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INPHYNI
INSTITUT DE PHYSIQUE DE NICE

Intensity Interferometry with optical telescopes: recent progress and future plans

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(*Intensity Interferometry at Calern*)

Institut de Physique de Nice (INPHYNI)

Université Côte d'Azur & CNRS

https://inphyni.univ-cotedazur.eu/sites/cold-atoms

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR
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The I2C consortium

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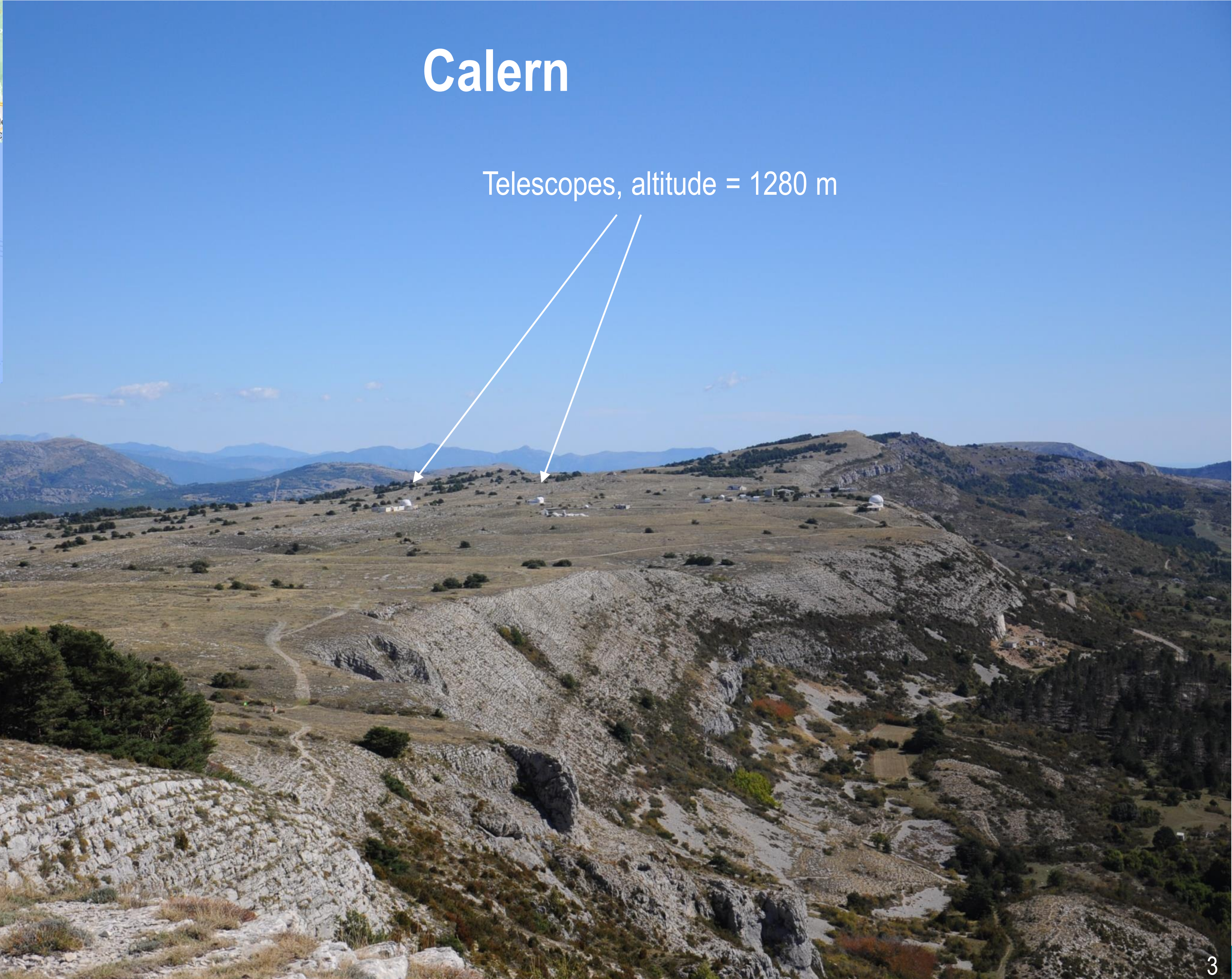
Calern

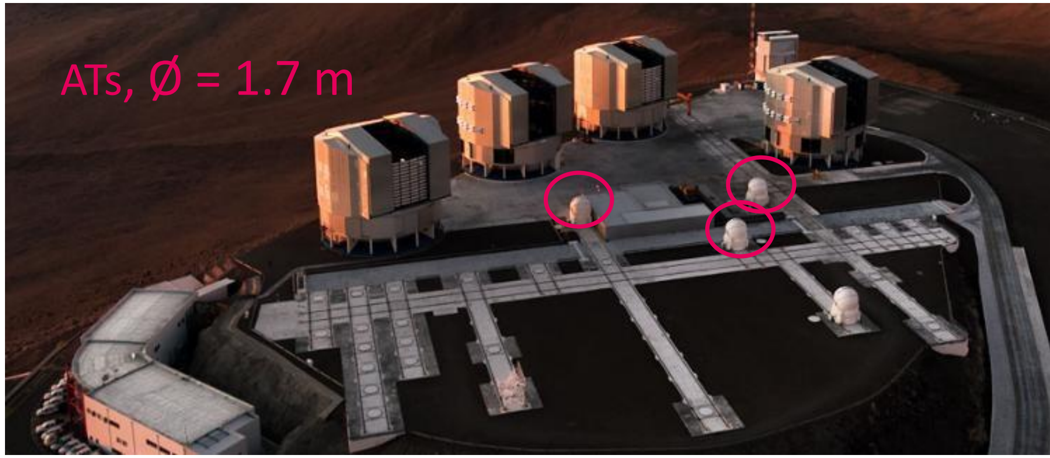

Cuébris
Briançonnet
Sospel
Levens
Carros
Plateau de Calern
30 km
Nice
Vence
La Trinité
Èze
Monaco
Saint-Jean-Cap-Ferrat
Parc naturel régional des Préalpes d'Azur
Cagnes-sur-Mer
Valbonne
Seillans
Montauroux
Mouans-Sartoux
Mougins
Vallauris
Antibes
Cannes
Les Adrets-de-l'Estérel
Théoule-sur-Mer
Google


Telescopes, altitude = 1280 m

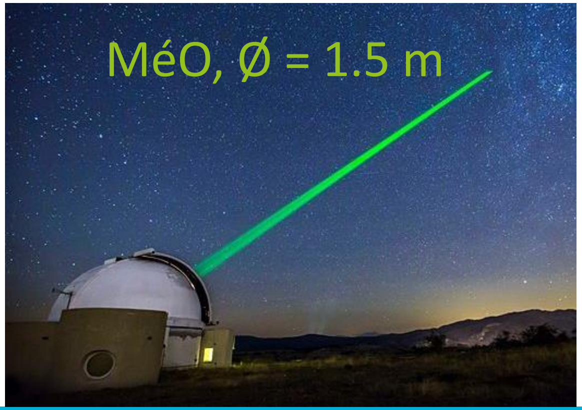
Our approach: SII with optical telescopes

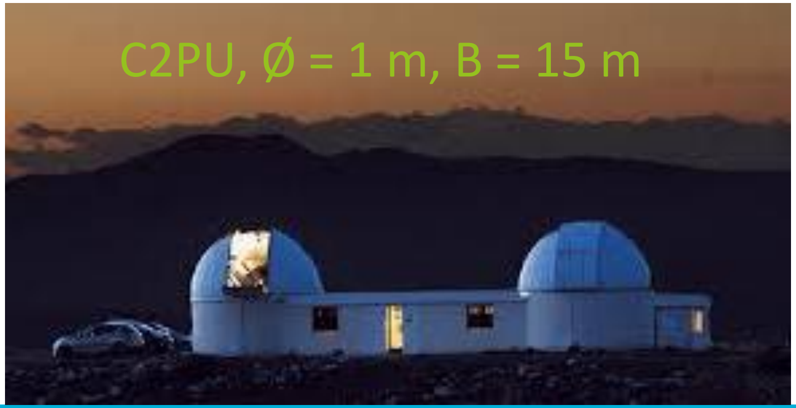
Drawback:
- Large arrays of large optical telescopes will never be available

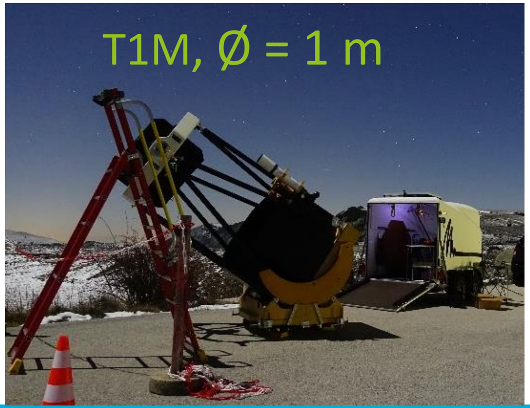
Advantages:
- The small PSF allows using the best detectors and other photonic technologies (fibers, narrow filters, etc.)
- The instrument can be adapted to any existing facility
- No big issue with the sky background



