Diving into the whirlpool

Understanding accretion in High-Mass X-ray Binaries with Vela X-1

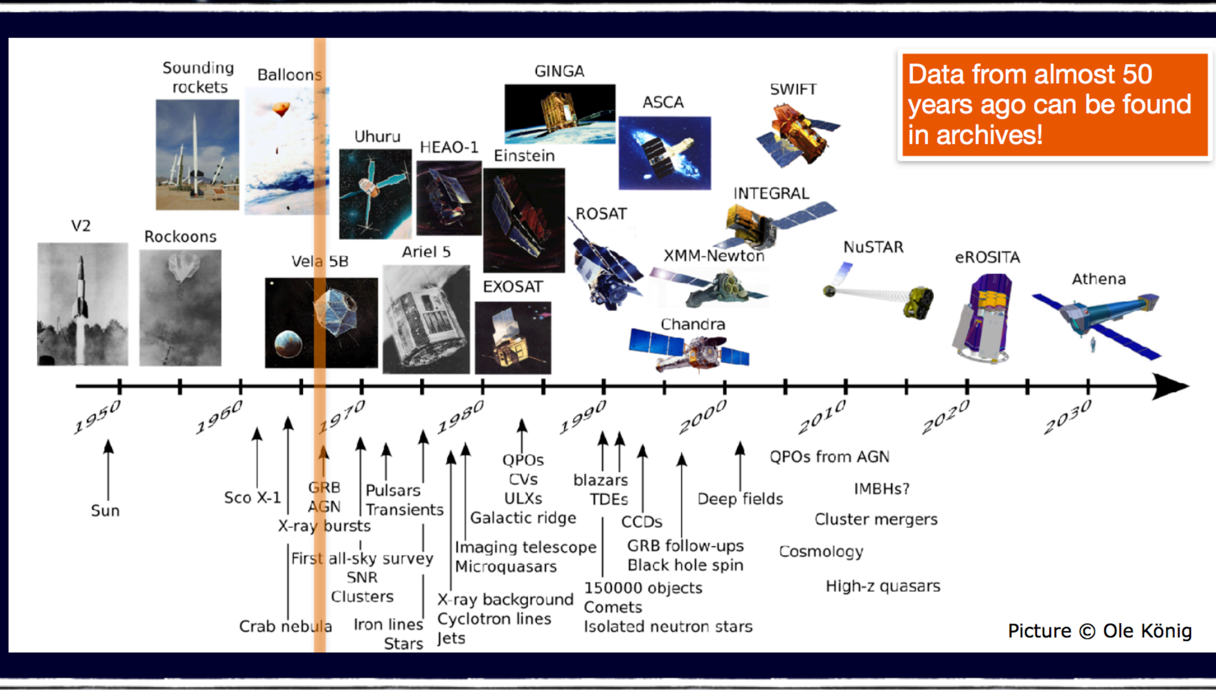
S. Martínez-Núñez (IFCA), P. Kretschmar, F. Fürst (ESA/ESAC), I. El Mellah (KU Leuven), M. Lomaeva, M. Guainazzi (ESA/ESTEC), V. Grinberg (Univ. Tübingen), A. Manousakis (Univ. of Sharjah/SAASST), S. Bianchi (Univ. Roma Tre), A. Sander (Armagh Observatory)

