Heliophysics 2050 Workshop Preceding

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Heliophysics 2050 Science Organizing Committee

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Overview

The Heliophysics 2050 Workshop is an event supported by NASA, NSF, and NOAA ahead of the next Solar and Space Physics Decadal Survey convened to enable conversations that will provide a common basis in preparation for the Decadal process. This community-led workshop will bring together diverse perspectives as we envision and embark on a multi-decadal strategy to advance heliophysics and identify near-term investigations to enable and inform future investigations. The workshop will be held virtually from May 3 to May 7, 2021.

The Science Organizing Committee (SOC) worked together to identify themes contained within and complementary to the white papers submitted for the workshop, and then constructed the following program around those themes. In the spirit of stimulating discussions among the community, all white paper submitters are encouraged to create and upload a full-length video presenting their white papers for the video gallery. During the five-day workshop, twelve oral sessions, including seven sub-disciplinary sessions and five special sessions focusing on cross-disciplinary fundamental physical processes, will be hosted to facilitate community discussions and Q&A. The theme of each oral session is described below. In addition, there will be a virtual poster session following each sub-disciplinary session to facilitate more focused and deeper discussions.

Registration for the workshop is free but required.

Day 1:

Oral Session 1: Solar interior, dynamo, and surface properties

Moderators: Sabrina Savage/Mark Linton

The key to understanding the dynamics of the solar system lies within its source -- the solar dynamo. While great strides have been made in probing the structure and variability of the solar interior in the past several decades, many questions remain regarding the ultimate drivers of solar activity emanating from flows deep within the convection zone and regulated by the Sun's vast magnetic field network. In order to realize significant progress towards understanding the fundamental drivers of the solar activity and the solar cycle that will bring about crucial advancements in our understanding of the Sun as our nearest stellar companion and its influences throughout the solar system at large by 2050, observations and investigations of the emergence and dynamics of the Sun's photospheric magnetic fields need to be broadened.

The interconnected, cross-scale solar magnetic system is a paramount input for driving atmospheric and activity cycle models, highlighting the need for expanded long-baseline, contextual synoptic campaigns. The necessity for direct polar measurements has become abundantly clear, as evidenced through revolutionary observations of the poles of both Jupiter and Saturn. Azimuthal variations and flux transport over the course of multiple solar cycles are key elements to unraveling the solar dynamo, and measurements of the polar fields, longitudinal flows, helioseismic imaging, and vector photospheric flow maps are vital components toward ensuring progress.

Understanding the local structure and evolution of photospheric magnetic fields are critical for understanding solar activity, namely, active region formation and evolution, chromospheric and coronal heating, and flare and coronal mass ejection energization. Multiple vantage points across the ecliptic plane are essential for tomographic reconstruction of the true orientation of these magnetic fields.

Other probes of diagnostic solar properties, particularly through broad-spectrum irradiance measurements and high-temperature spectroscopy, offer rewarding pathways to understanding global physical processes. Irradiance observations provide a simple, low-resolution link between variability in bulk plasma properties during quiet and active Sun in relation to the solar cycle and can be used as a straightforward comparison to other stars. Current irradiance measurements are spectrally limited and should be expanded to higher temperatures. Combining such investigations with high-temperature, high-resolution spectroscopy, particularly in the largely unexplored soft

X-ray regime, could revolutionize our understanding of heating near the solar surface, which energizes the Sun's atmospheric layers.

Many questions remain regarding the source of the Sun's activity cycle and the resultant global surface properties. This session aims to capture these questions and to set goals for making progress in the coming decades toward predicting activity as well as advancing our understanding of the fundamental physical processes driven directly by the solar dynamo.

Oral Session 2: Solar corona and inner heliosphere

Moderators: Noé Lugaz/Amir Caspi

The solar corona and inner heliosphere are the regions that connect the solar surface to Earth's and planetary magnetospheres and that mediate the mass, energy, and magnetic field transfer and coupling between the Sun and geospace. In the past few decades, the space science community has been moving towards a more holistic consideration of heliophysics, where interplanetary space is a key region for this coupling. To advance this goal, further concerted efforts to bridge different subcommunities in terms of observations, simulations, data access, missions, and foci are needed.

