Spatial distribution of accreting isolated neutron stars in the Galaxy

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Abstract

We present here the computer model of the distribution of the luminosity, produced by old isolated neutron stars (OINSs) accreting from the interstellar medium (ISM). We show, that for different mean velocities of OINSs the distribution of the luminosity has a torus-like structure, with the maximum at $\approx 5kpc$.

1 Introduction

In the last several years, the spatial distribution of old isolated neutron stars (OINSs) became of great interest (see, for example, Treves and Colpi (1991)). Several sources of this size were observed by ROSAT. Different regimes of interaction of the interstellar medium (ISM) and OINSs can appear: Ejector, Propeller (with possible transient source), Accretor, Georotator and supercritical regimes (see, Popov (1994) and Lipunov and Popov (1995)). Here we are interested only in accreting OINSs.

We use direct calculations of trajectories in the Galaxy potential, taken in the form (Paczynski (1990)):

$$\Phi_i(R,Z) = GM_i / \left(R^2 + [a_i + (Z^2 + b_i^2)^{1/2}]^2\right)^{1/2}$$

.

In the articles of Postnov and Prokhorov (1993, 1994) it was shown, that OINSs in the Galaxy form a torus-like structure. If one looks at their distribution and at the distribution of the ISM (see, for example, Bochkarev (1993)), it is clearly seen, that the maximums of two distributions roughly coincides. It means, that most part of OINSs is situated in dence regions of ISM. So, the luminosity there must be higher. Here we represent computer simulations of this situation.

2 Model

We made calculations on the grid with the cell size 100 pc in R-direction and 10 pc in Z-direction (centered at R=50 pc, Z=5 pc and so on). Stars were born in the Galactic plane. The system of differential equations was solved numerically.

In our model we assumed, that the birthrate of NSs is proportional to the square of local density. Local density was calculated using data and formulaes from Bochkarev (1993) and Zane et al. (1995).

Figure 1: The density distribution in R-Z plane

Figure 2: The luminosity distribution in R-Z plane for Maxwellian kick velocity (75 km/s)

Figure 3: The luminosity distribution in R-Z plane for Maxwellian kick velocity (150 km/s)

$$n(R,Z) = n_{HI} + 2 \cdot n_{H_2}$$

$$n_{H_2} = n_0 \cdot exp\left[\frac{-Z^2}{2 \cdot (70pc)^2}\right]$$

If $2kpc \le R \le 3.4kpc$, then

$$n_{HI} = n_0 \cdot exp\left[\frac{-Z^2}{2 \cdot (140pc \cdot R/2kpc)^2}\right],$$

For $R \le 2kpc$ $n(R,Z)$ was assumed to be constant:

$$n(R < 2kpc, Z) = n(R = 2kpc, Z)$$

Of course, it is not accurate, so for the very central part of the Galaxy our results are only a rough estimation.

If $3.4kpc \le R \le 8.5kpc$, then

$$n_{HI} = 0.345 \cdot exp\left[\frac{-Z^2}{2 \cdot (212pc)^2}\right] + 0.107 \cdot exp\left[\frac{-Z^2}{2 \cdot (530pc)^2}\right] + 0.064 \cdot exp\left[\frac{-Z}{403pc}\right]$$

If $8.5 \le R \le 16kpc$, then

Figure 4: The luminosity distribution in R-Z plane for δ-function kick velocity (75 km/s)

$$n_{HI} = n_{\infty} \cdot exp\left[\frac{-Z^2}{2 \cdot (530pc \cdot R/8.5kpc)^2}\right]$$

The density distribution is shown in the figure 1.

Kick velocity was taken both: in the Maxwellian form with the maximum velocity 150 km/s, 75 km/s and 35 km/s and as a δ-function with V=150 km/s, 75 km/s and 35 km/s (see discussion in Lipunov et al. (1996)).

Sound velocity was taken to be 10 km/s. Luminosity was calculated using Bondi formula:

$$L = \left(\frac{GM_{NS}}{R_{NS}}\right) 2\pi \left(\frac{(GM_{NS})^2 n(R, Z)}{(V_s^2 + V^2)^{3/2}}\right)$$

.

3 Results

On the figures 2-7 we represent the results for two velocity distributions. On the figure 8 the slice at Z=+5 pc for the maxwellian kick (V_{max}= 150 km/s) is shown.

As it is clearly seen from the figures, the distribution of the luminosity density (shown in arbitrary units) in R-Z plane forms a torus-like structure with the maximum at approximatelly 5 kpc.

Figure 5: The luminosity distribution in R-Z plane for δ-function kick velocity (150 km/s)

Figure 6: The luminosity distribution in R-Z plane for δ-function kick velocity (35 km/s)

Figure 7: The luminosity distribution in R-Z plane for maxwellian kick velocity (35 km/s)

Figure 8: Slice at Z=+5 pc for maxwellian kick velocity (150 km/s)

Figure 9: Total velocity (in arbitrary units) vs. kick velocity

4 Discussion and concluding remarks

The torus-like structure of that distribution is an interesting and important feature of the Galactic potential. Local maximums in the ISM distribution are smoothed (compare figures 1-7). As one can suppose, for low velocities we get greater luminosity. Stars with the Maxwellian distribution can penetrate deeper into the inner regions than stars with δ-function velocity distribution (especially it is clear for high Z - 200-400 pc for low velocity distributions) because we for maxwellian kick we have both: more low velocity and more high velocity stars.

On fig.9 we show dependence of the total luminosity of the galaxy (in arbitrary units) from the kick velocity for two types of distributions. We mark very interesting feature: intersection of the curves at ≈ 125 km/s.

As me made very general assumptions, we argue, that such a distribution is not unique for our Galaxy, and all spiral galaxies must have such a distribution of the luminosity density, associated with accreting OINSs.

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