Thirty Meter Telescope

国立天文台 TMT 推進室

PHYSICS&ASTRONOMY
THE UNIVERSITY OF TEXAS AT SAN ANTONIO

MICHI: A MIR Instrument for the TMT

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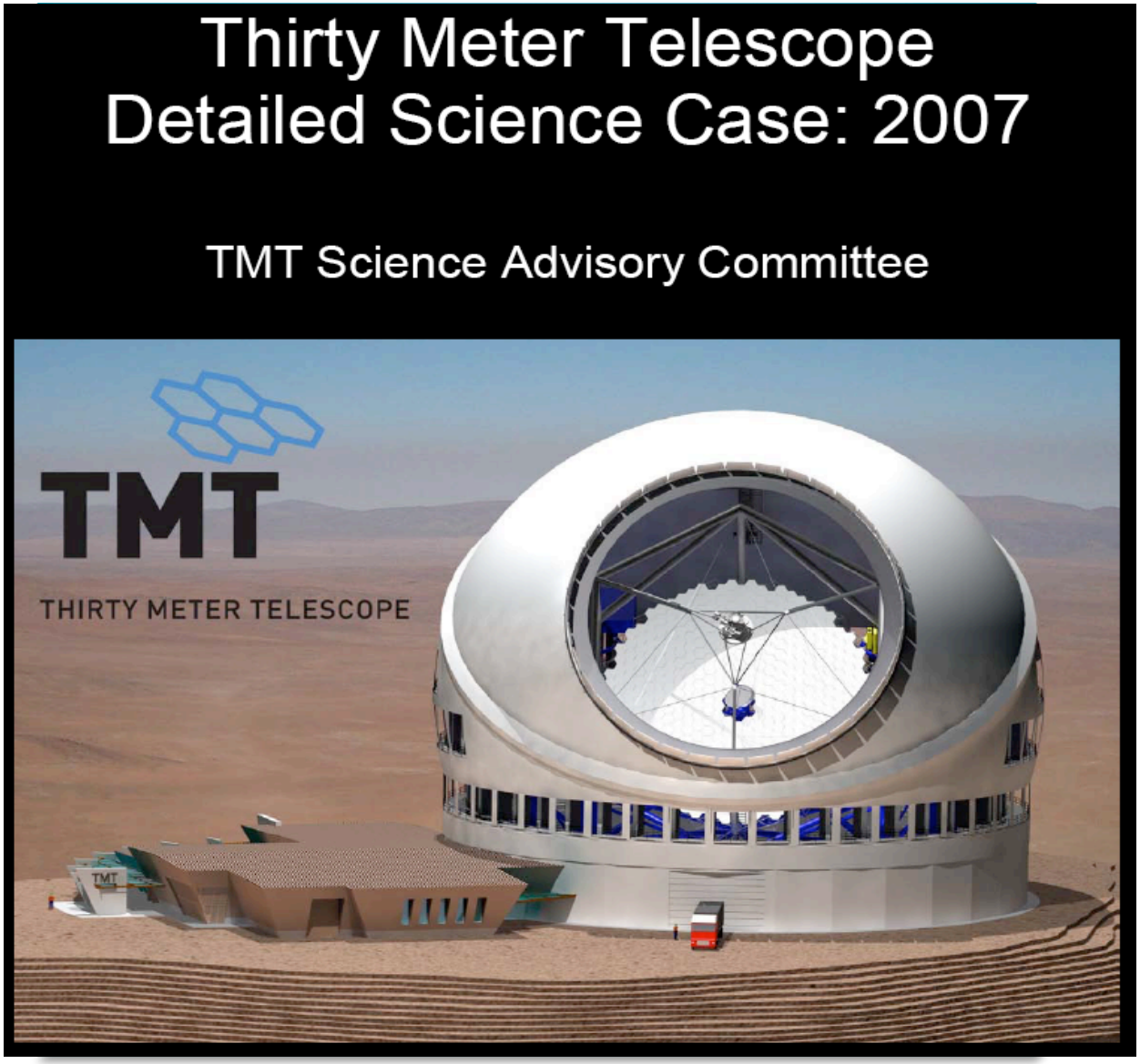
Outline

- TMT & MIR instrumentation
  - Original Science Cases => instrument spec.
  - MICHI - 未知
  - Current status
  - Connection to new (draft) ISDT science cases
  - Summary

TMT's Key Science Cases



TMT Science Addressed by MIR

1. What is the nature and composition of the Universe?	Lensed QSO's, high-z redshifted spectral lines to MIR wavelengths
2. When did the first galaxies form and how did they evolve?	Evolution via imaging & low-resolution spectra of redshifted lines
3. What is the relationship between black holes and galaxies?	AGN Studies, ULIRGS; extending from local to moderate-z
4. How do stars and planets form?	Disk analysis, imaging of planet 'fingerprints' in disk
5. What is the nature of extra-solar planets?	Low- and high-spectral resolution analysis of disk chemistry
6. Is there life elsewhere in the Universe?	High spectral resolution of bio-markers

MIR Transformative Science

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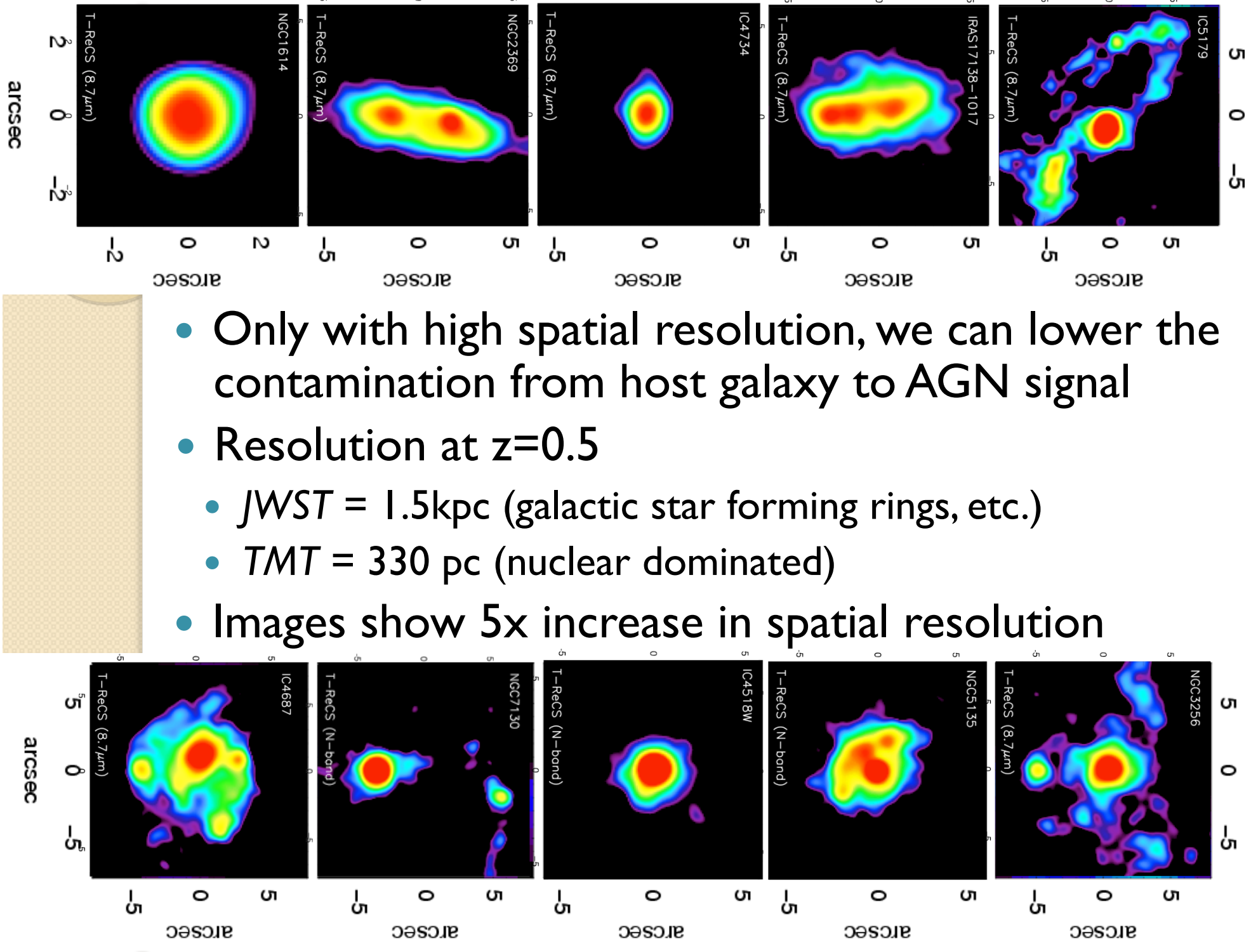
5. What is the nature of extra-solar planets?	Low- and high-spectral resolution analysis of disk chemistry
6. Is there life elsewhere in the Universe?	High spectral resolution of bio-markers

