Advancing Space Science Requires NASA Support for Coordination Between the Science Mission Directorate Communities

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Abstract. There is a growing awareness within the space science community that cross-disciplinary studies will make the greatest advances toward many major scientific objectives. This requires greater coordination and collaboration between the four communities represented by the Divisions of the NASA Science Mission Directorate. As an example, the Exoplanet Science Strategy (NAS, 2018) specifically points out that such collaboration is needed to advance exoplanet science and calls for a coordinated effort throughout the entire space science community. However, this need for coordination is not limited to the exoplanet community. The impact of space weather on the Earth and the planets in our solar system requires coordination between the Earth Science, Planetary and Heliophysics communities. Efforts to understand our habitable heliosphere in the context of astrospheres observed outside of our solar system requires coordination between the Heliophysics, Astrophysics and Planetary communities. Many professional societies and organizations now recognize this need and are beginning to bring scientists together, primarily in the form of topical workshops and Town Halls. We outline here specific steps that can be taken by NASA and by the space science community to further cross-disciplinary research. However, it is important to note that the only way that this effort can be successful is if it is initiated within NASA and is supported through directed resources provided by NASA to the community.

Motivation

The Exoplanet Science Strategy (NAS, 2018) explains that exoplanet science has been an "avalanche of unexpected discoveries," and outlines how detecting life on an exoplanet "will happen only when researchers bring together the combined insights of astrophysicists, planetary scientists, Earth scientists, and heliophysicists, and provide them the resources to collaborate." Furthermore, one of the main outcomes from the March 2017 NASA-sponsored Planetary Science Vision 2050 (PSV2050) community workshop (https://www.lpi.usra.edu/V2050/) was the recommendation to NASA to "consider cross-cutting opportunities with other divisions" (Mackwell et al., 2017). These findings demonstrate the growing awareness within the space science community that scientific progress is limited by the lack of pathways and resources for coordination among different research communities. Advancing exoplanet science, and space science in general, will require a fundamental change to how the communities listed above interact. This can only be achieved if leadership for this effort comes directly from NASA.

The NASA Headquarters Science Mission Directorate (SMD) is divided into four separate Divisions focused on specific areas of research: Earth Science, Planetary Science, Heliophysics, and Astrophysics. Historically, these Divisions have had limited ability to coordinate resources (e.g. funding, mission observations) for addressing science objectives that cross Divisions. This has resulted in missed opportunities for important discoveries. For example, Planetary missions to distant solar system targets, such as Galileo and Cassini, have historically not planned for measurements in the solar wind that could have made significant advances to Heliophysics science. Notably the novel energetic ion and neutral atom camera (INCA) on Cassini was not encouraged to search for energetic neutral atoms (ENAs) from the edge of the solar system until after the Cassini Jupiter flyby in 2001, which was four years after launch. A full-sky map was published in 2009 (Fig.1; Krimigis et al., 2009), which led to groundbreaking results on the structure of the heliosphere (Dialynas et al. 2017). All of this was done using observations that could have been made while Cassini was enroute to Saturn. Unfortunately, during Cassini's transit to Saturn, a planetary flagship mission was not encouraged to make observations that were intended to address science goals that would be relevant to a Heliospheric Division mission. These types of restrictions continued throughout the mission, and were imposed on objectives that were defined for extended mission proposals.

Additionally, the New Horizons spacecraft instrument payload does not include a magnetometer, which was not vital to the specific targets of the New Horizon mission, but the lack of these measurements of the solar wind, Jupiter's magnetospheric environment and the distant solar system from the New Horizons platform was a missed opportunity that it is hard to overstate. Furthermore, missions to the outer solar system could have contributed to exoplanet science by looking back at the Earth in transit at multiple points during the path outward. Finally, there have historically been many challenges for planetary scientists to make use of Astrophysics flagship missions, including limited support for solar system observation planning tools and difficulty obtaining monitoring campaigns. Significant inroads have been made with Hubble, Spitzer, and even Kepler operations, while JWST has given attention to solar system capabilities during its mission design phase. These lessons learned should be incorporated into the next generation missions from the beginning of the definition and design phases to ensure both adequate capabilities and maximum efficiency in scheduling and operations.

