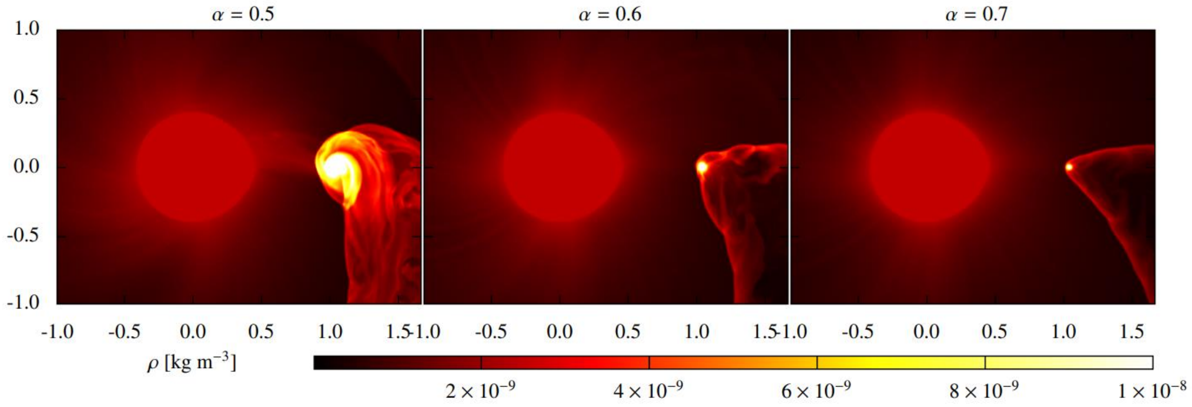
Exploring the donor wind environment in high-mass X-ray binaries

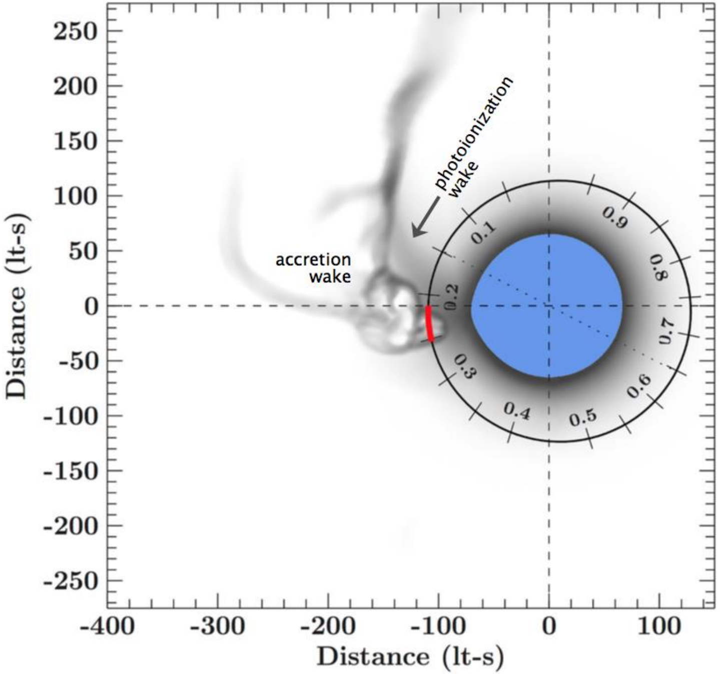


Submitted to A&A

Carlo Ferrigno, Enrico Bozzo, Patrizia Romano

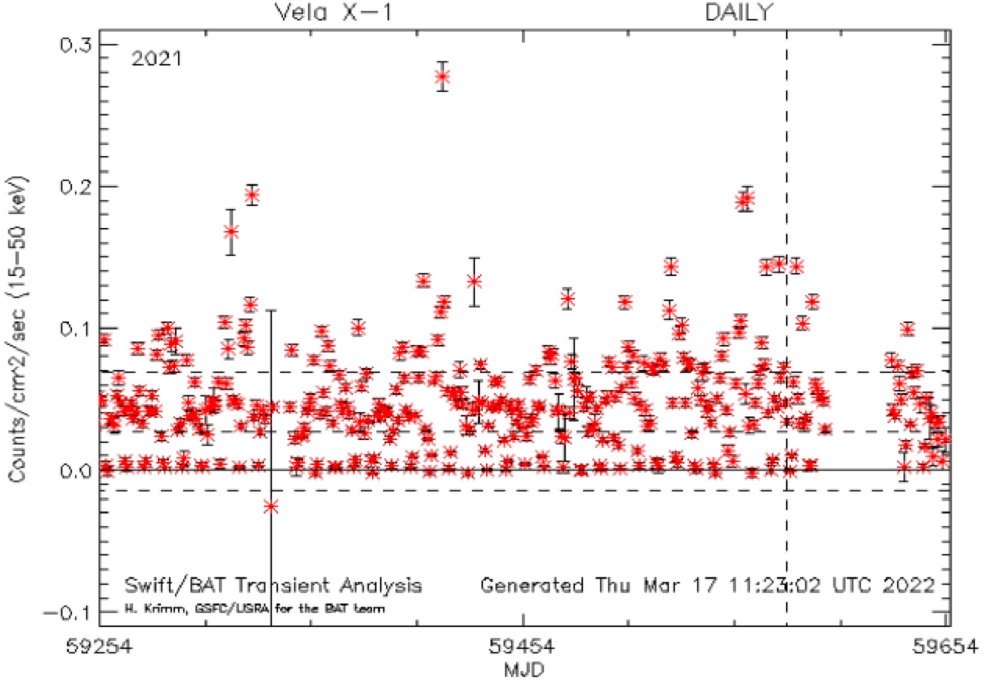
High-Mass X-ray binaries

- Systems composed by a massive star (typical ages < Gyr)
- mass transfer can happen via wind or Roche Lobe or a mix of the two
- compact object is not a white dwarf for evolutionary reasons

