New Reflections

New CSN5 experiment: LNF + INFN-Napoli

QuantumPath

Participation in CSN5 Call

INFN/Univ-Padova (RN), INFN/Univ-Roma1, LNL, LNF

S. Dell'Agnello and the SCF_Lab Team

July 1, 2015 – INFN-LNF, Preventivi 2016

SCF_Lab

Satellite/Lunar/GNSS

laser ranging/altimetry and Cube/microsat

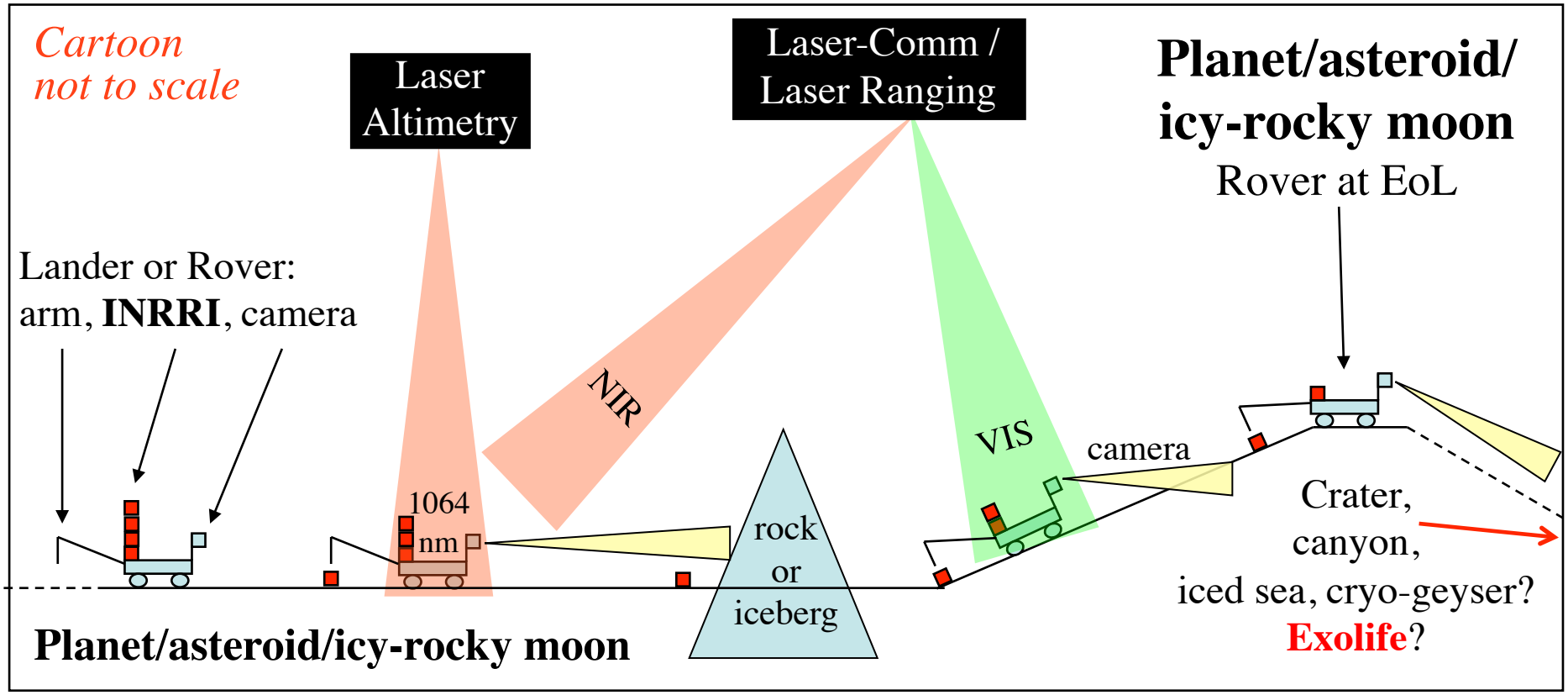
Characterization **F**acilities **Lab**oratory

