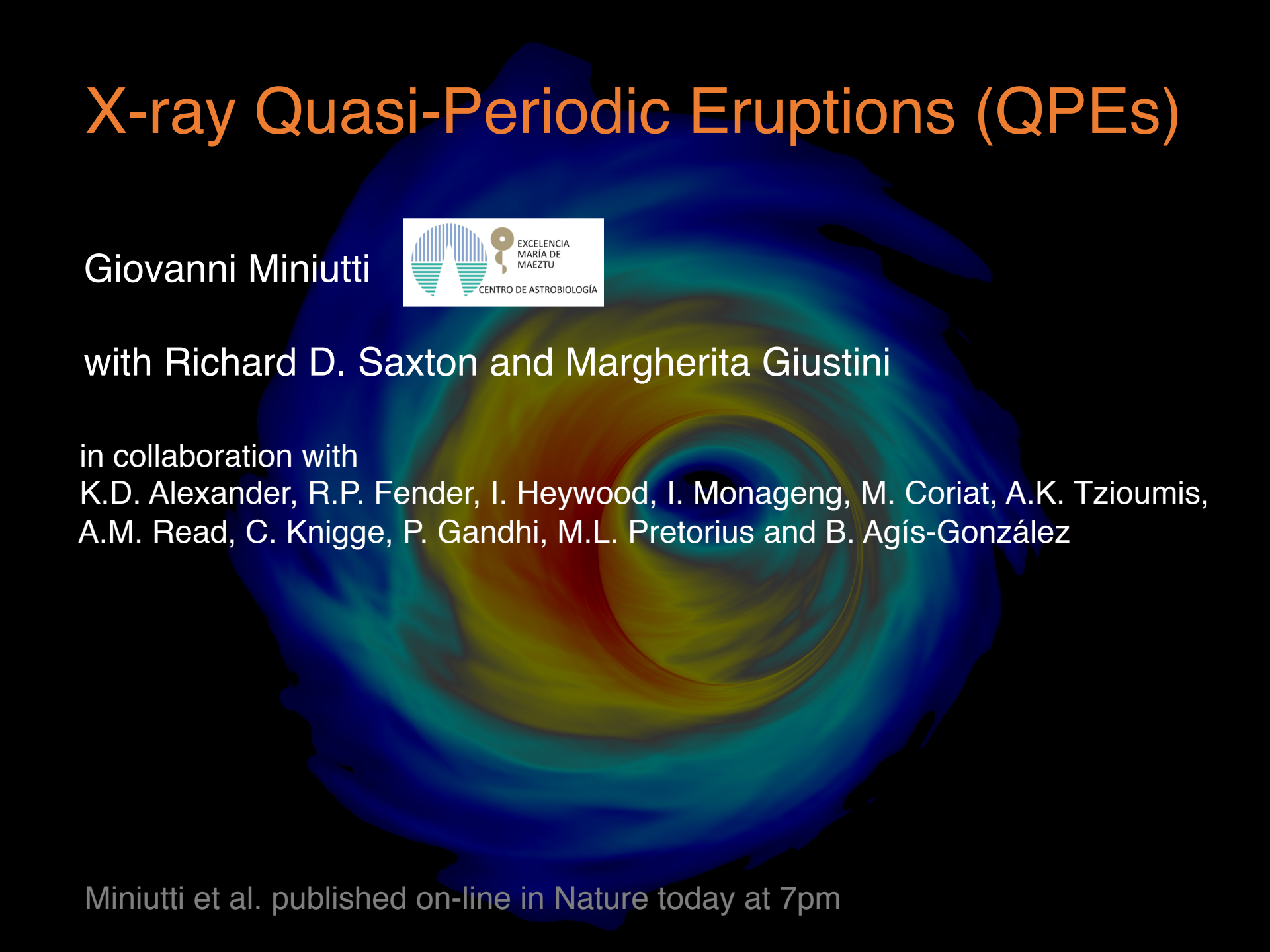
X-ray Quasi-Periodic Eruptions (QPEs)

Giovanni Miniutti

EXCELENCIA MARÍA DE MAEZTU
CENTRO DE ASTROBIOLOGÍA

with Richard D. Saxton and Margherita Giustini

in collaboration with
K.D. Alexander, R.P. Fender, I. Heywood, I. Monageng, M. Coriat, A.K. Tzioumis, A.M. Read, C. Knigge, P. Gandhi, M.L. Pretorius and B. Agís-González



Miniutti et al. published on-line in Nature today at 7pm

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media / social media embargo lifted at 7pm local time today

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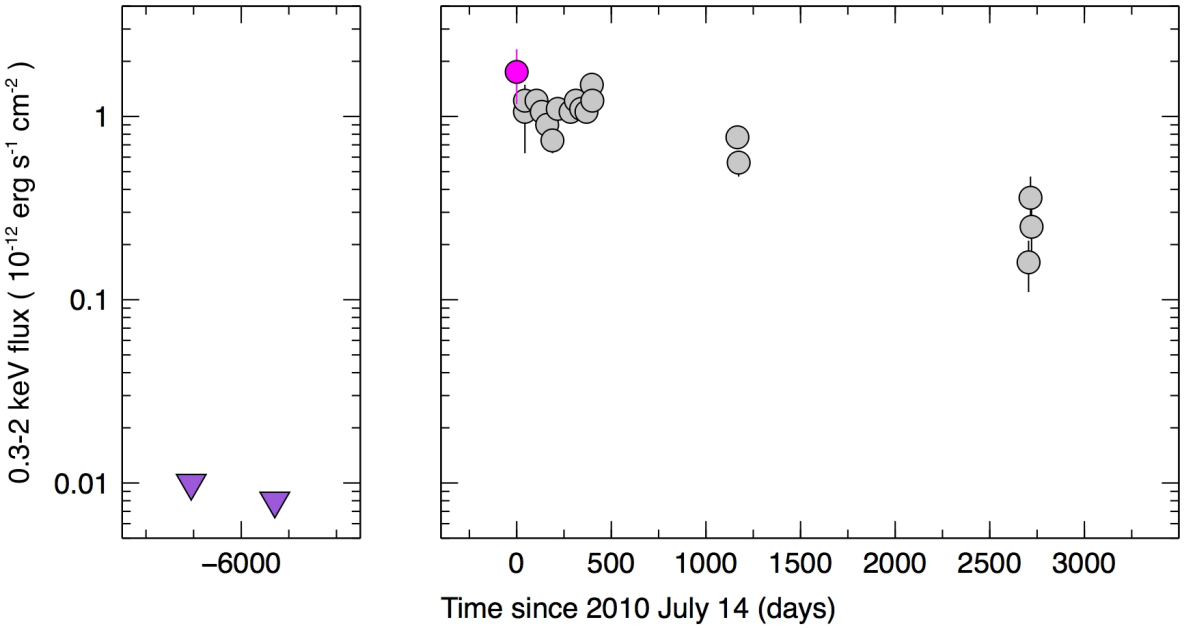


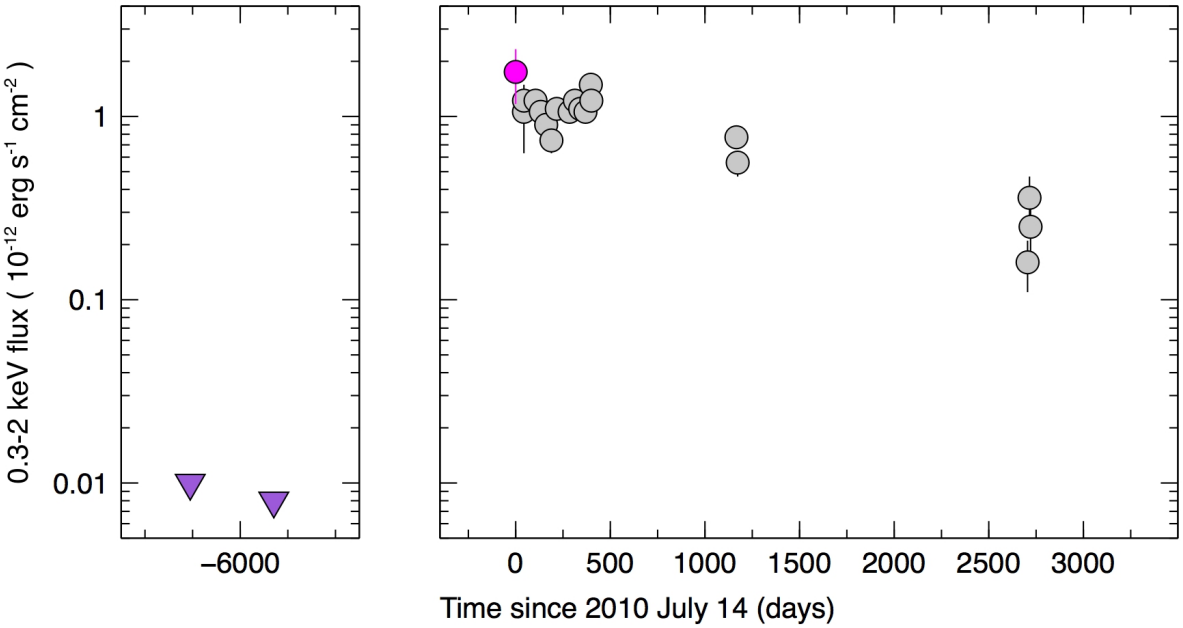
GSN 069 (2MASX J01190869-3411305) at z=0.018 near the Galactic South pole

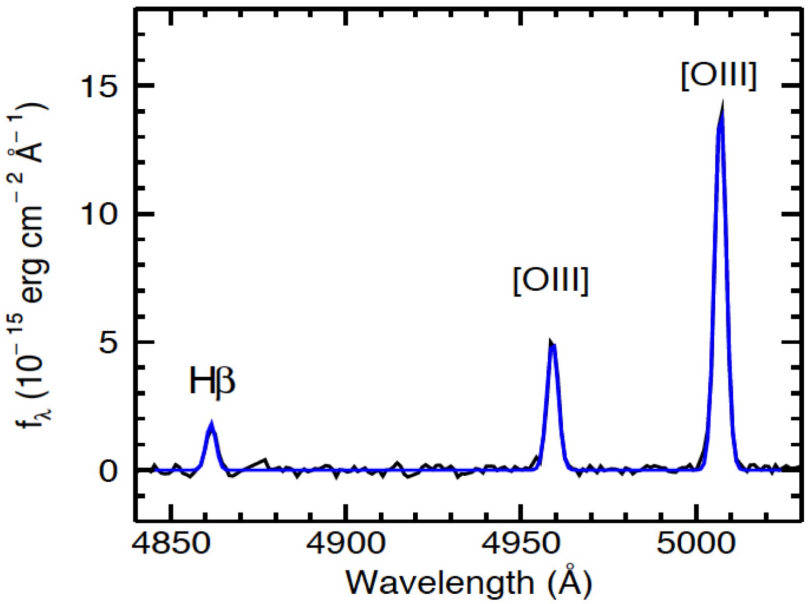
XMM slew detection on 2010 July 14 with $\sim 2 \times 10^{-12}$ erg s^{-1} in the 0.3-2 keV band

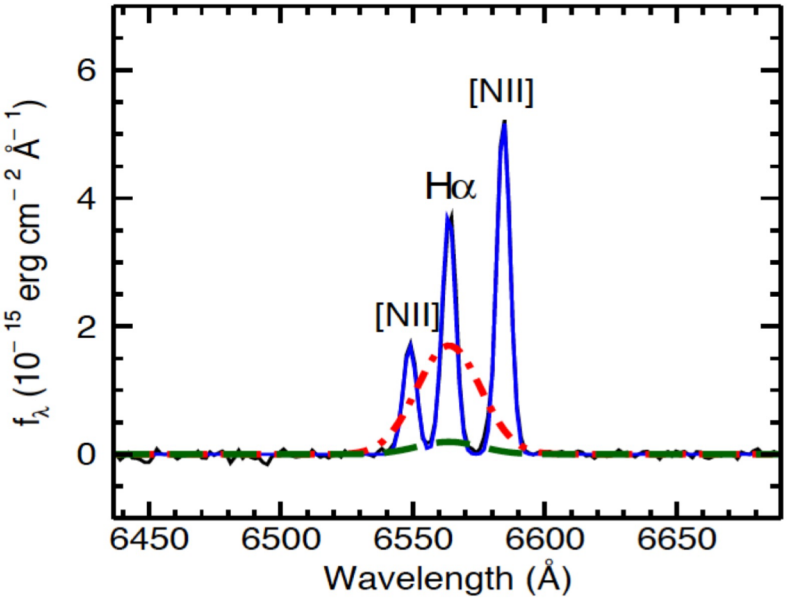
ROSAT (pointed) upper limits 16 years earlier → more than a factor 240 outburst

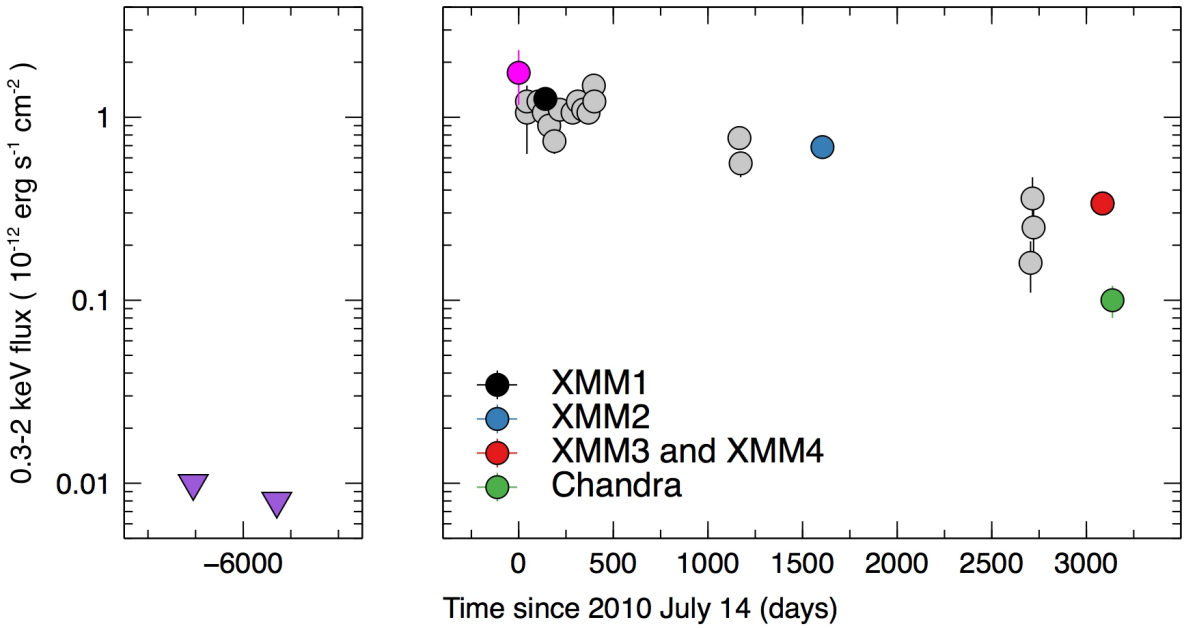
Swift monitoring shows long-term (9.5 years) decay consistent with long-lived TDE