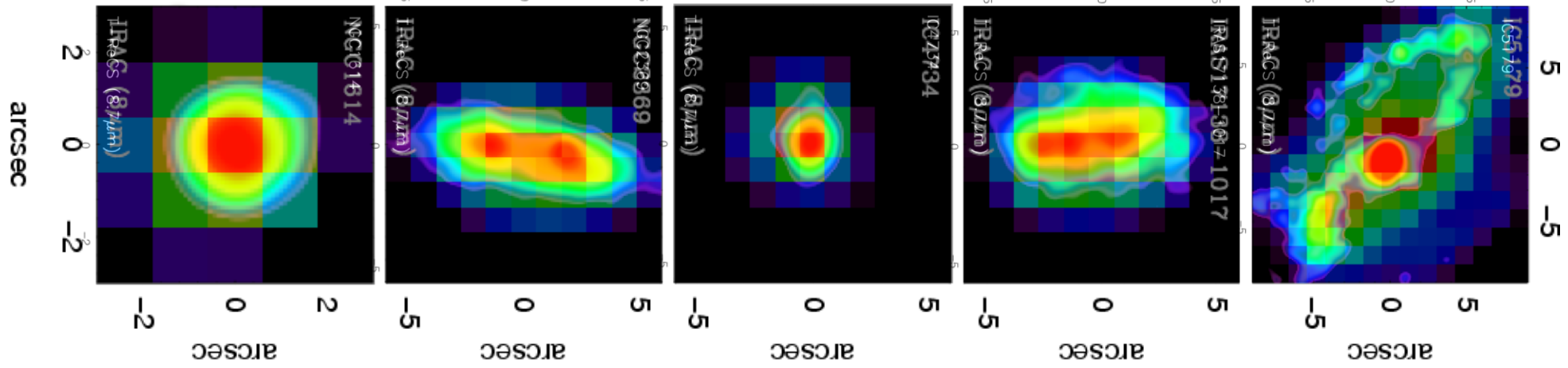
Lots of Discussions in USA & Japan

MICHI (未知) Concept

- Japanese lead by Y. Okamoto & M. Honda
  USA lead by C. Packham, M. Chun, & M. Richter
  - Strong MIR community interest in Japan & USA
  - NSF seed funding (PI: Packham) to define key science drivers & optical design
  - J-TMT funds (PI: Honda-san) for chopping & AO early R&D
- Instrument capabilities
  - High spatial resolution (0.063")
  - High spectral resolution (R~120,000)
  - Moderate spectral resolution (R~1,000)
  - IFU & polarimetry modes



- Only with high spatial resolution, we can lower the contamination from host galaxy to AGN signal
- 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



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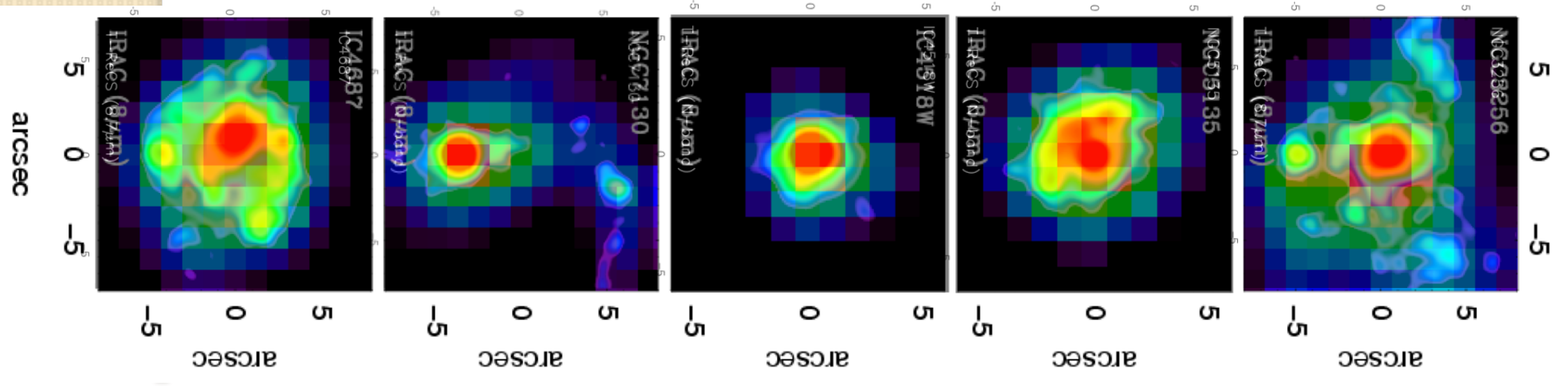
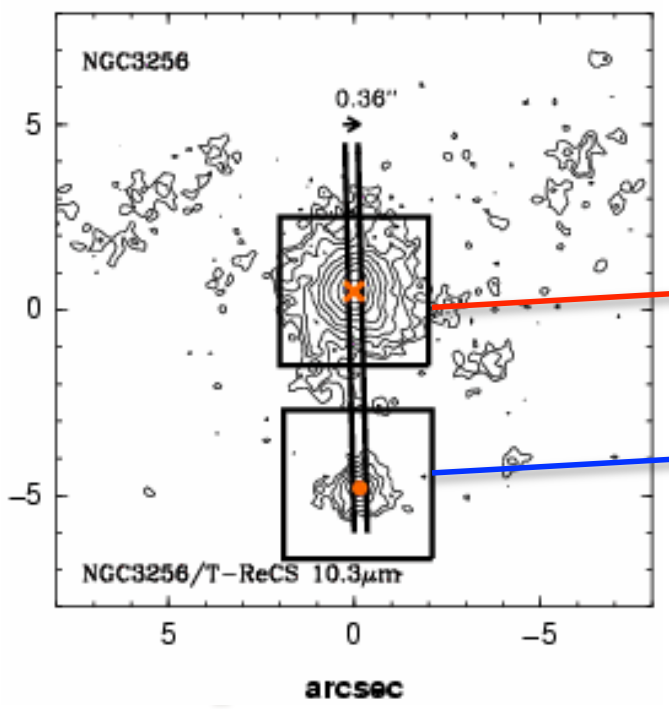
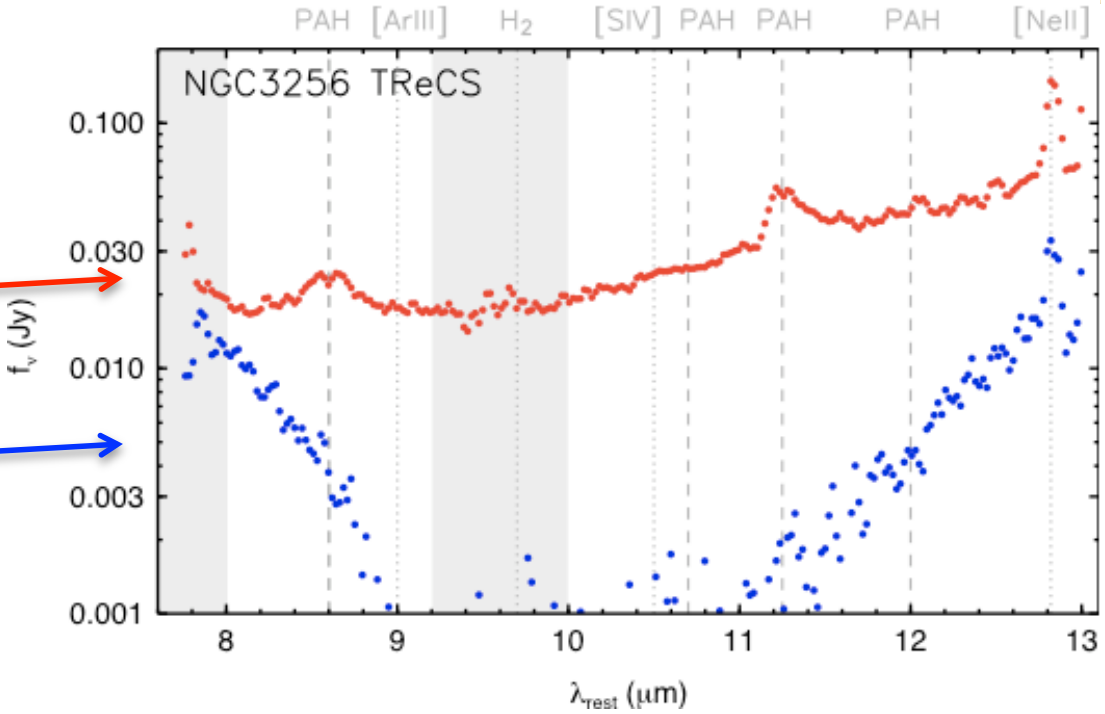


Spatial Resolution & Spectra

Diaz-Santos PhD Thesis

- Surrounding area contamination complicates interpretation
  - MIR constrains torus to <few pc & clumpy distribution
  - 1" resolution of nearby AGN shows AGN contribution (<)<30%
- Image quality & stability a problem for 8m's
  - JWST & AO systems on 30m-class telescopes => high Strehls





