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Some astrometric discussions on pulsar parameters by timing and VLBI

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Outline

1. Relations between pulsar parameters and ephemeris
2. Rough ideas of the pulsar time-space reference frame
3. Reference frame link based on MSPs
4. The pulsar observations of Chinese VLBI Network (CVN)
5. Summary

Ephemeris and pulsar parameters

- ✓ Besides the pulsar timing measurement errors, the largest remaining sources of potential errors also include the interstellar scattering, solar system **ephemeris** errors, atomic clock instability and gravitational waves etc. The latter 3 are systematic errors.
- ✓ Errors in ephemeris could cause a predominantly sinusoidal variation having a (long) period and phase associated with planet's orbital motion about the Sun.
- ✓ Spacecraft measurements are only sensitive to the individual planet, while pulsar timing is sensitive to the SSB.

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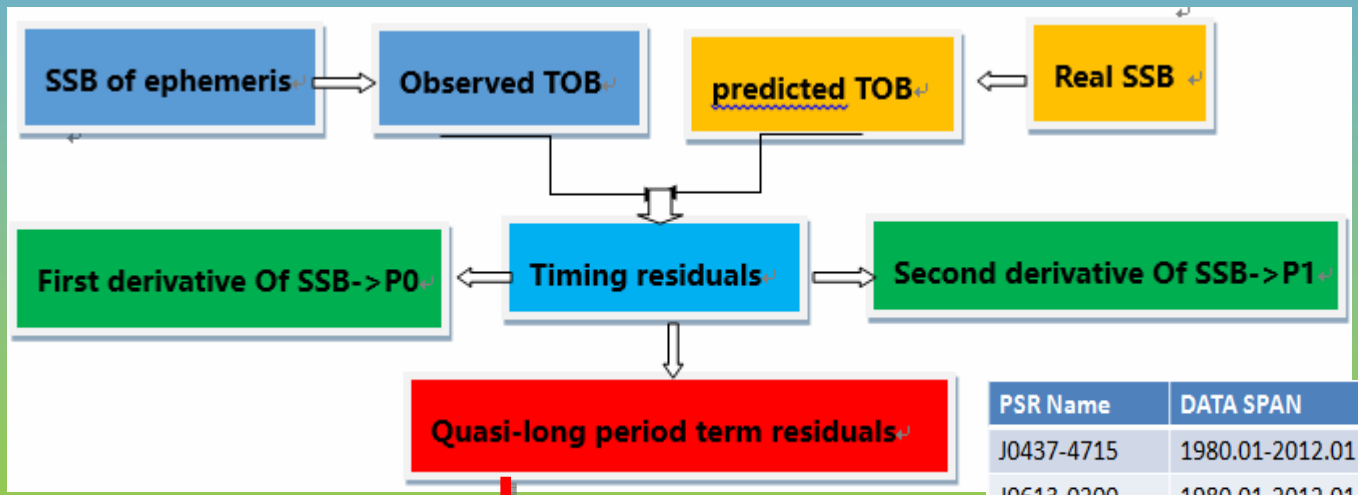
Timing residuals

$$T_{ob}^{c} = T_0 + nP_0 + \frac{1}{2}n^2 P_1$$

$$\Delta\vec{r}_{ssb}(n) = \delta\vec{r}_{ssb}(n) + \Delta\dot{\vec{r}}_{ssb} nP_0 + \frac{1}{2}\Delta\ddot{\vec{r}}_{ssb} n^2 P_1$$

Only the quasi-long period term residuals can be deduced.



$$\delta = \frac{1}{c}(\vec{k}\cdot\delta\vec{r}_{ssb}) + \varepsilon$$

PSR Name	DATA SPAN	RA	DEC	RMS(us)
J0437-4715	1980.01-2012.01	04:37:15	-47:15:09	0.199
J0613-0200	1980.01-2012.01	06:13:43	-02:00:47	1.52
J1022+1001	1980.01-2012.01	10:22:58	+10:01:52	1.63
J1713+0747	1980.01-2012.01	17:13:49	07:47:37	0.198
J1744-1134	1980.01-2012.01	17:44:29	-11:34:54	0.617
J1909-3744	1980.01-2012.01	19:09:47	-37:44:14	0.166
J1939+2134	1980.01-2012.01	19:39:38	+21:34:59	0.679

