# Intensity Interferometry with optical telescopes: Recent progress and future plans


William Guerin for the “I2C consortium”

(Intensity Interferometry at Calern – and beyond!)

*Institut de Physique de Nice (INPHYNI)*

*Université Côte d’Azur & CNRS*

# Calern


Cuébris
Levens
Sospel
D2204
Carros
Plateau de Calern
Saint-Jeannet
La Trinité
Monaco
Eze
D6085
30 km
Nice
Parc naturel régional des Préalpes d'Azur
Saint-Jean-Cap-Ferrat
Cagnes-sur-Mer
Valbonne
A8
Mouans-Sartoux
Mougins
Vallauris
Antibes
Cannes
A8
Théoule-sur-Mer
DN7
Google


Telescopes, altitude = 1280 m

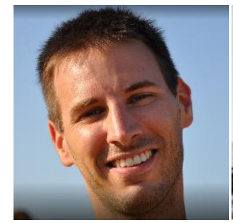
# The I2C consortium

## **INPHYNI**, cold-atom team




Robin Kaiser — William Guerin — Mathilde Hugbart — Guillaume Labeyrie

## **Géoazur**, MéO team




Clément Courde — Julien Chabé

**Former members:**
Nolan Matthews
(Post-doc, 2021-2023)
Antoine Dussaux
(Post-doc, 2015-2016)
Antonin Siciak
(PhD student, 2018-2021)

## **Lagrange (Observatoire de la Côte d’Azur)**



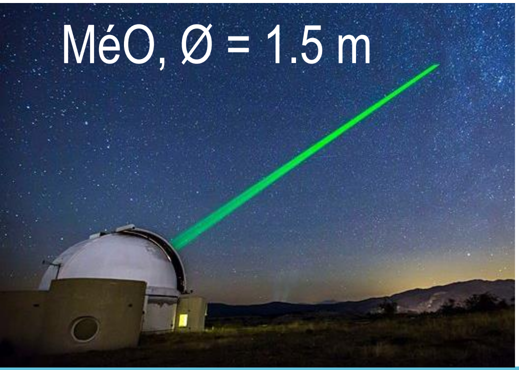

Farrokh Vakili — Jean-Pierre Rivet — Olivier Lai — Armando Domiciano

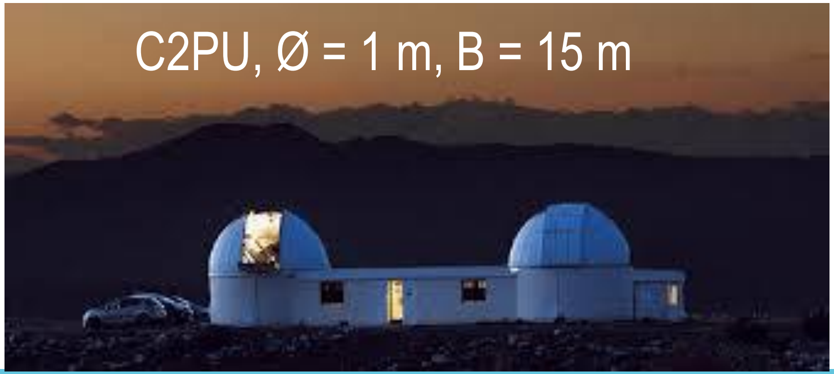
# Our approach: SII with optical telescopes

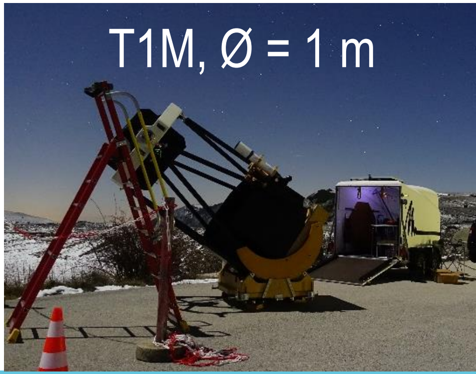
<u>Drawback:</u> Large arrays of large optical telescopes will never be available

<u>Advantages:</u>
- The optical quality 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

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



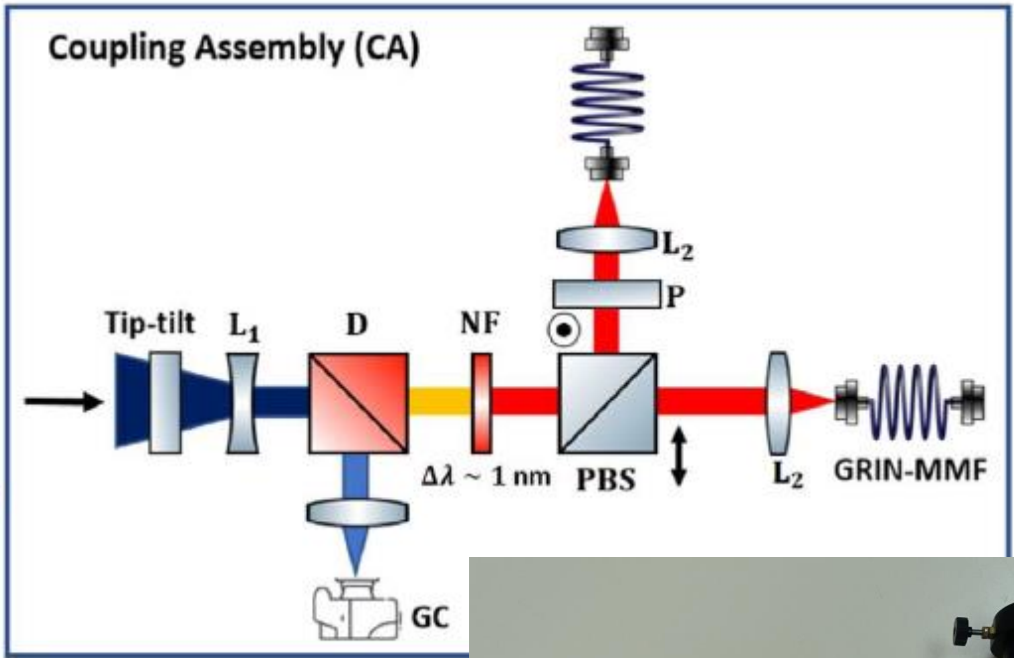



# Outline

- 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 ($\tau_c$ ~ 1ps)
- Two polarization channels
- Light injected in MMF (Ø = 100 µm)

