Testing the Suitability of Pulsars as Targets for Scintillometry Campaigns

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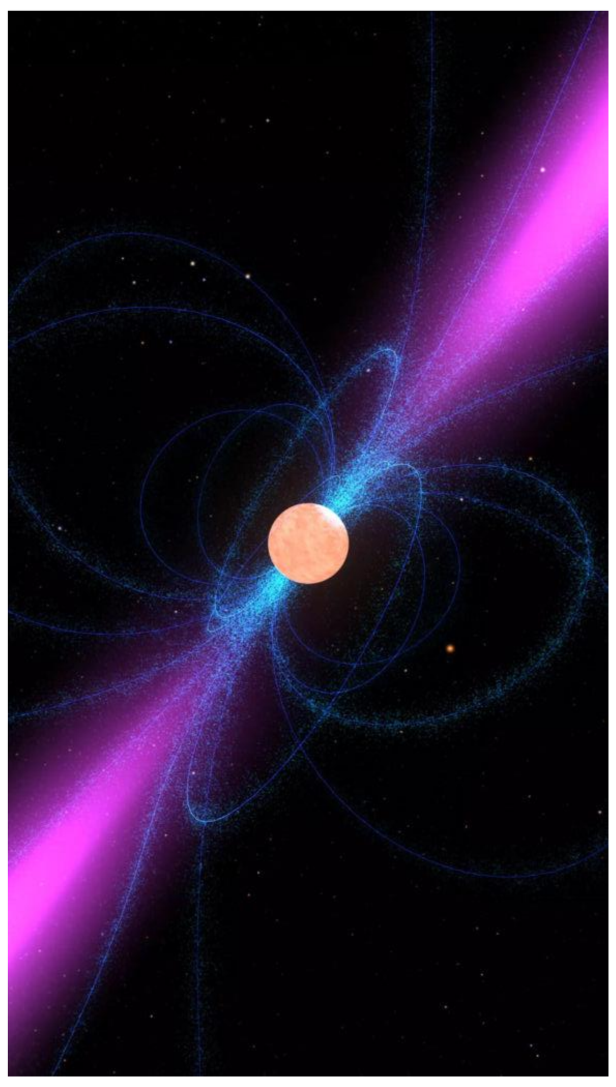
1. Introduction

Pulsars are highly magnetized rotating neutron stars that emit radio beams. Pulsar scintillometry is a technique used to study the variation of pulsar's radio signals that get scattered when passing through the interstellar medium (ISM). Using fluctuations in the observed intensity of these signals caused by scattering, it is possible to estimate some of the properties of the pulsar's systems, including the inclination of the orbit and distance to them [1]. Knowing one of these properties, it is possible to estimate the other parameter and its uncertainty by performing a Monte Carlo simulation. Furthermore, using the outcomes of this project, an observational campaign can be advised to study "favorable" pulsar systems with rather small uncertainties on distance and/or inclination parameters (e.g., ideally, $\Delta d_p \leq 1$ pc [2] to advise a campaign).



2. Simulations

The Estimate of the Inclination Error (Known Distance)

To estimate the uncertainty of the inclination, the synthetic data is generated for 1000 simulated systems with randomly chosen parameters for a campaign of 12 observations evenly spaced over a year. For each system, these parameters are retrieved using the scintillometric model, where the distance attained from the parallax measurements is fixed. Lastly, the inclination uncertainty is estimated using the Monte Carlo method. Figure 1 shows the distributions of inclination uncertainties for a specific pulsar.

