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On behalf of Galician Gaia Group

Galactic PNe CS properties and binarity from Gaia EDR3 astrometry and photometry

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Astronomy for All
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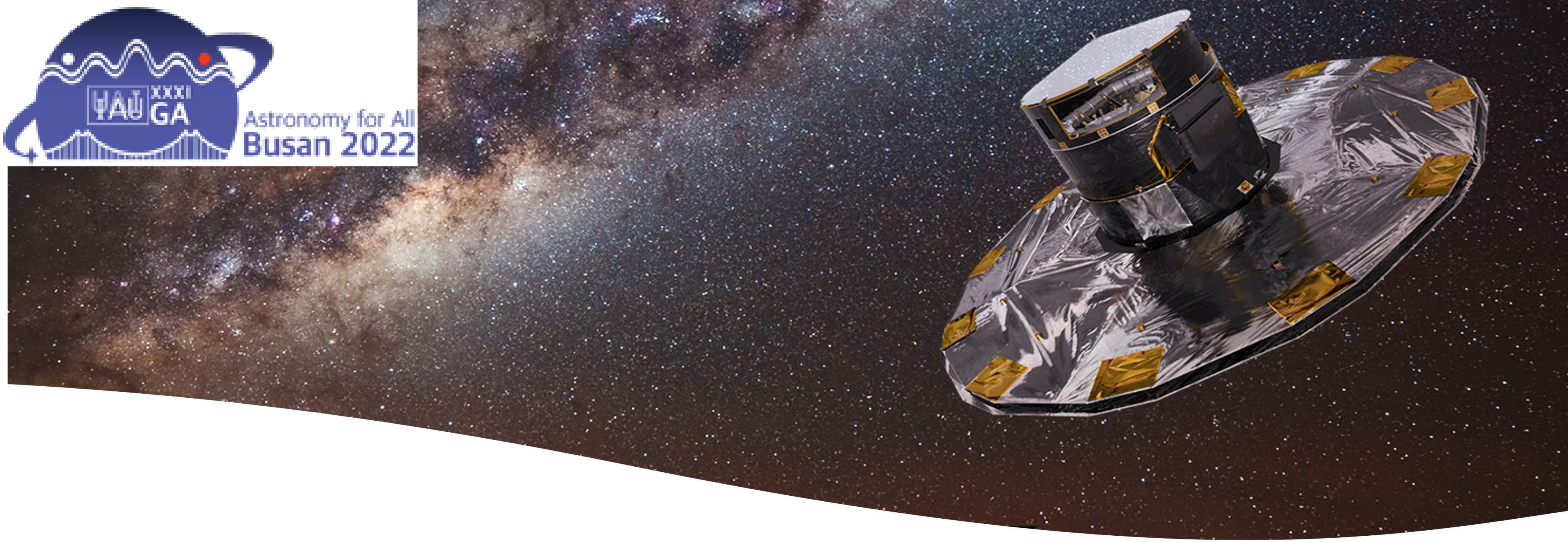


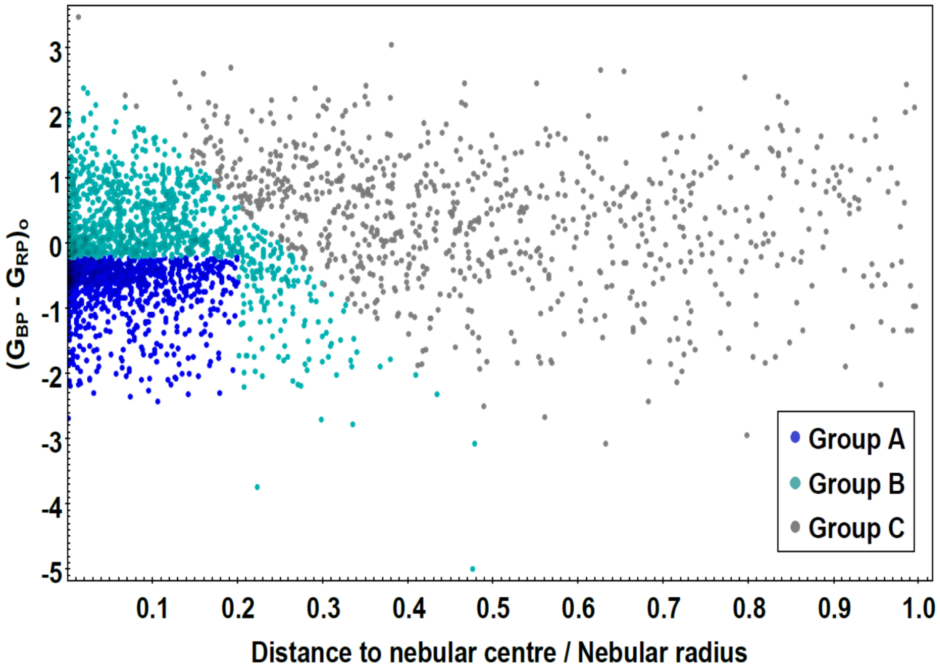
Aim:

1. Check PNe CS identification using Gaia Π and XP colors
2. Calculate distances, nebular sizes and luminosities
3. Locate CS in a HRD and obtain evolutionary parameters
4. Check consistency of spectral types and sizes with evolutionary ages
5. Incidence of binarity: Π+PMs → co-moving objects
   Astrometric quality → close binaries

1.- PNe CS identification using Gaia P and XP colors

- Problems in the dentification of CSPNe: intrinsically faint and hot (blue) stars, nebular emission
- Gaia provides colors and brightnesses for objects in the nebular field to about G=20

→ (GBP-GRP) and r/R can be used to propose CS candidates. Important: correct for reddening



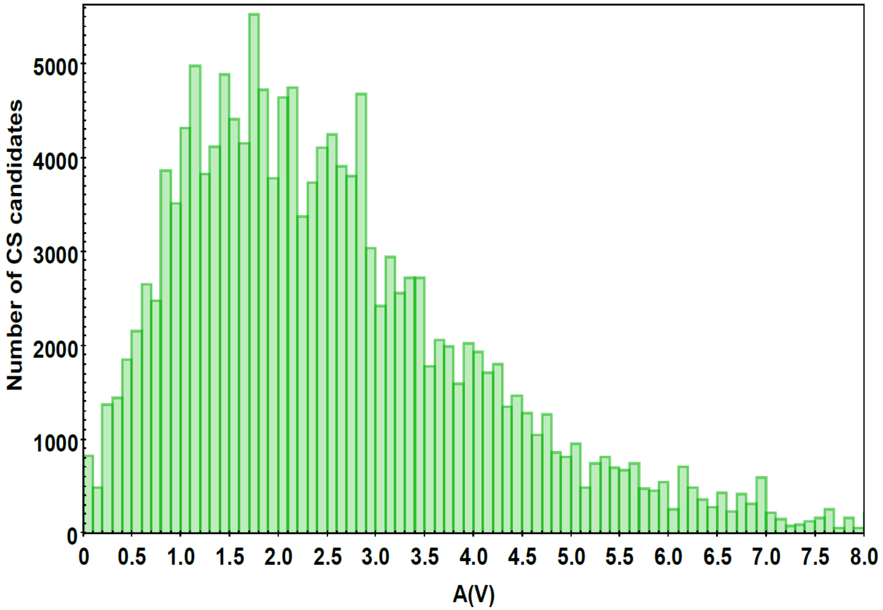


Fig. 1. Interstellar extinction distribution for all CS candidates. Obtained from Bayestar and SFD dust maps.

1.- PNe CS identification using Gaia P and XP colors

- Second step: selection based on EDR3 astrometric quality (RUWE, UWE, 30% relative errors) → sample of 405 Golden-EDR3 CSPNe (64% in group A)
- Distances obtained from a Bayesian approach by Bailer-Jones et al 2021, mean physical radii calculated