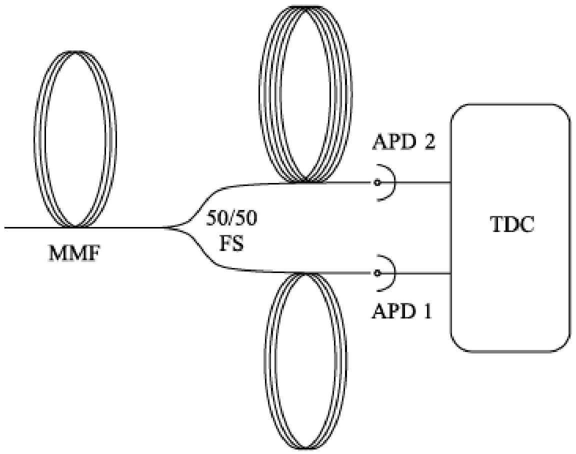
So far:

$\lambda$ = 780 nm or 656 nm (H$\alpha$)

# Detection setup

## 50/50 Multimode fiber beamsplitter

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




## APD: Single photon detector

*Excelitas*

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


## TDC: Time to Digital Convertor

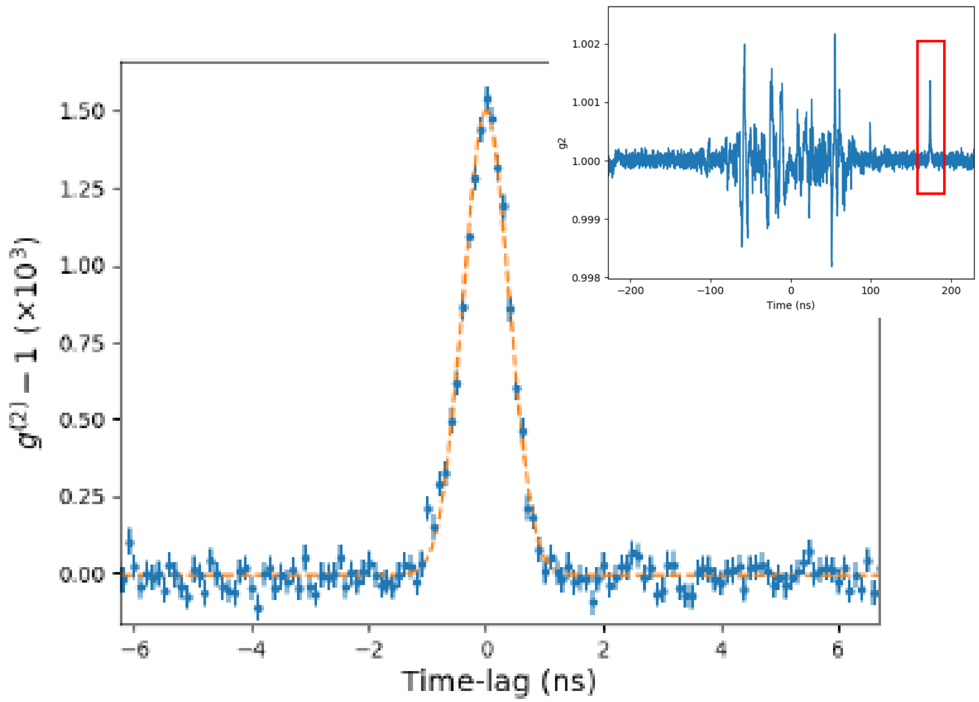
*Swabian Instruments*

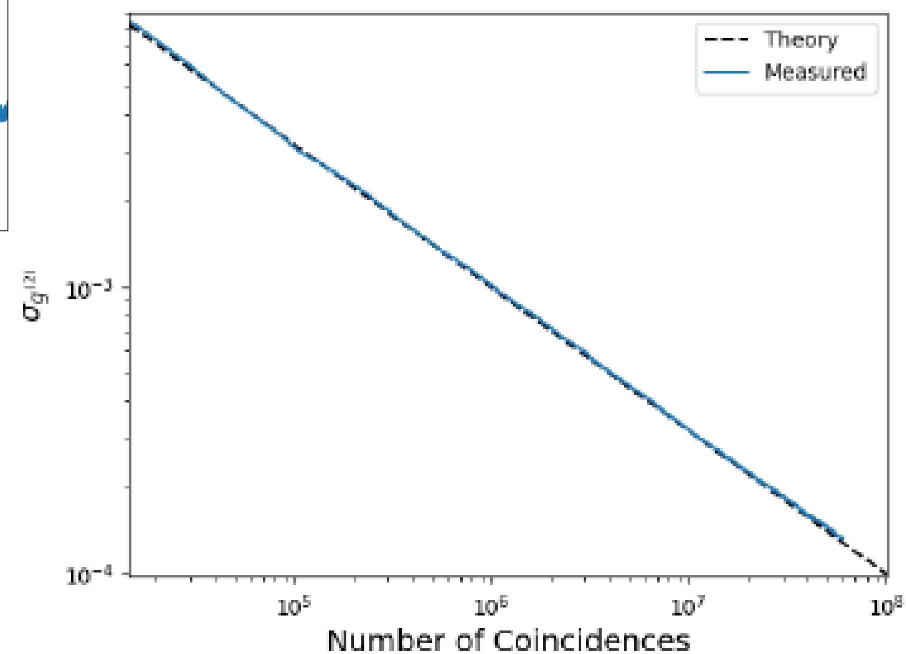
Cross-channel rms jitter = 12 ps

Max data transfer rate = 1 Gtags/s

# 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

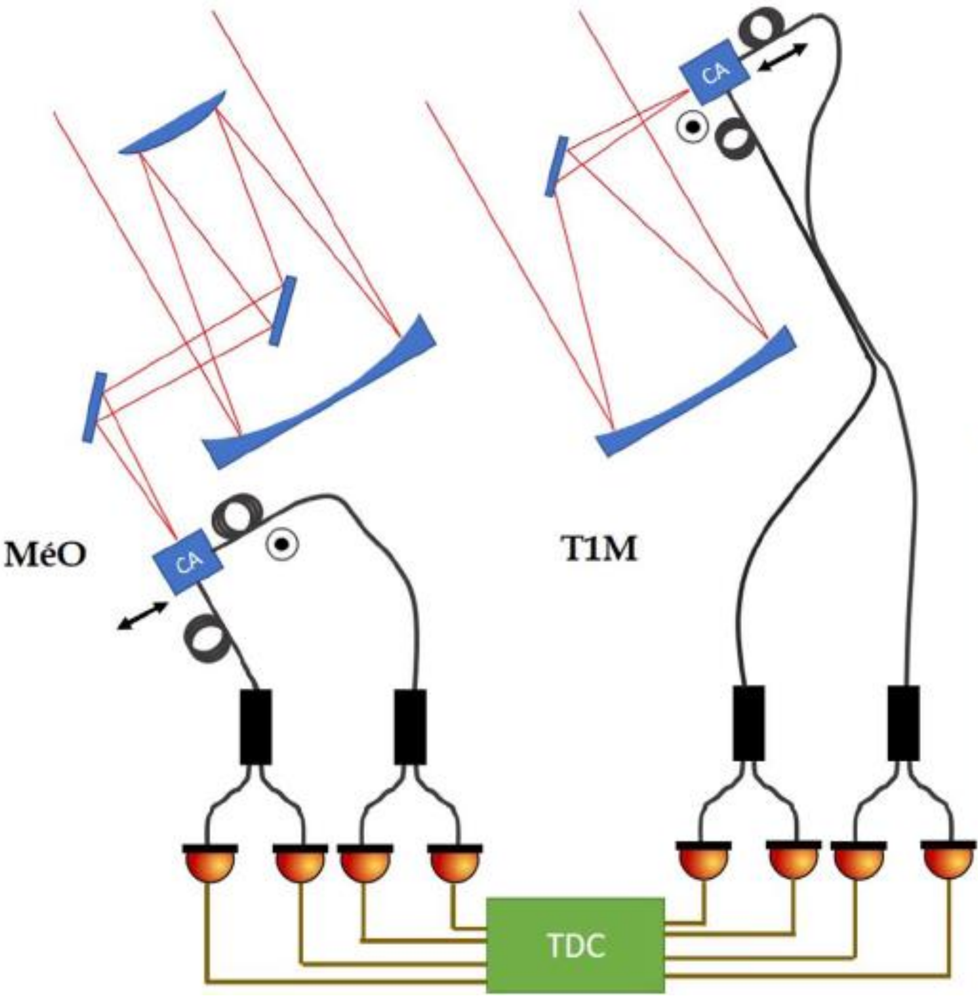
Example with:
- 2 telescopes
