MAGIC Intensity Interferometer as a powerful tool to understand massive stars

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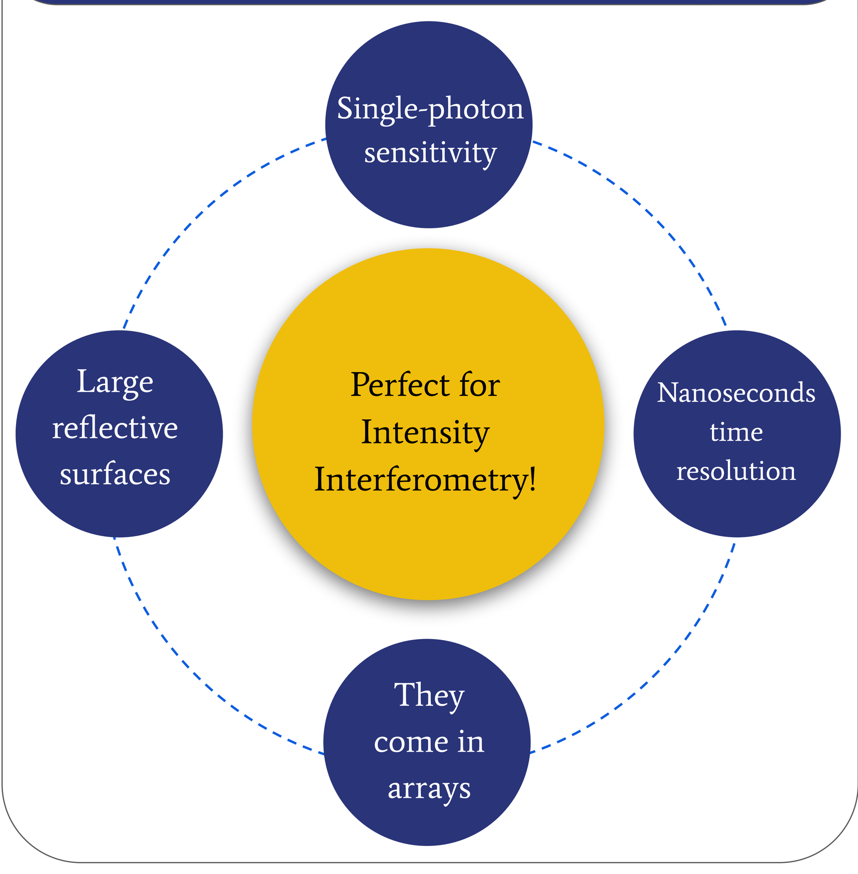
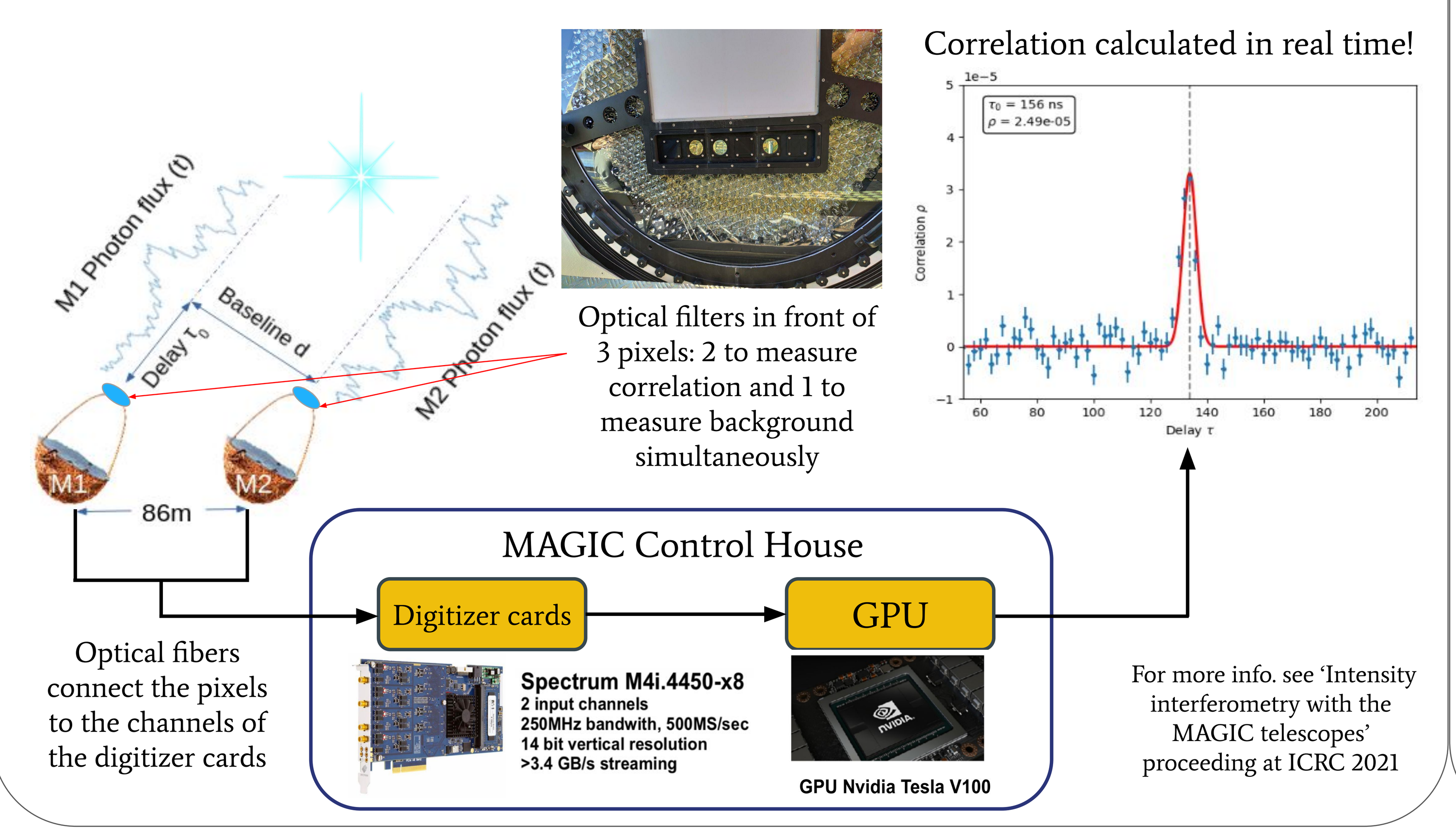
Abstract