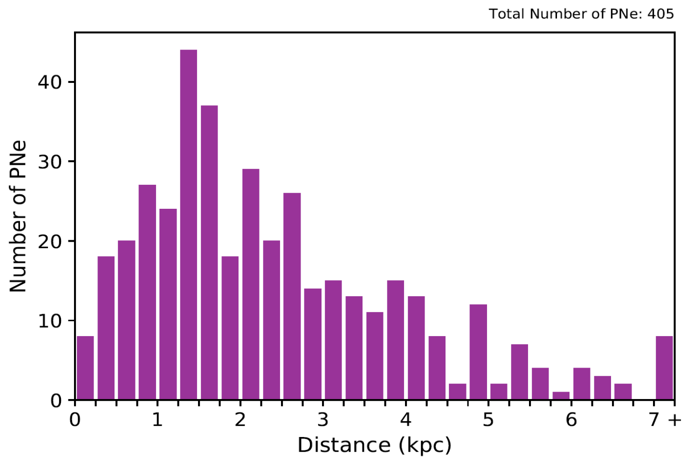


Fig. 5. Distance distribution of the GAPN-EDR3 sample.

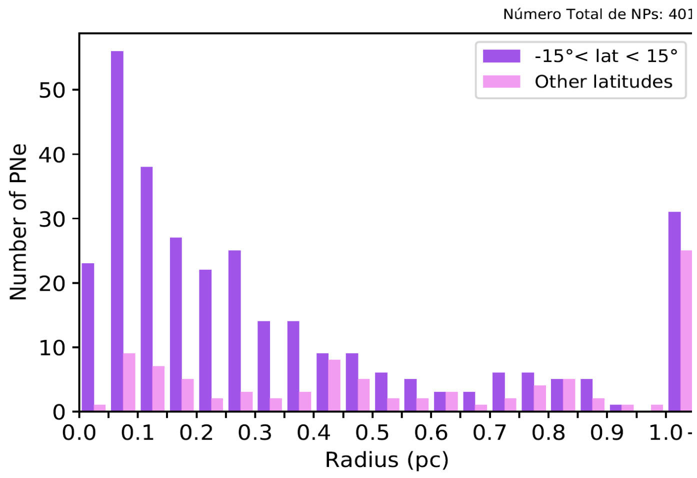
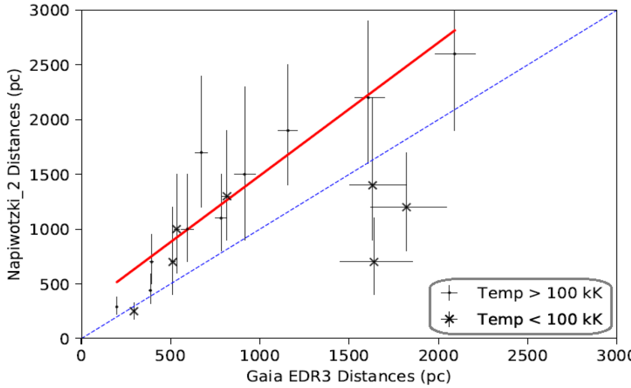
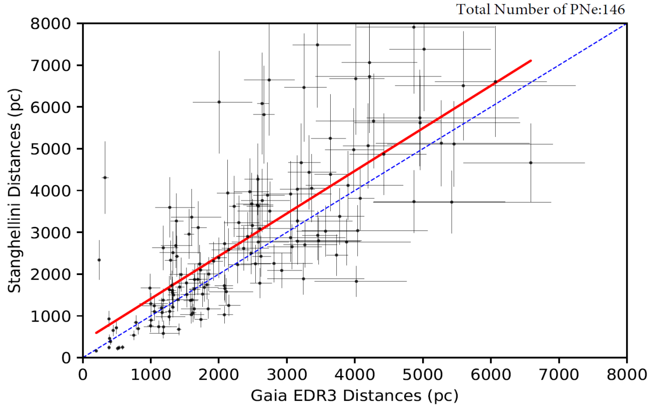


Fig. 12. Radius distribution of the GAPN-EDR3 sample.

