MISSING HARD STATES AND REGULAR OUTBURSTS: THE PUZZLING CASE OF THE BLACK HOLE CANDIDATE 4U 1630-472

F. CAPITANIO[1]

R. CAMPANA[2], G. DE CESARE[2], C. FERRIGNO[3]

[1]INAF-IAPS, Roma, Italy

[2]INAF-IASF, Bologna, Italy;

[3]INTEGRAL Science Data Centre for Astrophysics, Versoix, Switzerland

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Outline of the talk

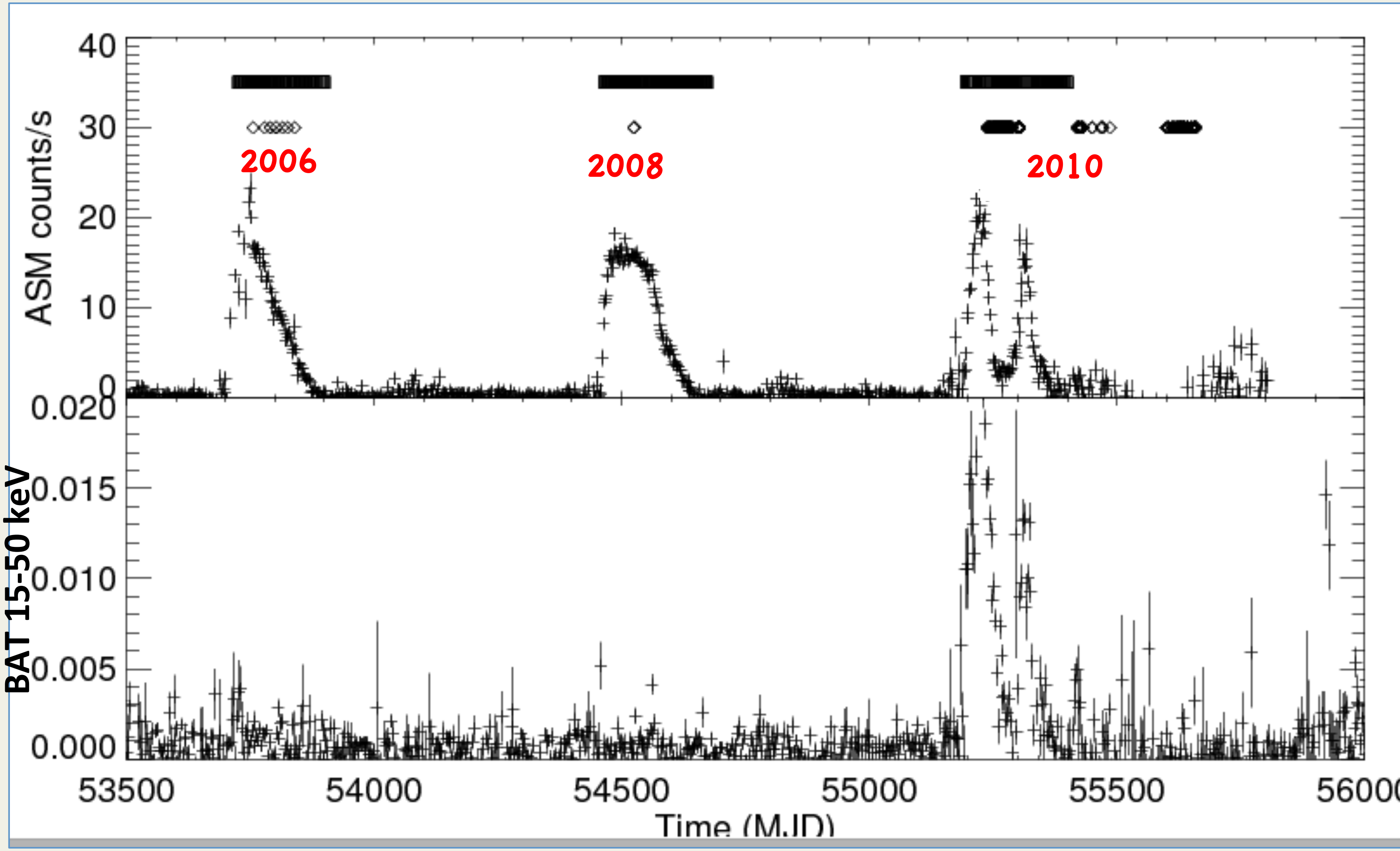
- What we know about 4U 1630-472
- The 3 outbursts observed by INTEGRAL and RXTE
- Light curve and spectral evolution
- Comparison among the 3 outbursts
- The equally time spaced (*ets*) outbursts
- The possible explanations for *ets* outbursts
- Results summary and discussion
- Conclusions

4U 1630-472

- BHC (e.g. kuulkers et al. 1998)
- No detection of any optical counter part
- IR detection: no conclusive results on the companion nature.
- Estimated period≈few days (Augustejin et al. 2011)
- Estimated distance: ≈10-11 kpc (Augustejin et al. 2011)
- Estimated mass (scaling technique): 10 M_{sun} (Seifina et al. 2014).
- Detection of two dips in the X-ray light curve: $i \geq 70°$ (kuulkers et al. 1998, Tomsick 1998)

- Often but not always: radio stationary and transient jets detection (Hjellming et al. 1999, Diaz Trigo et al. 2013)
- Sometimes lack of bright hard states (Tomsick et al. 1998)
- Periodical outbursts with a constant period of 600 days (Parmar et al.1995)

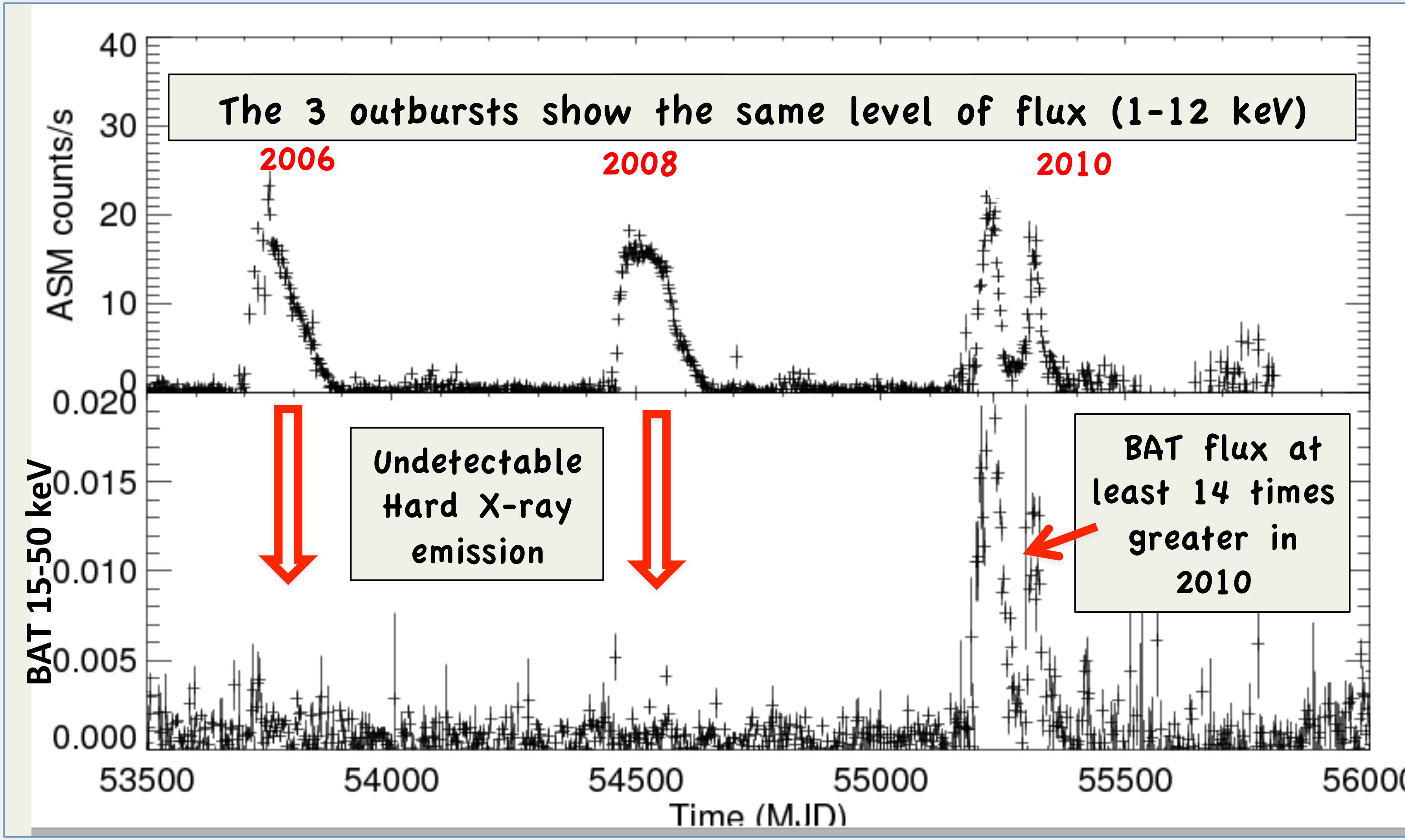
The 3 outbursts observed by INTEGRAL and RXTE



