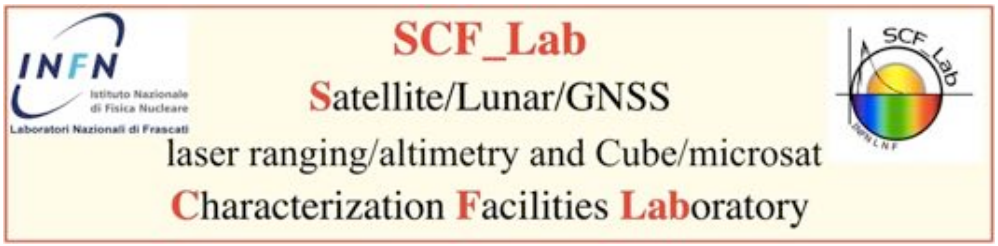
MoonLIGHT-2 / JointLab tra INFN-Frascati e ASI-CGS: prospettive e collaborazioni (in atto e future)

"Workshop sulla Gravitazione Sperimentale" INFN – CSN2 & ASI – CGS
(https://agenda.infn.it/event/24144/)
Nov. 12-13, 2020

S. Dell'Agnello (INFN) et al

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California



National / International Collaborators

S. Dell'Agnello[1] (presenting), L. Porcelli[1,2], M. Muccino[1], M. Tibuzzi[1], G. Delle Monache[1], L. Salvatori[1], C. Mondaini[1], O. Luongo[1], R. Vittori[1,4], M. Petrassi[1], L. Rubino[1], L. Mauro[1], R. March[1], G. Bellettini[1], U. Denni[1], L. Filomena[1], C. Rossi[1], V. Sanclimenti[1], G. Bianco[1,3], C. Benedetto[3], D. Dequal[3], R. Mugnuolo[3], S. Capozziello[1], G. Esposito[1] (et al @Naples), P. Villoresi, P. Vallone et al @Padua) D. Currie[5], J. Chandler[6,6bis], T. Murphy[6], C. Neal[7], R. Weber[8], E.S. Law[9], N. Gallegos[9], N. Boersma[10], L. Cacciapuoti[10], B. Day[11], A. Brown[12]

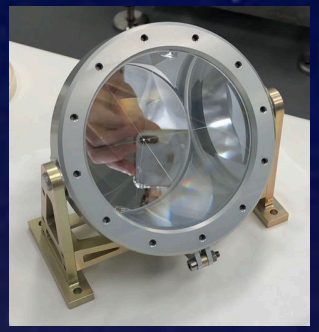
[1]Istituto Nazionale di Fisica Nucleare, Italy, [2]Univ. della Calabria, Italy
[3]ASI – Centro di Geodesia Spaziale (ASI–CGS), Matera, Italy
[4]Italian Air Force, ASI, Italy, and Embassy of Italy in Washington DC
[5]Univ. of Maryland at College Park, MD, USA
[6]Univ. of California at San Diego, CA, USA & [6bis]Center for Astrophysics, Harvard, MT
[7]Univ. of Notre Dame, PA, USA
[8]NASA-Marshall Space Flight Center (MSFC), AL, USA
[9]NASA – Jet Propulsion Laboratory (JPL), California Inst. of Techn., Pasadena, CA, USA
[10]ESA – European Space research and Techn. Center (ESTEC), Noordwijk, The Netherlands
[11]NASA – Ames Research Center (ARC), CA, USA
[12]NASA – Head-Quarters (HQ), MD, USA

NASA – ESA – INFN & ASI-CGS PROGRAM FOR THE MOON

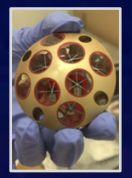
- INFN-LNF & ASI-CGS **Joint Lab** Agreement ➔ 2021 – 2026
- INFN – ESA Contract MPAc (MoonLIGHT Pointing Actuator) ➔ 2021 – 2023
- INFN Affiliation to NASA – SSERVI (Silicon Valley) ➔ from 2014
- ASI Association to NASA – SSERVI ➔ from 2017
- NASA – ASI General Agreement n. 1 on Artemis/LOP-G : ➔ from Oct 2019
- US Gov. – Italian Gov. (**ComInt**) General Artemis Accords: ➔ from Sep 2020

ASI–INFN Joint Lab on Laser Retroreflectors & Ranging

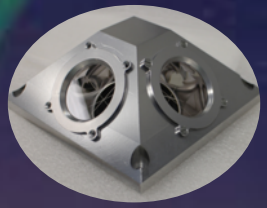
ASI – **INFN**– Ministry Foreign Affairs
collaboration with USA partners:
NASA, Universities, USGS,
NOAA-NIC, USA space industries



Moon
U. Maryland,
U. San Diego,
Industries,
NASA-
SSERVI



Mars, Moon;
Europa
NASA, ESA



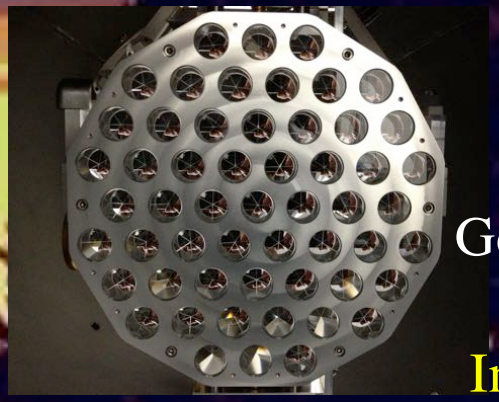
Earth
Observation
USGS, NOAA

Phobos/Deimos
NASA-SSERVI

Comet/asteroid
NASA-
SSERVI

ASI – Matera
Laser Ranging
Observatory

LAGEOS
NASA-
GSFC
LARES-2



Galileo
2nd
Generation
ESA,
Industries

Joint Lab INFN-Frascati & ASI-Matera

WP 2000
INFN-LNF Operations

- WP 2100 — **SCF_Lab Internal Special Facility**
- WP 2200 — **SCF_Lab2 Internal Special Facility**
- WP 2300 — **Project of Future Range Corrections**

