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EUV IMAGER AND SPECTROMETER FOR LYOT AND SOLAR ORBITER SPACE MISSIONS

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ABSTRACT

In the 2010 horizon, solar space missions such as LYOT and Solar Orbiter will allow high cadence UV observations of the Sun at spatial and spectral resolution never obtained before. To reach these goals, the two missions could take advantage of spectro-imagers. A reflective only optical solution for such an instrument is described in this paper and the first results of the mock-up being built at IAS are shown.

Key words: sun; FTS; imager.

. LYOT AND SOLAR ORBITER MISSIONS

. . LYOT mission

LYOT (Lyman α Orbiting Telescope) is a French solar mission proposal to be flown on a CNES micro -satellite. It is composed of three telescopes: a H-Lyman α coronagraph, a H-Lyman α disk imager, and a Fe XII 19.5 nm disk imager. The instrument was named after Bernard Lyot, the inventor of the externally occulted coronagraph. LYOT mission will address several key questions of solar physics related to space weather.

One of the main goals is the study of coronal mass ejections (CME): their detection, the study of the correlation between eruptive prominences and CME, and the identification of the precursors of CME in order to develop forecasting tools. To reach this goal, it is necessary to observe chromospheric events low in the Sun's corona. Another goal is to monitor the Sun's UV and EUV radiance and irradiance to have a better understanding of the dynamics of the Earth's upper atmospheric layers.

The payload proposed on LYOT is composed of three complementary instruments: the H-Lyman α disk imager and coronagraph will cover respectively from the Sun's center up to 1.1 solar radii ($R_\odot$) with a resolution of 1.1 arcsecond and from 1.1 to 3 $R_\odot$ with a resolution of 3 arcseconds. The second disk imager will observe the Sun in a hot line (Fe XII) with the same field of view and the same resolution. The combination of the two imagers will allow to have simultaneous observations of the same solar features in a cold line (H-Lyman α, 121.6 nm, 20 000 K) an a hot line (Fe XII, 19.5 nm,1 500 000 K).

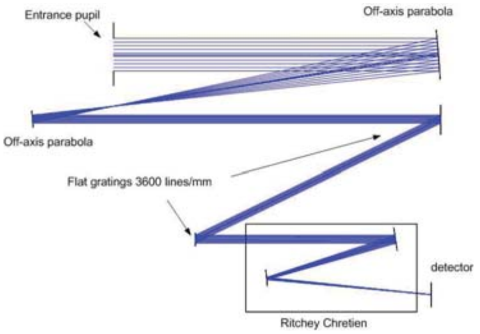

Figure 1. Optical layout of the H-Lyman α disk imager.

The H-Lyman α disk imager has been designed at IAS using Zemax® software. The novelty of the design is the use of two identical flat gratings to perform spectral selection, the second grating is mounted symetrically to compensate for the spectral dispersion of the first grating (Figure 1). The incident beam is imaged by an off axis parabola. At the focus the beam passes through a field stop. The diffraction pattern of the entrance pupil is eliminated by a lyot stop and the beam is collimated by another off axis parabola. Then the beam is diffracted in the first order by a flat grating. The second grating in reverse dispersion diffracts the beam on its normal, parallel to the incident collimated beam. Finally the beam is imaged by a Ritchey Chretien type telescope. With its particular design, the imager could be adapted to have a Fourier transform spectrometer channel, using both positive and negative first orders of diffraction from the first grating, acting as a beamsplitter.

1.2. SOLAR ORBITER mission

Solar Orbiter is a proposed ESA mission to be launched in 2014 (Colangelo et al. 2000). With its particular orbit, the spacecraft will allow several approaches within $45R_\odot$ to latitudes as high as 38 °. The orbiter will also permit heliosynchronous observations by matching the speed of the spacecraft to the Sun's rotation rate near perihelion. The main scientific objectives are the study of the magnetised plasma, the identification of the link between solar and heliospheric processes and the in situ measurements of fields and particles in the inner heliosphere. The proposed payload for Solar Orbiter consists of in situ and remote sensing instruments, among which a UV spectro-imager could be included.

