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# Wind braking of magnetars: to understand magnetar's multiwave radiation properties

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Magnetars are proposed to be peculiar neutron stars powered by their super strong magnetic field. Observationally, anomalous X-ray pulsars and soft gamma-ray repeaters are believed to be magnetar candidates. While more and more multiwave observations of magnetars are available, unfortunately, we see accumulating failed predictions of the traditional magnetar model. These challenges urge rethinking of magnetar. Wind braking of magnetars is one of the alternative modelings. The release of magnetic energy may generate a particle outflow (i.e., particle wind), that results in both an anomalous X-ray luminosity ($L_{\rm x}$) and significantly high spindown rate ($\dot{P}$). In this wind braking scenario, *only* strong multipole field is necessary for a magnetar (a strong dipole field is no longer needed). Wind braking of magnetars may help us to understand their multiwave radiation properties, including (1) Non-detection of magnetars in Fermi-LAT observations, (2) The timing behaviors of low magnetic field magnetars, (3) The nature of anti-glitches, (4) The criterion for magnetar's radio emission, etc. In the wind braking model of magentars, timing events of magnetars should always be accompanied by radiative events. It is worth noting that the wind engine should be the central point in the research since other efforts with any reasonable energy mechanism may also reproduce the results.





## 1 Introduction

Pulsars are rotating magnetized neutron stars. They are the end product of massive stars. Since the first discovery of pulsars in 1967 (Hewish et al. 1968), more and more kinds of pulsar-like objects are found. According to their energy sources, pulsars may be cataloged into four classes.

1. Rotation-powered pulsars. These include radio pulsars (including millisecond pulsars), rotation-powered X-ray pulsars, and gamma-ray pulsars.
2. Accretion-powered pulsars. For neutron stars in a binary system, accretion may power both their persistent and burst emissions.
3. Magnetars. Anomalous X-ray pulsars and soft gamma-ray repeaters are thought to be neutron stars powered by their super strong magnetic field.
4. Thermal-powered neutron stars. If neither of the above sources is available, then the neutron star can only radiation thermal photons (since it has a non-zero temperature). X-ray dim isolated neutron stars are thought to thermal-powered neutron stars.

Different energy sources may be at work in one source, e.g., there can be thermal emission in rotation-powered pulsars. Magnetar is a special kind of pulsar-like objects. They are discovered by the progress of multiwave observations of pulsars (X-ray observations rather than the traditional radio observations, Kouviotou et al. 1998). We are beginning to know more and more of magnetars in recent years. The study of magnetars may provide one way to unify different kinds of pulsar-like objects (Kaspi 2010).

### 1.1 Basics of magnetars

Anomalous X-ray pulsars (AXPs) and soft gamma-ray repeaters (SGRs) are believed to magnetars. They got their names due to historical reasons (Mereghetti 2008). Since 1970s, people know that there are two kinds of X-ray pulsars: rotation-powered X-ray pulsars (e.g., X-ray emissions of Crab and Vela pulsar) and accretion power X-ray pulsars (accreting neutron stars in binary system). AXPs have a X-ray luminosity higher (e.g., $10^{35}\ {\rm erg\,s^{-1}}$) their rotational energy loss rate. Therefore they can not be rotation-powered. At the same time, no binary signature is seen in AXPs. Then they are also not accretion-powered. The energy source of their X-ray emission is unknown at early times. Therefore, they got the name "anomalous X-ray pulsars". SGRs are recurrent bursts. Compared with classical gamma ray burst, SGRs' typical photon energy is lower. Therefore, they are named "soft gamma-ray repeaters". Up to now, we know that AXPs and SGRs belong to the same class of objects. They may be magnetars. Magnetars form a distinct kind of pulsar-like objects compared with normal pulsars. This can be seen directly form their distribution on the period period-derivative diagram of pulsars (Figure 1).

