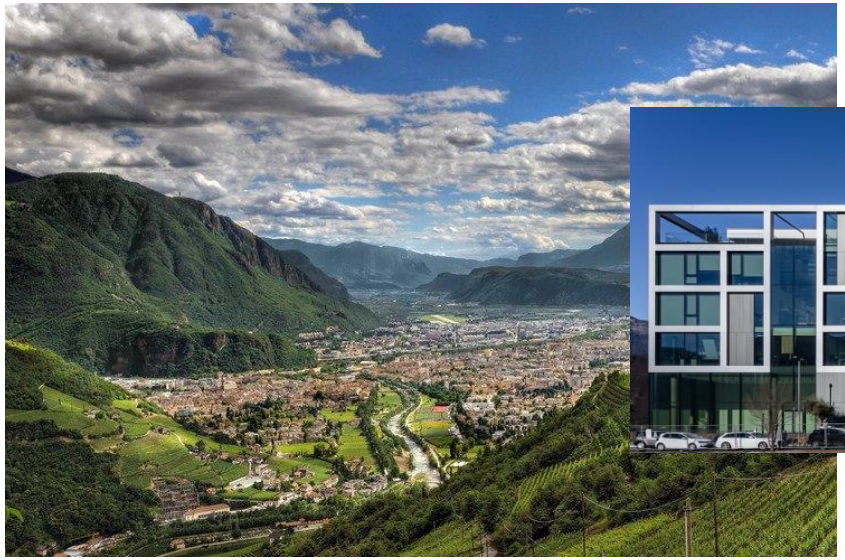
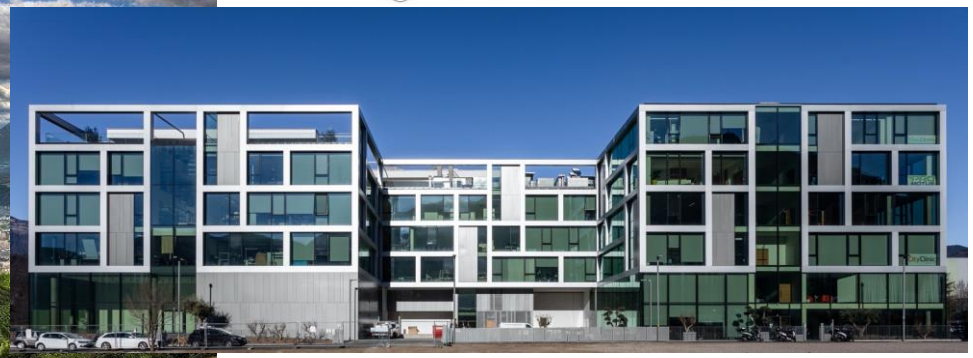
Leading the way in photon-counting technology and applications

2024-06-20 - ILRS Networks & Engineering SC meeting

Micro Photon Devices



AUTONOME PROVINZ BOZEN SÜDTIROL
PROVINCIA AUTONOMA DI BOLZANO ALTO ADIGE



- Founded in 2004
- Located in Bolzano (Italy)
- R&D office near Milano (Italy)
- Mission: to be the leader in single photon counting technology

Facts and figures

- Annual Turnover: **> 2 M€**
- Average Annual Growth : **13%** over the last 7 years
- Export: **93%** of production
- Employees: **8 full time**, up to 60 including parent company *Microgate s.r.l.*
- **Solid reputation** of high performance, reliable and robust products
- We make **OUR OWN SILICON** even if we are **fabless** (strong collaboration with Silicon -R&D and CMOS- and InGaAs/InP foundries)

Our markets

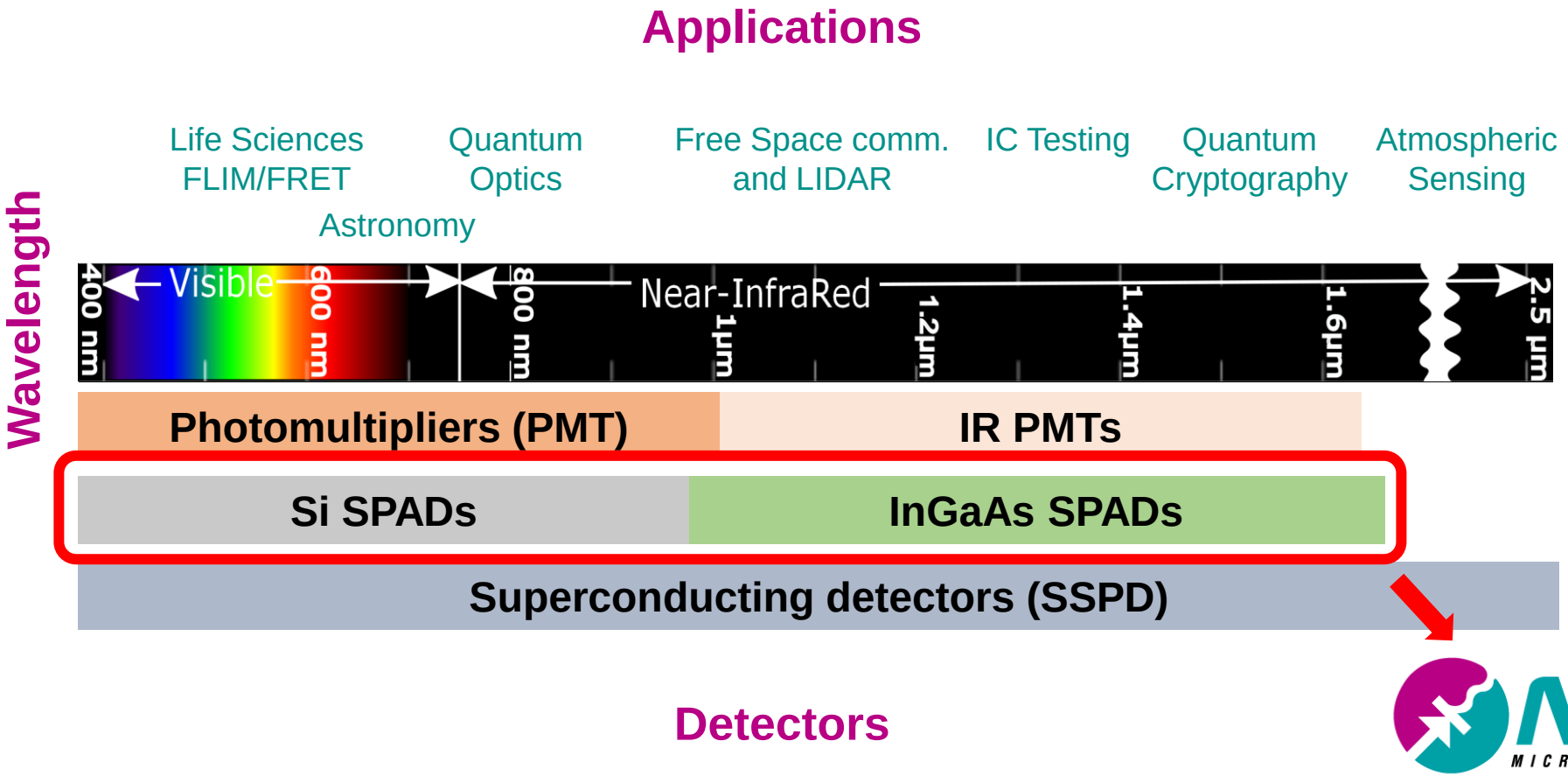
Universities

R&D Facilities

OEMs

- **Biomedical**
  - DNA and Drug discovery
  - Confocal Microscopy
  - Fluorescence Lifetime Measurements
  - Fluorescence Correlation Spectroscopy
  - Time Resolved Spectroscopy
  - Light Tomography
  - Single Molecule Spectroscopy
- **Industrial**
  - Particle Sizing
  - Metrology by Time-of-Flight Measurements
  - LIDAR - LADAR
- **Quantum Cryptography**
- **Astronomy**
  - Adaptive Optics
- **Custom Applications**

Single-photon detectors & applications



Single-pixel detectors

Photon Detection Module (PDM)

- LOW dark counting rates: down to **1 c/s**
- 20 µm, 50 µm and 100 µm active area diameter
- Ultrafast timing resolution (typ. **35 ps** FWHM)
- High quantum efficiency (up to **49% @ 550nm**)
- Robust, reliable and low power consumption

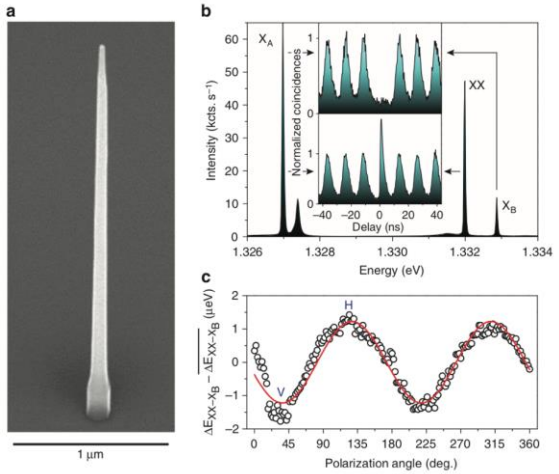
PDM

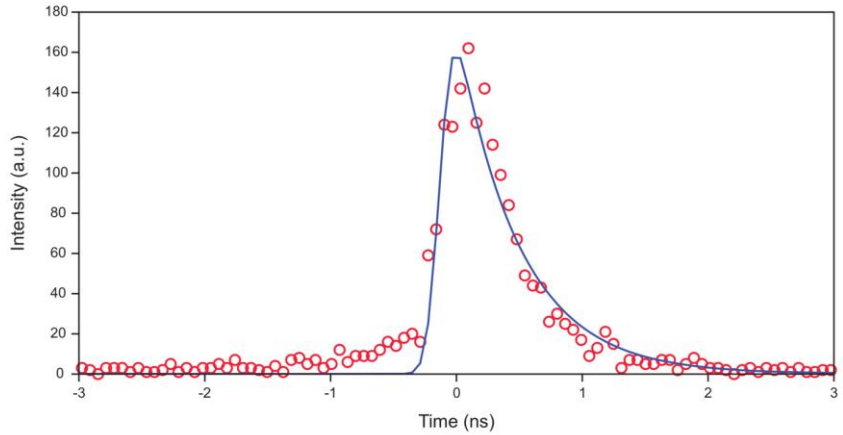
PDM-FC

- HIGH Coupling Efficiency (> 80%)
- FC/PC fiber receptacle
- SM Fiber Coupling with 20 µm SPAD
- MM Fiber Coupling with 50 µm and 100 µm SPAD
- Extremely reliable assembly

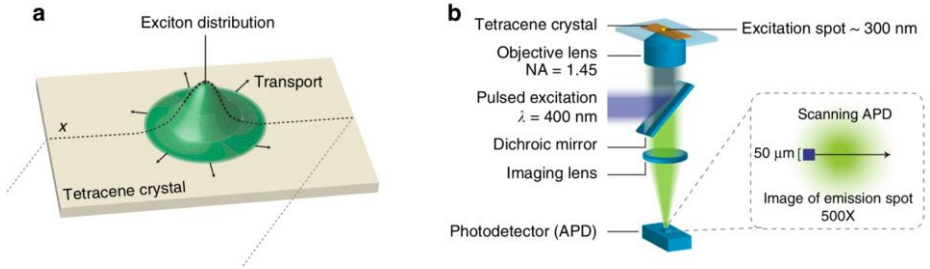
PDM application: fast lifetime measurement

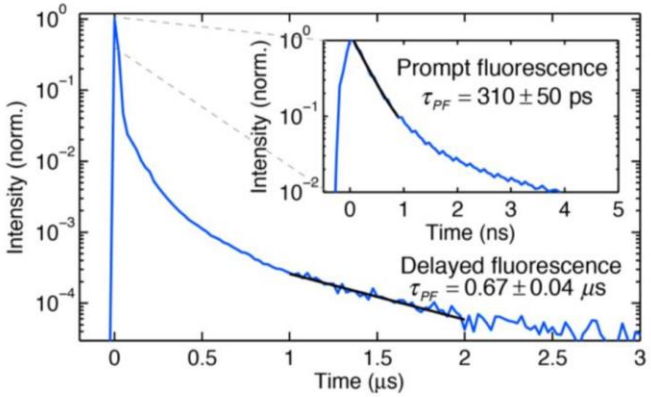
M. A. M. Versteegh, et al. “Observation of Strongly Entangled Photon Pairs from a Nanowire Quantum Dot.” *Nature Communications* 5, no. 1 (December 2014).





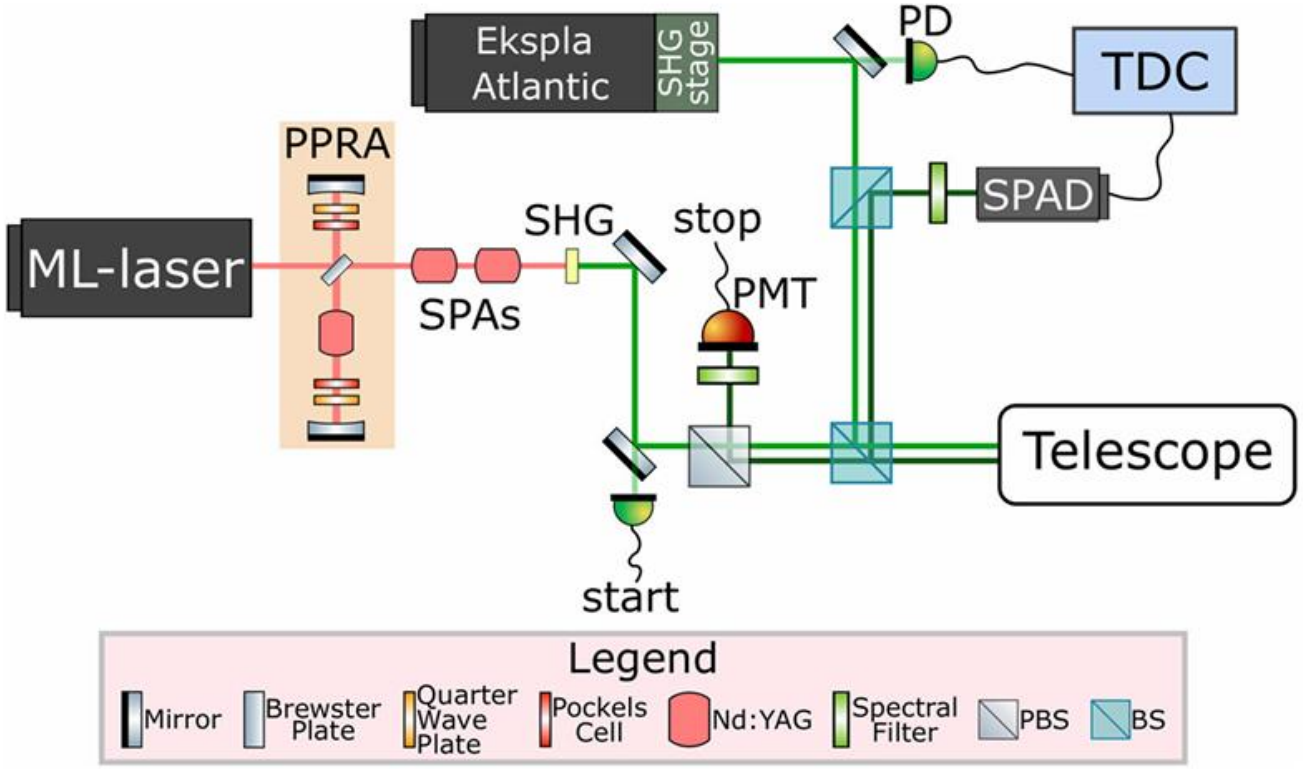
G.M. Akselrod, et al. “Visualization of Exciton Transport in Ordered and Disordered Molecular Solids.” Nature Communications 5, no. 1 (December 2014).





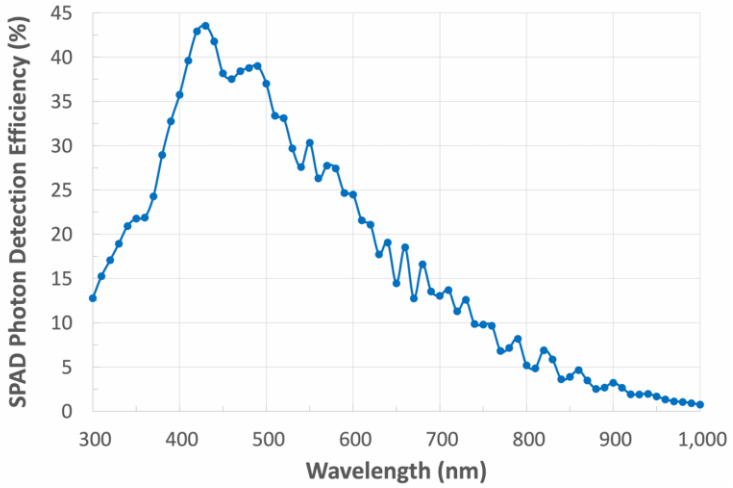
PDM application: Diffuse Correlation Spectroscopy (DCS)

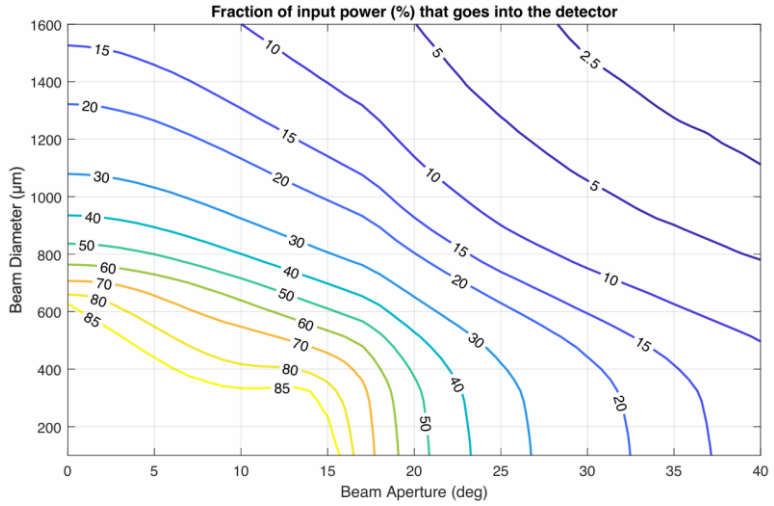
Daniele Dequal, et al. “100 kHz satellite laser ranging demonstration at Matera Laser Ranging Observatory.” *Journal of Geodesy*, (2021).

