3D Photoionization Modelling of the Bipolar Planetary Nebula NGC 2346

Carolina M. Carneiro & Denise R. Gonçalves
Observatório do Valongo -UFRJ, Brazil

Scientific Goal

The study of planetary nebulae (PNe) is extremely important in order to understand the evolution of low- and intermediate-mass stars. Photoionization codes intent to reproduce the interactions of the central stars' radiation with the nebular gas. By using this tool, we are able to determine the physical properties of both: nebula and central star. About 70% of the PNe are ellipticals and bipolars and 20% have round morphologies. The reason why the PNe present so different morphological types is not well understood yet. A well accepted suggestion is that the binary central stars could be partially responsible for the bipolar shapes. Considering that there is only one 3D modelling of a bipolar PN (NGC 6302; Wright et al. 2011) and also because NGC 2346 has a binary system as central star, this PN seems to be a excellent candidate for the 3D detailed modelling.

NGC 2346 and MOCASSIN Code

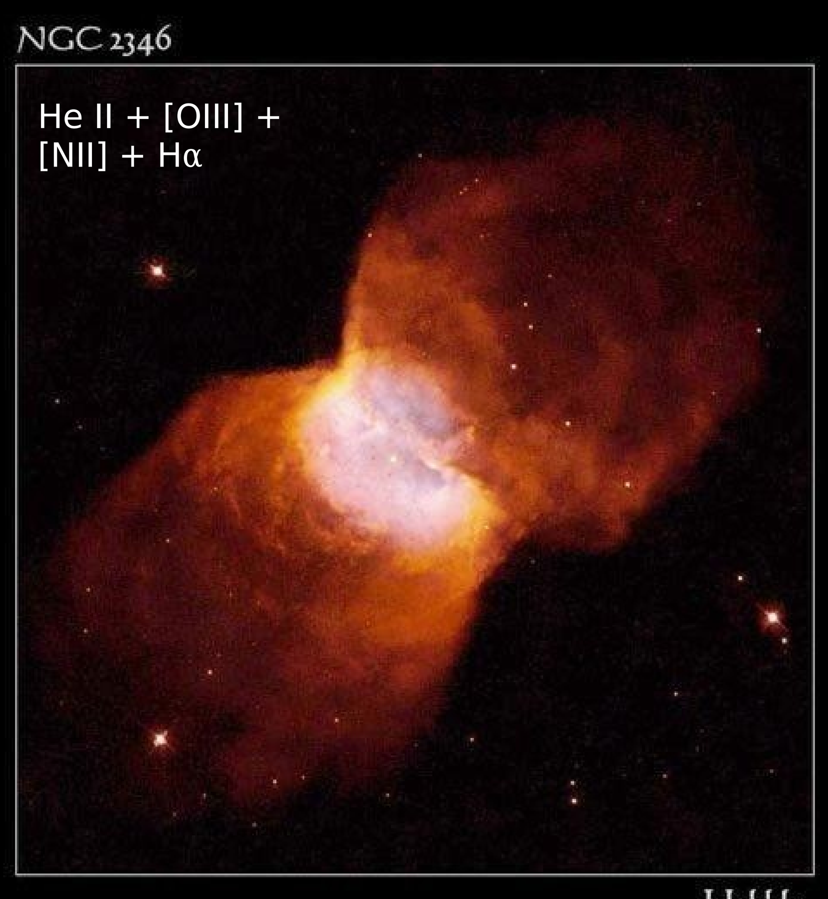


Image from Hubble Space Telescope
Source: PNIC – Planetary Nebulae Image Catalog

NGC 2346

This is a Type-I (Kingsburgh & Barlow 1994) bipolar PN of high excitation (Walsh 1983). Its dynamic age ranges between 3,500 and 4,700 years. It's central star is a single-lined spectroscopic binary (V651 Mon), with an orbital period of nearly 16 days.

Parameters from literature:

(i) Angular size: 3.1 x 0.75 arcmin^2;
(ii) Distance (d): 500 - 1,735 pc ;
(iii) Luminosity: 14 - 6,839 $L_\odot$;
(iv) T_{eff}: 60 - 150 kK.

MOCASSIN - Monte CArlo SimulationS of Ionized Nebulae - is a 3D photoionization code developed to provide realistic models of nebulae with arbitrary geometries and density distributions (Ercolano et al. 2003).

