Earth-Moon Lagrangian points as a testbed for general relativity and effective *quantum* field theories of gravity: an experimental point of view

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Outline

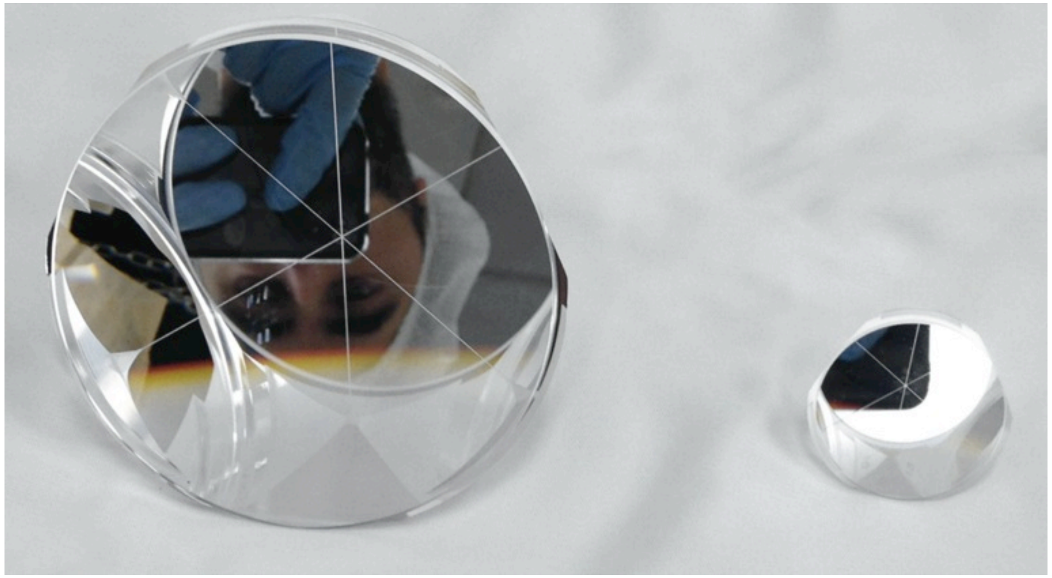
- Earth-Moon gravitational physics
- Lagrangian points
- Experimental approach to test new prediction
- SCF_Lab @ Frascati & international context

New generation lunar laser retroreflectors

MoonLIGHT
Moon Laser Instrumentation for General relativity High accuracy Tests

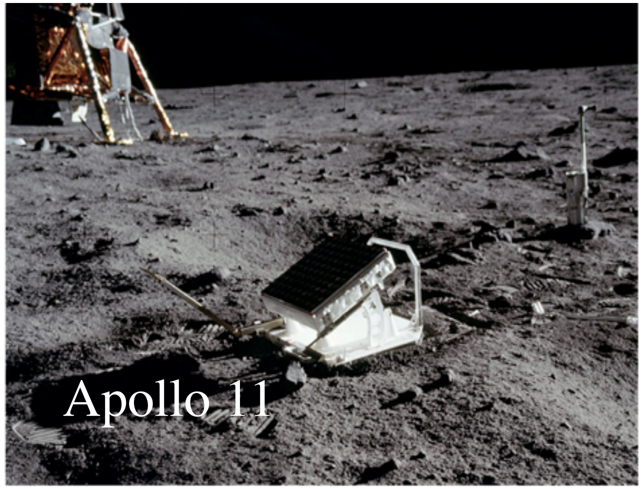
Largest, optically most accurate Suprasil reflectors ever

MoonLIGHT (new, 100 mmm)   Apollo (old, 38 mm)

