CORONAL DIAGNOSTIC SPECTROMETER

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GIS SOFTWARE USER MANUAL

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Revision list

Version 1, 19 May 1999	Original
Version 2, 1 July 1999	Converted to CDS software note 55
Version 3, 23 July 1999	Added approximate wavelength coverage; added `/cross_cor` keyword to `ghost_plot_one`; described `ghost_info;` added `/plot` and `/hardcopy` keywords to `ghost_buster;` `ghost_buster` prints wavelengths with the ghost cursor; added section on saving and restoring ghost sessions; `gis_calib` uses new calibration coefficients; described `gis_write_calib;` added the new routines to Appendix A.
Version 4, 11 Jan 2000	Expanded section on wavelength calibration

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1. Introduction

This software note will detail how to read, display, correct, and calibrate GIS data. The corrections are for the instrumental effects inherent in the detectors, and the calibrations are for intensity and wavelength. First are outlined the GIS set-up parameters used in the planning process required before each GIS observation, and then methods of reading and displaying the data. The detector effects and associated analysis tools are described, as well as detector calibration. Finally there is a section on ways of using calibrated spectral data.

The GIS specific correction and calibration routines described below are `gis_smooth` to remove detector fixed patterning, `ghost_buster` to remove ambiguities in the positions of some GIS data, and `gis_calib` to calibrate for other detector effects, such as electronic dead times, and effective areas. Note however, that GIS data before May 1996 were taken while the detectors were still settling, and the calibrations for such data are only approximate.

All these routines are written in IDL and form part of the CDS SolarSoft library. To make the CDS libraries available and invoke IDL within SolarSoft use the system commands:

```
setssw cds
sswidl
```

If using the CDS operations version of the IDL software then try the system command `cidl`, though this may vary at different sites.

Many routines are available within the CDS SolarSoft library. To find which routines are available for a particular task use the IDL command:

```
tftd [,'search_string', lines=lines, /prog, cat=cat]
```

this is similar to the UNIX apropos command; `tftd` searches the CDS SolarSoft IDL directories for all occurrences of the search word in routine descriptions For more information about individual routines read the routine header documentation with:

```
xdoc, 'routine_name'
```

1.1 Related Documents

The GIS software forms part of the CDS SolarSoft package put together at RAL, Oslo, Goddard, MSSL, and other places. The associated CDS Software notes are particularly useful and they come as part of the CDS SolarSoft program library distribution. A few of them are listed below; all the notes can be obtained from the web at *http://orpheus.nascom.nasa.gov/cds/software_notes.html*.

> CDS software note 54 - The GIS Instrument Guide, a detailed description of the GIS instrument.
>
> CDS software note 20 - CDS Quicklook Software User Manual is an introduction to the general CDS software available.
>
> CDS software note 22 - CDS on-line help utilities. To find your way about the IDL software in the CDS SolarSoft distribution.
>
> CDS software note 9 - The CDS Quicklook Data Structure. Gives more information about the 'quick look data structure' (qlds) and the data within it.

CDS software note 47 - The Component Fitting System for IDL. For fitting Gaussians/Voigt profiles etc. to spectra.

CDS software note 37 - Diagnostic Line Ratios (using CHIANTI) for CDS. Using the CHIANTI atomic physics databases with CDS data.

CDS software note 33 - The CHIANTI Synthetic Spectrum Program for CDS/SUMER.

CDS software note 50 - Differential Emission Measure analysis using CHIANTI.

1.2 GIS Observations

Unlike the NIS, observations with the GIS are astigmatic, and the whole of the spectrometer slit is used to produce the spectra. To cover an area larger than the normal GIS slits (2”×2”, 4”×4”, and for observations away form the solar disc 8”×50”) the scan mirror and slit are moved over an area of up to 4 arc minutes. Data from all four detectors are gathered simultaneously, and although the minimum integration time is 1 second per pointing, it takes about 15 seconds to transmit the data. Thus to cover an area of 10”×10”, using the 2”×2” slit and 50 second integration time per position takes just over 20 minutes.

Because the GIS electronic encoding is sensitive to the incoming count rate, different GIS set-up (GSET) parameters are needed for different expected count rates. Much of this selection process is automated when the observation is uplinked to the spacecraft, although the observer must specify the solar ‘zone’ beforehand.

The zone is a rough description of the solar activity expected in the observation. It can be one of:

- off limb: not on the solar disk. The expected maximum detector count rates for these areas are below 5 counts/second/pixel.
- quiet sun: any quiet area of the sun, including coronal holes. The expected maximum count rates are 20 counts/second/pixel.
- active region: active regions, including those on the limb. The expected maximum count rates are above 20 counts/second/pixel.

Once the zone and other observation parameters (raster size, slit, exposure time, exact location, etc.) are determined, the CDS planner at the Experiment Operations Facility can insert the GIS observation into the current plan. The combination of zone and slit selected will prompt the CDS planner to choose an appropriate GSET.

The GSETs themselves are pre-determined from special (raw) observations made with the GIS. A number of raw observations for each zone, each slit, each detector and for various high voltage settings, are examined by the GIS team at MSSL and the best selected to produce the current set of GSETs. The raw files associated with each GSET are also used to produce the ‘ghost information files’ discussed in Section 4.2.3.

There has been no change in the set of 11 GSETs needed for GIS observations since the end of commissioning , although regular checks have been made. Some changes have been noticed since the loss and recovery of SOHO, but these are small and not yet fully quantified.

2. Accessing GIS Data

2.1 Browsing the CDS Catalogue

With the utility `xcat`, GIS observations can be selected by name, date, etc.

```
xcat [,qlds, tstart=tstart, tend=tend]
```

Select ‘GIS only’ from the ‘Detector’ menu, and put the required dates in the ‘Start Time’ and ‘Stop Time’ fields. To view all catalogue entries put ‘`1-May-1996`’ in the ‘Start Time’ field. Data from before this date were taken while the detector sensitivities were changing, and should be used with caution.

If other instrument data are available, `xcat` also allows users to overplot the GIS field of view onto images taken by the other instruments, or NIS data. This option is available by selecting the ‘overplot FOV in image tool’ option under ‘Read and view fits file’.

