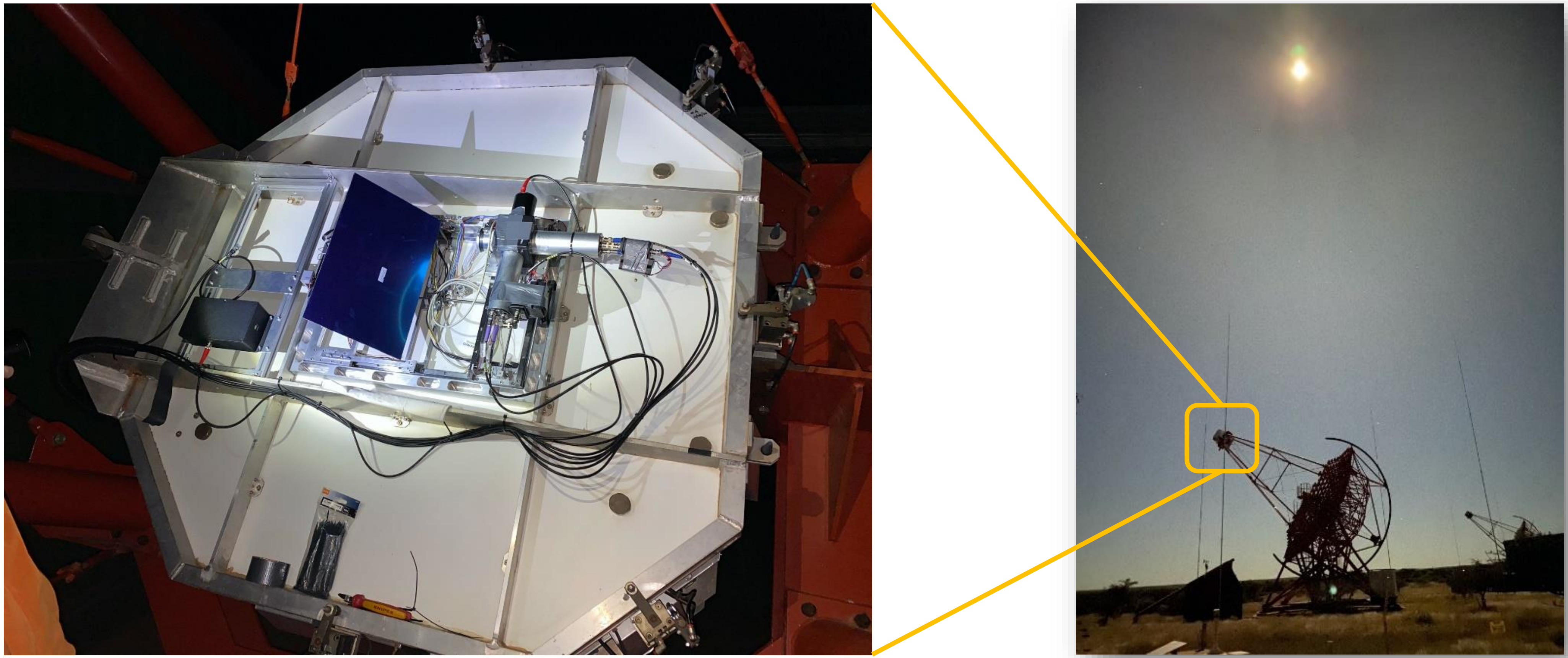
Friedrich-Alexander-Universität
Erlangen-Nürnberg

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

Andreas Zmija
Erlangen, 2024-07-30

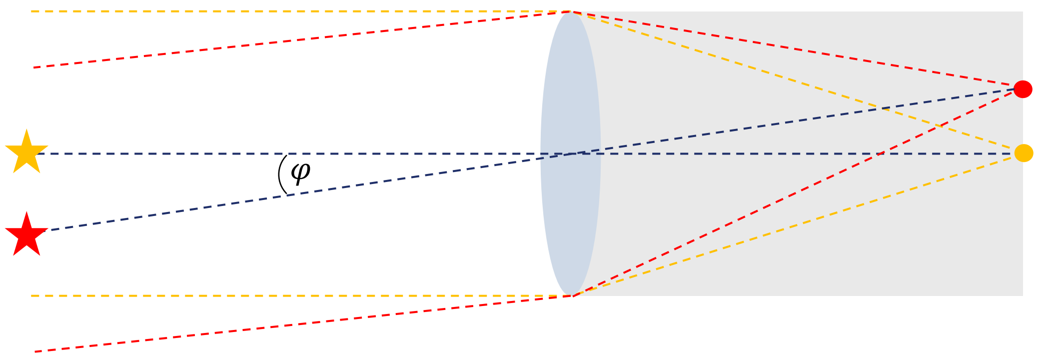
Something is going on under the moonlight

Something is going on under the moonlight



Boundaries of high-resolution Astronomy

- Angular resolution diffraction-limited by aperture size



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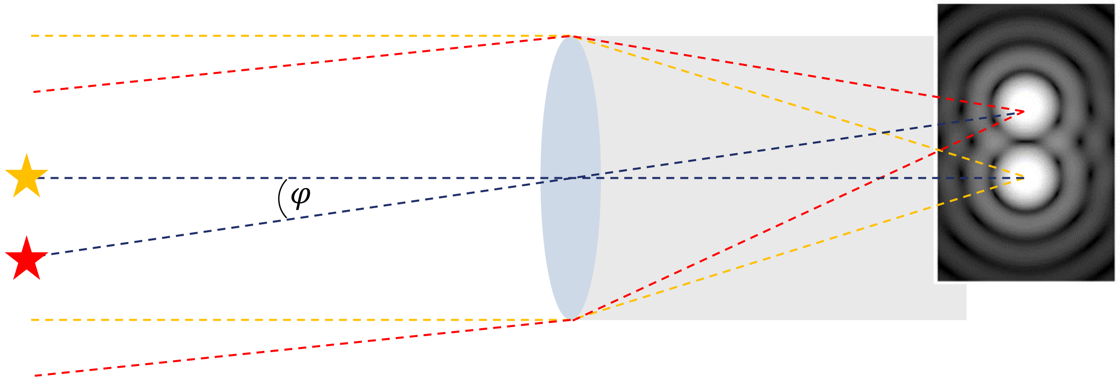

https://physicsworld.com/a/tapping-into-lights-hidden-information-to-push-fundamental-diffraction-limit/

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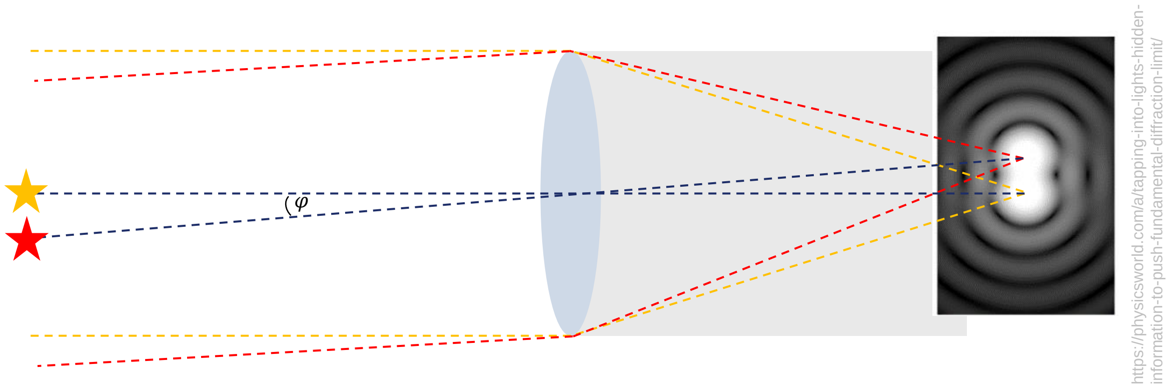

$$\varphi \approx 1.22\, {}^{\lambda}/_{D}$$

Boundaries of high-resolution Astronomy

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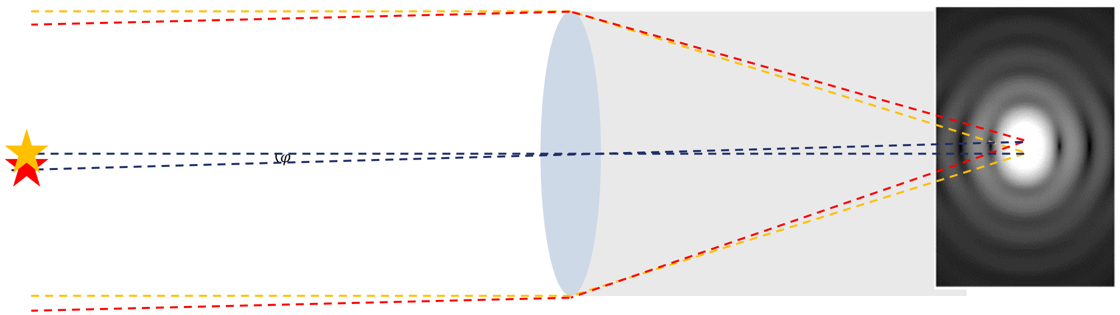

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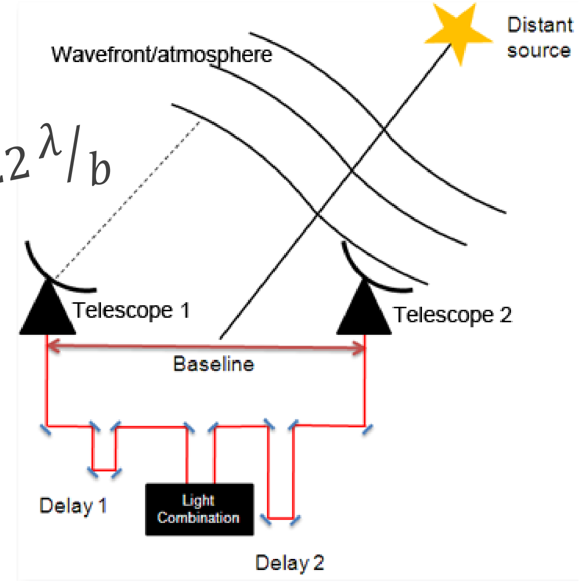
Boundaries of Interferometric Astronomy

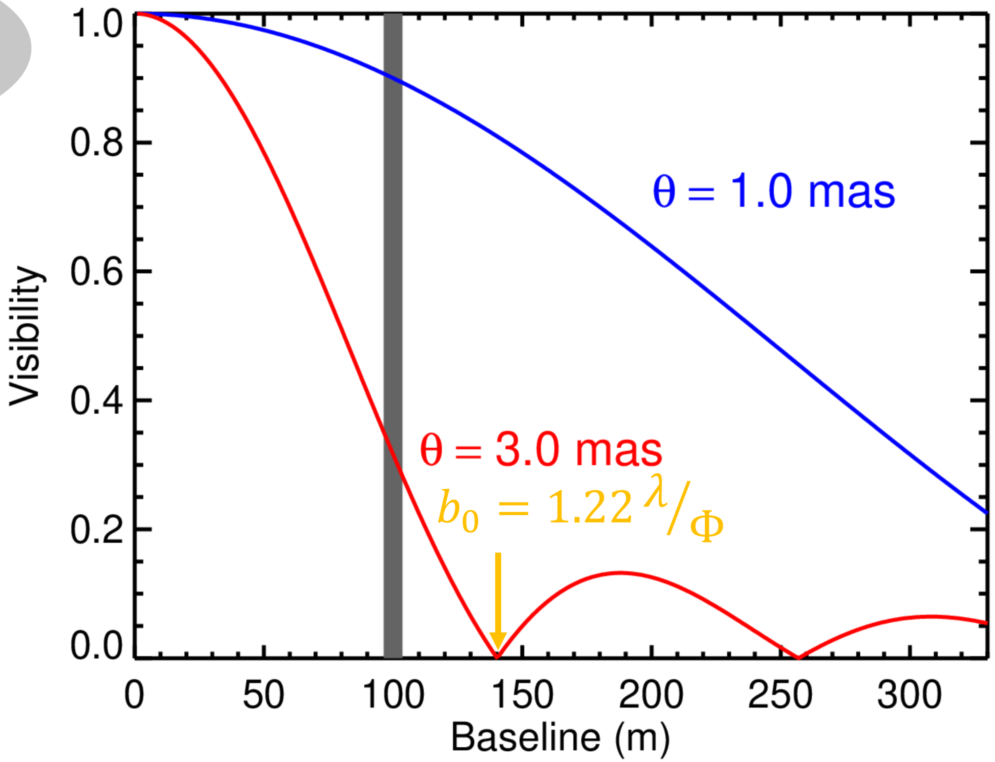
- High resolutions typically achieved by amplitude interferometers
- Baseline limitations due to atmospheric turbulences and technical challenges

$$g^{(1)} \propto \langle E_1 E_2 \rangle$$

First order coherence

$$\varphi \approx 1.22\,{}^{\lambda}/_{b}$$

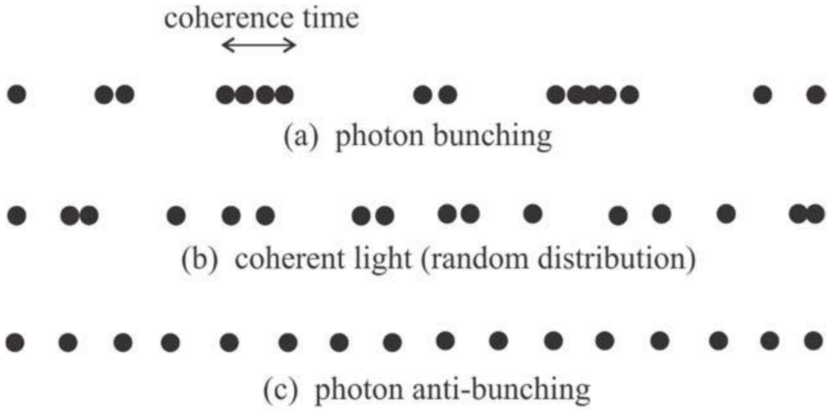




https://www.chara.gsu.edu/public/basics-of-interferometry

Coherence exists also at the photon level!

(in case of thermal emission)



Luo Qi - Non-classical multi-photon light from clusters of colloidal quantum dots (2019)

Coherence exists also at the photon level!

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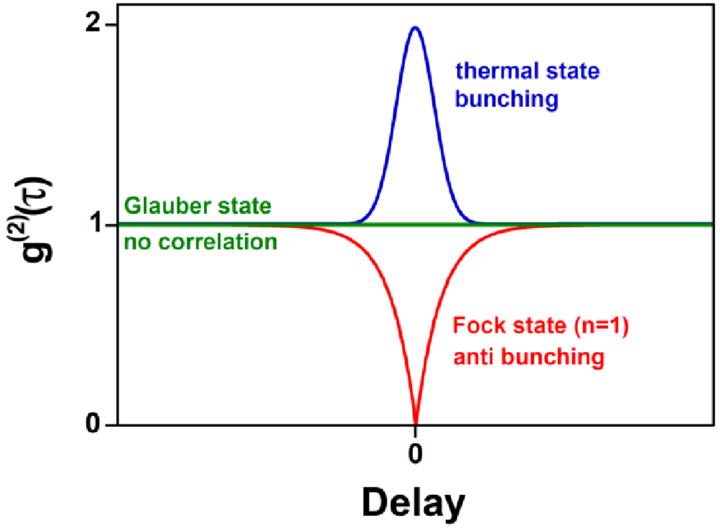
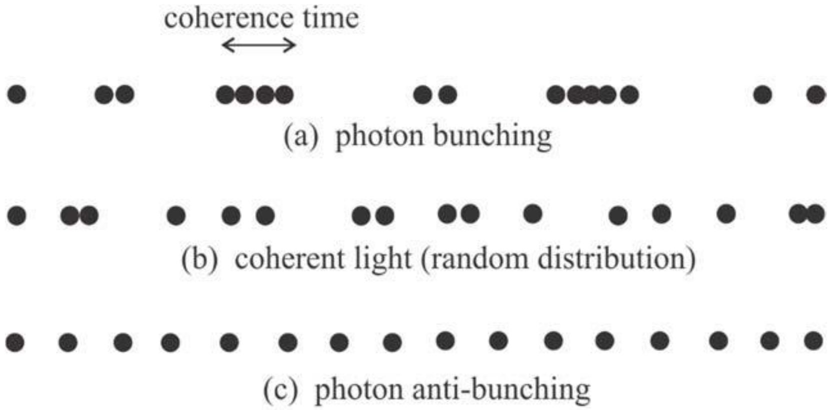
$g^{(2)} \propto \langle I_1 I_2 \rangle$

Second order coherence



https://www.kth.se/social/files/5cb1833856be5bf03c8165fa/Lecture%203%20Second-order%20Intensity%20Correlation%20Function.pdf



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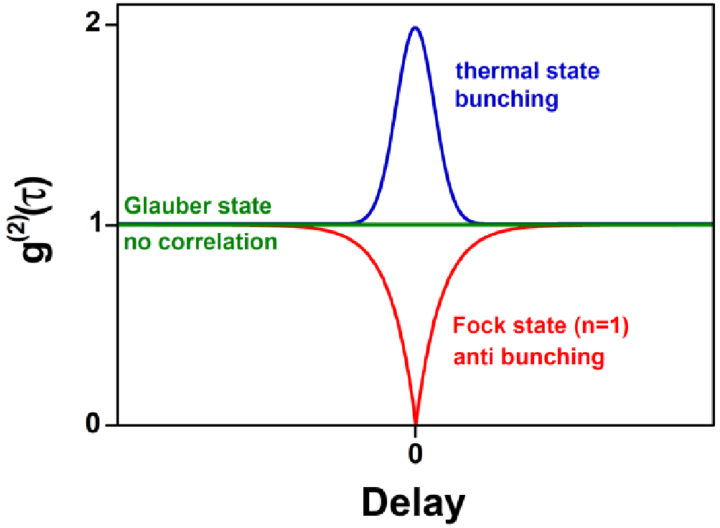

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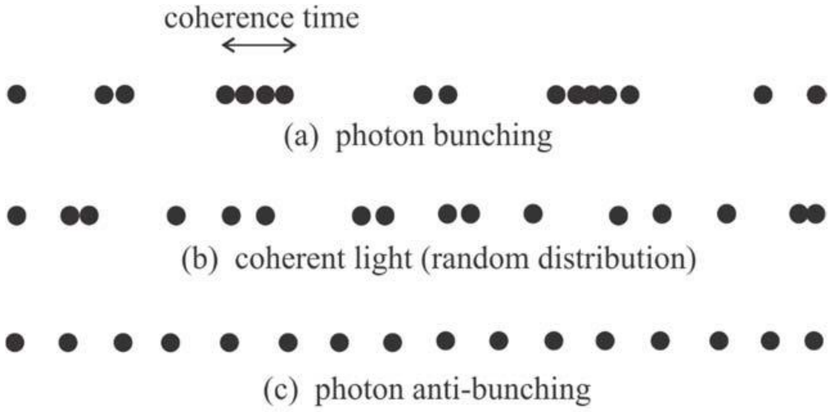
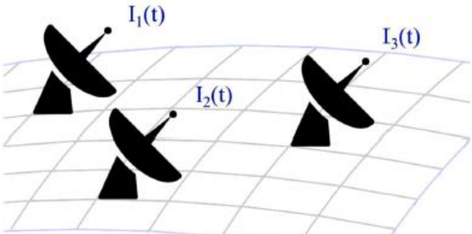


Luo Qi - Non-classical multi-photon light from clusters of colloidal quantum dots (2019)

- Photon bunching can be observed between multiple photon-counting telescopes



Dravins, Dainis, and Colin Carlile. "Kilometer-baseline optical intensity interferometry for stellar surface observations."

