Thirty Meter Telescope
国立天文台 TMT 推進室

NAOJ

MICHI – A Thermal IR Instrument for the TMT

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Presented on behalf of the 未知 team

Outline

- Science Case Highlights
- MICHI to bMICHI
- bMICHI requirements, capabilities
- Forward look
- Collaborations
- The TMT site
- Conclusions

[Initial Key] Instrument Specification

Wavelength Range	
Wavelength Range	L (3.42-4.12μm)[1], M (4.57-4.79μm), N band (7.3-13.8μm) [Q band (16.0-25.0μm) TBC]
Imager	
Field of View	24.4x24.4" at L&M bands 28.1x28.1" at N [&Q TBC] band
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N [&Q TBC] band
Spectral Resolution	R~10-100
Long-Slit Moderate Dispersion Spectrometer	
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N [&Q TBC] band
Wavelength Range	L, M, & N bands [Q band TBC]
Spectral Resolution	R~600 L, M, & N bands [Q band TBC]
Slit	28.1" length, diffraction limited to ~0.1"
High Dispersion Spectrometer	
Pixel Scale	11.9 mas per pixel at L&M bands 27.5 mas per pixel at N band
Wavelength Range	L, M, & N bands
Spectral Resolution	R~120,000 at L&N, R~100,000 at M, [R~60,000 at Q TBC]
Slit	2" length, diffraction limited to ~0.1"
Slit Viewer	Imager used as slit viewer
IFU Spectrometer	
Wavelength Range	N band (only)
Field of View	~0.175" (length) x ~0.07" (width), 10 slices
Pixel Scale	35.0 mas per pixel
Spectral Resolution	R~1,000
Disperser	Reflective gratings
Slicing Mirror Unit	10 spaxels

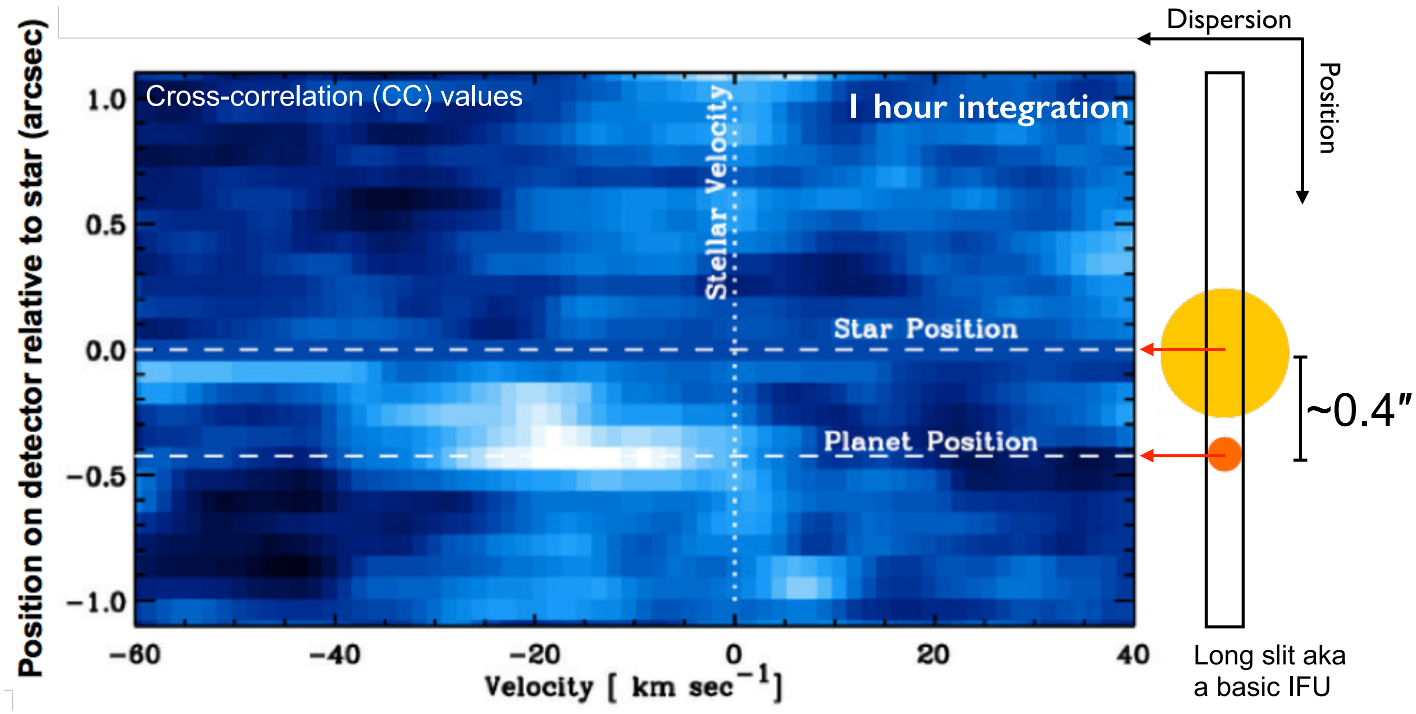
Exoplanet Atmospheres

- Very high dispersion spectroscopy (R≥100,000) can unambiguously identify molecular features in exoplanet atmospheres and probe their thermal structure
- C/O ratios measured with HDS may reveal planet formation mechanism and birth location in protoplanetary disk
  - SN proportional to $(N_{lines})^{1/2}$, wide spectral coverage in M band crucial
- Potentially can identify biomarkers, locate our nearest habitable rocky neighbors, and create maps of atmospheric surface features
  - NIR (i.e. CO) and MIR probe different biomarkers

Pioneering Work from VLT

(slides from Jayne Birkby)

Spectra extracted at every position along the slit and stellar/telluric profile removed



CO detected in β Pic b. Strongest CC at RV = -15.4±1.7 km/s at ~0.4″

Consistent with position from direct imaging and with a circular orbit. H_2O only seen at SNR~2. No methane.