WP 3000
Advanced Laser Payloads and Systems

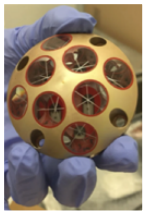
- WP 3100 — **Moon, Cislunar Space and LOP-DSG**
- WP 3200 — **Mars System**
- WP 3300 — **Galileo and EGNOS**
- WP 3400 — **Earth Observation & Space Geodesy**
- WP 3500 — **Studies for New Applications and Destinations**

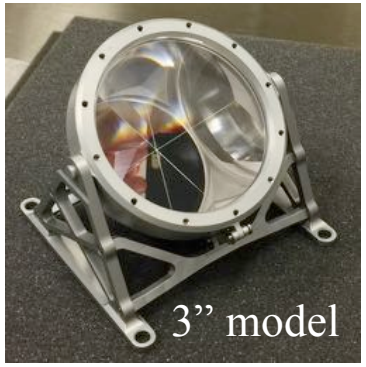
WP 4000
Testing of Gravity in the Solar System

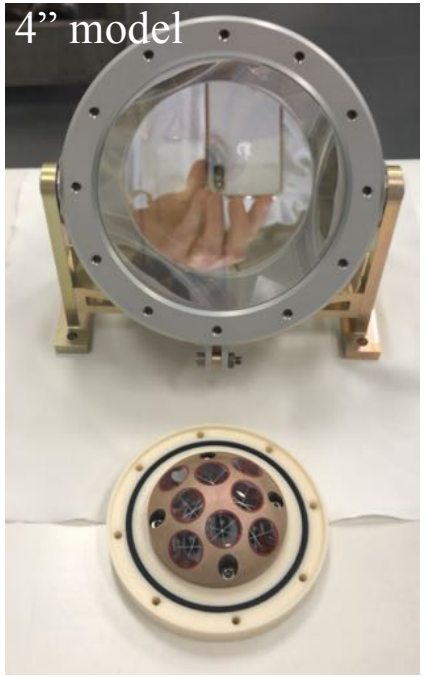
WP 5000
Theories of Gravity for the Solar System

WBS

ASI-INFN Agreement 2021-2026

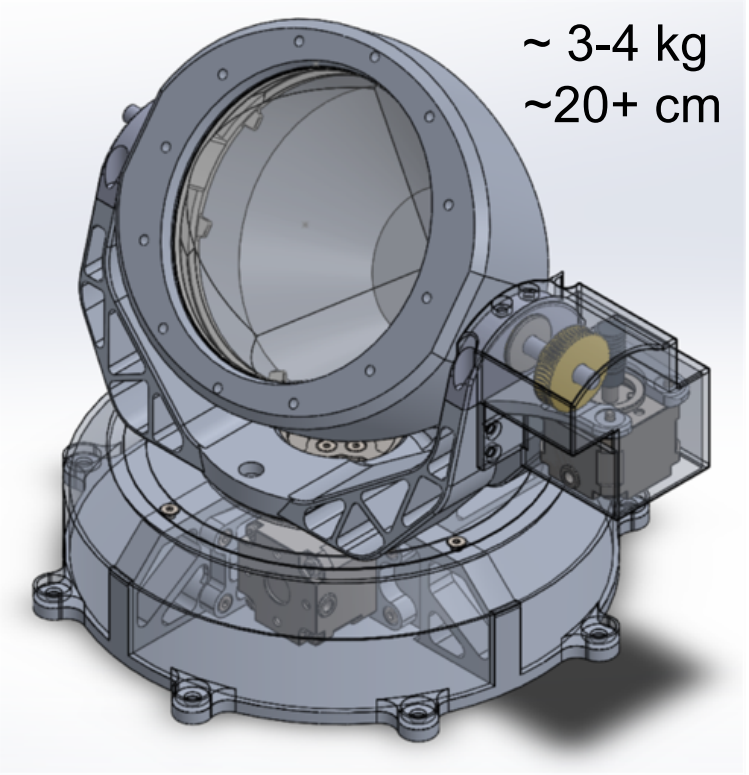






MPAc (MoonLIGHT Pointing Actuator)

- Selected in 2019 by ESA with Earth pointing actuator (dual gimbal)
  Within E3P (European Exploration Envelope Program)
- NASA-ESA have assigned a flight to MPAc (Reiner Gamma site)
  Contract extended from 1 to 2 years (up to flight) and T0 restarted at beginning of 2021
  Budget increased to cover extension



MOON

- Artemis is the “new Apollo” NASA lunar surface program
  - ✓ Artemis III mission to the South Pole: 1st human mission in 2024
    - ✓ **MoonLIGHT** science proposed for Artemis III
  - ✓ With “Artemis Accords” it becomes an international Program
  - ✓ Then series of landing missions from Earth and from LOP – G
    - ✓ **MoonLIGHT** instrument being proposed
- LOP – G (Lunar Orbital Platform – Gateway) is the “new ISS”
  - ✓ Inter-Governmental Agreement Coord. Committee of 11 ESA countries
  - ✓ Gateway for next Mars missions ➔ next slide

MARS

- NASA – ESA Mars missions, from Earth or LOP – G
  - NASA InSight 2018, NASA Perseverance 2020, ESA ExoMars 2022
    - ✓ Have INFN microreflectors & ASI Agreements with NASA/ESA
  - Laser Ranging / Lasercom in Mars orbit by NASA
  - Mars Sample Return program (MSR)
    - NASA Sample Retrieval Lander (SRL) and Perseverance
    - ESA Sample Fetch Rover (SFR)
      - ✓ With ASI will propose INFN retroreflectors for SRL & SFR

