Link of reference frames by pulsar observations

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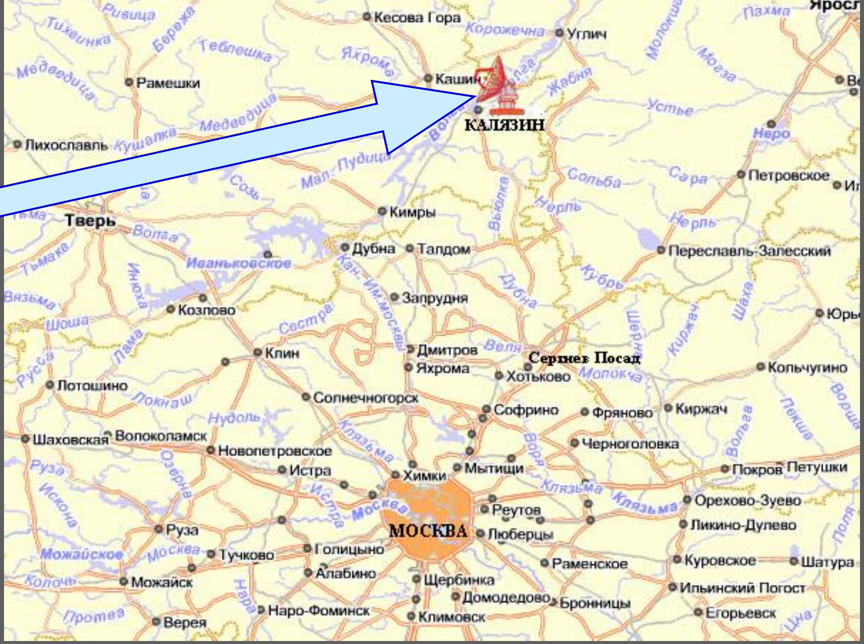
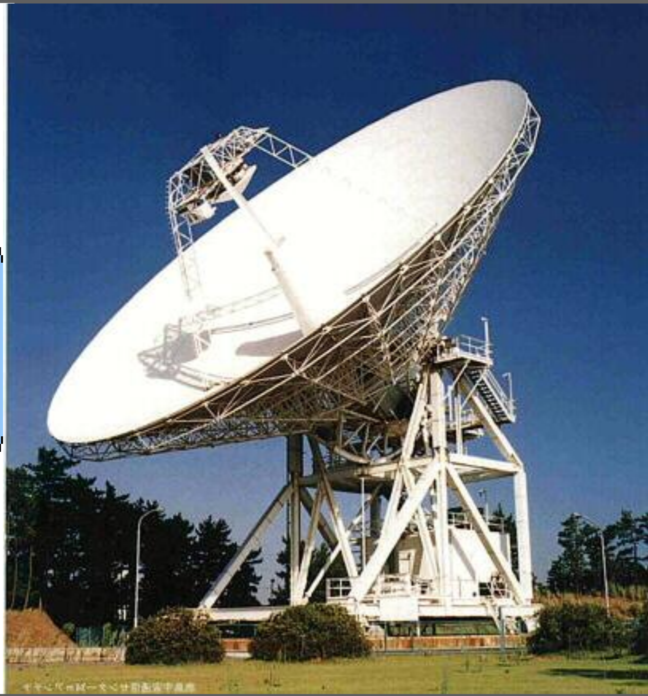
Introduction

- two sets of pulsar data are used
- pulsar VLBI experiments
- pulsar timing at RT-64
- results



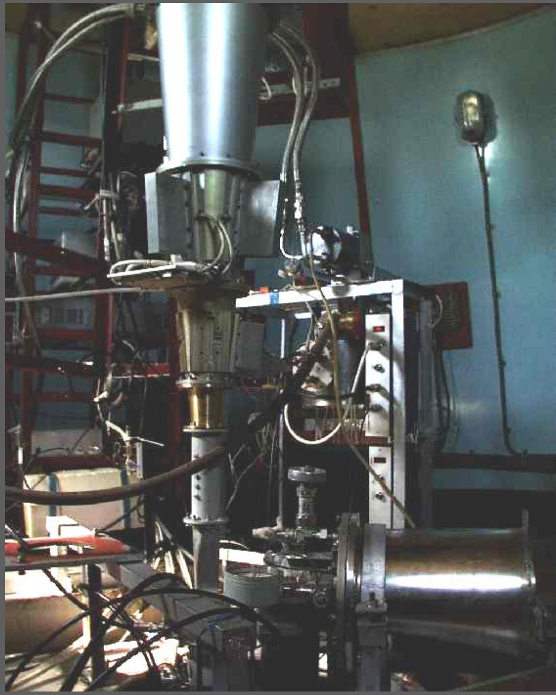
- 64 m radio telescope (Kalyazin, Russia)
- 34 m radio telescope (Kashima, Japan)
- K4 VLBI registrator
- K4 correlator

Kalyazin - Kashima baseline 7000km



Kalyazin 64m antenna control room

Parameters of interferometer Kalyazin - Kashima



- 7000km
- 1.4GHz, 2.2GHz

Station	Kalyazin	Kashima
Diameter, m	64	34
Efficiency, L/S	0.55/0.55	0.55/0.6
T_{sys}, L/S	20K/10K	20K/20K

Pulsars detected

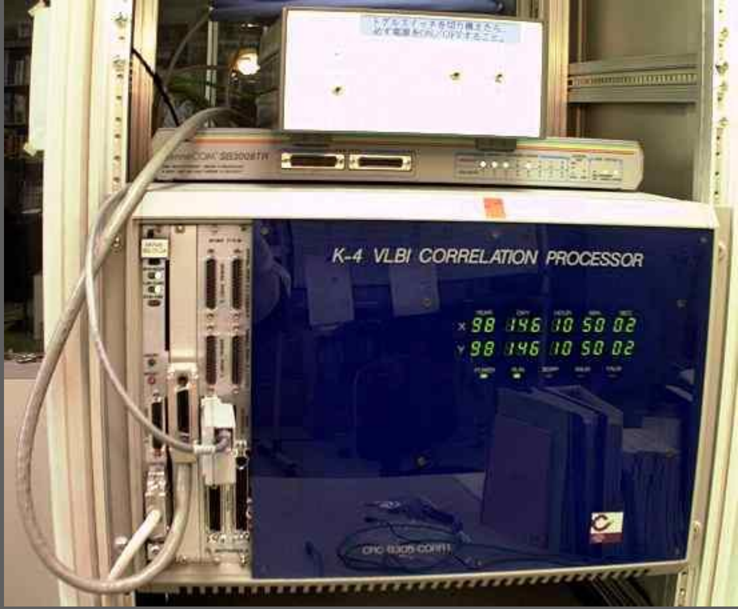
- March 1995: PSR B0329+54, B1933+16, B2021+51, B1937+21
- May 1996: PSR B0329+54, B0950+08
- May 1997: PSR B0329+54, B2111+46
- May 1998: PSR B0329+54, B0950+08, B1237+25

Kalyazin 64m - Kashima 34m sensitivity

Pulsars with flux > 20 - 30 mJy are detected (SNR >= 7).