2.2 Reading GIS data

GIS data are stored on disks as CDS FITS files. Most GIS analysis routines need a ‘quick look data structure’ (qlds) to process, and the FITS file can be converted into a qlds using `readcdsfits`. For example, to read in the GIS data set defined as study number s233 raster r00:

```
IDL> qlds = readcdsfits('s233r00')
```

The qlds contains the spectral data, some wavelength calibration information, ancillary information about spacecraft pointing, and much more. It is possible to browse all the information in the qlds with

```
IDL> show_struct, qlds
```

The pre-defined wavelength calibration (see CDS Software Note 54 - The GIS Instrument Guide) is performed automatically for the user when the data are read into a qlds.

With xcat it is also possible to read the selected observation into a variable, bypassing the need for readcdsfits.

```
IDL> xcat, qlds, tstart='28-Feb-1998', tend='28-Mar-1998'
```

This will display the CDS data catalogue (both GIS and NIS data) taken by the satellite between two dates in 1998. Select the program number (study) from the list, e.g. 10716, then the index (or raster) within the study, e.g. 0. Press ‘Read and view fits file’ and ‘Read and exit with ql in data structure’ to have the selected file read into the variable `qlds`.

3. Displaying GIS data

To display intensities of spectral lines the data need correcting and calibrating. However it is possible to display the original data without these corrections, as spectra or images.

3.1 Plotting Spectra

Generic programs such as `dsp_menu, qlds` can be used to display the data, although if a simple plot of the data is required use:

```
gis_plot, qlds, detector_no $
           [,/angstroms, /nm, /pixel, /logscale, waverange=[min,max]]
```

3.2 Images

If the qlds contains data from a two dimensional raster, the function `gt_bimage` can extract data from a wavelength region (or an individual spectral line) as an image

```
gt_bimage (qlds, lam1, lam2 [,xsolar=xsolar, ysolar=ysolar])
```

The approximate wavelengths covered by the GIS are 150-220, 255-340, 395-495, and 655-785Å. For example, to extract and plot a coarse map of the NeXIII line at 780Å from a previously read `qlds`, use the commands:

```
IDL> image = gt_bimage(qlds, 779, 781)
IDL> tvscl, congrid(image, 512, 512)
```

Then use the `xloadct` command to change the IDL colour table, if necessary.

GIS images (or spectra) can also be displayed with the snapshot utility. This will sum all the data in each exposure from individual detectors and display the resulting image. If the scan mirror or slit did not move during the observation then the spectra from each detector are displayed.

```
xcds_snapshot, qlds [,/spectra, /own_window]
```

3.3 Overlaying images

Another useful way of displaying the data is by creating 'map' data and using `plot_map` to overlay maps. For instance to overlay TRACE data defined in arrays `index` and `data`, with GIS data from detector 1 (window 0) defined in `qlds`:

```
IDL> index2map, index, data, tracemap
IDL> plot_map, tracemap, fov=[35,35], grid=10

IDL> map = mk_cds_map(qlds,0)
IDL> plot_map, map, /over
```

See the header documentation for `plot_map`, and the 'TRACE Analysis Guide' for more details about mapping and using TRACE data.

4. Correcting GIS Data for Instrument Effects

4.1 Fixed Patterning

Fixed patterning is an effect caused by the interaction of the GIS digital electronics with the analogue detector read-outs; it is very pronounced in some parts of the GIS spectra. Figure 1 shows a subset of data from detector 1. A boxcar smooth of the data will reduce the fixed patterning seen in the figure but increase the line widths somewhat; the increase depending on the size of the boxcar used. Thus instead a convolution with a Hanning function is used in the program `gis_smooth`. This function preserves the total counts in the spectral lines, without introducing artefacts in the background, or increasing the line widths.

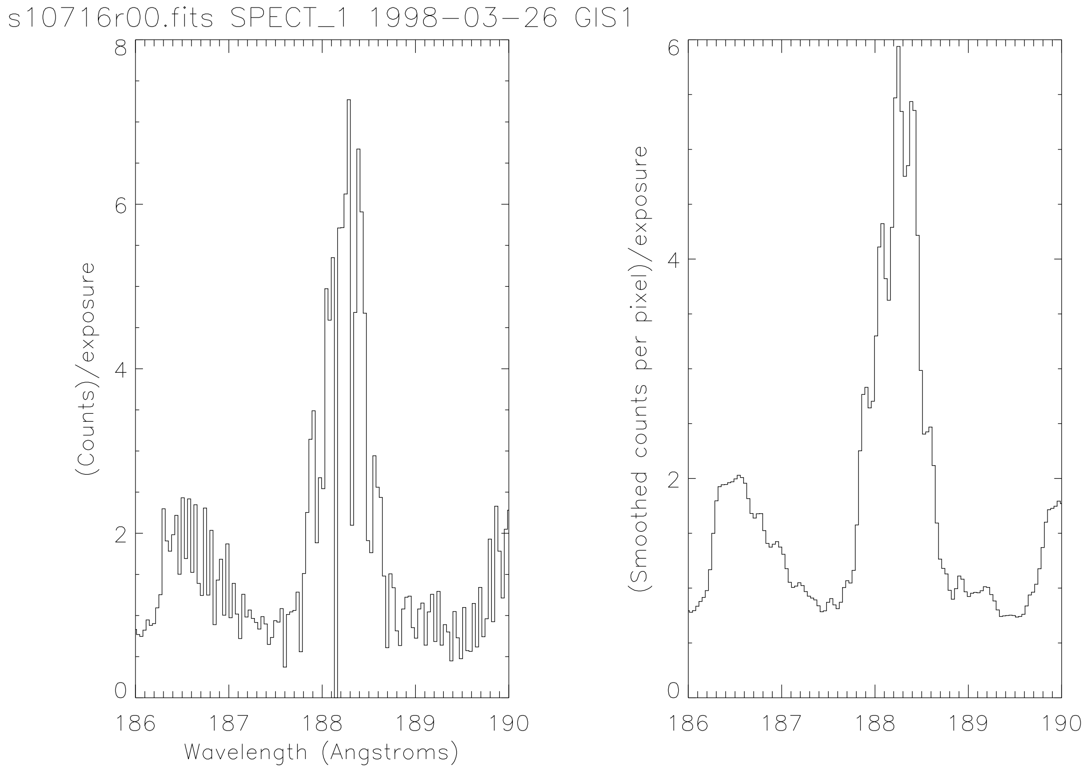

Figure 1: A plot of the data around an Fe XI line from study 10716, showing fixed patterning (left plot), where data shows large variations from pixel to pixel . The right plot shows the same data after running `gis_smooth`.

