*Proceeding Paper*

# Close Binary Stars in Planetary Nebulae through Gaia EDR3 †

**Iker González-Santamaría** [1,2,*], **Minia Manteiga** [2,3] **and Carlos Dafonte** [1,2]

1    Department of Computer Science and Information Technology, Campus Elviña sn, Universidade da Coruña (UDC), 15071 A Coruña, Spain; carlos.dafonte@udc.es
2    CITIC, Centre for Information and Communications Technology Research, Campus de Elviña sn, Universidade da Coruña (UDC), 15071 A Coruña, Spain; manteiga@udc.es
3    Department of Nautical Sciences and Marine Engineering, Universidade da Coruña (UDC), Paseo de Ronda 51, 15011 A Coruña, Spain
*    Correspondence: iker.gonzalez@udc.es
†    Presented at the 4th XoveTIC Conference, A Coruña, Spain, 7–8 October 2021.

**Abstract:** The aim of this work is to search for evidence of close binary stars associated with planetary nebulae (ionized stellar envelopes in expansion) by mining the astronomical archive of Gaia EDR3. For this task, using big data techniques, we selected a sample of central stars of planetary nebulae from almost 2000 million sources in an EDR3 database. Then, we analysed some of their parameters, which could provide clues about the presence of close binary systems, and we ran a statistical test to verify the results. Using this method, we concluded that red stars tend to show more affinity with close binarity than blue ones.

**Keywords:** astrometry; binary stars; Gaia EDR3; planetary nebulae

## 1. Introduction

Planetary Nebulae (PNe) are the stellar objects that are generated when low- and intermediate-mass stars eject and ionize the envelope that surrounds them, reaching their final phase of evolution. In some cases, they come from a binary star system, instead of being generated by a single star. These cases are of special interest, as they can provide information about the morphology, formation and evolution of the PNe [1].

Therefore, the aim of this work is to search for binary stars in PNe, concretely close binary systems, which should have more influence in the PNe than the wide binaries. In these cases, the closeness between both stars allows for mass transfer between them, and this effect could generate a stellar structure made of gas known as a common envelope. This would be the origin of some peculiar PN morphologies, such as bipolar ones (see Figure 1).

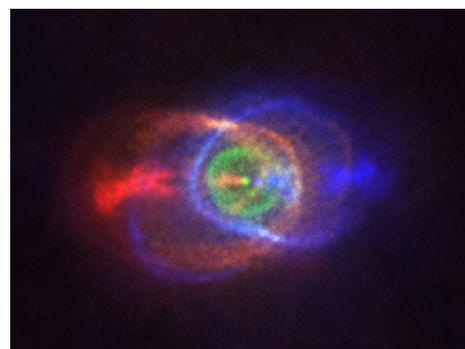

**Figure 1.** Common envelope between both stars in a close binary system.

To carry out this research, we relied on data provided by ESA's Gaia satellite, which was launched at the end of 2013 with the aim of making a star map of the Milky Way.

We made use of the recently published (December 2020) data archive from this mission: Gaia EDR3 (Early Data Release 3). This database contains astrometric and photometric parameters of almost 2000 million stellar objects, so its exploitation requires the use of big data techniques.

## 2. Materials and Methods

The first step was to select a galactic PNe sample on which to analyse the binarity of their Central Stars (CSs). To carry out this data-mining process, we created a cross-match between the PNe coordinates from the literature [2] and sources from the Gaia EDR3 archive. Through this procedure, we obtained a 2035 PNe sample with reliable CS identifications.

The detection of close binary stars is not an easy task, because the proximity between both stellar components means that they cannot be visually resolved as two separate sources. However, it is known that the presence of a companion star can influence the decrease in the astrometric data quality that Gaia measures for the CS. Consequently, to find some evidence of binarity, we analysed certain parameters of the EDR3 database that were related to this detection quality. One of these parameters was astrometric excess noise, which measures the disagreement between the observations of a source and the best-fitting standard astrometric model. Another significant parameter was the Image Parameter Determination (IPD) harmonic amplitude; this measures the deviation in the image centroid fitting. Other parameters that could be considered are uncertainties in the source coordinates, in Right Ascension (RA) and in Declination (Dec) units. We also included the Renormalised Unit Weight Error (RUWE) parameter, which is related to the goodness of fit to the models when a source is detected. As the Gaia satellite is scanning the sky constantly, it takes measurements throughout multiple epochs for each source during its mission. Therefore, the mentioned parameters were calculated by data-mining techniques, considering and processing all the data collected from different epochs.