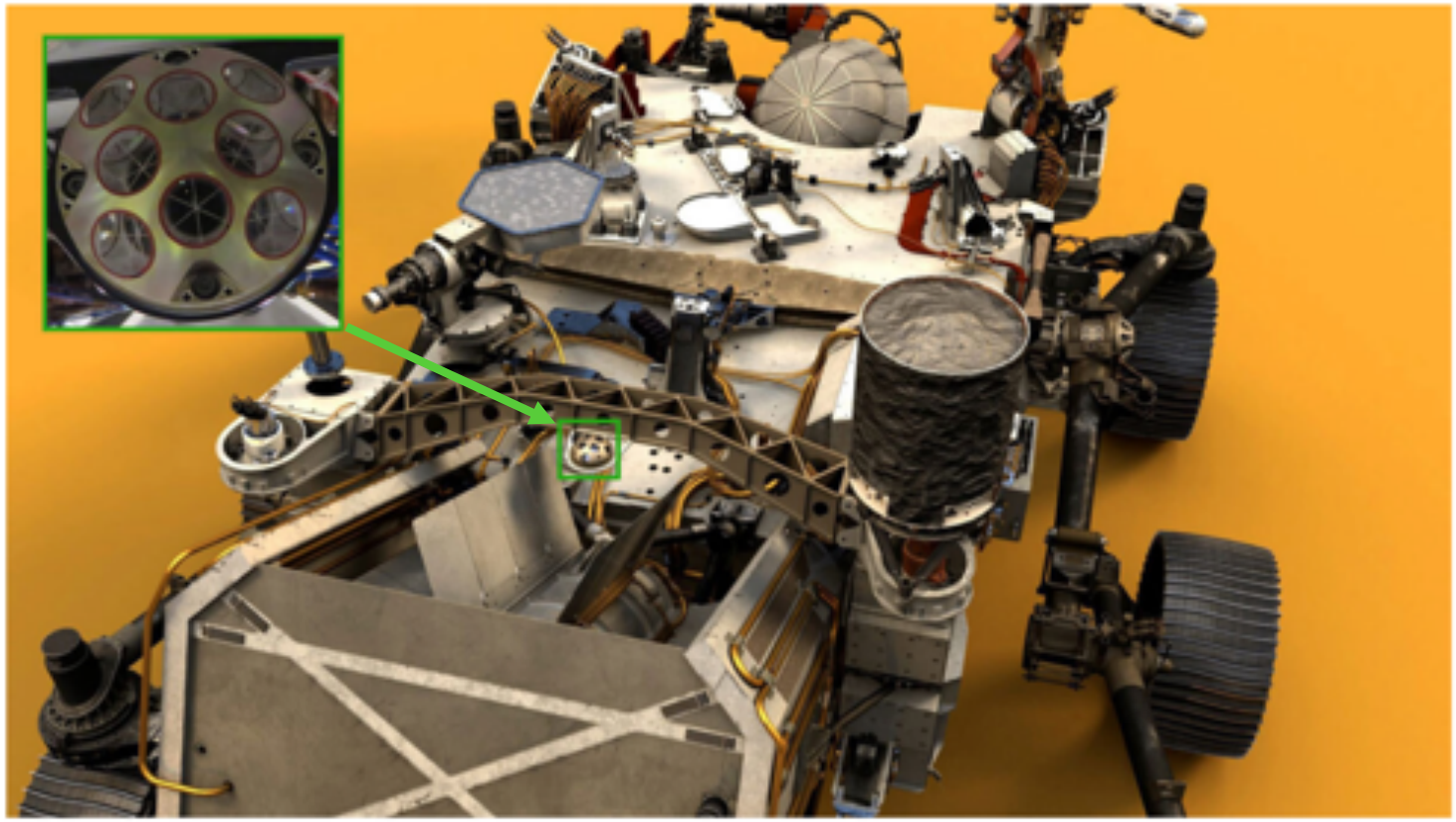
Italian microreflector on NASA Perseverance

