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The chemical composition of PNG 135.9+55.9, the most oxygen poor planetary nebula

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Abstract. PN G 135.9 +55.9 is an extraordinary nebula discovered recently in the Galactic halo (Tovmassian *et al.* 2001). The first studies estimated its oxygen abundance to be 1/100 of the solar value or even less.

Being extremely metal-poor, PNG 135.9+55.9 offers an unprecedented opportunity to check our understanding of the evolution of intermediate-mass stars at very low metallicity, by complementing the data obtained from metal-poor giants (Spite et al 2005). Indeed, PNG 135.9+55.9 and some of those stars are snapshots of the evolution of very similar stars at different times.

We present our most recent abundance analysis for this object, providing stringent limits on the abundances of C, N, O, and Ne, to be confronted with the predictions for the yields of low metallicity intermediate mass stars.

Keywords. ISM: planetary nebulae: individual (PNG 135.9+55.9), stars: AGB and post-AGB, stars: evolution

1. Introduction

PN G 135.9+55.9 (an object appearing in the Second Byurakan Sky Survey under the name SBS 1150+599A) has recently been recognized as a high excitation planetary nebula in the Galactic halo (Tovmassian *et al.* 2001). This planetary nebula is unique in several respects. First of all, it has an extremely low oxygen abundance, significantly lower than any other planetary nebula known so far (Tovmassian et al 2001, Richer et al 2002, Jacoby et al 2002, Péquignot & Tsamis 2005). Second, its nucleus is a spectroscopic binary, with a period of a few hours at most (Tovmassian *et al.* 2004). Third, the first estimates of the nature and masses of the two stellar components indicate that the object could be the progenitor of a Type Ia Supernova (Tovmassian *et al.* 2004). Each of these aspects, even taken alone, makes of PN G 135.9+55.9 a unique object.

Being extremely metal-poor, PN G 135.9+55.9 offers an unprecedented opportunity to check our understanding of stellar evolution and yields at very low metallicity by complementing the data obtained from metal-poor giants (Spite *et al.* 2005). Indeed, PN G 135.9+55.9 together with the stars studied by Spite *et al.* are snapshots of the evolution of very similar stars at different times. Therefore, they provide a unique occasion to constrain evolutionary models of these stars at different times and so to pin down the physical processes involved in their nucleosynthetic evolution. Stellar models with accurate predictions are now becoming available for the relevant stellar evolution stages and metallicities (Herwig 2004, Denissenkov 2004, Charbonnel *et al.* in preparation).

Our current photometric and spectroscopic observations of the core of PN G 135.9+55.9 (work in preparation) and our analysis of the binary orbit confirm that the companion is a massive compact object. We find the total mass to be close the Chandrasekhar limit, making PN G 135.9+55.9 a good candidate SN Ia progenitor within the double degenerate (DD) scenario. Napiwotzki *et al.* (2004) conducted a radial velocity survey (SPY) f or DD progenitors of SN Ia as a large programme at the 8m ESO VLT. Radial velocities of more than 1000 white dwarfs were measured and only one good SN Ia candidate was detected. This demonstrates the rareness of these objects (consistent with theoretical estimates). Had it not been for the PN and the extraordinary chemistry of PN G135.9+55.9 the DD central star would have remained unnoticed. PN G135.9+55.9 offers a unique advantage over all DDs known so far, including the progenitor candidate from SPY: the properties of the PN can be used to constrain the poorly understood common envelope phase proceeding the formation of the DD. Knowledge of the abundances will enable us to evaluate the dredge-up of processed material. This information is lost in all other DDs, because the surface abundances of WDs are strongly modified by diffusion processes.

PN G 135.9+55.9 is possibly the only object of its category that will ever be possible to analyze in some depth. Given that its study will contribute in an important way to many different fields in Astrophysics, it is important to try to get the maximum out of it.

2. Summary of previous oxygen abundance determinations in PN G 135.9+55.9

The first optical spectra that were obtained for PN G 135.9+55.9 showed no lines from heavy elements except a very weak [OIII] λ5007, with an intensity a few percent of Hβ. A photoionization model analysis fitting all the observational constraints available at that time suggested an oxygen abundance smaller than 1/100 of solar. A more accurate abundance determination requires an estimate of the stellar effective temperature (standard empirical methods for abundance determinations in planetary nebulae cannot be used for this object, since the electron temperature cannot be determined from observations in the usual manner). One way is to observe the [NeV] λ3426 and [NeIII] λ3869 lines. Richer *et al.* (2002) at CFHT and Jacoby *et al.* (2002) at MMT secured deep blue spectra in order to detect these lines. The object is faint, so the observations are not easy. Jacoby et al (2002) detected the [NeV] λ line at a level of 0.8 Hβ. Richer *et al.* (2002) found only an upper limit of 0.1 Hβ! As for the [NeIII] λ3869 line, Jacoby *et al.* (2002) measured an intensity about 10 times larger than Richer *et al.* (2002). These groups conducted independent photoionization analyses, both concluding that the O/H ratio is less than 1/100 of solar. However, their analyses were obviously to be redone, since they were based on conflicting measurements. After merging and discussing the two observational data sets, Péquignot & Tsamis (2005) conducted their own photoionization analysis and came to the conclusion that the O/H ratio lies between 1/30 - 1/15 of solar (still holding the record for the most oxygen poor planetary nebula!). Their analysis, however, did not take into account the line intensities observed in the ultraviolet by STIS on the HST, which provide important constraints on the carbon and nitrogen abundances, thus on the thermal balance of the nebula and, indirectly, on the oxygen abundance.

