

Technical Report 14

INTERFEROMETRIC IMAGING WITH THE NNTT

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The following are a set of notes produced for a presentation to the AURA NNTT Scientific Advisory Committee meeting on September 30, 1983. They include a number of unpublished concepts which, when used in reports or publications, should be referred to as MMT0 Technical Report Nr. 14. I have broken down these notes in the following set of sections and subsections.

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Appendices:

- A. J.M. Beckers, E.K. Hege, H.P. Murphy: The Differential Speckle Interferometer, SPIE Proceedings 445, paper 63.
- B. J. M. Beckers: Specifications for MMT Primary Mirror Performance, MMTO Technical Memorandum 82-18.
- C. J.M. Beckers, E.K.Hege, P.A. Strittmatter: Optical Interferometry with the MMT, SPIE Proceedings 444, paper 13.
- D. J.M. Beckers: A New Scheme to Coalign and Cophase a MMT Type Telescope, MMTO Technical Memorandum 83-9.
- E. J.M. Beckers, E.K. Hege: Combining the 6 MMT Beams with Minimum Amount of Effort, MMTO Technical Memorandum 82-20.
- F. J.M. Beckers: Optimizing Polygonal MMT Arrays for Maximum (u,v) Plane Coverage, MMTO Technical Memorandum 83-10.

1. SCIENTIFIC IMPORTANCE OF INTERFEROMETRIC IMAGING

I refer to the proceedings of the March 1981 ESO conference on the "Scientific Importance of High Angular Resolution at Infrared and Optical Wavelengths" (hereafter referred to as ESO) for an extensive discussion of this topic.

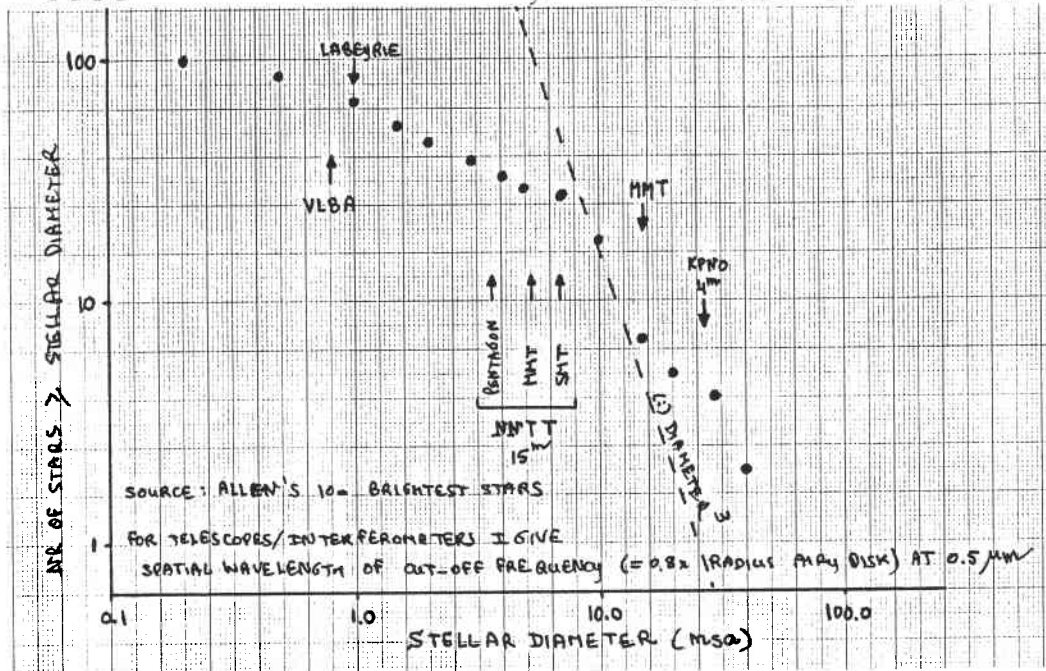
1.1 High Angular Resolution Imaging

This must be the prime reason for using the NNTT in an interferometric mode. Imaging means not only the determination of a single image parameter like the stellar diameter or the separation of a binary but the determination of the intensity distribution across the object under study if possible with spectrum and polarization analysis. Some astronomical examples:

1.1.1 Binaries - The most successful application of interferometric techniques have been the studies of over 600 binaries both in the optical and IR regions of the spectrum because of the simplicity of the object intensity structure and because of the relatively large separations available (in the 0.04 - 1.0 arc second range). Results give important information on orbits, stellar masses, M-L relation, and invisible companions of astronomic binaries. Techniques for determining separations and luminosity ratios are well advanced. The NNTT will push towards smaller separations.

