Planetary Nebulae in our Galaxy and Beyond
Proceedings IAU Symposium No. 234, 2006
M. J. Barlow & R. H. Méndez, eds.

DOI: 00.0000/X000000000000000X

bHROS high spectral resolution observations of PN forbidden and recombination line profiles

M. J. Barlow[1], A. S. Hales[1], P. J. Storey[1], X.-W. Liu[2], Y. G. Tsamis[1], M. E. Aderin[1]
[1]Dept. of Physics and Astronomy, University College London; [2]Dept. of Astronomy, Peking University

Abstract. We have acquired high spectral resolution observations (R=150,000) of the planetary nebulae NGC 7009 and NGC 6153, using bHROS on Gemini South. Observations of this type may provide a key to understanding why optical recombination lines (ORLs) yield systematically higher heavy element abundances for photoionized nebulae than do the classical forbidden collisionally excited lines (CELs) emitted by the same ions; NGC 7009 and NGC 6153 have notably high ORL/CEL abundance discrepancy factors (ADFs) of 5 and 10, respectively. Due to the opposite temperature dependences of ORLs and CELs, ORLs should be preferentially emitted by colder plasma. Our bHROS observations of NGC 7009 reveal that the [O III] 4363 Å CEL has a FWHM linewidth that is 1.5 times larger than that shown by O II ORLs in the same spectrum, despite the fact that all of these lines are emitted by the O^{2+} ion. The bHROS spectra of NGC 6153 also show that its O II ORLs have significantly narrower linewidths than do the [O III] 4363 Å and 5007 Å lines but, in addition, the [O III] 4363 Å and 5007 Å lines show very different velocity profiles, implying the presence of large temperature variations in the nebula.

Keywords. planetary nebulae: individual (NGC 6153, NGC 7009); line: profiles

1. Introduction

H II region and planetary nebula abundances derived from heavy element optical recombination lines (ORLs) should in principle be more accurate than those derived from collisionally excited (forbidden) lines (CELs) from the same ions, due to the exponential dependence upon the adopted nebular temperature of CEL abundances. However, a number of abundance surveys of PNe that we have recently published (Tsamis et al. 2004, Liu et al. 2004, Wesson et al. 2005) show that ORLs yield systematically higher heavy element abundances than those obtained from classical CEL forbidden line analyses, with abundance discrepancy factors (ADFs) of 1.6-3.0 obtained for most nebulae. For about 5-10% of nebulae, the ADFs are so large (5-80) that nebular temperature fluctuations (e.g. Peimbert 1967) cannot be invoked to reconcile the differences. It is important to resolve this problem, since standard temperature fluctuation analysis methods effectively adopt the higher ORL abundances, with profound implications for the mean abundances that are derived for our own and other galaxies from H II regions and PNe.

NGC 7009 and NGC 6153 are nebulae for which we have previously found very large enhancements in the recombination line abundances of the second-row elements carbon, nitrogen, oxygen and neon (Liu et al. 1995, Liu et al. 2000), with ORL/CEL ADFs of 5 and 10, respectively. Nebular temperature fluctuations are unable to account for these effects. However, models that invoke low-temperature hydrogen-deficient clumps appear viable as an explanation for the high recombination line abundances that are observed (see Liu et al. 2000 for more details). If the heavy element ORLs originate from much cooler material than do the classical forbidden lines, then an obvious prediction is that ORLs should have narrower lines widths than forbidden lines from the same ion. In order to test this prediction, we have obtained high spectral resolution (R=150,000) observations of these two high-ADF nebulae using the recently commissioned bHROS echelle spectrograph on the 8-m Gemini South telescope.

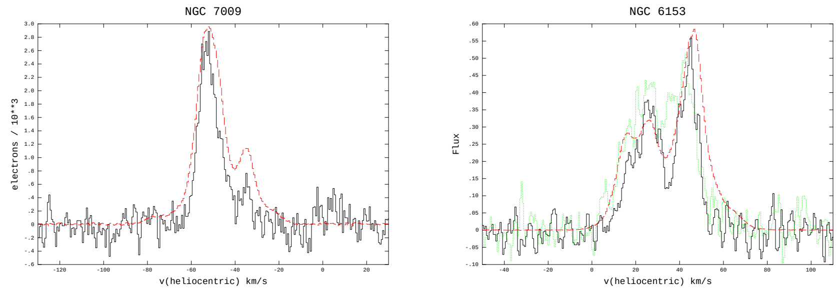

Figure 1. bHROS O II and [O III] profiles for NGC 7009 (left) and NGC 6153 (right). See text for details.

2. Results

Four 30-minute exposures on NGC 7009 were obtained with bHROS on July 27th 2005, placing its 0.9″× 0.9″ image-slicer on a bright edge region located 5.6″ NW of the central star, with the echellogram centred at 4267 Å. Fig. 1(a) shows a velocity plot of the co-added profile of the 4089, 4275 and 4349 Å O II lines (solid plot), together with the profile (after division by a factor of ten) of the [O III] 4363 Å CEL (dashed). These lines all arise from the O^{2+} ion, yet the linewidth of the O II main velocity component is measured to be 1.47 times smaller than that found for the same velocity component in the [O III] line, which for pure velocity broadening would yield a T_e from the [O III] line that is 2.2 times larger than that obtained from the O II lines. Clearly, the O^{2+} ORLs and CELs cannot originate from identical material.

Five 30-minute exposures were obtained on NGC 6153 on March 9th 2006 (a further five exposures were obtained on March 24th; the results shown here are from the March 9th observations). The 0.9″× 0.9″ large bHROS image-slicer was placed on a bright region located 7.4″ SE of the central star. The echellogram was centred at a longer wavelength (4650 Å) than for NGC 7009, to allow for the much higher reddening towards NGC 6153. Fig. 1(b) shows a velocity plot that compares the observed line profiles of the O II 4649 Å ORL (solid), together with those of the [O III] 5007 Å (dashed) and 4363 Å (dotted) CELs. The 5007 Å profile has been divided by a factor of 250 for comparison purposes. Once again, the O II ORL line profile shows much narrower velocity components than do the [O III] 5007 Å and 4363 Å lines, indicating that the O^{2+} ions giving the O II recombination emission are located in physically distinct regions from those giving the [O III] forbidden line emission. A big surprise, though, is that the two [O III] forbidden lines have very different velocity profiles. Of the three observed [O III] 5007 Å velocity components, the two blue-most components both have [O III] 4363 Å counterparts, but the gap between the middle and red-most 5007 Å component is infilled by emission in the case of the 4363 Å line, while only the blue side of the strongest 5007 Å velocity component has a counterpart in either the [O III] 4363 Å or O II 4649 Å profiles. Since the ratio of the [O III] 5007 Å to 4363 Å line intensities is a classical electron temperature diagnostic, the large variations in this ratio as a function of velocity indicate very large temperature variations within the nebula.

References

Liu, X.-W., Storey, P.J., Barlow, M.J., Clegg, R.E.S. 1995, *MNRAS* 272, 369

Liu, X.-W., Storey, P. J., Barlow, M. J., Danziger, I. J., Cohen, M. Bryce, M. 2000, *MNRAS* 312, 585

Liu, Y., Liu, X.-W., Barlow, M. J., Luo, S.-G. 2004, *MNRAS* 353, 1051

Peimbert, M. 1967, *ApJ* 150, 825

Tsamis, Y. G., Barlow, M. J., Liu, X.-W., Storey, P. J., Danziger, I. J. 2004, *MNRAS* 353, 953

Wesson, R., Liu, X.-W., Barlow, M. J. 2005, *MNRAS* 362, 424