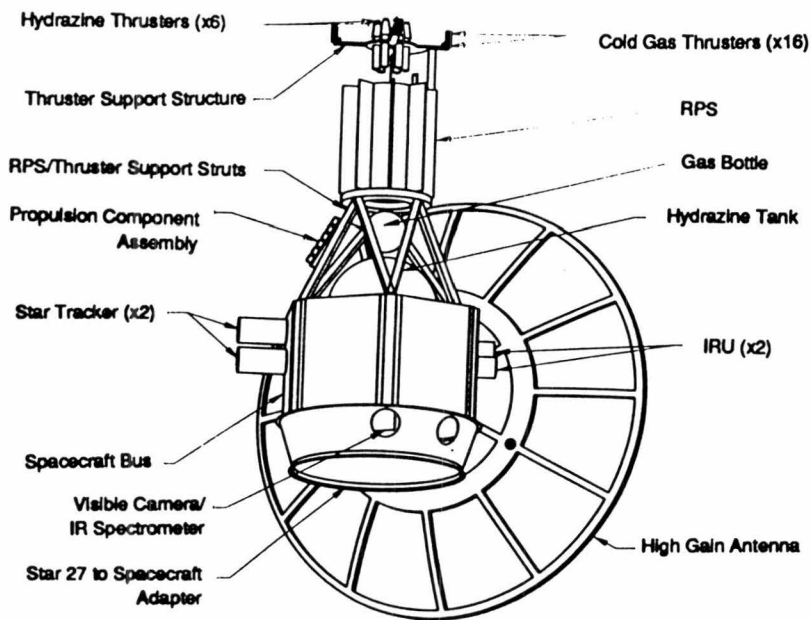


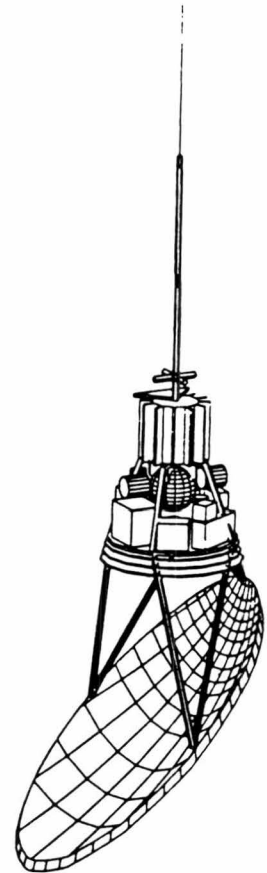
# SMALL INSTRUMENTS FOR SPACE PHYSICS

## PROCEEDINGS OF THE SMALL INSTRUMENT WORKSHOP HELD IN PASADENA, CALIFORNIA, 29-31 MARCH, 1993\*

EDITED BY B.T. TSURUTANI



*The baseline PFF spacecraft*



*The Small Solar Probe*

Production Coordinator: J.K. Arballo

Editorial Assistant: V. Rother

November 1993

\*The Workshop and efforts in producing this book were sponsored by  
Space Physics Division, National Aeronautics and Space Administration, Washington, D.C.



## AN ULTRAVIOLET PHOTOMETER FOR THE INTERSTELLAR PROBE MISSION

D. L. Judge, D. E. Shemansky<sup>1</sup>, P. Gangopadhyay, M. A. Gruntman<sup>1</sup>, H. Ogawa  
University of Southern California  
Space Science Center, SHS 274  
Los Angeles, CA 90089-1341

<sup>1</sup>University of Southern California  
Dept of Aerospace Engineering, RRB 222  
Los Angeles, CA 90089-1191

D. T. Hall  
Johns Hopkins University  
Dept of Physics and Astronomy  
Baltimore, MD 21218

H. Fahr  
Institute for Astrophysics  
Bonn University  
Auf dem Hügel 71, Bonn D-5300

V. Baranov  
Institute for Problems in Mechanics  
Russian Academy of Sciences  
prosp. Vernadskogo 101, Moscow 117421

### ABSTRACT

The distribution of the integrated emission of the H Ly $\alpha$  line at 121.6 nm in the heliosphere can be utilized to determine the atomic hydrogen density in the Very Local Interstellar Medium (VLISM) and to remotely sense the structure of the heliosphere shock region. The neutral gas distribution in the inflowing VLISM directly affects the solar wind primarily by charge exchange. The reaction has the effect of filtering the VLISM neutrals and modifying an otherwise uniform density distribution. This has been demonstrated recently in the utilization of Pioneer 10 and Voyager UVS data compiled as a function of location of the outward pointed detectors relative to the solar center. The analysis of these data has produced the first definitive evidence for the presence of a strong perturbation in the distribution of neutral atomic hydrogen in the VLISM in the upstream direction. The utilization of a two shock model has allowed the determination of the approximate position of the solar wind termination shock.

