Thirty Meter Telescope
国立天文台 TMT 推進室

PHYSICS & ASTRONOMY
THE UNIVERSITY OF TEXAS AT SAN ANTONIO

MIR & AGN

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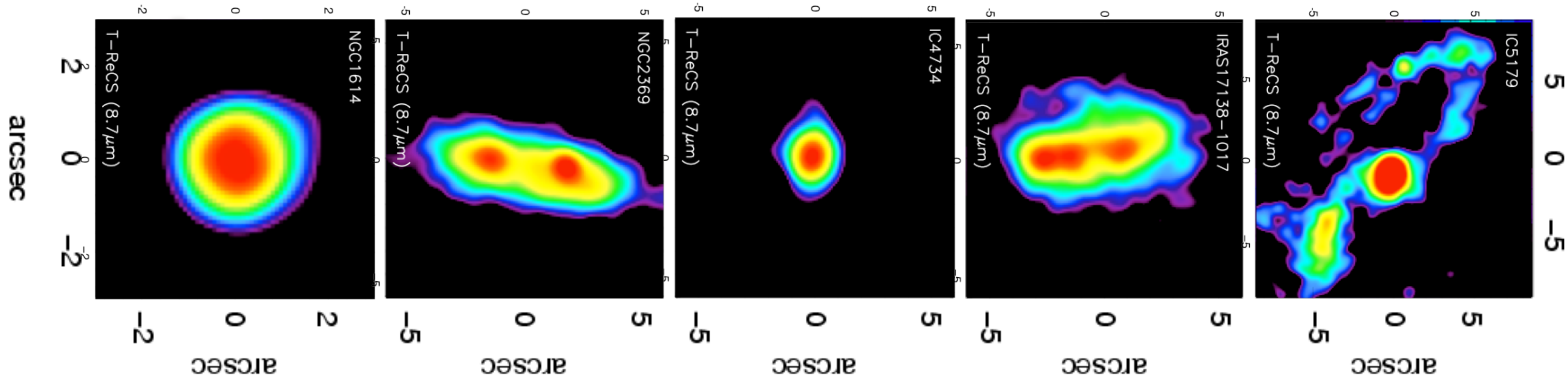
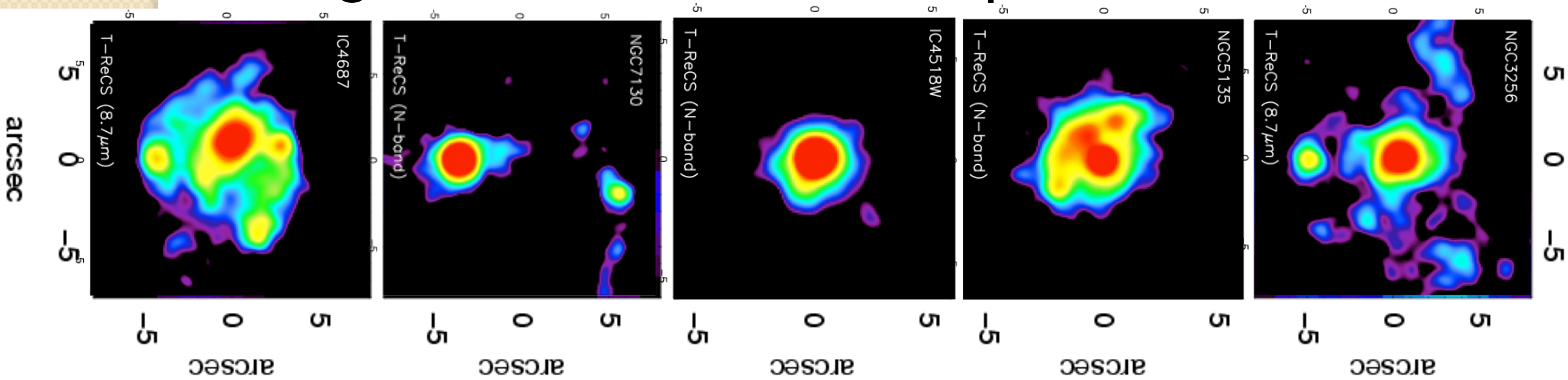
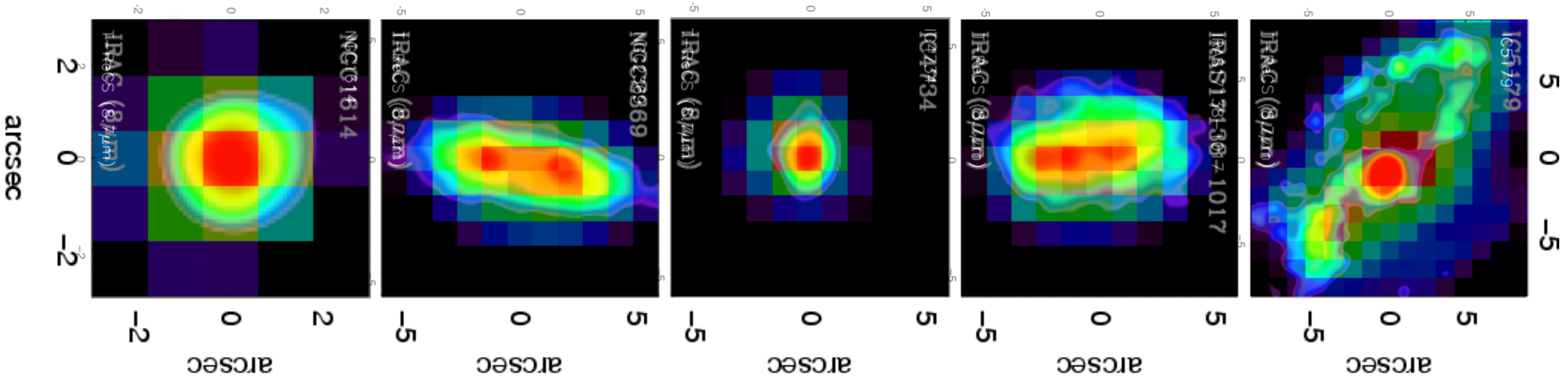
MICHI (未知) Concept

- 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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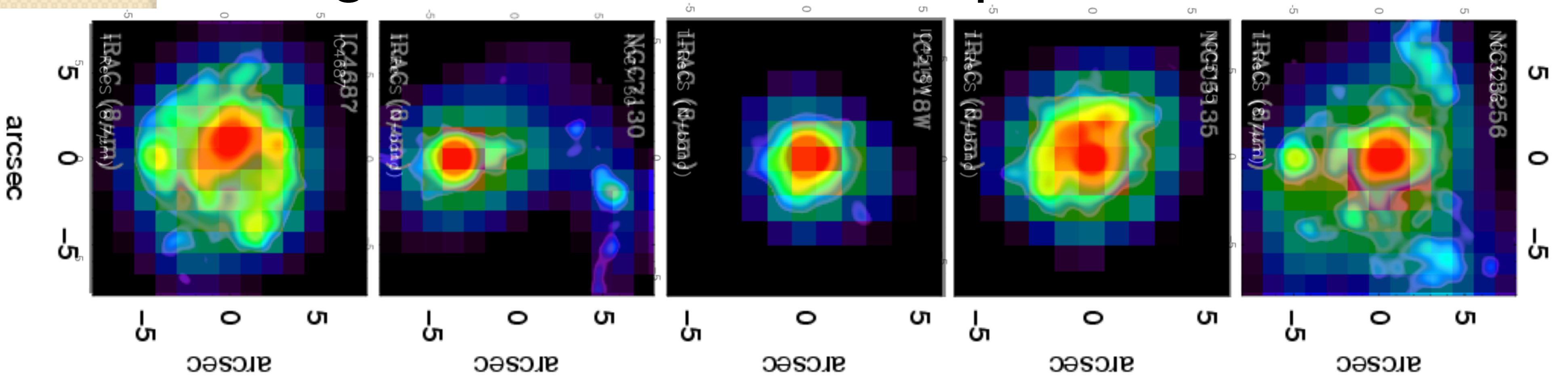
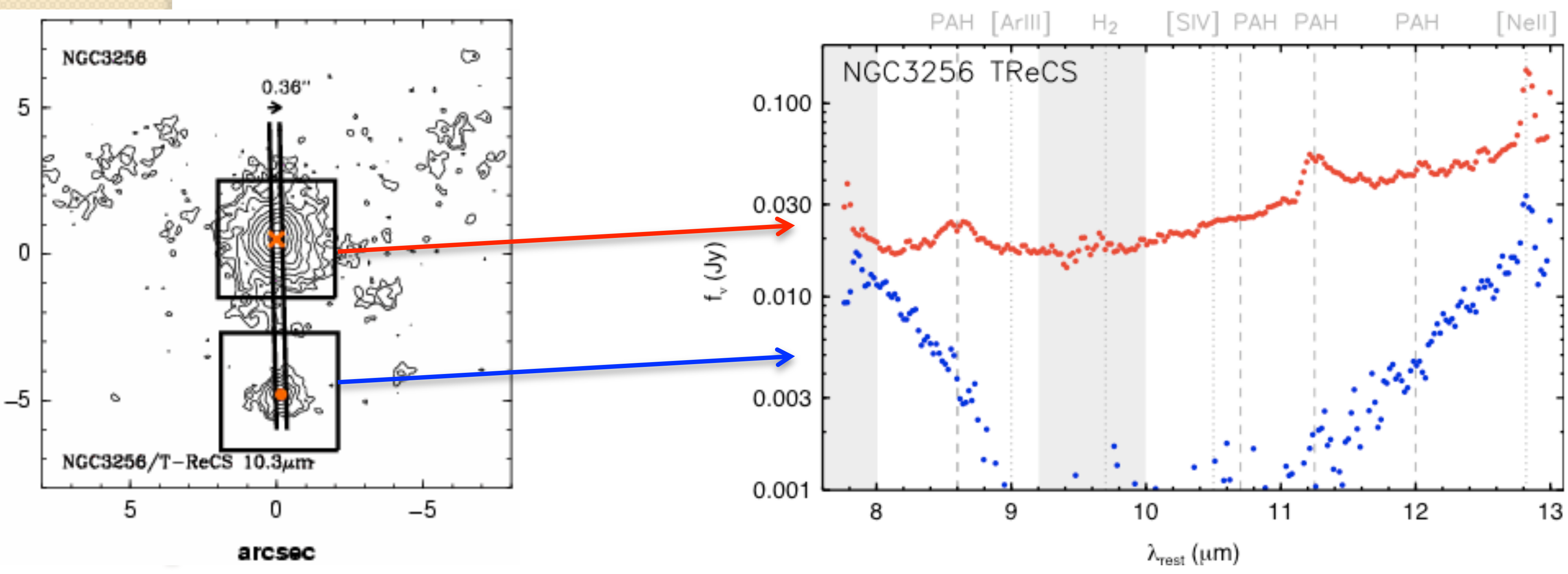


