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Research Note

C III and C IV line emission following K-shell photoionization

D. Petrini[1] **and E.P. da Silva**[2]

[1] Observatoire de la Côte d'Azur, Department G. D. Cassini, BP 229, F-06304 Nice Cedex 4, France (e-mail: petrini@obs-nice.fr)
[2] Departamento de Física, Universidade Federal, CP 6030, Fortaleza, Cearà, Brazil 60450 (e-mail: euclimar@fisica.ufc.br)

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Abstract. Soft X-ray irradiation on low density cold matter K-ionizes neutral carbon. The complete ionization process, single ionization and shake-off processes, followed by Auger decay produces excited states of C III and C IV ions. Consequently C III and C IV UV lines are produced directly with comparable intensities. Some relative intensities of observable lines are calculated.

Key words: atomic processes – atomic data – X-rays: general – ultraviolet: general

1. Introduction

Diffuse soft X ray emission in the sky has recently been investigated over a large energy range from 0.1 keV up to a few MeV (Fabian and Barcons 1992). Below about 0.5 keV most of this diffuse emission originates from the local galactic bubble which has a temperature around 10^6K (McCammon and Sanders 1990). An excess of emission at energies up to 2 keV is observed lying well above Boldt's (1987) single analytical fit for the 3–45 keV range. Ionized regions surrounding supersoft X-ray sources (Long et al 1981) act as soft X-ray generators outside the ionized regions with substantial power for photons with energies around 300 eV in the standard model of Rappaport et al (1994) (fig. 1). Photons in the 0.3–2 keV range are efficient for K ionizing the light cosmic elements C, N, O and Ne (with respective K-ionization energies 0.283, 0.399, 0.531, 0.874 keV). These photons may also ionize S and Ar atoms (with respective 2s and 2p L-ionization energies 0.193, 0.164; 0.287, 0.247 keV). Morever extended X-ray emission from planetary nebulae has been detected during the ROSAT All Sky Survey (Kreysing et al. 1992). The measured X-ray flux was interpreted as surface emission from the central star. The soft X-ray spectrum of NGC 6543 for example has its maximum near 0.4 keV. Previously

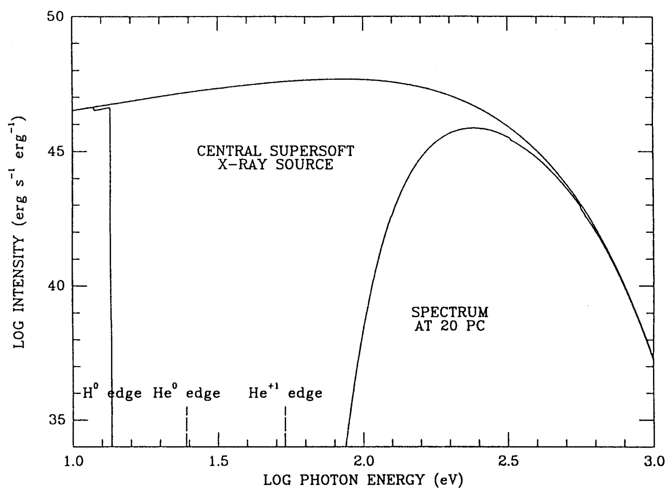

Fig. 1. Fig. 3 from (Rappaport et al 1994): Spectrum of the central supersoft X-ray source very near the source and at a distance of 20pc (beyond most of the ionization regions), for the case of the standard model. Ionization–edge energies for H and He are indicated for reference purpose. Note that the 20pc apparent source is not sufficient for the full shake off regime.

Manchado and Pottasch (1989) explained the high temperature observed in the halo of NGC 6543 by the hardening of the radiation field due to the optically thickness of the nebula itself, i.e. the more energetic photons reach the halo.