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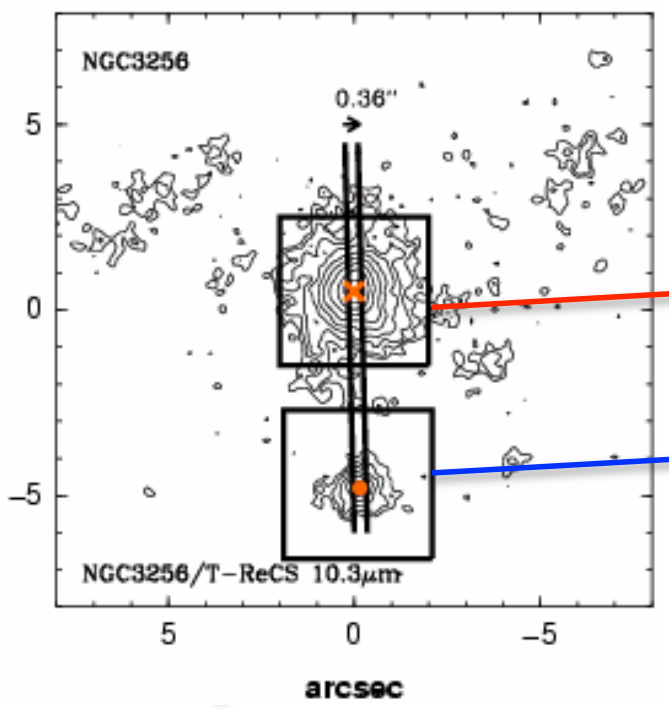
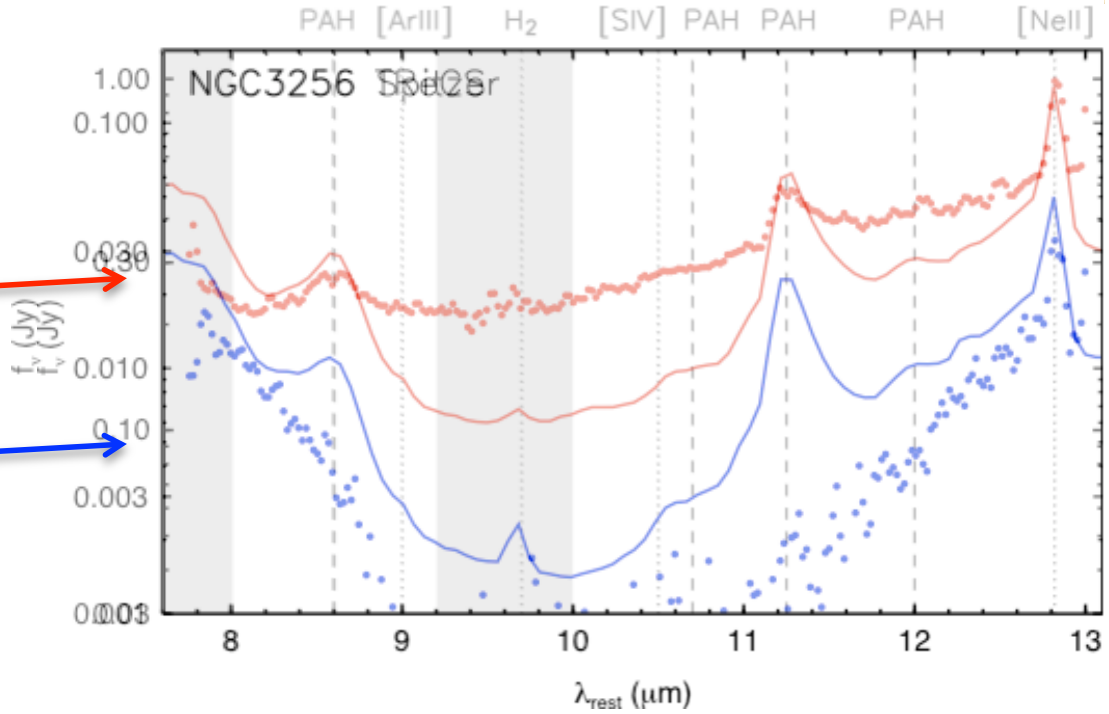
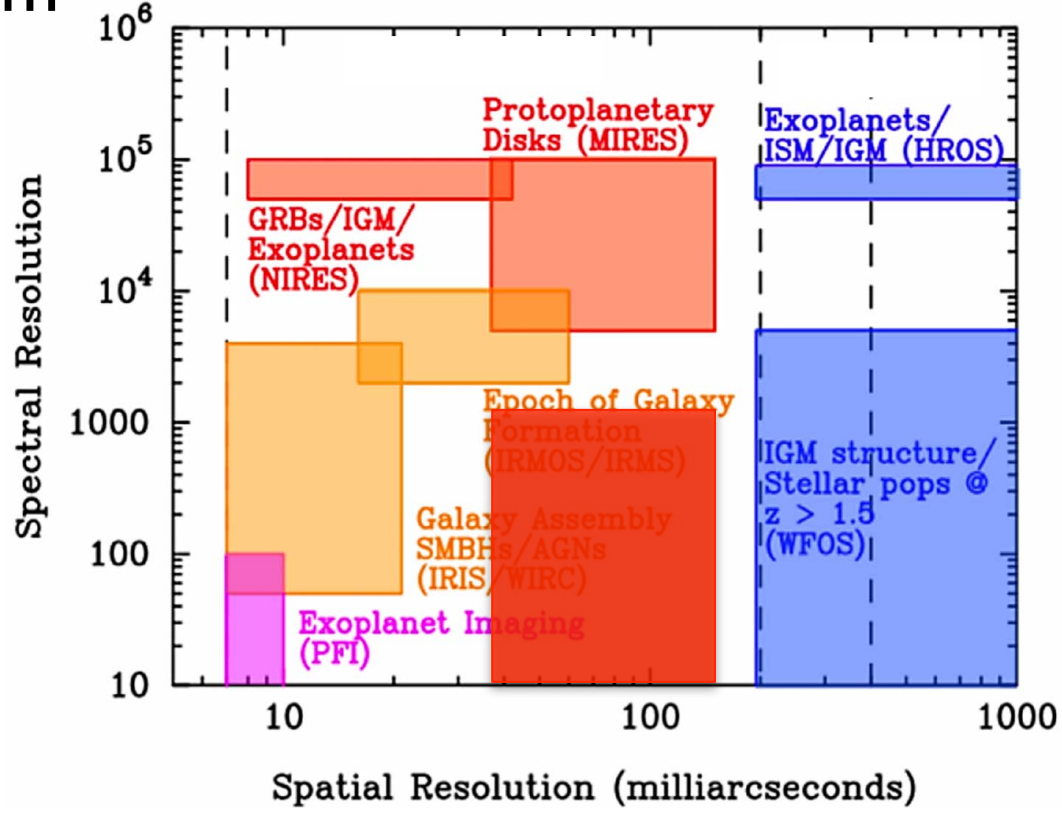


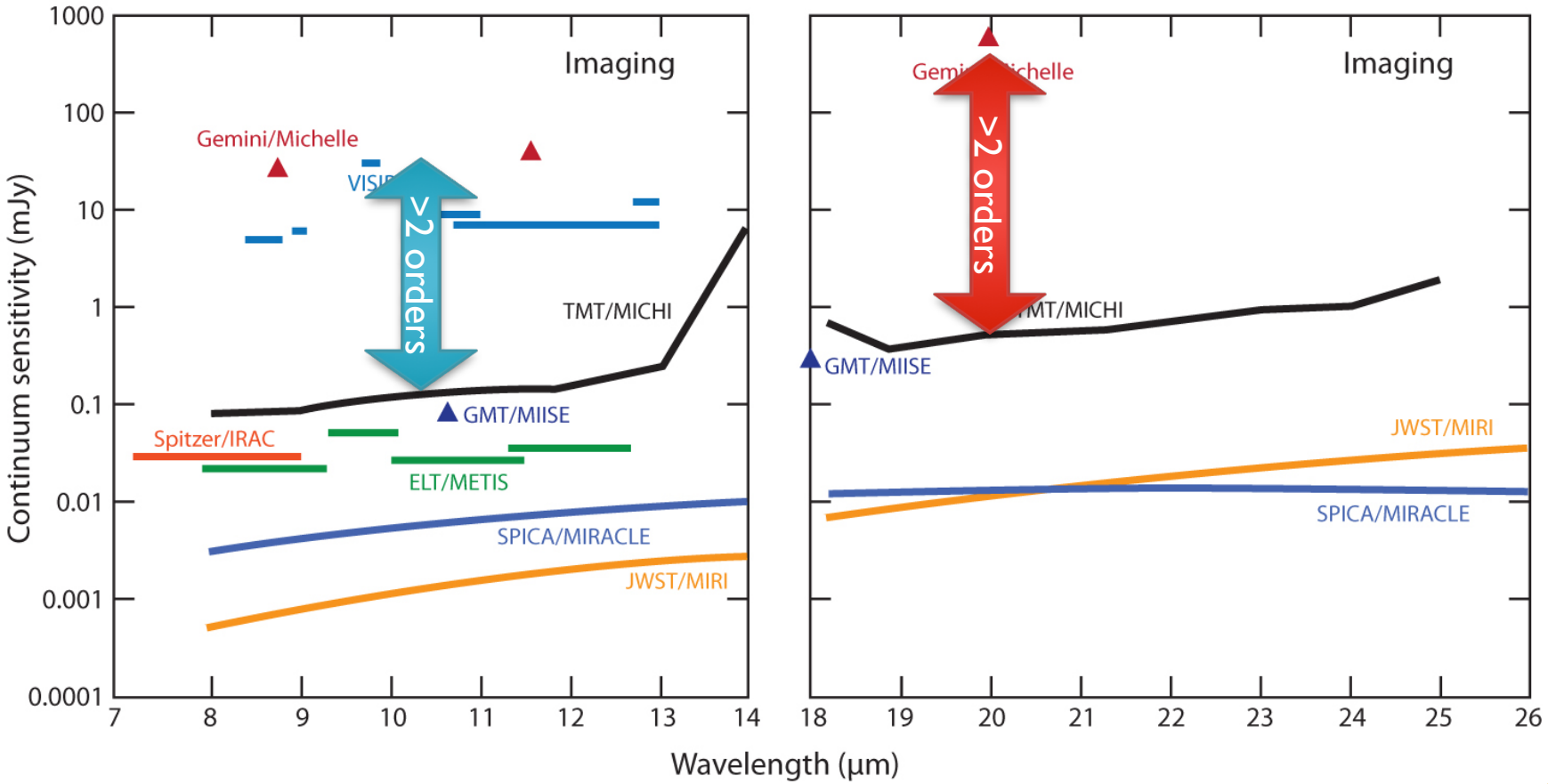


TMT Parameter Space

- 未知 fits very well into the wavelength and spatial/ spectral resolution plot of the *TMT*
- 未知 & the Mid-IR AO system (MIRAO) optimized for>7.5μm
  - MIRAO to offer excellent IQ at 3 & 5 μm
  - 未知 could offer limited 3 & 5 μm capabilities
    - Currently considering this point carefully