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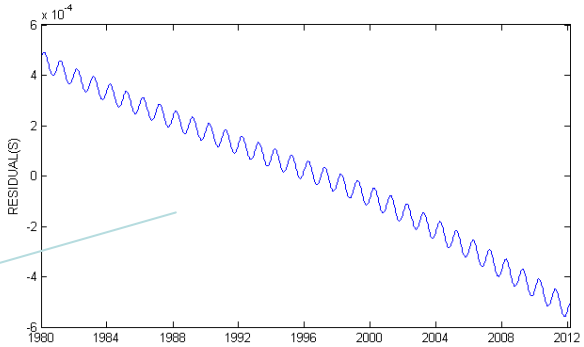
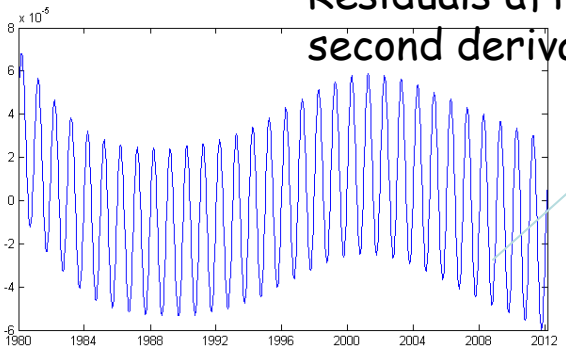
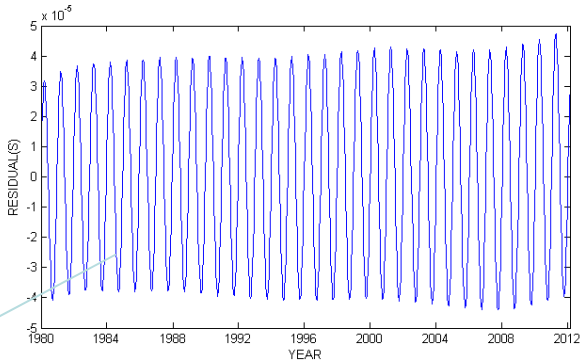
Simulations

Residuals after fitting second derivative of SSB

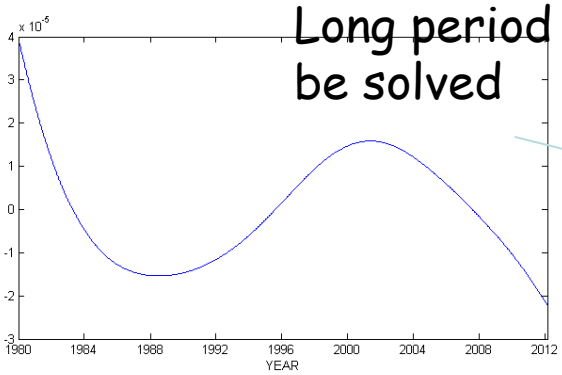
Original residuals







Long period terms can be solved



Short periods terms to fit the pulsar position etc.

Liang Li et al, prepared.

$$\delta = T_{ob}^{o} - T_{ob}^{c} = -\frac{1}{c}(\Delta\vec{k} + \Delta\vec{\mu}\cdot nP_0)\cdot\vec{r}_e - \frac{1}{c}\vec{k}\cdot(\delta\vec{r}_{ssb}(n) + \Delta\dot{\vec{r}}_{ssb}nP_0 + \frac{1}{2}\Delta\ddot{\vec{r}}_{ssb}n^2P) + \varepsilon T_{pax}$$

Ephemeris and pulsar parameters

- ✓ $\Delta\vec{r}_{ssb}$ can't be separated from the P0;
- ✓ $\Delta\ddot{\vec{r}}_{ssb}$ can't be separated from the P1;
- ✓ Quasi long period term can be solved.
- ✓Solutions satisfy: ~10 uniform distributed MSPs; high timing accuracy with long terms observations;
- ✓Difficulties: red noises caused by interstellar medium, GW, etc.

