Summary of the "White Dwarf and Neutron Star Isolated and/or Binaries" Session

—— Particle Acceleration around the Magnetized Compact Objects ——

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We summarize the presentations in this session from a point of view of particle acceleration in the vicinity of a magnetized neutron star and a white dwarf. We take the radio and hard X-ray emission as a clue for the particle acceleration, and summarize the results of the past observations in the literature. Efficient particle acceleration seems to be working only in the isolated, highly magnetized neutron stars. In the mass-accreting, highly magnetized objects, particle acceleration and even the production of hot, thin thermal plasma seem to be suppressed.

§1. Introduction

Many of the neutron stars, either isolated or in close binary systems, are bright in X-rays and have been good targets of X-ray astronomy. Similarly, cataclysmic variables (CVs) are bright in optical band, and their past observations contributed a lot to understand the nature of mass accretion onto the compact objects. Such neutron stars and white dwarfs are topics of this session. However, because these sources show large varieties in nature, it is difficult to summarize this session coherently. Instead, we take an alternative approach here, namely to overview the objects from a point of view of particle acceleration in their vicinities.

It is well known that relativistic electrons are efficiently accelerated in the magnetosphere of rotation-powered pulsars. A typical and well-known example is the Crab pulsar. Synchrotron emission from relativistic electrons is observed from the radio through γ-ray bands. This in turn means that a bright radio and a non-thermal (power-law) X-ray emission may be used to prove the particle acceleration. In particular, high sensitivity of Suzaku HXD makes it possible to look for a power-law emission extending up to the hard X-ray band from X-ray sources.[19] Hard X-rays may be produced by various mechanisms other than the synchrotron emission. However, because it is sometimes difficult to identify their origin, we summarize the radio and hard X-ray observations of the compact objects from literature regardless of the emission mechanism. We will discuss their nature afterward in §5.

§2. Isolated neutron stars

Isolated neutron stars include not only the rotation-powered pulsars but also the anomalous X-ray pulsars (AXPs) and the soft γ-ray repeaters (SGRs). Both AXPs and SGRs have an extremely high surface magnetic field, 10^{14}–10^{15} G, and are referred to as magnetars. It is known that efficiency of the particle acceleration

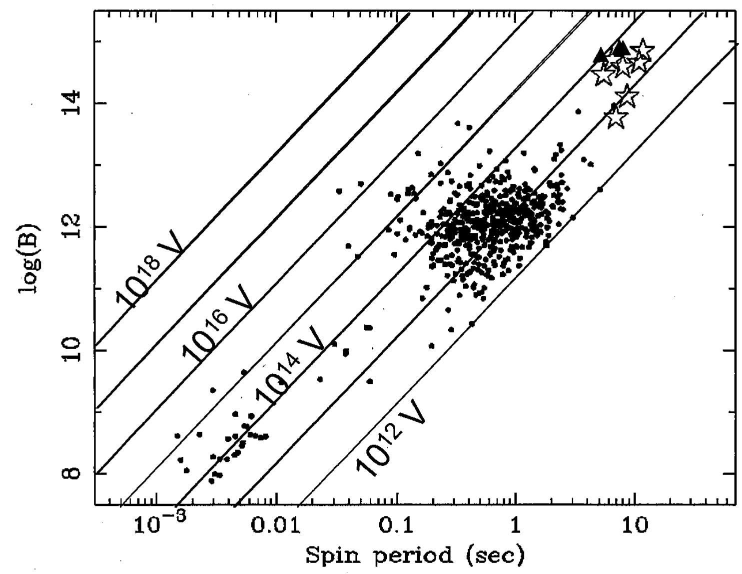

Fig. 1. Spin periods (P s) and surface magnetic fields (B G) of isolated neutron stars are plotted (B–P diagram). Dots represent rotation-powered neutron stars, stars anomalous X-ray pulsars (AXPs), and filled triangles soft γ-ray repeaters (SGRs). Potential drop across the polar cap estimated by Eq. (2·1) is also indicated. Parameters of the rotation-powered pulsars are taken from http://pulsar.princeton.edu/pulsar/catalog.shtml and Refs. 11), 16) and 8), those of AXPs from Refs. 16) and 26), and those of SGRs from Ref. 26).

