Thermal Emission from Binary Millisecond Pulsar Stars (MSPs)

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Abstract

Pulsar stars divided into two types depending on the periods of rotation, normal emission Pulsar and Millisecond pulsars (MSPs). In this paper, the effect of the strong magnetic field on the thermal emission in Millisecond pulsar stars is concentrated. Also the luminosity spin down (Lsp) are calculated depends on the periods (P), and Period derivative ($\dot{P}$) for sample stars which were adopted. The relation between internal and surface magnetic field is illustrated. The model that which adopted is Hallo Cone Model (HCM)). The total magnetic dipole radiation power (heating power Wh) of all super fluid neutrons in MSPs stars is calculated. For sample stars of MSPs , the value of transition period (P_{tr}) was determined by depending on the some properties of pulsar star. The results indicated that heating power of our model (A) would be larger than the model (B) that's due to the huge value of the moment of inertia (I). Also the results showed that the maximum surface luminosity of stars occurs at the values of Magnetic field ≥ 5.5 10^{12} Gauss.

Keyword: Neutron stars, Pulsars, emission of neutron stars-Spin down.

الانبعاث الحراري من نجوم الثنائية النابضة من نوع ملي ثانية

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الخلاصة:

النجوم النابضة تقسم إلى نوعين هما النجوم النابضة الاعتيادية و نجوم النابضة ملي الثانية وذلك اعتمادا على الفترة الزمنية للدوران. في هذا البحث تم التركيز على تأثير المجال المغناطيسي القوي على الانبعاث الحراري للنجوم الثنائية .

اعتمادا على الفترة الدورانية (P) ومشتقة الفترة($\dot{P}$) تم حساب تباطي أللمعانية لعينة النجوم التي تبنيت. العلاقة بين المجال المغناطيسي الداخلي والخارجي تم توضيحها أيضا. الموديل الذي تم الاعتماد عليه هو نموذج الاسطوانة الضوئية (HCM) . محصلة الانبعاث الحراري لجميع نيوترونات المائع لنجوم MSP تم حسابها . قيمة فترة الانتقال(P_{tr}) لنجوم الملي ثانية النابضة عينت وذلك بالاعتماد على بعض خواص النجم النابض. أشارت النتائج إلى إن نسبة التسخين للموديل التي تم اعتماده (A) كانت اكبر من الموديل (B) الذي تم مقارنته معه ويعزى ذلك إلى إن نسبة عزم القصور الذاتي (I) كانت قيمة كبيرة جدا لتلك النجوم . بينت النتائج أيضا إن أعظم قيمة للمعانية تكون عندما تكون قيمة المجال المغناطيسي اكبر من(5.5×10^{12} كاوس) .

Introduction

Pulsars are highly magnetized, rotating neutron stars which emit a narrow radio beam along the magnetic dipole axis. As the magnetic axis is inclined to the rotation axis, the pulsar acts like a cosmic light-house emitting a radio pulse that can be detected once per rotation period when the beam is

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directed toward Earth. For some very fast rotating pulsars, the so-called millisecond pulsars [1], the stability of the pulse period is similar to that achieved by the best terrestrial atomic clocks. Pulsars emit electromagnetic radiation and, in particular, magnetic dipole radiation as they essentially represent rotating magnets. These spinning neutron stars behave in similar way to light houses as showed in figure 1; this figure shows that the angle between rotation axis and magnetic axis (λ) varies between (0-90˚) [2, 3, 4].

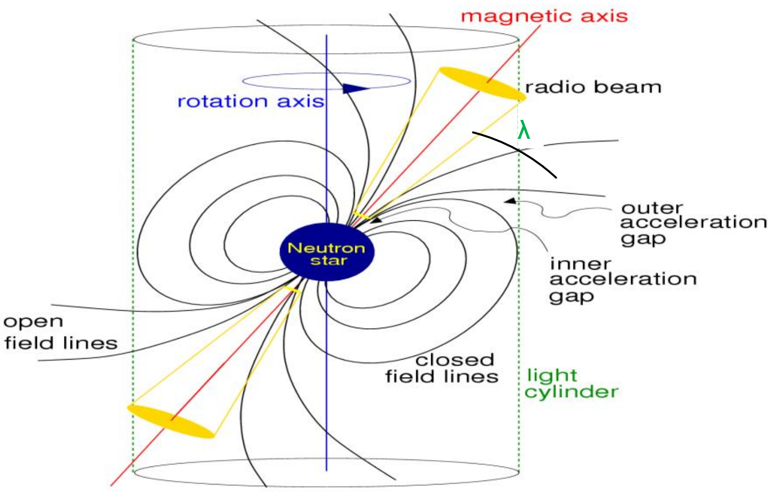

Figure 1- Halo Cone Model for Pulsar star [4]

