Communications Enabling Science from the 2050 Heliophysics System Observatory

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The difficulties associated with receiving telemetry from satellites severely limits the volume of scientific data that can be downlinked to scientists on the ground. Current missions must employ many techniques to reduce the data they transmit, such as compressing and pruning datasets, to meet the current restrictions of limited telemetry budgets. Yet future Heliophysics System Observatory missions will produce ever larger data volumes with higher resolution and cadence observations from constellations of satellites spread throughout the heliosphere¹. In addition, heliophysics missions often produce data for the Space Weather community that requires a low latency between observation and downlink. In light of current limitations, the infrastructure to receive NASA satellite telemetry must be expanded and modernized to support future science needs and the data-rich missions of the 2050 Heliophysics System Observatory.

The current communications landscape:
Communications with NASA science missions are primarily routed through the Deep Space Network (DSN), Near Earth Network (NEN), and Space Network (SN) using S, X, and Ka band radio transmissions. The DSN consists of three ground stations with a few large antennas separated by 120° near the equator and is primarily used for communicating with missions beyond lunar orbit. The NEN encompasses a number of ground stations with smaller antennas over a wide range of longitudes and latitudes. The SN is composed of the Tracking Data Relay Satellite constellation in geosynchronous orbit with two ground stations. Both the NEN and SN are primarily used to communicate with satellites near Earth.

The different capabilities of these networks lead to unique communication difficulties. A low- to mid-latitude Low Earth Orbit satellite may only have a line of sight to a NEN ground station once per day for a 10 minute pass, necessitating rapid data transfer. A mission far from the Earth may be able to view a DSN station for hours each day, but must compete with other satellites for downlink time. This leads to reductions in data volumes² that can be downlinked and delays in when those data reach the ground.

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¹ See for example the recent Medium-Class Explorer missions selected for concept studies
² In addition, as the distance to a spacecraft increases the downlink rate tends to drop, increasing the time necessary to transmit the same data for satellites at larger distances.
It is this relative sparsity of downlink time (utilizing any network) that causes science data to be pruned and compressed before they are transmitted to the ground. Scientists must select for transmission only the data that are most likely to satisfy their science goals. This slows down discovery by taking time and resources away from science investigations and creating unintended biases towards preferred phenomena. **To further our understanding of underlying physics requires complete in situ and remote sensing data sets to be delivered in larger volumes than ever before. To further our capability to predict space weather impacts requires these data to be delivered with low latency.**

**Mission case studies:**
The Magnetospheric Multiscale (MMS) Mission studies the plasma, particle, and field conditions throughout the Earth's magnetosphere. Due to its relatively close proximity to Earth, MMS communicates through all three NASA networks, but only downlinks data using the DSN. Over the life of the mission, only about 4% of the high resolution burst mode data has been downloaded, with the rest deleted to make room for new data. The selection of which data to downlink is often performed by (particularly early career) volunteers and takes valuable time that could be used studying those same data.

The Parker Solar Probe (PSP) studies the young solar wind and inner heliosphere in a highly eccentric heliocentric orbit. Because of its large distance from the Earth, PSP communicates with Earth exclusively through the DSN. The SWEAP instrument onboard PSP records data at ~0.2s temporal resolution but only initially downlinks survey-mode data with 7s resolution. It is then up to operators to determine which high resolution data to downlink. Due to the nature of PSP's orbit, the decision about which burst-mode data to downlink from a month-long orbit must be made quickly, occasionally within only a few days.

One strategy used to avoid limitations with data retrieval was the construction of a dedicated downlink station for the Solar Dynamics Observatory (SDO). This design choice enables SDO to collect and downlink well over a terabyte of compressed science data daily. The price for this capability was ~2.5% of the mission cost and ~5-10% of its annual operating budget. This may not be feasible for every heliophysics mission, but it demonstrates that it is possible to design missions with 100% science data retrieval, even with extreme data volumes, at a modest expense.

**Supporting the DSN:**
Accommodating the data requirements of future missions while maintaining the strong science output from existing missions will require deliberate attention and support toward improving existing data transfer capabilities. In particular, as there is an increasing need for heliophysics observatories to move throughout the heliosphere\(^3\), they will increasingly rely on the DSN for their communication needs. The heliophysics community should coordinate with other DSN

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\(^3\) See submitted white papers “**The Need for Consistent, Comprehensive Inner Heliosphere Data**” by Mason et al. and “**Multi-vantage-point solar and heliospheric observations to advance physical understanding of the corona and solar wind**” by Arge et al.
users\(^4\) to support DSN operations and advocate for the necessary upgrades that would expand current downlink capabilities to accommodate future solar and heliospheric missions. This should include evaluations of the scientific return of direct funding to DSN upgrades compared with mission development. For example, the DSN Aperture Enhancement Program proposed in 2009 planned to add six new 34-meter receivers and 80 kW high power transmitters (combined with planned decommissioning to yield an increased capacity of at least 30%) by 2025 for a total of $362.4 million, about the cost of a single Medium-Class Explorer mission. However, this expansion is behind schedule, and today there are fewer operational receivers than in 2014.

**Embracing new technologies:**
Future heliophysics missions should also explore alternate communication modalities and technologies to increase data return capacity. One way in which this could be accomplished is through networked communications architectures, such as the proposed LunaNet, enabling indirect ground communication. This could enable heliophysics science from unique perspectives (such as the L3 point behind the Sun from the Earth’s perspective) and with improved reliability, latency, and bandwidth by providing alternate data transmission pathways. These missions should also explore novel technology to increase bandwidths for data transmission. One promising example is optical laser communications. This technology has successfully been demonstrated numerous times for both up- and down-link in near-Earth and cis-lunar environments and will fly in deep space on the upcoming Psyche mission, where it is expected to provide 10 to 100 times increased bandwidth over traditional radio communications. Within the Heliophysics Systems Observatory, the SETH mission to investigate energetic neutral atoms in the solar wind that was recently funded for a nine month concept study would utilize a commercially available 2U laser communication module to enable 10 Mbps downlinks over distance greater than 0.1 AU.

**Recommendations:**
To enable Heliophysics science in 2050, it is essential that NASA ensures the accessibility of science data returned from future Heliophysics System Observatory missions by advocating for and investing in existing communications infrastructure and embracing the communications technologies of the future.

\(^4\) NASA Planetary Science and Astrophysics Divisions. Also, potentially Human Exploration Division with the impending return of human cis-lunar operations through the Artemis program.