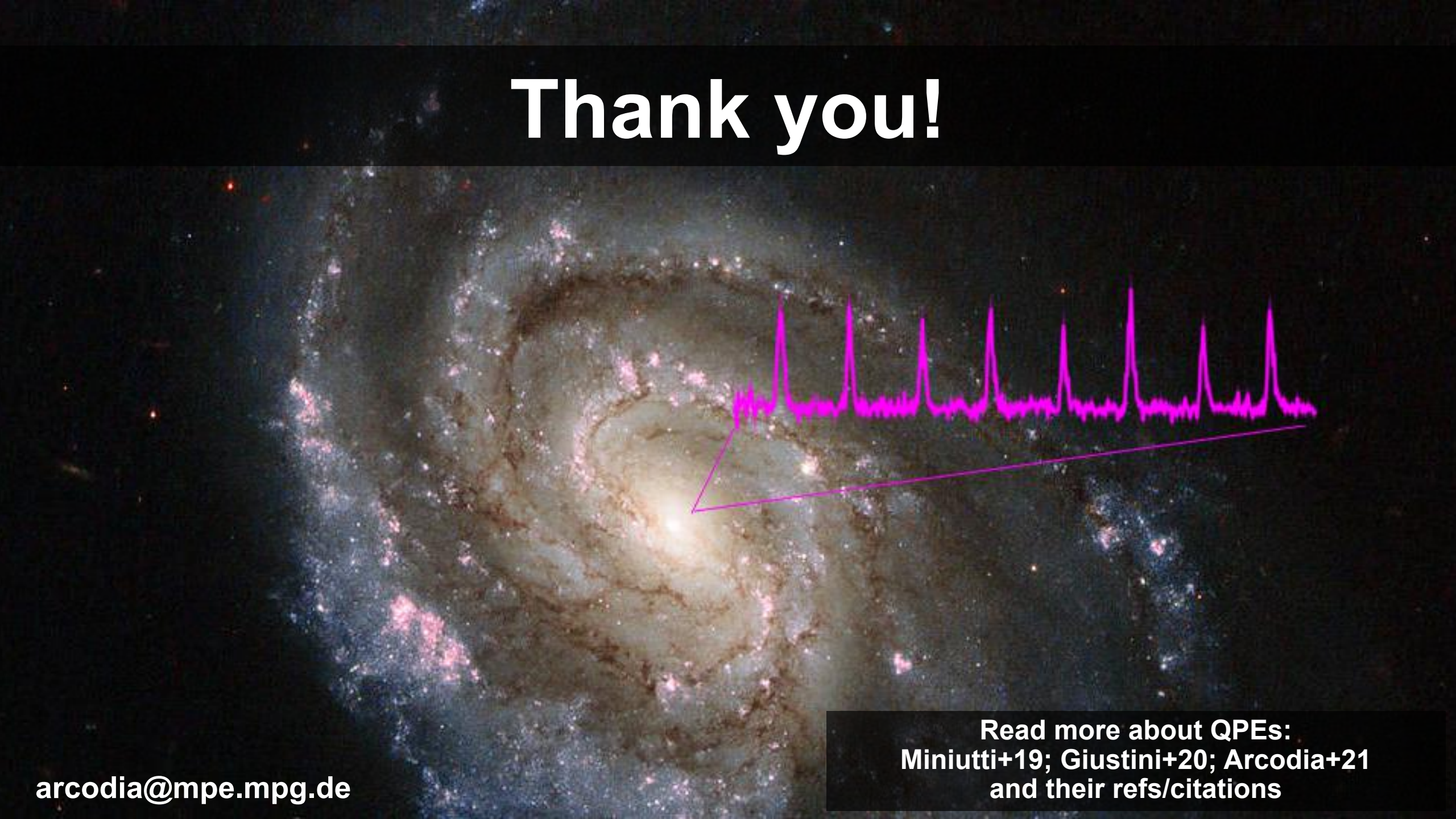
- We have found 2 with eROSITA, doubling the sample!
- Now found also in inactive galaxies (one needs “only” a low-mass SMBH)

