ESA's Nextgen Lunar Laser Retroreflector with Pointing Actuators for NASA's CP11 Mission

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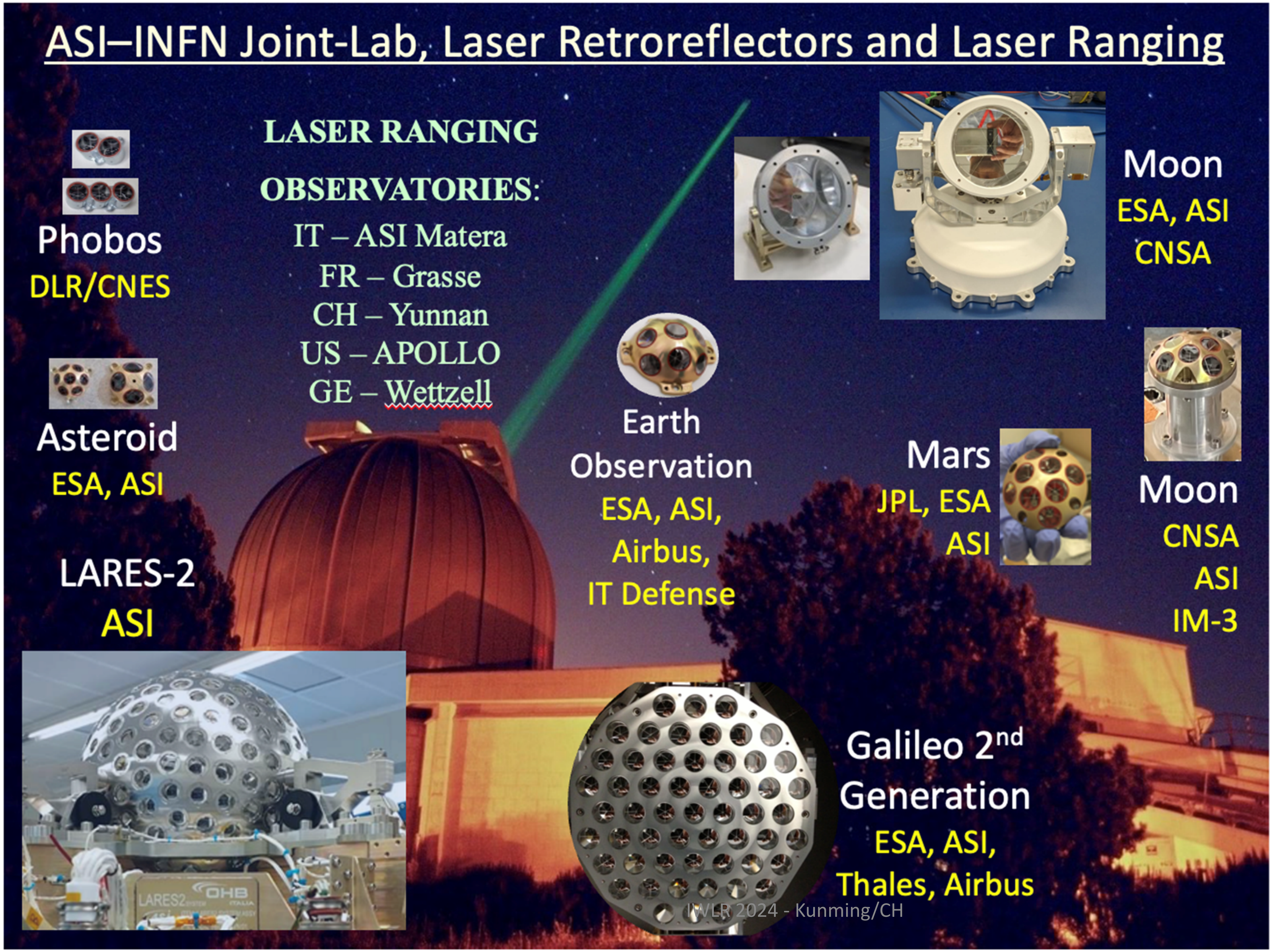
Outline

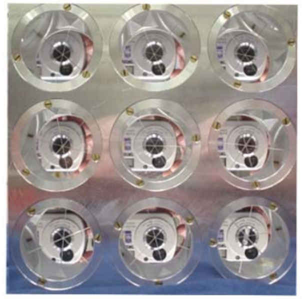
- ASI-INFN Joint Lab on Laser Retroreflectors and Laser Ranging
- Nexgen lunar laser retroreflectors
- Science / exploration objectives
- Instruments and current missions
- Prospects of LRR networks