The emission from the ≈1,500 radio pulsars (PSRs) discovered to date is generally thought to be powered by the loss of rotational kinetic energy due to magnetic braking. Radio pulsars with implied magnetic fields in the range (10^{13-14} G)have now been discovered, showing that radio emission can be produced in neutron stars with fields above the quantum critical field ($B_c = 4.4 \times 10^{13}$ G) [3].

Heating mechanisms that might cause detectable thermal x-ray emission from the surfaces of Pulsar stars have been review at early time at 1980 [4, 5]. Since nearly all of the heating processes, which have been considered, heat only the magnetic polar cap of Pulsar, the resulting thermal emission at Earth [3, 5]. The process proposed previously that should lead to global heating and, hence un pulsed emission is frictional dissipation between the crust and super fluid, interior of neutron star.

The first statistical analysis of the pulsar population with a view to determine their period evolution was done by Gunn and Ostriker [6]. It is remarkable that about 40 pulsars were known at that time the two conclusions they arrived at were remarkably prescient; first the dynamic ages of Pulsar deduced from their distances from the galactic plane, second the radio luminosities of pulsars must decrease with the age [7]. The characteristics age of millisecond Pulsars on average 2-3 orders of magnitude larger than that of normal Pulsars [7,8]. The P-Pdot diagram is useful for following the lives of pulsars, playing a role similar to the Hertz sprung-Russell diagram for ordinary stars. That is given the information about pulsar population and some magnetic properties of Pulsar stars [3].

The spin down rate according to the $P\dot{P}$ α P^2 mechanism were illustrated in this paper, another mechanisms contributing to the spin down of MSPs, named magnetic dipole radiation of Super fluid neutron in neutron stars are proposed. Also the luminosity of spin down was calculating relative to period and period derivative changing [9]. The energy observed in Pulsars is only a small of reaction of total rotation energy dissipated. The radiation must be emitted in relatively narrow beam, as shown in figure 1.

Basic Considerations of Model and Results

1- Emission models of pulsars

The emission model of pulsars is an important factor in the prediction of the magnetic field of pulsars. Unfortunately, no generally accepted model is available.

Therefore, we will discuss some alternative formulas for the emission of pulsars. The rotational energy of the pulsar may change by magnetic dipole radiation, accretion or other mechanisms according to the [5]

$$E = \tfrac{1}{2} I \Omega^2 \qquad (1)$$

$$\dot{E} = I \Omega \dot{\Omega} = -4\pi^2 I P^{-3} \dot{P} \qquad (2)$$

Where $\dot{E}$, $\dot{\Omega}$ and $\dot{P}$ are the time-derivatives of E, Ω and P, respectively (It has been assumed that the moment of inertia I is no function of time [1, 5]

$$\dot{E} = -(32\pi^4/3)\, c^{-3} \sin^2\lambda\, M^2 P^{-4}, \qquad (3)$$

Where M is the electro magnetic dipole moment of the pulsar and λ is the angle between *M and S* as shown in figure 1. Notes that the gravito magnetic dipole moment M does not occur since gravito magnetic dipole radiation does not exist. Gravito magnetic quadrupole radiation (for two point masses its energy formula coincides with the familiar expression for the gravitational quadrupole radiation may be present, however, but its influence is not considered in this work.

The electro- neutral have an anomalous magnetic moment [3, 9]

$$m = g m_n S \qquad (4)$$

Where the nuclear number g=-3.826, m_n is the nuclear magneton and S is the component of the spin angular moment. there is interaction leads to dipole radiation of the neutron magnetic moment for neutrons in circular motion such as those in super fluid vortexes the energy radiated by on neutron is [1,7]:

$$W = \frac{2\omega^4}{3c^3}\left[i \frac{i}{m_z} + \frac{\overline{mz}}{i} \right] \qquad (5)$$

Where $\overline{mz}$ the operator of the magnetic moment, ω *is* is the frequency of emitted photons is equal to the rotation frequency of the neutron, because of the high capacity of the stellar interior this radiation is observed and become a heating source.

