Intensity Interferometry with CTA

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UNIPD - INAF

on behalf of the ASTRI Collaboration for the CTA Consortium

Astrofisica con Specchi a Tecnologia Replicante Italiana

Involved Institutes

- University of Padova, INAF OATo, G. Naletto, C. Barbieri, G. Rodeghiero, L. Zampieri, D. Gardiol, S. Mancuso
- University of Lund, D. Dravins's group
- University of Utah, D. Kieda and S. Le Bohec's group
- Nice Observatory OCA, P. Nunez
- Nagoya University, A. Okumura

Overview

- Intensity Interferometry
- New perspectives for II with CTA
- Simulations: the ASTRI mini array case of study
- Cherenkov camera design solutions for II
- General considerations
- Future perspectives

Intensity Interferometry

- Intensity Interferometry relies on correlation between intensity fluctuations averaged over spectral band of electronics time resolution ≈ 10^{-9} s
- Widely used in particle physics
- Pioneered in Astronomy by Hanbury-Brown & Twiss with Narrabri Observatory and then dismissed
- Now undergoing a revival thanks to the new generation of Cherenkov Telescopes -> CTA

Intensity Interferometry

Interferometry of the intensity fluctuations in light

I. Basic theory: the correlation between photons in coherent beams of radiation

Interferometry of the intensity fluctuations in light

II. An experimental test of the theory for partially coherent light

Interferometry of the intensity fluctuations in light

III. Applications to astronomy

Interferometry of the intensity fluctuations in light

IV. A test of an intensity interferometer on Sirius A

By R. Hanbury Brown

Jodrell Bank Experimental Station, University of Manchester

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$$\gamma(r_i, t_i; r_j, t_j) \equiv \frac{\langle E^*(r_i, t_i) \cdot E(r_j, t_j) \rangle}{\sqrt{\langle |E^*(r_i, t_i)|^2 \rangle \langle |E^*(r_j, t_j)|^2 \rangle}}$$

$$\frac{\langle I_i I_j \rangle}{\langle I_i \rangle \langle I_j \rangle} = 1 + |\gamma_{ij}|^2$$

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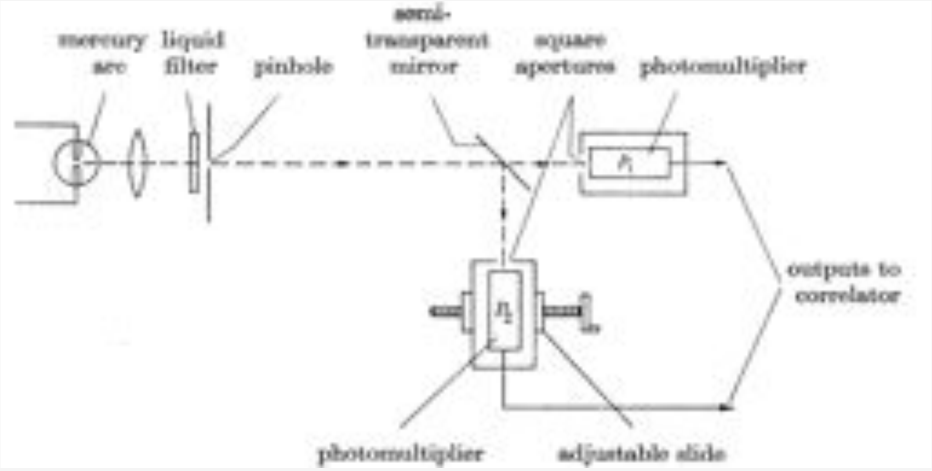

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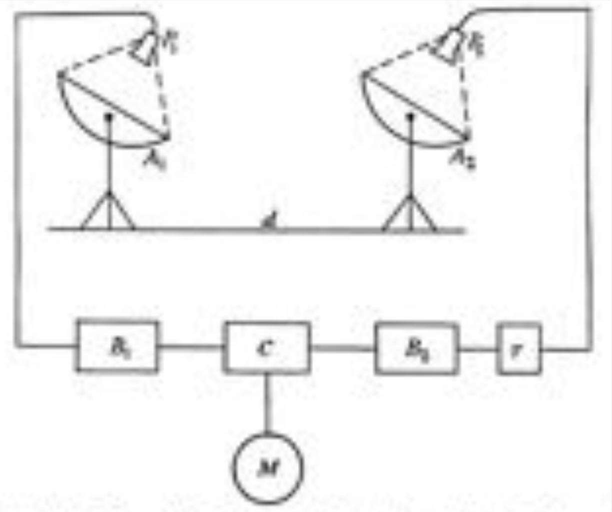

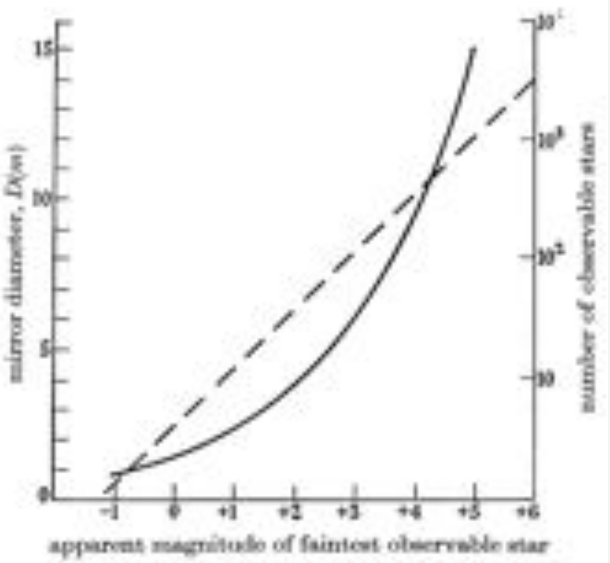

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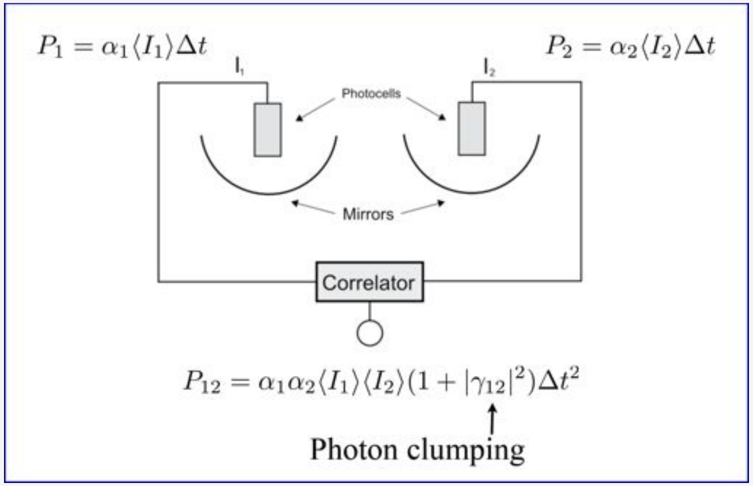

