MegaMIR: The Megapixel Mid-Infrared Instrument for the Large Binocular Telescope Interferometer

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ABSTRACT

The Megapixel Mid-infrared Instrument (MegaMIR) is a proposed Fizeau-mode camera for the Large Binocular Telescope operating at wavelengths between 5 and 28 μm. The camera will be used in conjunction with the Large Binocular Telescope Interferometer (LBTI), a cryogenic optical system that combines the beams from twin 8.4-m telescopes in a phase coherent manner. Unlike other interferometric systems, the co-mounted telescopes on the LBT satisfy the sine condition, providing diffraction-limited resolution over the 40" field of view of the camera. With a 22.8-m baseline, MegaMIR will yield 0.1" angular resolution, making it the highest resolution wide field imager in the thermal infrared for at least the next decade. MegaMIR will utilize a newly developed 1024 x 1024 pixel Si:As detector array that has been optimized for use at high backgrounds. This new detector is a derivative of the Wide-field Infrared Survey Explorer (WISE) low-background detector. The combination of high angular resolution and wide field imaging will be a unique scientific capability for astronomy. Key benefits will be realized in planetary science, galactic, and extra-galactic astronomy. High angular resolution is essential to disentangle highly complex sources, particularly in star formation regions and external galaxies, and MegaMIR provides this performance over a full field of view. Because of the great impact being made by space observatories like the Spitzer Space Telescope, the number of available targets for study has greatly increased in recent years, and MegaMIR will allow efficient follow up science.

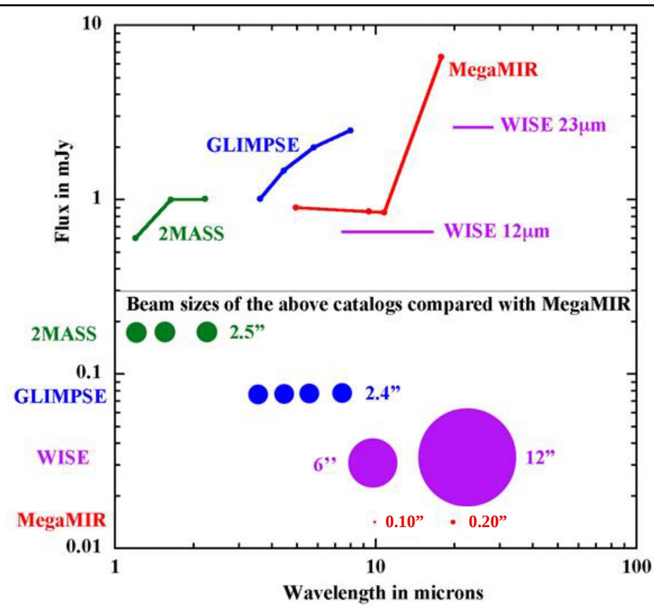

Figure 1: *A comparison of sensitivities and beam size between MegaMIR and various present and future ground and space based catalogs. The broadband sensitivities have been extrapolated from our experience with MIRLIN. Narrow band sensitivities will be slightly lower.*

1. INTRODUCTION

A large format infrared array, mounted on a large telescope at a good site, and operated at the diffraction limit in the thermal infrared, is a powerful tool for the exploration of the Universe at sub-arcsecond resolution. Such a system can dissect the dense cores of individual protostellar condensations, explore the structure and composition of planetary atmospheres, study individual star-forming complexes in the spiral arms of nearby galaxies, and separate the thermal and non-thermal components in active galaxies. Here we propose to exploit these benefits by linking the largest array available for 5-28 μm observations from the ground, a 1024x1024 Si:As array being developed by DRS Technologies (Mainzer et al. 2005), with the Large Binocular Telescope (LBT), a unique facility consisting of a pair of 8.4-m telescopes on a common mount. The LBT recently achieved two significant milestones – the announcement of "first light" using one of the primary mirrors, and the installation of the second primary mirror. MegaMIR will exploit the LBT's 22.8 m baseline in Fizeau imaging mode (Hinz et al. 2003) to yield angular resolution better than 0.1" at 10 μm over a 40" field of view. It will achieve almost 4 times the linear resolution, and almost 14 times the areal resolution, to be attained at the same wavelength by JWST. At the same time, it will have adequate sensitivity to follow up many of the interesting results from space missions such as the Spitzer Space Telescope and the Wide-field Infrared Survey Explorer (WISE). **MegaMIR will be the highest angular resolution wide field imager in the thermal infrared until the era of the 25-meter class giant telescopes.** The thermal infrared capability would complement the near infrared Fizeau camera LINC-NIRVANA being developed by a European consortium for the LBT (Herbst & Hinz 2004).

The new Si:As multiplexer is being prepared for fabrication at the foundry, and a fully operational sensor hybridized onto the multiplexer is expected in the October '06 time frame. NASA has funded the development of the Large Binocular Telescope Interferometer (LBTI, http://lbti.as.arizona.edu/). The LBTI is a cryogenically cooled instrument which is mounted on the center instrument platform of the LBT. The initial portion of the instrument is called the Universal Beam Combiner (UBC). It accepts beams from the left and right tertiaries and reimages them with reflective optics to provide a combined focal plane that is in phase across the full field of view of the beam combiner. MegaMIR will be fed by one of the optical ports of the UBC, resulting in the deployment of the world's largest ground-based mid-infrared camera on the world's largest telescope. The MegaMIR project builds on the experience of the JPL team in building and observing with MIRLIN, a 128x128 format thermal infrared that has been successfully used for a many years (Ressler et al. 1994). Table 1 summarizes the properties of MegaMIR as we envision it on the LBTI.

