4. THE NORMAL INCIDENCE SPECTROMETER

"I have the feeling that to most astronomers the Sun is rather a nuisance In the first place it at once halves the astromomer's observing time from 24 to 12 hours, and then during most of the rest of the time it continues its perversity by illuminating the Moon" - J.P.Wild.

4.1 Wavelength Coverage

The wavelength coverage of the NIS is limited - detector technology and instrument design dictated a rather difficult play off between spectral resolution and spectral coverage. However, in this case we must also consider the grating reflectance fall-off with decreasing wavelength; very few lines below ~300Å would have reasonable intensities. This puts an instrumental lower limit on the choice of wavelength for the NIS and was, in fact, the driver for having the GIS in the first place.

The detector system for the CDS NIS is the Goddard Space Flight Center Intensified CCD device - known as the VDS (Viewfinder Detector System) (see Thompson et al. 1992 and Harrison et al. 1995). It consists of a windowless microchannel plate intensifier tube which converts EUV radiation, through the photoelectric effect, to electrons which are then multiplied through an applied voltage. The resulting electron cloud due to the arrrival of a photon is then converted to visible light by a phosphor coated fibre-optic window. The visible light is then focused by a lens onto a 1024x1024 CCD with 21μm pixels. The CCD will normally be read out from all four corners. The read out time is 14μs for each retained pixel and 2μs for each discarded pixel. Thus, to read, and retain a full image takes 3.7s; to empty (discard) a CCD image takes 0.5s. There is a 0.5s recovery time for the microchannel plate after each read out.

For line separation, we require a resolving power ($\lambda/\Delta\lambda$) of over a thousand, and for flow studies, it would be desirable to view with a resolving power considerably higher, though this should not be the prime driver in an instrument whose principal goals are density and temperature diagnostic analyses. In early CDS science meetings the 150 - 800Å range was studied to identify regions of particular importance for density diagnostics and temperature coverage; the bands 317 - 400Å and 558 - 630Å were chosen as being of prime interest for the NIS system. The NIS design allows for the detection of two spectral bands by using a double grating system producing two vertically displaced spectra on the VDS detector.

The two selected wavelength ranges must be consistent with one another. The ranges, given as λ_1 - λ_2 and λ_3 - λ_4, must obey the relation

$$(d_x/d_y) = (\lambda_1/\lambda_3) = (\lambda_2/\lambda_4),$$

where d_x and d_y are the grating spacings. This relation comes about because the gratings and detector are fixed with respect to one another and the limits of each wavelength range must obey Bragg equation, $n\lambda = d\sin\phi$, i.e. we have the four relations: $\lambda_1 = d_x\sin\phi_a$, $\lambda_2 = d_x\sin\phi_b$, $\lambda_3 = d_y\sin\phi_a$ and $\lambda_4 = d_y\sin\phi_b$.

The actual wavelength ranges are given in Table 4.1.

Table 4.1: The NIS Wavelength Ranges

Band	1st Order (Å)	2nd Order (Å)	$\phi_a - \phi_b$
NI1	308-381	154-191*	7.06-8.77°
NI2	513-633	257-317	7.06-8.77°

(* The reflectivity at these wavelengths is too low for useful observation)

4.2 Resolving Power and Line Widths

Line width estimates and the factors which determine a useful spectral resolution are discussed in Section 3.2 - the same arguments are applicable here. In the NIS, the image of the slit is not as wide, in the plane of the detector, as it is for the GIS simply due to the smaller angle in the cosine function. Indeed, the angular range of 7.06 - 8.77° projects the 25µm slit (2 arcsecond) onto the detector with a width of 25.2µm, which is only 1.15 pixels. The resulting resolutions are given in Table 4.2.

Table 4.2: Resolutions and Resolving Powers (using 2 arcsec slit - 25 µ m).

λ (Å)	α (°)	Line Width (µm)	λ /Δλ	Δλ (Å)	Disp. (Å/mm)
308	7.08	25.2	3635	0.08	3.17
345	7.92	25.2	4080	0.08	3.17
381	8.75	25.3	4500	0.08	3.17
513	7.08	25.2	3635	0.14	5.56
573	7.92	25.2	4080	0.14	5.56
633	8.75	25.3	4500	0.14	5.56

4.3 Count-Rates

The method for estimating count-rates is given in Section 3.3, though in the NIS case, after the scan mirror, the beam misses the GI grating and is reflected off a toroidal grating before being directed to the NIS detector. The efficiency product, i.e. the product of the telescope, scan mirror, grating and detector efficiencies, and the telescope available area are the only factors which differ from the GIS case. The area is given in Table 1.2. The telescope and scan mirror efficiencies, ε_t and ε_m, are given as 0.25 and 0.8, as before. The grating efficiency, ε_t, is measured to be of order 0.02 in the 300 - 400Å and 500 - 600Å range. The detector efficiency is measured to be of order 0.16 in the 300 - 400Å range, and 0.13 in the 500 - 600Å range. Thus, the efficiency product is of order 6.4 x 10^{-4} and 5.2 x 10^{-4}, respectively. These values were used in estimating the countrates.

