Uncertainties in the estimate of the SiXI λ303.32 and HeII λ303.78 lines contribution to the coronal emission observed by the SCORE coronagraph

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ABSTRACT

In this report the main uncertainties affecting the estimate of the SiXI λ303.32 and HeII λ303.78 lines contribution to the coronal emission observed by the SCORE coronagraph are listed and provided. From the present analysis it turns out that the main critical parameter affecting the results is the selection of coronal electron temperatures T_e: for instance, an uncertainty by ±20% in T_e around 10^6K results in an uncertainty in the SiXI line intensity by ~ ±99%, while radiative and collisional components of the HeII line are affected by ~ ±34% and ~ ±27%, respectively. Moreover, significative uncertainties are also related to the selection of the SiXI ionization equilibrium and of the Si and He elemental abundances.

1. CLASSIFICATION OF POSSIBLE UNCERTAINTIES

The SCORE coronagraph onboard the HERSCHEL sounding rocket experiment (successfully launched on September 14, 2009) allowed for the first time the imaging observation of the coronal emission in the He II λ303.78 spectral line. The instrument observed the coronal emission in both the HeII λ303.78 and H I λ1215.78 spectral lines, proving the concept of a *multi-band coronagraph*. The SCORE coronagraph project has been led by the solar group of the INAF - *Osservatorio Astronomico di Torino*.
The data analysis is at present in progress: one of the aims of this analysis is to provide the first estimate of the He abundance in the corona, a fundamental parameter for understanding the solar wind acceleration. The first problem to solve in the above analysis is the estimate of the SiXI λ303.32 coronal emission: this line, centered only at 0.46Å from the HeII λ303.78 line, has been possibly integrated together with the HeII line in the SCORE pass-band filter, hence needs to be removed from the observed intensities.

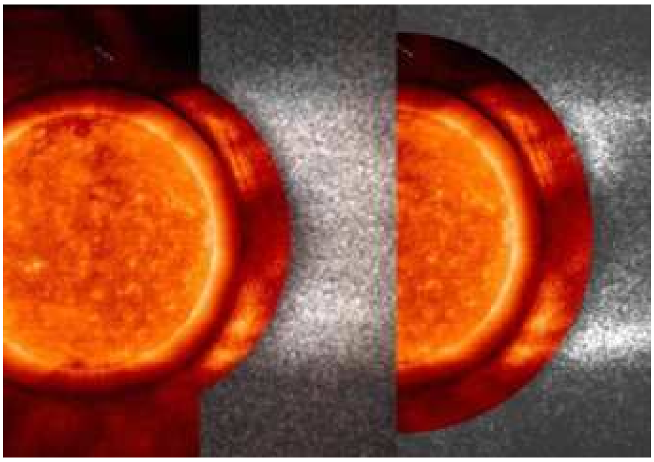

Fig. 1: the H I Lyman-α (left) and HeII (right) coronal emission observed by SCORE.

As a first step, it is possible to identify and classify all the possible sources of uncertainty in the estimate of both the expected SiXI and HeII line intensities. In particular:

- Type 1: uncertainties due to unknown physical quantities, usually assumed to be "constant" with altitude and latitude, hence in the integration along the line of sight (LOS). These quantities are the intensity and profile of the HeII exciting line, the Si and He abundances.

- Type 2: uncertainties due to unknown physical quantities more variable along the LOS, in particular the electron temperature and density, and the outflow velocity.
- Type 3: uncertainties due to many other effects such as variations in the unknown HeII emission and absorption line profile widths, temperature anisotropies, Active Region/Quiet Sun contrast, limb darkening/brightening, Doppler pumping, etc…

In this report we estimate the effects of the first 2 types of uncertainties, more important for a first order approximated estimate of the expected intensities, while type 3 uncertainties are not analyzed here: these uncertainties are possibly less important and affect the results only at the second order of approximation.

2. ESTIMATE OF TYPE 1 UNCERTAINTIES

The effect of these uncertainties is to results in a systematic error (i.e. systematic under or overestimate) of the expected line intensities. In particular, by assuming an uncertainty by ±20% in the exciting HeII line intensity $I_{ex}(HeII)$ and both in the He and Si elemental abundances $N(He)$ and $N(Si)$, the resulting uncertainties in the computed line intensities I_{comp} are simply:

$$\Delta I_{ex}(HeII) = 20\% \quad \Rightarrow \quad \Delta I_{comp}(HeII) = 20\%$$

$$\Delta N(He) = 20\% \quad \Rightarrow \quad \Delta I_{comp}(HeII) = 20\%$$

$$\Delta N(Si) = 20\% \quad \Rightarrow \quad \Delta I_{comp}(SiXI) = 20\%$$

In fact, both the collisional and radiative components of a spectral line are directly proportional to the elemental abundance of the emitting ion, while the radiative component is in first approximation directly proportional to the exciting disk line intensity.

