GETEMME, a project to explore the Martian satellites

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and the GETEMME core team

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What is GETEMME ?

Gravity, Einstein's Theory, and Exploration of the Martian Moons' Environment

Heritage of space geodesy around the Earth

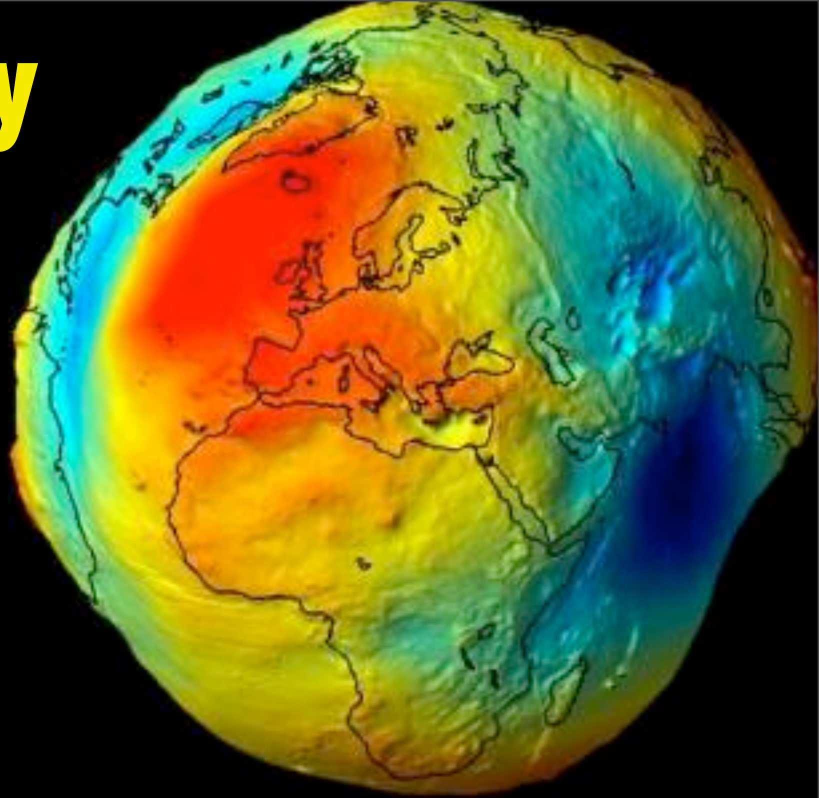
Heritage of radio-science experiments with probes

Heritage of how build an ephemeris

GETEMME = precise planetary geodesy in the martian system

Scientific motivations

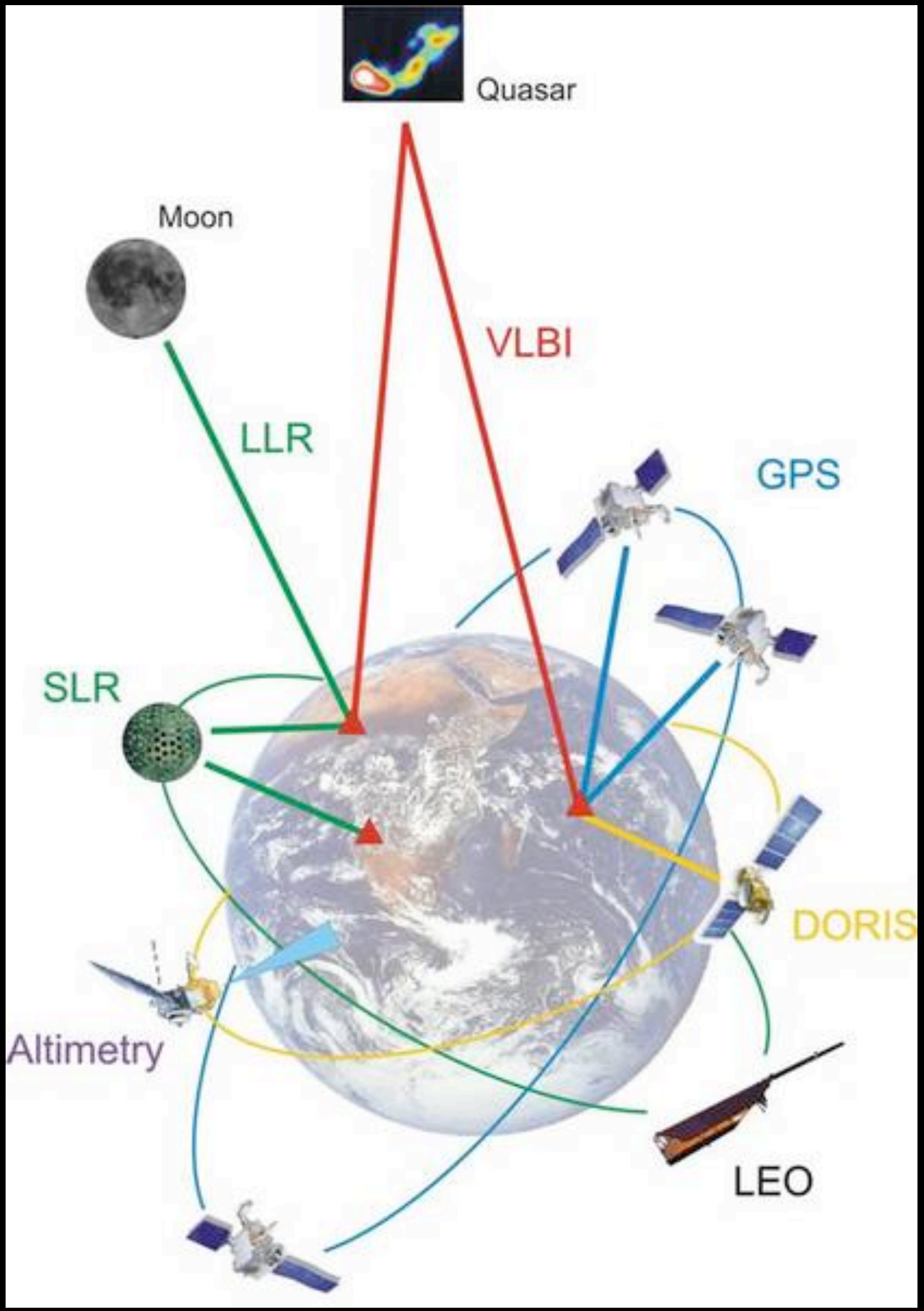
Go back to basics with Earth geodesy



direct study of Earth gravitational field (static, dynamical)

Earth precession/ nutation

Tidal dissipation in Earth/Moon system



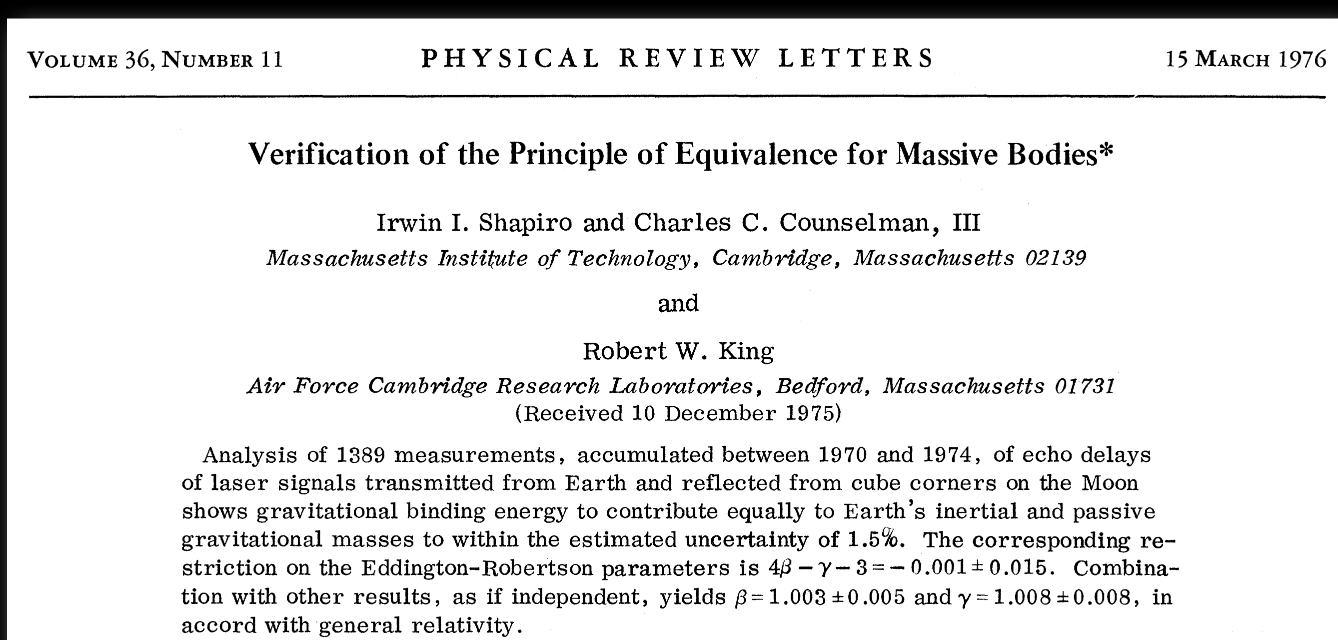
lageos satellite

Lunar Laser Ranging and fundamental physics

Now at centimer level...

And if inertial and gravitational masses are differents ?

Signal on orbital motion of the Moon so test weak equivalence principle



VOLUME 36, NUMBER 11 PHYSICAL REVIEW LETTERS 15 MARCH 1976

Verification of the Principle of Equivalence for Massive Bodies*

Irwin I. Shapiro and Charles C. Counselman, III
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

Robert W. King
Air Force Cambridge Research Laboratories, Bedford, Massachusetts 01731
(Received 10 December 1975)