The emission, produced by the scattering of the solar H Ly $\alpha$  source, is relatively strong and therefore easily identified and measured with the use of simple photometers. The dependence of emission strength on position relative to the Sun, and temporal variation, can be utilized to independently determine the density and distribution of the neutral hydrogen. It is possible to derive density independent of instrument calibration. Current technology can produce detectors with a high degree of long term reliability and stability.

The proposed instrument for a heliosphere probe is a two-sensor photometer. One narrow-FOV sensor is pointed in the antisolar direction and another at an angle with respect to the spin axis

of the spacecraft. The specific angle will be determined by consideration of the inclusion of stellar sources as a means of verifying sensitivity stability. A preliminary estimate of weight and power requirements is  $< 0.3$  kg and  $\sim 300$  mW.

## I. Introduction

The strong perturbation of the neutral atomic hydrogen VLISM gas distribution by a heliosphere termination shock has generally not been recognized. The recent two shock calculations by *Baranov and Malama*[1993] have dramatically emphasized the strong distributional variations in atomic hydrogen that can accompany the heliosphere termination. We propose here a simple method by which a heliosphere probe can remotely sense the location of the dynamic breathing heliosphere termination. The required instrumentation is rugged, compact, and low in cost, weight and power consumption.

The emission of H Ly $\alpha$  in the VLISM from scattering of the solar line is a well known phenomenon that has been modeled in the past with the assumption of a uniform source of inflowing gas unaffected by a solar wind termination shock [*Fahr, 1974 ; Thomas, 1978*]. The modeled distribution in the absence of a shock has been compared with a number of spacecraft observations in the inner solar system with spectrometers and photometers [*Ajello, et al., 1987 ; Lallement and Stewart, 1990 ; Lallement and Bertaux, 1990 ; Lallement et al., 1991 ; Pryor, et al., 1992*]. However, in the inner solar system the influence of the solar environment on the distribution of the inflowing gas is so strong that possible deviations from a uniform model are masked and difficult to detect. Observations from positions further out in the solar system have in fact shown early evidence for deviation from a uniform model [*Wu, et al., 1981*] but only recently has definitive evidence been accumulated in Voyager and Pioneer 10 UVS H Ly $\alpha$  observations showing the presence of a perturbed distribution associated with the termination shock [*Hall, et al., 1993*]. The evidence appears in the form of a deviation from a uniform VLISM model in the H Ly $\alpha$  antisolar emission brightness distribution, as a function of radial position in the solar system, as well as in angular position relative to the flow axis of the VLISM drawn through the center of the sun. A simple stable photometric instrument can therefore provide the basic information required to establish the termination shock position, given a suitable model.

## II. The distribution of heliospheric atomic hydrogen

We describe here the basic facts relating to current observations. *Hall, et al.*[1993] show the distribution of H Ly $\alpha$  in the VLISM as a function of radial position of the Voyager 1 and 2 and Pioneer 10 spacecraft up to January 1990, at which time, the spacecraft were located at 40, 31, and 48 AU, respectively. Pioneer 10 is located downstream in the VLISM and Voyager 1 and 2 are upstream. Figure 1, taken from *Hall, et al.*[1993], shows the basic observational geometry. The H Ly $\alpha$  monitors effectively detect scattering of the solar line in the VLISM 10 - 30 AU ahead of the spacecraft in the anti-sunward direction, the distance being limited by the combination of decline of solar flux with range and multiple scattering. Figure 2 from *Hall, et al.*[1993] shows the reduced data from Pioneer 10 and the Voyager spacecraft normalized at 15 AU. These data have been corrected for temporal variation of the solar H Ly $\alpha$  source. In an idealized uniform medium under optically thin conditions, the signal is expected to vary as