Operational Modes	
Imaging	5 – 28 μm
Spatial Resolution	0.10" @ 10 μm
Pixel Size	0.04"
Imaging Sensitivity (5-sigma, 1 hr)	0.8mJy @10um, 10mJy @ 20um
Instrument FOV	40 x 40"
Grism Spectroscopy	7 – 14 μm
Spectral Resolution	600 @ 7 μm; 300 @ 14 μm; 200 @20um
Filters Available	M; N; Qs; standard silicate set; 20 μm filter set; 7 – 14 μm Circular Variable Filter
Parameter	**Nominal Values**
Detector Material	High background Si:As
Array Size	1024 x 1024
Well Depth	Switchable; 5 x 10^6 or 9.6 x 10^4 e
Dark Current	128 e/s at T=8 K

Table 1: MegaMIR performance and capabilities on the LBTI.

MegaMIR's 1024x1024 array will have enough pixels to permit critical sampling over a 40" field of view on the 22.8-m baseline LBTI. As will be described below, this combination of high spatial resolution and a wide field will allow effective exploration of extended emission regions, including those taken from the Spitzer and WISE data bases. In addition, whole disk images of the large planets – Jupiter, Saturn, Mars, and Venus – can be obtained in a single exposure. For small extended sources, such as planetary nebulae, for example, MegaMIR's large field of view will permit on-chip chopping and nodding for maximum efficiency. For all these types of investigations, MegaMIR will be one to two orders of magnitude more efficient than current thermal infrared cameras, which use arrays no larger than 240x320 pixels.

Although no ground based thermal infrared camera will be as sensitive as Spitzer, MegaMIR's sensitivity will support systematic follow up of the brighter targets discovered by Spitzer, but with more than 800x the areal resolution. A particularly good example would be MegaMIR follow up of Spitzer's GLIMPSE survey. This survey of several hundred square degrees within 1 degree of the galactic plane is carried out with very short integrations and thus is a good match to MegaMIR's sensitivity. Figure 1 compares the projected broadband sensitivity of MegaMIR with the limiting fluxes of a number of data bases which will be mined for MegaMIR targets. Many of the millions of objects in these current and forthcoming data bases can be studied in detail by MegaMIR; with the higher resolution shown in Figure 1, MegaMIR can be effectively used to unravel complex or multiple sources found in these data bases.

We will incorporate grism spectroscopy into MegaMIR, achieving resolution as high as 500 at ~7 μm and extending into the 20 μm window as well. The resultant combination of long slit spectroscopy and high spatial resolution will enable important investigations with MegaMIR in planetary, galactic, and extragalactic science. With resolving powers of 300-to-600 in the 7-10 μm range, MegaMIR's grism mode will have significantly higher resolution than the Spitzer IRS (R~64-to-128).

With the success of Spitzer and the forthcoming results from WISE, mid-infrared astronomy is undergoing a revolution. MegaMIR – the large format, high sensitivity, high resolution camera – will provide a major increase in astronomers' capability to exploit the rich data bases of these missions. Even with the launch of JWST, MegaMIR will continue to provide unique high angular resolution capabilities.

2. MEGAMIR SCIENCE

As with any high performance, general purpose capability, MegaMIR can be expected to have impacts in many areas of astronomy. In this section we touch on fields that will take particular advantage of MegaMIR's unique characteristics.

2.1. Planetary Science

Venus, Mars, Jupiter, Saturn, can be imaged far more efficiently by a large-format camera than with the smaller formats currently available. In the mid-IR, angular resolution is dominated by diffraction rather than seeing. Thus, MegaMIR will combine the best spatial resolution available on Earth with the geometric control that is possible without mosaicking. In fact, the spatial resolution which could be achieved with MegaMIR on LBTI is, in general, better than has been achieved ***in situ*** by the infrared imaging instruments on Voyager, Galileo, or Cassini. Additionally, there is the additional advantage of observing almost the entire planet in one field of view. The whole-disk imaging possible with MegaMIR will enable time-resolved studies of variable phenomena with high efficiency, while the anticipated long operational lifetime of MegaMIR would enable synoptic studies as the planetary aspect changes relative to the sun.

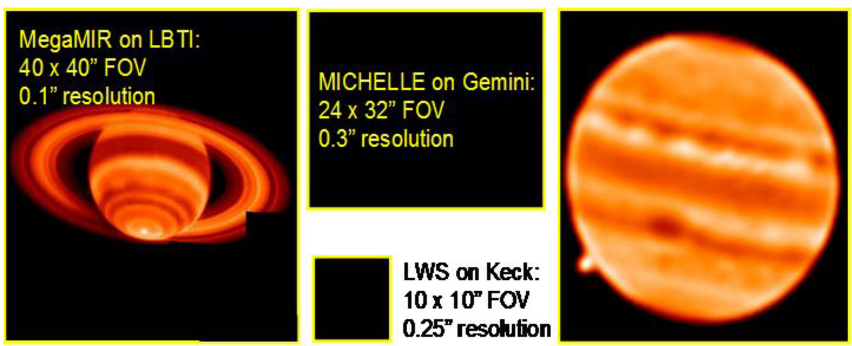

Figure 2: *Left panel is a full disk image of Saturn [Orton and Yamandra Fisher, 2005] obtained by mosaicking many LWS images with 0.5" resolution. This shows a very unexpected warm polar vortex at 18 μm. The right panel is a full disk image of Jupiter at 1.8" resolution with the MegaMIR grism slit superposed. Each full image is at the scale of the MegaMIR field of view; smaller rectangles show the MICHELLE and LWS fields of view.*