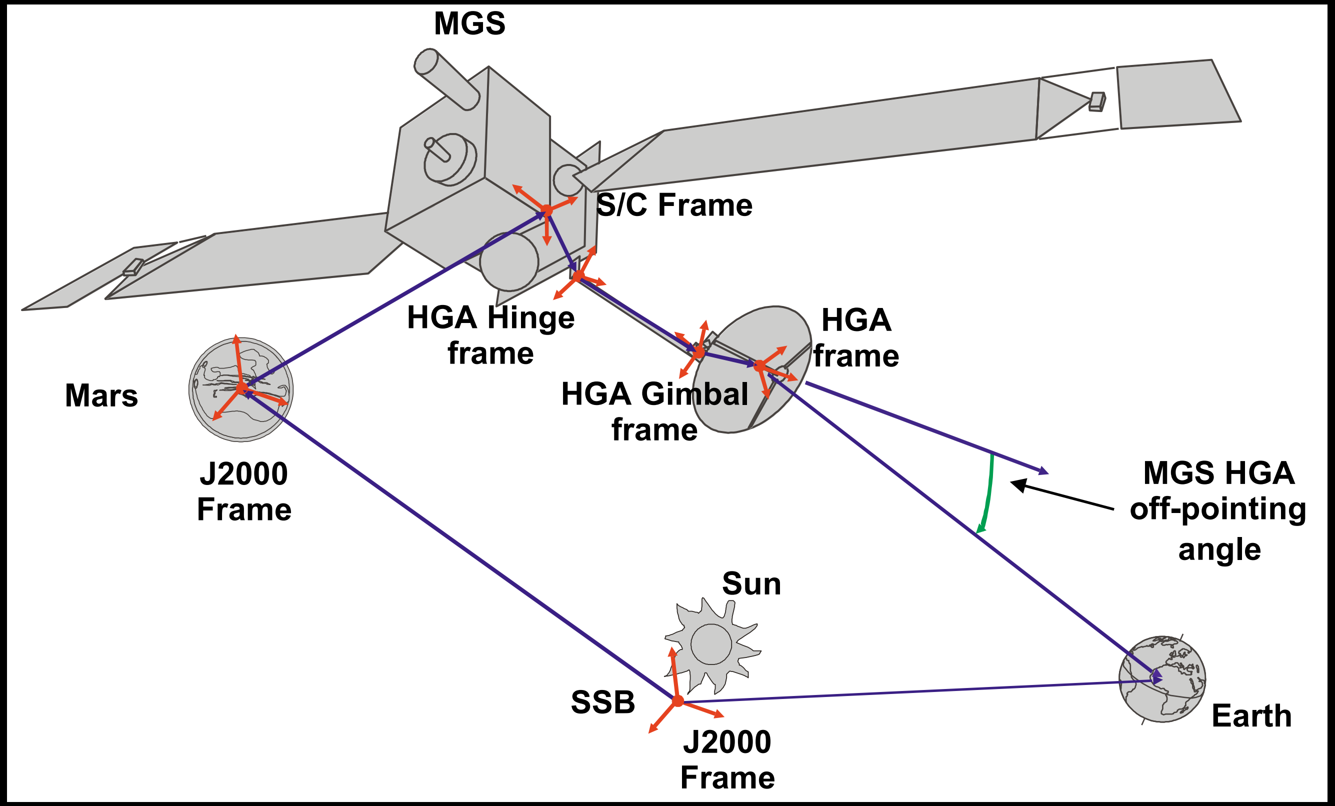
Analysis of 1389 measurements, accumulated between 1970 and 1974, of echo delays of laser signals transmitted from Earth and reflected from cube corners on the Moon shows gravitational binding energy to contribute equally to Earth's inertial and passive gravitational masses to within the estimated uncertainty of 1.5%. The corresponding restriction on the Eddington-Robertson parameters is $4\beta-\gamma-3=-0.001\pm0.015$. Combination with other results, as if independent, yields $\beta=1.003\pm0.005$ and $\gamma=1.008\pm0.008$, in accord with general relativity.

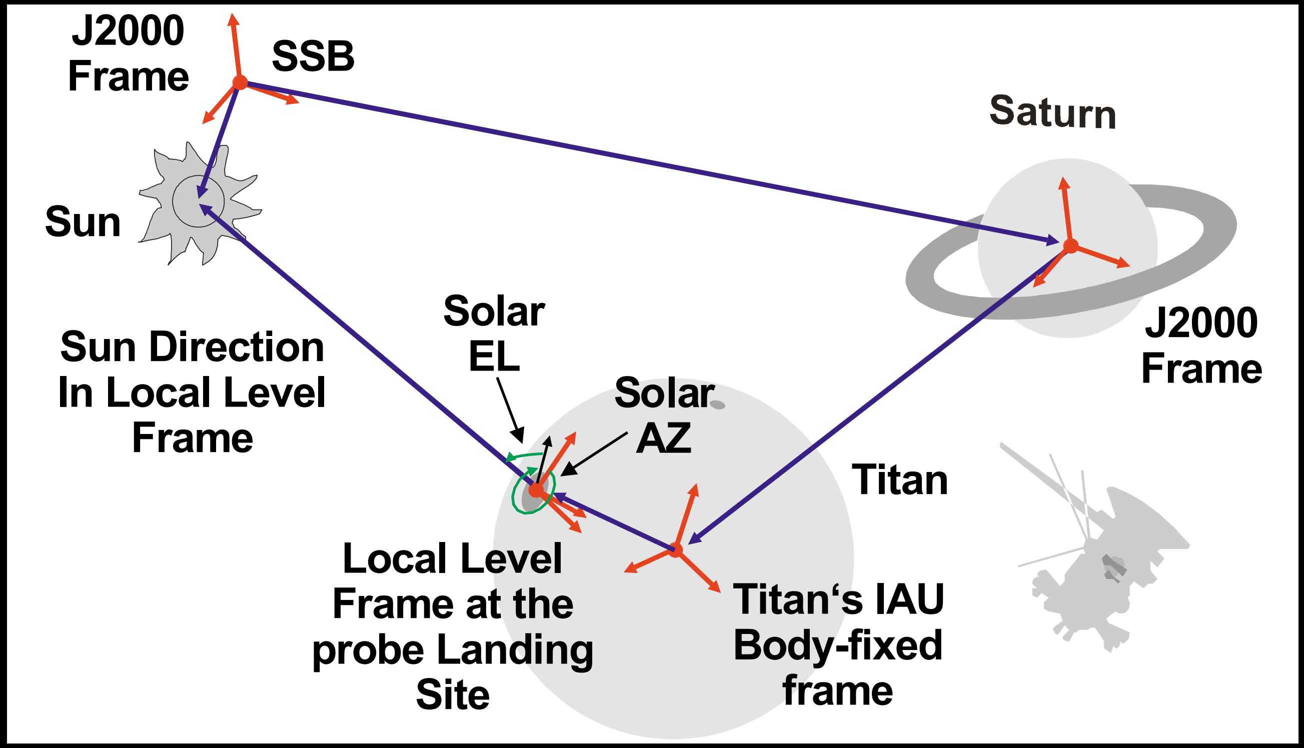
But also:

- Test strong equivalence principle
- Variation of gravitation constant G

First look at planetary geodesy

The key idea is the precise monitoring of a probe's trajectory by using radio-science technique.



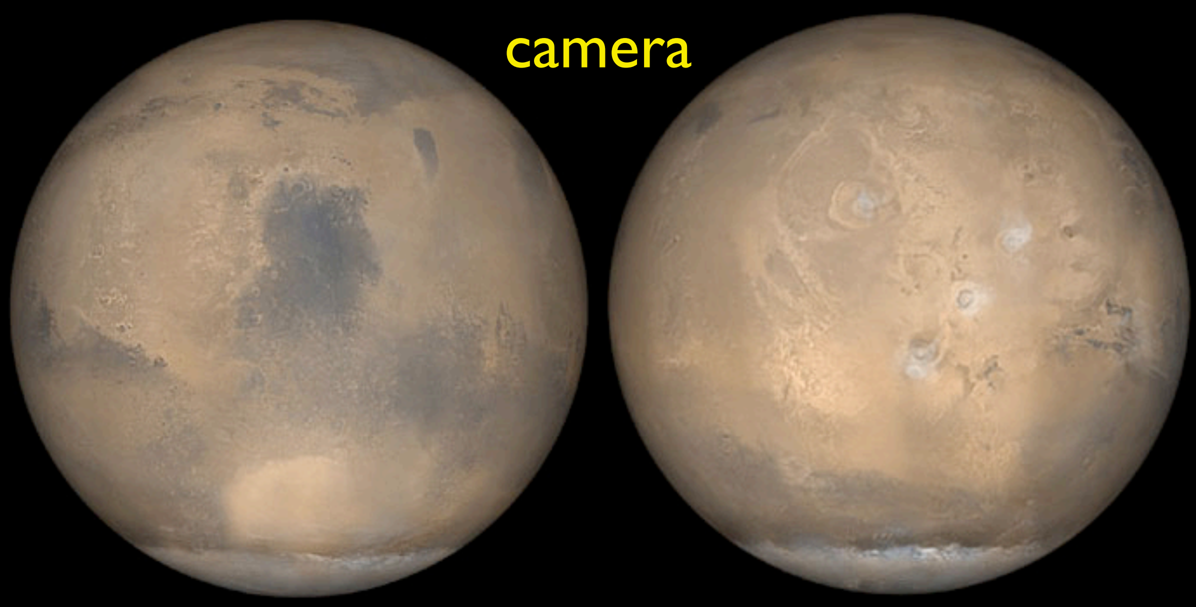


A lot of dynamical frames involved in this task

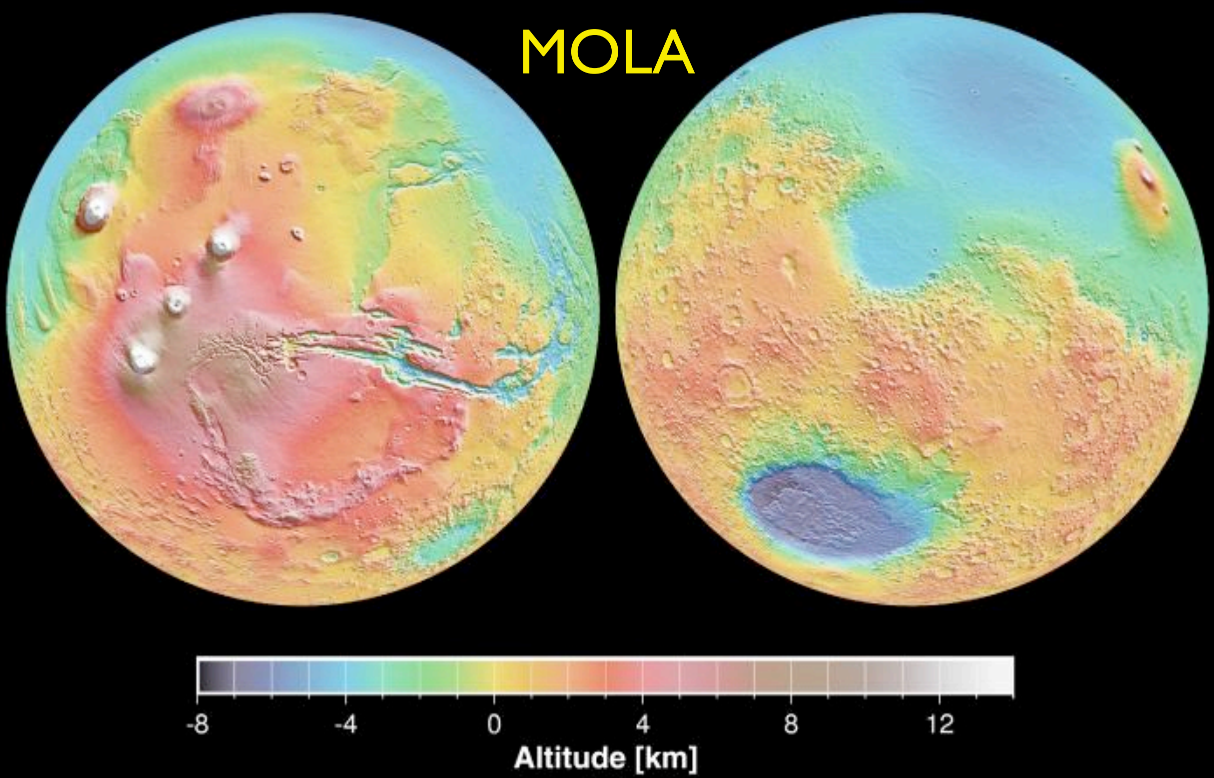
But at the end, with Doppler data of the probe...