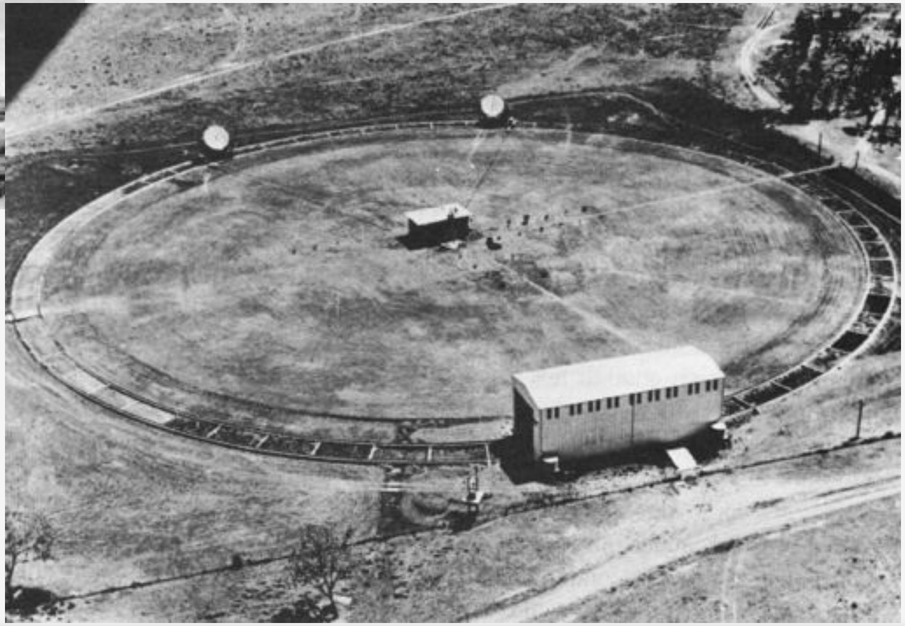

- Two movable low quality optics 6.5 m telescopes on a circular rail

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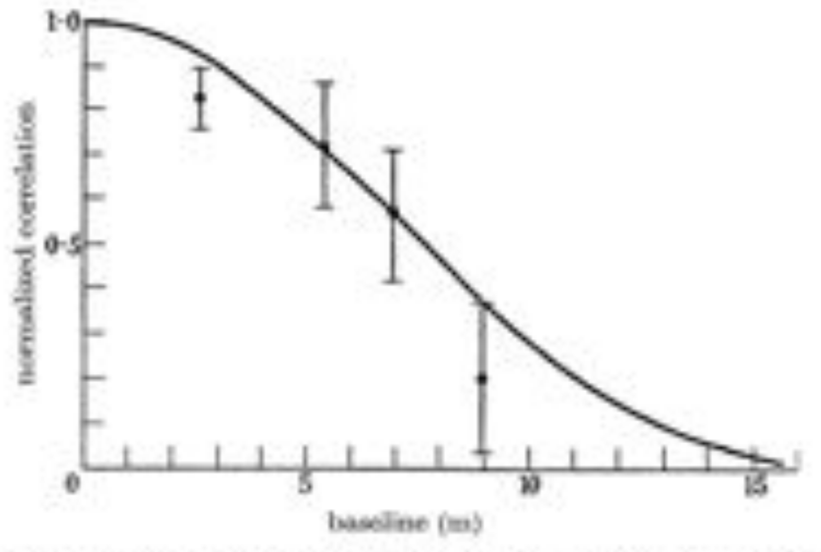

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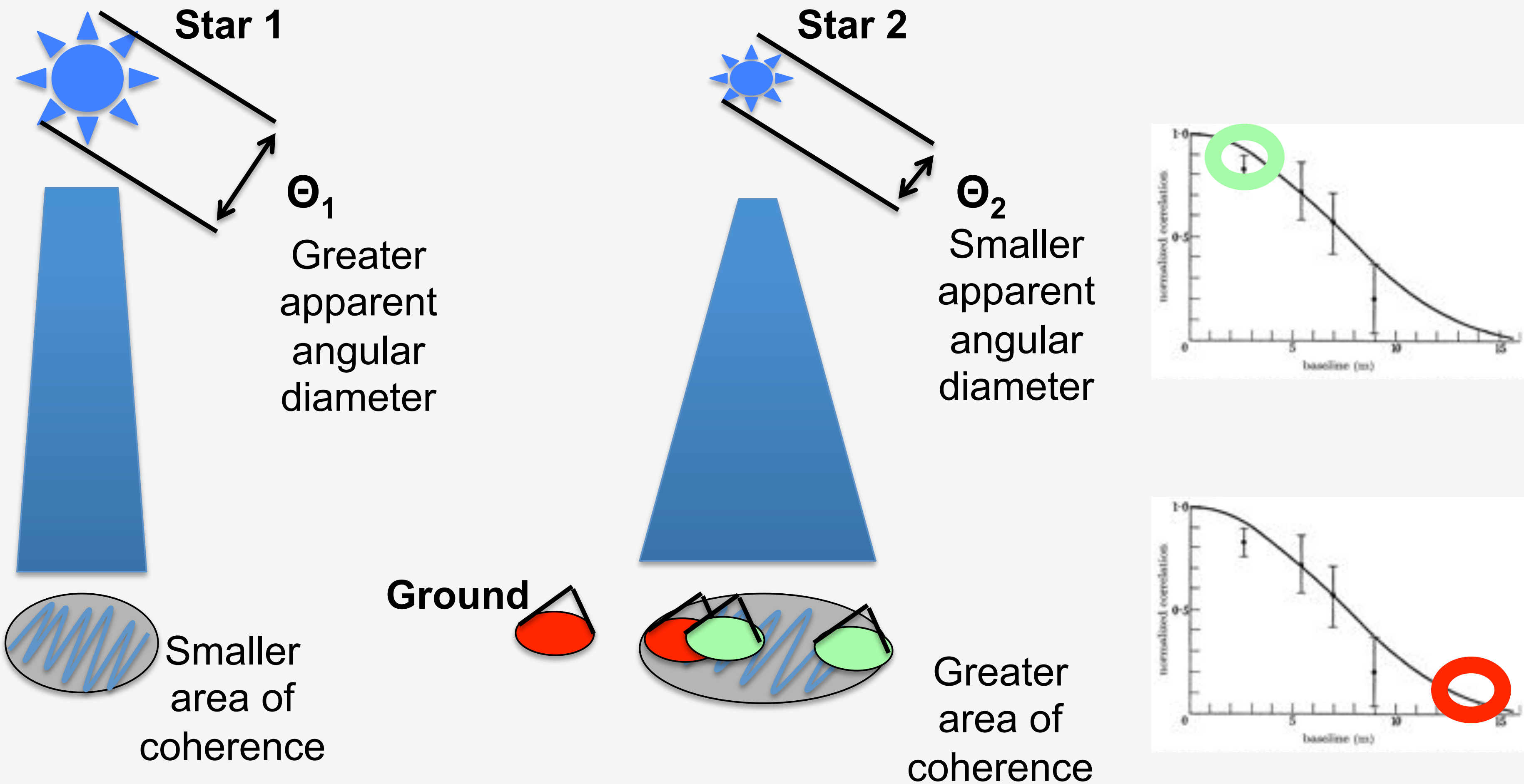
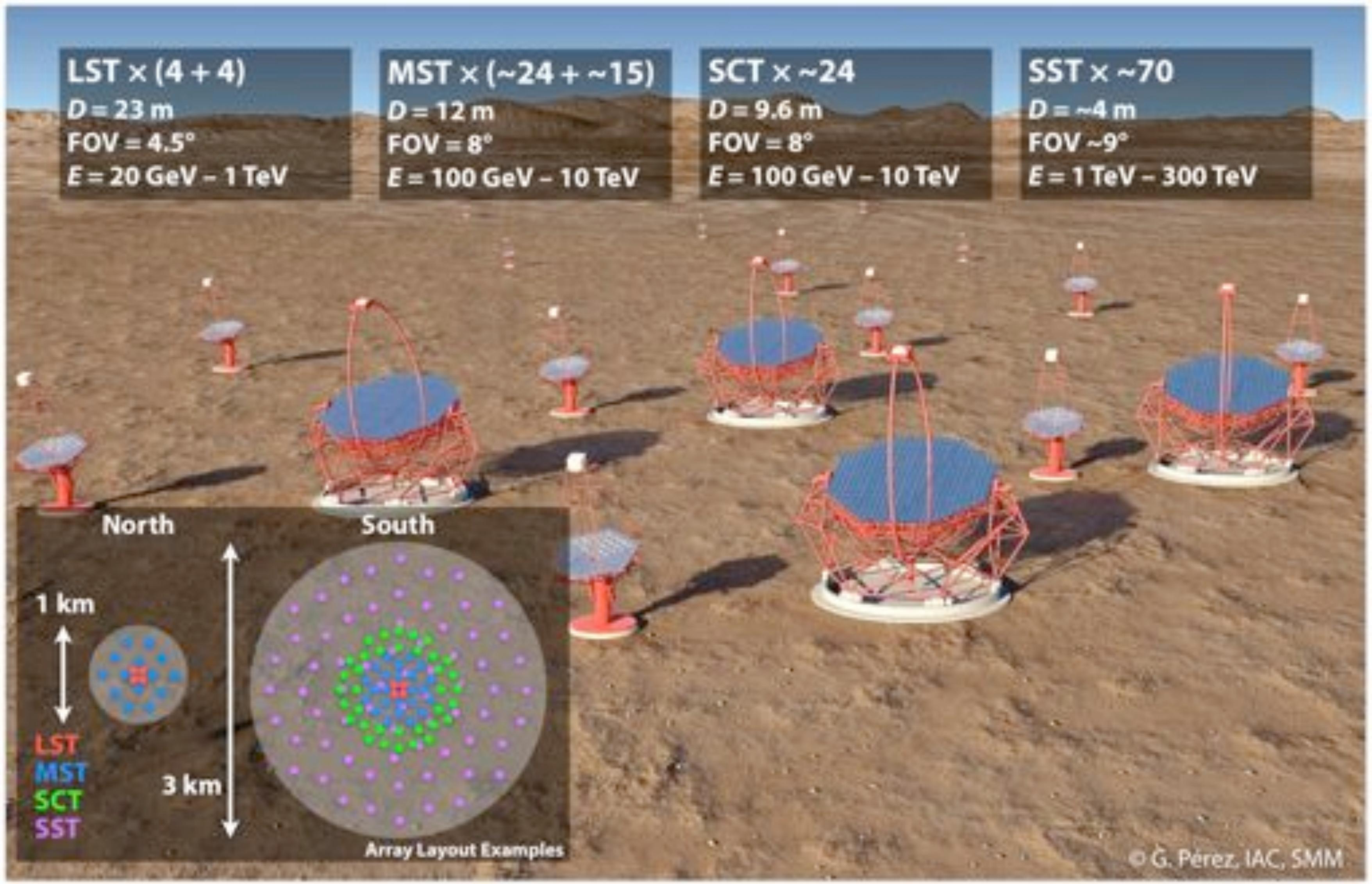