Spatial Resolution & Spectra

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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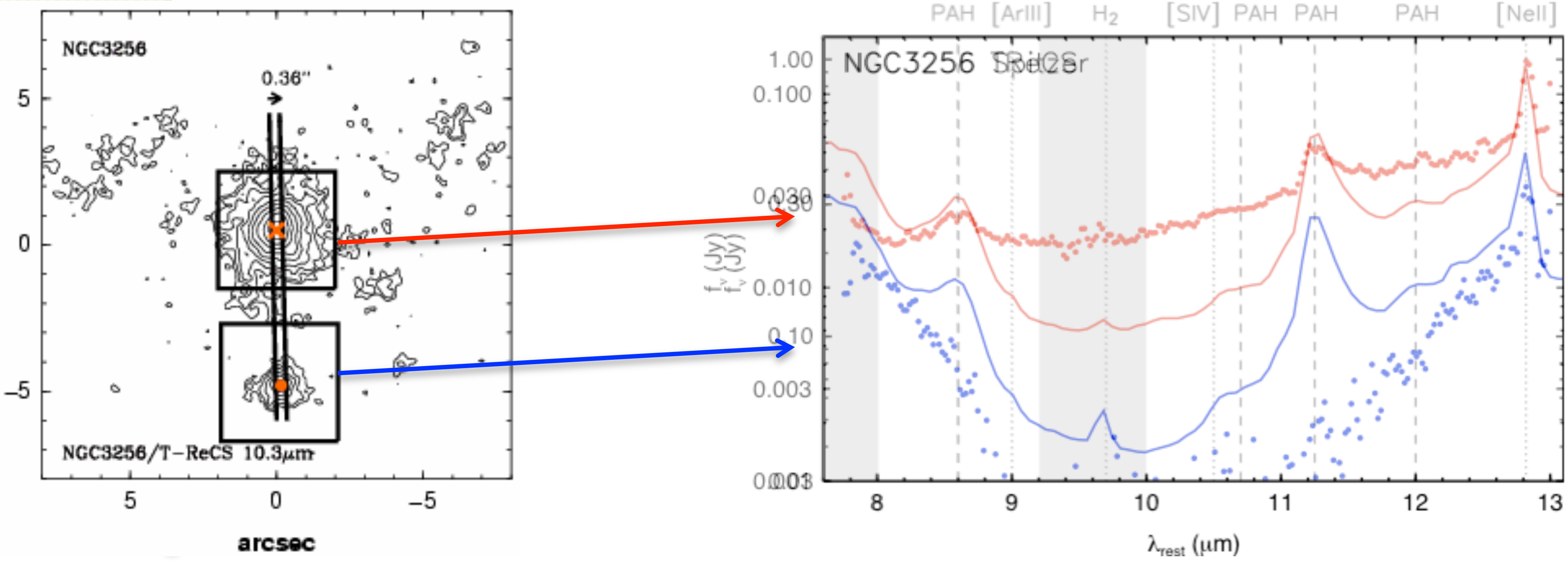
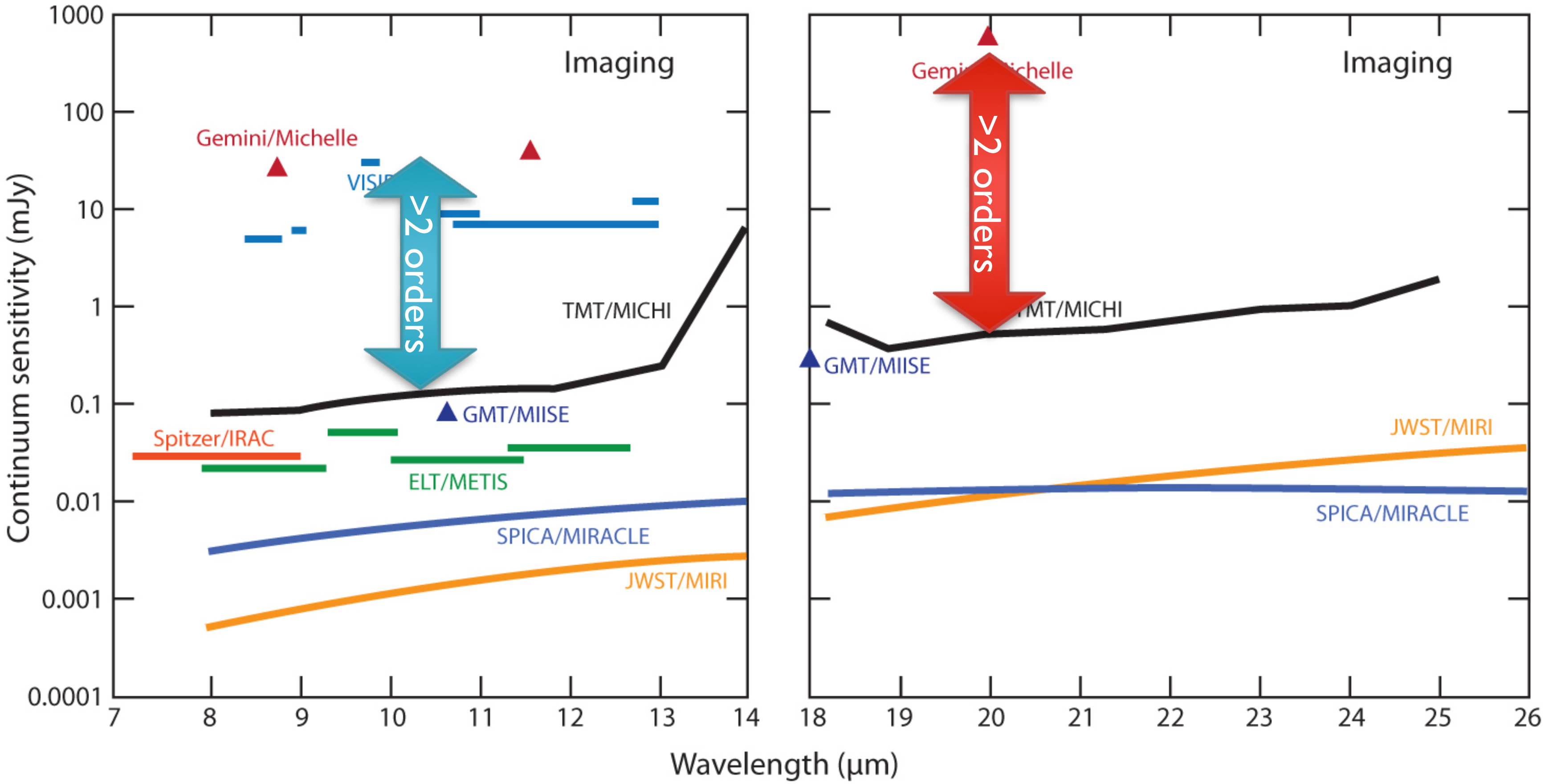
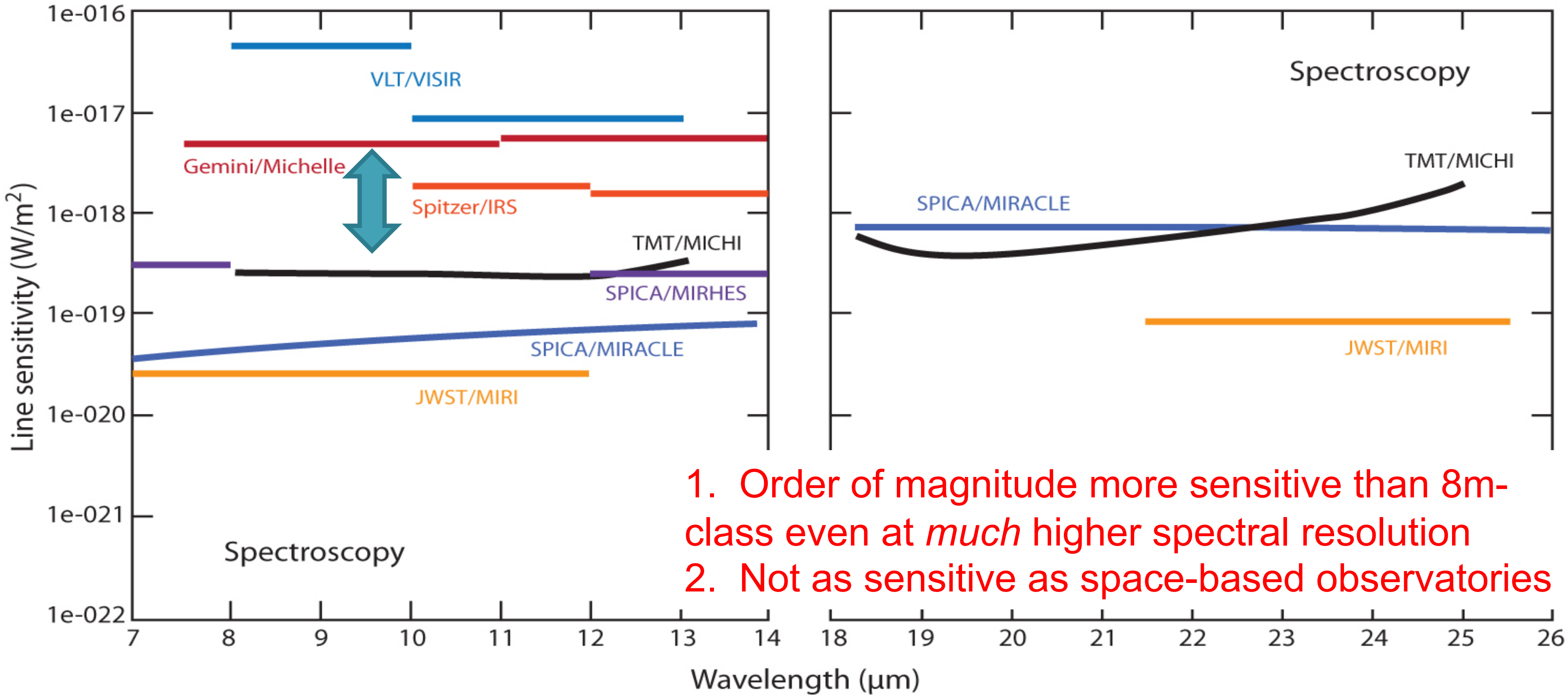


