Intensity interferometry with the MAGIC telescopes

Carlos Delgado for the MAGIC collaboration

Introduction to intensity interferometry I

Hanbury-Brown R., 1974, ”The Intensity Interferometer: Its Application to Astronomy”. Taylor & Francis, London

Van Cittert-Zernike theorem

The time correlation of amplitude of light at two points is linked to the Fourier transform of the image for thermal sources.

Time intensity correlation is linked to amplitude correlation and source flux

Requires large mirror areas, the highest possible bandwidth, high sampling rate. No strong requirement in optics.

No physics in this presentation, but has a potential to cover many topics in stellar dynamics.

Introduction to intensity interferometry II

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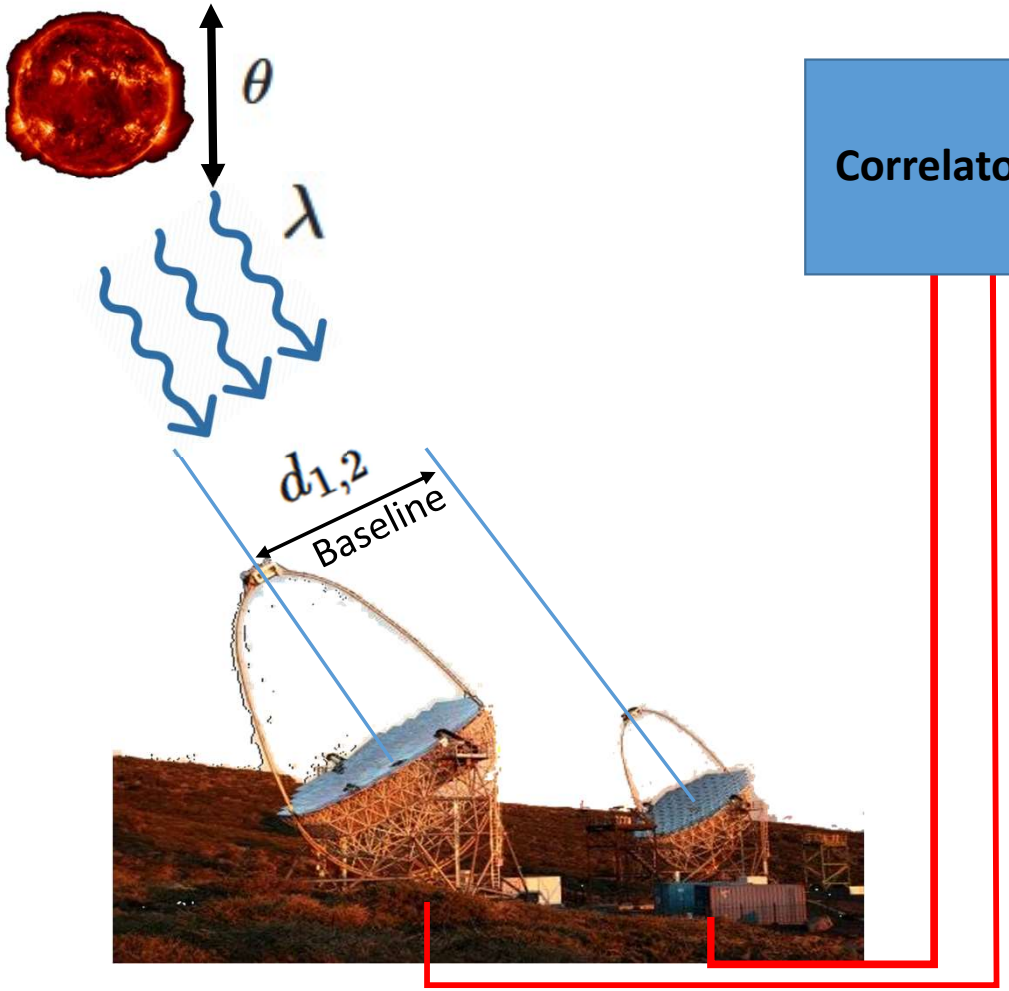
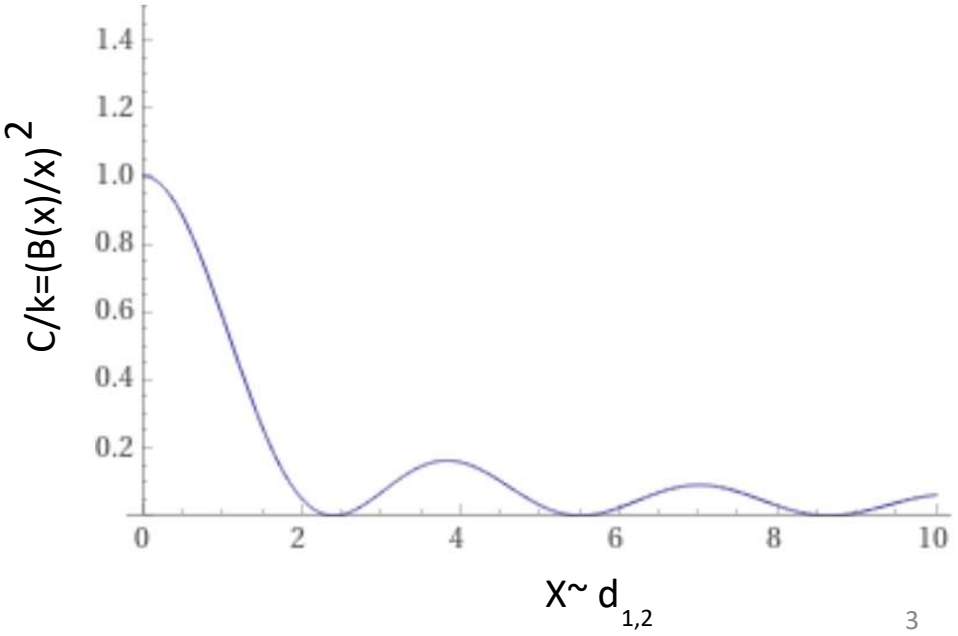


