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GROWING MAGNETIC FIELDS IN CENTRAL COMPACT OBJECTS

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RESUMEN

Estudiamos el efecto de un modelo de crecimiento del campo magnético en los llamados Objetos Compactos Centrales (OCCs). Tal evolución del campo magnético no es una idea nueva (Blandford, Applegate, & Hernquist 1983) pero sus implicaciones evolutivas no han sido estudiadas completamente (Michel 1994). Discutimos las nuevas clases de estrellas de neutrones, las cuales se presentan en cinco tipos reconocidos en los últimos diez años. Comentamos la posibilidad de que un pulsar magnetizado, débilmente rotante, pueda haberse formado en SN1987A.

ABSTRACT

We study the effects of growth models of magnetic fields in Central Compact Objects (CCOs). Such a field evolution is not a new idea (Blandford, Applegate, & Hernquist 1983) but the evolutionary implications not have been followed up completely (Michel 1994). We discussed the new class of neutron stars which belong to five main types that have mainly been recognized in the last ten years. The possibility that a rapid weakly magnetized pulsar might have formed in SN1987A is commented.

Key Words: pulsars: general — stars: neutron — supernovae: general — supernovae: individual (SN1987A)

1. INTRODUCTION

The last years have shown us that the observational properties of neutron stars (NSs) are remarkably diverse ranging from magnetars to rotating radio transients, from radio pulsars to isolated NSs, from central compact objects to millisecond pulsars. The observational manifestations of NSs are surprisingly varied, with most properties totally unpredicted. Particularly interesting are the so-called CCOs, defined as X-ray sources with thermal-like spectra observed close to the centers of SNRs without any counterparts in radio and gamma wavebands. They present blackbody temperatures of about a few hundred eV and have luminosities in the range 10^{33}–10^{34} erg s^{-1}. About ten such sources are known, including the famous RCW103, Cas A, Pup A, and Kes 79. The number of these objects is continuously increasing (Kaspi 2010).

Since the core-collapse supernova type II (SN II) are the expected progenitors of the strongly magnetized pulsars, it is interesting to assume that the magnetic field grows rapidly and saturates at about 10^{12} G. A reasonable argument to propose such solution is the absence of the a syncrotron nebula in these CCOs. This means, perhaps, that the pulsar has not radiated enough energy, because the magnetic field was very weak initially.

In the Rotation-Powered Pulsars (RPPs) the energy source is simply the progressive loss of rotational energy. Measurements of rotational the period P and its derivative $\dot{P}$ or, equivalently its frequency Ω and $\dot{\Omega}$, allow us to infer some basic quantities for these pulsars. A simple phenomenological evolution law

$$\dot{\Omega} = -k\,\Omega^n\,, \tag{1}$$

is often assumed, where n is the braking index. This allows to introduce the “spin-down age” of the pulsar,

$$\tau \equiv \frac{1}{n-1}\frac{P}{\dot{P}}\,. \tag{2}$$

A value of $n = 3$ is obtained when the energy loss is entirely due to magneto-dipolar radiation and then $k \approx \mu^2/Ic^3$ where μ is the pulsar's magnetic moment and I its moment of inertia. It is often also assumed that k is constant, but it is possible that, in general, k becomes a function of the time through the time evolution of the star's magnetic field **B**. We explored this possibility in this paper.

2. ANALYTICAL PROCEDURE

The equation (1) can be solved, in general, if $k = k_0 f(t)$. In this case k_0 is $k(t=0)$ and $f(t)$ is some funtion that saturate the magnetic field when $t \to \infty$, and satisfies $f(0) = 1$. In fact, we are interested

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in finding a solution $\tau = \tau(t)$

$$\dot{\Omega} = -k\Omega^n \rightarrow \tau = \frac{\tau_0}{f(t)} + \frac{k_0}{k}\int_0^t f(t)dt\,, \quad (3)$$

where τ_0 is the initial spin-down age. The braking index can indeed be measured from the second derivative of the period (presently only available for a few radio pulsars) and have a general formulation too

$$n = n_* + \frac{\dot{f(t)}}{f(t)}\frac{P}{\dot{P}}\,, \quad \text{with} \quad n_* = \frac{\Omega\ddot{\Omega}}{\dot{\Omega}^2} = 2 - \frac{P\ddot{P}}{\dot{P}^2}\,. \quad (4)$$

Finally, it is possible to obtain a general expression for the temporal evolution of the spin-down luminosity $\dot{E} = I\Omega\dot{\Omega}$ as

$$\dot{E} = \dot{E}_0 f(t)\left(\frac{\tau}{\tau_0}f(t)\right)^{-\frac{n+1}{n-1}}\,, \quad (5)$$

where $\dot{E}_0$ is the initial spin-down luminosity.