INTEGRAL observations (850 ks)

RXTE observations (800 ks)

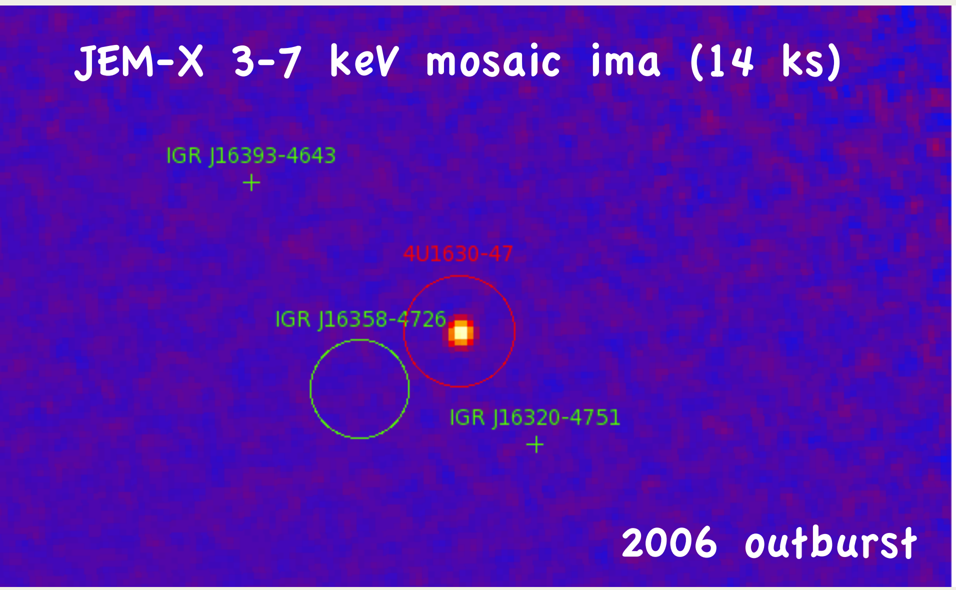
Light curve evolution of the 3 outbursts

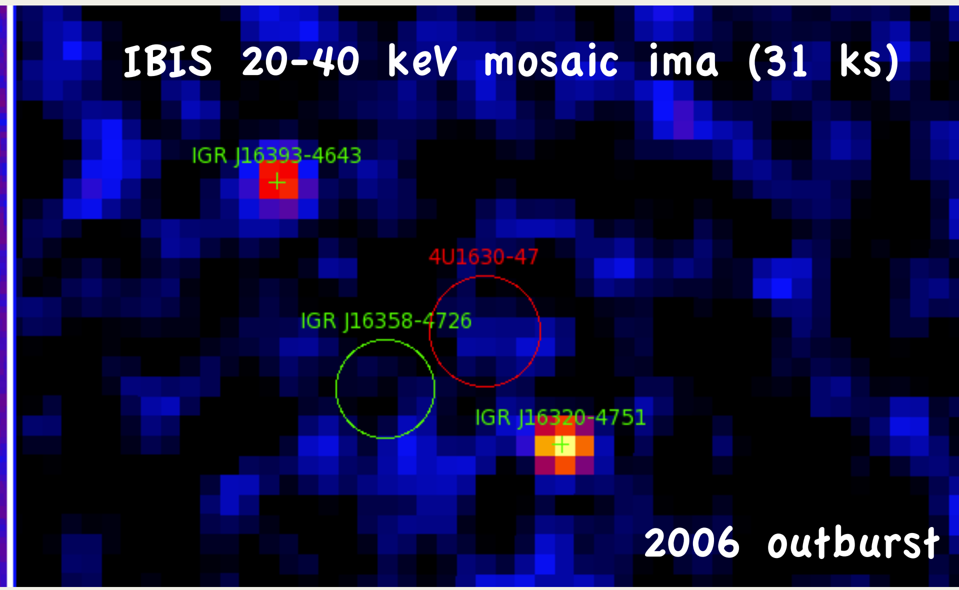


1σ BAT detection sensitivity is 5.3 mCrab for a full-day observation (Krimm et al. 2013)

Contamination by the nearby sources

The PCA FOV has a radius of 1°. Thus the data of 4U 1630-472 could be contaminated by two nearby HMXRB lying within the FOV: IGR J16320-4751 and IGR J16393-4643.
The latter source was not active during the 3 outbursts. While the former contaminates the PCA data with less than 50 counts/s