A very well known wind-accreting X-ray pulsar

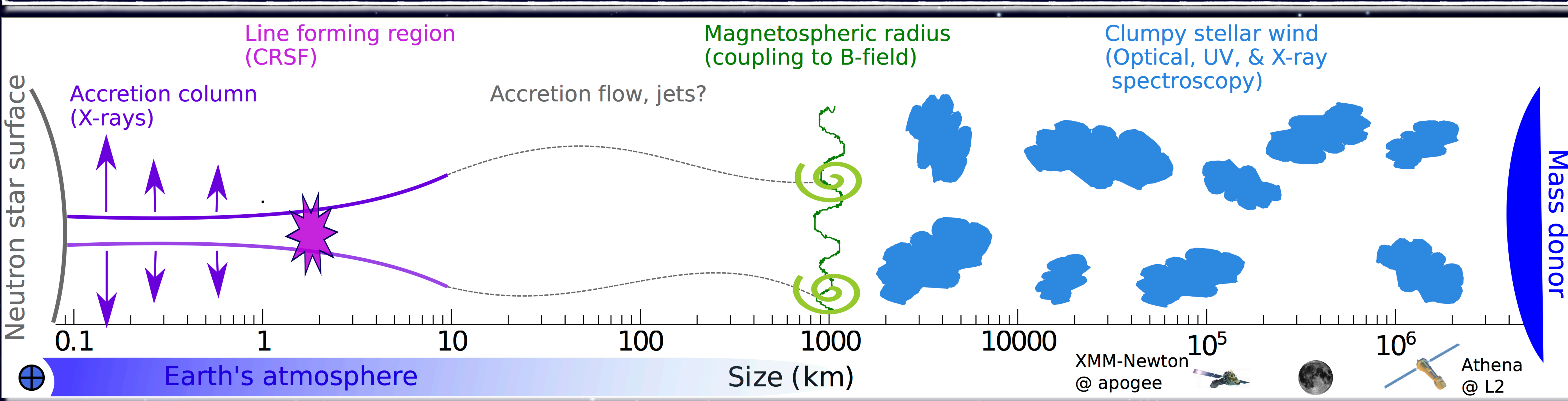
Vela X-1 was detected by rocket flights in 1966 (Chodil et al. 1967). As a bright & persistent X-ray source, it has been observed by every major X-ray satellite and various ground observatories. It thus has a particularly rich data set and well known system parameters to compare with modelling efforts.

Diagnostics at many different scales

Understanding a system like Vela X-1 requires to study scales ranging from the order of millions of km for the system as a whole down to less than a km for the X-ray emission created in the accretion column.



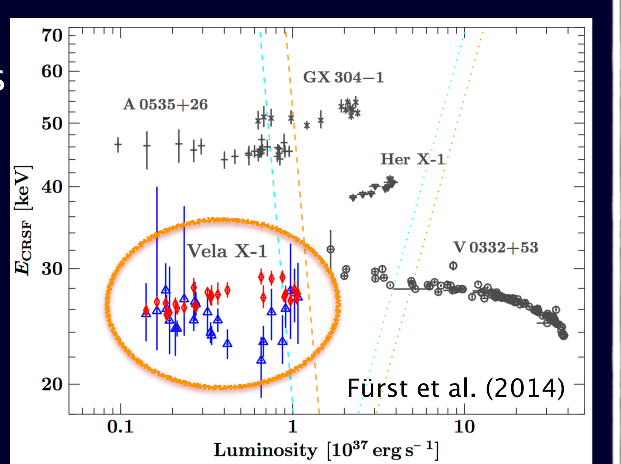
Distance	2.42 (2.25–2.60) kpc	[BJ18]
Donor star type, mass, & radius	B0.5Ia 17–27 $M_\odot$, 28–33 $R_\odot$	[GG16,F15, R11]
Mass loss by stellar wind	4×10^{-7} – 2×10^{-6} $M_\odot$ per year	[GG16,W06]
Neutron star mass	$1.9^{+0.7}_{-0.5}$ $M_\odot$	[GG16]
Orbital period	8.96438(6) d	[B97,K08,F15]
a sin i	113.89 lt-sec, i>70°	[B97,GG16]
Eccentricity	0.0898±0.0012	[B97]
Pulse period	~283 s (erratic variations)	



