LPQI
La Palma
Quantum Interferometer

https://lapalmaqi.es/

The La Palma Quantum Interferometer: The next frontier for microarcsecond resolution in optical astronomy

Francisco Prada and the LPQI Collaboration

Instituto de Astrofísica de Andalucía CSIC
Instituto de Astrofísica de Canarias

LPQI COLLABORATION























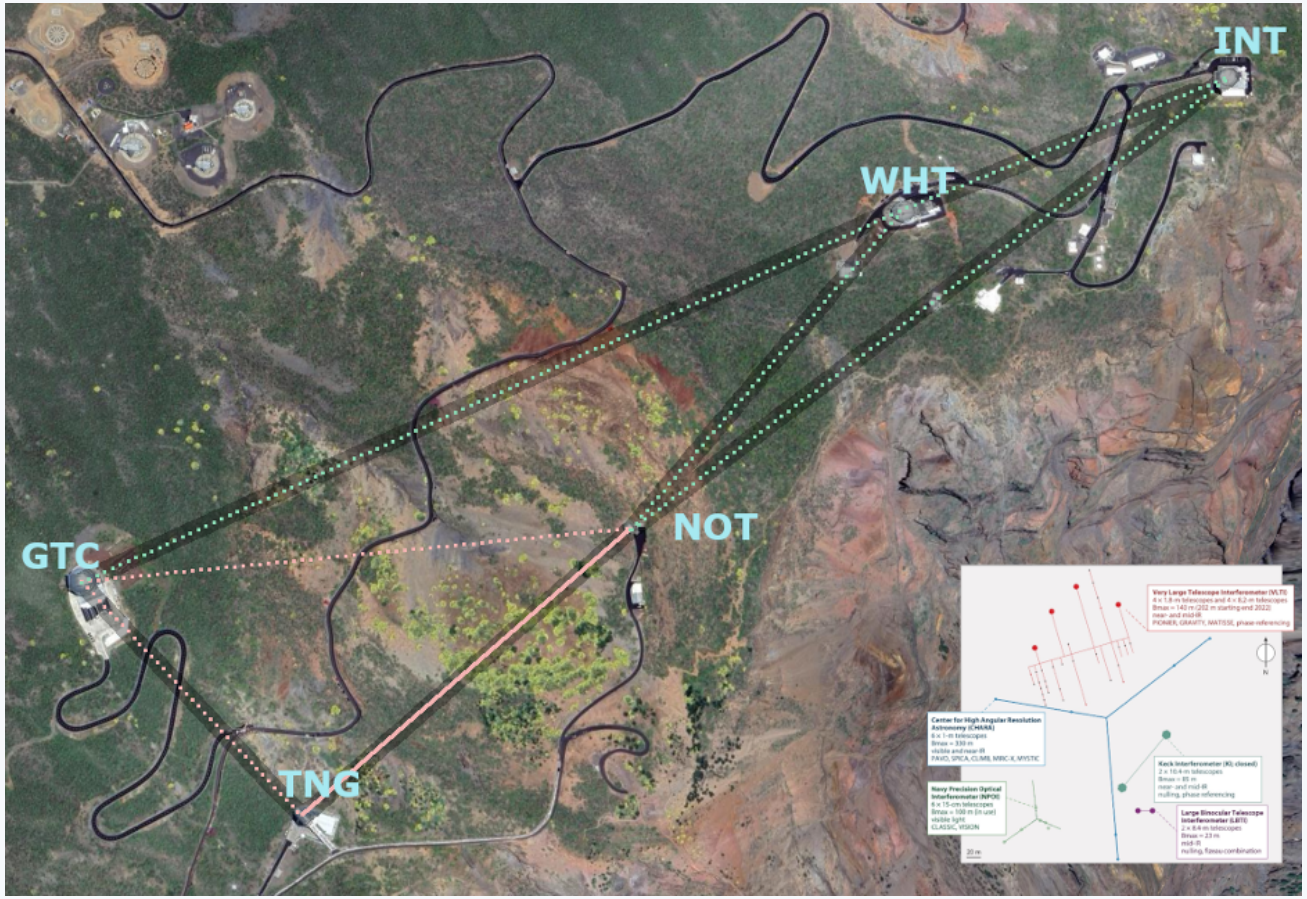






What LPQI is building

A visible-light intensity interferometer using the five largest optical telescopes at La Palma.



ORM telescope network: GTC, TNG, NOT, WHT, INT

See Di Fabrizio et al. SPIE 2026

Core idea

Correlate photon detections from multiple telescopes at Roque de los Muchachos (ORM) using SPAD photon-counting spectrographs and picosecond time synchronization.

Why it matters

The maximum baseline of 1.55 km sets the angular resolution. LPQI aims for about 50 µas in the visible band.

How it scales

High-resolution spectroscopy splits the photon stream into 10,000 independent wavelength channels, boosting SNR as $\sqrt{N_{channels}}$.

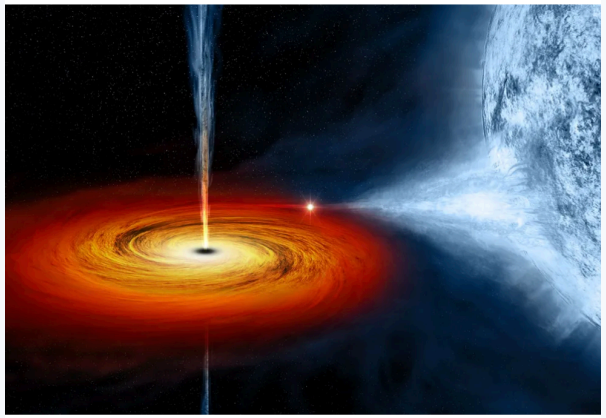
50 µas
target angular resolution

1.55 km
maximum baseline

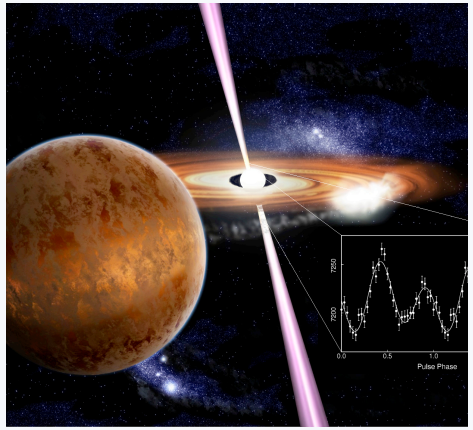
10,000
spectral channels

Science enabled by microarcsecond optical resolution

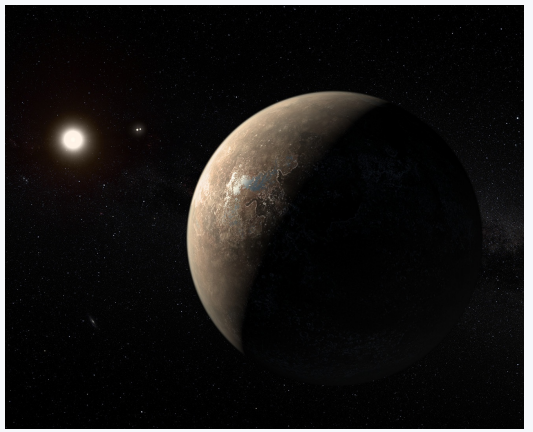
LPQI targets physics that is inaccessible to ground based adaptive-optics and space (HST, JWST) imaging.



Compact accretion and strong gravity



Millisecond pulsars and neutron stars



Earth-like planets

LPQI science cases include compact-object environments, black-hole accretion disks, neutron stars, nearby supernovae to measure the Hubble constant, ultra-fast transients, stellar surfaces, and Earth-like planets.

~1000×

better angular resolution than HST/ JWST at optical wavelengths

μas

astrometry and surface imaging regime

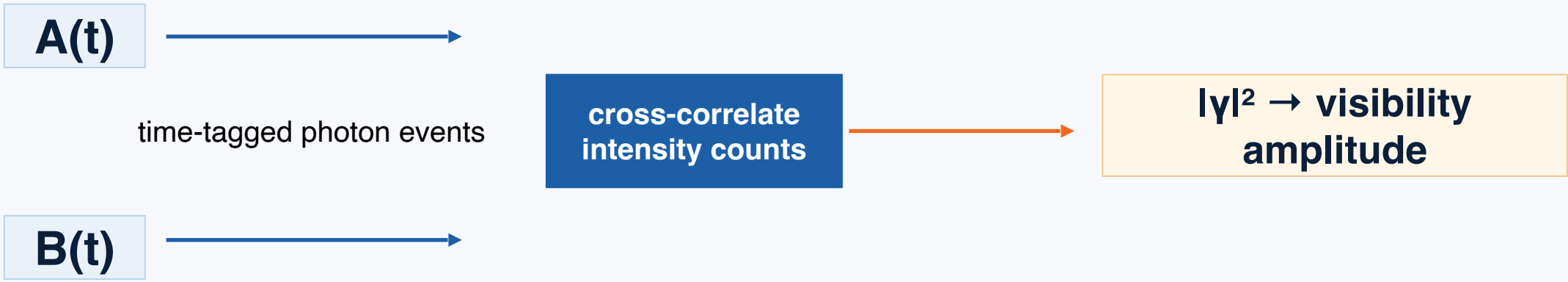
visible

photon-counting interferometry

Intensity interferometry: the measurement principle

LPQI measures correlations of photon arrival times, not optical phase.

