POSSIBLE EVOLUTIONS OF ISOLATED NEUTRON STARS

by

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ABSTRACT

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Neutron stars are end products of stellar evolution, like black holes and white dwarfs. Since they radiate in all bands of the electromagnetic spectrum and as their densities and magnetic fields are much higher than normal stars, they are essential objects for astrophysics and in general for physics. They have the highest magnetic fields known in the Universe. Evolution of different types of neutron stars is still an open question. In this work, we try to clarify the differences in the evolutions of different types of isolated neutron stars. We suggest three possible isolated pulsar evolution on the rotation period (P) versus temporal change in the P ($\dot{\mathrm{P}}$) diagram.

The P-$\dot{P}$ diagram for isolated radio and/or X-ray pulsars, anomalous X-ray pulsars, soft gamma repeaters, dim isolated thermal neutron stars and dim radio quiet neutron stars is constructed. The possible evolutionary tracks for isolated neutron stars are examined. Besides, possible existence of low-mass neutron stars is discussed.

ÖZET

IZOLE NÖTRON YILDIZLARININ OLASI EVRİMİ

Nötron yıldızları, karadelikler ve beyaz cüceler gibi, yıldız evriminin son ürünleridir. Işıma tipleri, yoğunlukları ve manyetik alan şiddetleri normal yıldızlardan çok daha fazla olduğu için astrofiziğin en ilgi çekici konusudur. Evrenin en yüksek manyetik alanına sahip nötron yıldızlarının kendi içlerindeki evrimide cevaplanması gereken bir sorudur. Biz bu çalışmada üç Radio/X-ray nötron yıldızının olası evrimini vererek nötron yıldızı tiplerinin evrimini açıklamaya çalıştık. Ayrıca nötron yıldızlarının kütle yarıçap ilişkisi hakkındaki çalismalar incelendi. Düşük kütleli ve geniş yarıçaplı nötron yıldızları olabileceği düşünülerek evrimlerinin daha kolay açıklanıp acıklanamıycağına bakıldı.

X-ray pulsarlar, anomalous X-ray pulsarlar, soft gamma repeaterlar, dim isole thermal nötron yıldızları ve dim radio quiet nötron yıldızları icin P-$\dot{\mathrm{P}}$ grafiği çizildi. Izole nötron yıldızlarının muhtemel evrim şekilleri incelendi. Bunun yanında, yarım-kütleli nötron yıldızı kavramı analiz edildi.

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A	Number of baryons
B	Magnetic field
G	Gravitational constant
L	Luminosity
M	Mass
P	Period
R	Radius
T	Temperature
c	Speed of light
d	Distance
k	Boltzman constant
B_p	Magnetic field at the pole
B_r	Radial magnetic field
E_F	Fermi energy
$\dot{E}$	Change in the Energy with respect to time
L_x	x-ray luminosity
M_E	Mass of the Earth
M_z	Main sequence mass
$M_\odot$	Mass of the Sun
R_0	True stellar radius
R_s	Schwarzschild radius
T_F	Fermi temperature
T_{core}	Core temperature
ΔP	Change in the period
ν	Frequency
$\dot{\nu}$	Derivative of the frequency
ρ	Density
ρ_0	Nuclear density

ρ_{drip}	Critical density for neutron drip
τ	Characteristic age
AXP	Anomalous x-ray pulsar
DITNS	Dim isolated thermal neutron star
DRQNS	Dim radio quiet neutron star
INS	Isolated neutron star
ISM	Interstellar medium
NS	Neutron star
PWN	Pulsar wind nebula
SGR	Soft gamma repeater
SNR	Supernova remnant
URCA	A process of nuclear reactions

1. INTRODUCTION

Recent understanding of the structure of neutron stars is defined by existing physical models, which of course are subject to revision. According to the current models, the matter at the surface of a neutron star is composed of ordinary atomic nuclei as well as electrons. The atmosphere of the star is roughly one meter thick, below which one encounters a solid “crust”. Proceeding interior, one encounters nuclei with ever increasing numbers of neutrons; such nuclei would quickly decay on Earth, but are kept stable by enormous pressures. Proceeding deeper, one comes to a point called neutron drip where free neutrons leak out of nuclei. In this region there are nuclei, free electrons, and free neutrons. The nuclei become smaller and smaller until the core is reached, by definition the point where they disappear altogether.

The exact nature of the super-dense matter in the core is still not well known. The term neutron-degenerate matter is often used, though that term incorporates assumptions about the nature of neutron star core material. Neutron star core material could be a superfluid mixture of neutrons with relatively small numbers of protons and electrons, or it could be composed of strange matter incorporating quarks heavier than up and down quarks, or it could be quark matter not bound into hadrons (a compact star composed entirely of strange matter would be called a strange star.). However so far observations have not yet indicated such exotic states of matter.

The electrodynamics of the pulsar magnetosphere are complicated , and neither these nor the mechanism responsible for the beamed emission are well understood. Though, high-energy observations of the last decade of the 20. century allowed us to understand the details of the emission mechanism step by step. Amongst the more than 1500 isolated neutron stars discovered up to date, several tens of them have been observed to radiate at high energies with space observatories. These observations have firmly established that the properties of neutron stars are indeed highly unusual, particularly, their gravitational and magnetic fields are truly immense.

In spite of the impressive achievements of the neutron star physics, a lot of work still remains to be done in this currently emerged field. First, the evolution of neutron stars, starting from their birth in supernova explosions, is far from being well understood. Until recently, a common prejudice had been that all neutron stars are born as rotation-powered pulsars, which slow down their rotation, eventually stop their activity and, after crossing a “death line”, get into the “pulsar graveyard”.

Are the anomalous X-ray pulsars (AXPs) and soft gamma repeaters (SGRs) indeed the magnetars or their unusual observational properties are due to quite different reasons? One more set of evolutionary questions is associated with the generation and evolution of neutron star magnetic fields. Although there is no doubt that very high magnetic fields exist in many neutron stars, there is no clear understanding of how they are generated and why they are so different in different kinds of neutron stars. One of the most important goals in studying isolated neutron stars is to determine the equation of state. Defining the equation of state may answer most of the questions. The most direct way to determine the equation of state (which depends on the internal composition) is measuring the masses and radii of neutron stars. In particular, neutron stars can be viewed as cosmic laboratories for studying nuclear interactions, general relativity and super-strong magnetic and electric fields.

2. NEUTRON STARS

Neutron stars are highly condensed stellar objects produced in supernova explosions. Progenitors of these compact objects are massive stars with zero-age-main-sequence mass $M_ZAMS \geq 7 - 8M_{\odot}$ excluding the case of stars in close binary systems which may lose larger amounts of mass during stellar evolution and hence may have shorter thermonuclear fusion lifetimes depending on the binary separation and the mass of the secondary component [1]. A newborn neutron star has core temperature T$_{core}$ $\sim$ 10^{11} K and it eventually cools down to T$_{core}$ $\sim$ 10^{8} K in about 10^{5-6} yr via neutrino reactions [2]. For older neutron stars, photon cooling takes place as the neutrino reactions are strongly dependent on the temperature. The outward pressure that supports these stars against gravitational collapse in the first approximation is the ideal degenerate neutron gas. A simple calculation shows that the neutron gas is highly degenerate: the Fermi energy of a degenerate gas is

$$E_F = (3\pi^2)^{2/3}\frac{\hbar^2}{2m}(\frac{N}{V})^{2/3} \tag{2.1}$$

where m is the mass of the degenerate particle and $\frac{N}{V}$ $\equiv$ n is the number density of the degenerate gas. If we take the nuclear density ($\sim$1.2$\times$$10^{38}$ cm^{-3}) as the average number density of the degenerate neutron gas, then we get E$_F$ $\cong$1.4$\times$$10^{-4}$ erg. So, the Fermi temperature T$_F$ $\equiv$E$_F$/k of the free neutrons which is on the order of 10^{12} K is much larger than the core temperature even for very young neutron stars.

