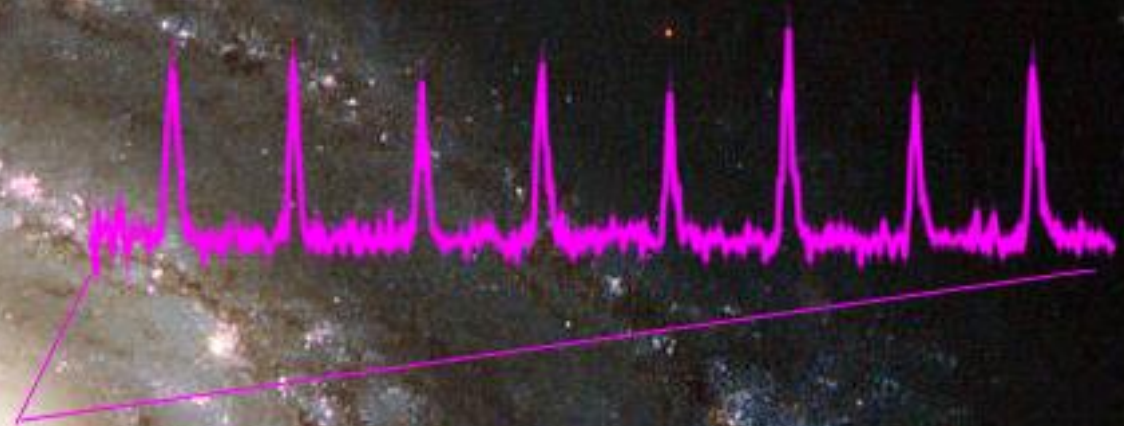


X-ray bursts from two quiescent galaxies: massive black holes awakening?

Riccardo Arcodia (MPE)

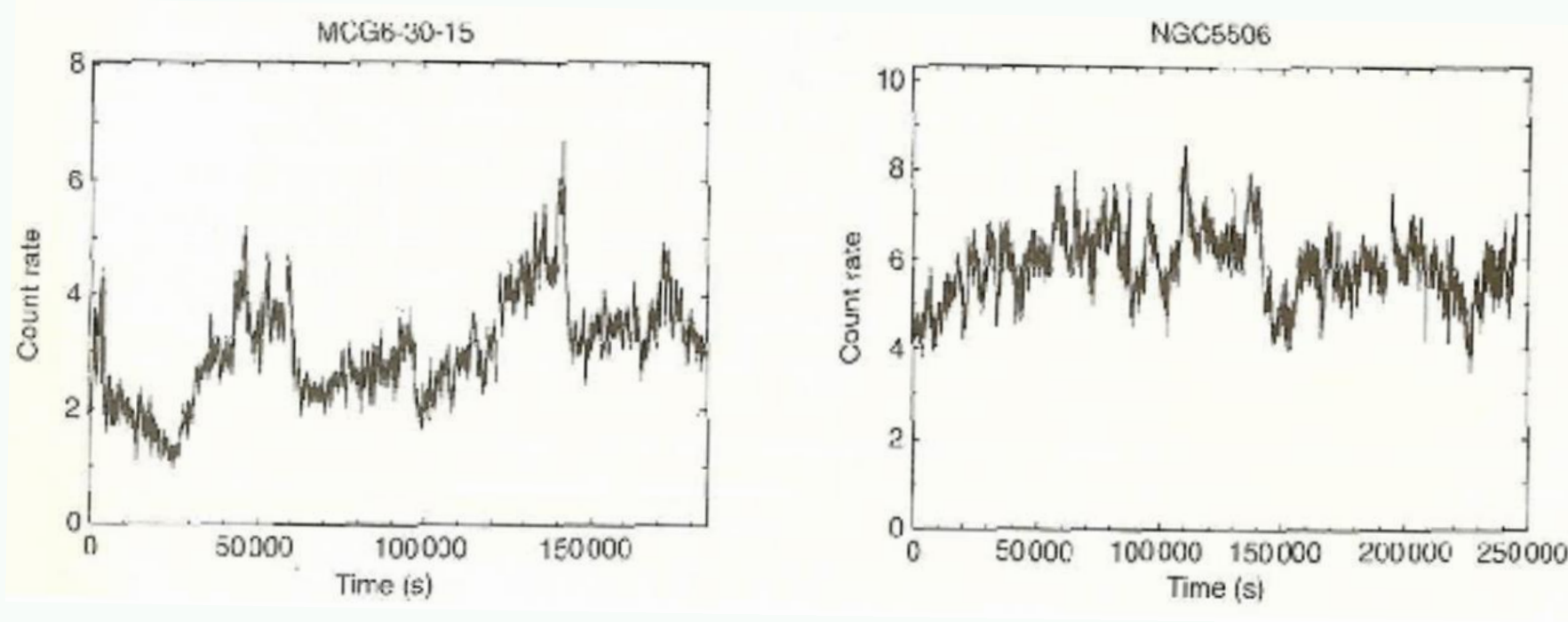


A. Merloni, K.Nandra, M.Salvato, J. Buchner, J.Comparat, A.Rau, M.E.Ramos-Ceja, J.Wolf, A.Malyali, D.Bogensberger (MPE), E. Kara, R.Remillard, D. Pasham (MIT, US), G.Lamer, M.Krumpe, A.Schwoppe (AIP, Potsdam), D.A.H.Buckley (SAAO, South Africa), K.Gendreau, Z.Arzoumanian (NASA/GSFC, US) & others

@Bologna
June 1st 2021

What we are used to seeing

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

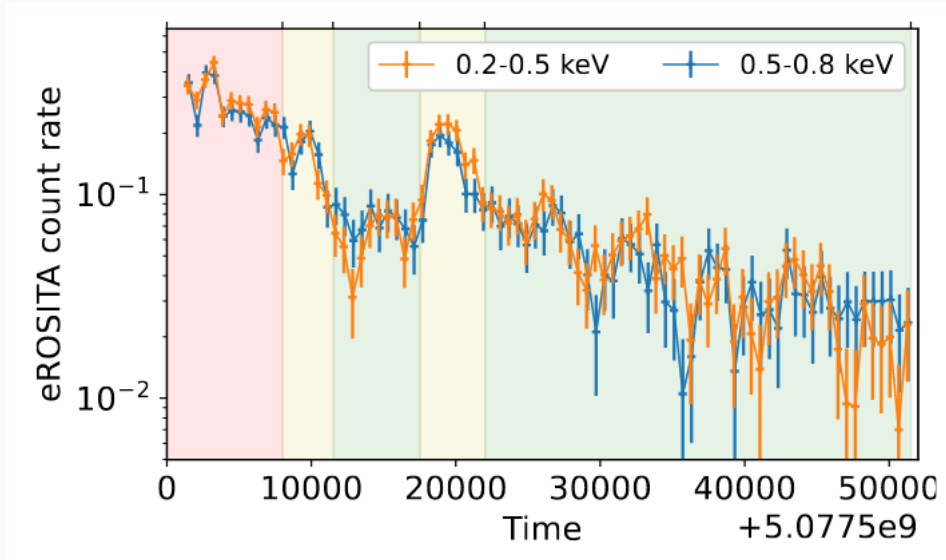


Pounds2014

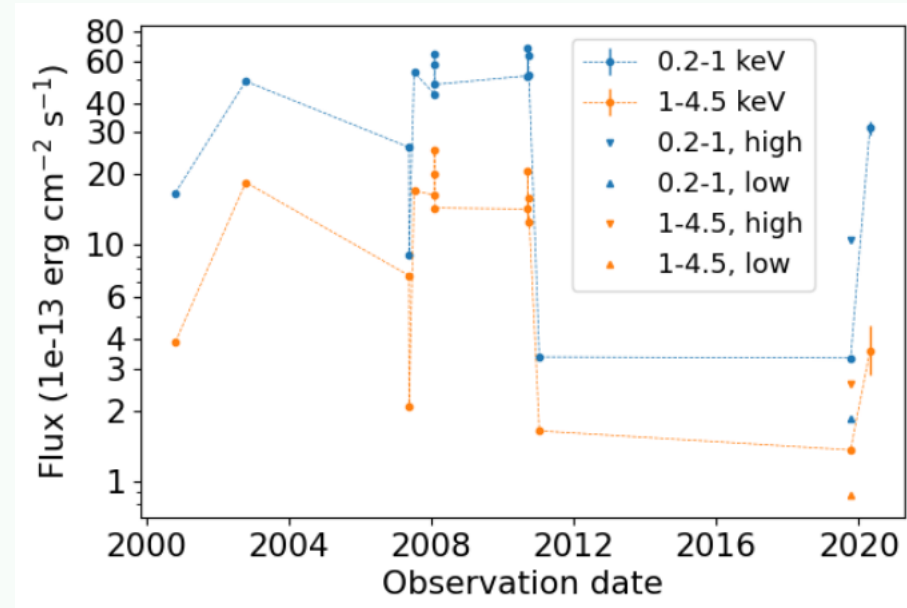
➔ X-ray variability on short timescales was in fact “evidence” of BHs existence

What we are used to seeing

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



Boller..RA..+2021



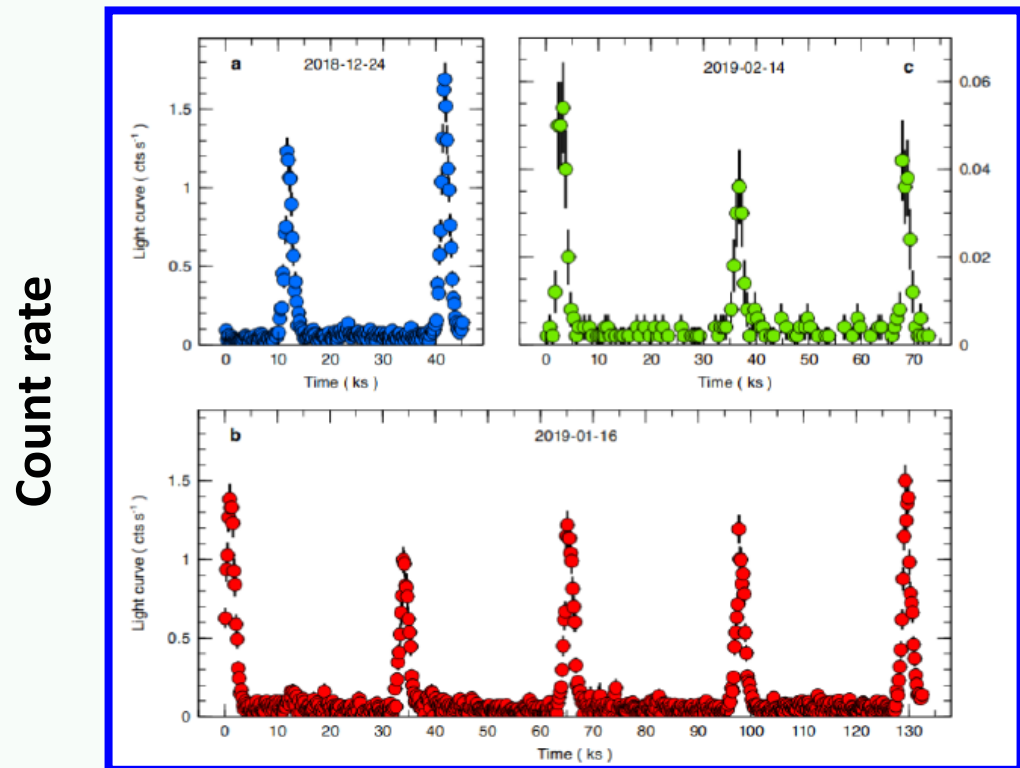
Boller..RA..+2021



We observe high-amplitude variability on short and long timescales

What we are NOT used to seeing

- First discovered in 2018-19 and presented by G. Miniutti et al. in Bologna (@X-ray Astronomy 2019)



Miniutti+19

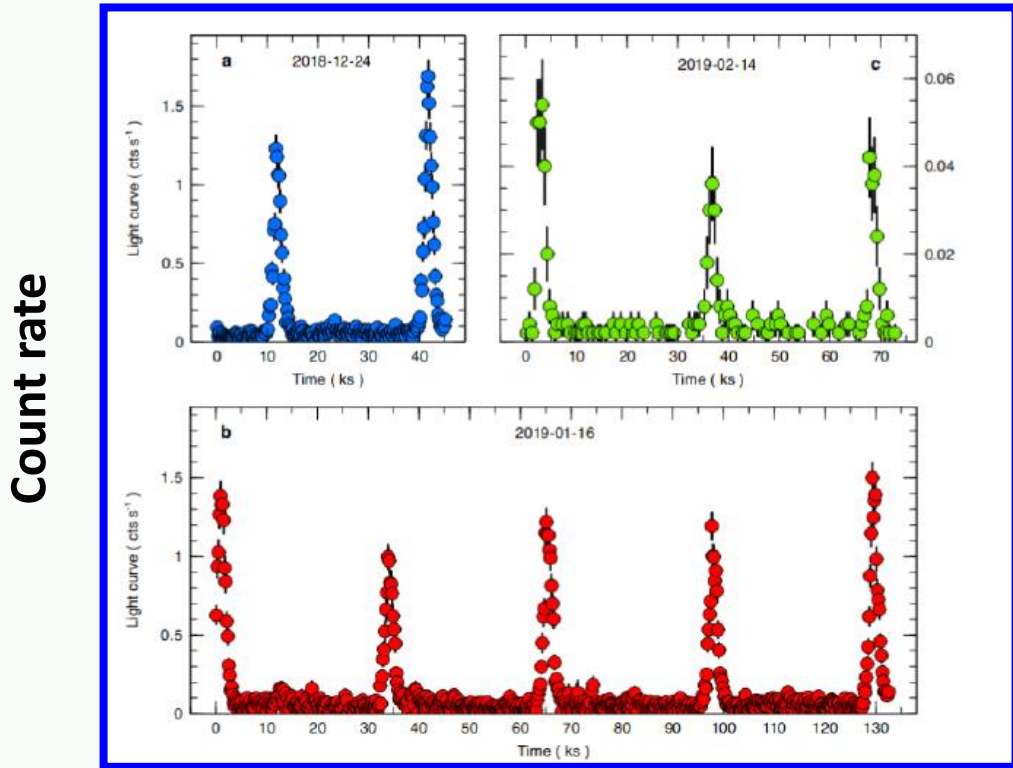
Time (few hours)



→ w/o this Conference, we might not have pursued our eROSITA/QPEs project!

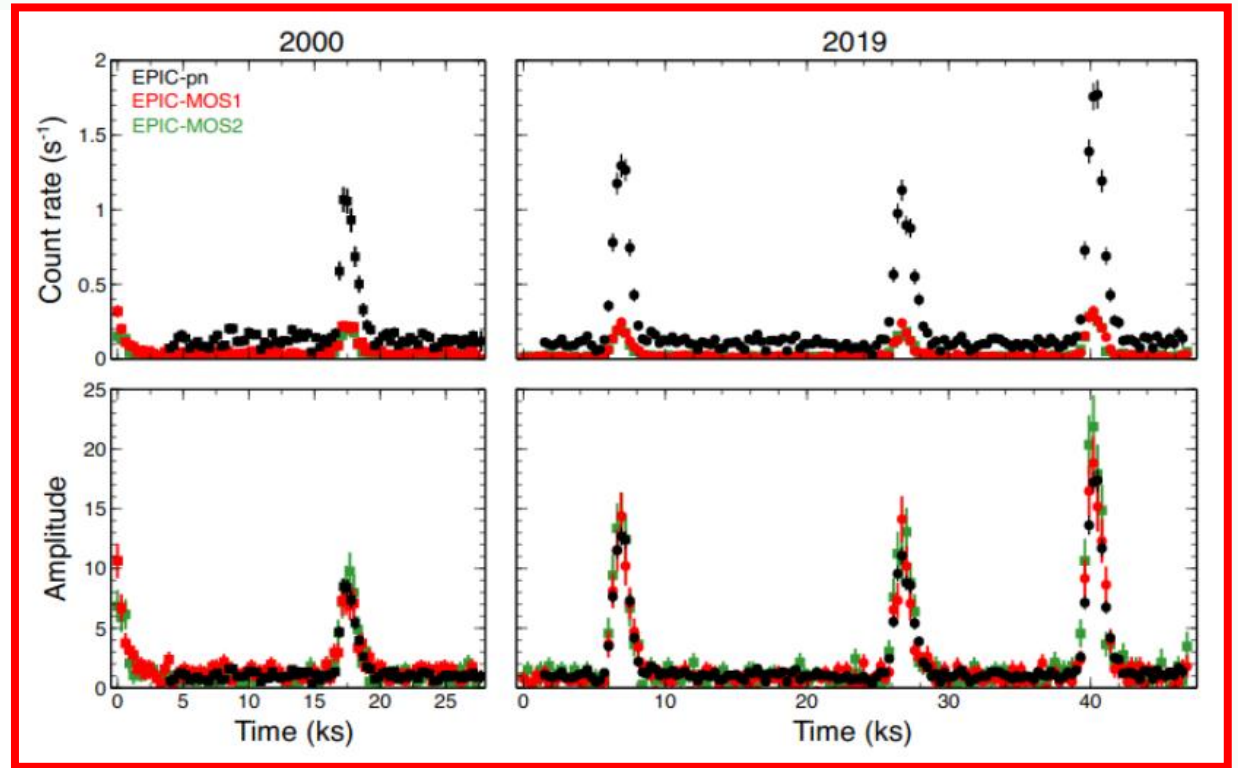
What are Quasi-Periodic Eruptions?

