THE SPIN-DOWN TORQUE DECAY WITH THE CHARACTERISTIC AGE FOR BINARY MILLISECOND PULSARS (MSPS) STARS

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Abstract

Millisecond pulsars (MSPs) type have properties differs from normal pulsars type. In this research the characteristic age are concentrated depends on the periods (P), and period derivative (P`) for a sample stars which adopted. Also the value of characteristic age for these stars is determined by depending on the (Ostriker and Gunn) model. The relation between luminosity and the characteristic age for a sample of MSPs stars are illustrated depending on pulse periods for these stars. The results indicate that the spin down torque must decay with the characteristic age for a sample stars which adopted. Also the results for these stars at distance 1.5 kpc from the galactic disk illustrated that the decay must due to the main energy loss mechanism is magnetic dipole radiation, they attributed this to tendency of rotation axis to align with magnetic axis as pulsar age . It is found that the radio luminosity of pulsars must decrease with age, in a good agreement with previous study.

تباطيءالعزم الدوراني مع العمر المميز للنجوم الثنائية النابضة من نوع (MSPs pulsars)

الخلاصة

النجوم النابضة من نوع الملي ثانية تختلف في خواصها عن النجوم النابضة من نوع اعتيادية الفترة . في هذا البحث تم التركيز على دراسة العمر المميز لعينة من نجوم الملي ثانية(MSPs)واستخراج قيمته بالاعتماد على نموذج (Ostriker and Gunn) وذلك من معرفة الفترة ومشتقة الفترة لهذه العينة من نجوم الملي ثانية .تم التركيز في هذا البحث ايضا على معرفة العلاقة بين لمعانية هذه النجوم وعلاقتها بفترة حياتها اي العمر المميز لهذه العينة من النجوم بالاعتماد على فترة كل نبضة لهذه النجوم. اوضحت النتائج ان العزم الدوراني للنجم يتباطئ مع زيادة العمرالمميزلهذه النجوم وخاصة النجوم الواقعة على مسافة (1.5kpc) من المستوى المجري. اوضحت النتائج ايضا ان التباطئ للنجم يحدث نتيجة فقدان الطاقة الرئيسية عن طريق اشعاع ثنائي القطب المغناطيسي وهذا يعزى الى ميل المحور الدوراني عن المحور المغناطيسي مع تقدم عمر النابض. كما اكدت النتائج ان اللمعانية الراديوية للنابضات من نوع الملي ثانية تقل مع زيادة العمر المميز للنجم النابض وهذه النتائج تتوافق مع النتائج لدراسة سابقة.

Introduction

Observations of individual pulsars clearly show that their periods lengthen as they age,[1]. Also it seen that they step functioning as pulsars after their periods have lengthened to ~1s, although this critical period seem to depend upon the strength of the magnetic field, (see Fig.1).

Is this simple picture consistent with the observed distribution of their periods and period derivatives. The first statistical analysis of the pulsar population with a view to determine their period evolution was done by Gunn and Ostriker (1970),[2]. It is remarkable that although only about 40 pulsars were known at that time, the following two conclusions they arrived at were remarkably prescient:

1-The dynamical ages of pulsar deduced from their distances from the galactic plane.

2- The radio luminosities of pulsars must decrease with age.

The characteristic age of millisecond pulsars on average 2-3 orders of magnitude larger than that of normal pulsars,[3].

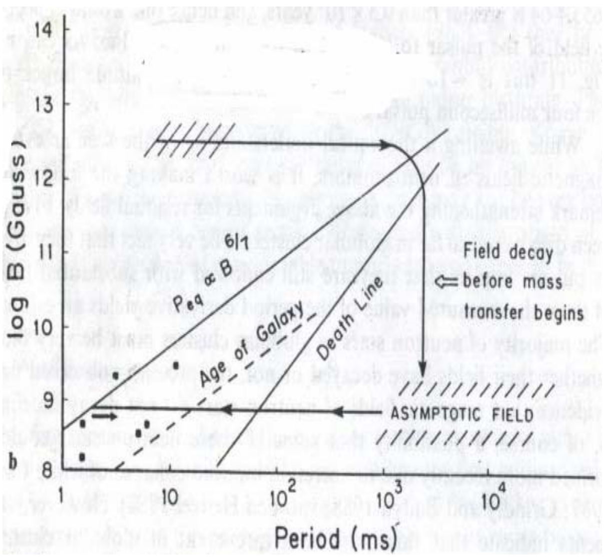

Figure (1): The life history for millisecond pulsars is shown; the neutron star was born in a standard supernova explosion its field would have decayed to the asymptotic value before mass transfers begins[1].

