Wind-fed supergiant X-ray binaries: Accretion from a clumpy stellar wind

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Wind-fed Supergiant High Mass X-ray Binaries

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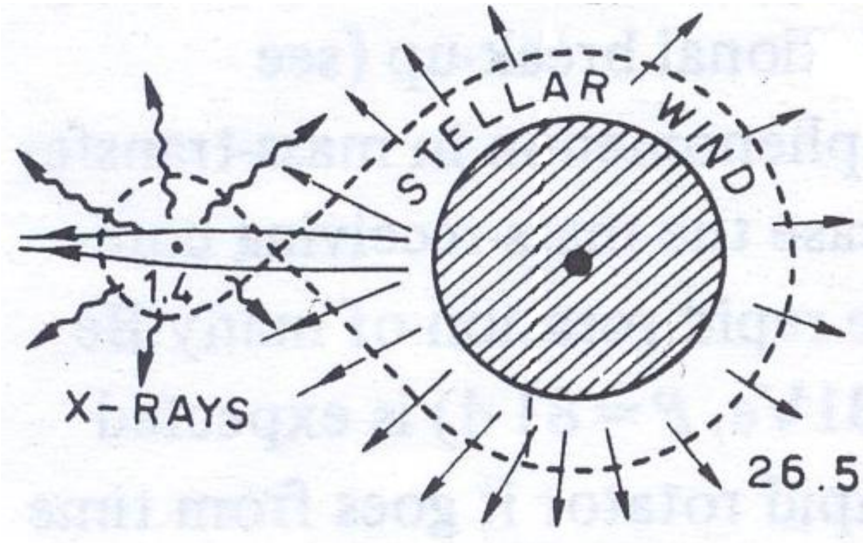
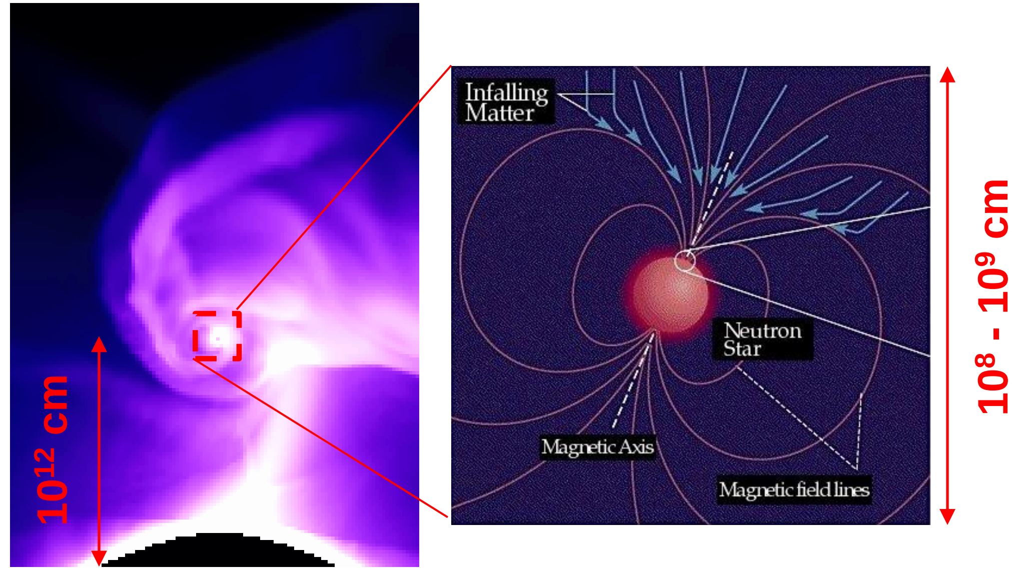
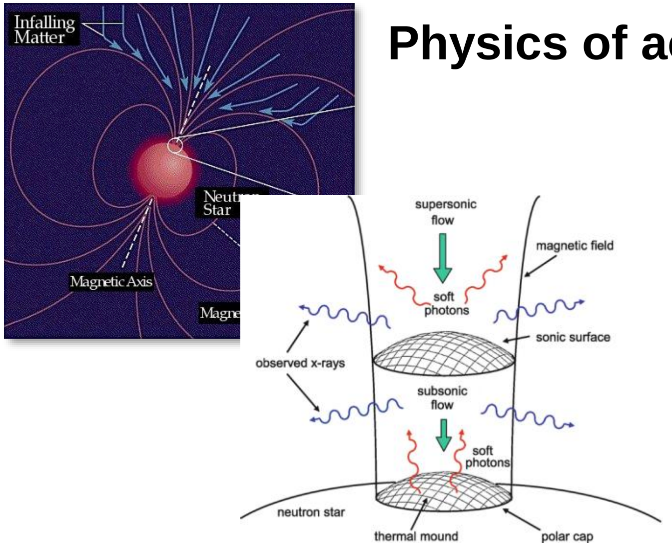




Wind-fed supergiant X-ray binaries

- O-B supergiant companion + an accreting compact object (typically NSs)
- Orbital periods 3-60 days, slow NS rotators (few seconds to hours)
- Persistent objects ("classical") with variability in the X-ray luminosity by a factor of ~10-100
- Transient objects (SFXTs) with variability up to 10^6 in few hours
- Average persistent luminosity depends from the orbital period
- Typically ~10^{34}-10^{36} erg s^{-1} but as low a ~10^{31}-10^{32} erg s^{-1} in SFXTs
- Flares/Outbursts can reach up to ~3×10^{38} erg s^{-1}