Snellen, Brandl, de Kok, Brogi, Birkby, Schwarz, 2014

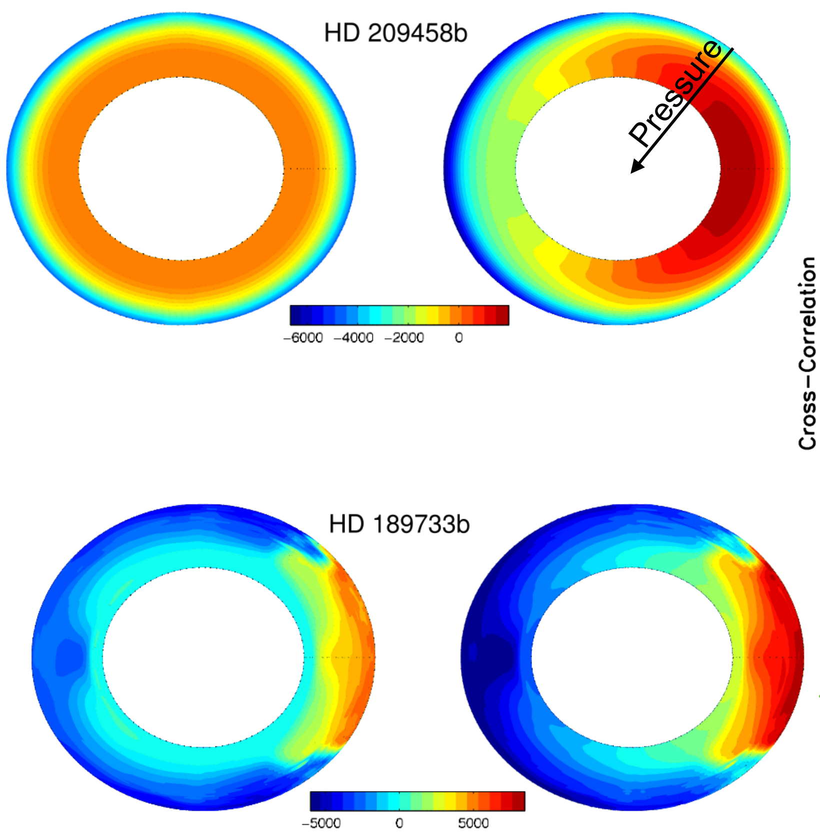
Rotation period of planet measured as 8.1 hours

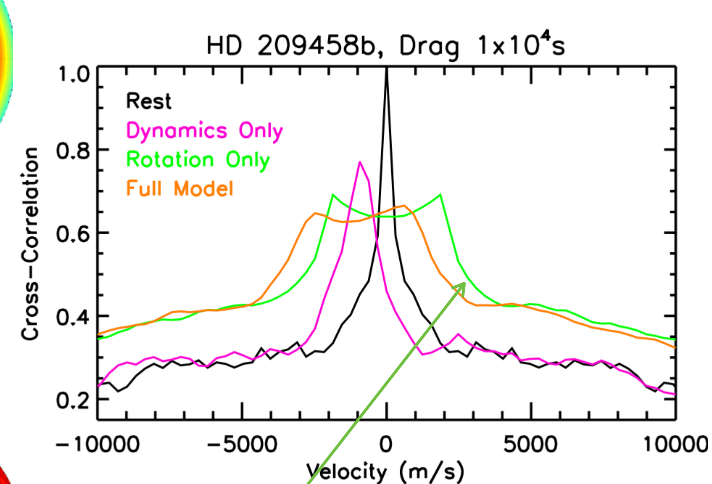
Exoplanet Atmospheres

(slides from Jayne Birkby)

