Ionization balance for optically thin plasmas: rates coefficients for all atoms and ions of the elements H to Ni and implication for the calculated X-ray spectrum

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ABSTRACT

The next coming X ray mission will allow us to measure the emission of the astrophysical X-ray sources with high energy resolution. Nevertheless to determine the relevant physical parameters describing the plasmas we need to compare observed data with a theoretical spectral model. We developed a new ionization balance code. This code has been already included in the spectral code SPEX. In this paper we show how the result of the standard analysis of XMM spectra could be affected by the use of different ionization balance code.

1. Introduction

Hot plasma are present in the universe in a variety of objects, from stellar corona to the intergalactic medium in clusters of galaxies. In the last years good quality data from space observatories like EINSTEIN, ROSAT, ASCA and SAX have been obtained spectrum of a X-ray source with even better energy resolution. This activity will have full bloom with the next coming X-ray space mission, like AXAF, XMM and ASTRO-E

To determine the relevant physical parameters describing the both astrophysical plasmas and laboratory plasmas, i.e. electron temperature, density distribution, ions and element abundance, we need to compare observational data with some theoretical spectral model.

From the early spectral models [see e.g. Raymond and Smith(1977), Mewe et al. (1972-1986), Landini and Monsignori Fossi (1990-1991), Sutherland and Dopita (1993)] up to date there have been a large number of improvements in the calculation of atomic parameters.

In this work we want to point out the relevance of using updated atomic data in the analysis of real X-ray spectra. We show the simulations of the some spectra produced with a new code (Mazzotta et. al 1998), in which the ionization balance has been calculated for all the elements from H (Z=1) to Ni (Z=28) for plasma temperatures ranging from 0.001-100 keV, using the most recent data for the ionization and recombination rates.

2. Ionization balance

To describe the ionization processes we refer to the work of Arnaud and Rothenflug (1985) and to the updating for the Fe ions of Arnaud and Raymond (1992) (hereafter AR85 and AR respectively). The contributions to the ionization rates are given for all the ions of H, He, C, N, O, Ne, Na, Mg, Al, Si, S, Ar, Ca and Ni from different atomic subshells separately. The other ions not included in the AR85 work are calculated by interpolation or extrapolation along the isosequence.

For the radiative recombination rates we followed Shull and van Steenberg (1982) and Landini and Monsignori Fossi (1991) and we interpolated for ions not included in the previous works. For the H-like, He-like, Li-like and Na-like isosequences we used the data of Verner and Ferland (1996) and for Fe ions Arnaud and Raymond (1992).

Most of our work was, indeed, dedicated to update the dielectronic recombination rates. For a detailed discussion see Mazzotta, Mazzitelli, Colafrancesco and Vittorio (1998), where the fitting parameters E_i and c_i to the dielectronic recombination rate,

$$\alpha_d = \frac{1}{T^{3/2}} \sum_{i=1}^{4} c_i \exp\left(\frac{E_i}{T}\right) \qquad [\mathrm{cm/s}], \tag{1}$$

are also give for all the ions from He trough Ni.

3. Results for the Coronal Equilibrium

The data we have collected are used to evaluate ionic abundance fraction.

As an example, in figure 1 we report the comparison of our ionic abundance fraction for some ions of Ni, from Ni XVI to NI XXII (panel a and b), and Ca (panel c), from Ca XII to Ca XVIII, with those given by AR85.

In the same figure we report, for each ion, also the percent variation near the peak of maximum ionic abundance. We found, depending on the temperature and on the ions considered, differences up to 1700%.

If we fix the temperature at which the ion abundance curves reach their maxima, we can see that generally the big differences found are due to a shift, depending on the considered ion, to higher or lower temperature with respect to the other considered case.

