SIHLA , a Mission of Opportunity to L1 to Map H Lyman Alpha Emissions from the Heliopause, the Interplanetary Medium, the Earth's Geocorona and Comets

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Abstract

SIHLA (Spatial/Spectral Imaging of Heliospheric Lyman Alpha pronounced as 'Scylla' [e.g. Homer, Odyssey, ~675-725 BCE] investigates fundamental physical processes that determine the interaction of the Sun with the interstellar medium (ISM); the Sun with the Earth; and the Sun with comets and their subsequent evolution. To accomplish these goals, SIHLA studies the shape of the heliosphere and maps the solar wind in 3D; characterizes changes in Earth's extended upper atmosphere (the hydrogen 'geocorona'); discovers new comets and tracks the composition changes of new and known ones as they pass near the Sun. SIHLA is a NASA Mission of Opportunity that has just completed its Phase A study (the Concept Study Report or CSR). At the time of the writing of this abstract NASA has not decided whether to fly this small satellite mission or its competitor (GLIDE: PI Prof. Lara Waldrop). SIHLA observes the ion-neutral interactions of hydrogen, the universe's most abundant element, from the edge of the solar system to the Earth, to understand the fundamental properties that shaped our own home planet Earth and the heliosphere. From its L1 vantage point, well outside the Earth's obscuring geocoronal hydrogen cloud, SIHLA maps the entire sky using a flight-proven, compact, far ultraviolet (FUV) hyperspectral imager with a Hydrogen Absorption Cell (HAC). The hyperspectral scanning imaging spectrograph (SIS) in combination with the spacecraft roll, creates 4 maps >87% of the sky each day, at essentially monochromatic lines over the entire FUV band (115 to 180nm) at every point

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in the scan. During half of these daily sky maps, the hydrogen absorption cell (HAC) provides a 0.001nm notch rejection filter for the H Lyman a. Using the HAC, SIHLA builds up the lineshape profile of the H Lyman a emissions over the course of a year. SIHLA's SIS/HAC combination enables us to image the result of the ion-neutral interactions in the heliosheath, 100 AU away, in the lowest energy, highest density, part of the neutral atom spectrum – H atoms with energies below 10eV. The novel aspects of SIHLA are the scope of the science done within a MoO budget. The SIHLA projected costs were below the $75M cap with a 31.3% reserve for Phase B-D. The re-purposing of a spectrographic that was part of the DMSP SSUSI line (a copy was flown and NASA TIMED/GUVI and as NASA NEAR/NIS). Risk is extremely low in this Class-D mission with all major elements at least at TRL6 at this time. SIHLA has a high potential for discovery. We expect that we will 1) First detection of the hot H atoms produced directly from the ion-neutral interactions at the heliopause; 2) First detection of structures in Interplanetary Medium H emission, 3) First detection of response of the Earth's extended (out to lunar orbit) geocorona to solar/geomagnetic drivers, 4) New UV-bright comets as they enter the inner solar system. SIHLA is a hyperspectral imager; at every point in the sky SIHLA obtains the entire FUV spectrum.

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SHILA: "Follow the Hydrogen" Throughout the Heliosphere

SHILA
Science Heliosphere Interstellar Large Aperture
Hydrogen Imager
Science Objectives
Science Measurements
Science Instrument
Science Mission
Science Data Products
Science Data Analysis
Science Data Archive
Science Data Distribution
Science Data Processing
Science Data Storage
Science Data Transmission
Science Data Collection
Science Data Acquisition
Science Data Management

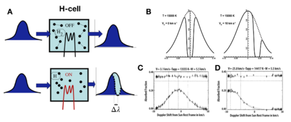
Time to completely map sky, days	~81	persistent gaps	~183
Earth geocorona	YES	Limited	NO
HH+O production (cometary)	YES	YES	NO
Point source maps	YES	NO	NO
Out of band & scattered light removal	YES	Limited	Limited
Star removal	YES	Limited	Limited
In-flight calibration and characterization	YES	Limited	Limited
Dedicated Point/Stare Mode Deep Surveys	YES	NO	NO
Heliospheric H lat/long variability (daily)	YES	YES	NO
Solar wind mass flux Determination	YES	No longer	NO
Solar Lyman α intensity	YES (inferred)	NO	NO
Solar EUV flux	YES (inferred)	NO	NO

[1] *Spacelight* capability.
[2] *Bertaux et al.*, [1995] Table 1.
[3] *McComas et al.* [2018] Table 14.