In the present note we discuss the possibility of observing some C III and C IV line emission due to the double process K-photoionization + Auger decay when soft X-radiation illuminates low density cold matter. Weisheit and Dalgarno (1972, 1973) have analysed the impact of simple K-photoionisation on the balance between the different carbon ionized stages. they considered the interstellar gas to be ionised by a diffuse X-ray background. The relative abundances of multiply ionized atoms that result from steady-state ionization are much larger than those computed ignoring innershell photoionization and

Send offprint requests to: D. Petrini

Table 1. Partial Auger widths from C II $1s2s^22p^2$ terms: 10.08 s = 10.08 10^{-4} a.u. for channel l=0. Total width in 10^{-4} a.u.. Ejected electron energy on the residual ground state (approximate values given in eV) = e.e.e..

	$^1S^e$	$^3P^o$	$^1P^o$	$^3P^e$	$^1D^e$	$^1S^e$	width	e.e.e.
$^4P^e$		11.01 p		10.08 s 0.55 d			22.64	263.7
$^2P^e$		0.43 p	2.98 p	11.81 s 0.46 d			14.12	266.8

Table 2. Partial Auger widths from C III $1s2s^22p$ terms: 1.21 d = 1.21 10^{-4} a.u. l=2 for the ejected electron. Total Auger widths in 10^{-4} a.u.. Ejected electron energy on the residual ground state (approximative values given in eV) = e.e.e..

	$^2S^e$	$^2P^o$	width	e.e.e.
$^3P^o$	8.18 p	1.22 d 15.82 s	25.22	245.0
$^1P^o$	0.11 p	0.2d 18.61 s	18.94	247.5

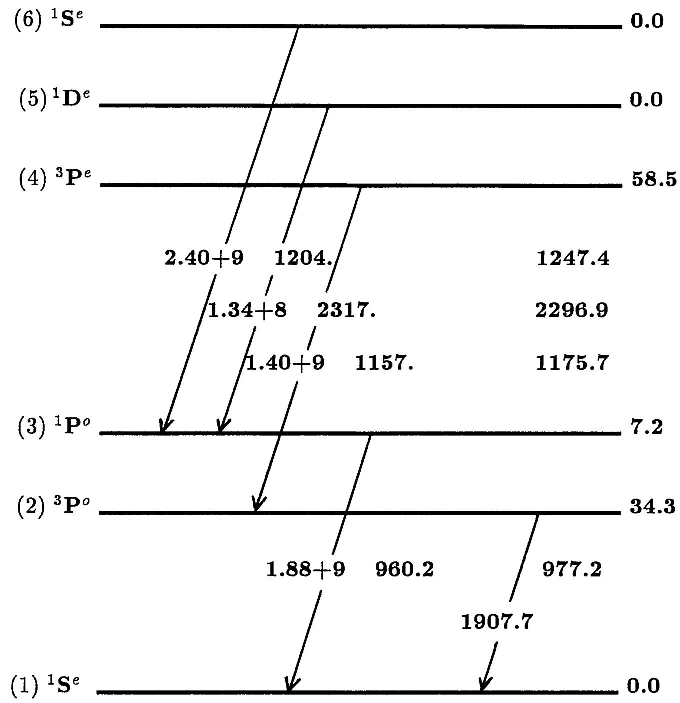

Fig. 2. Relative Auger rates to C III terms associated with configurations $1s^22s^2$, $1s^22s2p$ and $1s^22p^2$ assuming statistical weights for the C II initial 1s-hole terms are given on the right hand side. Dipole Opacity Project transition probabilities and wavelengths are shown (2.4+9 = 2.4 10^9 sec^{-1}, wavelength in AA). Wavelengths on the right are Wiese's values. The forbidden line 2-1, λ1907.7, is indicated.

Auger processes. However these authors paid no attention to X-UV line emission.