- Scenario currently under investigation: high-mass ratio binary



→ To be tested soon

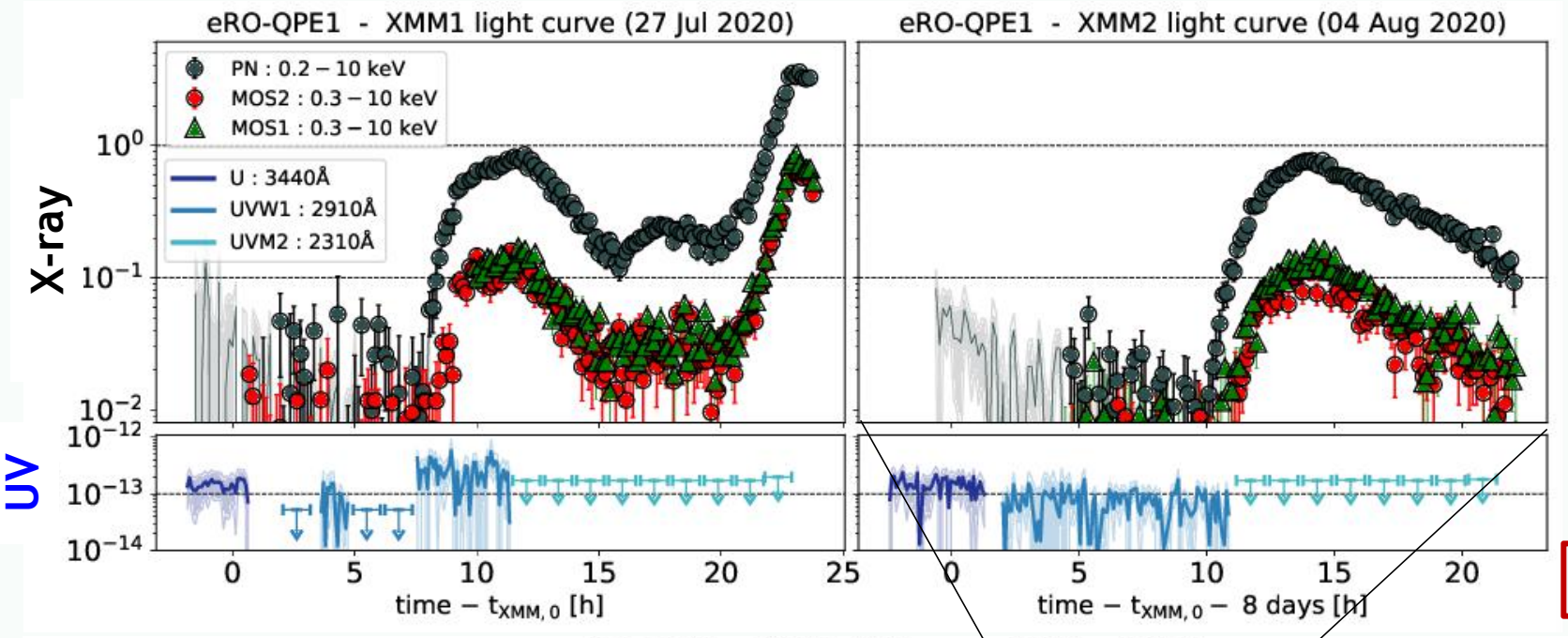
Thank you!



Read more about QPEs:
Miniutti+19; Giustini+20; Arcodia+21
and their refs/citations