Millisecond pulsars

When the first millisecond pulsar PSR(1937+21) with a period of 1.5ms was discovered by Backer et al.(1982), all indications were that the energy loss rate of this pulsar must be extremely small despite of its ultra short period, and this implied a magnetic field $\leq 10^9$ G,[4,5].

The first important point to note that their progenitors can not be the massive X-ray binaries,[6]. In order to spin up a neutron star to a period ~ millisecond it must accrete about $0.1M_{O}$. This implies that mass transfer must last for ~ 10^7years even at the maximum possible Eddington rate, [7]. In a low mass binary system in which the companion is less massive than the neutron star, mass transfer can last for a much longer time scale. Adopting a scale height of 300 Pc in the galaxy, a simple scaling suggests that there should be several thousand millisecond pulsars in the galaxy,[4,7].

The Standard Model

In a complementary model, Ostriker and Cunn (1970) considered an inclined magnetic with the rotational axes as shown in fig.(2). The main energy loss mechanism is due to the emission of magnetic dipole radiation whose luminosity will be determined by the strength of the magnetic field, that is mean the radio luminosity will be proportional to $|B|^2$, and the period of the power, [2].

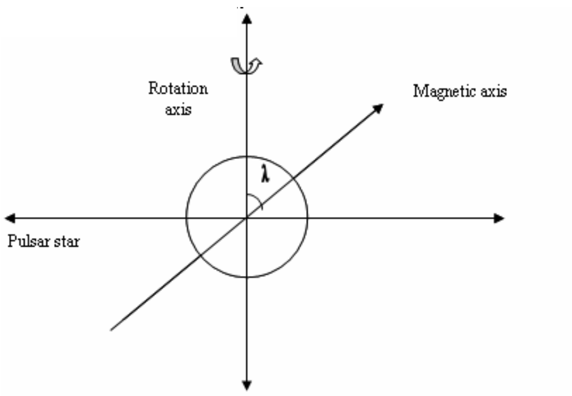

Figure (2): Ostriker and Gunn model [2].

Binary Millisecond Pulsars

The first binary pulsar PSR 1913+16 was discovered by Hulse and Taylor (1975) [8],although this was one among a population of nearly 150 pulsars, it was in a many ways, the most remarkable.

The basic idea is that PSR1913+16 is the first-born pulsar in a massive binary system, and its field is low because it was decayed from its original value in the time between the first supernova explosion,[9]. Its period is short because it was spun up during this phase to an equilibrium value appropriate for its magnetic field and mass accretion Eddington. The equilibrium period is determined by the magnetic field and the mass accretion rate, [1, 2]:

$$P_{eq} = (1.9_{ms}) B^{6/7} M^{-5/7} (M^{`}/M^{`}_{Edd})^{-3/7} R^{18/7} \quad (1)$$

Where B**:** the surface magnetic field in units of 10^8 G.

M: the mass of neutron star (n.s) in units of 1.5 M_{O}.

R: the radius of star in units 10^6cm.
$\grave{M}$: the accretion rate.
$\grave{M}_{Edd}$: the critical Eddington accretion= 1.5 $\times 10^{-8} M_O$
M_O: mass of sun

As the magnetic field decays the equilibrium period will decrease. The minimum equilibrium determined by the equation:

$$P_{eq} = (1.9_{ms}) \quad B^{6/7} \qquad (2)$$

The magnetic field strength determined by the following eq., [2, 10]:

$$B^2 = IC^3PP^{`} / (2\pi)^2 R \qquad (3)$$

where I is the total moment of inertia of the neutron star ($I=6.24 \times 10^{44}$ g cm^2),C is the light velocity ($C=3\times10^8$m/sec), $PP^{`}$ represents the spin down torque,.

The characteristic age of millisecond pulsar is given by:

$$T_{CH} = P/ P^{`} \qquad (4)$$

Where P is the period of pulse for millisecond pulsars and P` is the period derivative.

T_{CH} specifies how long a pulsar lives at that age. The important characteristics of the some binary pulsars are summarized in table (1), [2].

