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Thermal mass-loss of exoplanets in close orbits

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Abstract

During the last years, a large number of planets has been discovered which orbit their host stars at very close distances. The question arises how efficiently the radiation and particle environment of the host star has influenced the evolution of such planets. In this context we aim to study if super-Earths in close orbits, like CoRoT-7b and GJ 1214b, could be the remnants of more massive planets whose atmospheres were eroded.

1. Introduction

Atmospheric mass-loss of is an influential process for the evolution of planets, especially for those orbiting at close distances to the host star. Thermal escape is induced by stellar XUV radiation, which is known to be higher at young ages and decrease with time. Therefore, even planets found around rather inactive stars could have experienced substantial atmospheric losses in the past.

Among the lowest-mass exoplanets known so far are the transiting super-Earths CoRoT-7b [4] and GJ 1214b [1]. They orbit their host stars at very close distances of 0.017 and 0.014 AU, respectively. These objects are the lowest-mass planets discovered by transit missions to date and offer the unique opportunity to gain insight into their possible composition and structure due to the known radius.

2. CoRoT-7b and GJ 1214b

CoRoT-7b is a super-Earth with a density similar to that of Earth, which indicates that it is most likely made of rock or a mixture of water, ice and rock [8]. It orbits a distant (∼150 pc) G9V star [4] together with another, non-transiting super-Earth (CoRoT-7c) [8]. The slightly more massive GJ 1214b orbits a nearby (∼13 pc) M4.5[1] dwarf. Its mean density is much smaller than that of CoRoT-7b (cf. Tab. 1), which indicates an object intermediate between a terrestrial planet and an ice giant. The planet could possibly be composed primarily of water and possess a considerable atmosphere [1].

[1]http://simbad.u-strasbg.fr

Table 1: Properties of CoRoT-7b and GJ 1214b and their host stars. Data taken from [4] for CoRoT-7b (except * from [8]) and from [1] for GJ 1214b.

	CoRoT-7b	GJ 1214b
$M_{\rm pl}$ $[M_\oplus]$	4.8*	6.55
$R_{\rm pl}$ $[R_\oplus]$	1.68	2.678
$\rho_{\rm pl}$ [g cm^{-3}]	5.6*	1.87
a [AU]	0.017	0.014
M_* $[M_\odot]$	0.93	0.157
R_* $[M_\odot]$	0.87	0.211
$P_{\rm rot}$ [d]	23	83
age [Gyr]	1.2-2.3	3-10

3. Thermal hydrogen loss rates

For an estimation of the thermal hydrogen loss rates (in g/s), the modified energy-limited equation

$$\frac{dM_{\rm pl}}{dt} = \frac{3F_{\rm XUV}\eta\zeta}{4G\rho_{\rm pl}} \quad (1)$$

is used with the planetary mass $M_{\rm pl}$, the XUV flux at the planet's orbit $F_{\rm XUV}$, the heating efficiency η, the mass loss enhancement factor ζ, the gravitational constant G, and the mean planetary density $\rho_{\rm pl}$ (cf. [3]). The heating efficiency, defined as the ratio of the net heating rate to the rate of stellar energy absorption, is approximately 10–25%, although values up to 100% have been used in literature [3]. The mass loss enhancement factor $\zeta = 1/K$ considers the increased losses due to Roche lobe effects, in which

$$K = 1 - \frac{3}{2\xi} + \frac{1}{2\xi^3} \quad (2)$$

is the potential energy reduction factor due to stellar tidal forces and ξ is the ratio between Roche lobe distance and planetary radius [2]. This factor is of great importance for planets in very close orbits (≤ 0.02 AU).

As the XUV flux is currently unknown for both stars, it is approximated using average X-ray luminosity–age relations for G and M dwarfs [6, 7] and mean ages of 1.7 (CoRoT-7b) and 6 Gyr (GJ 1214b). The resulting mass-loss rates are shown in Fig. 1

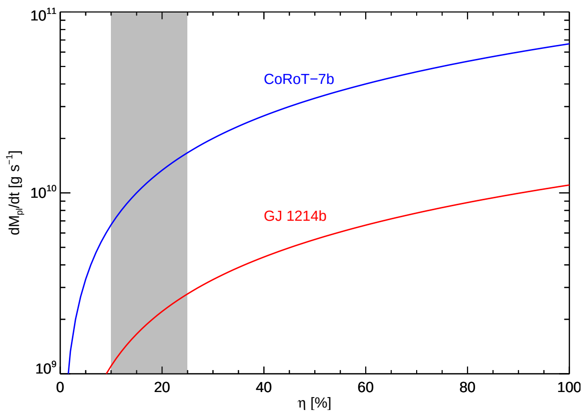

Figure 1: Current thermal hydrogen mass-loss rates of CoRoT-7b and GJ 1214b as a function of heating efficiency η. The shaded area marks the most realistic values of η [3].

4. Thermal losses over evolutionary timescales

The approach of [3] is used to model thermal hydrogen losses of sample planets with a range of masses and densities orbiting stars with the properties of CoRoT-7 and GJ 1214 at the orbital distances of their associated planets. Our studies show that even for low density planets thermal hydrogen loss is not efficient enough to erode gas giants with masses of Uranus or higher down to a core with CoRoT-7b's properties [5]. Even lower atmospheric losses are found for simulations with GJ 1214 as the host star.

5. Summary and Conclusions

We study thermal hydrogen loss rates of the two close-in transiting super-Earths CoRoT-7b and GJ 1214b. Our results show that mass-loss of gas giants integrated over the respective ages of the stars is not high enough to result in remnants with properties of CoRoT-7b and GJ 1214b.

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