未知 Imaging Sensitivity



- 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



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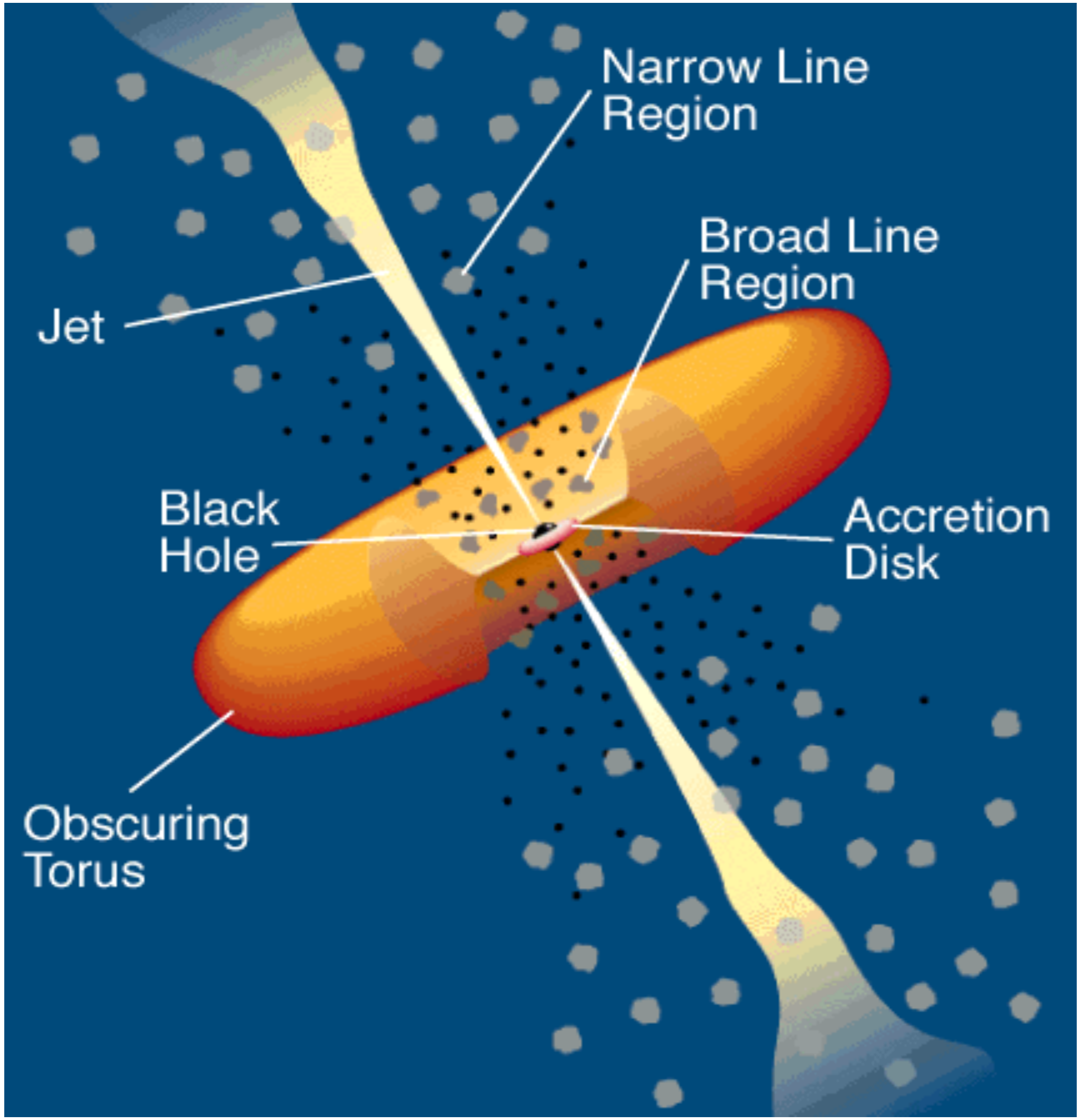
Standard AGN Paradigm



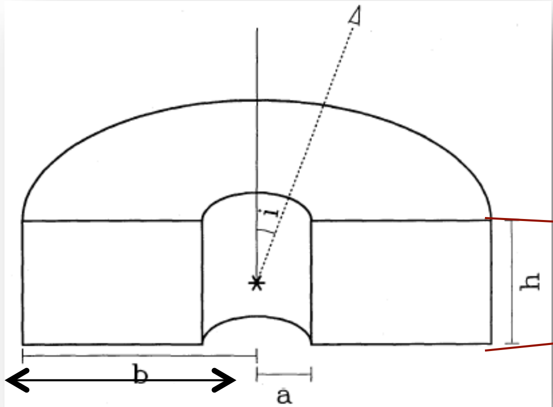
- Line of sight affords radically different views of the AGN central engine
- Obscuration due to the torus is fundamental to AGN theories
  - Detailed knowledge of the torus is crucial

Observing the Torus

- Difficult to (directly) observe at optical & NIR wavelengths as AGN & host galaxy swamp the signal
- Characteristic temperature is a few 100K
  - Blackbody emission peaks at ~30μm
    - 'Powered' by interception of high energy accretion disc emission, & reprocessed to longer wavelengths
- Ideally observed and MIR to mm wavelengths at highest available spatial resolution

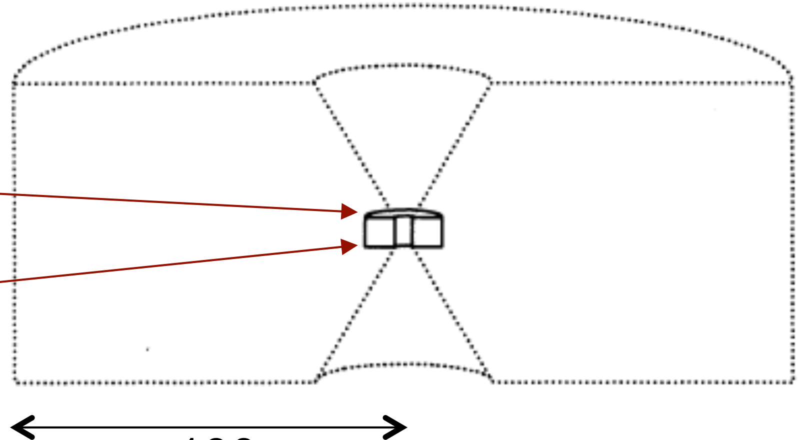
Modeling the Torus

Pier & Krolik 92



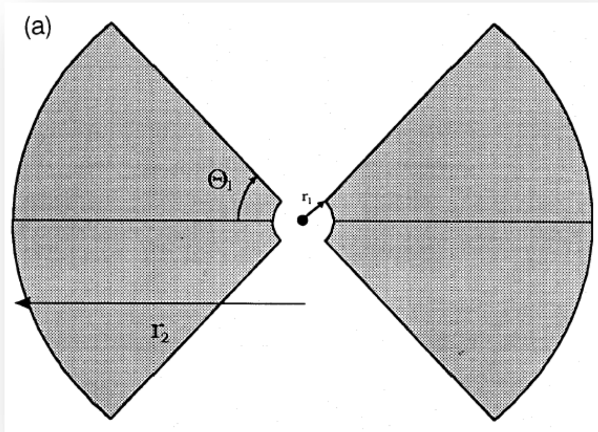
5-10 pc

Pier & Krolik 93

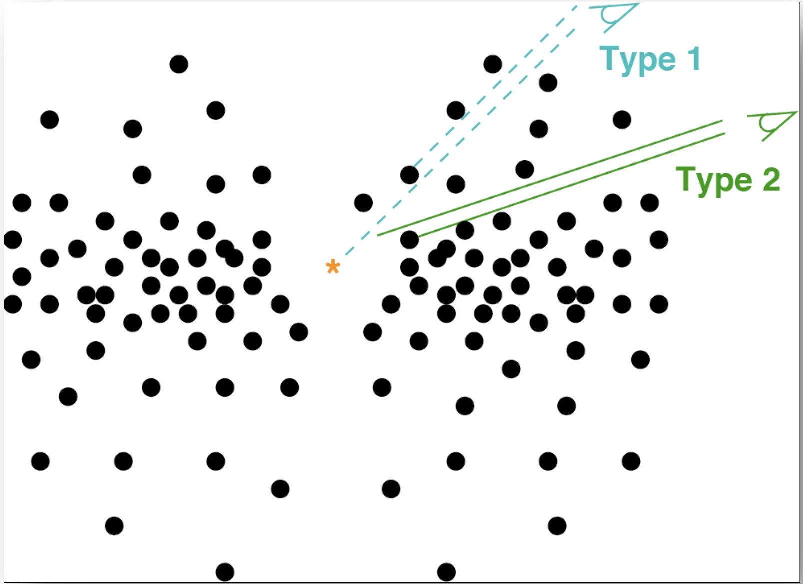


~100 pc

- Efstathiou et al (1996) estimate torus for NGC1068 R_{out} = 178pc
- Granato et al (1997)
  - Uniform density
  - R_{out} > 10 – 20 pc



