Instituto Geográfico Nacional
CENTRO NACIONAL DE INFORMACIÓN GEOGRÁFICA

YLARA

Yebes Laser Ranging Station (YLARA)

Development status 2022

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Yebes Observatory, IGN-CNIG

22nd IWLR 09-11-2022

YEBES

GOBIERNO DE ESPAÑA · MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA · INSTITUTO GEOGRÁFICO NACIONAL

EUROPEAN UNION
European Regional Development Fund
"A way to build Europe"

Infraestructuras Científicas y Técnicas Singulares

The beginning of the project: Yebes Observatory few years ago

Madrid (80 km)

Main building, laboratories and workshops

Meteo sensors

14 m RT

Gravimetry

Astrograph (2x40 cm)

Outreach pavilion

GNSS Receivers (x2)

Local tie (20 pillars)

40 m Radio Telescope + Hydrogen masers room

Anechoic Chamber

Solar Tower

13.2 m VGOS Radio Telescope (2013) RAEGE Project

ICTS - ERDF

- **Yebes Observatory is one of the Singular Scientific and Technological Infrastructures (ICTS)** in Spain, and the only one in the Castilla-La Mancha Region
- The ICTS are facilities, resources, equipment and services, unique in their kind, and dedicated to cutting edge high quality research and development, to promote transfer, exchange and preservation of knowledge, technology and innovation

EUROPEAN UNION
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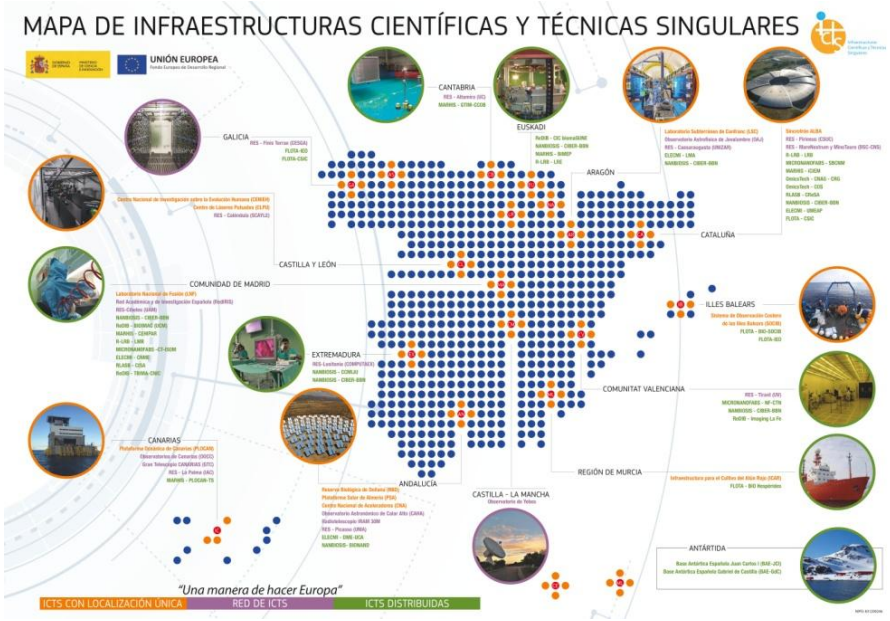
Infraestructuras Científicas y Técnicas Singulares



