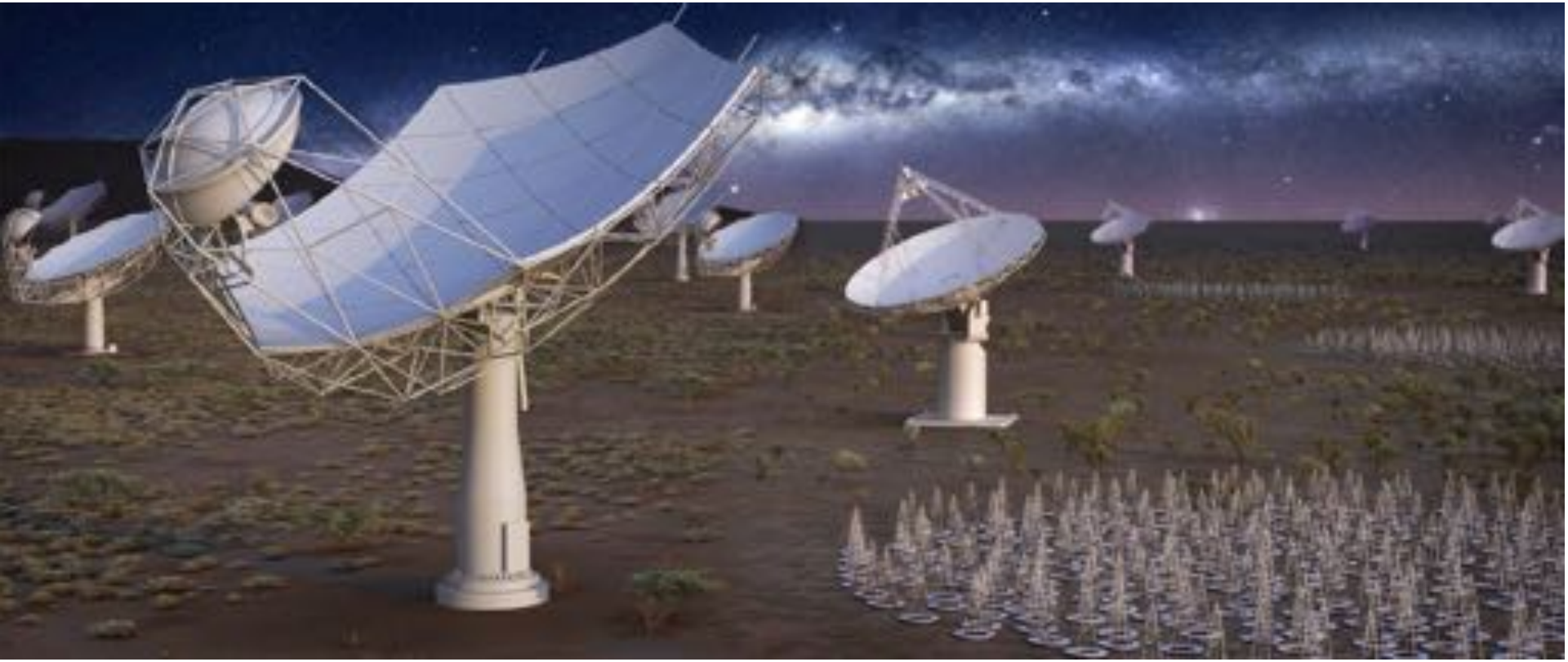
Progress Report of MOT-VERA
もっとVERAの進捗報告



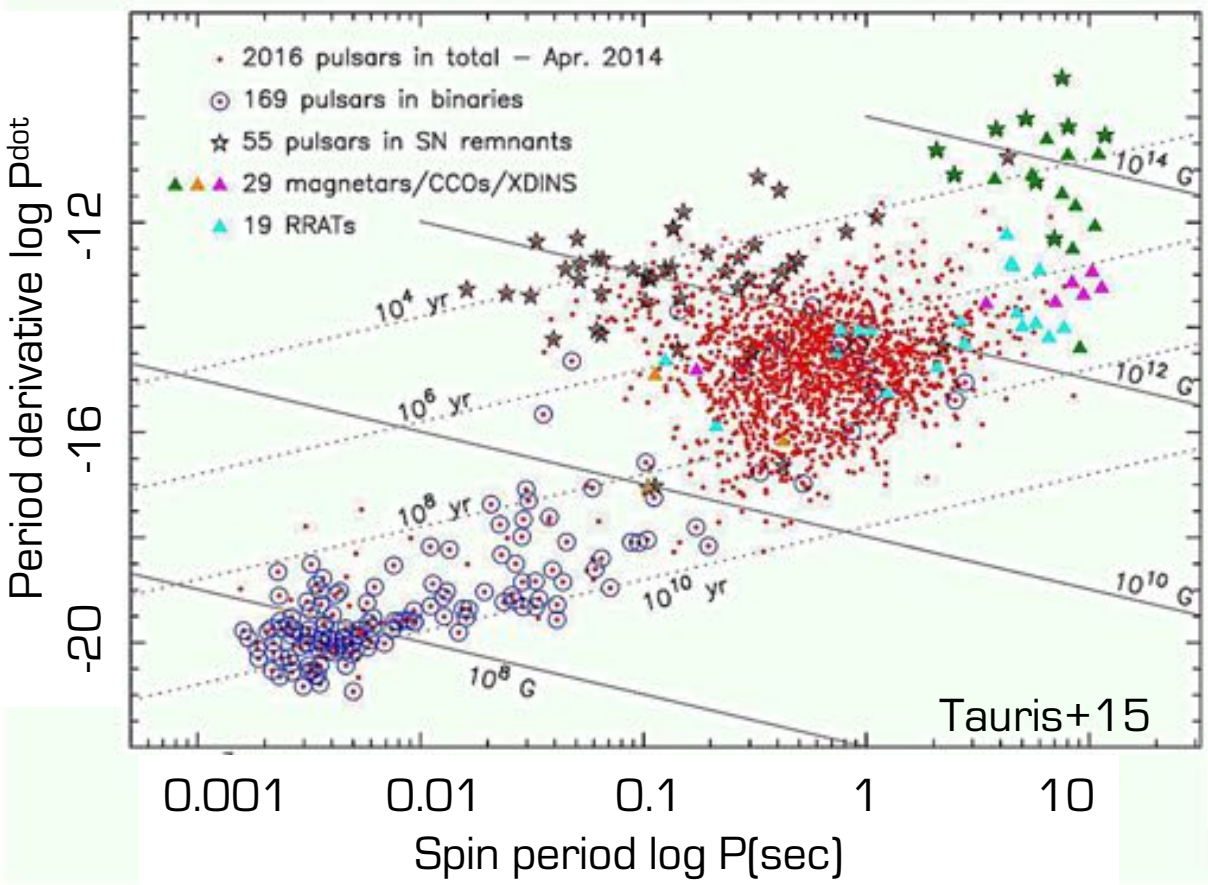
国立天文台 NAOJ National Astronomical Observatory of Japan