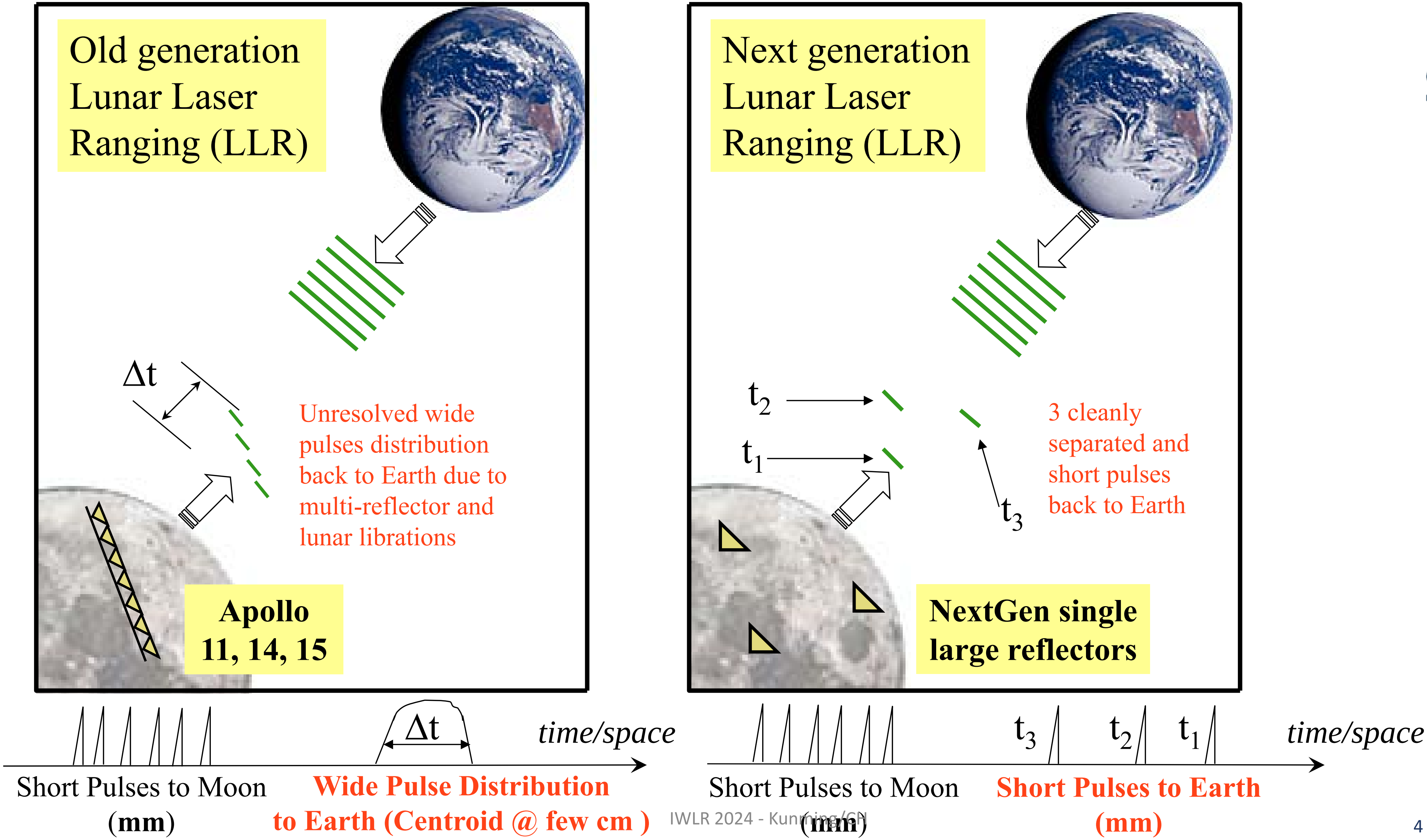


New!

Recent!

LRR arrays of many reflectors for ESA's LCNS satellites, of reference orbit: Extended/Elliptic Lunar Frozen Orbit (ELFO)





Old generation Lunar Laser Ranging (LLR)
Δt
Unresolved wide pulses distribution back to Earth due to multi-reflector and lunar librations
Apollo 11, 14, 15
Short Pulses to Moon (mm)
Δt
time/space
Wide Pulse Distribution to Earth (Centroid @ few cm)
Next generation Lunar Laser Ranging (LLR)
t2
t1
t3
3 cleanly separated and short pulses back to Earth
NextGen single large reflectors
Short Pulses to Moon (mm)
t3
t2
t1
time/space
Short Pulses to Earth (mm)

Scientific (F1-F2-F3) – Exploration (F3-F4) Objectives with the single, large retroreflector "MoonLIGHT"

(Moon Laser Instrumentation for Geneneral relativity/Geophysics High accuracy Tests)

Summary of scientific objectives	Primary Objective: - Investigation and study of interior structure. Additional Objective: - Investigations of General Relativity.	See: F1 F2
	General investigation and study of surface environment of the south pole of the Moon: - Surface geodesy and associated lunar reference frames. - Lunar resources, enabling exploration and research station / village. - PNT	See: F3 F4

Geophysics Goals (F1), General Relativity goals (F2)

- Geophysics: improve understanding of deep lunar interior (liquid and solid states, its sizes and shapes)
  - Each new instrument improves over Apollo/Lunokhod
  - Complementary to orbit sensing (like GRAIL, Chang'E)
  - Geophysics goals further improved if in a network.
  -
- General Relativity (GR): precision tests
  - Each new instrument improves over Apollo/Lunokhod
  - Improvement scales also with lasers' performance, detailed lunar interior modelling and number of laser reflectors and laser observations
  - Constrain new theories of relativistic gravity beyond GR: spacetime torsion, nonminimally coupled gravity, f(R)
  - Open windows to understanding dark energy / matter.

SCIENCE TEST OF GENERAL RELATIVITY	Apollo/Lunokhod [1] few cm accuracy (centroid of pulses back to Earth, slide 4)	Next-Generation [2] mm accuracy (first step)
Parameterized Post-Newtonian (PPN) β	$\|\beta-1\| < 1.1\times10^{-4}$	$< 10^{-5}$
Weak Equivalence Principle (WEP)	$\|\Delta a/a\| < 1.4\times10^{-13}$	$< 10^{-14}$
Strong Equivalence Principle (SEP)	$\|\eta\| < 4.4\times10^{-4}$	$< 3\times10^{-5}$
Time Variation of Gravitational Constant	$\|\dot{G}/G\| < 9\times10^{-13}\mathrm{yr}^{-1}$	$< 5\times10^{-14}$
Inverse Square Law (ISL) - Yukawa	$\|\alpha\| < 3\times10^{-11}$	$< 10^{-12}$
Geodetic Precession	$\|K_{GP}\| < 6.4\times10^{-3}$	$< 6.4\times10^{-4}$

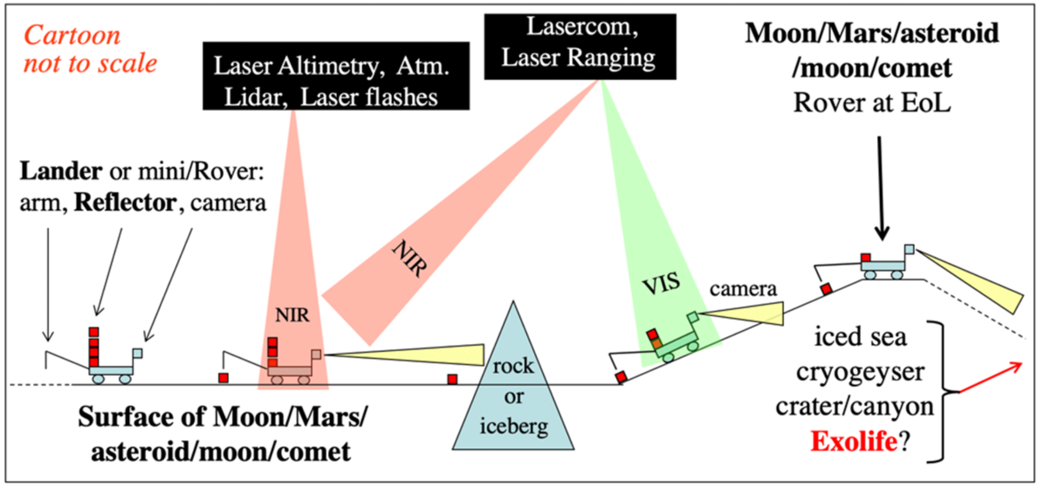
[1] J. G. Williams et al. Phys. Rev. Lett. 93, 261101 (2004)
[2] M. Martini, S. Dell'Agnello, Springer DOI 10.1007/978-3-319-20224-2_5 (2016)

Support to Positioning Navigation and Timing (PNT) & Lasercom

- Build a network of laser retroreflectors for the lunar surface (near & far-side) and lunar orbits; to be observed by ground laser stations and by orbiting lasers
  - Lasercom and Laser Ranging (like LLCD on NASA LADEE; OPTEL-D on the initial AIM mission of ESA)
  - Laser altimeters (NASA LRO, ESA Hera Lidar, MMX Lidar)
- Accurate positioning services for exploration, ISRU and colonization (ESA's ArgoNAUT and LCNS)
- New geodetic reference points realize an improved local lunar reference frame
- Large reflectors also give a direct tie to the ITRF/S (International Terrestrial Reference Frame/System), which includes Earth laser stations.

