THE NEUTRON STAR POPULATION IN THE GALAXY

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ABSTRACT. Properties of neutron stars are discussed and their density in Galaxy is roughly estimated. Their input in average galactic density is not large and they cannot be a reasonable dark matter candidates.

1. Introduction

Neutron stars (NS) are observed as radiopulsars, strong X-ray sources in close binaries: X-ray pulsars, X-ray bursters, X-ray sources with quasi-periodical oscillations (QPO); most transient X-ray sources also contain NS.

As the lifetime of radiopulsars and most of the strong X-ray sourses is much less then the age of Galaxy, overwhelming majority of NS will be neither radiopulsars nor strong X-ray sources. Gamma-ray bursters (GRB) have been proposed as a candidates for old nearby NS (Bisnovatyi-Kogan et.al.,1975). Discovery of hard transient X-ray pulsar in the strongest GRB of 05 March 1979 (Mazetz et.al.,1979) and results of spatial distribution of faint GRB (Mazetz et.al.,1981) give evidences in favor of this interpretation. Here we estimate spatial density of NS on the base of theoretical analysis and observational data.

2. Stellar evolution and supernovae

Estimations of the number of NS in Galaxy from theory of stellar evolution with birth rate function (theoretically) and from the pulsar and supernovae statistics (observationally) were presented by Shapiro and Teukolsky (1983). Assume Sulpeter birth rate function

$$\psi_s dm = 2 \times 10^{-12} m^{-2.35} \quad dm \quad stars \quad pc^{-3} yr^{-1}, \quad m = M/M_\odot. \tag{1}$$

This function is valid for mas interval $0.4 \leq m \leq 10$ and is steeper for larger masses. The birthrate of stars with masses in the interval $m_1 \leq m \leq m_2$ follows from (1) after integration

$$\Psi(m_1, m_2) = \int_{m_1}^{m_2} \psi dm = 1.48 \times 10^{-12} (m_1^{-1.35} - m_2^{-1.35}) \quad stars \quad pc^{-3} yr^{-1}. \tag{2}$$

The average mass of new born stars in mass interval $m_1 \leq m \leq m_2$ for Salpeter function is

$$\overline{m(m_1, m_2)} = 3.86 \frac{m_1^{-0.35} - m_2^{-0.35}}{m_1^{-1.35} - m_2^{-1.35}}. \tag{3}$$

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Shapiro and Teukolsky (1983) obtained $\rho_{ns}/\rho_T = 0.02$ (ρ_{ns} is average density of the NS, $\rho_T = 0.14$ $M_\odot$ pc^{-3} is total barionic mass density in Galaxy) adopting that NS were born by stars with masses on main sequence (MMS) $4 \leq MMS \leq 10 M_\odot$ and NS mass is equal to $1.4 M_\odot$. Now the lower MMS for NS birth is taken equal to about $8 M_\odot$ (see i.e. Bisnovatyi- Kogan,1989). The upper limit for MMS is not known. Taking into account progenitor mass of SN 1987A ($\sim 20 M_\odot$) and lower metallicity of stars in LMC we adopt for estimations the value $M_{lim} = 35 M_\odot$, for larger MMS collapse lead to formation black hole (BH). Masses of BH - stellar remnants, Cyg X-1 and A0620-00, are estimated between 4 and 15 $M_\odot$. For m_1=8 and m_2=35 we obtain with account of (2)

$$\rho_{ns}/\rho_T = 9.55 \times 10^{-3}. \tag{4}$$

For BH density these authors get ρ_{bh}/ρ_T=0.22, using m_{lim}=10 and M_{bh}=MMS with $\overline{m_{bh}}$=38.6, following from (3) at $m_2 = \infty$. Here we get $\rho_{bh}/\rho_T = 0.011$ for m_{lim}=35 and $\overline{m_{bh}}$ =10. Taking into account uncertanities, connected with stellar evolution in binaries, we obtain estimations

$$\rho_{ns}/\rho_T = 0.01 \div 0.03, \quad \rho_{bh}/\rho_T = 0.01 \div 0.03. \tag{5}$$

Corresponding birthrates in Galaxy will be

$$\dot{n}_{ns} = 0.01 \div 0.03 \quad yr^{-1}, \quad \dot{n}_{bh} = (1.5 \div 5) \times 10^{-3} \quad yr^{-1} \tag{6}$$

instead of values 0.021 and 0.0085 by Shapiro and Teukolsky (1983).

