

Solar B - EIS

**MULLARD SPACE SCIENCE LABORATORY
UNIVERSITY COLLEGE LONDON**

EIS Ground Based Software Requirements

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Prepared By	Neale Ranns, Alan Smith & R.A.Gowen	Date	09 Apr 2001
Authorised By		Date	
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	R Gowen	Orig
	K Al Janabi	
	M Whillock	
SLB-EIS Project Office	A Dibbens	

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1 Introduction

The purpose of this document is to provide an overview of the ground based software requirements for the *Extreme Ultra-Violet Imaging Spectrometer* (EIS) instrument on-board the Solar-B spacecraft. This document covers all the expected needs of the EIS software requirements from the technical and scientific planning stage through instrument status monitoring and data calibration and onto the important last step of data analysis.

Some of the software requirements may change as the mission evolves, however, in this document we hope to provide a broad platform upon which can be based the design specifications and eventually the programs themselves. In the solar community there presently exists a wealth of software particularly in the field of data analysis, provided by the SolarSoft package. It is not the intention here to elude to particular programs that can already perform the functions we site in this document. However, software from this source or others, whether taken as whole or adapted, will be considered a bonus.

The EIS instrument has the considerable advantage of heritage. The CDS instrument flown on the SoHO spacecraft was similar in design and produced very similar data products to that which EIS will produce albeit with better resolution. Many of the software requirements for the EIS instrument follow from experience gathered during the CDS mission.

1.1 Key Terms

Key Terms	Description
Line list	List of chosen spectral lines
Exposure	An exposure at one slit location
Raster	A sequence of rasters to build up an image
Study	A sequence of rasters
Observation	A study which can be repeated, pointing at the same object

2 Software Usability

All software produced by the EIS team is expected to be of the highest quality and very user friendly. In order to achieve this new software will be thoroughly checked and configuration controlled before being released into general circulation. All software must be concisely and clearly written and provided with clear explanations throughout the code as to the steps undertaken. This ensures user understanding and aids any further development and adaption to specific user needs. Software programs must be clearly named so as to be easily identifiable with the task they perform and not to be easily duplicated or accidentally used as variable names. Well selected program names makes the users task of searching for programs much simpler. All software must also provide the capability for a user to find the required program not only

through a search on the expected program name, but also using a text string which describes the users desired task. This may involve programs to conform to a certain structural template. Most importantly the software must be well documented and provide clear and concise instructions to users. The methods employed must be described in full. Software must exist to display these instructions and other program headers to the user.

It is the intention of the EIS team that all produced software be very user friendly. Documentation of methods and procedures must be clear and give a natural insight into the workings of the software.

New code written to fulfill any application must first be tested thoroughly. It will be placed in a test directory where it will be tested by designated members of the EIS team. When it is deemed suitable for general use it will be placed in the appropriate release directory. A procedure for the reporting and rectification of non-conformances will be set up.

3 Technical Planning

It must be possible for users to design their own observational studies to address a particular scientific question. Software must be available to all users to explore EIS setups (i.e. slit size, exposure times, line list etc.) and to view the expected data return. A Graphical User Interface (GUI) program is preferred.

3.1 User Study Design

The software must also incorporate the following instrumental hardware features

- **Telemetry and Compression:** If the users current observations exceed the EIS telemetry budget, the user must be informed of the consequences and where possible a list of solutions to remedy the situation. This may include the use of a new or different compression scheme, or suggested modifications of the study, i.e. line list, window width or raster area.
- **Feature Tracking:** The instruments ability to compensate for solar rotation between successive rasters can be accomplished by two methods. Firstly, repointing the primary mirror or secondly adjusting the spacecraft pointing. Which mechanism will be used is still to be decided. However, whichever is decided upon, software must be available to perform the appropriate calculation and make the subsequent updates to the users pointings if desired.
- **EIS individual Pointing:** Nominally all three instruments on Solar-B (EIS, the *X-Ray Telescope* (XRT) and the *Solar Optical Telescope* (SOT)) will all point to the same solar feature as determined by the spacecraft pointing. The EIS instrument possess the capability to change its individual pointing by ± 15 arc-seconds, by tilting the primary mirror. Software to implement this *Coarse Pointing* mode must also be available to the user.
- **Event Trigger:** The option to place the spacecraft in Event Trigger mode must be provided along with the capacity to enter secondary observational studies that are to be run in the event of the Event Trigger occurring.