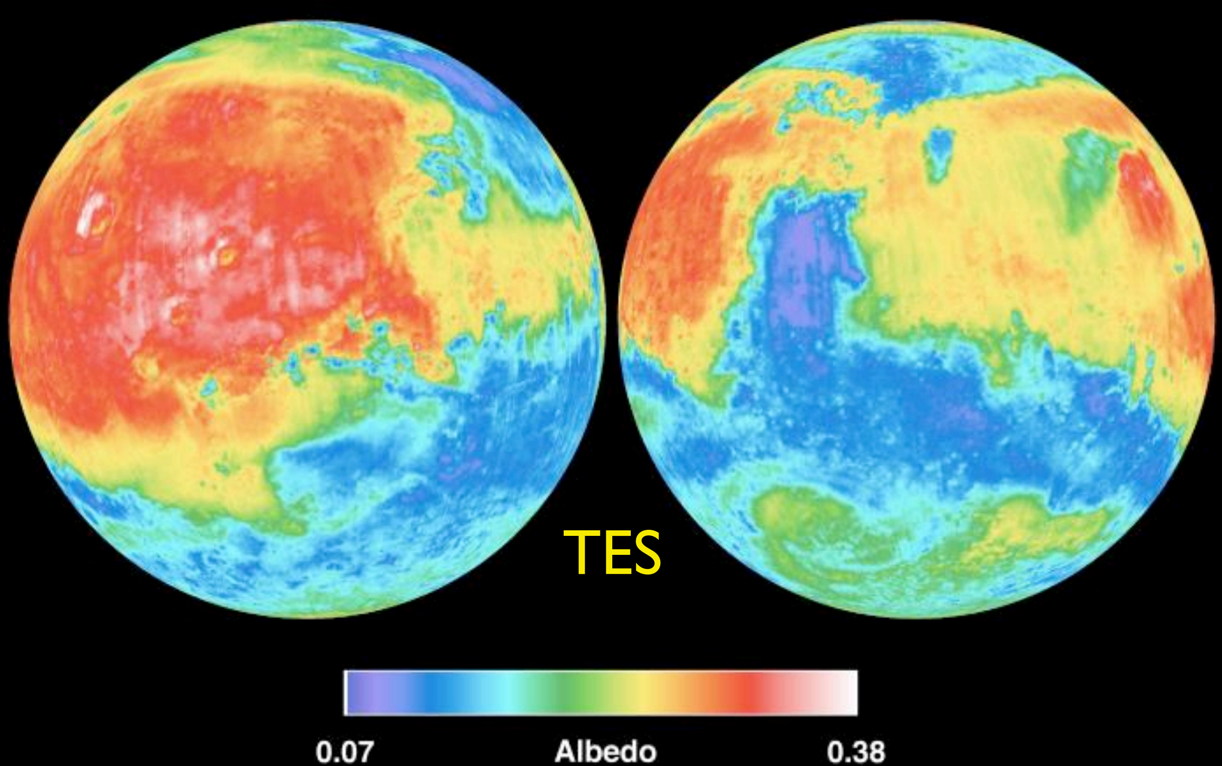
you can do the orbit + some physical informations

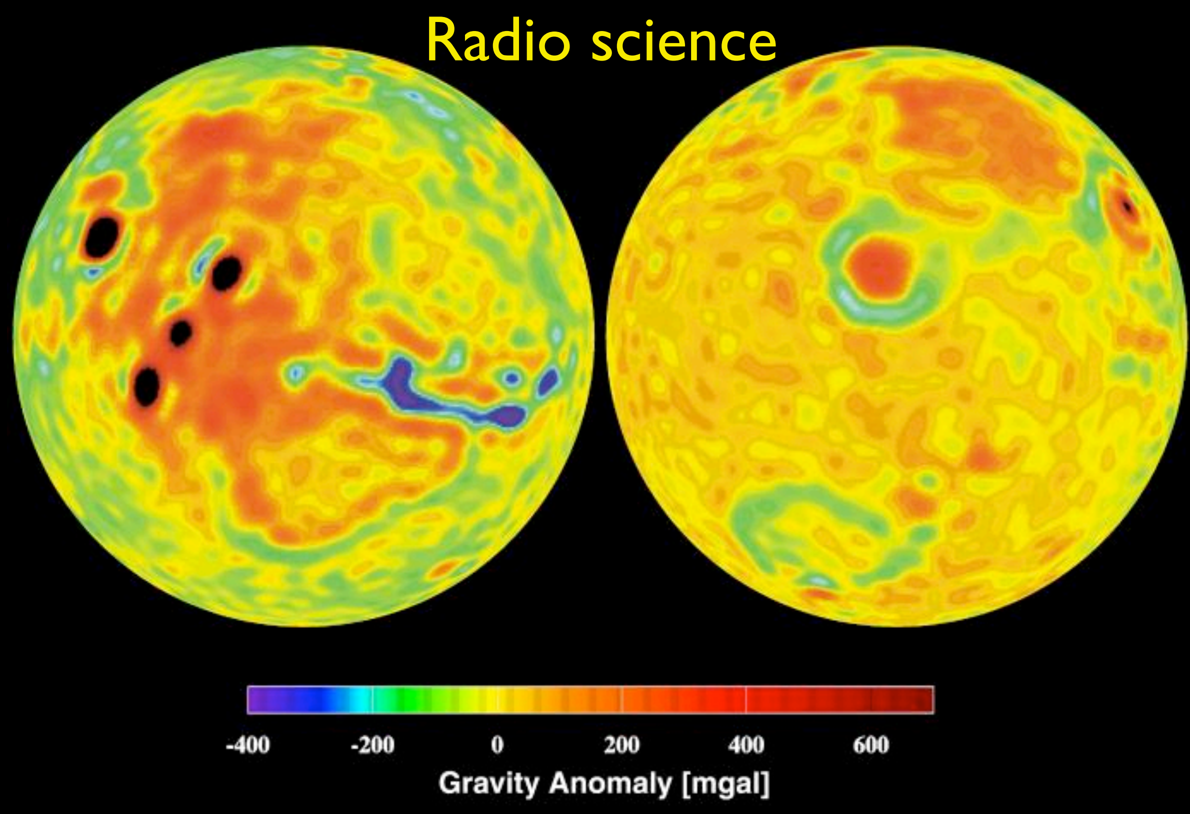
Mars as an example (MGS)



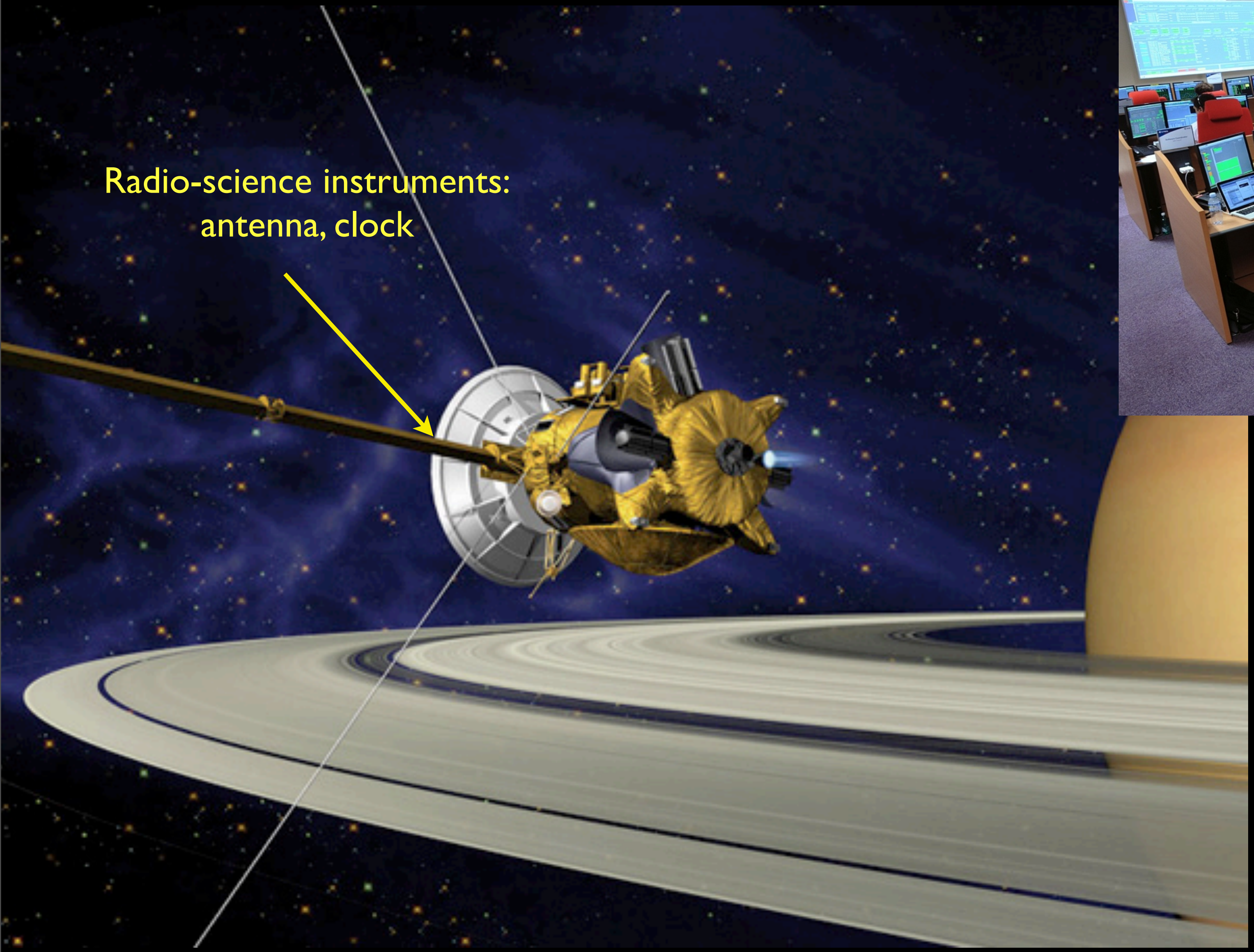
Global Views of Mars in late Northern Summer
MGS MOC Release No. MOC2-310, 18 April 2002