The total magnetic dipole radiation power of the entire neutron in neutron star is

$$Wm = \frac{11\pi\gamma^4}{3c^2h^2} m^2 \Delta B n^3 R^3 P^{-1} \qquad (6)$$

Where γ is the neutron gyro magnetic and density of state at the Fermi surface.

B is the magnetic field strength, Δ is the energy gap.

R *is* the radius of pulsar star (~10^4m),

P *is* the period.

n is the braking indices.

2- The Effect of Magnetic Dipole Radiation on the Spin down of Pulsar (MDRSN)

Both the MDRSN and neutrino cyclotron radiation of neutron lead to Pulsar energy loss $\propto P^{-1}$ [1, 2]. For simplicity, in the model which adopted, use these values, $\Delta \sim 2.35$Mev (theoretical value 2.5), n=10, $B \geq 10^{13}$G.

The ratio of average interior to surface magnetic field strength is at least of the order of unity, the condition should be satisfied for pulsar with mass $\geq 0.5\ M_\odot$. The transition period P_{tr} depends on properties of neutron star such as the interior structure and the internal magnetic field which are model dependent these lead to value of , $P_{tr} \geq 1.25$ which adopted in our model in comparison with model B, the value of $P_{tr} \geq 0.55$ [3,7] .

3- The Magnetic Dipole as a Heating Source

The magnetic dipole radiation for binary Millisecond pulsar with measured P and $\dot{P}$ depends on the spin down as [1, 8]

$$B=32\times10^{19}\,(P\dot{P})^{1/2} \quad (7)$$

The characteristic age can be calculated by depending on the period and period derivative as

$$t_c = 1/2\,(P/\dot{P}) \quad (8)$$

The heating rate (Eh) is given by the equation [2]:

$$Eh = 4\pi^2 f I\, P\dot{P}^{-3} \quad (9)$$

Where f is given by [1]:

$$f = Eh/Erot = \left[1+\frac{P_m}{P}\right] \quad (10)$$

Where *Erot* is the rotational energy. The total moment of inertia of the neutron star (I =6.24 $\times10^{44}$ g cm^2) [7,8]. Equation (10) demonstrates that the smaller value of P_m leads to larger heating rates also can expected heating rates by the effecting magnetic dipole [1,4].
The luminosity of spin down (L_{SP}) can be given

$$L_{SP} = 4\times10^{46} \quad P\dot{P}^{-3} \quad (11)$$

Table 1- represents the value of period (*P*) and period derivative ($\dot{P}$) for a sample of neutron stars. Surface magnetic dipole also estimated for binary Millisecond pulsar stars by choosing P_{tr} =1.25s and moment of inertia which is model dependent.

Table 1- The calculated values of magnetic field for adopted sample of MSPs are illustrated related to observations of periods and derivative period [2].

PSR	P_m (ms)	$\dot{P}$	f	B_S(G)
J2019+2425	4.5019	10^{-19}	0.9791	$4.6303*10^{12}$
J0621+1002	28.851	10^{-15}	0.9991	$5.8029*10^{12}$
J0951+1807	3.470	10^{-14}	0.9556	$3.5726*10^{12}$
J2229+2643	2.978	10^{-18}	0.9311	$3.0581*10^{12}$
J1012+1001	5.265	10^{-18}	0.9867	$5.3974*10^{11}$
J1022+1001	16.453	10^{-17}	0.9995	$5.6895*10^{12}$
B1257+12	6.219	10^{-19}	0.9991	$3.3864*10^{12}$
J1518+4904	40.935	10^{-19}	0.9999	$5.8536*10^{12}$
B1620-26	11.076	10^{-19}	0.9985	$4.2374*10^{12}$
J1640+2224	3.163	10^{-17}	0.9418	$3.2481*10^{12}$
J1713+0747	4.621	10^{-18}	0.9805	$4.7539*10^{12}$
B1855+09	4.570	10^{-15}	0.9799	$4.6930*10^{12}$
B1937+21	5.362	10^{-19}	0.9847	$5.5063*10^{12}$

The heating rate will increases when the periods of stars decreases so the heating rate will reach minimum value at high that of periods spin down of stars will occurred at minimum values of heating rate as shown in figure 2- and figure 3.

