Using Lyman-α transits to provide insight into atmospheric escape

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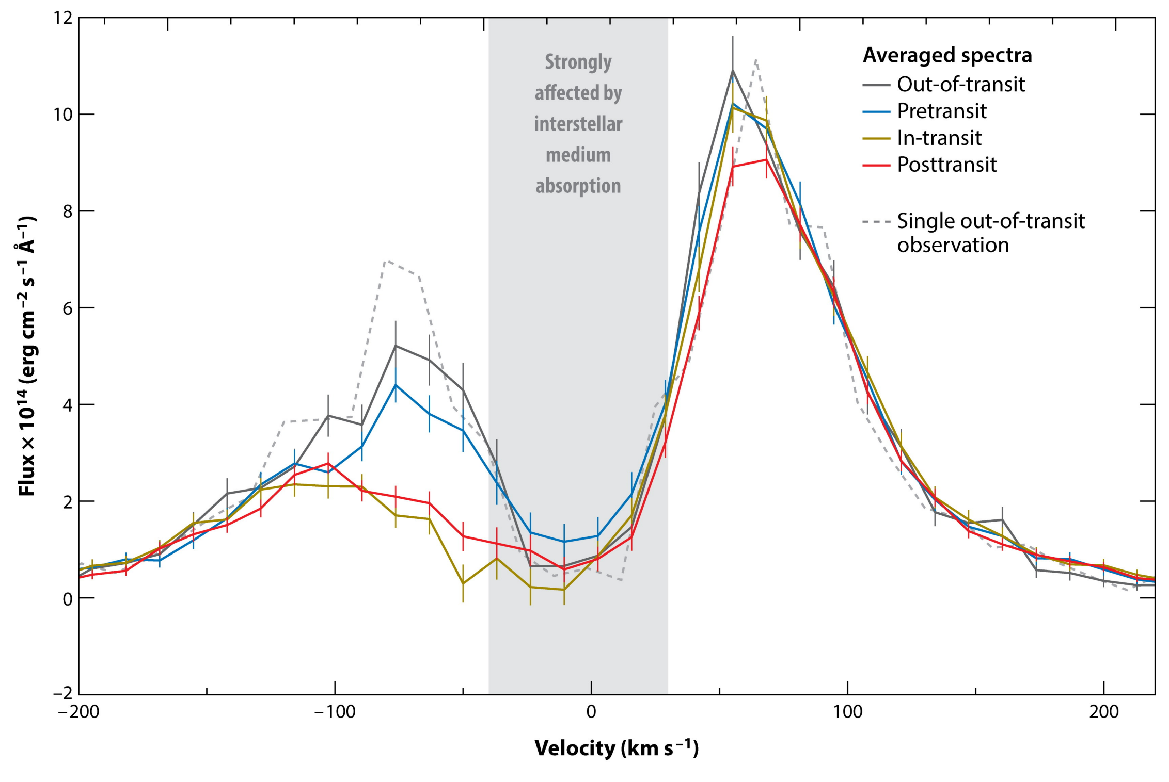
Introduction

Lyman-α transit transmission spectroscopy provides direct observational evidence of ongoing atmospheric escape. However observations are not easy to interpret since they depend on the interaction of the escaping gas with the space environment. Our aim is to create a simple physical model, which can highlight the important physics determining what we observe.

Observation of a Lyman-α transit



Owen JE. 2019.
Annu. Rev. Earth Planet. Sci. 47:67–90

Figure 1: Snapshots of the Lyman-α emission line of GJ436 during the transit of GJ436b. The in-transit and post-transit observations show significant absorption at blue shifted wavelengths, which can be interpreted as absorption by hydrogen moving towards the observer. Figure from Owen (2019), adapted from Ehrenreich et al (2013) with permission.

The line core is polluted due to absorption by hydrogen in the interstellar medium and geo-coronal emission hence is useless for modelling.

Simulations of atmospheric escape do not produce gas velocities large enough to explain the blue shifted absorption features. Interactions with the stellar wind, the generation of energetic neutral atoms and radiation pressure are thought to be mechanisms which could accelerate the gas to the required velocities to be detected.