Elachi (JPL)+Flamini (ASI) visiting SCF_Lab

New Reflections: R&D innovations

- Omni-directional Laser retroreflector CubeSat
  - OminiLaserCube (OLC): new space technology standard
- Laser retroreflectors for Phobos and Deimos
  - Mars center of mass for General Relativity
- Laser Retroreflectors for asteroids
  - H2020 SST (Space Surveillance and Tracking)
- Lagrangian-point Laser-ranging Gravity Explorer
  - Collaboration with INFN-Napoli
- Laser reflector for Geodetic Reference Antenna in SPace
  - Earth geocenter; GRASP mission, collaboration w/NASA-JPL

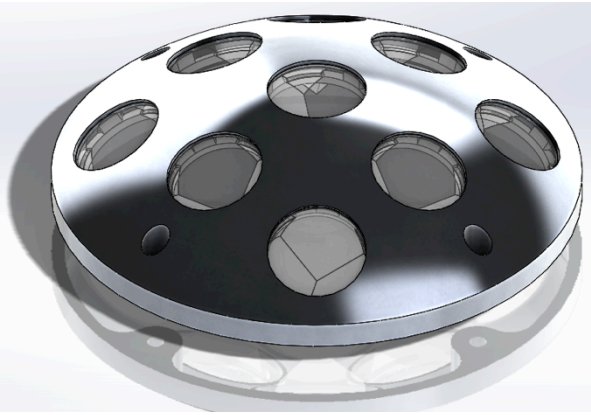
Laser retroreflectors for the solar system

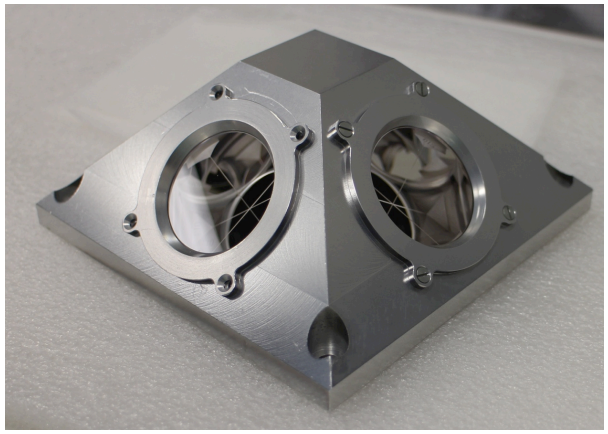


- Laser-locate Rover/Lander with laser retroreflector:
  - Laser Ranging/Comm to reflectors anywhere
- **Deploy networks**. Also on far side of Earth's Moon

Phobos/Deimos surface reflectors

- PANDORA: Phobos AND DeimOs laser Retroreflector Array
  - Reconstruct Mars center of mass for General Relativity
- GR test improvements with an MGN in the long term:
  - PPN Gamma (Sun-Mars)
    - Shapiro time delay with Viking landers in the 1970s
  - Gdot/G, $1/r^2$ law at 1.5 AU
    - PPN beta (Sun-Mars-Jupiter) not competitive with the Moon
- PEP (Planetary Ephemeris Program) by Shapiro, Chandler





