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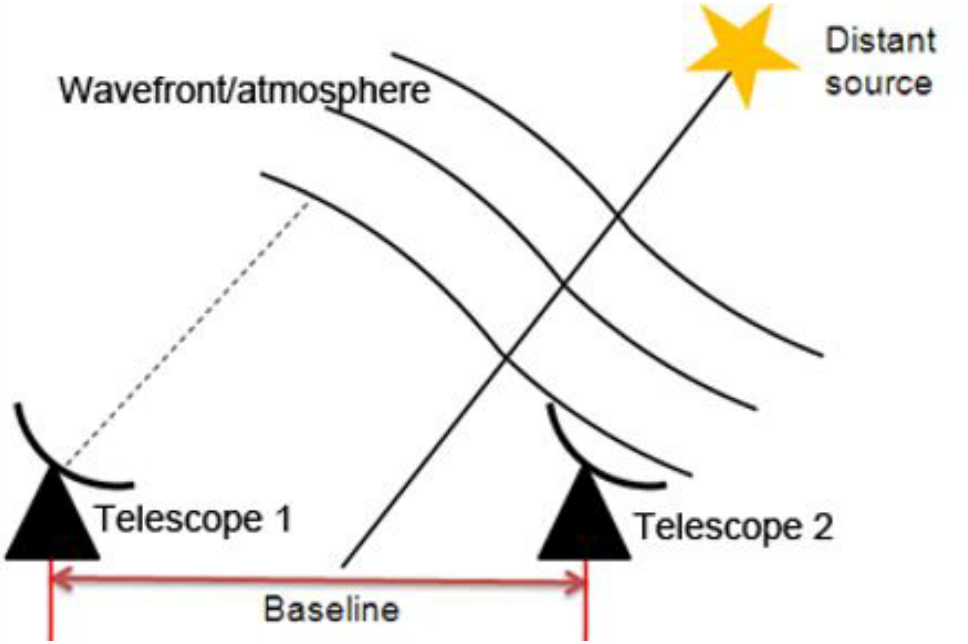
Stellar Intensity Interferometry with the H.E.S.S. telescopes

Naomi Vogel, Andreas Zmija, Gisela Anton, Stefan Funk,
Alison Mitchell, Frederik Wohlleben, Adrian Zink

The Concept of Stellar Intensity Interferometry

- **Main goal:** measure angular size of stars/objects
- What we need:
  - Telescopes with large light collection areas → “light buckets”
  - Star

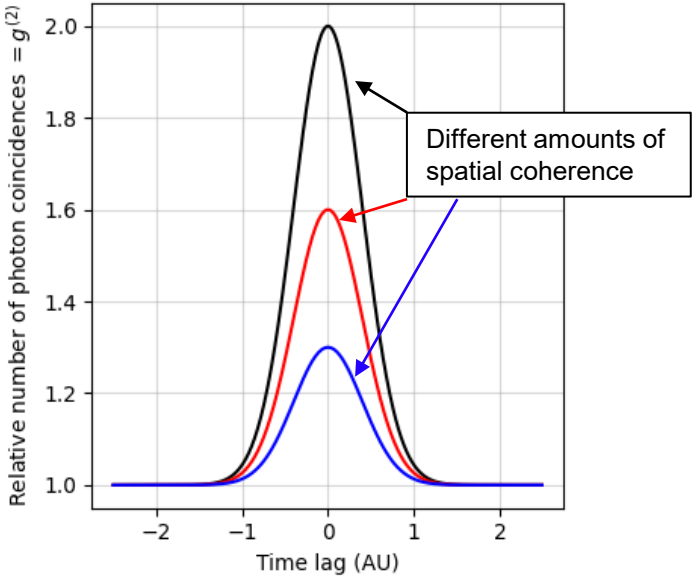


The Concept of Stellar Intensity Interferometry

Intensity Interferometry

- Recording photon stream in different telescopes and measure “photon bunching”

$$g^{(2)} - 1 \propto \langle \Delta I_1 \Delta I_2 \rangle$$

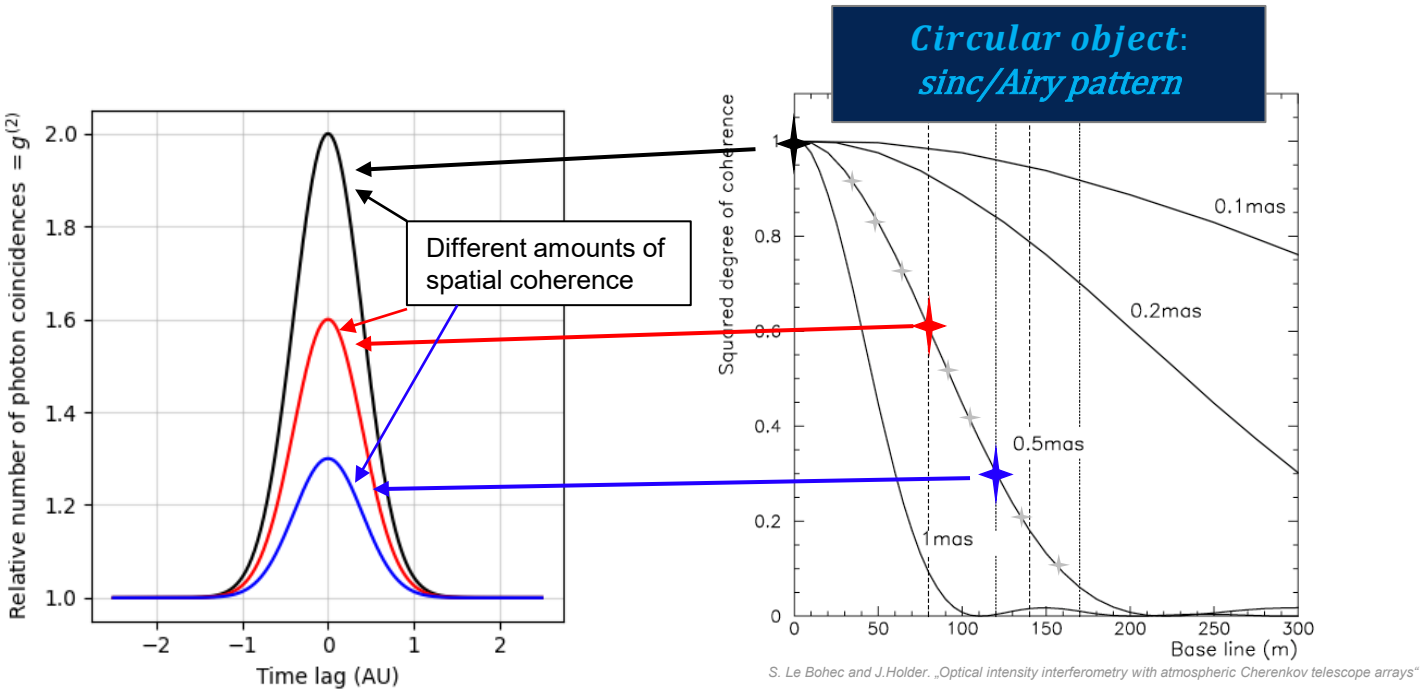


The Concept of Stellar Intensity Interferometry

Intensity Interferometry

- Recording photon stream in different telescopes and measure “photon bunching”

$$g^{(2)} - 1 \propto \langle \Delta I_1 \Delta I_2 \rangle \propto |FT\,[I\,(x,y)]|^2$$



S. Le Bohec and J.Holder. „Optical intensity interferometry with atmospheric Cherenkov telescope arrays“

The Concept of Stellar Intensity Interferometry

Intensity Interferometry

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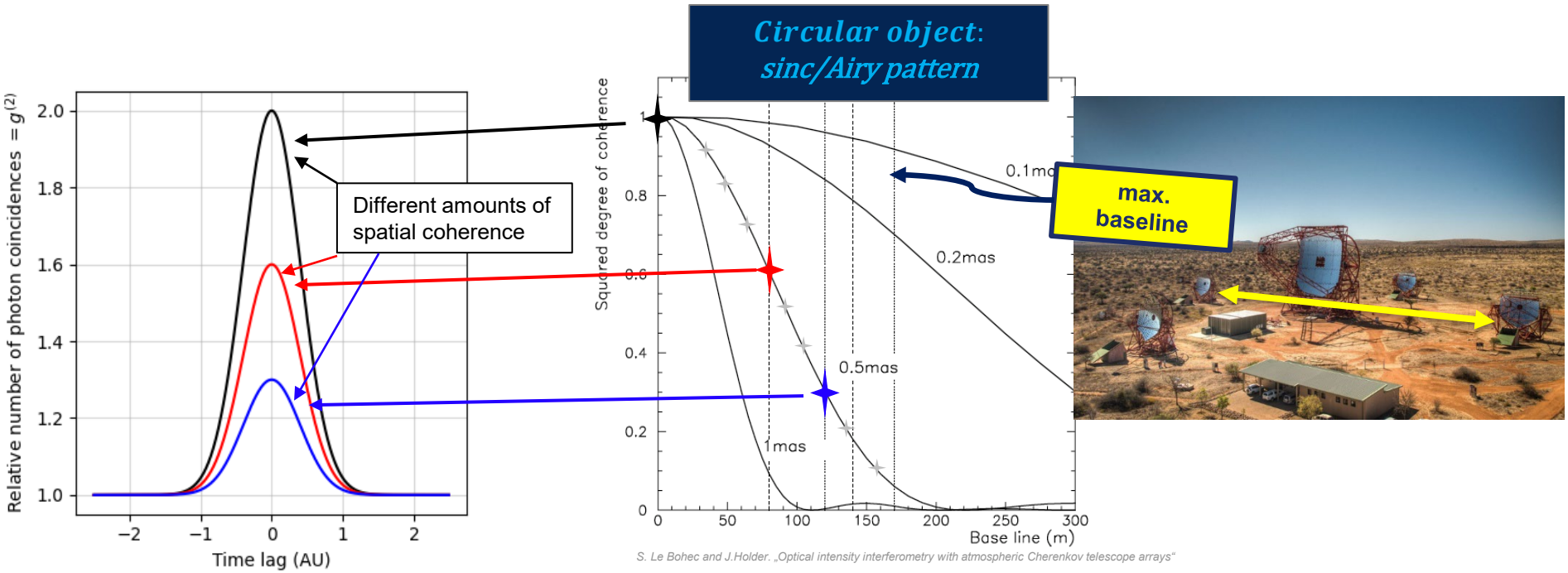

