MICHI: A Thermal-IR Instrument for the TMT

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UTSA & NAOJ

On behalf of the MICHI team

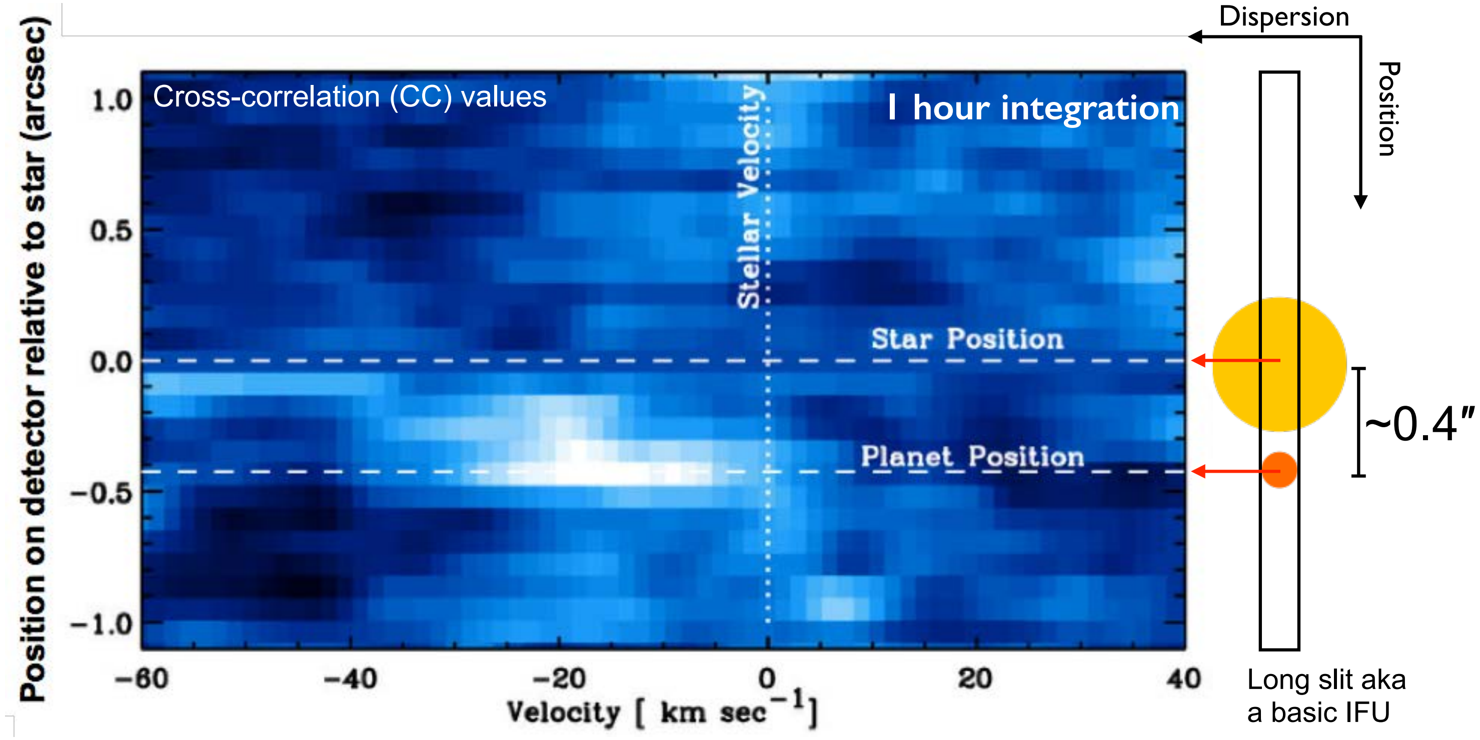
Outline

- 5 key science cases
- 4 key technical advances
- 3 collaborations
- 2 other transformative thermal IR observatories
- 1(+) Conclusion

1. Exoplanets: High Spectral Resolution

- Pioneering Doppler imaging work at VLT (slides from J. Birkby)
- Rotation period of planet measured as 8.1 hours
- Time needed on TMT is ~ few hours for nearby sources
- For the next advance, # sources in the few 10's for a few hours of TMT time
  - Similar # brown dwarfs available

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″

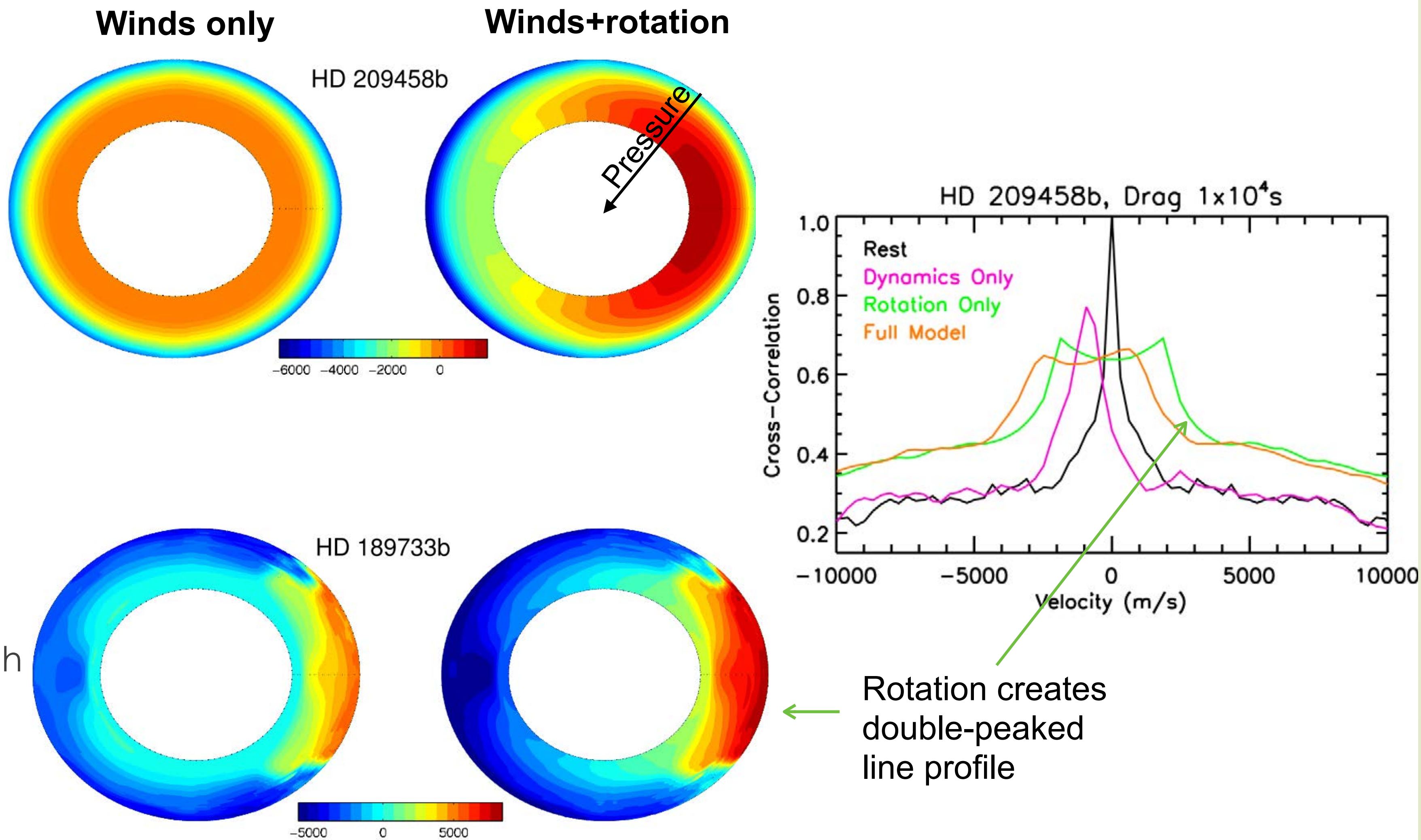
Consistent with position from direct imaging and with a circular orbit. H_2O only seen at SNR~2. No methane.