- **This laser retroreflector Network is the passive component of ESA's LCNS**
- These reflectors have consolidate/long space heritage (≥Apollo) and are long-lived, passive, maintenance free.

microreflectors deployed by landers & observed orbiters



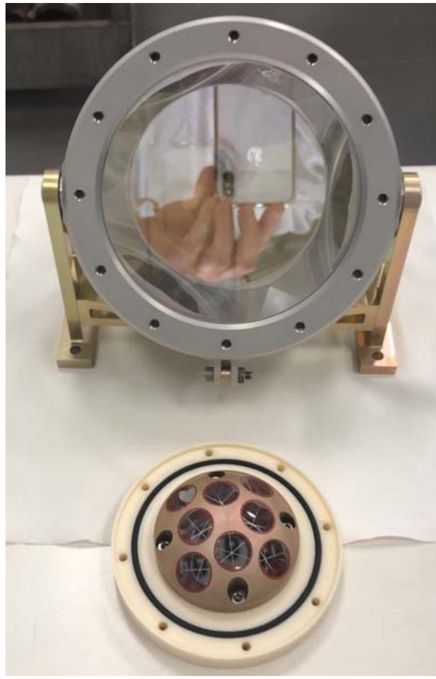
Laser positioning of Lander (or of Rovers deployed by Lander) with laser retro reflector also on the Moon **far side**

Missions <---- SUMMARIES ----> Instruments

- **MPAc = MoonLIGHT Pointing Actuators**
- **MPAc PFM1 and PFM2 - V1** (actuated).

  PFM1: NASA-CLPS flight 2025.
  PFM2: ESA will decide in 2025.
  PFM2 vibes @ESTEC Aug 2024**===>**

- **MPAc (P)FM3 - V2** (actuated & optimized):
  - Mandatory instrument identified by ESA as part of the payload suite for PNT NovaMoon on the 1st ESA lunar lander ArgoNET.
- **NGLR** (D. Currie PI, fixed pointing), US version: NASA CLPS flight in 2024.
- **INRRI**: see separate slides.



Earth Laser Observatories

- G. Bianco, C. Benedetto, L. Santamaria, ASI-Matera, Italy,
- S. Merkowitz, NASA-GSFC, APOLLO observatory, USA
- Yuqiang LI, et al, Yunnan Observatories, China
- C. Courde, Observatoire de la Cote D'Azur, France,
- U. Schreiber, Wettzell Observ./TU Univ., Munich, Germany

MPAc (P)FM3 - V2 for NovaMoon on ArgoNET (INRRI as option)

MPAc - V2 (possibly optimized): mandatory instrument identified by ESA as part of the payload suite for positioning & navigation **NovaMoon** on the 1st ESA lunar lander ArgoNET.

ESA UNCLASSIFIED – Limited Distribution – Limited Distribution

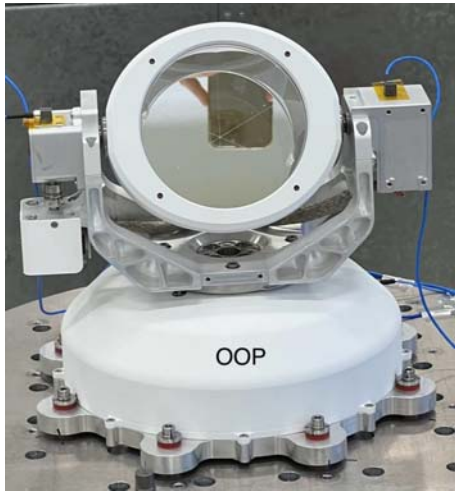
esa

3.2. Product Tree and Function Mapping

	Unit ID	Function Mapping	Element	Location	Baseline	Power Peak (W)	Power Nominal (W)	Mass (kg)	Notes
			NovaMoon						
TIMING-UNIT	**U1**	MF02/CF08	**Timing**						
	U1.1		Atomic Clock 1	Internal	Y	10	10	0.5	
	U1.2		Atomic Clock 2	Internal	Y	10	10	0.5	
	U1.3	F26	Atomic Clock 3 (Option)	Internal	N	10	0	0.5	Cold redundancy
	U1.4	F13	Synchronisation unit	Internal	Y	35	35	8	Internally redundant
COM-UNIT	**U2**	MF01/F23	**Communications**						
	U2.1		Moonlight COM transceiver	Internal	Y	40	0	2	
	U2.2		COM S-band Antenna	External	Y	0	0	0.5	
NAV-UNIT	**U3**	CF04/CF05/CF06/CF07/F12/F13/F14/F15/F16/F17/F18/F19	**Navigation**						
	U3.1		LANS Receiver 1	internal	Y	18	18	1	
	U3.2		LANS Receiver 2	internal	Y	18	18	1	
	U3.3		NAV S-band Antenna(s)	External	Y	0	0	1	
	U3.4	CF03/F22	Navigation processor	internal	Y	10	10	0.6	
	U3.5	F20	LANS Transmitter (Option)	internal	N	30	30	1	
	U3.6	F27	Extendible Boom (Option)	External	N	TBD	TBD	TBD	
VLBI-UNIT	U4	CF03/CF09.	**VLBI**						
	U4.1		VLBI Transmitter	internal	Y	20	0	1.5	
	U4.2		VLBI Antenna	external	Y	0	0	2	
	U4.3		APM	external	Y	12	0	5	
L	U5		**Laser Ranging**						

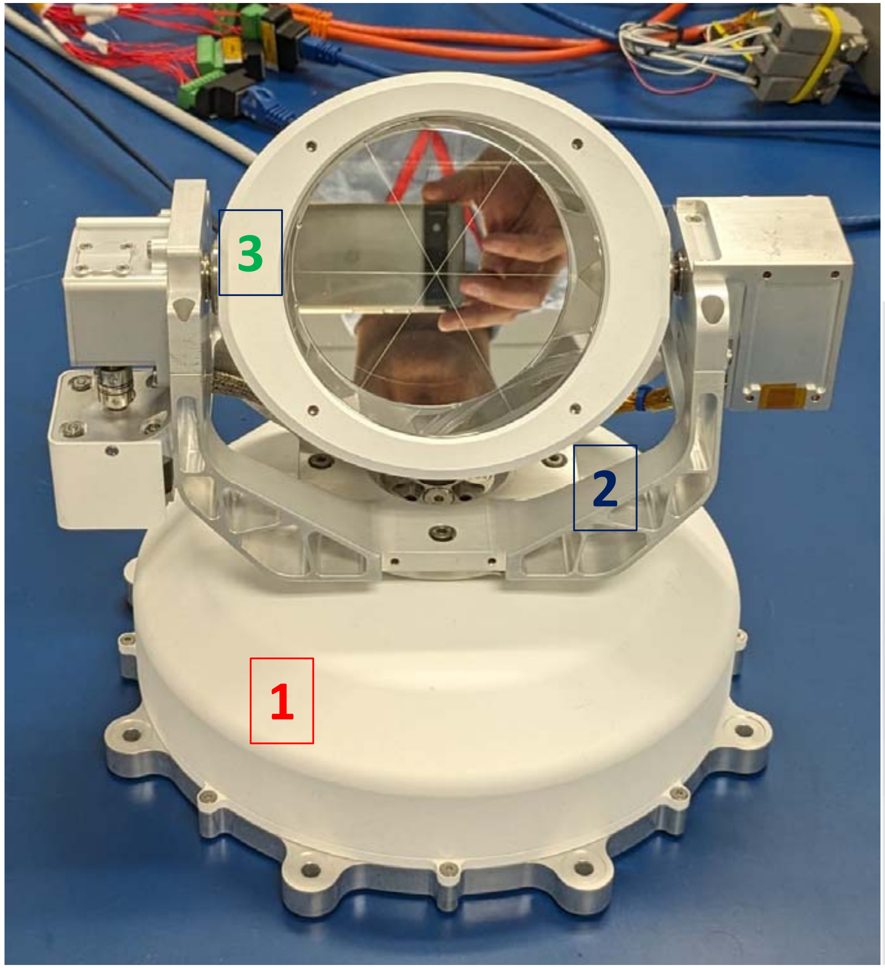
	Unit ID	Function Mapping	Element	Location	Baseline	Power Peak (W)	Power Nominal (W)	Mass (kg)
			NovaMoon					
	U5.1	CF03/CF10	Laser Retroreflector MPac	external	Y	12	0	5
	U5.2	F25	Laser Retroreflector INRRI (Option)	external	N	0	0	0.025
	U5.3	F24	Active Laser Retroreflector (Option)	external	N	35	0	10
NET-UNIT			**ArgoNET (see CPE and SNH)**					
		CF11/F23	DTE transceiver	Internal				
		CF11/F23	DTE antenna	External				
		F20/F22	SNH transceiver(s)	Internal				
		F20/F22	SNH antenna(s)	External				