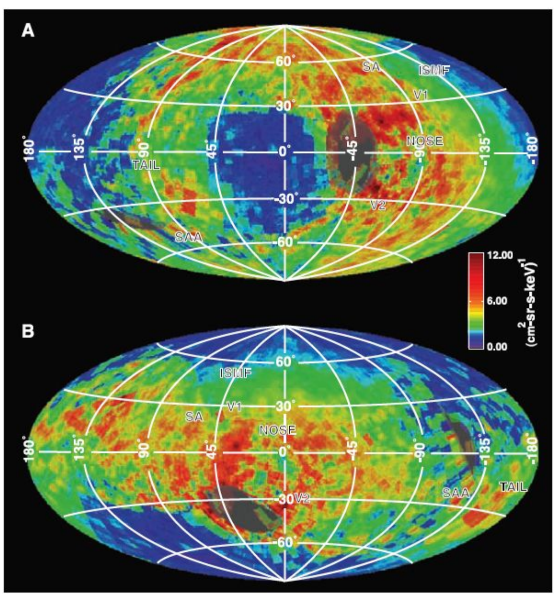

Figure 1 – Groundbreaking all-sky image of the Solar System astrosphere constructed from ENA observations with Cassini INCA 12-years after launch (Fig. 2 of Krimigis et al. 2009).

The need for extensive coordination between NASA Divisions is most obvious and immediate for exoplanet characterization. The exoplanet community is predominantly made up of stellar astrophysicists because their expertise with stellar characteristics is essential for enabling exoplanet detections. However, once detected, characterization of an exoplanet is best achieved via analogy with Solar System objects and requires expertise with understanding in situ Planetary and Heliophysics data in appropriate context (e.g. Robinson et al., 2014; Dalba et al., 2015; Mayorga et al., 2016). Limited understanding of planets in our own solar system that are most relevant to exoplanets, specifically Venus and the Ice Giants, creates a critical knowledge gap for studying exoplanets. The lack of in situ data from Venus makes accurately modeling the atmosphere from the surface to the exobase challenging. Any attempt to model the atmosphere of a Venus-like exoplanet, therefore, poses extreme challenges (see Astro2020 white paper by Kane et al., 2019). Planets in the mass and radius range of the Ice Giants currently represent the largest class of detected exoplanets, but this class of planet is the only one within our Solar System which has not been explored by a dedicated spacecraft mission leaving significant knowledge gaps (see Astro2020 white paper Rymer et al. 2019). Finally, the need to include Heliophysics expertise in exoplanet detection efforts was specifically called out in NAS (2018): "Theorists studying magneto-hydrodynamics, stellar activity, stellar astrophysics, and heliophysics should work closely with EPRV survey teams to model absorption line profiles... This approach should include close collaboration with the solar and stellar astrophysics communities, including theorists, modelers, and observers (Wright & Sigurdsson, 2018)."

Other examples of areas where cross-division coordination would be of high value include evaluating the heliosphere in the context of observations of astrospheres (see Fig. 2). The primary goal of an Interstellar Probe, which is currently being studied for the next Heliophysics decadal survey (McNutt et al., 2019), would be to travel outside of the heliosphere and take in situ measurements of the very local interstellar medium (VLISM; e.g. Frisch et al., 2011). However, such a mission would be studying our heliosphere, which is known to be habitable, as an astrosphere. Success requires coordination between the Astrophysics and Heliophysics communities. Additionally, such a mission would have high value for conducting Planetary science on its way out of the solar system (Mandt et al., 2019). Finally, studies of the Earth's upper atmosphere, which is impacted by both climate change (e.g. Emmert et al., 2004) and space weather (Schunk & Sojka, 1996), would benefit from greater coordination between the Earth Science, Heliophysics, and even the Planetary community. The Earth's mesosphere and thermosphere region is frequently nicknamed the "ignorosphere" because it falls between the areas of focus of the Earth Science and Heliophysics Divisions, and funding to study this region is difficult to obtain. By combining efforts to study the impact of climate change and space weather on the full Earth system, and using comparative planetology, greater progress on understanding the Earth can be made.

