P1.01

ROYAL OBSERVATORY OF BELGIUM

INFORMATION ON THE INTERIOR OF MARS, THE EARTH AND VENUS FROM ORBITERS AROUND THESE TERRESTRIAL PLANETS

OBSERVATOIRE MIDI-PYRÉNÉES

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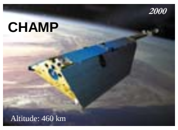
1. Abstract

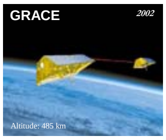
Spacecraft tracking with radio-science allows to gain insight into the structure and composition of the interior of planets. In particular this technique allows better understanding the planetary gravity field, rotation and orientation variations (polar motion, precession, nutations, and librations), and tides. For the Earth other techniques involving dedicated instruments on the Earth's surface such as superconducting gravimeters for tides and Very Long Baseline Interferometry for nutations can be used in addition to spacecraft observation. Spacecraft data from more advanced gravity instruments such as gradiometers (on GOCE) or microwave satellite to satellite tracking (GRACE) provide unprecedented accuracy on gravity. The paper aims at comparing the performances and results of these techniques.

2. Geodetic missions, data and processing

The new generation missions to the Earth

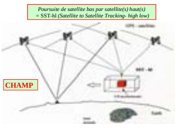


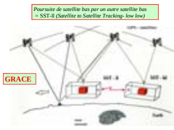
Geoid precision: **10 cm at 400 km**

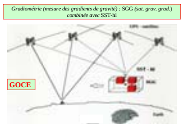


Geoid precision: **1 mm at 400 km**

Geoid precision: **1 cm at 100 km**





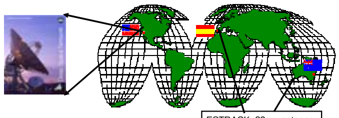


Previous generation (orbital perturbation method):
It relies on the Precise Orbit Determination (POD) of the spacecraft orbital motion. The limitation on the gravity solution is mainly due to the non-continuous tracking and to the contamination of the POD from the non-gravitational perturbations (atmospheric drag, …). The POD is performed on the basis of the fit of a spacecraft motion model to the tracking data of the velocity variations (Doppler effect on radio-tracking by DORIS system) and/or of the position variations (Laser ranging or SLR) of numerous satellites (such Lageos, Topex-Poseidon, Spot, …) with various orbital inclination and altitude (all above 800 km).

New generation (CHAMP & GRACE):
Still orbital perturbation method but with continuous tracking of position by GPS and additional SLR ranging of satellite orbiting at an altitude of about 460-490 km). The non-gravitational forces are better resolved through accurate accelerometer measurements (precision of $3\ 10^{-9}$ m/s^2). Additional inter-satellite micro-wave positioning (KBR link with a precision of ~ 1 micron), i.e. GRACE, allows better sensitivity to fine gravity anomalies and their temporal variations.

Last generation (GOCE):
It does not use accurate determination of orbital perturbation, but gravity gradient measurements (6 accelerometers with a precision of 10^{-11} m/s^2). It still uses continuous GPS tracking and additional Laser ranging with an orbital altitude as low as 260 km. It is expected to significantly improve the GRACE static gravity solution.

The most recent missions to Mars & Venus



ESTRACK: 32 m. antenna at New Norcia & Cebreros

Orbital perturbation method (only):
DSN and ESTRACK network of Earth's based antennas of diameter ranging from 25 to 70 meters.
Doppler and range tracking of spacecraft orbiting planets or Lander at planetary surface, using an X-band (at 8.4 GHz) radio-link. Precision on Doppler: 0.02-0.05 mm/s (1-3 mHz) and on range < ~1 meter (but bias of ~3-4 m). Accurate dating of data by using Maser clocks at the tracking stations.
Gravity solution are limited by non-continuous tracking (especially for Mars Express), by quasi-polar orbits, and by the contamination of the non-gravitational perturbations.

Precise Orbit Determination (POD) procedure using dedicated software (such as GINS)

GINS: Géodésie par Intégration Numérique Simultanée is a software, developed by the French space agency (CNES) and further adapted at ROB for planetary geodesy applications.
Used: for numerous Earth's satellite (GRACE, Lageos, …) and planetary spacecraft (MGS, ODY, MEX, …).

INPUT

Tracking data:
Doppler and range tracking data of spacecraft Doppler, GPS, Laser tracking of Earth's satellite + accelerometer data, satellite-to-satellite tracking data

Ancillary data:
spacecraft attitude, corrections on tracking data (relativistic and tides effects at tracking stations, …)

GINS software:
Iterative Least Squares fit of a spacecraft dynamical model on successive ***data-arcs*** of one to several day duration

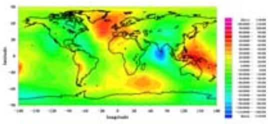
OUTPUT

- Accurate positioning of orbiter
- Normal matrix with information on:

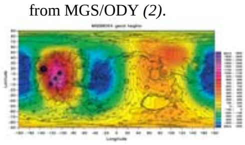
Gravity field and its time-variations, tidal Love number, rotation parameters of the planet, mass of the natural satellites, …

3. Gravity field and information on the interior

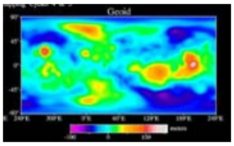
Geoid heights (in meters) from GRACE data *(1)*.



