Do Habitable Worlds Require Magnetic Fields?

D. Brain[1,2], K. Seki[2], H. Egan[1], R. Jarvinen[3], Y. Ma[4], M. Hölmstrom[5], R. Ramstad[1], T. Weber[1], R. Jolitz[1] ([1]U. Colorado, [2]U. Tokyo, [3]FMI, [4]UCLA, [5]IRF)

At present we know of one planet in the Universe that supports life: Earth. One reason for Earth's habitability is its residence in the traditional "habitable zone" of our star - the orbital distance where conditions are right for liquid surface water. Yet Earth is one of three planets that orbit in or near the habitable zone, indicating there are other criteria for surface habitability.

One possible criterion is the presence of a magnetic field to shield the atmosphere. Of Venus, Earth, and Mars, only Earth possesses a global dynamo magnetic field, and it has been widely assumed for decades that this magnetic field has prevented the atmosphere from being stripped away to space over time. Observational evidence in support of the idea that magnetic fields shield atmospheres includes isotope measurements from unmagnetized Venus and Mars suggesting they lost atmosphere relative to Earth, observations from the MAVEN spacecraft mission at Mars indicating that Mars lost substantial atmosphere over its history, and studies that show different responses of Earth and Mars to the same solar wind event.

The assumption that intrinsic magnetic fields shield atmospheres has been called into question in recent years. Spacecraft observations suggest that Venus, Earth, and Mars all have similar atmospheric escape rates, despite their difference in magnetization. Orbital observations from Earth further show that the energy flux of the solar wind is proportional to ion escape rates, indicating direct solar wind control of atmospheric escape even on magnetized planets.

We summarized the current state of research into this important question bridging the disciplines of space physics and planetary science. We presented results from a global hybrid plasma model for a Mars-sized planet that show that a weak magnetic field leads to *increased* ion escape rates as the planetary dipole strength is increased to the point where it is capable of standing off the solar wind from the atmosphere. For higher dipole strengths (though still weak), increasing the planetary field leads to *decreased* escape rates, as newborn ions become increasingly trapped in the planetary magnetic field.

We next presented the idea that the Martian case may hold important clues for answering our central question. This is because Mars is an unmagnetized planet possessing strong localized crustal magnetic fields, making it possible to compare unmagnetized and magnetized regions on the same planet. Comparisons between planets, while still valuable, are complicated by the many other ways in which planets differ (atmospheric composition, planetary size, ambient plasma conditions, etc.). We showed that current models and current observations all disagree to within more than an order of magnitude on the change in escape rates caused by crustal fields at Mars, highlighting the need for further investigation in the near term.

We finished by highlighting several research topics for the near future. These included ongoing efforts in our own research group (work on correlating magnetic field topology with ion outflow from crustal fields, modeling of Solar Energetic Particle deposition into the atmosphere, PIC modeling of crustal field cusps, and continued global hybrid modeling), as well as immediate needs for the community (resolve current discrepancies, new observations, new models, and a more coordinated community effort that includes a conference).

We closed by giving our current tentative answer to the title question from the presentation, "Do Habitable Worlds Require Magnetic Fields?" --- It depends! (upon the properties of the planet and the space environment)