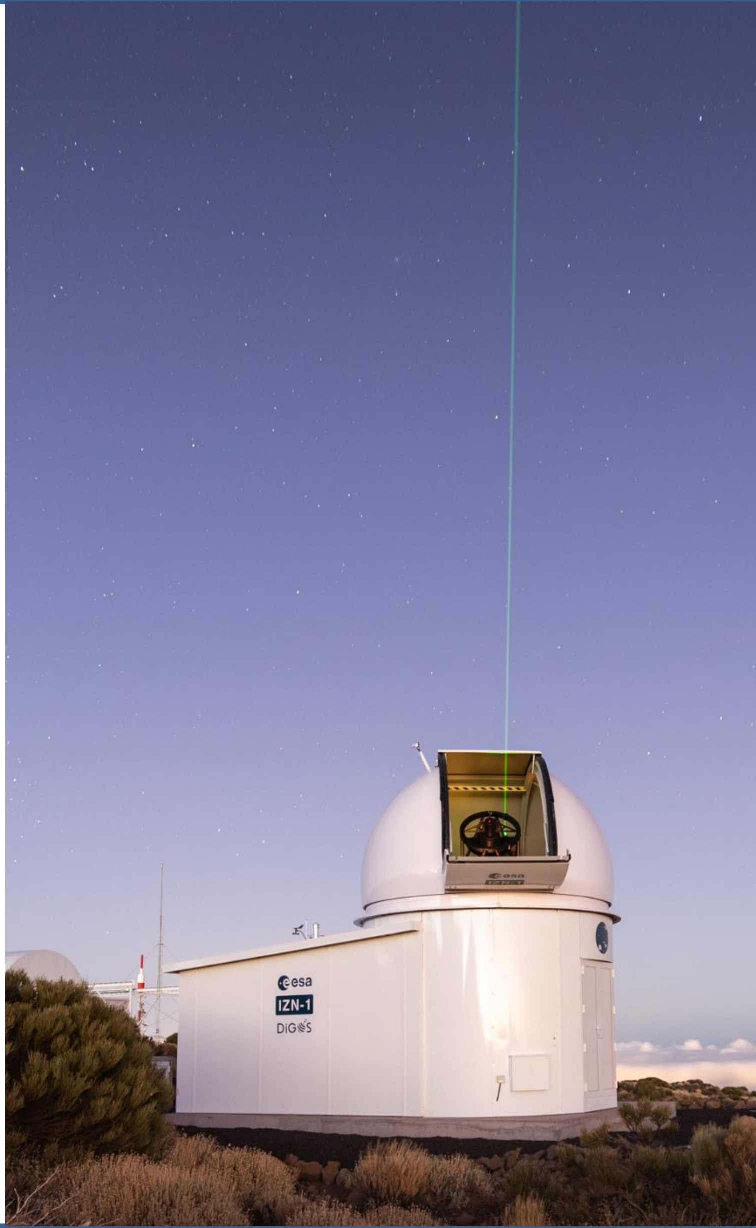
Laser Ranging Station for Cooperative Targets

Final Presentation

05.09.2022

Outline

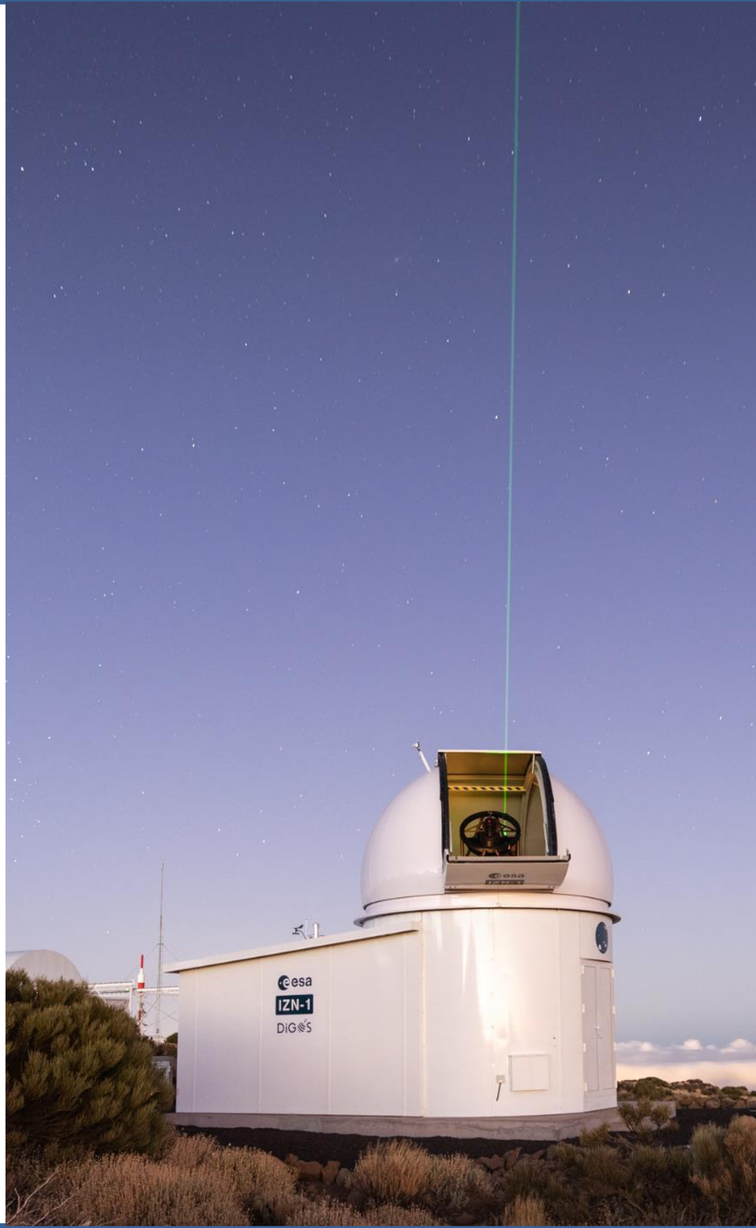


DiGOS is a system provider for turnkey Laser Stations

- Private German company, founded in 2014, ~25 employees (2022)
- Working domains
  - Geodetic & geophysical observation systems
  - System development, integration & operation
- National Innovation Price for “Turnkey Laser Ranging Stations” (2019)
- Strong connections into ILRS, SLR “research” Institutes

Capabilities and targets

- Role of (small) system integrator
- Providing solutions to challenging engineering tasks/problems
- Turn key stations (SLR, Debris, and derived systems)
- Efficient and economic system implementations,
- Own HW and SW products for selected applications
- Control system (automated in future) for applications with satellite tracking



History on ELRS / First discussions

- Ca. end 2015 first contacts with ESA
- Beginning 2016: First exchange of ideas for ESA SLR station with Igor Zayer
  - Technology demonstrator
  - Increase ESA’s technological and operational observation capabilities
  - Precise Orbit Determination (POD) of Galileo satellites, Galileo laser ranging
  - Debris as a future upgrade
- Initial budget consideration was too low for a new station

→ Idea: Refurbishment of historic 1m Potsdam-2 SLR telescope with “some” limitations

→ Early interest / support by GFZ & IWF!

History / Iterations towards Start of the Project

- During 2016 “Design to Budget”: various technical analyses, trade-offs, calculations, presentations, telco’s

→ Unused Potsdam telescope based option “buried” (performance and flexibility deficiencies/risks)

- End of 2016 first consideration of an own station including new COTS telescope to meet performance requirements

- **Sep. 2017 publication of ITT “ESA Laser Ranging Station for Cooperative Targets” (direct negotiation)**
- ESA-internal funding by GSTP, SSA, PECS, MOI → “fixed” geo contributions & return (DE, AT, CH, LV)
- Site infrastructure (concrete foundation, power, data, install & operation permit) ESA CFI
- Deployment on Tenerife or in La Silla within 24 months

- **State-of-the-art LRS with high flexibility to allow for further developments and demonstrations of**
  - Upgradability to fully automated operation
  - Upgradeability laser ranging of known non-cooperative (space debris) objects during both day and night,
  - hand-over from passive survey observations of unknown non-cooperative targets of <1m size for follow-on laser tracking at least in the most congested 800-km altitude band, as well as for re-entries
  - optical communication & adaptive optics
  - the development of associated technical and operational standards.