- In short: dramatic very-high-amplitude quasi-periodic soft X-ray bursts from galactic nuclei



Miniutti+19

Time (few hours)

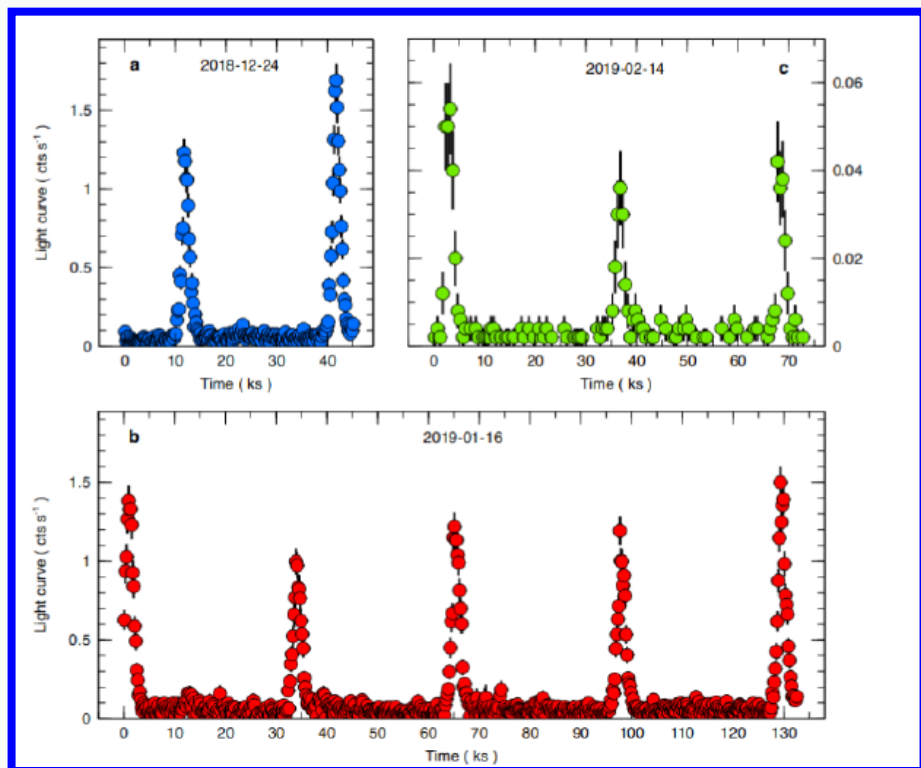


Giustini+20

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

What we knew before eROSITA

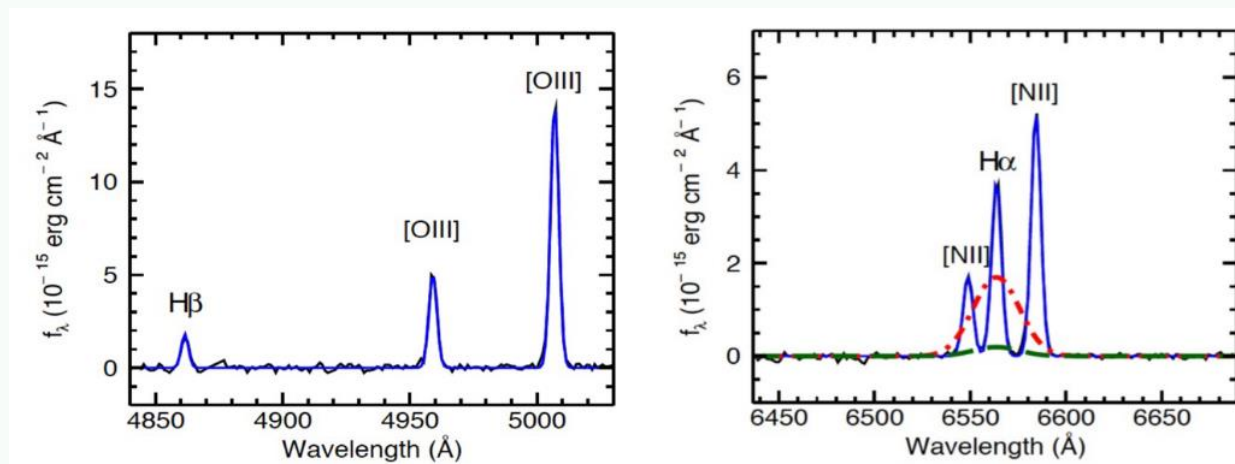
- Based on the first two QPEs



Miniutti+19



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

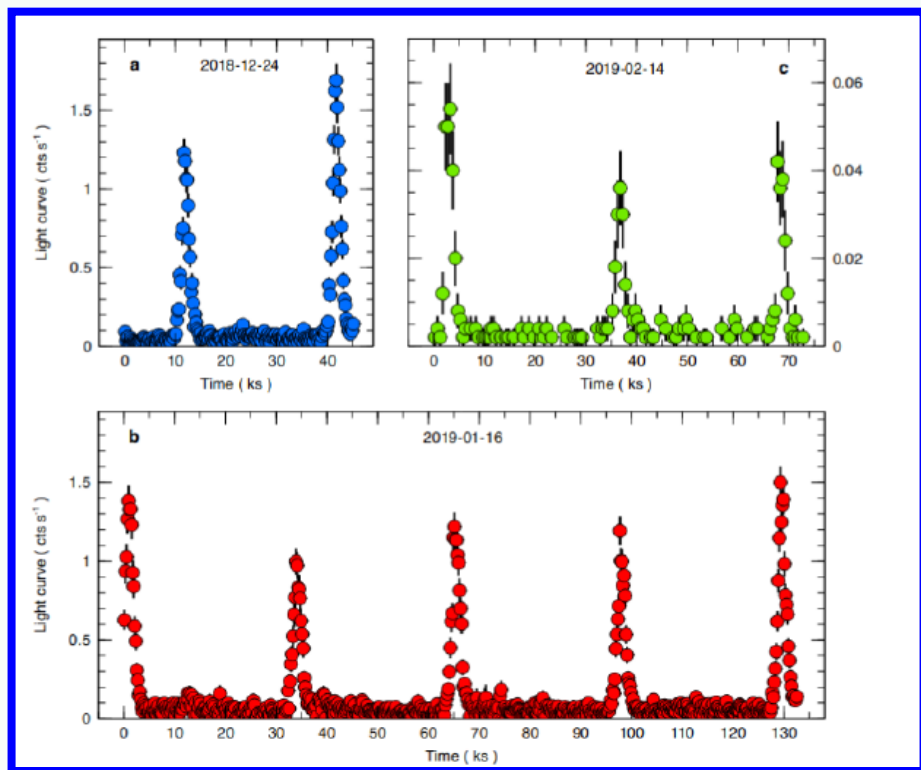


Miniutti+13

→ Narrow lines clearly AGN-ionized
[no changes 2001-2021]

What we knew before eROSITA

- Based on the first two QPEs

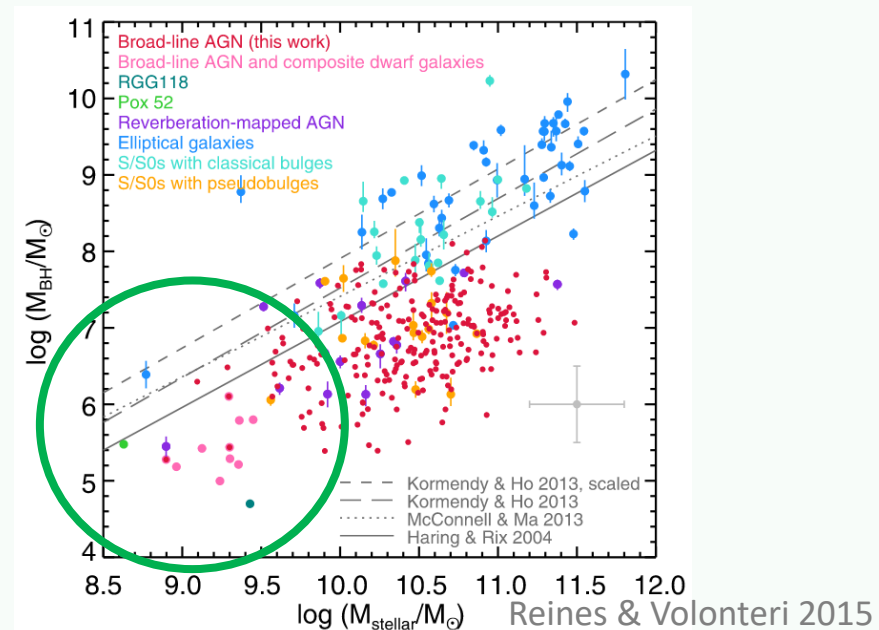


Miniutti+19

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

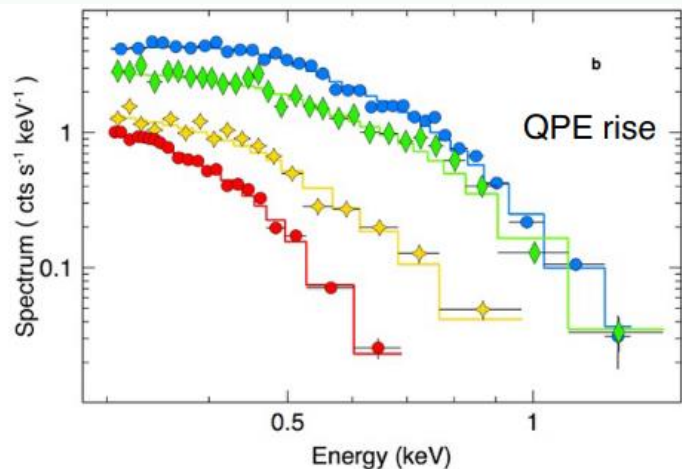
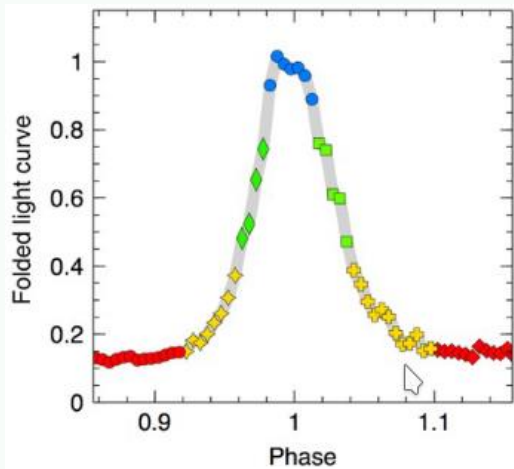
→ **low-mass AGN** ($10^5 - 10^7 M_{\odot}$) therefore low-mass galaxies

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



What we knew before eROSITA

- First interpretations (Miniutti+2019; Giustini+2020)

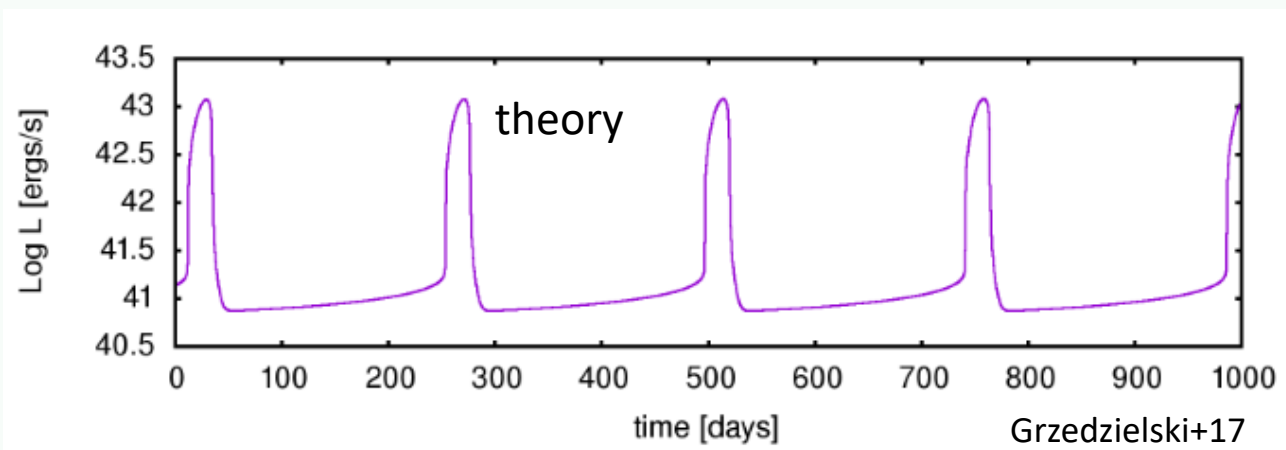


→ X-ray ultrasoft throughout

→ Based on their presumed active nature, suggested connection with soft-excess formation

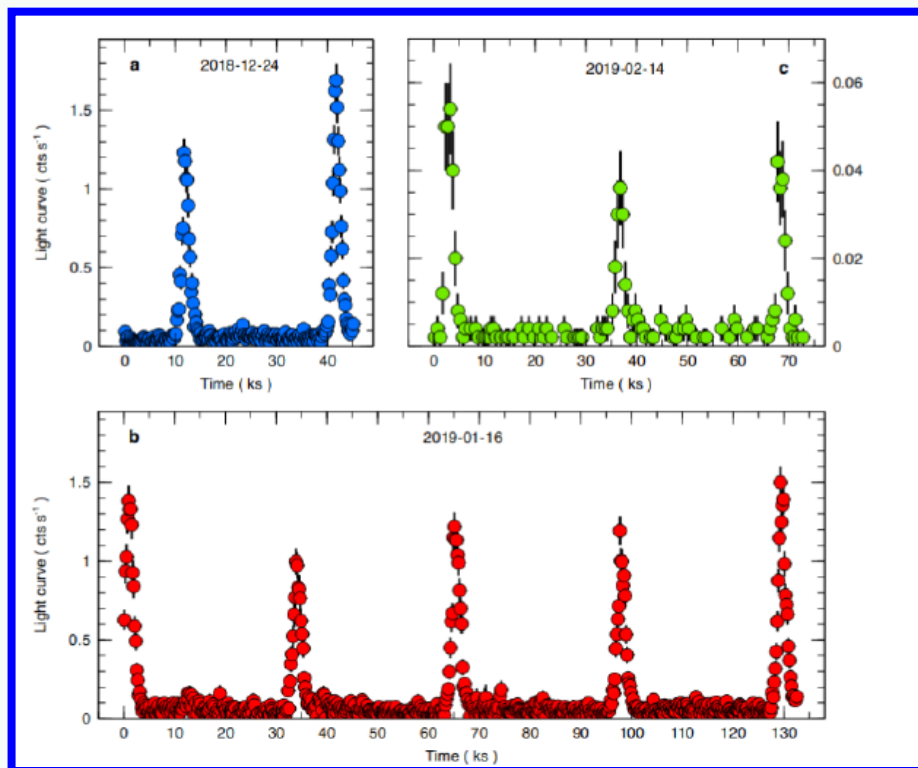
Limit-cycle radiation-pressure instabilities?

Miniutti+19



What we knew before eROSITA

- Based on the first two QPEs

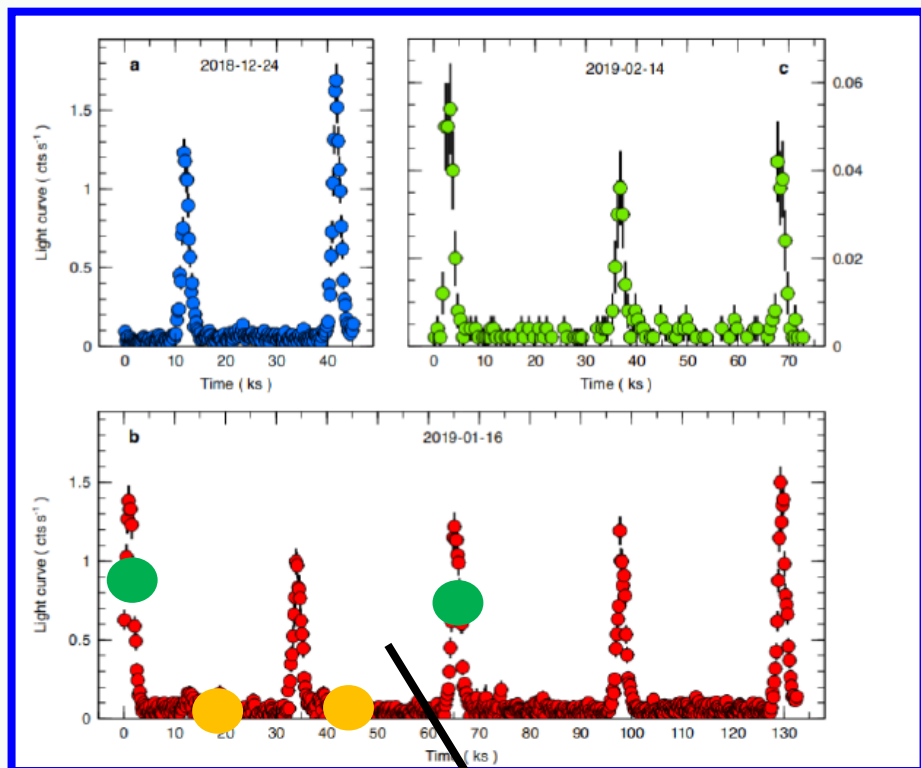


Miniutti+19

- extragalactic, **weird AGN**: no broad lines in optical spectra, no infrared “torus”
- **low-mass AGN** ($10^5 - 10^7 M_{\odot}$) therefore low-mass galaxies
 - Poorly studied mass regime for BH-galaxy co-evolution
- no obvious peculiarities at other wavelengths (only X-rays?)
 - **ideal application for eROSITA**

What we knew before eROSITA

- Based on the first two QPEs



Miniutti+19

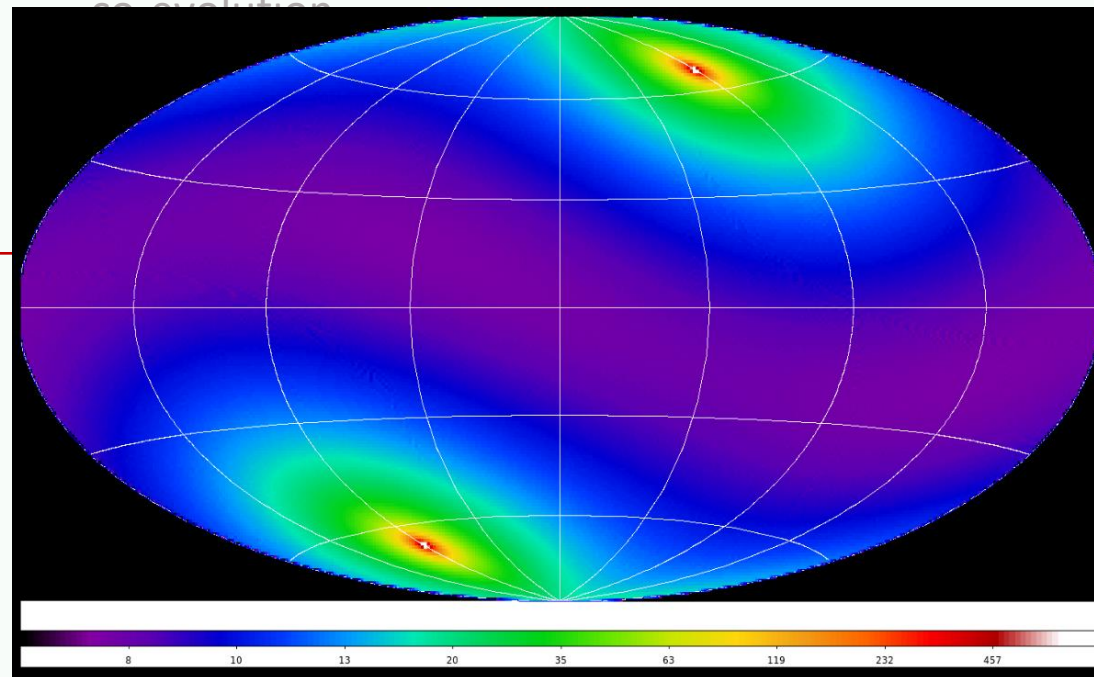
eROSITA scans every point in the sky for ~40s every ~4h for N times (N>5-6)

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

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

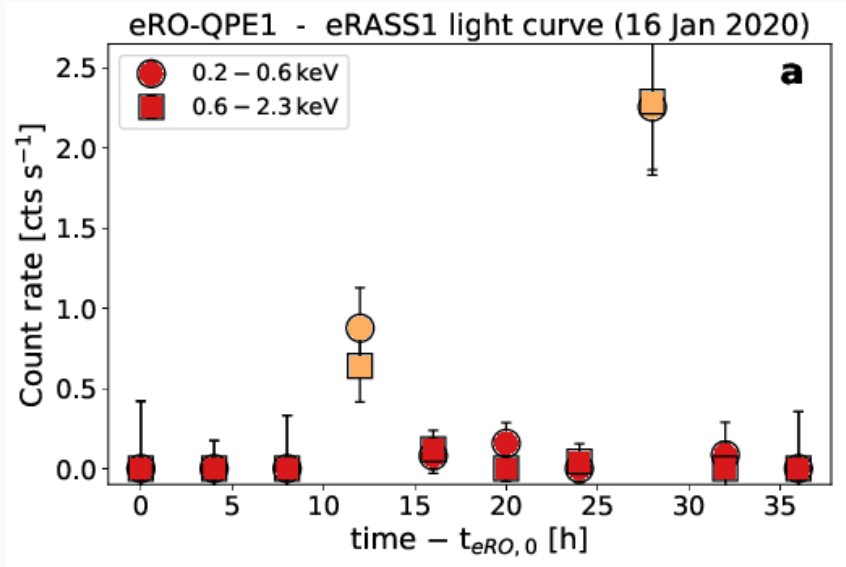
→ Poorly studied mass regime for BH-galaxy co-evolution