HDS is sensitive to line shape/shift from winds and rotation

Winds only **Winds+rotation**

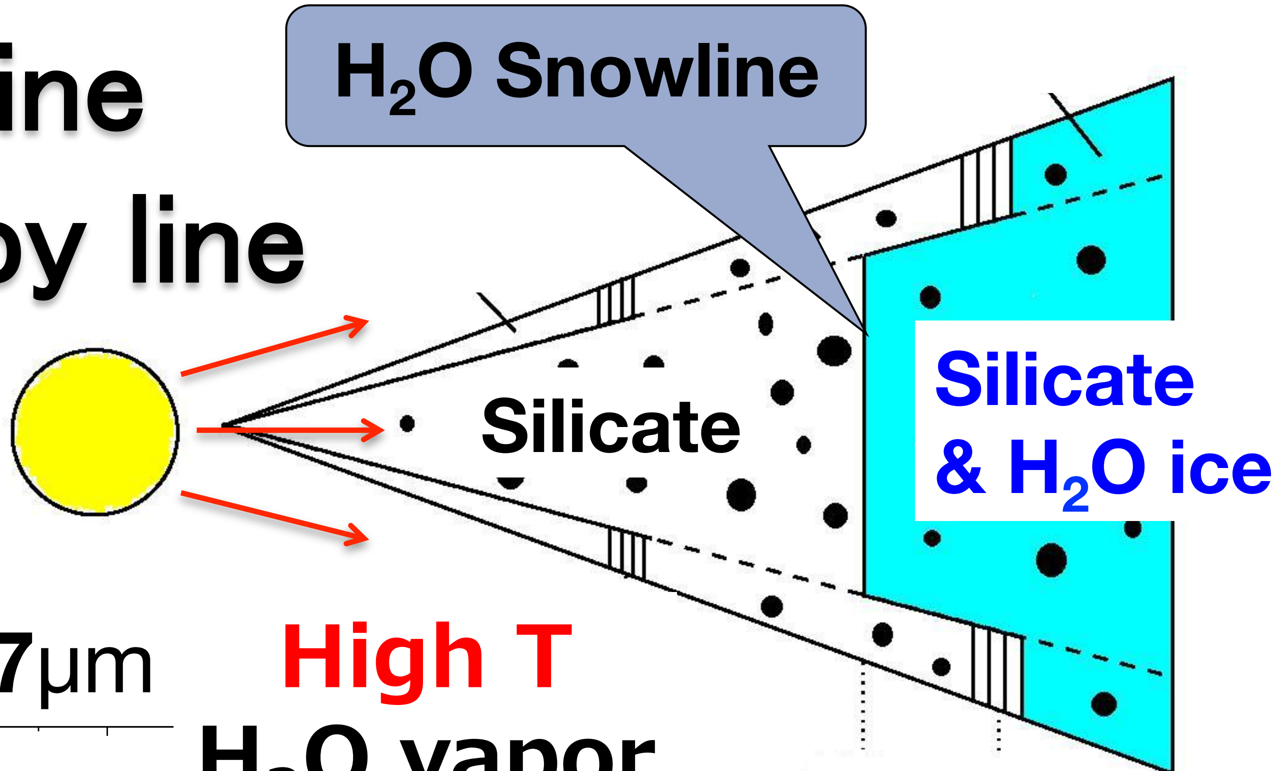




Rotation creates double-peaked line profile

Kempton et al. 2012; Showman et al. 2013

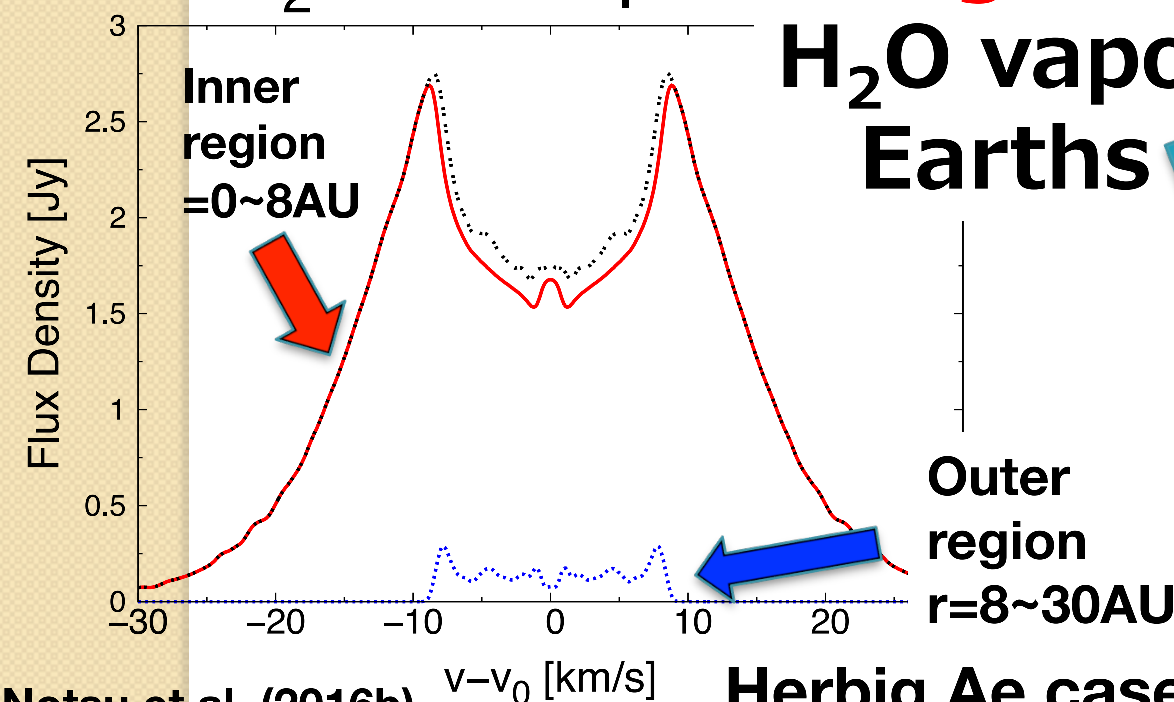
H_2O Snowline detection by line profile



High T
H_2O vapor
Earths

Low T
H_2O ice
Jupiters

o-H_2O **17.77μm**



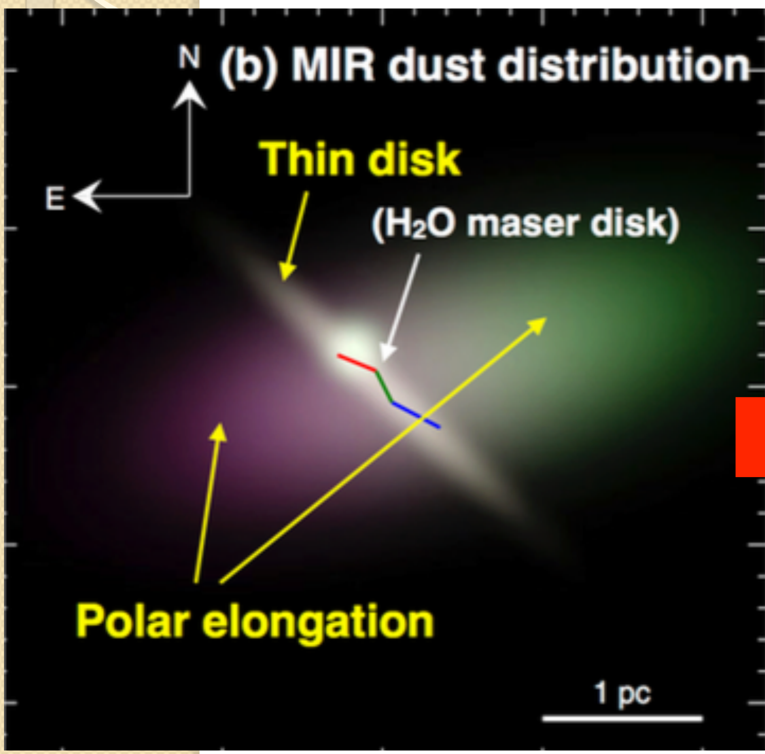
Herbig Ae case

Mid-IR High-R spectroscopy reveal snow line position !

