DOR Delay Model for CE-3 Experiment and VLBI Delay Model for MEX

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Outline

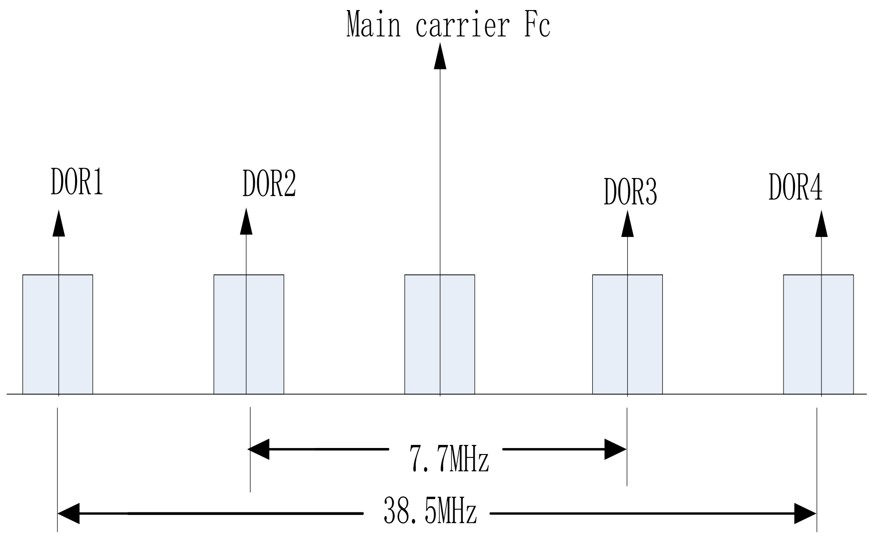
- DOR Delay Model for CE-3 Experiment

- VLBI Delay Model for MEX

Background

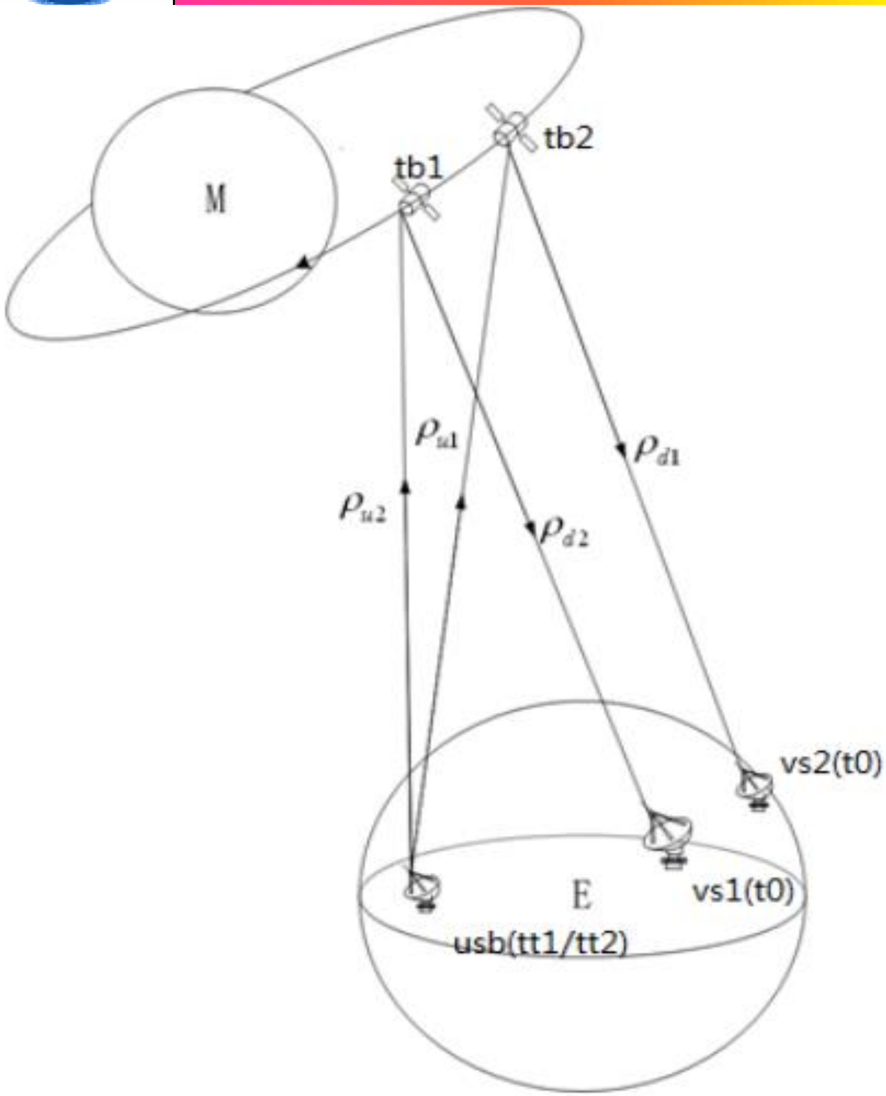
- The beacon of CE-3 satellite has several DOR tones used for VLBI tracking. In order to improve data transferring and processing efficiency, we tried the local-correlation method which was different from the one used in CE-3 project.