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



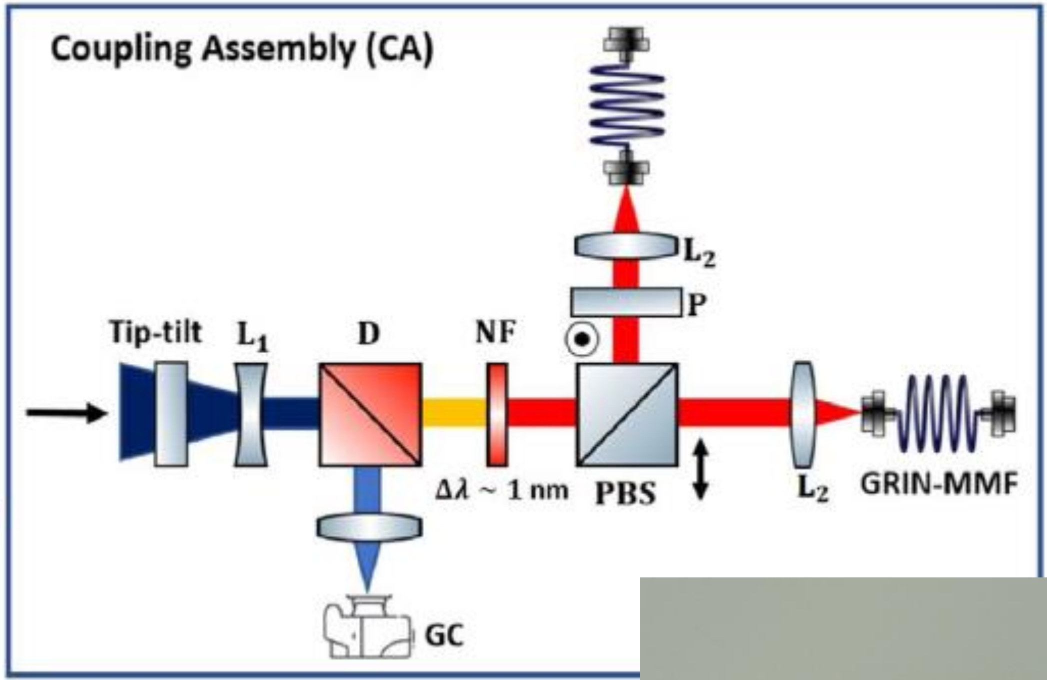




Outline

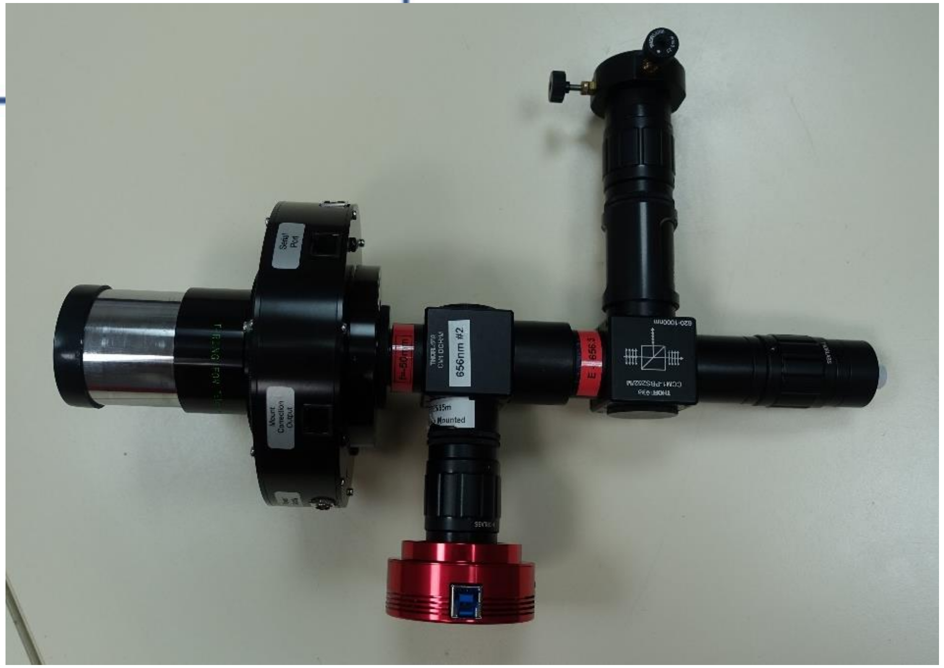
- The instrument
- Adaptability and portability
- One astrophysical result
- Prospects

Optical setup



Compact and transportable setup

- Only off-the-shelf components
- Collimated beam at the filter position
- Filter width $\Delta\lambda$ = 1 nm (τ_c ~ 1 ps)
- Two polarization channels
- Light injected in MMF (Ø = 100 µm)

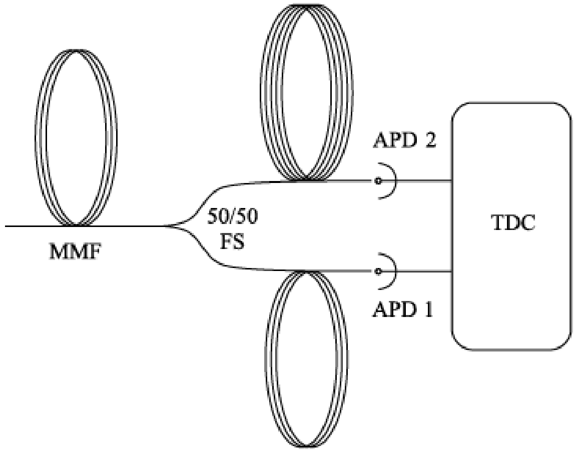


So far:
λ = 780 nm or 656 nm (Hα)

Detection setup

50/50 Multimode fiber beamsplitter

To measure the zero-baseline visibility and overcome the APD dead time



SPAD: Single photon avalanche detector

Quantum efficiency	$\eta \sim 70$ % (650 nm)
Max count rate	~ 20 MHz
Active surface	Ø = 180 µm
Jitter	$\tau_{el} \sim 500$ ps

Excelitas

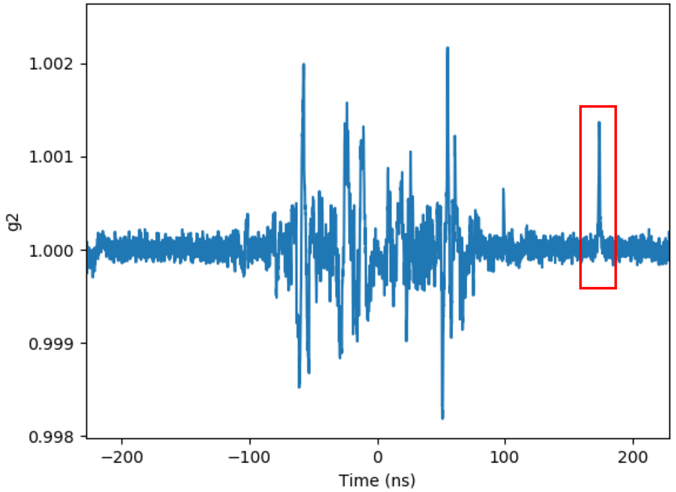
TDC: Time to Digital Convertor

Cross-channel rms jitter = 12 ps

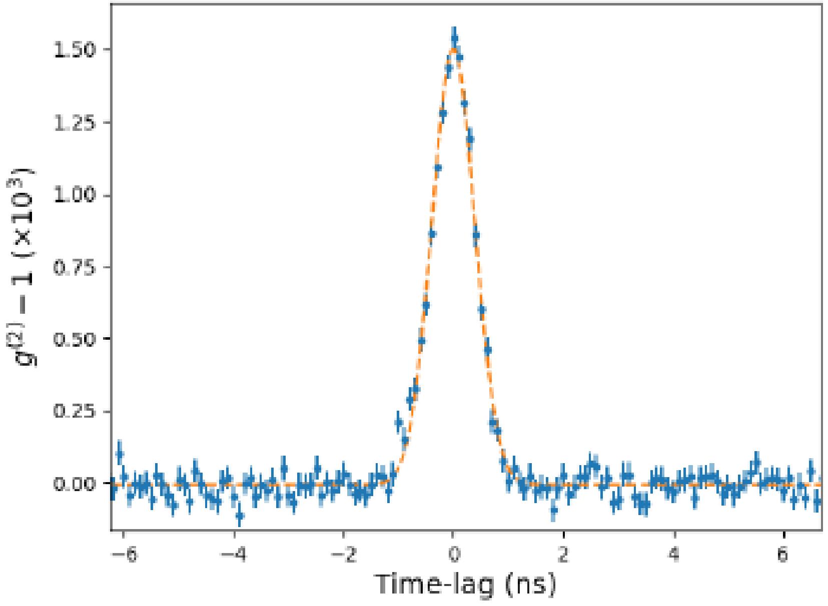
Max data transfer rate = 1 Gtags/s

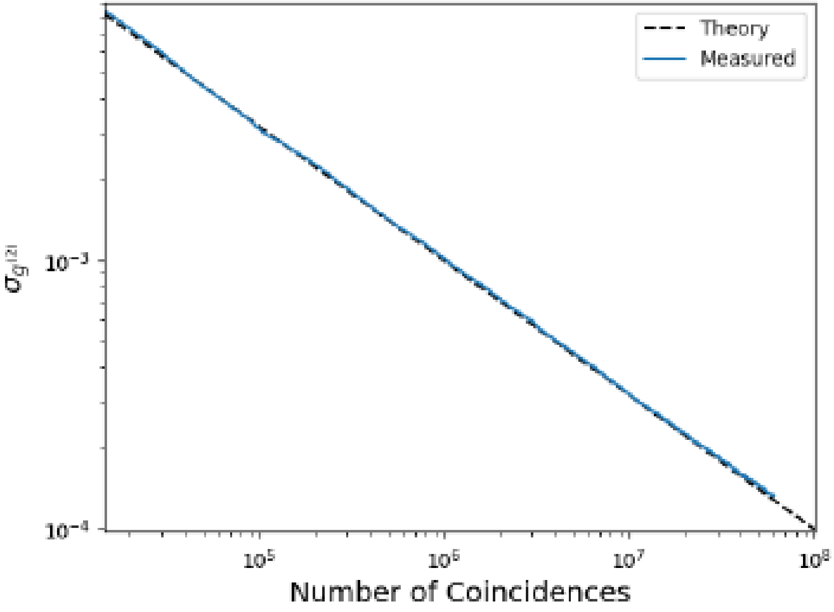
Swabian Instruments

Noise



Spurious correlations (induced by the TDC and/or by cross talk between APDs)
→ avoided using cable (electronic or optical) delays.





