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Effects of Exoplanet Planetesimal Carbon Chemistry on Habitability

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Abstract

We explore the effects of reported differences in C/O values for exoplanet host stars on the composition of planetesimals formed beyond the snow line in these systems. Since the value of C/O in a planet forming nebula has a strong effect on amount of oxygen available for water ice in an oxidizing nebula, exoplanet systems for host stars with C/O greater than the solar value may have planetesimals with very little or no water ice. Thus one the key chemical ingredients for habitability may be in short supply in carbon-rich, oxygen-poor systems even if planets exist in the 'habitable zone'.

1. Introduction

Stellar abundances of exoplanet host stars exhibit significant variations from solar in solid forming elements, both refractory and volatile (e.g. [1]). 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 [2, 3]. 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 [4]. 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 [2, 5]. We have estimated the composition of volatile and refractory material in extrasolar planetesimals using a set of stars with a wide range of measured C/O abundances [6-9] and compare them with early solar system materials [10].

		CHON			Redox
Star	C/O	Csolid	Mass Fraction - R:I:C	Density, Kg/m^3	CO/Total C
Sun	0.55	0.55	0.48/0.26/0.26	1751	1
HD108874	0.71	0.55	0.54/0.13/0.33	2015	1
55CnC	0.81	0.55	0.64/0.2/0.34	2432	1
HD17051	1.02	0.55	0.57/0.00/0.43	2299	0.8
HD27442	1.1	0.55	0.63/0.02/0.35	2422	0.4
HD4203	1.5	0.4	0.71/0.00/0.29	2645	0

Table 1. Planetesimal compositions for several stellar systems with a fraction, Csolid, of C in solid CHON particles

2. Effects of C/O and solid carbon phases

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 (C/O = 0.55; [C/O] = 0 dex) should have very water ice rich planetesimals, while water ice mass fraction decreases rapidly with increasing C/O until only ices of CO and CO_2 are left in significant proportions. Another significant factor for planetesimal composition is the amount of carbon that may be tied up in solid phases. Studies of astrophysical data for molecular clouds, accretion disks and constraints from solar system compositions suggest that a significant fraction (~0.4-0.70) of the carbon in accretion disks and the early solar nebula may be in refractory carbon-rich grains similar to the CHON particles identified in comets [11]. We investigate the composition of condensates for different stellar C/O values using the value of 0.55 for the fraction of C in CHON grains adopted by Pollack et al. (note that this in only coincidently the same number as the solar C/O ratio). For an oxidizing nebula, with CO as the dominant carbon-bearing gas, Table 1 shows the planetesimal compositions for several stellar systems investigated in [10], where R/I/C indicates the relative mass fractions of “Rock” (silicate plus metal), “Ice” (water ice), and “Carbon” (CHON) [12].

The water-poor condensates for systems with C/O>solar result, as noted above, from the limited amount of oxygen available for H_2O after accounting for O in refractory silicates, metal, carbon, and CO gas phases for oxidizing conditions. Figures 1-3 illustrate the fraction of the total available oxygen atoms tied up in these phases for the Sun, 55CnC, and HD17051.

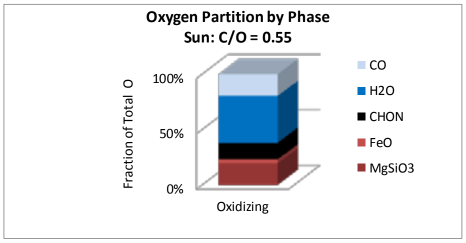

Figure 1

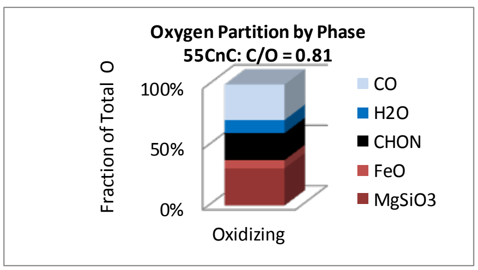

Figure 2

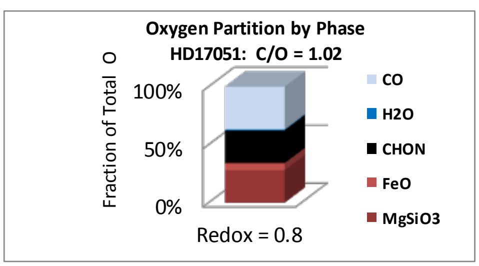

Figure 3

3. Discussion

For the assumed fraction of C in CHON, both carbon and oxygen are removed from the gas phase and the condensates for super-solar C/O values will be water-poor mixtures of silicates and metal, carbon, and carbon-bearing volatile ices, depending on temperature. For very carbon-rich systems, oxidizing conditions cannot be sustained beyond about C/O=1, due to the oxygen sequestered in solid silicates, oxides and CHON, for refractory C fractions within the Pollack et al. range of 0.4 – 0.7. HD4203 will be fully reducing even with the minimum 0.4 C in CHON from Pollack et al.

These results have implications for assessing the habitability of exoplanets since they constrain the amount of H_2O available beyond the snow line for dynamical delivery to inner planets, depending on the host star’s C/O in the circumstellar nebula. Thus a system with super-solar C/O might have planets located in the ‘habitable zone’ as well as available organic compounds, but still lack reservoirs of water-rich planetesimals.

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