$$4\pi I/\pi F \propto r^{-2} \quad (1)$$

with  $n = 1$ , where  $4\pi I$  is the observed brightness,  $\pi F$  is the solar source flux, and  $r$  is position in the solar centered system. In theory, utilizing a model for a uniform VLISM, the so called hot model of *Thomas[1978]* predicts that in the downstream direction,  $4\pi I/\pi F$  varies with a characteristic  $n < 1$ , while in the upstream direction, because of multiple scattering effects for larger values of  $r$ ,  $n > 1$ . Figure 2 shows that the observations have trends

in both the upstream and downstream directions that oppose the predicted trends. The differences are quite strong, particularly in the upstream Voyager data, where  $4\pi I/\pi F$  shows an  $n = 1$  behavior near 15 AU, but gradually changes to  $n = 0.35$  at 30 AU. Taking into account multiple scattering effects, this trend indicates a deviation from the hot model by a factor of  $\sim 2$  between 15 and 30 AU. The implication is that the upstream spacecraft are moving into a region of rapidly rising atomic hydrogen density. The trend is so rapid on a heliosphere scale, that it is indicative of an implied "wall" of atomic hydrogen looming ahead of the spacecraft.

A detailed model of the VLISM has recently been presented by *Baranov and Malama[1993]*, which includes the dynamic effects of a two shock model. The *Hall, et al.[1993]* results are consistent with this model, and a prediction has been obtained on this basis for the location of the termination shock in the upstream direction [*Hall, et al., 1993*]. The VLISM atomic hydrogen distribution modeled by *Baranov and Malama[1993]* is shown in Figure 3, for various angular positions relative to the VLISM bulk flow vector. Note that there are distinct differences in predicted number densities between long range upstream and downstream positions, as well as distinctive shape functions in the upstream regions.

It is clear on the basis of the current [*Hall, et al., 1993*] results that the distribution of atomic hydrogen in the region just beyond the edge of the solar system boundary is rapidly rising in density. The only plausible conclusion that we can draw is that the nonuniformity is driven by a heliospheric shock. The mechanism, involving charge exchange ( $H + H^+$ ), between collision partners having large differences in velocity, has been described by *Baranov and Malama[1993]*. There are various methodologies that can be used to obtain a remote measurement of the neutral hydrogen density, and the distribution in space. One or more of these can determine densities independent of absolute instrument calibration. The point that we wish to emphasize is that simple photometric instruments can be utilized to obtain the critical data. One drawback of the simple photometer is the lack of

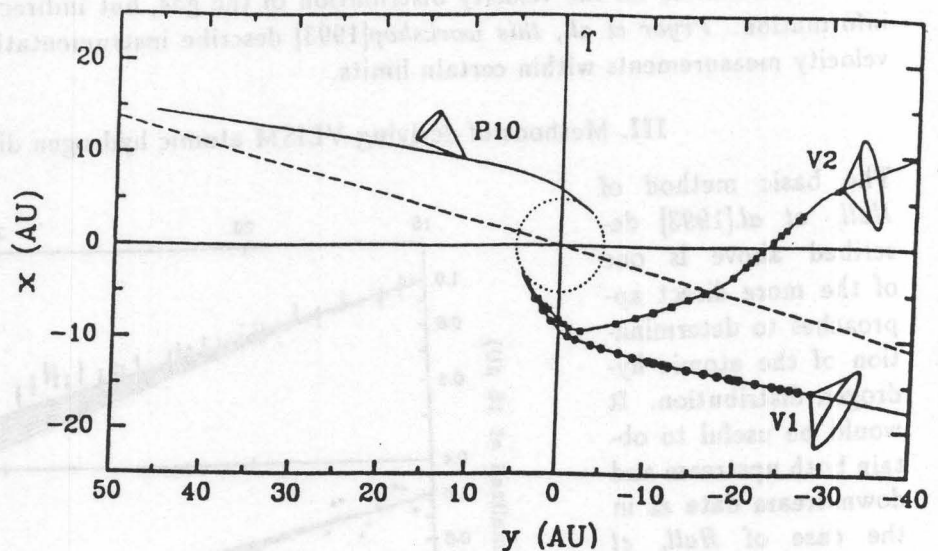


Figure 1: The trajectories of the Voyager and Pioneer 10 spacecraft projected onto the ecliptic plane. The dotted circle represents the orbit of Jupiter. The cones indicate the directions of observation giving the data plotted in Figure 2.

direct information on the velocity distribution of the gas, but indirect methods can provide such information. Pryor *et al.*, *this workshop*[1993] describe instrumentation that can directly obtain velocity measurements within certain limits.

