PHYSICAL PARAMETERS OF HII/PDR COMPLEX IN ORION BAR ESTIMATED BY OBSERVATIONS OF 8 MM RECOMBINATION LINES. EFFECTIVE TEMPERATURE OF θ^1 C Ori STAR

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ABSTRACT. Physical parameters of HII/PDR complex in Ori Bar were estimated using observations of recombination radio lines (RRL) of carbon (C), hydrogen (H) and helium (He) with RT-22 radio telescope in Pushchino. Possible structure of the complex is discussed. Effective temperature (T_{eff}) of the star ionizing Orion nebula was estimated. Obtained estimate provides additional constraint to existing “spectral class – T_{eff}“ calibrations for O-stars indicating that the θ^1 C Ori star with ≈ O6.5 V spectral class has T_{eff} in the range 36 000–37 500 K.

Key words: Stars: OB stars, parameters – Interstellar medium: HII regions, PDR – Spectroscopy: RRL

1. Introduction

Hot OB stars emit amount of UV photons which is sufficient to form ionized hydrogen region (HII region). In a thin intermediate layer between the HII region and the cold natal molecular cloud (MC), called Photo Dissociation Region (PDR), molecules are destroyed and atoms with ionization potential lower than that of hydrogen, mostly carbon, are ionized. Hydrogen (H) and helium (He) recombination radio lines (RRLs) are formed in the HII regions in a wide wavelength range. The RRLs of carbon (C) are formed in PDR. Theory of RRL formation in HII regions is well known (Sorochenko, Gordon 2003). Determination of the PDR parameters using carbon RRL data complemented by the data on the infrared CII and OI lines was recently elaborated (Sorochenko & Tsivilev, 2000; 2010).

Modern radio instruments allow observation RRLs of H, He and C in a single band and, thus, information on both HII region and PDR can be obtained simultaneously. Orion Bar is a HII/PDR complex in the Ori A nebula, one of the most studied astronomical objects. The Ori Bar is located at about 2' to the south-east of the Ori A center.

2. Observations and results

In order to study this HII/PDR complex we performed observations of H, He and C RRLs in the 8 mm range. The observations were carried out with RT-22 telescope in Pushchino toward 4 positions of Ori Bar and in the direction to the center of Ori A (see Figure 1). Physical parameters of the Ori Bar HII/PDR complex estimated from these observations are given in Table 1.

Ori A HII region has a core-halo structure of “blister” type and is formed at the MC boundary closer to observer (Poppi et al. 2007; Tsivilev et al. 1986). Based on the data obtained in this work and the data from literature one can come to the following conclusions. The thin layer of PDR envelopes the core of HII region (Ori Bar outlines the core boundary and its ionization front) and extends further outside the Ori Bar as a boundary between HII region halo and the MC. Our estimates of the hydrogen number density in the Ori Bar PDR are in the range ~$(1–3)\times10^5$ cm^{-3}. Estimates of PDR extent along the line of sight (L) are in the range 0.006–0.04 pc. The maximum value of L is realized in direction toward Ori Bar. Our value is smaller than in the literature, which can be explained by the presence of clumps in PDR. The PDR temperature decreases from 210–230 K to 140–150 K with the distance from the ionizing star θ^1 C Ori which apparently heats PDR material. It is possible that HII region exerts pressure on the ambient

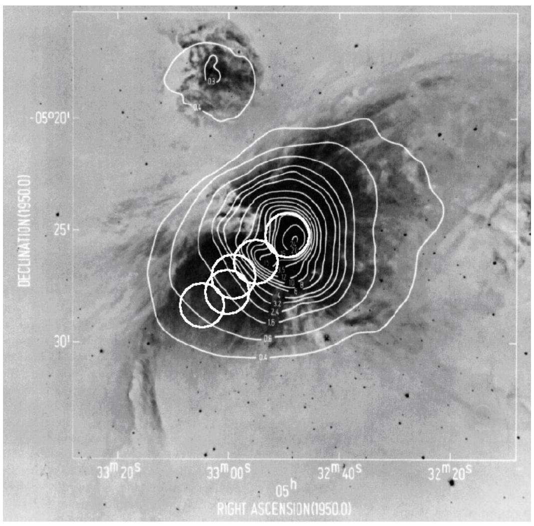

Figure 1: Optical image of Ori A region (in Hα and NII, Hua & Louise 1982). Contours (faint white lines) designate 23 GHz continuum (Wilson & Pauls 1984). White bright circles correspond to positions in which H, He and C RRLs were observed in this study. The size of white bright circles corresponds to the RT-22 telescope beam size