The solar dynamo and solar magnetism (Session 1) give rise to both the global and local magnetic structures of the corona and interplanetary space, which are key for transporting energetic particles, driving the solar wind, generating, channeling, and affecting solar eruptions, and creating corotating interaction regions. Progress to understand the time-dependent, three-dimensional, and non-potential natures of coronal and interplanetary magnetic fields are still needed. Solar eruptive events (from small-scale spicules and jets to large-scale flares and coronal mass ejections, CMEs) further connect the solar surface to the interplanetary space through energy, magnetic field, and mass coupling, with the low and middle corona being key regions where peak CME acceleration is reached and where acceleration of energetic particles is most efficient.

Key science questions include the 1) force balance of eruptive magnetic structures at different distances, 2) the locations where the evolution of the solar wind and of eruptions transitions from magnetically dominated to primarily hydrodynamical, and 3) the partition of energy between its thermal, kinetic, and magnetic components, including energy carried out by energetic ions and electrons. Further out, interactions between coronal and interplanetary structures mediate the mass and energy transfer and the transport of energetic particles. The peak CME speed is typically reached close to the boundary between the corona and the heliosphere, as defined by the region where the solar wind becomes super-Alfvénic ("the Alfvén surface," a region to be explored soon by PSP). While some progress has been made towards understanding the large-scale evolution and variation of transients in general, the moderate-scale is still largely unexplored and the physical causes and drivers of event-to-event variability are still unknown. In addition, the formation and properties of CME-driven shocks and sheath regions is an area where progress remains relatively elusive.

Fundamental Physical Process 1: Wave-particle interactions

Moderators: Larry Kepko/Merav Opher

Wave-particle interactions are fundamental processes that mediate the transfer of energy throughout all regions of the heliosphere. For example, when particle velocity distributions deviate enough away from local thermodynamic equilibrium, their free energy can be tapped to generate waves. On the other hand, waves can distribute energy to particles and subsequently lead to plasma heating. The direction of energy flow is often inferred, but not definitively proven.

This session will address the "chicken or the egg" problem in multiple heliospheric contexts and identify steps toward solving it.

Poster Session 1: The Sun and inner heliosphere

Session chair: Amir Caspi/Mark Linton

Day 2:

Oral Session 3: Magnetosphere

Moderators: Larry Kepko/Li-Jen Chen

This session encourages the magnetospheric community to consider how to raze our discipline boxes and consider the magnetosphere as a complex, inter-connected, multiscale system.

At the smallest scale, kinetic physics dominates the motions and effects of individual particles. Dynamics in this regime include thin current sheets and magnetic reconnection, wave-particle interactions, kinetic plasma instabilities, and particle acceleration. The largest scales are defined by the magnetospheric regions and boundaries, including the magnetotail, the ring current, radiation belts and plasmasphere, and the magnetopause. In between lie 'mesoscales,' including such features as bursty bulk flows (BBFs), flux transfer events (FTEs), Kelvin-Helmholtz vortices, and plasmaspheric plumes. This intermediate scale serves as the conduit for mass and energy flow, linking the bi-directional feedback between micro and macro. While tremendous progress has been made in understanding the dynamics of Earth's magnetosphere, this understanding is often focused on particular macroscale regions and/or on small spatial scales as the large volume of geospace has historically forced optimizing for high resolution or large area, but not both. In particular, the multiscale feedback between the micro and macro regime is undersampled and under-simulated, and important science questions remain.

Mass and energy enter the magnetosphere from the solar wind primarily through magnetic reconnection at the dayside magnetopause. Fundamental questions regarding the spatio-temporal scales of dayside reconnection and how they may be regulated by the ionosphere conductivity and mass loading stand open. Magnetic flux and mass is transported through reconnection to the nightside magnetosphere, and the accumulated energy drives the majority of magnetospheric dynamics through explosive magnetospheric substorms and the longer-duration geomagnetic storms by forming the ring current. The processes and effects of the energy release produce morphological changes throughout the magnetosphere and the conjugate ionosphere, such as tail flow bursts, subauroral polarization streams, structured plasmasphere boundary layer, excitation of various types of plasma waves, and energizing and populating the magnetosphere via ionospheric heavy ions. This session welcomes concepts and ideas that identify the science questions that need to be answered to advance our understanding of the magnetosphere as a system.

