Proposal for an
ISSI Team
on
Coordinated Determination of the Physical Hydrogen Parameters of the Local Interstellar Cloud from within the Heliosphere

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Executive Summary

After a similar ISSI Team activity has led to the compilation of a bench mark set of physical parameters for interstellar helium, we plan to bring together a set of complementary data sets towards a coordinated analysis of interstellar hydrogen. With UV backscattering observations available from SOHO, Ulysses, Galileo, Cassini, Voyager and Pioneer, pickup ions on Ulysses, the interstellar gas related deceleration of the solar wind observed on Voyager 2, and Voyager 1 expected to cross the termination shock within the coming 5 to 10 years, we are in a unique situation to derive the state of our local galactic environment from observations inside the heliosphere. As for He we can clearly anticipate a benchmark set of physical parameters for H from the planned coordinated data analysis together with global heliosphere modeling. Combined with the He results, the coordinated H analysis will provide information on the filtration of the interstellar gas on its way into the heliosphere and it will constrain substantially the composition and ionization state of the local interstellar cloud (LIC). Based on this information also the radiation environment of the LIC will be constrained.

Introduction and Motivation

Over the past two decades material from the local interstellar cloud (LIC) has become accessible to in-situ studies using pickup ion observations for a variety of species (Möbius et al., 1985; Gloeckler et al., 1993; Geiss et al., 1994) and direct detection of neutral He atoms (Witte et al., 1996). These new methods have joined forces with remote sensing of interstellar gas through observation of back-scattered solar UV (see compilation by Chassefière et al., 1986) and measurement of UV absorption lines in the spectra of neighboring stars (Bertin et al., 1993), which have developed over the past three decades. Each of these observation methods has its strengths and weaknesses. The particle measurements represent local samples of the LISM distribution in the inner heliosphere and depend on local ionization and transport processes, while the remote sensing techniques return line-of-sight integrals of the particle distributions with all the related ambiguities. Because all measurements are taken in the inner heliosphere the physical parameters that are deduced for the LISM outside the heliosphere from these observations are strongly model dependent. For an overview see reviews by, e.g., Axford (1972), Fahr (1974) and Holzer (1989).

In a dedicated ISSI Team we have analyzed the combined data sets from coordinated observation campaigns of the interstellar helium cone with in-situ and remote sensing methods together with the necessary supporting observations over three years from 1998 through 2000 and modeled these observations with the values derived from direct neutral gas observations. The results - a benchmark set of interstellar He parameters, which explains consistently the observations with all in-situ and remote sensing techniques, while calling for additional ionization by electron impact and the consideration of a full 3D modeling of the gas in the inner heliosphere - have been compiled into a group of publications for Astronomy & Astrophysics.

Based on the successful analysis of interstellar He, which provides pristine LIC parameters that not affected by processes the heliospheric interface region, we now propose to turn our coordinated investigations to a similar data set for interstellar hydrogen. The comparison between the two key species of the LISM will provide valuable constraints on the filtration of interstellar gas at the heliospheric boundary and into the related physical processes. Together with detailed global modeling this will lead to a substantially improved set for the bulk parameters of the main component of the LIC. This analysis will also provide further constraints on the ionization fraction of the LIC, which thus far can only be inferred (Frisch and Slavin, 1996), A Team for collaborative work at ISSI is proposed, which has direct access to all relevant data sets, has the expertise with modeling these data, and brings the expertise on global modeling inside, outside and across the boundary of the heliosphere.

Compilation of He Cone Results

The coordinated analysis of data obtained simultaneously with all three observation techniques at our disposal for interstellar He inside the heliosphere, i.e. backscattering of solar UV, pickup ion and direct neutral gas diagnostics, has essentially removed major differences and uncertainties in the results that were prevalent in the past (e.g. Chassefiere et al., 1986; Möbius, 1993). Led by direct neutral gas observations (Witte et al., 1996; 2002) for the dynamic parameters (n, T, v_B, □ and □) and by the analysis of He^{2+} pickup ions (Gloeckler et al., 1997; Gloeckler and Geiss, 2002), all the other observations could be modeled consistently with the same parameter set, provided that temporal and spatial variations of all ionization contributions and proper solar illumination of the neutral gas were taken into account. The fact that for the first time also direct measurements of the EUV ionization rate (Judge et al., 1998) and data about the illuminating HeI 584 Å line are available has reduced substantially the uncertainties during the analysis and allows a clear separation of additional ionization processes. Besides providing a first benchmark set of interstellar He parameters, this analysis strongly implies that significant additional ionization – at a higher rate than previously thought – is at work inside 1 AU, most likely electron impact ionization, and that latitudinal variations as well as north-south anisotropies of these effects have to be taken into account in the modeling. Past differences in the derived parameters and their uncertainties could be mostly traced to insufficient knowledge of these drivers for the observables and of instrumental calibrations

The results of the previous ISSI Team on interstellar He provide us with a physical parameter set that reflects the undisturbed dynamic and kinetic conditions of the LIC, because He is unaffected by the heliospheric interface. The better knowledge of the driver conditions inside the heliosphere, which favorably connect to proxies on a longer time scale (Viereck et al., 2001), can also be used to retroactively improve past observational analysis. Finally, these results are a stepping-stone for more complex analysis of H in the LIC, which, in combination with He, provide insight into the heliospheric boundary processes and a handle on the LIC composition and ionization state.