- Comparison of EDR3 distances with other indirect methods





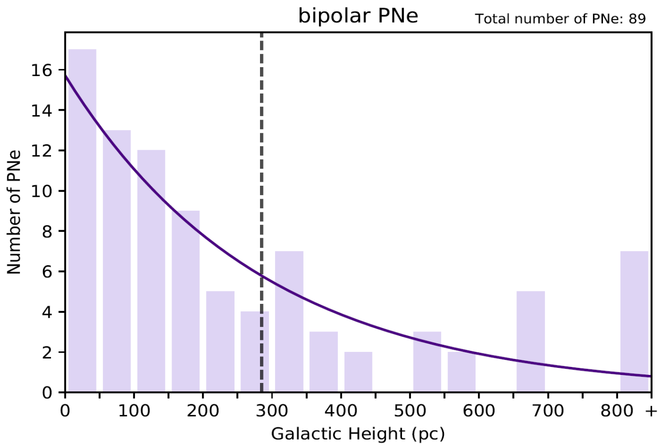
2.- Sizes + radial velocities: kinematical ages and "PNe visibility time"

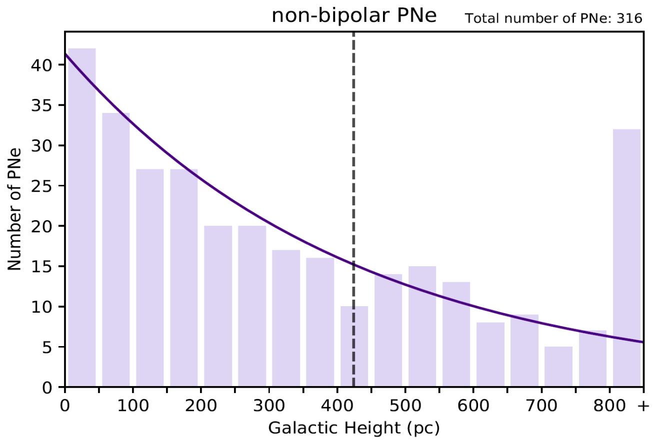
- From literature radial velocities and nebular sizes kinematical ages can be calculated, and then "PNe visibility time" as: $T_{\rm vis} = \frac{R_{\rm max}}{\langle V_{\rm exp} \rangle} = 27.8 \pm 11.7\,{\rm kyr}.$

- We also explore the relationship between morphology

and Galactic heigth

$$H_z^{\rm bipolar} = 285 \pm 8\,{\rm pc},$$
$$H_z^{\rm non-bipolar} = 424 \pm 7\,{\rm pc}.$$





