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S-PLUS, J-PLUS and J-PAS in the search for planetary nebulae

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Abstract. From the approximately 3,000 planetary nebulae (PNe) discovered in our Galaxy, only 14 are found to be members of the halo. Moreover, a systematic search for halo PNe was never done. We have developed tools to identify PNe in the Javalambre-Physics of the Accelerating Universe Astrophysical Survey (J-PAS) and related surveys, S-PLUS and J-PLUS, taking advantage of their great combination of narrow- and broad-band filters. The spectra of several classes of emission-line objects, which were convolved to the three photometric systems, were applied to the principal component analysis in order to find the most adequate combinations of colour to discriminate halo PNe from other objects. Here we propose colour-colour diagrams, based on these spectra. The diagrams separate halo PN candidates from other sources that resemble PNe (symbiotic stars; star-forming galaxies; cataclysmic variables; QSOs and extragalactic H II regions). We include, in our preliminary results, the photometry of a couple of halo PNe actually observed by the J-PLUS survey. Altogether, we show it is possible to discriminate halo PNe from other sources using different techniques which enclose important spectral nebular features.

Resumo. Das aproximadamente 3000 nebulosas planetárias (NPs) descobertos em nosso Galáxia, apenas 14 são membros do halo. Além disso, uma busca sistemática de NPs do halo nunca foi feita. Desenvolvemos ferramentas para detectar essas fontes no Javalambre-Physics of the Accelerating Universe Astrophysical Survey (J-PAS) e nos surveys, S-PLUS e J-PLUS, aproveitando sua ótima combinação de filtros estreitos e largos. Os espectros de vários tipos de objetos com linhas de emissão, que foram convolvidos para os três sistemas fotométricos, foram utilizados com a análise de componentes principais para encontrar as combinações de cor mais adequadas para discriminar NPs do halo de outros objetos. Aqui propomos novos diagramas cor-cor, que separam as NPs de outras fontes com linhas (estrelas simbióticas, galáxias formadoras de estrelas, variáveis cataclísmicas, QSOs e regiões H II extragalácticas). Incluímos em nossos resultados, a fotometria de um par de NPs observadas por J-PLUS. Ao todo, mostramos que é possível discriminar NPs de outras fontes usando diferentes técnicas que envolvem importantes características espectrais.

Keywords. Galaxy: halo – planetary nebulae – ISM: lines and bands

1. Motivation

Planetary nebulae (PNe) are a kind of emission line nebula that represent a short phase of the stellar evolution of low- and intermediate-mass stars ($0.8M_{\odot}$ - $8.0M_{\odot}$). During the unstable AGB phase, stars eject their outer layers into the interstellar medium resulting in an enrichment in heavy elements. Approximately, 3,000 PNe have been identified in our Galaxy (Parker et al. 2012). Of these, only fourteen objects are located in the Galactic halo (Otsuka et al. 2015). Halo PNe are interesting objects because they provide important information about the evolution of old and low-mass stars of in the halo, and allow the early chemical conditions of the Galaxy to be studied.

A number of new Galactic PNe were identified in the equatorial plane (Viironen et al. 2009) by using the $(r' - \mathrm{H}\alpha)$ vs $(r' - i')$ colour-colour diagram in the Isaac Newton Telescope (INT) Photometric Hα Survey of the Northern Galactic Plane (IPHAS; Drew et al. 2005). The multi-filter J-PAS, J-PLUS[1] and S-PLUS[2] surveys are more suitable surveys for searching PNe in the direction of Galactic halo. The combination of narrow- and broad-band filters in these surveys (in total, 56, 12 and 12, respectively) allow us to identify objects with prominent emission lines. We use the principal component analysis (PCA) to search for the most adequate combination of colours that distinguish halo PNe from their contaminants. Several colour–colour diagrams have been generated and explored in order to separate halo PNe from other emission line objects.

[1] The Javalambre-Photometric Local Universe Survey
[2] The Southern Photometric Local Universe Survey

2. Results

The synthetic magnitudes of various classes of objects were calculated for the filters in the three surveys, using available observed spectra, and a set of photo-ionization models for halo PNe. The spectra of PNe: DdDm-1, NGC 242 and MWC 574 were taken from Kwitter & Henry (1998), Kwitter et al. (2003) and Pereira & Miranda (2007), respectively, while the spectra of PNe H 4-1 and PNG 135.9+55.9 were obtained from the SDSS. The spectra of the rest of the objects: cataclysmic variables (CVs), star-forming galaxies and quasistellar objects (QSOs) with different redshift ranges are also from SDSS. Galactic disk symbiotic stars (SySts) were taken from Munari & Zwitter (2002) and IPHAS (Rodríguez-Flores et al. 2014), while the extragalactic SySts in IC10, NGC 185 and in NGC 205 were gathered from Gonçalves et al. (2015). Finally, H II regions in NGC 55 (Magrini et al. 2017) are also included in this analysis.