3.1.1 Accessible Study Archive

All previous observational studies must be archived so that they can be recalled by name, identification number or scientific objective for ease of re-running and/or modifying. When new studies are designed they can be cross checked against this archive to check for close or exact matches so that the user can examine the real data that was obtained from a similar observation. Cross checking and assigning an intelligent identification scheme will limit the size of the archive and aid new users in designing studies. The exact form of the identification scheme is yet to be decided. There shall be a validation process to ensure that studies cannot harm the instrument.

3.1.2 Error Prevention and Solutions

The software will trap impossible setups, out of range parameters and telemetry constraints, provide appropriate warning in context. It is hoped that this capability will evolve with time to becoming increasingly efficient and effective.

4 Science Planning

The EIS instrument is one of three instruments which will generally be used in a coordinated way and will observe similar regions of the Sun. For this reason the planning of EIS operations must take into account and be compatible with the planning of other Solar-B instruments.

Information shall be available to the EIS science planner as to the present state of solar activity to guide in the selection of an observational target to satisfy the science goals.

4.1 The Planning Tool

A GUI program used by the EIS planner to determine the nature of the observation is required. Using this program the user will be able to load particular studies and add the extra relevant parameters to define the observation (i.e. pointing, start and end times, target ID, number of repeats etc.). The program will supply the user with flag options that best describe the observations about to be undertaken. Some will be mandatory others optional, the details of these flags are still to be decided, but will likely include such things as Target Object ID, Event Trigger Activated, Science Goals etc. It is intended that subsequent users can search the database of observations on all and/or any such flags. The planning tool must also fulfill the requirements outlined in the following subsections

4.1.1 Access to EIS database and Catalogs

Details and data from all previous EIS observations must be available to the present EIS planner so they can make the relevant comparisons between the present data and those from different instrument setups. Any necessary modifications to the current observational study, that may improve the data, can then be identified and applied.

4.1.2 Access to other Solar-B databases and Catalogs

The EIS planner will require access to all other databases and catalogs from the other instruments on Solar-B.

4.1.3 Access to non-Solar-B data

The EIS planner will require access to as many relevant external observations as possible.

It will be necessary to display and interact with these available data sets as appropriate. For example, displaying the EIS field of view on an XRT, SoHO-EIT/MDI or Ground Based (GB) full disk image to visualize the target area and conversely to interactively specify a region of interest for the present EIS observational study. Software must be able to convert between different co-ordinate systems where required.

4.1.4 Access to Solar-B Ancillary Data

This is of particular importance to Solar-B instruments since the instrument pointing on the majority of occasions will be determined by the spacecraft pointing. Software must therefore be able to access and interpret this data. Other information, such as Deep Space Network (DSN) contact time for real time studies and spacecraft maneuvers will also need to be accessed.

4.1.5 Communication with the Deferred Command Store (DCS)

EIS observing plans must be sent to the DCS for communication with the spacecraft. Software must be available to do this and the planning tool be able to interface with it.

4.1.6 Final Observation Details

Once the EIS observing plan has been decided upon scientifically and thereafter in terms of commands to the instrument it will be necessary to add extra parameters before transmission to the DCS. It must also be possible to modify the plan up until the time it is transmitted the spacecraft.

4.2 Packaging the Observation

All parameters associated with the observation, defined by the planning tool, must be gathered and stored in a catalog. This catalog can then be searched by future users to find studies of interest.

5 Inter-Instrument Planning

In the majority of observations the three instruments on Solar-B will all point to the same target, indeed it is only EIS that can point separately from that defined by the spacecraft. To ease the

logistical problems of such co-ordinated observations, we may require a single planning tool that controls all three instruments in addition to or instead of planning tools for each individual instrument. This combined planning tool (CPT) must fulfill all the requirements of the EIS planning tool (listed in sections 3 and 4) and have the capability to perform similar tasks on XRT and SOT. Construction of the CPT will require consultation with the other instrument teams to include their own requirements.