The pulsar time-space reference frame

- ✓The reference frame is to describe the celestial body's position and PM etc.
- ✓ICRS: extragalactic radio sources;
- ✓Dynamical: satellites or planets in solar system;
- ✓Kinematic reference frame: stars or other celestial bodies in Galaxy;
- ✓Pulsars: 2000 (~200 MSP, ~80 X ray);

  potential applications in deep space auto-navigation;

  to standardize the pulsar measurements in astrometric applications and deep space auto-navigation .

The pulsar time-space reference frame

The parameters in the pulsar reference frame:

✓To define the conventional reference spot(CRS) as our origin.(not ephemeris SSB, but subtract the long term period items from ephemeris);

✓Pulsar astrometric parameters: PM,PI, positions etc;

✓Pulsar clock parameters: P0,P1, etc;

✓The long term period changes of CRS;

Conditions:

✓Based on one version ephemeris;

✓To select a group of MSPs (uniform distributed, regularly timing observed, with high TOA precision) ;

The pulsar time-space reference frame

Difficulties:

- ✓To accurately evaluate the quasi-instantaneous position separation from the conventional reference origin;
- ✓To deduce pulsar parameters based on pulsar experiments with high precision, especially for red noises;
- ✓To develop the program based on Tempo2;
- ✓To standardize the pulsar parameters for the frame applications;
- ✓To maintain the pulsar based space-time reference frame;

Reference frame tie based on MSPs

- ✓ Timing of pulsars referenced to SSB with earth ephemeris, while pulsar VLBI observations referenced to ICRF.
- ✓ Combined with two kinds of measurements, the earth ephemeris is aligned to ICRF.

Reference frame tie based on MSPs

The differences of pulsar positions obtained by the two ways.

- ✓Observations: radio timing and VLBI phase referenced to calibrators;
- ✓Technique: de-dispersion filter bank and correlator with pulsar binning;
- ✓Pulsar position Accuracy: timing~1mas, VLBI below 1mas;
- ✓Frame: timing-Earth frame, VLBI-ICRF;
- ✓Reduction software: timing-Tempo2&psrchive et al; VLBI AIPS;
- ✓ Difficulty: more difficult for VLBI method due to too low density of calibrators and low flux whith MSPs..
- ✓ Observed MSPs No.: much less for VLBI method..

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Reference frame tie based on MSPs

PSR name	MJD (days)	R.A. (hh mm ss)	DEC (dd mm ss)	Mu_R.A. (mas/yr)	Mu_DEC (mas/yr)	PX (mas)	REF
T: J0437-4715	52005	04 37 15.8147635(3)	-47 15 08.624170(3)	121.453(1)	-71.457(1)	6.65	[1]
V: J0437-4715	54100	04 37 15.883250(3)	-47 15 09.031863(3.7)	121.679(5)	-71.820(9)	6.396(0.054)	[2]
T: J0737-3039	52870	07 37 51.24795(2)	-30 39 40.7247(6)	--	--	-	[3]
V: J0737-3039	54100	07 37 51.248419(26)	-30 39 40.714310(99)	-3.82(0.62)	2.13(23)	0.87(14)	[2]
T: J1713+0747	54312	17 13 49.532628(2)	+07 47 37.50165(6)	4.924(10)	-3.85(2)	0.94(10)	[3]
V: J1713+0747	52275	17 13 49.5306(1)	+07 47 37.519(2)	4.75(10)	-3.67(15)	0.95(5)	[2]
V: J1939+2134	47892	19 39 38.56120(18)	+21 34 59.1316(24)	1.4	-0.6	-	[4]
T: J1939+2134	52601	19 39 38.561286(7)	+21 34 59.12913(15)	0.13(3)	-0.25(5)	0.4(4)	[5]
V: J2145-0750	54100	21 45 50.461901(98)	-07 50 18.462388(558)	-15.43(2.07)	-7.67(0.81)	-	[3]
T: J2145-0750	53040	21 45 50.46412(3)	-07 50 18.4399(14)	-9.66(15)	-8.9(4)	1.6(5)	[2]

$$\vec{X}_{ICRF} = A_{DE405}^{ICRF}\vec{X}_{DE405}$$

$$A_{DE405}^{ICRF} = \begin{pmatrix} 1 & \theta_z & -\theta_y \\ -\theta_z & 1 & \theta_x \\ \theta_y & -\theta_x & 1 \end{pmatrix}$$

✓With the above 5 published MSPs astrometric parameters to link the Earth ephemeris and ICRF

✓Frame tie method.