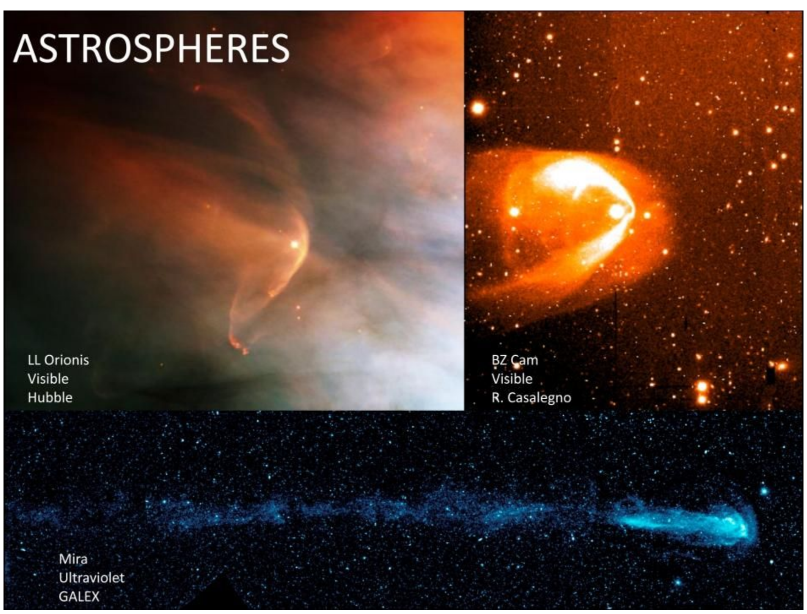

Figure 2 – Images taken of astrospheres, or heliospheres around other stars, by a variety of telescopes. Our heliosphere is known to have a planet that supports life, making it habitable. Since life has not yet been detected on an exoplanet, it is unknown if these astrospheres are also habitable. Studying the habitability of astrospheres requires cross-division coordination (image source: NASA/GSFC).

Furthermore, cross-discipline coordination is important not only within NASA but externally. The Federal Astronomy and Astrophysics Advisory Committee (AAAC) was chartered under the Federal Advisory Committee Act to "assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the National Science Foundation, the

National Aeronautics and Space Administration, and the Department of Energy". The AAAC, however, has only included representatives of each agency's astronomy and astrophysics division. Unlike at NASA where planetary, astronomy and astrophysics, and heliophsyics are separate divisions, both solar and planetary research falls under the purview of NSF's astronomy division. Therefore, representation from the corresponding NASA SMD divisions should be included in AAAC. Several of the facilities managed by the division of astronomical sciences at NSF are multidisciplinary and are used by both planetary and solar researchers. Enabling broad input from these fields a AAAC would facilitate collaboration between ground- and space-based astronomical assets.

Current Efforts

It is important to note that there are already many examples of successful efforts by NASA to coordinate resources across Divisions. One of the best examples is the Nexus for Exoplanet Systems Science (NExSS) research coordination network. This program provides researchers already receiving grants in programs for astrobiology and exoplanets supplemental funding and creates a network for collaborating across Astrophysics and Planetary science disciplines. It is specifically called out in the Exoplanet Science Strategy (NAS, 2018) for its success in advancing interdisciplinary efforts in the search for life outside the solar system. This program is an important step for Research and Analysis (R&A), but does not extend to mission funding. In addition to NExSS, NASA R&A has two cross-division Research Opportunities in Earth and Space Sciences (ROSES) programs that bring together the Astrophysics and Planetary science communities: Exoplanet Research Program (XRP) and Habitable Worlds (HW). Finally, in recognition of the need to extend this approach to space missions, a Heliophysics-funded predecadal study for an Interstellar Probe (McNutt et al., 2018; Mandt et al., 2019) was specifically tasked with reaching out to the Planetary and Astrophysics communities to seek input on a mission design capable of achieving compelling cross-division science goals. Although these efforts are an important beginning, there is more that NASA and the space science community can do.