The Intensity Interferometry technique consists of measuring the spatial coherence (visibility) of an object via its intensity fluctuations over a sufficient range of telescope separations (baselines). This allows us to study the size, shape and morphology of stars with an unprecedented resolution. Cherenkov telescopes have a set of characteristics that coincidentally allow for Intensity Interferometry observations: very large reflective surfaces, sensitivity to individual photons, temporal resolution of nanoseconds and the fact that they come in groups of several telescopes. In the recent years, the MAGIC Collaboration has developed a deadtime-free Intensity Interferometry setup for its two 17 m diameter Cherenkov telescopes that includes a 4-channel GPU-based real-time correlator, 410-430 nm filters and new ways of splitting its primary mirrors into submirrors using Active Mirror Control (AMC). With this setup, MAGIC can operate as a long-baseline optical interferometer in the baseline range ~40-90 m, which translates into angular resolutions of 0.5-1 mas. Additionally, thanks to its AMC, it can simultaneously measure the zero-baseline correlation or, by splitting into submirrors, access shorter baselines under 17 m in multiple u-v plane orientations. The best candidates to observe with this technique are relatively small and bright stars, in other words, massive stars (O, B and A types). We will present the science cases that are currently being proposed for this setup, as well as the prospects for the future of the system and technique, like the possibility of large-scale implementation with CTA.