Goals of a Combined Analysis of LISM H in an ISSI Team

As with the He analysis the goal of this team is to provide a benchmark set for the physical LISM parameters of H (density, bulk velocity and temperature) at the termination shock. However, since the He parameters are already determined, the anticipated results will allow us to take further steps. Firstly, the differences between the He and H parameters will set very tight constraints on the physical processes in the heliospheric interface region that will lead to filtration of most of the LISM species, except He (Zank et al., 1999). Secondly, having established the filtration the measurement of LISM abundances inside the heliosphere and detailed modeling will be used to deduce a LISM abundance pattern for the neutral gas component (Izmodenov et al., 1999; Müller et al., 2000). Finally, these results will be compared with the quantitative predictions for the ionization state of the LISM based on modeling of the radiation environment of our galactic neighborhood (Frisch and Slavin, 1996). Ultimately, this will provide a profound test of the model assumptions and will thus link up with direct observations of the local UV and X-ray environment (Wolff et al., 1999).

Analysis Approach of the H ISM ISSI Team

As with our previous successful work on the interstellar He several complementary data sets obtained from different techniques are available for H of the LISM. Several instruments capable of mapping the backscattered Ly□ radiation from interstellar H are currently distributed throughout the heliosphere. SOHO SWAN (Bertaux et al., 1988) has been and is collecting a comprehensive set of Ly□ full sky maps from L1 over the entire solar cycle with intensity and Doppler shift information (Quemarais et al., 1999). Detectors with a combination of sensitivity to Ly□ and Ly□ are at various distances from the sun on Galileo (Barth et al., 1997), Cassini, the Pioneers (Gangopadhyay et al., 2002) and the Voyagers. In addition, the Ulysses GAS instrument serves as a valuable Ly□ detector at high latitudes (Pryor et al., 2001). Between ≈3 and 5 AU Ulysses SWICS is collecting H pickup ions over this solar cycle, which allow the monitoring of the H density distribution inside the Ulysses orbit and thus the derivation of the He density at the termination shock (Gloeckler et al., 1997; Gloeckler and Geiss, 2001). Finally, the increasing deceleration of the solar wind with distance from the sun provides an independent account of the H density at the termination shock (Wang and Richardson, 2003).

From our past experience with the He analysis it is obvious that the particle observations, in general, produce better constrained results for the density. Therefore, we plan to start with a careful cross-examination of the density results provided by the pickup ion observations and by the solar wind deceleration. To evaluate pickup ion observations quantitatively (and also the UV scattering observations) careful modeling of the neutral distribution in the inner heliosphere is needed, which includes the proper treatment of the solar activity dependent ionization and radiation pressure (Rucinski and Bzowski, 1995; Bzowski et al., 1997) and to possibly monitor these effects directly. The solar wind flux that is responsible for charge exchange, the expected main channel for H ionization is directly observed with SWICS. We plan to augment the knowledge of the ionization by analyzing the Lyman continuum UV flux from UARS. SWAN observations will provide the radiation pressure. The deceleration of the solar wind involves a difference measurement between the solar wind speed in the inner heliosphere (at Ulysses or an Earth-orbiting spacecraft) and at the distance of Voyager 2. MHD modeling is used to predict the speed expected at Voyager 2 based on speeds in the inner heliosphere, then the density of the interstellar H is adjusted to fit the observations. These calculations can be performed only when two spacecraft are at the same heliolatitude or near solar maximum, when heliolatitudinal speed gradients are small (Wang and Richardson, 2003). While this method is not affected by inner heliosphere modifications of the LIC gas, it relies on long term cross calibration of sensors in the inner and outer heliosphere and the proper modeling of the solar wind flow. Both density values, from pickup ion and from solar wind observations, are given increasing constraints for their upper limit by increasing minimum distance of the termination as Voyager 1 moves out (Gloeckler et al., 1997; Gloeckler and Geiss, 2001).

In particular, the SOHO SWAN observations provide the means to determine the bulk velocity vector and temperature from resonant absorption measurements (Quemarais et al., 1999). As a byproduct of these observations the fractional compensation μ of the sun's gravitation by radiation pressure can be deduced. Combining the sky maps from different phases of the solar cycle together with concurrent information on the solar illumination UARS and the SOHO instruments will reduce the error bars for both observables.

We will then move on to modeling the UV backscatter sky maps obtained with SOHO SWAN, Galileo, Cassini, Pioneer, Voyager and Ulysses GAS, based on the parameter set as obtained through the methods described above, similar to our approach for He. This modeling will explicitly include solar cycle variations (Bzowski et al., 1997; Tobiska et al., 1997), radiation transfer effects (Keller et al., 1981; Quemarais and Bertaux, 1993). As in the case of He, the observations from various locations in the heliosphere should provide a handle on additional ionization effects and spatial dependencies that so far may not be so well known. Making use of the observations of the main ionization effects will enable us to isolate additional effects.