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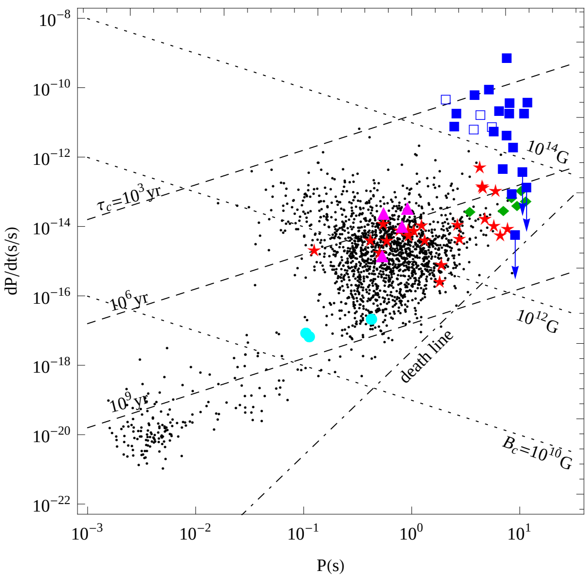


**Fig. 1** Distribution of magnetars on the period period-derivative diagram of pulsars. Blue squares are magnetars, while empty squares are radio-loud magnetars. Green diamonds are X-ray dim isolated neutron stars, cyan circles are central compact objects, red stars are rotating radio transients, magenta triangles are intermittent pulsars, and black dots are rotation powered pulsars (including normal pulsars and millisecond pulsars). Figure 1 in Tong & Xu (2011), with updates.

The first giant flare of magnetars was observed in 1979 (Mazets et al. 1979). The magnetar idea (neutron stars with magnetic fields as high as $10^{14}-10^{15}\,$G) was proposed by several authors in 1992 (Duncan & Thompson 1992; Usov 1992; Paczynski 1992). It was Paczynski (1992) who pointed that the super-strong magnetic field may explain the super-Eddington luminosity of the 1979 giant flare. Timing observation of the period and period derivative of one SGR (by RXTE) was thought to be the confirming evidence of magnetars (Kouveliotou et al. 1998). By assuming that the nuetron star is slowed down by emitting magnetic dipole radiation, the neutron star's surface magnetic field is (Tong et al. 2013a)

$$B = 3.2\times10^{19}\sqrt{P\dot{P}}\,\mathrm{G}, \tag{1}$$

where $B$ is the star's surface magnetic field, $P$ is the pulsation period, $\dot{P}$ is the period derivative. For SGR 1806−20, its period and period derivative are $7.47\,$s and $8.24\times10^{-11}$, respectively (Kouveliotou et al. 1998). According to the magnetic dipole braking assumption, SGR 1806−20 is a neutron star with age of 1500 years[1] and surface magnetic field as high as $8\times10^{14}\,$G. Therefore, it is a young neutron star with super-strong magnetic field[2](i.e., magnetar). Later, not only SGRs but also AXPs are thought to be magnetars. In 2008, the traditional magnetar model was (Mereghetti 2008): 1) Magnetars are young neutron stars; 2) These neutron stars have dipole magnetic field higher than the quantum critical field[3]; 3) The multipole field of these neutron stars may be even higher, e.g., as high as $10^{14}-10^{15}\,$G. The dipole field of magnetars provides the braking torque, while the multipole field is responsible for the burst, super-Eddington luminosity, and persistent emissions of AXPs and SGRs.

Since 2006, more and more multiwave observations of magentars are available (from radio to optical and IR, soft X-ray and hard X-ray, and gamma-ray etc). There are observations which are consistent with the magnetar model. These observations are for the magnetar model if AXPs and SGRs are magnetars. Therefore, these observations are model depend evidences for the magnetar model (Tong & Xu 2011). Meanwhile, we see accumulating evidences of failed predictions of the traditional magnetar model (Tong & Xu 2011). The discovery of a low magnetic field magnetar in 2010 challenged the traditional magnetar model directly (Rea et al. 2010; Tong & Xu 2012). The low magnetic field magnetar (SGR 0418+5729) is an old neutron star with surface dipole field less than $7.5\times10^{12}\,$G. But at the same time, it can have magnetar-like activities. It will not be too incorrect to say that none of the predictions of the traditional magnetar model is observed. The failed predictions of the traditional magnetar model require rethinking the magnetar idea. There are 3+1 things to do concerning magnetars