in the rotation-powered pulsars can be measured by the induced electric potential drop across the polar cap region. Here, the potential drop ϕ can be expressed with the angular frequency (Ω) and the dipole magnetic moment (μ) of the neutron star, and the speed of light (c) as:

$$\phi = \frac{\Omega^2\mu}{c^2} = 6.7 \times 10^{12} \left\{\frac{B}{10^{12}\mathrm{G}}\right\} \left\{\frac{P}{1\mathrm{sec}}\right\}^{-2} \quad \text{volts,} \qquad (2\cdot1)$$

where B and P are the surface magnetic field and spin period of the neutron star, respectively.

The potential drop ϕ is plotted in the B–P diagram together with the parameters of the isolated neutron stars (Fig. 1). Although the magnetars have a potential drop comparable to the middle aged pulsars, this does not necessarily mean that relativistic particles are accelerated in them. In fact, no persistent radio emission was so far detected from the magnetars (see §2.3). This is interpreted that the pair-creation cascade is suppressed under their extremely high magnetic fields.

2.1. *Hard X-ray emissions from the magnetars*

AXPs are known to have steep energy spectra in the soft X-ray band. However, hard X-ray observations have revealed that the energy spectra become significantly hard above ~ 10 keV. Because the hard tail was detected from many of the AXPs, it is now considered to be one of their common properties (eg. Ref. 10)). Although the origin of the hard tail is not known yet, similarity to the middle aged pulsars, e.g. Vela pulsar, in both the pulsating nature of the emission and the spectral shape, is pointed out.[14)] Presence of the similar hard tail is also known in SGRs.[7)] Thus the hard tails in AXPs and SGRs are considered to have a common origin.

2.2. *X-ray emission from high B radio pulsars*

As seen in Fig. 1, some of the rotation-powered pulsars have a surface magnetic field close to that of the magnetars. We refer these sources as high B radio pulsars. If the hard X-ray emissions from the magnetars are related to their large magnetic fields, these high B radio pulsars may also have a hard X-ray emission.

No hard X-ray emission was detected from these sources so far. In PSR J1718–3718 ($B = 7.4 \times 10^{13}$ G, $P = 3.3$ s), the best upper limit in the 2–10 keV band was obtained from the ASCA archives.[16] The upper limit is 3–8 $\times 10^{33}$ erg/s, while the spin-down luminosity of the source is 1.7×10^{32} erg/s. On the other hand, X-ray emission was indeed detected from PSR J1847–0130 ($B = 9.4 \times 10^{13}$ G, $P = 6.7$ s), although it was a soft thermal emission ($kT \sim 0.15$ keV) from the neutron star surface.[13] Bolometric luminosity was estimated as 0.1–5 $\times 10^{33}$ erg/s (spin-down luminosity is 1.6×10^{33} erg/s). Because the X-ray luminosities of the AXPs are typically 3 orders of magnitude larger than the spin-down luminosities, it is clear that X-ray emission of at least these two high B radio pulsars is different from that of the AXPs and SGRs. Just a high magnetic field may not be enough for the unique activities of AXPs and SGRs.[21]

2.3. *Radio emission from the magnetars*

If the hard X-ray emission from the magnetars indicates the presence of high energy electrons, radio emission may be expected from them. In spite of deep radio observations, however, no persistent radio emission has been detected from the magnetars (eg. Ref. 26)). Only the transient emission has been detected.

XTE J1810-197 is a transient AXP, which became active in 2003 and sustained its activity more than a year.[12] Associated with this activity, transient radio emission was detected.[9] The emission was highly variable unlike for the rotation-powered pulsars,[1] and showed very high degree of polarization.[2] Similarly, radio emission so far detected from SGRs was the transient emission from SGR 1900+14 after the giant flare in 1998.[5] Because the radio emission from the magnetars are associated to their outbursts, it is considered to have a different origin than the magnetospheric emission from the rotation-powered pulsars.

