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Are AXPs/SGRs magnetars?

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Abstract

Anomalous X-ray Pulsars and Soft Gamma-Ray Repeaters have been generally recognized as neutron stars with super strong magnetic fields, namely "magnetars". The "magnetars" manifest that the luminosity in X-ray band are larger than the rotational energy loss rate, i.e. $L_X > \dot{E}_{\rm rot}$, and then the radiation energy is coming from the energy of magnetic field. Here it is argued that magnetars may not really exist. Some X-ray and radio observational results are contradicted with the magnetar model.

(1) The X-ray luminosity of PSR J1852+0040 is much larger than the rotational energy loss rate ($L_X/\dot{E}_{\rm rot} \simeq 18$), but the magnetic field is just 3.1×10^{11} G. Does this X-ray radiation energy come from the magnetic field?

(2) In contrast to the above, the magnetic fields of radio pulsars J1847-0130 and PSR J1718-3718 are higher than that of AXP 1E 2259+586, why is the radiation energy of those two radio pulsars still coming from rotational energy? Furthermore, the magnetic field of the newly discovered SGR 0418+5729 with the lowest magnetic field is 3.0 e13 G, lower than the critical magnetic field $B_{\rm C} = 4.414\,{\rm e}13\,{\rm G}$) (Esposito et al. 2010).

(3) Some "magnetars" also emit normal transient radio pulses, what is the essential difference between radio pulsars and the "magnetars"?

The observational fact arguments will be presented at first, then we discuss in what situation the conventional method to obtain magnetic field could not be correct.

1 Introduction

Anomalous X-ray Pulsars (AXPs) and Soft Gamma-Ray Repeaters (SGRs) have similar characteristics (see, e.g. Mereghetti et al., 2009; Kaspi, 2007; 2009). Timing analysis gives no evidence of orbit motion, no evidence to show AXPs and SGRs in binary systems. Hulleman et al. (2000) found that the optical emission from the AXP (4U 0124+61) is too faint to admit a large accretion disk. AXPs and SGRs are recognized as the new classes of young objects ($P/(2\dot{P}) \sim 10^3 - 10^5$ yr), along with other young neutron star families, and the magnetic fields are super strong (5.9×10^{13} G to 10^{15} G). They do not manifest themselves as radio pulsars, like the dim isolated neutron stars (DINs) and the center compact objects (CCOs), which suggests alternative evolutionary paths for young neutron stars (Ertan et al. 2009). The most peculiar observed fact is that all AXPs and SGRs have stable persistent pulsed X-ray emission with the luminosity of $L_X \sim 10^{34} - 10^{36}\,\mathrm{ergs\,s^{-1}}$, well in excess of the spin down energy of these sources, i.e., $L_X > \dot{E}_{\rm rot}$. A very important question is then: what does the radiation energy come from? To answer this question, some models are suggested. Meanwhile, the "magnetar" model is widely accepted, which is isolated neutron stars with super strong magnetic fields (Duncan & Thompson 1992; Thompson & Doncan 1995), and the radiation energy is coming from the magnetic field decay (Thompson & Doncan 1996).

For AXPs and SGRs, the widely accepted assumption is that the rotational energy is carried out by the dipole magnetic radiation. This is just the fact what we have observed for radio pulsars. So radio pulsars are named as "spin-down powered" neutron stars. Unfortunately for AXPs and SGRs, no direct link between rotational energy and the dipole magnetic radiation has been found so far, thus any calculations for the value of magnetic field obtained from P and $\dot{P}$ could not be reliable.

Furthermore, there are some observations that challenge the "magnetar" model.

(1) X-ray observations show at least one CCO, PSR J1852+0400, in the supernova remnants Kes 79, shows "anti-magnetar" properties: the field is low (3.1×10^{10} G), but X-ray emission is larger than the spin down energy, $L_X > \dot{E}_{\rm rot}$. What does the radiation energy come from? Does it also come from the magnetic field?

