Solar Heliospheric Lyman Alpha Profile Effects (SHAPE)

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Abstract:
We propose to create an ISSI team to study the effect of solar Lyman alpha (121.6 nm) radiance and irradiance variability on the heliosphere. In particular, we will investigate the variability in the line profile over the solar cycle from both theoretical and observational perspectives. The standard solar irradiance data product available to the scientific community has been binned to 1 nm intervals, losing all information about the line shape. Heliospheric and planetary observations and models have become more sophisticated in recent years, and the wavelength dependence of the variability in the line profile is now a significant source of uncertainty.

Currently, the heliospheric and planetary science communities take the published 1 nm irradiance variability and apply a scaling factor to estimate the variability of the line core. The scaled solar irradiance variation is used to calculate the ratio of radiation pressure to gravitation (known as μ) for the hydrogen in the heliosphere. This in turn is used to compute the backscattered Lyman alpha which is compared to observations from the Solar Wind ANisotropies (SWAN) instrument on the Solar Heliospheric Observatory (SOHO). The heliospheric model authored by the Moscow group (Izmodenov et al. 2013) can use the true Lyman alpha line profile as an input, and we will compare the results of their calculations to observations.

Finally, we have new observations of interplanetary hydrogen from the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission. During the cruise phase, the Imaging Ultraviolet Spectrometer (IUVS) has measured Lyman alpha emission in high resolution echelle mode. This dataset will dovetail perfectly with our analysis of the spectrally resolved heliospheric model results.

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The goal of the proposed ISSI team is to improve our understanding of physical processes on the Sun and in the heliosphere. We will start with the solar atmosphere. The resonance line of hydrogen at 121.6 nm is the alpha transition of the Lyman series. It is formed in the transition region, although it is such an optically thick line that it really includes contributions from many layers of the Sun's atmosphere. In addition, the Lyman alpha radiance is a strong function of position on the Sun. Active regions represent concentrations of magnetic activity, and the Lyman alpha emission from these localized areas on the solar surface is much larger than the emission from the surrounding quiet Sun. As the Sun rotates, these bright spots illuminate the heliosphere much like a series of spotlights. The amount of activity on the Sun also varies over an approximately 11 year cycle. The total Lyman alpha irradiance changes by nearly a factor of two over the solar cycle, and there are also significant changes to the line profile with time (Curdt and Tian 2010). Each solar cycle is unique, and the current maximum features a significant asymmetry between the north and south hemispheres of the Sun. Activity in the northern hemisphere has already begun to decline, while the activity level of the southern hemisphere is still increasing. The Earth, other planets, and the heliosphere all see an ever-changing illumination by Lyman alpha photons.

Lyman alpha is the most important spectral line for the interplanetary medium and is also a significant driver for the atmospheres of the planets and the Earth. For many atmospheric models, the spectral resolution is very low. Therefore, the standard solar spectral irradiance (SSI) data product is binned to 1 nm intervals in the ultraviolet. That may be sufficient for some applications within the Earth science community, but as models become more sophisticated, the need for higher resolution SSI will increase.

The relative variability of the solar spectrum binned to 1 nm intervals is obviously not the same as the variability of the full resolution spectrum. Heliospheric models have tried to simulate the Lyman alpha line variability by applying a scaling factor to the 1 nm data (Quémerais et al. 2013). Current analysis methods allow this scaling factor to change over the solar cycle, but as can be seen in Figure 1, the scaling factor actually varies from one rotation to the next. In the figure, we have plotted the 1 nm daily average as the solid red line, and the peak of the Lyman alpha line for each individual spectrum as the diamond symbols. For solar rotations with moderate activity levels such as those in mid-2004, the relative variation between the two are very similar. But for rotations with larger activity levels, the 1 nm data product significantly underestimates the variability of the line core.

The scaling factor is used to calculate the ratio of radiation pressure to gravitational attraction (known as μ). It is one of the fundamental parameters of the interplanetary medium, and determining its value accurately is crucial to understanding the behavior of the heliosphere. As an important test case, we will study the effect of the variation in the Lyman alpha line shape on the heliosphere. Our team will bring together experts in solar physics, solar observing instrumentation, and heliospheric modeling. We plan to assemble a time series of spectrally resolved Lyman alpha data for at least two solar cycles, using data from the Solar Radiation and Climate Experiment (SORCE), the Upper Atmosphere Research Satellite (UARS), the Solar Heliospheric Observatory (SOHO), and the Solar Dynamics Observatory (SDO).