This section is TBD.

6 Collection, Maintenance and Distribution of the Data

6.1 Telemetry Capture

Software must exist to capture the spacecraft telemetry and store it into a telemetry file before being processed into FITS file format (FFF).

6.2 Produce FITS files from telemetry files

Creating FITS files from the telemetry will involve extracting the details associated with the observation from the planning files and extracting the science data from the telemetry files and writing the details to the FITS headers. At the same time characteristics of the actual data (e.g. basic statistics) must be supplied to the EIS observational catalog and added to the planning files. The FITS file header labels will be chosen in order to conform to SolarSoft standards.

Each FITS file will contain data from a single raster. The nomenclature scheme for the FITS files is still to be finalized, however preliminary proposals are to include;

- EIS raster file identifier (1 character)
- 1 character observation type identifier (i.e. Science, calibration etc..)
- Raster Number (3 characters)
- Date (6 characters)
- Time (4 characters)

The presence of a searchable catalog implies that it not be necessary for users to search for observations using a directory listing of file names. However, should the user wish to, the above nomenclature scheme makes this possible.

It is noted that during the conversion from telemetry files to FITS files some processing of the data will occur (e.g. JPEG Decompression) hence the files are no longer level 0 data. Level-0 data would correspond to a direct conversion of the telemetry files to FITS files with no manipulation of the data. FITS files with the decompression applied will thus be referred to as level-1 FITS files.

Observations that have been interrupted by the Event Trigger or other means will have the data padded with invalid values and a FITS header keyword added to indicate as such. Users will be notified when accessing such a FITS file at the calibration stage.

Level 1 data files shall contain a history prior processing including applied calibrations.

6.3 Creation of quick look data

Software will be available to provide *Quick Look* data from the telemetry files, and to provide quick look data to other instrument teams.

6.4 Archiving and Distribution of the Data

The EIS science archive will consist of level-1 FITS files with a separate catalog of associated observational parameters. The medium for storage is still to be decided, however preliminary plans are to use CD-ROMS, depending on the state of alternative technologies nearer the launch date.

Software will be required to write the files to the storage medium, read the data from it and provide a user interface to search the database and extract data from it. The search and extract tools must be able to search on all flags specified at the planning stage (Section 4.1). Software tools are also required to duplicate the database for export to other institutions and mirror sites.

6.5 Archiving and Distribution of the Software

The master copy of the EIS software will be kept and maintained at MSSL. Regular distribution of the entire software tree, subsets or updates will regularly be required to other organisations. Software tools will be required to write the software to a suitable transport medium and be readable on all popular operating systems. Alternatively and/or additionally the software will be stored on a secure server which will allow network access to authorized users at other institutions to copy electronically.

7 Quick Look Software

Quick Look Software shall allow quick look data to be assessed and displayed in near real-time for early scientific assessment of the data, for planning purposes, and to assess instrument health.

Quick Look Software shall provide access to EIS Observation Catalog (database) including planning and 'as-run' information.

This interface shall also allow preparation of general SQL requests.

8 EIS Observation Catalog

All information relevant to each EIS observation (each FITS file) will be stored in a database which is termed the catalog. This database will be maintained using a commercial relational database management system (RDBMS). The actual software package to be used is yet to be determined. Outlined in the following sections are the specifications required of the RDBMS. These fall principally into two categories; the form of the RDBMS itself and its interface.

8.1 RDBMS Specifications

This section is based on experience with the SOHO CDS.

- O Compatible with SQL
- O OS independent
- O Secure from non-authorized users
- O Import and Export flat ASCII files

Above all the EIS catalog database must be efficient. Over the mission life time it is expected that more than one million observations Assuming 1 minute rasters and 3 year mission lifetime) will be taken. Each observation will have associated with a lot of extra information that is intended to ease the users search for datasets they require. This will amount to a considerable database.