Objective:

- 1st Operational prototype Laser Ranging Station for cooperative targets supporting Space Traffic Safety at excellent European site (e.g. Tenerife) with high weather availability

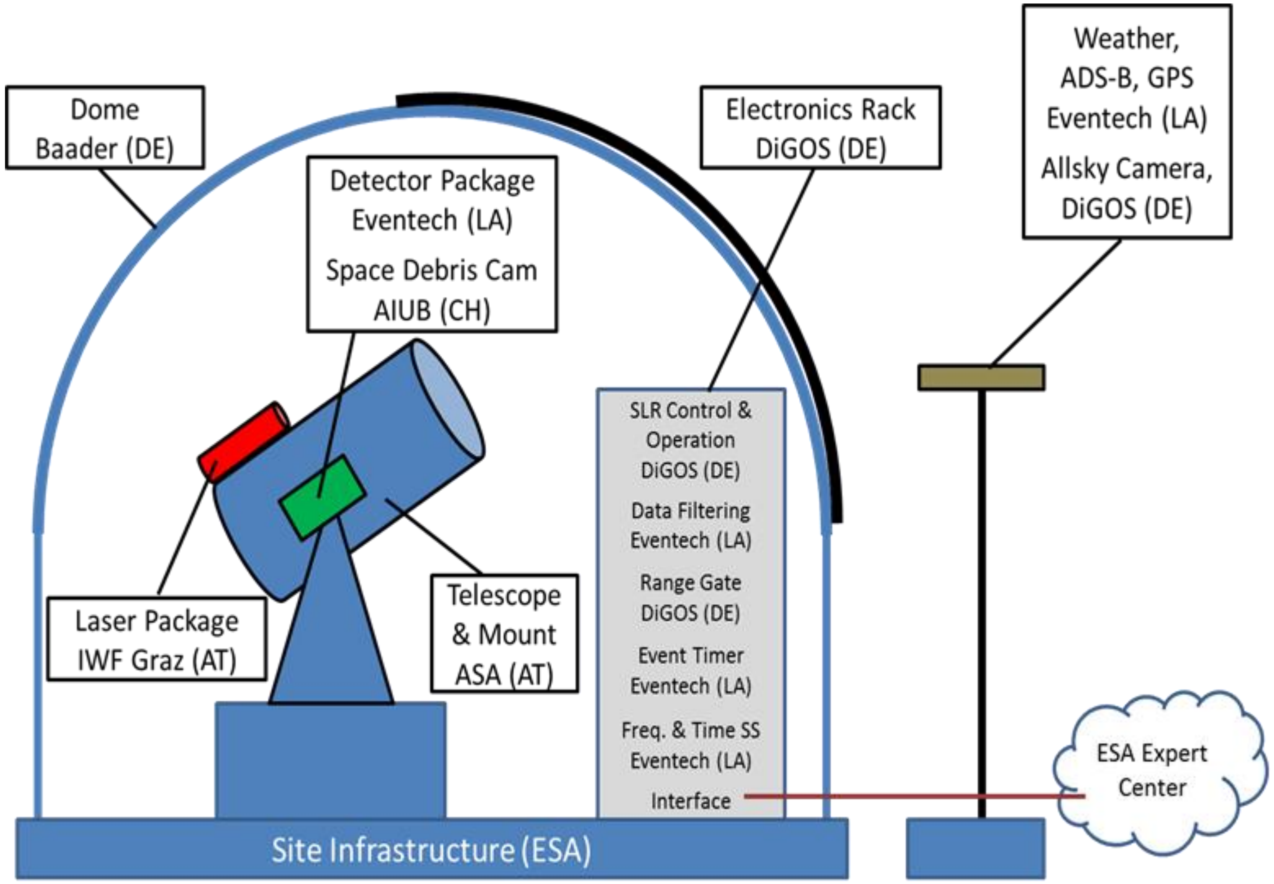
Technical Requirements (Ranging [~mm] of Galileo spacecraft at 23.000 km):

- Rx Telescope (80cm) with stable pointing (~1 arcsec)
- (slit) dome fro environmental protection
- Pulsed Laser Source with high-enough energy in green & IR
- Time-gated, high-bandwidth, photon-counting detector
- Precise system timing control (psec), calibration & analysis S/W prepared for automation
- Auxiliary sub-systems enabling automation (weather station & interlocks)

Site Operations Requirements:

- Operational Concept & Procedures satisfying Laser Safety (local & air traffic) & de-conflicting with passive astronomical observations (disturbance from laser stray-light)
- Hosting Agreement & Laser Operating License (ESA)

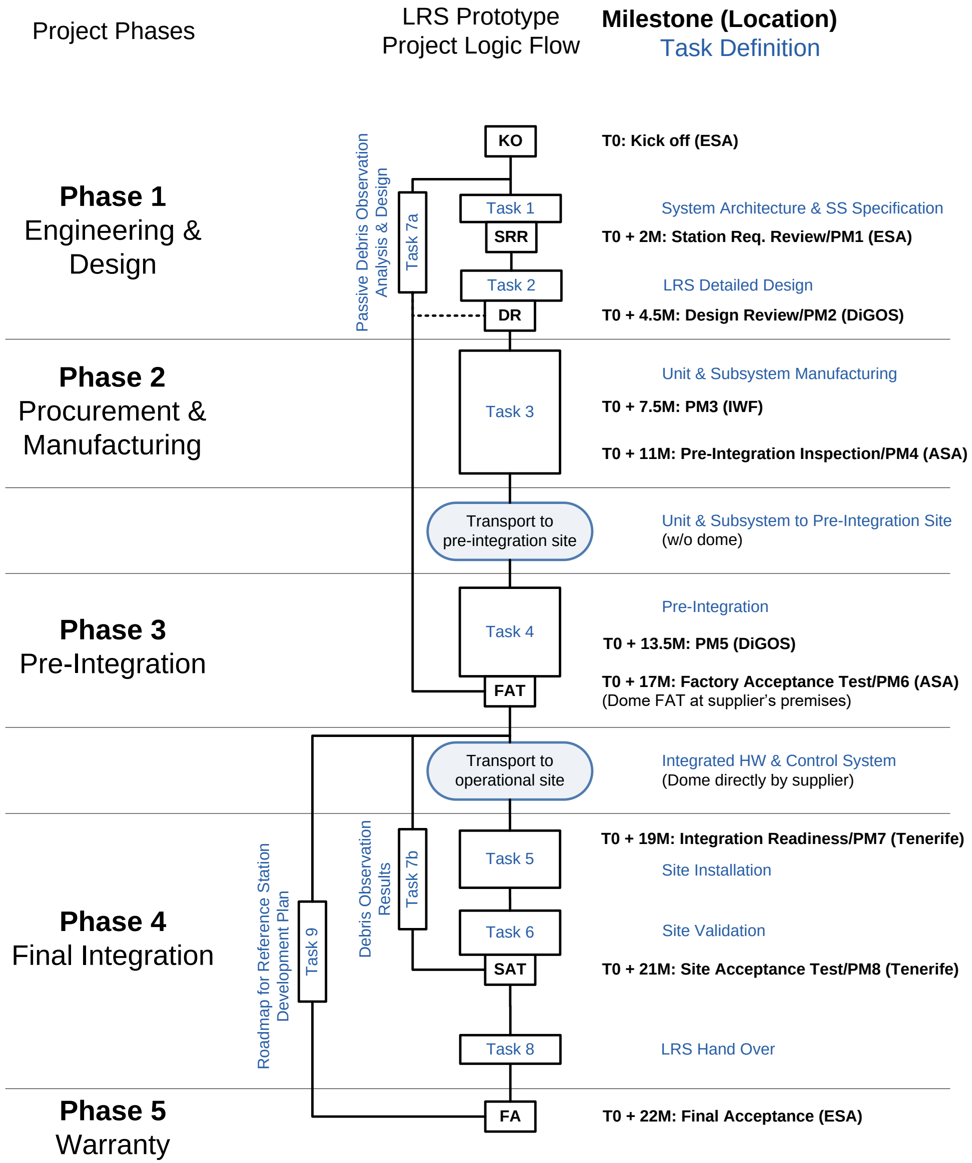
- DiGOS Potsdam GmbH (DE) as prime contractor for the turn key delivery of the station and providing the control system plus auxiliary HW
- Subcontractors & Suppliers:
  - ASA Astrosysteme GmbH (AT) delivering the telescope assembly
  - Baader Planetarium GmbH (DE) leader in astronomical dome
  - Austrian Space Research Institute/Institut für Weltraumforschung (IWF), Graz (AT) providing the LRS laser packages & IR detector
  - Eventech Ltd (LV) together with the Institute of Astronomy, Riga providing the LRS event timer, a detector package, data filtering and additional electronics
  - Astronomical Institute University of Bern, AIUB (CH) for passive-optical tracking technology and providing an optical camera for testing space debris tracking