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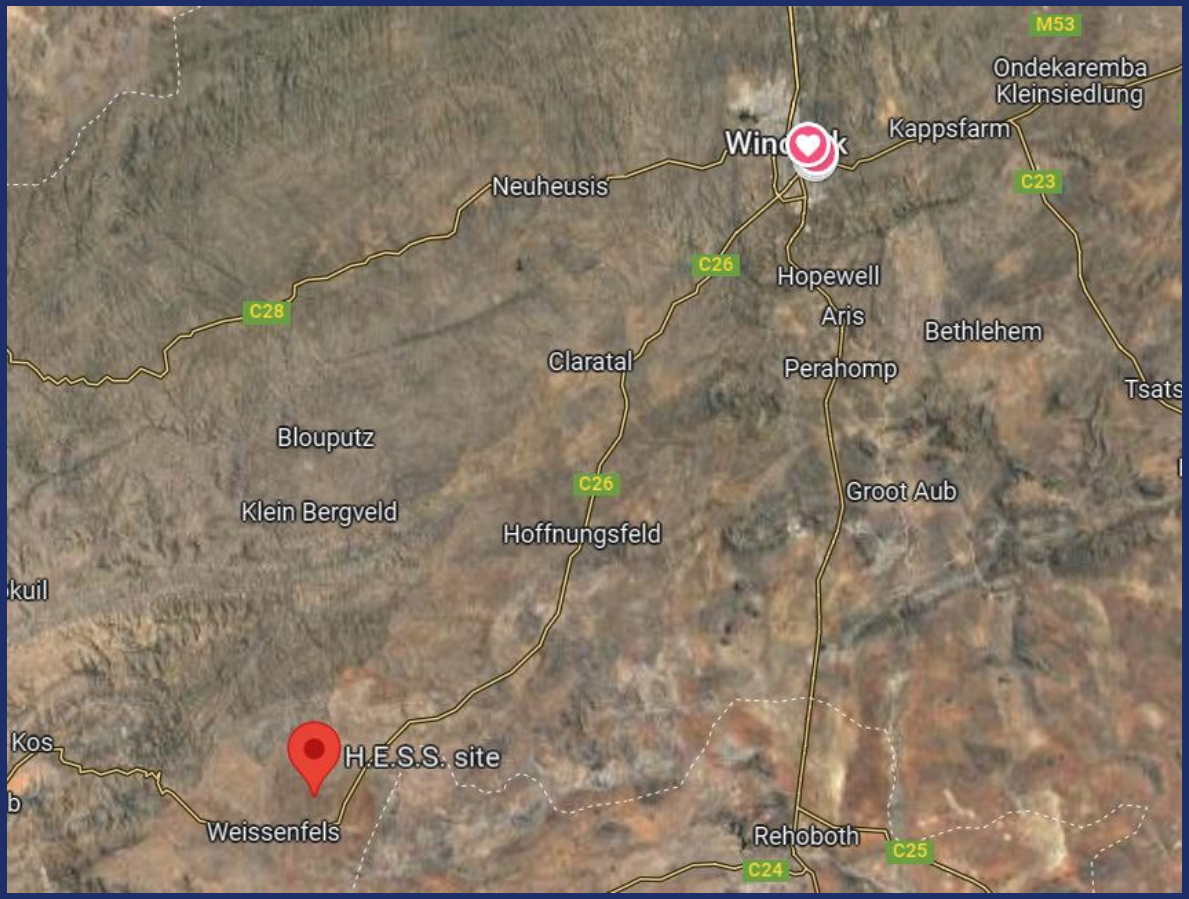
Namibia
Swakopmund
Windhuk
Google


M53
Ondekaremba
Kleinsiedlung
Kappsfarm
Neuheusis
C23
C26
Hopewell
C28
Aris
Bethlehem
Claratal
Perahomp
Tsats
Blouputz
C26
Groot Aub
Klein Bergveld
Hoffnungsfeld
H.E.S.S. site
Weissenfels
Rehoboth
C25
C24

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H.E.S.S.

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU

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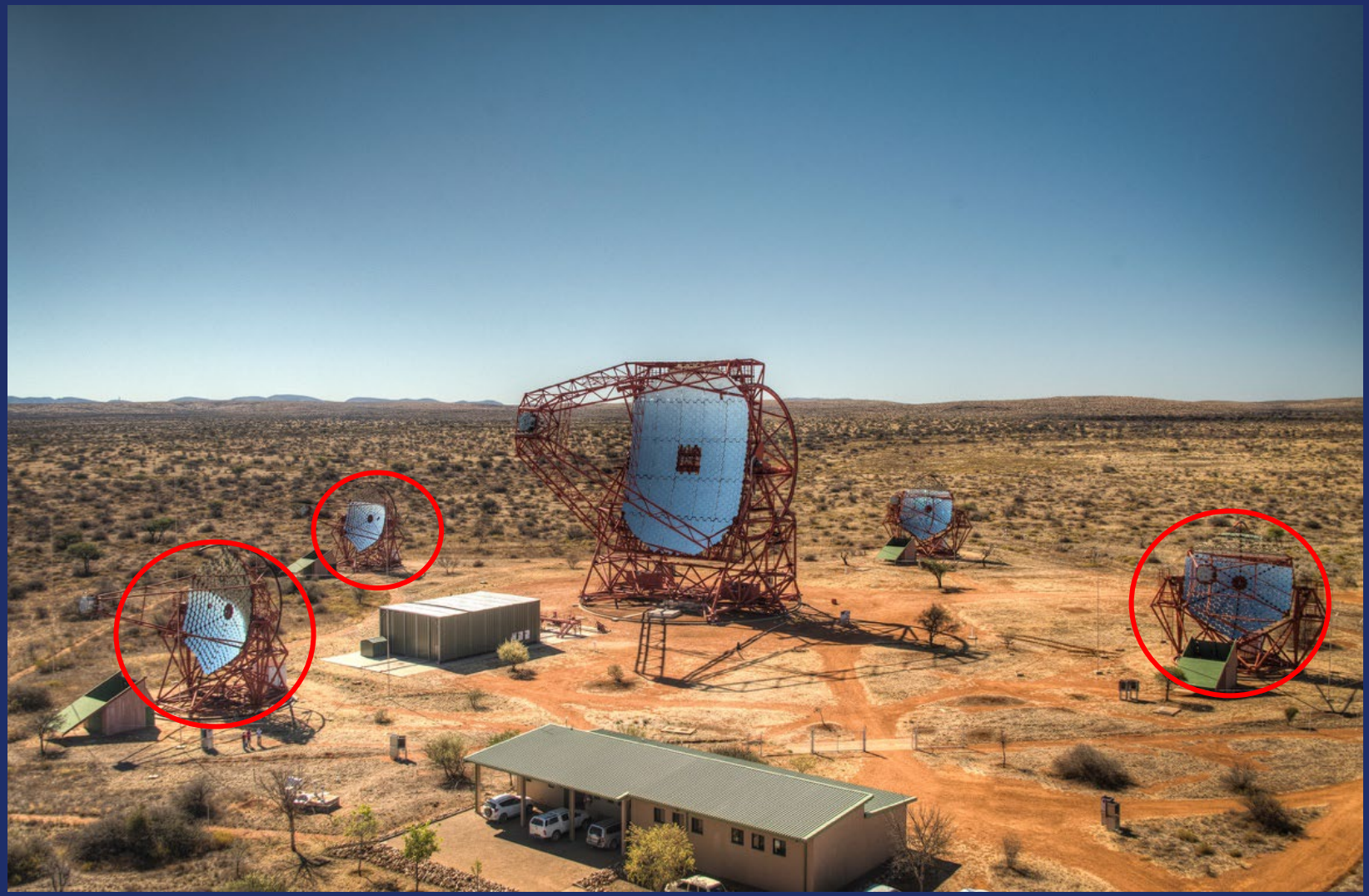
ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU

High Energy Stereoscopic System



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H.E.S.S.

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

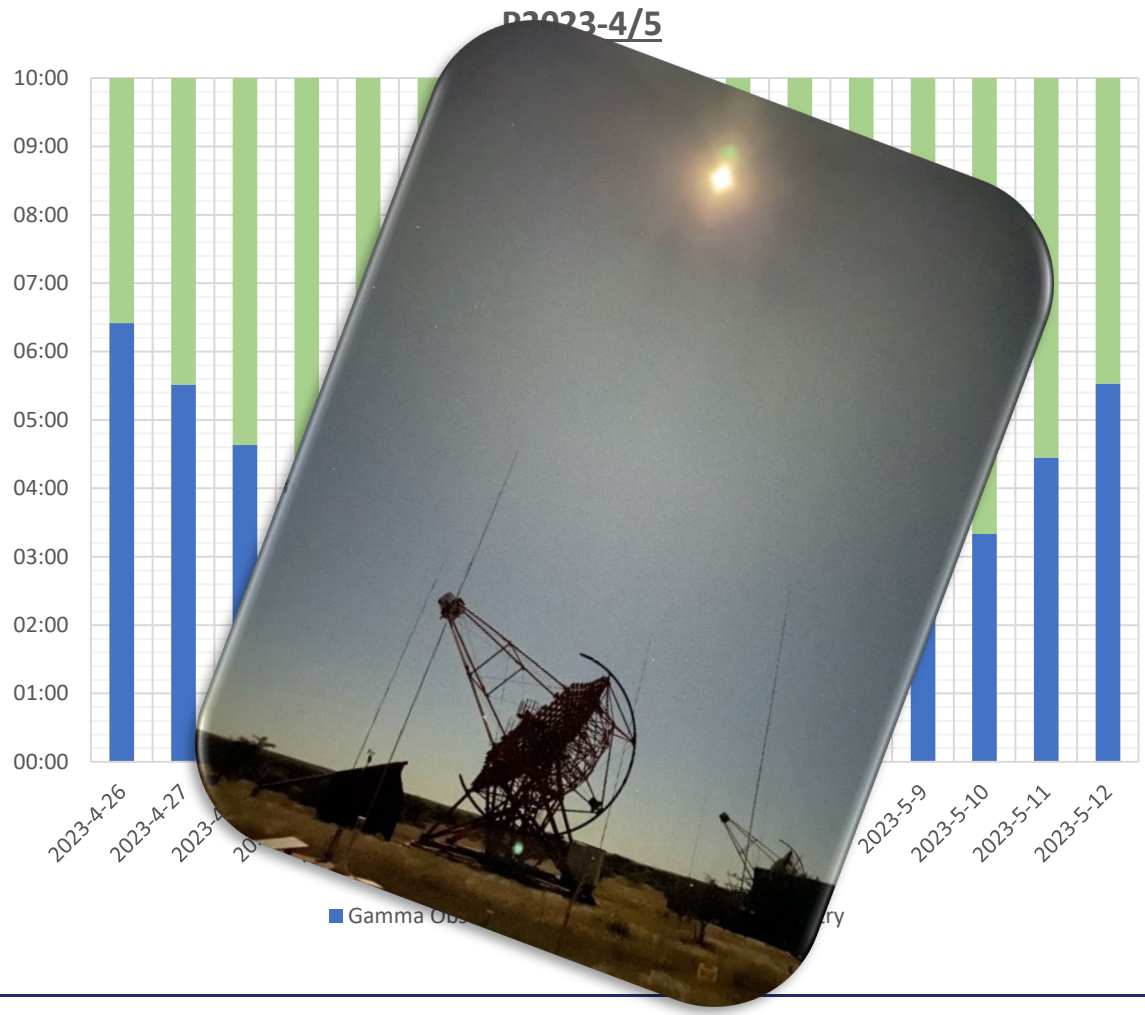
FAU

High Energy Stereoscopic System

Measurement Schedule

When do we measure?

