Radio Exploration of Planetary Habitability: Conference Summary

T. Joseph W. Lazio (Jet Propulsion Laboratory, California Institute of Technology), A. Wolszczan (Dept. Astronomy & Astrophysics, Center for Exoplanets and Habitable Worlds, Pennsylvania State University), M. Güdel (Dept. Astrophysics, University of Vienna), Rachel A. Osten (Space Telescope Science Institute), Jan Forbrich (Dept. Astrophysics, University of Vienna), M. M. Jardine (School of Physics & Astronomy, University of St. Andrews),
and
P. K. G. Williams (Harvard-Smithsonian Center for Astrophysics)

ABSTRACT

Radio Exploration of Planetary Habitability was the fifth in the series of American Astronomical Society’s Topical Conference Series. Notable aspects of the conference included the interdisciplinary nature of both the topics and the intellectual breadth of the participants, the diversity of approaches to studying this topic presented by recent discoveries and of the participants themselves, the expanding meaning of the topic of “star-planet interactions,” and the expectation of an increasingly statistical approach to the topic. Potential areas of future research include the actual extent to which planetary magnetic fields shield planetary atmospheres; the planetary dynamo process itself, particularly once multiple extrasolar planetary magnetic fields are confirmed; and “planet-star interactions.” A major topic of the conference concerned observational opportunities, highlighted by a number of new or upcoming, specialized observatories to observe exoplanets especially at radio wavelengths. This article summarizes these main points of the conference and expands briefly upon these potential avenues for future investigation. A future meeting on this topic, given the variety of data sets being generated over the next few years, is warranted.

Subject headings: astrobiology — planets and satellites: magnetic fields — planet-star interactions — stars: activity — stars: magnetic field — radio continuum: planetary systems — radio continuum: stars

1. Motivation

Low-mass stars, i.e., stars with masses significantly below one solar mass, have been regarded as exciting targets for planet searches, because of their abundance compared to the Sun-like stars, and their desirable properties from the standpoint of sensitivity of radial velocity and transit surveys. On-going and upcoming ground-based searches, such as CARMENES and the Habitable Planet Finder, and space missions such as K2, Gaia, and TESS are expected to deliver a large number of potentially habitable planets. Planets around low-mass stars with biosignatures detectable over interstellar distances are likely to be located close to their parent stars, motivating a growing need to investigate stellar activity and its influence on habitability of possible planetary companions.

In our solar system, recent results from the MAVEN spacecraft have provided spectacular and persuasive evidence that it was the activity of the young Sun that stripped Mars of its original atmosphere. In addition to low-mass stars, stellar activity of young, solar-type stars may also be a consideration in assessing the current and future habitability of planets. Even though the period of high activity is typically much shorter for solar-
type stars than for low-mass stars; nevertheless, it does cover the era of the formation of a crust, an ocean, and a secondary atmosphere on a planet like Earth.

Complementing studies of stellar activity, research on planetary habitability must also include detection of extrasolar planetary magnetic fields across the entire range of planet masses and ages. There are a variety of potential techniques for detecting and studying planetary magnetic fields, but, guided by the experience in our solar system, the radio emission generated by magnetic, kinetic, and unipolar star-planet interactions is the most promising approach. The unipolar interaction between an unmagnetized object and a magnetized object, for which the Jupiter-Io interaction is the exemplar, could generate radio emission from main sequence stars with orbiting planets, but also from planets around white dwarfs, planets around brown dwarfs, and moons around extrasolar gas giants.

The recognition that radio wavelength observations represent a powerful approach for broadening the study of planetary habitability comes at a time when a new generation of broadband receivers and high time-frequency resolution data acquisition hardware offer unique tools for detailed investigations of the phenomena that are relevant to these topics.

Of course, all the above issues cannot be addressed properly without further theoretical and observational developments in various areas, among which we emphasize magnetic field generation in fully convective stars, stellar magnetic activity, and coronal mass ejection (CME) generation as factors that are crucial for planetary habitability, as are number of related topics.

Radio Exploration of Planetary Habitability was the fifth in the series of American Astronomical Society’s Topical Conference Series designed to explore these topics. The following sections summarize broad themes resulting from the conference and highlights from the sessions.

2. Overview

The week was marked by a number of stimulating presentations and vigorous discussion. In part, this discussion was enabled by a meeting structure in which portions of each session were devoted to open discussion among all participants, led by session chairs. Many participants commented that they found this structure, and the preservation of blocks of time for discussion, to be among the most productive aspects of the meeting, allowing questions and issues to be explored more fully.

In a meeting of this length, it is not possible to summarize all of the results. Presentations from the meeting are available at the AAS Web site. Nonetheless, several themes were apparent.

