EPSC Abstracts
Vol. 6, EPSC-DPS2011-617-1, 2011
EPSC-DPS Joint Meeting 2011
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Heavy element and volatile enrichment of exoplanets: Effects of stellar composition on silicates and ices in planetesimals

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Abstract

We investigate the expected composition of planetesimals around stars with varying C/O ratios, under a variety of circumstellar nebula conditions. These condensate compositions can be used to estimate the amount of heavy element and volatile enrichment in giant planets accreting material from beyond the snow line in these systems. In systems with sub-solar C/O planetesimals will be rich in H_2O ice compared with the solar system, while systems with higher C/O will have less H_2O and more silicate and metal, as well as CO in solid form if cold enough.

1. Introduction

In the solar system, the gas and ice giants are known to have significant enrichments in volatiles and heavy elements over solar abundances. Accretion of ice-rich planetesimals has been suggested as the source of these enrichments [1]. These methods have been recently applied to the hot Jupiter HD 189733b to constrain the interpretation of spectrally derived C and O abundances in the planet's atmosphere [2, 3]. These studies assumed that the circumstellar nebula and star have close to solar elemental abundances since the star has close to solar metallicity.

Stellar abundances of exoplanet host stars exhibit significant variations from solar in solid forming elements, both refractory and volatile (e.g [4]). The C/O ratio is particularly important in determining the refractory (silicate and metal) to volatile ice ratio in material condensed beyond the snow line [5, 6]. Given the observed range in stellar C/O in exoplanet host stars, condensates might range from more water and volatile rich than solar system objects to volatile poor and silicate/metal rich [7]. In addition, for more carbon-rich stars (C/O >~0.8) refractory material in the inner part of the systems might be dominated by carbides rather than silicates [5, 8]. We estimate the composition of volatile and refractory material in extrasolar planetesimals available for enrichment of exoplanet atmospheres using a set of stars with a wide range of measured C/O abundances.

Table 1: Stars used and C./O values

Star	C/O	[C/O]
HD19994	0.32	-0.23
HD177830	0.35	-0.19
HD213240	0.51	-0.03
Sun	0.55	0.00
Gl777A	0.63	0.06
HD72659	0.68	0.09
HD108874	0.71	0.11
55Cnc	0.81	0.17
HD17051	1.02	0.27
HD27442	1.10	0.30
HD4203	1.51	0.44
WASP 12	0.45	-0.09

2. Data and calculations

Stellar abundances for exoplanet host stars used are from [9-12]. Table 1 lists the stars and their measured C/O ratios. Abundances of Si, Fe, Ni and S were also reported for most stars. Solar values of S were used if not reported and solar P was assumed for the volatile ice calculations. The amount of silicate ($MgSiO_3$) and metal (FeO, FeS, Ni) in the refractory condensates was determined as described in [6]. The remaining O in the gas phase H_2O and CO and the stellar composition values were then used to calculate the volatile ice condensation chemistry beyond the snow line in the circumstellar nebula following [3]. The composition of the resulting silicate/metal and ice condensates as function of C/O ratio is shown in Figure 1 for an oxidizing nebula and a midplane temperature as low as 20K, where CO ice and clathrate become important (depending on clathration efficiency – 100% assumed here).

3. Discussion

Figure 1 demonstrates that the volatile ice content of planetesimals in these systems varies significantly with C/O, controlled primarily by the availability of O for H_2O ice condensation. Systems with C/O less than the solar value should have very water ice rich planetesimals, while water ice mass fraction decreases rapidly with increasing C/O until only more volatile ices of CO and CO_2 are left in significant proportions. For warmer nebula conditions (T>~50K) condensates become increasingly silicate and metal rich until C/O ~ 0.8, where the silicate plus metal mass fraction is ~ 1. The C/O ratio for 55Cnc is close to this limit and planets in that system may have been enriched with silicate/metal rich, volatile poor, planetesimals. For larger C/O ratios, the system would become more reducing, with CH_4 becoming the major carbon-bearing gas and possibly including C as solid hydrocarbons in the condensates.

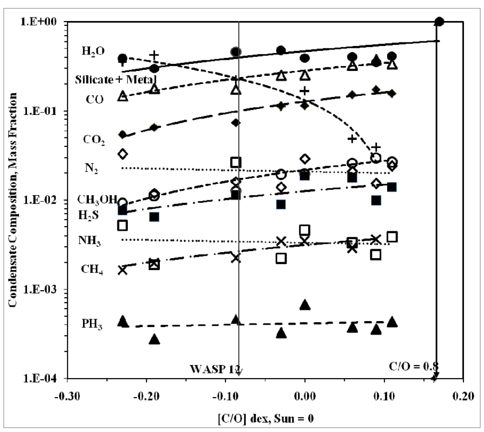

Figure 1: Condensate composition vs [C/O]

4. WASP 12b

WASP 12b, a transiting hot Jupiter has been reported to have an atmospheric C/O > 1 [13]. In this case the composition of the planet seems not to reflect the stellar composition, which has a sub-solar C/O. Planetesimals with the composition shown in Fig. 1 for this star cannot easily explain this C/O enhancement, suggesting that either O is sequestered in the planet or the nebula C/O in the planet forming region was depleted in O (or enriched in C) compared with the stellar value [14].

Acknowledgements

Part of this work (TVJ) has been conducted at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA. Government sponsorship acknowledged. NM acknowledges support from NASA HST and JPL/Spitzer grants.

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