Physics of accretion in extreme conditions

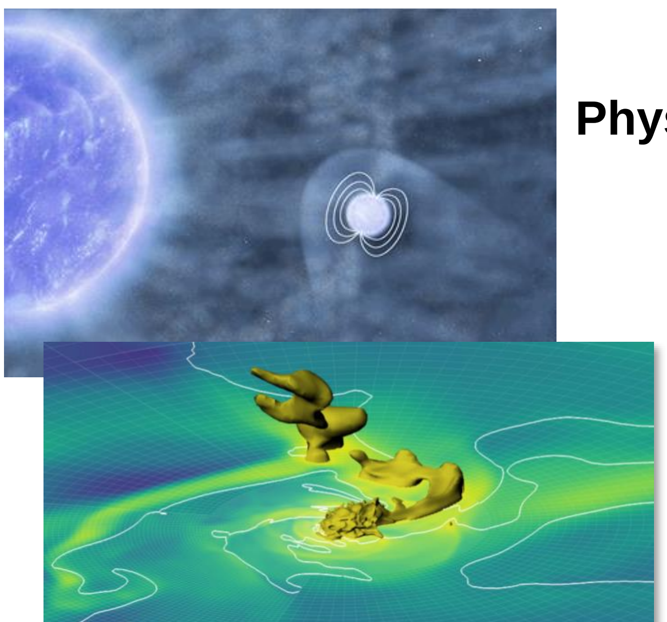
Accretion columns

Supersonic/subsonic flows, shocks

Radiation within and through the magnetic walls

Cyclotron resonant scattering absorption features

Radiation in presence of extreme gravitational fields



Physics of clumpy stellar winds

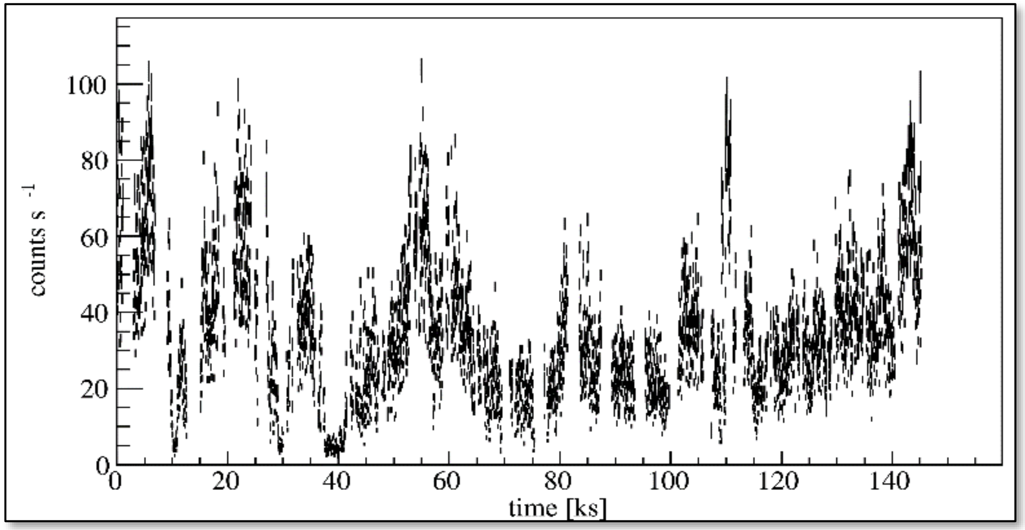
NS as an in-situ probe of the supergiant star wind

Physical properties of the wind

Interaction X-rays – stellar wind, photoionization

Clump ingestion onto the NS

The Supergiant Fast X-ray Transients



(Suzaku/XIS; 0.5-12 keV; Odaka 2013)

Vela X-1 (classical SgXBs)

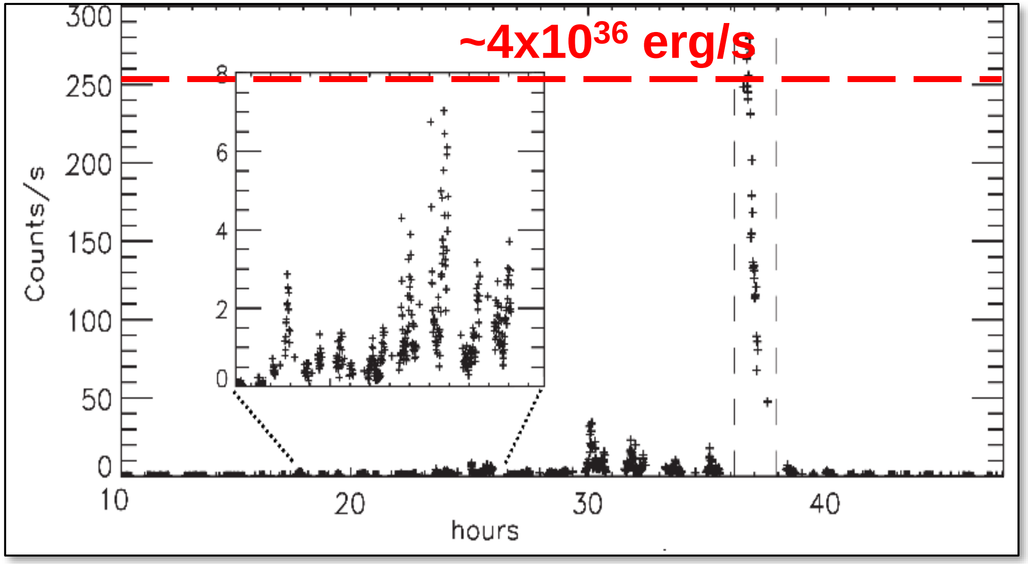
Orbital period 8.9 days (B supergiant)

Average luminosity 4×10^{36} erg/s

Luminosity variations ~20-50

NS accreting from supergiant wind

Variability due to wind clumps



(Suzaku/XIS; 0.5-12 keV; Rampy 2009)

IGRJ17544-2619 (transient SFXT)

Orbital period 4.9 days (B supergiant)