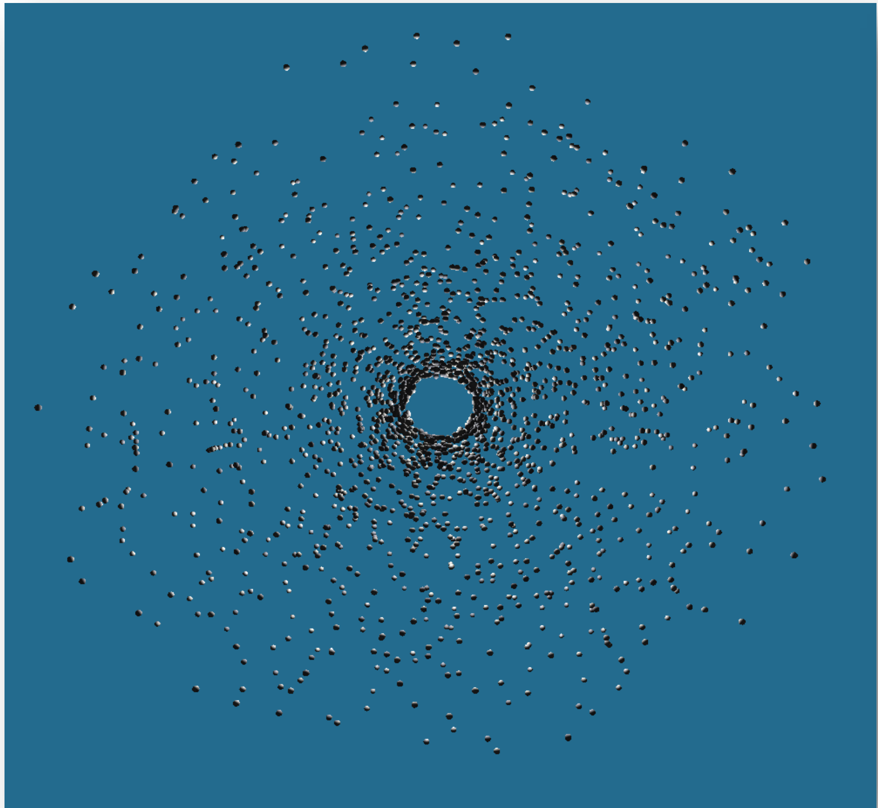
Clumpy Torus Model



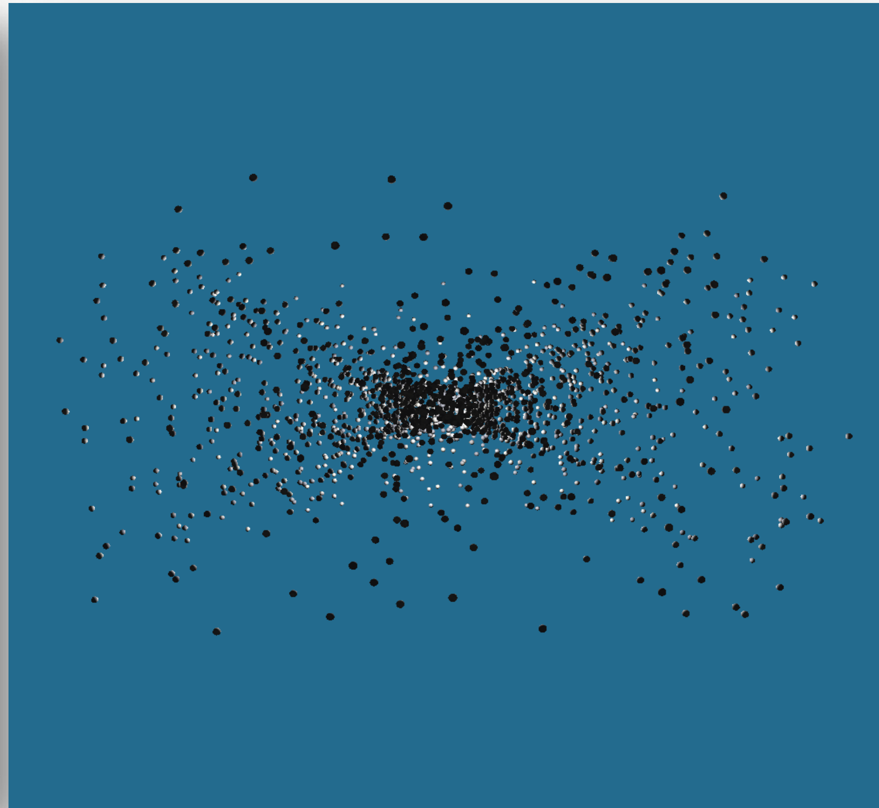
- Clumpy torus model of Nenkova et al. (2002)
  - Clouds follow power law distribution
  - Clouds concentrated in equatorial plane
  - Distributed with scale height σ
  - τ_v of each cloud = 40-100+ Av
  - Type 2 number of clouds along pencil-beam line of sight ~8

Key Advantages of Clumpy Torus

- Clumpy distribution puts cooler dust (on protected side) closer to nucleus than continuous dust distribution
  - Far more compact torus
  - Very different spectral shapes

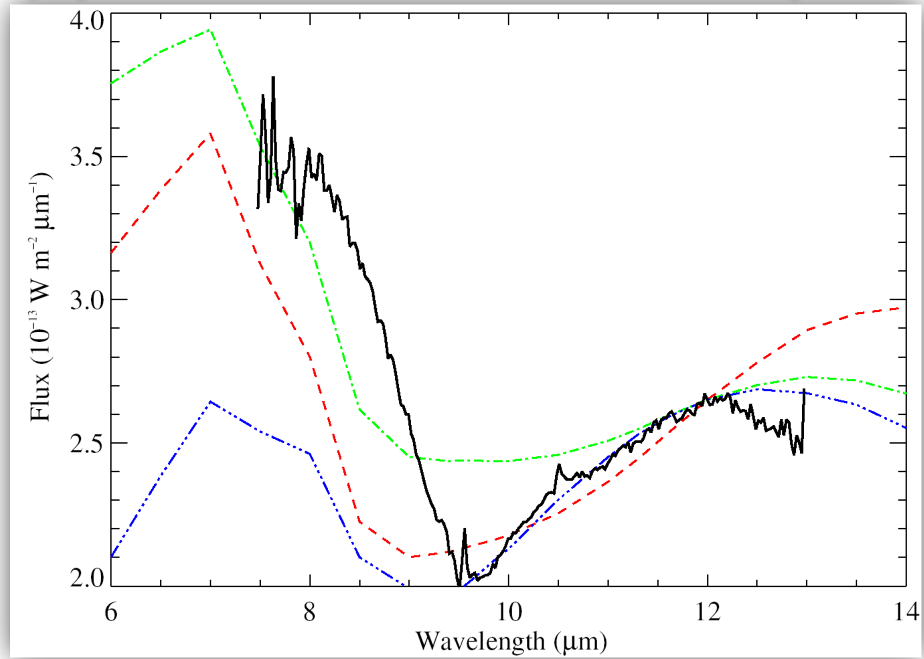


Pole-on



Edge-on

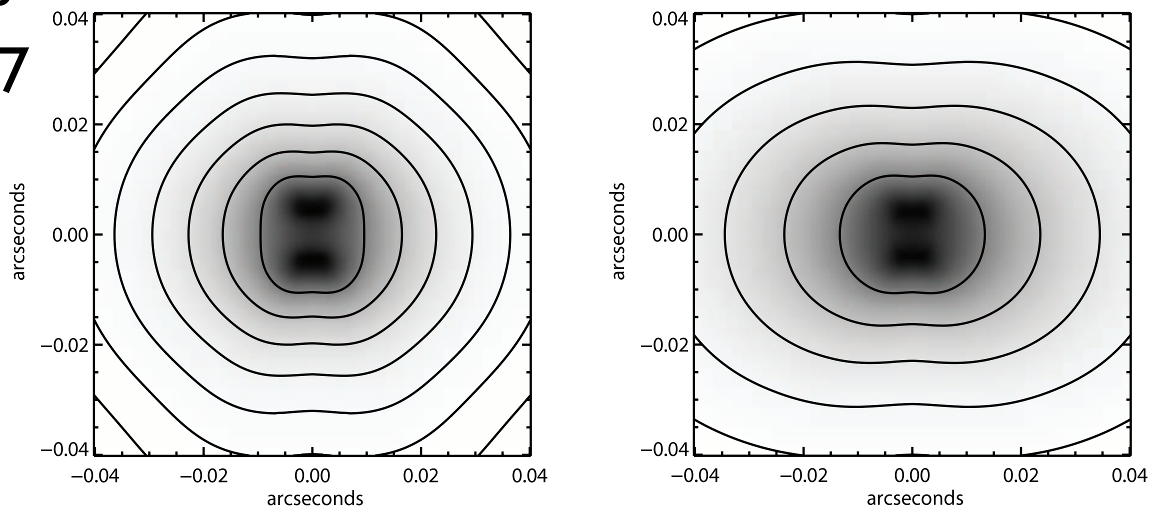
Clumpy Torus Model Spectral Fits



- Fits of the clumpy torus model to the 10µm spectrum of NGC 1068 (heavy solid line)
- Torus size best fit ~3pc
- Entirely consistent with MIR interferometric observational result of Jaffe et al. (2004)

