Planetesimal Compositions in Exoplanet Systems

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1. The Solar System

In our solar system, the composition of planetesimals formed beyond the 'snow line' is believed to depend strongly on the abundances of C and O in the solar nebula, the redox state of C (i.e. CO rich vs. CH_4 rich regions), and the amount of carbon in the form of solid organics. These factors largely determine the fraction of rock plus metal, *f(r–m)*, versus volatile ice in condensates, and therefore the material (uncompressed) density of the condensates [1].

For "warm" nebula models where mid-plane temperatures are >~50K, CO and CH_4 remain in the gaseous state and water ice (and some hydrates) is the primary condensed volatile ice. In the outer solar nebula, CO is expected to be the dominant C-bearing gas, resulting in less O available to form water ice, and therefore higher values of *f(r-m)*. In warmer circumplanetary environments with higher density, kinetic considerations are expected to produce more reducing conditions, with CH_4 being the primary carbon species [2], resulting in more water ice and lower values of *f(r-m)*. In "cool" nebula models, with lower mid-plane temperatures, more volatile ices and clathrates, including CO, CH_4 and, H_2S, are added to the water ice and *f(r-m)* is lower.

2. Exoplanet Systems

Exoplanet host stars have observed metallicities that cluster around the solar value or higher. However, the detailed compositions for major planet forming elements are observed to differ significantly. Assuming this reflects equivalent differences in the protoplanetary nebulae from which planets formed in these systems, we can estimate the range of possible *f(r-m)* in systems for which stellar composition data are available (the most important solid forming elements being C, O, Si, S, Fe and Ni for these purposes). Stellar data are from two surveys [3, 4], with a total of 25 exoplanet host stars, and ten stars compiled for a study of diversity in extrasolar terrestrial planets [5]. Also, an example of a host star of a transiting planet, WASP-12 was included [6]. We calculated *f(r-m)* for these compositions, assuming water is the only condensed volatile, following the solar composition scheme developed in [1,7]. As expected, the condensate rock plus metal fraction is generally correlated with metallicity, [Fe/H]. However, it is even more strongly influenced by the C/O ratio. Figure 1 shows *f(r-m)* vs. [C/O], in dex with Sun=0, for both the oxidizing and reducing nebula cases. Note that for C/O > ~0.8 both cases become 'oxygen' starved, with little or no water ice for the most carbon-rich stars.

The total range of *f(r-m)* possible in these systems is considerably greater than the solar case (~ 0.47-0.76).

3. Composition of Planetesimals vs Stellar C/O

To explore the range of planetesimal composition as function of the C/O ratio of the host star, we combined the *f(r-m)* calculation from [1] with a more complete thermodynamic treatment of the volatile ices [9,10,11]. We used the set of stars compiled by Bond et al. [5], covering a wide range of C/O stellar values and calculated the mass fraction of each condensed species for both "warm" and "cool" nebular cases. Silicate plus metal fractions for the "warm" case are similar to the values in Fig. 1, reduced by the addition of small amounts of ices containing CO_2 (oxidizing) and NH_3 hydrates (reducing). For the "cool" cases, larger amounts of CO and CH_4 ices reduce *f(r-m)* still further. Fig. 2 illustrates the relative proportions of the condensed phases for oxidizing conditions over a range of stellar C/O. Note that for the extreme carbon-rich star HD 4203, lack of O produces a shift to reducing conditions.

