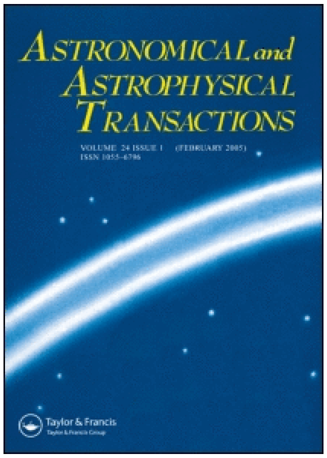

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SPATIAL DISTRIBUTION OF THE LUMINOSITY OF ACCRETING ISOLATED NEUTRON STARS IN THE GALAXY

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We present here a computer model of the distribution of luminosity, produced by old isolated neutron stars accreting from the interstellar medium. We show that for different velocity distributions of old isolated neutron stars the luminosity distribution has a torus-like structure, with a maximum at ≈ 5 kpc.

KEY WORDS Accretion, neutron stars, interstellar medium, Galaxy

1 INTRODUCTION

In the last several years, the spatial distribution of old isolated neutron stars (OINSs) has become of great interest (see, for example, Treves and Colpi, 1991). Several sources of this type were observed by ROSAT.

Different regimes of interaction of the interstellar medium (ISM) and INSs can appear: ejector, propeller (with possible transient source), accretor, georotator and supercritical regimes (see Popov, 1994; 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):

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

with a quasi-spherical halo with the density distribution in the form:

$$\rho = \frac{\rho_0}{1 + (d/d_0)}, \quad d^2 = R^2 + Z^2.$$

In the articles of Prokhorov and Postnov (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 maxima of two distributions roughly coincides. This means that most parts of OINSs are situated in the dense regions of the ISM. So, the luminosity there must be higher. Here we represent computer simulations of this situation.

2 THE MODEL

We solved numerically the system of differential equations. Statistics were collected on the grid with the cell size 100 pc in the R-direction and 10 pc in the Z-direction (centred at $R = 50$ pc, $Z = 5$ pc, and so on). Stars were born in the Galactic plane ($Z = 0$).

In our model we assumed that the birthrate of NSs is proportional to the square of the local density. The density was constant in time. The local density was calculated using data and formulae from Bochkarev (1993) and Zane *et al.* (1995).

$$\begin{aligned} n(R,Z) &= n_{\rm HI} + 2\cdot n_{\rm H_2}, \\ n_{\rm H_2} &= n_0 \cdot \exp\left[\frac{-Z^2}{2\cdot(70{\rm pc})^2}\right]. \end{aligned}$$

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

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

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

$$n(R < 2\,{\rm kpc}, Z) = n(R = 2\,{\rm kpc}, Z).$$

Of course, this is not accurate for small R, so for the very central part of the Galaxy our results are only a rough estimation (see Zane *et al.*, 1996).

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

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

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

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

The density distribution in the RZ plane is shown in Figure 1.

The kick velocity was taken both in the Maxwellian form with a maximum velocity 150 km s^{-1}, 75 km s^{-1} and 35 km s^{-1}, and as a δ-function with the same velocities (see the discussion on the kick velocities in Lipunov *et al.*, 1996).