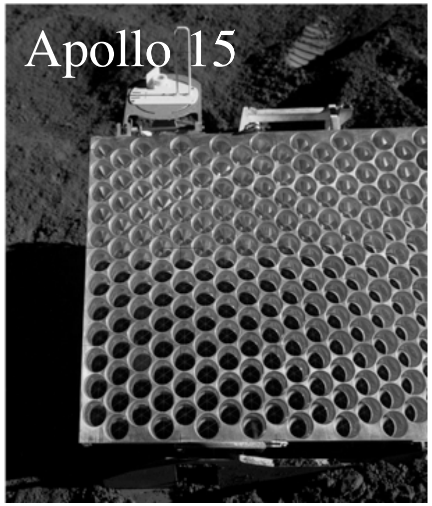


Tests of General Relativity with MoonLIGHTs

Precision test of violation of General Relativity	Time scale	Apollo/Lunokhod few cm accuracy*	MoonLIGHTs 1 mm	MoonLIGHTs 0.1 mm
Parameterized Post-Newtonian (PPN) β	Few years	$\|\beta-1\|<1.1\times10^{-4}$	10^{-5}	10^{-6}
Weak Equivalence Principle (WEP)	Few years	$\|\Delta a/a\|<1.4\times10^{-13}$	10^{-14}	10^{-15}
Strong Equivalence Principle (SEP)	Few years	$\|\eta\|<4.4\times10^{-4}$	3×10^{-5}	3×10^{-6}
Time Variation of the Gravitational Constant (Gdot)	~5 years	$\|\dot{G}/G\|<9\times10^{-13}yr^{-1}$	5×10^{-14}	5×10^{-15}
Inverse Square Law (ISL)	~10 years	$\|\alpha\|<3\times10^{-11}$	10^{-12}	10^{-13}
Geodetic Precession (GP)	Few years	$\|K_{GP}\|<6.4\times10^{-3}$	6.4×10^{-4}	6.4×10^{-5}