[Miniutti et al. 2013; Shu et al. 2018]


0.3-2 keV flux (10^-12 erg s^-1 cm^-2)
1
0.1
0.01
−6000
0
500
1000
1500
2000
2500
3000
Time since 2010 July 14 (days)


f_λ (10^−15 erg cm^−2 Å^−1)
15
10
5
0
Hβ
[OIII]
[OIII]
4850
4900
4950
5000
Wavelength (Å)


f_λ (10^−15 erg cm^−2 Å^−1)
6
4
2
0
[NII]
Hα
[NII]
6450
6500
6550
6600
6650
Wavelength (Å)



Focus on the highest quality observations

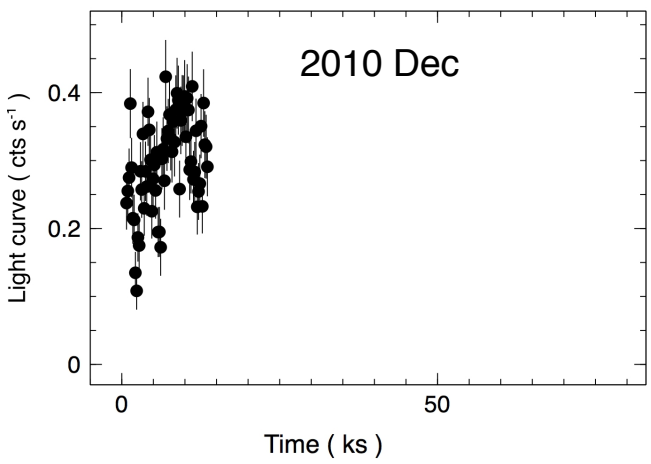
XMM1 – 2010 December ~ 11 ks

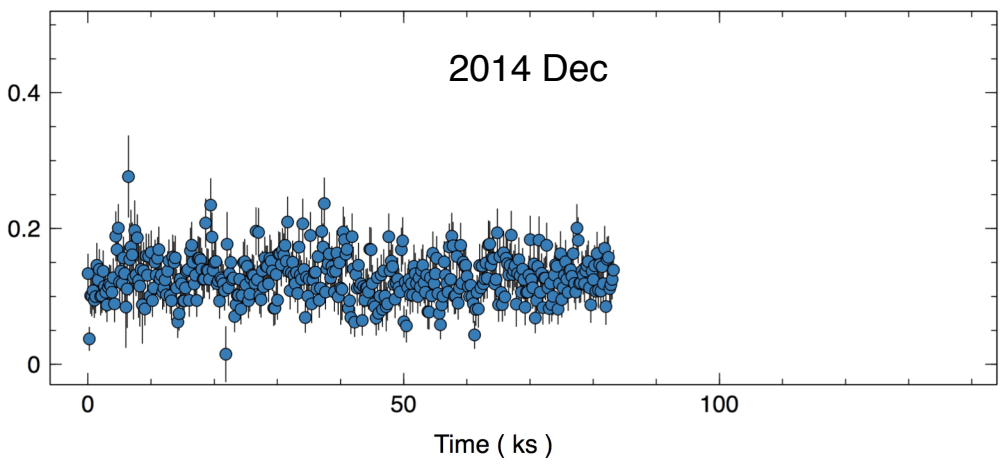
XMM2 – 2014 December ~ 83 ks (quasi simultaneous with HST/STIS)

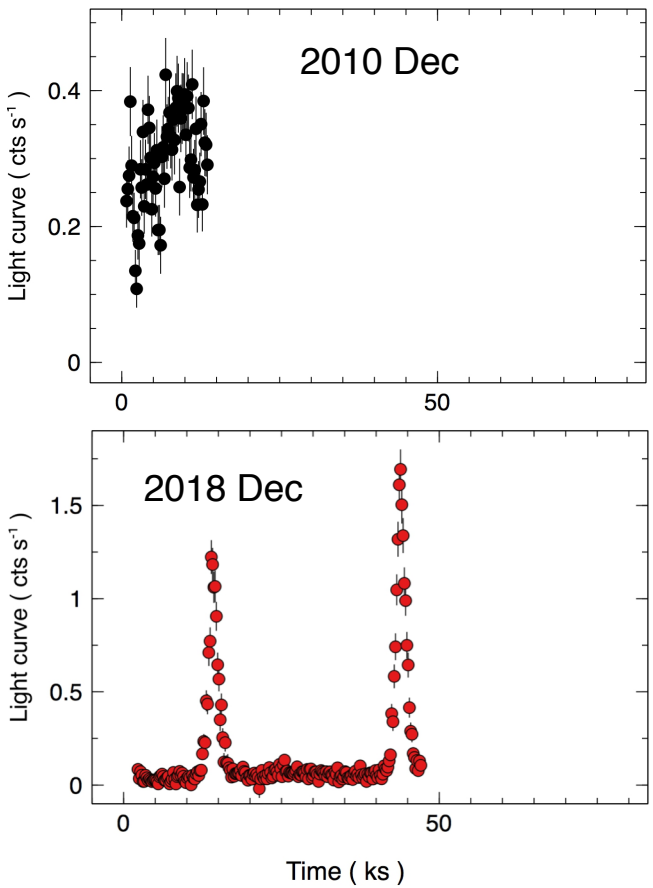
XMM3 – 2018 December ~ 45 ks (quasi simultaneous with HST/STIS)

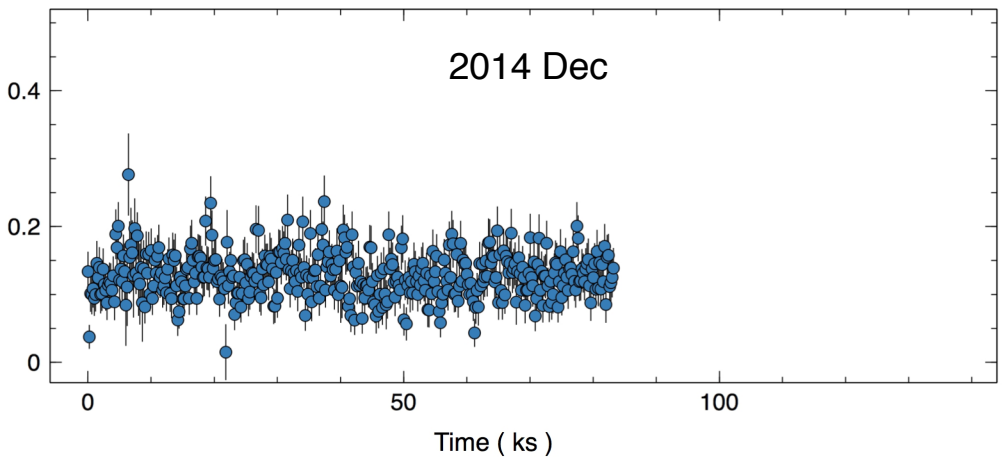
XMM4 – 2019 January (DDT) ~ 133 ks

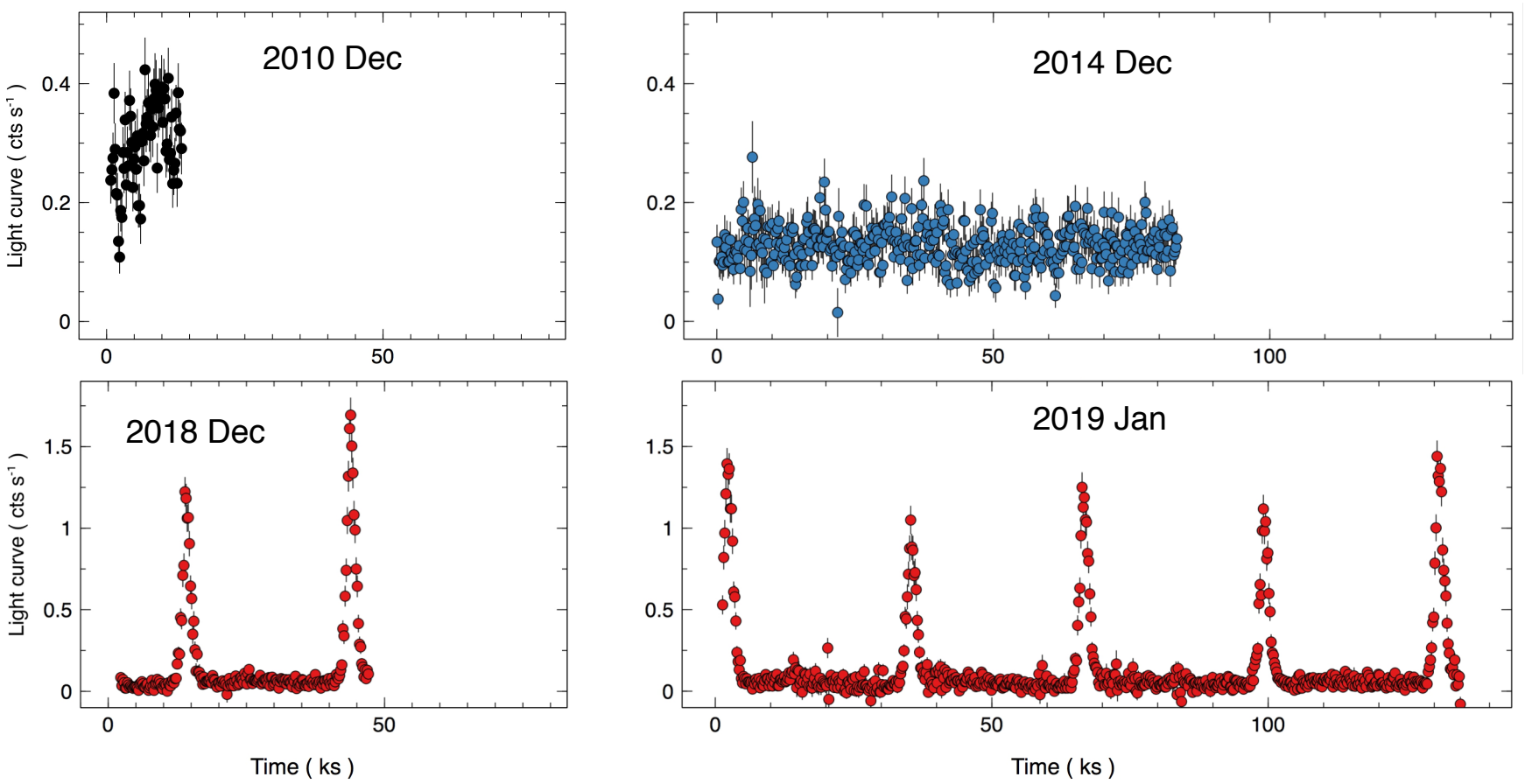
Chandra – 2019 February (DDT) ~ 73 ks (quasi simultaneous with ATCA, VLA, MeerKAT)

