TAILORED MODELS OF THE H II REGION S311

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We present a grid of photoionization models for the Galactic H II region S 311 (NGC 2467), located beyond the Solar circle. We compare the modelling results with observational data from single slit spectrophotometry of the brightest zone of the nebula taken with the Very Large Telescope (VLT). We have adopted two different group of models: one characterized by a spatial density distribution determined from Hα images of the object and a second one characterized by a constant density derived from the observed forbidden line intensity ratios. We have fitted several temperature, density, radiation strength and abundance indicators to the observations by introducing appropriate stellar parameters and the ionising flux distribution. These stellar properties have been derived from stellar atmosphere models applied to the central ionising star of the nebula.

THE CLIENT

The study of Galactic H II regions together with their ionising sources is essential to understanding the physics of these objects. Moreover these studies are very useful to validate stellar atmosphere models and photoionization codes. One of the problems in the modelling of Galactic H II regions -that we also address- is that the results of the code must be corrected by the slit size and position.

S311 (also known as NGC 2467) is an H II region located outside the Solar circle at a Galactocentric distance of 10.43 kpc (assuming the Sun at 8 kpc). From the morphology of its Hα image (figure 1) it seems reasonable to assume that a spherical geometry is a good approximation for this nebula.

Figure 1. Image of S311 obtained with the 2.5m Nordic Optical Telescope in the Roque de los Muchachos Observatory, La Palma, Spain. The image is a RGB composition of images in broad-band filters U (blue) and V (green) and narrow-band filter Hα (red)

THE TAILORS TAKE THE MEASUREMENTS

The Star

We have obtained the stellar parameters and then the ionising flux distribution of HD64315 (O6e) -the main ionising source of S311- through the modelling of its optical spectra. H I, He I and He II lines have been fitted by using FASTWIND, an spherically symmetric, NLTE model atmosphere code that takes into account line blanketing and mass loss effects (Santolaya Rey et al. 1997). We have found that the best fit corresponds to T_{eff}= 38000±1000 K, log(g)=4.0±0.1 dex and $R/R_{\odot}$=12. The ionising flux distribution has been obtained with WMBASIC (Pauldrach et al. 2001). The total number of Lyman continuum photons is $Q(H^0)=10^{49.06}$ ph s^{-1}. For details of the methodology followed on the stellar modelling see poster 3.80 (Simón-Díaz et al.)

The Nebula

The nebular models were made running CLOUDY (v.95.06 beta5) photoionization code (Ferland et al. 1998). We have assumed two different hypothesis about density:

CASE A) The nebula is characterized by a hydrogen density distribution described by:

$$N_e = N_0 \times e^{-\left(\frac{r}{4.71}\right)^2} \qquad (1)$$

where r is the distance to the star in parsecs and N_0 is the central density.

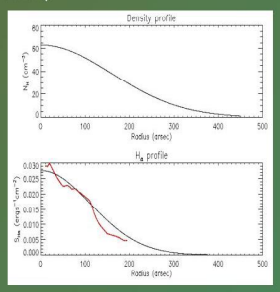

Figure 2. Density law was derived reproducing the observed continuum-subtracted Hα surface brightness distribution, S(Hα), which is proportional to N_e^2 and was obtained from the flux calibrated and narrow band Hα CCD image. The surface radial brightness profile was well reproduced by a spherical model with density derived from equation (1). Red line is the observed surface radial brigthness profile.

CASE B) The nebula has a constant density, which has been derived from the combination of densities derived from several observed line ratios which are shown in Table 2.

WHY DO WE WANT A TAILORED SUIT?

The aim of this work is to reproduce all the observational constraints within a certain degree of tolerance, but in particular we are interested in determining the C^+ contribution to the total abundance of carbon. We have derived an ionization correction factor (ICF) from the calibration of Garnett et al. (1999) to take into account the C^+ contribution to the total carbon abundance. Our main aim is to reproduce the ICF of carbon from coherent models with well-known inputs (nebular abundances, ionising flux distribution and luminosity of the ionising star) that fit most of the observational constraints.

THIS WORK CANNOT BE POSSIBLE WITHOUT THE HELP OF...

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The spectrophotometric data were taken on 2003 March 30, with the Ultraviolet Visual Echelle Spectrograph (UVES) at the VLT Kueyen telescope, in Cerro Paranal Observatory (Chile). The narrow band Hα CCD image was taken on 2004 March 19 at the 2.56m Nordic Optical Telescope (NOT) at Roque de los Muchachos Observatory (La Palma, Canary Islands, Spain) using the ALFOSC (Andalucía Faint Object Spectrograph and Camera)

We have done a detailed analysis of the chemical abundances of S311 from the spectral data. A brief summary of the quantities we have derived for the physical conditions and abundance ratios is showed in the following tables:

Table 1. Abundances ratios obtained from nebular analysis of S311. Ionization correction factors (ICFs) were used to correct for the unseen ionic species. The ICF scheme is the same than in García-Rojas et al. (2004) except for carbon which is from Garnett et al. (1999)

Element	12+log(X/H)
He	10.99
C	8.39
N	7.38
O	8.40
Ne	7.39
S	6.77
Cl	4.94
Ar	6.66

Temperature	
[N II](λ6548+6583)/(λ5755)	9500±250 K
[O III](λ4959+5007)/(λ4363)	9000±200 K
[Ar III](λ7136+7751)/(λ5192)	8800^{+700}_{-850} K
[S III](λ9069+9532)/(λ6312)	9300±350 K
Density	
[O II](λ3726)/(λ3729)	260±110 cm^{-3}
[S II](λ6716)/(λ6731)	360^{+140}_{-120} cm^{-3}
[Cl III](λ5518)/(λ5538)	550^{+650}_{-550} cm^{-3}

Table 2. Temperature and density diagnostics of S311 used to constrain photoionization models.

