The Earth's Irregular Motion and Pulsar Timing

Dong Jiang

YunNan Astronomical Observatory

May 09, 2011 @ NAOs, CAS

Pulsar timing is the regular monitoring of the rotation of the neutron star by tracking (nearly exactly) the times of arrival of the radio pulses. The key point to remember is that pulsar timing unambiguously accounts for every single rotation of the neutron star over long periods (years to decades) of time.

The Earth's Irregular Motion show the changes of Universal time (length of days), which are subject to variations due to the zonal tides (smaller than 2.5 ms in absolute value), to oceanic tides (smaller than 0.03 ms in absolute value), to atmospheric circulation, to internal effects and to transfer of angular momentum to the Moon orbital motion. Fundamentally, it orgin from N-Body problem.

We will discuss the measurement of The Earth's Irregular Motion that use pulsar timing in the theory, and The effect of irregular movement of the Earth to use pulsar timing detect gravitational waves.
We want to learn the more knowledge of tempo2 in this Conference, and find the Collaborator in this area.

The Earth's Irregular Motation

We can see Polar motion as regular Motion for it can be predicted[Chen Ding et al., preprints].

The Earth's Irregular Motion show the changes of Universal time (length of days).
From the 1950s, after analysised astronomical measurements, astromer discover that the speed of the earth's rotation has a seasonal cycle, slow spring, fall faster, in addition to has half a year cycle. The amplitude of annual variation of about 20 to 25 ms, mainly caused by seasonal variations in the wind.
Earth's rotation, there are still irregular changes which the reason is unknown.

Variations in the duration of the day

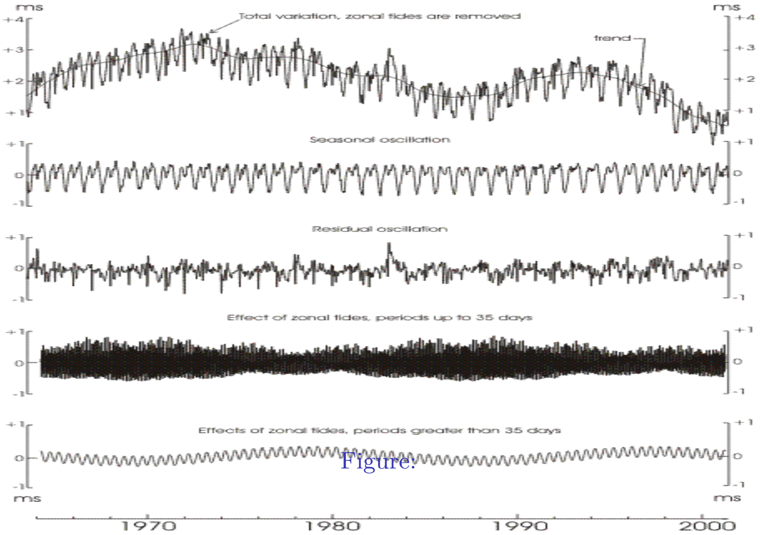

Figure:

Variations in the duration of the day

The variations in LOD can be split into several components, according to their causes.
The total variation is shown in the upper part of the figure, without oscillations induced by the tides of the solid Earth and oceans, are shown separately for the long and short periods.
The dynamical influence of the liquid core of the earth and climatic variations in the atmosphere account for slow variations (trend in the upper part of the figure).
The rest of the atmospheric excitation can be split into a seasonal oscillation and residual oscillation, which includes 50-day oscillations as well as large anomalies like the one associated with the 1983 El Niño event. Yearly values of LOD since 1623 are available.