NEO (Near Earth Objects): asteroids/comets

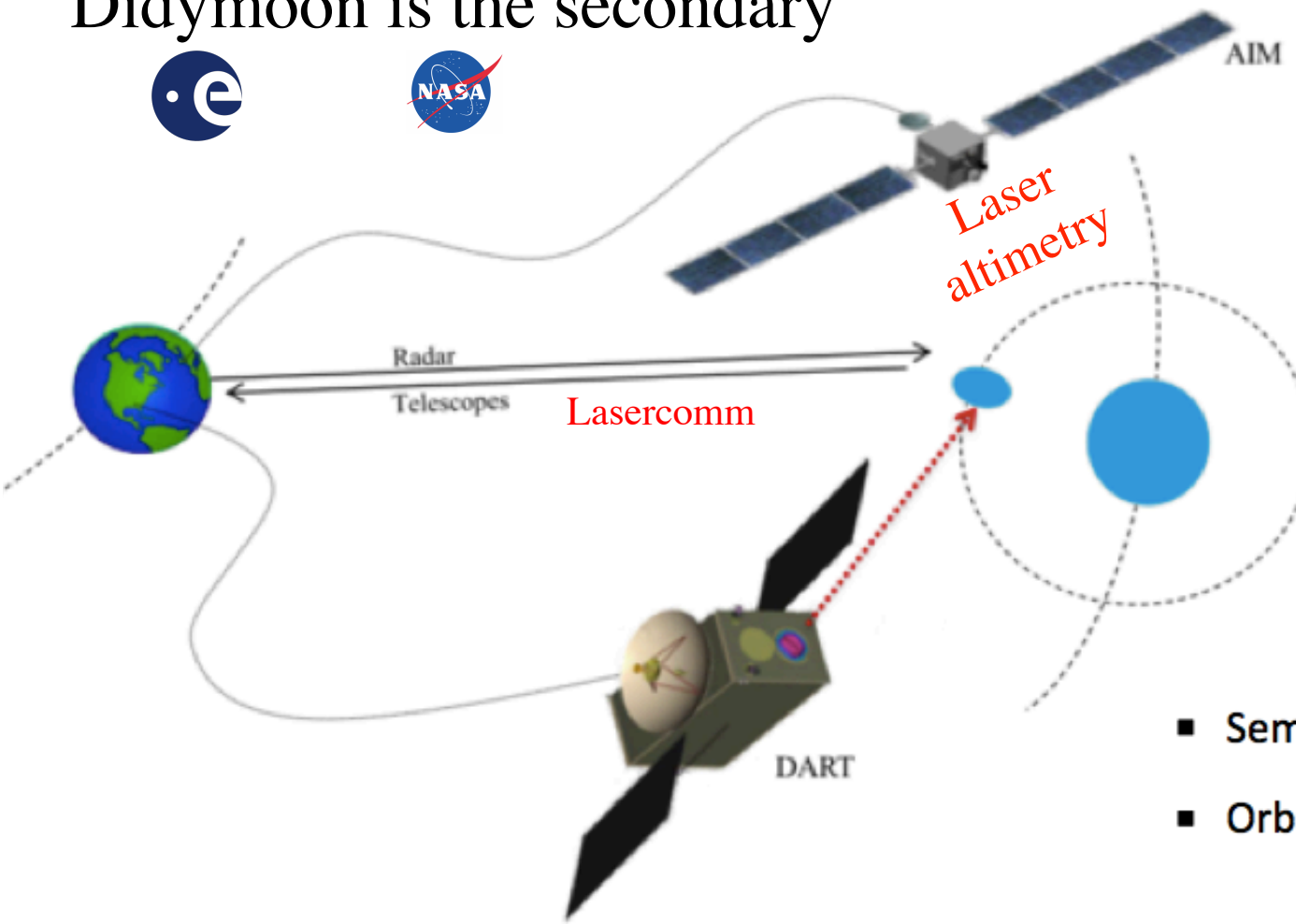
- Laser retroreflectors as NEO positioning and geodetic targets
- H2020 interest for Space Surveillance and Tracking
- Asteroid retrieval, redirection, deflection (ion-beam, laser?)
- Laser-guide directed forms of energy or ballistic interceptors
- To be landed / dropped on asteroids (watch for escape velocity)

Disk

Sphere

Asteroid mission & science, an example

AIM(ESA)-DART(NASA) mission to
The Didymos double asteroid (1-2 AU)
Didymoon is the secondary

