Why and How to Increase Cross-Divisional Opportunities

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The Case for Cross-Divisional Science

Robotic space exploration, especially to far reaches of the solar system, is by its very nature difficult and expensive. As such, it behooves the entire space science community to work collaboratively to maximize the scientific return of missions, regardless of the primary funding Division. In the future, NASA should offer increased support and more opportunities enabling cross-Divisional science.

Perhaps the greatest example of cross-Divisional science from a past mission comes from the *Voyager* mission, which was designed to conduct a grand tour of the outer Solar System and rendezvous with all four of the Giant planets on its journey to the edge of the heliosphere, providing some of the first direct glimpses of the other worlds in our solar system. Since both *Voyager* spacecraft were already outfitted with the necessary in-situ instrumentation, their outbound trajectories also presented a unique opportunity for the Heliophysics and Astrophysics communities: a chance to sample the outer limits of the solar system and its interface with the interstellar medium for the first time. Thus, in Jan 1990, the *Voyager Mission* ended and the *Voyager Interstellar Mission* officially began. These intrepid explorers yet again boldly went where no spacecraft had gone before, becoming humanity's first interstellar explorers and providing our species' first (and to-date only) in-situ observations of our solar system's termination shock, heliopause, heliosheath, and local interstellar medium.

There are many other missions that undertook cross-Divisional science via serendipitous opportunities or as afterthoughts. A notable example comes in the form of energetic neutral atom (ENA) imaging. Such imaging of the heliospheric boundary came from an unlikely source: the INCA instrument on the *Cassini* spacecraft en route to Saturn. Though designed and proposed to investigate Saturn's magnetosphere, during its cruise to Saturn, INCA obtained images of the heliospheric boundary at previously unmeasured energies. The INCA observations provided evidence that the heliosphere is closed (i.e., a "bubble"), which directly contradicted initial conclusions from IBEX that the heliosphere is open (i.e., has a comet-like tail).

Flybys have also provided opportunities for cross-Divisional observations over the years. *Cassini* flybys of Earth provided unique measurements, including resolution of a low energy beam in the plasmasheet and magnetospheric populations as far away as 6,000 R_E downtail. Most recently, the *Parker Solar Probe* mission completed several of its planned flybys of Venus, as it drives its perihelion ever further into the Sun's corona, enabling investigations of the Venusian bow shock, pick-up ions, and potential whistler waves from lightning at Venus. Likewise, the *Ulysses* flyby of Jupiter accessed previously un-investigated regions of the Jovian magnetosphere, including higher magnetospheric latitudes, the dusk sector, and inner magnetosphere, and revealed evidence of volcanic activity on Io.

Finally, long cruise durations to outer solar system planetary targets often provide many opportunities to acquire additional observations, like the previously-discussed heliospheric ENA images from *Cassini*, *in-situ* studies of the solar wind and the evolution of solar wind transients beyond 1 AU, and remote UV observations of interplanetary hydrogen.

Potential Future Targets

Below are two outer solar system science targets that are of great interest to the space physics community and provide prime opportunities for initiating cross-Divisional missions and investigations by 2050. These are of course not the only avenues for studying solar wind-magnetosphere interactions, magnetospheric dynamics, magnetosphere-ionosphere coupling. and moon-magnetosphere interactions, but are representative and focus on exotic laboratories in our solar system.

The Ice Giant Magnetospheres: The Ice Giants (Uranus and Neptune) are the least explored and least well-understood planets in our solar system and leave a gaping hole in the completeness of our survey of potential magnetospheric regimes, as underscored by the 2013 Decadal Survey Panel on Solar Wind-Magnetosphere Interactions:

> *"[It is] essential that NASA's Heliophysics Division partner with the Planetary Division to ensure that appropriate magnetospheric instrumentation be fielded on missions to other planets. In particular, the SWMI panel's highest priority in planetary magnetospheres is a mission to orbit Uranus."*

In addition to addressing fundamental magnetospheric, solar wind-magnetosphere interaction, and magnetosphere-ionosphere coupling questions of interest to the space physics community, a long cruise to either Ice Giant would also provide an opportunity to study the evolution of the solar wind, acceleration processes, and interplanetary shocks at large heliospheric distances. Additional ENA images of the heliospheric boundary from the outermost regions of the solar system, like *Cassini*, in concert with those at Jupiter and/or Earth, could provide 3D mapping of the heliospheric boundary that might provide important constraints in the debate over the heliosphere's shape.

