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. Lomaeve, 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 discovered by the Pion-Gamma satellite in 1966 (Chodil et al. 1967). As a bright and persistent X-ray source, it has been observed by almost every 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.

Absorption traces large and small structures

Various satellites find strong absorption columns N\textsubscript{H} from Vela X-1 as expected from large structures in stellar wind, while lower absorption levels can be observed at the same orbital phase at different times.

Manousakis (in progress) running hydrodynamic simulations, taking into account photo-electric feedback, finds that the adiabatic cooling caused by large scale structures in the wind. There are strong variations 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.

Line forming region

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Puzzling variations in cyclotron lines

Cyclotron Resonant Scattering Features (CRSFs) are 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.

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 (\(\text{clumpy medium}\)), but also radiative recombination continua (RRC)

Loimeyra et al. (in prep.) analyse XMM-Newton RCG 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\textsuperscript{2+} 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 orbital 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 various assumptions and analysis techniques.

Sander et al. (2018), calculating the wind and 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 at the usual assumed velocity 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 lower 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, 83 [BJ18]


van Loon et al., 2001

Dupree et al. (1980)

Prinja et al. (1990)

van Loon et al. (2001)

Sander et al. (2018)

Watanabe et al. (2006)

v\textsubscript{w} = 1700 km/s

v\textsubscript{w} = 1100 km/s

v\textsubscript{w} = 600 km/s

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\[\text{References}\]

The curves are shifted arbitrarily to better show the variations.

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