→ no

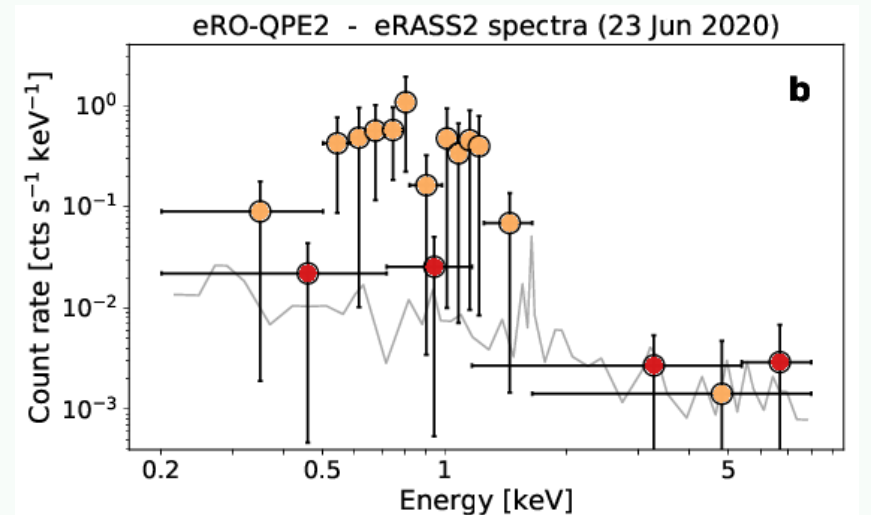
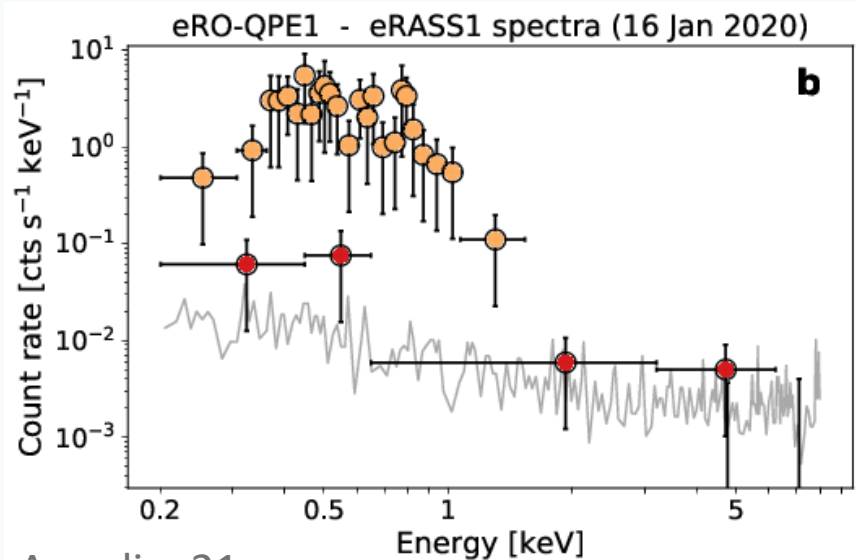
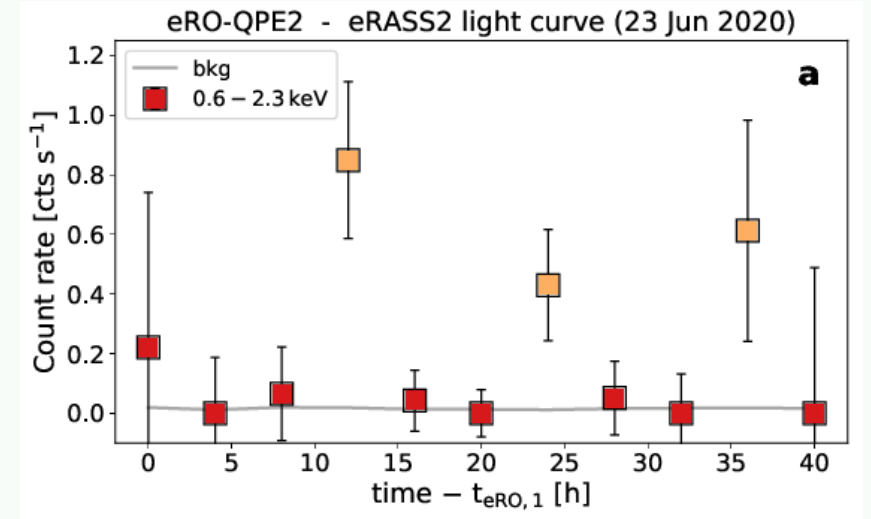


First discoveries with eROSITA

- Report of X-ray results + new physical insights (Arcodia+2021, Nature)

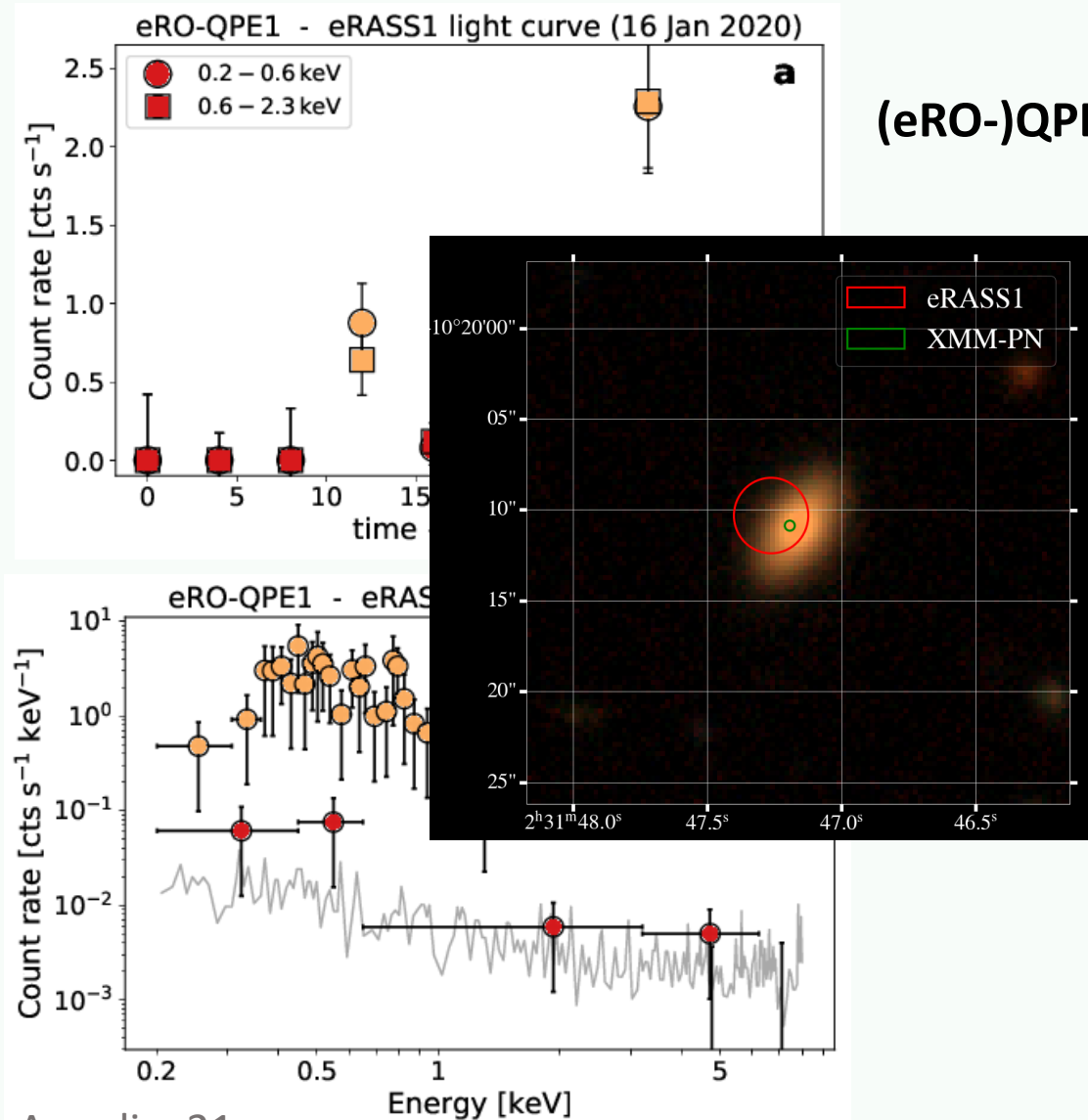


(eRO-)QPE1 QPE2

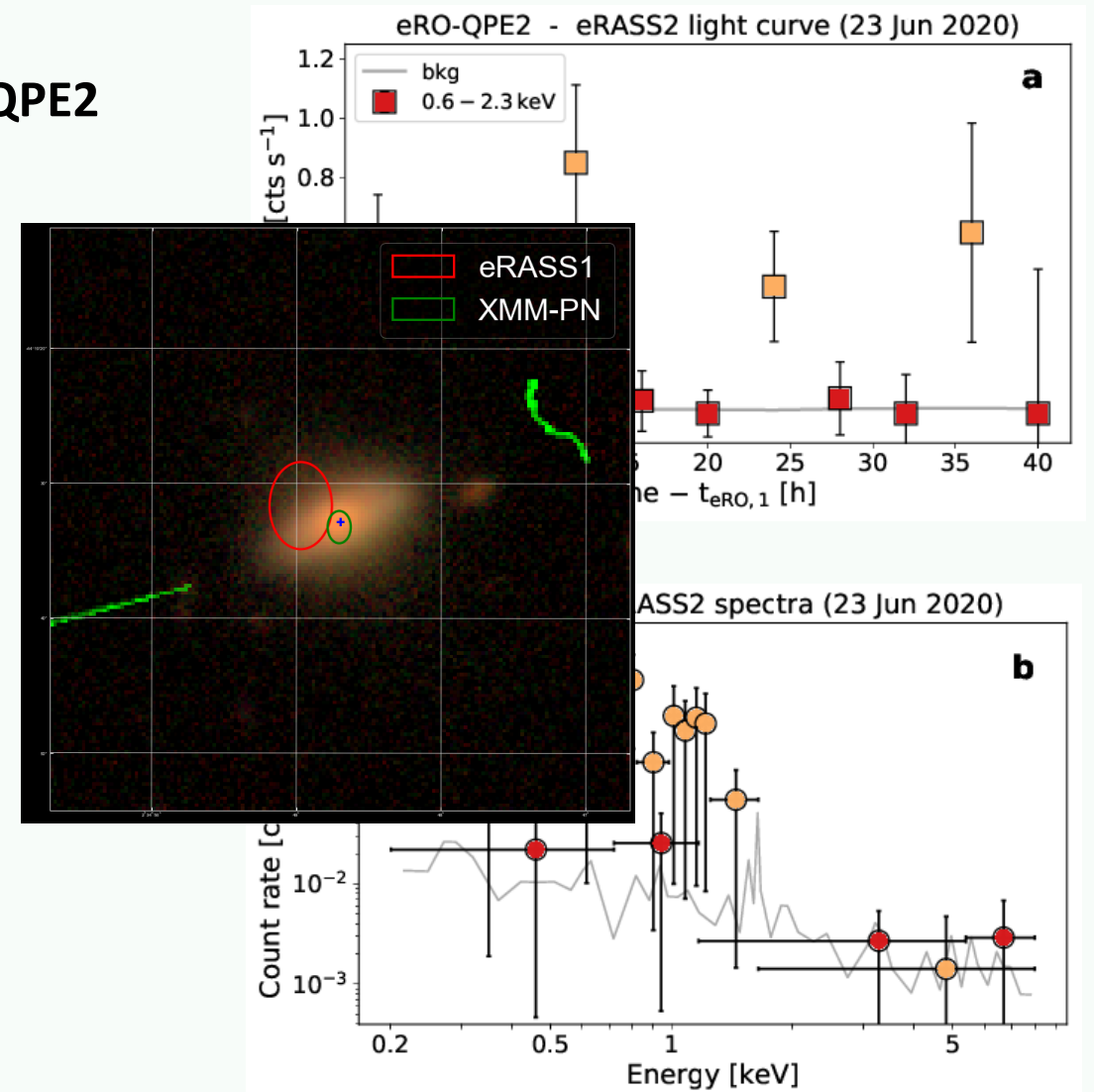


First discoveries with eROSITA

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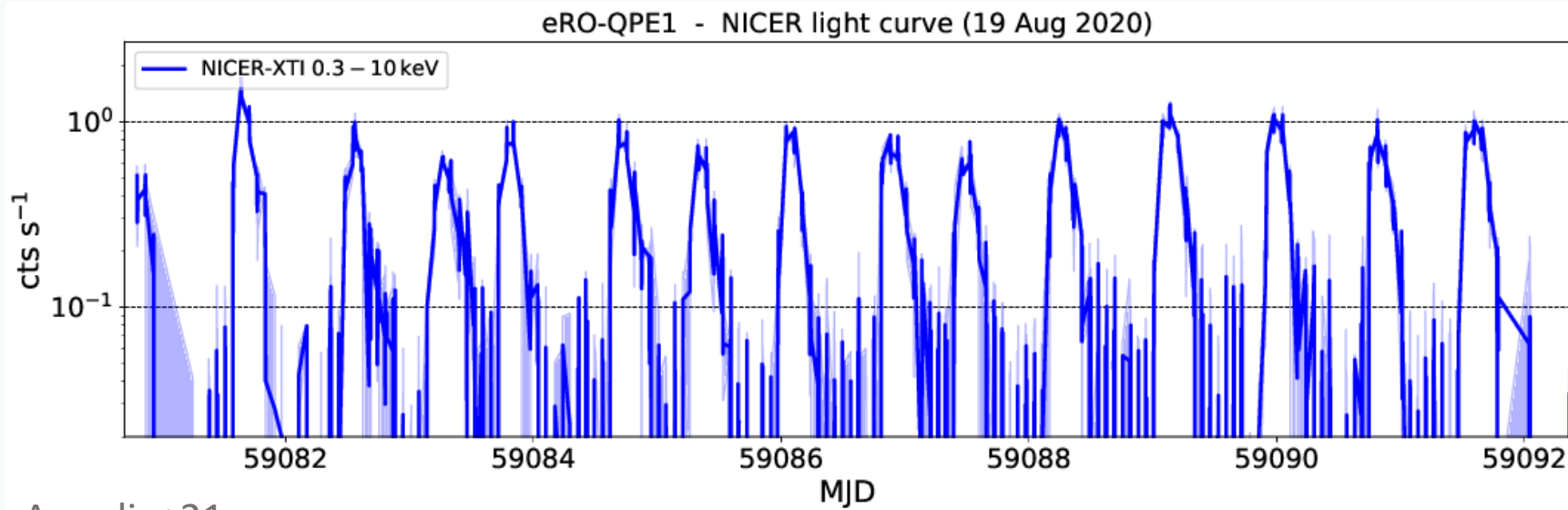
(eRO-)QPE1 QPE2



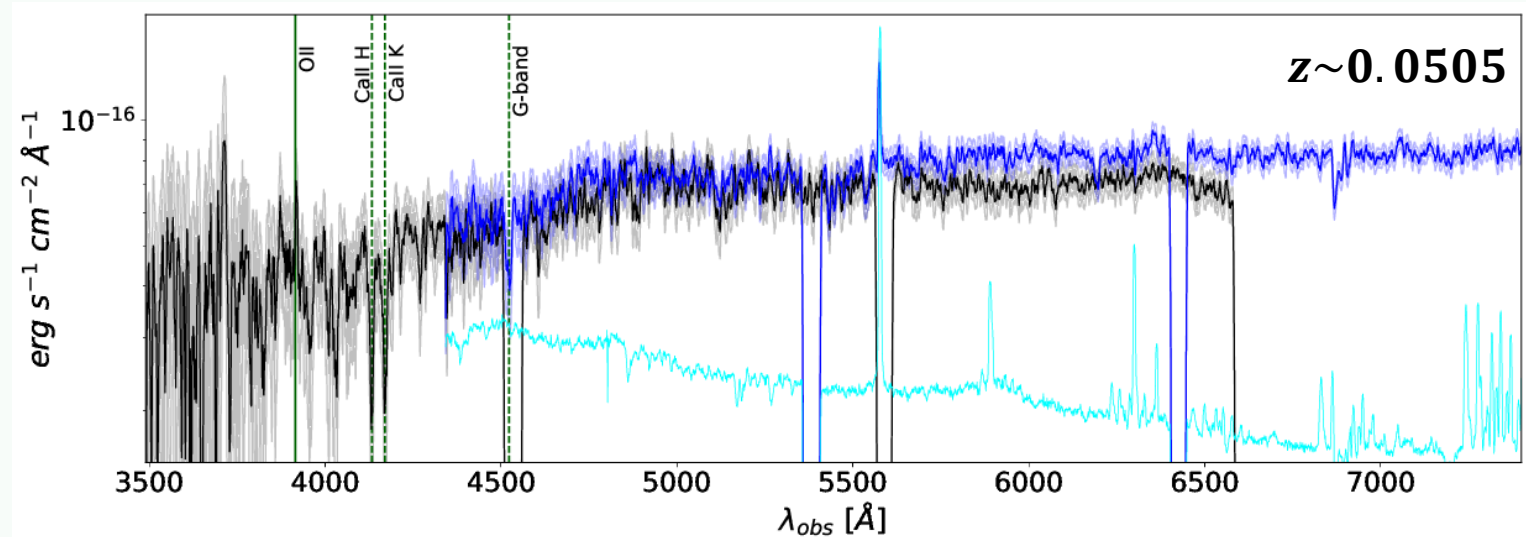
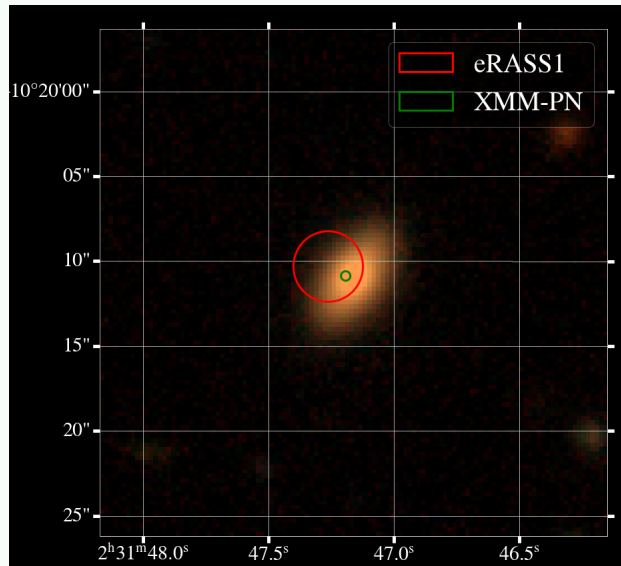
First discoveries with eROSITA: eRO-QPE1

- QPE1: followed-up in X-rays (XMM+NICER) and optical (SALT, SAAO)