Neutron star masses M are in the range of $1 - 2$ times that of the sun ($M_{\odot}$), whereas typical radii are only $10 - 12$km. But these ranges come from observations. Lattimer [3] has observational data for both isolated and binary pulsars. In Shapiro [2] there are several models which try to give maximum and minimum values for masses and radii. It is not easy to give minimum mass value but from observations and theories it can be said that maximum mass of a neutron star must be smaller than $3M_{\odot}$. The average interior density is greater than that in a large atomic nucleus, $\rho_0 = 3\times10^{14} g/cm^3$. Support against gravitational collapse in a neutron star is provided by the quantum-mechanical Fermi pressure of the neutrons and other particles in the interior. Neutron stars were first proposed by Landau and Baade and Zwicky in the beginning of 1930s. First calculations of the structure of neutron stars were carried out by Oppenheimer and Volkoff in 1939 using an equation of state of an ideal degenerate neutron gas and based on general theory of relativity. While observing the radio sources (interplanetary scintillations), J.Bell, a graduate student of A. Hewish, observed a radiosource with a period of 1.377 sec at a frequency of 81.5 MHz. The interpretation of this observation as neutron stars was first done by Gold [4].

Before the chance discovery of the first neutron star (as a radio pulsar), some scientists did some very important works and made some essential predictions on neutron stars. Pacini [5] calculated the magneto-dipole emission of a rotating neutron star and predicted the radio pulsar. Zeldovich and Guseinov [6] introduced the idea of searching neutron stars and black holes in close binary systems in order to detect them as accreting sources (pulsed X-ray emission in the case of neutron stars and X-ray disk emission in the case of black holes).

Neutron stars characteristically are strongly magnetized, with surface magnetic fields ranging from 10^8 G to 10^{15} G. Their rapid rotations and large magnetic fields combine to accelerate particles to extremely high energies, generating energetic winds (slane) of synchrotron-emitting particles spiraling in a wound-up magnetic field. The structure of these nebulae is determined by the energy input from the central pulsars as well as the structure and content of the medium into which they expand. Neutron stars consistently dissipate their rotational energy via relativistic winds. Confinement of these outflows generates luminous pulsar wind nebulae (PWN), seen across the electromagnetic spectrum in synchrotron and inverse Compton emission, and in optical emission lines when they shock the ambient medium. PWNs also move through a series of distinct evolutionary states, moderated by the pulsars location (inside a SNR vs in interstellar gas) and the surrounding medium conditions (cold ejecta vs shocked ejecta vs ISM).

They generate magnetic winds with particles that are accelerated to energies in excess of a TeV. They are born hot $T \approx 10^{11}$ K, but cool rapidly due to neutrino production in their interiors. Details of the interior structure of such stars remain poorly understood owing to our incomplete understanding of the strong interaction at densities larger than the nuclear density.

Neutron stars were empirically confirmed first as radio pulsars in 1968 [7], and these objects continue to dominate neutron star (NS) statistics. Currently there are over 1500 pulsars cataloged, and the number grows steadily. If one includes the number of observed X-ray binary systems, most of which are thought to contain a neutron star, the total number of observed neutron stars is approximately 2000. Yet a neutron star is born in the Milky Way every 30 to 100 years based on observations of supernovae in Sb-type galaxies [8], suggesting that the total population is 10^8 - 10^9 objects, depending on the Galaxy's star formation history. Of these neutron stars, only the relatively young ones will be detected as radio pulsars, provided they are aligned favorably and have detectable luminosity; after about 1-100 million years, the pulsar will have radiated away its rotational and internal energy, and the pulses will cease.

2.1. Structure of Neutron Stars

Neutron stars contain matter in one of the densest forms found in the universe. Matter in their cores possesses densities ranging from a few times ρ_0 to an order of magnitude higher. Here $\rho_0 = 3 \times 10^{14} g/cm^3$ denotes the density of normal nuclear matter. The number of baryons forming a neutron star is of the order of A$\approx 10^{57}$. The understanding of matter under such extreme conditions of density is one of the central but also most complex problems of physics. Commonly used model is below [1]:

Outer crust: heavy nuclei in the form of a Coulomb lattice in β-equilibrium and a relativistic degenerate electron gas, $10^6 \leq \rho \leq 4.3 \times 10^{11}$ g cm^{-3}. Here, $\rho_{drip} = 4.3 \times 10^{11}$ g cm^{-3} is the critical density for neutron drip, at which the ratio of neutron number to proton number (n/p) in heavy nuclei reaches a critical number.

Inner crust: a combination of neutron-rich nuclei lattice, free neutrons in the form of a superfluid neutron gas and an electron gas, $4.3 \times 10^{11} \leq \rho \leq 2 \times 10^{14}$ g cm^{-3}. For

$\rho > \rho_{drip}$, the ratio n/p becomes so large that stable nuclei to exist some neutrons are thrown out of the nuclei and become free. Up to the nuclear density ($\rho_0 = 2 \times 10^{14}$ g cm^{-3}), free neutron gas, electron gas and Coulomb lattice of heavy nuclei coexist together.

Outer core: superfluid neutrons, a small concentration of superfluid protons and electrons, $\rho > 2 \times 10^{14}$ g cm^{-3}. At the nuclear density, the nuclei begin to dissolve and at higher densities neutrons and protons will no longer bind to each other. As known experimentally, at nuclear densities there occurs a phase transition to a paired state for both neutrons and protons [2]. Hence, the neutrons and the protons in the outer core will be in the form of superfluid except for the youngest neutron stars which have very high thermal energy comparable to the latent heat for the phase transition.

Inner core: Whether a diverse core of a neutron star exists and what it may be composed of is uncertain. This is because the behavior of matter at such high densities and energies is difficult to model, even using experimental evidence from particle accelerators, as the strong interaction between hadrons at very high densities is not known well.

It has been postulated that a solid neutron core may exist, or even quark matter. At a density around $4 \times 10^{11} g/cm^3$, you reach the "neutron drip" layer. At this layer, it becomes energetically favorable for neutrons to float out of the nuclei and move freely around, so the neutrons "drip" out. Here, it must be said that the properties of Neutron stars are sensitive to the equilibrium equation of state in the density regime above neutron drip. So that, physicists build equations of state above and below neutron drip.

On the other hand, at such extreme densities numerous subatomic particle processes are expected to compete with each other and novel phases of matter - like the quark-gluon plasma, being sought at the most powerful terrestrial particle colliders - could exist. The strangeness-carrying s quark may also play a key role for the composition of neutron star matter.

A strange star or quark star is a hypothetical type of star composed of strange matter, or quark matter. This is an ultra-dense phase of matter that is theorized to form inside particularly massive neutron stars. It is theorized that when the neutrons which makes up a neutron star are put under sufficient pressure due to the star's gravity, the individual neutrons break down into their constituent quarks. Some of these quarks may become strange quarks and then form strange matter. The star then becomes known as a "strange star" or "quark star". Generally, it is suggested that low-mass strange stars, with weaker magnetic fields than that of normal pulsars, could result from accretion-induced collapses of white dwarfs. But, it is not as simple as neutron stars to determine the masses and radii of strange stars.