- So, the corresponding time delay model used in local-correlation should be taken into account. And the definition of this delay also differed from normal VLBI delay model.



DOR tones of CE-3

DOR delay model



- Two different down-link stations vs1 and vs2 receive simultaneously signals bounced by the spacecraft and transmitted by a up-link station(usb station)at the different epoch.
- down-link stations : VLBI stations (such as : Miyun, Kunming)
- up-link station : USB station(such as : Jiamusi, Kashi)
- the transmission of the signal separately at the transmit time tt1 and tt2
- the signal at the CE-3 orbiter separately at the time of bounce tb1 and tb2
- the reception of the signal at the receive time t0

sketch of DOR signal's transmission, bounce and reception

DOR geometric delay principle

The approximation of the range formulas :

$$\rho_{d1}(t_0)=\left|r_{d1}\right|=\left|(r_{\mathrm{M}}+r_s(\mathrm{t_{b1}}))-(r_{\mathrm{E}}+r_{v_1}(t_0))\right|$$

$$\rho_{d2}(t_0)=\left|r_{d2}\right|=\left|(r_{\mathrm{M}}+r_s(\mathrm{t_{b2}}))-(r_{\mathrm{E}}+r_{v2}(t_0))\right|$$

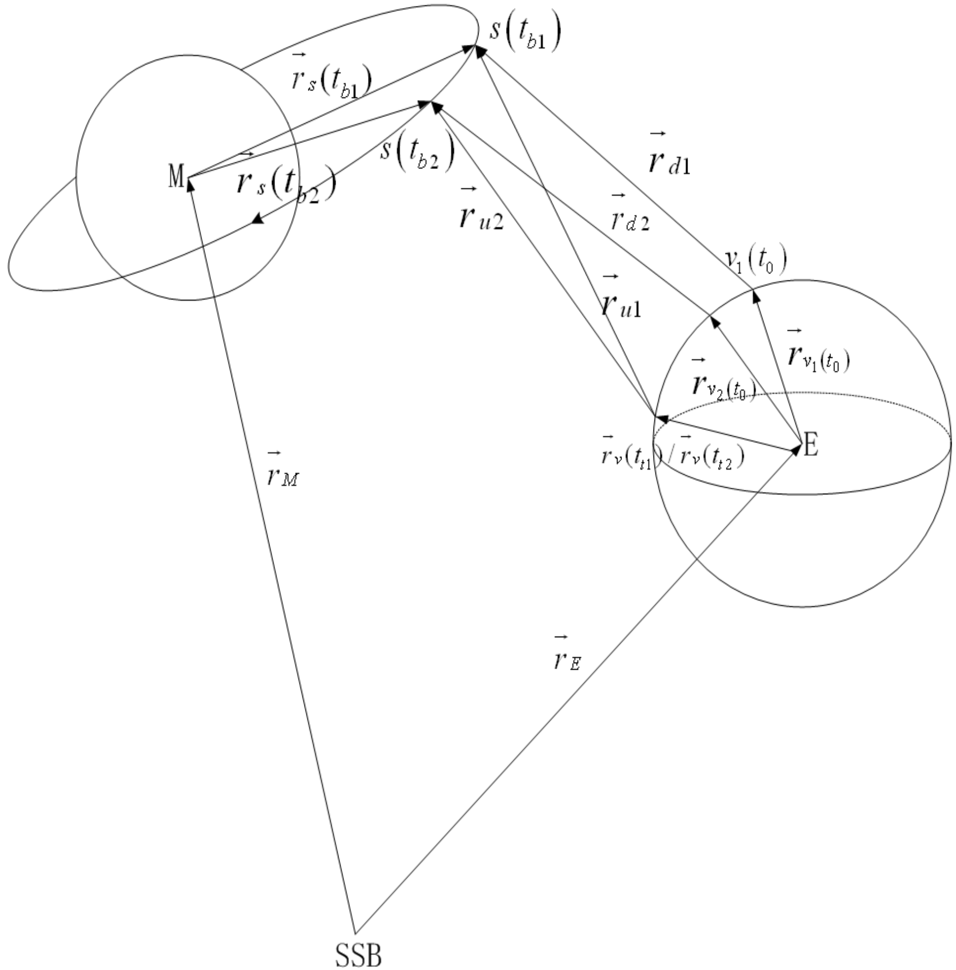
$$\rho_{u1}(t_0)=\left|r_{u1}\right|=\left|(r_{\mathrm{M}}+r_s(\mathrm{t_{b1}}))-(r_{\mathrm{E}}+r_v(t_{t1}))\right|$$