2. FOURIER TRANSFORM SPECTROSCOPY

Spectrometry is a high performance analysis tool for solar physics studies, it gives information about the nature of elements detected in the area of interest, their temperature, pressure, speed and abundance. Fourier Transform Spectroscopy (FTS) is an ideal solution for imaging systems because there is no need to scan the region of interest with a slit to get a 2D map. Also, the resolution of such systems is theoretically unlimited. The working principle of FTS is based on the fact that the intensity at each point of the interference pattern, recorded as a function of the optical path difference (Eq. 1), is the Fourier transform of the spectrum of the incident light (Eqs. 2-3) as described in Chambelain (1979) and Thorne et al. (1999). The light to be analysed (solar emission in this case) is fed into an interferometer, and the modulation of the interference pattern is obtained by a variation of the optical path difference between the two arms of the interferometer.

The main relations between the observed signal and the spectrum are following:

- intensity in the interference pattern due to spectral component dk:

  $$i(k,\delta)dk = 2i_0(k)\cdot[1+\cos(k\delta)] \qquad (1)$$

  where $k = \frac{1}{\lambda}$ $\delta =$ optical path difference
  and $i_0(k) =$ spectral distribution of intensity

- total intensity in the interference pattern:

  $$I(\delta) = \bar{I} + \int_{\Delta k} i_0(k)\cdot\cos(k\delta)dk \qquad (2)$$

- the Fourier transform of the intensity yields to the spectral distribution of intensity of the incident light:

  $$i_0(k) = \int I(\delta)\cos(k\delta)d\delta \qquad (3)$$

3. IFTSUV MOCK-UP

3.1. Optical design

The mock-up of an imaging Fourier transform spectrometer in UV (IFTSUV) is being built at IAS in order to test and validate the working principle of such a spectrometer (Lemaire 2000, 2002).While the real spectrometer must work between 100 nm and 1 5 nm, the validation mock-up is designed to work at 200 nm with only reflective optical surfaces. IFTSUV optical design is based on a folded Michelson interferometer. In this case, the incident beam is diffracted in the +1 and -1 orders by a flat grating which acts like a beamsplitter. Each diffracted beam is intercepted by a second grating which cancels the dispersion and defines a 40 nm bandpass. Then each beam is reflected by a fixed and a moving mirror and sent back to a collimator which recombines the beam at its focus. (Figure 2). In order to have a smaller and symetric system, both arms of the interferometer are moving. Both sides of the moving mirror reflect the beams of the interferometer. The moving mirror is mounted on a translation stage controlled by piezo positioners with capacitive position sensors (Polytec PI®) to nanometer accuracy.

3.2. Mock-up parameters

The resolving power expected is around 4000 which will give a spectral resolution of 0.02 nm and is given by Eq. 4.

$$\mathcal{R} = \frac{8}{\phi^2}\times\frac{d^2}{D^2} = \frac{2L}{\lambda_0} = \frac{\lambda_0}{\delta\lambda} \qquad (4)$$

where $\phi =$ angular field
$d =$ beam diameter on the first grating
$D =$ entrance pupil diameter
$\lambda_0 =$ working wavelength
$\delta\lambda =$ spectral resolution
and $2L =$ total equivalent displacement of the mirror

The translation stage moves by steps, the interferogram is not continuous. In order to avoid aliasing, it is necessary to choose carefully the scanning parameters. The total equivalent optical path difference over the whole scanning range is 800 μm and the mirror moves by steps of 105 nm. Therefore, it takes approximatively 7500 steps to get a 40 nm wide spectrum.

3.3. Experiment status

The IFTSUV mock-up is mechanically set up and is being aligned. As the instrument works in UV, it is necessary to have high quality optical surfaces and a very accurate alignment of the optical system. The precision needed is of the order of a few nanometers and as the two beams are recombined at the focus of the collimator, the angular tolerance is about one arcsecond.

The alignement is performed in several steps. First, the instrument is used in visible light with a green laser, the system works in autocollimation on the two symetric gratings. A visible CCD detector is used to check the superposition of the images given by each beam of the interferometer. The system is roughly aligned when a modulation of the intensity can be detected during a scan of the mirror. This detection of the modulation is made by a radiometer (one pixel detector).