Main input parameters: shape and intensity of the ionizing continuum, effective temperature, nebular composition and density distribution of the gas.

Main output parameters: nebular electron temperature and density, ionization stage of the elements, ionic and total abundances, central star's effective temperature and luminosity, and distance of both nebula and central star.

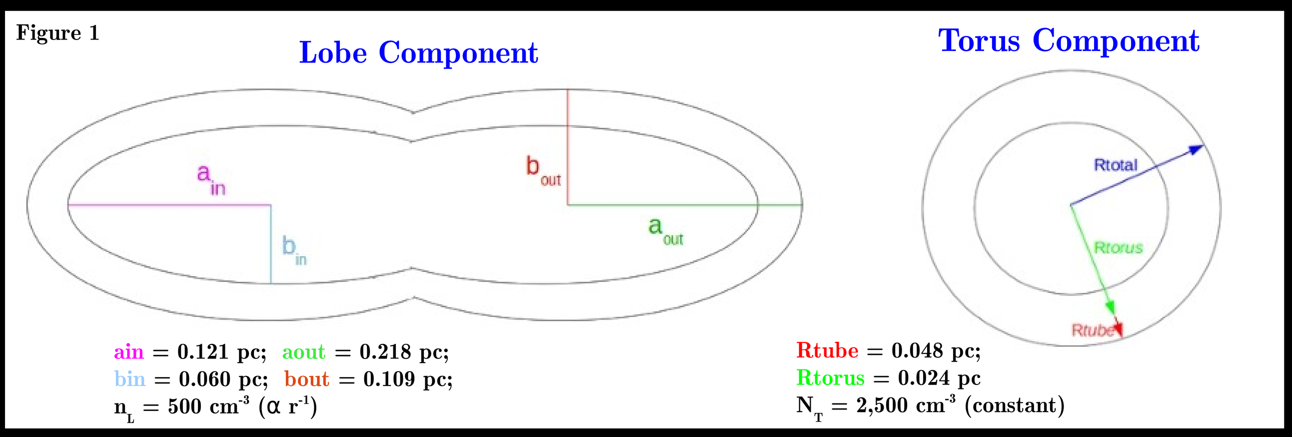
Results and Future Prospects

Here we present the results of the gas-only best model, considering the ionizing source as a blackbody, as well using an atmospheric model.