Cherenkov Telescopes



MAGIC Telescopes Setup



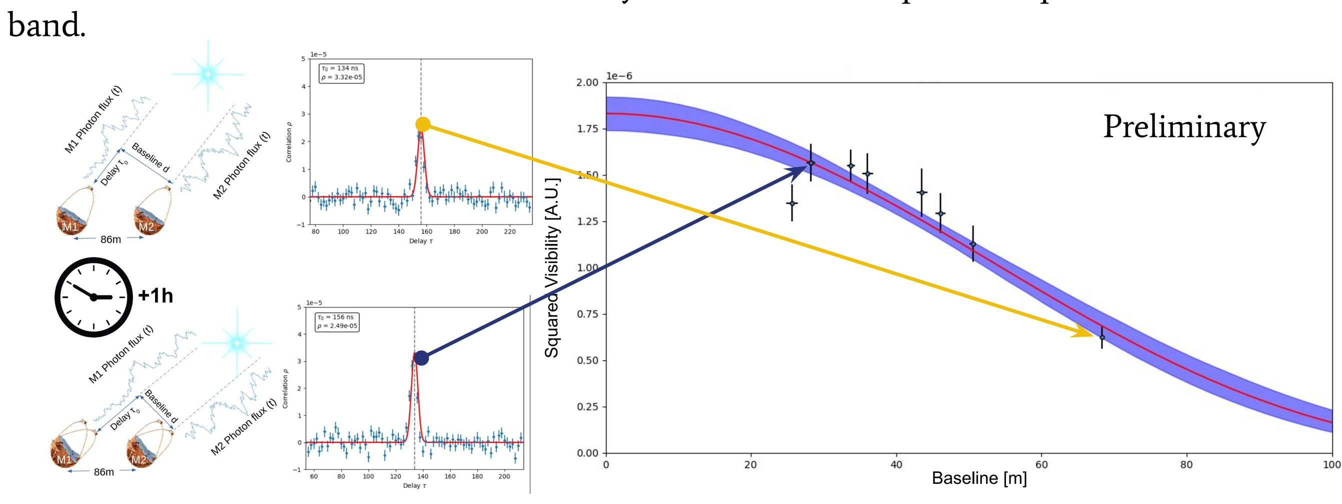
Intensity Interferometry Technique

By measuring the spatial correlation (visibility) over a sufficient range of baselines ↔ delays we can construct a model of the object ⇒ angular size.

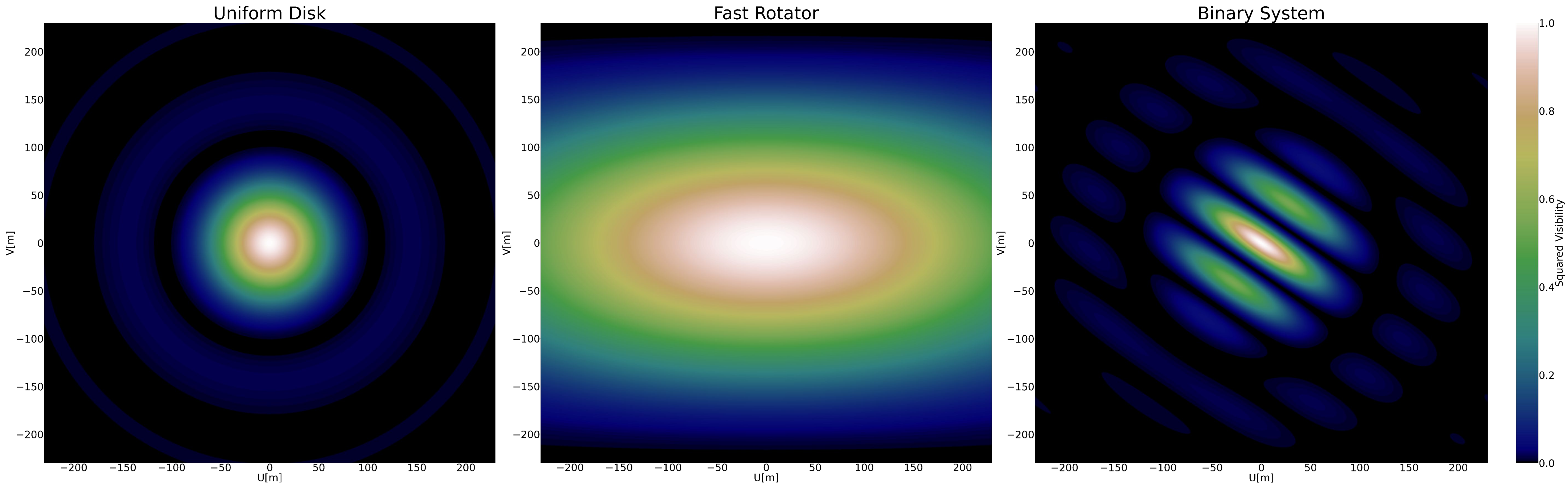
$$Squared\ Visibility = |V^2| = \left(\frac{2 \cdot B_1(\pi \cdot Baseline \cdot \theta / \lambda)}{\pi \cdot Baseline \cdot \theta / \lambda} \right)^2$$