The Model

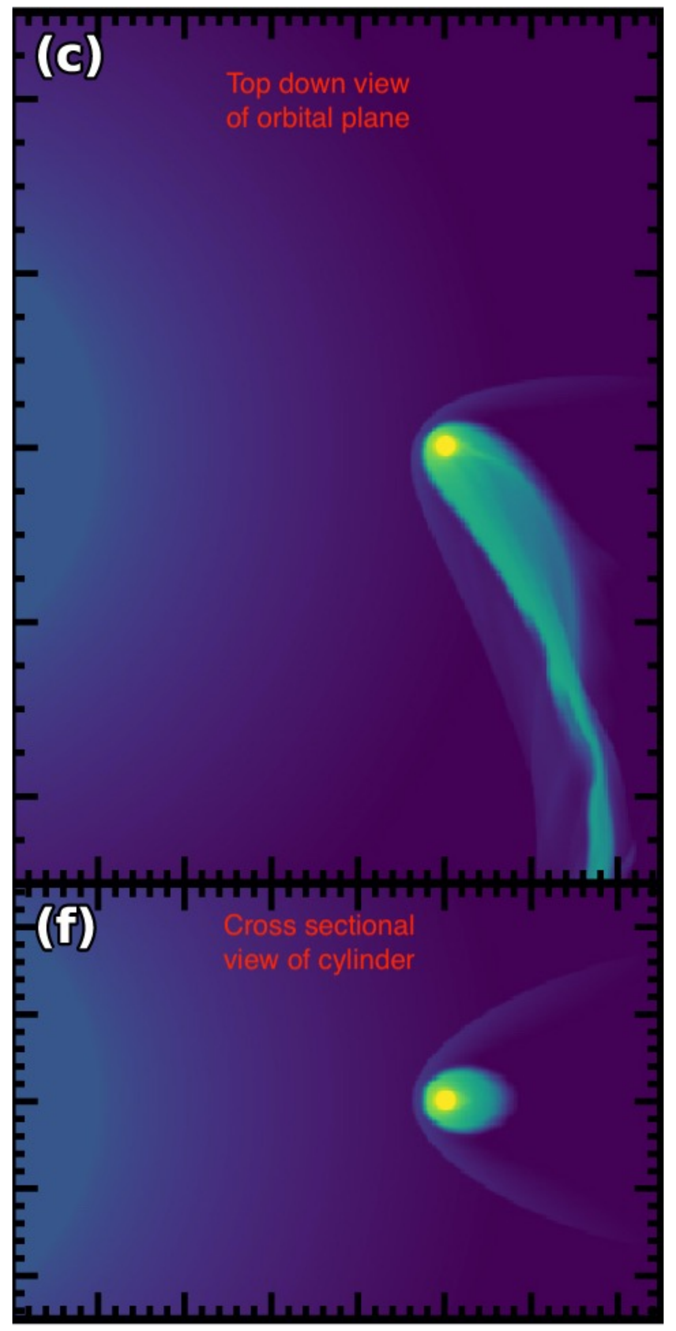