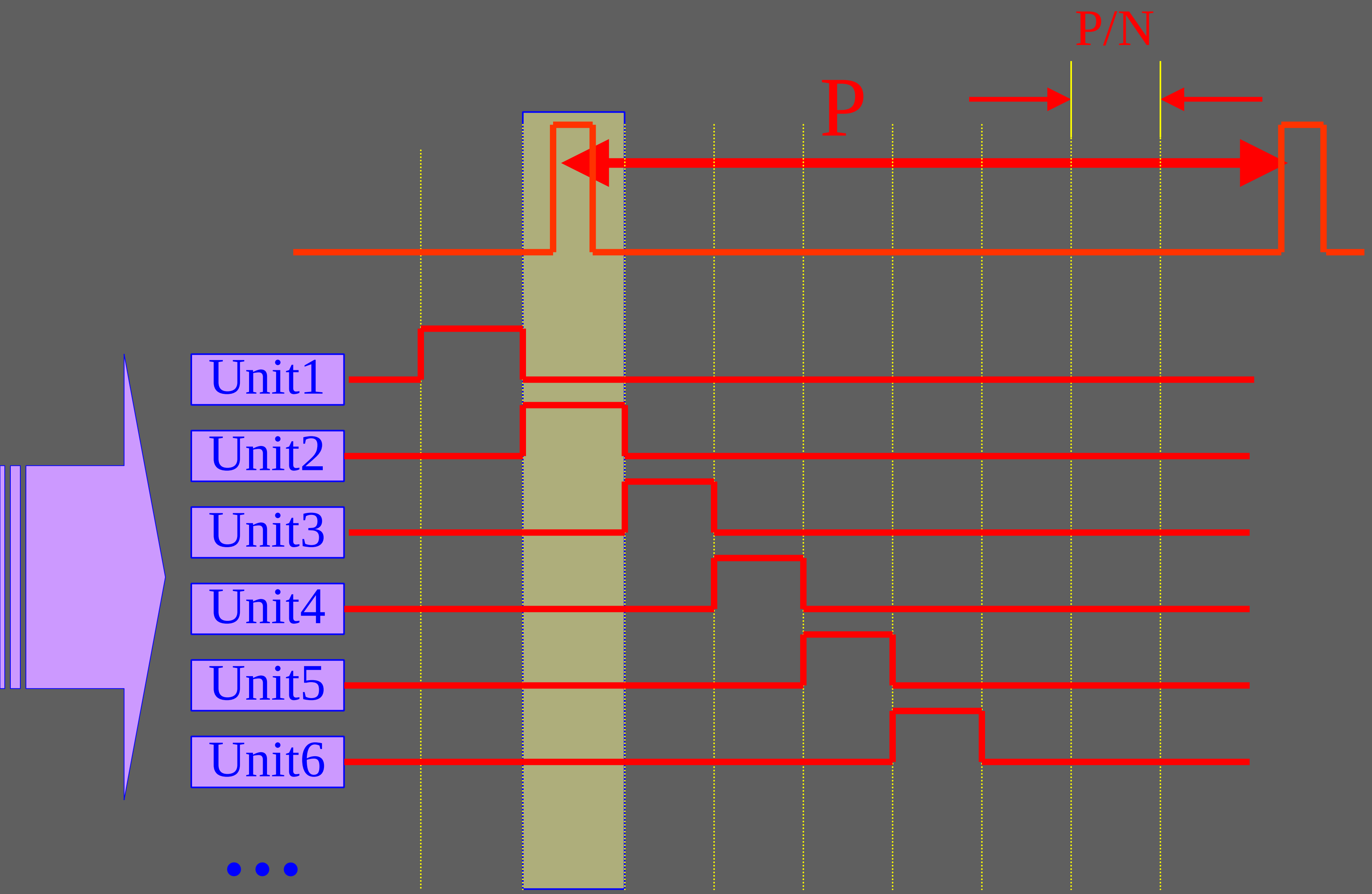
$$S_{\min} = 25\,\mathrm{mJy}\sqrt{\left(\frac{300\ \sec}{T}\right)\left(\frac{40\,\mathrm{MHz}}{\Delta f}\right)\left(\frac{20}{N_{\mathrm{div}}}\right)}$$

K4 correlator



- 16 unit X 18 lag = 288 lag
- 68040 CPU, GP-IB, Ethernet
- Pulsar Gate
- IERS Conventions (1996)

Gate-function



M.Sekido, Pulsar astrometry by VLBI, PhD thesis, Tokyo, 2001

CALP

Algorithm from the paper (Doroshenko, Kopeikin, 1990) have been used to predict pulsar phase and apparent period:

$$c(t_i - t_i') = \vec{k}_i \vec{r} - \frac{1}{2R}[\vec{k}_i \times \vec{r}]^2 + \Delta_{\mathrm{orb}} + \delta t_{rel} + 10^{-2} \frac{DM}{2.41} \frac{1}{f_{obs}^2}$$

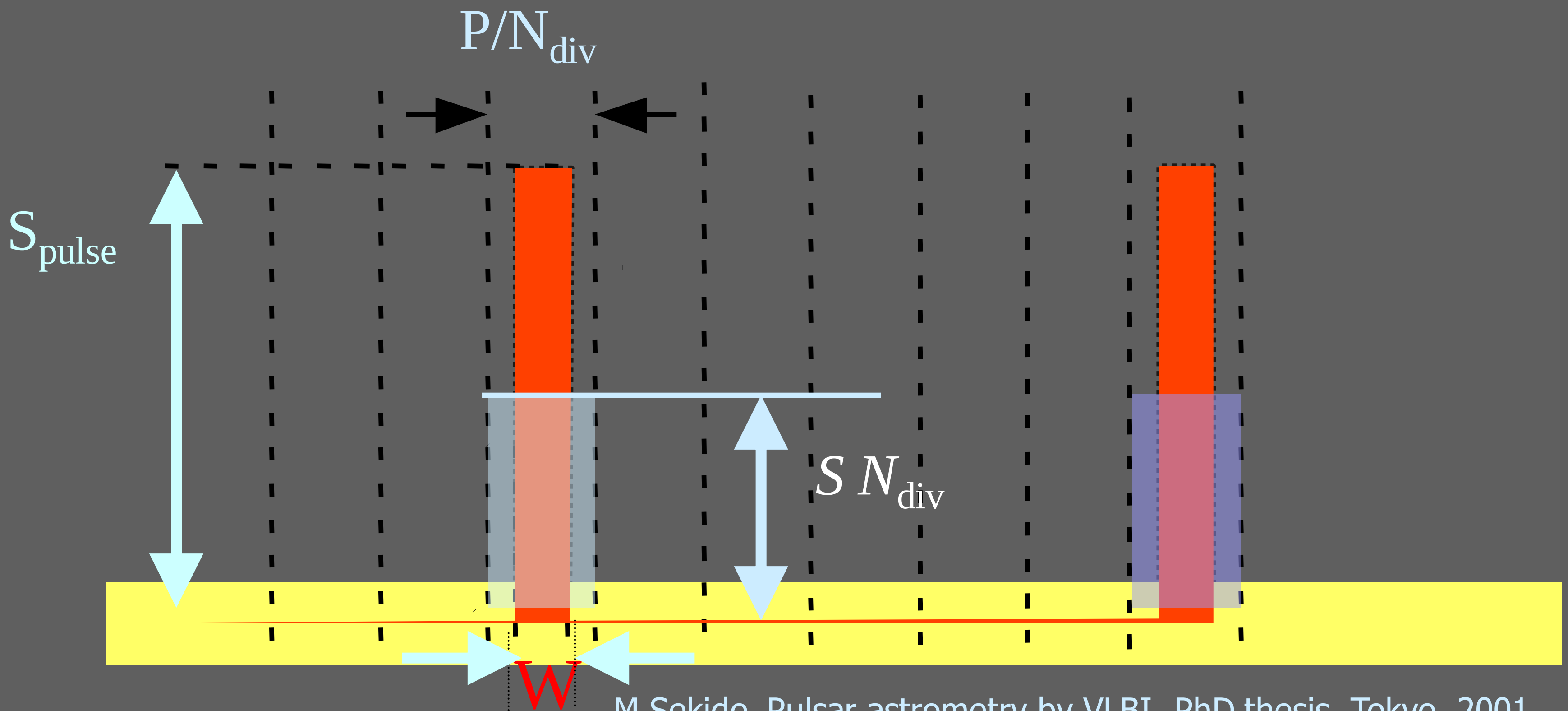
Pulsar Gate: Signal to Noise Ratio

$$\rho \propto S_{\mathrm{pulse}} \times N_{\mathrm{div}}, \quad W < \frac{P}{N_{\mathrm{div}}},$$

$$SNR \propto \rho \sqrt{\frac{T}{N_{\mathrm{div}}}} \sim \sqrt{N_{\mathrm{div}}}.$$

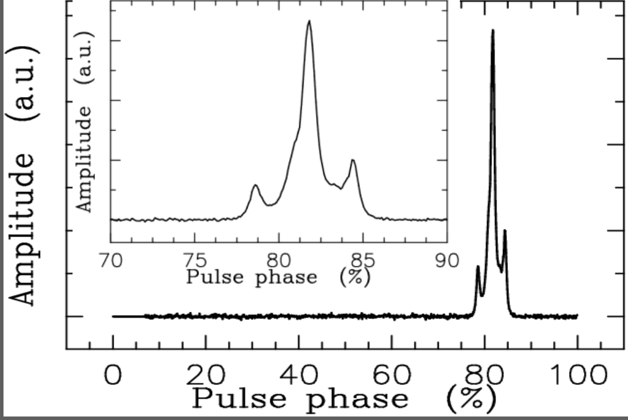
$$\rho \propto S_{\mathrm{pulse}}, \quad W > \frac{P}{N_{\mathrm{div}}},$$

