Solar UV bursts—a new insight to magnetic reconnection

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ISSI location: Bern

The Sun's activity is widely believed to be driven through small-scale magnetic reconnection events that heat plasma and drive plasma flows. The recently-launched Interface Region Imaging Spectrograph (IRIS) spacecraft gives high spatial resolution access to the Sun's chromosphere and transition region and has revealed a particular class of highly-energetic events termed ultraviolet bursts (UVBs) with a several-order of magnitude increase in radiation and 100's of km/s plasma flows, occurring on spatial scales of 500 km (Peter et al. 2014, *Science*). Their properties suggest that we have reached a fundamental energy release event on the Sun that can be fully probed using the current suite of solar instrumentation. The team will develop new observing campaigns utilizing a wide range of ground-based and space-based observatories (Swedish Solar Telescope, Dunn Solar Telescope, Solar Dynamics Observatory, Hinode and IRIS) to fully characterize how the events are driven by the magnetic field and how the released energy is distributed through the solar atmosphere. The key physical parameters will then be used to develop models for the events to determine their significance for the heating and dynamics of the solar atmosphere. Measuring and modeling the energy transfer and heating of the UVBs is a timely, focused and tractable problem uniquely suited to the ISSI meeting format.

1. Introduction and overview

Solar active regions display very intense, short-lived brightenings at temperatures around 10^5 K that we term ultraviolet bursts (UVBs). The recently-launched IRIS satellite has revealed these events in exquisite detail as tiny, highly-energetic events that are intimately tied to the evolution of the local magnetic field. The importance of UVBs lies in their being a *fundamental magnetic reconnection event* that is bright enough to be studied in detail with modern instruments, yet simple enough to present a tractable problem for theorists. Our team comprises an ideal mix of observers, spectroscopists and theorists to make a significant advance in the understanding of magnetic reconnection in the astrophysical context.

2. Scientific rationale

The Sun produces a wide range of transient events from tiny spicules in the quiet Sun, to large flares and coronal mass ejections. Almost all of these events are believed to be the product of subsurface flow patterns that drive the magnetic field into a configuration whereby magnetic reconnection can take place in the outer layers of the atmosphere. The photosphere and chromosphere are routinely observed at high spatial resolutions of $0.1''$ to $0.2''$ by ground-based observatories and the Solar Optical Telescope (SOT) on board the Hinode satellite. But there remained a large disconnect between the detailed observations of the lower layers and the transition region and corona that were only observed at $\geq 1''$ resolution by satellite-borne instruments. This changed in 2013 when the Interface Region Imaging Spectrometer (IRIS) was launched, giving $0.3''$ resolution at transition region temperatures of 10^5 K. *Only with the current suite of ground- and space-based instrumentation can we definitively bridge the gap between the surface drivers and the consequences in the solar atmosphere.*

Our provisional definition of a UVB is a small-scale brightening ($\lesssim 1''$) seen in either of the IRIS Si IV emission lines (Figure 1) with intensities and widths much larger than average quiet Sun values. (More clearly defining UVBs and relating them to previously studied solar features will be a part of the project.) A particular focus will be on how UVBs correspond to the well-known Ellerman Bombs (EB) that are the most spectacular of all small-scale photospheric phenomena, but are not believed to leave an imprint on the higher layers of

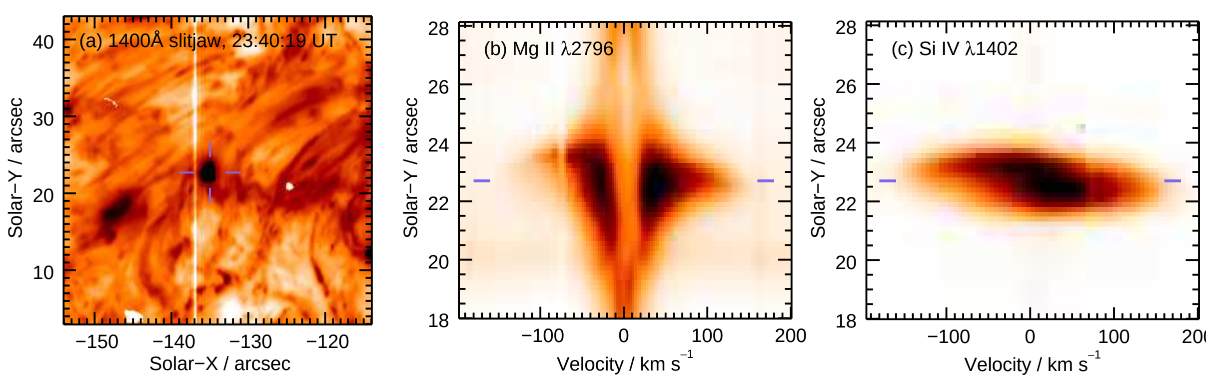

Figure 1: An example of a UVB. Panel (a) shows an IRIS slitjaw image (inverse log-intensity); the location of the UVB is indicated by a cross. Panels (b) and (c) show the Mg II λ2796 and Si IV λ1402 line profiles along the IRIS slit. Dark regions correspond to higher intensity.

the atmosphere (Rutten et al., 2013). Although discovered almost 100 years ago, EBs have been the subject of intense interest recently from both observational and theoretical aspects, and several of the team members are acknowledged EB experts.