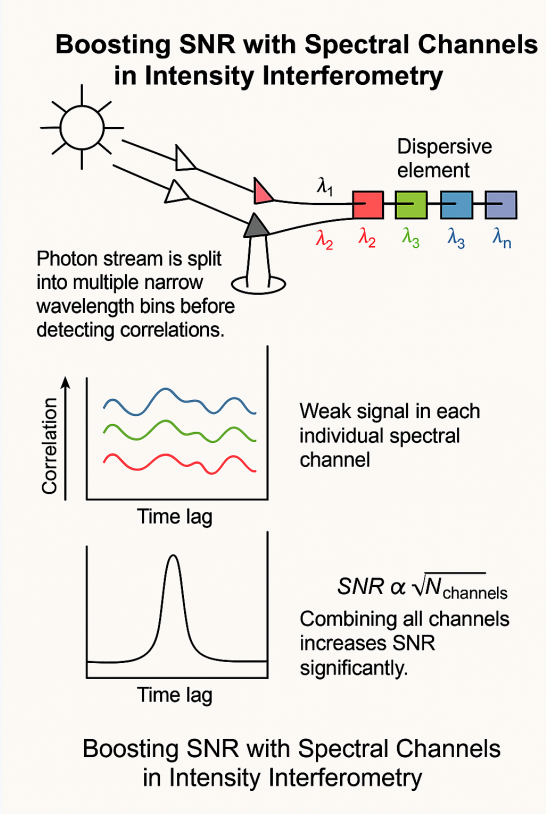
Photon streams from telescope A and telescope B



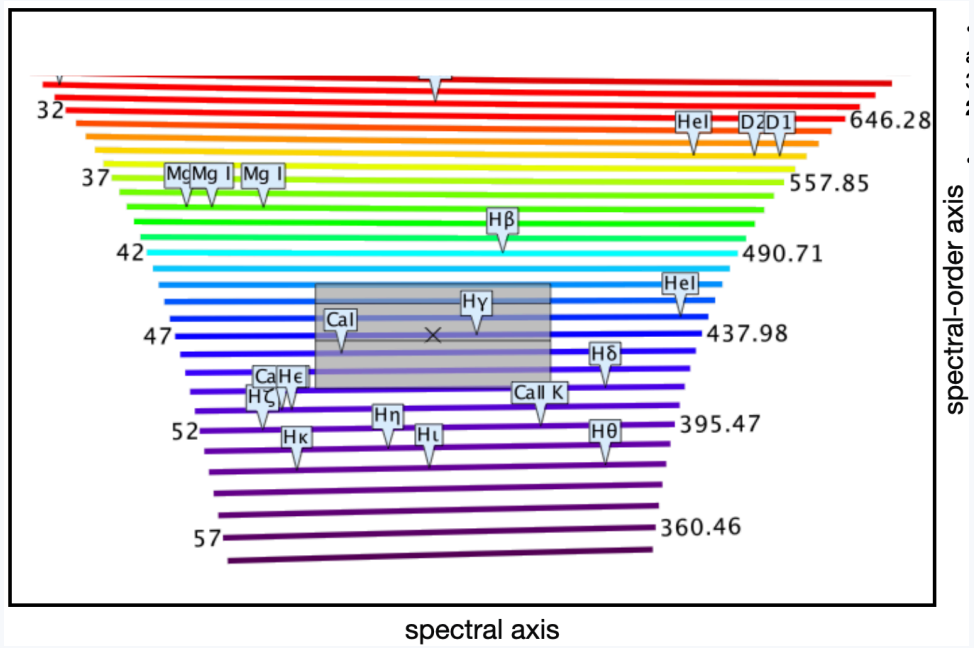
- Insensitive to atmospheric phase turbulence in the way amplitude interferometry is not.
- Requires high photon statistics and picosecond-level synchronization.
- Best matched to bright sources and many independent spectral channels.

Why LPQI uses spectroscopy

Many spectral channels turn visibility measurements into a practical facility.



Spectral channels boost the total SNR



Echellogram: thousands of independent channels

SNR scales as

$$SNR \propto \sqrt{N_{channels}}$$

LPQI goal

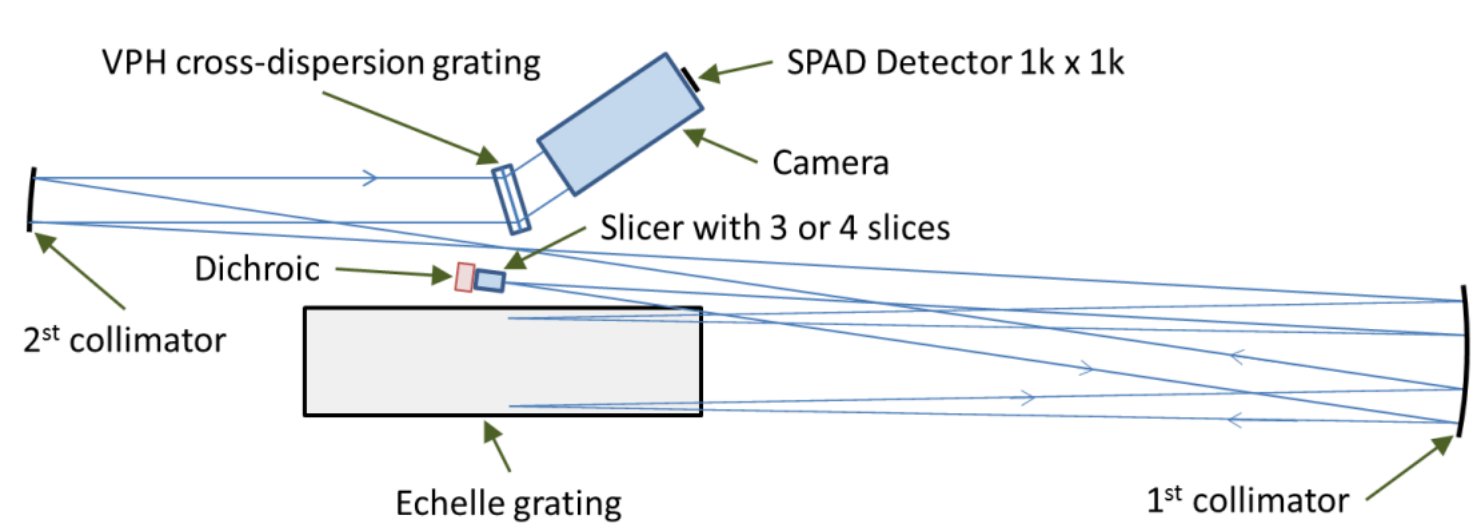
High-resolution spectroscopy across the visible range delivers up to 10,000 channels. This converts a difficult single-filter measurement into a scalable interferometric observable.

10,000

wavelength channels

FIRNAS: the first LPQI spectrograph step

High-resolution spectroscopy is the route to sensitivity.



Conceptual optical layout for FIRNAS at the INT

See Content et al. SPIE 2026

First spectrograph

FIRNAS is proposed as the first LPQI spectrograph on the Isaac Newton Telescope.

Design goals

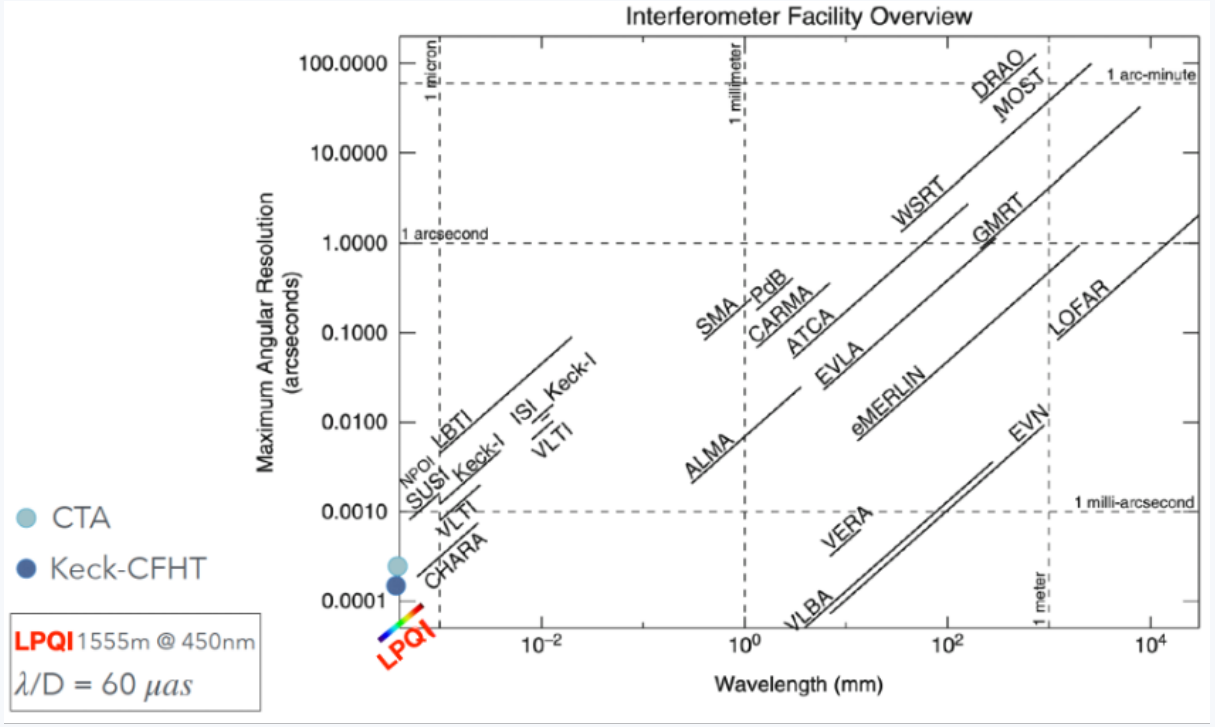
Echelle spectrograph with R ≈ 10,000, many wavelength channels, and a large-format 1k x 1k SPAD detector under development.

Scaling logic

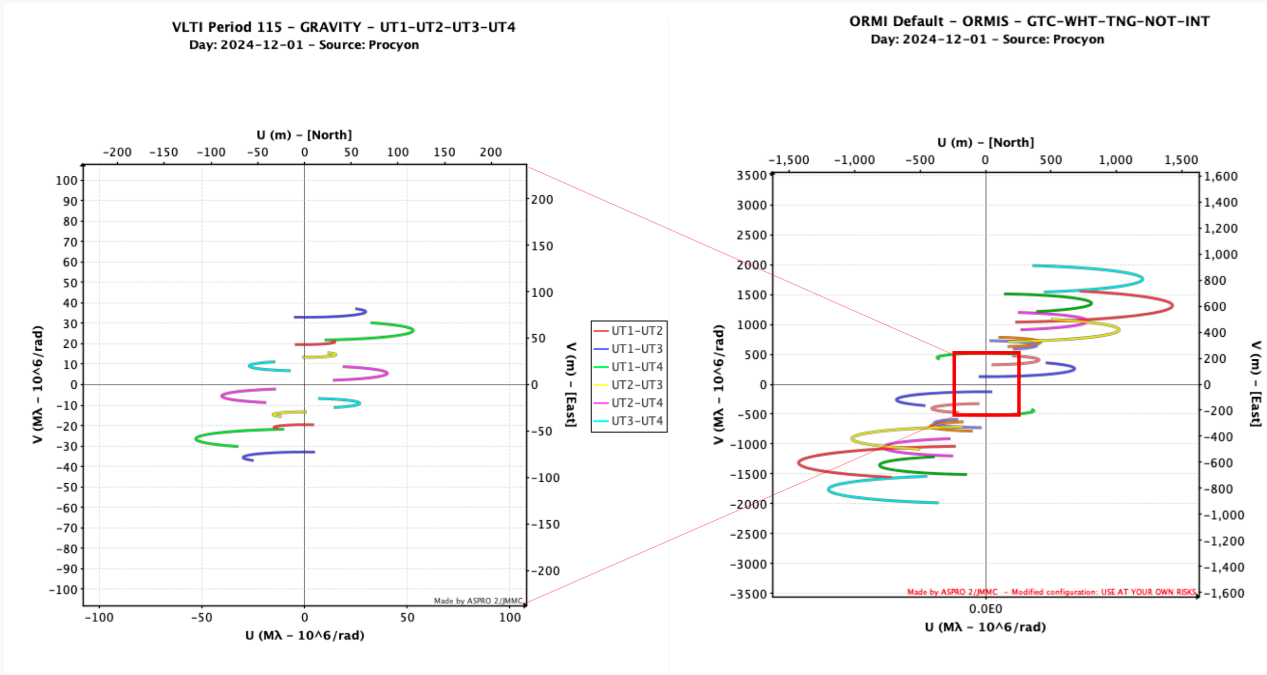
Ultimately, all LPQI telescopes will receive similar spectrographs to maximize baselines and sensitivity.