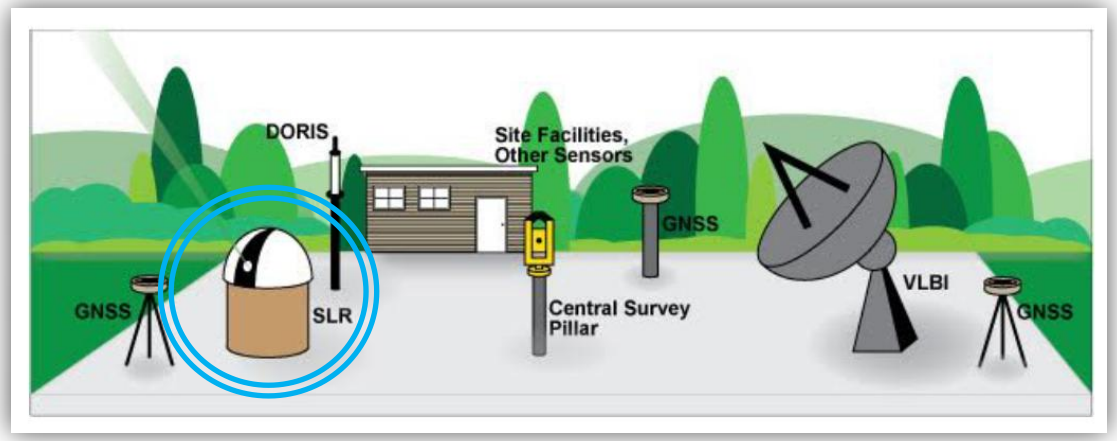
- **ERDF, Operational Programme Smart Growth 2014-2020 - Ministry of Science, Innovation and Universities (MINCIU) of Spain** (FICTS1420-11-12)
- Co-financing the **Operation:** Development Infrastructures and Laboratory Activities for Space Geodesy at Yebes Observatory, **YDALGO**
- Through the CNIG (National Center for Geographic Information), autonomous agency attached to the IGN (National Geographic Institute)

YDALGO Operation

Development Infrastructures and Laboratory Activities for Space Geodesy at Yebes Observatory

Two objectives:

- Improvements in infrastructures and equipment for mechanical workshops and laboratories (electronics, microwaves and cryogenics)
- The expansion of the instrumentation for space geodesy by means of the construction and operational setting up of a **satellite laser ranging station (SLR)** with the characteristics and capabilities required for its integration in the international network of SLR stations, turning Yebes into a **Geodetic Fundamental Station**

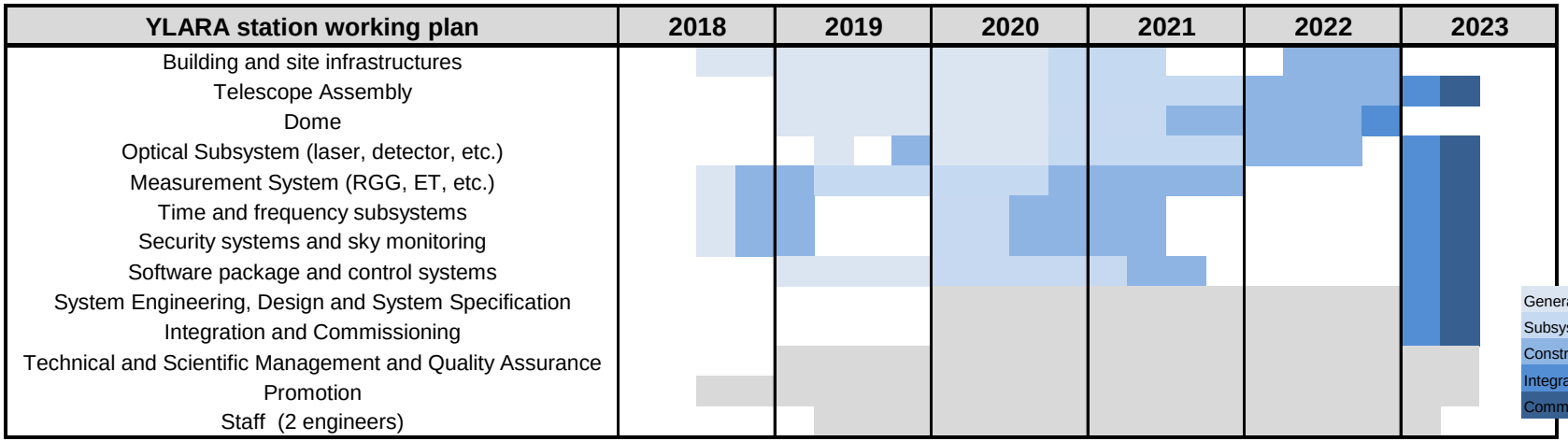


General requirements

- Observations to satellites equipped with retro-reflectors (mainly geodetic satellites and GNSS)
- Fulfilling the requirements of the GGOS project and contributing to the ILRS network
- Modular and flexible design: flexibility for future upgrades or new applications implementation and easy maintenance