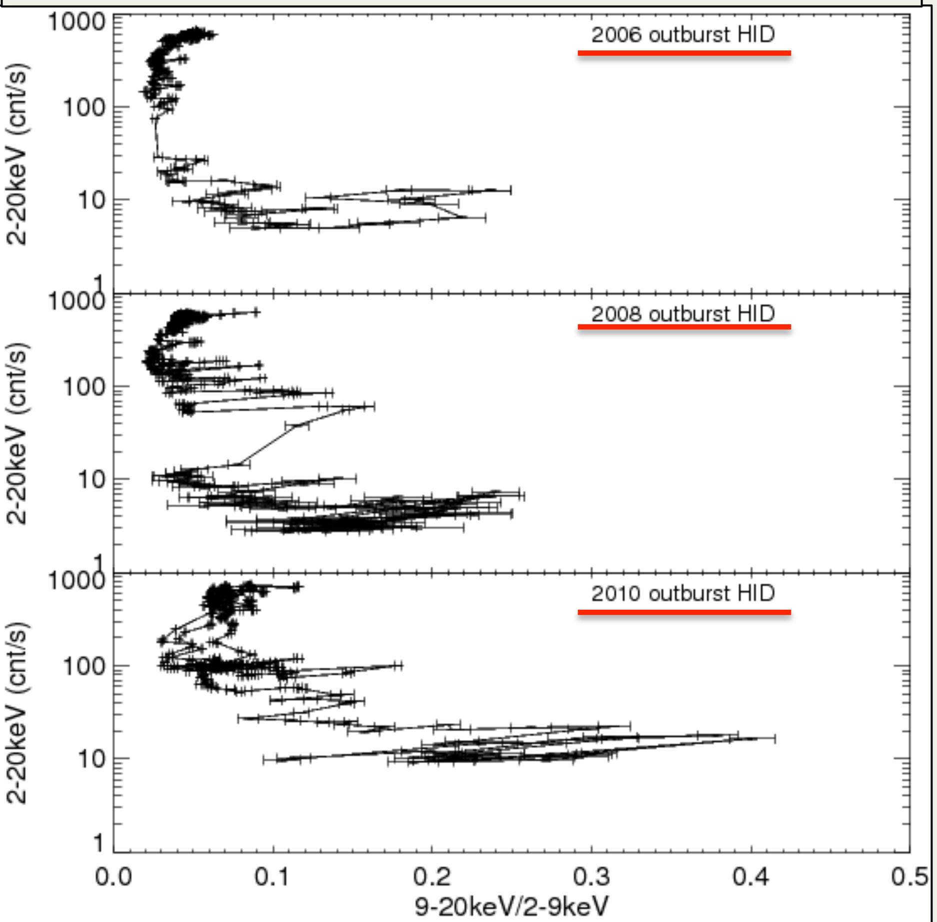


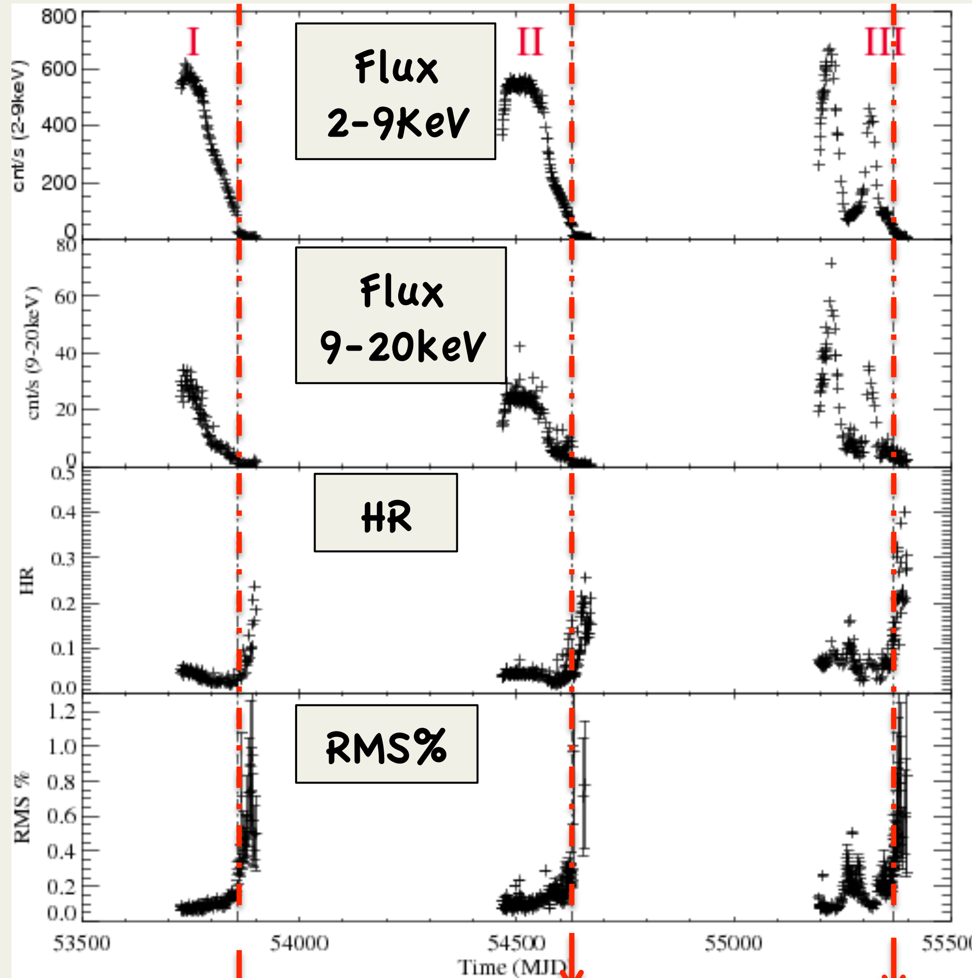


20-40 keV IBIS upper limits : 2006: 3mCrab (31ks)
2008: 5mCrab (25ks)

3-7 keV JEM-X detection level: 2006: 270mCrab
2008 no JEM-X coverage

Hardness intensity diagram:



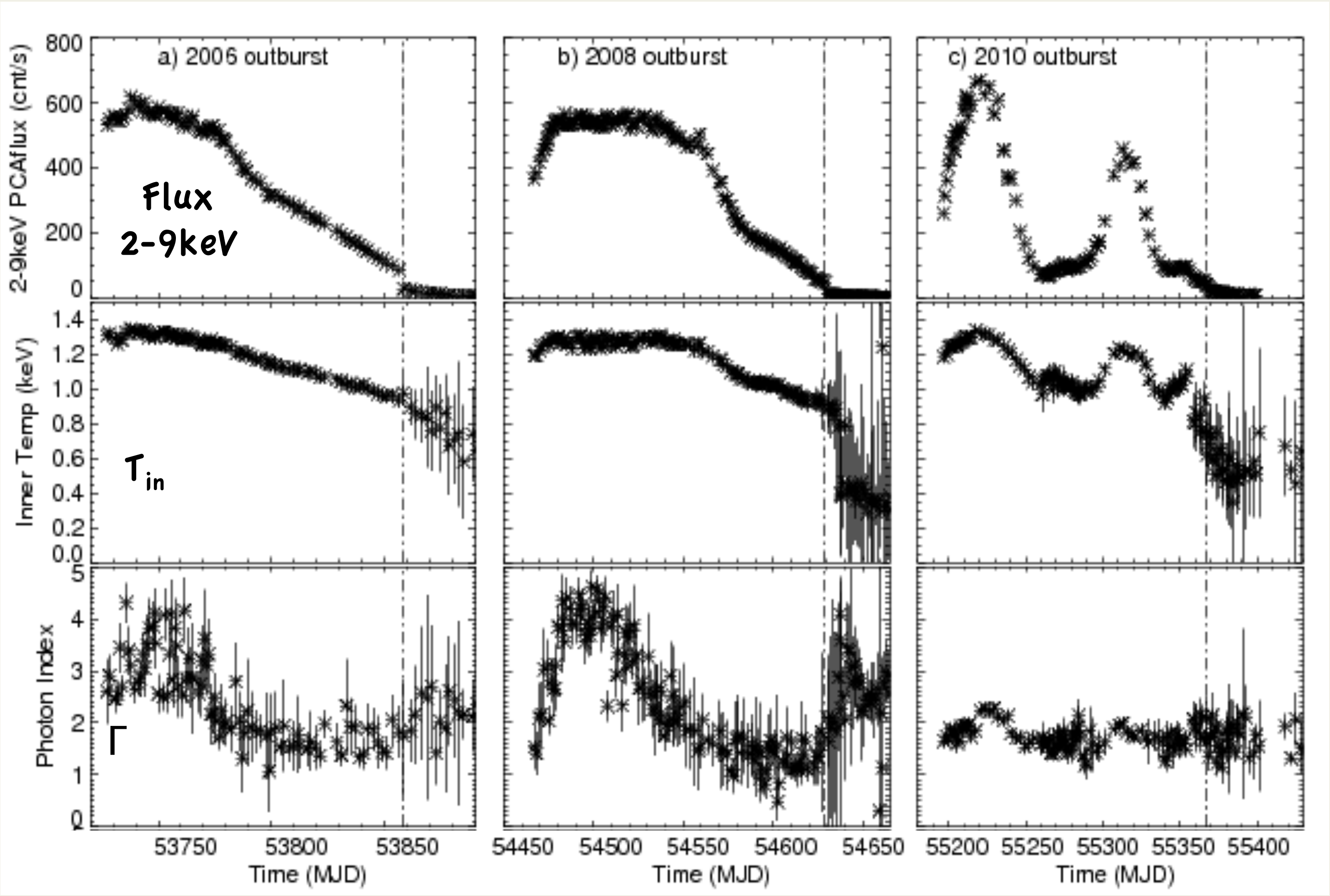


The HR is mostly identical for the 2006 and 2008 outbursts
While the HR of the 2010 outburst evolves at higher energies