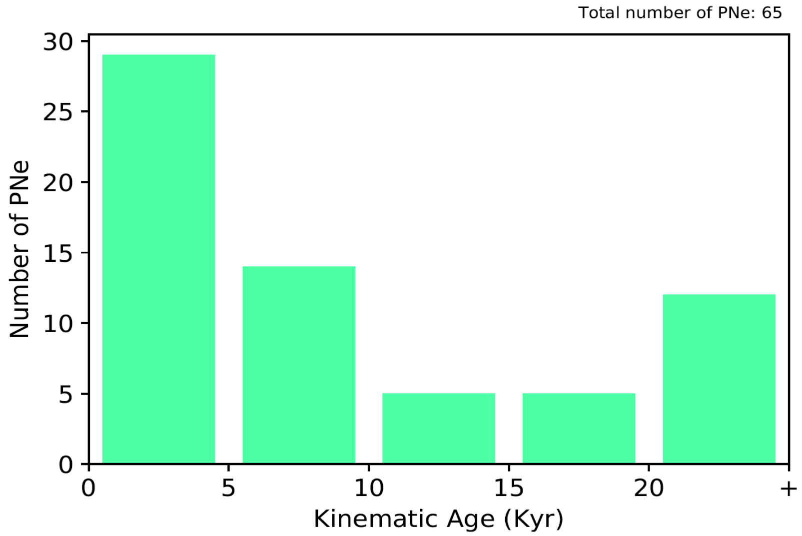


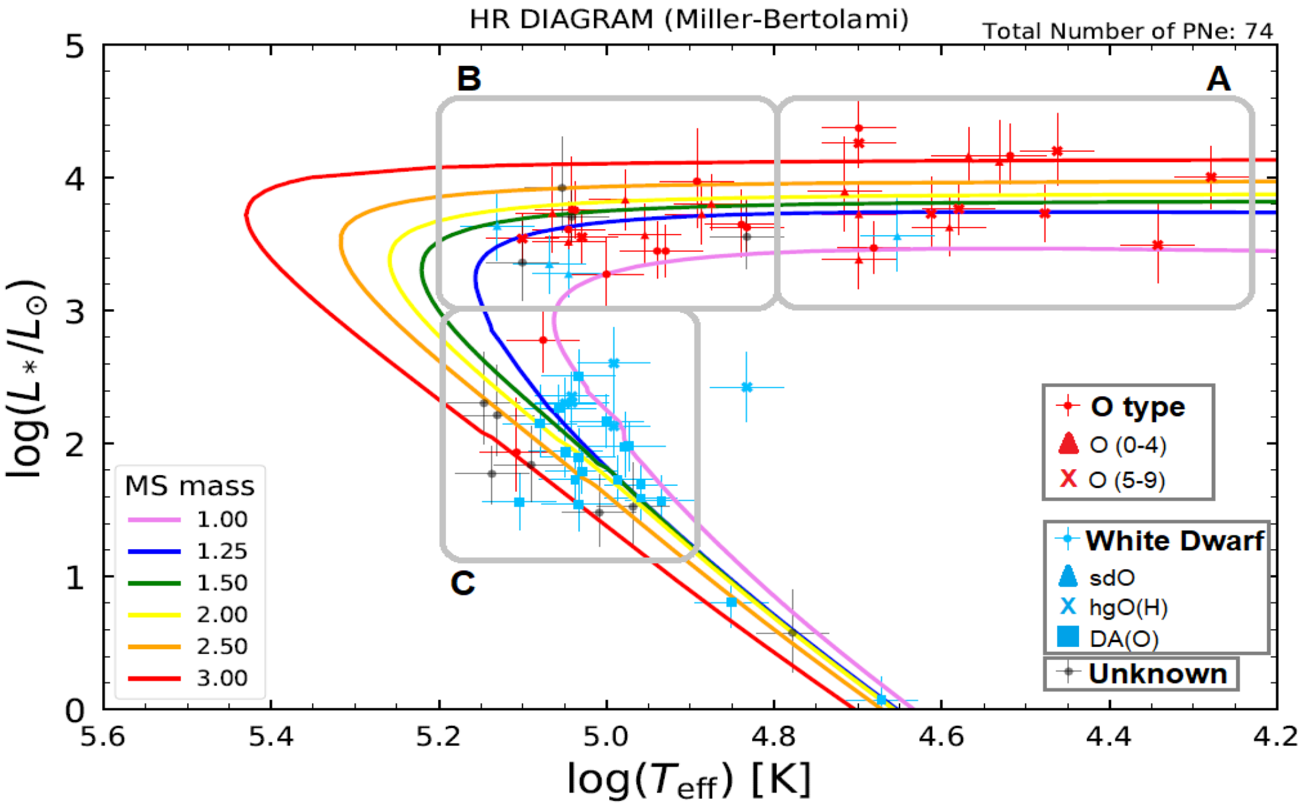
Fig. 16. Kinematic age distribution of 65 objects selected from the GAPN-EDR3 sample.

3.-HDR location and evolutionary parameters

- Gaia distances can be used to update luminosities values while temperatures were taken from the literature (Zanstra method). CS are too hot to use DPAC CU8 parameterizations. We checked the reliability of the CS identification. We also plot CS spectral classifications (Weidman, 2020) and Miller-Bertolami (2016) evolutionary tracks for post-AGB stars.

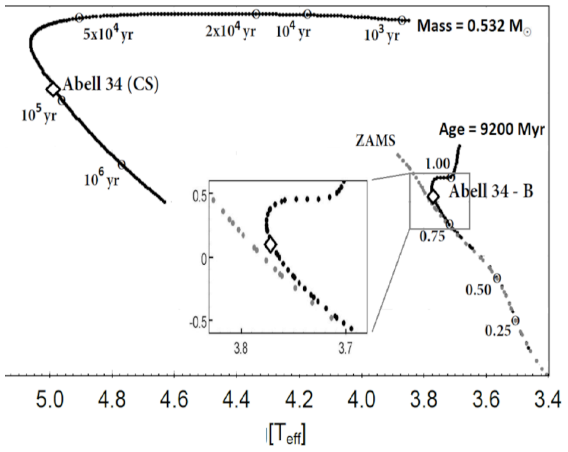
Table 1. Mean values (with uncertainties) of different parameters in three regions of the HR diagram.