Geoid heights (in meters) from MGS/ODY *(2)*.

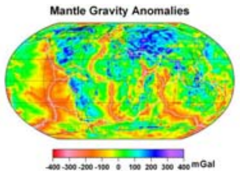


Geoid heights (in meters) from Magellan *(3)*.



Earth

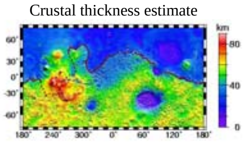
Mantle Gravity Anomalies



The effect of the crust on gravity has been subtracted to reveal the upper mantle contribution *(5)*

Mars

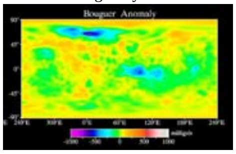
Crustal thickness estimate



Combined analysis of gravity and topography can provide the 'Moho' depth assuming mean crustal density value *(4)*.

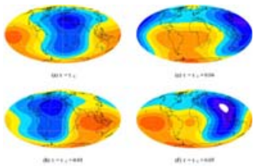
Venus

Residual gravity anomalies



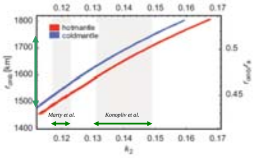
The effect of topography on gravity anomalies have been substracted assuming mean crust density value.

Earth's deep interior



Earth's core mass redistribution, due to outer core dynamics are expected to generate time-variations on surface gravity *(6)*. However, it is needed to correct observed gravity variations from mantle, and hydrosphere (atmosphere, ocean, hydrology) mass redistribution

Mars' deep interior



k_2 tidal Love number estimates of Mars from the MGS and ODY POD *(2,7)* indicates a liquid core inside Mars. Nevertheless, a large discrepancy between different studies remains, thus yielding a range of possible value for the core radius of about 250 km.

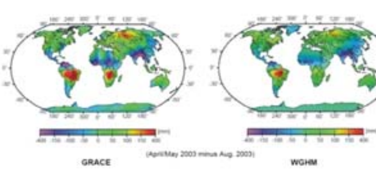
Venus' deep interior

k_2 tidal Love number estimate of Venus is 0.295 +/- 0.066 from the Magellan POD *(8)*, which indicates a liquid core inside Venus, but its radius cannot be well constrained.

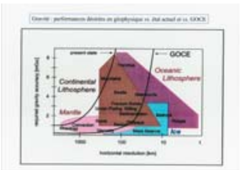
4. Conclusion & perspectives

- The gravity field of the Earth provides additional constraints on its interior. A large improvement is expected from the current GRACE and GOCE missions.
- For Mars and Venus, the gravity field provides the main information on their interior, so far. Nevertheless, more precise gravity determination is still needed (involving orbiter with non-polar orbits for Mars' time variable gravity).
- Geodetic measurements, involving orbiter and/or Lander(s), can improve our knowledge of Mars' interior.

Perspective for the Earth

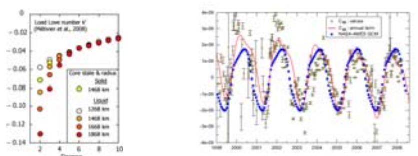


The time-variable gravity (from GRACE) allow to better constrain the Earth's surface mass distribution (such as hydrological model – WGHM). In turn, it would permit to identify the possible signature of the outer core on the time-variable gravity.



The GOCE mission will significantly improve the spatial resolution of the static gravity field. It will provide new constraints on geophysical processes (continental lithosphere, …)

Perspective for Mars



Expected signature (upper bound) of the liquid core and of surface mass redistribution on Mars' long wavelength gravity field. The time-variations of the degree-2 (i.e. the dynamic oblateness) could not yet be detected due to weak sensitivity of the near-polar orbits of the spacecraft.

Radio-link between one Lander (or more) and the Earth, between an orbiter and a Lander (or more), and between the orbiter and the Earth to accurately monitor (over at least one Martian year) the variations of the orientation of Mars' rotation axis (i.e. its nutations), from which new constraints on the core state and size can be obtained (10).

*References: (1) Lemoine et al. 2007, Adv. Space Res., **39**, 1620; (2) Marty et al. 2009, Planet. Space Res., **57**, 350; (3) Sjogren et al. 1997, **in Venus II**, 1125; (4) Zuber et al. 2000, Science, **287**, 1788; (5) Kaban, GFZ, Postdam, Germany; (6) Kuang & Chao 2003, Geodyn. Series, **31**, 193; (7) Konopliv et al. 2006, Icarus, **182**, 23; (8) Konopliv & Yoder 1996, Geophys. Res. Lett., **23**, 1857; (9) Métivier et al. 2008, Icarus, **194**, 476; (10) Dehant et al., this meeting.*