SN frequency in Galaxy is estimated as $R_{sn} = 1/28 \div 1/60$ yr^{-1} by different authors (Shapiro and Teukolsky, 1983) in accordance with theoretical estimations (6). In some SN explosions star is totally disrupted (presumably in SN I), so lower limit in (6) better coinside with SN statistics. It indicates that fate of massive stars in close binaries does not differ much from single stars.

3. Pulsar birthrate

Obtaining of pulsar birthrate from observations require a knowlege of luminosity evolution, form of the pulsar beam, magnetic field decay function. For exponential luminosity decay with time constant 4×10^6 yr, the minimum pulsar birthrate was found to be one every 230 years in Galaxy. Observational data show that beams are elongated in the latitude direction and beaming factor may be about 2. With account of uncertainties the birthrate of pulsars in Galaxy is estimated as one over $30 \div 120$ years (Taylor and Stinebring,1986) in exellent agreement with theoretical estimation (6).

4. X-ray sources and neutron star formation in binary systems

X-ray searches from the satellites lead to discovery of more then 100 bright sources, identified as NS in close binary systems. Total number of accreting neutron stars in Galaxy is of the same order, so their number is much less then total number of radiopulsars (about 10^5). Reminding that almost half of stars on the main sequence belong to binaries, we come to conclusion, that disruption of binary during formation of NS occures frequently and the number of NS remaining in pairs is about 10^{-3} of all NS in Galaxy.

Large percent of disrupted pairs and existance of pulsar velocities much larger then orbital in pairs show that Blaauw effect cannot explain this phenomena and indicate to their recoil origin. Bisnovatyi-Kogan and Moiseenko (1991) proposed mechanism of violation of mirror symmetry during formation of rotating NS with toroidal and poloidal components of magnetic field in progenitor. Consider dipole field in combination with symmetrical toroidal, having the same sign in both hemispheres. Nonuniform contraction during collapse lead to differential rotation and generation of additional toroidal field from poloidal one. Newly generated poloidal field have different signs in two hemispheres and the sum of original and generated toroidal fields have no mirror symmetry. Amplification of toroidal field by twisting lead to magnetorotational explosion (Bisnovatyi-Kogan,1989), whoose mirror asymmetry is determined by initial value of toroidal field. In order to get pulsar velocity ~ 300 km/s symmetrical part of toroidal field must be about 5×10^{14} Gs (Bisnovatyi-Kogan and Moiseenko, 1991). This value exeed the dipole pulsar magnetic fields ~ 500 times what is like the ratio of spot and large scale magnetic fields in Sun.

5. Recycled pulsars and LMXB

About 1/3 of bright X-ray sources belong to low-mass X-ray-binaries (LMXB), consisting of NS and low-mass star with $M \leq\sim M_{\odot}$. These objects are rather old (about 10^8 years) and have small magnetic fields. Accretion disk reaches a surface of NS and accellerates its rotation up to millisecond periods. After ceasing of mass transfer NS transformes into radiopulsar, which has a name of "recycled radiopulsar" (RR). The transformation of X-ray sources into radiopulsars was first considered by Bisnovatyi-Kogan and Komberg (1974).

Most numerous sample of RR originates from LMXB. About half of LMXB are situated in globular clusters leading to suggestion of the origin of LMXB in tidal capture of a red dwarf by NS (Fabian, Pringle and Rees, 1975). Among 42 known RR only 11 lay outside globular clusters. This is connected mainly with selection effect inherent to the search procedure. RR contain about 10 % of all known radiopulsars so their input in average galactic density is small. Radiopulsars are related to RR by one of three main properties:

1.belonging to globular cluster
2.belonging to close binary system
3.very small (less then 10 msec) period.

Usually RR obtain 2 or 3 of these properties. In addition all RR have magnetic fields 1 - 3 order of magnitude less then the smallest magnetic fields of ordinary radiopulsars. This confirms the suggestion of magnetic field decay during accretion made by Bisnovatyi-Kogan and Komberg (1974).

