MICHI (未知): A MIR Instrument Concept for the *TMT*

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A mid-infrared (MIR) imager and spectrometer is under consideration for construction in the first decade of the *Thirty Meter Telescope's* (*TMT*) operation. When combined with a MIR adaptive optics system, the instrument will afford 15 times higher sensitivity, 4 times better spatial resolution (0.08") than 8m-class telescopes, and ~4.5 times better spatial resolution than the *JWST*. Additionally, its huge light gathering power opens a new window of high-dispersion spectroscopy in the MIR. We discuss the key science drivers, from star and planet formation to galaxies and black holes and cosmology; science drivers which are in close synergy with the recent Decadal report. We flow down our science cases to produce fundamental and optional instrument capabilities, including imaging, long-slit and IFU spectroscopy, and polarimetry.

Science Drivers

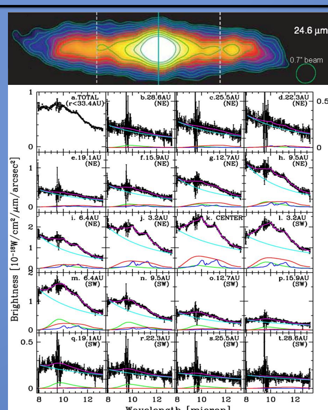
We identify three primary areas of astrophysics that are ideally matched to mid-IR (MIR, 7.5-25μm) observations, offering both broad and transformative science from the *TMT*. These areas are (i) star and planet formation, (ii) evolved stars and the ISM, and (iii) extragalactic and cosmology. These fields mesh extremely well with four of the six key science drivers of the TMT, as described in the Detailed Science Case, as well as those highlighted in the Astro 2010 Decadal report.

Diffraction limited imaging of circumstellar disks will search for evidence of planet formation, such as pericenter glow or perturbations in the disk, and follow up low- to moderate-resolution spectroscopy will probe the rich dust chemistry which could supply seed materials for life on forming exoplanets. Observational efficiency can be dramatically improved using a integral field unit, which would make effectively impossible observations (due to time constraints) routine. High-resolution spectroscopy will afford the opportunity to make detailed chemical analysis, unavailable on space based platforms.

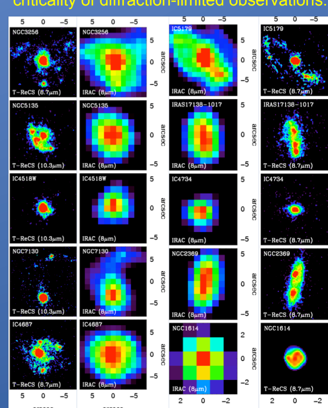
Gas and dust ejected from dying stars are key to our understanding of the chemical evolution of the Universe and the circulation of materials. A detailed low- to moderate-resolution spectroscopic study at high-spatial resolution will provide a firm statistical characterization, impossible with 8m class telescopes.

Observing in synergy with the *JWST*, MICHI will make diffraction-limited imaging and low- to moderate-resolution spectroscopic observations of various extragalactic objects. The very high-spatial resolution of the *TMT* will disentangle emission mechanisms in AGN, distinguish between starburst and AGN energy sources in ULIRGs, and probe CDM substructures of lensed QSOs to test CDM models of structure formation. MICHI enables AGN and ULIRG observations to a much higher z than current 8m, where AGN and black hole evolution may become apparent, and permit a statically significant probe of lensed QSOs, impossible on 8m class.

TMT and MICHI permit multiple cycles of scientific discovery and follow-up, whereas the much shorter lifetimes of space based observatories cannot perform such programs.



MIR observations of the debris disk around Beta Pictoris (above). Note the wealth of information in the spectroscopy data, and the hint of a planetesimal breakup in the imaging data. 8m and *Spitzer* images of AGN are shown below, demonstrating the criticality of diffraction-limited observations.



Requirements & Initial Design

From a detailed examination of the primary science cases, we found the following key requirements for the instrument, as well as possible enhancements.