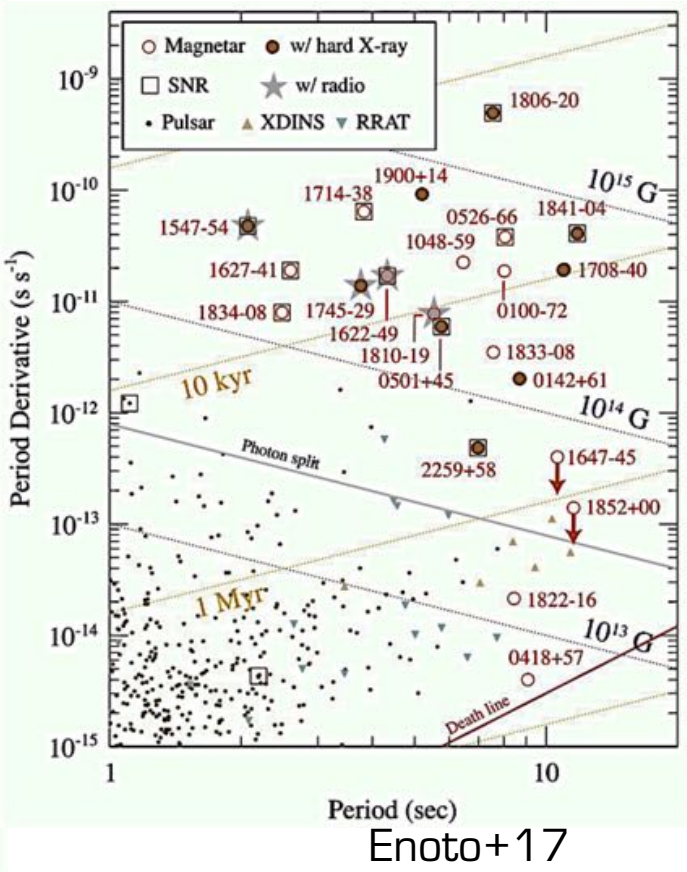
MIZUSAWA VLBI OBSERVATORY
国立天文台水沢VLBI観測所

Takuya Akahori

PM | Section of Future Project

Pulsar and Magnetar





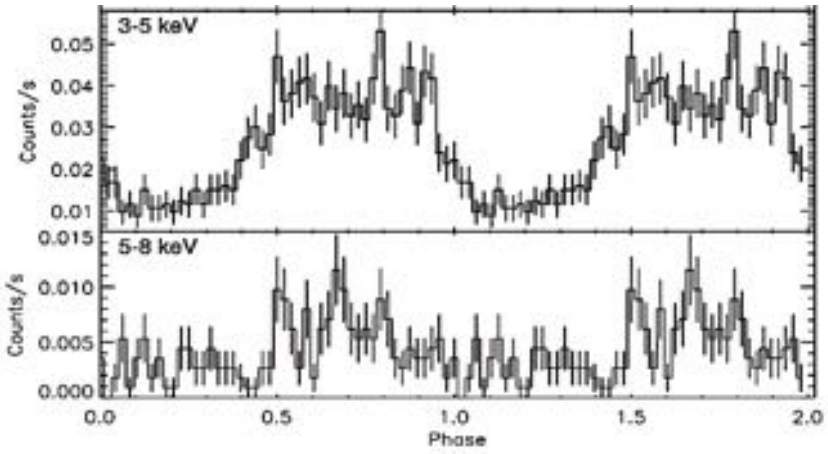
- **A slow-rotating (>2 sec), fast spin-down [>1 ms/yr] NSs**
  - Magnetic Breaking? → Strong magnetic field (>10^{14} G dipole field)
  - Even stronger that the quantum critical field (=4.4x10^{13} G, $r_g \sim \lambda_e$)

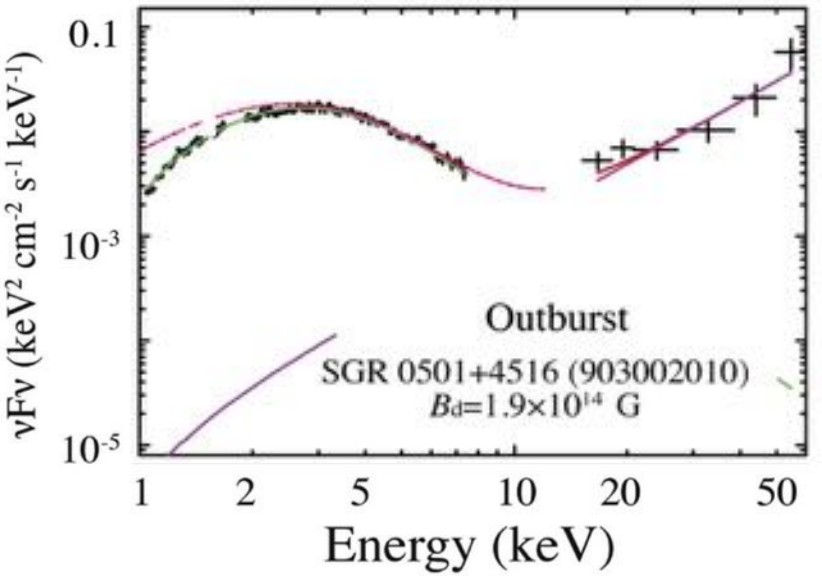
Magnetars: E.g. SGR 0501+4516

- In Aug 22 2008, found by Swift as an X-ray transient
- Pulsation of X-ray emission: period = 5.76 sec → a rotating star?
- Spin period decreases → If it is by electromagnetic breaking, $B \sim 2 \times 10^{14}$ G → Magnetar !
- X = thermal (BB) + non-thermal (power-law), then NT decreased faster than BB

