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Distance scale calibration from kinematic analysis of an ensemble of the galactic planetary nebulae

V.V. Akimkin[1], I.I. Nikiforov[2*], A.F. Kholtygin[2]

[1]*Astronomical Institute of the Russian Academy of Sciences, Russia*
[2]*Sobolev Astronomical Institute of St. Petersburg State University, Russia*

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We study the kinematics of ensembles of planetary nebulae (PNe) of the Galactic disk using the PN distance catalogues by Acker (1978), Cahn et al. (1992), and Phillips (2004). Formal values for the Galactic center distance, R_0, derived from kinematic analysis of the PNe with distance scales accepted in the catalogues were found to be low, from 5 to 7 kpc. To correct these underestimated distance scales we renormalized the PN distances using the ratios of formal R_0 values to a best modern value of $R_0 = 7.9$ kpc deduced from many original estimates. A new catalogue of distances for the Galactic disk's PNe was created by averaging the kinematically corrected distances to PNe obtained for the catalogues mentioned above. New distances for Peimbert's types I and II PNe are in a good agreement with distances by Stanghellini et al. (2008). Our new catalog of PNe distances was used to recalibrate statistical distance scales for all types of PNe.

Keywords: Galaxy; Planetary nebulae; Kinematics; Distance scales; Galactic center distance

A study of an ensemble of the galactic planetary nebulae (PNe) is a popular tool to test the models of the Galactic evolution [15]. However, the distances to PNe are badly known. More or less exact distances found from the trigonometric parallaxes of the central stars of PNe are known only for 16 objects [11]. For the great majority of galactic PNe one has to use statistical distance scales, whose calibrations are based on the reliability of the individually known PN distances. Unfortunately, the individual distances to PNe obtained by various methods are often strongly different. Stanghellini et al. [21] used the Magellanic Cloud PNe as the distance calibrators. It should be mentioned that the exactness of the distance to the Magellanic Clouds themselves is not very high (e.g. [6, 17]).

In this work, we try to calibrate existing distance scales for Galactic disk PNe applying the spatially-kinematic modeling the PN ensemble – the method proposed by Nikiforov and Bobrova [16]. It assumes a cylindrical model of the rotation of PNe, it means that the rotation velocity of any PN depends only on its distance to the rotation axis of the Milky Way and does not depend on its height over the Galactic plane. Having an ensemble of the objects with known heliocentric distances and radial

*Corresponding author. Email: nii@astro.spbu.ru

velocities we can find the optimal parameters of a model of their Galactic rotation, among them the distance of the Sun to the Galactic center, R_0. Preliminary results of such approach are described by Kholtygin et al. [13]. As sources of data we used PN distance catalogues [1, 2, 18] and the catalogue of radial velocities [22].

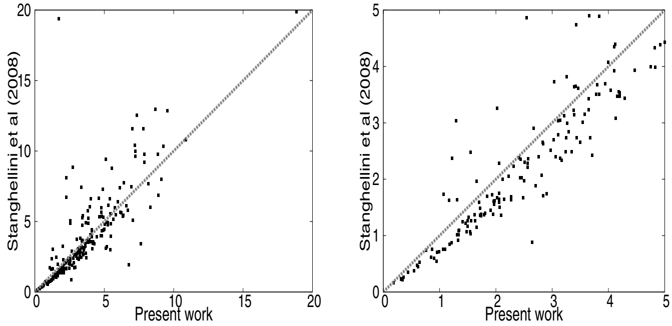

Figure 1 **Left:** A comparison of distances r to PNe derived in this paper and in [21]. **Right:** The same as in the left panel, but for $r < 5$ kpc.