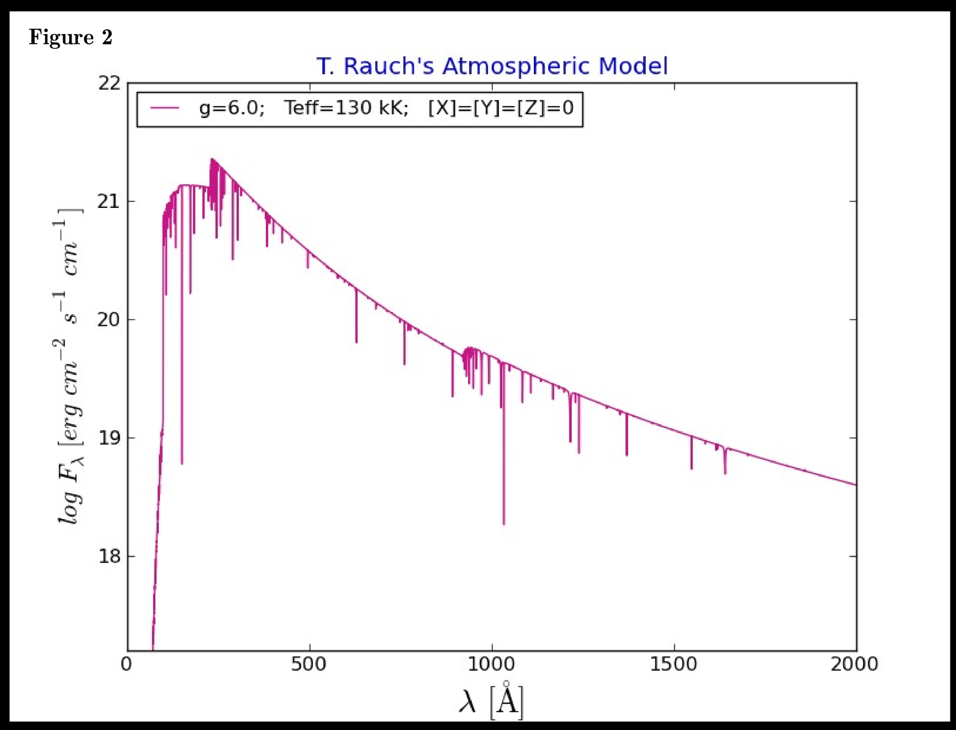
Input Parameters

(i) Distance = 1 kpc;
(ii) Luminosity = 300 $L_\odot$;
(iii) T_{eff} = 130 kK.
(iv) He/H=0.09, C/H=5.30x10^{-4}, N/H=1.20x10^{-4}, O/H=3.00x10^{-4}, Ne/H=3.50x10^{-5}, S/H=3.70x10^{-6}, and Ar/H=2.74x10^{-7} .

The density distribution we used is shown in Figure 1, and the stellar spectral energy distribution in Figure 2.



http://www.sc.eso.org/~rwesson/codes/mocassin/mocassin_gridmaker.php



Ion	I_{bb}/I_{obs}	I_{ATM}/I_{obs}	σ_{obs}	Refs.
HeI λ4471	0.70	0.68	factor 2	K76
HeI λ5876	0.77	0.75	40%	S76
HeII λ4686	1.12	1.20	40%	K76
[NII] λ5755	0.74	0.83	40%	S76
[NII] λ6548	0.97	1.06	40%	S76
[NII] λ6584	0.98	1.07	20%	S76
[OII] λ3726	2.43	2.67	20-30%	K76
[OII] λ3729	1.22	1.37	20-30%	K76
[OIII] λ4363	1.23	1.42	factor 2	K76
[OIII] λ4959	1.06	1.13	20%	K76
[NeIII] λ3868	0.99	1.08	factor 2	K76
[SII] λ6717	0.91	0.99	40%	S76
[SII] λ6731	1.15	1.25	40%	S76

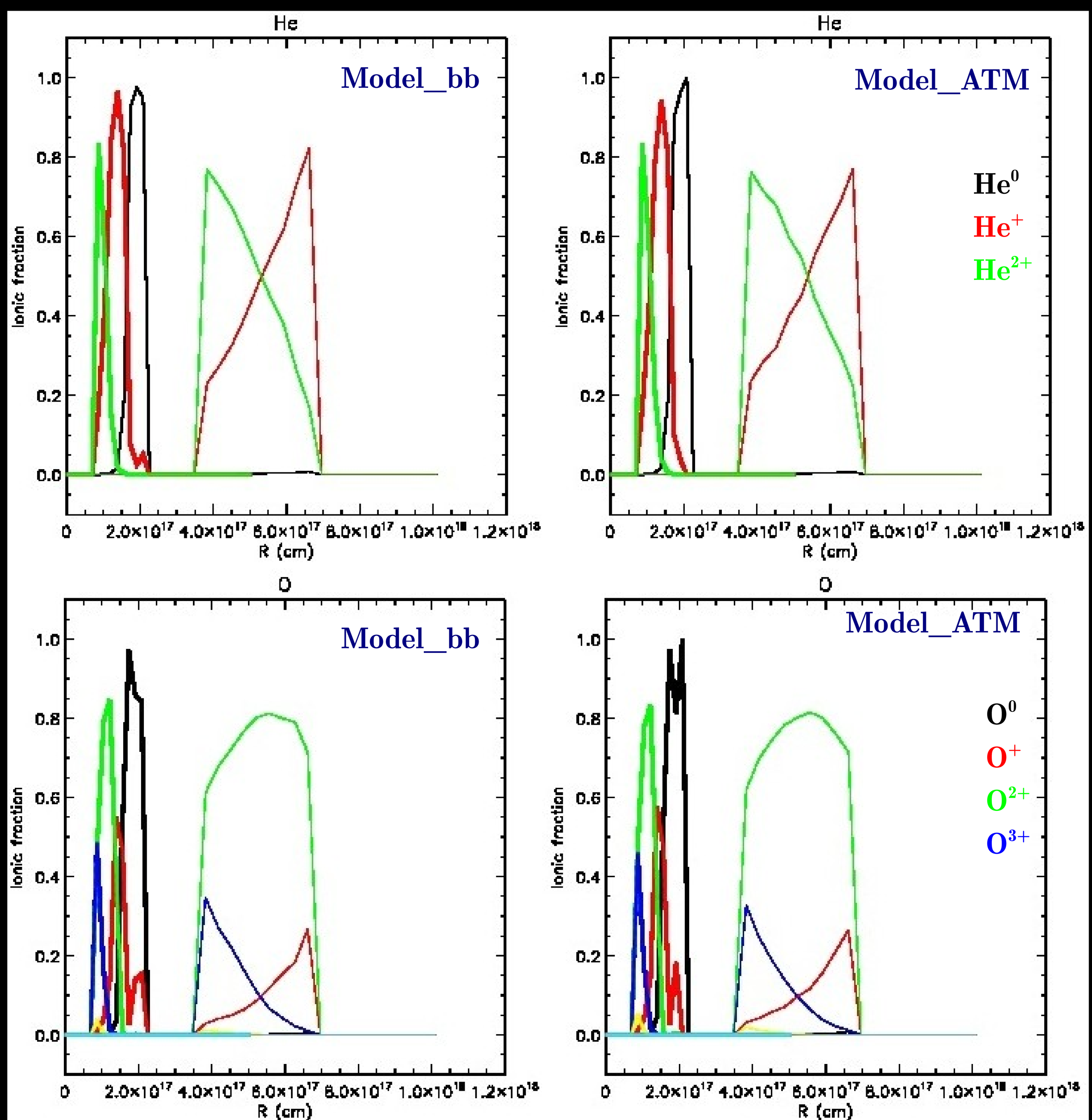
I_{obs}: observed line intensities
I_{bb}: modeled line intensities (blackbody)
I_{ATM}: modeled line intensities (atmospheric model)
σ_{obs}: observed line intensity's errors
$F(H\beta)_{obs}$ = (4.70 ± 1.05) x 10^{-12} erg cm^{-2} s^{-1}
$F(H\beta)_{mod\_bb}$ = 5.39 x 10^{-11} erg cm^{-2} s^{-1}
$F(H\beta)_{mod\_ATM}$ = 5.16 x 10^{-11} erg cm^{-2} s^{-1}

