Neutron Stars and Pulsars: Challenges and Opportunities after 80 years
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Population synthesis of young neutron stars

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Abstract. We investigate the fortune of young neutron stars (NS) in the whole volume of the Milky Way with new code for population synthesis. We start our modeling from the birth of massive OB stars and follow their motion in the Galaxy up to the Supernova explosion. Next we integrate the equations of motion of NS in the averaged gravitational potential of the Galaxy. We estimate the mean kick velocities from a comparison the model Z and R-distributions of radio emitting NS with that for galactic NS accordingly ATNF pulsar catalog. We follow the history of the rotational velocity and the surface magnetic field of NS taking into account the significant magnetic field decay during the first million year of a neutron star's life. The derived value for the mean time of ohmic decay is $2.3 \cdot 10^5$ years. We model the subsample of galactic radio pulsars which can be detected with available radio telescopes, using a radio beaming model with inhomogeneous distribution of the radio emission in the cone. The distributions functions of the pulsar periods P, period derivatives $\dot{P}$ and surface magnetic fields B appear to be in a close agreement with those obtained from an ensemble of neutron stars in the ATNF catalogue.

Keywords. methods: data analysis, methods: statistical, stars: neutron, magnetic fields, pulsars: general

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1. Introduction

The method of population synthesis allows us to probe both the initial state of the modeled ensemble of NSs and details of its evolution. The assumptions about spatial distribution and kinematic of pulsars ensemble were detailed in Igoshev & Kholtygin (2011). Here the principles of survey modeling are reported. Commonly, the model of pulsars survey is based on the radiometer equation (see below for details). We follow this approach with one exception due to modern observational results. We introduce a pulse-width versus period relation based on the consideration by Maciesiak & Gil (2011).

2. Model of survey

A pulsar is detected if its luminosity exceeds the noise at some confidence level. The limiting flux density $S_{\rm lim}$ is given by the radiometer equation:

$$S_{\rm lim} = \frac{\sigma\beta(T_{sys} + T_{rec})}{G\sqrt{N_p \tau_{obs} \delta\nu}} \sqrt{\frac{W_e}{P - W_e}}, \tag{2.1}$$

where T_{rec} is the receiver temperature on cold sky, T_{sky} is the sky background temperature, G is antenna gain, N_p is the number of polarizations, $\delta\nu$ is the receiver bandwidth, t_{int} is the integration time, P is pulsar period, W_e is the effective pulse width, σ is a signal to noise threshold and β is a constant accounting for various system losses.

The observed pulsar width can be written as following:

$$W_e = \sqrt{W^2 + \tau_{samp}^2 + \left(t_{samp}\frac{DM}{DM_0}\right)^2 + \tau_{scatt}^2}\,. \tag{2.2}$$

Here W is the intrinsic pulse width, t_{samp} is the sampling interval, and τ_{scatt} is the pulse broadening due to interstellar scattering. We suggest to take into account observational properties of the half-power widths of core components verified by Maciesiak & Gil (2011):

$$\omega = \frac{2^\circ.45P^{-0.5}}{\sin\alpha} \tag{2.3}$$

Those authors show that this dependence well describes the ensemble of Galactic NSs. In Eq. (2.3), α is an angle between rotational axis and magnetic dipole. This empirical law was firstly introduced by Rankin (1990) in her work for pulsars with inter-pulse emission. Recently, this relation was tested for majority of normal pulsars by Maciesiak & Gil (2011). Moreover, authors noticed that even in case of conal emission pulse-width statistic are in good agreement with Eq. (2.3).

Therefore, instead of classical value $W = 0.05P$ we apply (2.3):

$$W = \frac{6.81 \cdot 10^{-3}}{\sin\alpha}\sqrt{P} \tag{2.4}$$

The flat angle distribution of the pulsars emission is modeled in our population synthesis. The relation (2.4) naturally explains dispersion of values which is modeled as Gaussian distribution in Lorimer *et al.* (2006). For the value of DM_0 we use its standard definition:

$$DM_0 = \frac{N_{ch}t_{samp}\nu^3}{8299\delta\nu_{ch}} \tag{2.5}$$

In this expression ν is the observational frequency and $\delta\nu_{ch}$ is the receiver bandwidth.

