TAC Proposal: Observing the solar surface convection with SUNRISE

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December 7, 2018

1 Scientific Justification

The Introduction: Developing a better understanding of the processes that govern the solar dynamics and activity and predicting space weather requires the comprehension of how the large and small-scale magnetic fields interact with the plasma flows and of how the conversion of energy between its mechanical, magnetic, radiative and thermal forms takes place. The flux emergence process drives the magnetic evolution of the corona and leads to conditions that are conducive to the onset of coronal mass ejections and flares that can disturb the Earth's magnetosphere and upper atmosphere, and cause disruptive geomagnetic storms (Abbett & Fisher, 2010). The solar photosphere is the key region hosting flux emergences and features at different spatial scales such as bipolar active regions, magnetic flux tubes and granulation. Hence, observing the solar photosphere via high-resolution imaging and photometric methods can provide us with a wealth of information on the topology and dynamics of these features (Solanki et al. 2010).

The primary goal of this study will be to obtain data to reconstruct intensity maps, Dopplergrams and vector magnetograms. We plan to use the high-resolution images to extract information about the surface convection and magnetic fields which drive the solar activity. With this data, we also aim to validate the existing MHD models at various spatial scales (see Solanki et al. 2010) and to use the obtained time series as an input in a trained neural network to investigate the dynamics of solar surface granulation and magnetic flux tubes via intensity maps and magnetograms (see Tremblay et al. 2018). These observations could also be used as boundary conditions in data-driven simulations or for data assimilation in a model to predict the evolution of features at the solar surface.

As we're currently headed towards a solar minimum that is forecasted to arrive in 2019 and Solar Cycle 24 comes to an end, these data will mainly enable new insights into the Quite Sun, specifically surface granulation and small-scale brightness variations. We also expect that active regions would still be present although the probability of coming across with one would be lower relative to a solar maximum.

The Experiment Hardware: We propose to use the balloon-borne solar observatory SUNRISE, to obtain data to reconstruct 2D magnetic field maps during its next flight in July 2019 during the next solar minimum and to investigate the dynamics of solar surface granulation and magnetic flux tubes via intensity maps, magnetograms and Dopplergrams. SUNRISE is a 1-meter Gregorian telescope that is designed to be flown on a zero-pressure stratospheric long duration balloon to investigate the photospheric activity at a resolution of about 0.1 arcsec on the Sun. It extends the long tradition of solar balloon missions being conducted since the mid 1950s (for example, see Schwarzschild 1959; Wittmann & Mehltretter 1997; Bernasconi et al. 2002) enabling to observe the Sun from an altitude sufficiently high to reduce the distorting effects of the Earth's atmosphere significantly. Another advantage that it offers is to allow access to a specific UV band (214-397 nm) that is not possible to observe from the Earth. During its third flight, we propose to use two of its main instruments: The SUNRISE Filter Imager (SuFI), a UV filter imager providing images at violet and near ultra violet wavelenghts with a FOV of 15×40 arcsec^2 and the Imaging Magnetograph eXperiment (IMax), an imaging magnetograph/dopplergraph enabling us to make inferences about its magnetic field from images in polarized light covering 50×50 arcsec^2. It has also some support instruments such as wavefront sensor and correlation tracker for active telescope control and tip-/tilt mirror for image stabilization (Solanki et al. 2010).

Dynamics of the photospheric features: The emergence of solar magnetic field, tangling of magnetic field lines which eventually produces reconnection, convective collapse and cancellation of magnetic fields can be further understood by analyzing the plasma velocity fields, brightness variations, granulation and flux emergence hosted by the solar surface.

With SUNRISE instruments, the solar surface could be investigated with high spatial resolution of around 100km also in the near-ultraviolet between 200 nm and 350 nm, a region which is inaccessible from the ground due to the absorption of these wavelengths in the ozone layer. At these wavelengths tiny temperature fluctuations within the convective cells are observed with high intensity contrast. With the help of these data, our numerical simulations of solar surface convection can be put on a firm observational basis (Abbett et al. 2010).