Bessel function of 1st kind

$$C = k\left(\frac{B_1(\pi \cdot d_{1,2} \cdot \theta/\lambda)}{\pi \cdot d_{1,2} \cdot \theta/\lambda}\right)^2$$



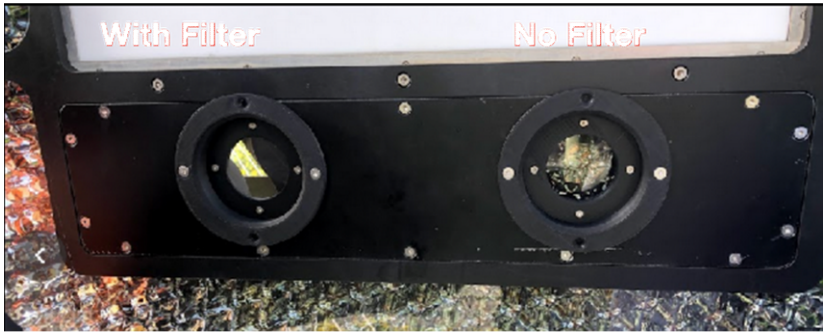
MAGIC telescopes as intensity interferometer

MAGIC consists of two Imaging Atmospheric Cherenkov Telescopes (IACTs) separated 86m for Very High Energy gamma-ray astronomy (energy range 30 GeV –100 TeV).

- Two large mirrors(17 m diameter), with an active mirror control system.
- Mirror parabolic shape: time spread of isochronous signal <1 ns.
- Sensitivity to near UV and optical wavelengths (optimal between 300 and 550 nm).
- Photodetectors (PMTs) with fast time response (2.5 ns FWHM) and good single photoelectron response (noise factor F∼1.15).
- Fast electronics all the way to the readout (few hundred MHz bandwidth).