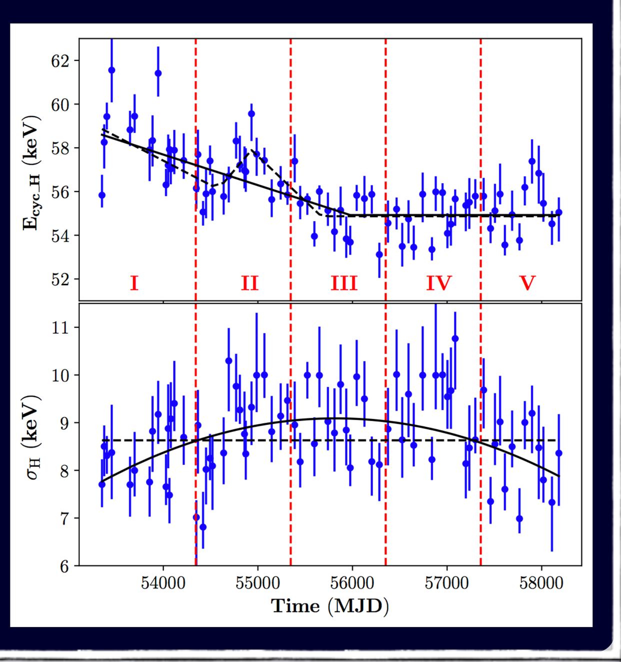
Puzzling variations in cyclotron lines

Cyclotron Resonant Scattering Features (CRSF, a.k.a. cyclotron lines) are found in a subset of all accreting X-ray pulsars (Staubert et al. 2019).

They are the most direct measure of magnetic field strength in these systems. Variations in the observed centre energy imply changes in the (height of the) emission region.



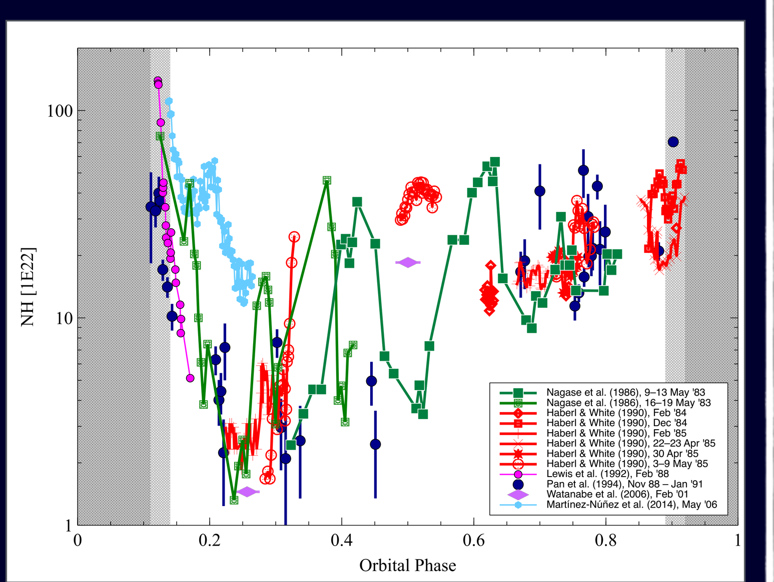
Fürst et al. (2014) found indications for a positive correlation with luminosity in the centroid energy of the first harmonic, but no clear picture of variations in the fundamental line.



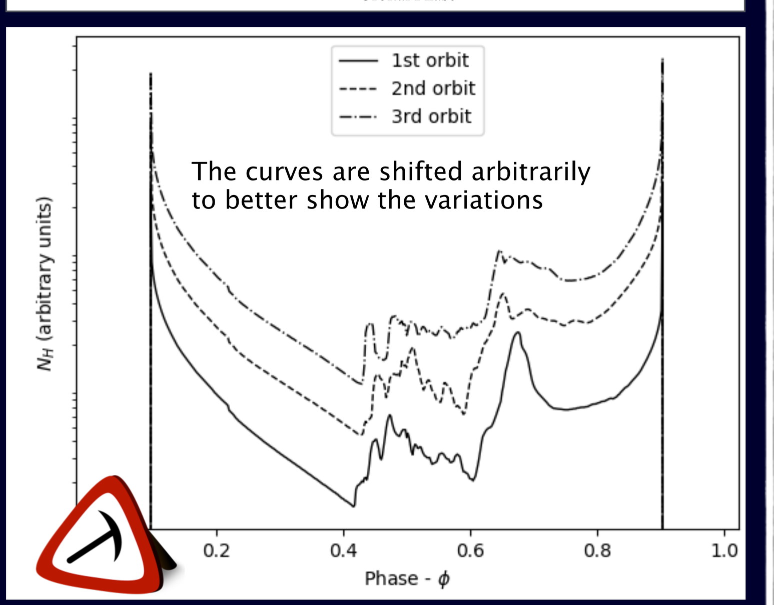
Ji et al. (2019) found a possible long-term trend in the cyclotron line energy, despite an otherwise very stable source.

