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A new planetary nebula around the hot subdwarf star 2MASS J19310888+4324577

A. Aller [1], A. Ulla[1], L. F. Miranda[1,2], P. Thejll[3], R. Oreiro[4], C. Rodríguez-López[4], M. Manteiga[5], and E. Pérez[1]

[1] Departamento de Física Aplicada, Universidade de Vigo, Campus Lagoas-Marcosende s/n, E-36310 Vigo, Spain
[2] Consejo Superior de Investigaciones Científicas, C/ Serrano 117, E-28006 Madrid, Spain
[3] Danish Climate Centre at the Danish Meteorological Institute, Lyngbyvej 100, DK–2100 Copenhagen, Denmark
[4] Instituto de Astrofísica de Andalucía - CSIC, Glorieta de la Astronomía, s/n. E-18008, Granada, Spain
[5] Departamento de Ciencias de la Navegación y de la Tierra, Universidade da Coruña, Rua de Maestranza, E-15001 A Coruña, Spain

Abstract

Hot subdwarf O (sdO) stars are blue low-mass stars on their way to the white dwarf phase, although their origin is not well understood yet. They occupy a broad region in the HR–diagram and, therefore, different formation channels have been proposed so far in order to explain their evolutionary status. Among them, a binary scenario and a post–AGB origin are possible. In this paper, we present the first results of an ongoing project to search for planetary nebulae (PNe) around sdOs. Narrow–band images reveal a multi–shell PN around 2MASS J19310888+4324577 (hereafter 2M1931+4324). The nebula consists of a bipolar and an elliptical shell, with the major axes perpendicular to each other, and high–excitation outer knots and filaments. Intermediate–resolution spectroscopy allows us to confirm the sdO nature of 2M1931+4324 and that it is the central star of the nebula. The recently report binary nature of 2M1931+4324 and its association with a multi–shell PN favors the idea that binary stars play an important role in the formation of complex PNe.

1 Introduction

Hot subdwarf O stars (hereafter sdOs) are evolved blue objects out the end of the Extreme Horizontal Branch (EHB). While it is commonly accepted that they will end their lives as white dwarfs, their current position in the HR-diagram remains an open question. It is still

unclear which mechanism (or mechanisms) causes them to lose large amounts of mass until a carbon-oxygen core is left together with thin helium and hydrogen burning envelopes (see e.g., [3]).

In fact, the sdO population seems to be a rich mixture of objects coming from different formation channels (including both single and binary scenarios), in contrast to their cooler cousins, the hot subdwarf B stars (or sdBs). While sdBs seem to be a homogeneous group, sdOs show a large variety of spectral features. They are found in a wide area of the HR-diagram with effective temperatures ($T_{\rm eff}$) between $\simeq$ 40000 K and $\simeq$ 100 000 K, and surface gravities ($\log(g)$) between $\simeq$ 4.0 and $\simeq$ 6.5 [13], as well as large differences of chemical composition. According to their position in the HR-diagram, sdOs are classified as luminous, those located in the post-AGB traces, or compact, those with lower $T_{\rm eff}$ and higher surface gravity, occupying the post-EHB traces (see, e.g, [8]). Even though luminous sdOs appear related to post-AGB evolution, only a few of them have been found to be associated with a planetary nebula (PN). The first detections of these sdO+PN systems date back to the late eighties: LSE 125 and LSS 2018 [2], LSS 1362 [4], and RWT 152 [10]. In addition, a small number of central stars of PNe have been also classified as sdOs (e.g., [12, 7]).

We are involved in a comprehensive research to identify new PNe around known sdOs by means of deep narrow-band imaging and intermediate-resolution long-slit spectroscopy. As a part of this project, we present the discovery of a PN around the sdO 2M1931+4324, that has been recently found to be a binary star [5].

2 Observations and results

Extended emission around 2M1931+4324 was detected for the first time in August 2010 at El Roque de los Muchachos Observatory (La Palma, Canary Islands, Spain). A narrow-band [O III] image (combination of three images with an exposure time of 1800 s each) was obtained with the Wide Field Camera at the 2.5 m Isaac Newton Telescope. The nebula was also observed in July 2011 with the Calar Alto Faint Object Spectrograph (CAFOS) at the 2.2 m telescope on Calar Alto Observatory (Almería, Spain) in order to obtain a narrow-band Hα image. In this case, two images were taken with an exposure time of 1800 s and 2400 s each.

