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Astrophysical Plasmas: Codes, Models, and Observations (Mexico City, 25-29 October 1999)
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X-RAY PLASMA DIAGNOSTICS FOR TOTALLY AND PARTIALLY PHOTOIONIZED PLASMAS SUCH AS WARM ABSORBERS IN AGN

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RESUMEN

Gracias a la nueva generación de satelites de rayos-X, como *Chandra* y *XMM*, se pueden obtener espectros de alta sensibilidad y resolución. En particular, se pueden separar las tres líneas más intensas (resonantes, de intercombinación y prohibidas) de iones de baja carga (baja Z) como el He, en plasmas no solares. Basados en estas tres líneas, presentamos diagnósticos para densidad, procesos de ionización y temperatura totalmente o parcialmente ionizados por fotoionización. Estos poderosos diagnósticos pueden ser usados en plasmas calientes como los de AGN, galaxias con brotes de formación estelar, binarias de rayos-X, etc. En particular, pueden ser usados en los absorbedores tibios que se ven en AGN (Porquet & Dubau 2000), que son herramientas importantes para entender las regiones centrales de diferentes tipos de AGN (Seyferts 1 y 2 y cuasares de bajo y alto corrimiento al rojo).

ABSTRACT

Thanks to the new generation of X-ray satellites such as *Chandra* and *XMM*, high resolution and high sensitivity spectra are available. In particular, for the first time, the three most intense lines (resonance, intercombination and forbidden) of low charged (low Z) He-like ions are split for non-solar plasmas. We present density, ionizing process and temperature diagnostics, for totally and partially photoionized plasmas, based on ratios of these three lines. These powerful plasma diagnostics could be used for hot astrophysical plasmas such as AGN, starburst galaxies, X-ray binaries, etc. In particular, they could be applied to the Warm Absorbers often seen in Active Galactic Nuclei (Porquet & Dubau 2000), which is an important tool for understanding the central regions of different types of AGN (Seyfert 1 and 2, high and low redshift quasars).

Key Words: **GALAXIES: ACTIVE — TECHNIQUES: SPECTROSCOPIC – X-RAYS: GALAXIES**

1. A BRIEF INTRODUCTION TO WARM ABSORBER

Warm Absorbers (WA) have been found, a few years ago, to be an important component of the central regions of Active Galactic Nuclei. Indeed, it is assumed they are located between the Broad Line Region (BLR) and the Narrow Line Region (NLR), and even inside the BLR (Otani et al. 1996; Porquet et al. 1999). This medium is assumed to be a photoionized plasma, but some additional ionization process is not ruled out (Porquet & Dumont 1998; Porquet et al. 1999). This is why we can consider that WA could be either totally or partially photoionized (photoionization plus collisional ionization). The existence of WA has been revealed by observations of significant absorption edges in X-ray spectra near 0.8 keV, implying column densities of 10^{21}–$10^{23}\,\mathrm{cm}^{-2}$. These features are seen in at least 50% of Seyfert 1 (Reynolds 1997), thus WA is a common characteristic of these objects. This medium is assumed to be not only an absorber but also a multi-wavelength

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[2]DARC.

emitter (e.g., with optical coronal lines: Porquet et al. 1999). Besides, in Seyfert galaxies soft X-ray emission lines are also observed. In particular, the He-like X-ray lines are of particular interest since their ratios are used as plasma diagnostics, as discussed in the next section. Given that WA are either totally or partially photoionized, we study two ionization models: totally photoionized plasmas (with "pure" photoionization), and hybrid plasmas (with photoionization plus an additional ionization process).

2. X-RAY PLASMA DIAGNOSTICS

He-like ions have an interesting atomic structure, they emit three main lines (n = 2 shell), which are close in wavelengths: resonance (called w), intercombination ($x+y$), and forbidden lines (z). As shown by Gabriel & Jordan (1969), the combination of the ratio of these lines can be used to derive the electronic density (n_e) and temperature (T_e):

$$R(n_e) = \frac{z}{x+y} \quad and \quad G(T_e) = \frac{(x+y)+z}{w} \; . \tag{1}$$

As pointed out by Pradhan (1985) and Liedahl (1999), these diagnostics could also be used for the study of photoionized plasmas.