- 2 polarization channels
- zero-baseline correlations on all channels

→ 4 correlation functions at zero baseline

→ 4 cross-correlation x 2 polarizations

→ 12 correlation functions on the fly

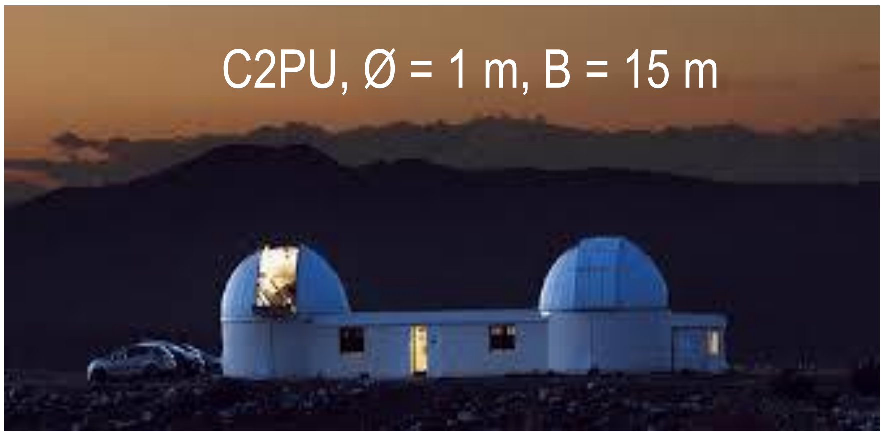
- They're all added up for the analysis (no polarization effect expected)
- They're all saved every 10 s, then shifted in time to compensate for the time-varying OPD, then added up.
- We don't record (so far) all photons!

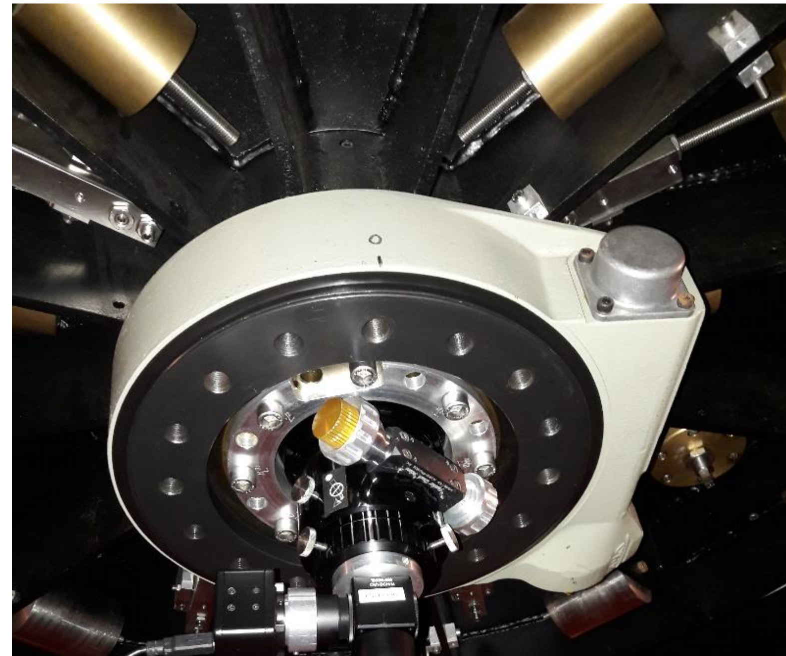


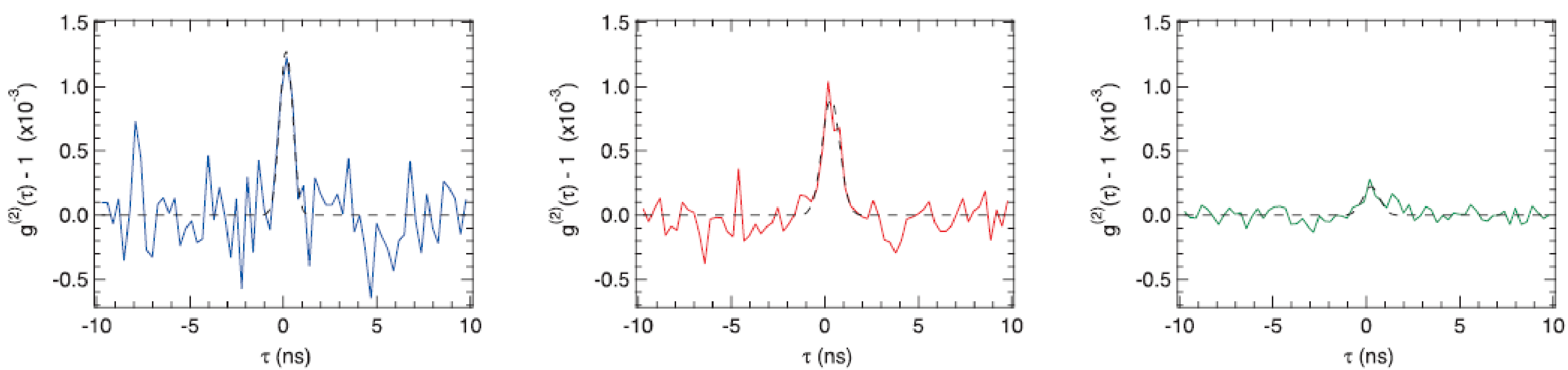
# SII @ C2PU

First demonstrations at C2PU:
Cassegrain foyer, equatorial mount

The simplest!





