Heliospheric Constellation: Understanding the Structure and Evolution of the Solar Wind


1 Institute of Geophysics and Planetary Physics and Department of Earth and Space Sciences, UCLA, Los Angeles, CA 90095-1567
2 Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
3 Center for Space Physics, Boston University, Boston MA 02215
4 The Aerospace Corporation, El Segundo CA, 90245-4691
5 Los Alamos National Laboratory, Los Alamos, NM 87545
6 Space Environment Center, NOAA, Boulder CO

Abstract. The Heliospheric Constellation (HELICON) mission concept calls for the first constellation of spacecraft to make coordinated measurements of the solar wind magnetic field, plasma and energetic particle distributions and composition in order to determine scale-lengths of solar wind structures and to resolve ambiguities in temporal and spatial variability. Specifically, HELICON enables the resolution of a wide array of critical questions of solar wind structure and dynamics. The HELICON’s Science Objectives are as follows: (1) Determine the structure and evolution of expanding interplanetary coronal mass ejections, (2) Use supra-thermal and energetic particles to determine the source populations of solar events and the scale sizes of Interplanetary Coronal Mass Ejections (ICMEs) and Corotating Interaction Regions (CIRs) (3) Determine the structure and nature of the heliospheric current sheet, and (4) Examine the causes of variability in the solar wind. This brief report describes the mission concept and scientific rationale for such a mission.

INTRODUCTION

While we have learned much about solar wind structure and dynamics from single spacecraft observations, we have been stymied in our attempts to unambiguously test our understanding of the physical processes controlling the solar wind because with only one or two uncoordinated measurements we cannot separate spatial from temporal variability. The four major HELICON science objectives answer several of the fundamental problems in heliospheric physics that can only be solved with coordinated, simultaneous, multi-spacecraft observations. The next sections describe the mission concept, instrument suite, and conclude with how the mission answers the four major HELICON science objectives.

MISSION DESCRIPTION

HELICON consists of six identical spacecraft (Figure 1) in heliocentric orbit. One triad leads the Earth at 1AU with increasing inter-spacecraft spacing throughout the course of the mission. The other triad is in a one-year period elliptical orbit with perihelion at 0.8AU and aphelion at 1.2AU. Figure 2 shows how the orbits evolve over a course of a year in the middle of the prime mission. The orbital positions (and hence spacecraft separations) have been determined using The Aerospace Corporation’s Satellite Operations Analysis Program (SOAP). One year after launch, the spacecraft sets are radially aligned within a 25° longitudinal band with the elliptical spacecraft between 1.15 and 1.2AU. Three months later, the spacecraft are longitudinally spread across 60° with the spacecraft ranging in distance from 0.9 to 1.1AU. Every six months the spacecraft “weave” back and forth with this same pattern.

Each spacecraft includes an identical instrument suite that continuously samples the solar wind with a 1-minute resolution. The instrument suite consists of a UCLA-built magnetometer with a range of +/- 1000 nT and a precision of +/- 0.05 nT; a Los Alamos...
National Laboratory-built solar wind plasma analyzer that can measure electrons (from 3 eV to 8 keV) and ion composition (from 0.4 to 10 keV/q) with an energy resolution of 5% and a mass resolution of 20%; and an Aerospace Corporation-built energetic particle instrument that can measure electrons (from 15 keV to 2 MeV) and ion composition (from 0.7 to 10 MeV for heavy ions and 0.08 to 10 MeV for protons) with a mass resolution of 10%.

**SCIENCE OBJECTIVES**

**Structure and Evolution of ICMEs:** The magnetic and density structure of Interplanetary Coronal Mass Ejections (ICMEs) can only be well determined with multi-spacecraft in situ observations. The current paradigm of the three-dimensional structure of ICMEs can be tested in three ways with HELICON: (1) At multiple longitudes at constant radial distance to determine the azimuthal stretching of the structure (Figure 3); (2) At multiple locations along the axis of the structure to measure the bending of the axis, and (3) At multiple radial distances to determine the radial evolution of the structure. The IMF and solar wind observations can be used at each location independently and the data can be inverted to give local structure and orientation or they can be combined in a model that allows stretching, bending, and expansion.