2.2. Thermal properties of Neutron Stars

As mentioned above, neutron stars are born very hot (T$\sim 10^{11}$ K), but cool rapidly down to T$\sim 10^{8}$ K due to neutrino production in their interiors. Initially a NS cools mainly via the neutrino emission from its core. The beta-equilibrium with respect to the reactions

$$n \longrightarrow p + e + \overline{\nu_e} \tag{2.2}$$

$$p + e \longrightarrow n + \nu_e \tag{2.3}$$

where ν_e and $\overline{\nu_e}$ stand for electron neutrino and antineutrino, respectively. These reactions are called direct URCA processes. But we need extra nucleons on the right and the left hand sides to conserve the energy-momentum, so the reactions must be:

$$n + N \longrightarrow p + N + e + \overline{\nu_e} \tag{2.4}$$

$$p + N + e \longrightarrow n + N + \nu_e \tag{2.5}$$

at low densities. These reactions are the modified forms of the reactions given above and hence they are called modified URCA processes. As the rate of modified URCA reactions is more strongly dependent on temperature ($\sim$T^8) compared to the rate of direct URCA reactions ($\sim$T^6), the modified URCA reactions are predominant especially at relatively low densities. There are also some other nuclear reactions for neutrino cooling with varying degrees of importance [2].

A powerful neutrino outburst in a supernova explosion lasts for about a few ten seconds. Afterwards the neutrino flux decreases rapidly in time. Cooling of a NS is accompanied by the loss of its thermal energy which is mainly stored in the stellar core. The energy is carried away through two ways: first, by neutrino emission from the entire stellar body (mostly from the core), where the most powerful neutrino reactions take place, and second, by heat conduction through the internal stellar layers towards the surface, and further, by thermal emission of photons from the surface. The neutrino cooling dominates at the initial cooling stage, while the photon cooling dominates later, when the neutrino luminosity becomes weak. At supernova inward explosion, there are several mechanisms (angular momentum transport, magnetic torques) take place. From the simulations [9] with these mechanisms, it's predicted that for supernovas around $15M_\odot$, pulsar periods at birth must be near 15 ms.

SNRs are formed as a result of SN explosions with energies $10^{49} - 10^{51}$ erg, and in some cases, even with energies several times smaller than 10^{49} erg (e.g. Crab SNR) and with energies higher than 10^{51} erg (e.g. Cas A SNR).

3. PULSARS

A pulsar is a neutron star which emits beamed electromagnetic radiation. This radiation may be thermal emission from the hot magnetic poles or from the surface of the neutron star if the temperature has a non-uniform distribution on the surface and/or non-thermal synchrotron emission from the magnetic poles by acceleration of particles in pulsar's magnetosphere. The magneto-dipole radiative power of pulsars is given as

$$L = \frac{B_p^2 R^6 \Omega^4}{6c^3} Sin^2\alpha \tag{3.1}$$

where B_p is the strength of the dipole magnetic field at the magnetic pole, R is the radius, Ω=2π/P is the rotational velocity, c is the speed of light in vacuum and α is the angle between the rotation axis and the magnetic axis [10]. The surface magnetic field of pulsars can be a combination of the surface dipole field formed by the collapse of the progenitor star parallel to the dipole magnetic field axis and a magnetic field created by superconducting entrainment currents which will be parallel to the rotation axis [11].

The"pulses" of high-energy radiation we see from a pulsar are due to a misalignment of the neutron star's rotation axis and its magnetic axis. Pulsars pulse because the rotation of the neutron star causes the radiation generated within the magnetic field to sweep in and out of our line of sight with a regular period. We have observational data for pulsars as:
-Pulsars have periods in the range 1 ms to 10 s.
-These periods increase very slowly (except "glitches")
-These periods are accurate, that is, they are measured to 15 significant digits.

An example calculation for the radius of an object with rotation period 2 ms as follows: The angular velocity of a system must be smaller than the speed of light: $2\pi R/P < c$, $R < Pc/2\pi$, taking 2ms for period, 3×10^8 m/s for c we have: $R < 100$

km. An object with a radius less than 100 km is too small to be a white dwarf, and black holes don't really have surfaces that could be rotating, this leaves neutron stars as the only possibility. That is, pulsars are rotating neutron stars. On the other hand, white dwarfs can be observed directly in optical telescopes during their long cooling period. The gravitation of white dwarfs is not as much as neutron stars gravitation, so at rotation at periods lower than 1 sn white dwarfs will disperse. Black holes can only be observed indirectly through the influence they exert on their environment. Eventually, there is one possibility remains for pulsars, they are neutron stars.

The most well known type of neutron star, both theoretically and observationally, is the radio pulsar which is observed to radiate also in other bands of the electromagnetic spectrum in some cases. There are basically two selection effects which reduce the probability of detecting radio pulsars: beaming fraction (it is a possibility that the beaming factor for pulsars decreases with age) and the luminosity function [12]. With constructing the luminosity function, the determination of the number distribution of PSRs as a function of luminosity was aimed. Effect of the background radiation is another influence to be considered when detecting pulsars [13].

Radio pulsars are rotation-powered neutron stars, are found both in isolation and in binary star systems, and are observed to emit radiation at all frequencies from radio to optical to gamma rays. Pulsars, fast rotating neutron stars, are powered by rotational kinetic energy and lose energy by accelerating particle winds and by emitting electromagnetic radiation at their rotational frequency, ν.

$$\dot{\nu} = -\kappa \nu^{n} \tag{3.2}$$

where κ is a positive constant which determined by the moment of inertia and the magnetic dipole moment of the pulsar and n is the braking index. But, rotation-powered radiation cannot alone be responsible for this slowdown. The observed braking indexes of all young pulsars are smaller than 3.0. This shows that there must be additional torques other than magnetic dipole.

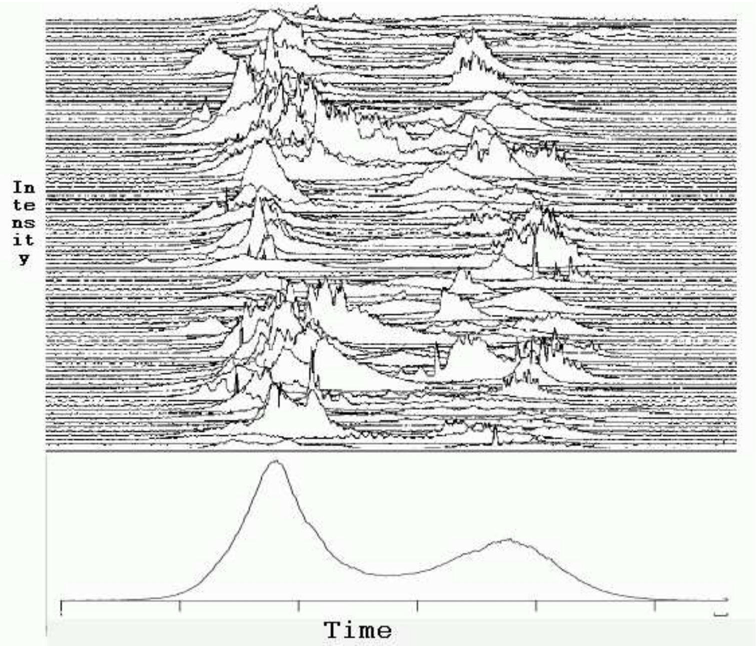

Figure 3.1. Integrated profile

Pulsars emit highly accurate periodic signals (mostly in radio waves), and we sum up the single signals to get the integrated profile like in the example figure 3.1. The emitted accurate periodic signals beamed in a cone of radiation, centered around their magnetic axis. These signals reveal the period of rotation of the neutron star, which radiates, like a light-house, once per revolution. The lighthouse effect is caused by the dipolar magnetic field not being aligned with the rotation axis of the neutron star. As a consequence of the magnetic field, pulsar radiation is highly polarized. In some cases the fraction of linear polarization in the total radio emission is close to 100 per cent. On the other hand, the circular polarization is the highest among observed natural sources of electromagnetic radiation.