1. What's the origin of strong magnetic field in magnetars and pulsars? This is relevant to whether AXPs and SGRs are magnetars or not.
2. What's the emission mechanism of magnetar multiwave radiation properties? The multiwave emission mechanism of magnetars remains illusive.
3. The birth and environment of magnetars. The environment of magnetars possibly includes: fallback disks, pulsar wind nebulae, supernova remnants, and binary companions (if the magnetar is in a binary system).
4. The relation between magnetars and other pulsar-like objects. Magnetars are just a special kind of pulsars. Therefore, we must understand various pulsar-like objects at the same time. We want to know what's the relation between magnetars and X-ray dim isolated neutron stars (XDINSs), central compact objects (CCOs), high magnetic field pulsars (HBPSRs), and most importantly normal pulsars.

There exist several alternative modelings of magnetars (Tong & Xu 2011).

1. Twisted magnetosphere model (Thompson, Lyutikov & Kulkarni 2002). The magnetar magnetosphere may be globally twisted. And a partially twisted magnetosphere

[1] The characteristic age is defined as $P/(2\dot{P})$.

[2] For normal pulsars, their typical magnetic field is $\sim 10^{12}$ G

[3] The quantum critical field is defined as when the electron cyclotron energy equals its rest mass energy, $B_{\rm q}=\frac{m_e^2c^3}{e\hbar}=4.4\times10^{13}\,$G. In a magnetic field higher than the quantum critical value, quantum electrodynamics must be employed to treat the microscopic processes.

 

model was also investigated (i.e., corona model of magnetars, Beloborodov & Thompson 2007; Beleborodov 2009).
2. Wind braking of magnetars (Tong & Xu 2012; Tong et al. 2013a). In the wind braking model, magnetars are neutron stars with strong multipole field. A strong dipole field is no longer needed. A particle outflow dominates the rotational energy loss rate of magnetars. The multipole field is responsible for the braking torque, persistent and burst emissions of magnetars. In the wind braking model of magnetars, timing events of magnetars should always be accompanied by radiative events.
3. Magnetothermal evolution model (Vigano et al. 2013). Coupled evolution of magnetic field and temperature of neutron stars may explain the surface thermal emission of various kinds of pulsar-like objects.
4. Fallback disk model (Alpar 2001; Alpar, Ertan & Kaliskan 2011). A neutron star with a fallback disk may explain some aspects of magnetars. And there is already a disk found in AXP 4U 0142+61 (through optical/IR observations, Wang, Chakrabarty & Kaplan 2006).
5. Accretion induced star-quake model (Xu, Tao & Yang 2006; Xu 2007). The self-confined quark star surface can explain the super-Eddington luminosity of magnetar giant flares. Accretion from a fallback disk is responsible for the spindown and persistent emissions. A quark star with a fallback disk may provide another way unifying different kinds of pulsar-like objects.
6. Quark-nova remnant model (Ouyed, Leahy & Niebergal 2007, 2011). After the supernova, there may be a transition from a neutron star to a quark star. This is dubbed as a quark-nova. A quark star with some kind of quark-nova remnant may explain several pulsar-like objects (including AXPs and SGRs).
7. White dwarf model (Paczynski 1990; Malheiro, Reuda & Ruffini 2012). If the central star of AXP and SGR is a white dwarf, then the rotational energy of the white dwarf is enough to power the persistent emissions of AXPs and SGRs.

The first three models are in the magnetar domain (i.e., they all involve neutron stars powered by strong magnetic field). The last four models are more or less beyond the magnetar model.

