Estimate of the FeXIV λ5303 coronal "green line" radiances for the PROBA-3 ASPIICS coronagraph

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ABSTRACT

In this report I describe all the assumptions made for the simulation of the expected FeXIV λ5303 coronal line radiance at different altitudes and latitudes. Radiances have been computed inside a coronal streamer and a coronal hole from 1.05 up to 2 solar radii, by assuming electron temperatures, densities and plasma outflow velocities derived by previous authors for the minimum of solar activity cycle. Resulting radiances are found to be in good agreement with observed and computed values provided in the literature. Results from the computation described here have been used to estimate the counts expected on the detector of the ASPIICS coronagraph designed for the PROBA-3 mission and on the CorMag telescope designed to observe from Tatakoto Island the next solar eclipse of July 11, 2010.

1. INTRODUCTION

A very large number of observations have been historically performed in the visible light spectral band centered at 5303 Å on the FeXIV, also known as the famous "green line". The coronal green line originates in the inner corona at a temperature of ~ 2 MK, most favourable for the FeXIV ion to be generated. Nevertheless, images of FeXIV coronal line radiances photometrically calibrated are very scanty, for many reasons. First, radiances measured in this line are usually employed, together with the sunspot number, as an indicator of variability of solar activity during the previous cycles (see e.g. Sýkora & Rybák 2010 for a recent study). For this reason, FeXIV line radiances are usually averaged over very broad latitude and/or altitude coronal regions and over long observation intervals, mixing all together different coronal structures.

Second, FeXIV line radiances are provided in the literature in many various units such as: c.u. (coronal units), i.e. the irradiance (emitted power) of the spectrum of the solar disk center in the width of $\Delta\lambda = 10^{-16}$ m at the wavelength 530.3 nm (e.g. Rušin et al. 2004); a.c.u. (absolute coronal units; e.g. Sýkora & Rybák 2005); millionth of the total brightness $B_\odot$ of the solar disk (10^{-6} $B_\odot$; e.g. Guhathakurta et al. 1993); c.i. (coronal index), i.e. the averaged daily irradiance (power) emitted by the green corona into 1 steradiant towards the Earth (W sr^{-1}) as measured from ground-based observations; ratio between the FeXIV line and the continuum intensities (e.g. Raju & Desai 1993). Because of the many different technique of observations (spectrograph or narrow pass-band filter) and the use of different methods of intensity calculations (photometry), different results have been obtained with different instruments. These problems have been discussed in detail by, e.g., Sýkora (1971), Rybanský (1975), and Altrock (1994). Unfortunately, there are large discrepancies between them. Also, many works on the green line performed with more recent instrumentations as the LASCO/C1 coronagraph onboard SOHO focused only on the centroid line shifts and the line widths, neglecting the problem of photometric calibration (e.g. Mierla et al. 2008).

As a consequence, looking in the literature it is very hard to find plots or tables providing the absolute FeXIV calibrated coronal line radiances (in phot cm^{-2} s^{-1} sr^{-1}) as a function of the altitude above the limb at fixed latitude. Hence, it is necessary to compute the expected calibrated FeXIV radiances. This information is of fundamental importance in order to estimate the expected number of counts on the detector of a coronagraph observing in this line. In particular, results described here have been used to estimate the expected number of counts on the detector of the ASPIICS coronagraph designed for the PROBA-3 satellite and also on the detector of the CorMag telescope, which has been built by the Team at INAF-Turin Astronomical Observatory to observe the next solar eclipse of July 11, 2010 from Tatakoto Island in the French Polynesia. In the next section (§2) the assumptions made in the computation are described, while in section §3 resulting FeXIV radiances are provided and compared with a few previous measurements from the literature. Tabulated FeXIV radiances are provided in the Appendix (§4).

