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The Role of Atmospheric Nitrogen as a Geo-Biosignature

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Abstract

Nitrogen is an essential element in the building blocks of life and Earth's biosphere. We show that the geobiological nitrogen cycle is a fundamental factor in the Earth's long-time habitability and most likely on Earth-like exoplanets. We discuss the evolution of the Earth's nitrogen atmosphere and its relation with the biosphere. Then we suggest hypothetical atmospheric evolution scenarios: i.) A stagnant-lid regime world where neither plate tectonics nor life evolves, although the Earth like planet has a liquid water ocean on its surface. ii.) An anoxic world where plate tectonics evolves and a liquid water ocean is present on the planet's surface, but no life or only anoxic life forms originated. iii.) An Earth-analogue world with an origin and evolution scenario similar to the Earth. iv.) A world where a terrestrial planet evolved similar to the Earth, but all life forms become extinct. After discussing possible evolution scenarios, we argue that terrestrial planets with nitrogen-dominated atmospheres facilitate an operating plate tectonic regime connected with an enhanced probability of highly developed life forms, whereas the absence of such features most likely implies CO_2-dominated atmospheres.

1. Scientific Relevance

The evolution of an Earth-like planet and its atmosphere is strongly related to the planet's formation process, the host star's activity controlling the escape of a possible hydrogen/helium dominated protoatmosphere, the evolution of the secondary atmosphere, and the planet's impact history including its initial volatile and water inventories [1]. On Earth, about 4.0 billion years ago, a nitrogen dominated atmosphere started to rise during the Archean eon and life as we know it originated. The origin and evolution of life on Earth has been responsible for the modification of atmospheric composition and climate [2]. The biological modulation of the Earth's atmosphere had been extensively discussed [3]. Recent simulations of the atmospheric-biological interaction over geological times on Earth-like planets indicate that the presence of nitrogen and oxygen in combination could be a possible signature of an oxygen-producing biosphere [4]. Although oxygen and ozone are necessary ingredients for the evolution of complex life forms, several theoretical studies have shown that oxygen may also abiotically build up in an exoplanet's atmosphere [5,6]. The possibility of abiotic atmospheric oxygen and ozone in terrestrial exoplanet atmospheres in combination with water implies that such a composition is not necessarily an evidence for a particular planet to be populated by multicellular life forms. One should note that nitrogen is an essential element for life on Earth and it is also involved in limiting nutrients that control autotrophic CO_2 fixation, which in turn is connected to the climate, weathering, and the redox state of Earth's surface over geologic timescales. Our main aim is to investigate how the complex interplay between geophysical factors and life influences atmospheres on terrestrial (exo-)planets. Further we raise the question of which scenarios lead to nitrogen dominated atmospheres on Earth-like planets.

2. Conclusions

We show a strong correlation between a nitrogen dominated atmosphere and water, oxygen and ozone as biosignatures for highly developed life forms on terrestrial planets. The composition of atmospheres originates from complex interactions between the atmosphere, lithosphere and biosphere. Since life forms play an important role in maintaining the nitrogen dominated atmosphere on Earth, if such life and interactions are rare, we expect the atmospheres of most terrestrial planets in the habitable zones to be CO_2-dominated. This molecule presents a number of absorption bands in the infrared, therefore making it detectable from the ground with high-resolution spectrographs attached to the ELTs. Our hypothesis could therefore be proven by characterizing the atmosphere of the Earth-size planets detected by TESS and PLATO.

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