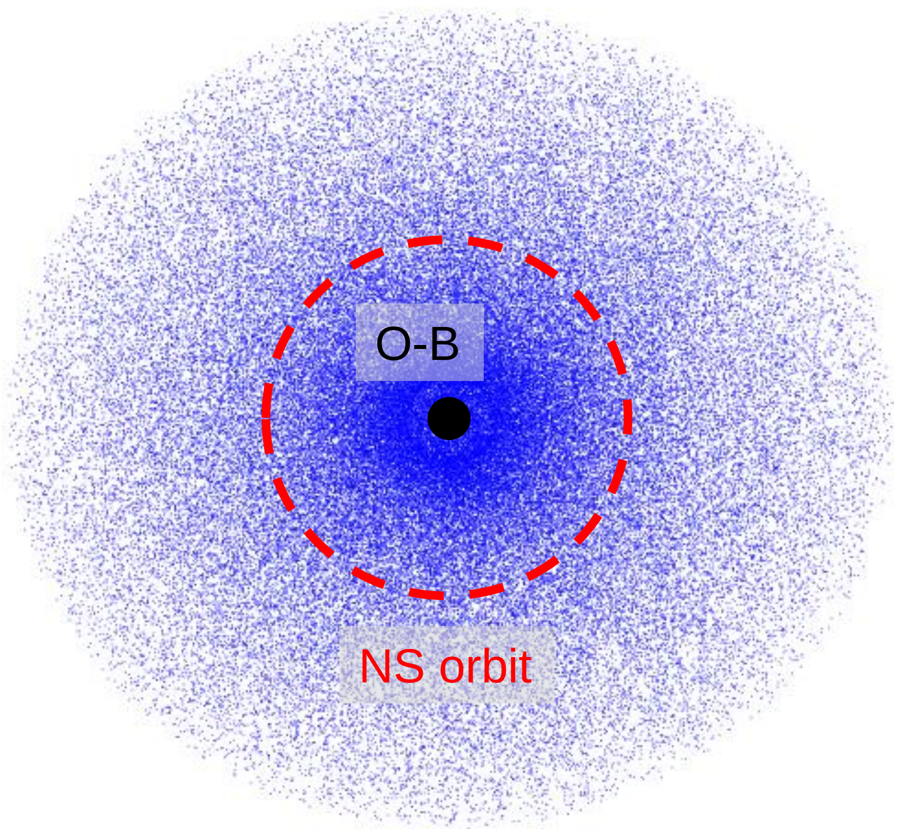
Average luminosity: 4×10^{34} erg/s

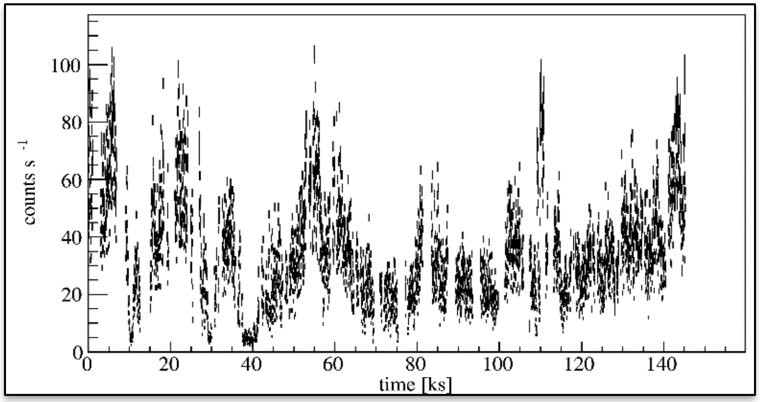
Luminosity variations ~10^4-10^6

NS accreting from supergiant wind

Sporadic hour-long flares

Variability due to clumps + ??





Stellar wind mass captured by the NS per unit time

V_W ~ 1000-3000 km/s

$\dot{M}_W$ ~ 10^{-6}-10^{-5} $M_\odot$ /yr

Accretion X-ray luminosity from captured stellar wind mass

$$L_{acc} \sim \frac{GM_{NS}\dot{M}_{capt}}{R_{NS}} \propto \rho/V^3_W$$

Variations into density and velocity of the wind lead to «instantaneous» changes to the X-ray luminosity

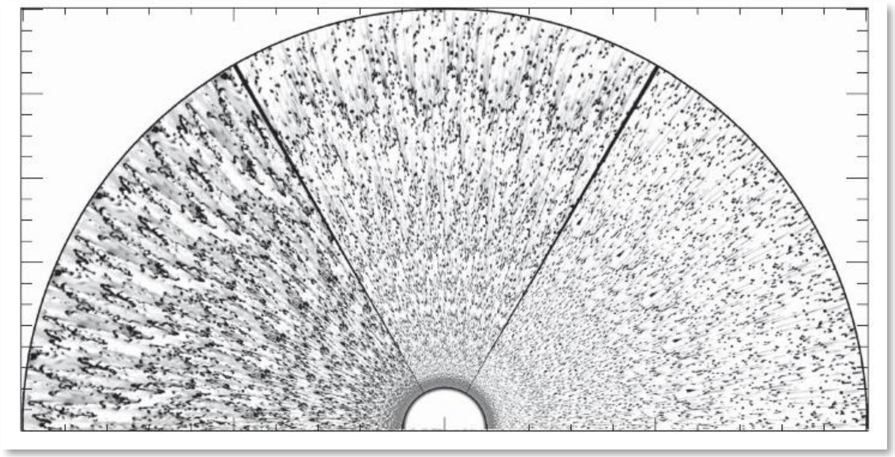
$\Delta\rho$ ~ 10
ΔV_W ~ 2-3

⇨ ΔL_X~ 10-100

(in't Zand 2005; Negueruela 2008, Walter 2007)

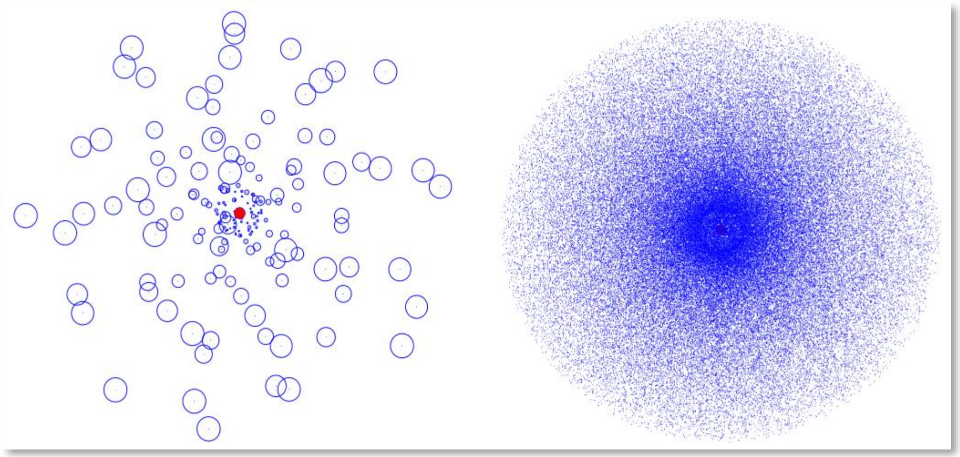
Clumps in supergiant stellar winds

- Predicted theoretically ~1980: instabilities of radiatively driven winds (Lucy & White 1980)
- Features in Opt./UV spectra: «outward moving inhomogeneities» (Eversberg 1998)



Hydrodynamical simulations:
1D: very massive clumps ($\Delta\rho \sim 10^4$)
2D: instabilities prevent large clumps

(Feldmeier 1997; Oskinova 2012; Dessart 2002, 2005)



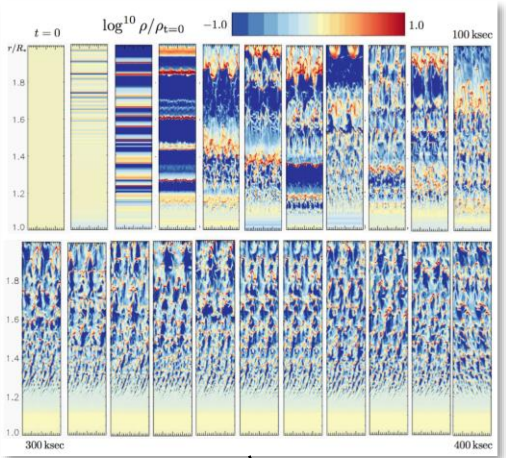
Quantitative spectroscopy:
Ad hoc clumps distributions + radiative transport to simulate Opt./UV spectra

