RevMexAA (Serie de Conferencias), **33**, 137–139 (2008)

MASSIVE STARS AND THEIR SURROUNDING NEBULAE: A COMBINED APPROACH

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RESUMEN

Presentamos los primeros resultados de un proyecto dedicado al estudio combinado de estrellas masivas y sus regiones H II asociadas en la Galaxia. Mediante el estudio de regiones ionizadas por una única estrella pretendemos comprobar la validez de las predicciones de la nueva generación de modelos de atmósfera de estrellas masivas en términos de distribución de flujo ionizante. En nuestros análisis consideramos el efecto de las posibles distribuciones de densidad del material ionizado. Para ello hacemos uso de varios tipos de observaciones, tanto estelares como de la región H II.

ABSTRACT

We present the first results of a project aimed at the combined study of massive stars and their surrounding nebulae by means of a detailed study of Galactic H II regions ionized by only one massive star. With this, we intend to check the validity of the new generation of massive star model atmosphere codes in terms of ionizing flux distribution. We take into account the effect of the nebular density distribution in our analyses. Various types of stellar and nebular observations have been collected for this purpose.

Key Words: H II regions — ISM: ionization models — ISM: individual (M 43) — stars: early-type — stars: individual (HD 37061)

1. INTRODUCTION

The intense far ultraviolet radiation emitted by early OB-type stars ionizes the interstellar medium, generating the so-called H II regions. These ionized regions can be used to derive properties of the associated stellar population (e.g. star forming rates, age). However, since the properties of H II regions crucially depend on the spectral energy distribution (SED) of the massive star population, and this part of the stellar flux is generally unaccesible to direct observations, the predictions resulting from massive star atmosphere codes are a crucial ingredient.

The new generation of NLTE, line blanketed model atmosphere codes (Hubeny & Lanz, 1995; Hillier & Miller 1998; Pauldrach et al. 2001; Puls et al. 2005), which include a more realistic description of the physical processes characterizing the stellar atmosphere, produces quite different ionizing SEDs than the previous plane-parallel, NLTE/LTE, hydrostatic models (Mihalas & Auer 1970; Kurucz 1992; Kunze 1994). Some notes on this, and on the consequences on the ionization structure of H II regions, can be found in Gabler et al. (1989), Rubin et al. (1995), Najarro et al. (1996), Sellmaier et al. (1996) and Stasińska & Schaerer (1997). Although new predictions seem to go in the right direction (viz. Giveon et al. 2002; Morisset et al. 2004), non-negligible differences can be found between the different stellar atmosphere codes (viz. Martins et al. 2005; Puls et al. 2005).

We are performing a study of Galactic H II regions ionized by only one massive star to check the validity of the ionizing SEDs predicted by the new generation of massive star model atmosphere codes. In forthcoming papers we will present the complete combined study of the various nebulae and their ionizing stars; here we show some preliminary results from our study of M 43.

2. OBSERVATIONAL DATASET

Stellar and nebular observations were carried out with the Wide Field Camera (WFC; narrow-band imaging in Hα, Hβ, [O III] and [S II]) and the Intermediate Resolution Spectrograph (IDS; spectroscopy of the ionizing star in the range 4000–5000 Å + the Hα region, and long slit nebular spectroscopy in the range 3600–9700 Å); both instruments attached to the Isaac Newton Telescope (INT). The long slit nebular observations were divided into smaller apertures along the nebular radii.

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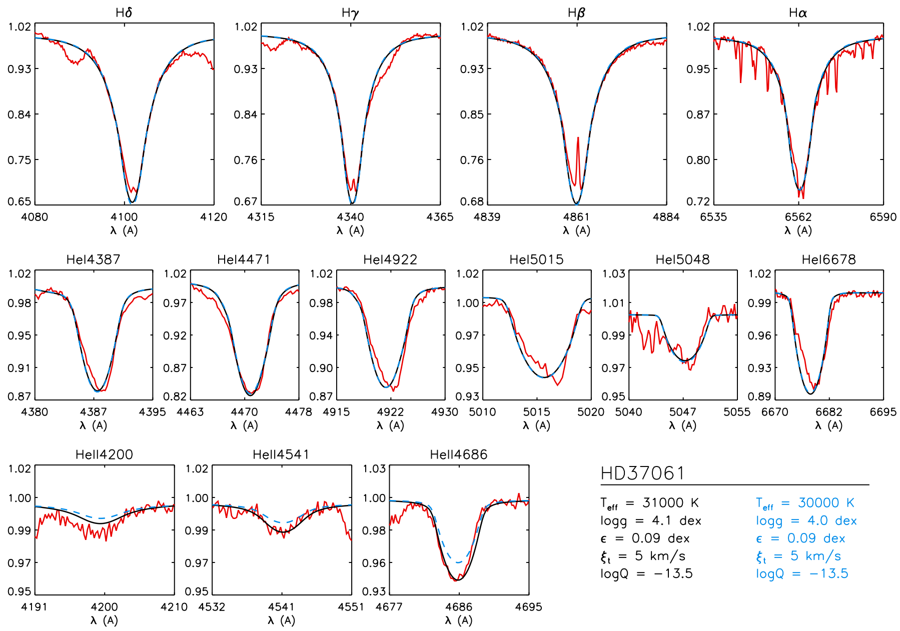

Fig. 1. Fitting of FASTWIND synthetic profiles (broadened to $v \sin i = 210$ km s^{-1}) to the optical H and He lines of HD 37061. Two sets of stellar parameters are shown to illustrate the accuracy of the stellar parameters determination.

