2. THE PRIME EUV LINES

"The Sun from east to west who all doth see, On this low globe sees nothing like to thee."
William Drummond (1585-1649)

In this section we explore the lines of prime interest to CDS-related science, that is, the *tools* to be used by the CDS community. Density sensitive pairs, temperature studies through ratios and differential emission measure studies, dynamic studies and even flare-like lines are discussed and listed.

2.1 Density Sensitive Line Pairs

It is well known that some ratios of emission lines can be used as indicators of densities. The CDS wavelength ranges have been chosen carefully in order to include many of these ratios, suitable for a wide range of temperature regimes.

In this section we attempt to highlight those ratios which are of most use for the GIS and NIS components of CDS. Previously, we tended to list every density sensitive ratio available, regardless of the ability of CDS to detect the lines, of the dynamic range of the ratio or the distribution between spectrometers. Thus, Table 2.1 includes those ratios which satisfy the following:

- Both lines must fall within the CDS wavelength ranges.
- The ratio must change by a factor of 5 or more in 3 decades of density, and be single valued across that range.
- The spectral intensities of the line pair must be such that we can reasonably expect to detect them.

In Table 2.1 the character g, n or b in column 2 denotes that the pair can be detected in the GIS, NIS or both. Cases where one line falls within each spectrometer are of less value as the two spectrometers will not be used at the same time. However, these are listed in Table 2.2 since operations could be performed using alternate observations in GI and NI.

Several line ratios in Table 2.1 are marked with up to three asterisks (∗). This is a ‘quality rating’ (the more asterisks, the better). Two or three asterisks indicate that both lines constituting the ratio are well observed, free from blends (lines are regarded as blended if their peaks are closer than 0.42Å), and of reasonable intensity. For lines marked with one asterisk some blending with weaker lines is possible.

The remaining, unmarked line ratios will require greater caution during the analysis to identify the lines or subtract a contribution from other blended lines.

In the tables, densities are given in units of cm^{-3}. Some ratio values are bracketed - these are projected from available data, where the appropriate densities were not given. Relevant references are given at the end of the tables.

Table 2.1: CDS Prime Density Sensitive Pairs

Ion	**λ(Å)**	**10^7**	**10^8**	**10^9**	**10^{10}**	**10^{11}**	**Ref**
Mg VI	**314.55/ 400.68g**	**-**	**0.00**	**0.04**	**0.16**	**0.21**	**BM**
Mg VI	**314.68/ 400.68g**	**-**	**0.01**	**0.07**	**0.25**	**0.36**	**BM**
Mg VII *	**319.03/ 278.40g**	**-**	**0.13**	**0.55**	**1.20**	**1.4**	**K1**
Mg VII	**280.74/ 278.40g**	**-**	**0.05**	**0.22**	**0.56**	**0.69**	**K1**
Mg VII **	**319.03/ 367.67n**	**-**	**0.35**	**1.58**	**(3.9)**	**(5.0)**	**MB**
Mg VII *	**319.03/ 429.93g**	**-**	**0.35**	**1.71**	**4.31**	**5.58**	**MB**
Mg VII	**280.74/ 429.93g**	**-**	**0.14**	**0.76**	**2.21**	**3.03**	**MB**
Mg VII	**320.50/ 429.93g**	**-**	**0.03**	**0.16**	**0.48**	**0.66**	**MB**
MgVIII **	**430.47/ 436.62g**	**1.58**	**0.91**	**0.59**	**0.55**	**0.54**	**D2**
MgVIII	**315.02/ 335.23b**	**3.63**	**4.47**	**5.89**	**6.31**	**6.31**	**D1**
MgVIII **	**315.02/ 430.47g**	**1.66**	**2.24**	**3.31**	**3.47**	**3.63**	**D1**
MgVIII **	**436.62/ 313.74g**	**0.78**	**1.12**	**1.41**	**1.51**	**1.50**	**D1**
Si VIII	**276.84/ 319.83g**	**-**	**0.02**	**0.08**	**0.19**	**0.42**	**BM**
Si VIII *	**216.92/ 319.83g**	**-**	**0.13**	**0.18**	**0.29**	**0.61**	**BM**
Si IX ***	**349.87/ 341.95n**	**-**	**1.32**	**3.06**	**(4.0)**	**-**	**MB**