Table (1): Binary millisecond pulsars

PSR	P_{ms}	Log $P^{`}$	Log B(G)
1957+20	1.6	-19.9	8.1
0021-72A	4.5	-15.0	10.8
0021-72B	6.1	-14.4	10.3
1620-26	11.1	-18.1	9.5
1913+16	59.	-17.1	10.4
0655+64	195.6	-18.2	10.1
1855+08	5.4	-19.8	8.1
1937+21	1.6	-19.0	8.6
1821-24	3.1	-17.8	10.3

By using eq. (4), the characteristic age is calculated.

Fig. (3) presents the relation between the spin down torque $PP^{`}$ and the pulsars age $P/P^{`}$. It implies certain points in the interpretation of a plot of $PP^{`}$ versus ages $P/P^{`}$:

1- The older millisecond pulsars defined as having greater ages, because $P/P^{`}$ specifies how long pulsars lives at that age.
2- Very long period millisecond pulsars, to be observable, have particularly large surface magnetic field.
3- Pulsars with high $PP^{`}$ are missing.

The Residual Field of Pulsars

Any suggested mechanism for field decay with a time constant of a few million years must also explain why this decay "stop" or "slow down", Jones(1988) has suggested that the rate of expulsion of the flux from the neutron drip solid due to Hall drift may itself be a strong function of the field entrained in this region. With decreasing flux density, the Hall drift becomes negligible and further decay of the field will be governed by Ohmic dissipation in the neutron drip solid,[11].The values of magnetic field (**B**) were calculated by using eq. (3). Figures (4, 5) show that the relations between the periods with B and the value of **B**/P^2. The dipole component of surface magnetic field (**B**) can be estimated using the (P) and (P`) of each millisecond pulsar, assuming a purely dipolar magnetic field, this shown in fig. (4) as a function of period. 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. As the field begins to decay, the tracks of pulsars will be swing downwards and eventually become vertical that is could be due to field decay .that is indicate the field decay comes from the recycled pulsars. Pulsars with much shorter

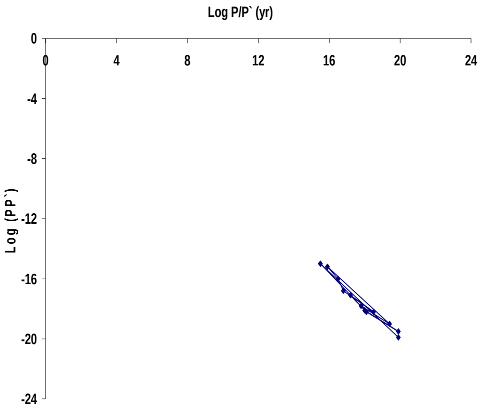

Figure (3): The spin-down toque(PP) decay versus the characteristic (p/p) for millisecond pulsars

periods (millisecond pulsars) have been detected and their numbers are rapidly growing. In a good agreement with recently discovered pulsars in gLobular clusters, which must surely be old, also, have very low fields.

Table (2) presents the values of magnetic field with the periods and flux densities for MSP_S pulsars:

PSR	P_{ms}	B 10^8(G)	S_m (mjy)
J0621+1002	28.8	68.4	0.3
J0751+1807	3.4	10.17	0.8
J1012+5307	5.25	2.8	1.2
J1022+1001	16.4	8.4	1.9
J1024-0719	5.6	3.35	0.4
J1620-26	11.07	33.1	0.8
J1640+224	3.16	.0.971	0.2
J1643-1224	4.62	2.96	1.4
J1713+0747	4.57	1.96	2.7
J1744-1134	4.06	1.86	0.7
B1855+09	5.30	3.31	2.3
B1973+21	1.55	4.101	2.0
J2051-0827	5.50	2.45	0.3
J2145-0750	16.05	6.41	2.2
B1534+12	37.90	97.12	0.04

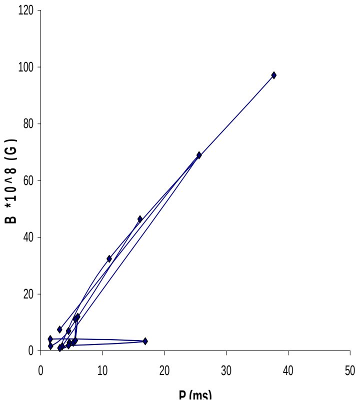

Figure (4): The relation between magnetic field (B and the period of MSPs stars)