50 counts/s flux limit for data contamination by nearby sources

Spectral evolution
Flux variation vs model parameter evolution

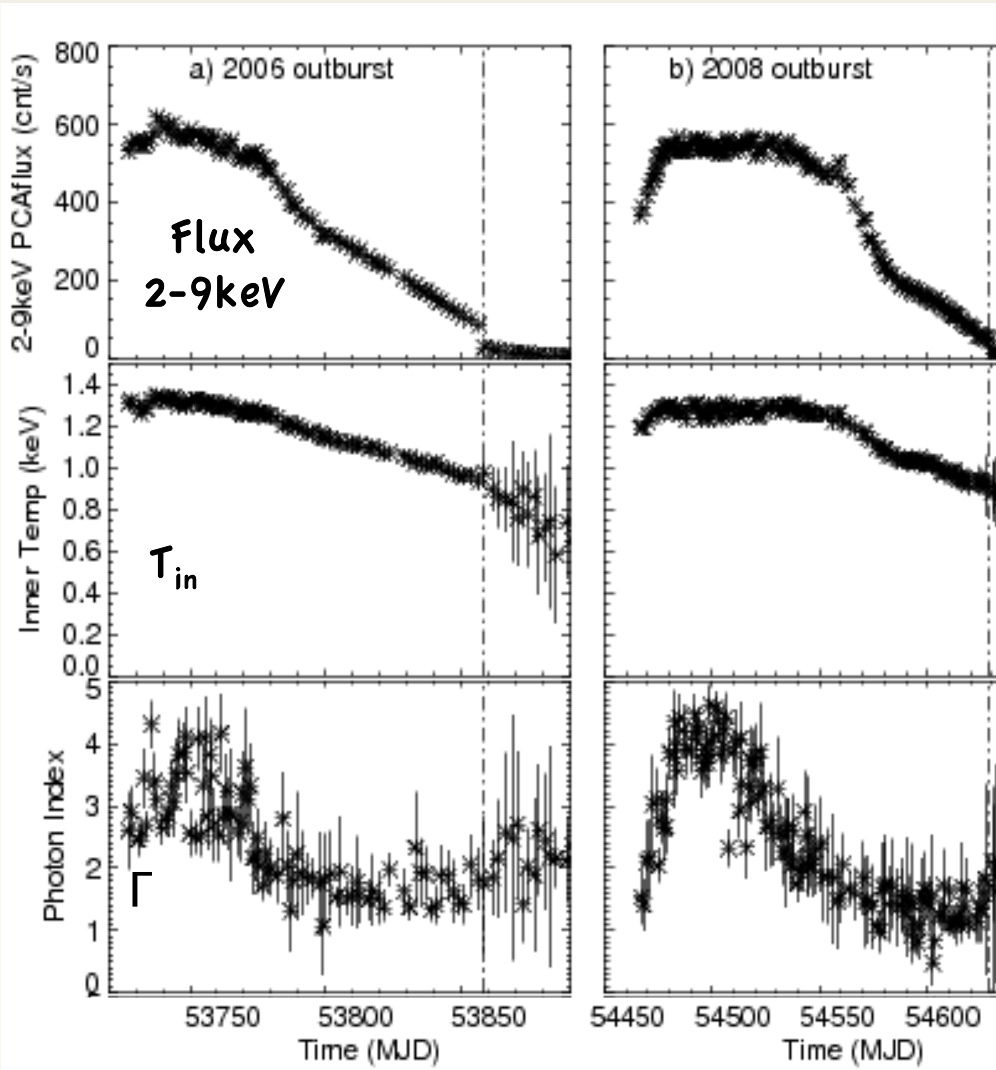
wabs*(diskbb+pow)



2006 2008 2010

Spectral evolution
Flux variation vs model parameter evolution

wabs*(diskbb+pow)



2006 2008

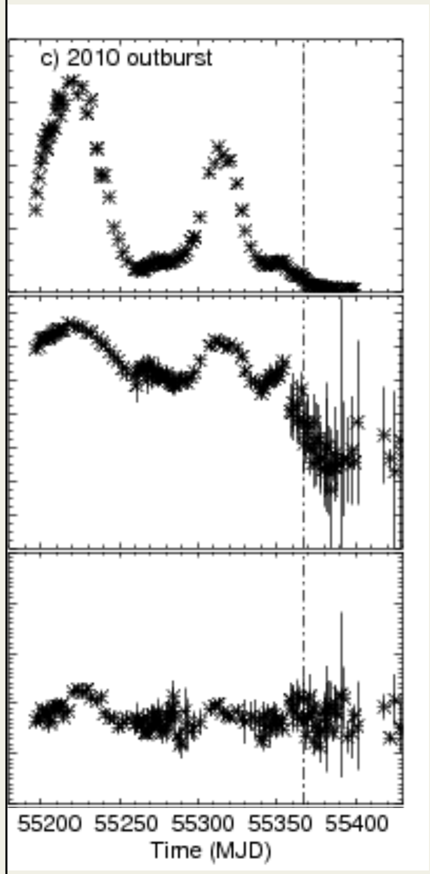
The 2006 and 2008 outbursts have almost the same spectral evolution.

- The Dsikbb dominates the spectra from the first obs. till the end of the two outbursts.
- Even if required in the fit, the power law component has low flux especially at the beginning ($F<4\times10^{-11}$ ergs cm^{-2} s^{-1}) with very soft values of photon index
- At the end of the outbursts the photon index remains mostly constant ≈1.8.
- No cut-off until 30 keV.

Spectral evolution
Flux variation vs model parameter evolution

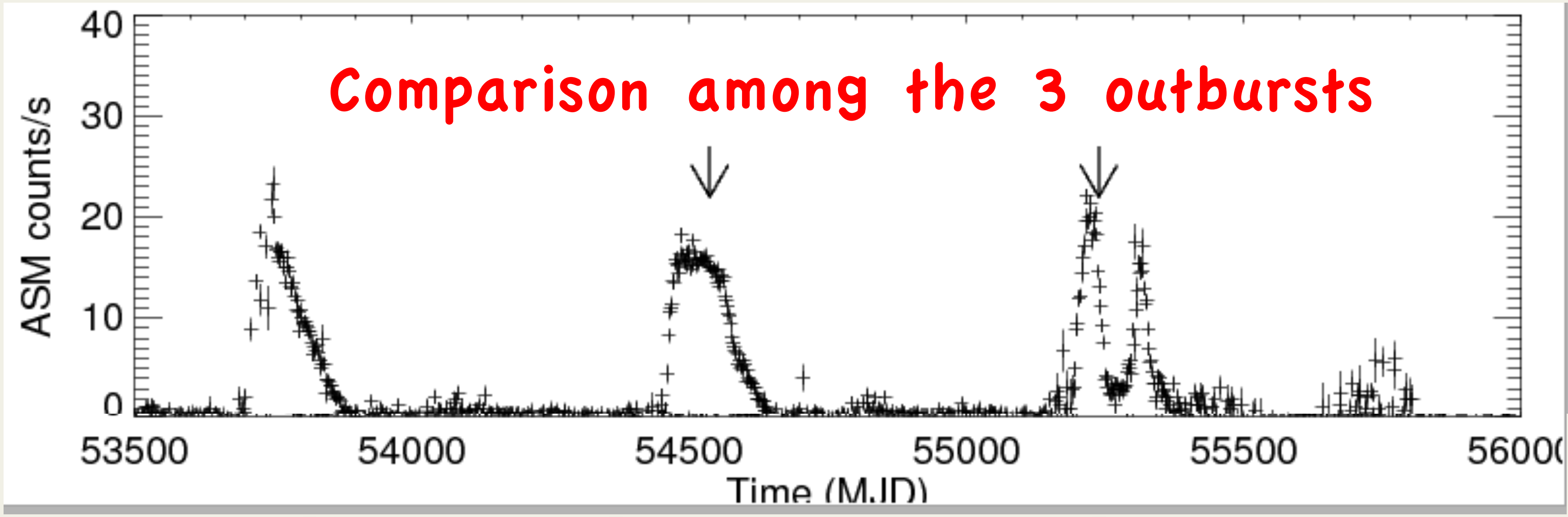
The 2010 outburst shows different evolution

- The light curve shows two subsequent softening with an increase of both the inner temperature and the photon index.
- As for the previous outbursts, during the final phases, the diskbb component remains prominent.
- the averaged value of the photon index is of ≈1.7.
- The 2010 outburst is clearly detected in BAT and IBIS.
- The IBIS data show no cut-off until 150-200 keV