YLARA Project: Development plan

- Initial works to apply for the ERDF started in 2016, studying the status of the SLR technique around the world to define the main characteristics and goals of our station + Yebes staff training about the SLR technique and market study
- In January 2018, ERDF for the YDALGO operation were approved
- General specifications establishment and initial subsystems acquisition during 2018 and 2019. Location selection
- Year 2020: turnkey system solution led by the company TTI (Spain) supported by DiGOS (Germany). Contract for the construction, installation, integration and commissioning of the complete station. Site infrastructure provided by Yebes
- Main subsystems installation at Yebes: from October 2022 to May 2023 ⇨ station Commissioning: June - July 2023

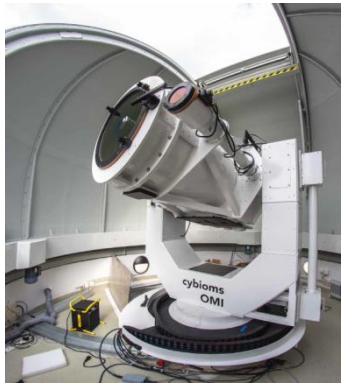


YLARA Project Requirements

Technical requirements

- Biaxial system with different configurations for transmitting the laser pulses: **Piggy-back or Coudé focus**
  - Receiving telescope, main mirror diameter between > 70 cm, min. 2 switchable Nasmyth foci, blind pointing accuracy < 5” RMS
  - Transmitting telescope 5 - 10 cm aligned with the receiving telescope, with an adjustable beam divergence
  - Az/El mount, Azimuth slew rate > 12°/s, Elevation slew rate > 5°/s
- Laser for SLR: installed in piggy-back configuration, > 1 kHz, < 10 ps, > 250 mW @ 532 nm

SP-DART CONCEPT
Tracking up to Geostationary Satellite with 15 uJ Laser and 70 cm Astronomy Telescope. P. Wang, et al, 2016

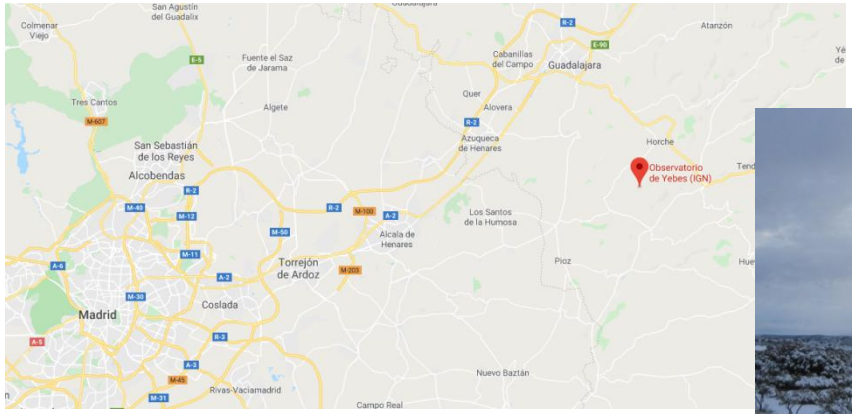


Metsähovi kHz SLR system
Bistatic telescope 50/10 cm
Classical Design
Näränen & Raja-Halli, FGI-2016