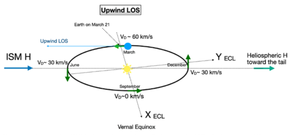
The Hydrogen Absorption Cell

The HAC is a key component of SIHLA and implements a design proven in flight on the Pregoso-5 and 6, Nozomi, and SOHO/SWAN missions. The HAC enables the extraction of the all-important shape of the line spectrum of the backscattered Lyman α radiation [Quémerais, 1999; Quémerais et al., 2000] for pixel line-of-sight (LOS) in the sky. A H-absorption cell is simply an evacuated glass vacuum tube (ØT 11.1 ; ØY 4.5) partially filled with a few hundred pascals of H2. A filament is used to dissociate H2 into H. The H reaches a Maxwellian distribution within seconds of the filament being powered. The filament temperature can be adjusted by changing the voltage applied. The active H cell absorbs a part (DI) of the incoming spectrum centered on the Doppler-shifted Lya wavelength ID=Iα(1+VD/c) determined by the doppler shift between the H cell and the LOS-integrated relative velocity of H flow seen from the spacecraft: VD=E(ΦS*Vx/c-VH) (A & B in the figure below). The ratio (R=ION/IOFF) of HAC ON (attenuated line-integrated) to HAC OFF (unattenuated line-integrated) intensities can be measured in any chosen direction. The physically important quantity is the "Absorption Fraction" A=1-R = DI(ID)/sdI(ID)(c) because it is proportional to the Doppler-shifted intensity I(ID). Full sky maps of the absorption fraction (one A-value for each 0.8° pixel) will be obtained every 12 hours by SIHLA: the difference between one 6-hr map of the line-integrated intensity (IOFF) which is itself a useful quantity, is followed by one 6-hr map of (ION), which is the attenuated line-integrated intensity.

From a 6-month set of these "A-maps", we can obtain the line shapes in individual pixels (as follows). The Earth (and SIHLA) have an orbital (vector) velocity (Vx/c) of 30 km/s that varies around the Sun, while the H-atom flow through the heliosphere (deflected by its passage through the interface) has a (vector) velocity (VH) ~23 km/s that is steady in time. Thus, the absorption fraction (A)—and hence the line shape I(ID)—for each particular pixel in the sky is traced out every 6 months by the variation in the LOS Doppler shift (VD) in that pixel. In the figure below, C & D show the absorption fraction (A=1-R) for crosswind LOS (C) and upwind LOS (D) as a function of the LOS component of the S/C velocity (LOS=Vx/c) obtained from one year of SWAN observations. To zeroth order, the center of the back-scattered emission line I(ι) will correspond to the maximum A-value over 6-months. From the line shape of the backscattered radiation, we can obtain line moments such as the line center and the line width, which directly reflects the velocity and (to first order) the 'temperature' of H atoms along the line-of-sight (LOS) [Quémerais, 2000].

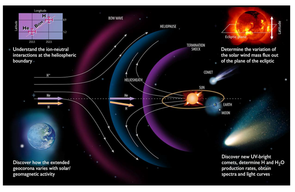


(A) A schematic representation of the change in the recorded signal when the HAC is ON or OFF. When ON, the position of the absorption feature relative to the line center of the input ISM H line is determined by the LOS relative velocity of the S/C and the ISM. (B) Example of the spectra with absorption for different magnitudes of VD. (C & D) One year of SWAN absorption data for a crosswind (C) and upwind (D) LOS [Quémerais et al., 1999]. SIHLA provides coverage of the entire range of observable Doppler shifts for every point in the sky every 6 months. Pop 1 and Pop 2 coverage are continuously resampled along various LOS with much shorter revisit times.