MAGIC intensity interferometer

Automatic deployment of filters
(2 pixels per telescope)



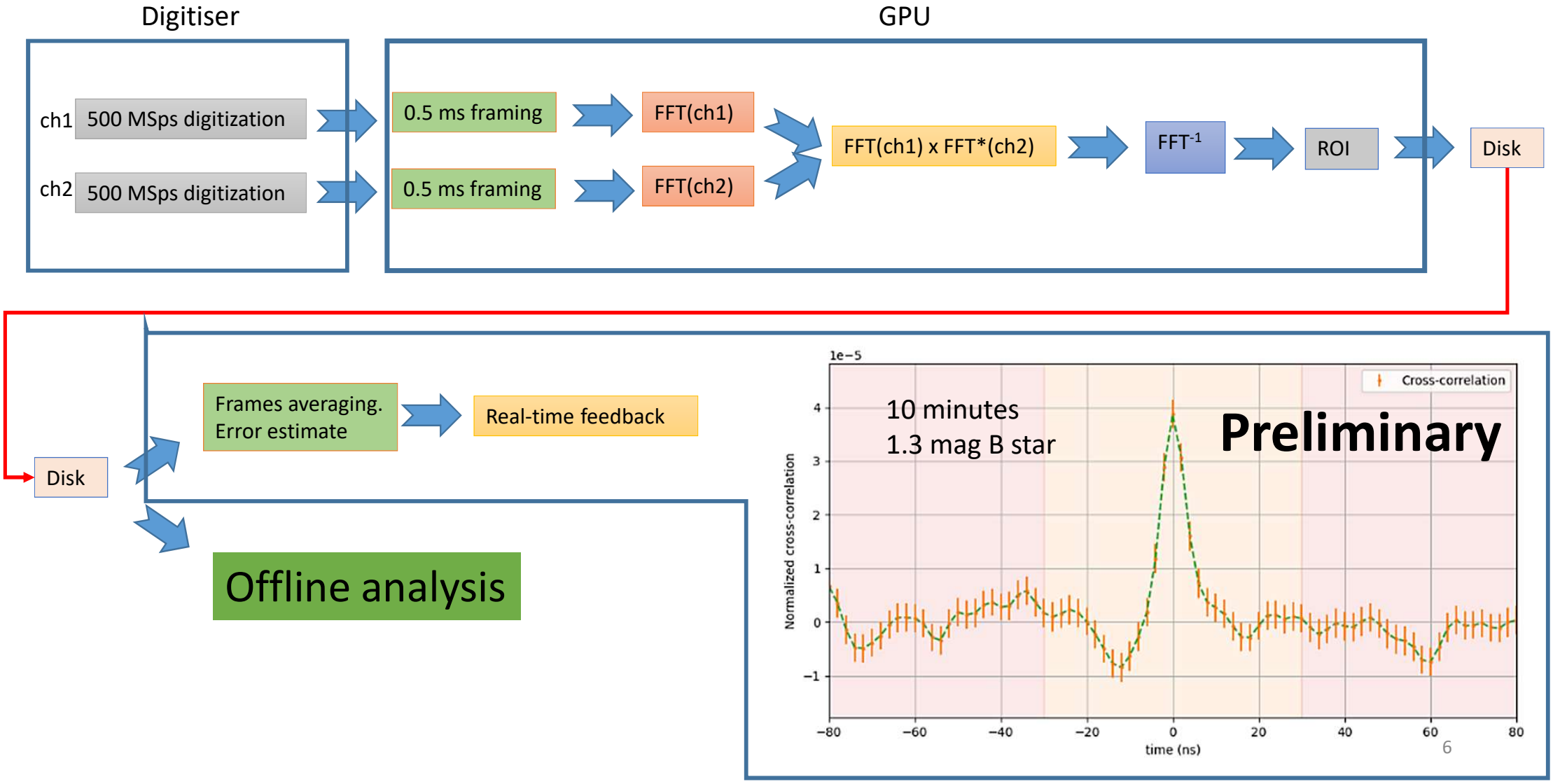
At MAGIC counting house

Digitialisation 500 MS/s, 14bits resolution

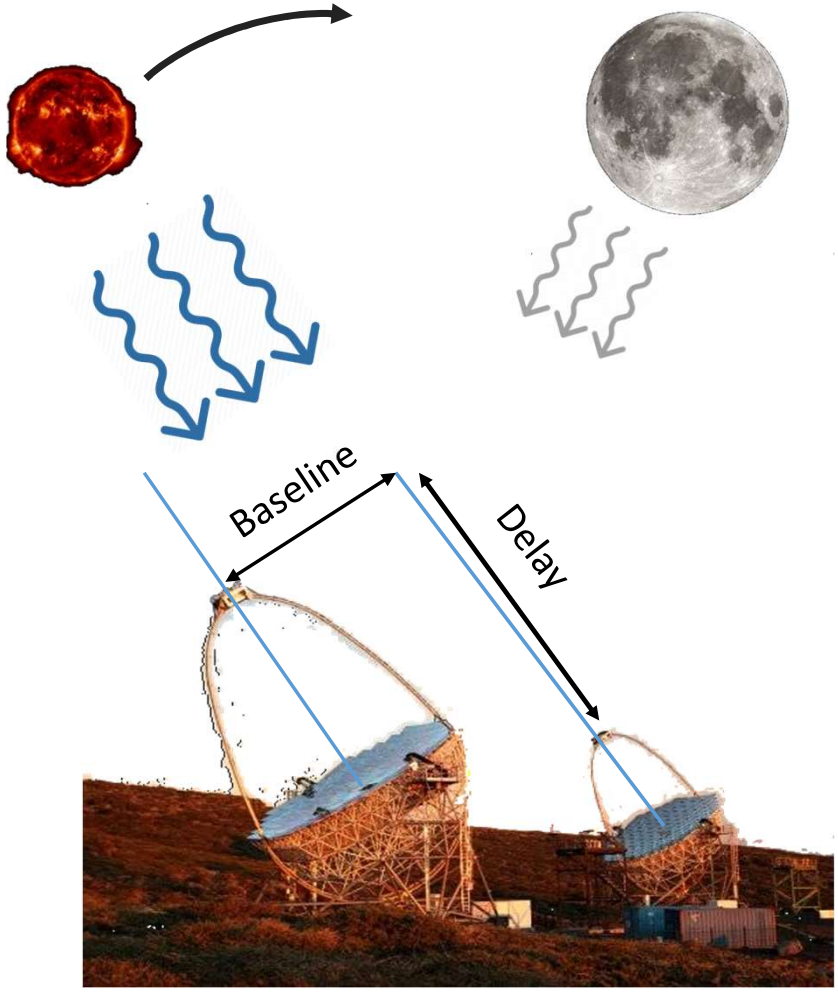
Spectrum M4i.4450-x8
digitizer card

Real-time computation of correlation in
a dedicated server (+GPU)

Intensity interferometer DAQ real-time feedback



Offline analysis (simplified)



- Compensate delay change due to tracking Compute baseline.
- Average correlation frames in a baseline bins
- Subtract Moon diffuse light.
- Extract correlation by fitting to the expected shape (Gaussian).
- Build Correlation vs baseline
- Fit with angular diameter and normalization as free parameters