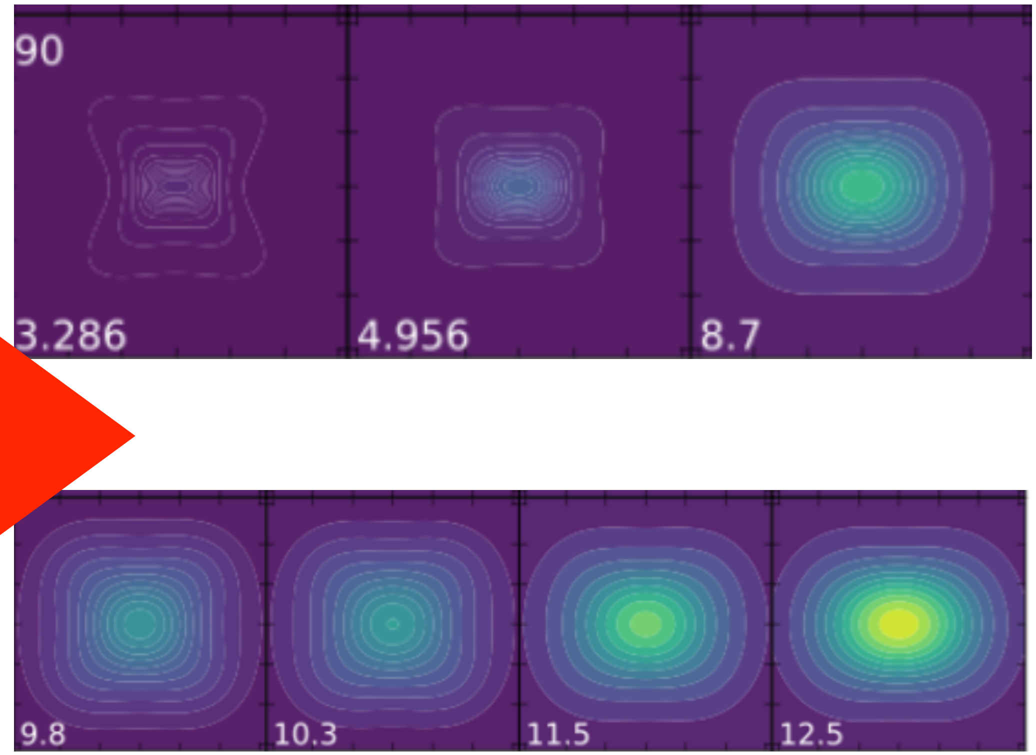
Notsu et al. (2016b)

Resolving the AGN Torus Through the L, M, & N Bands (Lopez-Rodriguez et al.)

VLTI (image synthsied)



TMT (convolved with expected PSF)

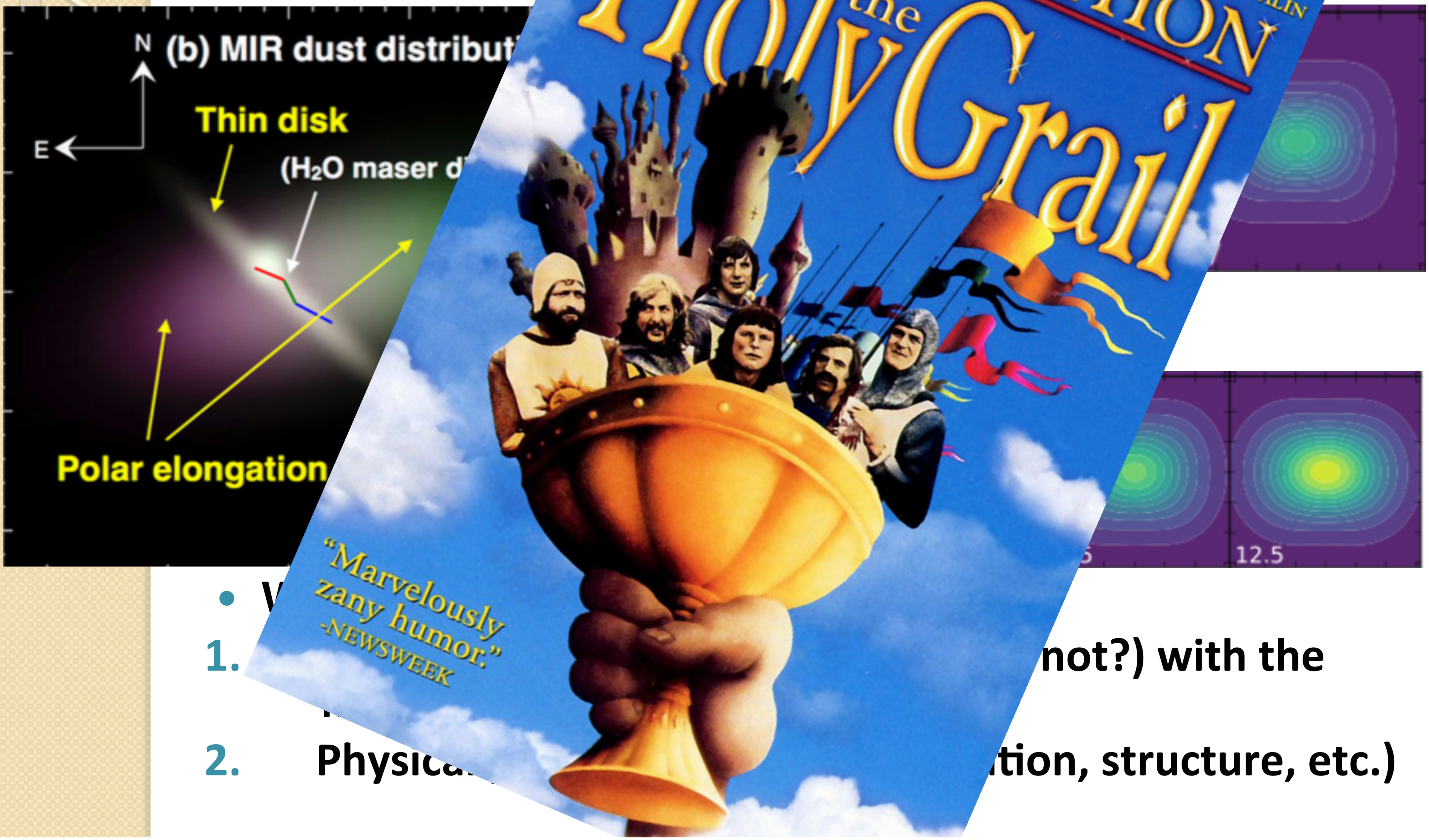


- **We'll obtain**

1. **Dust distribution (polar direction or not?) with the help of (clumpy) torus models**
2. **Physical parameters (M_{dust}, inclination, structure, etc.)**

