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BLINC: a testbed for nulling interferometry in the thermal infrared

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ABSTRACT

A key technology in NASA's plans for a Terrestrial Planet Finder (TPF) is nulling interferometry in the thermal infrared. This technique suppresses the overwhelming light from a star in order to study its immediate surroundings. To further develop nulling interferometry we have built the BracewelL Infrared Nulling Cryostat (BLINC). The instrument is designed to achieve high precision cancellation of an artificial source in the lab and of starlight on the telescope. Our goal is to achieve suppression of >10,000 both with a laser source and a broadband source over a 20% bandwidth. This is sufficient for ground-based observations with even short baseline interferometers since the finite diameter of the star does not allow suppression greater than that for most nearby sources. BLINC uses two parts of the MMT pupil to create an interferometer of 2.7 m diameter elements separated by 4 m. Active compensation for phase variations between the two apertures will be used to maintain the cancellation of the starlight in the presence of atmospheric turbulence. When combined with the adaptive secondary of the MMT to remove high order aberrations, BLINC will be able to achieve suppression of 10,000. This will allow detection of zodiacal dust around nearby stars as faint as 10 times the solar level and detection of companions large than 10 Jupiter masses for systems less than one billion years old. BLINC serves as a prototype for nulling with the Large Binocular Telescope which will be able to see zodiacal dust as faint as solar level and Jupiter mass or larger companions. Thus both in technological and scientific background BLINC will help begin the search for Earth-like planets.

Keywords: nulling, interferometry, infrared, planet finding

1. INTRODUCTION

Looking for extrasolar planets by attempting to directly detect them is an extraordinarily difficult problem due to their relative faintness (10^6-10^7 in the infrared) compared to their parent star and their small separation from the star (0.1 " for a planet 1 AU from its star at 10 pc). To successfully detect a planet with normal imaging a telescope many tens of meters in diameter would be needed to provide the required spatial resolution. Nulling interferometry is a technique first proposed by Bracewell (1978) to overcome this problem. The method uses two modest size apertures whose light is suitably interfered to cancel out the overwhelmingly brighter star. By ridding the focal plane of the photon noise associated with the star it is possible to detect much fainter circumstellar structure and companions than would be otherwise possible.

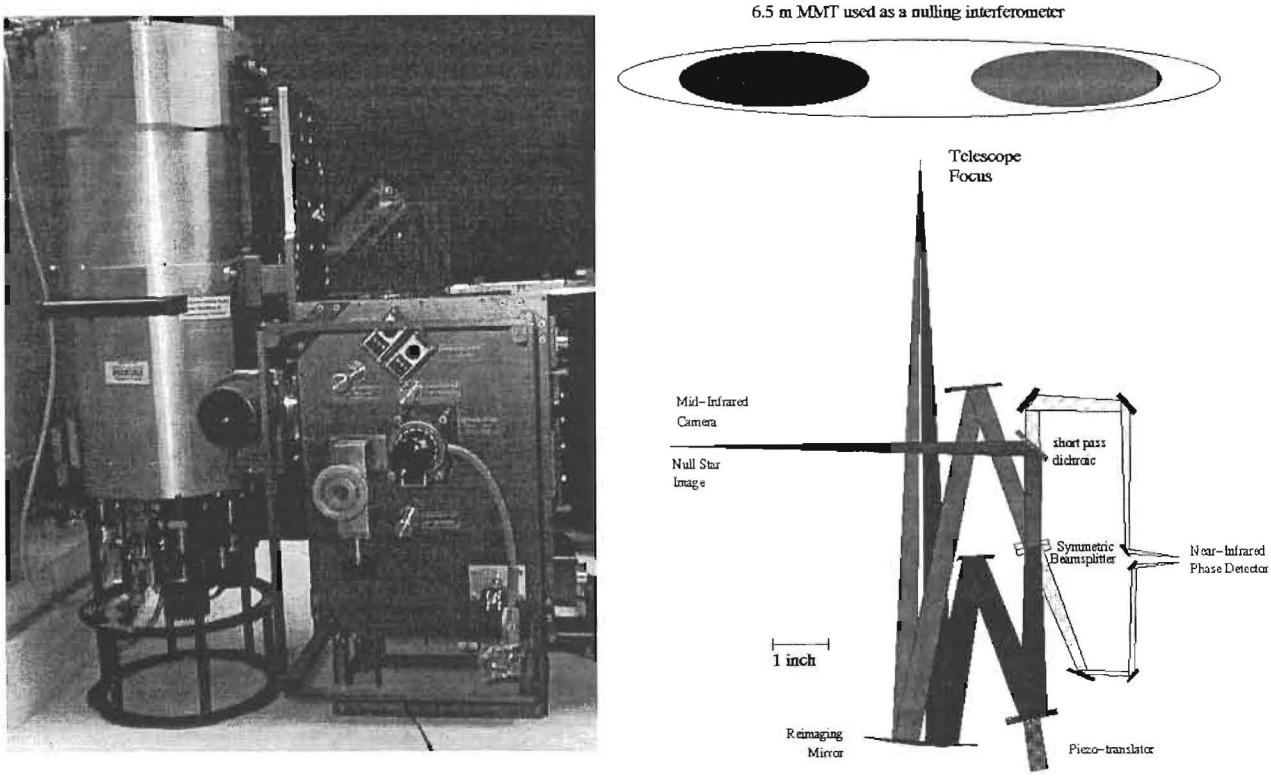
We first demonstrated the feasibility of nulling interferometry in the infrared using two of the six mirrors of the Multiple Mirror Telescope (MMT). A simple beamcombining setup was constructed to combine the light from the two telescopes out of phase. Atmospheric turbulence limited us to a nulled image with a peak of 4% of the constructive image. Even with this level of suppression we were able to begin studying circumstellar environments. For example, we were able to form a direct image of the dust outflow surrounding Betelgeuse free of starlight contamination (Hinz et al. 1998).

