Radiometric Calibration of MOSES

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We present analysis of radiometric calibration data for MOSES, the Multi-Order Solar EUV Spectrograph. MOSES is an EUV imaging spectrograph which uses a spherical grating to feed three rear illuminated CCDs, one for each of the m = 0 and m = ±1 spectral orders of the grating. MOSES was calibrated end-to-end at the EUV radiometric calibration facility at Rutherford Appleton Laboratory, using a well characterized hollow cathode source traceable to the BESSY synchrotron. We analyze these data and present the end-to-end instrument response (DN per incident photon) for each of MOSES three CCD channels.

Radiometric Source

For calibration, we used the secondary radiometric source[1],[3] at Rutherford Appleton Labs (RAL) Assembly and Integration Facility. Source operating conditions were 2A, 500V, with He used as the carrier gas. The source photon flux at 30.4 nm is measured to be 4.89e7 photons/s, with 12.8% relative standard uncertainty[3],[5].

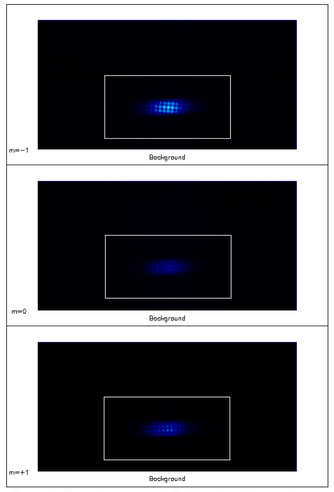
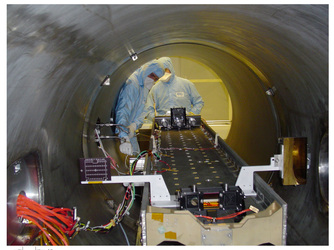
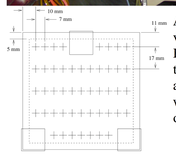


Figure 1: Typical exposures (Te filters) in all spectral orders, post processing. The thick white frame on the perimeter shows the region in which pixels are considered to be part of the background. The thin interior box shows the subframe summed over to obtain the total counts in each image.





Above: Moses payload in vacuum chamber at RAL. Below and left of center is the aperture target (shown at left) used for alignment when scanning the source over our aperture.

Data

Data was collected over from March 10 - March 17, 2005. Exposures were taken with source incident on all clear aperture positions, excluding Row 1. For a typical aperture position, 9 100s exposures were taken, with a 100 s dark exposure taken after each set before moving to a new aperture position. Typical exposures for the three spectral orders are shown left. The cross hatch pattern on the image is the shadow of the nickel mesh supporting the filters. Measurements were repeated at some aperture positions to check source stability. Measurements were also repeated at some aperture positions to estimate the transmission ratios of the Al and Te filters (see figure 2 and adjacent paragraph).

Analysis

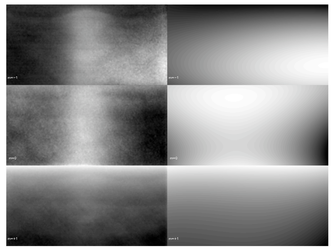
The basic data reduction and analysis procedure consisted of:
1.)Background subtraction
2.)Flat Fielding
3.)Clean images for particle hits, bad pixels, dust shadows, etc.
3.)Sum total counts in image, divide by exposure time
4.)Take median value of estimated count rates from the 9 exposures at each aperture position, divide by source photon flux to obtain instrument response at each aperture position.
5.)Average responses over aperture to obtain mean instrument response for each spectral order.

Table 1: MOSES Instrument Overview.

Primary Mirror	Spherical Holographic Grating
Focal Length	474 cm
Aperture	64 cm^2
Coating	B_4C/Mg_2Si Multilayer
Lines in Passband	He II 303.8Å, Si XI 303.3Å
Groove profile	Laminar
Groove Frequency	950 l/mm
Groove Depth	4 nm
Land Width	500 nm
Detectors	3 e2v CCD42-20 rear-illuminated CCDs
Pixel size, numbers	13.5 μm, 2048x1024 arrays
Pixel Angular Subtent	0.59 arcsec
Filters	1500Å Al on Ni mesh

Background Estimation

We estimated our backgrounds using two methods:
1.)Smoothed averages of dark exposures,
2.)3rd order polynomial fits to the pixels in the thick white frame regions in figure 1, considered to be a part of the background.



A B

Backgrounds estimated from A) averaged , smoothed scaled dark frames, and B) polynomial fit to border pixels of light images.

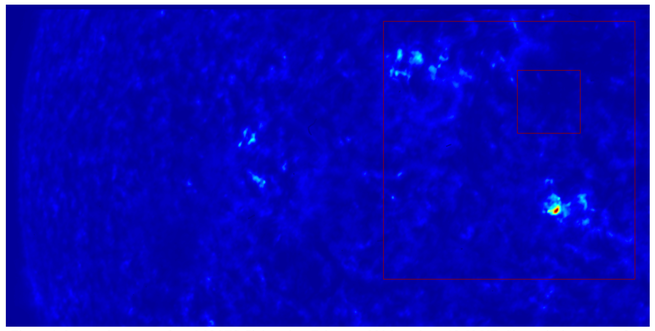


Figure 4: 3 second exposure from MOSES flight, taken February, 2006, at about 18:50 UT. Shown is the region of interest (large red box) and averaging subframe (small red box) used to build histogram of quiet sun HeII intensity.

