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The Halo of NGC 2438 revisited

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NGC 2438 is the classical multiple shell or halo planetary nebula (PN). Its central star and the main nebula are well studied. Also, it was target of various hydrodynamic simulations. About a decade ago, this initiated a discussion on whether the halos are mainly containing recombined gas, or if they are still (photo)ionized. The latter might be caused due to filling factor of the main nebula being well below unity. We investigated with a deeper look on morphological details (ray-like structures) and multiple position slit spectra the properties of the outer shell and the halo. Moreover, as the classical diagnostic diagrams ([S II] 6716/32, [O III] 5007/4363, etc.) are not usable at densities below 100 particles per cubic centimetre, we discuss theoretical investigations towards new diagnostic tools and the feasibility of investigating this low density material with optical spectroscopy.

The Halo of NGC 2438 revisited

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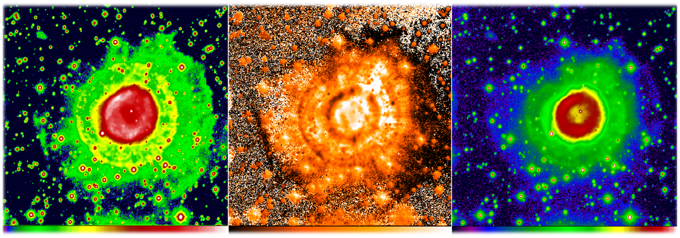
NGC 2438 is the classical multiple shell or halo planetary nebula (PN). Its central star and the main nebula are well studied. Also it was target of various hydrodynamic simulations. About a decade ago, this initiated a discussion whether the halos are mainly containing recombined gas (Schönberner & Steffen, 2002, RevMexAC, 12, 144) , or if they are still (photo)ionized (Armsdorfer et al. 2003, IAUS, 209, 511). The latter might be caused due to filling factor of the main nebula being well below unity. We started a deeper look on morphological details (ray like structures) and multiple position slit spectra to obtain the properties of the outer shell and the halo. Moreover, as the classical diagnostic diagrams (e.g. [SII] 6716/32) are not usable at densities below 100 particles per cubic centimetre, we tried to move towards new diagnostic tools to investigate this low density material with optical spectroscopy.

Fig. 1: The H_α+[NII] (left), [OIII] (right), both in a log scale, and the line ratio image [OIII] / H_α+[NII] (middle). Despite the large dynamical range of the radiation the "colour" varies only by a factor of two from the mean value.
The ray like structures in the halo clearly follow "holes" in the main nebula. This strongly suggests that the intensity variations (from ray to inter ray region by a factor of two) originates from "leaking" UV radiations. The rays are not prominent in the colour image. Thus the variation of the excitation ratio is small.



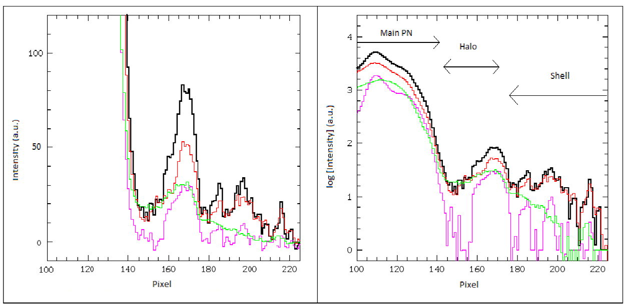
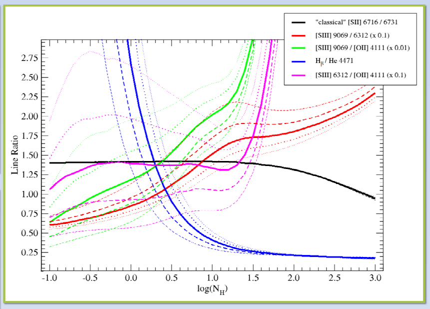


Fig. 2: The flux of the H_α+[NII] (black line), H_α (red), [NII] (magenta) and [OIII] (green) lines from the centre towards W taken from two SAAO spectra. The halo is pronounced towards the edge by the [NII] line. This line is known to be sensitive to shocks. This causes the enhancement of the halo edge in the "colour" image of figure 1. The pure [OIII] / H_α ratio has only small variations.
Thus direct imaging (as it contains [NII] at nearly all observatories) is not well suited for this kind of investigations. The halo is well pronounced in the high ionization stage of [OIII]. In Cloudy models we are able to obtain such a state only with filling factors $\varepsilon < 0.2$.
A detail map using all of our spectra taken at 10 different positions will allow us to obtain more input for our models.

Fig. 3: The line ratios for a photoionized gas at a distance of 10^{16} m from the 110 000 K central star (thick lines) and the results for +10 000, +20 000 (dotted lines) and -10 000, -20 000 K (dashed lines).
The [SII] line ratio "saturates" at densities below N_H = 100. On the other hand it shows no influence by the hardness of the radiation field.
Other line ratios don't behave that well. But in a combination of the suggested line groups we are able to obtain a solution too.



Discussion:
As the main nebula and the shell of NGC 2438, due to its position far from the galactic plane and due to the outer shells, is not influenced by ISM interaction, it is a perfect target for this investigation.
The line ratios show us hardly any variation in the excitation of the gas between the main nebula and the halo. This leads us to the suggestion, that the small scale clumpiness of old PN (typical filling factor $\varepsilon \cong 0.1$) allows a sufficient amount of UV radiation leaking to the halo, to photoionize it. The "recombination" halo postulated by Schönberner & Steffen (2002) by using 1D-hydros ($\rightarrow \varepsilon = 1.0$) leads to $T_e \leq 3\,500$ K.

Theoretical predictions show line ratios useable for the investigation at densities towards a few particles cm^{-3}. These line ratios, other than for the classical diagnostic diagrams, have to be combined to filter abundance effects and the temperature of the central star.

Although the first look showed us lines in our spectra, deeper and redder ([SIII]) spectroscopy is required.

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