A particularly spectacular example of the implications of this is shown in Figure 2, which is a mosaic of several dozen images taken with the 10x10" field of view of the LWS on Keck. This shows, totally unexpectedly, a warm polar vortex at Saturn's South Pole with a long-lived hot "tip" at the pole itself. This image is one of the most widely circulated images ever obtained at Keck. MegaMIR's large field of view will permit efficient studies of this and other Saturnian phenomena, including the properties of slowly moving zonal waves and the influence of ring shadowing on the atmospheric thermal and dynamical structure *with five times the resolution of the image in Figure 2.*.

Venus ranges in size from 30" to 60", making it a good match to our 40x40" field of view. Venus has interesting cloud structure, including a polar vortex with the appearance of a "polar dipole" (Diner et al. 1976, Taylor et al. 1980) at each pole - the southern component of which has never been thoroughly investigated.

Jupiter's 42" diameter is also suited for this format. The capability which MegaMIR would bring to image Jupiter's disk will shed light on several phenomena which have been beyond the practical mosaicking capabilities of the Keck-1

LWS. The ~0.1” resolution provided by MegaMIR on LBTI will provide breakthroughs in the investigation of dynamical structure in the Great Red Spot perimeter, merging white ovals, 5 μm hot spots, and polar vortices. At the same time, the capability to carry out R~500 spectroscopy at high spatial resolution will allow us to search for enhancement or depletion of gaseous constituents and to determine the temperature structure and abundances of hydrocarbons in Jupiter’s stratosphere as a function of altitude in its auroral-heated regions.

One of the biggest appeals of 0.1" resolution may well be realized when acquiring images of Uranus (3.8” diameter) and Neptune (2.4” diameter). These are faint objects (brightness temperatures ~55-85 K in the 7-24 μm range) but we know so little about them, with no real spatial resolution on them since the Voyager flybys in the mid-1980's.

2.2. Galactic Science

Thermal infrared studies with MIRLIN and other modern cameras on large telescope have resolved the infrared emission from circumstellar disks (Wahhaj et al 2003, 2005; Telesco et al. 2005), evolved stars (Jura and Werner 1999), and dust-embedded young stellar objects (Ressler and Barsony 2003, Rebull et al 2003), among other compact sources. These images have provided unique information about the structure, energetics and composition of these diverse objects, many of which are not seen at visible or near infrared wavelengths. Extended emission from regions like the core of the Orion Nebula and the Galactic Center has been imaged and studied in detail – often by mosaicking several separate frames - illuminating the temperature and density structure in these complex regions. For a limited number of sources, spectra have been obtained at high spatial resolution but moderate spectral resolution. In the case of the β Pictoris debris disk, Weinberger et al. (2003) and Okamoto et al. (2004) have found evidence for compositional changes with radial position in the disk which may correlate with the location of belts of planetesimals orbiting within the dust disk. MegaMIR, with its diffraction-limited images, moderate resolution spectroscopy, and background-limited sensitivity, will support these types of studies and a wide range of galactic science studies. MegaMIR will go beyond the cameras which produced these results by providing a much larger field of view with significantly better spatial resolution, enabling exciting new scientific opportunities.

Although Spitzer can reach sensitivity levels far fainter than one could hope to reach with MegaMIR – or with any ground-based instrument – the Spitzer databases will invite numerous opportunities for high spatial resolution follow up with MegaMIR. Spitzer has an 85 cm aperture, so that its linear resolution is 28 times worse than MegaMIR’s. Figure 3a and 3b show Spitzer images of an embedded star forming core that is heavily confused at IRAC wavelengths. Follow up ground based near infrared observations (Figure 3c) reveal a complicated, fragmenting core which demands follow up with MegaMIR’s wide field and high resolution.

MegaMIR follow up of Spitzer’s GLIMPSE survey should be particularly fruitful scientifically. This survey imaged