Resolving the A... Through the L, M, & N Ban... et al.)

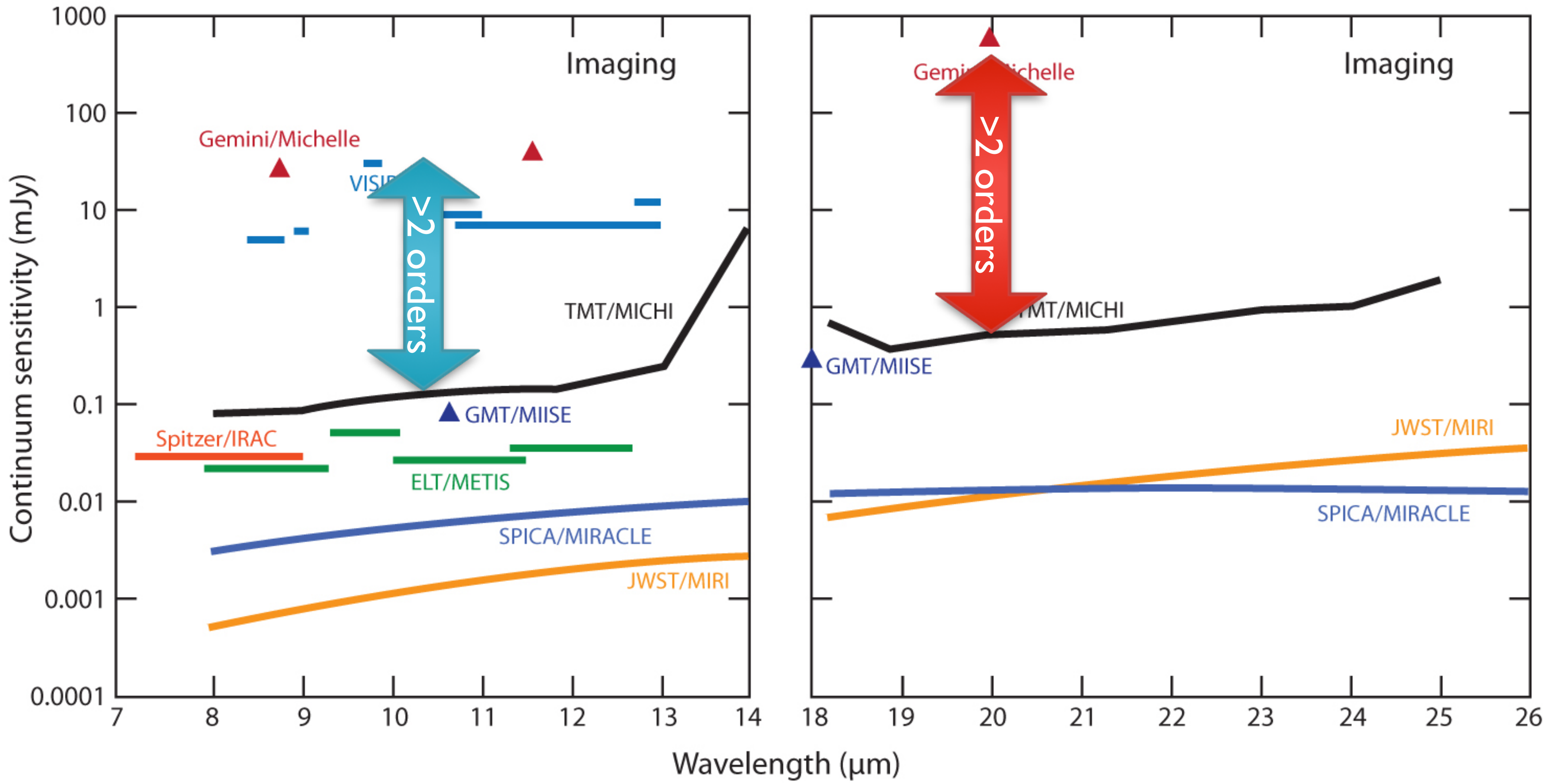
VLTI (image synthsied) ... PSF)



- W...

1. ... not?) with the
2. Physica... tion, structure, etc.)