Jupiter's Radiation Belts: New insight and understanding enabled by the *Van Allen Probes* mission drastically shifted the paradigm for Earth's radiation belts. We know now that outer radiation belt electrons up to ~8 MeV are produced by a combination of local acceleration of an injected seed population of 10s to ~300 keV electrons by whistler-mode chorus waves and inward radial diffusion from the heart of the outer belt after enhancement events. We also now know that the inner radiation belt electrons surprisingly appear to exist only up to ~1 MeV and that the two-belt structure for those ≤1 MeV electrons is not uniform or stable, but highly energy-dependent and sporadically flooded with 100s of keV electrons via injection processes that remain poorly understood.

The Jovian system has the strongest radiation belts in the solar system, including high-intensity populations of several 10s of MeV electrons, and also many of the same plasma wave modes known to be critical for shaping Earth's radiation belts. Discovering the nature of such extremely efficient acceleration of relativistic electrons will greatly advance our understanding of processes that drive particle acceleration throughout the universe, such as at Giant planets and possible exoplanetary magnetospheres, and the production of cosmic rays in astrophysical objects and events. To enable such discoveries, a dedicated mission specifically designed to study Jupiter's radiation belts, the greatest particle accelerator in the solar system, is needed.

The Heliophysics Division (HPD) could fund the development and instrumentation of a small satellite to be delivered to Jupiter as a secondary payload via rideshare on the same launch vehicle as a future planetary science-focused mission to Jupiter funded by the Planetary Science Division (PSD).

Enabling Cross-Divisional Heliophysics

While such a cogent collection of successes could make the achievement of cross-Divisional science seem routine or easily achievable, they are indeed rare, and there are significant challenges to realizing such science opportunities. The current funding structure within NASA is one such challenge to cross-Divisional science, although recent efforts within the HPD and other Divisions suggest that such impediments may be weakening. There are several approaches that NASA and the broad scientific community can adopt to create and successfully capitalize on more cross-Divisional science opportunities in the future. First, healthy communication, both across focused scientific communities and vertically between the leadership and staff at the respective space agencies and NASA Divisions, can be increasingly facilitated and encouraged. In practice, this includes active advocacy for cross-Divisional opportunities and investigations across the scientific communities; this includes white papers to the respective Decadal Surveys, and proposals for cross-disciplinary science investigations that leverage the existing infrastructure for funding (e.g., technology demonstration opportunities, rideshares, missions of opportunity, etc.). Most importantly, cross-Divisional science opportunities need to be *identified early on* and purposefully planned with adequate support provided by *each* of the NASA Divisions with vested interest in an upcoming mission or program. This advanced, detailed planning and support should be implemented whenever feasible while remaining cognizant of the current fiscal realities. Many previous opportunities were not even conceived of until after mission launch. Early identification, support, and planning should even enable multiple spacecraft to be delivered to planetary systems of interest using rideshare opportunities. Cross-divisional opportunities conceived early on will undoubtedly yield increased and optimized science return from all future missions and programs to the benefit of multiple NASA Divisions.

The framework necessary to enable more cross-Divisional collaborations may already exist, and should be further utilized where possible. Intentional collaborations between the HPD and other Divisions on future missions throughout the solar system should be undertaken, the same way that mission partnerships are forged with other space agencies, like ESA and JAXA, with the Divisions either jointly funding the mission, independently selecting and funding investigations for the mission, and/or hosting payloads or secondary payloads/rideshares on missions funded by either Division. Of course, “hosting” instruments or payloads on missions can give rise to its own risks and challenges, especially if the instrument would be manifested on the primary spacecraft itself; this would also be very difficult for the competitive PI-led Discovery and New Frontiers programs in PSD. However, if planned and supported early in the development of new programs and missions, appropriate requirements can be defined such that future AOs can explicitly allow for and encourage cross-Divisional Science Enhancement or Technology Demonstration Opportunities (TDO) and/or hosted or standalone Missions of Opportunity (MoOs). For example, the *Trident* flyby mission of Neptune’s moon Triton currently being considered for the Discovery program, has excess mass and may provide the only access to the Neptune system for a generation – the ability to provide an additional space physics instrument, like an ENA imager or energetic particle sensor, would be incredibly beneficial to both the HPD and PSD. It should be possible for one Division (e.g., HSD) to offer funding to support a TDO or MoO attached to a prime mission supported by another Division (e.g., PSD). Likewise, HPD could augment PSD missions with additional funding to provide heliospheric measurements during long interplanetary cruise phases.

Another option could be to allow for larger cost caps for opportunities, such as MoOs, Explorers, and other programs, depending on their target. For example, something like the PSD SIMPLEX program, which allows for small-satellite-focused missions to other planets, with focus on solar and space physics science objectives could be envisioned to enable Heliophysics science in intentionally-planned cross-Divisional efforts.

The devil is of course in the details for how this can be implemented, especially given timelines, schedules, costs, and risks that must be considered, but the potential scientific rewards surely justify the effort to try to implement such efforts by 2050.