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Mining of the Milky Way Star Archive Gaia-DR2. Searching for Binary Stars in Planetary Nebulae †

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Abstract: The aim of this work is to search for binary stars associated to planetary nebulae (ionized stellar envelopes in expansion), by mining the astronomical archive of Gaia DR2, that is composed by around 1.7 billion stellar sources. For this task, we selected those objects with coincident astrometric parameters (parallaxes and proper motions) with the corresponding central star, among a sample of 211 planetary nebulae. By this method, we found eight binary systems, and we obtained their components positions, separations, temperatures and luminosities, as well as some of their masses and ages. In addition, we estimated the probability for each companion star of having been detected by chance and we analyzed how the number of false matches increase as the separation distance between both stars gets larger. All these procedures have been carried out making use of data mining techniques.

Keywords: Gaia DR2; planetary nebulae; binary stars; astrometry

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1. Introduction

This work is focused on the study and analysis of planetary nebulae (PNe), the stellar objects that are generated when stars of low and intermediate mass, reaching their final phase of evolution, ionize the envelope that surrounds them. For this task, we have used the Gaia Data Release 2 (GDR2) database, which contains astrometric and photometric parameters of around 1.7 billion stellar objects, so its mining requires the use of big-data techniques. Gaia is an ESA satellite that was put into orbit in late 2013 with the aim of making a star map of the Milky Way.

The initial objective of our study was to generate a catalog of PNe, starting from different bibliographic sources and identifying their corresponding central stars (CSs) in Gaia DR2. To carry out this data mining process, we performed a cross-match between the known coordinates of the PNe and the coordinates of the sources in the Gaia DR2 database. As a result, a total of 1571 CSs with known parallaxes (angle of variation in the sky when observing an object between two opposite times of the year) were identified. From the parallaxes we can derive the distances at which the objects are. To do this, we use a Bayesian statistical approximation method, which assumes an exponentially decreasing probability density space for distances. Knowing the distance to the PNe has a great importance, since it allows us to calculate the intrinsic parameters of its CS from the observational ones. For a more detailed study, we selected those objects with the best astrometric accuracy, we called this sample the Golden Astrometry Planetary Nebulae (GAPN).

The Gaia archive also allows to search for stars gravitationally linked to the CSs of these PNe, which would form a binary star system. The presence of binary stars in PNe allow us to better understand the formation and evolution of this late stellar evolutionary phase, Boffin [1]. It can also shed some light on its relationship with the aspherical morphologies of PNe.

2. Materials and Methods

The extremely precise measurements of parallaxes and proper motions (velocities in the plane of the sky) in Gaia DR2 has allowed us to search for co-moving stars in a region around each CS of the GAPN sample. Thus, we analyzed all the objects around each CS, and we selected those with coincidence in the astrometric parameters (parallaxes and proper motions) within their measurement errors, which would allow them to be classified as co-moving stars. To discard random coincidences, the probability density of the astrometric values in each field around the CSs was calculated, and the probability of finding an object with such coincident values with those of the CS was calculated, obtaining very low, practically negligible probabilities.

In addition, we also did an analysis about how the number of false matches increases as a function of the increase in the separation distance between both stars. To estimate this number of false matches, we analyzed an adjacent region to that of the CS with the same searching radius as the original region, and we obtained the number of co-moving objects to the CS in this area. By plotting the distribution of these false matches against the separation distance between the two stars, we were able to determine a maximum separation value for our selection of binary systems.

3. Results

By applying this searching procedure, we have been able to find eight binary systems as CSs of the PNe in our sample, with projected separations of less than 15,000 AU. One of them could even be a triple system. We have determined some astrometric parameters of these binary systems, as positions, proper motions or angular and physical separations. All these values can be consulted in Table 1.

Table 1. Astrometric data of the central and companion stars of each system.