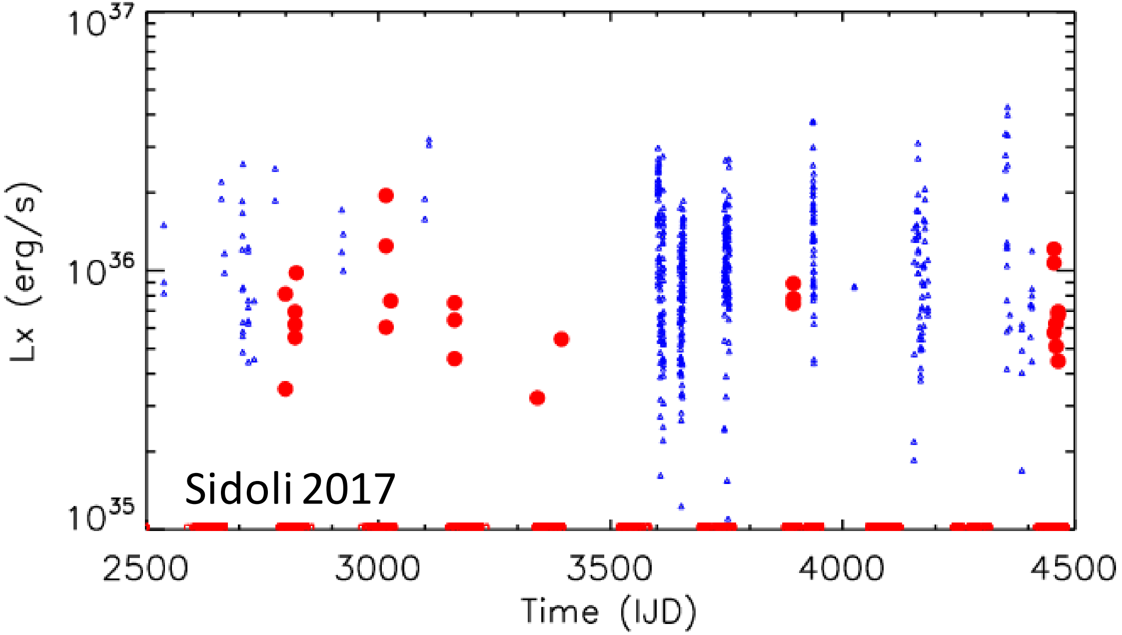


Classical HMXB

- Variable emission
- Typically with lognormal distribution
- Sometimes low states



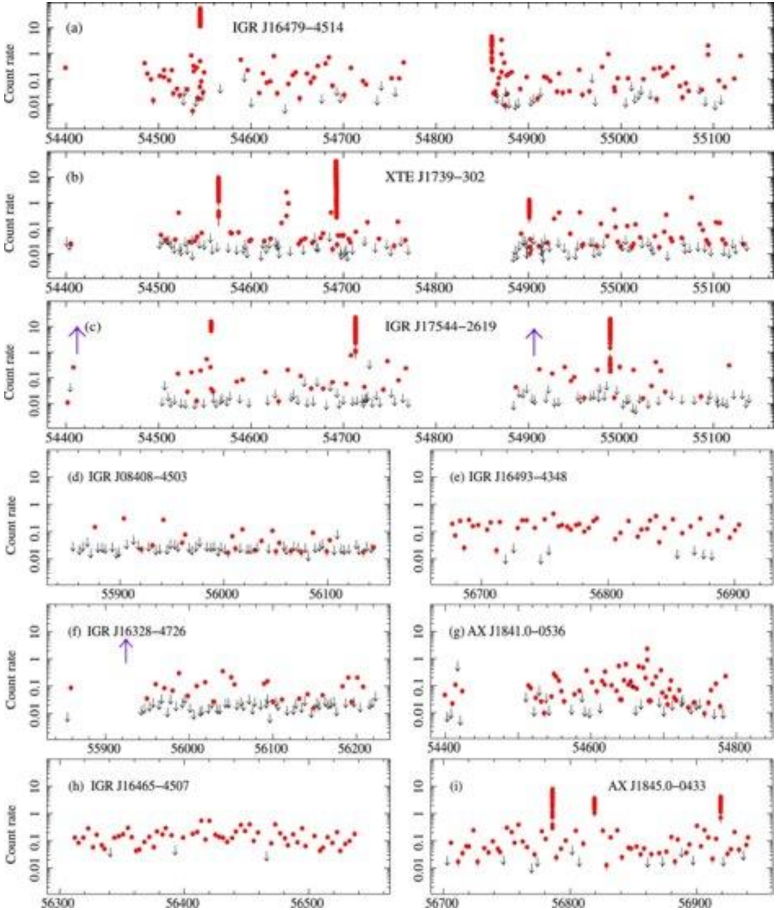
Classical Sg-HMXB and SFXTs



- Discovered with INTEGRAL monitoring for galactic plane
- A subclass of High-Mass X-ray binaries which exhibit swings of luminosity of the order of 10^3-10^5. (from 10^{32} to 10^{37} erg/s)

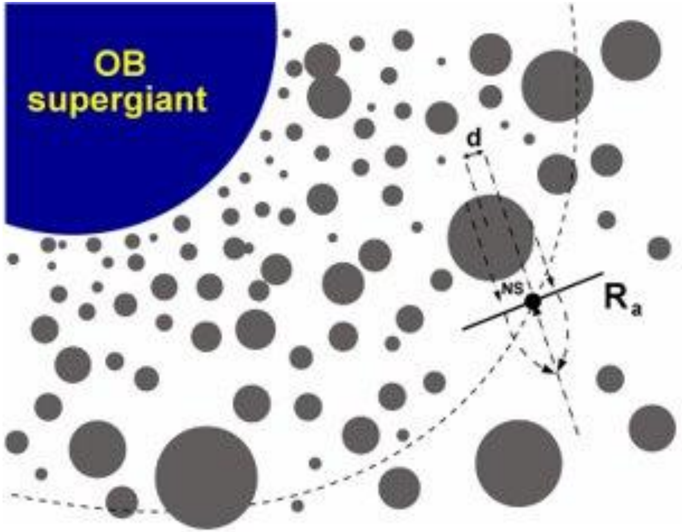
Duty cycle of SFXTs

- The duty cycle is much lower than classical HMXB
- 5% of time in outburst; (Sidoli & Paizis, 2018)
- Most time in intermediate or low level
- Inactive for 5-50% of the time

