

# Discovery of a new high-ionization planetary nebula in LAMOST

Luis A. Gutiérrez Soto

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## 1 Introduction

Planetary nebulae (PNe) represent the last stage of evolution of low- and intermediate-mass stars ( $0.8M_{\odot}$  -  $8.0M_{\odot}$ ). The PNe phase begins when gas is ejected from the red giant stars late in their lives and subsequently this gas is ionized by the radiation field coming from the remnant star. An emission nebula expands, a glowing shell of ionized gas until lost in the interstellar medium. Then the dying star core becomes a white dwarf.

The number of the PNe discovered in the galaxy is relatively low ( $\sim 3,500$ ). However, this current number of PNe represents only about 15-30% of the estimated total of Galactic PNe (Frew, 2008; Jacoby et al., 2010) showing that a small fraction of the PNe have been cataloged (Frew, 2017). If this is true, there will be a much larger number of PNe in the Galaxy than if a special condition is required. The models of Moe & De Marco (2006), for example, predict that there are  $46\,000 \pm 22\,000$  for the general case, but only 6600 (De Marco & Moe 2005) if close binaries (e.g. common-envelope phase) are required. Miszalski et al. (2009) confirm earlier estimates that the binary fraction of PN central stars is only 10–20% of all PNe, and thus, binarity is not likely to be a major factor in the formation process. If true, there should be many PNe waiting to be found in the Galaxy. This means that the search for planetary nebulae becoming an important task, that every time is more difficult, due to many of the undiscovered PNe are probably the more distant and then the more the weak. And because many of them, probably, are located in clouds of dust. And note that planetary nebulae only last for about 5,000–25,000 yr (Badenes et al., 2015), making them a very short-lived part of the stellar life cycle. But is important to discover new planetary nebula? the answer could be very obvious and is related with the idea that PNe provide vital clues for the understanding late-stage stellar evolution and Galactic chemical enrichment. Their strong emission lines allow the determination of abundances, expansion and radial velocities, and CSPN temperatures. The PN phase enriches the ISM with nitrogen, carbon, helium, and dust, important components in the formation of future generations of

stars. PNe yield information on the nuclear burning, dredge up, and mass loss in the stellar progenitor (see Kwitter & Henry, 2022 for an excellent recent PN review). Thus, we need to know the number of PNe in the Galaxy in order to develop accurate models of the chemical enrichment rates since the initial burst of Type II supernovae when the Galaxy was young.

PN studies have been hampered by three problems: (i) the previous lack of accurate distances to most Galactic PNe; (ii) obtaining representative PNe samples of the true population diversity (Parker et al., 2022), and (iii) their unknown progenitor masses. The first problem has prospects of resolution via accurate Gaia CSPN distances, though many CSPNe remain too distant and faint for Gaia DR3 and correct CSPN identification remains an issue for some (Parker et al. 2022). The second problem is being addressed by deep, narrow-band, wide-field surveys, e.g., Parker et al. (2005), Drew et al. (2005), and Drew et al. (2014). For the third problem of progenitor masses, these can only be accurately determined for PNe in Galactic globular and open clusters (OCs). These allow precise distance determinations from color–magnitude diagrams (CMD) and Gaia (Fragkou et al., 2022).

## 2 Surveys

### 2.1 GAIA EDR3

### 2.2 Pan-STARRS DR1

### 2.3 LAMOST

The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, also named Guoshoujing Telescope) is a telescope dedicated for spectroscopic sky survey. There are 4000 fibers within a diameter of 1.75 meters (corresponding to  $5^{\circ}$  in the sky) at the focal surface (Cui et al., 2012). The Low-Resolution Spectroscopic Survey (LRS) of LAMOST began in October 2011, with a spectral resolving power ( $R = \lambda/\Delta\lambda$ ) of about 1800 and a wavelength coverage of 3700–9100 Å (Zhao et al., 2012). The first year observation was for the pilot survey (Luo et al. 2012; Zhao et al. 2012), and the regular survey began