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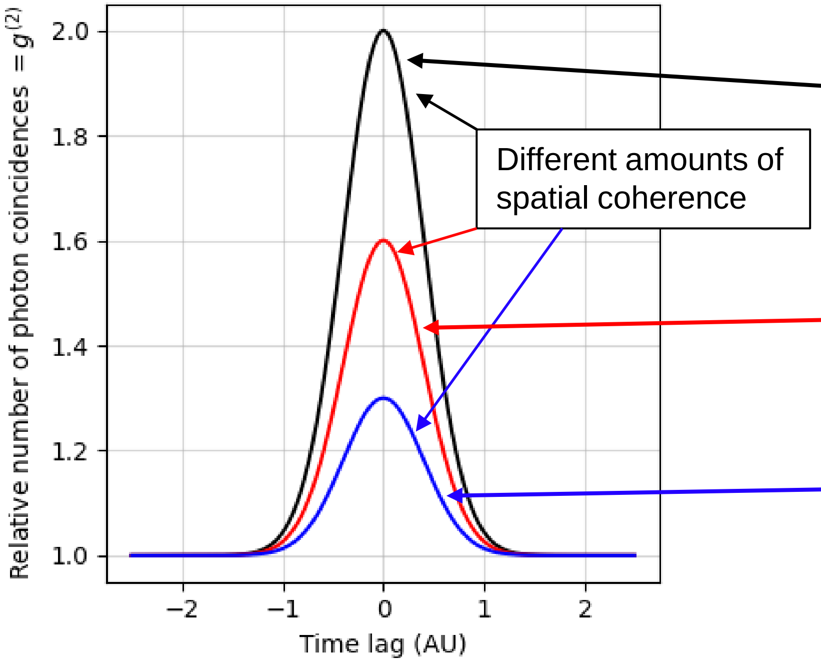
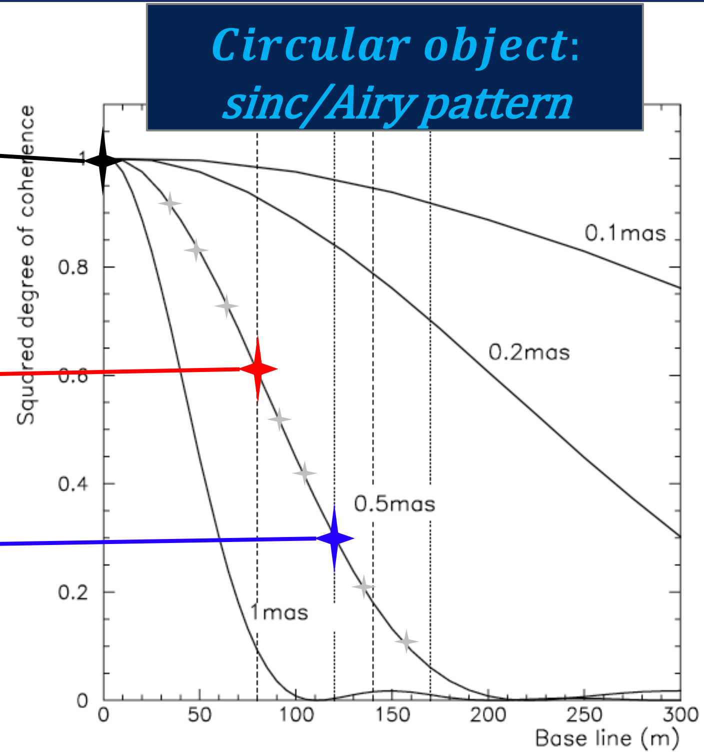
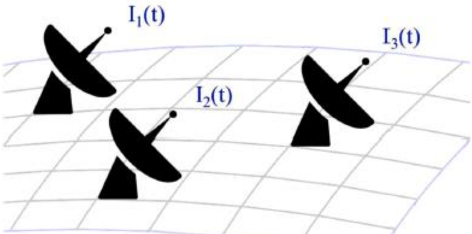




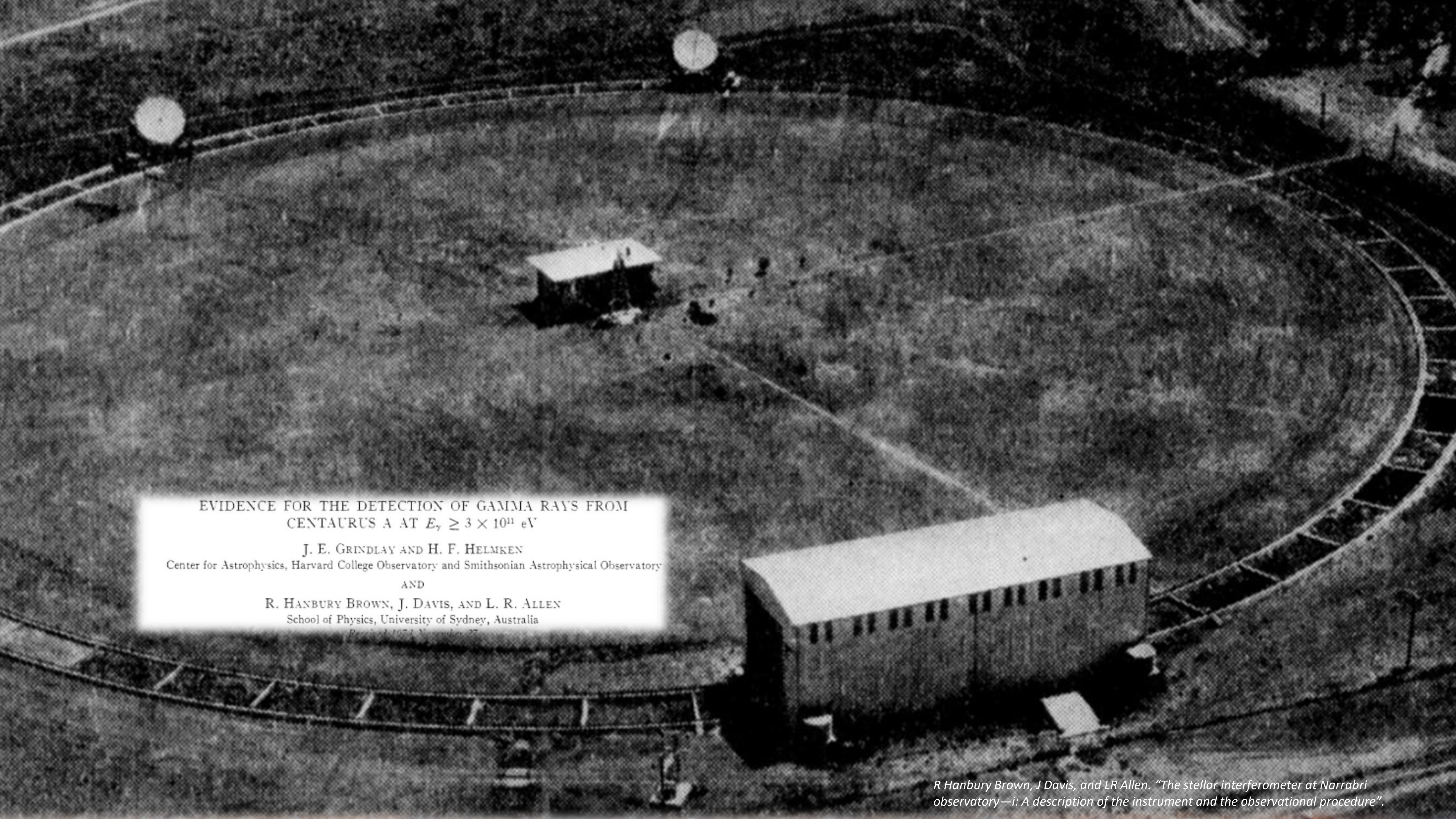
S. Le Bohec and J.Holder. „Optical intensity interferometry with atmospheric Cherenkov telescope arrays"

- Photon bunching can be observed between multiple photon-counting telescopes
- Height of the bunching peak = Intensity interferometry visibility
- Works at large baselines and through turbulent atmosphere!
- Telescopes preferably large, but no very high time resolutions or very good optical qualities required



Dravins, Dainis, and Colin Carlile. "Kilometer-baseline optical intensity interferometry for stellar surface observations."

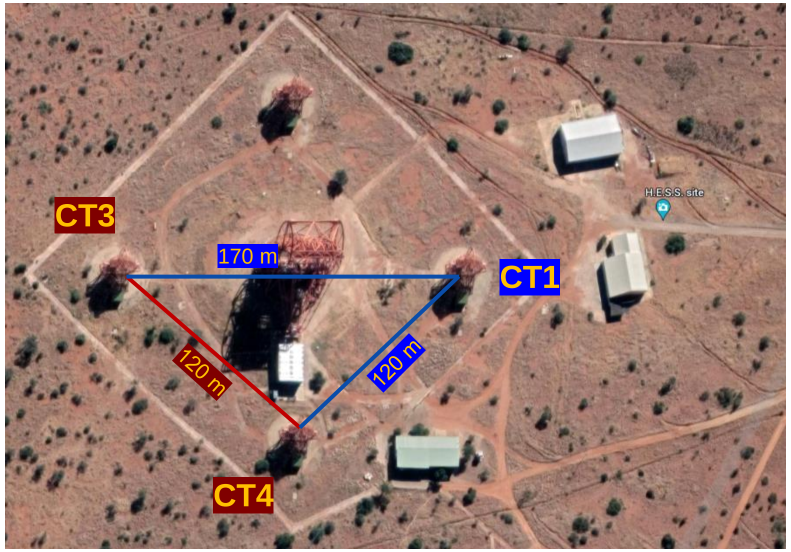

How about this one?



R Hanbury Brown, J Davis, and LR Allen. "The stellar interferometer at Narrabri observatory—i: A description of the instrument and the observational procedure".

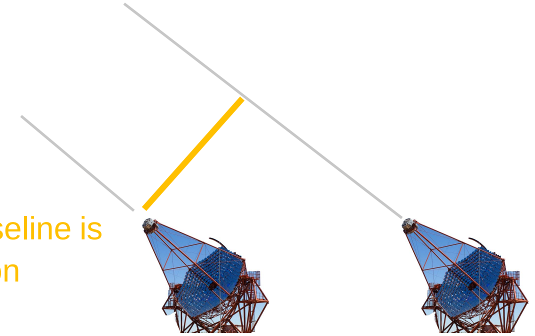
How to implement Intensity Interferometry to H.E.S.S.

Telescope selection



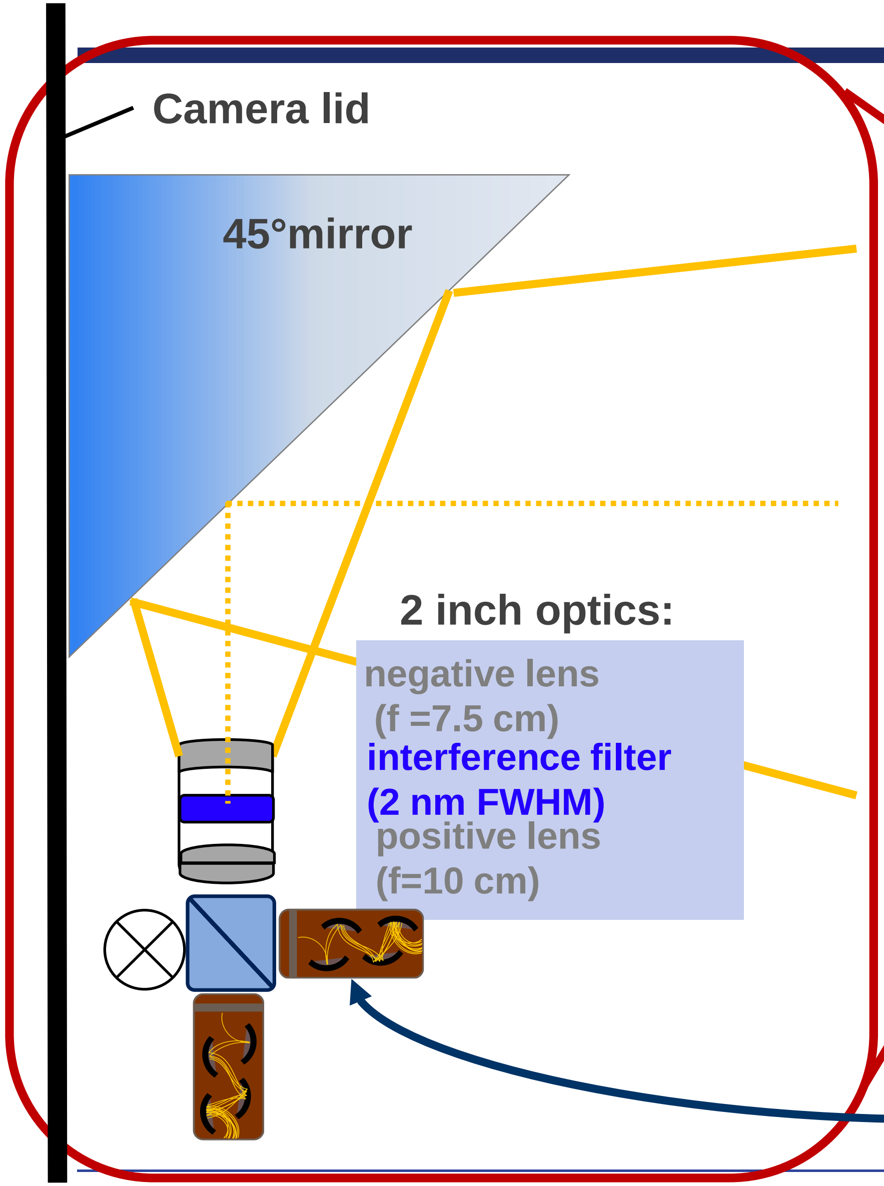
2022 April 8 to April 23

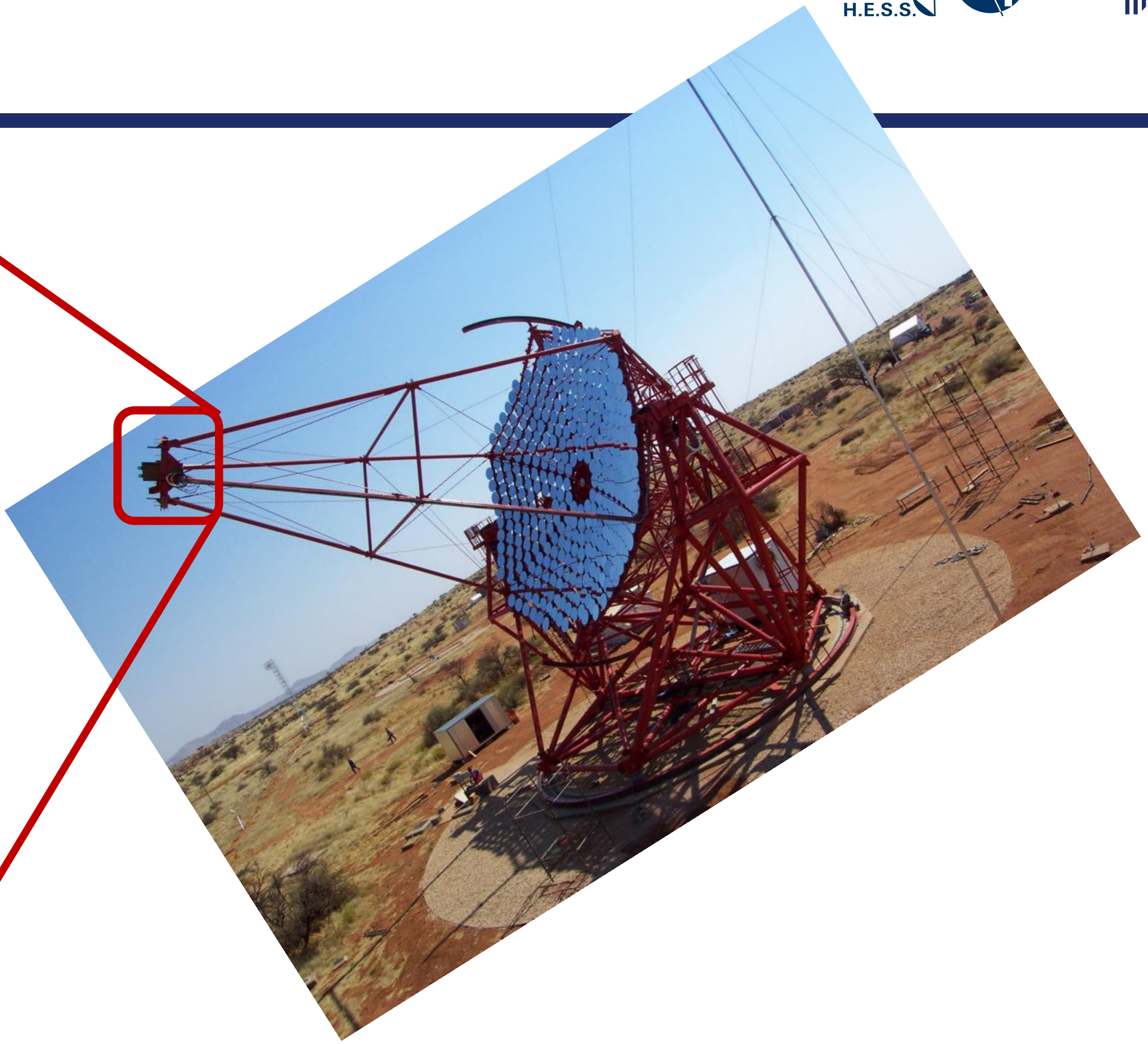
2023 April 25 to May 12



Implementation into H.E.S.S.

