CHEMICAL MODELS OF THE PROTOPLANETARY DISKS FOR EXTRASOLAR PLANETARY SYSTEMS.
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Introduction: It is widely known that extrasolar planetary host stars are, to some degree, chemically anomalous. Spectroscopic studies of these stars have revealed that the metallicity of the host star is higher than that of other F, G and K type stars not known to harbor planetary companions [1-12]. Trends may also exist in the abundance of Li, C, N, [5] Na, Mg and Al [13]. However, such trends in these elements are yet to be seen in a wide selection of planetary hosts.

Another aspect of these systems that has not yet been widely addressed is the issue of the chemical nature of the system as a whole. What condensates can we expect to find in these systems? What are these planets made of? Not only are these questions intriguing in their own right but they also impact on planetary formation and migration models currently being developed (e.g. [14], [15]), in addition to having major astrobiological implications.

This study begins to answer some of these questions by examining the equilibrium composition of the original nebulae of 6 known extrasolar planetary host stars, in direct comparison to the solar nebula. In doing this we hope to determine what compounds we would expect to see both within the system as a whole and ultimately also within the extrasolar planets themselves.

Abundance Calculations:

Target Stars and Elements. The target stars of this study were all selected based on their various metallicity values. They were chosen to represent a high metallicity value (HD 145675), a low metallicity value (HD 6434) and a metallicity value close to the median value observed in known extrasolar planetary host stars (HD 16141). In addition to these three stars, an additional three known host stars belonging to the Anglo Australian Planet Search (AAPS) were included. As for the previous stars, these were selected to represent the highest metallicity (HD 30177), lowest metallicity (HD 23079) and median metallicity (HD 39091) of known planet hosts stars within the AAPS. Each of these planetary systems also contains just one known planetary companion.

In order to determine the equilibrium composition of the protoplanetary nebulae, we assumed that they are initially homogenously mixed and thus that the stellar composition can be used as a proxy for the original compositions. For the purposes of this study, we selected the 15 most abundant elements within the universe (H, C, N, O, Na, Mg, Al, Si, P, S, Ca, Ti, Cr, Fe and Ni). These elements are also the most important for both solid formation (e.g. O, Mg, Si, Fe) and astrobiology (e.g. C, N, S, and P). As a result of the various spectroscopic studies already completed, stellar abundances for 12 of these 14 elements are already available. Stellar abundances were obtained from [13] (Fe, Na, Ma, Al), [16] (N), [17] (C, S) and [18] (Si, Ca, Ti, Cr and Ni). All of these abundances are taken from the same working group, meaning that each abundance was produced in the same way, thus minimizing any possible systematic errors between different studies. As stellar abundances for O and P have not yet been published, solar ratios (from [19]) were used for each of the stars.

Equilibrium Composition. The chemical software package HSC Chemistry Version 5.1 was utilized here to determine equilibrium abundances of gaseous and solid compounds. Each calculation was done over the temperature range 3K to 6000K with a total pressure of 10^{-6} bars. This method has been utilized successfully in other studies (e.g. [20])

Abundance Results: Example abundance distribution plots can be seen in Figures 1 and 2. These figures focus in on the region where $T \leq 2000K$ as this is where condensation first begins to occur. Using the nominal nebular model of [21], this corresponds to the region of the midplane located beyond 0.75AU at t=0.

From these figures we can clearly see that the abundances and species present follow broad general trends. High-temperature inner regions (T>1000K, initially within 4.2AU) are dominated by gaseous H, CO and N_2, with minor amounts of solid iron, Mg-orthopyroxene and forsterite also present. The cooler (outer) regions of the disk are dominated by gaseous H_2, H_2O, CH_4 and NH_3, with solid water, Mg-orthopyroxene, forsterite and iron. Considering the composition of our solar system, this broad trend is approximately what one would expect to see – inner terrestrial planets composed of pyroxene, olivine and iron with CO_2-rich atmospheres and outer gas giant planets with a rocky core of material surrounded by H_2 atmospheres with traces amounts of CH_4, NH_3 and H_2O. As one would expect, there are variations in the exact amount of each species present in each stellar nebula.

It was also determined that while the metal-poor star HD23079 has a higher amount of water ice present in its cooler regions, it also has the least amount of solid silicate material in its nebula, while the metal-rich star HD145675 has the most solid silicate material. For example, for every 1kmol of H in the system, HD145675 has a peak abundance of 1x10^{-4} kmol of Mg_2SiO_3 vs. 2.34x10^{-5} kmol in the HD23079 system.

The metal-poor star HD6434 ([Fe/H] = -0.52) is additionally unusual in that it has a high C/N ratio (135 vs. 4 for solar abundance). This C enhancement results in the disk chemistry being dominated by carbonaceous species (Figure 3). The inner disc is composed of graphite and gaseous CO, while the cooler outer disc is composed of gaseous CH_4 with some H_2O (both solid and gaseous) also present. Silicon is present only as minor trace amounts of solid forsterite in the inner disc and Mg-orthopyroxene in the outer disc.

Clearly these results have implications for both planetary composition and planetary formation theories, as they assist us in determining both the composition and amount of solid material initially present and its location within a proto-planetary nebula. Two implications of fundamental importance are the effects on the evolution of the planetary bodies themselves and also on the development of life itself. These aspects will be studied in detail in the future work.