QPE1



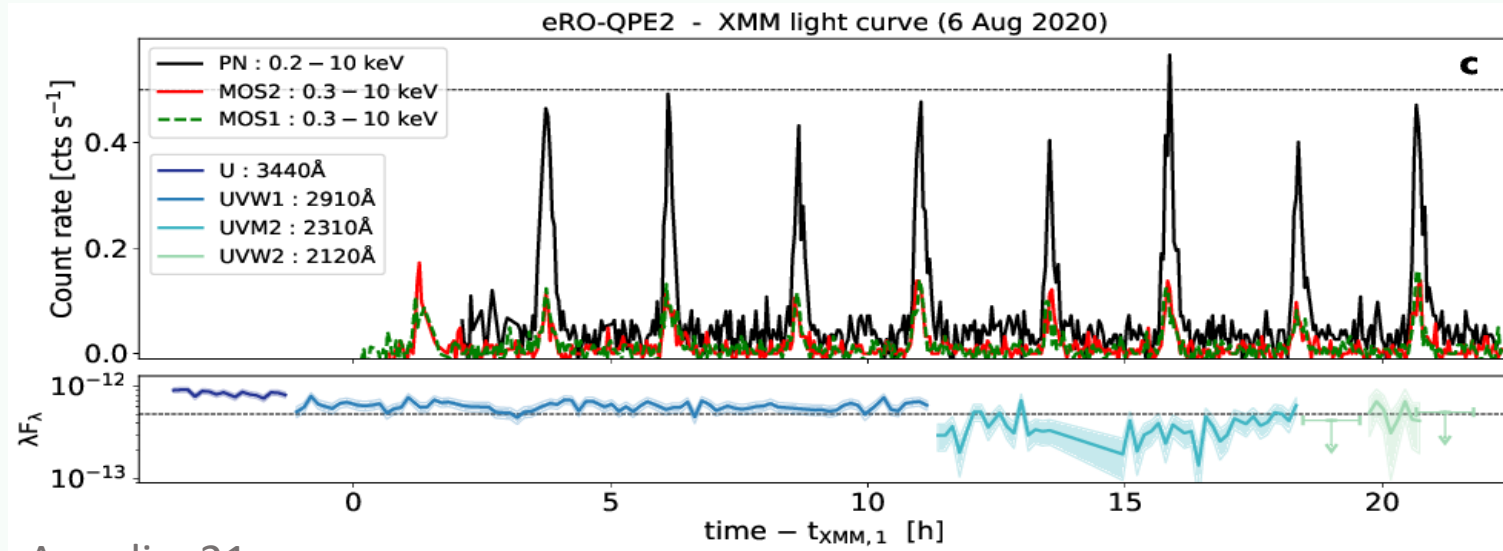
Arcodia+21



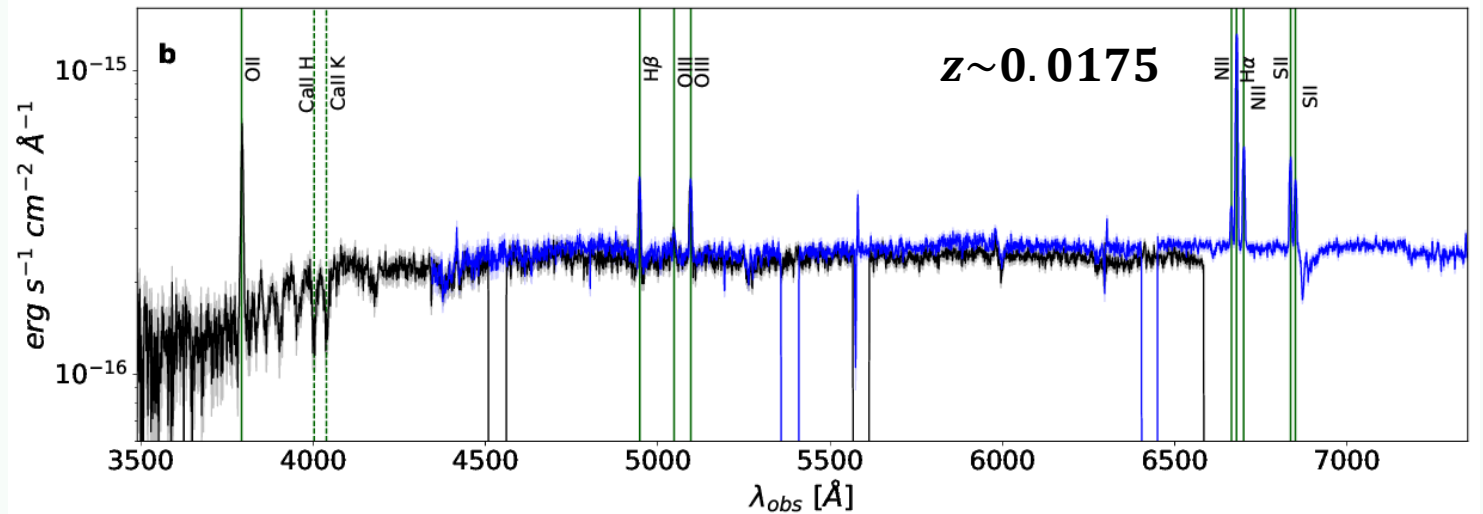
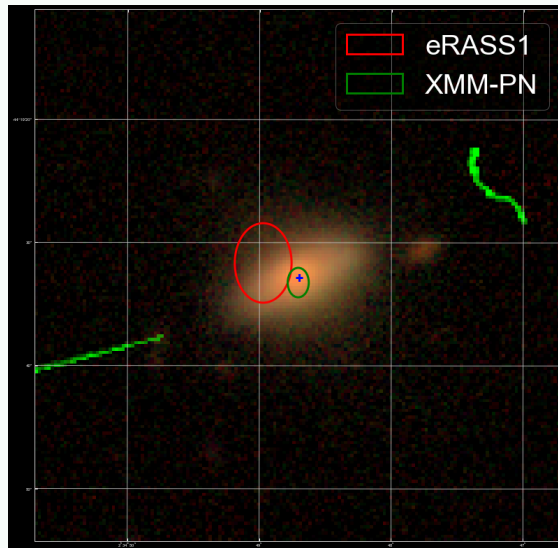
First discoveries with eROSITA: eRO-QPE2

- QPE2: followed-up in X-rays (XMM) and optical (SALT)

QPE2

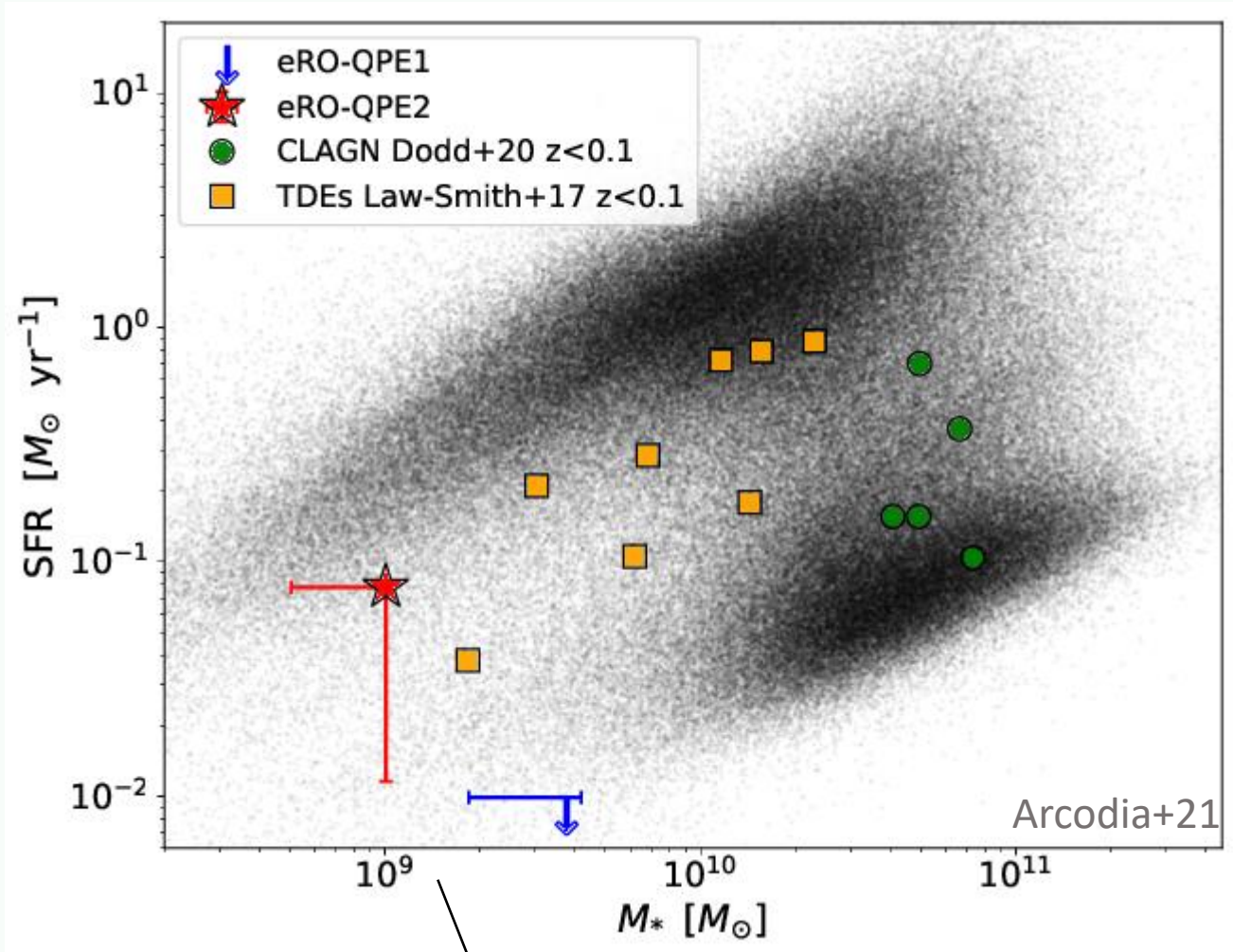


Arcodia+21



A poorly explored range of BH-galaxy evolution

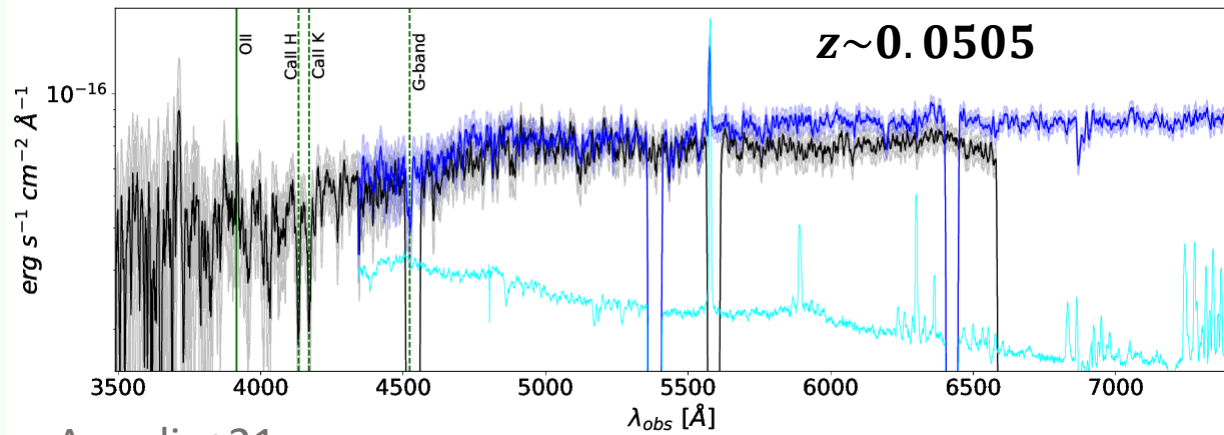
- QPEs seem to be found in low-mass galaxies



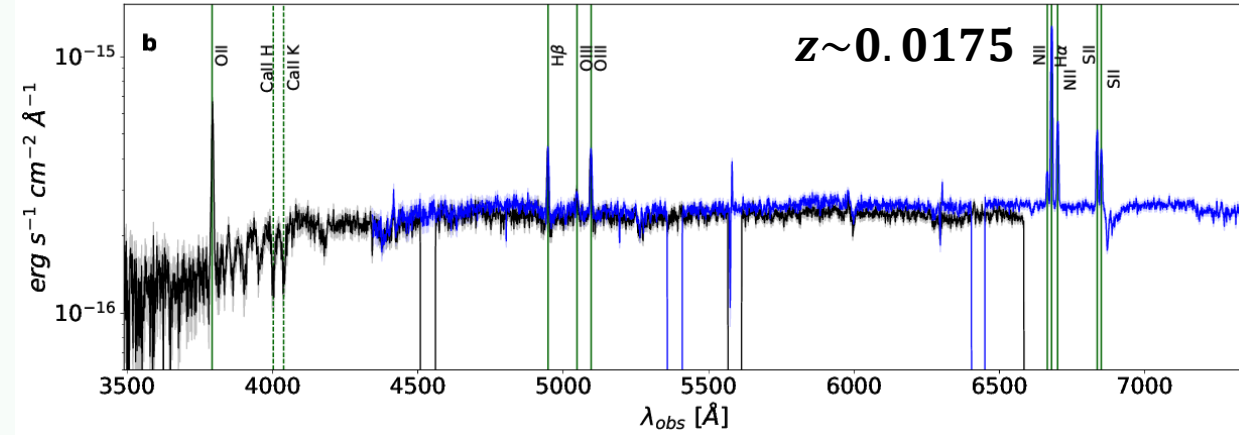
Poorly studied regime

Massive black holes awakening?

- Optical spectroscopy indicates inactive nuclei (passive or star forming) !!!

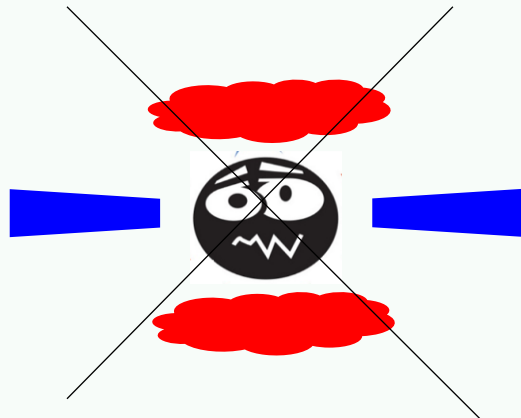


Arcodia+21



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

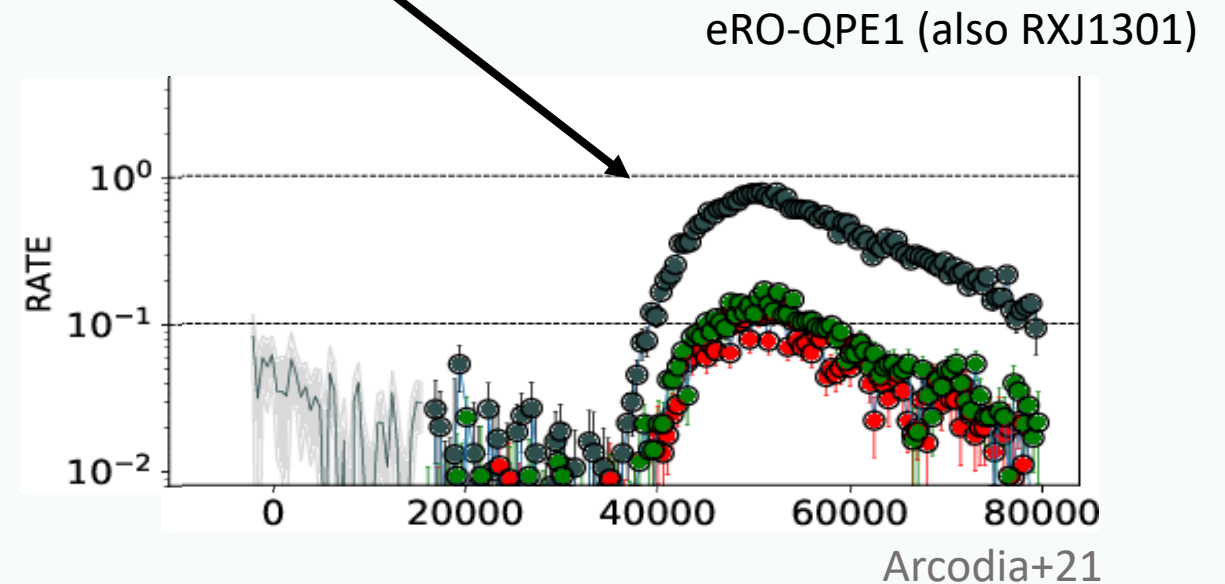
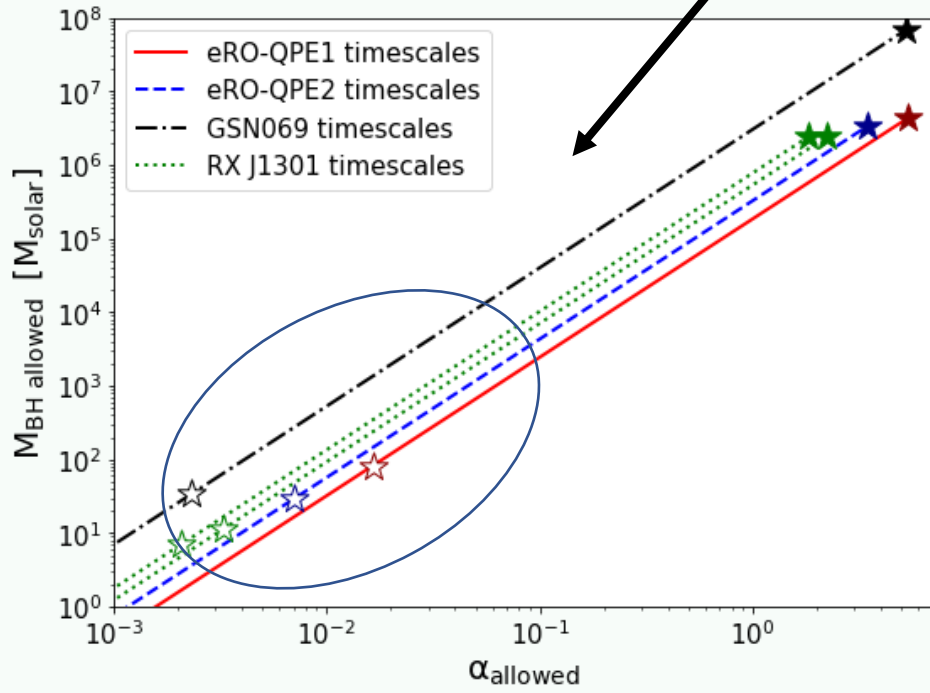
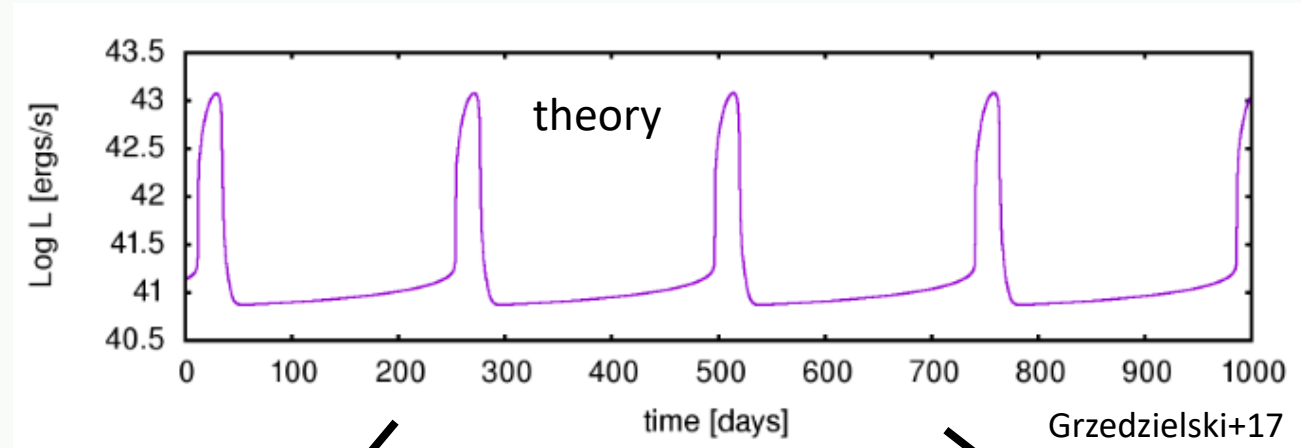
→ QPEs might not need a pre-existing AGN flow, probably just a (low-mass) SMBH



