The Effect of Si and O Element Abundances on Planetary Formation

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Abstract

Our research aims to investigate the effect of different element abundances on planet formation. In this study, we used a catalog by E. Delgado Mena et al. (2010) and investigated Si, C, O, Ni, Fe abundances for different systems: the systems that have planets and the systems that do not have any planets. We found the systems with planets have richer element abundances than those which do not have a planet system. The difference in element abundances for these systems shows that richer environments are favorable for planetary formation. The reason for this behavior is that the terrestrial planets consist of silicate and other compounds. Our research shows the possibility for a star to have a planetary system is higher when the environment is rich in element abundances.

1 Purpose

We aim to research the stars with the certain element abundances in order to investigate their probabilities of having a planetary system. Terrestrial planets consist of mostly silicate minerals. Therefore, in our study, we target Si and O element abundances.

2 Data Set

In our research, we used a data set which was also used by E. Delgado Mena et al. (2010). This data set consists of 312 stars: with their spectrum, [Si/H], [C/H], [O/H], [Ni/H], [Mg/H], [Fe/H], [C/O], [Mg/Si] abundances, T_{eff}, $\log g$, and parameters of atmospheric models. Among these stars, 80 of the have planet systems. These exoplanets are terrestrial planets with the mass varying between $2M_{\oplus}$ to $20M_{\oplus}$ and their surface temperatures varies between $5100 \leq T_{eff}(K) \leq 6400$.

3 Silicate Mineral

More than 92% of the Earth consists of silicate minerals. Silicate tetrahedron ($Si0_4^{-4}$) molecule is the main constituent of silicate minerals. This molecule has a ${}_{14}Si$ atom in the center and ${}_{6}O$ atoms on its vertices. Each O atom has one valence electron. Therefore, silicate tetrahedron ($Si0_4^{-4}$) can easily grow and construct new materials. Si and O atoms have strong interactions within silicate tetrahedron ($Si0_4^{-4}$).

These interactions are 40% ionic and 60% covalent. Therefore, silicate tetrahedron can form new bonds and can construct strong molecular chains.

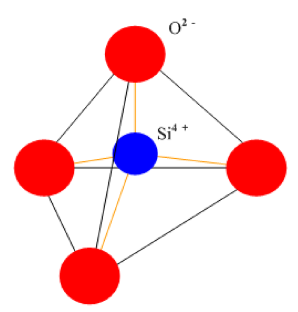

Figure 1: Silicate tetrahedron molecule

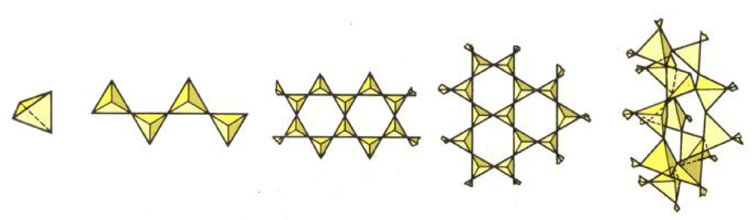

Figure 2: Silicate tetrahedron chain molecule structures

Different numbers of silicate tetrahedron molecules can form chain or ring structures that are complex and big in structure. In Earth, these molecules construct 78 different silicate minerals by combining with different elements.

Ring-structured silicate molecules can be aligned in such a way to construct crystal compounds. Chain and ring structures is showed in Fig. 2. In this paper, silicate should be understood as silicate tetrahedron molecule.

4 The Solar Hypothesis

The Solar Hypothesis explanation of the Solar System formation:

This is one of the most widely accepted theories about the formation of our Solar System. At the very beginning of the formation, the nebula is in equilibrium with its vicinity. The fluctuations in the equilibrium, which are caused by supernova explosions, density waves, or shockwaves, trigger the formation. The system starts collapsing towards the center. Consequently, a protostar forms in the center. Since angular momentum must be preserved, the material around the protostar starts to assemble in a plane.

This material around the protostar mostly consists of gas and dust grains. These gases and dust started to assemble by colliding each other and have grown enough to have gravitational effects. The beginning of the formation of these objects are not well understood in this theory. It has been thought that the growth of these objects is affected by electric forces in atomic scales.

In time, these objects have grown to form planetesimals by gravitational interactions and by collisions between themselves, and these planetesimals have grown to form protoplanets. Consequence of the interactions of these protoplanets is the Solar System itself as we see today.

5 Silicate in Planet Formation Theories

The key question in planet formation theories is the growth of dust grains to form planetesimals. There are different ideas to explain this problem. In general, the problem is explained by the combination of dust grains with ice and soft rocks.