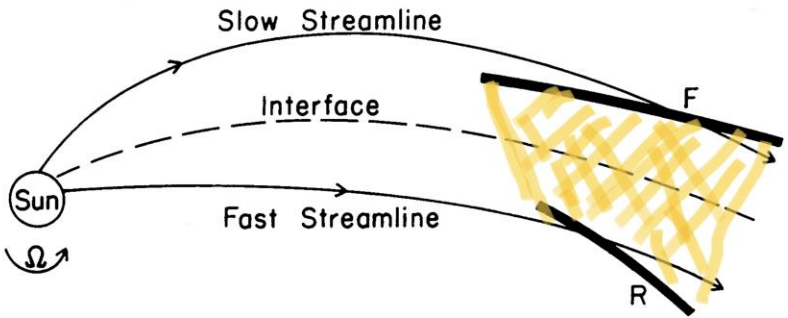


Clumpy wind

- The structure of the wind of massive stars is most probably inhomogeneus with overdense regions dubbed "clumps"
- The idea is to use the compact object as a probe

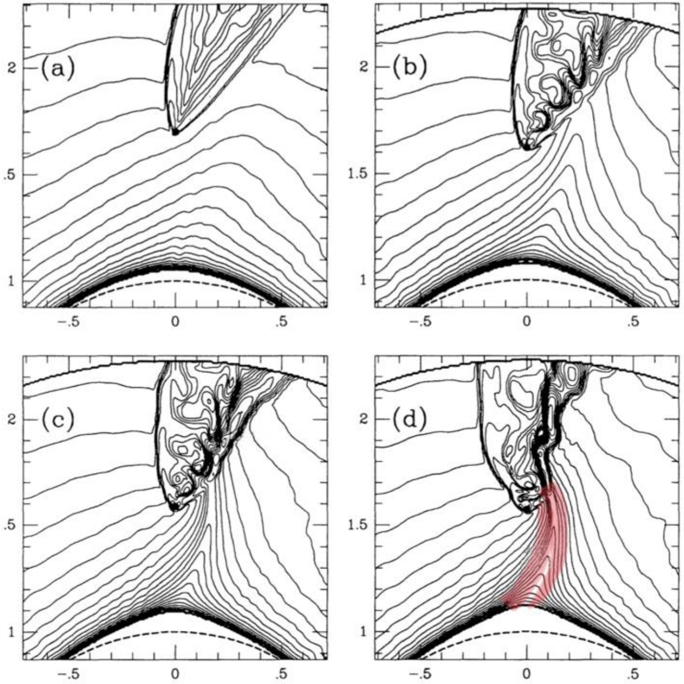


Corotating Interaction regions



- Predicted in the 70s
- Observed in the Sun
- They originate when a rotating star emits winds with different speed.
- Over-density and higher temperature.
- Delimitated by forward and reverse shocks

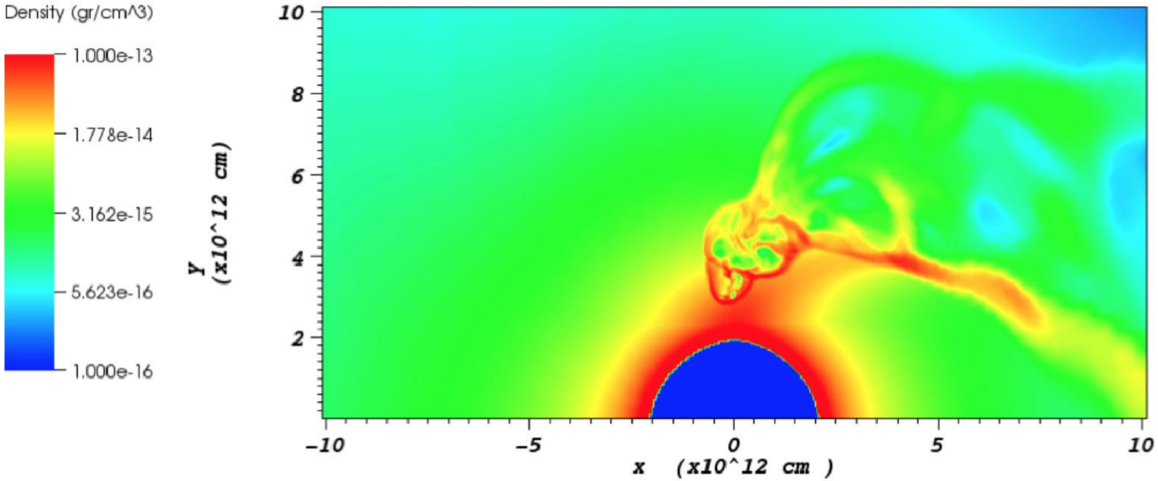
Tidal streams



Blondin (1991)

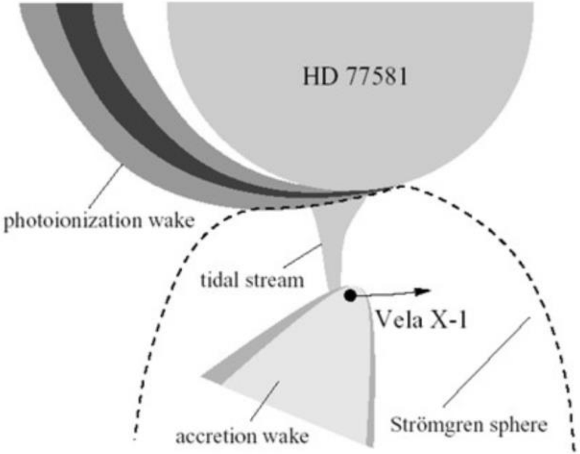
- They develop as a consequence of tidal pull if the system is close enough
- They do not necessarily impact the accreting object
- They are stationary in time
- They can explain enhanced absorption at certain orbital phases

Accretion wakes



- The motion of the compact object perturbs the wind
- It creates a variable accretion wake with shocks that change rapidly.

… and photoionization sphere



Principal components for wind-accretion:

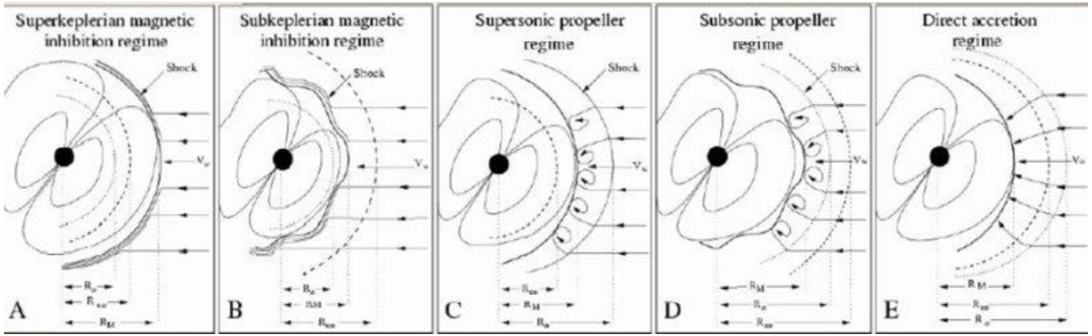
- Ionized Strömgren region (wind ionized by X-rays from compact object).
- Accretion shock around compact object (orbital velocity typically > velocity of sound!).
- Ionization wake where material is overdense.

