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DIAGNOSTIC OF PHYSICAL CONDITIONS IN AGN BROAD EMISSION LINE REGIONS

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Abstract. Using a well known method for laboratory plasma diagnostic, the Boltzmann-plot, we discuss the physical properties in Broad Line Region (BLR) of Active Galactic Nuclei (AGNs). We apply the Boltzmann-plot method to Balmer lines on a sample of 14 AGN, finding that it may indicate the existence of "Case B" recombination or Partial Local Thermodynamical Equilibrium (PLTE).

1. INTRODUCTION

The emission lines of Active Galactic Nuclei (AGN) are produced over a wide range of distances from the central continuum source, and under a wide range of physical and kinematical conditions (see Osterbrock, 1989; Krolik, 1999 and references therein). The line strengths, their widths and shapes are powerful tools for emitting gas diagnostics in different parts of the emitting region of an AGN. The physics in the Broad Line Region (BLR) is more complicated than in the Narrow Line Region (NLR). The photoionization, recombination and collisions can be considered as relevant processes in BLRs.

Different types of the physical conditions and processes can be assumed in order to use the emission lines for diagnostic of emission plasma (Osterbrock, 1989; Griem, 1997; Ferland et al., 1998). Although "in many aspects the BLRs are physically as closely related to stellar atmospheres as traditional nebula" (Osterbrock, 1989), the plasma in the BLR probably does not come close to being in complete Local Thermodynamical Equilibrium (LTE). However, there may still be the Partial Local Thermodynamical Equilibrium (PLTE) in the sense that populations of sufficiently highly excited levels are related to the next ion's ground state population by Saha-Boltzmann relations, or to the total population in all fine-structure levels of the ground-state configuration (see Griem, 1968, 1997).

The aim of this work is to test the existence of PLTE, and discuss the possibility of estimation of the relevant physical processes and plasma parameters in BLRs using the Boltzmann-plot of Balmer lines.

2. THEORETICAL REMARKS

As a simple case let us consider the optically thin plasma. In the case of plasma of the length ℓ along the line of sight, spectrally integrated emission line intensity (I_{lu}) is given as (see e.g. Griem, 1997; Konjević, 1999)

$$I_{lu} = \frac{hc}{\lambda} g_u A_{ul} \int_0^\ell N_u dx \approx \frac{hc}{\lambda} A_{ul} g_u \ell \frac{N_0}{Z} \exp(-E_u/kT_e), \qquad (1)$$

where λ is transition wavelength, g_u statistical weight of the upper level, A_{ul} transition probability, Z the partition function, N_0 the total number density of radiating species, E_u the energy of the upper level, T_e electron temperature and h, c, k are the well known constants (Planck, speed of light and Boltzmann constant, respectively).

If the plasma is in PLTE, the population of the parent energy states belongs to a Boltzmann distribution uniquely characterized by their excitation temperature (T_e in Eq. (1)), and this temperature may be obtained from a Boltzmann-plot when the transitions within the same spectral series are considered

$$\log(I_n) = \log \frac{I_{ul} \cdot \lambda}{g_u A_{ul}} = B - AE_u, \qquad (2)$$

where I_{lu} is relative intensity of transition from upper to lower level ($u \to l$), B and A are constants, while A indicates temperature and we will call it the temperature parameter.

If we can approximate the $\log(I_n)$ as a linear decreasing function of E_u then: a) it indicates that PLTE may exist at least to some extent in the BLR; b) if PLTE is present, the population belonging to a Boltzmann distribution is uniquely characterized by its excitation temperature. Then we can estimate the electron temperature from Eq. (2), $T_e = 1/(kA)$, where $k = 8.6171 \cdot 10^{-5}$eV/K is the Boltzmann constant; c) if PLTE is present we can roughly estimate the minimal electron density in BLR. Here, we should mention that "Case B" recombination of Balmer lines can bring the $\log(I_n)$ *vs* E_u as linear decreasing function (Osterbrock, 1989). But, regarding the physical conditions (electron densities and temperatures) in BLRs in this case the constant A is too small ($A < 0.2$) and the Boltzmann-plot cannot be applied for diagnostics of electron temperature even if PLTE exists (see discussion in Sec. 4). Moreover, in this case Boltzmann-plot method can be used as an indicator of "Case B" recombination in BLRs of some AGN.

Taking into account that the Balmer lines originate from the same series, we can use the Boltzmann-plot relation for testing the existence of PLTE or "Case B" recombination. Also, here we should mention that we will assume that ℓ, the length of the Balmer line formation region, is the same for all Balmer lines.