Si IX * **	**345.13/ 341.95b**	**-**	**1.55**	**2.19**	**(2.4)**	**-**	**MB**
**Si IX ** **	**292.76/ 341.95g**	**-**	**0.39**	**0.77**	**(0.9)**	**-**	**MB**
Si IX * **	**296.12/ 341.95g**	**-**	**1.50**	**2.97**	**(3.4)**	**-**	**MB**
**Si X * **	**347.40/ 356.04n**	**4.90**	**3.54**	**1.38**	**0.68**	**0.63**	**D1**
S X	**180.72/ 264.24g**	**-**	**0.05**	**0.13**	**0.22**	**0.44**	**BM**
S X	**177.55/ 264.24g**	**-**	**0.01**	**0.01**	**0.06**	**0.17**	**BM**
S XI	**215.93/ 281.42g**	**-**	**0.03**	**0.07**	**0.40**	**1.91**	**MB**
S XI	**190.37/ 281.42g**	**-**	**0.01**	**0.03**	**0.17**	**0.91**	**MB**
S XI	**217.64/ 281.42g**	**-**	**0.00**	**0.01**	**0.04**	**0.21**	**MB**
S XII * **	**288.41/ 299.50g**	**0.08**	**0.07**	**0.05**	**0.02**	**0.01**	**VM**
Fe X	**175.27/ 174.53g**	**-**	**0.02**	**0.07**	**0.30**	**-**	**J,M**
**Fe XI * **	**180.41/ 181.14g**	**-**	**19.0**	**11.0**	**6.2**	**4.6**	**J,M**
Fe XI	**184.41/ 181.14g**	**-**	**0.02**	**0.02**	**0.06**	**0.43**	**M**
**Fe XI * **	**179.76/ 181.14g**	**-**	**0.14**	**0.36**	**1.30**	**3.1**	**D3**
Fe XI	**184.70/ 181.14g**	**-**	**0.11**	**0.23**	**0.77**	**1.3**	**D3**
**Fe XII * **	**186.87/ 193.51g**	**-**	**0.09**	**0.40**	**1.02**	**2.1**	**D3**
Fe XII	**196.64/ 193.51g**	**-**	**0.03**	**0.12**	**0.30**	**0.60**	**D3**
Fe XII * **	**338.27/ 364.47n**	**-**	**0.04**	**0.15**	**0.36**	**0.65**	**M**
Fe XIII	**196.53/ 200.02g**	**-**	**-**	**0.23**	**0.80**	**1.90**	**D3**
**Fe XIII * **	**202.04/ 200.02g**	**-**	**17.0**	**3.5**	**1.6**	**1.1**	**M**
Fe XIII	**201.12/ 200.02g**	**-**	**3.8**	**1.5**	**0.95**	**0.90**	**M**
**Fe XIII * **	**202.04/ 203.79g**	**-**	**0.1**	**0.7**	**2.8**	**3.7**	**MY**
Fe XIII * **	**318.12/ 320.80b**	**-**	**-**	**0.21**	**0.40**	**0.93**	**D3**
Fe XIII * **	**320.80/ 348.18n**	**-**	**0.1**	**0.6**	**2.4**	**3.0**	**MY**
Fe XIII * **	**318.12/ 348.18n**	**-**	**0.0**	**0.1**	**1.1**	**2.8**	**MY**

Fe XIII *	**359.64/ 348.18n**	**-**	**0.1**	**0.5**	**1.7**	**2.0**	**MY**
Fe XIV *	**219.12/ 211.32g**	**-**	**0.04**	**0.19**	**0.76**	**1.6**	**J,M**
Fe XIV *	**264.80/ 274.20g**	**-**	**0.63**	**0.90**	**2.3**	**3.2**	**M**