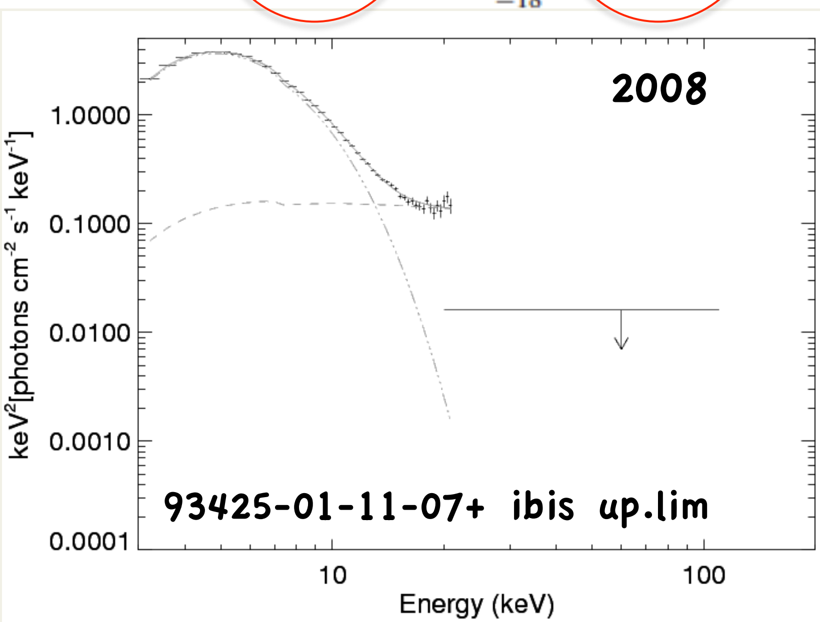


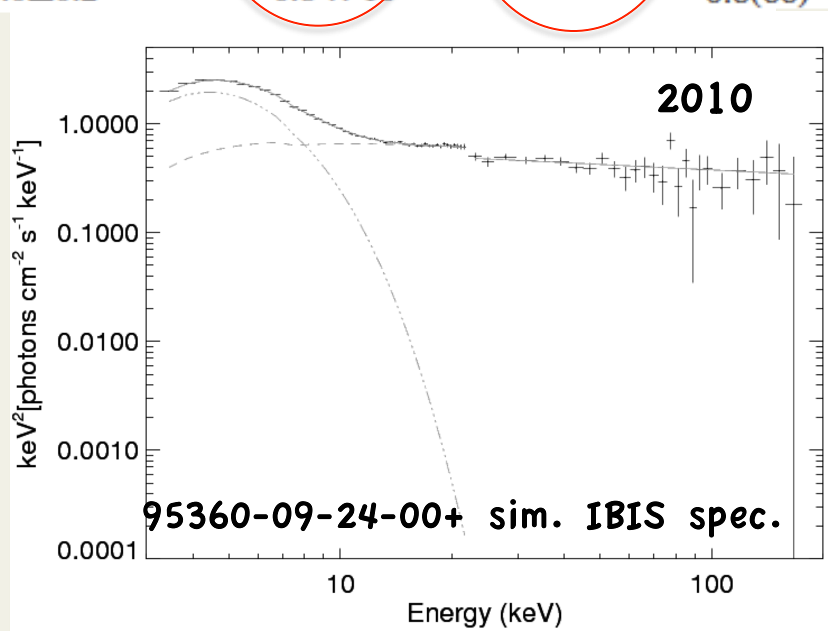
2010

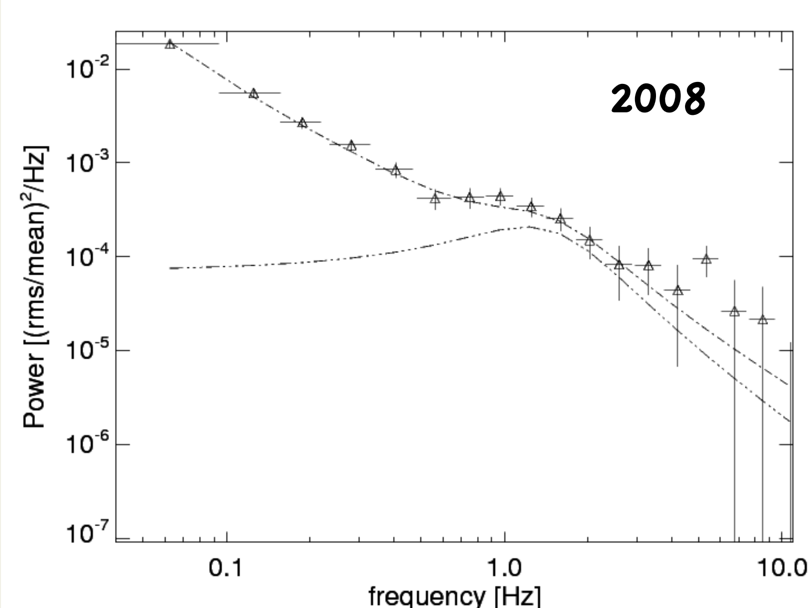
Comparison among the 3 outbursts

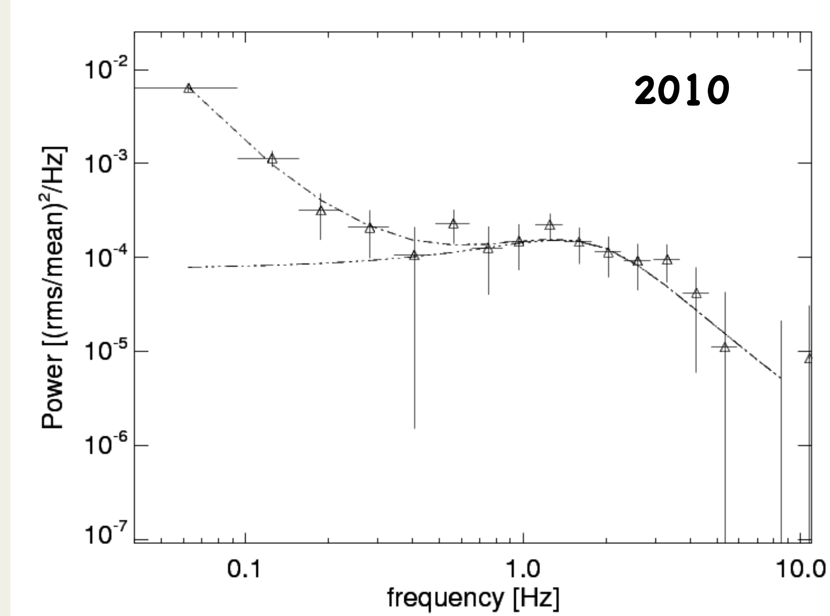


PCA obs. ID	T_{in} (keV)	N_{disc}	Γ	N_{pow} (ph keV^{-1} cm^{-2} s^{-1})	$\mathrm{Flux}_{2-10\,keV}$ (erg cm^{-2} s^{-1})	rms	χ^2_{red}(d.o.f.)
93425-01-11-07	1.31±0.01	340±13	2.3±0.2	$0.3^{+0.2}_{-0.1}$	1.3×10^{-8}	0.091	1.1(52)
95360-09-24-00	1.21±0.02	243^{+20}_{-18}	2.2±0.1	1.0±0.2	0.8×10^{-8}	0.067	0.8(66)