$$\rho_{u2}(t_0)=\left|r_{u2}\right|=\left|(r_{\mathrm{M}}+r_s(\mathrm{t_{b2}}))-(r_{\mathrm{E}}+r_v(t_{t2}))\right|$$

DOR time delay formula:

$$\tau_{\mathrm{DOR}}(t_0)=t_{t2}-t_{t1}$$

$$=\frac{\rho_{d2}+\rho_{u2}}{c}-\frac{\rho_{d1}+\rho_{u1}}{c}$$



DOR geometric delay principle

Space-time system

Input	Coordinate system	Time system
Station position	ITRS	UTC
Spacecraft orbit	GCRS	UTC
EOP(earth orientation parameter)		UTC
Ephemerides	BCRS	TDB

- **The full time-scale transformation chain is as follows:**

  UTC->TAI->TT->TCG->TCB->TDB

- **The coordinate transformation chain is :**

  ITRF ->GCRS ->BCRS

ITRS : International terrestrial reference system

GCRS : Geocentric celestial reference system

BCRS : Barycentric celestial reference system

Shapiro Effect

The total gravitational delay can be represented by the following formula:

$$\tau_{grav} = \frac{GM_s}{c^3} \ln \frac{R + r + \rho + \ln \frac{GM_s}{c^2}}{R + r - \rho + \ln \frac{GM_s}{c^2}}$$

$$+ \sum_{i=1}^{10} \frac{GM_i}{c^3} \ln \frac{R_i + r_i + \rho_i}{R_i + r_i - \rho_i}$$

R(i): the distance from the i'th planet to the spacecraft

r(i): the distance from the i'th planet to the observable station

ρ_i **: the distance from spacecraft to the observable station**

Experiment

- Observed object:
  CE-3 spacecraft

- Observation Code & Date
  s3c07a (2013.12.07)
  s3c08a (2013.12.08)
  s3c09a (2013.12.09)

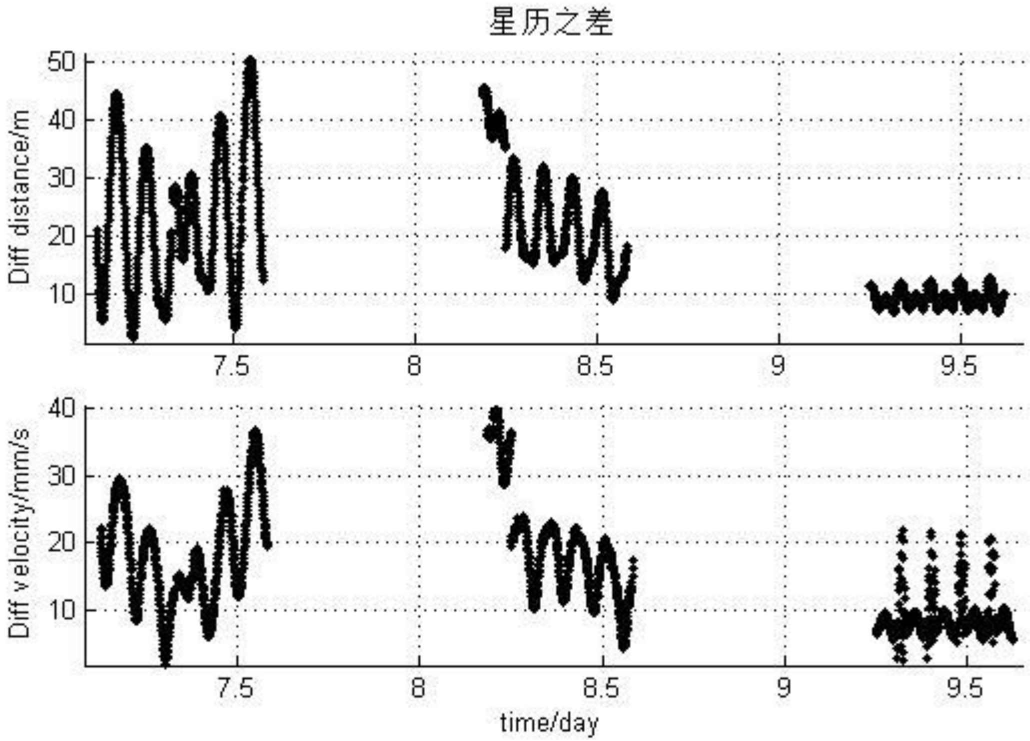
- Spacecraft position
  100*100Km orbit around lunar