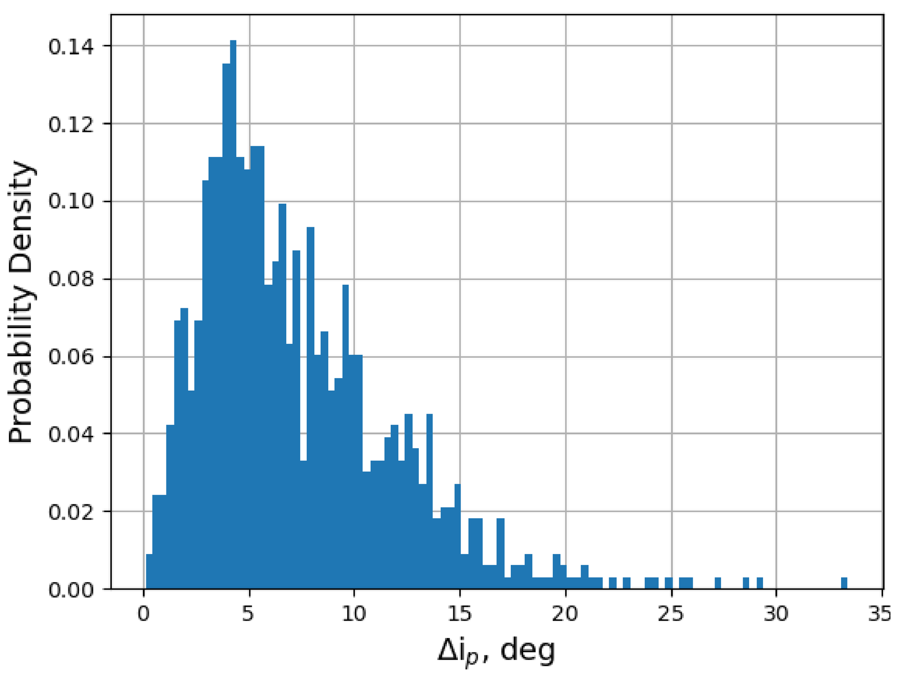


Figure 1a: the simulated distribution of the uncertainty of the orbital inclination of the pulsar Δi_p in degrees for J1857+0943.

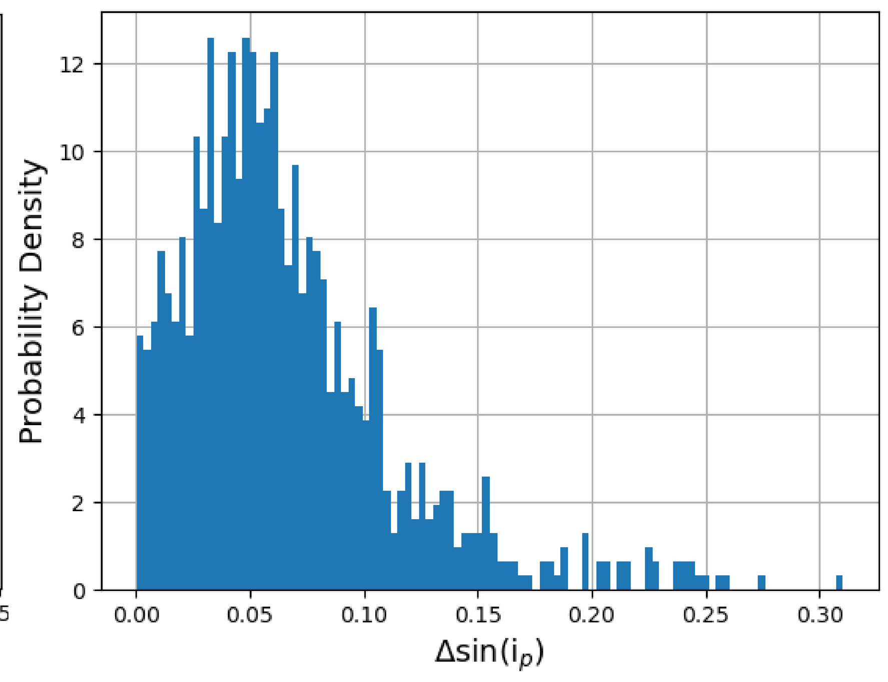


Figure 1b: the simulated distribution of the uncertainty of the sine of the orbital inclination of the pulsar $\Delta\sin(i_p)$ for J1857+0943.

The Estimate of the Distance Error (Known Inclination)

A similar procedure was employed to estimate the uncertainty of the distance to the pulsar for the systems with known inclinations. Since measuring an exact value of the inclination is challenging due to multiple solutions of the sine function, three different types of inputs were used in order of priority: the inclination, the sine of the inclination, and the "stigma" parameter [3] that can be converted to the sine of the inclination.