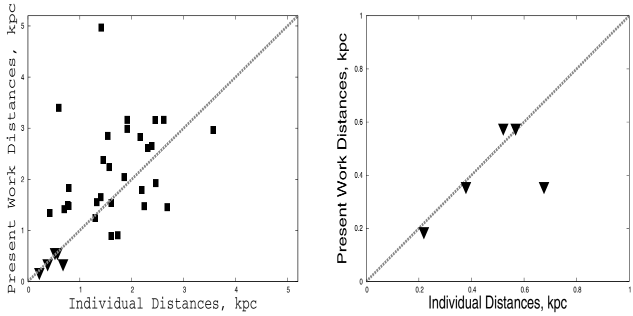

Figure 2 **Left:** A comparison of the individual distances and statistical distances obtained in the present work. Filled triangles mark PNe with known parallaxes and squares mark all other PNe with known individual distances. **Right:** The same as in the left panel, but for individual distances found from the parallaxes.

For each catalogue we obtain the model parameters. The resulting formal value for the distance to the Galactic center, $R_0^{(\mathrm{f})}$, is used to correct the scale of distances to nebulae in the catalogue considered. The correction factor is $G_{\mathrm{scale}} = R_0^{(\mathrm{b})}/R_0^{(\mathrm{f})}$, where $R_0^{(\mathrm{b})} = 7.9 \pm 0.2\,\mathrm{kpc}$ is the "best value" for R_0 derived from an combination of results published [17]. The corrected distances r_i^{corr} to PN can be calculated as

$$r_i^{\mathrm{corr}} = G_{\mathrm{scale}}\, r_i\,. \qquad (1)$$

We next average for each PN the corrected distances from different scales and so produce our synthetic distance scale kinematically calibrated. In Fig. 1 we compare, for common objects, our distances with those obtained by Stanghellini et al. [21]. We see a good agreement between the scales over all interval of distances, but for nebulae

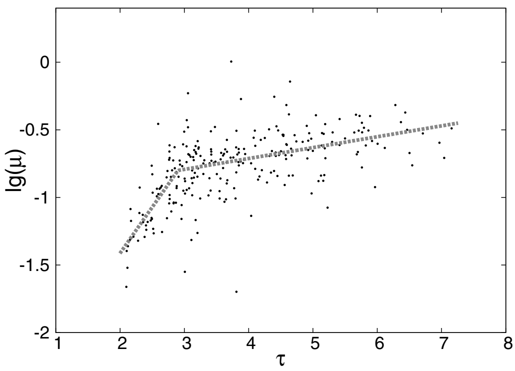

Figure 3 A dependence of the parameter $\log \mu$ on a value of τ for kinematically calibrated distances. Points mark individual nebulae, the dashed line shows the approximation (2).

at $r < 5$ kpc the distances from [21] are 15–20% lower then ours (see Fig. 1, right panel).

In the left panel of Fig. 2 we plot our distances against those found from the trigonometric [11] and spectroscopic parallaxes [4], from an analysis of the expansion of nebulae [8, 9, 10, 14], from the interstellar extinction in environments of nebulae [7, 12] and also the distances to PNe which are members of open clusters [3]. We see a good agreement between our data and the individual distances.

In the right panel of Fig. 2 we compare our distances and those found by Stanghellini et al. [21] with the most exact values of distances derived by Harris et al. [11]. We see that our data are in a good agreement with those from [11].

The statistical distances by Stanghellini et al. [21] are based on a calibration of relation between the ionized mass of PN $\mu = 1.505\times10^{-3}\, r^{5/2}\, \theta^{3/2} F^{1/2}$ and the optical thickness parameter $\tau = \log\left(\frac{4\theta^2}{F}\right)$. 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 fit to the distance scale based on our kinematically calibrated PN distances is

$$\log \mu = \begin{cases} 0.08\tau - 1.04\,, & \tau \geq 2.89, \\ 0.69\tau - 2.80\,, & \tau \leq 2.89. \end{cases} \qquad (2)$$

In Fig. 3 we demonstrate the quality of the fit (2). This fit gives us a better agreement with the individual distances to PNe than any other statistical scale.

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