SF2A 2006
D. Barret, F. Casoli, T. Contini, G. Lagache, A. Lecavelier, and L. Pagani (eds)

LIQUID WATER ON AN EXTRASOLAR PLANET?

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Abstract. Microlensing technique used to detect extrasolar planets is sensible to low-mass planets orbiting a few AU away from their stars. The detection of OGLE-2005-BLG-390Lb (hereafter, OGLE-390Lb) around an M star from the Galactic bulge (Beaulieu et al. 2006) unveil the existence of few-Earth-masses and cold ($\sim$ 40 K) planets. These frozen planets might nonetheless host liquid water underneath an ice shell, due to a strong radiogenic heating at the bottom of the ice layer. Heating and cooling are depending upon the mass ratio ice/rock and the age of the planet. OGLE-390Lb seems too old to have a subsurface ocean for any value of the ratio ice/rock; however, liquid water below an ice shell was certainly present in the past for several billion years. See Ehrenreich et al. (2006b) for details.

1 Introduction

New instruments and techniques designed to detect extrasolar planets have permitted the lowering of the planet mass detection threshold to tens of $M_\oplus$. The lightest objects detected *via* radial velocimetry lie at the mass boundary between telluric and ice giant planets. However, the detected planets have pretty small semi-major axis. The microlensing technique recently allowed Beaulieu et al. (2006) to detect a $5.5^{+5.5}_{-2.7}$-$M_\oplus$ planet orbiting at $2.6^{+1.5}_{-0.6}$ AU from a $0.22^{+0.21}_{-0.11}$-$M_\odot$star. It is potentially the lightest exoplanet detected so far. Its M star has a luminosity reaching only $\sim 0.01\ L_\odot$. Hence, the amount of energy per surface unit this planet receives from its star is comparable to that of Pluto in the Solar System (~ 0.1 W m^{-2}). The planet OGLE-390Lb can be a cold and massive analog of the Earth, or alternatively be similar to a frozen ocean-planet having retained a lot of water (Léger et al. 2004). In both cases, the question arises if the planet is entirely frozen or if liquid water can exist close to the surface. To answer that question, we focus on the phase study of water (H_2O) in the first $\sim$ 100 km under the planetary surface, using observational constrains and similarities with icy satellites of the Solar System. A full description of our model is given in Ehrenreich et al. (2006b).

2 Structure of the planet and presence of liquid water

Models of possible internal structures for Earth-mass extrasolar planets have already been developed (Sotin et al. 2006; Valencia et al. 2006). The amount of H_2O within the planet strongly influences the radius for a given planetary mass. We consider different enrichments of the planet in H_2O, namely 0.025, 25, and 50%wt of the planetary mass. The 0.025%wt-H_2O case corresponds to a rocky planet with a H_2O content similar to the Earth one. For both other cases, 25 and 50%wt-H_2O, the planet can be an ocean-planet. Due to the low surface temperature, the volatile material present in OGLE-390Lb must be condensed as an ice shell. Since the planet is massive enough to be completely differentiated, the ice shell must be overtopping a denser rocky core, in a situation similar to that of the icy moons of giant planets in the Solar System. The internal heat flow determines the temperature profile within the planet, and particularly within the ice layer. Knowing that the most probable age of OGLE-390Lb is 10 Gyr, the main source of internal heat at present time is the decay of long-lived radioactive isotopes of uranium, thorium, and potassium. The heat production is proportional to the abundances of the radioactive isotopes within the silicates. Shall the planet contain radioactive material more abundantly than Earth, it would indeed produce more heating.

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Although liquid water cannot exist on the surface, a liquid layer can exist *below the low-pressure ice-*I *shell*. This ice shell is heated from below by the decay of radioactive elements. An ocean can be present if the temperature profile crosses the melting curve of ice I. There are two cases to be considered: (1) If the planet is water-poor (0.025%wt), the heat produced by silicates can be transferred either by conduction or convection across the low-pressure ice-I mantle (Fig. 1, top). (2) If the planet is water-rich (25 or 50%wt), the ice mantle consists of two parts: a low-pressure ice-I/II shell and a high-pressure ice-VI/VII shell (Fig. 1, bottom). The high-pressure mantle allows the heat to be transferred very efficiently by convection from the silicates up to the base of the low-pressure ice-I mantle. The heat is then transferred across the low-pressure ice-I shell by conduction or convection. The absence or presence of liquid water can be constrained by considering the extreme cases when the heat is transferred only by conduction or when the convection is set up.

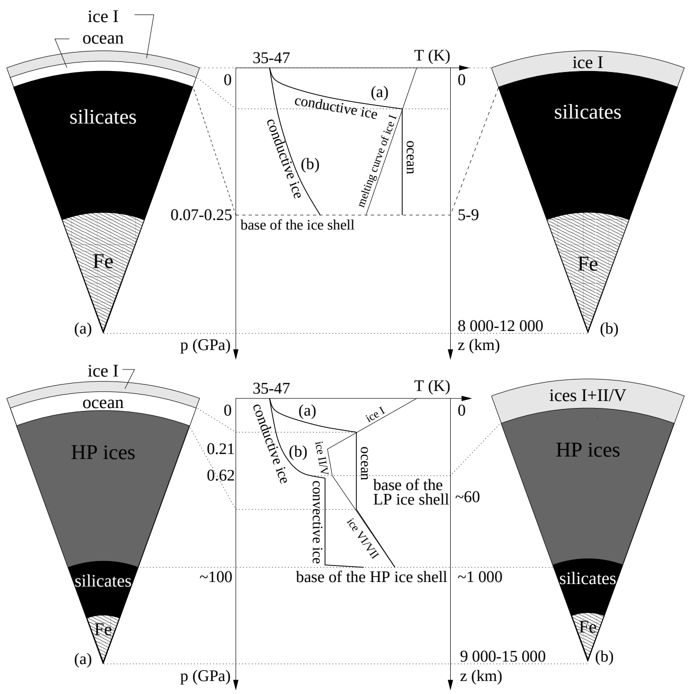

Fig. 1. *top* Possible internal structures and temperature profiles for a water-poor OGLE-390Lb, with a terrestrial fraction of water (0.025%wt). *bottom* For a water-rich OGLE-390Lb (with 25 or 50%wt H_2O).

3 Conclusions

Since OGLE-390Lb orbits a few AU away from a faint M star and is about 10-Gyr old, it is likely to be entirely frozen. The radiogenic heat production rate is not sufficient to prevent a subsurface ocean from freezing completely. However, remnant heat and larger radiogenic heating in the past allow us to suggest that a liquid ocean must have been present during several billion years. In similarity with the icy satellites of the Solar system, this liquid water was located below low-pressure ice I. Microlensing detection technique has now the potential to unveil a population of ice giants, frozen ocean-planets, and other snowball Earths. It opens new perspectives for exoplanetology.

References

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