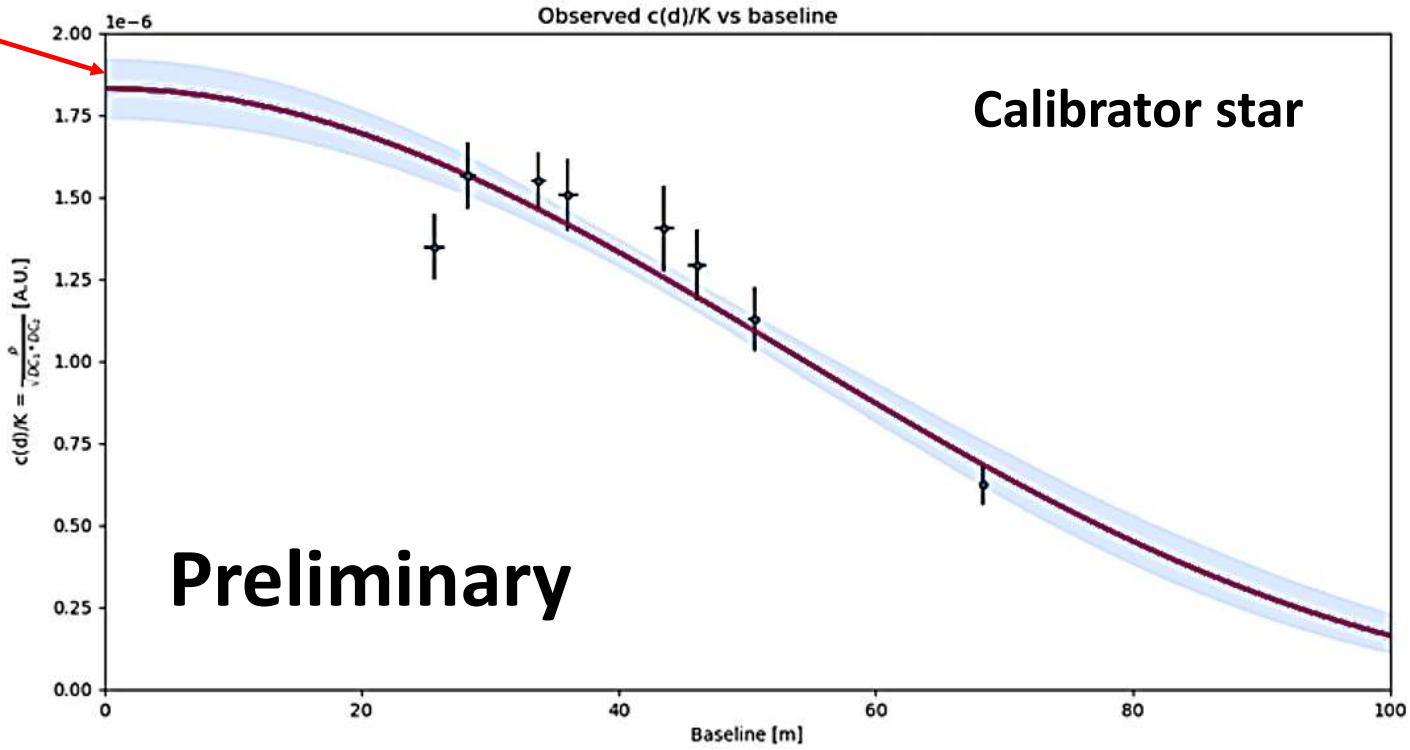
Long baseline interferometer

- Correlation between one pixel on each telescope: baseline between ~20 and 86 m

Zero baseline correlation

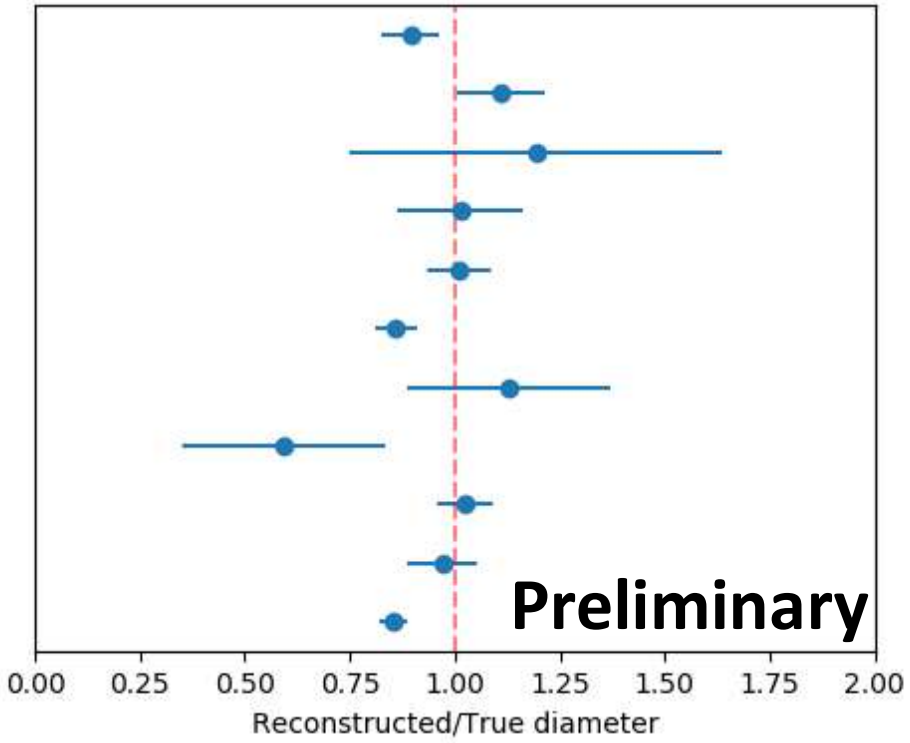
Independent of the source.