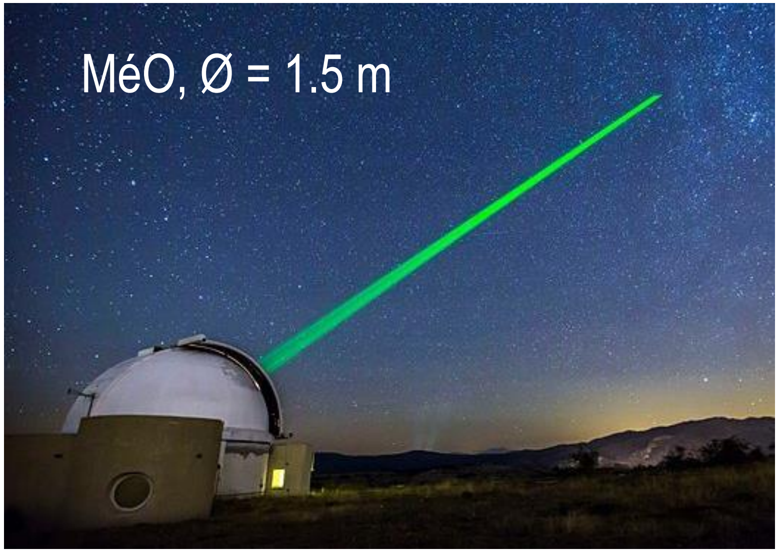

*MNRAS* 2018

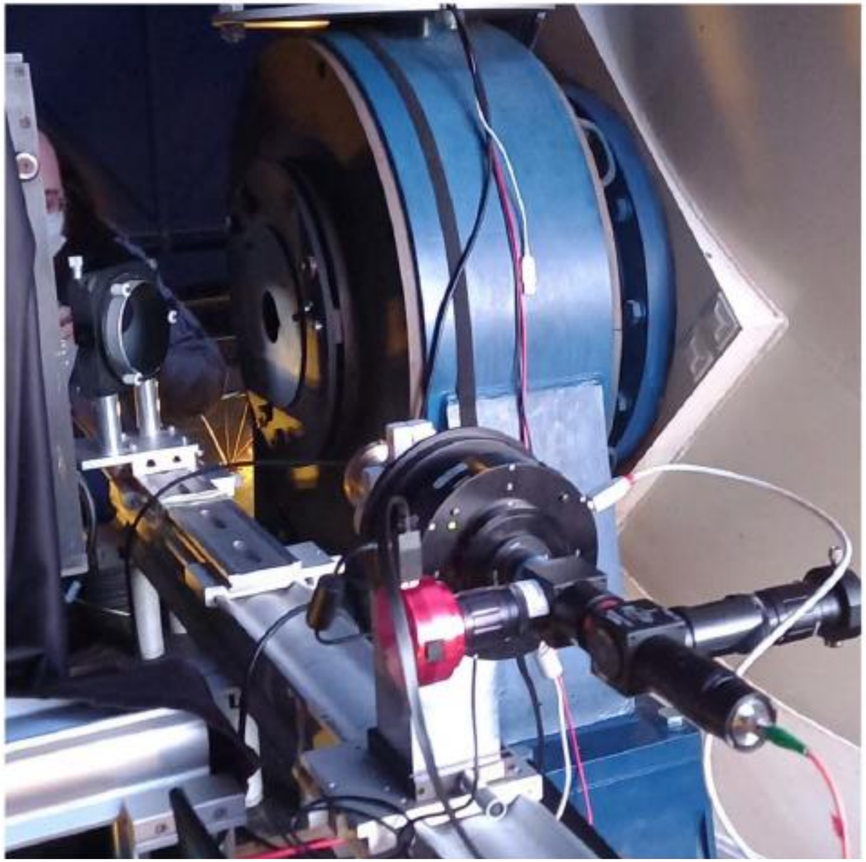
(a) β Ori. (b) α Lyr. (c) α Aur.

# Adaption to MéO

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

+ derotator!



