Planetary Nebulae in our Galaxy and Beyond
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Thick Disk Planetary Nebulae

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Abstract. In this work we attempt to find Planetary Nebulae(PNe) belonging to the thick disk population of the Galaxy, based on the proper motion and radial velocity data of the objects available in literature, by using a simulation and Bayesian likelihood analysis. Making use of the established kinematical properties of the thick disk/thin disk/halo (TD/D/H) population of the Galaxy, we compute likelihoods of TD/D/H membership of 66 nebulae by fully taking into account the uncertainties associated with their proper motion and radial velocity data. We find 12 candidate PNe whose probability of belonging to the thick disc is 80% or greater, of which 9 PNe have a TD membership probability greater than 90%. Spectroscopy of the TD candidates is being planned and we hope this will shed light on the chemical characteristics of the TD population of the Galaxy, in the context of Planetary nebulae.

Keywords. Planetary Nebulae, Thick Disk, Bayesian inference

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1. Introduction, Data and Analysis

Following its discovery by Gilmore & Reid (1983), the Galactic thick disk has been the subject of numerous investigations which have shown it to be a stellar component distinct from the thin disk and halo, and to have implications on the early history of the Galaxy. For a review, see Wyse (2005). The Galactic thick disk in the context of Planetary Nebulae (PNe) has been studied by Kerber *et al.*(2004) where they selected candidate thick disk PNe from a sample of 4 PNe, for which accurate proper motion data are available, by integrating their orbits in the Galactic potential. The largest body of proper motion data of PNe available in literature is due to Cudworth (1974), who has proper motion measurements of about 66 PNe. But the uncertainties in the data are large rendering accurate orbit calculation of these objects unfeasible. We use a kinematical approach, assuming a Schwarzschild distribution for the space velocities. The Schwarzschild distribution is characterized by the space velocity dispersions and the asymmetric drift; from observations, these are known to have different values for the TD, D, H populations. Since the errors in the PNe proper motions are large, the errors in the space velocities are not obtained by adding up the errors in proper motion (and distance) in quadrature. But simulation and Bayesian analysis provides a way of extracting information about TD/D/H membership, in spite of the large errors in proper motion.

1.1. *Simulation and Bayesian Analysis*

We assume values for the velocity ellipsoid parameters of the TD/D/H populations from stellar studies (Bensby *et al.* 2003). Compiling proper motion data for 66 PNe from Cudworth (1974) and Acker *et al.*(1998), with radial velocity data from Durand *et al.*(1998), we apply the following procedure to compute the relative probability for TD/D/H membership:

1. Generating a synthetic TD population in velocity space (U,V,W) which follows the corresponding Schwarzschild distribution and with a Galactic rotation curve (Fich *et al.* 1989) as input, we compute ρ, μ_α and μ_δ and hence the distribution functions F(ρ), G(μ_α), H(μ_δ). Given the distribution function F(ρ) for the synthetic TD population located at the position corresponding to a PN, and given that the observed value of radial velocity for the PN is ρ_{obs} with uncertainty $\Delta\rho_{obs}$, we have from Bayesian inference, $P(Model \mid data) = \frac{P(data|model) \times P(model)}{P(data)}$

- Models $\equiv$ TD, D, H and data$\equiv (\rho_{obs}, \Delta\rho_{obs}), (\mu_\alpha, \Delta\mu_\alpha), (\mu_\delta, \Delta\mu_\delta)$

2. $P(\rho_{obs}, \Delta\rho_{obs} \mid TD) = \int$ F(ρ).Gaussian(ρ_{obs},$\Delta\rho_{obs}$).dρ
gives the likelihood of getting ρ_{obs} within uncertainty $\Delta\rho_{obs}$, given the model TD. P(TD) is given by the TD fraction at the location of PN (as a conservative estimate, we use the local fraction ie. 0.06 for TD, 0.94 for D and 0.0015 for H)

3. Repeat step **2** using the proper motion distribution functions to get $P(\mu_\alpha, \Delta\mu_\alpha \mid TD)$ and $P(\mu_\delta, \Delta\mu_\delta \mid TD)$ respectively.

4. L$(\rho_{obs}, \Delta\rho_{obs}, \mu_\alpha, \Delta\mu_\alpha, \mu_\delta, \Delta\mu_\delta \mid TD)$=
P(ρ_{obs}, $\Delta\rho_{obs} \mid TD) \times P(\mu_{\alpha,obs}, \Delta\mu_{\alpha,obs}$ | TD)$\times$ P($\mu_{\delta,obs}, \Delta\mu_{\delta,obs}$ | TD)

5. Repeat steps **1** to **4** with models D, H to get L(...| D), L(...| H) and their ratio $\frac{L(...|TD)}{L(...|D)}$ gives the relative probability of the object belonging to TD and D. The final identification of membership of the object in TD, D or H is decided by the criterion, as to which of the probabilities is the highest (Rao 1965).

2. Results

We find 12 PNe with TD membership probability $\geqslant$ 80%. Of these A33, NGC 6853 and NGC 7293 have membership probabilities lying between 80% and 90%. The rest have membership probabilities greater than 90%. Five PNe in the sample have direct distance estimates and using these we calculate their mean height from the plane $|z|$ = 637 pc, suggesting that they may indeed belong to the TD population. Accurate distances and proper motions of PNe are expected with the upcoming missions like SIM and GAIA. However, our method provides a way of making use of the existing proper motion data, taking into account the uncertainties involved, to identify candidate thick disk PNe. The method is not very sensitive to distance since proper motion is the dominant source of uncertainty in the space velocities of PNe in our sample and has been accounted for correctly.

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