Object	RA (°)	Dec (°)	Parallax (mas)	Distance (pc)	Sep. (AU)	PM_{RA} (mas/yr)	PM_{Dec} (mas/yr)
Abell 24 (CS)	117.9065	3.0059	1.40 ± 0.15	691^{+70}_{-59}	-	-4.37 ± 0.23	-0.75 ± 0.14
Abell 24 (B)	117.9067	3.0021	1.32 ± 0.07	725^{+29}_{-27}	9912	-4.25 ± 0.11	-0.97 ± 0.09
Abell 33 (CS)	144.788	-2.8084	1.01 ± 0.10	932^{+77}_{-67}	-	-14.76 ± 0.17	9.42 ± 0.15
Abell 33 (B)	144.7878	-2.8089	1.11 ± 0.09	856^{+57}_{-51}	1542	-14.94 ± 0.15	9.62 ± 0.14
Abell 34 (CS)	146.3973	-13.1711	0.83 ± 0.12	1118^{+144}_{-115}	-	3.08 ± 0.19	-9.13 ± 0.24
Abell 34 (B)	146.3954	-13.1693	0.81 ± 0.06	1155^{+56}_{-51}	10,472	3.23 ± 0.09	-9.11 ± 0.11
NGC 246 (CS)	11.7639	-11.872	1.92 ± 0.11	506^{+70}_{-59}	-	-16.96 ± 0.22	-8.88 ± 0.13
NGC 246 (B)	11.7647	-11.8727	1.77 ± 0.06	547^{+10}_{-10}	2118	-16.61 ± 0.09	-8.76 ± 0.08
NGC 3699 (CS)	171.991	-59.9579	0.62 ± 0.11	1506^{+279}_{-205}	–	-3.19 ± 0.16	1.14 ± 0.15
NGC 3699 (B)	171.9922	-59.9585	0.58 ± 0.07	1571^{+146}_{-123}	5036	-3.22 ± 0.10	1.07 ± 0.10
NGC 6853 (CS)	299.9016	22.7212	2.63 ± 0.06	372^{+6}_{-6}	-	10.39 ± 0.09	3.66 ± 0.09
NGC 6853 (B)	299.9005	22.7197	2.56 ± 0.06	382^{+7}_{-6}	2453	10.22 ± 0.09	3.81 ± 0.09
NGC 6853 (C)	299.8997	22.7202	2.30 ± 0.52	457^{+181}_{-101}	3322	9.13 ± 0.64	3.78 ± 0.78
PHR J1129-6012 (CS)	172.4594	-60.2022	0.41 ± 0.09	2159^{+448}_{-320}	-	-6.64 ± 0.14	2.34 ± 0.12
PHR J1129-6012 (B)	172.4573	-60.2022	0.35 ± 0.09	2482^{+576}_{-400}	9551	-6.84 ± 0.38	2.70 ± 0.12
PN SB 36 (CS)	268.5868	-39.1772	0.57 ± 0.08	1610^{+192}_{-156}	-	4.43 ± 0.11	-4.75 ± 0.10
PN SB 36 (B)	268.5831	-39.1761	0.70 ± 0.08	1331^{+128}_{-108}	14,880	4.43 ± 0.10	-4.78 ± 0.09

In addition, by obtaining the photometry of the companion stars, we were able to adjust their spectral energy distributions (SED) to theoretical models and then estimate their temperatures and luminosities. Moreover, by locating the companion stars in a color-magnitude diagram together with the PARSEC isochrones in Gaia DR2 passbands (Evans [2]), we could estimate some of their evolutionary ages and masses. Thus, we had the possibility to compare all these parameters with the CSs ones, obtained in our previous work, González-Santamaría [3].

4. Discussion

By using data mining methods and the accurate astrometry of Gaia, we have been able to select a small sample of CSPNe, with known and precise parallaxes, among a total of around 1.7 billion sources in Gaia DR2 database. Then, we have had the possibility to estimate their distances, and this knowledge has enabled us to derive their intrinsic properties from the observational ones.

Furthermore, the combination of the parallaxes with the proper motions has allowed us to search for companion stars to the CSs. We have applied quite strict selection criteria in order to avoid selecting any false co-moving object. We also have used a big-data method to estimate the probability of having select by chance any of the companion stars, by analysing the probability distribution of the astrometric parameters in the field around each of the CSs.

In the near future, with the launching of Gaia DR3, it is expected to be more quantity of astrometric data and with more accuracy. This will allow us to detect more binary systems associated to PNe.

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

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