The end to end calibration was applied to MOSES flight data (figure 4) to estimate the HeII intensity [erg/(cm^2 s ster)] of quiet sun. The averaging subframe was centered at a random point in the region of interest, and the mean count rate was computed. The intensity is calculated via

$$I = \frac{mean\ count\ rate}{A \cdot \theta^2 \cdot R} \cdot E_\gamma \left[\frac{erg}{cm^2\ s\ ster}\right]$$

where A is MOSES aperture, θ is the angle subtended by MOSES pixels in radians, R is the mean instrument response in [DN/photon], and E_γ is the photon energy. The intensity was calculated for 10^4 subframes, and are the results are displayed as a histogram in figure 5. The average HeII intensity was measured to be about 6800 erg/(cm^2 s ster).

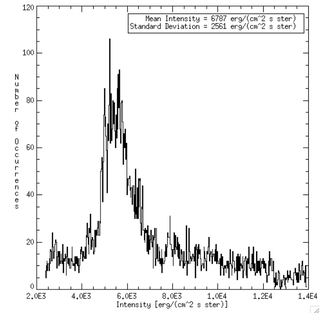


Figure 5: Histogram of quiet sun HeII 30.4 nm intensity. Averaging subframe is 118"x118", and the region of interest is 8'x8'.

Results

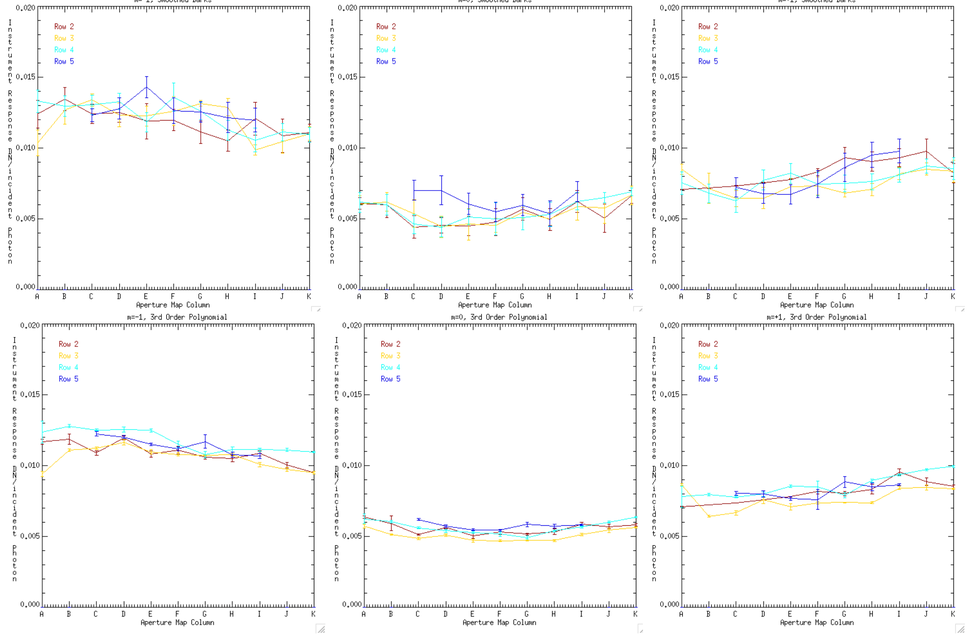
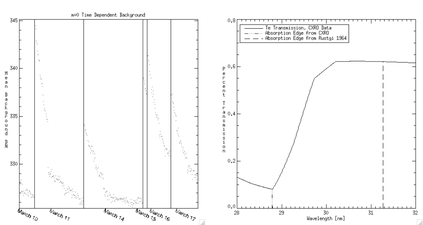


Figure 3: From left to right, estimated instrument response for MOSES m=-1, m=0, and m=+1 spectral orders as a function of aperture position. The top row shows results from smoothed dark backgrounds, and the bottom shown results from polynomial backgrounds. Error bars are estimated from the mean absolute deviation of the counts estimated from all 9 exposures at each aperture position, added in quadrature with the count errors expected from source uncertainty. The table at right gives the responses averaged over the full aperture.

Table 2: MOSES response averaged over aperture, estimated using two types of background subtraction. Response is given in units of DN/incident photon.

Spectral Order	Smoothed Darks	3rd order polynomial
m=−1	0.0121	0.0111
m=0	0.0056	0.0055
m=+1	0.0078	0.0081



2a

2b

Background estimation was complicated by two factors. Figure 2a shows a time dependent offset to the background, as measured from the mean value of "background" pixels. The averaged darks were scaled to account for this offset.

Secondly, we used Te filters for most of the experiment, the intent being to filter out FeXV 284Å emission, based on data from CXRO[2]. Te is in fact an excellent *absorber* of our target 304Å line[6] (figure 2b). The result is low count rates and high sensitivity to errors in background subtraction. We therefore estimated total counts within a subframe countaing the focused source spot.

We made repeat measurements at the K2 and F2 aperture positions in the m=+1 order using an Al filter which was later used in flight. Transmission ratios of the Al to Te filters were measured to be, on average, 37.4 for the polynomial backgrounds, and 44.3 for the smooth dark backgrounds. Total counts derived from data taken using the Te filters were scaled by the filter ratios.

Conclusion

We have measured the end to end instrument response of the MOSES rocket payload in all three spectral orders, using the secondary radiometric source at Rutherford Appleton Labs. The estimated responses are in good agreement with the relative responses measured from the flight data.

We have used these calibration results to estimate the quiet sun HeII 30.4 nm intensity, about 6800 erg/(cm^2 s ster).

Acknowledgments

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References

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