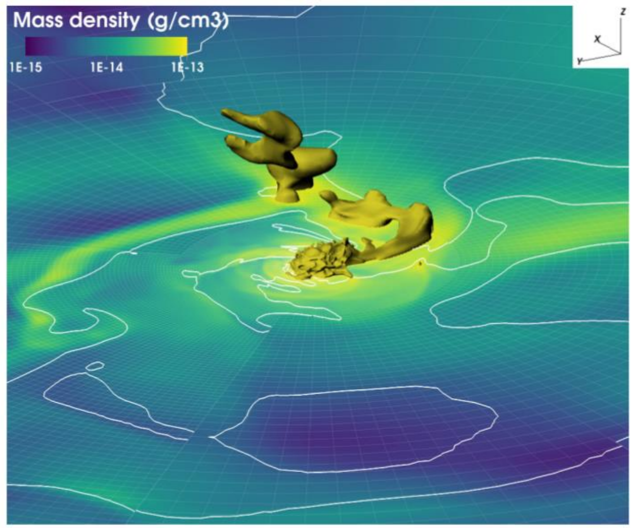
(Surlan 2013)

$\Delta\rho \sim 10$
$\Delta V_W \sim 2\text{-}3$ (Driessen 2019)

Clumps affect estimates of mass loss rates from massive stars with large induced uncertainties with repercussions in many fields of Astronomy & Astrophysics (Rubke 2023)

Clumpy wind accretion: simulations

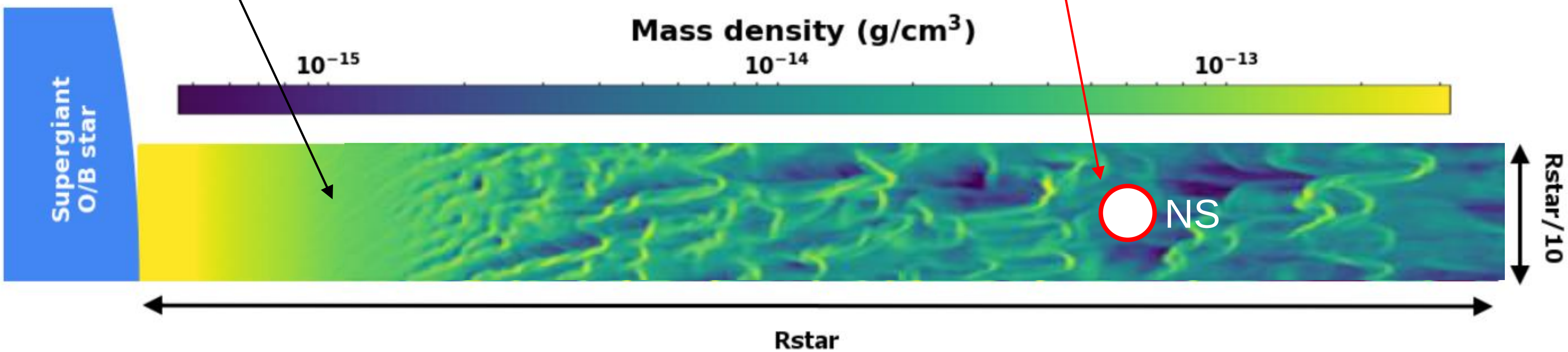


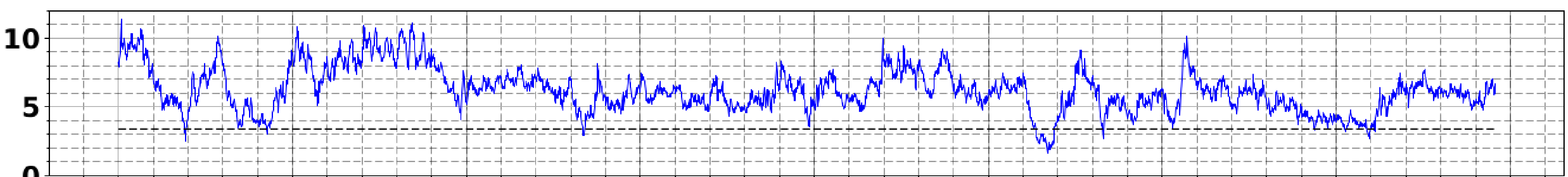


3D simulations from the 2D hydro+radiation wind

Promising results in the computation of synthetic lightcurves (El Mellah 2017)

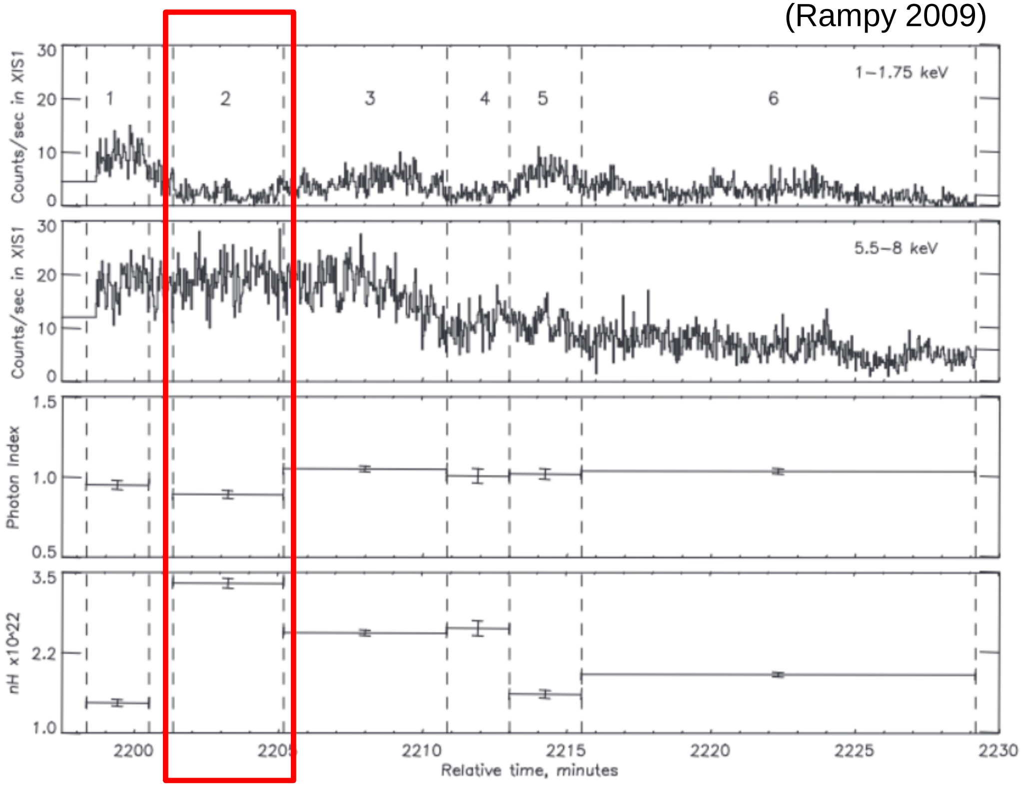
X-ray feedback onto the wind not included

