Determination of the Point Spread Function for the Normal Incidence Spectrometer of the Coronal Diagnostic Spectrometer on SOHO

Project Proposal

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29th October 2004
**Introduction**

This document describes the proposal for a project to determine the Point Spread Function (PSF) of the Coronal Diagnostic Spectrometer (CDS) Normal Incidence Spectrometer (NIS) on the Solar and Heliospheric Observatory (SOHO) spacecraft. It covers the background to such a project; the aims; motivation; method; expected results and the preliminary results that have been obtained.

**Background**

The background for this project can be split into two broad areas, a description of the hardware that the project is based on and a discussion of the currently defined nature of the PSF.

**The Coronal Diagnostic Spectrometer on SOHO**

The Solar and Heliospheric Observatory (SOHO) is one of most successful scientific missions ever carried out [1]. It is positioned at the L1 Lagrange point and carries out continuous observations of the Sun. The Rutherford Appleton Laboratory (RAL) constructed the Coronal Diagnostic Spectrometer (CDS) instrument [2] on SOHO. The instrument has two modes of operation, the Grazing Incidence Spectrometer (GIS) and the Normal Incidence Spectrometer (NIS). It is the NIS instrument that will be studied in the project. It has two wavebands on the detector, arranged one above the other, these are known as NIS 1 (308 – 381 Å) and NIS 2 (513 – 633 Å). It can expose these wavebands with one of three slits, each 240 arcsecs in the solar y direction and 2, 4 and 90 arcsecs in the solar x. The instrument is pointed using six individually controlled legs attached to the optical bench and ‘rasters’ or spatially resolved images can be built up using a scanning mirror.

**The CDS NIS Point Spread Function (PSF)**

The PSF is an optical characteristic of the instrument that defines how much a point source would spread by as imaged on the detector. This is a critical parameter as it effectively defines the spatial resolution of the instrument and can also, if accurately determined, be used in so-called ’de-convolution’ routines. This process allows images to be sharpened and cleaned by precisely knowing the distortion or ‘convolution’ that they have gone through initially due to the instrument. The PSF for NIS is given in the SOHO CDS user guide [3] as

\[
PSF(r) = \left(\frac{J_1(br)}{\pi r^2}\right)^2
\]

where J is the first-order Bessel function and b has a value of 0.31. This gives a curve with FWHM(x)=6 arcsecs and FWHM(y)=8 arcsecs. This is based on work published by Pauluhn et al. in 1999 [4] which used cross-calibration of data from CDS and another SOHO instrument, SUMER. It was however only undertaken with the 4” slit of CDS and did not make comment as to any differences between the two wavebands or differences when using other slits. A further issue with this data is that it was gathered prior to an 83 day period during 1998 when the SOHO spacecraft lost contact with Earth [5] and tumbled with power or attitude control. The unexpected thermal conditions during this period are thought to have greatly affected several of the instruments.

Later post-loss work was carried out [6,7] but not published, it used the 1999 Mercury transit data. It was made clear in this data that the Pauluhn et al. study did not completely characterise the PSF of CDS NIS and that it may have changed significantly following the loss and recovery of SOHO in 1998.
Aims

The aim of this project is to accurately determine the PSF of the CDS NIS on SOHO. The complexity of the instrument means that there are several parts to achieving this primary aim. These parts stem from the various different configurations of the CDS instrument. The PSF is thought to be different for both wavebands of the normal incidence spectrometer on CDS and also different for all of its different slits due to a combination of telescope PSF and a PSF due to the slit being out of focus. Therefore there is a clear need to determine a distinct PSF for each of the three slits. Of particular interest is the 2” slit as it can theoretically produce the highest resolution images. There are also the two different wavebands, NIS 1 and NIS 2, for which separate PSFs will be required. When all of the PSFs have been determined it will be necessary to compare them and see if any correlation exists.

A further aim, should time allow, is to work the data from the PSF determination into a deconvolution routine that would allow images to be sharpened using the data.

Motivation

The motivation for this project lies with the reason why sharper images are necessary - in terms of the solar features that are being observed. There are vast numbers of papers that have been published concerning different features on the Sun and the possible clues that these give to the processes that drive the Sun.

The motivation behind a better understanding of the Sun stems from a number of disciplines. A major reason is that the Sun because it is our closest star and so gives us clues as about the detailed structure and dynamics of other stars. Also important is the effects that Solar processes have on life on Earth, particularly high radiation events such as Coronal Mass Ejections that can damage satellites and electronics in high latitude. Finally, studying the Sun may give clues as to the origins and destination of our Solar System.

Studying fine detail on the Sun gives the evidence and data on which theories about the Sun can be built. Fine detail can also test predictions of various models of the Sun and the Solar corona.

There are several different elements of fine detail on the Sun that are of particular interest. These include flux tubes and coronal loops – both projections from the surface of the Sun carrying plasma guided by magnetic fields. Recent ground based studies [8] have observed structure within loops and flux tubes that appear homogenous to CDS due to the PSF. This effect has also been noticed with the higher resolution images from the TRACE spacecraft [9] that show loops which appear as single strands to CDS to actually contain far more fine structure. Features known as blinkers [10] have also been observed by CDS and appear to be the same size as the predicted PSF, indicating they may be point-like sources being spread by the PSF. Greater resolution will be required before a more in depth study can be undertaken into these new phenomena.