2.1. *Atomic Data*

In order to obtain accurate line ratios, we have calculated atomic data over a wide range of temperatures for radiative and dielectronic recombinations[3], and collisional excitation rates[4] from the ground level, which should be considered in hybrid high-temperature plasmas. For both atomic processes (recombination and excitation), radiative cascades from n > 2 levels have been taken into account in the calculation of the population of the n = 2 shell levels (related to w, $x+y$, z). Indeed, cascades are of great importance especially for the z forbidden lines. The rate coefficients and more details about the calculations can be found in Porquet & Dubau (2000).

2.2. *Ionizing Process Diagnostic*

In "purely" photoionized plasmas, radiative recombination is the dominant process. In hybrid plasmas, collisional excitation is also important since the temperature is high enough to permit excitations from the ground level. Radiative recombination rates show that the level connected to the intercombination ($x+y$) and to the forbidden (z) lines are favored, and thus implies stronger triplet lines (x, y, z) than the singlet resonance lines (w). On the contrary, collisional strengths favor the level connected to the w resonance line. Then, totally photoionized media emit weak resonance (w) lines compared to forbidden (z) or to intercombination ($x+y$) lines. In hybrid plasmas, the behaviour is the opposite (see Fig. 1).

2.3. *Density Diagnostic*

The ratio R is constant below some critical density ($n_{\rm crit}$), the forbidden lines are then intense, and above $n_{\rm crit}$, the ^{3}S$_1$ level (forbidden line) is depopulated to the ^{3}P levels (intercombination lines) via collisional excitation inside n = 2. Then, the intensity of forbidden (z) lines decreases while the intensity of intercombination ($x+y$) lines increases. This inversion occurs (approximately) within two orders of magnitude in density. Thus, inside this range, R is very sensitive and gives an accurate estimate of the density (see Fig. 1). Summarizing, when we observe that the ratio R is constant, we obtain an upper limit for the density. When R becomes sensitive to the density, we obtain a good density estimate. If R tends to zero ($z \rightarrow 0$), we obtain a lower limit for the density.

[3]Radiative recombination dominates at low temperatures whereas dielectronic recombination dominates at high temperatures (considering recombination processes).

[4]Collisional excitations inside the n = 2 shell occur even at low temperatures.

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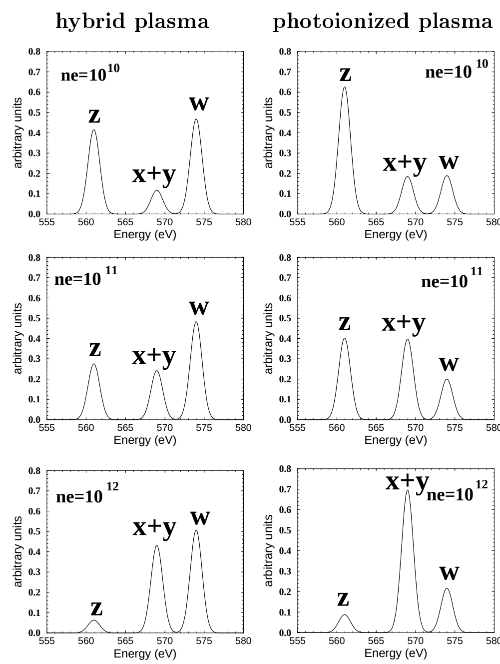

Fig. 1. O VII theoretical spectra constructed using the RGS (*XMM*) resolving power ($E/\Delta E$) for three density values (in cm^{-3}). This corresponds (approximately) to the range where the ratio R is very sensitive to the density: z, forbidden lines; $x+y$, intercombination lines; w, resonance lines.

3. CONCLUSION

For the study of Warm Absorbers, we propose two powerful diagnostics for the electron temperatures and densities. The first of them could be used to determine the ionization process: totally or partially photoionized medium. Calculations of atomic data and line ratios are available in Porquet & Dubau (2000). The determination of the physical parameters of WA in different types of AGN will have a great impact in undertanding unified models.

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