LPQI baseline advantage

Largest five optical telescopes at ORM provide a 1.55 km optical interferometric array.



World-wide Interferometer Facilities



Comparison of UV plane coverage of LPQI and VLTI.

At 400 nm, $\lambda/B_{max} \approx 55$ μas for $B_{max} \approx 1550$ m. This is the key LPQI facility-level science driver.

Technology innovation stack

LPQI is a transdisciplinary instrumentation program.

SPAD sensors	single-photon arrays designed and validated in Spain
Readout electronics	TDC/FPGA timestamping, event management, high-speed links
Synchronization	White Rabbit over kilometers of fiber with picosecond precision
Spectrographs	Echelle spectrographs with thousands of independent channels
Cryogenic cameras	integrated SPAD heads for stable low dark current rate operation
Data/AI pipelines	massive event streams, correlations and visibility inference

First proof point: SPAD astronomy on Betelgeuse

A 64×64 SPAD camera demonstrated fast photon-counting astronomy during Leona's occultation (Prada et al. 2024)

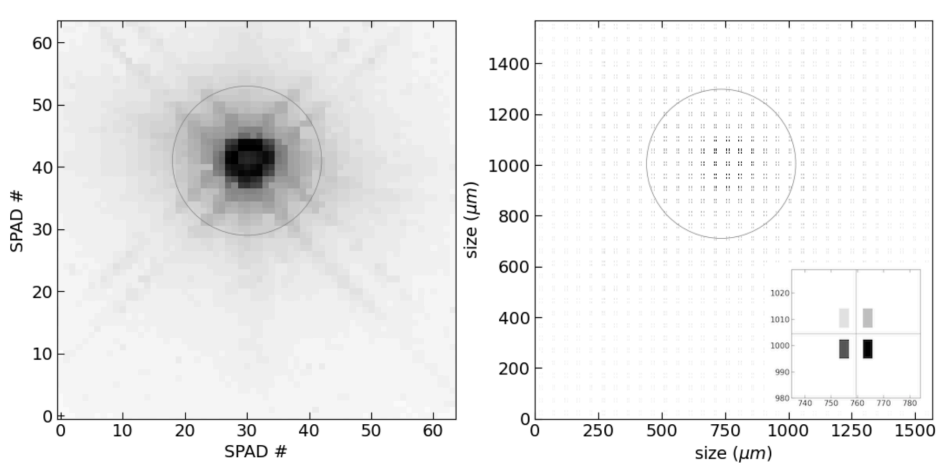
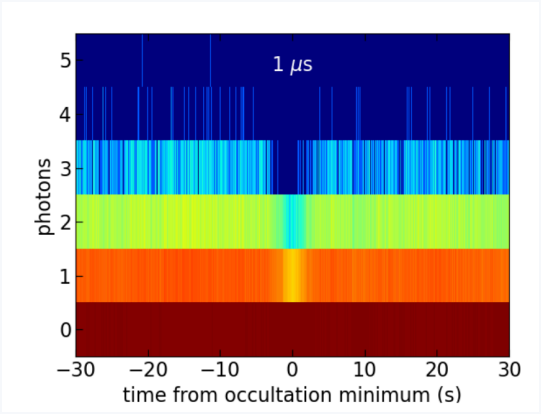
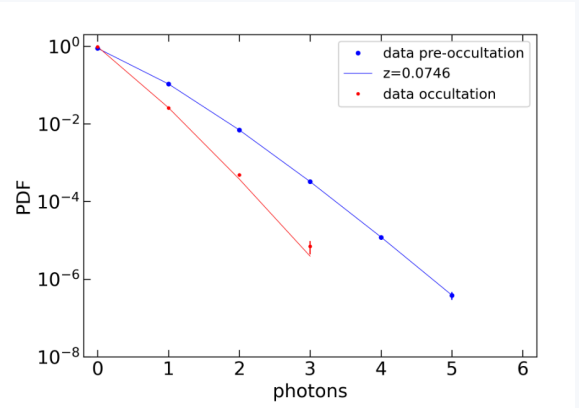


Fig. 1. Defocus image of Betelgeuse during a single-chord occultation on December 12, 2023, captured with our SPAD camera from AstroCamp observatory in Nerpio, Southeast Spain. The right panel reveals a 64 × 64 pixel image, displaying SPAD pixel arrangement. The inset offers a closer view of the 2 × 2 SPAD arrangement within each pixel. The left panel showcases a symbolic SPAD image, illustrating Betelgeuse defocus and diffraction features. Our analysis focuses on counting photons within a circular aperture avoiding fainter diffraction spikes, remaining constant throughout the study and comprising *X* pixels on the detector. The image corresponds to a 50-second data capture period.

Betelgeuse occultation observation





Photon statistics from the event

$$\theta_s = \theta_{\text{ast}} \left(\frac{1}{\sqrt{1 - I_{\text{drop}}}} \right).$$

Angular diameter estimation method

Result

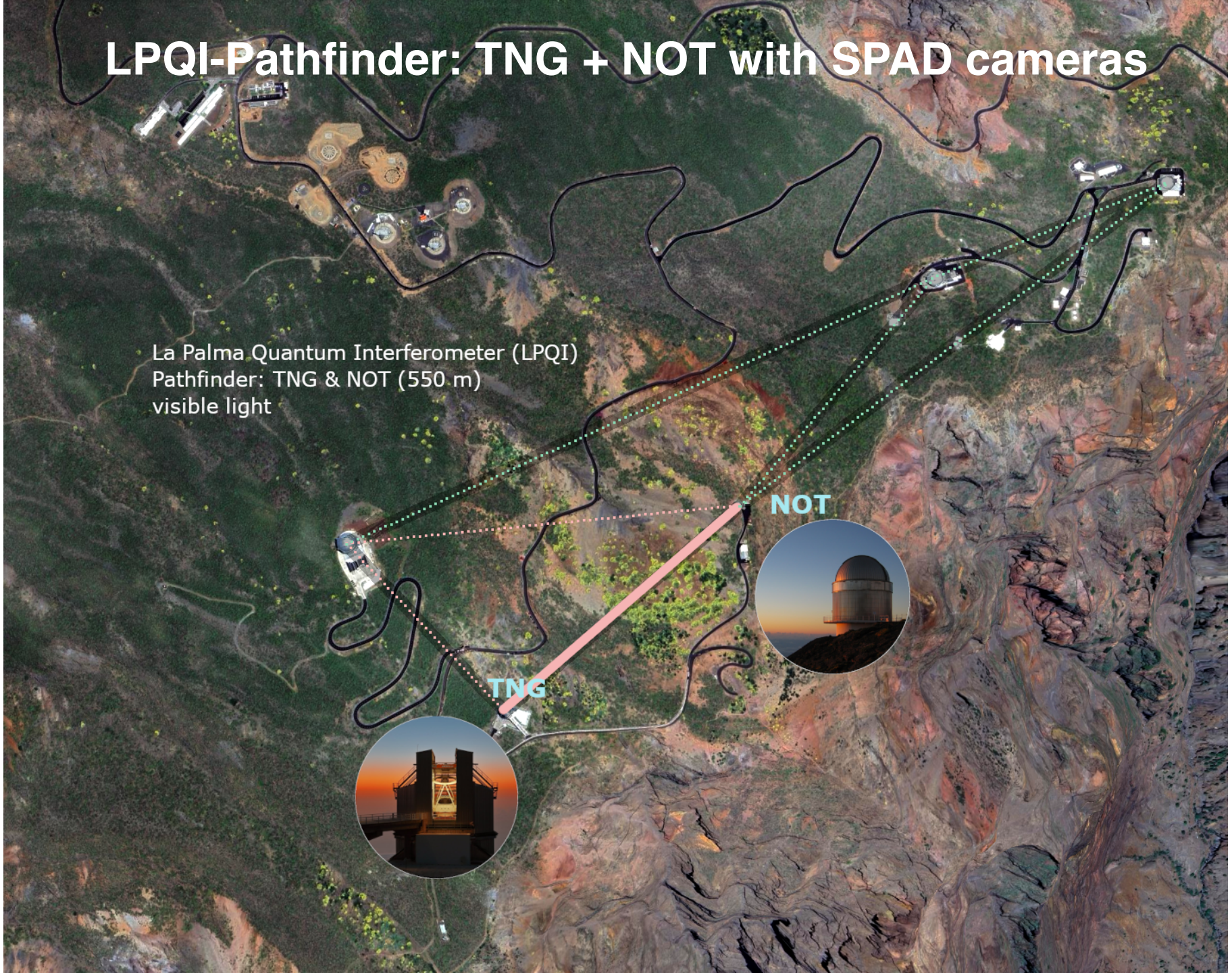
The observation produced a direct visible-band angular-diameter estimate of Betelgeuse. It catalyzed the LPQI collaboration and validated quantum astronomy using 2D SPAD detector as a pathfinder technology.