Opto-mechanical setup

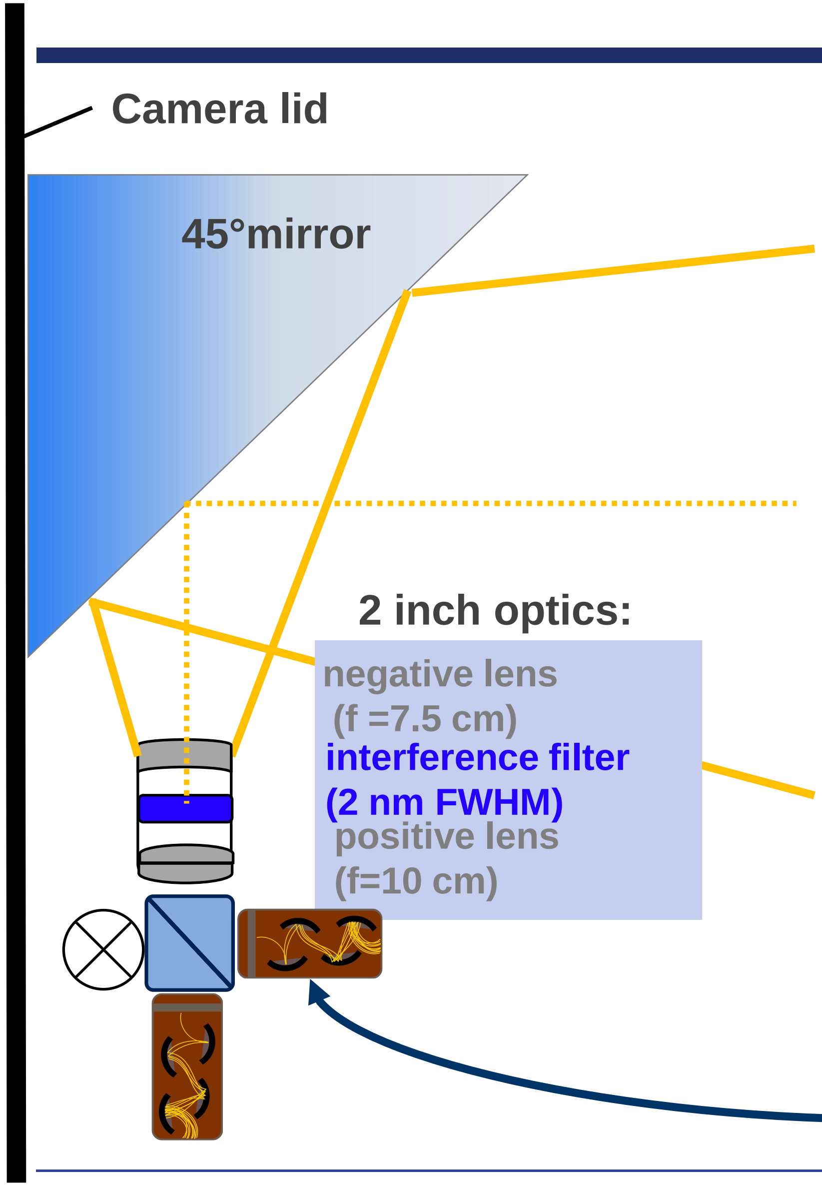


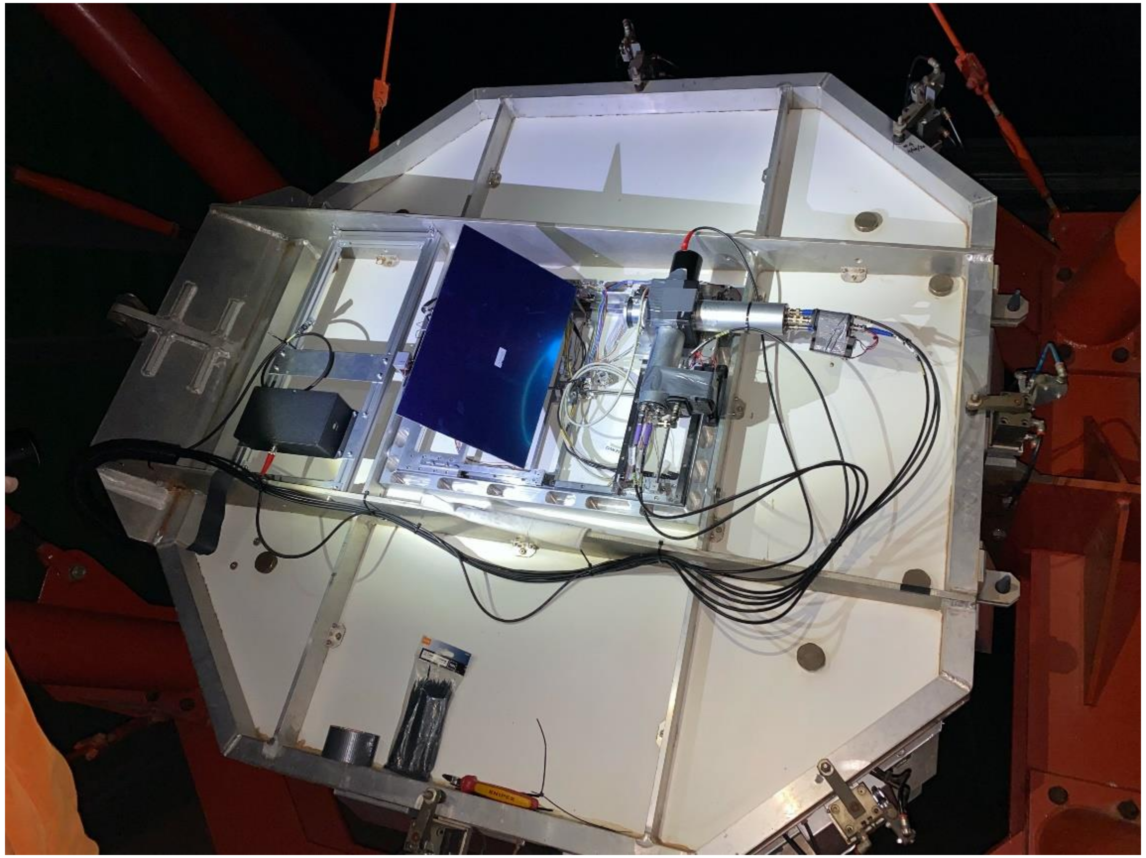


zero-baseline measurement option

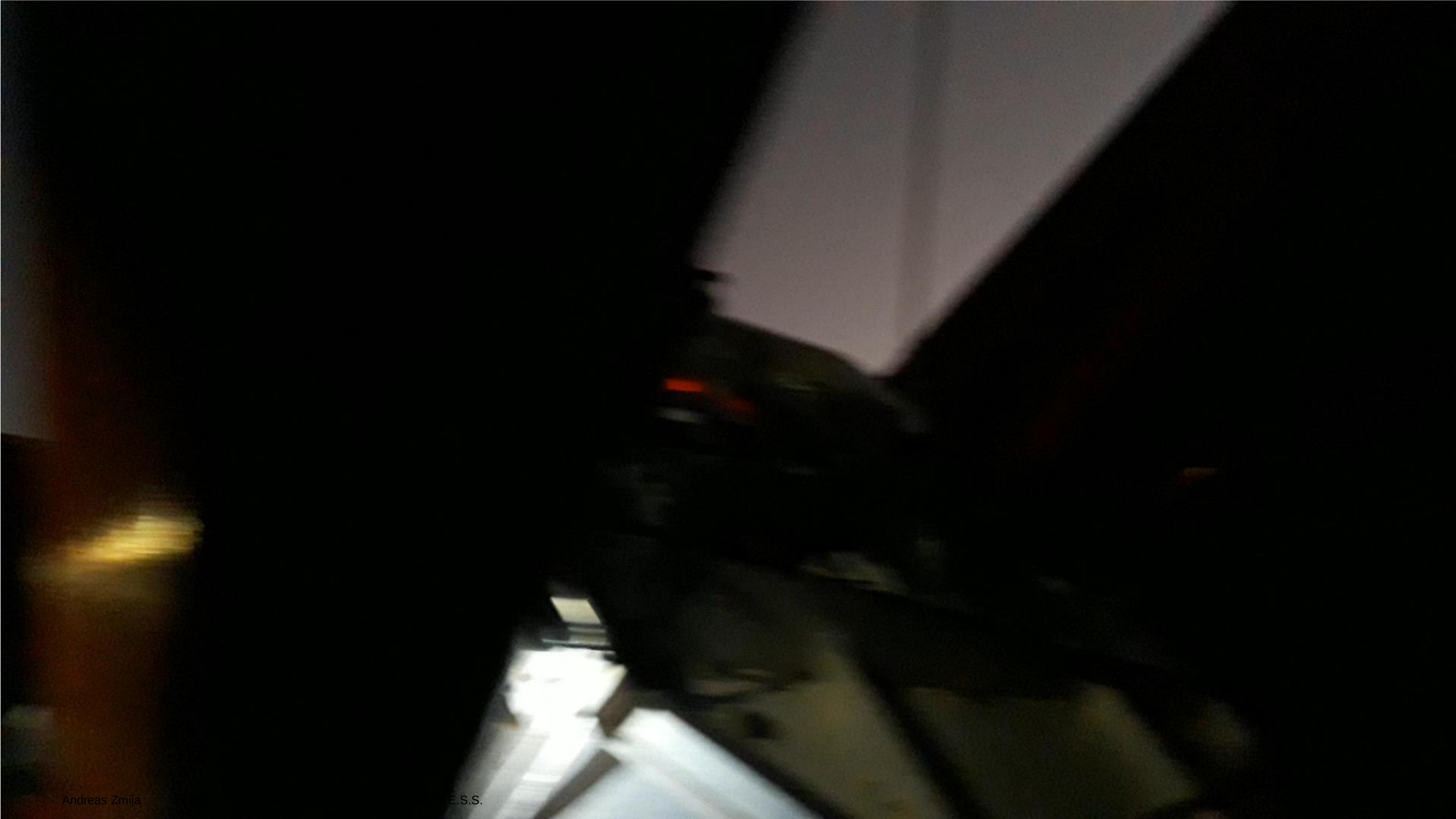
Implementation into H.E.S.S.

Opto-mechanical setup



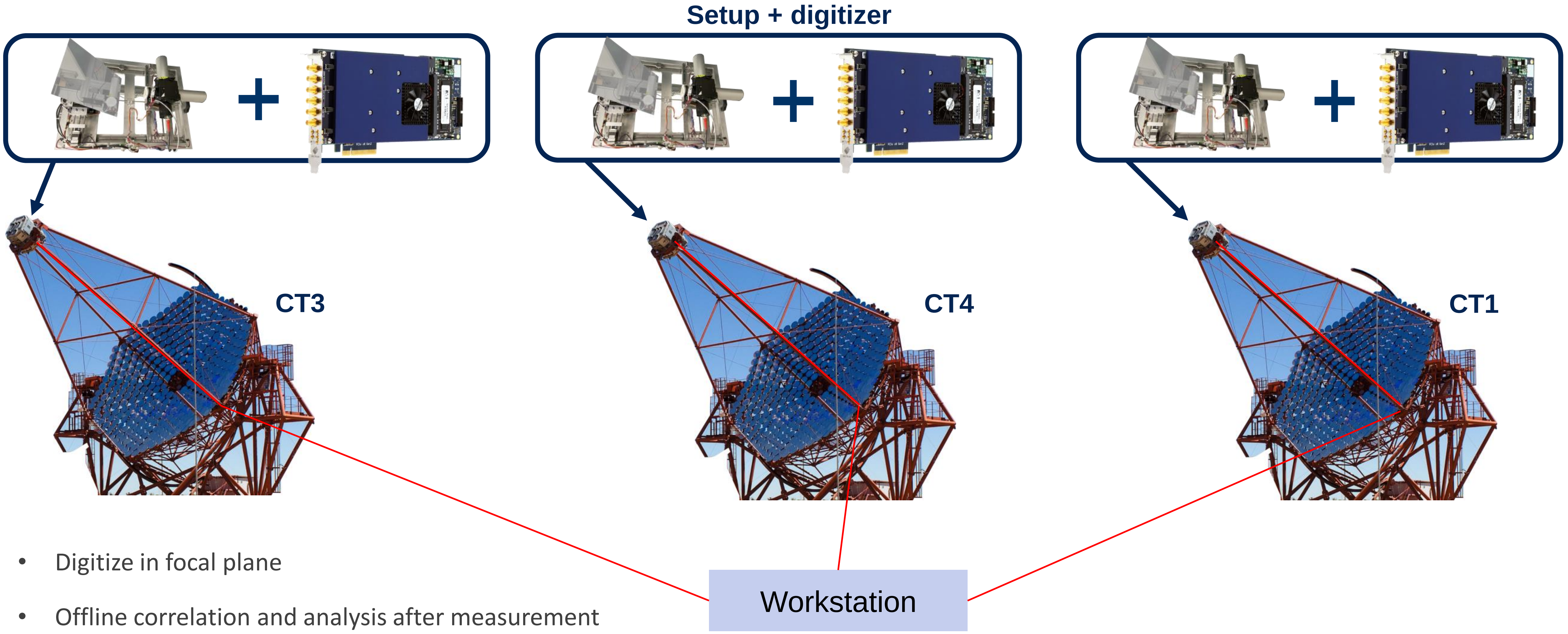


zero-baseline measurement option



2nd H.E.S.S. campaign

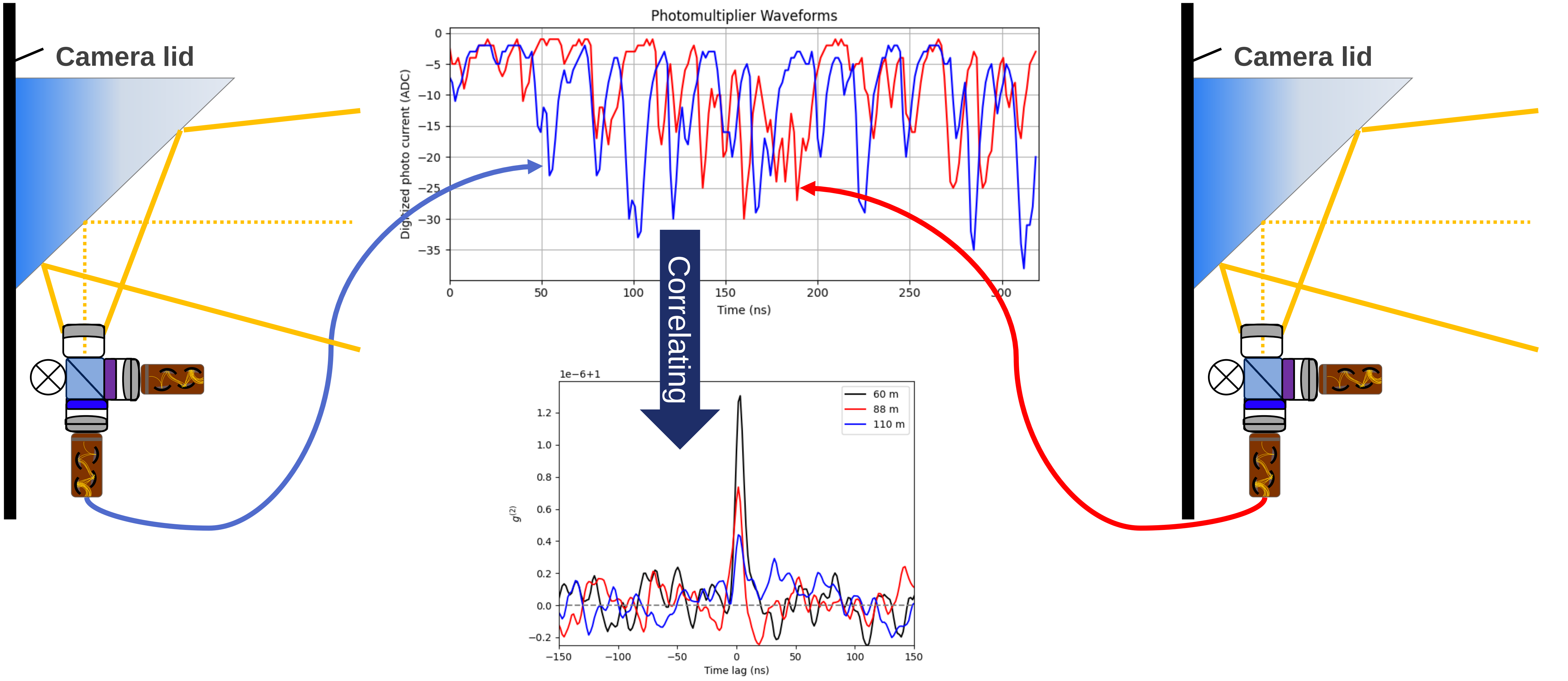
Measurement Setup – 3 telescopes



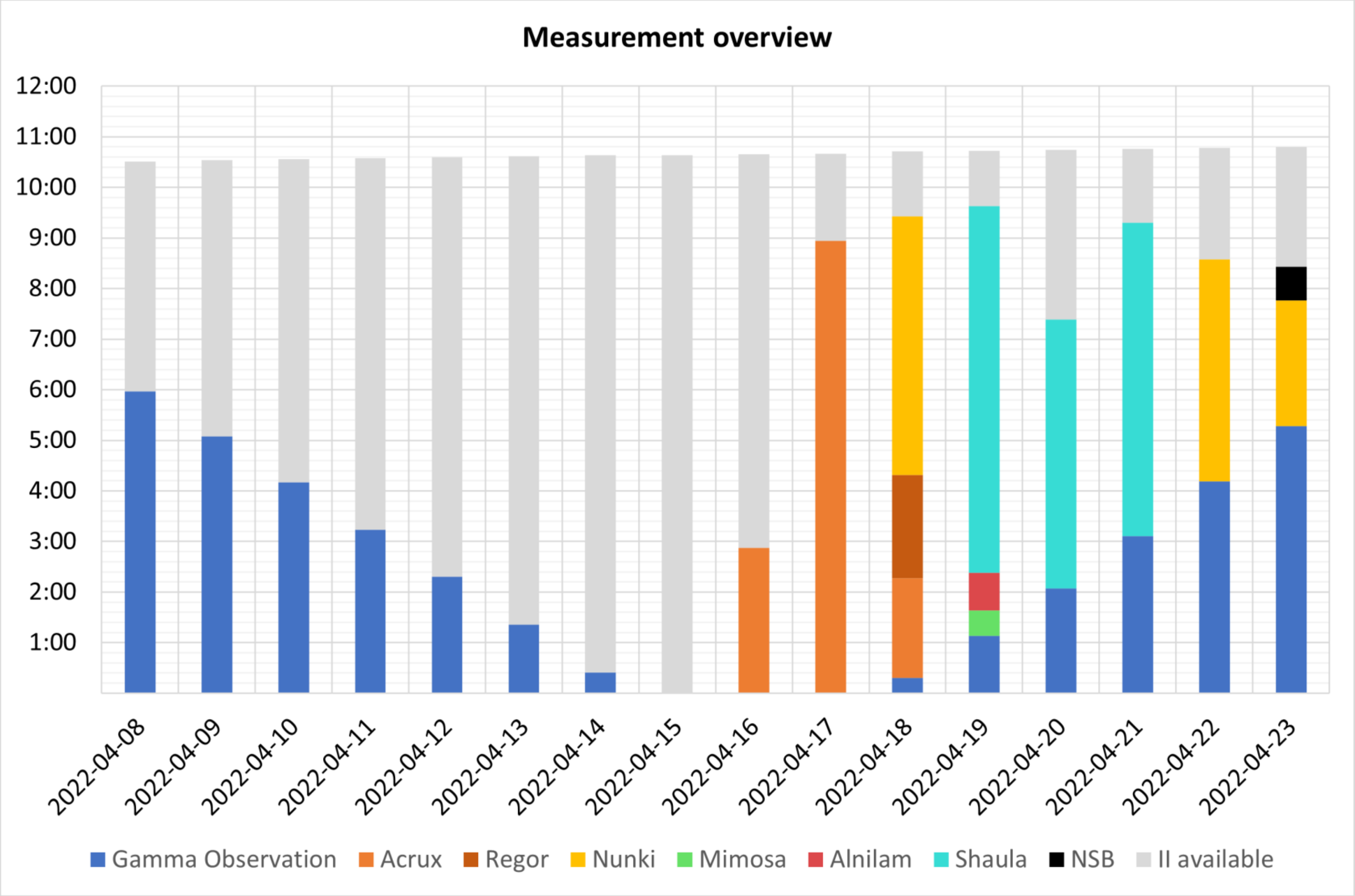
- Digitize in focal plane
- Offline correlation and analysis after measurement