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

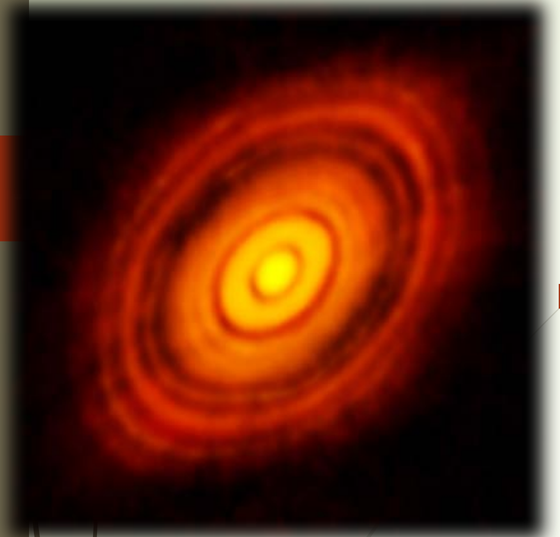
1. Exoplanets: High Spectral Resolution

- Technique can also measures molecular abundances & infers atmospheric chemical processes
- Uniquely possible with high spatial & spectral resolution
  - May require coronograph for some objects

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



Kempton et al. 2012; Showman et al. 2013

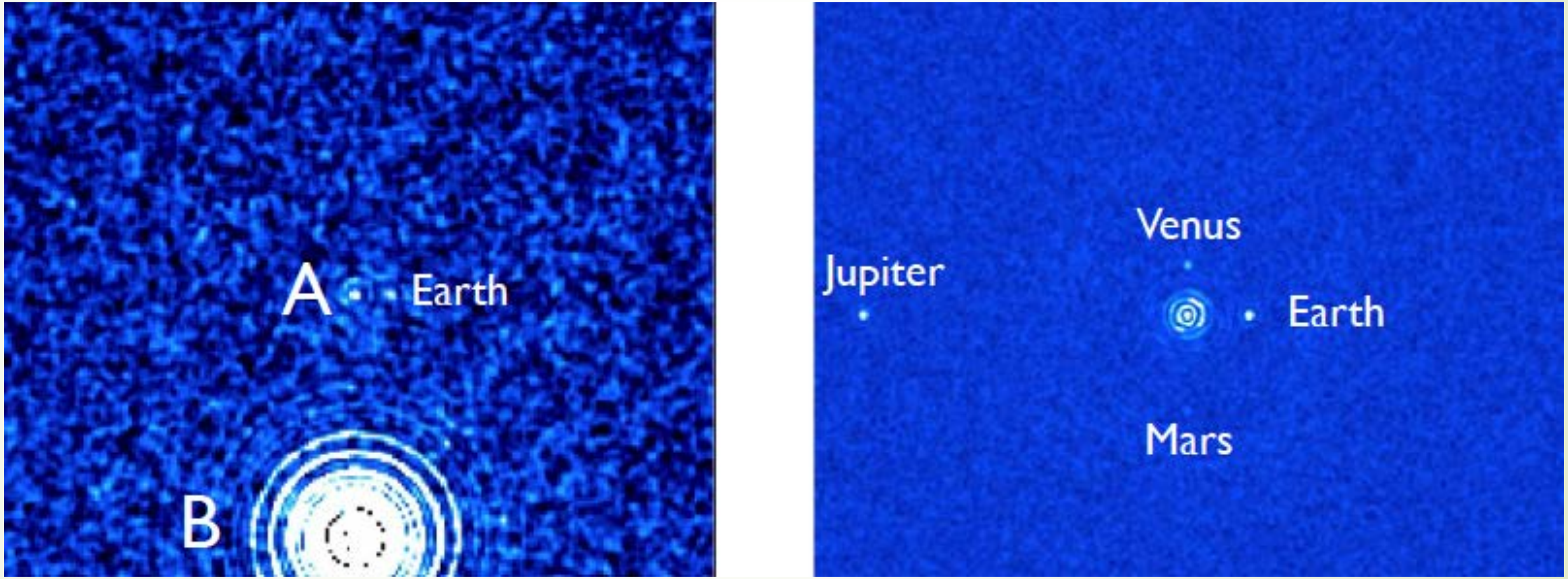


1. Exoplanets: High Spectral Resolution

- Planets 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 disc
- This has been proposed to create observable spectroscopic signatures in the 4.7µm rovibrational CO lines (TMT DSC & Regály et al. 2014)
  - Prospect of using kinematic gas tracers to detect the growth of giant protoplanets and their interaction with the disc
- Observations will reveal connection between discs & planets
  - Key step toward the final goal of understanding planet formation

2. Exoplanets: High Spatial Resolution

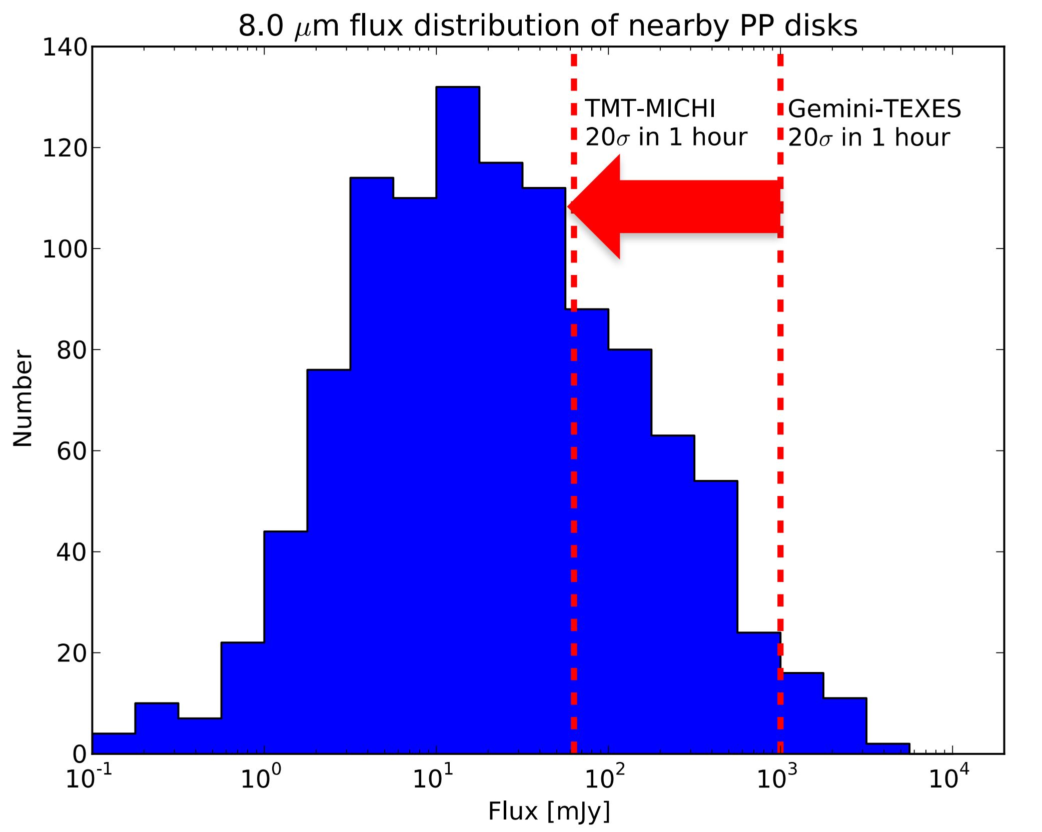
- N-band direct imaging simulations of our ‘exo-Solar System’ around Alpha Centauri
- Number of sources limited (~10), but science return is of course high
- To know more about this science case, see C. Marois' talk during the high-contrast imaging splinter session



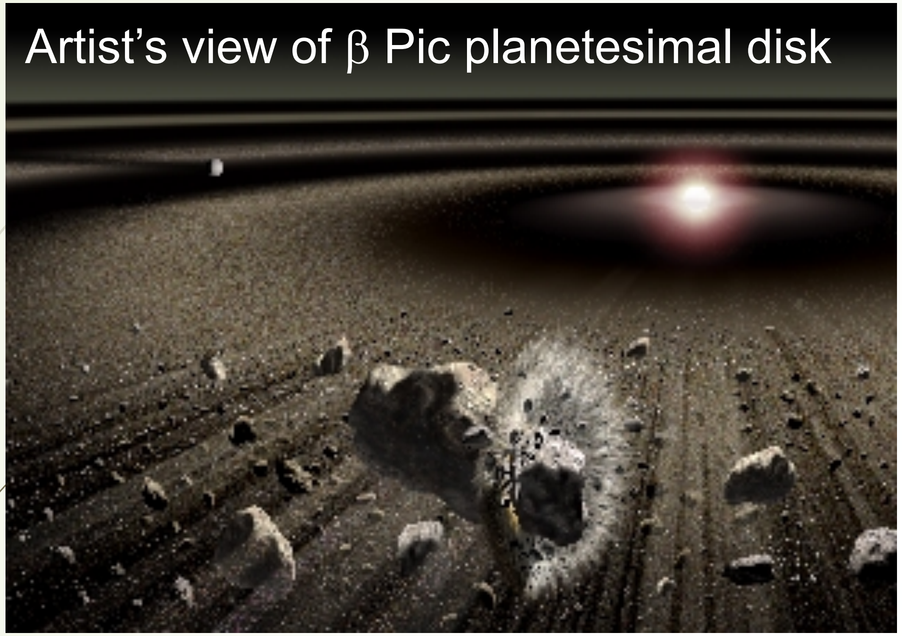
Left: Simulated Gemini 100h exposure. Right: Similar simulation for 25h TMT
Courtesy of C. Marois

