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Influence of the dipolar magnetic field on the hot jupiter envelopes

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Abstract

In this report we discuss possible influence of the proper magnetic field on the gaseous envelopes of hot jupiters.

1. Introduction

Hot jupiter exoplanets, have a number of outstanding features, caused mostly by their proximity to the host star, e.g.: gas outflowing from the planet's atmosphere to the star, as it happens in close binary stars. Gas-dynamical modeling shows that, if the dynamical pressure of the stellar-wind is high enough to stop the outflow from the vicinity of the inner Lagrangian point, a quasi-closed non-spherical envelope, bounded by the bow-shock of a complex shape, forms in the system. The aim of our current study is to estimate the possible variations of the structure and dynamics of flows in the envelope of a hot jupiter due to the presence of the planetary magnetic field.

2. Reduction of mass loss due to hot jupiter magnetic field

The results of three-dimensional MHD computations of a hot jupiter with the parameters of the object WASP-12b [1] show that the presence of a magnetic field leads to appreciable variations of the matter flow structure. In the solution without magnetic field, the overflow of the Roche lobe by the planetary atmosphere leads to the formation of an open envelope with a mass-loss rate of ~1.5 10^{10} g/s. In spite of the fairly weak magnetic field of the planet (a strength of ~0.1 the magnetic moment of Jupiter), the MHD solution differs appreciably from the purely gas-dynamical solution: for the same parameters of the atmosphere, the propagation of the stream from the vicinity of L_1 occurs perpendicular to the magnetic-field lines and is stopped by the pressure of the stellar wind at a distance of ~14 R_{pl} from the planet, forming a quasi-closed envelope. The mass-loss rate in the solution with the magnetic field was ~4 10^9 g/s. This reduction (by ~70%) of the mass-loss rate due to the influence of the magnetic field makes it possible for exoplanets to form closed and quasi-closed envelopes in the presence of more strongly overflowing Roche lobes than is possible without a magnetic field.

3. Pulsations in the envelopes of hot jupiters possessing magnetic fields

Three-dimensional MHD modeling on time scales appreciably exceeding the time for the formation of the envelope [2] show that the presence of a magnetic field appreciably changes the flow patterns in systems whose parameters lie within the range enabling the existence of quasi-closed envelopes. An important difference of the MHD flows from purely gas-dynamical flows is the existence of a pulsation regime for the outflow of matter. Pulsation in the outflow of matter through the inner Lagrange point L_1 arises when the outflowing gas cannot simultaneously overcome the dynamical pressure of the wind and the tension of the magnetic-field lines. In this case, the gas accumulates in regions surrounded by closed magnetic-field lines until there is a rupture in the direction toward the star (in the vicinity of L_1), during which the accumulated matter forms a flow. The stream that is formed shields the vicinity of L1 from the stellar wind, making it possible for the flow to recover. After the re-establishment of the flow, the matter in the vicinity of L_1 rapidly dissipates, and the tension of the magnetic-field lines again becomes sufficient to confine the matter, leading to a new cessation of the flow. After the dissipation of the stream, the stellar wind finally closes off the vicinity of L_1, and the cycle of the accumulation of matter begins again.

Computations conducted for a dipolar field geometry with the dipole axis oriented perpendicular to the orbital plane have shown that the pulsation period for the solution with magnetic moment $\mu = 0.125\mu_{Jup}$ is ~0.27 of the orbital period. This pulsational outflow

regime should substantially influence the observational manifestations of the extended envelopes of hot jupiters.

4. Summary and Conclusions

The discovery of the possible existence of huge quasi-stationary envelopes around a number of hot jupiters (i.e., with sizes appreciably exceeding their Roche lobes) and the need to correctly take into account their properties when interpreting observational data require a careful analysis of the main physical processes influencing their atmospheres. One important factor is the possibility that the planet has a magnetic field. It was shown that the presence of even a modest dipolar magnetic field of a hot jupiter (with a magnetic moment approximately 1/10 the magnetic moment of Jupiter) influences the properties of the planetary atmosphere, in particular, leading to expansion of the range of parameters for which a giant, quasi-closed envelope can form around the planet. It was also established that the presence of a planetary magnetic field reduced the mass-loss rate from the envelope, since matter flowing out from the inner Lagrange point moves perpendicular to the field lines.

Three-dimensional MHD modeling also show that pulsations arise in the atmospheres of hot jupiters possessing dipolar magnetic fields, with characteristic periods $\sim 0.27 P_{orb}$. In the case considered, when the system contains a giant envelope fed by a stream of matter from the inner Lagrange point, the presence of such pulsations gives rise to appreciable variations in the gas-dynamical structure of the flow. In particular, pulsations of the atmosphere lead to tearing off of part of the flow and sharp fluctuations in the size of the envelope, leading to variations in the envelope's observational properties.

Acknowledgements

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References

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