NASA Science MARS EXPLORATION PROGRAM

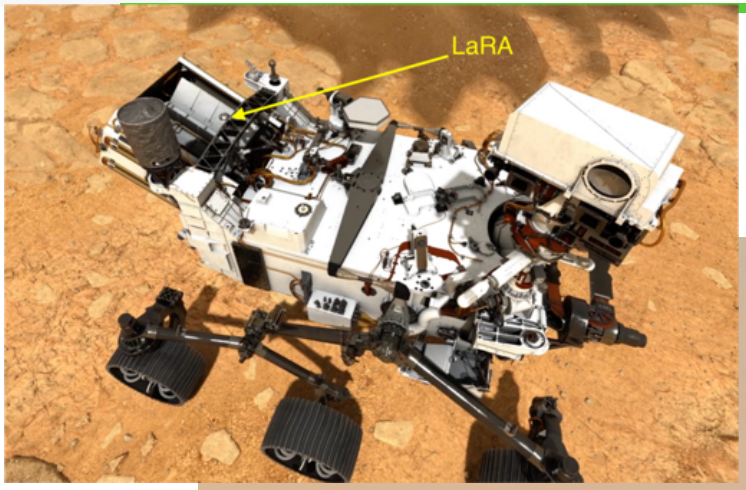
NEWS | September 28, 2020

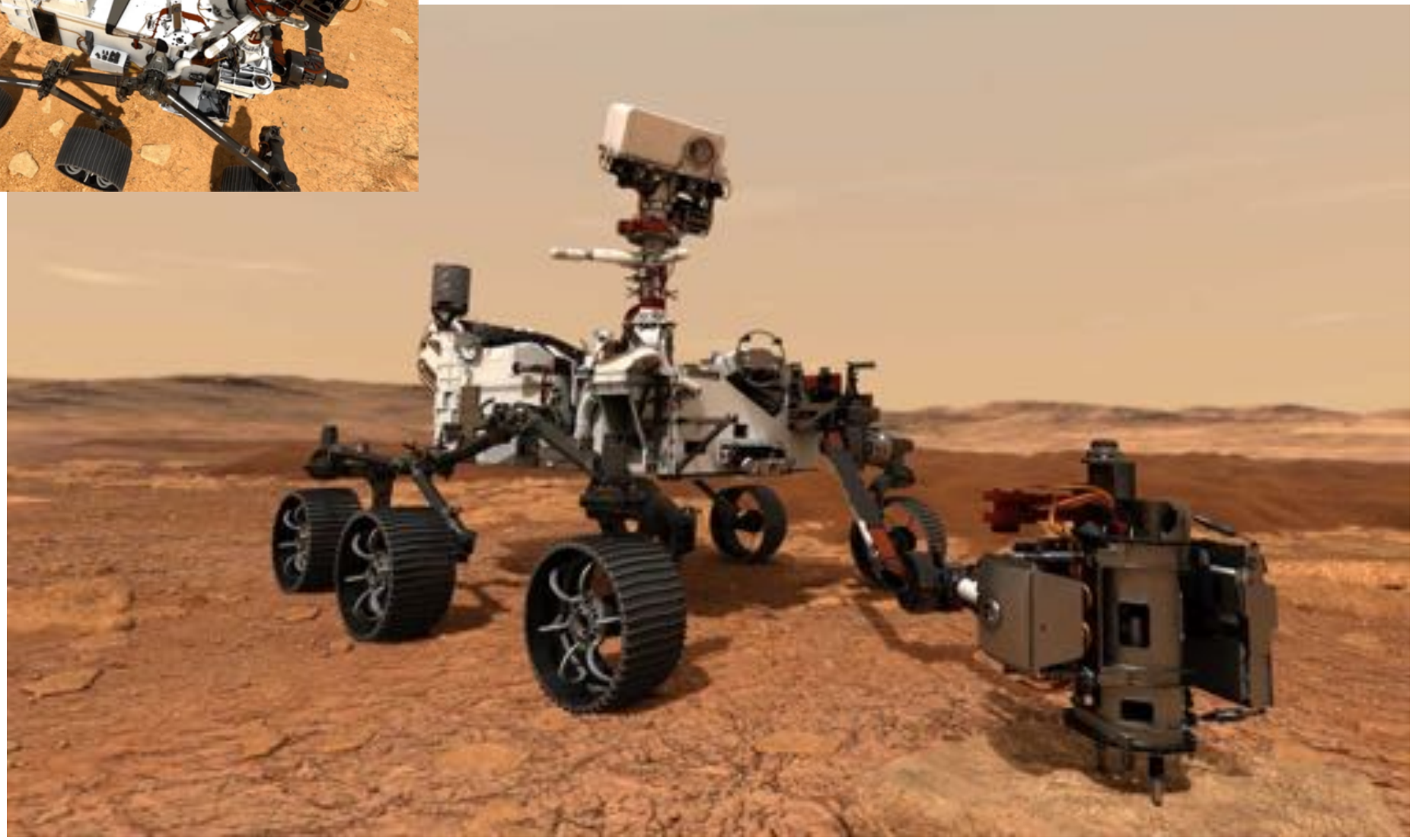
NASA's New Mars Rover Is Ready for Space Lasers

