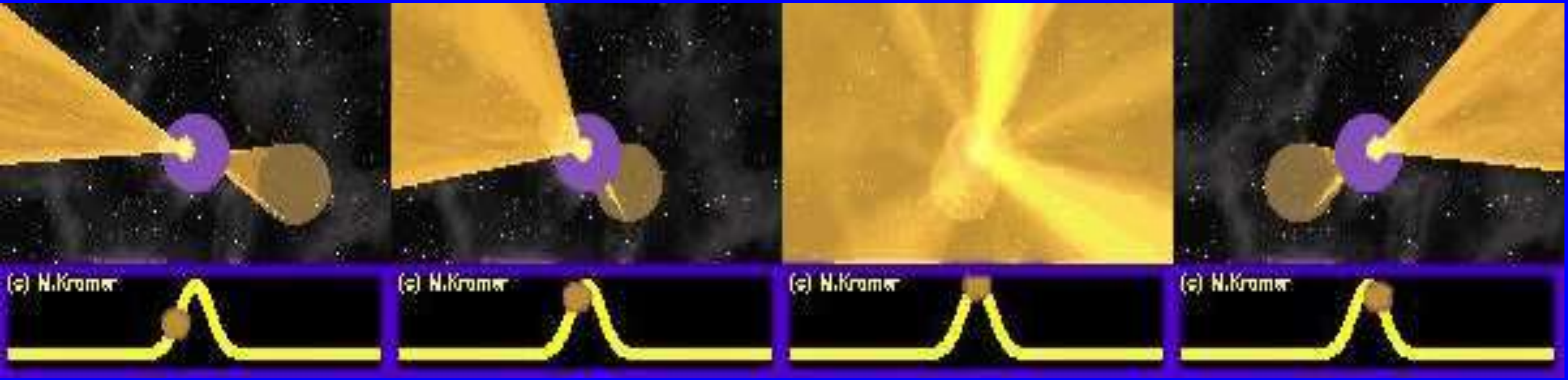
Pulsar study using SKA

Osamu KAMEYA

（NAOJ, Mizusawa VLBI Observatory）



Workshop on East-Asian Collaboration for SKA
in Daejeon, Korea on 2011 December 1

SK-J Pulsar SWG

Asada, Hideki (Hirosaki Univ.)

Daishido, Tsuneaki (Waseda Univ.)

Fujishita , Mitsumi (Tokai Univ.)

Kameya, Osamu (NAOJ)

Ohira,Yutaka (Osaka Univ. /KEK)

Ohnishi, Kouji (Nagano National College of Technology)

Sekido, Mamoru (NICT, Kashima)

Seto, Naoki (Kyoto Univ.)

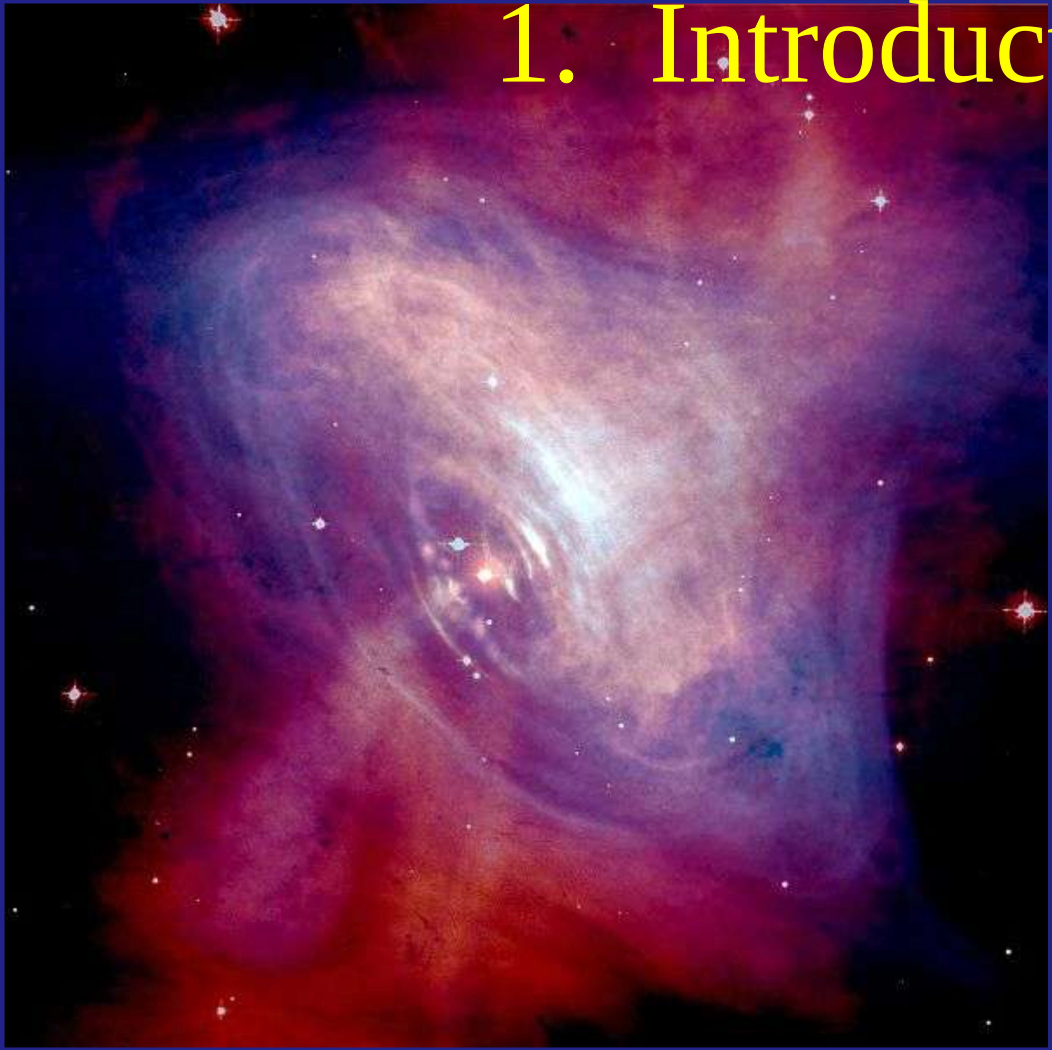
Shibata, Shinpei (Yamagata Univ.)

Takefuji, Kazuhiro (NICT, Kashima)

Terasawa, Toshio (Univ. of Tokyo)

1. Introduction of pulsars
2. Activities of Japanese groups
3. Pulsar study by using SKA

1. Introduction of pulsars



http://en.wikipedia.org/wiki/File:Chandra-crab.jpg

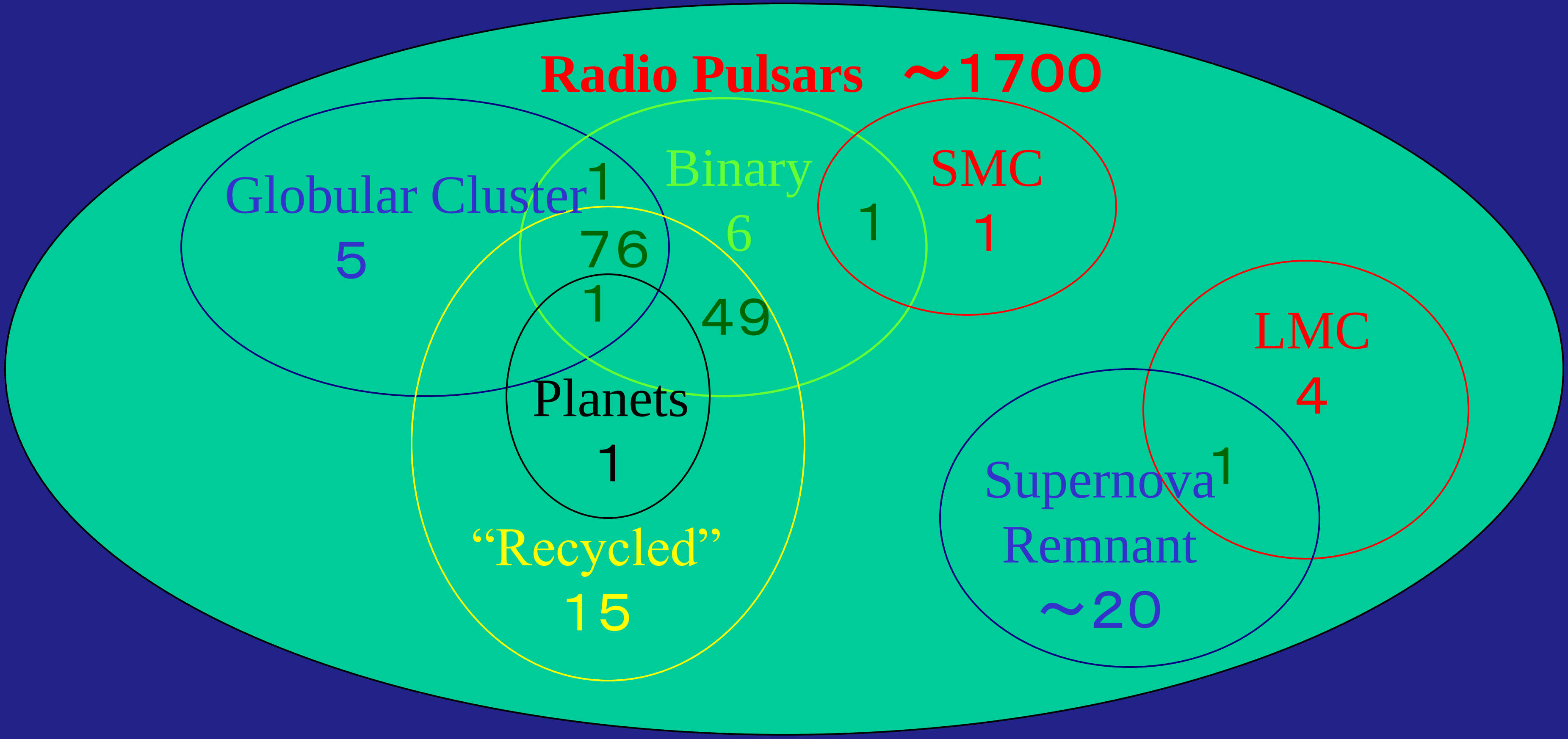
Crab Pulsar by Chandra(X-ray blue) optical (red)

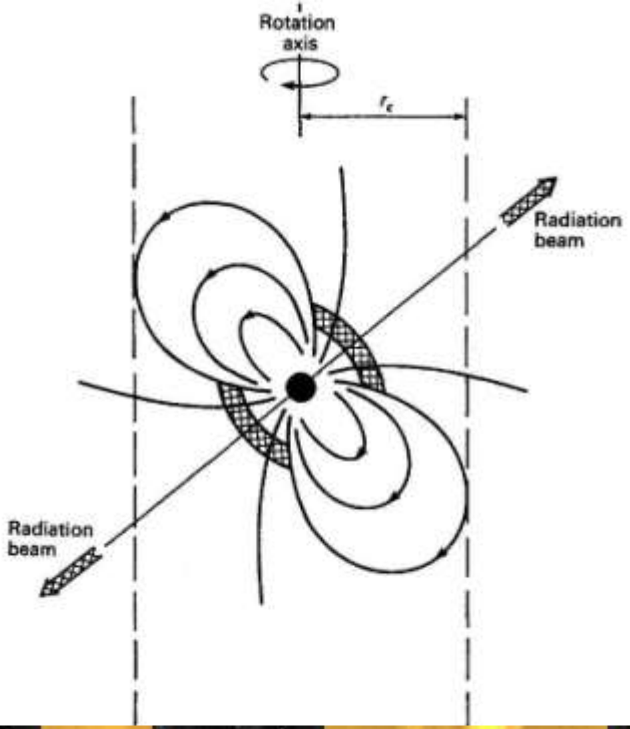
Pulsar

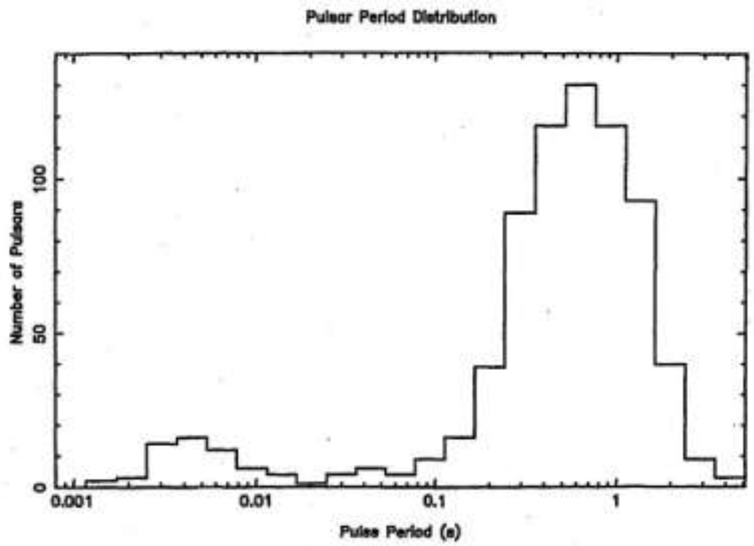
- Magnetic field：$10^8 \sim 10^{14}$Gauss
- Gravitation：10^9G
- Voltage difference in magnetosphere：10^{12}V

Firstly detected pulses from B1919+21
28 November, 1967
by J.Bell & Hewish.
44years ago!