3. Protoplanetary Discs: High Spectral Resolution

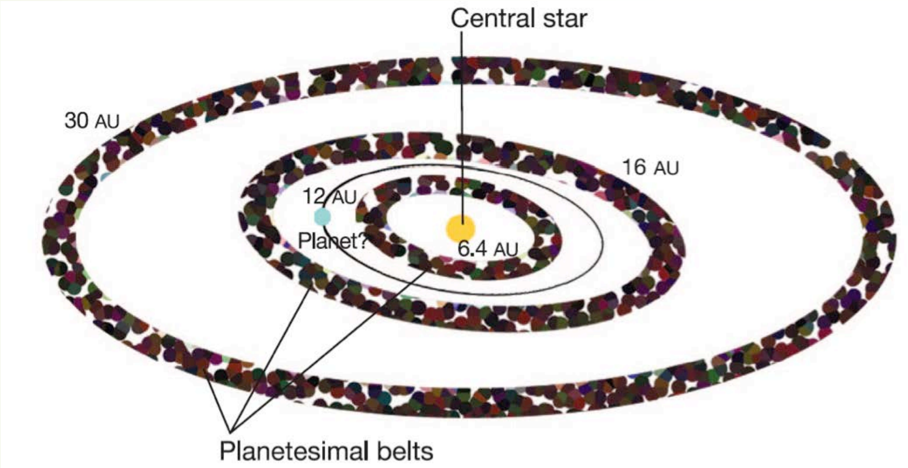
- Spitzer protoplanetary disc observations of strong emission shows oxygen & carbon species (e.g. Najita+2013)
  - C/O ratio relation between disks and exoplanet atmosphere (Oberg+2011)
- Snow line in discs important to probe water location
  - Observed by *Spitzer*, requiring high spatial & spectral resolutions
- Huge increase in available objects
  - 8m (~30) to 30m (~100's)
- Possibility of pre-biotics at such resolutions

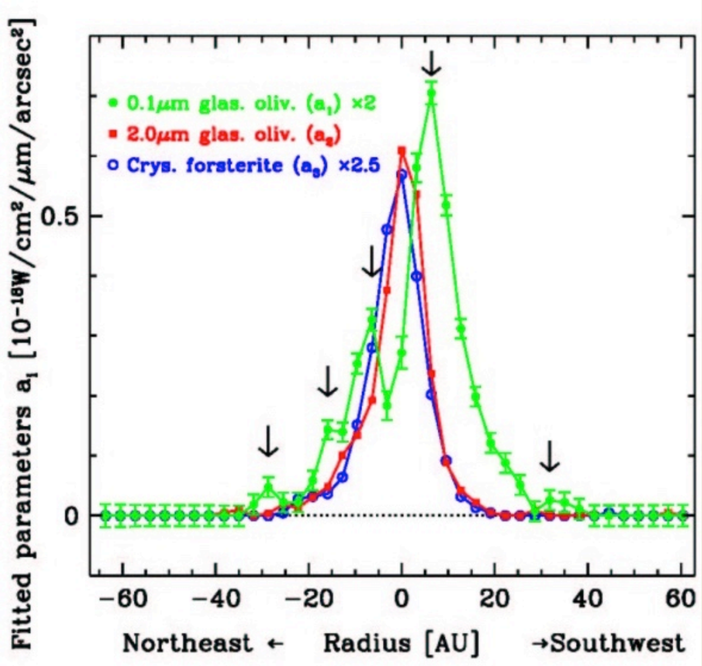


4. Protoplanetary Discs: High Spatial Resolution



- Spatially resolved N-band spectra of β Pic debris disk (Okamoto+2004)
- Spatial difference of dust feature
  - Central condensation of crystalline silicate grains
  - Several local peaks of small amorphous silicate
  - Hints of planetesimal belts and planet





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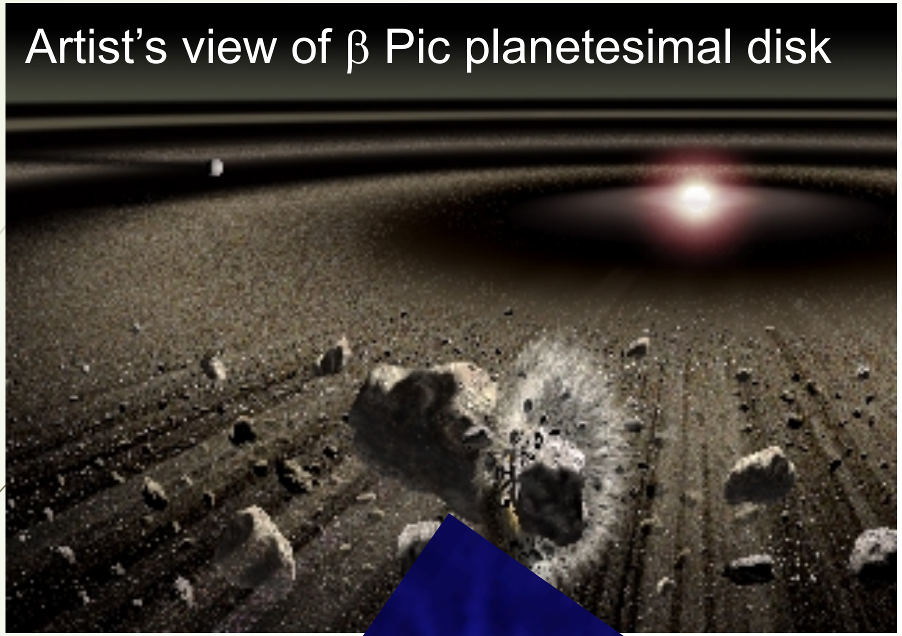