Recommendations for NASA

There are several steps that NASA could take to advance interdisciplinary research which would advance cross-division space science.

Assign cross-division representatives to the NASA SMD Advisory Committees: The NASA Advisory Committees play a critical role by directly advising Division Directors on strategic decisions being made by NASA, and are important for shaping the future of space science. Providing cross-division representation on all Advisory Committees will provide input needed to advance cross-division coordination.

Request cross-division representatives to serve on decadal survey committees: The decadal surveys are the foundation of future space exploration. In order to enable cross-division coordination it is critical that cross-division discussions are included in the decadal survey process. For example, the next Astrophysics decadal survey committees are now forming and would benefit from having experts in Earth Science, Planetary Science and Heliophysics to provide input on areas where exoplanet characterization and stellar physics could benefit from cross-division coordination.

Additionally, members of the Astrophysics community would enhance the Planetary and Heliophysics decadal surveys by providing input on observations needed within the solar system to advance exoplanet research.

Incorporate cross-division science objectives into active and future missions: The example of the heliophysics science loss because of limitations placed on Cassini, both during transit to Saturn and during mission operations, provides a valuable argument for making changes to current missions. Steps that NASA could make to open up opportunities on active and future missions include:

- Evaluate active directed missions for their cross-division science potential and coordinate funding between Divisions to provide for experts who will work with mission teams to achieve the objectives. The Planetary Science Participating Scientist program is an ideal model for achieving this.
- All future directed mission studies should include an evaluation of cross-division science potential, similar to the effort being made for the Interstellar Probe study and the Large Astrophysics Mission Concept Studies.
- New and extended mission proposals should be encouraged to consider the feasibility of adding cross-division science objectives and report on the results of this evaluation in the relevance section. Any cross-division goals should receive sufficient support from NASA and should not cut into the primary objectives of the mission.
- Consider mechanisms by which multiple science Divisions may support development of new cross-disciplinary strategic mission concepts and contribute funding to their formulation.

Establish additional formal interdisciplinary networks, institutes, and R&A programs: As recommended by the Exoplanet Science Strategy (NAS, 2018), "Building on the NExSS model, NASA should support a cross-divisional exoplanet research coordination network that includes additional membership opportunities via dedicated proposal calls for interdisciplinary research." Coordination networks that focus specifically on other valuable cross-division research would enable focused efforts and advance space science. Pilot programs at NASA Centers (Science Innovation Funds), universities, and research centers have shown the value of interdisciplinary collaborative initiatives to address focused science questions. For exoplanets, areas that would benefit from greater coordination include: atmospheric loss and evolution, magnetospheres, and ocean worlds beyond the solar system. Other areas that would benefit from similar programs include: atmospheric dynamics, ocean worlds, aeronomy, and the study of astrospheres. Although a couple of ROSES R&A programs are listed as cross-disciplinary, reviews have not always been favorable toward all Divisions represented by the program and have limited opportunities for proposers. Dedicated institutes and expanded ROSES R&A programs would enhance these efforts to advance these fields more quickly.

Create opportunities for mission scientists to participate in interdisciplinary networks: For example, the current NExSS program is designed to support researchers working on R&A grants relevant to astrobiology and exoplanets. This approach does not provide an opportunity for researchers who primarily receive funding for work on NASA missions to engage with the network. Scientists working on missions like Cassini, New Horizons, the Europa Clipper, and any potential future missions to Venus and/or the Ice Giants would have valuable input to programs like NExSS. Allowing these scientists funding to participate in established networks would add value to the program.

