Diving into the whirlpool – understanding accretion in High-Mass X-ray Binaries with Vela X-1

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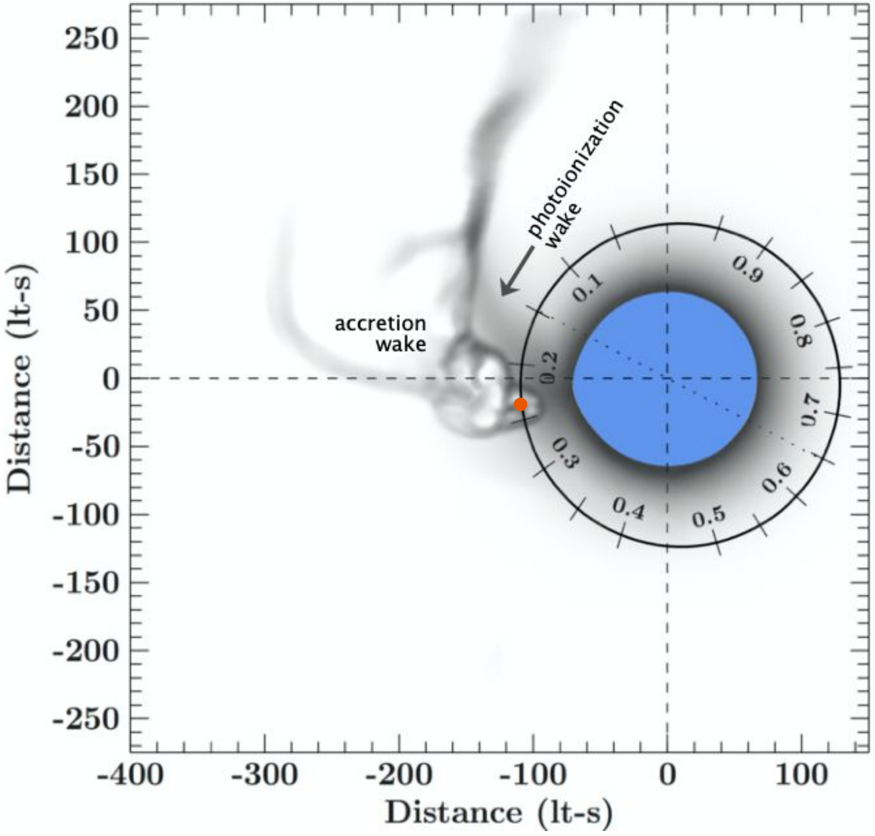
The eclipsing high mass X-ray binary Vela X-1 consists of an accreting X-ray pulsar orbiting an early type supergiant with an orbital period of ~ 9 days. It was discovered as an X-ray source by the Uhuru satellite and it has been observed since then by every X-ray observatory. Due to its brightness and variability as well as the large observational archives, Vela X-1 is the Rosetta stone for studies of wind accretion onto neutron stars. We discuss the X-ray observational properties of the system in conjunction with the supergiant properties to test recent accretion models in high mass X-ray binaries, ranging from detailed descriptions of the wind acceleration (e.g., Sander et al. 2018) to the modelling of the structure of the flow of matter close to the neutron star (e.g., EL Mellah, Keppens & Sundqvist 2018). We report new results on the impact of the wind clumpiness on the X-ray time variability and how the revised downwards wind speed implies dramatic consequences for the accretion process such as the formation of a wind-captured disc beyond the neutron star magnetosphere. Such a structure remains to be observed but its indirect signatures through jets or the torques it applies on the neutron star could well be within our observational grasp.

Vela X-1: a well-known classical wind-fed supergiant binary system?

Distance (1)	2.42 (2.25–2.60) kpc
Donor star type, mass & radius (2)(3)	B0.5Ia, 17-27$M_\odot$, 28-33$R_\odot$
Mass-loss by stellar wind(2)(4)	4×10^{-7}- 2×10^{-6} $M_\odot$ per year
Accretor (NS) (2)	1.9+0.7-0.5 $M_\odot$
Orbital period (3)(5)(6))	8.964357±0.000029 d
a sin *i* (2,5)	113.89 lt-sec, *i* > 70 deg
Eccentricity (5)	0.0898±0.0012
Pulse period	~283 s (erratic variations)

(1) Bailer-Jones+ (2018)
(2) Giménez-García+ (2016)
(3) Falanga+ (2015)
(4) Watanabe+ (2006)
(5) Bildsten+ (1997)
(6) Kreykenbohm+ (2008)



Wind accretion: blowing the wind but at what speed?