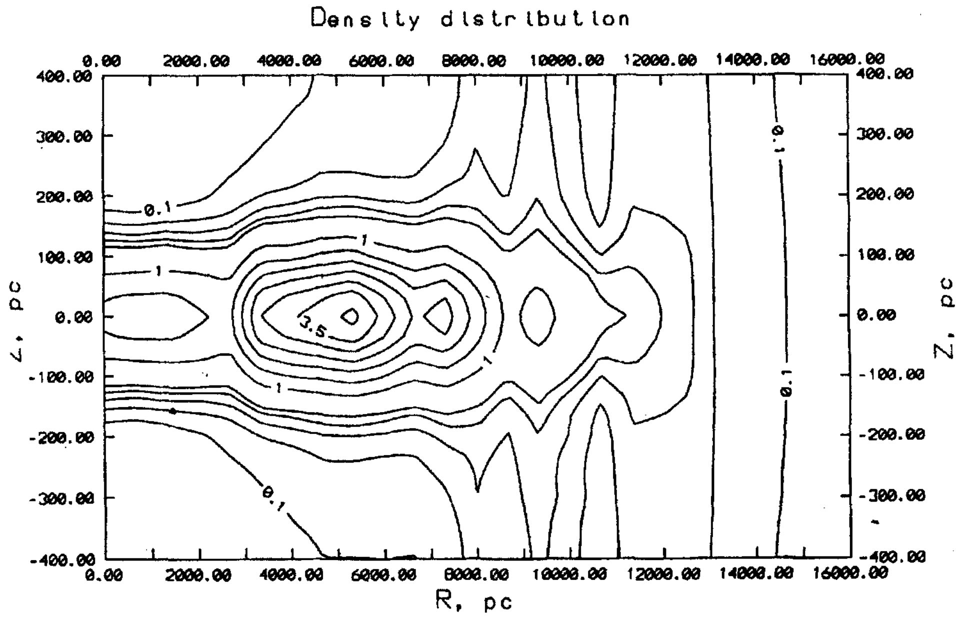

Figure 1 The distribution of the density of the interstellar medium in the Galaxy in the RZ plane.

The sound velocity was taken to be 10 km s^{-1} everywhere. The accretion luminosity was calculated using the Bondi formulae:

$$L = \left(\frac{GM_{NS}\dot{M}}{R_{NS}}\right),$$

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

3 RESULTS

In Figures 2–7 we represent the results for two velocity distributions. Luminosity is shown in arbitrary units.

In Figure 8 the slice at $Z = +5$ pc for the Maxwellian kick ($V_{max} = 150$ km s^{-1}) is shown: luminosity (in arbitrary units) vs. radius. As we calculated the "whole Galaxy", the figure is not symmetric. Differences for positive and negative radii demonstrate also how precise our method is.

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

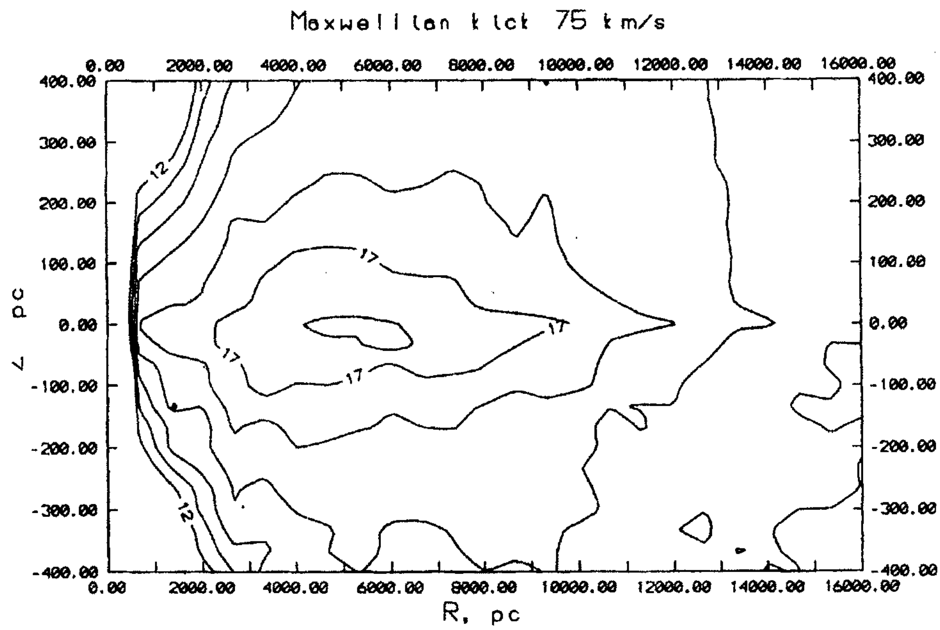

Figure 2 The luminosity distribution (in arbitrary units) in the RZ plane for a Maxwellian kick velocity (75 km s^{-1}).