To smooth the data within a qlds use:

```
gis_smooth, qlds [,smoothsize=size]
```

The option `smoothsize` exists to change the size of the function used, but the default (`smoothsize=7`) works under normal circumstances.

To assist with the smoothing operation, any missing data in the data set are estimated automatically, the smooth is applied, and then the original missing data marked as missing again. It is not recommended to replace missing GIS data separately *before* using any of the GIS processing software, it is taken into account already by the programs.

4.2 Ghosts

An effect in the GIS detectors is the presence of 'ghosts'. These are displaced spectral lines, or parts thereof, caused by an ambiguity in the encoding used by the electronics. The routine `ghost_buster` is used to remove or return ghosts in the GIS data.

When the GIS is in raw data mode, it transmits the data from one detector as a series of co-ordinate pairs from the detectors. When these co-ordinates are plotted they form a spiral (see the GIS Instrument Guide) where the spectral dimension lies along the length of the spiral, and the intensity is the number of counts at each position along the spiral. To translate these pairs into spectral position, a Look up Table (LUT) is used as part of the on-board GIS processing. The parameters that define the LUT, plus the high voltage setting, form the GSET mentioned earlier. Every GSET includes a different set of LUT parameters, and the LUTs are calculated by the on-board GIS processor for each detector immediately before the first observation using that GSET.

The ambiguity (or ghosting) in spectral data does not occur over the whole spectral range, but where the thin spiral arms broaden and overlap each other. If a spectral line is ghosted, it is confined to occur only at specific locations in adjacent spiral arms. It is these facts that are used in `ghost_buster`. The counts in a ghost must be added to the counts at the original location to produce the correct line intensity.

In ghosted areas, which cover 40% to 50% of the data, it is easier to separate the original line from ghosts where there are no blends. Thus ghosted areas in quiet sun observations are easier to correct than in an active region; although the unghosted areas remain unaffected for all observation zones.

4.2.1 Displaying GIS Ghost details

The output from `ghost_plot_one` (e.g., Figure 2) displays GIS data with an emphasis on sorting ghosts from original data

```
ghost_plot_one, qlds, detector_no [,/sample, /nm, /angstroms] $
             [,/logscale, /pixels, waverange=[min, max], /cross_cor]
```

This routine allows many switches to modify how the data are plotted. For instance, `waverange` can be used to zoom into a particular region of interest, by specifying a minimum and maximum wavelength to be plotted; and `sample` plots a sample theoretical spectrum.

The routine first adds all the data from an observation into one spectrum per detector, then plots the data with information to help find possible ghosts.

Figure 2 was produced using:

```
IDL> qlds = readcdsfits('s10716r00')
IDL> gis_smooth, qlds
IDL> ghost_plot_one, qlds, 1, /sample, /angstroms
```

The areas of the resulting plot are described from the top:

- theoretical quiet sun spectrum: This is the spectrum requested with the `/sample` keyword. There are a number of warnings that come with the sample spectrum, see `xdoc, 'ghost_plot_sample'` for details. The spectrum is intended only as an aid to ghost restoration, the intensities of lines are only approximate.
- left shifted spectrum and (correlation): The spectrum plotted is a copy of the observed data, but shifted to the left by one spiral arm. Any ghost that occurs can only be from an original line one arm to the left or to the right. As the ghosting scale is not linear, the amount of shift varies across the detector.
  If the `/cross_cor` keyword is used, the correlation plotted is a computer generated likelihood between the original and shifted spectra. This estimates where the ghosts are by performing a cross correlation of the original and shifted spectra, and if the absolute cross correlation coefficient is greater than 50% it plots a thick bar. This is only a guide to where the program thinks ghosts may be located, and is easily confused by line blends. By default the correlation is not plotted.
- right shifted spectrum, A copy of the observed data shifted to the right, with the optional correlation.