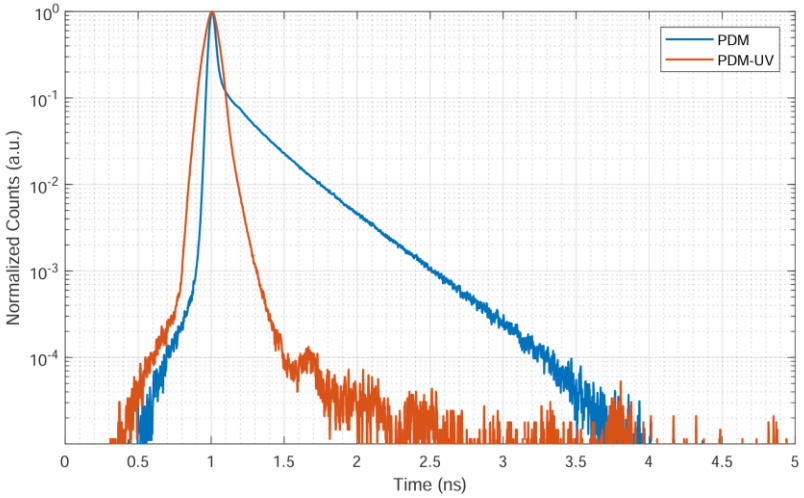


PDM-UV-EC

- Enhanced collection efficiency thanks to **custom focusing optics**
- **100 times equivalent area improvement** (i.e. 50 µm → 500 µm SPAD diameter) for nearly-collimated beams
- Timing jitter < 100 ps FWHM, DCR < 100 cps







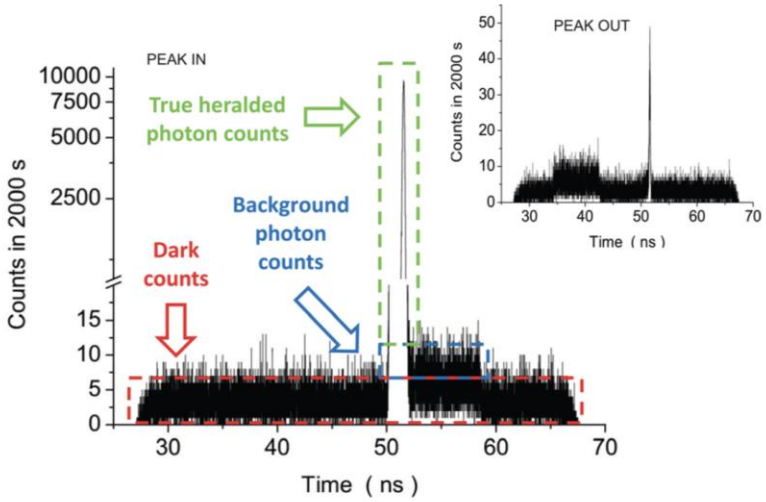
PDM-IR

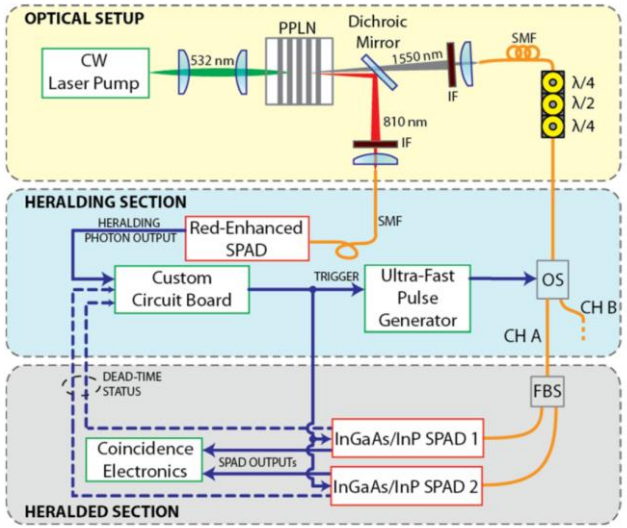
- Cooled **InGaAs/InP SPAD** for detection up to 1700 nm
- Free-space, SMF-28 and MMF GI 50 µm fiber-pigtailed versions
- Includes a pulse generator for gating, a front-end circuit for avalanche sensing and fast circuitry for detector quenching and resetting.
- **PDE > 25%** at 1550 nm
- DCR as low as **400 cps** and timing jitter **<100 ps** FWHM
- Up to 100 MHz gating or free-running operation
- Fully programmable

PDM-IR applications:

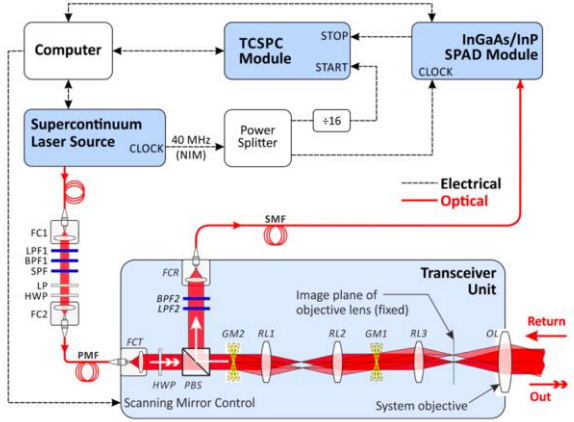
quantum communications and km-range LIDAR

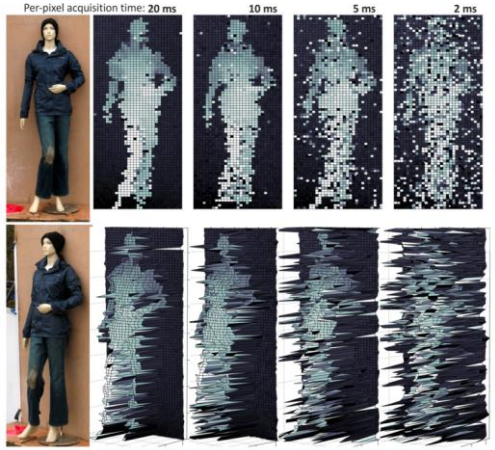
G. Brida, et al. "An Extremely Low-Noise Heralded Single-Photon Source: A Breakthrough for Quantum Technologies." Applied Physics Letters 101, no. 22 (2012)



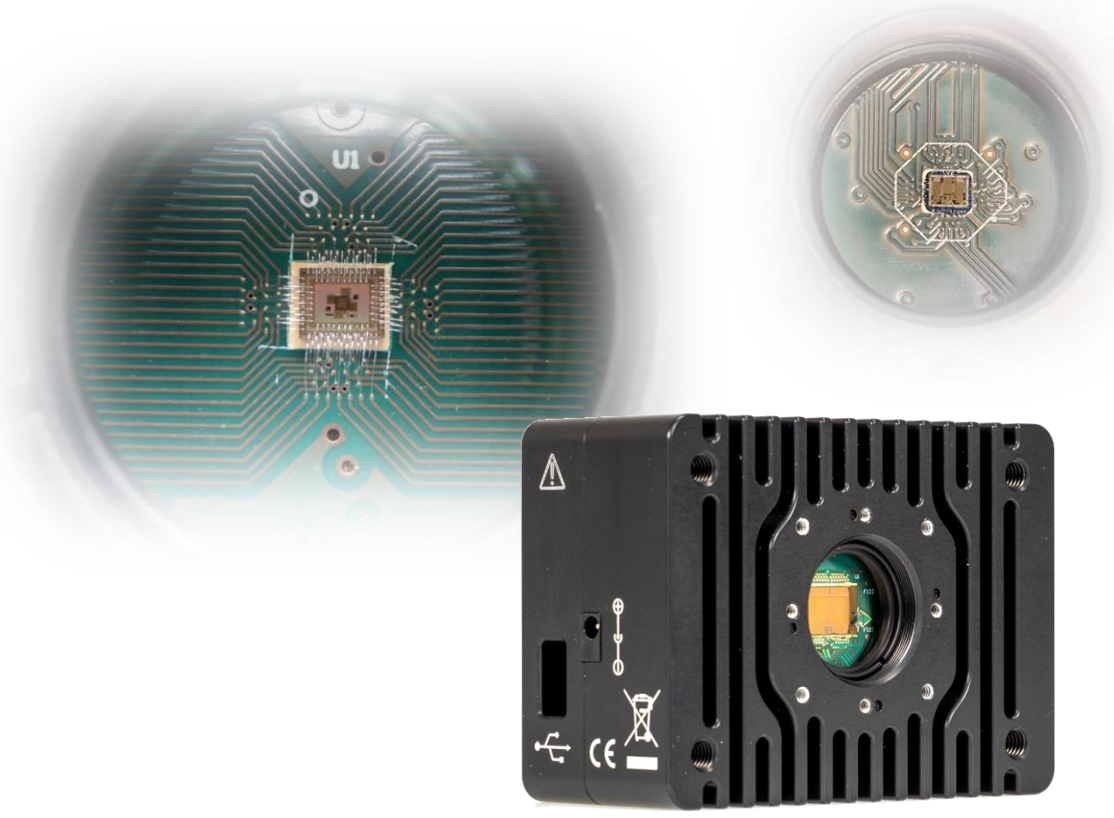


McCarthy, et al. "Kilometer-Range Depth Imaging at 1550 Nm Wavelength Using an InGaAs/InP Single-Photon Avalanche Diode Detector." Optics Express 21, no. 19 (2013)

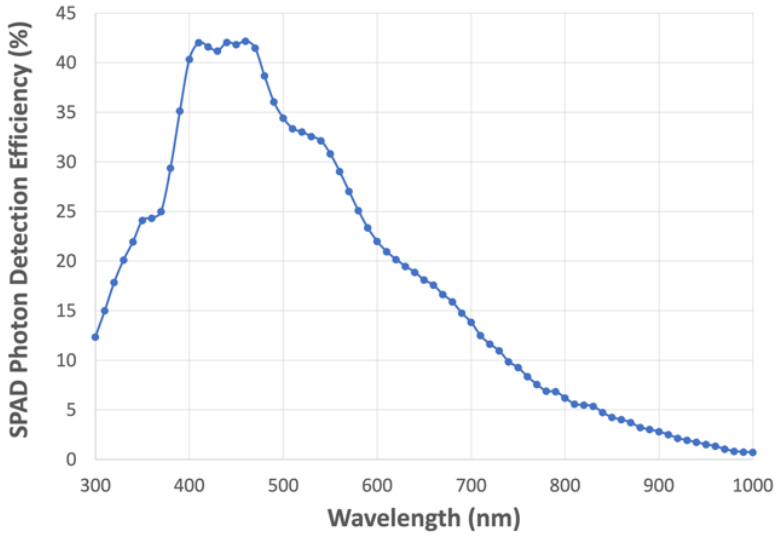




CMOS imaging cameras



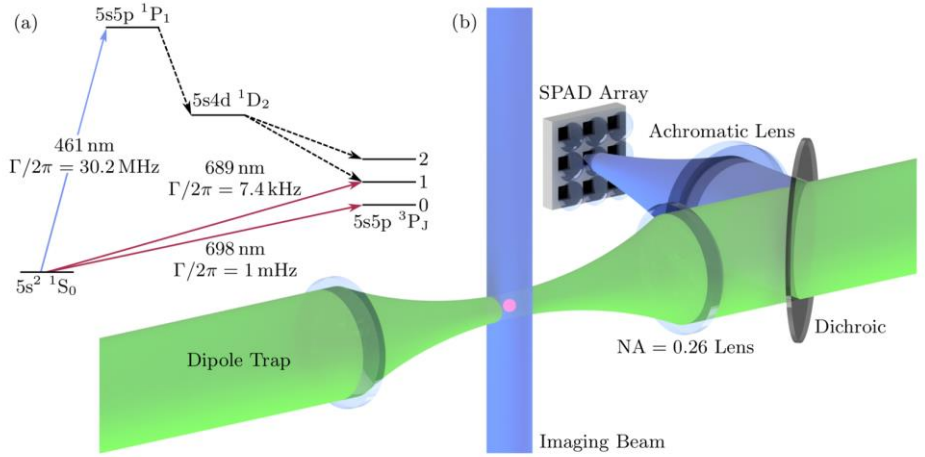
Hermes



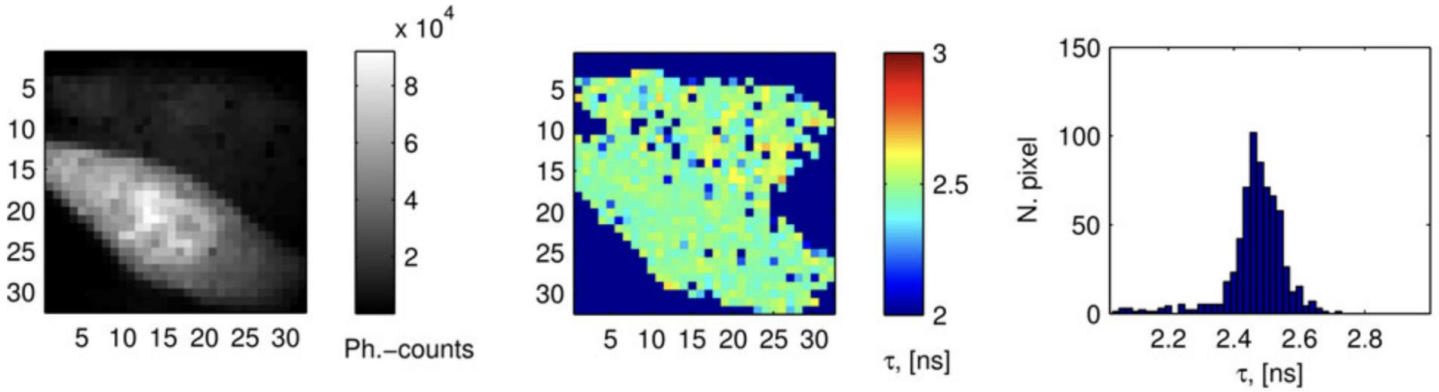
- **32 × 64 SPAD** pixels, fully parallel operation
- PDE: **36%** @ 400nm
- Version with **microlens** array available
- 3 counters (2 up/down) optimized for measuring phase shift and intensity
- Up to **96 kframes/s**
- Low noise: ~**100 c/s** for 95% of the pixels
- 3 independent ultra short time gates (2 ns)
- Standard high speed “in-camera” FLIM-mode
- USB 3.0 interface, SDK provided

Hermes applications: physical experiments & FLIM

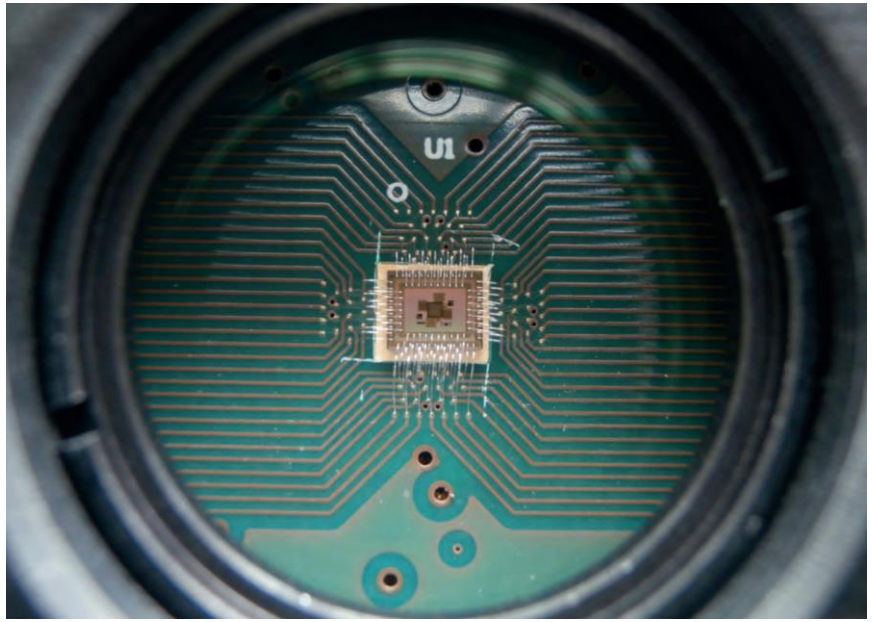
N. C. Jackson "Number-Resolved Imaging of ^{88}Sr Atoms in a Long Working Distance Optical Tweezer." ArXiv:1904.03233 [Physics], 2019.

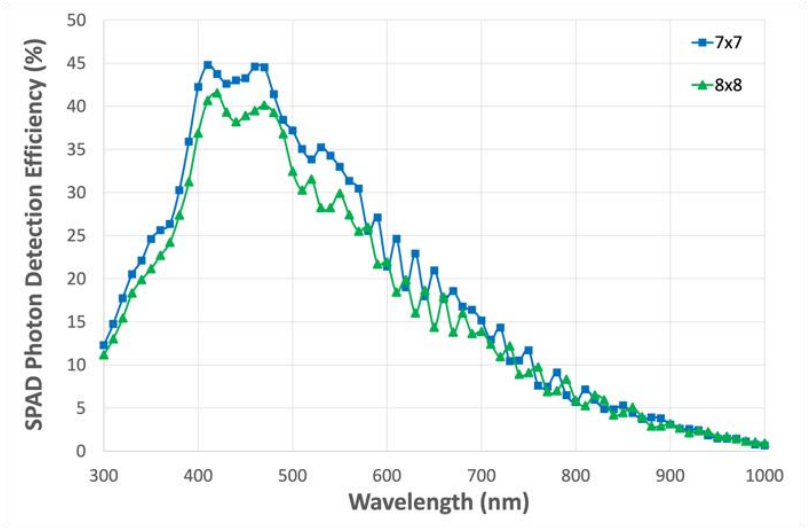


M. Vitali, et al. "A Single-Photon Avalanche Camera for Fluorescence Lifetime Imaging Microscopy and Correlation Spectroscopy." IEEE Journal of Selected Topics in Quantum Electronics 20, no. 6 (2014)



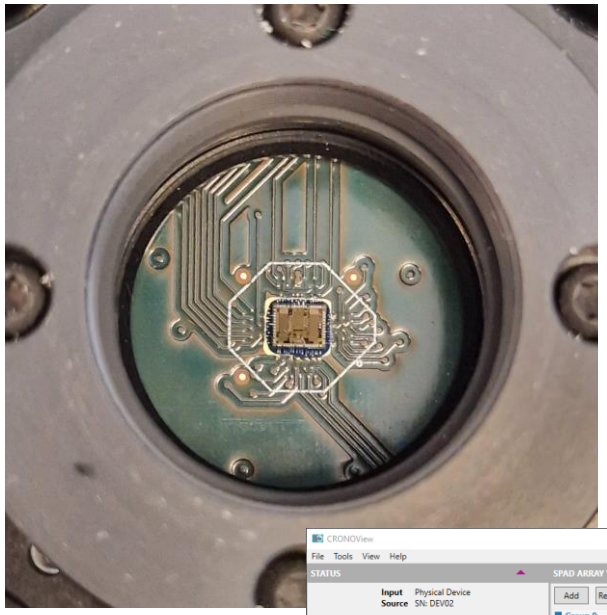
Argo

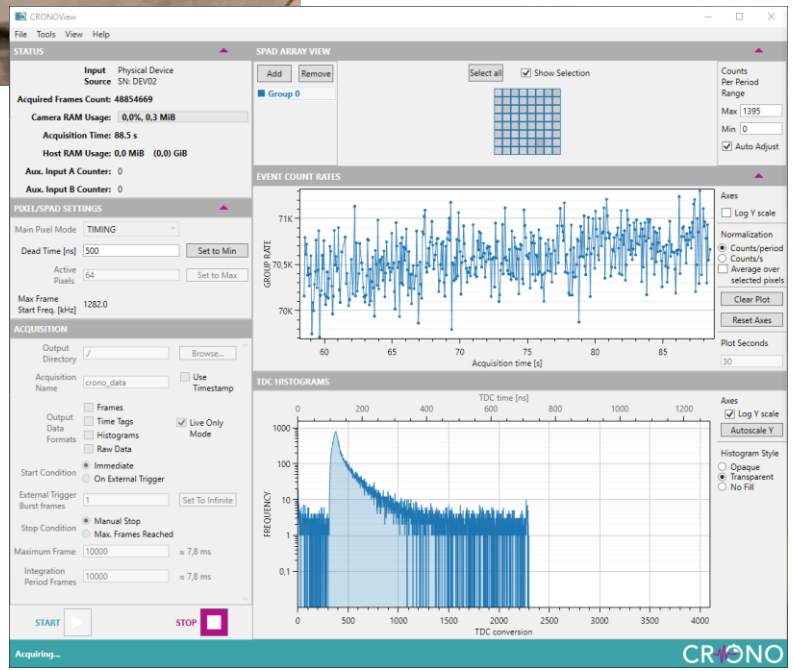




- **7×7** or **8×8** SPAD pixels with direct outputs
- Timing jitter **< 150 ps** FWHM – 7×7
- Timing jitter **< 180 ps** FWHM – 8×8
- DCR **< 500 c/s** for at least 85% of pixels
- LVDS timing outputs
- 12.6% native fill factor, **74%** with MLA