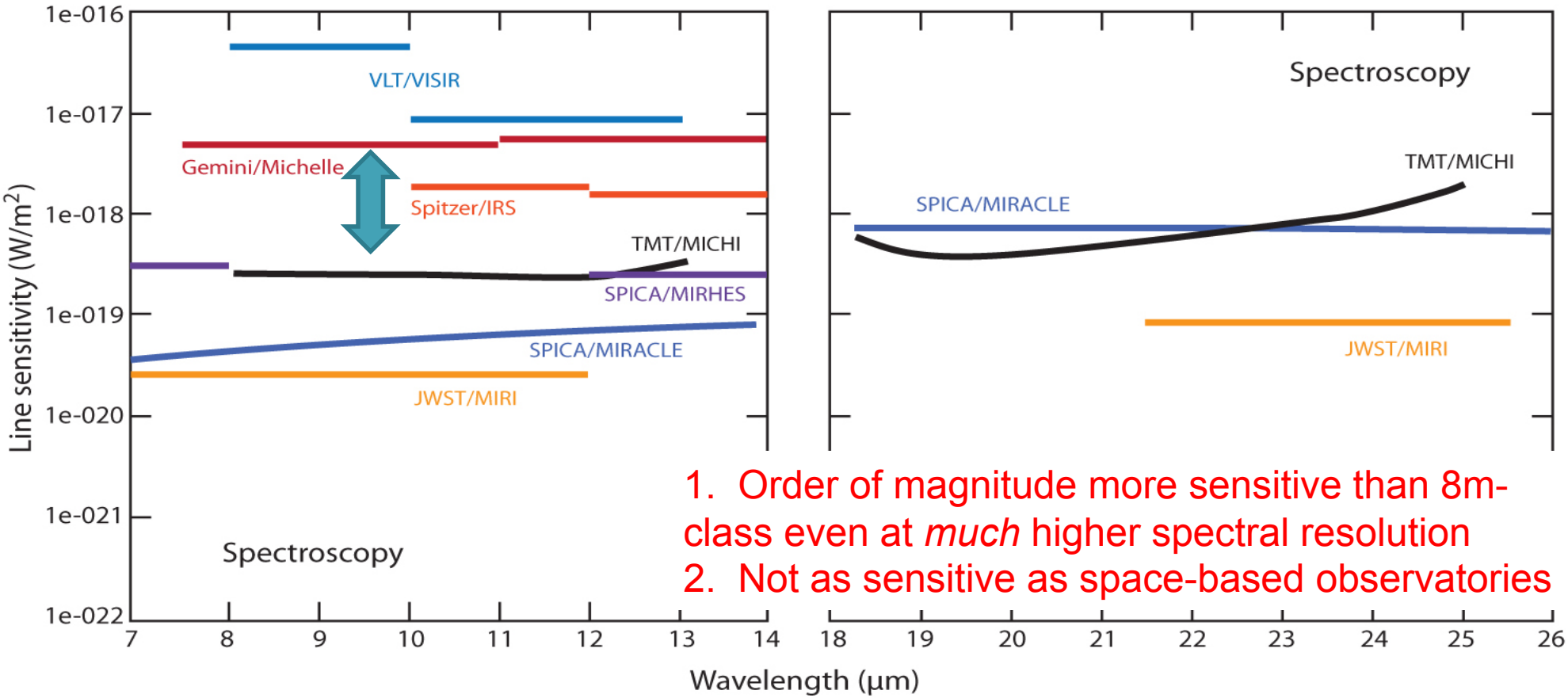


未知 Imaging Sensitivity



- 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

未知 Spectroscopic Sensitivity



1. Order of magnitude more sensitive than 8m-class even at *much* higher spectral resolution
2. Not as sensitive as space-based observatories

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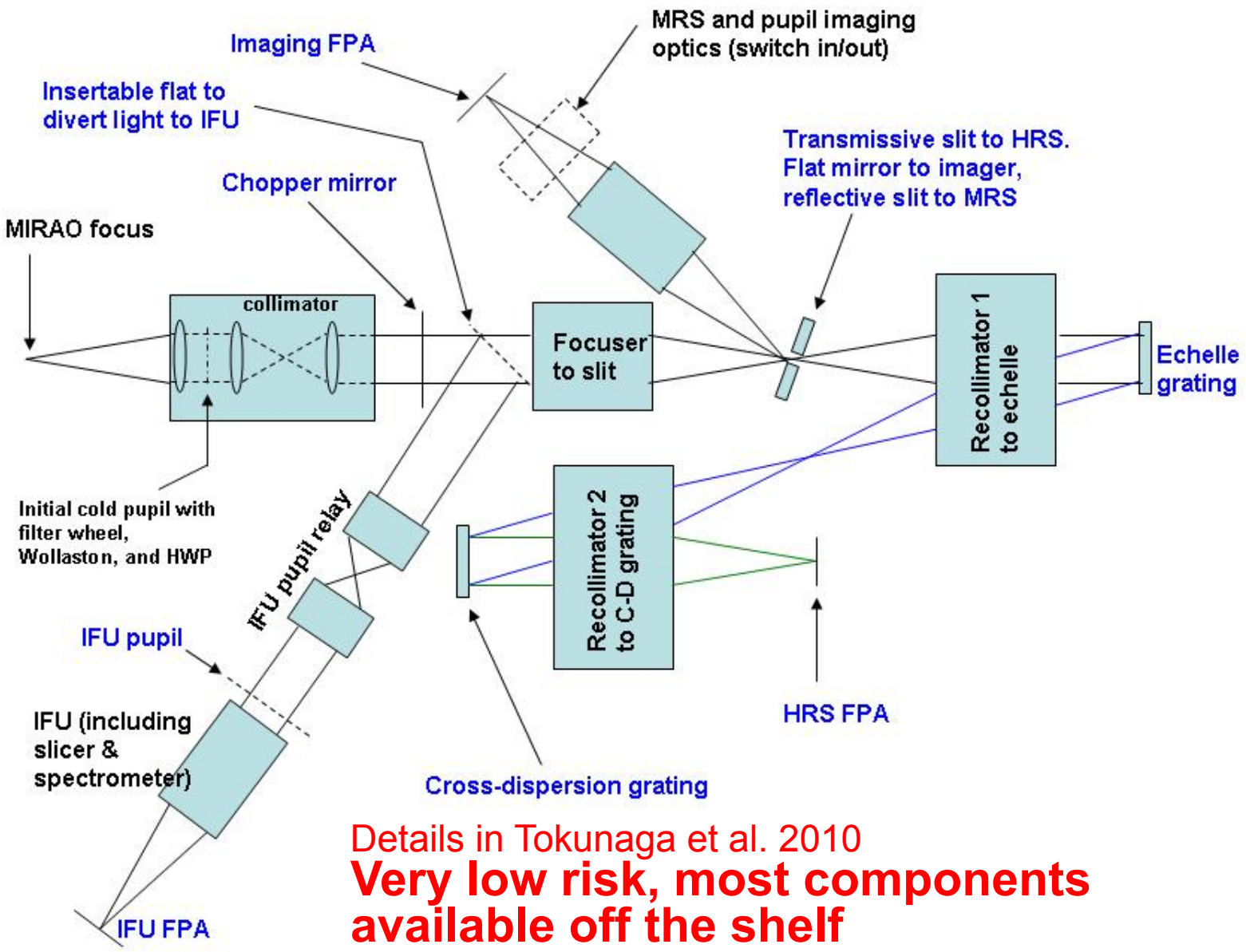
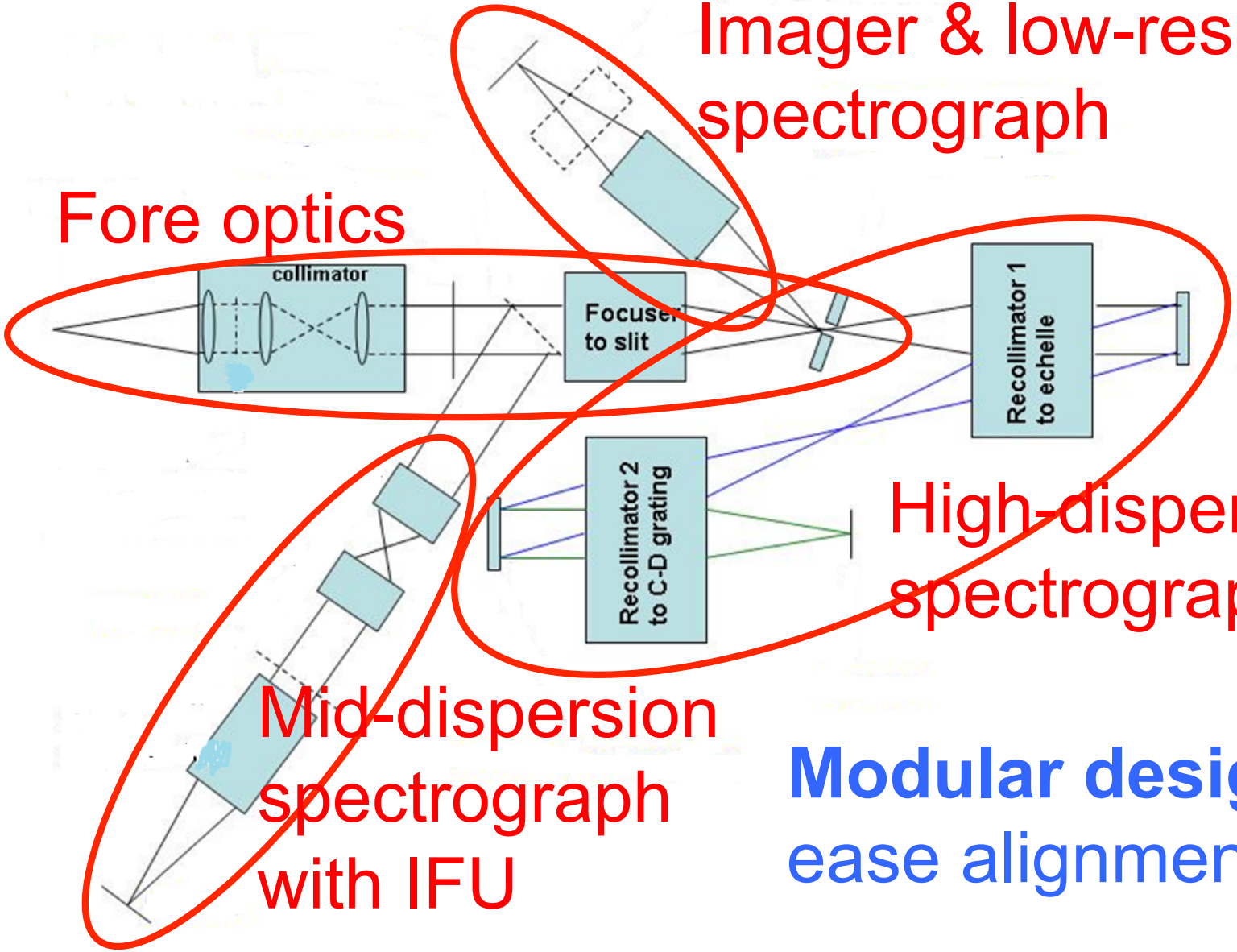
Block Diagram of Optics