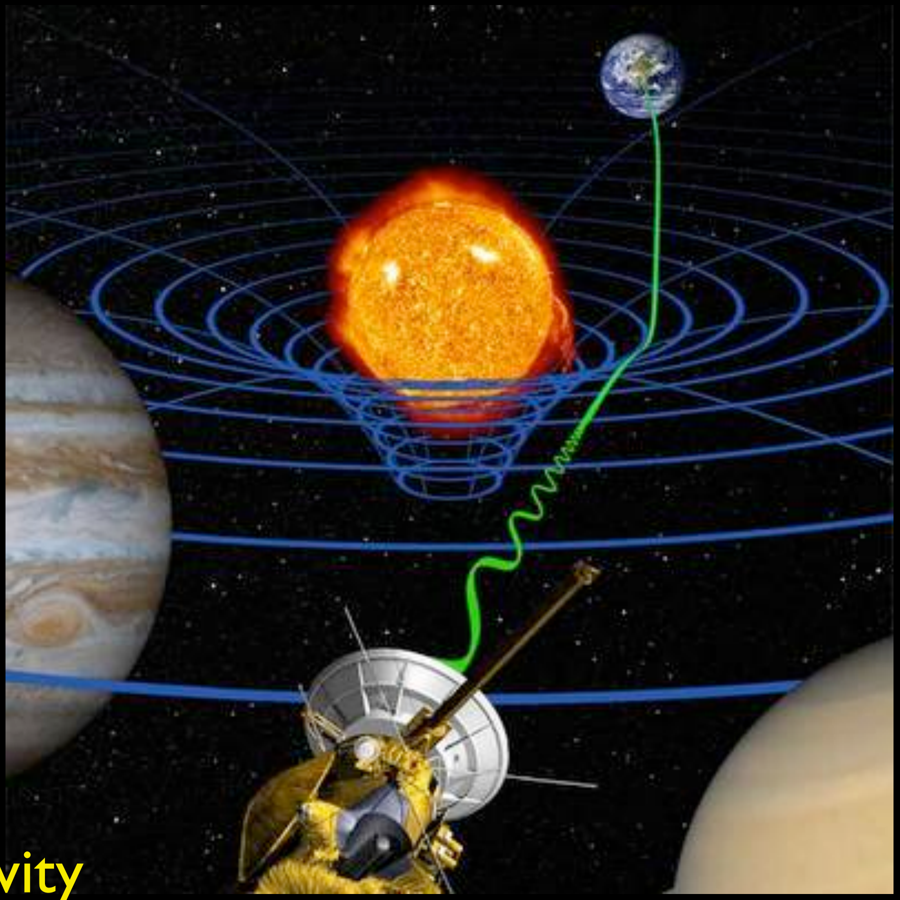






planetary geodesy and relativity



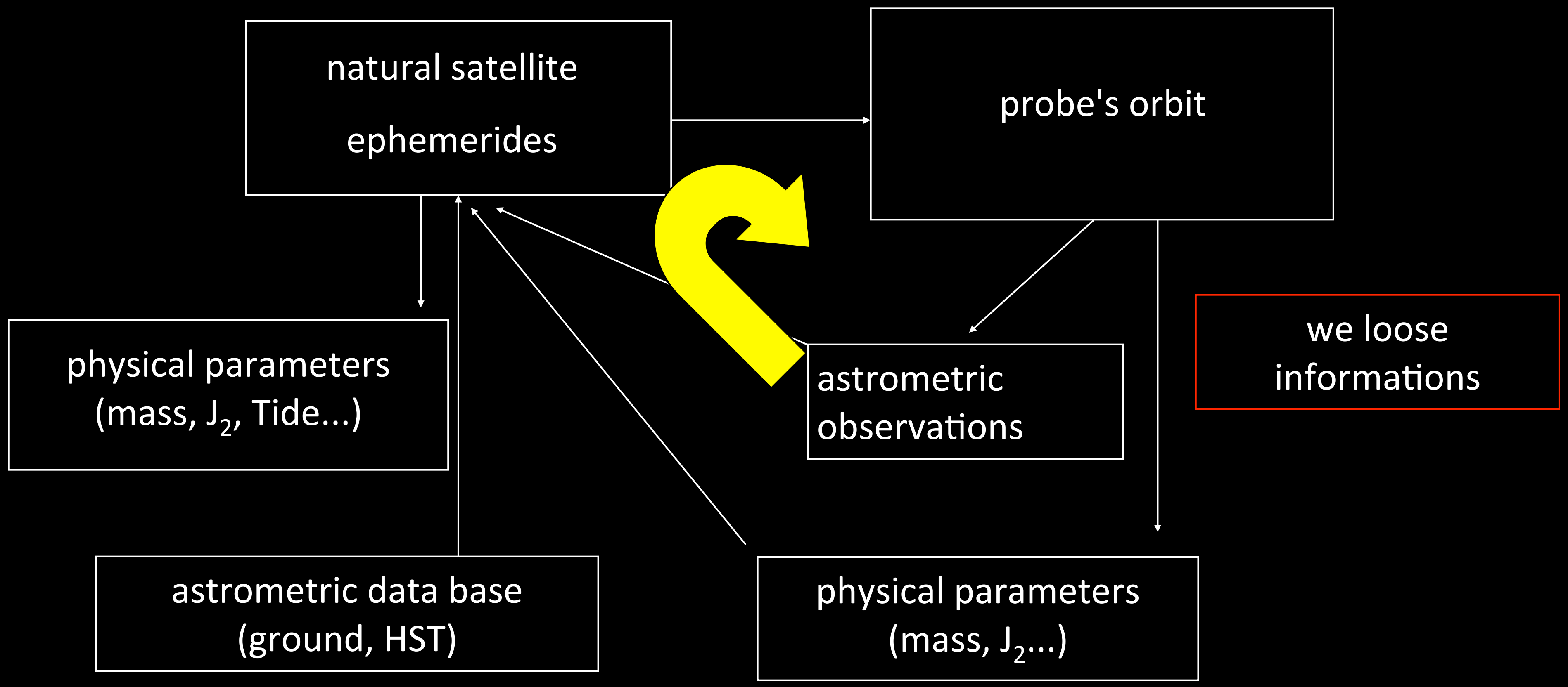


Conjonction between Earth and Cassini, September 2003 ⟷ Maximum of relativistic deflection

Nowadays best test of post-newtonian gravity

Bertotti *et al.* 2003, *Nature*, **425**, 374

So what we do now



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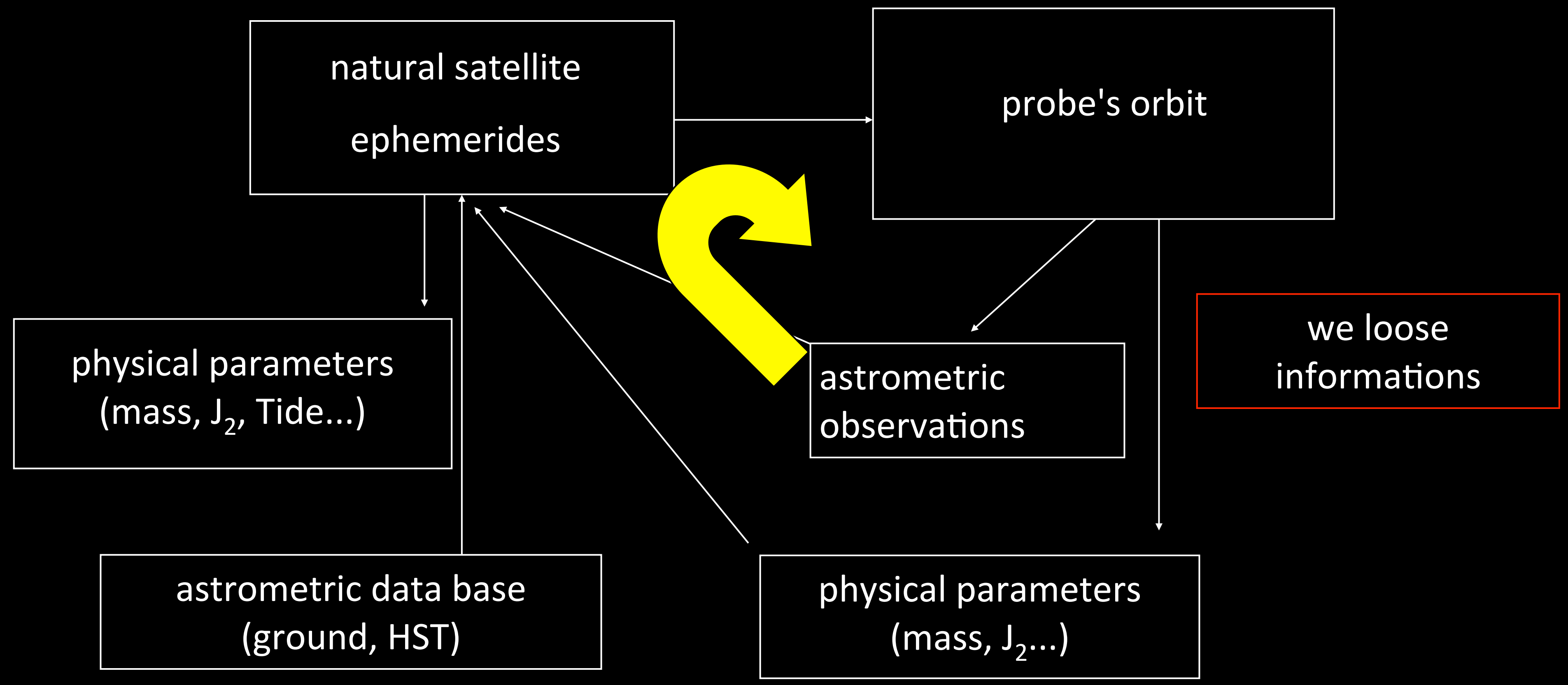
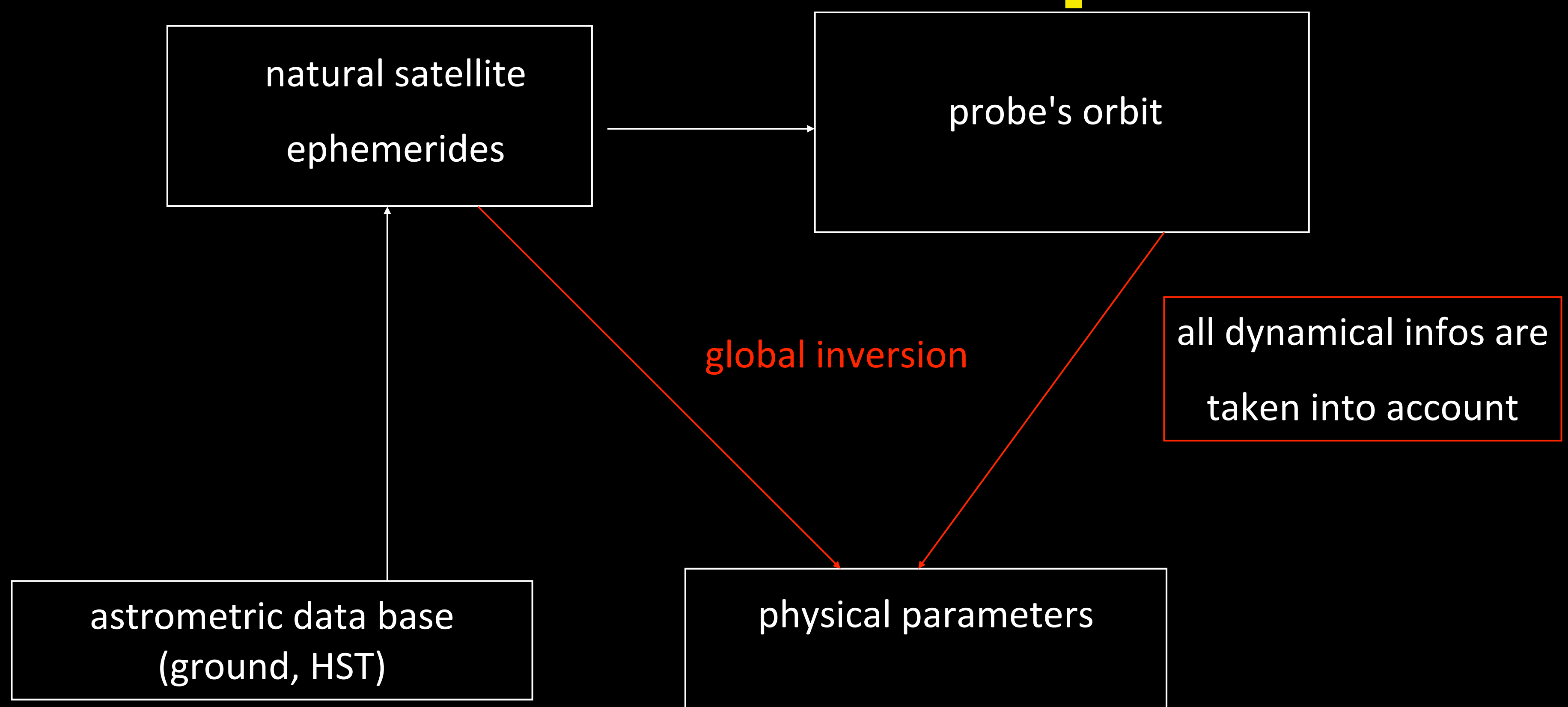