arcodia@mpe.mpg.de

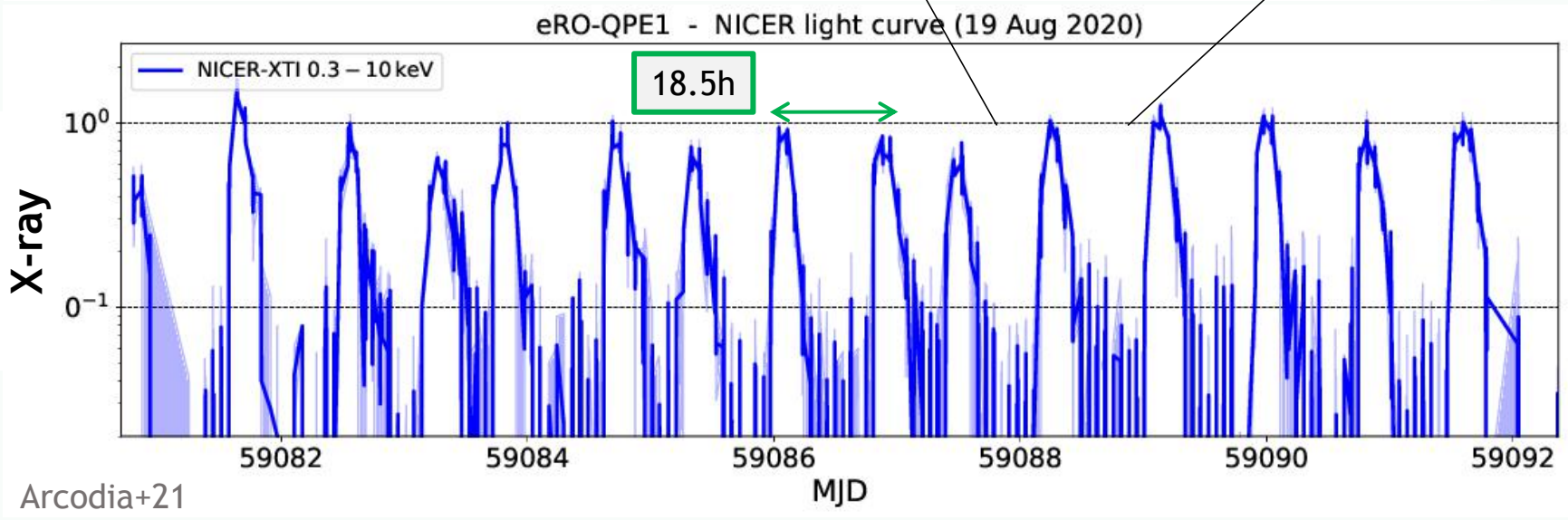
First discoveries: eRO-QPE1



QPE1

$Lx^{peak}_{0.5-2keV} \approx 1e43\ erg\ s^{-1}$

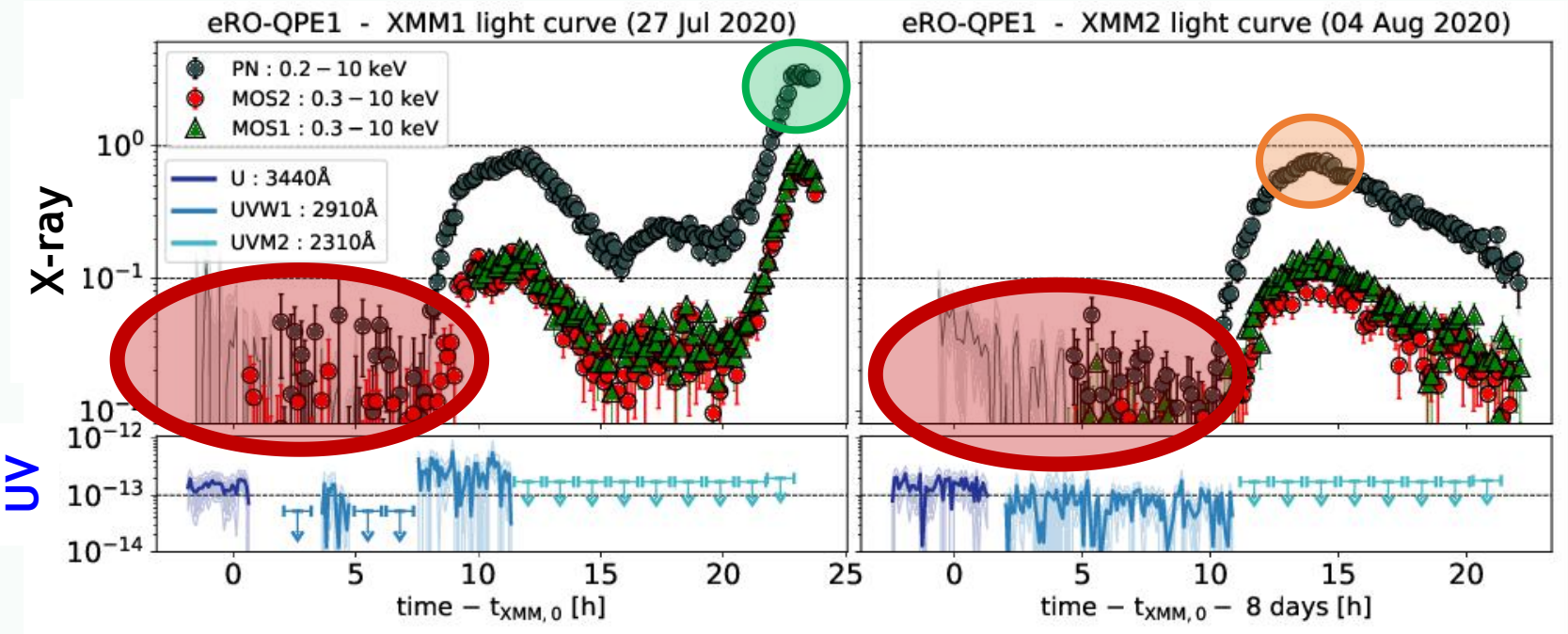
2 x 1 day!

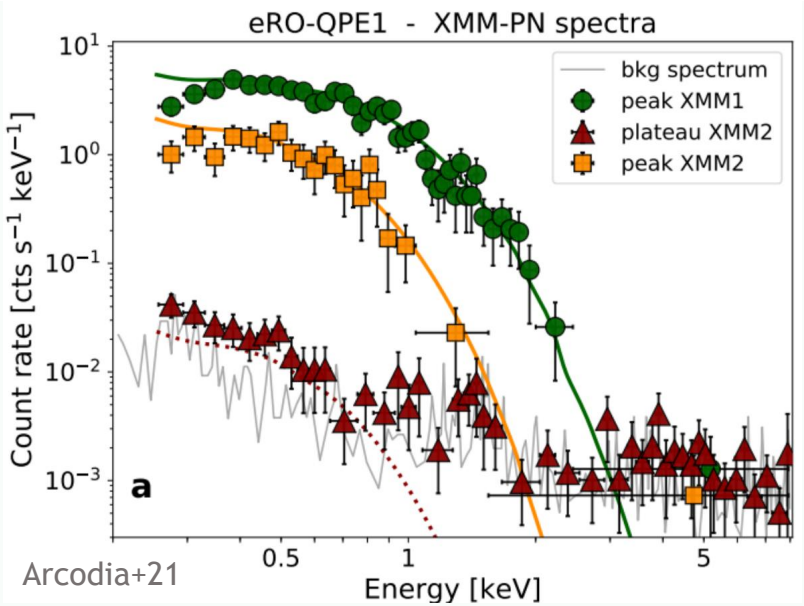


11 days!