### III. Methods of deriving VLISM atomic hydrogen distribution

The basic method of Hall, *et al.*[1993] described above is one of the more direct approaches to determination of the atomic hydrogen distribution. It would be useful to obtain both upstream and downstream data as in the case of Hall, *et al.*[1993], but the upstream data set is critical, and this set can be used alone to obtain information on the boundary of the heliosphere, particularly now that upstream/downstream comparative results have been established. Photometric measurements from an upstream spacecraft at various angles to the VLISM bulk velocity vector can also be utilized for the neutral distribution measurements [Hall, *et al.*, 1993]. The shape of

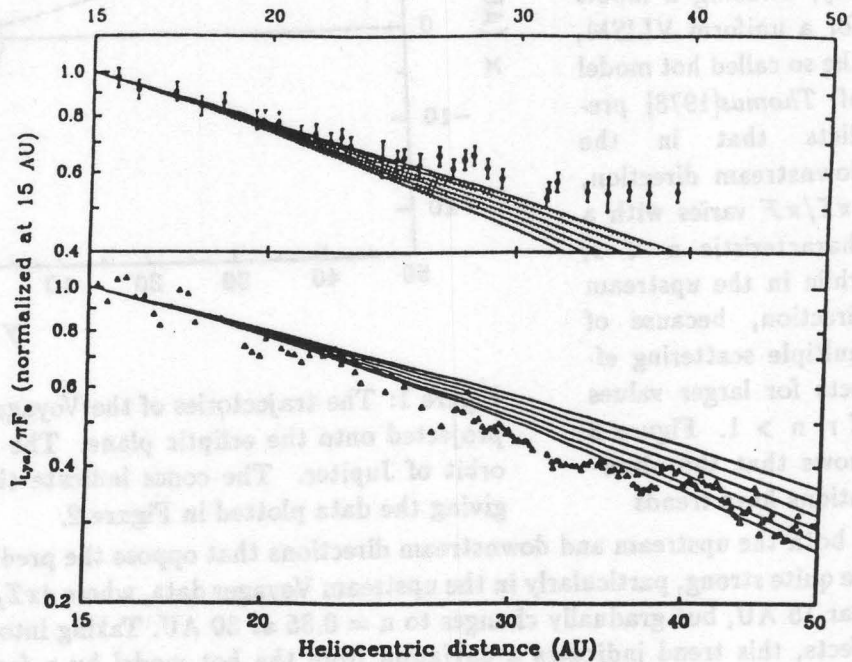


Figure 2: Voyager and Pioneer 10 H Ly $\alpha$  intensities adjusted to constant solar flux and normalized at 15 AU, compared to hot H model radiative transfer simulations. In the top panels Voyager 1 and 2 data are shown as circles and squares respectively. The solid and dotted lines show the hot H model V1 and V2 simulations respectively. The lower panel shows the Pioneer 10 observations and models. The model is specific to orientation and utilizes the Thomas[1978] hot H model distribution. RT simulations are shown for [H] = 0.04, 0.06, 0.08, 0.12, 0.14 cm<sup>-3</sup>, from top to bottom in all cases.

the distribution has a dependence on the density of the incoming VLISM gas, and apart from absolute strength of the emission, this characteristic can be used to infer the gas density. Another method of determining neutral hydrogen density in the  $\sim 10 - 20$  AU vicinity of the spacecraft has been described by Shemansky, *et al.*[1984]. This method depends on the presence of distinct temporal variability in the solar H Ly $\alpha$  line. The method is restricted to those time intervals when the sun shows distinct variability, but it does provide a means of establishing a measurement of density, entirely independent of absolute instrument calibration. Solar H Ly $\alpha$  variability was particularly strong during 1982, and the Pioneer 10 and Voyager 2 data for that period was utilized by Shemansky, *et al.*[1984] to determine H density in the 30 - 50 AU region downstream and the 15 - 25 AU region upstream. The data utilized in the calculations is shown in Figure 4. The results