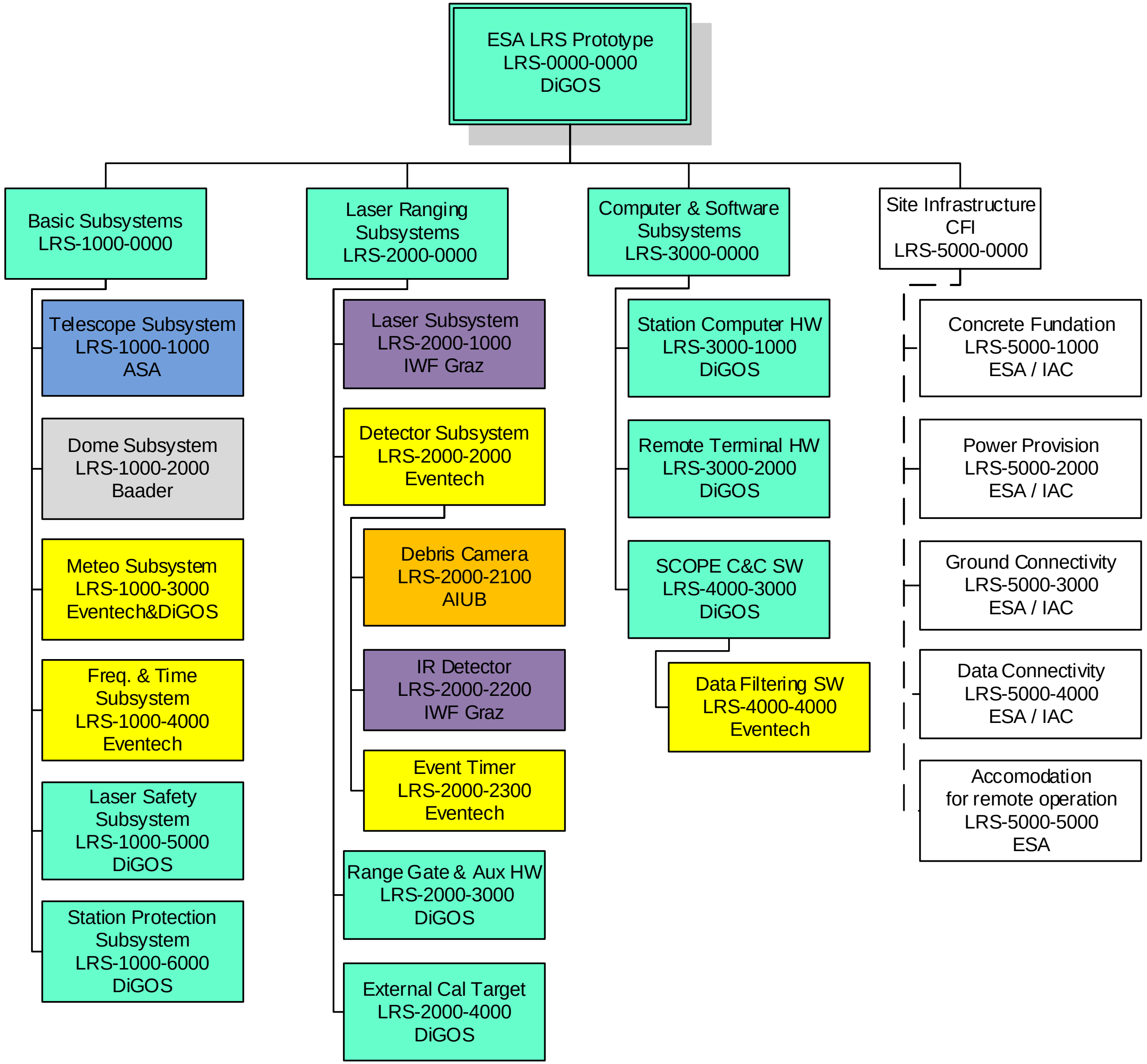
Project Logic & Start of the Project

- Nov 2017 – Mar 2018 negotiations & clarifications
  - Site selection process
  - Link budget calculations
  - Software BIPR & Latvian contribution

- Contract signature on 22.03.2018



Product Tree



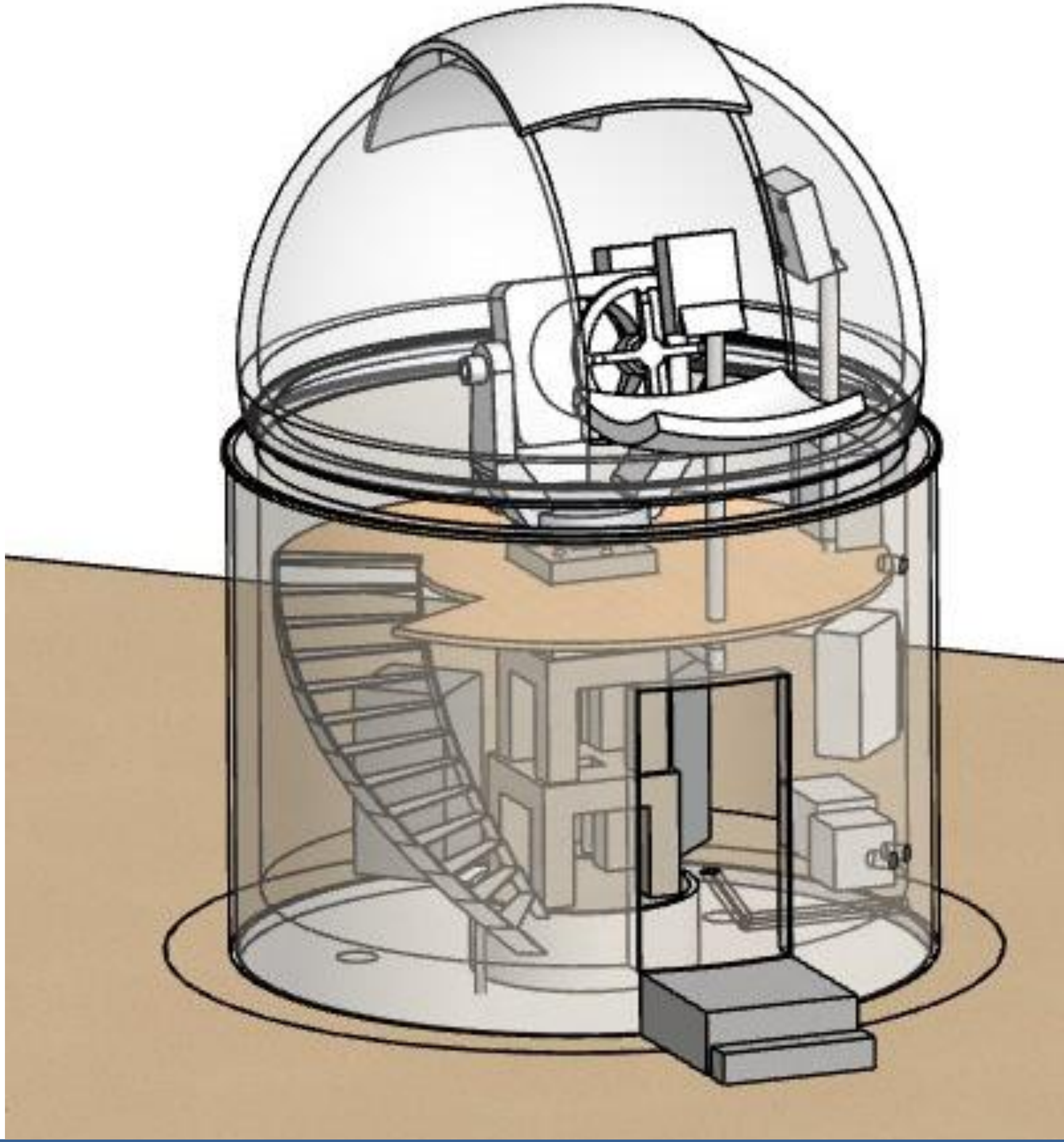
DiGOS

Main Subsystems

- Telescope: 80cm Ritchey-Chretien, 4 foci, pointing accuracy <5 arcsec
- Dome: 4.2m slit-type
- Detector Package: C-SPAD (532nm) & IR-SPAD (1064nm)
- Laser Package: 532 & 1064nm, <10ps pulses, ≤500μJ p. pulse, 400Hz
- Timing & Frequency: GNSS timing appliance, central freq. distribution
- Event Timer: ~3.5ps RMS
- Laser Safety & Station Protection Subsystems
- Integrated, Command & Control System
  - Commercially maintainable, upgradeable

Realization & Implementation

- Kick-off with subcontractors in April 2018
- System Requirements Review (SRR) in June 2018
  - External interfaces (site, predictions, etc.)
  - Safety subsystem & logic
  - Debris performance outlook
- Initial site design as one cylindrical building (ESA CFE) as base for the dome
- Later change to complete station base/ station provided by DiGOS with separate control room
  - Only foundation work as ESA provision