3. ESTIMATE OF TYPE 2 UNCERTAINTIES

The estimate of these uncertainties is more complicate, because it is necessary to assume an electron density, temperature and outflow velocity profiles as a function of altitude for the integration along the LOS and to take also into account the Doppler dimming effect. As a temperature profile I assumed the analytical expression given in Vasquez et al. (2003); moreover, because the following analysis focuses only on the estimate of uncertainties in a coronal streamer, I assumed the density profile given by Gibson et al. (1999) and the outflow velocities given by Strachan et al. (2002) and Noci & Gavriuseva (2007). For the computation I also assumed: a) HeII disk intensity from F. Auchère PhD Thesis (measured by SOHO/EIT data); b) He and Si coronal abundances given by Feldman et al. (1992) and Raymond et al. (1997), respectively; c) ionization equilibrium of Shull & Steenberg (1982) and Arnaud & Rothenflug (1986); atomic parameters provided by the CHIANTI (v.5.2) spectral code. It turns out that, by assuming an uncertainty by 20% in the electron density, the resulting uncertainty in the line intensities are:

$$\Delta n_e = 20\% \quad \Rightarrow \quad \begin{array}{l} \Delta I_{col}(HeII) = 43\% \approx 40\% \\ \Delta I_{rad}(HeII) = 22\% \approx 20\% \\ \Delta I_{col}(SiXI) = 43\% \approx 40\% \end{array}$$

This was expected, because the radiative component of a spectral line is roughly proportional to n_e, while the collisional component is roughly proportional to n_e^2. More interestingly, by assuming a ±20% of uncertainty in the outflow velocity v_{out} (error bar centered around the value of v_{out} = 100 km/s), the resulting uncertainty in the line intensities are:

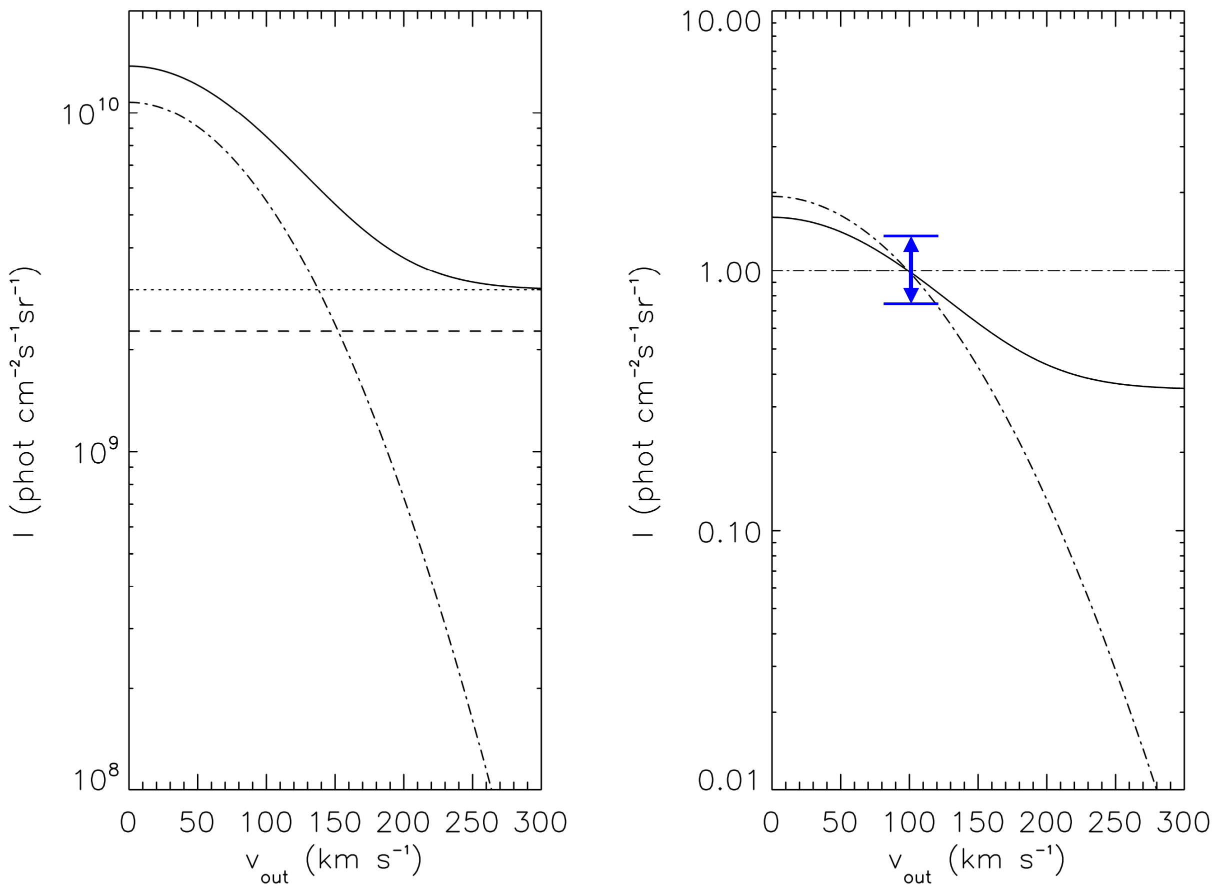

Figure 2: the collisional (dotted), radiative (dash-dotted) and total (solid) HeII line intensities and the SiXI line intensity (dashed) at fixed altitude as a function of the outflow velocity. The two panels show the absolute (left) and relative (right) variations of the expected line intensity. The error bar in the right panel shows the expected uncertainty for an error by 20% in the outflow velocity around 100 km/s.

$$\Delta v_{out} = 20\% \quad \Rightarrow \quad \begin{array}{c} \Delta I_{col}(HeII) = 0\% \\ \Delta I_{rad}(HeII) = 25.7\% \\ \Delta I_{col}(SiXI) = 0\% \end{array}$$

In order to better show the effect of the outflow velocity variations, Fig. 2 shows the expected HeII intensity (radiative, collisional and total intensity) at fixed altitude for different values of v_{out} (pumping by SiXI neglected): for a constant absolute uncertainty (i.e. Δv_{out} = 20 km/s) in the outflow velocity, the uncertainty in the estimate of the HeII radiative component is larger for larger v_{out} values, because as v_{out} increases the slope of the curve for the radiative component also increases.

In any case, the most critical unknown parameter is the electron temperature. In particular, by assuming a ±20% of uncertainty in the electron temperature T_e (error bar centered around the value of $T_e = 10^6$ K), the resulting uncertainty in the line intensities are:

$$\Delta T_e = 20\% \quad \Rightarrow \quad \begin{array}{c} \Delta I_{col}(HeII) = 26.8\% \\ \Delta I_{rad}(HeII) = 34.2\% \\ \Delta I_{col}(SiXI) = 99.6\% \end{array}$$

