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New kinematic distance scale for the Galactic planetary nebulae

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Abstract. We analyze the kinematics of disk planetary nebulae (PNe) to derive the formal Galactic center distance, R_0, for three catalogues of PNe distances. Then we correct the catalogues' distance scales renormalizing the PNe distances by the ratios of formal R_0 values to a best modern value of $R_0 = 7.9$ kpc. The created new catalogue of disk's PNe distances was found to be in a good agreement with distances by Stanghellini *et al.* (2008). Our catalogue of PNe distances was used to recalibrate the statistical distance scale for all Galactic PNe.

Keywords. Planetary nebulae: general, Galaxy: kinematics and dynamics

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1. Kinematic modelling and renormalization of PNe distances

In this paper we use the method of kinematic modelling PNe ensemble by Nikiforov & Bobrova (1999) (see details also in Nikiforov 1999, see preliminary results in Kholtygin *et al.* 2010). With the assumption of axisymmetric rotation, the heliocentric radial velocity V_r of an object of a disk subsystem, can be represented by the following model:

$$V_{r,\mathrm{mod}} = \left[-2A(R-R_0) + \textstyle\sum_{i=2}^{n} \theta_i \, (R-R_0)^i\right] \frac{R_0}{R} \sin l \cos b - \mathbf{v}_0, \qquad (1.1)$$

where R is the distance to the Galactic axis, R_0 is the Sun–Galactic center distance; l and b are the Galactic coordinates of the object; $\mathbf{v}_0$ is the contribution of the solar motion relative to the system of objects (PNe); K is the k-term; A is the Oort constant.

For each catalogue of PNe distances, we derive the set of optimal model parameters R_0, $A, \theta_2, \ldots, \theta_n, \mathbf{v}_0, K$ by the nonlinear least-square fit; for every sample of PNe, the optimal degrees n is also determined. An obtained formal R_0 value, $R_0^{(\mathrm{f})}$, is used to correct the scale of distances to PNe in the catalogue. The correction factor is $G_{\mathrm{scale}} = R_0^{(\mathrm{b})}/R_0^{(\mathrm{f})}$, where $R_0^{(\mathrm{b})} = 7.9 \pm 0.2$ kpc is the current "best estimation" of R_0 (Nikiforov 2004). The corrected distances r_i^{corr} to the i-th PN can be calculated as $r_i^{\mathrm{corr}} = G_{\mathrm{scale}}\, r_i$.

In Fig. 1 we compare our and Stanghellini *et al.* (2008) distances for common objects. Overall we see a good agreement between the scales, but for PNe with $r < 3$ kpc the distances by Stanghellini *et al.* (2008) are 15–20% lower then ours (Fig. 1, right panel).

We also find a good agreement between our data and the most of individual distances (Harris *et al.* 2007; Stanghellini *et al.* 2008).

2. New calibration of the distance scale for PNe

The optimal parameters and correction factors G_{scale} for the catalogues considered are presented in Table 1. The corrected distances were determined for more than 300 PNe.

The statistical distances by Stanghellini *et al.* (2008) are based on a calibration of relation between the ionized mass of PN $\mu = 1.505 \times 10^{-3}\, r^{5/2}\, \vartheta^{3/2}\, F^{1/2}$ and the optical

Table 1. Parameters of kinematic models for different ensembles of PNe.

Catalogue	Number of PNe	$n_{\rm opt}$	A, km s^{-1} kpc^{-1}	$\langle R_0 \rangle$, kpc	$G_{\rm scale}$
Acker (1978)	233	1	15.5 ± 1.2	5.39 ± 0.48	1.47 ± 0.06
Cahn *et al.* (1992)	277	2	12.6 ± 1.0	5.65 ± 0.44	1.40 ± 0.05
Phillips (2004)	219	1	12.3 ± 0.8	6.70 ± 0.51	1.16 ± 0.06

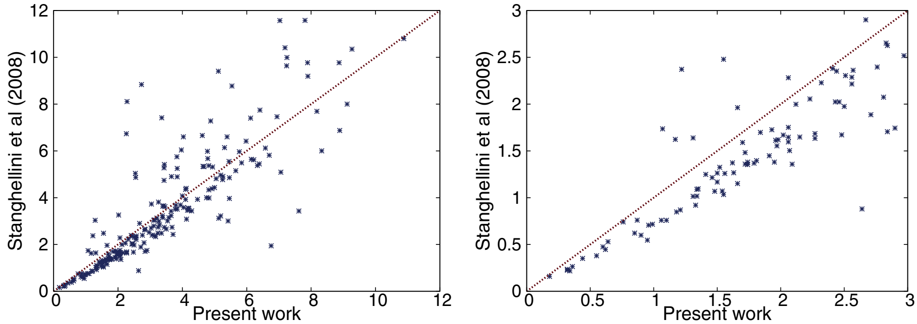

Figure 1. *Left:* A comparison between distances r to PNe (in kpc) obtained in this paper and in Stanghellini *et al.* (2008). *Right:* The same as in the left panel, but for $r < 3$ kpc.

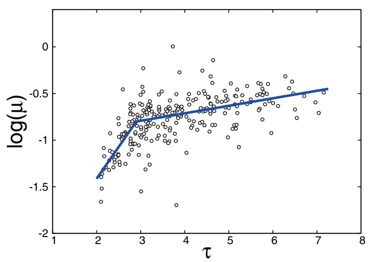

Figure 2. The parameter $\log \mu$ vs. τ for kinematically calibrated distances. The empty circles mark individual nebulae, the solid line shows the approximation (2.1).

thickness parameter $\tau = \log\left(4\vartheta^2/F\right)$. Here r is the distance to an PN in parsecs, ϑ is the nebular radius in arcseconds, and F is the nebular flux at 5 GHz. The best fit to the distance scale based on our kinematically calibrated PNe distances is as follows:

$$\log \mu = \begin{cases} 0.08\tau - 1.04, & \tau \geqslant 2.89, \\ 0.69\tau - 2.80, & \tau \leqslant 2.89. \end{cases} \tag{2.1}$$

In Fig. 2 we demonstrate the quality of the fit (2.1). This fit gives us a better agreement with the individual distances to PNe than any other statistical scale.

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