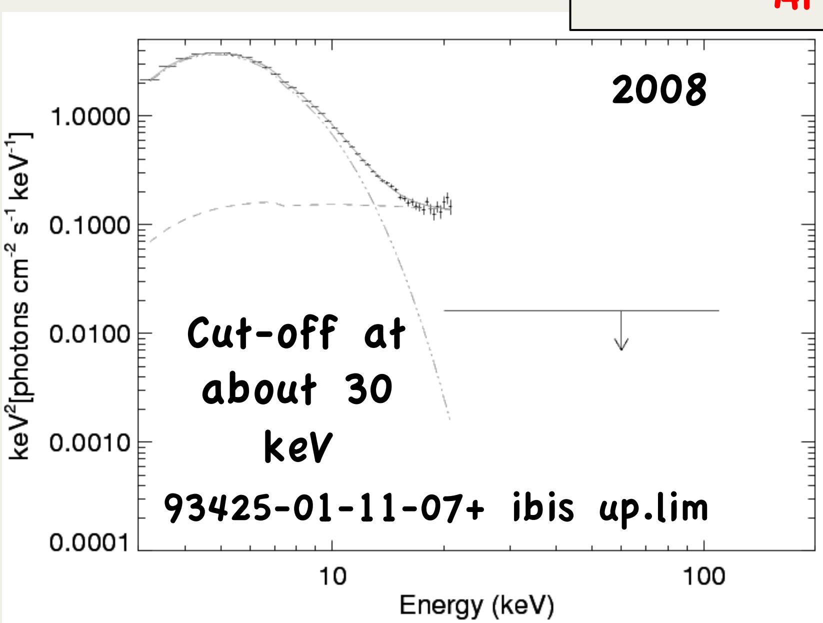


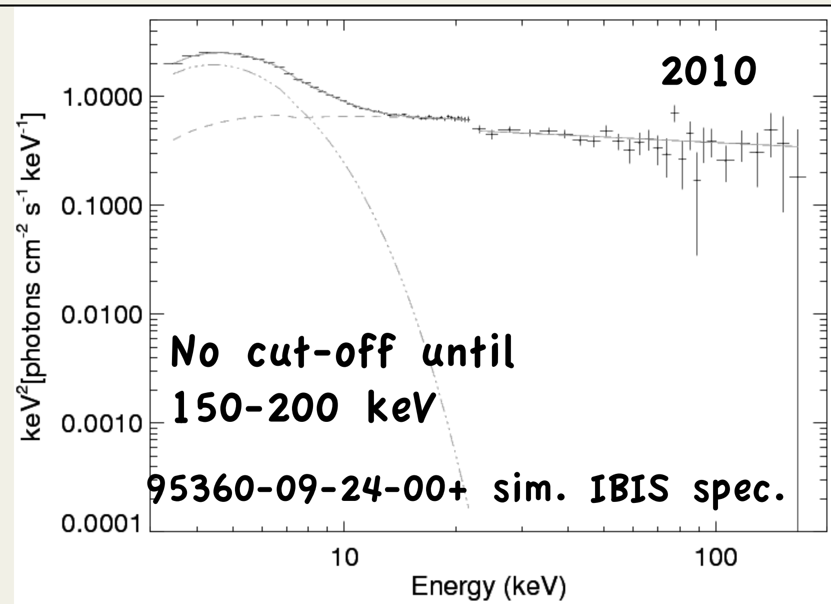


Similar power spectra

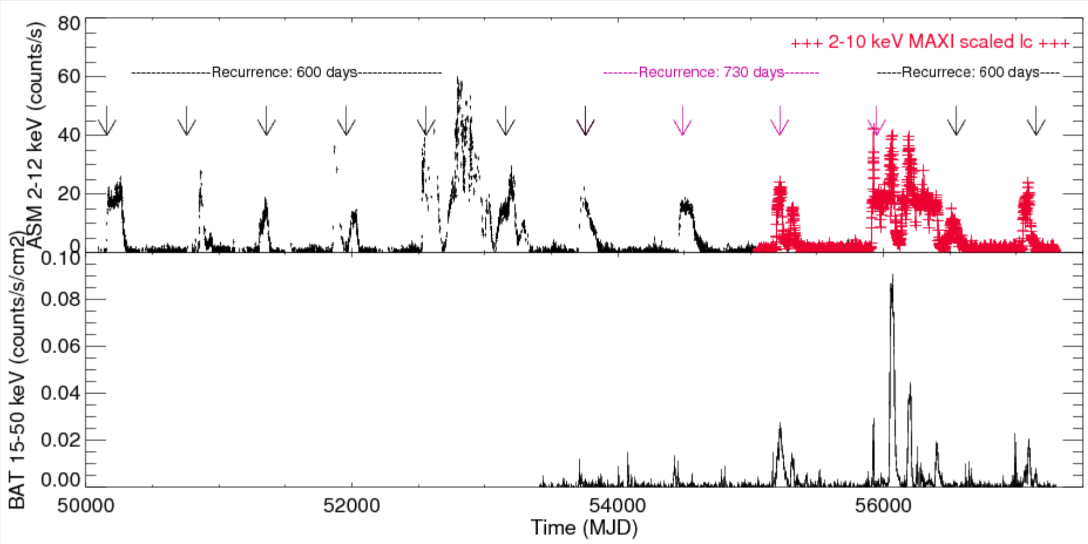
Very similar behaviour below 30 keV, very different behaviour above 30 keV

Are disc and corona uncorrelated?





Comparison among the 3 outbursts



The 2006, 2008 2010 outbursts seem not to follow empirical relations, reported in the works of Yu&Yan (2009), Yu et al. (2007) and Wu et al. (2010), that imply a correlation between disc and corona

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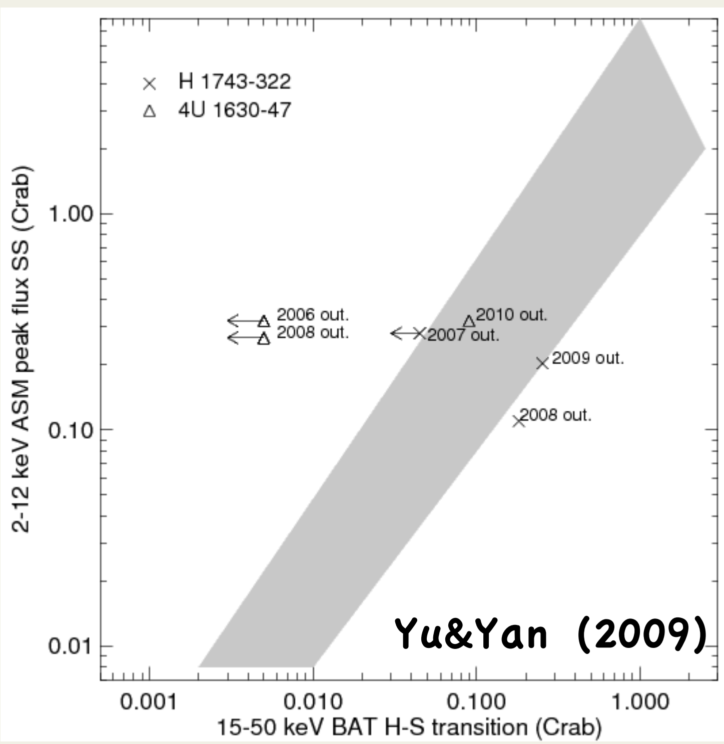
1) a constant waiting time imply a constant hard X-ray luminosity peak of the subsequent outburst.



2) The relation between the X-ray HS to HSS transition luminosity peak versus the subsequent HSS luminosity peak.

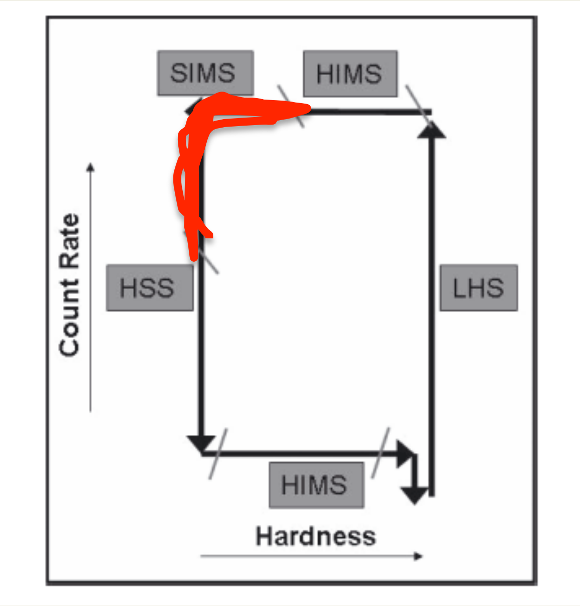
2006 and 2008 outbursts are totally outside the correlation. In fact, the HS-HSS transition should have occurred before the start of the PCA observation campaign at very low fluxes. the 2010 outburst, instead, is almost in agreement.