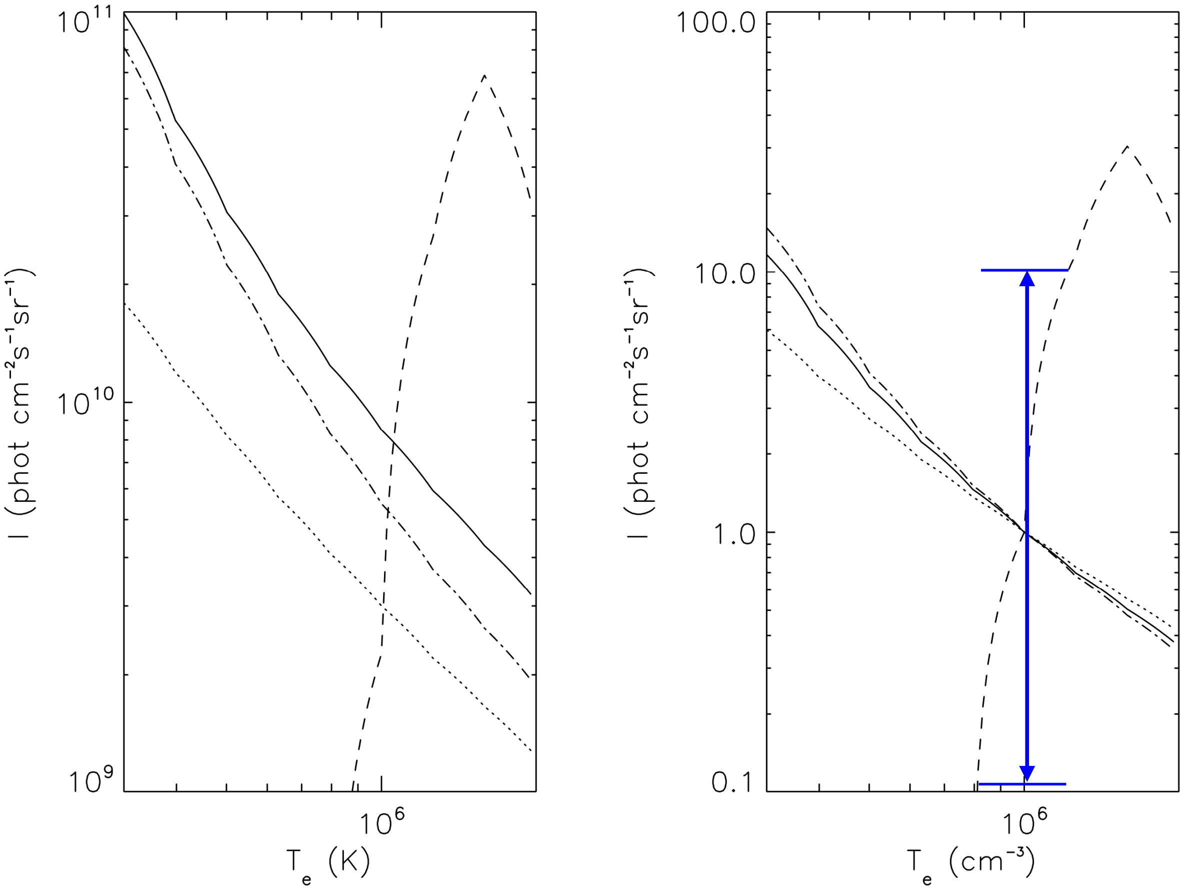

Figure 3: the collisional (dotted), radiative (dash-dotted) and total (solid) HeII line intensities and the SiXI line intensity (dashed) at fixed altitude as a function of theelectron temperature. The two panels show the absolute (left) and relative (right) variations of the expected line intensity. The error bar in the right panel shows the expected uncertainty for an error by 20% in the electron temperature around 10^6 K.

This implies that a ±20% uncertainty in T_e is sufficient to conclude that the SiXI intensity cannot be estimated, as its uncertainty becomes almost ±100%. This very large uncertainty is due to very high slope of the SiXI line emissivity around 10^6 K: in particular, Fig. 3 shows the expected HeII (radiative, collisional and total intensity) and SiXI intensities at fixed altitude for different values of the electron temperatures.

Before concluding, I point out that another significative source of a systematic uncertainty is provided by the existence (in the CHIANTI spectral code) of different computations for the ionization equilibria: in particular, version v.5.2 of CHIANTI lists up to 9 different files available in the database for the ionization equilibria of different ions. Each one of these different files results in different percentages of ions He^{1+} and Si^{10+} formed at a given temperature. Nevertheless, changes in the He^{1+} ion ionization equilibrium are negligible, while changes for the Si^{10+} ion are much larger. Absolute and relative variations of computed line intensities at constant temperature, density and outflow velocity for different ionization equilibria are shown in Fig. 4, while corresponding ionization equilibrium files are listed in Table 1. From these plot I conclude that the expected uncertainties due to the selection of the ionization equilibrium file are:

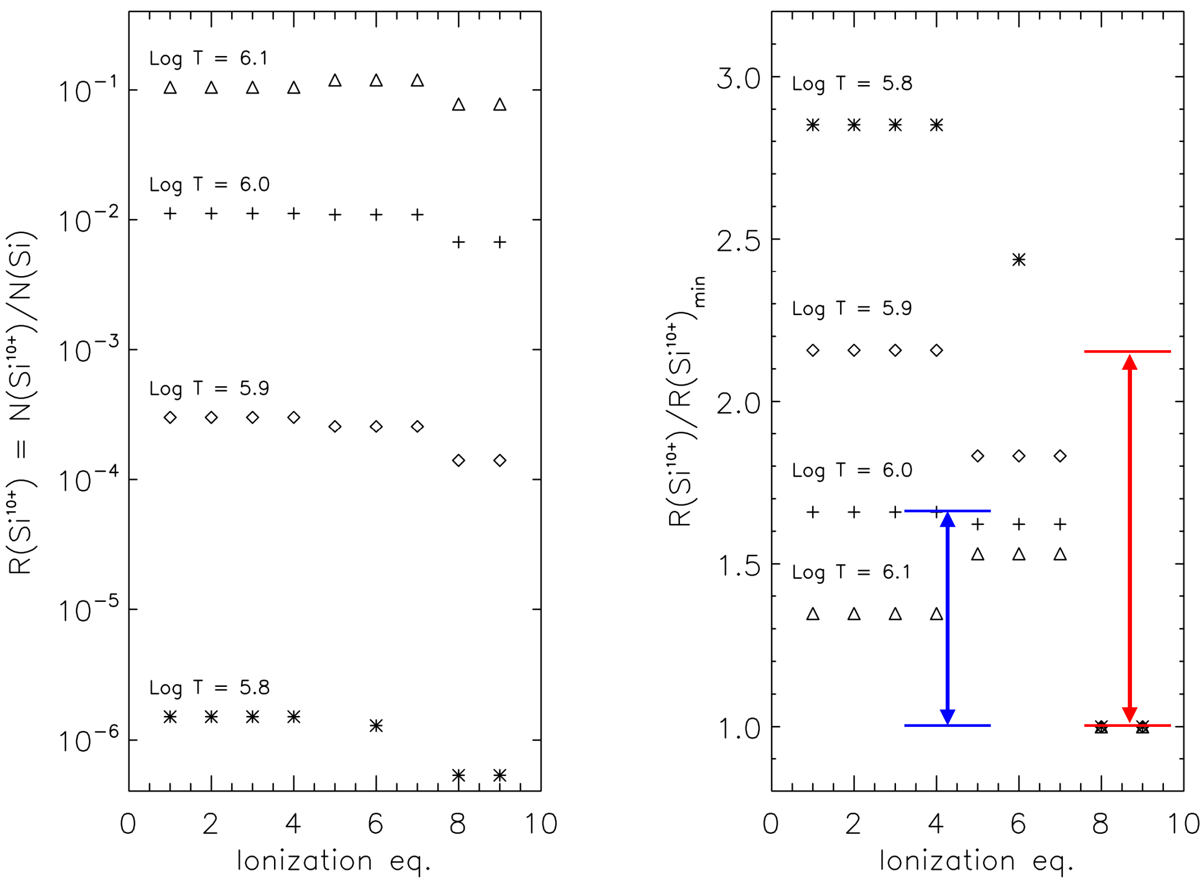

Figure 4: the absolute (left) and relative (right) variations of the expected ionization equilibrium for the Si^{10+} ion for different ionization equilibrium files and different tremperatures. The error bars in the right panel shows the expected total uncertainty for a temperature of $10^{6.0}$ K (blue) and $10^{5.9}$ K (red) .

n	Ionization Eqilubrium
1	Arnaud & Rothenflug (1985)
2	Arnaud & Rothenflug (1985) + Arnaud & Raymond (1992)
3	Arnaud & Rothenflug (1986)
4	Arnaud & Rothenflug (1986) + Landini & Monsignori Fossi (1991)
5	Mazzotta et al. (1998)
6	Mazzotta et al. (1998)
7	Mazzotta et al. (1998) + Landini & Monsignori Fossi (1991)
8	Shull & Steenberg (1982) + Arnaud & Rothenflug (1986)
9	Shull & Steenberg (1982) + Arnaud & Rothenflug (1986) + Landini & Monsignori Fossi (1991)

unknown ionization eq. $\Rightarrow$ $\Delta R(He^{1+})_{6.0} = 1.0\%$, $\Delta R(Si^{10+})_{6.0} = 32.9\%$; $\Delta R(He^{1+})_{5.9} = 0.3\%$, $\Delta R(Si^{10+})_{5.9} = 57.8\%$

Hence, any estimate of the SiXI line intensity has an *intrinsic* uncertainty by ~ ± 30% due to the selection of the Si^{10+} ionization equilibrium to be used in the computation. This uncertainty increases for smaller temperatures, and goes up to ~ ± 58% for T = $10^{5.9}$ K.

4. CONCLUSIONS

This report shows that the most critical parameter in the SiXI λ303.32 line intensity determination is the assumed values of the electron temperature; nevertheless, significative uncertainties arise also from the selection of the ionization equilibrium file, while uncertainties related to the unknown density and outflow velocity are less important.