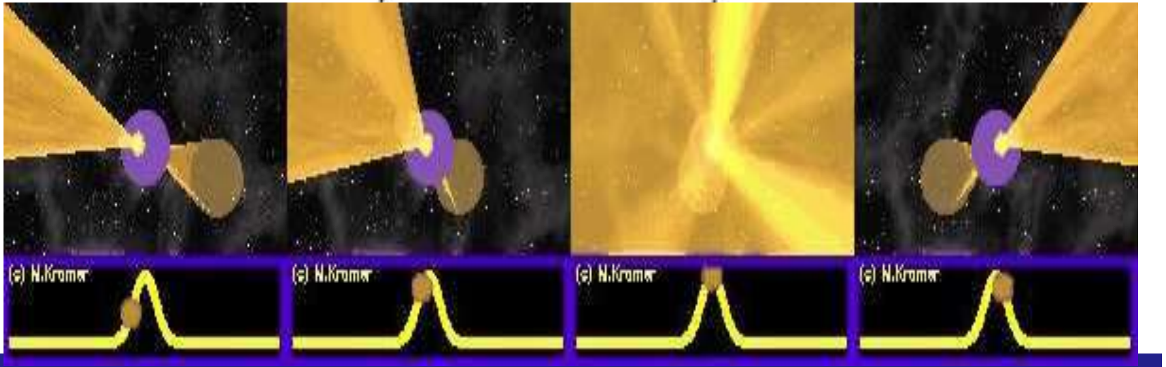
Duncan R. Lorimer “Binary and Millisecond Pulsars”、2005







The distribution of the periods of pulsars.



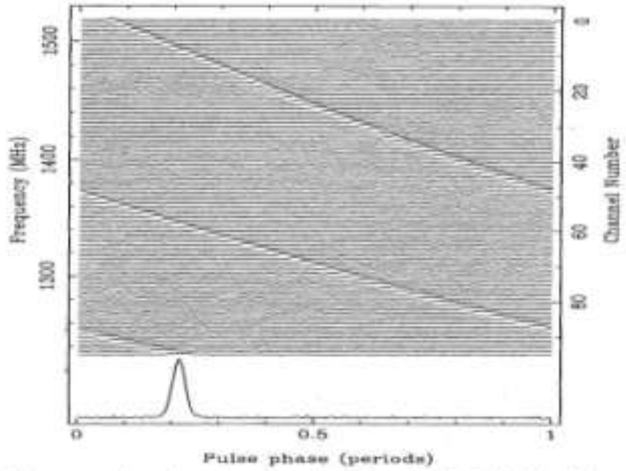


Fig. 3.1. Frequency dispersion in pulse arrival time for PSR B1641−45, recorded in 96 adjacent frequency channels, each 3 MHz wide, centred on 1380 MHz.

Lyne &Graham-Smith, 1998, **Pulsar Astronomy**,
Cambridge Univ. Press

Dispersion Measure

$DM=A(t1-t2)(1/\nu1^{2} - 1/\nu2^{2})^{-1}$, $A=2.410\times 10^{-16}\ cm^{-3}pc$

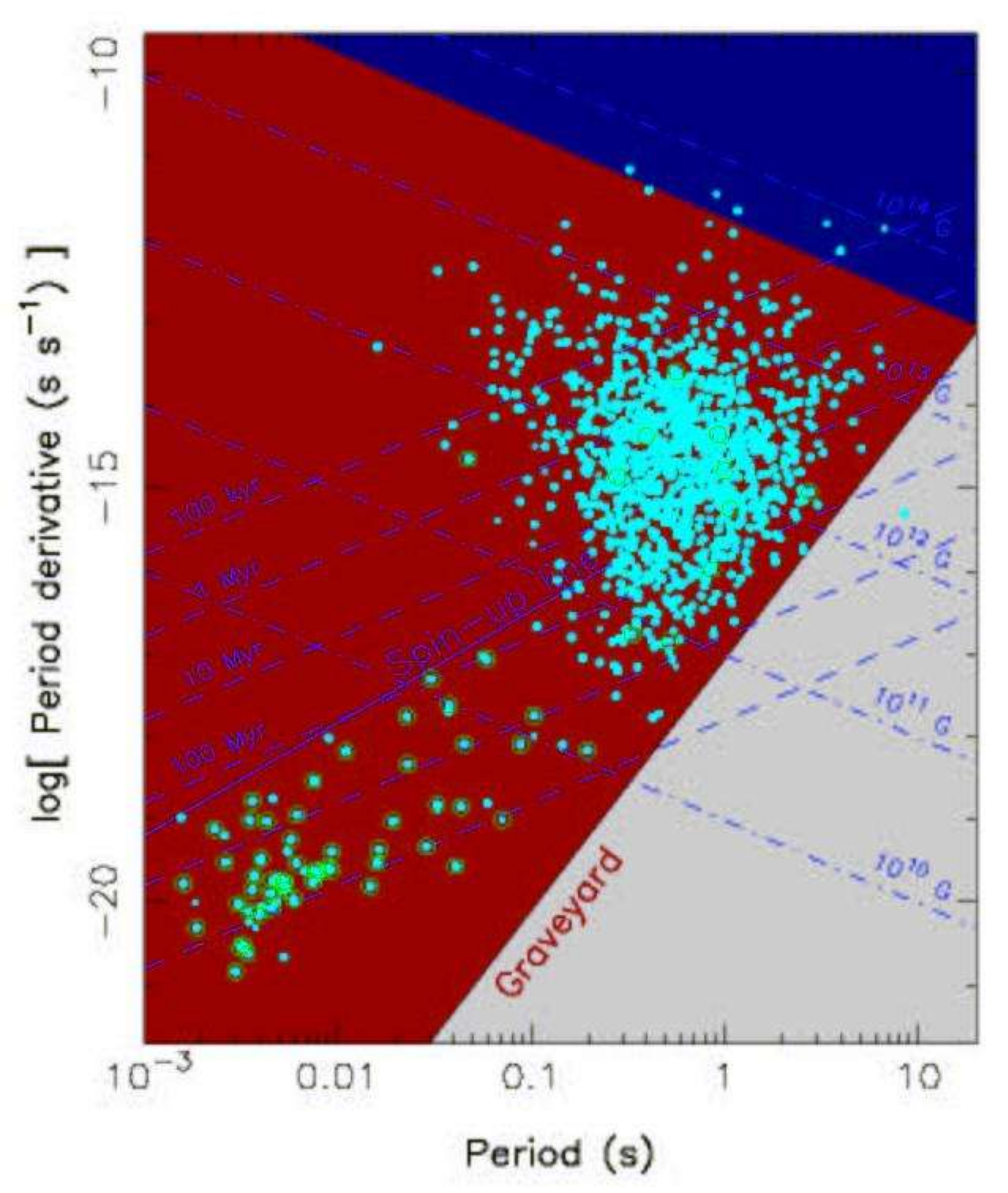
Duncan R. Lorimer “Binary and Millisecond Pulsars ”、2005

$$\tau c = P/(2dP/dt)$$

$$B = 3.2 \times 10^{19} (P (dP/dt))^{1/2}$$

Lyne &Graham-Smith, 1998, **Pulsar Astronomy**, Cambridge Univ. Press

Period and dP/dt



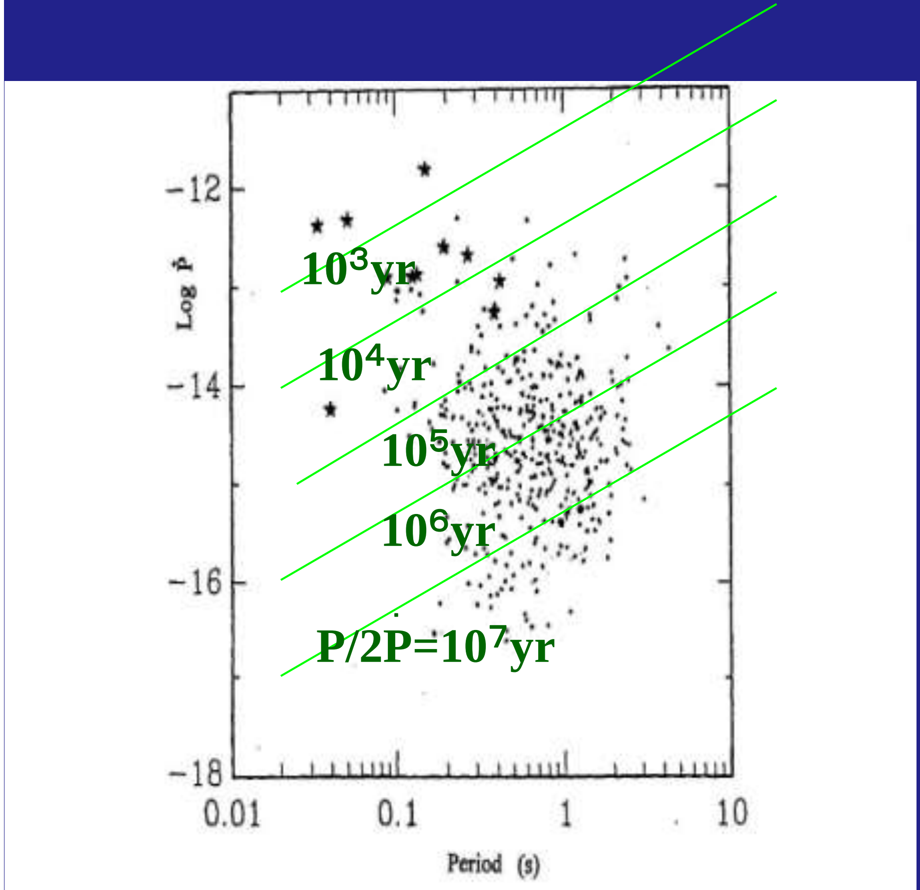


Fig. 5.2. The $P - \dot{P}$ diagram: logarithmic plot of the first derivative of the period against the period. Binary and millisecond pulsars are omitted from this plot: see Figure 10.1. Young pulsars associated with supernova remnants are shown starred.

What is interesting by the Pulsar research?

- Know the distribution of pulsars in our Galaxy.

  (Positional astronomy of pulsars)
- Determination of distance of pulsars:

  Estimation of precise physical parameters of pulsars

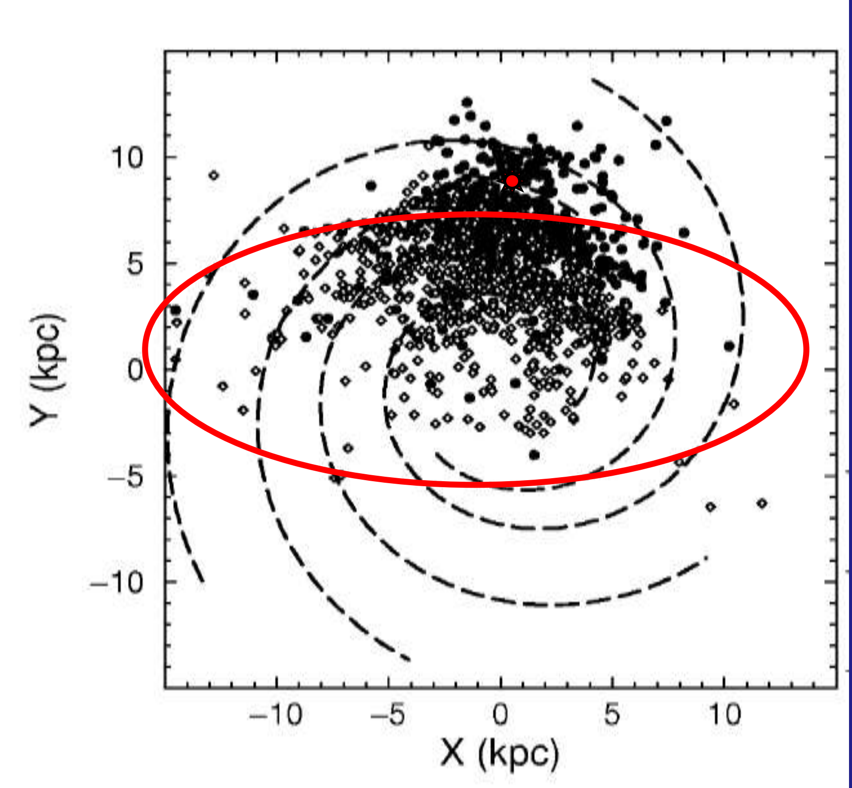
  which improves theoretical models of pulsars.
- Estimation of physical values: contribution to theoretical physics(ex. change of Gravitation constant).
- Measure real velocity transverse to the line of sight.
- Know distribution of mean electric density toward pulsars. $DM=d\cdot n$
- Discovery and research in new phenomena of pulsation mechanism.