Table 2 – Product Tree

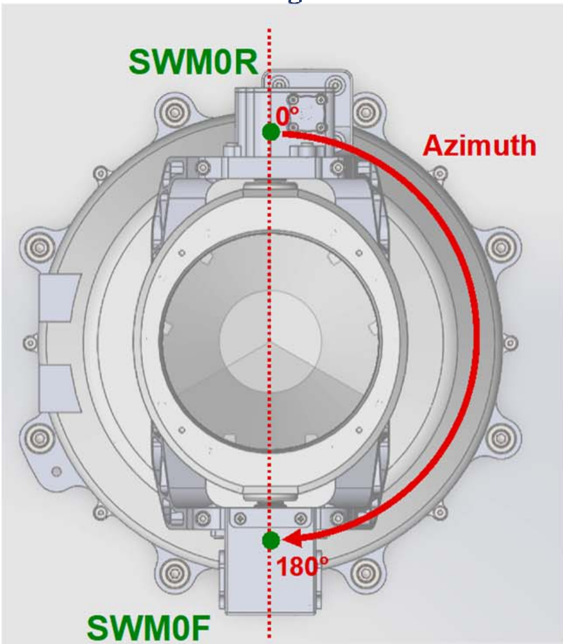


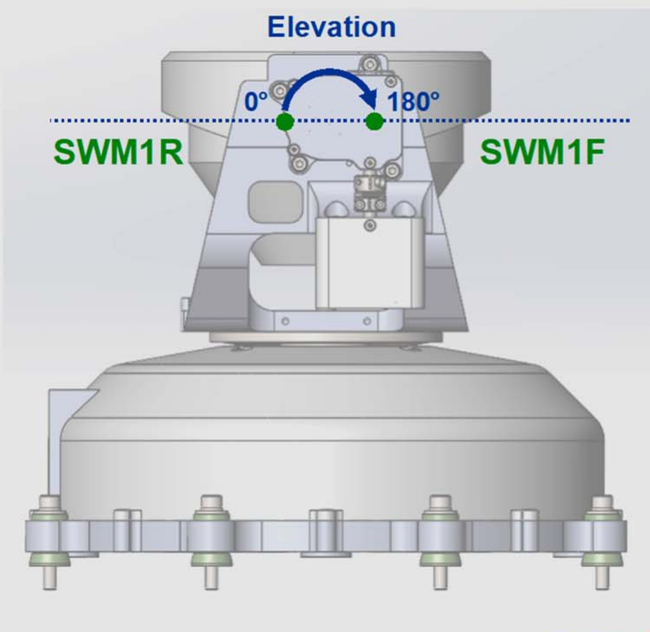
The MPAc (MoonLIGHT Pointing Actuator)

The European instrument MPAc: the 1st lunar laser retroreflector with dual pointing actuators.

