Monitoring limb asymmetries of WASP-76b with ESPRESSO

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Motivation

WASP-76b has previously shown signs of atmospheric asymmetry between the leading and trailing limbs, most notably in the "kinked" cross-correlation trail of atmospheric species first seen with ESPRESSO (Ehrenreich et al. 2020).
The origin of this kink has been theorised as a global affect, such as a temperature asymmetry or non-uniform cloud distribution (Savel et al. 2022).

We aimed to compare multiple ESPRESSO transits of WASP-76b with a realistic rotational broadening kernel, which allows us to model each limb separately, and thus constrain the atmospheric parameters of the leading/trailing limbs over time.

ESPRESSO Observations of WASP-76b

We analysed three transits of the ultra-hot Jupiter WASP-76b with ESPRESSO, with one of the transits (T3) not yet reported in the literature.

For each of the transits, we retrieve abundances of various neutral metals (Fe, V, Cr, Mg, Na) as well as VO, for each of the atmospheric limbs. Furthermore, we also constrain the limbs' vertical T-P structure and atmospheric dynamics separately.

The Rotating Annulus broadening kernel:

$$G(\Delta v) = \begin{cases} \dfrac{\sqrt{(1+d)^2 - (\Delta v/\Delta v_{rot})^2}}{d} & \text{, for } r_1 \leq |x| \leq r_2 \\ \dfrac{\sqrt{(1+d)^2 - (\Delta v/\Delta v_{rot})^2} - \sqrt{1 - (\Delta v/\Delta v_{rot})^2}}{d} & \text{, for } |x| < r_1 \end{cases}$$

This kernel describes the broadening profile of a rotating annulus, such as that of a transiting planet's atmospheric terminator – assuming solid-body rotation.

Each half of the terminator, the leading *morning* limb and the trailing *evening* limb, can be separated in velocity and modelled separately with their own set of atmospheric parameters (see Fig. 2 below).

Thus, we can retrieve separate dynamics, abundances, and *T-P* profiles for each half of the atmosphere (see Figs. 3 & 4 below).

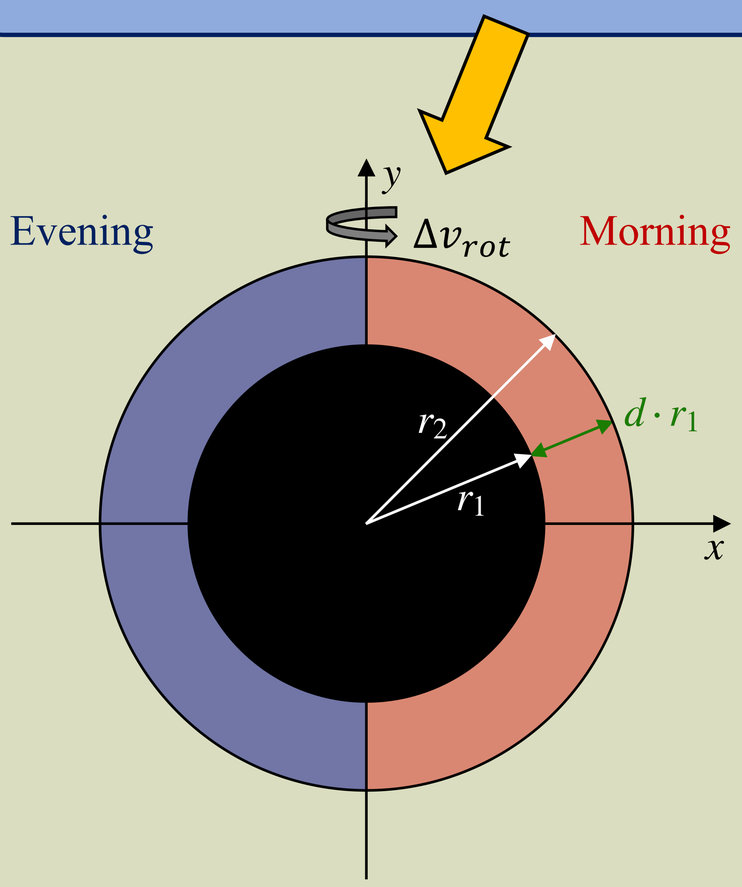

Fig. 1. A schematic diagram of a rotating terminator, with morning (*red*) and evening (*blue*) limbs shown.

