

Towards the measurement of the size of a White Dwarf star

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on behalf of the IC4Stars collaboration

Stellar Intensity Interferometry Workshop 2026
Oct-2026
La Palma, Spain

Our approach: SII with optical telescopes

Drawback:

- Large arrays of large optical telescopes will never be available

Advantages:

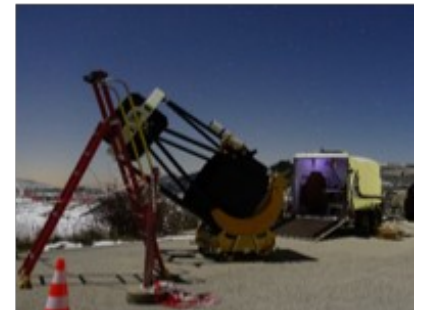
- The small PSF allows using the best detectors and other photonic technologies (fibers, narrow filters, etc.)
- The instrument can be adapted to any existing facility
- No big issue with the sky background

Methodology:

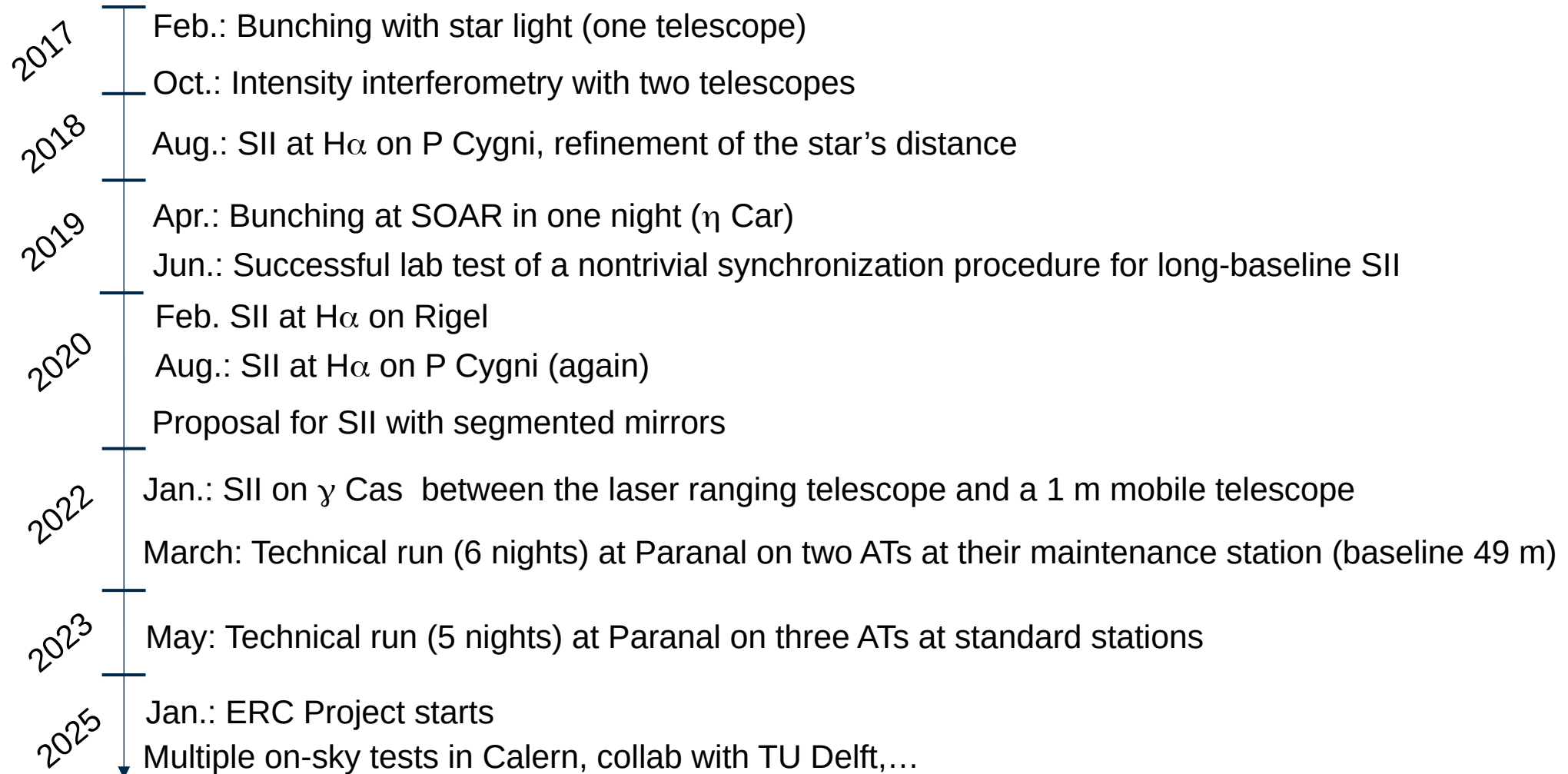
- Step-by-step progress
- Tests and calibrations in the lab (at INPHYNI)
- On-sky demonstrations at **Calern**
- Go to **bigger facilities...**

Instrument:

- Photon-counting regime (shot-noise limited)
- Compact and transportable
- Real-time computation of the $g^{(2)}$.



A few Milestones



IC4Stars (Intensity Correlations for Stars)

Team:

INPHYNI, cold-atom team



Robin
Kaiser

William
Guerin

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Guillaume
Labeyrie

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Jean-Pierre
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Géoazur, MéO team



Clément
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Julien Chabé



- Sarah Tolila
- Andreas Zmija
- Federico Izraelevitch-Patitucci
- Ilian Ellafi

IC4Stars (Intensity Correlations for Stars)

Project overview:

- Develop quantum-optics measurements in astrophysics using modern photon-counting techniques.
- Measure the angular diameter of white dwarfs beyond the reach of direct optical interferometry.
- Search for astrophysical quantum light sources, particularly random lasing, through second-order photon correlations.

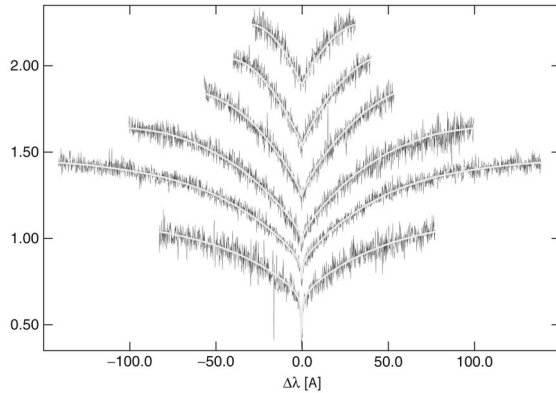
Motivation: Sirius B

Spectra, modeling, stellar parameters

Star atmosphere modeling

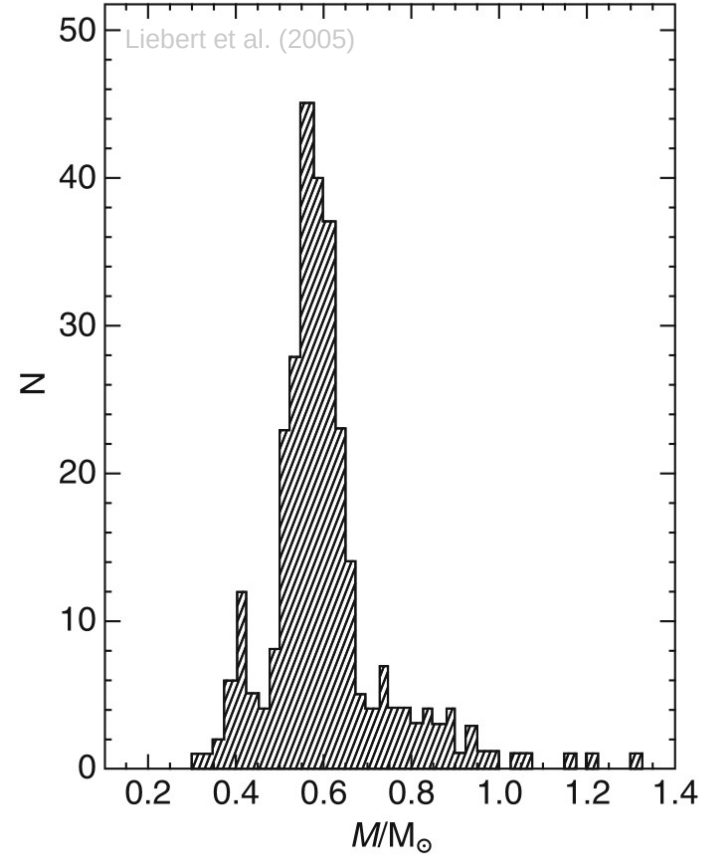
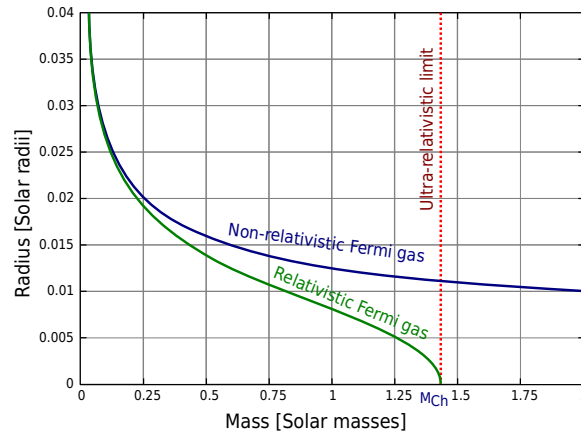
→ Surface gravity and effective temperature