Space weather prediction: Physical processes triggering eruptive events on the solar surface are currently not well-understood. Although this mission will mostly focus on the Quite Sun, we aim to use the obtained data to improve the statistics regarding active regions and faculaes. These statistics may also capture the signature of the mechanism(s) driving eruptive events such as solar flares and coronal mass ejections and could be useful in making predictions (Jonas et al. 2017). In general, observing the quite and active solar features in almost unstudied near-ultraviolet spectral region with SUNRISE improve predictions concerning space weather (Solanki et al. 2017).

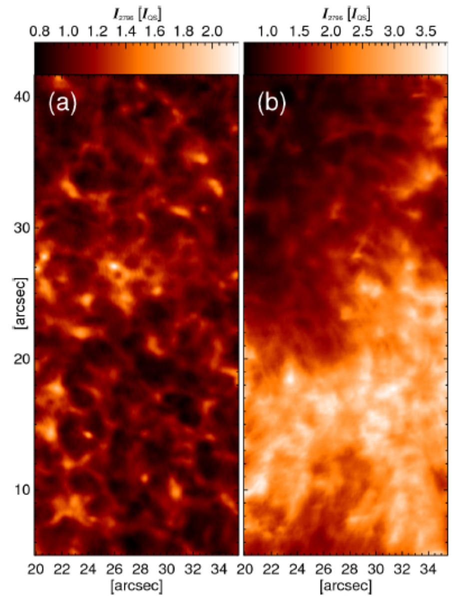

Figure 1: Images recorded by SuFI in the Mg II filter during the second flight. Panel (a) displays a part of the Quiet Sun while in Panel (b) a weak active region.

2 Technical Justification

The 2019 Flight description: The launch is planned to take place from ESPRANGE (67.89° N, 21.10°E) near Kiruna in Northern Sweden on a cloudless, perfectly windstill day, following an approximate trajectory shown in Fig. 2. Based on the previous two SUNRISE flights, the instrument is expected to reach a float attitude of 30-40km, after an ascent lasting about 3.5h. Like the first two flights, the balloon is expected to stay above most of the ozone in Earth's atmosphere, allowing high-quality data in the UV at 214 nm, 300 nm, 312 nm and 396.7 nm.

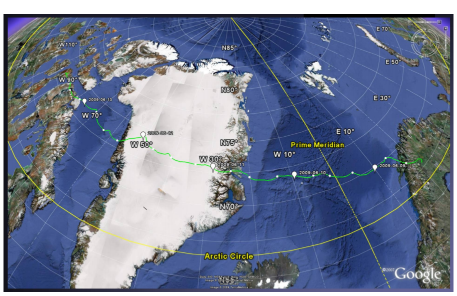

Figure 2: Planned trajectory of the third SUNRISE flight.

Observation details: The total observation time is estimated to be about 5 days during the entire mission that takes approximately a week with take-off and landing. Observing times and modes with each instrument are summarized in Table 1 and Table 2.

SuFI will mainly provide fraction-limited images (see Table 1) at 300nm and at 396.7nm with a pixel size 0.01983-0.02069 arcsec varying with the wavelength in both the broader and the narrower channel centred on the core of the Ca II h line to investigate the bright areas in connection with the flux emergence are also visible in Ca II h (Centeno et al. 2016; Danilovic et al. 2016). As in Sunrise II, we also plan to collect high resolution images in the Mg II k line in the solar chromosphere which is coupled to the chromospheric temperature. This is useful to study quiet photospheric regions contain a large amount of horizontal magnetic field that produces Horizontal Internetwork Fields (Riethmuller et al. 2013; Danilovic et al. 2014).

IMaX operating in the Fe I 525.02 nm, will provide images in polarized light at a spectral resolution of 85 mÅ. The full Stokes vector in five wavelengths observed at a noise level of 0.001 is obtained in 30 s, which is typically the cadence (Solanki et al. 2010). We aim to use various modes of IMax differing in the number of Stokes parameters as shown in Table 2. Here L refers to the mode where only I and V are considered, whereas V refers to full Stokes vector observed. Following number denotes the wavelength points and the second one is the number of images accumulated per wavelength point. These polarization components observed will be used to construct Dopplergrams to investigate the traverse component of the velocity field as shown at the bottom right images in Fig. 3.

