Multi-frequency observations of a radio magnetar with Japanese radio telescopes

Sujin Eie (Mizusawa VLBI Observatory, NAOJ / Univ. of Tokyo)

Video credit: NASA's Goddard Space Flight Center
Intro

Magnetars

- X-ray/$\gamma$-ray outbursts stronger than ordinary radio pulsars’ energy
- Young (< $10^4$ yrs), strongly magnetized ($10^{14} \sim 15$ G) neutron stars
- **Magnetically powered star?**
  (Duncan & Thompson 1992)
- ~30 magnetars/2800 known pulsars

Image credit: ESO/L. Calçada
**Intro Radio-loud Magnetars**

- 6 known so far (increasing!)
- Fast & large variations in profiles, intensity, polarization with time and frequency (e.g. Camilo+07, Kramer+07, Lazaridis+08)
- (Generally) Flat spectrum in radio band \( \alpha \approx -0.5 \) (Camilo+07)
- “transients” (i.e. radio-loud \( \rightleftharpoons \) radio-quiet)

<table>
<thead>
<tr>
<th>Name</th>
<th>Radio detection</th>
<th>( P ) (s)</th>
<th>( B ) ((10^{14} \text{ G}))</th>
<th>( \tau_c ) (kyr)</th>
<th>( D ) (kpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>XTE J1810-197</td>
<td>2004</td>
<td>5.54</td>
<td>2.1</td>
<td>11</td>
<td>3.5</td>
</tr>
<tr>
<td>1E 1547.0-5408</td>
<td>2007</td>
<td>2.07</td>
<td>3.0</td>
<td>0.69</td>
<td>4.5</td>
</tr>
<tr>
<td>PSR J1622-4950</td>
<td>2010</td>
<td>4.33</td>
<td>2.7</td>
<td>4.0</td>
<td>~ 9</td>
</tr>
<tr>
<td>SGR J1745-2900</td>
<td>2013</td>
<td>3.76</td>
<td>2.3</td>
<td>4.3</td>
<td>8.3</td>
</tr>
<tr>
<td>Swift J1818.0-1607</td>
<td>2020</td>
<td>1.36</td>
<td>6.8</td>
<td>0.24 - 0.31</td>
<td>4.8 / 8.1</td>
</tr>
<tr>
<td>SGR J1935+2154</td>
<td>2020</td>
<td>3.24</td>
<td>2.2</td>
<td>3.6</td>
<td>4.4</td>
</tr>
</tbody>
</table>

(Galactic FRB!
(FRB 200428)
: Fluence \( \approx 1.5 \text{ MJy ms}! \)
(Bochenek+20)

(Kaspi & Beloborodov 2017; Eatough+20; Lower+20; Mereghetti+20)
Questions

- How much variable are their radio pulsations? And why?

- What are differences between magnetars and ordinary (young) pulsars in emission behavior and in evolutionary phases?

- What triggers their radio emission? Where did they high B come from?

Methodology

- Magnetars / Pulsars
- Pulsar kick
- Origin?
- Host supernova remnant

Single-dish observations at MHz - GHz

VLBI observations
Target XTE J1810-197 (PSR J1809-1943)

- Discovered in 2003 (X-ray) in 2005-2006 (radio)
  → The first radio magnetar (Ibrahim+04, Halpern+05, Camilo+06)
- Radio-silent since Oct 2008 (Camilo+16)
- Period = 5.54 s
- DM = 178 pc cm$^{-3}$
Target XTE J1810-197 (PSR J1809-1943)

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- Reactivated in radio band on Dec 18th 2018 (Lyne+18)

- No associated SNR found (Ding+20, VLBA, obs in 2019~2020)
Observations w/ telescopes in Japan

* We could not achieve VLBI results.

2018.12.08
Radio detection (Lyne+18)

**litate**
0.3 GHz
31 m X 16.5 m X 2

**Kashima**
2 GHz
34 m
(RCP)

**Hitachi**
6, 8 GHz
32-m
(LCP) (RCP)

**VERA**
22 GHz
20 m X 4
(LCP)

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low-VLBI?

EAVN & EAVN

SKA pathfinder & EAVN

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2018
12.13
12.18
1.7
1.9
1.21
2.15
3.4
3.31
4.23
6.11

2019

[Legend: □ Fully detected
O No-detection
X Only a few single pulses]
Results Flux variations

- ~5 times fainter in 6 months @ 7 GHz
- The flux decline is weaker than the previous radio-bright period (1 year later the X-ray outburst) @ 1.4 GHz
- Slower transition in early phase of radio outburst.
- Daily variations include narrow-band & wide-band.
Results GHz-peaked spectrum (GPS)

- Not actually “flat” spectra
- GPS feature are ALSO seen from radio magnetars (e.g. Kijak+13)
- 10% pulsars with GPS at ~ 1 GHz
- Thermal free-free absorption model
- XTE J1810-197: $\nu_{\text{peak}} \approx 3 - 7$ GHz

### Table

<table>
<thead>
<tr>
<th>Flux density (mJy)</th>
<th>Frequency (GHz)</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### XTE J1810-197

- [1] Dai+19
- [3] Pearlman+19

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Eie et al. in prep

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2021.05.26-28 East Asia SKA Science Workshop 2021 (EASKA2021)
Results Double peaks!

- Double-peaked spectrum at a few GHz and 100-200 GHz
- Different emission mechanisms in the cm and the sub-mm bands?
Prospects with SKA for magnetars

Tracing the radio behavior (in much longer timescale) in the very low frequency range (SKA-Low; 50 - 350 MHz) in the range with the first peak and turn-down point (SKA-Mid; ~ 24 GHz)

SKA-Low

SKA-Mid

Frequency [GHz]

Mean flux density [mJy]

2018-12-18\(^{[1, 2]}\)

2019-03-25\(^{[4]}\)

2019-02-16\(^{[3]}\)

2018-12-18

2019-01-07

2019-01-21

2019-02-15

2019-03-04

2019-04-23


[3] Pearlman et al. 2020


Eie et al. in prep
Prospects with SKA for magnetars

“Spatial-temporal analysis”

Time variations of radio pulses
+ Short-period velocities (when high ν)

Relations between magnetospheric activities and the surroundings?
Synergy between SKA and ngVLA

- Wide-band radio spectra
- High variability of magnetar radio emission requires wide-band, simultaneous observations

Eie et al. in prep

[3] Pearlman et al. 2020
Wrap-up

- Radio magnetars would be one of the best sources among neutron stars observable from low to high radio frequency

- We confirmed XTE J1810 has negative spectra in 2.3-22 GHz throughout our 7-months observing period.
  - turn-over between 3 - 8 GHz
  - link with GHz-peaked spectra pulsars

- We support XTE J1810 would have double-peaked as well.
  - Ultra wide-band observations with SKA (low & mid) would

- We aim at single-dish ⇄ VLBI using SKA!

- FRB origins?

Thank you for listening!