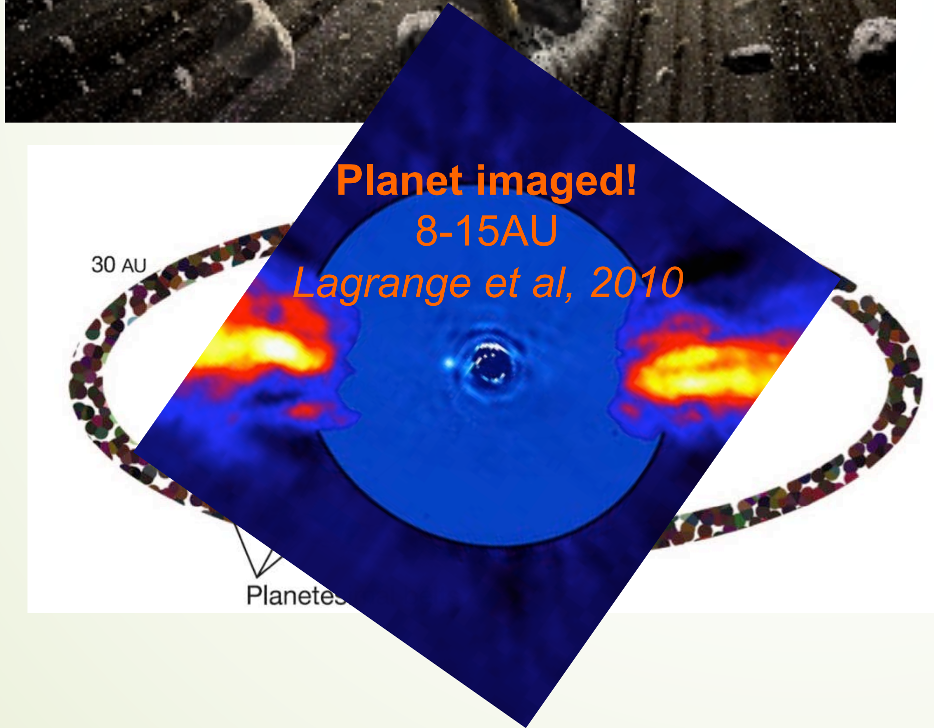

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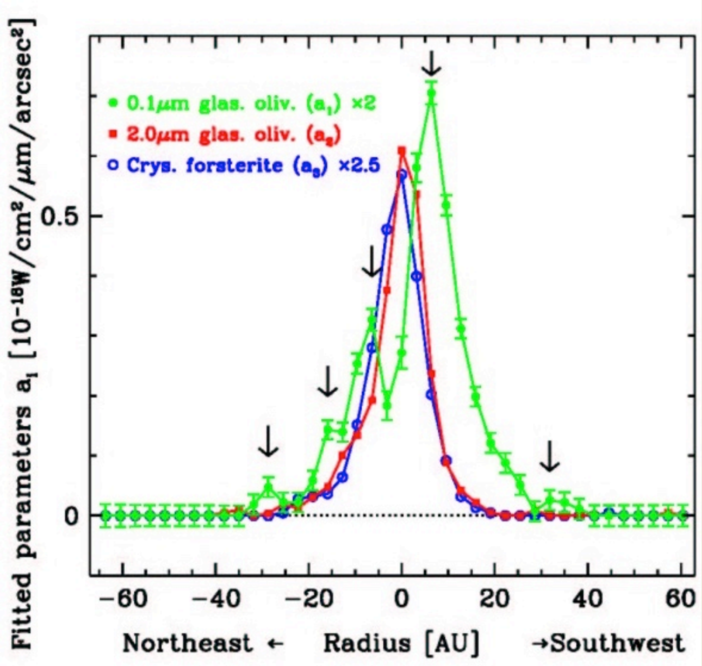
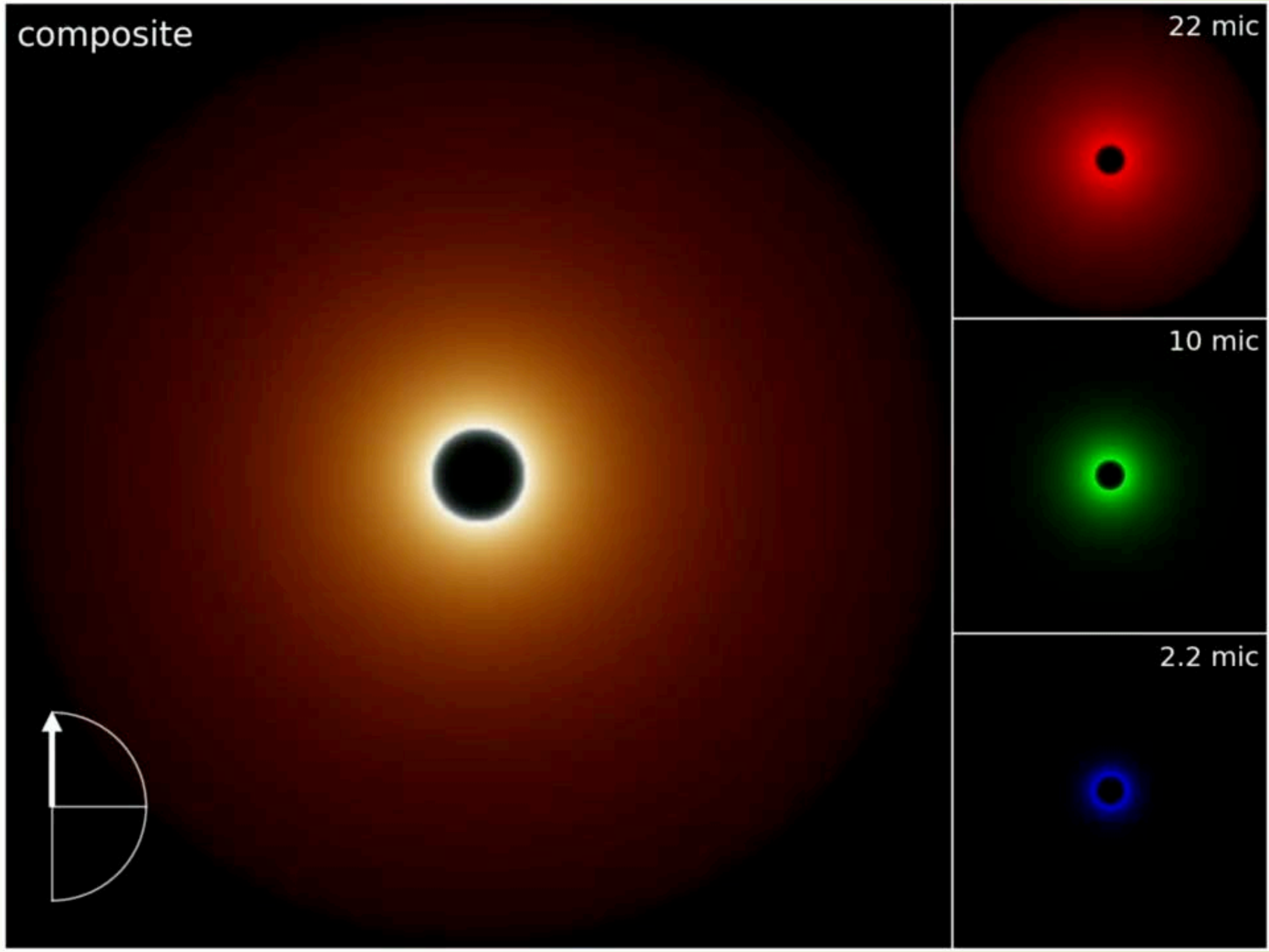


5. AGN: Imaging & Spectroscopy

- Torus is the cornerstone of AGN unified theories
- Spatially resolved with ALMA (Garcia-Burillo et al., 2016)
  - Outer edge/connection to host galaxy?
- JWST will advance inflow/outflow theories greatly
  - But will ***not*** resolve the torus
- 30m resolution at thermal-IR required as torus emission peaks at these wavelengths, & stellar dilution is low
  - Imaging & low-spectral R



Torus models using CLUMPY (Nenkova et al. 2002, 2008a,b): Movie courtesy of E. Lopez-Rodriguez

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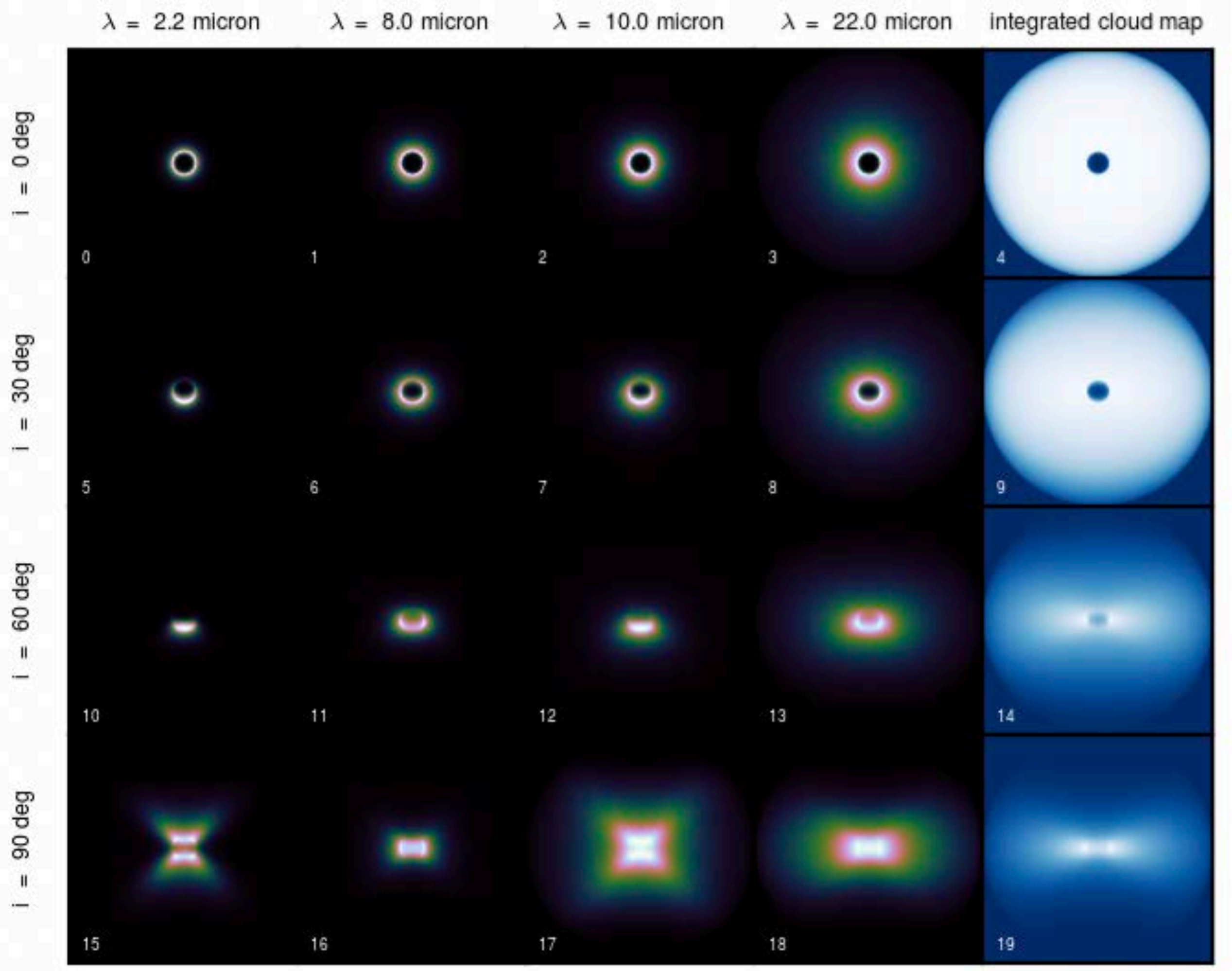

CLUMPY models of dust distribution & IR emission
(Nikutta, Lopez-Rodriguez, Ichikawa, Levenson, Packham)