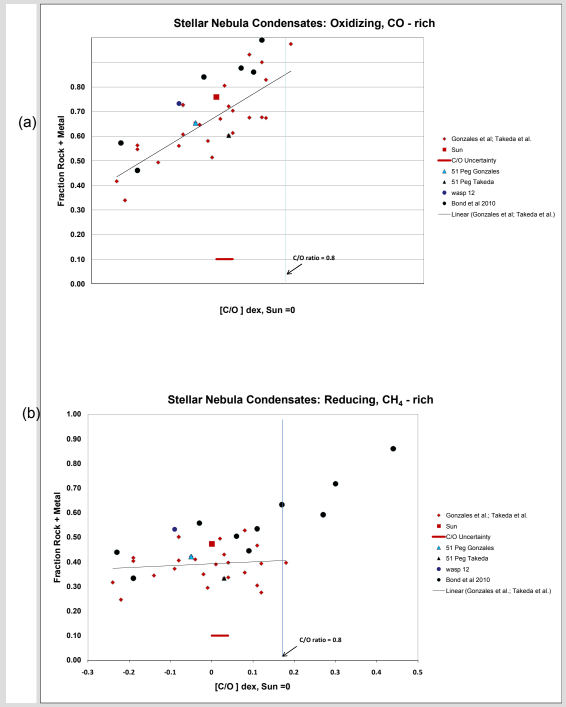

Figure 1 *Rock-metal fraction f(r-m) vs C/O. [C/O] is expressed as logarithmic units, dex, relative to the Sun = 0, [C/O] = log $(C/O)_{star}$ – log $(C/O)_{Sun}$. (a) Oxidizing: All carbon in gaseous phase as CO (b) Reducing: All carbon in gaseous phase as CH_4. Solar values are from Asplund et al. (2009) [8].*

4. Summary

- Exoplanet systems around stars with different compositions from the Sun may have planetesimals formed beyond the ''snow line'' which have a greater range of rock and metal, carbon and ice proportions than solar system planetesimals.
- The fraction of rock plus metal in extrasolar planetesimals is most strongly dependent on the C/O ratio in their stellar nebula rather than metallicity, [Fe/H].
- These characteristics may be investigated for extrasolar systems in the future through their impact on the refractory and volatile content of extrasolar planetesimal belts and the amount of heavy element enrichment of extrasolar giant planets (e.g. Mousis et al. 2009, [9]).

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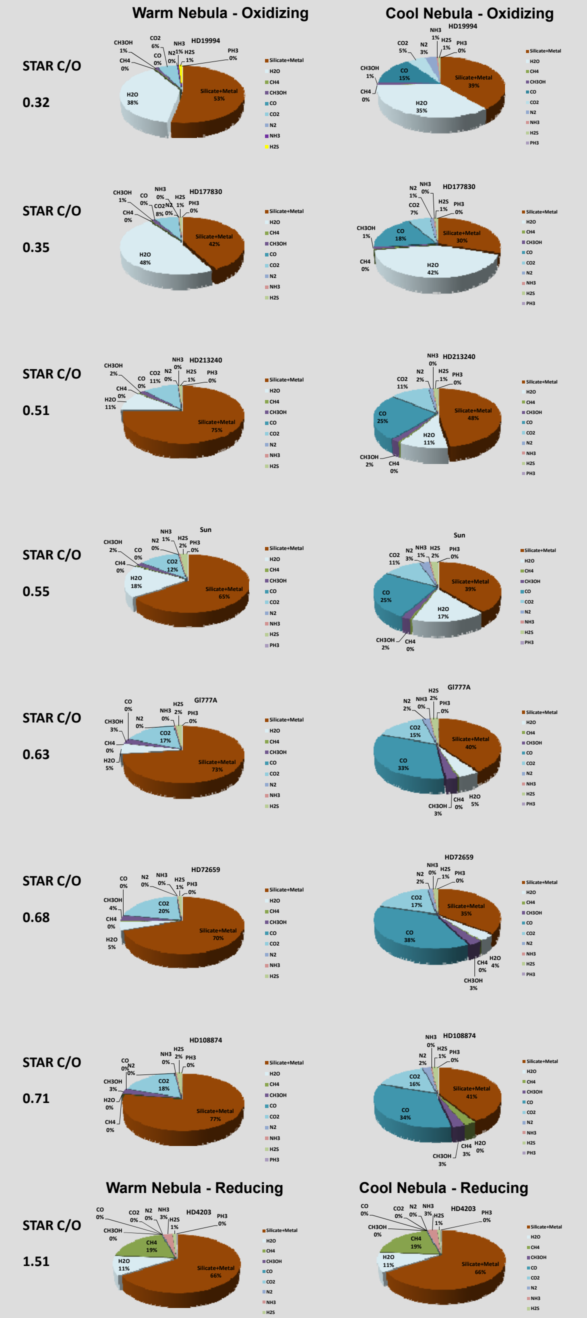
Fig. 2 Planetesimal Composition



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