2. THE BRACEWELL INFRARED NULLING CRYOSTAT (BLINC)

Based on our first experiments with telescope nulling we have designed and built an interferometer for the refurbished 6.5 m MMT. A photograph of the instrument and optical layout is shown in Figure 1. Although the optical layout is similar there are several improvements compared to the prototype instrument. To increase sensitivity we have enclosed the interferometer in a cryostat. Alignment and phasing of the interferometer is possible with the instrument cooled and evacuated using a number of feedthrough actuators in the case. The cryostat was built by Infrared Laboratories, Inc. of Tucson, Arizona.

The method we use to achieve achromatic suppression of light balances a slight excess of path-length in one beam with a suitable thickness of dielectric in the opposite beam. Using only a difference of path-length to achieve the half wave phase difference allows suppression over only a very small bandwidth. Inserting a suitable thickness of dielectric (in our case ZnSe) in the opposite beam allows us to balance the dispersion in the path-length difference with the dispersion in the dielectric. This technique permits a very simple beam combination while allowing a suitably wide bandpass for suppression.

In addition this technique has two advantages not possible with other techniques that rotate one pupil with respect to the other to achieve the null. First, it is possible to arrange the number of reflections in each beam to be equal so that the images from the two sides of the interferometer are identical, and not mirror images of one another. Other ways of achieving a null require that any off-axis sources form two mirror images to either side of the nulled source. The dielectric technique allows us better sensitivity to faint companions by being sensitive to a centroid shift of the nulled light due to an off-axis source. It also allows us to form direct images of more complex structures such as circumstellar disks. The second advantage of using the dielectric approach is the ability to actively control the null using shorter wavelength light. Since our method of achieving a null is only "pseudo-achromatic", that is, achromatic only over our science passband, it is possible for the shorter wavelength light to have a phase difference between the beams which is markedly different from half of a wave. The design of our beamsplitter provides for a ¾ wave phase shift at 2.2 μm when it is a ½ wave at 11 μm. A ¾ wave phase shift corresponds to light which is halfway between constructive and destructive interference for both outputs of the beampslitter. Any variation in path-length between the two arms will be detected by one output getting dimmer while the other output gets brighter. For example, a 10 nm path change corresponds to a 6% change between the brightness of the 2.2 μm images, a differential signal that would be easy to detect for a bright star, but would only cause the null residual at 11 microns to be 2×10^{-5}. We point out that the technique is completely common path with the nulled light, does not degrade the signal to noise ratio of the nulled light, and is unique to the pseudo-achromatic way of achieving the null.