Parameter	Region A	Region B	Region C
Number of PNe	*17*	*24*	*29*
$\langle R \rangle$ (pc)	0.08 (0.02)	0.23 (0.13)	0.75 (0.32)
$\langle T_{\rm eff} \rangle$ (kK)	39 (9)	100 (17)	109 (11)
$\langle M \rangle$ ($M_\odot$)	1.98 (0.50)	1.57 (0.42)	1.87 (0.62)
$\langle T_{\rm evo} \rangle$ (kyr)	16.0 (3.8)	22.0 (1.5)	53.5 (30.3)
$\langle T_{\rm kin} \rangle$ (kyr)	5.5 (2.5)	6.4 (1.9)	34.7 (8.9)



4.-Incidence of binarity: co-moving objects

- Gaia astrometry, Π+PMs, can be used to search for wide binaries among EDR3 Golde sample of CSPNe: coincidence of three astrometric measures within 2,5 σ times the uncertainty
- 8 co-moving systems with r≤ 20 000 AU



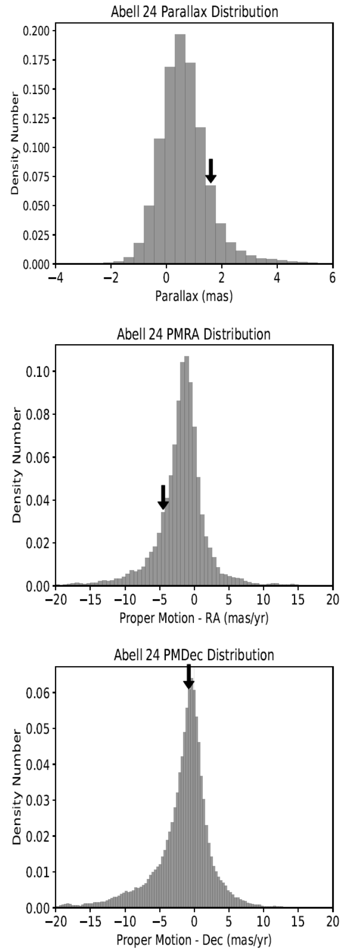


Table 3. Data from new binary systems detected in GAPN-EDR3.

Object	RA (°)	Dec (°)	Separation (AU)	Distance (pc)	Parallax (mas)	PM$_{RA}$ (mas yr^{-1})	PM$_{Dec}$ (mas yr^{-1})	$G_{BP}-G_{RP}$ (mag)
NGC 6720 (CS)	283.3962	33.0291	–	783^{+29}_{-32}	1.29 ± 0.05	1.73 ± 0.08	2.36 ± 0.08	−0.79
NGC 6720 – B	283.3915	33.0324	14 448	1093^{+346}_{-220}	1.05 ± 0.26	1.22 ± 0.24	2.56 ± 0.24	−0.23
NGC 6781 (CS)	289.6170	6.5387	–	494^{+19}_{-19}	2.03 ± 0.07	-6.93 ± 0.11	-4.17 ± 0.09	−0.51
NGC 6781 – B	289.6189	6.54012	4139	470^{+34}_{-29}	2.15 ± 0.19	-6.64 ± 0.19	-3.79 ± 0.16	2.66
PN G030.8+03.4a (CS)	278.8805	−0.2640	–	546^{+82}_{-53}	1.92 ± 0.27	2.01 ± 0.22	-8.85 ± 0.18	0.43
PN G030.8+03.4a – B	278.8800	−0.2612	5425	533^{+169}_{-98}	2.18 ± 0.44	2.66 ± 0.35	-8.51 ± 0.29	1.66
Possible Triple System								
Fr 2–42 (CS)	298.4000	−10.3255	–	129^{+1}_{-1}	7.76 ± 0.06	-11.48 ± 0.09	-16.52 ± 0.08	−0.23
Fr 2–42 – B	298.4001	−10.3249	304	130^{+1}_{-1}	7.68 ± 0.06	-10.92 ± 0.09	-15.78 ± 0.08	−0.20
Fr 2–42 – C	298.3880	−10.3320	6528	128^{+1}_{-1}	7.78 ± 0.10	-10.96 ± 0.12	-16.14 ± 0.09	−0.03

Notes. All parameters are obtained or derived from *Gaia* EDR3. Colours are extinction corrected.

