On the Influence of Coronal Mass Ejections on the Hot Jupiter Atmospheres

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HD 209458b

We have considered the gas dynamics of the interaction of a coronal mass ejection (CME) from a star with the atmosphere of a hot Jupiter exoplanet. Two specific flow-patterns that form in two cases of a quasi-closed (Fig. 1, b1) and closed (but distorted by the planet's gravity) (Fig. 1, a1) gaseous envelopes of the planet are considered. With the adopted parameters for the atmosphere, an appreciable fraction of the envelope is located beyond the Roche lobe in both models. During the interaction with the CME, this part of the envelope, and even some of the envelope that is located within the Roche lobe, becomes gravitationally unbound from the planet, and is ejected from the system. When simulating, we assume that the parameters of stellar wind and CME correspond to those of the Sun. We show that a typical CME can sweep out the outer parts (located beyond the planet's Roche lobe) of the asymmetric envelope, which results in a significant increase of the mass loss rate of the planet's atmosphere when it passes through the propagating CME.

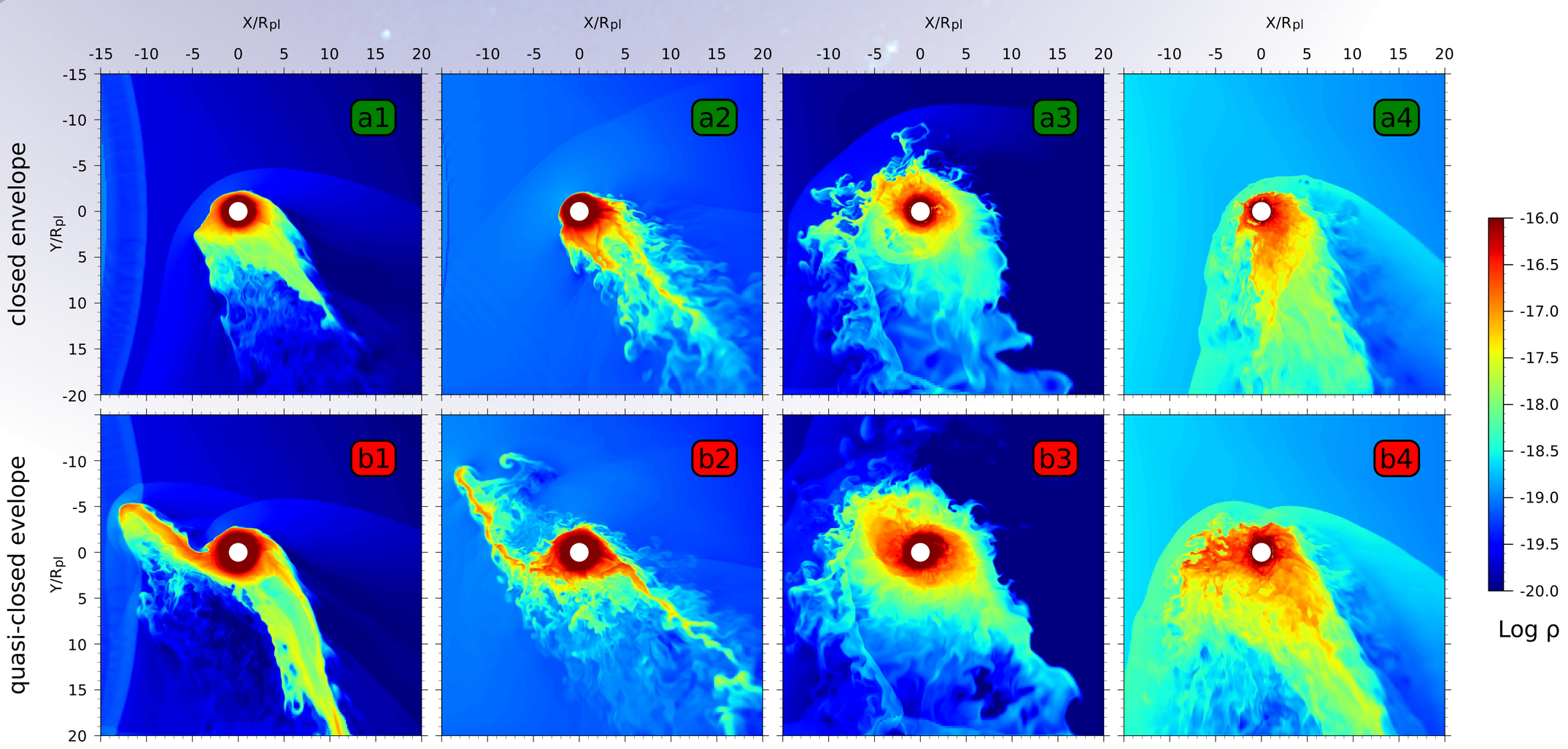

Figure 1. Distribution of the density in exoplanet envelopes subject to the action of a CME, for various moments in time. Upper row of diagrams corresponds to closed envelope, lower row to quasi-closed envelope. A cross section of the envelope in the orbital plane is shown, the star is located to the left, and the white circle at the center represents the planet. The a1 and b1 diagrams correspond to beginning of first phase of CME (initial stationary distributions, first wave of CME is visible on the left), the a2 and b2 to end of first phase, the a3 and b3 to end of second phase, the a4 and b4 to end of third phase CME.

