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Galactic planetary nebulae as absolute probes: The view from Gaia

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Abstract. We searched the first Gaia data release for Galactic central stars of planetary nebulae (CSPNe) for parallaxes in order to determine the distances of the hosting PNe. For the small sample of PNe for which a comparison is available, we show that distances derived from Gaia parallaxes agree, within the uncertainties, with the individual PN distances derived by other reliable methods. While Gaia parallaxes available for Galactic CSPNe are still few, and with high uncertainties, we studied the possibility of building a PN distance scale by using the Gaia distances as calibrators. We found that a scale built on the relation between the linear nebular radius and its surface brightness has promising future applications.

Keywords. planetary nebulae: general; stars: distances

1. Motivation

Distances are among the most important basic parameters needed to study the physics of planetary nebulae (PNe) and their central stars (CSs). Large sample of Galactic PNe with reliable individual distances are sought for in a variety of applications. Distances to PNe have been derived from spectroscopic binary CSs, cluster membership, reddening, and nebular expansion, in ~ 40 Galactic PNe (see Stanghellini *et al.* 2008, and references therein), which represents a small fraction of the sample of several hundred, spectroscopy-confirmed Galactic PNe (Frew *et al.* 2016). Statistical distances, calibrated on these known distances, are commonly used. The problem with some of the statistical distance calibrators is that they rely at some level on modeling and assumptions. For example, reddening distances assume that the interstellar absorption toward a PN is similar to that of nearby stars, and does not account for possible patchiness in the ISM, while expansion distances assume that PN ejecta evolve homogeneously without acceleration. As a consequence, both the individual distances and the distance scale derived based on those can be severely misleading. The best individual distances are those derived for spectroscopic binary CSs, but only few of those are available to date.

2. Parallaxes of CSPNe in the first Gaia data release

The first Gaia data release (DR1, Gaia Collaboration *et al.* 2016) a few weeks ago has allowed us to retrieve the CSPN parallaxes that have been measured by Gaia with sufficiently low uncertainties to allow a distance determination. By searching DR1 against the

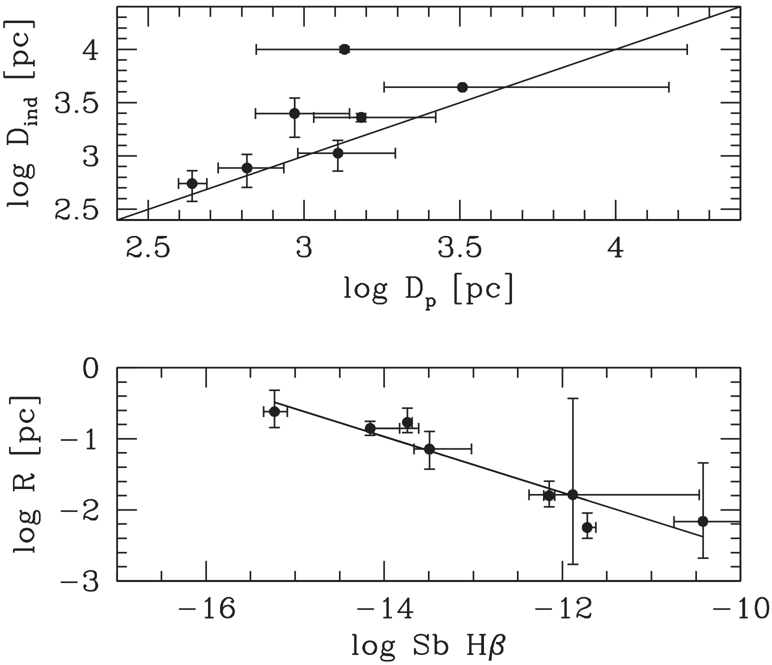

Figure 1. Top panel: Comparison between Gaia parallax distances and independent distances, as given in Table 1. Bottom panel: The physical radius – surface brightness relation obtained by calibrating with Gaia parallaxes. The resulting linear fit of the data, log R [pc] = -0.4 log Sb Hβ - 6.5, is an initial guess of the Galactic PN distance scale derived from the first Gaia release. Excluding Sa St 2-12 from the fit does not vary the correlation significantly.