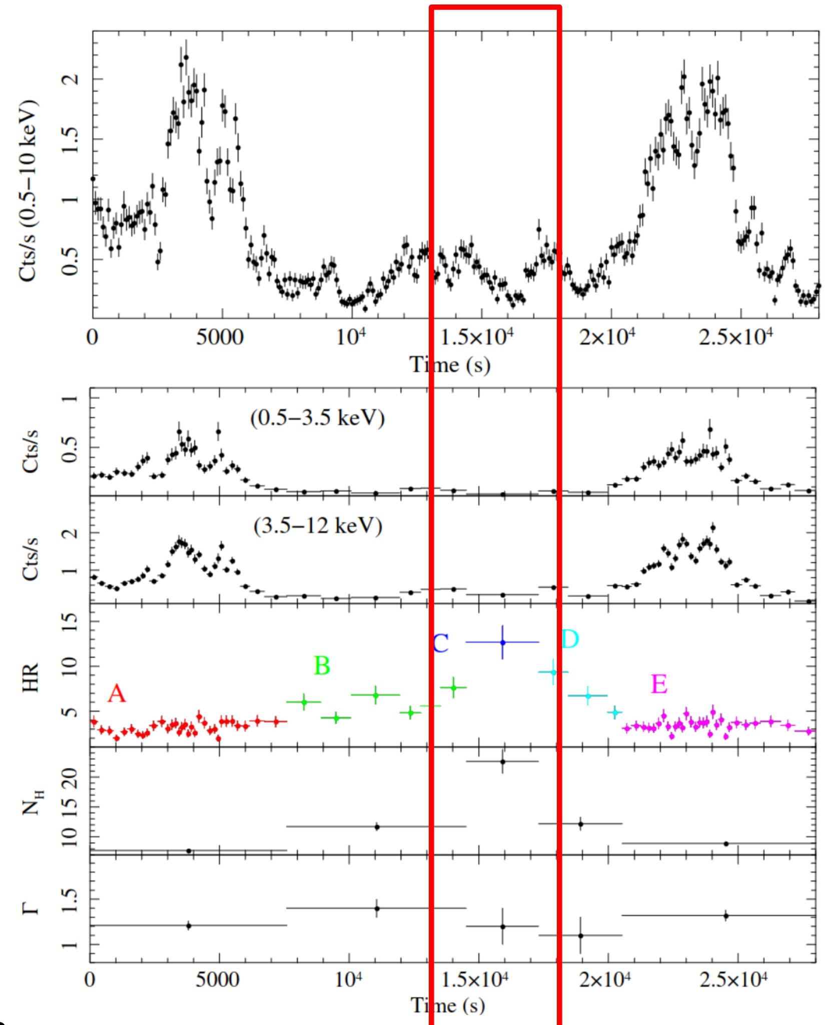




Involving sudden increases in the local absorption column density for few x100 s

(Rampy 2009)