The IRIS observations are critical as they show many EB-like events that are achieving transition region temperatures (Figure 1), significantly broadening the interest of UVB studies. A critical issue is then whether some UVBs can achieve coronal temperatures that would demonstrate such events are not only testing grounds for magnetic reconnection theory, but may also be significant for coronal heating. Early studies of IRIS UVBs have indeed demonstrated that UVBs can yield significant coronal emission (http://pyoung.org/talks/aas2014).

Our project will be guided by the work previously done on EBs as these are the closest analogs to UVBs. We therefore summarize their key properties. EBs are uniquely identified through their signature in spectra of the Hα absorption line, which develops enhanced emission in the wings that extends out to several Å from line center. They are specifically associated with moving magnetic features (MMFs), either from a sunspot or marking emerging flux in the core of an active region, and field cancellation occurs at the site of the EB.

Prior to the launch of IRIS, Rutten et al. (2013) distinguished two types of UVB events discussed in the literature: one is a classic EB that has no effect on the overlying chromospheric canopy, whereas the second is a "flaring arch filament" (FAF) that has a more extended structure and shows upper-atmosphere heating. This suggests that the background magnetic topology in which the small-scale magnetic reconnection is occurring may be critical in determining if hot plasma is created in the event and transferred to the upper atmosphere. IRIS is the only instrument capable of clearly distinguishing the two types of event.

Based on the observational evidence, a simple model for an EB involves a partially-submerged magnetic field. The Parker instability results in the depressed field line falling deeper into the Sun. The two oppositely-directed field lines above it reconnect, releasing energy that is responsible for the enhanced wings of Hα. Partially-submerged fields can naturally arise in the moat flow from sunspots (Thomas et al., 2002) and are seen in magnetic field extrapolations of real data (Pariat et al., 2004). Recent 3D flux emergence simulations (Toriumi & Yokoyama, 2011; Cheung et al., 2010) have demonstrated that newly emerged magnetic fields run above the photosphere in an undulating manner, and are subject to reconnection where the field dips below the surface. This serves to release dense photospheric plasma from the field, enabling the loops to rise further and lead to the development of arch filament systems and coronal loops. Therefore EBs are fundamental signatures of the flux emergence process. The fact that a certain class of events (FAFs) is able to heat the solar atmosphere has important implications for coronal heating, and the cause of this will be investigated in this project.

Peter et al. (2014) presented the first observations of UVBs giving four examples identified in a single scan of an emerging active region. They suggested a connection with EBs, but due to the lack of contemporaneous spectrally resolved, chromospheric observations, they were unable to fully establish the link, although their interpretation of the events was very similar to that for EBs. We note that the events occur near small loops belonging to an arch filament system and so may be FAFs, the second type of UVB discussed by Rutten et al. (2013). The events discussed by Young (http://pyoung.org/talks/aas2014) are distinct and associated with MMFs in a sunspot moat flow, although the active region was emerging flux at the time.

The connection of UVBs to EBs is an important one, but we also plan to investigate the relationship of UVBs to other, previously identified transition region phenomena such as explosive events (Dere et al., 1989), blinkers (Harrison, 1997) and sunspot dots (Tian et al., 2014b). Explosive events demonstrate strong line broadening, like UVBs, which has been cited as evidence for magnetic reconnection (Innes et al., 1997), but generally do not have a strong intensity signal. Blinkers are short-lived flashes in the transition region, and a small sub-set achieve intensities consistent with UVBs (Parnell et al., 2002; Young, 2004). The sunspot dots are mostly weaker and more short-lived than UVBs, and do not seem to be associated with emerging flux, however the most intense events may be UVBs. Identifying the differences and similarities with these events will be part of the project, and team members Madjarska and Tian have significant experience from the SOHO/SUMER instrument.

3. Goals

Our over-arching goal is to understand UVBs as fundamental magnetic reconnection events for which we can use high-resolution chromospheric and transition region diagnostics to constrain the magnetic reconnection process. Specific goals to achieve this objective are:

1. Obtain new coordinated data-sets of UVBs using IRIS, Hinode, the Dunn Solar Telescope (DST), and the Swedish 1-m Solar Telescope (SST).
2. Identify a specific UVB archetype (or types) that show a consistent magnetic evolution and upper atmosphere signature.
3. Make 3D models of the event archetype to reproduce the evolution and heating.
4. Perform radiative transfer modeling to reproduce the observed emission line profiles, particularly Hα, Ca II , Mg II h & k, C II and Si IV.
5. Derive physical parameters of reconnection from the modeling, including velocity flows, heating, and heat-input timescales, and compare with observed parameters.

4. Timeliness

This project is driven by the new data returned by the IRIS spacecraft (launched in 2013) which is returning the first long-term sub-arcsecond resolution spectroscopy of the solar upper atmosphere. Peter et al. (2014) described the first UVB observations in one of the five first-results IRIS papers published in *Science*. In addition studies of EBs have been reinvigorated by new high-resolution, high-cadence ground-based observations and advances in theoretical work, which have led to 10 papers in the past two years, many by team members (e.g., Berlicki & Heinzel, 2014; Rutten et al., 2013; Vissers et al., 2013).

