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Pulsar Motions in Our Galaxy

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Abstract We simulate motions of 2×10^5 pulsars in our Galaxy with Monte-Carlo method and try to understand the evolution of pulsar height distribution. Within about 8 Myr, pulsar height distribution can be fitted by a Gaussian function with a scale height linearly increasing with time. An extra exponential function is necessary to be added to the Gaussian function to fit the height distribution afterwards. The Gaussian scale height increases linearly until about 40 Myr. After about 200 Myr, the height distribution is stabilized. Based on the simulation results, we obtain the initial 1D velocity dispersion of $80\,\mathrm{km\,s^{-1}}$ for millisecond pulsars.

Pulsar motions have been involved in population synthesis (e.g. Bhattacharya et al. 1992), but not explicitly clarified. Some authors tried to deduce scale height evolution theoretically, but they had to assume a simple Galactic potential (e.g. Arnaud & Rothenflug 1981) or a simplified height evolution (Narayan & Ostriker 1990). In this contribution, we explore the height evolution with Monte-Carlo simulation.

The initial height distribution of pulsars is assumed to be a Gaussian with a scale height of 60 pc as that of the progenitors i.e. OB stars (Maíz-Apellániz 2001). The radius distribution is assumed to follow a Gamma function (Paczyński 1990). The final results are insensitive to the form of initial height or radius distribution. Initial velocity is the vectorial sum of Galactic rotation velocity and kick velocity from asymmetric supernovae explosions. We assumed the kick velocities follow a Maxwellian distribution, with trial 1D velocity dispersion σ_k =100, 200, 300 and $400\,\mathrm{km\,s^{-1}}$, respectively. After comparing all the potentials available, we used the one given by Paczyński (1990) which could reproduce the Galactic rotation curve and the local volume density near the Sun better than others.

Provided these initial conditions described above, we solved the Newtonian kinetic equations using *4*th order Runge-Kutta method with an adaptive step size (Press et al. 1992), then tracked all the pulsars from 0 Myr to 500 Myr. The scale heights are shown in Figure 1. Within about 8 Myr, the distribution can be fitted very well by a Gaussian function with a scale height h_g increasing linearly with time as $h_g \approx h_0 + \sigma_\mathrm{k} t$. As time goes, a peak appears near the Galactic plane more and more prominently, so the distribution has to be fitted by a Gaussian function *plus an exponential function* with a scale height h_e. The scale height h_g keeps linear increase until about 40 Myr. After about 200 Myr, both h_g and h_e gets stabilized.

Now we try to understand the distribution of available pulsars using the simulation results.

Because the height distribution is stabilized after about 200 Myr, the birth rate, if does not vary much with time, has no effects on the final distribution. We can compare height distribution of our simulated pulsars with that of observed MSPs directly. The K-S test was employed to check the consistency of the distribution of known MSPs and the distribution from simulation with initial 1D velocity dispersion from $30\,\mathrm{km\,s^{-1}}$ to $180\,\mathrm{km\,s^{-1}}$. Finally, we

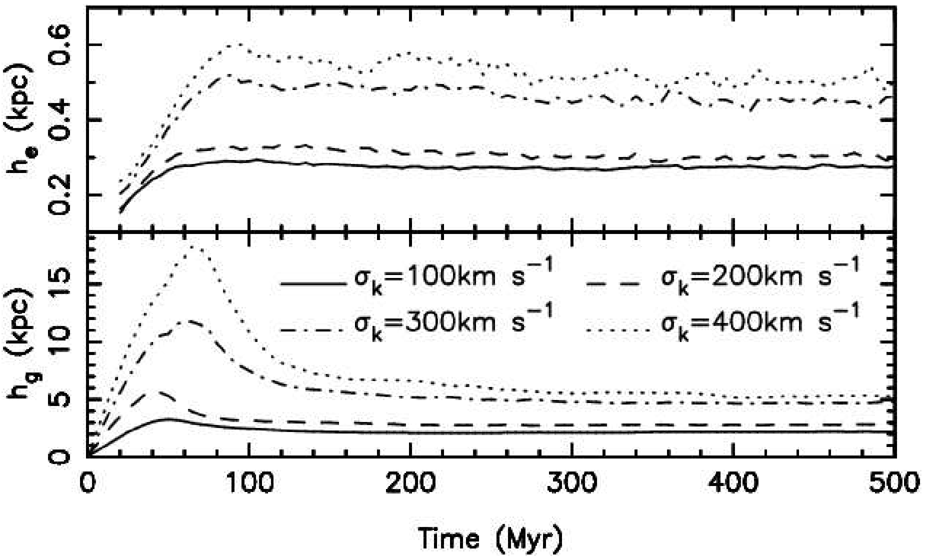

Fig. 1 The evolution of scale heights of Gaussian components h_g (lower panel) and exponential components h_e (upper panel). Different lines correspond to different initial 1D kick velocity dispersion (σ_k).

found that $\sigma_\mathrm{k} = 80\,\mathrm{km\,s^{-1}}$ was the best (Figure 2). So the most possible initial 1D velocity dispersion for MSPs is about $80\,\mathrm{km\,s^{-1}}$.

We binned all known pulsars with characteristic ages 1 Myr< τ <8 Myr into 4 groups. Through Gaussian fitting, we obtained four scale heights which should have linear relation with ages. Surprisingly, the resultant 1D velocity dispersion is $31\pm13\,\mathrm{km\,s^{-1}}$, too small compared with 3D velocity dispersion of $500\,\mathrm{km\,s^{-1}}$ by Lyne & Lorimer (1994). We understand that the distances of most pulsars are less that 8 kpc and they were discovered in low latitude surveys (e.g. $|b| < 5°$ in Parkes multibeam survey (Manchester et al. 2001)). The high velocity pulsars with a velocity of 400 km s^{-1} will statistically move to 800 pc in 2 Myrs, that is 5.7° at 8 kpc. So the majority of known pulsars are low speed old pulsars plus some high speed young pulsars. The population synthesis would be difficult to constrain the initial velocities using this sample of low speed known pulsars available.

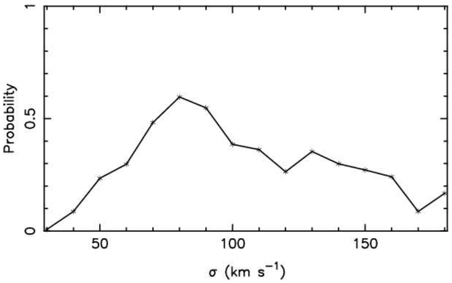

Fig. 2 The K-S test for 1D velocity dispersion of MSPs between simulated and known MSP populations.

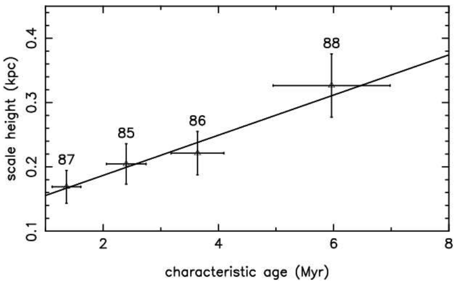

Fig. 3 The scale heights versus characteristic ages of known normal pulsars, indicating a kick velocity dispersion of $31\pm13\,\mathrm{km\,s^{-1}}$. The number of pulsars in each bin is marked at the top.

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