CME (Farrell et al.)

Phase	1	2	3	4
Duration (hours)	–	8.5	13	22
N (cm^{-3})	10^4	4×10^4	6×10^3	10^5
T (K)	7.3×10^5	3.7×10^6	5.8×10^5	2.2×10^5
V (km/sec)	100	133	144	111

Table 1. Parameters of the stellar wind during the passage of the CME

The mass loss rates in the equilibrium solutions are 2.0×10^9 g/s for closed and 3.0×10^9 g/s for quasi-closed envelopes shown in Fig. 2 by the dashed horizontal lines in the first and fifth phases. The total amount of matter lost by the exoplanet during the passage of the CME is 5×10^{15} g for closed and 1×10^{16} g for quasi-closed type of envelope. This exceeds the mass lost in the stationary solutions during the same time (taking into account the return to the stationary state), $\Delta t_{cl} \sim 0.78 P_{orb}$ for closed and $\Delta t_{qc} \sim 0.85 P_{orb}$ for quasi-closed, by a factors of 11 and 14 accordingly.

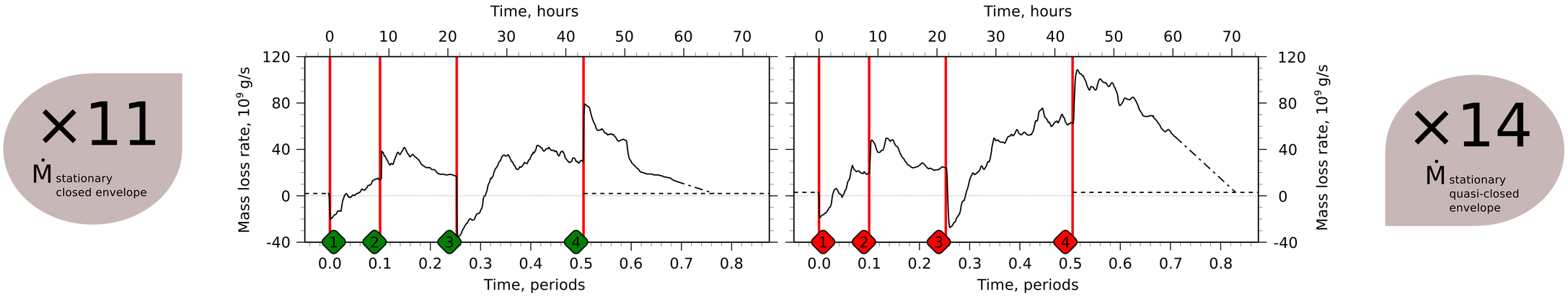

Figure 2. Mass loss rate during the passage of the CME around a closed (left) and quasi-closed (right) envelopes. The various phases of the CME are divided by the vertical red lines.

Take-away message

Let us suppose that the star displays solar-type activity; i.e., the rate at which CMEs pass the atmosphere of the planet is ~2 per month. In this case the total mass loss over a year will be increased by factors of 2.8 and 3.3 for the closed and quasi-closed envelopes, compared to their equilibrium values.

References

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W. M. Farrell et al., Journal of Geophysical research, Vol. 117, E00K04, doi:10.1029/2012JE004070, 2012.