Peculiarities of the 3 outbursts

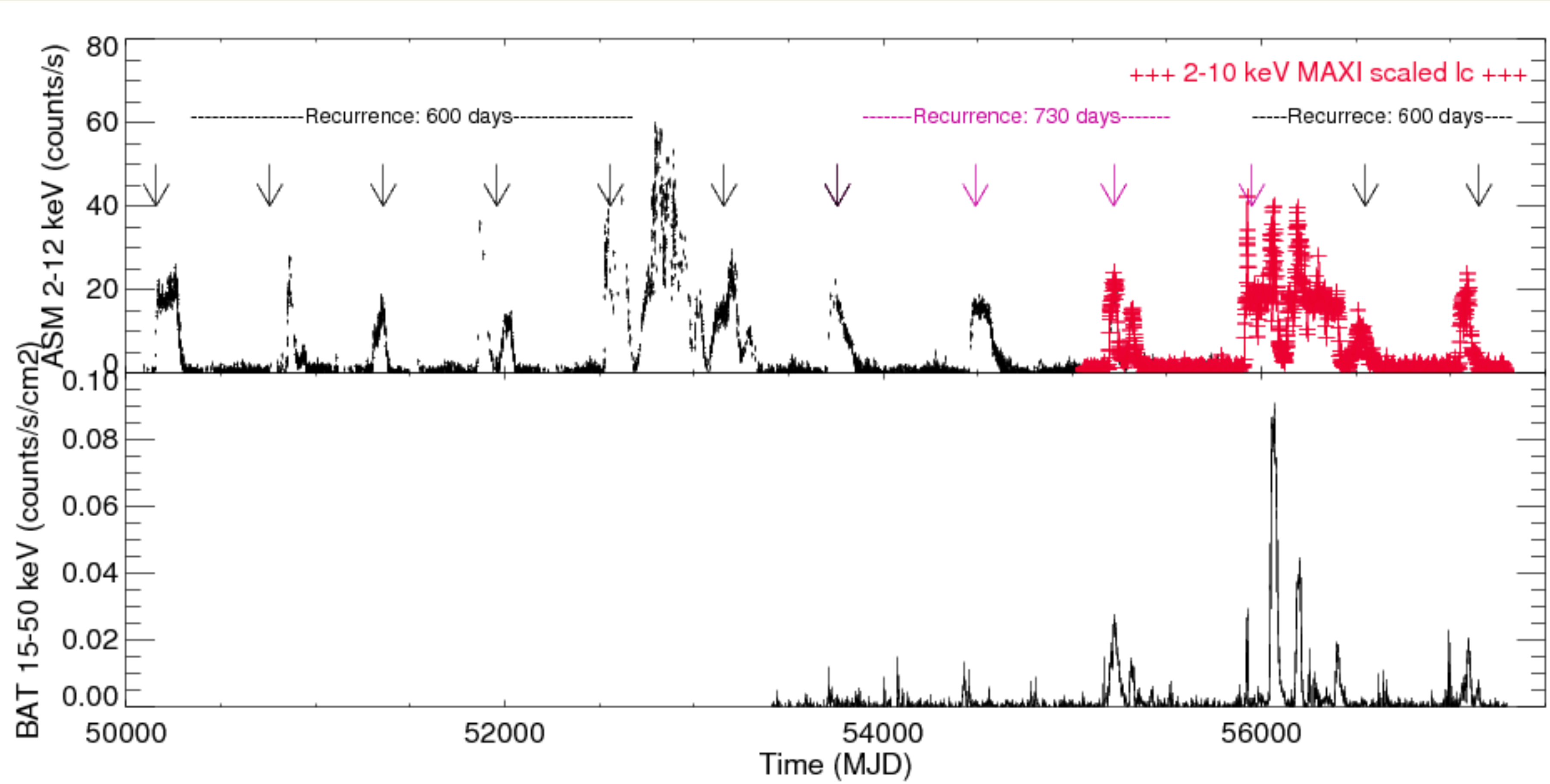
2006-2008-2010 outbursts evolve differently respect to the standard outbursts generally observed in a BH X-ray binary:

- No radio detection at least for 2006 and 2010 outbursts just from the early phases of the outbursts: 13d and 8d after the alert respectively (Gallo et al. 2006, Carvelo et al 2010)
- No hard state detection in the very early phases in 2006 and 2008 outbursts and no hard X-ray detection
- No hard state detection in the very early phases in 2010 outburst but quite huge hard X-ray emission.

These are not standard BH X-ray binary outbursts.
They seem to not follow the entire Q-track diagram



The equally time spaced outbursts (ets)



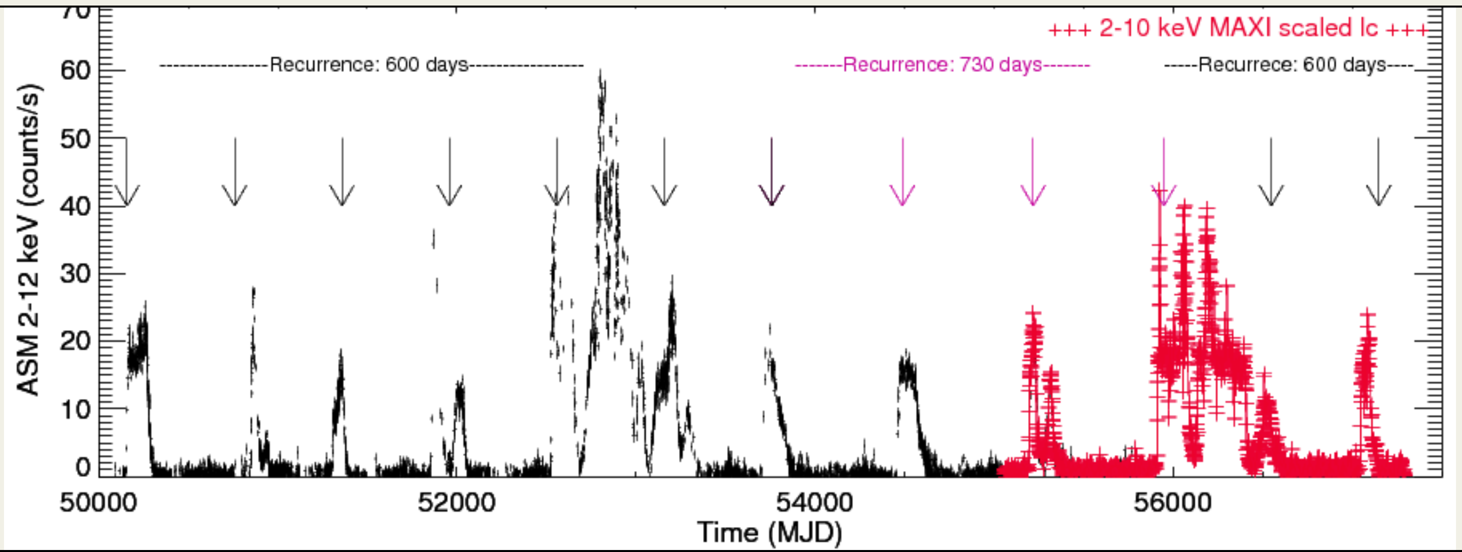
After the 2006 outbursts the period increase from 600d till 730d. After 2012 the period length shorten again at 600d,

As for 2002-2004 outburst the 2012-2013 outburst covers the totality of the 600d period and a secondary peak corresponds exactly to the predicted starting date of a new outburst.

Equally time spaced outbursts, possible explanations: 1) the limit cycle hypotheses

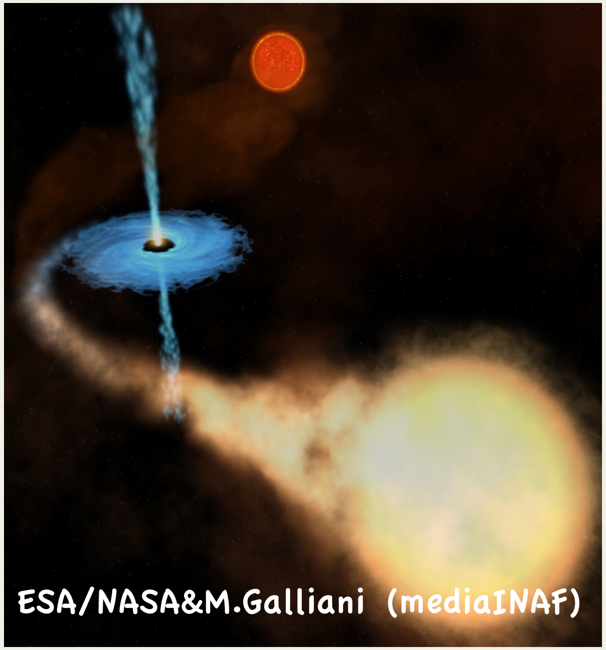
- A limit cycle of accretion disc ionization instability is the standard mode to explain the periodical outbursts in dwarf novae (Lasota 2001).
- 4U 1630 period and outbursts duration are compatible with a limit cycle of a BH system (Janiuk & Czerny 2011).
- The time profile is not always the one expected, 'fast rise and exponential decay' (FRED; Lasota 2001). Other factors such as the accretion rate variation from the companion could superimpose other outbursts to those produced by the limit cycle modifying the FRED profile.