HELICON determines the relationship between the plasma composition structure and the magnetic topology at each location within the ICME to relate the structure to its coronal source. HELICON measures the presence or absence of bi-directional suprathermal electrons throughout the structure to determine its connectivity to the Sun and its magnetic topology. By examining this relationship at six different locations in space, HELICON provides a very rigorous test of our understanding of the 3D geometry of the structures and their relationship to the coronal magnetic field. The HELICON spacecraft separations span the ICME size estimates of 10° to 60° in longitude and from 0.1 to 0.25AU in the radial direction. Studies with WIND and NEAR show that over this range of longitude scales concurrently observed ICMEs have structure that is nearly identical at the shortest distances, to being nearly opposite at the greatest distances. Similarly WIND and NEAR revealed significant radial evolution over a distance of 0.2AU [Mulligan et al., 1999]. Because of the 15 unique spacecraft pairs, nearly the full range of these separations is made simultaneously during much of the mission.

**Scale-Size of Solar/Interplanetary Events:** HELICON tests our understanding of the acceleration process, energetic particle transport, and scale-size of events by making simultaneous measurements of the energetic particle flux, composition, and IMF at a wide range of scale-lengths. In particular, HELICON answers many of the questions regarding ICME-driven shocks and CIRs.

**ICME events:** HELICON samples energetic particles from interplanetary shocks associated with fast coronal mass ejections. The simultaneous measurements, at different rigidities and at different locations along the shock front, determine how the source strength depends on particle rigidity and heliolongitude. The only existing multi-spacecraft measurements of ICME-related events have shown dramatic differences in the time-intensity profiles across longitudes as small as ~25° [e.g. Reames, 1999].

Figure 2: The HELICON satellite configuration evolves with time and is shown at four intervals during the prime mission. The constellation configuration alternates between having the two sets of spacecraft radially aligned (at month 12 and 18) to longitudinally spread (at month 9 and 15) every 3 months as the elliptical orbit spacecraft “weave” back and forth around the 1AU spacecraft.
Therefore, HELICON is well configured in heliolongitude to probe the acceleration and transport along the shock.

**Particle acceleration and transport in CIRs:** HELICON addresses key questions of Corotating Interaction Regions (CIR)-related composition by taking a snapshot of the particle population at different longitudes at the same time, thus separating the effects of corotation from time dependence in the corotating frame. Since some CIRs populate the IMF with energetic ions and electrons for many tens of degrees of heliolongitude, only a multiple-platform constellation such as HELICON can sample the CIR acceleration sites from different locations along the reverse shock at the same time.

The only previous radial survey of CIR-related energetic ions near 1AU used the Helios 1 & 2 spacecraft [Van Hollebeke et al. 1978]. Based on the Helios results, it is expected a radial gradient in particle intensity within a single CIR as large as a factor of 5 over the radial sampling of HELICON (0.2AU).

Therefore, to achieve our science objectives with respect to the source and scale-size of solar energetic particle events, HELICON needs to identify solar wind transients such as shocks and CIRs at a range of scale-lengths from these structures. Making measurements of the magnetic field, bulk plasma moments (n, T, V), suprathermal electron flux and energetic particle flux at a wide range of energies (20 keV to several MeV) will accomplish our objectives.

**Nature and Structure of the Heliospheric Current Sheet:** HELICON makes simultaneous measurements above, below, and within the HCS at a wide range of scale-lengths (See Figure 4) in order to address the three-dimensional structure of the HCS. The combined IMF measurements, plasma composition, and suprathermal electron direction information determines the magnetic topology and connection to the Sun to test models of the HCS structure such as those of Crooker et al. [1996].

The perturbation of the HCS due to transients in the solar wind are also examined by making field and particle measurements both within the transients, at the HCS, and across the boundary between them. By making simultaneous observations across the HCS over a range of azimuthal and radial scale lengths, HELICON unambiguously separates spatial from temporal dynamics and better understands the relative role of forcing at the Sun compared with dynamics caused by the interaction of streams in the interplanetary medium.