References: [1] Gonzalez, G. (1997) *MNRAS*, *285*, 403. [2] Gonzalez, G. (1998) *A&A*, *334*, 221. [3] Gonzalez, G. & Vanture, A. D. (1998) *A&A*, *339*, L29. [4] Gonzalez, G., Wallerstein, G. & Saar, S. H. (1999) *ApJ*, *511*, L111. [5] Gonzalez, G. & Laws, C. (2000) *AJ*, *119*, 390. . [6] Butler, P. R. et al. (2000) *ApJ*, *545*, 504. [7] Santos, N. C., Isralian, G. & Mayor, M. (2000) *A&A*, 363, 228. [8] Gonzalez, G. et al. (2001) *AJ*, *121*, 432. [9] Santos, N. C., Isralian, G. & Mayor, M. (2001) *A&A*, *373*, 1019. [10] Smith, V., Cunha, K. & Lazzaro, D. (2001) *AJ*, 121, 3207. [11] Reid, I. N. (2002) *PASP*, 114, 306. [12] Fischer, D. A. & Valenti, J. (2005) *ApJ*, *662*, 1102. [13] Berião, P. et al. (2005) Submitted to A&A, astro-ph/0504157. [14] Rice, W. K. M. & Armitage, P. J. (2003) *ApJ*, *598*, L55. [15] Papaloizou, J. C. B. & Nelson, R. P. (2005) *A&A*, *433*, 247. [16] Ecuvillon, A. et al. (2004) *A&A*, *418*, 703. [17] Ecuvillon, A. et al. (2004) *A&A*, *426*, 619. [18] Bodaghee, A. et al. (2003) *A&A*, *404*, 715. [19] Asplund, M., Grevesse, N. & Sauval, A. J. (2004) astro-ph/0410214. [20] Pasek, M. et al. (2005) *Icarus*, *175*, 1. [21] Hersant, F., Gautier, D. and Huré, J. (2001) *ApJ*, *554*, 391.

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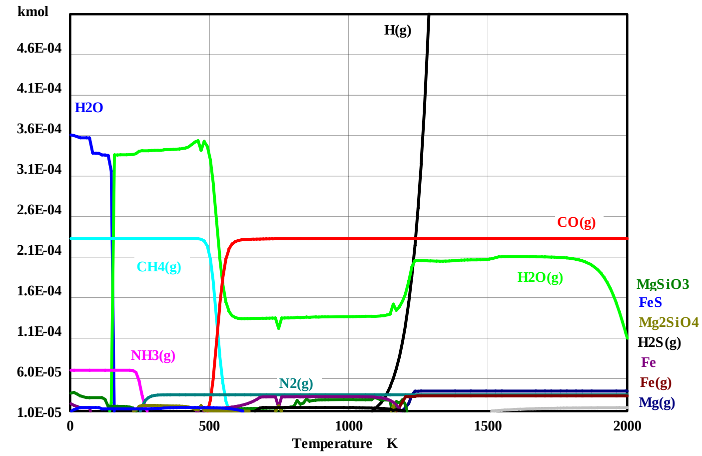

Figure 1: Solar abundance distribution.

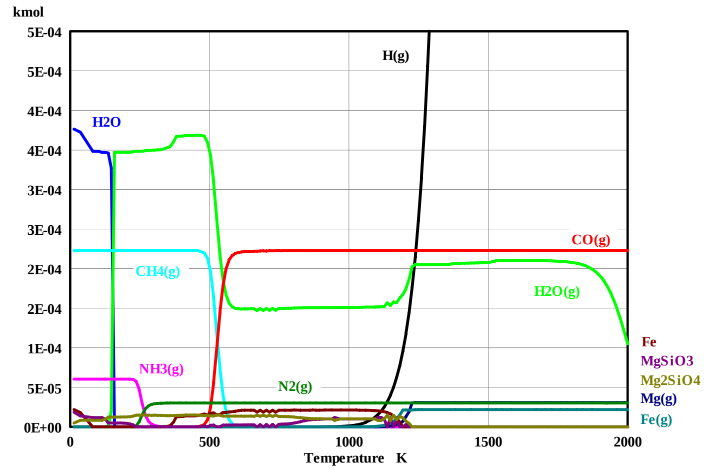

Figure 2: Abundance distribution for HD23079.

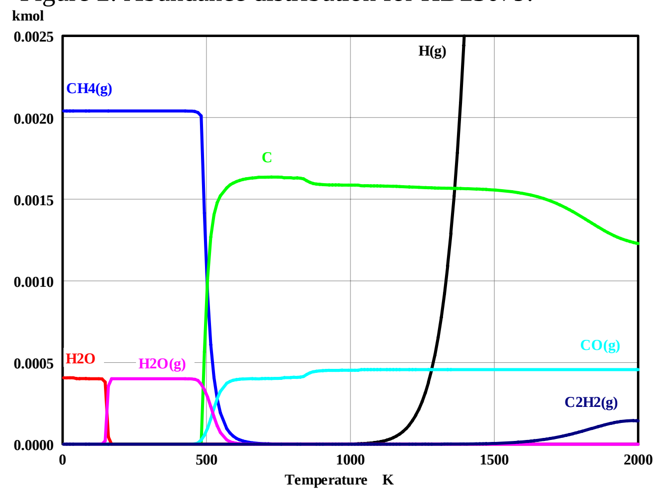

Figure 3: Abundance distribution for HD6434.