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4.-Incidence of binarity: unresolved pairs

Even though binary stars with separations of less than 0.18–0.60 arcsec are not included as separated sources in *Gaia* EDR3 (Lindegren et al. 2021), the excellent quality of *Gaia's* source detection algorithm, the crossmatch procedure, and the joint astrometric solution for parallaxes and proper motions allow us to address the detection of close binarity signs in our set of CSs by analysing the statistics of these measurements.

- Blue, (GBP-GRP) ≤ -0,2 and red stars have different statistics in Gaia astrometric quality parameters

- Red CS have noisier astrometry, and also higher photometric uncertainty

→ It is posible that red CS are close binary systems

Table 4. Mean values (with uncertainties) of the astrometric and image-fitting quality parameters for blue and red CSPNe samples.

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

Notes. *p*-values and *D*-values from a Kolmogorov–Smirnov statistical test between both samples and over those parameters, are provided.

5.- Conclusions

- Gaia astrometry, Π+PMs, **allowed a comprehensive análisis of the Galactic PN system**, that we estimate to be complete to within **2 Kpc**.
- Gaia made it possible to confirm the **identification of the CSPNe**, determine their distances and sizes, recalculate their luminosities and kinematical ages, and study in detail their evolutionary status.
- We found that the "**visibility time**" of Galactic PNe is around 28 000 years, the mean radius is 0,5 pc and 50% have evolutionary ages below 10 Kyrs
- Gaia astrometry allowed the discovery of 8 **co-moving pairs**, and several triple systems
- Statistics on the astrometric and photometric quality parameters (from epoch measurements) give relevant information about CSPNe with central "red" stars: their parameters are noisier and they are drawn from a statistically different sample, confirming that Gaia epoch observations will help us to study **the incidence of close binaries among CSPNe**.

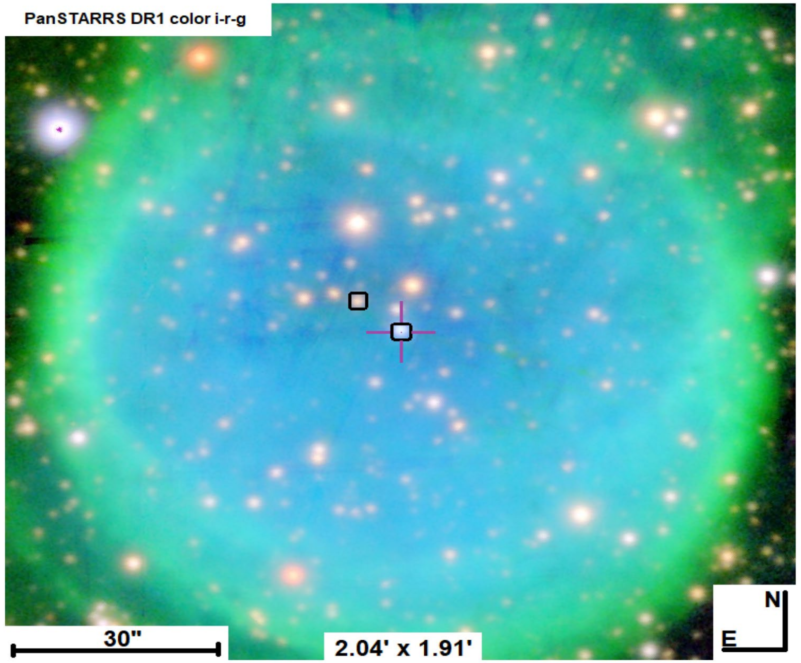

Fig. 22. Image of a possible binary system in NGC 6781, showing the location of both the CSPN (with a cross) and the comoving companion. Image from the *Aladin* sky atlas (CDS).

References:

Gonzalez-Santamaría et al.

A&A 656, A51 (2021)
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