Possibly formation of small disk around NS.

- X-rays from the compact object ionize the wind and slow it down, because there are no more line resonances to accelerate it (CAK model)

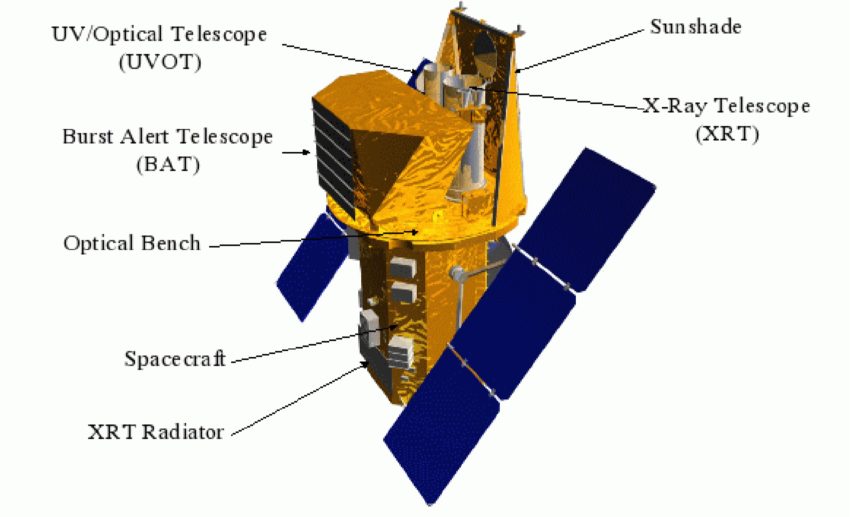
Need something more?

- Models:
  - Clumpy wind accretion
  - Magnetic gating
  - Subsonic settling accretion + magnetic reconnection



Ducci et al. (2009)
Grebenev (2007) Bozzo et al. (2008)
Shakura & Postnov (2011, 2014)

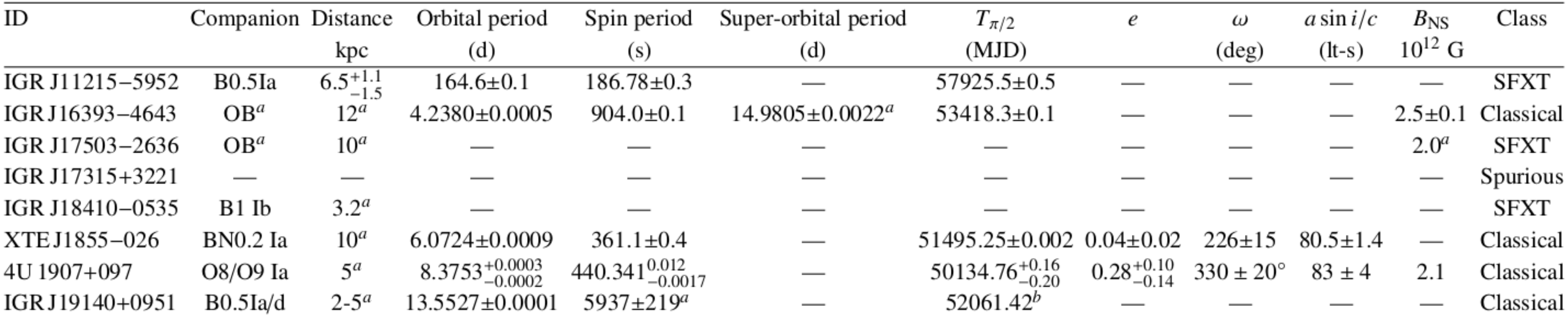
Instruments



Niels Gehrels Swift observatory
Large FOV coded mask BAT (15-150 keV)
X-ray telescope (0.5-10 keV) plus UV
Effective long monitoring (large structures)

XMM-Newton observatory
3 large Effective area X-ray telescopes
(0.1-11 keV) PN, EMOS1, EMOS2
Plus grating and OM (wind clumps)