- **No radio emission**

Rea+09; Camero+14; Enoto+17

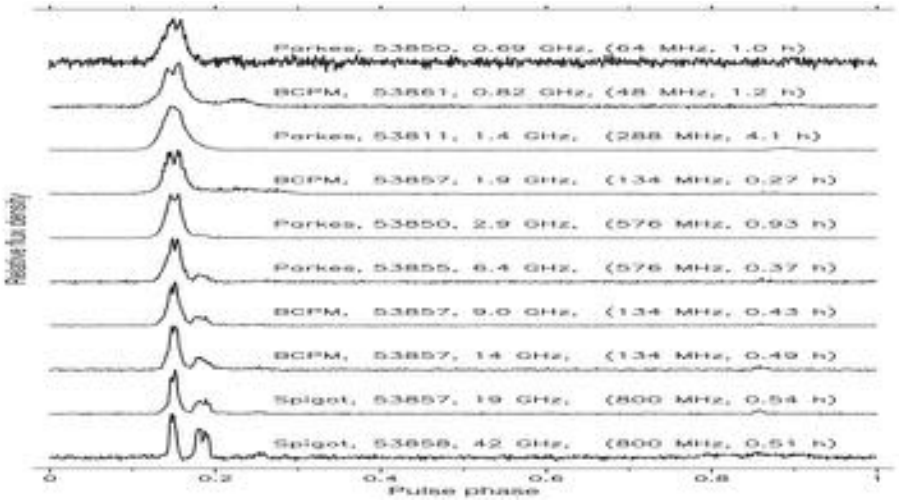




Radio Emission from Magnetars

■XTE J1810-197

- Discovered in 2003 as an X-ray pulsar with a spin period of 5.54 s, Bd = 3 x 10^{14} G (Ibrahim+04)
- In 2004, radio emission was found at 1.4 GHz (Halpern+05).
- In 2006, radio pulsation was found [Camilo+06]. It has a very flat (~0) and variable spectrum (Kramer+07; Lazaridis+08]



Camilo+06

■PSR J1622-4950

- Discovered in 2009 as a radio pulsar with a spin period of 4.32 s, Bd = 2.8 x 10^{14} G (Levin+10)
- X-ray follow-up indicated a quiescent (non-burst) BB
- Radio remained ~a few year

Date (yyyy-mm-dd)	Central Frequency (MHz)	Flux Density (mJy)	Spectral Index (α)
2008-11-22	5312	33.0 ± 0.3	-0.13 ± 0.04
	8768	30.9 ± 0.6	
2008-12-05	4800	40.4 ± 0.3	-0.44 ± 0.04
	8256	31.9 ± 0.6	
2009-12-08	5500	13 ± 1	$+0.2 \pm 0.2$
2010-02-27[a]	9000	14.3 ± 0.8	

Anderson+12

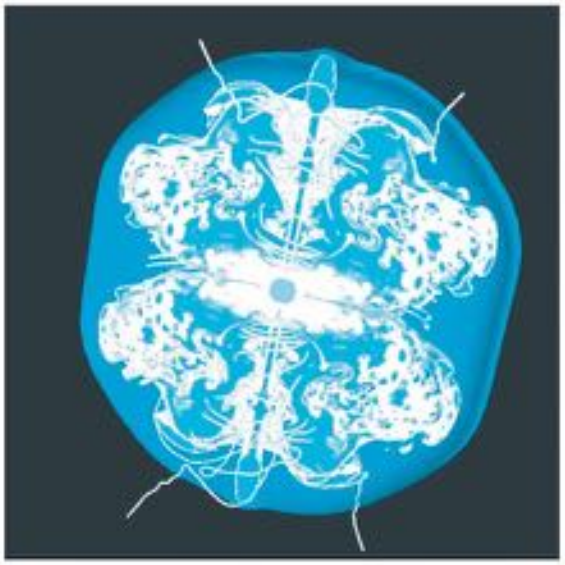
Magnetar tends to have a flat radio spectrum ... c.f. FRB

2. Importance of Astrometry

Issues and Hypotheses

1. What is the origin of strong B?

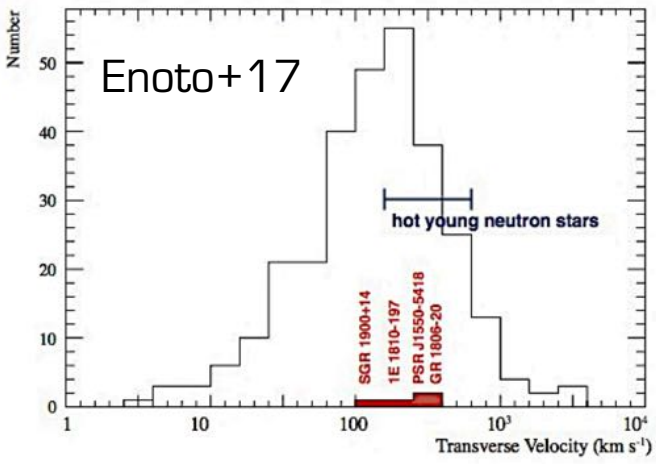
- Fossil? Dynamo action through the standing accretion shock instability (SASI) in a high-mass progenitor?
- Hypothesis: Correlation between NS's B-field and the progenitor's SNR morphology?
- Method: Identify the progenitor SNR = measure the magnetar's location and velocity



Takiwaki-san's Geppou

2. What is the trigger of outburst?

- Motivated by issue1, a magnetar has a high velocity of several 100km/s? The ISM collides with the magnetar and accretes onto it (like X-ray binaries)?
- Hypothesis: Magnetars have higher velocity?
- Method: Measure the magnetar's velocity