Figure 1 (left) shows a colour composite image of the nebula around 2M1931+4324 obtained by combining the Hα (green) and [O III] (blue) images. Figure 1 (right) shows the Hα image. The nebula presents a multi-shell morphology consisting of a bipolar structure of $\simeq 4' \times 2'$ in size and its major axis orientated at position angle (PA) $\simeq 55°$, and an elliptical structure of $\simeq 5' \times 2'$ in size and its major axis orientated at PA $\simeq 145°$. As it can be seen in Fig. 1, the nebula is significantly brighter in Hα than in [O III], suggesting a low-excitation (see also below). Additionally, the [O III] image reveals a long filament as well as diffuse emission outside the main shells, which extend from the north to the southeast. The absence of these outer structures in the Hα image suggests that they present high-excitation. The existence of axisymmetric shells around a hot sdO (see below) strongly suggests a PN nature for the detected nebula.

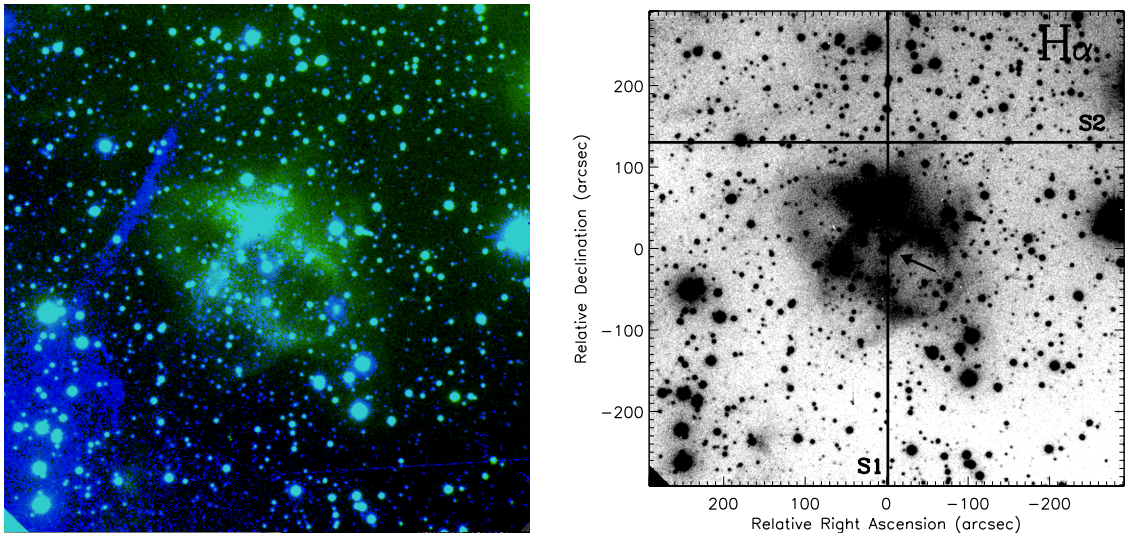

Figure 1: *Left panel:* Colour composite image obtained by combining the [O III] (blue) and Hα (green) images of 2M1931+4324. *Right panel:* Grey-scale reproduction of the Hα image. Both images have the same scale, indicated in the Hα image, in which the central star is also arrowed.

We have obtained intermediate-resolution, long-slit spectroscopy of the object in July 2011 with CAFOS. Gratings B-100 and R-100 were used. Spectra were acquired in two different slit positions (denoted S1 and S2 in Fig. 1, right) in order to cover the central star, the brightest nebular regions and the outer filament. Figure 2 shows the blue stellar spectrum of 2M1931+4324 (slit position S1, see Fig. 1). The spectrum is dominated by strong and narrow ionized helium absorption lines and hydrogen Balmer absorption lines that are blended with the corresponding He II Pickering ones because of the moderate spectral resolution ($\simeq$ 2 Å pixel^{-1}). The spectrum also shows Ca IIλ3934 and Na I$\lambda\lambda$5890,5895 absorption lines. High-resolution spectroscopy of the central star is necessary to decide whether these absorptions are due to the interstellar medium or could be attributed to a late-type companion. Moreover, the absence of the He Iλ4471 absorption line in the spectrum indicates a $T_{\rm eff} \geq 60\,000$ K [11] and, therefore, that 2M1931+4324 is the central star of the nebula.