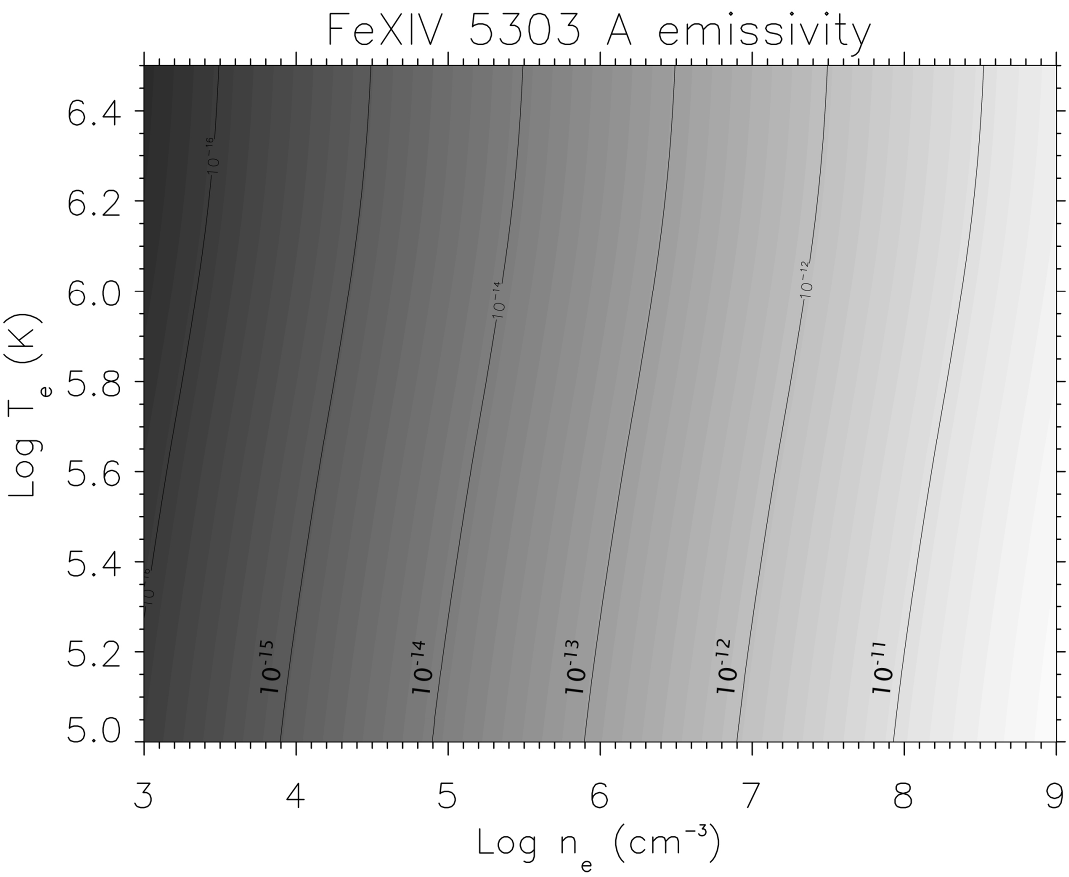

Figure 1: the FeXIV λ5303 line emissivity (erg cm^{-3} s^{-1}) provided by the CHIANTI spectral code for different electron densities (*x* axis) and temperatures (*y* axis); the Figure shows that the line emissivity is mainly dependent on the electron density.

2. THE COMPUTATION

In typical physical condition of coronal plasmas (low densities and high temperatures) spectral line intensities are in general related to the atomic excitation due both to the absorption of photons emitted from the underlying levels of solar atmosphere (radiative excitation) and to collisions with thermal electrons (collisional excitation), followed by spontaneous emission. In general the line intensity (or radiance) I_{ij} is related to the line emissivity P_{ij} which is given by

$$P_{ij} = h\nu_{ij} N_j\left(X^{+m}\right)A_{ji} \quad (erg\ cm^{-3}s^{-1})$$

where $N_j(X^{+m})$ is the number density of ions X^{+m} of element X and A_{ji} is the Einstein coefficient for the spontaneous emission for the transition j→i. Given P_{ij} the line intensity I_{ij} is given by

$$I_{ij} = \frac{1}{4\pi}\int_{-\infty}^{+\infty} P_{ij}\,dz \quad (erg\ cm^{-2}s^{-1}sr^{-1})$$

where the integration is performed along the line of sight. The largest source of uncertainty in the latter equations is the number density $N_j(X^{+m})$, because of the unknown coronal abundance of the element X and of the many processes possibly modifying the particular ionization state +m and the j-level population of the X atom.