- Adjust measurement time to gamma ray observations
- Intensity Interferometry during full moon
- Small field of view → insensitive to straylight of moon
- Pick suitable stars



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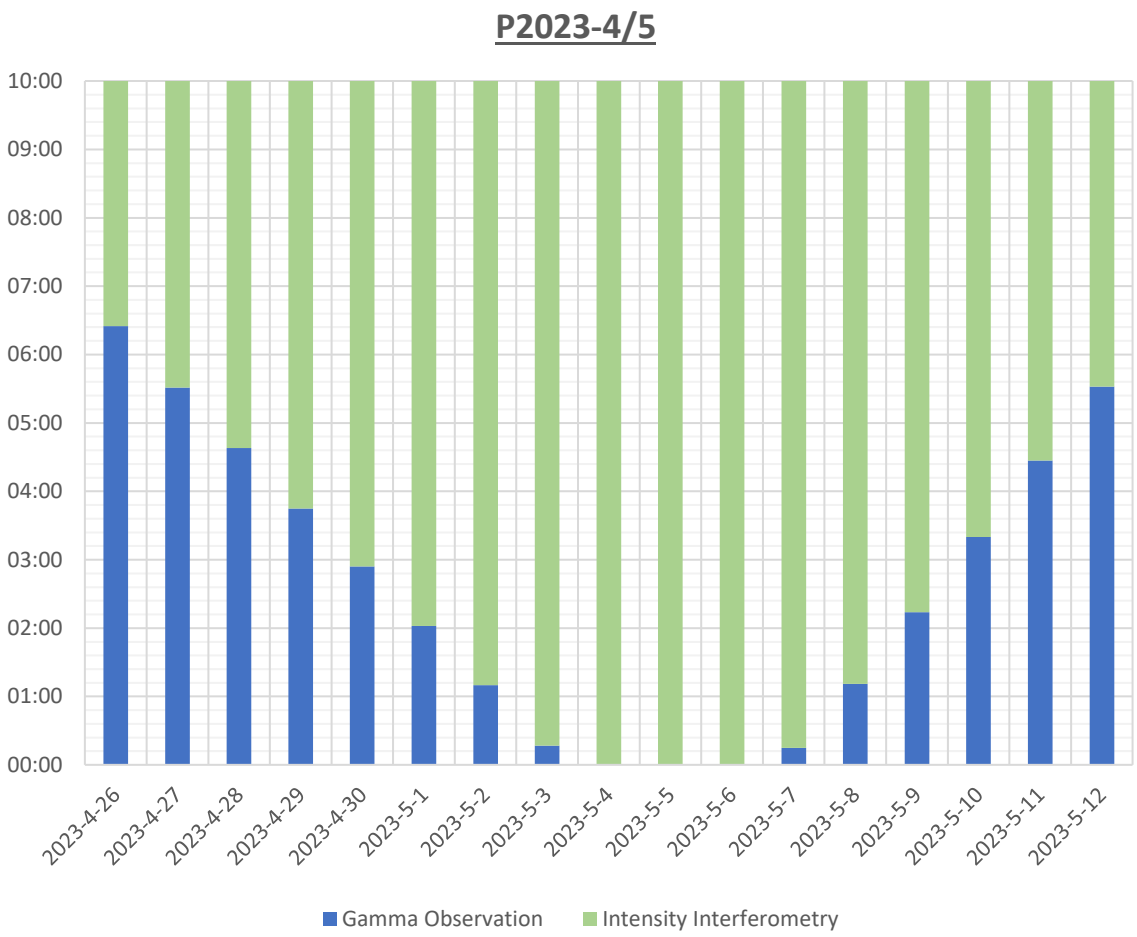
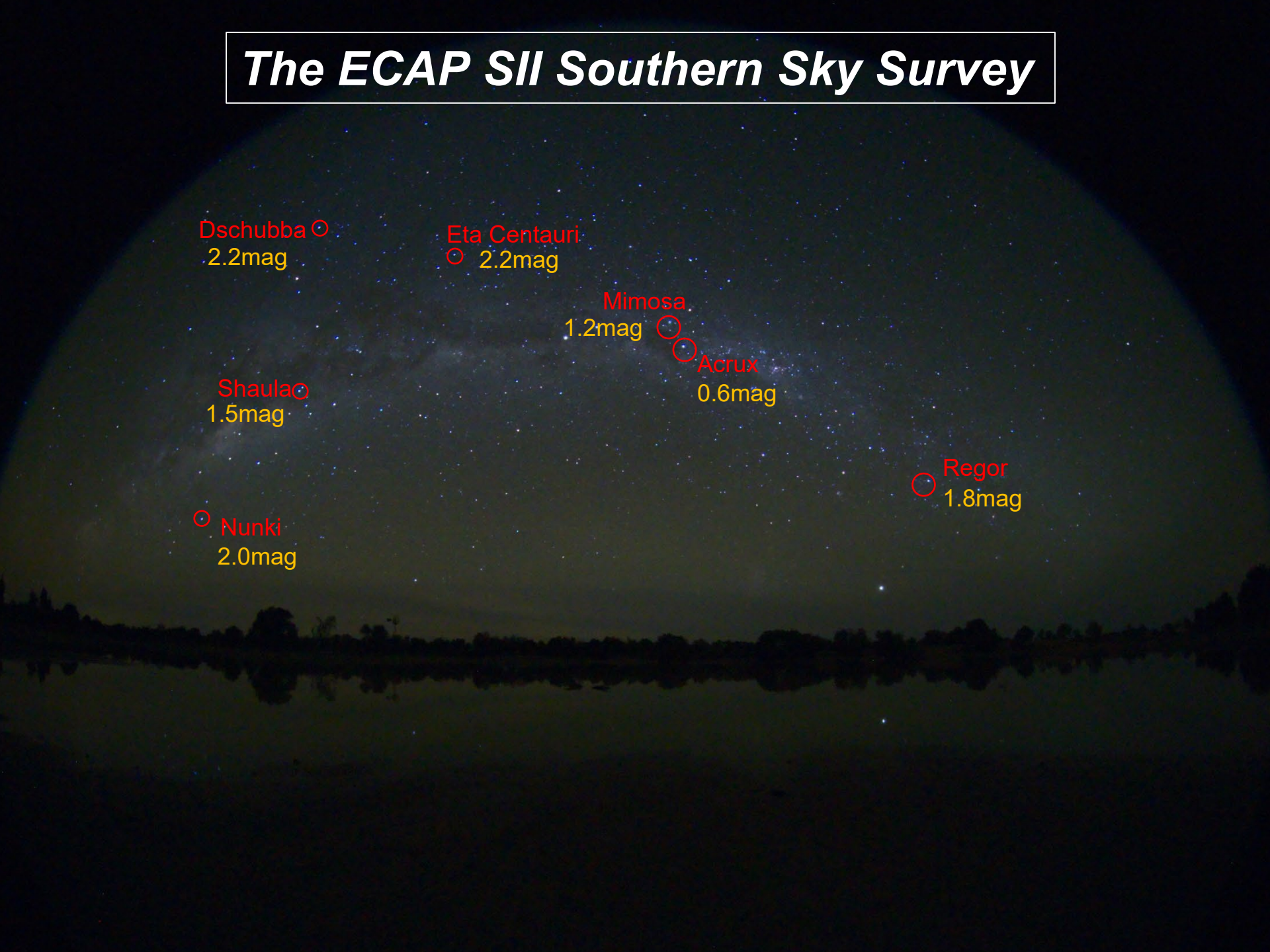
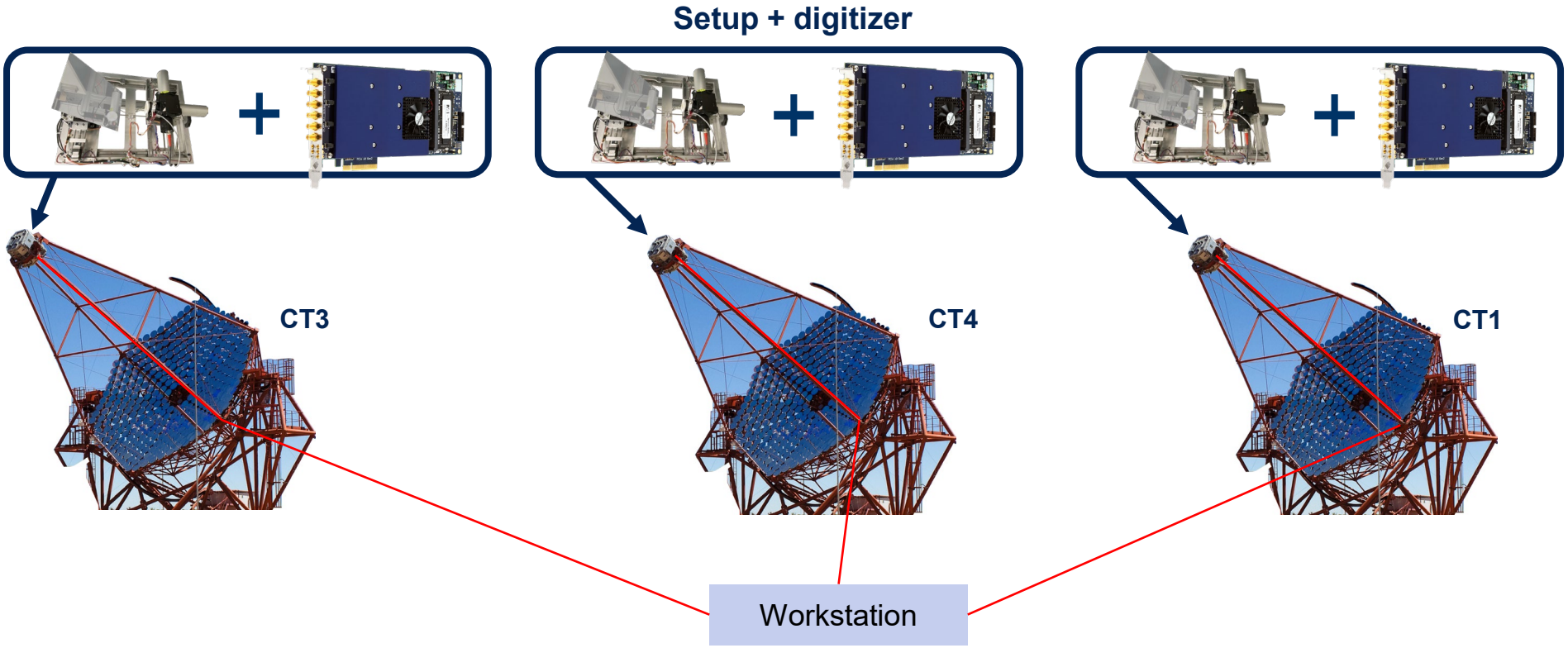