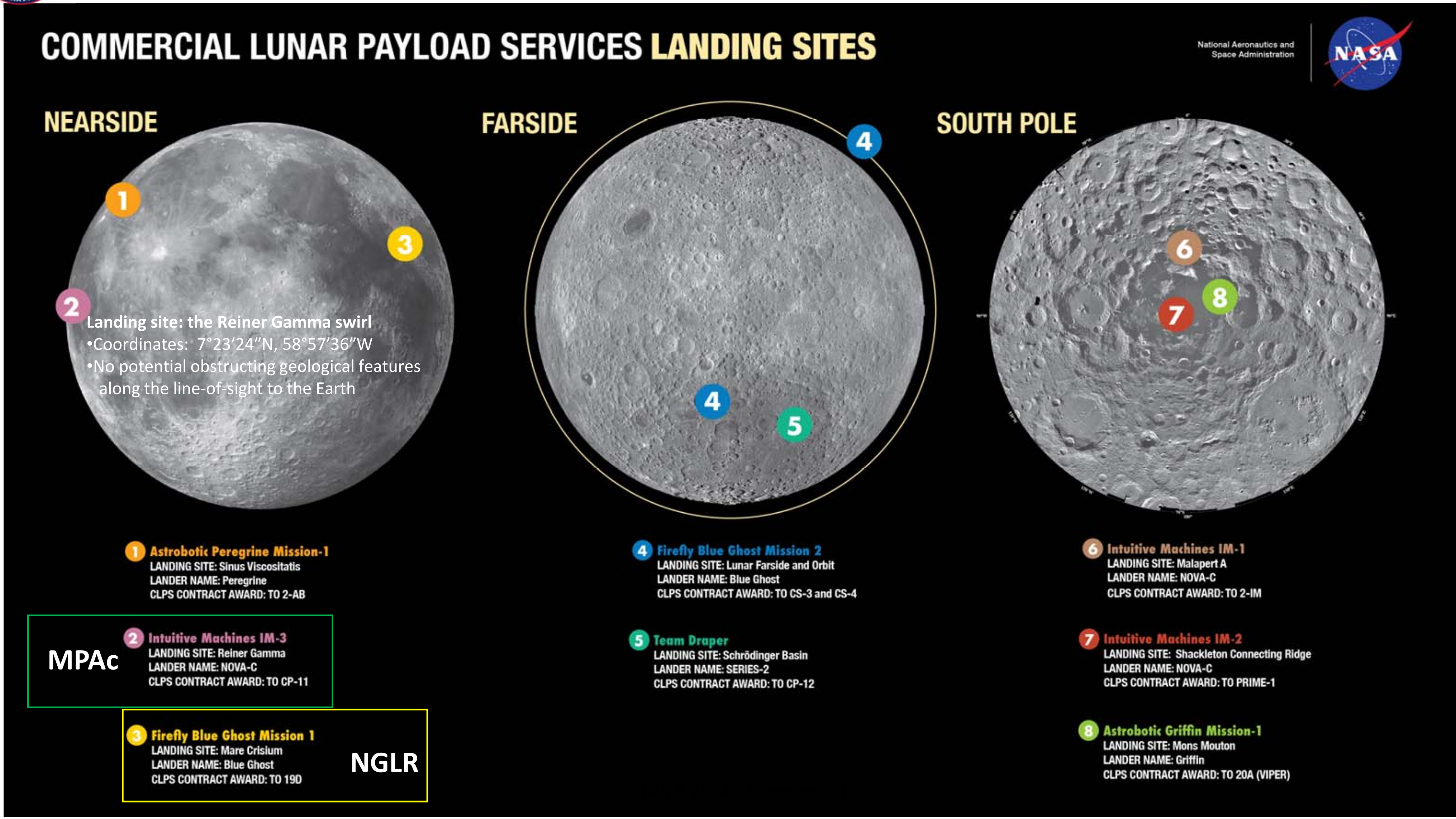


1. **Azimuth frame:** ideal range of rotations from 0° to 180°, imparted by a stepper motor and limited by 2 limit switches.
2. **Elevation frame:** ideal range of rotations from 0° to 180° imparted by a stepper motor and limited by 2 limit switches.
3. **CCR Housing** is a completely passive block that holds **MoonLIGHT** (**Moon L**aser **I**nstrumentation for **G**eneral relativity/geophysics **H**igh-accuracy **T**ests) and contains its integration structure.





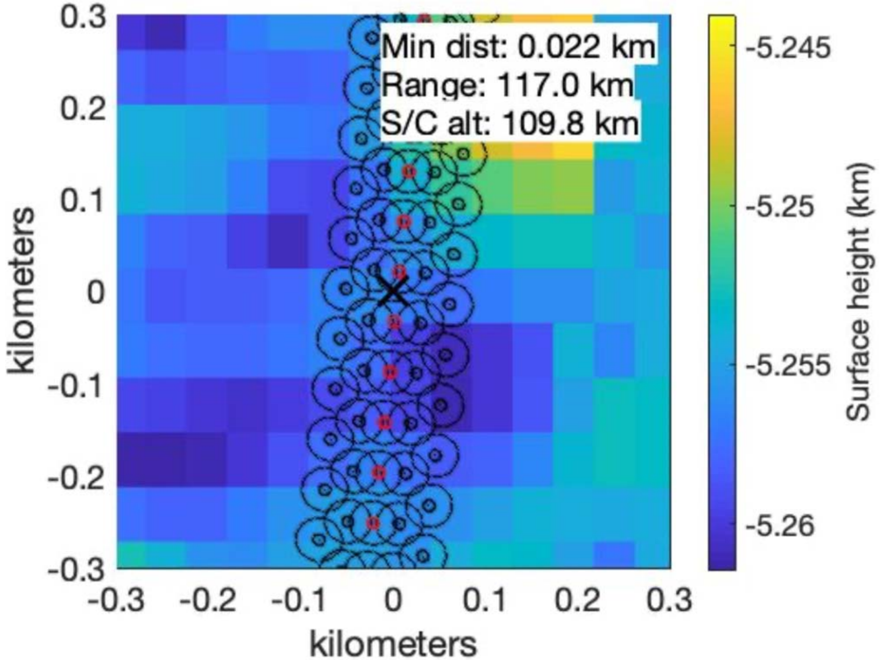
Overview of NASA-CLPS missions

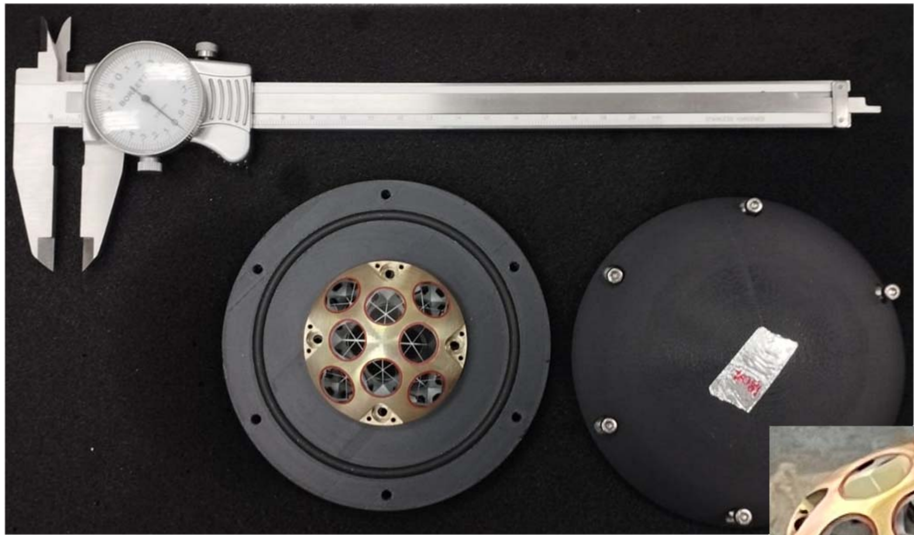


Mission <----- INRRI 2024 -----> Instrument

- **INRRI**: 1 on Chang'E-6 of CNSA, landed on the farside in June 2024
- **Observed** by NASA laser altimeter on LRO !!