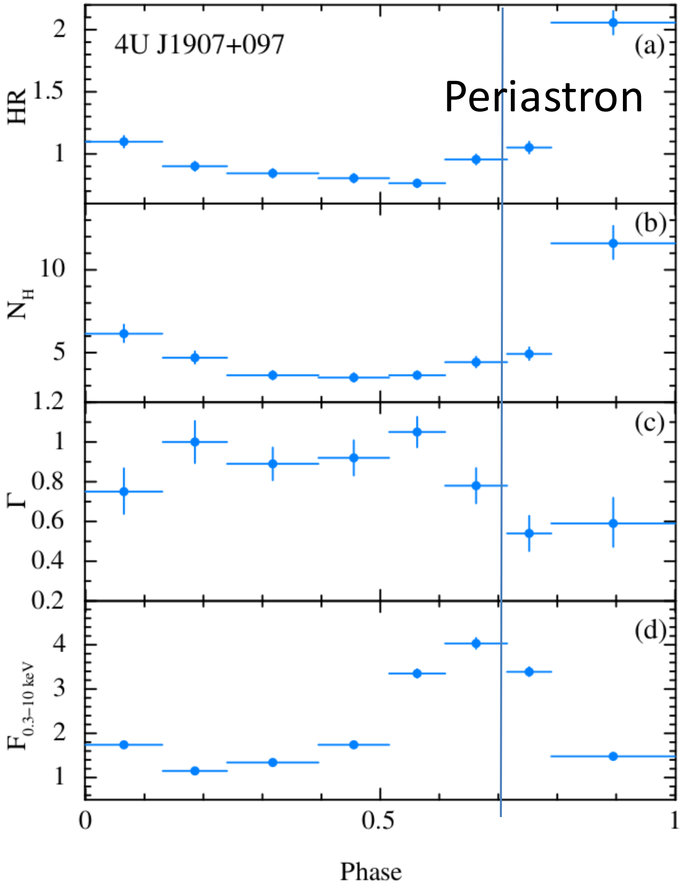
Sources



ID	Companion	Distance kpc	Orbital period (d)	Spin period (s)	Super-orbital period (d)	$T_{\pi/2}$ (MJD)	e	ω (deg)	$a\sin i/c$ (lt-s)	$B_{\rm NS}$ 10^{12} G	Class
IGR J11215−5952	B0.5Ia	$6.5^{+1.1}_{-1.5}$	164.6±0.1	186.78±0.3	—	57925.5±0.5	—	—	—	—	SFXT
IGR J16393−4643	OB^{a}	12^{a}	4.2380±0.0005	904.0±0.1	14.9805±0.0022^{a}	53418.3±0.1	—	—	—	2.5±0.1	Classical
IGR J17503−2636	OB^{a}	10^{a}	—	—	—	—	—	—	—	2.0^{a}	SFXT
IGR J17315+3221	—	—	—	—	—	—	—	—	—	—	Spurious
IGR J18410−0535	B1 Ib	3.2^{a}	—	—	—	—	—	—	—	—	SFXT
XTE J1855−026	BN0.2 Ia	10^{a}	6.0724±0.0009	361.1±0.4	—	51495.25±0.002	0.04±0.02	226±15	80.5±1.4	—	Classical
4U 1907+097	O8/O9 Ia	5^{a}	$8.3753^{+0.0003}_{-0.0002}$	$440.341^{0.012}_{-0.0017}$	—	$50134.76^{+0.16}_{-0.20}$	$0.28^{+0.10}_{-0.14}$	330 ± 20°	83 ± 4	2.1	Classical
IGR J19140+0951	B0.5Ia/d	2-5^{a}	13.5527±0.0001	5937±219^{a}	—	52061.42^{b}	—	—	—	—	Classical

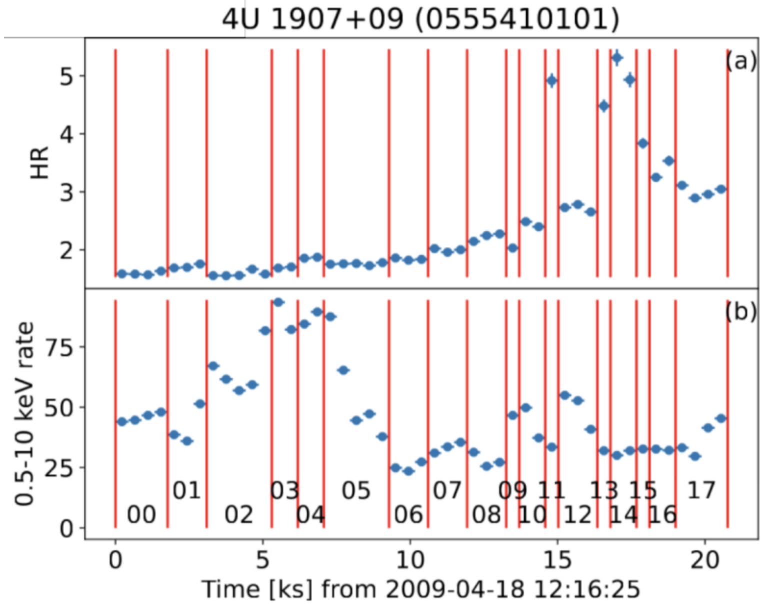
4U 1907+097/Swift

- Swift Monitoring binned by orbital phase
- Classical system with slowly rotating neutron star (403 s)
- One (1 is) observation per week with Swift from March to September 2015
- We fit the spectra with a simple power-law with absorption
- High flux at periastron. Enhanced absorption with neutron star possibly behind an accretion stream.



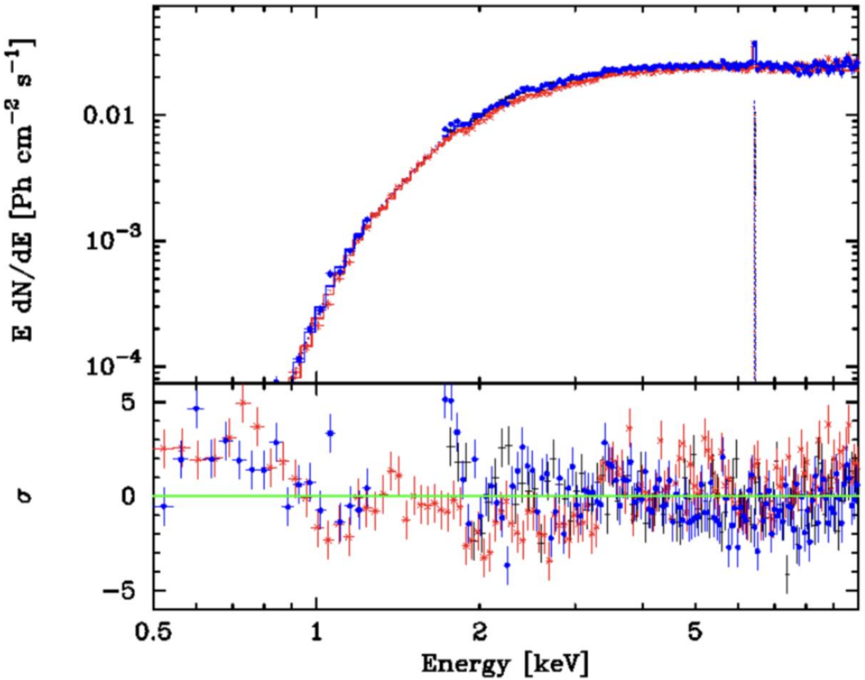
4U 1907+097/XMM

- We bin at the spin period (2.2631 mHz), compute the hardness and investigate the spectral variations, when the HR changes significantly based on Bayesian block analysis.
- We try to understand what model parameters drive the spectral variabilty