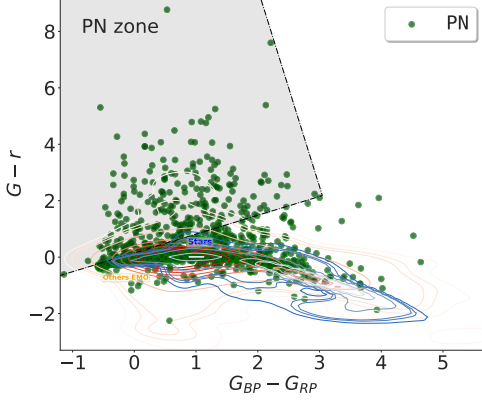


Figure 1:

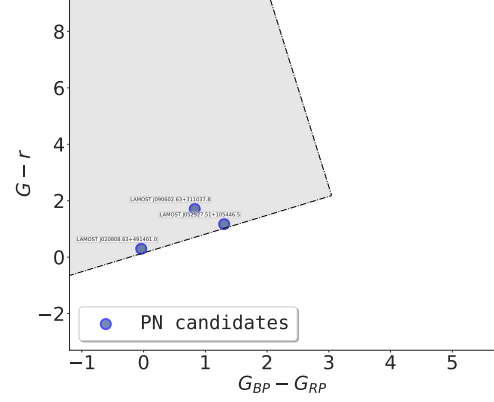


Figure 2:

in September 2012

### 3 Methodology

At the beginning the idea was to identify for new planetary nebula in GAIA. I started to constructed possibles color-color diagrams to separate PNe from other emission lines objects and stars using GAIA only. The separation was not good because PNe, normal stars and other emission line stars like CVs occupy the same region in the diagram. Then, I decided to move to Pan-STARRS and combining the two surveys Pan-STARRS and GAIA. I found one color diagram that isolate the PNe with, I suppose, strong  $H\alpha$  emission line. By using the  $(G - r)$  versus  $(G_{BP} - G_{RP})$  color-color is possible to separate those PNe excess in the in the  $r$ -broad-band filter as is possible to see in the Fig 1. Fig 1 shows that the many of the PNe have value in the color  $G - r = 0$ , however several PNe cover the interval in this same color between 0 and 8, and span between -1 and 5. The orange contours represent other emission line objects that includes CV, SySt, YSOs, AeBe stars and SNRs. The contours becoming white at the outside indicating that the number of objects decrease significantly. And the blue contours signify stars from Gaia Collaboration et al. (2021). Where they occupy the region with  $(G - r) = 0$ .

All indicate that the PNe with strong  $H\alpha$  can be selected with this color criteria?. Then, to see the possibility of using this color criterion to select these PNe, by testing and using the emission line catalog from Škoda et al. (2020). First, they identify emission line objects from LAMOST implementing a machine learning approach. Then, they divided their final sample of emission line objects in tree subgroups. Those with SIMBAD coincidences, those that are listed by Hou et al. (2016) and another list that are neither

cross-matched with SIMBAD nor listed by Hou et al. (2016). To testing the possibility to find for new PNe with the color criteria explained above, we applied it directly in the new list, which present objects not reported previously in the literature, which is a list with 1000 objects.

Four objects met this condition as is possible to see in the Fig 2. We downloaded the low resolution spectra of these objects. Tree objects of them display strong  $H\alpha$ , but are not display the other emission lines topically of PNe like [O III], He II, [S II], among other. But the three look likes as PNe. Because, it displays He II emission lines, the Balmer ones, [O III], among others. Fig 3 the spectra of the new PN finding in the list of emission line of Škoda et al. (2020). This PNe seem a very high ionization object, by eye is possible to see that the He II emission line is as strong as the  $H\beta$  line. Given the LAMOST spectra are not calibrated in flux but they are flux relative, then I think that some ratio line can be calculated. Could be?

The images of the PN called LAMOST J020808.63+491401.0 are shows in Fig 4. *Left panel* exhibits the PanSTARRS coloured images <sup>1</sup>, which was performed by combining the  $g$ ,  $r$  and  $i$  filters in the blue, green and red colour channels, respectively. The image shows clearly a nebular component surrounding a central star. *Right panel* shows the WISE RGB image, with the filter W1, W2, and W4 in the blue, green and red channels, respectively.