## 2 Toward an understanding of magnetar multiwave radiation properties

### 2.1 Non-detection in Fermi-LAT observations

In the traditional model of magnetars, magnetars are neutron stars with both strong dipole field and strong multipole field. Although the magnetic field at the magnetar surface is very high, the magnetic field in the outer magnetosphere is relatively low. Therefore, particles may be accelerated in the outer magnetosphere and magnetars are expected to be high-energy gamma-ray emitters detectable by Fermi-LAT (Cheng & Zhang 2001). However, the X-ray luminous AXP 4U 0142+61 is not detected in Fermi-LAT observations (Sasmaz Mus & Gogus 2010). There is also no significant detection in Fermi-LAT observations of all AXPs and SGRs (Abdo et al. 2010). Then there are conflicts between outer gap model in the case of magnetars and Fermi-LAT observations (Tong, Song & Xu 2010, 2011). AXP 4U 0142+62 should have been detected by Fermi-LAT. The present observational upper limits are already below the theoretical calculations for some parameter space. There are possibly two solutions for this conflict:

1. AXPs and SGRs are fallback disk systems. Then most of them are not expected to be gamma-ray emitters.
2. AXPs/SGRs are magnetars braked down by a particle wind. If a particle outflow dominates the magnetar's rotational energy loss rate, then the corresponding surface dipole field can be much lower (i.e., 10-100 times smaller). Meanwhile, in the presence of a particle wind, vacuum gaps can not exist in the magnetosphere.

Fermi deeper observations may help us to distinguish between the fallback disk model and magnetar model for AXPs and SGRs.

### 2.2 Hard X-ray emission cutoff

The soft X-ray spectral of magnetars are uausally made up of two components: a blackbody component (with temperature $\sim 0.5\,\mathrm{keV}$) and power law component (with a photon index $\Gamma \sim 3-4$). Extrapolating the soft X-ray components, magnetars are not expected to luminous in the hard X-ray range. However, INTEGRAL observations found that many magnetars are detected in hard X-ray (Gotz et al. 2006). The hard X-ray can be fitted with a power law with photon index $\Gamma \sim 1$. And the hard X-ray energy output is about half the magnetar's total electromagnetic energy output. Therefore, the hard X-ray component of magnetars is a distinct component compared with the soft X-ray component. And it is an indispensable part of the magnetar's energy budget. There are various proposals for the origin of hard X-ray emission both in the magnetar model and the fallback disk model. And the hard X-ray emission cutoff is crucial to distinguish between different models.

A possible cutoff in the hard X-ray emission of AXP 4U 0142+61 is reported recently (Wang, Tong & Guo 2013). Using nearly nine years INTEGRAL observations, a possible cutoff of $\approx 130\,\mathrm{keV}$ is seen. With a cutoff of $130\,\mathrm{keV}$, we can rule out hard X-ray emission models involving ultra-relativistic electrons. Both the microscope and bulk motion of electrons should be at most mildly relativistic. During the nine years interval, the total hard X-ray luminosity is relatively stable. Therefore, a persistent source of electrons are needed rather than transient. Therefore, there must exist a persistent component of particle outflow. Hard X-ray Modulation Telescope (known HXMT, by China) can determine the cutoff energy more accurately in the future.

### 2.3 Soft X-ray timing behavior

#### 2.3.1 Wind braking of magnetars

In timing study of magnetars, the magnetic dipole braking assumption is often employed (Kouveliotou et al. 1998). However, the magnetic dipole braking assumes an perpendicular rotator in vacuum. Therefore, it is just an pedagogical model (Li et al. 2013). The non-detection of magnetars by Fermi-LAT, the timing difference between magnetars and high magnetic field pulsars, and most importantly the varying period derivative of magnetars, these observations may imply that magnetars have a different braking mechanism from that of normal pulsars (Tong et al. 2013a). Both pulsars and magnetars should be braked down by a particle wind (i.e., a mixture of particles and electromagnetic fields). The difference between them is that for pulsars magnetic dipole braking is valid to the lower order approximation. The particle wind mainly causes higher order timing effects, e.g., braking index, timing noise. However, for magnetars magnetic dipole braking is incorrect even to the lowest order approximation. Therefore, in timing study of magnetars we must employ the full formalism of wind braking.