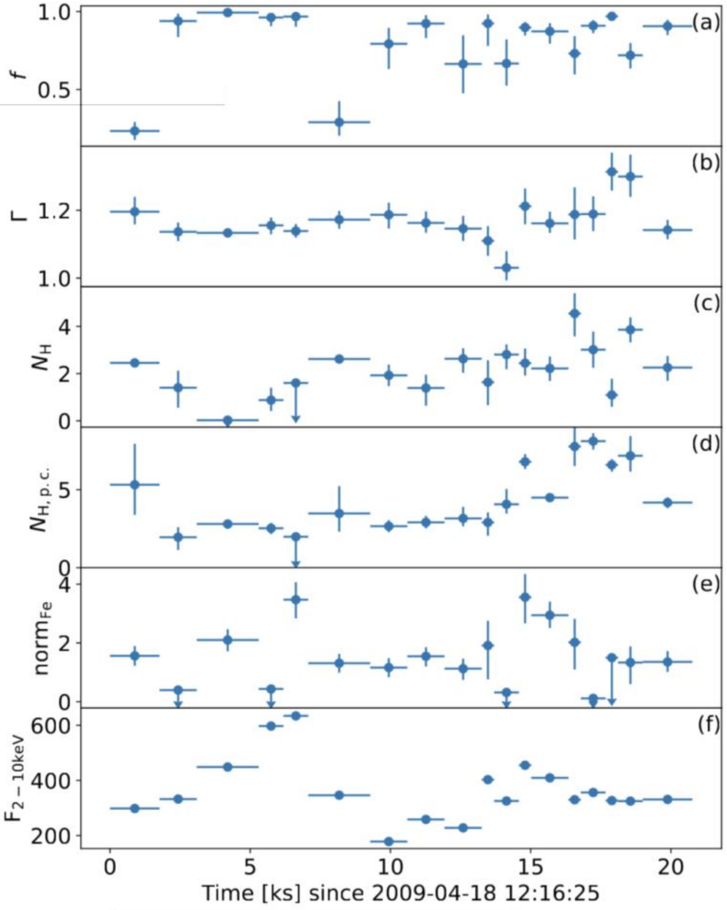
4U 1907+097/XMM

- PN and MOS1 operated in timing mode, MOS2 in small window
- We use a power law with full absorption and partial covering (TBABS*PCFABS*(PEGPOW+Gauss)
- Some residuals are due to systematic
  calibration uncertainties.
- Uncertainties with MCMC



4U 1907+097/XMM

- Main variability is at the end of observation and it is mainly due to enhancement of the partial covering component, supporting the idea that clumps in the wind are the driver, together with marginal intrinsic variability of the slope
- The main flare is preceded by lower absorption



Possible scenarios

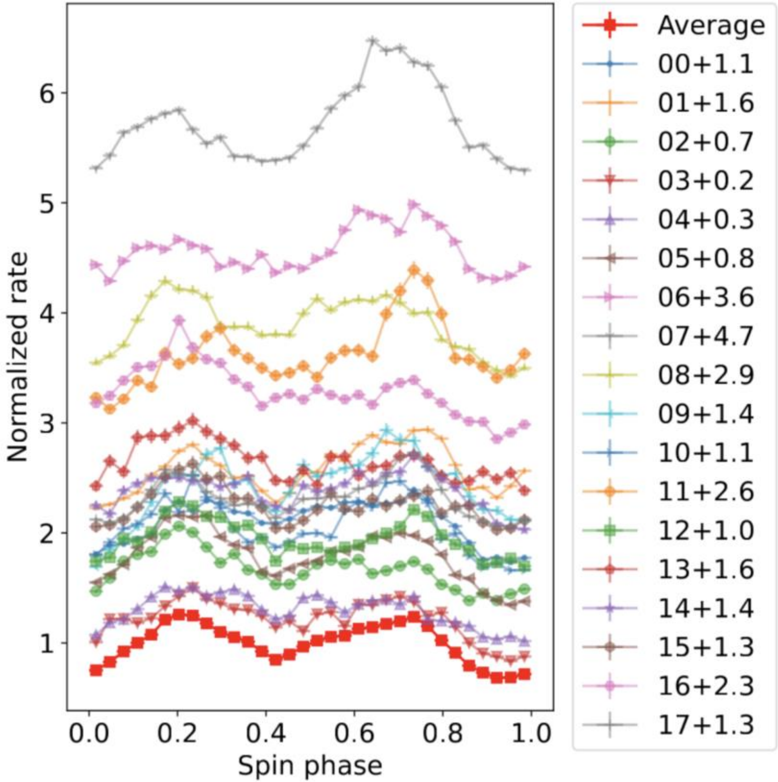
- There is not a unique Correlation between flux and absorption.
- If the NS passes through a clump it might accrete more and become brighter while being absorbed.
- It can become so bright that it can photoionize the clump
- If it passes behind, it is simply attenuated.
- If the clump is small, it can be swallowed

How is the wind environment linked to accretion ?

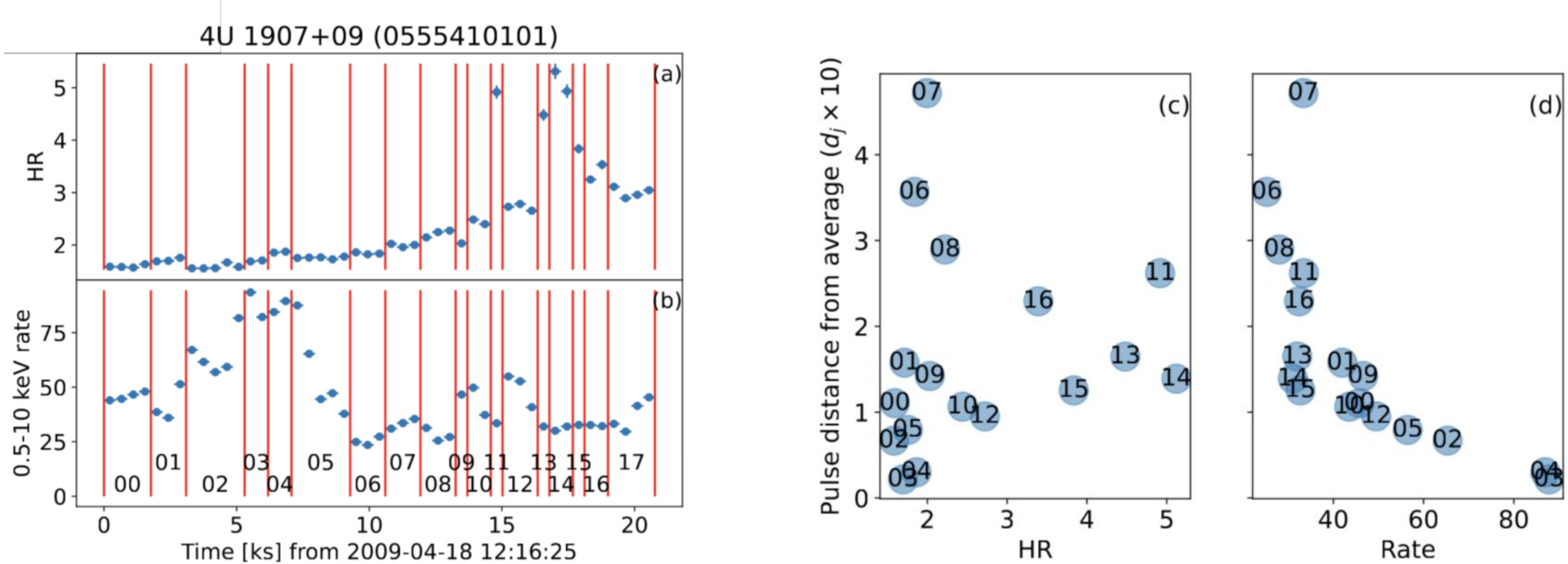
- We fold the light curve at the spin period within each time interval used for spectral extraction and computed its distance from the average