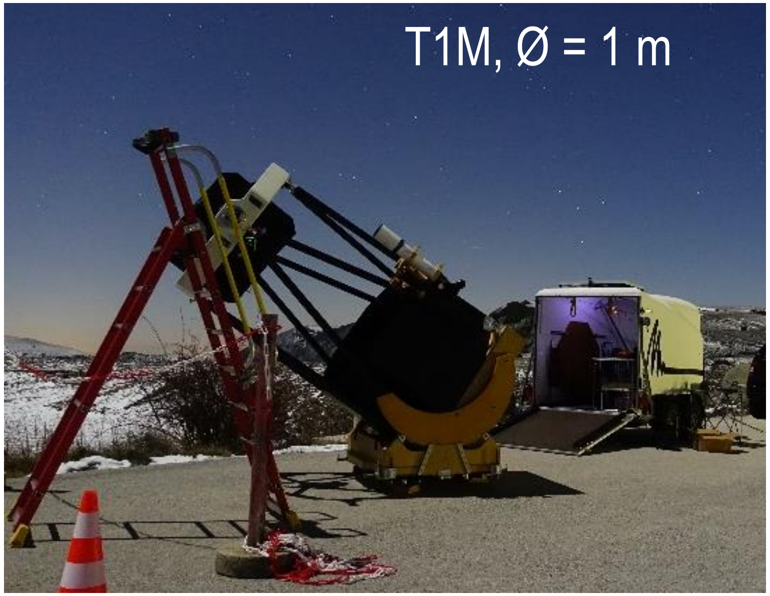



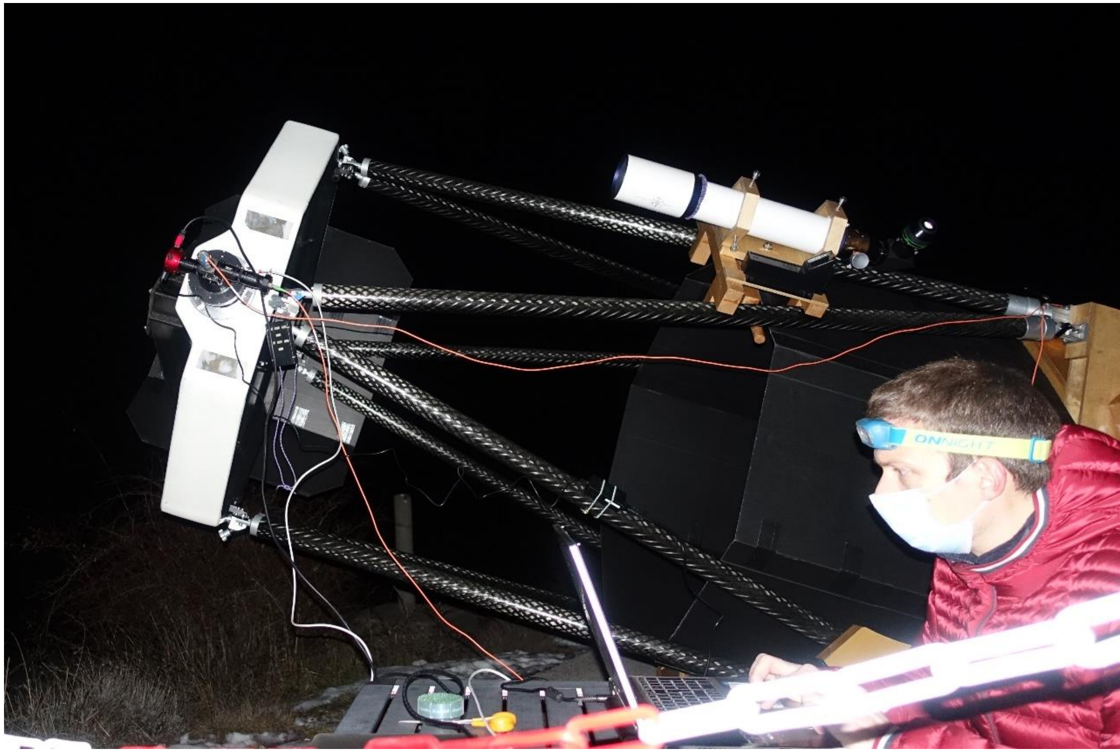
# Adaption to a portable telescope

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

+ tip-tilt correction!

Private property of David Vernet

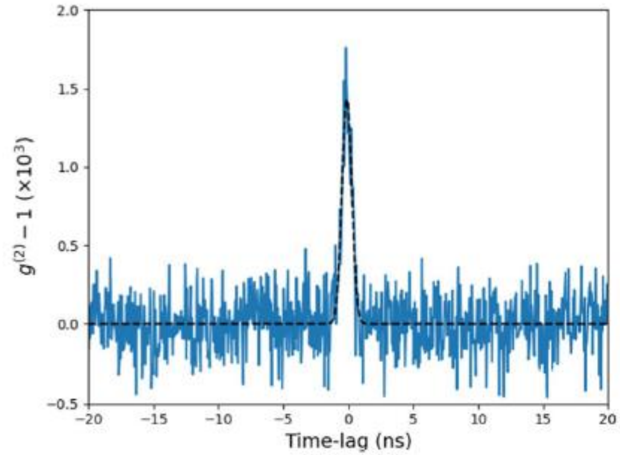


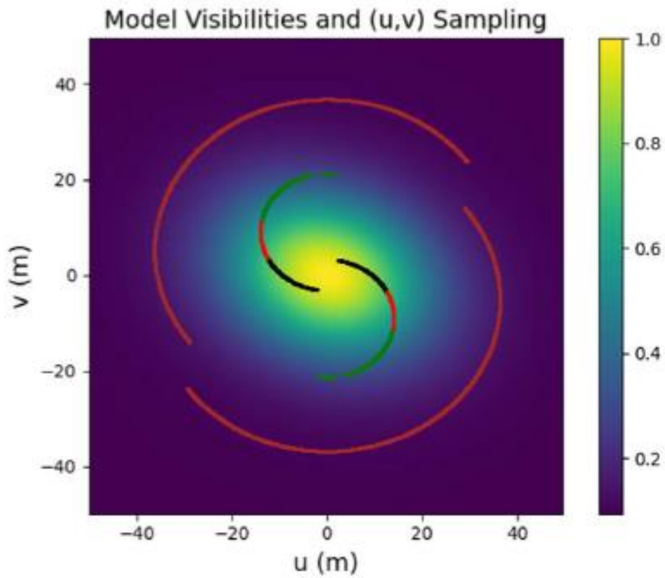



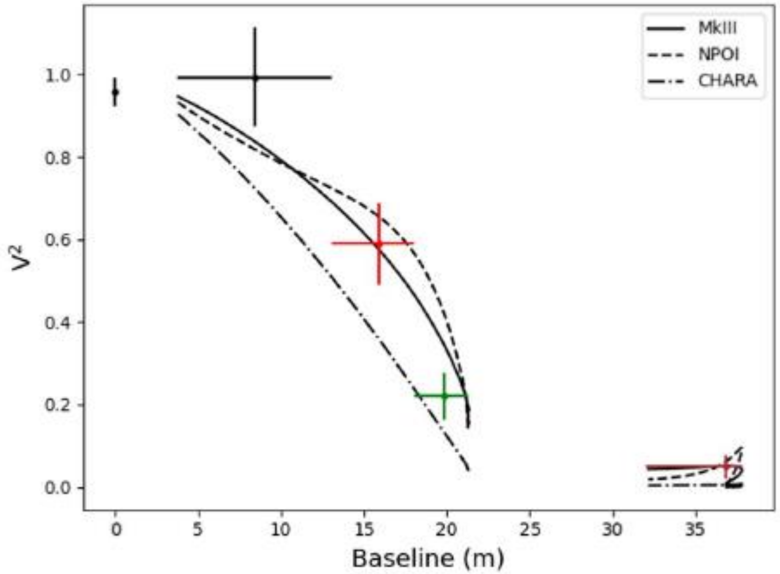
# SII between MéO and T1M

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

Gaussian anisotropic envelope (disk)
Results consistent with previous measurements



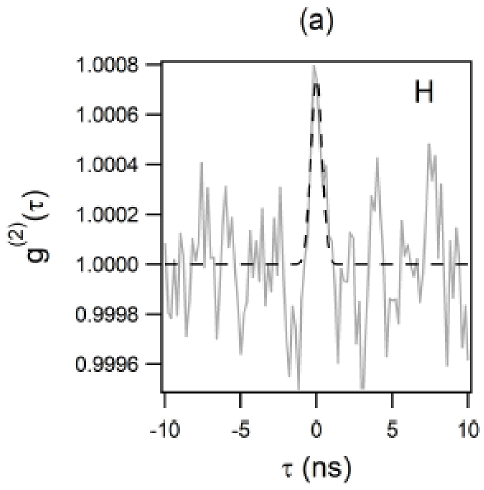




Matthews *et al.*, *Astron. J.* **167**, 117 (2023)