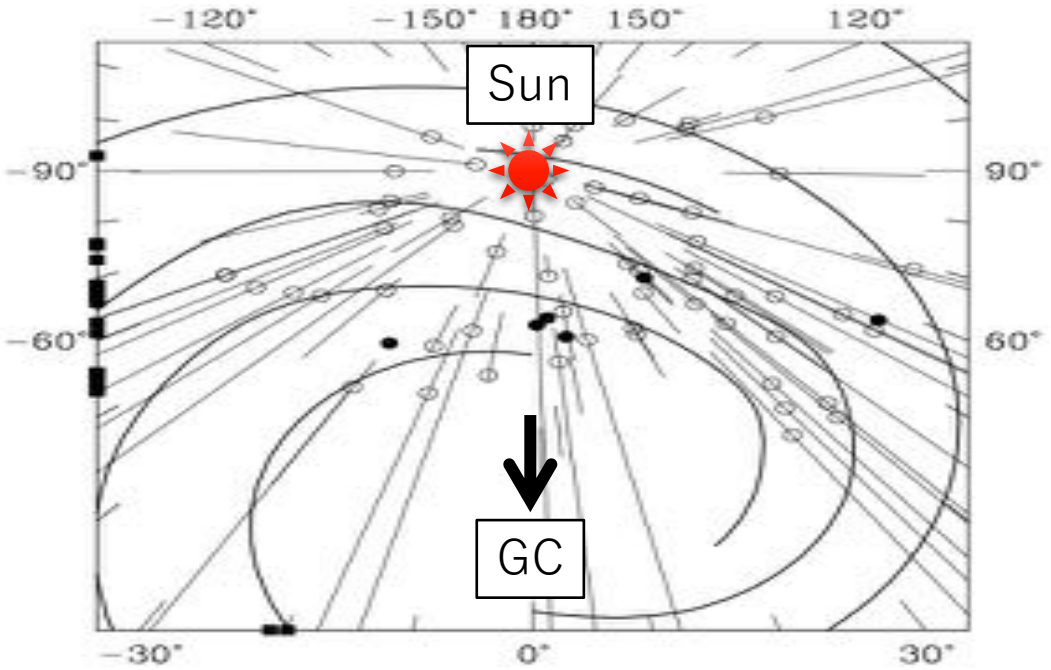
Missing Link: Magnetar and SNR

■SNR HB9 - SGR0501

- Association?

Method	Distance to HB9 (kpc)
Galactic Rotation	0.8 ± 0.4
Radial velocity of Hα filaments	~1.1
Sedov model	~1.1
S-D relation	1.3-1.8
Perseus arm	~2
Outer arm	~5

D_{DM} =1.8 kpc
(nearby pulsar 0458+46, 23' away)

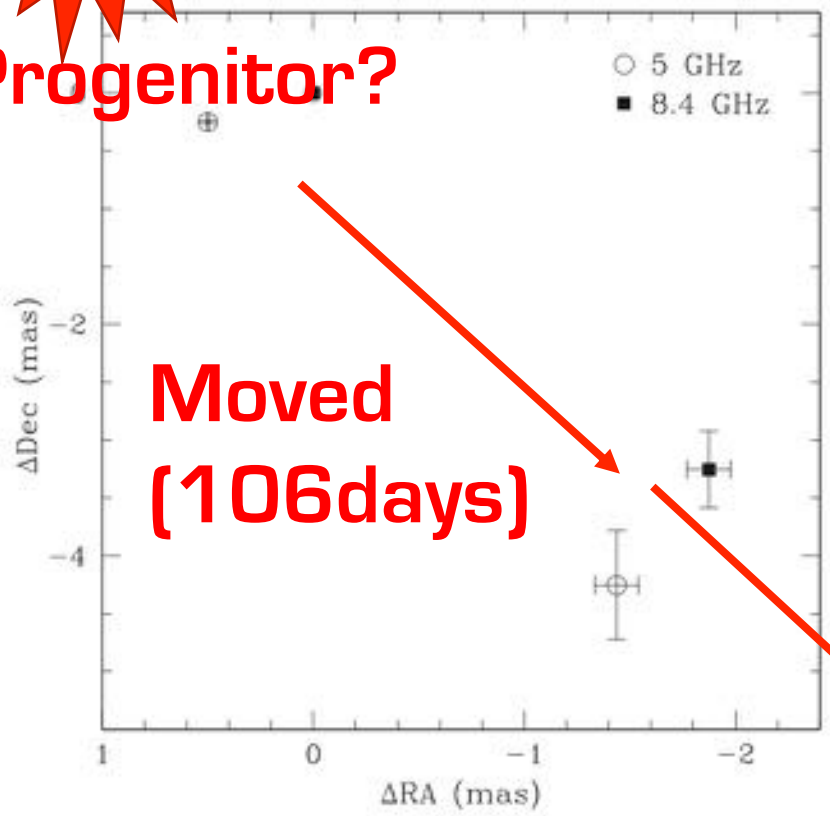


Distance from DM: Cordes, Lazio (2002) NE2001

The Chandra upper limit of 0.32"/yr may reject this progenitor (Mong & Ng 18, assuming D=5kpc)

VLBI Observation of XTE J1810

Progenitor?



Moved
(106days)

The Astrophysical Journal, 662:1198–1203, 2007 June 20

VLBA MEASUREMENT OF THE TRANSVERSE VELOCITY OF THE MAGNETAR XTE J1810−197

D. J. Helfand,[1] S. Chatterjee,[2] W. F. Brisken,[3] F. Camilo,[1] J. Reynolds,[4]
M. H. van Kerkwijk,[5] J. P. Halpern,[1] and S. M. Ransom[6]