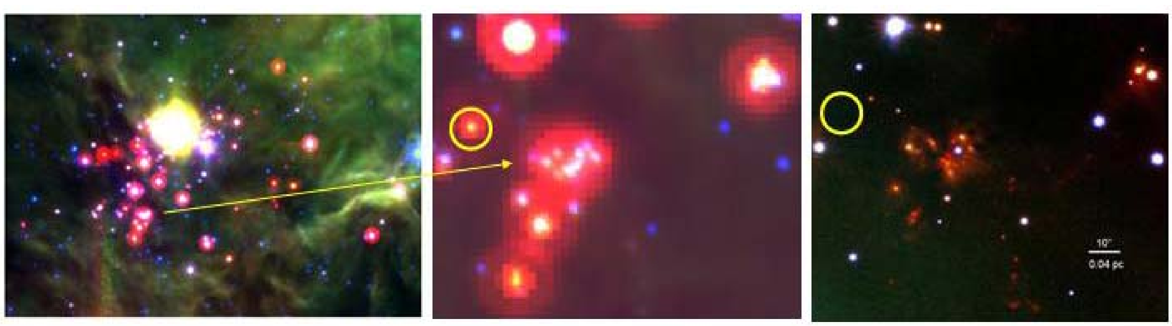

Figure 3a (left) *Spitzer image of a portion of a star formation complex in NGC 2264. The color code is blue=3.6 μm, green=8.0 μm, and red=24 μm.* ***Figure 3b (center)*** *Blow up of a particularly interesting and crowded region of the Spitzer image. The field of view is 80 x 60”.* ***Figure 3c (right)*** *A ground-based J (blue), H (green), and K (red) of the same region at 0.35” resolution, showing a complex cluster of sources with a dynamical lifetime of ~40,000 yrs. (Young et al. 2006) MegaMIR can measure the thermal infrared emission from these objects at even higher spatial resolution, determining the luminosity and dust mass of each of these protostars. As a flux reference, the bright source on the left edge of Figure 3b (circled in yellow) that is not visible in 3c is roughly 85 mJy at 8 μm and thus easily detectable with MegaMIR.*

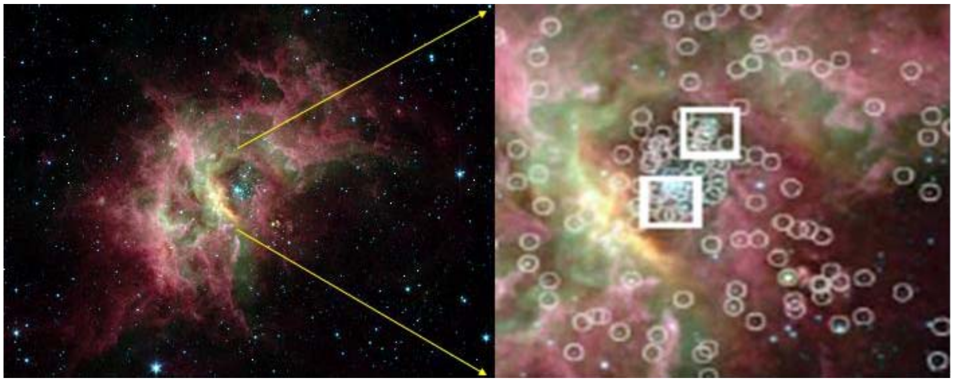

Figure 4a (left)*: GLIMPSE image of a >30x30 arcmin region centered on the previously known Westerlund 2 cluster which excites RCW49.* ***Figure 4b (right)*** *A blow up of the central regions of this image in which the circles indicate stars with infrared excesses suggestive of circumstellar envelopes or disks, while the white squares are the MegaMIR field of view.*

several hundred square degrees near the galactic plane in the four IRAC bands, producing spectacular images rich in point sources, diffuse emission, and a variety of emission nebulae. The limiting sensitivity achieved by GLIMPSE – which was limited to short exposures to achieve its areal coverage - is comparable to that which MegaMIR can achieve, and of course many of the GLIMPSE sources will be much, much brighter than this. As discussed by Benjamin et al (2003), the GLIMPSE high reliability catalog will contain about ten million point sources of all types, any of which is bright enough for study with MegaMIR in overlapping and adjacent wavelength bands. If these sources were uniformly distributed [which will certainly *not* be the case], there would be about two dozen in each MegaMIR field of view. As a specific example, consider the massive star-forming region RCW49, which was featured in several of the first publications from the GLIMPSE team (Whitney et al, 2004). RCW49 itself is not visible from the Arizona, but is just an example of the richness of the GLIMPSE data base. The GLIMPSE survey of the Northern Galactic Plane, already completed, will contain numerous similar nebulae accessible to MegaMIR.

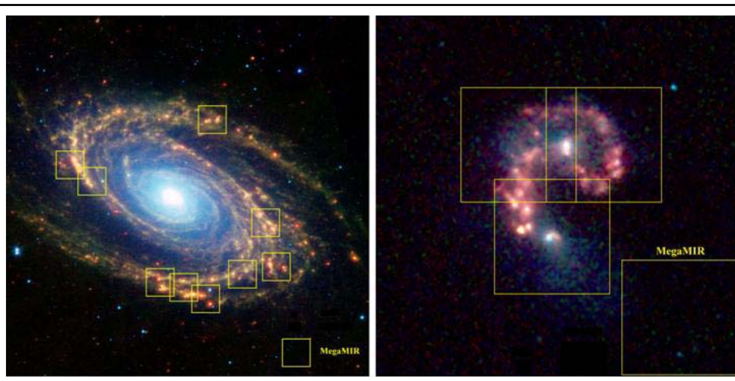

Figure 5a (left): *The Spitzer image of M81 (Gordon et al 2004) using IRAC and MIPS. The star forming regions in the spiral arms stand out clearly but the resolution of Spitzer is not sufficient to bring out their morphological details. At the distance of M81 the 0.1" resolution of MegaMIR at 10 μm translates to 1.7 pc.* ***Figure 5b (right)*** *The Spitzer image of the Antennae (Wang et al 2004). A large amount of star formation is triggered by the collision and the 0.1" resolution translates to 10 pc, sufficient to identify possible globular clusters in formation.*

Figures 4a and 4b give an idea of the quality and information content of the GLIMPSE data base. Many of the hundreds of dust embedded stars in RCW49 are brighter than 10th magnitude (6.5 mJy) at 8 μm and thus should be well within reach of MegaMIR at 10 μm or beyond. These observations can rapidly characterize the population of dusty stars in this region, with multiple sources in each MegaMIR frame. These data will mitigate the confusing effects of the larger Spitzer beam at the longer wavelengths, and permit searches for trends in the characteristics of these stars with position in RCW49 and, with similar data on other GLIMPSE regions, from young cluster to young cluster throughout the galactic plane. For both this program and the NGC 2264 observations referred to earlier, grism spectroscopy with MegaMIR's ~0.1" slit, much narrower than the 4" slit of the Spitzer IRS spectrograph, will allow detailed compositional and mineralogical studies of individual targets.