New perspectives for II with CTA



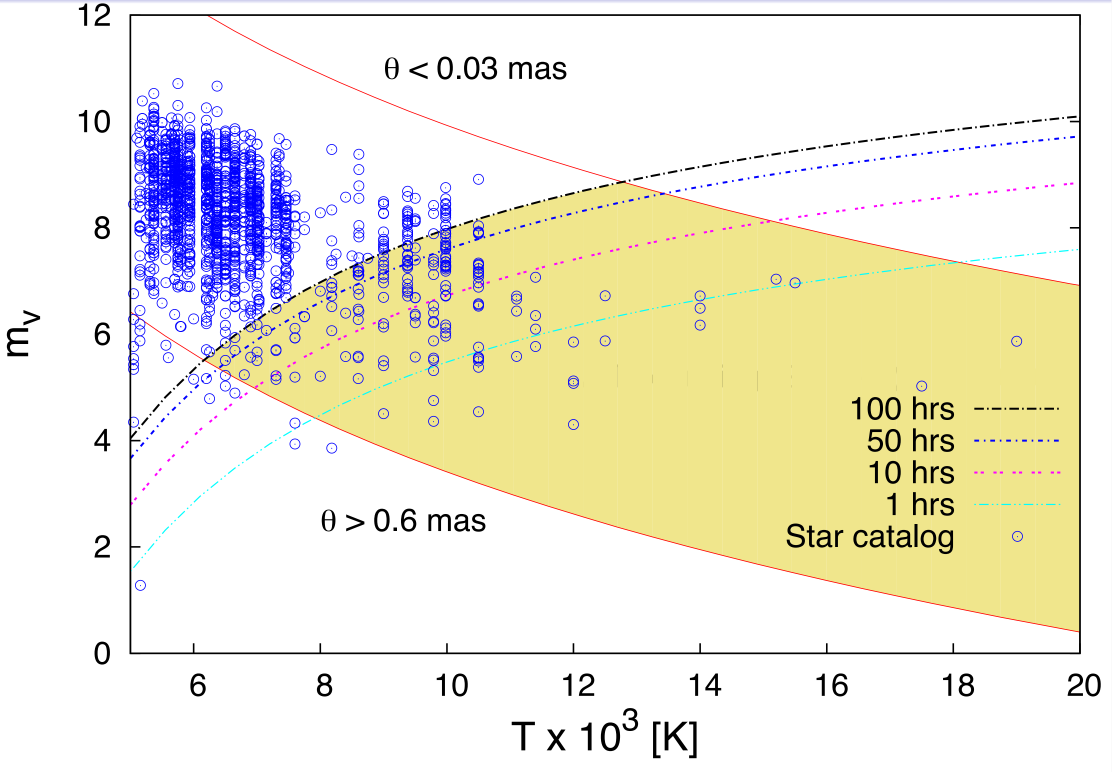
New perspectives for II with CTA

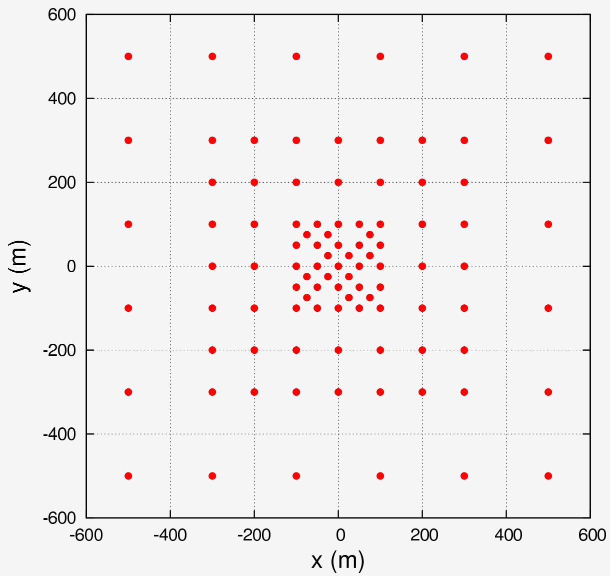
- **Modern Intensity Interferometry**
- An array of large light collectors -> CTA
- The telescopes are combined by software, nothing actually is interfering
- Implementation of fast (10^{-9}s) detectors

- **Potentialities:**
- Huge number of baselines -> N(N-1)/2
- Good U-V plane coverage
- Insensitive to atmosphere perturbations

