Systematic surveys of non-thermal emission from white dwarfs with Suzaku

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\textbf{Abstract}

One hundred years after their discovery, the origin of cosmic rays is still a topic of great interest for astrophysics. Supernova remnants and neutron star (NS) pulsars are considered as textbook cases of particle acceleration sites in our Galaxy, but many unresolved quantitative problems remain. In searches for new classes of particle acceleration sites, we focus on magnetized white dwarfs (MWDs), which have the same kinds of rotating magnetospheres as in NSs and may contribute non-negligible fractions of Galactic cosmic-ray electrons (Ostriker 1968). Since the initial phase of Suzaku scientific operation, we performed systematic X-ray surveys of MWDs (10 observations, 710k sec in total) and found some hints of non-thermal emission from accelerated particles from three binary MWDs (Terada et al. 2008, 2010), although no evidence was found from isolated MWDs (Harayama et al. 2013).

\textbf{Key words:} Particle Acceleration – stars: white dwarf

1. White Dwarf Pulsar

It is important to search for new classes of origin of Cosmic-rays other than textbook cases like supernova remnants (SNRs) and neutron star (NS) pulsars. One possible new site is bow shock regions of run away stars (Terada et al 2012) from an analogy of SNRs, and another is magnetized white dwarfs (WDs) as an analogy of NS pulsars. The contributions of WDs to Galactic Cosmic-rays should be non-negligible (Ostriker and Hartwick 1968) since the number density of WDs are three order of magnitude larger than that of NSs. According to simple comparisons between WDs and NSs on induced electric potentials in magnetospheres, magnetic WDs have a sufficient potentials to accelerate particle like NS pulsars (at $10^{14} - 10^{16}$ volts), as demonstrated in the Hillas diagram (Hillas 1984). Therefore, we call such WDs as “white dwarf pulsars” (Terada 2013).

In 1980s to 1990s, systematic surveys for non-thermal emissions from WDs were performed in radio band and coherent radio emissions suggesting 1 – 100 MeV electrons are found from AE Aqr and AM Her (Bastian et al 1988; Abada-Simon et al 1993; Channugam & Dulk 1982; Dulk et al 1983). Similarly, searches for TeV emissions from these two objects are performed. Several groups reports the detection of TeV emission from AE Aqr (Meintjes et al 1992, 1994; Bowden et al 1992; Chadwick et al 1995), but the detections were not confirmed in longer observations with Whipple (Lang et al 1998).

In 1990s, from a precise measurement of spin derivative, the AE Aqr was recognized as “millisecond pulsar equivalent” of NS pulsars (de Jager 94), which has large spin down luminosity $L_{sd}$ reaching $10^{33}$ erg s$^{-1}$. Such a huge amount of $L_{sd}$ can be interpreted by a stronger magnetic field strength than normal in this class (Ikhsanov 1998, 1999). However, no further systematic searches for WD pulsars were performed in 1990s and the beginning of 2000s. Therefore, we performed a systematic surveys for possible non-thermal emission from WD pulsars in the hard X-ray band with Suzaku (Terada et al 2008, 2010, 2011, 2014; Harayama et al 2014).

2. Suzaku Survey

In searches for signatures of the particle acceleration in WDs, we survey possible non-thermal X-ray emissions from magnetized WDs with Suzaku (Mitsuda et al 2007), as summarized in Table 1. We first try to get pulsar-like signals from the most prominent object, AE Aqr, and...
Table 1. Summary of Suzaku observations

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Type*</th>
<th>P</th>
<th>B</th>
<th>Obs.</th>
<th>Exp.</th>
<th>ref</th>
<th>Non Ther. †</th>
</tr>
</thead>
<tbody>
<tr>
<td>AE Aqr</td>
<td>Binary (IP)</td>
<td>33 s</td>
<td>50 MG</td>
<td>Oct 2005</td>
<td>70 ks</td>
<td>Terada+ 08</td>
<td>6 x 10^{29}</td>
</tr>
<tr>
<td>AM Her</td>
<td>Binary (P)</td>
<td>3.1 hr</td>
<td>13-30 MG</td>
<td>Oct 2008</td>
<td>100+50 ks</td>
<td>Terada+ 10</td>
<td>Merginal 1 x 10^{29}</td>
</tr>
<tr>
<td>AE Aqr†</td>
<td>Binary (IP)</td>
<td>33 s</td>
<td>50 MG</td>
<td>Oct 2009</td>
<td>160 ks</td>
<td>Terada+ 12 &amp; (prep)</td>
<td></td>
</tr>
<tr>
<td>EUVE J0317-85.5</td>
<td>Isolate</td>
<td>725 s</td>
<td>450 MG</td>
<td>Jul 2009</td>
<td>60 ks</td>
<td>Harayama+ 13</td>
<td>None &lt; 1.5 x 10^{28}</td>
</tr>
<tr>
<td>IGRJ00234+6141</td>
<td>Binary (IP)</td>
<td>561 s</td>
<td>?</td>
<td>Jun 2010</td>
<td>80 ks</td>
<td>Terada+ (prep)</td>
<td>None</td>
</tr>
<tr>
<td>V2487 Oph</td>
<td>Binary (IP?)</td>
<td>235 s</td>
<td>?</td>
<td>Oct 2010</td>
<td>50 ks</td>
<td>Terada+ (prep)</td>
<td>1 x 10^{34}</td>
</tr>
<tr>
<td>EUVE J1439+75.0</td>
<td>Isolate</td>
<td>?</td>
<td>10 MG</td>
<td>May 2012</td>
<td>40 ks</td>
<td>Harayama+ (prep)</td>
<td>None &lt; 2 x 10^{29}</td>
</tr>
<tr>
<td>PG 1658+440</td>
<td>Isolate</td>
<td>?</td>
<td>2.3 MG</td>
<td>Jul 2012</td>
<td>50 ks</td>
<td>Harayama+ (prep)</td>
<td>None &lt; 1 x 10^{28}</td>
</tr>
</tbody>
</table>

* ‘P’ and ‘IP’ in binary systems represent Polar and Intermediate Polar, respectively.
† Non thermal and/or hard X-ray component in erg s^{-1}. ‡ Multi-wavelength simultaneous campaign.

have found a hard X-ray pulsation in above 2 keV (Terada et al. 2008). This pulsation is similar to that in NS pulsar systems. We further triggered a multi-wavelength simultaneous campaign of the object with optical telescopes, Suzaku in X-rays, and H.E.S.S. in TeV gamma-ray. We found no significant signals in TeV band due to a bad condition for H.E.S.S., but we confirmed that the pulsed component shows very-low abundance spectrum in X-ray band, implying that it is non-thermal origin (Terada 2014).

In systematic surveys of non-thermal X-rays from magnetized WD binaries, it is crucial to avoid strong thermal radiation normally observed in this class (Patterson 1994; Terada et al. 2001, 2004; etc). Therefore, we took following three approaches; 1) observe another promising object AM Her but in very low state to reduce thermal contributions, 2) check X-ray spectra of “hard” WDs reported by INTEGRAL or Swift (IGR J00234+6141 and V2487 Oph), and 3) try “isolated” WDs, in which thermal black body appears in very low energies (EUVE J0317-85.5, EUVE J1439+75.0, and PG 1658+440).

The results are summarized in Table 1. Hard X-ray component was required for two objects plus one marginally. For reference, X-ray luminosities are compared with spin down luminosities (although it is NOT a direct measurement values) in Figure 1. Only AE Aqr could be a WD pulsar.

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