Tables 4.3 and 4.4 show the estimated count-rates for the two NIS bands. They are plotted in Figure 4.1. The count-rates are for quiet Sun intensities for a 2x2 arcsecond area of the Sun.

Table 4.3: Estimated Count Rates per line per 2x2 arcsec for the 308-381Å Band.

Ion	Wavelength (Å)	Quiet Sun	Active Sun
Fe XIII	311.55	0.0	0.0
Mg VIII	311.77	1.8	6.2
Fe XIII	312.16	2.8	9.2
C IV	312.42	0.0	13.6
Mg VIII	313.73	4.6	13.6
Si VIII	314.35	0.4	2.0
Mg VIII	315.02	3.4	11.4
Si VIII	316.22	1.4	3.0
Mg VIII	317.01	4.0	11.8
Fe XIII	318.14	1.4	4.6
Mg VII	319.03	0.4	9.2
Si VIII	319.83	2.0	4.0
Fe XIII	320.80	5.6	18.4
Fe XV	321.78	3.8	12.6
Fe XV	327.02	3.8	12.8
Cr XIII	328.26	2.4	3.4
Al X	332.77	1.6	6.2
Fe XIV	334.17	12.4	50.4
Mg VIII	335.23	1.4	4.6
Fe XVI	335.40	4.4	195.8
Fe XII	338.26	2.0	6.6
Mg VIII	339.00	2.0	6.6
Fe XI	341.11	0.6	2.4

Si IX	341.95	2.4	3.6
Si IX	345.13	4.4	7.2
Fe X	345.74	0.4	1.6
Fe XII	346.85	0.0	0.0
Si X	347.40	7.0	28.4
Fe XIII	348.18	6.0	20.6
Mg VI	349.13	1.0	7.2
Si IX	349.87	4.2	10.4
Fe XII	352.11	2.0	7.0
Fe XI	352.67	0.0	0.0
Fe XIV	353.83	5.2	20.94
Si X	356.04	3.6	15.0
Fe XIV ?	356.11	0.0	0.0
Fe XI	356.54	0.8	3.4
Fe XI	358.67	0.4	1.6
Fe XIII	359.64	3.4	26.0
Fe XIII	359.84	0.0	0.0
Fe XVI	360.76	1.4	140.2
Fe XII	364.47	4.6	27.6
Fe X	365.54	0.0	0.0
Mg VII	367.67	0.0	0.0
Mg IX	368.06	23.8	120.8
Fe XI	369.16	1.4	5.2
Ca XVII	371.40	0.6	2.4

In quiet Sun and active Sun conditions we find approximately 140 and 860 counts per second over one complete 2 arcsecond cross section of the detector. To estimate the total rate, from this band for the detector, these must be multiplied by 120 (pixels), i.e. 16800 and 103200. We find individual pixel intensities of up to approximately 20 and 200 per second for quiet and active Sun conditions.

Table 4.4: Estimated Count Rates per line per 2x2 arcsec for the 513-633Å Band.

Ion	Wavelength (Å)	Quiet Sun	Active Sun
Si XII	520.67	1.4	29.2
He I	522.20	1.4	12.7
O III	525.80	1.2	2.6
F VI	535.20	0.06	0.35
He I	537.03	3.9	34.3
?	537.80	0.0	2.5
Ne IV	541.10	0.35	1.4
Ne IV	542.00	0.0	0.0
Ne IV	543.80	0.52	2.0
Al XI	550.00	0.46	8.1

