Earth is more than one planet: the many faces of Earth history as analogs for habitable exoplanets.

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Earth is the best studied planet and the only known world with surface water and a biosphere. Thus, it provides a crucial starting point to guide our search for other habitable worlds in other planetary systems. Yet the exoplanets we have thus far discovered have surprised us in many ways, and our first observations of terrestrial planets in their stars habitable zones will unquestionably continue this trend of the unexpected.

To guide our studies of the rich diversity of exoplanets we will someday encounter, it is instructive to consider the different environmental conditions and dominant biospheres that existed during our planet’s long history to broaden our understanding of the types of habitable planets that might exist elsewhere. Some phases of Earth history are dramatically different from modern Earth, yet they are still, by definition, “Earth-like.” In this presentation, I will provide an overview of what Earth through time tells us about biosignatures and environmental conditions that we might find on exoplanets dissimilar to modern Earth.

For instance, during the Archean (4-2.5 billions of years ago), Earth likely had a flourishing anaerobic biosphere (including methane-producing organisms) and a robust inventory of greenhouse gases to keep the surface temperature clement against the fainter younger sun. The atmosphere lacked the oxygen that is such an important biosignature to modern Earth. Instead, methane was likely present in abundance (2-3 orders of magnitude more than what is in the atmosphere today) as an important greenhouse gas and as a key biosignature of this anoxic environment (e.g. Krissansen-Totton et al. 2018). Methane may have occasionally been present at a high enough abundance to trigger the formation of a global organic haze, dramatically impacting the planet’s climate and environmental conditions and acting as a kind of novel, non-gaseous biosignature (e.g. Zerkle et al. 2012; Arney et al 2016). Hazy Archean Earth is arguably the most alien planet we have geochemical data for and so is a useful datapoint for expanding our thinking of the kinds of habitable and inhabited environments that may be possible.

During the Proterozoic, (2.5 billion – 541 million years ago), significant oxygenation of the atmosphere occurred, transforming the chemical character of atmosphere in a powerful way. However, in the mid-Proterozoic, atmospheric oxygen levels may have been only 0.1% of the present atmospheric level, precluding directly detectable oxygen spectral features for remote observations. Instead, ozone, a photochemical byproduct of oxygen, may have been the only indirect spectral evidence of oxygen for this kind of low-O2 atmosphere (e.g. Schwieterman et al. 2018). This is because ozone has an extremely strong absorption feature at UV wavelengths that is a highly sensitive indicator of low O2 levels. Nitrous oxide levels may also have occasionally been elevated during the Proterozoic, a potent greenhouse gas and a type of biosignature (Roberson et al. 2011; Buick 2007). Yet methane levels may have been suppressed during the same time period (Olson et al. 2016), diminishing its importance as a biosignature and as a greenhouse gas.

Last but not least, modern Earth is the planet we will always understand best, and it can be used to validate models we will use to constrain and understand the properties of exoplanets. Yet remembering that the atmosphere of modern Earth is representative of only about 13% of Earth’s total inhabited history is sobering and urges us to look back in time when we consider what may be possible on other Earth-like worlds.