§3. Magnetic white dwarfs

Although we have discussed only the neutron stars so far, particle acceleration may be occurred in the magnetic white dwarfs. The B–P diagram is not appropriate to include the white dwarfs, because it use the surface magnetic field as a parameter. Instead, a magnetic dipole moment, which does not depend on the radius of the star, is more appropriate. Therefore, we introduce μ–P diagram as shown in Fig. 2; here μ represents a dipole magnetic moment of the star. Both the isolated white dwarfs and those in cataclysmic variables (CVs) are included in the diagram. As seen from the figure, magnetic white dwarfs have a large magnetic dipole moment because of their large radius in spite of the low surface magnetic field. It is interesting to point

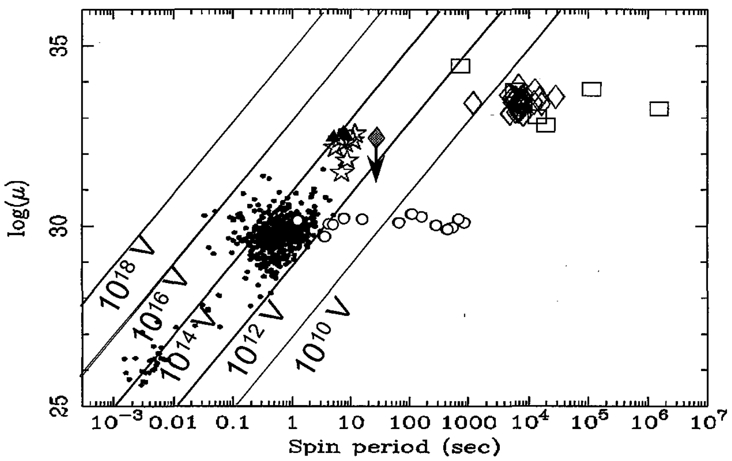

Fig. 2. Spin periods (P s) and the dipole magnetic moments (μ G cm^3) of white dwarfs and neutron stars are plotted (μ–P diagram). Symbols also used in Fig. 1 have the same meaning. Open squares represent isolated white dwarfs, open diamonds magnetic CVs, open circles accretion-powered X-ray pulsars. A shaded diamond, which means an upper limit, indicates AE Aqr. Parameters of the accretion-powered X-ray pulsars are taken from Ref. 15), and those of the white dwarfs from Ref. 25).

out that one of the magnetic white dwarfs, AE Aqr, although its dipole magnetic moment is not known, probably locates very close to the AXPs.

AE Aqr is one of the magnetic CVs, which includes the fastest rotating white dwarf. It is considered to be in the propeller regime and most of the accreted matter is expelled from the system. AE Aqr has been detected from radio to X-rays, and possibly in TeV γ-rays.[17)] Therefore, efficient particle acceleration may be occurred in this system. Using Suzaku, non-thermal, hard X-ray emission was searched from AE Aqr, which resulted in a marginal detection.[23)] If this hard emission is confirmed, it would be the first detection of non-thermal X-ray emission from a white dwarf.

Because the CVs are generally dim in hard X-ray band, it is convenient to use the radio band to look for the evidence of particle acceleration. Radio emission was so far detected from 5 CVs according to the 5 GHz survey.[20)] Most of the emission was either variable or associated with the flares. Because circular polarization is lacking, the emission is considered to have a different origin from the radio pulsars.[20)] Mildly relativistic electrons may be responsible for the emission, although details are not known. Some dynamical process related to the mass accretion is suspected.