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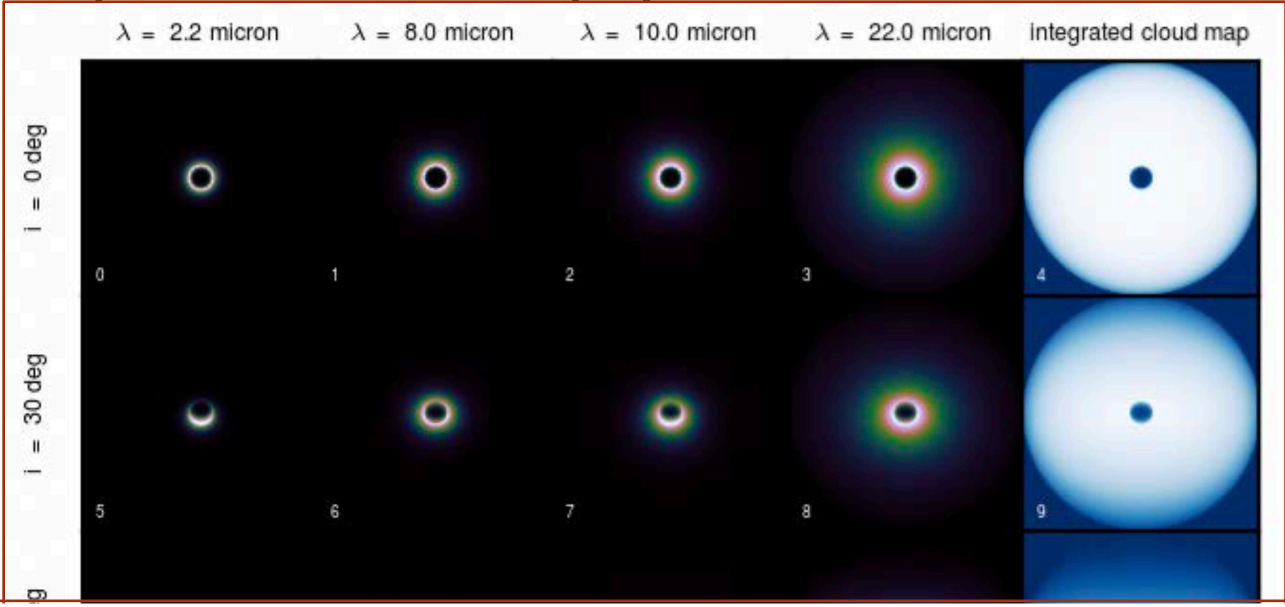
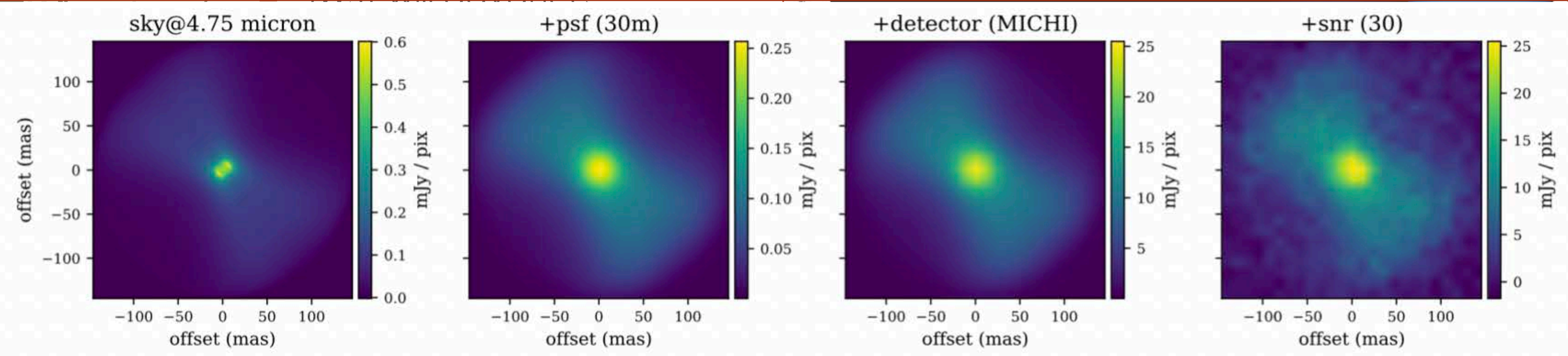
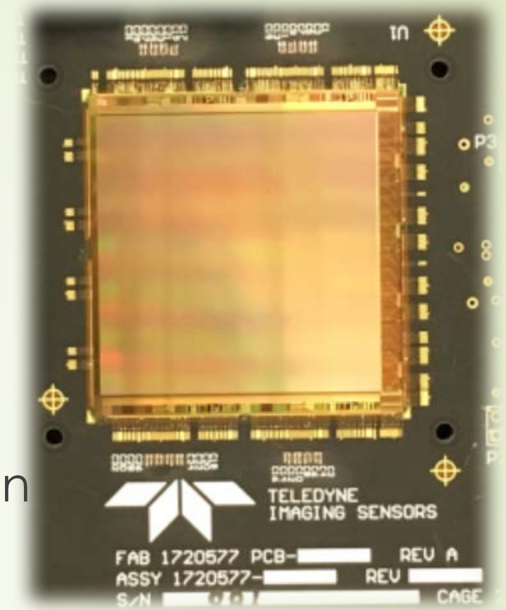




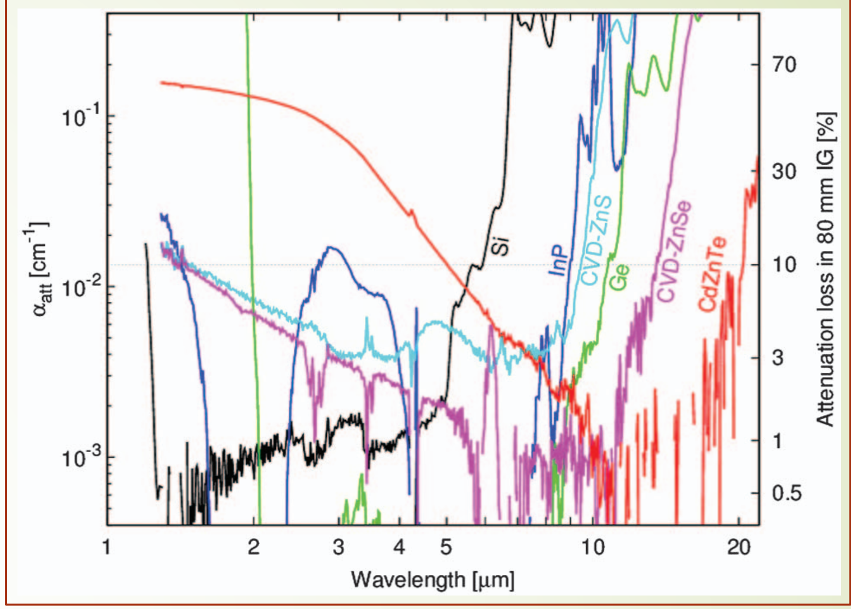
Technical Drivers: Arrays

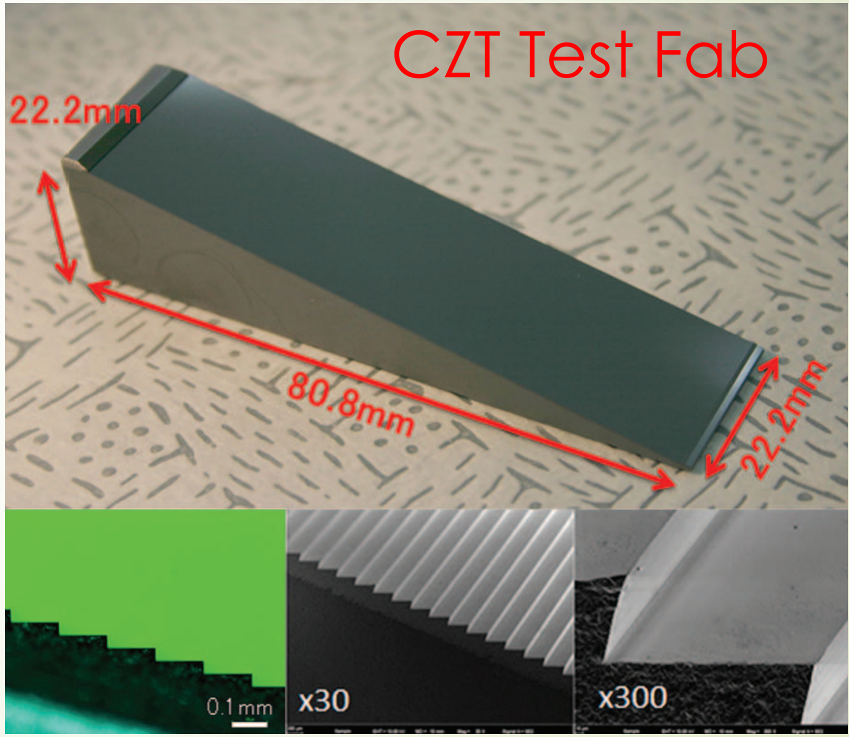


- MICHI was baselined the $1K^2$ Raytheon Aquarius array
  - Currently used in JWST/MIRI and adapted for ground use in VLT/VISIR & TAO/MIMIZUKU
  - Operates at 5-26μm, QE~40%, some ELFN issues
  - Raytheon does not plan for long-term availability of of this product
- Array consortium formed (lead by Ives (ESO) and Packham) to improve Aquarius performance (esp. ELFN and QE)
- However, Teledyne's GeoSnap HgCdTe $1K^2$, $2K^2$, or $3K^2$ is in delivery phase
  - Already several arrays delivered to an unnamed customer, test device to be delivered to consortium member for testing 1st quarter of 2018
  - Operates at 3-14.5μm, QE>>40%, likely no ELFN issues (fast frame rates, deep wells), but details need to be confirmed using test device
  - 14-bit ADC on chip, read-out electronics status TBC

Technical Drivers: IGs

- Immersion gratings hold promise of achieving high spectral R & relatively small pupil
  - Size reduced by the refractive index
- Ideal materials for thermal-IR are Ge (n~4.0) & CZT (n~2.7)
  - Ge excellent transmission <12μm, used on instruments already
    - Excellent candidate for L&M bands
  - CZT excellent transmission 3 to ~15μm; expensive
    - Excellent candidate for N band
  - Difficult to get BBAR on Ge from 3-14μm, but using 2 IGs we can optimize the AR coatings
- Work lead from Japan (Universities of Tokyo & Kyoto Sangyo, in collaboration with Canon)