Different from these theories, our study led us to an alternative explanation for this problem. We already know that silicate molecule tends to grow and construct chain and ring structures. Moreover, it is known that the dust grains, in the beginning of the formation, are mostly comprised of silicate. When these dust grains collide, silicate molecules can form bonds and the tendency of silicate to grow can cause dust grains to assemble and consequently gravitation will be significant enough to form bigger structures.

6 Conclusion

If silicate is responsible for the assembly of dust grains as we have proposed in the previous section in this paper, the stars formed in silicate-rich environments should be more efficient in the means of forming planets. To verify this, we investigated [Si/H] and [O/H] abundances for the stars that have planets and for those without planets. When we plot star distributions against [Si/H] and [O/H] abundances, we came to the conclusion that the distribution of stars in the plots are consistent with our prediction (see Figure 3).

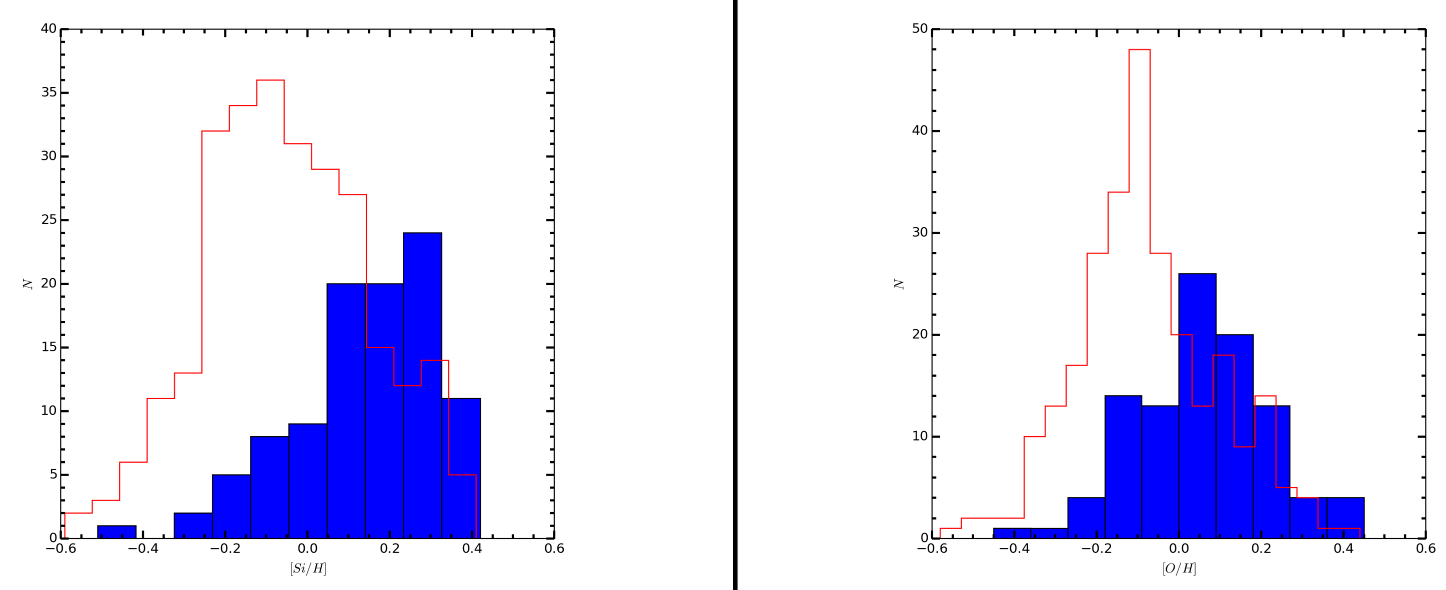

Figure 3: Blue histograms show the systems with planets, whereas red histograms show the systems without planets.

As seen from histograms above, when the environment is richer in Si and O, which are the constituents of silicate molecule ($Si0_4^{-4}$), the possibilities of finding stars that have planets are higher. This behavior is more obvious for $[Si/H] \geq 0.15$ and $[O/H] \geq 0.00dex$. By assuming these values as boundary conditions, the numeric and statistical results are:

- 13% of the sample that do not satisfy the boundary conditions have planets.
- 53% of the sample satisfying the boundary conditions have planets.
- The poorer the environment is in Si and O abundances, the probabilities of finding a system with planets is smaller, whereas the richer the environment, the higher the probability.
- Si and O abundance is related to planet formation.

As we have shown in our results, this relation is supported by further surveys.

7 Acknowledgments

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