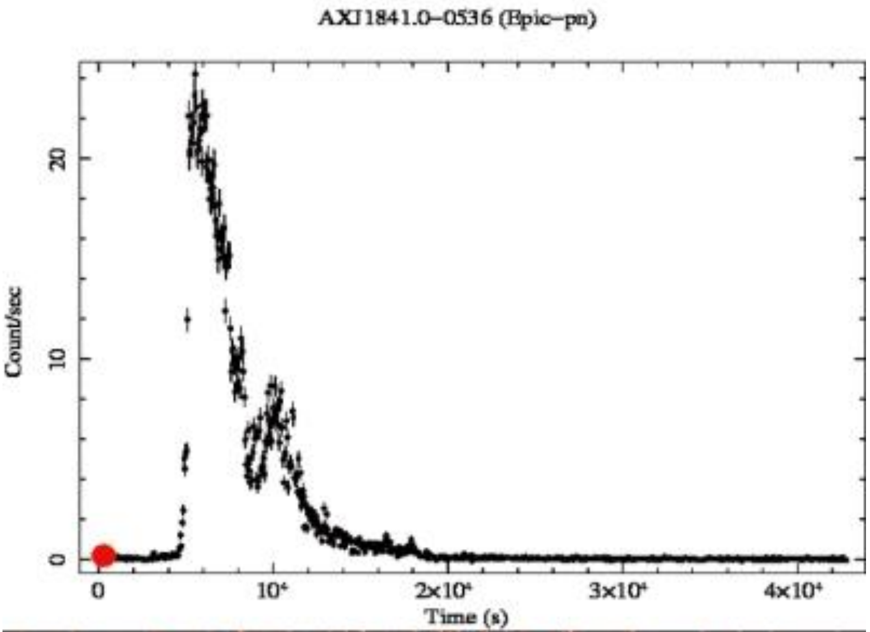


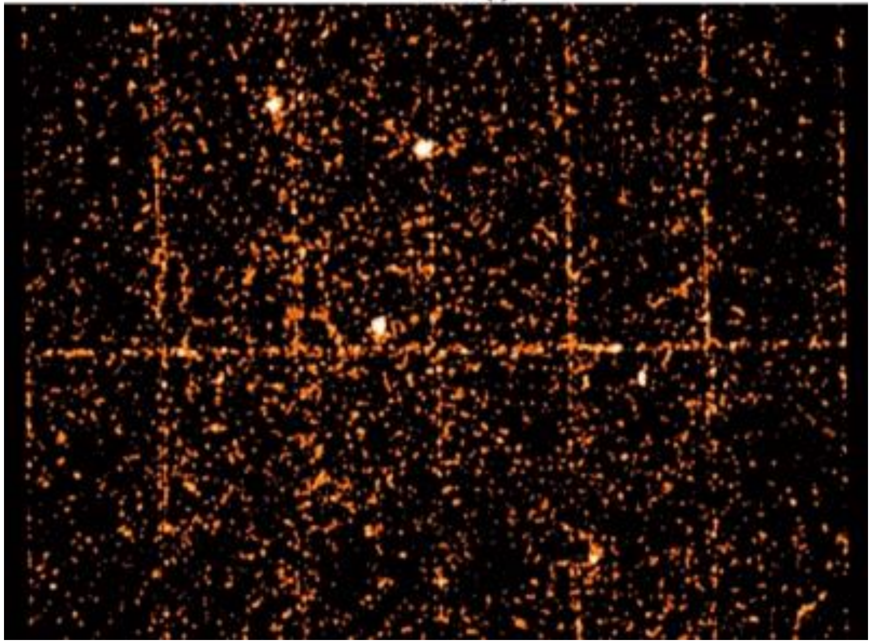


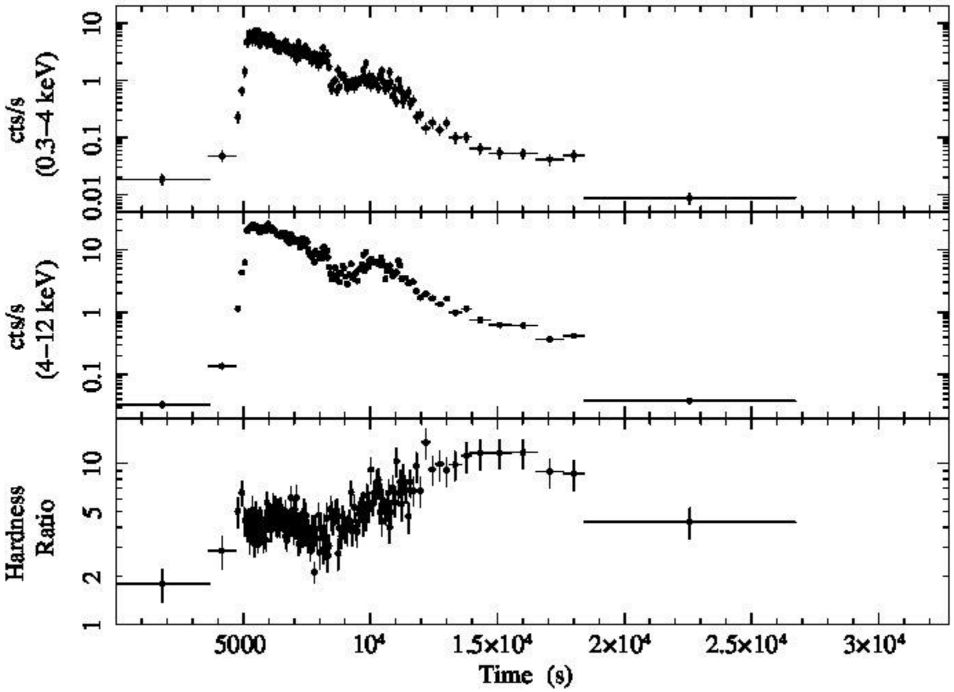
Similar events detected in many sources with different instruments

Monitoring campaign on-going with XMM-Newton

(Bozzo 2017, 2022)







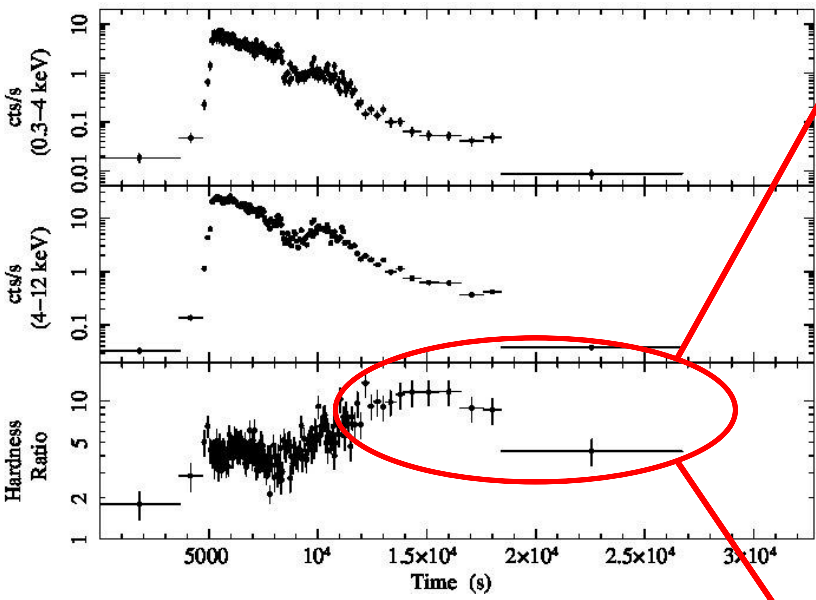
Flare from the SFXT IGRJ18410-0535

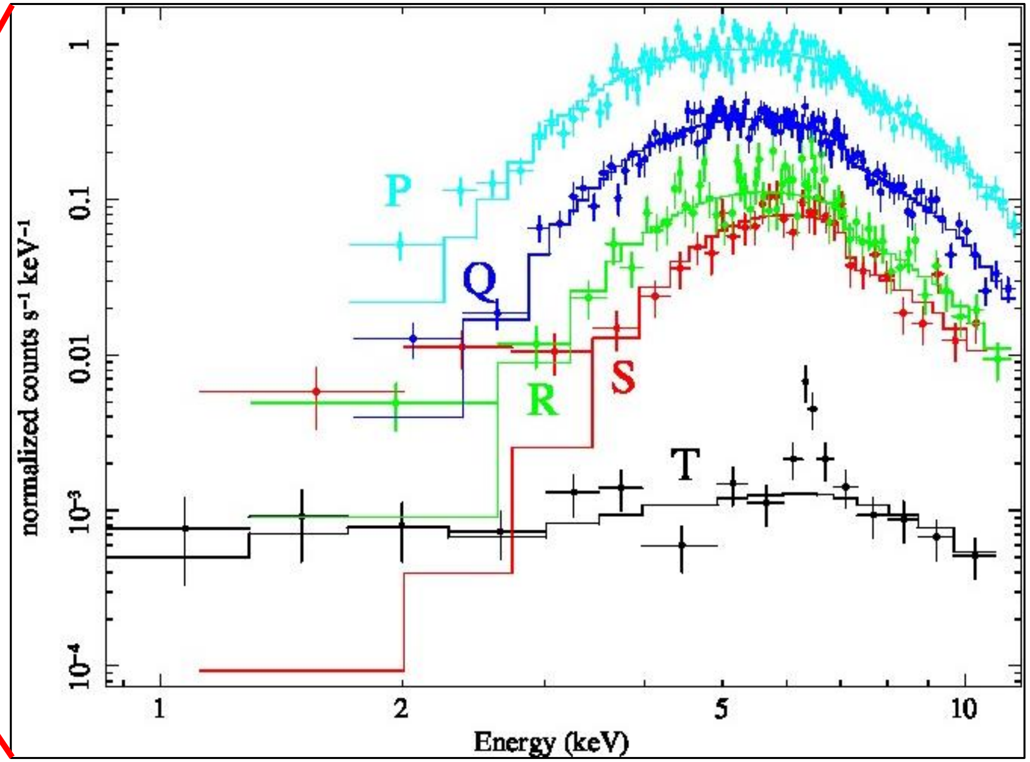
15 ks XMM, total variation in luminosity 10^5