Details in Tokunaga et al. 2010

Very low risk, most components available off the shelf

Block Diagram of Optics



Imager & low-res spectrograph

Fore optics

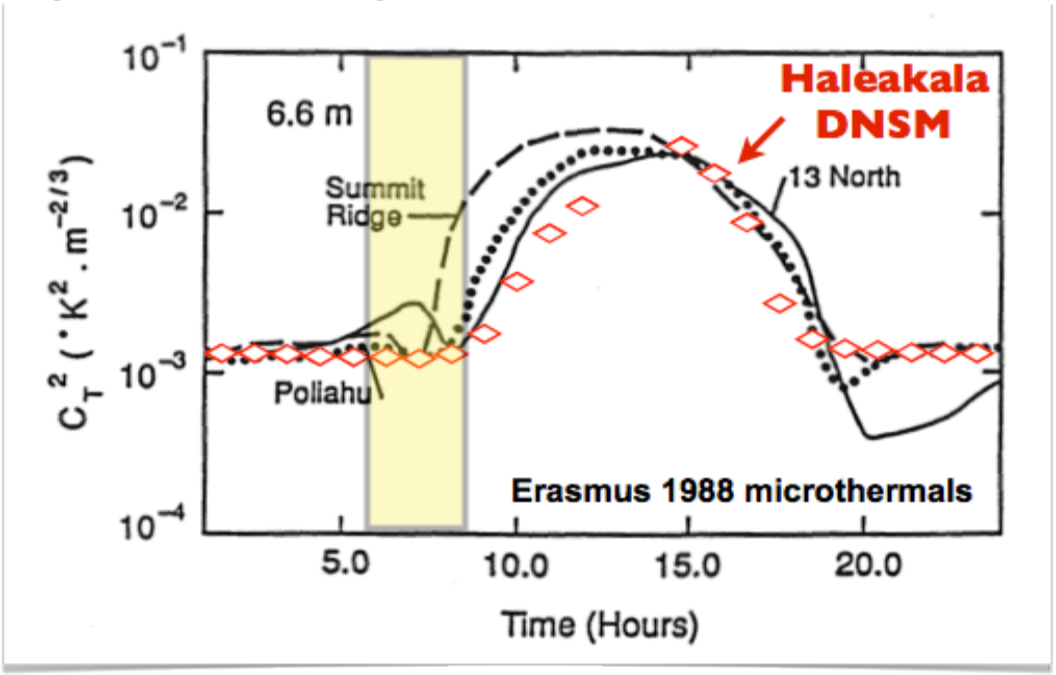
High-dispersion spectrograph

Mid-dispersion spectrograph with IFU

Modular design to ease alignment

Mid-IR Adaptive Optics (MIRAO) & Daytime Observing

- Daytime observing
  - MIRAO/未知 could exploit excellent seeing conditions in early morning hours
  - Appears feasible with no loss in performance for many bright objects; affords extra **1-2 hours per night** of TMT observing time
    - Need to understand operational implications
  - R&D efforts
    - New NB filters in hand to be used on Subaru's AO system soon
    - We appreciate the help of the Subaru AO team (especially Hayano-san)



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%
TMT	30m	90%
JWST	6.5m	80%
Gemini	8.1m	~20-30%

未知 Status

- Science cases (Okamoto, Packham, Tokunaga, et al. 2010) 'flowed' down into requirements
- Requirements addressed by feasibility level design (Tokunaga, Packham, Okamoto, et al. 2010)
- Reference document produced (2010)
  - Packham et al. 2011a, 2011b, Okamoto et al. 2010
- Presentations at TMT instrument/science workshops (2011, 2013, 2014)
- Updating science cases to enhance 'killer-apps'
  - Exo-planets, extragalactic as foci
  - Connection to new ISDT outputs being considered
- Graduate students exchanged over past years
- NSF MSIP proposal

NSF MSIP Reviews

- Submitted $4.4M proposal to NSF's MSIP
  - Thanks to the *TMT* & SAC for their help & approval
- Review comments very helpful:
  - The proposal makes a strong case for the necessity of a mid-IR camera with high dispersion capabilities at the TMT. The proposed science drivers (e.g. gas dynamics and organic molecules in YSOs, characterization of extrasolar planet atmospheres, study of AGN tori and Solar System observations) squarely fit with the primary science objectives motivating the construction of TMT and are at the forefront of astronomy.
  - Given that the NSF participation in the TMT is still not confirmed, there is an element of risk that this instrument will not be accessible for the broader astronomical community outside the TMT consortium.
  - It would complement future contemporaneous facilities such as JWST

NSF MSIP Reviews

- Intellectual merit is well presented and very compelling
- The thought that has gone into the scientific impact is impressive and complete
- If NSF participation in TMT is a realistic possibility, this proposal represents a positive step for the U.S. astronomical community. The science is compelling and well presented. The group has the right experience and expertise to make this effort successful
- The science case for MIR with TMT is broad and compelling
- The science case for a mid-IR instrument on a 30m telescope is strong, and the preliminary design of this complex instrument is important and worthy of funding

ISDT Connections

- ISDT (International Science Definition Teams) updating science cases for TMT
  - Last TMT science case was produced 2007
- Illustrative science cases from selected draft versions of the ISDT products follow

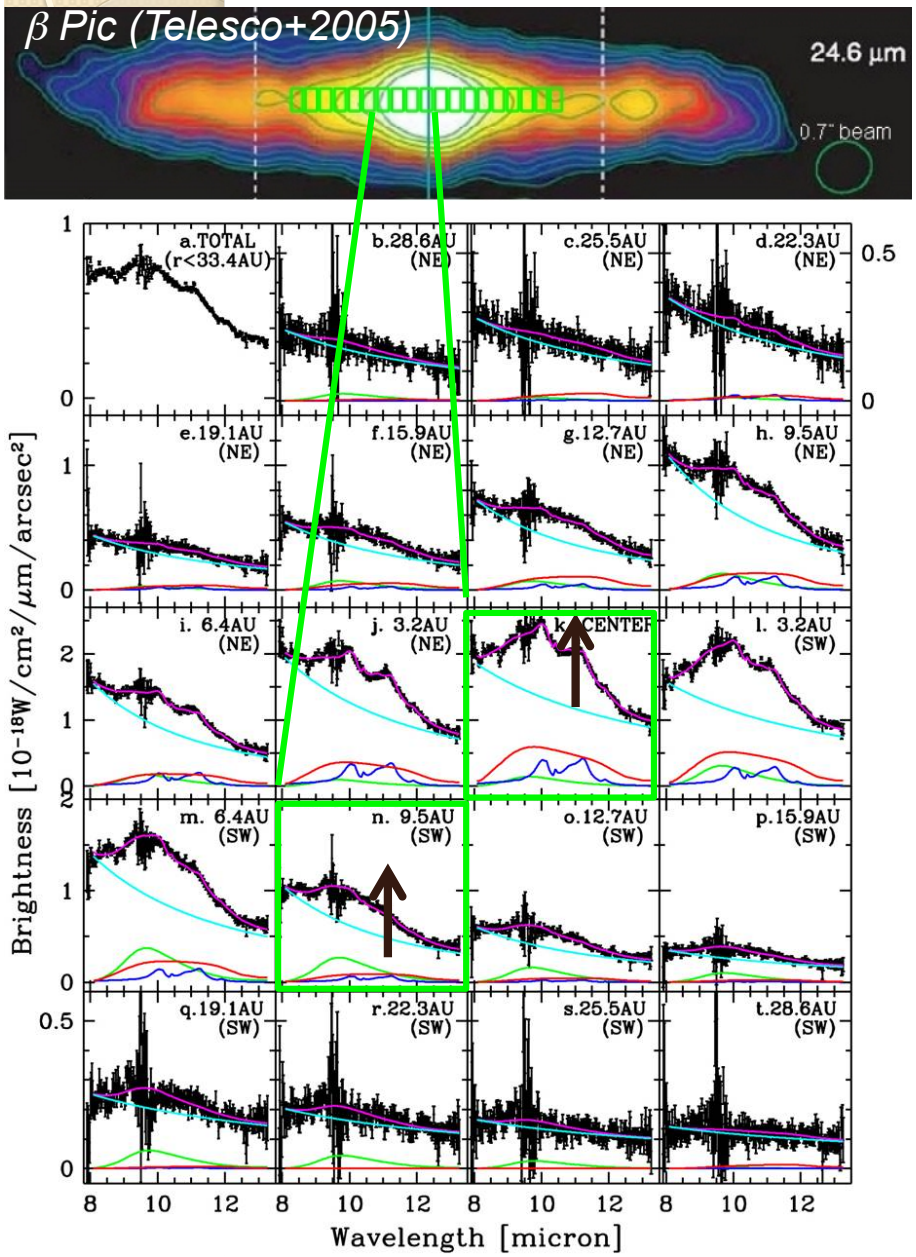
[Our] Solar System

- Thermal waves in gas-giant planets will probe the chemistry & atmospheres that give rise to features such as the Great Red Spot
- Volcanoes on Io can be used as occultation source(s) revealing complex structures in the Jovian atmosphere
  - IFU could reveal 5-10 occultations simultaneously
- Io will be resolved by up to 26 resolution elements
  - Where does the SO_2 atmosphere comes from: volcanoes or sublimation?
- Mars' atmosphere will be resolvable
  - Able to measure the abundances