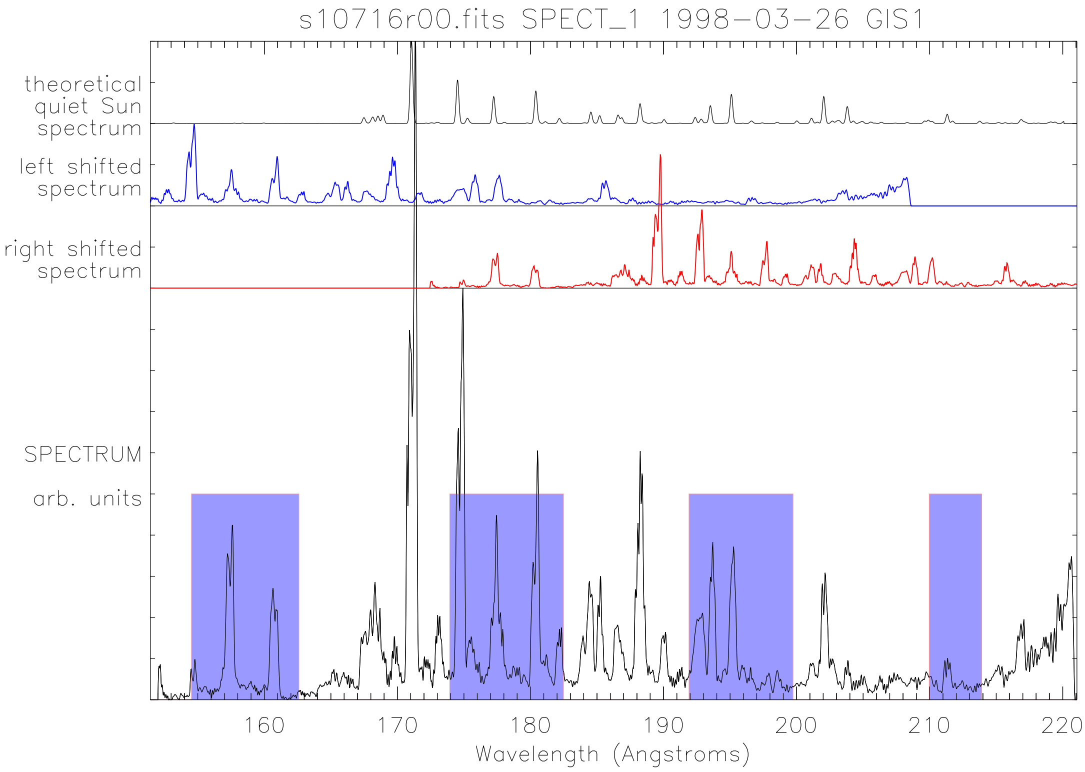

Figure 2: The output plotted from `ghost_plot_one`, with the panels explained in section 4.2.1.

- SPECTRUM: The lower part of the plot contains a summary of the data, where all the exposures in the observation have been added together. The vertical scale is in arbitrary units to show most of the lines, but to enhance the weaker lines plot logarithmically with `/logscale`.

The grey boxes underlying the plot are information from ‘ghost information files’; which show where the ghosts are expected. Figure 2 shows an example of GIS data where the spectral lines between about 174Å and 181Å are repeated (i.e., ghosted) between about 154Å and 162Å. Both these areas are marked as having ghosts.

To summarise the data from all four detectors in a similar way use

```
ghost_plot_all, qlds [ /angstroms, /nm]
```

4.2.2 Finding Ghosts

To check whether a line is ghosted, or itself a ghost, can be explained with Figure 2.

Suppose we have seen a line, and want to check it; for example there is a spectral line on the plot between 160 and 161Å. This line is in the ghosting regions defined by the grey bars on the plot. The first check is to look at the ‘theoretical quiet sun spectrum’; it shows that there are no lines at this location. This may be a fault with the theory; however further checking shows that the ‘left shifted spectrum’ also has a line at this point. This strongly suggests that the line at about 160Å is a ghost and needs to be pushed to the right to correct the line. The manual ghost correction software explains the process of moving the line in more detail, as well as overlaying a 'ghost cursor' on the plot. This cursor shows exactly where lines would come from if they are ghosts.

Alternatively, if we are familiar with this area on the solar spectrum we know there is an FeXIII line at 202Å (see Appendix C). To see whether this line need correcting, first notice that it is a clear area of the plot, i.e., not in a ghosting area. Neither the left nor right shifted spectra show lines at this point, and thus this line is free from ghosts.

4.2.3 Ghost Information files

Ghost information files are used to define where the ghosts are. They are used automatically by both the ghost plotting software and the ghost reduction software. They contain pixel location vs. expected ghosting for each GSET, and are included in the CDS SolarSoft directories. All currently used GSETS have an associated ghost information file, which is stored with other GIS calibration files addressed by the environment variable `CDS_GIS_CAL_INT`.

The information in these files comes from inspecting the raw files associated with each GSET, and checking where the overlap of spiral arms occurs. The files will be updated with more information, such as estimated amounts of ghosting as well as positions, as this becomes available.

To read the contents of the ghost information file associated with a particular qlds and detector, use the command

```
ghost_info, qlds, detno [,info, /noprint, /nm, /angstroms]
```

this will print the information from the ghost information file pixel by pixel, including wavelength calibrations, ghost amounts and positions.

4.3 Ghost Correction

There are currently two modes for ghost correction: manual and ghost free. By default, `ghost_buster` works in ghost free mode. If, from using `ghost_plot_one`, the region of interest does not need correcting then use ghost free mode. Once the ghosted areas have been removed with this mode, then the data can be further calibrated without problems.

If the region does need correcting, then run in manual mode. Care must be taken with manually corrected data; it is possible to run `ghost_buster` without making any changes, yet the software still allows further calibration. Because the corrected count rates must be used for the count rate dependant gain depression calibration (see below), it is important to replace the ghosts in any region of interest before calibrating further. Only ghosts of the lines within the region of interest need to be moved, all others can remain in place without affecting the calibration.

If spectral lines need to be fitted, it is recommended to correct for ghosts first, calibrate the data, and then fit the lines.

In either mode, it is possible to run `ghost_buster` again in the same or a different mode, although if it is run on the same detector a warning will be displayed. To reset all spectra to the uncorrected state it is necessary to re-read the qlds from the data file.

4.3.1 Ghost free mode

This mode uses the ghost information files (section 4.2.3) to return only those areas of the GIS spectra that show very little (less than about 5%) or no ghosting.

```
ghost_buster, qlds [,/plot ,/hardcopy ,/angstroms ,/nm]
```

Between 50% and 60% of each spectrum is returned, and ghost free mode is available for all GSETs. Only one parameter is needed, the qlds; use the `plot` and `hardcopy` switches to see the changes applied to the qlds. For example:

```
IDL> ghost_buster, qlds
```

After using ghost free mode, blocks of data from the known ghosting regions will be missing from the qlds. The areas remaining can be used without needing ghost correction.

4.3.2 Manual mode

Manual mode allows the user to move ghosted lines within a single detector. To run in manual mode supply two parameters, the qlds and a detector number.

```
ghost_buster, qlds, detector_no [,/hardcopy, /angstroms, /nm $
          /sample, /logscale, /plot, /angstroms, $
          save=save_struct]
```

Manual mode allows the user to specify which GIS spectral lines to relocate. The program gives hints by using `ghost_plot_one` (Section 4.2.1). to show the spectrum with overlying spectra shifted both to the left and to the right, a cross correlation with these spectra, and an estimate of the amount of ghosting in each direction. It also uses a ‘ghost cursor’ to show exactly where a spectral line would ghost.

The main cursor is a solid vertical line, either side of it is a dotted ghost cursor. The dotted lines are where any selected data will be moved to (i.e., they correspond to the next or previous spiral arms). The spacing between the dotted lines and the main cursor vary across the spectrum, as do the shifted spectra. Below the dotted lines and main cursor are printed the corresponding wavelengths for those points.