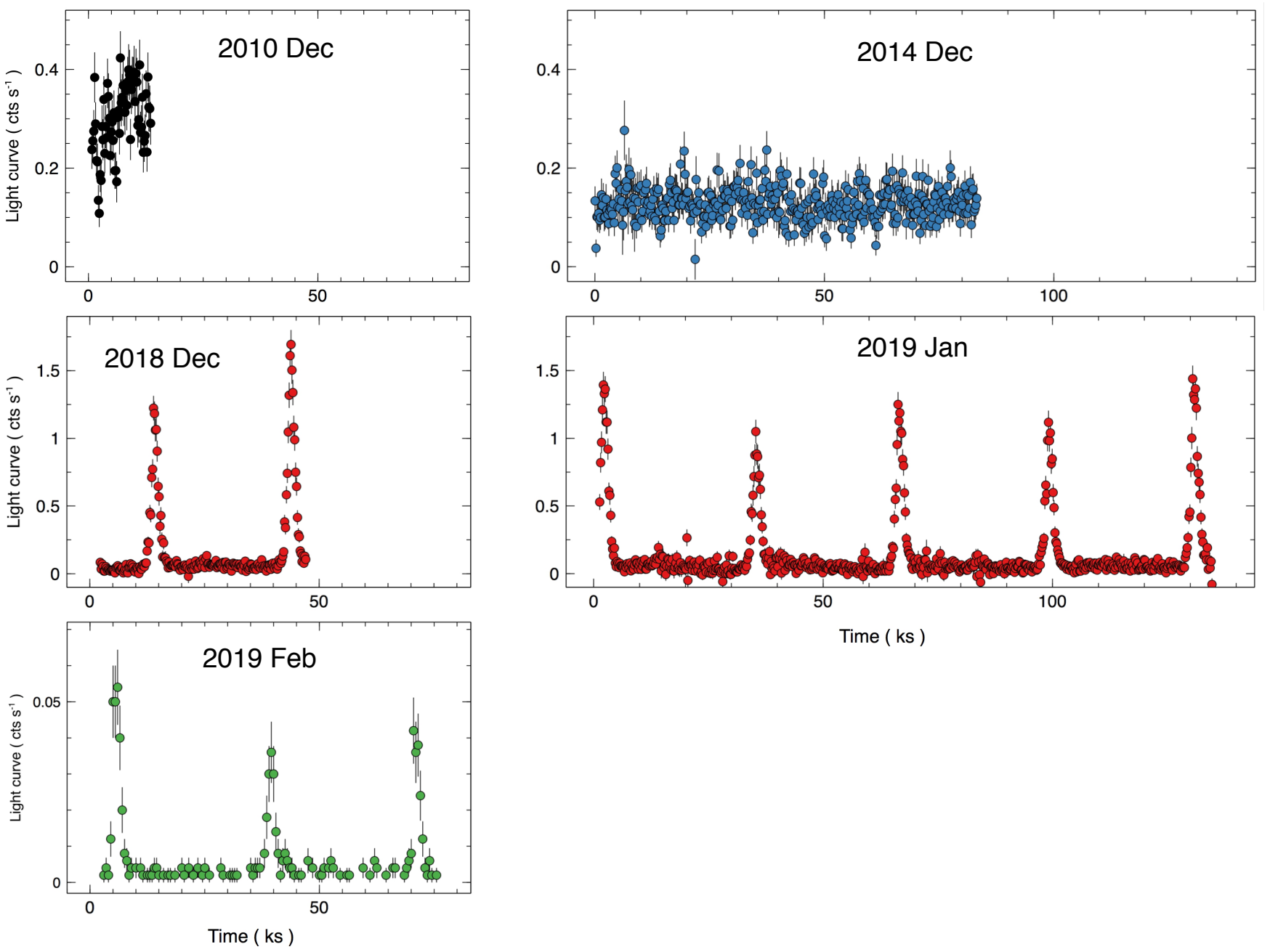

2010 Dec
Light curve (cts s^{-1})
0.4
0.2
0
0
50
Time (ks)

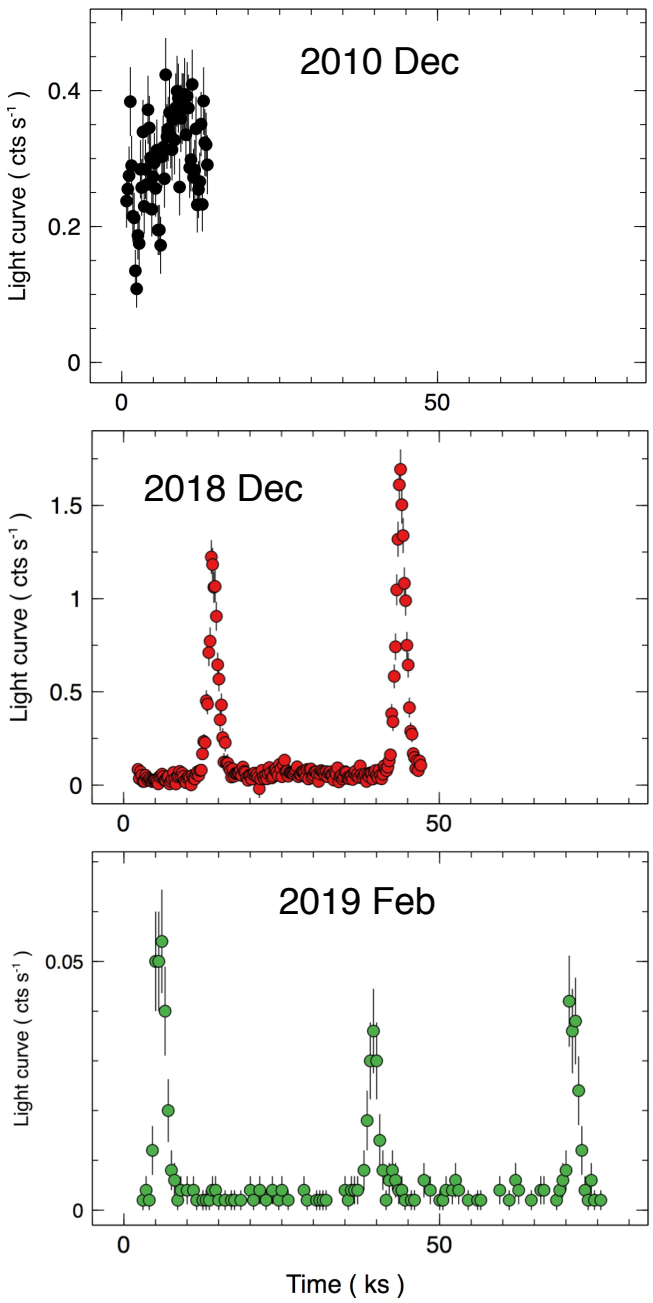

2014 Dec
0.4
0.2
0
0
50
100
Time (ks)

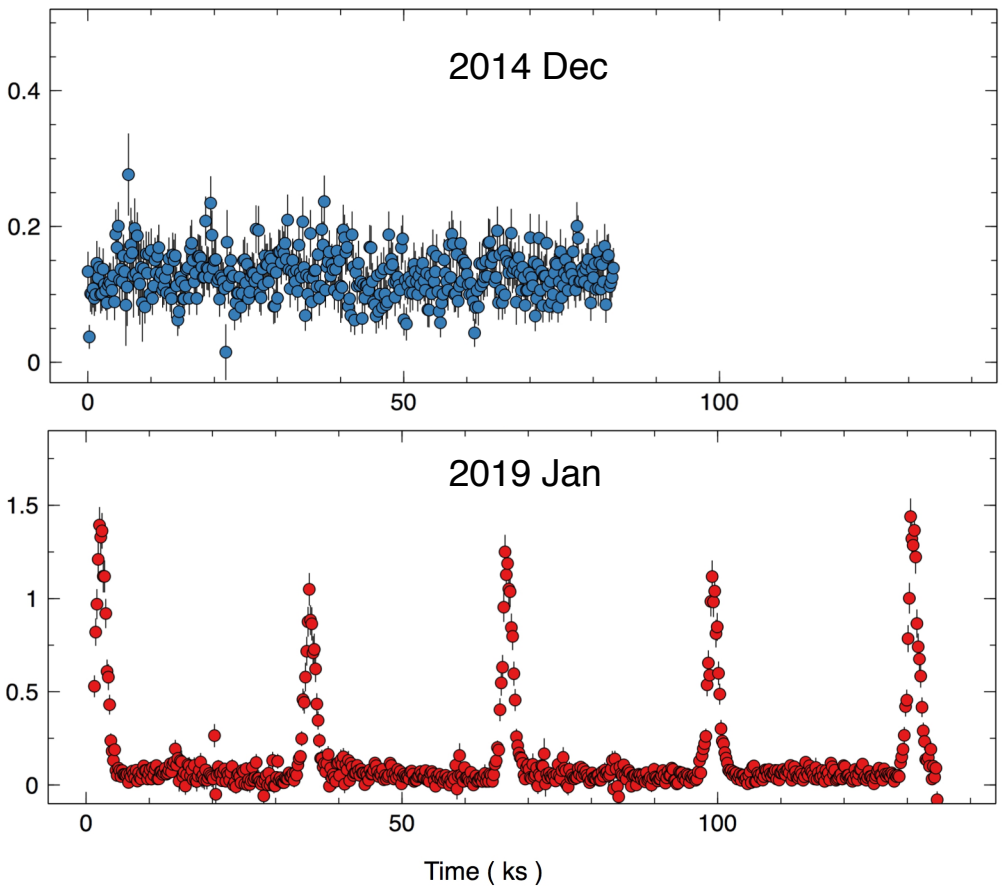

2010 Dec
2018 Dec
Light curve (cts s^{-1})
Time (ks)
0
0.2
0.4
0.5
1
1.5
50


2014 Dec
0
0.2
0.4
50
100


2010 Dec
2014 Dec
2018 Dec
2019 Jan
Light curve (cts s^{-1})
Time (ks)
0
0.2
0.4
0.5
1
1.5
50
100


2010 Dec
2014 Dec
2018 Dec
2019 Jan
2019 Feb
Light curve (cts s^{-1})
Time (ks)
0
0.2
0.4
0.5
1
1.5
0.05
50
100

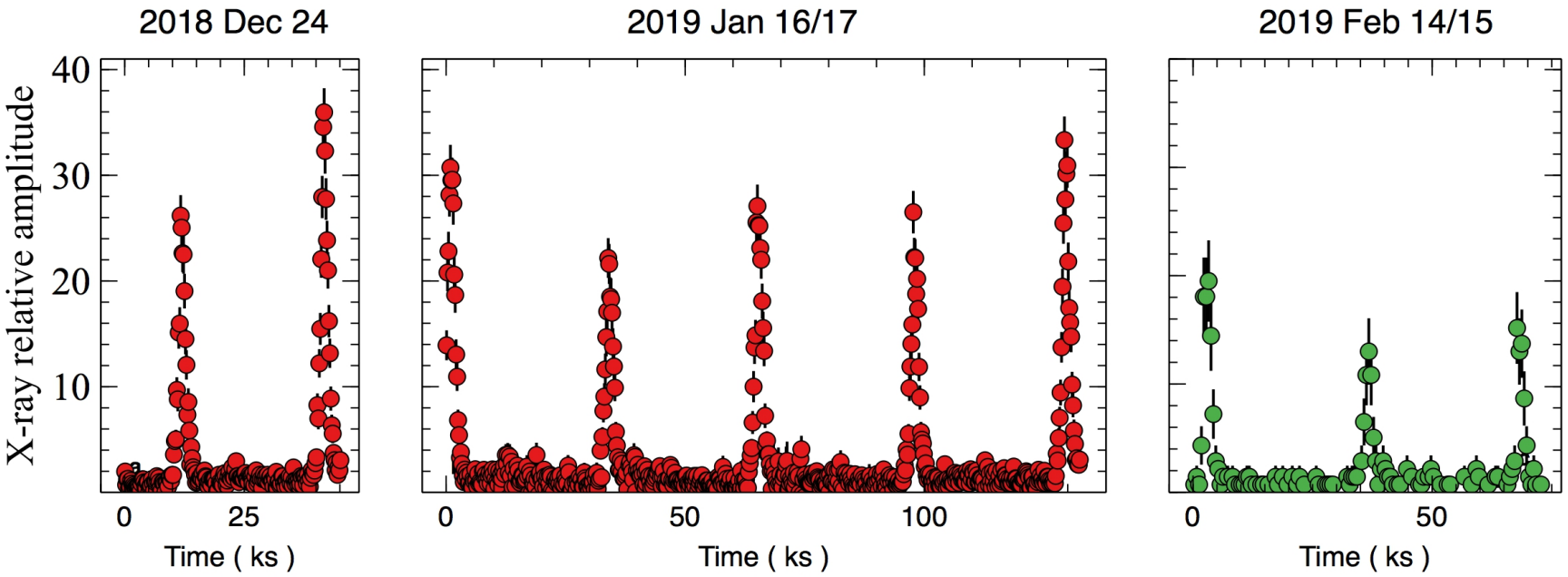




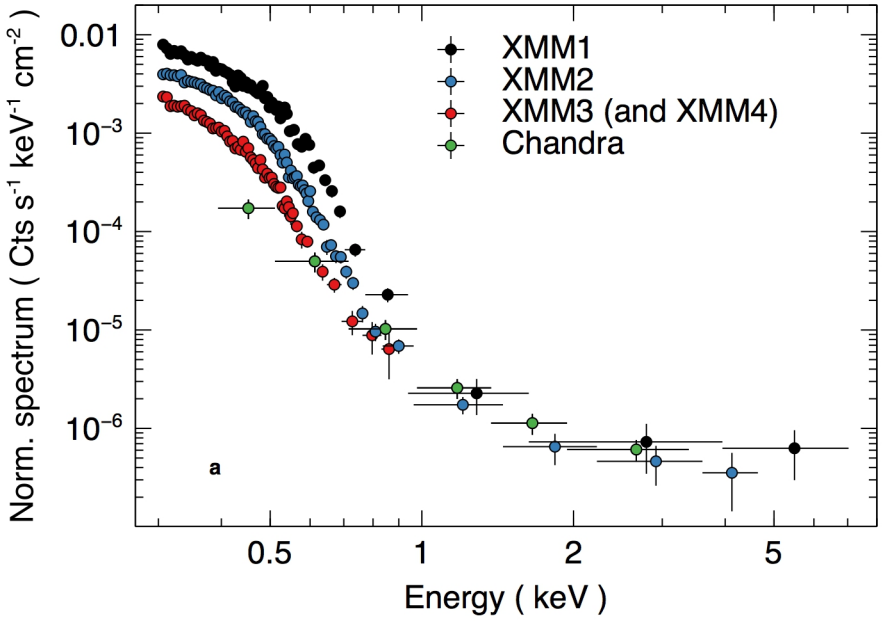
Short-lived, high amplitude, quasi-periodic

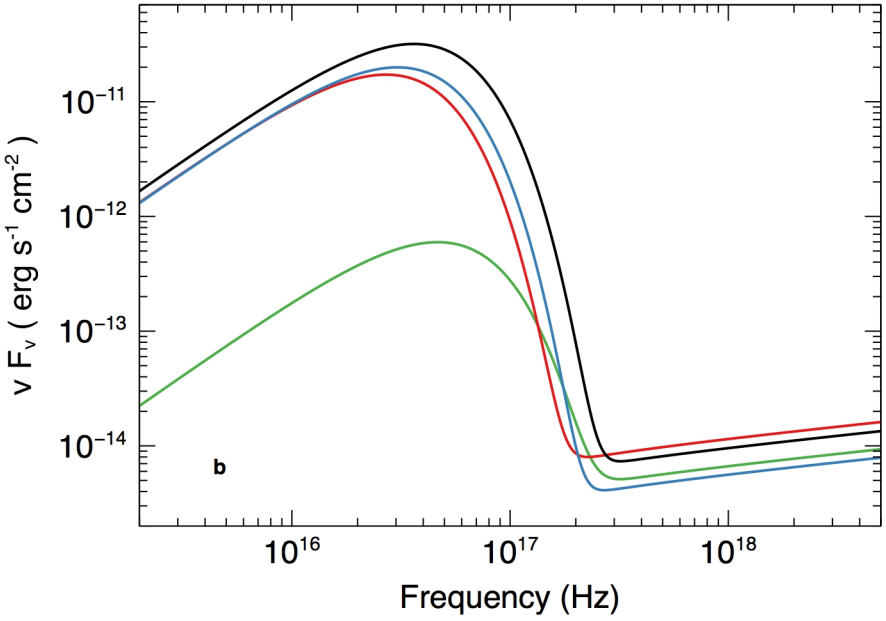
→ X-ray Quasi-Periodic Eruptions (QPEs)