- **Target**
- Sub-milliarcsecond resolution and imaging

New perspectives for II with CTA

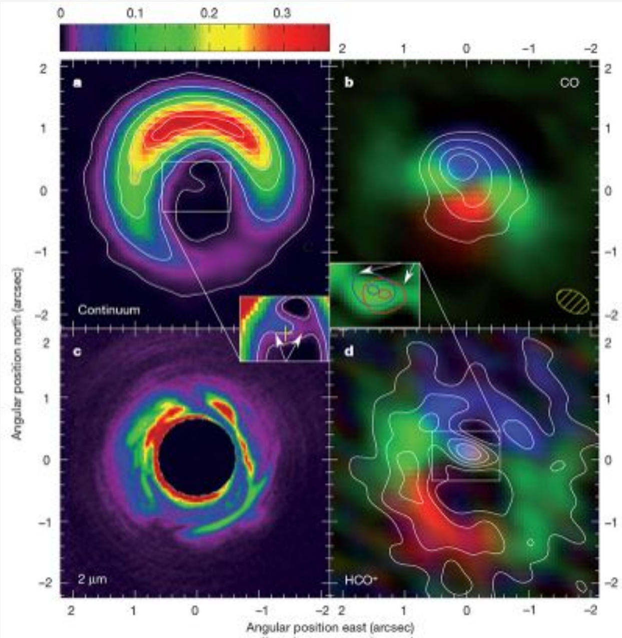


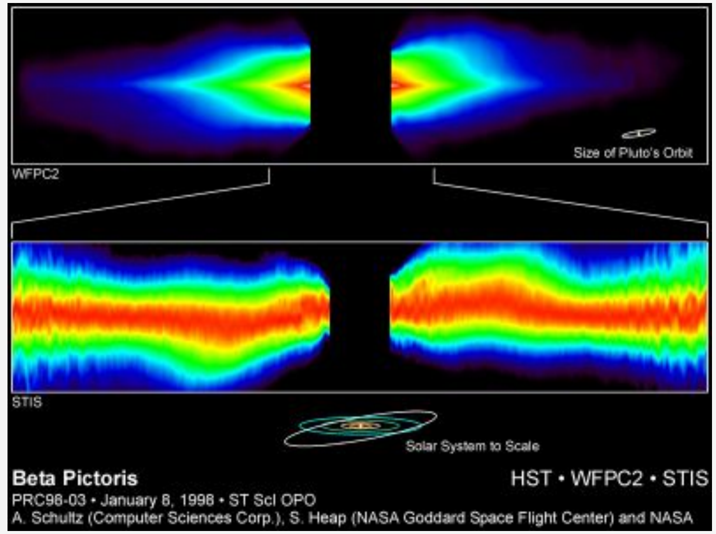


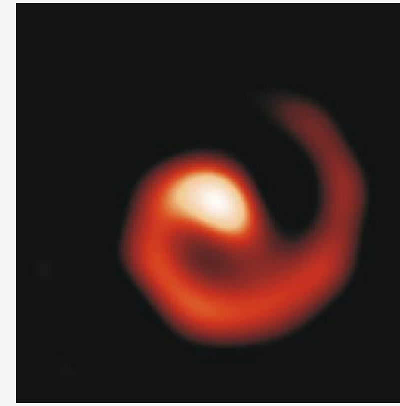
- N = 97 telescopes
- $\alpha = 0.3$
- A = 100 m^2 -> 10 m diameter

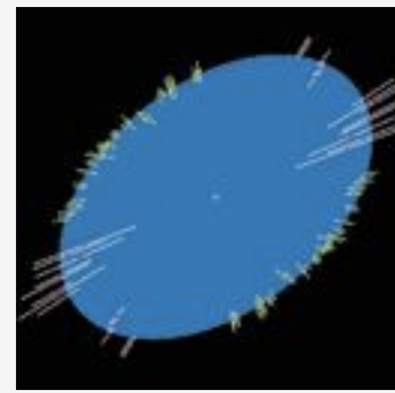
- Nunez et al. 2012 MNRAS

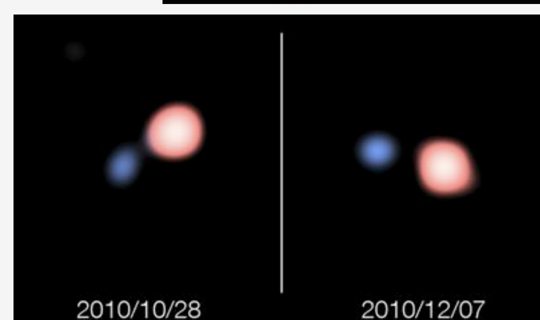
New perspectives for II with CTA











- Protoplanetary disk around stars
- Exoplantes transits
- Fast rotating Be stars
- Wolf Rayet stars
- Iteracting binaries

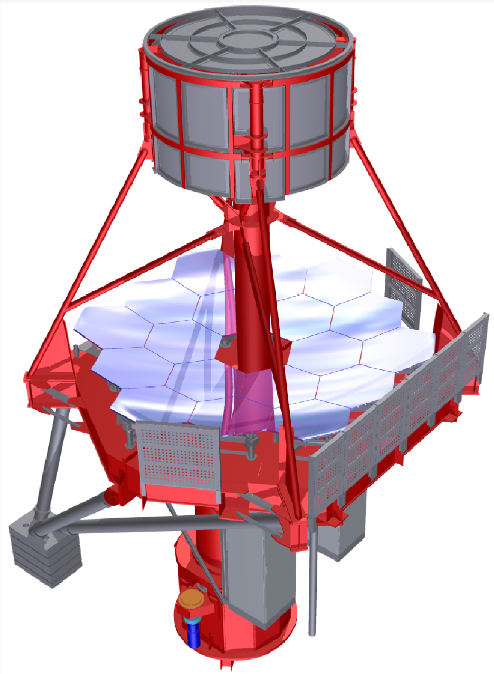
II with ASTRI/CTA mini array

- **Case of Study**:
- **7** ASTRI SST-2M telescopes, **21** simultaneous baselines
- Baselines up to ≈ 700 m
- $\lambda/B \approx 0.16$ mas @ $\lambda = 550$ nm

- SSTs potentiality for II:

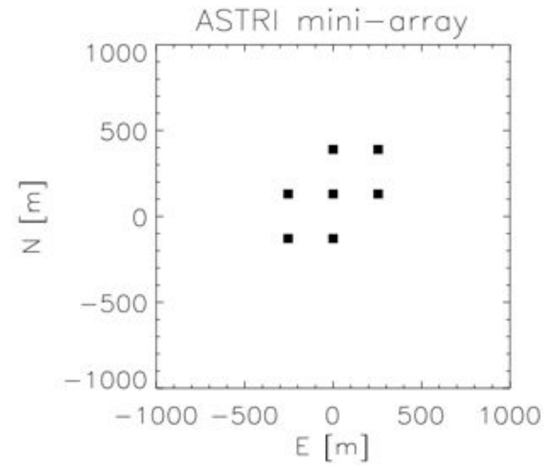
Huge number of baselines

Largest baselines



Location: Canary Islands

Well know site for Astronomy



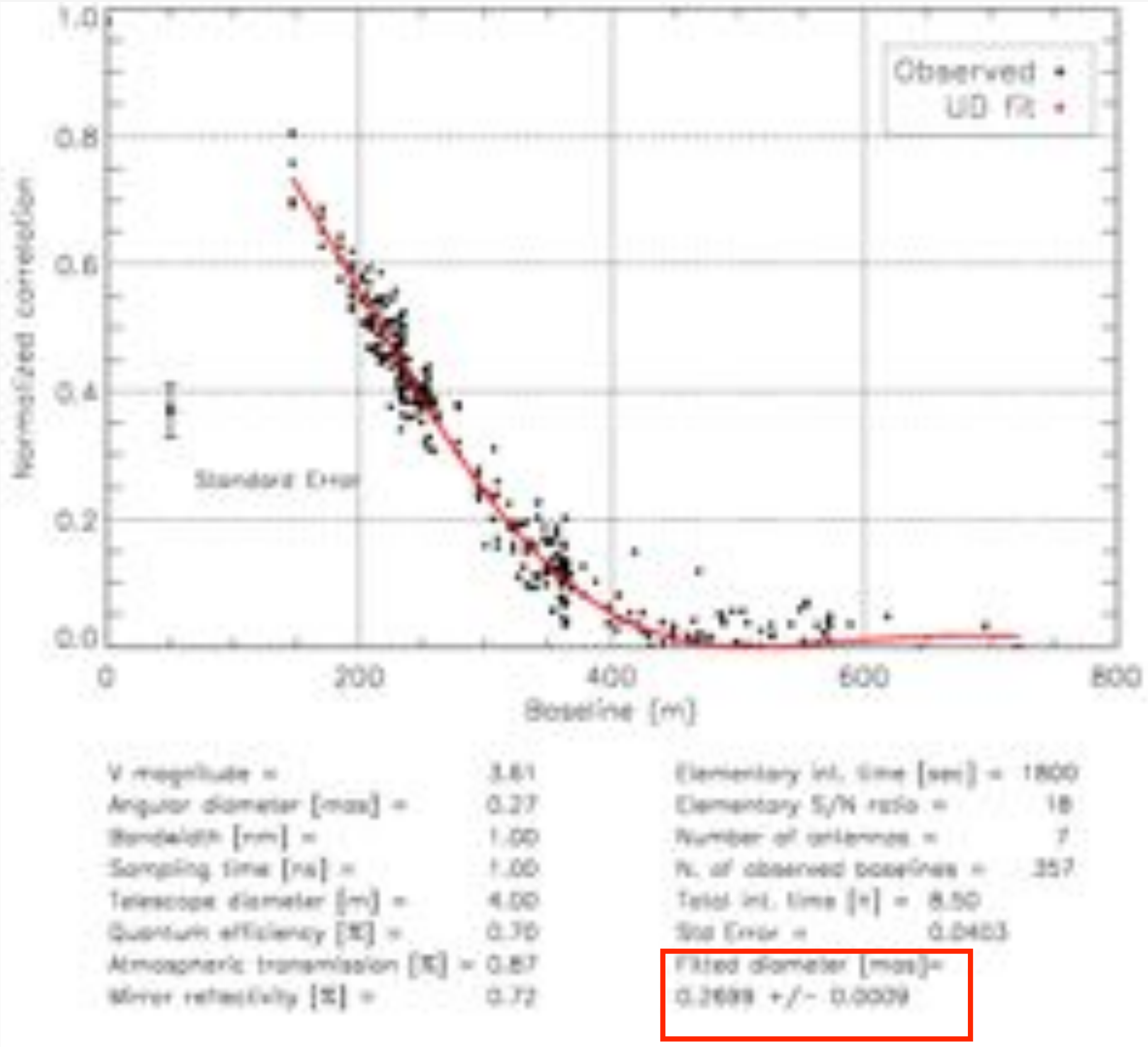
Geometry

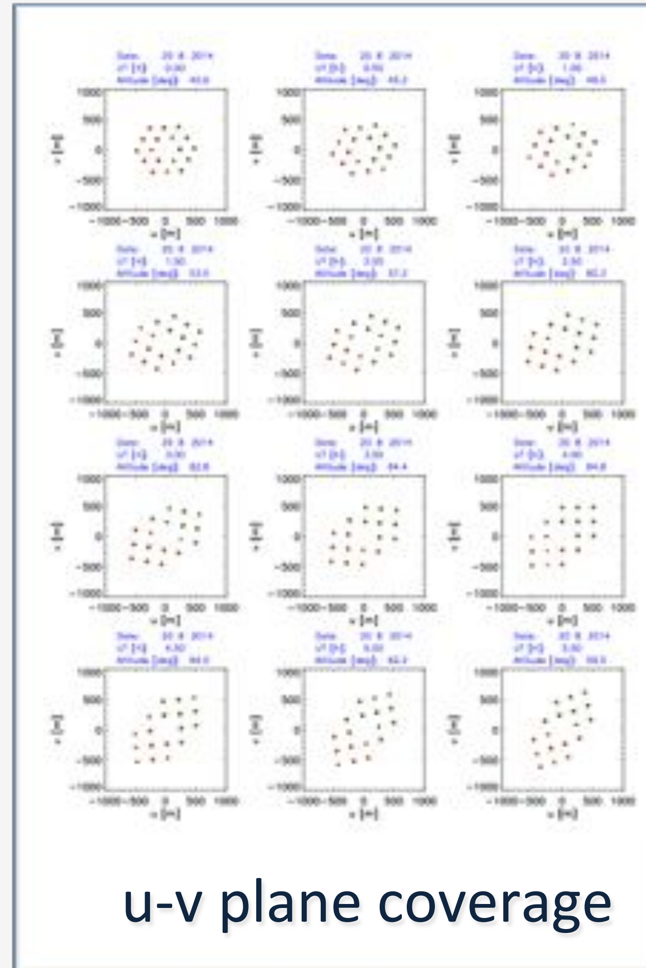
II with ASTRI/CTA mini array

- **Study highlights – INAF OATo Simulator**
- Code completely written in IDL
- Visibility model based on semi-classical approach (Jensen 2010)
- **Improvements** account for Night Sky Background (NSB) and estimation of visibility errors
- La Palma NSB model (Preuβ et al. 2002), equivalent to star of $m_V = 8$ for an ASTRI SST-2M telescope
- Simple star model fit (Uniform Disk)
- Versatile, can accommodate different telescope geometries
- Designed to simulate real observations