Measurement limited by photon statistics down to 1% (at least).
Coherence time agrees with the measured spectral filter.

Matthews *et al.*, *Proc. SPIE* **12183**, 121830 (2022)

Data acquisition

Example with:

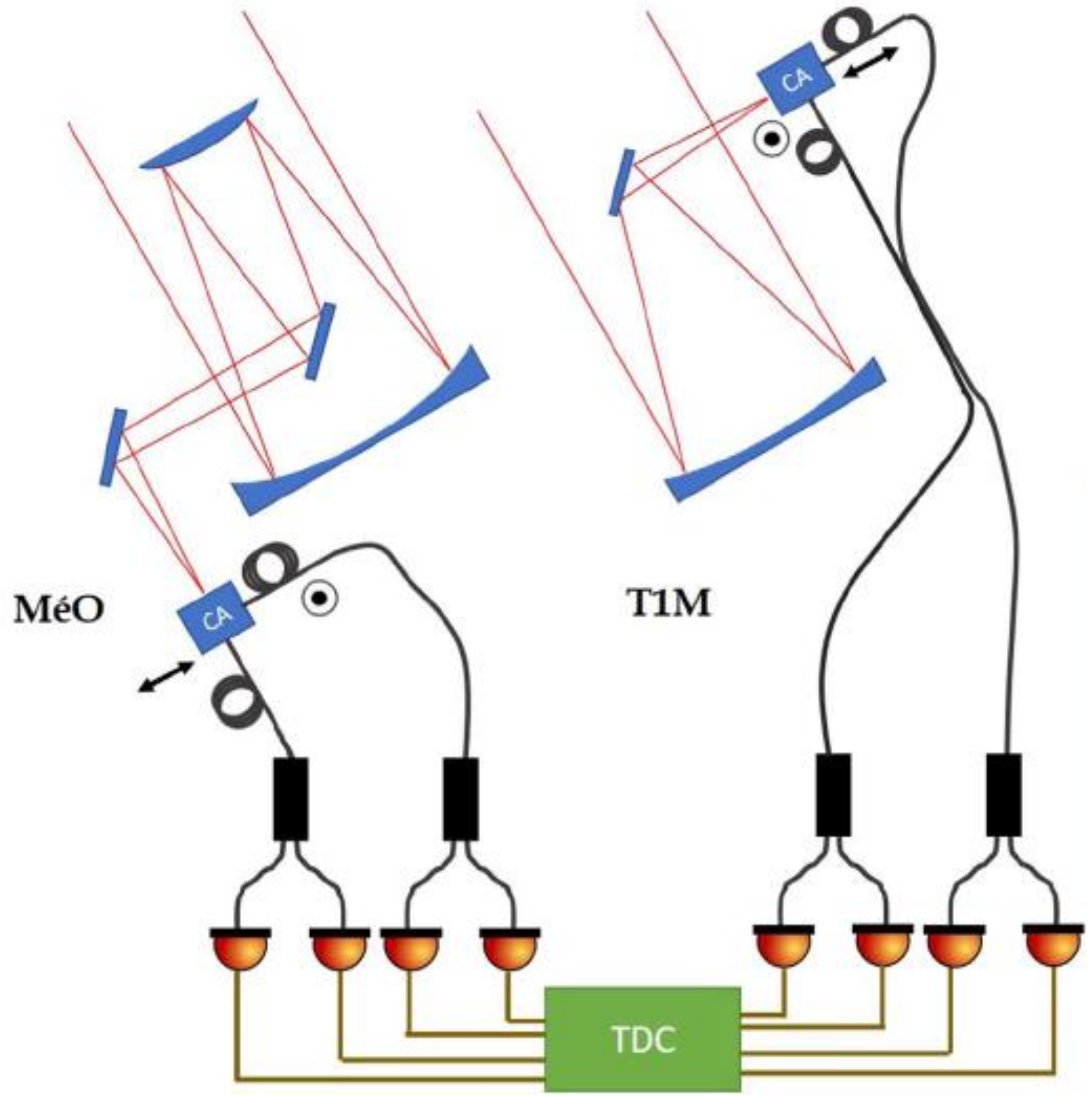
- 2 telescopes
- 2 polarization channels
- zero-baseline correlations on all channels

→ 4 correlation functions at zero baseline

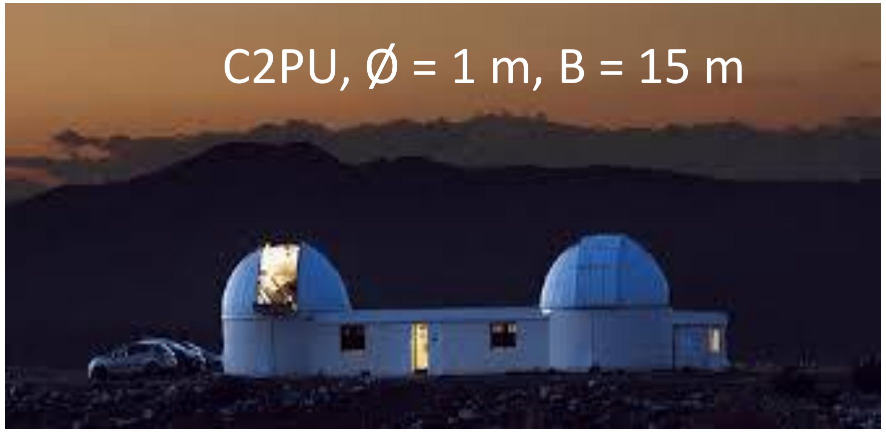
→ 4 correlation functions x 2 polarizations

→ 12 correlation functions on the fly

- They're all added up for the analysis (no polarization effect expected)
- They're all saved every 10 s, then shifted in time to compensate for the time-varying optical-path difference, then added up.
- We don't record (so far) all photons!

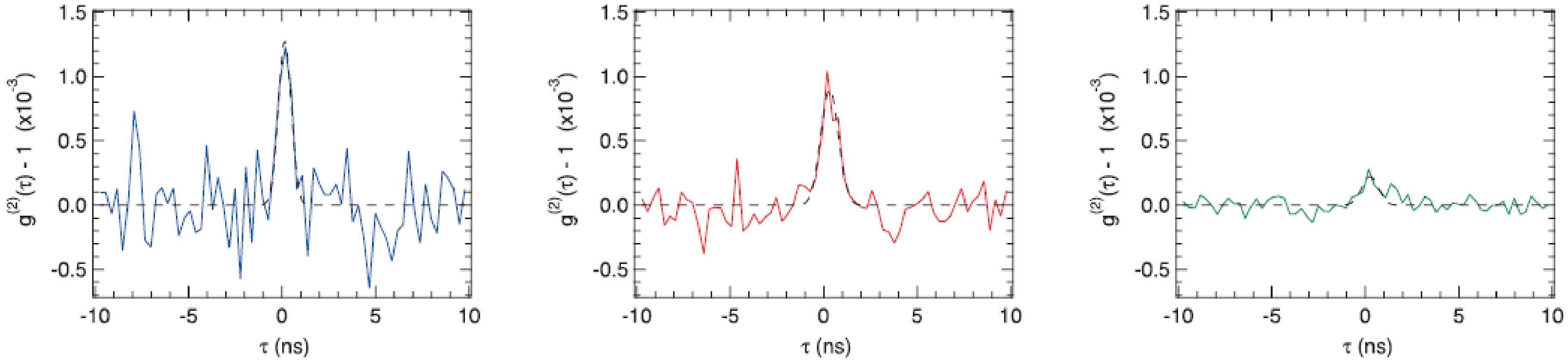


SII @ C2PU



The simplest!