New insights: inconsistent with instabilities

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

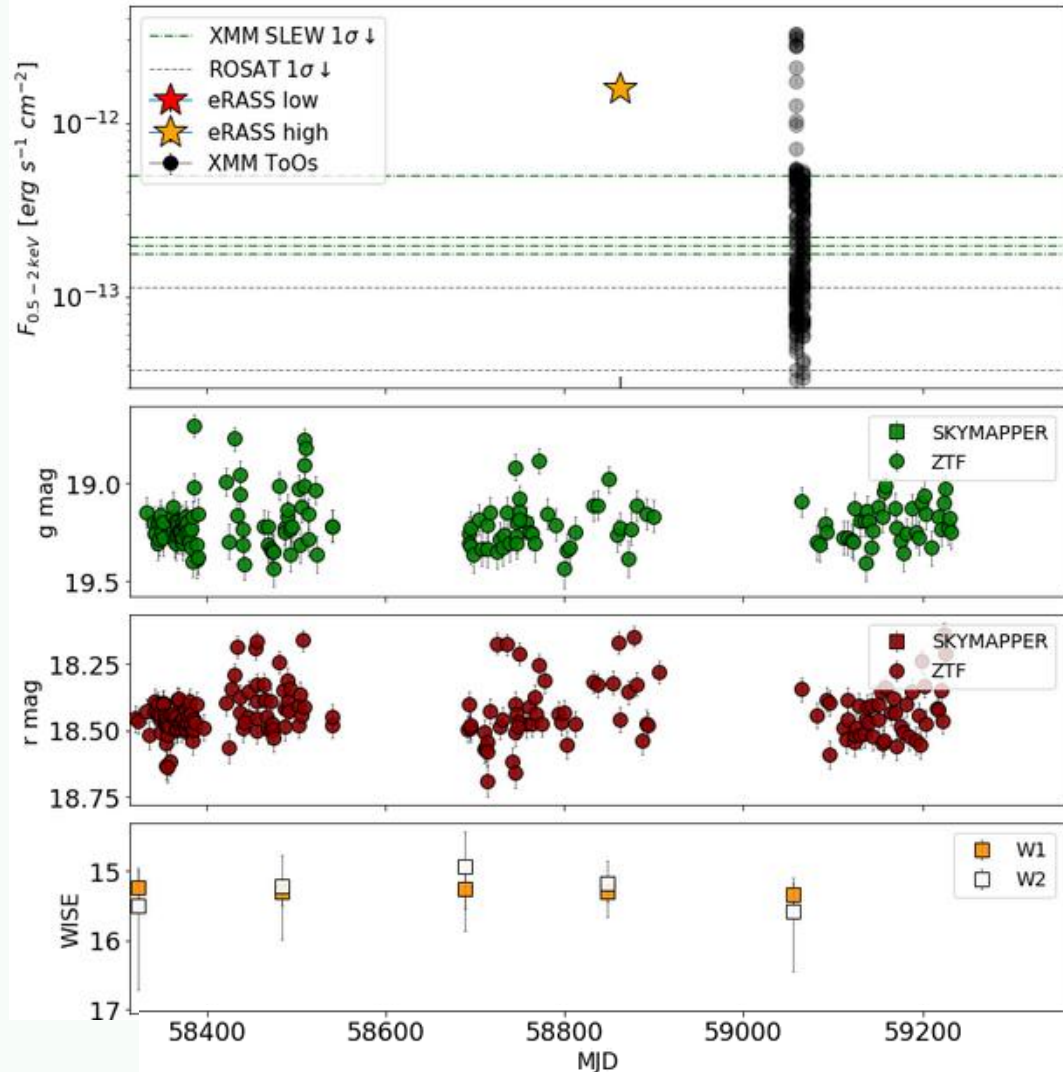
Janiuk+02,11; Merloni&Nayakshin06; Grzedzielski+17; Sniegowska+20



New insights: binary?

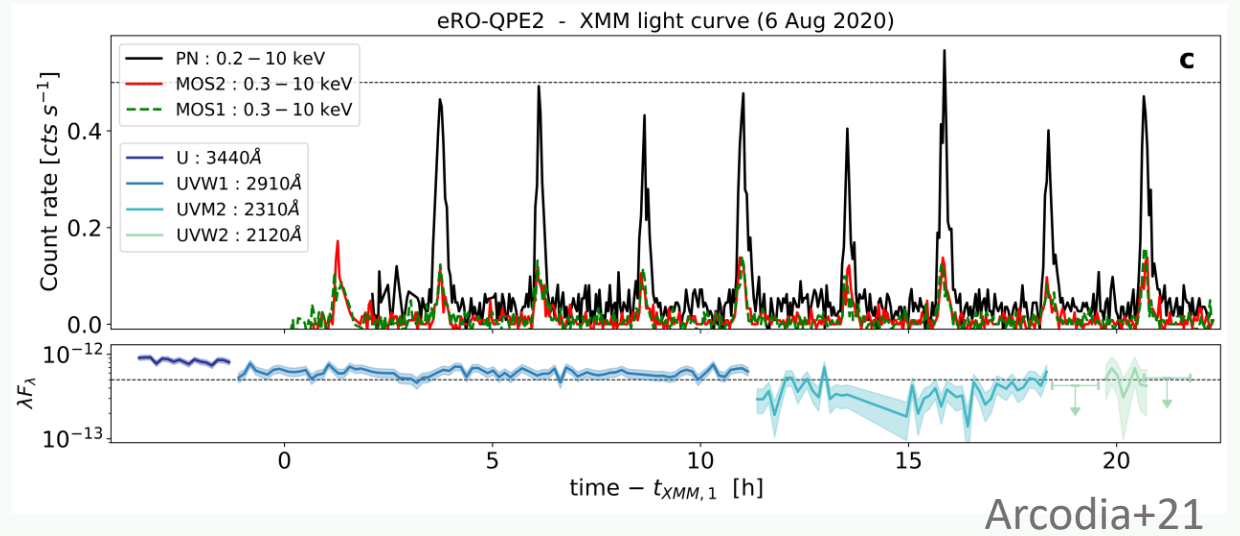
- Binary of compact objects with mass-ratio ~ 1 unlikely

eRO-QPE1



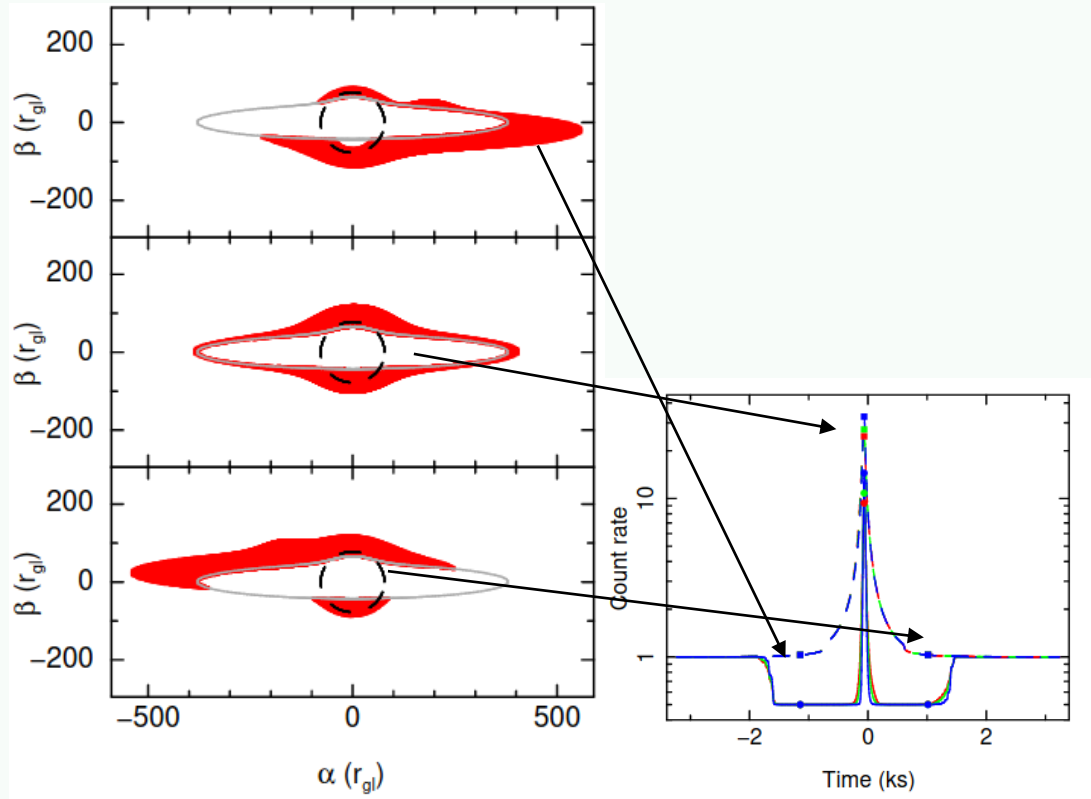
→ No sign of sinusoidal/periodic variability in opt-UV-IR

eRO-QPE2



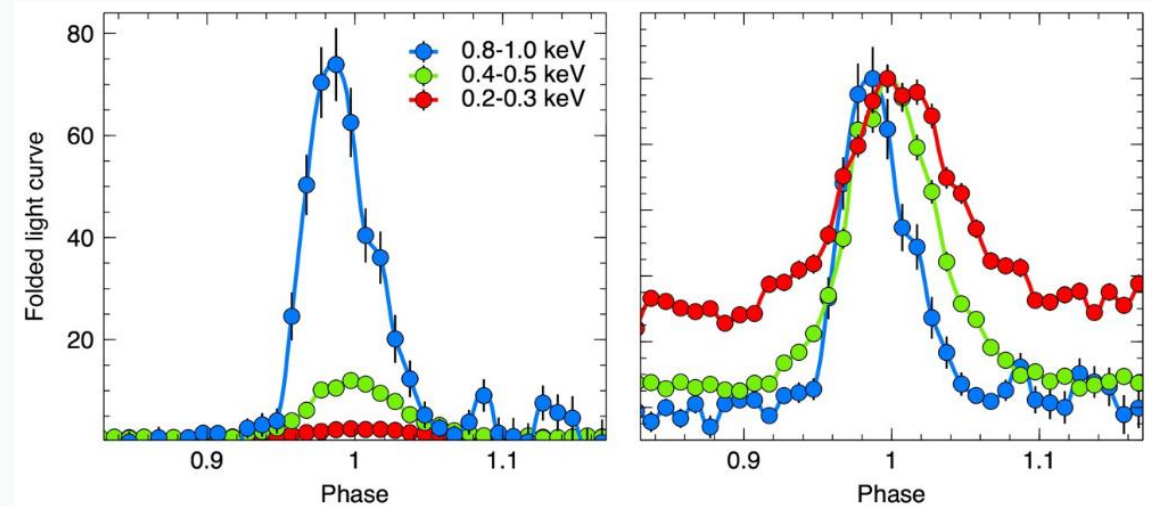
New insights: binary?

- Binary of compact objects with mass-ratio ~ 1 unlikely



Ingram+21

- No sign of sinusoidal/periodic variability in opt-UV-IR
- Binary self-lensing could produce sharp bursts, but achromatic [against strong E dependence in QPEs] e.g. Ingram+21

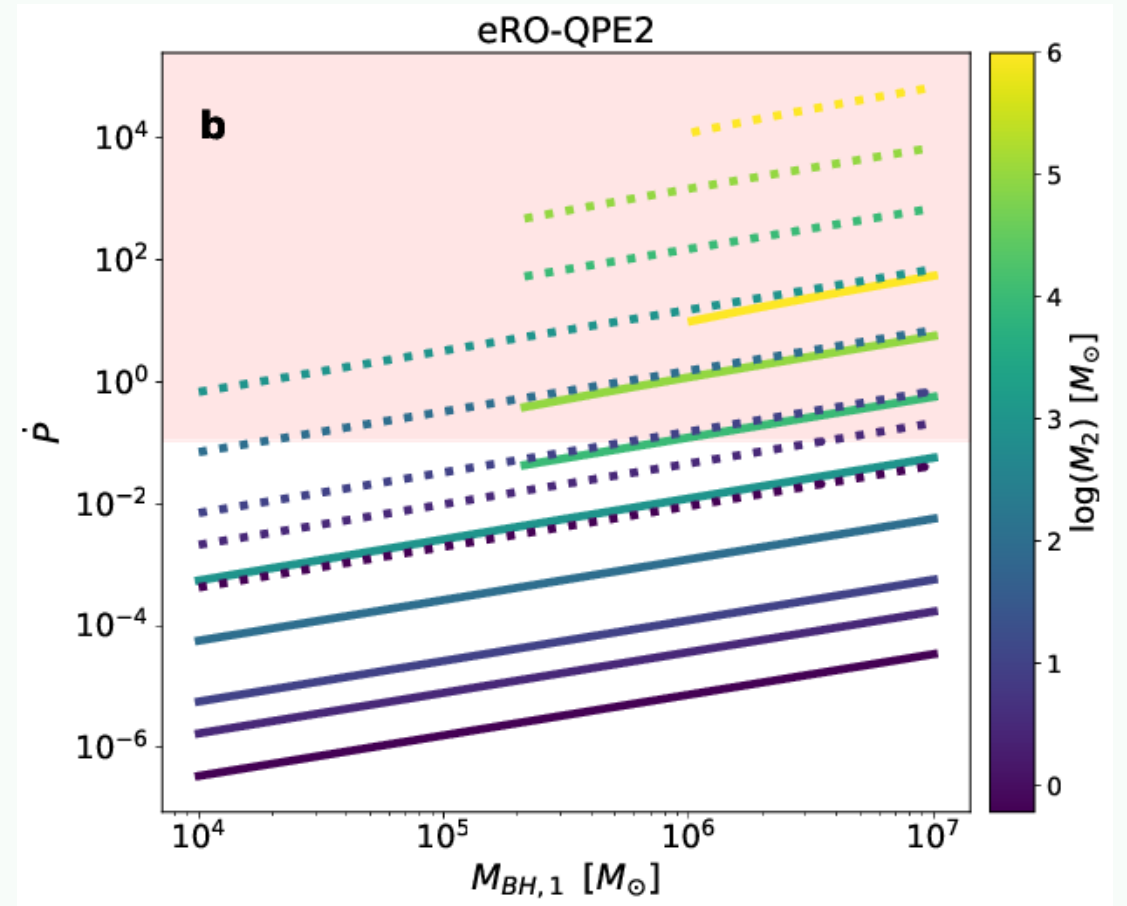
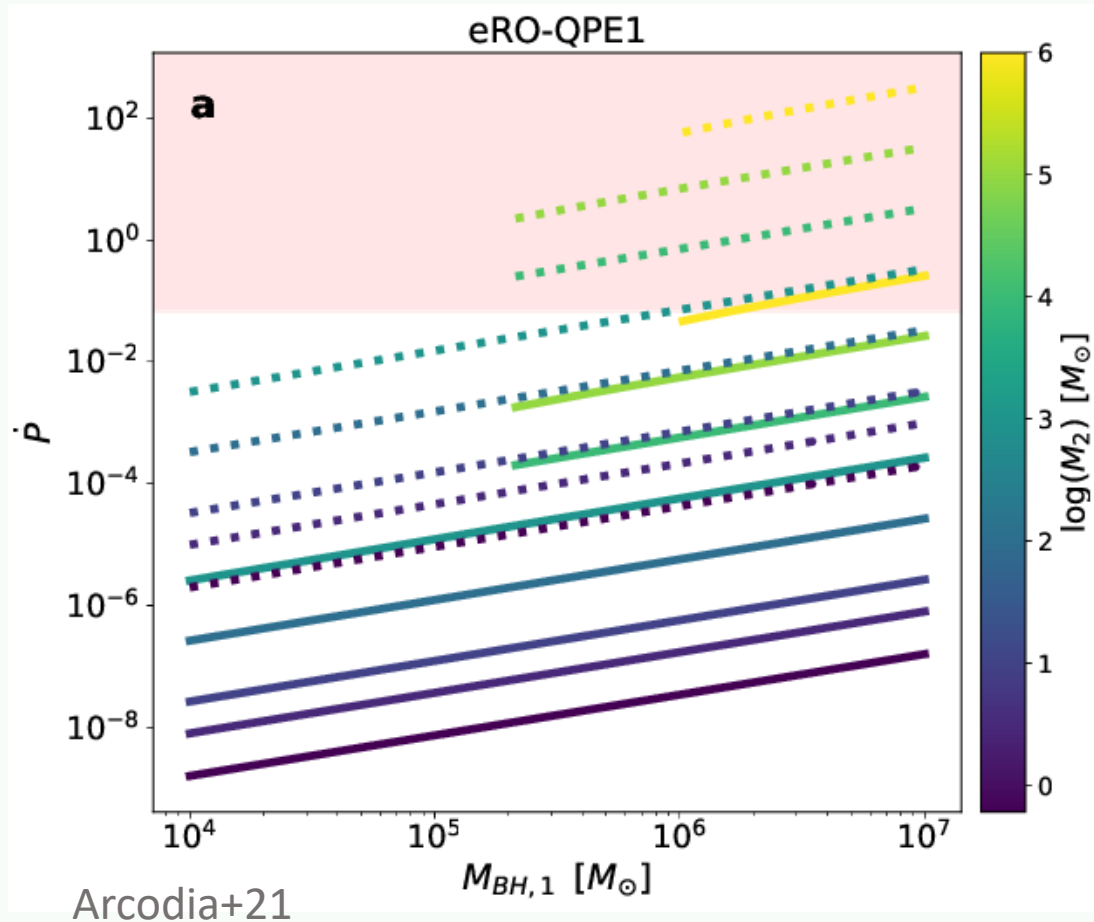


Miniutti+19

New insights: binary?

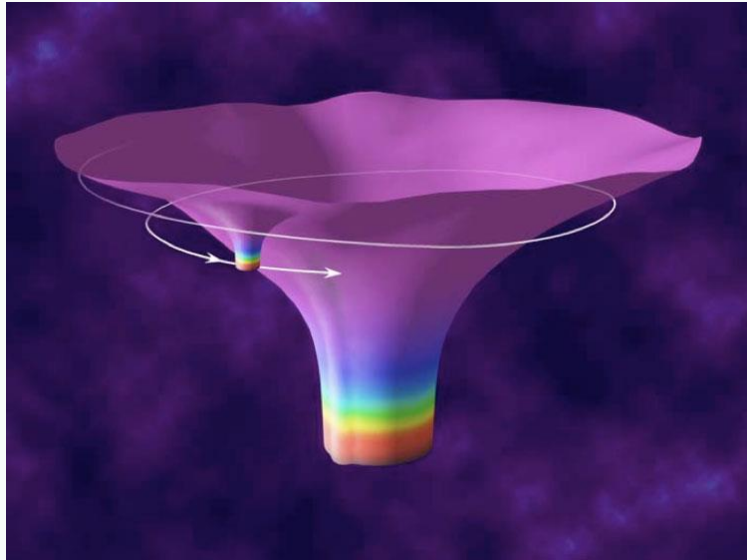
- Binary of compact objects with mass-ratio ~ 1 unlikely

→ we'd have observed a strong \dot{P} already and they would be very close to merger [and too common w.r.t. observations]

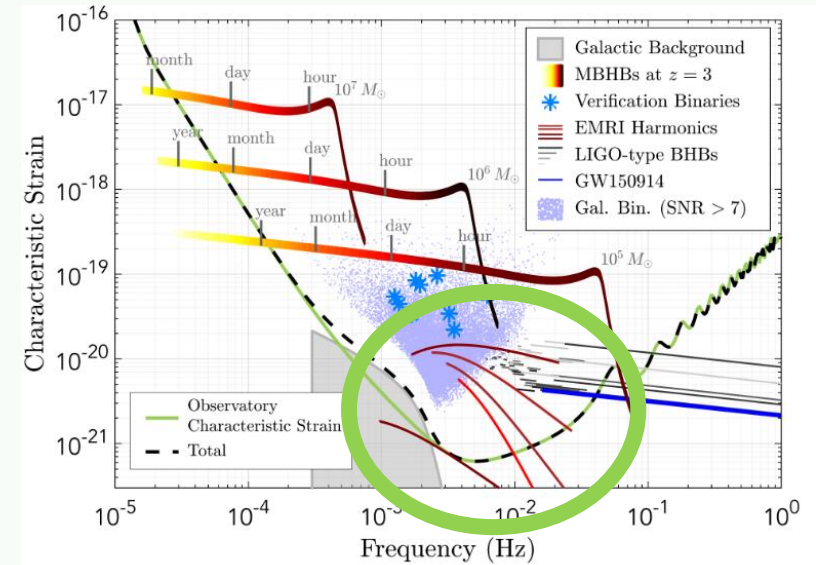


New insights: binary?