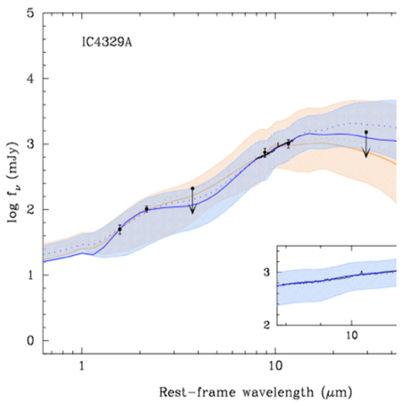
Key Torus Size Constraints

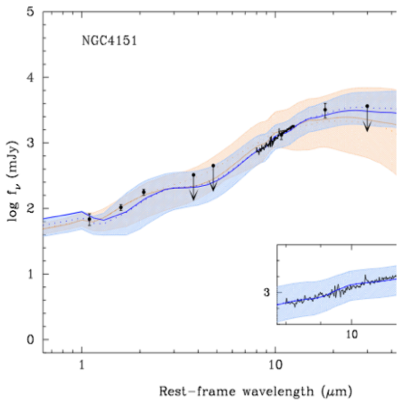
- Centaurus A torus <0.19", 3.1pc
  - Radomski et al. 2007
- Circinus torus <0.2", 4pc
  - Packham et al. 2005
- NGC1068 torus <0.4", 3pc
  - Mason et al. 2006; Jaffe et al. 2004; Packham et al. 2007
- NGC4151 torus <0.4", <35pc
  - Radomski et al. 2003
- MIR torus SED M87 shows *no* evidence of torus emission
  - Perlman et al. 2001, 2007
- Torus is at TMT's diffraction limit…

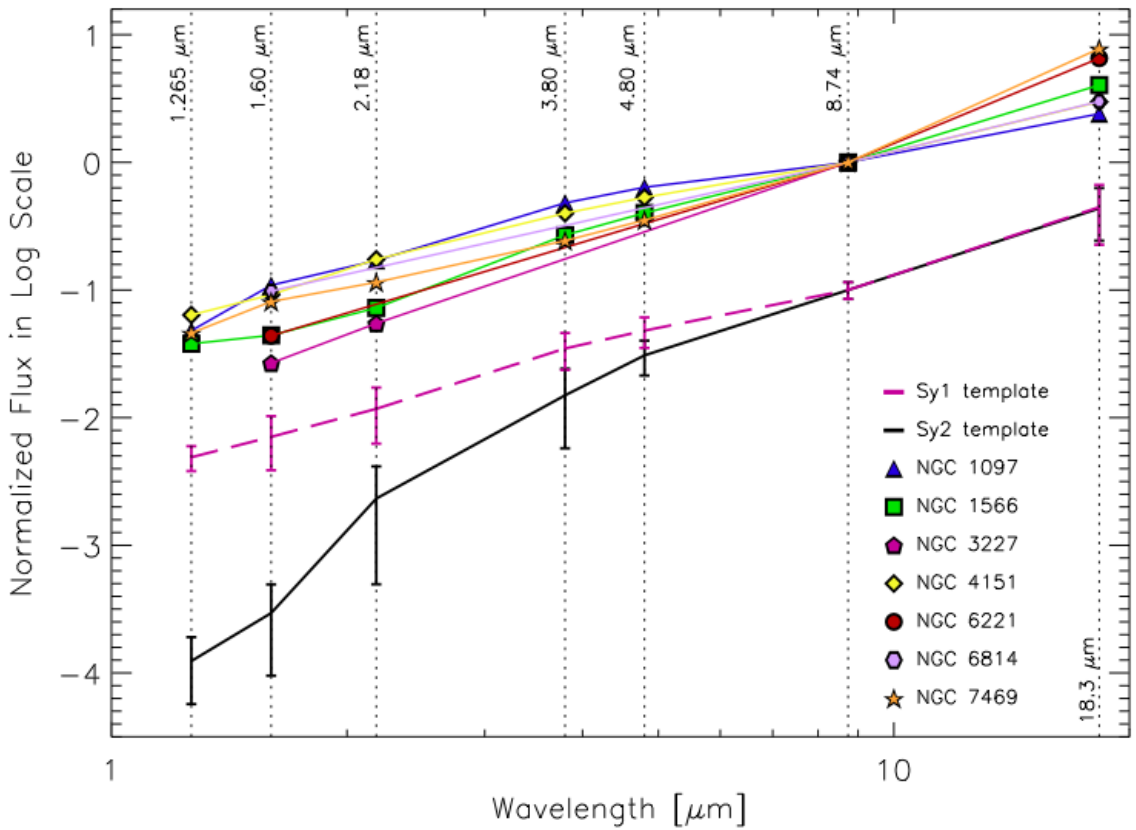


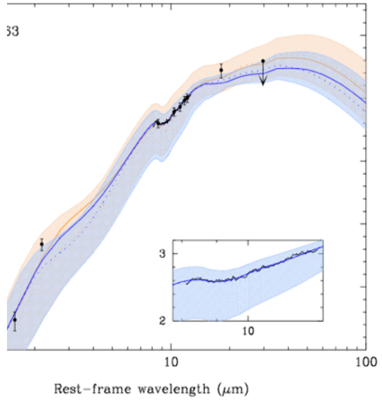
Initial Survey Results

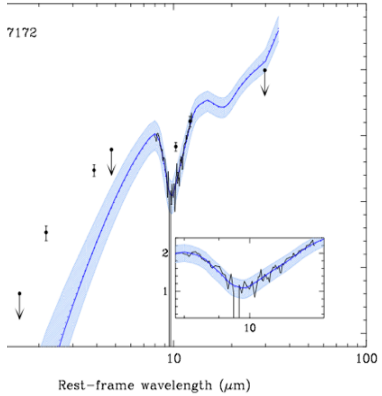
- NIR & MIR data allow detailed comparison between Seyfert AGN and construction of templates
- Bayesian fitting gives error estimates from multi-dimensional fitting