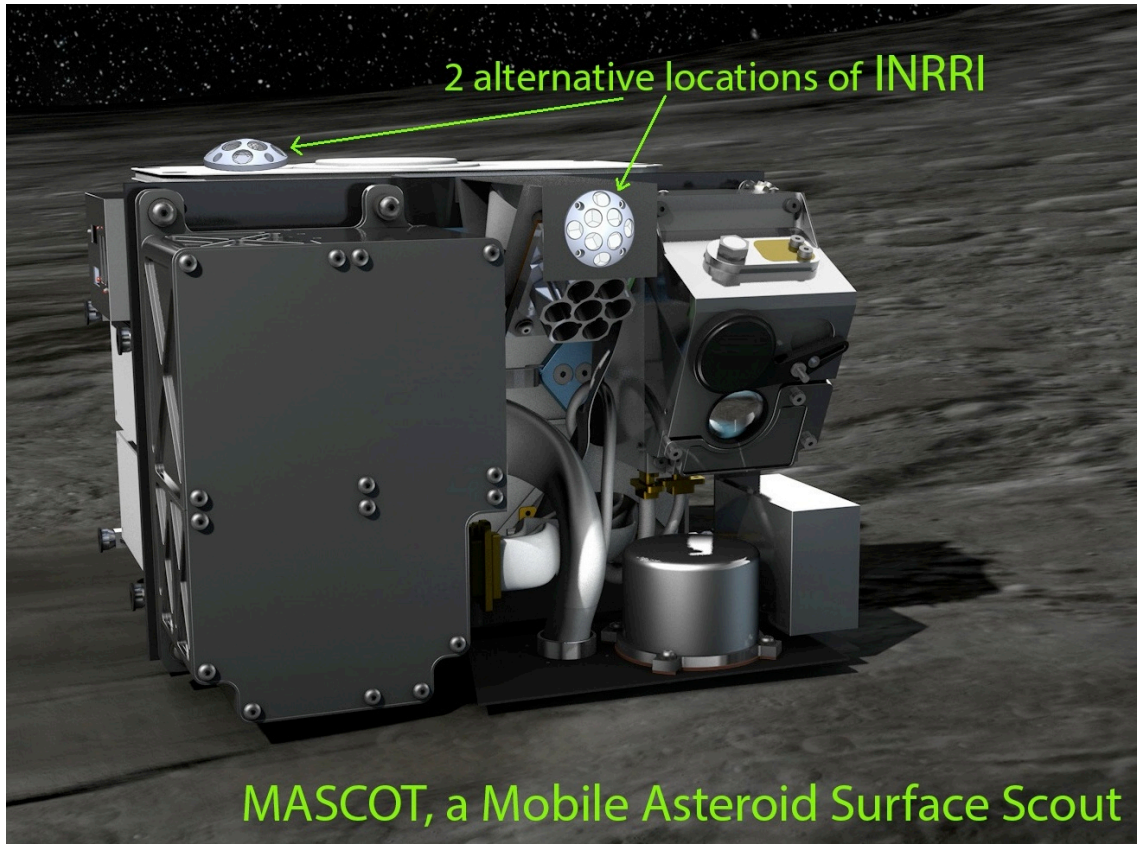


- Eccentricity: 0.384
- Inclination: 3.4 deg
- Geometric albedo: 0.147
- Diameter primary: 800 m
- Diameter secondary: 170 m
- Separation: 1100 m
- Orbital period secondary: 11.9 h

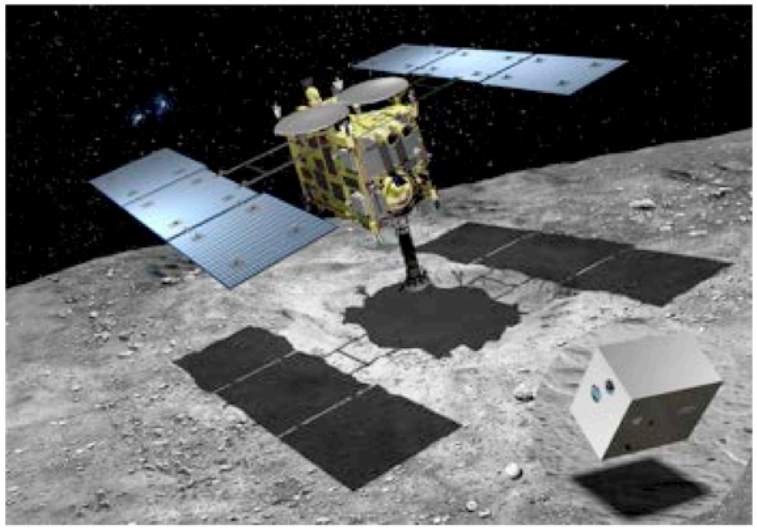
- Semi-major axis: 1.644 AU
- Orbital Period: 770.14 days