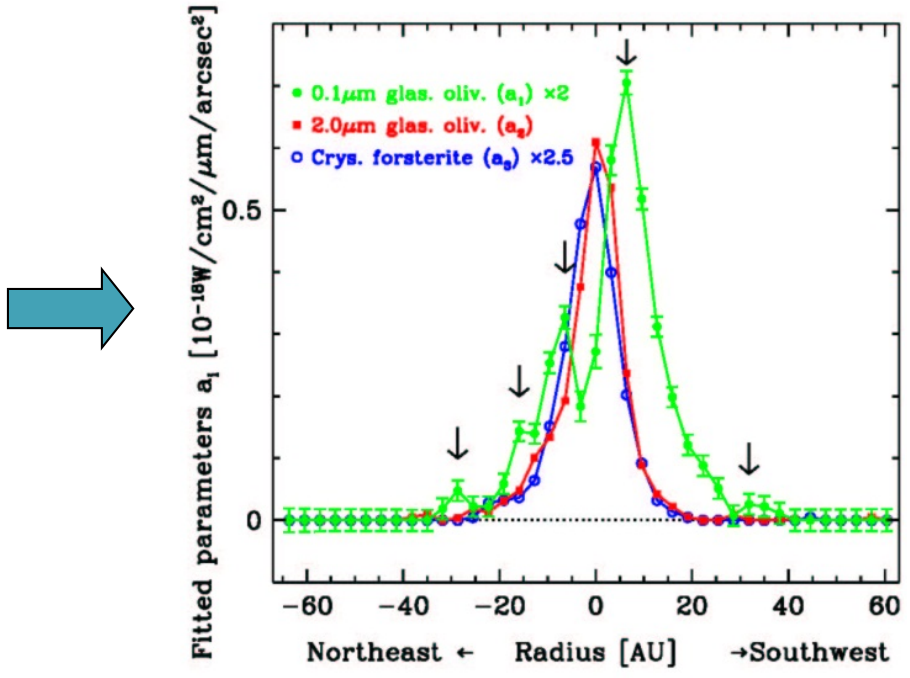
Birth of Stars & Planets

- Star formation process & trigger
- Class I binary protostars can be resolved by 未知 in nearby SF regions
  - Complementary to ALMA's Class 0 goals
- Heated dust around massive protostars
  - 1,000 AU structures resolved to distance of 3 kpc
- Protoplanetary discs are precursors of planets, and hence life
  - When, where and how do planets form/evolve?
  - MIR can probe the building blocks & mechanisms of planetary formation

IFU Spectroscopy of Planet Forming Disks



- 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



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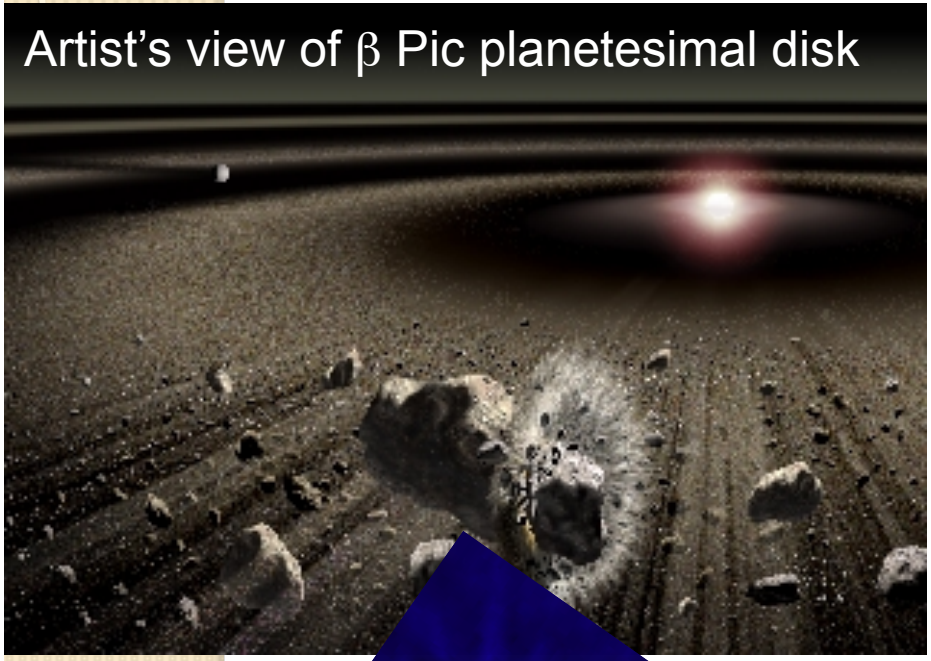

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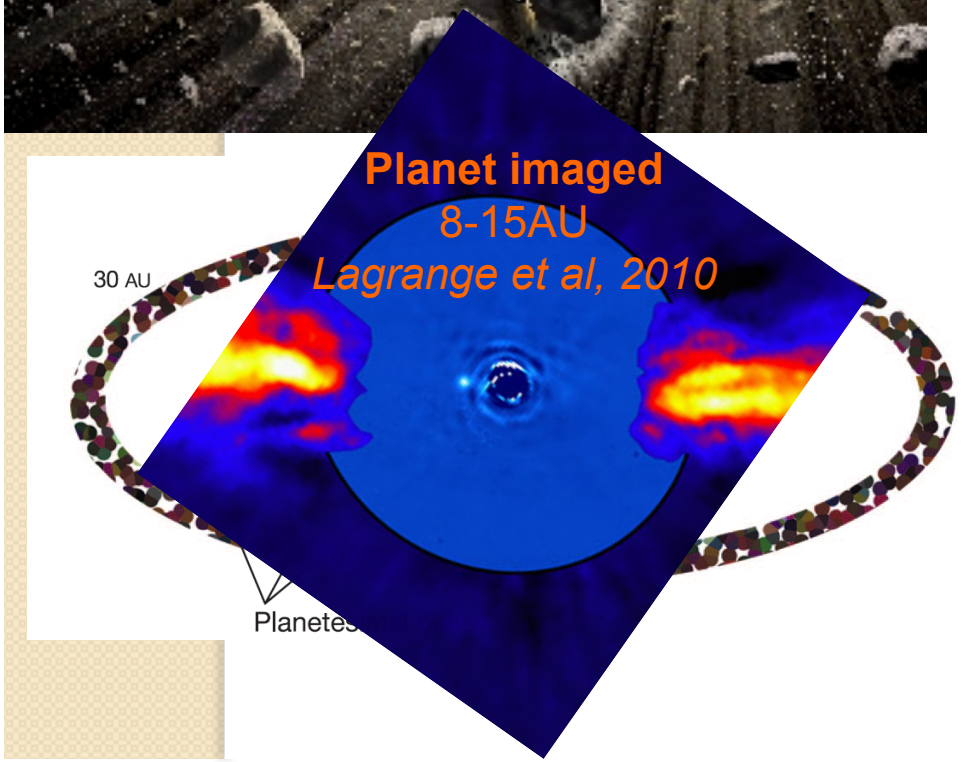