where θ is the angular size and λ is the central wavelength.

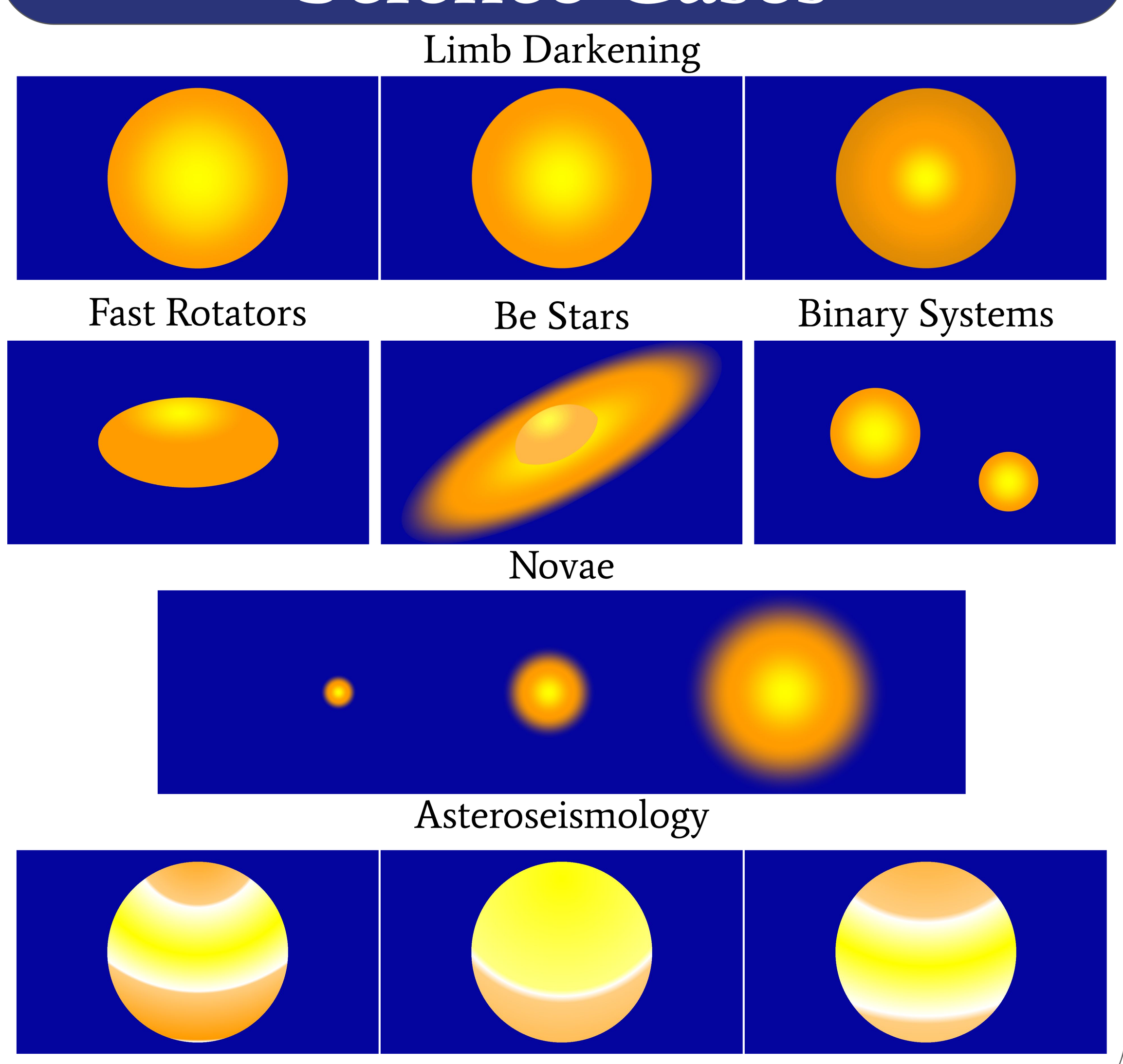
In order to do this we observe the intensity fluctuations (not phase/amplitude!) in the blue band.