And what would be useful to improve the situation ?



GETEMME: even we want to go beyond

Normally, orbits of Mars probes have:

- inclination with respect to the plane of the Mars equator
- an eccentricity

A lot of desaturations => precise orbit = arc of some days

Imagine now:

- equatorial circular orbit
- onboard accelerometer, only radio-science experiments
- possibility to do some space metrology with the moons (determination of Moon-probe distance)

And even we want to go beyond !

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or... you can say that your moons can be seen as *natural* probes !

Why the martian system ?

Phobos and Deimos are rocky satellites, you can put on them some reflectors

- Up to last November : complementary with Phobos Grunt
- Exploration of Deimos

With the failure of Phobos Grunt, possibility to do a full experiment concerning the Martian moons

Phobos and Deimos have short orbital periods (7 and 30h):

- our Moon => roughly 1 month
- we are searching for secular precession (tide, relativity)

We need longer *gravitational time* for precession

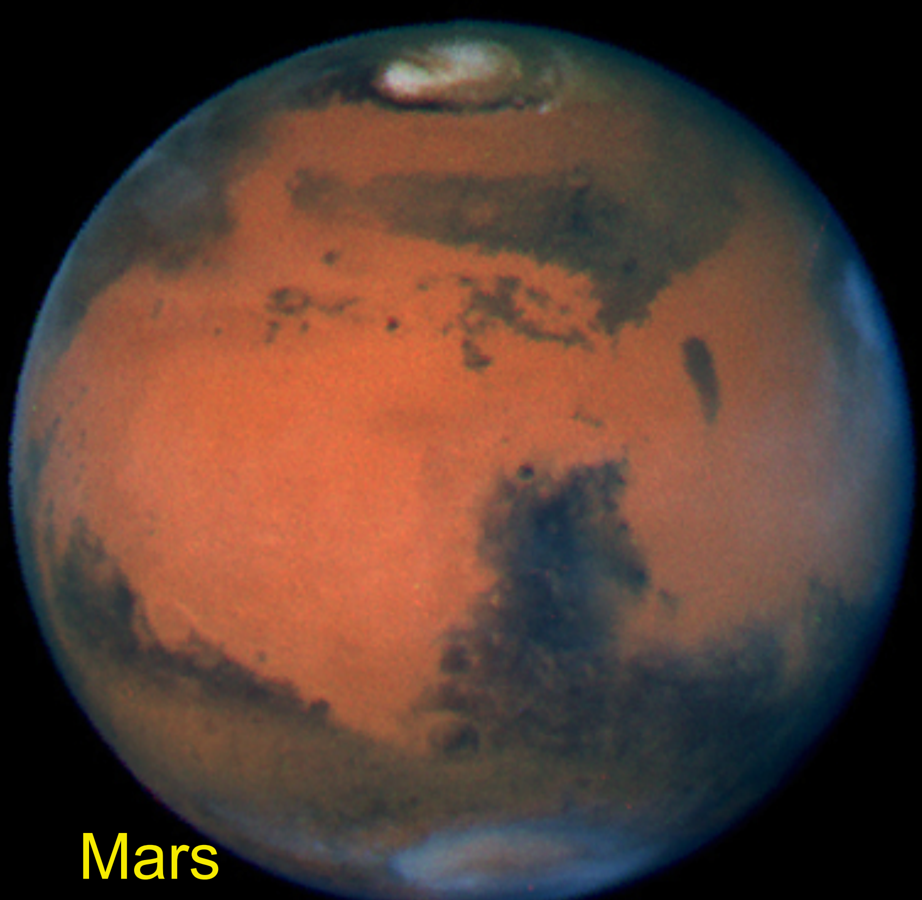
30 yrs of LLR is roughly 413 orbits of the Moon
2yr of Phobos is 2500 orbits

GETEMME in technical words

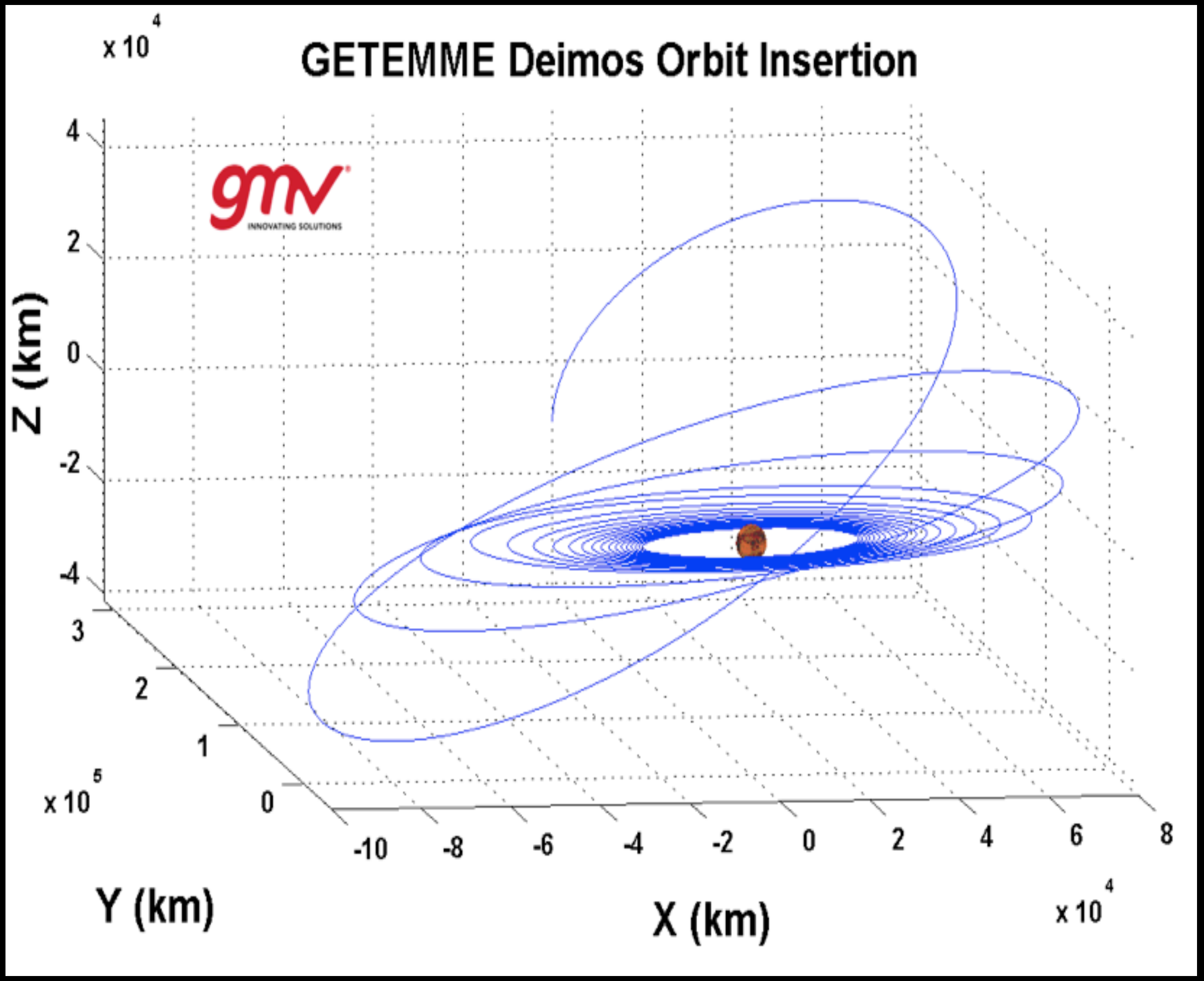
GETEMME Mission Scenario

- Launch on Soyus Fregat
- Transfer to Mars with arrival 2 years after launch
- Deimos rendezvous, comprehensive mapping, and deployment of two Laser reflector stations
- Transfer to Phobos, mapping and deployment likewise…
- Transfer to final orbit (1500 km above Mars) and begin scientific Laser ranging campaign