8.2 Interface Specifications

The interface requirements can be divided into two sections: an interface for the administrator and one for the user.

8.2.1 Administrator Interface

We must be able to automatically populate the catalog using the output files from the planning tool including studies actually used. All information populated in this way shall be tagged as 'planned' or 'as run'. The form of these output files is to be decided but is likely to be flat ASCII files with each data entry separated with commas. The populating software language is still to be decided, however it must perform rigorous error checking to maintain the integrity of the database.

Automatic programs must also extract the relevant information for entry into the Solar-B catalog.

The software must provide the ability for an authorized user to manually edit the database when necessary. Logs must be maintained of all editing operations.

8.2.2 User Interface

The software must support an IDL GUI interface to the database. Users must be able to design queries to the database with the results viewable on screen and optionally printable. The software must also be able to extract the data into an IDL data structure and optionally extract the corresponding FITS files from a successful search and load them into the current IDL session.

The software must be able to repeat these abilities on other instrument catalogs and correlate that data with EIS catalog.

The user interface should access QL software.

9 Instrument and Detector Status Monitoring

Specific and routine observations will be taken to monitor the evolving status of the instrument and detector. Software must be capable of extracting the relevant information from these observations, with minimal user interaction. The extracted information and subsequent calibration parameters must be easily associated with the observations from which they were derived. All calibration parameters, present and archived, must be freely accessible by all analysis and calibration software and in some instances the planning tool. It may also be necessary for EIS engineers to directly access the calibration files.

9.1 Intensity Calibration

An absolute intensity calibration will exist from pre-flight laboratory tests, however, more tests *in situ* must be conducted to monitor changes. The intensity calibration consists of two parts, an overall detector efficiency and a pixel-to-pixel calibration (the flat-field). Various schemes have been proposed to monitor the changes in the intensity calibration which are listed in the following subsections.

9.1.1 Quiet Sun Monitoring

Under the accepted assumption that true Quiet Sun (QS) flux does not vary greatly, routine observations of Quiet Sun as close to disk center as possible (to avoid column depth variations) may be used to determine the change in detector efficiency overall and as a function of pixel (wavelength) position. These observations must be labeled as calibration at the planning stage, via the planning tool, and be easily identifiable in a catalog search. Selecting the most appropriate target area must be aided by access to full disk images during the planning stage.

9.1.2 Line Pair Ratios

There exists in the EIS wavelength range several pairs of emission lines whose intensity ratios are accurately known and do not change, i.e. they are not a function of plasma temperature or density. These line pairs are listed in the Grand-Book. Software must exist to extract the ratios of such line pairs automatically from observations.

9.1.3 Comparison with External Data

During the Solar-B mission there may exist the possibility to cross calibrate EIS with other instrumentation covering the same spectral range. Software must exist to accomplish this if the opportunity arises.

9.1.4 Flat Field

A pre-flight calculation of the flat field will exist from laboratory tests. *In situ* monitoring of changes due to the *burn in* can be accomplished using the wide slit (slot) which allows the *burn in* to be directly observed. The *burn in* results from the fact that the positions of the bright lines on the detector, which receive the largest dose over time, is fixed. Consequently the loss of sensitivity will be greatest in those areas.

Additionally the EIS instrument includes a set of diodes located behind the shutter which can illuminate the CCD. From this image a flat-field image can be calculated.

9.1.5 CCD Dark Current

The dark current as a function of temperature for the CCD to be used on EIS has been calculated to date. When observations commence and the final operating temperature of the device is known the dark current can be estimated. Images taken with the shutter closed can also be used to estimate the dark current.

9.2 Wavelength Calibration

The conversion of pixel number to wavelength is a central part of the analysis procedure, the accuracy of which is determined by the accuracy of the wavelength calibration. In the absence of an on-board calibration source this must be determined by other means. A pre-flight calibration will be available from laboratory experiments with HC lamps.