- Detector package: attached to the Nasmyth focus, CSPAD (532 nm), IR-SPAD (1064 nm)
- Other subsystems: Slit-type dome > 5 m, H-maser, GNSS timing receiver, meteo sensors, calibration system, RGG and Eventimer
- Station protection and safety subsystems: all-sky camera, ADS-B and FLARM systems, Mobotix cameras, etc.
- Station control and monitoring: flexible design, semi-autonomous operation

Yebes Observatory: Site Characteristics

- **Yebes Observatory**, Guadalajara
  - 3.08° W / 40.52° N, 915 m height
  - Good sky visibility
    - ~ 50 % days extremely clear, **no clouds**
      ⇨ excellent visibility
    - ~ 22 % days no observations, totally cloudy
  - Humidity ≤ 70%
  - Temperature range < 20°C (night-day)
  - Snow: 3-5 days per year
  - Wind information (2014-2019)
    - Mean of average speed 1.6 m/s = 5.8 Km/h
    - Mean of max. speed 8.9 m/s = 32 Km/h
    - Max. Speed: 28.5 m/s = 102,6 Km/h
    - Predominant Direction: SW
  - Seismic acceleration
    - 0.04 g horizontal
    - 0.04 g vertical



Yebes Observatory location (60 km from Madrid, NE)

YLARA station location

Location characteristics

- Near the main road ⇨ easy access
- Near offices and laboratories buildings
- Local tie integration
  - Invariant point: AZ/EL intersection
  - Unobstructed view from at least 3 pillars
  - Network extrapolation < 1 mm

YLARA: Site Infrastructure

Building construction evolution from May to November 2022

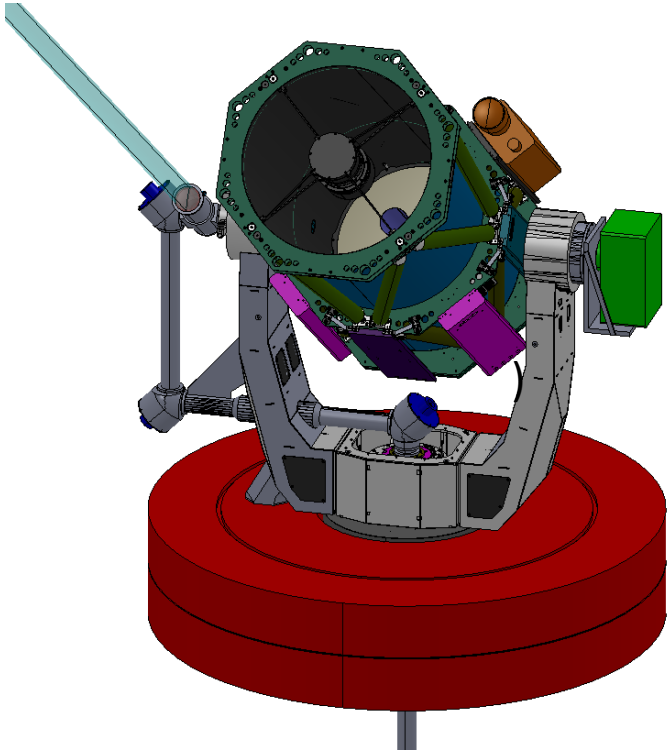





- **Dimensions:** 110 m^2
- **Distribution**
  - Ground floor: Control room, Coudé/laser room, dome access, AC/electrical power supply room and warehouse space
  - First floor: roof and dome area
  - Independent concrete pillar, anchored to bedrock
  - Access to the roof from outside