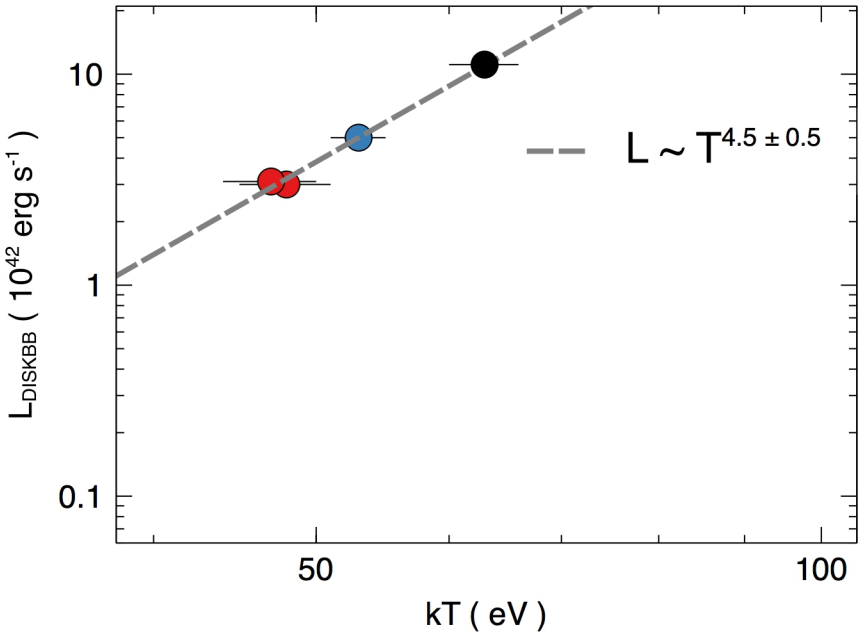
to distinguish them from gentler QPOs

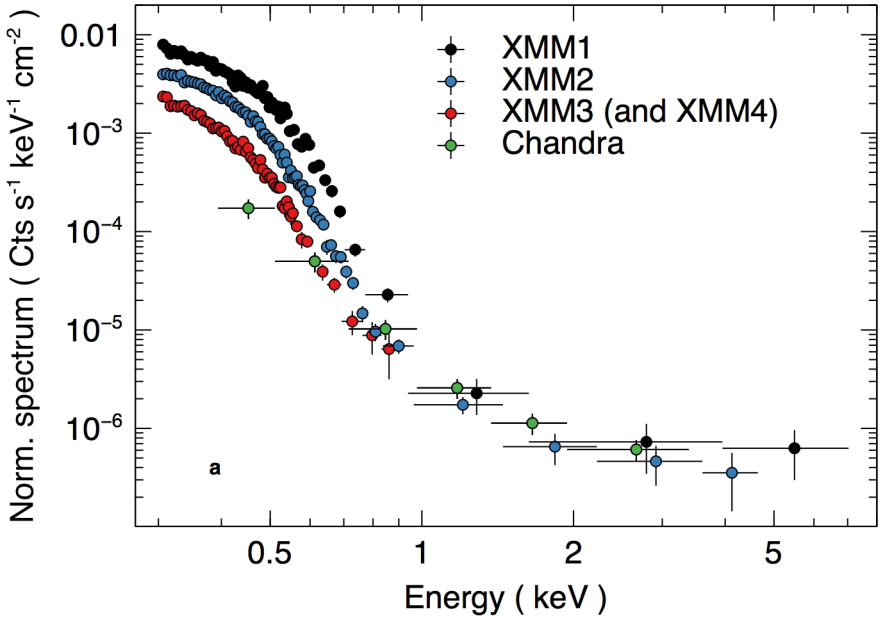


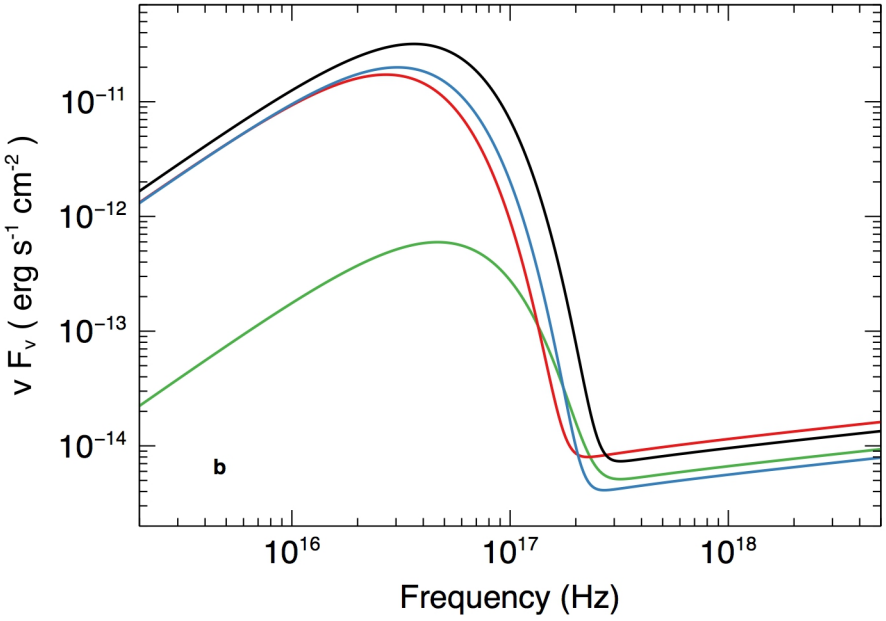
The quiescent level long-term evolution

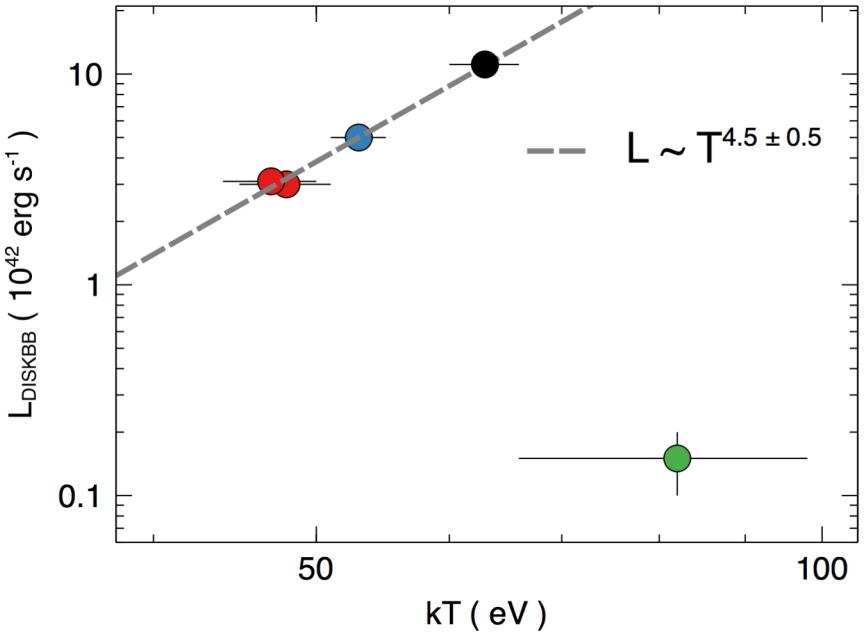

XMM1
XMM2
XMM3 (and XMM4)
Chandra
Norm. spectrum (Cts s^{-1} keV^{-1} cm^{-2})
Energy (keV)
a


v F$_\nu$ (erg s^{-1} cm^{-2})
Frequency (Hz)
b


L ~ T$^{4.5 \pm 0.5}$
L$_{DISKBB}$ (10^{42} erg s^{-1})
kT (eV)


XMM1
XMM2
XMM3 (and XMM4)
Chandra
Norm. spectrum (Cts s^{-1} keV^{-1} cm^{-2})
Energy (keV)
a


v F$_\nu$ (erg s^{-1} cm^{-2})
Frequency (Hz)
b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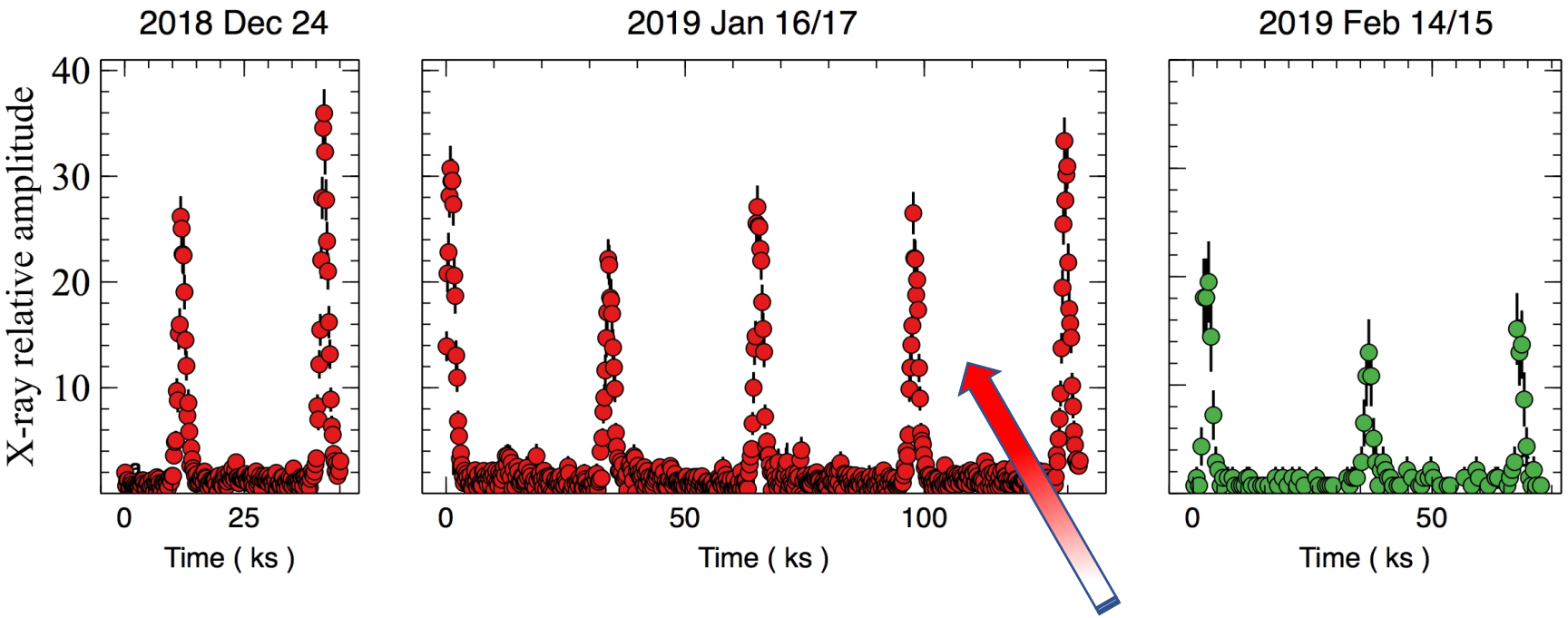
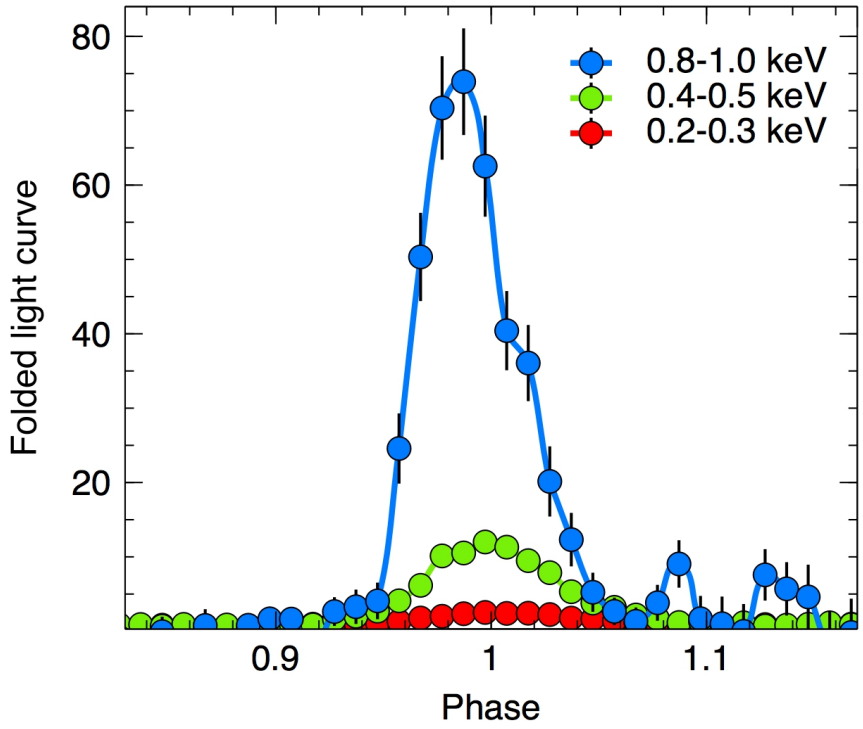
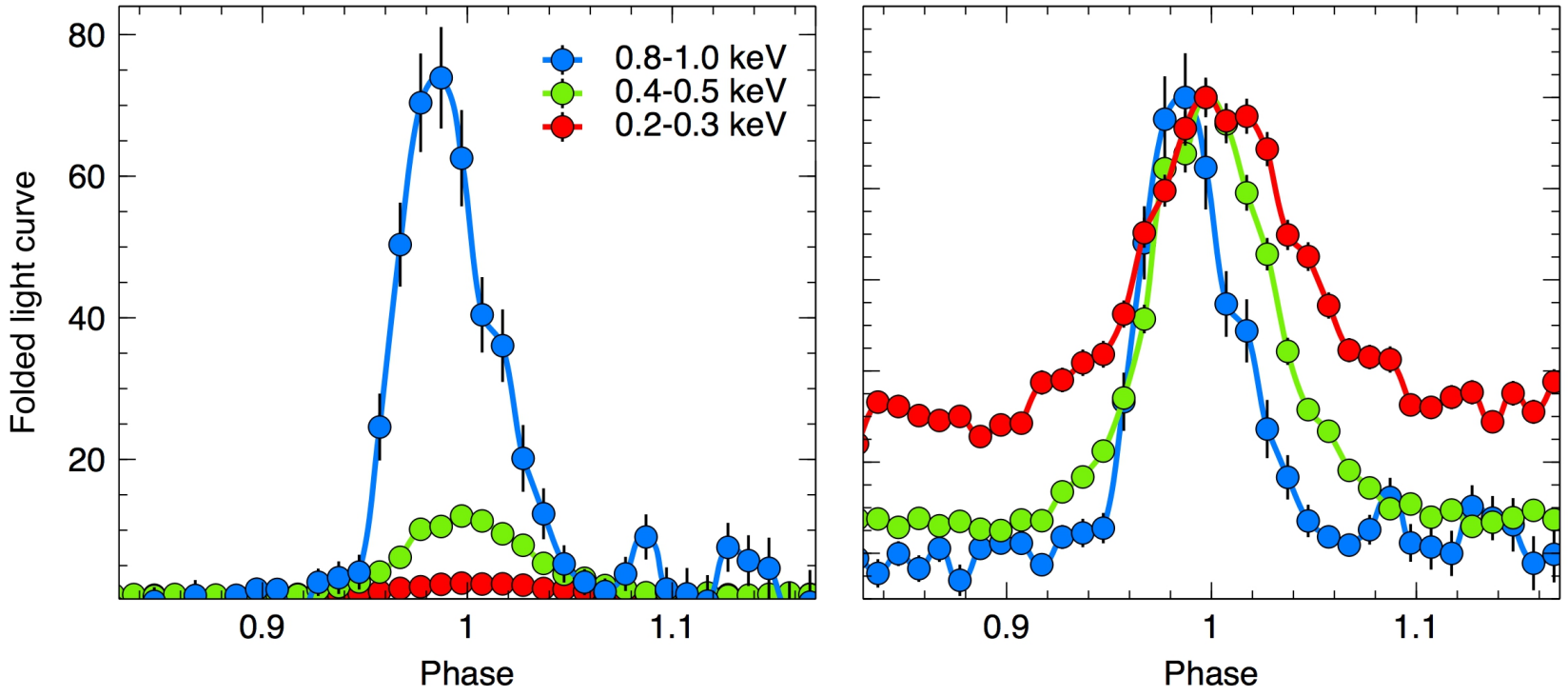
kT (eV)