LaRA,
Laser
Retroreflector
Array

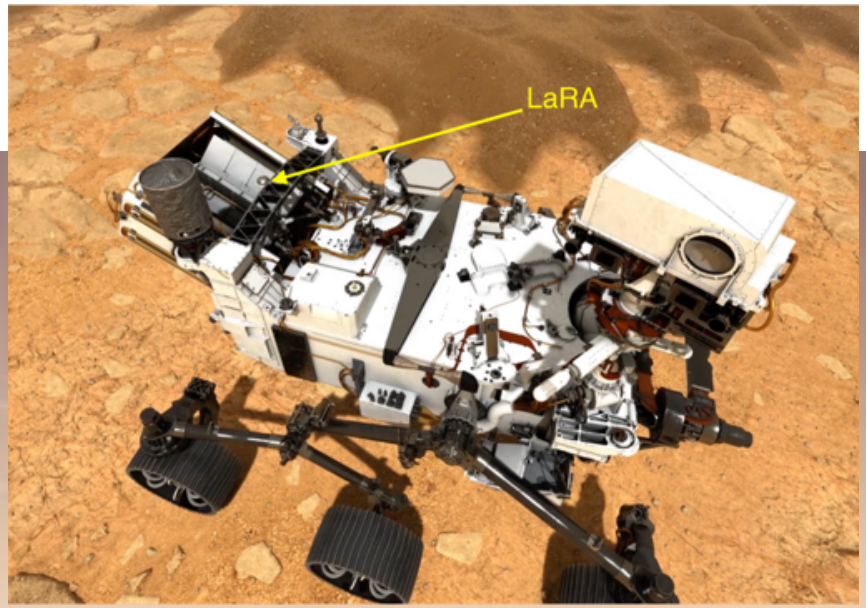


NASA Perseverance 2020 Rover



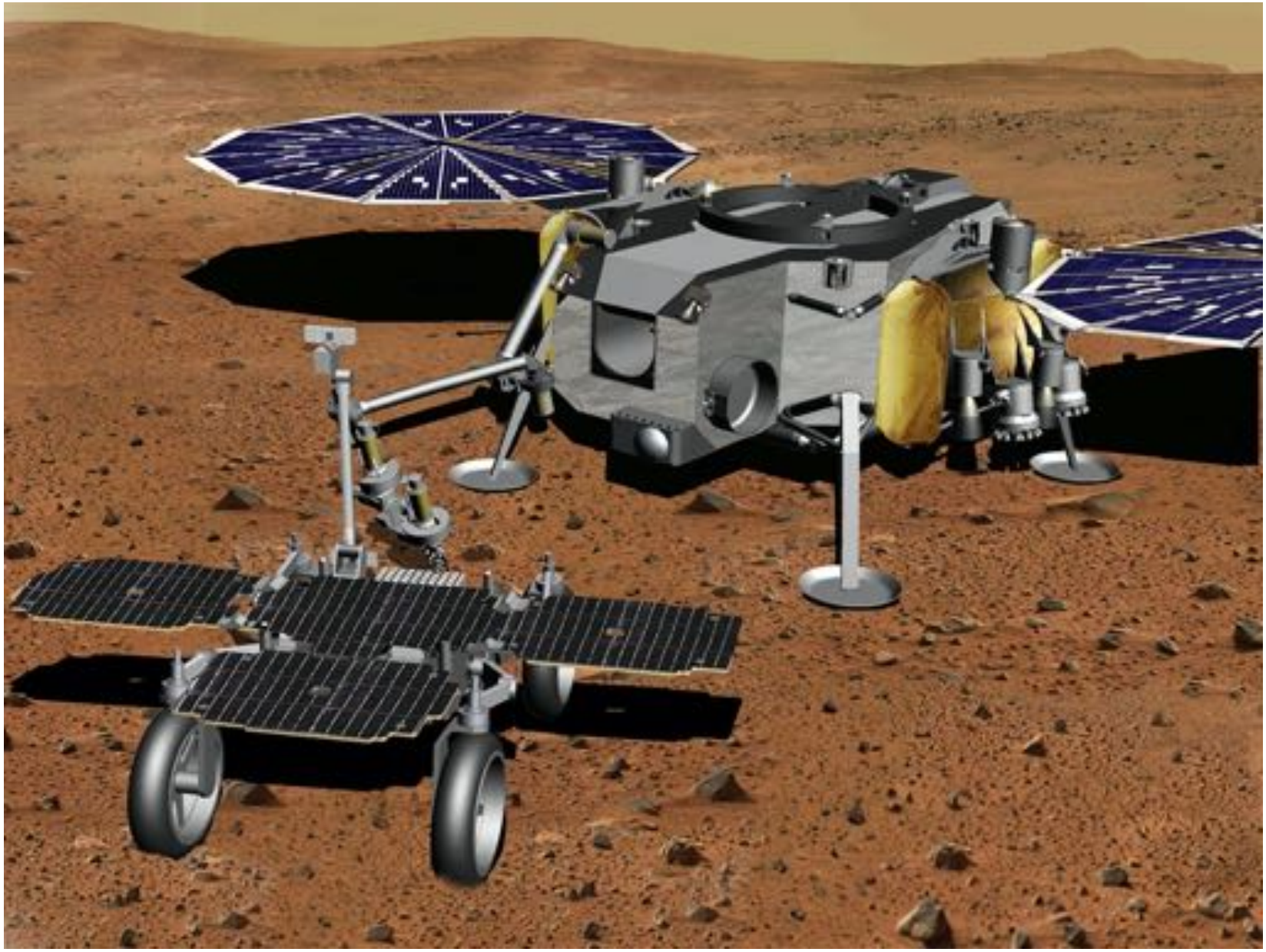


NASA Perseverance 2020 Rover

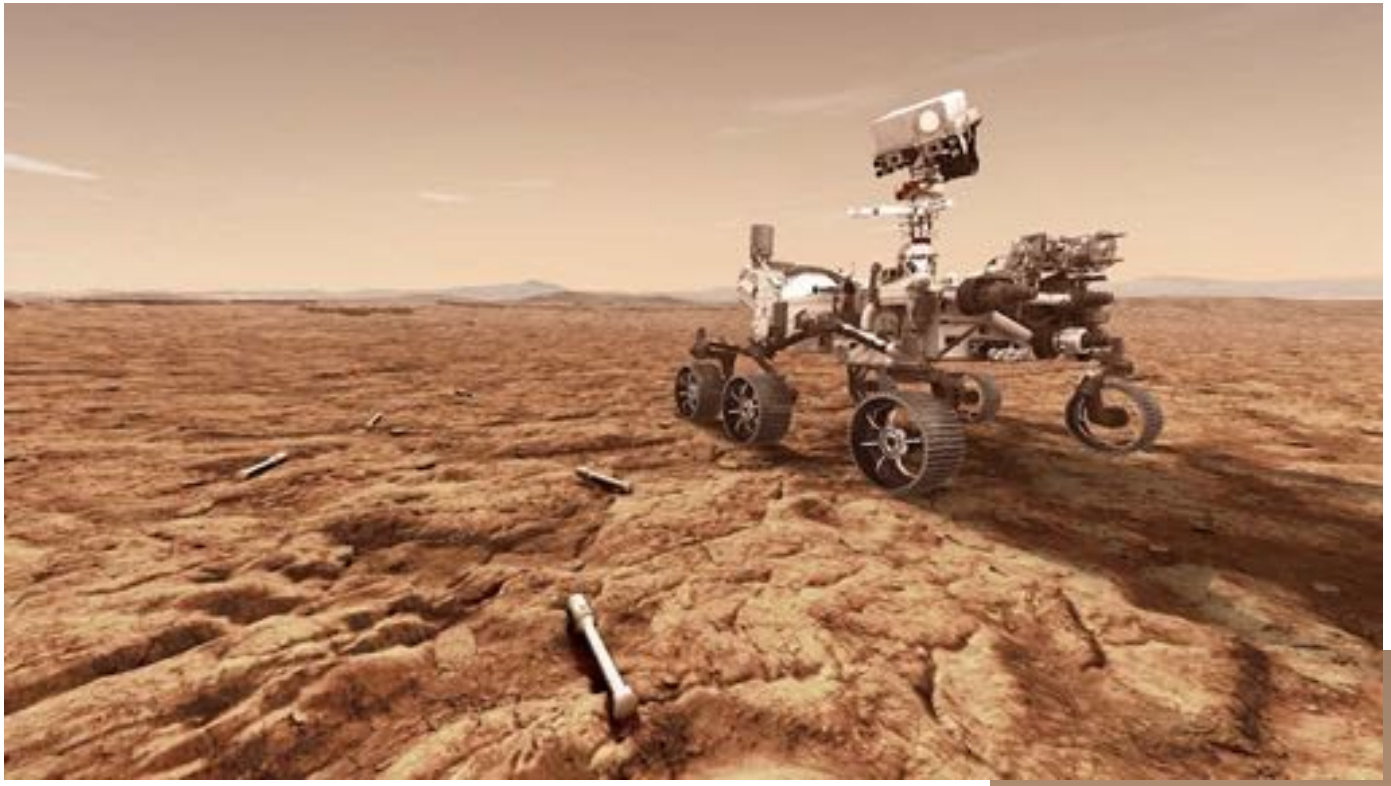


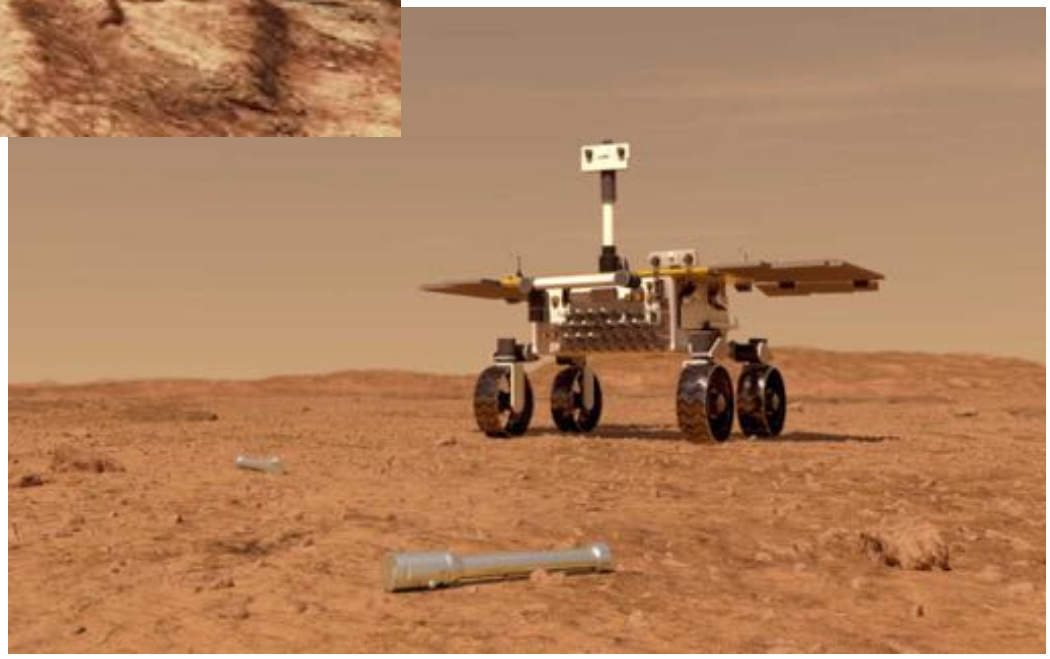
NASA – ESA Mars Sample Return Program

NASA Sample Return Lander & ESA Sample Fetch Rover



Fetch Rover gets Perseverance samples





Retrieved Mars samples sent back home