Coudé/laser Room

Telescope Assembly



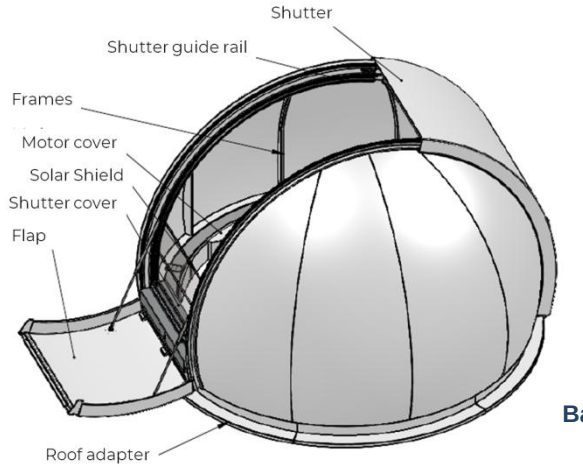
Telescope Assembly Overview

https://www.officinastellare.com/news-space/satellite-laser-ranging-slr-station-for-the-yebes-observatory-spain/

Customized RC700 model by Officina Stellare (OS)

- M1 diameter 700 mm, central obstruction diameter 290 mm
- 3 Nasmyth foci
- Operation rotation range on azimuth: -270º / +270º
- Operation rotation range on elevation: 90º, from horizon to zenith
- Atl-Azimuthal Mount. Slew rate: 12°/s for Az and El
- Total mass (mount + Rx telescope) ≈ 1500 kg
- Transmission path: composed by the Coudé path and the beam expander
  - Coudé path represents the mirror assemblies from CM1 to CM5
    - Coudé mirrors: D = 45,7 mm (useful mirrors diameter)
  - BEX represents the assembly that include the BEX eyepiece, BL3, the closing optical window and the flip mirror
  - Every component of the laser transmission path is provided with several sealing devices to guarantee the proper sealing

Dome subsystem



Baader 5.3 m dome major elements

Model	Slit Type 5,3 m
Structure	Fiberglass Reinforced Polyester + Steel ring adapter
Dome aperture	Horizontal lower flap and shutter
Aperture size	165 cm
Control	SW, remote control, manually closing
Operation	24/7
Azimuth max. rotation	24º/s
Station protection	Autonomous emergency weather station
Extra	Solar shield, UPS, dehumidifier
Temperature range	From -20 to 50ºC
Wind speed up to	250 km/h dome closed

Dome installation last October 27th, 2022

Time and frequency subsystem

H-Maser, iMaser 3000, T4 Science SA

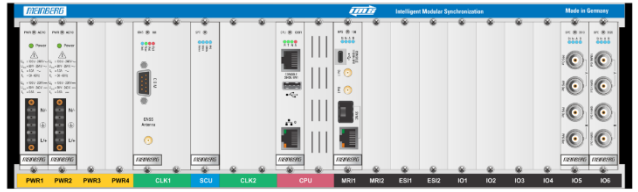
- Available at the Observatory for the RT observations
- Short Term Stability: 6 e-14 at 1 s
- Long term drift: 2 e-16 / day
- Accuracy of PPS < ± 50 ns
- The following output frequencies are available:
  - 2x 5 MHz output frequency (N type)
  - 2x 10 MHz output frequency (N type)
  - 4x 100 MHz output frequency (N type)…

H-maser, iMaser 3000, T4 Science

40 dB GPS L1/GLONASSL1/GALILEO E1 Timing Antenna

Lantime M3000 (Meinberg) + Timing Antenna

- Modular Synchronization platform
- Short Term Stability: 1 e-12 at 1 s
- Accuracy of PPS < ± 50 ns



Slot	Type	Module	Description
#1	PWR1	PWD-AD10	Power Supply 230 VAC
#2	PWR2	PWD-AD10	Power Supply 230 VAC
#5	CLK1	GNS-DHQ	GPS/GLONASS/Galileo/BeiDou Clock DHQ Timebase
#7	SCU	SPT	Standard Signal Distribution Unit
#10	CPU	CPU-C05F1	LANTIME Processor Unit
#12	MRI1	HPS100	PTP / SyncE / hardware NTP Interface
#20	IO5	BPE-2014	Fixed Outputs – 2x PPS, 2x 10 MHz / BNC Connectors
#21	IO6	BPE-2014	Fixed Outputs – 2x PPS, 2x 10 MHz / BNC Connectors