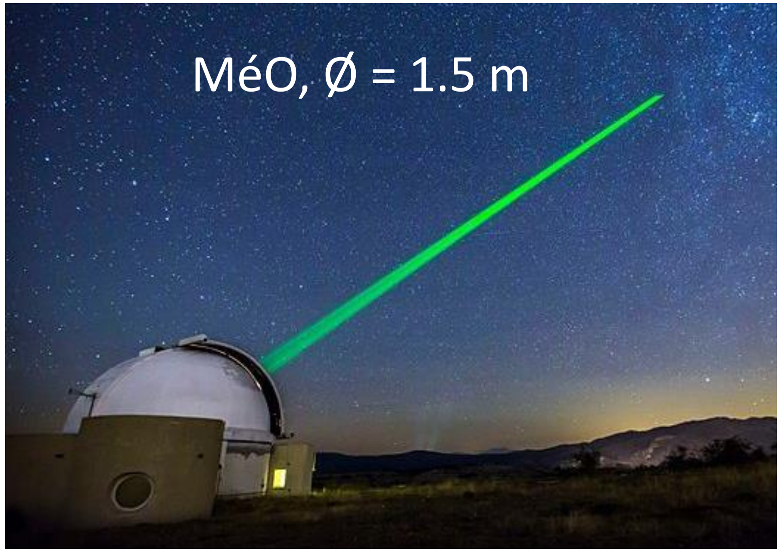
First demonstrations at C2PU:
Cassegrain foyer, equatorial mount

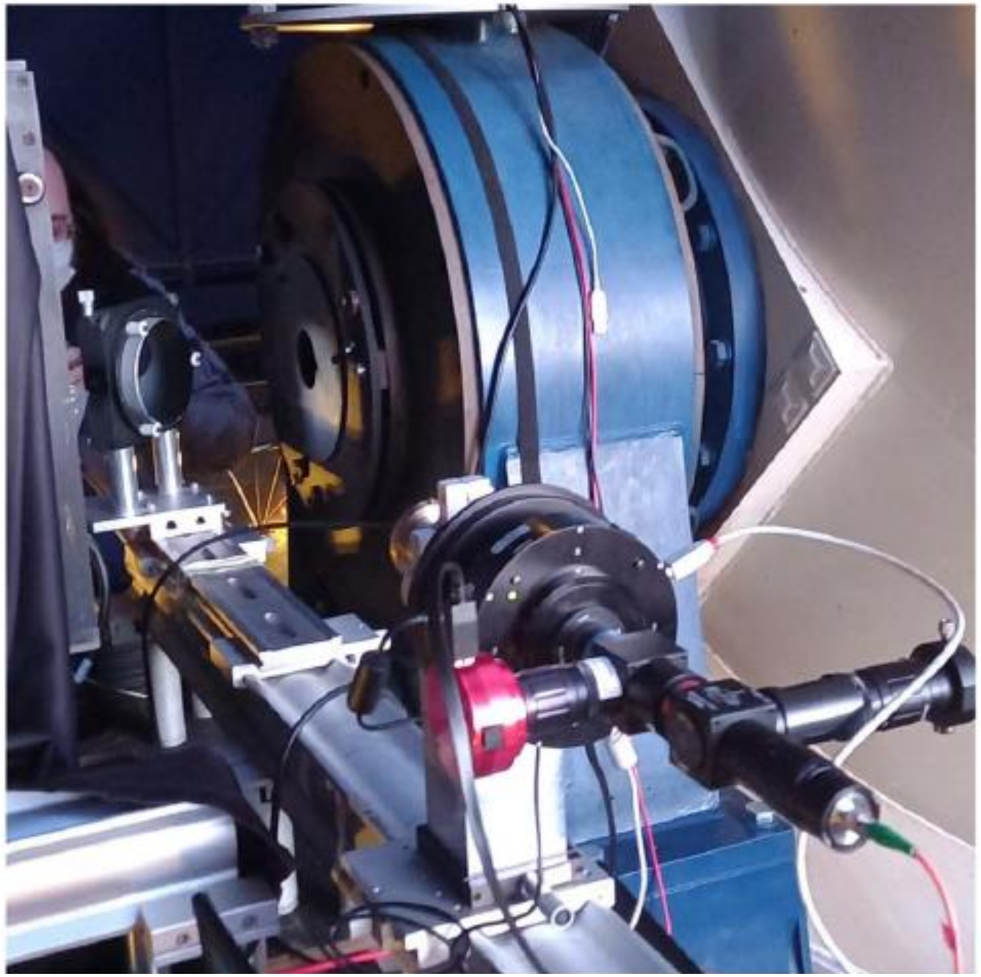


(a) β Ori. (b) α Lyr. (c) α Aur.

Guerin *et al.*, *MNRAS* **472**, 4126 (2017); *MNRAS* **480**, 245 (2018)

Adaptation to MéO

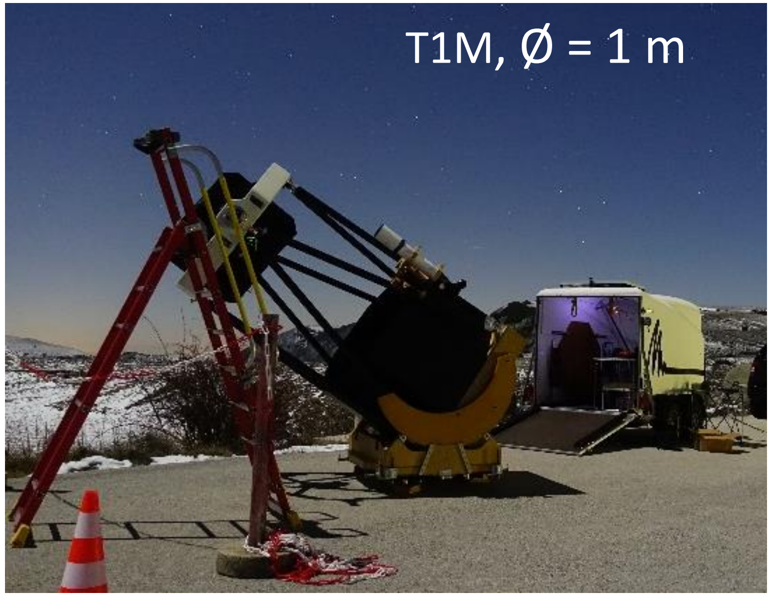




MéO: laser-ranging telescope at Calern
Ritchley-Chrétien configuration, alt-az mount, Nasmyth bench

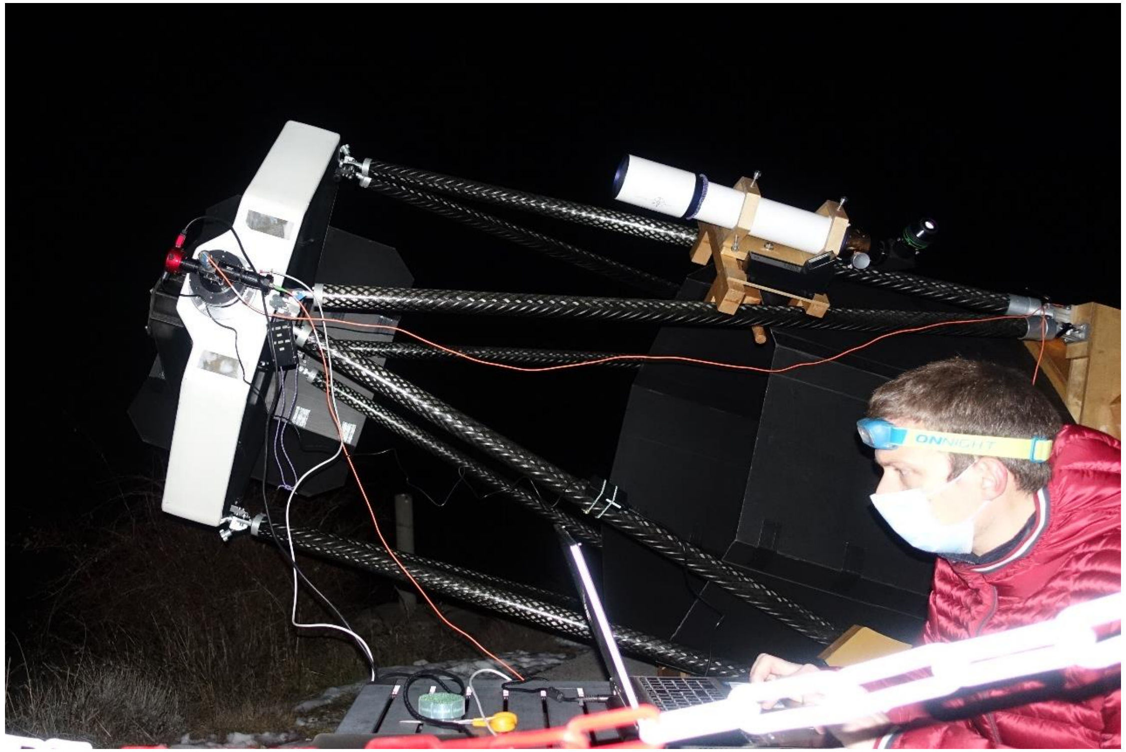
+ derotator!

Adaptation to a portable telescope



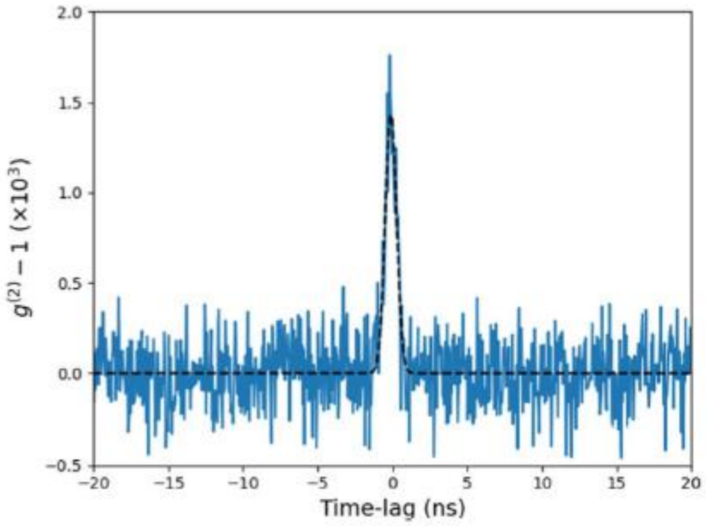
Adaptation to “T1M”, a portable telescope!
Newton configuration, Dobson-type az mount

+ tip-tilt correction!