Closer to home, at the ~150pc distance of the nearest star forming regions in Taurus and Ophiuchus, the 0.1" slit projects to ~15au, so the structure and composition of planet-forming disks can be probed on scales comparable to the size of our own solar system.

2.3. Extragalactic Astrophysics

Two of the areas of extragalactic astrophysics that will benefit greatly from the resolution and areal coverage provided by this new mid-IR instrument are star formation and AGN. The high resolution afforded in the mid-IR is vital to the study of star formation in our own galaxy, but when a target is so far away that a star forming region, a supernova remnant, or an AGN can fall into the same 1-2" beam, being able to separate these components becomes vital.

The resolution and sensitivity of MegaMIR on LBTI provides the ability to detect individual, moderate mass, pre-main sequence stars with in band luminosity ~5000 solar luminosities out to a distance ~1 Mpc; similarly, dust-embedded AGB stars can be detected to comparable distances. This gives great access to some of the closest extragalactic laboratories of star formation and evolution, including M31 and M33. MegaMIR follow-up of the detailed multi-wavelength study of M31 being carried out by the Spitzer MIPS team (Gordon et al, 2005) will be extremely useful in disentangling the detailed structure of star formation regions, which show complex morphology not unlike that shown in Figure 5.

The Spitzer image of M81 traces the peak star forming regions in the spiral arms of the galaxy, but without sufficient resolution the actual nature of the star formation, whether com-pact or extended, cannot be determined. Similarly for the colliding Antennae galaxies, the great dust penetrating power of Spitzer has highlighted the star formation that has been triggered by the collision of the two galaxies. One possible consequence of such a collision is the formation of globular clusters. The much greater resolution afforded by MegaMIR on LBTI would provide the diagnostic power to determine the method by which the star formation is progressing and give clues as to how such mergers may have affected the star formation history of the universe. Both of the above studies are made feasible by the large field of view of MegaMIR allowing quick coverage of large portions of M81's spiral arms and complete coverage of the star forming regions of the Antennae.

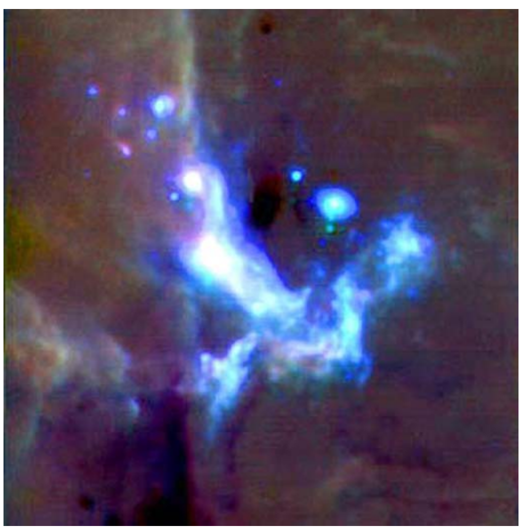

Figure 6: *On the left is the Galactic Center as imaged by the VLT (blue, green, red = 8.6, 12.8, 19.5 μm). MegaMIR on LBTI would offer 3x better spatial resolution than previous VLT images.*

For studying the emission from AGN and their circumnuclear environment, the 10 μm window offers two great advantages. First, it is very dust penetrating, and second, stars emit little at 10 μm and hence it is much easier than the optical or the near-IR to separate the non-stellar nuclear emission from the stellar bulge emission. Since we have an AGN at the center of our own Galaxy (Figure 6), we have a wonderful nearby laboratory to study the behavior of extragalactic AGN in a much closer context. For the AGN at the center of our Galaxy the 0.1" resolution on LBTI translates to 800 AU, and the linear coverage of the megapixel detector would be ~1.6 pc, giving a high resolution, wide area picture of the extremely complex structure at the center of our Galaxy. For nearby AGN, the resolution affords sub-parsec scale coverage (for NGC 1068 the scale is 0.12 pc and the region covered is 40 pc on a side). With this resolution and coverage the main mystery of how AGN get their fuel from tens of parsecs to less than a parsec can be addressed. Also a substantial effort can be made to quantify the effects of compact, circumnuclear star formation and its effect on nuclear fueling.

Ultra-luminous Infrared Galaxies (ULIRGs) are an intriguing subset of AGN where both a black hole with an accretion disk and vigorous star formation may be contributing to the copious amounts of infrared emission. High resolution imaging can help isolate the compact, black hole generated emission within the large amounts of extended, star formation generated emission. Then spectroscopy at high spatial resolution can separate the AGN emission from the star forming regions. This was successfully accomplished by Soifer et al (2002) for the prototypical ULIRG: Arp 220 (Figure 7).

