Supermassive Black Holes
with TMT and its Future-generation Instruments

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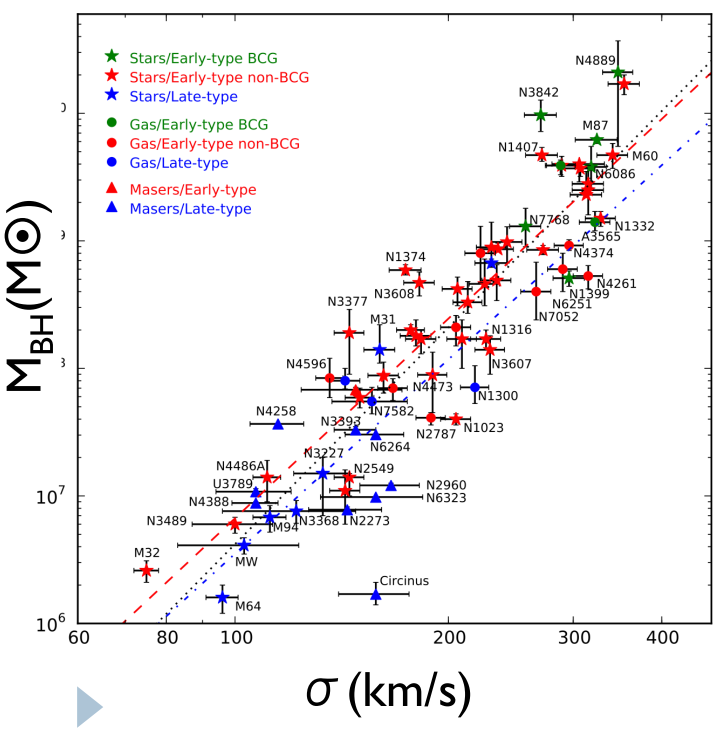
SMBH sciences: what do we care about?

- (1) Supermassive Black Holes (SMBH):
  - How many, how large, their properties, …

SMBH sciences: what do we care about?

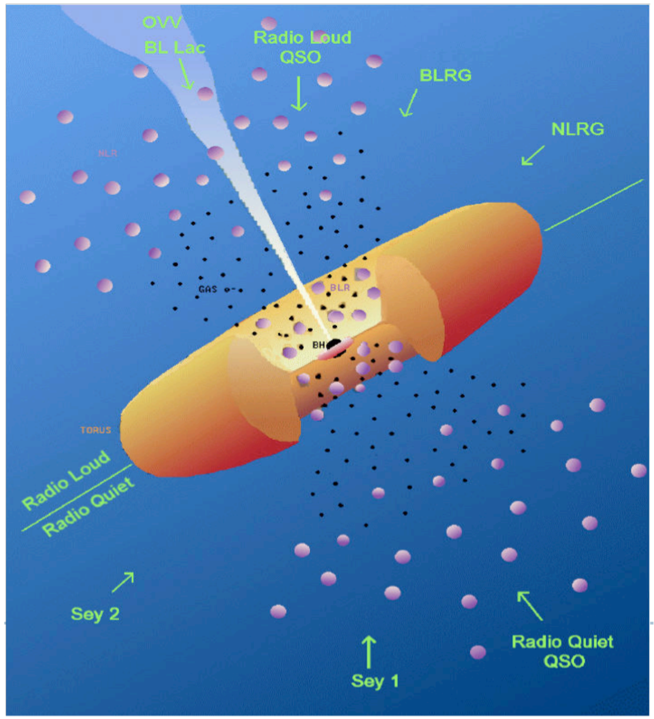
- (1) Supermassive Black Holes (SMBHs)
- (2) SMBHs & galaxies
  - How they interact and co-evolve (or not)