Crono





- **8×8** or **128×1** SPAD array with integrated TDCs
- 312.5 ps TDC resolution
- Frame rate > 1 Mframe/s
- PDE: **36 %** @ 400nm
- Fill factor ~10% and up to **78%** with MLA
- Internal or external hardware gating
- USB 3.0 interface, SDK provided

Other products

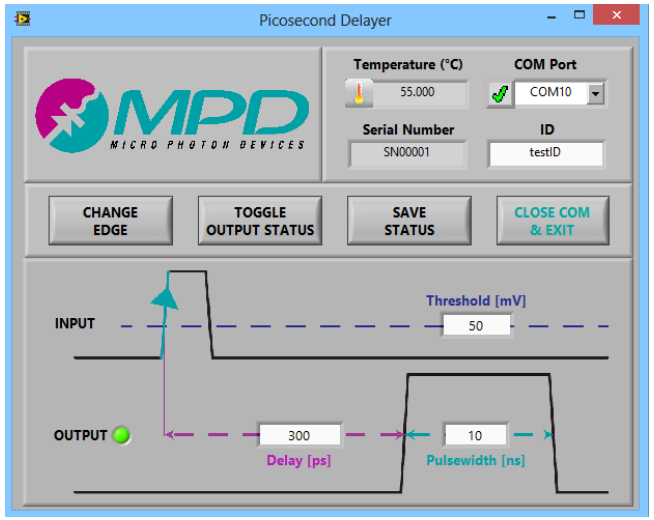
Quantum Random Number Generator (QNRG)

- Based on quantum physics
- Robust and low cost
- Up to 180 Mbps
- Low power consumption
- Easy to use

Dieharder, TestU01

Statistical Test Suites: **PASSED!**

Picosecond Delayer



- 50 ns maximum delay range
- TTL and NIM output pulses
- Up to 380 MHz bandwidth (NIM output)
- Programmable output width from 1 ns to 250 ns
- Typ. INL between +50 ps and -50 ps over full-scale range
- 10 ps step
- Random jitter typ. 5 ps RMS
- < 1 ms programming time
- USB interface
- All solid state, no coax cables

Contacts

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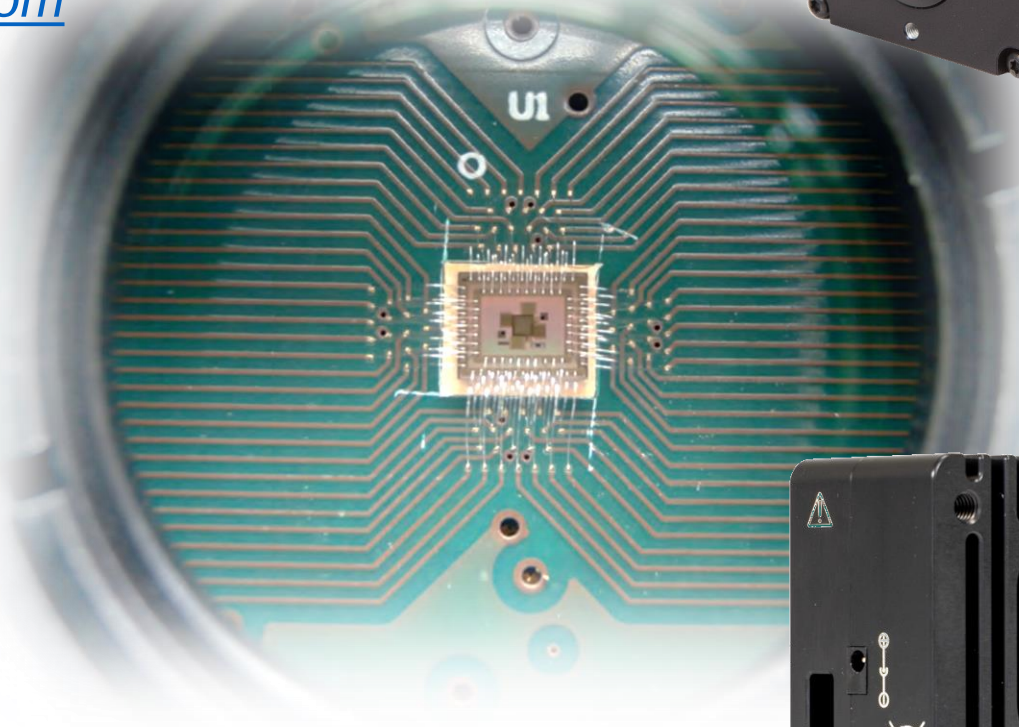

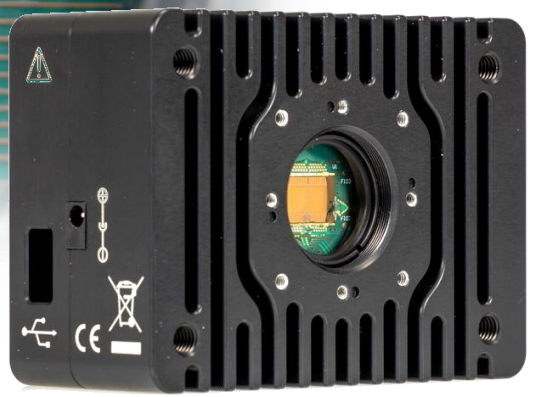

ILRS NESC meeting
20th June

Improvements in the last 6 months at SFEL station

LT CDR Manuel Angel Sánchez Piedra

ESTACIÓN DE SEGUIMIENTO LÁSER
REAL INSTITUTO Y OBSERVATORIO DE LA ARMADA

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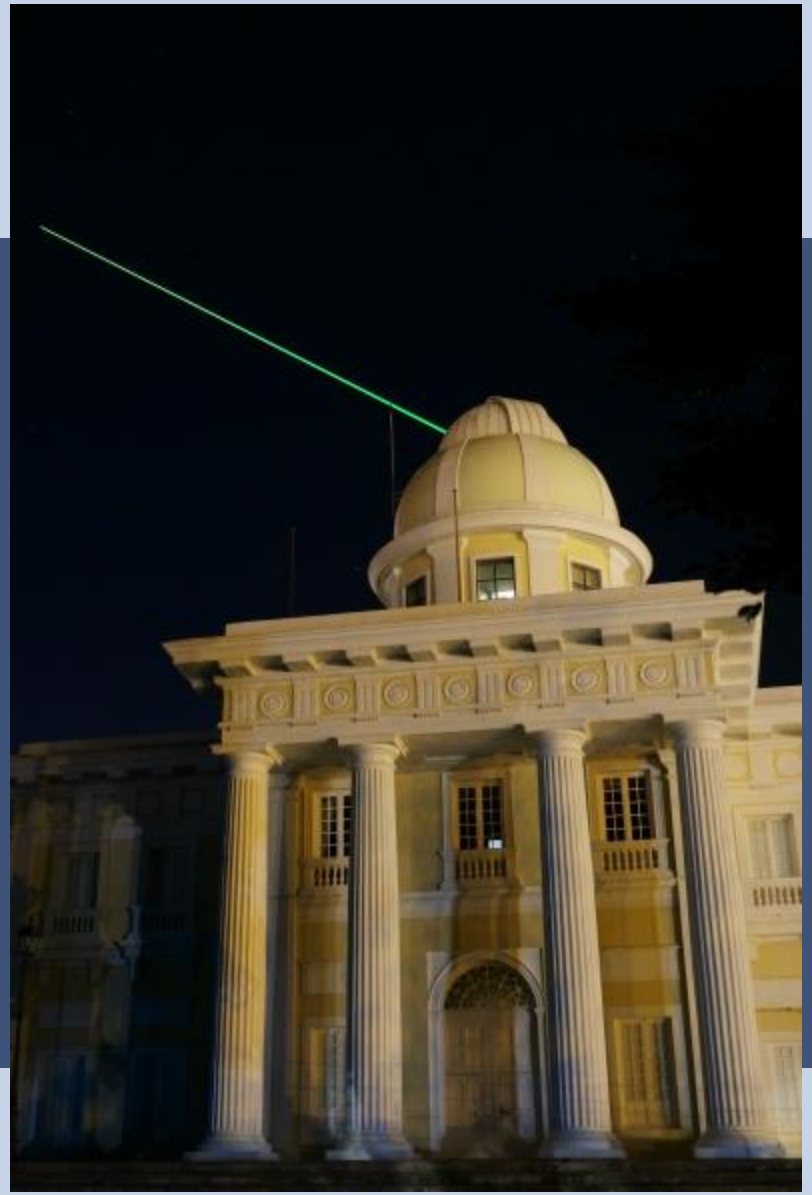
ESTACIÓN DE SEGUIMIENTO LÁSER
REAL INSTITUTO Y OBSERVATORIO DE LA ARMADA



1. Introduction

Historical background

ESTACIÓN DE SEGUIMIENTO LÁSER
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Oldest astronomical observatory in Spain (1753).

Created at the initiative of Jorge Juan.

Training of Midshipmen in Fields of Science such as Navigation, Geodesy and Astronomy.

Participation in relevant international position astronomy projects (e.g. Carte du Ciel - 1887).

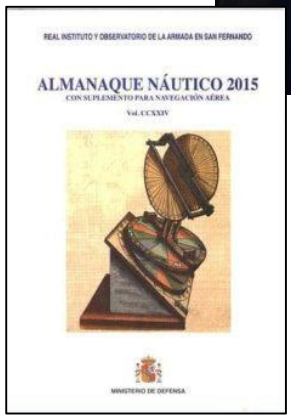
During its more than 250 years of operation, new missions for the Navy and for Spanish science were added to its original astronomical tasks.

The publication of the Annual Astronomical Ephemeris and the Nautical Almanac (1791).

The Deposit of Chronometers and Instruments of the Navy.

Meteorological (1811), magnetic (1879) and seismic (1898) observations

The scientific determination of time.



Historical background

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ROA has been a pioneer in Spain in the tracking of artificial satellites.

Photographic Techniques

- *1958. Baker-Nunn camera*
- *2010. TFRM Robotic Telescope Modernization*

SLR

- *1968. French Geodesic Campaign (CNES-GRGS)*
- *1979. Transfer agreement to Spain*

Overview of SFEL station

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*Both **collaborative object** and space **debris tracking**.*

SFEL has participated with national and international tracking networks, for geodetic and SST purposes:

ILRS - EUROLAS

S3T - EU SST

ESA

It has also collaborated with companies in the space sector

Overview of SFEL station

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Space debris *tracking*

- *LEO, 4 m^2*
- *EKSPLA NL317 (25W @532 8ns)*
- *SAP500 detector*

ILRS *tracking tasks.*

- *LEO-MEO*
- *EKSPLA PL2251 (500mW @532 30ps)*
- *C-SPAD detector*

FPGA-RGG
Event Timmer A032
PPS Synchronization with ROA Time Laboratory, Rubidium and Whitte Rabbit
Altazimuth mount

- *600 mm Cassegrain Telescope*
- *Launching Telescope - micrometric mechanical pointing*
- *Pointing Telescope - analogic camera + f12 telescope*

2. Infrastructure enhancements

Infrastructure enhancements

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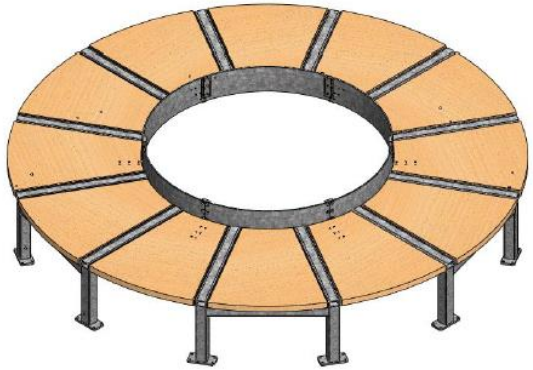
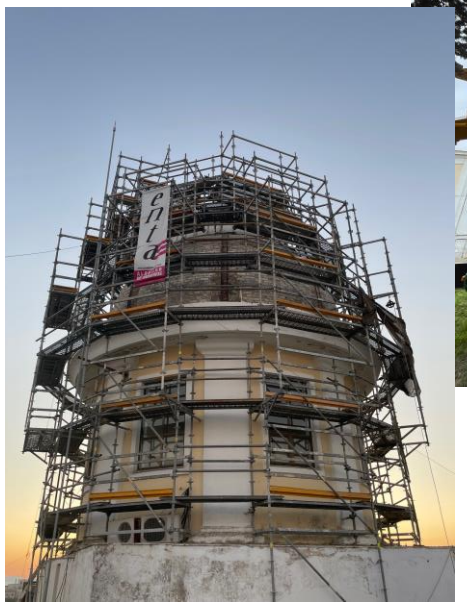
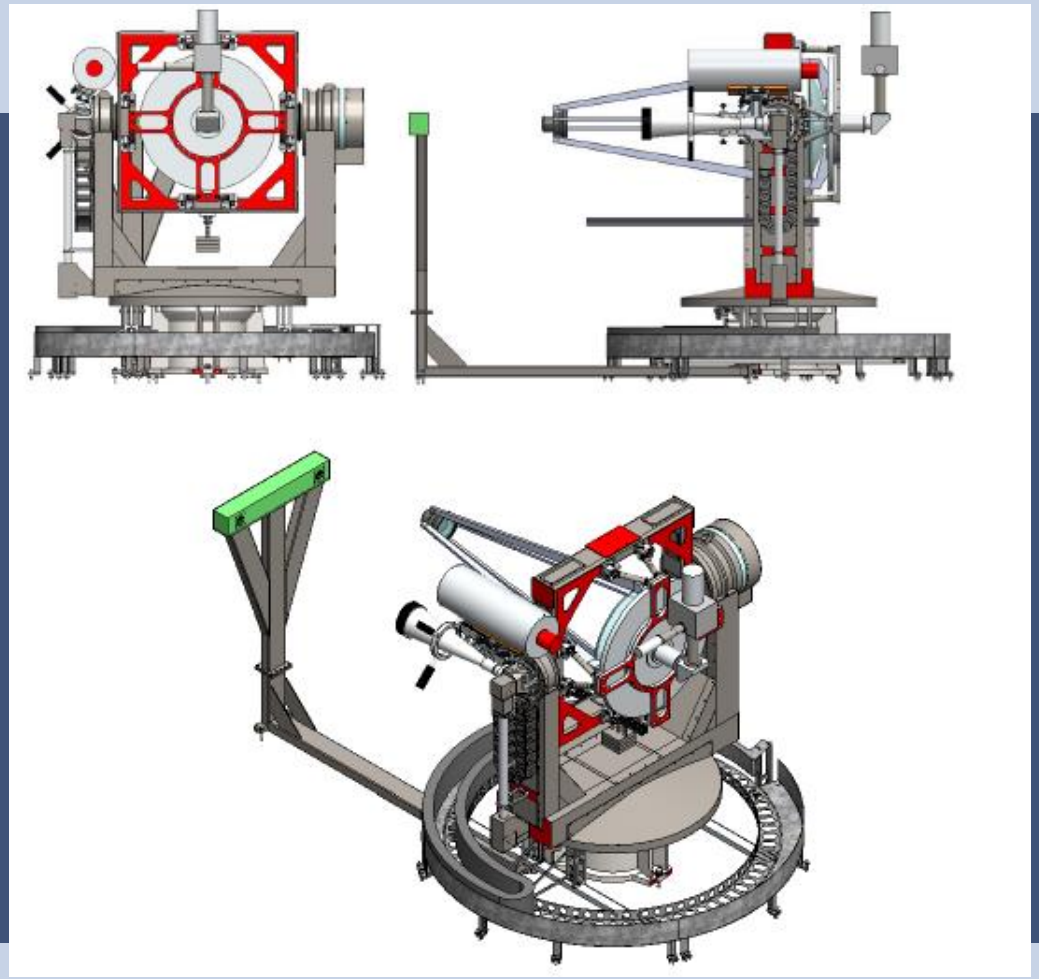
Water leaks during the last two winters in the dome of the main building.
Maintenance work since November to February.