2.4. WISE Follow-up

The GLIMPSE survey covers 240 square degrees of the galactic plane at 3.6, 4.5, 5.8, and 8.0 μm. The WISE survey, a NASA MIDEX mission launching in 2009 (Dr. N. Wright is the Principal Investigator; Mainzer et al. 2005), will extend the GLIMPSE coverage over the entire sky at 3.3, 4.7, 12, and 26 μm with a 40cm diameter telescope. As the mid-infrared equivalent to the 2MASS catalog, WISE will produce a lasting legacy for both galactic and extragalactic science. With a beam size of 7" at 12 μm but the high instantaneous sensitivity of a cryogenic telescope, however, WISE will be confusion-limited for many targets. MegaMIR's 0.1" beam and 40" of view offer ~5000x better areal resolution for confusion mitigation. Additionally, MegaMIR's sensitivity is quite competitive with WISE's in the wavelength range where the two facilities overlap. Thus, in addition to providing a general ability to study sources found by WISE, MegaMIR can follow up in greater detail both of WISE's key science topics: ultra-cool brown dwarfs (BDs) and ultraluminous infrared galaxies (ULIRGs).

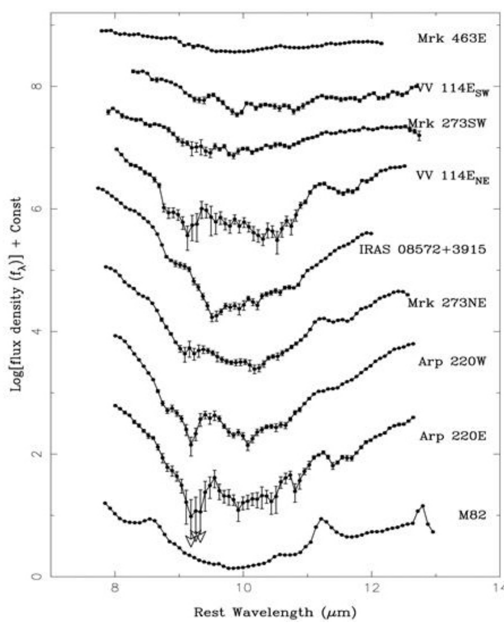

Figure 7 *Spectra of several ULIRGs from Soifer et al (2002) including Arp 220 where the two main components (E and W) are separated by high resolution ground based imaging.*

WISE will detect the nearest "star" to our Sun, which is likely not to be a star at all, but rather an ultra-cool planetary mass object. Such objects emit much of their luminosity in the thermal infrared at the 4.7 μm off-methane feature and between 10-25 μm. The coolest and dimmest of these objects, with T < 300K or greater distances, will appear only in WISE's 4.7 μm band, since strong methane absorption makes these objects dark at 3.3 μm, and WISE's 12 and 26 μm bands are not sensitive enough to detect them. These single band detections can be followed up with MegaMIR to allow confirmation of the WISE brown dwarf/planetary mass object candidate fluxes, obtain complete spectral energy distributions over the wavelengths at which cool brown dwarfs and planetary mass objects emit most of their radiation through narrow band photometry, and contribute to further study of our nearest galactic neighbors.

Local and distant ULIRGs found by WISE will also be observable by MegaMIR. These objects have flux densities of order 10-100 mJy at mid-IR wavelengths. The spatial extent of their mid-IR emission and the presence of spectral features from grism and CVF observations could be studied with MegaMIR. In addition, WISE will discover ~10,000 new debris disks, some of which may be spatially resolvable by MegaMIR.

3. INSTRUMENT DESCRIPTION

3.1. LBT Interferometer

The LBTI is a NASA-funded instrument designed to advance the capabilities of interferometry and coherent imaging for the goal of planet finding. The LBTI is cryogenically cooled and mounted on the center instrument platform of the LBT. The initial portion of the instrument is called the Universal Beam Combiner (UBC). It accepts beams from the left and right tertiaries and reimages them with reflective optics to provide a combined focal plane satisfying the sine condition. This ensures that the two beams are in phase across the full 40"x60" field of view of the beam combiner. The UBC has been designed for thermal infrared imaging from the beginning. By placing most of the optics inside a cryostat, the background emission from the optical elements is minimized. Alignment and fast phase corrections are provided by a fold mirror in each arm. An image of the entrance pupil is formed at these mirrors and cold masks are used to baffle out warm radiation from the surrounding telescope structure. The combined focal plane can be redirected by an insertable fold mirror to three separate camera ports. The straight through port is reserved for the nulling interferometer. The left port is planned to have a mid-infrared high resolution imager such as MegaMIR.

3.2. Optical Design

A conceptual design of the MegaMIR optical system is shown in Figures 8 and 9. A fold mirror directs the light into the right side port. The combined focal plane has an envelope of f/15 which gives a plate scale of 0.6"/mm. The beam is reimaged by two biconic mirrors. These mirrors form an intermediate focal plane and two pupil planes which will allow placement of filters and slits. The optical design reimages the beam to form a final focal ratio of f/5. This results in a pixel field of view of 0.04" and an array field of view of 40".