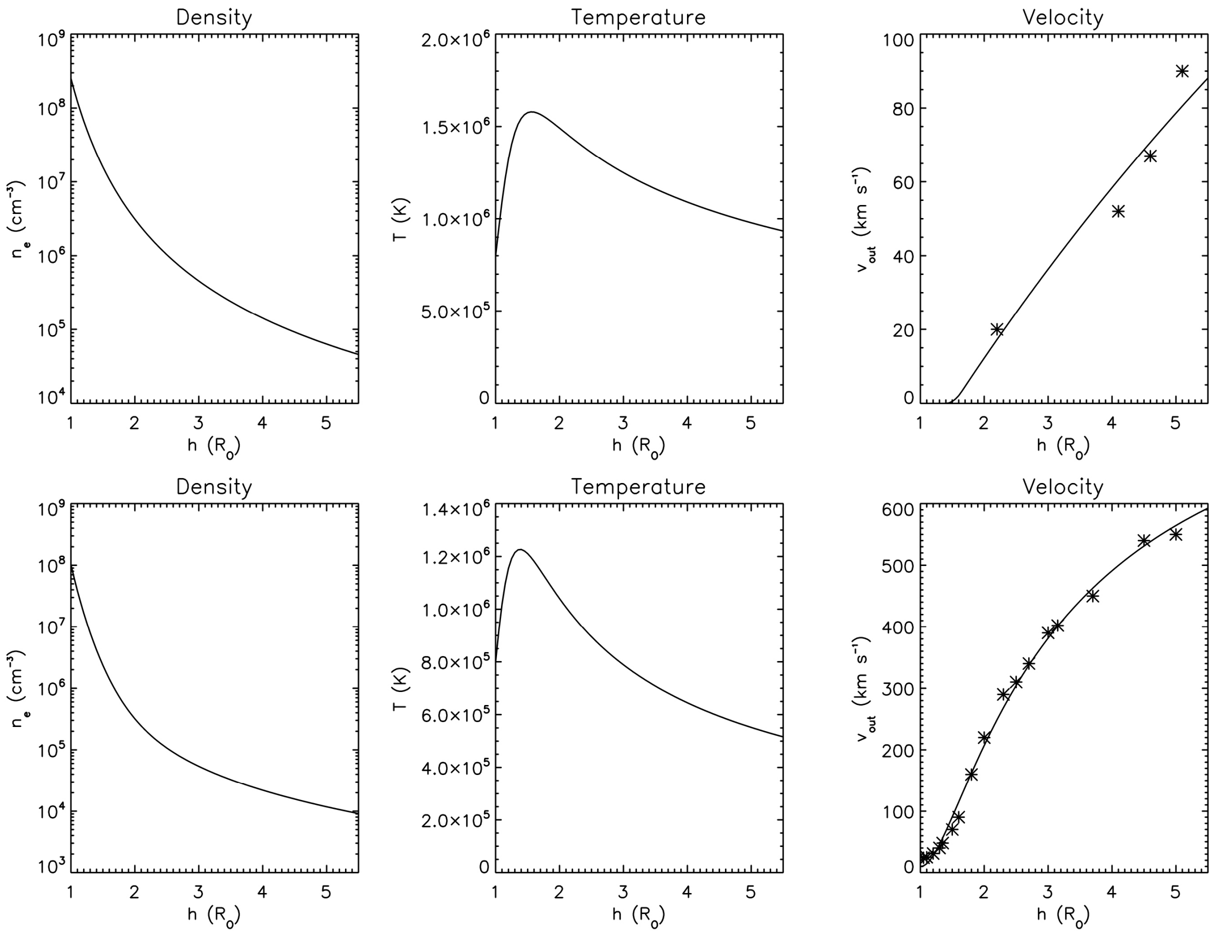

Figure 2: the input coronal density (left), temperature (middle) and outflow velocity (right) profiles for the computation in a coronal streamer (top panels) and a coronal hole (bottom panels). Right panels show the outflow velocity data points from the literature (stars) and the fitting curve (solid line); outflow velocity in a coronal streamer has been assumed to be 0 below ~ 1.5 solar radii (top right panel).

In this work the FeXIV 5303 line emissivities P_{ij} have been computed with the CHIANTI[1] spectral library (v. 6.0; Dere et al. 2009), freely distributed with the *SolarSoftware*[2]. For this computation I assumed a constant elemental abundance *N*(*Fe*) = 7.57 dex from Raymond et al. (1997) and the ionization equilibrium from Mazzotta et al. (1998); resulting FeXIV line emissivities computed with CHIANTI for a range of different electron densities and temperatures are shown in Figure 1. This Figure shows that the FeXIV line emissivity is mainly dependent on the unknown electron density.

