Geodesy instrument package on the Moon for improving our knowledge of the Moon and the realization of Reference Frames

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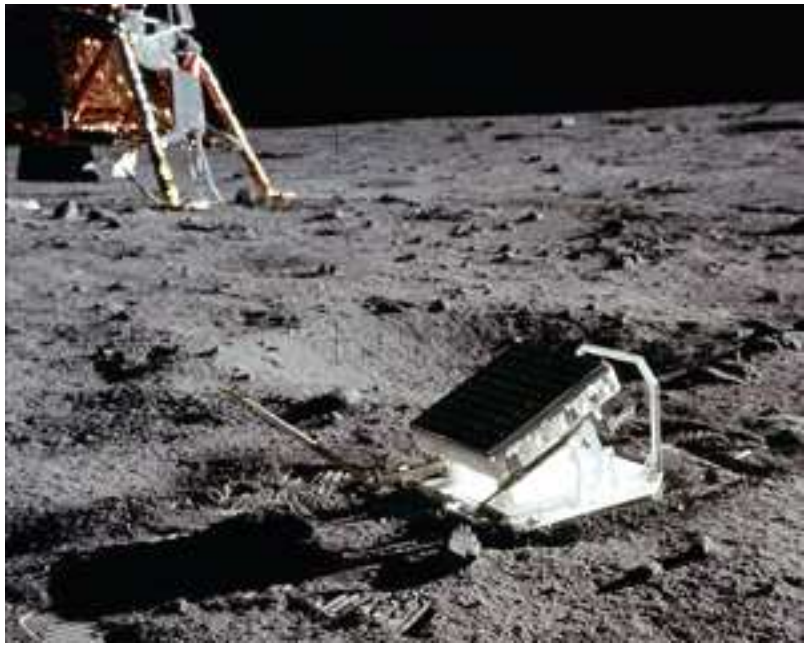
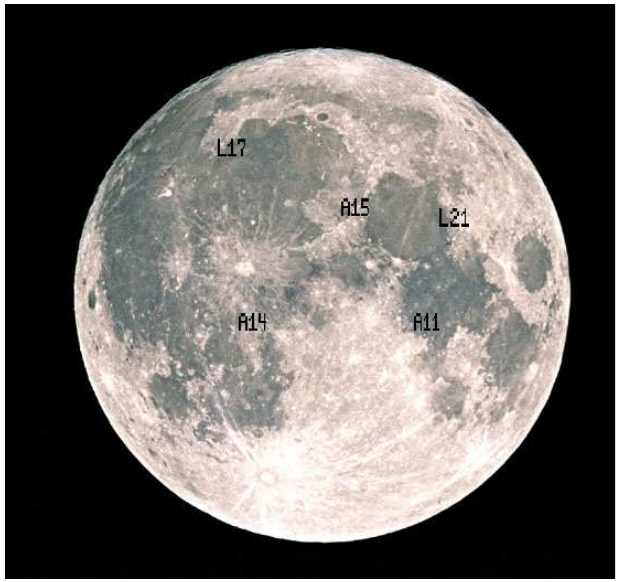
Objectives

- Owing to technological advances over the years, the measurement resolution could be improved by more than an order of magnitude.
- We propose the deployment of a set of geodetic instruments in order to improve the ranging measurements to the Moon, and thus knowledge about the interior of the Moon;
- and in addition, to improve the reference frame realizations.