The ECAP SII Southern Sky Survey



2nd H.E.S.S. campaign 2023

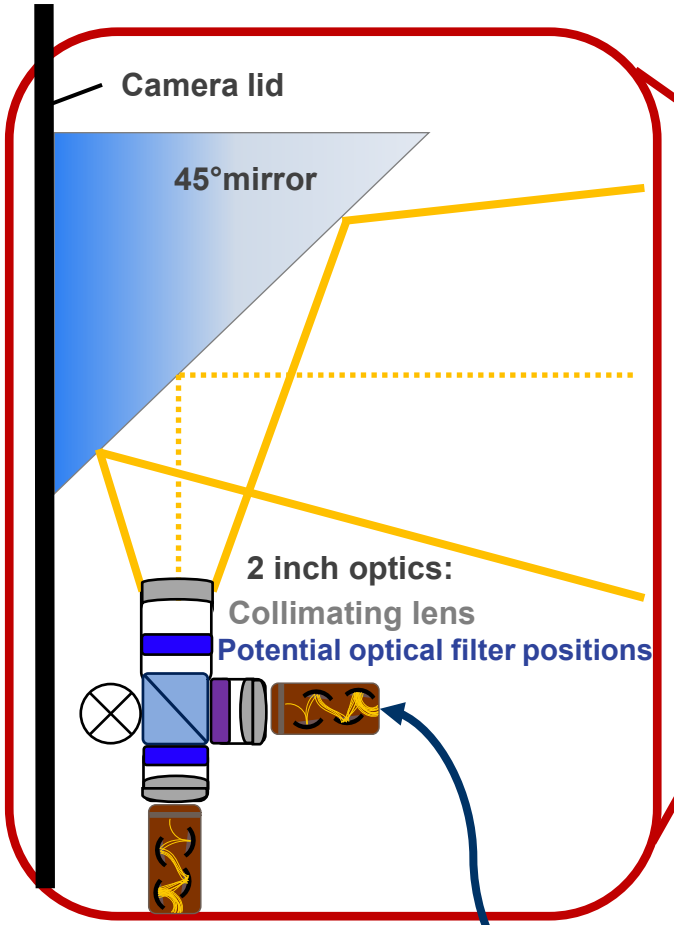
Measurement Setup – 3 telescopes

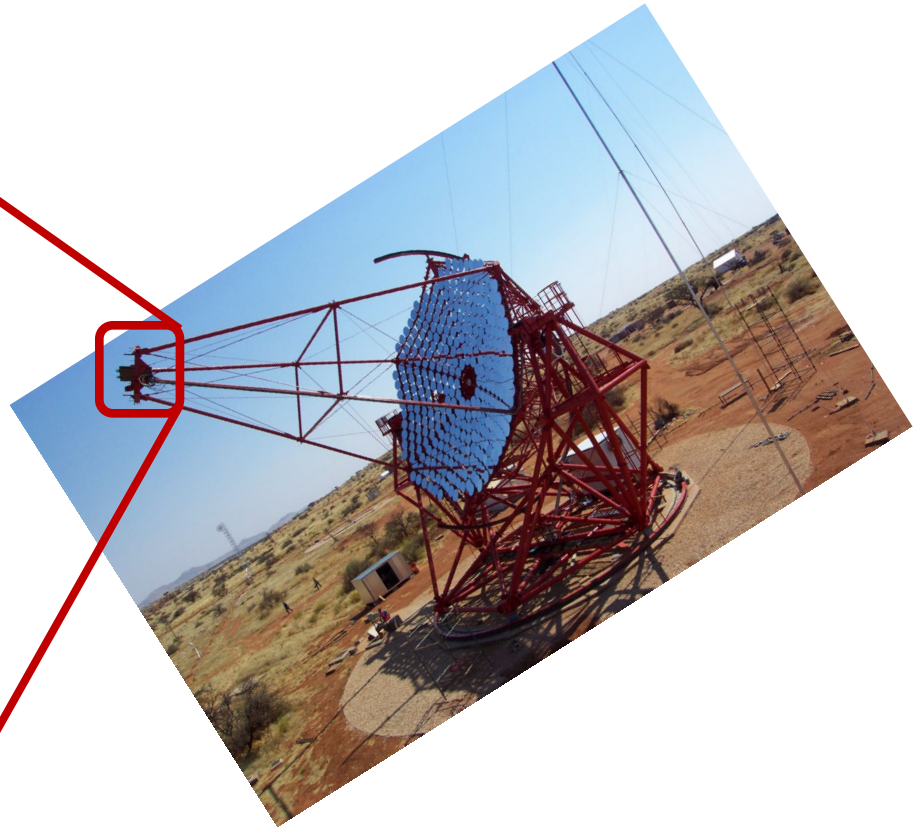


- Digitize in focal plane
- Offline correlation and analysis after measurement

2nd H.E.S.S. campaign 2023

Mechanical setup

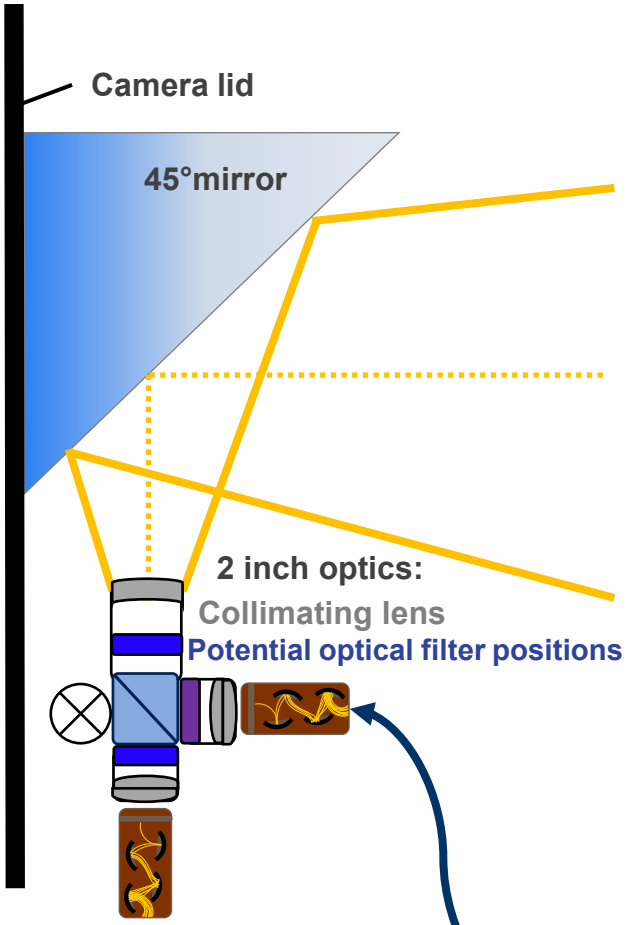




Either zero-baseline measurement or second wavelength band

2nd H.E.S.S. campaign 2023

Mechanical setup



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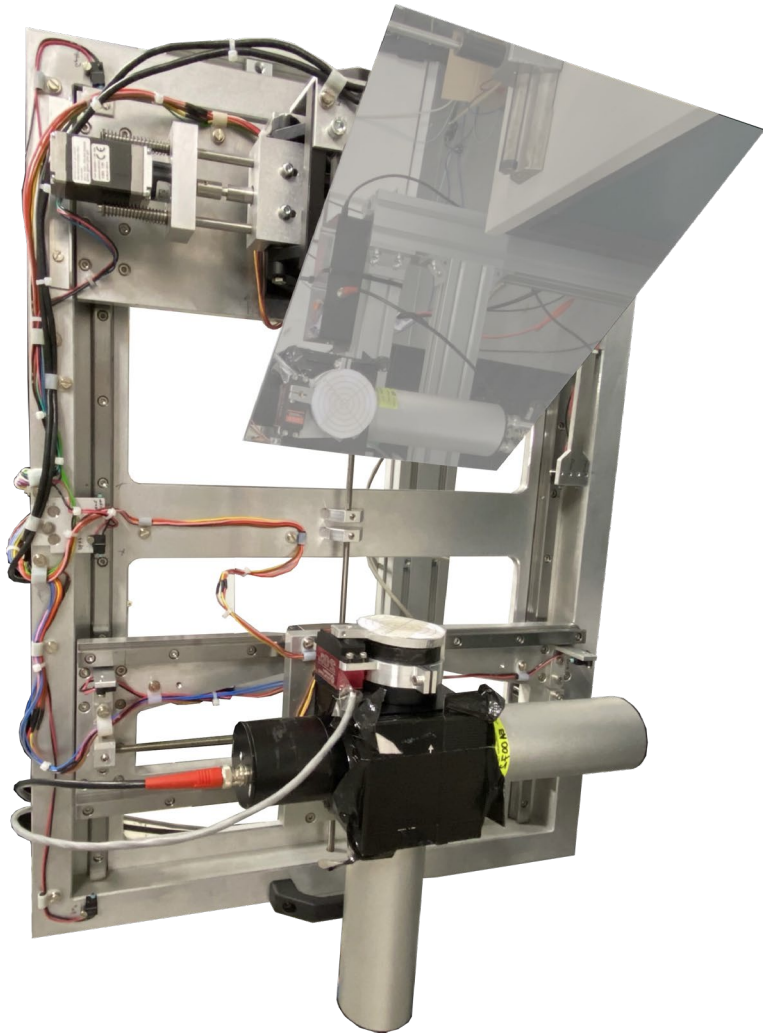
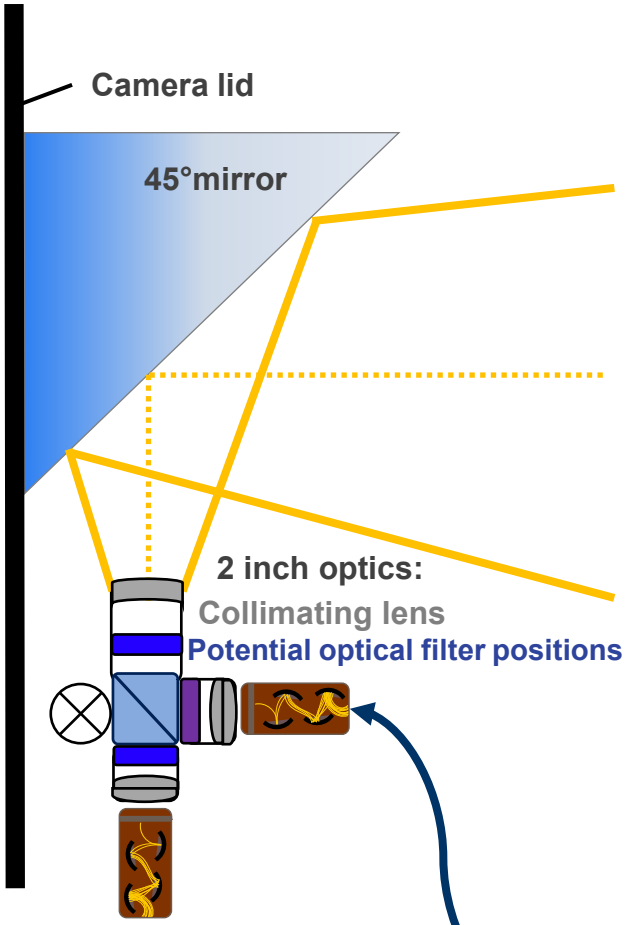
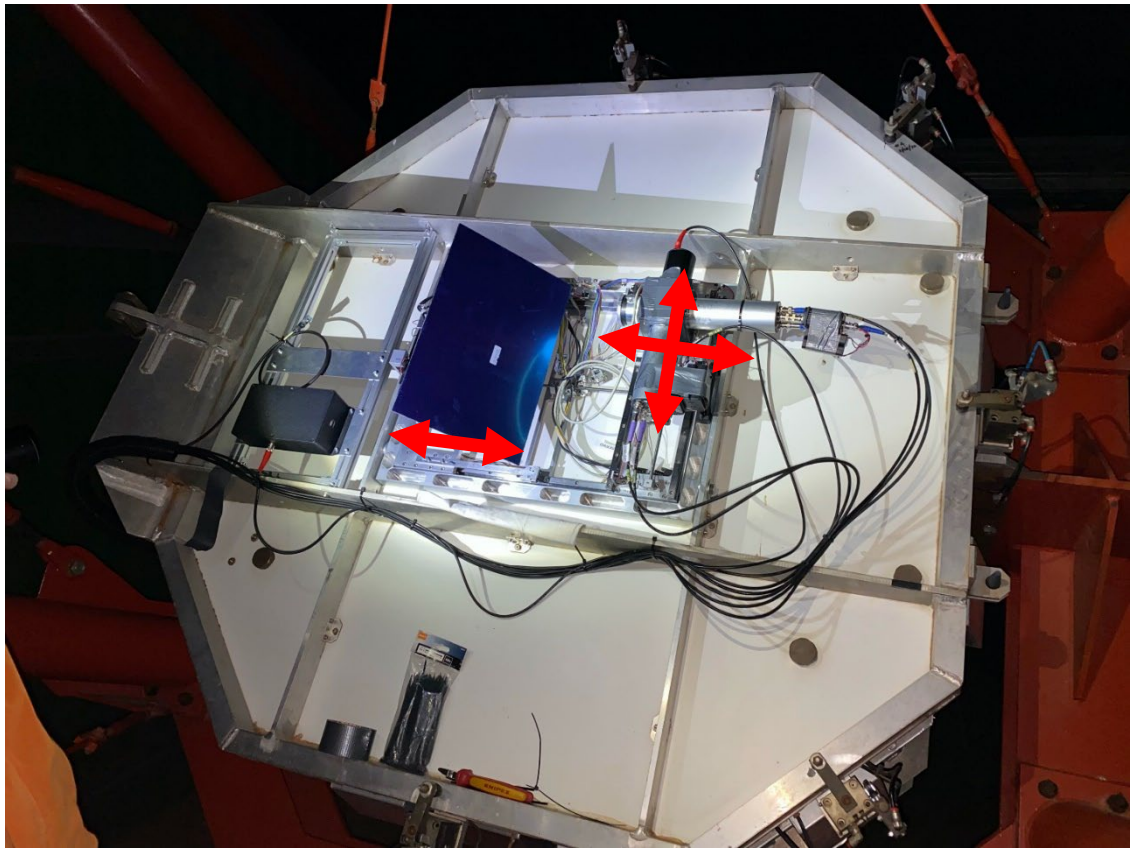