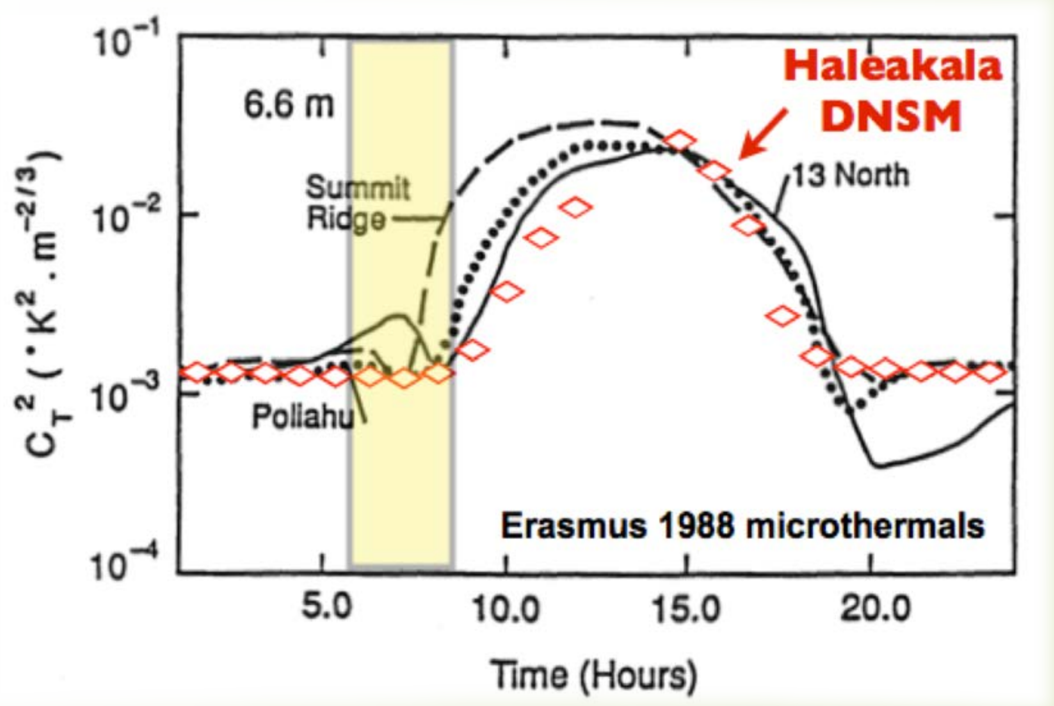




Ikeda et al, 2015

Technical Drivers: MIRAO (Mid-IR Adaptive Optics) & Daytime Observing

- Daytime observing
  - MIRAO/未知 could exploit best seeing conditions in early morning hours
  - Appears feasible with no loss in performance & affords an extra **1-2 hours per night** (at minimal cost)
  - We appreciate the Subaru team's R&D efforts
- Emerging strong connection to exoplanet groups
  - At TMT SF ~50% of 未知 & exo-planet splinter session is joint
  - Leveraged from science & MIRAO
  - Main links with Guyon, Marois, & Meyer



MIR Splinter Session

Wednesday November 8th: MICHI Key Science Cases

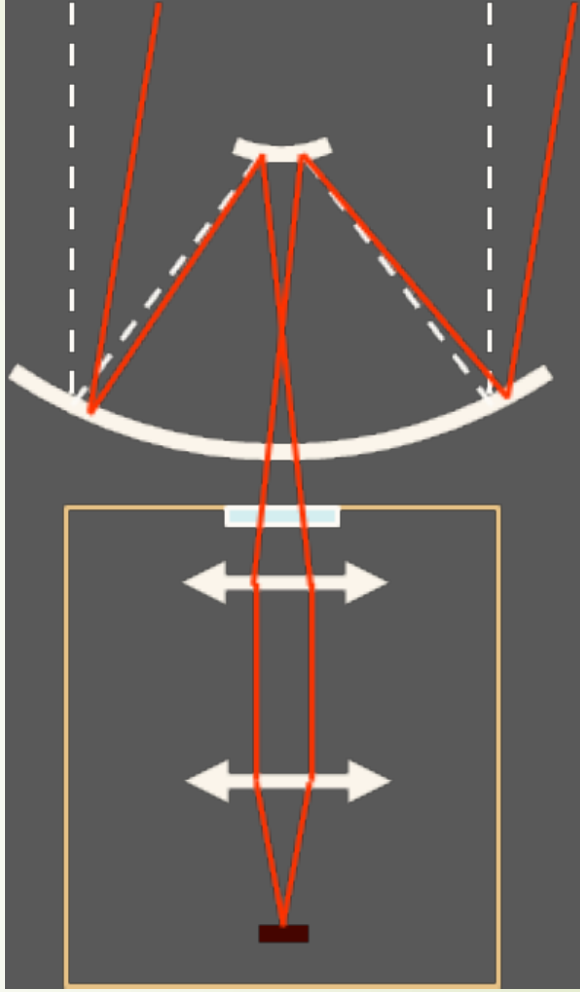
Start	Title	Speaker	Sub-title	Comments
14:30	Welcome & Goals	Chris & Christian	Joint with Exoplanet Splinter Session	Short welcome address and expression of the goals for the splinter session
14:35	L/M-band Imaging/spec.	A. Skemer		
14:50	Young disks/exoplanets	R. Dong		
15:05	Protoplanetary Disks	Honda-San		MICHI Science case 1
15:20	Exoplanet thermal	C. Marois		MICHI Science case 2
15:35	Science hires spectroscopy	D. Mawet		MICHI Science case 3
15:50	*Coffee break*			
16:10	Disc high spectral res	Greg		MICHI Science case 4
16:30	AGN & Torus	Ichikawa-san		MICHI Science case 5
16:50	Supporting Cases	Manoj & Vig		Other science cases that we will feature, limited to 1 page in the WP
17:05	Supporting Cases	Jessy, Chris, Honda-san		Other science cases that we will feature, limited to 1 page in the WP
17:20	Round table discussion	All		Discussion of current science cases, JWST/ALMA connections, mapping to instrument overview and WP
18:00	Adjourn			

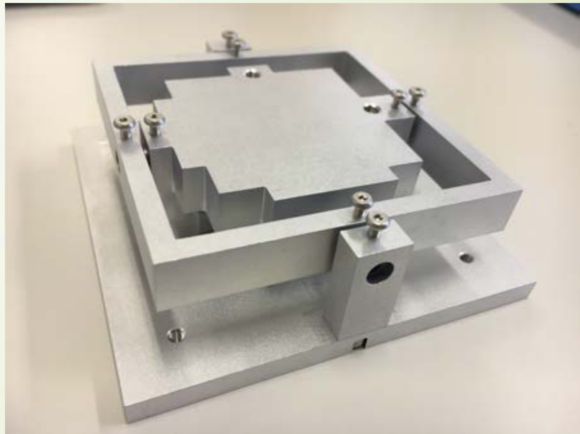
Thursday November 9th: Instrument Status

Start	Title	Speaker	Sub-title	Comments
9:00	MICHI	Chris	Joint with Exoplanet Splinter Session	Instrument overview
9:10	MIRAO	Mark		AO overview, daytime observing
9:20	PSI	M. Fitzgerald		Instrument overview
9:30	High-Res. Spect. + AO	Dimitri		
9:40	SCExAO as a prec. TMT inst.	Olivier		
9:50	Round table discussions	Chris & Christian		
10:15	*Coffee break*			
10:30	Detectors	Chris		New technology and changing from MICHI to bMICHI
10:40	Japan's R&D Activity	Honda-san		Development status
10:50	Immersion Gratings	? Chris ?		Current status of the IG for L&M, N bands
11:00	Polarimetry	Gopinathan & Manjunath		Implementation and discussion on the instrumental polarization
11:10	IFU	Sakon-san via skype?		Development status
11:20	Interactions	Chris		Interactaction and synergy with other TMT (and other 30m?) instruments
11:30	Round table discussion	All		Discussion of current science cases, mapping to instrument overview and WP
11:50	Summary	Chris & Honda-san		Conclusions of the session, outline of plenary presentation
12:00	Adjourn			

Technical Drivers: Cold Chopper

- To remove time-variable high-background, beam switching by an internal mirror at a pupil-plane is required (cold chopper)
  - f~5 Hz (duty cycle > 90%)
  - T~30K, vacuum
  - Power dissipation <<1W
- Currently a prototype for TAO/MIMIZUKU is undergoing testing/characterization
  - Could be the testbed/prototype for TMT/MICHI chopper





Collaborations: METIS

- Already several areas of collaboration, but could increase collaboration number and depth if MICHI proceeds
- Discussions with METIS PI (Brandl) raised possible areas
  - Array & electronics
    - Array consortium already anchored by Ives (ESO) and Packham (UTSA)
  - Cold chopping mirror
  - Data reduction software
    - High-level data interpretation, coronograph, IFU, etc.
    - PSF reconstruction from the WFS, how to get it to be useful for science obs
  - Personnel exchange between the groups, perhaps most easily imagined in AIV phases