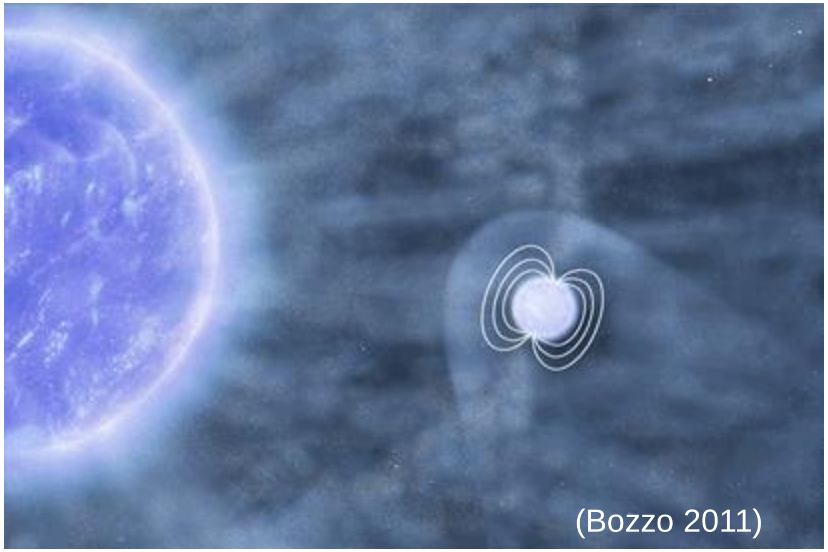
Peak luminosity $\sim 10^{35}$ erg/s

(Bozzo 2011)

Clumpy wind accretion: CCD-like spectral resolution






(Bozzo 2011)

Observations suggest the NS “ingested” a massive clump:

$$M_{\rm cl} \simeq 1.4\times10^{22}\ {\rm g}$$

$$R_{\rm cl} \simeq 8\times10^{11}\ {\rm cm}$$

About 0.6 x Supergiant Radius!!

Clumps in action: high resolution X-ray spectroscopy

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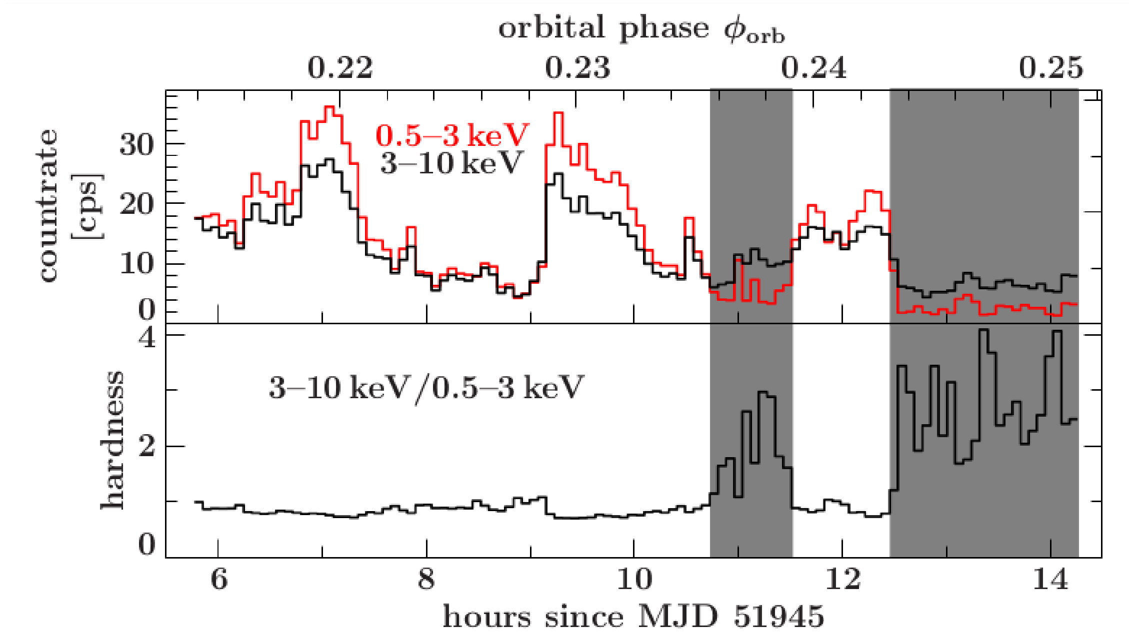
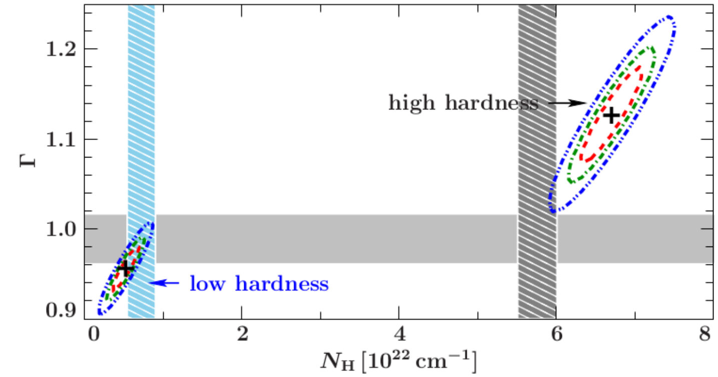
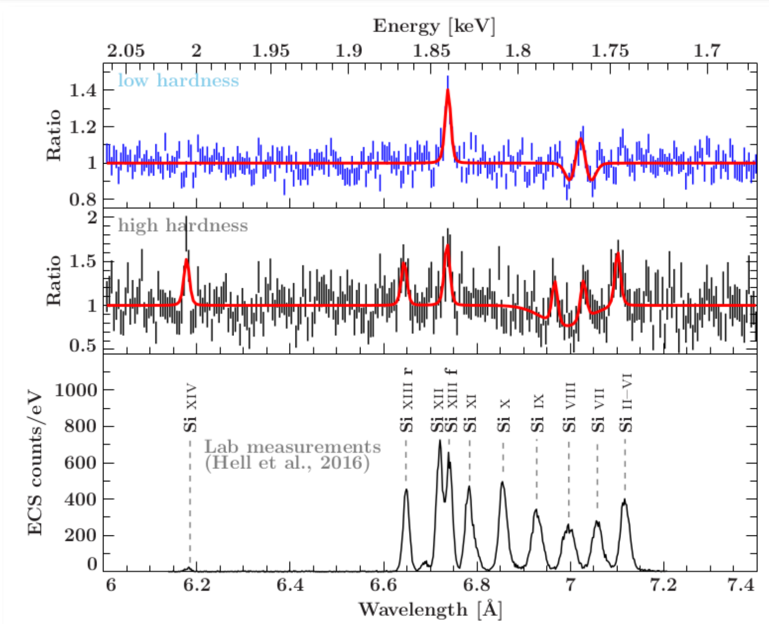