Can be calibrated with a calibrator source



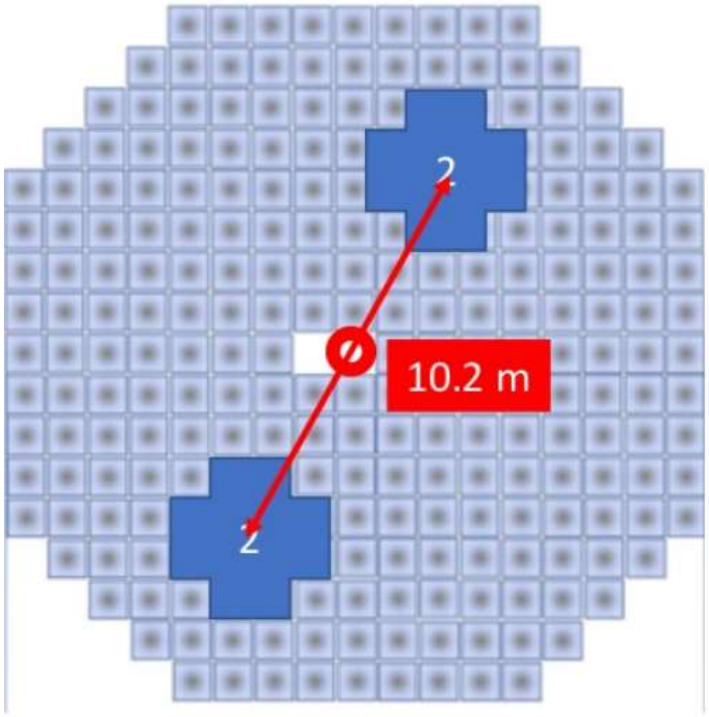
Long baseline interferometer

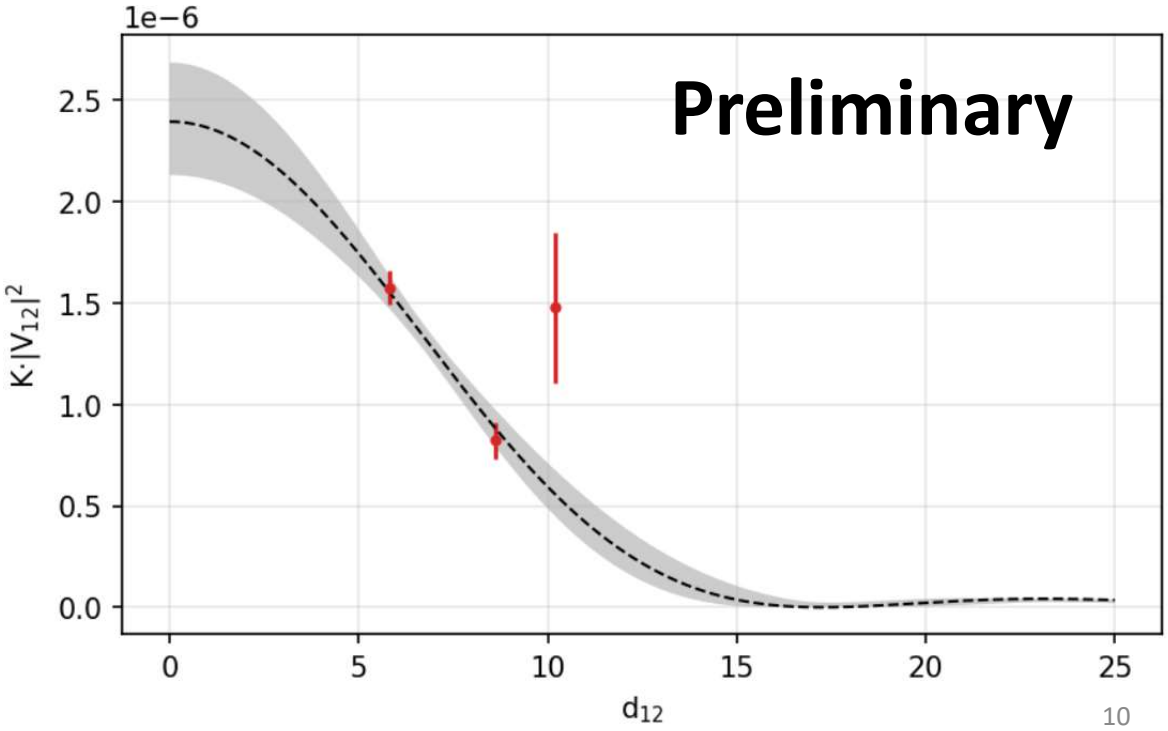
- Correlation between **one pixel on each telescope**: baseline between ~20 and 86 m
- Performance:
  - Observation of 11 stars (30 min each) with published diameters:
  - diameters between 0.2 and 0.8 mas, and brightness between 1.2 and 3.8 mag in B