Oral Session 4: Ionosphere-Thermosphere-Mesosphere

Moderators: Shasha Zou/Larry Paxton

The terrestrial ionosphere marks the inner edge of a sea of plasmas in our universe. It is electromagnetically connected to the magnetosphere and solar wind, i.e., driven from above, and is collisionally coupled to the thermosphere and, consequently, is driven from below as well. The coupled ionosphere-thermosphere (IT) system is directly driven by Poynting flux and energetic particles from above in the high-latitude region and is also affected by planetary and gravity waves as well as tides from the middle and lower atmosphere below. The modified IT system also feeds back to the magnetosphere through changing conductivity, altering closure currents, and supplying ionospheric heavy ions to the magnetosphere, which in turn affects magnetospheric dynamics such as reconnection rate and ring current evolution.

However, characterizing and quantifying the dynamic coupling and feedback in this regime is very challenging. Multiple white papers have emphasized the necessity of 3D regional and/or global heterogeneous observational networks to measure comprehensive physical parameters. The proximity of the terrestrial ITM system enables us to use diverse measurement techniques (in situ vs. remote sensing, ground- vs. space-based) to probe this highly coupled regime as a natural laboratory to study universal phenomena, such as plasma-neutral interactions. Knowledge gained in the terrestrial ITM system will be extremely valuable for our exploration of the planetary and exo-planetary environments.

This session provides the platform for the community to discuss these grand challenges, envision innovative solutions, and outline our path forward towards 2050.

Fundamental Physical Process 2: Magnetic reconnection

Moderators: Li-Jen Chen/Mark Linton

Magnetic reconnection underlies the explosive energy release in solar flares, coronal mass ejections, geomagnetic storms, and substorms – it is an engine behind space weather. It drives large-scale energy, mass, and momentum transport both in the corona and in planetary magnetospheres. Reconnection impacts not only large-scale but also meso- and small-scale dynamics. In regions where reconnection occurs or within the reach of its outflows, plasma conditions are strongly driven, giving rise to new regimes of wave generation and wave-particle interaction. Reconnection has been found to be ubiquitous in the solar corona, from small-scale Ellerman bombs up to large scale CMEs; in the solar wind at the heliospheric current sheet; at the bow shock and magnetosheath, where it presents pathways for energy to cascade from large-scale forcing to ion- and electron-scale dissipation; and at the heliopause and the heliosheath sector region.

The session invites ideas and visions that will push the research frontier of reconnection as well as its interplay with shock physics, turbulence, and wave-particle interaction.

Poster Session 2: The near-Earth space environment

Session chair: Larry Kepko/Larry Paxton

Day 3:

Oral Session 5: Space weather (Basics & Applied Research, Operations, & Human Exploration)

Moderators: Noé Lugaz/Larry Kepko

Space weather is the variation of the plasma, neutral, and electromagnetic environment in interplanetary and geospace, on time-scales of days and shorter, that can affect humans, their activities, and associated technologies. "Technology" is considered in the broadest sense so as to encompass the operations and survivability of satellites, spacecraft and aviation, human and robotic exploration (particularly safety), the impact of electromagnetic fields and currents on infrastructure (e.g., ground induced currents and the power grid, pipelines, and rails), and the impact of the space environment on signal propagation (e.g., GNSS signals, communications, radars, etc).

Near-Earth space is a natural laboratory enabling us to carry out and validate basic and applied research that is applicable at and en route to other planetary environments (e.g., Mars), the Moon, and cis-lunar space. Understanding space weather enables us to operate in and explore space with assurity.

Contributed white papers identified several gaps in our understanding. These gaps range from understanding the forcing of the coupled IT system at the 'bottom' of space to the ability to predict the orientation of the solar wind magnetic field (particularly the southern component, Bz), as well as predicting the occurrences of solar flares, CMEs, and CIRs, and their propagation trajectories.

This session will bring together the range of heliophysics expertise to identify the gaps in our knowledge and the approach to closing those gaps, with particular attention paid to identifying the practical implications of such closure. The session will work to develop a compelling statement and vision delineating how lessons learned in the near-term will impact capabilities in 2050.

