The Potential for Intensity Interferometry with γ–Ray Telescope Arrays

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Abstract

Intensity interferometry exploits a quantum optical effect in order to measure objects with extremely small angular scales. The first experiment to use this technique was the Narrabri intensity interferometer, which was successfully used in the 1970s to measure 32 stellar diameters at optical wavelengths; some as small as 0.4 milli-arcseconds. The advantage of this technique, in comparison with Michelson interferometers, is that it requires only relatively crude, but large, light collectors equipped with fast (nanosecond) photon detectors. Ground-based γ-ray telescope arrays have similar specifications, and a number of these observatories are now operating worldwide, with more extensive installations planned for the future. These future instruments (CTA, AGIS, completion 2015) with 30-90 telescopes will provide 400-4000 different baselines that range in length between 50 m and a kilometre. Intensity interferometry with such arrays of telescopes attains 50 μ-arcsecond resolution for a limiting m_v~8.5. Phase information can be extracted from the interferometric measurement with phase closure, allowing image reconstruction. This technique opens the possibility of a wide range of studies amongst others, probing the stellar surface activity and the dynamic AU scale circumstellar environment of stars in various crucial evolutionary stages. Here we focus on the astrophysical potential of an intensity interferometer utilising planned new γ-ray instrumentation.

Introduction

Optical intensity interferometry (I.I.) offers considerable advantages over Michelson interferometry over a large wavelength band by requiring less complex and therefore cheaper instruments, as demonstrated by the Narrabri intensity interferometer [1]. Several years ago it was noted that the optical requirements for an I.I. closely matched those of imaging atmospheric Cherenkov telescopes (IACTs) used in ground based γ-ray astronomy, chiefly a very large mirror area of modest optical quality. Since large arrays of IACTs are being planned it seems timely to explore the science benefits that the sharing of the optical systems of such an instrument would bring.

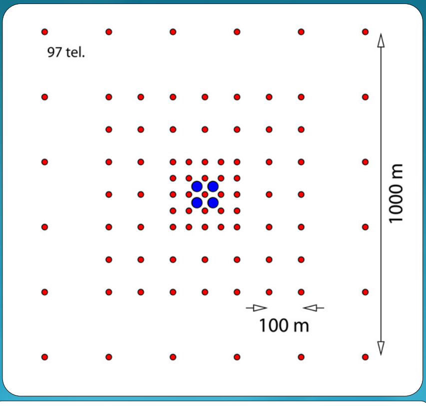

Figure 1: Possible layout for CTA. Small red dots are the 85 100m² dishes, large blue dots are the 4 600 m² dishes.

Cherenkov Telescope Arrays

The current generation of IACT arrays, such as VERITAS [2] and H.E.S.S. [3], comprise four telescopes each of 12m diameter compound mirrors (~100m² reflecting area) with on-axis point spread functions of FWHM≈0.05°. The telescopes carry pixelated cameras of photomultiplier tubes, with quantum efficiencies peaking in the blue, matching the Cherenkov spectrum. Telescope baselines are between 40m and 170m, depending on array layout and telescope spacing. The advanced γ-ray Imaging System (AGIS) [4] and the Cherenkov Telescope Array (CTA) [5] are proposed initiatives for an order of magnitude increase in sensitivity by constructing arrays of more and/or larger telescopes covering an area of ~1km². Figure 1 shows a potential layout of CTA, which would have 85 identical telescopes provide 3570 potential pairings that give 47 closely-spaced unique baselines ranging between 50m and 1000m.

I.I. with future IACTs is likely to operate in the visible wavelength region. The limiting magnitudes of the CTA layout shown in figure 1 are given in figure 2, along with the angular size scales they would probe. These specifications allow important studies regarding binary stars, stellar radii and pulsating stars with unprecedented resolution on scales of 10s of μ-arcseconds. Three of the potential science topics are highlighted below.

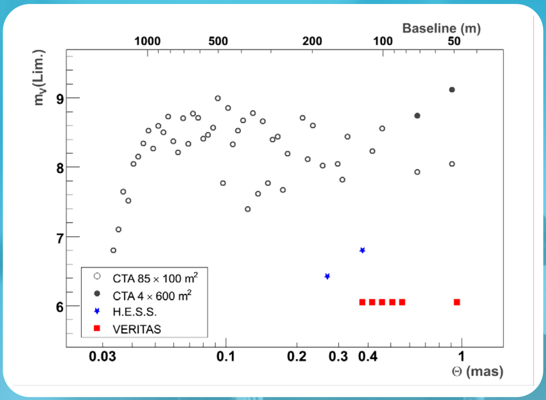

Figure 2: estimate of CTA sensitivity for I.I. as a function of the 47 non-redundant baselines for a 5σ detection in a 5 hour integration with 50% visibility.

Science Objectives

Star Formation

Key questions relating to the physics of mass accretion and pre-main sequence (PMS) evolution can be addressed through I.I. being able to resolve features on the stellar surface. Hot spots deliver direct information regarding accretion of material onto the stellar surface. Imaging of cool spots will constrain ideas regarding the interplay of rotation, convection and chromospheric activity. It is estimated that about 50 young stars with $m_v<8^m$ and ages in the range 8-50Myr are within reach of future IACTs. Measurements of their angular size can be used in the calibration of evolutionary tracks and deriving the properties of star forming regions and young stellar clusters.

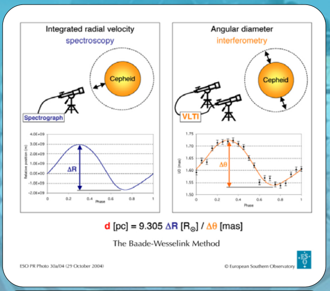

Figure 3: Schematic of the Baade-Wesselink method and Iinterferometry being used to constrain Cepheid variable paramteters..

Distance scales

Measuring the diameters of Cepheid variables with I.I. has far reaching implications, when combined with other measurements. The Baade-Wesselink method takes the luminosity and colour of a variable star at two times, t_1 and t_2, and combined with spectral measurements of the radial velocity provides an estimate of the radius. By adding in the I.I. angular size measurement one obtains the distance to the Cepheid and allow the calibration of the all important Cepheid period-luminosity relationship. Hipparcos shows that at least 60 Cepheids with $m_v<8^m$ are available to future I.I.-IACTs.

Rapidly Rotating Stars

Photospheric absorption lines show Be stars are close to break-up rotational velocities. Also, Balmer line emission show gaseous circumstellar discs that appear and disappear on timescales of months to years. These two properties are somehow related, but have many open questions about the detailed physical processes at play. Gravity darkening at the equator and brightening at the poles will always hamper absorption line measurements of rotational velocity, something which direct measurement of the shape of the rotating star is not (as demonstrated by VLTI observations of α-Eri [6]). Photometric studies indicate that the discs may evolve into ring structures before disappearing in to the interstellar medium, something that I.I. would be able to probe. There are about 300 Be stars brighter than $m_v=8^m$, roughly corresponding to a distance limit of 700pc.

Conclusions

Intensity Interferometry using the telescopes of future IACT arrays, such as CTA and AGIS, has the potential to make a major impact in several areas of stellar astrophysics and beyond. Whilst much research and development in this area is still required, such a major instrument could be realised at rather modest cost and as early as 2015.

References

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