Chang'E-6: 2024-213-23:53:50, inc. angle: 20.79°
Lunar time: Day
Return received

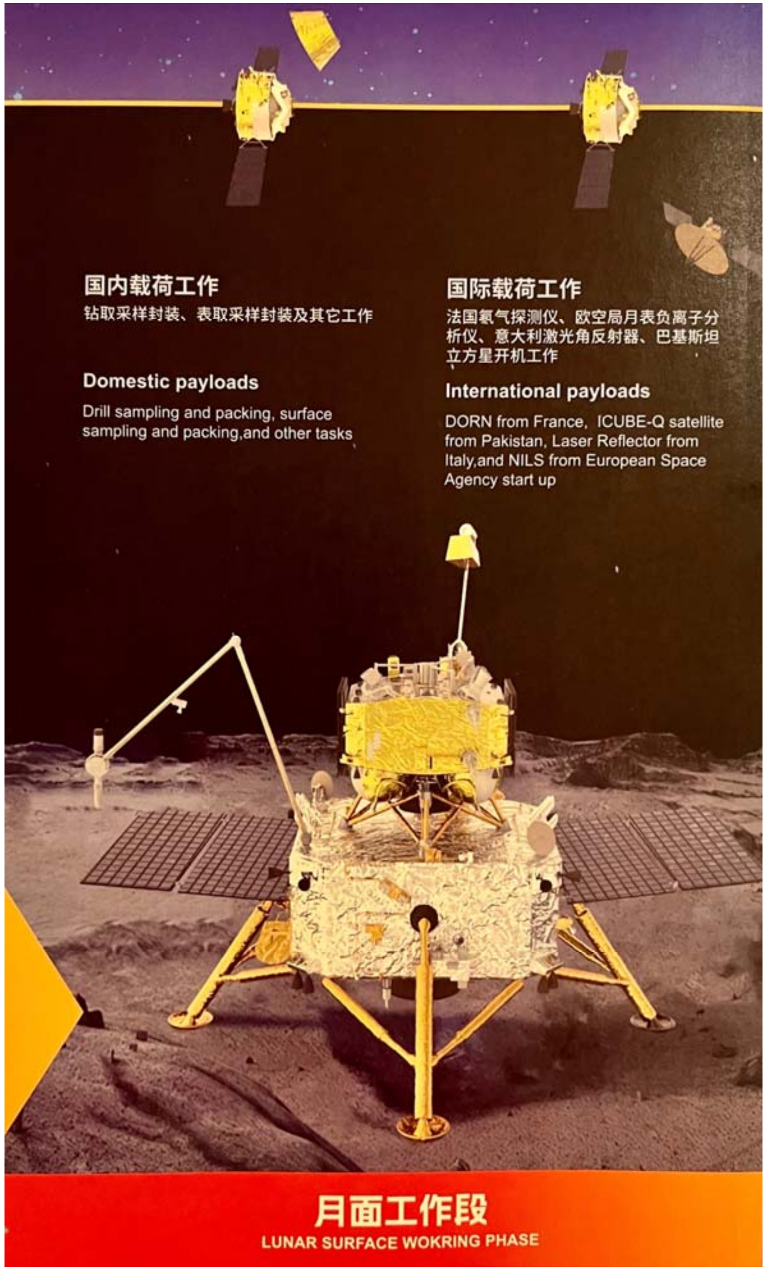


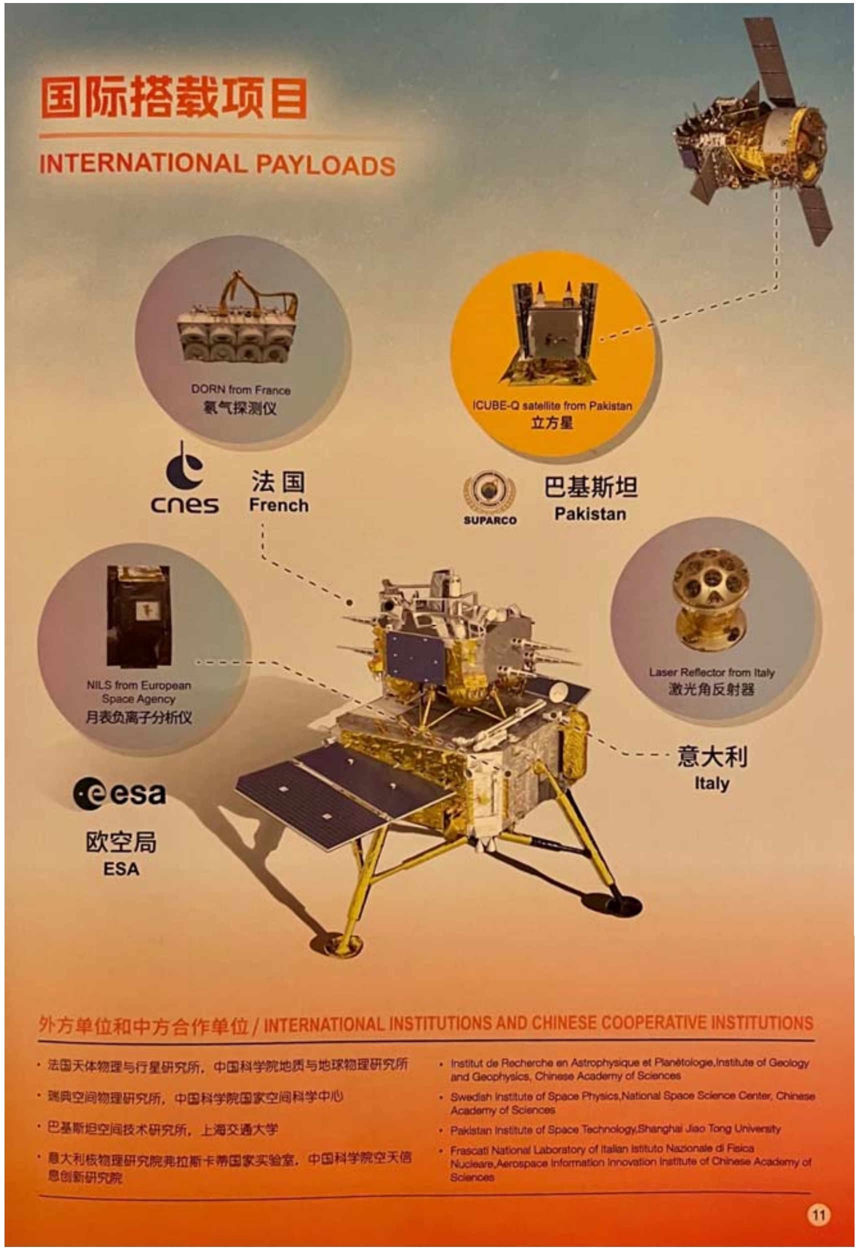


Lunar Observatories

- NASA, laser altimeter on LRO orbiter
- CNSA, laser altimeter on Chang'E-7

- ESA, future lasercom orbiters
- CNSA, laser altimeter on Chang'E-8





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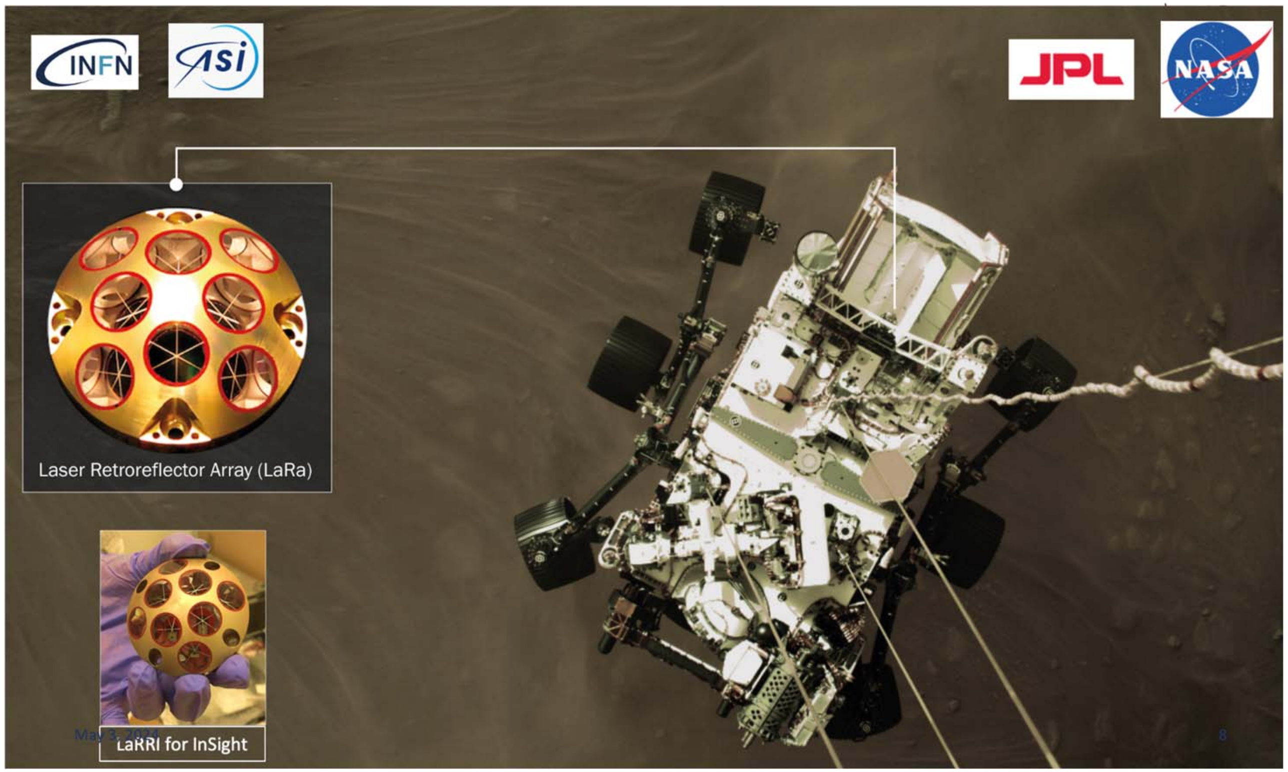
Mission <------ INRRI 2025 ----> Instrument