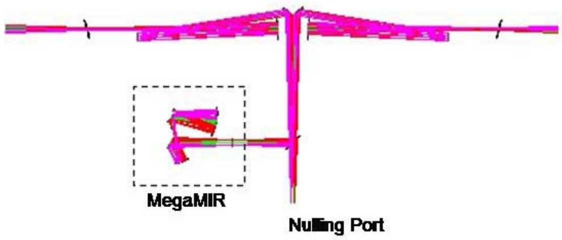

Figure 8. *Raytrace of the MegaMIR optical system including the Universal Beam Combiner. Rays from the two LBT telescopes enter from the right and left and are combined with the cryogenic optics. A pick-off mirror directs the beam to the MegaMIR camera. The beam going down is used by the nulling camera.*

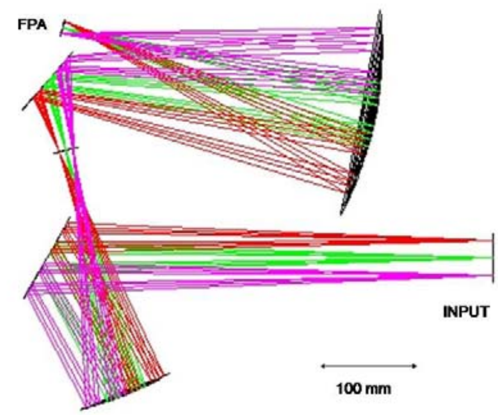

Figure 9. *Details of MegaMIR optical design.*

The two mirrors in the system will be fabricated with diamond-turning techniques. This approach gives us flexibility in our design and allows a compact system that can work over a wide wavelength range with a minimal number of optics.

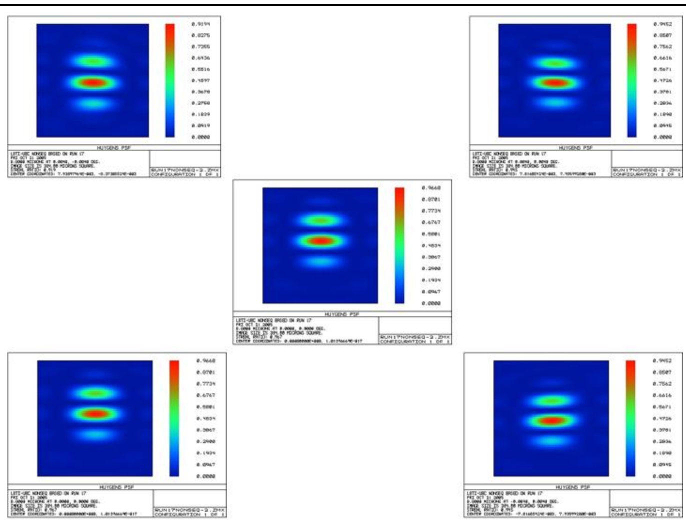

Figure 10. *Calculated MegaMIR PSFs. The resolution is 0.1" in the direction of the 22.8 m baseline and 0.3" in the orthogonal direction. As the parallactic angle rotates during tracking, the PSF rotates, providing spatial frequency coverage*

The high resolution of the LBTI can be preserved over the entire 40" field of view using the above design. We have modeled the design, including telescope and beam combiner, using ZEMAX. Figure 10 shows the resulting PSFs for the center and four corners of the array. It is likely this design can be further optimized and adjusted to improve its image quality, minimize the total envelope, and result in optics that is manageable to fabricate. However, the design shown above is already a viable concept. The PSFs generated by ZEMAX range from a Strehl of 98% on-axis to 92% off axis. These are generated for a wavelength of 9 μm.

3.3. Grisms and Filters

To achieve good spectral coverage over the 8-14 μm atmospheric window, we will procure a KRS-5-based grism manufactured by Carl Zeiss. Similar grisms are used in the MIRSI (Boston Univ. at the NASA IRTF) and MIDI (ESO at the VLTI) instruments, and related elements are routinely used in near-infrared instruments such as the FLITECAM 1-5 μm instrument for SOFIA, and the near-infrared coronagraph NICI at Gemini. Although the final design parameters will need to be negotiated with Zeiss, a grism with an incident beam of 20 mm diameter, wedge angle of 10 degrees, a groove spacing of 50 microns, and operated at 2^{nd} order will produce a spectrum with R=290 at 14 μm, and R=580 at 7 μm. Such a configuration is desirable since the use of a different order sorting filter in the other filter wheel will allow 16-26 micron spectroscopy with R=250-150 in the 1^{st} order. The transmission of such grisms is estimated at approximately 60%, primarily due to reflection losses at the surfaces. AR-coating the entrance surface can raise the efficiency somewhat, and we will investigate the possibilities as we finalize the grism design.

3.4. Detector Array

The MegaMIR FPA is a Si:As impurity band conduction (IBC) detector array hybridized with indium bump bonds onto a CMOS multiplexer. The IBC sensing chip is currently available and the current development effort is focused on the design, fabrication, screening and delivery of the CMOS multiplexer. DRS Technologies is producing the multiplexer. DRS has already successfully delivered low background 1024x1024 IBC arrays for the WISE project; their ground-based array development is heavily leveraged off of that successful work. The first hybrids should be available for test in October, 2006.

The current state of the art in mid-infrared FPA for high background applications is a 320x240 pixel format. The new DRS multiplexer provides a 13x increase in the pixelation and benefits from two key developments. One is the space-based astronomy-driven development that aims to produce megapixel format low background FPAs for missions such as WISE and JWST. The second is the continued improvements in high background imaging multiplexers driven by defense missile tracking applications. Key improvements have been incorporated into the MegaMIR readout design to provide stable biasing for the sensing array at the expected high photon fluxes as well as larger capacitance values to implement deeper integration wells. The preliminary specifications for the MegaMIR array are provided in Table 2.