hourly LOD

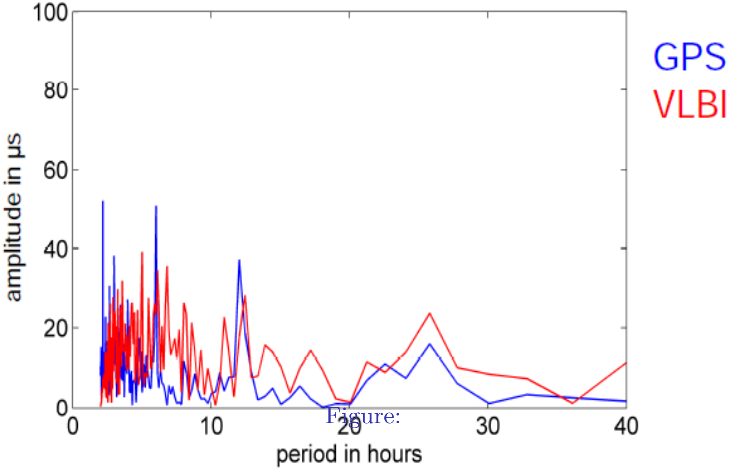

Figure:

hourly LOD

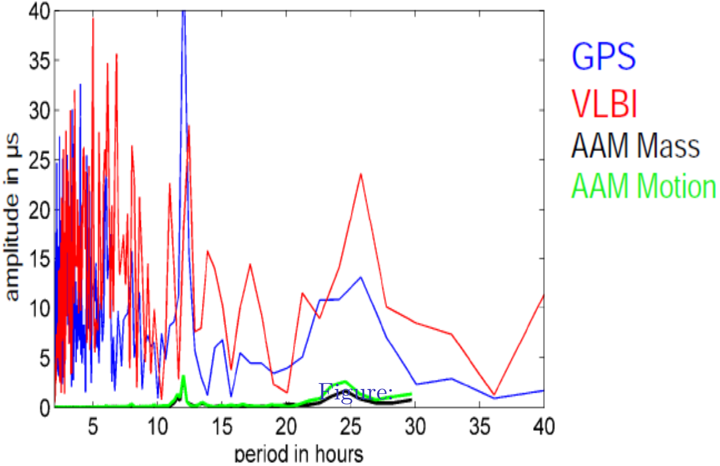

Figure:

The Earth's Irregular Motion orgin from N-Body problem, which include tides from zonal, oceanic and moon, atmospheric angular momentum et al.
The n-body problem is the problem of predicting the motion of a group of celestial objects that interact with each other gravitationally. Solving this problem has been motivated by the need to understand the motion of the sun, planets and the visible stars. Its first complete mathematical formulation appeared in Isaac Newton's Principia (the n-body problem in general relativity is considerably more difficult).
The stability of the Solar System is a subject of much inquiry in astronomy. Though the planets have been stable historically, and will be in the short term, their weak gravitational effects on one another can add up in unpredictable ways. For this reason (among others) the Solar System is Chaotic, and even the most precise long-term models for the orbital motion of the Solar System are not valid over more than a few tens of millions of years – providing that no more notable objects are discovered.

UT1

Universal Time (UT1) is a measure of the actual rotation of the earth, independent of observing location. UT1 is essentially the same as the now discontinued Greenwich Mean Time (GMT). It is the observed rotation of the earth with respect to the mean sun corrected for the observer's longitude with respect to the Greenwich Meridian and for the observer's small shift in longitude due to polar motion. Polar motion is regarlar Motion of the earth(18.6 years periods).

Since the earth's rotation is not uniform, the rate of UT1 is not constant, and its offset from atomic time is continually changing in a not completely predictable way which from the above Irregular Motion

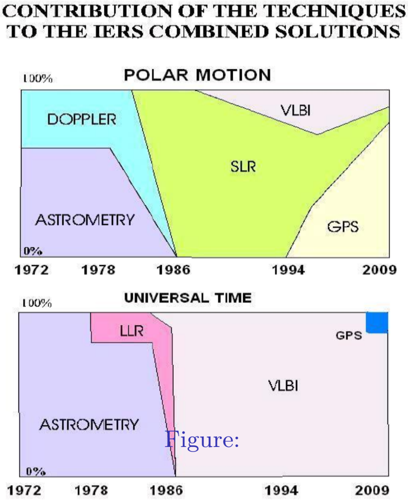
CONTRIBUTION OF THE TECHNIQUES
TO THE IERS COMBINED SOLUTIONS
POLAR MOTION
100%
DOPPLER
VLBI
SLR
ASTROMETRY
GPS
0%
1972
1978
1986
1994
2009
UNIVERSAL TIME
100%
LLR
GPS
VLBI
ASTROMETRY
0%
1972
1978
1986
1994
2009

