LMIRcam 3 - 5 μm Imager for the LBT Combined Focus

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LMIRcam is a 3 - 5 μm imaging system that will reside within the 10 μm Nulling Infrared Camera (Hinz et al) for operation at the coherent combined focus of the two mirrors of the Large Binocular Telescope (LBT). LMIRcam is being developed by a collaboration of the Univ. of Virginia, Univ. of Minnesota, Notre Dame and the Univ. of Arizona and is funded by the NSF and UVa.

The LBT's two 8.4-meter mirrors, separated by 14.4 meters on a single steerable platform, enable Fizeau (direct imaging) interferometry with 30 mas resolution at 4 μm over a field-of-view limited only by the isoplanatic angle. The maximum baseline of the two mirror configurations is 22.8-meters.

Instrument Design

LMIRcam and a 10 μm nulling camera (NIC) share the same cryogenic volume. After phase correction and coherent combination by the Universal Beam Combiner (UBC), the combined light of the LBT will come to a focus within NIC. A dichroic downstream of the combined focus will transmit short wavelength (< 5 μm) light into LMIRcam. Biconic 1 forms an intermediate focus where coronographic occulting masks and field stops/slits can be positioned on a wheel. The diverging light beyond the intermediate focus is re-imaged for a final time by Biconic 2 onto a Teledyne Imaging Systems Hawaii-1RG 5 μm cut-off HgCdTe array. The plate scale on the array will be 0.01"/pixel to take advantage of the angular resolution of the LBT. An image of the system pupil occurs just before the detector. Wheels for filters, coronographic pupils and grisms will be placed at this pupil image.

PSF

The Universal Beam Combiner (UBC) of the LBT Interferometer (LBTI) will, in conjunction with adaptive secondaries on each of the LBT's two primary mirrors, deliver near diffraction limited images to a combined Fizeau focal plane. Since the LBT pupil is a convolution of a single 8.4-meter aperture with a pair of delta-functions spaced by D=14.4-meters, the "horizontal" axis of the point source PSF is the product of the Airy disc of an 8.4-meter aperture multiplied by a double-slit diffraction pattern. The "vertical" axis of the point source PSF represents an Airy disk of a single 8.4-meter aperture. For this configuration the secondary peak intensity is 42% of the primary peak. The first null is located at λ/2D corresponding to 26 mas at 3.6 μm and 34 mas at 4.8 μm. The Strehl ratio is anticipated to exceed 80% at 3.6 μm and 90% at 4.8 μm. The small angular image size minimizes thermal background contamination yielding remarkably good sensitivity.

Science with LMIRcam

LMIRcam's high angular resolution and sensitivity will enable the direct imaging of extrasolar planets and the study of Galactic Star Formation (resolve structure in nearby accretion disks and resolve clusters containing massive protostars), extragalactic star formation, mass loss from evolved stars, dusty AGN and Quasars, gravitational lenses in the mid-infrared, and provide synergy with Spitzer, WISE and ALMA.

Direct Imaging of Extrasolar Planets

The unique high spatial resolution mid-infrared (MIR) capability of LMIRcam is well suited to the detection of self-luminous jovian planets orbiting at radii of several AU around stars within 50 parsecs, and proto-jovian planets at similar orbital radii in nearby star forming regions. Planets with masses greater than 2 M_Jup remain warm and detectable by LMIRcam for up to a billion years after formation yielding many targets of appropriate age among the local (d < 50 pc) population. LMIRcam can thus provide a census of the prevalence of jovian worlds at moderate to large orbital radii, complementing the sensitivity of radial velocity studies at small orbital radii. Planetary detection with LMIRcam depends on the behavior of scattered light from the two mirror diffraction-limited PSF and the MIR strehl ratios anticipated for the AO secondaries.

Coronography

Given the anticipated high strehl of the images, coronography will further suppress the "Airy" fringes of the Fizeau images at image radii greater than the focal-plane coronagraphic stop radius of order 2λ/D. Because of significant thermal background at these wavelengths, diffraction suppression will not substantially increase signal-to-noise due to photon noise or atmospheric speckle variations. However, PSF subtraction is typically limited to slowly changing optical aberrations. Scattered light from these aberrations interfere with the diffraacted light to create semi-static speckles in the focal plane. A recent attempt with the MMT demonstrated a 5 σ limit delta magnitude limit of 10.5 at M-band (Hinz et al. 2006) for an angular distance of 1 arcsec (5.1/D). In this context, the benefit of coronographic suppression at thermal infrared wavelengths is to limit the amount of energy in the diffraction pattern to reduce the brightness of semi-static speckles. The scattered light in typical M-band AO images is 10% of the light distributed in a halo which is similar to the Airy pattern. The diffraction `rings' in an image interfere with this light to create a varying background. To eliminate this effect a reduction of the diffraction by roughly a factor of 100 is necessary. Such performance can be realized by a range of coronagraphic implementations that utilize pupil plane phase manipulations (Codona 2004, Kenworthy et al. 2007) or a combination of focal plane masks and pupil plane stops (Swartzlander 2006).