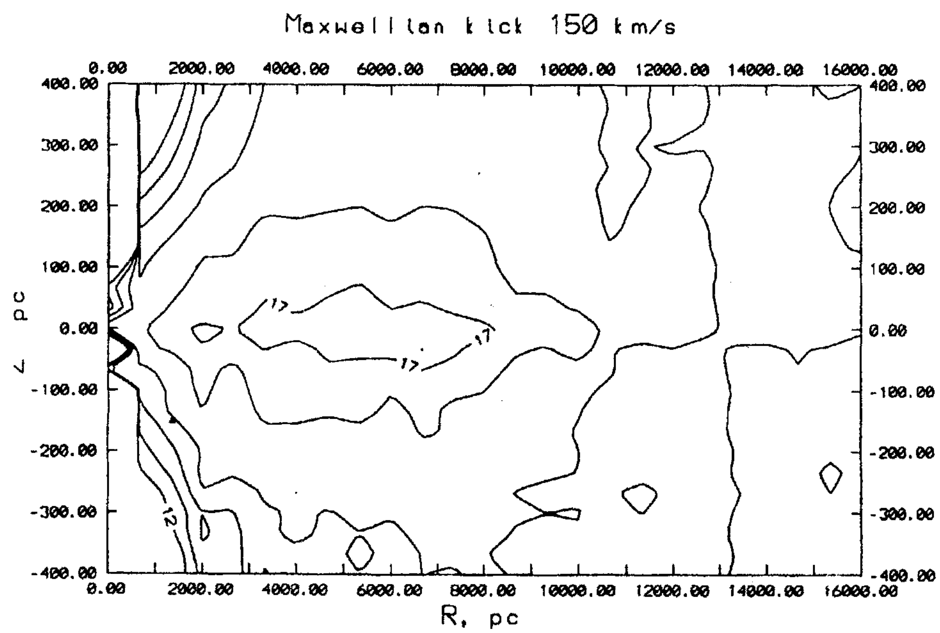

Figure 3 The luminosity distribution (in arbitrary units) in the RZ plane for a Maxwellian kick velocity (150 km s^{-1}).

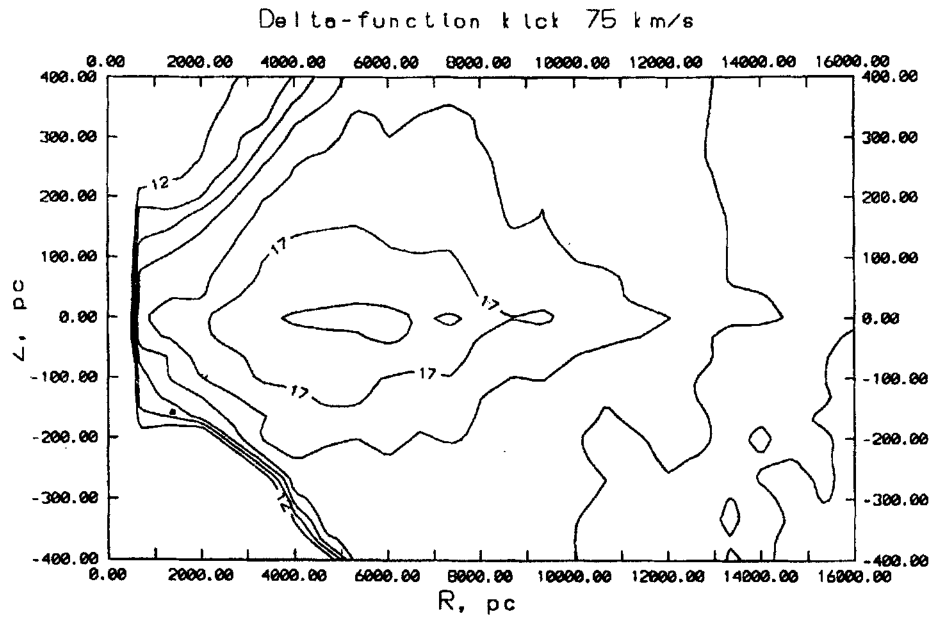

Figure 4 The luminosity distribution (in arbitrary units) in the RZ plane for a δ-function kick velocity (75 km s^{-1}).