When k is constant we recover the standar result for the spin-down age, braking index and spin-down luminosity.

2.1. *Case* $k = k_0 f(t)$

The more reasonable funtion $f(t)$ that satisfies $f(0) = 1$ and the condition of growth of $\mathbf{B}$ is $f(t) = \varepsilon + (1 - \exp(-\frac{t}{\tau_B}))$.

In this case we assume $\varepsilon \ll 1$ and τ_B is the field growth time-scale. The solution to spin-down age, the braking index and the spin-down luminosity for this funtion are

$$\tau = \frac{\tau_0 + t}{f(t)} - \tau_B\,, \quad (6)$$

$$n = n_* + \frac{\exp(-t/\tau_B)}{\tau_B f(t)}\frac{P}{\dot{P}}\,, \quad (7)$$

$$\dot{E} = \dot{E}_0 f(t)\left(1 + \frac{t}{\tau_0} - f(t)\frac{\tau_B}{\tau_0}\right)^{-\frac{n+1}{n-1}}\,. \quad (8)$$

The Figure 1 shows the Spin-down luminosity for several values of τ.

2.2. *Energy Change*

In addition, we want to find a general relation for the energy change based on the observable parameters. In this case:

$$E = \frac{1}{2}I\Omega^2 = \frac{(n-1)}{2}\tau\dot{E}\,, \quad (9)$$

$$\tau = \frac{1}{(n-1)}\frac{P}{\dot{P}}\,, \quad (10)$$

$$\dot{E} = I\Omega\dot{\Omega} = -4\pi^2 I P^{-3}\dot{P}\,, \quad (11)$$

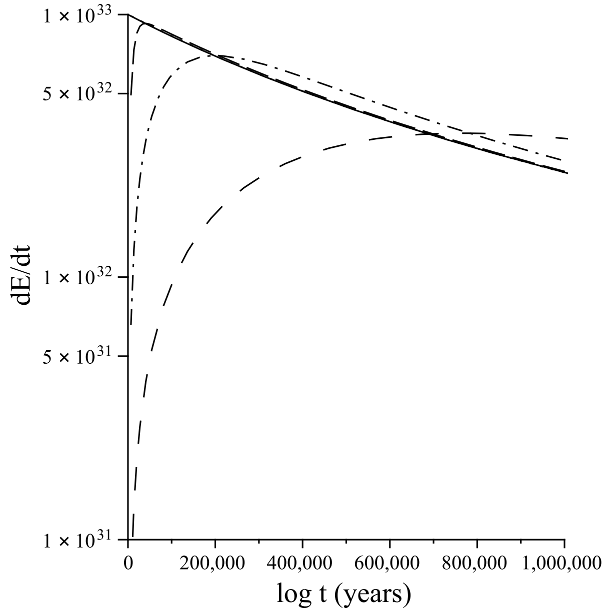

Fig. 1. Spin-down luminosity varying the spin-down initial age.

and we obtain

$$\Delta E = E_0 - E = \frac{(n-1)}{2}\left(\tau_0\dot{E}_0 - \tau\dot{E}\right)\,.$$

For the magnetic field growing case, the initial spin-down, the initial luminosity and the energy change allow us to associate the observable parameters with the theoretical model

$$\tau_0 = (\tau + \tau_B)f(t) - t\,, \quad (12)$$

$$\dot{E}_0 = \frac{\dot{E}}{f(t)}\left(\frac{\tau f(t)}{\tau_0}\right)^{\frac{n+1}{n-1}}\,, \quad (13)$$

$$\Delta E = \frac{(n-1)}{2}\dot{E}\left[\left(\frac{\tau f(t)}{\tau_0}\right)^{\frac{n+1}{n-1}}\left(\frac{\tau_0}{f(t)}\right) - \tau\right]\,.$$

For the SN1987A case, a CCO can emit less than the observed limits from this supernova even if 100 per cent of its spin-down power is reprocessed into IR emission by dust in the surrounding SN ejecta. So, we conclude that a CCO is a promising model for an unseen NS in SN1987A.

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