The heating of rotating binary MSPs star with crust dramatically changes its thermal evolution, as shown in figure 4- and figure 5- when the heating source become important depends on the strength of magnetic fields. Table 2- estimated the several of properties for the adopted model (A) and previous model (B) that Ostriker and Gunn were adopted it [6].

Table 2- The various properties of adopted Model (A) and Model (B) for the magnetic dipole radiation heating

PSR	Model A		Model B	
	Eh(erg / s)	T 10^6 (K°)	Eh (erg / s)	T 10^6 (K°)
0031-07	$3.3*10^{31}$	0.32	$1.1*10^{30}$	0.28
0194-16	$1.5*10^{31}$	0.46	$4.5*10^{30}$	0.40
0355+54	$9.7*10^{31}$	0.83	$8.3*10^{31}$	0.83
0402+61	$1.3*10^{33}$	0.70	$4.1*10^{32}$	0.69
0450+55	$1.1*10^{32}$	0.67	$3.5*10^{31}$	0.67
0540+23	$8.7*10^{33}$	1.1	$2.7*10^{33}$	1.11
0611+22	$2.9*10^{33}$	1.5	$9.0*10^{33}$	1.50
0727-18	$5.8*10^{33}$	1.0	$1.8*10^{33}$	1.03
0740-28	$1.0*10^{33}$	1.2	$3.2*10^{33}$	1.85
0743-53	$1.6*10^{33}$	0.73	$5.0*10^{32}$	0.73
0809+74	$5.5*10^{30}$	0.20	$1.7*10^{30}$	0.18
0826-34	$1.2*10^{31}$	0.25	$3.8*10^{30}$	0.22
0840-48	$5.9*10^{33}$	0.76	$1.9*10^{33}$	0.76
0905-52	$1.0*10^{33}$	0.65	$3.2*10^{32}$	0.65
0919+06	$5.3*10^{33}$	0.99	$1.6*10^{33}$	0.98
0922-52	$5.2*10^{33}$	0.98	$1.6*10^{33}$	0.94
0940-55	$4.3*10^{33}$	0.95	$1.3*10^{33}$	0.96

Spin down and magnetic field relation illustrated in figure 6- as the magnetic field decays the equilibrium period will decrease. The heating rate will increase when the period's stars decrease and reach minimum value at high those periods. As the periods of pulsars lengthen their trajectory will be horizontal as long as the magnetic field remains constant.

The rate of evolution a long these tracks depends upon the field strength and will be faster for the high field pulsars. The final spin period of such a recycled pulsar depends on the mass of the binary companion. A more massive companion evolves faster, limiting the duration of the accretion process and hence the angular momentum transfer. The results indicate that heating power of our model (A) would be larger than the model (B) that's due to the huge value of the moment of inertia (I)

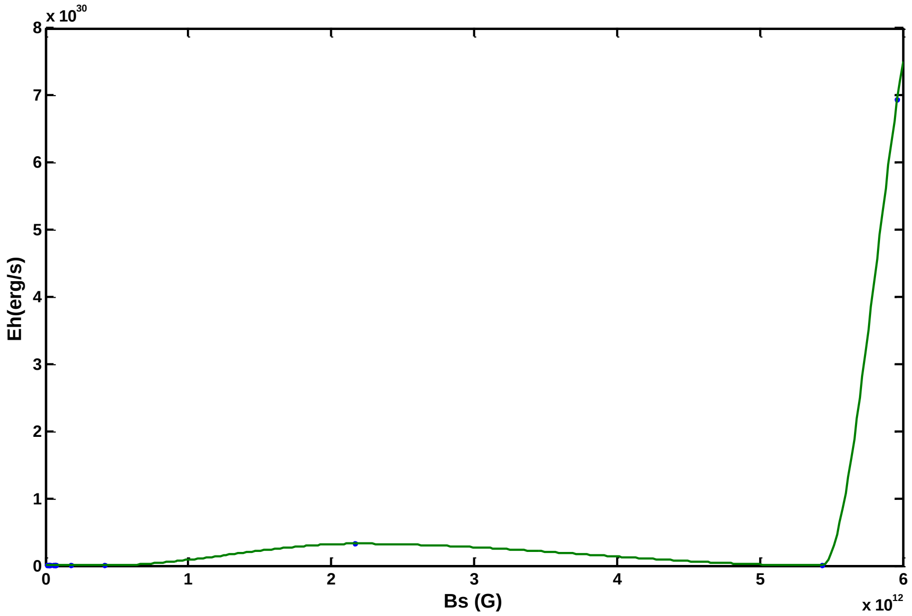

Figure 2- The relation between heating rate of energy a function of surface magnetic field.