Reference frame tie based on MSPs

The preliminary results:

	θ_x (mas)	θ_y (mas)	θ_z (mas)
DE405→ICRF(5MSPs)	-0.2±0.5	27.2±1.4	-23.3±1.6
DE405→ICRF(4MSPs)	-8.9±1.6	4.1±4.2	3.4±4.9
DE405→ICRF(3MSPs)	-8.4±0.5	5.4±0.3	1.9±0.2

✓4 MSPs : without MSP J1713; 3 MSPs: without J1713 & J1939 ;

✓The results changes a lot with the MSPs no;

✓The position differences of MSP J1713 by two ways are too large.

Reference frame tie based on MSPs

Future Plan:

✓ Pulsar PI plan is under the way by VLBA, which will expand the MSPs sample; CVN also observed MSPs now.

✓Pulsar timing observations will begin with Shanghai 65m antenna by the end of the year, and we will focus on more MSPs;

✓With more than 10 MSPs uniformly distributed, the accuracy of rotation angle will be greatly improved.

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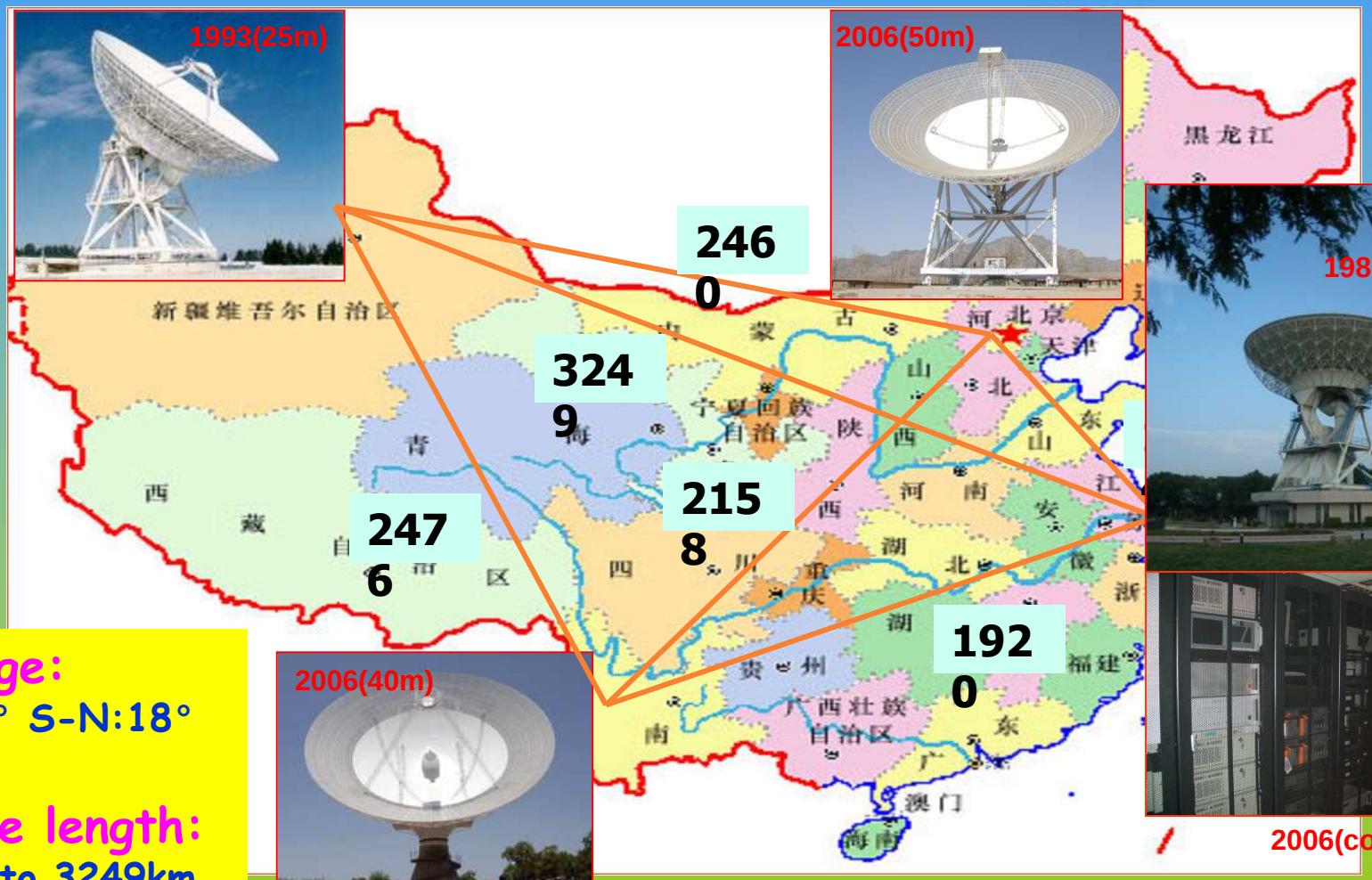
Chinese VLBI Network (CVN):

