Key Science Drivers for MICHI (未知), A Thermal IR Instrument Concept for the *TMT*

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A thermal-infrared imager/spectrograph is being investigated for possible construction in the early operation of the *TMT*. Combined with the MIR adaptive optics (AO) system (MIRAO), the instrument will afford ~15 times higher sensitivity at ~4 times better spatial resolution (0.07") at 10μm compared to 8m-class telescopes, and at much higher Strehl ratios (~4 times better). Additionally, through exploiting the large collection area of the *TMT*, a high-dispersion spectroscopy mode will be unrivaled by other ground- and space-based facilities. These combined capabilities offer the possibility for breakthrough science, as well as 'workhorse' observing modes of imaging and low/moderate spectral resolution. In this poster we summarize the primary science drivers that are guiding the instrument development.

MIR Science Drivers

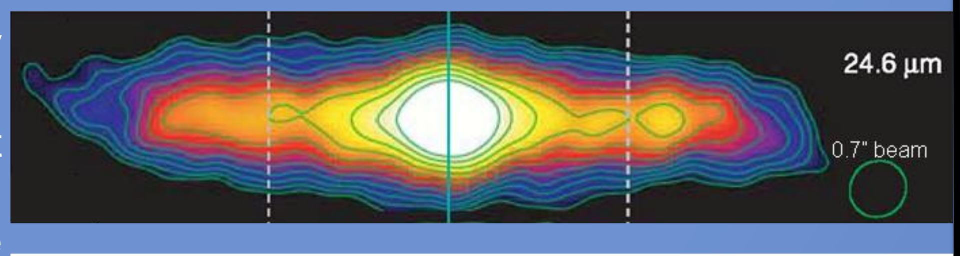
We identified three primary areas of astrophysics that are ideally explored through thermal-IR (MIR, 7.5-25μm) observations, affording broad and transformative *TMT* science. These are (i) star and planet formation, (ii) evolved stars and the ISM, and (iii) extragalactic and cosmology. These fields connect extremely well with the science *TMT's* Detailed Science Case (DSC). In this poster, we highlight MIR science cases especially likely to offer transformative type science:
(1) High spectral resolution science
(2) Disc & planetary formation/evolution, exoplanets
(3) Extragalactic observations

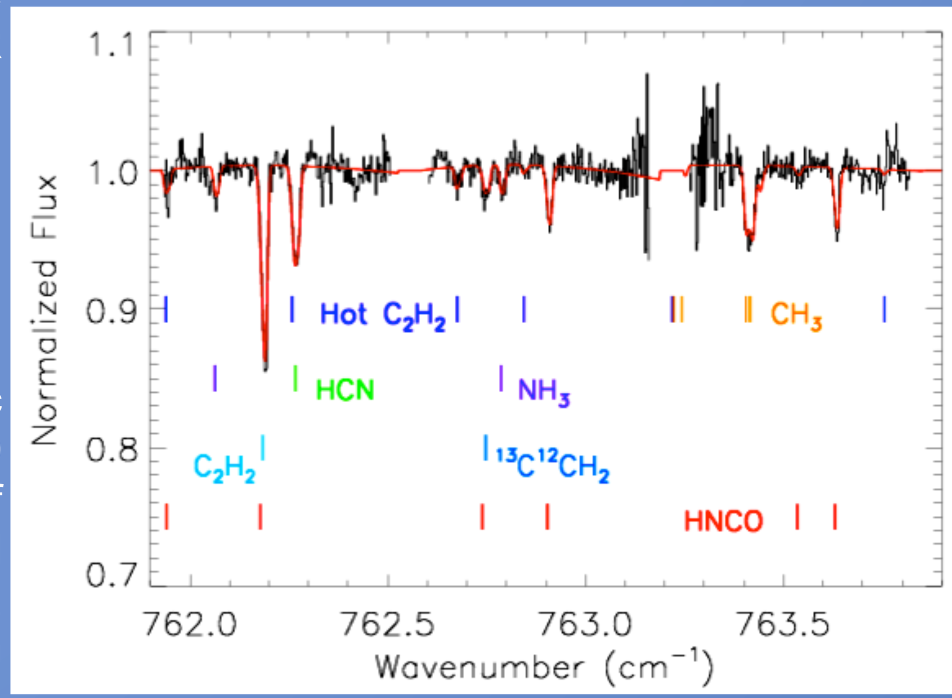
1. High Spectral Resolution

The *TMT's* aperture will enable MIR high resolution spectroscopic studies to progress from the current level (mostly the brightest 5-10 objects of a given class) to enable comparative studies of 100's of objects. For example, a typical solar mass T Tauri star can be studied in a volume that extends past Orion as opposed to just reaching Taurus – permitting study of cluster star formation, not just formation in small aggregates. Objects ~3 mags fainter become accessible, comparable to the gain between the Bright Star Catalog (~9,000 objects) and the HD Catalog (~360,000 objects). Surveys requiring 10 hrs of integration time per target will require 3 mins for the same S/N.