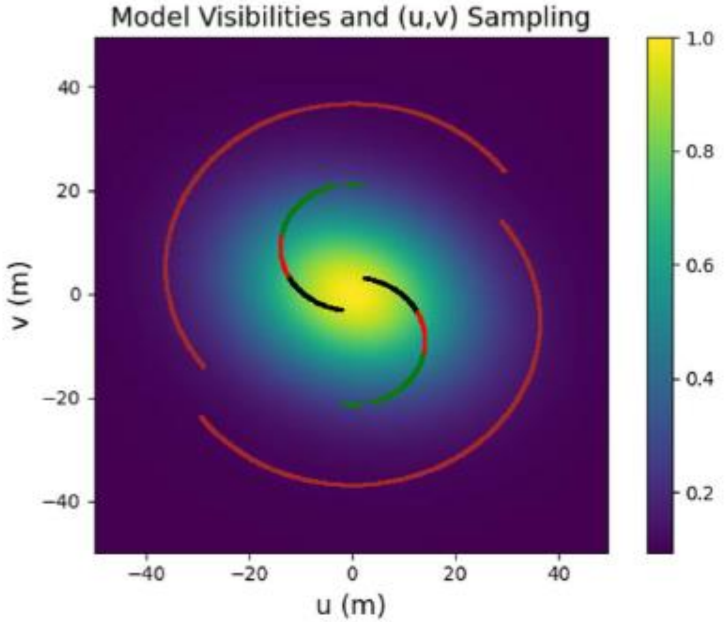


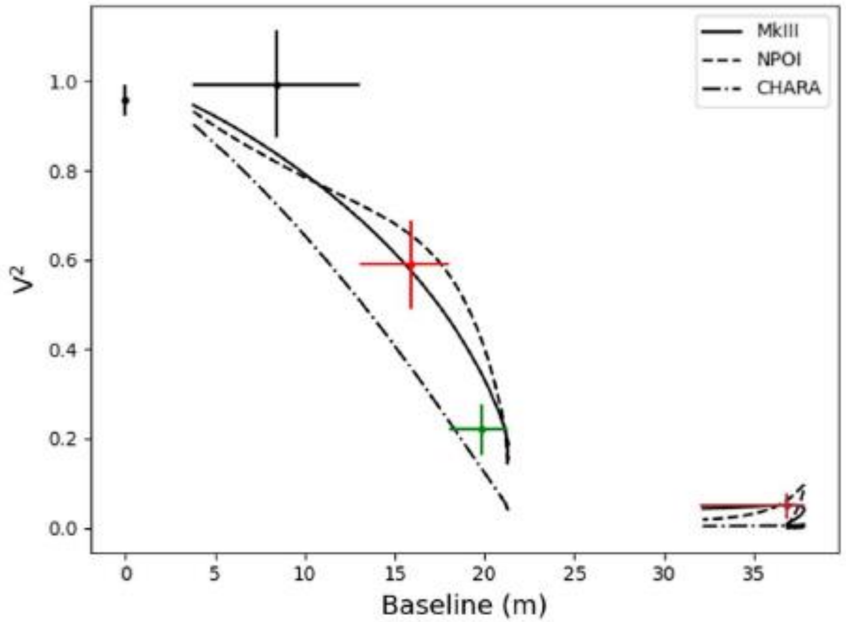
SII between MéO and T1M

Observation of the Hα envelope of γCas
Telescope separations = 18 m, 38 m



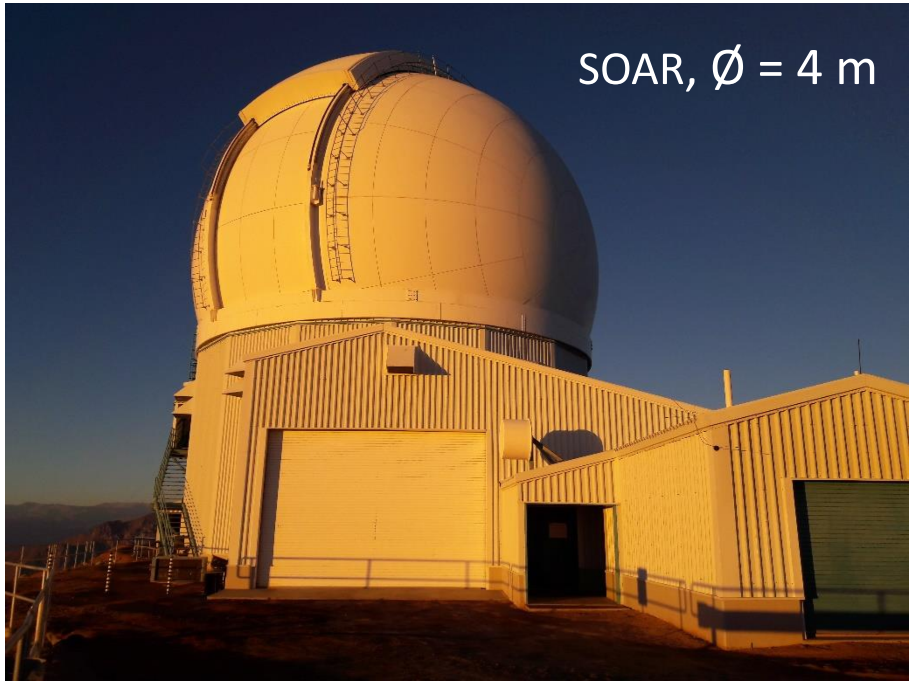
Gaussian anisotropic envelope (disk)
Results consistent with previous measurements



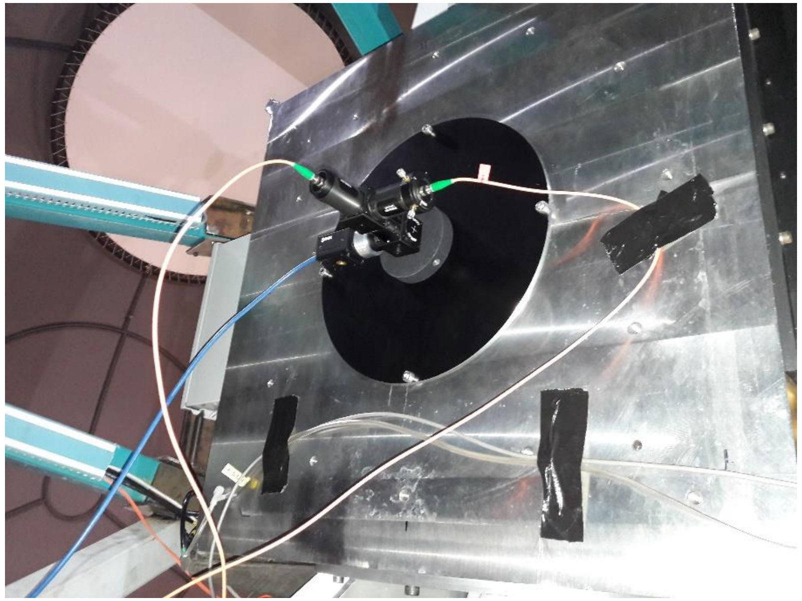


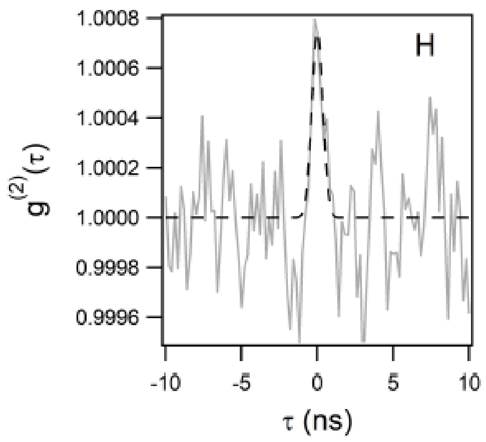
Matthews *et al.*, Astron. J. **167**, 117 (2023)