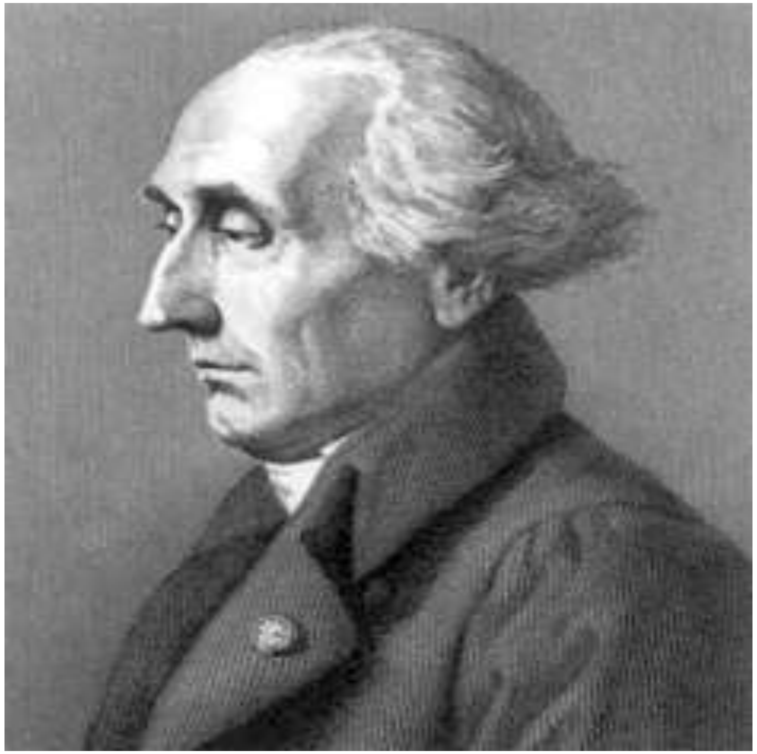


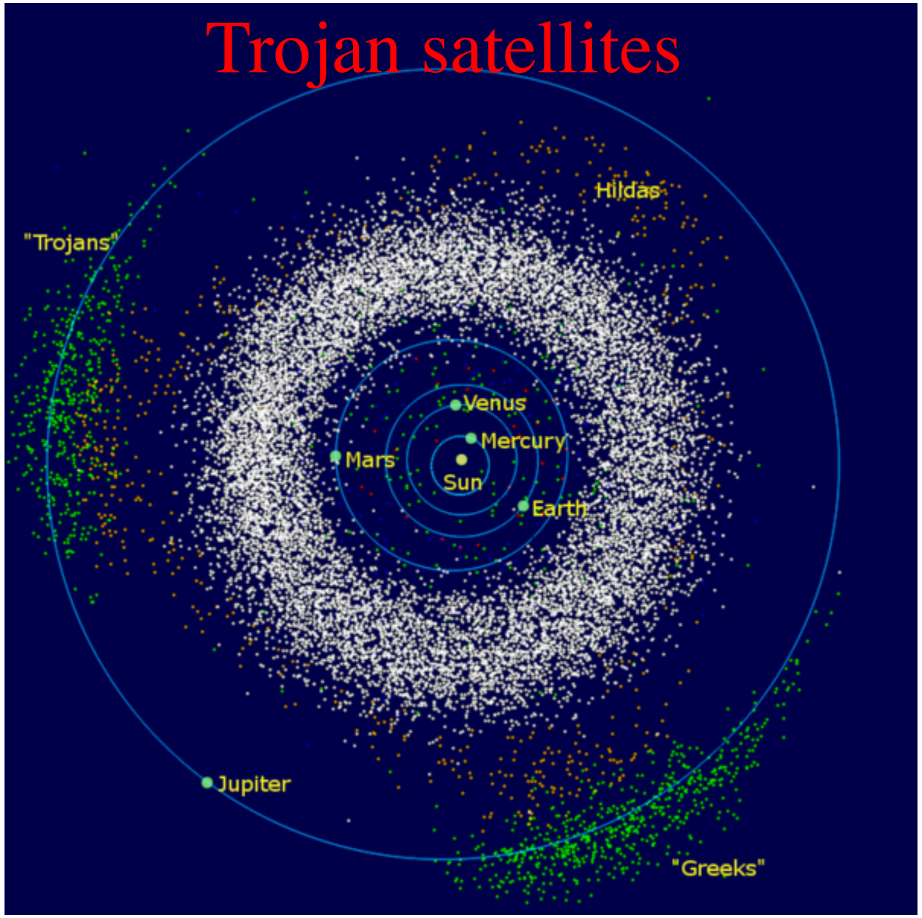
* PRL 93, 261101 (2004)
Gravity Probe B: $|K_{GP}|<2.8\times10^{-3}$



Giuseppe Luigi Lagrange,

born in Turin, Italy, on Jan. 25, 1736



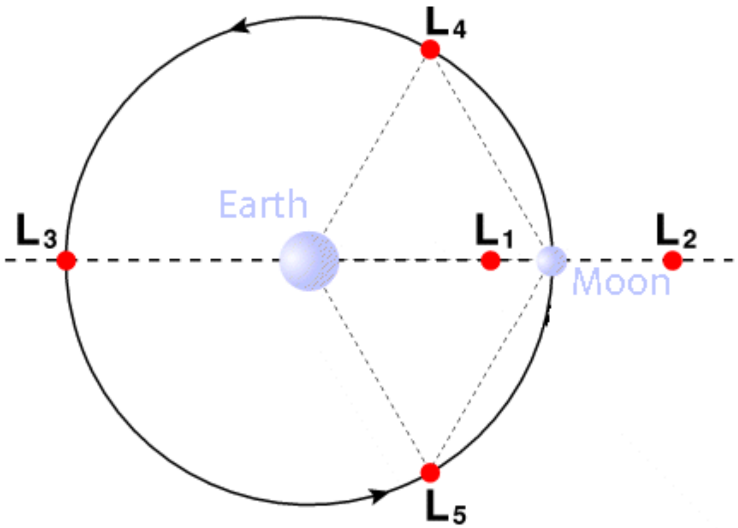


Earth-Moon Lagrangian points: New Physics

- E. Battista and G. Esposito, Phys. Rev. D 89, 084030 (2014)
- E. Battista and G. Esposito, Phys. Rev. D 90, 084010 (2014)
- **Quantum effects on Lagrangian points and displaced periodic orbits in the Earth-Moon system**
  - E. Battista, S. Dell'Agnello, G. Esposito, and J. Simo
  - *Phys. Rev. D 91, 084041 (2015) – Published 20 April 2015*
- **Earth-Moon Lagrangian points as a testbed for general relativity and effective field theories of gravity**
  - E. Battista, S. Dell'Agnello, G. Esposito, L. Di Fiore, J. Simo, A. Grado
  - *Accepted for Phys. Rev. D 92 (2015) – To be published this week*

Low-energy test of quantum gravity with Lunar-like Laser Ranging

$$V_Q(r) = -\frac{G m_A m_B}{r}\left(1 + \frac{k_1}{r} + \frac{k_2}{r^2}\right) + O(G^2)$$



$$k_1 \equiv \kappa_1 \frac{G(m_A + m_B)}{c^2}$$

$$k_2 \equiv \kappa_2 \frac{G\hbar}{c^3} = \kappa_2 (l_P)^2$$

l_p is the Planck length. K_1 depends on $\varkappa_2$

$\varkappa_1$ and $\varkappa_2$ result from quantum loop diagrams.