Dwarf novae like super-outbursts → the 2002-2004 or 2012-2013 outbursts



- Parmar et al. (1995) noticed, it is unlikely that the instability could maintain the phase for more than 40 yr

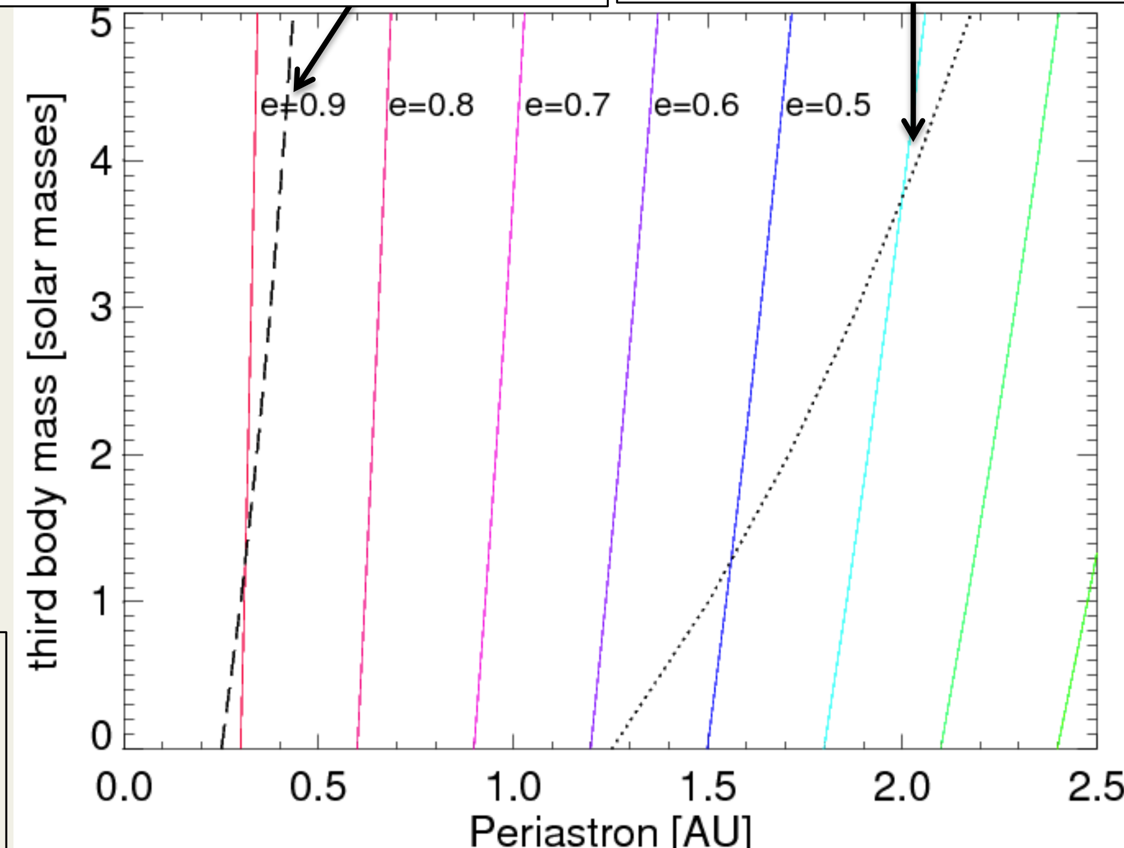
2) The third body hypothesis



A recent paper published by Naoz et al. 2015 hypothesizes that the X-ray binaries containing a BH could be generated by a third body system

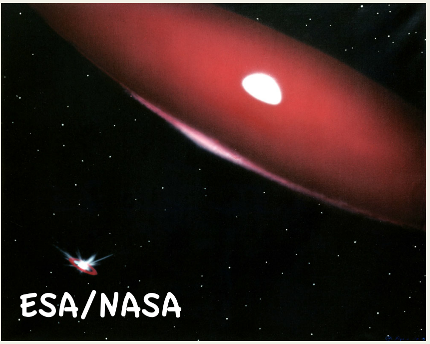
Binary separation critical distance 0.1 au

Bin. Sep. critical distance 0.5 au

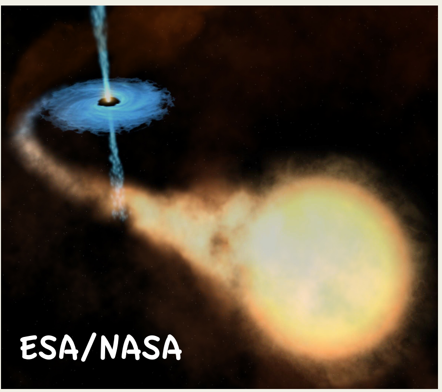


Periastron distance of a body orbiting around the binary star (period 600 d) in function of its mass at different values of eccentricity. The XRB is approximated as an heavy body of M = 10 M.

Less favourable causes of *ets* outbursts

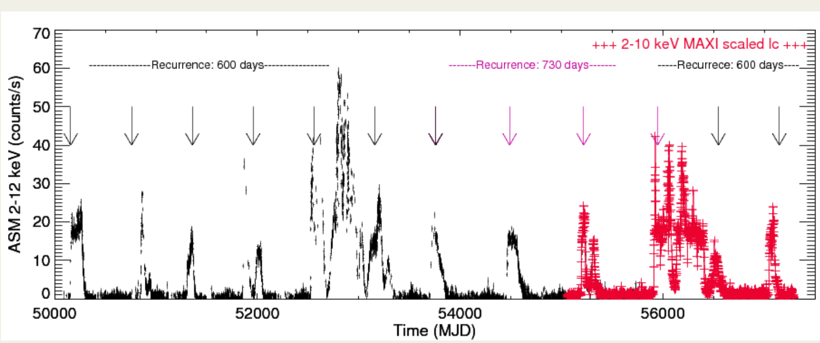


3) high eccentric orbit of the companion star implies a HMXRB, thus a massive companion star (Parmar et al. 1995). The IR data cannot exclude the Be nature of 4U1630, however the spectral behaviour, the duration of the outbursts and the signature of a BH are not in agreement with this hypotheses



4) A LMXRB in a wide eccentric orbit is unacceptable from an evolutionary point of view (old systems with circular orbit and short periods).

5) A subsequent capture of the companion star or a modification of its orbit due to interactions with other bodies are not-consistent with the Roche lobe overflow due to huge orbital period (600-700 d)



6) Trudolyubov et al. (2001):a constant refilling of the outer disc by companion's matter implies a constant quantity of accreted matter. This matter reaches, after 600 d, a critical mass and undergo an outburst.

same quantity of matter → same outburst luminosity

Results summary and Conclusions 1

- Only-soft outbursts? Lack of bright initial hard state or very sharp hard state: the source is observed always in soft-state (high or intermediate)

- The final HS should have a factor of few lower luminosity than the initial one. SWIFT/BAT 15-50 keV detection limit (initial HS): 10.6mCrab (2σ) → 0.5-0.005 mCrab (final HS), very near to quiescence luminosity

- The same source state do not imply the same behaviour above 30 keV (in this case disk and corona seems not correlated)

- The 2006 and 2008 outbursts are outside the Yu & Yan (2009) relations (Again disk and corona not correlated)

Results summary and Conclusions 2

- 4U1630 is the only BHC in RXTE data showing *ets* outbursts for more than 40 yr

- There should be an extra parameter that triggers the outbursts, having a periodical nature. The periodical triggers could force an increase of the disk temperature independent from the state of the accretion disk, the electron inflow and the mass accretion rate from the companion star.

- There are 2 plausible explanations that have both strong and weak points:

  a) a limit cycle of ionization instability. More obvious explanation. However to maintain the phase for more than 40yr is improbable.

  b) The presence of a 3rd body in the systems. However the temporary change in the outburst recurrence period is difficult to explain. Other phenomena such as Kozai effect or relativistic effects or 3rd body mass comparable with the other two have to be considered.

Thank you

Most of the results of this work have been published in:
Capitanio F., Campana R., De Cesare G, Ferrigno C., MNRAS 450, 3840-3854 (2015)