Both the topic and the participants were highly interdisciplinary. The topic necessarily draws on experience from within the solar system and from multiple extrasolar planetary systems. This in-
terdisciplinary nature presents both opportunities and challenges. The Sun and solar system planets can be studied at much higher time and spatial resolution than can other stars and extrasolar planets. Participants with expertise in heliophysics and planetary science presented multiple examples of physical processes that are witnessed only incompletely in the atmosphere of another star or in the interaction between a stellar wind and a planet’s magnetosphere whereas they can be studied at high resolution in the solar system: in the best case, spacecraft can be sent to solar system planets to provide in situ measurements. Examples might include the lift-off of a CME from the Sun, the impact of a CME on the atmosphere of an unmagnetized planet, or the electromagnetic interactions between Jupiter and its moon Io. There were members of various mission science teams present, and future meetings on this topic and related topics are encouraged to work to include representation from relevant mission science teams.

Conversely, the opportunity of high resolution in the solar system presented an obvious challenge, particularly in communication. When only relatively coarse temporal or spatial resolution is available (e.g., whole-disk averages of a star), detailed models may provide little guidance, and inferences from our particular old and inactive star or even extrapolations to stars of different activity levels, ages, or masses may risk questionable conclusions.

A notable example of the benefit of the interdisciplinary nature of this conference and a potential area for future research concerns the protective nature of planetary magnetic fields. Planetary magnetic fields commonly are taken as a requirement for providing shielding of planetary atmospheres from the solar wind, with the MAVEN observations of a CME’s erosion of the Martian atmosphere taken as a prima facie example. Nonetheless, planetary scientists note that the mass loss from the atmospheres of Venus, Earth, and Mars are approximately equal.

Another common theme was diversity. Extrasolar planetary systems contain planets not present in the solar system (e.g., super-Earths) allowing a broader range of planetary properties to be explored. Moreover, the stellar hosts of these extrasolar planets cover a diverse range of ages, activity levels, and spectral types, allowing a potential exploration of planetary habitability in a manner not accessible in the solar system. In an extreme example, the stars UV Ceti and BL Ceti are a binary and are presumably coeval, yet show dramatically different magnetic field structures and levels of activity. Many participants stressed the importance of being able to construct a more complete understanding of the possible development or evolution of planetary habitability as a result of the study of the various objects.

A prime example of diversity in this conference and an avenue for future research concerns the generation of planetary magnetic fields themselves. In the solar system, vastly different classes of planets appear able to generate and sustain planetary dynamos (terrestrial, ice giant, gas giant). There are clear differences between the characteristics of the magnetic fields of these different classes of planets, which is both suggestive that many extrasolar planets are likely to generate and sustain magnetic fields but also frustrating because the constraints on planetary dynamos are provided currently by only a small number of planets.

Then, there is diversity in the subtleties. From afar, Venus and Earth are sister planets, with nearly equal masses, perhaps similar originally outgassed atmospheres (of carbon dioxide, nitrogen, and water); but they have evolved in largely different directions, one supporting plate tectonics, a strong magnetic dynamo, and a water ocean while the other maintains a stagnant lid, has no dynamo and therefore lacks a magnetosphere while it keeps a dense carbon dioxide atmosphere devoid of water. The challenge to characterize extrasolar planets to this level is obvious, as important as these features may be for habitable environments.

The diversity of the participants themselves was also notable. As previously noted, their intellectual breadth spanned the traditional fields of planetary science, heliophysics, and astrophysics, with many participants knowledgeable in multiple aspects of these fields. Geographically, participants hailed from five continents. There was a deliberate effort to ensure experience and gender balance, with early- and mid-career and senior scientists all present and making presentations; of the 42 total presentations, seventeen were invited and women presented six of these (35%).
The role of star-planet interactions is an area of interdisciplinary research, a representation of the diversity of the field, and an area for future work. The focus of star-planet interactions is often on the effects of the star on the planet; examples include the aforementioned atmospheric erosion and the chemistry of a planet’s atmosphere in response to a star’s illumination (and changes thereof). Many participants noted that these star-planet interactions are likely to change with time, as the star evolves, and the growing number of extrasolar planetary systems allows this process to be studied in more depth and across the spectral and evolutionary sequence of stars.

However, it is increasingly recognized that the planetary effects on the star may also be important. Such processes may no longer be apparent in the solar system (though they may have been important in the early solar system), but they could include interactions between planetary and stellar magnetic fields, leading to changes in the stellar magnetic field, rotation, and potentially even evolution. A related aspect is that there is not a single, unique evolutionary sequence in stellar properties; for example, evolution of a star’s rotation rate may be affected by whether or not it has a close-in planet and whether or not that planet is magnetized; further evolutionary differences likely depend upon the initial rotation period of the host star and its subsequent spin-down due to a dynamo-driven wind.