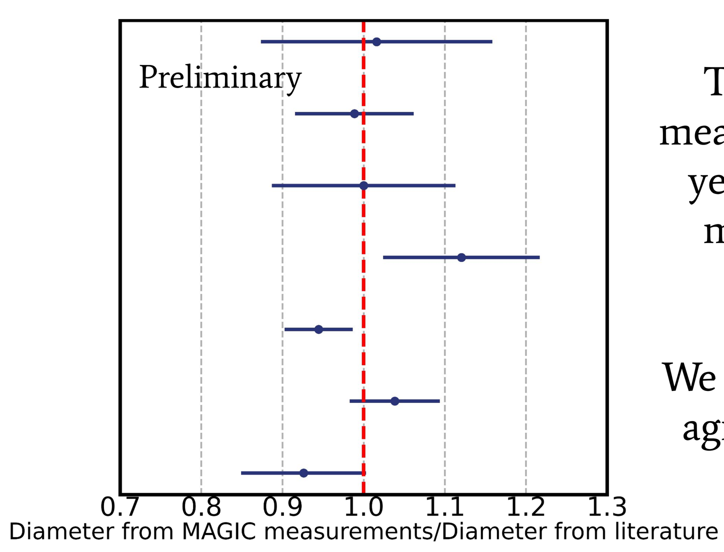
But measuring the visibility is actually a 2D problem that depends on the shape of the source. To solve it, we have to take a look at the UV plane (see below):