Deimos



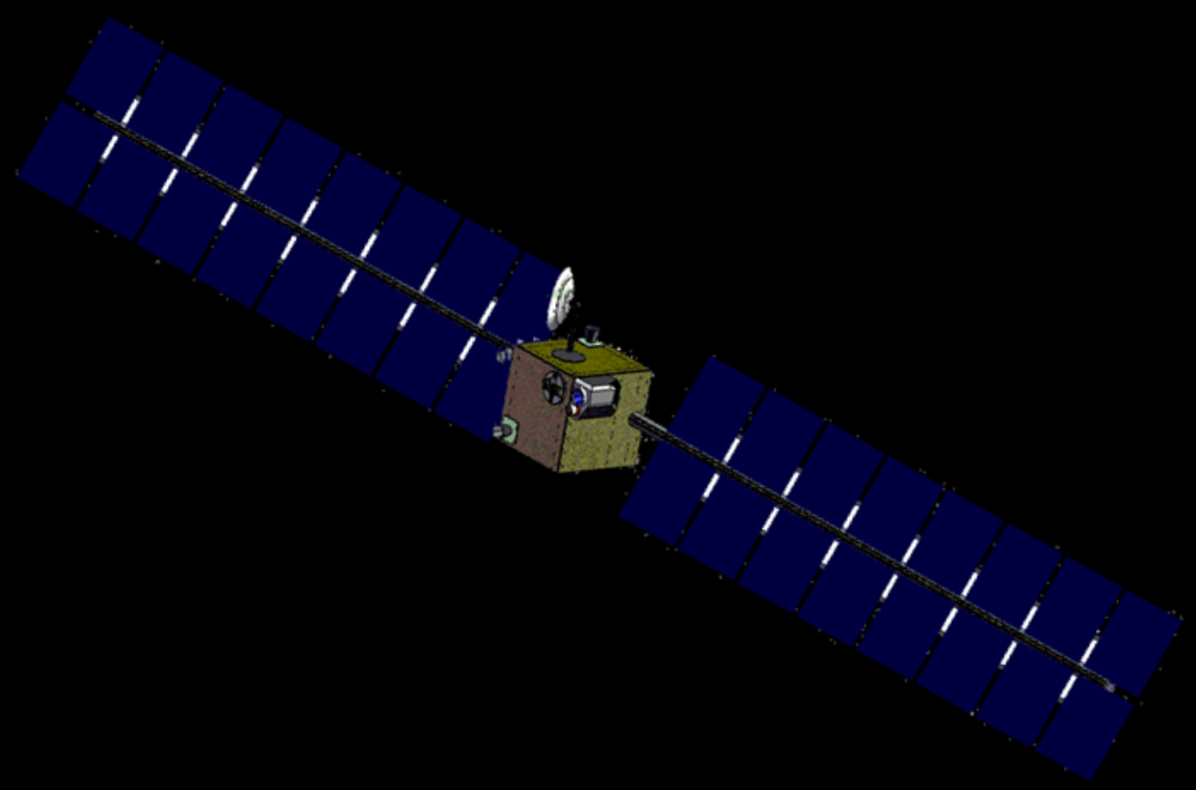
Mars



Phobos

GETEMME Measurement Objectives

- Full characterization of Phobos and Deimos using imaging, altimetry, spectro-photometry, and radio science
- Range measurements between S/C and Phobos / Deimos for 1 Martian year, > 100,000 shots each
- Asynchronous two-way range measurement from S/C to Earth / from Earth to S/C for 1 Martian year, > 50,000 shots each
- Range measurement accuracy: meter- accuracy for single shots; centimeter-accuracy by normal point formation



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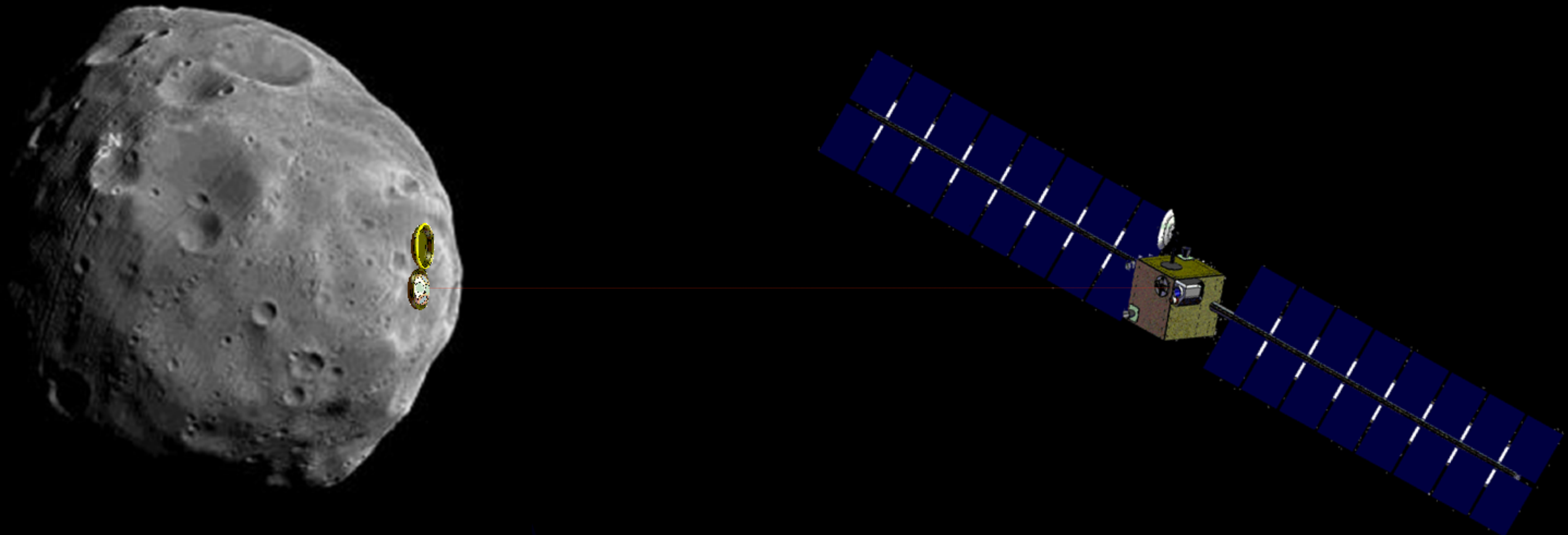
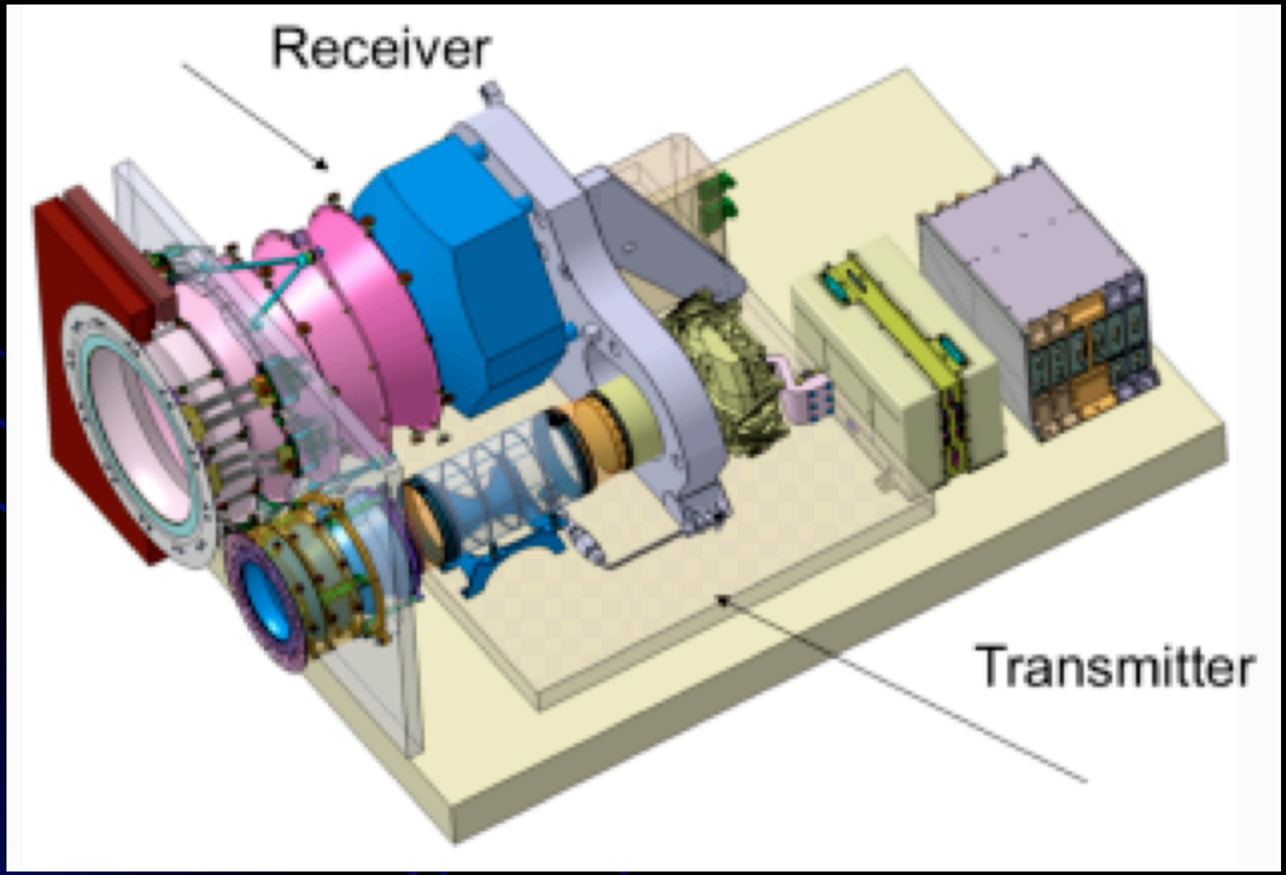


GETEMME Laser

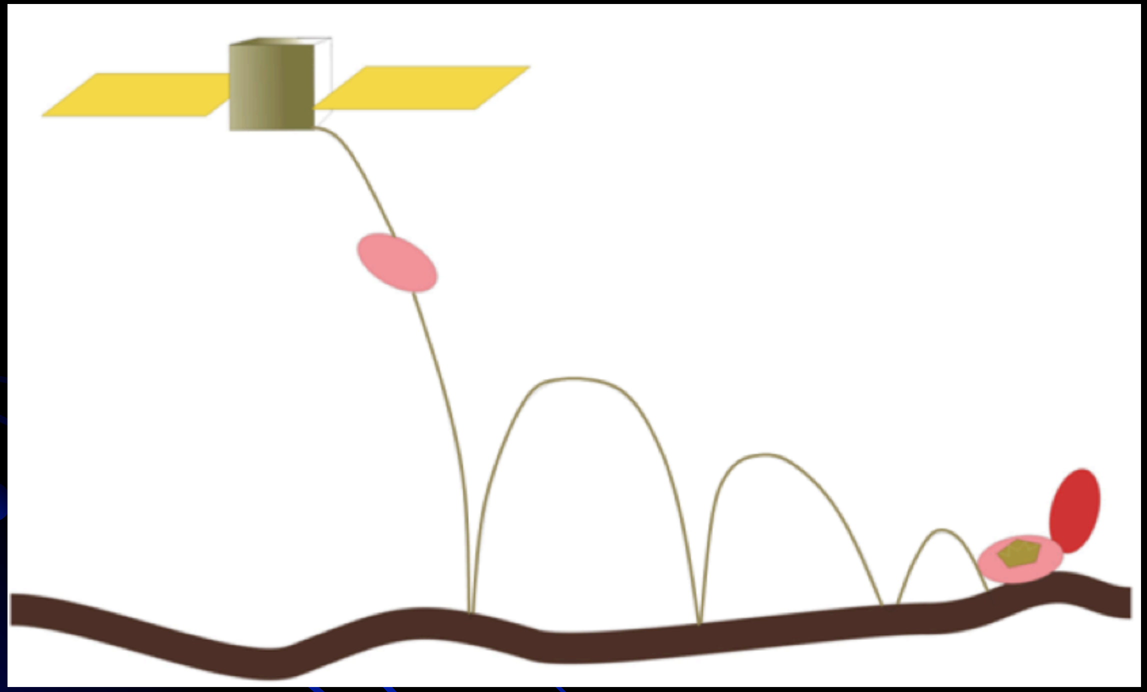
- Three applications
  - Range measurements to Phobos / Deimos reflectors,
  - asynchroneous Earth-ranging,
  - classic altimetry
- Heritage: BELA (Bepi Colombo Laser Altimeter)