Finally, multiple participants stressed the importance of moving toward large samples. The Kepler mission is perhaps the exemplar of how large and homogeneous data sets can open new opportunities. Missions such as Gaia and TESS and ground-based surveys (including, but not exclusively limited to, LSST), large data sets and comprehensive statistical analyses should become, and are becoming, the norm, rather than a future aspiration.

3. Stellar Activity and Star-Planet Interactions

This session covered a diversity of topics, ranging from theoretical investigations of dynamo models (both planetary and stellar) to observational constraints that ran the gamut of stellar rotation period measurements to pulsed radio emission. A point emphasized by multiple speakers is that the study of star-planet interactions has a requirement of understanding both the star and the planet. Many talks focused on one or the other of the system to further this understanding. The talks revealed that while much progress has been made in understanding stellar and planetary interactions, there is still much to be learned. The discussion periods were stimulated by thought-provoking comments in the talks.

With the expansion in capabilities over the past decade, the diversity of the magnetic properties of stars is much more apparent, with numerous new developments in understanding summarized. A connection to fundamental stellar parameters does not necessarily result in the ability to completely predict those magnetic properties: stellar twins are not necessarily coronal twins, with the stars UV Ceti and BL Ceti being prime examples. Observational constraints on stellar winds can be determined, but attempts to detect stellar coronal mass ejections directly, using a variety of low radio frequency instrumentation, has not met with success yet.

An emerging bimodality in rotation periods for low-mass stars suggests rapid rotational evolution. The diversity in magnetic topology may indicate bistability in dynamo behavior, a somewhat controversial theoretical idea. Clues from the geodynamo and solar system observations help with the vast parameter space between planets, brown dwarfs, and stars. Some other thought-provoking ideas: a re-examination of the inner bound of the traditionally defined habitable zone may be needed, to account for the impact of the stellar magnetic topology and its creation of severe space weather. Habitable zones for M dwarfs also intersect the zone where star-planet interactions occur, making for likely false positive detections of “habitable” planets.

4. Observations of Stars, Brown Dwarfs, and Exoplanets

This session was focused on observations across the entire mass range of objects. Due to events occurring within both the Cassini and Juno missions, no members from either science team were able to attend, but recent results have highlighted some of the exciting observations from those mis-
sions as they apply to the magnetic fields of gas giants.

Given that energetic particles easily generate radio emission by a variety of processes (synchrotron, gyro-synchrotron, gyrotron, and plasma resonances), and often in concert with magnetic fields, many of the presentations focused on radio wavelength observations. The diversity of radio telescopes available to execute such searches for evidence of planetary magnetic fields or star-planet interactions was apparent, with participants describing observations with established telescopes (Arecibo, Green Bank Telescope [GBT], Very Large Array [JVLA], Very Long Baseline Array [VLBA]) and new telescopes (Long Wavelength Array Owens Valley Radio Observatory [LWA-OVRO], the Low Frequency Array [LOFAR], the Murchison Widefield Array [MWA], the Hydrogen Epoch of Reionization Array [HERA]). In many cases, the search for radio emission from sub-stellar objects was not one of the motivating rationales for the telescope, yet it is becoming clear that these telescopes are well suited for such observations.

Particularly for the new telescopes, large fields of view or significant observing programs or both are feasible, enabling large data sets to be constructed (with either many targets monitored or long time series produced or both). In view of the Sun’s 11 yr activity cycle, the need for a diverse target set and long duration observations is clear.

Radio wavelength observations as part of a multi-wavelength suite of observations was also apparent, with participants describing observing projects motivated by the Kepler results and joint radio-UV or joint radio–X-ray observations motivated by solar observations. To date, the main recent focus for stellar high-energy work has been X-ray observations, but new observational capabilities have led to a renaissance of stellar radio astronomy and its complementary perspective on high-energy phenomena. Combining both X-ray and radio observations in the time domain, it is possible to study the entire sequence of magnetic energy release, from particle acceleration to energy transformation and heating. One signature of this scenario is the so-called Neupert effect of correlated radio and X-ray light curves, which has been discovered in solar observations and has also been found in nearby active stars. With better radio sensitivity, it is now becoming possible to extend such observations to different types of active stars, yielding new constraints on the high-energy irradiation of their vicinities, with potential consequences for habitability.

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REFERENCES

Radio Exploration of Planetary Habitability, AAS Web site, https://aas.org/meetings/aastcs-5

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