Lantime M3000 front and system setup

Meteorological subsystems and Station protection

Meteo and cloud sensors

Sensor/Parameter	Description	
Temperature and humidity sensors	Accuracy	Range
	±0.1°C	-40 - +120 C
	±0.8 % RH	0-100 % RH
Pressure sensor	±0.15 hPa	500 - 1100 hPa
Wind speed sensor	±3 % at 10 m/s	0 ... 60 m/s
Cloud sensor	Boltwood, Cloud sensor II	
Utility mast	8 m height	

Station Protection Unit, SPU

- Responsible to protect the station from potential damage caused by unsuitable or severe weather situations, formation of condensation water, ground accelerations and power outages
  - Seismic sensor
  - Rain sensor ON/OFF
  - Temperature and humidity sensors installed in the dome area outside
  - Indoor temperature and humidity sensors for monitoring the dome area (inside) and the Coudé room
  - E-stop buttons located at prominent locations
  - Cameras for remotely monitoring

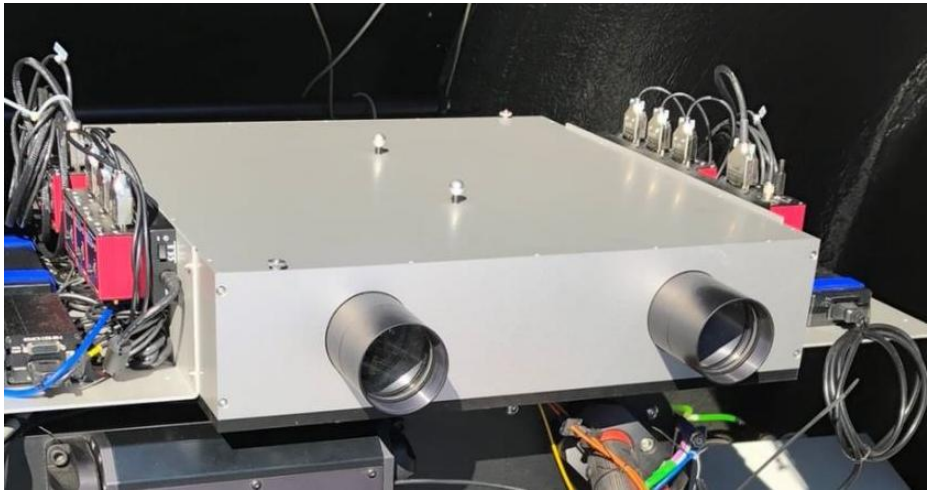
SPU front panel view, developed by DIGOS

Laser package

Laser package characteristics

- Mounted directly on top of the main mirror cell
- Laser Optics Package includes the laser head unit and the transmit optics for both 532 and 1064 nm λ and the start pulse detector
- Laser Support Electronics includes the pumping unit for the laser head, which will be placed on the back of the main mirror cell
- Two Laser Optics Electronic Boxes include all the electronics, such as the control units for the opto-mechanical elements of the Laser Optic Package

Paremeter	Description
Laser type	Nd:YAG
Pulse Repetition rate	1000 Hz
Energy per pulse	355 µJ avg @ 532 nm / 543 µJ avg @ 1064 nm
Pulse width	7 ps @ 532 nm / 8.5 ps @ 1064 nm
Beam Divergence	0.6 mrad (full angle)
Beam profile	Close to TEM00 mode
Beam diameter	< 1 mm