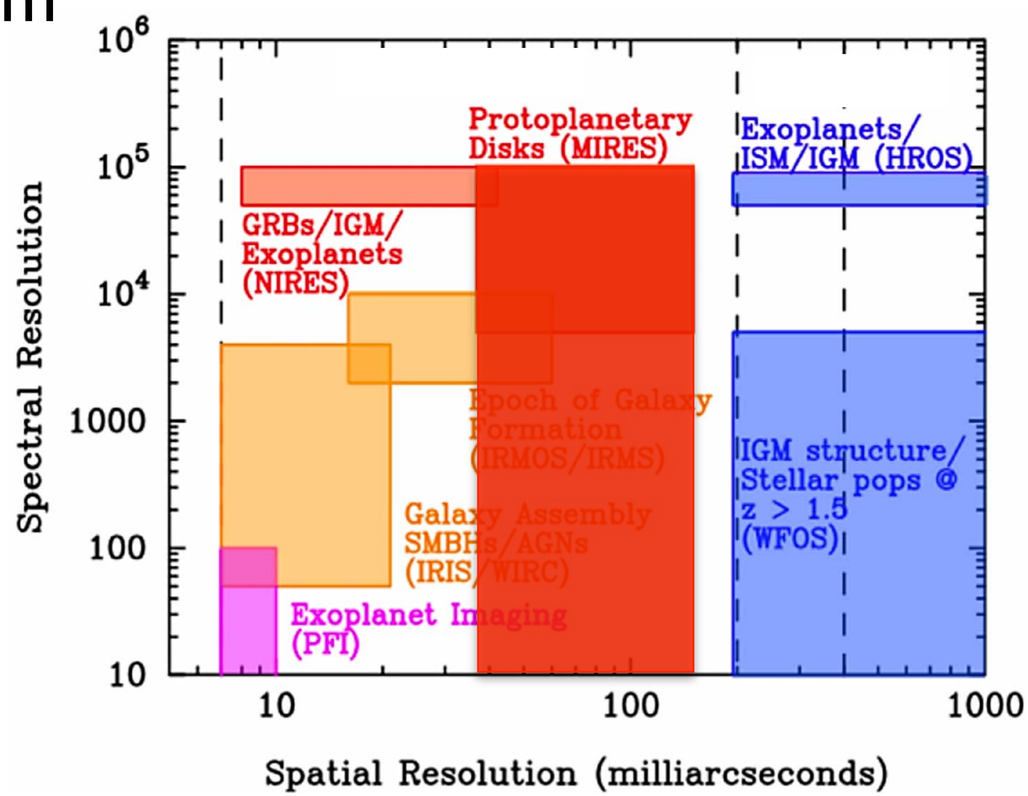
MICHI Imaging Sensitivity



- Notes
  - Point source sensitivity 10σ in one hour elapsed time
  - *E-ELT* at MIR offers D^4 performance boost from primary
  - Estimated from publications (simple scaling) or on-line calculators
    - Observing/conditions assumptions can be widely different between groups

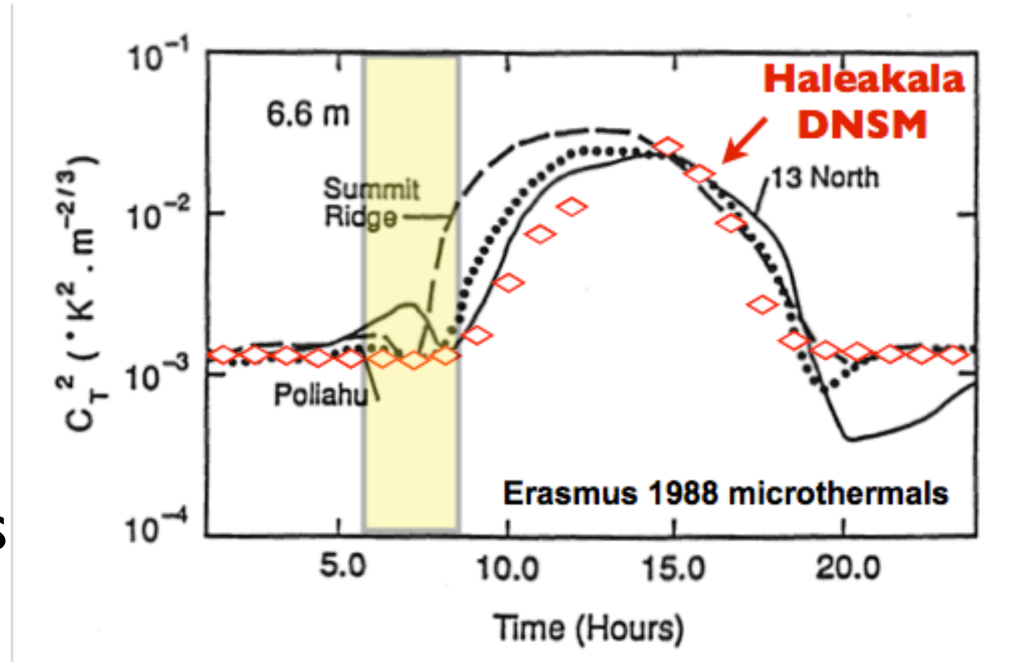
TMT Parameter Space

- MICHI fits very well into the wavelength and spatial/ spectral resolution plot of the *TMT*
- MICHI & the Mid-IR AO system (MIRAO) optimized for>7.5μm
  - MIRAO will offer excellent IQ at 3 & 5 μm
  - MIRAO is relatively easy



Mid-IR Adaptive Optics (MIRAO) & Daytime Observing

- Daytime observing
  - MIRAO/MICHI could exploit best seeing conditions in early morning hours
  - Appears feasible with no loss in performance and affords an extra **1-2 hours per night** (at minimal cost) of *TMT* observing time
  - R&D efforts
    - We appreciate the help of the Subaru AO team (especially Hayano-san)
  - MICHI splinter session to discuss this more



Strehl Ratios

- FWHM of images/spectra do not tell the whole story
  - Strehl ratio is also crucial of course, especially in regions where the source(s) is embedded in diffuse emission
    - Typical for MIR observations
  -

Telescope	**Size**	**Strehl (8μm)**
Spitzer	85cm	95%
Gemini	8.1m	~20-30%
GTC	10.4m	~19%
JWST	6.5m	80%
TMT	30m	90%

Evolutionary Step

- At TMT forum in 2014, clear expression from community of desire for
  - High spatial resolution
  - High spectral resolution (optical to MIR)
  - Lots of citations of MICHI
    - Strong support from community for more 'workhorse' capabilities for MICHI
  - Clear expressions of interest for L&M bands, but not currently covered by under-construction TMT instruments

MICHI to bMICHI

- 3-5μm requires HgCdTe arrays
  - And a final fold mirror to select the array
  - Fairly small complications as MICHI is essentially an all reflective design
- Low & high (R~120,000) spectral resolution
  - Working closely with the NIRES-R PI
- The science flow-down is crucial to establish the final instrument capabilities – we are in the phase now
  - Need to carefully select only the most promising instrument modes

Immersion Gratings

- Possible way to simplify the instrument is with immersion gratings
- Reduces size of grating/pupil needed by the refractive index of the substrate
  - This would be ~2-4, a significant reduction in the pupil and hence instrument size
- We are working with Kobayashi-san and KSU persons who are leading this development in Japan

MIMIZUKU

- MIR instrument for the 6.5m TAO (located in the Atacama) lead by Miyata-san (Tokyo)
- Like MICHI, based on the Aquarius array
- Close collaboration to combine efforts and leverage resources, and combine R&D tracks
  - For example, array & electronics, cold chopper development, etc.