Conditioning of the laser and control rooms
Renewal of the electrical installation
Installation of a technical floor in the dome







3. New mount project

New mount project

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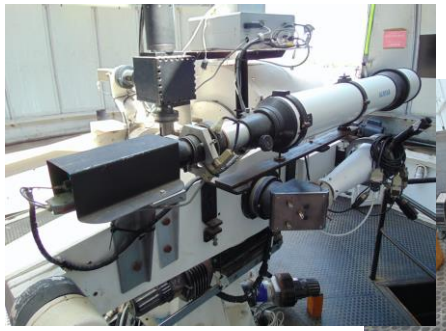
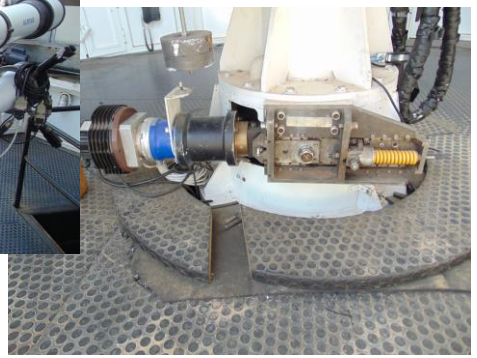
Previous mount

- *Altazimuth mount*
- *From the project carried out by CNES (1979).*
- *Nominal accuracy (6 arcsec). Test: real accuracy (≈20 arcsec).*

Drawbacks

- *Servomotors with gear systems with limited precision*
- *Excesive vibrations due to mechanical transmisión*
- *Gears have looseness due to wear*
- *Relative encoders. Homing to reset errors.*
- *Az & El cannot be used for complement observations*
- *Limited observational capacity for space debris.*
- *Highly coupled software*





New mount project

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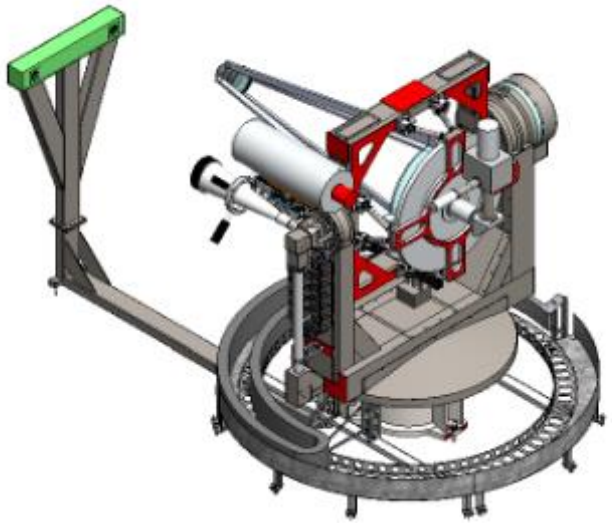
New Altazimuth Mount – AMELAS project
Developed by the Spanish company AVS (Basque Country).
Current Project status:

- *FAT tests finished*
- *Installation in ROA and SAT tests (from 25 JUN)*



Main characteristics

- *Accuracy <1 arcsec (static 1/100 arcsec)*
- *Direct Drive technology (less vibration, wear and maintenance).*
- *High speeds and accelerations (>12º/s y >15º/s^2).*
- *Invariant point precision < 1mm*
- *API design on demand*

  Operating modes, security layers, tracking mode (CPF, TLE and stars-mount model), daylight use (exclusión área-sun), etc…

New mount project

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4. Improvements in other subsystems

Improvement in other subsystems

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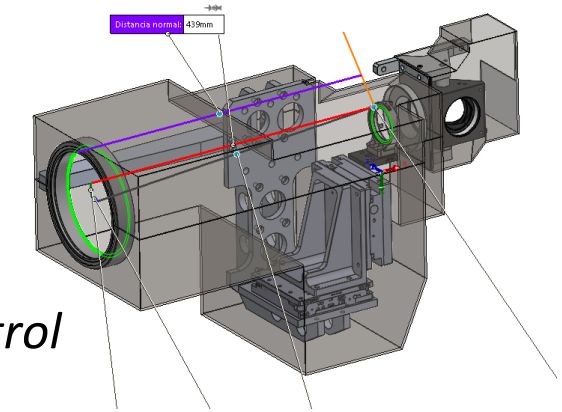
New ToF Measurement System

- *Eventech ESST 7 Series*
- *Extremely precise & reliable time tagging device*
- *1.5 ps RMS time-tag precisión*

New launcher telescope

- *Optomechnic based on COTS*
- *Beam pointing control and divergence control*



New finder telescope

Celestron RASA 8 + CMOS ZWO ASI 2600
Already tested in GNSS – useful for space debris

Improvement in other subsystems

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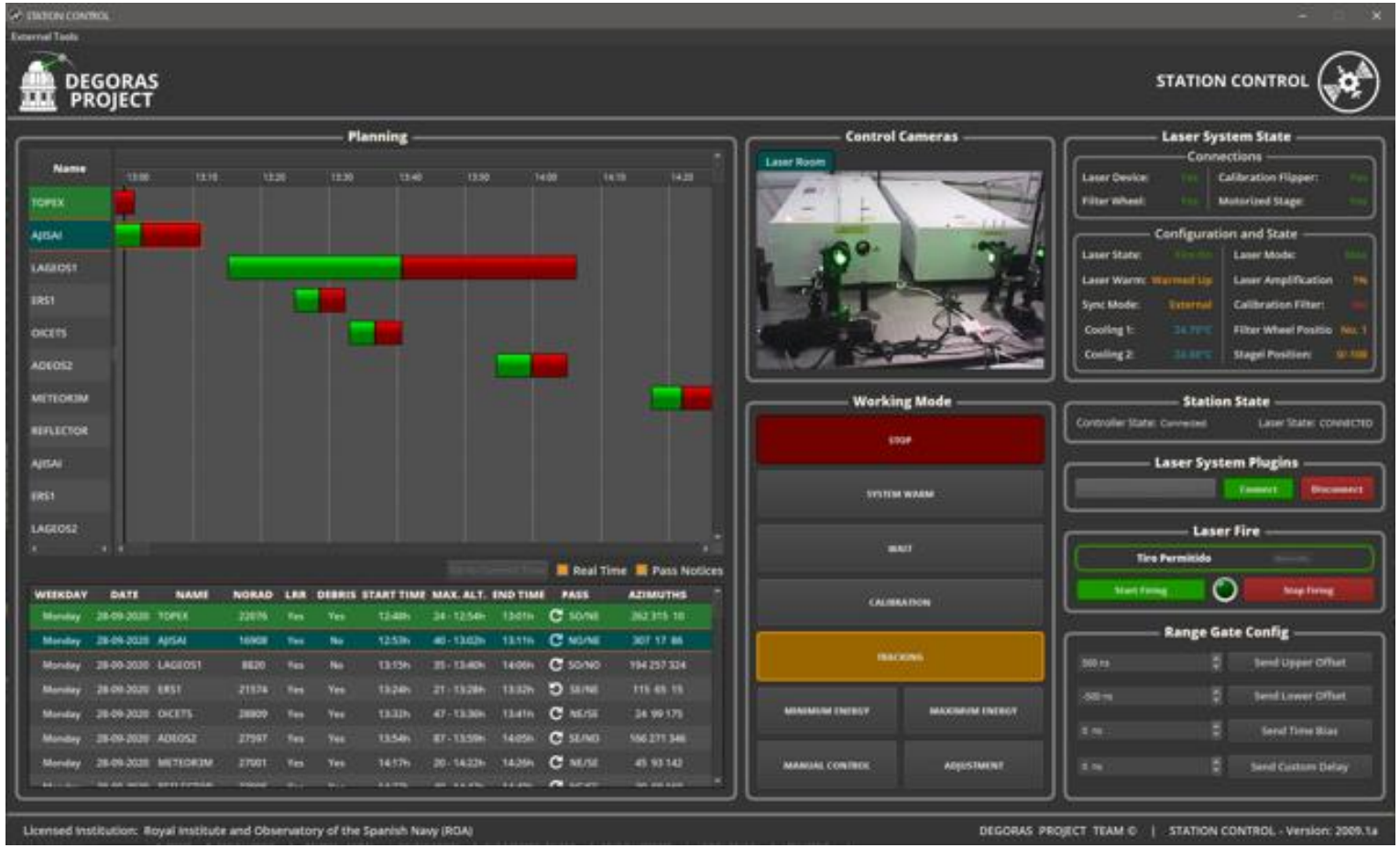

Software Development

- ***Station Control***
- *Tracking programme*
- *Space Objects Database*
- *Prediction Generator*
- *Safety System and air warning*

Improvement in other subsystems

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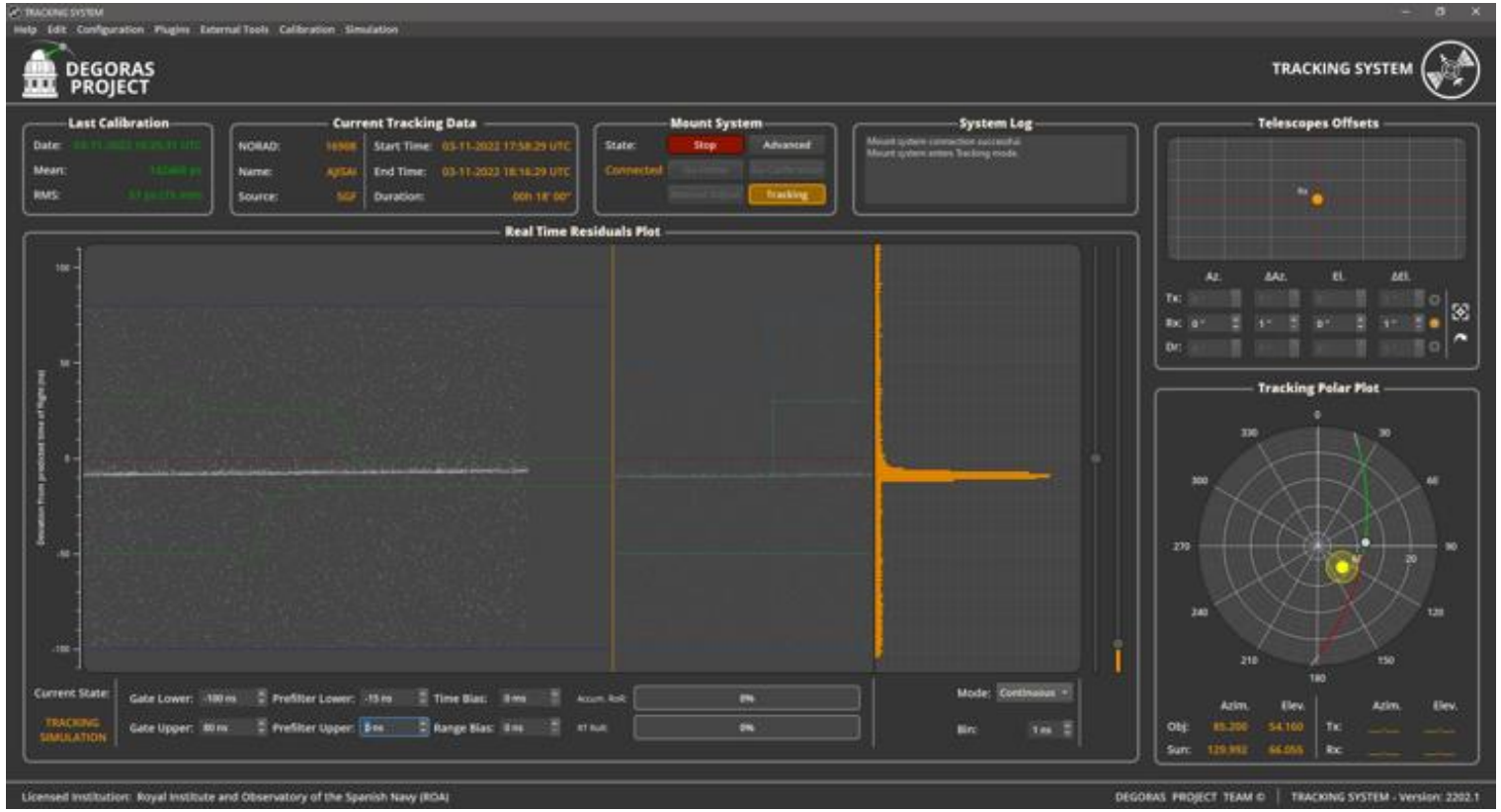
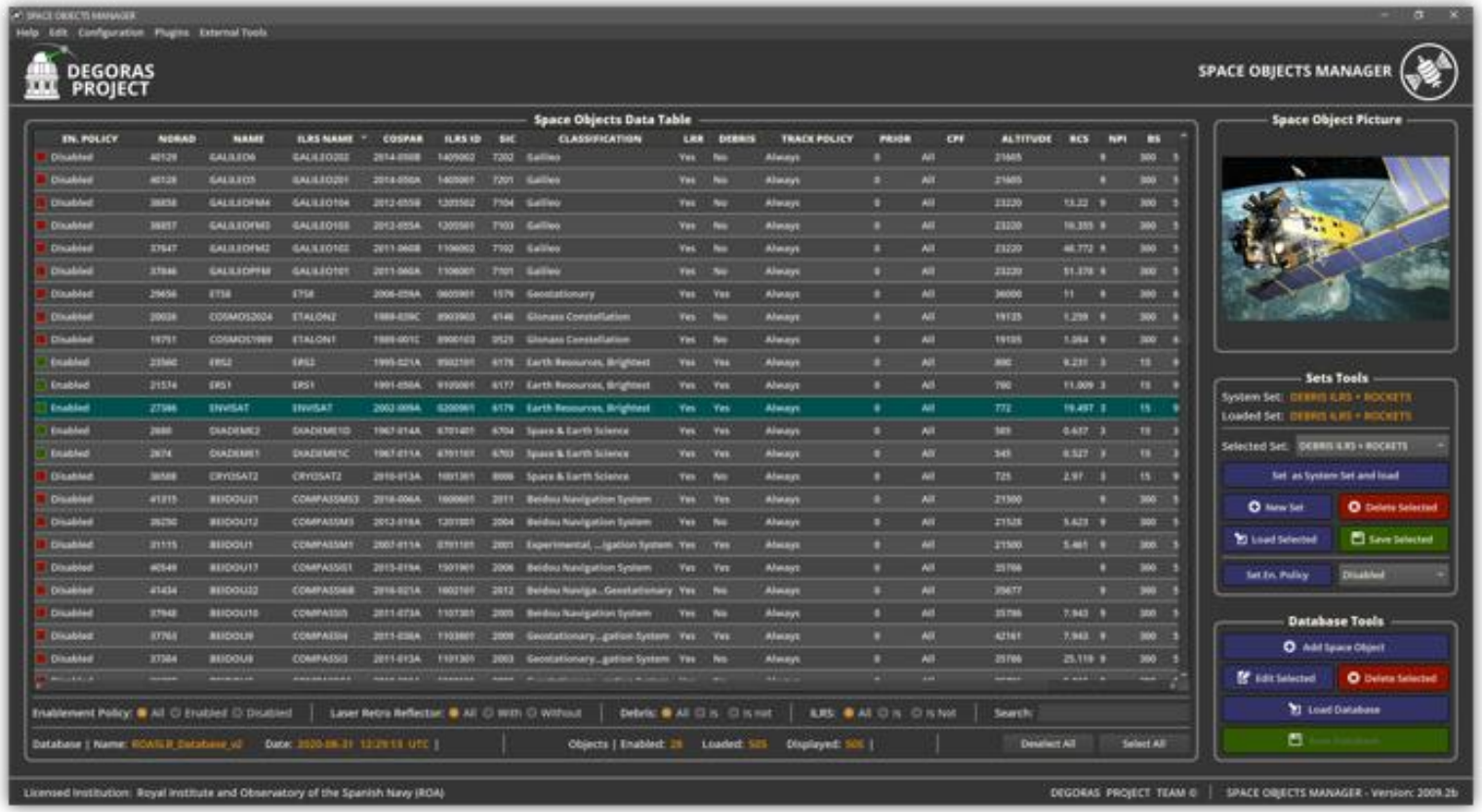


Software Development

- *Station Control*
- ***Tracking programme***
- *Space Objects Database*
- *Prediction Generator*
- *Safety System and air warning*

Improvement in other subsystems

ESTACIÓN DE SEGUIMIENTO LÁSER
REAL INSTITUTO Y OBSERVATORIO DE LA ARMADA



Software Development

- *Station Control*
- *Tracking programme*
- ***Space Objects Database***
- *Prediction Generator*
- *Safety System and air warning*

Improvement in other subsystems

ESTACIÓN DE SEGUIMIENTO LÁSER
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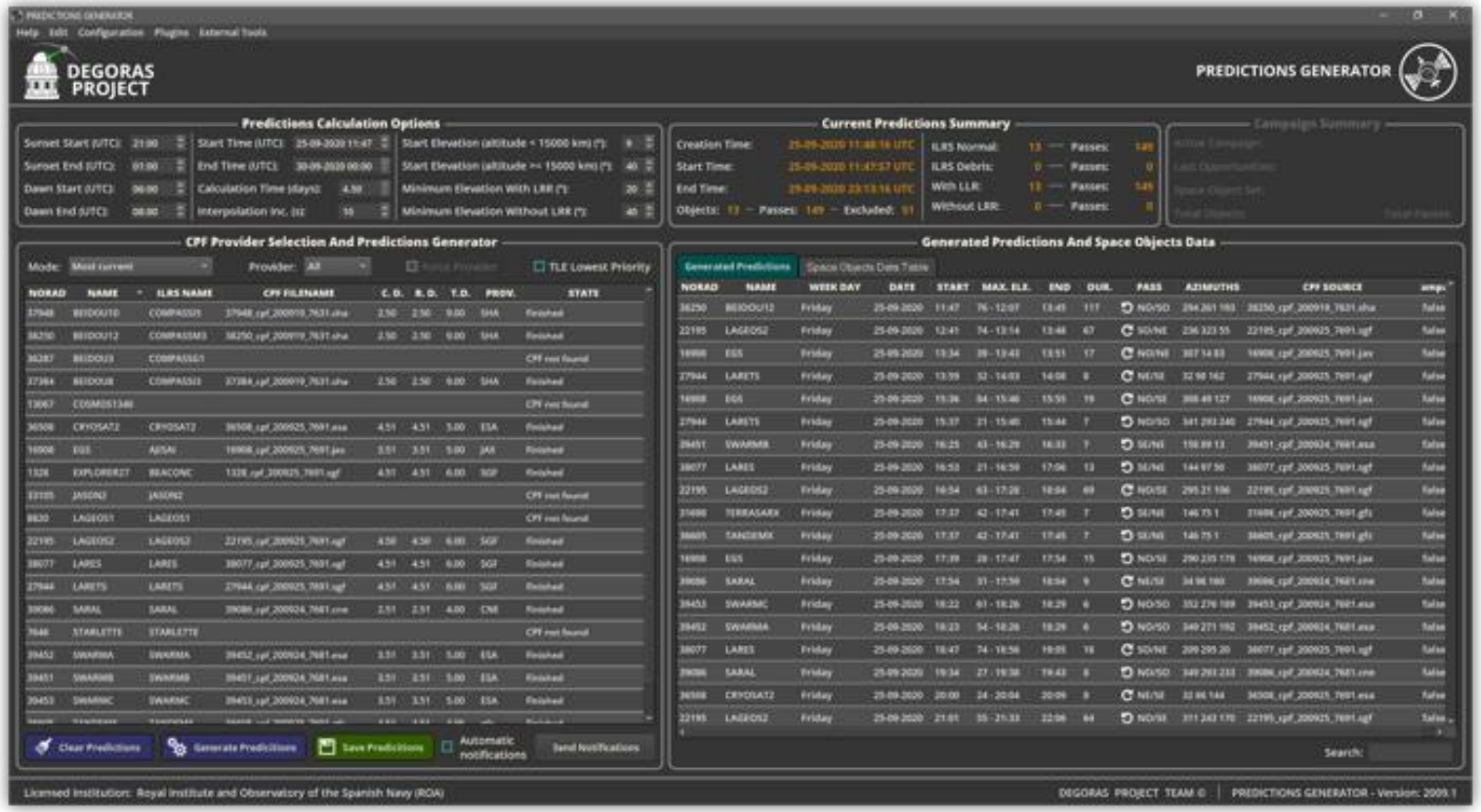

Software Development

- *Station Control*
- *Tracking programme*
- *Space Objects Database*
- ***Prediction Generator***
- *Safety System and air warning*