- They might be instead related to high mass-ratio binaries (low-mass SMBH + CO; King+2020)



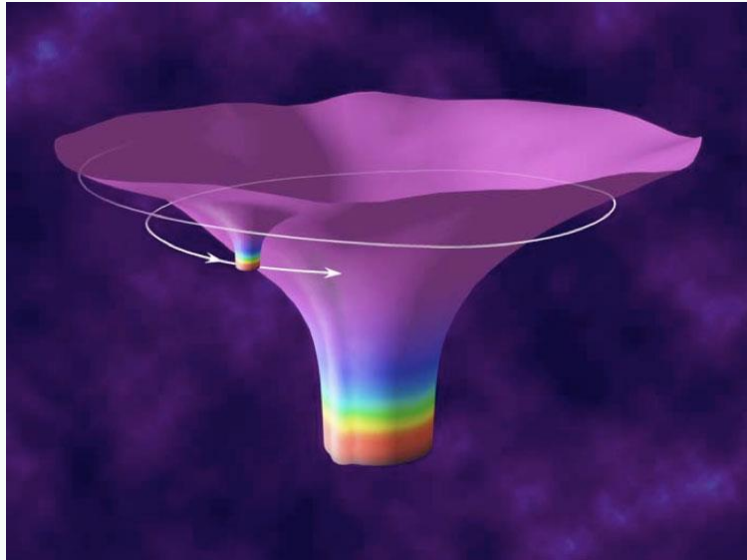
→ This could make QPEs the EM counterpart of extreme mass-ratio inspirals (EMRIs), detectable by LISA!!



Amaro-Seoane+17

New insights: binary?

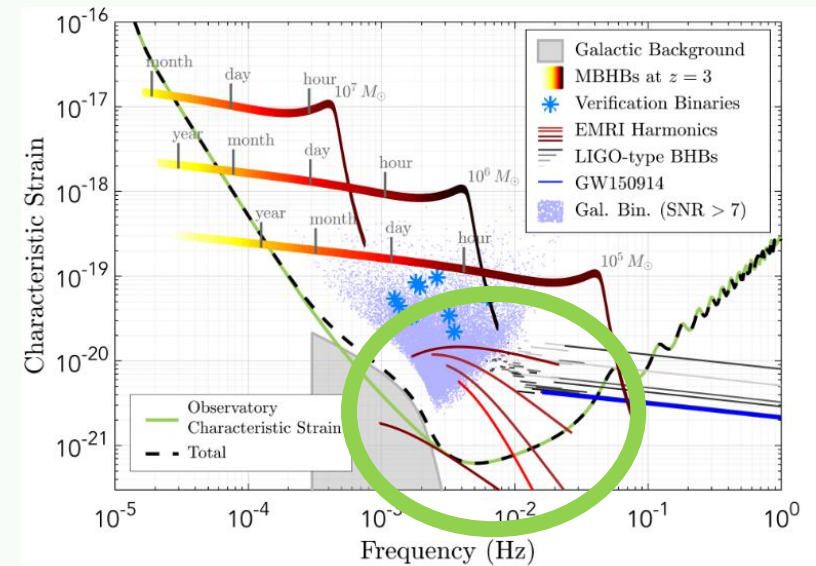
- They might be instead related to high mass-ratio binaries (low-mass SMBH + CO; King+2020)



→ This could make QPEs the EM counterpart of extreme mass-ratio inspirals (EMRIs), detectable by LISA!!

→ Qualitative comparison so far, but testable in next 1-2 yrs!

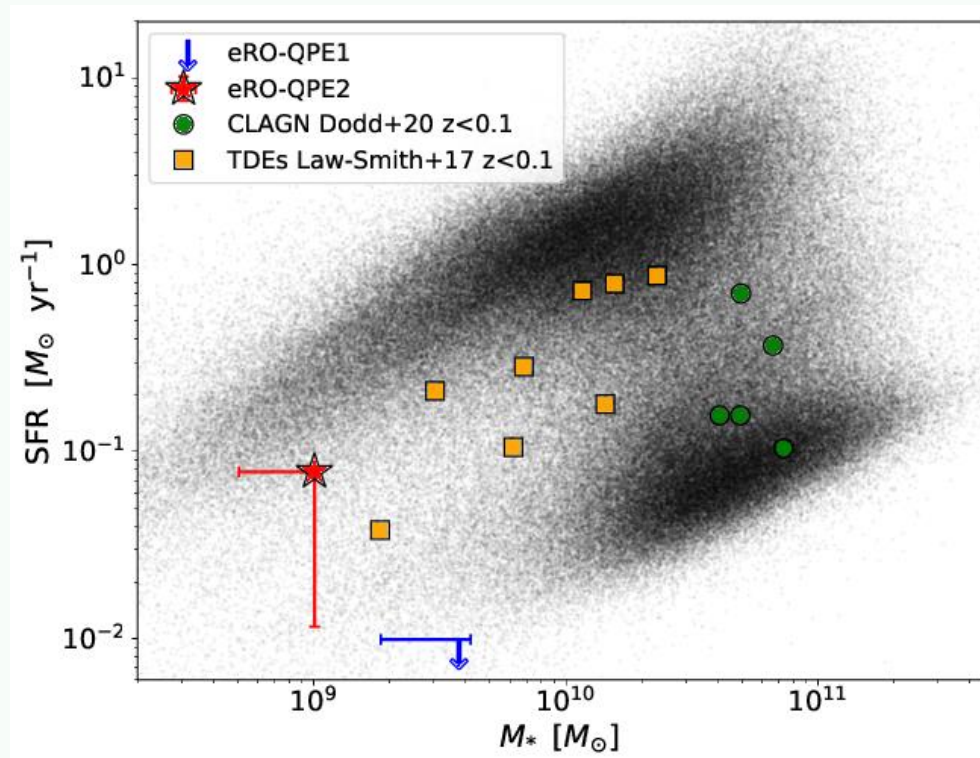
→ What causes the bursts? Unclear but see, e.g., King20; Sukova+21



Amaro-Seoane+17

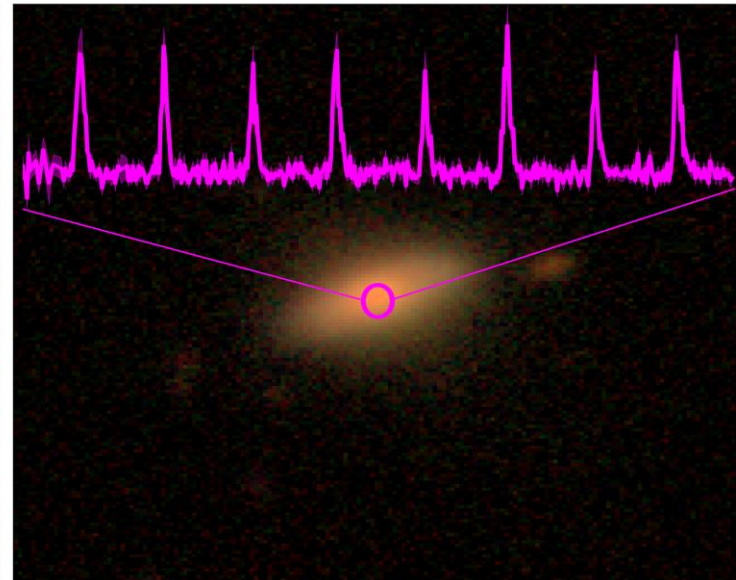
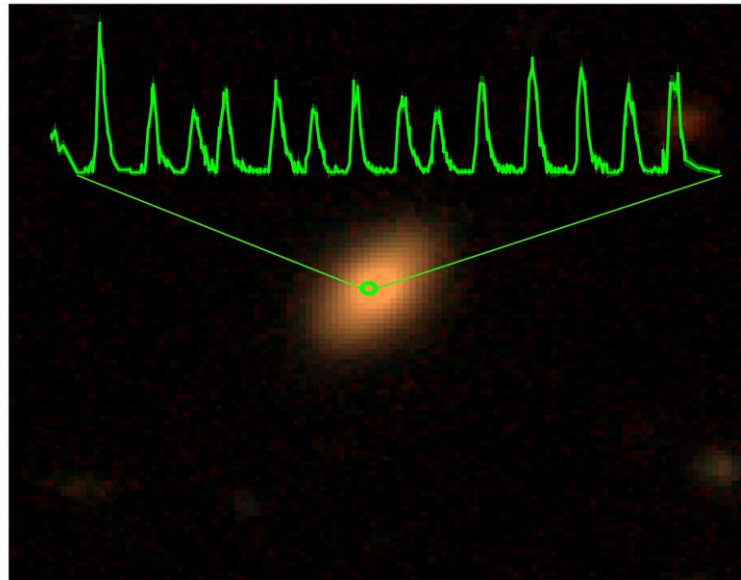
Summary

- 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



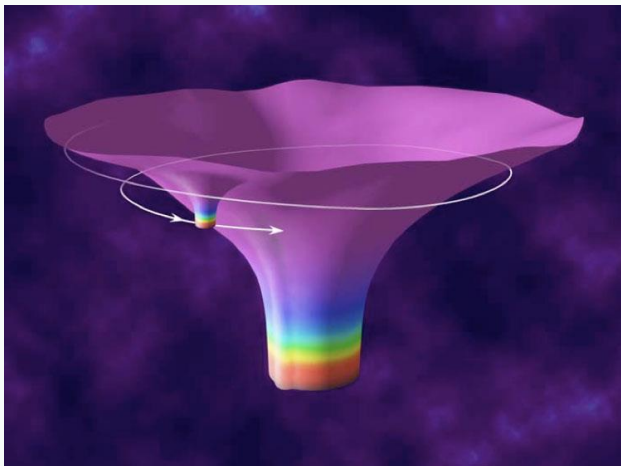
Summary

- QPEs are a new type of exotic X-ray phenomena related to BH accretion
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- We have found 2 with eROSITA, doubling the sample!
- Now found in inactive galaxies (one needs “only” a low-mass SMBH)



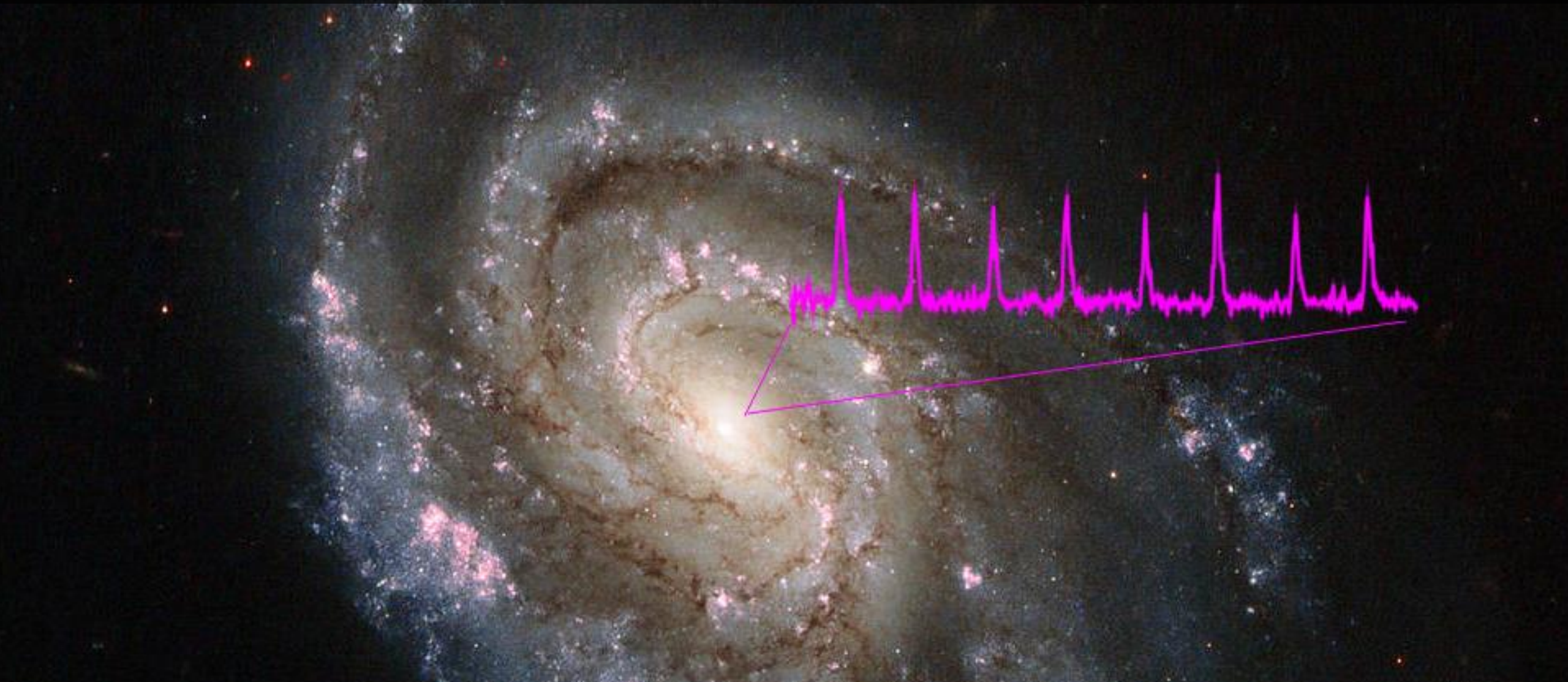
Summary

- 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 in inactive galaxies (one needs “only” a low-mass SMBH)
- Most likely scenario currently: high-mass ratio binary of compact objects



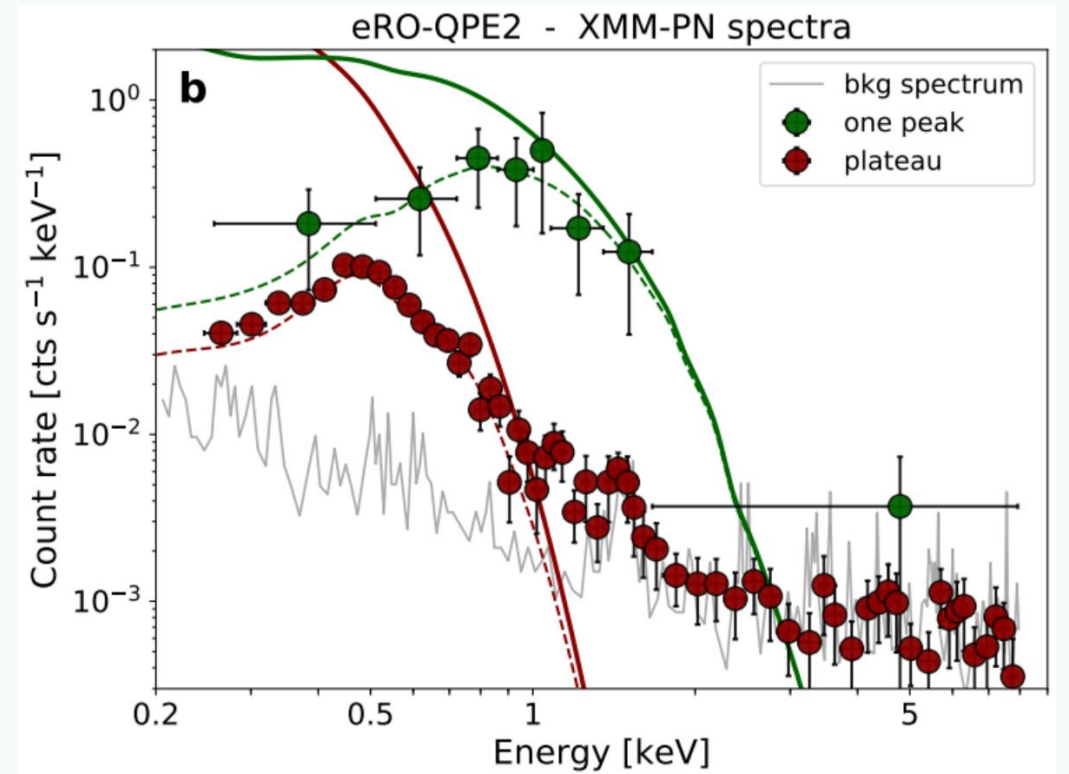
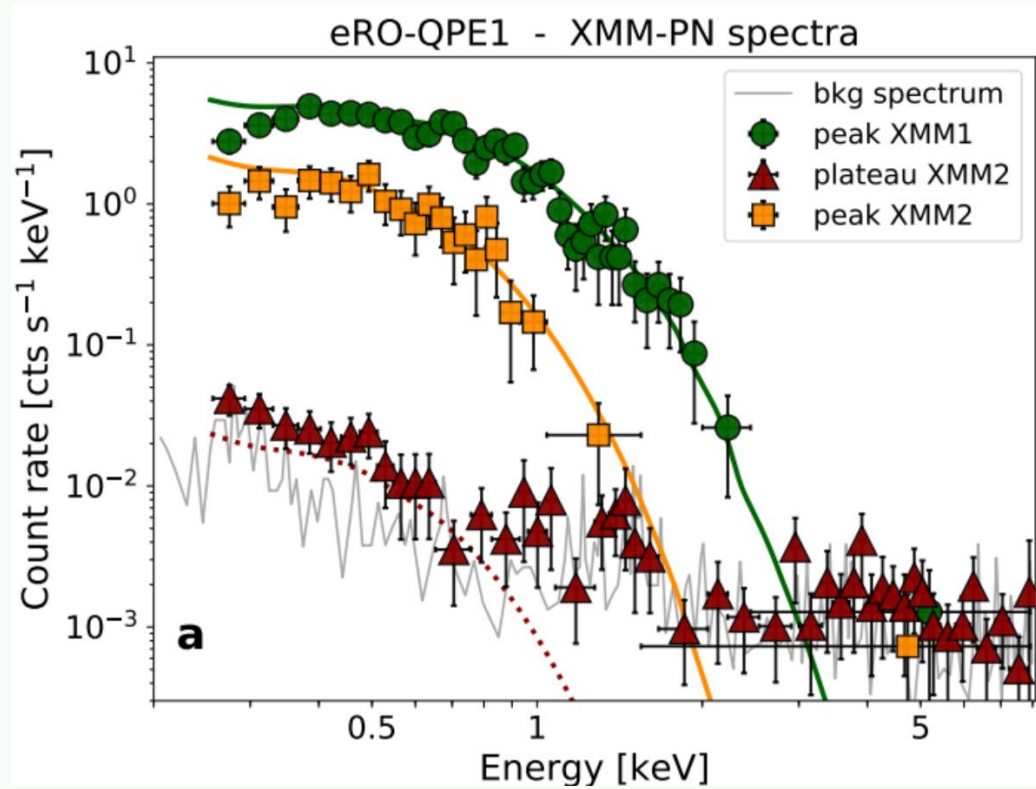
→ To be tested soon

Thank you!!

