Planetary Nebulae: Multi-Wavelength Probes of Stellar and Galactic Evolution
Proceedings IAU Symposium No. 323, 2016
X. Liu, L. Stanghellini & A. Karakas, eds.

doi:10.1017/S1743921317002113

A New Model of NGC 6210 to Solve its Abundance Discrepancy Problem

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Abstract. We present a model that solves the abundance discrepancy problem for NGC 6210. The model proposes a high abundance of CNONe elements that lowers the temperature of the central parts of the nebula. The colder gas model reproduces the observed intensity of the strong [N II] and [O III] emission lines, and increases the predicted weak recombination lines towards their observed values. We examine how the usual nebular diagnostic line ratios depend on model abundances.

Keywords. ISM: abundances, planetary nebula: NGC 6210

The discrepancy between abundances derived from collisionally excited lines (CELs) and from optical recombination lines (ORLs) is a long standing conundrum in the theory of interstellar nebulae. Usually ORL derived abundances are larger than CEL derived abundances. A model optimized to reproduce CEL intensities calculated by Bohigas *et al.* (2015) also shows an abundance discrepancy in the sense that it underestimates ORL intensities because the predicted O^{+2} column density is too low. We used the code CLOUDY (Ferland *et al.* 2013) to construct new chemically homogeneous models of NGC 6210 with increased CNONe abundances to reproduce CELs and ORLs simultaneously.

The models propose a binary star with $T_{\rm eff} = 179300\,$K, $L = 1635\,L_\odot$, $\log g = 7.0$, $T_{\rm eff} = 29700\,$K, $L = 1694\,L_\odot$, $\log g = 4.5$ as suggested by the relation between binarity and the abundance discrepancy problem (Corradi *et al.* 2015). The density profile was chosen to reproduce the observed intensities of [N II], [O II], and [O III] optical CELs, the [O III] 51.80 μm, and the He I 5876 Å and He II 4686 Å lines reported by Bohigas *et al.* (2015) and Pottasch *et al.* (2009). The density profile has a tail that decreases with radius as r^{-4} to produce the extended halo of the nebula.

The O abundance in the new model, $O/H = 1.33 \times 10^{-3}$, was chosen to reproduce the O II ORLs lines to eliminate the abundance discrepancy. The model produces an inner zone with temperatures as low as 6600 K due to the higher O^{+2} concentration, where the ORL emission is produced (see Fig. 1). The temperature rises at the edges of the O^{+2} zone thus increasing the [O III] optical emission, and producing a temperature gradient with a Peimbert parameter $t^2 = 0.04$. Images obtained by García–Rojas, *et al.* (2016) of another nebula with a high abundance discrepancy, NGC 6778, show a similar concentration of ORL oxygen emission inside the CEL oxygen emission.

The model calculated by Bohigas *et al.* (2015) with a lower O/H abundance uses a density profile varying as r^2. A comparison with observations in Table 1 shows that both models reproduce the lines to comparable accuracy, except for the [O II] emission. The

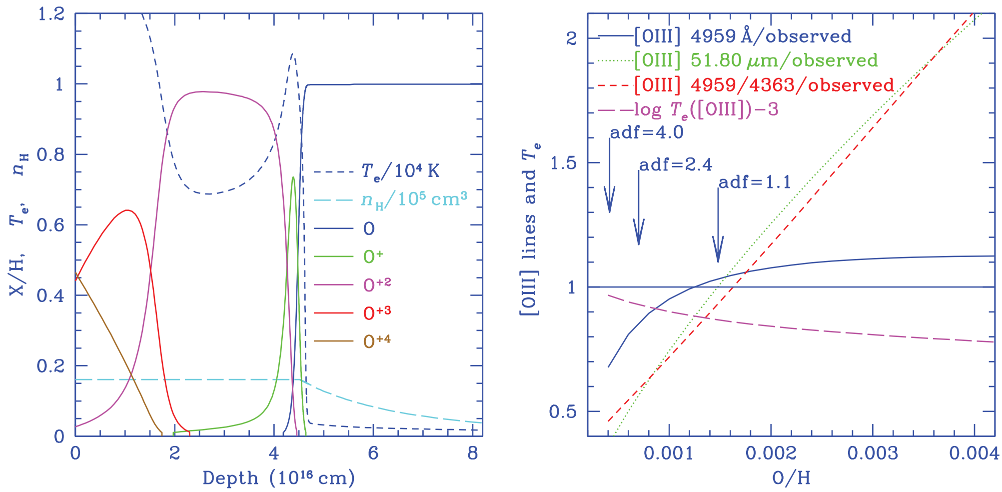

Figure 1. O ionization, electron temperature and density structure (left), and [O III] line intensities vs. O abundance (right) in our new model.

Table 1. A few comparisons of predicted and observed line intensities.

Model & Obs	O/H (10^{-4})	adf	[N II] 6584	[N II] ratio 6584/5755	[O II] 3726	[O III] 4959	[O III] ratio 4959/4363	[O III] 51.80	[O III] ratio 51.80/88.35	O II 4649 Mult V1	O II 4349 Mult V2
Obs[1]	4.10	4.0	15.68	54.4	18.33	343.40	58.3	151[4]	3.17[4]	0.446	0.113
Obs[2]	4.36	3.1	18.70	47.6	24.95	361.40	59.5			0.389	0.120
Low O model[1]	7.42	2.4	15.69	22.4	18.95	343.00	59.8	26.0	8.69	0.322	0.130
High O model[3]	13.3	1.1	15.68	43.4	48.45	332.69	61.4	53.3	8.19	0.423	0.169

[1] Bohigas *et al.* (2015), [2] Liu *et al.* (2004), [3] This work, [4] Pottasch *et al.* (2009)

[O II] emission appears asymmetrical in HST archival images (Guerrero *et al.* 2013), and therefore it is overestimated by our spherically symmetric model.

Figure 1 shows that the [O III] 4958 and 5007 Å lines vary little at high O abundances because of the decrease in electron temperature while the [O III] 51.80 μm does not depend on temperature. The abundance discrepancy factor adf=(O abundance from ORLs)/(O abundance from CELs) is given for the observed line intensities (4.0), the model abundance of Bohigas *et al.* (2015) (2.4), and the model with high O abundance (1.1).

References

Bohigas, J., Escalante, V., Rodríguez, M., & Dufour, R. J. 2015, *MNRAS*, 447, 817

Corradi, R. L. M, García–Rojas, J., Jones, D., & Rodríguez–Gil, P. 2015, *Ap. J.* 803, 99

Ferland, G. J., Porter, R. L., van Hoof, P. A. M., Williams, R. J. R., Abel, N. P., Lykins, M. L., Shaw, G., Henney, W. J., & Stancil, P. C. 2013, *RMxAA*, 49, 137

García–Rojas, J., Corradi, R. L. M., Monteiro, H., Jones, D., Rodríguez–Gil, P., & Cabrera–Lavers, A. 2016, *Ap. J. Lett*, 824, L27

Guerrero, M. A., Toalá, J. A., Medina, J. J., Luridiana, V., Miranda, L. F., Riera, A., & Velázquez, P. F. 2013, *A&A*, 557, A121

Liu, Y., Liu, X.–W., Luo, S.–G., & Barlow, M. J. 2004, *MNRAS*, 353, 1231

Pottasch, S. R., Bernard–Salas, J., & Roellig, T. L. 2009, *A&A*, 499, 249

https://doi.org/10.1017/S1743921317002113 Published online by Cambridge University Press