Passat laser system package

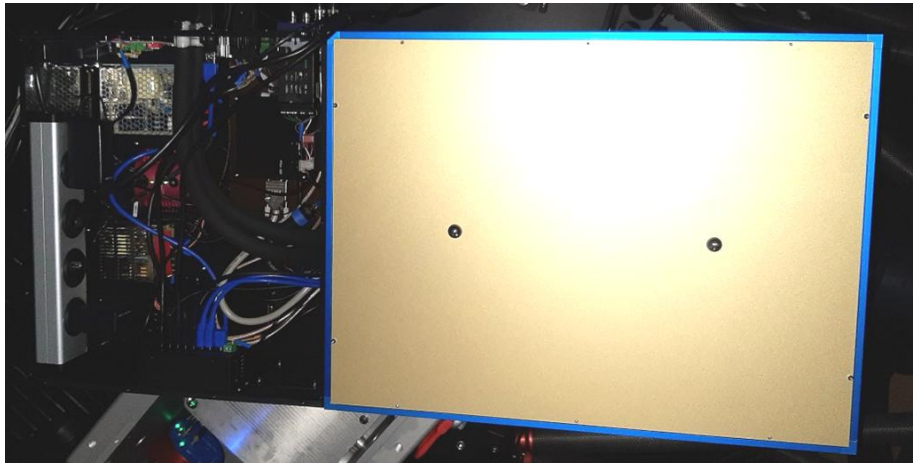
Laser Optics Package including with Laser Optics Electronic Boxes attached
Subsystem designed and integrated by (IWF) Graz

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN
IWF INSTITUT FÜR WELTRAUMFORSCHUNG

Detector package

Detector	λ	Diameter	QE @ λ
C-SPAD	532 nm	200 µm	> 40 %
Note: Same SPAD is used at IWF Graz including thermal stabilization, time walk compensation etc.			
IR-SPAD	1064 nm	80 µm	max 30 %
Note: InGaAsP SPAD			

Detector package, top view of the integrated package
Subsystem designed and integrated by (IWF) Graz



Detector package characteristics

- Single photon detection capability for satellite laser ranging
- Directly mounted on the first Nasmyth focus
- The following items are assembled within the optical package:
  - 532 nm C-SPAD + narrow band pass filter
  - 1064 nm IR-SPAD + narrow band pass filter
  - 3 cameras: beam direction, satellite observation and mount model creation
  - Preparation of optical path and interfaces for light curve detector
  - Mechanical elements (mounts, iris, shutters)
  - Thermal control elements (cooling tubes, heat exchangers)
- The electrical package contains:
  - Power supplies and electronics for all detectors and optical elements such as the iris and shutter
  - Additional electronics including a thermostat for thermal control

RGG and Event Timer

Model	Range Gate RG2 - Digos
Width	5 - 5000 ns
Pulse generation resolution	5 ns
Gating accuracy	≤ 5 ns
Clock & Synchronization	1PPS for time synchronization 10MHz for clock signal
Control SW	Commanded from the SLR station SW
Support capacity	2 laser trigger and 4 gate outputs
Back-scatter avoidance	Included

DIGOS, Range Gate RG2, frontal side

A033-ET/USB front (19" rack version)

A033-ET/USB back

Riga A033-ET/USB

- Resolution 3 - 4 ps, precision ≈ 5 ps
- Dead time 50 ns
- Internal clock: 100 MHz, locked to 10 MHz external reference frequency
- Interface: USB2, TCP/IP protocol

Laser safety subsystems

ADS-B Receiver

- Antenna specifications: omnidirectional, frequency: 1090 MHz, peak gain: 5.5 dBi
- GPS antenna
- Position every 0.5 seconds

Flarm receiver

- Antenna specifications: omni-directional, frequency: 868 MHz
- Also incorporate an ADS-B and transponder receiver
- GPS antenna