2. K-photoionisation and Auger process

Since we have already considered the neon case (Petrini and Farias 1994), relevant references can be found in this article. For light atoms, single K-photoionization occurs accompanied by two secondary processes which are far from negligible. Firstly, the *shake up* process refers to the simultaneous excitation of an outer shell electron (here 2s or 2p). Secondly, the *shake off* process refers to the simultaneous ionization of an outer shell electron (The carbon is left either in the triplet or singlet $1s2s^22p$ P^o term). The shake off process dominates and reaches its full efficiency for energies larger than twice the K-ionization energy (Åberg 1969). Morever this last process (noted KL ionization) is relatively important compared to the single K-ionization and it is expected to be large for carbon (Löw et al 1984). These authors find 0.33 for the KL/K production ratio for fluorine (Z=9) in good agreement with the sudden approximation theoretical result of Åberg (1969). There is no experimental result for carbon. It seems unlikely to us that the lighter atoms carbon, nitrogen and oxygen (with fewer 2p electrons) would have larger values imposed by the extrapolation towards lower Z according to the sudden approximation theory. If this feeling were wrong the C III /C II production ratio would increase as well as the C IV $\lambda\lambda$1549.1 relative intensity. The Auger decay for light atoms totally dominates the K_α radiative decay (Bambynek et al 1972) and populates mainly the $1s^22s^m2p^n$ excited states of the residual ion (here C III and C IV). Assuming low density cold matter illuminated by soft-X rays (that would be the case for material outside the ionized nebula close to a soft X-ray source), the neutral carbon, which is mostly in the ground state, is ionized and produces finally C III and C IV excited states. These states give rise to some X-UV lines such as 1247.4, 2296.9, 1175.7, 977.2, 1907.7] and 1549.1 Å. Some of these lines are unobservable due to Auger and radiative selection rules.

3. Results

Fig. 2 shows lines arising from the residual C III ion. The C IV $\lambda\lambda$1549.1 will compete with the C III lines. As suggested above, the KL/K production is larger than 0.4 in the full shake off regime (say 500 eV). Let us take an effective ratio to be 0.3 (minimizing the global shake off effect). In order to establish the relative intensities, we need the relative Auger rates from the $1s2s^22p$ $^1P^o$,$^3P^o$ C III terms and from the $1s2s^22p^2$ ^2P,^4P C II terms. For the single photoionization of the ^3P initial term, the ^2P and ^4P 1s-hole terms are produced according to their statistical weights. For KL ionization we assume the same rule (still a controversial assumption). We have calculated the Auger rates using the University College codes mentioned in our previous paper. Tables 1 and 2 give the results obtained. Fig. 3 contains the relative Auger rates and the Opacity Project dipole transition probabilities and wavelengths (Seaton et al 1992). The effective Auger rate for a definite transition is equal to the K or KL photoionization rate multiplied by the corresponding relative Auger rate. For C IV the Auger decay is mostly to the excited terms (75%). We note that the $\lambda\lambda$1907.7 which is fed directly and by cascade from the $^3P^e(4)$ term and the $\lambda\lambda$1157 are the most intense lines. The $\lambda\lambda$977.2/$\lambda\lambda$1157 intensity ratio is 0.15 and the C IV $\lambda\lambda$1550/C III $\lambda\lambda$1175.7 intensity ratio is roughly 1/4. These results have been obtained assuming low density cold matter irradiated by a soft-X ray source with an energy excess below 1 keV and assuming a statistical weight rule for the 1s-hole C III production. The shake up process, which finally gives rise also to C III excited states is expected to slightly modify these results.

4. Conclusions

C IV $\lambda\lambda$1548.2,1550.7 lines are directly produced in this model with intensities of the same order of magnitude as the C III $\lambda\lambda$1175.7 and $\lambda\lambda$977.2 lines. L-photoionization followed by Coster-Kronig radiationless decay (Bambynek et al 1972) in such situations, namely i.e. energy excess below 1keV, is efficient for producing, for example, sulphur and argon in doubly, triply and multiply ionized excited states, since the L_I and $L_{II,\,III}$ edges are 0.193; 0.164 keV and 0.287; 0.246 keV respectively. Studies of 2s-hole and 2p-hole Ar II and Ar III radiationless decays provide relative intensities of some Ar III , IV and V UV lines in cold matter undergoing X-ray irradiation.

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