The soft X-ray luminosity of magnetars $L_{\rm x}$ originates from their magnetic field decay. During the decay of magnetic field, a particle outflow may also be generated[4] (i.e., particle wind). A natural estimation of particle wind luminosity is that $L_{\rm p} = L_{\rm x}$ (the particle wind luminosity equals the soft X-ray luminosity). When the particle wind luminosity is known, we can calculate the spindown behaviors of magnetars in the wind braking scenario. The dipole magnetic field of magnetars in the case of wind braking is (Tong et al. 2013a)

$$\begin{aligned} B &= 4.0\times 10^{25}\frac{\dot{P}}{P}\,L_{\rm p,35}^{-1/2}\,{\rm G} \\ &= 4.0\times 10^{13}\frac{\dot{P}/10^{-11}}{P/10\,{\rm s}}\,L_{\rm p,35}^{-1/2}\,{\rm G}, \end{aligned} \quad (2)$$

where $L_{\rm p,35}$ is the particle wind luminosity in units of $10^{35}\,{\rm erg s^{-1}}$. In the wind braking scenario of magnetars, a strong dipole field is no longer needed. Magnetars are neutron stars with strong multipole field. The particle wind luminosity may have significant variations (as that of their X-ray luminosities). This may explain why many magnetars have a varying period derivative and other timing events. Since both the soft X-ray luminosity and the particle wind are from the magnetic field decay, the timing events of magnetars should always be accompanied by radiative events in the wind braking model.

[4] There must exist some amount of nonthermal particles because magnetars have nonthermal emissions, e.g., radio, optical, nonthermal soft X-ray and hard X-ray etc.

#### 2.3.2 Timing behaviors of low magnetic field magnetars

The discovery of low magnetic field magnetar SGR 0418+5729 has challenged the traditional magnetar model directly (Rea et al. 2010). A low magnetic field magnetar is thought to be a neutron star with relatively low surface dipole field (e.g., $\sim 10^{12}\,{\rm G}$, in order to explain the timing behavior) and much higher multipole field (e.g., $> 10^{14}\,{\rm G}$, in order to explain the persistent and burst emisions). However, when calculating the surface dipole field, the magnetic dipole braking assumption is employed. The real case may include both a dipole radiation component and a particle wind component. For SGR 0418+5729, its particle wind component may have been ceased. The magnetic field which is responsible for the star's spinning down is effectively $B\sin\theta$, where $\theta$ is the angle between the magnetic axis and the rotation axis (i.e., magnetic inclination angle). If SGR 0418+5729 has a small inclination angle, e.g., $\theta = 5^\circ$, its surface dipole may be as high as $10^{14}\,{\rm G}$. Therefore, SGR 0418+5729 may be a normal magnetar instead of a low magnetic field magentar (Tong & Xu 2012). It has a small period derivative because its magnetic inclination angle is small.

The second low magnetic field magnetar Swift J1822.3$-$1606 has different period derivatives reported (Rea et al. 2012a; Scholz et al. 2012). In the wind braking model of magnetars, the particle wind luminosity decreases with time after the outburst. This may result in a decreasing period derivative. Therefore, different period derivatives are obtained using different time span of timing observations (Tong & Xu 2013). Meanwhile, the fluctuation of the particle wind is also responsible for the large timing noise. Subsequent timing study can tell us whether wind braking is important in this source or not.

