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Carbon-rich planet formation in a solar composition disk: The example of WASP 12b

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Abstract

The recent observation of WASP 12b, a giant planet with a C/O value larger than that estimated for its host star, poses a conundrum for understanding the origin of this elemental ratio in any given planetary system. We propose a mechanism for enhancing the value of C/O in the disk through the transport and distribution of volatiles.We construct a model that computes the abundances of major C and O bearing volatiles under the influence of gas drag, sublimation, vapor diffusion, condensation and coagulation in a multi–iceline 1+1D protoplanetary disk. We find a gradual depletion in water and carbon monoxide vapors inside the water's iceline with carbon monoxide depleting slower than water.This effect increases the gaseous C/O and decreases the C/H ratio in this region to values similar to those found in WASP 12b's day side atmosphere.

1. Introduction

In the last few years, a large number of exoplanets has been detected and characterized. Most of those are "Hot Jupiters" (hereafter HJs), namely planets orbiting very close to their host stars. One of the most exotic HJs is the possibly carbon-rich planet WASP 12b, thought to have a superstellar C/O~1 ratio but with substellar C/H [1]. The C/O ratio is a key parameter for the chemical composition and evolution of planetary atmospheres since it controls the relative abundances of C- and O-bearing gases and solids. Studies suggest that at equilibrium, as the C/O ratio increases (<0.8) in the gas phase, all the available O goes into organics, CO, CO_2 and CH_3OH, so that the gas phase becomes H2O-free and the remaining C is in the form of CH_4 [2], [3]. The $CO/CH_4/CO_2$ ratios in planetary atmospheres are also affected by the possible existence of non equilibrium chemistry effects due to dynamical mixing and photochemistry [4]. The C/O ratio is also crucial for understanding the chemical evolution of protoplanetary disks [5]. The formation mechanism of WASP 12b with its superstellar C/O but substellar C/H ratio is a subject of intense ongoing research.

2. Methods

We explore the possibility of forming a giant planet with an atmospheric C/O ratio higher than that of its parent star. We use a transport model of major gaseous and solid C- and O-bearing volatiles that is based on the simultaneous dynamical evolution of their snowlines. The model takes into account the effects of aerodynamics of solid particles in presence of turbulence [6], in addition to the processes of sublimation [7], condensation [8], and coagulation [9]. The coupling of this transport model to a turbulent accretion disk model [10] allows tracking of the solid particles and gases of H_2O and CO (major C- and O-bearing volatiles) and the evolution of their respective snowlines. This allows us to compute the C/O ratios in planetesimals formed under various disk and gas phase conditions.

3. Results

The vapors concentrations evolution is presented in Fig. 1. In both cases, the vapor diffusion is much faster than replenishment. This leads to a gradual depletion in vapor concentration inside the iceline. This depletion is compensated by an increase in solids surface density near the iceline itself. The comparison of the two panels of Fig. 1 shows that the vapor depletion is much faster for H_2O than for CO. This is caused by the CO iceline that is much farther out than H_2O's iceline, giving CO vapor a longer distance to travel before condensation. This difference in the timescales needed to deplete water and CO vapor from the region inside the H_2O snowline leads to gas phase composition compatible with the observed abundances in WASP 12b's dayside atmosphere: for a long period of time, the CO vapor will be the major C and O bearing specie in that region, increasing the gas C/O ratio of the area to ~1. The C/O in this case is never exactly equal or higher than unity, the reason is the residual water vapor slightly decreasing the ratio. Even if the CO vapor exist in much higher concentrations than H_2O in this region, it is still depleted with respect to the initial stellar abundance, leading to a substellar C/H value. If WASP 12b accreted its atmosphere in this region of the protoplanetary disk, our model can explain all of the observed spectroscopic properties. Our model also applies for any other carbon-rich HJ sharing WASP 12b's properties. These results have been published in a recent paper [11].

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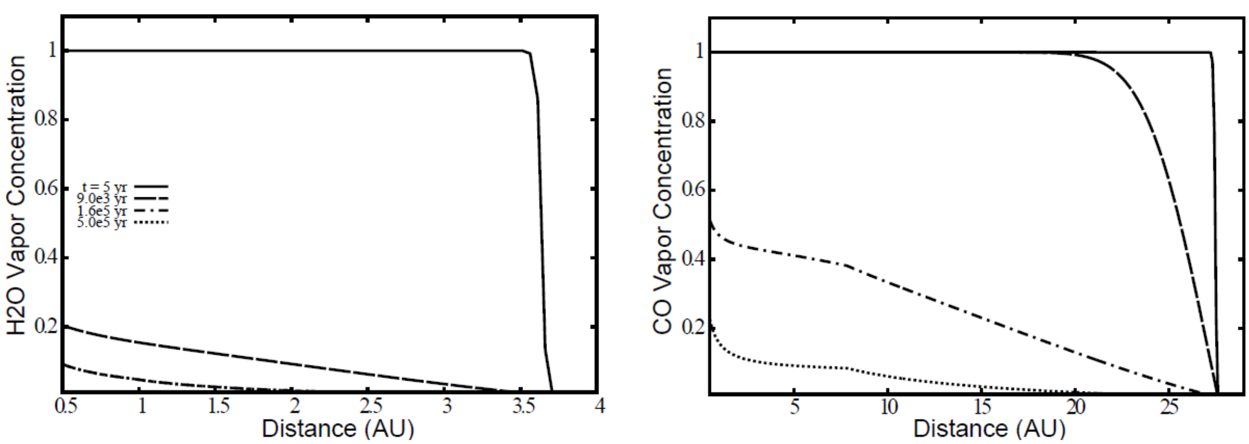

Fig. 1 The vapors concentrations of H_2O (left panel) and CO (right panel) inside their respective icelines as a function of time and distance to the star. In both cases there is a gradual depletion in the concentration due to diffusion being faster than replenishment. CO depletion is much slower than H_2O, leading to a CO--dominated inner nebula.