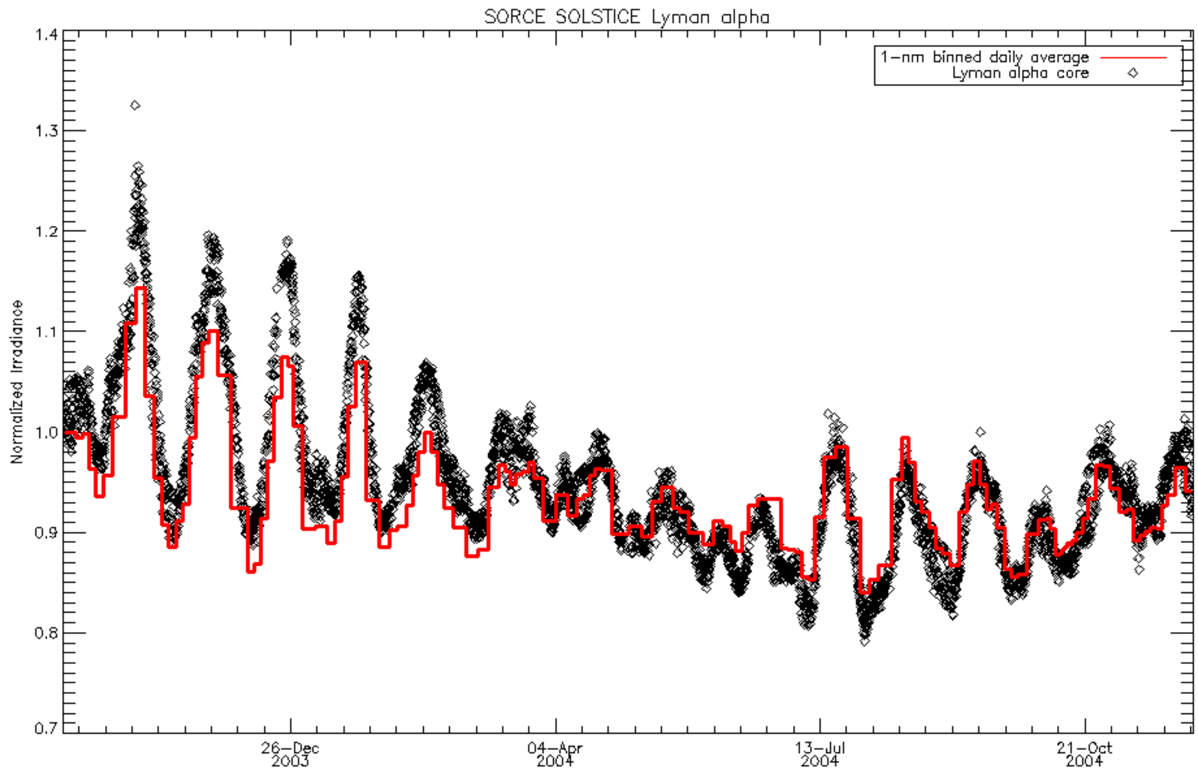

Figure 1. Time series of Lyman alpha solar spectral irradiance from SORCE SOLSTICE. The red curve shows the relative change of the daily averaged 1 nm binned spectrum. The black diamonds show the peak flux of the Lyman alpha line during each individual spectral scan at 0.1 nm resolution. During periods of moderate solar activity, the variation is comparable, but the 1 nm data product greatly underestimates the variability during times of high solar activity.

We will tailor this new dataset for use in the Izmodenov advanced model of the heliosphere (Izmodenov et al. 2013). This model is already designed to accept Lyman alpha line shape information, so the larger task will be to assemble the solar dataset. The model has successfully produced results in agreement with the broadband measurements of the Solar Wind ANisotropies (SWAN) instrument on SOHO (Bertaux et al. 1997, 1999), the instruments on Voyager 1 and 2 (Broadfoot et al. 1977), and the ultraviolet spectrometer ALICE on the New Horizons spacecraft (Gladstone et al. 2013). Cross-calibrating the various observations of the interplanetary hydrogen (IPH) was the main task of a previous ISSI working group, FONDUE. We can now build upon the results of that group's effort.

Figure 2 shows the Lyman alpha line profile obtained with the SOHO/SUMER instrument for a quiet Sun region on the solar disk. The plot clearly indicates the strong similarity in the shape of the line. At the same time the Lyman alpha lines shows a rather high variability, in particular of the line core, for the quiet Sun regime. This is of course even more pronounced in the case of active regions.