Arcodia+21

First discoveries: eRO-QPE1





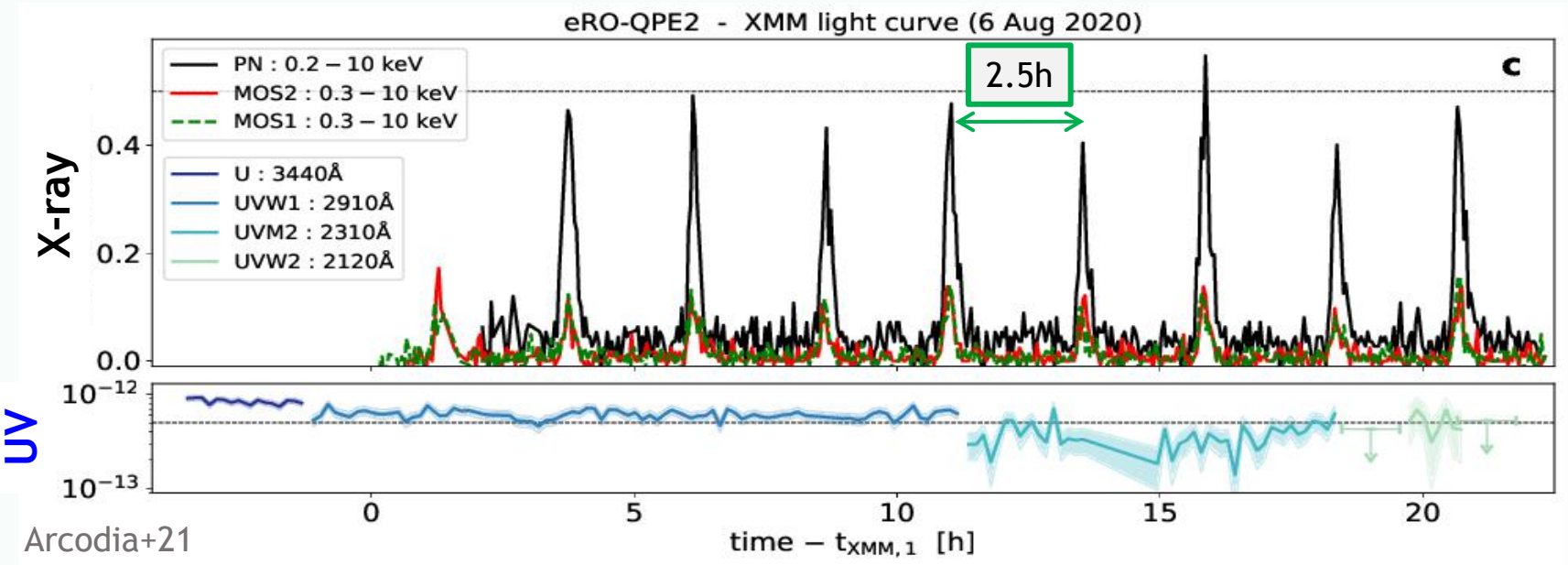
Arcodia+21

QPE1

$$Lx^{peak}_{0.5-2keV} \approx 1e43\ erg\ s^{-1}$$

First discoveries: eRO-QPE2

QPE2



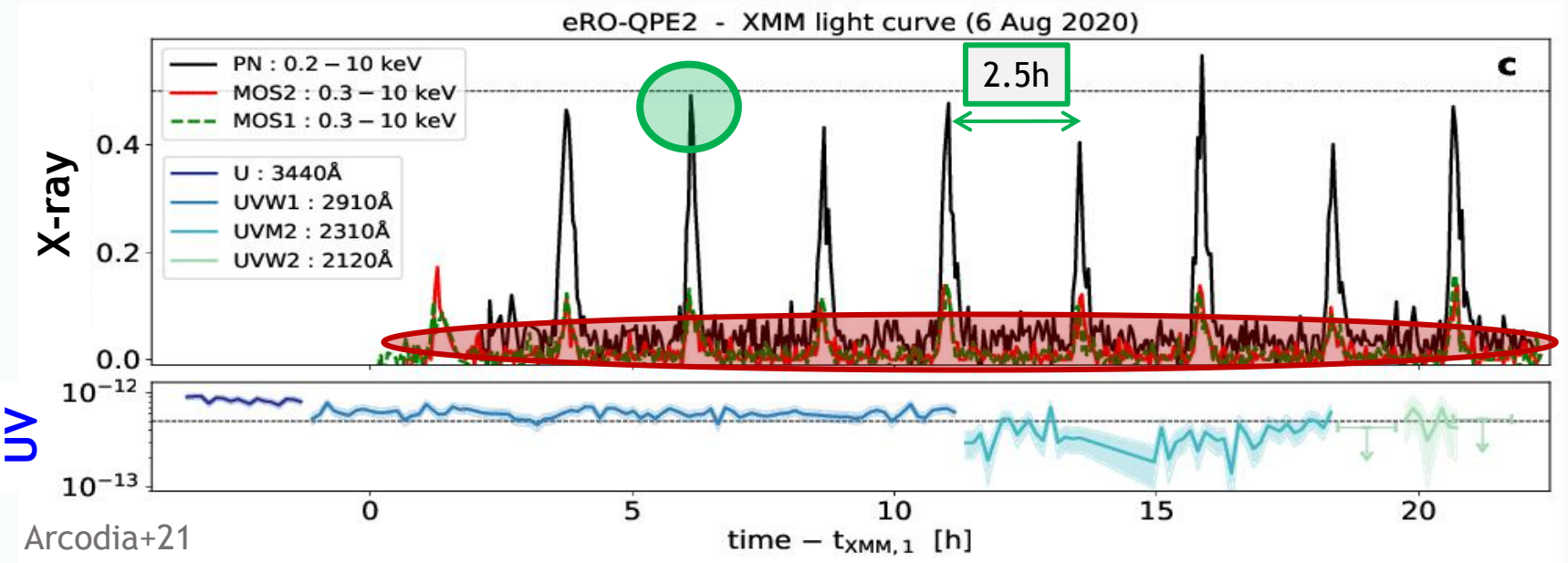
Arcodia+21

$Lx^{peak}_{0.5-2keV} \approx 1e42\ erg\ s^{-1}$

1 day!

