*RevMexAA (Serie de Conferencias)*, **38**, 5–6 (2010)

# INTENSITY INTERFEROMETRY WITH CHERENKOV TELESCOPES

D. B. Kieda,[1,2] S. LeBohec,[1] and P. Nunez[1]

RESUMEN

Se discuten las capacidades de arreglos de interferometría de intensidad estelar (SII) que se pueden construir usando la siguiente generación de arreglos de telescopios de Cherenkov de imágenes de aire (IACTs). Estos arreglos de IACT tendrán un gran diámetro de $\sim$ 100 m ($>$ 8 m de reflectores ópticos), ofreciendo cerca de 5000 líneas de base interferométricas, extendiéndose a partir de 50 m a más que 1000 m. La implementación del SII en arreglos de IACT permitirán imágenes de alta resolución ($<$ 0.1 mas) en anchos de banda cortos (bandas B/V), que son óptimas para el estudio de estrellas calientes.

ABSTRACT

We discuss the capabilities of Stellar Intensity Interferometry (SII) arrays which can be constructed using next generation of Imaging Air Cherenkov Telescopes (IACTs) arrays. These IACT arrays will have $\approx$ 100 large diameter ($>$ 8 m) optical reflectors, offering close to 5000 interferometric baselines, ranging from 50 m to more than 1000 m. SII implementation on IACT arrays will enable high resolution ($<$ 0.1 mas) imaging at short wavebands (B/V bands), which are optimal for study of hot stars.

*Key Words:* gamma rays: observations — instrumentation: interferometers — stars: imaging — techniques: high angular resolution — techniques: interfereometric



## 1. INTENSITY INTERFEROMETRY TECHNIQUE

The intensity interferometry technique measures the mutual coherence $|\gamma(d)|^2$ from fast temporal correlations between narrow optical waveband intensity fluctuations $\Delta i_1$ and $\Delta i_2$ observed by two (or more) telescopes separated by a baseline distance $d$ (Labeyrie et al. 2006):

$$|\gamma(d)|^2 = \frac{< \Delta i_1 \cdot \Delta i_2 >}{< i_1 >< i_2 >}, \qquad (1)$$

$|\gamma(d)|^2$ is the normalized Fourier transform of the source intensity angular distribution according to the van Cittert-Zernike theorem. When measuring $(\gamma(d))$, the signal to noise ratio (S/N) is determined by the shot noise in the incoming photon stream from each telescope:

$$(S/N)_{\rm RMS} = A \cdot \alpha \cdot n(\lambda)|\gamma(d)|^2 \sqrt{\Delta f \cdot T/2}, \qquad (2)$$

where A is the light collection area of one telescope, $n(\lambda)$ is the photon spectral density and $\alpha$ is the quantum efficiency (Hanbury-Brown 1974; LeBohec & Holder 2006). For typical telescope parameters (A $=$ 100 m$^2$, $\alpha$ = 30% and $\Delta$f = 100 MHz) and five hours of observation, a single baseline can provide measurements of $|\gamma|^2 = 0.3$ and $|\gamma|^2 = 0.03$ for a star with visual magnitude 4.8 and 2.4, respectively, with a 5$\sigma$ statistical significance. A key point is that the correlation $\gamma$(d) does not rely on the relative phase of optical waves at the different detectors This makes the technique relatively insensitive to atmospheric turbulence, allowing it to be used in the U and V bands(Daniel et al. 2009).

## 2. USING GROUND-BASED VHE GAMMA-RAY TELESCOPE ARRAYS FOR SII

Imaging Air Cherenkov Telescopes (IACT) are used for gamma-ray astronomy at Very High Energies (VHE, energies greater than 100 GeV). The IACT technique relies on the fact that VHE particles and gamma-rays initiate extensive air showers of high energy secondary particles in the atmosphere. Charged shower particles with sufficient speed will radiate optical Cherenkov light into the atmosphere. The Cherenkov light is detected by large ($>$ 10 m diameter) light collectors with excellent U/V band reflectivity equipped with fast electronics(Weekes 2003). IACTs are used in widely-spaced distributed arrays, employing 100 m inter-telescope distances to record stereoscopic views of each air shower. Because the design requirements of IACT arrays and SII arrays are generally similar, these observatories could be used for both types observation.

[1]Department of Physics and Astronomy, University of Utah, 115 S 1400 E #201, Salt Lake City, Utah, 84112-0830 (dave.kieda@utah.edu, lebohec@physics.utah.edu, nunez.paul@gmail.com).

[2]Corresponding Author.

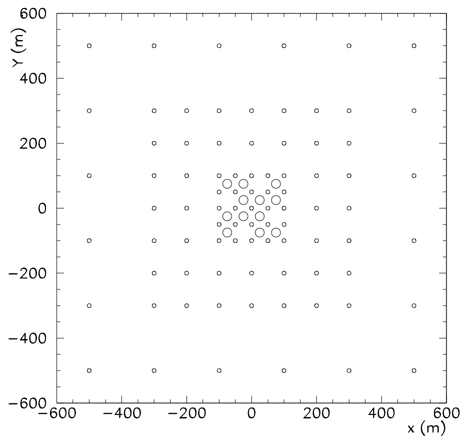


Fig. 1. One proposed lay-out for the future CTA Observatory. This configuration incorporates 85 100 $\mathrm{m}^2$ dishes (small dots) and twelve 600 $\mathrm{m}^2$ dishes (large dots).

