Exotic Exoplanets: Using NASA Exoplanet Archive data and Equilibrium Chemistry to predict an exoplanetary atmosphere with non-spontaneous syntheses of important basic molecules

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OBJECTIVES

This study aims to identify possible exoplanetary atmospheres in which reactions that produce fairly common molecules on Earth are non-spontaneous, and predicts the possible common substances that may be present in the atmospheres of such exoplanets.

MATERIALS AND METHODS

Methane and ammonia gas equilibrium chemistry were analyzed.

$C (s) + 2H_2 (g) \longrightarrow CH_4 (g)$

$N_2 (g) + 3H_2 \longrightarrow 2NH_3 (g)$

The ΔH and ΔS values were used to determine the minimum temperature required for the methane reaction to be non-spontaneous, and for the ammonia reaction to be spontaneous.

These temperatures were then separately used (approximating the exoplanet as a black body) to determine the amount of power that must reach any exoplanet in order to have an atmospheric temperature of at least that magnitude. The power was then used to determine the necessary flux the exoplanet must receive from its host star.

To determine possible exoplanets that could fit this criteria, the NASA Exoplanet Archive's Planetary Systems Table was used.

For exoplanets that had an identified equilibrium temperature, that value was used and cross-referenced with the temperatures needed for the reactions to determine if the exoplanet was suitable.

Exoplanets that met the criteria were compiled into separate lists for analysis.

INTRODUCTION

For the purposes of this project, exoplanetary atmospheric temperatures will be modeled using a black body approximation. Although there are numerous other factors that could impact the atmospheric temperature, it is difficult to take them all into account especially given that we have not identified in much detail the composition of the exoplanets we are "designing."

Here, I will analyze methane gas and ammonia, two gases that existed in high concentrations in Earth's primitive atmosphere, and identify conditions in which methane synthesis would be non-spontaneous, or in which ammonia synthesis would be spontaneous.

We can use the Gibbs Free Energy formula $\Delta G = \Delta H - T\Delta S$, where ΔG is the change in Gibbs Free Energy, ΔH is the change in standard enthalpy, T is the temperature, and ΔS is the change in standard entropy, to determine the spontaneity of the reactions

By finding temperatures that result in $\Delta G = 0$, we can use the black body approximation to determine stellar luminosities/distances that would be conducive to the reactions being non-spontaneous, and identify possible exoplanets in which this could occur, as well as the substances that may exist instead of methane (most likely graphene) and ammonia, and be present in larger quantities on those planets.

RESULTS

Methane gas:

- We have $\Delta H = -74.6$ kJ/mol and $\Delta S = -80.8$ J/(mol•K)
- $\Delta G = \Delta H - T\Delta S > 0 \longrightarrow T > 923$ K

Ammonia gas:

- We have $\Delta H = -46.1$ kJ/mol and $\Delta S = -391.2$ J/(mol•K)
- $\Delta G = \Delta H - T\Delta S < 0 \longrightarrow T < 118$ K

]A total of 4854 out of the 13073 exoplanets in the archive which had identified equilibrium temperatures fit the criteria for non-spontaneous methane synthesis.

A total of 7 out of the 13073 exoplanets in the archive which had identified equilibrium temperatures fit the criteria for spontaneous ammonia synthesis.

CONCLUSIONS

A large number of exoplanets exist in which methane synthesis is non-spontaneous, and very few exoplanets in which ammonia synthesis is spontaneous.

The atmospheric conditions in these planets can be further analyzed as well; the extremely high temperatures on exoplanets in which methane synthesis is non-spontaneous may also cause other reactions that are generally spontaneous on Earth to be non-spontaneous instead.

Future inclusions of additional exoplanetary data using black body approximations (as discussed below) could add to this analysis and provide deeper insight as well.

LIMITATIONS

There were numerous exoplanets that did not have an identified equilibrium temperature that were not analyzed in this paper. Future analyses would likely benefit from furthering the black body approximation and using itto approximate the stellar flux the exoplanet receives from its host star, on average, and comparing to the stellar flux required for the reactions to be non-spontaneous (with the assumption that stellar flux is the largest contributor towards the exoplanet's temperature). This could result in a larger dataset with further descriptions of exoplanet demographics.