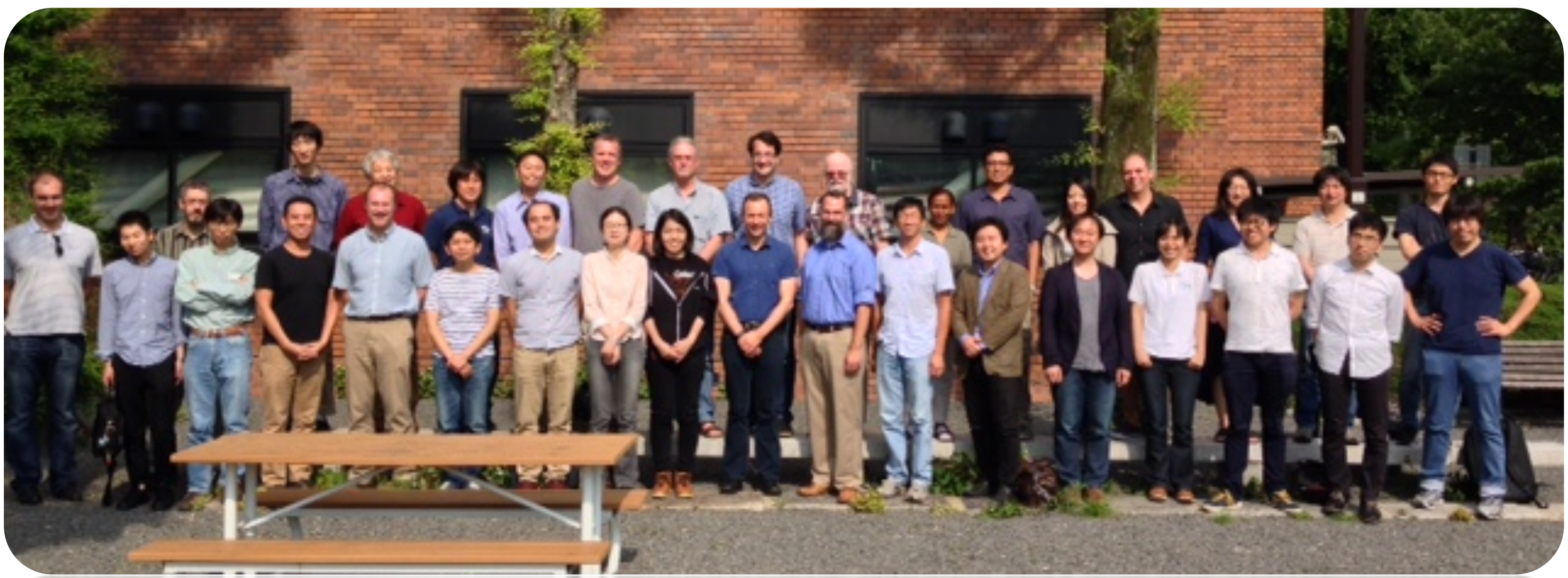
Science Team

- 7 sub areas, lead by the person(s) listed below
  - ~50 from Japan, USA, Canada, India, & China
- Finishing collecting science cases, summarizing, ranking
  - Input welcome – please talk to me or Honda-san
- We'll then flow the ranked science goals to requirements, then to instrument requirements
- Science team will remain crucial to give advice/ feedback throughout the instrument design and build

Science	Leader
AGN	Imanishi & Ichikawa
Astro-Chem	Pontoppidan
Cosmology	Minezaki
Discs	Honda
Dust	Sakon
Exoplanets	Kotani
SolarSystem	Ootsubo & Sarugaku