1.1.2 Stars - Application of interferometric imaging techniques has been much harder because of the fact that even the three largest northern hemisphere stars (α ORI, α SCO, α HER) are only marginally resolved (star diameters ~ 40 millisecond of arc (msa), KPNO 4^m resolution at $0.5 \mu m \sim 30$ msa). Many stellar diameters have been measured by means of two mirror amplitude and intensity

interferometry. The NNTT will bring many stars within reach for full imaging (resolution 4-8 msa in the optical). Astrophysical interest lies in the study of stellar surface structure,



convection, starspots, magnetic fields, stellar chromospheres and coronae, stellar rotation, oblateness, dust shells, etc., etc.

1.1.3 Galactic Nuclei - Perhaps marginally resolved in some objects with present telescopes, the size and structure of Seyfert Galaxy nuclei and other Active Galactic nuclei is of major importance for the understanding of the physics of these objects and for the identification of energy sources which may fuel quasars and BL Lac objects. Imaging of the latter themselves promises major advances in the understanding of the universe.

1.1.4 Solar System Objects - Speckle interferometry has been successful in the imaging of asteroids resulting in an improved understanding of the properties of these objects. It played a major role in the determination of the Pluto-Charon system. One looks forward to the use of the NNTT for the study of such diverse

objects as asteroids and the surface structure of satellites like Io. The NNTT will enable us to get $\sim 10^4$ resolution elements on Io. It will complement the fly by observations of this Jupiter satellite by providing time series of its surface activity.

1.2 IR Photometry

Another reason for interferometric imaging with the NNTT is the decrease of the sky background and its variations by the use of a smaller aperture which it allows. This directly increases the sensitivity in those cases where the photometry is background limited resulting in fainter limiting magnitudes.

1.3 Present Limitations.

In addition to the diameters of optical/IR telescopes, interferometric imaging is limited by the data analysis facilities and detectors available. I will come back to that in Sections 4 and 5. Another major limitation is the theory of image reconstruction from data which is badly disturbed by the earth's atmosphere. Major efforts are being made to overcome the problems imposed by the atmosphere. Various existing algorithms (Fienup, Knox-Thompson, Shift and Add, etc.) and new ones are likely to be available for use when the NNTT is completed. Differential Speckle Imaging (Appendix A) and phase referencing techniques are already functioning well.

1.4 NNTT Amplitude Interferometry vs Other Techniques

Other techniques exist for high angular resolution observations. These complement the research which can be done with the NNTT interferometric imaging rather than duplicate it. The Brown-Twiss intensity interferometer has (and can) measure stellar diameters to submillisecond of arc precision but only on

the brightest stars. It does not give images. Its main advantage lies in the loose tolerances it places on the phasing of the telescopes (~ 10 cm). The Labeyrie and Davis Amplitude Interferometers require precise phasing but can in return go much fainter. They cover a larger baseline than the NNTT but only cover three small patches in the image-Fourier Transform (or (u,v) plane) vs a filled (u,v) for the NNTT (see Section 2.3). In principle these amplitude interferometers may be able to image an object by doing image synthesis similar to the techniques used in radio astronomy. It is, however, cumbersome and time consuming. Optical/IR Heterodyne Interferometry using lasers as oscillators and detectors as mixers has been successfully used at some infrared wavelengths for cases where the limited sensitivity resulting from the $\sim 10^8$ Hz intermediate frequency (vs 3×10^{13} Hz at $10.6 \mu\text{m}$ and 5×10^{14} at 600 nm) is not a problem (Townes ESO pp 199). Because of its closeness to radio astronomy interferometry techniques, all or most of the algorithms developed in that field can be applied.

2. REQUIREMENTS PLACED ON NNTT ITSELF BY INTERFEROMETRY

In this section I will summarize the requirements placed on the NNTT when used for interferometric imaging. Where appropriate I will compare the present Segmented Mirror Telescope (SMT) concept and Multiple Mirror Telescope (MMT) concept with these requirements.

2.1 Phasing Precision

If there were no atmosphere to interfere with the imaging, the phase precision at which the electromagnetic waves are to