1. State of the art

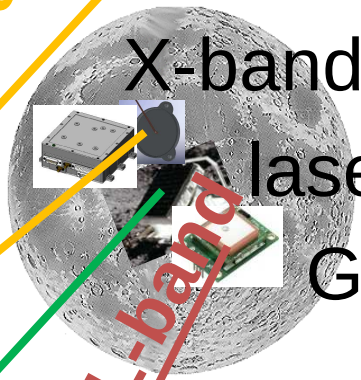
- Only Laser reflectors on the lunar surface





2. New design (1)

quasar



X-band transponder

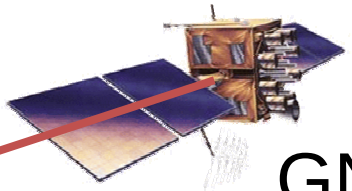
laser transponder

GNSS emitter

Microwave X-band

laser

Microwave L-band



GNSS satellite

2. New design (2)

- ✓ advanced Laser beacon / Laser receiver experiment to improve the Laser link budget substantially: While in the reflector case, the signal strength decreases with lunar distance *r* to the fourth power ($1/r^4$), for transponders, signal strength decreases with only $1/r^2$.
- ✓ microwave receiver/transmitter (transponder)
- ✓ with precisely known mechanical local ties to the Laser beacon
- ✓ GNSS microwave transmitter (P-code)
- ✓ space qualified Cesium clock
- ✓ new observing stations on Earth

3. Aims

- ✓ several geodetic stations on the Moon used simultaneously
- ✓ improve the modeling geometry and data quality
- ✓ not only distance observation and observation of velocity in the line-of-sight, but as well observations of the tangential position of the Moon with respect to the celestial frame
- ✓ realizing a “GPS/Galileo satellite on the Moon” that is tracked together with GNSS satellites by receivers on the ground and possibly on the future generation of GNSS satellites
- ✓ Objectives:
  - **✓improvement of the reference frames for the Earth**
  - **✓better understanding of the Moon’s interior**

Conclusions and perspectives (1)

- Velocity of the Moon with respect to the Earth at better than a few hundredths of mm/s.
- Together with the radial information from Laser ranging, the tangential component from VLBI will push the insight into the Moon's orbital behaviour including its libration to as yet unknown frontiers and there with obtain information on the core of the Moon.
- To combine all the currently available high precision space geodetic techniques, like Very Long Baseline Interferometer (VLBI) and compatibility with the Global Navigation Satellite System (GNSS) at the location of the landing sites on the Moon, to match the currently available equipment at geodetic observatories on the Earth.

Conclusions and perspectives (2)

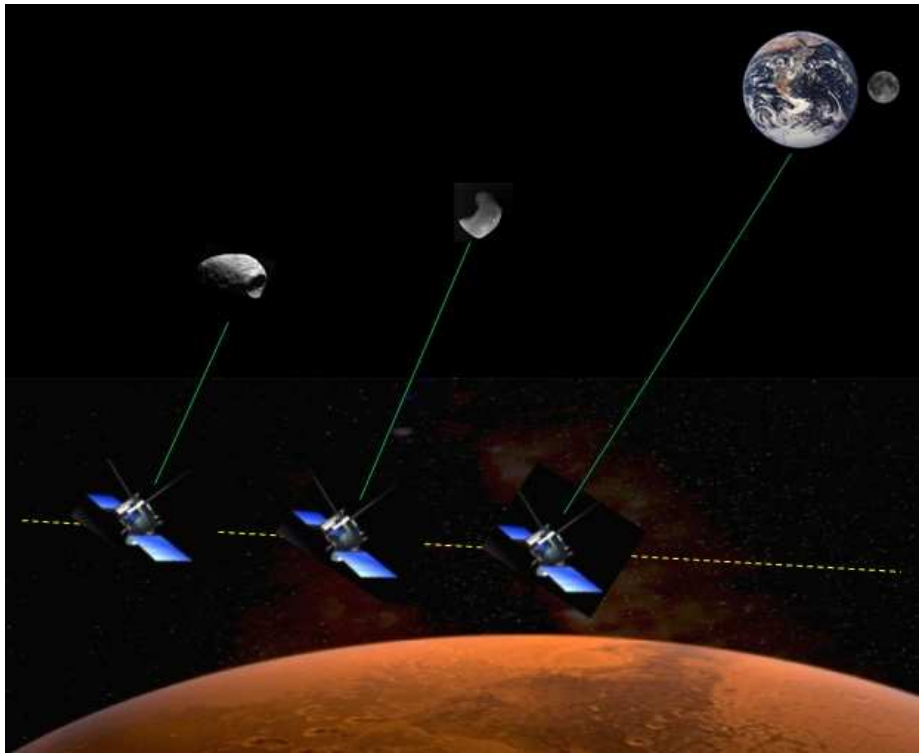
- Three of the major space geodetic techniques will be co-located on the lunar surface supporting the efforts for a rigorous combination of these techniques.
- Unified reference frame rather than a measurement-biased frame.
- A “GPS/Galileo satellite on the Moon” or the “Moon as a natural GPS/Galileo satellite” that is linked to VLBI will make it possible to directly refer the GNSS satellite constellations (and thus GNSS-determined station coordinates) to the ICRF (International Celestial Reference Frame).