① Imaging at N (7.3-13.5*μm*) & Q (16-25*μm*), FOV ~30"
② IFU at low-dispersion (*R*~250), ~2"x5" FOV
③ Long-slit moderate-dispersion spectroscopy at N & Q with the entire band across single array; *R*~810 at N, *R*~1,100 at Q
④ High-dispersion spectroscopy with *R*~120,000 at N, *R*~60,000 at Q
⑤ MIR AO system to enable diffraction-limited observations at N and Q
⑥ Cold internal chopper to enable imaging, low- and moderate-dispersion spectroscopy

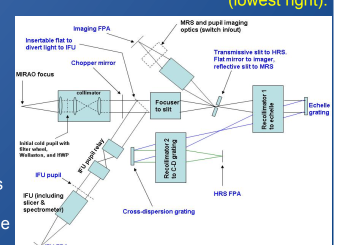
Possible enhancements
i. Polarimetry in imaging & some spectroscopy modes
ii. Coronagraph mode
iii. Aperture-masking mode

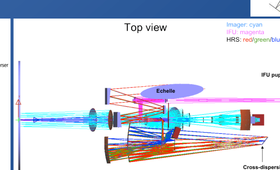
As we proceed to a further development stages, the detailed trade studies associated with implementation of the various modes of MICHI will be made, and the possible enhancements will only be incorporated if they are of minimal difficulty.

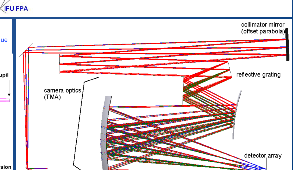
Our optical design answers the requirements through a modular approach, providing the capabilities listed (top right). Whilst a complex design, each module is constructed from TMAs, meaning each module can be aligned separately, greatly facilitating construction and testing of the instrument. We also assume that a MIR adaptive optics system will be available, as already designed by Chun et al (2006). We believe that all items needed for MICHI are either off the shelf or require little or no R&D to produce, and hence the instrument has little intrinsic technical risk.

Wavelength Range	
Wavelength Range	N band (7.3-13.8μm) and Q band (16.0-25.0μm)
Imager	
Field of View	28.1x28.1"
Pixel Scale	27.5 mas per pixel
Spectral Resolution	R~10-100
Low Dispersion IFU Spectrometer	
Wavelength Range	N band, Q band is optional
Field of View	~5" (length) x ~2" (width), 22 slices
Pixel Scale	35.0 mas per pixel
Spectral Resolution	R~250
Disperser	Reflective gratings
Slicing Mirror Unit	22 reflective slits
Long-Slit Moderate Dispersion Spectrometer	
Pixel Scale	27.5 mas per pixel
Wavelength Range	N band & Q bands
Spectral Resolution	R~810 at N, R~1,100 at Q *Entire N or Q band dispersed across array*
Disperser	Grisms (for N and Q bands)
Slit	28.1" length, 0.1-0.3" in width, reflective
High Dispersion Spectrometer	
Pixel Scale	27.5mas per pixel
Wavelength Range	N & Q bands
Spectral Resolution	R~120,000 at N, R~60,000 at Q
Disperser	Echelle and cross-disperser
Slit	2" in length, 0.1 to 0.3" in width, transmissive
Slit Viewer	Imager used as slit viewer
Polarimetry	
Operational Modes	Imaging- and spectro-polarimetry *Operational parameters the same as imager or long-slit low resolution spectroscopy*
Methodology	Dual-beam (Wollaston and Half Wave Retarder)
Wavelength Range	N (limited transmission up to ~23μm)
Pupil Imaging	
Operational Mode	Optimal alignment to telescope pupil to minimize thermal background radiation
MIR Adaptive Optics System	
Field of View	10" with 1 arcmin goal
Wavefront Quality	Requirement wavefront rms phase < 750nm, goal < 350nm rms
Sky Coverage	"All sky" and limited only by natural tip-tilt stars
Background Emission	AO system should not increase N-band emission by >15% over sky and telescope emission; absolute emissivity <1% for MICHI and MIRAO

Feasibility level design capabilities of MICHI are listed above. A schematic of the initial design highlights the modularity of the system (lower right), the optical layout (lowest left), the packaging (lowest center), and one of the two IFU sections (lowest right).







Further Information & Acknowledgements

The science drivers and flow down is discussed in Okamoto, Packham, Tokunaga et al (2010, SPIE, **7735**, 77355O) and the design by Tokunaga, Packham, Okamoto et al. (2010, SPIE, **7735**, 77352C). This work was supported by NSF grant number 0947189. We gratefully acknowledge the support of the *TMT* project office of National Astronomical Observatory (NAOJ), Y. Ikeda (Photocoding Inc.), and Optical Research Associates. Y.K.O. is supported by Grant-in-Aid for Young Scientists (A) (21684005) by the Ministry of Education, Culture, Sports, Science and Technology, Japan.