Figure:

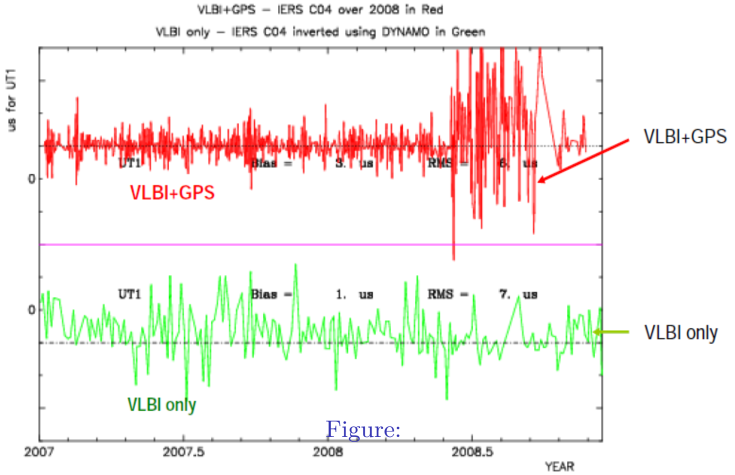
VLBI+GPS – IERS C04 over 2008 in Red
VLBI only – IERS C04 inverted using DYNAMO in Green
us for UT1
UT1
Bias =
3. us
RMS =
6. us
VLBI+GPS
1. us
7. us
VLBI only
0
2007
2007.5
2008
2008.5
YEAR

Figure:

Pulsar Timing

This unambiguous and very precise tracking of rotational phase allows pulsar astronomers to probe the interior physics of neutron or quark stars, make extremely accurate astrometric measurements, and test gravitational theories in the strong-field regime in unique ways.

The singal of Pulsar that we have received include three parts:
Pulsar noise from itself(Xiongwei in this Conference),
Propagation effects(Coles and Xiaopeng in this Conference),
The uncertainty of the telescope position(The Earth's Irregular Motion).

Pulsar Signal Process

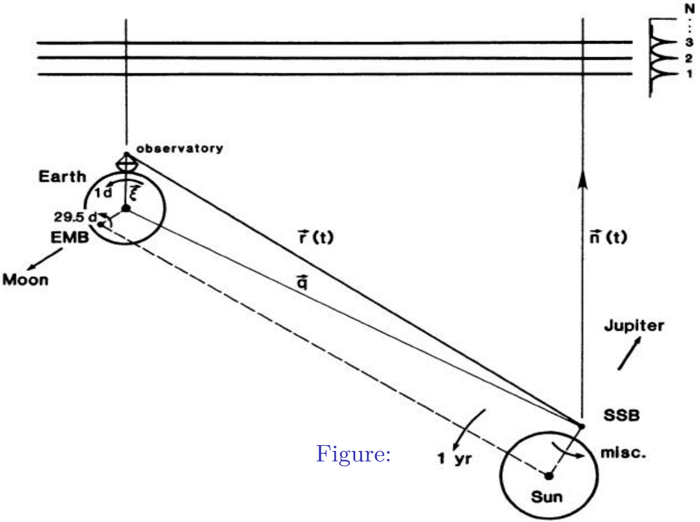

Figure:

The level of Pulsar Timing

TEMPO2, a new pulsar-timing package that contains propagation and other relevant effects implemented at the 1-ns level of precision (a factor of 100 more precise than previously obtainable)[Hobbs, G. B., Edwards, R. T. and Manchester, R. N., 2006].

Table: Corrections and their typical sizes for phenomena included in tempo2.

Correction	Typical value/range	tempo1
Observatory clock to TT	$1\,\mu$s	Y
Hydrostatic tropospheric delay	10 ns	N
Zenith wet delay	1.5 ns	N
IAU precession/nutation	~5 ns	N[a]
Polar motion	60 ns	N
ΔUT1	1μs	Y

[a] earlier precession/nutation model implemented

[b] observing frequency and pulsar dependent, typical value for 1400 MHz listed.