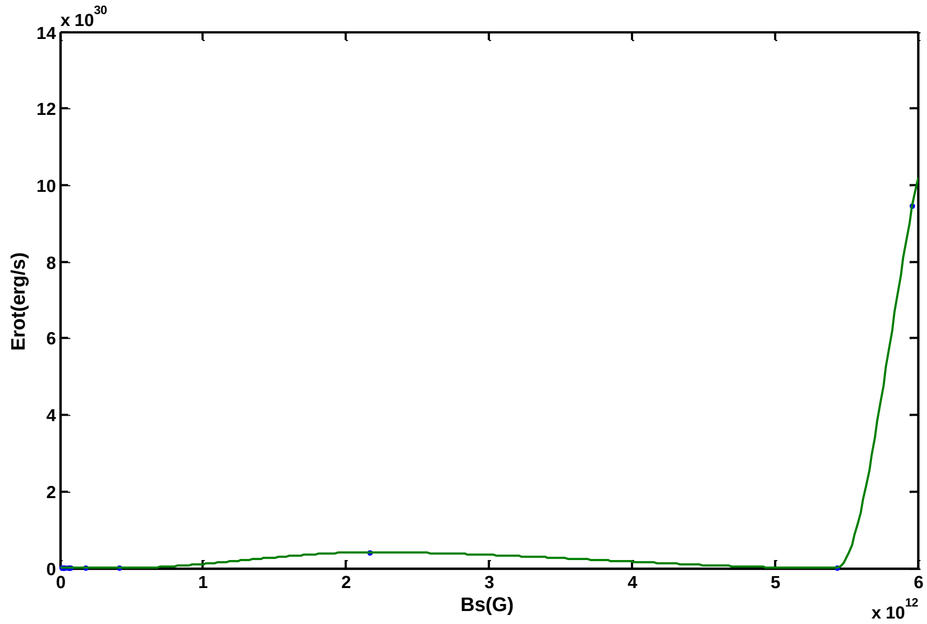

Figure 3- The relation between rotational energy as a function of surface magnetic field

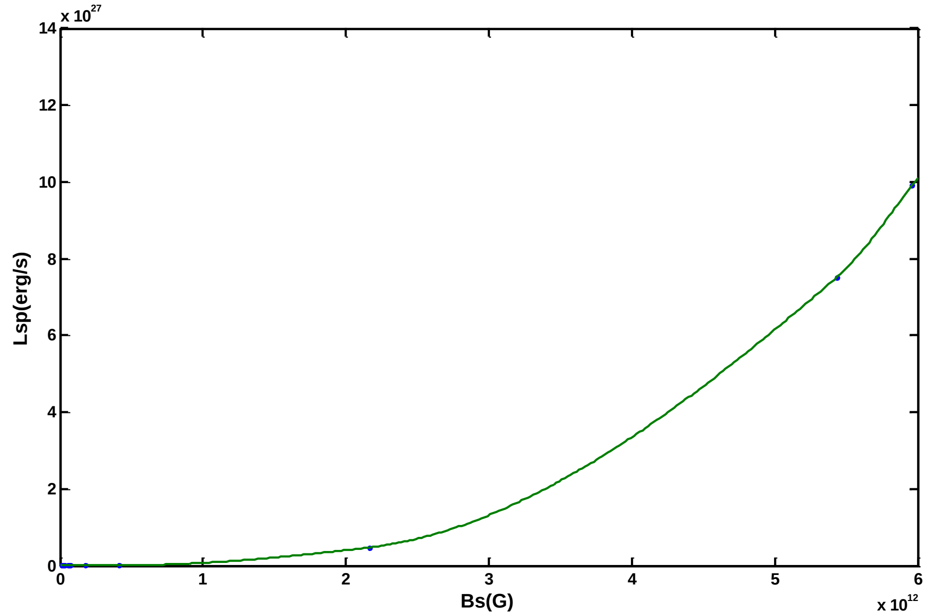

Figure 4- The relation between spin down luminosity of Binary Millisecond pulsars as a function of surface magnetic field of star.