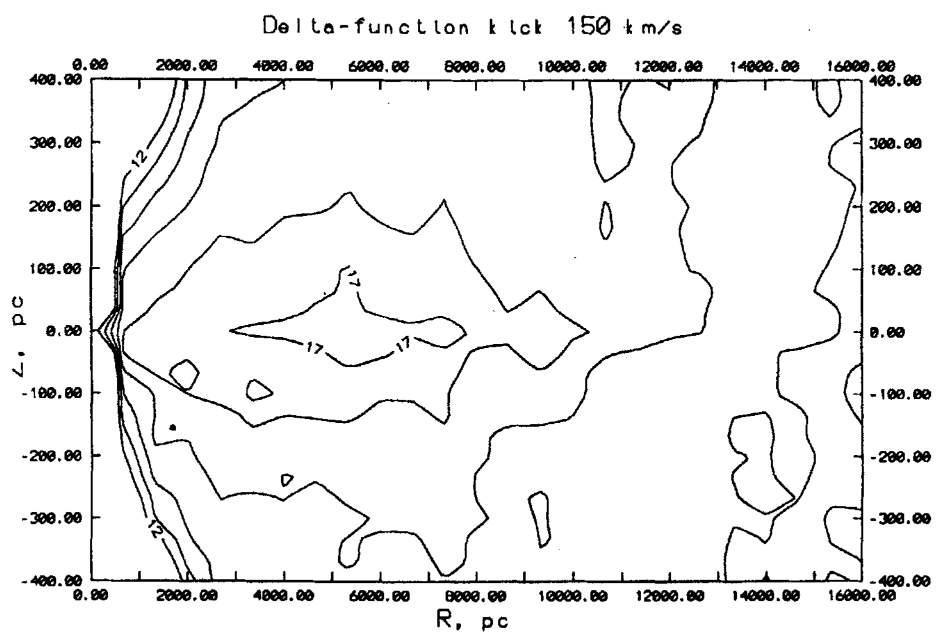

Figure 5 The luminosity distribution (in arbitrary units) in the RZ plane for a δ-function kick velocity (150 km s^{-1}).

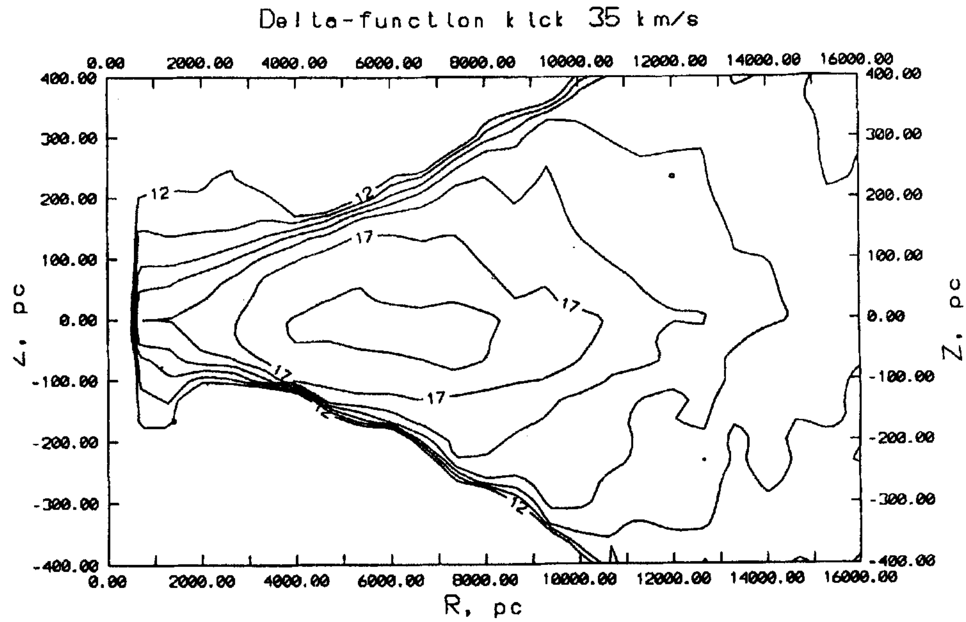

Figure 6 The luminosity distribution (in arbitrary units) in the RZ plane for a δ-function kick velocity (35 km s^{-1}).