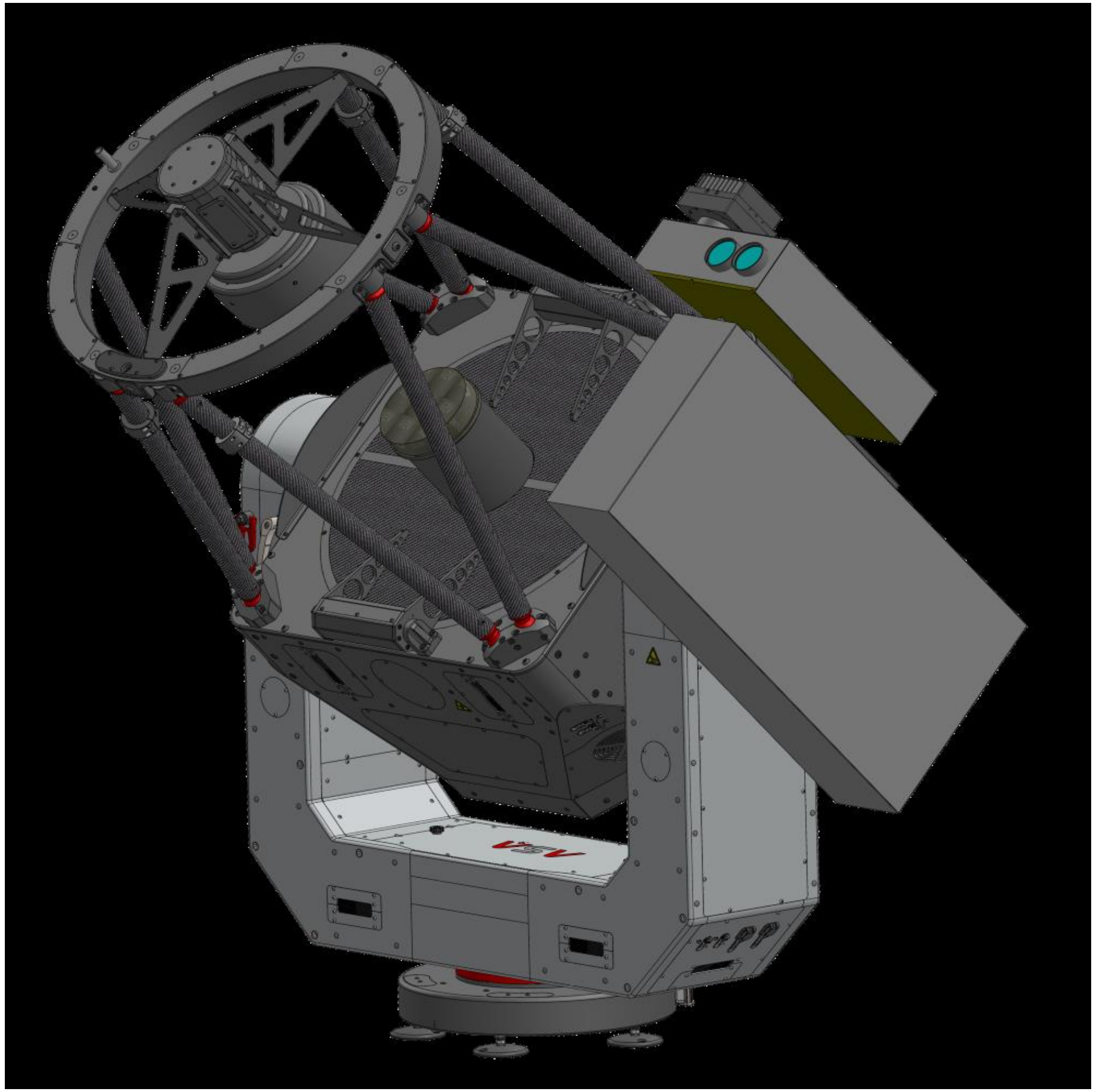
Realization & Implementation

- Design Review (DR) in Dec 2018
  - Status was considered in accordance with or beyond design review objectives
  - Nominal project specific work
  - No major design problems or incompatibilities were identified, however site infrastructure specification → design reference

→ CCN-1 in June 2019: Observatory type station base (Gambato) via new WP + extension of 4 months

- Pre-Inspection (PII) in Feb 2019
  - IWF: First successful ranging to Galileo, Glonass, Etalon with new Laser & Detector packages (AZ800 loaned by Uni Vienna)
  - ASA: Minor issues / questions wrt. interfaces, mount model & pointing of the telescope.

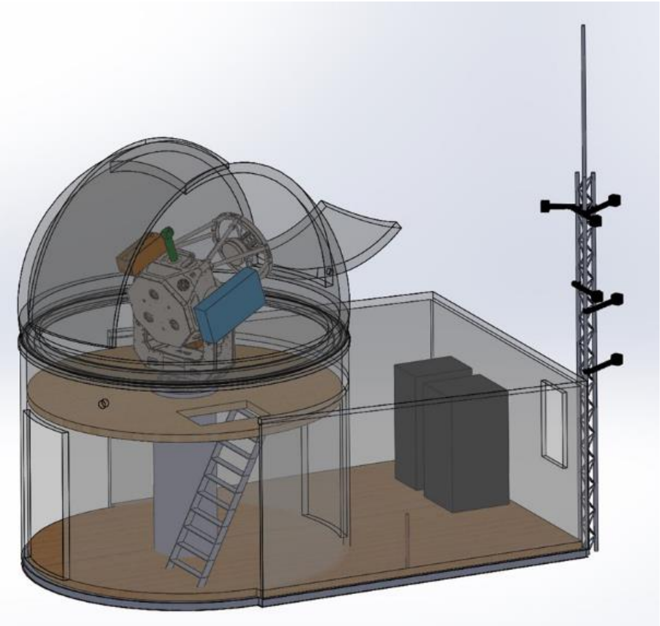
→ System pre-integration & testing in was agreed in Sandl

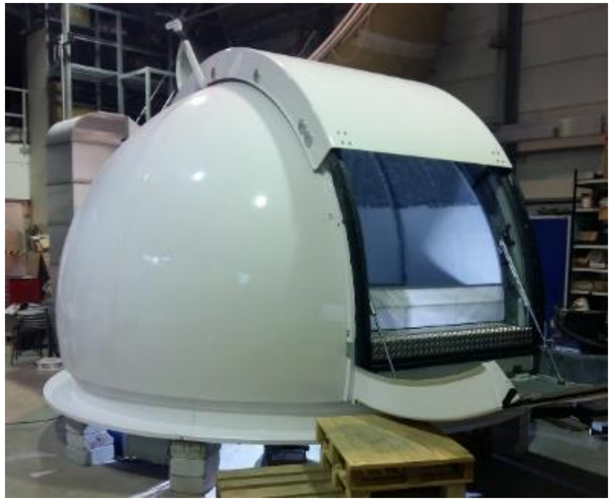


Realization & Implementation

- System FAT in Sandl in March 2020
  - Remote FAT due to Covid situation
  - System test results very good! (tracking, calibration, ranging)
  - More testing, fine tuning and characterization agreed (weather far from ideal)
  - Limited travel even within Austria (lockdowns)
  - Storage of dome
  - CCN to improve laser package for beam steering/, remote alignment capability, water cooling, power meter

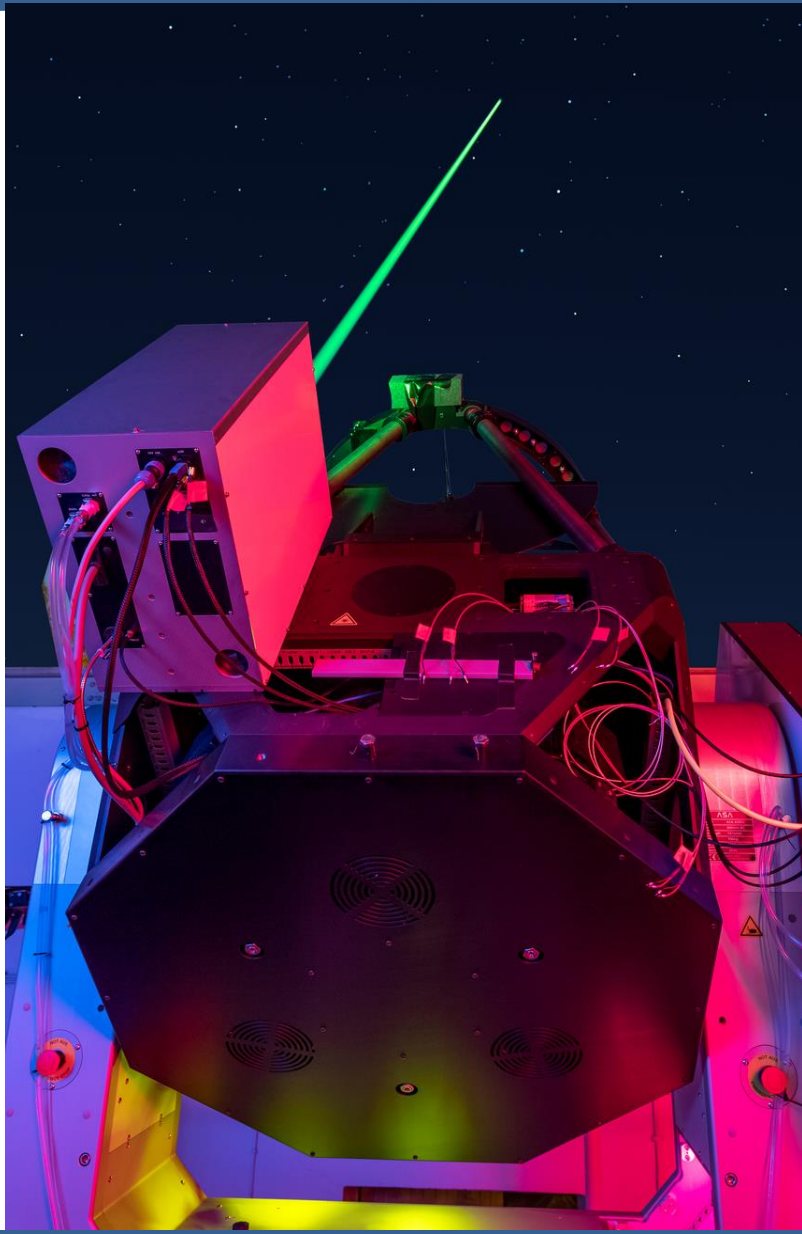
Class	532nm	1064nm	Total
LEO	3	2	5
LAG	1	2	3
GNSS	7	9	16
GEO	0	1	1
Sum	**11**	**14**	**25**





Realization & Implementation

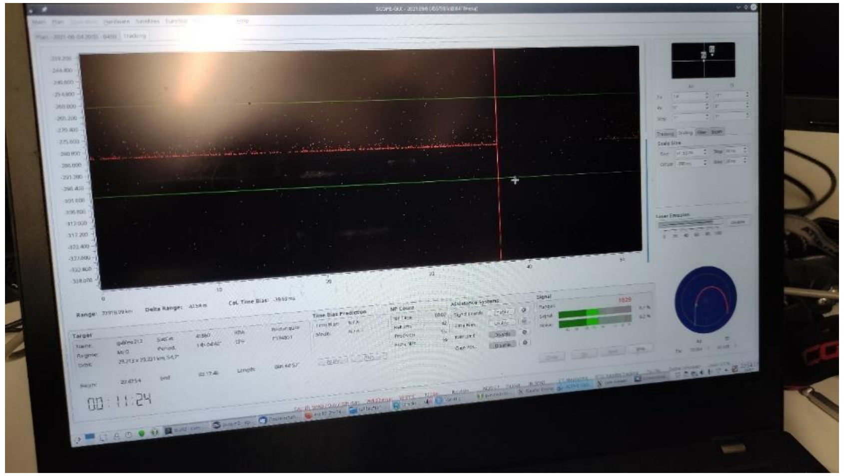
- Jan 2021 Clemens Heese (new ESA PM)
- Site preparation delays on Tenerife, Potsdam as test site made available
- Bundled CCN: ELRS test installation in Potsdam , schedule update, storage extension (dome)
- Objectives
  - Gain operational knowhow
  - Test of upgraded Laser Package (CCN) with water cooling + cabling, and re-verify mount model
  - Update of telescope firmware
  - Preparations for laser comms upgrade & recording of camera images + pointing angles for Flying Laptop
  - Priority is Galileo ranging (local tie measurement of ELRS in Potsdam will be checked to make real use of measurements)
  - Performance comparison with GFZ SLR station
- C19 Deployment Plan established