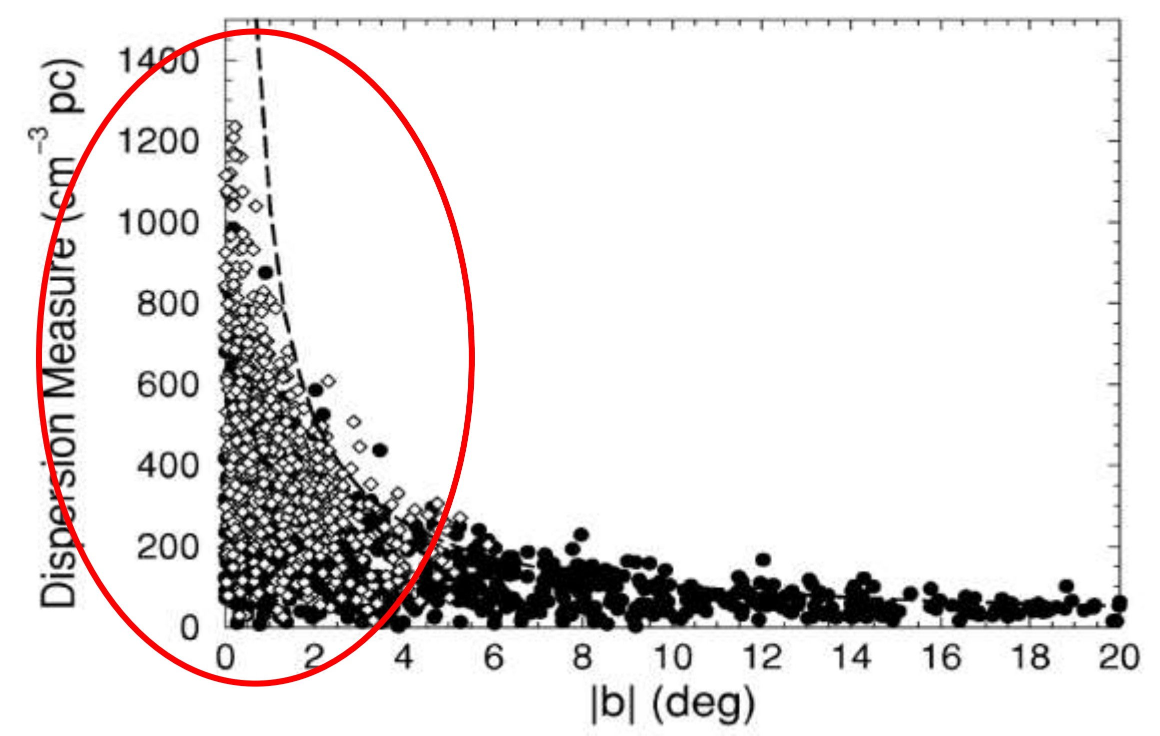
  giant pulse, binary pulsers, milliseconds pulsars etc,,,

Unbiased survey

- Parks Multi-beam Pulsar Survey（PMPS）: 13 beams
  - Taylor Catalog(1993) : 558
  - PMPS : **742** new
- **1789** pulsars from ATNF

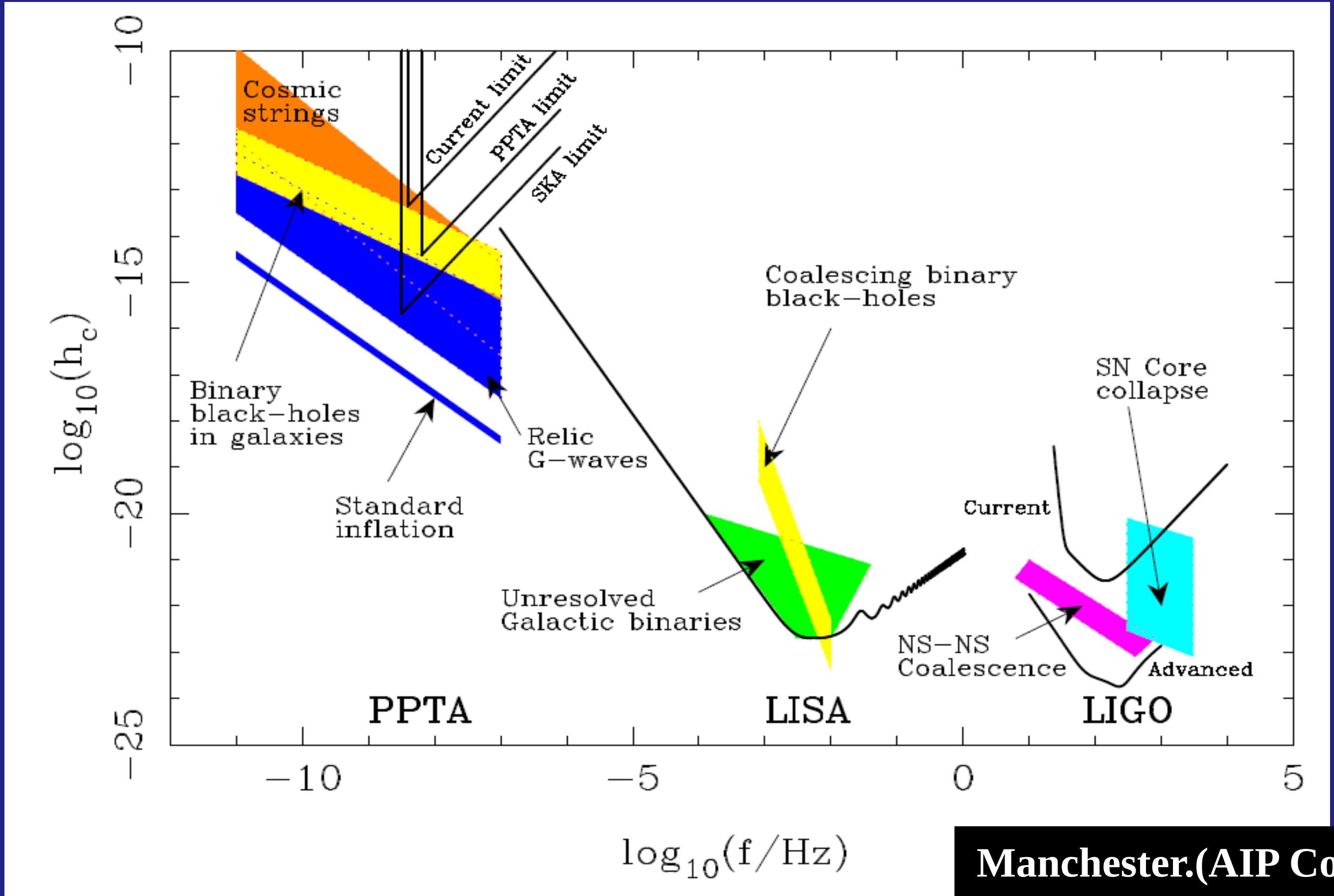
http://www.atnf.csiro.au/research/pulsar/psrcat/





Pulsar Timing Observations : Detection of Gravitation wave

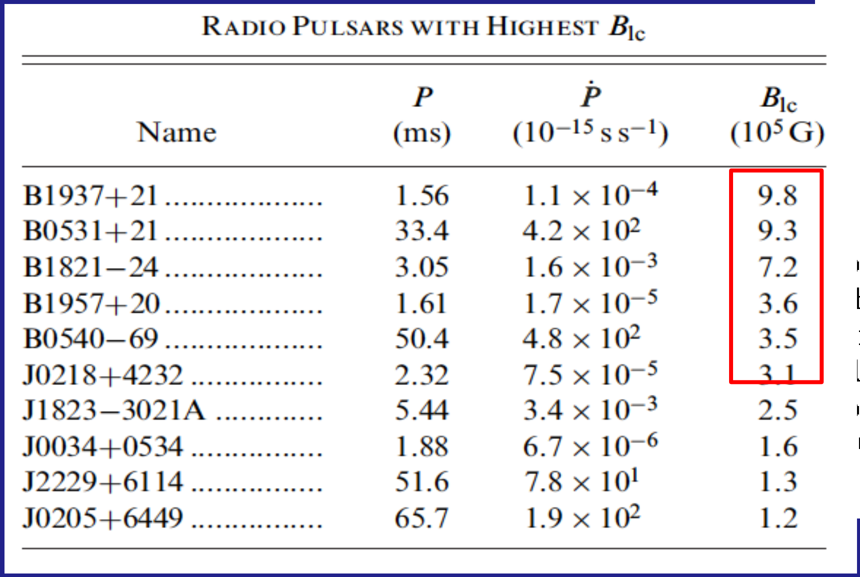
- Parks Pulsar Timing Array（PPTA)：measures pulse stability of 20 milli second pulsars every 2-3 weeks
- Comparation of Two clocks : detection of Gravitation wave



Manchester.(AIP Conf. 2007)

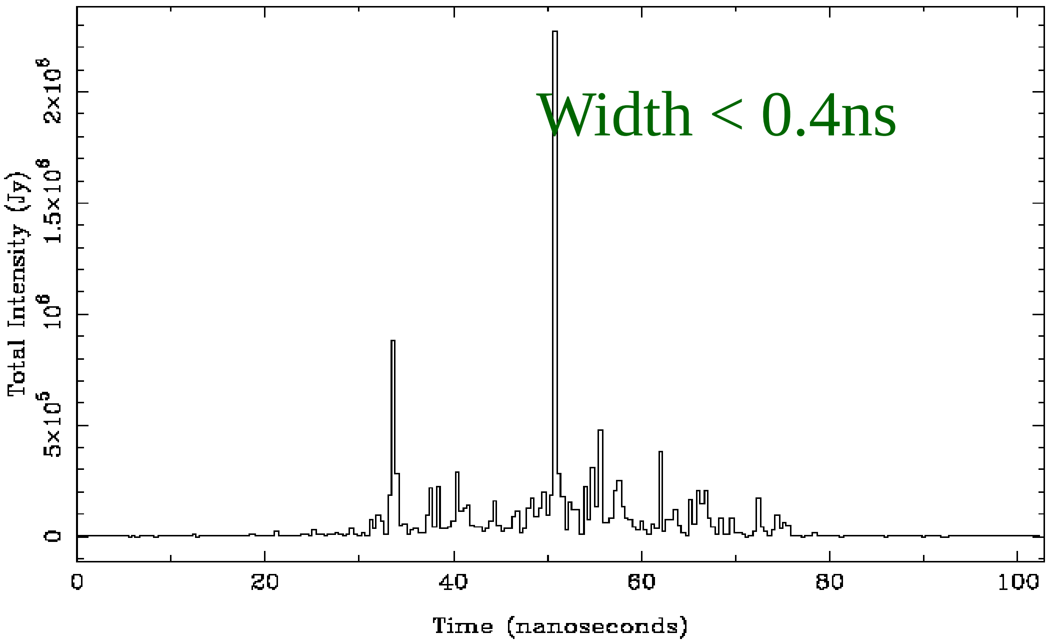
Giant Radio Pulse

- Pulsars with high magnetic filed often have GRPs.



RADIO PULSARS WITH HIGHEST B_{lc}

Name	P (ms)	$\dot{P}$ (10^{-15} s s^{-1})	B_{lc} (10^5 G)
B1937+21	1.56	1.1×10^{-4}	9.8
B0531+21	33.4	4.2×10^{2}	9.3
B1821−24	3.05	1.6×10^{-3}	7.2
B1957+20	1.61	1.7×10^{-5}	3.6
B0540−69	50.4	4.8×10^{2}	3.5
J0218+4232	2.32	7.5×10^{-5}	3.1
J1823−3021A	5.44	3.4×10^{-3}	2.5
J0034+0534	1.88	6.7×10^{-6}	1.6
J2229+6114	51.6	7.8×10^{1}	1.3
J0205+6449	65.7	1.9×10^{2}	1.2



Width < 0.4ns

FIG. 5.—Single MP recorded at 9.25 GHz center frequency over a 2.2 GHz andwidth and optimally dedispersed. The nanopulse shown is unresolved with he 0.4 ns time resolution afforded by our system. Despite the high peak intenity of this pulse, it is unlikely that it saturated the data acquisition system. The lispersion sweep time across the bandwidth is about 1.5 ms, so as sampled by ur data acquisition system, the dispersed pulse energy is spread over ≈7.5 × 0^6 samples.

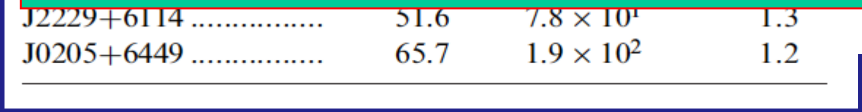
(Hankins&ELEK, ApJ,2007)

Giant Radio Pulse

Japanese Activity:

NICT Kashima34m Observing Giant Radio Pulses (by Drs. Sekido, Terasawa, and Takefuji, ,,,,)

>> Collaboration with VERA, Usuda 64m, etc.