Science Cases



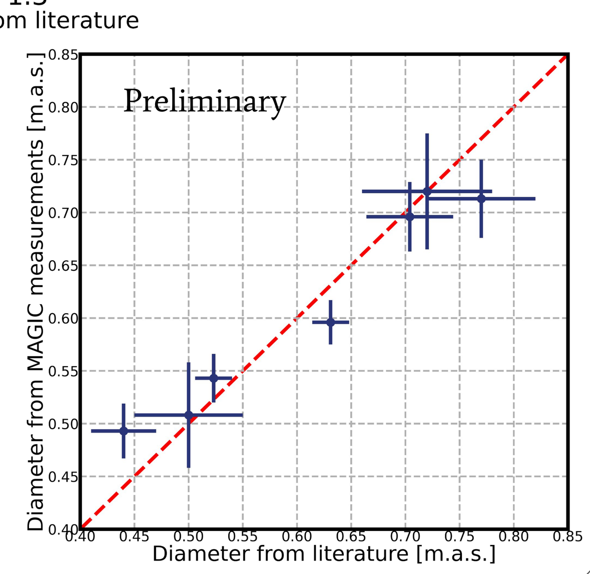
Results from 2021



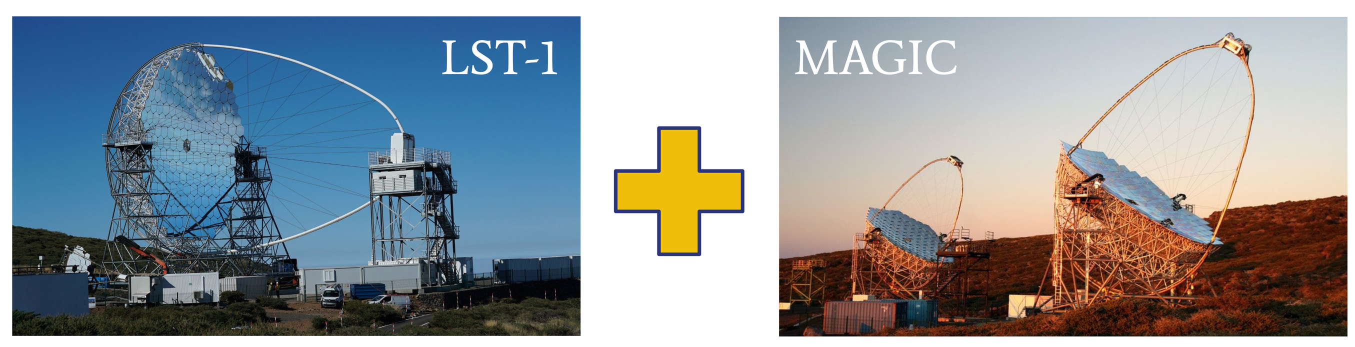
These are some of the measurements we took last year compared with the measured values from other experiments.

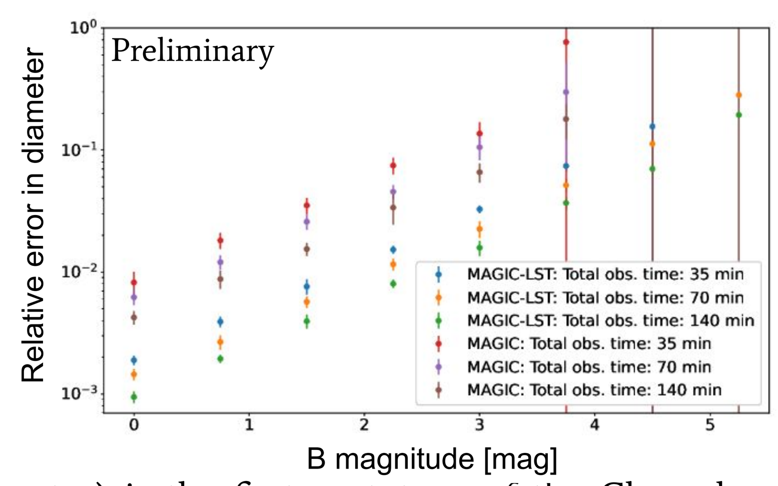
We can see that our results agree with the literature.

Within year 2022 we expect to measure the diameter of many more stars and study several science cases!



MAGIC+LST-1





LST-1 (23 m diameter) is the first prototype of the Cherenkov Telescope Array (CTA) built in La Palma, right next to MAGIC telescopes. Adding LST-1 to our setup would result in two additional simultaneous measurements at different baselines. According to our simulations, taking into account the better photon collection efficiency of LST1, with such an extended setup we could measure stars fainter by about 2 mag with the same precision.

Conclusions

- In the last few years it has been proved that is possible to apply the intensity interferometry technique with the MAGIC telescopes.
- The tentative calibration of the setup provides already star diameter measurements close to literature values.
- Adding LST-1 to the MAGIC setup requires only minor modifications, and can be done as soon as in 2022. MAGIC+LST-1 setup can be further extended to future LSTs, providing large boost in performance, due to linear improvement of the sensitivity with the number of telescopes and mirror area.

References

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