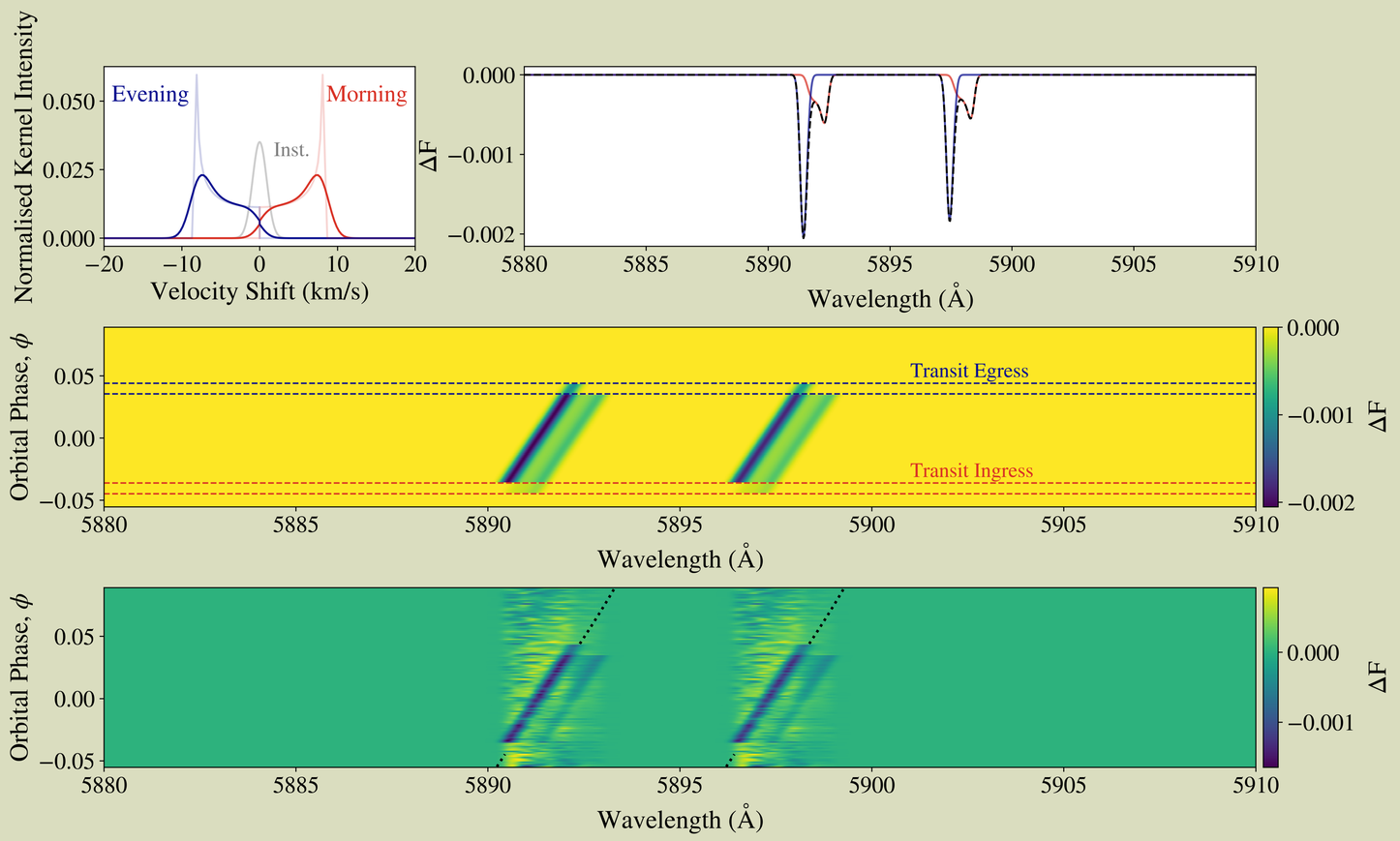

Fig. 2. A 1D Na model (*upper right*) broadened by our broadening kernel (*upper left*). This model is projected to the orbital phase and Doppler shifted (*middle*), before undergoing *SysRem* filtering (*lower*).

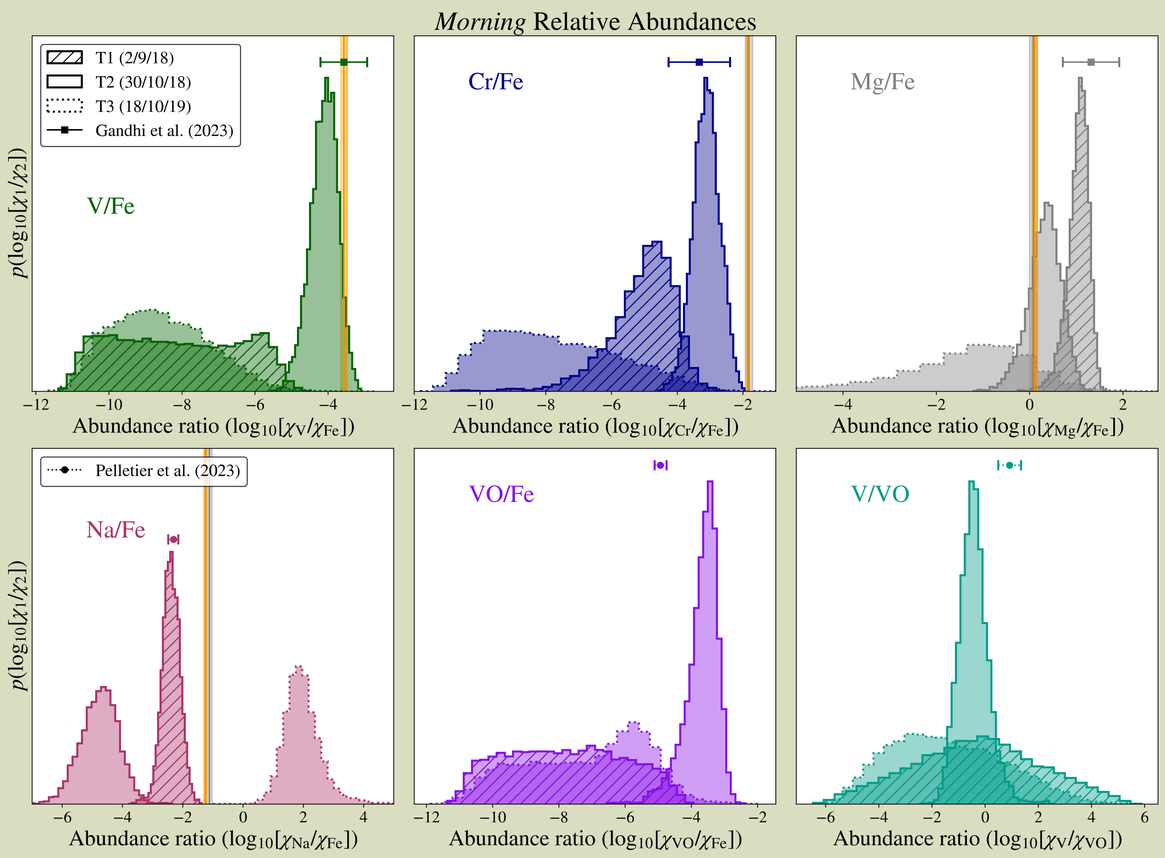

Fig. 3. Relative abundance comparison across each of the three transits, for the *morning* limb. Stellar (*grey*) and solar (*orange*) values are shown as vertical lines with 1σ contours, where available. Constraints from Gandhi et al. (2023) and Pelletier et al. (2023) are also shown.