The precision of the alignment is improved using an extended white light source instead of the green laser and adjusting the alignement to obtain maximum modulation of intensity in the whole field. The low temporal coherence will enable the visualisation of very small optical path differences between the two arms of the interferometer.

To perform those two steps, a combination of dichroic plates has been designed and added to the original optical set-up (Figure 2). When the instrument is working in UV, one of the dichroics separate UV light from visible light allowing the simultaneous detection of the UV and visible signals. The visible signal is used to control that the alignment is kept through the total displacement of the mirror.

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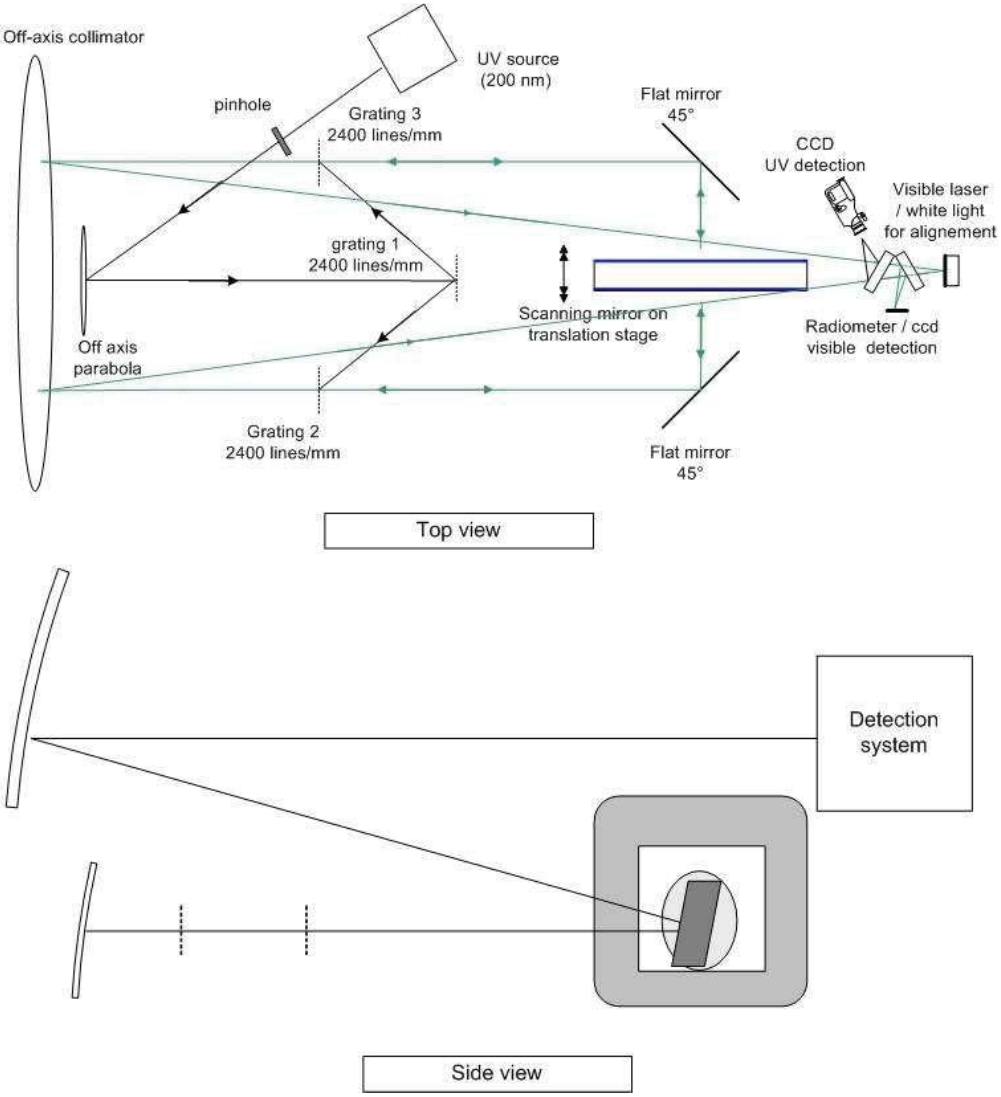

Figure 2. Optical layout of the IFTSUV mock-up being built at IAS.