64×64
first SPAD-array demonstrator

0 read noise
photon-counting regime

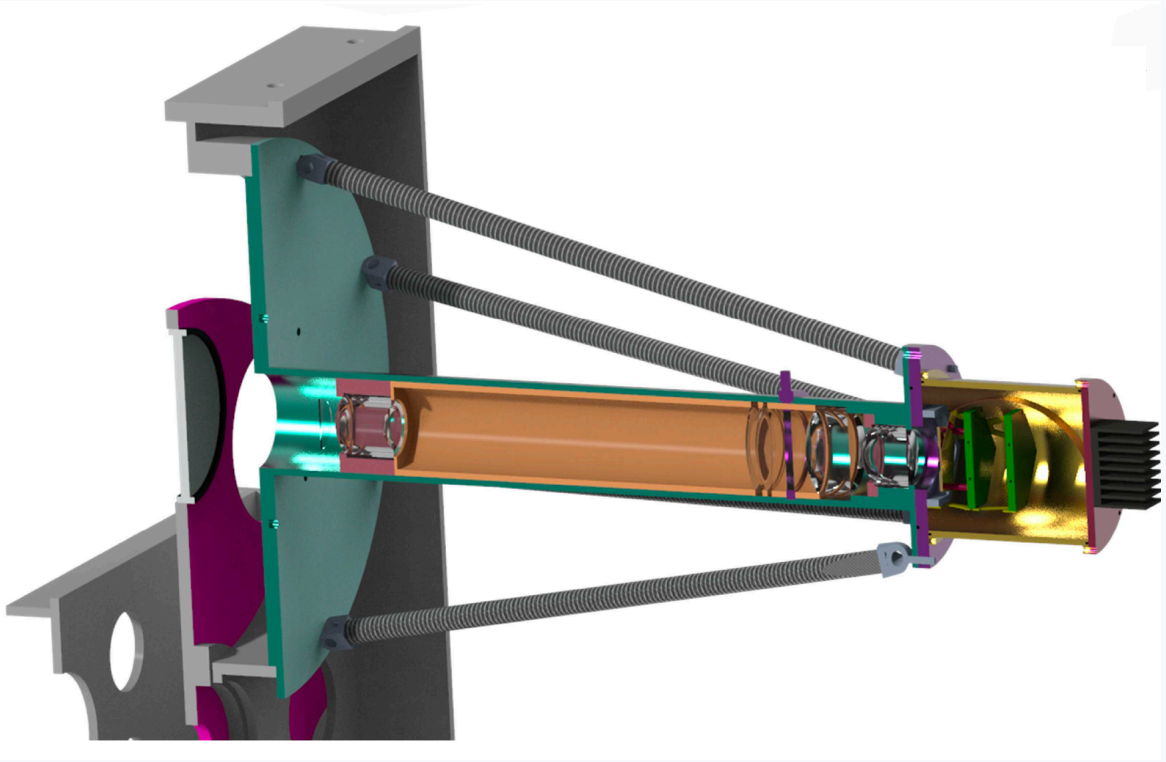
57.25 mas
estimated visible-band diameter

LPQI-Pathfinder: TNG + NOT with SPAD cameras

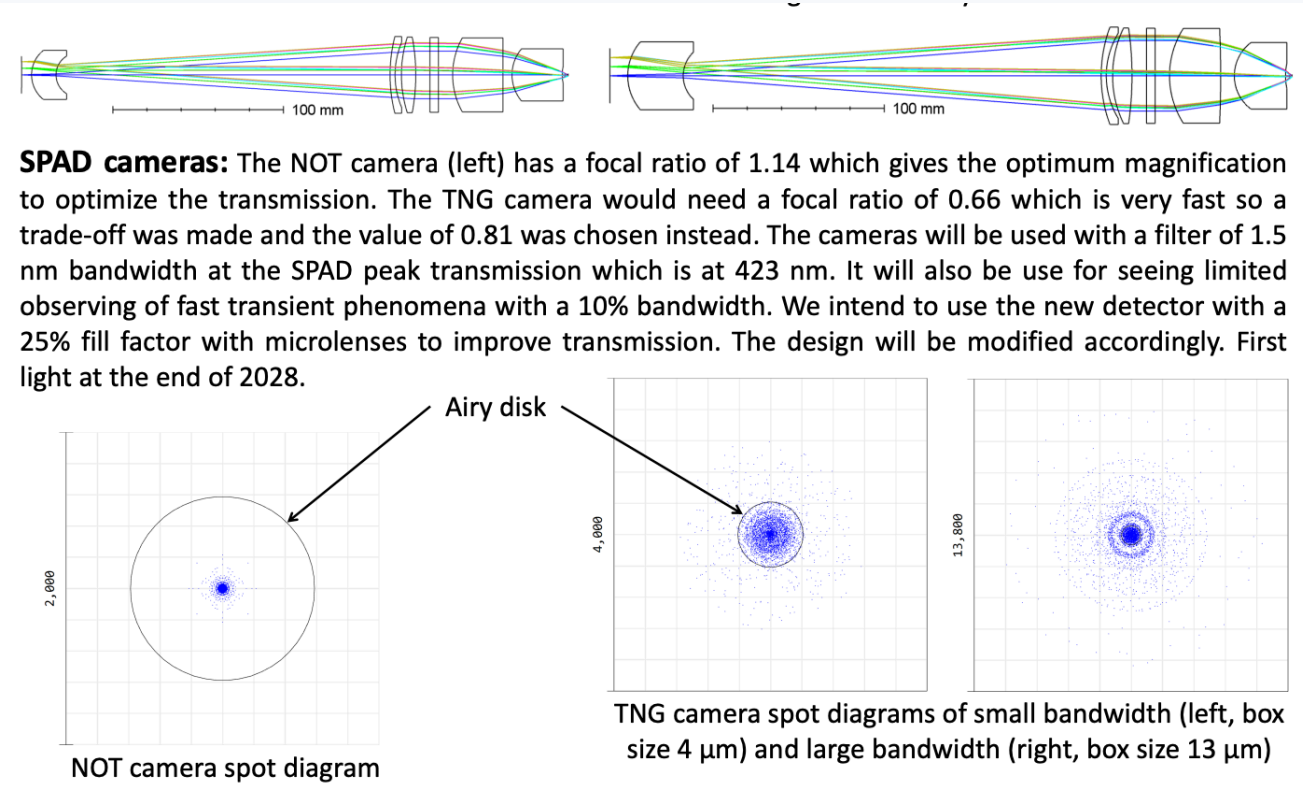


LPQI-Pathfinder: TNG + NOT with SPAD cameras

The first interferometric step focuses on a two-telescope narrow-band demonstrator.



TNG/NOT SPAD camera opto-mechanical concept



NOT and TNG camera optics / spot diagrams

See Content et al. SPIE 2026

See Di Fabrizio et al. SPIE 2026

2028
first light

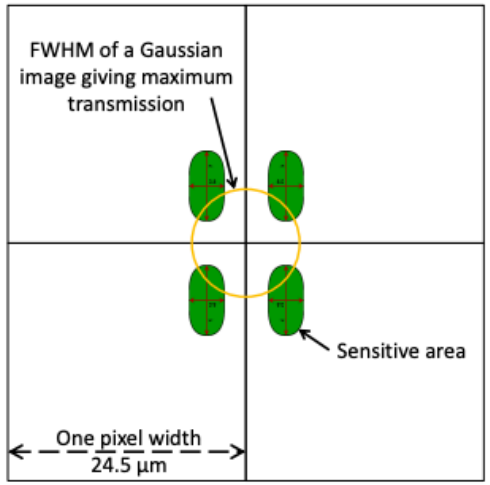
TNG + NOT
two-telescope pathfinder

~550 m
baseline

~180 µas
resolution goal

SPAD fill factor and optical coupling

The first detectors force the optics to compensate for sparse sensitive area.



SPAD detector: As a LPQI-Pathfinder project, we are planning to place a camera on the NOT telescope and another on the TNG telescope. The present detector that we have has 64 x 64 pixel with a time resolution of 0.8 ns. However, only 3.5% of the surface is sensitive and decentred in each pixel. The sensitive area are also clustered in groups of 4 around a pixel corner. A new detector with a 25% sensitive area and time resolution below 0.5 ns is now in production. Two methods were studied to improve the transmission:

1- Microlens arrays in front of the detector: The simplest design would use an unusual microlens array where all microlenses are off-axis (Fig. bottom left). Discussions with manufacturers suggests that it is feasible.

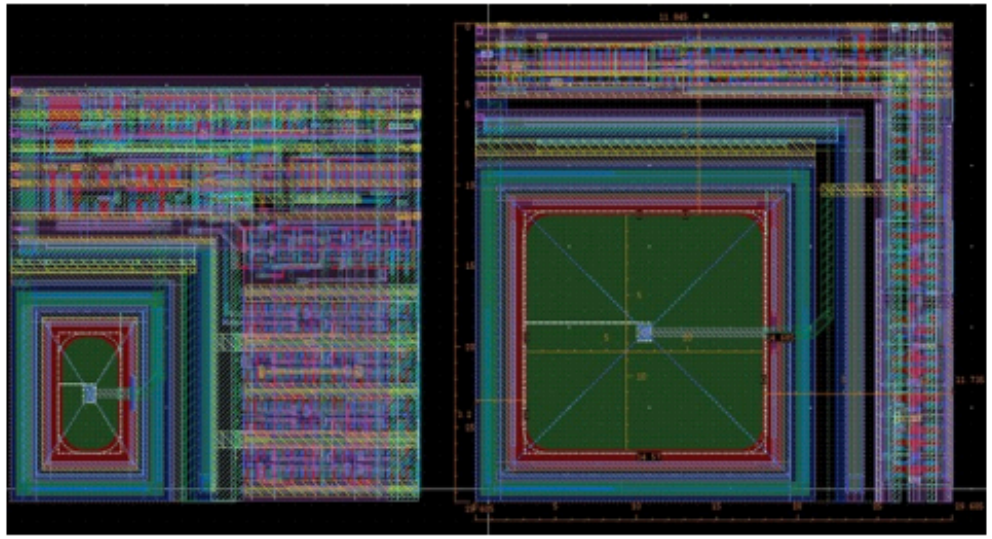
2- The camera takes advantage of the clustering of the sensitive areas to image the source on a cluster of 4 sensitive areas. The optimum gives about 21% transmission instead of 3.5% if the detector is uniformly illuminated. Since this is just a demonstrator project, this method was chosen for simplicity.

Off-axis microlens concept

See Content et al. SPIE 2026

Current detector (left)

64×64 pixels, only 3.5% sensitive area, decentered and clustered by groups of four.



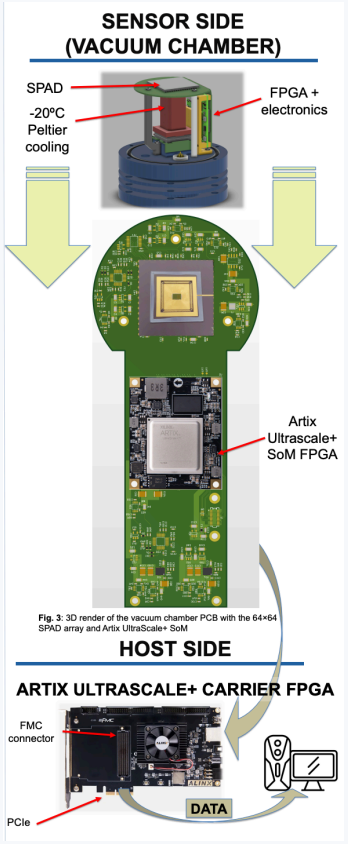
Pathfinder detector choice (right)

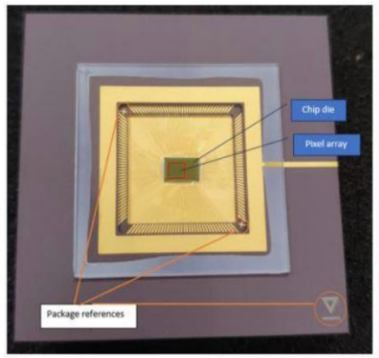
25% fill factor (100% with micro lenses) and sub-0.5 ns timing will simplify the optical design and improve throughput.