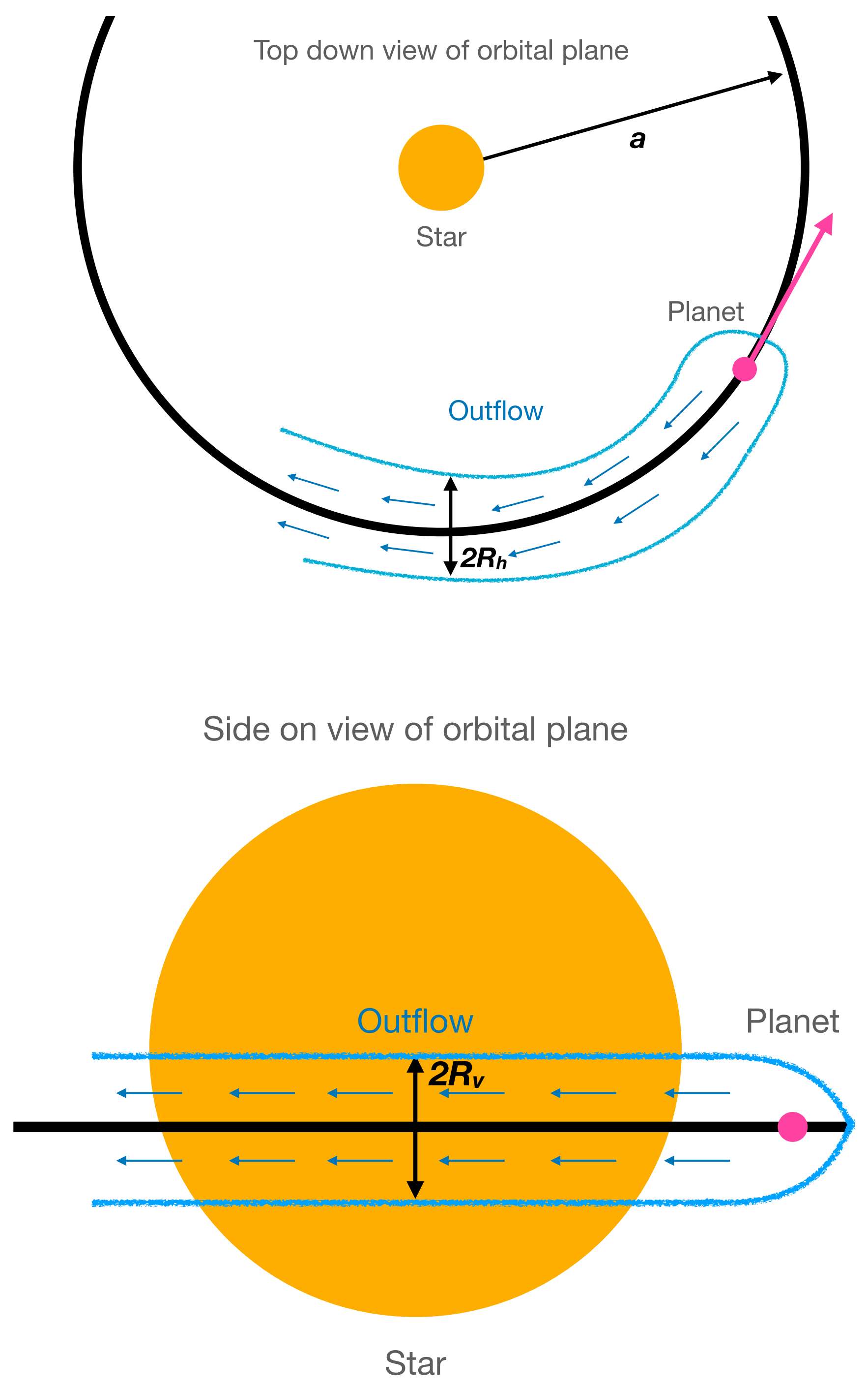