To move a ghost that has been identified, position the cursor to the left of the ghost and press and drag the left mouse button over the ghost. For instance, to move the ghost previously identified at around 160Å (Section 4.2.2), press the mouse button with the cursor just to the left of 160Å, keep it depressed and move to about 162Å. Let go of the mouse and enter `r` in the terminal window to move the line to the right. Repeat this procedure until all the lines of interest have been corrected.

When moving a ghost, remember to include enough background for line fitting on either side of the line of interest. It is possible to restore more ghosts by running the program again, on the same detector or any other. Use the `/plot` or `/hardcopy` keywords to see the final result; alternatively use `gis_plot` or `ghost_plot_one` when finished.

4.3.3 Saving and restoring `ghost_buster` sessions

By adding the `save = save_struct` keyword, it is possible to save the ghost corrections made in manual mode into an IDL structure variable. It is then possible to restore these corrections to uncorrected data with

```
ghost_buster, qlds, detno, restore = save_struct [,/plot, /hardcopy]
```

For example:

```
IDL> ghost_buster, qlds1, 1, save = save_struct
IDL> save, save_struct, filename='qlds1_det1.save'
```

and then at a later time

```
IDL> restore, 'qlds1_det1.save'
IDL> ghost_buster, qlds2, 1, restore = save_struct
```

The first call to `ghost_buster` is in manual mode, and the software will prompt for corrections to the data as outlined above. The corrections are stored in an IDL save file. The second call uses the restored information to reapply the corrections to a second data set. Note that both `qlds1` and `qlds2` must use the same GSET; and that the same detector (number 1 in this case) must be used.

4.4 Edge effects

Most detectors show edge effects, both as spikes and a gradual increase in the background. There are many causes for these effects, notably: a compression of the wavelength scale, causing an increase in the background; end spoiling in the microchannel plates, where the strong electric fields diverge at the ends of the detectors; changes in the solar background, mainly from the HeII continuum; and some very bright (solar) lines, seen especially in detector 2. Work is continuing on calibrating the non-solar effects.

5. Calibrating GIS Data

5.1 Wavelength Calibration

Wavelength calibrations are read in automatically when the fits file is converted into a qlds. The wavelength calibration can be accessed by the routines `wave2pix` and `pix2wave`, which translate the GIS pixel co-ordinates as necessary.

```
pixel = wave2pix (spec_id, wavelength [,/limit])
```

Where, for the GIS, `spec_id` is a string containing `GIS1 GIS2 GIS3` or `GIS4`, and `wavelength` can be a single value or an array. See the example program in Appendix B. Similarly

```
wavelength = pix2wave (spec_id, pixel)
```

Which will return the wavelengths of the pixel array for the spectrum. Again, `pixel` can be a single value or an array.

Variations of about 20% of a line width are expected between observations, caused mainly by GIS hardware temperature differences when observing different parts of the sun, or very high count-rates (more than about 40 counts/second/pixel) causing distortions in the electronic processing.

Note that the wavelength calibration varies with each GIS setup (GSET) used. Thus to compare two GIS observations that used different GSETs it is necessary to re-load the wavelength calibration. This is simplified with the routine `restore_wavecal`. For instance, below is part of an IDL session to over plot two GIS observations:

```
IDL> qlds_1 = readcdsfits('s8965r00')
IDL> qlds_2 = readcdsfits('s8966r00')

IDL> gis_smooth, qlds_1
IDL> gis_smooth, qlds_2

IDL> if (restore_wavecal(qlds_1) ne 1) then $
IDL>                                print, 'RESTORE_WAVECAL failed'
IDL> wave_1 = pix2wave('GIS1', findgen(2048))
```

```
IDL> data_1 = gt_windata(qlds_1, 0) ; window 0 is for detector 1

IDL> if (restore_wavecal(qlds_2) ne 1) then $
IDL>                            print, 'RESTORE_WAVECAL failed'
IDL> wave_2 = pix2wave('GIS1', findgen(2048))

IDL> data_2 = gt_windata(qlds_2, 0) ; window 0 is for detector 1

IDL> plot, wave_1, data_1/max(data_1), xrange=[187,190], psym=10
IDL> oplot, wave_2, data_2/max(data_2)
```

5.2 Intensity Calibration

As well as the ghosts and fixed patterning, the detectors and their electronics have non-linearities that need to be corrected. On the whole these corrections are small (less than 10%, but depending on count-rate). `gis_calib` will correct for these; and then if wanted it can calibrate into photons using the GIS calibration coefficients.

```
gis_calib, qlds [,errmsg=errmsg, /setmissing, /quiet, $
                           /steradian_m2, /arcsec2_cm2, /HeII]
```

By default the data will be returned as corrected counts per second per pixel. To convert to photons per second per solid angle per area use the `/arcsec2_cm2` or `/steradian_m2` switches.

The routine checks to make sure the routine `ghost_buster` has been run for all the detectors - if not the `/setmissing` switch can be used to mark the data from those detectors as missing. This switch can also be used to mark smaller parts of the data as missing if they cannot be calibrated for other reasons; this might include the occasional strong line that is too bright for the gain depression calibration, or whole detector count rates too high for the electronic dead time corrections.

The region around the HeII 304Å line is so bright that the detector efficiency is less than 1% of the original efficiency; by default this region is also marked as missing. It is possible to override this check with the `/HeII` switch, to allow the use of the HeII line for morphology, where absolute calibration is not necessary.

The GIS calibration coefficients used are those from the RAL pre-flight calibration tests[1], the coefficients can be viewed using the program `gis_write_calib`.

5.2.1 Calibration details

The corrections and calibrations made by `gis_calib` include:

- FIFO dead time: The dead time is a straightforward correction for an on-board First In First Out (FIFO) event queuing chip. It applies to all four detectors simultaneously, and involves a constant non extending dead time allowing 10^5 counts per second through unhindered, with small corrections for higher rates.
- Simple correction for Quiz-show dead time: The programmed Quiz-show correction is simply an upper limit on the rates; if photon events are less than 6 microseconds apart then the data are marked as uncalibratable. The maximum rate is then $1.0/(6.0\times10^{-6})$ or approximately 1.7×10^5 over all four detectors.