Optical layout of the Bracewell Infrared Nulling Cryostat (BLINC)

Figure 1. The BLINC and MIRAC3 dewars being tested in the lab. BLINC is the rectangular dewar. The optical schematic of BLINC is shown to the right. The interferometer splits the light from the telescope into the beams shown. These beams are combined at a symmetric beamsplitter. The 10 μm light is then sent to MIRAC while the 2 μm light is detected within BLINC.

The science camera we use for observations is MIRAC3, with an Arsenic doped Silicon array detector. The camera was built and is maintained by Bill Hoffmann as a joint project of the Smithsonian Astrophysical Observatory and the NSF. The camera optics allow us to form a single pupil stop for both arms of the interferometer after the beams have been combined in BLINC. It has a wide selection of filters available as well as a grism for dispersing the nulled light. This will be useful in diagnosing how the suppression varies with wavelength and in analyzing the residual light for evidence of silicate emission or other features expected in circumstellar disks. The two instruments are separated by a gate valve with a window inserted

in the flange. This allows the instruments to be operated separately if, for example, we wish to have BLINC open to the air, or to remove this window when both instruments are cooled and evacuated to increase the sensitivity. Due to this modularity it is possible to operate BLINC with different science cameras. In addition to MIRAC3 we plan to operate it with a HgCdTe array based camera capable of 4-5 μm operation.