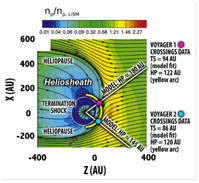
Over 1 year of observations SIHLA will scan Lyman α line profile in the upwind LOS twice in the range of Doppler shifts ~0-60 km/s. For the downwind direction in a similar way the line will be scanned in the Doppler shift range -60 -- 0 km/s.

SIHLA ADDRESSES HELIOPHYSICS AS A WHOLE



Mission Overview – SIHLA measures intensity and lineshape of interplanetary Ly-α to reveal hydrogen properties and ion-neutral interactions from the edge of the heliosphere to the inner solar system.

WHAT WILL WE LEARN?



Voyager 2 (VGR2) appears to be crossing the heliopause (HP) into the VLISM at a helioradius ~120AU Seven years ago, Voyager 1 crossed at 122 AU (indicated by the purple dot). State-of-the-art computer models (that include the all-important kinetic interaction between solar wind H+ and interstellar H) failed to predict either of these actual HP crossings (Izmodenov and Alexashov, 2015 [shown]). The rainbow color bar gives the normalized proton density, while the streamline arrows indicate the proton flow that diverts around the HP and causes the atomic collisions (and resulting charge exchange) with the inflow of interstellar H in the interface region. The calculation was constrained to give the observed termination shock (TS) crossings along the VGR1 and VGR2 directions projected onto the X-Z plane defined by the directions of the distant interstellar flow and magnetic field.

The HP crossings were predicted to be at ~180 AU and ~145 AU, respectively based on the TS crossing. The observed Voyager crossings of the HP are indicated by the colored dots on the yellow arc at r ~ 120 AU. They suggest that the upwind HP might be nearly spherical at this radius—and therefore dramatically smaller in extent than the upwind HP in the model. These gross discrepancies between the observed and modeled HP crossings require that we rethink our basic concepts of the global configuration of the heliosheath and heliopause, and they greatly increase the value and timeliness of new and more sophisticated remote sensing data to come from the next generation of instrumentation on the upcoming IMAP mission and this proposed SIHLA mission of opportunity.

SIHLA will determine whether the heliopause is comet-like or spherical. This is a fundamental question that demands an answer.

SIHLA will make discoveries from its first day of operations.

On the first day we will:

1) map the Earth's geocorona

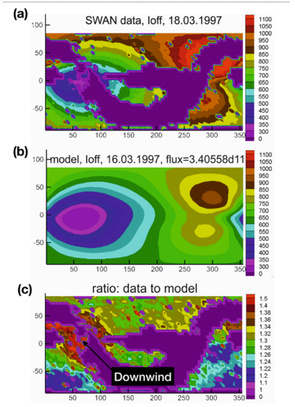
2) map the inner heliosphere H and from that establish the solar wind mass flux

3) map the Zero Doppler Shift Circle (ZDSC) and establish the flow direction of H into the heliosphere.

We may even be fortunate enough to see a UV bright comet. This will give us new and unique spectral observations of a comet. There are very few of these observations - they are so rare that every one of them is unique and valuable.

We expect to be in operation by the Spring of 2025. This will enable SIHLA to detect or refute the existence of a hot heliosheath component of hydrogen. The number density of hot H is important in establishing the balance between the external Interstellar Medium pressure and that of the solar wind outflow.

Additionally, the shape of the heliosphere, which is not known, is indicated by the upwind to downwind intensity ratio.



Large-scale discrepancy by 50% (panel c) exists between the Lyman α observations and state-of-the-art model in the heliospheric tail indicating inadequate description of the tail in the models. Purple area shows contaminated SWAN data.

AUTHOR INFORMATION

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SIHLA is a hyperspectral imager; at every point in the sky SIHLA obtains the entire FUV spectrum. This enables SIHLA to easily flag pixels contaminated by stars; obtain the spectrum of the Earth, viewed as an 'exoplanet' and observed the response of the exosphere and the thermosphere to solar/geomagnetic events; detect comets and determine their composition and how it varies at they enter and leave the inner solar system.