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Volatile enrichments and composition of carbon-rich giant planets: the case of WASP-12b

O. Mousis (1), N. Madhusudhan (2), T. V. Johnson (3), and J. I. Lunine (4)
(1) Université de Franche-Comté, Institut UTINAM, CNRS/INSU, UMR 6213, Observatoire des Sciences de l'Univers de Besancon, France (olivier.mousis@obs-besancon.fr / Fax: +33-381-666944), (2) Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA, (3) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, (4) Dipartimento di Fisica, Università degli Studi di Roma "Tor Vergata", Rome, Italy

Abstract

Carbon-rich planets (CRPs) are the exotic new members in the repertoire of extrasolar planets. We define a CRP as a planet with a carbon to oxygen (C/O) ratio ≥ 1. The first CRP atmosphere was inferred recently for the very hot Jupiter WASP-12b [1]. Here we show that it is not possible to reproduce the C/O ratio ≥ 1 observed in WASP-12b via the accretion of planetesimals formed in a disk whose gas phase elemental composition is similar to the one of the parent star. In order to reproduce the observed C/O ratio in the planet, one needs to invoke an oxygen abundance which is depleted by a factor of roughly two compared to that of the parent star, with the exact value contingent on the volatile-to-silicate fraction.

1 Introduction

CRPs possesses chemically distinct interiors, atmospheres, and formation conditions from the commonly assumed oxygen-rich planetary compositions, which are based on the solar C/O ratio of 0.5 [2]. Theoretical studies in the recent past had anticipated the existence of planets with high C/O ratios. The oxygen abundance, and hence the C/O, of Jupiter is presently unknown [3]. However, based on the lower-limit on O/H measured by the *Galileo* probe, [4] studied the hypothetical possibility of Jupiter being a CRP. If Jupiter were carbon-rich, they suggested, it could have formed with dominant tarry planetesimals instead of planetesimals dominant in water-ice as expected in the solar system based on the composition of minor bodies in the solar system. Here, we use a model based on the condensation sequence of ices in the circumstellar disk [5] to constrain the primordial conditions required for the formation of WASP-12b, and to estimate the elemental abundances in the planetary envelope, along with the apportionment of volatiles in the envelope.

2 Formation conditions

Close-in giant planets are thought to have originated in the cold outer region of protoplanetary disks and migrated inwards until they stopped at closer orbital radii. Here we assume that the giant planet was formed via core-accretion. We calculate the composition of the icy planetesimals accreted by the forming planet following the approach developed in Mousis et al. (2009b, 2011). The composition of planetesimals can be inferred from the formation sequence and the composition of the different ices formed beyond the snow line of the protoplanetary disk. This model has been used to interpret the observed volatile enrichments in the atmospheres of Jupiter and Saturn in a way consistent with the heavy element content predicted by interior models [5] and also the apparent carbon deficiency observed in the Hot Jupiter HD189733b [5, 6]. It is based on a predefined initial gas phase composition in which elemental abundances reflect those of the host star and describes the process by which volatiles are trapped in icy planetesimals formed in the disk.

3 Results: elemental abundances in WASP-12b

Two different cases of initial gas phase compositions are used in our protoplanetary disk model. In both cases, C, N, P and S elemental abundances derive from the analysis of the composition of the host star WASP-12 [7]. In the first case, we have assumed that the O elemental abundance in the disk corresponds to the stellar value. In this condensation sequence, the icy part of planetesimals is essentially made of a mix of pure condensates and clathrates. In this case, we find that the

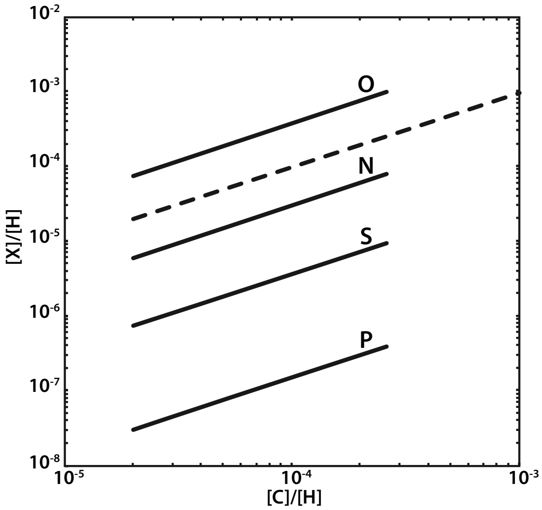

Figure 1: Volatile X abundance as a function of the carbon abundance calculated in the atmosphere of WASP-12b. The dashed line corresponds to the range of C and O abundances measured in the atmosphere.

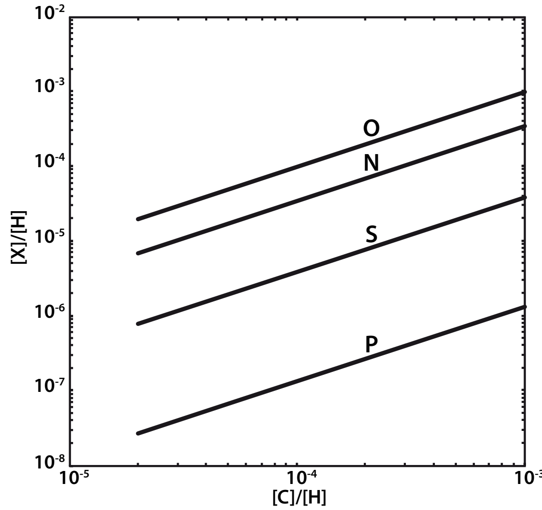

Figure 2: Same as Fig. 1 but for an O abundance 0.41 times lower than in WASP-12 in the protoplanetary disk. The dashed line corresponding to the range of C and O abundances measured in the planet's atmosphere is now superimposed with the calculations.

set of adopted elemental abundances is not consistent with the measured C/O ratio in the envelope (see Fig. 1), unless differential settling between O and C occurs in the interior of the Hot Jupiter WASP-12b. In the second case, we have adopted a substellar O abundance (by 41%) in the gas phase of the disk and, as illustrated by Fig. 2, we find that this assumption allows us to retrieve a composition of planetesimals that matches the observed C/O ratio in WASP-12b. In this case, because the oxygen abundance is strongly depleted compared to case 1, this element is only distributed between carbon bearing species and the remaing water becomes zero in the initial gas phase of the protoplanetary disk. This implies that the icy part of planetesimals formed in such conditions in the protoplanetary disk is only made of pure condensates.

4 Conclusions

We have shown that it is not possible to reproduce the C/O ratio observed in WASP-12b via the accretion of planetesimals formed in a disk whose gas phase elemental composition is similar to the one of the parent star. In order to reproduce the observed C/O ratio in the planet, one needs to invoke an oxygen abundance which is depleted by a factor of roughly two compared to that of the parent star, with the exact value contingent on the volatile-to-silicate fraction.

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