Armed with the combination of the physical parameters of He in the LIC and those of H at the termination shock, the input parameters for the modeling of the heliospheric interface processes and for the global heliospheric models that are scaled with the size of the heliosphere can be constrained. Within the interface interaction the deceleration, heating, filtration factor and ionization of H are intimately connected. Therefore, this analysis will also provide a key value for the LIC ionization state. In a recent analysis Izmodenov et al. (2002) performed a parameter study after setting the bulk velocity and temperature of the LIC to the current best values, using the universal abundance H/He = 10 and assuming a He ionization of 35% as found from UV absorption. This exercise constrained the size of the heliosphere, the H density and ionization. Of course, the detailed results are model dependent. Therefore, an attempt to compare the current two independent models (Izmodenov et al., 1999; Müller et al., 2000) and their assumptions for a set of identical starting parameters has already been initiated.

The anticipated better knowledge of the heliospheric filtration will also reduce error bars for the relative abundance of neutral O, N, and Ne in the LIC as deduced from inner heliospheric observations (Geiss et al., 1994; Cummings et al., 2002). As has been shown through extensive modeling of the LIC environment, assuming a variety of different scenarios for the UV and X-ray spectrum in the local galactic neighborhood, the abundance ratios for the neutral component of these species in the LIC varies widely in response to the radiation environment (Frisch and Slavin, 1996). Together with the ionization fraction of H, as deduced from the filtration, this will substantially narrow the choices of scenarios for the radiation environment.

Team, Planned Activities, Time Line and Anticipated Products

The purpose of this ISSI Team activity is to bring together members with diverse expertise and access to a wide variety of data sets to facilitate the coordinated analysis outlined above. Much of the detailed work will happen at the home institutions of the individual members, will involve additional scientists and will be coordinated by meetings, phone conversations and over the internet. Anticipated meetings and workshops at ISSI will be used (a) to define the coordinated work to be performed and (b) to synthesize the combined results and start the process towards publication.

To get the coordinated work started, a meeting of the full team will be planned either for late summer 2003 or in the first half of 2004. This meeting will consist of overview presentations on the results obtained thus with the key data sets and on the models that will facilitate the analysis. From there we will turn into a workshop mode, where subgroups (involving individual observation methods and modeling) will work on cross-examination and the definition of combined analysis time periods. At the end of the workshop we will define data sets that will be made available to all team members for further comparative work at their home institutions over the coming year. Approximately one year later late 2004 or first half of 2005 a second Team Meeting will be held at ISSI, where the findings of the combined analysis will be reported and discussed. This meeting will also be used to plan a series of publications during the second year, probably in a similar format as being finished right now by the previous ISSI Team for Astronomy & Astrophysics. An additional meeting in a small subgroup to finish these publications may be added a few months later. In all cases, members of the Team, who may not be able to attend, or scientists who bring additional expertise in one of the areas of concern may participate in the meetings via internet, a practice that was tried out successfully during the last meeting of the ISSI on interstellar He. During and after the completion of the Team activities we encourage strong engagement at national and international conferences. As in the case of the last Team activity the Team will also provide the nucleus for the planning of topical symposia during international conferences (COSPAR, AGU-EGS).

Eberhard Möbius will lead the activities with the experience gained from the previous ISSI Team on the interstellar He parameters and actively participate in the intricacies of pickup ion analysis. He will also bring in additional information as needed and as it develops. George Gloeckler brings in his Ulysses SWICS data on pickup ions and his overall analysis expertise for interstellar medium studies. John Richardson will contribute with his work on the solar wind deceleration and bring the Voyager plasma data. Rosine Lallement will lead the activities concerned with UV backscattering and bring in the SOHO SWAN data. The crucial absolute calibration of the SOHO SWAN data will be assisted by comparison with the near sun observations by UVCS (John Raymond). The UV analysis of interstellar H, which ultimately can be rolled back to the 1970's will be greatly enhanced by the availability of similar data from Galileo, Cassini, Pioneer Venus (Wayne Pryor), Ulysses GAS (Manfred Witte), and Pioneer 10 and 11 (Pradip Gangopadhyay). Annuschka Pauluhn, who works on related problems at ISSI will evaluate the solar illumination in Ly□. This coordinated analysis can only be successful and recover the full information by involving several layers of modeling. Maciej Bzowski will be responsible for the local modeling of H distribution in the inner heliosphere and its transformation into pickup ions. Vlad Izmodenov and Hans-Reinhard Müller bring two independent codes capable of global modeling of the heliosphere and diagnosing the critical processes at the heliospheric interface. It will be important to cross-check this critical piece of the puzzle. Hans-Jörg Fahr brings his long-term expertise on local and global modeling that runs from the beginning of heliospheric physics to date. Finally, Priscilla Frisch and John Slavin are the experts on the modeling of the physical conditions of the local bubble and its radiation environment.

As this series of two ISSI Teams is anticipated to make substantial progress in the understanding of our local interstellar medium, we suggest that in a final stage also a Review article be prepared in collaboration of some or all of the team members.

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