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A POSSIBLE CONNECTION BETWEEN MAGNETARS AND GAMMA-RAY BURSTS

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RESUMEN

Arguimos que las "magnetars", estrellas de neutrones con campos magnéticos fuertes ($B \gtrsim 10^{14}$ Gauss), pueden ser la fuente de algunos estallidos de rayos gamma (GRB), debido a efectos solo posibles en campos magnéticos intensos. La producción de axiones en los núcleos de supernovas por aniquilación de pares $e^+e^- \to a$ es posible en estos campos magnéticos. Una fracción de los $\sim 10^{53}$ erg de la energía de ligadura de la estrella de neutrones recién formada escapa en este flujo de axiones. Sin embargo, axiones en campos intensos decaen vía $a \to e^+e^-$ con vida media $\tau \sim 10^{-4}$ s, cerca de la estrella, produciendo el frente de choque en expansión relativista con $\sim 10^{51}$ erg ("bola de fuego") y el GRB. Por lo menos un GRB ha coincidido con una supernova Ic, apoyando este escenario.

ABSTRACT

We argue that magnetars, neutron stars with strong magnetic fields can be the powerhouses behind some gamma-ray bursts (GRBs), thanks to effects only possible in presence of high magnetic fields. The production of axions in supernova cores by pair anihilation $e^+e^- \to a$ is possible in such intense magnetic fields. A fraction of the $\sim 10^{53}$ erg of binding energy of the newly created neutron star escapes with this axion flux. However, axions in high magnetic fields decay through $a \to e^+e^-$ with mean life $\tau \sim 10^{-4}$ s, therefore close to the magnetar, producing the relativistic shock with $\sim 10^{51}$ erg ("fireball") and the GRB. At least one GRB was coincident with an "anomalous" supernova Ic, supporting this scenario.

Key Words: **MAGNETIC FIELDS – PULSARS: GENERAL – GAMMA RAYS: BURSTS – STARS: NEUTRON**

1. INTRODUCTION OR GAMMA-RAY BURSTS (GRBS)

The extragalactic origin of GRBs is pointed by hard X-ray data from the *Beppo-SAX* satellite, which detected events few hours after the burst with error circles $< 10'$ (Costa et al. 1997), allowing the detection of optical and radio transients (GRB970228, GRB970508) declining in time with a power law (Djorgovski et al. 1997; van Paradijs et al. 1997). Measurements of absorption by foreground galaxies indicated $z = 0.835$ (GRB970508, Metzger et al. 1997) and $z = 3.4$ (GRB971214, Kulkarni et al. 1998). There are some other important conclusions about GRBs: the energy released just in γ rays ranges from 10^{51} erg (GRB970228) to $\sim 10^{53}$ erg (approximately the binding energy of a neutron star), and at least one GRB (GRB980425) was in coincidence with an "anomalous" supernovae type Ib/c (Dominici et al. 1998; Galama et al. 1998). Up to eight other coincidences having been noted (Wang & Wheeler 1998).

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2. HOW CAN MAGNETARS GIVE ORIGIN TO GRBS

Magnetars are strongly magnetized neutron stars ($B \sim 10^{14}\,$G) with different properties than ordinary pulsars (like no detectable radio emission). They have been identified with Soft Gamma Repeaters (Duncan & Thompson 1992) and "Anomalous" X-ray Pulsars (AXPs) (Heyl & Hernquist 1999). Their existence is confirmed by observations: magnetars are the sources of SGR1806-20 (distance $\sim$ 14 kpc, $B \sim 8 \times 10^{14}\,$G) (Kouveliotou et al. 1998a) and SGR1900+14 (distance $\sim$ 7 kpc, $B \sim 8 \times 10^{14}\,$G) (Kouveliotou et al. 1998b).

A neutron star of radius R ($\sim 10^6\,$cm) and angular velocity Ω ($\sim 3000\,\mathrm{s}^{-1}$) induces an electric field $E_{ind} \simeq (\sqrt{2}/4c)\Omega RB(R/r)^3$, where r = distance from the magnetar. It requires $B > 4 \times 10^{15}\,$G on the surface to produce $E_{ind} > E_S = 1.4 \times 10^{14}\,$dyn/esu, the critical Schwinger field. A field stronger than E_S can spontaneously produce e^+e^- pairs (de Freitas Pacheco & Horvath 1998) and extract the magnetar rotational energy. A fireball is produced on surface if $\log(\Omega/\mathrm{s}^{-1}) > 18.482 - 1.064\,\log(B/\mathrm{Gauss})$ is satisfied, because the energy deposed on e^+e^- production dominates over other rotational energy losses. This provokes a transient of duration 2 ms – 200 s and energy $\sim 10^{52}\,$erg, identified with the GRB. Alternatively, some fraction of $3\times10^{53}\,$erg from the neutron star binding and thermal energy can be "deviated" from $e^+e^- \to \nu\bar{\nu}$ to $e^+e^- \to a$ (Horvath, de Freitas Pacheco, & Allen 1999). With a long mean free path particle, even for matter at nuclear densities, axions can transport huge amounts of energy from the magnetar interior to where a fireball can be produced.

Some processes are possible only in the presence of a magnetic field over critical value $B_S = 4.414 \times 10^{13}\,$G: $e^+e^- \longleftrightarrow a$ become dominant over $e^+e^- \to \nu\bar{\nu}$ (Skobelev 1997). The mean lifetime of axion decay through $a \to e^+e^-$ (KSVZ model, for $E_a{}^2 \gg eB$) is $\tau = 10^{-4}\,s\,(10^{-10}/g_{a\gamma}\,GeV)^2\,(E_a/10\,MeV)^{-1/3}\,(B/10^{-15}\,G)^{-4/3}$, where E_a = axion energy and $g_{a\gamma}$ = the axion-photon coupling. These axions decay within $\sim 10^7\,$cm, close to the magnetar surface, on the optically thick region, producing the fireball and GRB. This model is independent from rotation and works with the cosmologically interesting axion (Raffelt 1997) of mass $m_a \leq 10^{-3}\,$eV.

At least some GRBs may be heralding the birth of a magnetar. As noticed by Loeb (1993), if just $\sim 10^{-4}$ SNe give origin to magnetars (and $\sim 2/7$ are SN Ib, Ib/c or Ic), the observed frequency of GRBs ($\sim 2 \times 10^{-6}\,\mathrm{yr}^{-1}$ per L^* galaxy) can be explained through this model. Cen (1998) produced a picture unifying asymetrical SNe and GRBs. In his view, a relativistic jet could be produced along the rotation or magnetic axis of the protoneutron star, accountting for natal kicks, beaming and time-scales. Our mechanism is compatible with that picture, and the dependence of the axion creation and decay on the magnetic field can naturally explain preferred alignments with the magnetic axis.

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