R&D study: CubeSat (CS) for exploration

- CS as networked sensors or separate experiments for AIM goals
- Cubesats with retroreflector
- Laser georeferencing of Didymoon with reflectors on MASCOT-2 or dropped separately



Laser altimeter and lasercomm (OPTEL-D) by RUAG; MASCOT by DLR



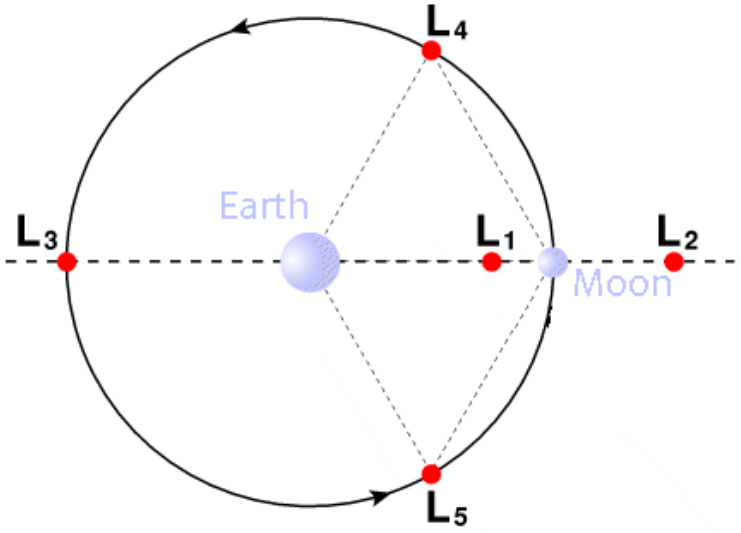
Artist's conception of HY-2 during sampling, also showing MASCOT landed on the surface. CREDIT:JAXA/Akihiro Ikeshita.

Paper on Lagrangian point New Physics

- **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 – Published 20 April 2015

- **The Earth-Moon system as a testbed for general relativity and effective field theories of gravity**
  - E. Battista, S. Dell'Agnello, G. Esposito, L. Di Fiore, J. Simo, and A. Grado
  - Submitted to PRD

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



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

where [23]

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

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

l_p is the Planck length. K_1 depends on $\varkappa_2$
$\varkappa_1$ and $\varkappa_2$ result from quantum loop diagrams.

Displacement of quantum from classical equilibrium points:
from few mm to ~1 cm, measurable with laser ranging.
L4/L5: stable points; L1/L2/L3 are unstable points

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

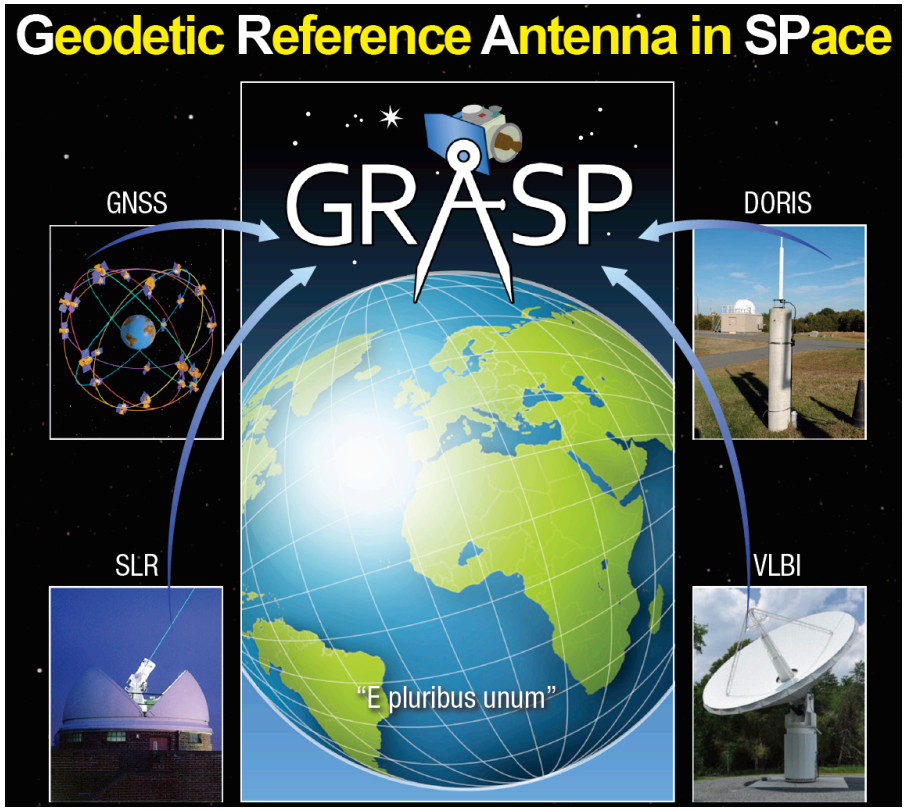
- Design a laser retroreflector to measure this new effect
- Design a suited mission and laser-guided propulsion system to reach and stop at Lagrangian points
- Study systematic effects: non-gravitational perturbations and multi-body gravitational effects