Table 2.2: CDS Cross-Spectrometer Density Sensitive Pairs

Ne V	**416.20/ 569.84**	**0.40**	**1.20**	**1.82**	**2.00**	**-**	**K2**
Ne V	**416.20/ 572.33**	**0.21**	**0.71**	**1.00**	**1.07**	**-**	**K2**
Mg VI	**314.55/ 400.68**	**-**	**0.00**	**0.04**	**0.16**	**0.21**	**BM**
Mg VI	**314.68/ 400.68**	**-**	**0.01**	**0.07**	**0.25**	**0.36**	**BM**
Mg VII	**319.03/ 278.40**	**-**	**0.13**	**0.55**	**1.20**	**1.4**	**K1**
Mg VII	**319.03/ 367.67**	**-**	**0.35**	**1.58**	**(3.9)**	**(5.0)**	**MB**
Mg VII	**319.03/ 429.93**	**-**	**0.35**	**1.71**	**4.31**	**5.58**	**MB**
Mg VII	**320.50/ 429.93**	**-**	**0.03**	**0.16**	**0.48**	**0.66**	**MB**
MgVIII	**315.02/ 430.47**	**1.66**	**2.24**	**3.31**	**3.47**	**3.63**	**D1**
MgVIII	**436.62/ 313.74**	**0.78**	**1.12**	**1.41**	**1.51**	**1.50**	**D1**
MgVIII	**315.02/ 335.23**	**3.63**	**4.47**	**5.89**	**6.31**	**6.31**	**D1**
Si VIII	**276.84/ 319.83**	**-**	**0.02**	**0.08**	**0.19**	**0.42**	**BM**
Si VIII	**216.92/ 319.83**	**-**	**0.13**	**0.18**	**0.29**	**0.61**	**BM**
Si IX	**349.87/ 341.95**	**-**	**1.32**	**3.06**	**(4.0)**	**-**	**MB**
Si IX	**345.13/ 341.95**	**-**	**1.55**	**2.19**	**(2.4)**	**-**	**MB**
Si IX	**292.76/ 341.95**	**-**	**0.39**	**0.77**	**(0.9)**	**-**	**MB**
Si IX	**296.12/ 341.95**	**-**	**1.50**	**2.97**	**(3.4)**	**-**	**MB**
Fe XI	**308.61/ 352.68**	**-**	**-**	**0.11**	**0.32**	**0.7**	**D3**

Fe XII	**338.27/ 364.47**	**-**	**0.04**	**0.15**	**0.36**	**0.65**	**M**
Fe XII	**290.99/ 364.47**	**-**	**0.10**	**0.20**	**0.35**	**0.70**	**M**
Fe XIII	**318.12/ 320.80**	**-**	**-**	**0.21**	**0.40**	**0.93**	**D3**
Fe XIV	**353.83/ 274.20**	**-**	**0.05**	**0.12**	**0.37**	**0.68**	**M**

References

BM = Bhatia, A.K. and Mason, H.E., 1980, M.N.R.A.S. 190, 925-929.
D1 = Dwivedi, B.N. and Raju, P.K., 1980, Solar Phys. 68, 111-123.
D2 = Dwivedi, B.N., 1988, Solar Phys. 116, 405-408.
D3 = Dere, K.P., Mason, H.E., Widing, K.G. and Bhatia, A.K., 1979, Ap.J. Suppl. 40, 341-364.
J = Jordan, C, 1965, Phys. Lett. 18, 3, 259 and 1966, MNRAS 132, 515.
K1 = Keenan, F.P, Kingston, A.E., Aggarwal, K.M. and Widing, K.G., 1986, Solar Phys. 103, 225-230.
K2 = Keenan, F.P., Aggarwal, K.M. and Widing, K.G., 1986, Solar Phys. 105, 47-50.
M = Mason, H.E., 1986, private communication
MB = Mason, H.E. and Bhatia, A.K., 1978, M.N.R.A.S. 184, 423-437.
MY = Mason, H.E. and Young, P, 1994, SOHO 3rd Workshop. in press.
VM = Vernazza, J.E. and Mason, H.E., 1978, Ap.J. 226, 720-728.