Adaptation to SOAR



Adaptation to **SOAR** (4 m, Cerro Pachon)
Nasmyth focus, alt-az mount



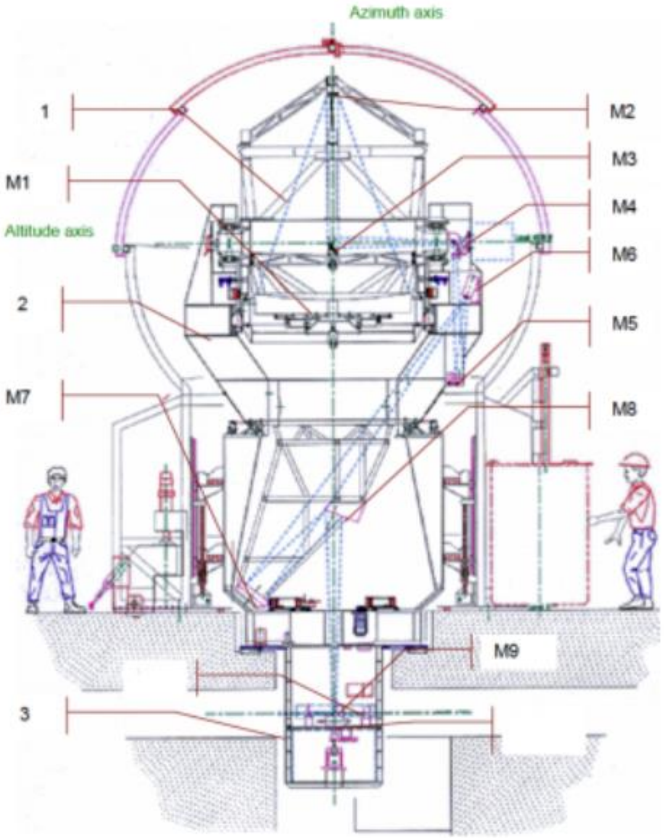


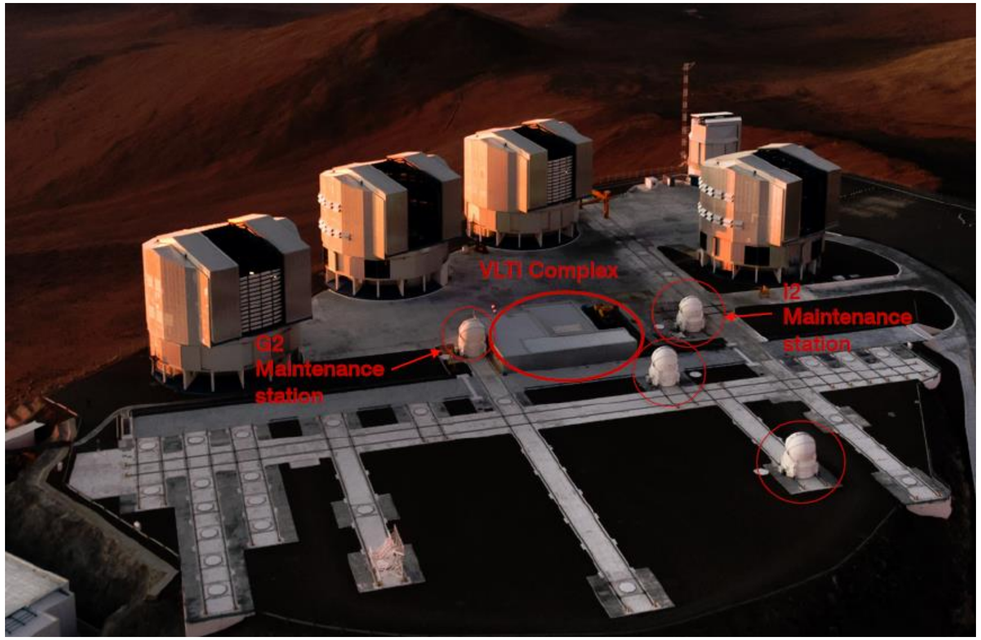
One-telescope experiment only!
Only one night of observation with poor weather!

Guerin *et al.*, Proc. SF2A 2021, p. 331

SII @ Paranal

Adaptation to the **Auxiliary Telescopes** (1.7 m, movable) at Cerro Paranal (ESO): More tricky: little space and it should not disturb the standard operation.

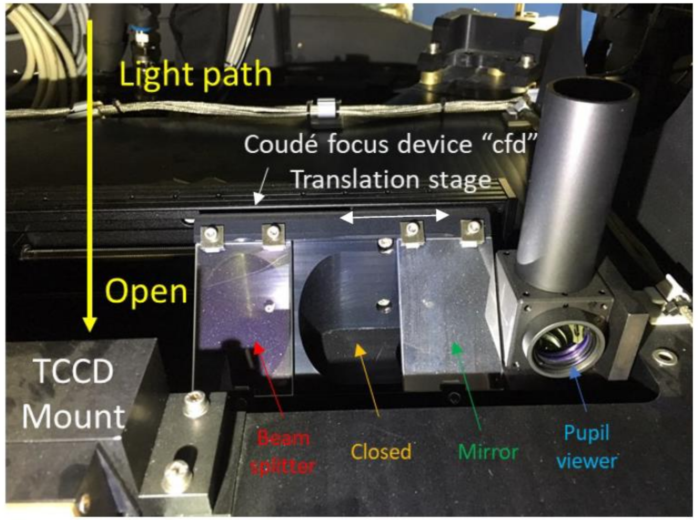


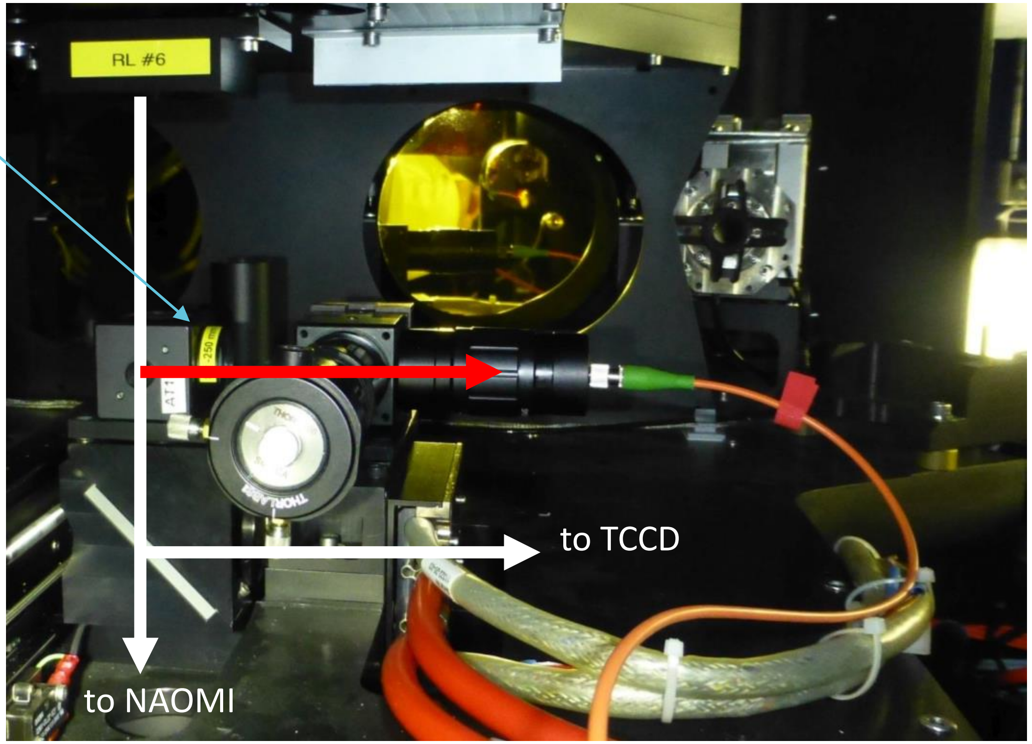


With the help of Pierre Bourget and Nicolas Schuhler (VLTI scientists)

SII @ Paranal

We pick up the light with a dichroic after M9 (Coudé focus). The module is fixed with magnets on a specifically-designed plate which can stay in place.

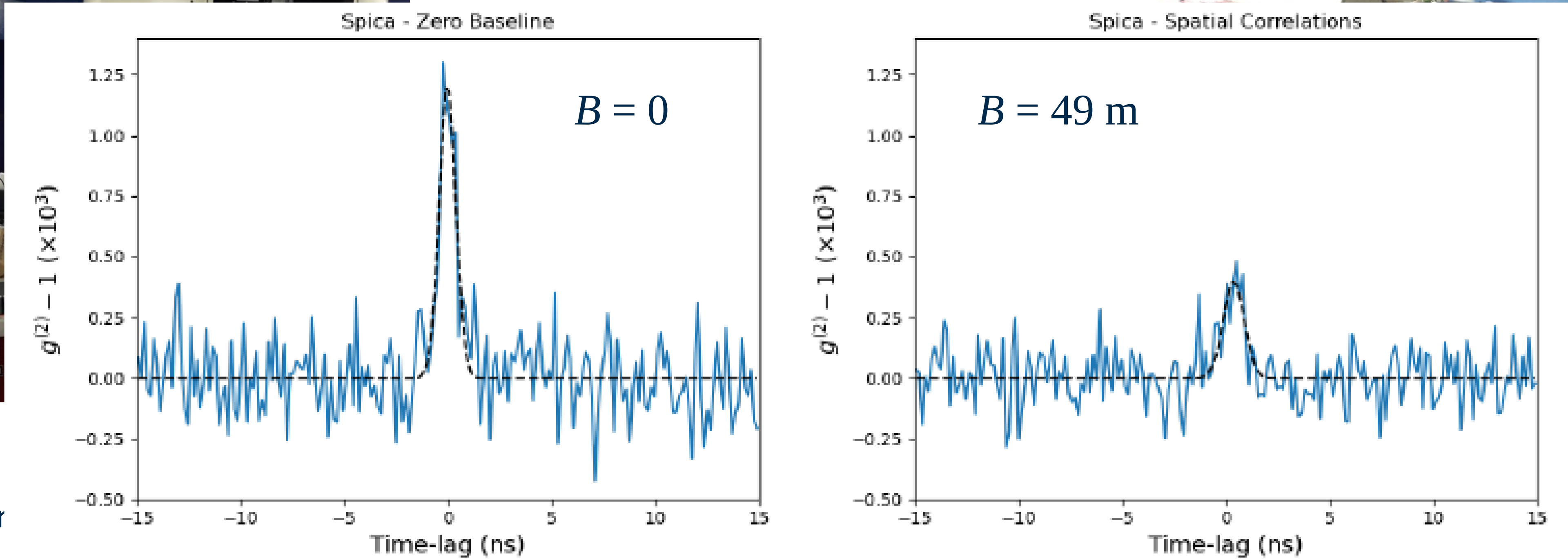




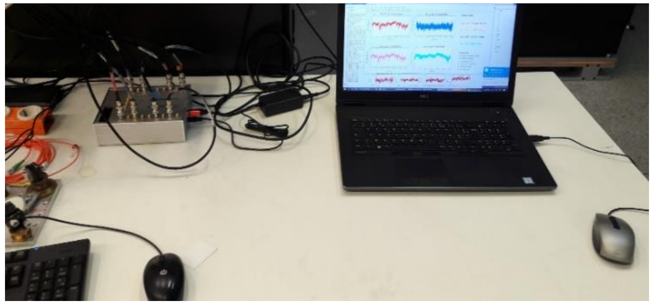
First run: maintenance stations (Baseline = 49 m)