---

[1] The Laboratory Calibration of the SOHO Coronal Diagnostic Spectrometer, J. Lang *et al.*, RAL Technical Report RAL-TR-1999-036. Submitted to Journal of Optics A.

- Analogue dead time: This involves an extending dead time of approximately 2½ microseconds. The data used to correct for this were measured before launch using the flight electronics and are read from a data file.
- Count rate dependant gain depression (also known as short term gain depression). If more than 5% error would occur in the measured rates, then the datum (at that point only) is marked as uncalibratable.
- Long term gain depression and flat field: Data files can be used to compensate for such gain depression. These data can also be used to make adjustments for changes in detector response over the illuminated areas.
- Detector / grating / telescope effective area. The calculations are based on a ground based calibration exercise for the whole of CDS. The relative calibration coefficients have since been verified in flight[2], but please note that there is currently a very large uncertainty in the absolute values.

6. Using calibrated spectral data

Various CDS and other SolarSoft routines exist to use the data once calibrated; most of these can be used with both NIS and GIS data. The generic `dsp_menu` program will work with both calibrated and uncalibrated data, but can have problems with small numbers.

```
dsp_menu, qlds [,qlds2 ,qlds3, ... ,/delete, /nocheck]
```

The other utilities mentioned in Section 3 will also work with calibrated data, Appendix B is a small IDL program that illustrates a few of these. More GIS specific software in this area is under development.

6.1 Extracting the data from the qlds

To extract the spectral data from a qlds always use `gt_windata` or `gt_spectrum`

```
data = gt_windata (qlds, window [,/nocheck, /quick, /nocopy, $
                     /nopadding ,errmsg=errmsg])
```

These routines will work with all storage schemes used for CDS qlds data. With GIS data, specify the qlds and the 'window', which is one less than the detector number. For example, to extract detector 3 data from a pre-defined qlds use

```
IDL> GIS3data = gt_windata(qlds, 2)
```

The returned data are a floating point array of up to 4 dimensions: spectrum (always 2048 pixels for the GIS), solar x, solar y, and time. The time dimension is only used for data that have multiple exposures at the same solar x, y point.

To get information about the extracted data use

```
gt_windesc (qlds, window [,/nocheck, /quick, /errmsg]
```

For example:

```
IDL> GIS3desc = gt_windesc(qlds, 2)
```

---

[2] See Landi, E., Del Zanna, G., Breeveld, E. R., Landini, M., Bromage, B.J.I., Pike, C.D.: 1999, Relative Intensity Calibration of CDS-GIS Detectors on SOHO using a Plasma Diagnostic Technique, Astronomy and Astrophysics Supplement, v.135, p.171-185

The returned structure tells us which units the data use (`GIS3desc.units`), the missing data flag (`GIS3desc.missing`), the wavelength range (`GIS3desc.wavemin`, `GIS3desc.wavemax`), etc. The command

```
IDL> xshow_struct, GIS3desc
```

will display all the information available in the structure. Also available is `gt_spectrum`, to get individual spectra from a raster:

```
result = gt_spectrum (qlds, window=window, yix=yix, xix=xix, $
  [tix=tix, lambda=lambda, xsolar=xsolar, ysolar=ysolar, time=time]
```

Where `window, yix, xix, tix` are the user supplied window (i.e., the detector number-1), and for each raster position the x, y and time indices. The time index is not normally used unless the raster has repeated exposures at the same position. If supplied, `lambda` will return the wavelength for each pixel in the spectrum, `xsolar` and `ysolar` are the locations on the sun in arc seconds from the sun centre and time is the time of the start of the exposure.

6.2 Line fitting

Many fitting procedures are available (see `tftd, 'gauss'` and `tftd, 'voigt'`) which can be used to fit various profiles and backgrounds to ghost free or ghost corrected GIS spectra. One of these is `ezfit`:

```
ezfit, wavescale, data, waverange, k=k
```

where `wavescale` and `data` are the X and Y variables, `waverange` can be used to limit the fit to a particular line, and `k` is the polynomial order of the background. Thus to fit a Gaussian plus background to a region in the first exposure of the above GIS detector 3 data:

```
IDL> wavescale = pix2wave('GIS3', indgen(2048))
IDL> data = GIS3data[*, 0, 0, 0]
IDL> waverange = [415, 420]
IDL> ezfit, wavescale, data, waverange, k=1
```

Another routine, `cds_gauss`, has been developed for use with CDS data:

```
yfit = cds_gauss(x, y, [a, k])
```

where `x` is the independent vector; `y` is dependent variable; `a` contains the returned coefficients and `k` defines the order of the polynomial to be fitted to the background.

A more complicated but very comprehensive fitting routine is `cfit`

```
yfit = cfit(x, y, a, fit [,sigmaa] [+keywords])
```

where `x, y` are the data to be fitted, `a` is an array of (nominal) parameter values - if defined then used as an initial guess to the fit; `fit` is a structure containing one tag for each component in the fit; `sigmaa` contains the errors for each of the parameter values in `a.` For detailed information about `cfit` see CDS software note 47 - The Component Fitting System for IDL.

Because of the complexities of fitting spectral lines in the ghosted areas, there are currently no GIS specific line fitting routines. This work is under continuous development to make more areas of the GIS detectors accessible; this should result in all of the quiet sun data being available, and most of the active region data.

6.3 Solar densities, temperatures and theoretical spectra

Once the intensities of selected lines have been determined, they can be compared with intensities produced by models of the solar atmosphere.

Many theoretical intensities can be found with the CHIANTI package, it was developed specifically for EUV line emissions, and enhanced to cover all the wavelength regions detected by the GIS, NIS, and SUMER. Use `chianti_ne` to get theoretical intensity ratios for density diagnostics, and then compare the observed ratio to get the densities. Similarly with `chianti_te` for temperature diagnostics. Enter

```
IDL> chianti_ne                ; or chianti_te
```

to run either program respectively. For example, to check the ratio of two Fe XI lines at 180.4Å and 188.3Å are density sensitive at 10^6K: Run `chianti_ne`, and ‘Select element’ Fe, ‘Select ionisation’ XI, enter one wavelength range between 180-190Å, ‘Log temperature’ 6, and finally press ‘calculate line intensities’. The plots show the line ratios, and the line numbers are identified underneath. For more information see CDS software note 37 - Diagnostic Line Ratios (using CHIANTI) for CDS. To save the data generated by either program press the ‘Save’ button, and a file containing the line ratios will be generated.