Table 1: Parameters of PDR and HII region in Orion A estimated in this study

Position of observations α_{1950} δ_{1950}	PDR T_k K	n_H, $\times 10^5$ cm^{-3}	L, pc	ME cm^{-6} pc	HII region T_e, K	$n(He^+)$ / $n(H^+)$, %
Orion Bar $5^h32^m55^s$ $-5^o26'30''$	234 - 200	1.17 - 1.56	0.041- 0.036	37.1 - 60.0	8380 (200)	8.2 (±.55)
Ori Bar-2 $5^h32^m59^s$ $-5^o 27'09''$	196	3.03	.010	62.0	7330 (270)	7.3 (±.7)
Ori Bar-3 $5^h33^m00^s$ $-5^o 27'50''$	145	3.14	.0058	38.7	7000 (250)	5.7 (±.66)
Ori Bar-4 $5^h33^m4.7^s$ $-5^o 28'27''$	152	1.24	.010	10.4	6600 (170)	4.8 (±.8)
Ori A $5^h32^m49^s$ $-5^o25'16''$	219	1.71	0.027	53.4	8170 (200)	8.3 (±.36)

MC. Data indicates presence of a gas density jump in the Ori Bar. This jump can result from interaction of HII region with MC and can initiate formation of new stars. Emission measure (EM) estimated from carbon RRLs is ~100±50 pc×cm^{-6} which puts restrictions on parameters of PDR represented by a two-component model (see details in the paper Tsivilev, 2014). Our estimates also show that θ^1 C Ori star alone has sufficient ionizing flux to provide ionization of the carbon in PDR.

Lines of the ionized gas formed in HII region are blue-shifted by 10–17 km/s with respect to the lines formed in PDR. This indicates that the hot ionized material is in motion relative to MC. This is expected in a blister-type model of Orion HII region. Electron temperature in the HII region decreases towards the periphery from 8 200–8 400 K to 6 600–7 000 K which was also confirmed by recent studies in the optics (Mesa-Delgado et al. 2008). Relative abundance of ionized helium to hydrogen decreases with the distance from the θ^1 C Ori star indicating that the size of ionized helium region is smaller than the ionized hydrogen one. This restricts the range of effective temperatures (T_{eff}) of the θ^1 C Ori star (Polyakov & Tsivilev 2007). Our model calculations show that T_{eff} of ionizing source is in the range 35 000–36 500 K. If we assume that the HII region is produced by a group of stars (Copetti & Bica 1983) then the actual T_{eff} of θ^1 C Ori should be higher by ~1000 K (Copetti & Bica 1983) and constrained by the range 36 000–37 500 K. Recent optical studies have shown that the spectral class of θ^1 C Ori is ≈ O7 V (Stahl et al. 2008). However, we think that the data of Stahl et al. (2008) clearly indicates that its spectral class is rather ≈ O6.5 V (see Figure 6 from Stahl et al. 2008). It is known that one of the important problems is calibration of OB stars, i.e. correspondence between the spectral class of a star and its T_{eff}. For example, for a star of O6.0 V spectral class Vacca et al. (1996) assign $T_{eff} \approx$ 43 600 K while Pottasch et al. (1979) assign much smaller value $T_{eff} \approx$ 36 500 K. The important result of this study is that our experimental data complemented by the HII/PDR complex modelling provides constraint for the calibration by assigning T_{eff} range 36 000–37 500 K to the star of ≈ O6.5 V spectral class.

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