of this calculation were puzzling at the time, because the upstream and downstream values did not conform to expectation on the basis of a uniform hot model; the values obtained,  $[HI] = 0.11 \text{ cm}^{-3}$  downstream and  $0.16 \text{ cm}^{-3}$  upstream were expected to be equal. However, we now find that these values are in good agreement with the recent *Baranov and Malama*[1993] model (see Figure 3). The three different approaches to the measurement of the VLISM atomic hydrogen distribution described here can all be established with the utilization of simple photometric instrumentation having the same functionality as the Pioneer 10 UVS, with the guaranteed extreme long term stability that modern technology now provides.

Two shock model: VLISM HI  
Baranov and Malama (1993)

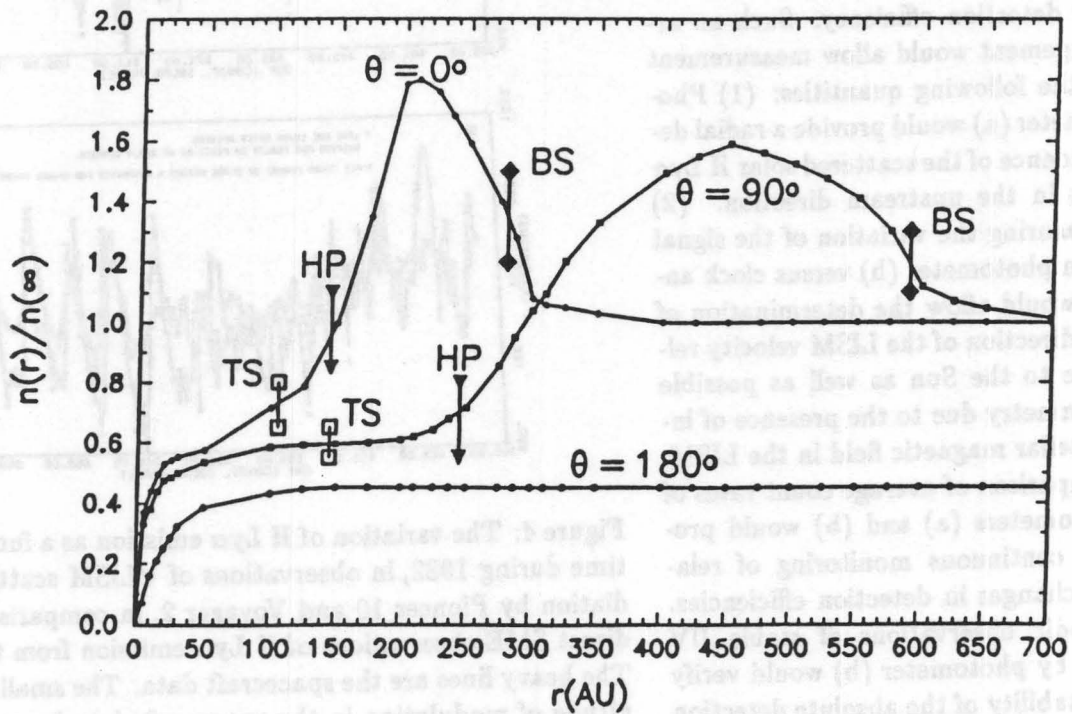


Figure 3: The normalized distribution of atomic hydrogen in the two shock model of *Baranov and Malama*[1993]. The distribution is shown along radial lines at indicated angles to the VLISM flow vector. The positions of the solar wind termination shock (TS), bow shock (BS), and heliopause (HP) are indicated on the Figure.

#### IV. A simple state of the art H Ly $\alpha$ photometric monitor

##### System design

The instrument is a simple two-sensor photometer measuring the integrated H Ly $\alpha$  line. One narrow-FOV sensor (a) would be pointed in the antisolar direction and another (b) at an angle with respect to the spin axis of the spacecraft (Figure 5). This angle will be selected in such a way as to include observations of stable UV stars to monitor the stability of the sensor detection efficiency. Such an arrangement would allow measurement of the following quantities: (1) Photometer (a) would provide a radial dependence of the scattered solar H Ly $\alpha$  flux in the upstream direction. (2) Measuring the variation of the signal from photometer (b) versus clock angle would allow the determination of the direction of the LISM velocity relative to the Sun as well as possible asymmetry due to the presence of interstellar magnetic field in the LISM. Comparison of average count rates of photometers (a) and (b) would provide continuous monitoring of relative changes in detection efficiencies. Periodic observations of stable UV stars by photometer (b) would verify the stability of the absolute detection efficiency, and by inference, monitor the stability of the absolute detection efficiency of photometer (a).