I2

G2



How to
stellar ir

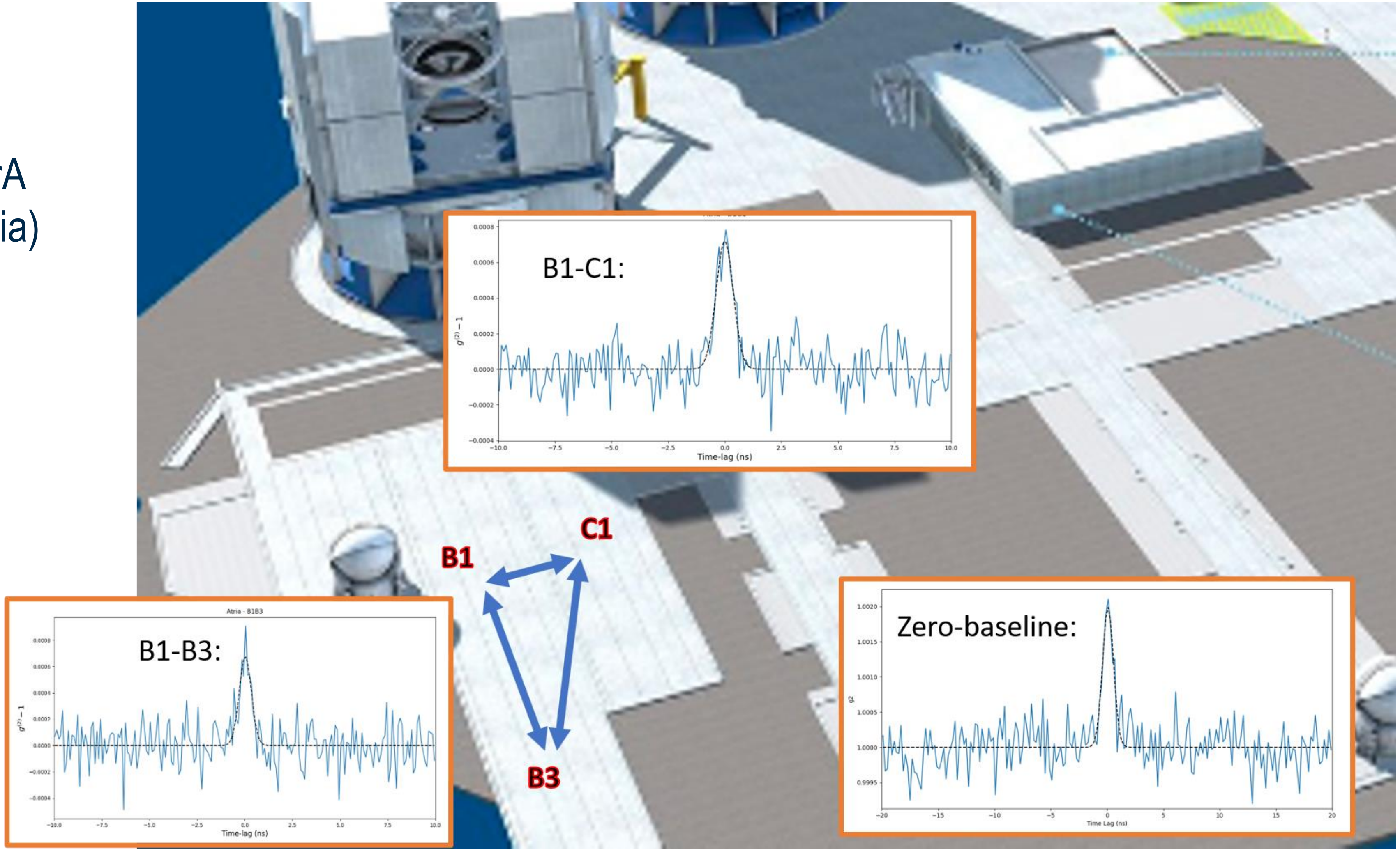


April 2022

Matthews *et al.*, Proc. SPIE **12183**, 121830 (2022)

Second run: 3 standard stations

αTrA
(Atria)

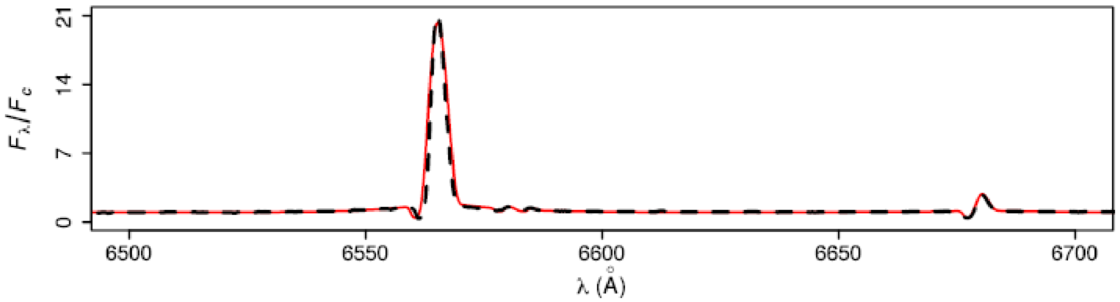


May 2023

Bunching reduced in an uncontrolled way because of a technical problem with some power supplies… ☹

Some astrophysical measurements: P Cygni's distance

Stellar model (CMFGEN) ← Spectroscopy



↓

Physical size (luminosity distribution)

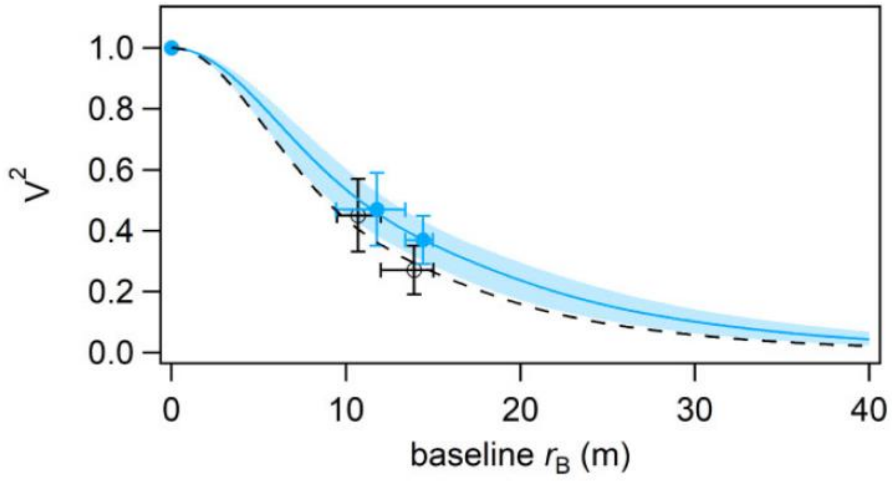
↓ ← Distance

$$d_{\text{PCyg, 2018}} = 1.56 \pm 0.25 \text{ kpc}$$
$$d_{\text{PCyg, 2020}} = 1.67 \pm 0.26 \text{ kpc}$$
$$d_{\text{PCyg, averaged}} = 1.61 \pm 0.18 \text{ kpc}$$
$$d_{\text{PCyg, eDR3}} = 1.60^{+0.21}_{-0.17} \text{ kpc}$$

Angular size (luminosity distribution)

↓

Visibility measurements



Rivet *et al.*, *MNRAS* **494**, 218 (2020)
Almeida *et al.*, *MNRAS* **515**, 1 (2022)

What's next ?

Increase the sensitivity!

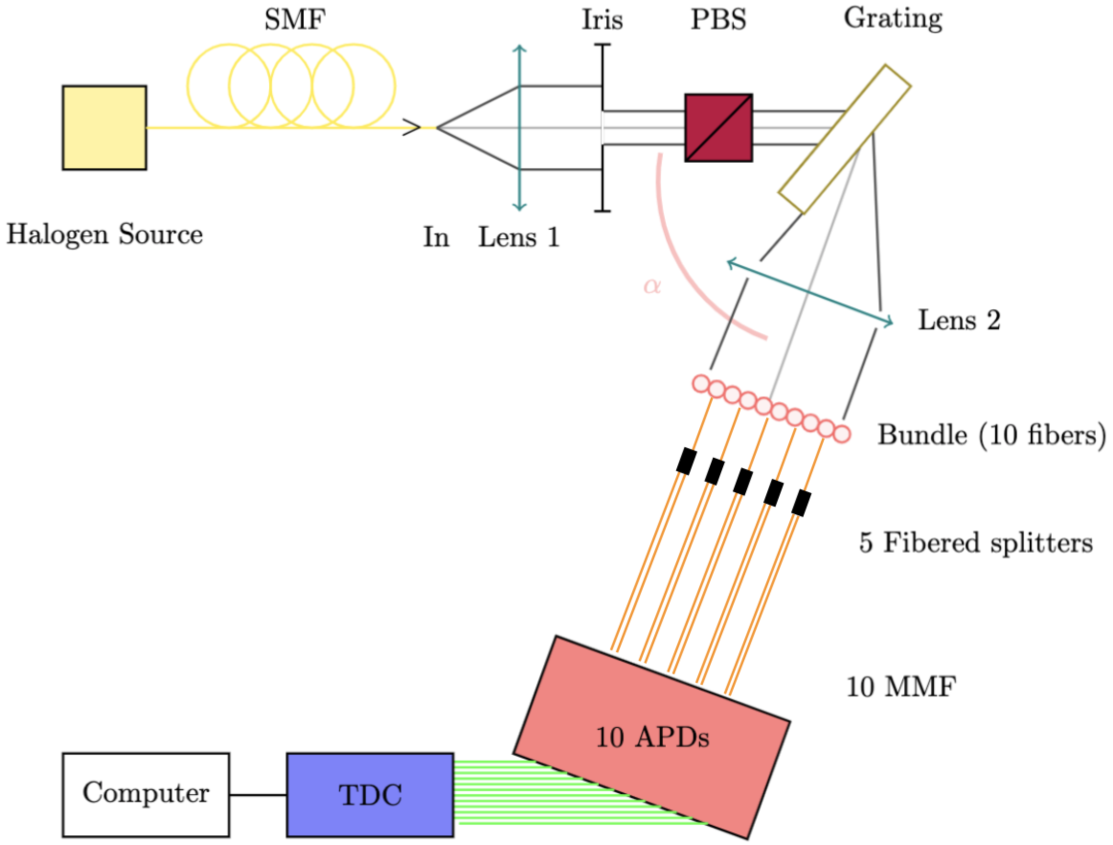
$$SNR = \sqrt{N_{channels}}\, A\, \eta\, F(\nu)\, |V(r)|^2 \sqrt{\frac{T_{obs}}{2\pi\tau_{el}}}$$