$$g = \frac{GM}{R^2}$$



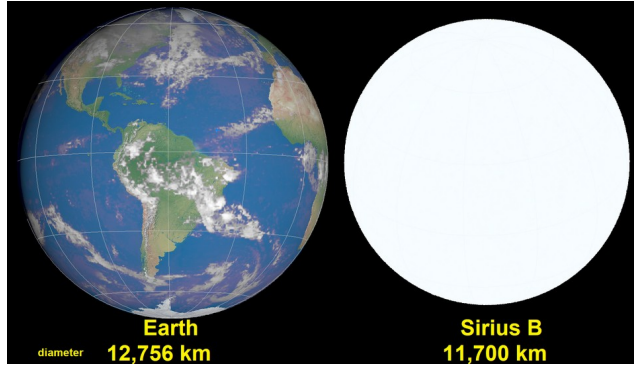
Chandrasekhar equation of state:

$$R = R(M)$$

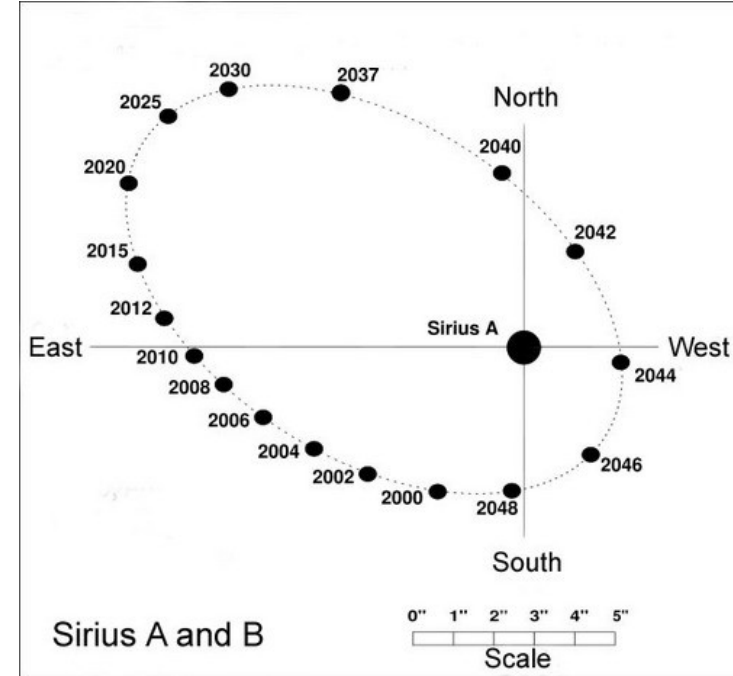
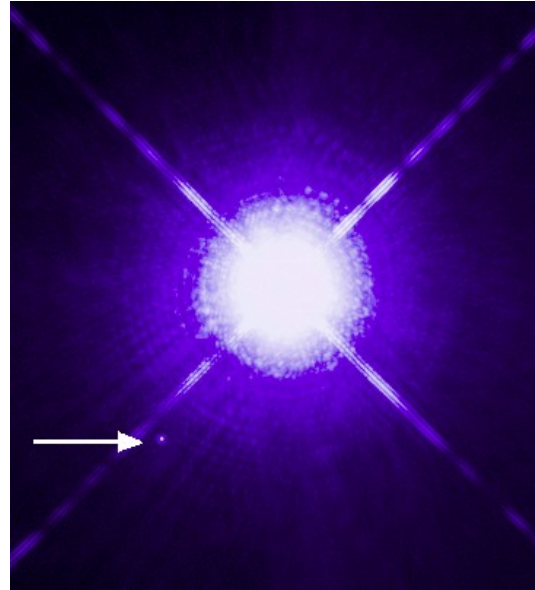


Objective: Sirius B

Wikipedia (Tomruen)



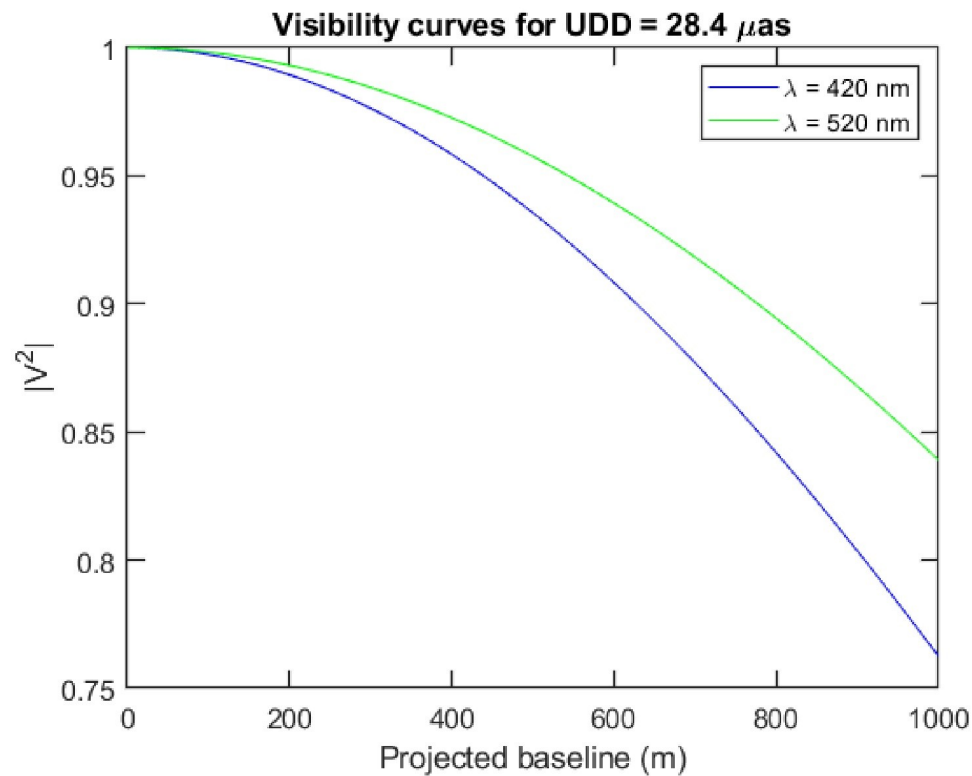
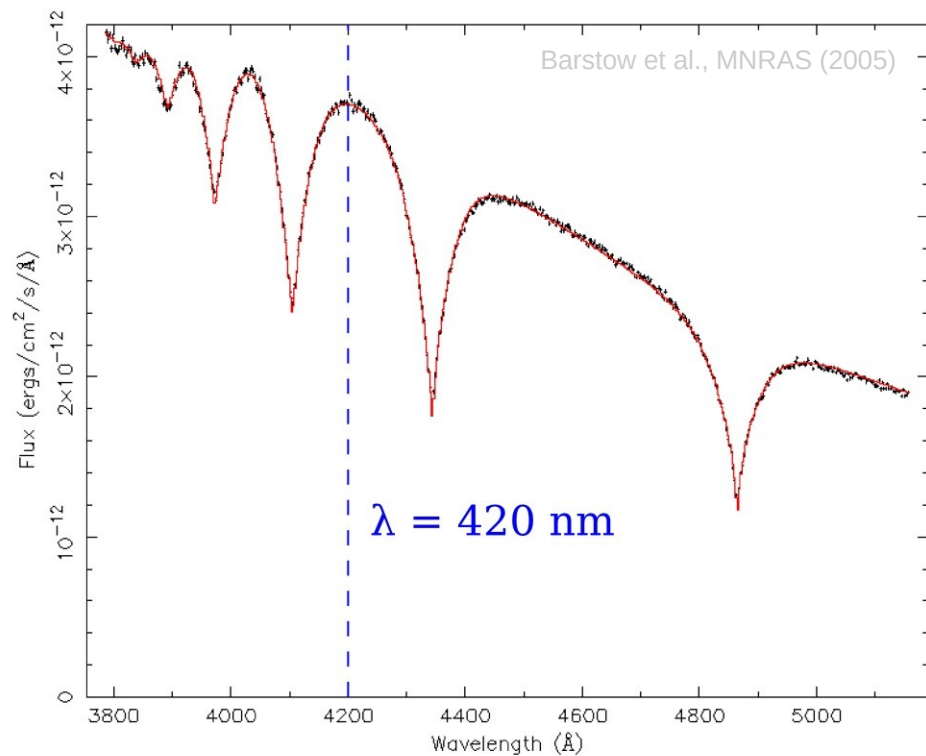
- $M_{\text{Sirius B}} \sim M_{\text{Sun}}$
- $D_{\text{Sirius B}} \sim D_{\text{Earth}}$
- $\theta \sim 30 \mu\text{as}$
- $m_{\text{B}} \sim 8.4$



Wikipedia (FrancescoA)

HST, NASA, ESA, H. Bond (STScI),
and M. Barstow (U. of Leicester)

