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A STATISTICAL APPROACH TO PLANETESIMAL CONDENSATE COMPOSITION BEYOND THE SNOWLINE BASED ON STELLAR CARBON-TO-OXYGEN RATIO

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Abstract

The ratio between carbon and oxygen is regarded an important driver of circumstellar and planetary chemistry, which can be used as a parameter to estimate the fractionation among refractory and volatile portions of a planet. From this motivation, nearly five hundred stars including some with planets discovered around them are investigated. The relation between the C/O ratio and fractions of icy and refractory species is traced for planetesimals expected to form in their protostellar disks. It is found that low C/O ratios lead to planets rich in ice, but poor in organic and other refractory materials. With increasing C/O ratios, ice fraction diminishes, where organics increase and other refractory materials dominate. Apart from that, the carbon portion incorporated in the solid phase, and redox state of the environment are altered to analyze their inuence on bulk formation for generated planets. Under zero solid carbon contribution, ice formation decreases and refractory formation increases with increasing C/O ratio. When the carbon contribution is considered to be entirely in the solid phase, refractory materials are not significantly affected by increasing C/O ratio while ice may even disappear. For reducing conditions, C/O ratio is not an obstacle to ice formation no matter how high. Under oxidizing conditions, however, water is not found where the C/O ratio is greater than 0.8. Bulk densities are also calculated according to alternative scenarios along with compositional distributions, and results are compared to Solar System objects. This study, therefore, exemplifies how a simple correlation can be drawn between stellar chemistry, redox state, and planetesimal composition.

1. Methodology

The stars dataset for the statistical study is taken from Petigura & Marcy (2011) [1]. This selection is based upon the fact that they collected nearby solar-type stars which have stellar atmospheres similar to that of the Sun. It is assumed also that planets around them formed nearly 4.5 Gyr ago along with their parent stars. 457 stars out of 947 are considered for further investigation since their measurements of elemental carbon, oxygen, nickel and iron are available. The abundance distribution of each star in this study follows the protosolar abundance pattern derived from the compilation of Asplund et al. (2009) [2] based on a realistic three-dimensional hydrodynamic atmospheric model.

2. Results

Out of 457 stars, those with minimum and maximum C/O ratios, the Sun, and two other stars are chosen as case studies. Figure 1 shows a summary of planetesimal compositions with increasing C/O ratios where a full condensation of fundamental constituents is assumed. Three of them (Sun, HD 11506 and HD 45652) are already known to harbor planets around them. The first straight forward inuence of the C/O ratio on the compositions is the ice fraction. The negative correlation between the two is visualized clearly from one C/O value to the next.

This planetary model for the protosolar nebula might be presented mostly by some moons around solar giants, or objects originated from the Kuiper Belt and beyond. Although this distribution implies the dominance in refractory components as observed in solar terrestrial planets, the contribution from ice would be too high for this category. For example, Earth, the wettest among solar rocky planets, contains only 0.02% water of its total planetary mass [3]. Abundant ice content along with organics may be reminiscent of the ice giants.

On the other hand, a major part of the distant objects in the Solar System, especially those beyond Neptune, are thought to be composed of ice-rock mixtures with ratios of 1:1 or 1:2 [4]. This composition model and the calculated density of 1.61 g cm^{-3} are compatible to some icy satellites of Saturn like Enceladus and Phoebe (1.61 g cm^{-3} and 1.64 g cm^{-3}, respectively), and some big satellites of Uranus like Ariel and Titania (1.59 g cm^{-3} and 1.66 g cm^{-3}, respectively.

3. Figures

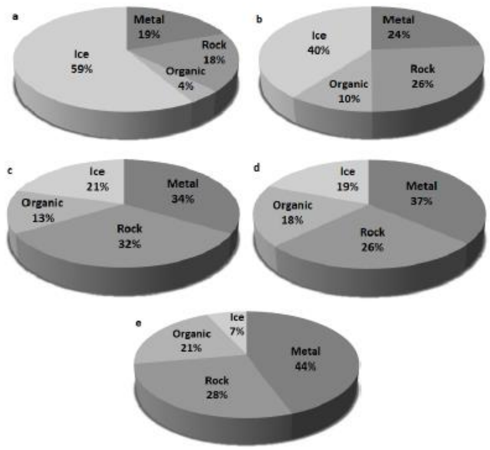

Fig. 1: Basic planetesimal compositions based on the stellar chemistry for a) HD 88656 (C/O: 0.21, bulk density: 1.35 g/cm-3); b) the Sun (C/O: 0.55, bulk density: 1.61 g/cm-3); c) HD 205353 (C/O: 0.81, bulk density: 2.11 g/cm-3); d) HD 11506 (C/O:1.07, bulk density: 2.09 g/cm-3); and e) HD 45652 (C/O: 1.35, bulk density: 2.58 g/cm-3).

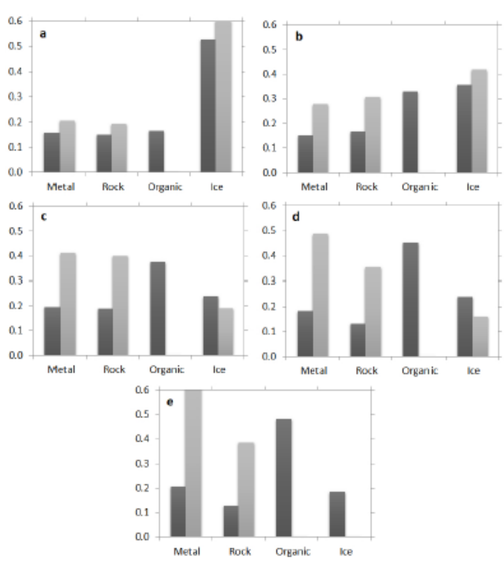

Fig. 2. Comparison of planetesimal compositions calculated for solid carbon ratio of 0% (light shades) and 100% (dark shades) based on fundamental stellar chemistry for a) HD 88656 (C/O:0.21); b) Sun (C/O: 0.55); c) HD 205353 (C/O: 0.81); d) HD 11506 (C/O: 1.07); and e) HD 45652 (C/O: 1.35).

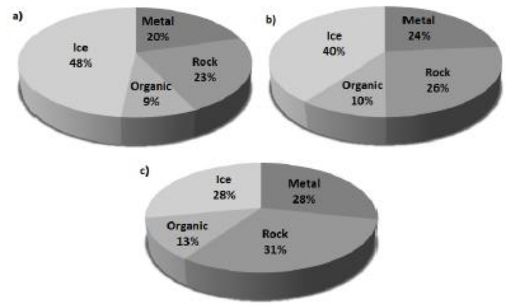

Fig. 3. The planetesimal compositions in the protosolar nebula with C/O: 0.55 calculated for a) reducing (bulk density: 1.47 g cm^{-3}); b) neutral (bulk density: 1.61 g cm^{-3}); and c) oxidizing (bulk density: 1.88 g cm^{-3}) conditions.

4. Conclusions

In light of the findings in this paper, in agreement with previous studies, it is seen that a higher C/O ratio in a protostellar disk will lead to the formation of denser, more refractory planetesimals. Low C/O ratios in contrary will result in the formation of more volatiles and ices. Depending on protostellar composition, it is possible to generate various types of planets in any stellar system, from ice or ocean planets, to totally arid ones. It is also possible to expect extrasolar systems to contain planets similar to the ones already found in Solar System, or very unusual ones from our point of view.

References

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