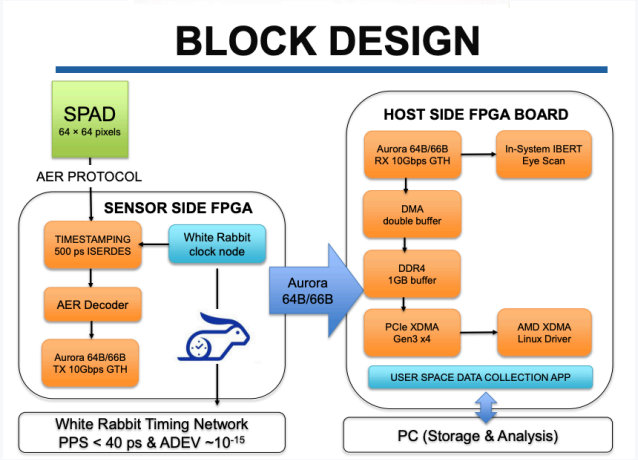
See Cosentino et al. SPIE 2026

Readout electronics for the LPQI-Pathfinder SPAD detector

From asynchronous SPAD events to synchronized data streams.







Front-end / back-end FPGA architecture

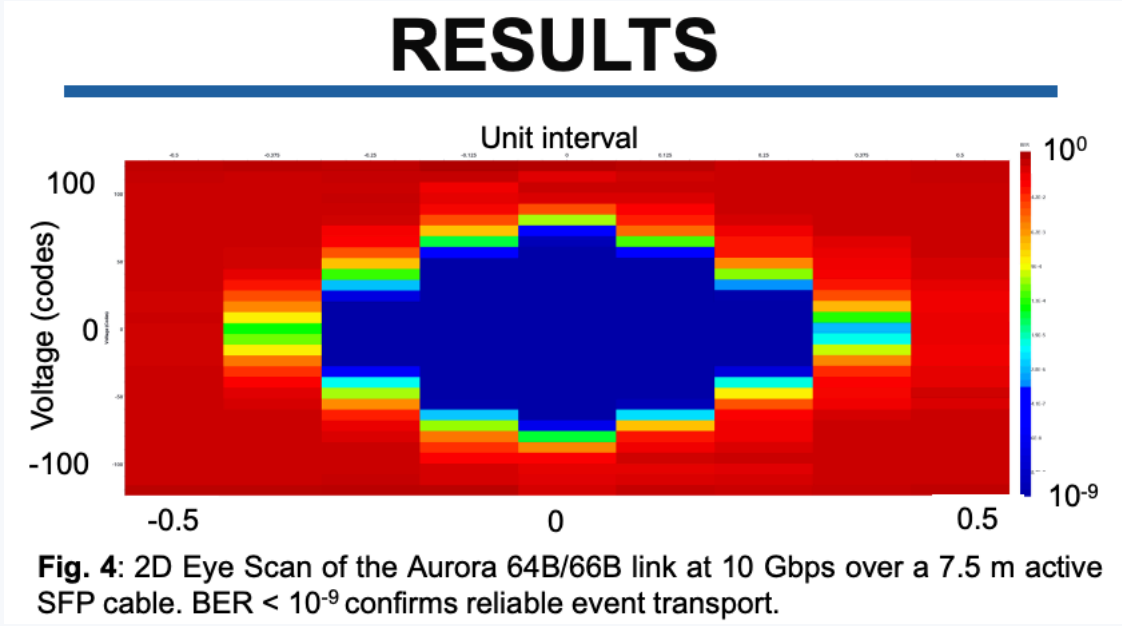


Fig. 4: 2D Eye Scan of the Aurora 64B/66B link at 10 Gbps over a 7.5 m active SFP cable. BER < 10^{-9} confirms reliable event transport.

Aurora 64B/66B 10 Gbps eye scan

500 ps
timestamping target

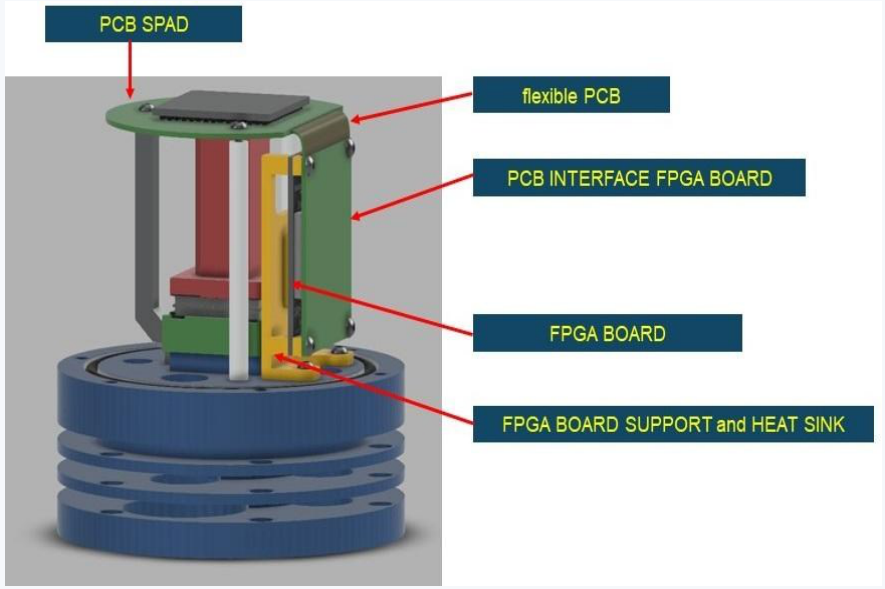
10 Gbps
Aurora serial link

<10^{-9}
validated BER

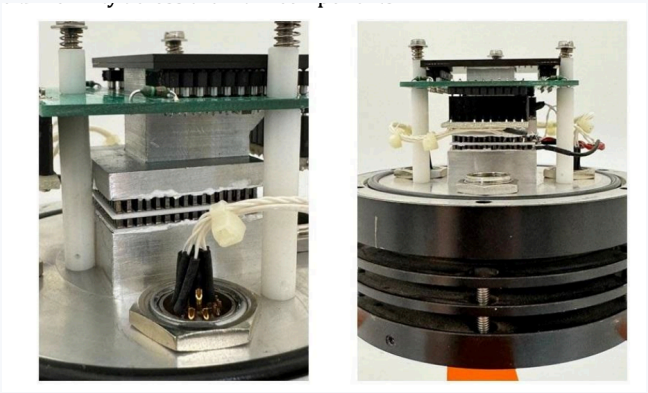
Two-FPGA architecture minimizes power and complexity inside the vacuum chamber while enabling accelerated processing at the acquisition computer. See Quintana et al. SPIE 2026

Integrated cryogenic SPAD camera head

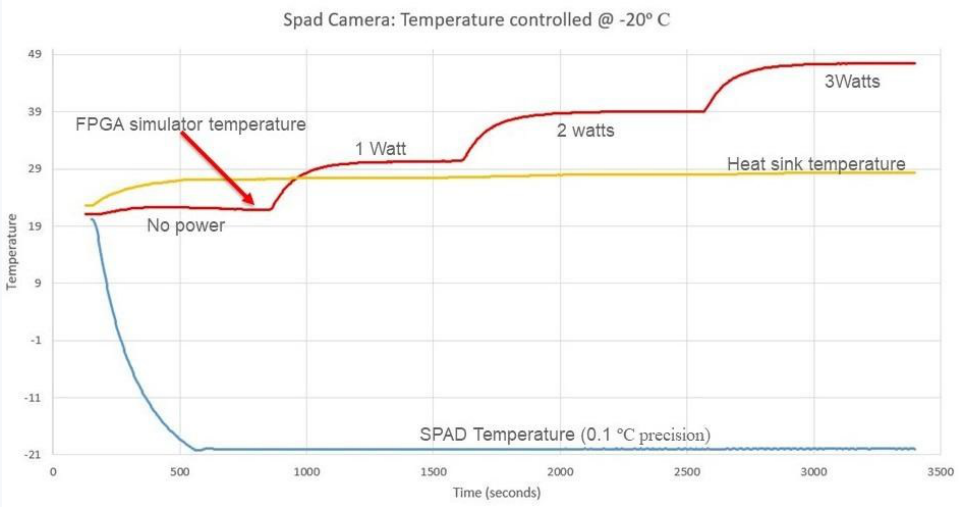
The detector, FPGA, thermal control and timing are co-designed as one module.



Compact vacuum-compatible camera-head architecture



Peltier module and cold-finger arrangement



Thermal validation at –20 °C

–20 °C
stable operation

±0.1 °C
regulation stability

Thermal validation under 0–3 W representative FPGA loads shows no localized overheating and supports SPAD integration. See Cosentino et al. SPIE 2026

Picosecond synchronization at ORM

White Rabbit is the timing backbone that turns telescopes into a coherent facility.