Realization & Implementation

- Installation on Tenerife (Teide Observatory) May to June 2021 & acceptance (SAT)
  - Phase 1: Station base & dome
  - Phase 2: Telescope, Laser & Detector packages, electronics, etc.
  - First demo with Galileo 212 on 04.06.2021
  - Remote operation towards SAT preparation
  - Additional delays due to laser outage, alignment & calibration tests, coordinates estimation, bad weather

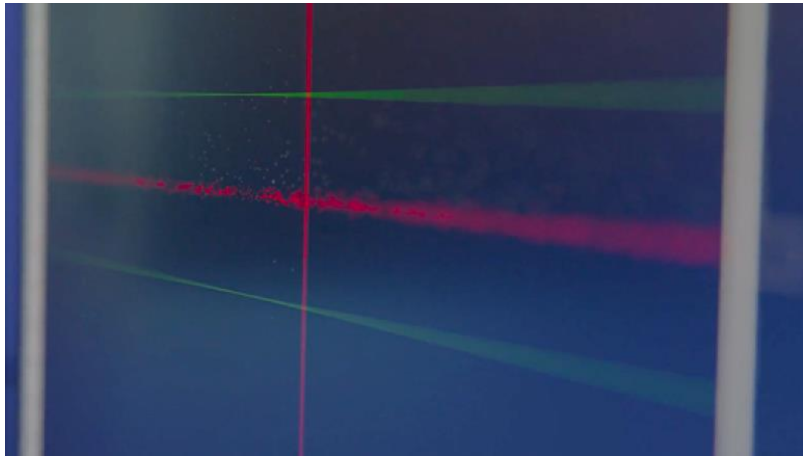
→ Too optimistic verification & acceptance approach

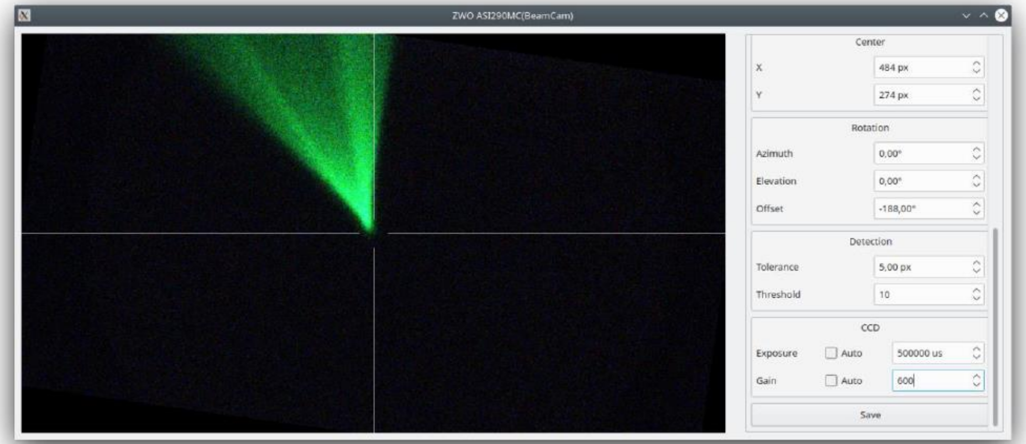


Realization & Implementation

- Site Acceptance Test (SAT) completed

IZN-1 SLR Performance





LAGEOS: 2.6 ± 8mm
LAGEOS-2: 1.5 ± 9mm

TARGET

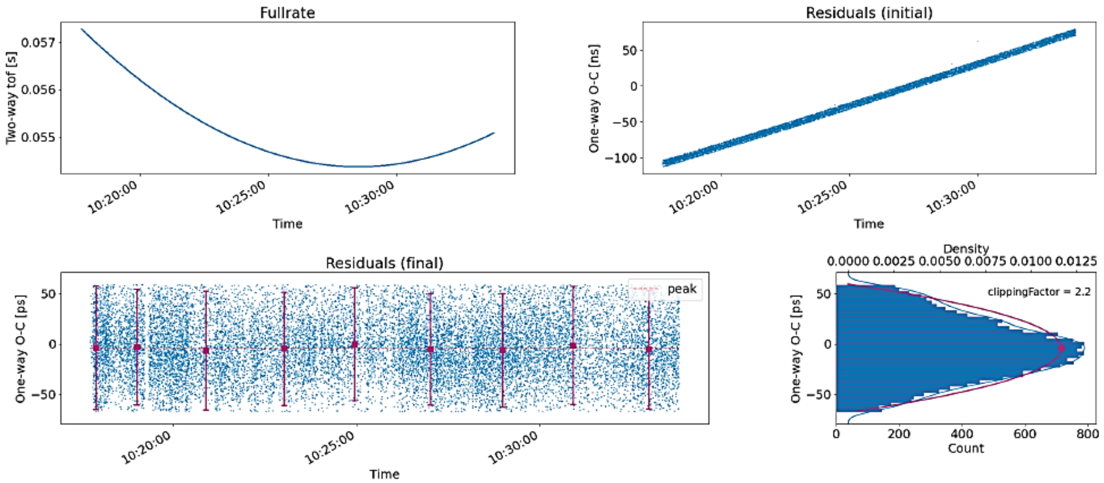
LAGEOS-1

WAVELENGTH (nm)

1064.0

EVALUATION

Returns	18951
RMS (1w, mm)	8.66
RMS (2w, ps)	57.74
TB (ms)	0.13
RB (m)	-0.51



IZN-1 SLR Performance

Batch 1
532nm

Sat	Date	Duration [min]	Range Bias [mm]	Time Bias [us]	Precision [mm]	Total NP	RMS [mm]
LAG1	2021/09/20 21:49	0	-6	-------.-	3	2	10
LAG1	2021/09/23 17:49	13	-2	1.9	1	8	12
LAG2	2021/09/28 18:27	22	-2	-7.8	1	9	10
LAG1	2021/09/29 16:51	0	0	-------.-	1	2	14
LAG1	2021/09/30 18:31	32	6	-1.9	2	13	10
AVG:	**5**	**14**	**-0.8**	**-2.6**	**1.6**	**6.8**	**11**

Batch 2
532nm

Sat	Date	Duration [min]	Range Bias [mm]	Time Bias [us]	Precision [mm]	Total NP	RMS [mm]
AVG:	**14**	**18**	**-2.9**	**0.2**	**1.7**	**8.5**	**10.0**

Batch 3
1064nm

Sat	Date	Duration [min]	Range Bias [mm]	Time Bias [us]	Precision [mm]	Total NP	RMS [mm]
AVG:	**14**	**21**	**3.3**	**3.0**	**0.9**	**11.3**	**9.6**

The pass-by-pass bias estimations for these batches using 532nm and 1064nm confirm the range bias <10mm.

IZN-1 Upgrade: Opto Comms

Space to ground laser communication

- CCSDS Standard Optical On-Off Keying (O3K)
- Typically 1550nm downlink & beacon laser
- License-free band, difficult to eavesdrop
- European Optical Nucleus Network (ESA) of Optical Ground Stations (OGS) developments ongoing
- Space Segment examples
  - Flying Laptop with OSIRIS (80MBit/s)
  - PIXL-1 with CubeLCT (100MBit/s)
  - TOSIRIS (10GBit/s)