The line intensities have been then computed as a function of altitude by assuming a radial profile for the unknown coronal electron density, temperature and outflow velocity of Fe ions in a coronal streamer and a coronal hole. In particular, temperature and density profiles have been assumed from Vasquez et al. (2003), which uses the density profiles from Sittler & Guhathakurta (1999). For the outflow velocity profile we used a compilation of different measurements from Antonucci et al. (2000), Gabriel et al. (2005), Telloni et al. (2007) (for coronal hole velocities) and from Strachan et al. (2002) and Noci & Gavryuseva (2007) (for coronal streamer velocities). Data points have been fitted with exponential curves in order to derive an analytic expression to be used for the integration along the line of sight (see Figure 2 for resulting profiles).

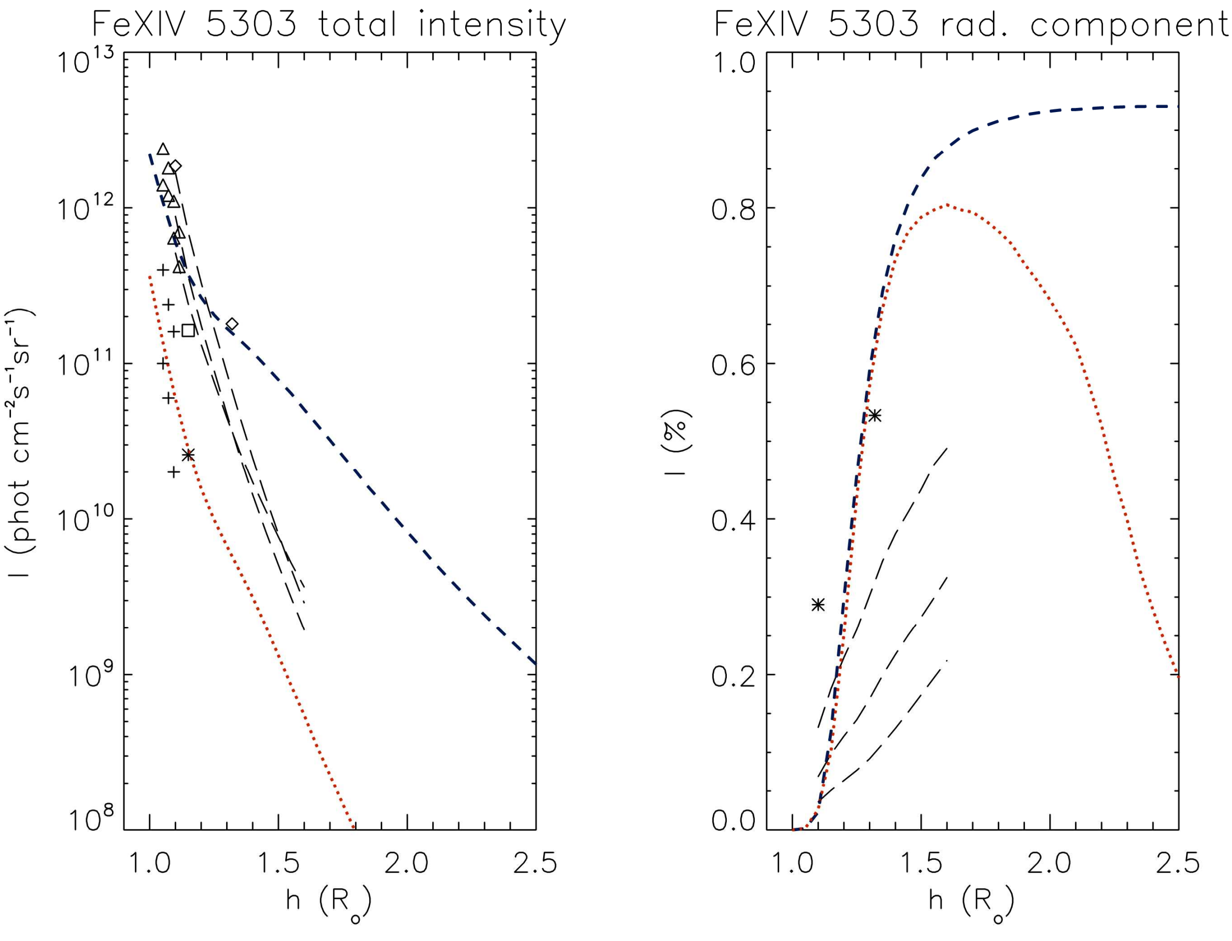

Figure 3, left: a comparison between the FeXIV intensity computed in a coronal streamer (blue dashed line) and a coronal hole (red dotted line) and the observed values reported in the literature by various authors (other lines and symbols – see text). Right: a comparison between the percentage of FeXIV radiative component computed in a coronal streamer (blue dashed line) and a coronal hole (red dotted line) and the observed values (long dashes and stars – see text).

