X-ray emission of massive stars as seen with ATHENA

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Context:

Massive O, B and Wolf-Rayet stars are key drivers of the ecology of the interstellar medium and play an essential role in the feedback processes of matter and energy at the level of their host galaxy. Here we highlight a few science cases where X-ray spectroscopy with ATHENA will provide precious insight into the physics of the stellar winds and the circumstellar environments of massive stars.

Structures in the outflows of magnetic massive stars:

- kG dipolar B fields are found in about 8% of (presumably) single massive stars
- These stars feature magnetically confined wind shocks (MCWS, Babel & Montmerle 1997, ud-Doula & Owocki 2002, ud-Doula & Nazé 2016).
- Head-on collision between the winds flowing from both hemispheres towards the magnetic equator generates hard X-rays.
- B-fields are frequently inclined wrt rotational axis → rotational modulation of X-ray emission.
- X-IFU: investigate the variability of the Fe XXV and Fe XXVI emission lines and Doppler-map the innermost parts of the MCWS.

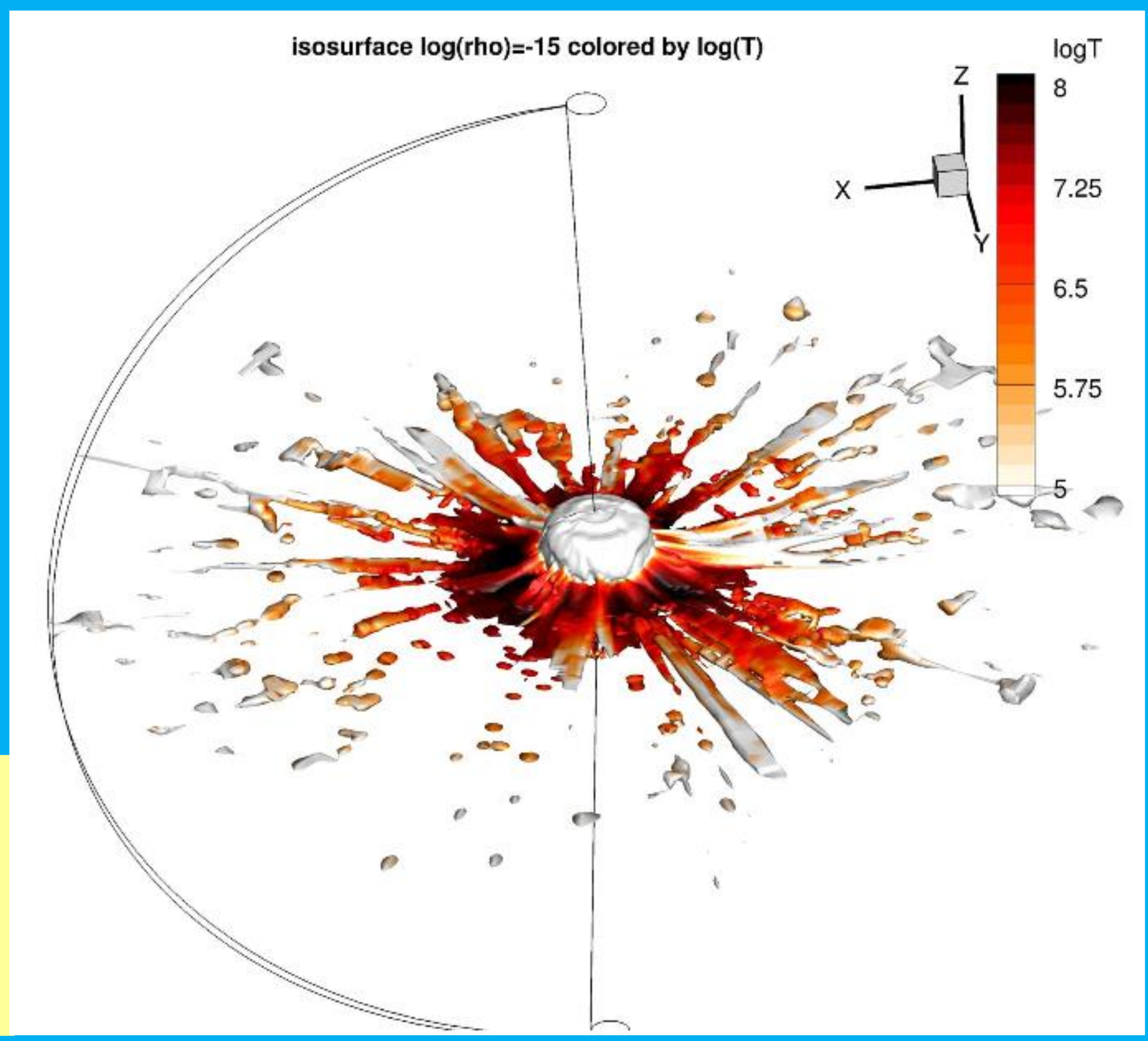

Fig.1: 3-D MHD simulation of the MCWS in HD191612. This star has a stellar wind magnetic confinement parameter $\eta_* = \frac{B_{eq}^2 R_*^2}{v_\infty \dot{M}}$ = 50. The iso-density surface with $\log \rho = -15$ (g cm^{-3}) is shown coloured according to the plasma temperature (from Nazé et al. 2016).

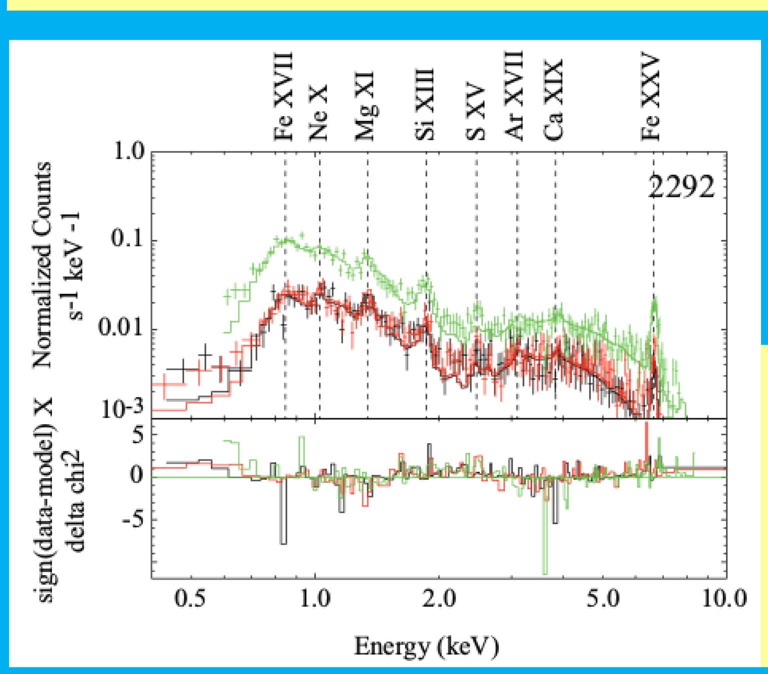

Fig.2: Observed EPIC-pn spectrum of the interacting wind binary V444 Cygni (Lomax et al. 2015) illustrating the prominent Fe XXV line complex.