Temporal evolution of the pulsar rotation can most simply be modeled as a power law:

$$\dot{\Omega} = k\Omega^n \tag{3.3}$$

where the power n is called 'the braking index' as it is related to the torques on the pulsar. Here, the conditions for n= 2 and n= 3 and their meanings will be investigated:

$$\Omega = \frac{2\pi}{P} \tag{3.4}$$

$$\dot{\Omega} = \frac{2\pi\dot{P}}{P^2} \tag{3.5}$$

$$\Omega^n = \frac{2^n\pi^n}{P^n} \tag{3.6}$$

by inserting eq. (3.5) and eq. (3.6) into eq. (3.3) we get

$$\frac{2\pi\dot{P}}{P^2} = k\frac{2^n\pi^n}{P^n} \tag{3.7}$$

$$P^{n-2}\dot{P} = k2^{n-1}\pi^{n-1} \tag{3.8}$$

It is seen from eq. (3.8) that when setting n= 2, $\dot{P}$ is equal to a constant. In the same manner when n= 3, $P\dot{P}$ is constant. The latter means that the magnetic field strength at the neutron star surface (eq. 3.9) is also constant for n=3.

$$B = 3.2 \times 10^{19}\sqrt{P\dot{P}}G \tag{3.9}$$

While examining the neutron stars period, physicists witnessed an interesting phenomena “decreasing of the period”, which is called “Glitch”. It is small but sharp decrease in the period, for example $\Delta p/p = 2 \times 10^{-6}$ for vela pulsar [14]. They explain this event as change in the rotational frequency of a neutron star upon an abrupt variation of the moment of inertia. Change in the moment of inertia may stems from star quakes (which is related with the crust of neutron star) or neutron star's accretion.

3.1. Emission Models For Pulsar Types

Pulsar radio and gamma-ray emission have been studied for about three decades, but we still lack an elaborated model to account for the emission from radio to gamma-rays at the same time. Up to now mostly used models are:
-Non-thermal emission from charged relativistic particles accelerated in the pulsar magnetosphere.
-Photospheric emission from the hot surface of a cooling neutron star. In this case a modified black-body spectrum and smooth, low-amplitude intensity variations with the rotational period are expected, observable from the optical through the soft X-ray range.
-Thermal soft X-ray emission from the neutron star's polar caps which are heated by the bombardment of relativistic particles streaming back to the surface from the pulsar magnetosphere
-Extended emission from pulsar-driven synchrotron nebulae. Depending on the density of the ambient interstellar medium.
-X-ray and gamma-ray emission from interaction of relativistic pulsar winds with a close companion star or with the wind of a companion star, in binary systems.

Four distinct classes of pulsars are currently known to astrophysicists according to the source of energy that powers the radiation:
(1) Rotation-powered pulsars, where the loss of rotational energy of the star powers the radiation
(2) X-ray pulsars, where the gravitational potential energy of accreted matter and high magnetic field are energy sources (producing X-rays that are observable from Earth)
(3) Dim Radio Quiet Neutron Stars and Dim Isolated Thermal Neutron Stars whose energies come from thermal case and rotational power. DITNSs spectrums obey pure thermal emission model. But, DRQNSs have power law component in their spectrum.
(4) Magnetars (AXP's and SGR's), where the decay of an extremely strong magnetic field powers the radiation.

For Magnetars the strong magnetic field means that the B field is in the range

$10^{14} - 10^{15}$ G, where B is the component of the surface dipole magnetic field perpendicular to the rotation axis (see figure 4.2). Here, it must be mentioned that the features detected in the spectra of some magnetars may be associated with resonant cyclotron scattering. If these features are interpreted as proton cyclotron lines then the corresponding magnetic fields are in the interval 10^{14-15} G. If they are interpreted as electron cyclotron lines then the magnetic fields turn out to be much smaller than the B values of these objects. There are two strong alternative models for AXP's and SGR's high magnetic field. The magnetar model proposes that these sources are isolated rotating neutron stars with surface dipole magnetic fields of $10^{14} - 10^{15}$ G, supplying their luminosity from the decay of the magnetic field. The magnetar picture also provides a model for the soft gamma-ray bursts. The spindown of the object is believed to obey a modified dipole spindown equation, $\dot{\nu} = -\kappa\nu^n$, where n = 3 for pure dipole radiation, and n can be greater than 3, when the decay of the magnetic field is driven by spindown [15]. In magnetar models the age of the neutron star can be estimated as a characteristic time $\tau = P/(n-1)\dot{P}$, assuming that the initial rotation period was much shorter than the current rotation period.

The accretion model is that the X-ray luminosity is due to accretion from a fall-back disk that is left over from the supernova that formed the neutron star. This model does not include a dynamical explanation for the gamma-ray bursts of the SGRs. It seeks to classify all kinds of young neutron stars as propellers and accretors from a fall-back disk. The similarities and differences of the different classes, including the radio pulsars, the dim thermal neutron stars, and the "radio quiet" neutron stars like the source in Cas A in addition to the AXPs and perhaps SGRs, are supposed to be due to the presence or absence of a fall-back disk and different disk initial conditions. In Neutron star history there are some small disks ($\sim 10M_E$) around Neutron stars observed, but these observations may not explain the magnetar properties. Such small disks present around old millisecond pulsars and they should be remained from low mass X-ray binary phase. Old millisecond pulsars are seen throughout the galaxy at radio wavelengths, but always in systems where the mass losing companion has stopped transferring material to the pulsar; the presence of accreting gas in the vicinity of the pulsar tends to block the radio signal from the pulsar.

4. NEW TYPES OF ISOLATED NEUTRON STARS

A relatively lately discovered class of X-ray sources are believed to be thermally cooling neutron stars, and rotation-powered pulsars. These are referred to in the literature as "isolated neutron stars" (INSs). The sources known as INSs are distinguished as showing no binarity property, no evidence for radio pulsations, nebulosity, or accretion, and X-ray emission characterized by very soft spectra that are well described by a blackbody, with no apparent magnetospheric contributions.

Although the origin of their X-ray emission has not been fully clarified as yet, the details for the formation of the spectrum are not clear. The recent measurement of relatively large proper motions for these sources, implying transverse velocities $\geq 150kms^{-1}$ [16], makes it unlikely that these are old ($\geq 10^7 yr$) neutron stars accreting from the interstellar medium. Most probably the X-rays arise from the cooling of younger objects with an inferred age of $\approx 10^5 - 10^6$ yr.

Isolated neutron stars play a key role in compact objects astrophysics being the only sources in which we can have a clean view of the compact star surface, without contamination from magnetospheric emission or emission from a binary companion or a supernova remnant. Detailed multiwavelength studies of the largest possible sample of INS candidates are therefore fundamental for tracking the evolutionary history of galactic neutron stars. We are still at a stage where every newly discovered INSs holds important information for understanding the properties of the whole class and may also show some peculiarities which import unique information.

Besides, timing studies of INSs will be of key importance in securing new spin-down measurements: this will provide a second independent measurement of the field strength and also will bring extra insights on the long-term behavior of INSs. When the presence of ultra-strong fields and the variability be confirmed, the supposed relation between INSs and AXPs, bring forward on the basis of the similarity in spin periods, becomes much substantial. In turn, this relation may provide the "missing link" among

INSs and magnetars, though the formation rates of these objects are significantly different [17]. If at least some of the INSs are the descendants of SGRs/AXPs, as their positions on the P-Pdot diagram and their lower temperatures may suggest, then explaining why evolution produces "quiet" and "dim" magnetars is still a challenge.