[1] See http://www.ukssdc.ac.uk/solar/chianti/.
[2] See http://www.lmsal.com/solarsoft/.

At each altitude the collisional component $I_c(FeXIV)$ has been computed as

$$I_c\left(FeXIV\right)=\frac{1}{4\pi}P_{ij}\left(n_e,T_e\right)\int n_e^2 dz\,,$$

while the radiative component $I_r(FeXIV)$ has been computed as

$$I_r\left(FeXIV\right)=\frac{1}{4\pi}0.83B_{ji}R_{Fe}\left(T_e\right)N\left(Fe\right)\int J_\nu(z)n_e dz\,,$$

where B_{ji} is the Einstein absorption coefficient, $R_{Fe}(T_e)$ is the Fe ionization fraction at temperature T_e, $N(Fe)$ is the Fe abundance, and $J_\nu(z)$ is the radiative excitation coefficient which is given by (Collin 2000)

$$J_\nu\left(z\right)=\frac{2h\nu^3}{c^2}\left[\exp\left(\frac{E_{ji}}{kT_0}\right)-1\right]^{-1}\left(\frac{R_\Theta}{z+R_\Theta}\right)^2,$$

where T_0=5800 K is the peak temperature of the blackbody photospheric spectrum (see Collin 2000 for details).

3. RESULTS

Resulting FeXIV 5303 line intensities are provided in Table 1 and in Figures 4 and 5 (see Appendix). A comparison between the computed values and a compilation of observations reported by other authors is shown in Figure 3. In particular, the left panel of Figure 3 shows the FeXIV line intensities observed by Fisher & Musman (1975) (star and box symbols for the coronal hole and coronal streamer, respectively), Rušin et al. (2004) (plus and triangle symbols for the coronal hole and coronal streamer, respectively), Raju et al. (1993) (long dashes for quiet, active and polar regions) and the intensities computed by Judge (1998) (diamond for the coronal streamer); the Raju et al. (1993) intensities have been computed by assuming the white light K-corona brightness provided by Allen (1972), because this author provides only the FeXIV intensity ratio with continuum. The above comparison shows in general a very good agreement with previous estimates, even if the computed curves are quite different with respect to those provided by Raju et al. (1993) above ~ 1.2 solar radii; this difference can be partly related to the different white light brightness of the corona observed by Raju et al. (1993), which is unfortunately unknown. The right panel of Figure 3 shows a comparison between the computed fraction of FeXIV radiative component in a coronal streamer (blue dashed line) and a coronal hole (red dotted line), the fractions reported by Raju et al. (1993) for quiet, active and polar regions (long dashes) and the fractions computed by Judge (1998) (star symbols): this comparison show a very good agreement with values computed by Judge (1998) and a small disagreement with values reported by Raju et al. (1993). Globally, the above comparisons show a quite good agreement between the computed and the observed values for the FeXIV intensities, which can then be considered as reliable for the estimate of counts expected on the coronagraph detectors.