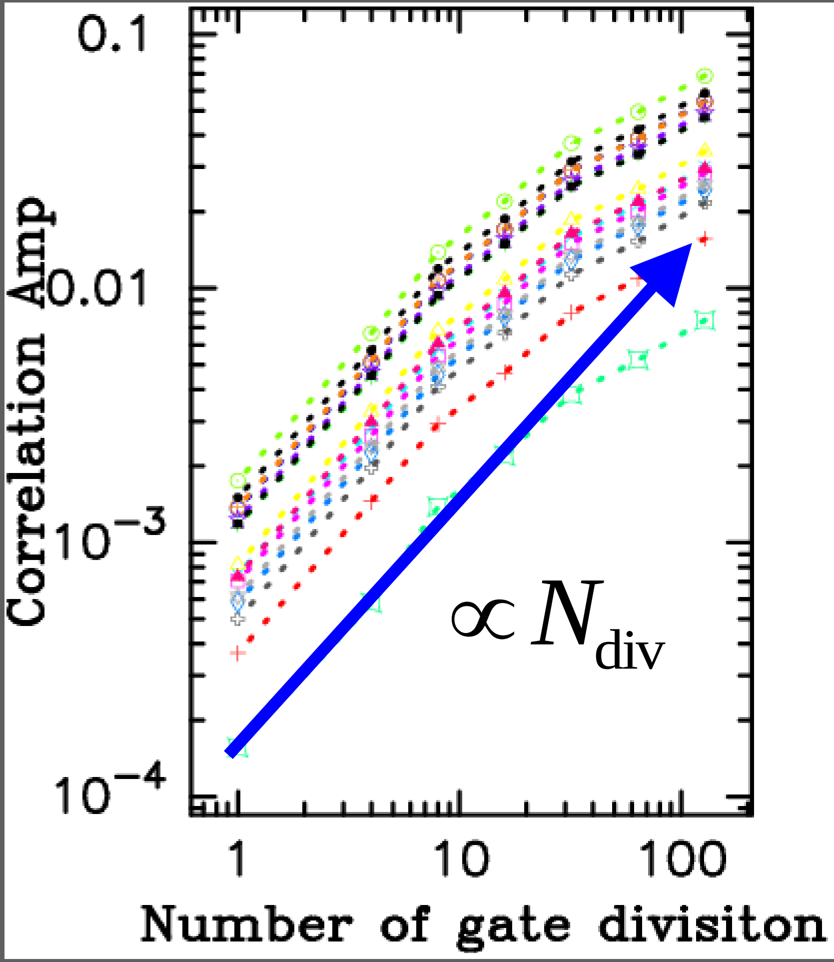
$$SNR \propto \rho \sqrt{\frac{T}{N_{\mathrm{div}}}} \sim \frac{1}{\sqrt{N_{\mathrm{div}}}}.$$

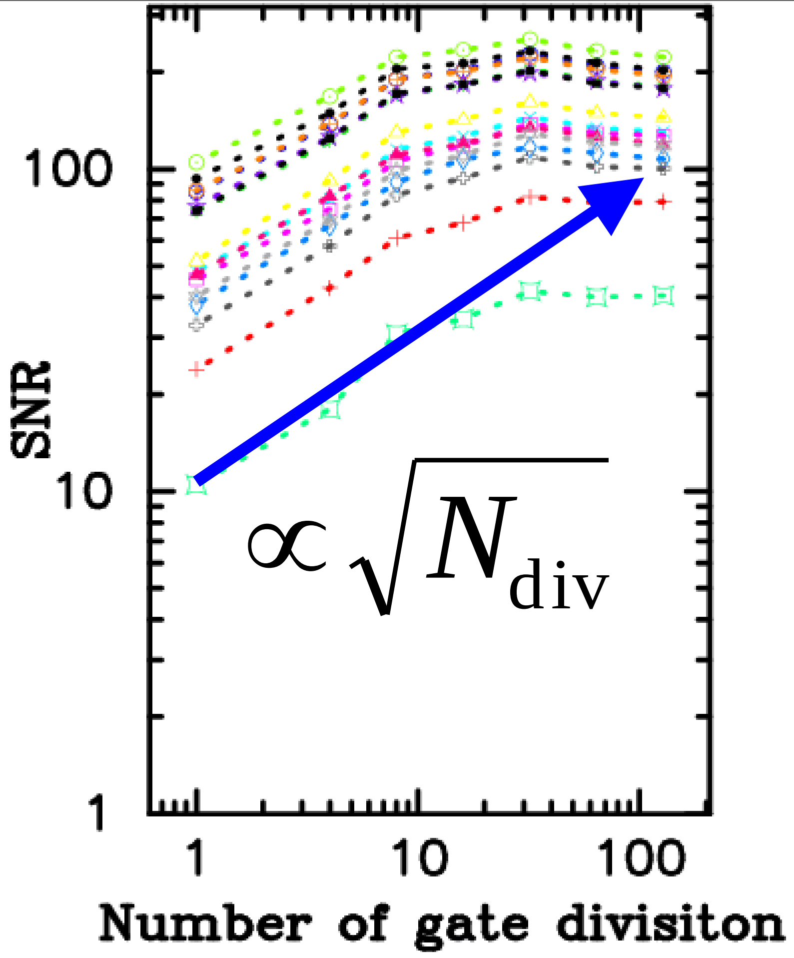


M.Sekido, Pulsar astrometry by VLBI, PhD thesis, Tokyo, 2001

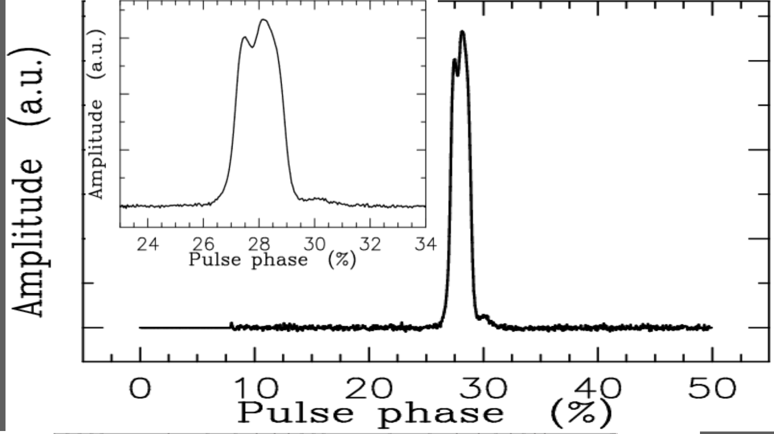
Correlation amplitude and SNR for PSR 0329+54