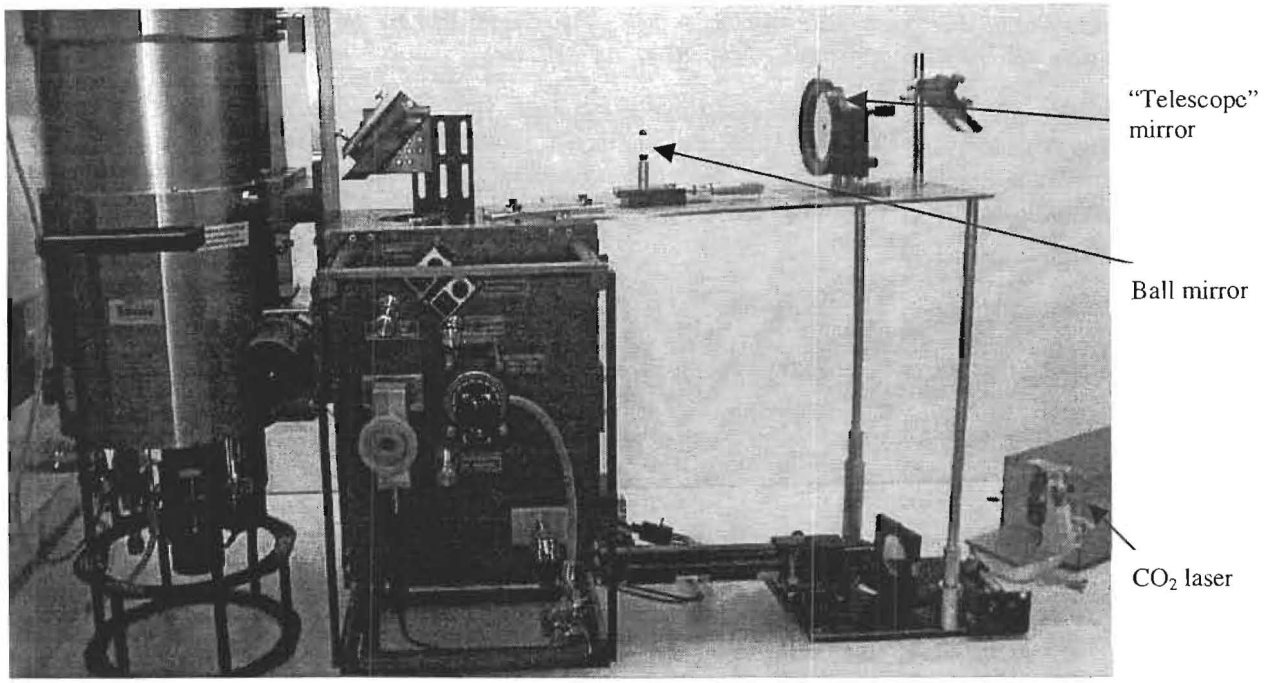


Figure 2. Laboratory setup to test nulling with BLINC. The CO_2 laser strikes a ball mirror illuminating a spherical light which creates a f/9 converging beam. The light is brought by a final fold mirror into BLINC and focused onto a 5 μm pinhole forming the artificial star.

3. TELESCOPE AND LABORATORY TESTS

BLINC has a dual purpose of exploring the limits of nulling both in the laboratory and on the telescope. We have tested the instrument on the Bok 2.3 m telescope on Kitt Peak in February 2000. The weather was poor enough to keep us from achieving a good null, but we were able to verify the ability to align and phase the instrument on the telescope. The instrument will be tested out soon on the 6.5 m MMT. It will be operated initially without any adaptive correction of the wavefront. The atmospheric turbulence will limit our suppression to approximately 1%, enough to begin looking at bright circumstellar material such as outflows around AGB stars. When the MMT's deformable secondary is ready BLINC will be coupled to it providing suppression of up to 10^4 with only two warm reflections in the beam. This will allow us to begin searching for fainter structure around nearby stars such as zodiacal dust and substellar companions for main sequence stars.

Laboratory tests have just begun with BLINC. The goal of the tests will be to show we are capable of achieving a null with 10^{-4} residual light over a 20% bandwidth in both polarizations. Our artificial "star" is a 5 μm pinhole placed at the focal plane of the telescope which is just inside the top surface of BLINC. This pinhole can be illuminated by a tunable CO_2 laser or a halogen light bulb for monochromatic or broadband tests of the instrument. The setup for laboratory tests is shown in Figure 2. Our current best results using a CO_2 laser are shown in Figure 3. The integrated residual light in the nulled image is 3×10^{-4} of the constructively interfered image. The best null achieved with a broadband source is a 2% residual over a 50% bandwidth. Both of these are preliminary results.

4. SCIENCE GOALS

As a nulling interferometer BLINC will be most useful in furthering our understanding of circumstellar environments that are too faint to see with conventional imaging. Our main goal at 10 μm is to characterize zodiacal type dust around nearby pre-main sequence and main sequence stars. Particularly it will be useful to use the interferometer to understand whether the far infrared excess around Vega-type stars first discovered by IRAS has any faint mid infrared component from dust closer to the

star. Coupled with the deformable secondary, BLINC will be able to detect circumstellar material down to 10-20 times the level of zodiacal dust in our solar system for the nearest stars (Hinz et al. 1999). This will be interesting both for our understanding of the evolution of planetary systems and to begin defining the requirements for a terrestrial planet finding mission. In addition BLINC will be able to search nearby stars for evidence of substellar companions by direct detection of their infrared emission. The models of Burrows et al. (1997) show that an ideal place for this is in the 4-5 μm region, where giant planets and brown dwarfs are unusually bright. We estimate that BLINC will be able to detect planets down to 10 Jupiter masses at 1 Gyr old for the nearest stars (Hinz et al. 1999).

The development of BLINC serves as a prototype nulling interferometer for the Large Binocular Telescope (LBT) now under construction (Hill and Salinari 2000). The common mount and deformable secondaries of the LBT make the telescope a uniquely powerful instrument for studying circumstellar environments. For example, at 10 μm we expect the LBT to be sensitive to zodiacal dust down to solar level, and at 5 μm to be able to detect 1 Jupiter mass companions as old a 1 Gyr for nearby stars (Hinz et al. 1999).