MICHI (未知) will be critical to probe planetary system formation. Other facilities will be optimal for characterizing the diversity of planetary systems, but 未知 allows probing planet formation environments for clues to the physical origin of this diversity. Higher excitation energy tracers, common in the MIR, provide a direct view of inner disc regions (<5AU region) where terrestrial and giant planets form.

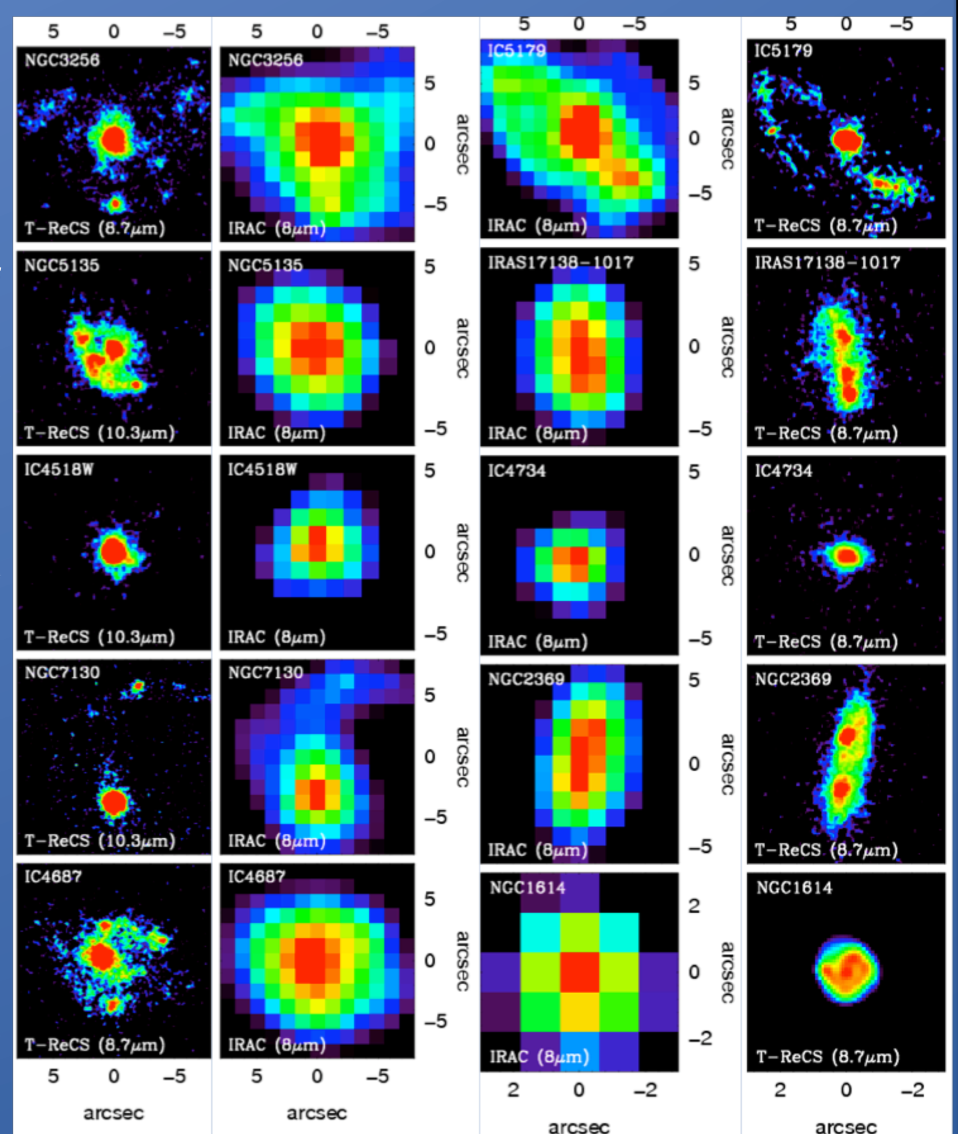
Many complex organic molecules (e.g., alcohols, aldehydes) are believed to be products of grain surface chemistry, but others (e.g., ethers, carboxylic and amino acids) could form through ion-molecule reactions in warm gas after the products of grain surface chemistry have been desorbed. Hence, a large number of extra-terrestrial organic and prebiotic molecules exist both in the Solar system and ISM. An inventory, formation, and evolutionary study of these molecules remains a key astrobiology goal.