Recent discoveries of 5 RR in M 15 (Anderson et.al.,1990; Manchester,1990) and 11 RR in 47 Tuc (Manchester et.al.,1991) arises problems of evolution of LMXB and RR. The number of RR exeeds number of LMXB in one cluster about 10 times so the lifetime of LMXB must be 10 times less then of RR if their origin is in common. This explanation arises difficulties, connected with formation of large number of binaries in globular cluster by tidal capture. Calculations of Bisnovatyi-Kogan and Romanova (1982) give the number of possible binary much less then that observed in 47 Tuc. The possible explanation may be related with nonmonotonic evolution. In past cores of globular clusters could be more dense with larger binary birthrate. Formation of several binaries could reverse evolution and lead to expansion of the core. RR in 47 Tuc could be remnants of this dense core phase.

6. Gamma-ray burst sources

The number of registrated GRB is about 500 and is of the order of number of radiopulsars. If GRB originate on old single nearby NS there is a direct genetic connection between radiopulsars and GRB sources. In models of starquakes with or without nuclear explosion (Bisnovatyi-Kogan et.al.,1975; Tsygan,1975) all NS, including living and dead radiopulsars are the sources of GRB. If energy of explosion leading to GRB is limited by $10^{36} \div 10^{39}$ ergs then they could be observed by existing detectors vith sensitivity not better 3×10^{-7} $ergs/cm^2 = F_{lim}$ from distances less then $200 \div 5000$ pc. Taking into account that sensitivity of most detectors is less then F_{lim} it follows that average distance to observed GRB is about half thickness of the galactic disk in accordance with their isotropic distribution over the sky.

Assume that all NS in Galaxy $(2 \div 7) \times 10^8$ stars, are uniformly distributed in the disk with thickness 400 pc and radius 15 kpc and all observed GRB arrive from the part of the disk with radius 200 pc around Sun. Then the number of NS taking part in visible GRB production is equal to $(0.3 \div 1) \times 10^5$. Adopting the average frequency of visible GRB about one per day we obtain that old NS must give birth to GRB every $(0.3 \div 1) \times 10^5$ days or every $100 \div 350$ years.

7. Upper limits on the number of neutron stars in Galaxy

Estimate a density on NS not using extrapolation of modern birthrate to earliest stages. Consider two kinds of estimations:
1.Production of heavy elements.
It is established that elements beginning from carbon are ejected into interstellar medium in SN explosions and amount of heavy elements ejected in one explosion is not less then 0.1 $M_\odot$. For the density of heavy elements $\rho_Z \leq 0.03\ \rho_T$ and NS mass 1.4 $M_\odot$ we get

$$\rho_{ns}/\rho_T \leq 0.4 \qquad in \quad all \quad SN \quad explosions. \tag{7}$$

2. Neutrino background.
Formation of NS leaves a signature in form of neutrino background (Bisnovatyi-Kogan and Seidov, 1982). Binding energy of NS $\sim 0.1 M_\odot$ is transformed into middle-energy neutrino with $E_\nu = 5 \div 30$ Mev. It follows from estimations of Bisnovatyi-Kogan and Seidov (1982), that NS with average density $\rho_{ns} = 0.03\rho_T$ at constant production rate equal to the present one give the background in Cl - Ar Solar detector about 2×10^{-3} SNU. If most NS were produced in early epoch of violent starbirth, the energy of neutrino in background is less due to redshift and a possibility of detection falls. Using of Ga - Ge neutrino detectors may give better constrains on early formed neutrino background and lower absolute upper limit on density of NS. After estimation of spectra and amount of energy produced during formation of BH in relativistic collapse, one may get similar constrains on density of BH from stellar collapses.

8. References

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DISCUSSION

HORVATH: In currently studied models of type II SN the final fate of the compact remnant turns out to be essentially determined by the mass of the iron collapsing core, which appears to be a non-monotonic function of the total progenitor mass. Would you predict a clear progenitor mass forming BH above and NS below from your magnetorotational driven explosions?

BISNOVATYI-KOGAN: The mentioned main sequence mass of 35 $M_\odot$ for the boundary between NS adn BH is very undefinite and may be considered as a personal opinion, based on experience in stellar evolution and supernova theory.

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