(2) Some authors argue that owing to the super strong magnetic field, so AXPs and SGRs are different from the normal radio pulsars: magnetars can not radiate in the radio band; and radio pulsars can not have super strong magnetic field. But recent observations show that some AXPs: XTE J1810-197 (Camilo et al. 2007) and 1E 1547.0-5408 (Camilo et al. 2008) can have normal radio pulse emission. On the other hand, some normal radio pulsars PSR J1847-0130 and PSR J1718-3718 do have super strong magnetic field , which are larger than that of one of the AXPs. In this case, can we say that the differences between "magnetars" and radio pulsars are coming from the difference of the magnetic field? If not, what is the real difference?

In § 2, we present the anti-magnetar observations in both X-ray and radio bands. In §3, it is argued that the magnetic field values of "magnetsrs" are incorrect. The conclusion and discussion are presented in §4.

Table 1: The parameters: spin period (P), period derivative ($\dot{P}$), characteristic age (τ_c) and Host object age ($\tau_{\rm host}$) and the Host name for three CCOs.

Name	P (ms)	$\dot{P}$ (s·s^{-1})	τ_c (yr)	τ_{host}(yr)	Host
PSR J1852+0040	105	8.7e-18	192e6	$\sim$ 7e3	Kes 75 (a)
1E 1207.4.5209	424	6.6e-17	>27e6	$\sim$ 7e3	SNR PKS 1209.51/52 (b)
RX J0822-4300	112	<8.3e-15	>0.22e6	3.7e3	SNR Puppis A (c)

(a)A CCO, in Kes 75 (Halpern & Gotthelf 2010).
(b)A CCO, in SNR PKS 1209.51/52 (Gotthelf and Halpern 2008).
(c)A CCO, in SNR Puppis A (Halpern & Gotthelf 2010).

2 Anti-magnetar observations: challenge to magnetars

Some anti-magnetar observations in both X-ray and radio bands are presented below, which challenges the existence of the magnetars with super-strong magnetic field.

2.1 X-ray observations: $L_x > \dot{E}_{rot}$ does not mean super-strong magnetic field at all

Halpern & Gotthelf (2010), using the data of XMM-Newton and Chandra, achieved phase-connected timing of the 105 ms X-ray pulsar PSR J1852+0040 that provides the first measurement of the spin-down rate of a CCO in a supernova remnants (See table 1). Some observations challenge the "magnetars":

(1) $L_X > \dot{E}_{\rm rot}$ but the surface magnetic strength B_s is low.

PSR J1852+0040, $P = 105$ ms, $\dot{P} = (8.68 \pm 0.09) \times 10^{-18}$ s s^{-1}, the surface magnetic field is $B_s = 3.1 \times 10^{10}$ G, which is the weakest magnetic field ever measured for a young neutron star. The X-ray luminosity $L_X = 5.3 \times 10^{33} (d/7.1 \text{ kpc})^2$ erg s^{-1}. The rotational energy loss is $\dot{E}_{\rm rot} = 3.0 \times 10^{32}$ erg s^{-1}, then $L_X/\dot{E}_{\rm rot} \simeq 17.7$.

Is the radiation energy still coming from the magnetic field?

(2) The characteristic ages of CCOs are not consistent with the companied SNR.

All CCOs are in SNRs (Halpern & Gotthelf 2010). The characteristic ages, $\tau_c = P/(2\dot{P})$, are not consistent with the ages of companied SNRs. For example, the characteristic age τ_c of PSR J1852+0040 is 192 Myr, but the age of companied SNR Kes 79 is 7 kyr.

This problem also appears for other CCOs. For example, the characteristic age of the CCO RX J0822-4300 (P=112 ms) is $\tau_c > 220$ kyr, but the age of companied SNR Puppis A is 3. kyr (Gotthelf & Halpern 2009). The characteristic age of the central

Table 2: A comparison between radio pulsars, AXPs and an anti-magnetsr.

Name	P (s)	$\dot{P}$ (s·s^{-1})	τ_c (yr)	$B_{\rm s}$ (G)	Note
PSR J1847-0130	6.7	1.3e-12	8.2e4	9.4e13	High-B Radio PSR(a)
PSR J1718-3718	3.3	1.5e-12	3.5e4	7.4e13	High-B Radio PSR(b)
PSR J1814-1733	4.0	7.4e-13	8.6e4	5.5e13	High B Radio PSR(c)
SGR 0418+5729	9.1	1.1e-13	4.1e6	3.0e13	Magnetar, no radio (d)
1E2255+586	7.0	4.9e-13	2.3e5	5.9e13	Magnetar, no radio(e)
XTEJ1810-197	2.1	2.3e-11	1.4e3	2.4e14	Magnetar, radio(f)
1E 1547.0-5408	5.54	1.2e-11	7.6e3	2.6e14	Magnetar, radio(g)
PSR J1846-0258	0.324	7.1e-12	7.2e2	4.9e13	$L_X/\dot{E}_{\rm rot} = 0.05$,no radio(h)
PSR J1852+0040	0.105	8.7e-18	1.9e8	3.1e10	Anti-mag.$L_X/\dot{E} = 17.7$,no radio(i)