§4. Magnetized neutron stars in close binaries

We would like to extend the search of particle acceleration from the CVs to mass-accreting, highly magnetized neutron stars. Because such neutron stars are observed as X-ray pulsars, we refer them as accretion-powered X-ray pulsars. We utilize the cyclotron resonance feature in the X-ray spectrum to estimate the surface magnetic field of the neutron star.[15),18)] As seen in Fig. 2, accretion-powered X-ray pulsars have similar magnetic dipole moments as the rotation-powered pulsars but have longer spin periods.

Radio emission from X-ray binaries is summarized in Ref. 4). No significant radio emission was reported from the accretion-powered X-ray pulsars with a typical upper limits of a few tenths mJy. It is suspected that a coherent process is hampered under the presence of mass accretion. However, situation may be different in the accretion-powered millisecond pulsars.

Transient radio emission was reported from the accretion-powered millisecond pulsar, SAX J1808.4-3658, associated with the flare.[22] This suggests an emergence of an active radio pulsar, whose presence was indicated by its large optical modulation.[3] However, nature of this transient radio emission is not known; further observations are necessary. If relativistic electrons are accelerated in the accretion-powered millisecond pulsars, hard X-ray emission may be expected. Hard X-ray emission extending up to $\sim$ 100 keV was indeed detected from SAX J1808.4-3658 with RXTE.[6] However, the energy spectrum is reminiscent to that of black hole binaries in the low/hard state. The hard X-ray emission is considered to be produced through thermal Comptonization of soft photons in a hot plasma ($kT \sim$ 20–60 keV).

§5. Summary

We summarize the past observations of magnetized neutron stars and white dwarfs in the hard X-ray and radio bands in Table I. When we interpret this summary, it should be noted that various emission mechanisms may be involved here. For example, hard X-ray emission does not necessarily require a coherent process of relativistic electrons, and can be produced even by a thermal plasma through Comptonization, if its temperature is high enough ($\sim 10^2$ keV). Thus the radio and hard X-ray emission is considered to reflect a different population of high energy electrons.

Isolated and mass-accreting compact objects show clear distinction. Radio emission similar to the rotation-powered pulsars is absent in the mass-accreting objects. This is probably because a coherent process of relativistic electrons does not work under the presence of mass accretion. On the other hand, hard X-ray emission is detected only from the magnetars among the isolated neutron stars. Several possibilities are suggested for the emission mechanism (eg. Ref. 24)), but the origin is not known yet. Because similar hard X-ray emission is missing in the high B pulsars, just a high magnetic field is not enough to cause the magnetar activities. Further theoretical and observational studies are required to understand why these two types

Table I. Hard X-ray emission may be originated from various mechanisms, eg. synchrotron emission, thermal Comptonization, etc.

	Hard X-ray Emission	Radio Emission
Anomalous X-ray Pulsars	Yes	Transient
Soft γ-ray Repeaters	Yes	Transient
High B Radio Pulsars	No	Yes
Magnetic CVs	(AE Aqr)	Variable
Accretion-Powered X-ray Pulsars	No	No
Accretion-Powered Millisecond Pulsars	Yes	Maybe

of objects are so different.

Mass accreting systems, both of white dwarfs and neutron stars, are rather quiet in radio and hard X-ray bands. This shows clear contrast with the low-mass X-ray binaries containing a weakly magnetized neutron star, in which the mass-accreting millisecond pulsars are also included. Many of them are bright in hard X-ray band, and are also bright in radio band in their particular state (eg. horizontal state of Z-sources). The hard X-ray emission is considered to be produced by a hot corona ($kT \sim 10^2$ keV) in a vicinity of the neutron star through Comptonization. Origin of the corona is not known, but may be related to the instabilities of the inner part of the accretion disk. Radio emission from the low-mass X-ray binaries is probably a synchrotron emission from the relativistic jets. Although it is not understood yet how the relativistic jets are created, presence of the inner part of the accretion disk is considered to be essential. Weak or no radio/hard X-ray emission from the magnetic CVs, and accretion-powered pulsars is probably because the inner part of the accretion disk is missing. In this sense, if the hard X-ray emission from AE Aqr is confirmed, it becomes an exceptional case probably related to the propeller regime of the system.

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