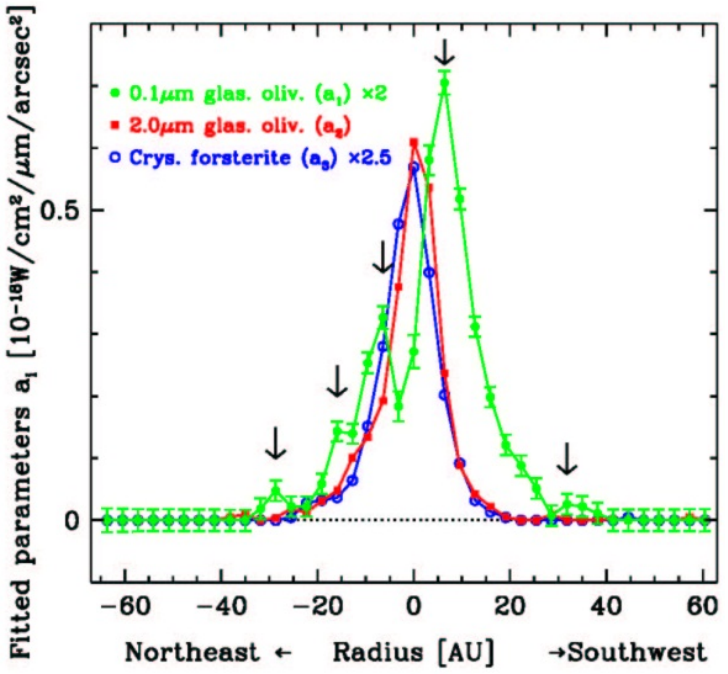

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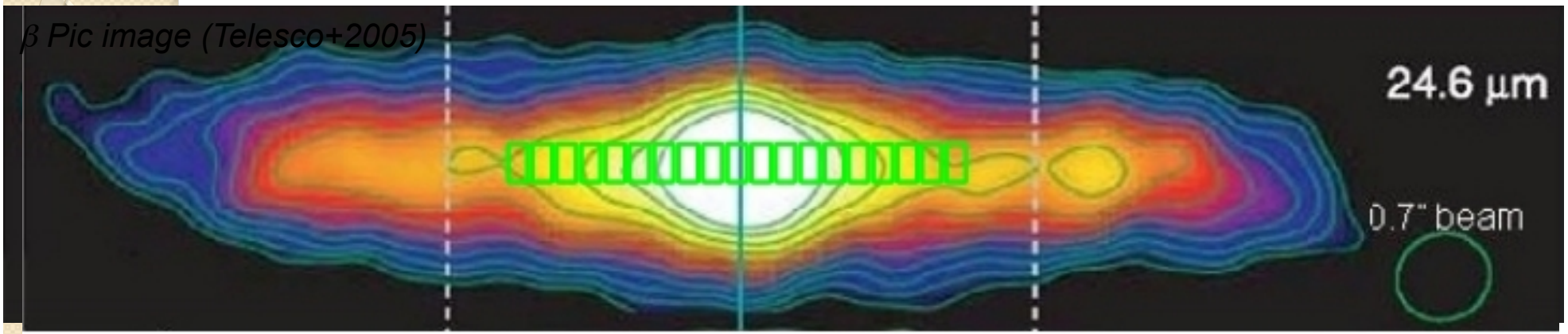
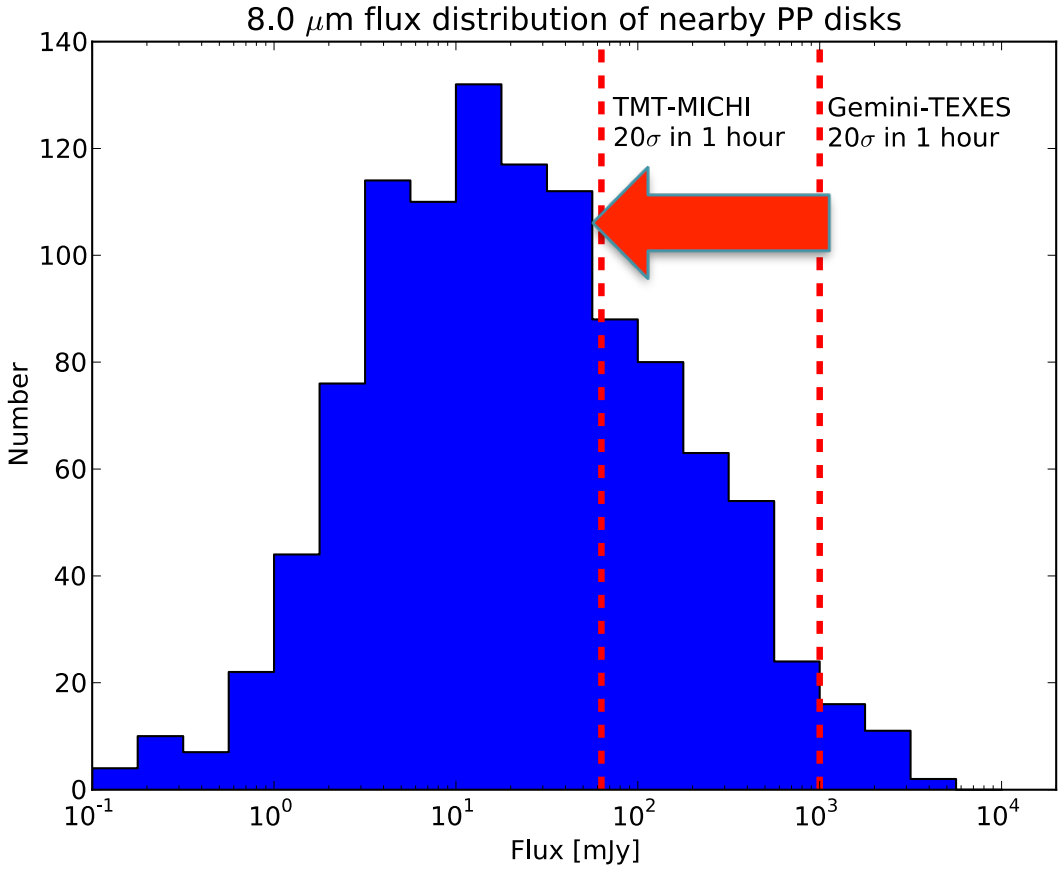


With an IFU, we can reveal 2D dust distribution

- For *face-on disks*, 2D dust distribution excellent for tracing planetesimal belts
  → Slit-scan → time-consuming, background variation/transparency can be very troubling
- Also eliminates slit loss, well matched to AO observations, fixed spectral resolution, flux calibration improved, and no slit positioning concern
- *"The Universe is not 1 Dimensional", R. Davies*

High Spectral Resolution (R~120,000) Source Numbers

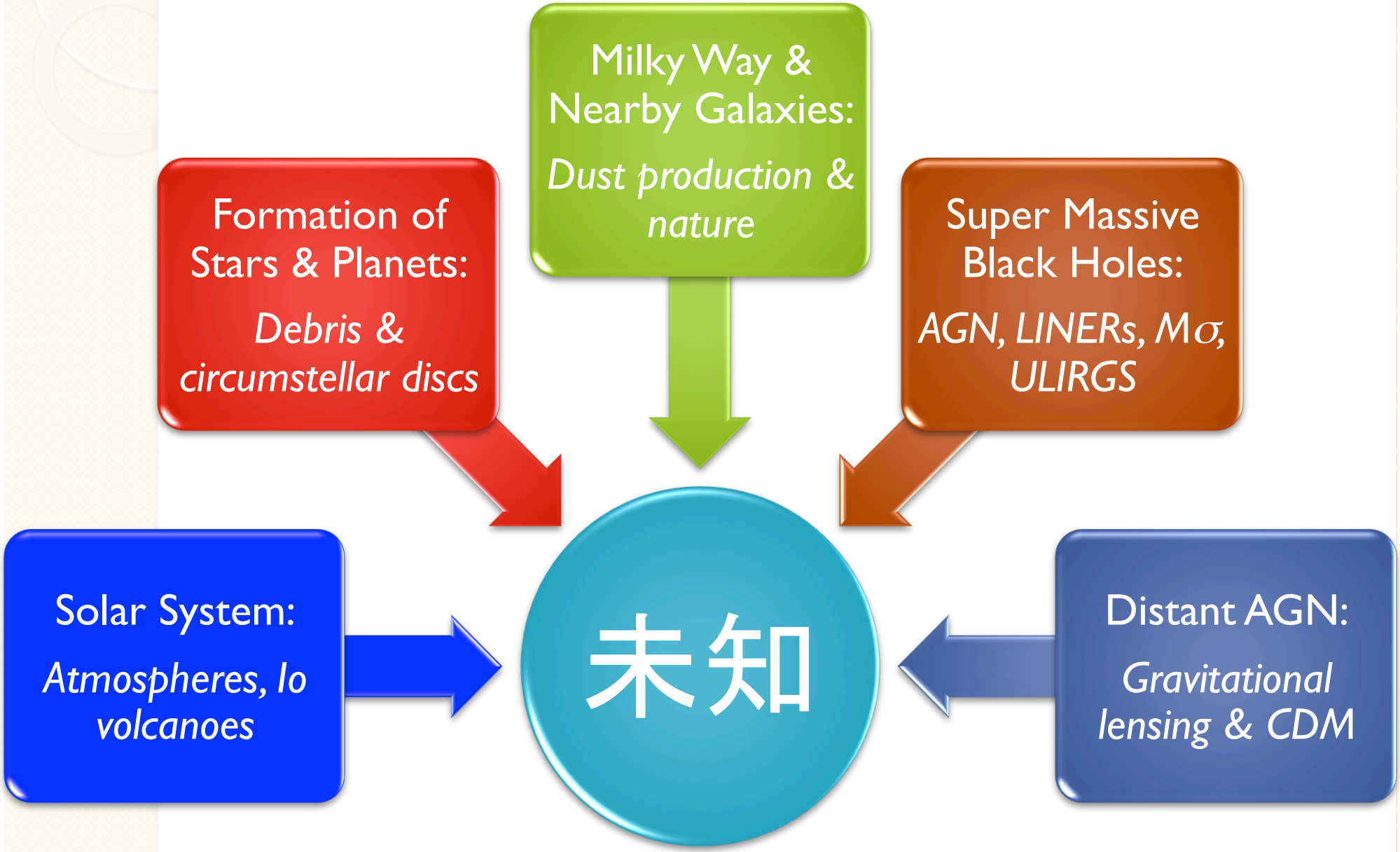
- Spitzer protoplanetary disc observations of strong emission shows oxygen & carbon species
- Snow line in discs important to probe water location
  - Observed Spitzer, requiring high spatial & spectral resolutions
- Huge increase in available objects
  - 8m (~30) to 30m (~100's)
- Possibility of pre-biotics at such resolutions



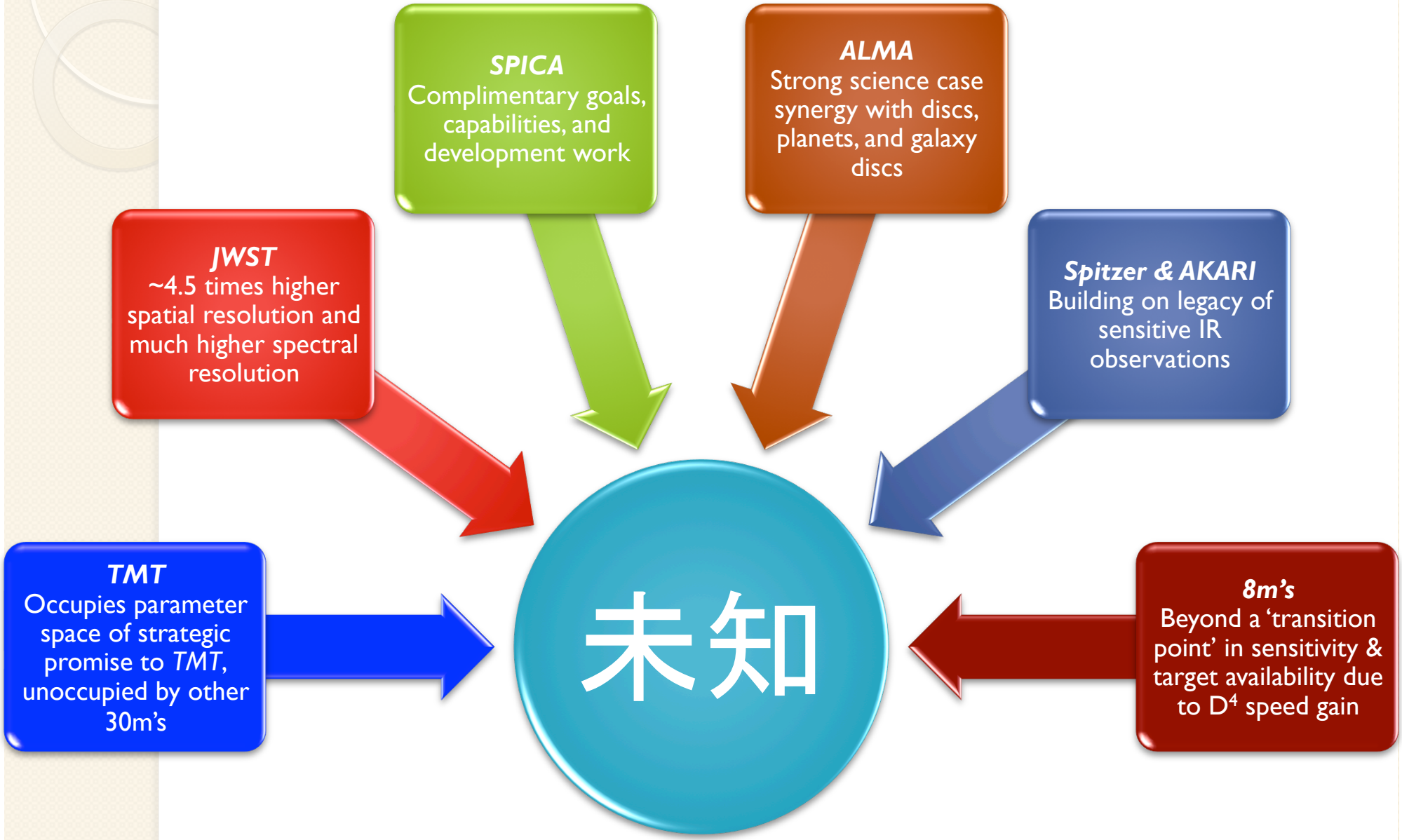
Extragalactic/AGN Observations

- The torus intercepts & re-radiates emission, peaking at MIR
  - Torus and activity rate shows change in morphology and perhaps existence, consistent with disc/wind models(?)
  - Need high spatial resolution to disentangle the stellar and/or nuclear dust emission from the AGN
- ULIRGs could be starburst or AGN dominated
  - High spatial resolution MIR can differentiate sources
- Understanding the connection of the SMBH to the host galaxy remains a key goal: $M\sigma$ relationship
  - Local galactic cores remain difficult to understand
- MIRI/JWST excellent sensitivity, but does not have the required spatial resolution; may not provide much progress
  - Brightness limits may prevent some objects to be observed (?)