Dupree+(1980)	v_∞ = **1700** km/s	IUE (selected lines & phases)
Prinja+(1990)	v_∞ = **1100** km/s	IUE, P Cyg profiles
van Loon+(2001)	v_∞ = **600** km/s	Modelling IUE lines
Watanabe+(2006)	v_∞ = **1100** km/s	Modelling Chandra X-ray gratings
Giménez-García+(2016)	v_∞ = **700^{+200}_{-100}** km/s	IUE + optical + 2MASS, SED fitting & modelling with PoWR code
Sander et al. (2018)	$v_\infty \approx$ **600** km/s	Detailed modelling with PoWR code, including X-ray effects

Essential system parameter estimate depends significantly on assumptions taken!

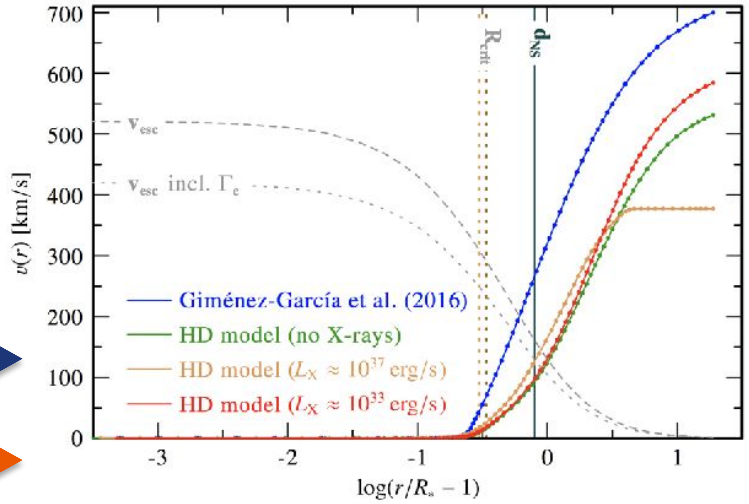
$$\xcancel{v(r) = v_\infty \left(1 - \frac{R_*}{r}\right)^\beta}$$

Sander et al. (2018):

- **Hydrodynamically consistent atmosphere model** describing the wind stratification, including effects of X-ray illumination in simplified way.
- Detailed study of contributions of different ions to wind acceleration.
- Velocity field turns out quite different from usually assumed β-law: **wind velocity** at distance of neutron star may be **much lower**.
- Flow of matter may be **very different.**