4 stations+ soft/hard-ware correlators



Coverage:
E-W:34° S-N:18°

Baseline length:
1115km to 3249km

Technical specs of CVN antennas

	Shanghai	Urumqi	Beijing	Kunming
Operation start	1987	1993	2006	2006
Structure	BWG, Cassegrain	BWG, Cassegrain	Prime focus	BWG, Cassegrain
Size in Diameter (m)	25	25	50 (30 +20)	40 (25+15)
Pointing precision (arc-sec)	20	15	19	28
Receiver bands	L, C, S/X, K	P, L, C, S/X, K	S/X	S/X,C
Tsys (K) (at S/X band)	65/65	/	65/	80/96
Efficiency (at S/X band)	42%/42%	54%/52%	60%/68%	60.2%/47.0%
SEFD (Jy) (at S/X band)	870/1000	680/480	220/~300	350/480
Recording terminal	Mark5A, VLBA, S2, K4	Mark5A, K4	Mark5A	Mark5A

The sensitivities of CVN

- ✓Antennas: SH(25m)+UR(25m)+BJ(50m)+KM(40m)+SH(65m recently).
- ✓Mark 5 terminal record system;
- ✓S/X band receivers.

Baseline sensitivity (mJy 512 Mbps for 128MHz @ Sband, 3min)

	SH	UR	KM	BJ
SH				
UR	4.91			
KM	3.52	3.25		
BJ	2.53	1.90	1.47	

The pulsar observations with CVN

- ✓Our plan: 7-10 MSPs with CVN (Shanghai 25m, Kunming 40m, Urumqi 25m and Beijing 50m, future Shanghai 65m).
- ✓The first successful MSP experiments with CVN 3 antennas (SH 25m, KM 40m, UR 25m) is J1939+2134 on April 8, 2012.
- ✓ Target-J1939+2134 : one of best candidate of frame link and in deep space auto-navigation applications; flux is ～9mJy at S band.
- ✓ Calibrator is J1935+2031; position: ~0.1mas; separation: ~1.5d.
- ✓ Observations: fast-switching mode, 9 hours, 1024Mbit/s
- ✓Correlator: DiFX