Objective: Sirius B



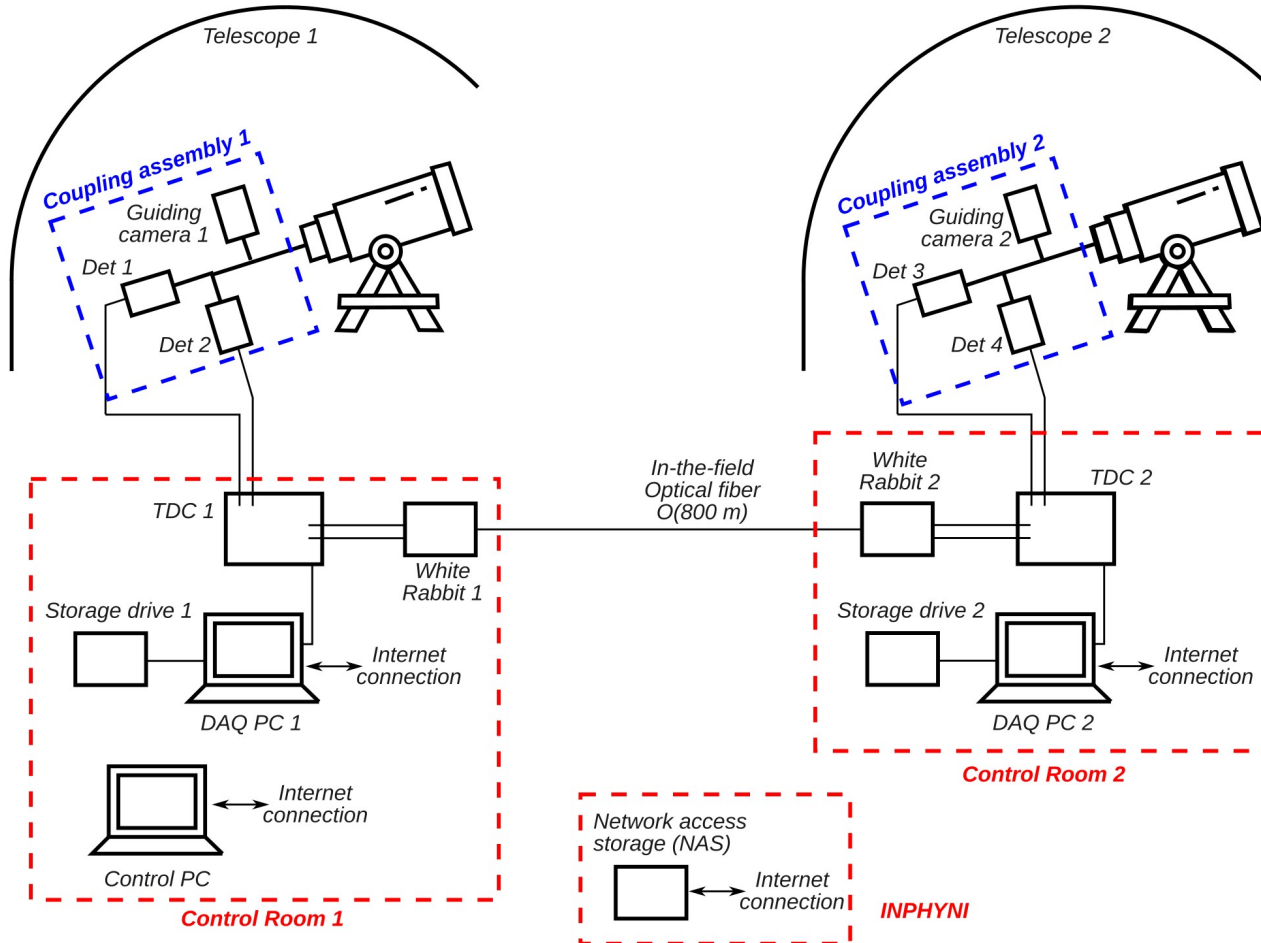
Objective: Sirius B, feasibility assessment

$$\text{SNR} \propto \frac{\text{Visibility}}{\text{squared}} \times \frac{\text{Light detection}}{\text{and throughput}} \times N_{\text{photons}}(\lambda) \times \frac{\text{Telescope}}{\text{Area}} \times \sqrt{\frac{T_{\text{observation}}}{\tau_{\text{resolution}}}} \times \sqrt{N_{\text{ch}}}$$

- Sirius B, $m_{\text{B}} = 8.4$
- $N_{\text{ph}}(\lambda = 420 \text{ nm}) = 4.6 \times 10^{-8} \text{ ph/m}^2\text{/s/Hz}$ (HST)
- Light detection and throughput ~ 0.1 (QE, atm, optics)
- Electronic jitter $\sim 35 \text{ ps RMS}$
- 16 spectral channels
- $\text{SNR} \sim 10$

$\therefore$ 2 nights at Subaru-Gemini (790 m)

Intensity Correlation for Stars, IC4Stars (2025 –)

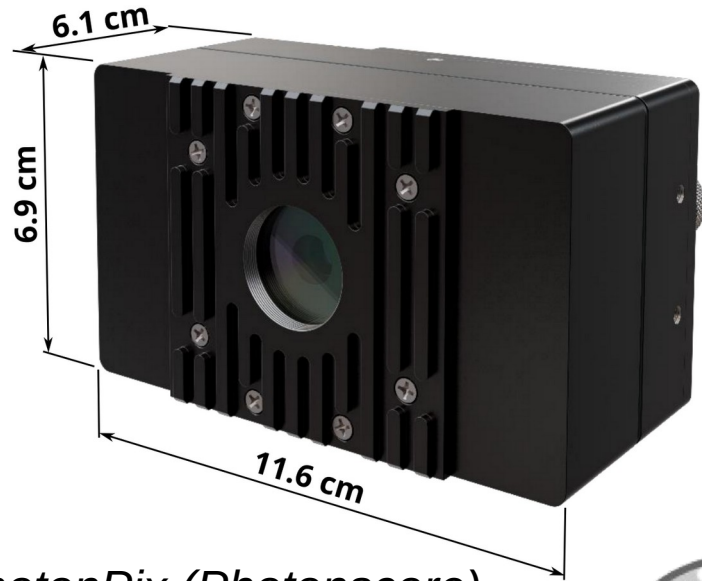


- Two Data acquisition stations (DAQ)
- Synchronized in the pico second scale
- Write the raw time tags of every detected photon on disk
- Compute $g^{(2)}$ off-line in software (in-the-field)

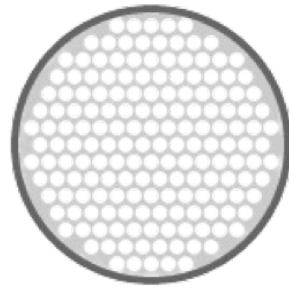


Unlocks long baselines

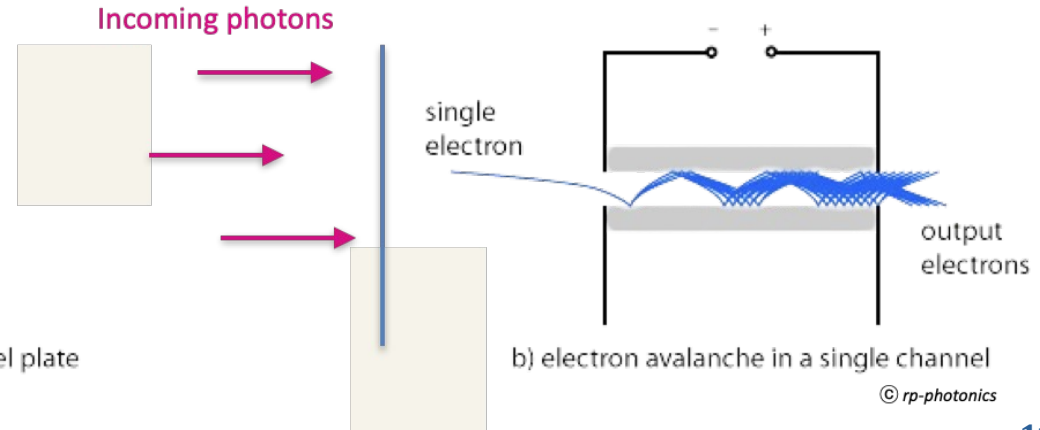
Fast single-photon detector



PhotonPix (Photonscore)

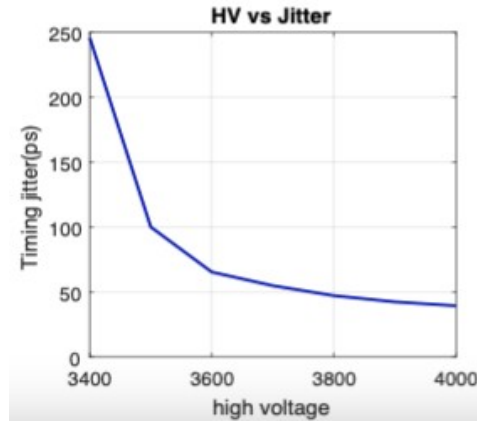
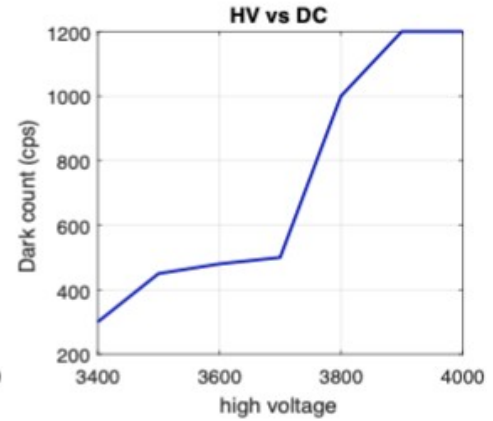
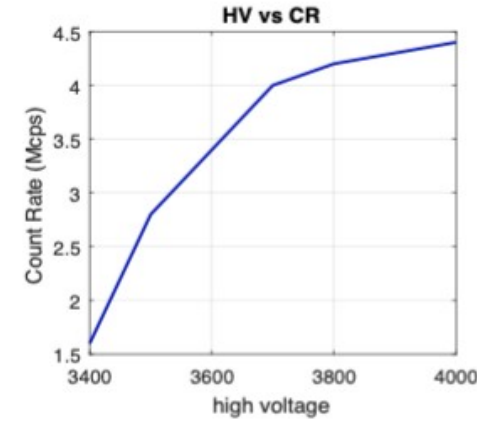
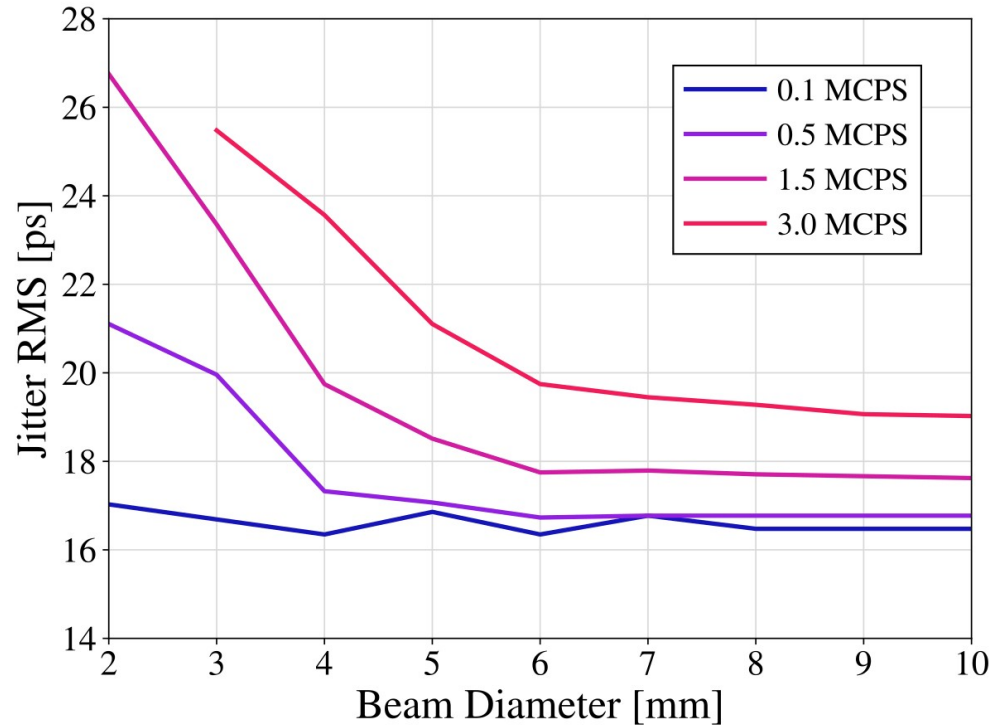