2nd H.E.S.S. campaign

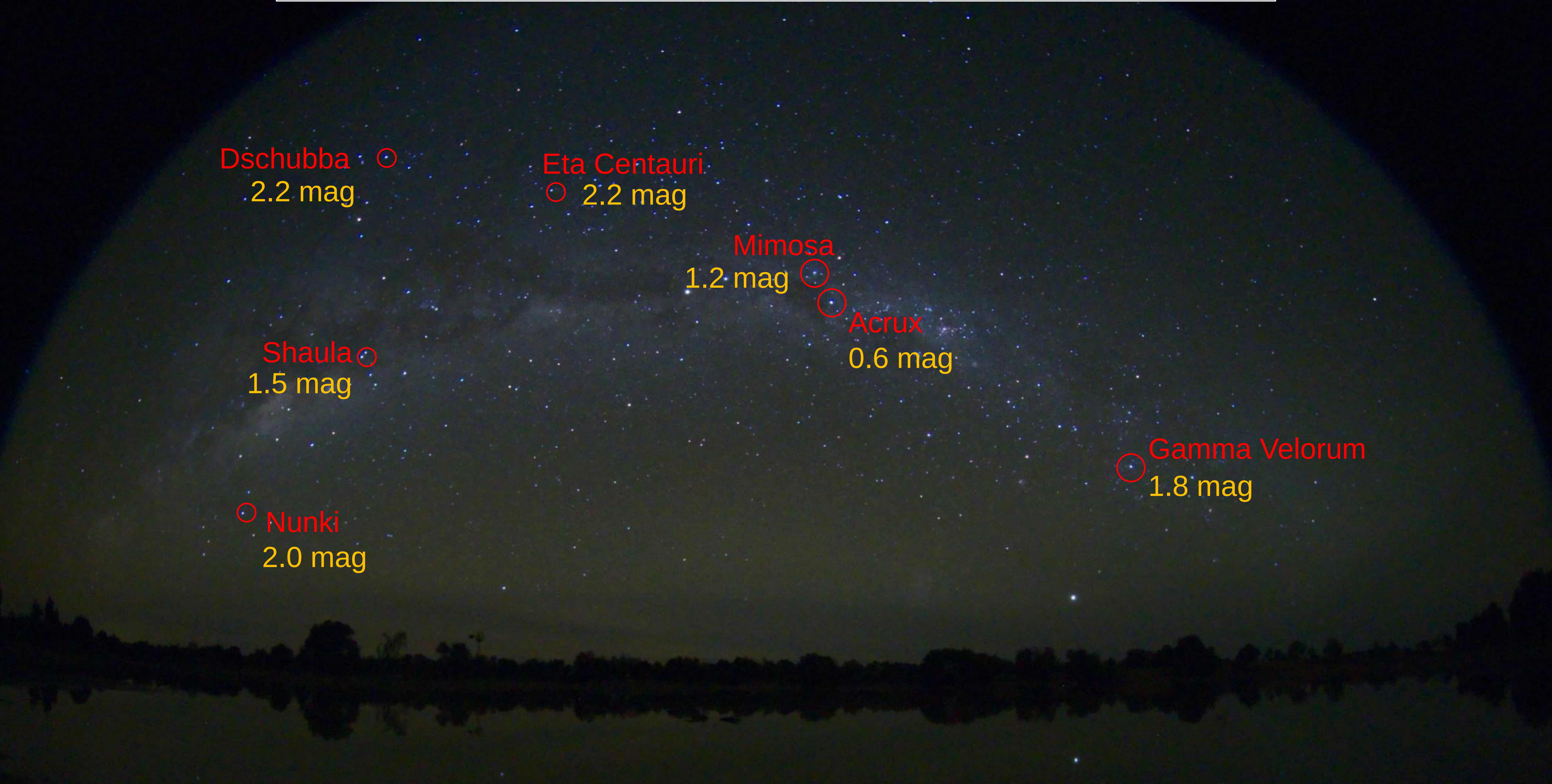
Auto correlation Shaula



Measurements during bright moon times



The ECAP SII Southern Sky Survey



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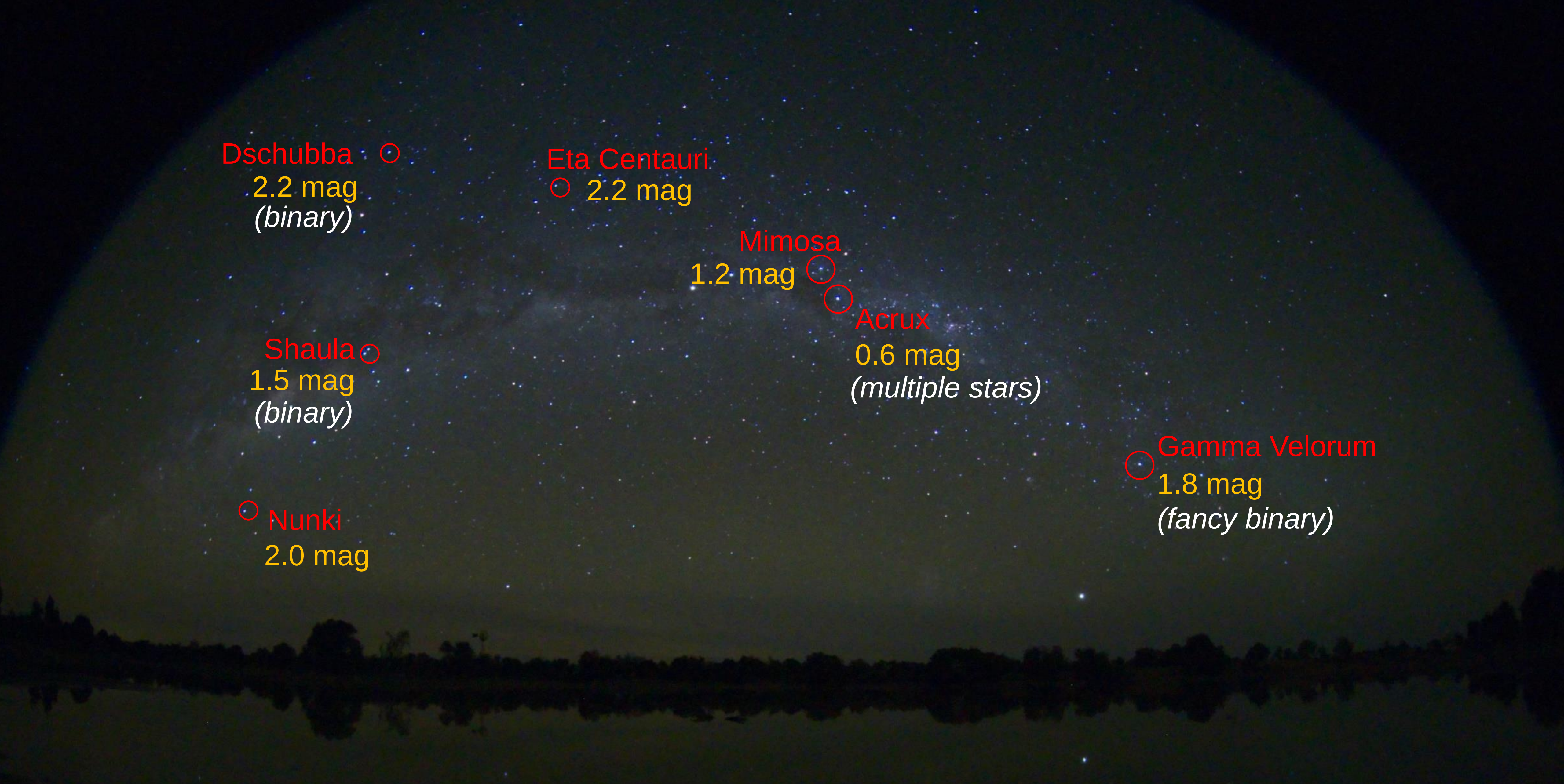
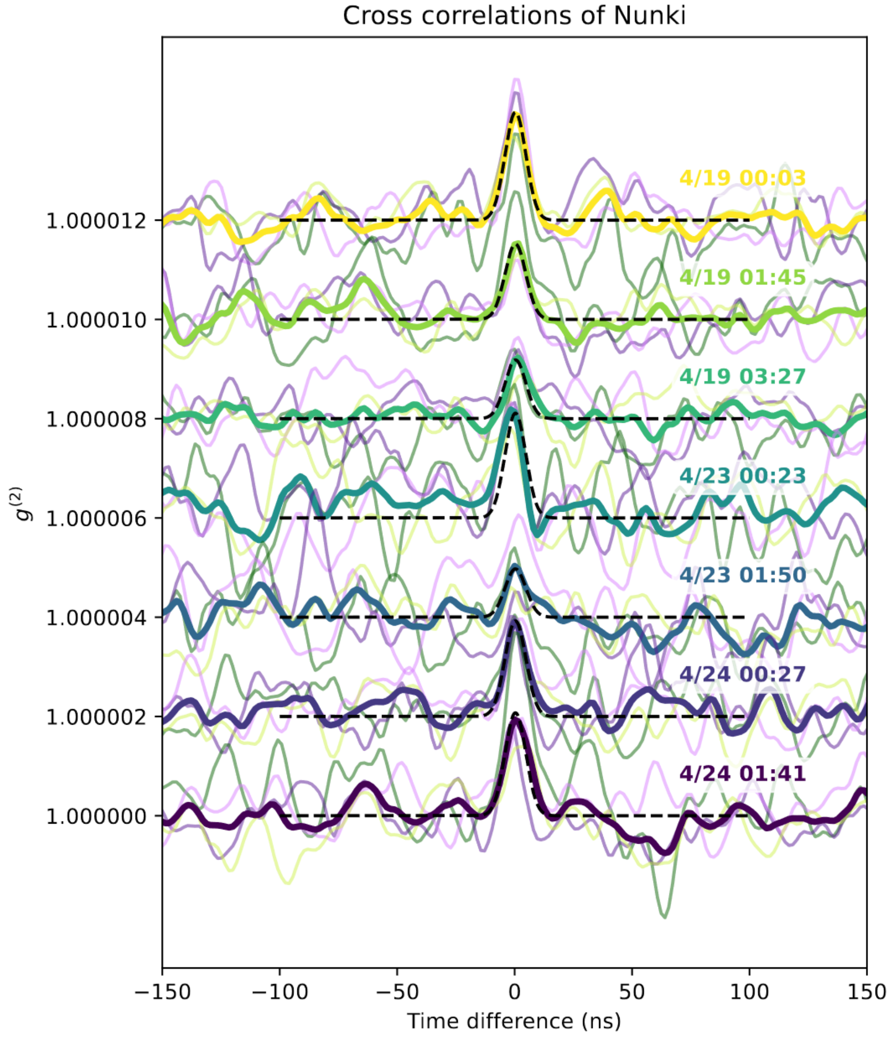
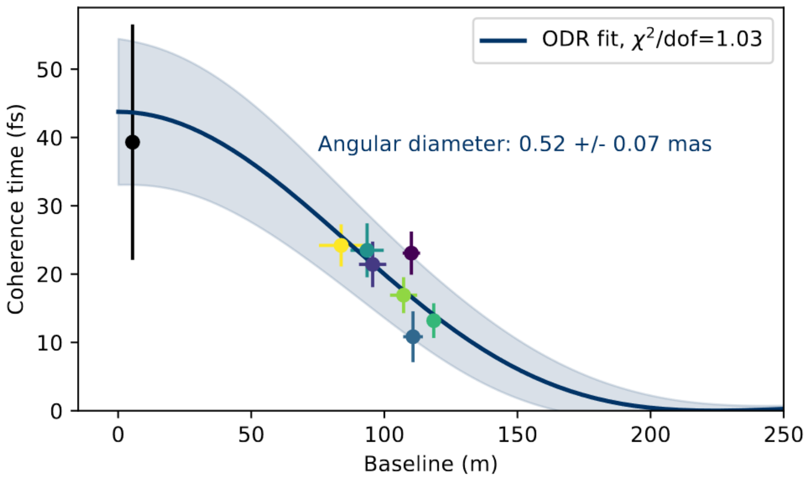


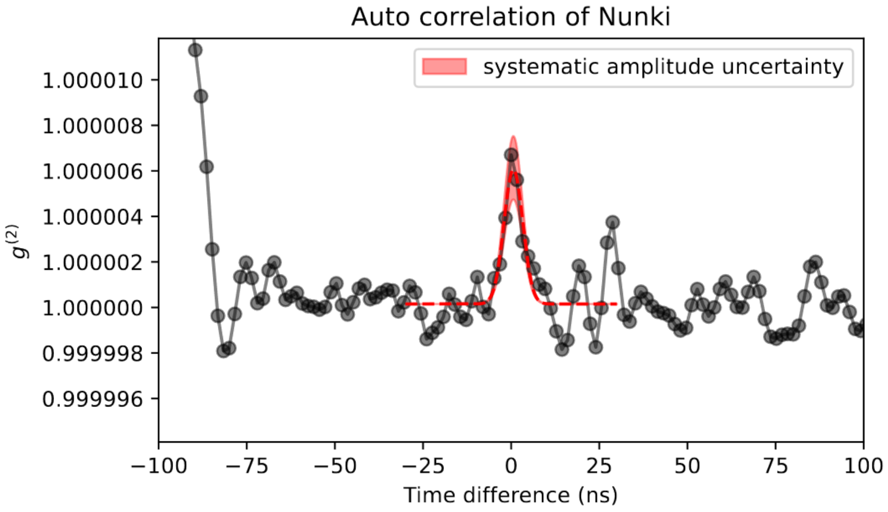
Results 2022

2022 Results

Spatial correlations of Nunki





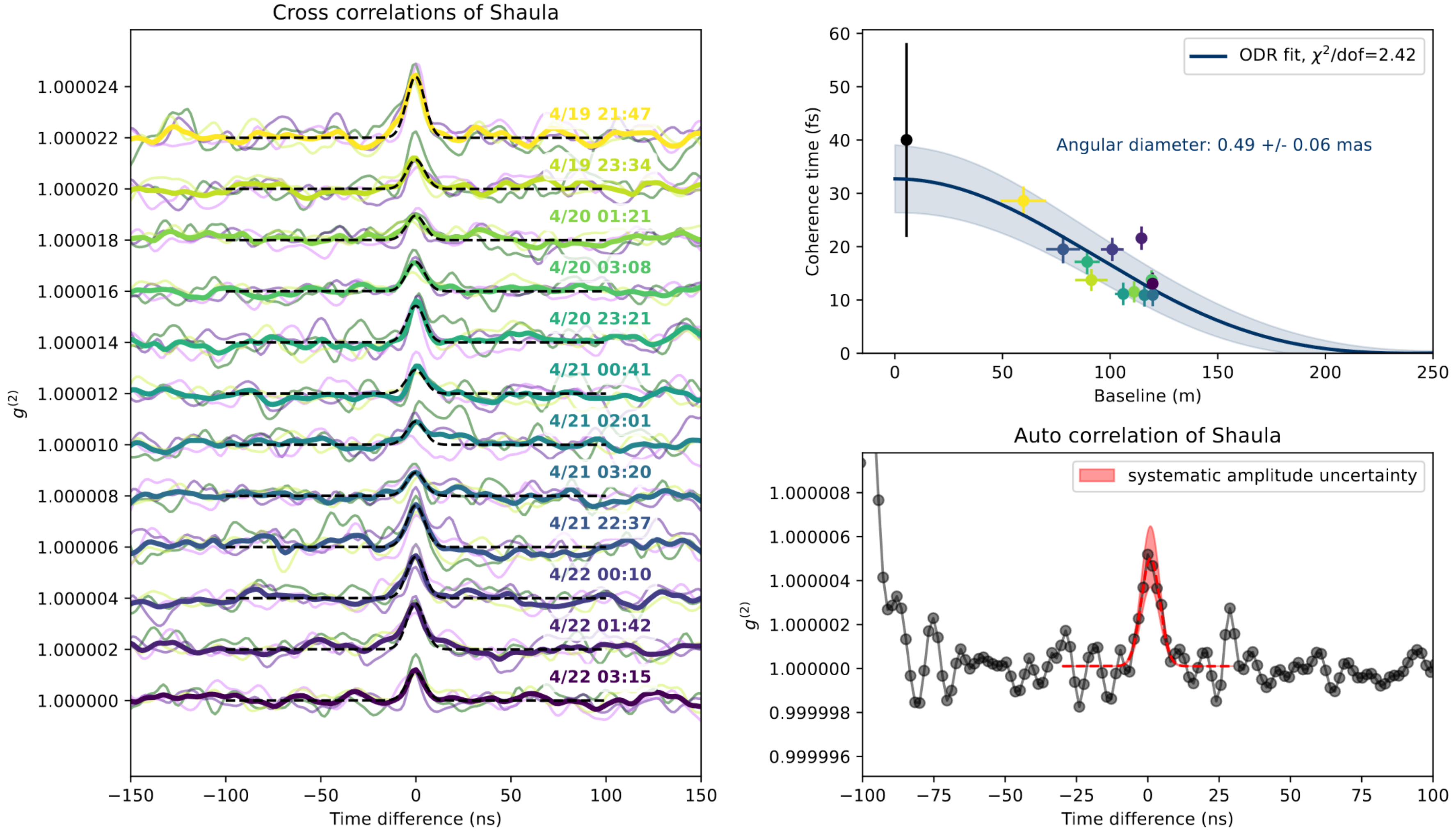


Literature values e.g.
$0.68\ mas$
(Underhill, IR photometry)