Oral Session 6: Outer heliosphere & local interstellar medium

Moderators: Merav Opher/Amir Caspi

As the Sun moves through the interstellar medium it carves a bubble called the heliosphere. A fortunate confluence of missions has provided a treasury of data that will likely not be repeated for decades. The measurements in-situ by the Voyager and New Horizon spacecraft, combined with the all-sky ENA images of the heliospheric boundary region by the Interstellar Boundary Explorer (IBEX) and CASSINI missions have transformed our understanding of the heliosphere. However, many fundamental features of the heliosphere are still not well understood. These aspects include the basic "shape" of the heliosphere, the extent of its tail, the nature of the heliosheath, and the structure of the local interstellar medium (LISM) just upstream of the heliopause (HP). Other remaining puzzles are: 1) The acceleration region and mechanism for anomalous cosmic rays (ACRs); the two Voyager spacecraft found no evidence of acceleration of high-energy ACRs at the termination shock (TS) but instead detected their increase of the ACRs as they moved across the heliosheath (HS). 2) The HS 30-50% thinner than current models predict 3) the plasma flows and energetic particles intensities are drastically different at V1 and V2. At V1 there is a stagnation region where there is no radial flow for 8 AU in front of the HP, while at V2 the radial speeds remain high until very close to the HP. 4) The magnetic field direction doesn't change at the HP and we don't know how far from the HP does the solar wind influence extend. 5) The significant increase in Galactic Cosmic Rays (GCRs) just prior to the HP crossings by both V1 and V2, and the unusual anisotropies observed in the LISM are not understood.

The ENA observations add to the list of puzzles. IBEX detected a global feature, the ribbon, that seems to be organized by the interstellar magnetic field. INCA on CASSINI measured a similar, but broader feature at higher energies. The source of these features is controversial; the models proposed to explain these features rely on assumptions for the interstellar conditions such as the draping of the interstellar magnetic field and the level of turbulence in the LISM.

Contributed white papers identified several gaps in our understanding. To date, our best large-scale computer models fail to reproduce critical observations, such as the size of the heliosphere, the plasma speeds and directions, and the width of the heliosheath.

Heliospheric observations indicate that processes such as turbulence, reconnection, wave-particle interactions and thermal conduction play a crucial role in the outer layers of the solar system; however, these processes have not yet been included in current global models. Observations by Voyager indicate that suprathermal particles, such as pickup ions (PUIs, ionized particles formed from the interaction of the ionized solar wind with the neutral interstellar H atoms), carry most of the plasma pressure in outer layers of the solar system. How these suprathermal populations evolve in response to kinetic effects, such as turbulence, reconnection and acceleration, is poorly understood, but given their energy contribution, they significantly impact global scales.

Fundamental Physical Process 3: Turbulence

Moderators: Jaye Verniero/Li-Jen Chen

Plasma turbulence is a universal phenomenon in which energy cascades from large to small spatial scales, and eventually dissipates into heat or particle energization. Understanding the dissipation and cascade, especially the transition from the inertial to the dissipation regime, represents a multi-decade outstanding problem in heliophysics and beyond.

This session welcomes ideas to identify major gaps hindering progress and suggest approaches moving forward for the next 40 years.

Poster Session 3: Space weather and outer heliosphere & local interstellar medium

Session chair: Noé Lugaz/Ian Cohen

Day 4:

Fundamental Physical Process 4: Plasma-neutral interactions

Moderators: Shasha Zou/Mark Linton

One of the fundamental questions in heliophysics is how the different types of matter interact to shape space and planetary environments. Plasma-neutral interactions are universal processes that describe the dynamic interactions between ionized plasma and neutral particles that lead to the transfer of charge, momentum, and energy between these two different types of matter. These processes are critical in a broad range of areas in the universe, such as heating in the solar chromosphere, energetics in the terrestrial ionosphere/thermosphere, solar wind interaction with planetary/cometary ionopause and interstellar medium and planetary atmospheric escape.

