MHD Effects of the Stellar Wind on Observations of Escaping Exoplanet Atmospheres

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AIMS

We model the effect of the stellar wind on the escaping atmosphere of a magnetised planet in the habitable zone of a low-mass M dwarf. We consider the implications of the wind-outflow interaction on potential hydrogen Lyman α observations of the planetary atmosphere during transits.

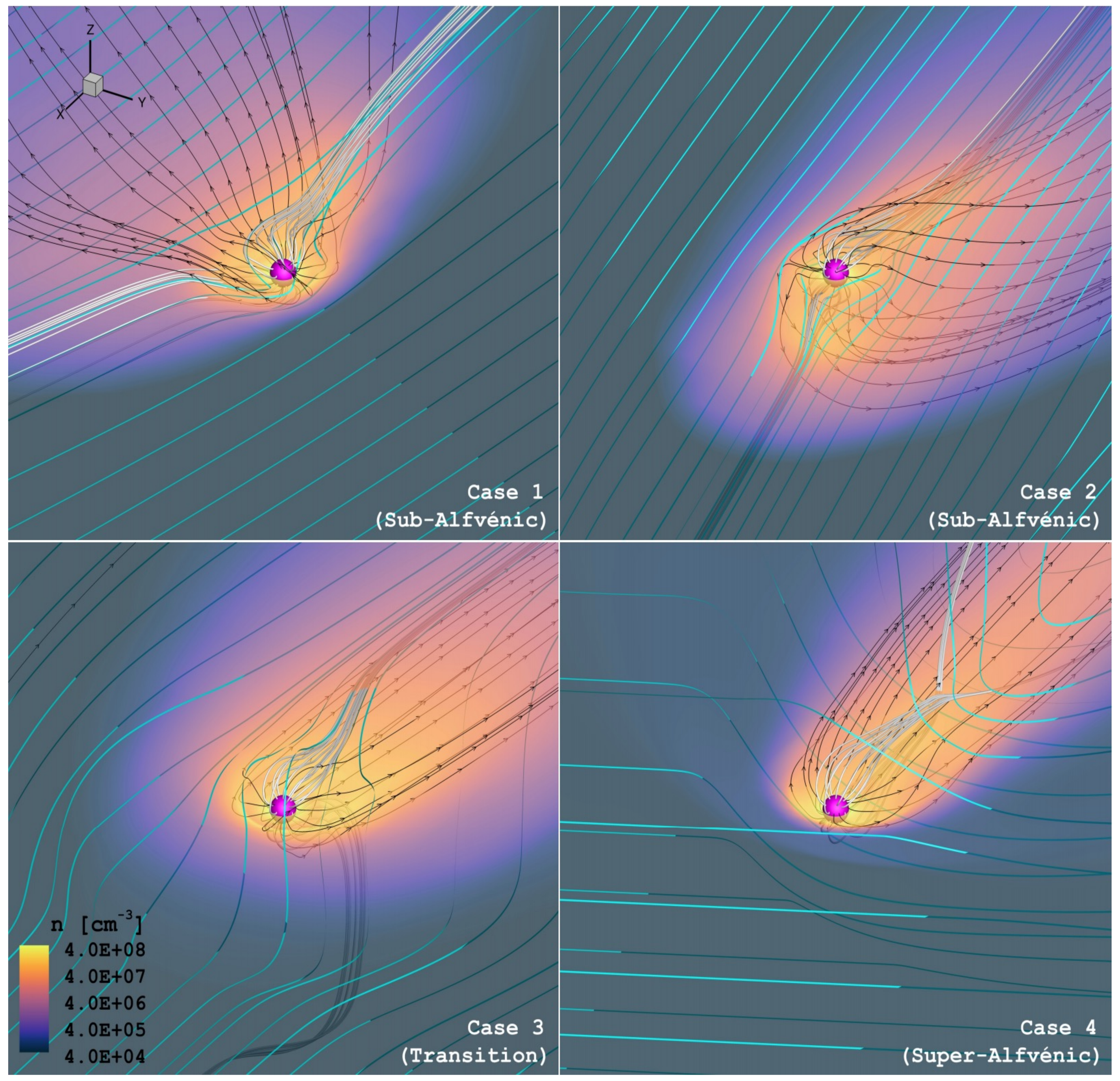
NUMERICAL METHOD

We use state-of-the-art 3D MHD models to examine the influence of stellar wind conditions experienced by a magnetised planet throughout its orbit. We use the TRAPPIST-1 system as the basis of our simulations and model the hypothetical planet to have an H-rich evaporating outflow, with a pre-defined mass loss rate. The stellar wind conditions are based on advanced magnetogram driven stellar wind models of TRAPPIST-1a.

We then use these MHD models to examine two aspects of the absorption transit signature: firstly, in a "grey" diminution of the background stellar light; and secondly, in the velocity-dependent absorption in the stellar Lyα emission profile.