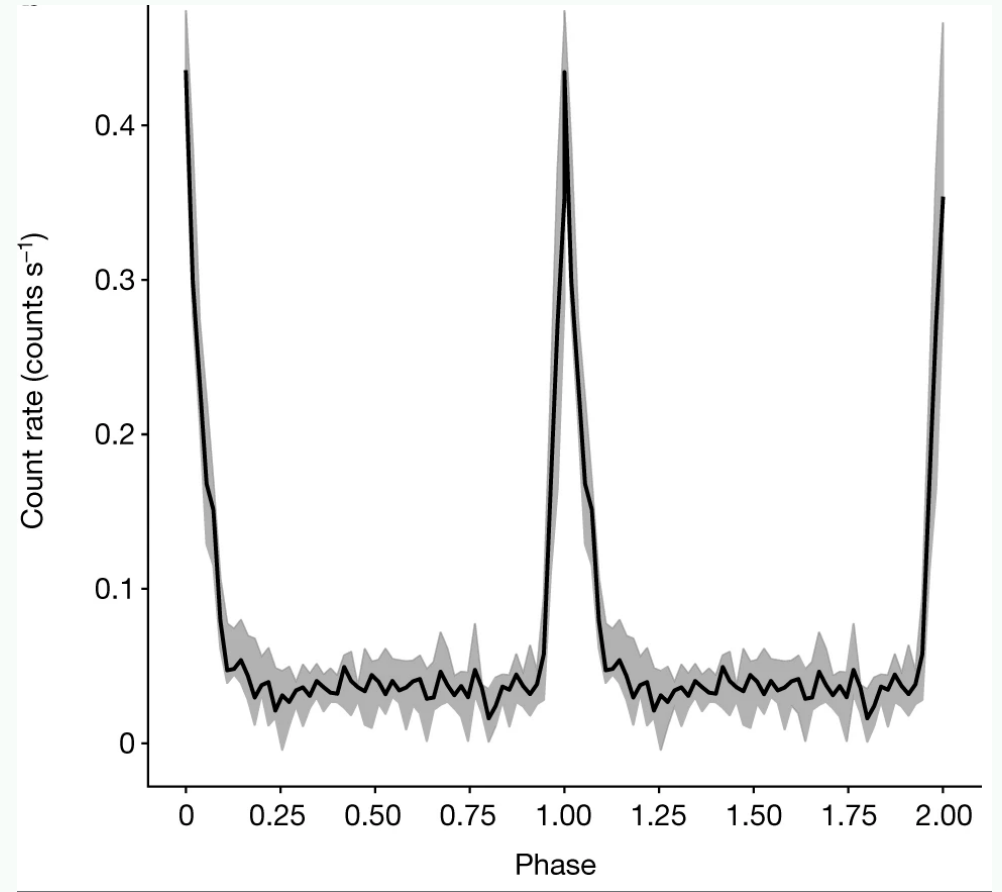
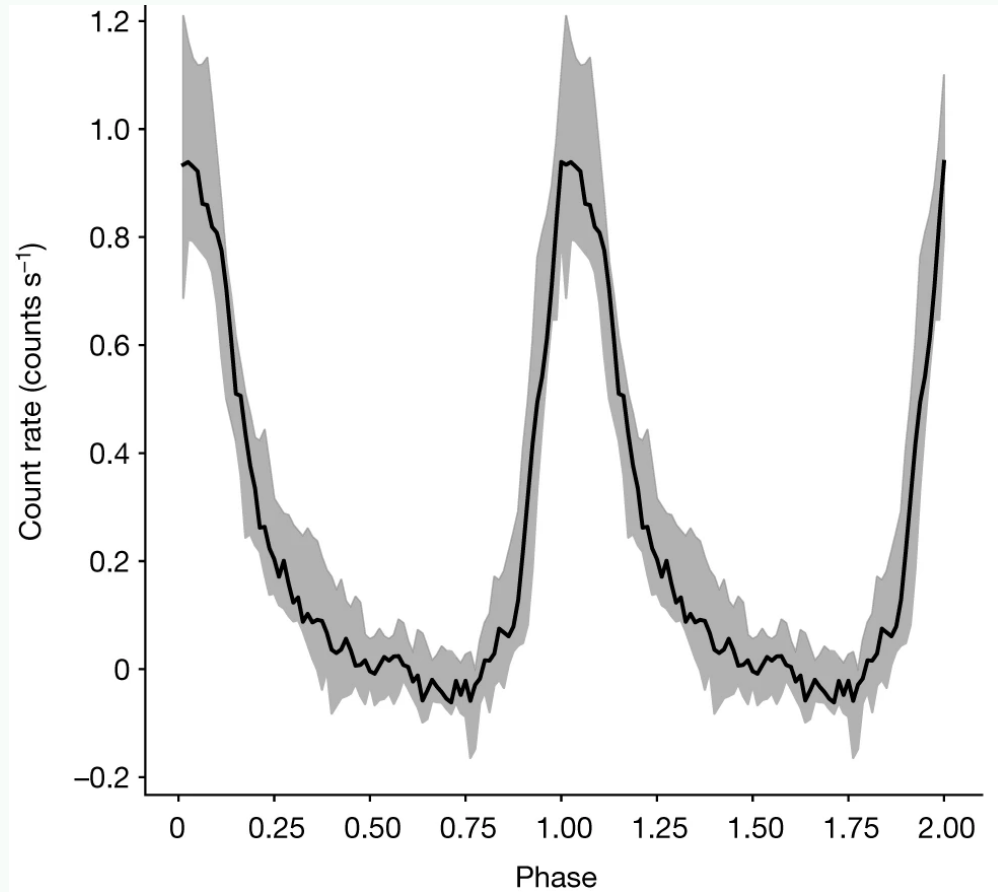


arcodia@mpe.mpg.de

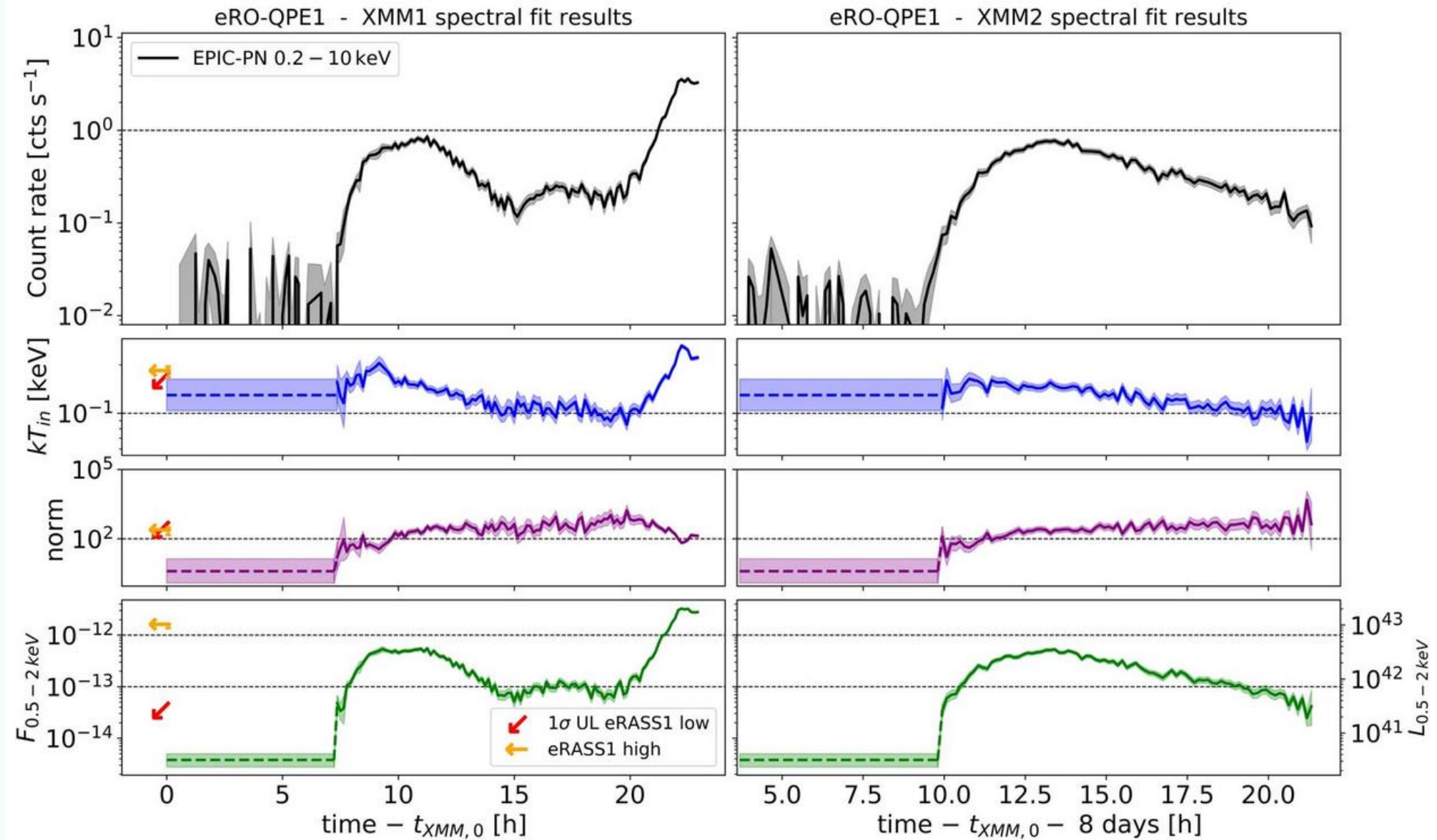
Extra



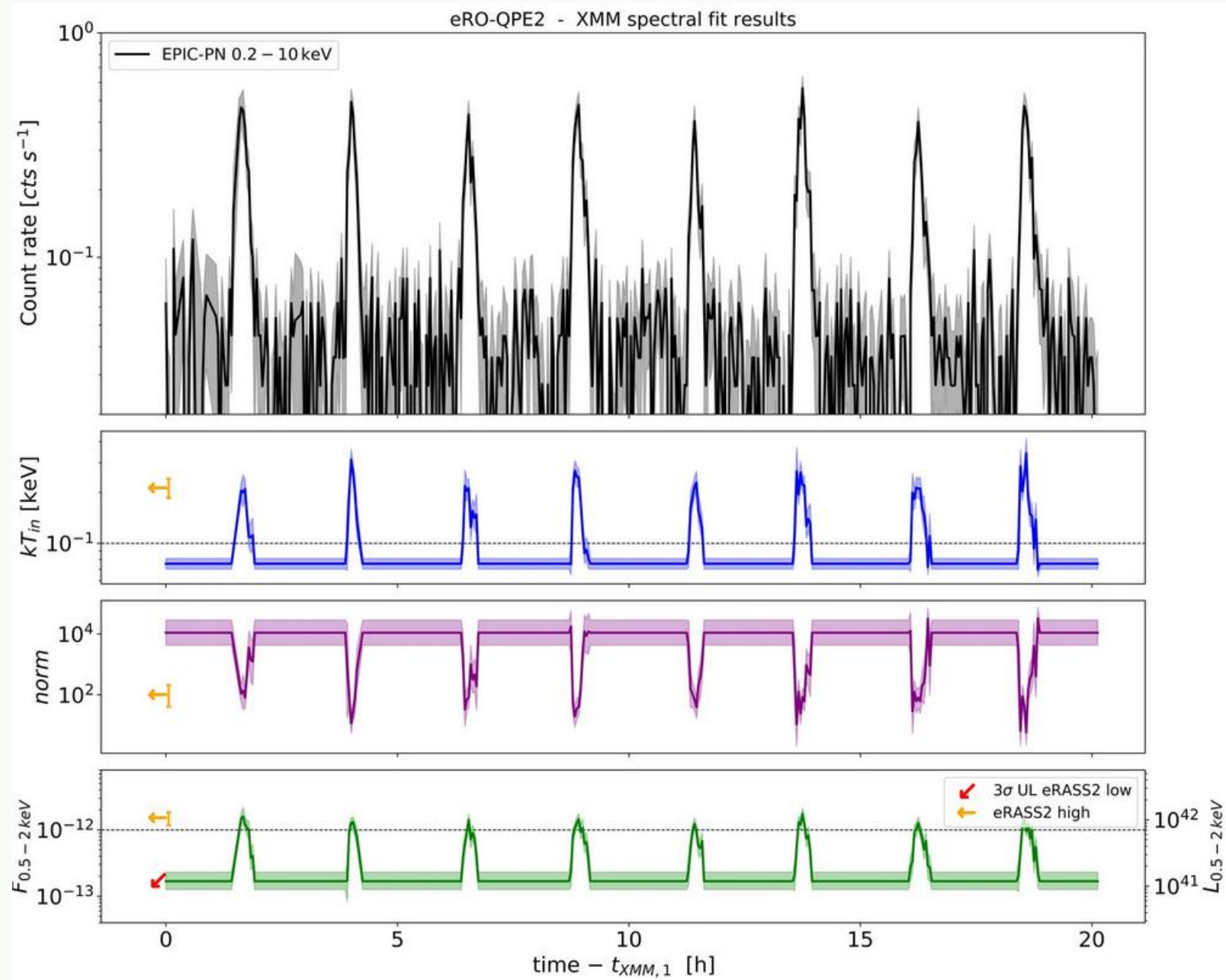
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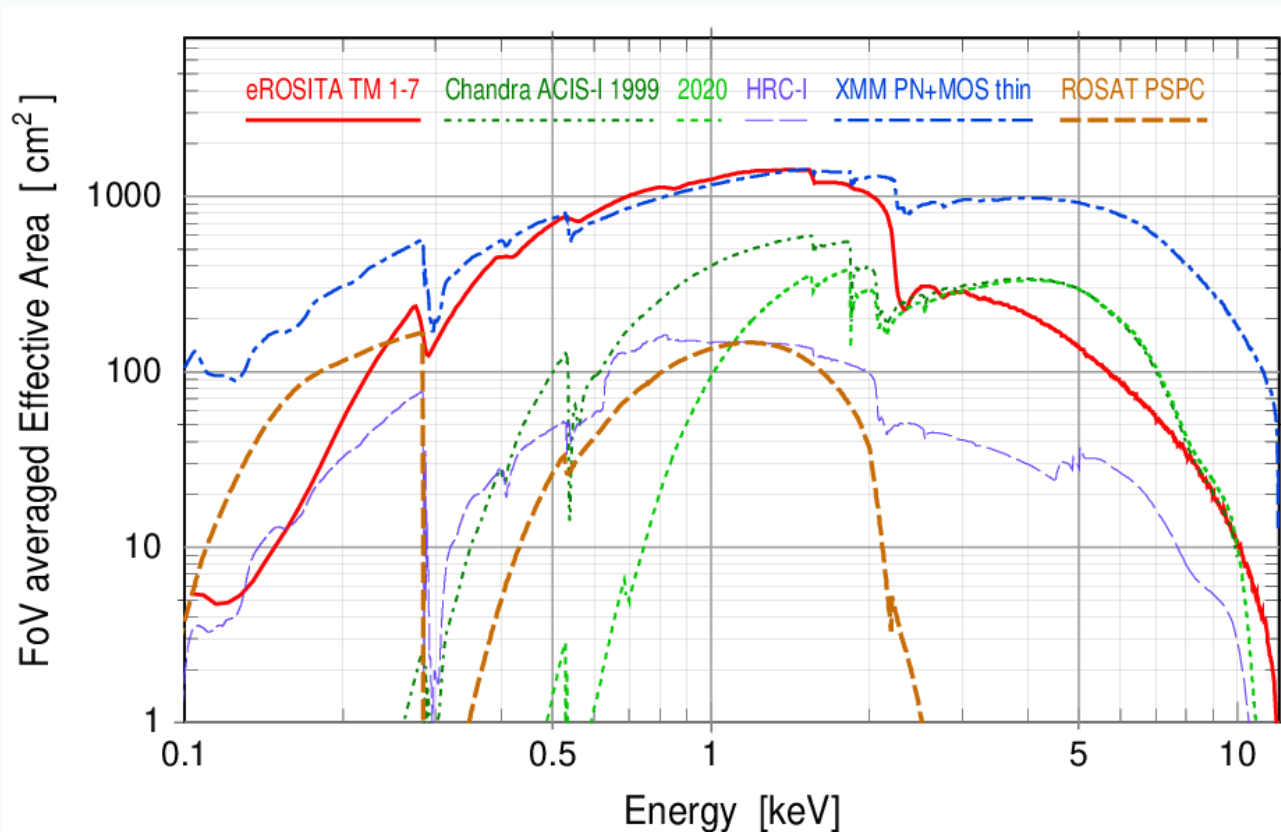
Extra