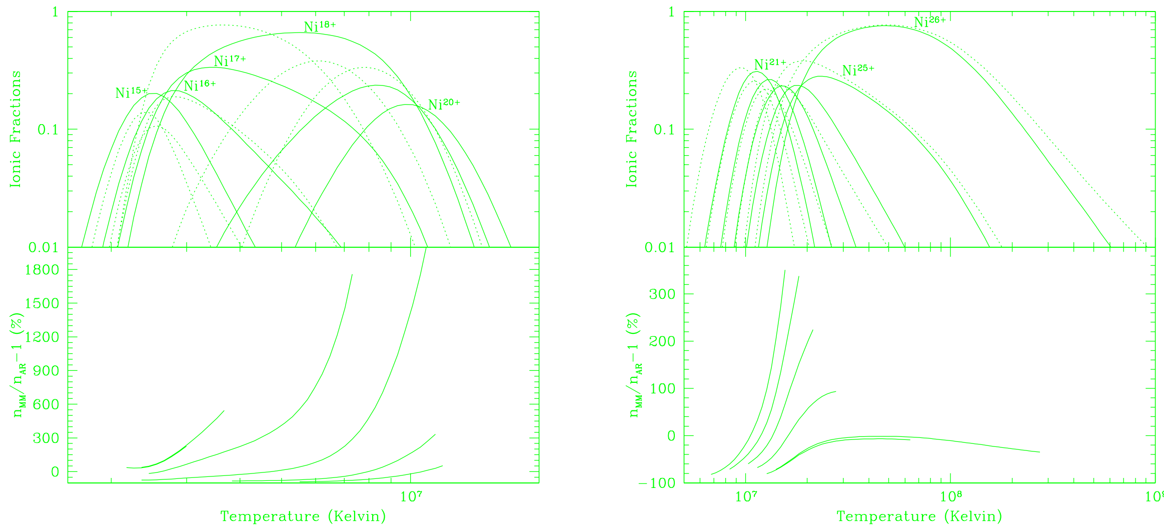

Fig. 1.— *Upper panel*: Ionic fraction vs. temperature for Ni ions, from Ni XVI to Ni XXVII. Solid curves: present work; dashed curves: AR85. *Lower panel*: percent variations in the ionic abundance fractions in the present work with respect to that of AR85. For each ion, the percent variations are evaluated only for a range of temperatures in which the respective ionic fractions are $> 10^{-1}$.

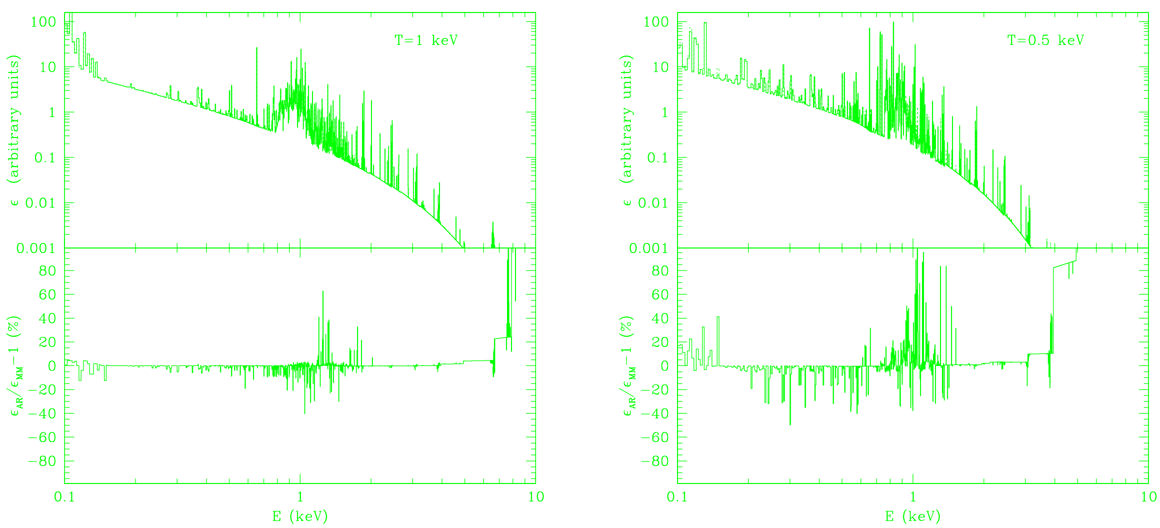

Fig. 2.— *Upper panel*: Comparison for the simulated spectra with a linear energy grid of 5 eV step size for temperature plasma $T = 1$ keV and $T = 0.5$ keV respectively. *Lower panel*: percent variations in the emissivity in the selected channel obtained using the present work ionization balance with respect to those of AR85.