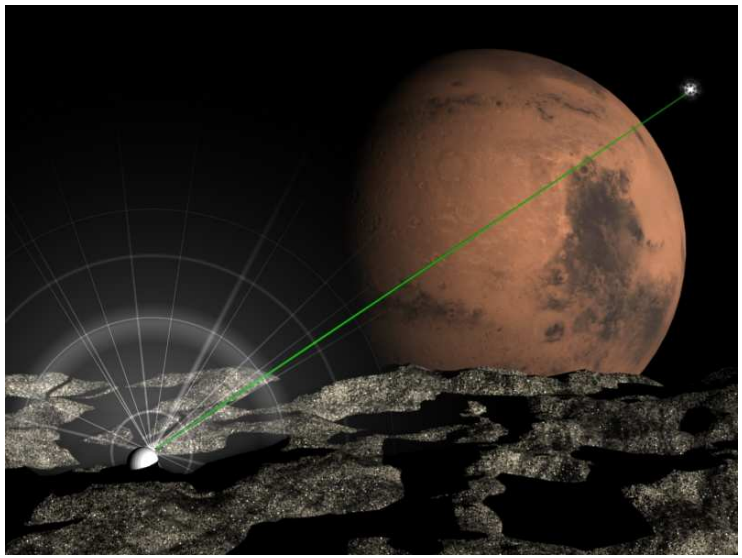
Complementary perspectives

- The described system design developed for the Moon, can be adapted to Phobos and Deimos, the two moons of Mars, or to landers on Mars. Geodetic experiments in the Mars system will allow us to constrain the interiors of Mars and its moons, study the origin of the Mars satellite system, and even testing relativity theory;
- e.g. GETEMME and Mars-GeO

GETEMME

Gravity, **E**instein's **T**heory, and **E**xploration of the **M**artian **M**oons' **E**nvironment mission).