Similarly, it is often useful to check theoretical spectra for possible line identifications and blends. The program `chianti_ss` can be used; for example to check the line identifications in a quiet sun GIS detector 1 spectrum: Run `chianti_ss`, select ‘Instrument’ GIS, ‘Select GIS spectral band’ 1, enter ‘Pressure (NeT)’ 1e15, ‘Select DEM file’ quiet sun, ‘Select Abundance file’ meyer_coronal, ‘Select Ion. Equilibrium file’ arnaud_rothenflug, and finally press ‘Calculate spectrum’. For more information see CDS software note 33 - The CHIANTI Synthetic Spectrum Program for CDS/SUMER.

Appendix A. List of useful routines

Some useful CDS and other SolarSoft routines, along with one-line descriptions. For detailed information examine the routine headers with `xdoc, 'routine_name'`.

`cds_fill_missing`	Fills MISSING pixels in QLDS.
`cds_gauss`	Fits Gaussian with constant, linear or quadratic background
`cds_snapshot`	Makes a thumbnail sketch of images from a CDS study
`chianti_ne`	Calculate and plot CHIANTI density sensitive line ratios
`chianti_ss`	Calculates and plots CHIANTI synthetic spectrum
`chianti_te`	Calculate and plot CHIANTI temperature sensitive line ratios
`cfit`	Make a best fit of the sum of components to the supplied data
`dsp_menu`	Selection of display modes for CDS QL data
`ezfit`	Easy Gauss fit to data
`ghost_buster`	Move GIS detector ghosts.*
`ghost_info`	Display the ghosting information associated with a QLDS*
`ghost_plot_all`	Plots all 4 GIS detector data with likely ghost regions*
`ghost_plot_sample`	Plots (or returns) a theoretical sample GIS spectrum*
`ghost_plot_one`	Plots a GIS detector data with likely ghost regions*
`gis_calib`	Applies calibration factors to GIS spectra.*
`gis_plot`	Summarise data from one GIS detector*
`gis_smooth`	Smoothes GIS spectra to 'remove' fixed patterning*
`gis_write_calib`	Prints calibration factors for GIS spectra*
`gt_bimage`	Return wavelength band integrated image.
`gt_spectrum`	Returns one-dimensional spectrum at specified point
`gt_windata`	Return block of detector data from one detector window.
`gt_windesc`	Return descriptor structure for one detector window
`integral_calc`	To compute the atomic data integral for use in column or volume emission measure work.
`mk_cds_map`	Make an image map from a CDS QL structure
`pix2wave`	Calculate CDS wavelength given a detector pixel location.
`plot_map`	Plot an image map
`readcdsfits`	Read and return the contents of a CDS FITS level-1 file.
`show_struct`	Display contents and breakdown of an IDL structure
`tftd`	Search for a string in header documentation
`utplot`	Plot X vs. Y with Universal time labels on bottom X axis.
`wave2pix`	Calculate detector pixel location given a CDS wavelength.
`xcat`	widget interface to CDS AS-RUN catalogue
`xcds_snapshot`	Widget interface to CDS_SNAPSHOT
`xdoc`	Front end to online documentation software.

* refers to GIS specific routines.

Appendix B. Example Program

Below is an example program that combines a series of exposures, and plots the total spectrum. The count rates within a section of the spectra are then plotted as an image.

```
pro example, study, detno, lam1, lam2
;
; study:        study filename (string)
; detno:        detector number, from 1 to 4
; lam1, lam2:   wavelength range to integrate over (in Angstroms)
;
; e.g. to pick the 277A line in detector 2 in study s7060r00 type:
;     IDL> example, 's10716r00', 2, 276, 278
;
; erb@mssl.ucl.ac.uk, 17 Feb 1999
;
    print, 'Reading ' + study, + ', detector number', + detno
    print, 'Plotting between wavelengths ', lam1, lam2
;
    qlds = readcdsfits (study)      ; read in the qlds
    ghost_buster, qlds              ; ghost free areas
    gis_calib, qlds, /arcsec2_cm2   ; calibrate
    cds_fill_missing, qlds          ; guess missing data
;
; plot an average spectrum
;
    window, 0
    ghost_plot_one, qlds, detno, /angstroms
;
; Take a slice of the data
;
    int_spec = gt_bimage(qlds, lam1, lam2, xsolar=xsolar, $
                          ysolar=ysolar)
;
    spec_id = 'GIS' + trim(detno)
    print, 'Pixels chosen:', wave2pix(spec_id, [lam1, lam2])
    print, 'Bottom left position on the sun:', $
                                min(xsolar), min(ysolar)
;
; plot the image
;
    window, 1
    loadct, 0
    tvscl, congrid(int_spec, 512, 512)
;
    return
end
```

Appendix C. Ghost free line lists

Below are tables of expected count rates per second for lines, for the 2”×2” slit, in ghost-free areas in the four GIS detectors.

The lists are originally from the CDS Scientific Report (‘Blue Book’) by Richard Harrison, Tables 2.1-2.6 and 3.3-3.7 with lines in ghosted areas removed.