$$d_j = \sum_{i=1}^{32} \frac{\left|p_{i,j} - \bar{p}_i\right|}{\sigma_{i,j}}$$

- Pulse profiles change most at the egress of the main flare when absorption is stable.



HR-Rate and Pulses



By construction, brighter pulses are close to the average, but the spread at lower intensity is remarkable. Hardness ratio does not seem to be correlated to the pulse variability.

IGR J17315-3221 a fake source

- This source was reported by a catalog by Krivonos and thought to be a SFXT.
- We re-analyzed all the INTEGRAL archive using MMODA python API with the new calibration and processed the image with sextractor.
- No source detected with a 3 sigma u.l. of 0.5 mCrab
- Note that Swift/XRT follow up gave no detection.

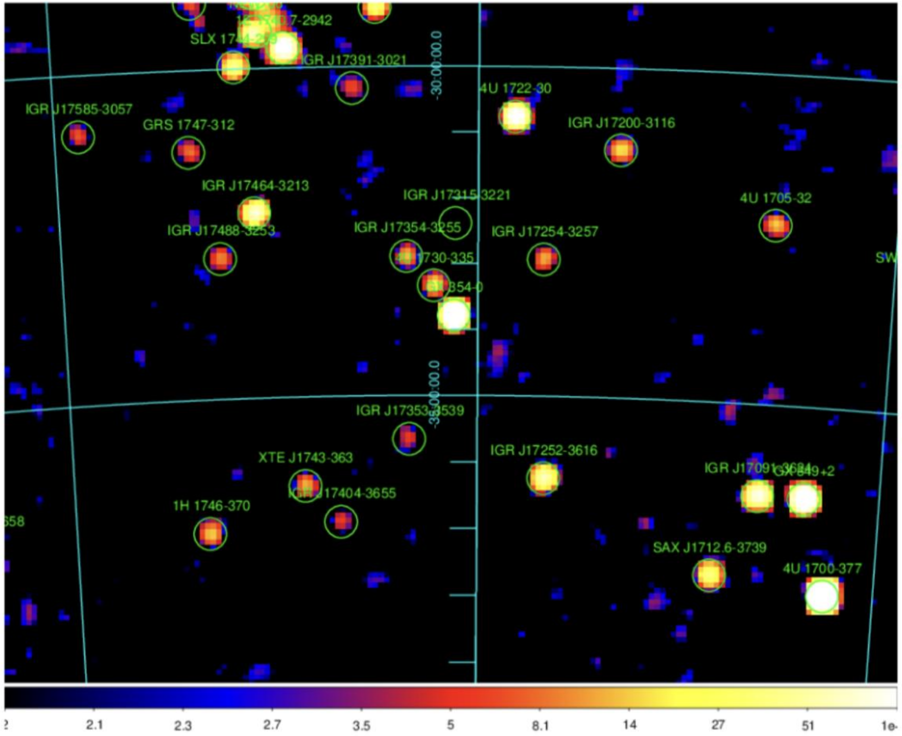
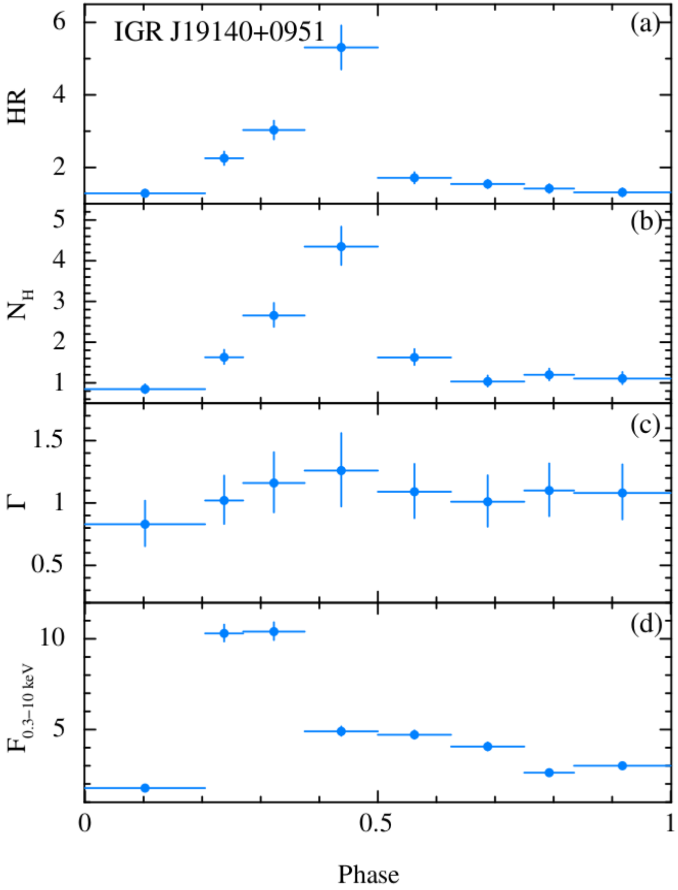


Fig. 14. *INTEGRAL* IBIS/ISGRI significance map in the 20–60 keV energy range of the region around