Method

Determining the PSF is made difficult by the fact that the Sun changes rapidly and the surface features are not yet well enough understood to determine if there are any that could be treated as point sources. The next best thing is a source of known shape and dimensions, an opportunity that was presented during the 2003 transit of Mercury. The passage of Mercury across the solar disc was well observed by CDS and it is this data that will form the basis for the project.

The project involves the analysis of images and the writing of computer routines in IDL that will be used to provide the final solution. It is intended that the project will undergo several major milestones en route to completion. These are listed below along with expected timescales for their completion. It is however necessary to note that these may eventually change depending on the results obtained.
Familiarisation with the software and instrument

*Week 1 – Week 4*

The work for this project will be conducted on a Unix workstation with the main programming language being IDL. The instrument, as described in the background section, is CDS on the SOHO spacecraft. The first stage of the project is to study literature and use hands-on practice to gain a much better knowledge of the use of these. This involves a self-taught course in Unix and IDL, to take up most of the first week. Then there are a number of specific tools, written in IDL, that can be used to view and process the CDS data. It will be necessary to learn about these in order to begin analysing data from the Mercury transit.

Identification of Mercury

*Week 4 – Week 7*

The next phase of the project will be to study the various observations that were carried out on CDS during the Mercury transit. From these it will be necessary to accurately determine where Mercury is visible and in which images. This will involve categorising the various studies according to the instrument set-up which was used to capture them. From there each frame can be studied for any detections of Mercury and a catalogue constructed showing which frames contain the planet.

Determination of the PSF

*Week 7 – Week 16*

Determining the PSF is the largest section of the project and therefore takes the majority of the time allotted for working on it. The actual act of determining the PSF involves many different activities and requires many different parameters to be taken into account. The first stage is to create assumed PSFs, one for the actual telescope and another for the other optics. The data needs to be studied carefully to produce an appropriate shape for these two point spread functions. These can then be convolved to produce a theoretical PSF for the instrument. These can then be tested against the data using various methods, such as convolving a computer generated ‘perfect’ image of Mercury and then comparing that to the actual images produced. Factors that will need to be taken into account when determining the PSF include the probable form of the function being a rotated ellipse rather than a perfect Gaussian circle. The function will also be likely to have wings to account for stray light in the detector. This can be determined from the Mercury images by studying the drop in light detected by the detector in areas containing Mercury. The deviance from zero counts will give an indication of the stray light leakage which can then be quantified by studying the images. As there are a number of frames it will be necessary to employ some form of integration in order to create an average PSF that suits all the images, given that their individual characteristics will all be somewhat different.

Image Deconvolution

*Week 15 – End (Time Allowing)*

A possible extension to the project will be to try and use a deconvolution routine from the public domain on the images from CDS. These routines allow the PSF to be entered and then attempt to sharpen the images using that knowledge. There may not be time enough to complete this task as it would involve length modification of the general deconvolution routine to fit the particular parameters of CDS. However, it would be a useful extra task to complete.

Expected Results

The results of this project will broadly fall into three categories – identified images of Mercury that are ready for analysis, as described in the preliminary results; Point Spread Functions and, time permitting, a deconvolution routine for the images.
The actual determination of the PSF is in a large part down to accurate work on identifying Mercury in the images beforehand. However, the eventual result is expected to be a set of functions that will define the PSF for the various operating modes of CDS. This involves the likely separate PSFs for NIS 1 and NIS 2 and also separate PSFs for the three different slits. It is expected that all of these will be different. However, some common characteristics are expected – all are expected to approximate Gaussians but with ‘wings’ and a dilution factor to account for stray light. It is also expected that the PSF will be ellipsoidal rather than circular and that this ellipse will have a rotation relative to the x and y axes of the images.

**Preliminary Results**

The early stages of the project have involved a great deal of familiarisation with the CDS instrument and in particular the IDL and Unix software that is necessary to operate the spacecraft and obtain and analyse the data. Early progress has led to definitions of the four different studies conducted during the 2003 Mercury transit.

Three of these were so-called sit-and-stare observations, where the slit is left pointing at the same point on the Sun and then multiple exposures are taken to produce a time sequence. The sit-and-stare observations were taken with the three different slits on the Normal Incidence Spectrometer part of CDS. There was the MERSS study, which used the 2 arcsec slit, the MERSSW, which used the 4 arcsec slit and the MERMOV series, which was intended to create a movie of Mercury moving across the surface of the Sun. The MERMOV studies were taken with 90 arcsec wide slit.

Another major result so far is to build on work carried out by RAL staff in cleaning images of targets such as Mercury. Looking at the method allowed an IDL program to be written that greatly enhanced the often indistinct Mercury images and helped minimise effects of the solar background. The method involved averaging frames that did not include Mercury and subtracting this from a frame that did contain Mercury. Figure 1 shows an example of Mercury in one of the MERMOV studies after having this technique applied.

![Figure 1](image)

**Figure 1. Mercury images from the 2003 transit showing original cropped image, averaged background of the cropped area and original image with the background subtracted**

The key benefit of doing this is that it now allows Mercury’s position in every one of the transit images to be clearly defined, ready for other processing methods that will be used to determine the PSF.
References