Improvement in other subsystems

ESTACIÓN DE SEGUIMIENTO LÁSER
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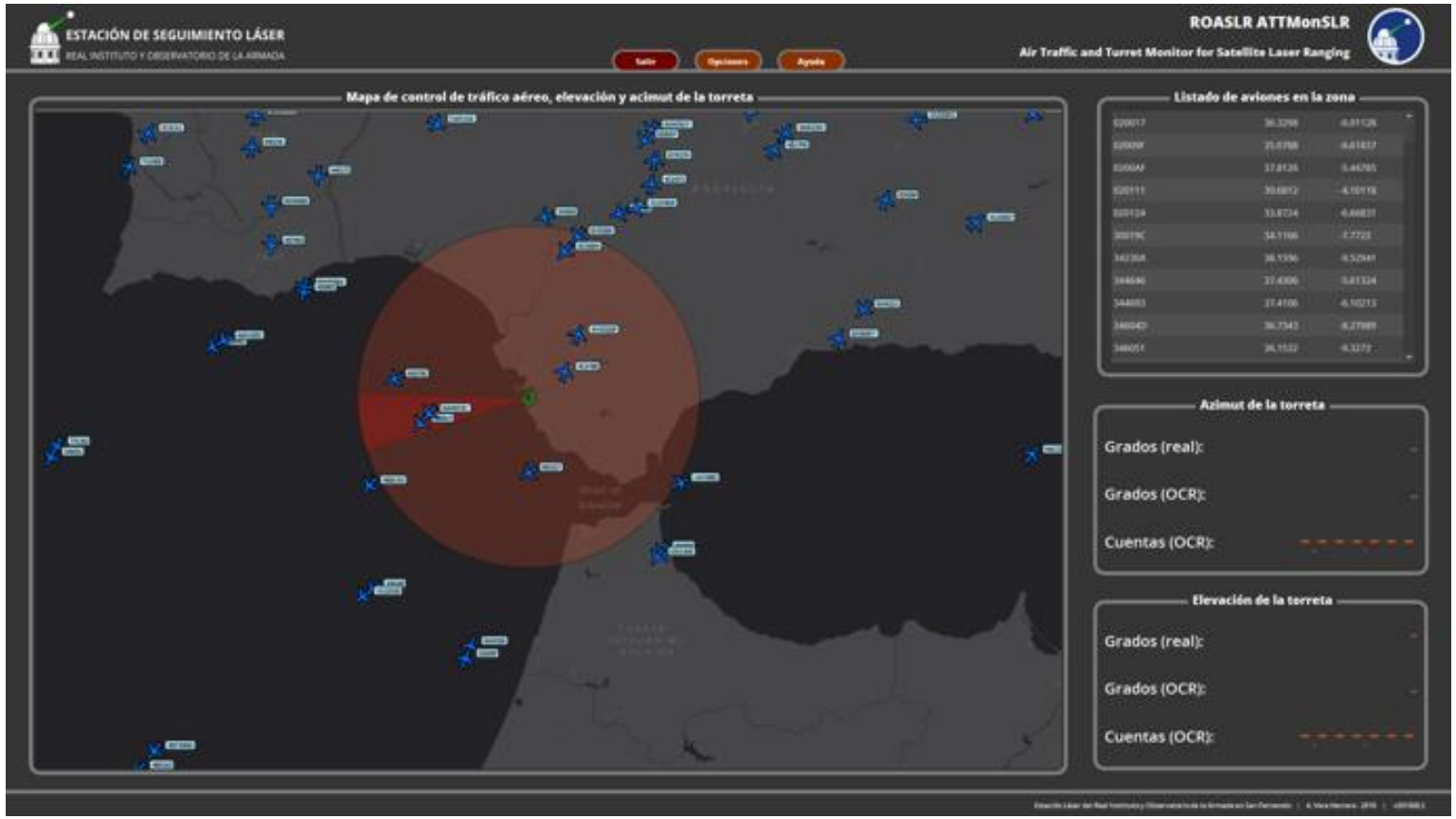
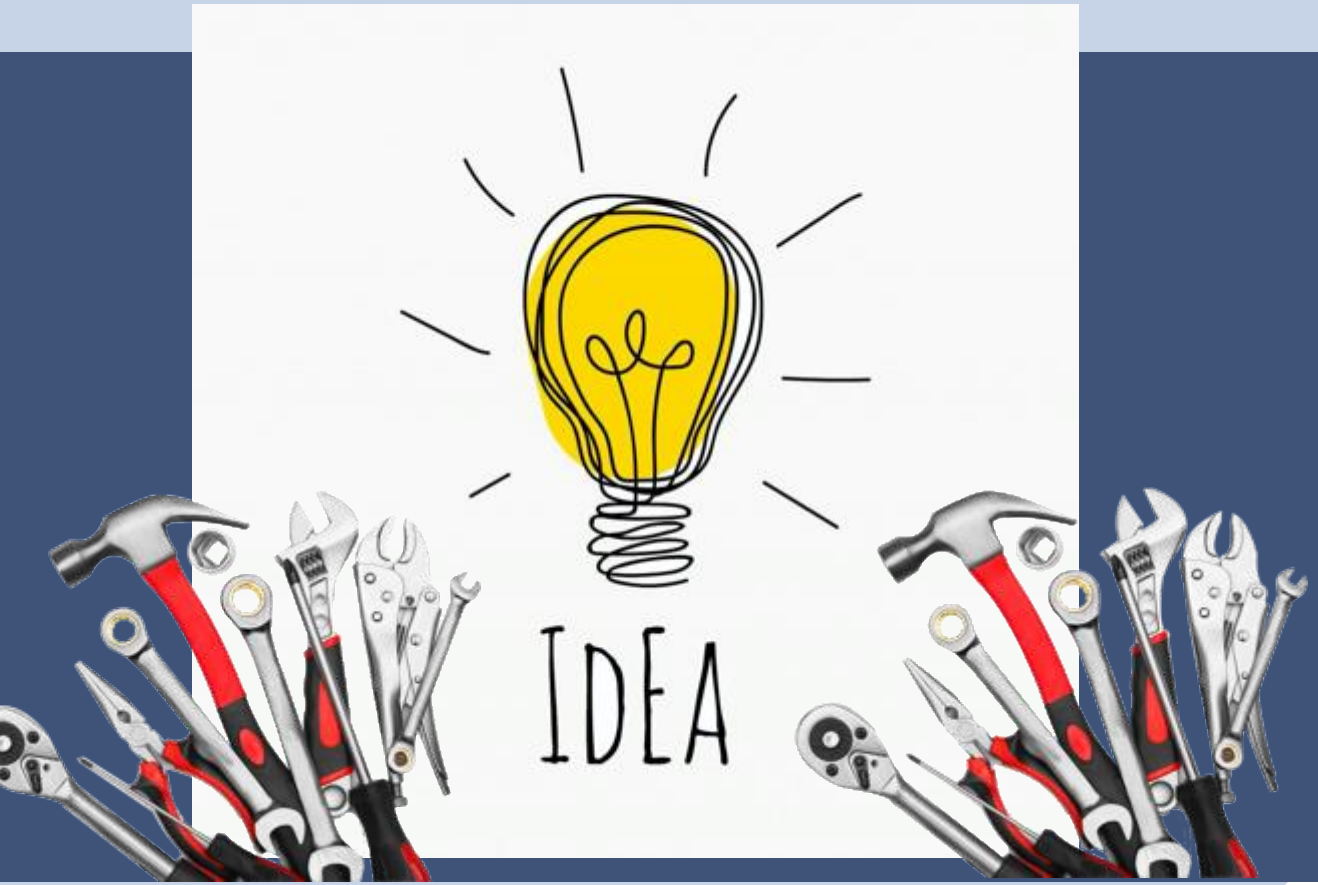


Software Development

- *Station Control*
- *Tracking programme*
- *Space Objects Database*
- *Prediction Generator*
- ***Safety System and air warning***



5. Future development projects

Future development project

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TERELAS

New Cassegrain telescope 800 mm
1 arcsec star image
Lighter and with greater reflectivity
Space debris

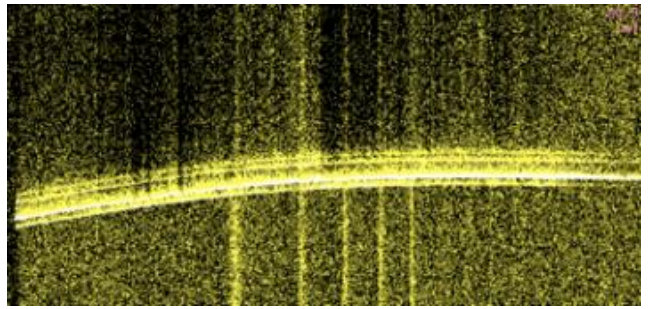
$$n_{pe} = \eta_q \left(E_T \frac{\lambda}{hc}\right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2}\right)^2 A_r \eta_r T_a^2 T_c^2$$

$$\sigma^2_{Total} = \sigma^2_{Pulso\ láser} + \sigma^2_{Detector} + \sigma^2_{Contador} + \sigma^2_{Satélite}$$

KIROA

New KHz laser
Combine in the same device characteristics required by ILRS and SST
532 nm, 1-5 KHz, 20 W, < 75 ps

$$\Delta R_{NP} = \frac{\sigma_{Total}}{\sqrt{N}}$$



CUPROA

Minimun speed 15º/s (re-entries)
Slit dome according to TERELAS
Integrated in station control SW

7. Conclusions

Conclusiones

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Conclusiones

- *After more than 40 years of life, SFEL has the experience acquired in this field and continues to be operational and with new functionalities.*
- *It maintains its own development capabilities and the ability to track collaborative objects and space debris.*
- *It has participated in both national (S3T) and international organizations (ILRS, EU SST, ESA) and the intention is to recover these collaborations as soon as possible.*
- *Currently, immersed in a profound modernization to bring it to the forefront of the state of the art*

Objective - In memory of Dr. Manuel Catalán

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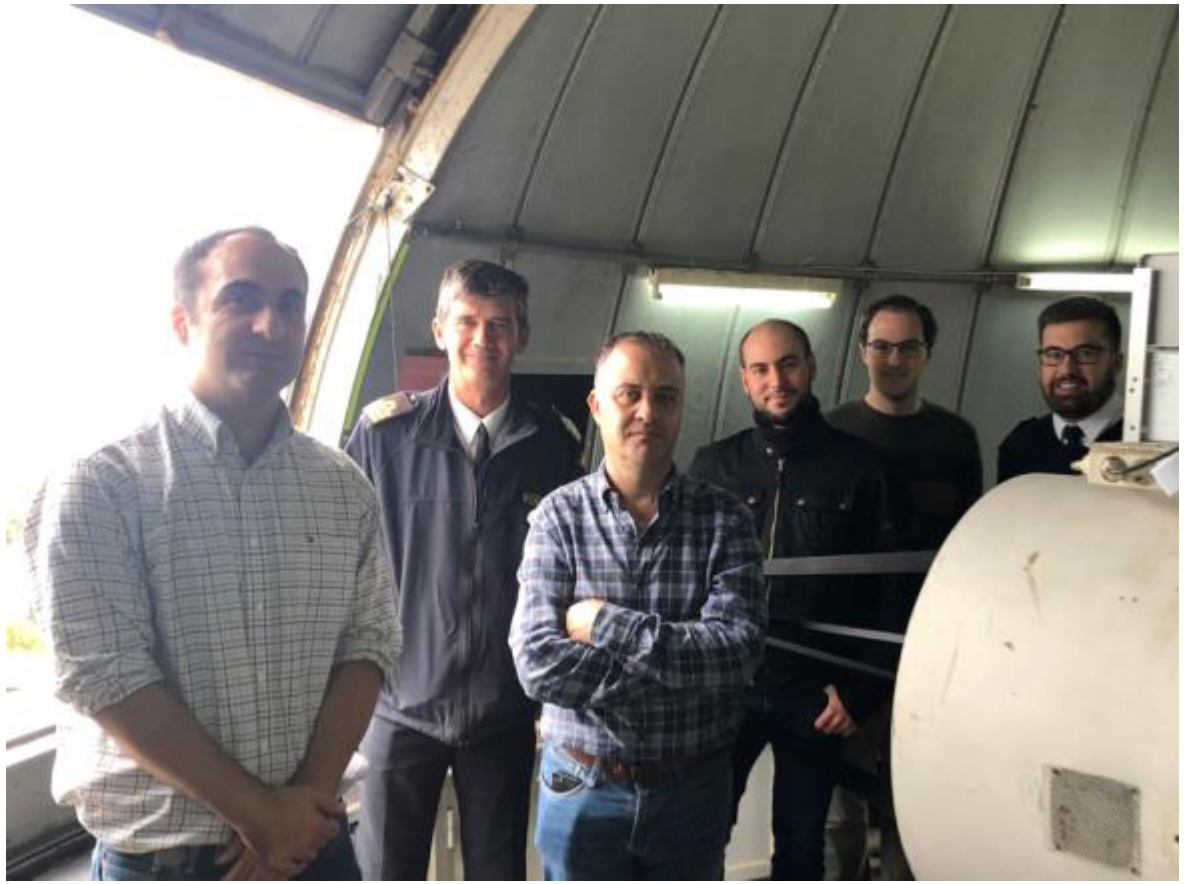


Staff is the most valuable resource

- *Cohesive group that works with enthusiasm to carry out all the projects we face.*

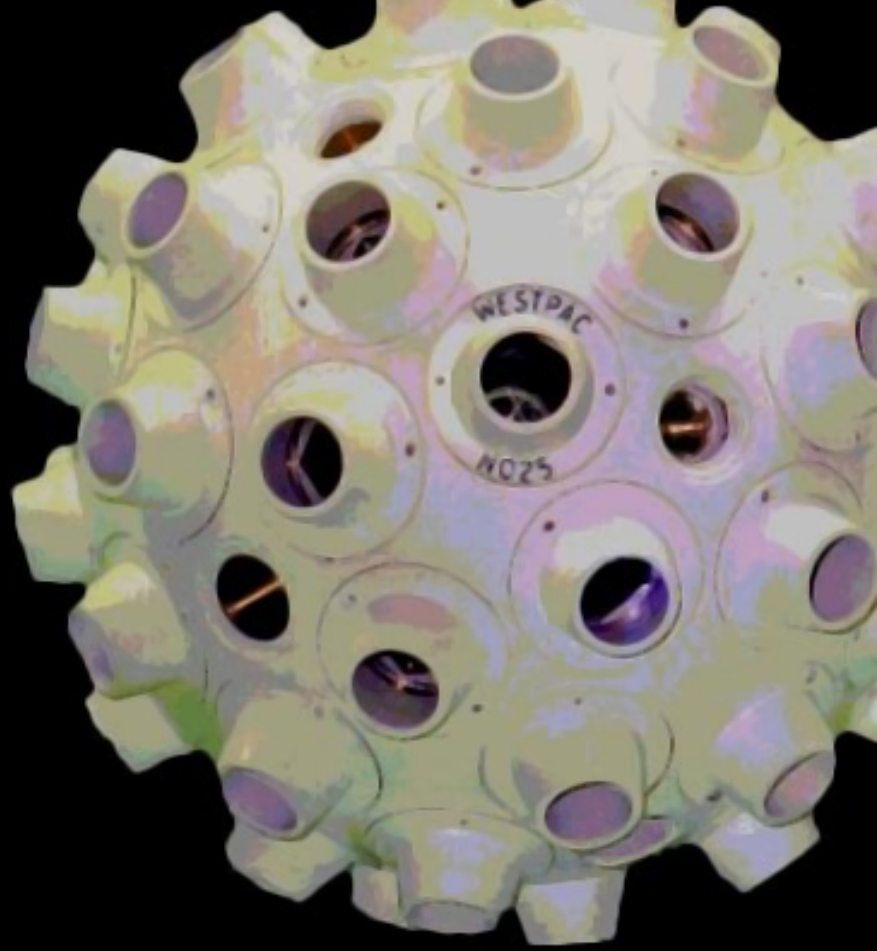
- *2 Navy officers (PhD students)*
- *4 engineers (different disciplines)*
- *2 observers*

LT CDR Manuel Ángel Sánchez Piedra
Head of San Fernando Laser Station

msanpie@roa.es

¡Thanks for your attention!

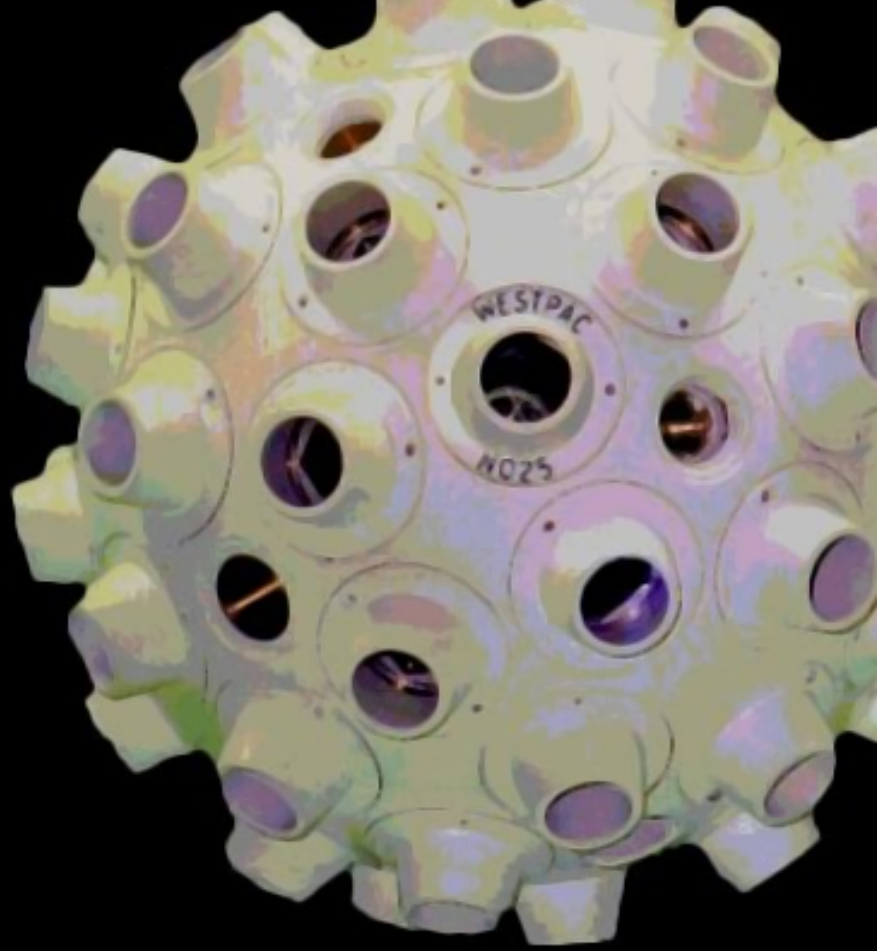
WESTPAC
-update



WESTPAC

Launch Date: **10 July 1998**
Orbit: **sun synchronous**
Inclination: **98 degrees**
Eccentricity: **0.0**
Perigee: **835 km**