IMax data will dominantly be captured in the V8-4 mode meaning that the Fe I 525.02 nm line will be recorded at eight wavelength positions with four accumulations at each wavelength, sampled being centered on -120, -80, -40, 0, 40, 80, 120 and 227 mÅ.

Table 1: Sample SuFI Observing and Exposure Times.

SuFI filter (nm)	Fraction of the observation time	Exposure time (ms)
5λ: 214,300,312,388,396.7 nm	54 %	2000, 50, 100, 500, 500
4λ: 300,312,388,396.7 nm	2 %	200, 100, 500, 750
3λ: 300,388,396.7 nm	33 %	50, 100, 500
2λ: 388,396.7 nm	8 %	250, 500
1λ: 396.7 nm	3 %	500

Data analysis & Deep Learning: With the acquired high-quality data both from SuFI and IMaX, we hope to improve statistics of existing theories concerning flux emergence, granulation and the nature of active regions and to investigate the magnetic field topology on the Sun. We will conduct a quantitative comparison of the Mg and Ca images and use the magnetograms to map the electric field distribution on the photosphere to understand how energy flows. The short time series that will be obtained with high cadence (20-40 s) will also help validating the MHD simulations of the Sun. The validated models can further be used to train a neural network that includes as much descriptive physics as possible.

Additionally, as the granulation is controlled by the dynamics of the photospheric plasma, we intend to reconstruct the line-of-sight (LOS) component of the velocity of the photopheric plasma motions which can only be estimated using the Doppler effect since there is no direct spectroscopic access to it. Different algorithms have been developed to trace these horizontal flows at the solar surface from continuum images and to reconstruct Dopplergram. We plan to conduct a LOS analysis with the help of one of these algorithms: DeepVel (Ramos et al. 2017), a already-trained deep neural network which has been also used in previous studies (see, Tremblay et al. 2018). It can produce an estimation of the velocity at every single pixel, at every time step and at three different heights in the atmosphere from just two consecutive continuum images. Fig. 4 shows how this network can be used to study the horizontal velocity field in fragmenting granules with the IMaX data with the capability of capturing very small vortices. This analysis is essential to get info about the transverse component of plasma motions/velocity field which is not observable.

The SUNRISE data could also be used as a benchmark to test methods correcting for the effects of Earth's atmosphere on ground-based observations such as the Asensio Ramos et al. (2018) neural network. This comparative study would require data in the same wavelengths at the same approximate time and spatial resolutions.

Table 2: Time Spans and Cadences of Various ImaX Modes that is planned to be used.

Mode	Cadence (s)	Expected noise (I_c)
V5-6	33	0.0010
V5-3	18	0.0012
V3-8	40	0.0011
L12-2	31	0.0012
L3-8	24	0.0015