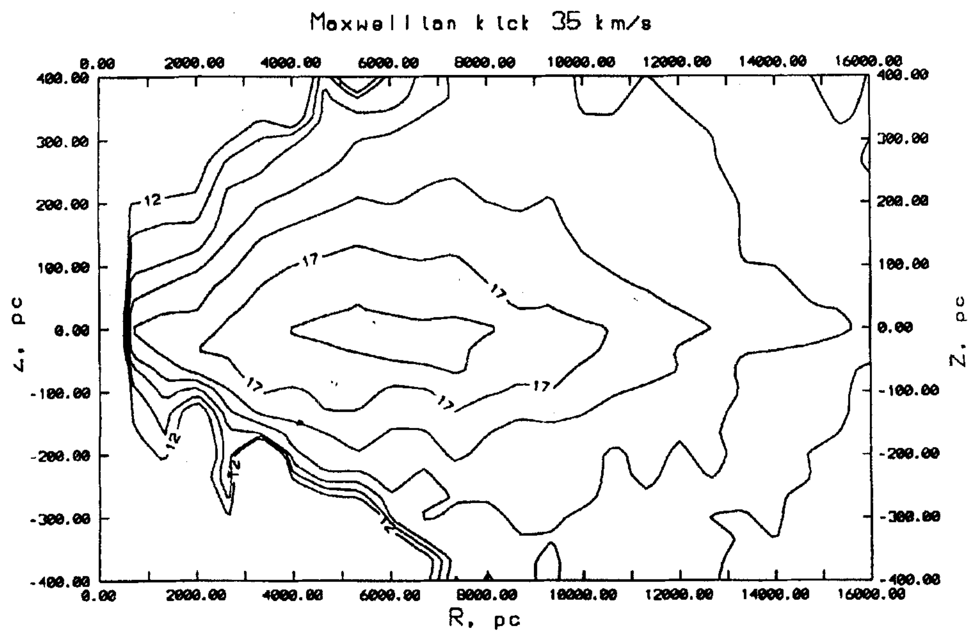

Figure 7 The luminosity distribution (in arbitrary units) in the RZ plane for a Maxwellian kick velocity (35 km s^{-1}).