Diagnostic Line Ratios	Observations	Model_bb	Model_ATM
n_e(cm^{-3}):			
[SII] λ6717/λ6731	1.02 (600)	0.81 (1,300)	0.81 (1,300)
[OII] λ3726/λ3729	0.88 (200)	1.73 (1,600)	1.71 (1,500)
T_e(K):			
[NII] (λ6584+λ6548)/λ5755	47.8 (14,100)	63.4 (11,900)	61.3 (12,100)
[OIII] (λ4959+λ5007)/λ4363	121.0 (12,000)	103.1 (12,800)	95.2 (13,200)

Conclusions

From the above results we see that there is no significant differences of using a blackbody or an atmospheric model as ionizing source. Although the agreement between the observed and modeled line intensities is quite reasonable, the Hβ flux is, in both cases, overestimated. We are running new models to solve this discrepancy. So far, our results suggest that NGC 2346: i) presents a density stratification; ii) has a hot central star (130 kK); and iii) has typical PNe electron density and temperature (n_e ~ 1,400 cm^{-3}; T_e ~ 12,500 K).

Ionization structures of He and O



Prospects

We are having problems to reach a satisfactory model including dust. Dealing with the dust module of MOCASSIN appear to be a more difficult task than only model the gas portion of the nebula. However this is mandatory for NGC 2346, which dust component is known from the literature (Su et al. 2004). We hope to solve this issue soon, and test the effects of dust in our models.

References:

Ercolano, B. et al. 2003, MNRAS, 340, 1136
Kaler, J. B. et al. 1976, ApJ, 203, 636 (K76)
Kingsburgh, R. L. et al. 1994, MNRAS, 271,257
Sabbadin, F. 1976, A&A, 52, 291 (S76)
Su, K. Y. L 2004, ApJS, 154,302
Walsh, J. R. 1983, MNRAS, 202, 303
Wright, N. J. et al 2011, MNRAS, 418, 370

Acknowledgement:
Thank you to the APN VI SOC and LOC and to the Observatório do Valongo for the financial support.