GIS CALIBRATION STUDY WITH A PLASMA DIAGNOSTIC METHOD

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ABSTRACT

A plasma diagnostic method developed at Arcetri is applied to a GIS active region spectrum in order to verify the relative intensity calibration between the four GIS detectors and to evaluate the wavelength dependent intensity calibration in each of these wavelength ranges. The diagnostic method compares all the measured lines of the same ion with the theoretical values calculated using the CHIANTI database. The ratios of the observed and expected intensities are plotted versus wavelength and systematic disagreements indicate calibration corrections. This method also provides a measure of the instrument sensitivity in the second order lines. The first results on the relative sensitivity are presented; further studies will be performed both for quiet and active spectra.

1. Introduction

The Coronal Diagnostic Spectrometer (CDS) on SOHO consists of two instruments: a grazing incidence spectrometer producing astigmatic spectra; and a normal incidence spectrometer which can provide images of the solar field of view, dispersed over two wavelength ranges. Together, the GI and NI spectrometers cover most of the extreme ultraviolet wavelength range from 150Å to 785Å (Harrison et al. 1995). The GI instrument has four detectors, with spectral ranges 151Å – 221Å, 256Å – 341Å, 393Å – 492Å and 659Å – 785Å, while the two NI detectors have ranges 307Å – 379Å and 513Å – 633Å.

This spectral band is extremely rich in emission lines from a large number of highly ionized ions of the most abundant elements, providing a unique diagnostic tool for investigating the temperature, density and chemical composition of the solar transition region and corona. Moreover it provides a laboratory for testing atomic physics models and theoretical calculations of collision rates and transition probabilities for ions formed at a range of temperatures from chromospheric to coronal.

Intensity calibration is a fundamental requirement for any scientific use of the spectrometer, but obtaining such information is not an easy undertaking in the extreme ultraviolet spectral range. A pre-flight calibration procedure was performed (Bromage et al. 1996) for a limited number of wavelengths throughout this region.

The large number of emission lines that are observed in the solar spectrum, coupled to the large amount of atomic data now available (CHIANTI - Dere et al. 1997, The Arcetri Spectral Code - Landi and Landini 1997a, ADAS - Summers et al. 1996) and a new temperature and density diagnostic technique (Landi and Landini 1997b), allow a rather more detailed investigation to be made of the shape of the current (in-flight) intensity calibration function. The procedure also indicates the relative performance of the detectors.

In the present poster we have applied this new diagnostic technique to the intensities of lines emitted from a Solar Active Region observed with the GI spectrometer, and we have derived correction factors to be applied to the preliminary intensity calibration of the instrument. This method has already been successfully applied to the CDS NI spectrometer (Landi et al. 1997).

2. The theoretical method

The method used for this calibration study is a byproduct of the temperature and density diagnostic procedure shown in Landi and Landini 1997b.

Here we present a very brief outline of the method. The intensity emitted by a thin plasma in a line is given by

\[
I_{ij} = \frac{1}{4\pi} \int h N_j (X^{+m}) A_{ij} dh \ ph \ cm^{-2} \ s^{-1} \ sr^{-1}
\]

(1)

We can define the Contribution Function as follows:

\[
G_{ij}(T, N_e) = \frac{N_j(X^{+m})}{N(X)} \frac{N(X)}{N(H)} \frac{N(H)}{N_e} A_{ij}
\]

(2)
To a good approximation it is possible to express $G_{ij}(T, N_e)$ as

$$G_{ij}(T, N_e) = f_{ij}(N_e, T) g(T)$$

(3)

where $g(T)$ is a function of temperature alone, is the same for all lines of the same ion and is mainly due to the ionization equilibrium. $f(N_e, T)$, mainly determined by the population of the upper level, is a linear function of $\log T$.