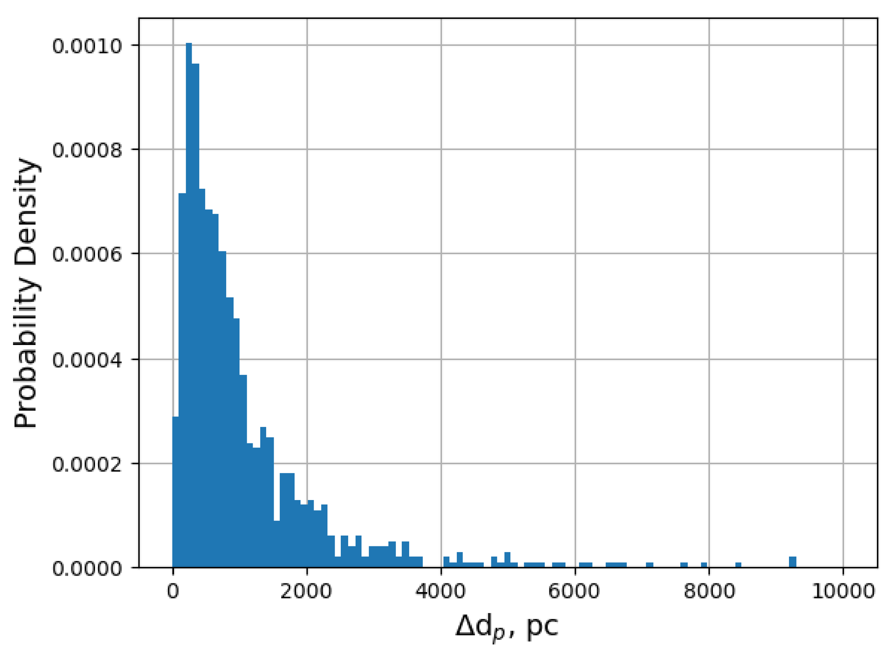


Figure 2a: the simulated distribution of the uncertainty of the distance to the pulsar system Δd_p in pc for J1909-3744.

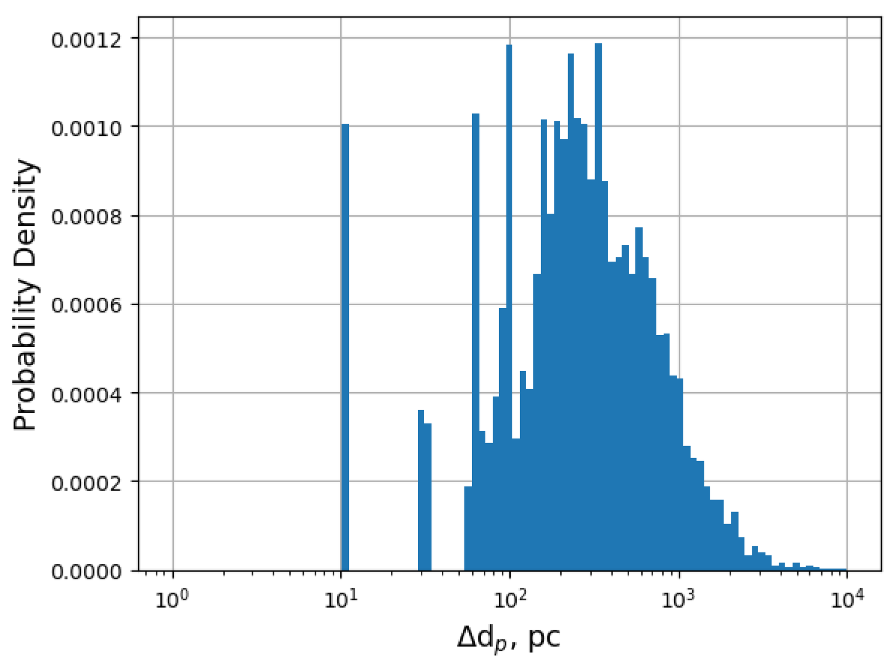


Figure 2b: the simulated distribution of the uncertainty of the distance to the pulsar system Δd_p for J1909-3744 in log scale.

3. Results: Estimated Inclination Error

The relationship between the known distance error and the inclination error (Fig.3a) or the sine of the inclination error (Fig. 3b) is observed to be linear, where a small rise of the distance error results in a slow increase of the inclination uncertainty.