J2229+6114	51.6	7.8×10^1	1.3
J0205+6449	65.7	1.9×10^2	1.2

(Hankins&ELEK, ApJ,2007)

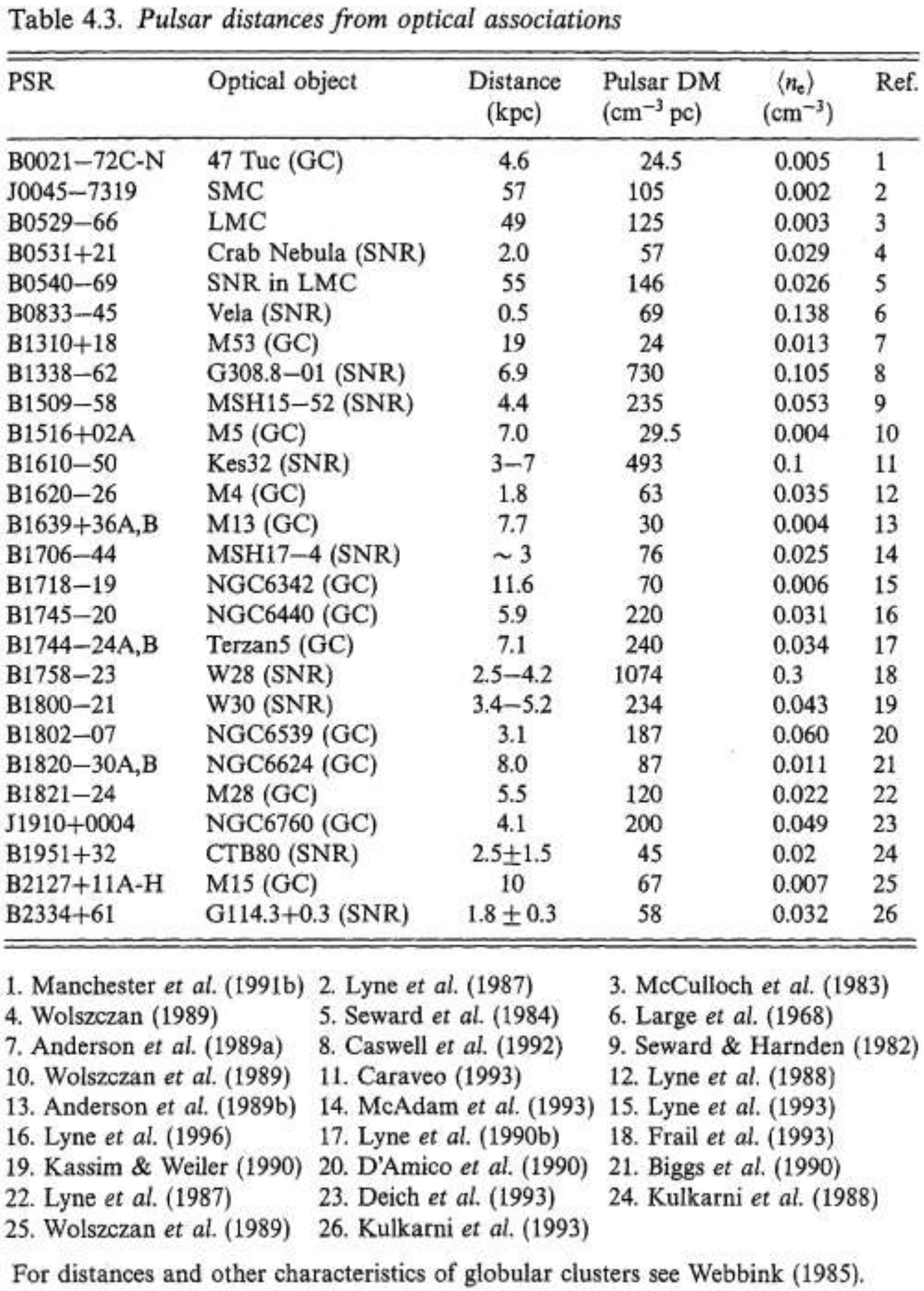


Table 4.3. *Pulsar distances from optical associations*

PSR	Optical object	Distance (kpc)	Pulsar DM ($\mathrm{cm^{-3}\,pc}$)	$\langle n_e \rangle$ ($\mathrm{cm^{-3}}$)	Ref.
B0021−72C-N	47 Tuc (GC)	4.6	24.5	0.005	1
J0045−7319	SMC	57	105	0.002	2
B0529−66	LMC	49	125	0.003	3
B0531+21	Crab Nebula (SNR)	2.0	57	0.029	4
B0540−69	SNR in LMC	55	146	0.026	5
B0833−45	Vela (SNR)	0.5	69	0.138	6
B1310+18	M53 (GC)	19	24	0.013	7
B1338−62	G308.8−01 (SNR)	6.9	730	0.105	8
B1509−58	MSH15−52 (SNR)	4.4	235	0.053	9
B1516+02A	M5 (GC)	7.0	29.5	0.004	10
B1610−50	Kes32 (SNR)	3−7	493	0.1	11
B1620−26	M4 (GC)	1.8	63	0.035	12
B1639+36A,B	M13 (GC)	7.7	30	0.004	13
B1706−44	MSH17−4 (SNR)	∼ 3	76	0.025	14
B1718−19	NGC6342 (GC)	11.6	70	0.006	15
B1745−20	NGC6440 (GC)	5.9	220	0.031	16
B1744−24A,B	Terzan5 (GC)	7.1	240	0.034	17
B1758−23	W28 (SNR)	2.5−4.2	1074	0.3	18
B1800−21	W30 (SNR)	3.4−5.2	234	0.043	19
B1802−07	NGC6539 (GC)	3.1	187	0.060	20
B1820−30A,B	NGC6624 (GC)	8.0	87	0.011	21
B1821−24	M28 (GC)	5.5	120	0.022	22
J1910+0004	NGC6760 (GC)	4.1	200	0.049	23
B1951+32	CTB80 (SNR)	2.5±1.5	45	0.02	24
B2127+11A-H	M15 (GC)	10	67	0.007	25
B2334+61	G114.3+0.3 (SNR)	1.8 ± 0.3	58	0.032	26

1. Manchester *et al.* (1991b) 2. Lyne *et al.* (1987) 3. McCulloch *et al.* (1983)
4. Wolszczan (1989) 5. Seward *et al.* (1984) 6. Large *et al.* (1968)
7. Anderson *et al.* (1989a) 8. Caswell *et al.* (1992) 9. Seward & Harnden (1982)
10. Wolszczan *et al.* (1989) 11. Caraveo (1993) 12. Lyne *et al.* (1988)
13. Anderson *et al.* (1989b) 14. McAdam *et al.* (1993) 15. Lyne *et al.* (1993)
16. Lyne *et al.* (1996) 17. Lyne *et al.* (1990b) 18. Frail *et al.* (1993)
19. Kassim & Weiler (1990) 20. D'Amico *et al.* (1990) 21. Biggs *et al.* (1990)
22. Lyne *et al.* (1987) 23. Deich *et al.* (1993) 24. Kulkarni *et al.* (1988)
25. Wolszczan *et al.* (1989) 26. Kulkarni *et al.* (1993)

For distances and other characteristics of globular clusters see Webbink (1985).

If the distance of pulsars is known, we can estimate interstellar ionized- gas density.

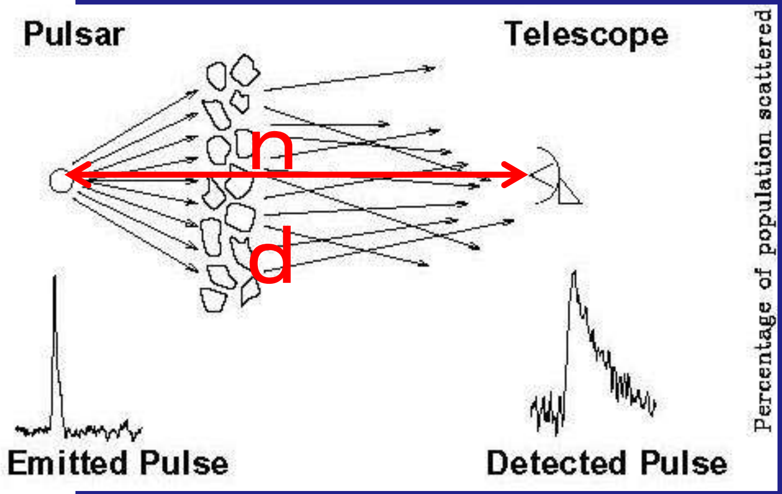
Lyne &Graham-Smith, 1998, **Pulsar Astronomy**, Cambridge Univ. Press