PHOBOS

- Phobos mission by JAXA
- Well underway, launch in 2024
  - ✓ Mars Moons eXplorer (MMX) lander and mini-rover
  - ✓ JAXA MMX Phobos orbiter with Laser Ranging
  - ✓ NASA “Aspen” Lidar in Mars orbits
  - ✓ With ASI and NASA-SSERVI will propose INFN micro and mini-LAGEOS retroreflectors for lander and mini-rover

‘Mars system’ =

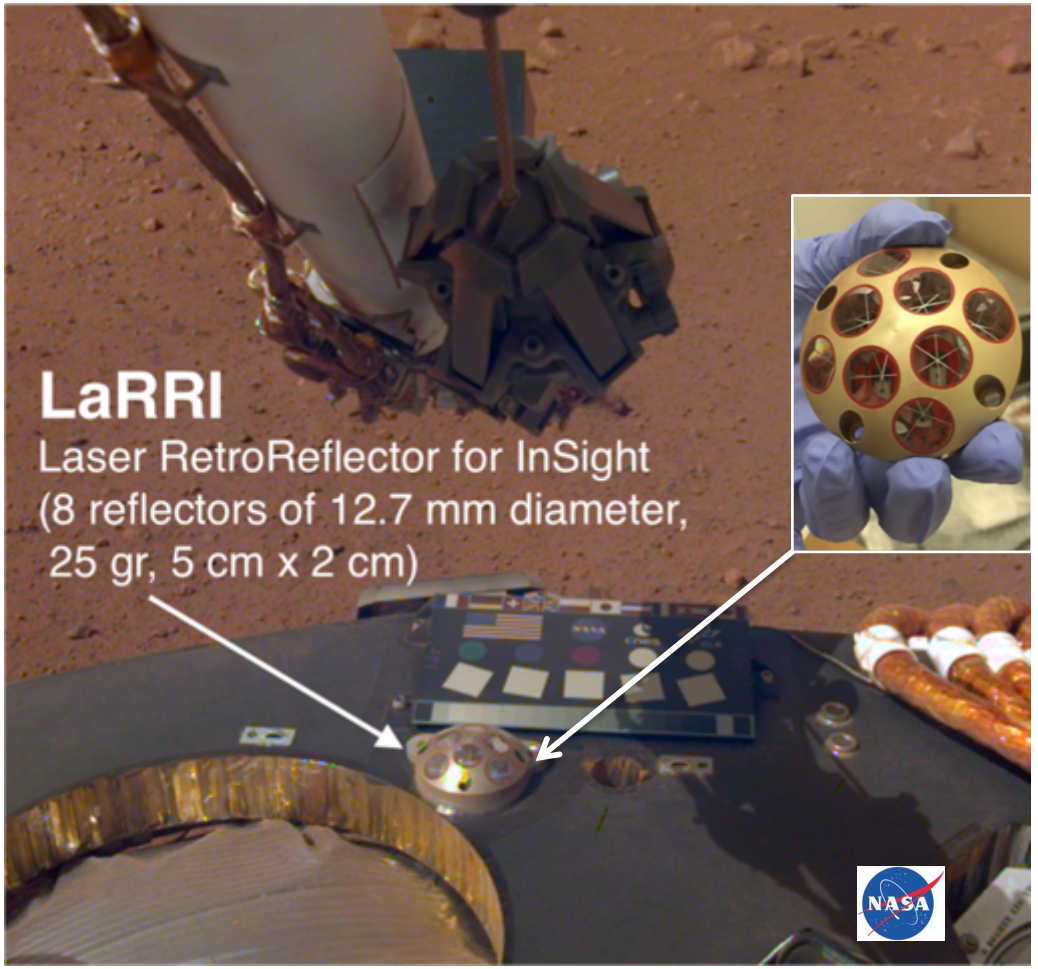
Martian surface
&
Phobos / Deimos

(plus associated orbiters)