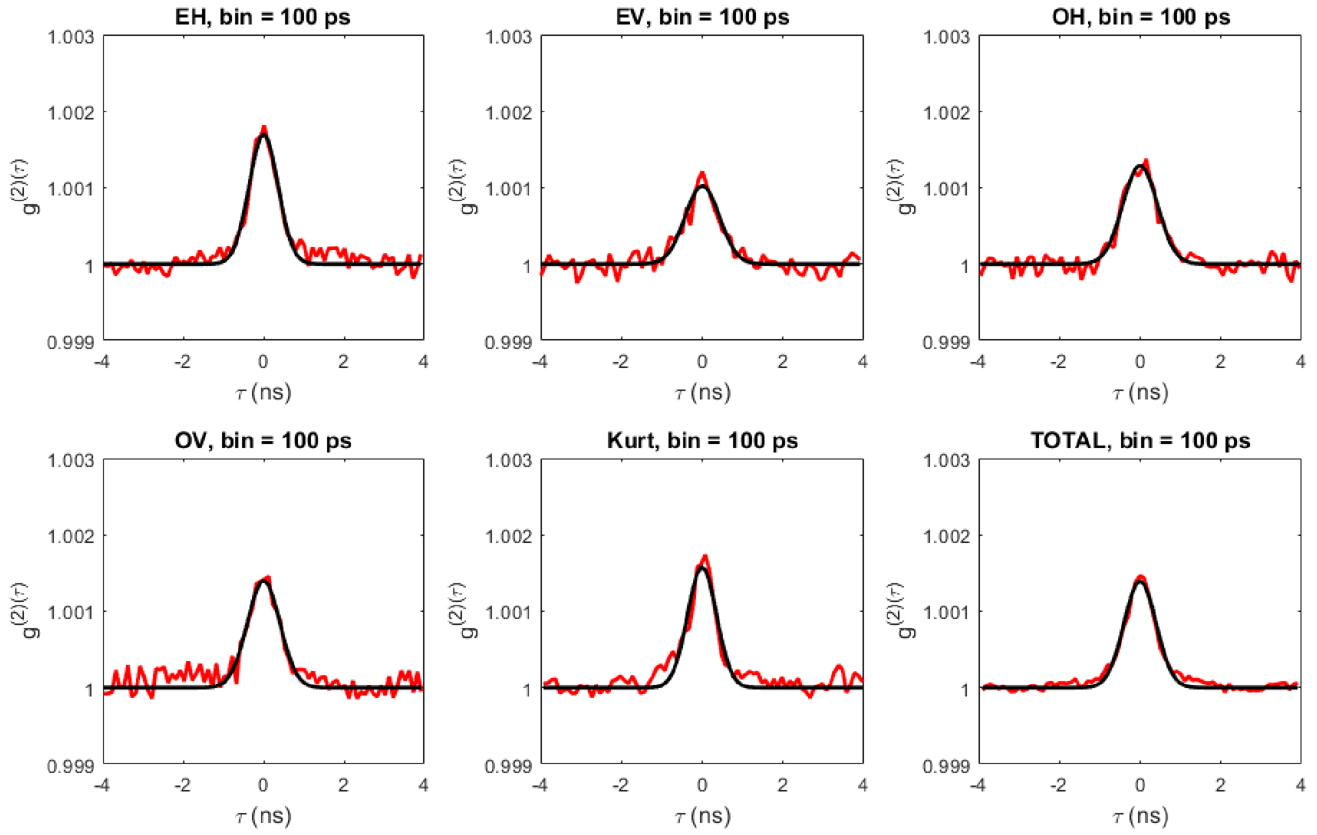
- **Better detectors** (e.g. SNSPDs): 500 ps → 20 ps → SNR ×5
- **Wavelength multiplexing**: 100 channels → SNR ×10
- **Bigger telescopes**: 1 m → 8m → SNR x64

+ **Very long baseline** (> 100 m)

- Two time taggers with a common clock distributed over telecom fibers (White Rabbit)
- All photons recorded & correlations computed off line (if necessary ?)

First lab tests of wavelength multiplexing





Single SNRs between 21 and 32 → $\Sigma(\mathrm{SNR}^2) = 59$

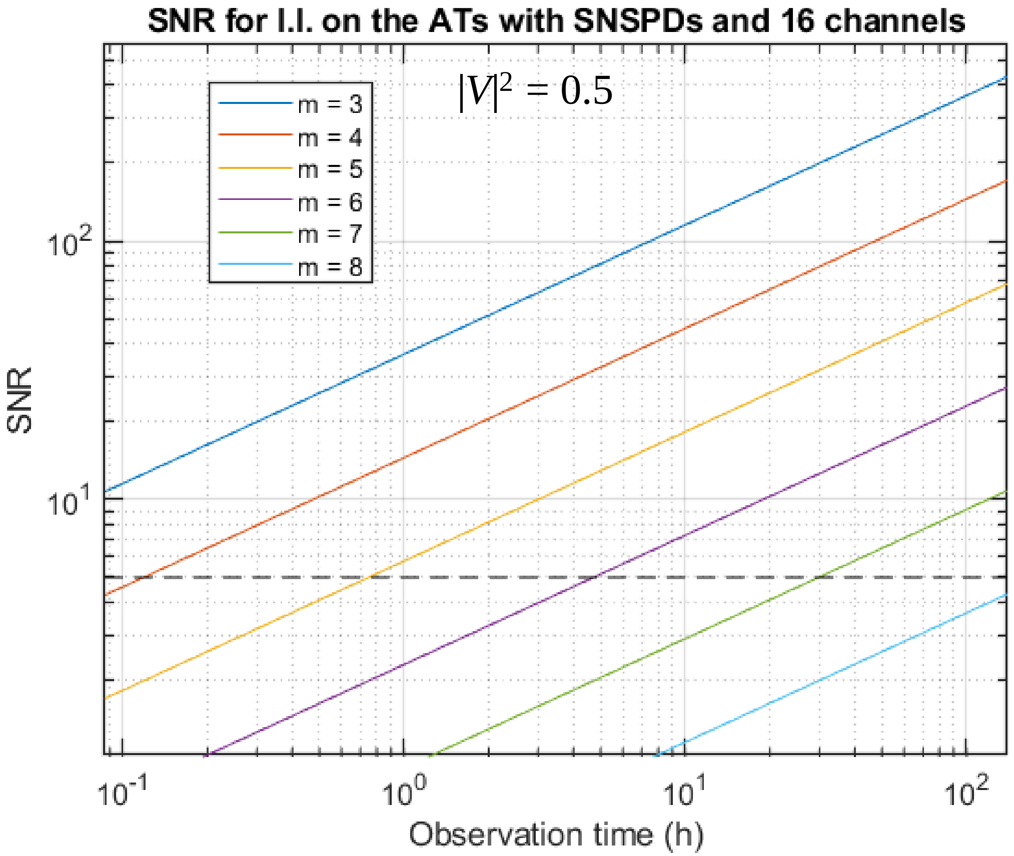
Measured SNR on the total curve: 51. Averaging not optimum!

Long-term goals

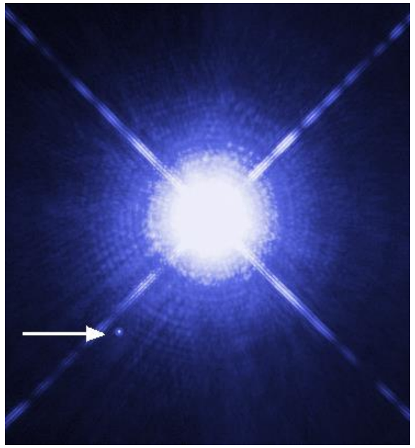
1) A visitor instrument at Paranal ?

- The 4 ATs (movable telescopes) are not used ~1 week/month!
- Currently, interferometry (VLTI) only works in the IR

→ Intensity interferometry could do the visible



2) Resolution of Sirius B at Hawaii



→ **next talks**

Thank you !

- Guerin *et al*., MNRAS **472**, 4126 (2017)
- Guerin *et al*., MNRAS **480**, 245 (2018)
- Rivet *et al*., Exp. Astron. **46**, 531 (2018)
- Lai *et al*., Proc. SPIE **10701**, 1070121 (2018)
- Rivet *et al*., MNRAS **494**, 218 (2020)
- Gori *et al*., MNRAS **505**, 2328 (2021)
- de Almeida *et al*., MNRAS **515**, 1 (2022)
- Matthews *et al*., Proc. SPIE **12183**, 121830G (2022)
- Matthews *et al*., Astron. J. **167**, 117 (2023)

https://inphyni.univ-cotedazur.eu/sites/cold-atoms/research/i2c

Open positions available !

(Picture by Serge Brunier)