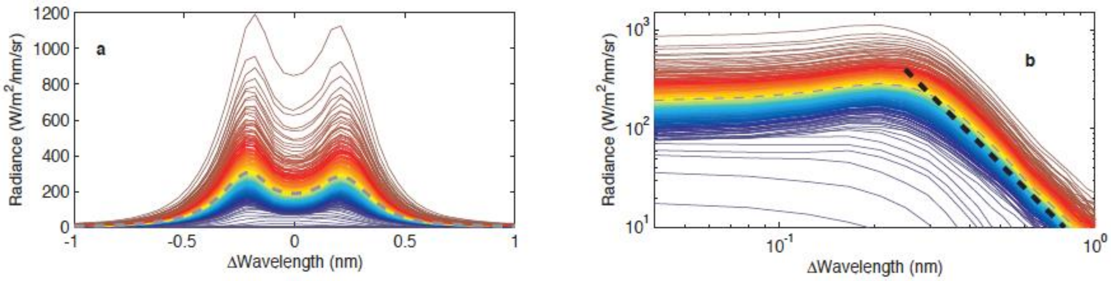

Figure 2: SUMER Lyman-observations are shown in linear scale (panel a) and logarithmic scale (panel b). Each line in the diagram represents the average of 100 observed profiles sorted by total intensity. The dashed black line in panel (b) displays the slope of-3.2 Wm^{-2} $nm^{-2}sr^{-1}$. From Schöll et al., 2014.

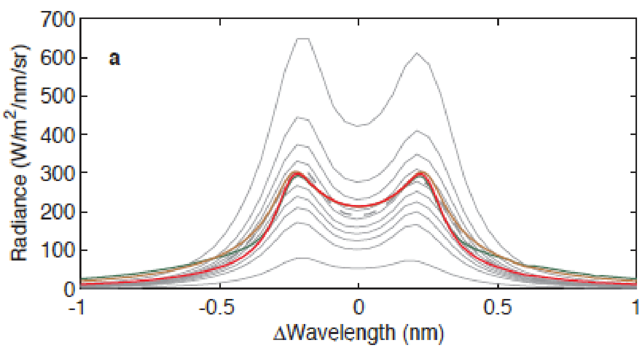

Figure 3 shows the observed (grey lines) and the modelled (red line) Lyman alpha line profiles using the COSI code.

During the SHAPE project, we plan to reconstruct the solar spectral irradiance (SSI) in the Lyman alpha spectral range. To do so, we will employ the COSI code (Haberreiter et al. 2008, Shapiro et al. 2010), and the latest calculations by Schöll et al. (2014) as well as the SOLMOD code (Haberreiter 2011). In order to determine the solar spectral variation over the Lyman alpha spectral line, the theoretical calculations will be combined with latest segmentation analyses of images taken with the Precision Solar Photometric Telescope (PSPT in Rome and Hawaii) and Michelson Doppler Imager (MDI, Scherrer et al., 1995) onboard the SOHO Mission, as described in Ashamari et al. (2014). By combining the theoretical Lyman alpha radiances for different activity features on the Sun (see Fig. 3 as example for the quiet Sun) with their area coverage identified from the image segmentation, we will derive the detailed time dependent spectral irradiance over the full Lyman alpha line profile. These analyses will allow us to investigate the different driving mechanisms responsible for the variation in the core and the wings of the Lyman alpha spectral line.

In addition to the IPH datasets mentioned above, new observations have become available. The Mars Atmosphere Volatiles and EvolutioN (MAVEN) mission launched in November 2013 (Lin and Jacosky 2012). During its cruise phase, it has begun taking observations of the IPH with the Imaging UV Spectrograph (IUVS) in echelle mode. We will be able to specify the exact observing geometry that the Izmodenov model should reproduce during the first meeting, and then examine the results at the next meeting a few months later.

During its prime science phase, the MAVEN mission will study the escape of H and O atoms from the upper atmosphere of Mars, both with low spectral resolution altitude profiles of the UV emissions and with an echelle channel that will resolve the Lyman alpha line profile. To interpret the Martian Lyman alpha profile, they will need a high quality solar Lyman alpha profile, which will then be an input to radiative transfer models. In particular, the MAVEN IUVS instrument will detect the Deuterium Lyman alpha emission which is 0.33 Angstroms shortward of the H line central wavelength. Knowing the solar flux at this wavelength will be key to the interpretation of the MAVEN data and to the derivation of the H and D line of sight densities.