First discoveries: eRO-QPE2

QPE2



Arcodia+21

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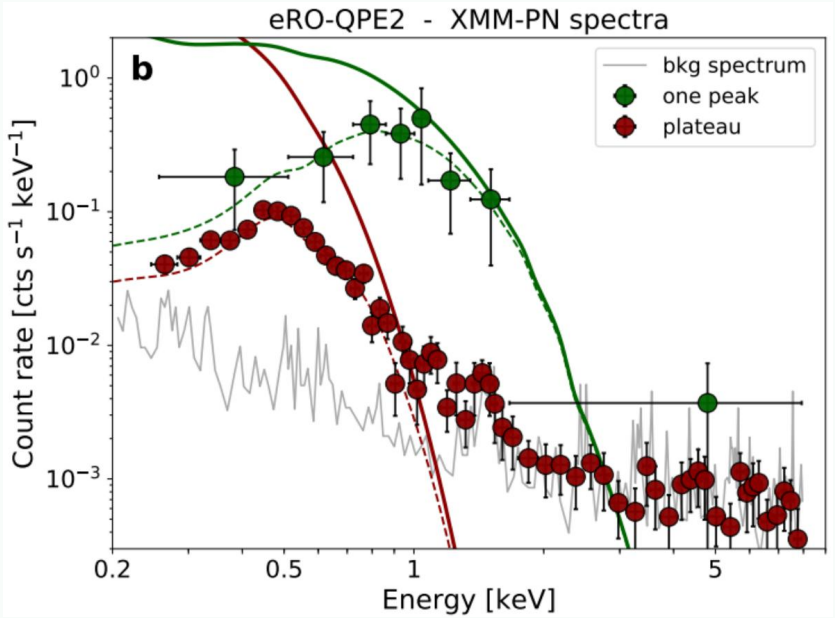
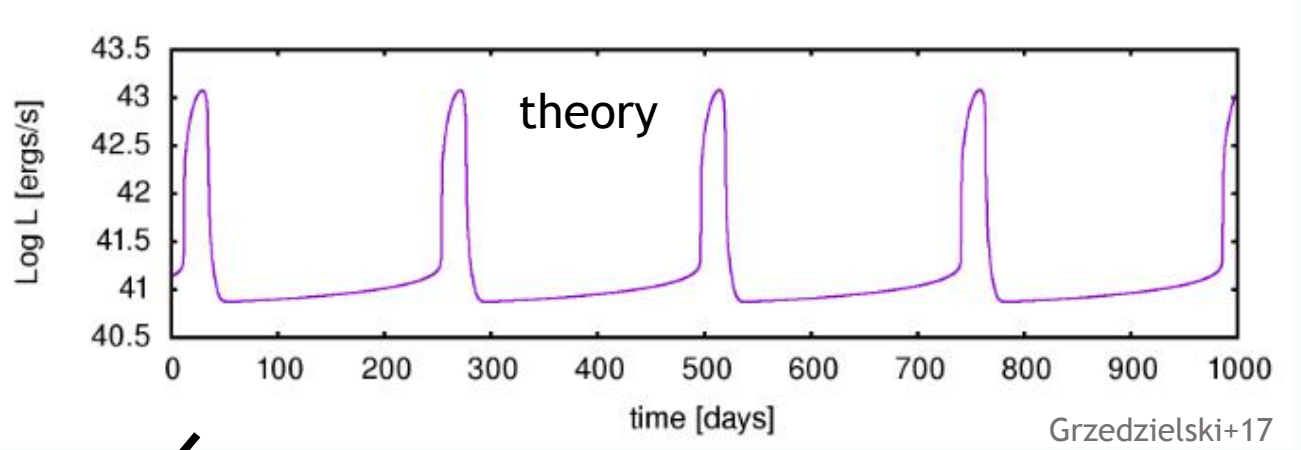


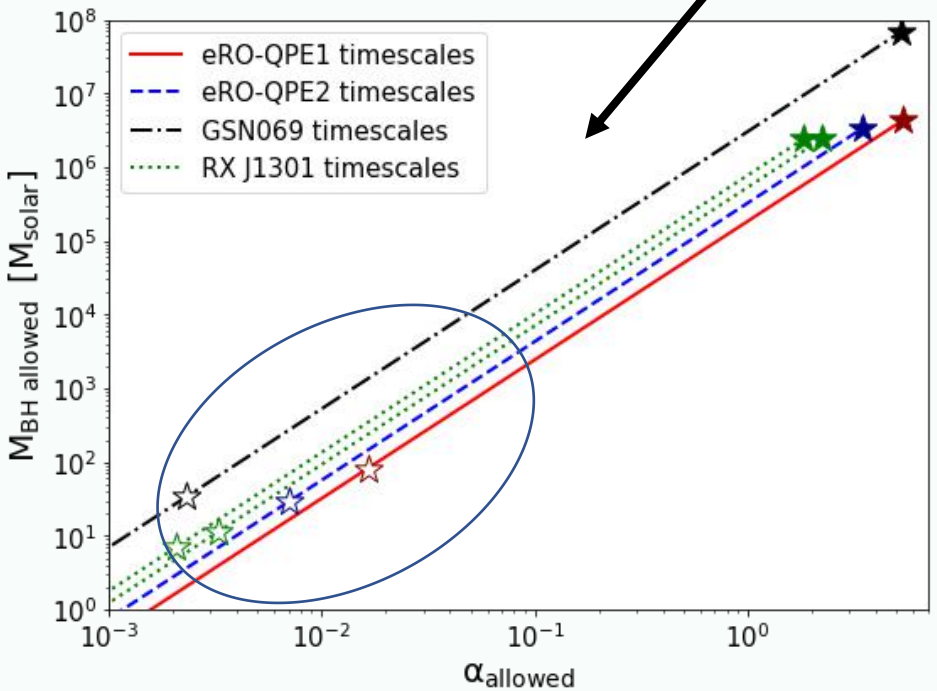
New insights: disk instabilities?