#### 2.3.3 Anti-glitch of magnetars

Pulsar are very stable clocks in the universe. At same time, detailed studies found several timing irregularities in pulsars: glitch (sudden spin-up of the pulsar) and timing noise etc. Up to now hundreds of glitches are observed in hundreds of pulsars (including several magnetars). All these glitches are spin-up events. Recently, an anti-glitch is reported in one magnetar (a spin-down event, Archibald et al. 2013). If confirmed by future observations, anti-glitches may require rethinking of glitch modeling of all neutron stars. Observationally, the anti-glitch is accompanied by an outburst event. The particle wind luminosity is higher during the outburst than during the persistent state. A stronger particle particle wind will cause a higher spindown rate during the outburst. After some time, a net spindown of magnetar is expected (i.e., anti-glitch). Therefore in the wind braking scenario, there are no anti-glitches. Anti-glitch is just a period of enhanced spindown. If there are enough timing observations, a period of enhanced spindown rate is expected (Tong 2013). A second anti-glitch event will help us to discriminate between different models.

Considering that the anti-glitch may be caused by an enhanced particle wind, the opposite case is also possible. During a time interval, the star's particle wind may be lower (or even ceased). After sometime, the star will look like to have a net spin-up. Observationally, this corresponds to the timing behavior of intermittent pulsars. The spindown behavior of intermittent pulsars is understandable in the pulsar wind model (Li et al. 2013). Therefore, both anti-glitch and the spin-down behavior of intermittent pulsars can be understood uniformly in the wind braking scenario.

### 2.4 Criterion for magnetar's radio emission

Originally, magnetars are expected to be radio quiet both in the magnetar model and the fallback disk model. However, transient pulsed radio emission from one magnetar was discovered in 2006 (Camilo et al. 2006). There are distinct properties of magnetar radio emissions: 1) Their flux and pulse profile vary with time. 2) They have a flat spectrum in the radio band. 3) The radio emission is transient in nature (with duration of years). We even do not know whether the magnetar's radio emission is from their magnetic energy or rotational energy. With three radio emitting magnetars at hand, the empirical "fundamental plane of magnetar radio emission" was proposed (Rea et al. 2012b). Rea et al. (2012b) proposed that a magnetar is radio-loud if and only if its persistent X-ray luminosity is smaller than its rotational energy loss rate. And the magnetar radio emission should come from their rotational energy. However, this proposal failed in one new source Swift J1834.9−0846 (Tong, Yuan & Liu 2013b). Swift J1834.9−0846 has persistent X-ray luminosity smaller than its rotational energy loss rate. Therefore, it should have radio emissions if the fundamental plane of magnetar radio emission is correct. However, it is not detected in radio using Nanshan 25 meter radio telescope (of Xinjiang Astronomical Observatory, Chinese Academy of Sciences). Green Bank Telescope also reported non-detection of this source (see references in Tong et al. 2013b). We observed this source using GMRT in 2013 January, which is also not detected. Therefore, at present we can only say that "low luminosity magnetars are more likely to have radio emissions" (Tong et al. 2013b). And the magnetar radio emission should come from their magnetic energy.

The reason why low luminosity magnetars are more likely to have radio emissions may be that they are more like to have similar magnetosphere to that of normal radio pulsars. According to the wind braking model of magnetars (Tong et al. 2013a), for low luminosity magnetars, the magnetic dipole braking assumption is correct to the lowest order approximation (the same as that of normal radio pulsars). Therefore, during the persistent state, a magnetosphere similar to that of normal radio pulsars is prepared. Then it is natural that they may have radio emissions.