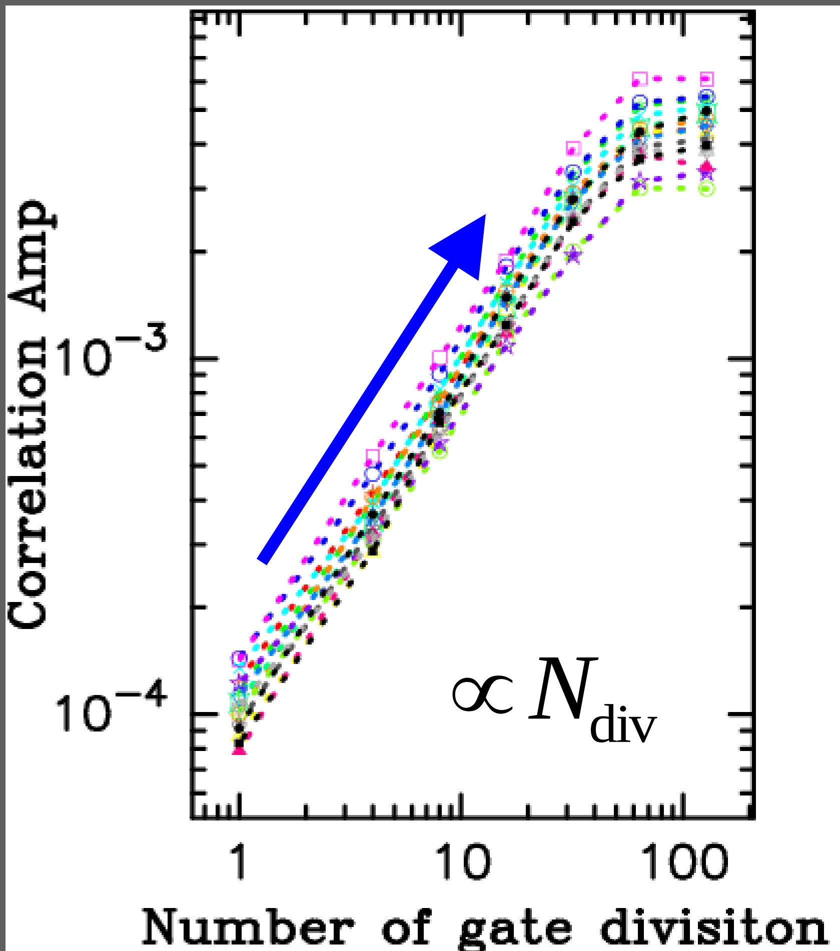


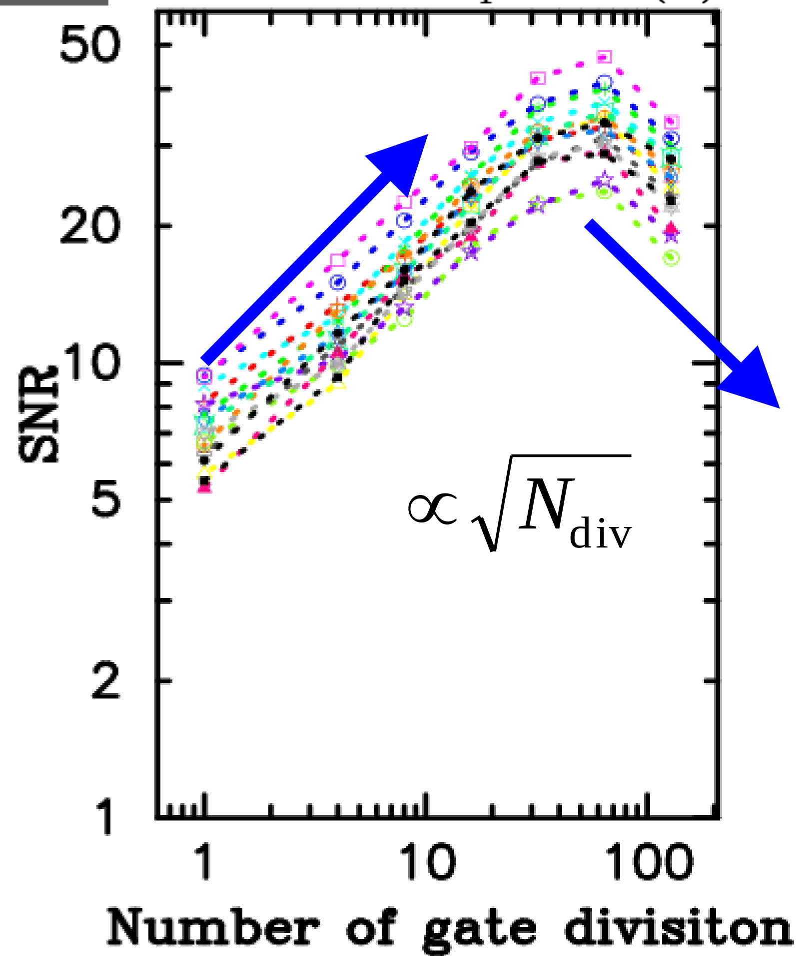




Correlation amplitude and SNR for PSR 1933+16

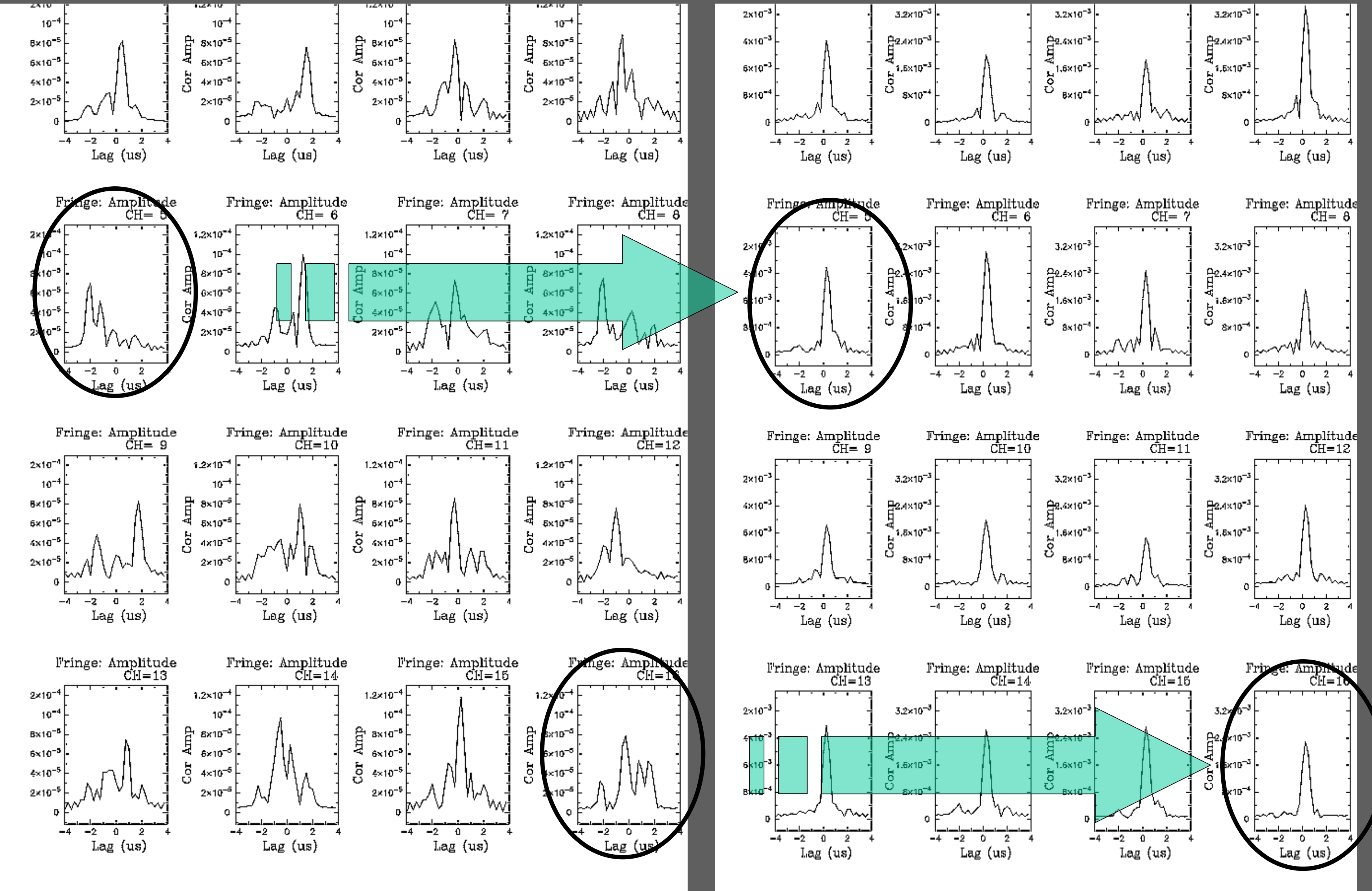






No Pulsar Gate

Pulsar Gate



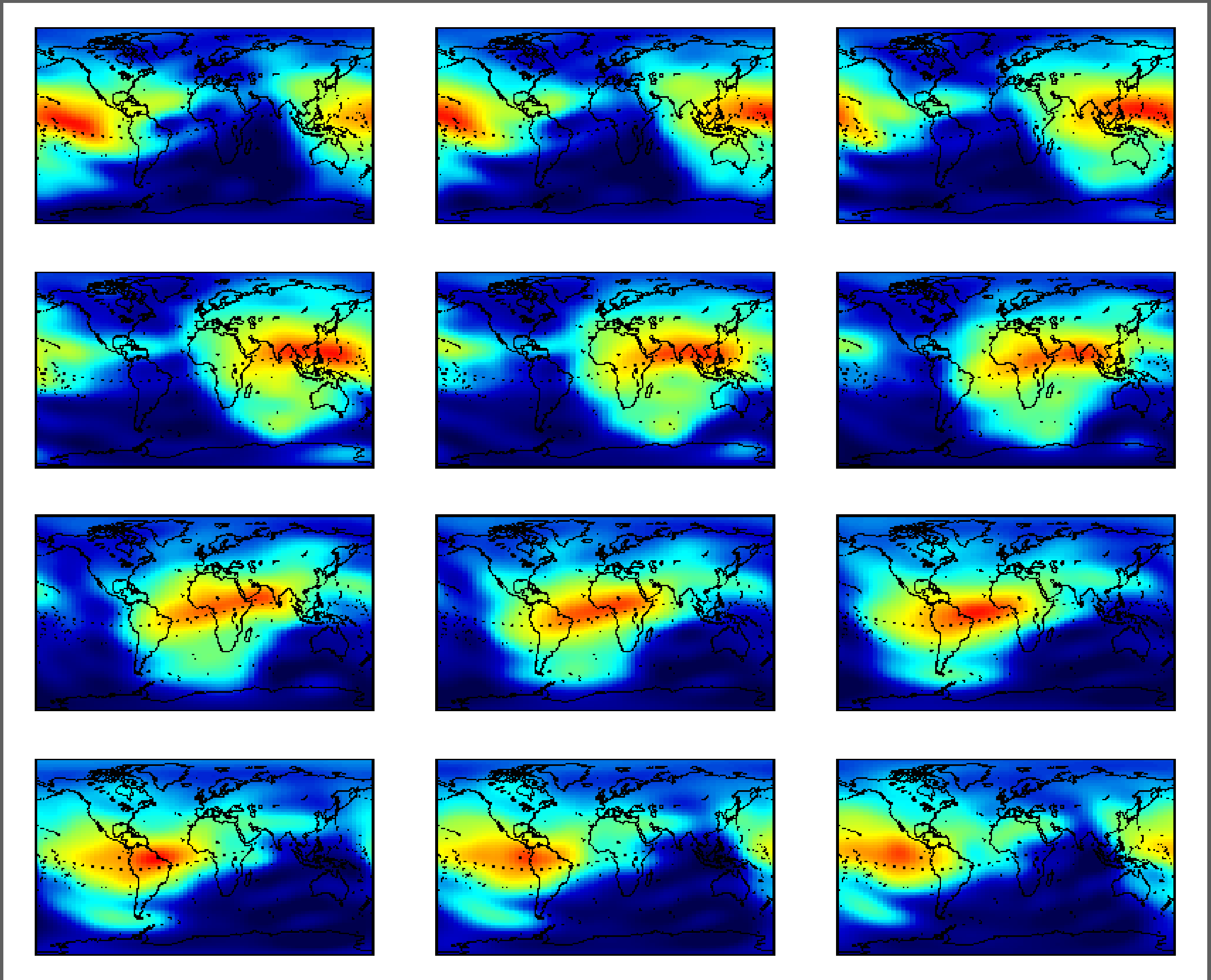
Global Ionosphere Map (GIM)