Absorption traces large and small structures

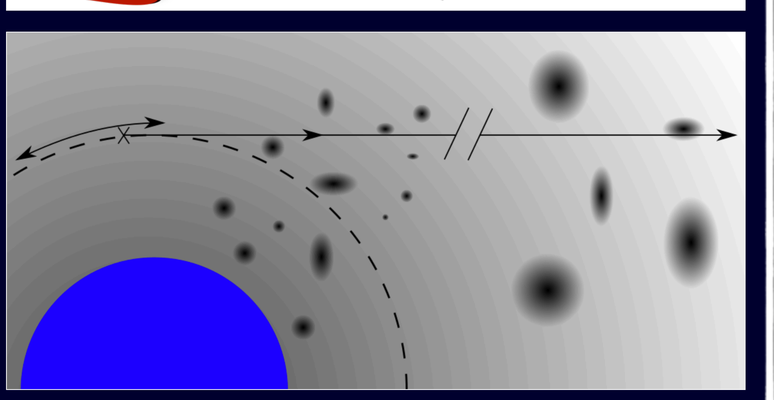
Various satellites find strong absorption column (N_H) variations along the orbit as expected from large structures in stellar wind. But very different absorption levels can be observed at the same orbital phase at different times!



Manousakis (in progress) is running hydrodynamic simulations, taking into account X-ray feedback, as in Manousakis & Walter (2015a, 2015b) to trace N_H variations caused by large scale structures in the wind. There are strong variations, varying between individual orbits, but not quite matching the data yet.



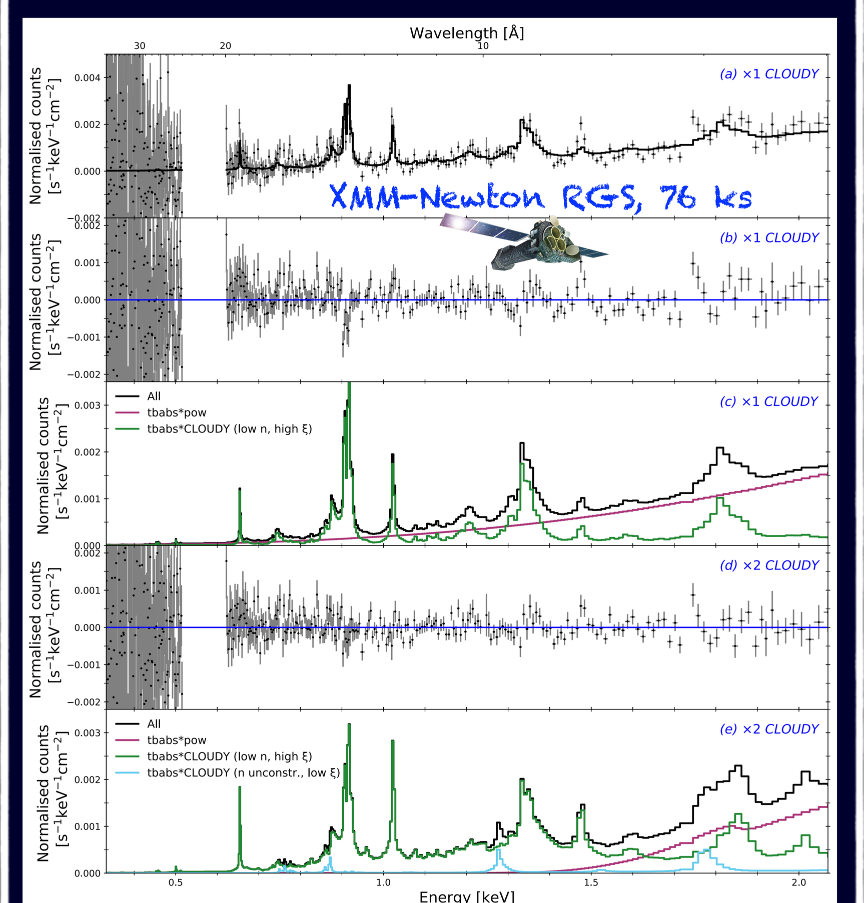
Grinberg et al. (2017) studied short-term variability caused by clumps crossing the line of sight. This effect alone is not enough to explain the observed variations.