Received 2007 January 23; accepted 2007 March 12

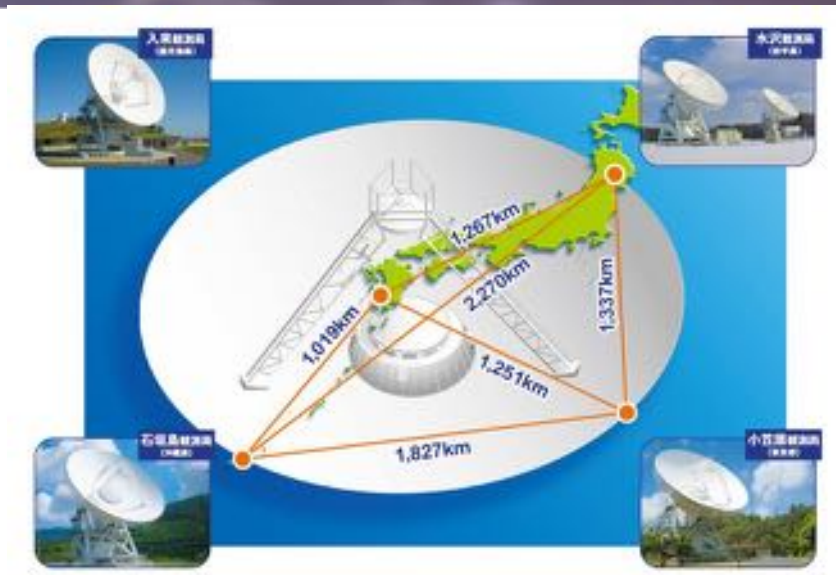
ABSTRACT

We have obtained observations of the magnetar XTE J1810−197 with the Very Long Baseline Array (VLBA) at two epochs separated by 106 days, at wavelengths of 6 and 3.6 cm. Comparison of the positions yields a proper-motion value of 13.5 ± 1.0 mas yr^{-1} at an equatorial position angle of 209.4° ± 2.4° (east of north). This value is consistent with a lower significance proper-motion value derived from infrared observations of the source over the past 3 years, also reported here. Given its distance of 3.5 ± 0.5 kpc, the implied transverse velocity corrected to the local standard of rest is 212 ± 35 km s^{-1} (1 σ). The measured velocity is slightly below the average for normal young neutron stars, indicating that the mechanism(s) of magnetar birth need not lead to high neutron star velocities. We also use Australia Telescope Compact Array, Very Large Array, and these VLBA observations to set limits on any diffuse emission associated with the source on a variety of spatial scales, concluding that the radio emission from XTE J1810−197 is >96% pulsed.

Subject headings: pulsars: general — stars: individual (XTE J1810−197) — stars: neutron — X-rays: stars

Moved
(10 years)??

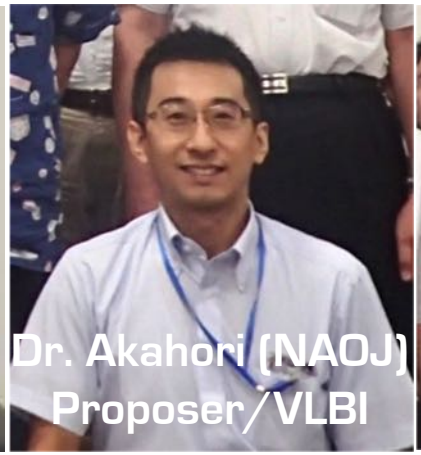
Angular Resolution (AR)

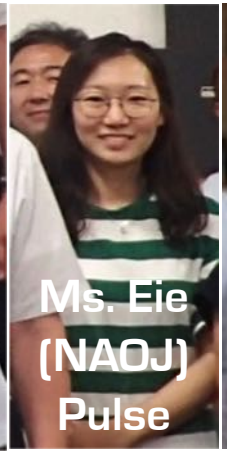


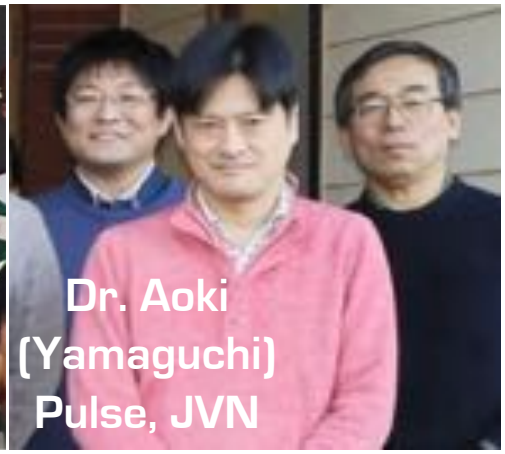
- **200 km/s @ 2 kpc → 1.7 mas/month**
- **AR = 5 mas (Baseline/1000km)$^{-1}$[f/10 GHz]$^{-1}$**
- **AR (VERA 22 GHz, 2000km) = 1.2 mas**
  - L-band (1.4GHz) requires 30000km baseline to achieve this AR → Need to monitor in a few years ← Radio outburst ends!
  - Emission at 22 GHz would be weak, but magnetar radio outburst may have a flat spectrum → VERA is promising!

Magnetar Observation Team of VERA

- **We are developing our experience of observing radio emission of NS/FRB toward the era of SKA**

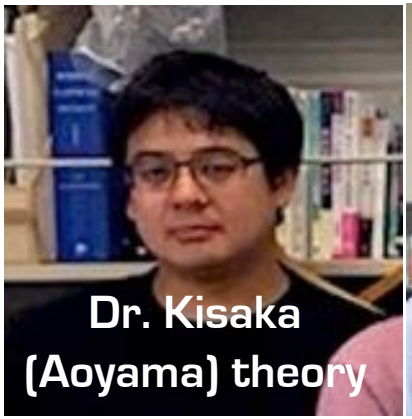


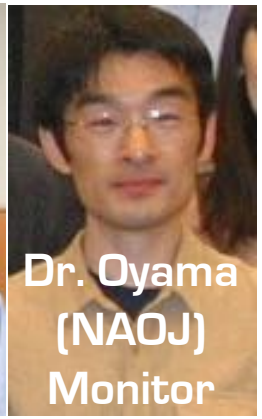




Prof. Terasawa
(NAOJ) Pulse

Prof. Honma
(NAOJ) Advisor





<u>More Contributors</u>
Prof. Yonekura (Ibaraki)
Prof. Misawa, Dr. Tsuchiya [Tohoku]
Dr. Sekido, Dr. Takefuji (NICT)

You are welcome to join us!