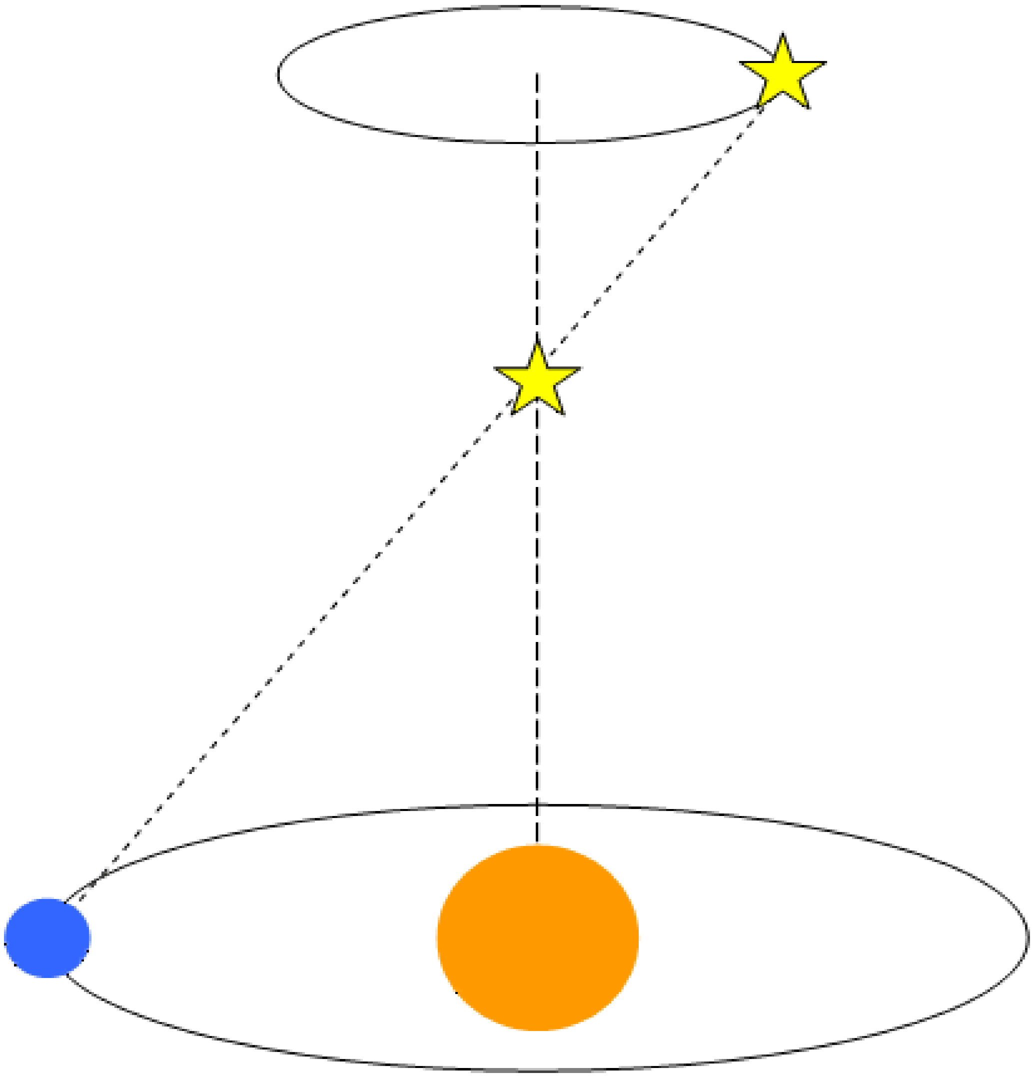
$$DM = d \cdot n$$

$$RM = \mathrm{const} \cdot B \cdot d \cdot n$$

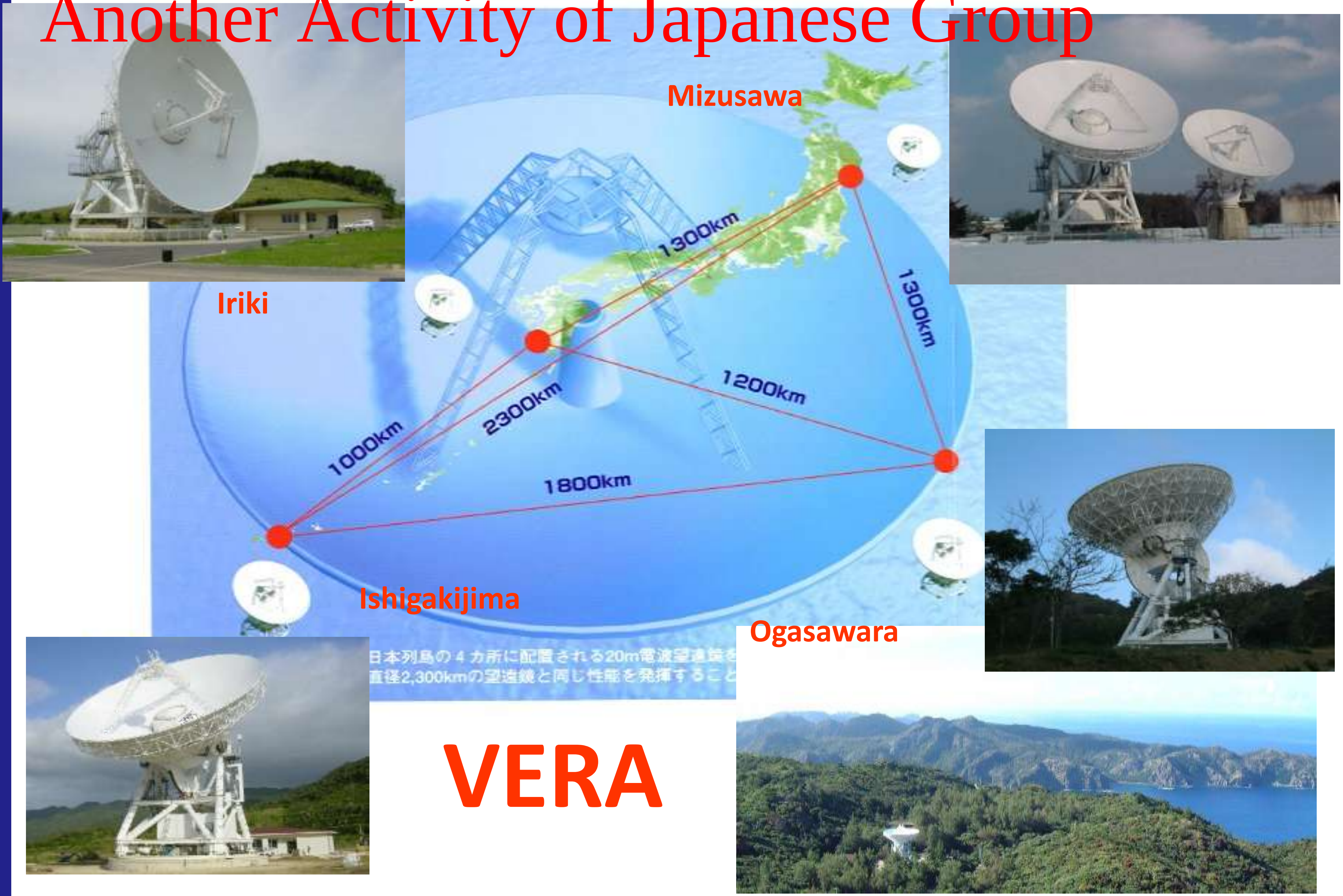
$$B = RM / (\mathrm{const} \cdot DM)$$

$$= 1.23\,\mu G\,(RM/\mathrm{rad\,m^{-2}})(DM/\mathrm{cm^{-3}\,pc})^{-1}$$





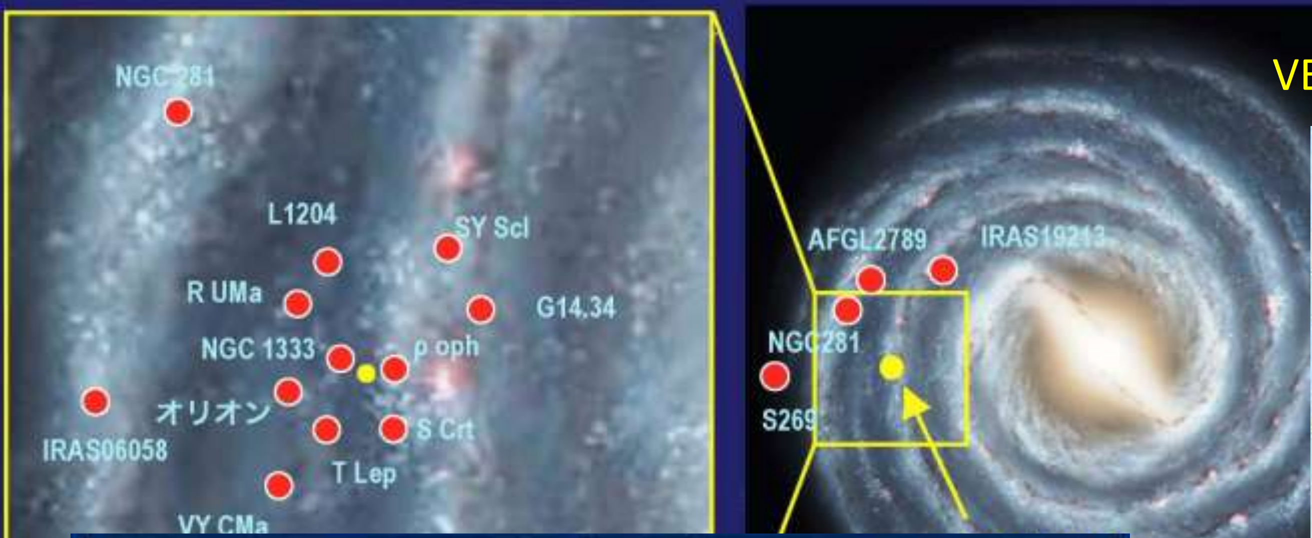
Another Activity of Japanese Group



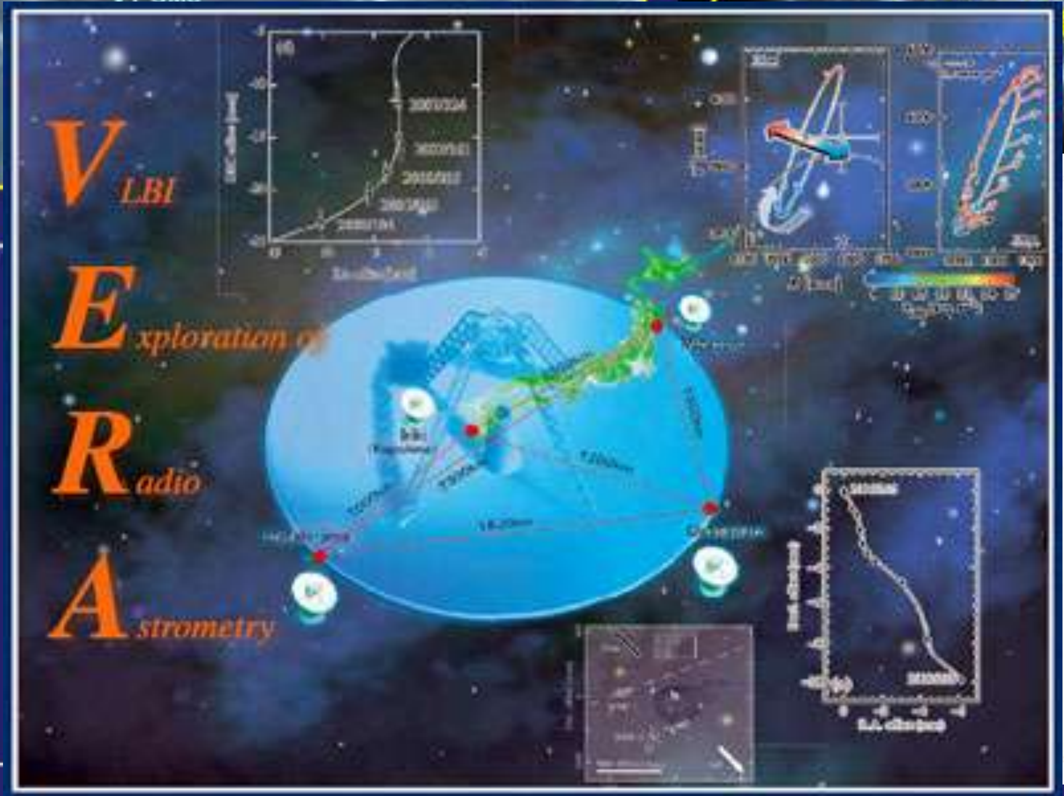
日本列島の４カ所に配置される20m電波望遠鏡を
直径2,300kmの望遠鏡と同じ性能を発揮すること