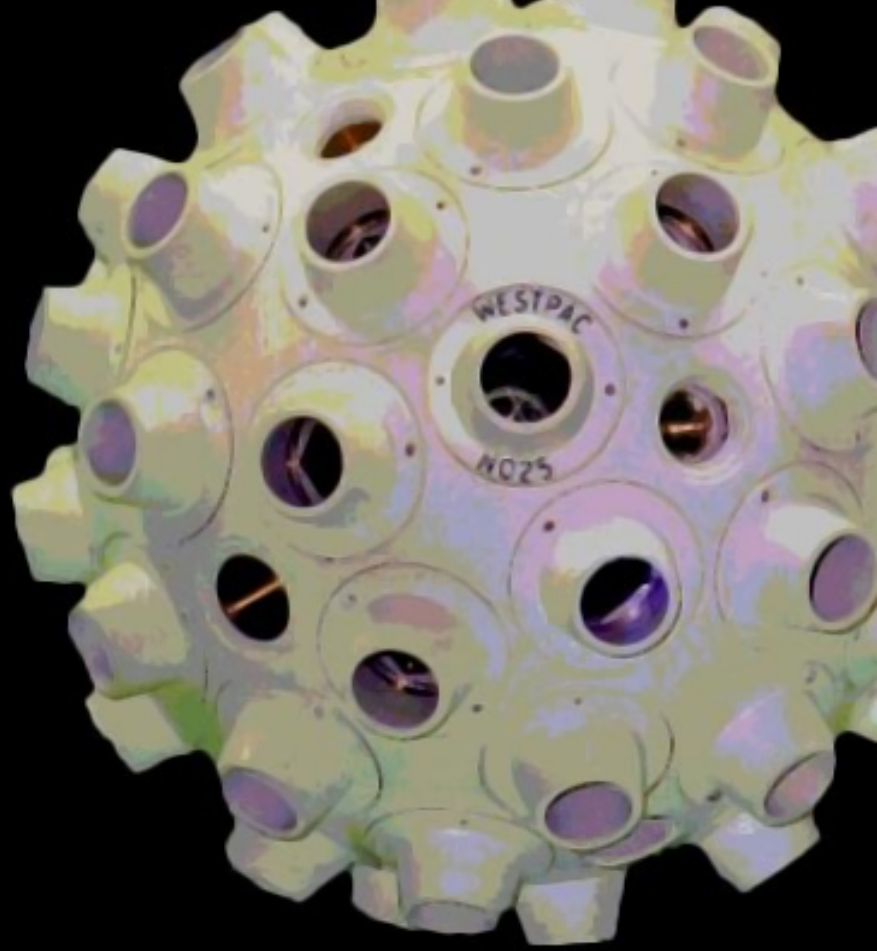
End of ILRS Support: **1 Dec 2002**



WESTPAC

NORAD number

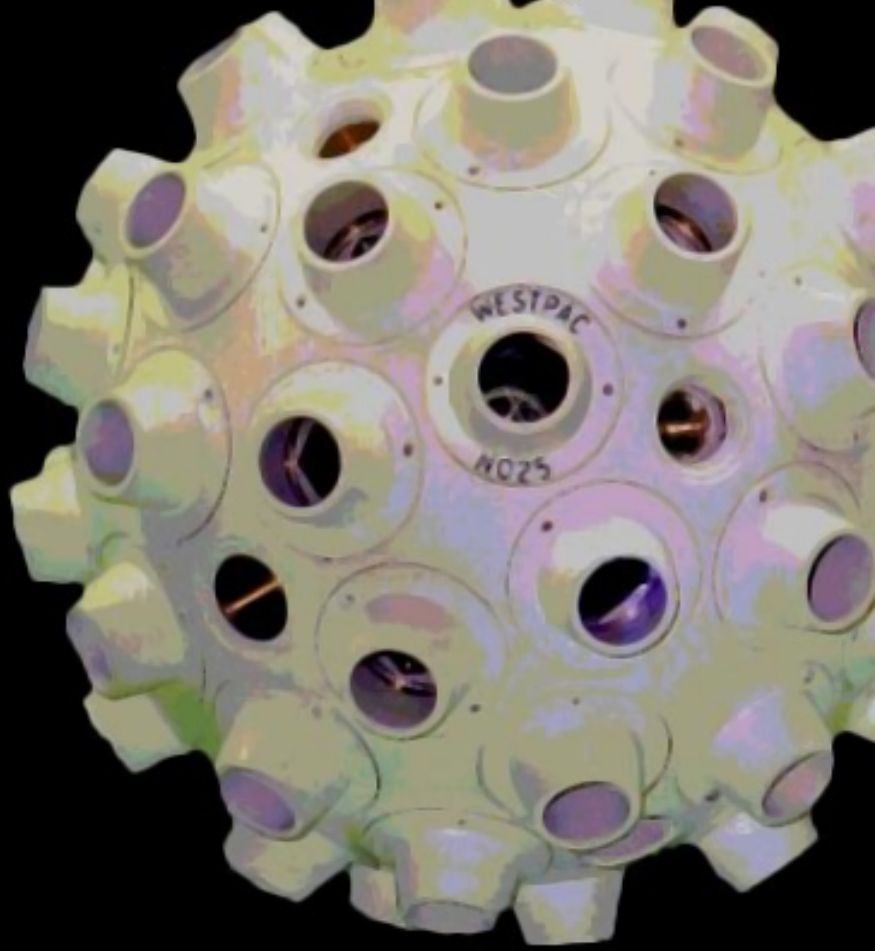
- WESTPAC was originally given the NORAD number **25394**
- This was later reassigned due to a clash with RESURS-O 1N4, which is a Russian natural resources sensing satellite.
- It was given the new NORAD number of **25398**.



WESTPAC

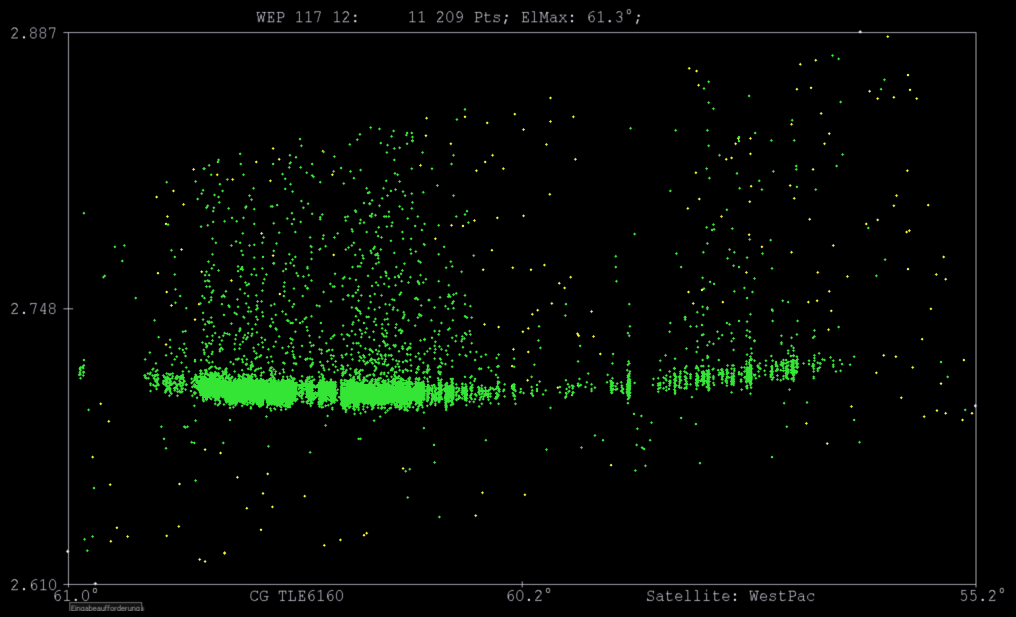
Some uncertainty remained:

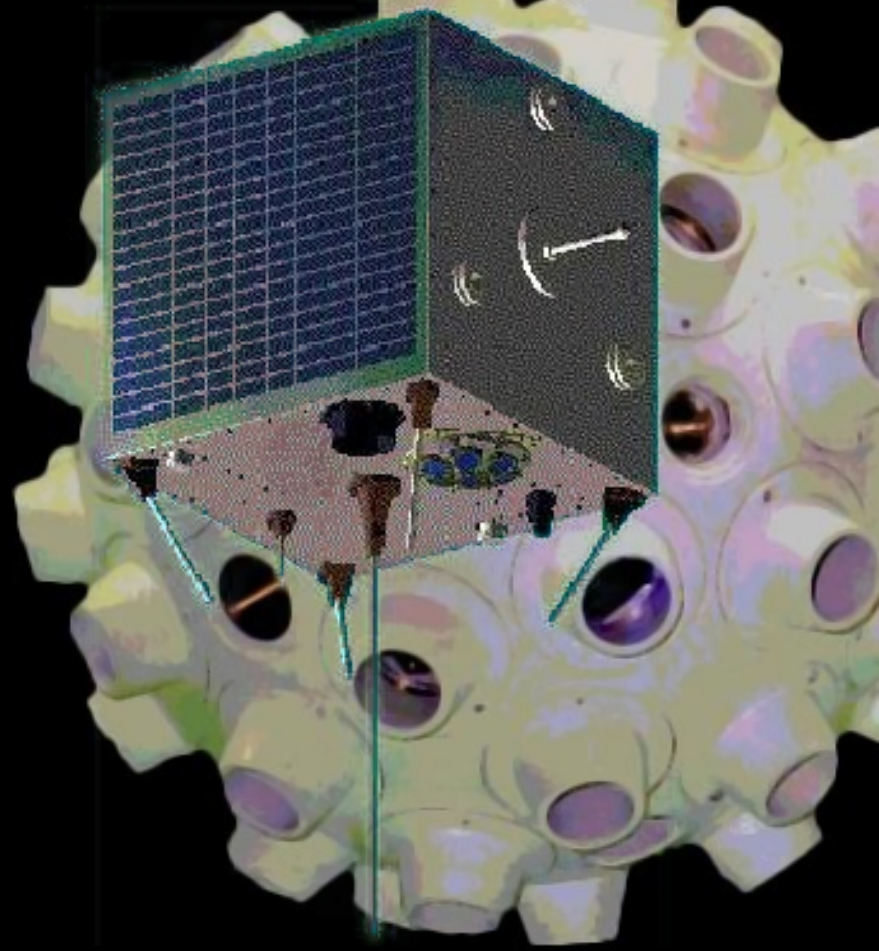
- Which NORAD number is WESTPAC?
- Which NORAD number was used to observe the older WESTPAC SLR data?
- When did the NORAD number change from **25394** to **25398?**



WESTPAC

Stations have been successfully tracking an object using TLEs with NORAD number **25398**.

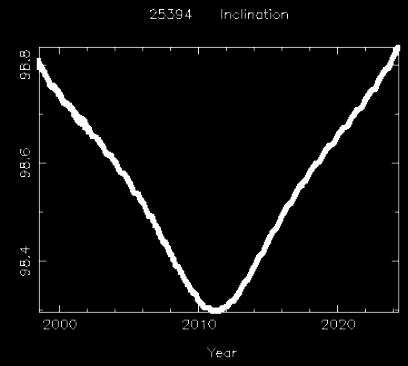


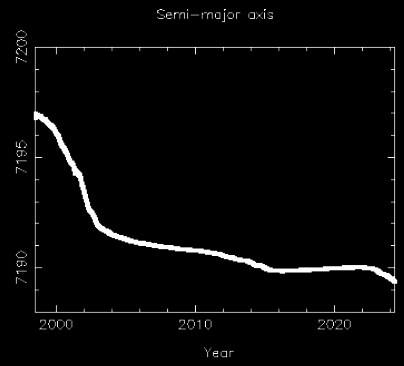


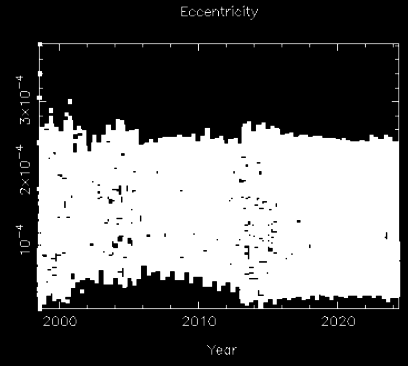
WESTPAC

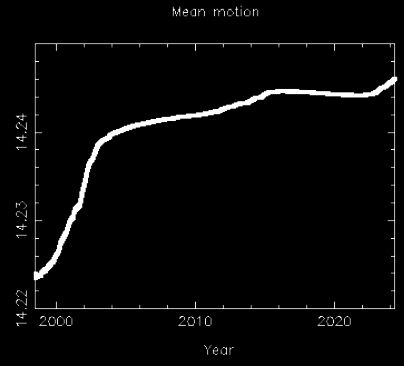
Are we certain that we are tracking the right target?

- Rob Sherwood took a look at the TLE history

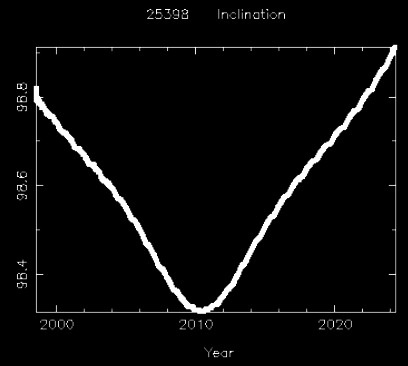


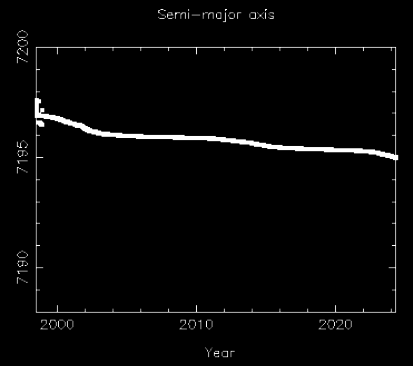


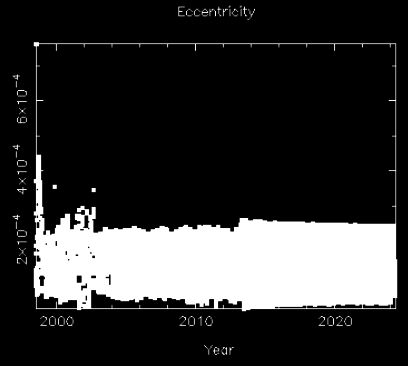


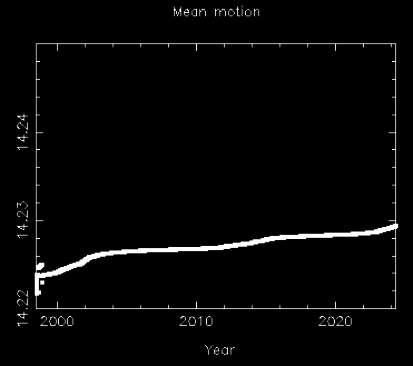


R. Sherwood





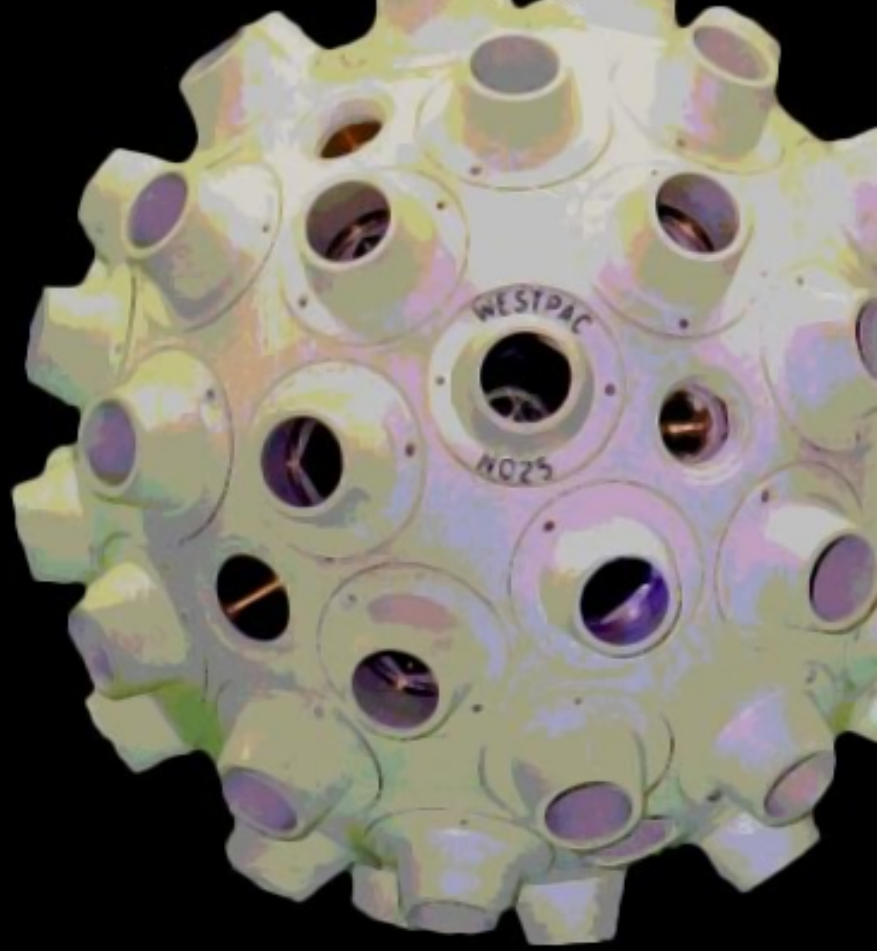




WESTPAC

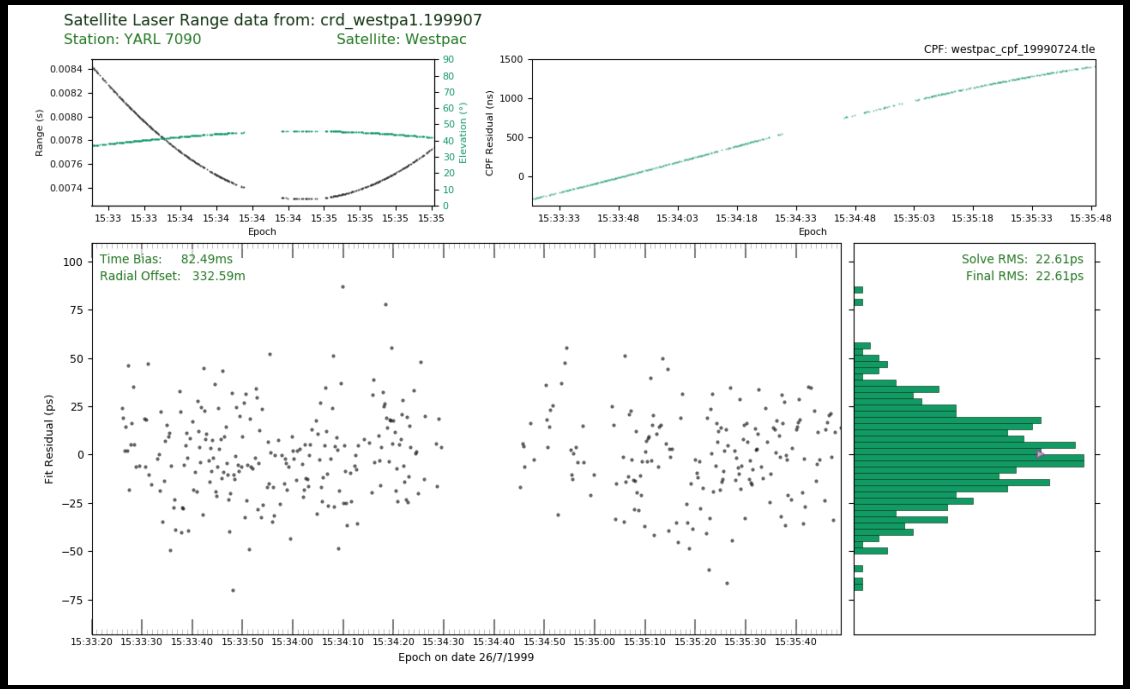
What about the archive SLR data?