9.2.1 In Flight Calibration

Plasma dynamics of highly ionized ions during quiet periods are generally low. Thus with large enough exposures and averaging, plasma dynamics can be removed to obtain a wavelength calibration. Software is required to accomplish this automatically from specifically designed observations (i.e. the same as for the QS monitoring Intensity Calibration) or others.

9.3 Point Spread Function

An initial telescope Point Spread Function (PSF) will be calculated from laboratory experiments, however in-flight monitoring will also be necessary. Possible mechanisms to achieve this include, Mercury transitions (if and when they occur) and Stellar EUV source observations.

In the light of such observations there must exist software able to,

- Locate the position of the source
- Track the source
- Extract and analyse the PSF profile

9.4 Pointing and Alignment

Knowledge of the absolute pointing of EIS is essential for the comparison of EIS image data with

data from other Solar-B instruments and ultimately other satellite and ground based images. Many forms of science analysis depend heavily on accurate image co-alignment. Consequently continual checks on the absolute pointing of EIS must be made. The software to accomplish this task must therefore be able to perform the following tasks.

9.4.1 Access to Spacecraft Attitude

In most instances the EIS pointing will be determined by the spacecraft attitude. Access to these parameters is therefore critical to the software requirements. These data will be made available by ISAS.

9.4.2 Relative offset of EIS from Solar-B

The two other instruments on-board Solar-B cannot point independently from the spacecraft, although SOT can compensate for spacecraft jitter using a tip/tilt mirror and correlation tracker. The task of aligning EIS images with those from these two instruments can be reduced to determining the relative offset of EIS to the spacecraft. Conversely image offset between EIS and XRT (for example) is equal to the relative offset of EIS from the spacecraft. Simultaneously limb observations with the three instruments, accompanied by the necessary software, can thus be used to calculate the offsets. Comparisons of HeII images of the solar Network from EIS with the optical images of SOT & XRT can also be used to deduce relative pointings.

Access to the SOT spacecraft jitter correction parameters may also be desirable if the jitter level becomes comparable to the EIS spatial resolution.

9.4.3 Coordinate Conversions

Coordinate conversion programs for converting between the coordinate scheme employed by Solar-B (arc-seconds from Sun centre) to that employed by other instrumentation and to heliographic coordinates, must be provided. Also for conversion to EIS mirror co-ordinates and vice-versa.

9.5 Stray and Scattered Light

The levels of stray and scattered light can be determined by first rastering over the whole Sun and then pointing the instrument well above the solar limb. Any residual flux in the off-point can be assumed due to scattered/stray light. From the full Sun scan the total flux can be calculated and hence the degree of scattered light.

9.6 Cosmic Rays

Cosmic rays are easily identified on a wavelength dispersed image as pixels that are considerably more intense than their eight nearest neighbours. Software to remove these spikes and any cosmic ray streaks is required.

9.7 Other Detector Features

As the mission proceeds it may become apparent that other detector features, that we are presently not aware of, are affecting the data. Observations and analysis for these features must be designed if the need arises.

10 Data Calibration

Before the data can be used for science analysis the data must be calibrated. The detector and instrument effects that must be accounted for were listed in the previous section along with a description of the methods for calculating the relevant parameters. The software to do this must be readily available and regularly updated using the latest calibration parameters. This is the one piece of software that is universal and should be used by all users of EIS data. It should therefore be easy to use, i.e. one or two steps, but well documented, both in the code and elsewhere to prevent its use as a 'black box' piece of software.

11 Data Analysis

The software required for data analysis will be wide and varied and in some cases specific to the needs of the individual user. However, certain aspects of data analysis will be common to most projects and it is this software that we describe here.

11.1 Input to IDL

The level one FITS files produced from the telemetry data (Section 6.2) and any other relevant information associated with it, must be read into IDL and stored in a data structure. The FITS header keywords in the data structure should conform to SolarSoft standards. The exact format of the data structure is still to be decided however it should be stored in a self explanatory way such that a user can manually extract the desired information should they choose. Programs are also needed to extract the information from the FITS headers.

All software must correctly propagate the errors associated in the data during any calculations.

