On the origin of hydrogen around HD 209458b

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Lecavelier des Etangs et al.[1] object to the conclusion by Holmström et al.[2] that radiation pressure alone cannot explain the Lyman-α absorption observed[3] during transits of HD 209458b. We agree that hydrogen atoms could be accelerated to large velocities (>130 km/s) by radiation pressure. However, when we state that *radiation pressure alone cannot explain the observations*[2], it is not about velocity magnitude. It is about the match to the observed spectrum. What we see with our model is that radiation pressure cannot explain the fairly uniform absorption over the velocity range 45 to 130 km/s (away from the star). With only radiation pressure, the drop will be sharp, as shown in the Supplementary Information[2], Fig. 3. Note that a four times higher radiation pressure compared to the default value was used in that simulation, to enable the hydrogen atoms

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to reach a velocity of 130 km/s. Even if we change the values of the different parameters in our model we cannot reproduce the observed uniform absorption over a large range of velocities. It is easy to show that a constant radiation pressure on a population of hydrogen atoms, in combination with a finite life time due to photoionization, will always produce an exponential drop of in density as a function of velocity. We have no reason to think that this would change if we used a more complicated model for the radiation pressure instead of a constant. Actually, the reduced radiation pressure for higher velocities should produce an even steeper drop off in density.

Lecavelier des Etangs et al.[1] also note that radiation pressure is not a free parameter, and that Holmström et al.[2] used a weak, constant, radiation pressure. We agree that radiation pressure is not a free parameter in principle. However, in our model we assumed a constant radiation pressure on the hydrogen atoms. Lecavelier des Etangs et al.[1] note, and show in a figure, that the radiation pressure decrease as the H atom gains velocity and moves out of the Lyman-α peak. To account for this effect we used a lower constant radiation pressure in our model. So, we do not argue that the radiation pressure is as low as in our model. It is simply a way to approximate the actual velocity dependent radiation pressure in our constant-radiation pressure model.

That the Energetic Neutral Atom (ENA) model needs a significant escape from the planet atmosphere[1] is incorrect. The only requirement for ENA production is that a sufficient number of hydrogen atoms are available for charge exchange with the stellar wind. This does not put any strong constraints on the escape of the planet's atmosphere. ENA production will occur independent of a large or small thermal escape rate, but the focus of Holmström et al.[2] was not to study the escape rate in detail.

Regarding the absorption in the red part of the spectrum, Lecavelier des Etangs et al.[1] note that it is barley significant, and that the ENA model[2] predicts too little absorption in the red part. However, ENAs can explain absorption in the red part, while radiation pressure cannot. Considering that this absorption is barley significant[1] we do not regard the fact that the ENA model predicts too little absorption as a problem.

Lecavelier des Etangs et al.[1] also state that the velocity spectrum cannot be directly translated into an absorption spectrum. We did not, at any point, directly translate the velocity distribution into spectral absorption. As explained in the Supplementary Information[2], we sampled the H cloud into velocity bins and columns parallel to the line of sight and covering the full stellar disk, in order to account for possible saturation effects.

Finally, Lecavelier des Etangs et al.[1] claim that stellar gravity is neglected by Holmström et al.[2]. That is partly correct. All forces on a hydrogen atom near the planet are accounted for by the planet's gravity and the Coriolis force in the rotating coordinate system. It is however correct that this is a simplified assumption as the hydrogen atoms move far away from the planet.

References

[1] Lecavelier des Etangs, A., Vidal-Madjar, A., & Desert, J.-M., The origin of hydrogen around HD 209458b, Nature, this issue.

[2] Holmström, M., Ekenbäck, A., Selsis, F., Penz, T., Lammer, H., & Wurz, P., Energetic neutral atoms as the explanation for the high velocity hydrogen around HD 209458b,

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[3] Vidal-Madjar, A., et al., An extended upper atmosphere around the extrasolar planet HD209458b, Nature, 422, 143-146 (2003)