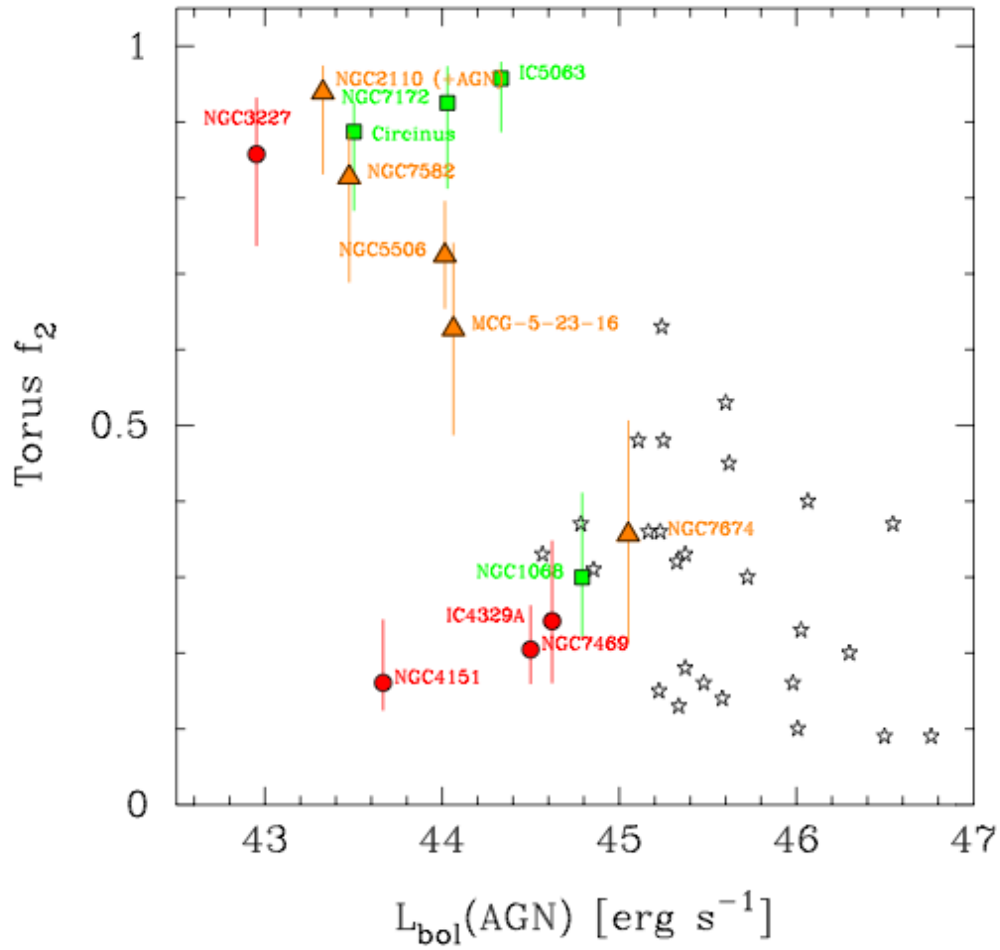




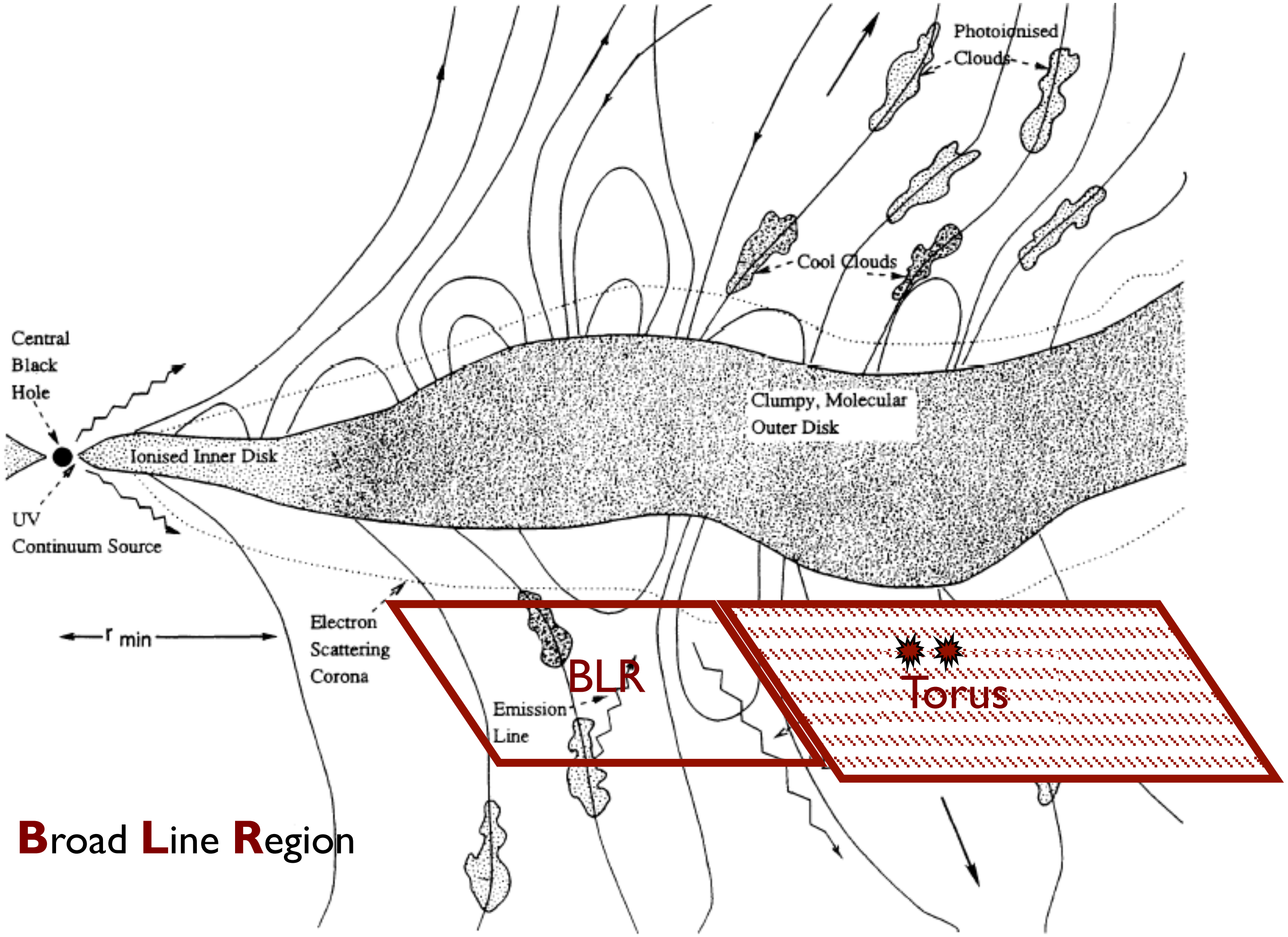


Strong Hints of Torus Differences

- Reprocessing efficiency vs. torus covering factor shows difference between Seyfert 1&2
- AGN L_{bol} vs. the torus geometrical covering factor (f_2) decreases with increased L_{bol}
  - Consistent with receding torus models



Grand Unification Theory



Broad **L**ine **R**egion

Torus Disappearance at L <~ 10^{42} erg s^{-1}

- At low accretion levels, torus dissipates
  - Liners (Maoz et al. 2005)
- No torus dust emission
  - M87 (Whysong & Antonucci 04; Perlman et al. 2004, 2007)
- Need high spatial resolution MIR and NIR observations
  - Imaging and low-spec. resolution needed

未知 SMBH evolution vs. time/energy

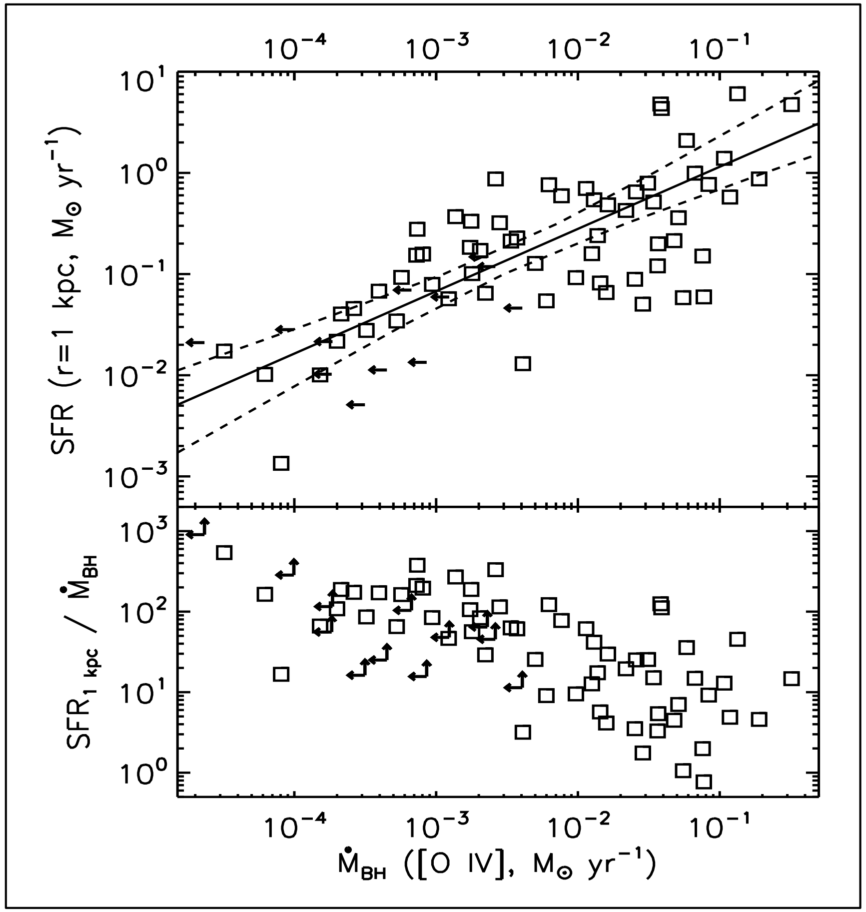
- The properties of the torus remain uncertain
  ①Nature of torus material & connection with host galaxy
  ②Properties, such as geometry & optical depth dependence on activity
  ③Dust properties vs. AGN luminosity/type?
  ④Nuclear (<100pc) starbursts in feeding and/or obscuring AGNs?
  ⑤Fueling of AGN
- 8m's can observe few 100 AGN in detail, TMT will be in the 1000's, or at much higher z (but still <1)
- LINERS very hard to observe well on 8m's
- AGN imaging & spectral observations of z<0.5 objects permit templates production of crucial importance for JWST & SPICA
  - Combined results allow torus properties, effect of radio loudness, and the host galaxy versus both the level of AGN activity vs. z be probed

未知 Summary

- Very preliminary (~feasibility) design achieved
- Science cases should be updated & flowed down to instrument requirements formally
- Imaging and low-spectral resolution at MIR
  - Also need 3-5μm
- LINERs can help address creation/sustaining of the torus
- Pushing to higher z important for templates
  - Needed for JWST/SPICA and in its own right
- Directly imaging the torus remains attractive goal, but tough

SMBH & Host Galaxy Connection

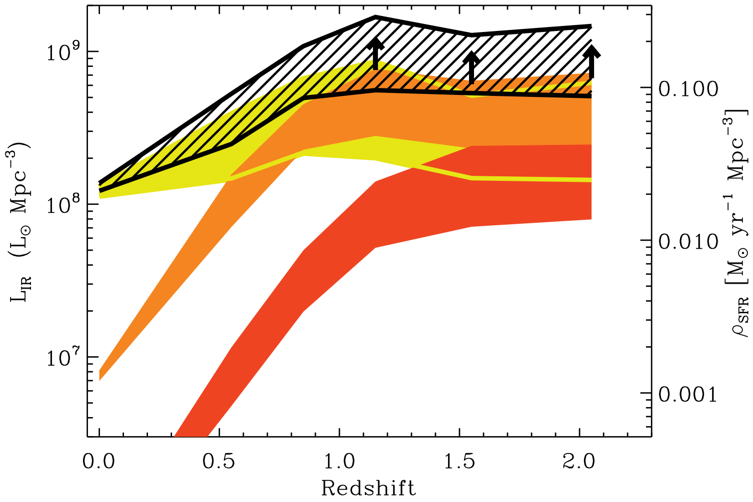
- SMBH & galaxy masses are directly proportional
  - Galaxy bulge mass (M_{bulge}) & stellar velocity dispersion (σ) are tightly correlated with the SMBH (M_{BH}), despite being spatially on hugely different scales, thus lacking direct connection
  - M_{BH} vs. M_{bulge} & M_{BH}-σ relation
- Co-evolution between the SMBH & galaxies, precise nature uncertain
- Spitzer observations (at [OIV] 25.9μm, 11.3μm PAH, and extended 24μm) show near-nuclear (<1 kpc) SFR is closely correlates to SMBH mass; breaks >~1kpc
  - Physical connection in the SFR in inner regions & SMBH mass