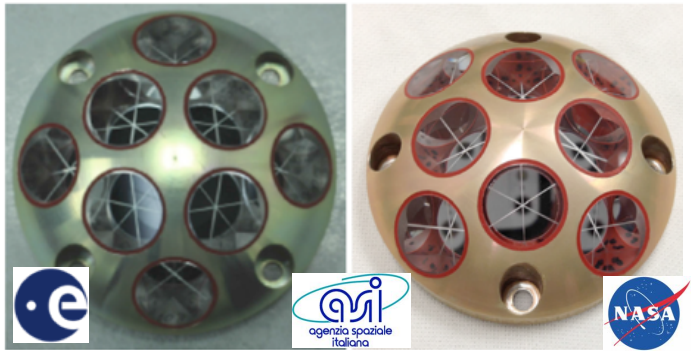
FM laser *microreflectors* delivered / flown by INFN-ASI for Mars

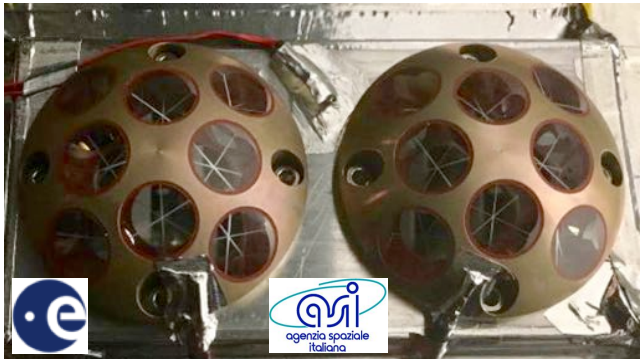
- Accuracy dominated by orbiting laser
- Additional crust tie points on orbiter maps
- Good performance in space conditions:
  L. Porcelli et al. Space Sci Rev, 215 (2019), Iss. 1
- PFM space qualifications (for InSight)
  - Bakeout: T = 97°C ± 1°C for > 48 hr
  - Contamin. Control & Planet. Protection
  - TVT: 3 cycles, max = +110°C ± 1°C, min = -135°C ± 1°C, w/2-hr dwell time
  - Random vibration & pyroshock (table)

Frequency (Hz)	PFM (g)
100	42
2000	2121
10000	2121



EXOMARS 2016 **INSIGHT 2018** **EXOMARS 2022** **(SPARE)** **MARS 2020** **(SPARE)**





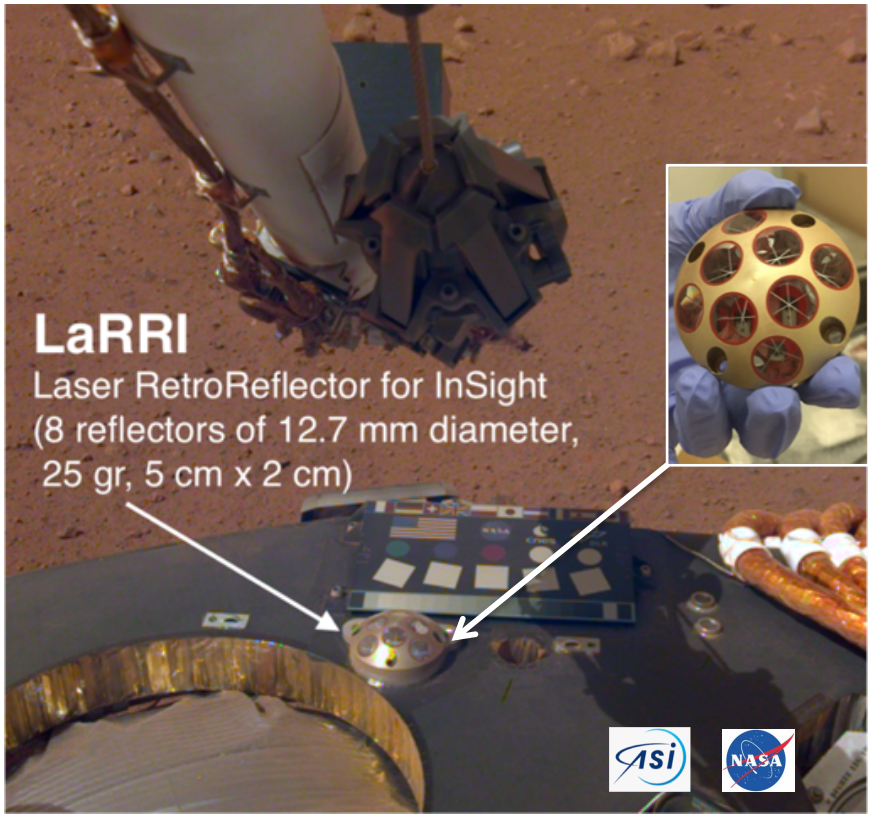
Mars Geo/physics Network (MGN)

of microreflectors

NASA: Insight 2018 Lander, Mars 2020 Rover

ESA-ASI: Schiaparelli Lander, ExoMars 2022 Landing platform

InSight 2018 (NASA)



ExoMars 2022 (ESA)

Test General Relativity w/Mars rovers/landers

- Network of passive microreflectors on Mars surface
- Test of General Relativity at 1.5 AU
  - Estimate Mars center of mass, like Selenocenter with lunar reflectors
  - PPN b (strong equivalence principle) (Sun-Earth-Mars-Jupiter)
  - Gdot/G (gravitational constant) (Sun-Mars)
  - $1/r^2$ force law (Yukawa potential) (Sun-Mars)
  - PPN g (spacetime curvature) (Sun-Mars)
- PEP (Planetary Ephemeris Program) simulations
- Literature & physics discussion (a few picks):
  - 'Historic' Shapiro time delay with Vikings, 1970s
  - J. Anderson, J. Williams, Class. Q. Grav. 18 (2001) 2447
  - S. Turyshev et al, arxiv:1003.4961v2, 3 Sep 2010 & its many refs.
- Same program with reflectors on Phobos & Deimos