ISDT Connections



Science Synergies

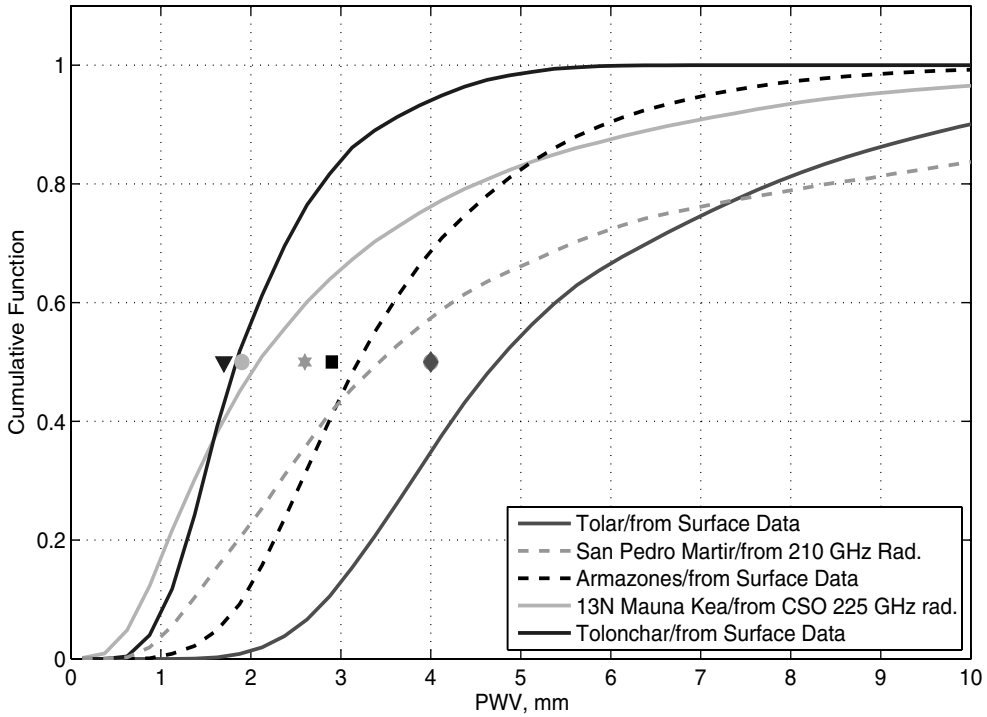


未知 Summary

- Very preliminary (feasibility level) design achieved
- Science cases should be updated & flowed down to instrument requirements formally
  - Japan/USA collaboration is strong
- ISDT connections are strong
- Science synergies to other observatories clear
- Reviews from NSF MSIP generally positive
  - But still didn't get any money...!
- Good collaborations with E-ELT METIS

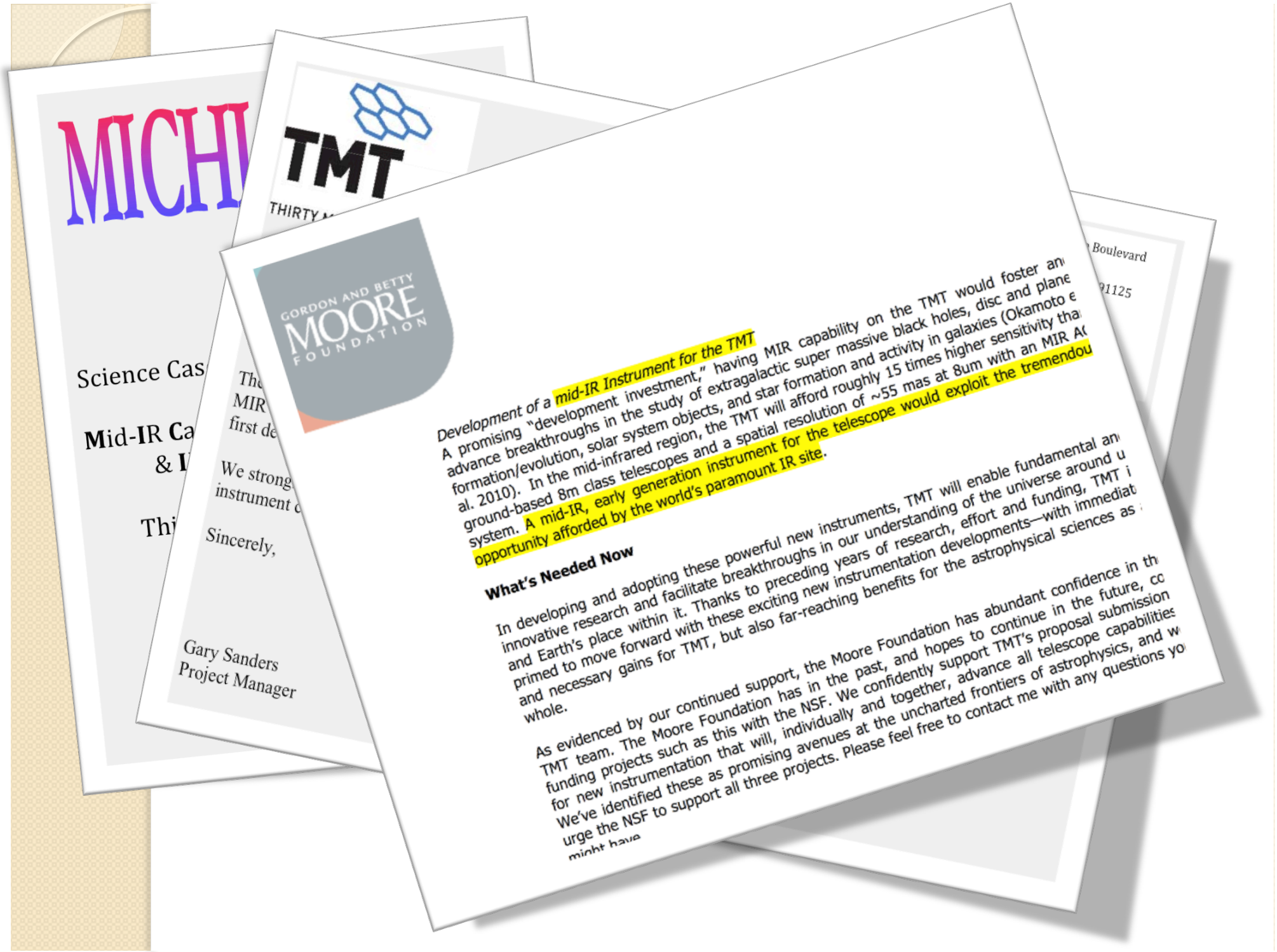
Extra Slides

TMT/MK as the Premier MIR Site



Site	*Total Time [hr]*	*Relative to MKO*	*Total Time without 20 microns [hr]*	*Relative to MKO without 20 microns*
Armazones (E-ELT)	360	1.81	310	1.68
Mauna Kea (TMT)	199	1	185	1

- PWV median of Mauna Kea(MK) is 1.86mm, Armazones 2.87mm
  - Many more, and/or superior, MIR nights => better results
- Time needed to complete observing program on TEXES (R~100,000) *Gemini* proposals demonstrates MK's superiority
- 未知 is the only 30m instrument to offer
  - 20μm capability
  - High spectral resolution
  - MIR IFU
  - Polarimetry



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GORDON AND BETTY MOORE FOUNDATION

Development of a mid-IR Instrument for the TMT

A promising "development investment," having MIR capability on the TMT would foster an
advance breakthroughs in the study of extragalactic super massive black holes, disc and plane
formation/evolution, solar system objects, and star formation and activity in galaxies (Okamoto e
al. 2010). In the mid-infrared region, the TMT will afford roughly 15 times higher sensitivity tha
ground-based 8m class telescopes and a spatial resolution of ~55 mas at 8um with an MIR Ad
system. A mid-IR, early generation instrument for the telescope would exploit the tremendou
opportunity afforded by the world's paramount IR site.

What's Needed Now

In developing and adopting these powerful new instruments, TMT will enable fundamental an
innovative research and facilitate breakthroughs in our understanding of the universe around u
and Earth's place within it. Thanks to preceding years of research, effort and funding, TMT i
primed to move forward with these exciting new instrumentation developments—with immediat
and necessary gains for TMT, but also far-reaching benefits for the astrophysical sciences as
whole.

As evidenced by our continued support, the Moore Foundation has abundant confidence in th
TMT team. The Moore Foundation has in the past, and hopes to continue in the future, co
funding projects such as this with the NSF. We confidently support TMT's proposal submission
for new instrumentation that will, individually and together, advance all telescope capabilities
We've identified these as promising avenues at the uncharted frontiers of astrophysics, and w
urge the NSF to support all three projects. Please feel free to contact me with any questions yo
might have

Sincerely,

Gary Sanders
Project Manager

Boulevard

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