Ionosphere data were taken from the

Center for Orbit Determination in Europe (CODE) in Bern University

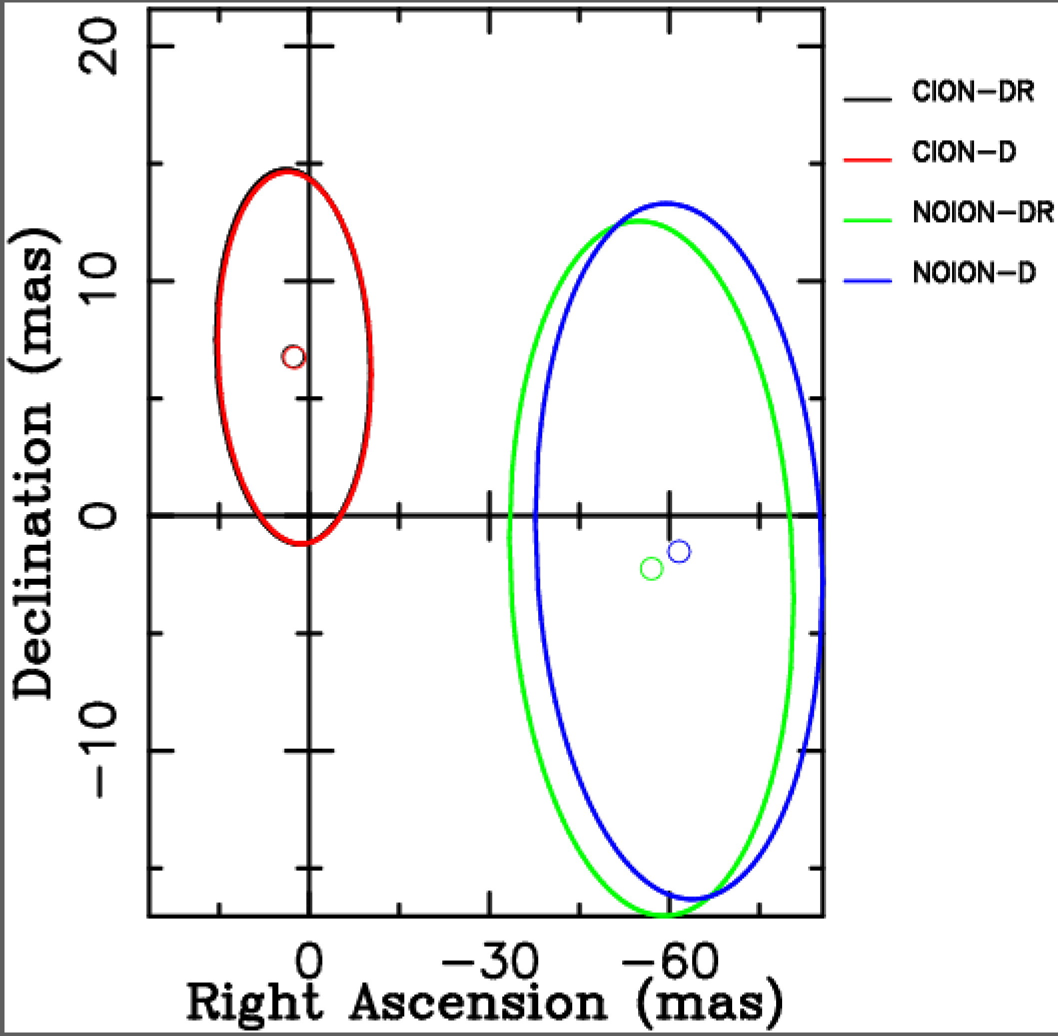
- 140 stations of IGS network
- Data Format
  - IONEX Format / Bern ION File
  - started 1995 1 1
  - distributed over Internet

Global Ionosphere Map/CODE



ICRF (0133+476)

- ICRF source 0133+476 (0.26mas)
- Experiment: 1996 May
- TEC data applied: shift 60 mas
- Software: Calc/Solve



Error Budget

- Station Coordinates (Kalyazin): H: 3 cm, V: 50 cm 4 mas
- ITRF - WGS84: 10cm 1 mas
- EOP (WOB, UT1 - UTC, CEP): 0.6 mas
- ISS: 0.1 - 0.6 mas
- Formal error of SOLVE analysis:

  2 - 100 mas

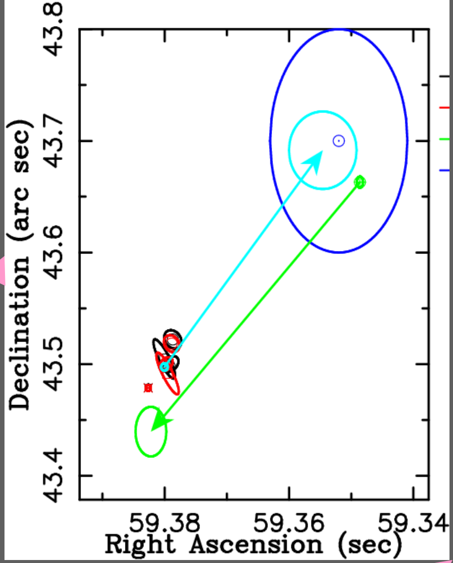
PSR 0329+54

$\alpha: 03^h32^m59.38000 \pm 0.0005$

$\delta: 54^o34'43''.498 \pm 0.004$

$\mu_\alpha: 13.5 \pm 3.6$ mas/yr

$\mu_\delta: -12.1 \pm 2.8$ mas/yr

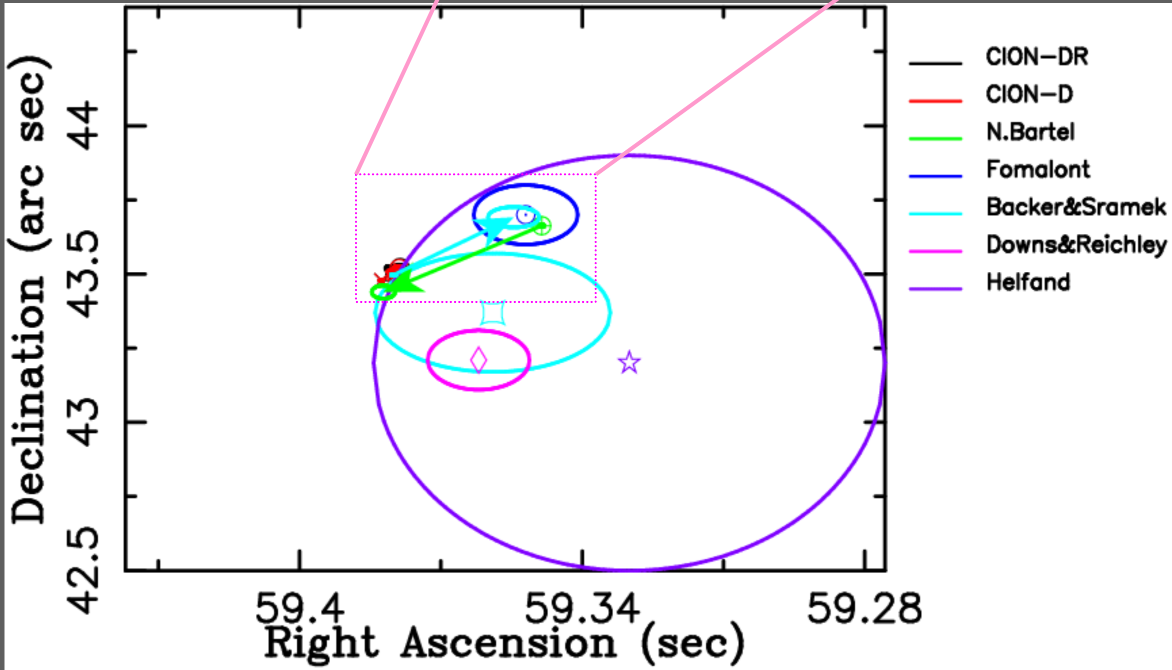


$\alpha: 03^h32^m59.3758 \pm 0.0004$

$\delta: 54^o34'43''.518 \pm 0.003$

$\mu_\alpha: 17.2 \pm 0.4$ mas/yr

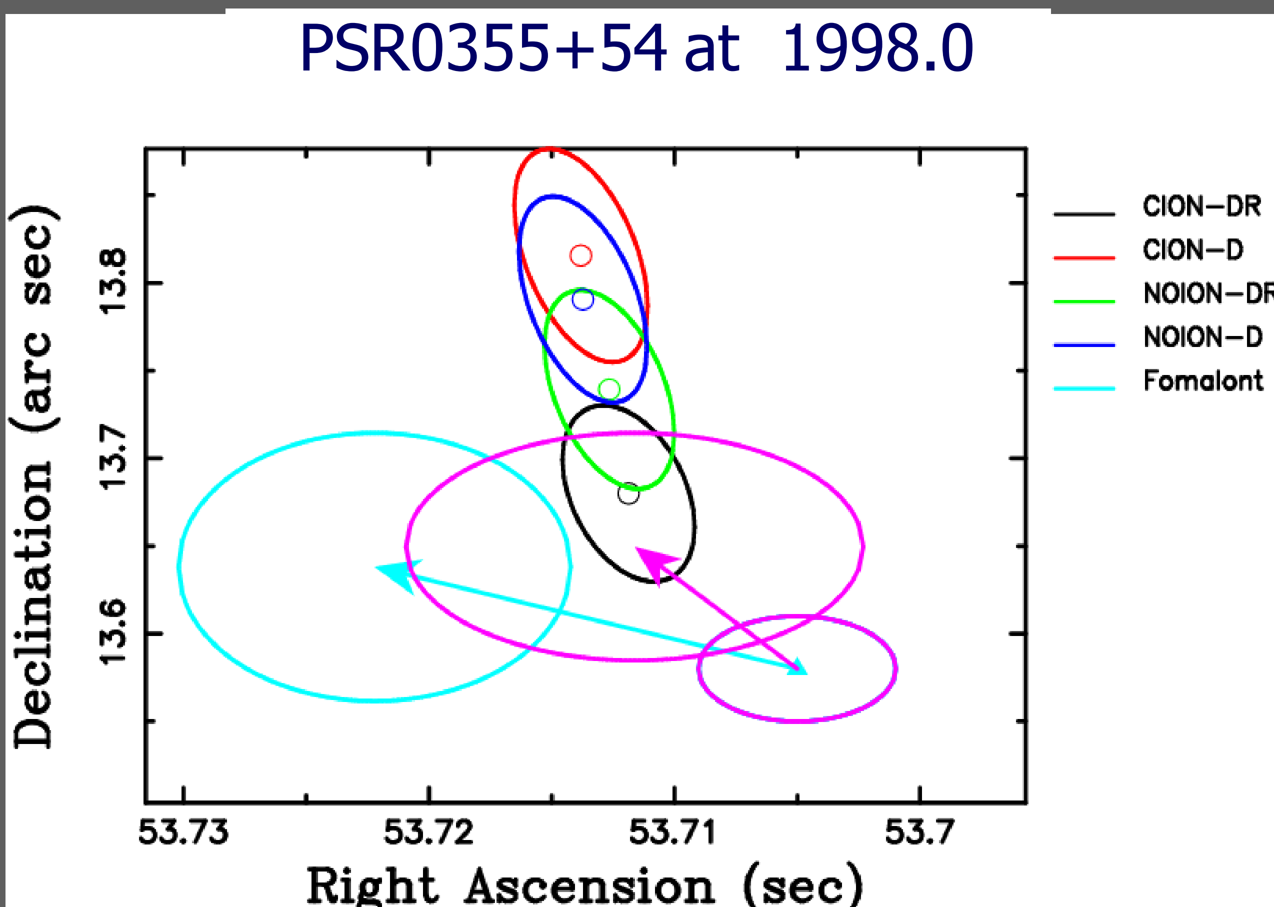
$\mu_\delta: -10.5 \pm 0.4$ mas/yr



PSR 0355+54

$\alpha : 03^{h}58^{m}53^{s}.7119 \pm 0.003$

$\delta : 54^{o}13'13''.6800 \pm 0.05$

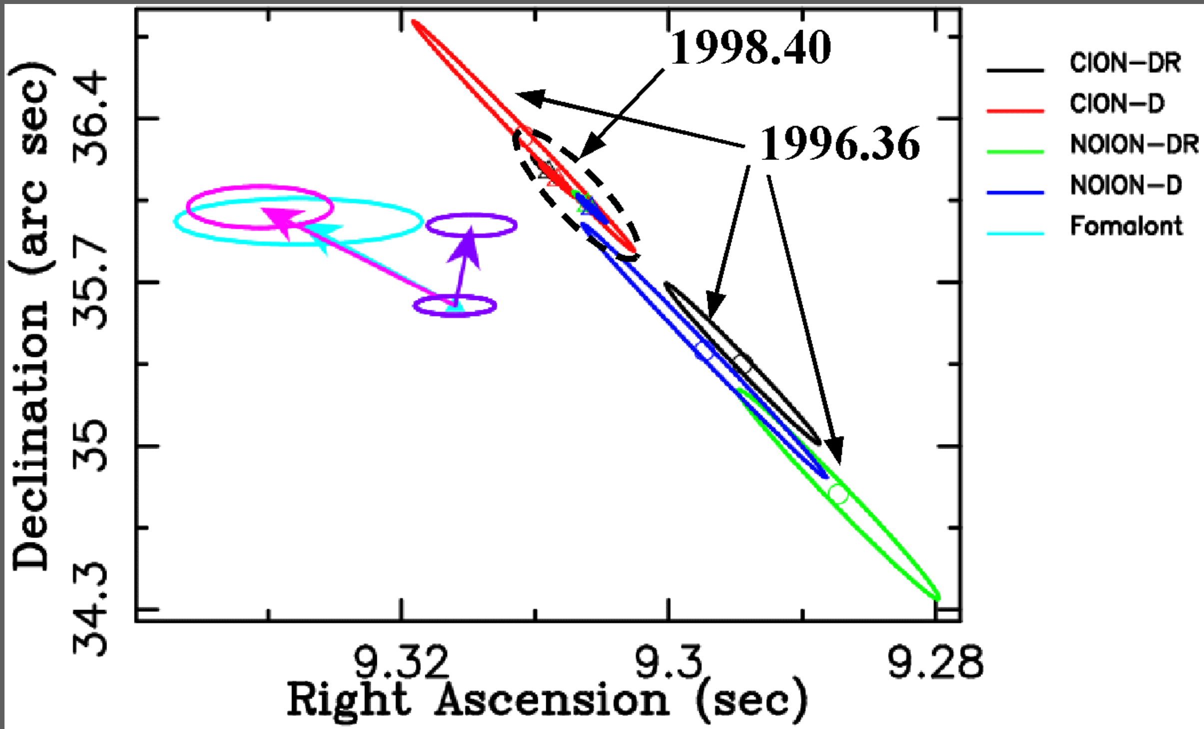


PSR 0950+08

$$\alpha : 09^{h}53^{m}09.308 \pm 0.001$$

$$\delta : 07^{o}55'36''.157 \pm 0.06$$

Fomalont (1992), Gwinn (1986), Lyne (1982), Brisken (2000)