Table 1. Summmary of abundance results for PN G 135.9+55.9

	a	b	c	d	Sun
12+ log O/H	5.8 – 6.5	6.2 – 6.9	7.2 – 7.8	6.6 – 7.1	8.7
Ne/O	0.5	4.3	< 0.2	0.3 – 1	0.2
C/O				3.6 – 5.8	0.5
N/O				0.9 – 1.2	0.14

a Richer *et al.* 2002; b Jacoby *et al.* 2002; c Péquignot & Tsamis 2005; d Stasińska *et al.* 2005, in preparation.

3. Our ongoing study of PN G 135.9+55.9

In May 2003, we re-observed PN G 135.9+55.9 at the CFHT in the blue with much better spectral resolution and signal-to-noise (Tovmassian *et al.* 2004). These observations confirmed the large intensity of [NeV] λ3426 found by Jacoby et al (2002) and low intensity of [NeIII] λ3869 found by Richer *et al.* (2002). We have also collected and analysed other spectra of this object, taken on different telescopes, so as to obtain a realistic evaluation of observational uncertainties. We (Stasinska *et al.* 2005, in preparation) are presently conducting a photoionization model analysis, using as constraints the line intensities (or upper limits) obtained in the optical spectra (ground based observations) and UV spectra (STIS and FUSE observations), together with the spatial information provided by the STIS image of this planetary nebula. The STIS and FUSE data indicate that the carbon and nitrogen abundances are not as large as postulated by Péquignot & Tsamis (2005). Consequently, the O/H ratio is significantly lower than estimated by those authors.

Our strategy for the photoionization modelling is to find the minimum and maximum value of O/H that is compatible with all the observational data. The lowest O/H is obtained with the lowest value of the central star effective temperature that is compatible with *i)* the observed value of [NeV] λ3426/[NeIII] λ3869 (in order to have the smallest possible proportion of oxygen in unseen ionization stages: O^{+++}, O^{++++}) and *ii)* the lowest abundances of C, N and Ne compatible with the observed intensities or upper limits (to reduce cooling and thus keep the emissivity of [OIII] λ5007 as high as possible. The highest O/H is obtained with the reverse conditions.

Column d of Table 1 gives the abundances we estimate presently for PN G 135.9+55.9. These are preliminary results, since we intend to bring refinements in the photoionization model analysis, principally as regards the spectral energy distribution of the stellar ionizing radiation and the nebular geometry.

4. Planned observations of PN G 135.9+55.9

We have obtained time on the Spitzer Space Telescope to do infrared spectroscopy of this object. The measurement of the [OIV] λ 25.9μm line should enable us to obtain a value of O/H with an accuracy of around 10–20%, and, consequently, accurate values of C/O, N/O and Ne/O. We also expect at least a rough estimate of the sulfur abundance (and perhaps of the argon abundance). The determination of the helium abundance requires more refined modelling, taking into account deviation from case B recombination theory for hydrogen. Within about one year from now, we expect to have a complete picture of the abundance patterns in this pivotal planetary nebula.

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References

Denissenkov, P.,2004, *Mem.S.A.It* 75, 328
Herwig, F., 2004, *ApJS* 155, 651
Jacoby, G. H., Feldmeier, J. J., Claver, C. F., *et al.* 2002, *AJ* 124, 3340
Napiwotzki, R. *et al.* 2004, *Rev Mex. A & A*, 20, 113
Péquignot, D., Tsamis, Y. 2005, *A&A* 430, 187
Richer, M. G., Tovmassian, G., Stasińska, G., *et al.* 2002, *A&A* 395, 929
Spite, M., Cayrel, R., Plez, B.,*et al.* 2005, *A&A* 430, 655
Tovmassian, G. H., Stasińska, G., Chavushyan, V. H., *et al.* 2001, *A&A* 370, 456
Tovmassian, G. H., Napiwotzki, R., Richer, M. G., *et al.* 2004, *ApJ* 616, 485

https://doi.org/10.1017/S1743921305005892 Published online by Cambridge University Press