**Source of Solar Wind Variability:** HELICON samples a wide range of spatial/temporal scales due to the wide range of spacecraft separations. Presently, we do not know if solar wind variability on the 0.1-10 hour time scales is caused by changes in the wind from a single source (time variability) or from sampling wind from different sources (spatial variability) or both. Assuming a ballistic mapping, the difference between the spacecraft longitude and the source longitude is given by \( \Delta \phi = \Omega \Delta t \), where \( \Delta t = R_{sc}/V_{sc} \) is the travel time of the solar wind parcel from the Sun to the spacecraft. Thus, two spacecraft separated in longitude and/or radius sample solar wind from...
different locations at the same time and sample solar wind from the same location at different times. For a solar wind velocity of 400 km/sec, spacecraft at the same longitude but separated radially by 0.1AU measure solar wind from sources separated by about 6º at the same time or from the same source region with a time difference of 10 hours; spacecraft separated by 6º but at the same distance from the Sun provide similar sampling. With spacecraft separations ranging from 0.0001 to 0.3AU HELICON samples time scales ranging from 1-200 hours and source size (at the source surface) of 0.6º to 100º and resolves the ambiguity.

HELICON, by separating temporal and spatial changes in the composition, can give information about the scales of the physical processes involved in this intermittent release; e.g., the time scales over which the composition remains constant can be related to the loop size. Active region time scales are typically minutes to hours and thus one would expect large temporal variation at these scales in solar wind from active regions. If slow wind near the current sheet is in blobs [Wang et al., 1998], expected temporal variations in density are on the order of several hours. As another example, plasma sheets at the heliospheric current sheets typically take 1-10 hours to pass by a spacecraft, corresponding to an angular size of 0.6º -6º. HELICON is able to determine the temporal and spatial scales of solar wind.

**CONCLUSIONS**

Heliospheric Constellation (HELICON) is the first mission to make coordinated, simultaneous, multi-point measurements to study the radial and longitudinal evolution of a single parcel of the solar wind. It measures both spatial and temporal variations of solar wind streams in order to sample scale-sizes never before observed. HELICON consists of six identical spacecraft in two sets of three, each having distinct one-year period heliocentric orbits. One triad orbits the Sun at 1AU and the other triad in an elliptical orbit from 0.8 to 1.2AU. The spacing of the six HELICON spacecraft evolves through the mission, allowing measurements of multiple scale-lengths of the solar wind ranging from <1º to 90º in longitude and 0.0001 to 0.3AU in the radial extent. Joint studies, such as with the WIND and NEAR spacecraft, have shown that these separations are precisely those needed to measure the structure of interplanetary coronal mass ejections, corotating interaction regions, and the heliospheric current sheet.

HELICON enables the resolution of a wide array of critical questions of solar wind structure and dynamics. The HELICON’s Science Objectives are as follows:

- Determine the structure and evolution of expanding interplanetary coronal mass ejections
- Use supra-thermal and energetic particles to determine the source populations of solar events and the scale sizes of ICMEs and CIRs
- Determine the structure and nature of the heliospheric current sheet
- Examine the causes of variability in the solar wind.

HELICON examines the evolution of stream structure as a function of distance from the Sun and time, thereby enabling the examination of both the interaction of solar wind streams and the effects on stream structure by variations at its source. HELICON provides for the first time the ability to study energetic particles simultaneously at many points along interplanetary shocks to unambiguously determine the particle sources and their transport. Finally, HELICON provides the information needed to develop predictive capabilities such as correlation lengths, correlation times, and the radial scale length of shock evolution. These studies are essential for the use of remotely obtained heliospheric data to predict conditions at the Earth with the advance warning desired by many users of space weather data.

The HELICON mission concept and satellite configuration are evolving to take advantage of advances in satellite design and instrument miniaturization. The HELICON mission is designed to fit under a NASA MIDEX cost-cap. The HELICON mission is a partnership between UCLA, NASA JPL, Los Alamos National Laboratory, and The Aerospace Corporation.

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**REFERENCES**