One of the differences between AXPs, SGRs and other pulsars is their high magnetic fields. It's also higher than the quantum critical limit (eq. 4.1). Because of this highness they are the very famous objects which subject to the most of the astrophysics probes.

$$B_{cr} = \frac{m_e^2 c^3}{e\hbar} \cong 4 \times 10^{13} G \tag{4.1}$$

Guseinov [18] introduce the idea of possible existence of low-mass neutron stars to explain the positions and possible evolution of SGRs/AXPs on the P-$\dot{P}$ diagram without any need for very high magnetic field (B$\leq 10^{14}$ G). Magnetic dipole radiation of neutron stars is given as

$$L = \frac{2}{3}\frac{\mu^2 \omega^4}{c^3}\sin^2\beta = \frac{2}{3}\frac{B_r^2 R^6 \omega^4}{c^3}\sin^2\beta \tag{4.2}$$

where μ is the magnetic moment, ω the angular velocity, c the speed of light, β the angle between the rotation axis and the magnetic field axis, B_r the real dipole magnetic field and R the radius of neutron star. On the other hand, the rate of rotational energy loss of spherically symmetric neutron stars which have rigid body rotation is given as

$$\dot{E} = \frac{4\pi^2 I \dot{P}}{P^3} \tag{4.3}$$

where I is the moment of inertia, P the spin period of pulsar, and $\dot{P}$ the time derivative of P. From expressions (4.2) and (4.3) we get

$$\dot{P} \propto \frac{B_r^2 R^4}{MP} \tag{4.4}$$

where M is the mass of pulsar. So, a neutron star with M$\sim 0.5 - 0.7 M_\odot$ must have $\sim 4-9$ times larger $\dot{P}$ compared to a neutron star with M$\sim 1.4-1.5 M_\odot$ if both neutron stars have the same B_r and P values (considering also the increase in R when M is smaller). For such a low mass neutron star the propeller mechanism can work more efficiently to spin down the pulsar in relatively very short time and the reconnection of the magnetic field can occur more easily to produce the γ-ray bursts.

In addition, the apparent radius R is related to the true stellar radius R_0 which is usually quoted in the literature by

$$R = R_0 (1 - \frac{R_s}{R_0})^{1/2} \tag{4.5}$$

where $R_s = 2GM/c^2$ is the Schwarzschild radius [19]. For a standard neutron star of 1.4 solar mass the true radius is $R_0 = 14$ km, and thus considerably larger than the usual standard radius of 10 km. So that, reducing the NS mass to $\sim 1.2 M_\odot$ and increasing the radius by ~ 20 km, would be an ideal state for Neutron stars.

Furthermore, decreasing the compactness $(2GM/c^2R)$ is required for the other mechanisms other than gravitation work properly. The Compactness (M/R ratio) can be acquired from gravitational redshift. From the gravitational redshift ($\cong GM/c^2$R) at the surface of the neutron star, the ratio between its mass and radius may be measured, providing a very strong constraint on neutron star models. Such models give physicists an experimentally testable “handle” on properties of matter at highest nuclear densities.

Namely, rotation of a general relativistic star cannot increase the maximum NS mass appreciably ($\leq$ 20 per cent). Likewise, neutron stars masses obtained from observations are approximately accurate. So, decreasing the compactness can be done also by increasing the radius of NS alone.

4.1. Emission Mechanisms of Isolated Neutron Stars

The high-energy, pulsed emission from rotating magnetized neutron stars is usually explained in the framework of either the polar cap model [20] or the outer gap model [21]. Although the existence of such gaps is plausible, these models still suffer from the lack of a self-consistent solution for the pulsar magnetosphere and are based on the assumption that the magnetic field structure is that of a (Newtonian) rotating dipole. The starting point of both models is the model proposed by Goldreich Julian in 1969, which describes the basic physics of a neutron star magnetosphere.

4.1.1. Polar Cap Model

In the polar cap model the γ emission from the pulsar comes from its polar caps according to the following mechanism. The huge induced electric field pulls charged particles out from the stellar surface and accelerate them along the strong magnetic field lines, radiating curvature or synchrotron radiation in their instantaneous direction of motion. Since the charged particles are so energetic, the radiation may be in the GeV to TeV energy range (γ rays). As these γ photons move through the strong magnetic field of the pulsar, they tend to interact with the background field producing electron-positron pairs via

$$\gamma + B \longrightarrow e^{+} + e^{-} \tag{4.6}$$

These synchrotron photons can also be γ-rays, so they can generate more pairs which create more photons, and so on. This result in a cascade of pair production which terminate when the photons have lost enough energy that they can no longer produce pairs. As the magnetic poles and field lines rotate with the star, the accelerated charged particles radiate in a sweeping beam, and is seen as a a train of pulses if the beam happens to sweep across our line of sight during the star's rotation, in the same manner as does light from a lighthouse.

The acceleration of particles in the atmosphere is studied by Tagieva [22]. They

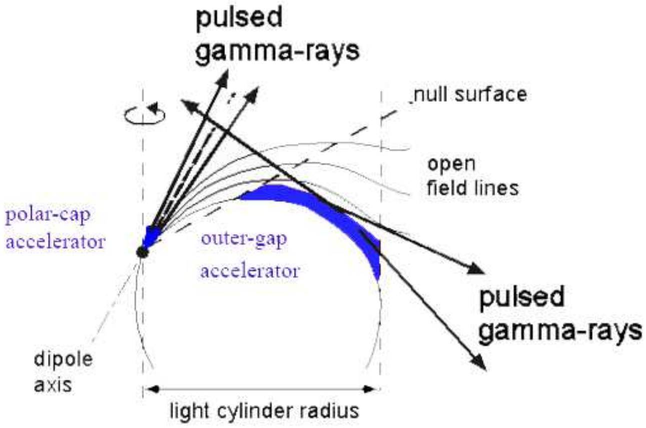

Figure 4.1. Accelerator models

assign that electric field intensity of neutron stars tears off charged particles from the surface of neutron star and triggers the acceleration of particles. Electrons and protons are accelerated mainly in the field of magnetodipole radiation wave. Power and energy spectra of the charged particles depend on the strength of the magnetodipole radiation.

4.1.2. Outer Gap Model

In the outer gap model, a number of alternative regions in the magnetosphere have been proposed for the origin of the pulsar emission, but mainly for the high energy radiation. Among these, the presently most favored one is the outer gap emission. Cheng proposed a mechanism for producing the observed emission from the Crab and Vela pulsars in γ-ray to optical wavelengths, in which high-energy pulsar emission is generated in vacuum gaps existing in the outer regions of the magnetosphere. This gap is formed between the $\overrightarrow{\Omega} \cdot \overrightarrow{B} = 0$ null surface (which defines the charge-separated regions) and the light cylinder, along the last closed field line.

4.2. Different Types of Isolated Neutron Star

There are several different types of isolated neutron star: radio pulsars some of which also radiate in other bands of the electromagnetic spectrum; dim radio quiet neutron stars (DRQNSs) which are dim in X-rays, not detected in radio band and all of which are connected to supernova remnants (SNRs); dim isolated thermal neutron stars (DITNSs) which are also dim in X-rays and not detected in the radio, and which have long spin period (P) contrary to DRQNSs (except Geminga which has short spin period but which shows DITNS characteristics); anomalous X-ray pulsars (AXPs) and soft gamma repeaters (SGRs) which have $L_x/\dot{E} > 1$ (where L_x is the X-ray luminosity and $\dot{E}$ is the rate of rotational energy loss) with long spin periods and which show gamma ray bursts and X-ray flares.

Radio pulsars are believed to be born on the upper-left part of the $P-\dot{P}$ diagram and evolve to the right part. Some radio pulsars (some of which have also been detected in X-rays)are located on the lower-left part of the diagram. The birth locations of these pulsars on the diagram is an open question. More importantly, the birth locations of SGRs/AXPs and DITNSs on the diagram are also unclear. If we can identify some sources which are younger appearances of these different types of neutron star, we can guess where they come from on the diagram, and furthermore, we can have more information on different characteristics of these neutron stars.