4. APPENDIX

COMPUTED FeXIV RADIANCES (phot cm^{-2} s^{-1} sr^{-1})						
	CORONAL STREAMER			CORONAL HOLE		
h (R_O)	I_{rad}(FeXIV)	I_{co}l(FeXIV)	I_{tot}(FeXIV)	I_{rad}(FeXIV)	I_{col}(FeXIV)	I_{tot}(FeXIV)
1.05	1.88E+09	1.11E+12	1.11E+12	3.01E+08	1.40E+11	1.41E+11
1.1	1.38E+10	5.87E+11	6.01E+11	1.55E+09	5.79E+10	5.95E+10
1.15	4.71E+10	3.25E+11	3.72E+11	2.88E+09	2.53E+10	2.82E+10
1.2	7.94E+10	1.87E+11	2.66E+11	3.94E+09	1.17E+10	1.56E+10
1.25	9.36E+10	1.11E+11	2.05E+11	4.24E+09	5.66E+09	9.91E+09
1.3	9.93E+10	6.86E+10	1.68E+11	3.83E+09	2.87E+09	6.70E+09
1.35	9.79E+10	4.34E+10	1.41E+11	3.10E+09	1.52E+09	4.61E+09
1.4	8.98E+10	2.82E+10	1.18E+11	2.31E+09	8.34E+08	3.15E+09
1.45	7.78E+10	1.87E+10	9.65E+10	1.59E+09	4.76E+08	2.07E+09
1.5	6.57E+10	1.27E+10	7.85E+10	1.04E+09	2.81E+08	1.33E+09
1.55	5.52E+10	8.80E+09	6.40E+10	6.74E+08	1.71E+08	8.45E+08
1.6	4.44E+10	6.21E+09	5.06E+10	4.42E+08	1.08E+08	5.49E+08
1.65	3.60E+10	4.45E+09	4.05E+10	2.75E+08	6.98E+07	3.45E+08
1.7	2.89E+10	3.24E+09	3.22E+10	1.79E+08	4.65E+07	2.26E+08
1.75	2.30E+10	2.39E+09	2.54E+10	1.15E+08	3.17E+07	1.46E+08
1.8	1.84E+10	1.79E+09	2.02E+10	7.43E+07	2.22E+07	9.65E+07
1.85	1.46E+10	1.35E+09	1.60E+10	4.87E+07	1.59E+07	6.46E+07
1.9	1.18E+10	1.03E+09	1.29E+10	3.12E+07	1.16E+07	4.28E+07
1.95	9.49E+09	8.00E+08	1.03E+10	2.09E+07	8.66E+06	2.95E+07
2	7.64E+09	6.25E+08	8.27E+09	1.41E+07	6.57E+06	2.07E+07

Table 1: the FeXIV 5303 line intensities computed at different altitudes between 1.05 and 2.0 solar radii in a coronal hole and a coronal streamer. This Table provides both the radiative and collisional components to the total line intensity.