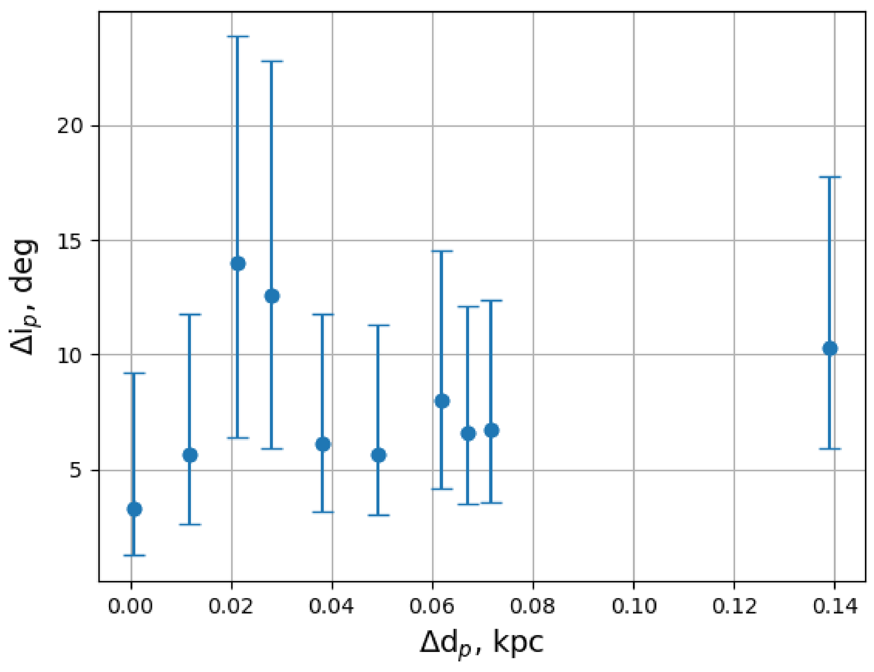


Figure 3a: the relationship between the known distance uncertainty Δd_p and the estimated uncertainty of the orbital inclination Δi_p for select pulsar systems.

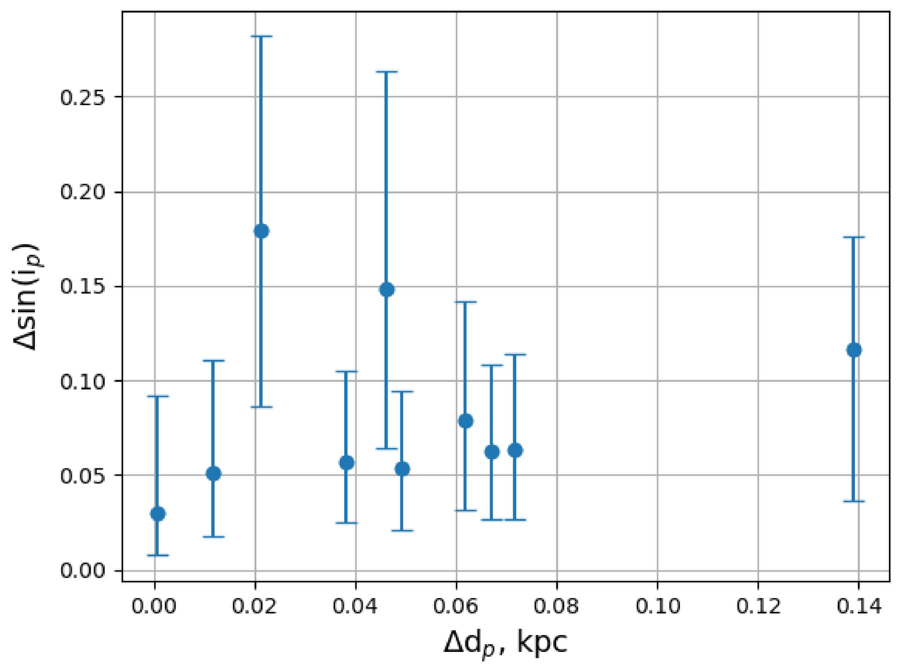


Figure 3b: the relationship between the known distance uncertainty Δd_p and the estimated uncertainty of the sine of orbital inclination $\Delta\sin(i_p)$ for select pulsar systems.

4. Results: Estimated Distance Error

Figure 4 suggests a similar relationship between the known error of the inclination (where all types of input were converted to the sine of inclination) and the estimated error in the distance: a slight increase in a distance error implies a small rise of the inclination error.

Figure 5 illustrates the relationship between the estimated error in the distance to the pulsar and the ecliptic latitude of the system, which suggests a constant correlation.