  - Brightest one used as calibrator for **zero baseline correlation**



Short baseline interferometer

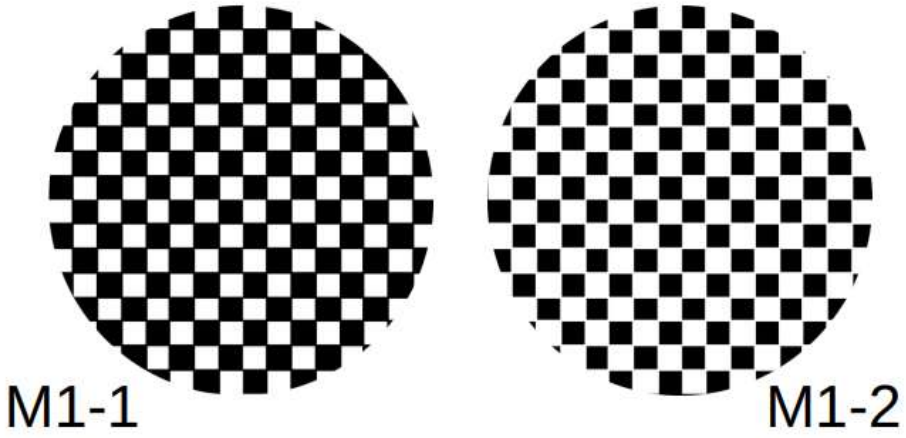
- **two pixels on a single telescope**: baseline between 0 and 15 m
- Possible thanks to MAGIC AMC: splits the mirror in submirrors focused to different pixels
- Allows measuring diameters for large stars.