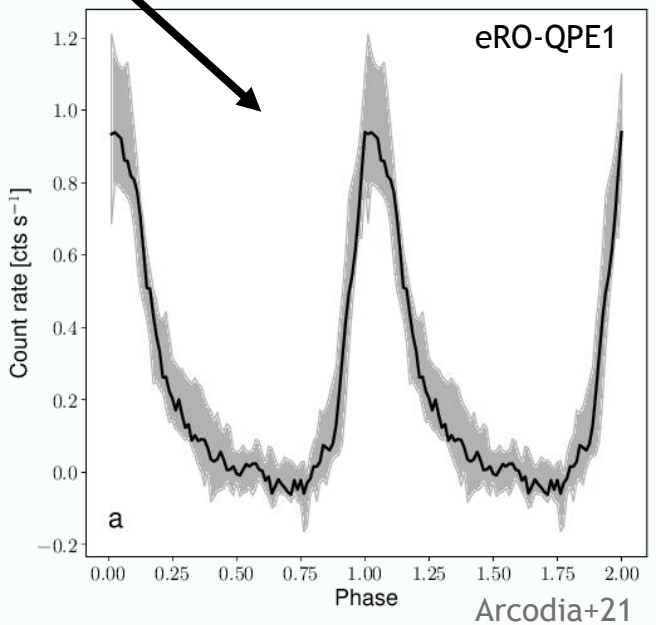
- The observed X-ray properties are inconsistent with current models of radiation pressure disk instabilities