QPE properties (from the 2019 Jan observation)



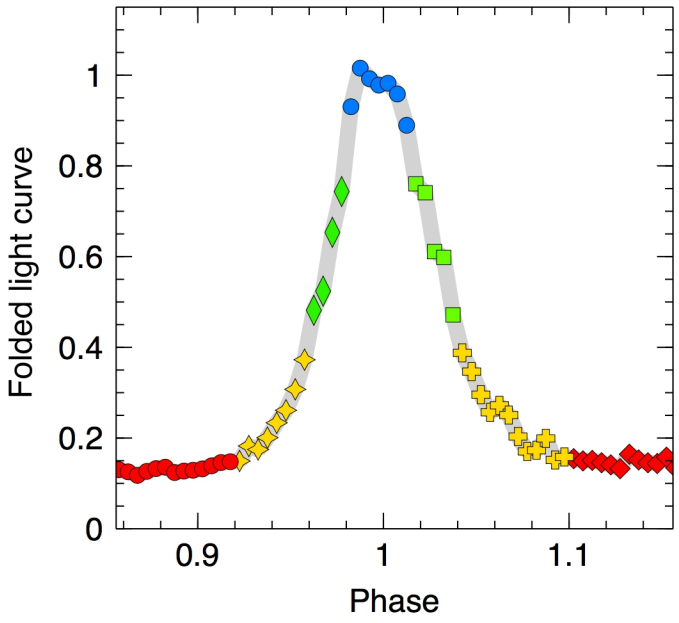
QPEs have much higher amplitude at higher energies

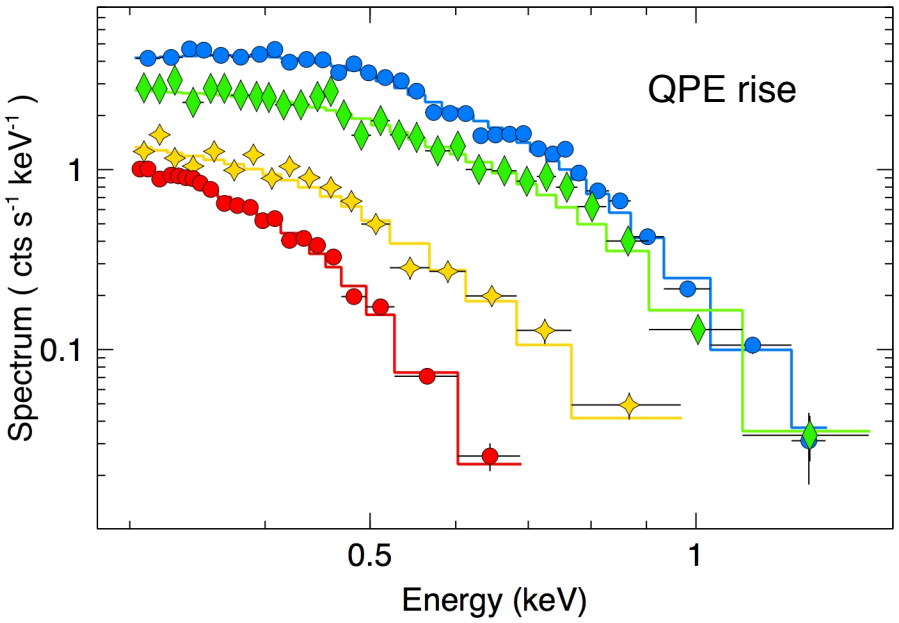


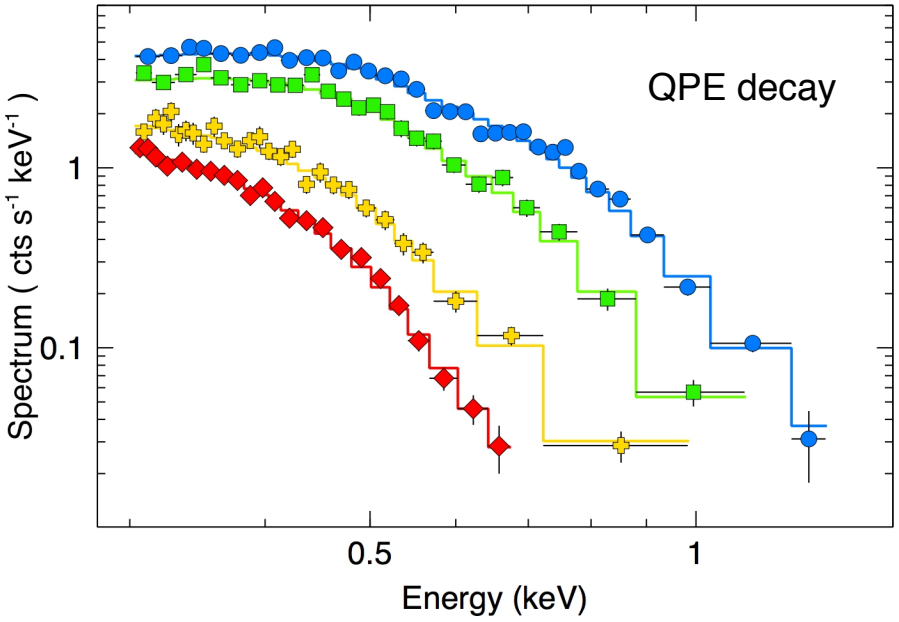
QPEs have much higher amplitude at higher energies

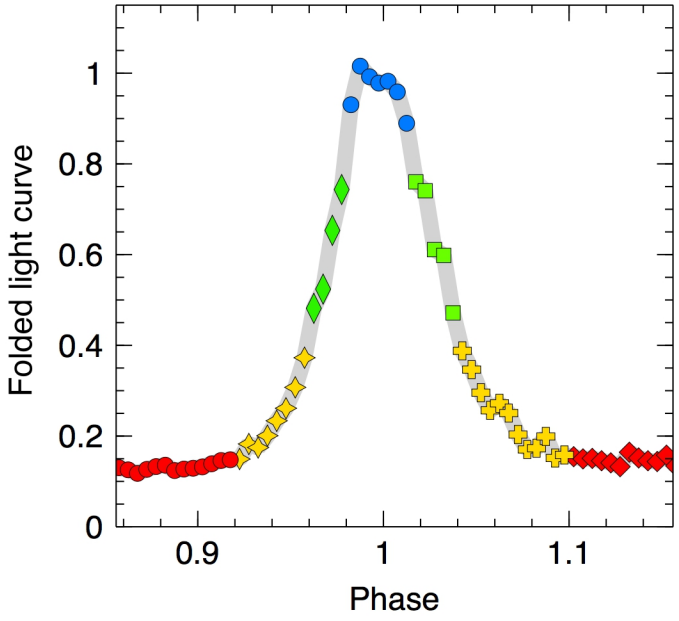
QPEs peak earlier at higher energies

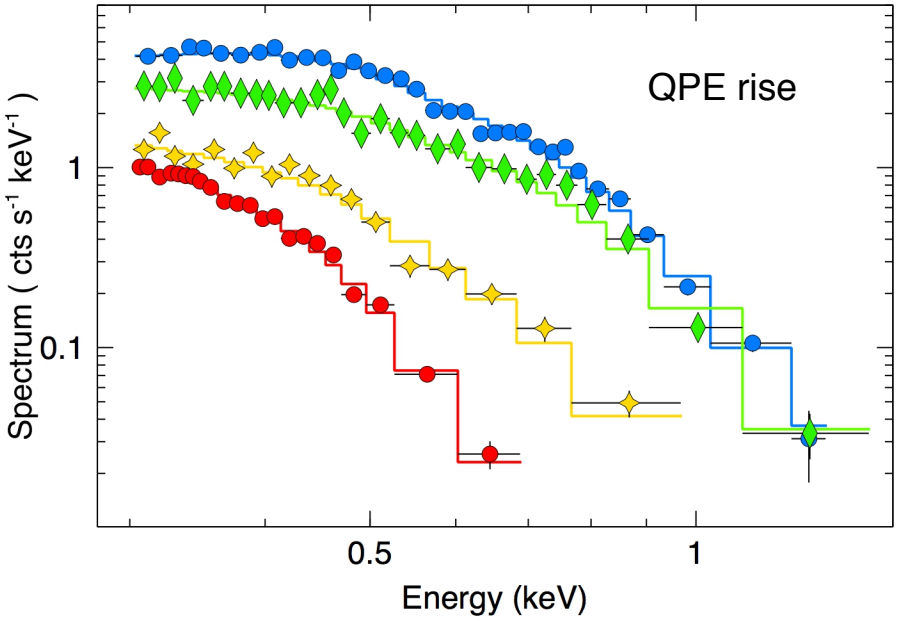
QPEs are faster (narrower) at higher energies


Folded light curve
Phase
0
0.2
0.4
0.6
0.8
1
0.9
1
1.1


QPE rise
Spectrum (cts s^{-1} keV^{-1})
Energy (keV)
0.1
1
0.5
1


QPE decay
Spectrum (cts s^{-1} keV^{-1})
Energy (keV)
0.1
1
0.5
1





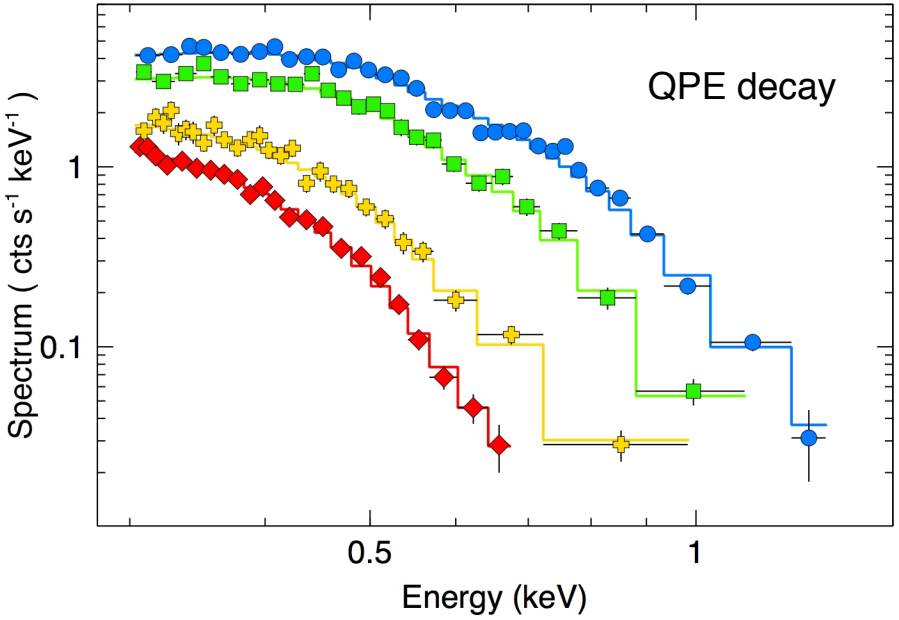
QPEs are smooth, short-lived oscillations

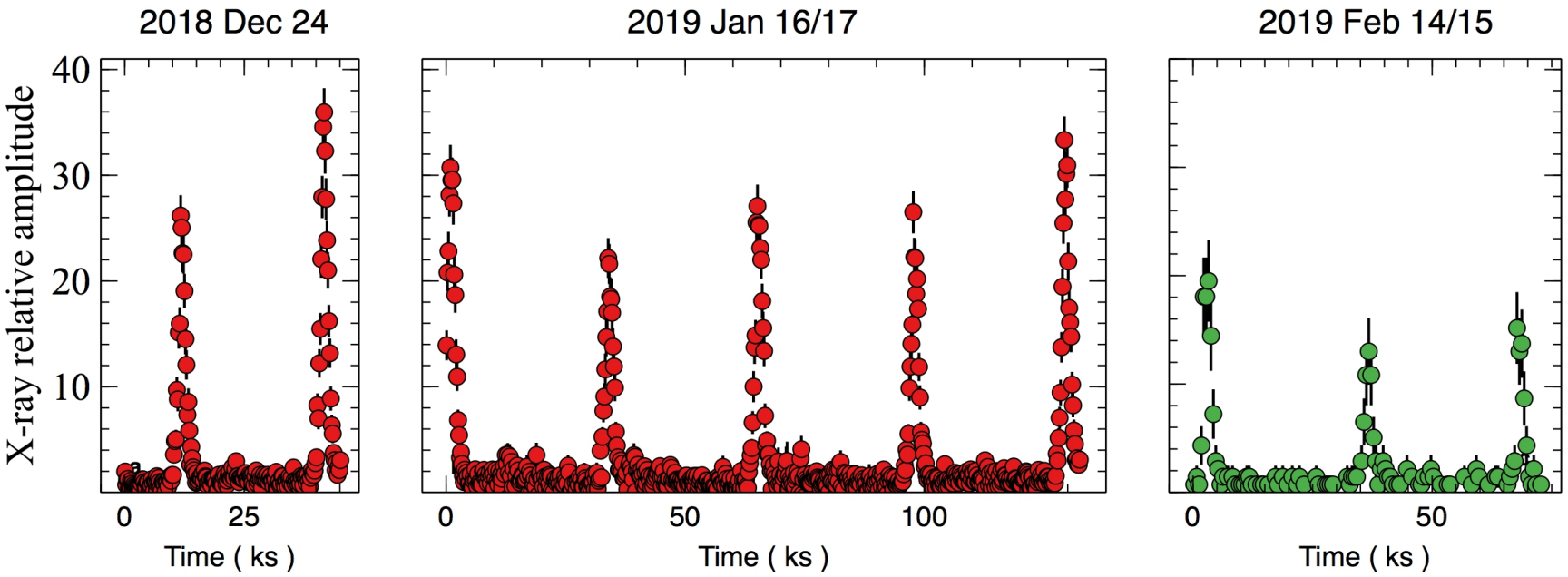
between

‘cold’ (~ 50 eV)