Figure 3 shows the integrated nebular spectrum obtained at S1. Only Hα, Hβ and [O III]$\lambda\lambda$4959,5007 emission lines are detected. The [O III]/Hβ line intensity ratio of $\simeq$ 1.6 indicates a very low excitation PN. Remarkably, no low-excitation emission lines (in particular, due to [N II]), are detected in the spectrum, as typically found in low-excitation PNe. This result suggests that the nebula could present a deficiency of heavy elements, which should be investigated by much deeper spectra. The spectrum of the outer filament (obtained at S2, see Fig. 1, and not shown here) only exhibits extremely faint [O III]$\lambda\lambda$4959,5007 emission lines, confirming its high-excitation.

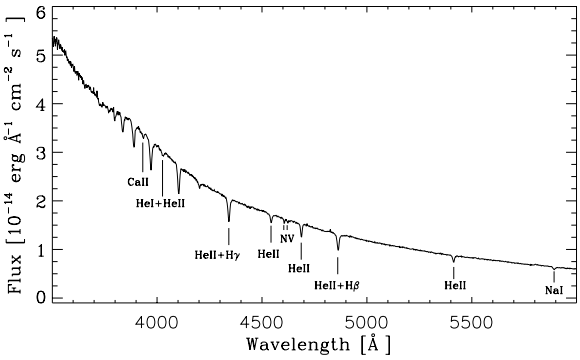

Figure 2: CAHA CAFOS blue spectrum of 2M1931+4324 in the range $3500 - 6000$ Å. Some absorption lines are labelled.

3 Conclusions

We report on the detection of a faint nebula around 2M1931+4324 by means of deep narrow-band Hα and [O III] images. This star has been classified as sdO [9] and has been found to be a binary system [5]. The nebula consists of two axisymmetric shells, a bipolar one and an elliptical one, whose major axes are perpendicular to each other. Outer high-excitation structures are also detected in the [O III] image. Our optical spectrum of the star, confirms its sdO nature and indicates a $T_{\rm eff} \geq 60\,000$ K. These results strongly suggest a PN nature for the detected nebula and that 2M1931+4324 is its central star. The nebular spectrum only shows Hα, Hβ and [O III]$\lambda\lambda$4959,5007 emission lines, and indicates a very low-excitation PN. This is in contrast with the absence of low-excitation nebular emission lines (e.g., [N II]) and could indicate a deficiency of heavy elements in the nebula.

The presence of a multi-shell PN around the binary 2M1931+4324 provides support for the idea that binary stars play a crucial role in the formation of complex PNe (see [1] and references therein; [6]). A in-depth spectroscopic analysis of 2M1931+4324 is mandatory in order to obtain the atmospheric parameters ($T_{\rm eff}$ and $\log(g)$) for the target which, in term, will allow us to impose constrains on its evolution.

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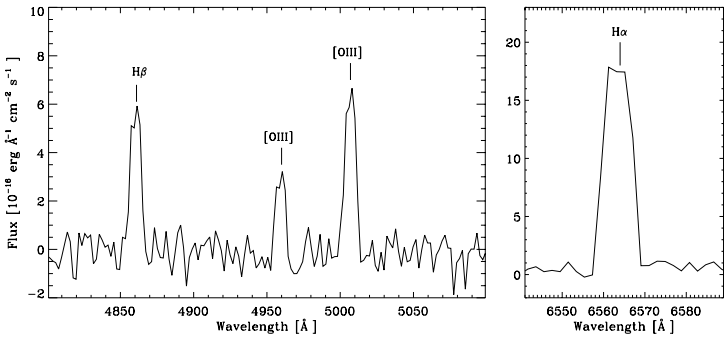

Figure 3: CAHA CAFOS spectra of the detected emission lines from the PN around 2M1931+4324.

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