see Sniegowska+20 as well



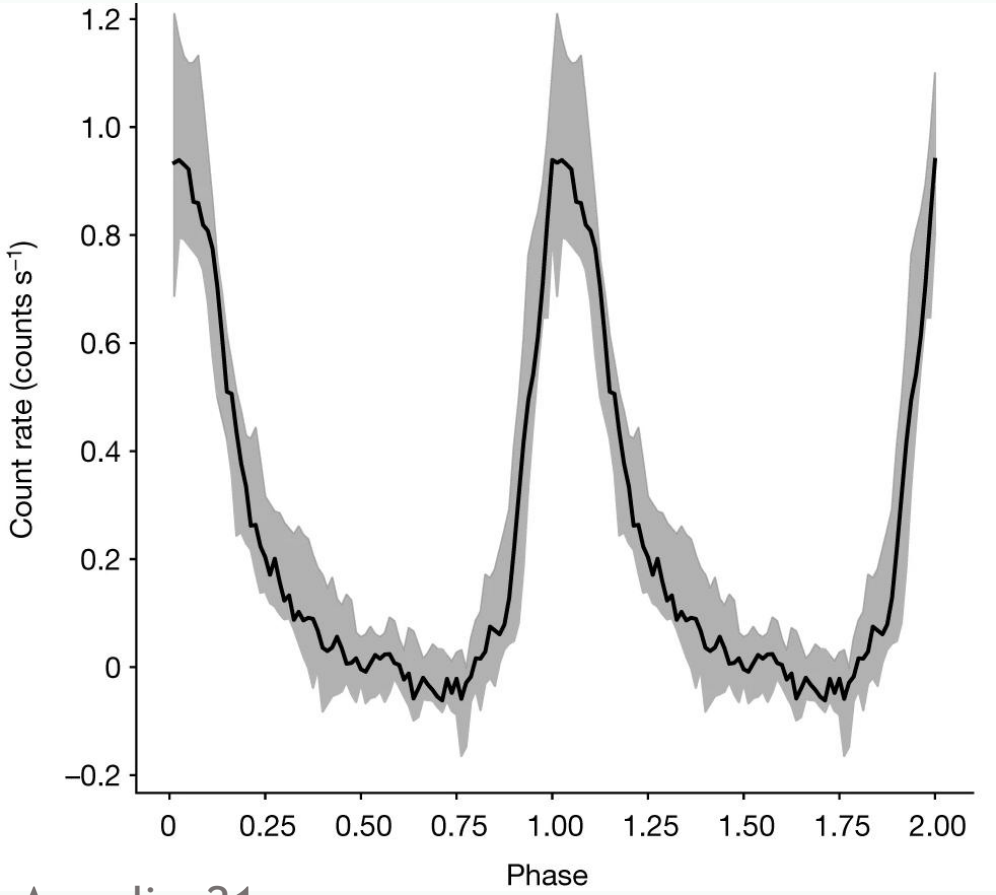
Grzedzielski+17



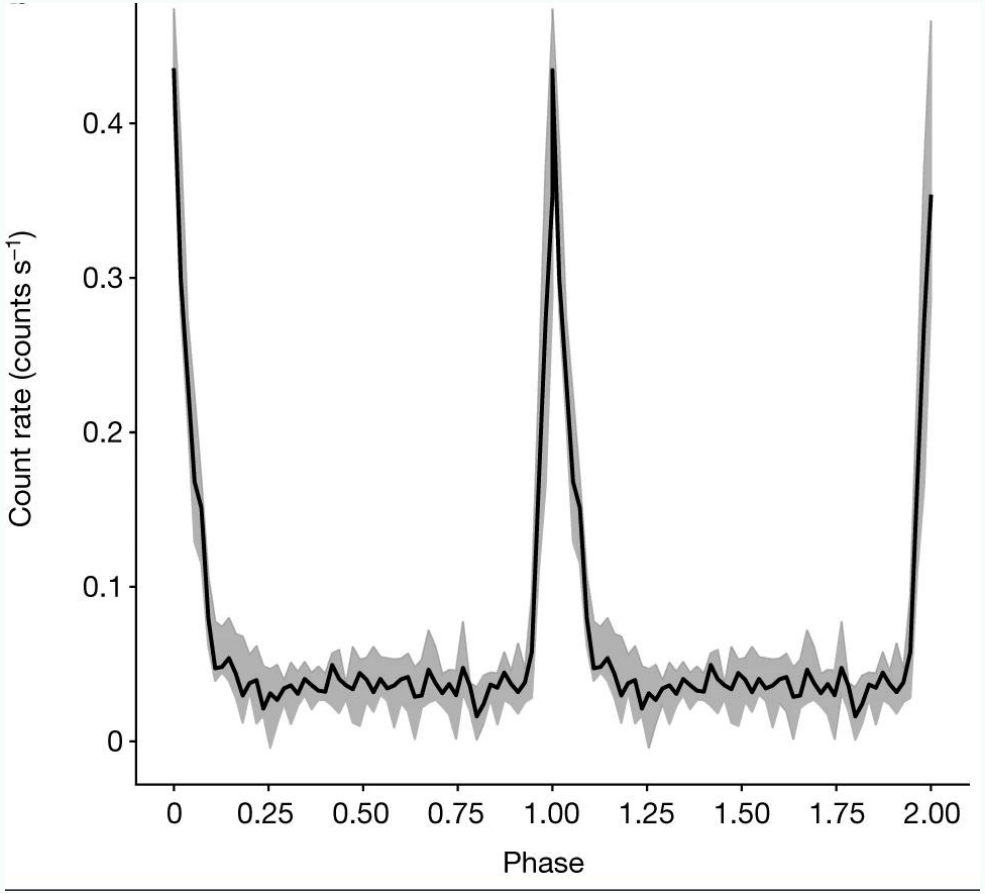


Arcodia+21

Extra



Arcodia+21



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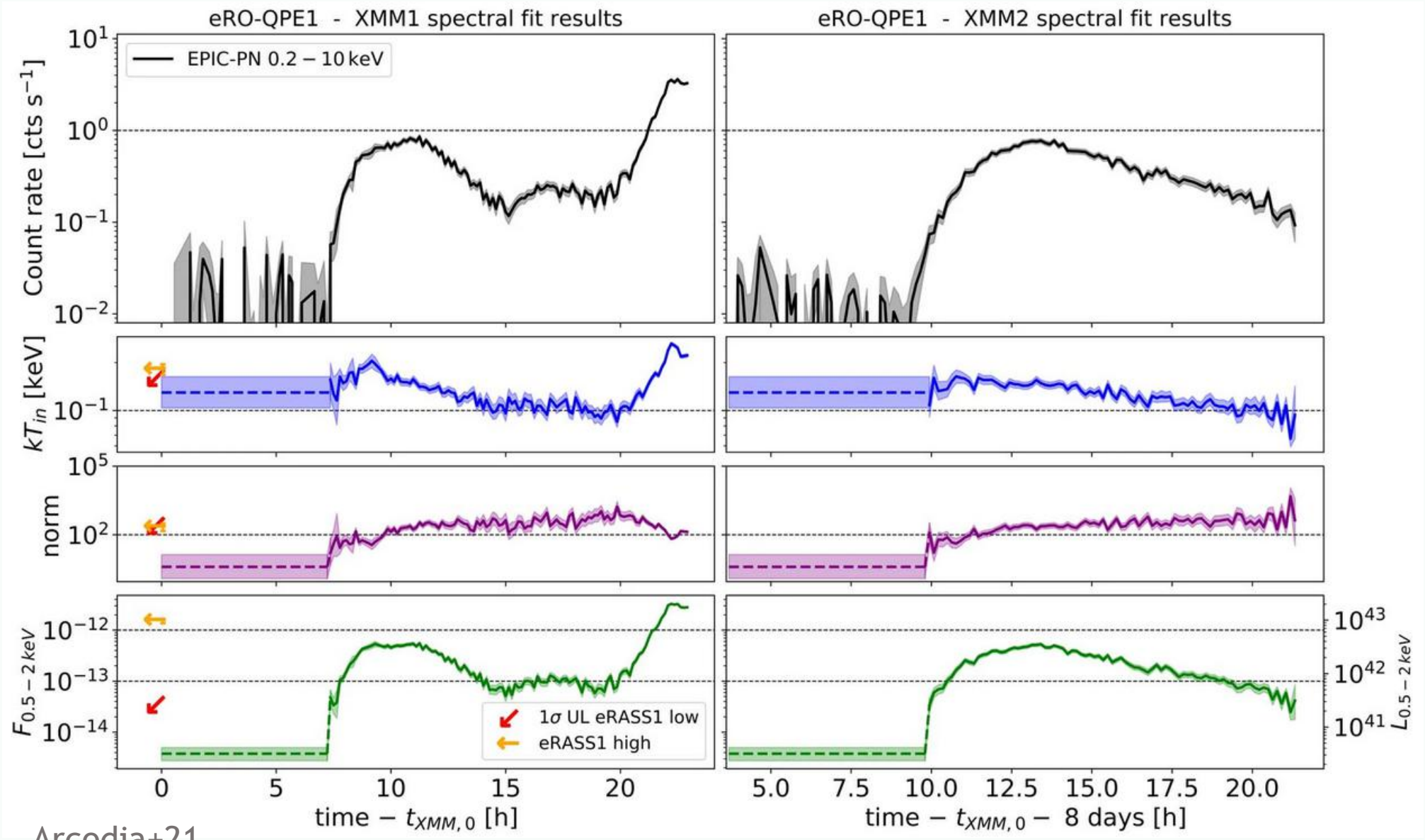