II with ASTRI/CTA mini array

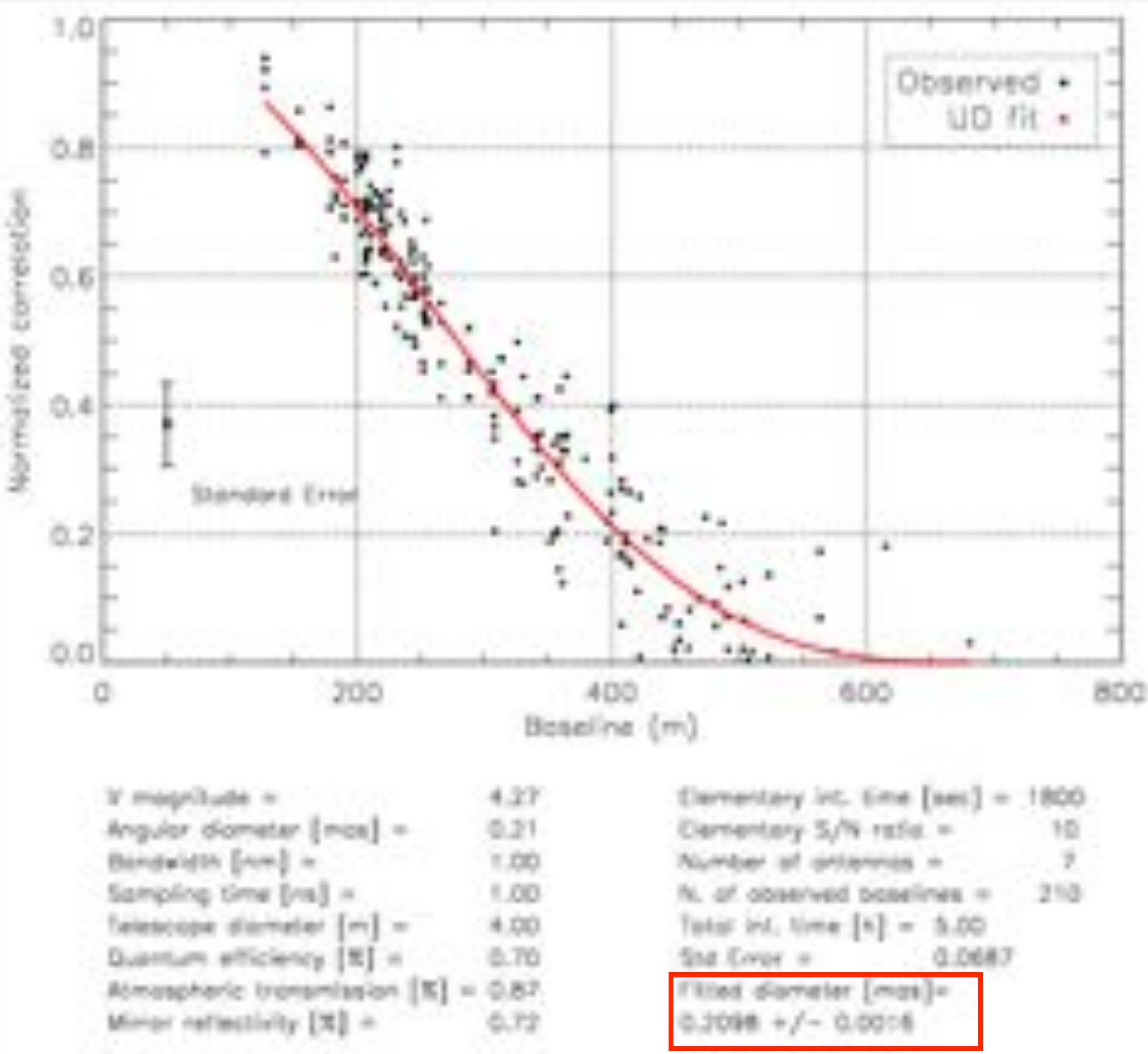
ζ Cas: m_V=3.61, θ=0.27 mas, t=8.5 h

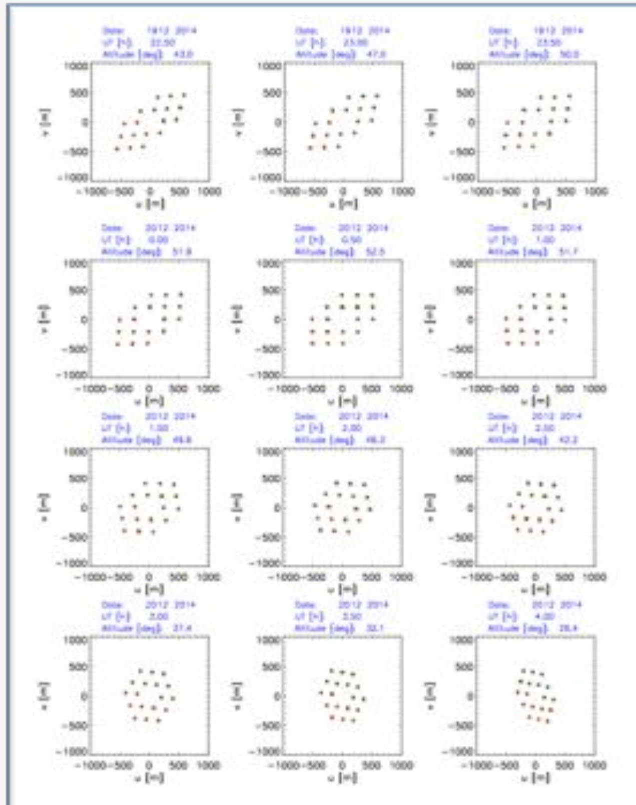




II with ASTRI/CTA mini array

λ Eri: m_V=4.27, θ=0.21 mas, t=5 h

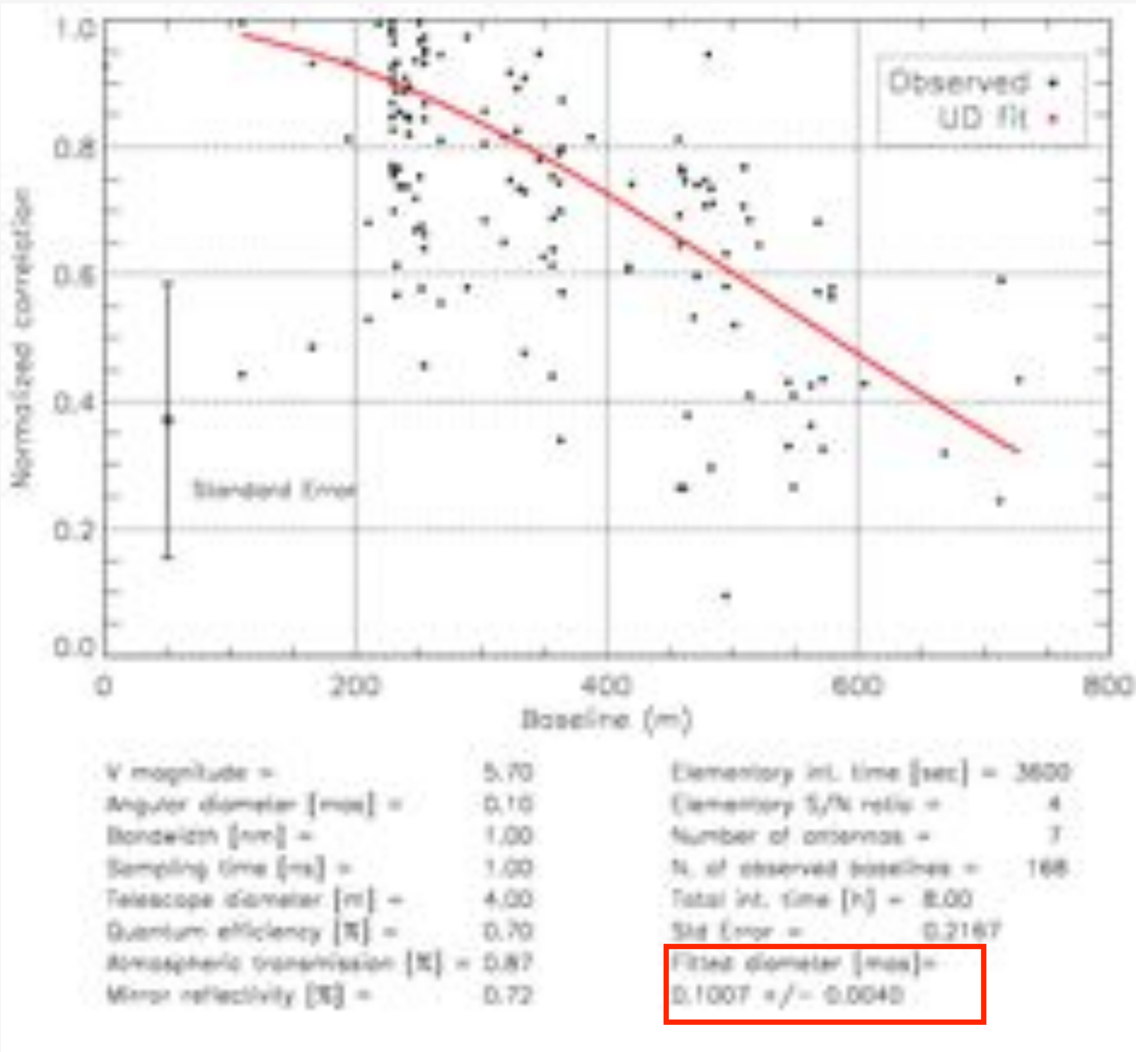


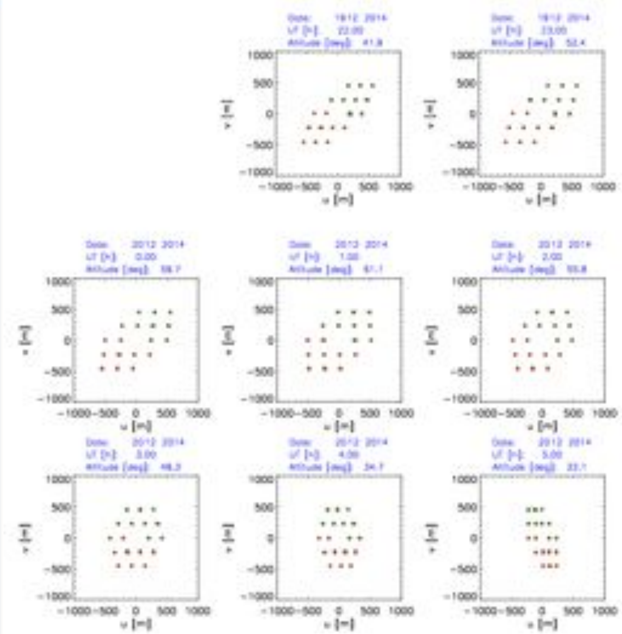


u-v plane coverage

II with ASTRI/CTA mini array

HR 1781: m_V=5.70, θ=0.10 mas, t=8 h





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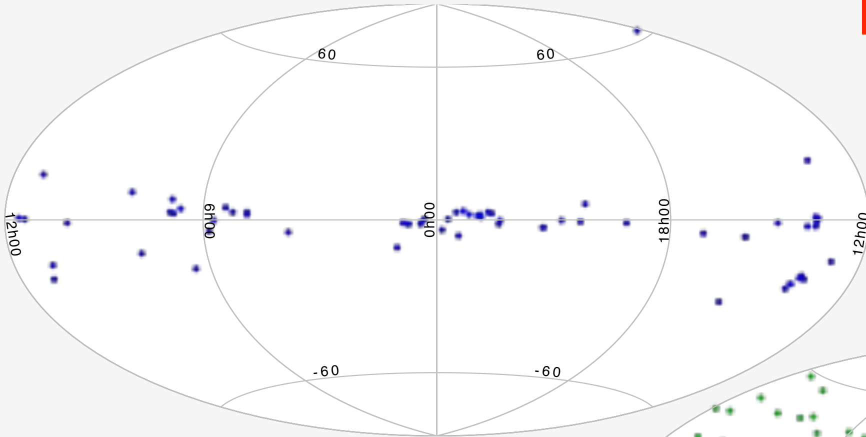
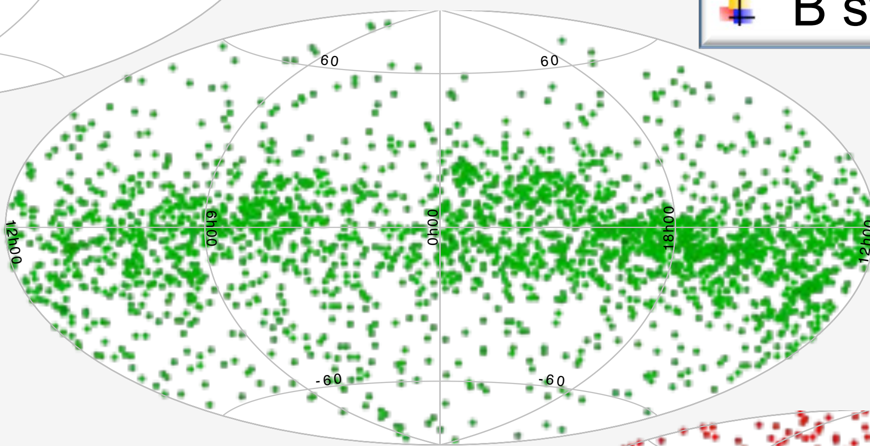
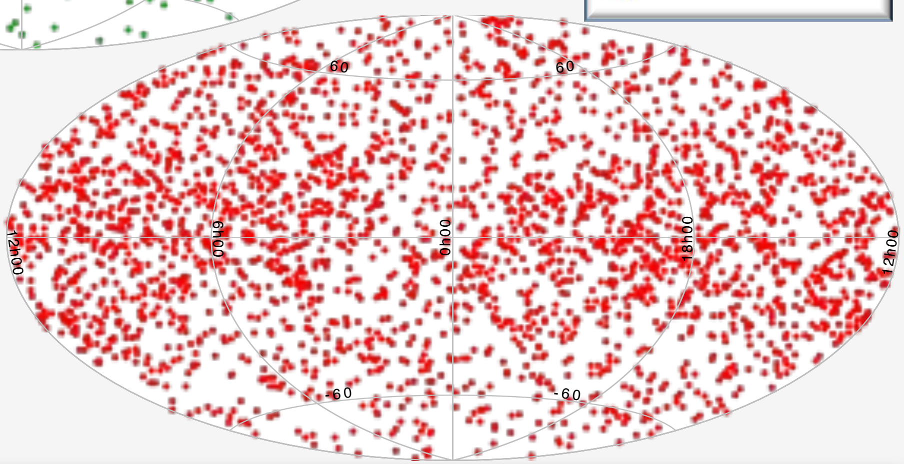