The photometric technique proposed here reflects our unique 20+ year experience with the Pioneer 10/11 ultraviolet photometers [Carlson and Judge, 1974]. The Pioneer photometer consists of two channel electron multipliers detecting photoelectrons from two sensitive surfaces. Bendix-4028 channel electron multipliers were used and they showed exceptional stability until 1986, after roughly 15 years of continuous operation. Even after changes in the absolute detection efficiency were found, it was possible to account for these changes during data reduction [Hall, et al., 1993].

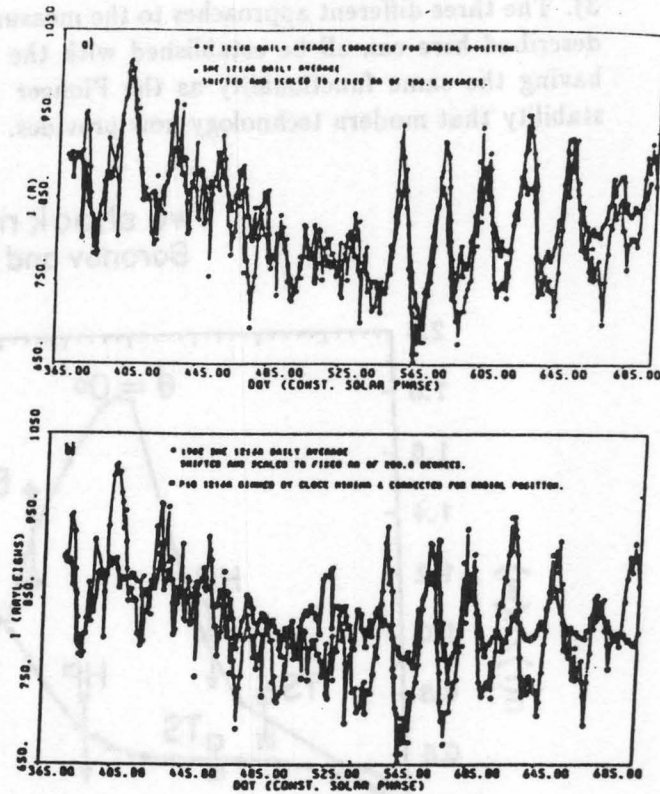


Figure 4: The variation of H Ly $\alpha$  emission as a function of time during 1982, in observations of VLISM scattered radiation by Pioneer 10 and Voyager 2, in comparison with direct SME observations of H Ly $\alpha$  emission from the sun. The heavy lines are the spacecraft data. The smaller magnitude of modulation in the spacecraft data is attributed to multiple scattering. Voyager 2 is positioned just beyond 10 AU, and Pioneer 10 at 30 AU, in 1982.

*High stability, high throughput detector, and electronic control system*

The proposed photometer would consist of two identical channels each consisting of a channel electron multiplier and a filter. Several changes in design, as compared to the Pioneer photometers, would be introduced.

1. Evaluation of the currently commercially available channel electron multipliers would be performed to determine the most stable detector. Special attention will be given to the newly developed multipliers with high count rate capability.
2. The short wavelength channel (in the Pioneer photometers) used for the detection of 584 Å radiation would be eliminated.
3. A simple electrostatic deflector to prevent entrance of charged particles into the instrument would be installed.
4. A second H Ly $\alpha$  photometer would be incorporated.
5. The principal configuration of the electronics scheme would remain

basically the same as the Pioneer UVS. It would, however, be completely redesigned and rebuilt on the basis of modern components.

The Pioneer photometer weighed 600 g with power consumption of 600 mW. It is safe to assume that with new technology, the weight of the new two-channel photometer could be reduced to 300 g with power consumption of not more than 300 mW.

