Possibility of Earth's and Moon's gravity fields determination from Radioastron orbital data

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Current Earth Gravitational Research

Earth Gravitational Models: EGM2008, EIGEN, GGM, etc.
Use of satellite tracking data on LAGEOS, GRACE, CHAMP, GOCE, ect.

- SLR tracking
- Satellite-to-satellite tracking (SST)
- Gravity gradiometry

Theory of planetary motion.

Conventional Earth gravitational parameter (TCG):

$$\mu_E = 3.986004418 \cdot 10^{14} m^3/s^2$$

What orbit is optimal?

Simplified (Keplerian) motion

$$T = 2\pi\sqrt{\frac{a^3}{\mu_E}}, \quad \frac{dT}{T} = \frac{3}{2}\frac{da}{a} - \frac{1}{2}\frac{d\mu_E}{\mu_E}, \quad \frac{\sigma_\mu}{\mu} = 2\frac{\sigma_T}{T} + 3\frac{\sigma_a}{a}.$$

The greater period and semi-major axis, the better μ is known (with less than proportional uncertainties growth).
Satellites involved in Earth gravitation filed research:

- relatively low altitude orbits
- as a result, dependency on high order harmonics
- variation of μ_E may be interpreted as a small change in scale of reference frame, which harder to observe on circular orbits.

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RadioAstron orbit. Required precision

Earth

μ_E — 2 m. position accuracy, 30 cm range accuracy.

C_{20} — 7 cm. position accuracy, 1 cm range accuracy

Moon

μ_M — 40 cm. position accuracy, 15 cm range accuracy

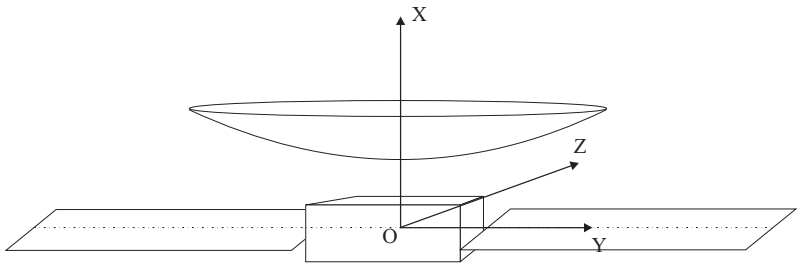
Peculiarities of the dynamics

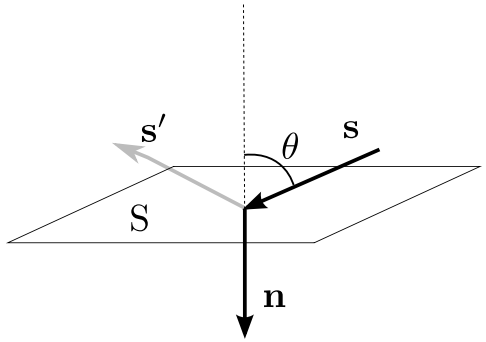
- Solar radiation pressure highly dependable on the satellite's orientation. Absolute value can changes by 10 and more times between two different orientation.
- Flywheels unloading.
  Velocity increment of 3-7 mm/s about every day.

Data sources

- Lack of laser ranging data:
  - not many opportunities for tracking
  - almost lunar distances
  - tracking session requires certain orientation of the satellite

Solar radiation modeling





Three elements

- Space-radio telescope antenna
- Central unit
- Solar panels

Optical properties of of RA surface elements are expressed as linear combination of black body and perfect mirror.

$$\mathbf{F}_p = \Phi_0 \cos\theta(2C_R \cos\theta \mathbf{n} + \\ +(1 - C_R)\mathbf{s}),$$

C_R^{SRT} and C_R^{SB} are included in solve-for parameters.

Shadow on SRT is calculated for different orientation of the satellite.