(a) High magnetic field pulsar (High-B PSR) (Mclaughlin et al. 2003); no X-ray.
(b) High-B PSR (Hobbs, G., et al. 2004; Kaspi1 & McLaughlin 2005); low X-ray.
(c) High-B PSR (Camilo et al. 2000); no X-ray.
(d) A newly discovered SGR with the lowest magnetic field (lower than the critical magnetic field $B_{\rm C} = 4.414e13\,{\rm G}$) (Esposito et al. 2010).
(e) A glitching AXP (Kaspi 2007).
(f) A transient radio-emitting AXP (Halpern et al. 2005; Camilo et al. 2006).
(g) A transient radio-emitting AXP (Camilo et al. 2007).
(h) A rotation-powered pulsar with High-B, $L_X/\dot{E}_{\rm rot} = 0.05$; surrounded by a PWN and a SNR shell in Kes 75; no radio emission. There are AXP-like bursts (Gotthelf et al. 2000; Archibald et al. 2008).
(i) A CCO ("anti-magnetar") in the center of the SNR Kes75, $L_X/\dot{E} = 17.7$; no radio (Halpern & Gotthelf 2010).

source 1E 1207.4-5209 (p=424 ms) in the SNR PKS 1209.51/52 is $\tau_c > 27\,\mathrm{Myr}$ or $\tau_c = 200-900$ kyr (Shi and Xu 2003), but the age of companied SNR PKS 1209.51/52 is 7 kyr (Gotthelf & Halpern 2008).

Where does the problem come from? Is the calculated characteristic age correct? If the characteristic age calculated from P and $\dot{P}$ is incorrect, how about the magnetic field?

2.2 Radio observations: the difference between radio pulsars and magnetars does not originate from the difference of magnetic fields

Previous observations mainly show that: (1) no radio emission from "magnetars" are observed; (2) the magnetic fields of "magnetars" are stronger than those of normal radio pulsars. It is then generally believed that these differences are caused by the difference of the magnetic fields.

Recent observations show that all these two differences are confused: some radio pulsars have stronger magnetic field than that of one AXP; radio emission from some AXPs are observed clearly after X-ray flare.

2.2.1 The magnetic field of radio pulsars larger than one "magnetsrs"

In table 2, a comparison between four high-B radio pulsars and three AXPs is presented. One can see that the magnetic fields of PSR J1847-0130 (9.4×10^{13} G) and PSR J1718-3718 (7.4×10^{13} G) are lager than that of 1E 2255+586 (5.9×10^{13} G). Beside this, the magnetic fields of few other pulsars are closer to that of 1E 2255+586. Such as PSR J1814-1733, the magnetic field is 5.5×10^{13} G.

PSR J1846-0258 is a rotation-powered pulsar with High-B. The magnetic field is 4.9×10^{13} G. The X-ray emission luminosity is smaller than that of the spin-down energy, e.g. $L_X/\dot{E}_{\rm rot} = 0.05$. It is surrounded by a PWN and a SNR shell, in Kes 75. This pulsar has not been observed in radio band, but there are AXP-like bursts and magnetar like transition (Gotthelf et al. 2000; Archibald et al. 2008).

All these observations present a confusion, do the differences of these objects come the difference of the magnetic field strength?

2.2.2 Radio emission observed from some "magnetsrs"

A typical radio emission has been observed from AXP XTE J1810-197 in 2004 January, one year after outburst (Halpern et al. 2005; Camilo et al. 2006; Lazaridis et al. 2008). The period of XTE J1810-197 is $P = 5.54$ s, the magnetic field is 2.6×10^{14} G. The radio pulse profiles are observed at many frequencies (Camilo et al. 2006).