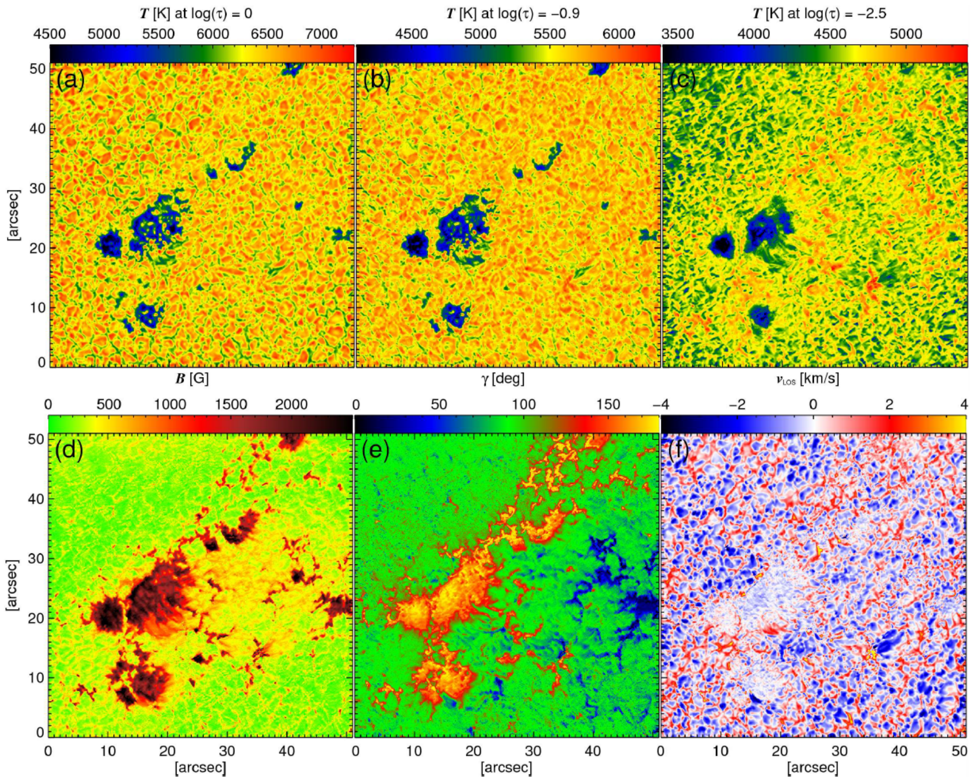

Figure 3: Best-fit atmospheric parameters deduced from the inversion of the Stokes vectors recorded by SUNRISE/IMaX during the second flight. Upper row of panels, (a)-(c): temperature $T(log\tau = 0)$, $T(log\tau = -0.9)$ and $T(log\tau = -2.5)$. Lower row, (d)-(f): magnetic field strength B, magnetic field inclination γ, and the line-of-sight velocity V_{LOS}. Positive velocities indicate downflows. γ is relative to the line-of-sight direction (Fig. 8 of Solanki et al.2017

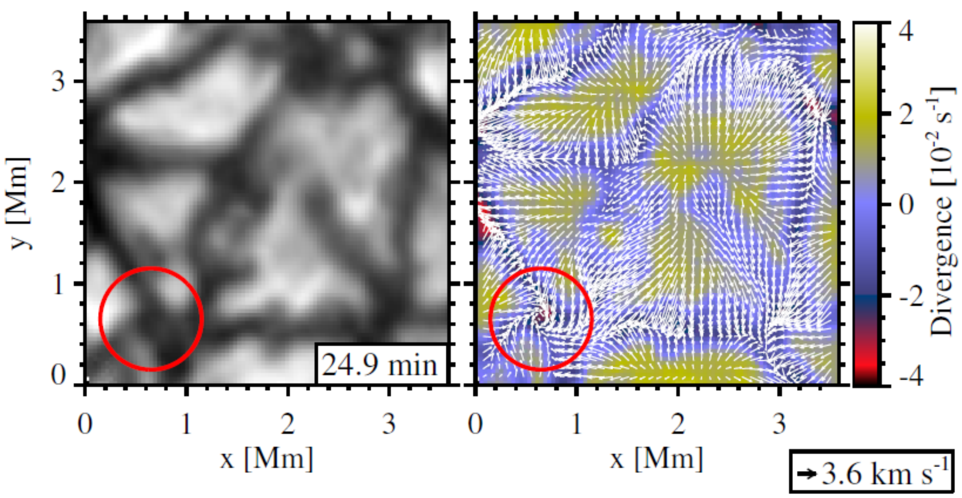

Figure 4: *Left*: Evolution of granules as seen in close-ups of continuum intensity maps. *Right*: The instantaneous horizontal velocity field (*white arrows*) and divergence map (*background image*) at three heights in the atmosphere, corresponding to the optical depth $\tau = 1$ as shown in the bottom panel of Fig. 3 of Asensio Ramos et al. 2017.

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