MIR imaging of the β Pictoris debris disc (top, Telesco et al. 2005), which with spectroscopic data hints at a planetesimal collision or breakup. Portion of the data observed by Knez et al. (2009) toward NGC 7538 IRS 1 illustrates that a small part of the spectrum can be used to measure C_2H_2, $^{13}C^{12}CH_2$, HCN, CH_3, HNCO, and NH3 (above).

8m and *Spitzer* images of AGN (below), showing the criticality of high spatial resolution ground-based extragalactic observations.



2. Disc & Planetary Formation/Evolution, Exoplanets

The MIR contrast between stars and planets is relatively low in general when compared to shorter wavelengths. However, due to the limited sensitivity, 8m class ground-based telescopes has not achieved direct detection of exoplanets at 10μm window. With the *TMT*, the point source sensitivity is sufficient to permit detection of gas giants. If a gas giant is in thermal equilibrium with irradiation by the central star, 未知 will be capable of detecting them to a few AU from nearby (~10pc) early type (AFG type) stars. If the planet is young (~1Gyr) and its temperature is determined by internal heating (Burrows et al. 2004), detectability is easier.

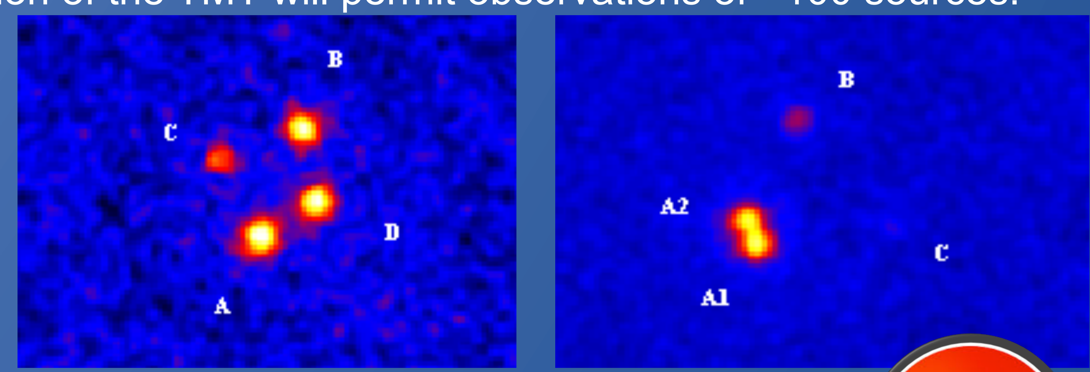
Observations of protoplanetary discs are fundamental to our understanding of planet formation. Okamoto et al. (2010) discuss the importance of understanding protoplanetary and debris discs as building blocks of planets, along with the signatures of proto-planets and collisions and their effect on planetary formation and chemistry. An emerging area is the UIE (unidentified infrared emission) features in discs. Kwok & Zhang (2011) suggested that mixed aromatic-aliphatic organic nanoparticles could be the carrier of the feature. As the proposed particle is a complex compound including oxygen, nitrogen, sulfur, etc., these organics could be ingredients of pre-biotic molecules, such as nucleic acid. Thus observations of the spatial distribution of UIE in discs will trace the spatial distribution of organics in discs, suggestive of how organics are dispersed to early planets.

3. Extragalactic Observations

The DSC stressed the importance of SMBHs to both astrophysics and cosmology. There is a clear connection between the SMBH and galaxy properties, as shown through the M_{BH} vs. M_{bulge} and M_{BH}-σ relationships, demonstrating that the galaxy bulge mass (M_{bulge}) and the stellar velocity dispersion (σ) are tightly correlated with the SMBH (M_{BH}), despite being spatially on widely different scales. This correlation strongly implies some form of coevolution between the SMBH growth and the growth of the galaxy bulge, but the precise nature of this relationship remains uncertain. Understanding the precise nature of this relationship will help to address two crucial questions in cosmology: (1) which formed first, the SMBH or the galaxy, and (2) how did SMBHs form so shortly after the big bang? The SMBH will often show a level of 'activity' arising through accretion of gas and dust, leading to an AGN. The study of AGN has recently been invigorated through 8m observations of the central and torus. MIR observations of the torus show it to be a complex, clumpy, with tentative hints that the torus structure is (at least partially) dependent on the level AGN activity. Possible other effects could be the level of radio emission (radio loud/quiet AGN) and that of the host galaxy, as well the precise fuelling of AGN. The complex interplay between the host galaxy and AGN remains poorly constrained, and is a goal of the DSC. Fueling of the AGN, and direct imaging or spectroscopy of the interact between the torus and host galaxy remains crucial.