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)

The Geodetic Reference Antenna in Space (GRASP) Mission

Y. Bar-Sever, B. Haines, M. Heflin, D. Kuang, A. Sibois *JPL*

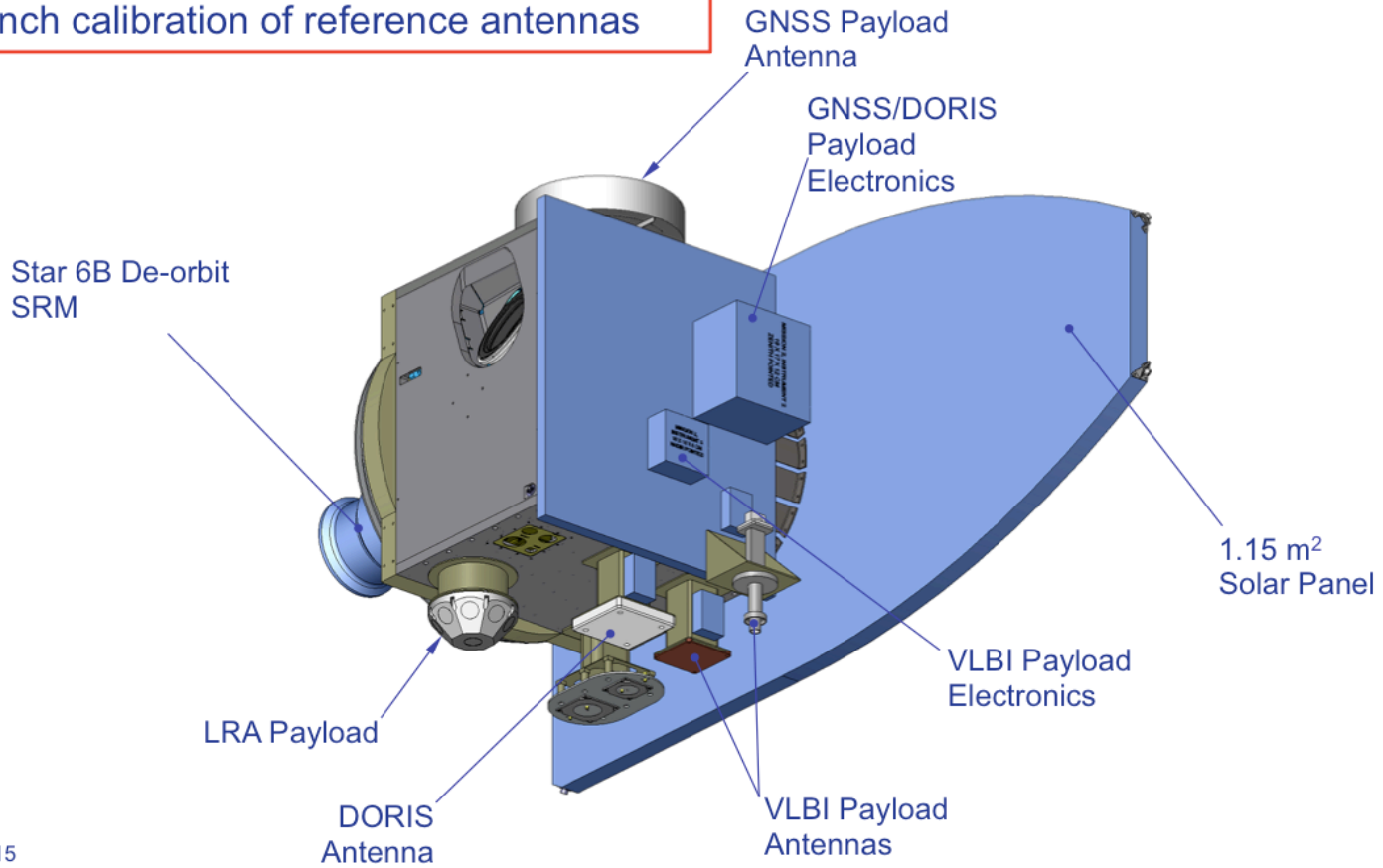
Steve Nerem, CU Boulder



Multi-technique positioning in space: GRASP

Most complete geodesy-focused mission ever. International. INFN for laser retroreflectors. Goals for Earth center of mass: ~1 mm accuracy, 0.1 mm/yr stability

Orbit: 850x1350 Sun-synch
Collocate geodetic sensors and CM to 1 mm
1 mm orbit determination
Pre-launch calibration of reference antennas



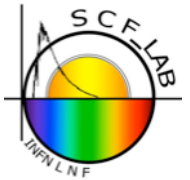
YEB, Apr 2015

Picosec/sub-psec laser ToF calibrations

- Laboratory-measured laser range correction mandatory
- Laser ToF done with MCPMTs or streak cameras
- Applications: LaGrEx and GRASP

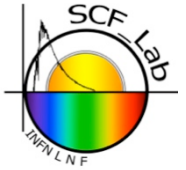
- Need accurate and stable optics, electronics, mechanics
- Specialized expertise exists @LNF and @ASI-Matera
  - ASI-CGS has 1 sub-psec streak camera
  - INFN-LNF has 3 streak cameras online, 1 @DAΦNE and 2 @SPARC_LAB

New Reflections: Team, Requests



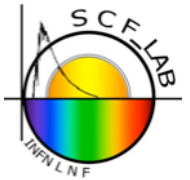
- LNF, SCF_Lab: 6.5 FTE
- INFN-Napoli: 1 FTE
  - G. Esposito, E, Battista, A. Grado
  - Found new General Relativity effect