Fundamental Physical Process 5: Shock physics

Moderators: Jaye Verniero /Li-Jen Chen

Collisionless shocks are effective particle accelerators and turbulence generators. Shocks dissipate energy in supersonic flows into heat and particle acceleration, and in the process, trigger instabilities and generate wave fluctuations covering ion to electron scales. Planetary bow shocks and interplanetary shocks impact magnetospheres. The termination shock, the largest shock in the heliosphere, also brought us surprises as to not accelerating the expected anomalous cosmic rays. There are several suggestions that perhaps turbulence plays a critical role in shock acceleration. This session solicits ideas and thrusts on fundamental questions of shock dissipation and particle acceleration, as well as how shock processes stir up disturbances that influence magnetospheres.

Oral Session 7: Expanding the Frontiers of Heliophysics (Planetary Magnetospheres / Habitability / Exoplanets / the Sun-as-a-Star)

Moderators: Larry Paxton/Ian Cohen/Amir Caspi/Merav Opher

Building on the resounding successes of the Heliophysics community, the time is ripe to definitively expand the frontiers of Heliophysics research into realms that would have bi-lateral benefit from interdisciplinary exchange of knowledge. Our local solar and planetary system provides us with a laboratory with which to understand fundamental processes occurring throughout the universe. Conversely, external astrophysical sources provide unique opportunities to utilize statistical measurements to help resolve key questions about our own system that would otherwise be unattainable. Rapid technological and observational advancements in the fields of Heliophysics, Earth Science, Astrophysics, and Planetary Science have cleared the path for fostering innovation and growth in such cross-collaborative frameworks.

Opportunities now exist to use stellar-source solar analogs to explore Sun-like behaviors through meaningful statistical studies characterizing parameters such as magnetism and activity evolution. Likewise, exploring the processes at work within the diverse planetary systems within our own solar system will provide important tests for our understanding of planetary magnetospheric dynamics and establish bounds on the diversity of processes that could be expected from exoplanetary systems. Planetary habitability studies could greatly benefit from examining the variability in broad-spectrum irradiance of the Sun and solar analogs as well as from cross-comparisons of the evolution of the heliospheric boundary structure with that of astrospheres around exoplanets. The heliosphere is an immense shield that protects the solar system from harsh, galactic radiation. This radiation affects not only life on Earth, but human space exploration as well. The heliosphere is a template for all other astrospheres, enabling predictions about the conditions necessary to create habitable planets.

Even within our own system, applying knowledge gained from space weather studies of the other planets and related objects could resolve ambiguities that arise from studies within the geospace environment and provides unique insights into extreme environments, which is also applicable to other astrophysical systems.

This session seeks to discuss Heliophysics studies such as these that have far-reaching interdisciplinary counterparts that probe underlying physical mechanisms common across regimes.

Poster Session 4: Expanding the Frontiers of Heliophysics and Heliophysics as a Community in 2050

Session chair: Sabrina Savage/Jaye Verniero

Day 5:

Oral Session 8: Heliophysics as a Community in 2050

Moderators: Ian Cohen/Jaye Verniero/Sabrina Savage/Shasha Zou

As the Heliophysics community looks ahead to 2050, we must assess the state of our field as both a community and scientific discipline. In order to develop a long-term vision and short- and medium-term enabling strategies, we must articulate the community's ambitions for Heliophysics over the next several decades in terms of scientific understanding and exploration; community demographics and teaming approaches; the strategic implementation of modern infrastructure, technology, and methodologies; collaborations with other scientific disciplines; and alignment of programmatic considerations. In short, we must define the vision for what Heliophysics is and what it should be by 2050.

This session addresses a wide range of these topics and other future-looking considerations as our field develops a multi-decadal approach to solar and space physics research. In particular, discussions focused on breaking down the traditional "siloed" or "hyper-specialized" structure of sub-communities within Heliophysics as well as how to enable and foster collaboration with other space and terrestrial science communities, such as Planetary Science, Astrophysics, Earth Science, and atomic and laboratory plasma physics. The session also considers how to strengthen inclusion, diversity, equity, and access (IDEA) within the community as well as developing and sustaining healthy, multi-generational approaches for teaming. Furthermore, the session focuses on pressing needs for large-scale coordinated infrastructure development, advanced space launch and data transmission and processing capabilities, and suggestions for programmatic changes to help enable science goals envisioned for Heliophysics in 2050. Finally, the session also considers the benefits for the field of expanding citizen science efforts, education and public outreach, and implementation of modern computational and analytical approaches (e.g., machine learning, artificial intelligence, data mining).