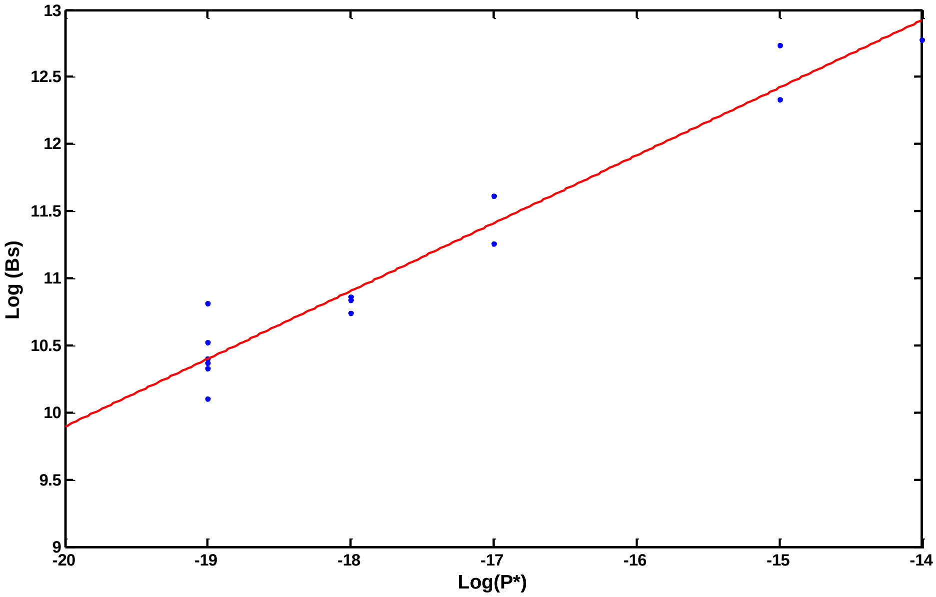

Figure 5- The relation between surface magnetic field as a function of period derivative.

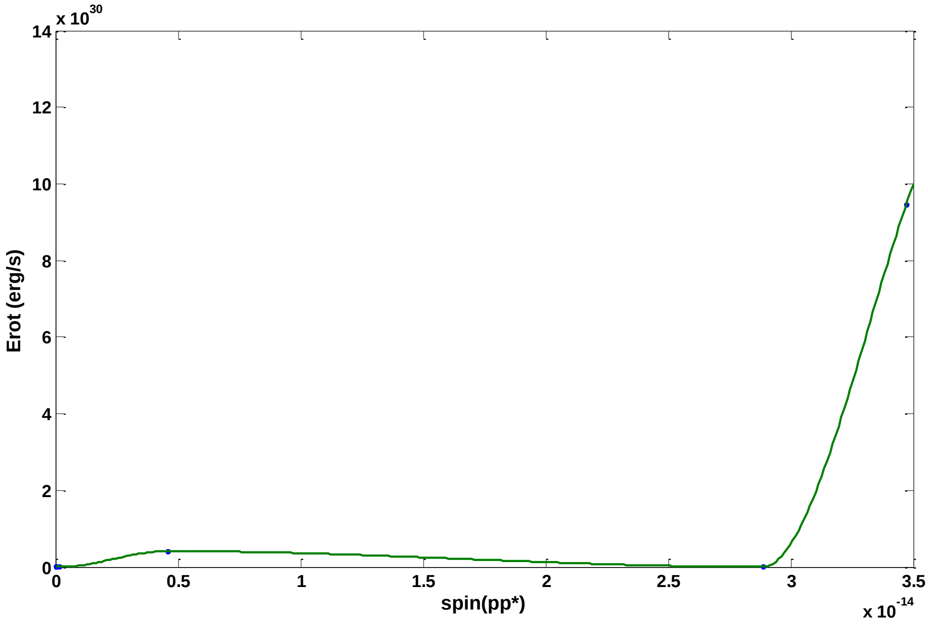

Figure 6- The relation between rotational energy as a function of spin down of Millisecond pulsars.

The rate of loss of rotational kinetic energy $\dot{E}\ \alpha\ P^{-3}\ \dot{P}$ (also is known as the ‘spin-down luminosity’) is shown in figure 2. The rotating energy will reach maximum value when spin down of star reaches value > 3×10^{-14}. As expected, these are highest for the young and millisecond pulsars.