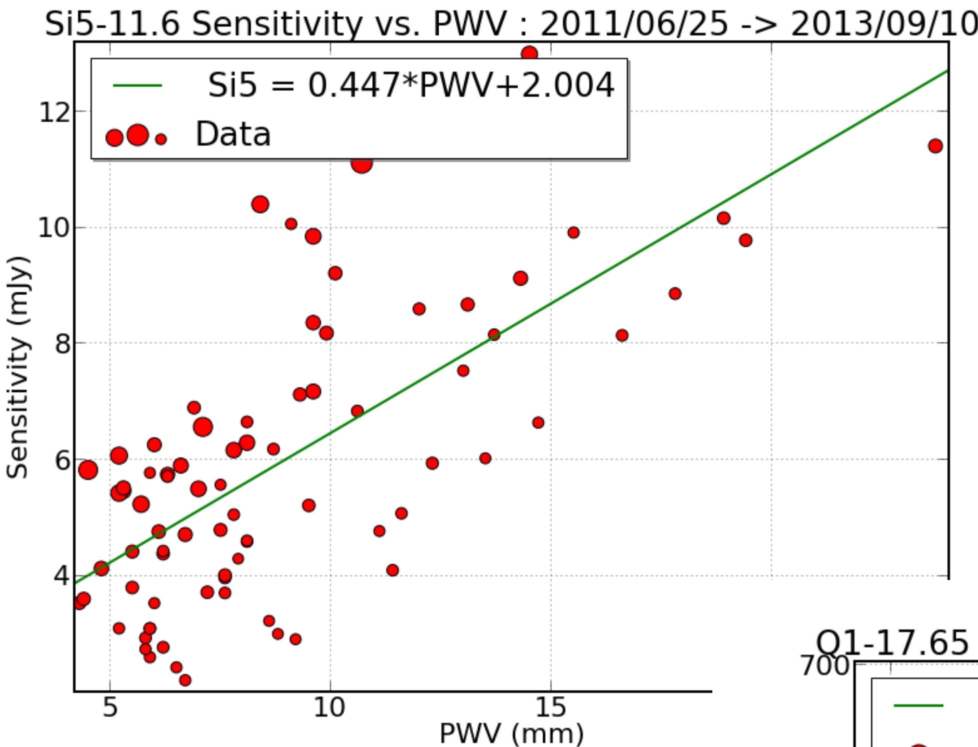
MICHI Workshop Yesterday

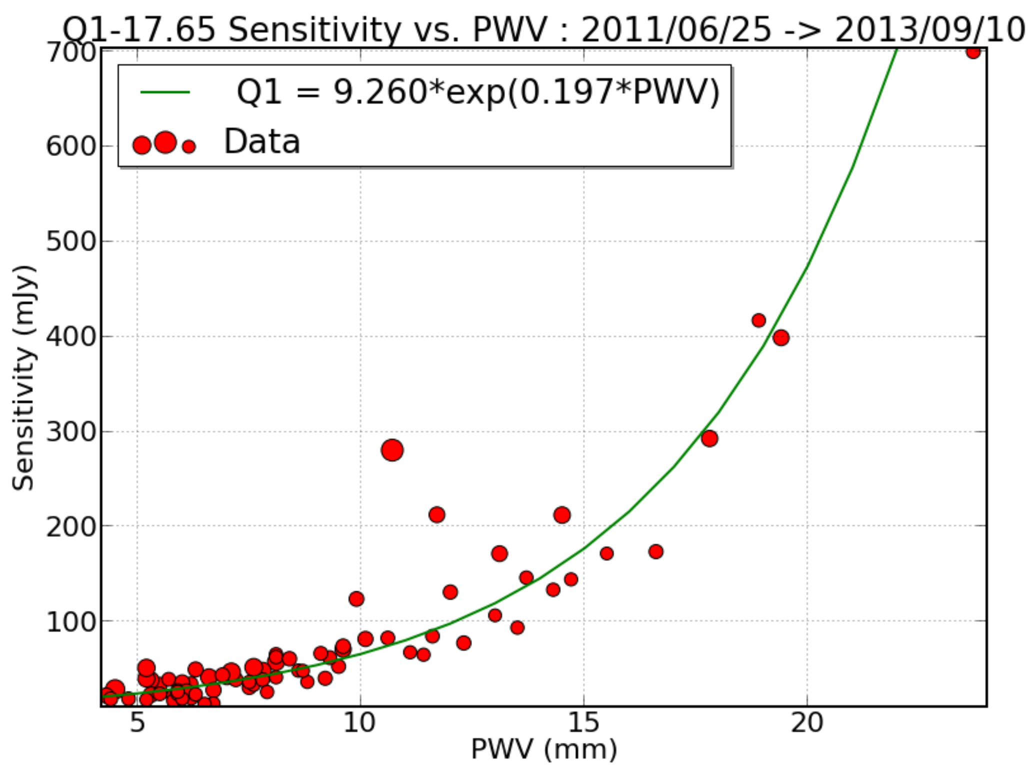
- 35 participants from all partner countries and TMT Observatory
- Thanks to those who helped make it a success!



What if MK is not the TMT site?

- We ran a mid-IR camera (CanariCam) on La Palma for several years
- In a clean part of the 10μm window (i.e. away from the O_3 and edges), when the PWV changes from 5mm to 15mm, the sensitivity degrades by a factor ~2
  - However, a night with low PWV and bad IQ yields similar sensitivity as a night with high PWV and good IQ
- For the the 20μm window, when the PWV varies from 5mm to 15mm the sensitivity is degraded by a factor of ~10





- NB: Possible offset in absolute value of PWV – this is made using GPS method

The Take Home

- MK is by far our favored site, but even a 'wet' site like La Palma can still do great MIR science
  - Albeit needing a longer exposure time, and careful filter selection
- Comparing MICHELLE (MK) to T-ReCS (CP), more MIR papers came from T-ReCS as
  - The instrument was easier to use
  - Gemini South performed better (especially the chopping secondary) compared to Gemini North
- GMT doesn't plan a thermal-IR instrument, and E-ELT has 5 mirrors before the instrument compared to TMT's 3, so emissivity should be better on TMT
- The final site is a crucial but not unique parameter

Connection to Other Facilities

- JWST-MICHI is clear and obvious
  - Where spatial and spectra resolution is needed, TMT/MICHI, where sensitivity is required JWST/MIRI
  - JWST at low resolution (spatial/spectral), TMT/MICHI for detailed characterizations
- ALMA-MICHI
  - Synergy especially with discs, and inner regions of inflow/outflow of AGN
- TMT-MICHI
  - Combination with IRIS will afford 1-13μm(+) spectral coverage
  - Science case of PFI-like instrument connects supremely well to bMICHI and the associated exoplanet cases using high spectral resolution (doppler imaging)

Conclusions

- MICHI affords both transformative & broad science cases (wide discovery space) in high profile TMT focal points
- Broad community support, including all TMT partners
  - Recently exemplified through MICHI workshop
- Synergistic with TMT and other facilities
- Exploits the TMT's strengths, especially at MK
- Daytime observing – [almost] free observing
- Few components need R&D
- The science & instrument team is strong, we're ready to go

Extra Slides

Difference with METIS/E-ELT

- Better site (?)
- Less upstream mirrors, lower thermal background
- High spectral resolution, especially in the N band
- Not a difference, but easy to make the case that high-Strehl imaging and low-spectral resolution at LMN is a fundamental workhorse-type instrument