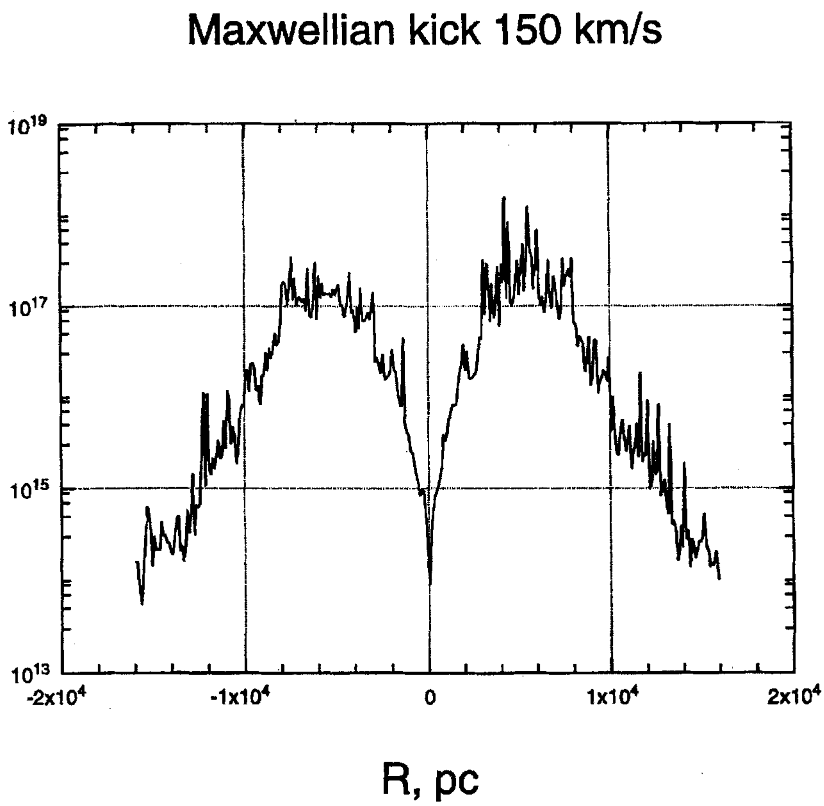

Figure 8 Slice at $Z = +5$ pc for the luminosity distribution for a Maxwellian kick velocity (150 km s^{-1}).

4 DISCUSSION AND CONCLUDING REMARKS

The torus-like structure of that distribution is an interesting and important feature of the Galactic potential. Local maxima in the ISM distribution are smoothed (compare Figures 1–7): we have several local maxima for the ISM distribution, but only one for the luminosity distribution. 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 a δ-function velocity distribution (this is especially clear for high Z–200–400 pc for low velocity distributions) because for a Maxwellian kick we have both lower velocity and higher velocity stars. High velocities can compensate orbital motions, and the star can be born with low angular momentum. Since for most parts of the Galaxy orbital velocities are greater than these kick velocities, for δ-function distributions it is impossible to reach the central region from distant regions. For high velocities (say, $V_{\rm kick} \approx 300$ km s^{-1} the situation will change.

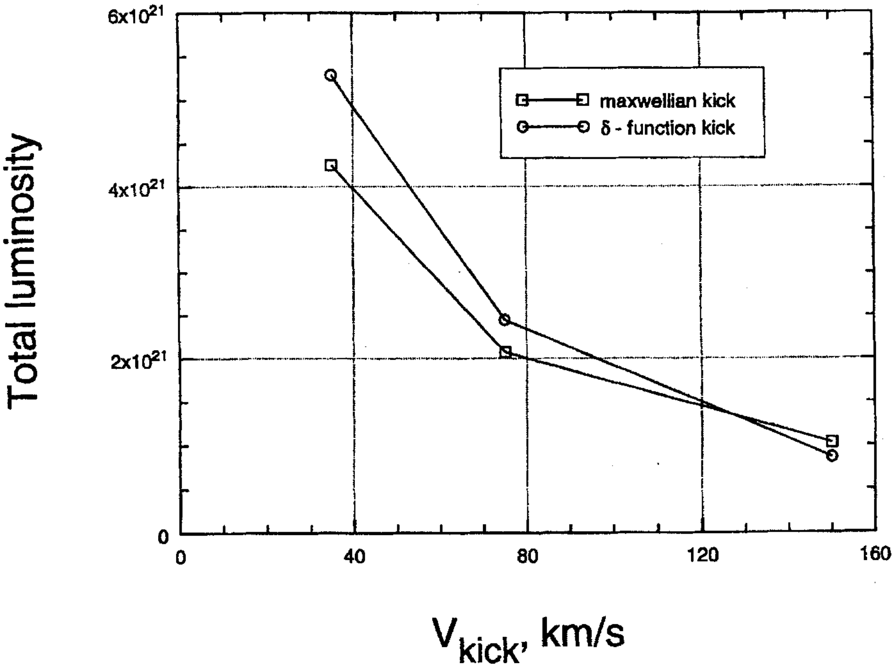

Figure 9 Total luminosity of the accreting isolated neutron stars in the Galaxy (in arbitrary units) vs. kick velocity.

In Figure 9 we show the dependence of the total luminosity of the accreting INSs in the Galaxy (in arbitrary units) on the kick velocity for two types of distributions. We note one very interesting feature: the intersection of the curves at $V_{\rm kick} \approx 125$ km s^{-1}.

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

Aknowledgements

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