a) front view of microchannel plate



- QE ~ 33 % at 420 nm, **PDE ~ 22 %**
- Jitter ~ 18 ps RMS
- Dark Count Rate < 100 CPS
- Sensitive diam. = 8 mm (easy to focus)
- Large size and requires cooling

Fast single-photon detector

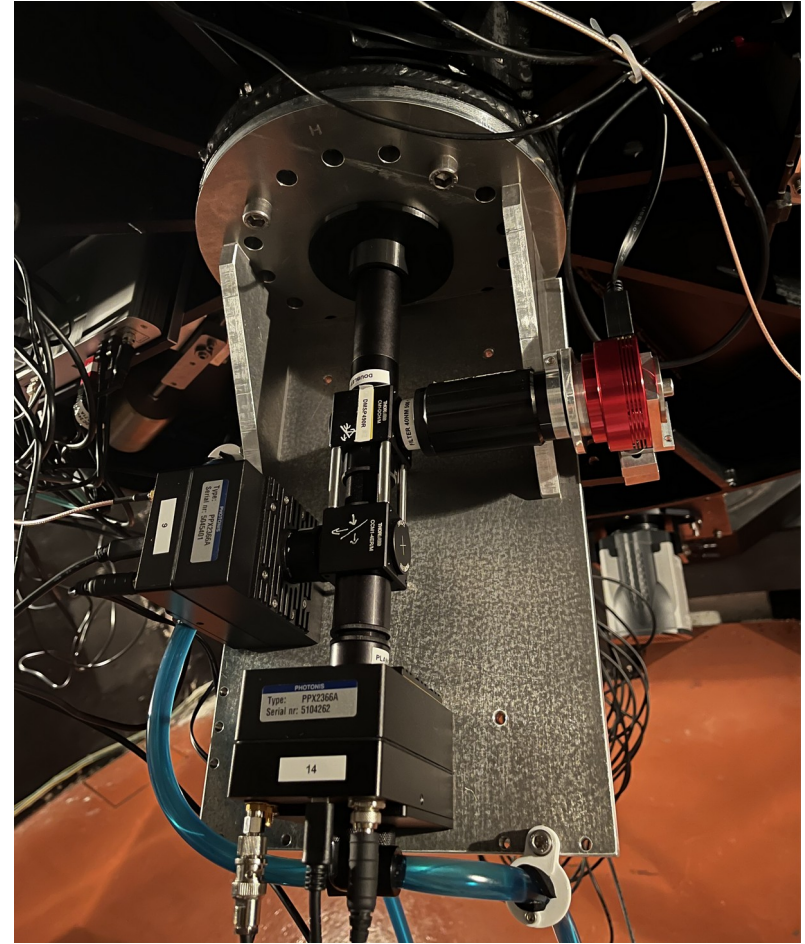
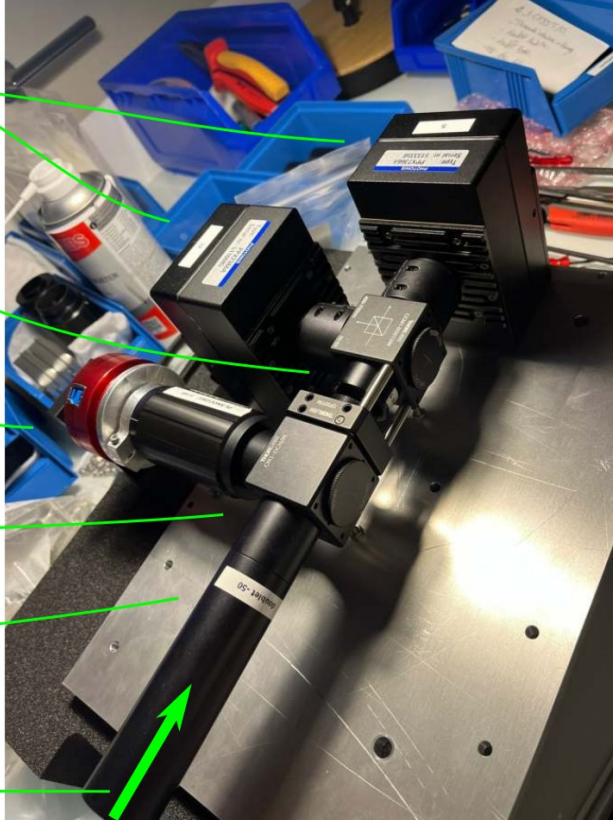


Detector no.15

+ internal parameters: High Voltage, Zero Cross and Threshold VS jitter, dark count and count rate

Optical module

- Detectors
- Beam splitter + 1 nm filter
- Lens + Guiding camera
- Dichroic
- Divergent lens
- Light from telescope