‘warm’ (~ 120 eV)

phases





QPE analogy with Changing-Look AGNs

QPEs and changing-look AGNs [e.g. MacLeod et al. 2016]

AGNs showing (often unfeasibly) rapid continuum rise or decay accompanied by the appearance or disappearance of the optical broad lines

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AGNs showing (often unfeasibly) rapid continuum rise or decay accompanied by the appearance or disappearance of the optical broad lines

If related to QPEs:

→ similar numbers of CL AGNs in the rise or decay phases (QPEs are symmetric)
→ appearing/disappearing soft excess associated with the rise/decay phases

The two CL AGNs **Mrk 1018** and **Mrk 590** seem to be consistent with the latter

QPEs and changing-look AGNs [e.g. MacLeod et al. 2016]

- **Mrk 1018**
  [Cohen et al. et al. 1986; McElroy et al. 2016; Noda & Done 2018]

  type 2→1 transition ~ 1980 and type 1→2 transition ~ 2010
  the latest decay is well monitored (Swift and XMM) and the soft X-ray excess disappeared

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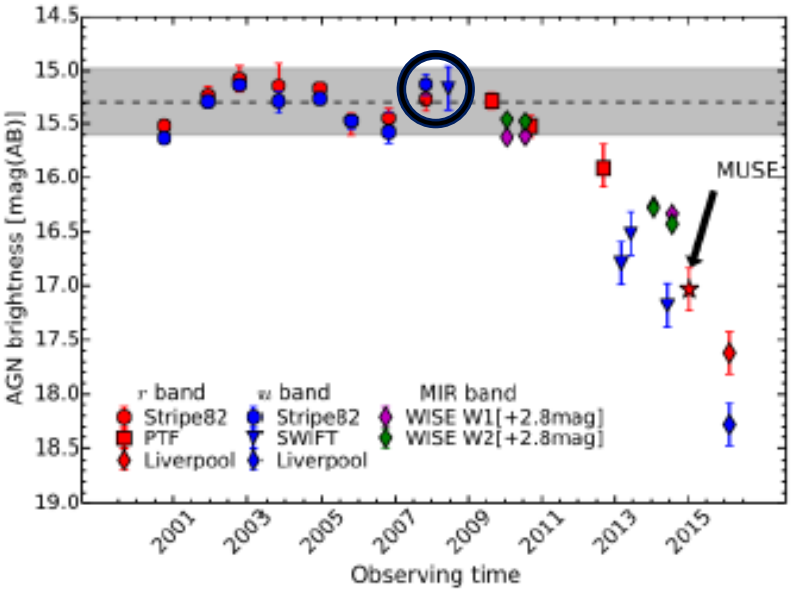

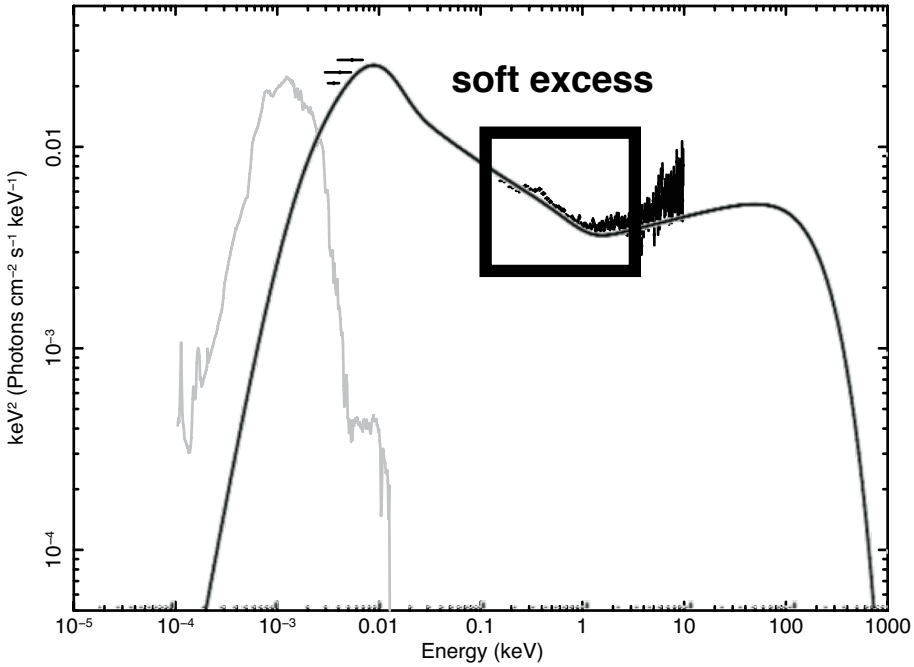

courtesy of Chris Done

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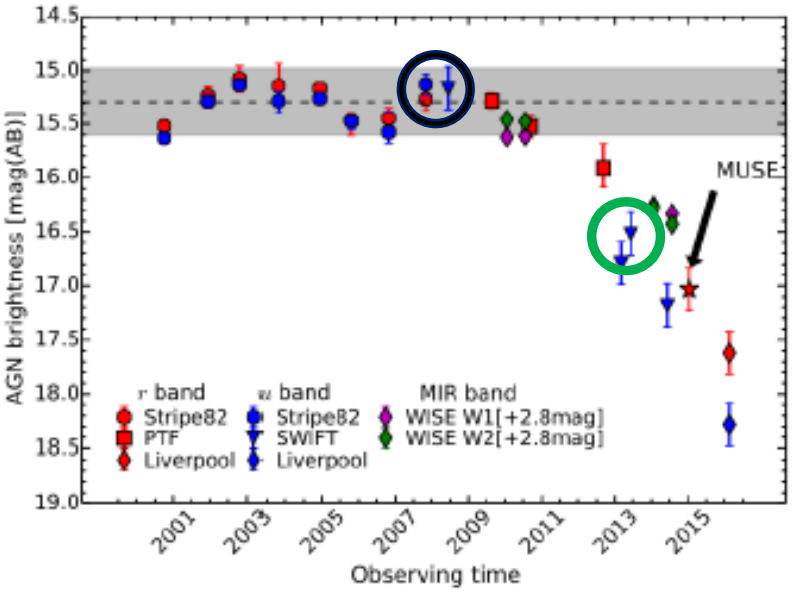

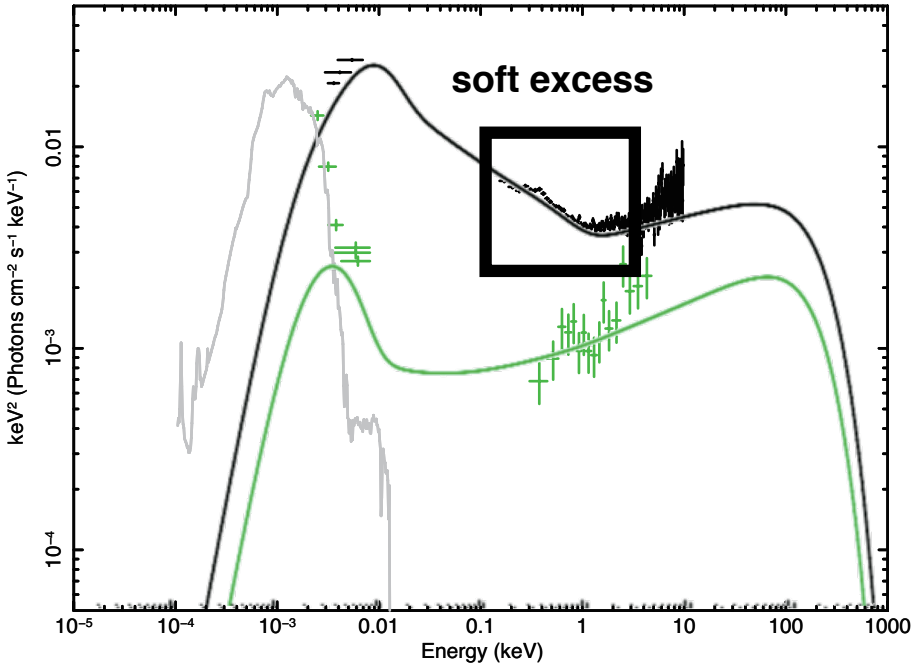

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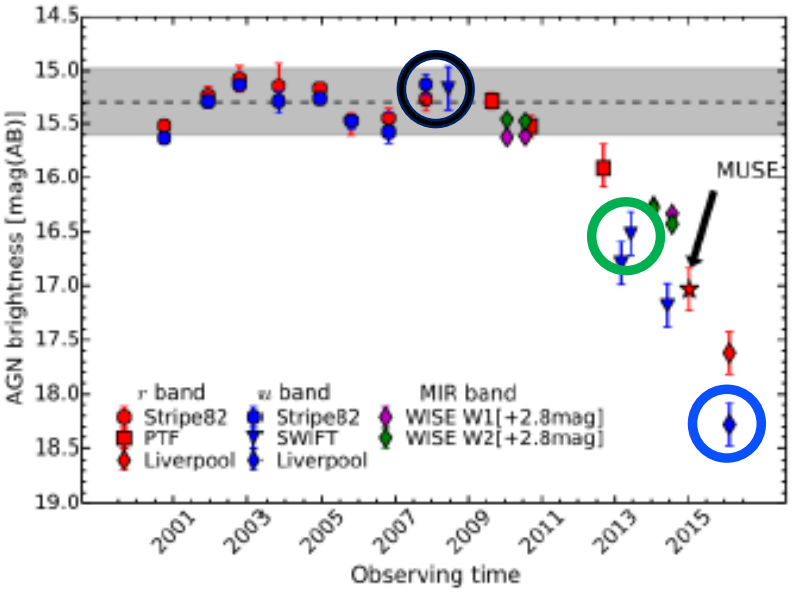
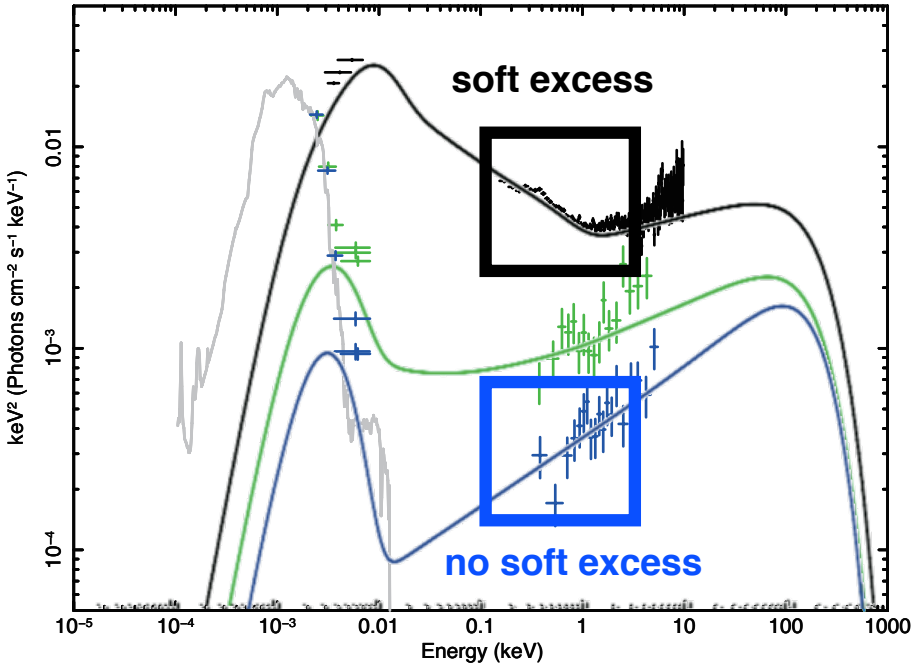




courtesy of Chris Done

(some) Possible QPE physical origin

QPEs are a new phenomenon that still requires further study

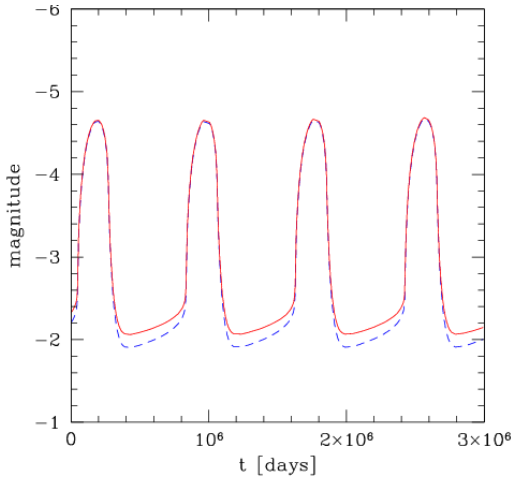
Few possible scenarios appear to be worth exploring in the future

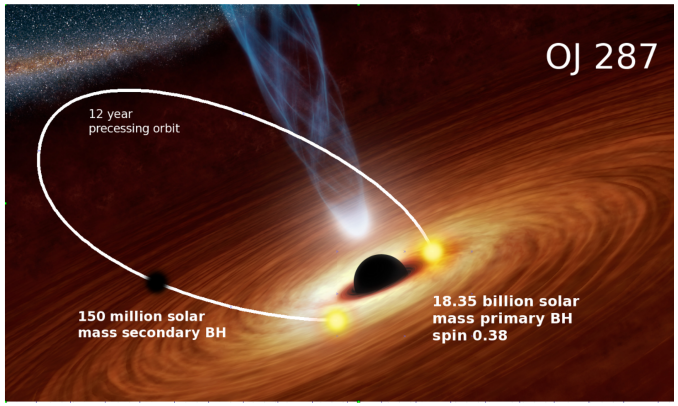
1. Limit-cycle oscillations due to disc instabilities

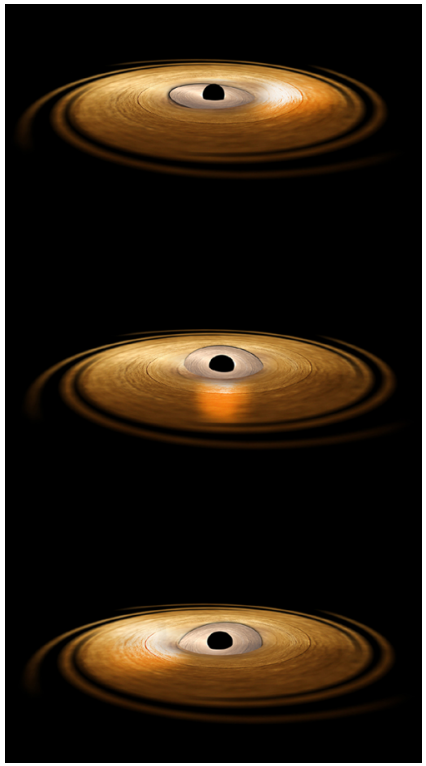
2. Interactions with a secondary orbiting body

3. Inner precessing torus-like flow with X-ray emitting funnel

4. … Ideas ? Contact us !