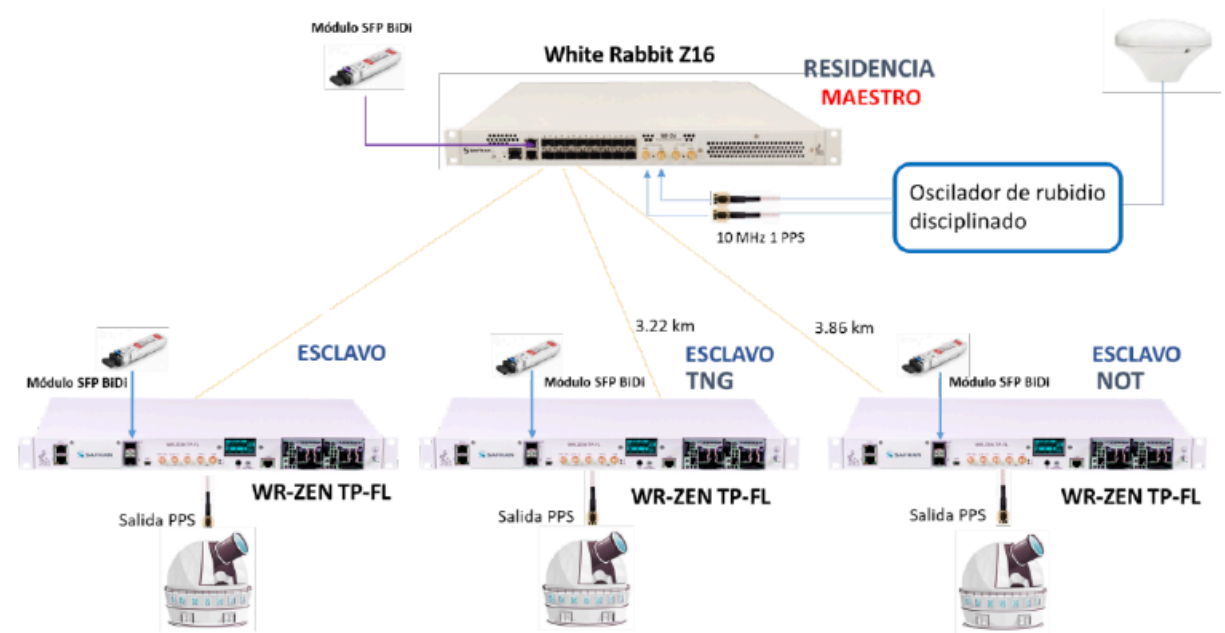
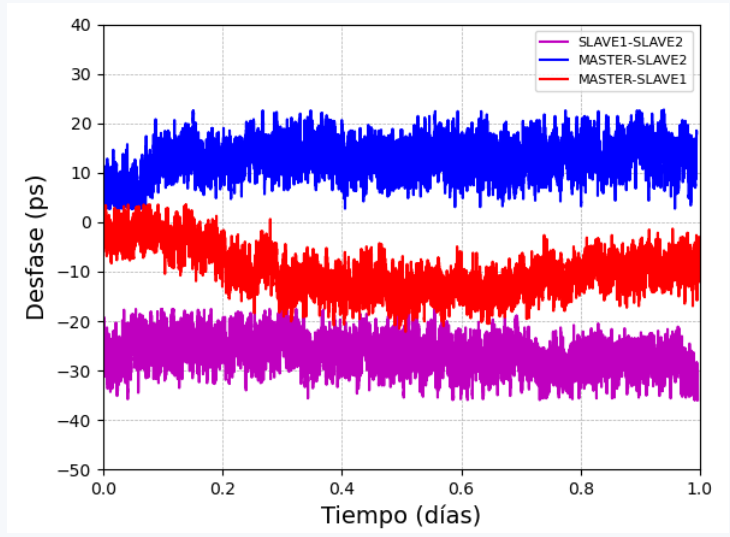
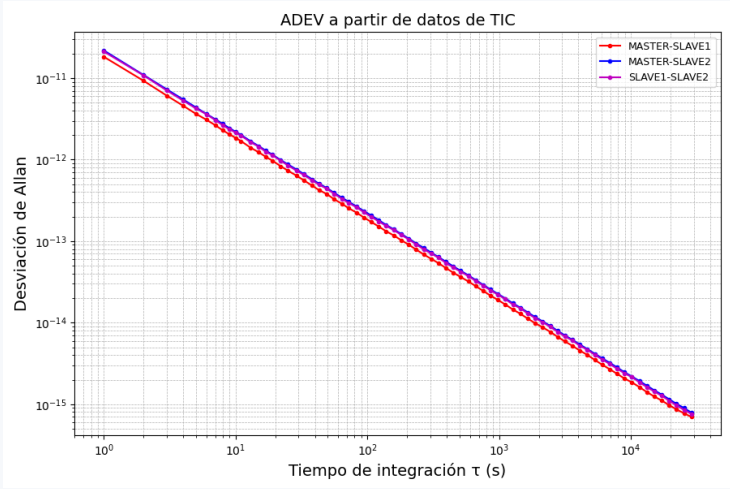


Fig. 2. Esquema del montaje propuesto del caso 1.

White Rabbit synchronization layout for the LPQI-Pathfinder (NOT + TNG with 550 meters baseline)

See Quintana et al. SPIE 2026





Measured White Rabbit stability results: the standard deviation remains below 4 ps

Status

Synchronisation instrumentation has already been successfully tested at ROA, and all hardware installed at the site on 8 October. Calibration of the system will be performed on 26-30 October. This infrastructure is the first step for the LPQI-Pathfinder.

Path to a 2k × 2k astronomical SPAD sensor: CDTI-Teledyne Contract

Large-format 3D Back Side Illuminated SPAD detector through staged development and industrial procurement.

Industrial path

Teledyne won the CDTI tender to deliver a pre-commercial large-format BSI SPAD sensor over a 37-month development period starting April 2026.

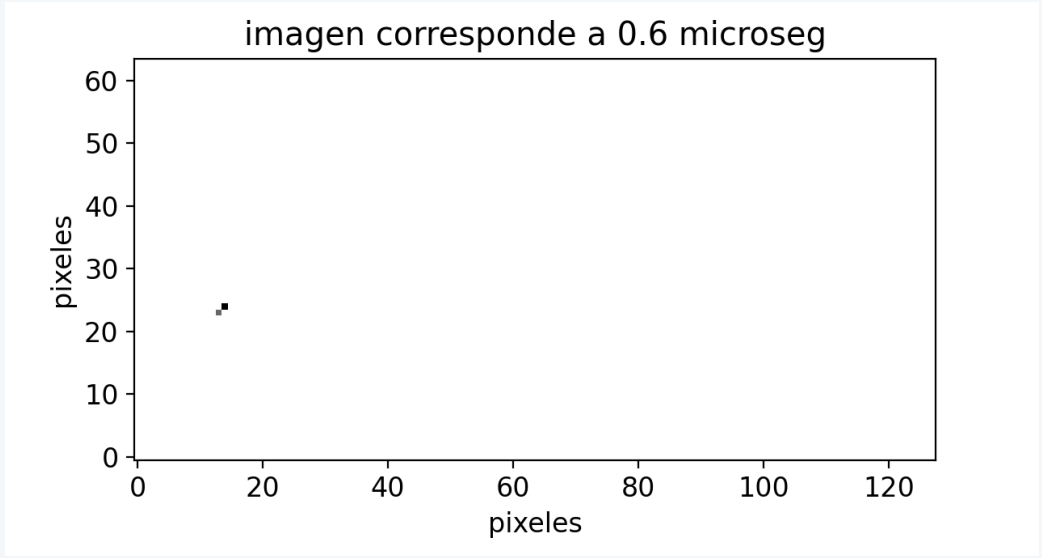
Validation path

IAA-CSIC supervises technical validation, including laboratory tests and verification.

See Di Fabrizio's poster 14148-96 on Tuesday for mode details.

GOBIERNO DE ESPAÑA · MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES · CDTI INNOVACIÓN
Cofinanciado por la Unión Europea · MINISTERIO DE HACIENDA · Fondos Europeos

Path to a 2k × 2k astronomical SPAD sensor: HAMAMATSU 3D-BSI SPAD



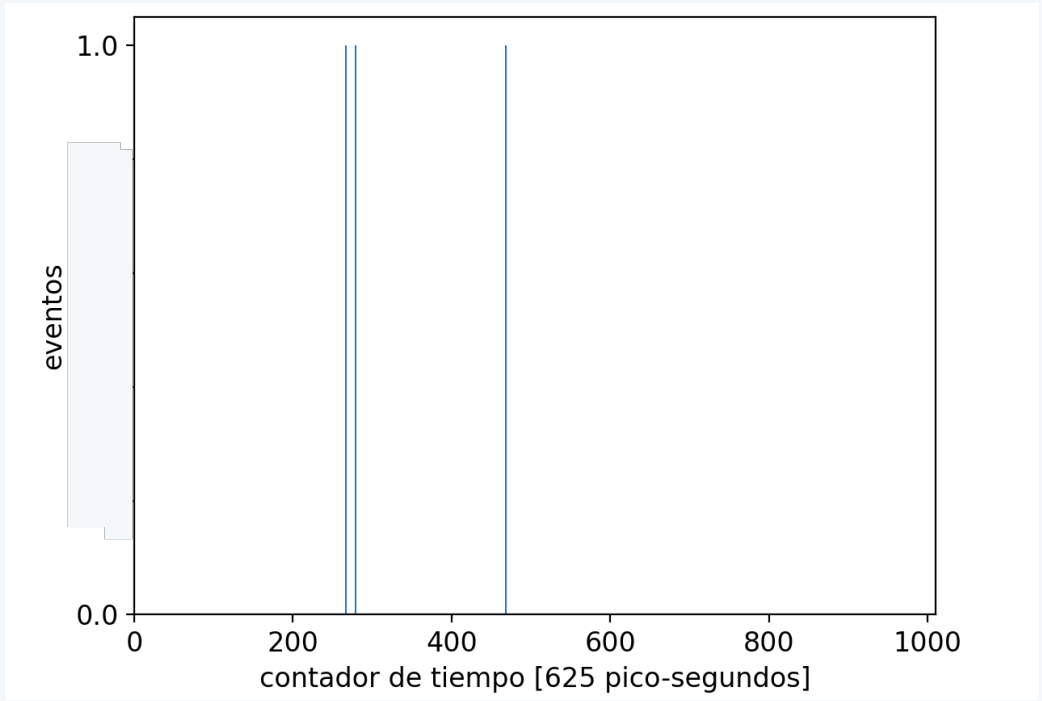
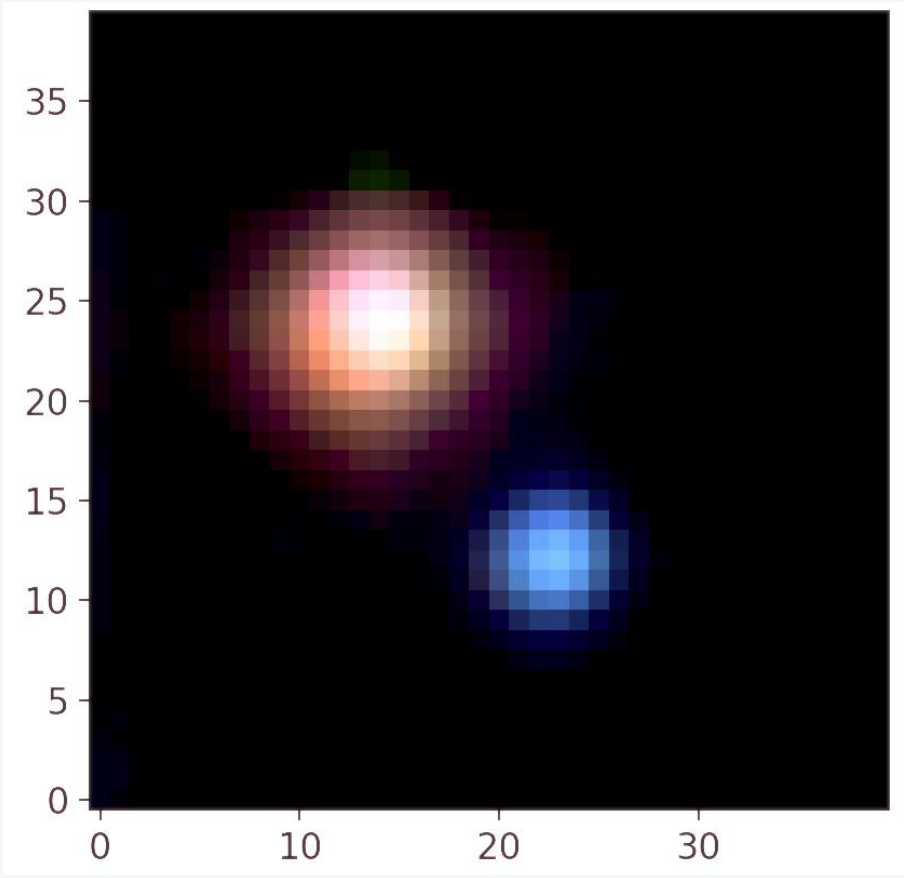


Imagen RGB de dos segundos, reconstruida a partir de 3,3 millones de exposiciones de 0.6 microsegundos



Observaciones de Albireo A y B con un prototipo SPAD de HAMAMATSU 3D-BSI de 64 × 128 píxeles y telescopio de 150 mm en el campus UAM. Publicación en preparación - Colaboración UAM–HAMAMATSU.