VERA

Position of masers measured by VERA

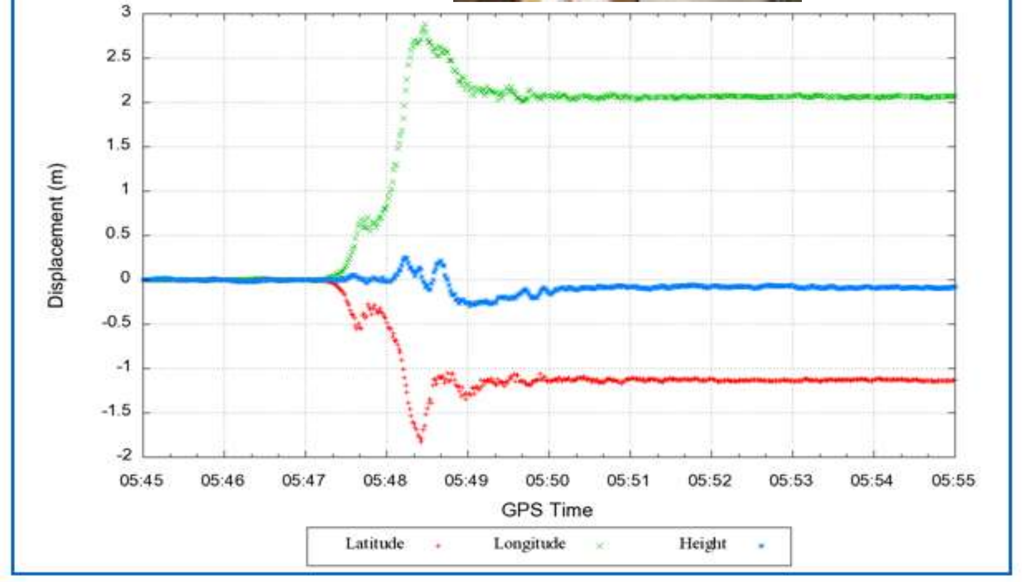


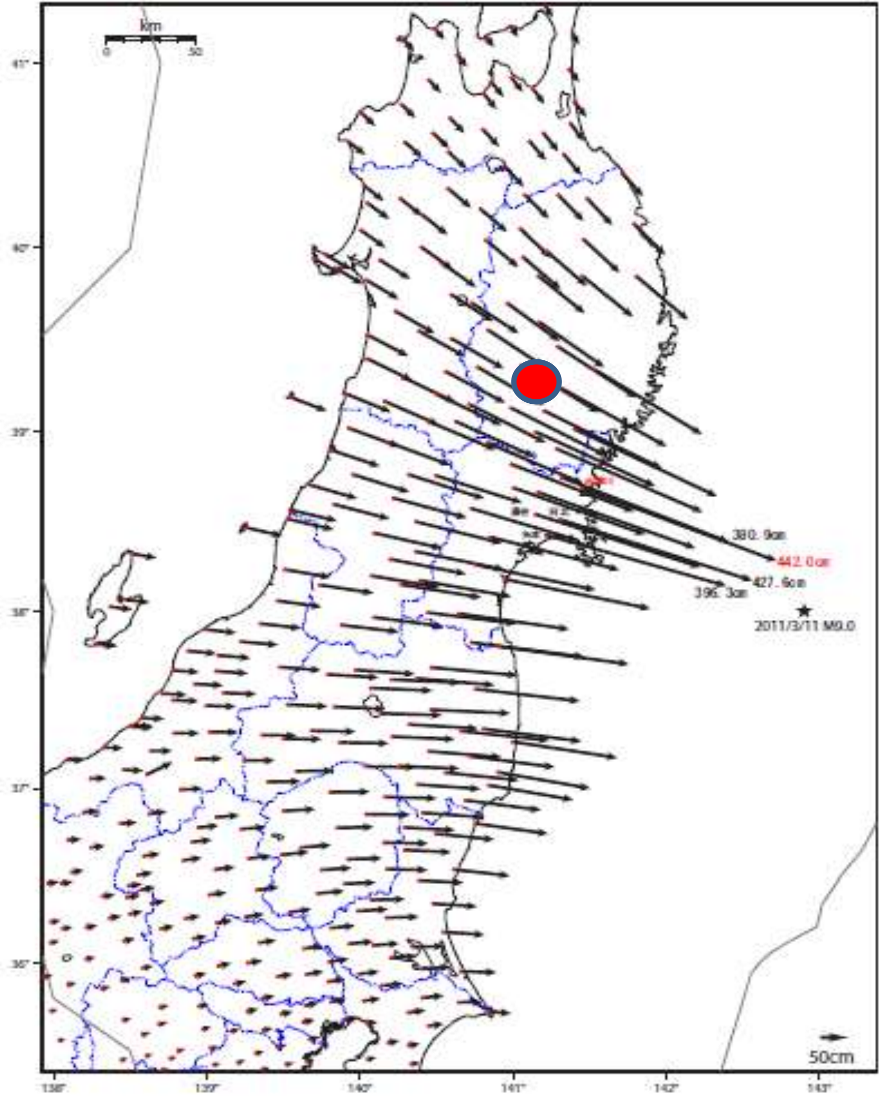
VERA+JVN+KVN+Chinese VLBI >>EAVN

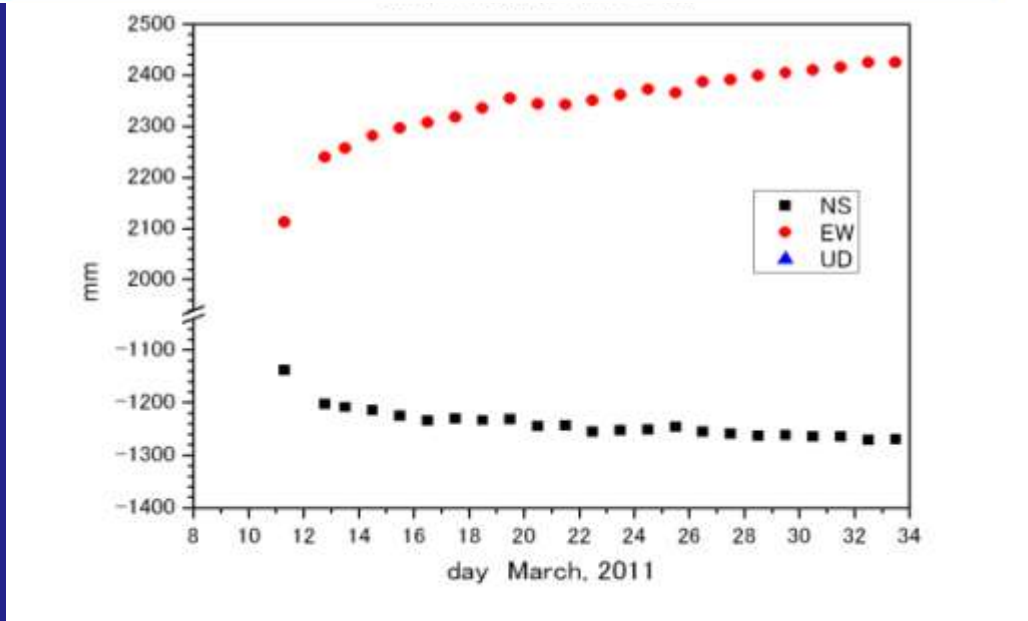


Changes in the position of the Mizusawa station

on March 11, 2011







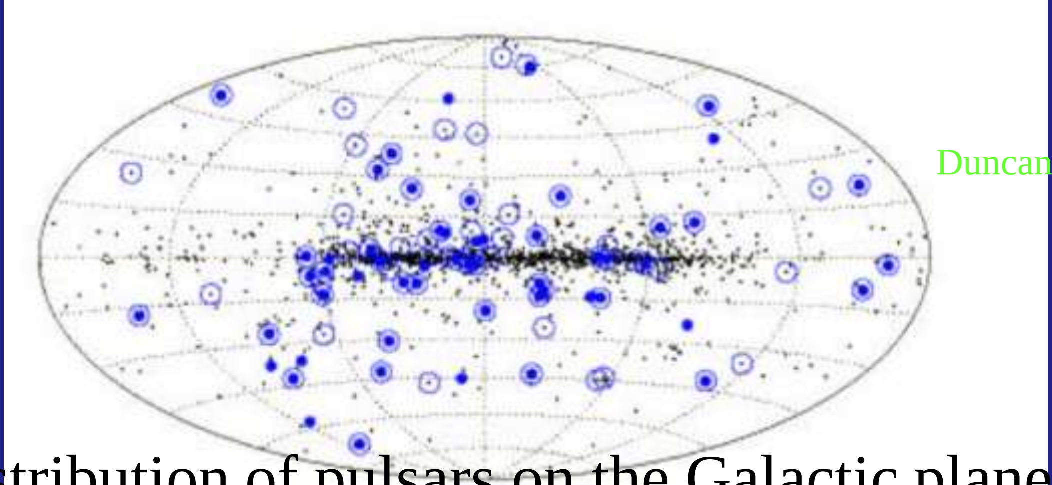
Damage to Mizusawa 20m station by the big earthquake

Some teeth alignment pins came off.

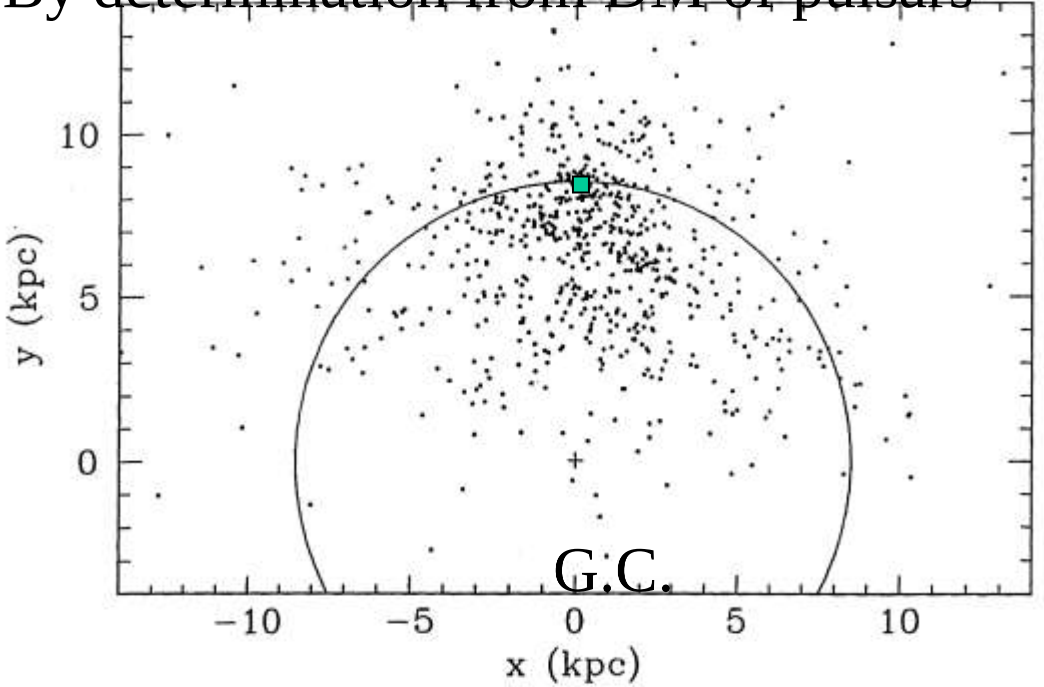
Repaired in August

Distribution of pulsars

Duncan R. Lorimer “Binary and Millisecond Pulsars ”、2005



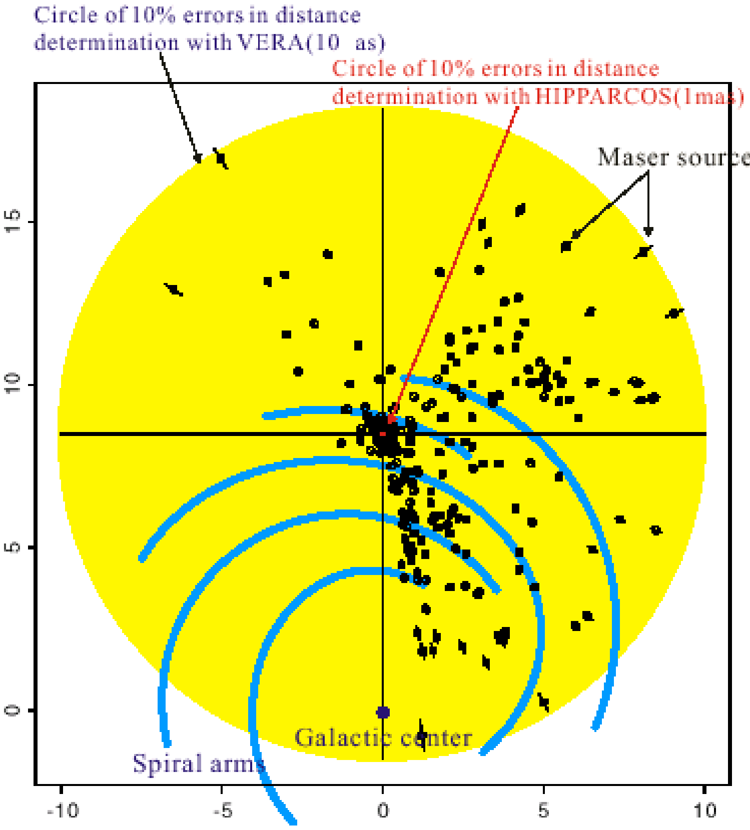
Distribution of pulsars on the Galactic plane
By determination from DM of pulsars

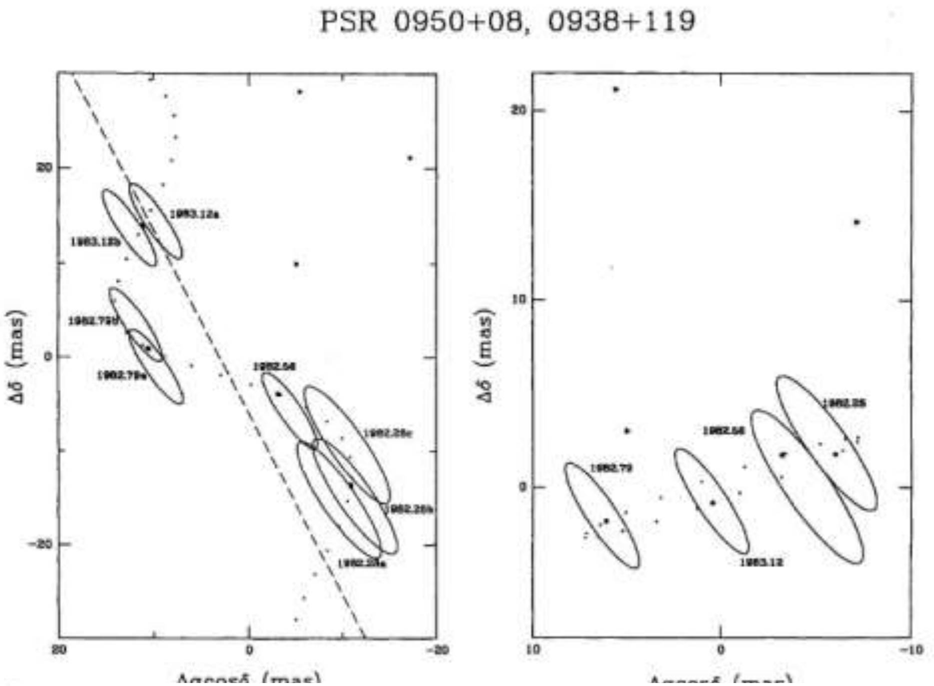


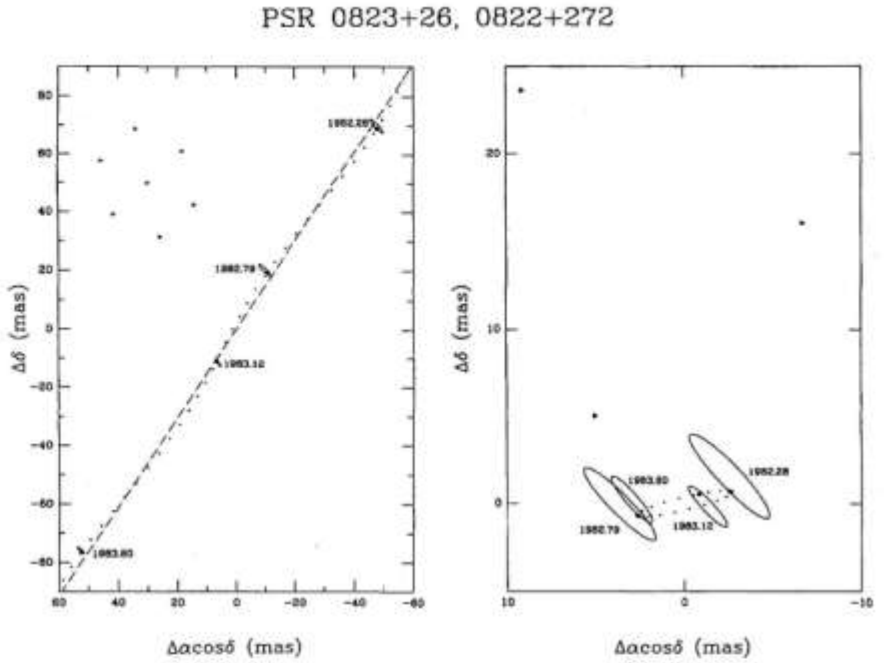
G.C.

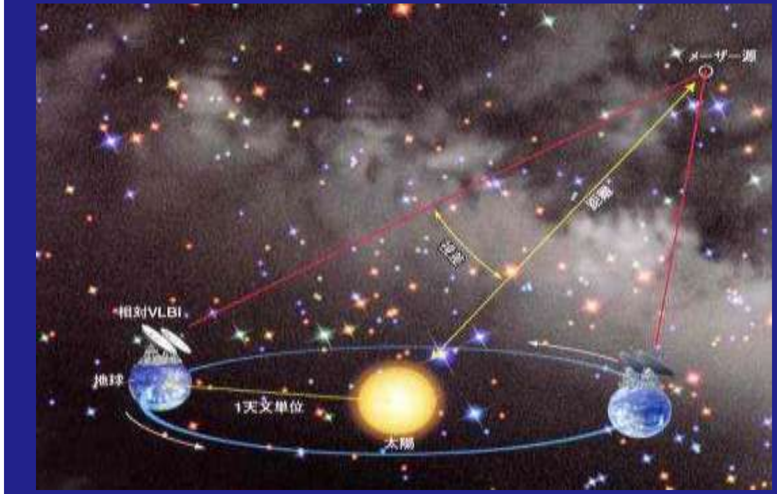
Tylor, Manchester, and Lyne,
ApJ Supple, 88, 529, 1993

Distribution of known H_2O maser sources near the Galactic plane and their expected errors of distance determination.