- up-link station:
  Jiamusi

- down-link station:
  Miyun(50m)、Kunming(40m)、Nanshan(25m)、Tianma(65m)

- DOR main carrier frequency:
  about 8.470GHz

Application: Result of orbit determination



The result shows that there are a few dozen meters of discrepancy between orbit determination result and reference orbit. The equivalent delay difference is less than 1 ns.

The position and velocity discrepancy between orbit determination result and reference orbit.

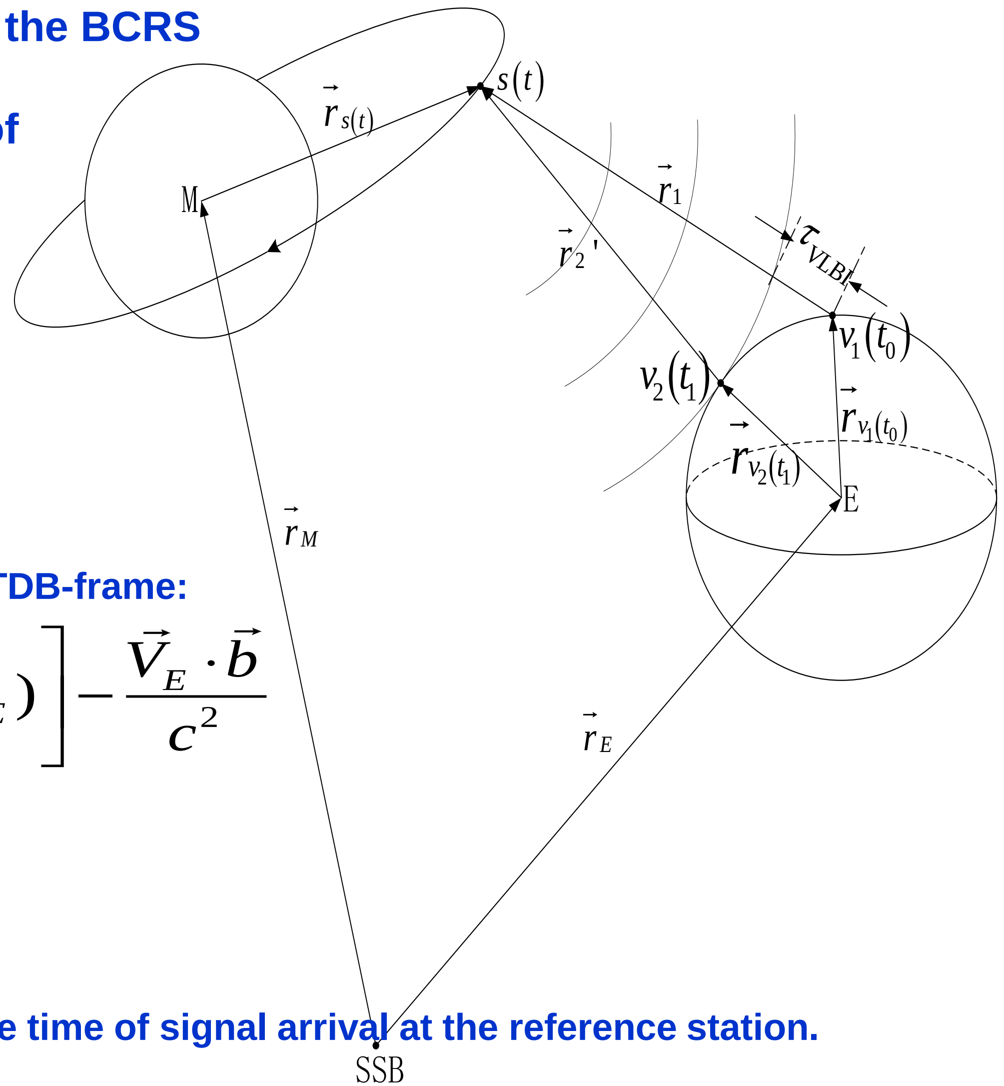
VLBI delay for MEX

- VE:

  the velocity of the Earth in the BCRS
- UE:

  the gravitational potential of all solar system bodies excluding the Earth, evaluated at the geocenter
- LC:

  constant



VLBI delay in the geo-centric TT-frame, transformed from VLBI delay in barycentric TDB-frame:

$$t_0 - t_1 = \frac{T_0 - T_1}{1 - L_C}\cdot\left[1 - \frac{1}{c^2}\left(\frac{V_E^2}{2} + U_E\right)\right] - \frac{\vec{V}_E\cdot\vec{b}}{c^2}$$

$$\vec{b} = \vec{r}_0(t_1) - \vec{r}_1(t_1)$$

the vector b is GCRS baseline vector at the time of signal arrival at the reference station.