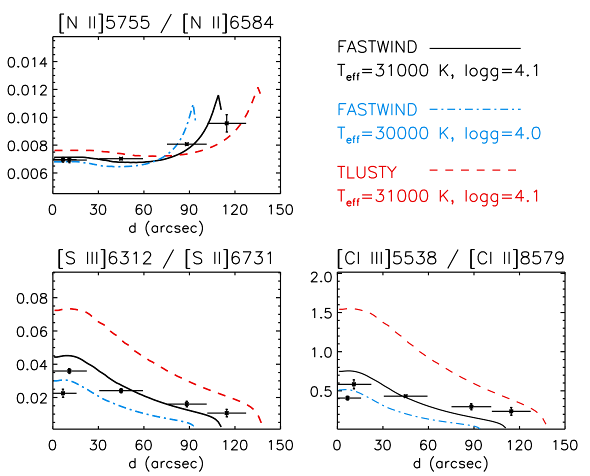

Fig. 2. Spatial variation of various nebular line ratios resulting from three CLOUDY constant density spherical models. Each model uses a different predicted SED. FASTWIND models are the ones used in Figure 1 (same color code); a TLUSTY model with the same stellar parameters as the FASTWIND model which best fits the optical H and He lines (Figure 1) has also been considered for comparison. Nebular observations from long slit spectra are also included.

3. STELLAR AND NEBULAR ANALYSES

M 43 is an apparently spherical H II region, ionized by HD 37061 (classified as B1 V, though our spectrum clearly shows the He II 4541 line, indicating that the star is rather B0 V–B0.5 V). The stellar parameters of HD 37061 were obtained by visual fitting of FASTWIND (Puls et al. 2005) synthetic profiles to the optical H and He lines (see Figure 1). Once the SED resulting from the FASTWIND model was rescaled to fit $M_{\rm v} = 3.5$ (from the stellar photometry and considering a distance of 450 pc), a value of $\log Q({\rm H}^0) = 47.2$ could be derived. This later value is in good agreement with the nebular Hα luminosity calculated from the WFC Hα image, indicating that the nebula is ionization bounded. From the nebular [S II] 6731/6716 line ratio we inferred $N_{\rm e} = 550$ cm^{-3}. In a first approach, we have used the nebular abundances derived by Rodríguez (1999).

4. PHOTOIONIZATION MODELS

Figure 2 illustrates three of the diagrams we used to compare the predictions of photoionization models (CLOUDY, Ferland et al. 1998) with the observed nebular constraints. The first one is an indicator of the nebular temperature, while the other two illustrate the nebular ionization structure. These plots compare three constant density spherical CLOUDY models: two of them take the SEDs from FASTWIND models with different stellar parameters, while the third one was calculated using the SED from a TLUSTY (Hubeny & Lanz 1995) model with the same parameters as the FASTWIND model which best fits the optical H and He lines. The differences between the photoionization models are important. Note, however, that geometries other than spherical and non-constant density distributions can affect the result (Morisset et al. 2005). This will be also taken into account when inferring which model better fit the nebular constraints. In forthcoming papers we will present the complete analysis in detail.

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DISCUSSION

N. Walborn - I believe that the central star of M 43 is B1 V, as I recall, but there is no He II 4541 at that spectral type and it cannot have a $T_{\rm eff}$ of 31,000 K. So something is wrong with the spectral type or the data. Moreover, B1 nebulae are 50% emission and 50% reflection, so that must be taken into account if it is B1.

S. Simón-Díaz - I'm quite sure about the data and, as you have seen, the He II 4541 line is clearly present in the spectrum, so my suggestion is that a review of the spectral type is needed. Note that our study is independent of the spectral type classification of the star as we obtain the stellar parameters by direct fitting of the FASTWIND lines to the observed lines. I totally agree with your second comment, and this is taken into account when measuring the nebular emission lines.

N. Przybilla - The differences in the ionizing fluxes for the different codes may be well related to the atomic input data. It has to be stressed that despite the basic physics of stellar atmospheres is well understood, there can be large discrepancies (by many orders of magnitude) in cross-sections, depending on the assumptions made. The improvements made by the Opacity and IRON projects are a big step forward into the right direction, but there are many critical data still missing. We have to improve on this, otherwise we may not be able to resolve the discrepancies found from different model analyses.

A. Herrero - A remark to Norbert's comment. The importance of atomic data can never be strongly enough emphasized, but although the basic physics of the models is the same, its implementation into codes is different, and they use different approximations. So, the differences between code results may have different origins, not only differences in the atomic data.

S. Simón-Díaz - And it is always useful to compare the predictions of the various stellar atmosphere codes with the observations to test their reliability. Many efforts have been devoted to check line predictions in the optical, ultraviolet and infrared spectral ranges. Our approach is oriented to study which nebular constraints are the optimal to test the predicted emergent stellar Lyman continuum.