- O stars



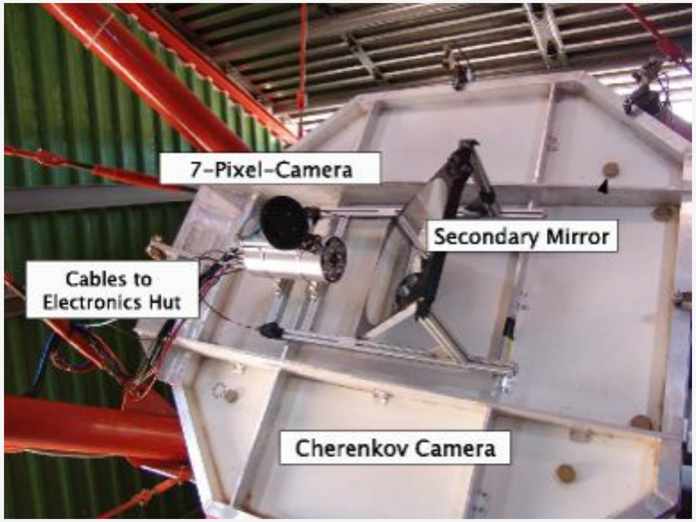
- B stars

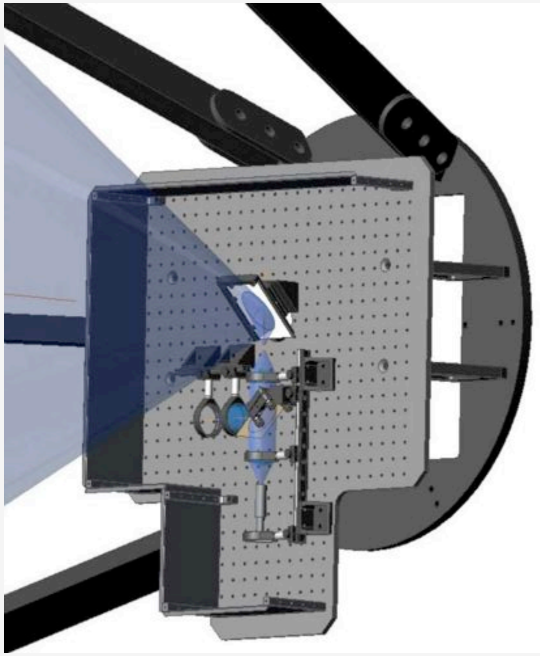


- A stars

- Hot stars with $m_V < 7$ from the Hipparcos Catalogue, Vizier

StarBase, HESS, MAGIC

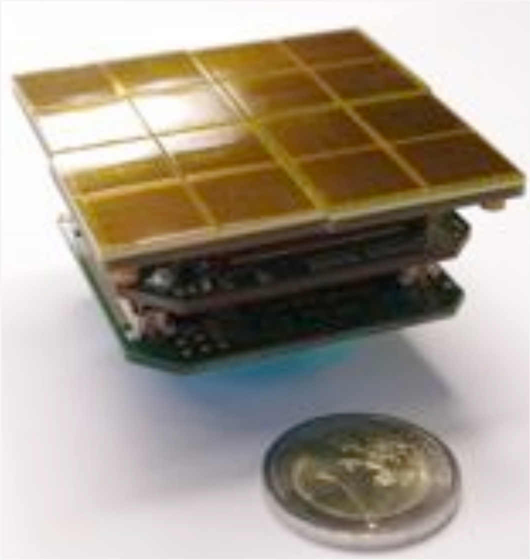


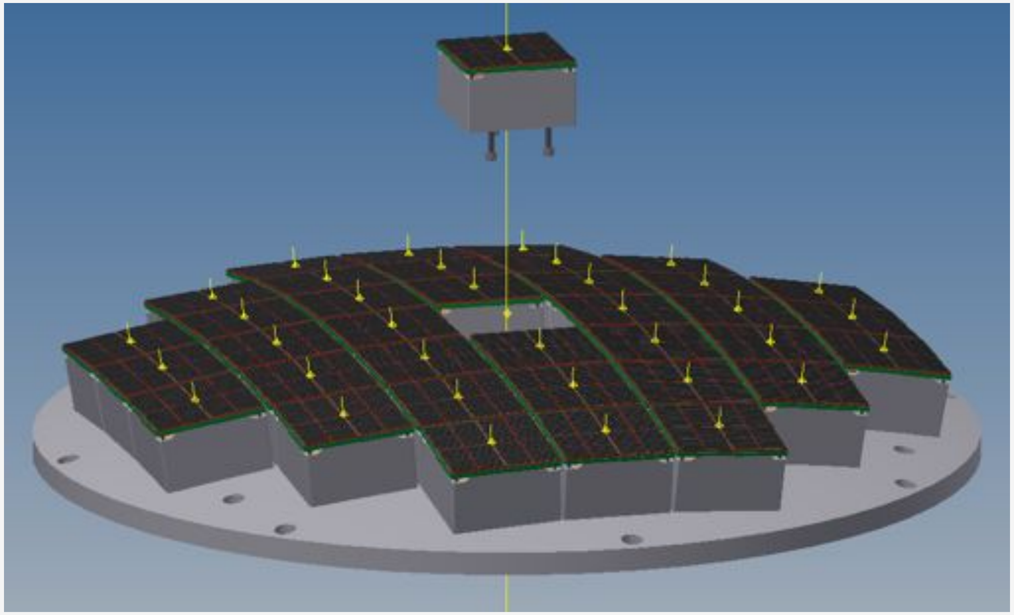


- **Star Base** -> dedicate focal plane, S. Le Bohec SPIE 2012, 7734-48
- **MAGIC** -> PMT inside the camera focal plane, F. Lucarelli et al. NIMA 589 (2008) 415-424
- **HESS** -> Detector mounted on the camera LID, Diel et al. 2008, http://arxiv.org/abs/0812.3966v1

