

BIOSIGNATURES ON SUPER-EARTHS WITH HYDROGEN-DOMINATED ATMOSPHERES. S. Seager^{1,2}, W. Bains¹, R. Hu³, A. Zsom². ¹ Department of Earth, Atmospheric and Planetary Sciences, MIT, 77 Mass. Ave., Cambridge, MA 02139, USA. ² Department of Physics, MIT, 77 Massachusetts Ave., Cambridge, MA 02139, USA, ³ Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA

Background. Planets with masses intermediate between Earth and Neptune that have a defined, solid surface and a thin atmosphere (“Super-Earths”) are a new class of potentially habitable planet without precedent in our Solar System, but which have been suggested to be common by recent exoplanet surveys. It is plausible that such planets will retain or acquire an atmosphere dominated by hydrogen. We have explored what atmospheric signatures life might produce on such worlds.

Approach

We have computed the likely production and atmospheric removal rates of the gas products of energy metabolism, biomass building, and a small sample of secondary metabolite gases that are made by life on Earth. Gas removal by atmospheric photochemistry was modeled [1]. Volatile production rate was calculated in two ways. For gases produced as a byproduct of energy capture, the flux of gas was calculated from the known thermodynamics of maintaining life, as described in [2]. For other gases, production rates per unit biomass were scaled from known maximum terrestrial rates. In both cases, the biomass required to create a flux sufficient to generate spectroscopically detectable amount of gas was calculated, and if the mass was unrealistic, the gas was ruled out as a potential biosignature.

Results

Energy capture reactions.

Both gas production and gas removal mechanisms are different in an H₂-dominated atmosphere from those on any solar-system Earth-like planet. In solar system planets, gas removal is dominated by reaction with ·OH and :O radicals, whereas in the H₂-dominated atmosphere, removal is usually dominated by reaction with ·H [3]. Energy capture reactions in an H₂-dominated environment will produce reduced compound such as H₂S and CH₄ which cannot be unambiguously differentiated from geochemically produced volatiles. An exception is ammonia (NH₃), whose production is exergonic in an H₂-dominated world. Geochemical production of NH₃ is likely to be very slow, photochemical removal even in an H₂-dominated atmosphere will be rapid, and so detection of NH₃ in an H₂-dominated super-earth atmosphere may be a biosignature.

Photosynthesis. We examined the plausibility of photosynthesis in an H₂-dominated environment [4]. The H₂ in an H₂-dominated atmosphere is a potent greenhouse gas, allowing liquid water on the surface of a super-earth orbiting a sun-like star at 10AU. Enough light energy reaches the surface of such worlds to support photosynthesis; however the most plausible volatile product of photosynthesis is hydrogen, which cannot be distinguished from atmospheric hydrogen. Ammonia is also a possible photosynthetic product.

Secondary metabolites. Life on Earth produces a number of gaseous products for reasons other than energy capture or biomass building, such as CH₃Cl. We examined a sample of these other metabolic products, and identified ones that are plausible candidates for biosignatures on an H₂-dominated world.

Conclusions

A habitable environment is possible on an H₂-dominated super-earth, and such planets have a wider habitable zone than planets with an oxidized atmosphere like Earth or Mars. However detecting life on an H₂-rich super-Earth may be harder than detecting life on a true Earth analogue, as its most plausible photosynthetic byproduct will be H₂, and many energy capture reactions will generate gases that cannot be distinguished from those from geochemical. We put forward ammonia as a candidate biosignature gas for an H₂-dominated rocky planet.

References

- [1] Hu, R. et al (2012) *Astrophysical Journal*, 761:166 (29pp)
- [2] Seager, S. et al (2013) *Astrophysical Journal* 775: 104 (28pp).
- [3] Seager et al (2013) *Astrophysical Journal* 777: 95.
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