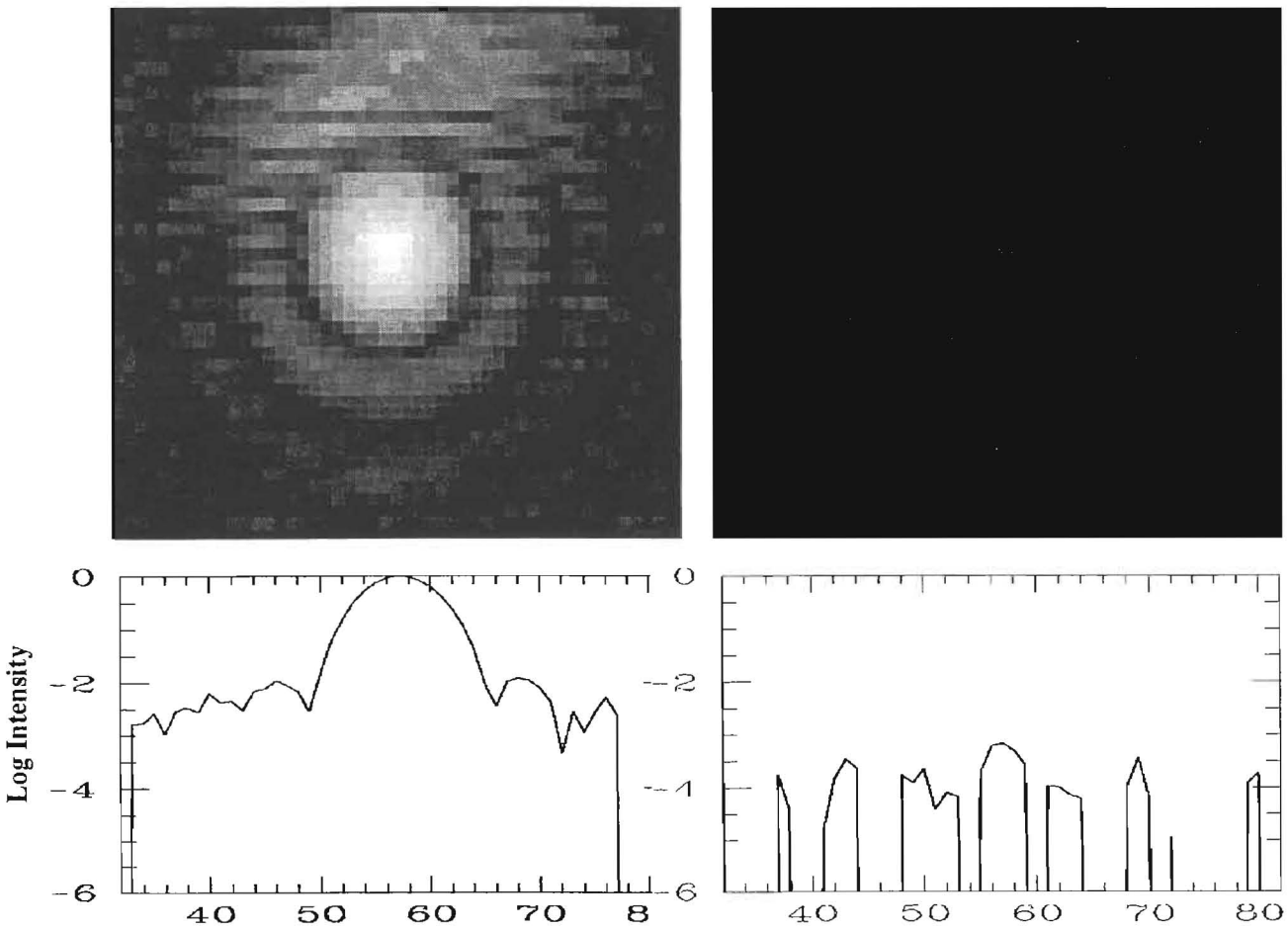


Figure 3. Images of the artificial source at constructive and destructive interference of the interferometer. The images are logarithmically scaled to show the large variation in brightness. The integrated flux of the nulled image is 3×10^{-4} of the constructive image. The light of the entire Airy pattern of the source as well as the scattered light near the top of the image disappears in the nulled image. Integration time was 0.5 s for both frames.

5. ACKNOWLEDGEMENTS

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