Either zero-baseline measurement or second wavelength band

2nd H.E.S.S. campaign 2023

Mechanical setup

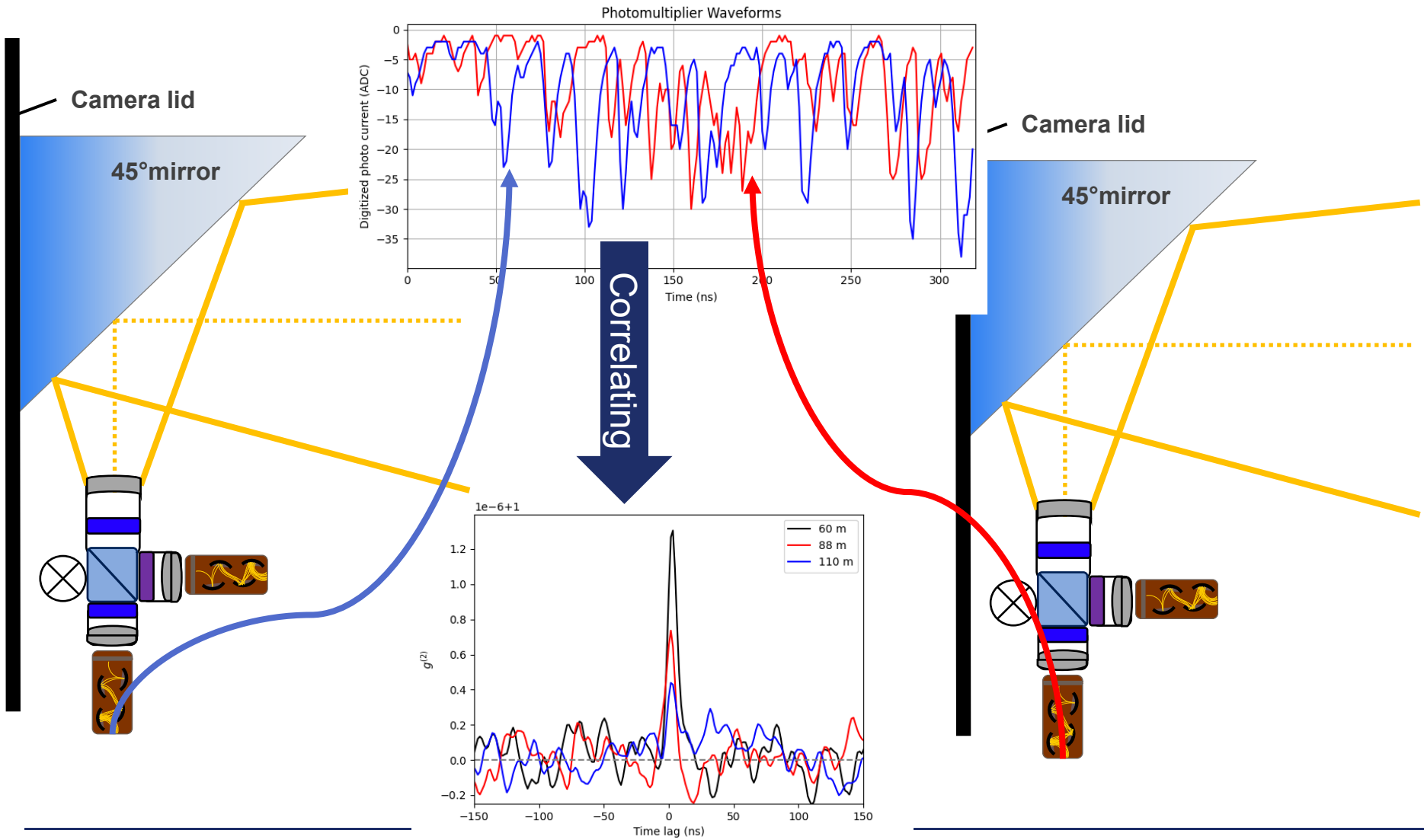




Either zero-baseline measurement or second wavelength band

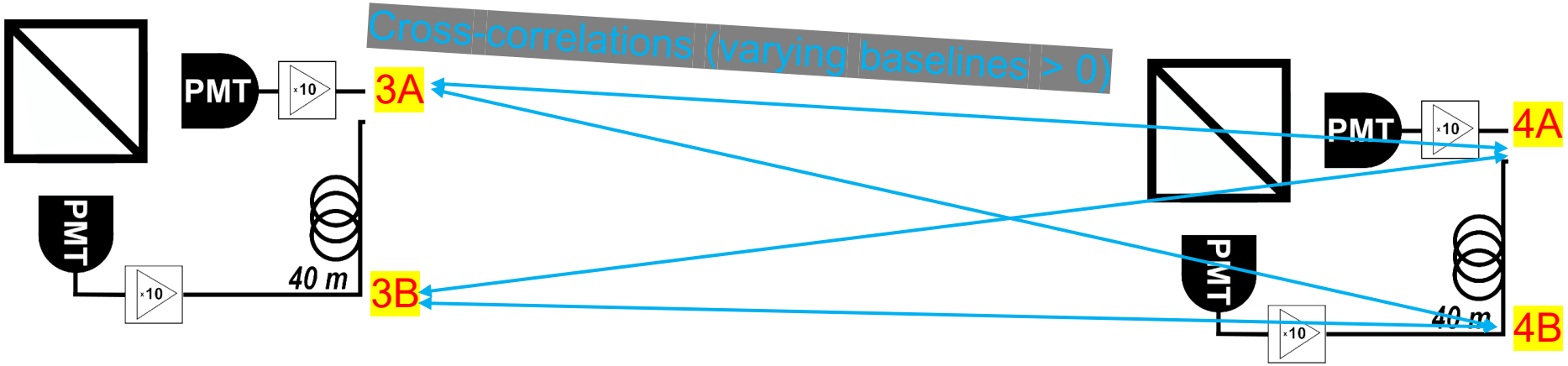
2nd H.E.S.S. campaign 2023

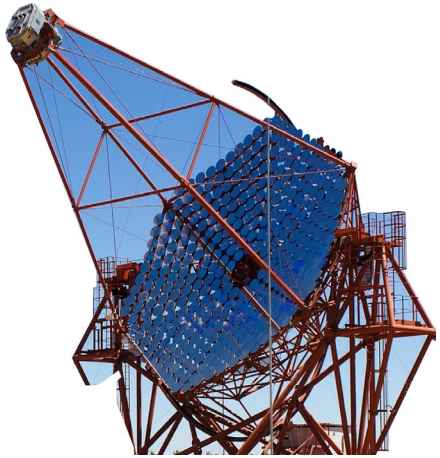
Correlation

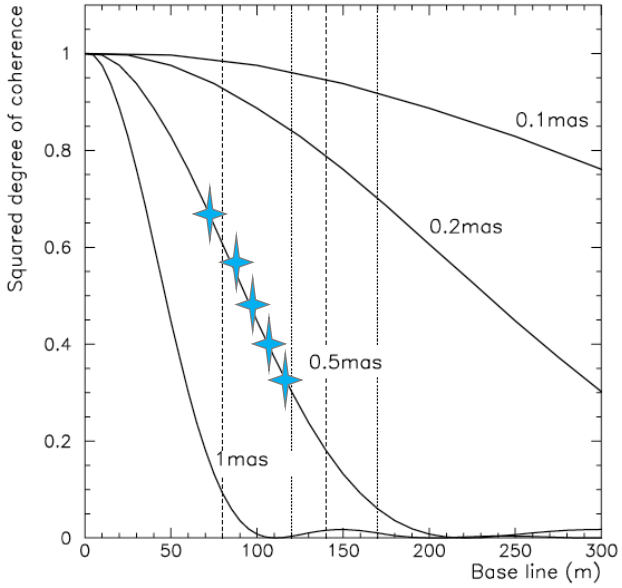


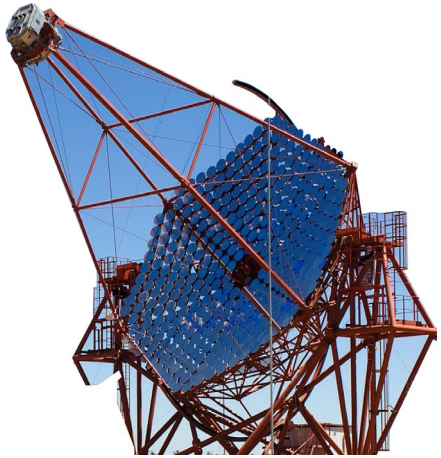
Analyses

Correlation channels



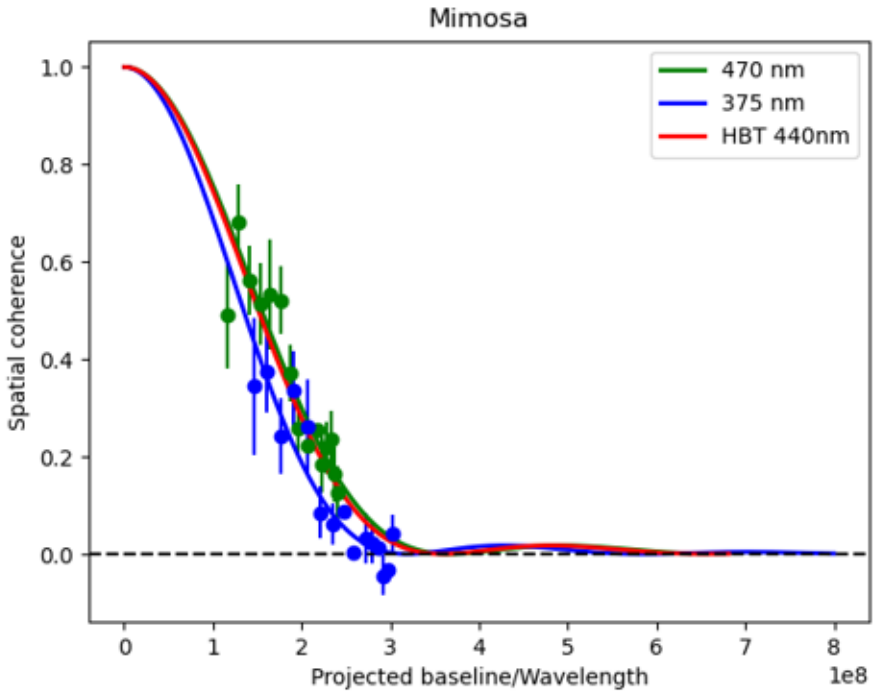






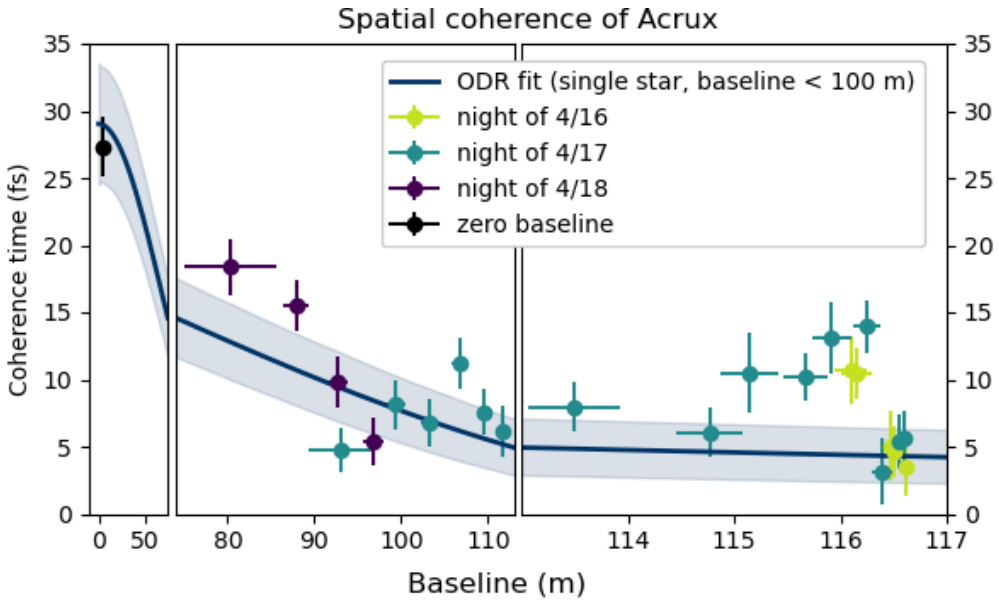
Results

Preliminary



Source	Mimosa (Beta Crux)
Magnitude (mag)	1.2
Spectral type	B0.5III
System	Single star
HBT time (h)	178.7
HBT diameter (mas)	0.702 ± 0.022
Time (h)	6.5
Diameter (mas)	470nm: 0.687 +/- 0.028 *375nm: 0.804 +/- 0.040*