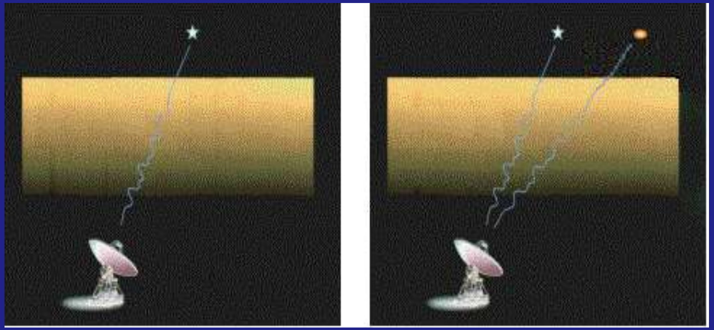








Parallax measurement

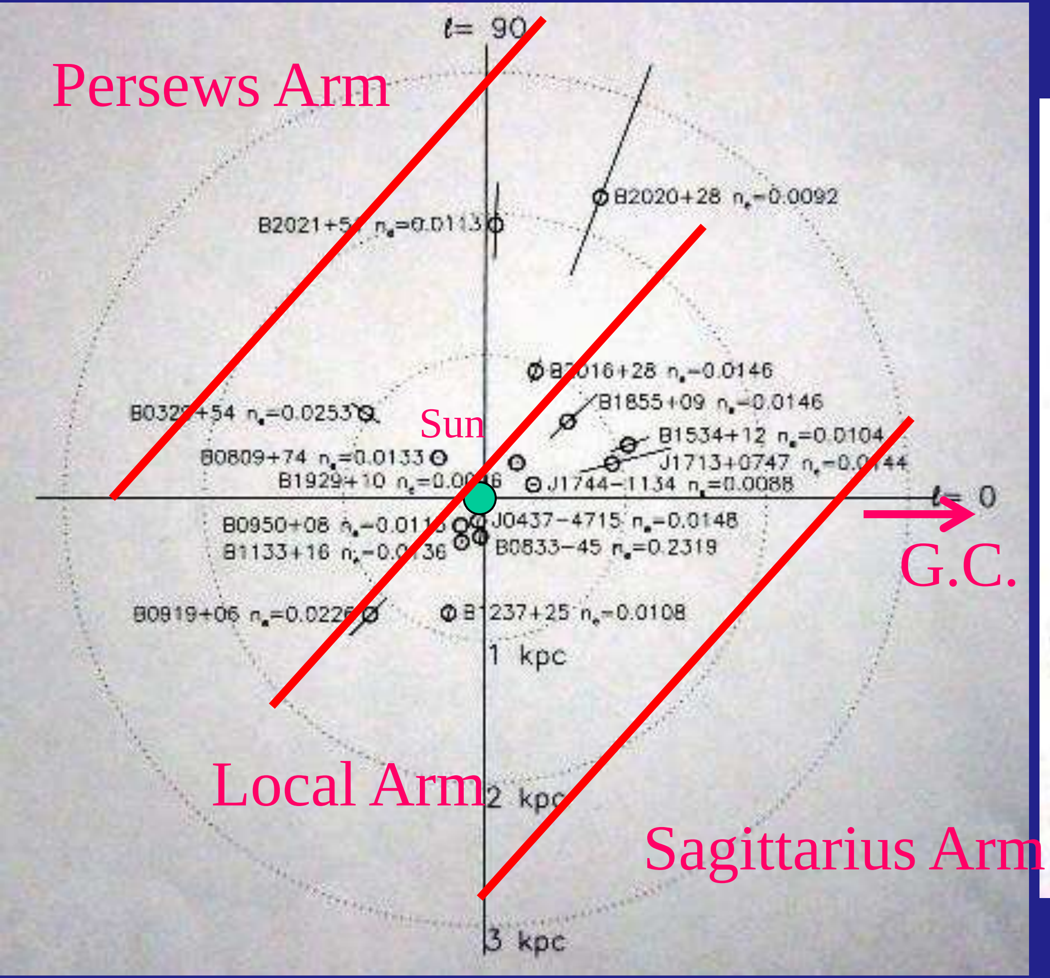


Differential VLBI

Gwinn et al. 1986

Arecibo, North American VLBI 1.66GHz
PSR0950+08 7.9(0.8)mas
PSR0823+26 2.8(0.6)mas

Position of pulsars based on the parallax measurement of them.(Left)
Derived Parameter of IMS by pulsars (Right).



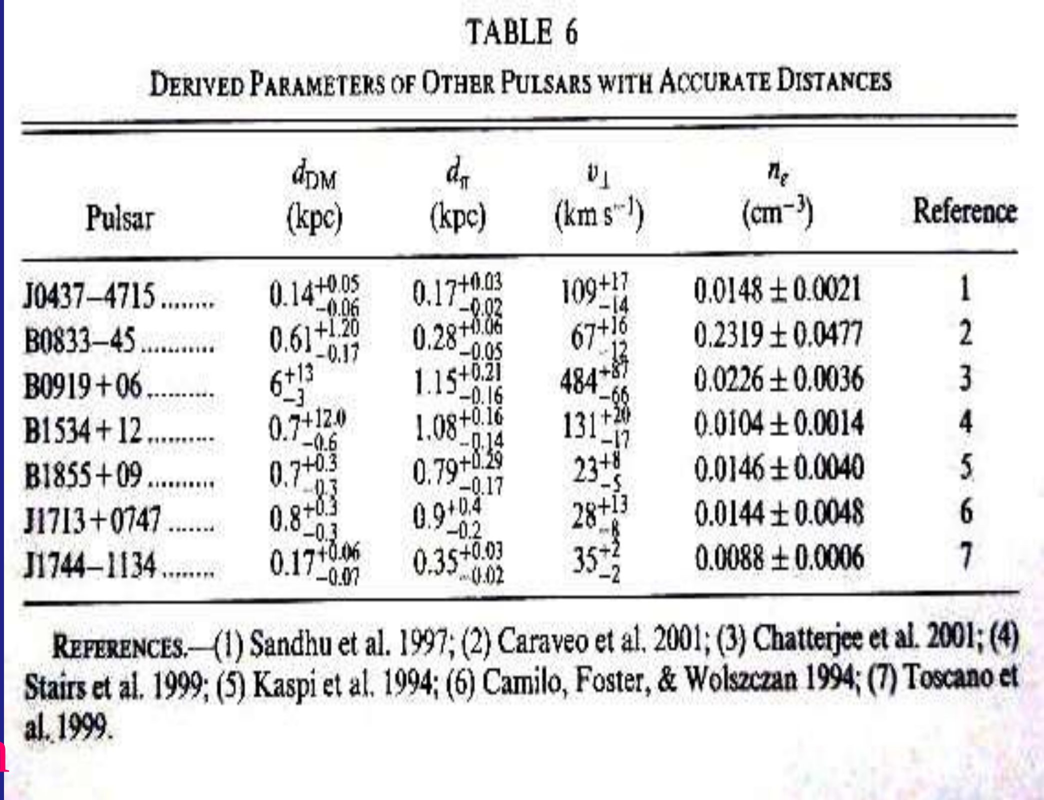


TABLE 6

DERIVED PARAMETERS OF OTHER PULSARS WITH ACCURATE DISTANCES

Pulsar	$d_{\rm DM}$ (kpc)	d_π (kpc)	$v_\perp$ (km s^{-1})	n_e (cm^{-3})	Reference
J0437−4715	$0.14^{+0.05}_{-0.06}$	$0.17^{+0.03}_{-0.02}$	109^{+17}_{-14}	0.0148 ± 0.0021	1
B0833−45	$0.61^{+1.20}_{-0.17}$	$0.28^{+0.06}_{-0.05}$	67^{+16}_{-12}	0.2319 ± 0.0477	2
B0919+06	6^{+13}_{-3}	$1.15^{+0.21}_{-0.16}$	484^{+87}_{-66}	0.0226 ± 0.0036	3
B1534+12	$0.7^{+12.0}_{-0.6}$	$1.08^{+0.16}_{-0.14}$	131^{+20}_{-17}	0.0104 ± 0.0014	4
B1855+09	$0.7^{+0.3}_{-0.3}$	$0.79^{+0.29}_{-0.17}$	23^{+8}_{-5}	0.0146 ± 0.0040	5
J1713+0747	$0.8^{+0.3}_{-0.3}$	$0.9^{+0.4}_{-0.2}$	28^{+13}_{-8}	0.0144 ± 0.0048	6
J1744−1134	$0.17^{+0.06}_{-0.07}$	$0.35^{+0.03}_{-0.02}$	35^{+2}_{-2}	0.0088 ± 0.0006	7

REFERENCES.—(1) Sandhu et al. 1997; (2) Caraveo et al. 2001; (3) Chatterjee et al. 2001; (4) Stairs et al. 1999; (5) Kaspi et al. 1994; (6) Camilo, Foster, & Wolszczan 1994; (7) Toscano et al. 1999.

Ex. Brisken et al. 2002

Parallaxes of 47 Pulsars

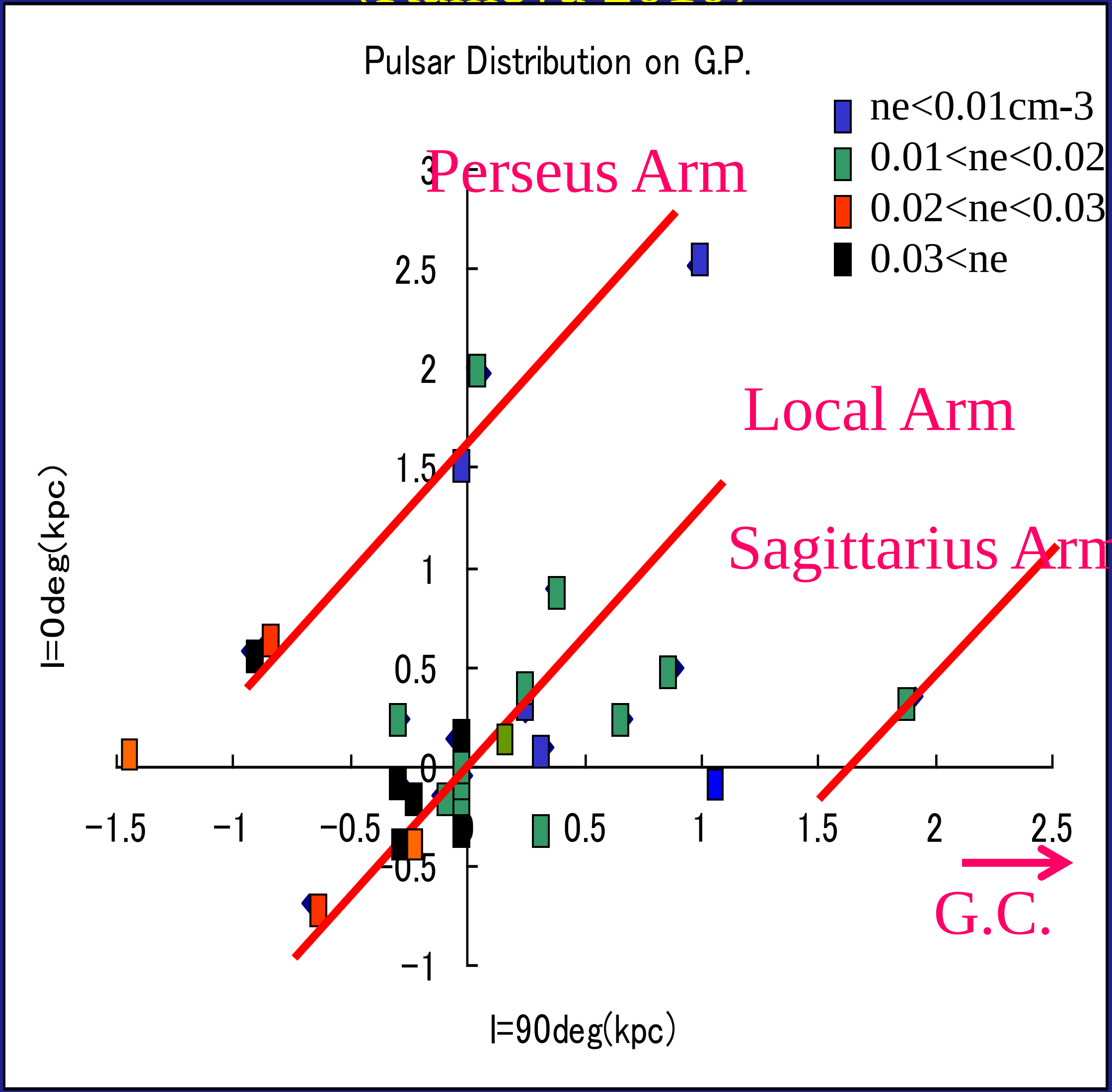
Brisken & Chatterjee & others 28 pulsars