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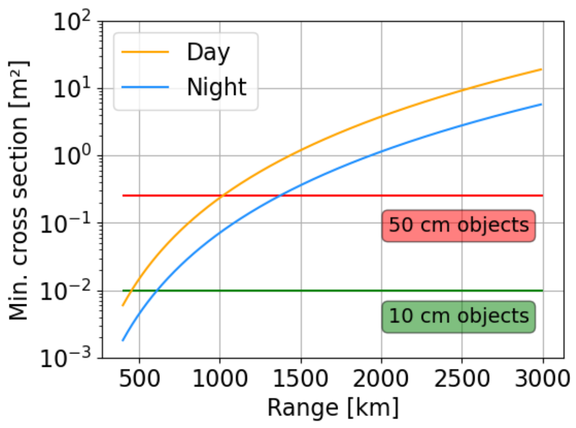
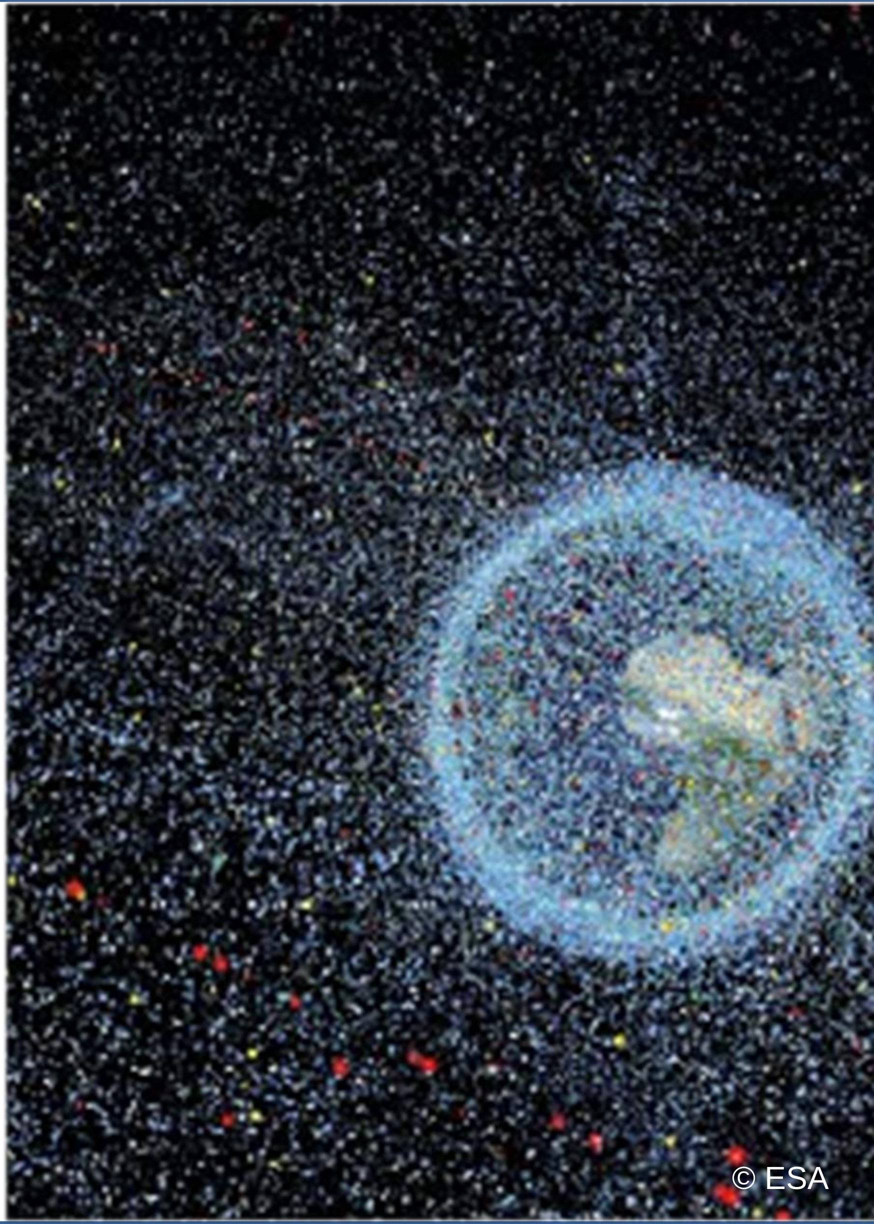
Recent IZN-1 Upgrade Contract: Space Debris Laser Ranging

DiGOS

- Context: Space Situational Awareness
- Collision avoidance is a first step to mitigate crashes in space
- Using SLR technology to measure orbit of space debris to increase knowledge about potential collision with satellites
- IZN-1 Upgrade contract running
- “Split configuration”
- Challenges & limits:
  - Reliable day & night operation
  - Technology not yet mature
  - Does not allow “scanning of the sky” (à priori information required)
  - Uncooperative targets: Distinguish between debris & “unknown” targets
  - Object size from rocket bodies & upper stages to CubeSATs





Summary

- A challenging project last not least through the CoVID situation
  - Long storage
  - Long offset from FAT to installation and final acceptance
  - Also offset from FAT to SAT was a „burdon“ for the team (details/specifics during installation)
- Team spirit and results in general positive
  - It was the first time of this team composition
  - It was the first turn key project for DiGOS for SLR

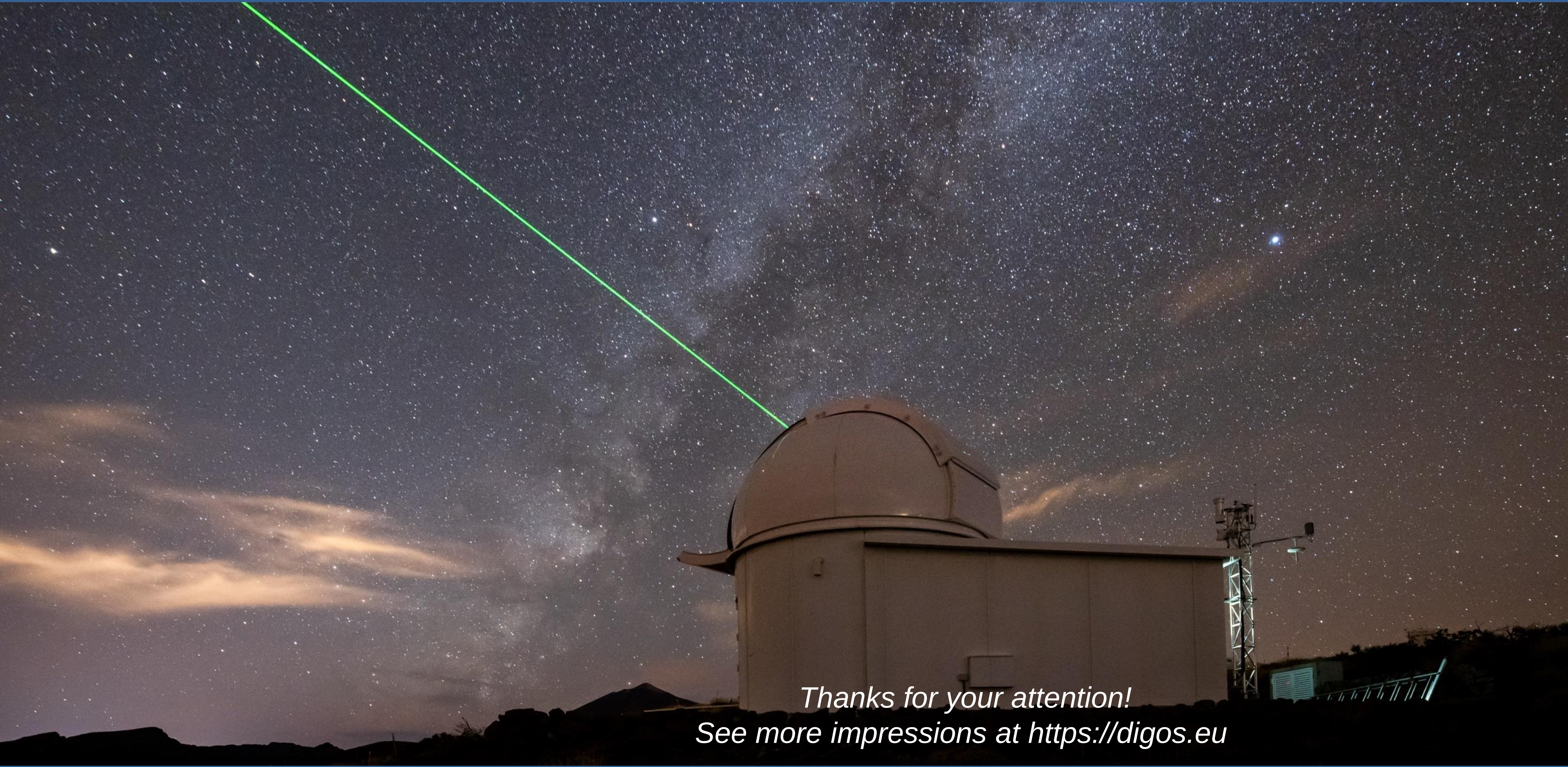
- ELRS is performing well and is ILRS registered/accepted „IZN-1“ (quality standards)
  - It is modern, flexible and capable station
  - Well suited for future „challenges“

- Remote operation (from any internet accesible location) works well
  - On site support for emergency situations very important for situations as
    - Power outage and recovery
    - Lightning „recovery“

- Shared operation scheme evolved over time
  - DiGOS operate the station for ESA (since August 2022)

Some Remarks

- DIGOS is
  - proud (and relieved) having achieved SAT/FA for ELRS
- **DiGOS is gratefull for having had the chance to build and deliver ELRS to ESA**
  - Was strongly in support of the position DiGOS has now in the SLR community
- JAXA is having (soon) a „sibbling“ type station. SAT currently under preparation.
- SLR and laser ranging in general is a dynamic environment
  - Trend to higher repetition rates
  - Trend to combined SLR and Debris station
- As a major lessons learned a configuration change to a „split configuration“, separating Rx and Tx side is followed
  - Basis of the GLRS (G2G) testbed contract
  - Allowing accomodation of additional powerfull debris lasers , in addition to SLR
  - Allowing MHz lasers for SLR without interleaved operation
  - Allowing transportable station solutions by keeping dome sizes more compact



Thanks for your attention!