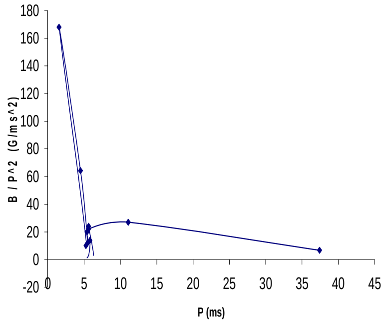

Figure (5): The potential drop (B/P^2) vesues the periods of millisecond pulsars stars

The Luminosity Evolution of Pulsar

According to Gunn and Ostriker model in 1970 year, the radio luminosity of pulsars decline with age will be determined by the strength of the perpendicular component of the magnetic field and the angular velocity of the neutron star in a manner shown below,[2]:

$$L=(2/3Ic^3)B^2 R^6 \sin^2 (\lambda) \omega^4 \qquad (5)$$

Where:
I is the moment of inertia of neutron star (n.s)
R is the radius, ω is the angular velocity
λ is the angle between the rotation axis and the magnetic axis.
From this equation it follows that the slow down rate of the pulsar (PP\`) is proportional to the square of the star magnetic field and inversely proportional to the period ($PP^{`}\alpha\ B^2\sin^2\alpha$).This relation provided the basis for estimating the surface field strength from the measured period (P) and period derivative (P\`), as shown in table (1) with table (2). The radio luminosity at 400 MHz is given by the equation,[5]:

$$L=S_m d^2 \qquad (6)$$

Where S_m is the flux density in (mJ) units, and d the distance in (kpc) units.
Fig.(6) shows the relation between radio luminosity with the period for our sample of millisecond pulsars(MSP_S) located in the distance (d) 1.5 kpc from the galactic disk.
In figure (7), we presented the relation of characteristic age (P/P\`) with the luminosity (L). The results indicated that radio luminosity of MSPs which adopted must also decline with the age, clearly shows that the luminosity must also depend upon some negative power of the period. Investigating possible relationships of the spectral properties of MSP_S to spin parameters such as period, magnetic field, spin down luminosity ($\alpha P^{`}P^{-3}$),In calculating these values, for pulsars was pointed that there might be tendency for the flux density to correlate with the characteristic age of MSPs, younger pulsars tend to have steeper spectrum than older MSPs.

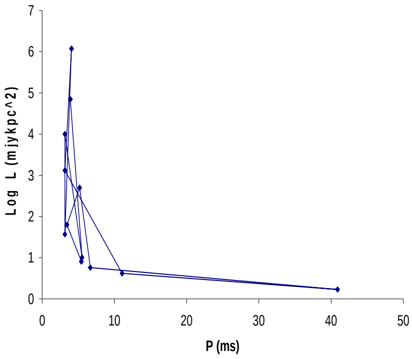

Figure (6): The relation between luminosity (L) and period (P) for MSPs stars at distance 1.5 Kpc

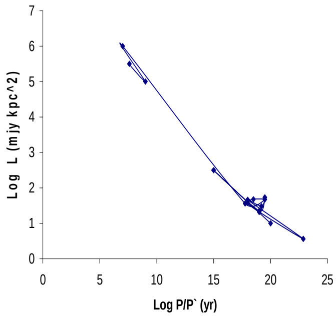

Figure (7): The relation between luminosity (L) with the characteristic age (P/P) for MSPs pulsars

As a result, the millisecond pulsars (MSPs) in the galactic disk with the characteristic ages between (10^{12} yr) and (10^{15}yr) have density between (0.8+¯2.3), while those with characteristic age between (10^{14} yr) and (10^{19} yr) exhibit a mean flux density of(0.3+¯2.2),these results are in a good agreement with the results obtained by Kramer in 1998, [12].

Conclusions

1- The spin down torque decay will take place at characteristic age between (10^{14}-10^{20} yr) for a sample stars which adopted.

2-The results indicated that the potential drop (B/P^2) will increase at periods ≤10 ms for MSPs at 1.5 kps from the galactic disk.

3- The maximum value of radio luminosity (L) is obtained when the characteristic age (T_{CH}) values (≤ 10^9 yr).

4- The results indicated that the MSPs stars with characteristic ages between (10^{12} yr – 10^{15} yr) have flux density between (0.8+¯2.3),while the stars with characteristic age(10^{14}yr - 10^{19} yr) have flux density of (0.3+¯2.2).

5- Binary millisecond pulsars stars with high PP` are missing, so the maximum values of magnetic field strength will be at high values of periods for MSPs stars.

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