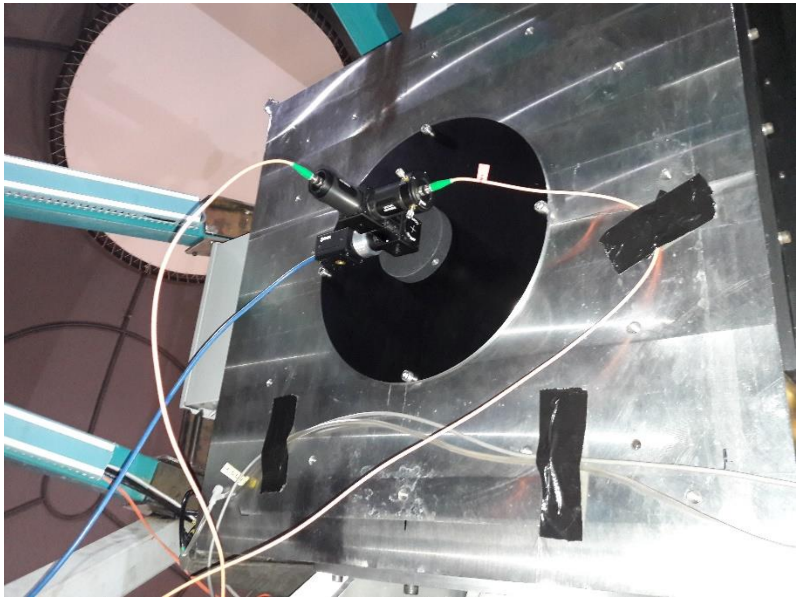
# Adaption to SOAR

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

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

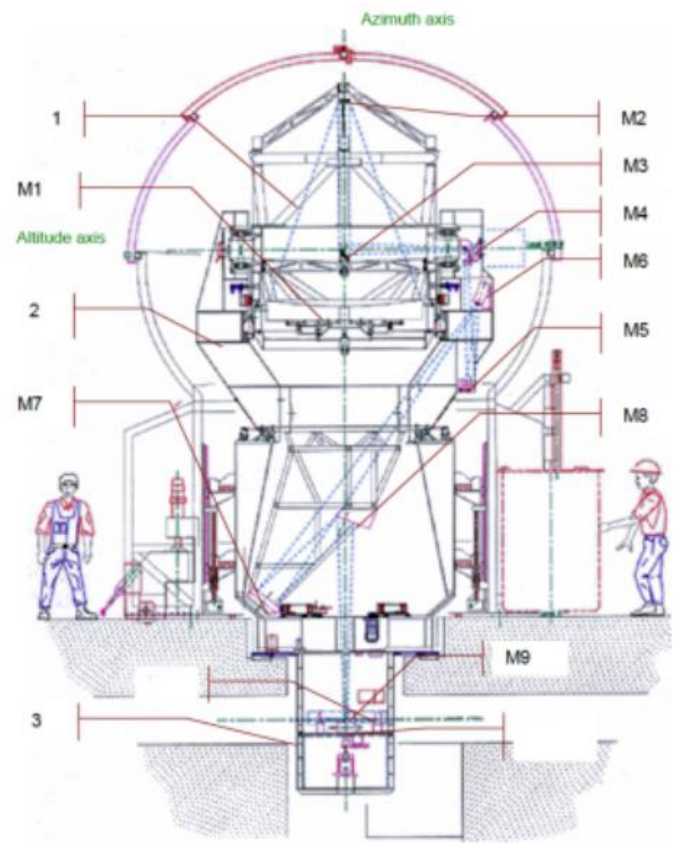






# SII @ Paranal

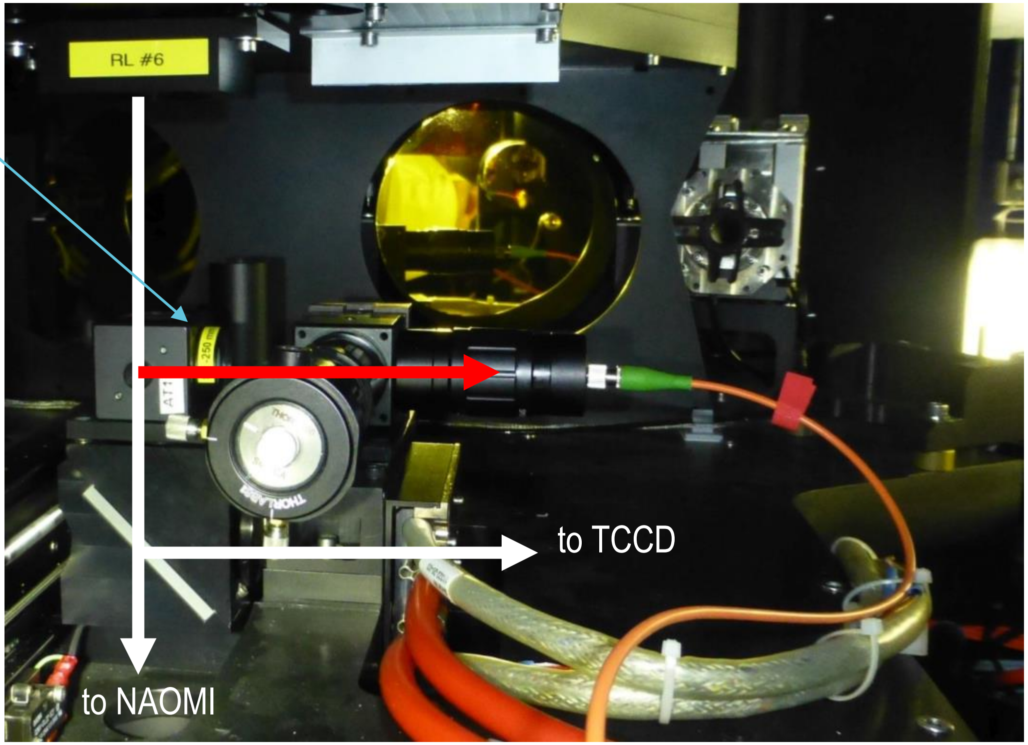
Adaption to the **Auxiliary Telescopes** (1.7 m, movable) at Cerro Paranal (ESO): More tricky: little space and it should not disturb the standard operation.

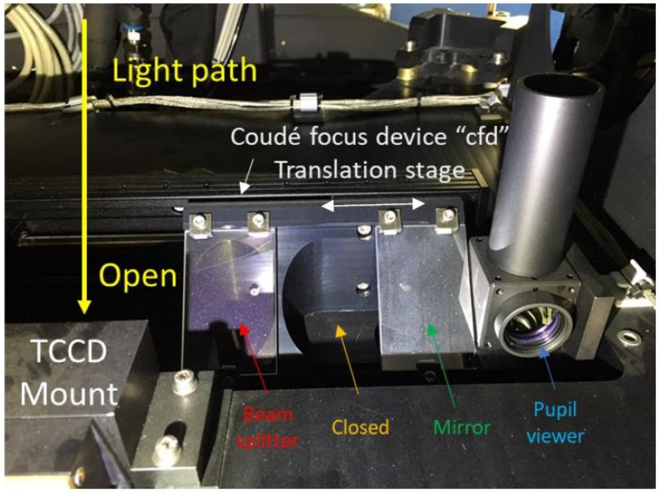




With the help of Pierre Bourget and Nicolas Schuhler (VLTI scientists)

# Adaptability and portability (5)

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.