Zmija et. al. (2023) - „First intensity interferometry measurements with the H.E.S.S: telescopes.“

2022 Results

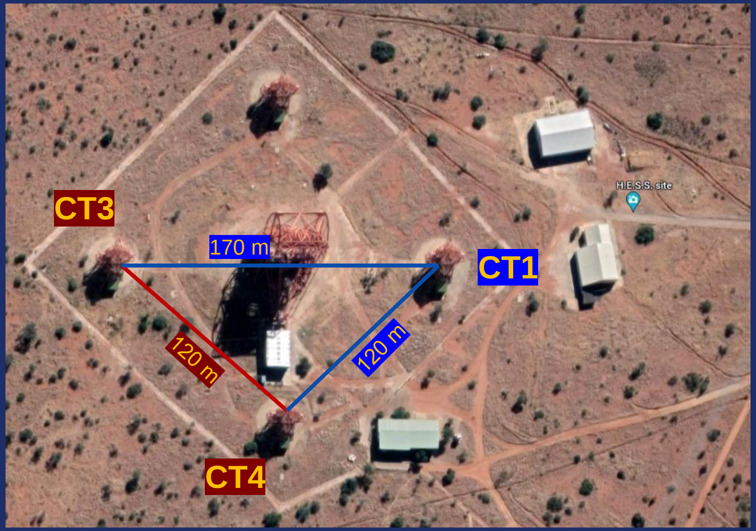
Spatial correlations of Nunki

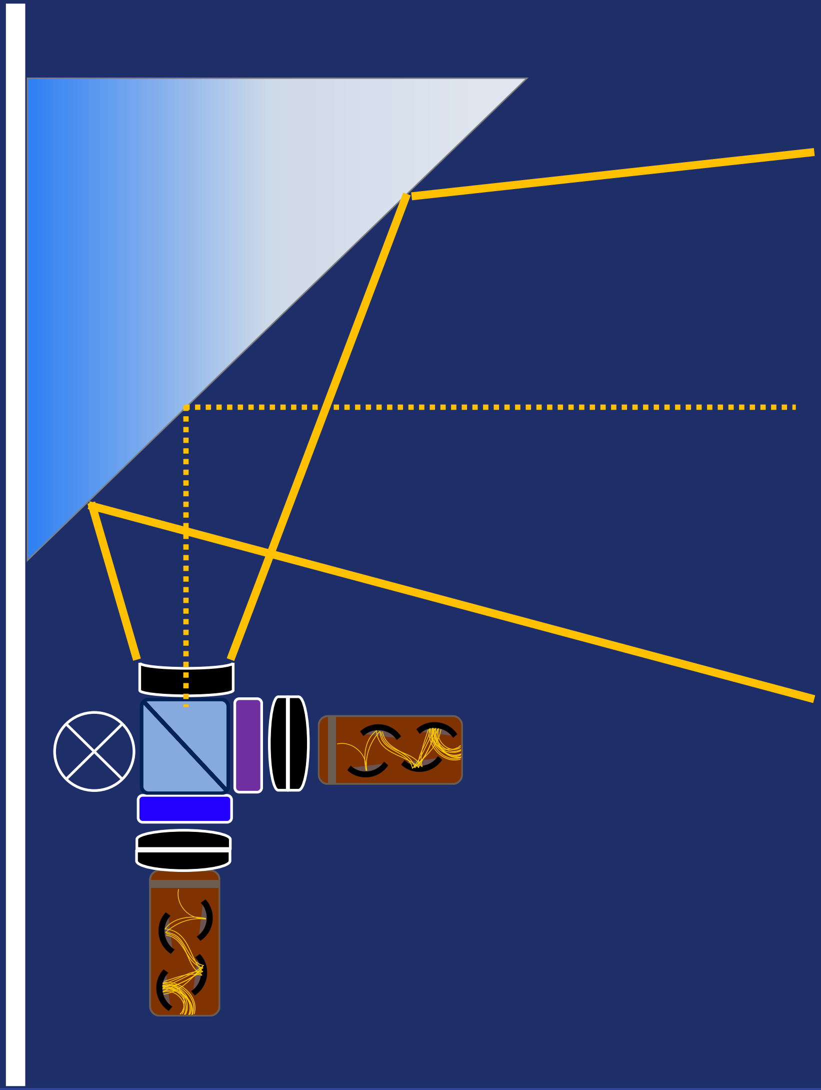


Literature values e.g.
$0.43 \pm 0.14\ mas$

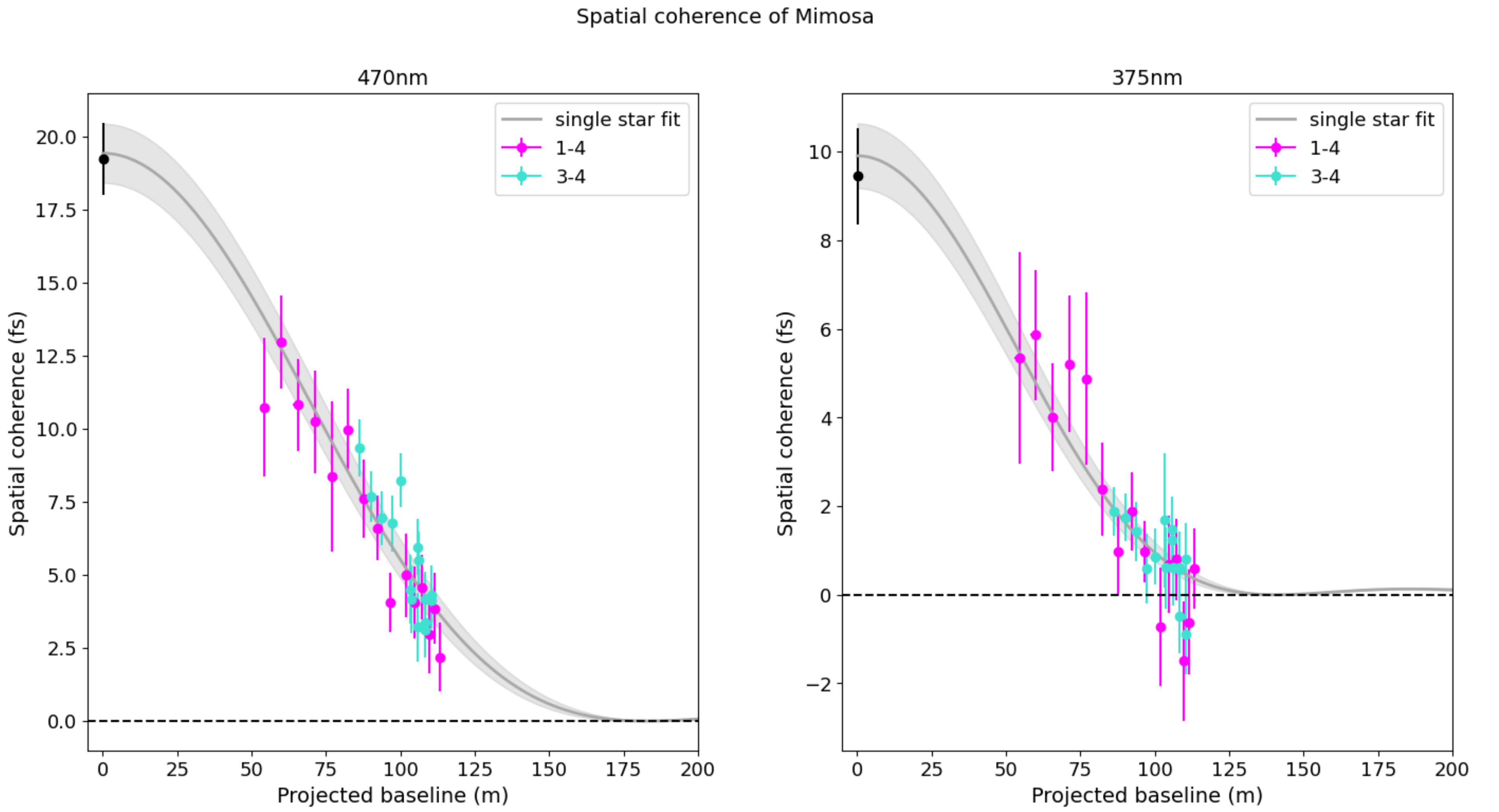
Zmija et. al. (2023) - „First intensity interferometry measurements with the H.E.S.S: telescopes."

Results *2023*
Dual color measurements
(and three telescopes)





Visibility curves in two colors



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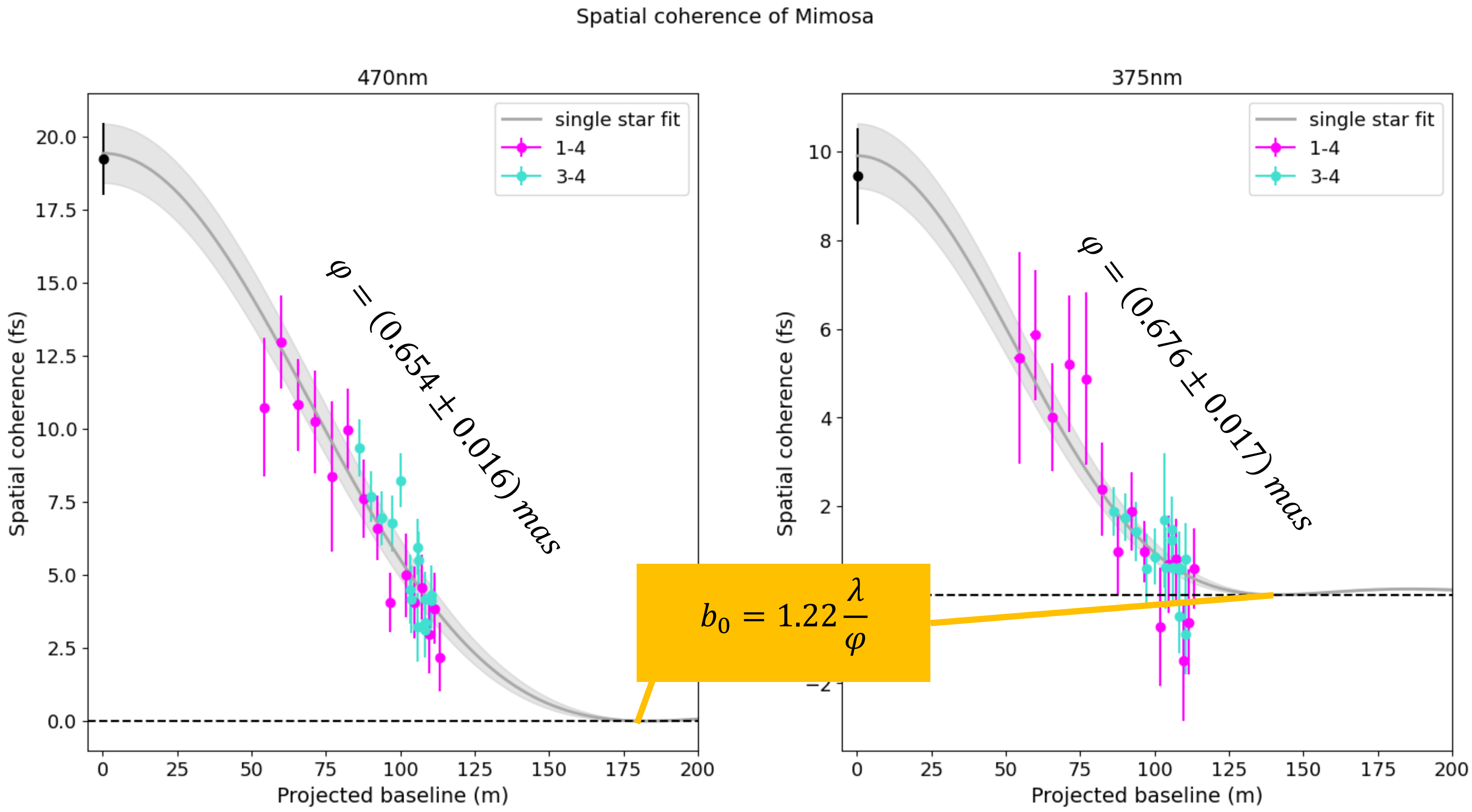
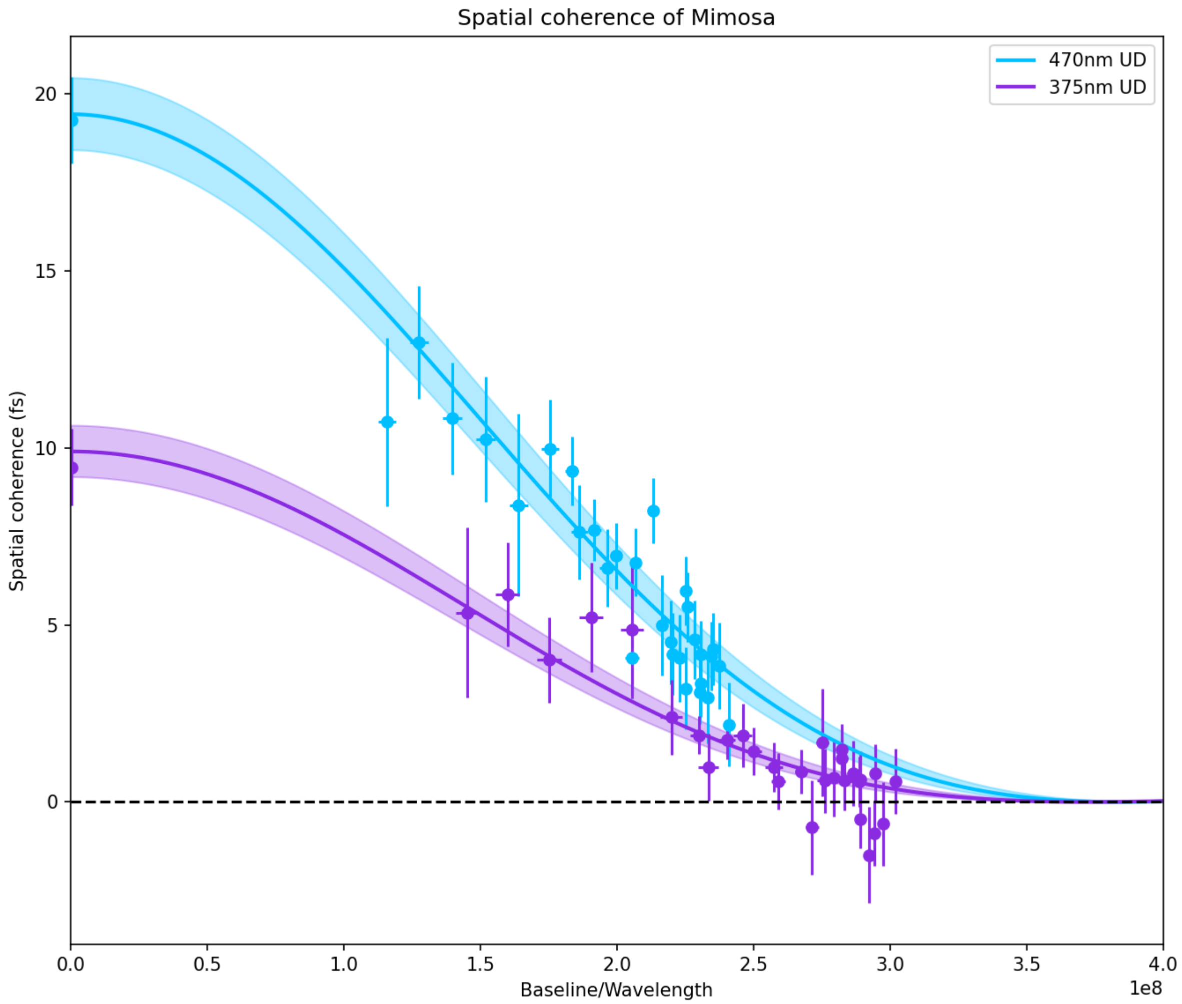


$$b_0 = 1.22\,\frac{\lambda}{\varphi}$$

Visibility curves in two colors

- Spatial coherence scales linearly with wavelength
- Two colors effectively extend baseline range