See more impressions at https://digos.eu

Backup

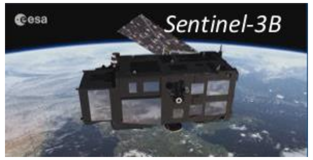
- Backup slides

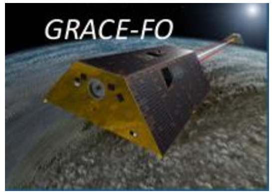
Laser Ranging Satellites

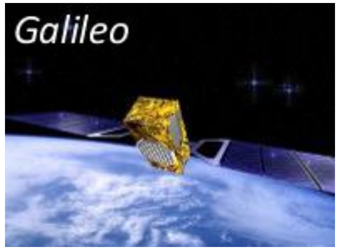
- 100+ satellites routinely tracked by SLR stations worldwide

- New & approved missions
  - S-NET (4 cubesats/testing inter-satellite communication)
  - Sentinel-3B (altimeter mission/restricted tracking)
  - GRACE-FO (2 satellites/gravity measurements)
  - Tiangong-2 (Chinese spacecraft)
  - Beidou-3M (4 GNSS satellites)
  - PAZ (SAR mission)
  - ICESat-2 (laser altimetry mission/restricted tracking)
  - Astrocast Precursor (2 cubesats/engineering testing)
  - GNSS (Galileo, IRNSS, BeiDou/Compass, etc.)
  - Constellations, etc.

→ ***Cooperative Targets***



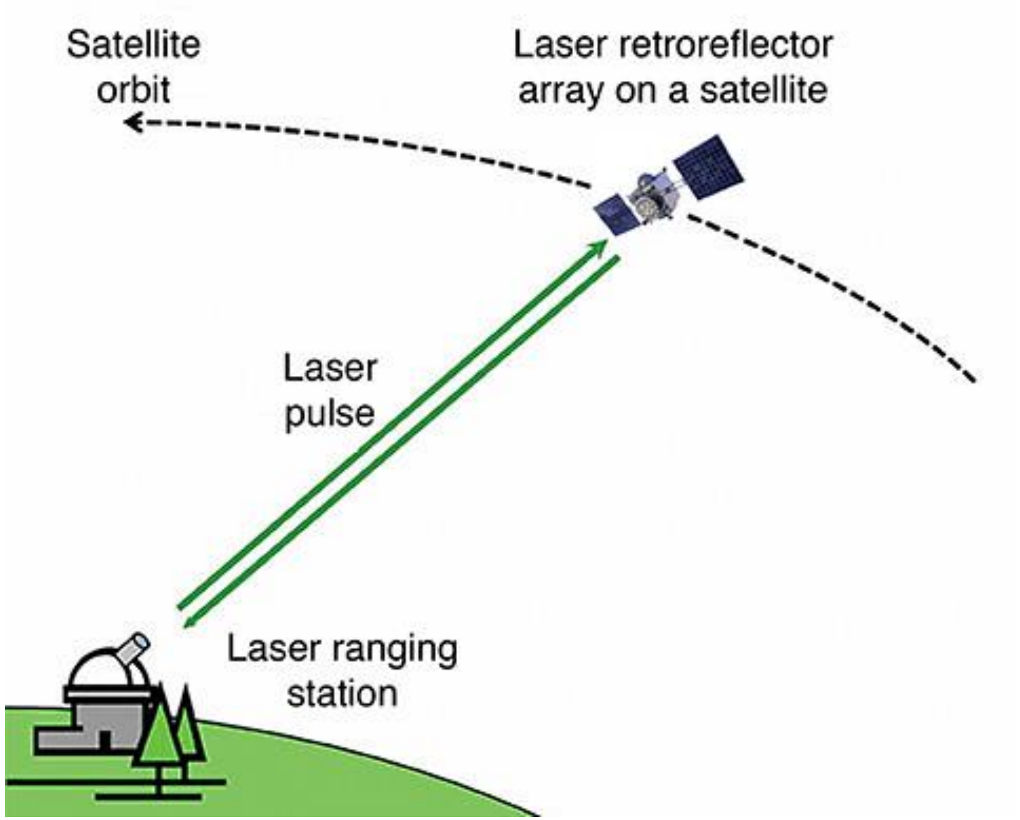




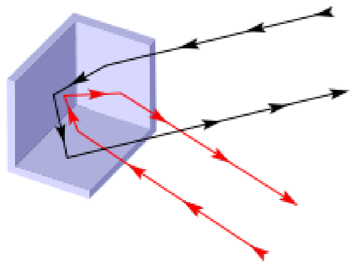
Satellite Laser Ranging

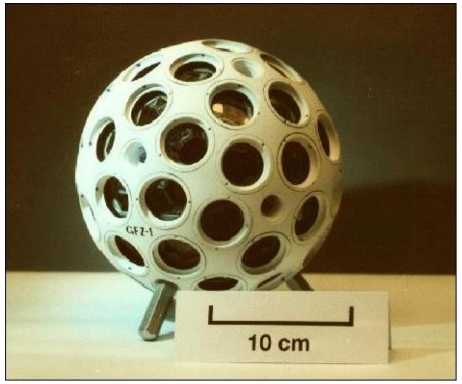
The precise measurement of the roundtrip time-of-flight of an ultra-short laser pulse between an SLR ground station and a retroreflector-equipped satellite which is then corrected for atmospheric refraction using ground-based meteorological sensors

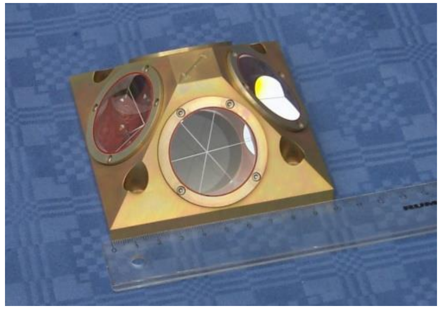
- Unambiguous time-of-flight measurement
- 1 to 2 mm normal point precision
- Passive space segment
- Simple refraction model
- Night / Day Operation
- Near real-time global data availability
- Satellite altitudes from 400 km to 36,000 km and the Moon
- Centimeter to millimeter accuracy satellite orbits

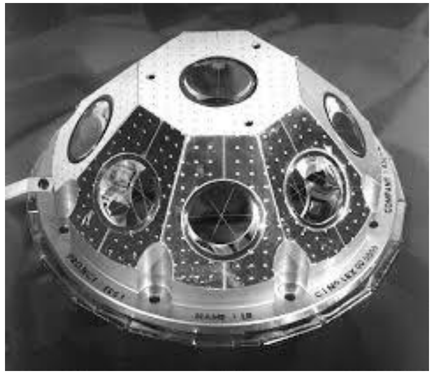


Laser Ranging Satellites









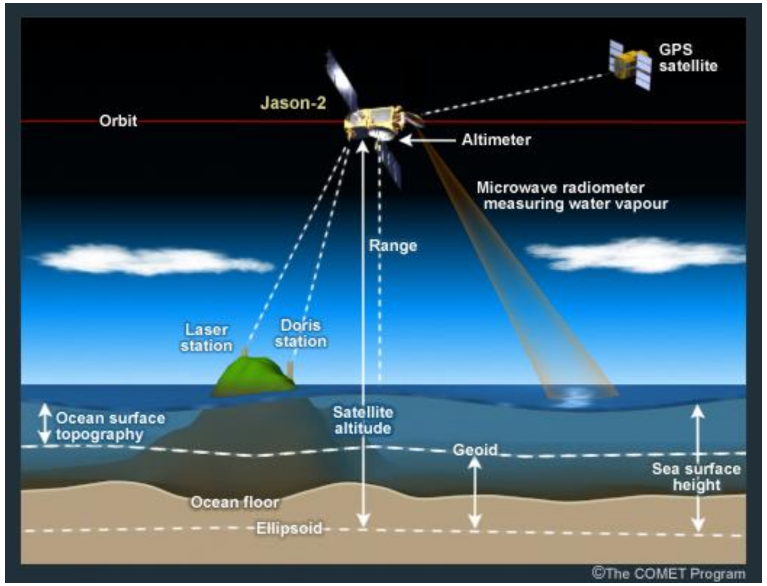
- Different retroreflector designs are in use
  - Mostly corner cubes, hollow reflector designs under consideration
  - Cannon ball satellites as passive geodetic targets
  - Pyramid shaped LRR for LEO (e.g. GRACE, Swarm, PAZ, TandemX, …)
  - Single retroreflectors for Cube Satellites
  - Larger arrays of different shapes for GNSS / GEO / Luna

Uses of SLR data

- Main application
  - SLR and LLR are one of the fundamental technologies of geodesy besides GNSS, VLBI, Doris and gravimetry

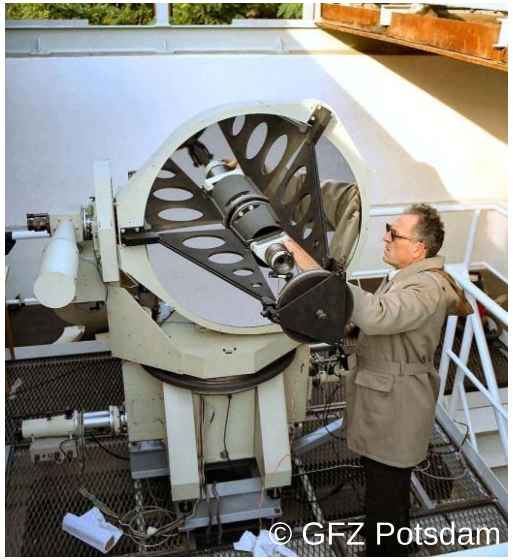
- Main scientific contributions
  - Monitoring of Earth rotation parameters (polar motion and length of day)
  - Monitoring of 3-dimensional deformations of the solid Earth (station coordinates and velocities), time-varying geo-center coordinates
  - Static and time-varying coefficients of the Earth’s gravity field
  - Calibration / validation of microwave instruments onboard of satellites (altimeter, GNSS orbits)