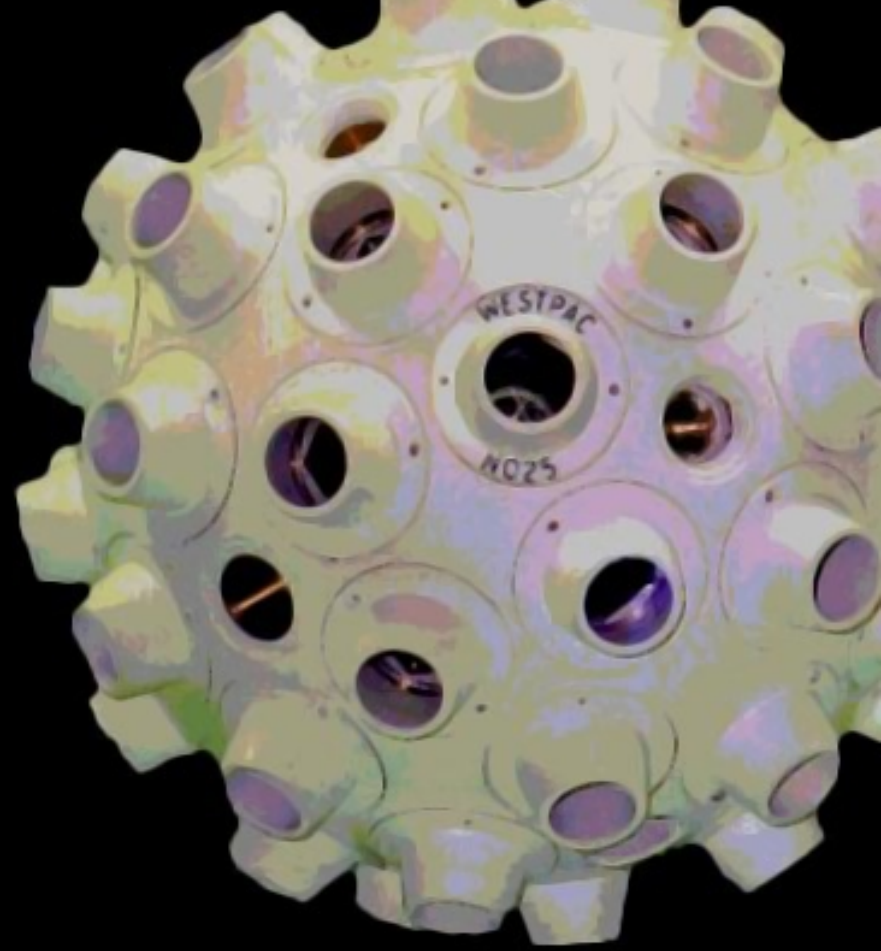
- It was possible to process the SLR data observed in 1998 and 1999 by:
  1) Converting TLEs to CPFs
  2) Converting MERIT II full-rate data to CRD data, using the sample code by R. Ricklefs available on the ILRS website.