Increased HR due to increased absorption largely variable on few ks timescale



(Grimberg 2017, Amato 2021)



High resolution spectroscopy reveals how stellar wind respond to X-rays:

- Dual cold/hot medium with different ionizations states
- Ionized medium distributed also in relatively large region between the Supergiant and the NS
- «Averaged» picture of the wind, not clump by clump

Clumps in action: high resolution X-ray spectroscopy

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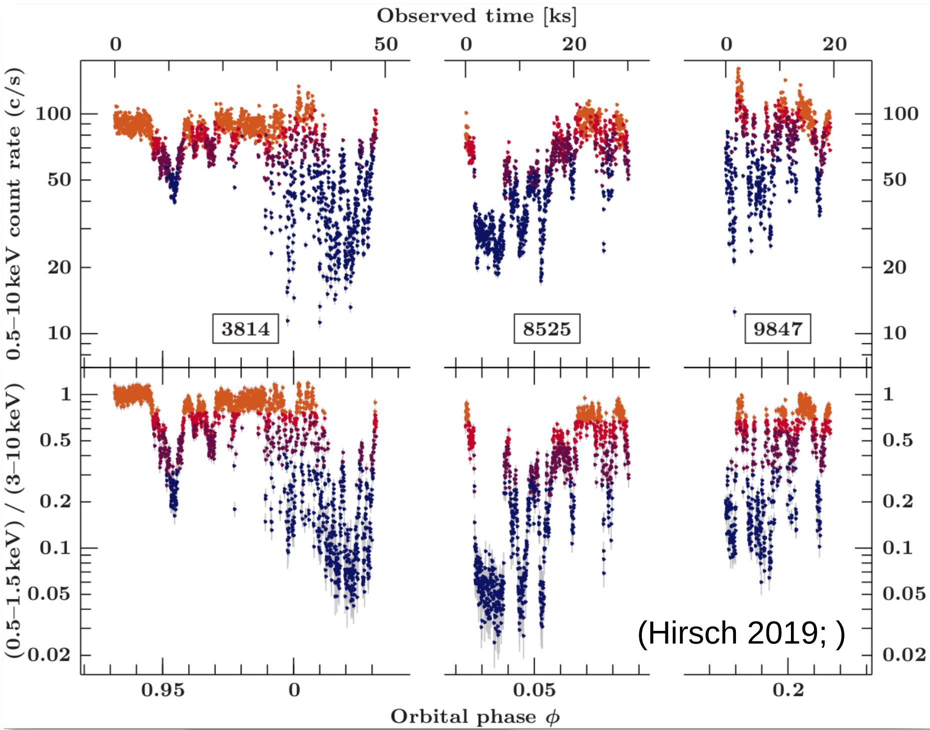
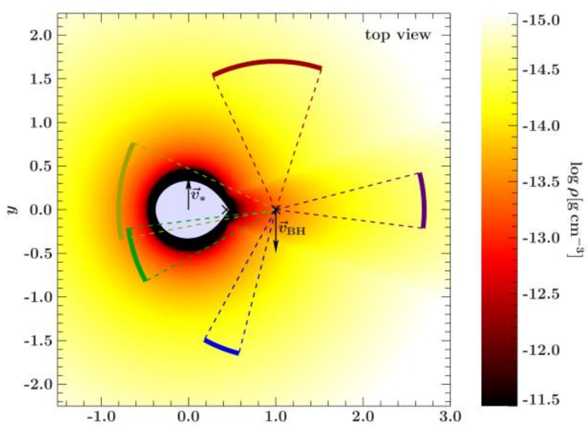
Clumps along the line of sight and obscuration events: the focused wind in Cyg X-1

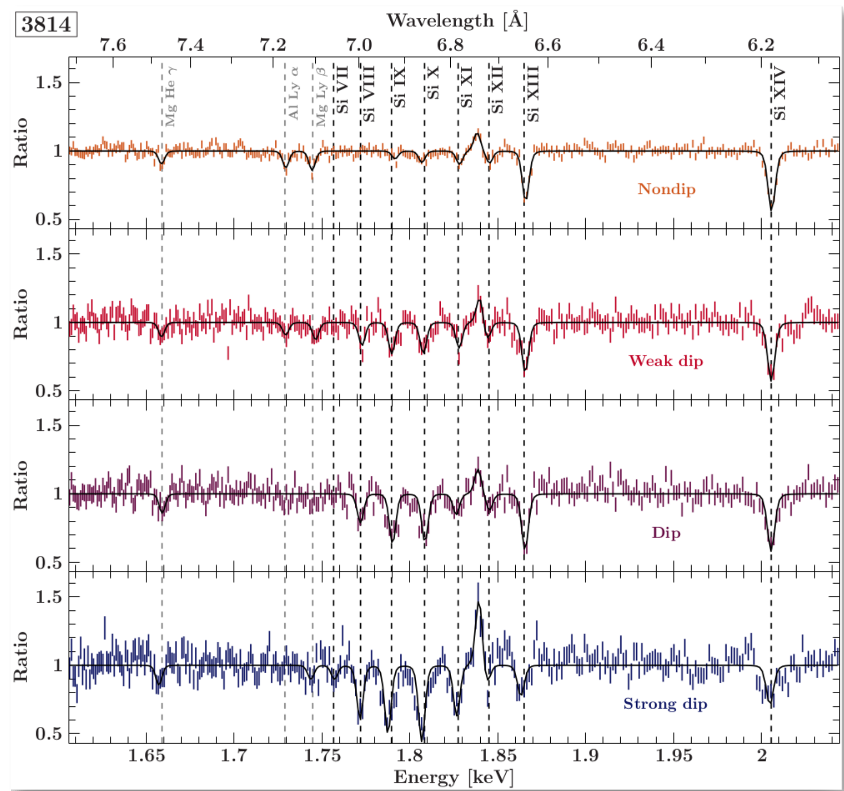


(Hirsch 2019;)

Measure the response of clumps to the X-ray illumination → reveals intrinsic properties of the clump composition and physical properties

(Miškovičová 2016)





Conclusions

- Renewed interest for wind-fed HMXBs due to their role as independent probes of massive star winds (beside being precious laboratories for accretion processes in highly magnetized environments)

- Low energ resolutions observations (CCD-like) provide convincing evidences of the existence of clumps populating the NS environments, but difficult to get solid and reliable estimates of the stellar wind physical properties

- High resolution X-ray spectroscopy grants access to much more reliable probes of the stellar wind physical parameters, but so far investigations can only be done on the «averaged» wind rather than on individual clumps

- Large improvements providing access to study of individual clumps and their response to the X-ray illumination from the NS expected with XRISM (possibly) but more certainly with the NewAthena/XIFU

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