- New applications
  - Space debris tracking
  - Optical Direct-To-Earth communication / Laser Comm
  - Quantum Key Distribution
  - Time transfer



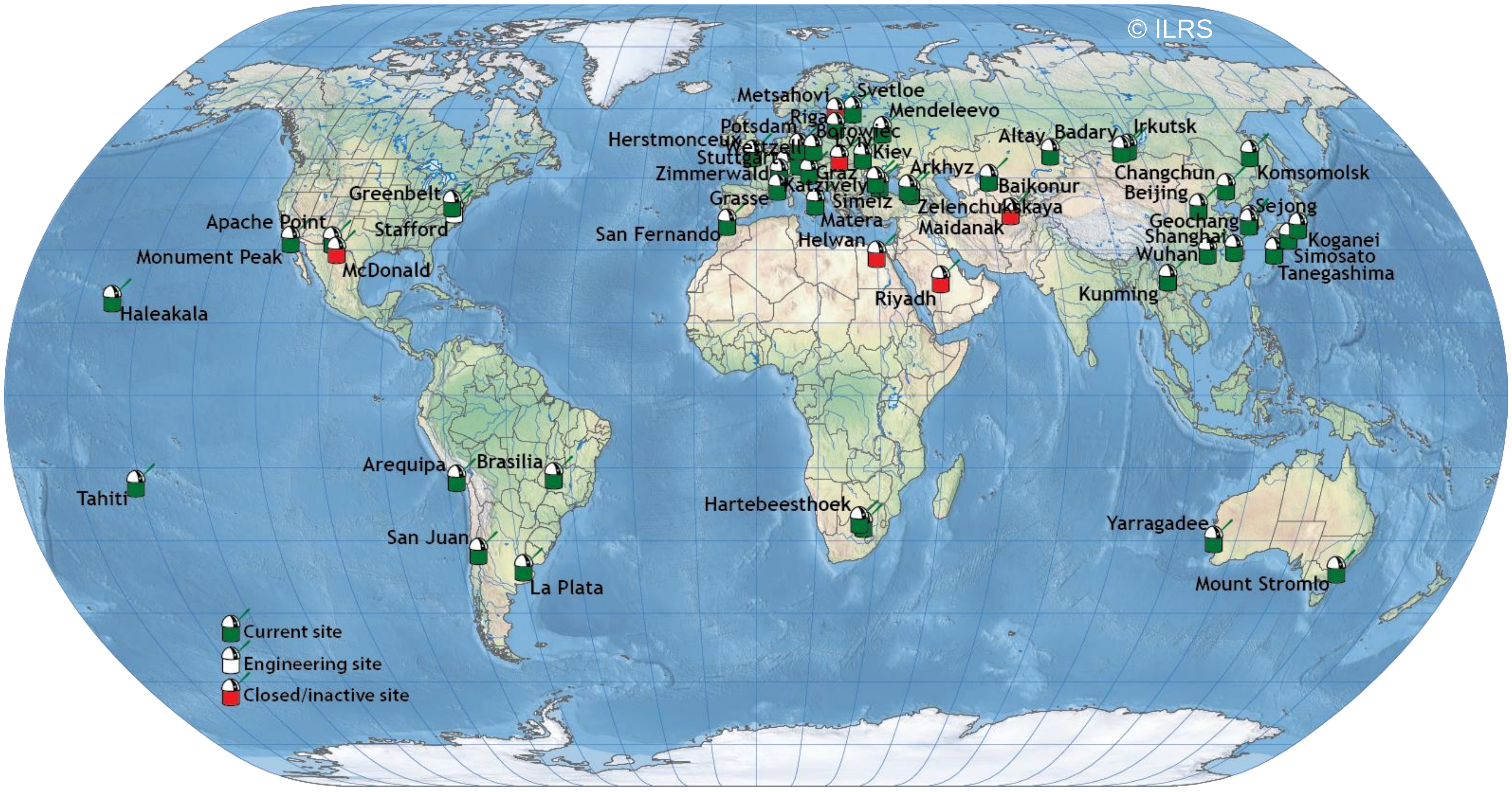
Laser Ranging Technology

- First Generation
  - Mostly Ruby laser with repetition rates of ≤1Hz
  - Pulse length 10-40 ns
  - Tracking satellites up to 6000km (LAGEOS)
  - Accuracy 1-2 meters
- Second Generation
  - Ruby lasers and frequency-doubled Nd:YAG
  - Pulse length 2-5 ns
  - Tracking satellites up to 19000km (ETALON)
  - Accuracy several decimeter
- Third Generation
  - Mostly frequency-doubled Nd:YAG laser
  - Repetition rates of 5-10Hz
  - Pulse length 35-400ps
  - Energy 20-100mJ per pulse
  - Tracking satellites in very low orbits (GFZ-1)
  - Accuracy of about 1cm
- Forth Generation
  - Mostly frequency-doubled Nd:YAG laser
  - Repetition rates of 1-2kHz
  - Pulse length of 5-30ps with <1mJ energy per pulse
  - SPAD or C-SPAD detectors
  - Accuracy 1-2 mm (per normal point)



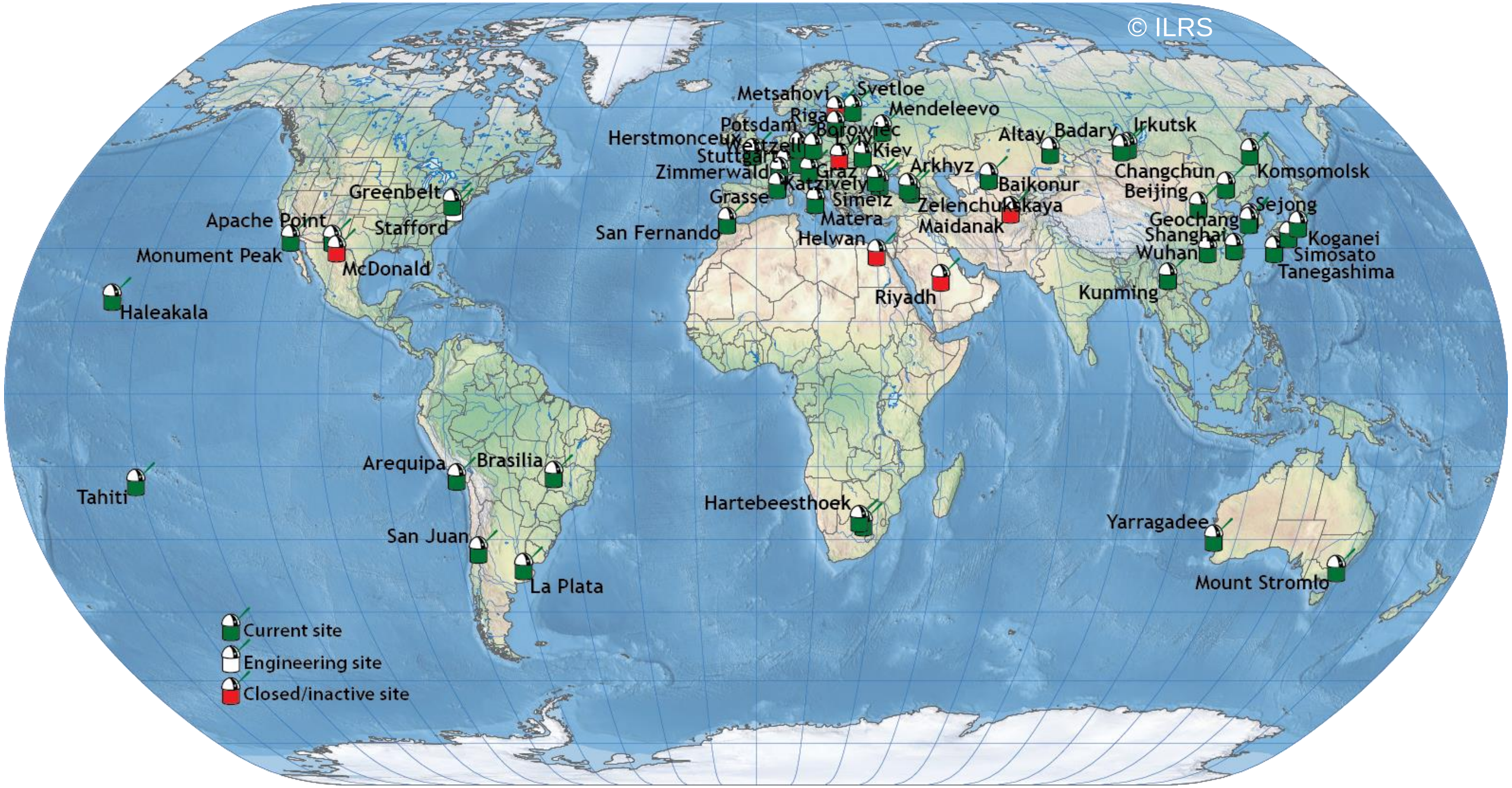
ILRS Station Network

DiGOS



- Stations were built by different institutes at different times using different technologies
- Mix of new and old technologies within stations due to updates
- Average age of stations >20 years

ILRS Station Network



- Many geographic gaps, primarily in Latin America, Africa, Oceania, Antarctica
- Several new stations planed or already under construction
- Some of the oldest stations will be replaced in the next years