EPSC Abstracts
Vol. 11, EPSC2017-816-1, 2017
European Planetary Science Congress 2017

The Atmosphere and Internal Structure of GJ 1132 b

O. Mousis, Aguichine, A., Brugger, B., Deleuil, M.
Aix Marseille Université, CNRS, LAM, UMR 7326, 13388, Marseille, France (olivier.mousis@lam.fr)

Abstract

We aim at investigating the possible internal structures of the exoplanet GJ 1132 b whose physical properties have been recently refined from multi-wavelength observations of a series of transits. Because this planet potentially harbors an atmosphere, we also discuss the influence of hydrodynamic escape on its internal structure.

Introduction

Discovered transiting exoplanets are known for their very small orbital periods. A planet with an Earth-like mass is then much closer to its host star than planets in the Solar system, and thus receives a much higher amount of irradiation. Therefore, such a planet experiences a very high XUV-driven escape of gases from its exosphere, which leads to major changes in the composition of the atmosphere. Here we aim at investigating the possible internal structures of the exoplanet GJ 1132 b whose physical properties have been recently refined from multi-wavelength observations of a series of transits [1]. Because this planet potentially harbors an atmosphere [1], we also discuss the influence of hydrodynamic escape on its internal structure.

Model

We refer the reader to [2,3] for a full description of the interior model used in this work. Following [1], we assume that the atmosphere of GJ 1132 b is dominated by H_2, with a limited amount of H_2O. We also postulate that hydrodynamic escape is favored by the high equilibrium temperature of the planet (∼644 K [1]) and that the escaping hydrogen atoms drive off heavier atoms (here oxygen) through drag effects. Under those circumstances, we assume that the gas-loss is energy-limited, meaning that the different species are fully dissociated in atoms in the atmosphere. The energy input received by the planet is given by the product $L_{XUV} \left(\frac{R_p}{2a}\right)^2$, where L_{XUV} is the host star XUV luminosity, R_p and a are the planet's radius and semi-major axis, respectively. The mass-loss rate $\dot{m}$ (kg s^{-1}), determined from the balance between the energy input times an efficiency factor ϵ and the gravitational energy of escaping atoms, can be expressed as:

$$\dot{m} = \epsilon \frac{L_{XUV} R_p^3}{\mathcal{G} M_p (2a)^2} . \quad (1)$$

where M_p is the planet's mass. The total mass loss is then computed by integrating $\dot{m}$ over time. The efficiency coefficient ϵ is assumed to be 0.1, based on the work of [4] who computed its value as a function of a planet's mass and radius. The total mass loss flux F_M (kg s^{-1} m^{-2}) can be expressed as the sum of the mass loss fluxes of all atoms:

$$\begin{aligned} F_M &= F_H + F_O + \dots \\ &= m_H f_H + m_O f_O + \dots \end{aligned}$$

where m_X is the mass and f_X is the atomic flux (atoms s^{-1} m^{-2}) of the atom X. The total mass loss flux is related to the mass loss rate by $\dot{m} = F_M(4\pi R_p^2)$. Because hydrogen is the dominant escaping atom that drags away all the other heavier species [5], its mass loss rate is then [5,6]:

$$F_H = \frac{F_M + m_O x_O (m_O - m_H) \frac{b_O g}{kT}}{1 + \frac{m_O x_O}{m_H x_H}} , \quad (2)$$

where x_X is the fraction of atom X in the atmosphere ($x_O = 1/3$ for water), k is the Boltzmann constant, T is the exosphere temperature, g is the surface gravity and b_X is the collision parameter between hydrogen and the atom X [7]. All the other mass loss fluxes can be easily determined from F_H and some parameters. With this toy model, one can compute the loss of any species present in the planet's atmosphere, provided that hydrodynamic escape was effective.