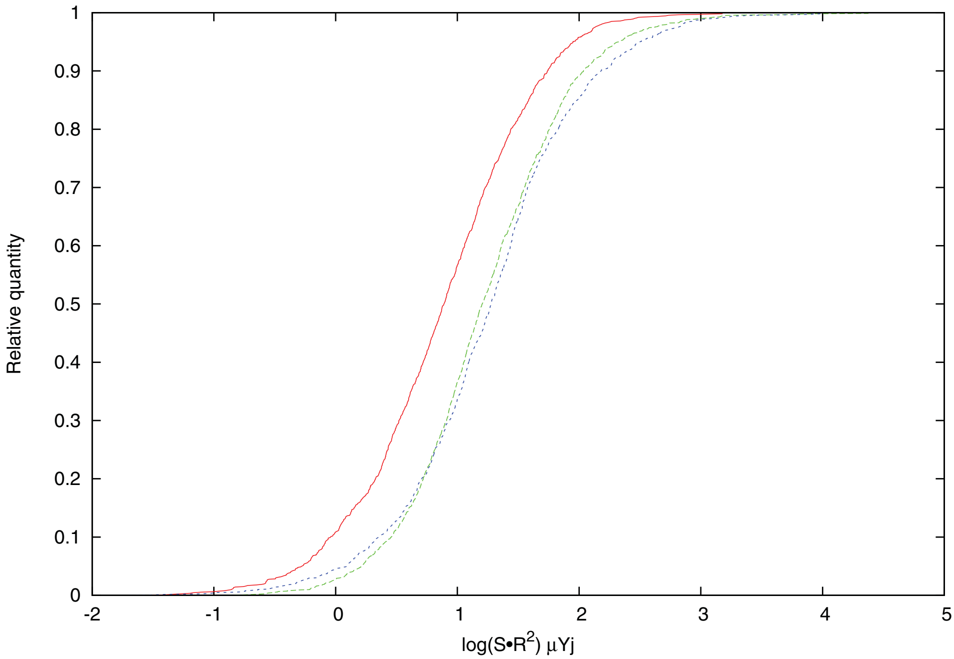

Figure 1. Cumulative distribution of the luminosity function L for pulsars. Solid (red) line shows the distribution for Faucher-Giguere & Kaspi (2006) model, dashed (green) line corresponds to our model with suggested by Maciasiek & Gil (2011) pulse-width relation and dotted (blue) line to the sample of isolated radio pulsars from ATNF catalog (Manchester *et al.* 2005).

We find the relation for τ_{scatt} suggested in Lorimer *et al.* (2006) does not well fit the observational distribution of radio pulsars by their radio luminosities, while the formula suggested by Cordes & Lazio (2002):

$$\tau_{scatt} = 1.10 SM_{\tau}^{6/5} \nu^{-22/5} D. \tag{2.6}$$

gives a reliable result. Here SM_{τ} is the scattering measure from the model of electron density in our galaxy NE2001, and D is the distance to the radio pulsar.

To test our model of the population synthesis we calculate the distribution of the radio luminosity $L = SD^2$ for our model ensemble of pulsars. Here S is the pulsar's radio flux in Yu at 1400 GHz. The obtained distribution is plotted in Figure 1. A comparison of our data with obtained for population synthesis model by Faucher-Giguere & Kaspi (2006) and for real pulsar ensemble from the ATNF catalog (Manchester *et al.* 2005) leads us to conclude that our approach produces good agreement with the real luminosity distribution.

3. Conclusions

We show that the Maciesiak & Gil (2011) relation for the intrinsic pulsar width W lets us model the Parkes and Swinburne multibeam surveys with our population synthesis code. We also conclude that the classical model of luminosity by Faucher-Giguere & Kaspi (2006) should be multiplied by factor of eight in order to obtain the correct share of the brightest pulsars in the whole pulsar ensemble.

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