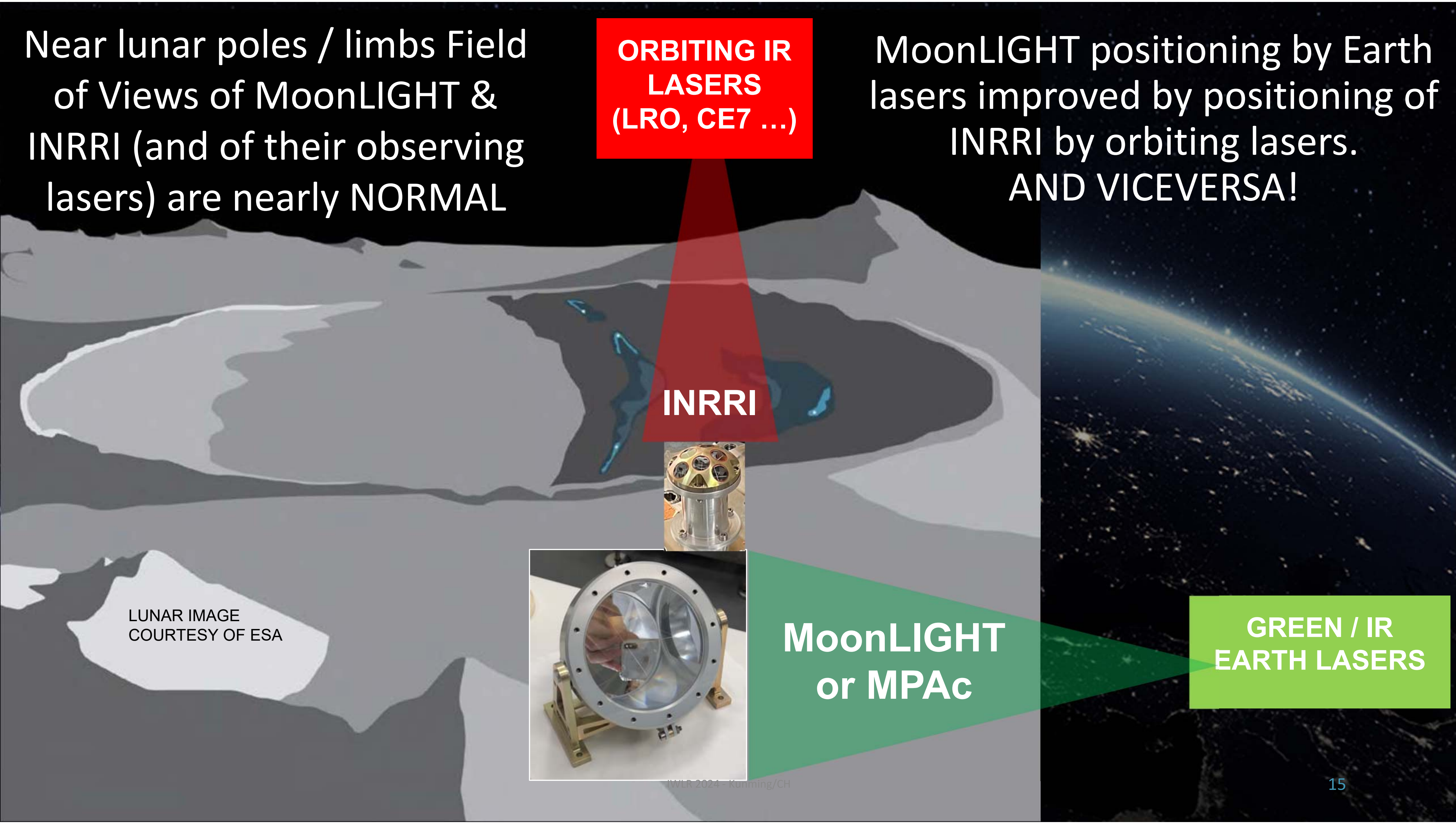
- **LaRA2:** spare FM2 of the NASA rover Perseverance now on Mars.

- **LaRA2 flight in 2025 with iSpace-3**, Japan commercial mission, supported by ASI-INFN Agreement n. 2023-59-HH.0.