MICHI Science Case

- The TMT is ideal for higher z objects, as all key emission lines & features are observable
  - The [SIV] line (10.5μm) is a good substitute with superior ground-based sensitivity instead of the [OIV] line
- MICHI will be able to extend this to a larger distance (median distance ~60Mpc), with an angular resolution of only ~20pc as projected on the galaxy
  - Decisively isolate the SMBH from the diffuse surrounding star formation affording a mass estimate of the SMBH
  - Well within the 1kpc limit for the SFR estimate

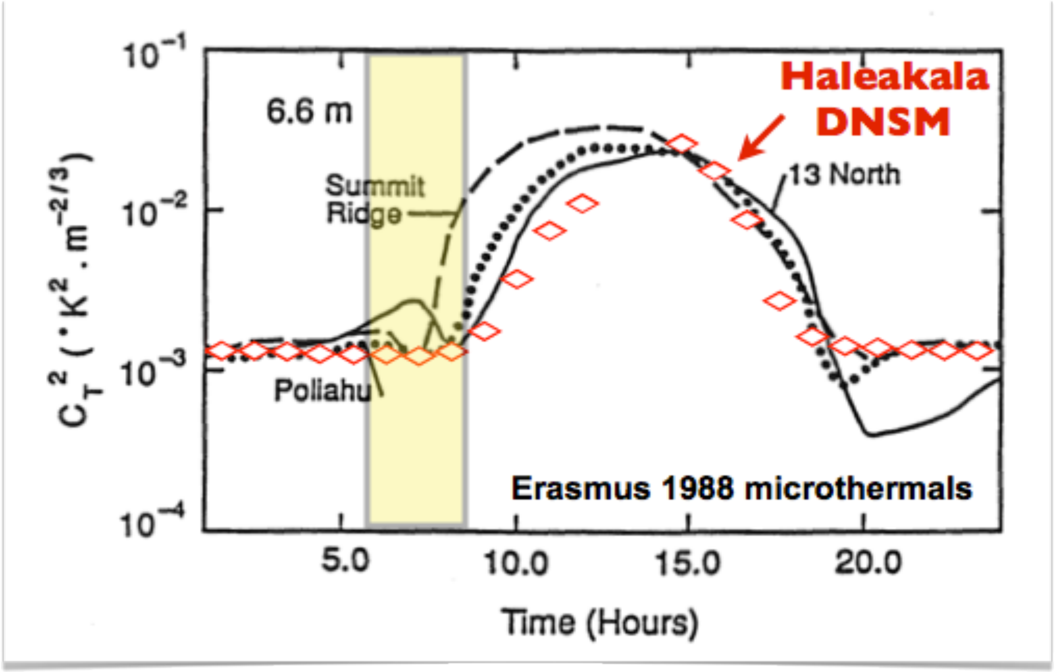
ULIRGs At Moderate z



- ULIRGs show large IR luminosities ($L_{IR}>10^{12}L_o$)
  - Starburst or AGN responsible, but hidden behind obscuring dust
- Important to trace the history of both AGN & galaxies
  - Links detailed AGN characterization to the cosmological evolution
- Key problem is the distinction of AGNs from compact starburst objects, as the IR emission is typically highly obscured
  - Best investigated at 20μm
- Observing the emission surface brightness can eliminate starburst emission in very bright luminous objects
- ULIRGs are more prevalent at moderate z, probing the emission source in the local universe & constructing templates is crucial preparation for follow-on space-based observations
  - Understanding ULIRGs versus z is a powerful method to investigate the evolution of AGN & galaxies, effects on each other

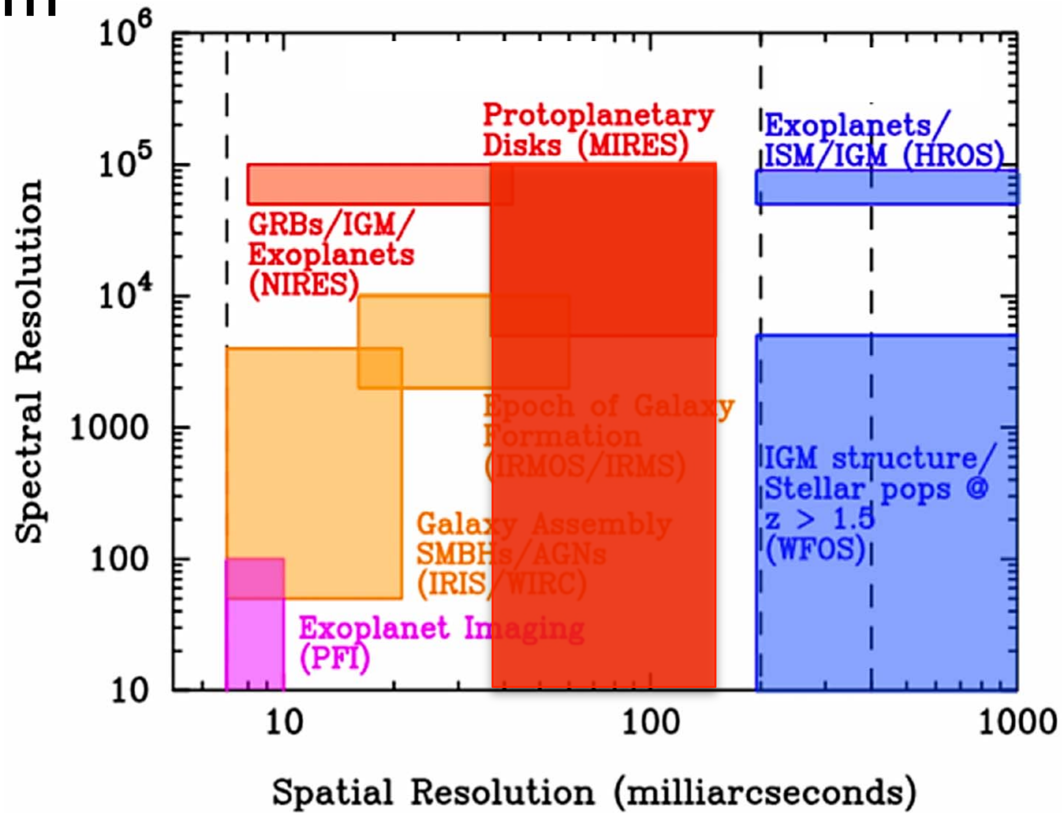
Mid-IR Adaptive Optics (MIRAO) & Daytime Observing

- 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)



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



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)

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

NSF MSIP Reviews

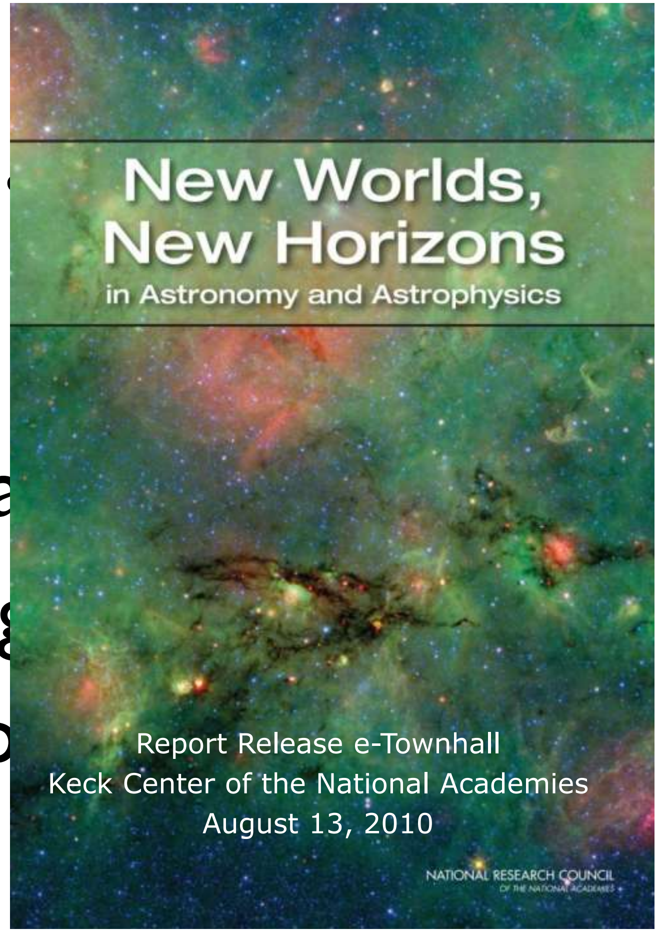
- Submitted $4.4M proposal to NSF's MSIP
  - Thanks to the *TMT* & SAC for their help & approval
- Review comments very helpful:
  - The proposal makes a strong case for the necessity of a mid-IR camera with high dispersion capabilities at the TMT. The proposed science drivers (e.g. gas dynamics and 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