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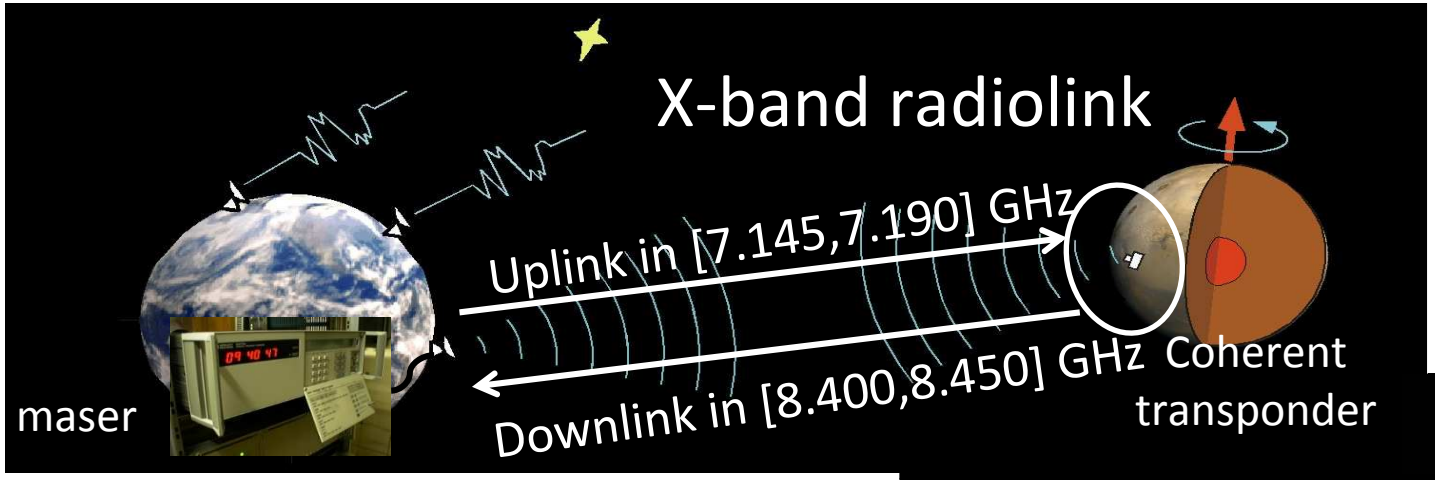
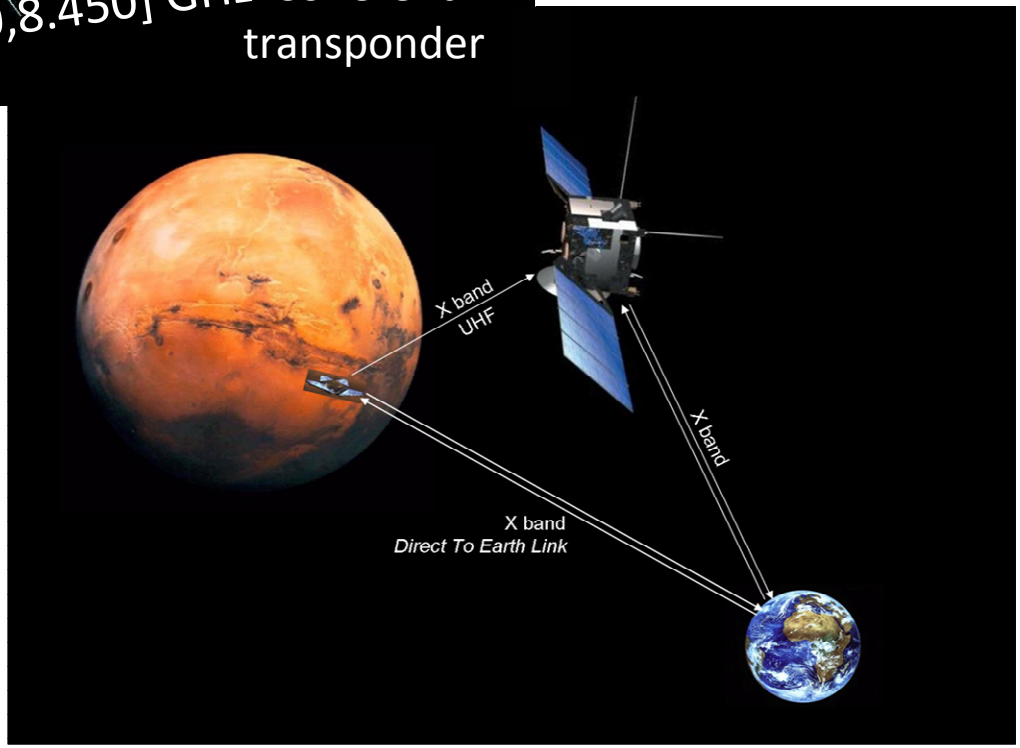
Mars-GeO
Mars Geophysical Observatories