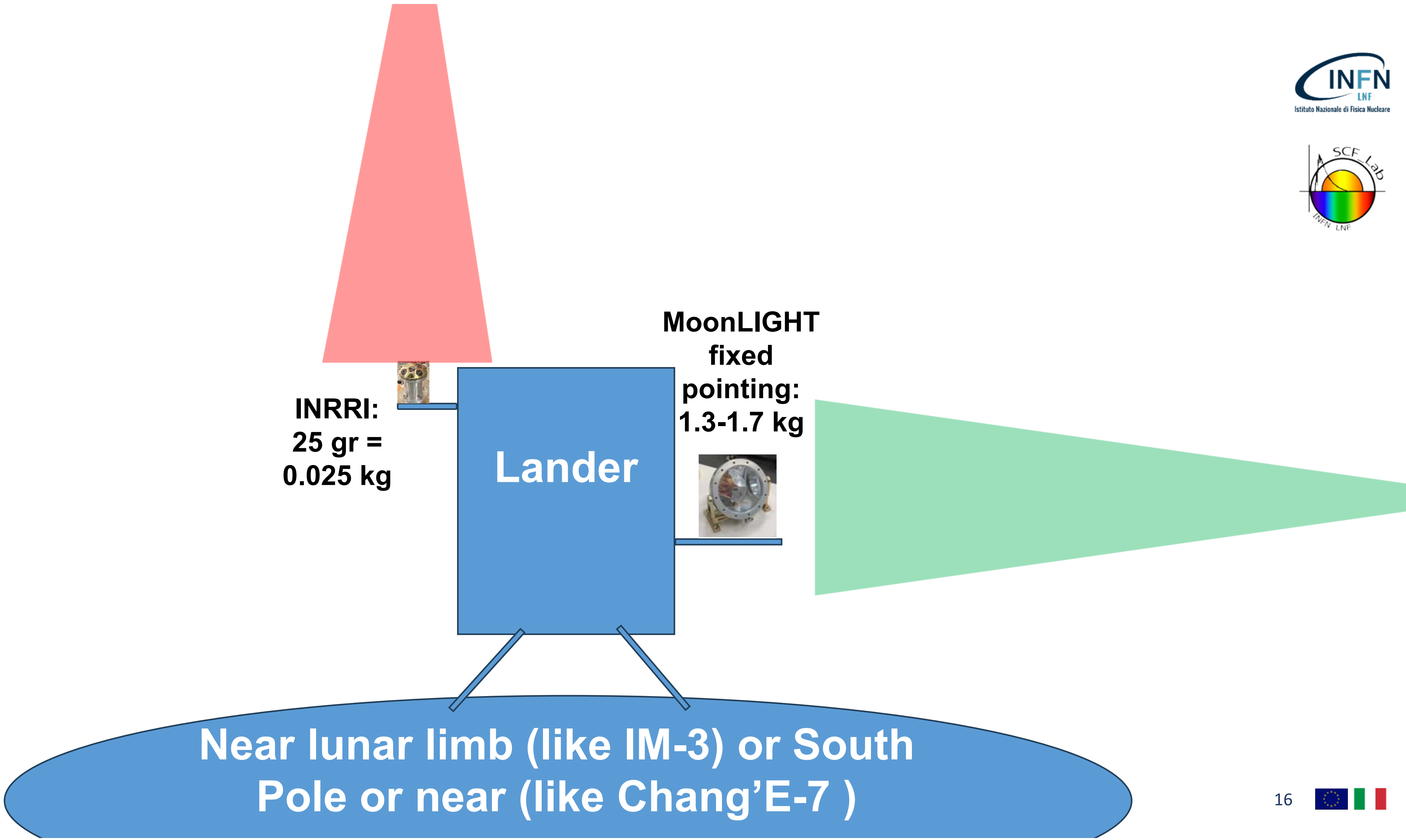


Lunar observatories

- NASA, laser altimeter on LRO orbiter
- CNSA, laser altimeter on Chang'E-7
- ESA, future lasercom orbiters (hopefully)
- CNSA, laser altimeter on Chang'E-8



Near lunar poles / limbs Field of Views of MoonLIGHT & INRRI (and of their observing lasers) are nearly NORMAL
ORBITING IR LASERS (LRO, CE7 ...)
MoonLIGHT positioning by Earth lasers improved by positioning of INRRI by orbiting lasers.
AND VICEVERSA!
INRRI
LUNAR IMAGE COURTESY OF ESA
MoonLIGHT or MPAc
GREEN / IR EARTH LASERS


INRRI:
25 gr =
0.025 kg
Lander
MoonLIGHT
fixed
pointing:
1.3-1.7 kg
Near lunar limb (like IM-3) or South
Pole or near (like Chang'E-7)

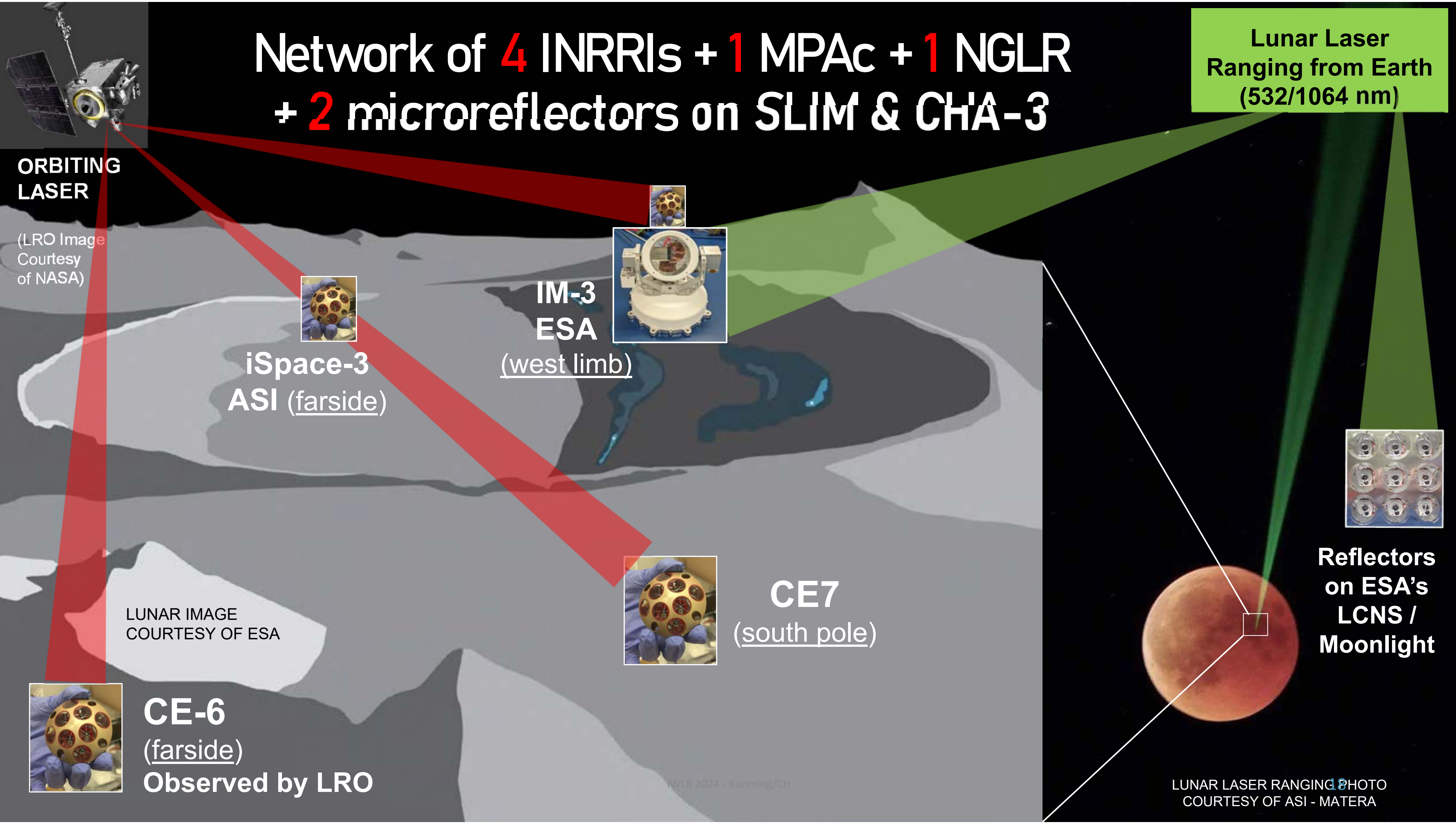
Lander Nova-C (USA) of

Intuitive Machines-3

for the 2025 flight
NASA-CLPS “CP11”

MPAc on a side shelf

INRRI microreflector
on top.


Network of 4 INRRIs + 1 MPAc + 1 NGLR
+ 2 microreflectors on SLIM & CHA-3
Lunar Laser Ranging from Earth (532/1064 nm)
ORBITING LASER
(LRO Image Courtesy of NASA)
IM-3
ESA
(west limb)
iSpace-3
ASI (farside)
CE7
(south pole)
LUNAR IMAGE COURTESY OF ESA
CE-6
(farside)
Observed by LRO
Reflectors on ESA's LCNS / Moonlight
LUNAR LASER RANGING PHOTO
COURTESY OF ASI - MATERA