Mars test of General Relativity (*PEP simulations)*

- Assume MGN of microreflectors (non-ideal, ~all north)
  - Phoenix (68N, 234E), Viking1 (22N, 50W), Viking 2 (48N, 258W)
  - Curiosity (4S, 137E), Opportunity (2S, 354E)
- Assume data rate: 1 laser normal point (NP) every 7 Sols
  - Weather/ops limitations; visibility from orbiter like MRO is once/Sol
- Accuracy: 10 cm-10 m (Mars ephemeris ~100-50 m)
  - Earth-orbiter: radio ranging; or laser (à la LLCD) or laser transponder experiments (MLA/MOLA). Orbiter-surface: laser ranging/altimetry

Time span/NP Accuracy	**Accuracy on β-1**	**Accuracy on γ-1**	**Accuracy on $\dot{G}/G$**
10 years / 10 m	1.7 x E-04	7.2 x E-04	3.8 x E-14
10 years / 1 m	3.7 x E-05	1.6 x E-05	1.4 x E-14
10 years / 10 cm	7.4 x E-07	3.2 x E-06	2.9 x E-15
Best accuracy now Data/mission *Analysis group*	**<1 x E-04** Lunar/Merc. Ranging *JPL, CfA-INFN, …*	**2.3 x E-05** Cassini *Bertotti et al*	**9 x E-13** Lunar Laser Ranging *JPL, CfA-INFN, …*

Phobos/Deimos surface reflectors

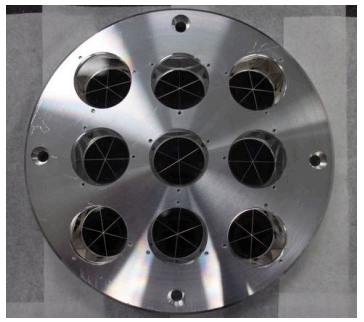
- **PANDORA**: Phobos ANd DeimOs laser Retroreflector Array
  - Various models developed by INFN for different missions
- Reconstruct Phobos-Deimos orbits → focii of orbits is the Mars center of mass → test of General Relativity at 1.5 AU from Sun
  - PPN β (strong equivalence principle) (Sun-Earth-Mars-Jupiter)
  - Gdot/G (gravitational constant) (Sun-Mars)
  - $1/r^2$ force law (Yukawa potential) (Sun-Mars)
  - PPN γ (spacetime curvature) (Sun-Mars)
- PEP (Planetary Ephemeris Program) orbital SW, in use at LNF, developed at Harvard-Smithsonian CfA (Center for Astrophysics) by I. Shapiro, R. Reasenberg, J. Chandler since 1960/70s

Phobos/Deimos surface laser retroreflectors

- **PANDORA**: Phobos ANd DeimOs laser Retroreflector Array
- Developed in Italy, with ASI-CGS and NASA-SSERVI
- **Phobos laser/lidar planetary science investigations** (by A. Brown, NASA)
  - *Learn about the subsurface by monitoring Phobos' orbital evolution*
  - *Using the laser for returns from Phobos, it would help our laser return budget equation if there were a retroreflector rather than just a dusty regolith*
  - *Importance of tracking the decline of the orbit of Phobos, which is the fastest in the solar system, and understanding why and how much that tells us about the interior of Mars is super-important for understanding things like the state of the orbit and obliquity of Mars, which (intensely) controls the Martian climate*
- **2016 Phobos MMX Science workshop (Berlin), Instrument/measur. goals**:
  - "*High accuracy range measurements from spacecraft to (a retroreflector on) the platform to help model orbital motion, rotation, and interior structure of Phobos*".

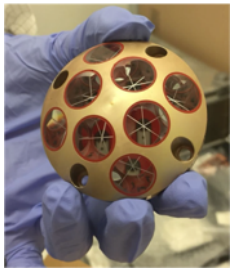
Payloads *customized* for Phobos/Deimos surface

- PANDORA designs for observation by <u>Mars orbiters with laser</u>
  - **Long baseline** (order of Phobos orbit perigee/apogee), 6000 km
  - Subgroups of reflectors with *customized* specs, to ensure laser return at varying velocity aberrations, that is, varying relative distances (near/far) and speeds (fast/slow) between the laser on the Mars orbiter and PANDORA on Phobos
  - PANDORA designs if **deployed on the lander**:
    - **PANDORA-F**: flat reflector array (top right)
    - **PANDORA-H**: hemispherical array (middle right)
  - PANDORA for direct **release on the surface**:
    - **PANDORA-S**: spherical array (bottom right)

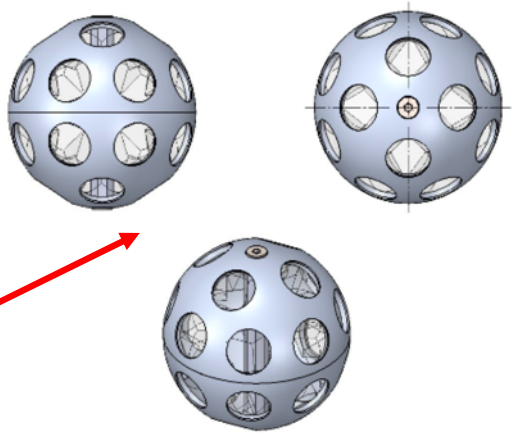


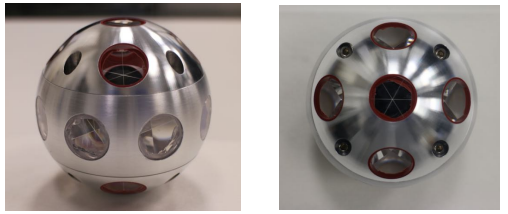
Payloads *customized* for Phobos/Deimos surface

- PANDORA designs for observation by <u>orbiters near/at Phobos</u>
  - **Short baseline** (tens, hunded km) ➔ compact/light designs, like Mars **lander/rover** microreflectors (InSight 2018, Mars 2020, ExoMars 2016/2022)



  - Small spherical arrays, developed for direct **release on the surface** of asteroids/comets
    - Different, customizable designs depending on the mission details
      - 4-8-9-24-28 nano/microreflectors





ESA Call for Ideas for an "European Large Logistics Lander" (EL3): >300 ideas, we were selected for the next step: a study Topical Team on Geo/Physics