With the usual definition of the Differential Emission Measure as

$$D.E.M. = \varphi(T) = N_e^2 \frac{dh}{dT}$$

(4)

the effective temperature $T_{eff}$ may be evaluated as

$$\log T_{eff} = \frac{\int g(T) \varphi(T) \log T \,dT}{\int g(T) \varphi(T) \,dT}$$

(5)

and an effective emission measure $L_{ij}(N_e)$ may be computed

$$L_{ij}(N_e) = \frac{I_{obs}}{G_{ij}(T_{eff}, N_e)}$$

(6)

The diagnostic method relies on the observation that if we plot all the $L$-functions of the same ion, calculated with line fluxes derived from a well-calibrated spectrum, versus the electron density, all the curves meet in a common point ($N_e^*, L(N_e^*)$). Moreover the $L$-functions of non-density dependent lines must overlap and cross at the same point as the others.

Examples are given in Figure 1.

It may occur that some $L$-functions do not cross the meeting point. When proper care has been taken to exclude misidentifications, blendings and inaccurate atomic data, the difference must be due to relative calibrations problems.

To calculate the $L$-functions of a given ion it is necessary to compute the effective temperature $T_{eff}$. This quantity is strictly tied to the Differential Emission Measure of the source, so the first step of the procedure is to determine this function. We selected the brightest and best theoretically known density independent lines, and we evaluated through them the Differential Emission Measure distribution along the observed line of sight.

For each ion, the effective temperature $T_{eff}$ for each line is then evaluated and the $L$-functions are displayed at that effective temperature versus electron density in order to verify line overlapping (for density independent lines) or proper crossing (for density dependent ones).

The Intensity Correction Factor is measured for all the lines whose $L$-functions do not meet at the common crossing point and that are not affected from any blending or atomic physics problem.

This procedure is applied separately for each ion.

3. The observation

To perform this procedure, a set of high signal to noise spectra of active regions has been analyzed; they belong to the GISAT observing sequence s455400. Details of the GISAT observing sequences are reported in Harrison et al. 1995.

More than 300 lines have been measured and most of them have been identified. Some of the density insensitive observed lines have been used also for the Differential Emission Measure analysis.

Count rates and errors are evaluated using the standard CDS package. Conversion to intensity has been based on the pre-flight calibration.

We have also taken account of "ghosts", trying to correct for this effect when possible. Sometimes the ghosting effect can be a real problem for GIS spectrum analysis and must be removed. An example of the "ghosting-like" regions in the GIS 1 channel is given in Figure 4.

4. Results

4.1. The Differential Emission Measure

A simple iterative procedure, developed by two of the authors (Landi and Landini 1997b) has been applied to the brightest density insensitive lines to compute the Differential Emission Measure. The result is shown in Figure 2. Each line is plotted at the effective temperature and at the Differential Emission Measure value necessary to fit the observed over synthetic intensity.

The Arcetri Spectral Code has been used and the numerical codes have been run using the Feldman chemical composition. Since several lines coming from different detectors have nearly the same $T_{eff}$, the Differential Emission Measure study allows a first check on
the relative sensitivity between the four GIS channels. In order to get the best agreement between observed and synthetic intensities it has been necessary to increase the intensity of the two Ne VIII lines at 770.4 Å and 780.3 Å observed at the end of the GIS 4 detector, so that these lines could match the GIS 2 and GIS 3 lines having the same $T_{eff}$. It is important to notice that nothing can be said concerning the other wavelengths covered by GIS 4.

No relevant changes in the element abundances was required, although some indication exists for problems in the O/Ne and Mg/Ne abundances.

4.2. GIS internal calibration

Our study aimed both to provide relative intensity calibration between the four GIS channels and the wavelength dependent sensitivity of each channel providing the necessary corrections to the pre-flight calibration of Bromage et al. 1996. Here we give a brief summary of the results:

• GIS 2 and GIS 3 channels do not need any relative correction. The L-functions of the Mg VII, VIII, IX, S XIV, Fe XV and XVI lines observed in both detectors agree with each other.

• There is some evidence that GIS 1 intensity should be increased up to 50%. Nevertheless it is not easy to understand the behaviour of GIS 1 relative to GIS 2 and 3 due to several blending and ghosting problems involving the lines of the ions observed in these channels.