METIS
Mid-infrared E-ELT Imager and Spectrograph

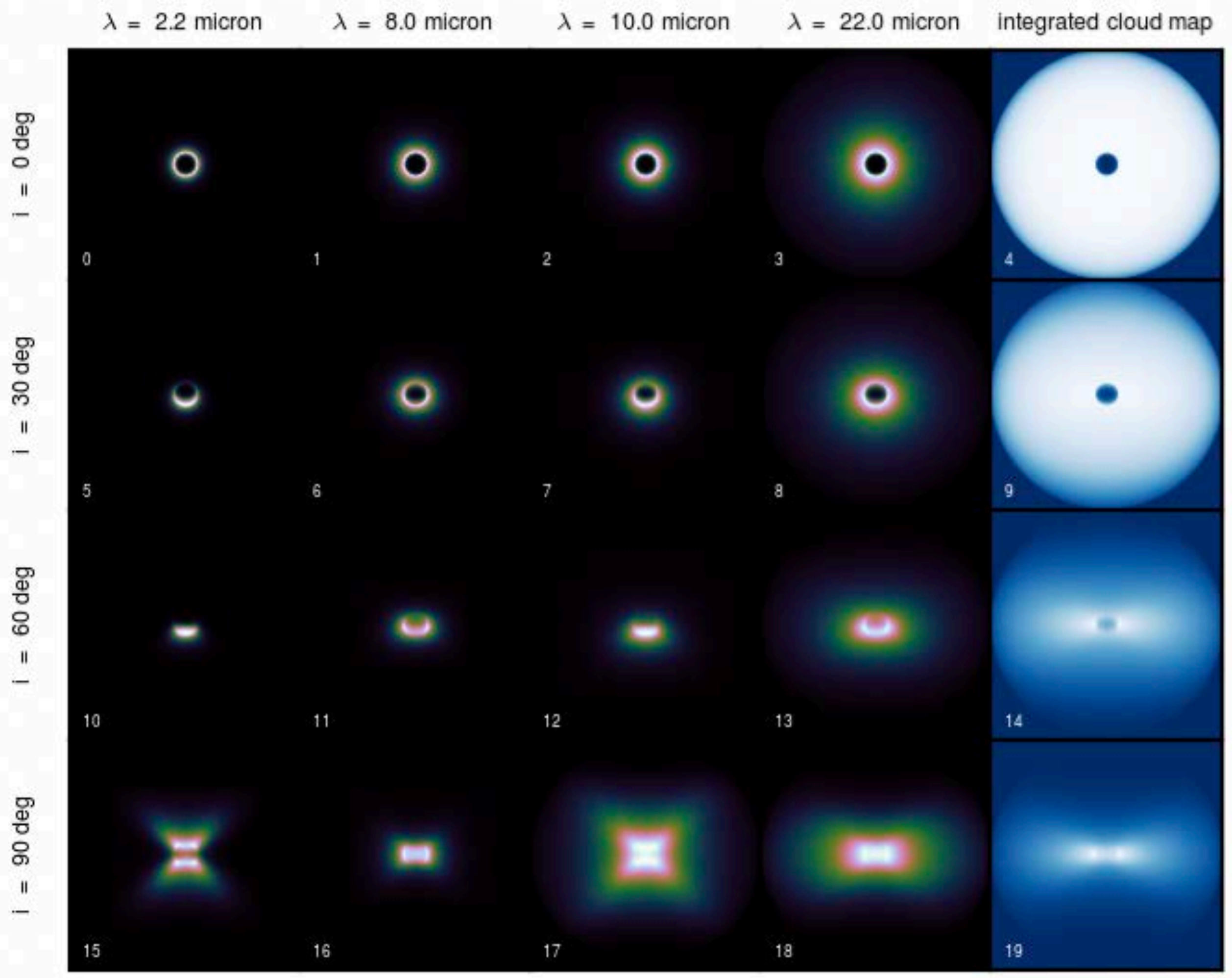
Collaborations: PSI

- PSI & MICHI offer a continuous wavelength coverage for exoplanets from 1-14μm(+)
- Considering to use the common technical core of MIRAO for both instruments
- See Mark Chun's presentation in the splinter session

Collaborations: IRIS

IRIS
Infrared Imaging Spectrograph

- Science links are clear through, for example, the AGN science case
  - High spatial but low spectral resolution needed 1-14μm



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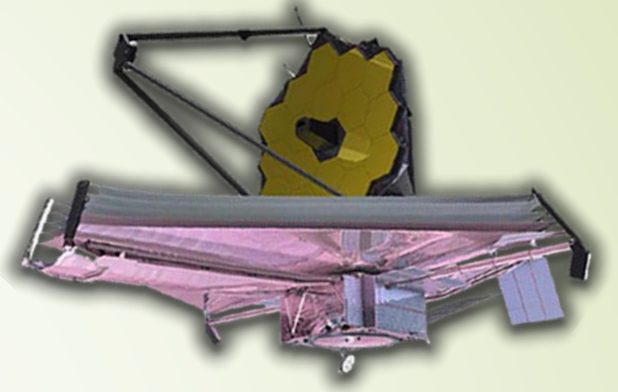
Comparisons: JWST



MICHI
L band 0.024", ~100K
N band 0.054", ~100K

- JWST will clearly have far greater sensitivity, but is limited in spatial & spectral resolutions
  - NIRcam/spec (2.4-5μm) spatial R ~0.126", spectral R~100, ≤2,700
  - MIRI spatial R ~0.22", Spectral R~100, ≤3,710
- Unique combination afforded by TMT of
  - Excellent sensitivity & high spatial resolution (IWA) essential for exoplanet direct imaging, disc work, & AGN
  - Excellent sensitivity, & high spectral/spatial resolution essential exoplanet atmosphere & disc *characterization*
- *Follow-up of JWST observations will often require the combination of sensitivity, spatial & spectral resolution*
  - ***TMT/MICHI on MKO is arguably the ideal follow-up machine***

Comparison to METIS

- Currently not planned to offer LTAO capability
- Currently not planned to offer high spectral R at N band
- MKO is the premier 30m thermal-IR of the 30m's
- Is essentially in a locked-down design
  - Changes that might be desirable after JWST might be difficult to implement
  - The delay of 2nd gen. instrument start for MICHI could be an advantage in this respect
- However, collaborations in obvious areas (as noted before) could reduce costs & risk, and/or improve MICHI

Why MICHI Now?

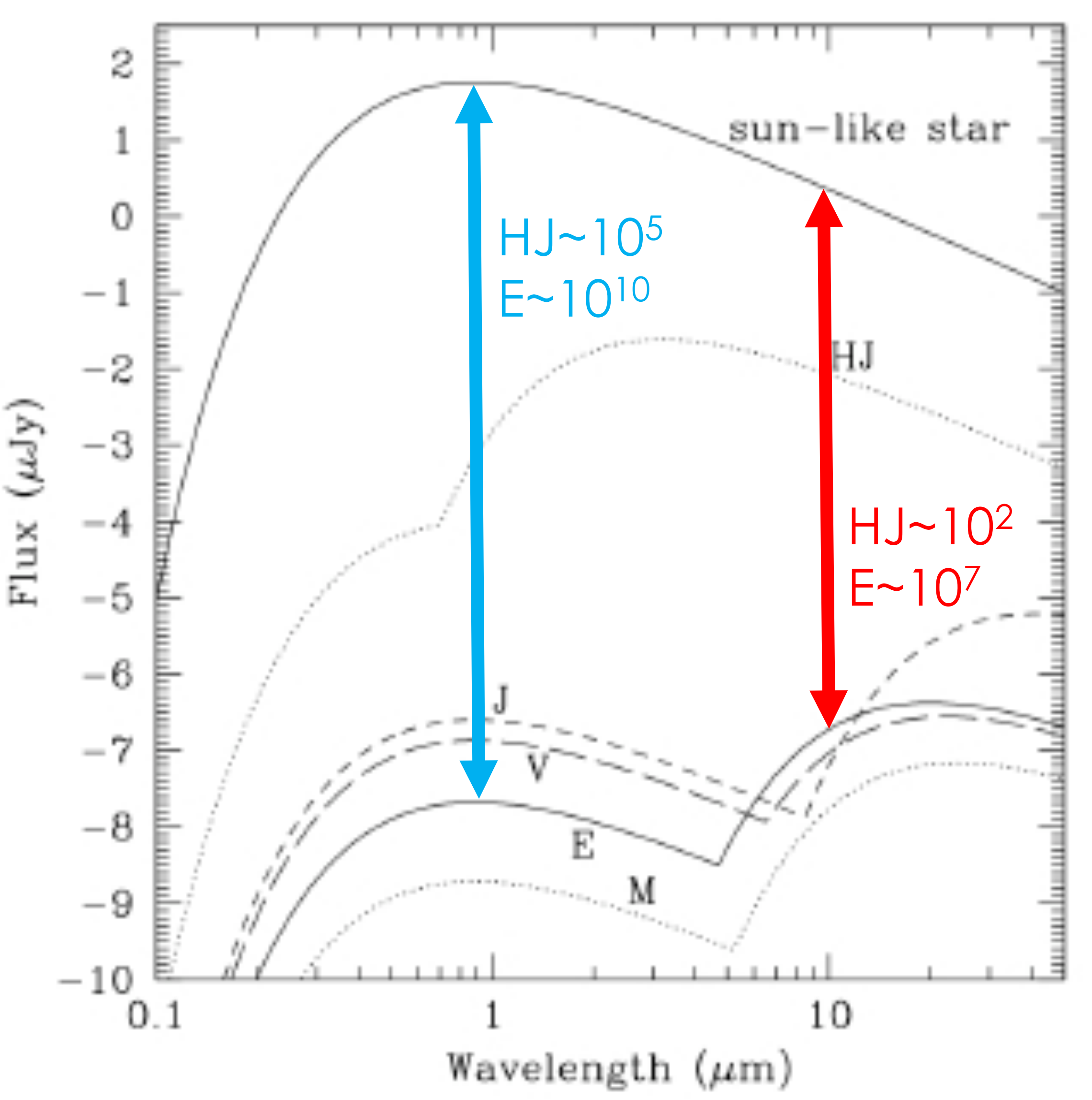
- TMT & E-ELT essentially in a dead-heat for operations start
- Exoplanet science remains a hot topic, great interest in L&M
- JWST follow-up will be crucial in the 30m era
  - Again stress that TMT on MKO is the premier thermal-IR 30m site
- Synergy of MICHI/PSI science & technology strong
- Collaborations with METIS possible now, more challenging if we move further out of sync
  - Technical, personnel, & science exchanges possible