Future adventures

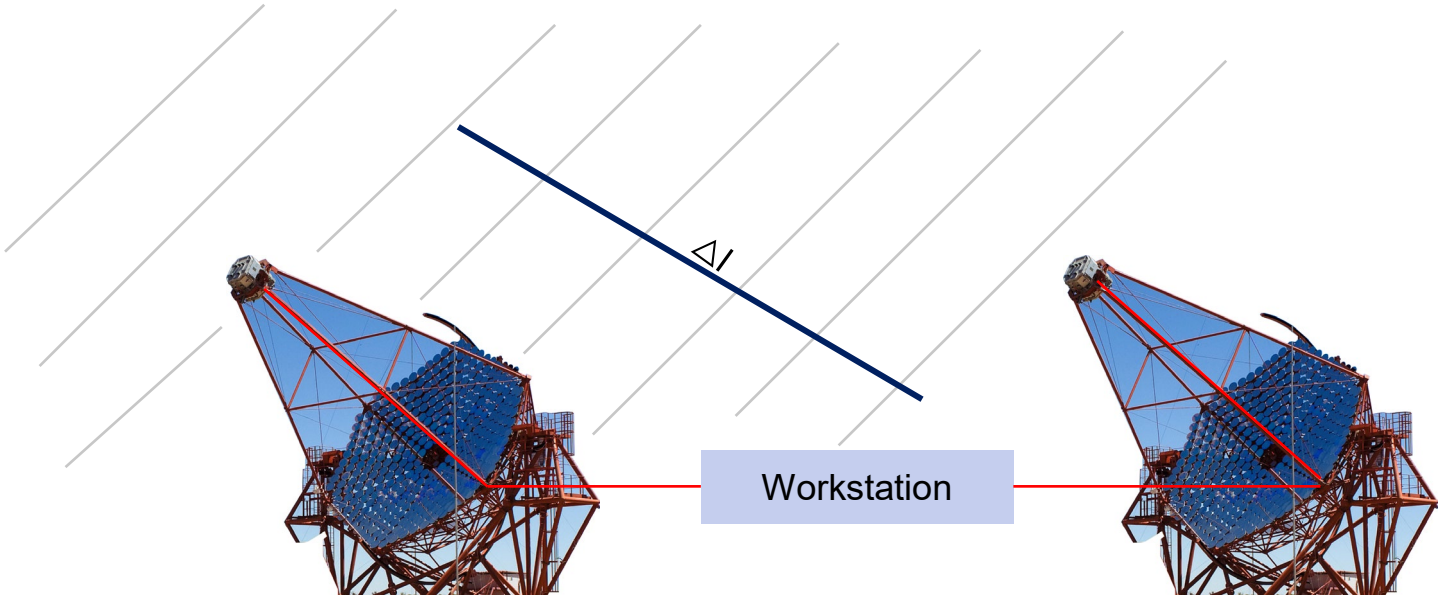


- More complex measurement/ analysis methods
  - Binary stars/ multiple stars
- Extension to more telescopes
- Install permanent setups


Thank you for listening!

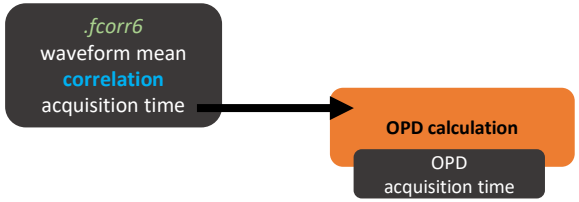
Analyses

Correlation channels – Optical path delay

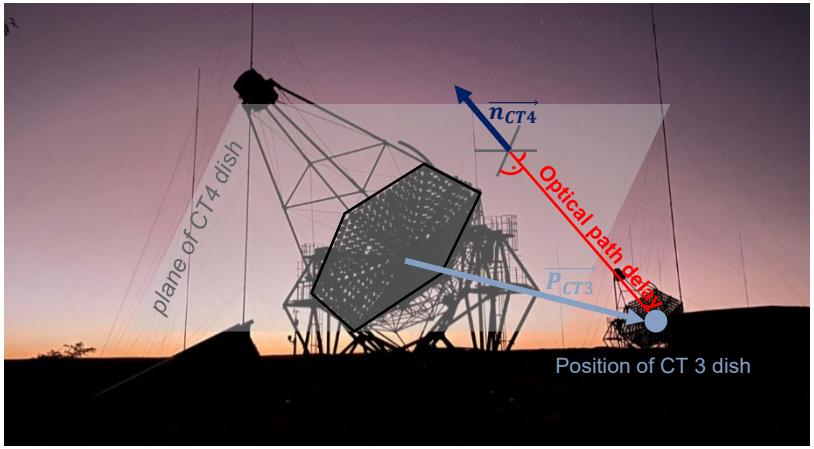


- Correlation between telescopes require optical path delay correction

Optical path delay



- File acquisition time and source information (ra/dec) yield alt/az position = Pointing position of the telescopes

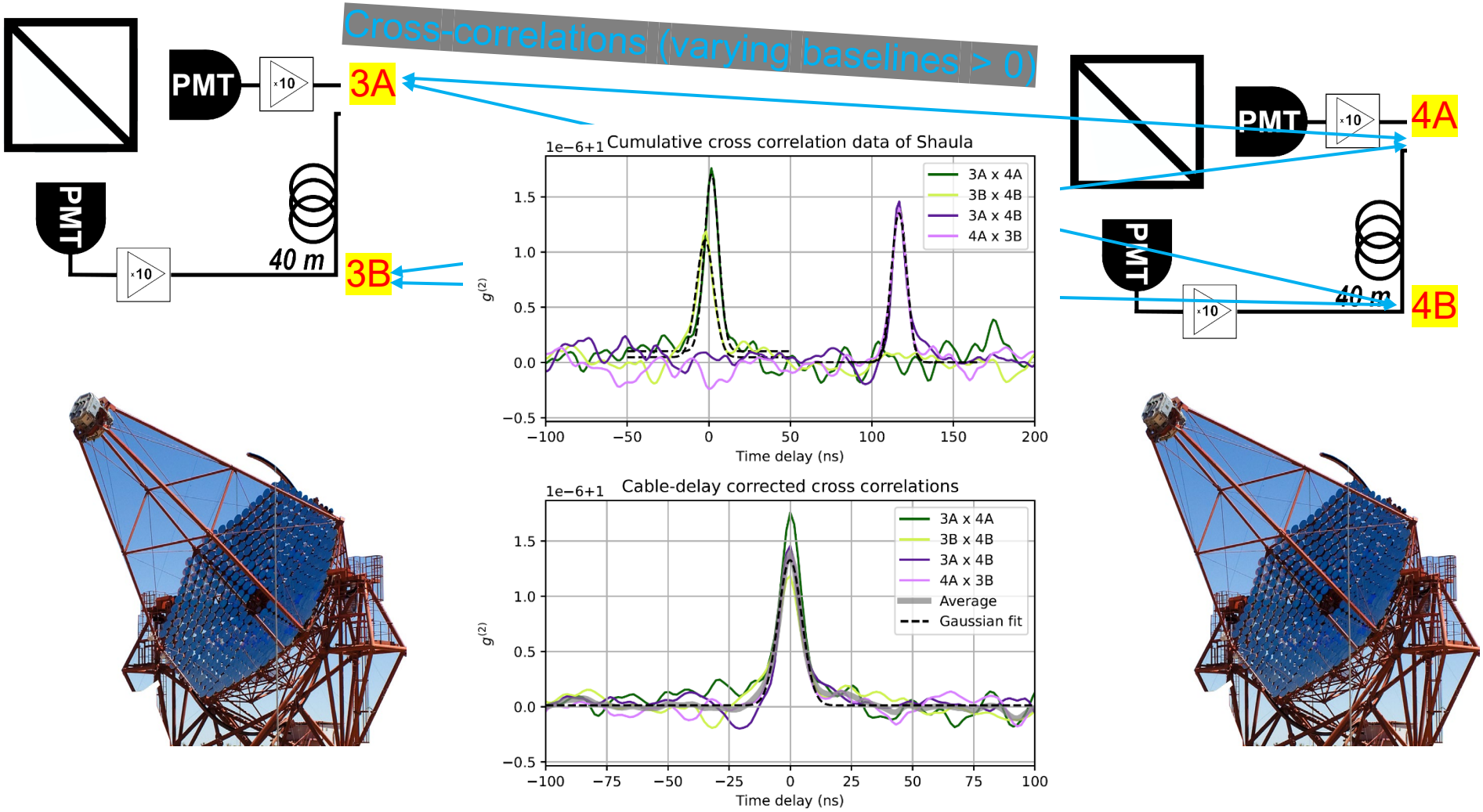


- Optical path delay is distance between the **position of the CT3 dish** and the **plane defined by the CT4 dish** (perpendicular to pointing direction)