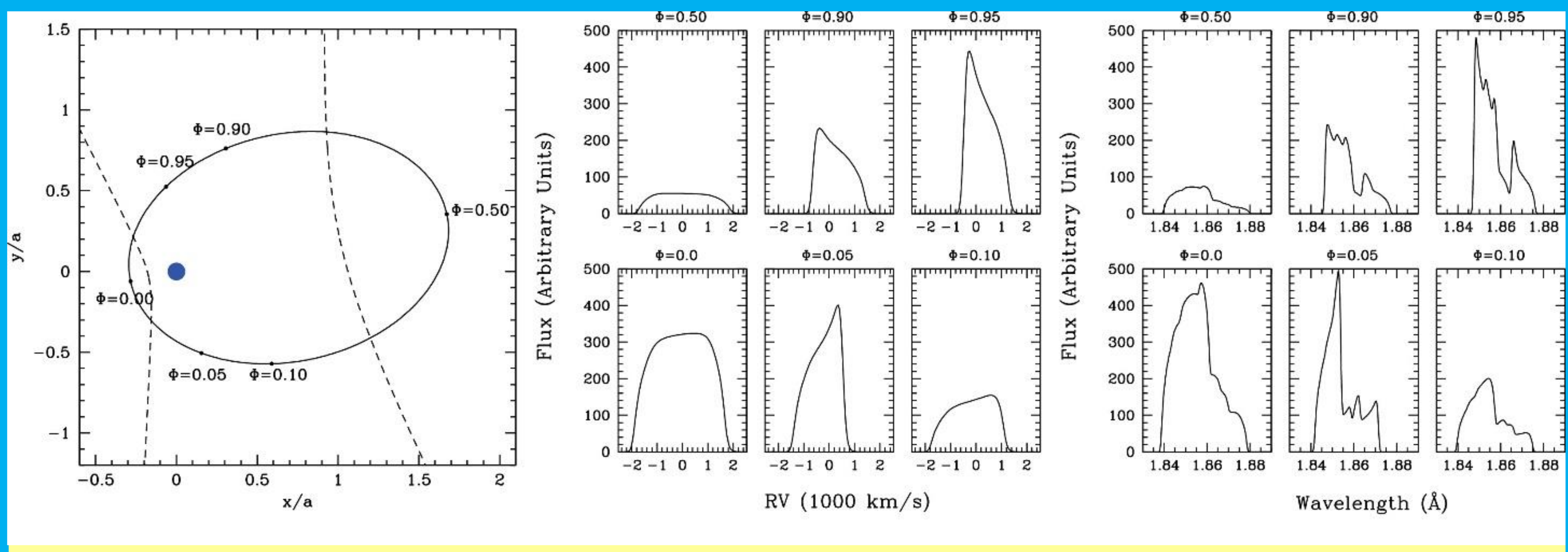

Fig.3: Left: orbit of an eccentric massive binary. Middle: synthetic line profiles for the orbital phases shown on the left. Right: synthetic Fe XXV triplet profiles for the same orbital phases (from Rauw et al. 2016).

Interacting winds in massive binaries:

- ≥ 50% of Galactic O-stars ∈ binary systems (Sana et al. 2012).
- Interactions of stellar winds in binaries can produce a hard and strong X-ray emission (e.g. Stevens et al. 1992, Rauw & Nazé 2016).
- X-ray emission lines arising in wind interaction zone (e.g. Fe XXV, Fig. 2) probe the post-shock conditions in wind interaction zone and the dynamics of the hottest gas (Henley et al. 2003, Mossoux 2013, Rauw et al. 2016).
- X-IFU: monitor the orbital changes of these lines which reflect the changing orientation of the system and, in the case of eccentric systems, also the changing properties of the wind interaction as the separation between the stars varies (see Fig. 3).

Understanding the hard X-ray emission of γ Cas stars:

- γ Cas stars = Be stars with Keplerian circumstellar decretion disk displaying unusually bright and hard (kT ≥ 10 keV) X-ray emission (Smith et al. 2016).
- 22 objects known, but probably many more (Nazé & Motch 2018).
- Two scenarios: (1) inefficient accretion onto white dwarf (Murakami et al. 1986) or neutron star in propeller regime (Postnov et al. 2017), or (2) magnetic star-disk interactions (Robinson et al. 2002).
- WFI: reveal for the first time the presence or absence of γ Cas stars in lower metallicity environment (SMC).
- X-IFU: unveil the detailed morphology of the Fe XXV, Fe XXVI and fluorescent Fe Kα lines (Fig. 4) thus discriminating between the two competing scenarios (Fig. 5)

