Variations of Solar Radius Observed with RHESSI

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The Solar Aspect System (SAS) of the rotating (at 15 rpm) RHESSI spacecraft has three subsystems. Each of these measures the position of the limb by sampling the full solar chord profile with a linear CCD using a narrow bandwidth filter at 670 nm. With a resolution of each CCD of 1.7 arcsec/pixel, the accuracy of each of the 6 limb positions is theoretically better than 50 mas using 4 pixels at each limb. Since the launch of RHESSI early 2002, solar limbs are sampled with at least 100 Hz. That provides a database of currently 4 x 10^9 single radius measurements. The main function of SAS is to determine the RHESSI pointing relative to Sun center. The observed precision of this determination has a typical instantaneous (16 Hz) value of 50 to 100 mas (rms). We show and discuss first results of variations of solar radius observed with RHESSI.

The SAS Instrument

• Design	3 independent subsystems on rotating S/C
• Optics	f/40 coated lens 670 nm (12 nm FWHM) bandpass filter 1550 mm focal length
• Sensor	three linear CCDs with 2048 pixels length: 13 μm/pixel, total 26mm width: 13 μm/pixel integration: programmable, typical 700 μsec resolution: 10 bit @ 128 Hz
• Sun Image	14.4 mm
• Field of View	single CCD: 59 arcmin high resolution: 27 arcmin
• Resolution	1.73 arcsec/pixel 0.133 arcsec/μm

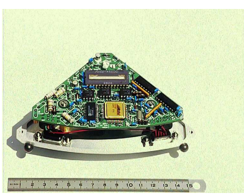
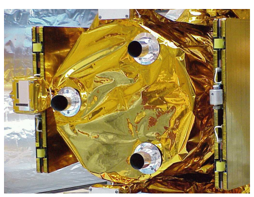
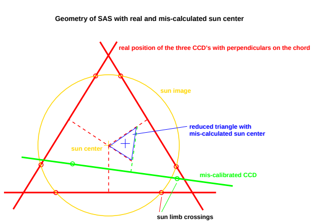


Image of one of the three SAS sensors with the front−end electronics. The cover with the integrated blocking filter is not shown.



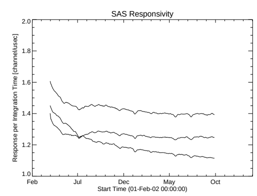
The image of the sunny side of the integrated spacecraft shows the three baffles for the SAS lenses which are coated with a bandpass filter.



The drawing on the left shows a sketch of the SAS geometry. The three lenses focus the solar disc at 670 nm onto the three linear CCDs. Knowing the effective geometry and relating the three subsystems correctly leads to the indicated reconstruction of the sun center. Any deviation from the correct geometry leads to an ambigious reconstruction and therefore a non-vanishing reduced triangle.

The 9 free parameters defining the relative geometry of all SAS feature can be fitted using the enornous statistics of measured Sun limb crossings. A set of wrong parameters leads to an inconsistent reconstruction of the Sun center.

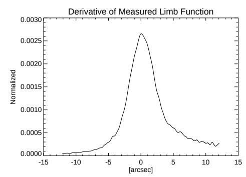
The Calibration

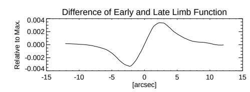


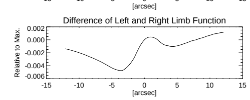
Frequent readouts of the full solar profile allows a precise measurement of the responsivity.

The responsivity for each of the three SAS subsystems is measured in channels per μsec. The overall decrease of responsivity is caused by degrading of the lenses. Whereas two of the three subsystems are stabelized over time, one lens still continues to degrade. This remaining degrading doesn't compromize the data since the integration time can be adjusted in order to use the full resolution of the data.

The smaller changes in responsivity, on the time scale of weeks, is correlated with the varying duration of exposure to sun light and a subsequent small variation of the temperature of the sensor.







The PSF of the three subsystems has not been measured prior to flight. Therefore it has to be estimated analysing the data. The main contribution to the width of the core is the diffraction at the lens and chromatic abberation. The estimated value prior to flight is 4.3 arcsec (FWHM).

Averaging over serveral 10'000 of profile measurements results in a well sampled limb profile function. This measured limb profile contains the physical solar limb darkening at 670 nm convoluted with the instrumental response.

In first order, the solar profile at 670 nm can approximated with a step function. Therefore, the derivative of the measured and normalized limb profile gives a rough estimate of the core of the PSF. The measured width of 4.5 arcsec (FWHM) confirms the integrated measured profile.

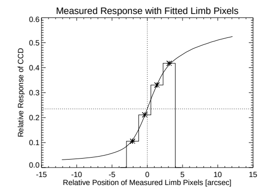
In order to measure the side lopes of the PSF, the measured profiles have to be deconvoluted using a model for the limb darkening function.

The measured limb profile function differs for the three subsystems. Moreoever, it varies in time and space.

The upper plot shows the difference between an averaged limb profile for a time range early in the mission and an equivalent limb profile later in the mission. This difference suggests clearly that the limb profile flattens over time, which means that the width of the PSF increases in time. Wiggles (e.g. at 10 arcsec) indicate information about the side lobes of the PSF.

The lower plot shows the difference between averaged limb profiles at two opposite off-axis angles for one subsystem. The measured limb profile, and therefore the PSF, depends significantly on the off-axis angle. Therefore, coma effects of the lens can and have to be quantified.

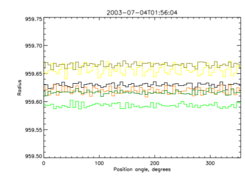
Status of Data Analysis

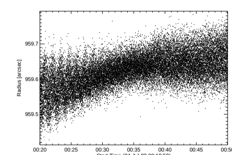


For every integration time, the four triggered pixels at each of the measured solar limb are fitted to the corresponding measured (averaged) limb profile function. The statistics of the data shows that the determination of the solar limb has an rms error of approximately 50 mas.

Therefore, for every cycle (16 Hz) 6 radii can be calculated. This forms an enormous database of relatively high precision solar radii measurements.

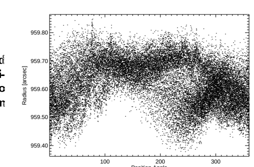
Data for one orbit binned into 5-degree bins in heliographic position angle, showing each of the six independent radius measurements. The discrepancies reflect the current level of calibration.





Individual points plotted as a function of time for the same orbit. This gives a feeling for the large number of measures available, and the distribution of points indicates the presence of systematic error terms that are not fully corrected yet.

Individual radius measurements plotted as a function of the heliographic position angle. The rich structure seems to carry information about discrepancies in the calibration.



Conclusion
Outlook

At this point we have completed most of the work on sensor calibration and are in the process of tweaking it to suppress systematic terms of many kinds. The data shown above establish that these terms will be controllable at the level of milli-arcsec. We hope to apply these data to many purposes, especially helioseismology and the observation of solar shape variations with position and time.