astrometric positions corresponding to spectroscopically confirmed Galactic PNe (Acker *et al.* 1992, and updates) we found parallaxes for 8 CSPNe whose uncertainties are below 100%, thus usable for a positive distance determination. In Table 1 we list these targets (Cols. 1 and 2), the measured parallaxes of their CSs (3), their distances derived from Gaia parallaxes (4), and, if available in the literature, the independent distances (5), with the reference coded in Column (6). Independent distances are from spectroscopic parallaxes, except for M 1-77 and NGC 2346, whose distances are derived with the extinction method. Note that the distance to Su Wt 2 may refer to a companion star rather than the CS. It is also worth noting that the PN nature of Sa St 2-12 may be uncertain. The high relative error of trigonometric parallaxes and the non-linear relations among the physical parameters forbid a direct application of the first-order error propagation formula; left and right (asymmetric) error bars are therefore estimated by inserting $x \pm \sigma(x)$ into the corresponding functional relation, $\sigma(x)$ being the known standard deviation of the observed quantity x. Gaia parallax distances of CSPN span a broad range, and they agree with other independent distances within the errors, as shown in Fig. 1, where we plotted the available independent distances for the Gaia PN set against the best individual distances available in the literature. The best match is for nearby PNe, as expected, but even for PC 11, for which CS spectroscopy sets it at 10,000 pc, the two distances agree within the large parallax uncertainties. Note that all errorbars of the independent distances do not account for the intrinsic method uncertainties,

Table 1. Distance of Galactic PNe from Gaia parallaxes and from other methods.

Name	**Alias**	**p±σ(p)** [mas]	**log(D$_{\rm p}$)** [pc]	**log(D$_{\rm ind}$)** [pc]	ref
PN G038.2+12.0	Cn 3-1	1.932±0.656	$2.71^{+0.18}_{-0.13}$	...	...
PN G089.3-02.2	M 1-77	1.072±0.357	$2.97^{+0.18}_{-0.13}$	$3.025^{+0.15}_{-0.22}$	HW88
PN G165.5-15.2	NGC 1514	2.286±0.239	$2.64^{+0.05}_{-0.04}$	$2.74^{+0.12}_{-0.17}$	A15
PN G215.6+03.6	NGC 2346	0.778±0.269	$3.11^{+0.18}_{-0.13}$	$3.025^{+0.12}_{-0.17}$	G86
PN G272.1+12.3	NGC 3132	1.524±0.364	$2.82^{+0.12}_{-0.09}$	$2.89^{+0.13}_{-0.18}$	C99
PN G311.0+02.4	Su Wt 2	0.655±0.277	$3.18^{+0.24}_{-0.15}$	3.36±0.04	E10
PN G331.1-05.7	PC 11	0.741±0.682	$3.13^{+1.10}_{-0.28}$	4.00±0.03	P10
PN G334.8-07.4	Sa St 2-12	0.310±0.243	$3.51^{+0.66}_{-0.25}$	3.64	P04

which are typically very hard to quantify, as discussed in the original references listed in Table 1.

3. The Galactic PN distance scale from Gaia parallaxes

While there are still too few calibrators, and their uncertainties remain relatively high, the relation between physical radius and surface brightness is well defined (see Fig. 1, bottom panel) at all surface brightness in our range. We use the surface brightness of PNe measured in Hβ, after correcting for the interstellar extinction. The linear correlation coefficient of the two sets of parameters of Fig. 1 (bottom panel) is 0.95, showing a very tight correlation between the distance-dependent vs. the distance-independent parameter, make it a very promising distance scale. It is worth recalling that future data releases from Gaia will provide parallaxes of stars with V<15 mag with a precision of 0.03 mas (Lindegren *et al.* 2016). From Acker *et al.* (1992) we find that there are ∼50 Galactic PNe in this magnitude range, and whose statistical distances are estimated to be smaller than 3000 pc (Stanghellini *et al.*, 2008). For this group of PNe, Gaia will provide final parallaxes of better than 10% relative uncertainties. For another ∼40 PNe the estimated parallax relative uncertainties will be of the order of 20%. This wealth of new data will definitely help to constraint the scale. The present work is preliminary to set the stage for these future data sets.

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