2.2 Temperature Sensitive Lines

Temperature dependence of line intensities arises because of the temperature dependence of the ion abundance and through the temperature dependence of the collisional excitation rates. One can derive a temperature by examining the relative intensities of emission lines from different ions and assume that the contributions from different ions are produced at the temperature of the maximum of the ionisation balance. This assumes that that we can use the equilibrium ionisation balance - which may not always be the case in dynamic situations.

In practice, since we are viewing integrated emission along a line of sight, and, therefore, a range of temperatures, it is probably better to derive the differential emission measure - i.e. determine how much matter there is as a function of temperature. For this, one would require a range of emission lines produced by ions with a wide range of temperature of maximum abundance. To eliminate elemental abundance problems, this can be done with a range of ions of the same elements, e.g. iron, magnesium or silicon.

Some emission line ratios, in the CDS wavelength range, which are temperature sensitive due to the temperature dependence in excitation rate coefficients are given in Table 2.3. As with the density tables above, we have included only lines which we may expect to see and ratios with variations which may be determined. We do not claim that the table is exhaustive. In the first column, the suffixes *n*, *g* and *s* denote NIS, GIS or SUMER wavelength ranges. Since the temperature sensitive line pairs tend to be widely spaced in wavelength, they often cross between spectrometers and, in the case of O VI, between instruments!

Returning to analyses requiring a range of ions, preferably from the same element, Table 2.4 provides a summary of suitable lines. None of the individual element ranges covers the entire temperature range; it is probably best to minimise the number of elements used and to ensure good temperature overlap to allow the best normalisation.

Table 2.3: Temperature Sensitive Ratios

Ion and Ratio	Range of Sensitivity (K)	Reference
O III 702.98g/599.59n	$10^{4.4}$-$10^{5.5}$	Keenan, Aggarwal, ApJ. 344,522,1989
O V 172.17g/629.73n	< 1.0 x 10^{6}	
O VI 173g/1032s	< few x 10^{6}	Heroux, Cohen, Malinovsky, Sol. Phys. 23, 369, 1972
O VI 184g/1032s	< few x 10^{6}	Heroux, Cohen, Malinovsky, Sol. Phys. 23, 369, 1972
Ne V 359n/572.20n	10^{5}- 10^{6}	Lang, J. de Physique 49, C1-59, 1988
Ne V 365n/572.20n	10^{5}- 10^{6}	Lang, J. de Physique 49, C1-59, 1988
Ne V 416.20g/569.20n	10^{5}- 10^{6}	Keenan, Aggarwal, Widing, Sol. Phys. 105, 47, 1986
Ne V 416.20g/572.20n	10^{5}- 10^{6}	Keenan, Aggarwal, Widing, Sol. Phys. 105, 47, 1986
Mg IX 705.80g/368.06n	< 2 x 10^{6}	Doyle, Mason, Vernazza, Astr. Astroph. 150, 69, 1985
Mg IX 705.80g/749g	< 2 x 10^{6}	Doyle, Mason, Vernazza, Astr. Astroph. 150, 69, 1985
Si XI 604n/580.90n	< few x 10^{6}	Doyle, Mason, Vernazza, Astr. Astroph. 150, 69, 1985

Table 2.4 lists the suitable lines from Fe, Mg, Si and Ne plus their approximate temperature of maximum abundance. Where possible, two emission lines from each available ion, involving a ground state transition, are listed. Lines with obvious blends are not used. Several ions and several lines of interest are not available. All of the lines are from the GIS component of CDS - this spectrometer supplies the coverage required. Only limited studies of a similar nature can be done with the NIS.