Figure 2&3: Snapshots of the density structure of an escaping planetary atmosphere interacting with a strong stellar wind. The star is positioned out the left side of box in line with the planet. Figure taken from McCann et al (2019).

Guided by 3D hydrodynamics simulations of the interaction between the escaping gas and the stellar wind performed by McCann et al (2019), shown in figures 2 & 3, we model the outflowing gas in an elliptic cylinder. The geometry is outlined in figures 4 & 5. In this simple model, we keep the axis of the cylinder, height and depth constant.

The stellar wind exerts a radial pressure force therefore the gas gets progressively radially accelerated as it travels along the cylinder. Similarly, as the gas travels along the cylinder, it gets progressively ionized by EUV radiation.

In order to see a transit the gas must be accelerated to sufficiently high velocities whilst remaining neutral enough to be optically thick to Lyman-α. The competition between these two factors determines whether the transit of the cylinder can be observed.



Figures 4&5: These show the geometry of cylinder and its orbit. Figures taken from Owen et al (in prep)

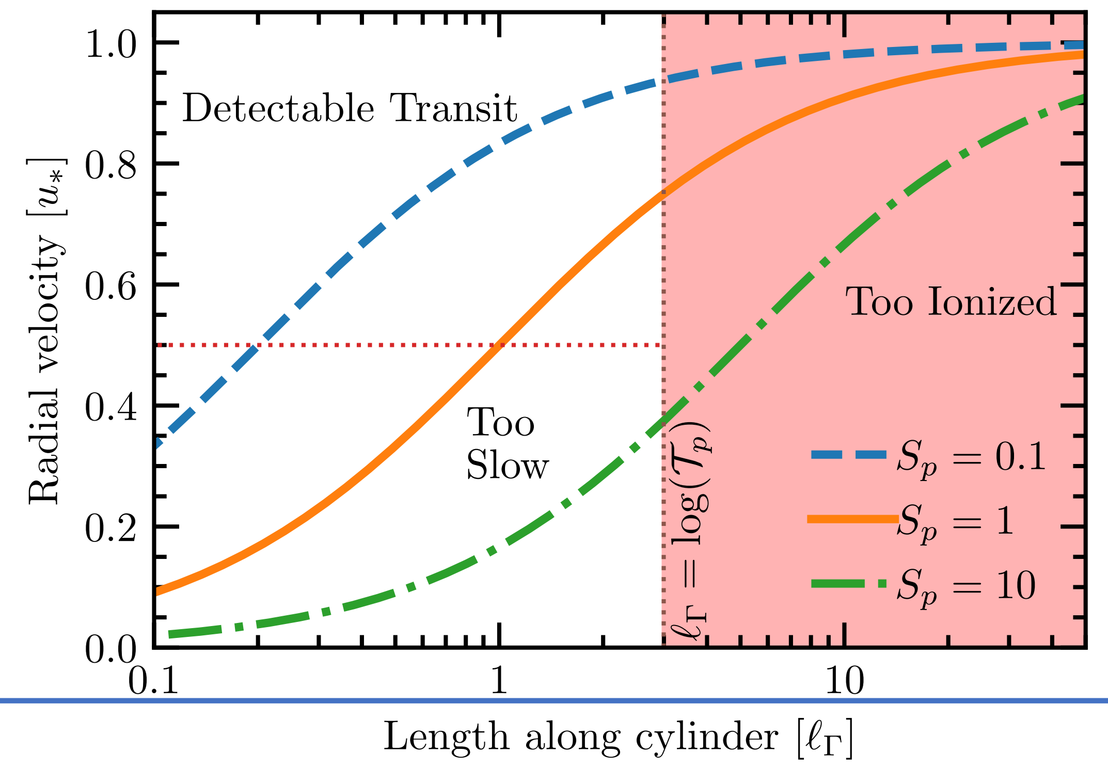


Fig 6: This highlights how the competition between stellar wind pressure and EUV flux determines the presence of an observable transit. S_p is a parameter that tracks the strength of the planetary wind compared to the stellar wind. Lowering S_p, whilst keeping the EUV flux constant, accelerates the hydrogen gas more quickly and makes the transit more detectable. Figure from Owen et al (in prep)

Example Transits

Using the model, we can do synthetic transits for different classes planets with an escaping hydrogen atmosphere.