Extra

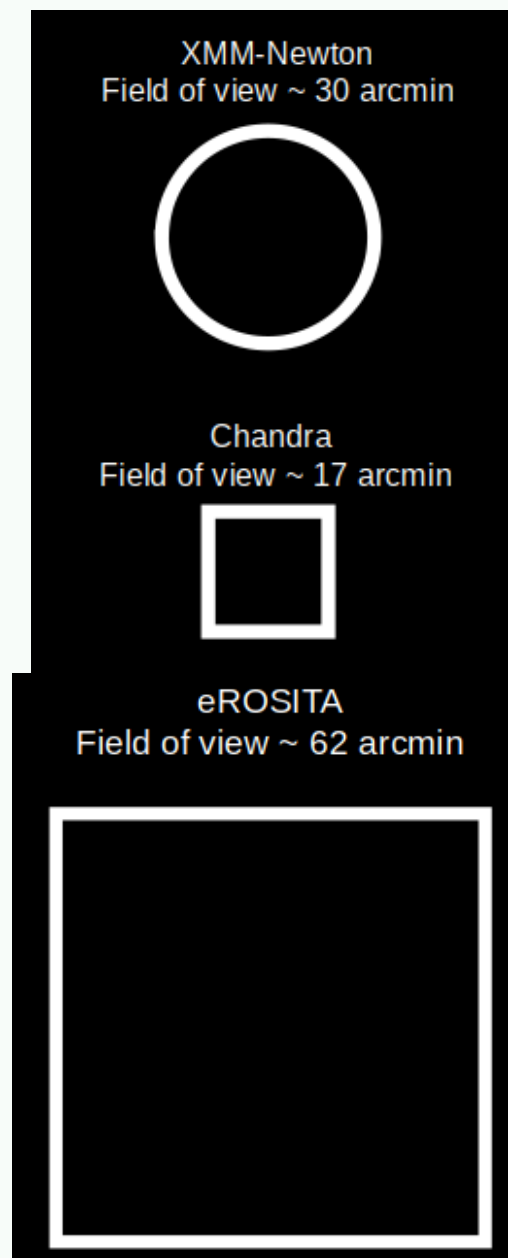


Finding QPEs with eROSITA

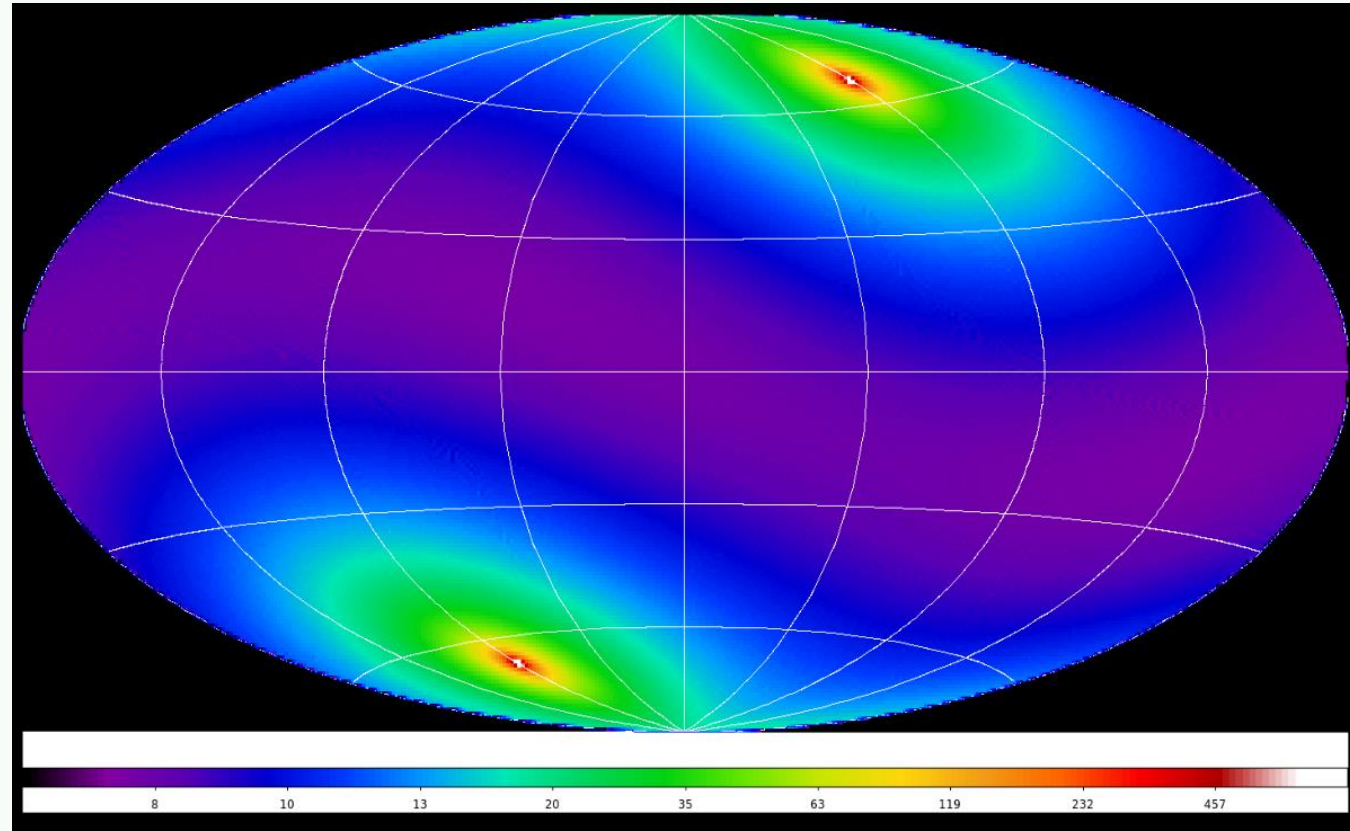
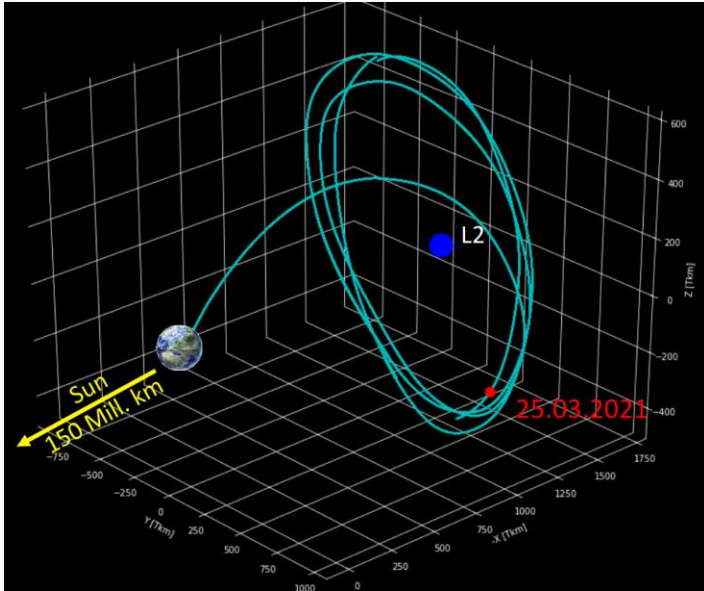


Courtesy A. Merloni & P.Predehl @MPE

- XMM-like EA + larger FoV = 5x grasp @1keV



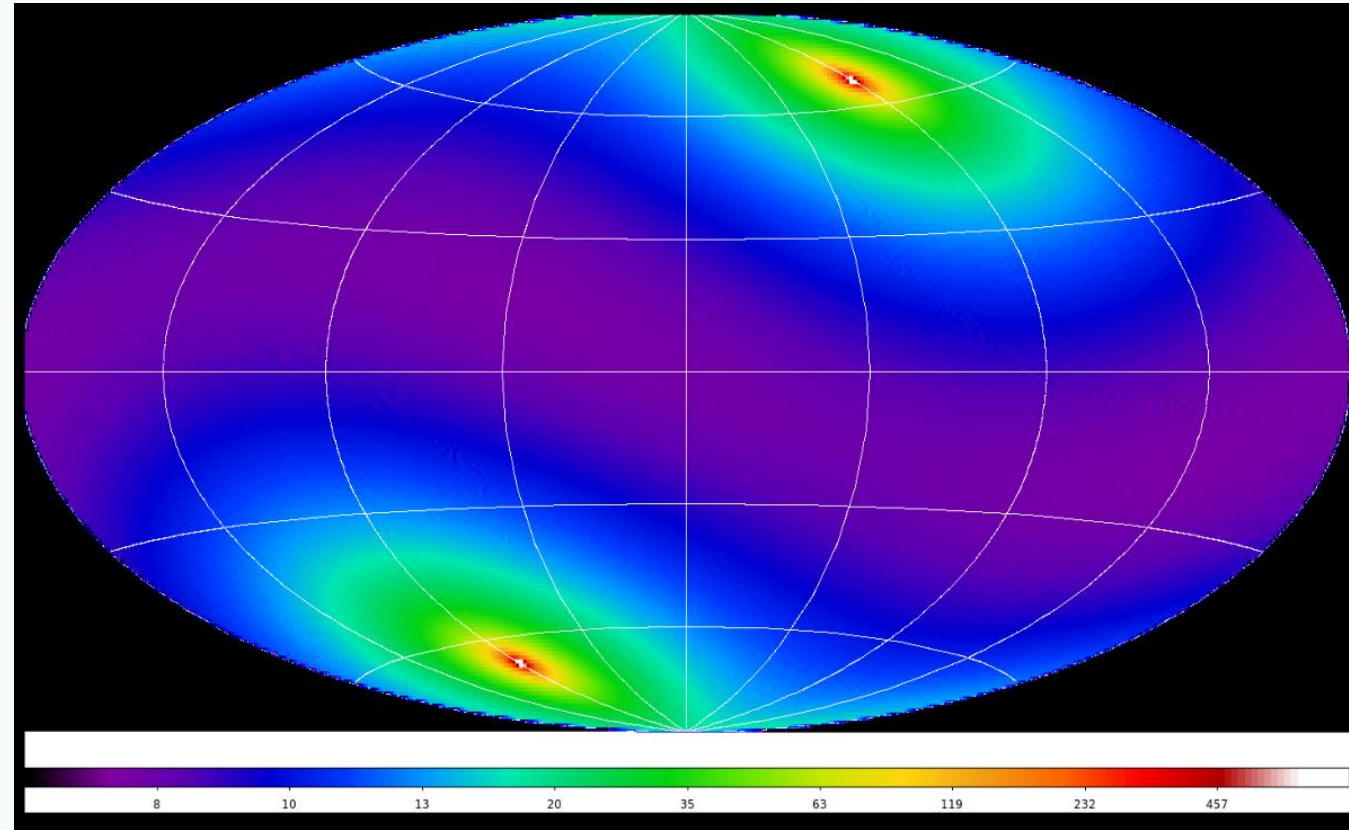
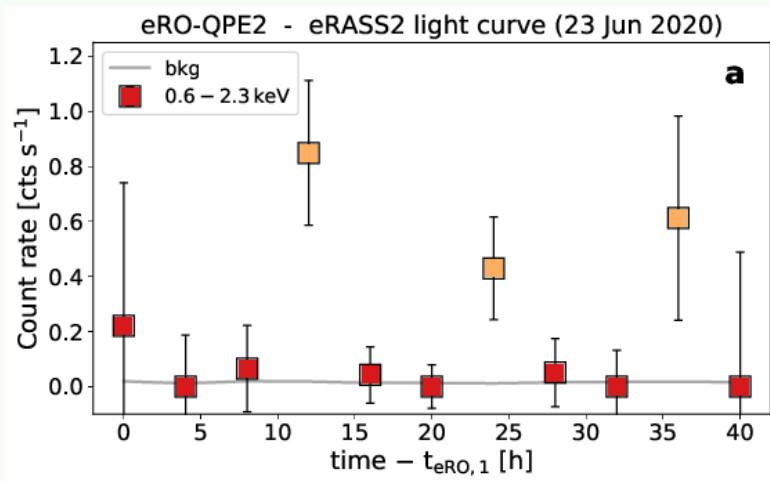
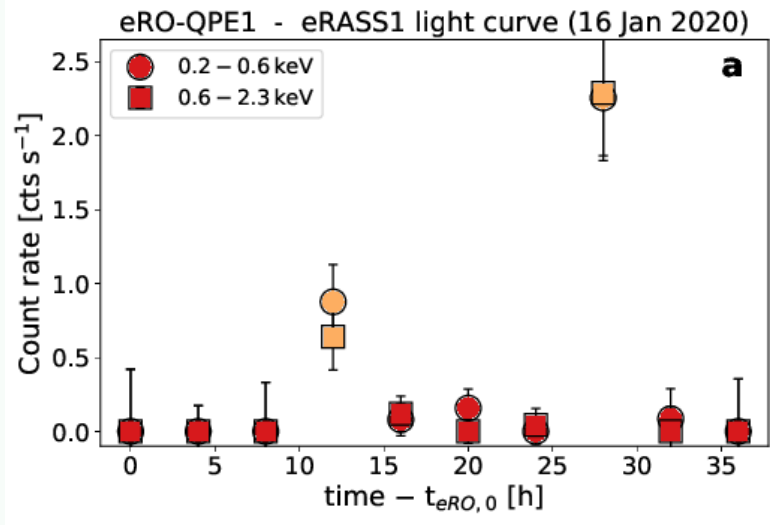
Finding QPEs with eROSITA



Courtesy A. Merloni & P.Predehl @MPE



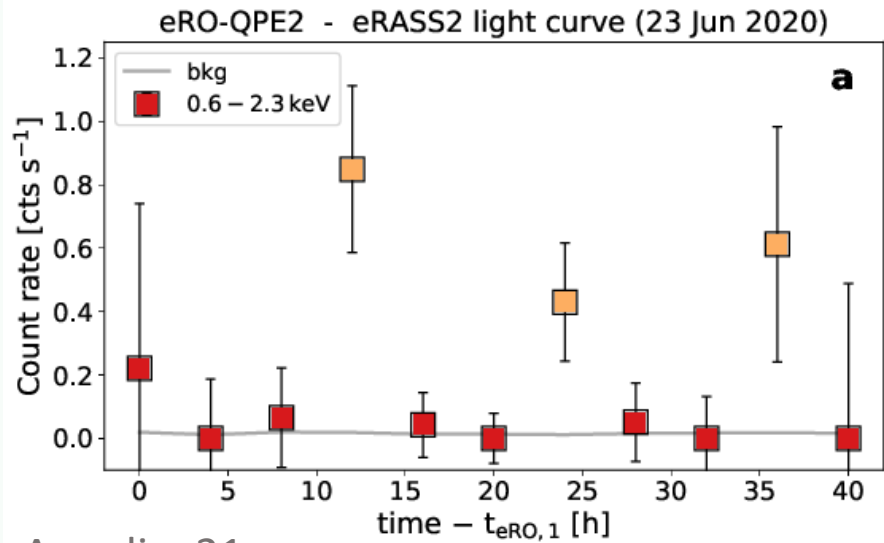
Finding QPEs with eROSITA



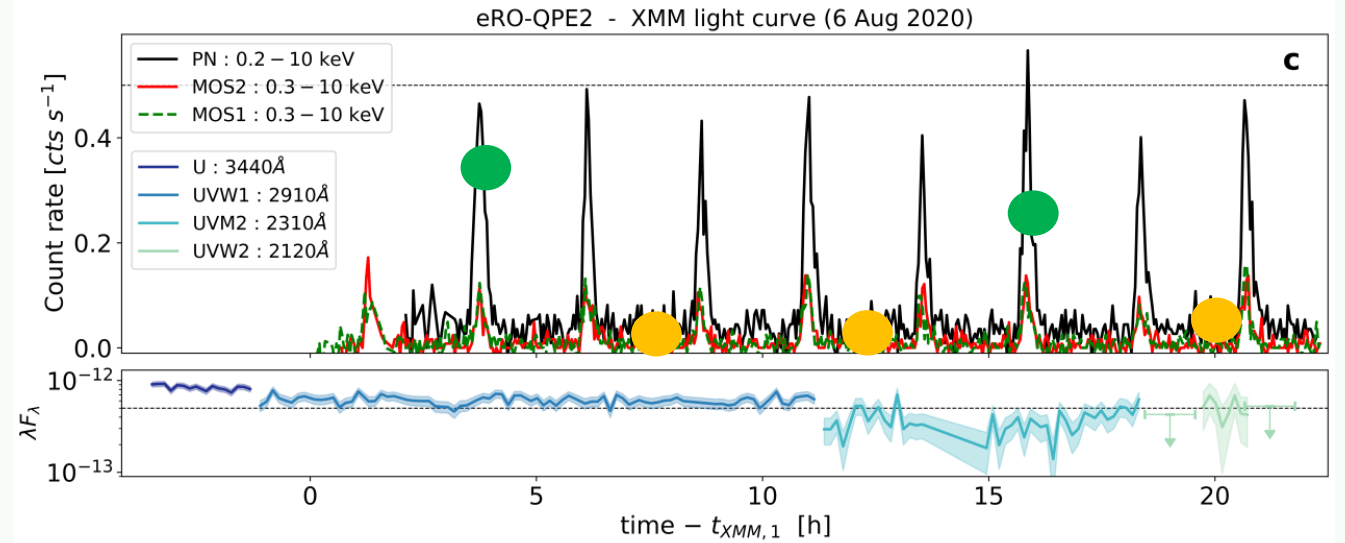
Courtesy A. Merloni & P.Predehl @MPE

Finding QPEs with eROSITA

- We monitor all light-curves of every X-ray source
- Follow-up if it shows clear high-amplitude alternating variability and extragalactic

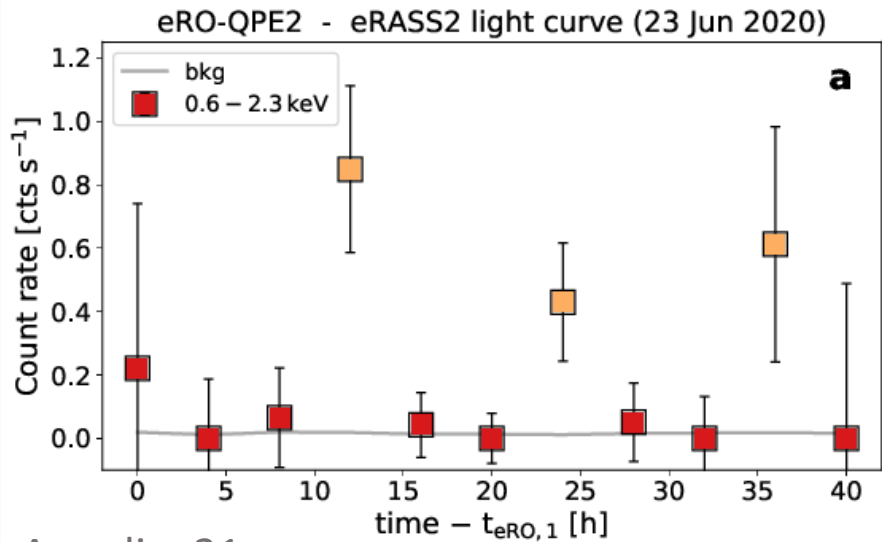


Arcodia+21

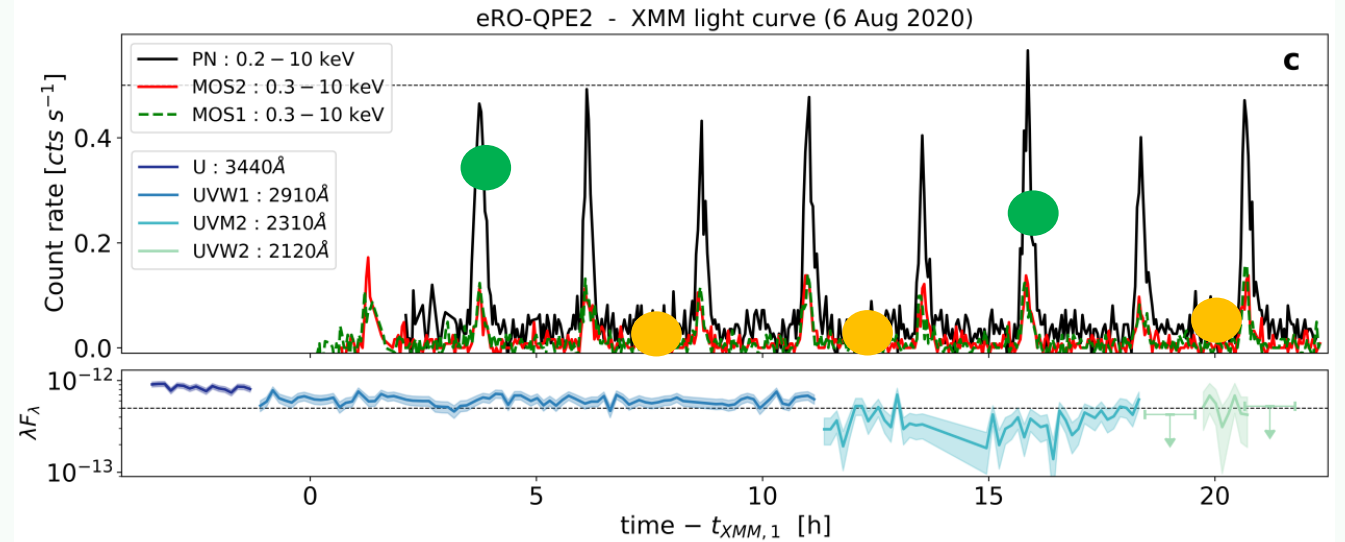


Finding QPEs with eROSITA

- We monitor all light-curves of every X-ray source
- Follow-up if it shows clear high-amplitude alternating variability and extragalactic



Arcodia+21



For each that we find there are $\sim 1/\text{duty_cycle}$ that we miss (in this case $\sim \text{few}$)

→ From simulations and extrapolating from eRASS1+2: expected $\sim 1\text{-}2$ per year

Finding QPEs with eROSITA

- Crucial to be sensitive to bright states with some significance w.r.t. faint

$z \sim 0.0175$