Using Pulsar Timing to Monitoring the changes of UT1 in real time

Current precision of the new solution:
Polar motion : 50 μas
UT1: < 10 μs
LOD : 20 μas
Nutationoffsets : 60 μas

VLBI accuracy of UT1 today:
- 6-7μs from 24h
- 10-15μs from 1h

Using Pulsar Timing to Monitoring the changes of UT1 in real time

PSR J0737-4715 is the most stable pulsar, the best TOA can have 100 ns in once observation, most of it is 1 μs. [Verbiest, J. P. W., M. Bailes, W. A. Coles, et al. 2009]

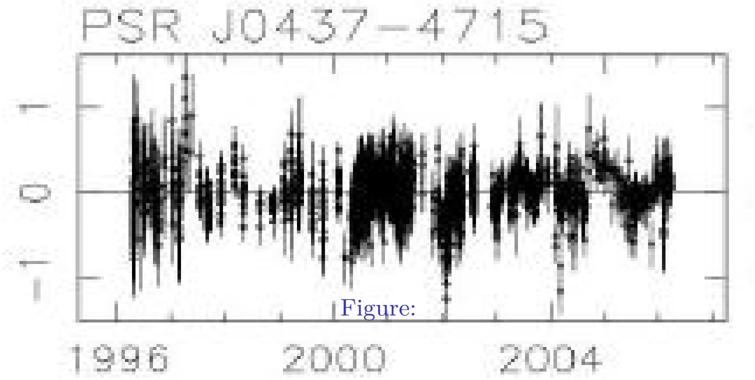

Figure:

Techniques contributing to IERS

Technique	since	EOP	Time Res.	Present accuracy
ASTROMETRY	1899	Pole UT1 Nutation	5 days " "	Pole: 20 mas UT1: 1 ms Nutation: 40 mas
DOPPLER	1972	Pole	2 days	Pole: 10 mas
LLR	1969	UT0	1 day	UT0: 0.1 ms
SLR	1976	Pole LOD	3 days "	Pole: 150 µas LOD: 100 µs/d
VLBI	1981	Pole Nutation UT1	7 days " sub-daily - 7 days	Pole: 100 µas Nutation: 60 µas UT1: 6 µs
GPS	1993	Pole LOD	sub-daily "	Pole: 50 µas LOD: 25 µs/d
DORIS	1995	Pole	3 days	Pole: .5 mas

Figure:

Contribution of the various techniques to IERS

Table: The number of stars matches the relative contributions of techniques

PRODUCTS	LLR	VLBI	SLR	GPS	DORIS	Pulsar
Extragalactic ref. Frame		⋆⋆⋆				
Tie to solar system	⋆⋆⋆	⋆				Y
Tie to Earth						
Precession-nutation	⋆⋆	⋆⋆⋆	⋆	⋆		Y
Universal Time	⋆	⋆⋆⋆				Y
Earth Rotation						
High-frequency UT		⋆⋆⋆	⋆	⋆⋆		Y
Polar Motion		⋆⋆	⋆⋆	⋆⋆⋆	⋆	Y
Terrestrial Reference Frame						
Network coverage		⋆	⋆	⋆⋆	⋆⋆⋆	Y
Long-term geocenter	⋆	⋆⋆⋆	⋆⋆	⋆		
Tectonic plate motion		⋆⋆⋆	⋆⋆	⋆⋆⋆	⋆⋆⋆	
Densification		⋆	⋆	⋆⋆⋆	⋆⋆	

Using Pulsar Timing to Monitoring the changes of UT1 in Real Time

VLBI accuracy of UT1 today:
- 6-7μs from 24h
- 10-15μs from 1h

Pulsar TOA accuracy of UT1 today(0737-4715):
- 100ns - 1μs from several minutes

We advise that use pulsar TOA as a independent tool which contribution to IERS.

Plan: give a simulation like Chen et al. study polar motion use pulsar timing, apply for telescope time(at least two telescopes in the same time) to observe PSR J0737-4715(1937+21?), long term, tens of TOA each hour.