New large effect, & test, of General Relativity

L_i	General Relativity-Newton	Quantum-General Relativity	Quantum-Newton
L_1	-7.61 m	-0.62 mm	-7.61 m
L_2	9.40 m	-0.39 mm	9.40 m
L_3	-1.13 m	-1.48 mm	-1.13 m
L_4	(2.73 mm, -1.59 mm)	(-1.46 mm, -0.86mm)	(1.27 mm, -2.45 mm)
L_5	(2.73 mm, -1.59 mm)	(-1.46 mm, -0.86mm)	(1.27 mm, -2.45 mm)

New large effect, & **test**, of General Relativity

- Design a laser retroreflector to measure this new effect
- Design a suited mission and laser-guided propulsion system to reach and stop at Lagrangian points
- Study systematic effects: non-gravitational perturbations and multi-body gravitational effects
- Lagrangian-point Laser-ranging Gravity Eplorer (**LaGrEx**)
- 1^{st} generation experiment for a new test of GR

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Key remarks

- The 7.61 m correction looks measurable, hence encouraging
- L2 is behind the Moon, L3 not a ‘popular’ destination
- It is possible to conceive a new laser ranging test of general relativity by measuring this correction to the L1 Lagrangian point, an observable never used before in the Sun-Earth-Moon system. Such an experiment requires controlling the propulsion to precisely reach L1, an instrumental accuracy comparable to the measurement of the lunar geodesic precession, understanding systematic effects resulting from solar radiation pressure and heating of the satellite that leads to photon emission, and multi-body gravitational perturbations.
- Much harder task: to measure the tiny deviations of effective gravity from GR in the Sun-Earth-Moon system.

Tasks of INFN-Napoli

- Napoli contribution is mainly devoted to *Theoretical modeling*

Analysys of gravitational perturbation

- Computation of the propulsion needed to stay precisely at L_1 or L_4.
- Analysis of effects due to the presence of many bodies.

Analysys of non gravitational perturbation

- Deep study of solar radiation pressure.
- Heating Effects of satellites with consequent photons emission.

SCF_Lab @Frascati & international context

INFN and ASI, NASA Partnership

SCF_Lab Team with JPL Director, C. Elachi, & ASI Chief Scientist, E. Flamini

International Partnerships

Eight international partnerships collaborate with U.S. based SSERVI researchers on a no-exchange-of-funds basis.