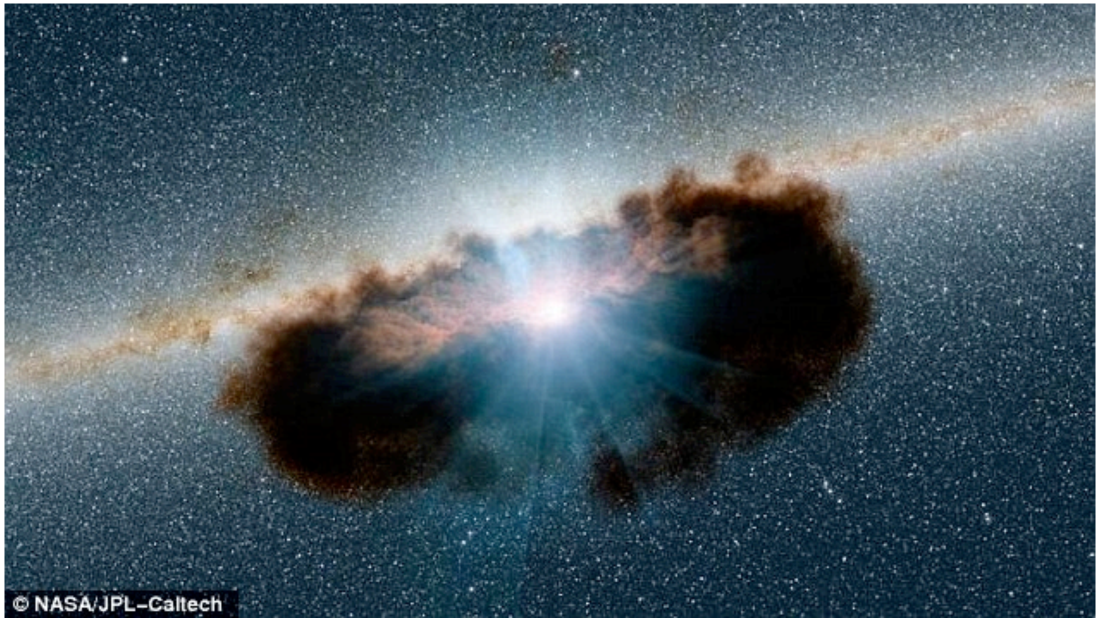
McConnell & Ma, 2013



SMBH sciences: what do we care about?

- (1) Supermassive Black Holes (SMBHs)
- (2) SMBHs & galaxies
- (3) Inner structures of Active Galactic Nuclei (AGNs)
  - Accretion disk, broad-line region, torus, narrow-line region





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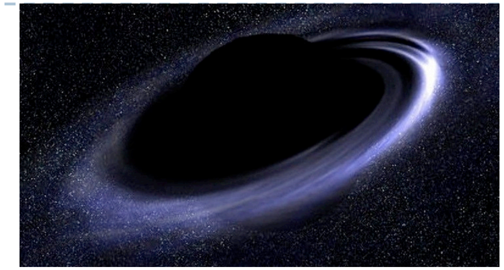
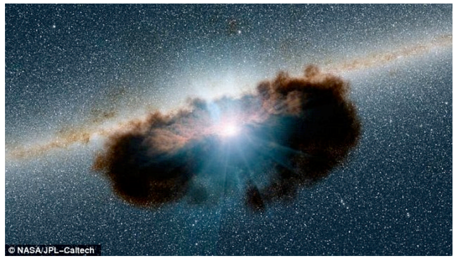


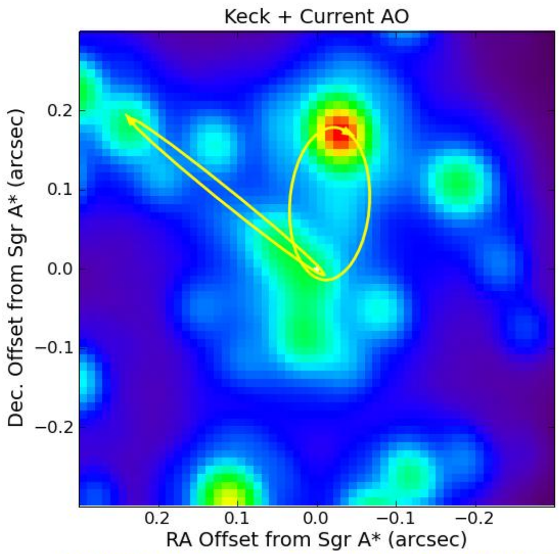
- (2) SMBHs & galaxies

- (3) Inner structures of Active Galactic Nuclei (AGNs)

