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The cometary tail of giant extrasolar planets at small orbital distance

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Abstract. We estimate the radius of the exosphere of giant planets at small orbital distance from their parent star. It can be larger than the planet's Roche lobe, thus giving rise to a significant evaporation of the planet. The stellar wind of the parent star transforms this evaporating material into a giant permanent cometary-like tail. We discuss some possible observable consequences of the presence of this tail, in particular for 51 Peg.

1. The evaporation rate of giant planets in close orbits

After the probable discovery of four giant extrasolar planets very close to their parent star (Mayor & Queloz 1995, Butler *et al.* 1997), their internal structure and atmosphere has been investigated, but without considering the influence on the planet of the gravitational field of the star. We investigate hereafter how this gravitational field modifies the configuration of the system.

The equilibrium temperature of the giant extrasolar planets, deduced from the balance of the energy budget between the incoming radiation received from the star and the thermal radiation of the planet, is given by

$$T_{eq} = T_*(1-A)^{1/4}\left(\frac{R_*}{2a_{Pl}}\right)^{1/2} \tag{1}$$

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where A is the planet albedo, T_* and R_* the star's temperature and radius and a_{Pl} the planet's orbital distance to the star. Here we neglect greenhouse effects. For a planet with an albedo of 0.7 in orbit at 0.05 AU from a solar-type star, T_{eq} = 1200K. At this temperature, the evaporation rate of the atmosphere is low for a mass of the planet of $0.5M_{Jup}$. But Chassefière *et al.* (1996), have estimated an evaporation rate of the exosphere of $10^{36}s^{-1}$ atoms of H. This results in an hydrodynamic escape of species (CO, CO_2, CH_4, H_2O, ..) present in the exosphere. From the energy input by the UV flux of a G2 star (10^{23} Watt), they estimate a temperature of the exopshere of $\sim 10^4$ K, leading to an exopshere radius of $\sim$ 10 R_{Jup}. This is significantly larger than the radius of its Roche lobe $R_R \approx a_P(M_{Pl}/3M_*)^{1/3}(= 4R_{Jup}$ if $M_{Pl} = 0.5M_{Jup})$. As a consequence, the escape leads to a mass transfer from the planet to a region for which we hereafter investigate the geometry.

2. The shape of the escaped gas cloud.

We assume that the usual dynamics of mass transfer in binary stars can be applied to the present case. After escape from the Roche lobe, the matter follows a spiraling trajectory which ends on a circle with a radius

$$R_{circ} = a_{Pl}(1+q)(b_1/a_{Pl})^4 \tag{2}$$

called the circularization radius (Frank *et al.* 1985), q being the mass ratio M_{Pl}/M_* and b_1 the distance of the Lagrange point L_1 to the star. In the present case, the very small mass ratio M_{Pl}/M_* leads to $b_1 = a_{Pl}$ and thus to

$$R_{circ} = a_{Pl}. \tag{3}$$

But then another phenomenon enters into the game, the radiation and wind pressure from the star.

Because of the high radiation densities, we expect the escaped molecules to be dissociated and ionized quickly. The ions created then interact with the solar wind, in particular with the star's magnetic field frozen in the solar wind flow. If we assume no internal magnetic field for the planet, we have a situation similar to a large, permanent, cometary plasma tail. In such a tail, the ions created are picked-up by the magnetic field in the solar wind flow and accelerated in the direction of the solar wind flow. For a rough estimate of the direction of the ion tail created, we assume the solar wind to stream radially away from the star. The ions are created with an initial velocity equal to the orbital velocity V_{Pl} of the planet. For a velocity component of the ions $V_I(r)$ in the tail in the radial direction at a distance r from the star, the tail makes with the radial direction an angle $\alpha(r) = arctan(V_{Pl}/V_I(r))$. For a stellar wind of 100 km/s, angles of tens of degrees to the radial direction are possible. However, this angle will depend on the actual parameters of the solar wind flow and on the complicated interaction of the ions with the solar wind.

3. Observable consequences

3.1. Absorption of the star's flux by the planet tail

The transverse size R_T of the tail is at least the size of the exosphere, *i.e.* at least $10R_{Jup} = 1R_\odot$. Thus, at a distance $a = 0.05$ AU, the probability that the tail makes a transit in front of the parent star is $(R_* + R_T)/a \geq 20\%$. It is statistically likely that in a near future at least one planet (with a mass $\leq 8M_{Jup}$ at 0.05 AU from the star) will have its tail crossing the line of sight of the star. This configuration should result in absorption features by the ions present in the exosphere and in the tail (CO, CO_2, CH_4, H_2O, ...). The spectral lines should have a profile resulting from the convolution of different lines at different blue-shifts. Indeed, the ions in the exosphere have a negligible thermal velocity ($\sim$ 1km/s), whereas the ions in the tail have a velocity attaining a few hundreds of km/s, resulting in a blue-shift of $\sim 20\mathring{A}$ at 2μ. The inclination of the direction of the tail with respect to the star-planet vector may induce temporal modulation of these absorption features along the orbital phase. Indeed, if the tail is inclined with respect to the line of sight, the observer sees at different orbital phases different parts of the tail, and thus ions with different velocities, resulting in a blue-shift variable with time.