- **22 pulsars are better than 100μarcsec.**

PSR J0030+0451	3.4(0.6)mas	Lommen et al. 2005 timing	
	3.3(0.9)mas	Lommen et al. 2006 timing	
	4.1(0.7)mas	Abdo et al. 2009 timing	
PSR B0031-07	0.93(0.08)mas	Chatterjee et al. 2009	1
PSR B0108-1431	4.17(1.42)mas	Deller et al. 2009	
PSR B0136+57	0.37(0.04)mas	Chatterjee et al. 2009	2
PSR B0329+54	0.94(0.11)mas	**Brisken et al.** 2002	
	<1.5mas	Chatterjee et al. 2004	
PSR B0355+54	0.91(0.16)mas	Chatterjee et al. 2004	
PSR J0437-4715	**6.65(0.07)mas**	**Verbiest et al. 2008 timing**	**3**
	6.3(0.2)mas	Hotan et al. 2006 timing	
	6.396(0.054)mas	**Deller et al. 2008 VLBI+timing**	
PSR B0450-18	0.65(1.40)mas	Chatterjee et al. 2009	
PSR B0450+55	0.84(0.05)mas	Chatterjee et al. 2009	4
PSR J0538+2817	0.68(0.15)mas	Ng et al. 2007	
	0.72(0.12)mas	Chatterjee et al. 2009	
PSR J0613-0200	2.1(0.6)mas	Hotan et al. 2006 timing	
PSR B0630-2834	3.01(0.41)mas	Deller et al. 2009	
PSR B0656+14	3.47(0.36)mas	**Brisken et al.** 2003	
		Golden et al. 2005	
RX J0720.4-31.25	2.8(0.9)mas	Kaplan et al. 2007 HUBBLE	
PSR B0737-3039	0.87(0.14)mas	Deller et al. 2009	
PSR B0809+74	**2.31(0.04)mas**	**Brisken et al.** 2002	5
PSR B0818-13	0.51(0.04)mas	Chatterjee et al. 2009	6
PSR B0823+26	**1.8(0.4)mas**	**Gwinn 1984**	
	2.8(0.6)mas	**Gwinn et al. 1986**	7
VELA pulsar	3.4(0.7)mas	Caraveo et al. 2001 HUBBLE	8
	3.5(0.2)mas	Dodson et al. 2003	9
PSR B0919+06	0.31(0.14)mas	Fomalont et al. 1999	
	0.83(0.13)mas	Chatterjee et al. 2000	
PSR B0950+08	7.9(0.8)mas	Gwinn et al. 1986	
	3.6(0.3)mas	**Brisken et al.** 2001	
	3.82(0.07)mas	**Brisken et al.** 2002	10
PSR J1022+1001	2.5(0.8)mas	Hotan et al. 2006 timing	
PSR J1024-0719	1.9(0.8)mas	Hotan et al. 2006 timing	
PSR B1133+16	2.80(0.16)mas	**Brisken et al.** 2002	
PSR B1237+25	**1.16(0.08)mas**	**Brisken et al.** 2002	11
PSR B1451-68	2.2(0.3)mas	Bailes et al. 1990	
PSR B1508+55	**0.415(0.037)mas**	Chatterjee et al. 2005	
	0.47(0.03)mas	Chatterjee et al. 2009	12
PSR B1534+12	0.925(0.13)mas	Stairs et al. 1999	
PSR B1541+09	0.13(0.02)mas	Chatterjee et al. 2009	13
PSR J1559-4438	0.384(0.081)mas	Deller et al. 2009	
PSR J1713+0747	**0.89(0.08)mas**	Splaver et al. 2005 timing	
	1.1(0.1)mas	Hotan et al. 2006 timing	
	0.95(0.06)mas	Chatterjee et al. 2009	14
PSR J1744-1133	2.8(0.3)mas	Toscano et al. 1999 timing	
	2.1(0.4)mas	Hotan et al. 2006 timing	
PSR B1857-26	0.5(0.6)mas	Fomalont et al. 1999	
PSR B1929+10	21.5(8.0)mas	Salter et al. 1979,	
	<4mas	Backer & Sramek 1982	
	3.02(0.09)mas	**Brisken et al.** 2002	
	2.77(0.07)mas	Chatterjee et al. 2004	15
PSR J1909-3744	**0.88(0.04)mas**	Hotan et al. 2006 timing	16
PSR B1933+16	0.22(0.12)mas	Chatterjee et al. 2009	
PSR B2016+28	1.03(0.10)mas	**Brisken et al.** 2002	17
PSR B2020+28	0.37(0.12)mas	**Brisken et al.** 2002	
PSR B2021+51	0.95(0.37)mas	Campbell et al. 1996	
	0.50(0.07)mas	**Brisken et al.** 2002	18
PSR B2045-16	1.05(0.03)mas	Chatterjee et al. 2009	19
PSR B2048-1616	1.712(0.909)mas	Deller et al. 2009	
PSR B2053+36	0.17(0.03)mas	Chatterjee et al. 2009	20
PSR J2124-3358	4(2)mas	Hotan et al. 2006 timing	
PSR B2144-3933	6.051(0.560)mas	Deller et al. 2009	
PSR J2145-0750	2.0(0.6)mas	Loehmer et al. 2004 timing	
PSR B2154+40	0.28(0.06)mas	Chatterjee et al. 2009	21
PSR B2310+42	0.93(0.07)mas	Chatterjee et al. 2009	22

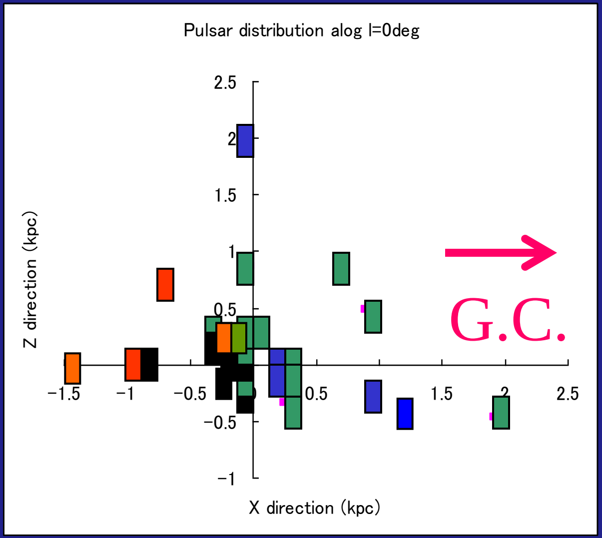
Results of n_e for parallax data

（Kameva 2010）



Left:
Distribution of pulsars and interstellar ionized gas density on the Galactic plane

Right:
X VS Z



Pulsar observations by Japanese Activity

１. Pulsar VLBI observations using VERA & Kashima34m, and Japanese VLBI Network stations. Also collaborate with Asian countries.

6.8GHz, 2GHz or 1.7/１. 4GHz

higher sensitivity > large antennas & add pulsar gating machanism to the Software correlator

(with Dr. Oyama).

2. Observations of Giant pulse of pulsars

with NICT group (Drs. Sekido, Terasawa, and Takefuji, ,,,)

SKA（Square Kilometer Array)

Frequency band：0.1－10GHz(25GHz)

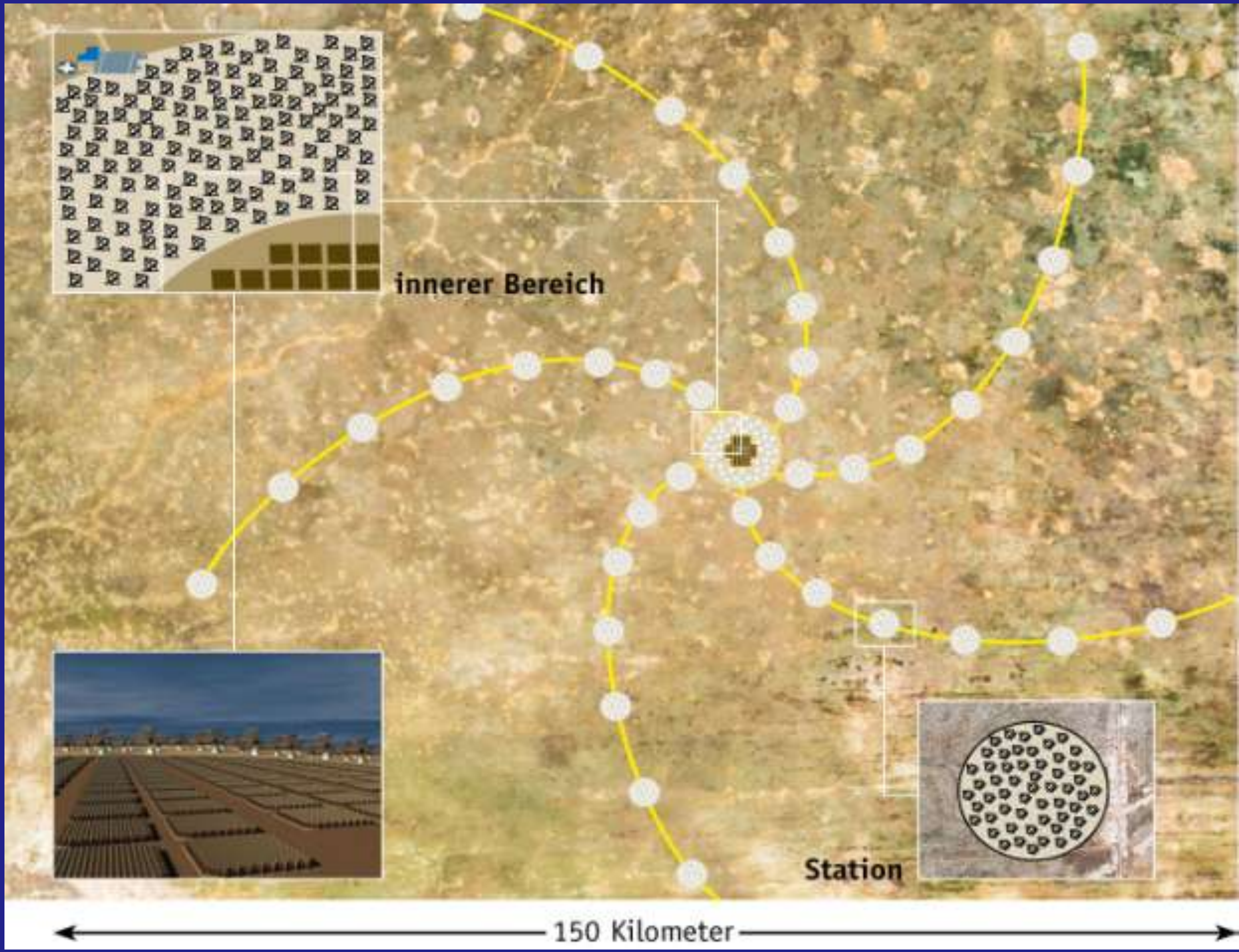
Low-band: 100-500MHz

Mid-band:500MHz-10GHz

High-band: 10GHz-25GHz

Antennae：

- Aperture Array (Low band)
  Dense AA, Sparse AA
- 2000-3000 dishes (Mid band)
  WBSPF, PAF



Longer Baseline（～9000km） is necessary for pulsar study!

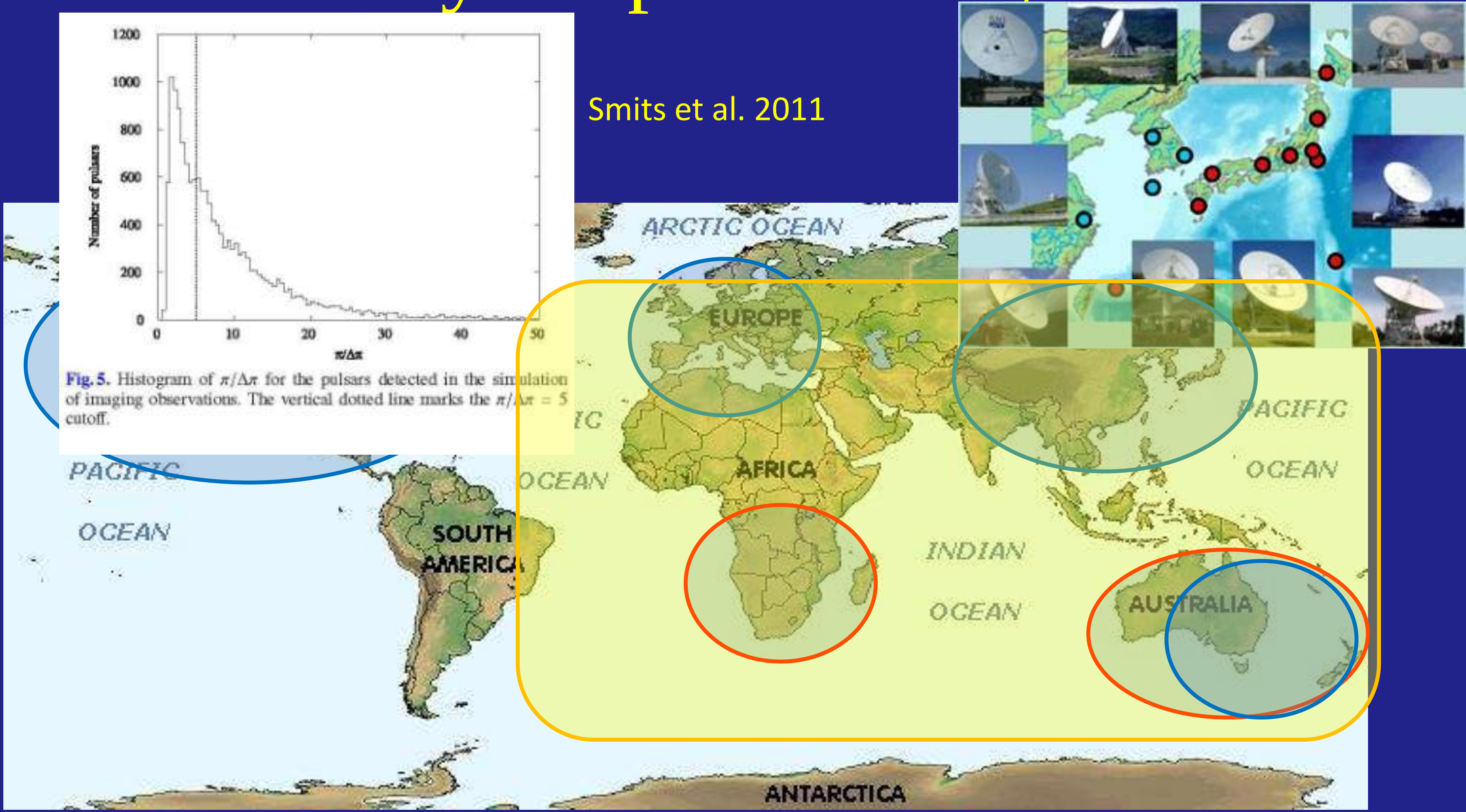


Fig. 5. Histogram of $\pi/\Delta\pi$ for the pulsars detected in the simulation of imaging observations. The vertical dotted line marks the $\pi/\Delta\pi = 5$ cutoff.

Smits et al. 2011

Summary

- SKA can discover pulsars whole in our Galaxy.
- Determination of distances of pulsars:
  - improve theoretical model of pulsars.
  - density distribution of interstellar ionized gas.
- Pulsar timing observations are important for study of Giant pulses and detection of gravitational wave etc.
- Japanese groups have some activities on pulsar study.

  (GP and VLBI astrometry etc)