β-law

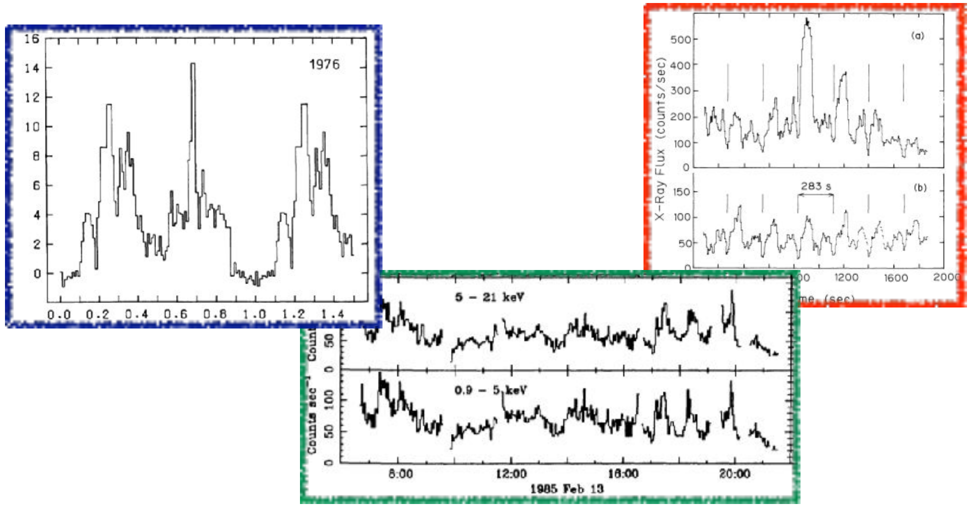
HD Model

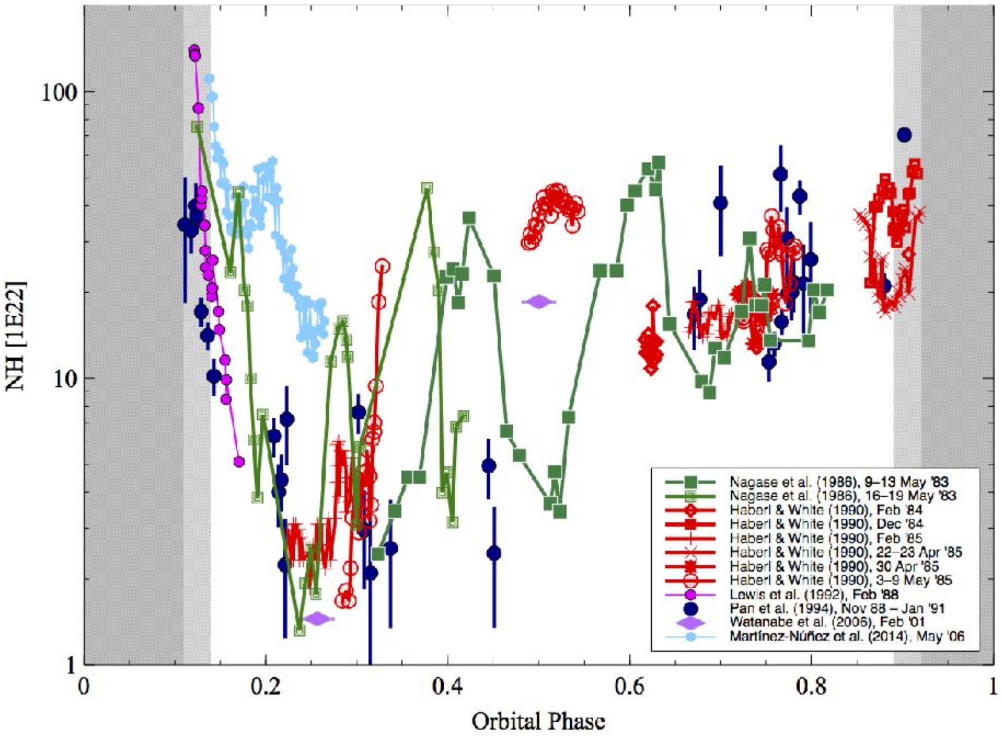


Sander et al. (2018)

X-ray properties

- Flux variations are observed on many time scales: orbital: ~1–10 d; within orbit: hours – days & pulse period: minutes
- No two orbits are the same, but there are stable mean patterns
- The flux can change from one pulse to next





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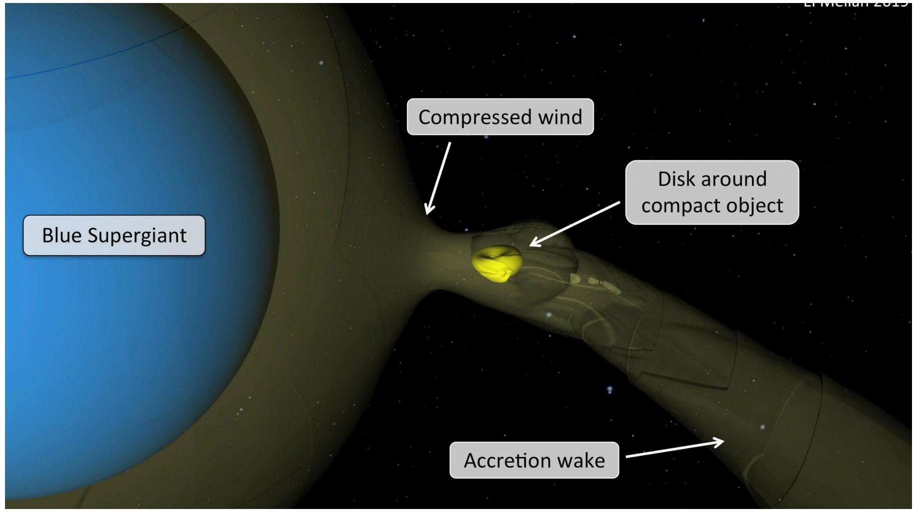
- Various satellites find strong NH variations along orbit as expected from large structures.
- But same phases can look very differently at different times!

Current picture: wind-fed or disk-fed? Maybe both!

El Mellah et al. (2019): wind launching mechanism to compute 3D streamlines + gravitational and X-ray ionizing influence of the NS on the wind +cooling once the flow enters the Roche lobe of the accretor → Although the donor star does not fill its Roche lobe, the wind can be significantly beamed and bent by the orbital effects

Two possible accretion scenarios:

1. v_{wind} close to the NS ~ $v_{orbital}$ → the bow shock becomes highly asymmetric and a disk-like structure may form
2. Higher v_{wind} 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

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