MHD RESULTS

We show the atmospheric outflow is dragged and accelerated upon interaction with the stellar wind, resulting in a diverse range of planetary magnetosphere morphologies and plasma distributions which are strongly dependent on the local stellar wind conditions.



Magnetospheric structure of a planet situated at the orbit of TRAPPIST-1e. The magnetised planet is represented by a magenta isosurface and was modelled to have a hydrodynamic outflow. The stellar wind flows from the positive x-axis. The range of stellar wind conditions were extracted from a 3D MHD simulation of TRAPPIST-1a by Garraffo et al. 2017. The colour scale shows an equatorial projection (plane z = 0) of the particle number density. Planetary magnetic field lines connected to the planet are shown in white, while stellar field lines are shown in cyan. The planetary outflow is denoted by velocity streamlines (black with arrows). Note that the lines transition in colour as they pass through the equatorial plane. The motion of the planet is towards the positive y–axis.

Stellar Winds Drive **Strong Variations** in Exoplanet Evaporative Outflows and **Transit Absorption Signatures.**

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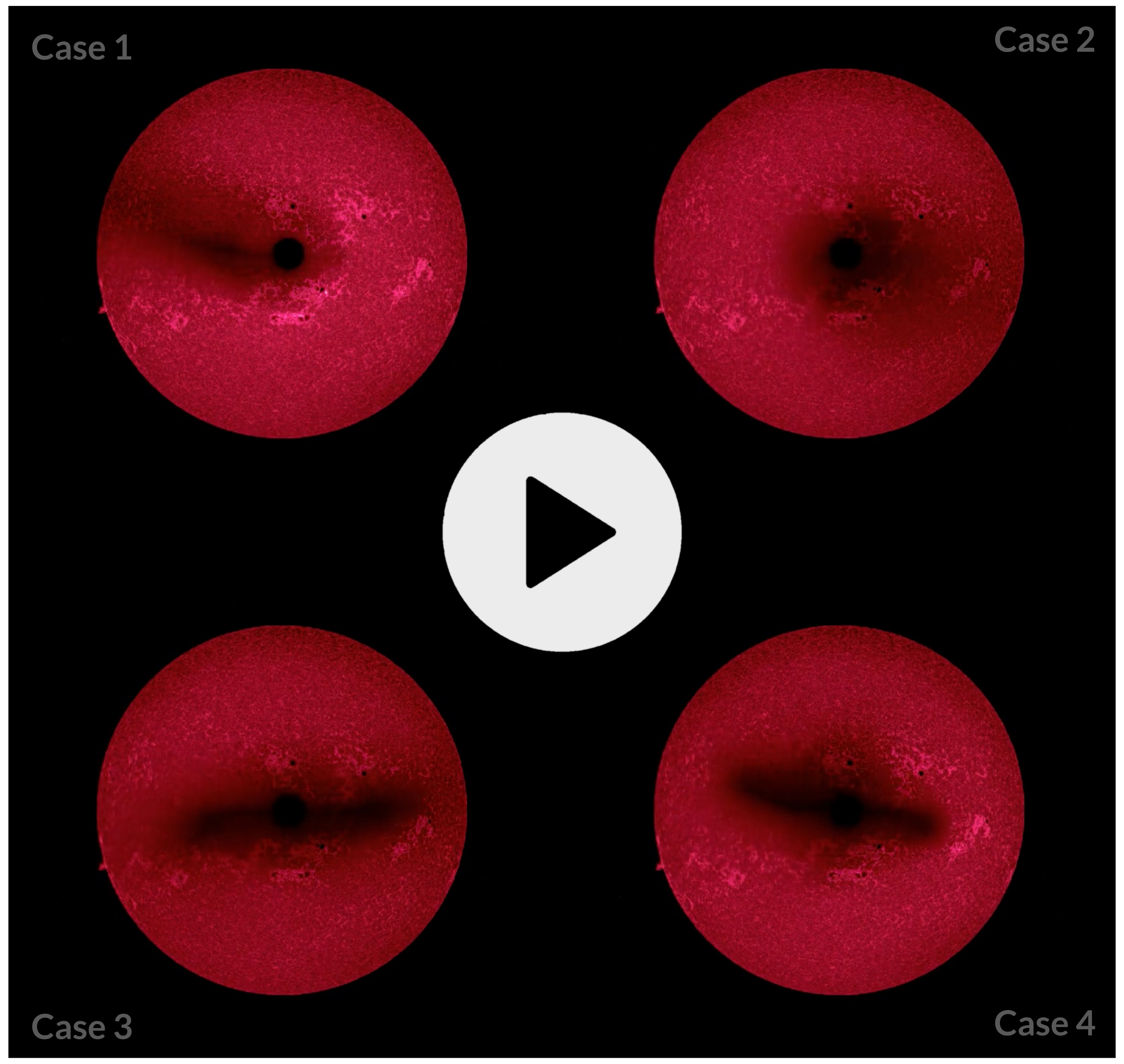
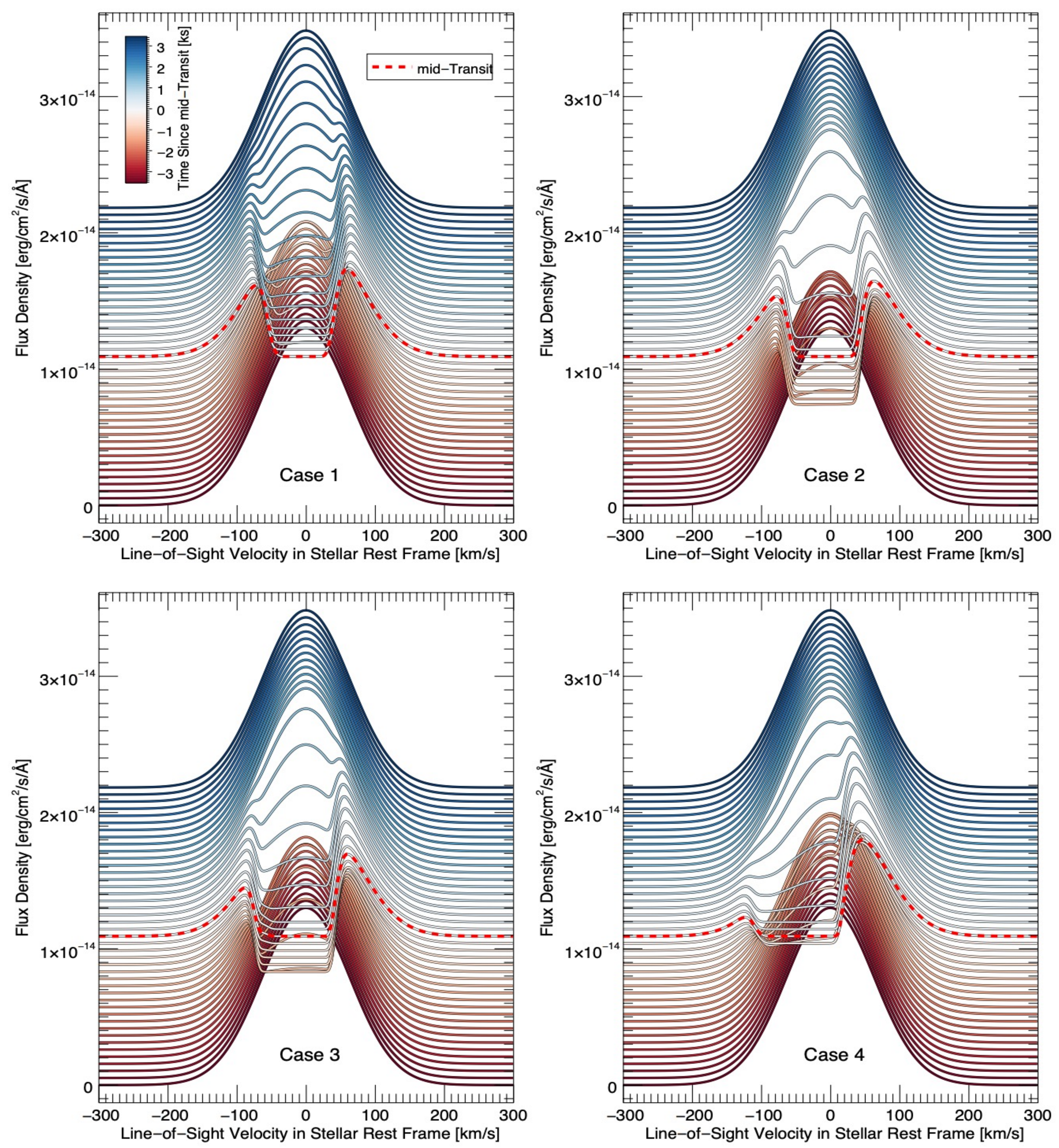
LYMAN α RESULTS

The Lyman α observational signatures depend strongly on the local wind conditions at the time of the observation and can be subject to considerable variation on timescales as short as an hour. The wind-outflow interaction provides an explanation for observed variations in transit absorption features.



Example stellar disk intensity images showing absorption within the simulated evaporating planetary envelope columns computed using grey Lyman α absorption. In each case, the planet transits from left to right and is shown at an arbitrary phase. Attention is drawn in particular to the quite different spatial distributions of the absorption in each case, indicating that no two transits will be exactly alike.



Stellar Lyα emission line profiles computed for the transits of Cases 1–4 as a function of line-of-sight velocity in the stellar rest frame. Profiles are shown at regular time intervals covering slightly more than ±3 ks from mid-transit. Successive profiles are offset vertically for clarity.