Outdoor installation: general view

Outdoor installation: All sky camera

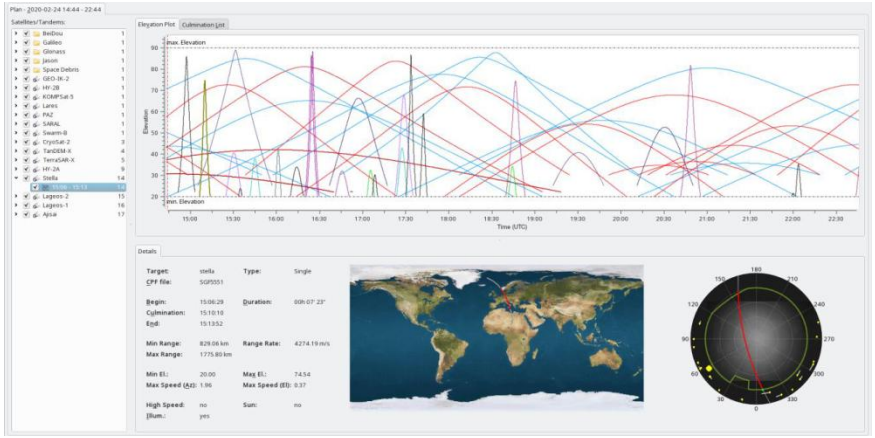
All sky camera

- Fisheye circle “illuminated” 8.8 Million pixels
- Detector resolution 4600x3520 pixels
- FoV: 180°x180°
- Pixel scale 2.9 arcmin/pix
- Daylight imaging

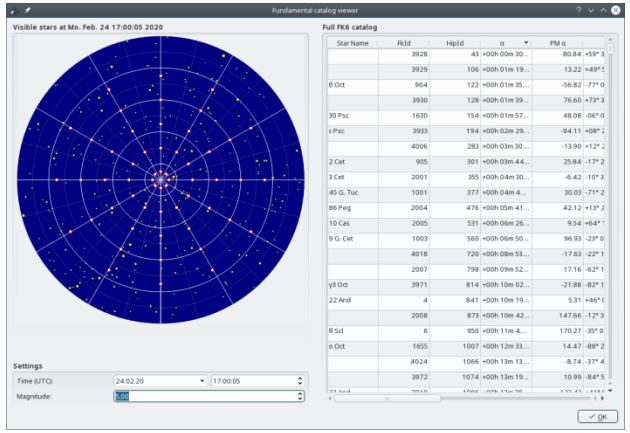
All sky camera: night images

Station Control and Software Subsystem

- **SCOPE**
  - Originally developed in 2012 by DiGOS
  - Installed in: Potsdam, Metsähovi, ESA and JAXA SLR stations
  - Modern, easy to use SLR control system that includes many pre-automated assistance systems
  - Main Characteristics
    - Command and control of all station hardware and safety components in real-time.
    - Ability to support a wide range of hardware types and configurations: telescope, laser, RGG, detectors, dome, meteorological station, security systems, station protection subsystems, time and frequency systems, calibration...)
    - Intuitive user interface to monitor and perform all SLR operations
    - Possibility of introducing easily new modules and functionalities
    - Semi-autonomous operation of SLR system: track scheduling generation (automatically), prediction centers selection, data filtering, Normal point generation, adapted to the format required by the ILRS, reporting generation and transmission to data centers, archival and storage, etc.
    - Include simulation tool for software verification, troubleshooting and training



Screenshot visible passes for 8 hours



Telescope Mount Calibration, Screenshot of FK6 viewer with red dots marking the center of each sector

New and future applications of the YLARA Station

Space Debris Observations

- Important application of the current policy of the European Union (EU) and the European Space Agency (ESA)
- IGN will contribute to SST activities (Space Surveillance and Tracking), as requested from Spanish administration
- For several years, several SLR stations are carrying out space debris observations (monostatic / bistatic observations)
- Recent acquisition of a laser system for SD observations
- Installation in the Coudé room

Other applications

- The YLARA design also have to take into account future observations, tests, experiments, etc., of interest for Yebes Observatory internal projects
- Under study the advantages and drawbacks
- Laser communications, time transfer, light curve, etc.

Innolas SpitLight EVO II/III Models

Model	SpliLight EVO II
Repetition rate	200 Hz
Pulse Energy	> 350 mJ @ 1064 nm > 200 mJ @ 532 nm
Beam diameter	7 mm
Divergence	< 0,5 mrad full angle
Pulse duration	5 - 8 nm

THANK YOU!