Summary and conclusions

QPEs in GSN 069 are fast, repeating oscillations between
- cold (~ 50 eV) disc-dominated
- warm (~ 120 eV) soft-excess-dominated

states

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QPEs may
→ be key for our understanding of soft excess origin and formation
→ provide a framework within which to interpret CL AGNs anf othe rapid variable objects

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→ provide a framework within which to interpret CL AGNs anf othe rapid variable objects

The QPE's physical origin needs to be firmply established: a few viable hypothesis out there

Summary and conclusions

QPEs in GSN 069 are fast, repeating oscillations between
cold (~ 50 eV) disc-dominated
warm (~ 120 eV) soft-excess-dominated
states

QPEs appear around ~ 0.5 Eddington in GSN 069 during the long-term decay that may be due to a TDE between 1994-2010, although the Sey 2 nature of GSN 069 has to be noted

QPEs are relatively stable and they are present over at least ~ 2 months

The ~ 80 eV 'cold' state during Chandra may indicate that QPEs a stable soft X-ray excess is forming which may suppress QPEs once established

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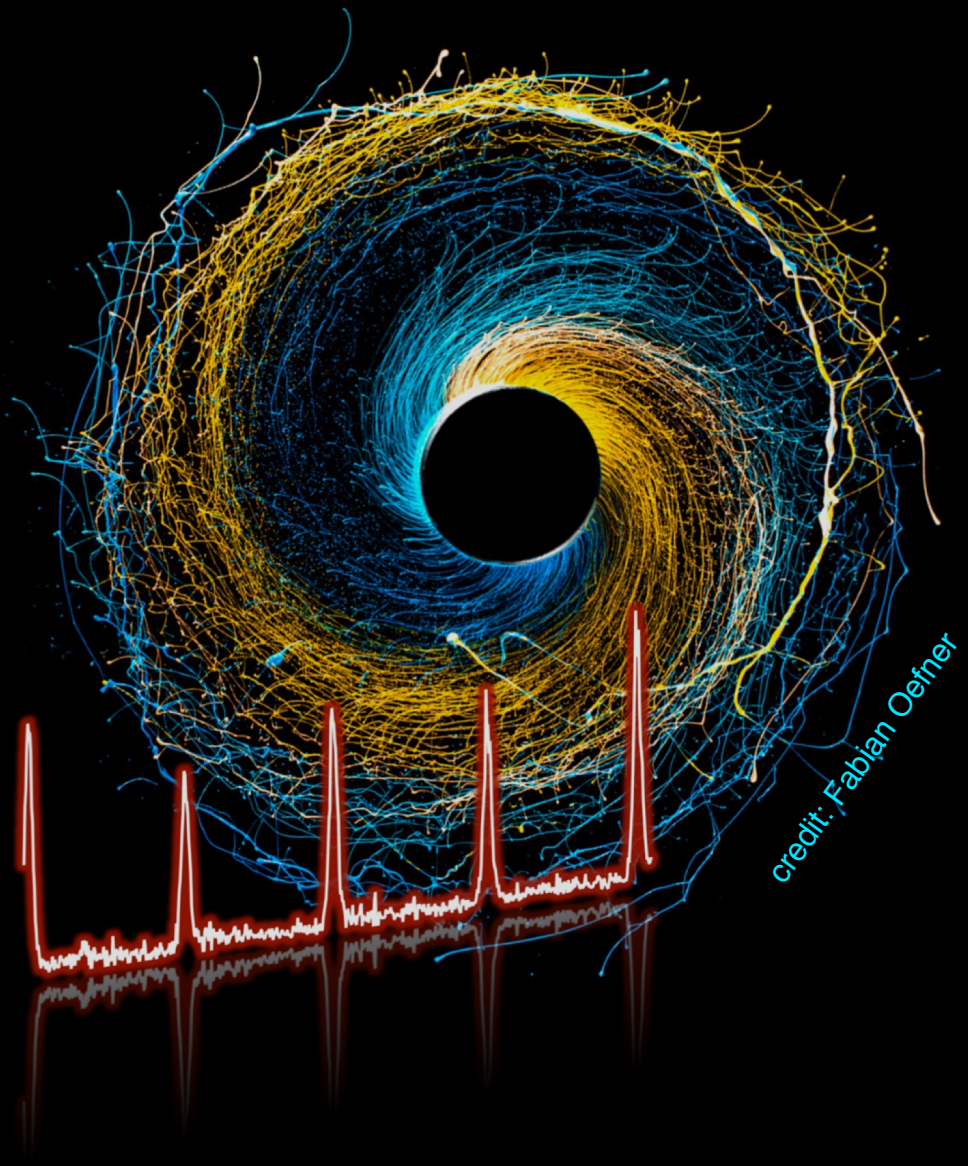
We are looking for other QPE AGNs in other galaxies: stay tuned
→ see poster No. 402 by Margherita Giustini !


credit: Fabian Oefner

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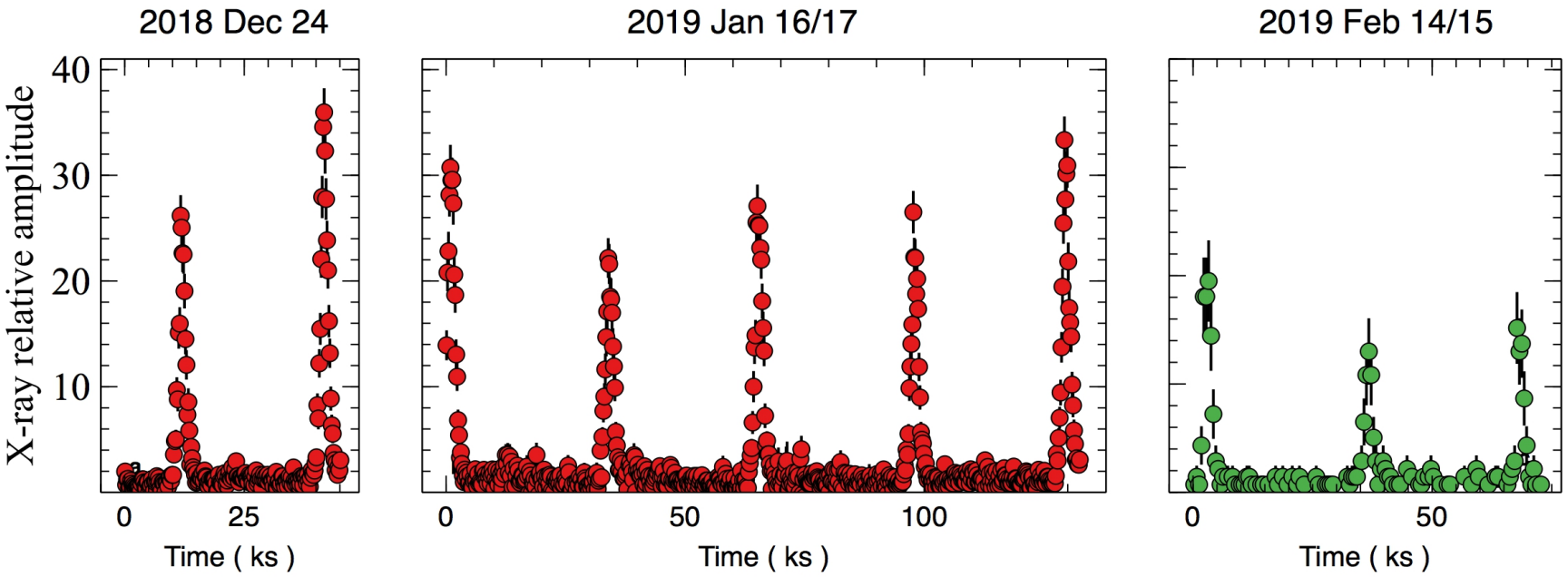
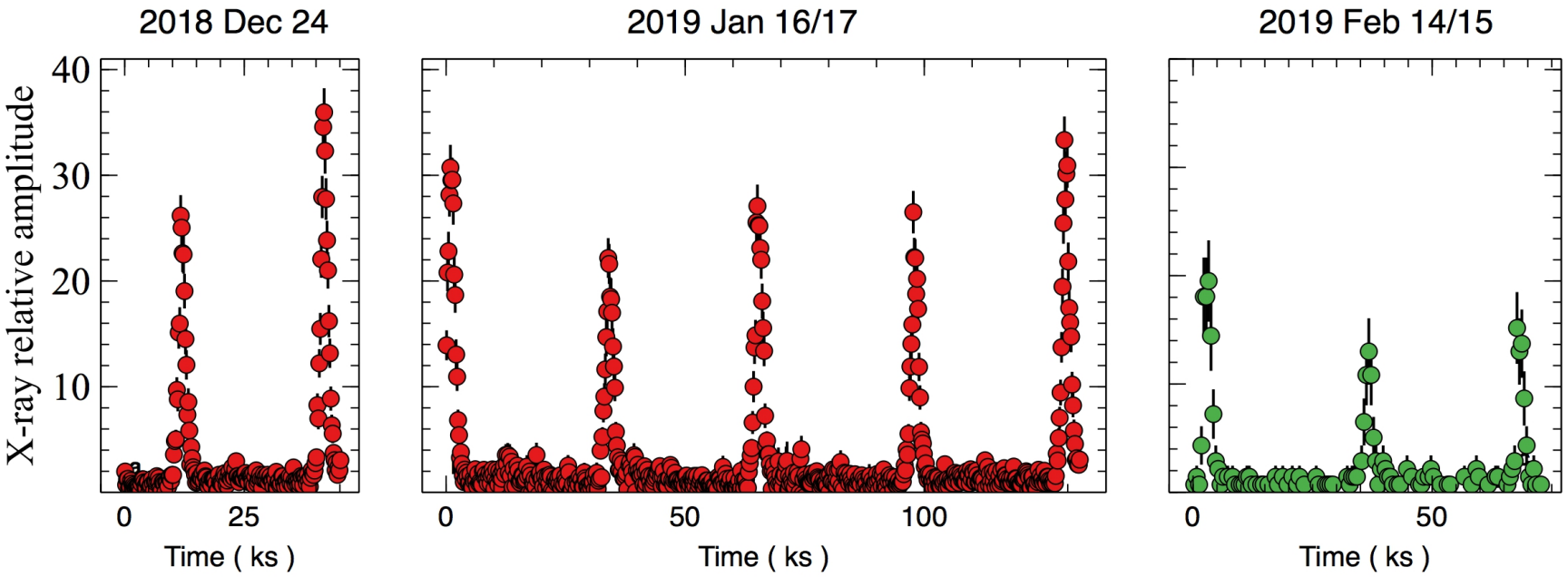


Back-up slides



The quiescent level long-term evolution

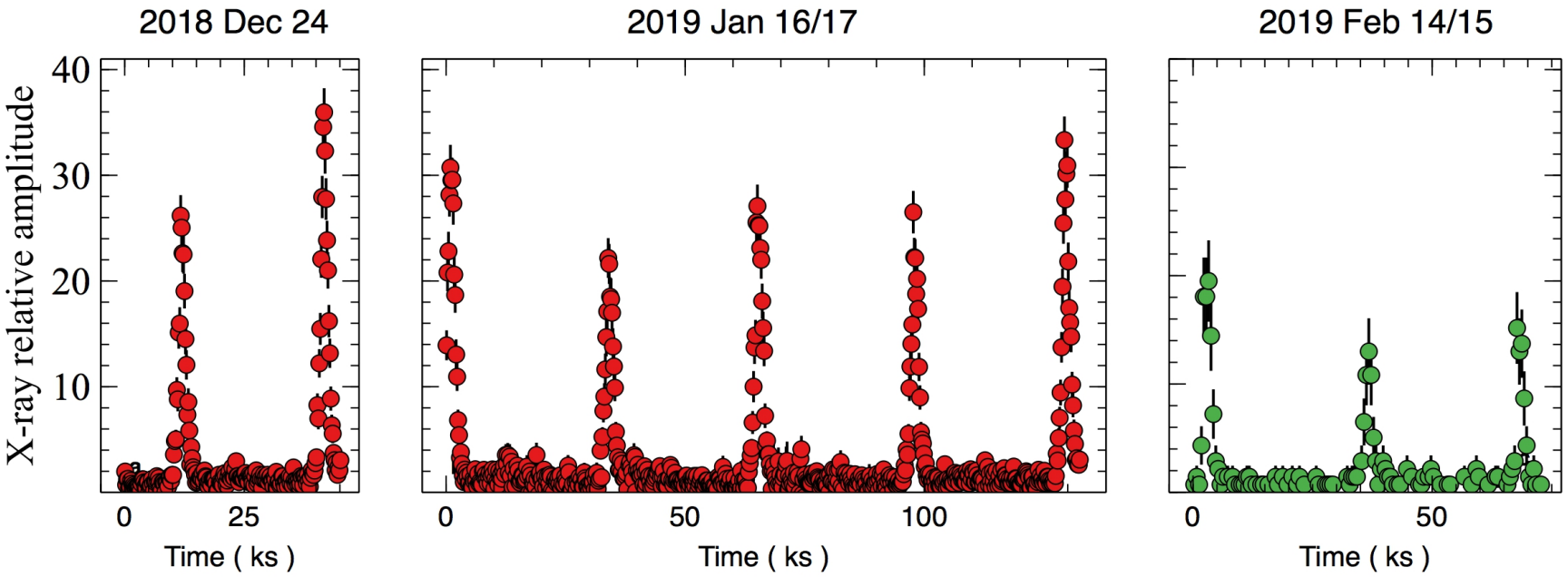
L_X (max) ~ 1 × 10^{43} erg s^{-1} and **L_{bol} (max) ~ 5 × 10^{43} erg s^{-1}**

L ∝ T^4 untill January 2019 which can be used to infer **M_{BH} ~ few × 10^5 $M_\odot$**

→ hence, the Eddington ratio approximately decays fro ~ 1 to 0.1

Chandra data suggest that a **transition between a disc-dominated and a soft-excess-dominated state** takes place in less tan one month (2019 January-February)