4.2.1. Connections with X-ray Pulsars

There may be a relationship between Galactic X-ray pulsars and different types of neutron star [24]. Here, an analysis is made for X-ray pulsars J1846 − 0258, J1811 − 1925, and X- ray/radio pulsar J0540 − 69. The observational data of these pulsars examined and the possibility that these pulsars can be in early phases of different types of neutron star is discussed.

X-ray pulsar J1846 − 0258 can be in an early phase of anomalous X-ray pulsars and soft gamma repeaters if its average braking index is ~ 2.0. The position of J1846 −

0258 on the P-$\dot{P}$ diagram together with its possibly small average braking index ($n = 1.86$ with the assumption of no glitch and/or significant timing noise) suggest that this pulsar may be in a phase preceding SGRs/AXPs. Another measured value of the braking index [23], n = 2.65, is also significantly less than 3, the value expected from magnetic dipole radiation, implying another physical process must contribute to the pulsars rotational evolution. The X-ray luminosity of J1846 − 0258 is on the order of $10^{35} erg/s$ which is typical for SGRs/AXPs. Moreover, the $L_x/\dot{E}$ value is ~ 0.016 which is very large compared to radio pulsars (more than 6 times larger than $L_x/\dot{E}$ value of Crab pulsar). For SGRs/AXPs $L_x/\dot{E} > 1$ (the name anomalous comes from this fact) and if the X-ray luminosity of J1846 − 0258 does not drop significantly in the next $\sim 10^4$ yr its $L_x/\dot{E}$ value will be similar to those of SGRs/AXPs.

X- ray/radio pulsar J0540 − 69 seems to be evolving in the direction to the dim isolated thermal neutron star region on the $P - \dot{P}$ diagram. This pulsar in Large Magellanic Cloud is one of the youngest and most luminous rotation powered pulsars. It was first observed as a 50 ms X-ray pulsar and later it was detected as a faint radio pulsar with a 640 MHz flux ∼ 0.4 mJy. It's $\dot{P}$ value is 4.8×10^{-13} s/s. The average braking index of this pulsar is small (n∼ 2.2) that it comes to a position close to DITNS RX J0720.4 − 3125 in $\sim 10^6$ yr which must be about the age of DITNS RX J0720.4 − 3125 (∼cooling age). Because of this, J0540 − 69 can be in a former phase of at least some of the DITNSs.

X-ray pulsar J1811 − 1925 must have a very large average braking index (∼ 11) if this pulsar was formed by SN 386AD. This X-ray pulsar can be in an early phase of the evolution of the radio pulsars located in the region P∼ 50 − 150 ms and $\dot{P} \sim 10^{-14} - 10^{-16}$ s/s of the P-$\dot{P}$ diagram. The spin down age of pulsars can be calculated as

$$t = \frac{P}{(n-1)\dot{P}}[1 - (\frac{P_0}{P})^{n-1}] \tag{4.7}$$

where P_0 is the initial spin period of pulsar. SNR G11.2 − 0.3 is probably related to the supernova (SN) of 386AD. If J1811 − 1925 is the compact remnant of SN 386AD, then its age (t) is 1618 years. Then, if its $P_0 \sim 62$ ms, it's n must be $\sim$ 11. So, this pulsar seems to be evolving downwards on the P-$\dot{P}$ diagram with a sharp decrease in $\dot{P}$ and very small increase in P.

4.3. Evolution of Neutron Stars on the P-$\dot{\mathbf{P}}$ Diagram

Although the evolution of Neutron stars on the P-$\dot{P}$ diagram (Fig 4.2) has been studied since 1970s, there are still some uncertainties and open questions about the evolution of these objects. Widely used definitions of τ and B (i.e. for n= 3) will be used unless another definition is given. On the P-$\dot{P}$ diagram, Neutron stars must move along constant magnetic field lines if no additional torque other than the magnetodipole radiation torque is present. Besides, the magnetic field decay is necessary to explain the evolution of PSRs based on the actual/available observational data and especially to get rid of the discrepancy between τ and t. Actually, luminosity change of PSRs, narrowing of the radiation beam and turning-off of PSRs create difficulties in determining the evolutionary tracks of PSRs on the P-$\dot{P}$ diagram (Fig 4.2).

It must be mentioned that radio pulsars are credited to be born on the upper-left part of the P-$\dot{P}$ diagram (Fig 4.2) and move to the right part. Some radio pulsars are located on the lower-left part of the diagram (see Fig 4.2). The birth locations of these pulsars on the diagram and the tracks of their evolution is a question. More importantly, the birth locations of DITNSs and SGRs/AXPs on the diagram are also unclear.

As emphasized at above section, X-ray pulsar J1846 $-$ 0258 can be in an early phase of anomalous X-ray pulsars and soft gamma repeaters if its average braking index is $\sim$ 2.0. And, X- ray/radio pulsar J0540 $-$ 69 can be in an early phase of dim isolated thermal neutron star on the $P-\dot{P}$ diagram. Finally, X-ray pulsar J1811$-$1925 pulsar seems to be evolving downwards on the P-$\dot{P}$ diagram with a sharp decrease in $\dot{P}$ and very small increase in P.

