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An imager with added value for the Solar Orbiter mission

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Abstract

Our current ways of observing the Sun with spectrometers and imagers are limited. With a slit spectrometer, we require time to build up a 2-D image which results in temporal blurring. When we use a traditional imager, we have no ability to measure and detect line-of-sight flows or to discriminate contributions from gas at different temperatures in the imager passband, causing spectral confusion of the images. For Solar Orbiter, the combination of an exciting new viewpoint of the Sun, and the best resolution of the corona ever seen, means that we require the best time cadence and velocity information that we can get. The spatial resolution expected from the imager on Solar Orbiter will reach approximately 70 km. At such a resolution in the corona, we expect to see the fundamental magnetic flux tubes, which are predicted to have high velocities. This is also the scale at which we will be able to search for evidence basic physical processes such as magnetic reconnection. We will describe the design of an imager that gives not only high quality images, but also provides simultaneous information about plasma flows and temperature. A prototype instrument is being flown on a NASA sounding rocket next year. The concept will be described, along with some methods of extracting the spectroscopic information.

Keywords: Solar physics; Spectroscopy; Imaging

1. Introduction

Solar Orbiter (SO) is an approved ESA mission, and is expected to be launched in approximately 2014. This unique mission will strive to answer new scientific questions that can be addressed due to the novelty of the orbit and its payload. There are a number of unique aspects to the payload and orbit that are listed below:

- In situ AND remote sensing observations from 0.2 AU.
- At least twice the spatial resolution than currently exists for remote sensing observations.
- Polar views of the corona/heliosphere: co-rotation and interaction of outward moving plasma, towards the end of the mission.
- Co-rotation of SO with the Sun over limited periods.
- Simultaneous viewing from different directions (assuming other active missions, in near-earth orbit).

The novelty of this mission will bring a huge advance in solar and solar–terrestrial physics. There are a number of science topics that will be focused on. Some that are directly applicable to the imager are listed below:

- Acceleration of the fast solar wind: by studying the physical, ionic, and chemical properties of the wind in situ, close to where it is accelerated, we will be able to investigate the acceleration mechanism.

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- Solar origin of the slow solar wind: by studying the slow wind and the fast/slow configuration closer to the Sun, it will be possible to relate the wind to solar structures and their magnetic configurations, determined by remote sensing.
- Physics of the Sun's poles, their rotation, dynamo and magnetic configuration: remote sensing, never before achieved for these regions, will address a number of outstanding questions regarding the role and influence of the poles.
- Acceleration and heating through reconnection in the transition region/corona interface region: high resolution remote-sensing observations aim at resolving these structures.
- The role of the inner heliosphere in solar–terrestrial processes: the out-of-ecliptic view of interplanetary disturbances will answer many questions arising in the Space Weather domain.

The science goals of the mission will be best achieved by connecting the in situ and remote-sensing datasets. One of the high priority instrument for the mission in the EUV Imager (EUI) since we will need high resolution, time-resolved imaging of the atmosphere. The ESA strawman payload includes an EUV imager (EUI). The EUI consists of a full Sun imager (FSI) and a high resolution imager (HRI). In the strawman both of these are traditional imagers. The HRI consists of three telescopes with baseline wavebands covering 133, 174 and 304 Å. The ESA technical documentation can be obtained from http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=33281.

However, we know that imaging is even more powerful when coupled with spectroscopy, giving us quantitative measurements of dynamics, and other plasma parameters. Solar Orbiter will show us detail that we can currently only theorise. In order to link what is happening on the disk to the in situ results it in important to have information on outflowing material from the Sun. To take advantage of this fully we need to have high temporal, high spatial and high spectral resolution with a large field of view. We cannot do this with a slit spectrograph because of spatial/temporal confusion. We cannot do this with narrow band imagers due to temperature confusion. Even narrow-band imagers will cover more than one spectral emission line. The varying contributions of different temperature plasma within the band will change as the solar plasma fluctuates. It would be highly advantageous to have an instrument that can give both imaging and spectral capability – and with a reliable design.

Due to its unique orbit, the Solar Orbiter mission requires us to design instruments in a novel way, but yet with engineering simplicity. The orbit will suffer from thermal and particle fluctuations more extreme that any remote sensing imager has experienced. Instruments with no moving parts are preferable. We will have limited commanding ability so the instruments must be able to function autonomously. The telemetry restrictions are severe, so novel modes of operation and advanced compression schemes are required. There are severe mass restrictions due to the orbit, and hence light-weight materials and a smaller telescope are an advantage.

In this paper, we will describe our proposed imager for the Solar Orbiter mission. This would replace the EUI HRI. Our instrument will have the advantage of producing not only images, but also spectral information. Another advantage of our instrument is that it gives a field of view approximately the size of an active region, and hence has a greater chance of observing interesting phenomena.

2. Spectral and spatial information simultaneously

Previously, instrumentation have obtained spectral information by either using a lit (as in the case of the SOHO coronal diagnostic spectrometer (CDS) and solar ultraviolet measurements of emitted radiation (SUMER) instruments) or by using a slitless spectrograph. The latter image only in the $n = +1$ orders and hence the product is essentially images in the different spectral lines overlapped. Both methods provide extremely useful information, but are limited by either temporal confusion or spatial confusion.

We will use the instrument concept developed for the Multi-Order Solar EUV Spectrograph (MOSES) to be launched on a rocket flight in 2005 (see Thomas and Kankelborg, 2001). A multi-order imaging spectrograph is an imager that allows spectral information to be obtained by observing in three spectral orders ($n = 0$, $n = -1$ and $n = +1$ orders). Since there is no slit to raster, all the data obtained are co-temporal allowing dynamic events to be observed in a unique way. The $n = +1$, -1 images contain spectral information, with the wavelength direction being opposite in these two orders. The combination of the three images allows the images to be reconstructed with a final product being intensity images and Doppler velocity images.

In summary, using deconvolution techniques, both images and spectroscopic information can be extracted. This gives *both imaging* and *spectroscopic* information with *no loss of field of view* or *temporal resolution*. All these attributes are critical with such a close view of the Sun. More information on the MOSES rocket flight can be obtained from http://solar.physics.montana.edu/MOSES.

3. Our design: the high resolution spectroscopic imager (HIRESI)

Following the results of industrial studies, ESA has requested some further technical constraints on the