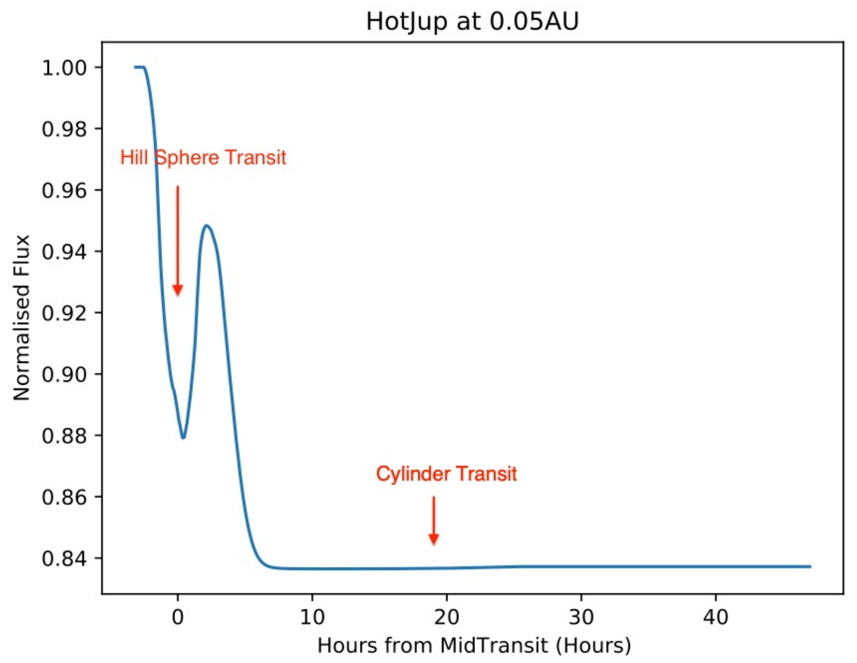


Fig 7: This shows an example transit for a close Hot Jupiter. There are two features. A short shallow feature corresponding to the hill sphere transit, and then a long deep feature corresponding to the cylinder.

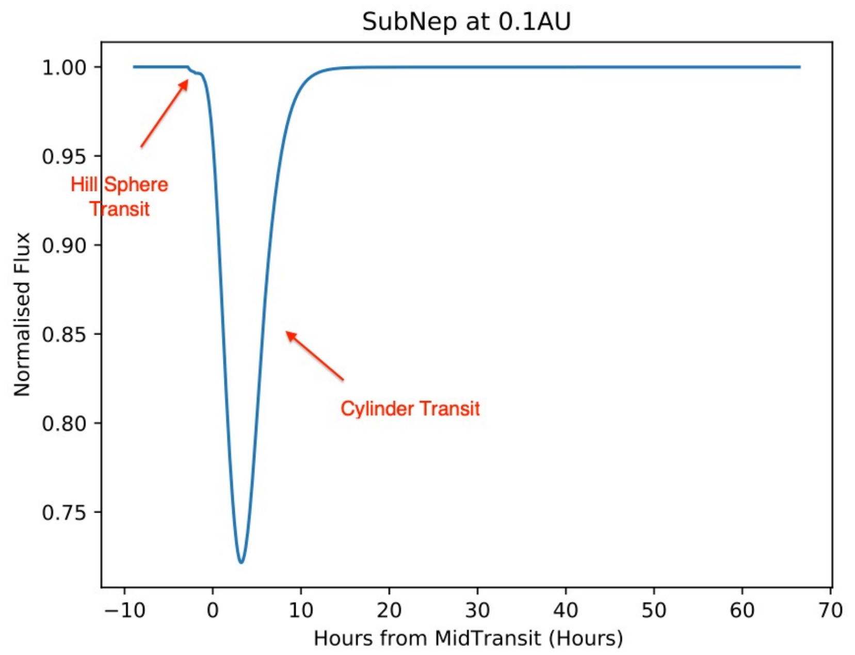


Fig 8: This shows an example transit for a typical Sub-Neptune. There is a deep long feature resulting from the transit of the cylinder.

Conclusions and further work

We will look to make the model more realistic by dropping the assumptions that the height, depth and axis of the cylinder are constant in line with hydrodynamics simulations. Since it is computationally simple, we hope to evaluate the model over a large range of parameters to aid understanding of which planets are good targets for detection of atmospheric escape via Lyman-α transits.

References

Ehrenreich D., et al., 2015, Nature, 522, 459

McCann J., Murray-Clay R. A., Kratter K., Krumholz M. R., 2019, ApJ, 873, 89

Owen J., 2019, AREPS, 47, 67