Table 3. Optical nebular radius derived by Dutra et al. (2003) and Hα luminosity derived from our continuum-subtracted Hα flux calibrated image have been used as constraints of the nebular size and brightness respectively.

Other observables	
L(Hα)[a]	6.1×10^{36} erg s^{-1}
Radius[b]	2.693×10^{19} cm

[a] From Hα flux calibrated image
[b] From Dutra et al. (2003)

IS S311 A GOOD-LOOKING NEBULA WITH ITS NEW SUIT?

- ✓ The best constant density model (φ=0.002) reproduces physical conditions very well, but fails when it tries to fit the observed ionization parameter and, consequently, the ionic abundances.
- ✓ Exponential density law model with φ=0.002 fits the observed ionization parameter and the abundances reasonably well.
- ✓ The models provides a C/H ratio which is a 15% smaller than the one derived using the calibration from photoionization models of Garnett et al. (1999).
- ✓ The nebula is matter bounded. From the Hα luminosity computed from the models and the number of ionising photons, $Q(H^0)$ we have that a fraction of 50-60% of the photons escape from the nebula.
- ✓ Further studies are going on in order to improve the accuracy of the models.

A MADE-TO-MEASURE SUIT

We have computed a grid of models for each assumption of density distribution (exponential law or constant). From the comparison of our data with the estimation of the total number of Lyman continuum photons, N_L, by Albert et al. (1986) or that obtained from our stellar analysis, φ=0.004 or φ=0.005. Assuming the exponential density law, the nebula becomes more clumpy that with constant density, and we have obtained a filling factor of φ=0.002. So, we have assumed five different values of the filling factor in our models, from φ=0.001 to 0.01, that cover a range which is coherent with the observed values.

Following Stasinska et al. (2004) we present our results in figures 3 to 5 as plots of the values of σ_P=(log P_{mod}-log P_{obs})/t versus each observational constraint P. The parameter t is the accepted tolerance in dex for each constraint and has been assumed 0.1 dex for all except for radius for which is 0.03 dex (that depends on the assumed uncertainty for the distance to the nebula). We have chosen 23 observational constraints that could give us value information about the ionization structure of the nebula, temperature, density, radiation hardness, abundances indicators and, finally, radius and luminosity in Hα.

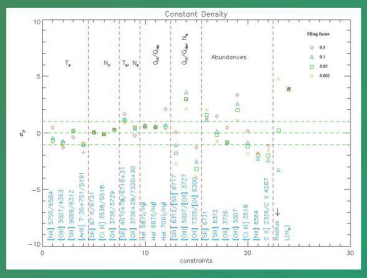

Figure 3. Constant density models (N_e=310 cm^{-3}) are constructed assuming different filling factors to constrain the nebular size. The models in this figure are ionization bounded. For φ=1 the nebula is too small and the slit is located outwardly. Decreasing filling factors expands the nebula but Hα luminosity increases too, so we have to constrain the size of the nebula to the observed optical radius and trying to fit Hα luminosity by decreasing the filling factor; then the nebula will become matter bounded. Density law models have a very similar behaviour.

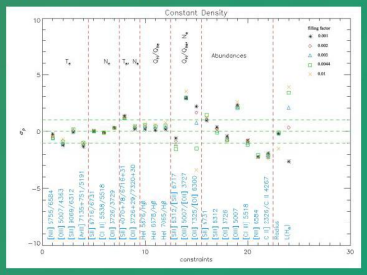

Figure 4. In the case of constant density matter bounded models, the model with φ=0.002 provides the best fit to the observed luminosity in Hα. Other constraints are not affected by the filling factor. As it can be seen, the ionization parameter, which is proportional to [O III]/[O II] ratio, is too high, and the C II]/C II ratio is too low. Constraints involving temperature and density fit the observations reasonably well (temperature) or very well (density)

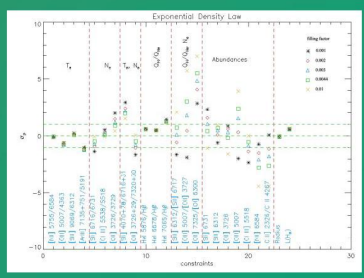

Figure 5. In the case of a exponential density law, a model with φ=0.002 resolves the problem of the ionization parameter. Moreover, abundance indicators improve significantly and the C II]/C II ratio provides a C/H ratio which only differs from the one derived using the ICF of Garnett et al. (1999) in a 15%. The density dependent [S II] and [O II] line ratios are not well fitted by these models, probably because they give local density values.