  - Analysis of systematics: non-gravitational perturbations, multi-body effects
- Requests to LNF Services
  - DR: SPCM: ~3 mo, Elettronica: ~2 mo
- Requests to CSN5: ~70k

Call led by INFN/U-Padova: QuantumPath



- Pathfinder for Space Quantum Physics (QuantumPath)
- Delay choice experiment on ground at ASI-Matera
  - Quantum interference physics with laser photons (polarization degrees of freedom) shot on existing passive laser retroreflectors
  - Similar to KLOE physics with neutral K mesons
- LNF: design, construction of prototype micro-satellite
  - Mechanical frame
  - 3 specialized laser retroreflectors, as space repeaters
  - Specification and acquisition of Faraday rotator to manipulate polarization of retroreflected laser photons
  - New active space system, partial mechanical-optical prototype

QuantumPath: Team, Requests



- National Coordinator: INFN/Univ-Padova
  - Group of P. Villoresi (U. Information Eng.)
  - Quantum laser (polarization) communication & encryption
  - 10-yr work at lunar laser station of ASI-Matera
- INFN/U.-Roma1
  - Group of P. Mataloni & F. Sciarrino
  - Quantum communications with integrated electro-optical circuits
- LNL: radiation damage
- LNF, SCF_Lab: ~4 FTE
- Requests to LNF Services
  - DR: SPCM: ~3 mo
- Requests to CSN5: under discussion