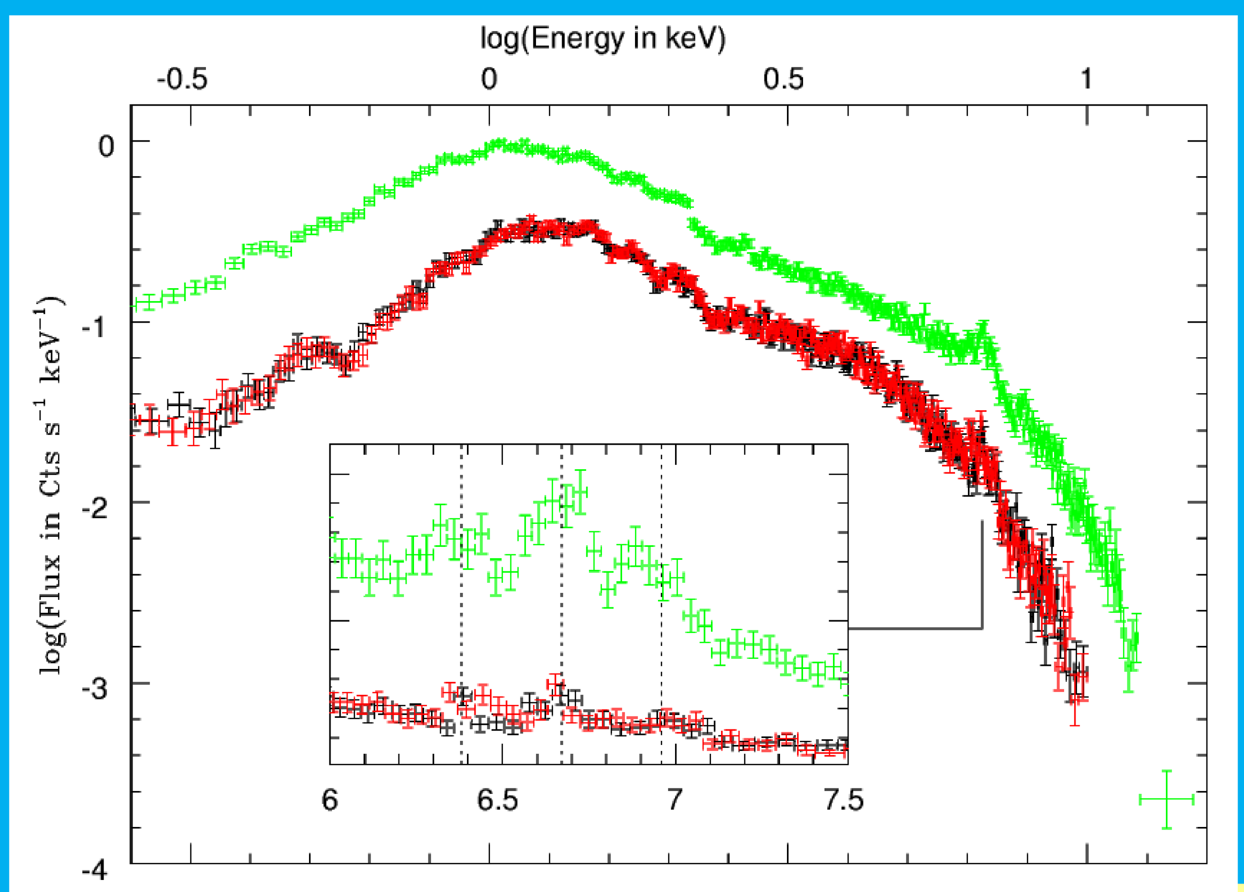

Fig.4: EPIC spectra of the γ Cas star π Aqr. The insert zooms on the region between 6 and 7.5 keV clearly unveiling the fluorescent Fe Kα, Fe XXV and Fe XXVI lines (Nazé et al. 2017).

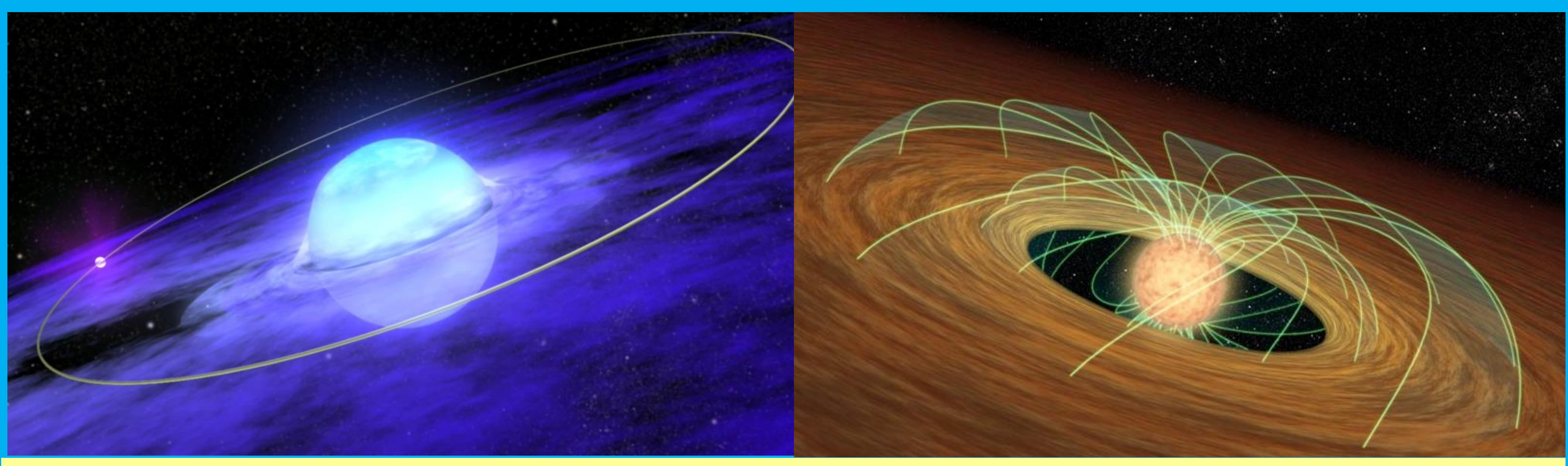

Fig.5: Schematic view of the competing scenarios for γ Cas stars: accretion by a compact companion (left) or magnetic star-disk interaction (right).

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