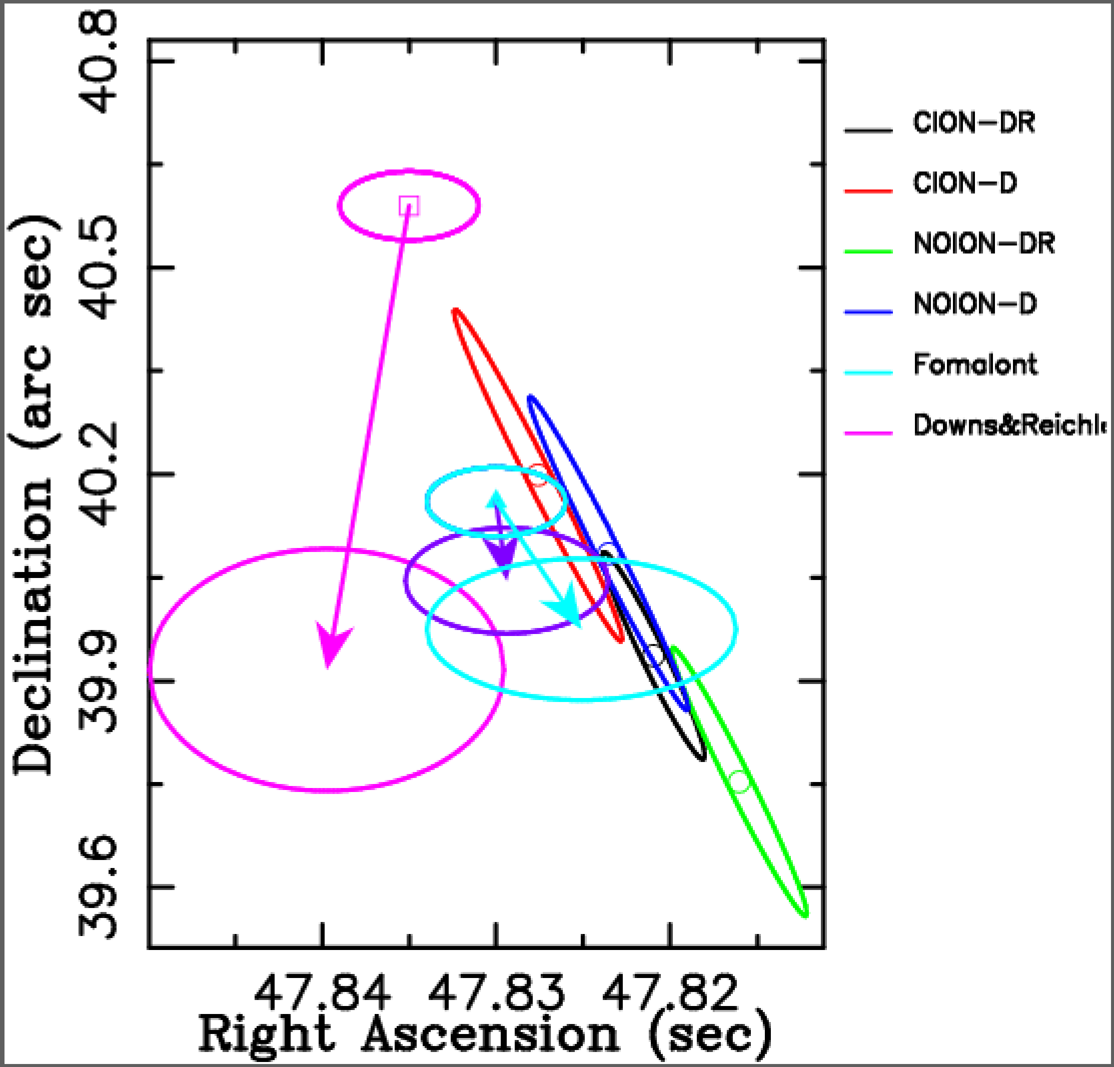


PSR 1933+16

- Downs & Reichly (timing:1983)
- VLA Fomalont et al. (1992)

$\alpha : 19^{h}35^{m}47.827 \pm 0.004$

$\delta : 16^{o}16'40''.3 \pm 0.2$

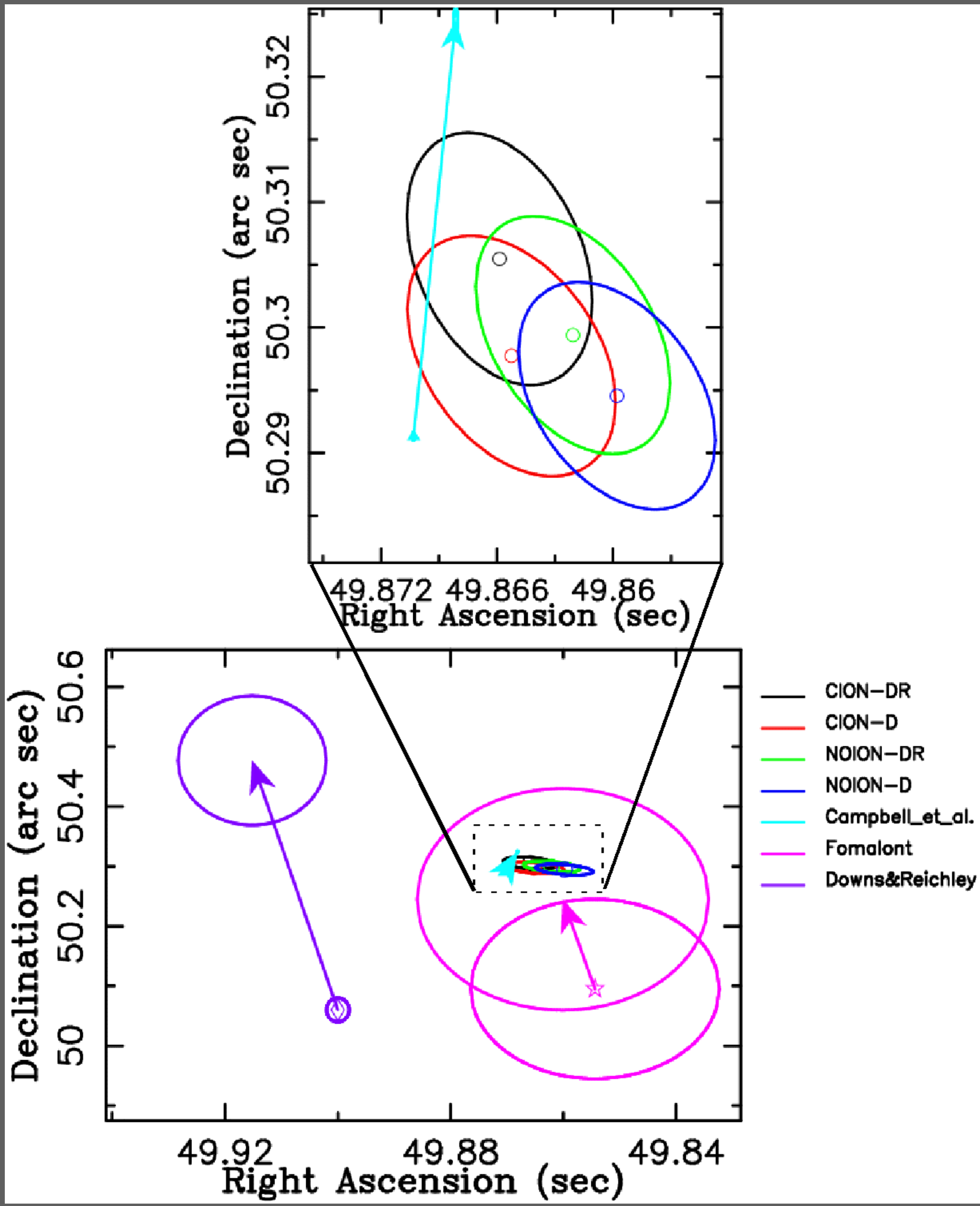


PSR 2021+51

- Fomalont et al. (1992) + Lyne et al. (1982), Campbell et al. (1986)