We highlight that significant work is already in progress by team members on the project topic. For example, IRIS-Hinode Operations Plans 250 (PI: Katsukawa) and 267 (PI: Young) are targeted towards EBs and UVBs and have been run several times, and team members Reardon, Vissers and Rouppe van der Voort have obtained several joint data-sets between IRIS and the ground-based SST and DST. Several team members already have significant experience analyzing IRIS data (Young et al., 2015; Peter et al., 2014; Tian et al., 2014a; Huang et al., 2014; Heinzel & Kleint, 2014). Theoretical work on modeling EBs and flux emergence is underway by team members Heinzel, Berlicki, Danilovic and Toriumi (Berlicki & Heinzel, 2014; Danilovic et al., 2015; Toriumi, 2014). In particular, the 3D codes of Cheung et al. (2010) and Toriumi & Yokoyama (2011) already exist, as does the radiative transfer code of Berlicki & Heinzel (2014). The ISSI team will serve to bring added value to these efforts through knowledge-sharing and collaboration.

5. Expected output

The following outputs will be generated from this project:

1. A comprehensive set of new, coordinated data-sets of UVBs that will be listed and described on the team website.
2. A classification of the most intense UV brightenings in active regions that identifies signatures and causes. In particular to identify a well-defined, common event archetype that is suitable for theoretical modeling.
3. A time-dependent 3D model that is capable of reproducing the magnetic evolution that leads to UVBs.
4. A radiative transfer model that can be applied to the event archetype to reproduce observed line profiles and yield physical parameters for the event.
5. A set of parameters describing the reconnection process that have been validated through modeling.

Items 2–5 will all lead to papers to be published in the refereed literature.

6. Team

The team members are listed below. Members Young, Peter, Tian, and Huang, Madjarska are experts on coronal and transition region UV spectroscopy; members Rutten, Schmieder, Reardon, Vissers, Rouppe van der Voort and Katsukawa are experts on chromospheric spectroscopy; and members Danilovic, Heinzel, Berlicki, Toriumi and Cheung are experts on 3D simulations and radiative transfer modeling. In addition members Young, Katsukawa, Tian, Cheung, Vissers, Reardon and Rouppe van der Voort all regularly perform science operations for Hinode, IRIS, DST and SST, the principal observatories used for the project.

7. Project schedule

The project requires two five-day meetings in Bern. We anticipate the first meeting taking place in the November 2015 to January 2016 timeframe. The period prior to the first meeting will be used by the team members to assess existing observations and obtain new observations, and begin the identification of the event archetypes to which the project will be focused. The first meeting will then allow discussion of the event types and identify the key challenges for the modeling effort. Following this meeting the observers will perform a comprehensive analysis of the UVB archetypes, deriving the physical parameters. The modelers will work in coordination with the observers to reproduce the events and their parameters. The second meeting will take place in the November 2016 to January 2017 timeframe, where results will be presented and discussed. Final activities and actions from the project will be decided and the work will be completed in summer 2017.

The goals of our project are ambitious but are achievable within a 2-year timeframe because significant effort is already underway. Several IRIS UVB data-sets have already

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Yukio Katsukawa	NAOJ	Japan	F
Maria Madjarska	Armagh Observatory	UK	F
Kevin Reardon	National Solar Observatory	USA & Italy	F
Rob Rutten	University of Oslo	Norway	F
Shin Toriumi	NAOJ	Japan	F
Brigitte Schmieder	Observatoire de Paris	France	F
Gregal Vissers	University of Oslo	Norway	F
Mark Cheung	Lockheed Martin	USA	NF
Petr Heinzel	Czech Academy of Sciences	Czech Republic	NF
Luc Rouppe Van Der Voort	University of Oslo	Norway	NF

TL – team leader; F – funded team member; NF – non-funded team member; Tr – recipient of Travel refund.

been obtained and studied, and statistical studies are underway; coordinated campaigns have been performed with IRIS, the SST, the DST and Hinode and new campaigns are in preparation; 3D modeling codes for flux emergence have been written and tested; and radiative transfer codes for modeling IRIS emission lines and Hα have been written and tested. Our project is then one of coordinating the data analysis efforts in a systematic way, and ensuring that the modeling efforts are directly driven by the observations.

8. Added value provided by ISSI-Bern

The ISSI International Team framework is the ideal one for bringing together a small group of researchers to work intensively on a common topic. Our project is ideally matched to the goals of ISSI as we will combine ground and spaced-based data-sets with theoretical modeling to achieve a deeper understanding of a physical process that is relevant to both solar physics and the wider astrophysics community. Bern is the preferred location for our project based on the geographic locations of the participants.

9. Facilities required

The room for up to 14 people is requested with projection and internet facilities. Participants will bring their own computing equipment.

10. Financial support

Financial support is requested for the 12 team members indicated in the table above. The team leader is Peter Young who has funding from other sources, and the travel refund will be transferred to Zhenghua Huang.

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