On axis detector

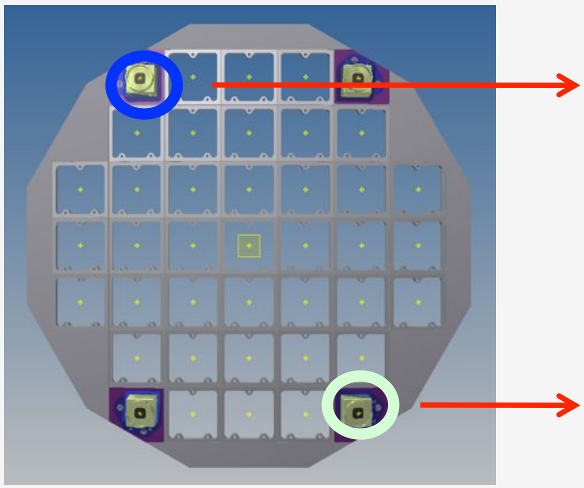
- A PDM equipped with filter or ad hoc detector
- Physical constraints ≈ 57 x 57 x 50 mm
- Thermal constraints -> low heat production
- Optical constraints -> no vignetting of surrounding PDMs
- Dedicated electronics and data handling
- Need of cooling the PDM to limit dark current

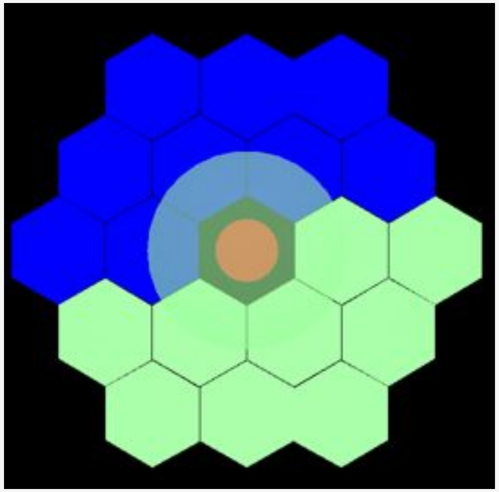


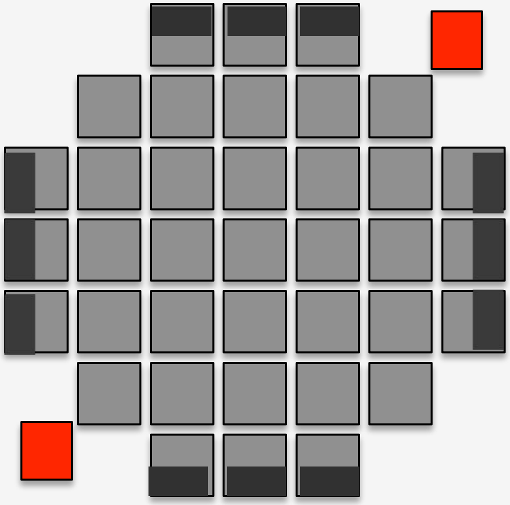


Off axis detector

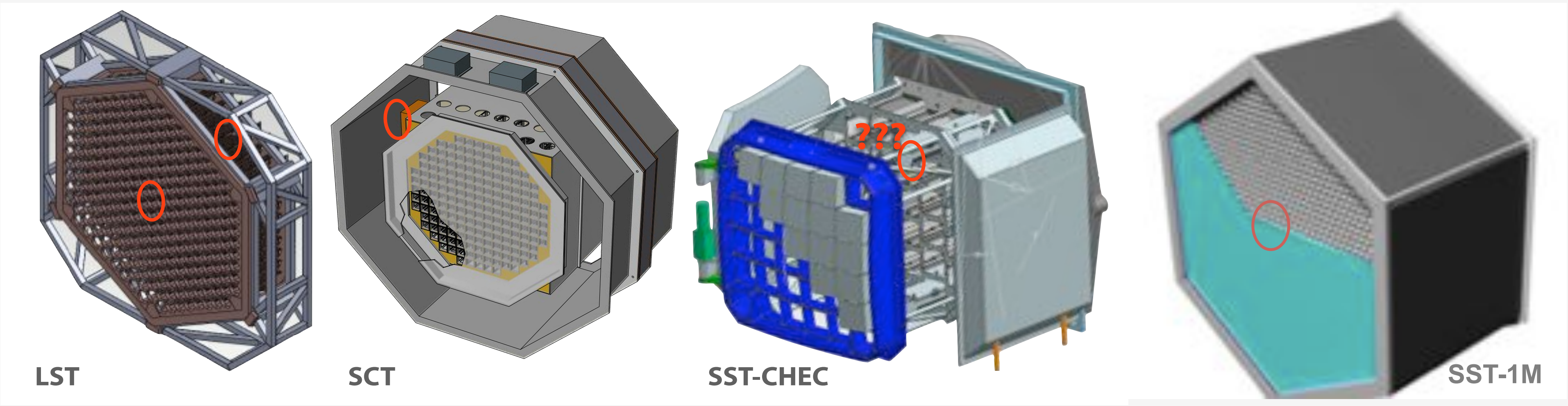
- Installing a PDM or a dedicated detector with optics and filter
- Exploiting space at the corners of the camera focal plane
- Two units already allocated for AO CCD cameras
- Physical constraints ≈ 50 x 50 x 50 mm
- Thermal constraints -> low heat production
- Dedicated electronics and data handling







Other CTA cameras



- Image from A. Okumura presentation at HBT Workshop Nice 2014

Desiderata for HBTII with CTA

- Photon counting regime
- Time tagging resolution: < 1 ns
- Dead time: ~ 50 ns (20 MHz max count rate with one detector)
- Acquisition mode: continuous (for hours of observation)
- Spectral sensitivity: visible (with good efficiency in blue)

- Resolution element: few $arcsec^2$ optimal / few $arcmin^2$ acceptable
- Narrow band filters (e.g. @400 nm, @800 nm; $\Delta\lambda/\lambda$ ~1-2%)
- Expected event rate ~tens of MHz
- Expected data rate ~tens of MHz @40-50 bits/event

- from G. Rodeghiero, G. Naletto, C. Barbieri, L. Zampieri presentation ASTRI mini-array science meeting, Padova 2014

General considerations

Trade off between telescopes

- Davies-Cotton 1M have smaller M1 obstruction than 2M telescope solutions
- LSTs and MSTs offer greater sensitivity than SSTs but higher spread in photons arrival times
- Schwarzschild Couder configuration gives the best design isochronicity

e.g. ASTRI SST-2M **3e-12 s** to **1e-11 s** from 0 to 4.8 deg in FoV

Davies Cotton **0.11e-9 s/m** scaled to M1 size (arXiv:astro-ph/0507617)

- SSTs provide a huge number of baselines and high angular resolution in terms of overall array

Future Perspectives

- **Horizon 2020 calls FET:**
- NOVEL IDEAS FOR RADICALLY NEW TECHNOLOGIES - RESEARCH PROJECTS

- Deadlines of the Calls:

  29 September 2014

  29 September 2015

- This is the time to strengthen the efforts toward the creation of an international network to boost these ideas on a concrete Project roadmap

European Commission

HORIZON 2020

The EU Framework Programme for Research and Innovation

Future Perspectives

- Output of HBT Workshop at Nice OCA May 2014

- Growing interest in Intensity Interferometry with CTA

- **Urgent actions**
- Writing Science Requirements Level A/B
- Creating an international working group/network

Nice Workshop on Intensity Interferometry and Related Topics

Text and pictures: Dainis Dravins (Lund Observatory), Elliott Horch (Southern Connecticut State University), Dave Kieda (The University of Utah), Tiphaine Lagadec (Lund Observatory), Vinay Malvimat (Indian Institute of Technology Kanpur), Paul D. Nuñez (Collège de France & Laboratoire Lagrange, Nice), Akira Okimura (Nagoya University & University of Leicester), Genady Pilyavsky (Arizona State University), Erez Ribak (Technion, Haifa), Gabriele Rodeghiero (University of Padova), Dmitry Strekalov (JPL, Pasadena), Tina Wentz (University of Zurich), Olaf Wucknitz (Max-Planck Institute for Radio Astronomy, Bonn)