Arcodia+21

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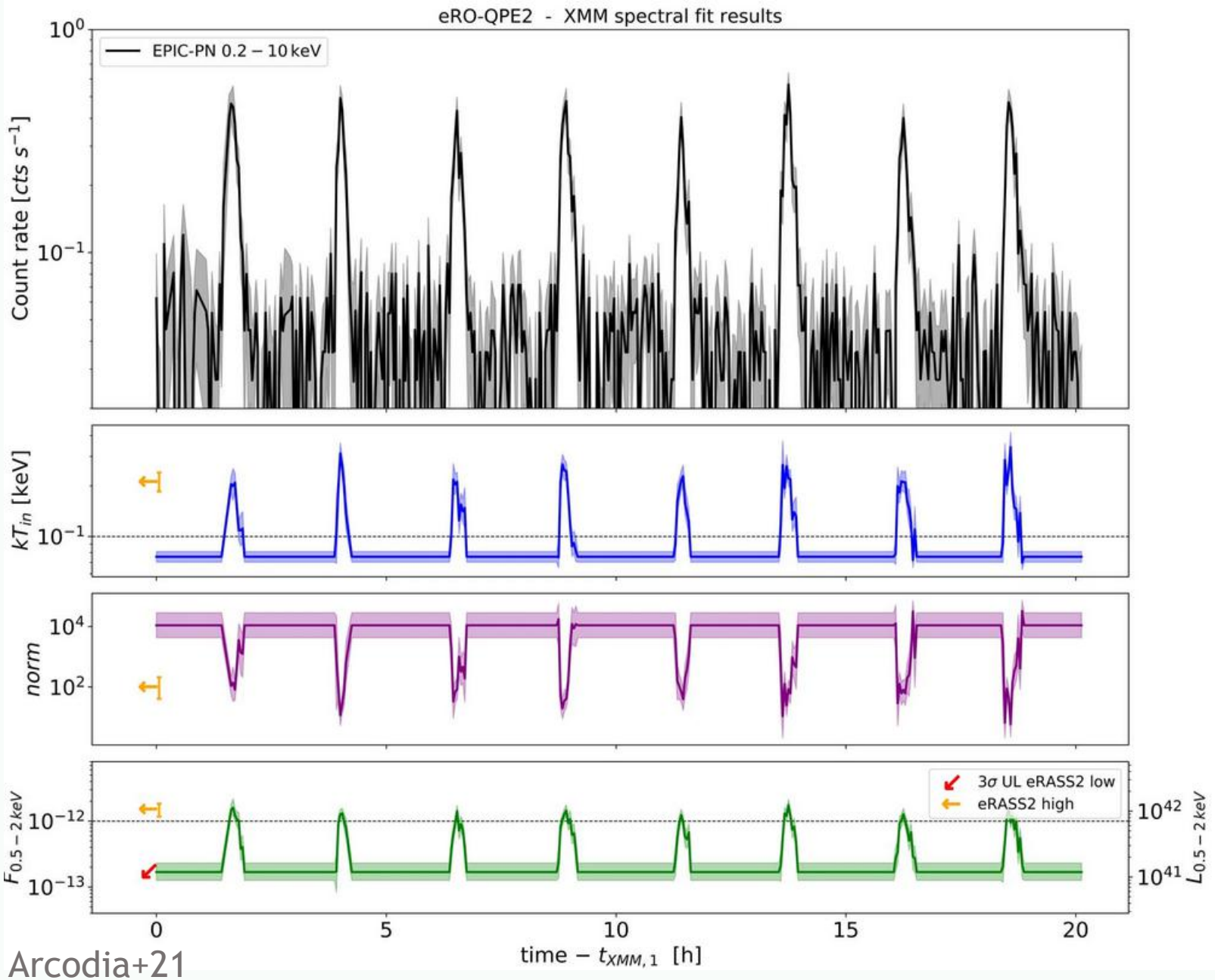

Arcodia+21