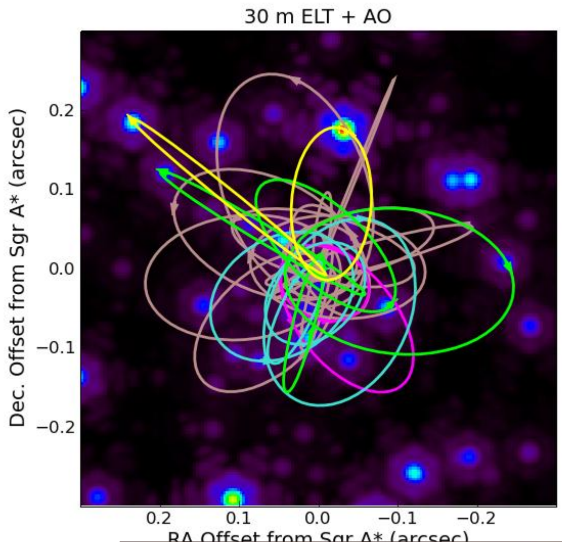


(I) Super-massive Black Holes

- Our Milky Way and M31



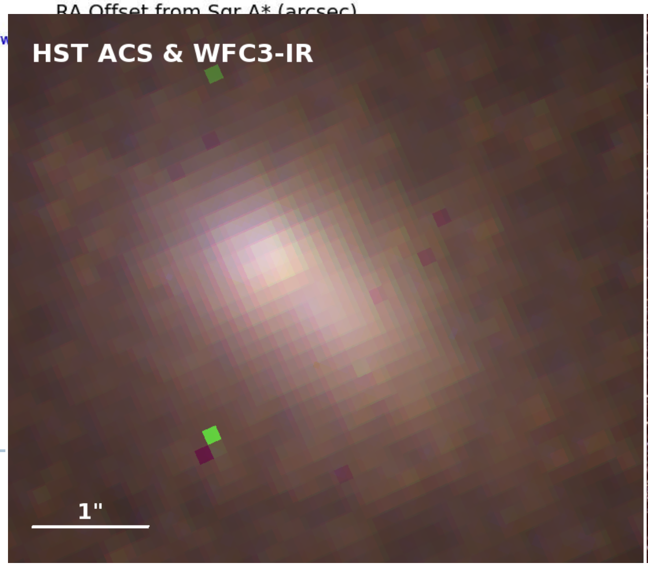
http://www.astro.ucla.edu/~ghezgroup/gc/pictures/Future_GCorbits.shtml