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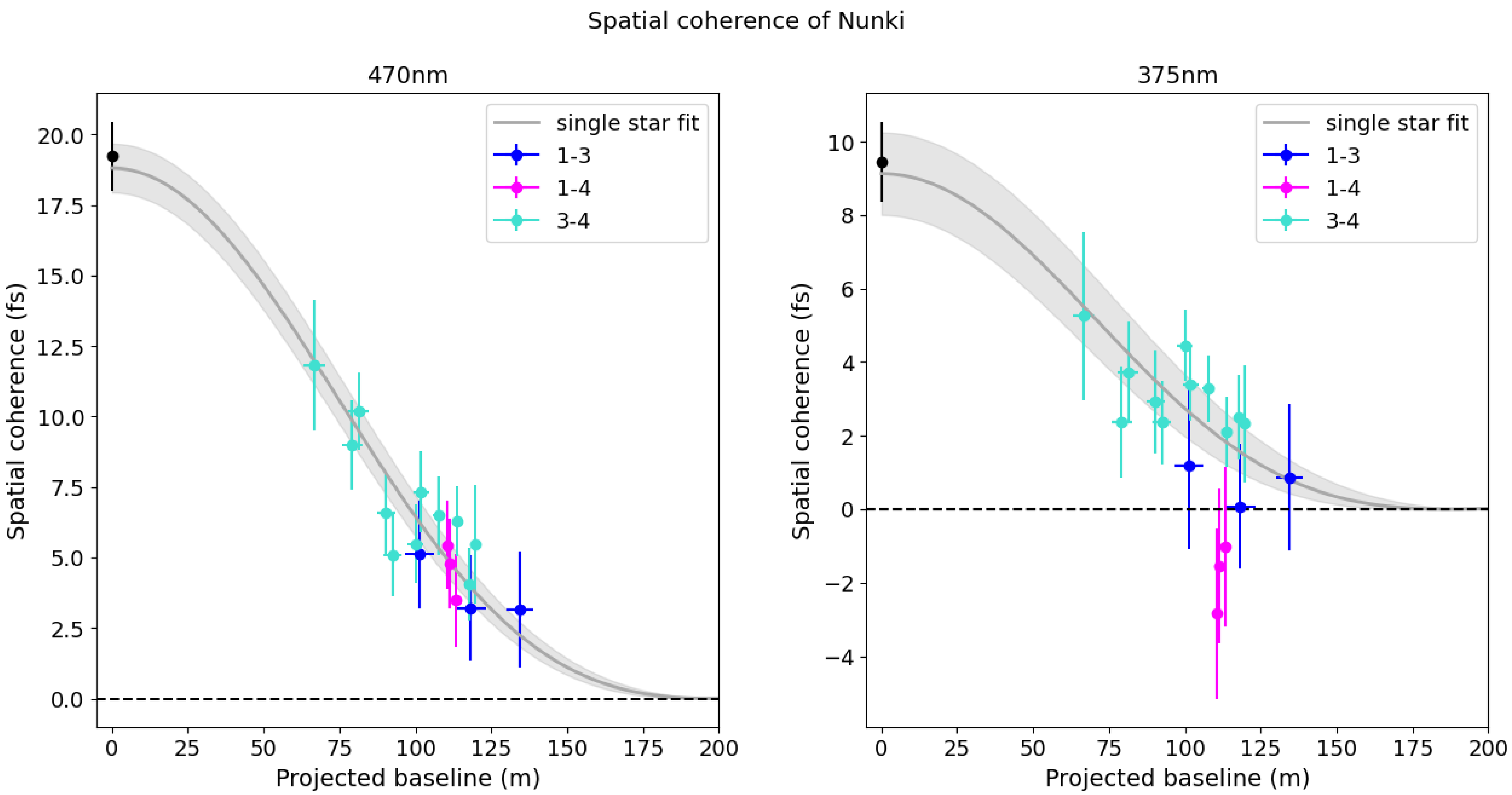
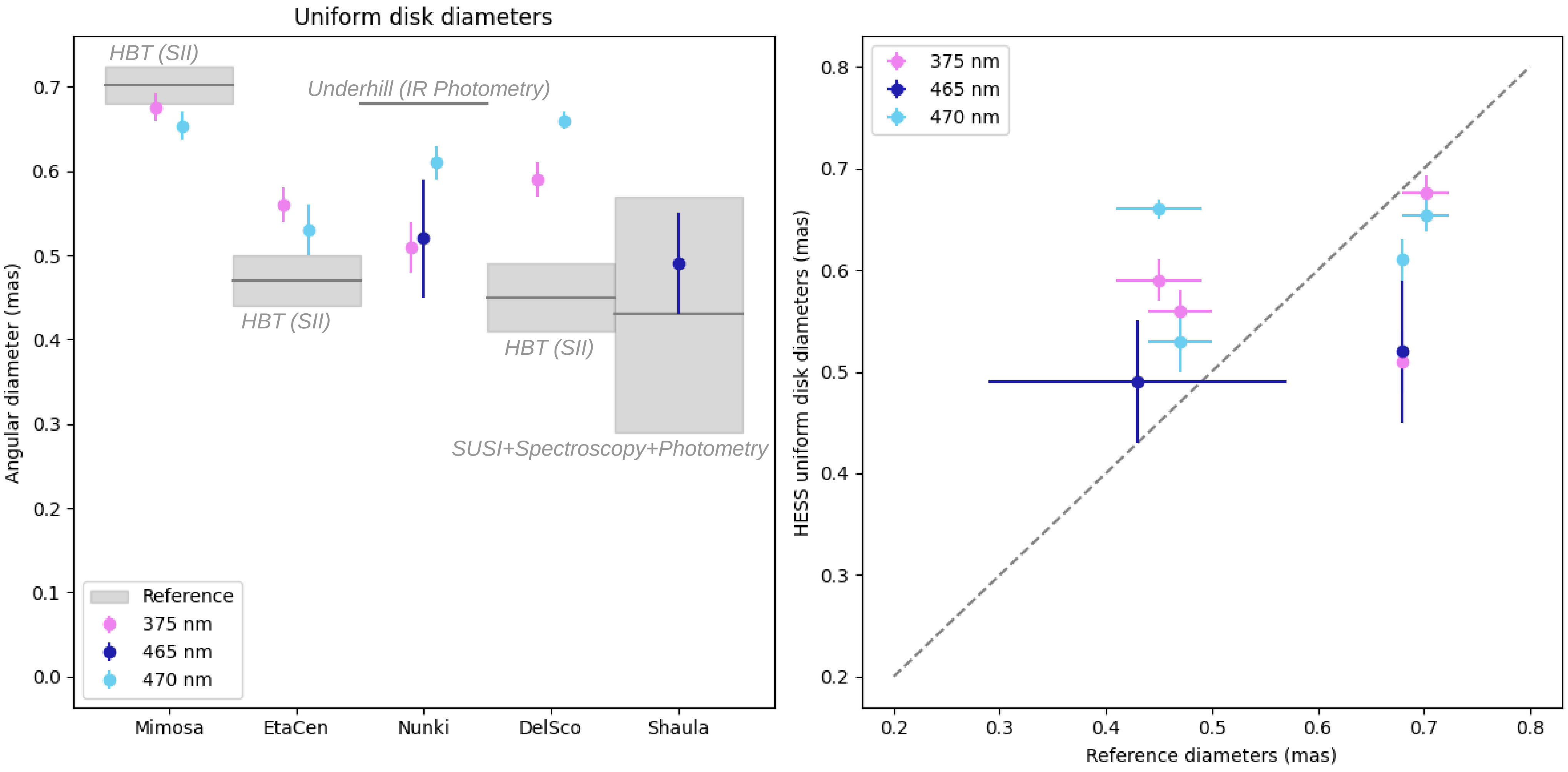
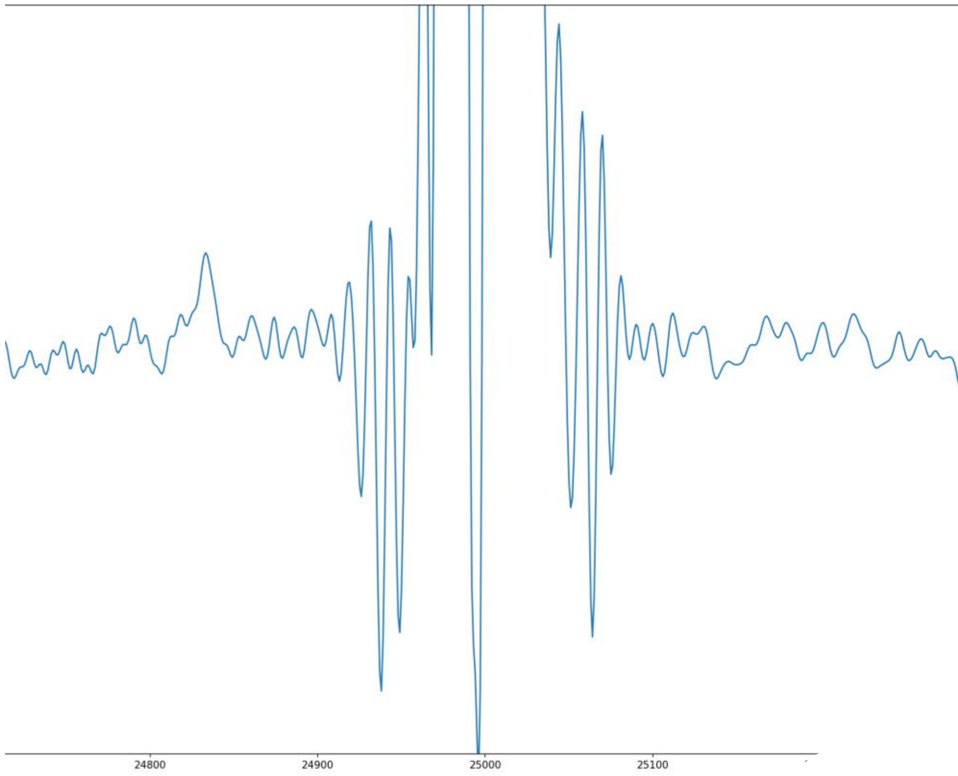


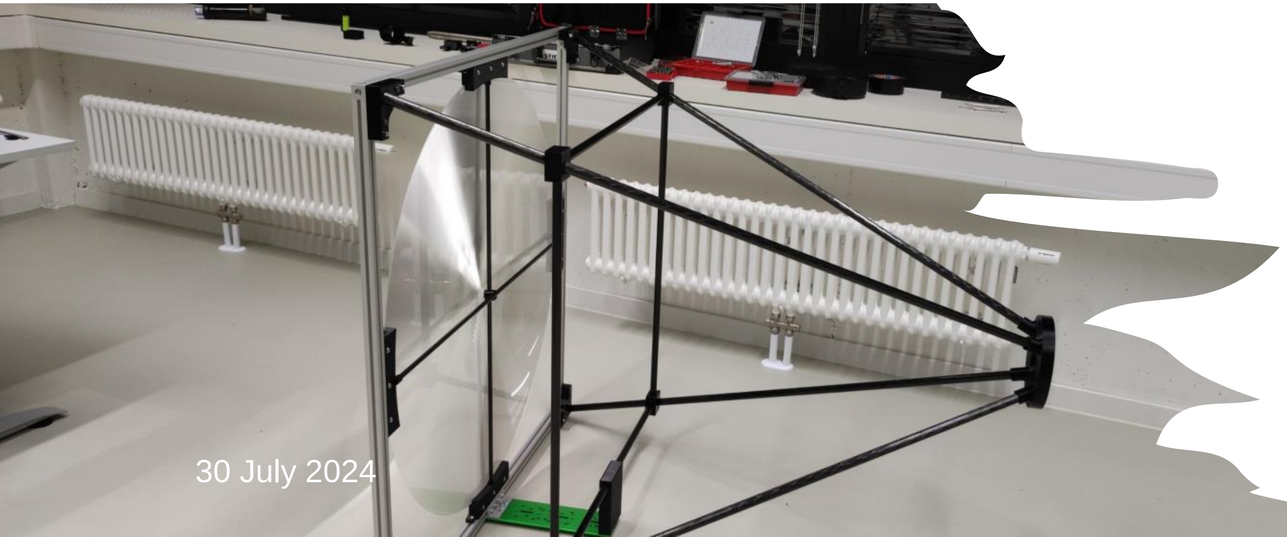
Data comparison



The future of SII at H.E.S.S.

- Await decision about funding proposal
- Install setup on all 4 Phase I telescopes
- Install “permanent” setups for (partly) remote operations
- FlashCam tests at CT5 (CTA prospect)

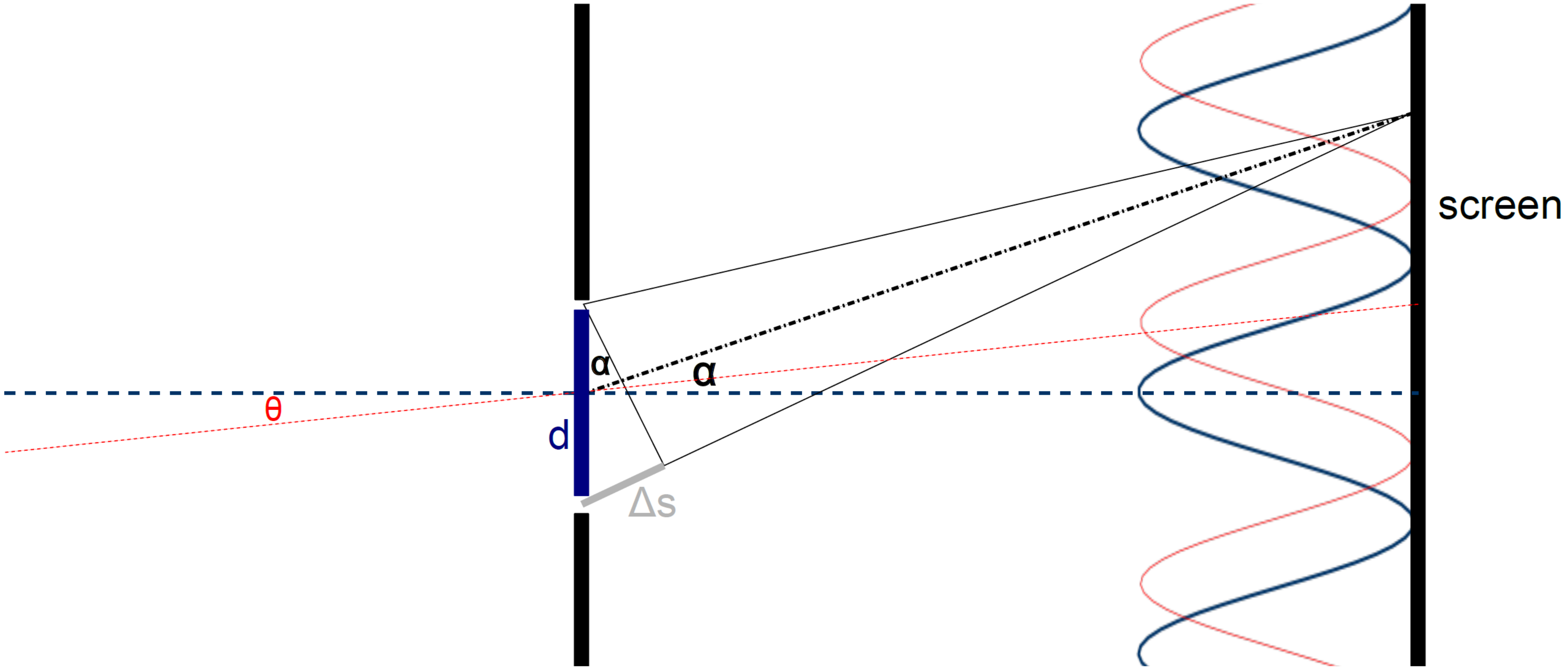




MI²SO – Intensity Interferometry *at* ECAP

Mobile Intensity Interferometer for Stellar Observations


Thank you for paying attention!


screen
α
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First order coherence

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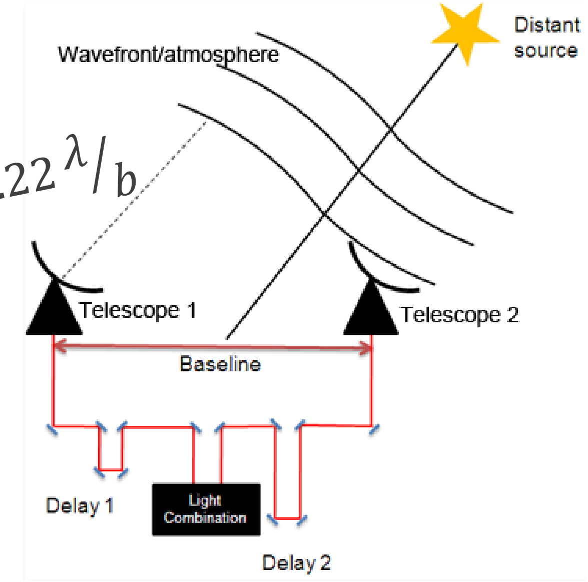
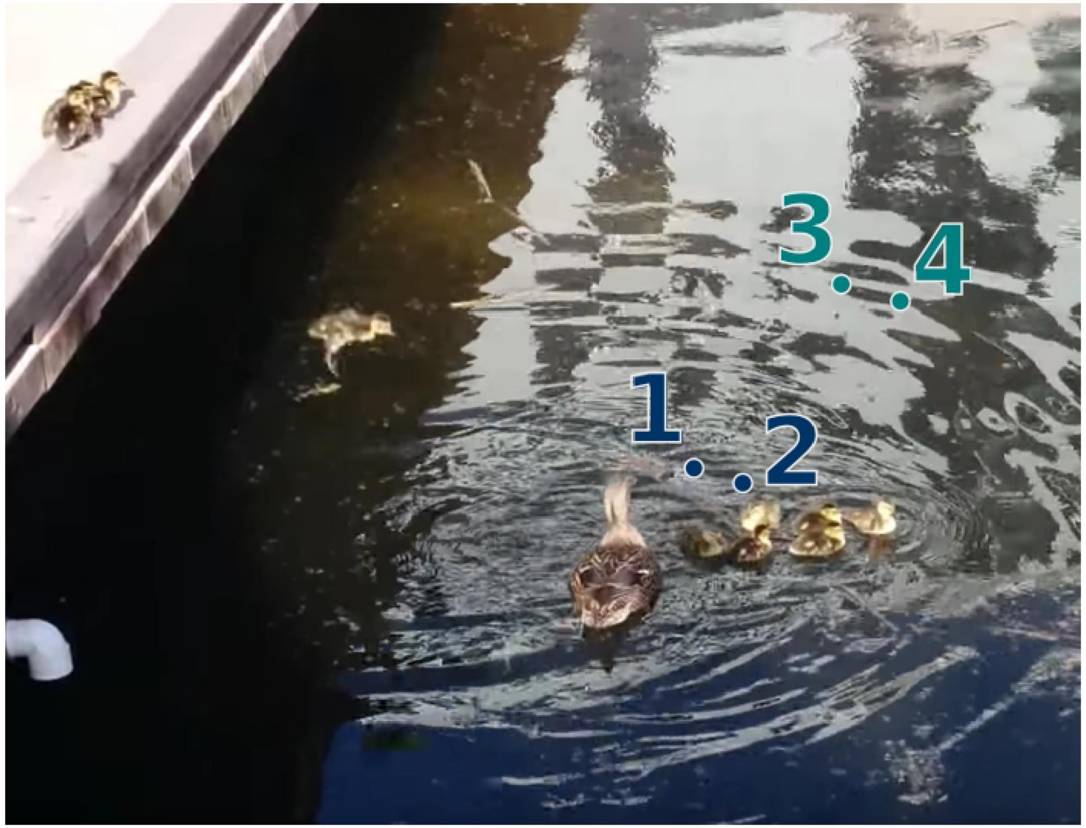
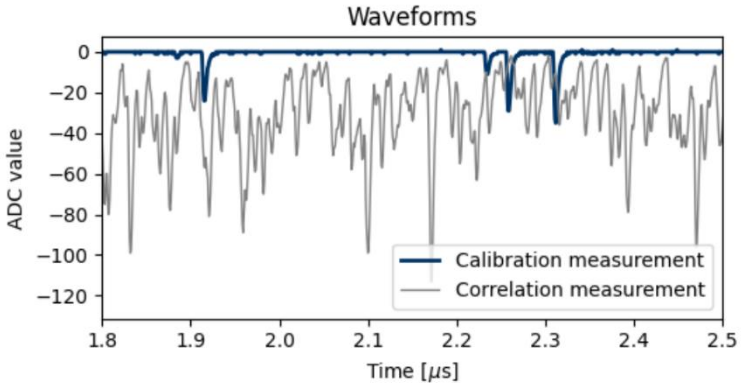
$$\varphi \approx 1.22 \, \lambda / b$$