### 4 Model

Despite the LAMOST spectra are not in physical flux unity, they have flux relative. This means it

<sup>1</sup>This RGB images were made by implementing the python package `aplpy` (Robitaille, 2019)

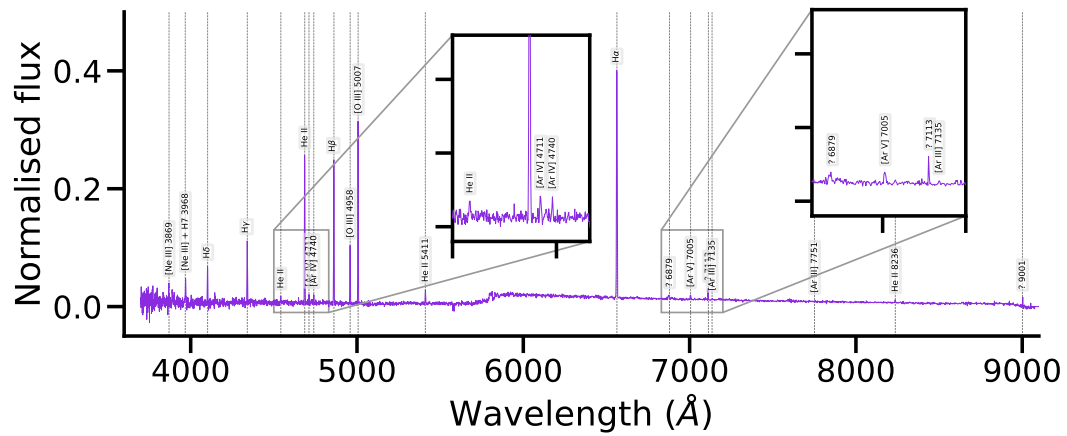


Figure 3:

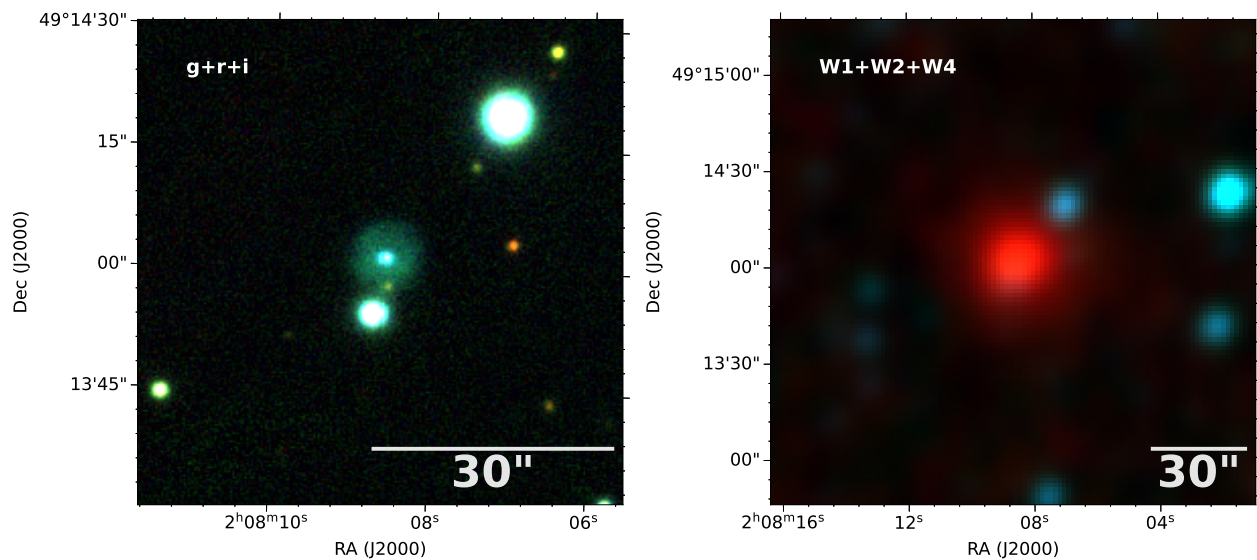


Figure 4:

is possible compare it with other spectra in physical units. For that, I think, it is pertinent to compare the LAMOST spectra of our PN with models. Fig 5 shows a comparison between LAMOST spectra and a CLOUDY modelled spectra from Gutiérrez-Soto et al. (2020). Note that only is an example for illustrative intentions. This model was taken from a grid of models that reproduce spectra from the Galactic halo. For this, it don't exist a real matches between the two spectra. I will a performed a grid of PN models that better reproduce the LAMOST spectra of our candidate. However, almost all the line are reproduce with this model, that could be interesting, because the temperature effective of this model is  $130 \times 10^3 \text{K}$ , indicating a very high excitation object. Maybe, it will be good idea estimate ratio lines to confirm that! is it possible with this spectrum? Voy a crear modelos CLOUDY para intetentar reproducir este espectro.

## 5 Comparing with other PNe

Fig 7

## References

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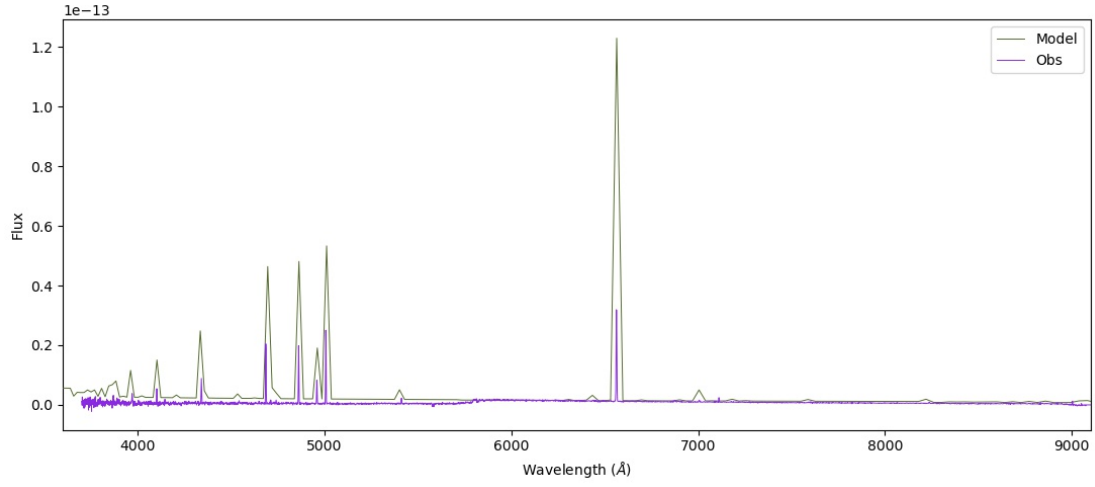


Figure 5:

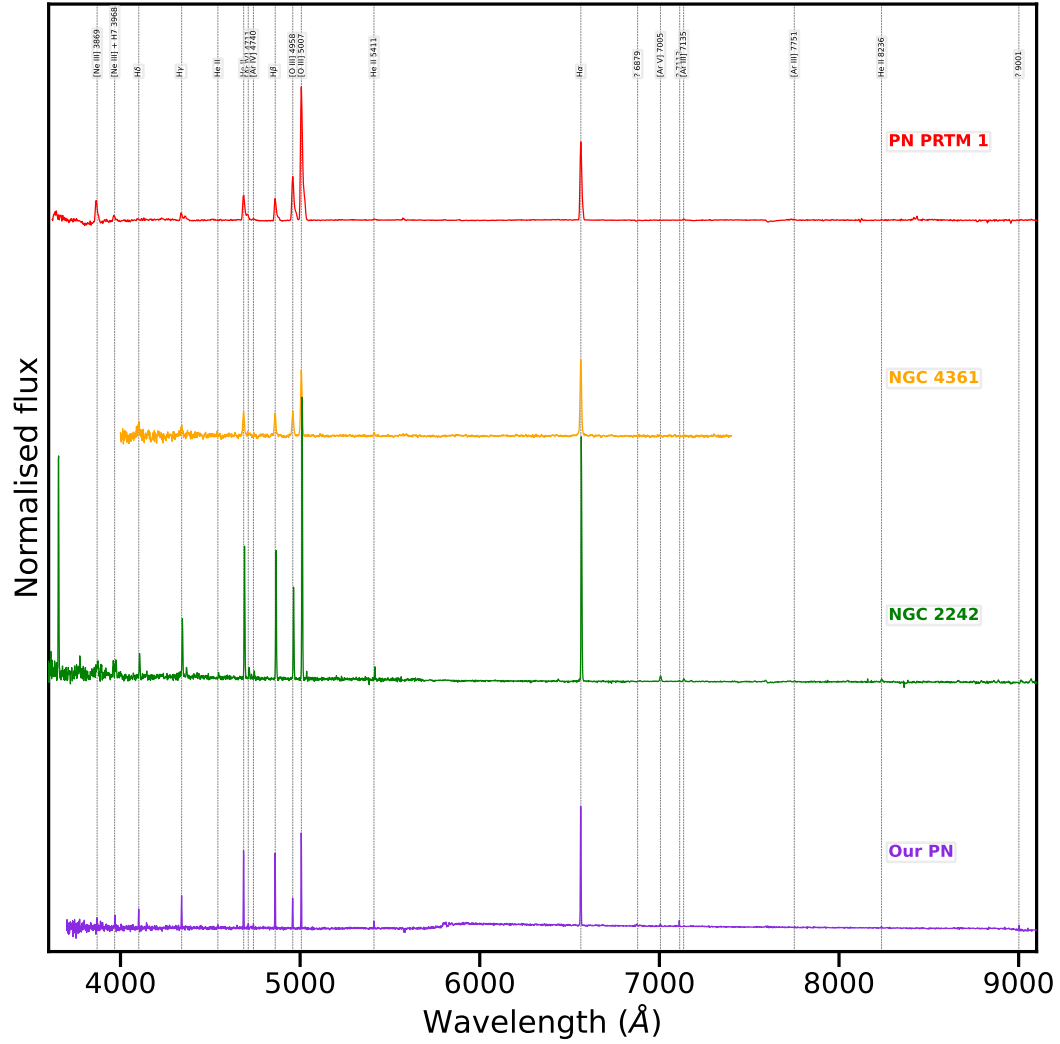


Figure 6: Comparing the new PNe with other high halo palnetary nebulae...

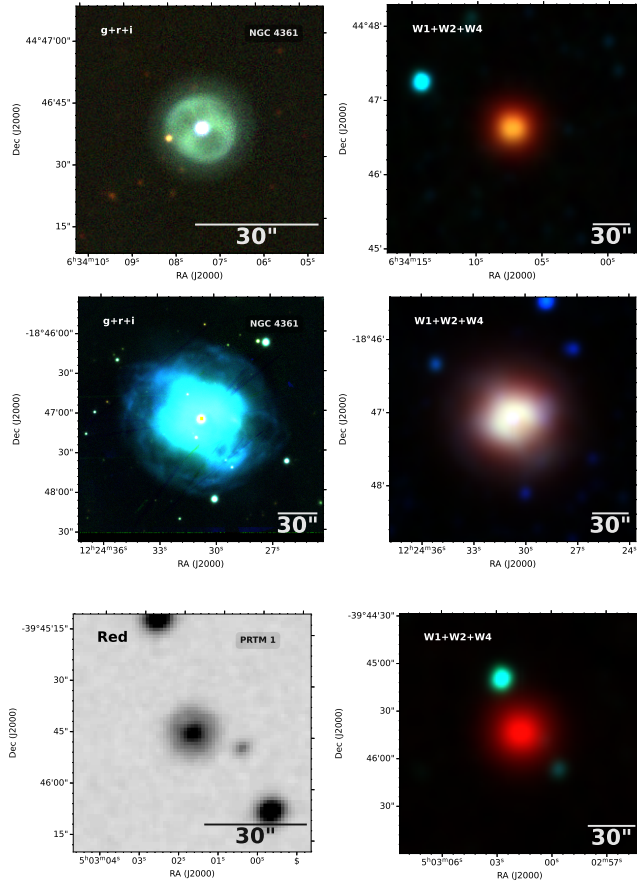


Figure 7: Other high ionization PNe in the optical (*right*) and IR (*left*). For comparison.