Modeling the unload of flywheels

Telemetry data provides:

- time of activation of stabilization system engines, t_k
- precise quaternion of orientation at given time, $\mathbf{q}$
- command obtained by onboard control system, which contains the mass of the fuel to be utilized by certain engine, Δm_k

Telemetry data is converted into velocity increments. At the moment direction of such increments is considered to be known precisely from the satellite orientation. Absolute values of the increments Δv_k are included into solve-for parameters. Functional to be minimized gains additional terms:

$$\Phi = \sum_j \mathbf{\Xi}_i^T \mathbf{P}_i \mathbf{\Xi}_i + W \sum_j (\Delta v_j^0 - \Delta v_j)$$

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Improvement of a priory knowledge of $\{\Delta v_i^0\}$

Modeling of stabilization system work

For every small engine activation

- Flywheels rotation speed sensors
- Telemetry data
- Change of angular momentum

$=>$

- Position of the engine
- Change of linear momentum
- Change of angular momentum

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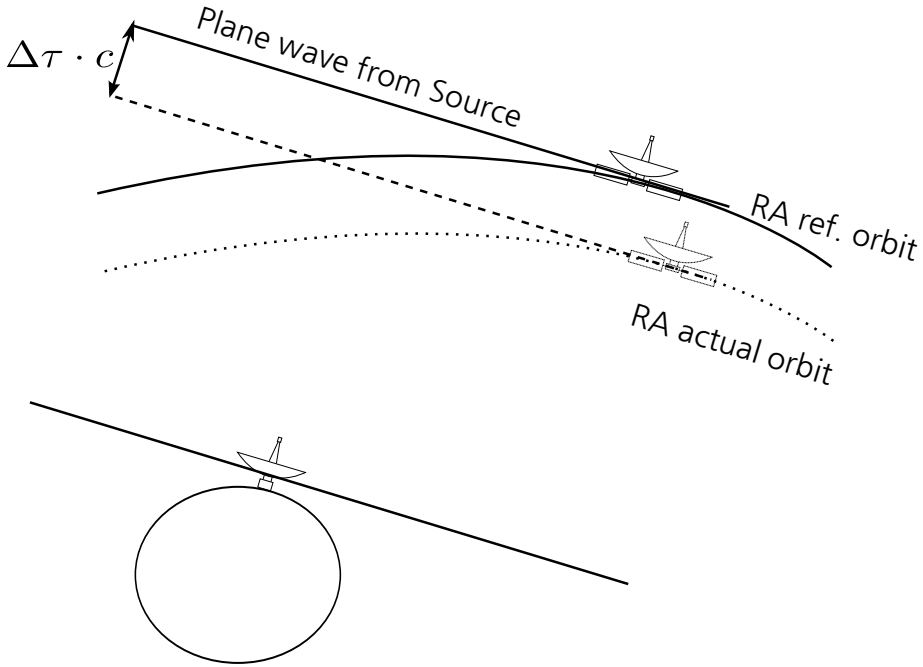
After-correlation analysis

- Picked up delay residuals from reference orbit $\Delta\tau$ and its derivatives $\dot{\Delta\tau}$ can be used in precise orbit determination
- Great errors ellipsoid truncation in direction of radio-source
- The more stations participate at the same time the better



Close cooperation of correlation team and orbit determination team is required

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Simultaneous open-loop Doppler measurements (VIRK)

Utilization of high-accuracy measurements of range rate in different directions $\{\dot{D}_1, \dot{D}_2, \dot{D}_3 \ldots\}$
Even two simultanieus Doppler signals are much more informative than one

The signal can be received by any station within radiation pattern of VIRK-antenna.

PRIDE expriments.

Summary

- RadioAstron has unique combination of high elliptical orbit and facilities to precise orbit determination.
- The orbit is appropriate for researching central part of Earth gravitational field. The accuracy required is believed achievable with using SLR, interferometric and precise Doppler data.
- Interferometric data (correlation residuals) is a vital part of RadioAstron orbit determination and should not be ignored.
- The signal from RA high-gain antenna can (should) be used for obtaining accurate orbital data, not just single Doppler.