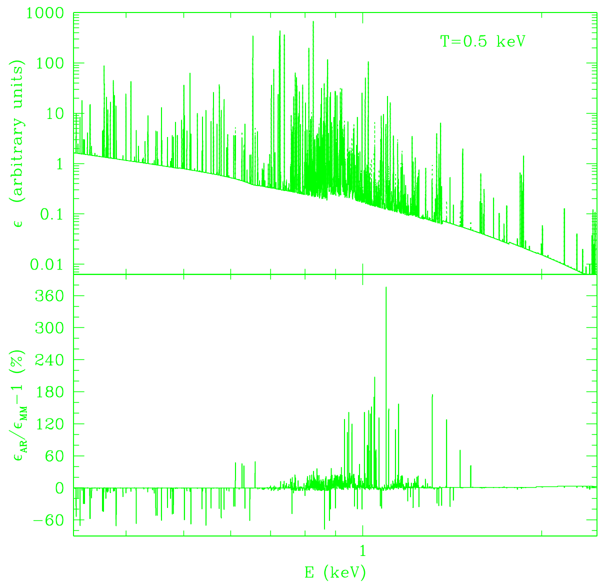

Fig. 3.— Same as fig. 2 but for a 0.5 keV temperature plasma and using the XMM-RGS spectral resolution

4. Implication for the Computed X-Ray Spectra

Our data are already included in the Software Package SPEX (Kaastra and Mewe 1992-1995, SRON Utrecht) for the computation and the modeling of X-Ray spectra.

Differences in the computed ionic fraction reflect in differences in the line power emission. To discuss quantitatively this issue, we simulated the X-ray emissivity spectrum using the SPEX code choosing for the ionization balance the data of AR95+AR or our data. In Figure 2 we report the comparison for the simulated spectra for 4 different plasma temperatures using a linear energy grid of 5 eV step size.

As expected we find differences that are significant only for low temperature plasmas. This because in a high temperature plasma the elements are almost fully ionized or in a high ionization state and the ionization and recombination coefficients for those isosequenze can be calculated more easily.

In figure 3 we report the comparison for the simulated spectra for 0.5 keV temperature plasma using the XMM-RGS spectral resolution. In the lower panel we can note a line for which the variation is up to 360%. This is a consequence of the big variation in the ionic fraction of the Ni XVIII and Ni XIX ions between the two ionization code at this temperature (see fig 1)

5. Conclusions

We collected all the recently released atomic data to improve the ionization balance calculation.

Our code give the ionization balance for all the atoms and ions form H ($Z = 1$) to NI ($Z = 28$) (to date there are no other similar public code).

Our results yield differences in the ion abundance and, then, in the power of X-ray lines. We showed that this effect is very important when the plasma temperatures is below 2 keV as in this case lines contribute substantially to the total X-ray emissivity.

We showed as with the energy resolution of the RGS instruments of XMM, we found relevant differences in the expected emissivity for a single channel by using different ionization balance code.

REFERENCES

Arnaud, M., Raymond, J. 1992, ApJ, 398, 394 (AR)

Arnaud and Rothenflug 1985, A&AS, 60, 394 (AR85)

Gronenschild, E. H. B. M., Mewe, R. 1978, A&AS , 32, 283 (Paper III)

Landini, M., Monsignori Fossi, B. C. 1990, A&AS, 82, 229

Landini, M., Monsignori Fossi, B. C. 1991, A&AS, 91, 183

Mewe, R. 1972, Solar Phys., 22, 459 (Paper I)

Mewe, R. 1975, Solar Phys., 44, 383 (Paper II)

Mewe,R., Gronenschild, E.H.B.M. 1981, A&AS, 45,11 (Paper IV)

Mewe, R., Gronenschild, E. H. B. M., van den Oord, G. H. J. 1985, A&AS, 62, 197 (Paper V)

Mewe, R., Lemen, J. R. van den Oord, G. H. J. 1985, A&AS, 65, 551 (Paper VI)

Mazzotta, P., Mazzitelli, G., Colafrancesco S. and Vittorio N.,1998, A&AS in press

Raymond, J.C., Smith, B.W. 1977, APJS, 35, 419

Shull,J.M., Van Steenberg,M. 1982, APJS, 48, 95

Sutherland, R. S. and Dopita, M. A., 1993, APJS, 88, 253

Verner, S.A., Ferland, G. J. 1996, APJS, 103, 467

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