However, the large point spread function and mirror an-isocronicity in IACT telescope design imposes constraints on the limiting magnitudes of stars than may be SII imaged (LeBohec & Holder 2006; LeBohec et al. 2008; Daniel et al. 2009).

## 3. CAPABILITIES OF AN SII IMPLEMENTED WITHIN THE CTA/AGIS IACT ARRAYS

Next generation IACT arrays such as CTA (CTA 2009) and AGIS (AGIS 2009) are planned for construction and operation during the decade 2010–2020. These square kilometer arrays will use up to 100 telescopes (Figure 1) providing up to 5000 base-lines ranging from $\sim 50\,\mathrm{m}$ to $\sim 1.4\,\mathrm{km}$. Calculations indicate that a CTA-type IACT array used as an SII observatory would allow direct imaging on angular scales between several mas to less than 0.1 mas(Daniel et al. 2009). In particular, a five hour observation by a single pair of CTA 600 $\mathrm{m}^2$ telescopes will provide $|\gamma|^2 = 0.3$ and $|\gamma|^2 = 0.03$ measurements for visual magnitude 6.7 and 4.3 stars, respectively.

The SII technique provides a measurement of the magnitude of the Fourier transform of the image, but does not directly measure the phase information of the Fourier transform. Several phase reconstruction techniques have been proposed which employ higher order intensity correlations to recover the phase information (Gamo 1963; Fontana 1983; Marathay et al. 1994; Vildanov et al. 1998). One method exploits the analyticity properties of the Fourier transform to establish a relation between finite differences in the magnitude and in the phase of the Fourier transform (Holmes & Belen'kii 2004). A typical implementation used to recover high resolution source images with a CTA-like array is illustrated in Figure 2.

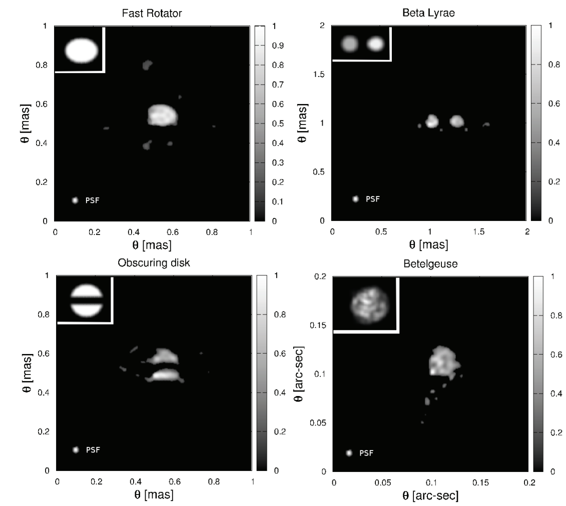


Fig. 2. Four examples of reconstructed images from a simulated SII observation using an IACT telescope array. The simulation uses a wavelength of $\sim 400\,\mathrm{nm}$ with one hundred CTA-like telescopes and a inter-telescope separation of $\sim 100\,\mathrm{m}$. The pristine image is shown at the top left in each example. The images were produced (Nunez & LeBohec, in prepararion) using an algorithm based on the Cauchy-Riemann equations (Holmes & Belen'kii 2004). The analysis does not yet include a realistic noise component.

This method has been demonstrated to be very robust against potential noise contamination (Holmes, in preparation). These reconstruction techniques are currently still in the development stage.

## REFERENCES

AGIS 2009, `http://gamma1.astro.ucla.edu/agis`

CTA 2009, `http://www.mpi-hd.mpg.de/hfm/CTA/`

Daniel, M., de Wit, W. J., Kieda, D. B., LeBohec, S., Nunez, P., & Ribak, E. 2009, arXiv:0906.3276v1

Fontana, P. R. 1983, J. Appl. Phys., 54, 473

Gamo, H. 1963, J. Appl. Phys., 34, 875

Hanbury-Brown, R. 1974, The Intensity Interferometer. It's application to astronomy (London: Taylor & Francis)

Holmes, R. B., & Belen'kii, M. S. 2004, J. Opt. Soc. Am. A, 21, 697

LeBohec, S., et al., 2008, in AIP Conf. Proc. 984, The Universe at Sub-second timescales, ed. D. Phelan, O. Ryan, & A. Shearer (Melville: AIP), 205

LeBohec, S., & Holder, J. 2006, ApJ, 649, 399

Labeyrie, A., Lipson, S. G., & Nisenson, P. 2006, An Introduction to Optical Stellar Interferometry (Cambridge: Cambridge Univ. Press)

Marathay, A. S., Hu, Y. Z., & Shao, L. 1994, Opt. Eng., 33, 3265

Vildanov, R. R., et al. 1998, Turkish J. Phys., 22, 949

Weekes, T. 2003, Very High Energy Gamma-Ray Astronomy (Bristol, UK: Institute of Physics)