Result of Deep VLBI Imaging

Sta	τ_0	T_{rx}	T_{sys}
MIZ	0.12	83	121
IRK	0.09	93	135
OGA	0.11	86	131
ISG	0.20	97	186

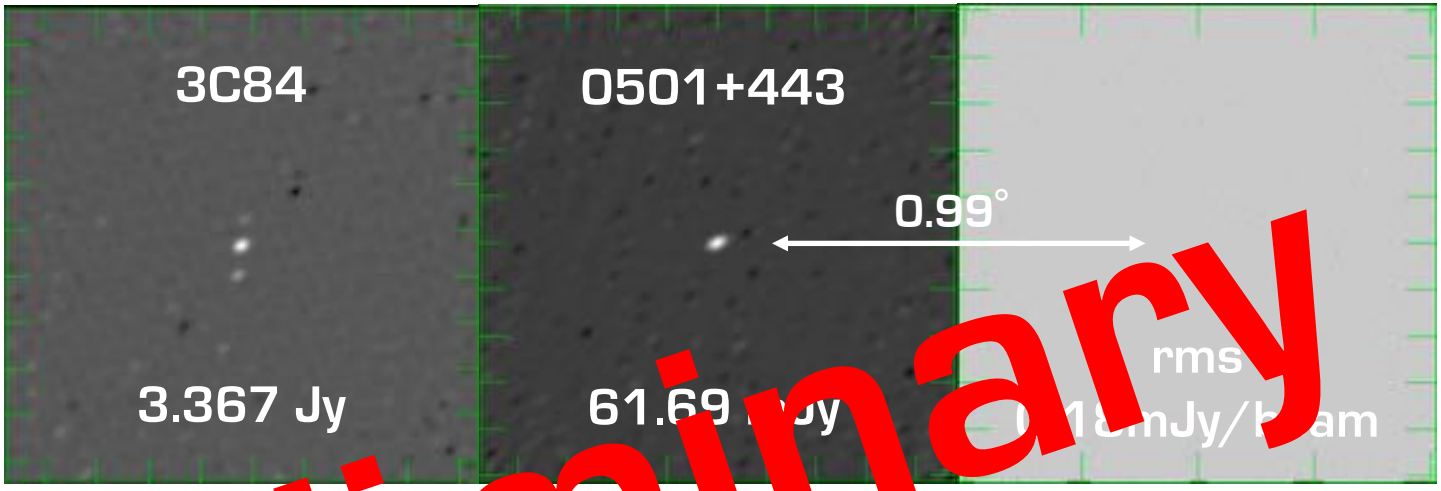
10hr

End	τ_0	T_{rx}	T_{sys}
MIZ	0.14	85	142
IRK	0.08	96	142
OGA	0.10	89	135
ISG	0.18	110	189

Sta	τ_0	T_{rx}	T_{sys}
MIZ	0.15	71	
IRK	0.25		232
OGA	0.19	11	203
ISG	0.26	176	

End	τ_0	T_{rx}	T_{sys}
MIZ	0.17	88	157
IRK	0.21	124	229
OGA	0.29	143	278
ISG	0.23	114	216

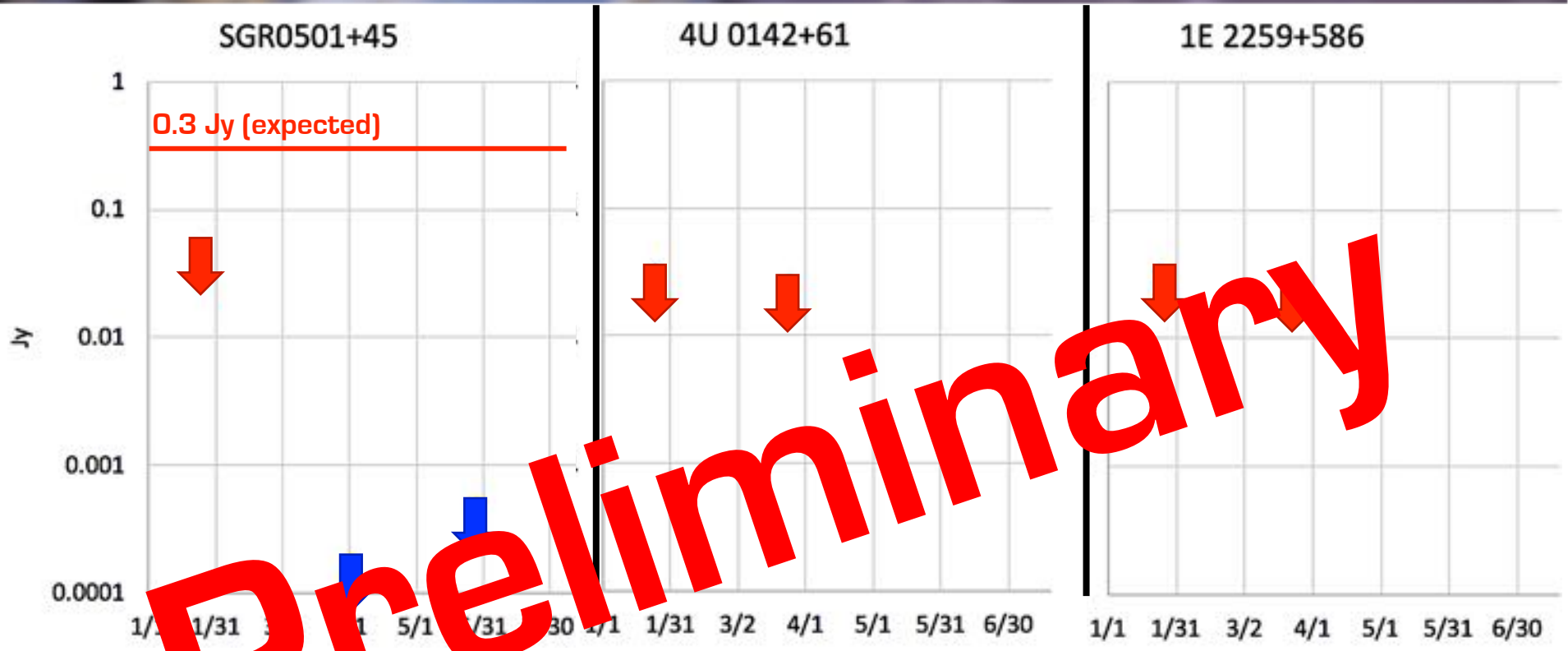
R18093A(2018/4/3)



Preliminary

3. Progress of Observation (SGR0501)
Results of Monitoring

BW = 128 MHz
BW = 2048 MHz



Preliminary

- No radio outburst was detected
- An upper limit of 0.2-0.5 mJy → top 20% of known normal radio pulsars are excluded

MOT VERA Campaign

litate 31m (0.3 GHz), Kashima 34-m (2 GHz), Hitachi 32-m (7/8 GHz), four VERA 20m (22 GHz), and NICER and Swift

19.02.16他?