Conclusions

- We believe compelling 5 key science cases, & numerous supporting cases make MICHI a strong 2nd gen instrument
  - Science case links to PSI & common technical foundation of MIRAO
- Science team has >50 active researchers from all TMT partners
  - We invite researchers to join & provide science cases
  - ***Join us for the thermal-IR and/or exoplanet splinter sessions***
- Technical team includes USA, Japan, India, & Canada
  - R&D in progress, & nascent connections to METIS
  - MICHI working well as a science/instrument team for several years
- *Excited for thermal-IR instrument on world's best thermal-IR site, primed for JWST (& ALMA) exploitation, defined science cases, links to other TMT & 30m instruments, & established/proven team*

Exoplanets: High Spatial Resolution

- Black body fluxes of solar system objects observed at 10pc (Seager & Deming 2010)
  - 3 order of magnitude gain going to thermal-IR, but background becomes more problematic
- Low spectral resolution to afford basic characterization of atmospheres & clouds for J & HJs



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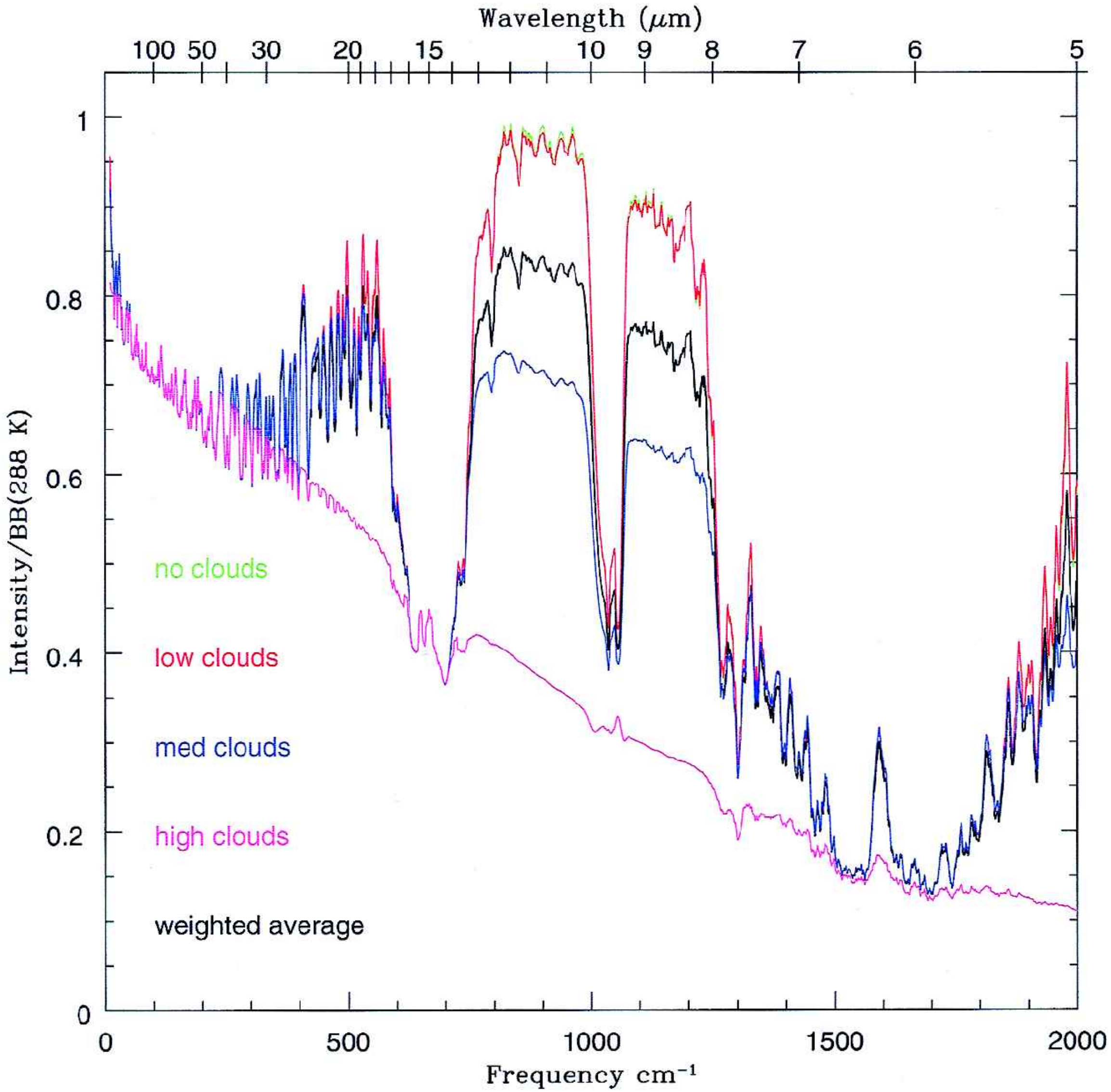

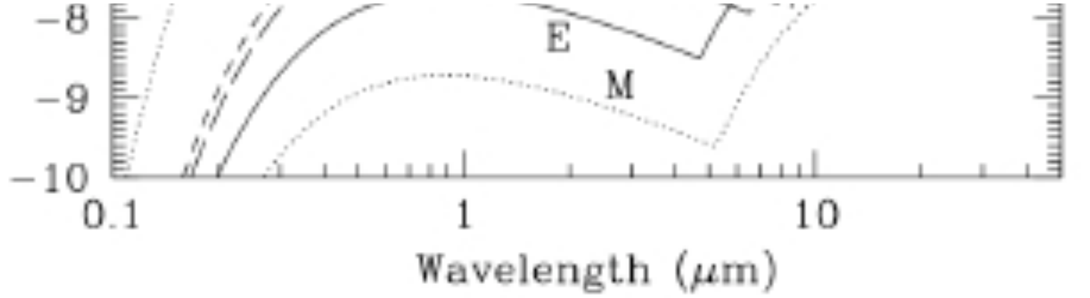

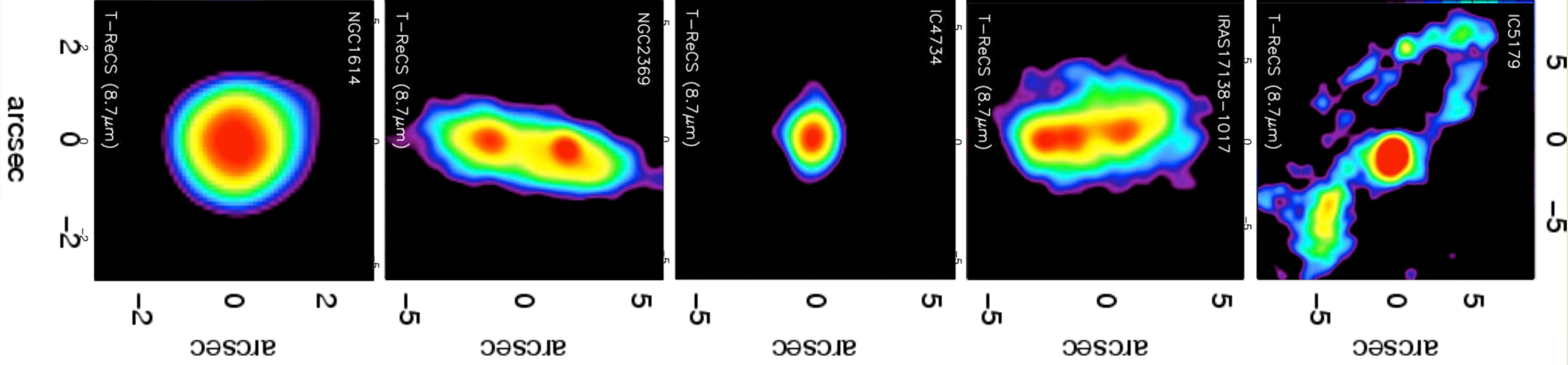

High spatial R reduces galaxy contamination

- Resolution at z=0.5
  - *JWST* = 1.5kpc (galactic star forming rings, etc.)
  - *TMT* = 330 pc (nuclear dominated)
- Images show 5x increase in spatial resolution
- *Toward resolving the BLR – noteworthy as all flew into BLR*