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Mars-GeO

Mars Geophysical Observatories
2010 M-mission proposal

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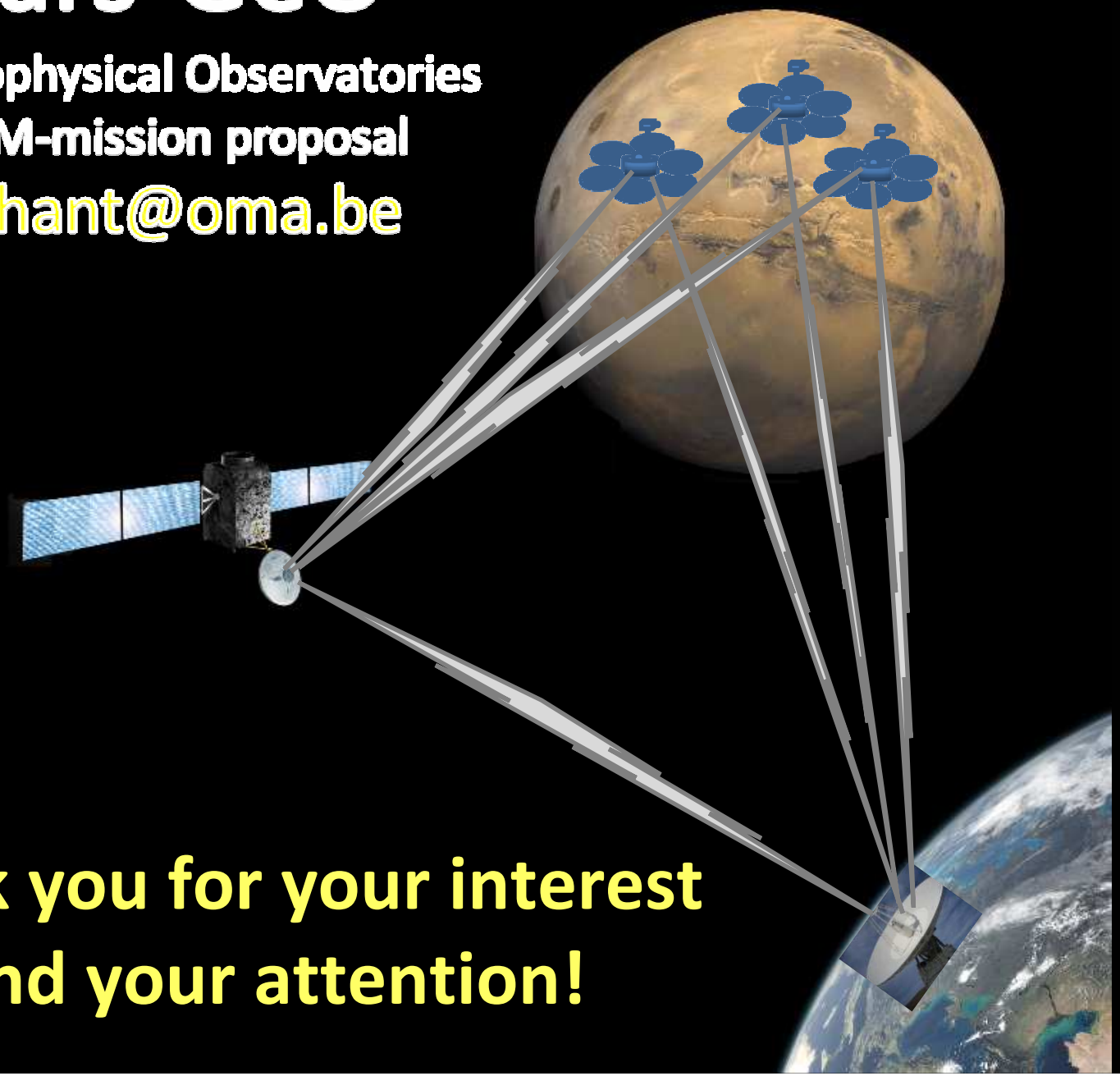

Thank you for your interest and your attention!