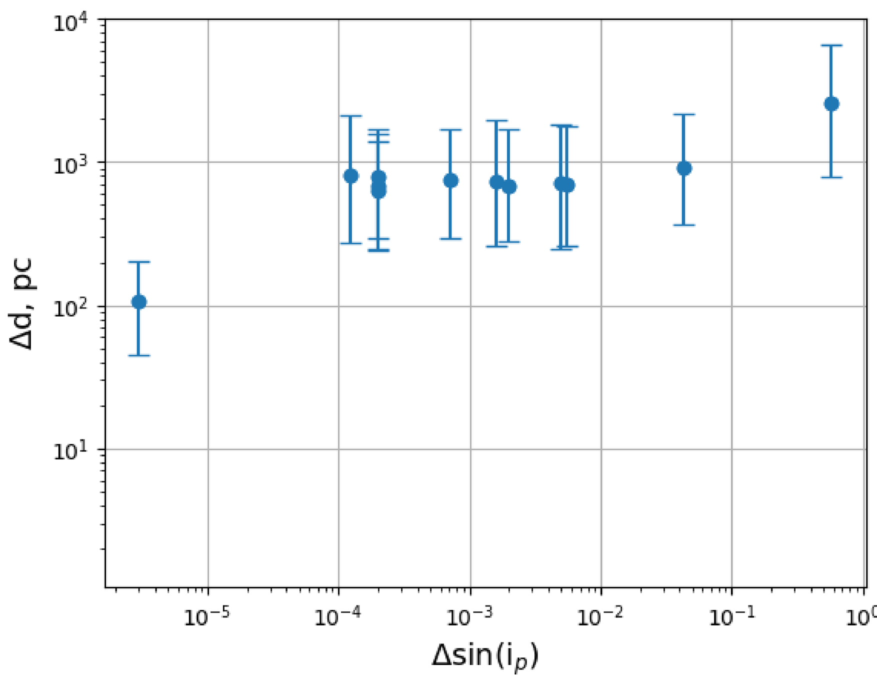


Figure 4: the relationship between the known sine of inclination uncertainty $\Delta\sin(i_p)$ and the estimated uncertainty of distance to the pulsar Δd_p for select pulsar systems.

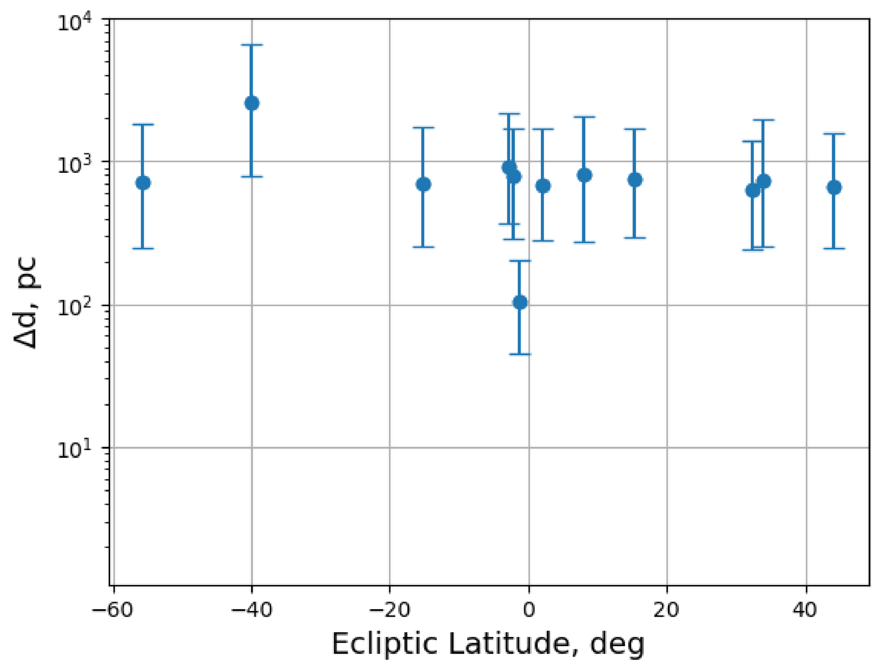


Figure 5: the relationship between the estimated distance uncertainty Δd_p and ecliptic latitude of the pulsar for select pulsar system.

5. Conclusion and Next Steps

It is clear that the distance and inclination uncertainties illustrate a slow linear correlation. This suggests that uncertainties have low sensitivity to error: even if the measurements of one quantity are not exactly true, it does not marginally affect the other measurement and its error, so the major uncertainty source must come from observational measurements. However, it is important to highlight that small errors as $\Delta d_p \leq 1$ pc [2], which are favorable for a potential observational campaign, were neither observed nor practically simulated. It will likely force the reconsideration of the threshold for the observational campaign.

Fig.5 suggests that the ecliptic position of the pulsar system on a sky map does not depend on the distance error, implying that targets close to the ecliptic plane are as good as the ones near the ecliptic poles.

The next steps for this study would be to compile a larger dataset and test this simulation for more pulsars for which all needed parameters are known. It would also prove beneficial to request an observational campaign on the closest systems to study their properties better and, hopefully, find more precise relationships and measurements.

Another important investigation would be to vary parameters that describe the observational campaign and observe the behavior of the simulations as the values of these parameters change.

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