Table 2.4: Lines in the GIS range suitable for a Differential Emission Measure Analysis

Ion	Wavelength (Å)	LogT (K)
Ne I	735.90	4.4
Ne I	743.70	4.4
Ne III	489.50	4.9
Ne V	482.10	5.5
Ne VI	399.83	5.6
Ne VI	401.14	5.6
Ne VII	465.22	5.7
Ne VIII	770.40	5.8
Ne VIII	780.30	5.8
Mg VI	399.20	5.6
Mg VI	400.68	5.6
Mg VII	277.04	5.8
Mg VII	278.40	5.8
Mg VIII	313.73	5.9
Mg VIII	317.01	5.9
Mg IX	705.80	6.0
Si VII	272.60	5.8
Si VII	275.37	5.8
Si VIII	319.83	5.9
Si VIII	316.22	5.9
Si IX	296.12	6.0
Si IX	345.12	6.0
Si X	261.06	6.0
Si X	271.99	6.0
Fe VIII	168.18	5.6
Fe VIII	186.60	5.6
Fe IX	171.07	6.0

Fe IX	217.10	6.0
Fe X	174.53	6.1
Fe X	177.24	6.1
Fe XI	188.22	6.1
Fe XI	192.81	6.1
Fe XII	193.51	6.2
Fe XII	195.12	6.2
Fe XIII	203.79	6.2
Fe XIII	213.77	6.2
Fe XIV	211.32	6.3
Fe XIV	220.08	6.3
Fe XV	284.16	6.3
Fe XVI	335.40	6.4
Fe XVII	200.80	6.5

2.3 Lines for Dynamic Studies

CDS is not suited to the identification of small flows in the atmosphere. However, flows of order several tens of km/s may be detected and are expected. A good tool for the identification and tracking of flows would be a line list of bright, well separated lines produced by a good range of temperatures. Such a list is given in Table 2.5.

Table 2.5a: Lines suitable for Dynamic Studies - GIS

Ion	Wavelength (Å)	LogT
O III	702.98	4.9
N IV	765.14	5.0
Ne VI	401.14	5.6
Ne VII	465.22	5.7
Ne VIII	770.40	5.8
Fe IX	171.07	6.0
Fe X	174.53	6.1
Fe XI	188.22	6.1
Fe XII	195.12	6.2
Fe XIII	203.79	6.2

Fe XIV	211.32	6.3
Fe XV	284.16	6.3

Table 2.5b: Lines suitable for Dynamic Studies - NIS

Ion	Wavelength (Å)	LogT
He I	584.33	4.3
O III	599.59	4.9
O IV	554.52	5.3
Ne VI	562.83	5.6
Mg VIII	313.73	5.9
Mg IX	368.06	6.0
Fe XII	364.47	6.2
Fe XIII	320.80	6.2
Fe XIV	334.17	6.3
Fe XV	327.02	6.3
Fe XVI	335.40	6.4

2.4 Lines for High Temperature Studies

Although SOHO is not a flare mission, it is useful to identify any flare-like emission lines. Lines from the iron ions Fe XXI-XXIV are good candidates; lines in the CDS wavelength ranges are listed in Table 2.6

Table 2.6: Lines Suitable for High Temperature Studies

Ion	Wavelength (Å)	GIS/NIS	Ion	Wavelength (Å)	GIS/NIS
Fe XXI	151.50	GIS	Fe XXII	292.46	GIS
Fe XXI	270.52	GIS	Fe XXII	349.3	NIS
Fe XXI	335.9	GIS/NIS	Fe XXIII	154.27	GIS
Fe XXI	409.9	GIS	Fe XXIII	166.74	GIS
Fe XXI	587.9	NIS	Fe XXIII	173.31	GIS
Fe XXII	155.92	GIS	Fe XXIII	180.10	GIS
Fe XXII	161.74	GIS	Fe XXIII	263.76	GIS
Fe XXII	217.30	GIS	Fe XXIV	192.02	GIS