In addition, the colour of the star could also shed light on the presence of a possible binary system. The CSPNe usually have blue colours (indicators of a high temperature, capable of ionizing the PN). Therefore, stars detected as having reddish colours could be related to the presence of a companion star that is overshadowing, and consequently reddening, the central star. Therefore, with the aim of analysing this possible effect, we decided to separate our PNe sample into two subsets: blue and red stars. Then, in order to independently analyse their relationship with binarity, we calculated the mean values of each Gaia EDR3 parameter given for each subset.

## 3. Results

As a result, we found that the subset of red stars tends to have higher mean values in these quality parameters than the blue stars subset. This means that the quality of measurements is worse in the case of red stars.

We obtained much more astrometric excess noise for red stars than for blue ones, while the IPD harmonic amplitude showed similar values for both subsets, interms of mean. Regarding the coordinate uncertainties and RUWE parameter, we also obtained slightly higher values for red stars than for blue ones. Therefore, red CSPNe would have more probability of belonging to a binary system. In Table 1, the mean values for each parameter in each subset can be observed.

Furthermore, with the aim of corroborating this hypothesis, we performed a Kolmogorov–Smirnov statistical test over these parameters and between both subsets, to analyse the similarity between both samples (red and blue). The $p$-values and D-values obtained from this analysis are shown in Table 1. For $p$-values below 0.1, the null hypothesis that both samples are similar can be rejected, with a significance of 99%. If the corresponding D-value is greater than 0.153, the null hypothesis can be also rejected.

Therefore, all values (except RUWE) indicate a non-similarity between both subsets. This confirms that the subset of red stars tends to have more affinity with binarity than the subset of blue stars.

**Table 1.** Mean values (with uncertainties) of different detection quality parameters for both samples (blue and red stars). In addition, the obtained $p$-values and D-values from a Kolmogorov–Smirnov statistical test between both samples and over those parameters are provided.

| Parameter | Blue Stars | Red Stars | $p$-Value | D-Value |
|---|---|---|---|---|
| Astrometric Excess Noise | 0.287 (0.060) | 0.393 (0.076) | 0 | 0.358 |
| IPD Harmonic Amplitude | 0.043 (0.015) | 0.043 (0.013) | 0 | 0.217 |
| RA error | 0.047 (0.013) | 0.053 (0.017) | 0.001 | 0.177 |
| Dec error | 0.044 (0.010) | 0.049 (0.015) | 0.001 | 0.189 |
| RUWE | 1.013 (0.051) | 1.059 (0.042) | 0.080 | 0.117 |

## 4. Discussion

Using Gaia accurate astrometry and data-mining methods, we were able to collect a PNe sample with reliable CS identifications, from almost 2000 million sources in Gaia EDR3 database.

Then, using this sample, we carried out a statistical analysis of several quality parameters, which enabled us to clarify which type of star has a higher possibility of forming a close binary system. In this type of system, both components cannot be visualised as separate sources, and it may be necessary to apply a statistical method to draw any conclusions.

Next year, with the launch of Gaia DR3, a greater quantity of astrometric and photometric data are expected, with increased accuracy. This will allow us to shed more light on the close binarity in PNe.

**Author Contributions:** Conceptualization, M.M.; methodology, I.G.-S. and M.M.; software, I.G.-S.; investigation, I.G.-S., M.M. and C.D.; writing—original draft preparation, I.G.-S.; writing—review and editing, M.M. and C.D.; supervision, M.M. and C.D. All authors have read and agreed to the published version of the manuscript.

**Data Availability Statement:** This research has made use of data from the European Space Agency (ESA) Gaia mission, processed by the Gaia Data Processing and Analysis Consortium (DPAC): [https://gea.esac.esa.int/archive/] .

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Boffin, H.M.J.; Jones, D. *The Importance of Binaries in the Formation and Evolution of Planetary Nebulae*; Springer: Berlin/Heidelberg, Germany, 2019. [CrossRef]
2. Parker, Q.A.; Bojicic, I.S.; Frew, D.J. HASH: The Hong Kong/AAO/Strasbourg $H_\alpha$ planetary nebula database. *J. Phys. Conf. Ser.* **2016**, *728*, 032008. [CrossRef]