X-ray spectroscopy to disentangle the wind structure

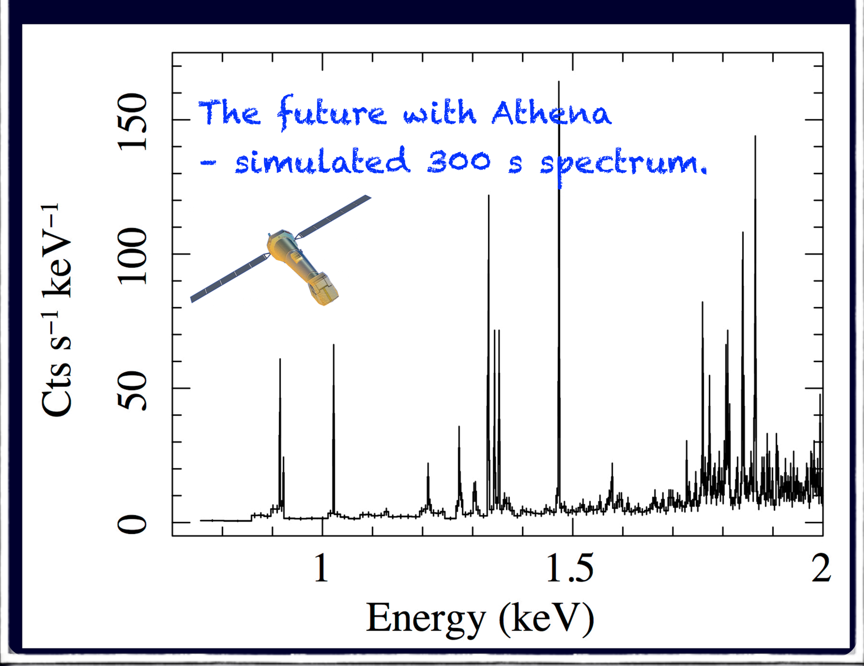
X-ray line studies of Vela X-1 have found a variety of fluorescence lines at different ionisation states (→ clumpy medium), but also radiative recombination continua (RRC).

Loameva et al. (in prep.) analyse XMM-Newton RGS data of an observation including a highly absorbed phase followed by a bright flare. In the pre-flare data, they find multiple lines of photo-ionised elements (O, Ne, Mg, Si) as well as an O VII RRC feature on top of the continuum. Using the CLOUDY code to model photo-ionisation, the spectral fit is improved by allowing for two plasma components with different levels of ionisation.



In the future XRISM/Resolve and especially Athena/X-IFU will enable studies on shorter time scales, capturing the dynamics at higher time resolution.

Athena/X-IFU will allow detailed X-ray spectroscopy on the time scale of the pulse period of Vela X-1!