• There is no other evidence that supports the correction factor found for the Neon lines of GIS 4 relative to GIS 2 and 3.

• It has not been possible to measure accurately the internal wavelength-dependent sensitivity of each channel due to the uncertainties given by the ghosting problems. Anyway it is possible to say that there is no evidence for great corrections to the pre-flight intensity calibration.

4.3. Second order calibration

Several observed spectral features are second order lines; they have been included in the procedure and the amount of disagreement from the common crossing point for these lines is used to evaluate the relative efficiency of second order lines compared to first order. Only GIS 3 and 4 show the presence of second order lines. In the GIS 3 wavelength range it is possible to observe the GIS 1 spectrum longward 200 Å at second order so we can also derive direct measurements of the GIS 3 second order sensitivity. GIS 2 and GIS 4 have a common spectral range in the interval 330-340 Å including the very strong Al X, Fe XIV and Fe XVI lines which prove to be very useful for a direct determination of the GIS 4 second order sensitivity.

4.3.1. GIS 3 second order calibration

Several Fe XII, XIII and XIV second order lines fall in the GIS 3 spectral range, nevertheless blending and ghosting of other GIS 3 lines limits severely the determination of the GIS 3 second order intensity calibration. The best diagnostics for our purposes are the Fe XIII lines 202.1 Å and 203.8 Å observed in the 400-405 Å region, which can be directly compared with the GIS 1 intensities. The GIS 3 L-functions require a correction factor of 8.7 in order to match the GIS 1 counterparts, involving a second order sensitivity of 11% relative to the first order one. Also Fe XIV helps in this study with two lines, which unfortunately require some preliminary blending and ghosting corrections. They confirm the Fe XIII measure.

Nothing can be said about wavelength dependence of the second order intensity calibration because of the paucity of second order lines available in GIS 3.

4.3.2. GIS 4 second order calibration

GIS 4 is richer of strong second order lines and allows a more precise study involving also the wavelength dependence of the detector sensitivity. The results derived from the most reliable observed lines are reported in Figure 3.

It is possible to see that there is a strong wavelength dependence below 690 Å and that the sensitivity appears to be fairly constant longward of that limit, requiring a mean correction factor of 9 ± 2 for the GIS 4 second order intensities corresponding to a second order sensitivity of ≈ 11% relative to the first order.

It is important to note that these measures are subject to the relative intensity calibration of the four GIS detectors. This was not a problem for GIS 3 since GIS 3 and GIS 1 required no strong relative calibration correction, but GIS 4 is more uncertain (see Differential Emission Measure section) so the present results should be considered with caution.
5. Conclusions

In this work the intensity calibration of the CDS grazing incidence spectrometer is discussed and compared with the preliminary pre-flight calibration. Use is made of a plasma diagnostic technique aimed at evaluating the temperature and density distribution of matter along the line of sight of the observation.

The new version of the Arcetri Spectral code (Landi and Landini, 1997a), which includes Arcetri and CHIANTI database and the Minor Ions dataset, has been used.

Special care has been taken for the ghosting problems, which seems to be the most limiting problem for the GIS calibration study. The relative sensitivity of the four GIS channels has been checked, finding that some small correction is required for GIS 1, while the GIS 4 calibration is more uncertain and probably needs some greater correction. No evidence for a wavelength dependent correction has been found for any of the four windows. Also the second order calibration has been investigated, measuring its value relative to the first order for GIS 3 and 4. A wavelength dependent curve has been determined for GIS 4 due to the presence of a great number of strong second order lines.

Further studies are in progress for determining a more precise intensity calibration using spectra coming from active and quiet regions. Moreover further work is in progress in order to correct more effectively the ghost problem, since in the present work this was the main source of uncertainty. The presence of ghosts also forced us to limit our study only to the strongest lines in the spectrum since often the weaker lines were dominated by ghosts.

REFERENCES