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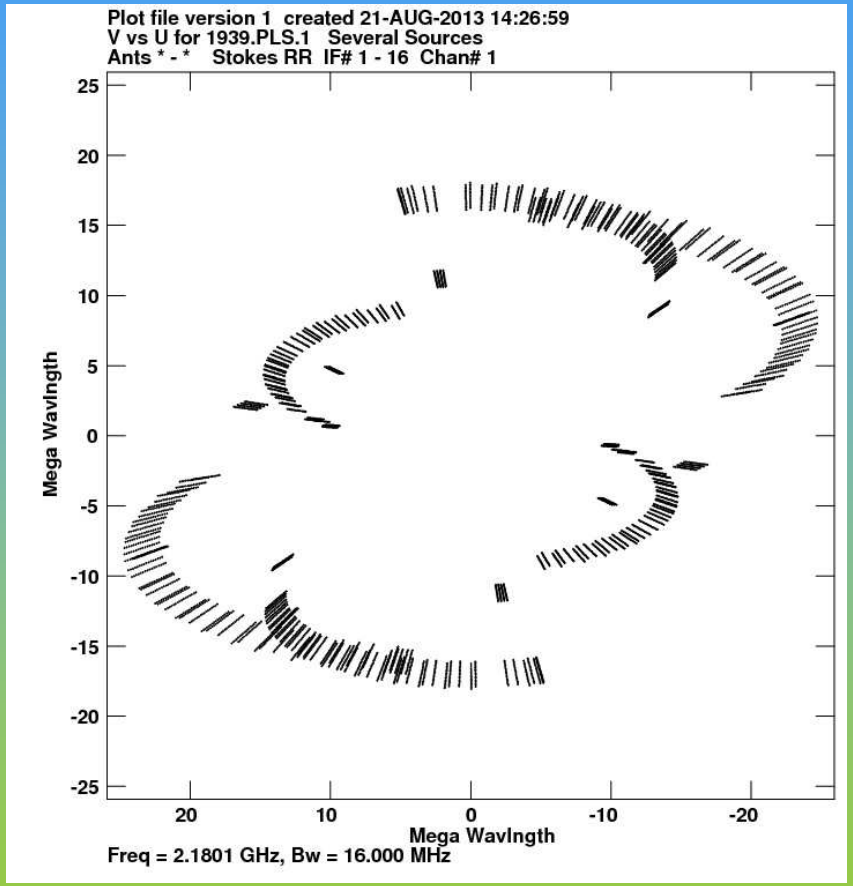
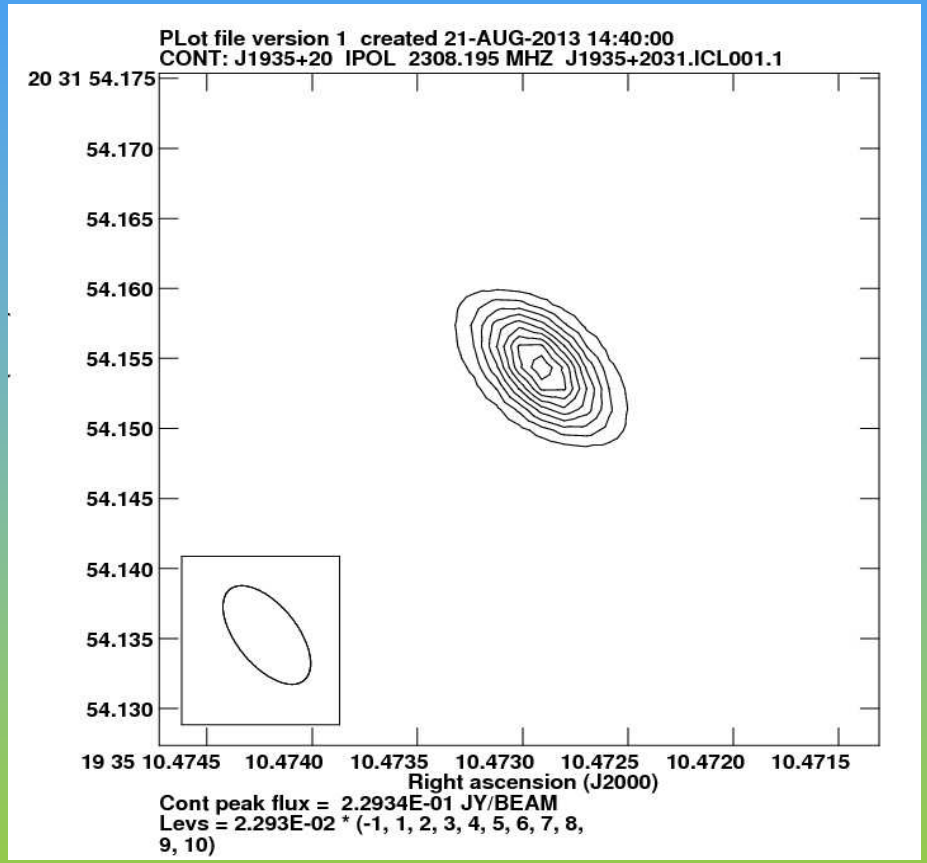
The pulsar observations with CVN