Table 3: The characteristic ages (τ_c) and the Host object ages ($\tau_{\rm host}$) of some magnetars.

Name	P (s)	$\dot{P}$ (s·s^{-1})	τ_c (yr)	τ_{host}(yr)	Host
SGR 1806-20	7.46	10e-10	1.2e3	(3-5)e6	MSC (a)
SGR 1900+14	5.16	10e-10	0.8e3	(1-10)e6	SNR: CTB 109 (b)
1E 2259+586	7.0	4.84e-13	2.28e5	1.7e4	SNR: CTB 109 (c)

(a) A magnetar in the Host object of massive star cluster (MSC) (Fuchs et al. 1999; Bibby et al. 2000).
(b) A magnetar in the Host object of CTB 109 (Vrba et al. 2000).
(c) A magnetar in the Host object of CTB 109 (Hughes et al. 1981; Iwasawa et al. 1992; Marsden et al. 2001).

Another AXP 1E 1547.0-5408 also observed transient pulsed radio emission following X-ray bursts (Camilo et al. 2007). The period of 1E 1547.0-5408 is $P = 2.069\,$s, with a surface field strength of $B_s = 2.2 \times 10^{14}\,$G.

The pulsed radio emission of these two objects are similar as the typical emission from normal radio pulsars. Some authors argue that the radio spectrum of AXPs is approximately flat, which is different from normal radio pulsars. But there are 10 percent of radio pulsars have flat spectrum (Dick Manchester, private conversation). After the pulsed radio emissions from AXPs have been observed, some authors took calculations to show that, in the case of strong magnetic field, the radio emission could still be observed. Our question is that if this is the case, why was the pulsed radio emission radiated just after outburst and observed only in some time?

3 Do super strong magnetic fields really exist in AXPs & SGRs?

As we discussed above, all characteristic ages of CCOs do not agree with the ages of the related SNRs. If we believe that the ages of SNRs are correct in most situations, then we should ask why the characteristic ages are different from each other so much? Here it is argued that, the values of magnetic field, rotational energy loss rate and characteristic age obtained from P and $\dot{P}$ are incorrect for AXPs and SGRs.

How about the magnetars? From the Table 3, one can see that the same thing happens in the case of "magnetars". The characteristic ages (τ_c) of "magnetars" and the Host object ages ($\tau_{\rm host}$) are very different (e.g. Shi & Xu 2003).

Our suggestion is that: using period P and period derivative $\dot{P}$ to get the super strong magnetic fields is incorrect for AXPs and SGRs!

4 Conclusion & discussion

From the discussions above, our conclusions are drawn as follows:

1. An anti-magnetar (PSR J1852+0040) shows that the X-ray luminosity is larger than the rotational energy loss rate, that is $L_X/\dot{E} > 1$. The magnetic field is 3.1×10^{10} G. Where does the radiation energy come from? Can we say that it is also coming from the magnetic energy?

We argue that in the case of $L_X/\dot{E} > 1$, using P and $\dot{P}$ to get the magnetic field is incorrect, flow-out particles and the parallel magnetic component, $\mu_{\|}$, should be taken into account, which contributes to the rotational energy loss (Xu & Qiao 2001).

2. The differences of "magnetars" and the radio pulsars are not from the difference of the magnetic field strength. The transient pulsed radio emission from "magnetars" is a kind of typical radio emission as similar as the one observed for normal radio pulsars. The flat spectrum of magnetars is not different from normal radio pulsars. An important thing is that, to show the distinct difference between the transient pulsed radio emission from the magnetars (that is related to the outburst) and the normal radio pulsars.

3. Many authors show that how to produce the observed phenomena of magnetars, but never to show the differences between normal radio pulsar and magnetars. For example, why magnetars have high energy radiations but nor for the radio pulsar PSR J1847-0130.

We argue here that a acceptable theory, related to observations of manetars, should show the difference between magnetars and other objects.

4. Producing the very strong outbursts is a key question for any model about the AXPs & SGRs. If the very high energy of the outburst does not come from the magnetic field, where oes the energy come from? Only accretion may not satisfy this request. Some possible quark star models should be taken into account, e.g. Cheng & Dai (1998), Cheng et al. (2000); Xu, Tao & Yang (2006).

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