Fig. 1 displays the S-PLUS colour-colour diagram (J0515 – J0660) vs (J0515 – J0861). Halo PNe with strong Hα emission are placed at the upper left. The J-PLUS colour-colour diagram (J0660 – gSDSS) vs (J0660 – rSDSS) is presented in Fig. 2. Note that the known PNe: H 4-1 and PNG135.9+55.9 (blue and green circles with errorbars, respectively) observed in the J-PLUS survey, during the phase of the data science verification, are located

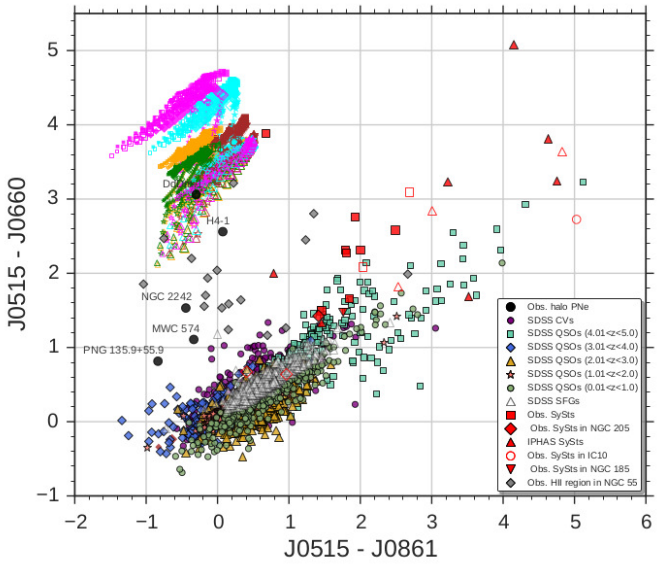

Figure 1. The S-PLUS colour-colour diagram (J0515-J0660) vs (J0660-J0861). Families of cloudy modelled halo PNe (the pink, cyan, orange, green and brown symbols) spanning a range of halo PN properties are included. These models represent different sets of nebular abundances, with densities of 6000 cm^{-3} (filled symbols) and 3000 cm^{-3} (empty symbols), for a spherically symmetric nebula of 2.7″ in radius, at a distance of 10 kpc. Central star black-body effective temperatures and luminosities are from 50×10^3 to 250×10^3 K, in steps 10×10^3 K; and 0.5, 1.0, 5.0 and 10×10^3 $L_\odot$. The rest of the symbols are as follows: halo PNe (black circles); QSOs with redshift in the range from 0.01 to 1.0 (light green circles); 1.01 to 2.0 (light orange stars); 2.01 to 3.0 (light orange triangles); 3.01 to 4.0 (light blue diamonds); and 4.01 to 5.0 (green boxes), CVs (violet circles); star-forming galaxies (black, open triangles); symbiotic stars (red boxes); extragalactic symbiotic stars (red diamonds); symbiotic stars from IPHAS (red triangles); extragalactic H II region (gray diamonds).

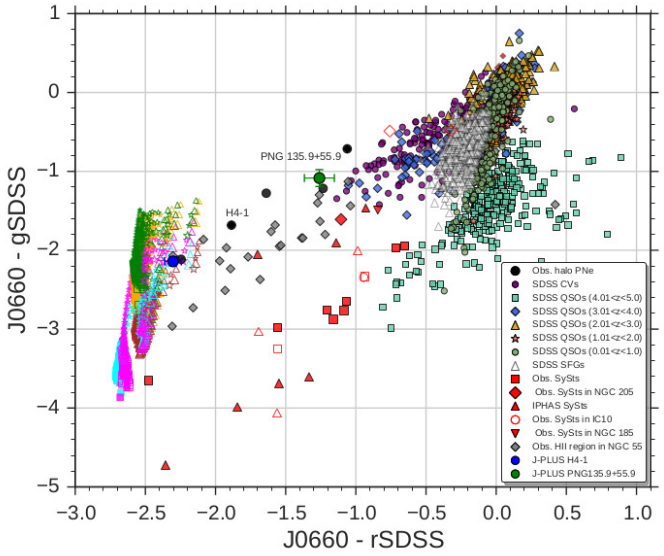

Figure 2. The J-PLUS colour-colour diagram (J0660 – gSDSS) vs (J0660 – rSDSS). The blue and green symbols with errorbars are the J-PLUS observations for H 4-1 and PNG 135.9+55.9 respectively. The rest of the symbols are the same as in Fig. 1.

very close to the regime where halo PNe are expected. The J-PAS colour-colour diagram (J4200 – J5001) vs. (J4200 – J8400) is shown in Fig. 3. The J4200 - J5001 colour is prominent for modelled and some observed halo PNe, due to the strong [O III] emission. The halo PNe MWC 574 and PNG135.9+55.9 are found at the bottom side of the diagram in the regime of QSOs. This may be associated with the very low O abundance in these PNe (e. g. Sandin et al. 2010), which results in a J4200 – J5001 colour index close to zero. A combination of colours from narrow- and broad-band filters seems to be efficient in the identification of PNe.

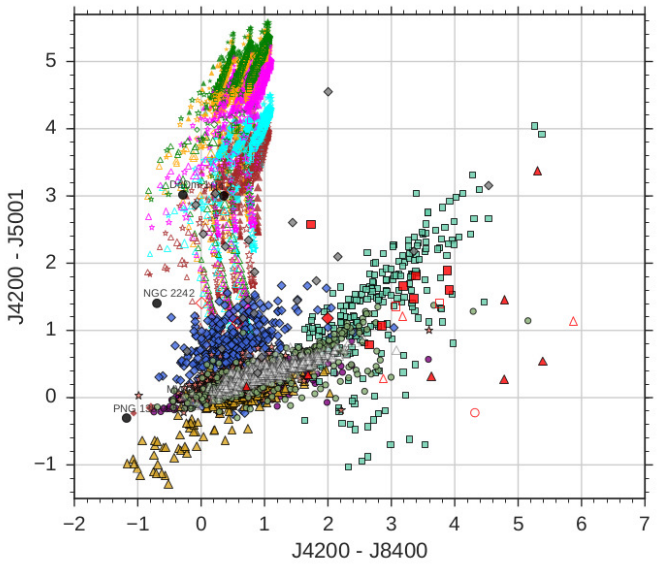

Figure 3. The J-PAS colour-colour diagram (J4200 – J5001) vs (J4200 – J8400). The symbols are the same as in Fig. 1.

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