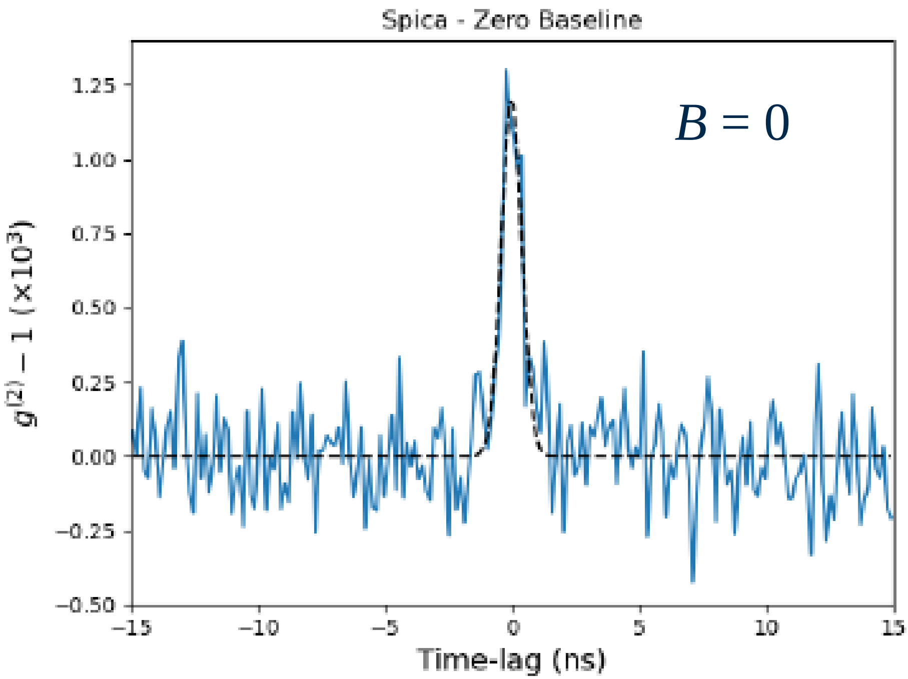


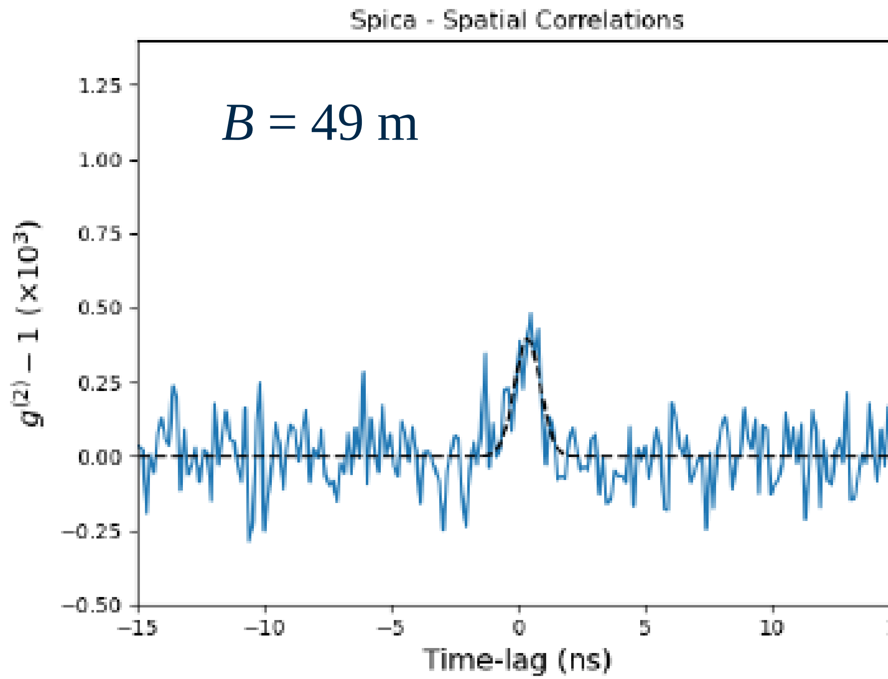



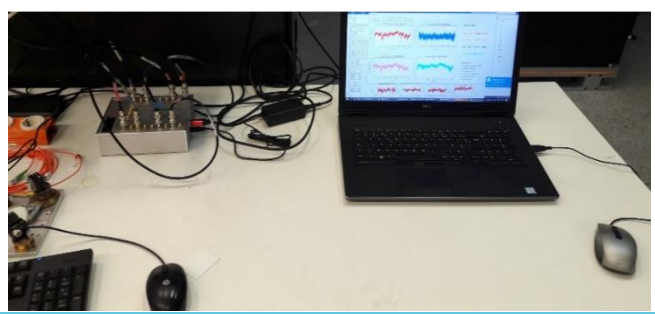
# First run: maintenance stations (49 m)