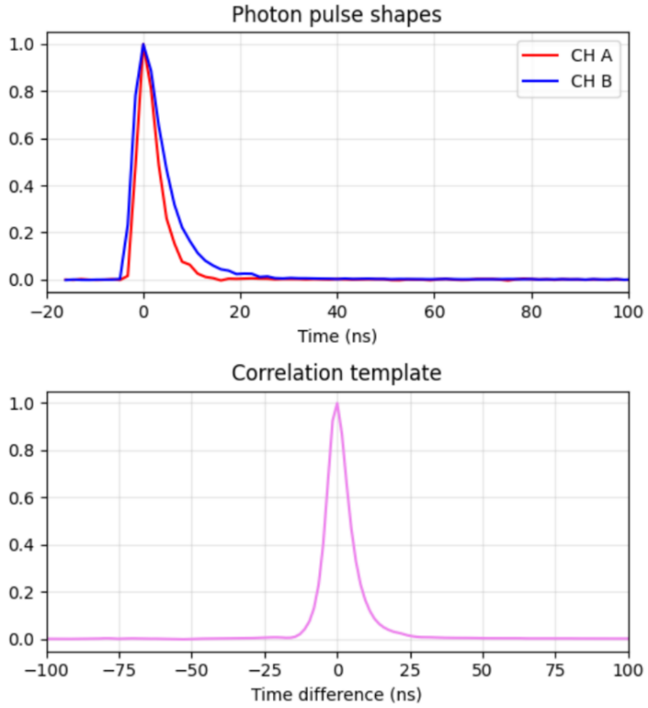


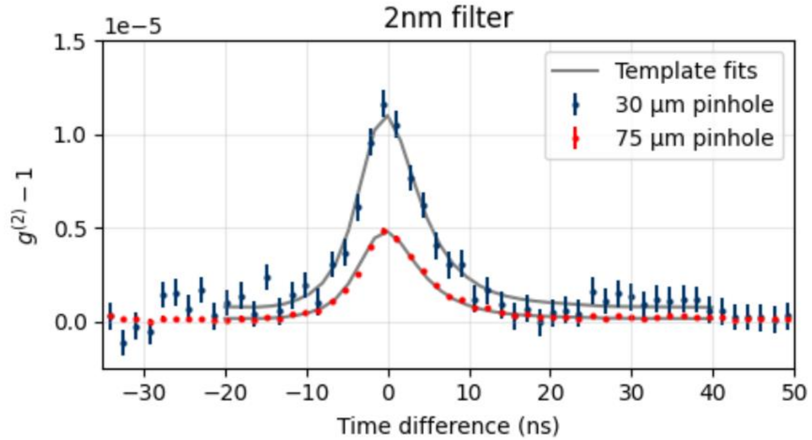


A.Zmija - Design and characterization of an intensity interferometer with thermal light sources (2019)

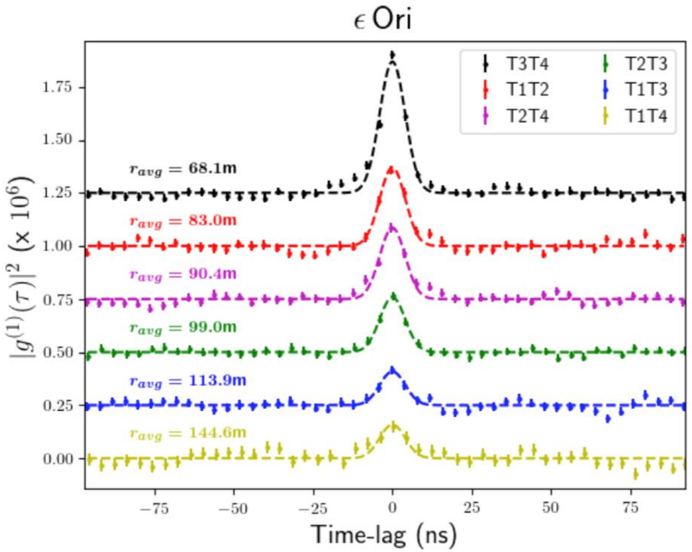
Preparatory investigations in the lab



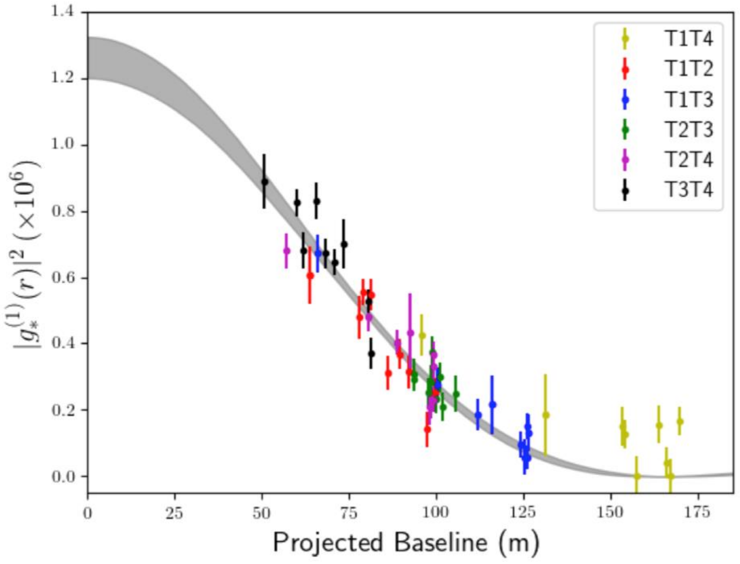




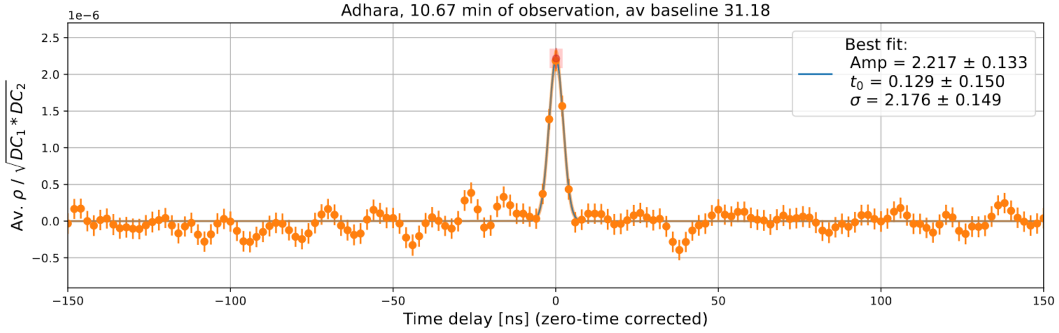
IACT Intensity Interferometry in the Northern Hemisphere



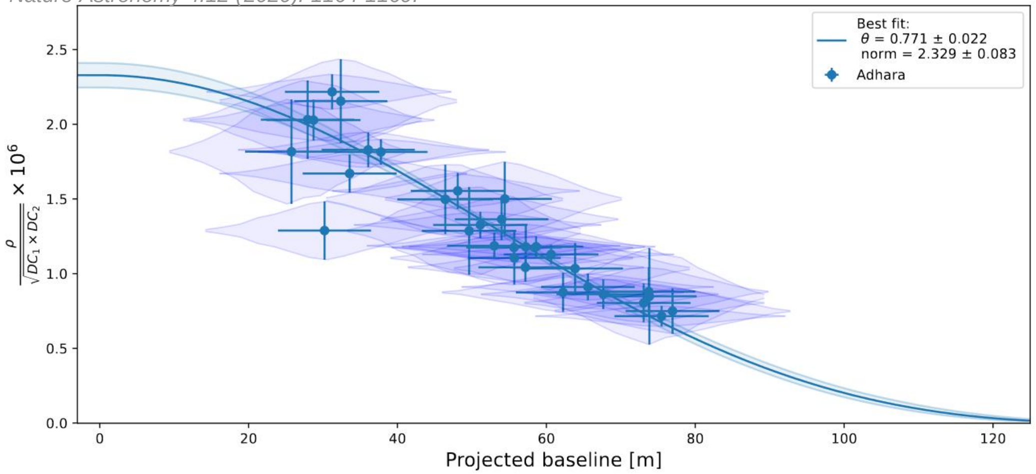
VERITAS
(2020)



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

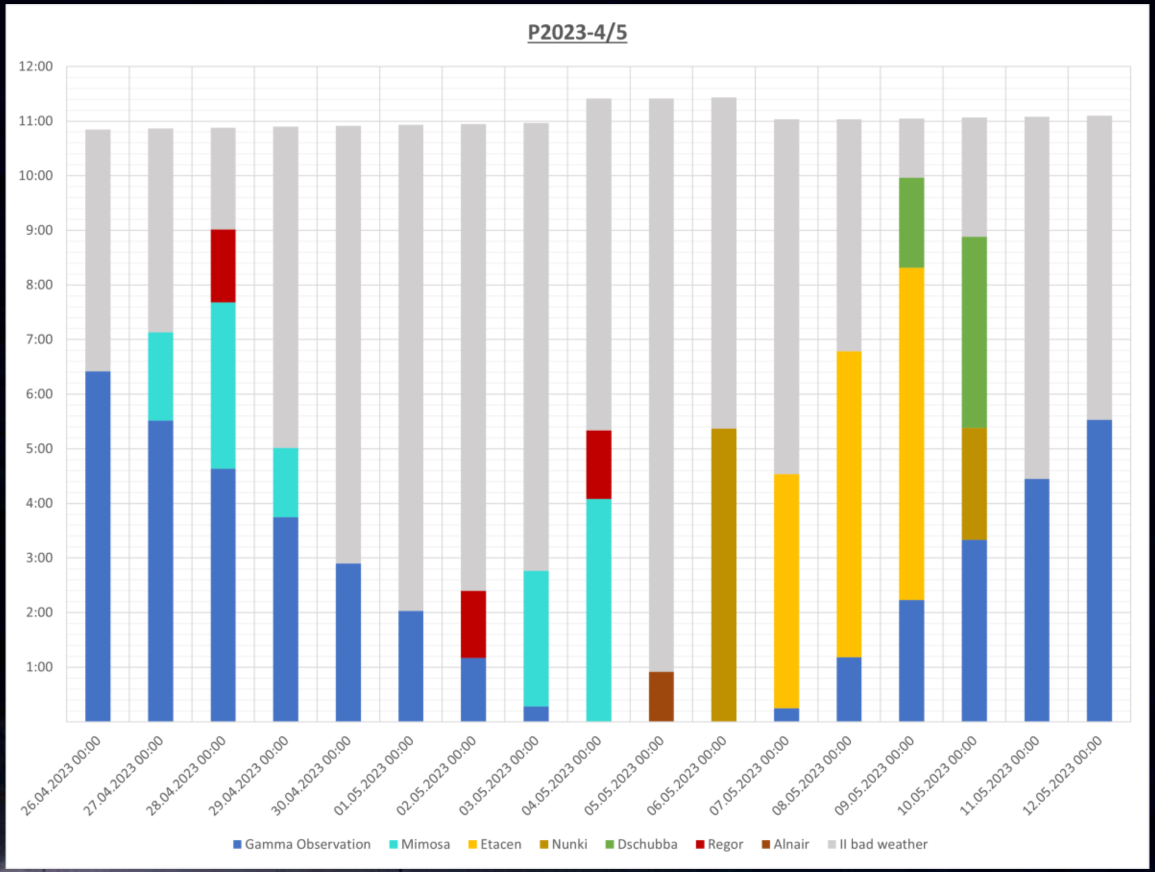


MAGIC
(2022)

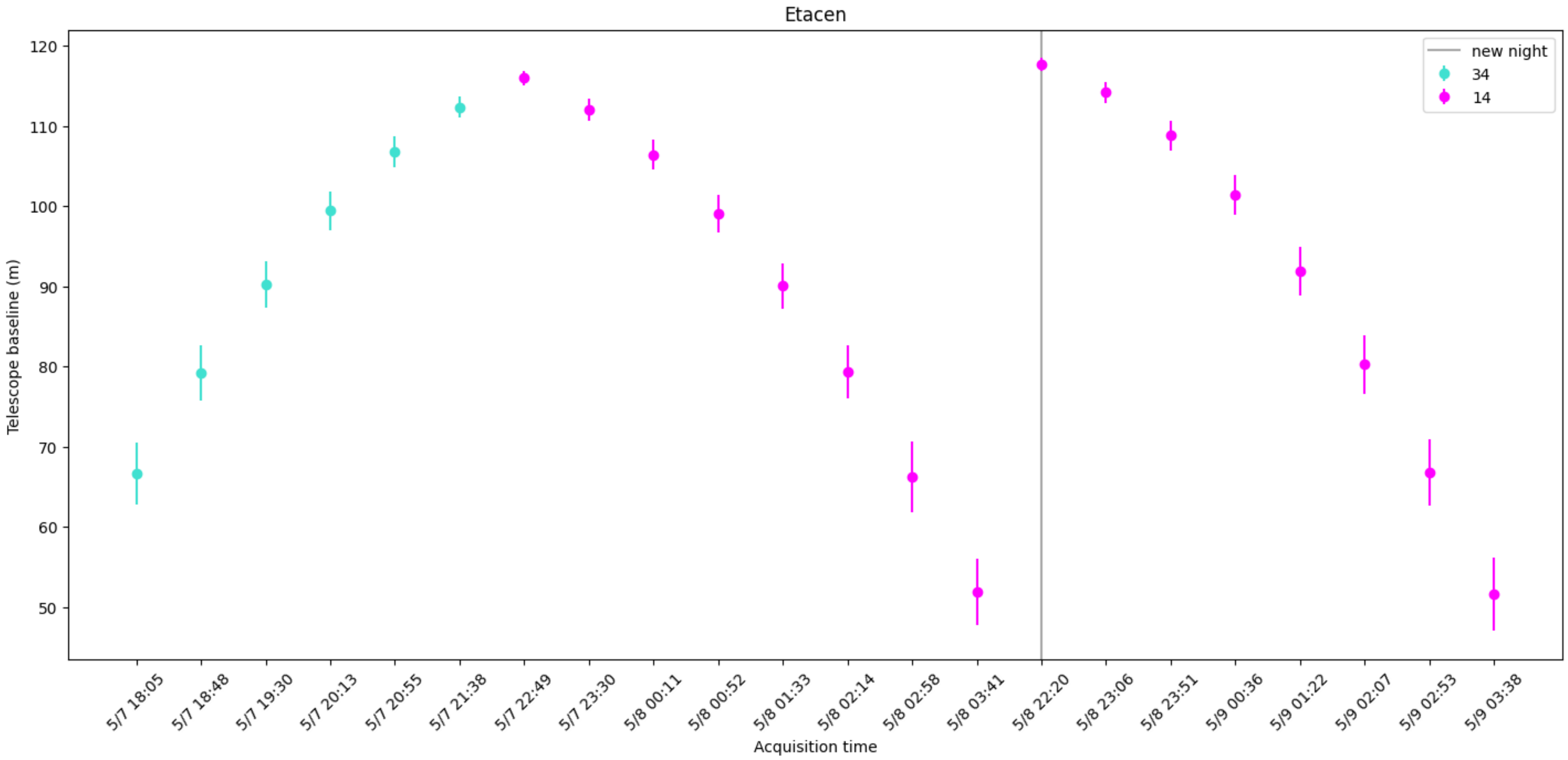


Adapted from: Cortina, Juan, et al. "First measurements and upgrade plans of the MAGIC intensity interferometer." Optical and Infrared Interferometry and Imaging VIII. Vol. 12183. SPIE, 2022.