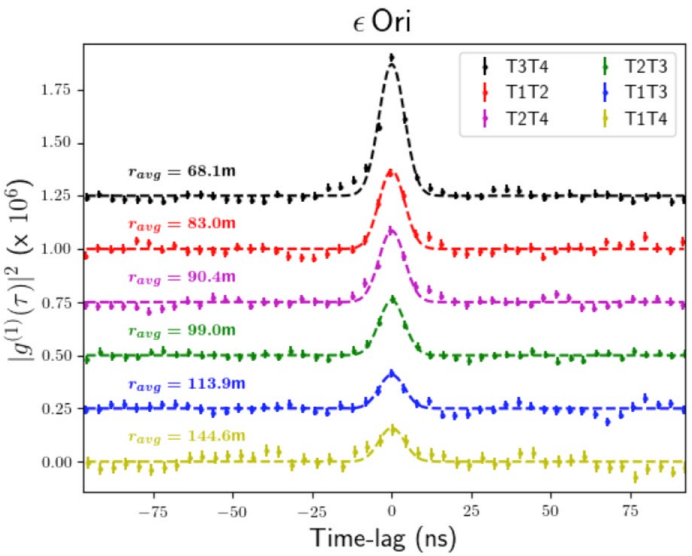
$$OPD = \overrightarrow{n_{CT4}} \cdot \overrightarrow{P_{CT3}}$$

Analyses

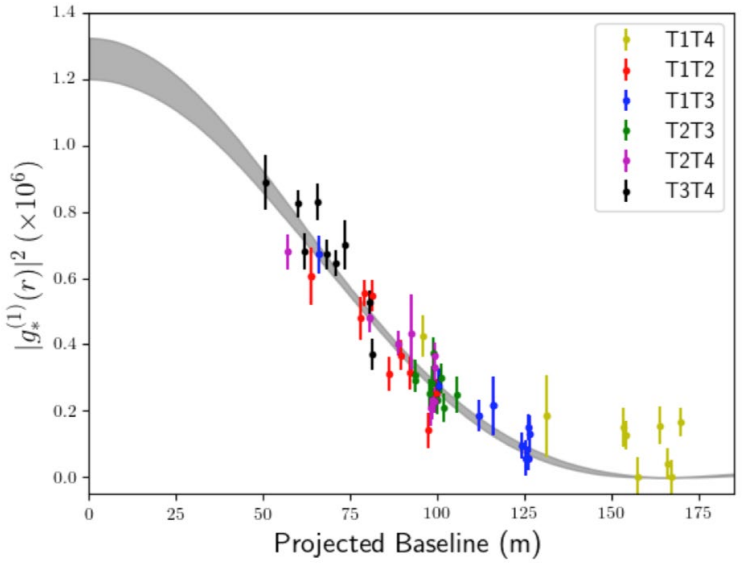
Correlation channels – Cross correlation cable delay



IACT Intensity Interferometry in the Northern Hemisphere

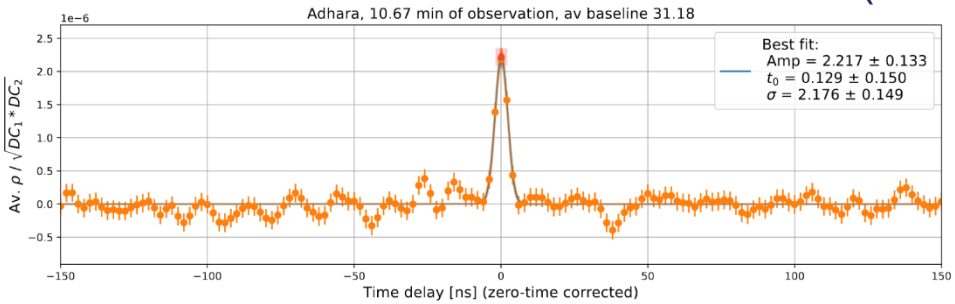


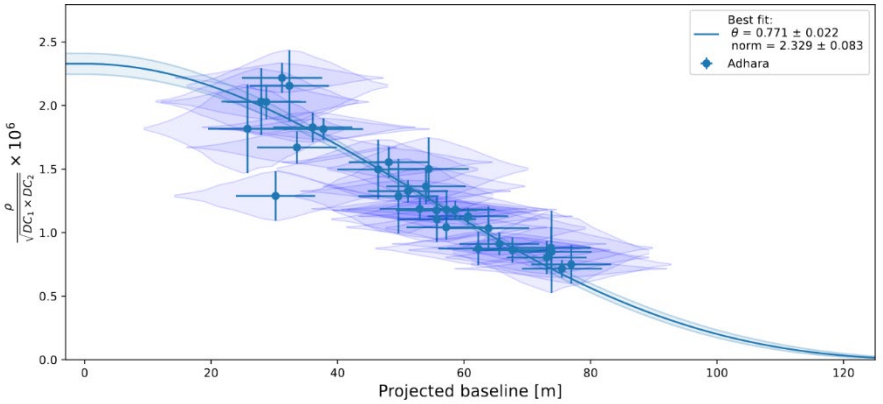
VERITAS (2020)



Abeysekara, A. U., et al. "Demonstration of stellar intensity interferometry with the four VERITAS telescopes." Nature Astronomy 4.12 (2020): 1164-1169.

MAGIC (2022)





Adapted from: Cortina, Juan, et al. "First measurements and upgrade plans of the MAGIC intensity interferometer." Optical and Infrared Interferometry and Imaging VIII. Vol. 12183. SPIE, 2022.

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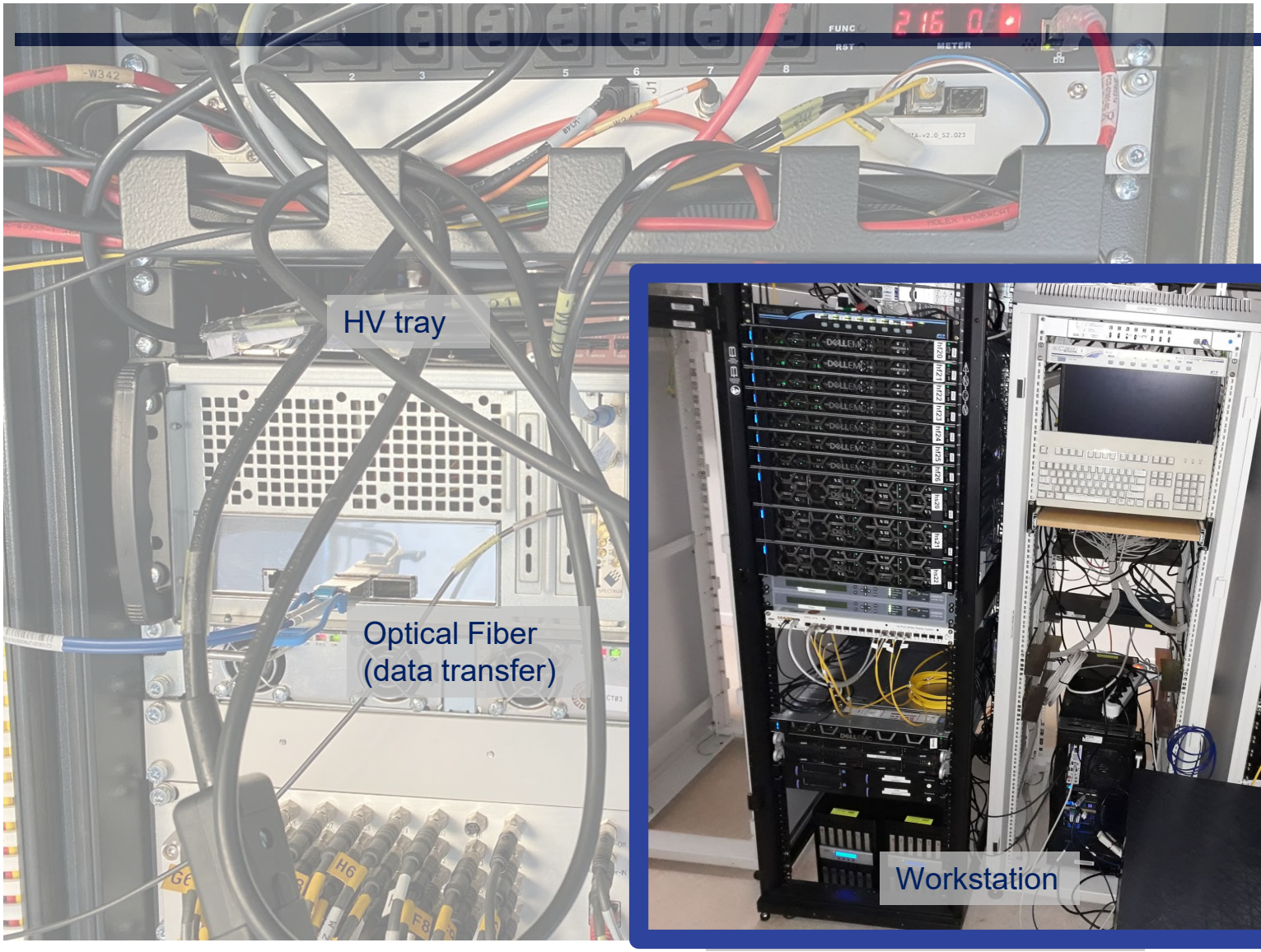
Camera backplane