## 3 Summary and prospect

Multiwave observations, especially high-energy observations, have discovered increasing kinds of pulsar-like objects. Among them, magnetars form a different population from that of radio pulsars. The magnetar model may provide one way to understand different kinds pulsar-like objects. Originally, magnetars are thought to be neutron stars with superstrong dipole field. This must be wrong since there exist high magnetic field pulsars. Later, magnetars are thought to be neutron stars with both strong dipole field and strong multipole field. However, this is also incorrect because we have discovered several low magnetic field magnetars. We now know that the key difference between normal pulsars and magnetars is the absence or presence of strong multipole field. Normal pulsars are neutron stars without strong multipole field, while magnetars are neutron stars with strong multipole field. A strong dipole field is no longer needed in the wind braking model of magnetars. The decay of multipole field will generate a particle outflow (i.e., particle wind). This particle wind is responsible for both the spindown and multiwave radiation (at least nonthermal radiations) of magnetars. The wind braking model of magnetars (Tong et al. 2013a) may explain the correlation between magnetar timing and radiation properties, e.g., decreasing period derivative after outburst, period derivative variations during the persistent state (radiation flux variations are also observed). In general, in the wind braking model, the timing events of magnetars should always be accompanied by radiative events. The timing of low magnetic field magnetars, anti-glitch of magnetars, can be understood safely in the wind braking model. The existence and property of particle wind can also help to explain the high-energy gamma-ray, hard X-ray, and radio observations of magnetars. More investigations of the wind braking model of magnetars and more multiwave observations can tell us whether magnetars are wind braking or not.

The wind braking model and other alternatives (e.g., the corona model of magnetars) share some merits. One point is that: once the particle outflow is generated, the subsequent plasma process does not depend on where the particle comes from, i.e., the wind engine. Besides that the particles may be generated by magnetic field decay, other energy mechanisms (e.g., star quake) could also be the source of power. At present, we discuss the following two possibilities for the source of particle wind.

1. The magnetar model. The magnetic energy is the ultimate energy source. Magnetic activities (e.g., trigger by seismic activities) is responsible for the star's activities. In the magnetar model, the free parameters are: the dipole field and multipole field (or poloidal and toroidal field) in the magnetosphere, the dipole field and multipole field in the crust, and the crust shear modulus etc.
2. The quark star with fallback disk model. Quark star may be more stable than neutron star. The self-bound quark star surface can explain the super-Eddington luminosity

 

of magnetars naturally. A quark star with fallback disk can explain the persistent radiation and timing, and burst properties of AXPs and SGRs. Meanwhile, fallback disk systems may also unify different kinds of pulsar-like objects. The free parameters in the quark star with fallback disk model are: surface dipole field, accretion rate, the shear modulus, and quark star mass, etc. In this regime, the puzzling behaviors of anomalous X-ray pulsars and soft gamma-ray repeaters relate essentially to the challenging problem: the equation of state of cold matter at supra-nuclear density (Xu 2011).

The underlying energy source is the fundamental problem in studying pulsar-like objects. Whether magnetars exist or not, whether quark stars exist or not, they are both big problems in pulsar researches.

### 3.1 Prospect: magnetars in astrophysics

From Figure 1 we see that there are various kinds of pulsar-like objects. The study of magnetars may help us to achieve the "grand unification of neutron stars" (Kaspi 2010). At present, we are far from the ultimate truth. If we try to understand pulsar-like objects from the magnetar point of view, we may have the following picture of magnetars in astrophysics:

1. The currently observed anomalous X-ray pulsars and soft gamma-ray repeaters are magnetars (neutron stars with strong multipole field).
2. X-ray dim isolated neutron stars may be dead magnetars. Their simple thermal X-ray spectrum may require a magnetized neutron star atmosphere.
3. The central compact objects will become magnetars in the future or they are disk braked magnears. The X-ray hot spot may due to the presence of strong crustal field or due to accretion heated polar cap.
4. High magnetic field pulsars can also have magnetar-like activities, e.g., bursts (as has been already observed). Since they have high surface dipole field, some of them may also have strong multipole field.
5. A normal pulsar can also have magnetar-like activities although with a low probability. Considering that the total number of normal pulsars is significantly larger than magnetars, therefore observing one burst (or outburst) from normal pulsars is not impossible.
6. If a magnetar is born in a binary system, we may see an accreting magnetar. The key point is can we see magnetism-powered activities in accreting systems? An accreting neutron star with high surface dipole field should not be called an accreting magnetar. It is just an accreting high magnetic field pulsar.
7. The formation of magnetars in other galaxies may be one of the central engine of gamma-ray burst. The large rotational energy of the rapidly rotating magnetar is the energy source. The magnetar strength magnetic field can extract the star's rotational energy in a short time scale. And this sudden energy release will result in a gamma-ray burst