✓UV coverage

✓Calibrator: J1935+2031

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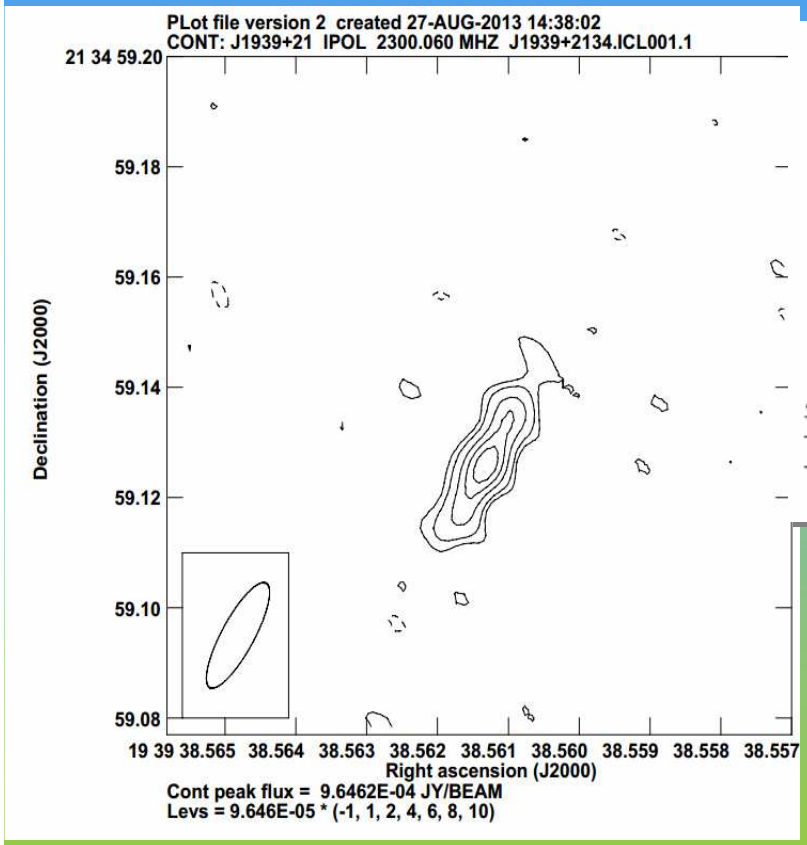
The pulsar observations with CVN



✓MSP J1939+2134

✓The epoch, MJD56025. position :

Serial No	$\alpha(J2000.0)$	$\delta(J2000.0)$	$Obsfreq$
	h m s	^{o} ′ ″	GHz
1^a	19 39 38.56130	21 34 59.1267	2.2
2^b	19 39 38.55835	21 34 59.1294	1.4

^{ab} Results are respectively reduced from CVN in S band and timing observations by Nancy in L bands[7,8].

Reasons:

(1)Timing results is based on DE202

(2) Different frames

Plan:

The experiment for J1939 on Sep 5, another 2-3 experiments later to get the PI & PM parameters.

Summary

- ✓From simulations, the long-period term of ephemeris SSB can be deduced, but it is still the challenge as for observations due to red noises.
- ✓Plan to establish the pulsar space-time reference frame.
- ✓It is still difficult to get good reference frame link based on MSPs due to few common MSPs by two ways. But it is promising in near future.
- ✓Pulsar timing observations will be observed by Shanghai 65m radio antenna by the end of this year. And several pulsars have been successfully observed by CVN, and more weaker pulsars in the future.

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Thank you!