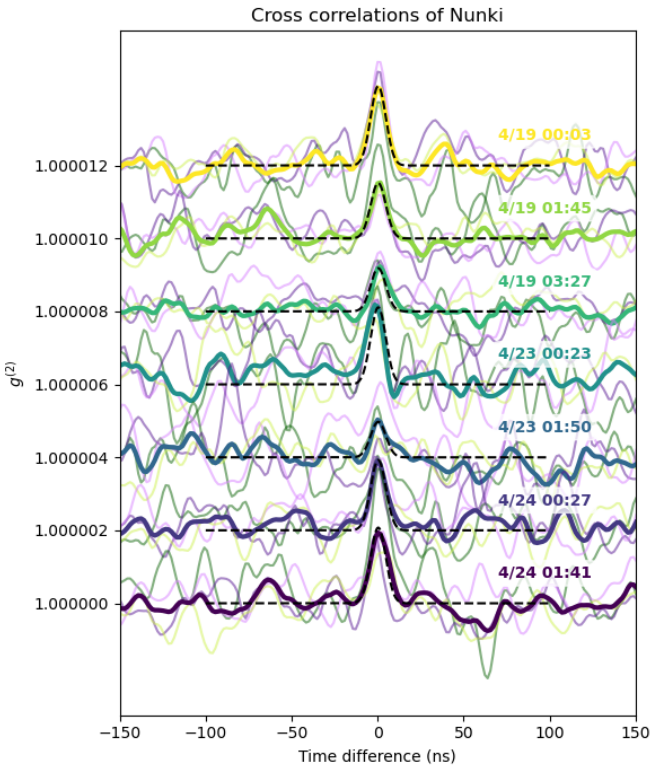
2nd H.E.S.S. campaign 2023

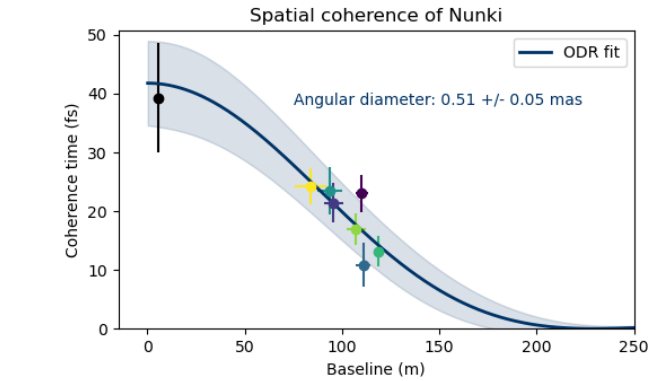
Camera backplane and server room

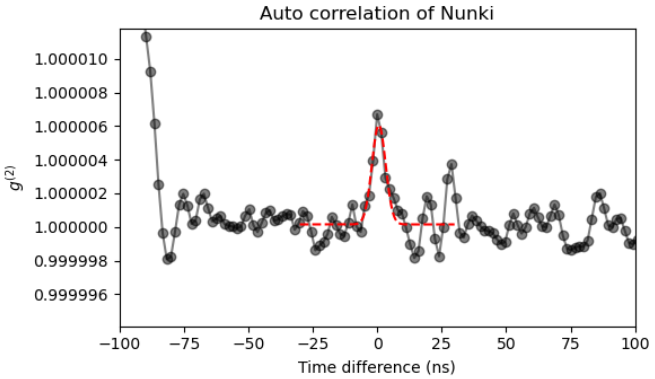


Results

Nunki (Sigma Sagitarii)

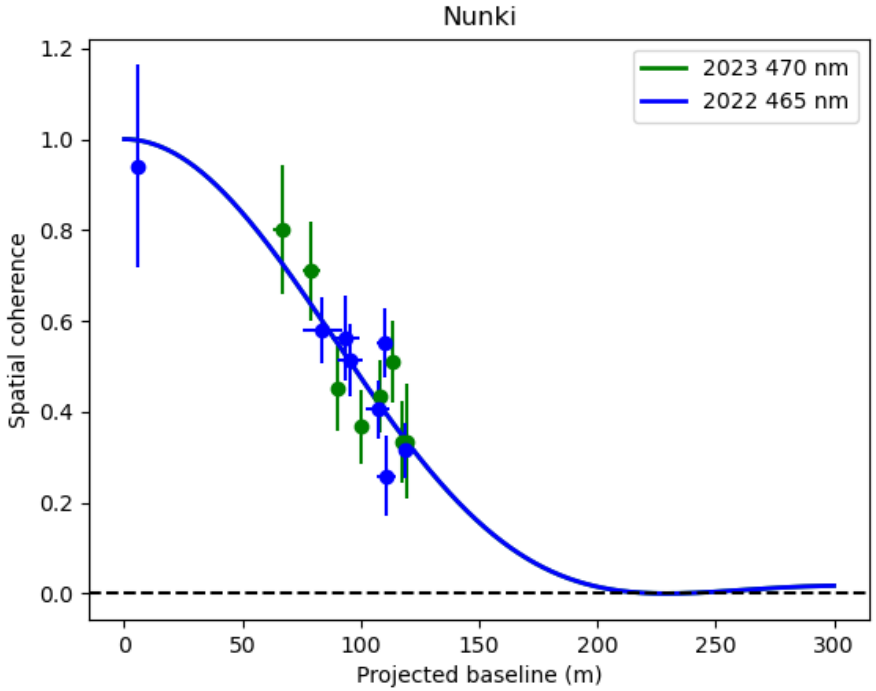






Literature values e.g.
$0.60\ mas$
(Hipparcos)

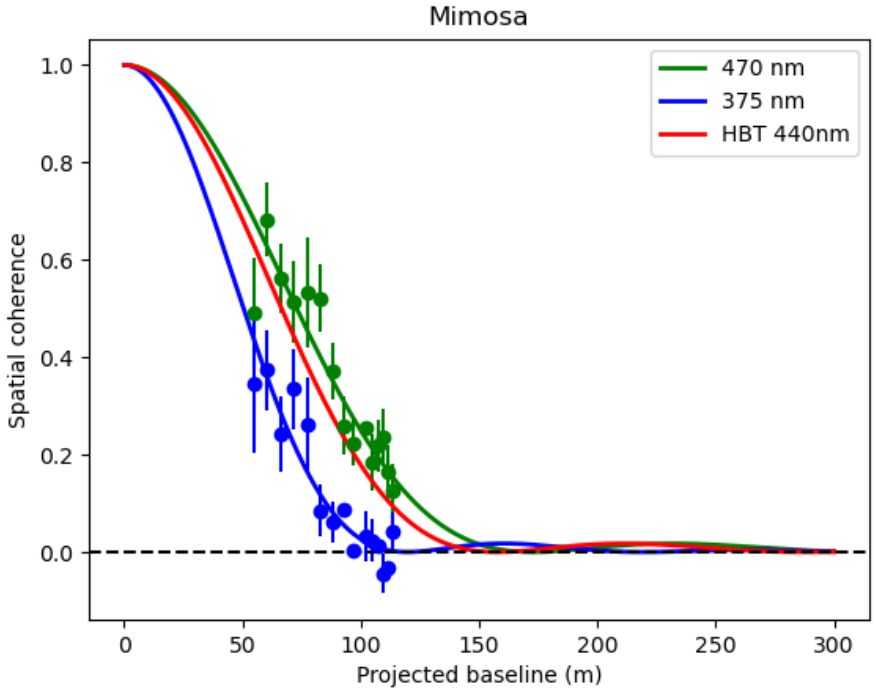
Results



Source	Nunki (Sigma Sagittarii)
Magnitude (mag)	2.05
Spectral type	B2V
System	Single star
HBT time (h)	0
Hipparcos (mas)	0.6
Time (h)	5.5
Diameter (mas)	470nm: 0.501 +/- 0.071 *465nm: 0.51 +/- 0.05*

Results

Preliminary



Source	Mimosa (Beta Crux)
Magnitude (mag)	1.2
Spectral type	B0.5III
System	Single star
HBT time (h)	178.7
HBT diameter (mas)	0.702 ± 0.022
Time (h)	6.5
Diameter (mas)	470nm: 0.687 +/- 0.028 *375nm: 0.804 +/- 0.040*

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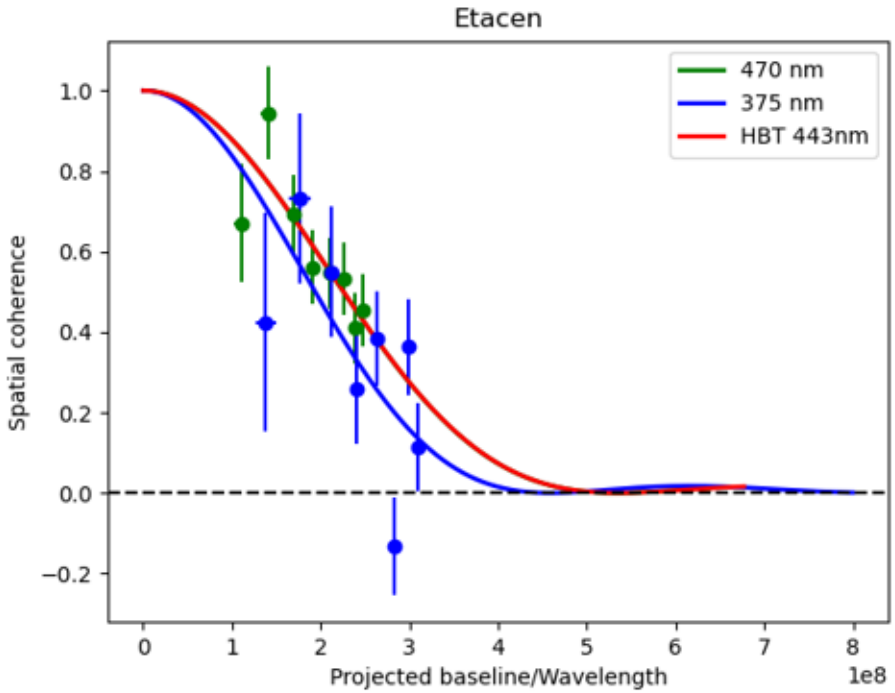
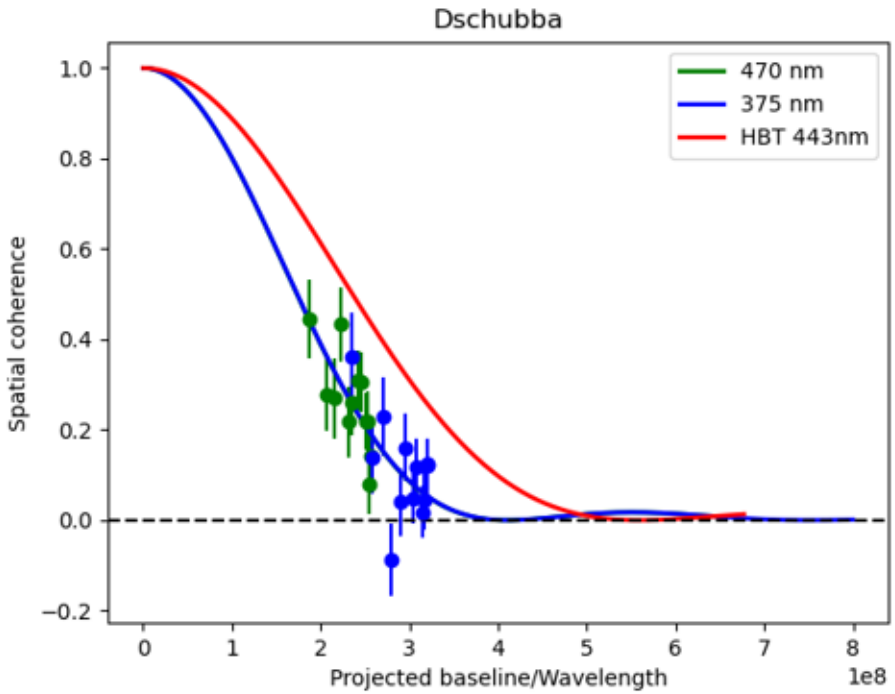


Source	Eta Centauri
Magnitude (mag)	2.35
Spectral type	B1.5Vne
System	Single star
HBT time (h)	98
HBT diameter (mas)	0.47 ± 0.03
Time (h)	9.9
Diameter (mas)	470nm: 0.511 +/- 0.043 *375nm: 0.580 +/- 0.061*

Results



Source	Dschubba (Delta Scorpii)
Magnitude (mag)	2.2
Spectral type	B0.3IV
System	Binary star
HBT time (h)	115.1
HBT diameter (mas)	0.45 ± 0.04
Time (h)	5.1
Diameter (mas)	470nm: 0.613 +/- 0.072 *375nm: 0.612 +/- 0.081*