2-10 keV L_X very weak and ~ constant over ~ 10 years



QPE properties

QPEs recur about every 9 hours with peak $L_X \sim 5 \times 10^{42}$ erg s^{-1}

QPE amplitude is max in 0.6-0.8 keV (~ 100) and no QPEs are present below ~ 0.1 keV

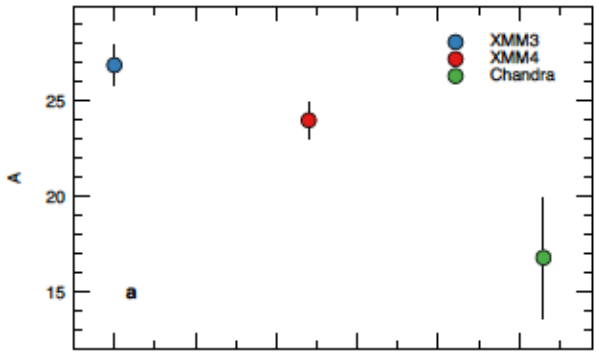
QPEs peak earlier and are narrower (faster) when measured at higher energies

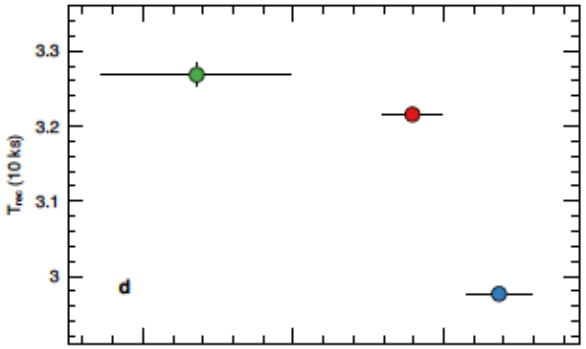
QPEs are fast oscillations between 'cold' (~ 50 eV) and 'warm' (~ 120 eV) states

→ **transient ecursions into soft-excess-dominated states ?**
→ **Chandra quiescent state (~ 80 eV) as intermediate stage of soft excess formation ?**

QPE properties long-term evolution

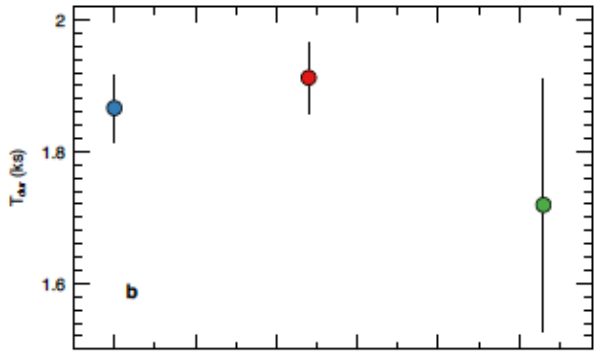
QPE amplitude

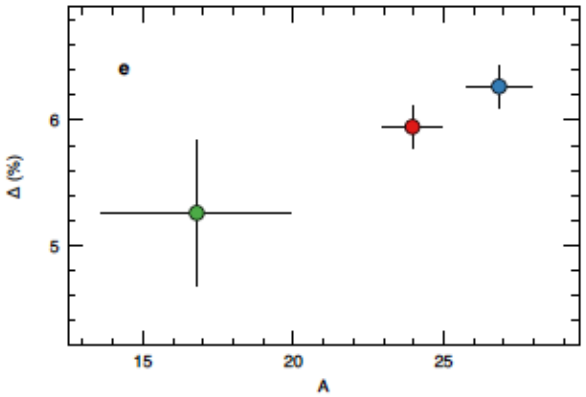




QPE recurrence

QPE duration

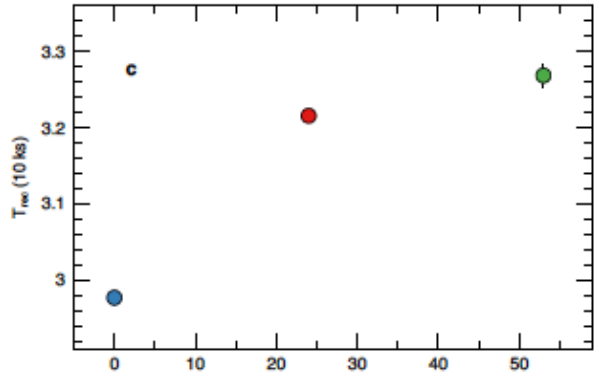




QPE duty cycle

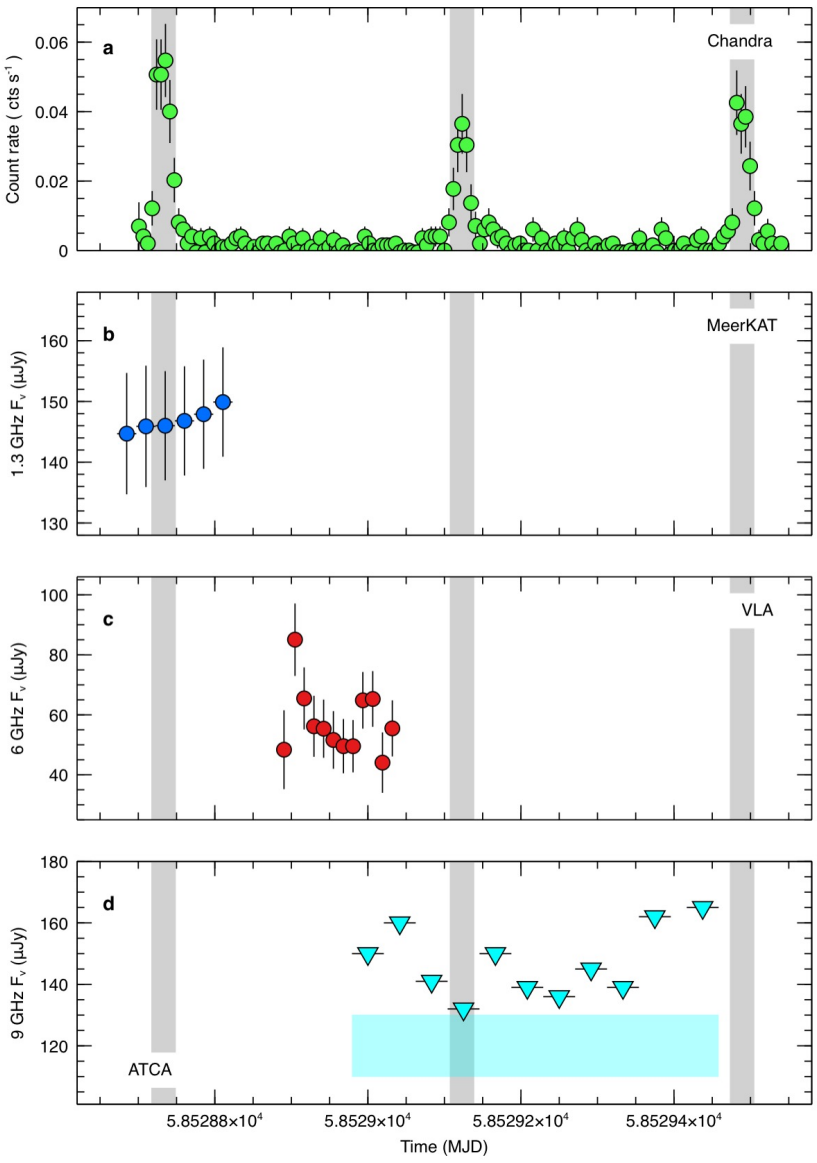
QPE amplitude

QPE recurrence

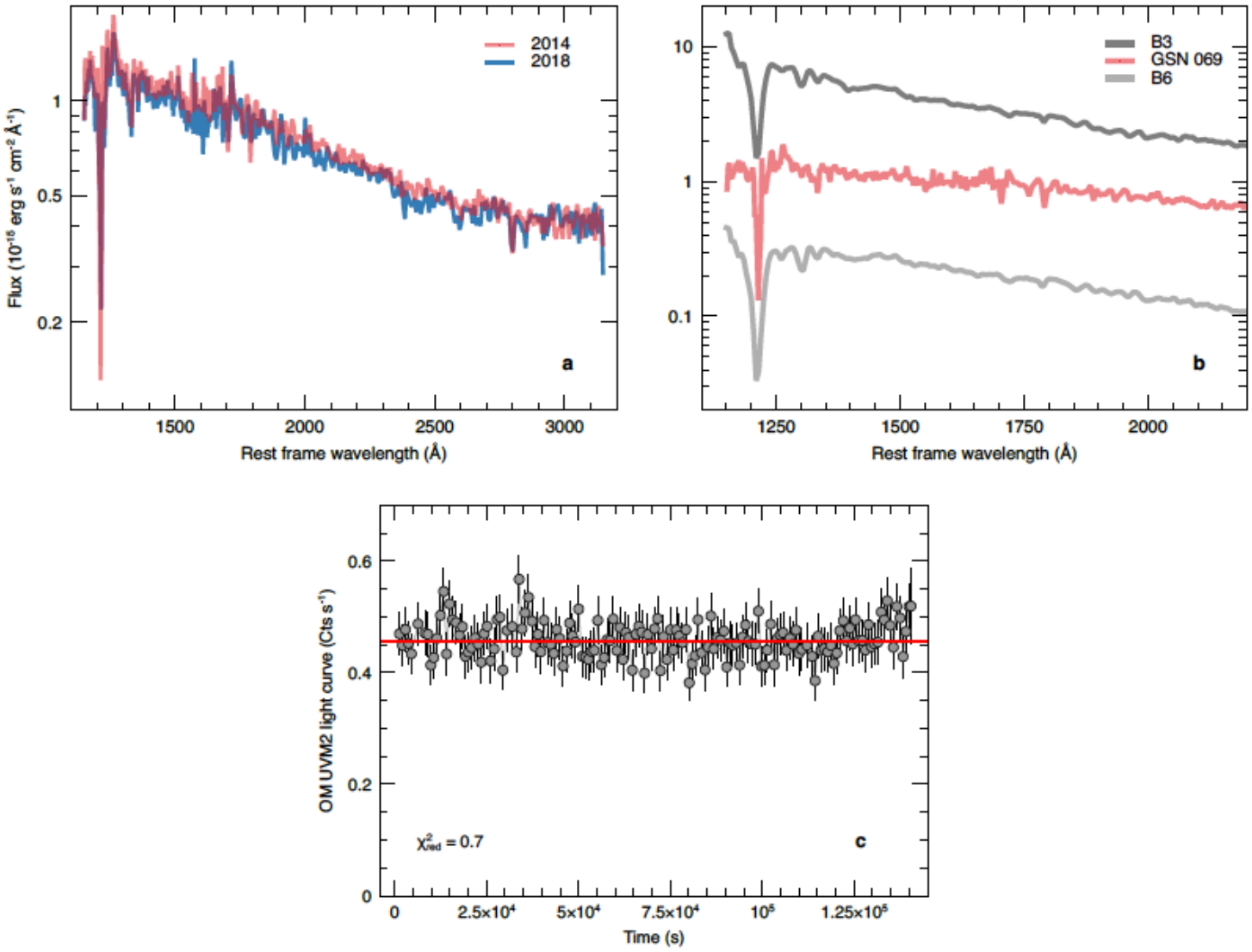


Time since 2018 Dec 24

The 2019 Feb Chandra/MeerKAT/VLA/ATCA campaign

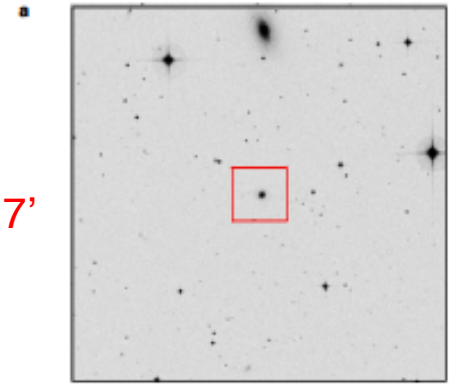


UV properties of GSN 069: a nuclear stellar cluster ?

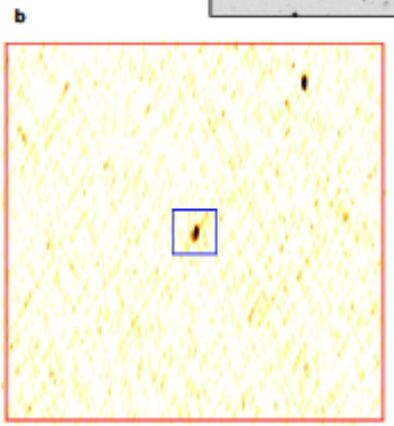


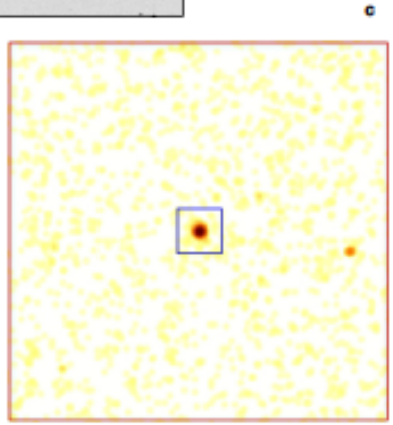
X-ray source position

DSS 12’ x 12’
red square 1.7’ x 1.7’



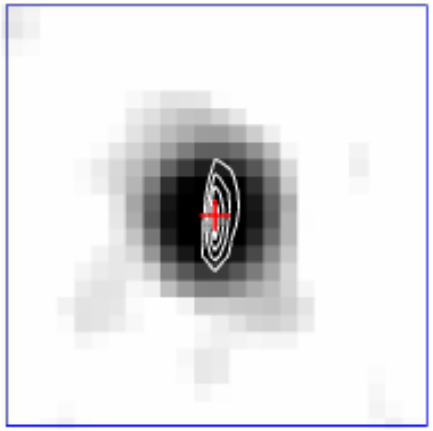
VLA 1.7’ x 1.7’
blue square 12” x 12”





Chandra 1.7’ x 1.7’
blue square 12” x 12”

Chandra 12” x 12”
with VLA 6GHz and
2MASS position



QPEs and changing-look AGNs [e.g. MacLeod et al. 2016]

- **Mrk 590**
  [Denney et al. 2014; Rivers et al. 2012; Longinotti et al. 2018Mathur et al. 2018; Raimundo et al. 2019]

  the continuum faded away during the past ~ 2 decades
  the broad emission lines gradually disappeared
  the soft X-ray excess faded away

  Mrk 590 is now awakening and broad lines have been recently detected
  + a weak soft X-ray excess also re-emerged !

  → **possibly recurrent phenomenon**
  → **possible confirmation of QPE/CL AGNs association via the soft excess**