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## References

Abdo, A.A., et al.: 2010, ApJ 725, L73
Alpar, M.A.: 2001, ApJ 554, 1245
Alpar, M. A., Ertan, U., Kaliskan, S.: 2011, ApJ 732, L4
Archibald, R.F., Kaspi, V.M., Ng, C.Y., et al.: 2013, Nature 497, 591
Beloborodov, A.M., Thompson, C.: 2007, ApJ 657, 967
Beloborodov, A.M.: 2009, ApJ 703, 1044
Camilo, F., Ransom, S.M., Halpern, J.P., et al.: 2006, Nature 442, 892
Cheng, K.S., Zhang, L.: 2001, ApJ 562, 918
Duncan, R. C., Thompson, C.: 1992, ApJ 392, L9
Gotz, D., Mereghetti, S., Tiengo, A., et al.: 2006, A&A, 449, L31
Hewish, A., Bell, S.J., Pilkington, J.D.H., et al.: 1968, Nature 217, 709
Kaspi, V. M.: 2010 PNAS, 107, 7147
Kouveliotou, C., Dieters, S., Strohmayer, T., et al.: 1998, Nature 393, 235
Li, L., Tong, H., Yan, W.M., et al: 2013, arXiv:1312.1016
Malheiro, M., Rueda, J.A., Ruffini, R.: 2012, PASJ 64, 56
Mazets, E.P., Golenetiskii, S.V., et al.: 1979, Nature 286, 587
Mereghetti, S.: 2008 A&ARv, 15, 225
Ouyed, R., Leahy, D., Niebergal, N.: 2007, A&A 473, 357
Ouyed, R., Leahy, D., Niebergal, N.: 2011, MNRAS 415, 1590
Paczynski, B.: 1990, ApJ 365, L9
Paczynski, B.: 1992, ACTA ASTRONOMICA 42, 145
Rea, N., Esposito, P., Turolla, R., et al.: 2010, Science 330, 944
Rea, N., Israel, G. L., Esposito, P., et al., 2012a, ApJ, 754, 27
Rea, N., Pons, J. A., Torres, D. F., et al. 2012b, ApJ, 748, L12
Sasmaz Mus, S., Gogus, E.: 2010, ApJ 723, 100
Scholz, P., Ng, C. Y., Livingstone, M. A., et al., 2012, ApJ, 761, 66
Thompson, C., Lyutikov, M., Kulkarni, S.R.: 2002, ApJ 574, 332
Tong, H., Song, L.M., Xu, R.X.: 2010, ApJ 725, L196
Tong, H., Song L.M., Xu, R.X.: 2011, ApJ 738, 31
Tong,H., Xu, R.X.: 2011, Int.Jour.Mod.Phys.E 20, 15
Tong,H., Xu, R.X.: 2012, ApJ 757, L10
Tong, H.: 2013, arXiv:1306.2445
Tong, H., Xu, R.X.: 2013, Research in Astron. Astrophys. 13, 1207
Tong, H., Xu, R.X., Song, L.M., Qiao, G.J.: 2013a, ApJ 768,144
Tong, H., Yuan, J.P., Liu, Z.Y.: 2013b, Research in Astro. Astrohys. 13, 835
Usov, V. V.: 1992, Nature 357, 472
Vigano, D., Rea, N., Pons, J.A., et al.: 2013, MNRAS 434, 123
Wang, Z.X., Chakrabarty, D., Kaplan, D.L.: 2006, Nature 440, 772
Wang, W., Tong, H., Guo, Y.J.: 2013, arXiv:1311.0107
Xu, R.X., Tao, D.J., Yang, Y.: 2006, MNRAS 373, L85
Xu, R.X.: 2007, Advances in Space Research, 40, 1453
Xu, R.X.: 2011, Int. Jour. Mod. Phys. E, 20(S1), 149