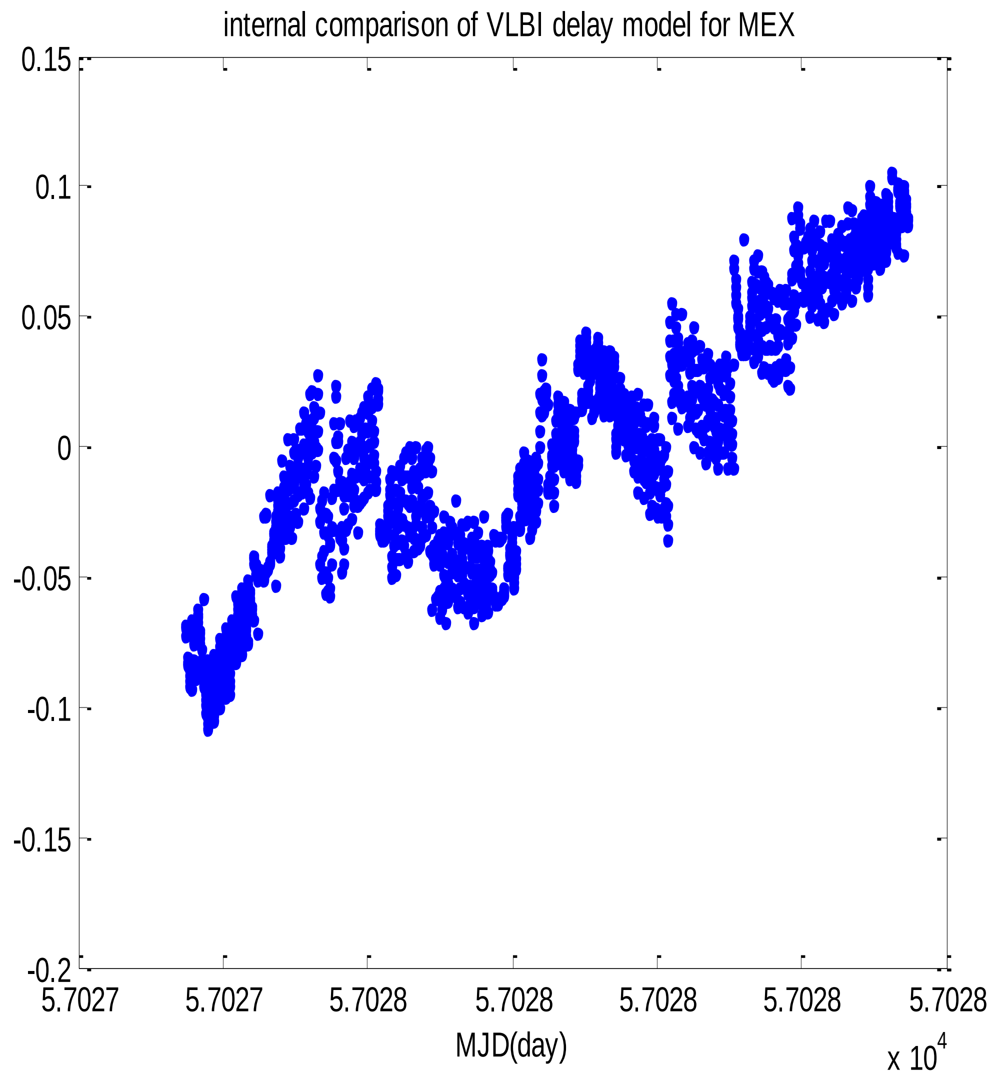
VLBI delay for MEX

- Observed object:
  MEX
- Observation Date & Time
  2015.01.03 :
  00:00:00~ 23:59:00
- Stations**:**
  Sheshan(25m), URUMQI(25m)
- Epheméride**s**
  DE421
- Coded by **:**
  Fortran

MEX VLBI time delay

- **Difference between this result of VLBI delay calculation and Mr. Tong's is almost less than 0.1ns**

- **Mr. Tong's result was used in phase referencing observations and considered as very accurate**



internal comparison of VLBI delay model for MEX

- Hoping further comparisons with any other software or organization

- Thank you for your attention!