Note that this list is specifically for the ghost free areas of observations taken with GSET 41 (quiet Sun, 2"×2" slit), although the positions of ghosting are similar for all the GSETs. A detailed check of ghosting in an observation can be made with `’ghost_plot_one, qlds, detno’`

DETECTOR 1

Ion	Wavelength (Å)	Quiet Sun Intensity
Ni XIV	164.13	0.4
Ar X	165.49	0.0
Fe VIII	167 - 168	2.0
Ni XIV	169.68	0.0
Fe IX	171.07	8.8
O V	172.17	0.1
O VI	172.93 - 173.08	0.7
O VI	183.94 - 184.11	0.4
Fe X	184.54	2.2
Fe XI	184.79	0.2
Fe VIII/Ni XVI	185.22	0.8
Fe VIII	186.60	0.5
Fe XII	186.88	2.4
Fe VIII	187.23	0.0
Fe XI	188.22	8.2
S XI	188.67	0.3
Fe X	190.04	1.3
Fe XIII/SXI	191.26	0.3
Fe XIII	200.02	0.7
Fe XII/XIII	201.12	2.0
Fe XIII	202.04	0.9
S VIII	202.61	0.4
Fe XIII	203.79	3.7
Fe XIII	204.26	0.0
Fe XIII	204.94	0.6
S X	208.32	0.0
Fe XIII	208.68	0.0
Fe XIII	209.62	0.0
Si VIII / Si XII	214.76 - 215.15	0.8
Si VIII	216.90	0.6
Fe XII	217.27	0.0
S XII	218.18	0.4

Fe XIV	219.12	2.0
Fe XIV	220.08	2.6

DETECTOR 2

Note that the He II and blended Si XI lines at 304Å are not included because the intensity of these excessively bright lines cannot be calibrated.

Ion	Wavelength (Å)	Quiet Sun Intensity	Active Sun Intensity
Si X	261.06	1.5	
Fe XVI	262.98	1.3	
Fe XIV	274.20	5.7	
Si VII	275.37 - 275.76	0.5	
Mg VII	276.15	0.2	
Si VII / Si VII	276.77 - 276.85	0.2	
Mg VII / Si X	277.04 - 277.27	2.3	
Mg VII / Si VII	278.40	0.5	
S XI	281.42	0.5	
S XI	281.83	0.0	
S XII	299.50	0.2	
Fe XI	308.54	0.0	0.0
Fe XIII	318.14	0.9	2.9
Si VIII	319.83	1.3	2.5
Fe XIII	320.80	3.5	11.5
Fe XV	321.78	2.3	7.9
Fe XV	327.02	2.4	8.0
Fe XII	338.26	1.2	4.2

DETECTOR 3

Ion	Wavelength (Å)	Quiet Sun Intensity	Active Sun Intensity
Ne V	416.20	0.2	0.8
Fe XV	417.26	1.1	34.6
S XIV	417.60	3.9	32.4
C IV / Ca X	419.50 - 419.74	0.7	3.0
Mg IX	438.60	0.2	0.8
Mg IX	444.03	0.4	2.8
Ca XV	445.00	0.0	3.6
S XIV	445.70	0.2	3.0
Si IX * / Mg VII	450.73	0.0	0.0
Ne VII	465.22	4.4	36.1
Ca IX	466.23	0.0	2.7
Ne IV	469.80	0.3	1.2
Ne III	489.50	0.2	1.2

* Second order line blend

DETECTOR 4

Ion	Wavelength (Å)	Quiet Sun Intensity	Active Sun Intensity
N III	685.83	1.1	2.2
C II	687.20	0.3	0.5
Ca IX	693.80	0.3	1.6
Al III	696.00	0.0	0.1
Mg IX * / Ne I	735.90	0.4	2.6
O V	758.60	0.4	2.1
O V	759.44	0.0	0.0
O V	760.40	0.9	4.4
O V	762.00	0.0	0.0
N III	764.00	0.0	0.0
Ne VIII	780.30	1.4	16.1
S XI	782.00	0.0	0.2
Mg VIII	783.00	0.2	0.7

* Second order line blend

BRIGHTEST GHOST FREE LINES VISIBLE WITH THE GIS

The Si XI 303Å and He II 304Å line are not included because the intensity of these excessively bright lines cannot be calibrated.

Ion	Wavelength (Å)	Quiet Sun Intensity (counts/second)
Fe IX	171.07	8.8
Fe XI	188.22	8.2
Fe XIII	203.79	3.7
Fe XIV	220.08	2.6
Fe XIV	264.79	4.2
Fe XIV / Si VII	274.20	5.7
Fe XV / Al IX	284.16	22.3
Fe XIII	320.80	3.5
S XIV	417.60	3.9
Ne VII	465.22	4.4

GIS PRIME DENSITY SENSITIVE PAIRS IN GHOST-FREE REGIONS

Note the lines marked with 'n' are NIS lines

Ion	Wavelengths (Å)
Mg VII	280.74 / 278.40
S XI	215.93 / 281.42
S XI	190.37 / 281.42
S XI	217.64 / 281.42
Fe XII	338.27 / 364.47n
Fe XIII	202.04 / 200.02
Fe XIII	201.12 / 200.02
Fe XIII	202.04 / 203.79
Fe XIII	318.12 / 320.80
Fe XIII	320.80 / 348.18n
Fe XIII	318.12 / 348.18n

GIS GHOST-FREE TEMPERATURE SENSITIVE LINE RATIOS

Note that ’n’ is for NIS lines and ’s’ for SUMER lines

Ion and Ratio	Range of Sensitivity (K)
O V 172.17 / 629.73n	< 1.0 x 10^6
O VI 173 / 1032s	< few x 10^6
O VI 184 / 1032s	< few x 10^6
Ne V 416.20 / 569.20n	10^5-10^6
Ne V 416.20 / 572.20n	10^5-10^6

GHOST-FREE LINES IN THE GIS RANGE SUITABLE FOR A DIFFERENTIAL EMISSION MEASURE ANALYSIS

Ion	Wavelength (Å)	LogT (K)
Ne VII	465.22	5.7
Ne VIII	780.30	5.8
Si VII	275.37	5.8
Si VIII	319.83	5.9
Si X	261.06	6.0
Fe VIII	168.18	5.6
Fe IX	171.07	6.0
Fe XI	188.22	6.1
Fe XIII	203.79	6.2
Fe XIV	220.08	6.3
Fe XVII	200.80	6.5

GHOST-FREE GIS LINES SUITABLE FOR HIGH TEMPERATURE STUDIES

Ion	Wavelength (Å)
Fe XXIII	154.27
Fe XXIII	166.74
Fe XXIII	173.31
Fe XXIII	263.76
Fe XXII	217.30
Fe XXIV	192.02