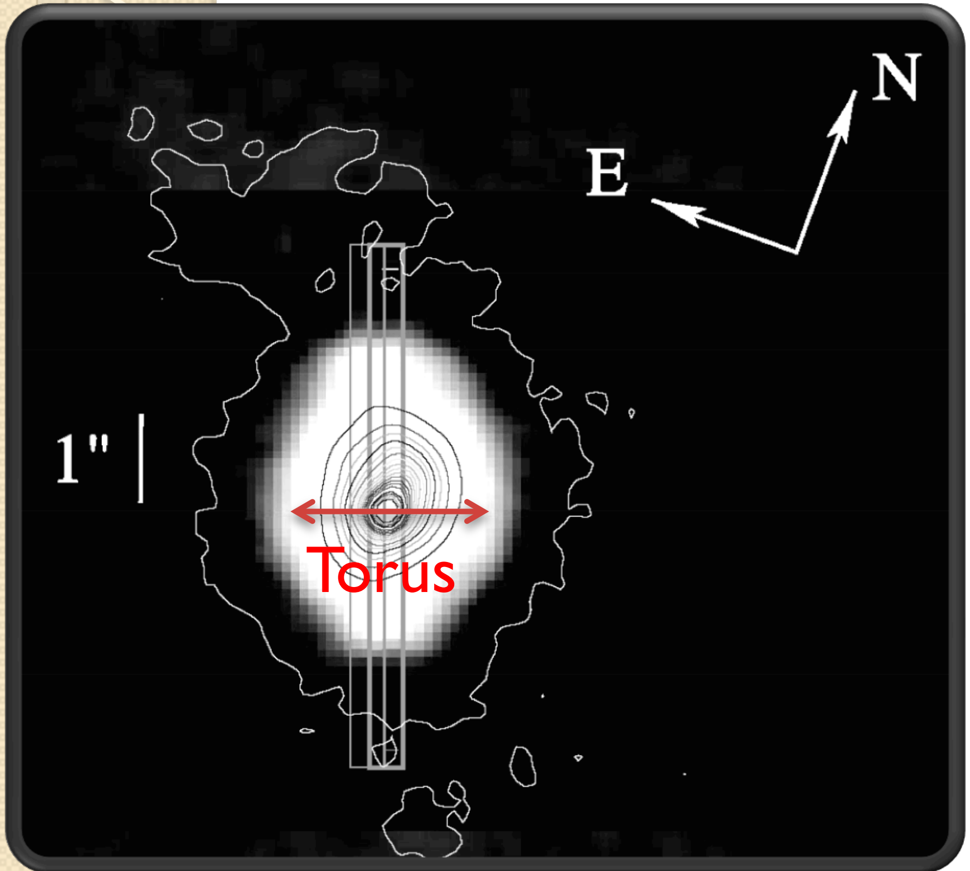
- Intellectual merit is well presented and very compelling
- The thought that has gone into the scientific impact is impressive and complete
- If NSF participation in TMT is a realistic possibility, this proposal represents a positive step for the U.S. astronomical community. The science is compelling 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

Why Should Anyone (Still) Care About AGN?

- Connection between host galaxy and AGN remains unclear
  - M_σ relationship
  - Evolution of AGN and host
  - Cosmological connections?
  - Black hole formation
- Much still unknown/unclea
- Interesting in their own ri
- Lab for high energy astrop



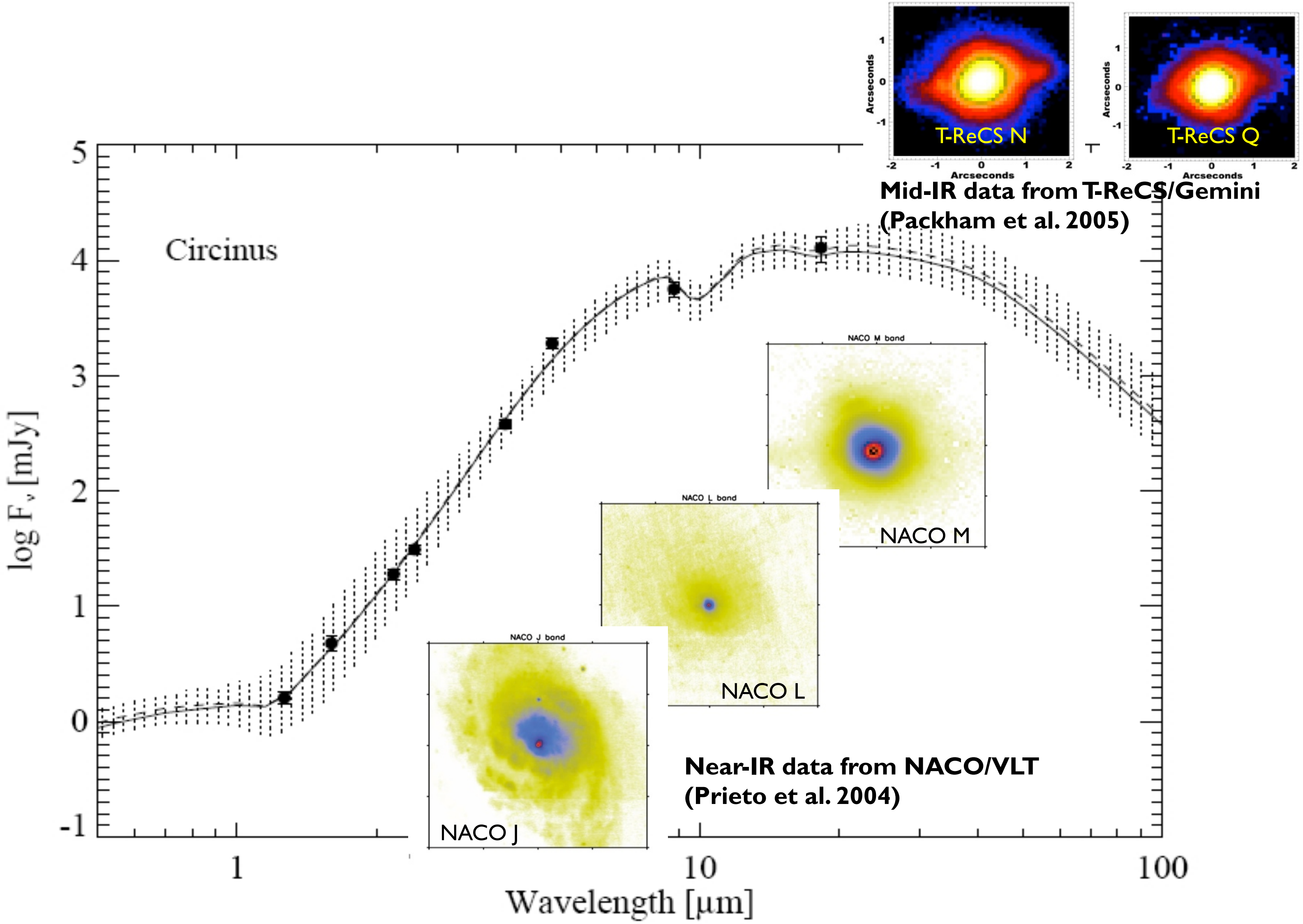
Imaging & Spectroscopy of NGC1068
Mason et al. 2006



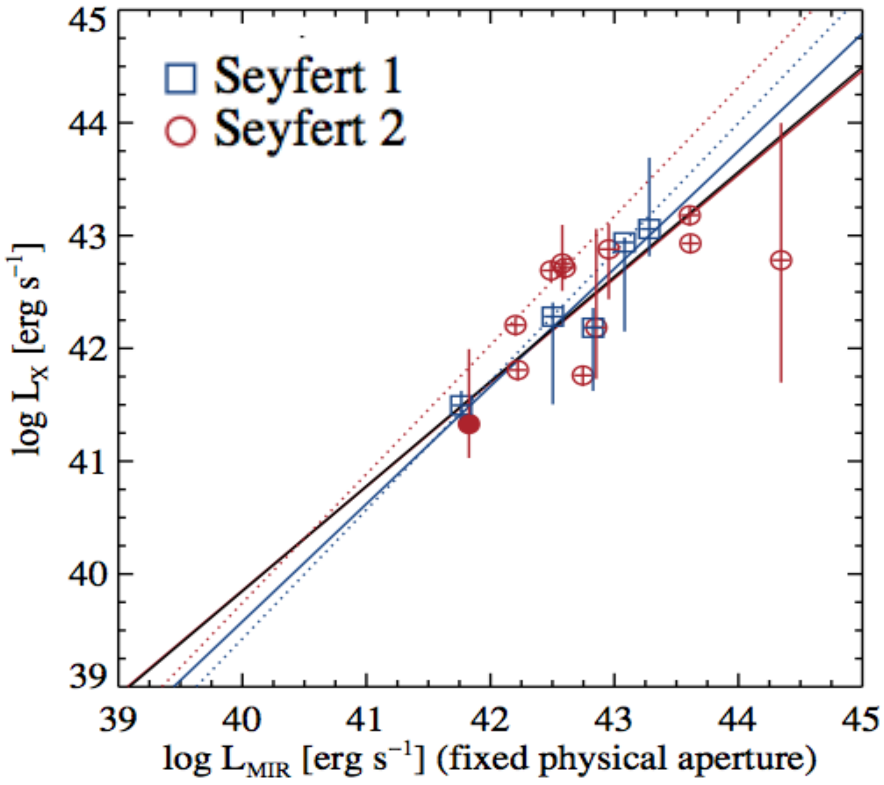
- Archetypal Sy AGN
  - Sy 2 in total flux,
    Sy 1 in polarized flux
- If large torus (r>15pc) present in NGC1068, easily resolvable at our 8m MIR resolution
  - 9.7μm image shows no evidence of extension attributable to the torus
- Nuclear spectra inconsistent with homogenous torus model predictions

NIR-MIR SED Fitting

Ramos Almeida et al. 2011



X-Ray to MIR Correlation



- Strong correlation across luminosity range and independent of Seyfert type (r<100pc, Levenson et al. 2010)
  - High spatial resolution needed to reduce contamination
- No significant difference between Seyfert 1 and 2
- MIR emission of the torus is nearly isotropic
  - Clumpy torus models show MIR emission is insensitive to the viewing angle
  - Homogenous torus models produce significantly stronger (several orders of magnitude) MIR emission in Seyfert 1's

Receding Torus Model

- The dusty inner edge of the torus is described by (Lawrence 1991)
  - The sublimation temperature of dust
  - The temper
- Dust sublim
- This implies the torus w luminous ob
- Our results this model