The team members were chosen for their expertise in topics relevant to the team concept. The team leader, Martin Snow, is the instrument scientist on the SOLar-STellar Irradiance Comparison Experiment (SOLSTICE) on both SORCE and UARS. The two instruments have measured Lyman alpha solar irradiance on a daily basis since 1991. Werner Curdt is the current PI for the SUMER instrument on SOHO, which has been making measurements since the mid-1990s, and he is an expert on Lyman alpha observations. The spectral resolution of SUMER is much higher than SOLSTICE and can measure the Lyman alpha profile of various disk features down to 2 km/s free from geocoronal absorption (Curdt et al. 2008). Matthieu Kretzschmar is a Co-I of PROBA2/LYRA, which has been making high time-cadence observations of Lyman alpha since 2009. Based on her expertise in radiative transfer and solar irradiance reconstruction, Margit Haberreiter will join the SHAPE team. She will carry out the reconstruction of the Lyman alpha line profile. Moving away from the Sun, Eric Quémerais is the PI of the SWAN instrument on SOHO, which has been measuring the Lyman alpha backscatter from the IPH for nearly two decades. The newest IPH measurements will come from MAVEN. John Clarke is leading the analysis of the MAVEN IPH observations, and will have access to the latest data. Greg Holsclaw was chosen for his extensive knowledge of the MAVEN IUVS and the IPH observations from MESSENGER. Finally, we have Vlad Izmodenov on our team. He is the leader of the IPH modeling effort at Moscow State University. He is well known to ISSI, having served on many successful working groups and teams in the past.

Our overall plan will be to break the problem into three parts. The first part will concentrate on the solar observations. The questions that we will answer from this ISSI team are: Can we extract the true solar Lyman alpha variability from the existing record of radiance and irradiance measurements? Can we reconstruct the Lyman alpha profile with the COSI and SOLMOD codes based on image segmentation from PSPT and SOHO/MDI observations? What are the needs of the modeling community in terms of wavelength resolution and time cadence? Can we extend the current dataset farther into the past using proxies?

The second task will be to use the new Lyman alpha dataset as input to an IPH model. We can use an IPH model as a test case for the new data product, but it would be equally relevant to use a planetary atmosphere or Earth atmosphere model. This middle task will also offer the opportunity to revise choices made in assembling the Lyman alpha data product if deficiencies are discovered during integration with the IPH model. We also plan to make use of the well-timed new IPH observations from MAVEN described above.

The third task will be to analyze the agreement of the new model results with the SWAN and MAVEN observations. Our new Lyman alpha dataset will produce publishable results on spatially resolved Lyman alpha observations, line profile variability over the solar cycle, and comparison to long-term proxies for Lyman alpha that are used in climate models.

Proposed Schedule:

First team meeting in late 2014: *The Solar Source*. We will begin with the theoretical calculation of the Lyman alpha line profile in the solar atmosphere and compare it to available solar observations. The goal will be to produce the appropriate time-varying line profile which best represents the solar cycle. This profile will then be given to the heliospheric modelers.

Second team meeting in mid 2015: *A Tale of Two Hemispheres*. Solar cycle 24 has a larger asymmetry between the northern and southern hemispheres than has been recently observed. Can we use the spatially resolved observations of the Sun to further improve our understanding of the physical processes of the heliosphere? We will begin to examine the results of using the line profiles from the first team meeting as inputs to the heliospherical models. By the time of this meeting, high resolution observations of interplanetary hydrogen emissions should be available from the MAVEN mission. The exact conditions of the observations can be discussed with the modelers to prepare for the final meeting.

Third team meeting in late 2015 or early 2016: *All's Well That Ends Well.* Comparison of heliospheric model results using realistic Lyman alpha line profiles will be compared to broadband SWAN measurements as well as the high-resolution MAVEN observations. Presentations of team papers: Spatially resolved solar observations, line profile variability over the solar cycle, improvements in the heliospheric models due to improved line shape input, and comparison of the model results to the MAVEN observations.

Benefits from ISSI-Bern participation:

The international team described here will be able to combine our separate areas of expertise to tackle the problem of wavelength dependent Lyman alpha emission from the Sun over long timescales. This team includes members from the US, France, Germany, Switzerland, and Russia who would otherwise have difficulty in collaborating on this project. In particular, the direct interaction between the solar observers and modelers from the west and the heliospheric modelers from Moscow is becoming more difficult in today's political climate. The exchange of ideas at ISSI is a unique opportunity for these groups to interact. The objectives of the proposed team fit in well with the goals of ISSI to analyze and evaluate existing data from several spacecraft and to integrate them with theoretical models.

ISSI Facilities:

No special equipment is required. Access to the internet and to projectors during the meeting is highly desired.

Financial support:

The financial support of ISSI is requested in accordance to the general policy described in the call for proposals: per diem and hotel for all participants, plus travel expenses for one team member.

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