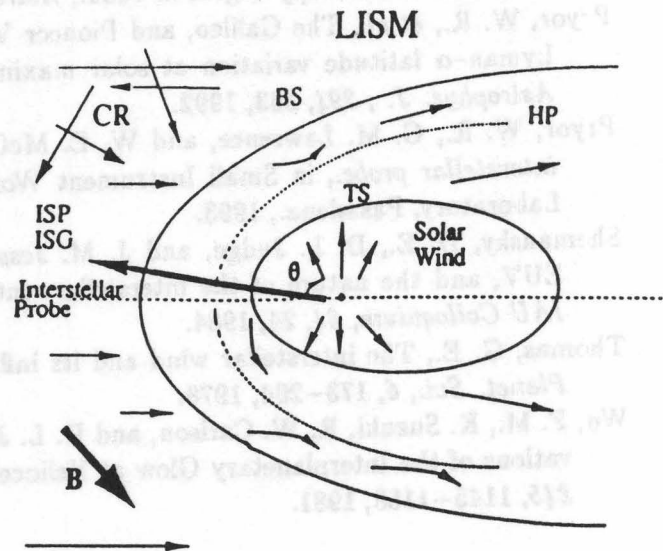


Figure 5: Configuration of the heliosphere and orientation of the proposed H Ly $\alpha$  monitor.

#### References

- Ajello, J. M., A. I. Stewart, G. E. Thomas, and A. Graps, Solar Cycle Study of Interplanetary Lyman-Alpha Variations: Pioneer Venus Orbiter Sky Background Results, *Astrophys. J.*, **317**, 964-986, 1987.
- Baranov, V. B., and Y. G. Malama, The model of the solar wind interaction with the local interstellar medium. Numerical solution of the self-consistent problem, *J. Geophys. Res.*, *in press*, 1993.
- Carlson, R., and D. Judge, Pioneer 10 Ultraviolet Photometer observations at Jupiter encounter, *J. Geophys. Res.*, **79**, 3623-3633, 1974.
- Fahr, H. J., The Extraterrestrial UV-Background and the nearby interstellar medium, *Space Sci. Rev.*, **15**, 483-540, 1974.
- Hall, D. T., D. E. Shemansky, D. L. Judge, P. Gangopadhyay, and M. A. Gruntman, Heliospheric hydrogen beyond 15 AU: Evidence for a Termination shock, *J. Geophys. Res.*, *in press*, 1993.
- Lallement, R., and J. L. Bertaux, Deceleration of interstellar hydrogen at heliopause crossing suggested by Lyman-alpha spectral observations, *Astron. Astrophys.*, **231**, L3, 1990.

Lallement, R., J. L. Bertaux, E. Chassefière, and B. Sandel, Interplanetary Lyman- $\alpha$  observations with UVS on Voyager: Data, first analysis, implications for the ionization lifetime, *Astron. Astrophys.*, **252**, 385, 1991.

Lallement, R., and A. I. Stewart, Out-of-ecliptic Lyman-alpha observations with Pioneer-Venus: Solar wind anisotropy degree in 1986., *Astron. Astrophys.*, **227**, 600, 1990.

Pryor, W. R., et al., The Galileo, and Pioneer Venus ultraviolet spectrometer experiments: Solar Lyman- $\alpha$  latitude variation at solar maximum from interplanetary Lyman- $\alpha$  observations, *Astrophys. J.*, **394**, 363, 1992.

Pryor, W. R., G. M. Lawrence, and W. E. McClintock, *A compact hydrogen absorption cell for interstellar probe.*, in Small Instrument Workshop., edited by B. Tsuritani., Jet Propulsion Laboratory, Pasadena., 1993.

Shemansky, D. E., D. L. Judge, and J. M. Jessen, Pioneer 10 vs. Voyager experiments in the EUV, and the nature of the interstellar- interplanetary medium, *Local Interstellar Medium IAU Colloquium*, **84**, 24, 1984.

Thomas, G. E., The interstellar wind and its influence on the interplanetary environment, *Earth Planet. Sci.*, **6**, 173-204, 1978.

Wu, F. M., K. Suzuki, R. W. Carlson, and D. L. Judge, Pioneer 10 Ultraviolet Photometer Observations of the Interplanetary Glow at Heliocentric Distances from 2 to 14 AU, *Astrophys. J.*, **245**, 1145-1158, 1981.