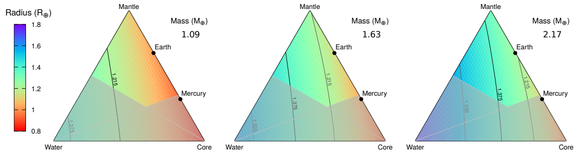

Figure 1: Ternary diagrams displaying the investigated compositional parameter space of GJ 1132 b for three values of the planet's mass: the minimum, central, and maximum values inferred by [1], using 1σ uncertainties. Also shown are the isoradius curves denoting the planet's surface radius measured by [1] with the 1σ extreme values. Two areas of the diagrams are excluded from the study, based on assumptions on the solar system formation (darkened zones; see [3] for details).

Results

Figure 1 shows the possible interiors of GJ 1132 b, assuming its mass and surface radius are 1.63 ± 0.54 $M_\oplus$ and 1.375 ± 0.16 $R_\oplus$, respectively [1]. The uncertainties on the determination of the planet's physical parameters are too large to allow disentangling between fully rocky interiors and interiors containing a substantial portion of water. Figure 2 represents the amount of hydrogen atoms that could escape via blowoff from GJ 1132 b. It shows that 100 EOH of hydrogen can be lost by GJ 1132 b in less than $\sim$100 Myr at its current orbit.

Discussion

The important loss of oxygen atoms via hydrodynamic escape suggests that the planet's atmosphere could be fed by a substantial hydrosphere. If hydrodynamic escape is an effective mechanism, then GJ 1132 b would more likely belong to the family of ocean planets than any other type of solid planets.

References

[1] Southworth, J., Mancini, L., Madhusudhan, N., Mollière, P., Ciceri, S., Henning, T. 2017. Detection of the Atmosphere of the 1.6 $M_\oplus$ Exoplanet GJ 1132 b. The Astronomical Journal 153, 191.

[2] Brugger, B., Mousis, O., Deleuil, M., Lunine, J. I. 2016. Possible Internal Structures and Compositions of Proxima Centauri b. The Astrophysical Journal 831, L16.

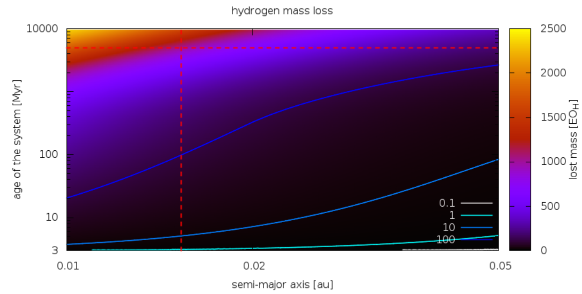

Figure 2: Mass of hydrogen lost by escape expressed in unit of Earth Ocean equivalent content of Hydrogen (EOH) as a function of time and distance from the host star (1EOH = 1.53×10^{23} g).

[3] Brugger, B., Mousis, O., Deleuil, M., Deschamps, F. 2017. Constraints on low mass Exoplanets Interiors from Stellar Abundances. The Astrophysical Journal, submitted.

[4] Owen, J. E., Jackson, A. P. 2012. Planetary evaporation by UV & X-ray radiation: basic hydrodynamics. Monthly Notices of the Royal Astronomical Society 425, 2931-2947.

[5] Hunten, D. M., Pepin, R. O., Walker, J. C. G. 1987. Mass fractionation in hydrodynamic escape. Icarus 69, 532-549.

[6] Bolmont, E., Selsis, F., Owen, J. E., Ribas, I., Raymond, S. N., Leconte, J., Gillon, M. 2017. Water loss from terrestrial planets orbiting ultracool dwarfs: implications for the planets of TRAPPIST-1. Monthly Notices of the Royal Astronomical Society 464, 3728-3741.

[7] Hodges, R. R., Jr. 1993. Collision cross sections and diffusion parameters for H and D in atomic oxygen. Journal of Geophysical Research 98, 3799-3805.