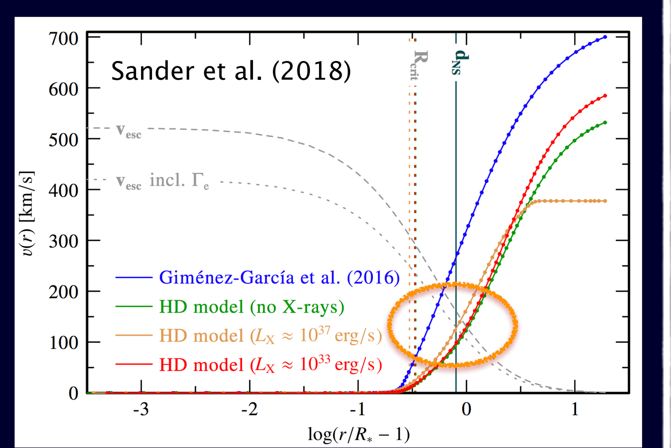


Blowing in the wind – but at what speed?

Different authors have come up with distinct terminal wind speeds, based on varying assumptions and analysis techniques.

Dupree et al. (1980)	v_∞ = 1700 km/s
Prinja et al. (1990)	v_∞ = 1100 km/s
van Loon et al. (2001)	v_∞ = 600 km/s
Watanabe et al. (2006)	v_∞ = 1100 km/s
Giménez-García et al. (2016)	v_∞ = 700^{+200}_{-100} km/s
Sander et al. (2018)	$v_\infty \approx$ 600 km/s

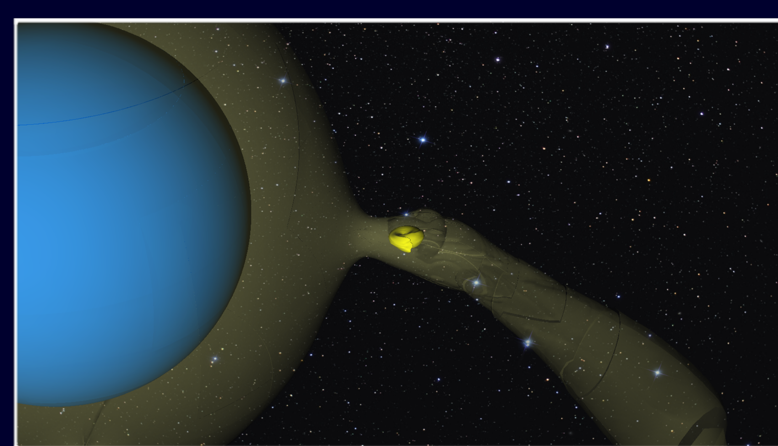
Sander et al. (2018), calculated a hydro-dynamically consistent atmosphere model describing the wind stratification and including effects of X-ray illumination in a simplified manner. They found much lower wind speeds close to the neutron star than in the usually assumed β-velocity law for the acceleration of the wind. Modelling efforts have so far mostly used higher wind speeds.



Wind-fed or disk-fed? Maybe both!

Detailed simulations by El Mellah et al. (2019) find two possible accretion scenarios:

1. When the wind speed close to the neutron star is on the order of the orbital speed, the bow shock becomes highly asymmetric and a disk-like structure may form.
2. For higher wind speeds no disk is formed, closer to classical wind accretion



The influence of clumps in the wind on the properties of a transitional wind-captured disk remains to be studied, as well as observational tools to identify disk signatures.

References

Bailer-Jones et al., 2018, AJ, 156, 58 [BJ18]
Bildsten et al., 1997, ApJS, 113, 367
Dupree et al., 1980, ApJ, 238, 969
El Mellah et al., 2019, A&A, 622, A189
Falanga et al., 2015, A&A, 577, A130 [F15]
Fürst et al., 2014, ApJ, 780, 133
Giménez-García et al., 2016, A&A, 591, A26 [GG16]
Grinberg et al., 2017, A&A, 608, A143
Ji et al., 2019, MNRAS, 484, 3797
Kreykenbohm et al., 2008, A&A, 492, 511 [K08]
Manousakis & Walter, 2015a, A&A, 575, A58
Manousakis & Walter, 2015b, A&A, 584, A25
Prinja et al., 1990, ApJ, 361, 607
Sander et al., 2018, A&A, 610, A60
Staubert et al., 2019, A&A, 622, A61
van Loon et al., 2001, A&A, 375, 498
Watanabe et al., 2006, ApJ, 651, 421

Get the poster on your mobile device