19.02.16?

18.12.18
19.01.07
19.01.21
19.02.16

18.12.18
19.01.07
19.01.21
19.02.16

18.12.18
19.01.07
19.02.16

18.12.18
19.01.07
19.02.16

VERA VLBI
(1 mas resolution)
(10μas parallax)

19.01.07
19.02.16

18.12.18
19.01.07
19.01.21
19.02.16

18.12.18
19.01.07
19.01.21
19.02.16

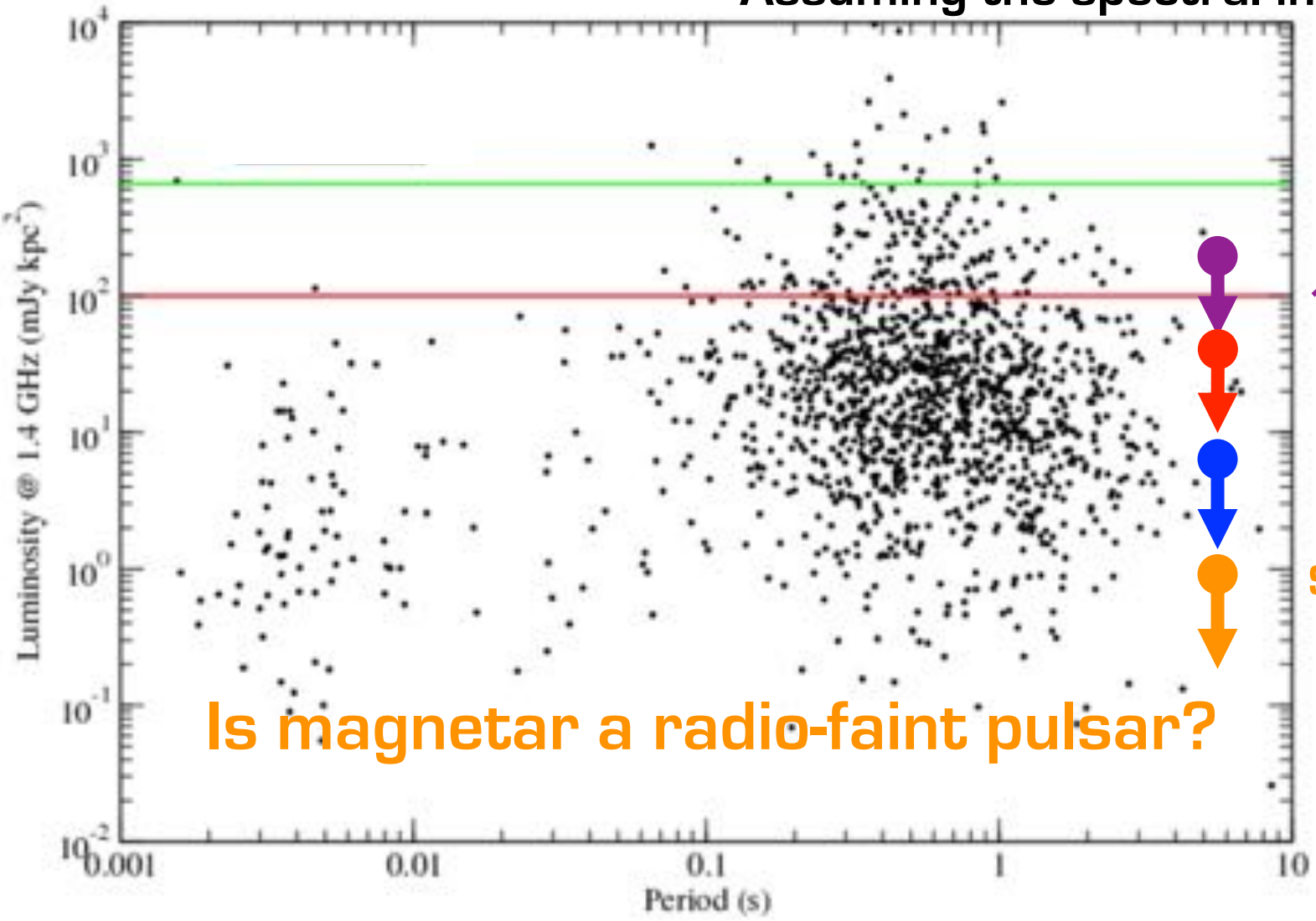
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Thanks to Terasawa-san, Honma-san, Enoto-san, Kisaka-san for their encouragements

Google Earth

Results of Monitoring

Assuming the spectral index = -2



Square Kilometre Array

■SKA is a pulsar hunter

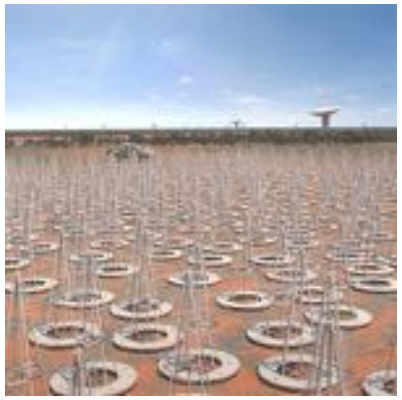
- Wide field of view
- LOW: 25.1 [0.1GHz/f]^2 deg^2
- MID: 1.37 [GHz/f]^2 deg^2
- Multi-beam backend system (Low: 167, MID: 500)