Canada
PI: Gordon Osinski,
U. of Western Ontario

Germany
PI: Ralf Jaumann
DLR

Israel
PI: Shlomi Arnon
Ben-Gurion U. at the Negev

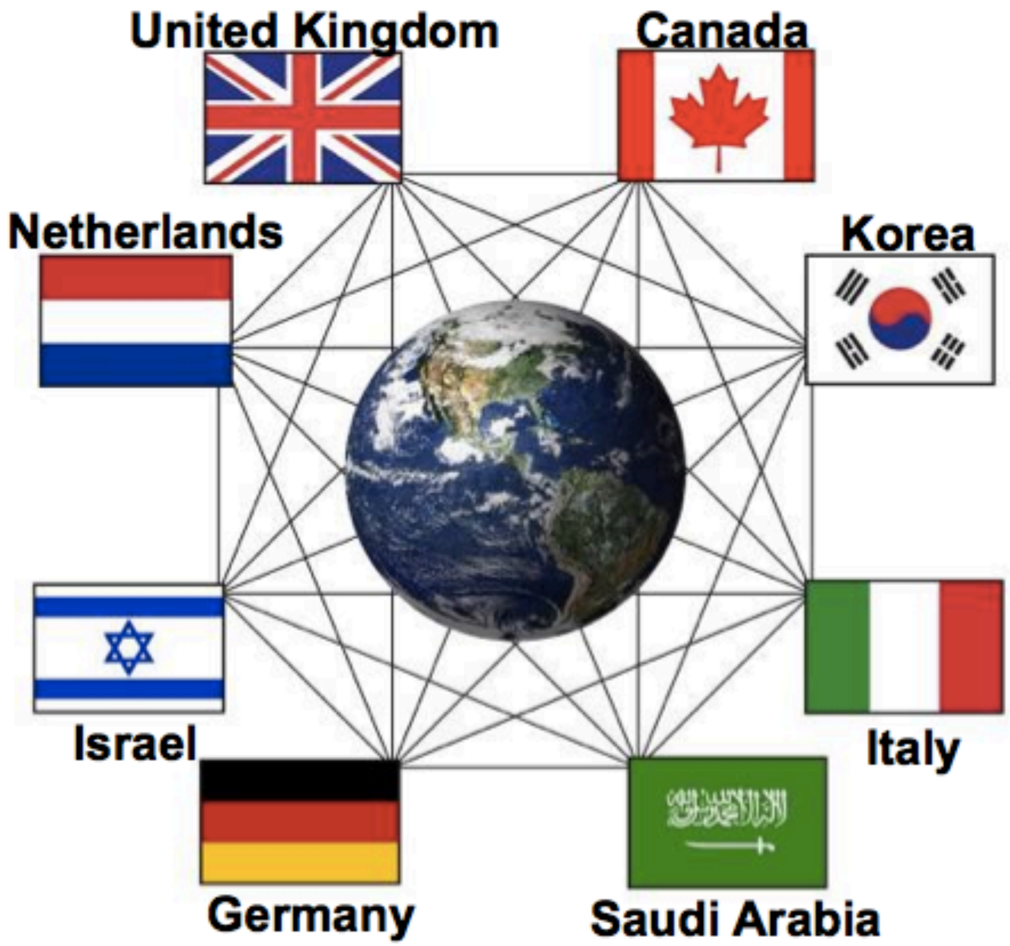
Italy
PI: Simone Dell'Agnello
INFN

Kingdom of Saudi Arabia
PI: Abdulaziz Alothman
King Abdulaziz City for Sci & Tech (KACST)

Korea
PI: Gwangyeok Ju
Korean Aerospace Research Institute (KARI)

Netherlands
PI: Wim van Westrenen
VU U. Amsterdam

United Kingdom
PI: Mahesh Anand,
Open U.



****Additional Partnerships under development include Australia and France***

3rd European Lunar Symposium

- Berlin (2012), London (2014), Frascati (2015)
- Science of the Moon
  - Science on the Moon
  - Science from the Moon
  - Future Lunar / Cislunar Missions

MOON EXPRESS

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

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MEDIA RELEASE

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Moon Express Announces First International Multi-Mission Payload Agreement with The INFN National Laboratories of Frascati and the University of Maryland

"MoonLIGHT" Lunar Laser Ranging Array Will Bring New Insights into General Relativity

Frascati, Italy (May 15th, 2015) – Moon Express, Inc. (MoonEx) has announced a multi-mission payload agreement with The National Laboratories of Frascati (INFN-LNF) and the University of Maryland to deliver a new generation of lunar laser ranging arrays to the Moon. Under the agreement, "MoonLIGHT" instruments will be carried on the first four Moon Express missions and used in conjunction with Apollo Cube Corner (CCR) Retroreflector arrays to test principles of Einstein's General Relativity theory, add to international scientific knowledge of the Moon, and increase lunar mapping precision that will support the company's future lander missions.

"MoonLIGHT" Payload Agreement Announcement in Frascati, Italy. L-R: Jack Burns, CU; Doug Currie, UMD; Simone Dell'Agnello, INFN-LNF; Bob Richards, Moon Express

The payload announcement was made today in Frascati, Italy, right after the European Lunar Symposium, during a Global Exploration Roadmap workshop of the International Space Exploration Coordination Group (ISECG), attended by officials national space agencies and lunar scientists from around the world.