The spin-down luminosity of the star as shown in figure 4- that goes into feeding the Pulsar emission is recovered after integration of the nebular emission over a wide range of frequencies،usually extending from the radio to the X-ray and even γ-ray band.

The results indicate that the rotating magneticdipole model, in which the pulsar loses rotational energy through magnetic dipole radiation, was dramatically confirmed with the discovery that the spin-down power predicted for the pulsars was a nearly perfect energetic match with the radiation of its synchrotron nebula. The rotating dipole model also accounts for the observed rate of spin-down of the MSPs pulsars, with required surface magnetic fields ($B \approx 10^{12}$ G) for the adopted MSPs pulsars.

The older millisecond pulsars defined as having greater ages, because $P / \dot{P}$ specifies how long pulsars lives at the age. Older pulsars are not, either because their origin medium (Super nova explosion) have faded to invisibility or because the supernova explosions expelled the pulsars with enough speed that they have since escaped from their parent SNRs. The bulk of the pulsar population is older than 10^5 yr but much younger than the Galaxy (10^{10} yr) [10, 11]].

The observed distribution of pulsars in the $P\dot{P}$ diagram indicates that something changes as pulsars age [10, 9]. One controversial possibility is that the magnetic fields of old pulsars must decay on time scales 10^7 yr, causing old pulsars to move almost straight down in the $P\dot{P}$ diagram until they fall below into the graveyard below the death line and cease However, strongly spun-up pulsars would always have very small angular spread of open field lines at one of the poles on the stellar surface, and further consequences of this should be explored radiating radio pulses. The pulsar spins up and is recycled into a radio millisecond pulsar when P and $\dot{P}$ have been altered such that the pulsar has crossed the death-line again in the other direction.

Conclusions

1- The results indicate that the very long period's millisecond pulsars, to be observable, have particularly large surface magnetic field.

2- The maximum values of spin down luminosity (Lsp) of the Binary MSPs is obtained when the values of magnetic dipole radiation magnetic field is $\geq 5\times10^{12}$ G.

3- The heating rate will increase when the period's stars decrease and reach minimum value at high those periods. As the periods of pulsars lengthen their trajectory will be horizontal as long as the magnetic field remains constant. The rate of evolution a long these tracks depends upon the field strength and will be faster for the high field pulsars.

4- As the field began to decay, the tracks of pulsars will be swing downwards and evolution and eventually become vertical that could be due to field decay.

5- The results indicated that rotating energy will reach maximum value when spin down of star reaches value $> 3\times10^{-14.}$

6- The results estimated that the millisecond pulsars (shorter periods) are rapidly growing, in a good a agreement with the recent discovered pulsars in Globular clusters which must surely be old, and have low magnetic field.

Refferences

1. Siegfried, R. **2008.** Modern Astronomy, Wiley-VGA, Morierback, USA, pp:256-260**.**
2. Dereck, M. **2003.** Non –Quiescent X-Ray Emission from Neutron stars and Black hole, Stanford University, USA.
3. Kramer, M. **2004**. General Relativity with Double Pulsars, SLAC Summer Institute on Particle physics (SSIO4).
4. John, A. and Tomas M. **2013.** Massive Pulsar in Compact Relativistic Binary, *Astrophysical J.*, 2, pp:250-267.
5. Werner, B. **2009**. Neutron Star and Pulsars, Astrophysics and Space Science Library., 357, pp:345-367.
6. Ostriker, J. and Gunn, J. **1971.** Pulsars their origin and Evolution, *Astrophysical J.*, 165: 523.
7. Sundus, A.**2008.** The Spin down Torque decay with the Characteristic Age for binary Millisecond Pulsars (MSPs), *Iraqi Journal of Science*, 49(1), pp:239-243.
8. Veritas C., *et.al.* **2011.** Detection of Pulsated Gamm rays above 100 Gev from the Grab pulsar, *Astrophysical J.*, 105, pp:1365.
9. Rankin, J. and Suleymanovo, S. **2006.** Emission Mechanisms of Radio Pulsar, Astronomy and *Astrophysical J.*, 105, pp:2966.
10. Kaspi, V., *et*.al. **1994.** On the Spin Down of PSR B1509-58, *Astrophysical J.*, 422, pp:83-86.
11. Donald G., *et.al*.**2012.** The Astronomy Revolution, CRC Press, Taylor &Francis Group, New York. pp:10-50