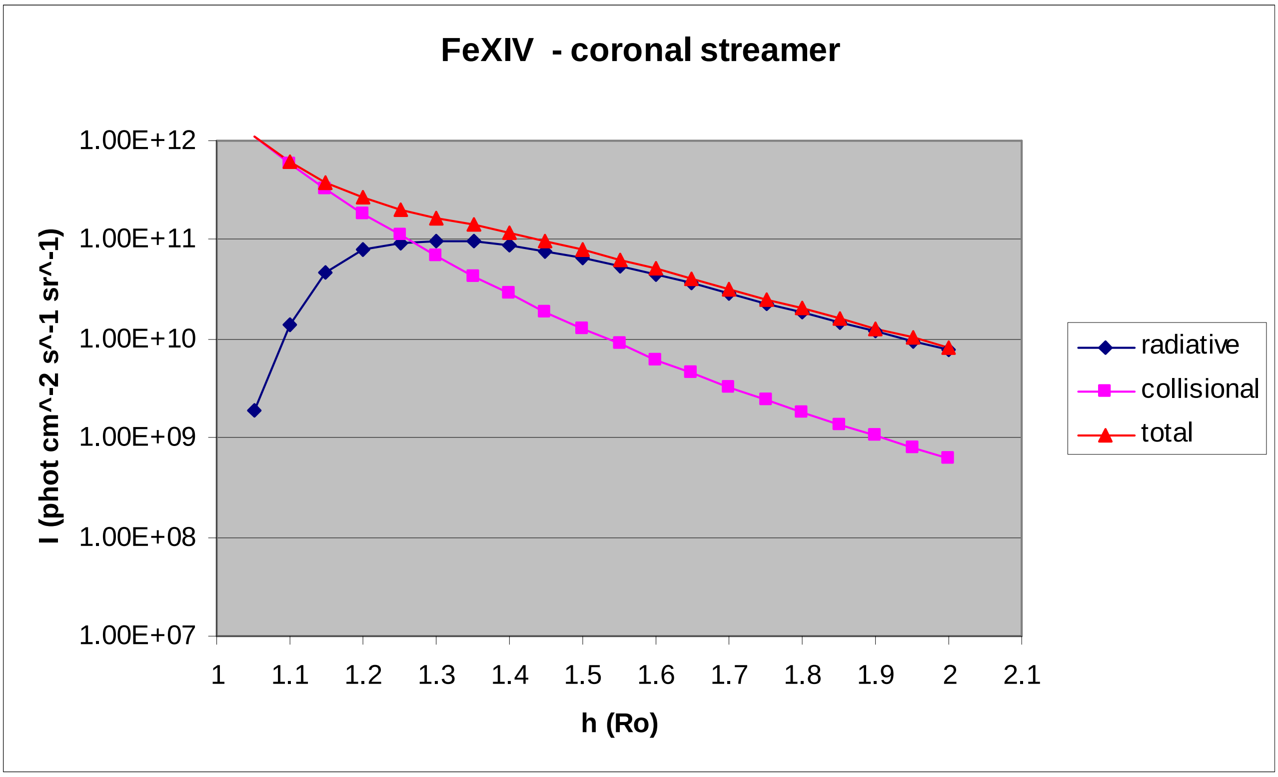

Figure 4: the FeXIV line intensity expected in a coronal streamer; the plot shows both the radiative and collisional components between 1.0 and 2.0 solar radii and the resulting total intensity.

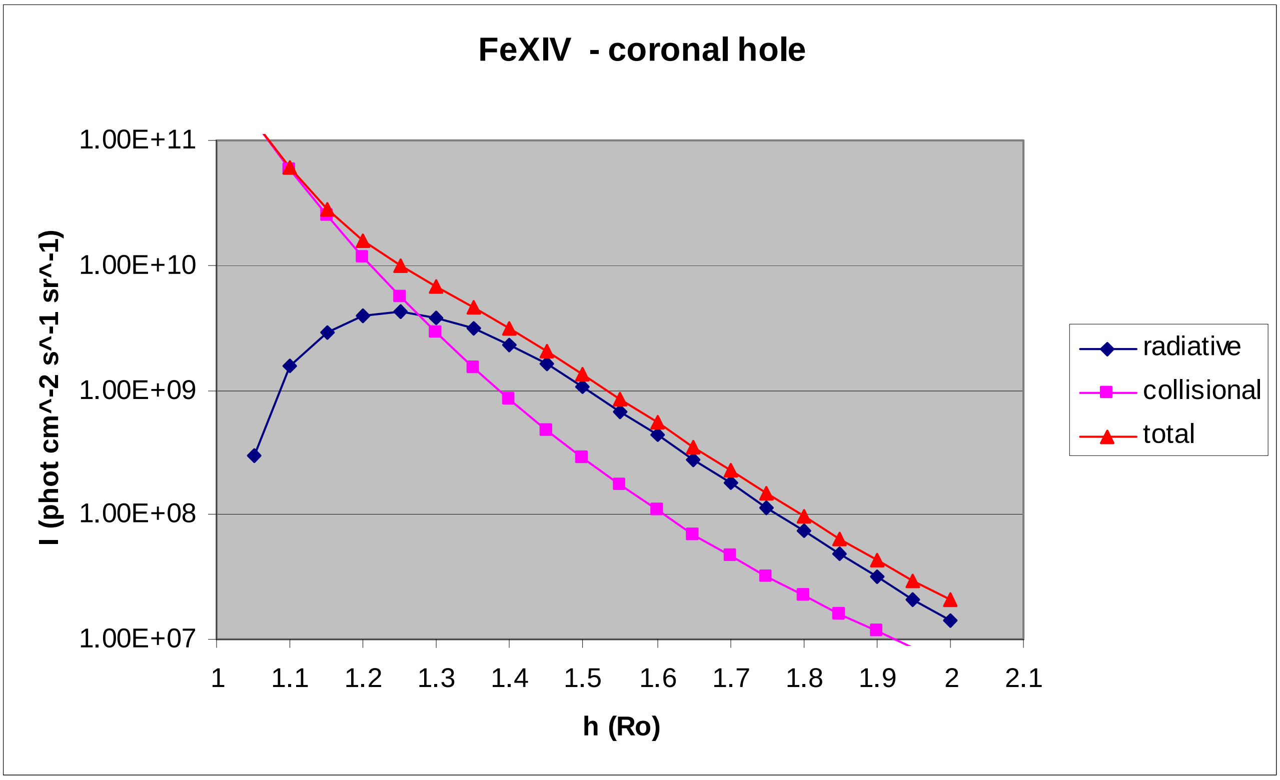

Figure 5: the FeXIV line intensity expected in a coronal hole; the plot shows both the radiative and collisional components between 1.0 and 2.0 solar radii and the resulting total intensity.

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