O IV	553.33	9.1	21.0
O IV	554.08	0.0	0.0
O IV	554.52	27.3	63.2
O IV	555.28	5.5	12.7
Ca X	557.76	1.1	7.5
Ne VI	558.59	0.52	3.4
Ne VII	561.70	0.0	0.0
Ne VI	562.83	0.36	6.7
Al XI	567.80	0.35	4.3
Ne V	569.20	0.35	1.5
Ne V	572.20	0.52	2.4
Ca X	574.00	0.46	2.7
Si XI	580.90	0.55	3.8
He I	584.33	32.9	330.3
Ar VII	585.72	0.0	0.0
Fe XIX	591.40	0.0	0.0
S XI	592.00	0.23	0.78
Ca VIII	597.20	0.12	0.43
O III	599.59	1.9	3.5
Si XI (2)	606.66	0.72	10.7
He II (2)	607.56	24.7	361.4
O IV	608.40	0.38	1.6
MgX/OIV	609.79	5.9	38.0
O II	616.60	0.23	0.5
K IX	621.40	0.06	0.23
Mg X	624.94	2.5	19.3
O V	629.73	16.3	49.7

Figure 4.1: Quiet Sun count rates per pixel for a 2x2 arcsecond slit for the two NIS Bands (see Table 4.3 and 4.4). Some lines may be truncated at the top to better show other, weaker lines. Solar continuum is not shown in this figure.

The total count rate along a 2 arcsecond strip is of order 145 and 1044 per second for quiet and active conditions, for the longer wavelength range. Thus, for the full image we anticipate 17400 and 125300 counts per second, respectively (though it seems unlikely that an active region would fill the length of the slit). In this band we have the second order He II line at 606Å. This produces the most extreme count rates in the NIS channels with an intensity of 360 per second. Assuming a modest line width, we should expect to cater for a maximum of 1000 counts per second per pixel.

The VDS has a maximum count (not count rate) per pixel of 4095 (due to the 12 bit A/D conversion, not the saturation level of the wells of the CCD) which translates to a maximum accumulation time of ~ 10s in the most active conditions before some pixels saturate. However, we may choose to saturate the 304Å line - there would be no adverse effect on surrounding wells for accumulations of at least 200000, i.e. 550s in the worst conditions.

Table 4.5 lists the brighest of the NIS lines from both wavelength ranges. The countrates are estimated per 2x2 arcecond area on the Sun, as in Tables 4.3-4.4 above.

Table 4.5: The 18 Brightest NIS Lines.

Ion	Wavelength (Å)	Quiet Sun	Active Sun
Mg VIII	313.73	4.6	13.6
Mg VIII	317.01	4.0	11.8
Fe XIII	320.80	5.6	18.4
Fe XIV	334.17	12.4	50.4
Fe XVI	335.40	4.4	195.8

Si X	347.40	7.0	28.4
Fe XIII	348.18	6.0	20.6
Fe XIV	353.83	5.2	20.94
Fe XII	364.47	4.6	27.6
Mg IX	368.06	23.8	120.8
He I	537.03	3.9	34.3
O IV	553.33	9.1	21.0
O IV	554.52	27.3	63.2
O IV	555.28	5.5	12.7
He I	584.33	32.9	330.3
MgX/OIV	609.79	5.9	38.0
Mg X	624.94	2.5	19.3
O V	629.73	16.3	49.7

The NIS-VDS *image* appears as two spectra with spatial information in one direction, i.e. they are images of a slit, dispersed by wavelength. The format is shown in Figure 4.2.

Since the VDS sees both spectra at the same time, the total count rate is the sum of the numbers given above. For the three NIS slits, these numbers are tabulated in Table 4.6.

Figure 4.2: The VDS Detector Image Showing the Two Spectral Ranges.

Table 4.6: Total Detector Counts for the VDS for Quiet Sun and Active Sun Conditions

2"x240" slit Quiet	2"x240" slit Active	4"x240" slit Quiet	4"x240" slit Active	90"x240"slit Quiet	90"x240"slit Active

34200	228500	68400	457000	1539000	10281600

Although the total count-rate increases with the slit size, the count-rate per pixel remains the same since the slit is imaged.

Again we may define a minimum desired count-rate. For the detection of the prime spectral lines, a detection of intensities at about the $1s^{-1}$ level is the minimum requirement; a detection at the $0.1s^{-1}$ level would be the goal. The CDS capability will be dependent on background effects such as scatter, dark current etc... From the detector, we expect a dark count of order less than 1 per pixel per second and a constant CCD readout noise level of less than 1 per pixel. Rather than constant background being a problem, it is the variations in the background which will limit us and for the detector this amounts to about 1 count over a 100s integration. This varies as the square root of the integration time i.e. 0.3 count over 10s and 0.1 in 1s. For a 100s accumulation, the weaker prime lines will achieve counts ten times the detector variable signal, and the continuum level may be expected to be of the order of the variable signal. For a 250s accumulation, these factors rise to 16 and 1.6.