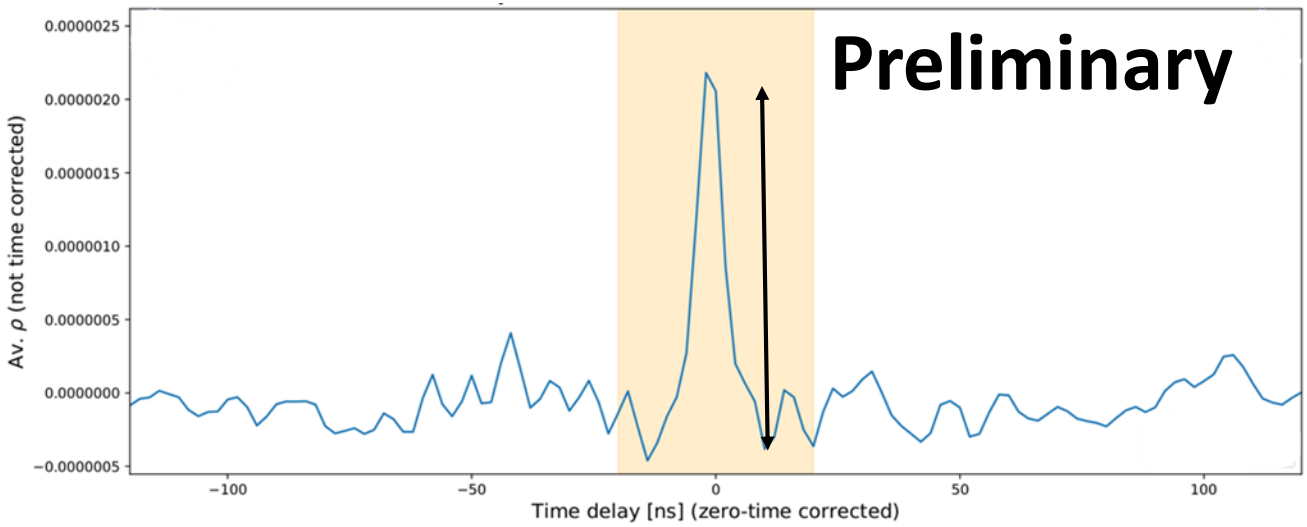


Short baseline interferometer

- **two pixels on a single telescope**: baseline between 0 and 15 m
- Possible thanks to MAGIC AMC: splits the mirror in submirrors focused to different pixels
- **Allows measuring the zero baseline correlation directly.**



Proof of concept of direct ZBC with M1



Conclusions

- We presented the MAGIC intensity interferometer.
- Automatic deployment and operation of the hardware proven to be possible.
- Regular operation proven to be possible.
  - Real-time computation of correlations and online feed-back running regularly.
- Long baseline correlation data taken regularly.
  - Benchmark measured stellar diameters agree with published ones even if the analysis can still be improved.
- Short baseline correlation proven to be possible.
- Direct measurement of zero baseline correlation proven to be possible.
  - Maybe a unique feature of MAGIC (in current IACTs generation)

Plans

- Improving the high level analysis:
  - Calibrate the system and ensure we understand the analysis, sensitivity and systematics.
  - Consolidate the observations plan: take at least 100 hours per year.

- Moving to 4 pixels simultaneously:
  - Will measure long baseline correlations and zero baseline correlation at the same time.

- Scale the real-time correlator to more than 4 channels.

Thanks!