Through gravitational lensing of the MIR emission of distant quasar tori, tests of the CDM model of cosmology is afforded. A serious issue for CDM models is they predict the existence of 100's of dark satellites or "CDM subhalos" (masses of $10^{7-9}M_{\odot}$) in a galaxy-sized halo (totaling ~$10^{12}M_{\odot}$), in sharp contrast to the observed number of about twenty Milky Way satellites. To clarify this, gravitational lensing offers invaluable insights into halo structures, which works as a lens for a remote source such as a QSO and are highly sensitive probes for the *internal* mass distribution of the lensing object. However, the number of objects available on 8m class telescope (~10) has been exhausted, but the combined sensitivity and spatial resolution of the TMT will permit observations of ~100 sources.

11.7μm images of Q2237+030 (left) and MG0414+0534 (right) taken from Subaru (Minezaki et al. 2009) showing multiply lensed images, indicative of microlensing (left) and the subhalo (right).



未知 Future Development Path

new

Enhanced Science Drivers at 3-5μm

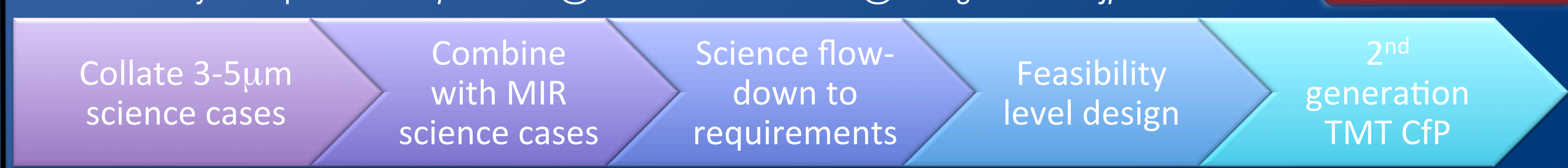
At the 2014 TMT forum and after careful reading of the DSC, the 未知 team heard clearly from the community of (a) support for many of the science capabilities 未知 affords, (b) desire for high spectral resolution capabilities, including 3-5μm, and (c) interest in 3-5μm imaging at high Strehl ratios. As the MIR AO system can already deliver (c), and as 未知 has already been designed around the dual goals high spatial and spectral resolution, we are carefully considering the possibility of incorporating a 'blue' (3-5μm) arm to 未知. As 未知 is an all reflective design, at a 0^{th} level the initial technical complication is centered around the need for 3-5μm arrays (perhaps HgCdTe extended wavelength Hawaii arrays). A limiting component may be the entrance window, but this can be changed if and when needed. We envision the blue arm to have similar capabilities to that of 未知, namely high spectral resolution (R~100,000), low resolution (R~1,000) and high Strehl ratio imaging capability. We note that adding a blue arm to MIRES was a key committee response to the design of MIRES in 2006.

3-5μm science cases include (1) high dispersion spectroscopy of molecular lines in protoplanetary discs, (2) high dispersion spectroscopy of gas and dust clouds, (3) direct imaging observations of exoplanets, and (4) probing AGN and inflow/outflow using the 4.7μm CO line. As an example, we combine science cases (1-3) to the field of discs and exoplanets. As stated in the DSC, "planets can dynamically interact with their parent disk, leaving footprints which could be more readily detected than planets themselves. A giant planet may open a gap in the gas disk, inducing local non-Keplerian velocity fields with characteristic structure and time variability. This has been proposed to create observable spectroscopic signatures in the 4.7μm rovibrational CO lines (e.g., Regály et al. 2014). Therefore, while *TMT* may detect protoplanets through broad-band imaging of their thermal continuum emission, there is also the prospect of using kinematic gas tracers to detect the *growth* of giant protoplanets. *TMT* is able to detect gas tracers in the optical and infrared at very high spatial resolution; 40 mas for the four main CO isotopologues around 4.7μm that trace the velocity field of the protoplanetary material, as well as a host of tracers of accretion onto the planet itself." As such, we feel that these observations will reveal the most compelling and exciting period as the connection between disks and planets can be established, a key step toward the final goal of understanding planet formation.

Below is our initial flow-chart for the tasks we must follow in the coming year (assuming a 2nd generation CfP in 2016). Perhaps the key task, if the science case for 3-5μm is compelling, is how can the existing 未知 design be simplified to allow a blue arm to be added? We must understand if immersion gratings and/or coronography are appropriate for 未知, and if they can help to simplify or not overly complicate the instrument design.

JOIN US!

We welcome your input at *chris.packham@utsa.edu* or *hondamt@kanagawa-u.ac.jp*



Further Information & Acknowledgements

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