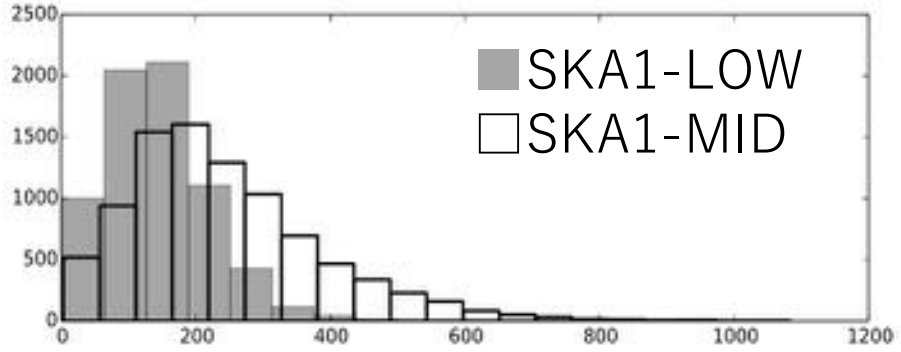
■SKA1-MID (2027-2032)

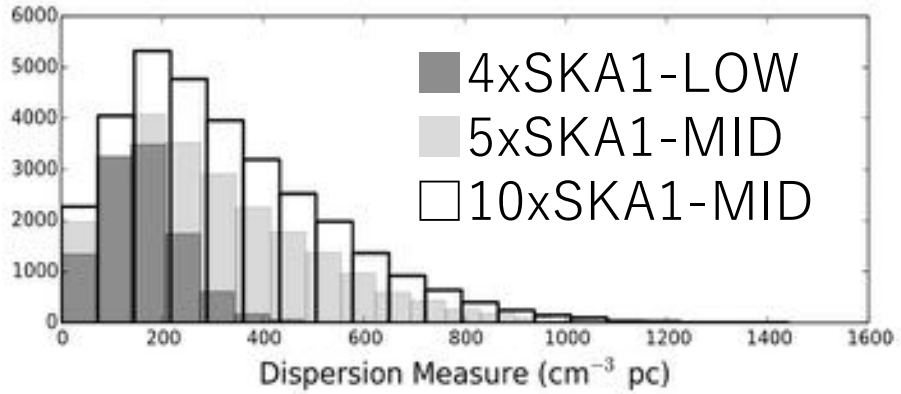
- #9000 normal pulsars
- #1400 MSP

■SKA2-MID (2030's)

- #30000 normal pulsars
- #3000 MSP







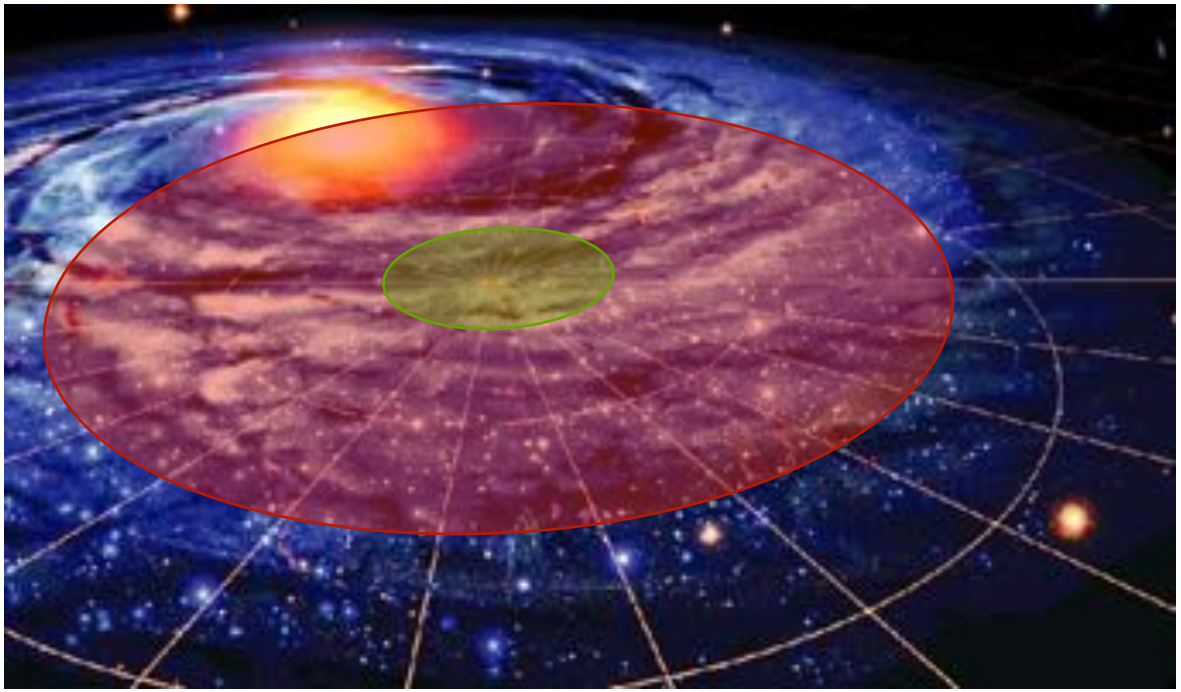
4. Future Prospects
SKA-VLBI

■**Current: VERA @ 22 GHz, angular resolution ＝ 1.2 mas**

- 200 km/s @ 2 kpc → 1.7 mas/month (a few x 10 μmas parallax)

■**Future: SKA-VLBI (w EAVN) @ 22 GHz → 0.25- 0.35 mas**

- 200 km/s @ 8 kpc → 0.4 mas/month (~10 μmas parallax)



We will obtain magnetar's

✓ **accurate distance**

✓ **and velocity,**

which unveil

✓ **progenitor SNR**

✓ **and the origin of strong B-field!**

Summary

■Radio Observation of Magnetars

- VLBI astrometry is a key to understand the origin of magnetars
- We are developing a magnetar observing team in Japan
  - SGR 0501, XTE J1810, ...
  - Also FRB is our scope
- SKA will become a game-changer of this research topic

おまけ

[告知] SKA研究会の開催

- 2019年9月2日(月) - 6日(金)
- 国立天文台三鷹すばる棟大セミナー室
- パルサー・マグネター・FRBはキートピックの一つです
- 日程の確保をお願いします