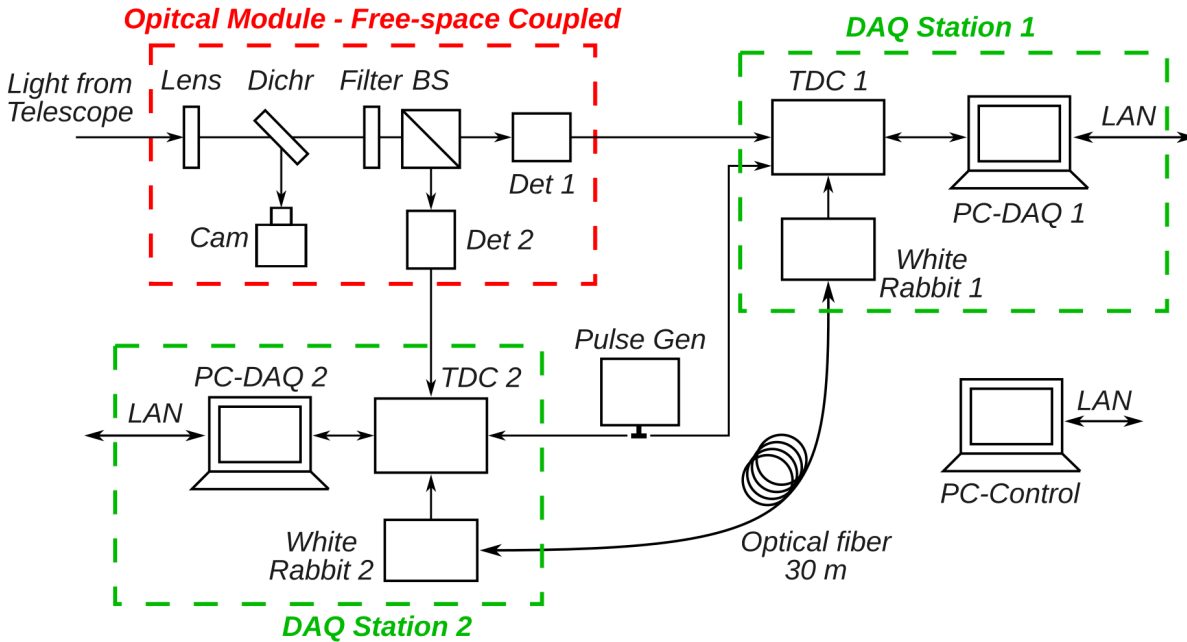


Observation campaign at C2PU - Observatoire de la Côte d'Azur Apr-2026

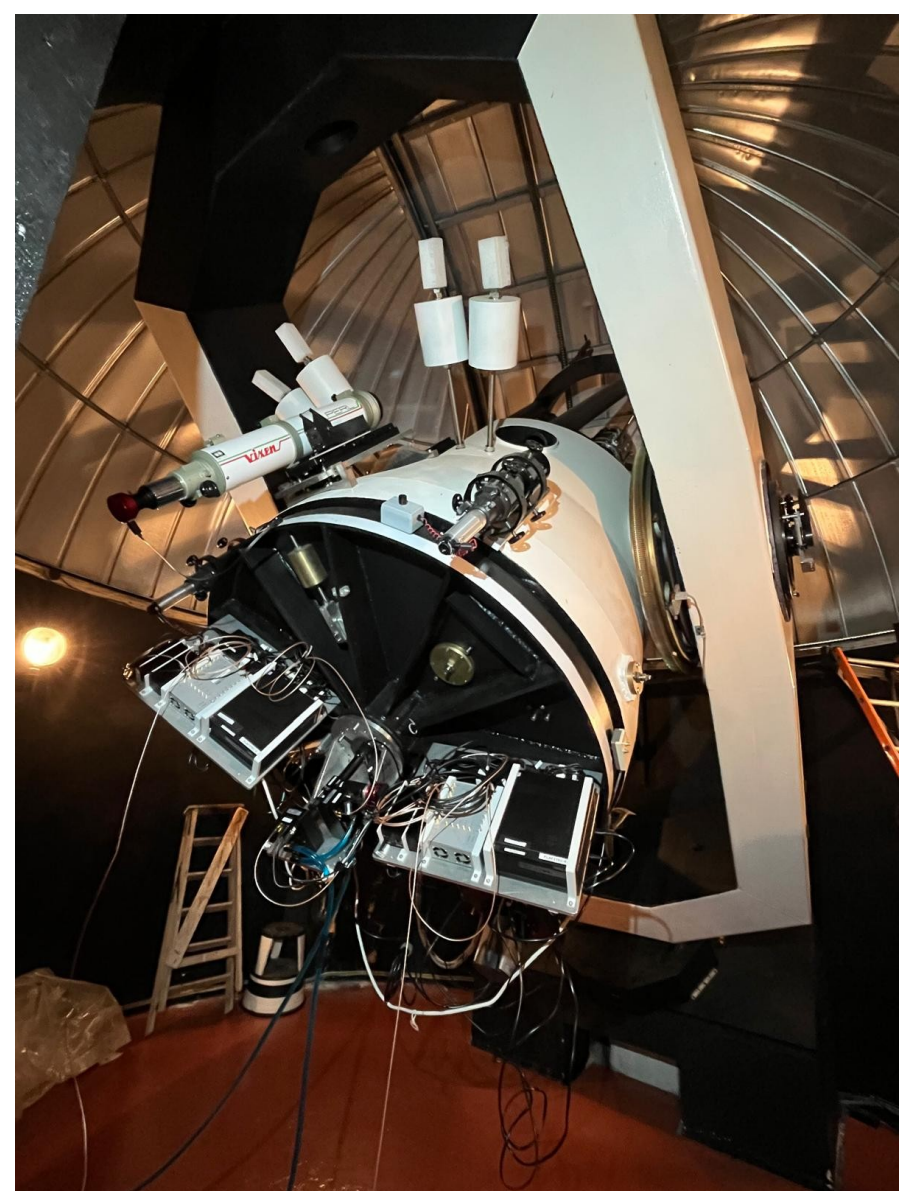


Observation campaign at C2PU

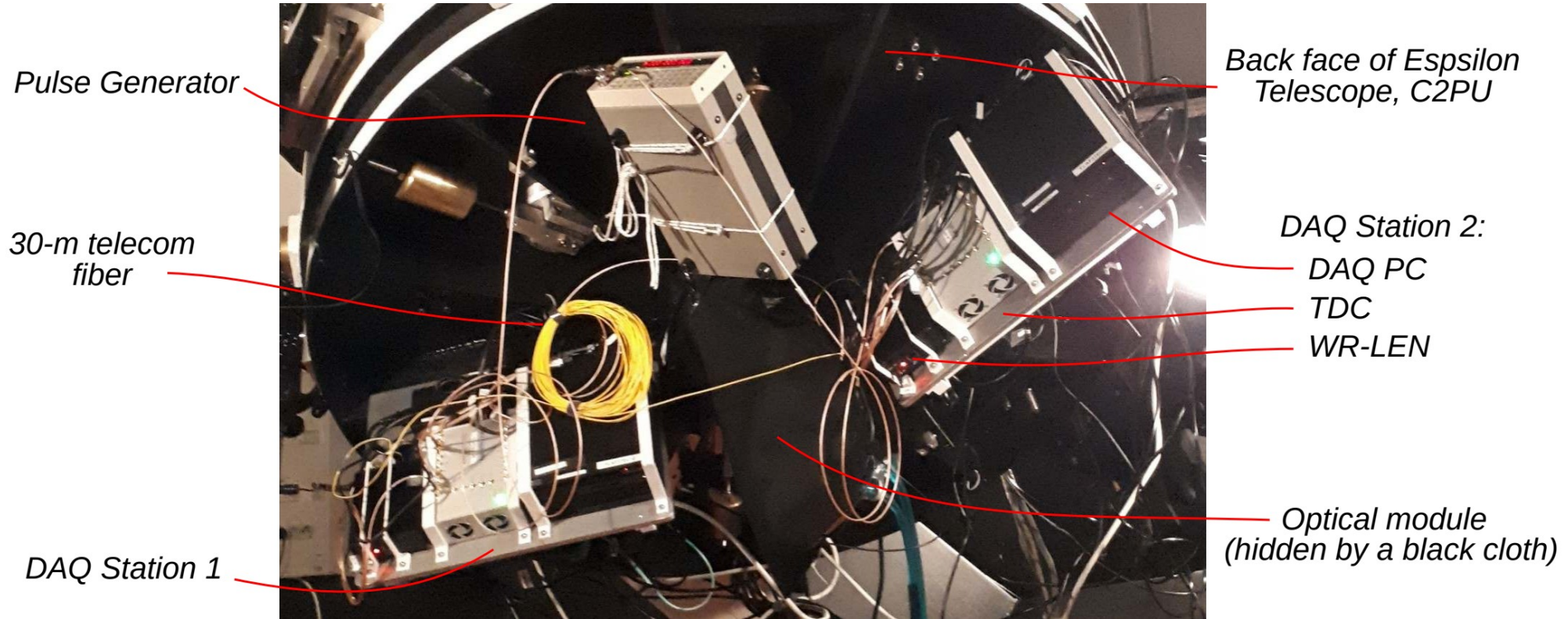
- Observatoire de la Côte d'Azur



- Raw time tags written on disk
- DAQ Stations sync'ed with 30 m fiber
- Off-line $g^{(2)}$ computation in software (in-the-field)
- Approx 6 min of computation per hour of DAQ



Observation campaign at C2PU - Observatoire de la Côte d'Azur



Single-Photon detector: PhotonPix, Photonscore
TDC: Time Tagger Ultra, Swabian Instruments
White Rabbit: WR-LEN, Safran
Pulse Generator: DS345, Stanford Research Systems

Observation campaign at C2PU - Observatoire de la Côte d'Azur

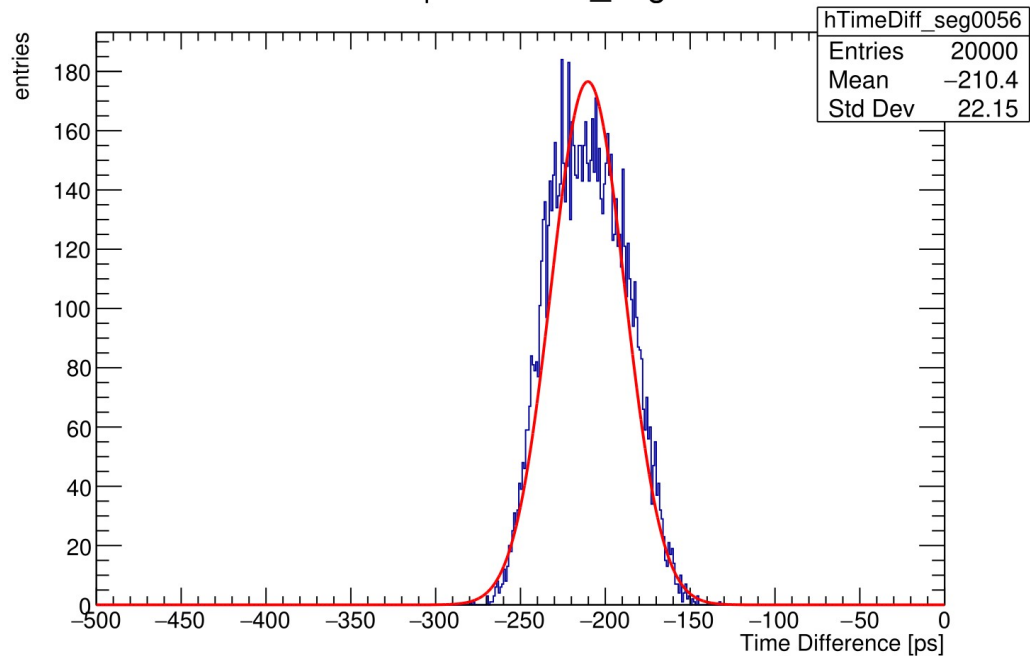


Observation run parameters:

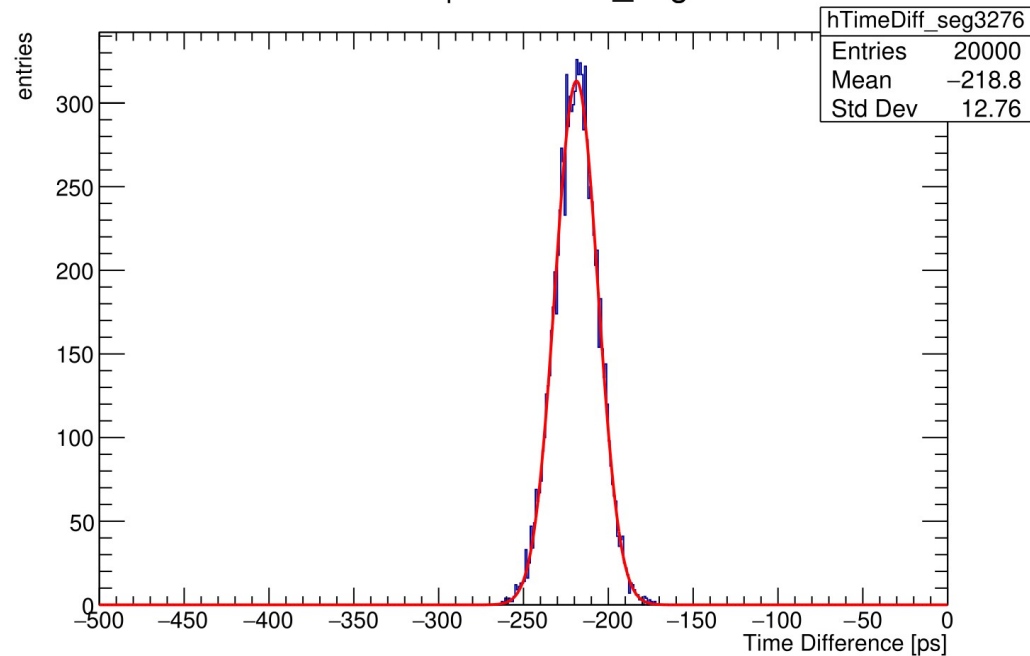
- Three nights, 21.5 h total.
- Count Rate = 1.6 MCPS (average)
- Main targets = Regulus and Vega
- $\lambda_0 = 417 \text{ nm}$
- $\Delta\lambda = 1 \text{ nm}$ (interference filter)
- $\sim 2 \text{ TB}$ of raw time-tags