Variations in the duration of the day

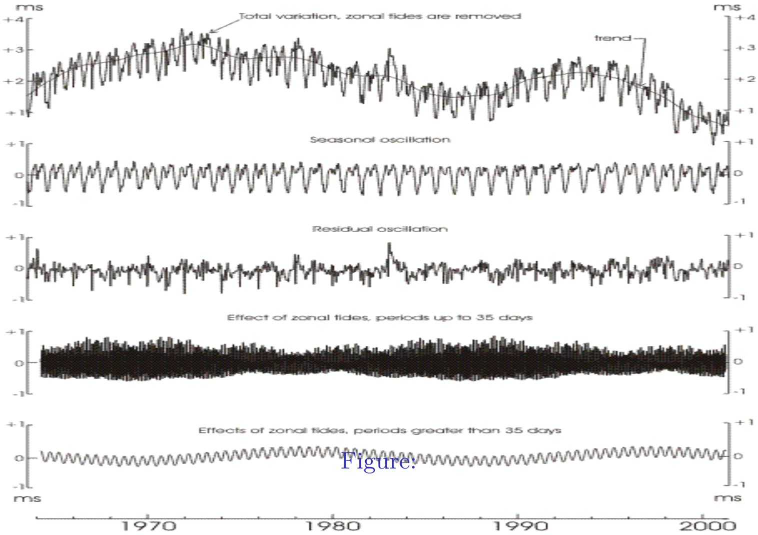

Figure:

Using Pulsar Timing to Measure the Earth's Glitch

The massive earthquake also is the reason that the change of the earth rotation.
UT1's change in the massive earthquake:
Japan(2011) -1.6μs/day
Chile(2010) -1.26μs/day
Indiaso(2004) -6.8μs/day

Using Pulsar Timing to Rebuilding Ephemeris Time

The term ephemeris time (often abbreviated ET) can in principle refer to time in connection with any astronomical ephemeris.

At present the accuracy of ephemeris time is low, only reach about 0.1s or so. But its biggest advantage is that it is a uniform time system, and make observations to the actual location of objects from the Astronomical Almanac and the theoretical calculated exactly the same position, so that a variety of specific astronomical phenomena more accurate.
When observing pulsar, we will use JPL ephemeris (DE405) give the earth position.
Here we advise that use Pulsar TOA provide Ephemeris time (i.e. a really real time earth ephemeris).

Pulsar Signal Process

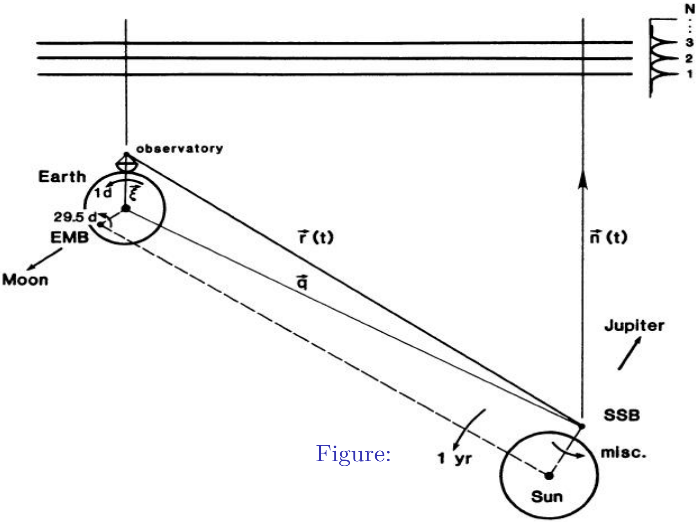

Figure:

The effect of irregular movement of the Earth to use pulsar timing detect gravitational waves

When using Pulsar Timing detect gravitational waves, we need at least twenty pulsar have the TOA accuracy in 100ns. That means we must remove the noise from pulsar itseslf, Propagation effects in the path, and the uncertainty of the telescope position from Newton's Chaos.
In Hobbs et al.,2006, they see Observatory clock to TT($1\,\mu$s), Polar motion(60 ns) and ΔUT1(1μs) as input parameters.
We think we can have the best accuracy about it from pulsar TOA after use High-density observations and Model fitting. This process see it as output parameters, and it also will improve the TOA's accuracy.

40M Telescope in YunNan Astronomical Observatory, KunMing

Thanks, Please give the advices and comments.

Figure: Welcome your visit and Collaboration !