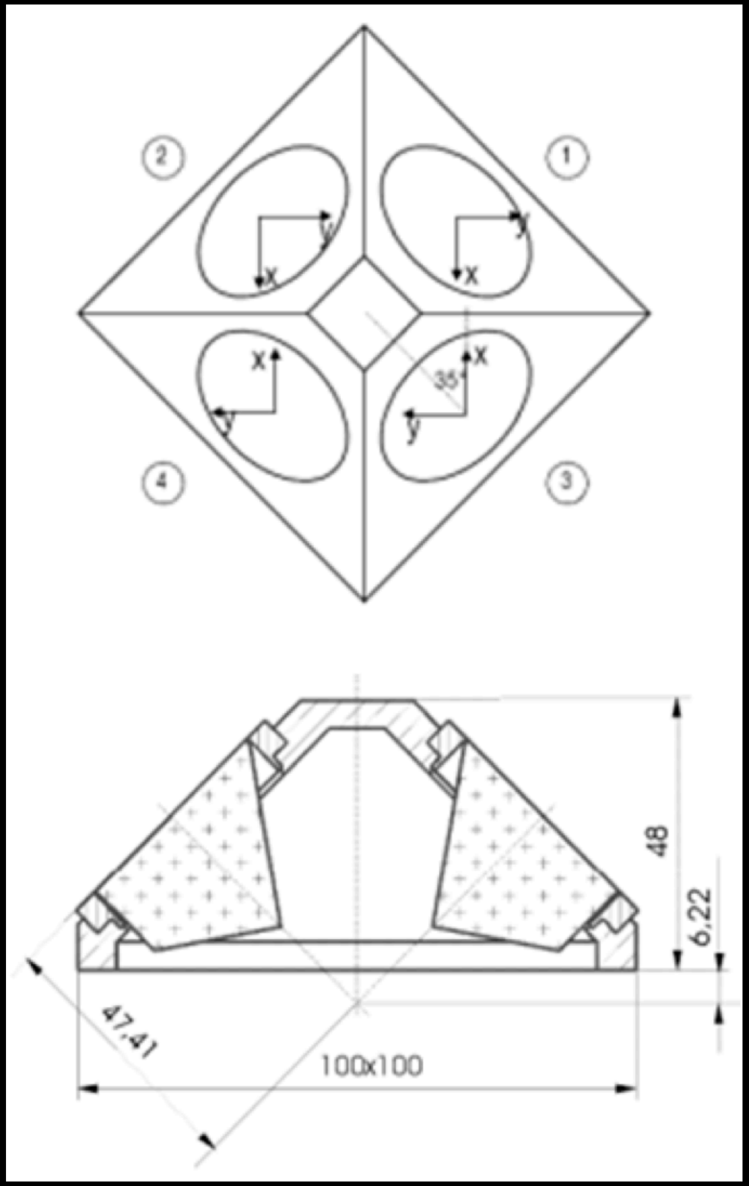


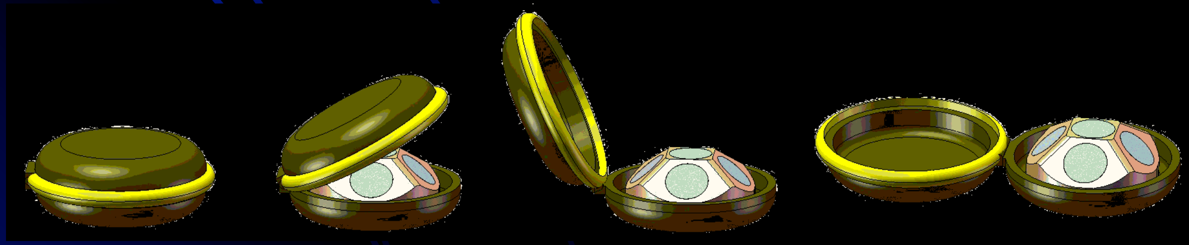
Laser type	Nd:YAG
Frequency	1064 nm
Energy	50 mJ (BOL), 40 mJ (EOL)
Repetition rate	10 Hz
Pulse duration	3-8 ns
Pulse width	5,5 ns +- 2,5 ns (50% of peak [FWHM])
Beam Diameter	74 mm (Aperture of BEX)
Beam Divergence	50 micro rad +- 10 micro rad
Receiver sensor	Silicon APD (Avalanche Photo Diode)
Telescope diameter	20 cm
Focal Length	1250 mm
Field of view telescope	450 micro rad

GETEMME Reflector Stations

- 4 landers, 2 on each satellite near side (to allow measurements of librations)
  - low touch-down velocity: < 10 m/s
  - open cover after deployment
  - battery power for few hrs after landing
  - stay passively on the satellite surfaces for years …