Complications…

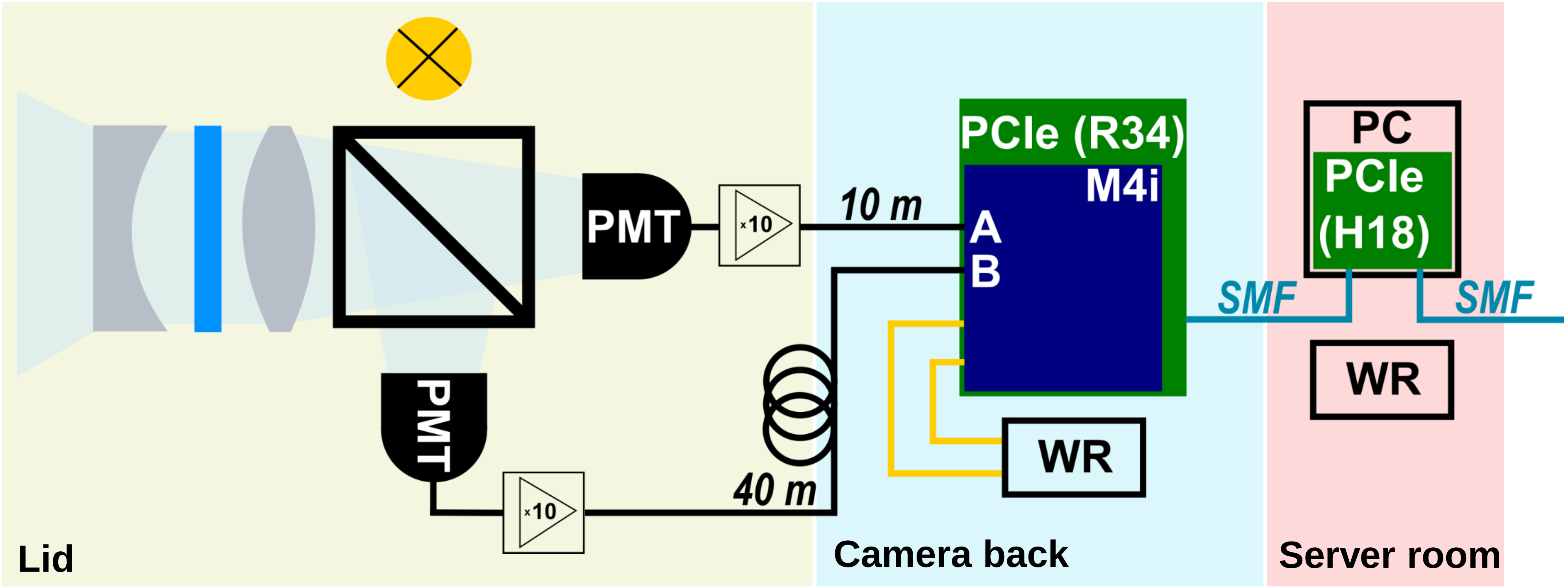


Complications: broken amplifiers



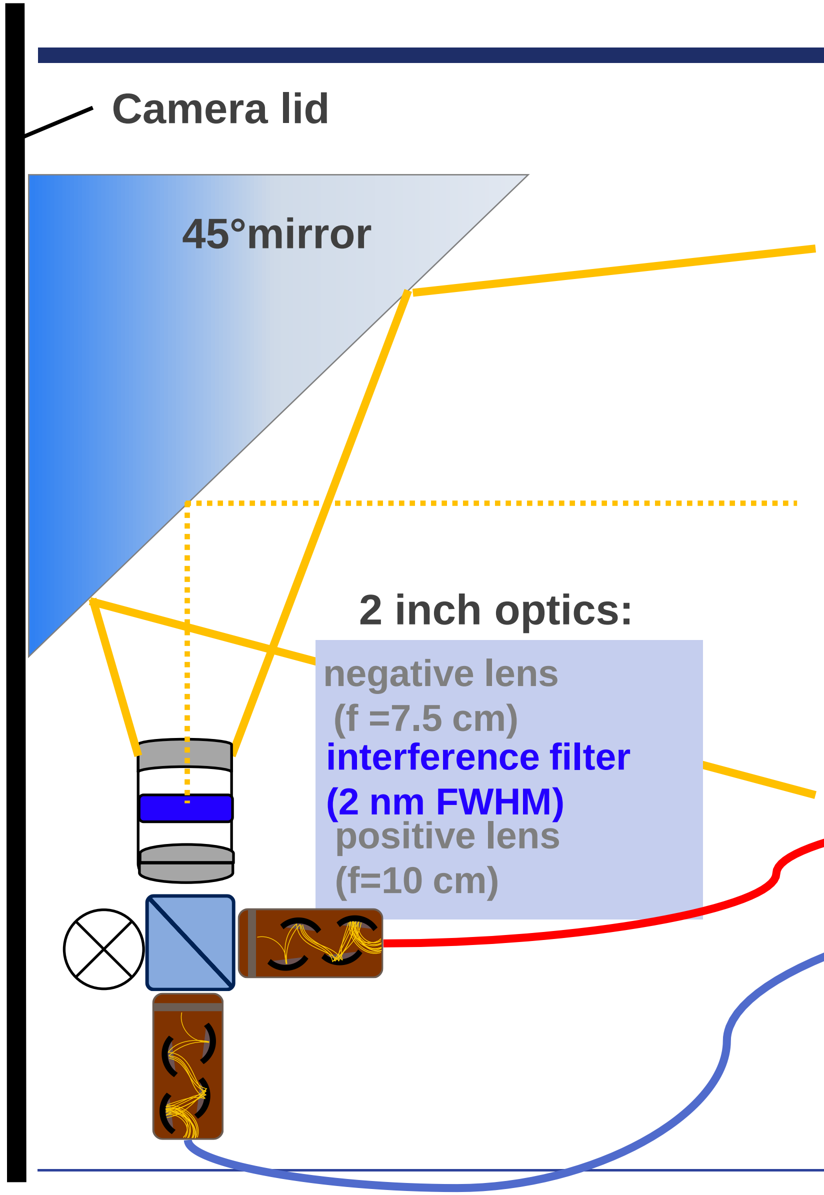
H.E.S.S. campaign 2022

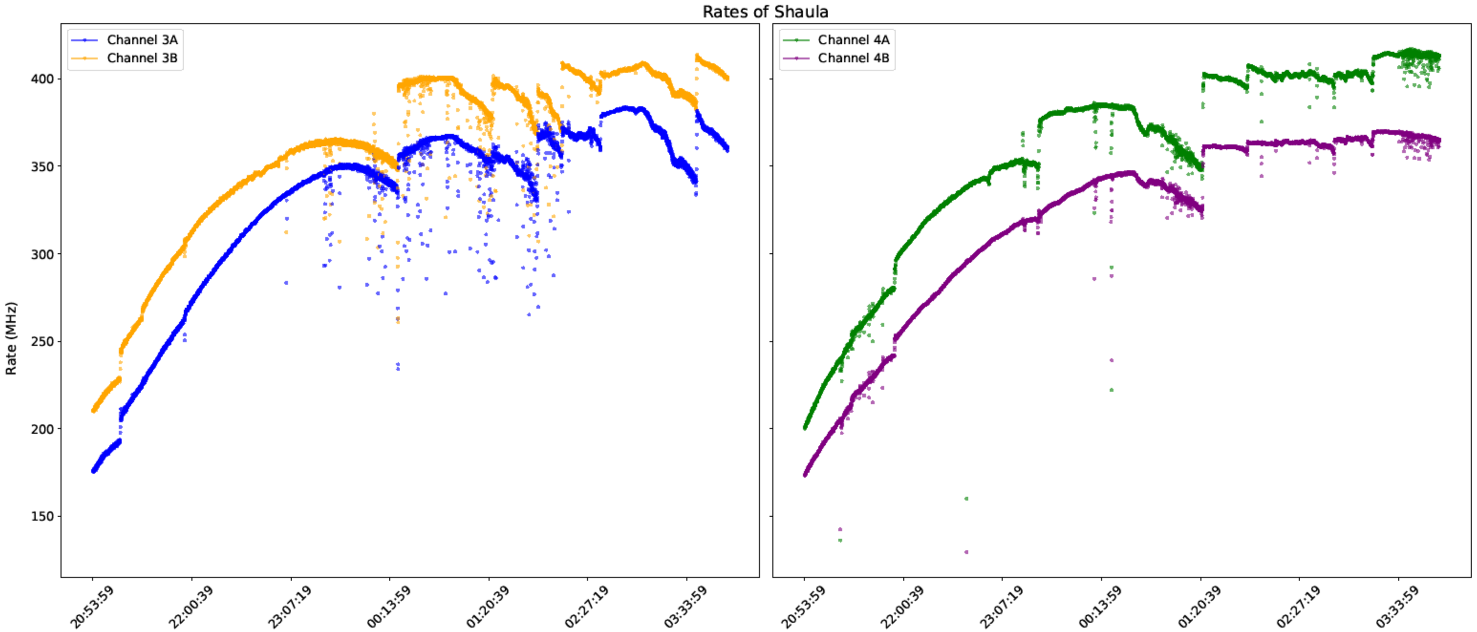
Measurement setup

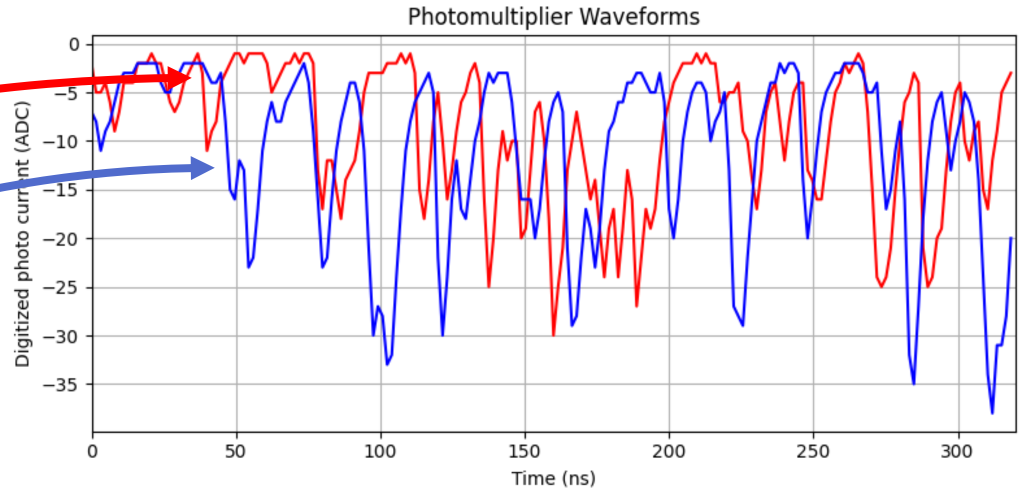


- Digitize in focal plane (camera back)
- Offline correlation and analysis after measurement
- Synchronization with White Rabbit (existing on site)

Photon rate measurements

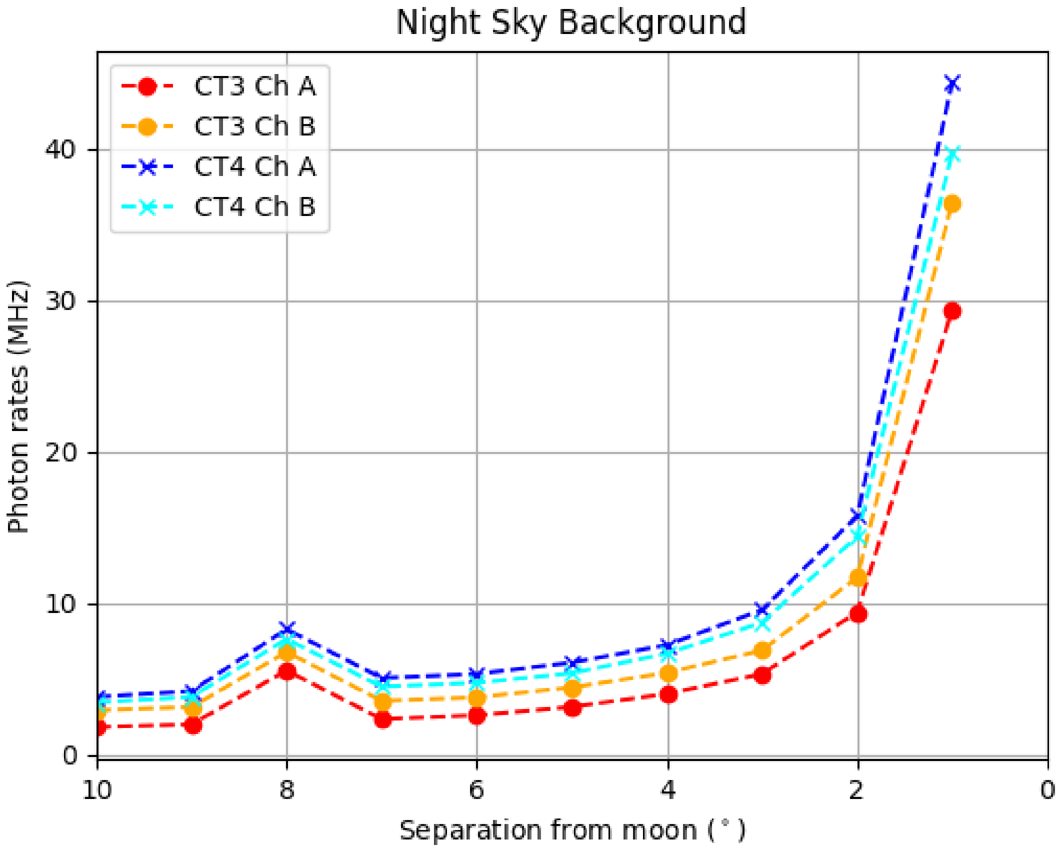






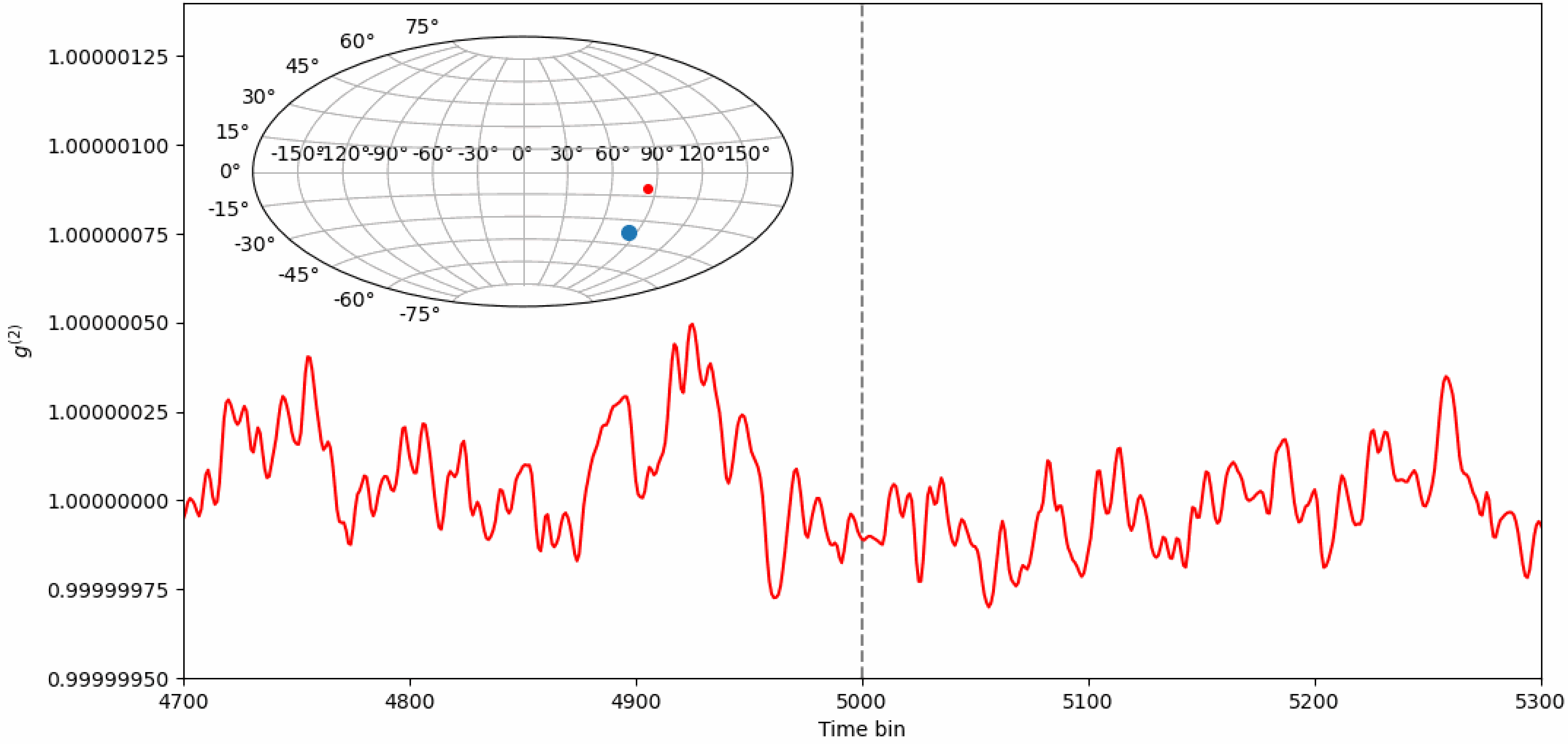
Results

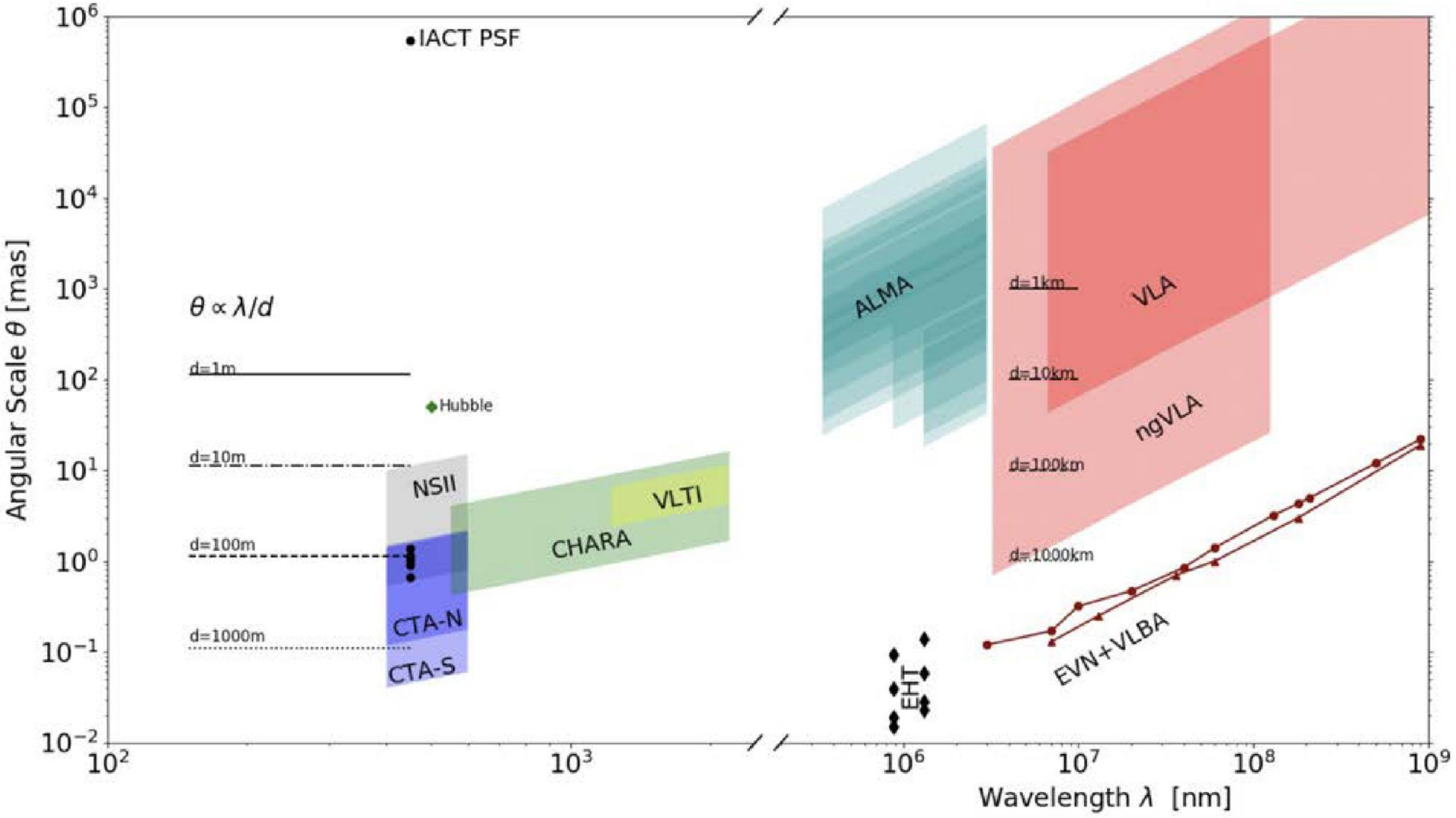
Moonlight measurements



Results

Optical path delay correction





IACT PSF
$\theta \propto \lambda/d$
d=1m
Hubble
d=10m
NSII
d=100m
CTA-N
d=1000m
CTA-S
CHARA
VLTI
ALMA
d=1km
VLA
d=10km
ngVLA
d=100km
d=1000km
EVN+VLBA
EHT
Angular Scale θ [mas]
Wavelength λ [nm]