$\alpha : 20^{h}22^{m}49^{s}.866 \pm 0.005$

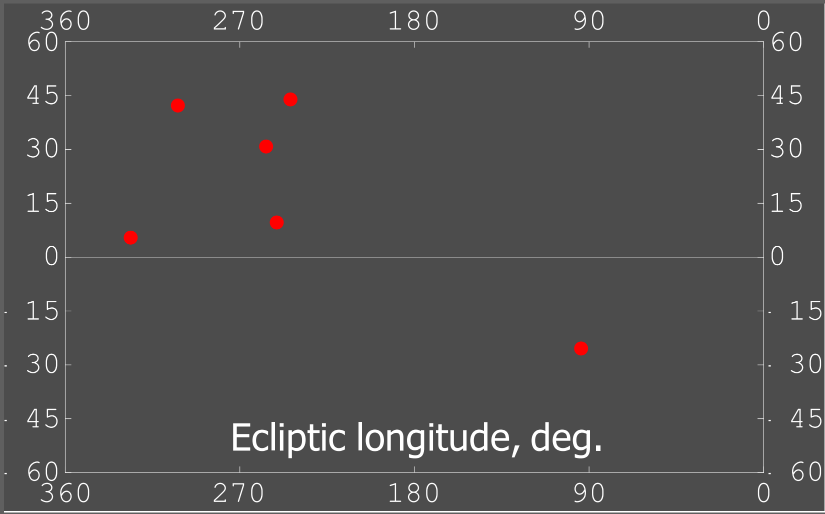
$\delta : 51^{o}54'50''.305 \pm 0.01$



Pulsar timing observations

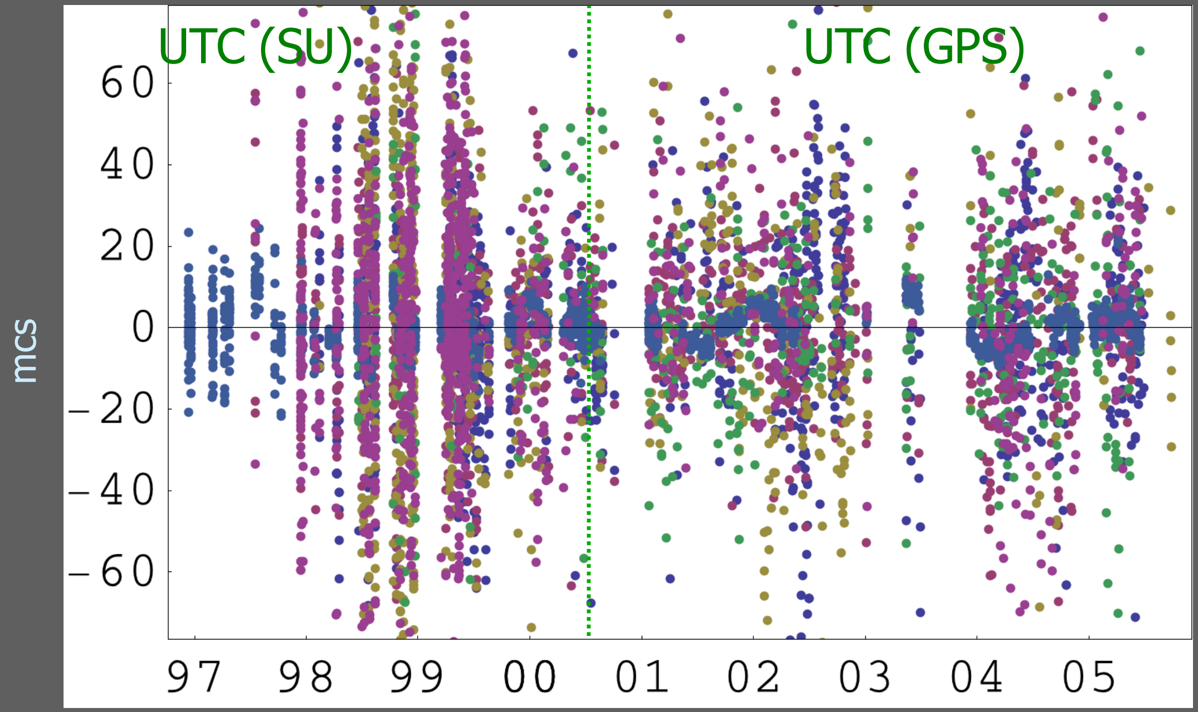
Pulsar name	Spin period, ms	DM, $cm^{-3} \cdot pc$	Binary period, days	RMS, mcs	Instrum. error, mcs
J0613-0200	3.062	38.78	1.2	14.8	0.30
J1640+2224	3.163	18.42	175.46	5.4	0.17
J1643-1224	4.622	62.41	147.02	11.6	0.47
J1713+0747	4.570	15.99	67.83	10.5	0.16
J1939+2134	1.558	71.04	-	2.2	0.53
J2145-0750	16.052	9.00	6.84	14.9	0.12

Distribution of pulsars on the sky



Pulsar timing observations were carried out with 64 m radio telescope of Kalyazin radio astronomy observatory (KRAO) at frequency 610 MHz in bandwidth 2 x 3.2 MHz (Oreshko V.V., *Pulsar timing instrumental errors. AC-600/1600 facility*. Proceedings of the Lebedev Physical Institute, Moscow, 2000, v. 229, p. 110 (*in Russian*).

Pulsar timing observations



Post-fit timing residuals of 6 millisecond pulsars.

1. Ilyasov, Yu. P.; Oreshko, V. V.; Potapov, V. A.; Rodin, A. E., *Timing of Binary Pulsars at Kalyazin, Russia*, 2004, IAUS, 218, 433,
2. Ilyasov Yu.P., Imae M., Hanado Yu., Oreshko V.V., Potapov V.A., Rodin A.E., Sekido M., Astr.Lett., 31, 33, 2005,
3. Potapov V.A., Ilyasov Yu.P., Oreshko V.V., Rodin A.E. Astr.Lett., 29, 282-287, 2003.
4. Rodin A.E., Astr. Rep., 55, 132-141, 2011.

Pulsar coordinates

PSR	Epoch	RA (J2000)		DEC (J2000)		Reference
VLBI coordinates						
B0329+54	50814	03h 32m	59s.3816(5)	54º 34'	43".486(4)	Rodin, Sekido (2000,2002)
B0355+54	49791	03h 58m	53s.713(3)	54º 13'	13".75(10)	Rodin, Sekido (2000,2002)
B1257+12	48794	13h 00m	03s.05005(5)	12º 40'	56".7043(30)	Nunes, Bartel (1998)
B1937+21	46854	19h 39m	38s.5613(4)	21º 34'	59".130(3)	Bartel et al. (1998)
B2021+51	49058	20h 22m	49s.8703(4)	51º 54'	50".291(3)	Campbell et al (1996)
Timing coordinates						
B0329+54	40621	03h 32m	59s.3107(80)	54º 34'	43".657(99)	Rodin, Sekido (2000,2002)
B0355+54	48382	03h 58m	53s.707(3)	54º 13'	13".62(4)	Arzoumanian et al (1994)
B1257+12	49750	13h 00m	03s.05780(4)	12º 40'	56".478(1)	Wolszczan (1994)
B1937+21	47530	19h 39m	38s.560210(2)	21º 34'	59".14166(6)	Kaspi et al. (1994)
B2021+51	48382	20h 22m	49s.867(60)	51º 54'	50".31(5)	Arzoumanian et al (1994)

Timing coordinates were corrected for the influence of the timing noise (A.Rodin, High-precision pulsar astrometry in the presence of low-frequency noise, PhD thesis, Lebedev Phys. Inst., Moscow – 2000.)

PSR	Ephem.	Epoch, MJD	RA (J2000)		PMRA, mas/yr	DEC (J2000)		PMDEC, mas/yr	RMS, mcs
J0613-0200	DE200	49512	06h 13m 43s	.97306(10)	1.87(0.21)	-02º 00′ 47″	.0723(44)	-9.88(0.65)	25.538
	DE405			.97389(10)	2.11(0.21)		.0707(44)	-9.90(0.65)	25.518
	DE414			.97381(10)	2.11(0.21)		.0692(44)	-9.91(0.65)	25.517
	DE421			.97382(10)	2.10(0.21)		.0692(44)	-9.91(0.65)	25.517
J1640+2224	DE200	49360	16h 40m 16s	.74159(12)	1.51(0.21)	22º 24′ 09″	.0056(20)	-10.00(0.27)	21.037
	DE405			.74273(12)	1.70(0.21)		.0094(20)	-10.02(0.27)	21.065
	DE414			.74266(12)	1.70(0.21)		.0077(20)	-10.02(0.27)	21.065
	DE421			.74267(12)	1.696(0.21)		.0077(20)	-10.02(0.27)	21.066
J1643-1224	DE200	49524	16h 43m 38s	.15506(36)	5.63(0.79)	-12º 24′ 58″	.737(19)	2.00(3.2)	43.808
	DE405			.15566(36)	5.93(0.79)		.734(19)	1.93(3.2)	43.809
	DE414			.74266(36)	6.08(0.77)		.0077(20)	1.46(3.2)	43.829
	DE421			.74267(36)	6.07(0.77		.0077(20)	1.46(3.2)	43.829
J17130747	DE200	48799	17h 13m 49s	.52682(22)	4.38(0.34)	07º 47′ 37″	.5499(57)	-3.03(0.59)	23.771
	DE405			.52768(23)	4.65(0.34)		.5521(57)	-3.06(0.59)	23.764
	DE414			.52760(23)	4.65(0.34)		.5504(57)	-3.05(0.59)	23.760
	DE421			.52761(23)	4.64(0.34)		.5504(57)	-3.05(0.59)	23.760
B1937+21	DE200	50100	19h 39m 38s	.560116(14)	-0.204(0.034)	21º 34′ 59″	.14101(28)	-0.794(0.050)	5.274
	DE405			.561243(14)	0.006(0.035)		.13483(29)	-0.746(0.050)	5.314
	DE414			.561133(14)	0.003(0.035)		.13361(29)	-0.746(0.050)	5.312
	DE421			.561143(14)	-0.001(0.035)		.13360(29)	-0.746(0.050)	5.313
J2145-0750	DE200	49460	21h 45m 50s	.46671(73)	-1.15(1.77)	-07º 50′ 18″	.244(29)	-28.3(4.8)	42.264
	DE405			.46744(73)	-0.88(1.77)		.256(29)	-28.2(4.8)	42.274
	DE414			.46737(73)	-0.88(1.77)		.256(29)	-28.2(4.8)	42.273
	DE421			.46738(73)	-0.89(1.77)		.256(29)	-28.2(4.8)	42.273

Rotation angles

	A_x, mas	A_y, mas	A_z, mas	dot A_x, mas/yr	dot A_y, mas/yr	dot A_z, mas/yr
DE200→ DE405	-0.802 ± 0.062	-13.252 ± 0.071	-11.892 ± 0.027	0.009 ± 0.008	0.121 ± 0.009	-0.251 ± 0.004
DE405→ DE414	-1.625 ± 0.014	0.573 ± 0.017	1.180 ± 0.006	0.0003 ± 0.0007	-0.0013 ± 0.0008	0.0028 ± 0.0003
DE414→ DE421	0.0158 ± 0.0008	-0.0550 ± 0.0010	-0.1443 ± 0.0004	0.00156 ± 0.00012	-0.00424 ± 0.00015	0.00662 ± 0.00006
DE200→ DE421	-2.37 ± 0.12	-12.75 ± 0.15	-10.84 ± 0.05	0.005 ± 0.015	0.119 ± 0.018	-0.244 ± 0.007
DE405→ DE421	-1.610 ± 0.014	0.518 ± 0.017	1.036 ± 0.006	0.0019 ± 0.0007	-0.0055 ± 0.0009	0.0094 ± 0.0003
DE200→ ICRF	-3.8 ± 2.3	-13.1 ± 2.7	-18.9 ± 5.5			

Thanks for attention!

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