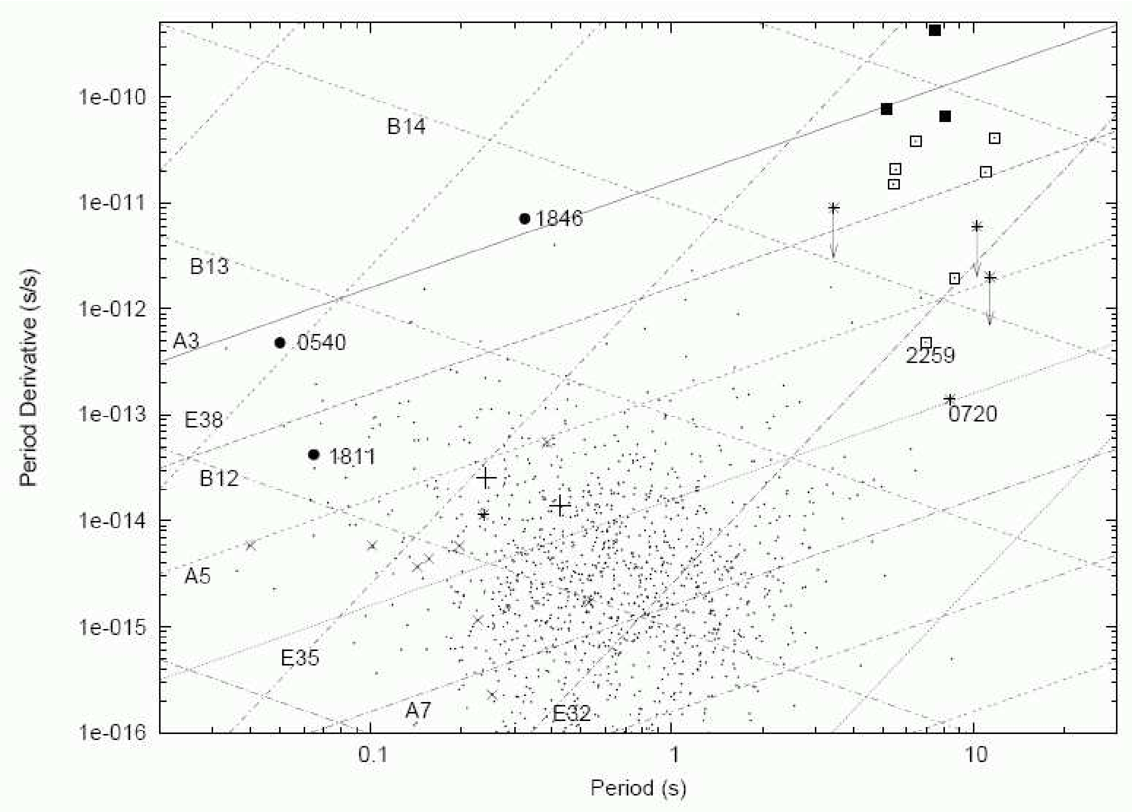

Figure 4.2. Period Vs Period Derivative

The graph above is drawn using the data from table 4.1, table 4.2, table 4.3 and table 4.4. The data are taken from [24, 25]. It is the spin period vs. time derivative of spin period diagram of different types of pulsar. Filled circles represent Galactic X-ray pulsars J1846 − 0258 and J1811 − 1925, and X-ray/radio pulsar J0540 − 69 in LMC. Filled squares and open squares display SGRs and AXPs, respectively. Asterisks represent DITNSs (for 3 of them the upper limits on their $\dot{P}$ values are shown with arbitrary arrows). DRQNSs are displayed with sign +. Radio pulsars are shown as small dots. Radio/X-ray pulsars in the region $\tau = 10^5 - 210^7$ yr are shown with sign X. B12-B14, E32-E38, and A3-A7 indicate $B = 10^{12} - 10^{14}$G, $\dot{E} = 10^{32} - 10^{38}$ erg/s, and $\tau = 10^3 - 10^7$ yr, respectively. The P and $\dot{P}$ values of radio/X-ray pulsars are from Becker and Aschenbach [26].

Table 4.1. The data of DRQNSs

Name	P (s)	$\dot{P}$ (s/s)	τ (kyr)	d (kpc)	kT_{eff} (kev)	$L_x/\dot{E}$
1E1207.4-5209	0.424	0.14	340- 480	2.1	0.25	0.1
1E0820-4247				2	0.15	
CXOJ2323+5848				3.2		
RXJ0002+6246	0.2418			3.5	0.10	0.0002
RXJ0007.0+7302				1.4		
RXJ2020.2+4026				1.5		0.0009
CXOJ0852-4615				1	0.40	
B0633+1748	0.237		350	0.16	0.048	0.00003

Table 4.2. The data of DITNSs

Name	P (s)	$\dot{P}$ (s/s)	τ (kyr)	d(kpc)	kT_{eff} (kev)	$L_x/\dot{E}$
RXJ1836.2+5925				0.43	0.043	
RXJ1856.5-3754				0.13	0.062	
RXJ0720.4-3125	8.4	0.3-0.6	1500	0.3	0.085	55
RXJ0420.0-5022	3.45	< 92		0.4	0.057	
RX J0806.4-4123	11.37	< 18		0.4	0.095	
RX J1308.8+2127	10.3	< 9	7-14	0.4	0.091	
1RXSJ214303.7+0654	9.44	11	140	0.3	0.09	
RXJ1605.3+3249				0.3- 0.4	0.092	

Table 4.3. The data of AXP's

Name	P (s)	$\dot{P}$ (s/s)	τ (kyr)	d (kpc)	kT_{eff} (kev)	B (10^{14}Gauss)
4U 0142+61	8.7	0.21	67	2	0.46	1.3
1E 1048.1-5937	6.45	3.3	3.4	3	0.63	3.9
1RXS J170849-4009	11	2.25	5.8	< 7	0.44	4.7
XTE J1810-197	5.5	1.5	5.7	~ 10	0.67	2.9
AX J1845-0258	7	0.13-0.2	5-8	10		
1E 2259+586	7	0.06	200	3.6	0.41	0.60
1E 1841-045	11.8	4.1	4.7	7	0.44	7.1
CXOU 010043-7211	8	1.9		57	0.41	3.9

Table 4.4. The data of SGR's

Name	P (s)	$\dot{P}$ (s/s)	$\tau(kyr)$	d(kpc)	kT_{eff} (kev)	B (10^{14}Gauss)
SGR 0526-66	8.1	6.6	1.9	50	0.53	7.4
SGR 1627-41	6.4				0.63	
SGR 1806-20	7.47	8.3	1.96	15		7.8
SGR 1900+14	5.16	6	0.71	10	0.43	5.7

5. CONCLUSIONS

This work begins with an investigation of the properties of super dense neutron star matter. The comparison of neutron stars with other compact objects is revised. A commentary about neutron star masses and radii is made with the help of fundamental formulas. We also tried to view the structures, emission models and other properties of different types of neutron star. Later, the questions of "are radio/X-ray pulsars progenitors of AXPs, SGRs and isolated NSs?" and "are DRQNSs and DITNSs descendants of X-ray pulsars or AXPs?" are tried to be answered. In fact, we need full data for pulsars, like their relations with supernova remnants and exact information about their emission mechanisms, to make good estimations on neutron star evolution. After giving the observed data of three Radio/X-ray pulsars, we estimate the possible evolution of these pulsars on the P-$\dot{\mathrm{P}}$ diagram. Finally it's postulated that some neutron stars may have masses $\sim 1\ M_\odot$ (or yet a bit smaller) and radii $\sim 15 - 16$ km, in order to explain their positions and evolution on the P-$\dot{\mathrm{P}}$ diagram and their magnetic fields.

Neutron stars are extremely dense high magnetic field degenerate neutron gases with smaller amounts of some other particles. In this sense, studying these objects gives possibilities to determine and/or extend the limits of some existing fundamental theories and models in physics.

In this work, physical properties and evolution of different types of neutron stars which show very different observational characteristics compared to each other are examined and possible evolutionary scenarios for some of these types are suggested and discussed.

Braking index measurements of very young radio and/or X-ray pulsars lead to the result that there exist some extra torques on neutron stars in addition to the magneto-dipole radiation torque when they are very young. As the origin of magnetars (highly magnetized neutron stars which experience gamma-ray and X-ray bursts) is still an open question, small braking index values of very young pulsars should be studied carefully to clarify whether they can be related to magnetars or not. Strong X-ray pulsar J1846-0258 is the only known example of a possible premagnetar neutron star based on its position on the P-$\dot{\mathrm{P}}$ diagram and measured braking index values together with some other observational data. Identifying a neutron star to be in an early phase of magnetar evolution, even if there exists only one such candidate observationally, is important because of some reasons: first of all, almost all the magnetar models are based on the assumption of rapid field decay of which the physics is not well known at such extremely high magnetic fields (about 10^{17} Gauss initially). If these objects have indeed not so high magnetic fields initially, i.e. if there is no field decay since the birth of these objects (about 10^{15} Gauss or less initially), then there will be a much more smooth evolution for all the types of isolated pulsars. Also, the existence of B-decay (a real decay in the magnetic field itself or a temporal decrease in the angle between the surface dipole magnetic field and the rotation axis) in the case of radio pulsars only after several million years since their birth (as shown by Guseinov et al. based on kinematic age versus characteristic time comparisons of a large sample of pulsars) can be easily understood and fused to magnetar evolution if there is no such very rapid field decay from extremely high values down to the present magnetic fields for magnetars. The positions of high-B radio pulsars (which have been detected in the last few years) also give evidence and support a more or less uniform distribution and a smooth evolution for different types of isolated pulsars. Based on these ideas, J1846-0258 which is a relatively less examined pulsar should be observed and analyzed more intensely to understand the physics of high magnetic field isolated pulsars in general.