3.2. Possible effect of the spectral lines of 51 Peg.

The observational situation for the planet 51 Peg b is presently (mid 1997) not clear. Perhaps the shape of at least one absorption line is changing with the period of 4.2 days found by Mayor and Queloz (Gray 1997a); perhaps the 51 Peg system is a binary star seen face on (Pan *et al.* 1997).

Since there are indications that the orbital inclination of 51 Peg b is not far from 90^o (François et al. 1996), the absorption effect by the tail discussed above is perhaps observable for this system. This has led us to search for such absorption features in the IR spectrum of 51 Peg (Coustenis *et al.* 1997). Could this kind of absorption be responsible for a bisector variation (Gray 1997a) of the lines, if real, at visible wavelength? The column density in front of the star, resulting from the escape, is $10^{18} - 10^{19}$ atoms/cm^2, giving an optical depth of $10^{-2} - 10^{-3}$, at the wavelength of absorption lines.

In the case of an absorption caused only by the exopshere, a strictly transverse velocity would not distort the lines. Radial velocities of thermal origin in the exosphere would give an effect symmetrical with respect to the central wavelength of the absorption lines. Thus the origin of the asymmetry of spectral lines (measured by the bisector span) is to be understood. We see three possible explanations:

- It can be due to a non radial keplerian velocity if the planet orbit is not strictly circular. An eccentricity e gives a radial velocity variation along the orbit with an amplitude $\Delta V = 1/2eV_{Pl}$. Since for 51 peg b $V_{Pl} \approx 100km/s$, an eccentricity $e = 10^{-3}$ would lead to $\Delta V = 50m/s$, which is of the order of the bisector variation claimed by Gray (1997a). This value for e is largely compatible with the present upper limit of 10^{-2} for e (Mayor & Queloz 1995).

- The asymmetry, and its variation in time, are due to a slight variation in blue-shift along the orbital revolution, as discussed in section 3.1.

- Another possibility is the Zeeman displacement of the lines produced by the magnetic field of the star-planet system. A field B gives a Zeeman displacement, translated in velocity, of: $\Delta V = c5.10^{-23}\lambda n^4(1+M^2)B^2$ cm/s (λ in $\AA$ and B in Gauss). For line doublets with differential strengths, this can result in an apparent distortion for unresolved lines. At 6000 $\AA$, a magnetic field of 3×10^3 Gauss would be necessary to explain the distortion observed in 51 Peg (for n and M equal 5). We note that this effect depends on the quantum numbers characteristic of the spectral line under consideration.

In conclusion, the claim that "a planet cannot alter the shapes of the spectral lines" (Gray 1997b) seems, at the present stage, unproven.

Finally, if the inclination of the orbit is low (say a few degrees), thus given the planet a mass of a few M_{Jup}, the Roche lobe would be larger than 10 R_{Jup}. It cannot be excluded at the present stage that it is surrounded by a large Saturn-like ring, thus heated up to 1400 K, perhaps giving rise to an dust tail. It would have an IR spectrum peaking at $\sim 2\ \mu$. With a radius of 1.7 $R_\odot$ (8 $\times R_{Saturn-rings}$), it would mimic, in the K band, a low mass star companion (see Pan *et al.* 1997).

3.3. What is, finally, the mass of 51 Peg?

We want to emphasize an important consequence of the effect of variation of the distortion of lines, whatever their explanation is.

If a periodic bisector variation with amplitude ΔV_{Bis} and a keplerian displacement ΔV_K are both present, the effective velocity amplitude is $\Delta V_{Eff} = \Delta V_{Bis} + \Delta V_K$. The resulting apparent mass $\underline{M_A}$ of the planet, deduced from ΔV_{Eff} instead of ΔV_K ($\Delta V_{eff} = M_A/M_* \sqrt{GM_*/a}$), would then be different from the real mass M_{Pl}, and thus incorrect. Depending on the sign (unknown at the present stage) of the effect giving the bisector variation, the mass of the planet can be higher or lower than the value (0.5 M$_{Jup}$) used for the present calculations. A lower mass would give a smaller Roche lobe; in this case, the effects discussed here would be quantitatively larger than our present estimates.

References

Butler, P., Marcy G., Williams E., Hauser H. & Shirts P. 1997, ApJL, 474, L115

Chassefière, E., Coustenis, A., Wittenberg, R., Schneider, J., Penny, A., & Greene, T. 1996, in Searching for Life in the Solar System and Beyond. A Research Discussion Meeting. The Royal Society, London, UK - 31 October 1996

Coustenis, A., Schneider, J., Wittemberg, R., Chassefière, E., Greene, T., Penny A. & Guillot T. 1997, These Proceedings

François, P., Spite, M., Gillet, D., Gonzalez, J.-F., & Spite, F.,1996, Astron. & Astrophys., 310, L13

Frank, J., King A., & Raine, D., 1985, in Accretion Power in Astrophysics, (Cambridge Univ. press)

Gray, D. 1997a Nature, 385, 795

Gray, D. 1997b, http://phobos.astro.uwo.ca/~dfgray/51-peg.html

Mayor M., & Queloz, D., 1995, Nature, 378, 355
Pan, X., Kulkarni, S., Colavita, M. & Shao, M. 1997 These Proceedings