11.2 Plotting and Image Display

Plotting and displaying images from the data structures may be required before a detailed analysis of the data is undertaken. This will, for instance, allow the user to quickly view the data to recognize certain solar/instrumental features or solar events. Each data structure will contain data from a single raster. The usual form of this will be a three dimensional array; two spatial

dimensions and a wavelength dimension. A series of data structures from sequential observations will hence provide essentially a five dimensional array ($x,y,\lambda,t, nwin$) where $nwin$ is the number of line windows.

Software must hence be able to create the following with user supplied input ranges for any dimension;

- **Line Profiles:** Intensity versus λ at any given x,y,t .
- **Lightcurve:** Intensity versus time at any given x,y,λ .
- **Images:** 2D intensity in x and y , at any given λ,t , or summed/averaged over λ,t .
- **Movies:** Images against time at any given λ , or summed/averaged over λ .

11.3 Specials

Routine observations that have a special purpose, e.g. calibration or synoptic studies, may require separate visualization tools optimized to extract the desired information.

11.4 Spectral Line Fitting

One fundamental step in EIS data analysis will be the fitting of spectral line profiles to the data. This will ultimately allow the user to extract accurate Intensity measurements, from single and/or blended lines, and derive plasma parameters. The software to perform the fitting must have a certain amount of flexibility, since each dataset can potentially include different wavelength regions. The user must be able to specify the following when fitting line profiles.

- The wavelength windows to fit
- The wavelength range
- The profile shape (Gaussian, Lorentzian, etc. depending on the instrument profile)
- Number of components to fit
- Provide initial guess to the fit parameters

The user should at each stage be offered intelligent default values (especially the profile shape) and be guided by the relevant atomic data (when choosing the number of components).

When the user has selected their preferences the software should be able, if desired, to loop through the data set fitting each pixel with the specified function.

The output data products from the line fitting software should be in a data structure with the same dimensions as the input data structure. The format of the output data product should be such that it is compatible with the plotting and image display software that was used for the raw input data (Section 10.2) so that the user can now display images of the fit parameters and hence, after conversion to physical units, produce;

- Intensity Maps
- Velocity Maps (Dopplergrams)

- O Line Width Maps
- O Emission Measure Maps (In conjunction with the relevant atomic data)

11.4.1 Calculation of Plasma Parameters

After fitting the data, plasma parameters (Temperature and Density) can be calculated from the ratios of certain emission lines. The list of line pairs suitable for these diagnostics are listed in the GrandBook, but should also be kept online for easy user reference. The relevant atomic data must also be stored online for general use in defined directories.

The software should thus be able to produce;

- O Temperature (T_e) Maps
- O Density (n_e) Maps

11.5 Calculation of Synthetic Spectra

Software must be available to produce synthetic spectra in the wavelength ranges covered by the EIS instrument. Independent software packages already exist that can perform this task namely CHIANTI and ADAS. Which package the EIS software will use has yet to be confirmed, however the user must be able to specify all the relevant conditions as input parameters, such as temperature, density, ionization (non)equilibrium, (Non) Maxwellian electron distribution etc..

At present the calculation of detailed synthetic spectra is a time and CPU consuming process. However with the rapid advancement in computer technology at ever affordable costs we anticipate that by the launch date the calculation demands will not pose a problem.

11.6 Differential Emission Measure Codes

The EIS wavelength ranges contain a multitude of lines formed over a large temperature range. The calculation of Differential Emission Measures (DEMs) for solar features, and their variation, will form a major part of EIS data analysis. There are several existing numerical codes that can calculate the DEM from line intensities. These must be integrated with the EIS software and data structures.

12 Software Testing

We require the ability to test all elements of the software described in the preceding sections. This will require a mock-up of the EIS hardware and on-board software. This could be implemented by having microprocessors running the on-board software and being addressable by a workstation. Timing loops could mimic the actions of the detectors and mechanisms. Simulated dummy data can then be inputted to simulate the data received by the detectors. A telemetry stream can then be simulated and subsequently the resulting telemetry files.

The whole process performed by the ground based software, from conversion to FITS file format to the creation of temperature maps, can then be tested using the simulated data.