Results: sync with 500-m fiber, on-sky

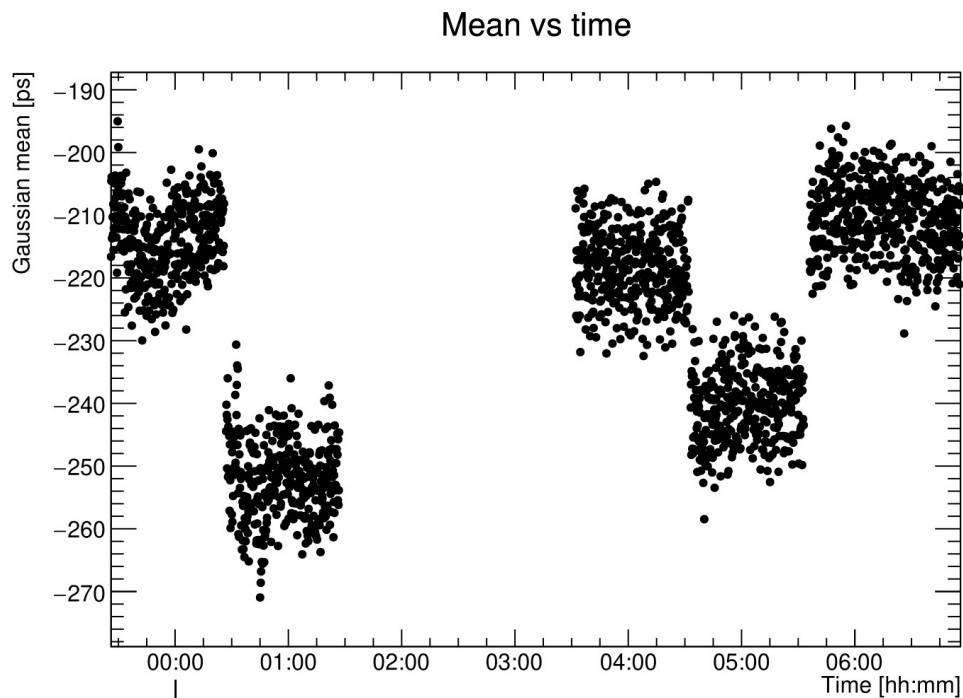
t = 56 s | hTimeDiff_seg0056



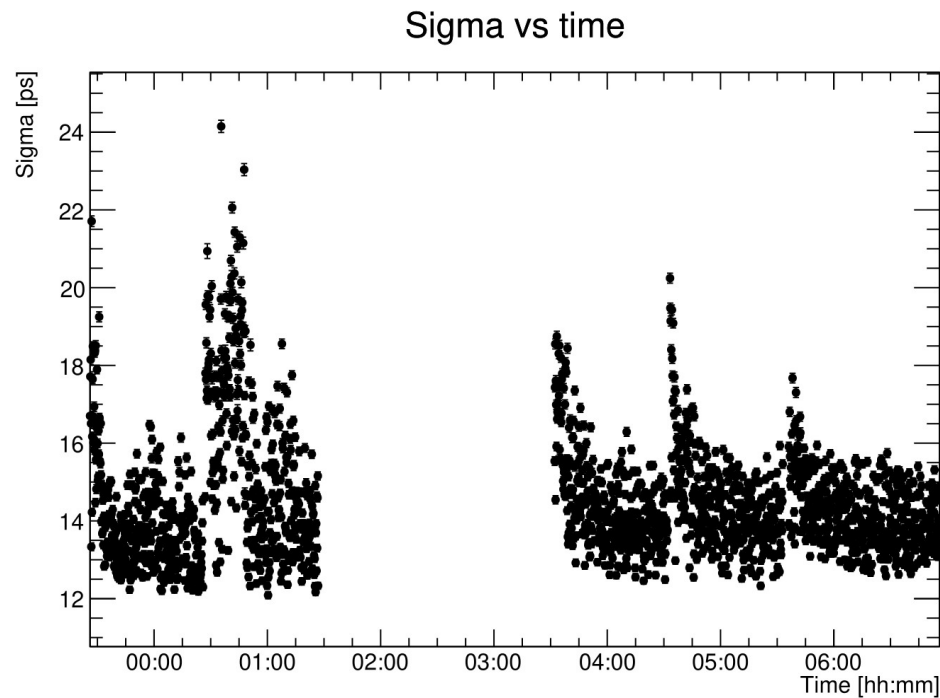
t = 3276 s | hTimeDiff_seg3276



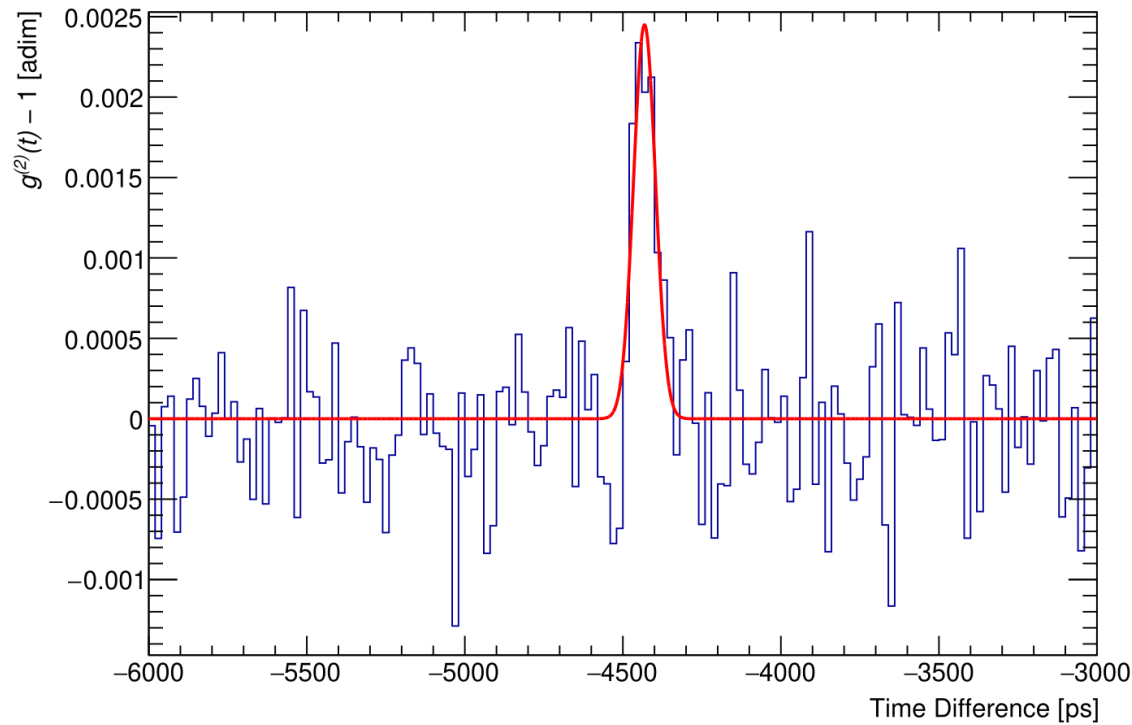
Results: sync with 500-m fiber, on-sky



Midnight: 00:00 h of 3-Apr-2026



Results: bunching



Parameter	Unit	Expected	Measured On-sky	Expectation rationale
SNR	[adim]	8.28	8.2	Formula calculation
Coherence Time	[ps]	0.492	(0.426 ± 0.051)	Filter transmission data
Jitter, RMS	[ps]	31.7	(34.7 ± 4.4)	Lab measurements

Jitter Budget, RMS	Unit	Measured (lab)
DAQ Jitter (lab)	[ps]	18.9
Detector Jitter (lab)	[ps]	18.0

SPIE Telescopes 2026
DOI: 10.1117/12.3104836
arXiv: 2606.25817

IC4Stars Sirius B Roadmap

- **Stage 1: One spectral channel**

- Data acquisition validated on-sky. To be tested at Hawaii on Feb 2027.
- Optical module validated on-sky.
- Full deployment at Hawaii on late 2027 on sky.