3. REDUCTION OF THE DATA

In order to test the existence of PLTE in BLR, we use HST observations obtained with the Space Telescope Imaging Spectrograph (STIS) and Faint Object Spectrograph (FOS), covering the wavelength ranges 2900-5700 Å and 6295-6867 Å (rest wavelength). From the very large data base of AGN spectra at HST archive we selected the objects using following selection criteria: a) the observations covered the

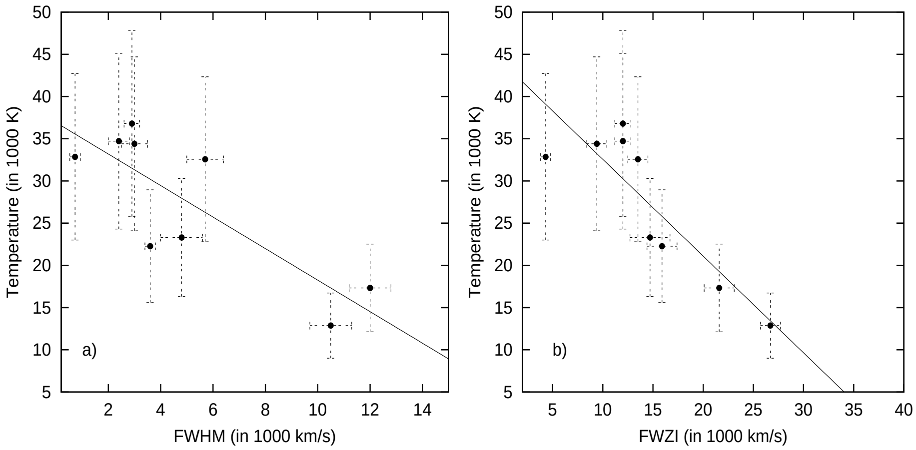

Fig. 1: The measured electron temperature using by Boltzmann-plot (only for the AGN where A> 0.3 indicates the PLTE presence) as a function of velocities measured at: a) Full Width at Half Maximum; b) Full Width at Zero Intensity of an averaged profile from Hα and Hβ ones.

Balmer series line wavelength region; b) the observations were performed on the same day; c) all the lines from Balmer series can be recognized and all have relatively well defined shapes; d) we considered only low red-shifted objects.

The spectra were reduced by the HST team. We transformed the wavelength scale to zero red-shift taking into account the cosmological red-shift of the objects (Véron-Cetty and Véron, 2000). Thereafter that we estimated and subtracted the continuum. Estimated error of 5% - 10% due to subtraction of the continuum is included in the cumulative error. The fluxes of the lines were measured by using the DIPSO software.

To perform a test we subtracted the narrow and satellite lines from Balmer lines. To estimate the contribution of these lines we used a multi-Gaussian analysis (see Popović 2003).

On the other hand, the reddening effect can influence the Balmer lines ratio (see e.g. Crenshaw and Kraemer, 2001; Crenshaw et al., 2002 and references therein) and consequently temperature parameter obtained by Boltzmann-plot. Here the Galactic reddening was taken into account using the data from NASA's Extragalacitc Database (NED). In order to test the total (Galactic + intrinsic) reddening influence we have considered the case of Akn 564, where the reddening data are given by Crenshaw et al. (2002). We estimated that the reddening effect can contribute to the Boltzmann-plot slope around 30%-40% .

4. RESULTS

Using the fact that the Balmer lines belong to the same spectral series, we apply the Boltzmann-plot method to test the presence of PLTE in BLR and discuss the relevant physical processes in a sample of 14 AGN. The more detailed discussion will be given in Popović (2003), here we give the main conclusions from this test:

1) From the 14 selected AGN, we found that in 9 AGN Boltzmann-plot indicated

the existence of PLTE in BLR, while in the case of 4 of them the Boltzmann-plot indicated "Case B" recombination in BLR. In remaining 1 AGN the Boltzmann-plot cannot be applied.

2) The estimated BLR electron temperatures using Boltzmann-plot where PLTE exists are within a range (1.3 - 3.7)$\cdot 10^4$ K (within 30% accuracy). They are in good agreement with the previous estimations.

The electron densities in BLR have been considered for optically thin and optically thick plasma and we found that:

i) For optically thin plasma, the electron density in the case of PLTE, at least in some parts of BLR, should be higher than conventionally accepted for BLR.

ii) For optically thick plasma, the electron density in the case of PLTE is in agreement with the one conventionally accepted for BLR.

On the other hand, the electron temperatures estimated by using Boltzmann-plot tend to be velocity dependent as a linear decreasing function of random velocities measured at FWHM as well as at FWZI (see Fig. 1).

Although, an alternative of PLTE in some AGN may be very high intrinsic reddening effect, the Boltzmann-plot method may be used for fast insight into physical processes in BLR of an AGN prior to applying more sophisticated physical models.

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