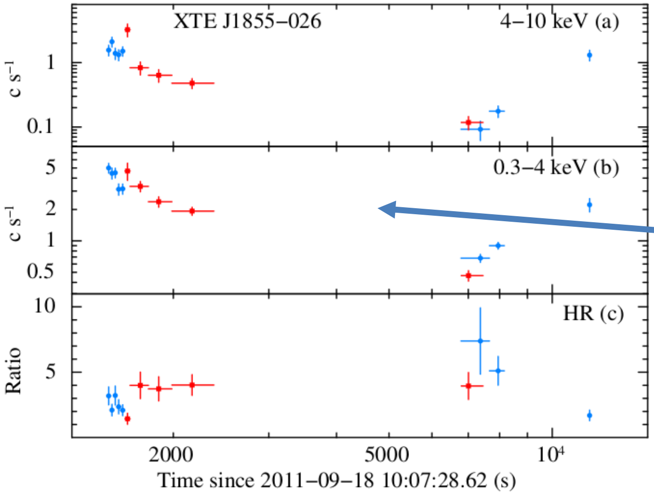
IGR J1940+0951

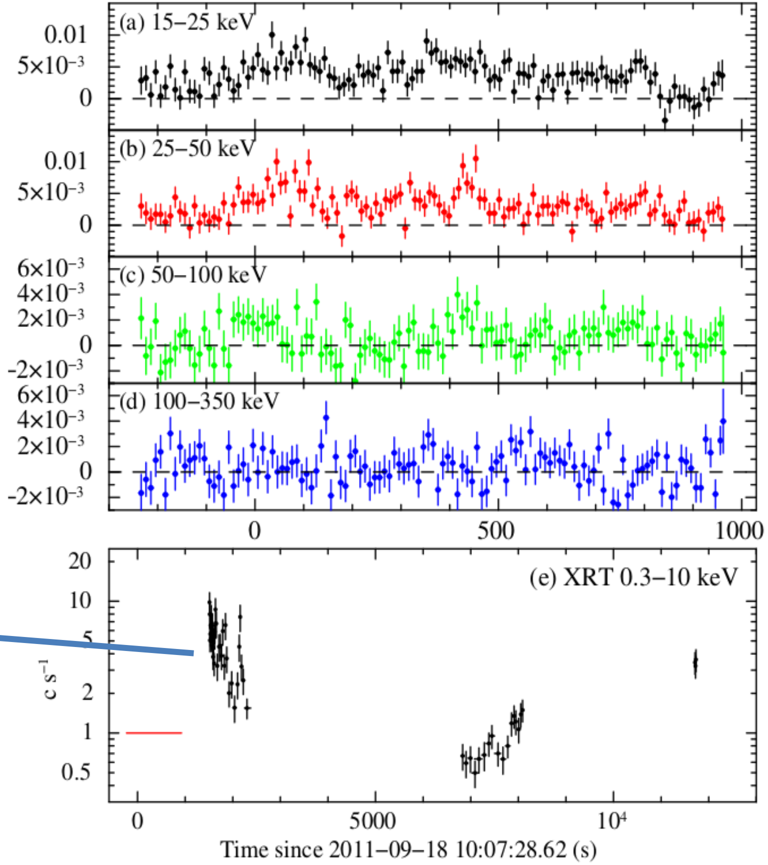
- Classical supergiant
- Orbital-phase resolved spectral analysis on 2015 monitoring with 2 obs of 1 ks per week
- Peak at phase 0.2–0.4 consistent with the 15–50 keV Swift/BAT orbital profile using 15 years of continuous monitoring
- Possibly characterized by a non-negligible eccentricity and a large structure located close to the NS and moving with it, possibly a gas stream
- Unconfirmed spin period of 5 ks, not possible to determine exactly the orbit.



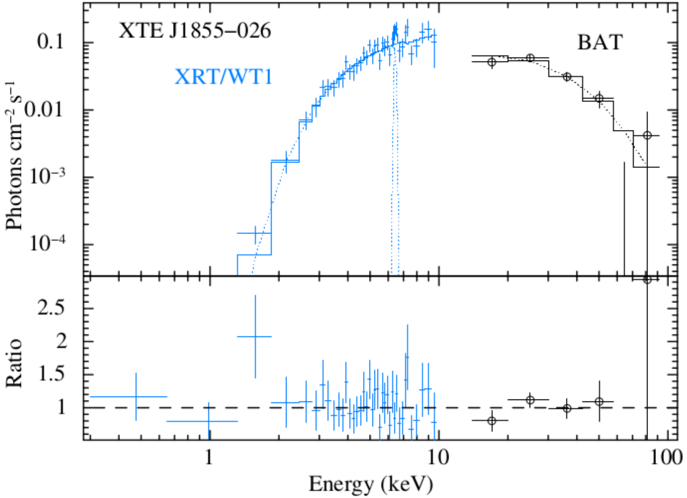
XTE J1855-026

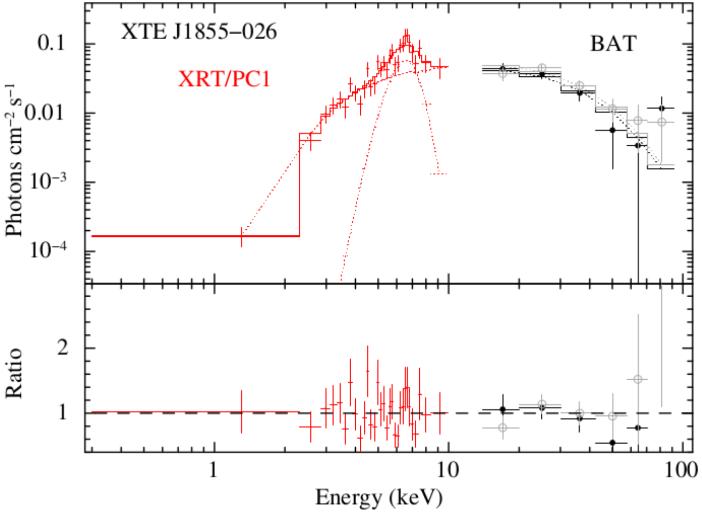
- A classical system with peculiar strong outbursts
- We analyze BAT and XRT data from one of them on 18 Sept 2011





XTE J1855-026





Absorbed power-law with high-energy cutoff and iron line, as typical of HMXB.

a progressive rise of the absorption column density

new drop of the absorption column density during a rebrightening of the source

Conclusions

- Archives have a huge potential that is to be exploited.
- Long-term monitoring with Swift/XRT (or others) provide us with the possibility to reveal large-scale structures in the wind of supergiant stars.
- The usage of large effective area facilities allow us to explore smaller structures, the presence of clumpy structures is confirmed by our results, but the complex phenomenology needs to be further characterized.