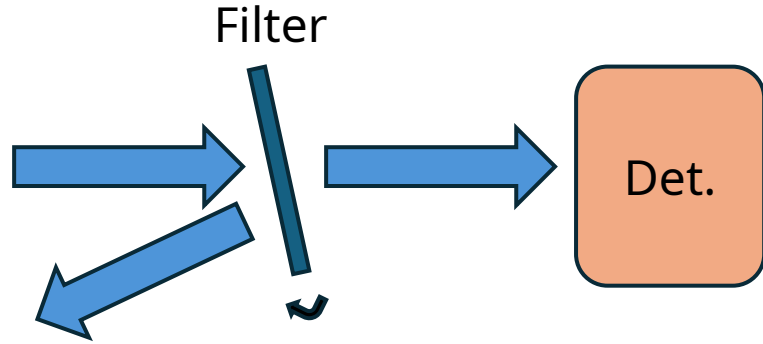


IC4Stars Sirius B Roadmap

- **Stage 1: One spectral channel**
 - Data acquisition validated on-sky. To be tested at Hawaii on Feb 2027.
 - Optical module validated on-sky.
 - Full deployment at Hawaii on late 2027 on sky.
- **Stage 2: 16 spectral channels**
 - Same Detectors and DAQ of Stage 1
 - Upgrade: Optical multiplexing
- **Stage 3: Order 100 spectral channels**
 - Upgrades in DAQ, multiplexing and detectors (SPAD arrays, SiPMs, SNSPD)

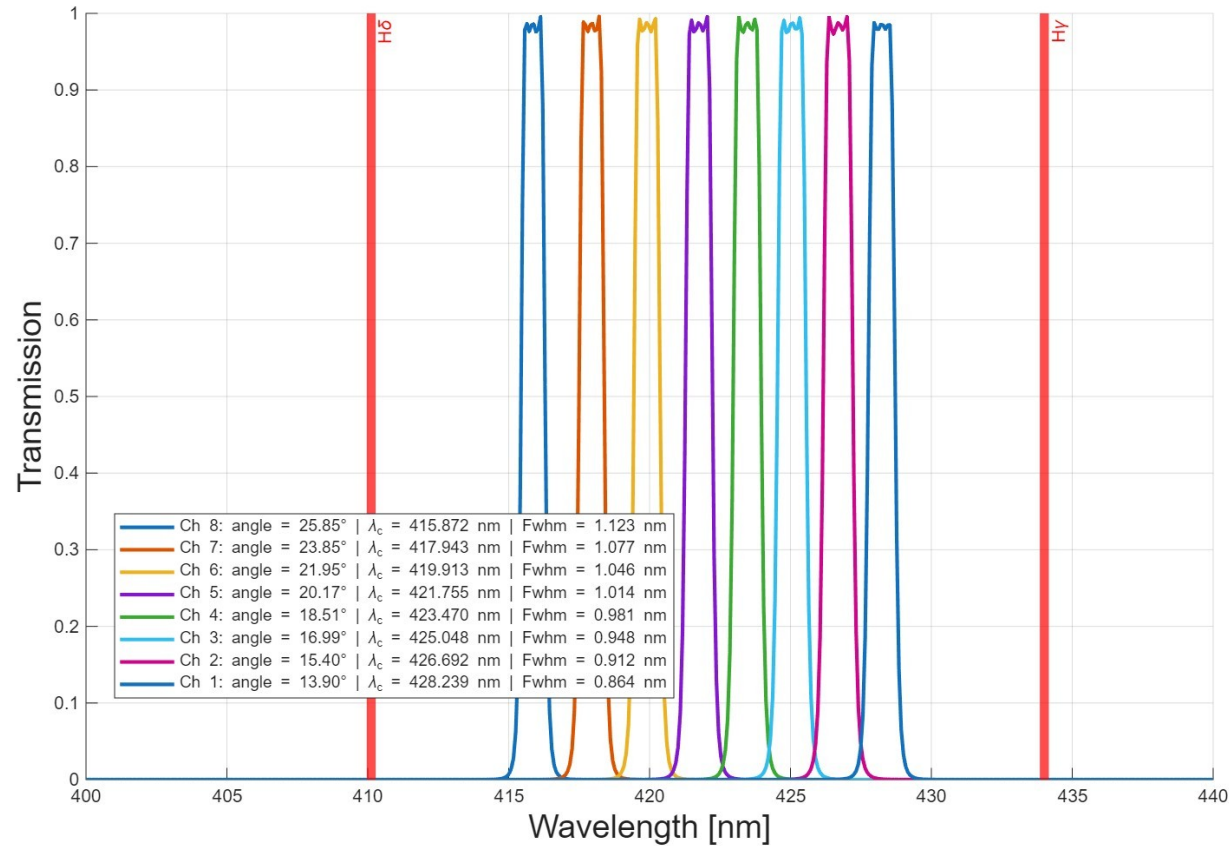
Stage 2 R&D: Multiplexing with discrete detectors

Design: Filters in cascade



Alluxa Filters:

- 1 nm bandwidth
- OD6
- $T \sim R \sim 97\%$
- Shift ~ 1 nm/deg



Stage 2 R&D: Multiplexing with discrete detectors

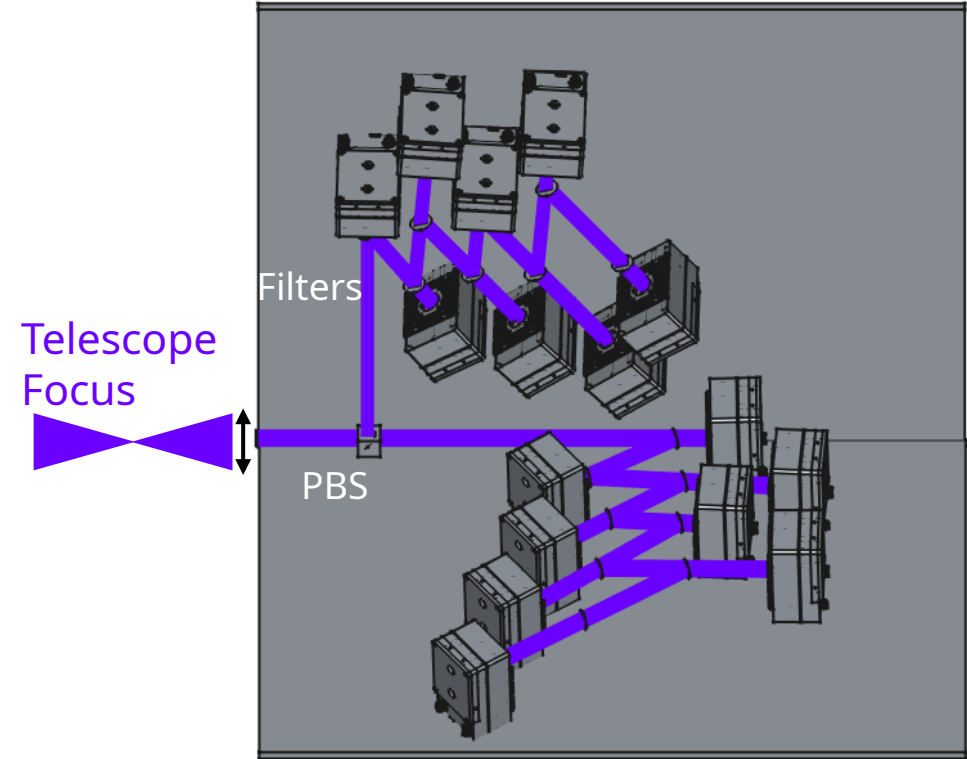
Design: Filters in cascade

- To optimize SNR, **both polarization and spectral multiplexing** are used
- Filters are efficient in a single polarization
- Free space design

	Photon budget
Det. QE	25%
Instr.	88%

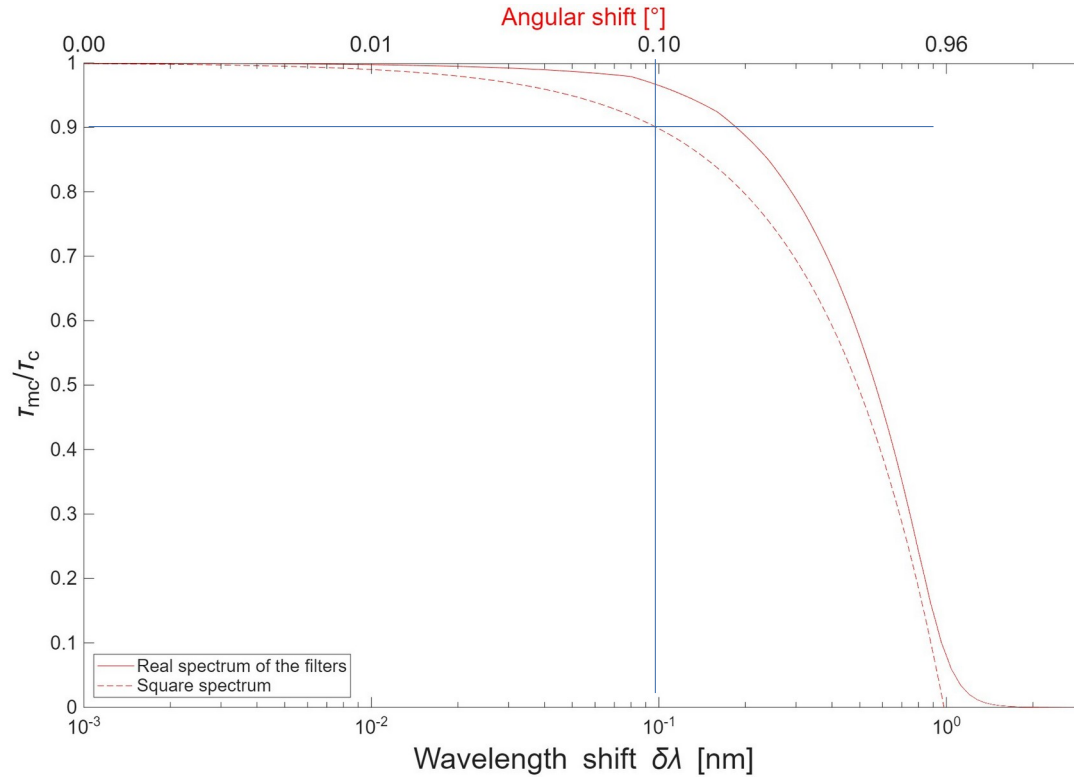
Gain in SNR:

- Theoretical = 4 (16 channels)
- **Design = 3.07**



Stage 2 R&D: The challenge of the mutual coherence time

Loss of SNR due to λ_0 mismatch



Design requirement:

- 0.1 nm mismatch
- 0.1 deg mechanical tolerance

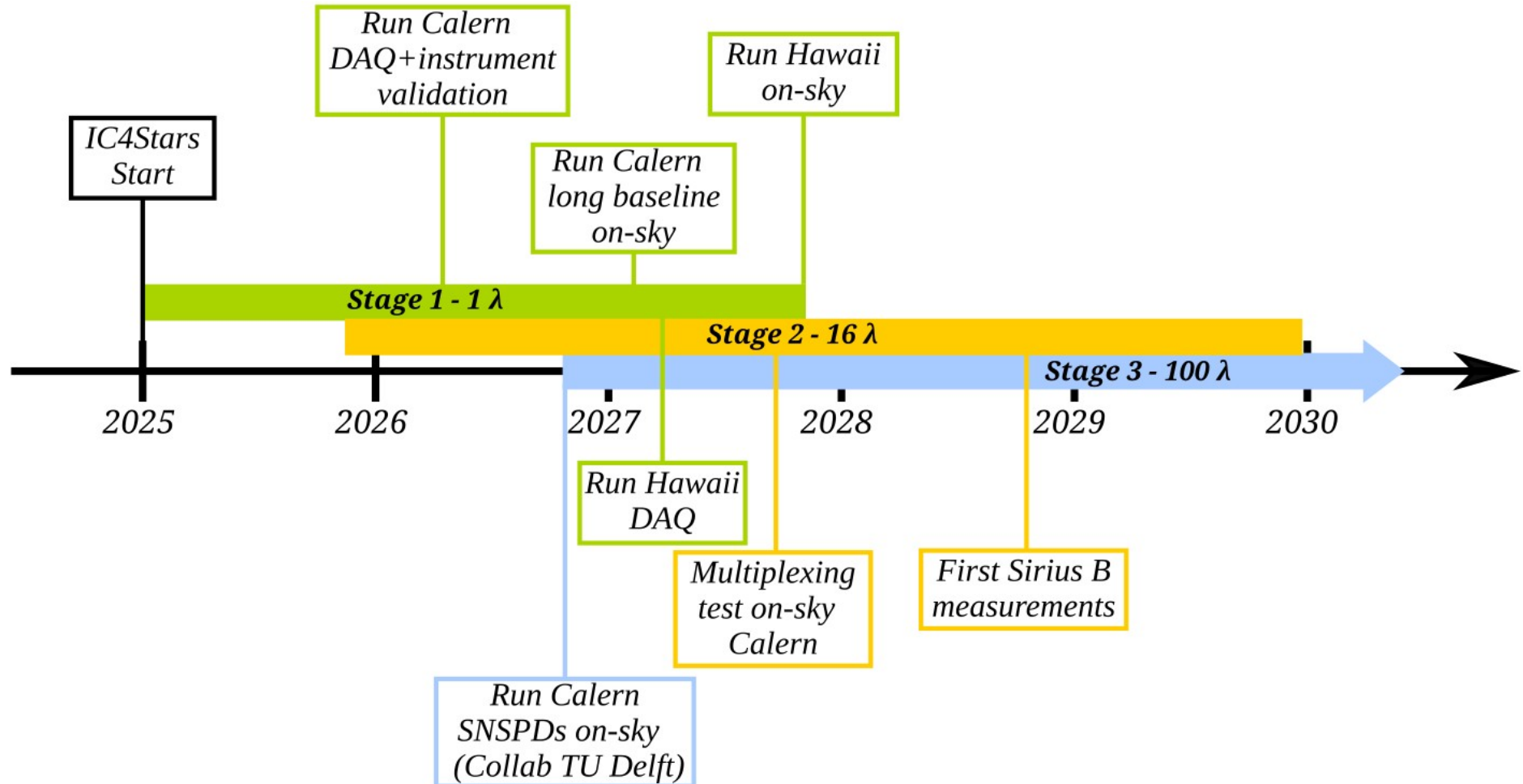
Stage 3 R&D, Collaboration with TU Delft

Superconducting nanowire single-photon detectors (SNSPDs)

- Collaboration with TU Delft, Calern campaign Nov-2026
- C2PU 2×1 m telescopes, 15 m baseline
- $H\alpha$ band, fiber-coupled optical module, MMF, 100 μm core
- 4 pixels per channel, FWHM (1 pixel). Jitter = 50 ps at 1 MCPS



IC4Stars Sirius B Roadmap

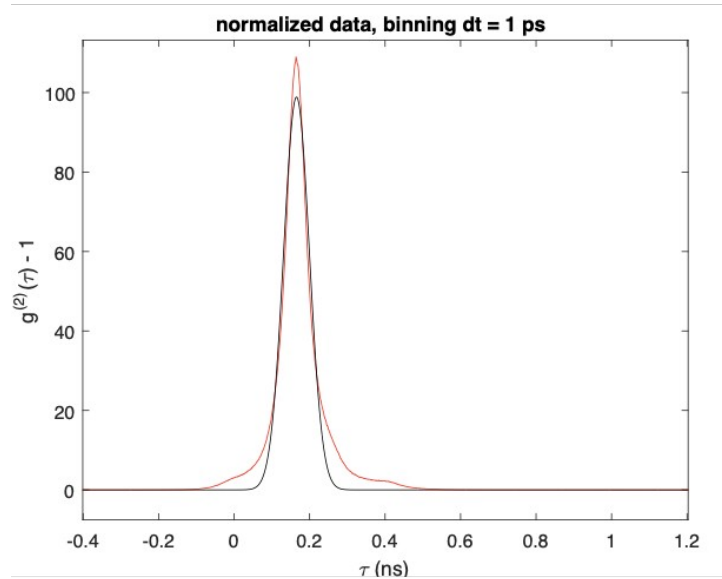


Outlook - Objective: Sirius B

- IC4Stars current status:
 - Stage 1 R&D completed.
 - Overall Time jitter 35 ps RMS On-sky, raw time-tags.
- Scheduled short-term plans to deploy the setup:
 - **November 2026:** SNSPDs at C2PU (Collab. TU Delft)
 - **January 2027:** Long baseline, at C2PU + MéO (150 m)
 - **February 2027:** DAQ sync at Hawaii
- Work-in-progress:
 - Stage 2, Wavelength multiplexing, 16 spectral channels
 - Stage 3, scalable setup (SNSPDs, SPADs arrays, SiPMs)
- Future challenges:
 - Blockage of Sirius A.
 - Geodesy at 35 ps ~ mm scale

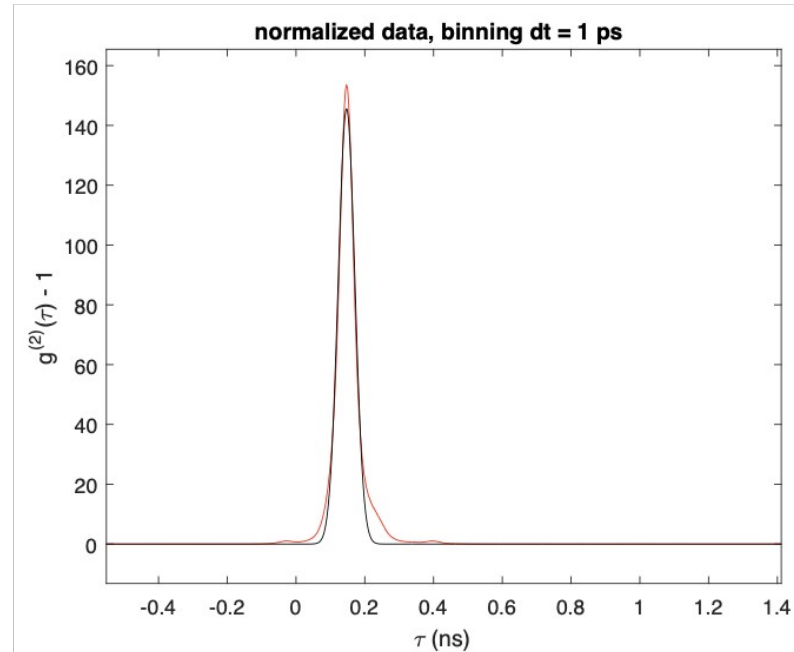
g2 with laser, 2 dets (5+9), 1 TDC (2 channels: 1m + 2m SMA/SMA) ; CR = 4,4 Mcps

Datasheet param



J = 112 ps (FWHM)

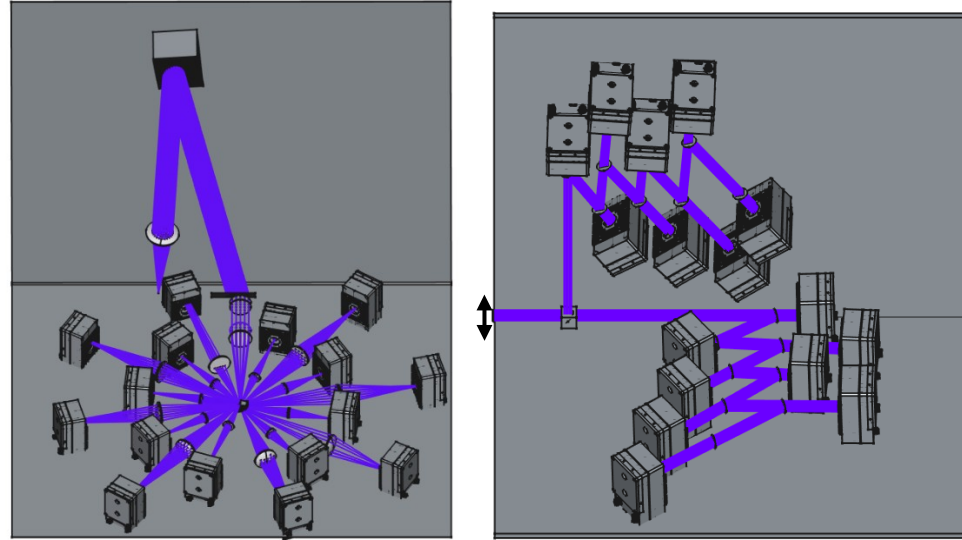
Modified param



J = 57,9 ps (FWHM)

x

Stage 2 R&D: BONUS – Comparison Grating vs Filters



	Grating Instr.	Filters Instr.
Fibered ?	Yes	No
Spectral bandwidth per channel	0.9 nm	0.81-1.10 nm
Temporal resolution	43.6 ps	38.9 ps
Transmission	54%	88%
Modulation f.	1.00	0.95