The Pathfinder demonstrates LPQI's feasibility

A well-defined implementation that reduces technical and organisational risks.



LPQI-Pathfinder

- Build two SPAD single-filter cameras for the NOT and TNG telescopes, separated by 550 metres
- Validate the detectors, electronics, synchronisation, cameras and software, and obtain the first science results
- Installation at NOT–TNG on December 2027
- Obtain the first interferometric results in spring 2028, with an angular resolution of 150 μas

LPQI roadmap: phased growth to a facility

2025-2026 | 2027-2028 | 2029 | 2030 | 2035

SPAD, readout, criogenics cameras & synchronisation
- New SPAD 64x64
- Thermal and QE tests
- Readout and sincronization tests
- Data system

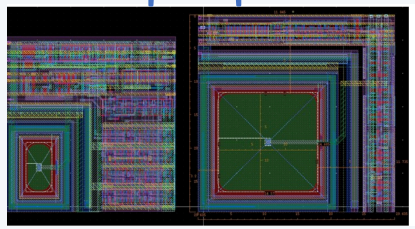
LPQI-Pathfinder
- Construction and first light of SPAD optical cameras at TNG and NOT for narrow-band intensity interferometry

Large format 2k x 2k SPAD
- Laboratory tests
- Verification

LPQI – Phase I
- First large-format SPAD on FIRNAS spectrograph mounted at the INT

LPQI – Phase II
Full LPQI facility
- Five telescopes with similr spectrographs
- Maximum number of baselines
- 50μas resolution

SPADs



3% (current) → 25% (new) fill factor + microlenses 100% fill factor

2D SPAD technology, IMSE-US/CSIC

3D BSI large format SPAD for astronomy:

- CDTI-Teledyne CPP contract to deliver a large-format 3D-BSI SPAD sensor on March 2029: First Phase completed and currently under evaluation. IAA-CSIC supervises technical validation, including laboratory tests, via a CDTI-CSIC Agreement.
- HAMAMATSU collaboration with EPS-UAM & IAA-CSIC.

Cofinanciado por la Unión Europea
Fondos Europeos

LPQI facility target

Five telescopes, high-resolution spectroscopy, and a large-format SPAD detector.

Full ORM array

GTC • TNG • NOT • WHT • INT

Maximum baseline ≈1.5 km

Maximum number of baselines and throughput

Instrumentation

1K×1K SPAD detector

High-resolution Echelle spectrographs

Picosecond synchronization and correlation pipeline

Science reach

Limiting magnitude goal: ~13

Angular resolution: ~50 µas

Long-term microarcsecond astronomy operations

5
optical telescopes

1K×1K
SPAD array

g≈13
limiting magnitude

50 µas
resolution

LPQI presentations at SPIE 2026:

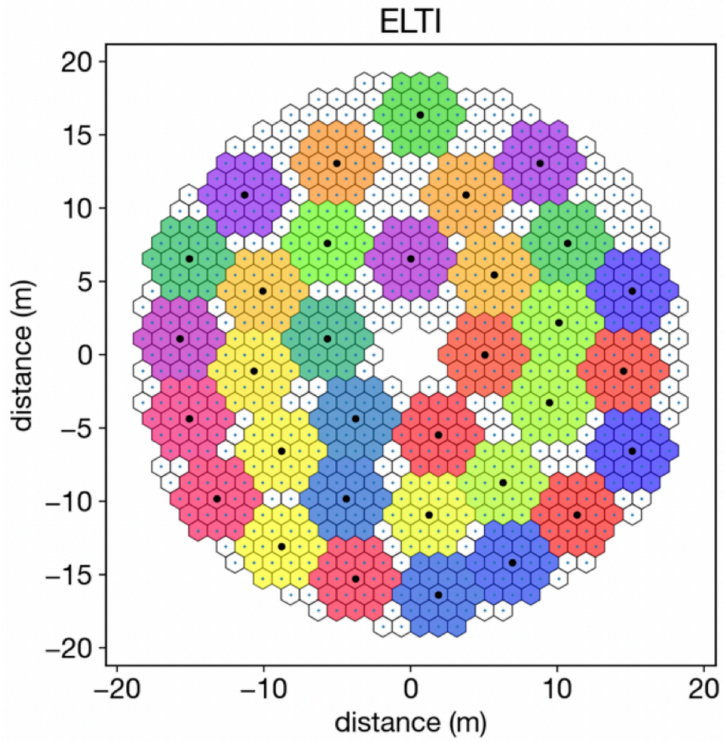
- Luca Di Fabrizio et al.
- Robert Content et al.
- Álvaro Quintana et al.
- Rosario Cosentino et al.

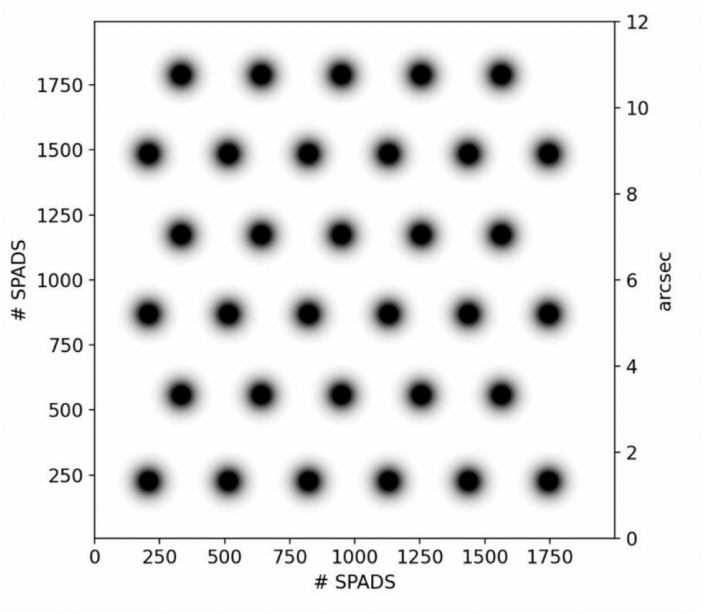
The Extremely Large Telescope Interferometer (ELTI)

F. Prada[1,2], E. Pérez[1], S. Fernández-Acosta[3], K. N. Rai[4], and J. Sánchez-Bermúdez[5]

[1] Instituto de Astrofísica de Andalucía CSIC, Granada, Spain; [2] Instituto de Astrofísica de Canarias, Tenerife, Spain; [3] GRANTECAN, Breña Baja, La Palma, Spain; [4] Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, India; [5] Instituto de Astronomía, Universidad Nacional Autónoma de México, México

Core idea: Use the segmented primary mirror of the ELT as a multi-aperture optical intensity interferometer, combining large-format SPAD detectors with high-dispersion spectroscopy to achieve milliarcsecond-scale angular resolution.





- The ELT M1 segments are grouped into 33 effective 7.25-m apertures, each made of 19 segments, using 627 of 798 primary-mirror segments (79% of M1).
- The 33 sub-pupils produce a fixed 33-image pattern on a 2k × 2k SPAD detector.

7.25 m
per sub-pupil

79%
M1 segments used

33
sub-pupils

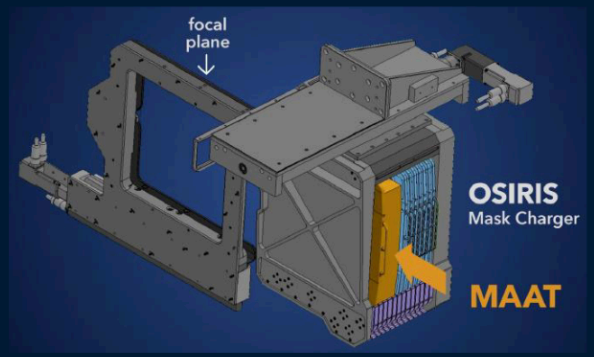
ELTI turns the ELT primary mirror itself into the beam-combination system, creating a multi-aperture optical interferometer.

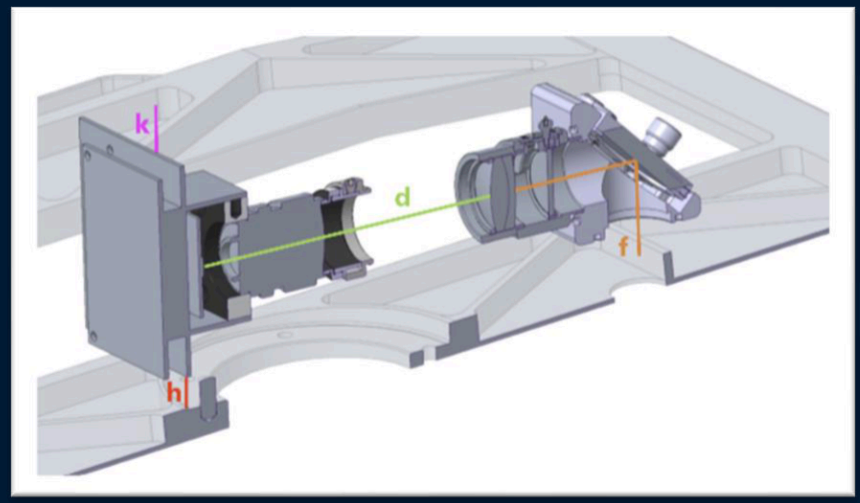
LPQI Intensity Interferometry Proof of Concept at GTC

Francisco Prada, Enrique Pérez, Joel Sánchez, Ernesto Sánchez, Guillermo G. de Rivera, Kilian Henríquez, Manuela Abril, Héctor de Paz & Sergio Fernández on behalf of the LPQI and GTC teams

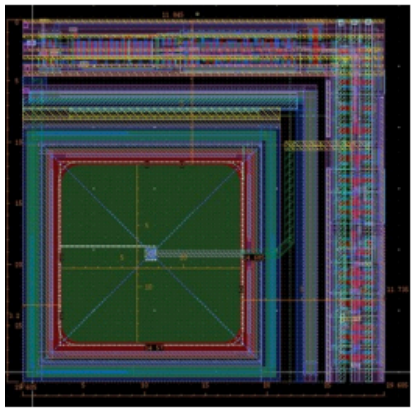
MAAT@OSIRIS and lessons learned for this PoC

Re-imaging optics (99um/") + 1nm Filter @400nm + 64x64 existing SPAD as a Focal Plane Mask in OSIRIS





Req 2: As a visitor instrument, contribution from GTC engineering & scientific staff must be modest.