Parameter	**Value**	**Units**	**Comments**
Format	1024 x 1024		
Integration Mode	Ripple		
Pixel Pitch	18	μm	
Detector Material	Si:As		
Band	5-28	μm	
Integration Control	Variable		
Read Noise	< 1000	e^-	10 msec integration time
Dark Current	<12,800 <10	e^-/s e-/s	at 10K at 6K
QE	> 57%		
Well Capacity	<5.0E+06 Max > 96E+03 Min	e^-	Controlled by gain select
Operability	> 99%		
Non-uniformity	< 2%		Limited by measurement accuracy
Linearity	< 10%		
Frame Rate	~ 100	Frames/sec	
Number of Outputs	16		
Data Rate	~ 7E6	Pix/s/output	

Table 2. MegaMIR Detector Characteristics

3.5. Cryogenic System

We are baselining a simple rectangular cryostat with a single optical bench suspended on G-10 hangers from an intermediate radiation shield. All of the optical elements will be mounted on this bench, which will also have an optically tight housing. Our group has extensive experience designing cryogenic systems for wavelengths as long as the submillimeter, particularly concerning issues of stray light baffling and thermal control. Figure 11 shows a conceptual layout within the LBTI structure showing that the current optical design will fit within the volume constraints of the existing beam combiner. During the first six months of this investigation, we intend to optimize the design.

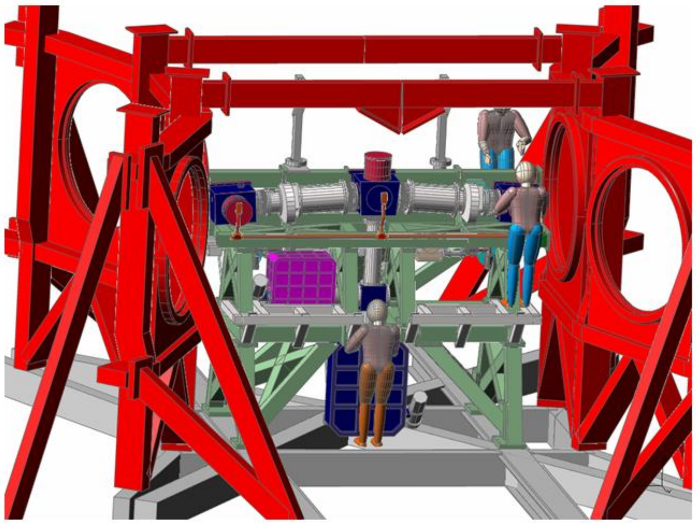

Figure 11. MegaMIR within the LBTI structure. The MegaMIR cryostat is the volume depicted in purple. The LBT telescope structure is depicted in red, and the LBTI structure is depicted in green. The PT-407 cryocooler is attached to the cryostat at a 45° angle to accommodate the range of elevation angles.

Recent developments in high performance cryocoolers permit us to get the temperatures required with a relatively simple cryogenic system. We will use a Cryomech PT-407 pulse tube cryocooler which is available to this project. The unit provides 0.7 W of cooling at 4 K and 25 W of cooling at 77 K, well above the needs of MegaMIR. The performance of pulse tube cryocoolers depends somewhat on orientation—a potential concern for an instrument like MegaMIR since it tracks in azimuth with the telescope. We have done experiments, however, that demonstrate virtually no performance falloff at 45° tilt. By mounting the unit at so it tilts through -45° to +45°, we can cover the full range of azimuths.

3.6. Mechanisms

MegaMIR requires two mechanisms, a filter wheel and a slit mechanism for the grism system. To maximize our mechanical flexibility, we propose a simple filter wheel driven by Phytron cryogenic stepper motors. Early on, we plan to conduct a trade study for the slit mechanism between a slit wheel mechanism derived from the filter wheel design and a simple swing arm mechanism. If possible, we will duplicate the filter wheel, but the decision will depend on the available space on the optical bench and the accessibility of the field locations.

3.7. Electronics

MegaMIR will produce data at a prodigious rate. With 1024^2 pixels, 16 outputs, a well depth of 5×10^6 electrons in high gain mode, and an anticipated background of 5×10^8 electrons/pixel/sec, we expect to run the new array at 100 Hz, or 16 x 7 mega-samples/s. Coadding individual exposures for two dither positions can drastically reduce the data rate that must be stored to disk. We require 14 bit digitization with 32 bit wide words for coaddition. Coadding by a factor of 100 will reduce the aggregate data rate to ~3.3 Mbytes/sec. We will need processors with memory buffers large enough to support this level of coadding. These electronics, while fast, are now available on the commercial market.

We have produced a breadboard of a design based on an Analog Devices AD9248-65 A/D converter and an Analog Devices BF353 Digital Signal Processor (DSP) for each of the 16 channels. The A/D converter provides 14-bit conversions at up to 65×10^6 samples/s and the DSP performs coaddition of individual frames to reduce the aggregate data rate. We have adopted this highly parallel approach given the low cost of the individual components. Clocking for the device is controlled by a master DSP driving a custom level shifting board.

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