I2

G2



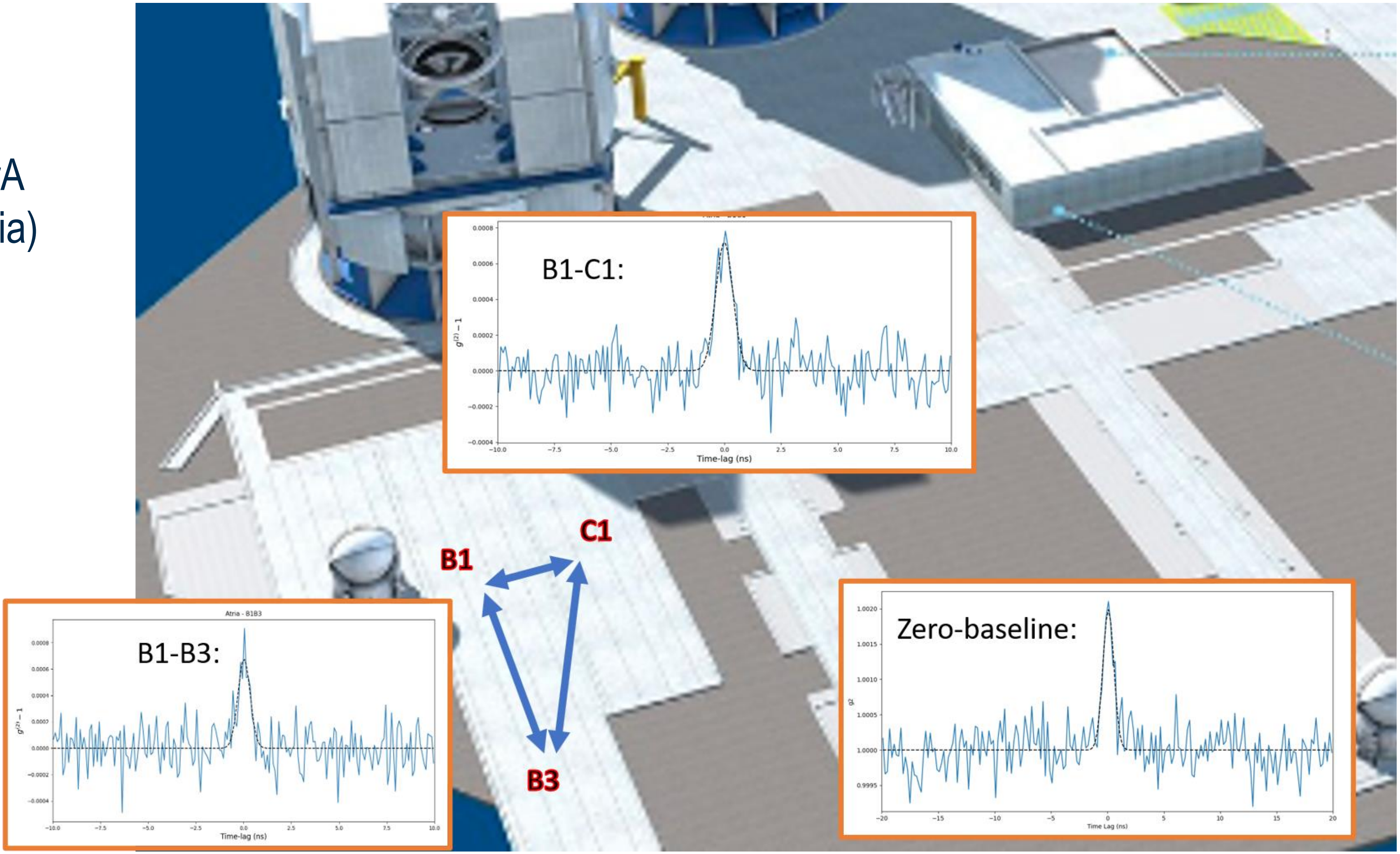



April 2022

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

# Second run: 3 standard stations

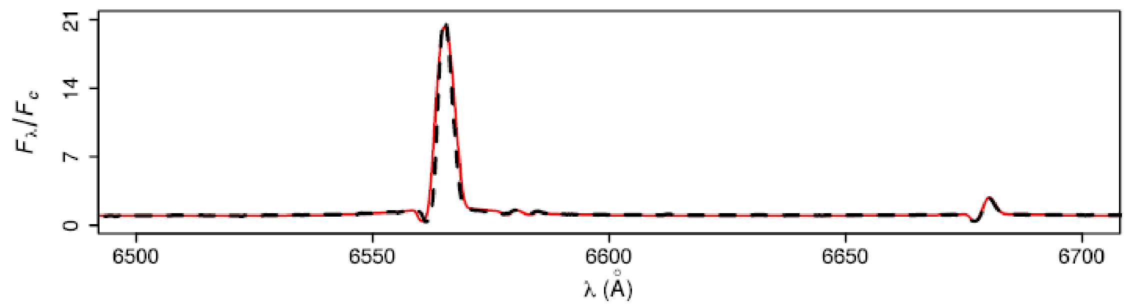
αTrA
(Atria)




May 2023

# Some astrophysical measurements...

Stellar model (CMFGEN) ← Spectroscopy




↓

Physical size
(luminosity distribution)

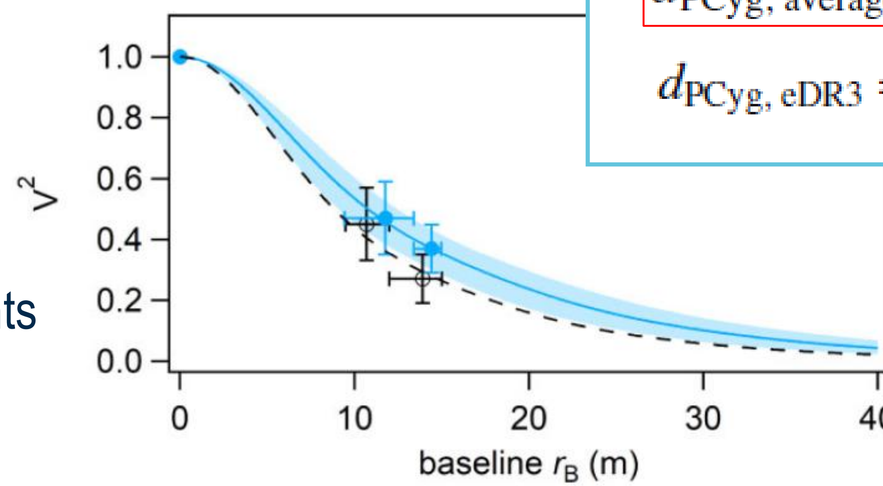
↓ ← Distance

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

Angular size
(luminosity distribution)

↓

Visibility measurements




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

# Roadmap for increasing the sensitivity

Current setup: good SNR (~10) on an unresolved magnitude 0 star in a few hours (1 night)

How to improve?

1) Improve the electronic temporal resolution

APDs (500 ps) → SNSPDs (20 ps) → SNR ×5

2) Multichannel measurements (wavelength multiplexing)

Dispersion into 100 wavelength channels → SNR ×10

→ 4.2 mag.

3) Go to large telescopes ?

Ø = 1 m → Ø = 8 m → SNR × 64

→ 8.8 mag.

# Prospects

<u>Next steps:</u>

- Intensity interferometry with SNSPDs (collaboration with TU Delft)
- Towards wavelength multiplexing
- Long distance distribution of a sync signal
- Go to shorter wavelengths

<u>Longer term:</u> 2 main goals

- **A visitor instrument at Paranal ?**

  → extension of the VLTI to short wavelengths

  (the ATs are not used one week per month!!!)

- **Resolution of Sirius B ($m_V$ = 8.4) at Hawaii ?**

# Sirius B

- Maximum baseline = 630 m: Keck (10 m) – CFHT (3.6 m)
- $\lambda$ = 420 nm

→ partial resolution


With $N_{channel}$ = 16, $\tau_{el}$ = 20 ps,

QE = 90%, throughput = 20%:

**SNR = 6 in 1h ☺**

We've got letters of support from Keck, CFHT and the Institute for Astronomy of Hawaii University. ERC proposal has been submitted...

# Thanks !

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

(Picture by Serge Brunier)