WESTPAC

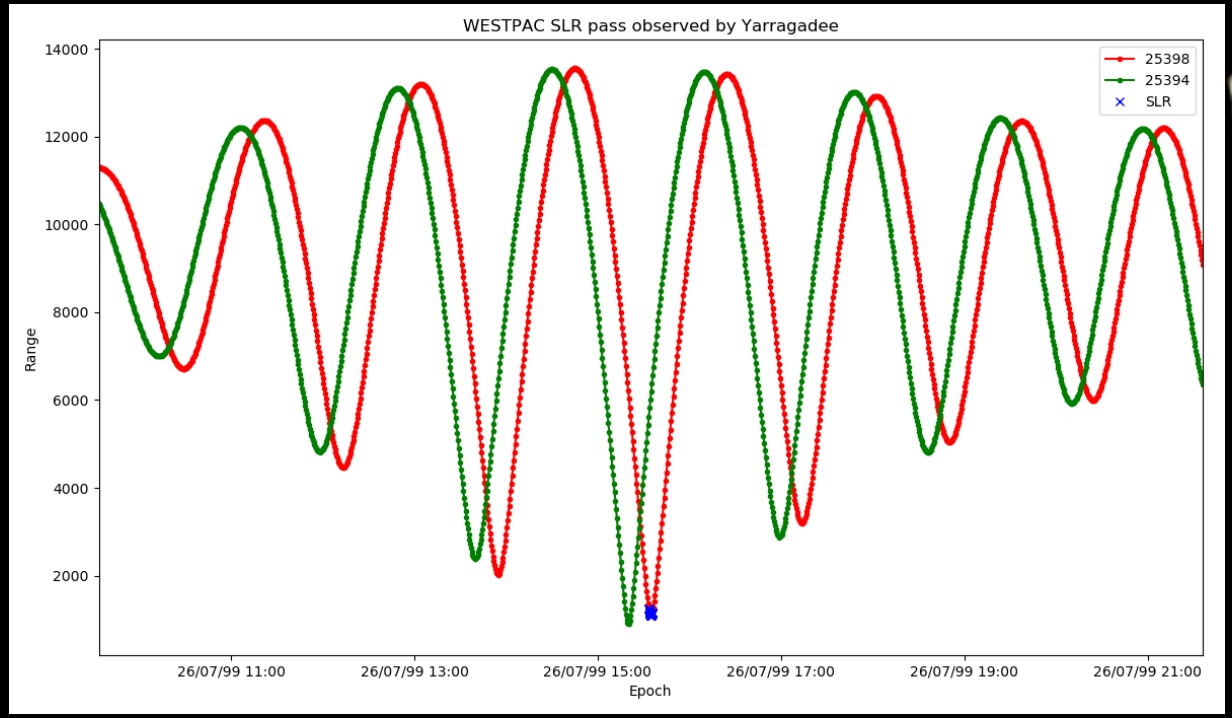
Yarragadee

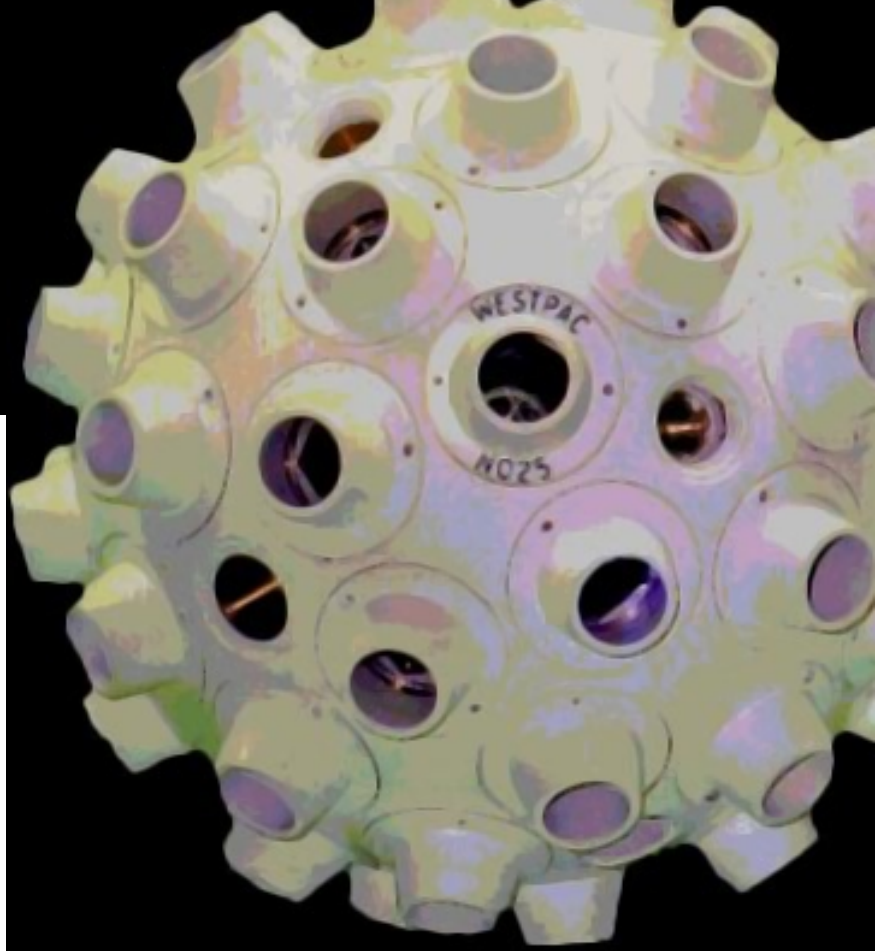




WESTPAC

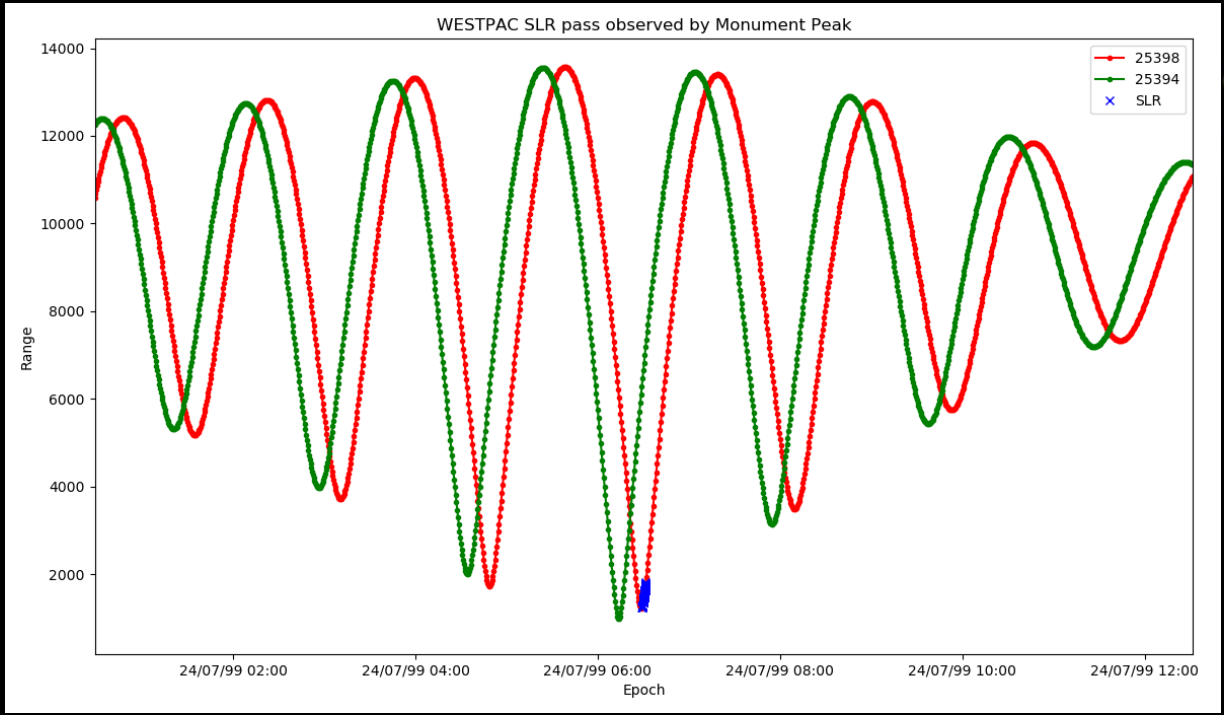
Yarragadee

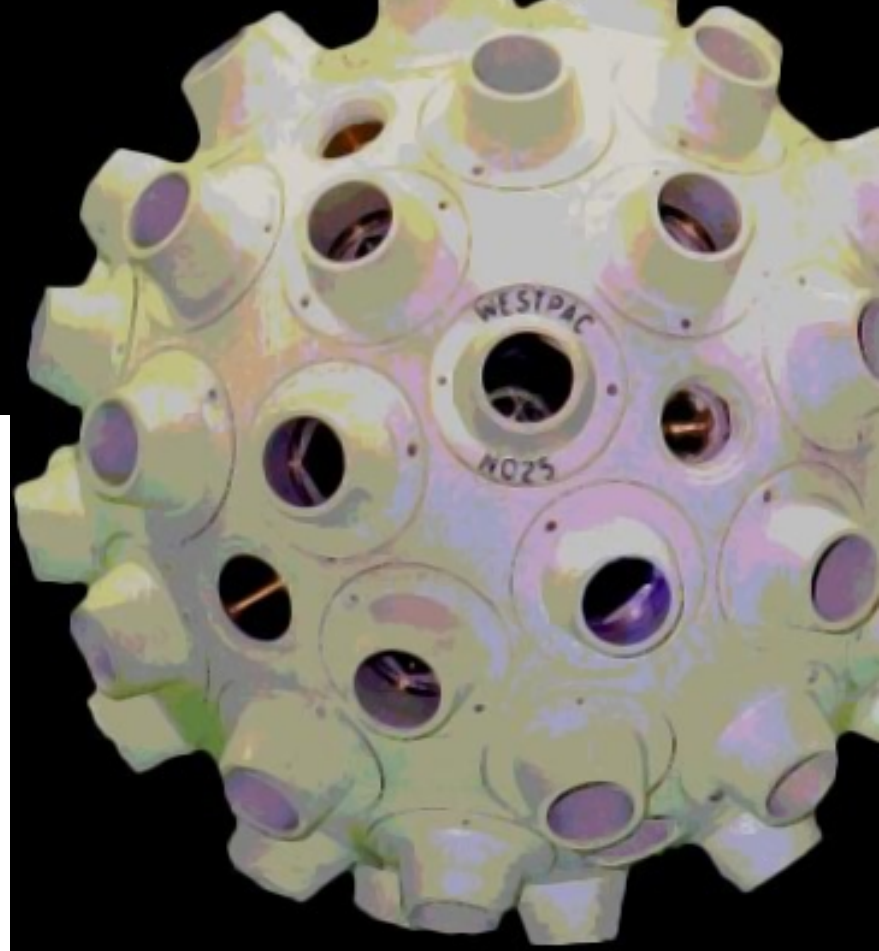




WESTPAC

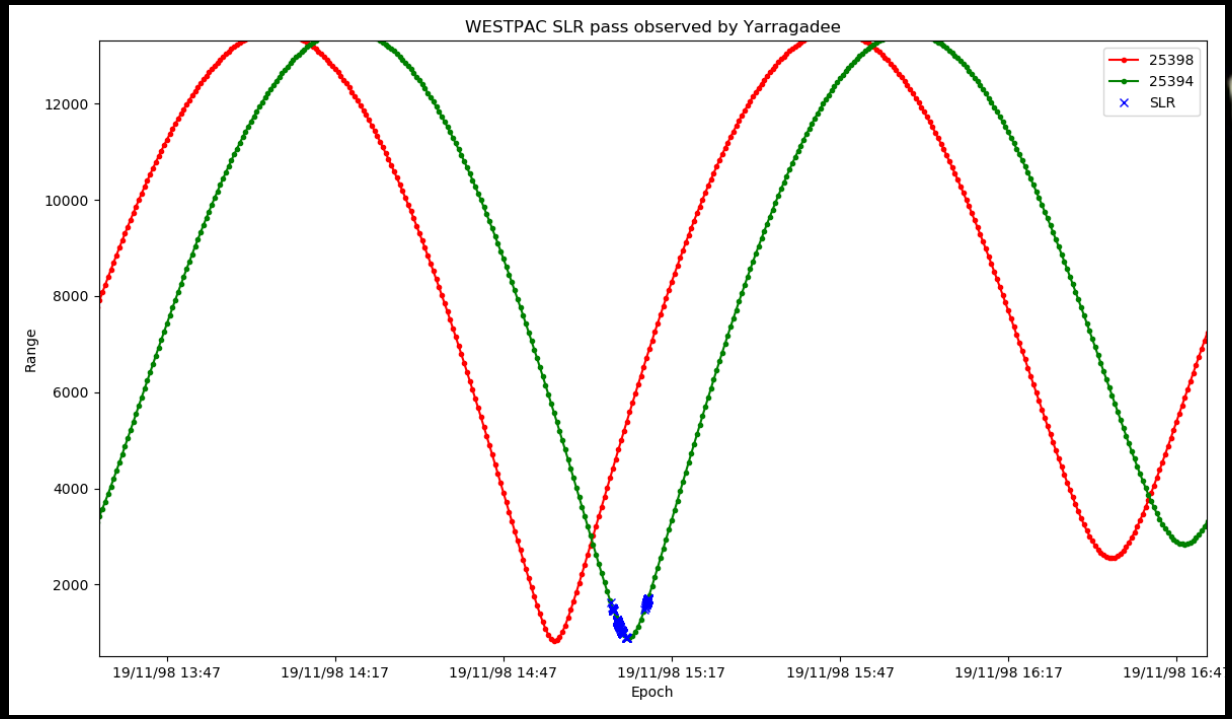
Monument Peak

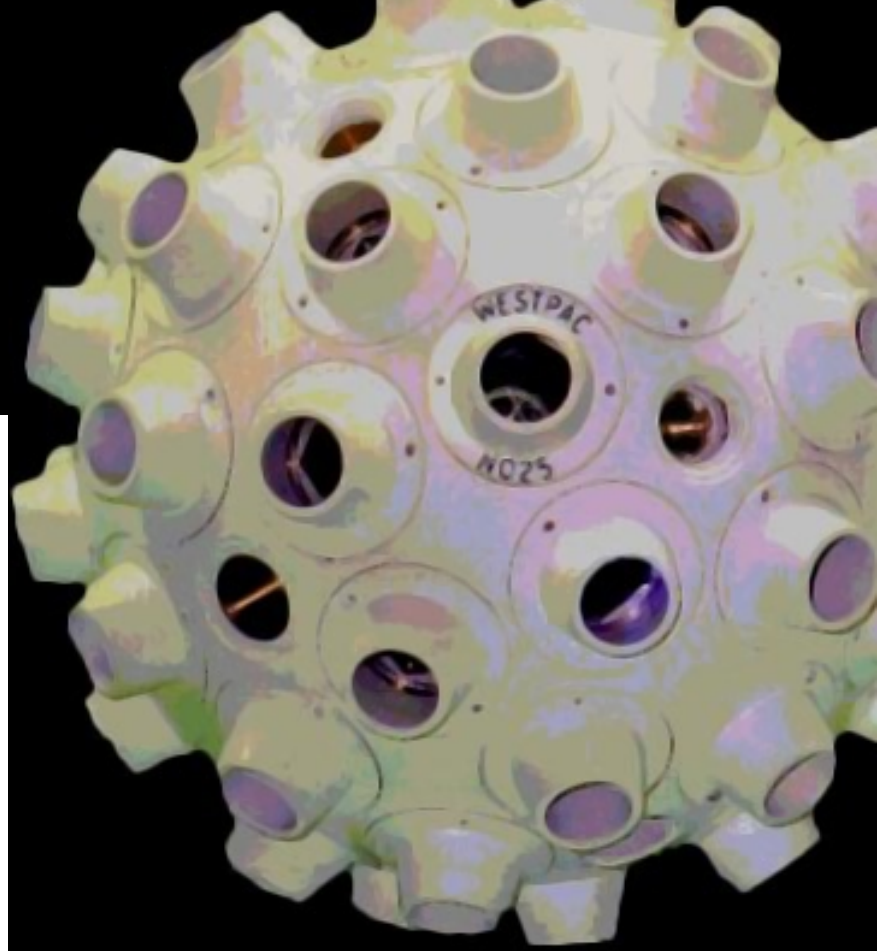




WESTPAC

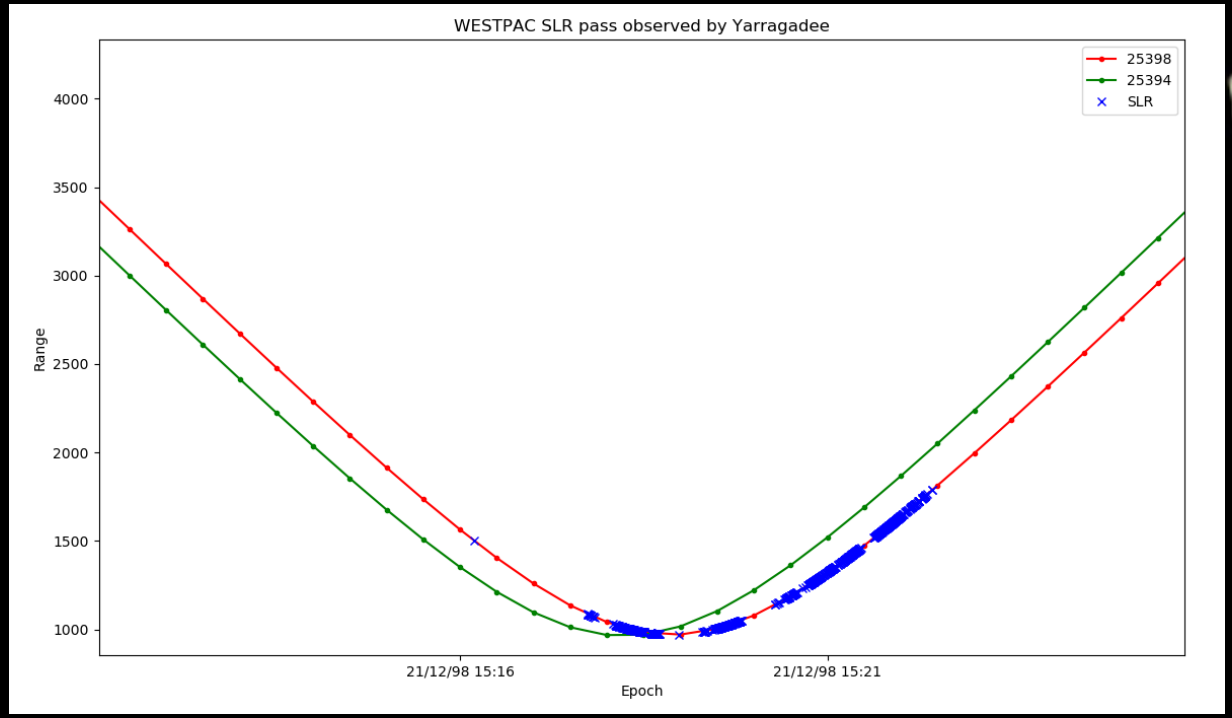
Yarragadee

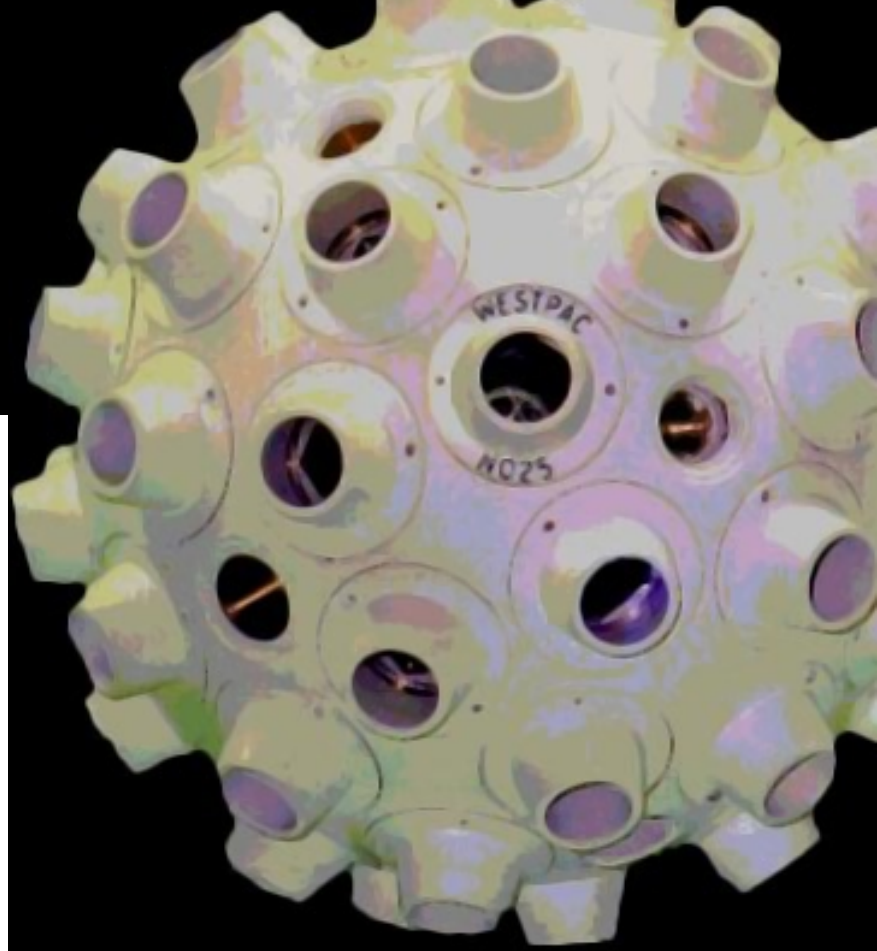




WESTPAC

Yarragadee

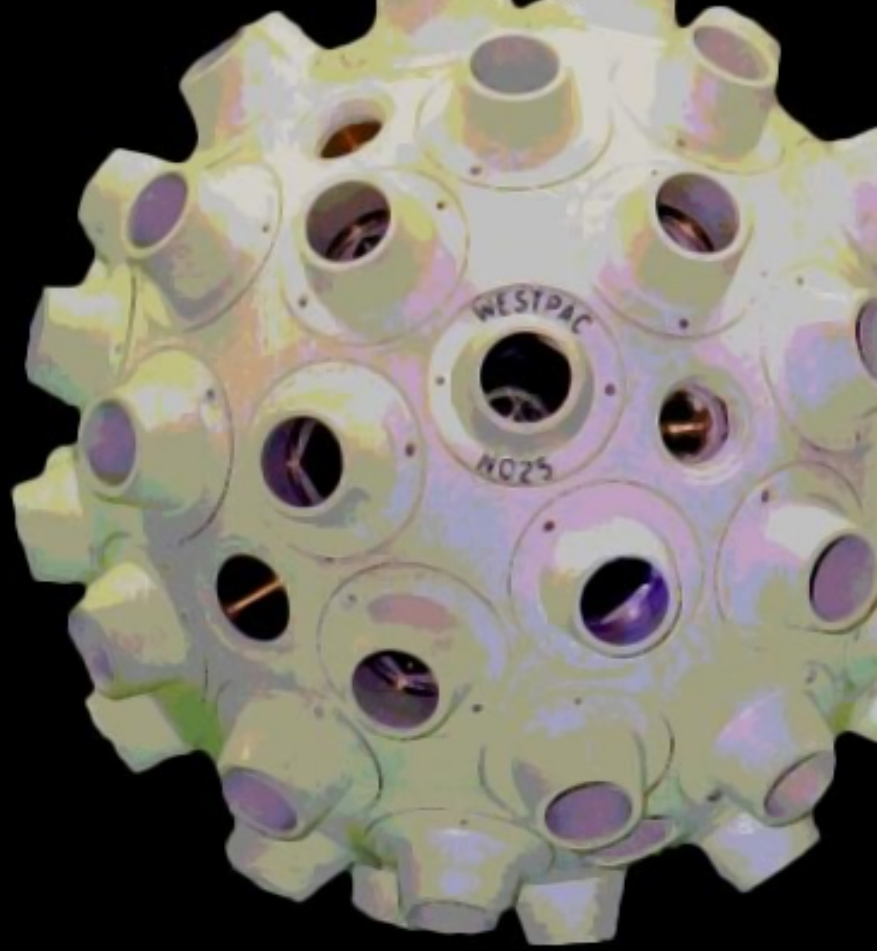




WESTPAC

NORAD Number

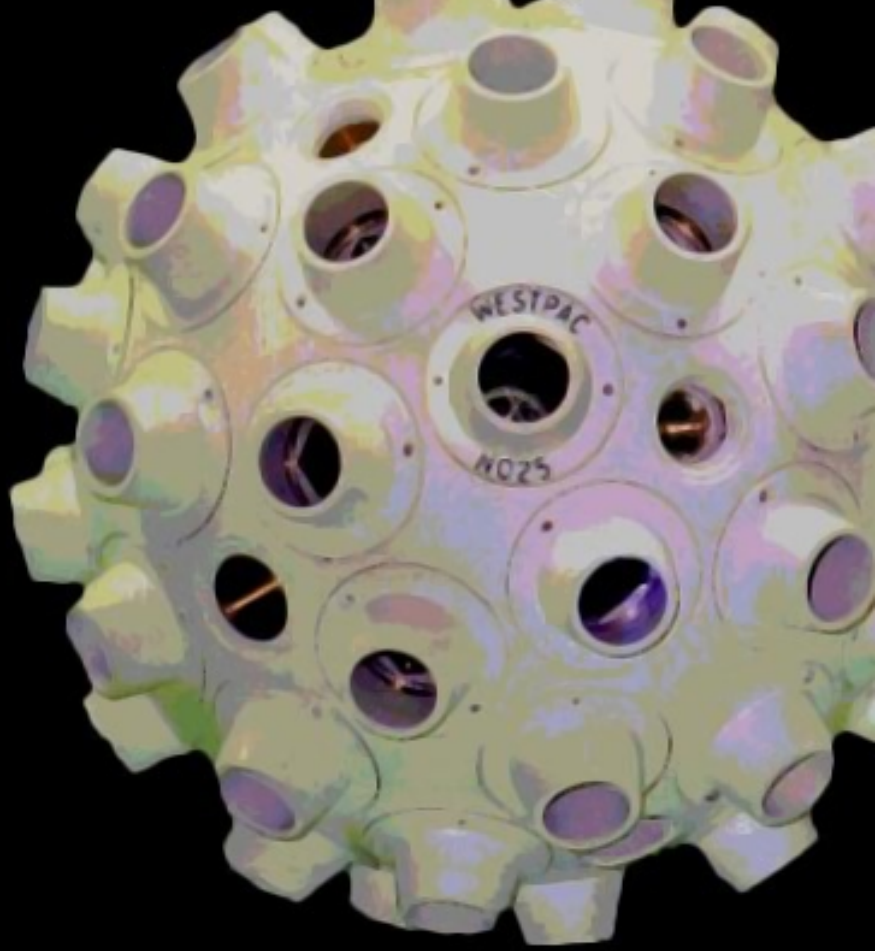
- The WESTPAC NORAD number was 25394 but changed to **25398** in December 1998.
- This object can be observed by SLR and shows a history of stable orbits.



WESTPAC

CPFs are now available

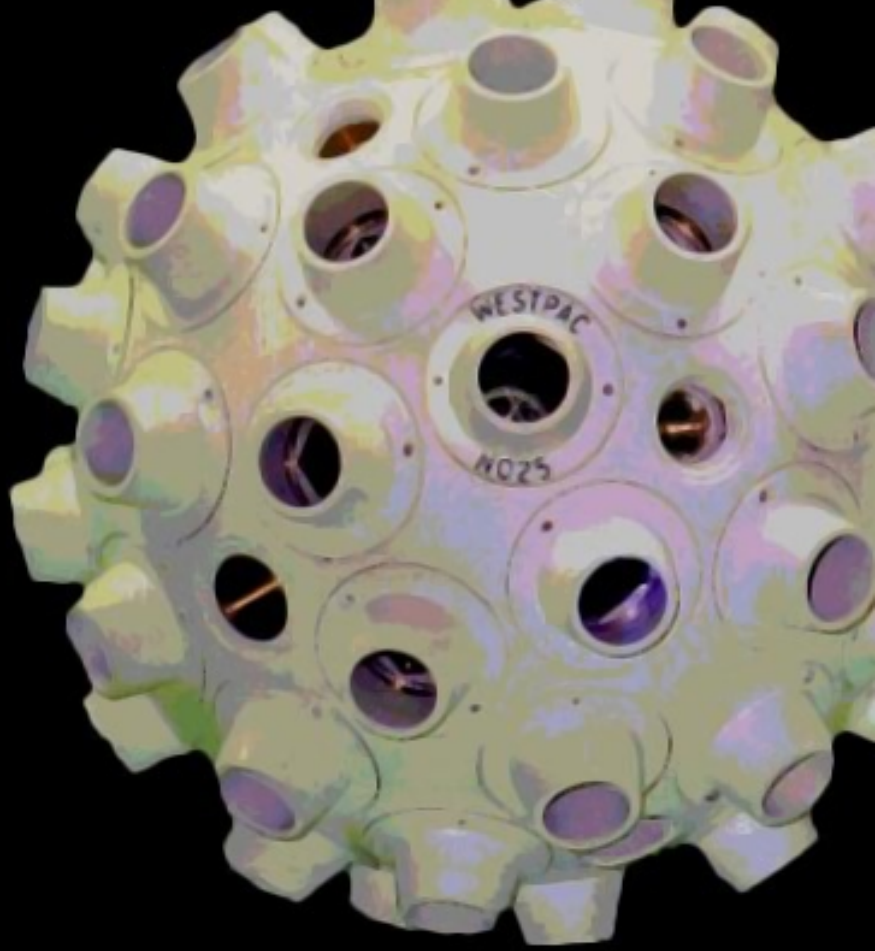
- Graham Appleby has included WESTPAC in the routine orbit prediction service at the SGF, Herstmonceux.
- These are produced daily and are available from EDC.
- They currently have a NORAD number of 25394, but this will soon be changed.



WESTPAC

What’s next?:

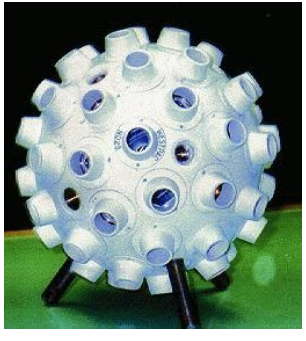
- We are now confident in the target.
- Future data needs to be submitted with the correct number, 25398.
- The quality of the CPFs should be assessed.
- Daylight passes can be attempted with the CPFs.



WESTPAC News

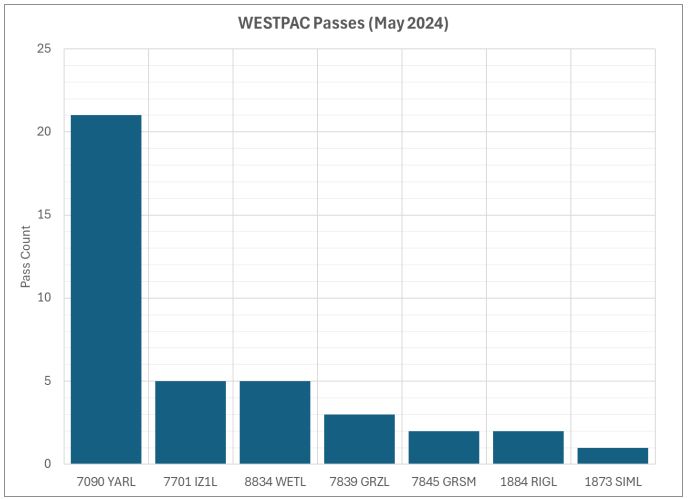
- Since last meeting we are confident which satellite is WESTPAC and SGF (NERC) is providing daily predicts
- We have been using a COSPAR and NORAD Ids of 9804301 and 25394; respectively, but the correct ILRS COSPAR and NORAD IDs are 9804305 and 25398; respectively
- How far back in time do we correct for erroneous COSPAR and NORAD IDs? And who should fix the data?
- Should WESTPAC be added to the priority list?
- WESTPAC is not easy to track. Will there be adequate WESTPAC data set to generate meaningful scientific results?

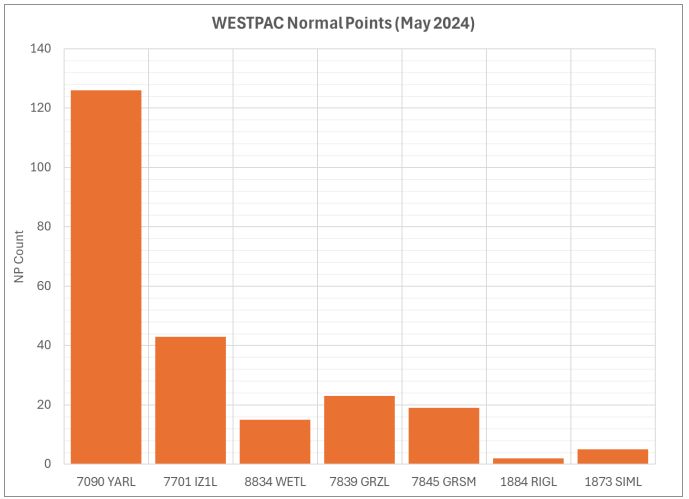
Name	NORAD ID	Int'l Code	Launch date (YYYY-MM-DD)
RESURS O1-N4	25394	1998-043A	1998-07-10
FASAT B	25395	1998-043B	1998-07-10
TMSAT	25396	1998-043C	1998-07-10
TECHSAT 1B	25397	1998-043D	1998-07-10
WESTPAC	25398	1998-043E	1998-07-10
SAFIR 2	25399	1998-043F	1998-07-10

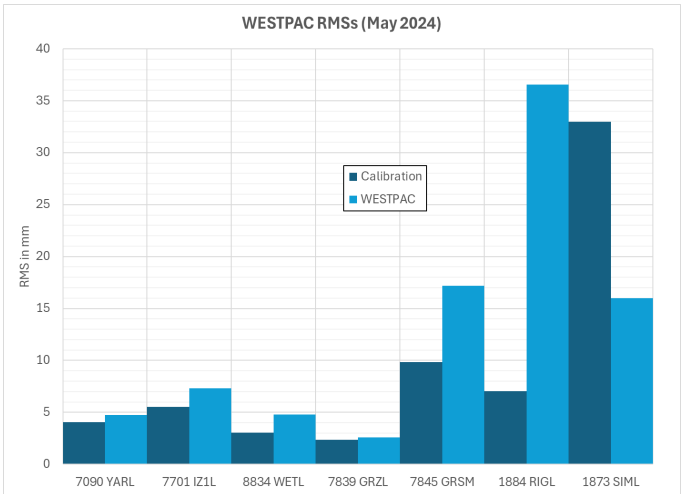


Date Type	COSPAR ID	NORAD ID	SIC
CSTG Normal Points	9804301	N/A	N/A
CSTG Sampled Data	9804301	N/A	N/A
MERIT II Fullrate Data	9804301	N/A	N/A
Predicts (Tuned IRV)	N/A	N/A	8801
CRD Normal Points	9804301	25394	8801
CRD Fullrate	9804301	25394	8801
Predicts (CPF)	9804301	25394	8801

WESTPAC May 2024 Tracking Statistics







Station	Pass Count	NP Count	Cal RMS in mm	WESTPAC RMS in mm	Min NP Range in km	Max NP Range in km	NP Return Rate Min in %	NP Return Rate Max in %	Bin Size in Seconds	Comments
7090	21	126	4.1	4.7	833	2117	0.7	66.7	15	
7701	5	43	5.5	7.3	860	1740	2.3	76.1	8, 15	return rate was 76% in one NP bin
7839	3	23	2.4	2.6	976	1746	0.6	3.4	8	Standard ILRS Bin Size is 15 seconds
8834	3	15	3.0	4.8	861	1225	0.2	1.7	15	2 of 3 passes were at dual wavelengths
7845	2	19	9.8	17.2	1162	2664	6.0	64.7	15	WESTPAC RMS 2x their Calibration RMS
1884	2	2	7.0	36.6	1638	1687	7.8	12.5	15	WESTPAC RMS 5x their Calibration RMS
1873	1	5	33.0	16.0	1092	1340	2.0	8.7	15	WESTPAC RMS 0.5x their Calibration RMS

- **Should all stations use the ILRS standard 15 second bin size?**