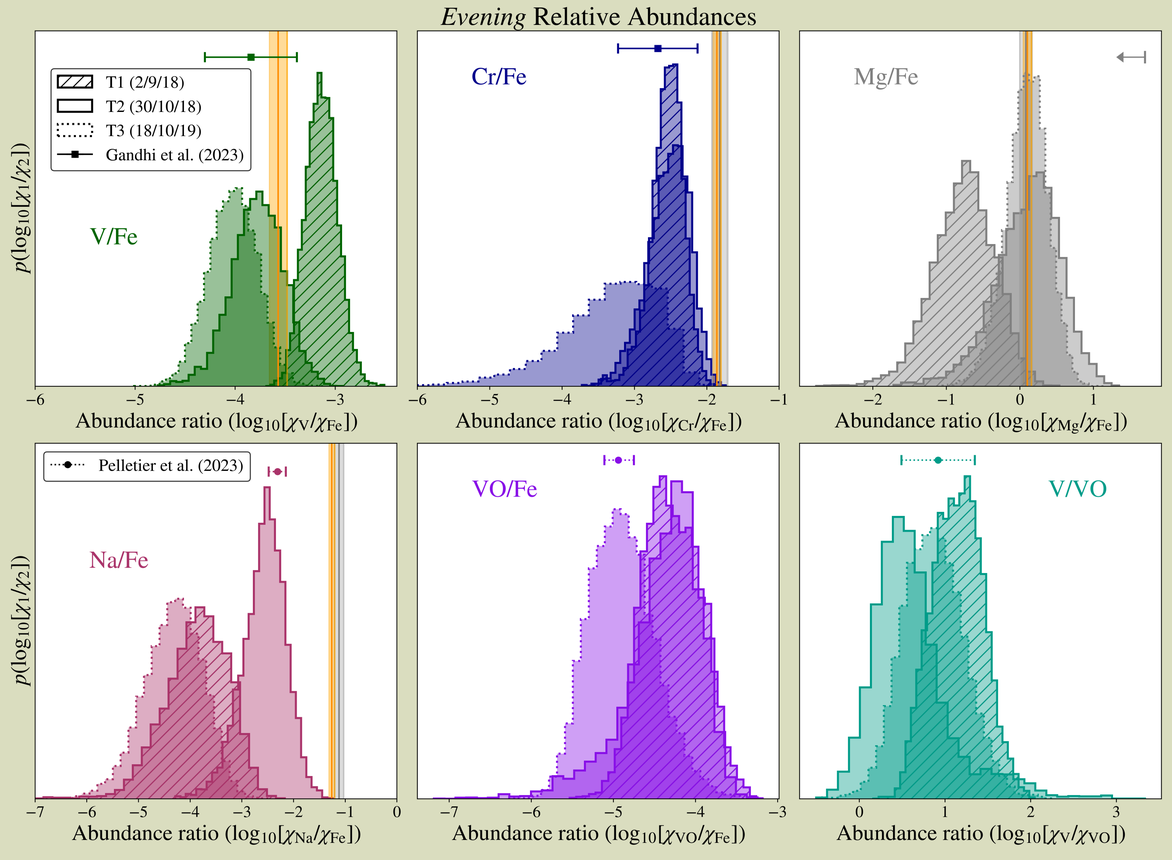

Fig. 4. Relative abundance comparison across each of the three transits, for the *evening* limb. Stellar (*grey*) and solar (*orange*) values are shown as vertical lines with 1σ contours, where available. Constraints from Gandhi et al. (2023) and Pelletier et al. (2023) are also shown.

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