Fund cross-division meetings between the space science communities: The ROSES Topical Workshops, Symposia, and Conferences is limited to meetings addressing objectives for the Earth Science, Planetary and Heliophysics Divisions and as it is written does not appear to be a useful mechanism for enabling meetings about cross-division research. A separate program focused entirely on workshops that enable cross-division collaboration is needed in future ROSES calls.

Enable broad collaborations between ground- and space-based astronomical assets to facilitate multi- and interdisciplinary research. By including representation from the Planetary and Heliophysics divisions at NASA in AAAC, NASA could improve collaborations with the NSF's division of astronomical sciences because research from these fields falls within the purview of the NSF's division of astronomical sciences and therefore would fall under the committee's charter.

Actively work to eliminate barriers to a socially healthy community: NASA is in the most powerful position to eliminate barriers such as discrimination and harassment that prevent the space science community from being healthy and diverse. This is because much of the discrimination and harassment that seriously harm the community is directly connected to the abuse of power that comes from receiving NASA funding. As stated in the Exoplanet Science Strategy (NAS, 2018): "To maximize scientific potential and opportunities for excellence, institutions and organizations can enable full participation by a diverse workforce by taking concrete steps to eliminate discrimination and harassment and to proactively recruit and retain scientists from underrepresented groups." Furthermore, the synthesis conclusions from the PSV2050 Origins session states: "A diverse, socially healthy, and continually growing workforce within a planetary science field that has programmatic balance will enable fresh ideas that are not limited by thinking that has stagnated." One important step that has been employed by the Space Telescope Science Institute (STScI) is to institute a double-blind peer-review system for Hubble Space Telescope proposals, described in Physics Today as "a first-of-its-kind peer-review process for allocating time on NASA's workhorse space telescope has the potential to level the playing field for women and other marginalized groups in science" (https://physicstoday.scitation.org/do/10.1063/PT.6.3.20190301a/full/). This type of approach represents a valuable first step that NASA could take as the primary funding source for the majority of space science research. In addition to this, NASA has the power to take the lead on eliminating discrimination and harassment by Principal Investigators, Co-Investigators and Project Managers that is enabled by the power these individuals attain by having the opportunity to manage NASA funding. If NASA declines to take the lead on this issue, progress in resolving these problems will be incremental at best.

Recommendations for the Space Science Communities

There are several steps that the space science communities can take that will support and enhance efforts by NASA to enable cross-division coordination.

Inventory community needs: If the NASA Divisions encourage cross-division science goals, community input on defining these goals will be needed. Members of all communities should begin discussions to evaluate which outstanding questions exist within their respective areas that are also needed to advance science for other communities. For example, the Astrophysics and Planetary communities should work together to assess which questions about our own solar system need to be answered to advance exoplanet characterization.

Advocacy for observations that benefit multiple communities: Despite broad relevance, planetary science missions to Venus and the Ice Giants have been pushed to the sidelines by other goals within the Planetary community that have a narrower focus, as, for similar reasons, has any effort to fund a dedicated solar system telescope. This has prevented in situ observations that are needed for advancing exoplanet research. Advocacy from the astrophysics community in support of Venus and Ice Giants missions and a solar system telescope is needed to raise the priority of these missions within the overall science community. The same can be said for an Interstellar Probe, which would focus on Heliophysics science, but could also be used to benefit Planetary and Astrophysics research.

Actively work to eliminate barriers to a socially healthy community: As stated in the recommendations to NASA, the Exoplanet Science Strategy (NAS, 2018) points out that discrimination and harassment serve as barriers to the participation of critical talent in the future of exoplanet science. The space science community as a whole needs to take action to eliminate these barriers. The most direct action that every member of the community can take is to attend Bystander Intervention training, now offered at many science conferences, and implement the methods included in that training. Additionally, the community can advocate that NASA and leading institutions within the space science community take action to eliminate discrimination and harassment in space science.

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