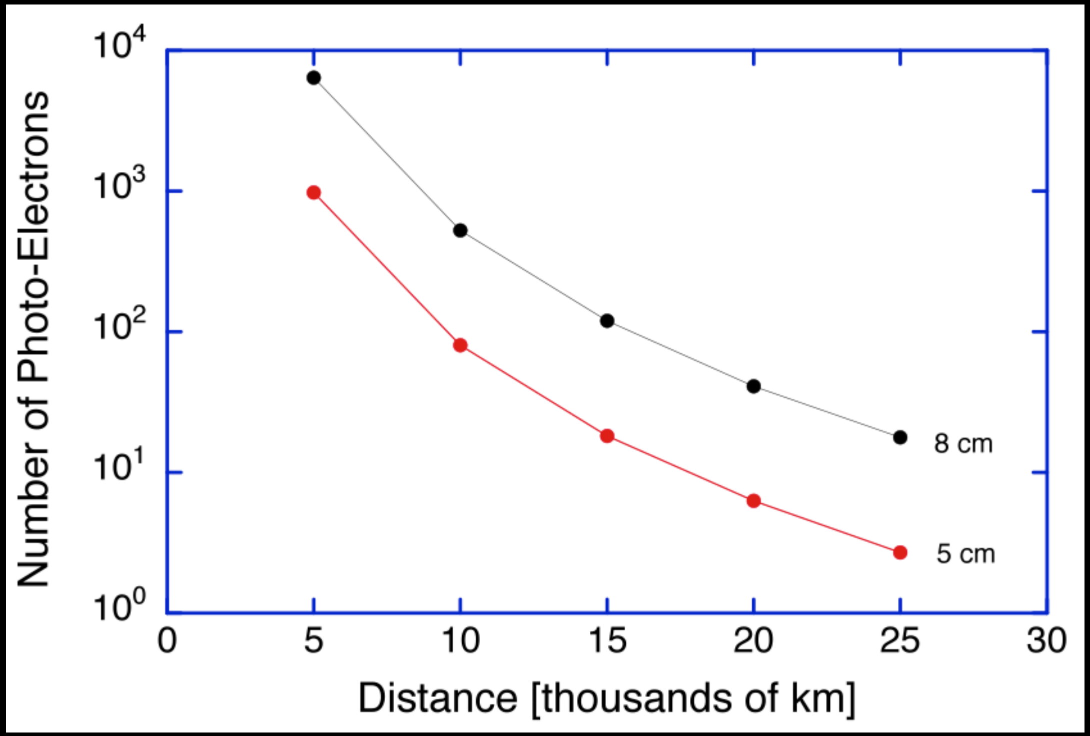




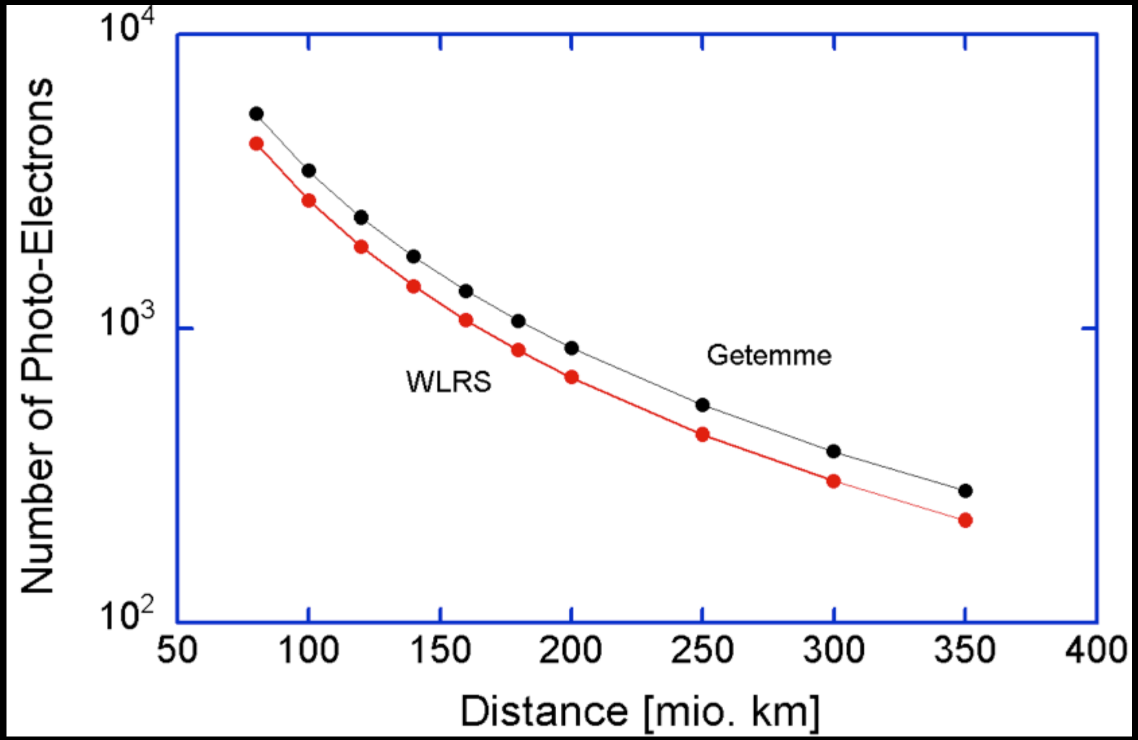


Retroreflectors /
Heritage: Champp

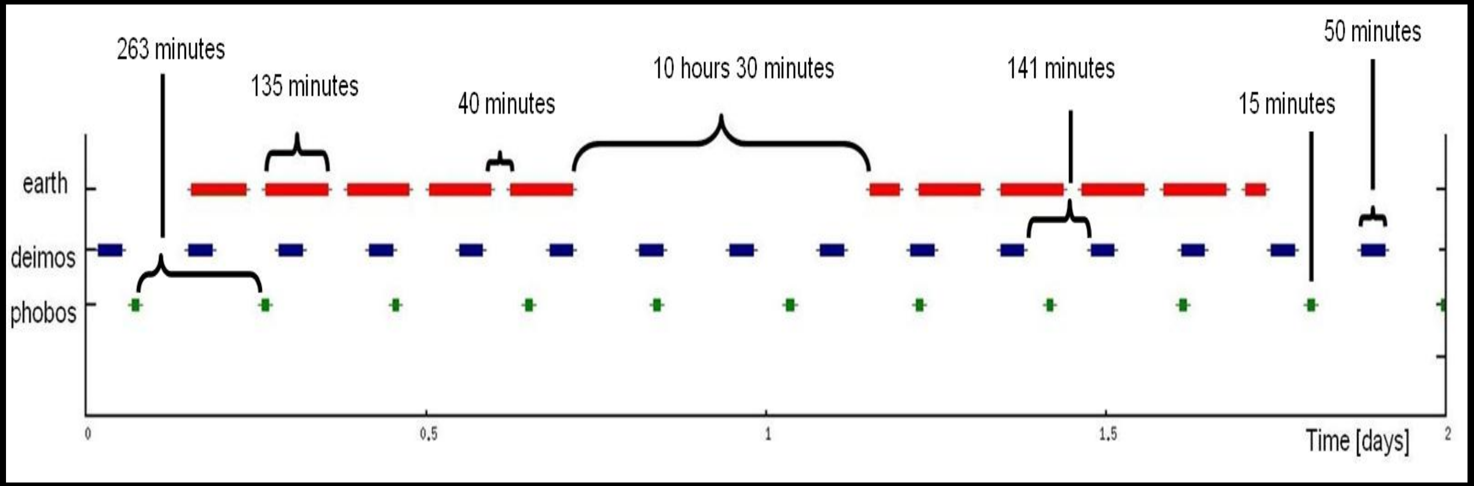
GETEMME Link Budgets



Photon link budget for different Phobos/Deimos reflector sizes



Photon link budget for Earth ranging



Phobos / Deimos ranging schedule

Challenge: delicate balance must be found between Laser power, reflector size, receiver size, Laser beam spreading, and Laser pointing accuracy

GETEMME Pointing Requirements

- Laser operation characteristics
  - Distance to Deimos: up to 20,000 km
  - Laser spot size at Deimos: < 2 km
  - Required beam divergence: < 100 µrad (BELA: 50 µrad)
  - 100 µrad ≈ 0.01° (SRC pointing accuracy!)
  - seems well feasible!

- Is it possible to track a target with this required accuracy?
  - Spacecraft speed wrt Deimos: > 2 km/s
  - Must accurately track target at 0.01° / s for ≈ 1 hour
  - may be challenging!

GETEMME Proposal Team:

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Scientific numbers as a conclusions

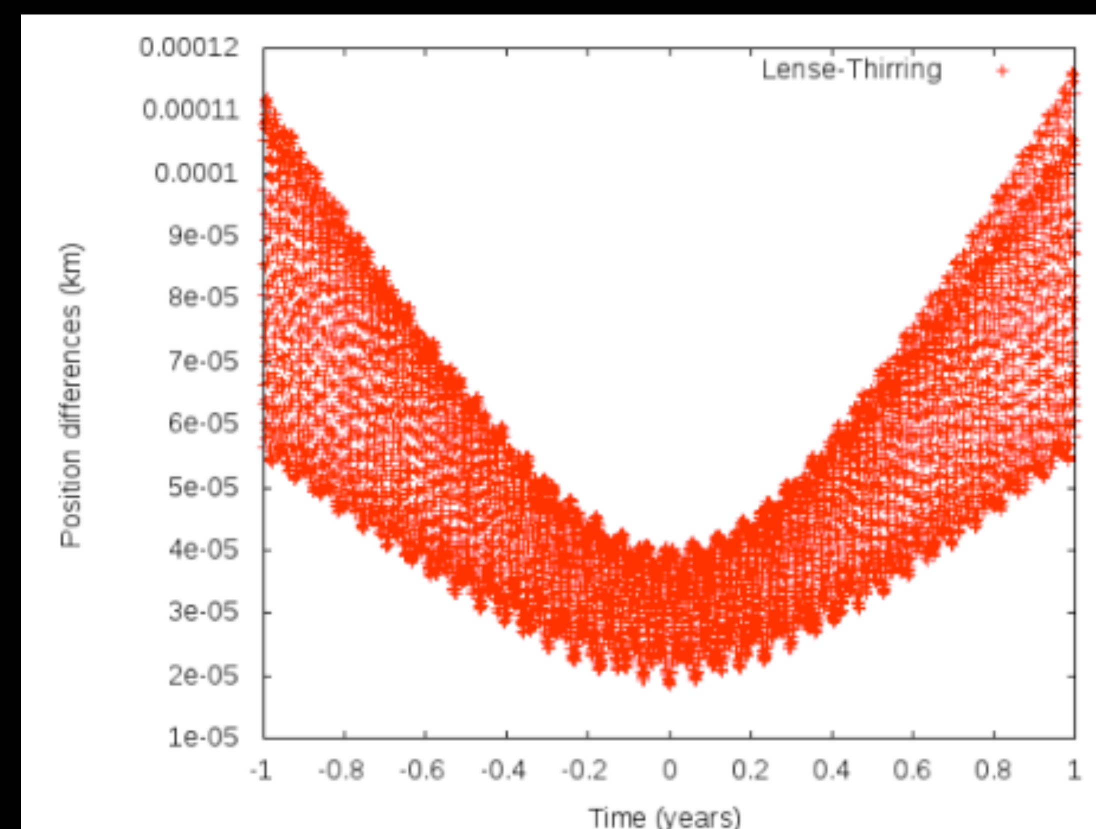
This new way of precise planetary geodesy will lead to

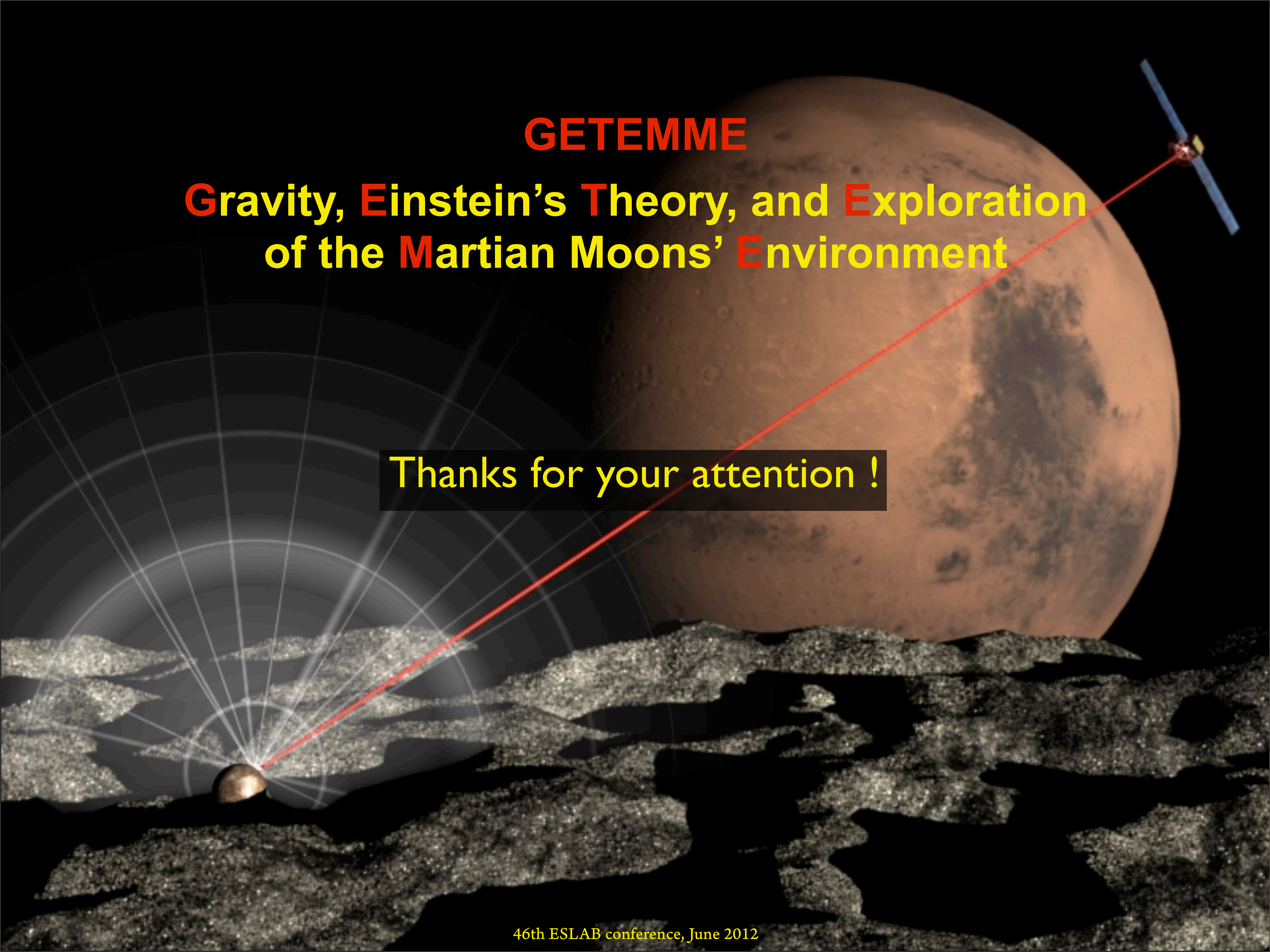
- Improve test of General Relativity by a factor 100 on pericenter precession
- Improve drastically our accuracy of Phobos and Deimos ephemerides
- Improve our knowledge of libration of Phobos and more generally of what we know about Martian moons

Table 1 Example of the expected accuracy on few key physical parameters of the Mars system, after considering 2 and 4 years of GETEMME data, respectively

Parameter	2 years	4 years	Today accuracy
Temporal variations of J_2	9.2×10^{-15}	5.8×10^{-15}	5×10^{-10}
Secular variation of Mars J_2	1.5×10^{-17}	2.7×10^{-18}	–
k_2 (Solar tide)	2.0×10^{-6}	9.9×10^{-7}	1×10^{-2}
k_2 (Phobos tide)	4.0×10^{-5}	2.0×10^{-5}	–
k_2 (Deimos tide)	1.8×10^{-3}	8.5×10^{-4}	–

Parameter	2 years	4 years
Phobos c_{20}	1.5×10^{-5}	5.4×10^{-6}
Phobos c_{21}	3.0×10^{-7}	2.1×10^{-7}
Phobos c_{22}	2.6×10^{-6}	9.0×10^{-7}
Deimos c_{20}	1.5×10^{-3}	5.3×10^{-4}
Deimos c_{21}	3.2×10^{-6}	1.2×10^{-6}
Deimos c_{22}	2.5×10^{-4}	9.0×10^{-5}





GETEMME

Gravity, Einstein's Theory, and Exploration of the Martian Moons' Environment

Thanks for your attention !