One of the pulsars with measured braking index values is the young X-ray pulsar J0540-69 located in the Large Magellanic Cloud. For this pulsar, there are a lot of independent braking index measurements performed by different groups of astronomers. Most of these measured values are in the range 2.0-2.2 which is the smallest average braking index value among all such measurements for isolated pulsars except Vela pulsar for which the measured braking index value is most probably due to the strong glitches. X-ray pulsar J0540-69 experiences strong torques (the origins of which are not yet clear) on itself other than the magneto dipole radiation torque and this will lead to an effective increase in it B-value considerably if it continues to evolve with such a small average braking index during these early phases of its evolution on the P-$\dot{P}$ diagram. So, this X-ray pulsar may be in an early phase of dim isolated thermal neutron stars and the very small radio luminosity of this object together with its other observational characteristics which are similar to radio quiet neutron stars' should be examined in more detail to understand the lack of detected radio emission from dim radio quiet neutron stars based on a possible relation between these objects.

Another strong X-ray radio quiet very young pulsar is J1811-1925 which was probably formed by the historical supernova SN 386AD. Opposite to the case of J1846-0258 and other young pulsars with measured braking index, this X-ray pulsar possibly has a very large braking index based on the huge difference between its real age and the age of the supernova remnant which it is physically connected to. In principle, it is possible to assume that J1811-1925 was born with an initial rotation period very close to its present value. On the other hand, such an initial rotation period (about 62 milliseconds) is still long enough to create serious problems for theories on core collapse supernovae and formation of such slowly rotating neutron stars. Recent models predict shorter initial rotation periods by at least a factor of two within the uncertainty limits. If the average braking index of J1811-1925 is actually large, the position and possible such evolution of this X-ray pulsar can be used to explain the positions of X-ray and/or radio pulsars located on the lower left part of the P-$\dot{P}$ diagram as it is not clear where such pulsars are located initially and how they evolve on this diagram if one assumes that pulsars are born on the upper left part of the diagram (i.e. with short periods and high $\dot{P}$ values.

REFERENCES

1. Guseinov, O. H. and A. O. Allakhverdiev and S.O. Tagieva and O. Taskin, "Origin of pulsars with $0.1s < P < 0.3$ s and 5×10^5 years $< \tau < 107$ years after the second supernova explosion in high-mass X-ray binaries", *Astronomical and Astrophysical Transactions* , Vol. 23, pp. 385-394, 2004.

2. Shapiro, S.L. and S.A. Teukolsky, "Black Holes, White Dwarfs, and Neutron Stars", Wiley-Interscience, New York, 1983

3. Lattimer, J. M. and M. Prakash, "The Physics of Neutron Stars", *Science*, Vol. 304, pp. 536-542 , 2004.

4. Gold, T., "Rotating Neutron Stars as the Origin of the Pulsating Radio Sources", *Nature*, Vol. 218, pp. 731, 1968.

5. Pacini, F., "Equilibrium for neutron stars", *Memorie della Societa Astronomia Italiana*, Vol. 36, pp. 323, 1965.

6. Guseinov, O. Kh. and Ya. B. Zel'Dovich, "Collapsed Stars in Binary Systems", *Astronomicheskii Zhurnal*, Vol. 43, pp. 313, 1966.

7. Little, L. T. and E. Hewish, "Radio source structure derived from interplanarary scintillation", *Monthly Notices of the Royal Astronomical Society*, Vol. 138, pp. 393, 1968.

8. Cappellaro, E. and F. Mannucci and M. V. Della and N. Panagia and R. Maiolino and A.Petrosian and M. Turatto, "The supernova rate per unit mass", *Astronomy and Astrophysics*, Vol. 433, pp. 807-814, 2005.

9. Heger, A. and S. E. Woosley and H. C. Spruit, "Presupernova Evolution of Differentially Rotating Massive Stars Including Magnetic Fields", *The Astrophysical Journal*,

Vol. 626, pp. 350-363, 2005.

10. Lipunov, V. M., “Astrophysics of neutron stars”, Springer-Verlag, New York, 1992

11. Sedrakian, D. M., “Generation of a toroidal magnetic field in rotating neutron stars”, *Astrophysics*, Vol. 49, pp. 83-87, 2006.

12. Guseinov, O. H. and E. Yazgan and S.O. Tagieva and S. Ozkan, “The Pulsar Luminosity Function”, *Revista Mexicana de Astronoma y Astrofsica* , Vol. 39, pp. 267-274, 2003.

13. Guseinov, O. H. and A. Ankay and O. S. Tagieva, “Effects of the background radiation on radio pulsar and supernova remnant searches and the birth rates of these objects”, *Astronomical and Astrophysical Transactions*, Vol. 23, pp. 503-507, 2004.

14. Downs, G. S., “Macroscopic and Microscopic Behavior Following Four Large Jumps in the VELA Pulsar PSR0833-45”, *PULSARS / IAU SYMP. 95 - BONN, AUGUST 26-29 1980 P.277, 1981*. pp. 83-87, 2006.

15. Ruderman, M. and T. Zhu and K. Chen, “Neutron Star Magnetic Field Evolution, Crust Movement, and Glitches”, *Astrophysical Journal* , Vol. 492, pp. 267, 1998.

16. Kaplan, D. L. and M. H. Van Kerkwijk and J. Anderson, “The Parallax and Proper Motion of RX J1856.5-3754 Revisited”, *The Astrophysical Journal* , Vol. 571, pp. 447-457, 2002.

17. Guseinov, O. H. and A. Ankay and O. S. Tagieva, “Birth Rates of Different Types of Neutron Stars and Possible Evolutions of these Objects”, *International Journal of Modern Physics D*, Vol. 14, pp. 643-656, 2005.

18. Guseinov, O. H. and A. Ankay and O. S. Tagieva, “Influence of Neutron Star Parameters on Evolutions of Different Types of Pulsar”, *Astrophysics and Space Science*, Vol. 298, pp. 553-558, 2005.

19. Haberl, F. and J. E. Trumper and V. Burwitz and V.E. Zavlin, “The puzzles of RX J1856.5-3754: neutron star or quark star?”, *Nuclear Physics B*, Vol. 132, pp. 560565, 2004.

20. Ruderman, M. A. and P. G. Sutherland, “Theory of pulsars - Polar caps, sparks, and coherent microwave radiation”, *Astrophysical Journal*, Vol. 196, pp. 51-72, 1975.

21. Harding, A. K., “Gamma-ray Pulsars: Models and Predictions”, *High Energy Gamma-Ray Astronomy*, Vol. 558, pp. 115, 2001.

22. Guseinov O. H. and A. Ankay and S.O. Tagieva : *Acceleration of particles in pulsar magnetosphere and the X-ray radiation*, http://www.arxiv.org/PS_cache/astro-ph/pdf/0401/0401114.pdf, 2004.

23. Livingstone M. A. and V. M. Kaspi : *A Braking Index for the Young, High-Magnetic-Field, Rotation-Powered Pulsar in Kes 75*, http://arxiv.org/PS_cache/astro-ph/pdf/0601/0601530.pdf, 2006.

24. Ankay, A. and E. Yazgan and S. Şahin and G. Karanfil, “Early Phases of Different Types of Isolated Neutron Star”, *International Journal of Modern Physics D*, Vol. 14, pp. 1075-1082, 2004.

25. Thompson, C. and P. M. Woods: *Soft Gamma Repeaters and Anomalous X-ray Pulsars: Magnetar Candidates*, http://www.arxiv.org/PS_cache/astro-ph/pdf/0406/0406133.pdf, 2004.

26. Becker, W. and B. Aschenbach, “X-ray Observations of Neutron Stars and Pulsars: First Results from XMM-Newton”, *Proceedings of the 270. WE-Heraeus Seminar on Neutron Stars, Pulsars, and Supernova Remnants*, Munchen, p. 64, 2002.