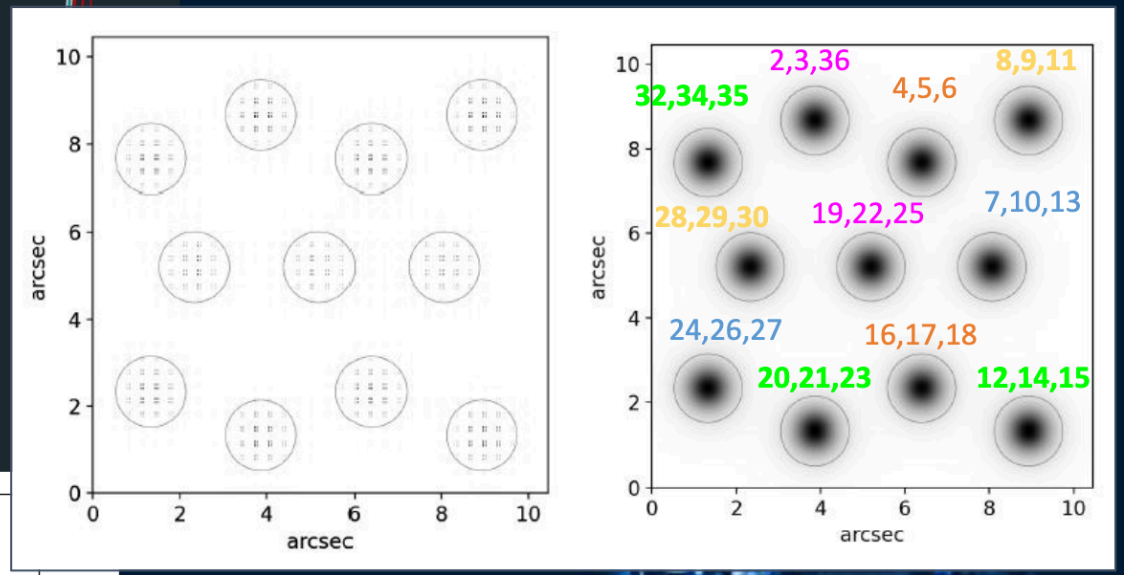
Our IMSE-US/CSIC SPAD
AND
HAMAMATSU 3D-BSI Prototype

Intensity Interferometry at GTC - PoC

11 sub-pupils of 3 **segments each re-imaged on a single 3.5% fill-factor SPAD**



Pattern on SPAD will remain fix using the ***GTC pupil-tracking mode***



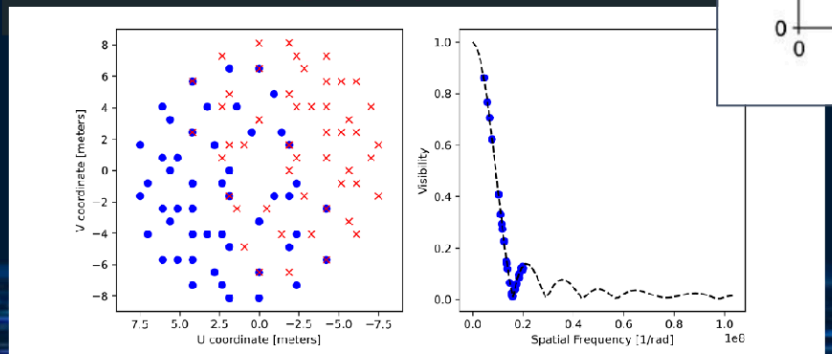


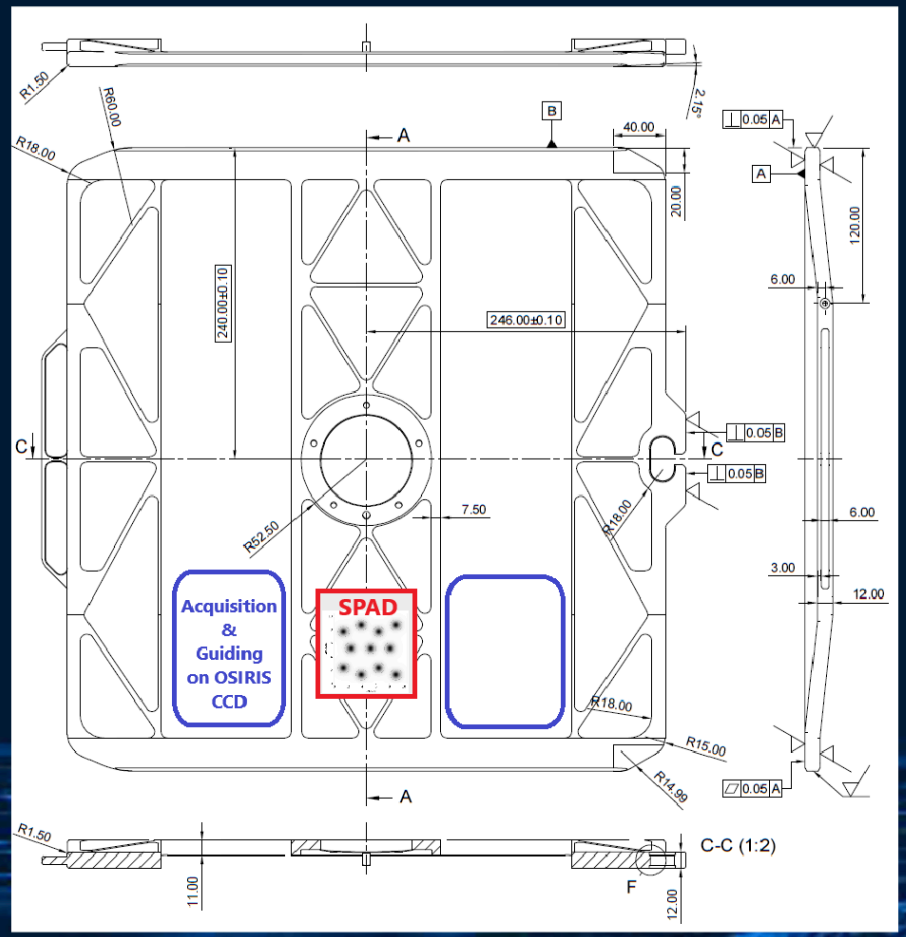
Fig. 7. Left panel, UV-plane coverage with the 55 baselines obtained from the 11 sub-pupils (referenced to the spatial center, as indicated by the white spots in Figure 5). The right top panel shows the simulation of the visibility for a uniformly illuminated disk with a diameter of 10 mas.

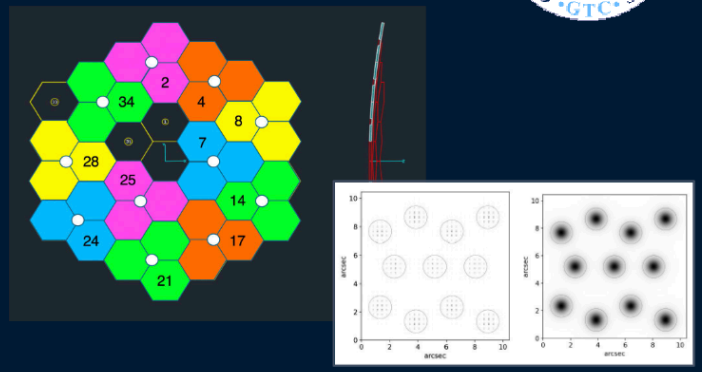
Break the symmetry?

Intensity Interferometry at GTC – PoC – Prep. TESTS

Pupil configuration and acquisition and guiding tests

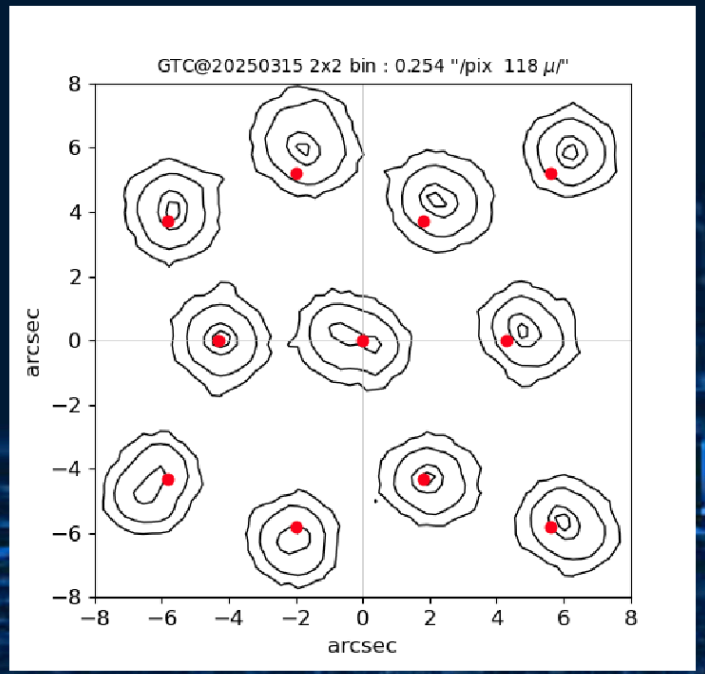
*Pattern on SPAD shall remain fix and stable using the **GTC pupil-tracking mode***





Test data taken with OSIRIS (Mar2025).

M1 was not fully stable. Guiding script in progress



Congreso Futuro 2026, Enero, Chile

Matt Mountain,

Presidente de la Association of Universities for Research in Astronomy (AURA), EE.UU.



Visión de futuro para redes cuánticas de telescopios

«Si podemos desarrollar tecnologías cuánticas en Chile, podemos entrelazar estos telescopios para crear un sistema singular», señaló Mountain. Esta red cuántica de telescopios, distribuidos por las llanuras del norte del país, permitiría construir imágenes de tal resolución que no solo veríamos un «punto azul» a la distancia, sino que se podrían distinguir **océanos, continentes e incluso ciudades** en planetas que orbitan otras estrellas.