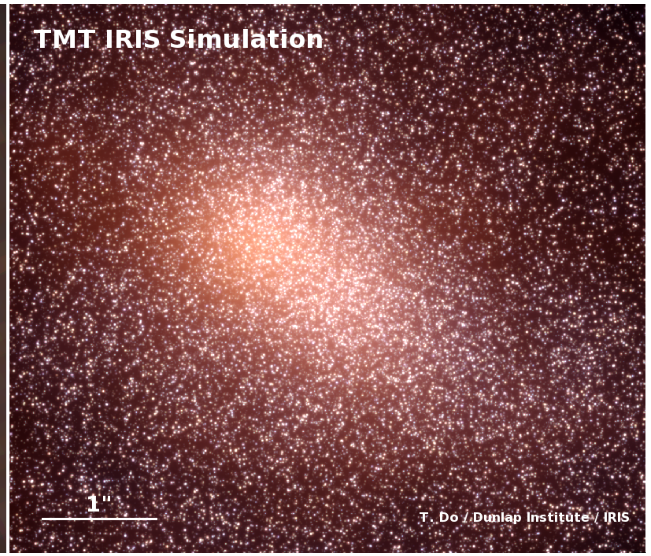


http://ww

Galactic center

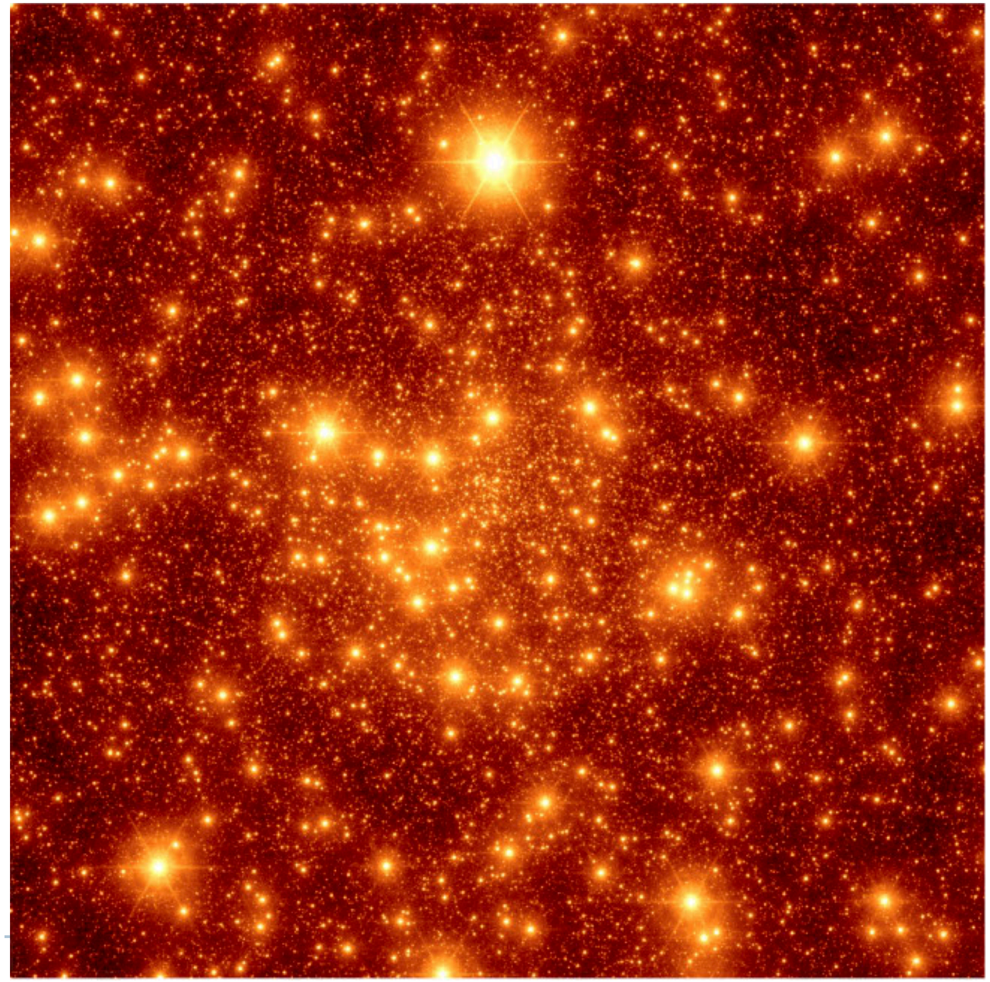
M31





(I) Super-massive Black Holes

- Our Milky Way and M31
  - AO-based deployable multi IFUs
    - The star cluster in GC:
      - 10 arcsec x10 arcsec
    - Extragalactic globular clusters.
    - R>20,000, chemical composition of extragalactic globular clusters
  - Chemical composition of resolved stars in nearby nuclei, globular clusters in M31, M33:
    - R>8000, Fe/H, alpha/Fe, possibly some individual alpha element
    - AO-fed high spectral resolution spectrograph:
      - R>20,000



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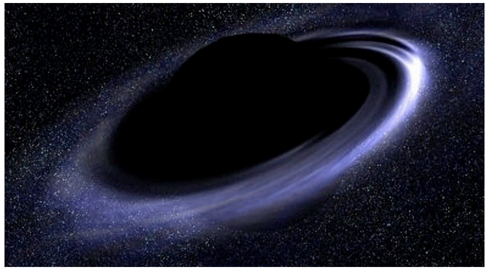


SMBH demographics: over masses

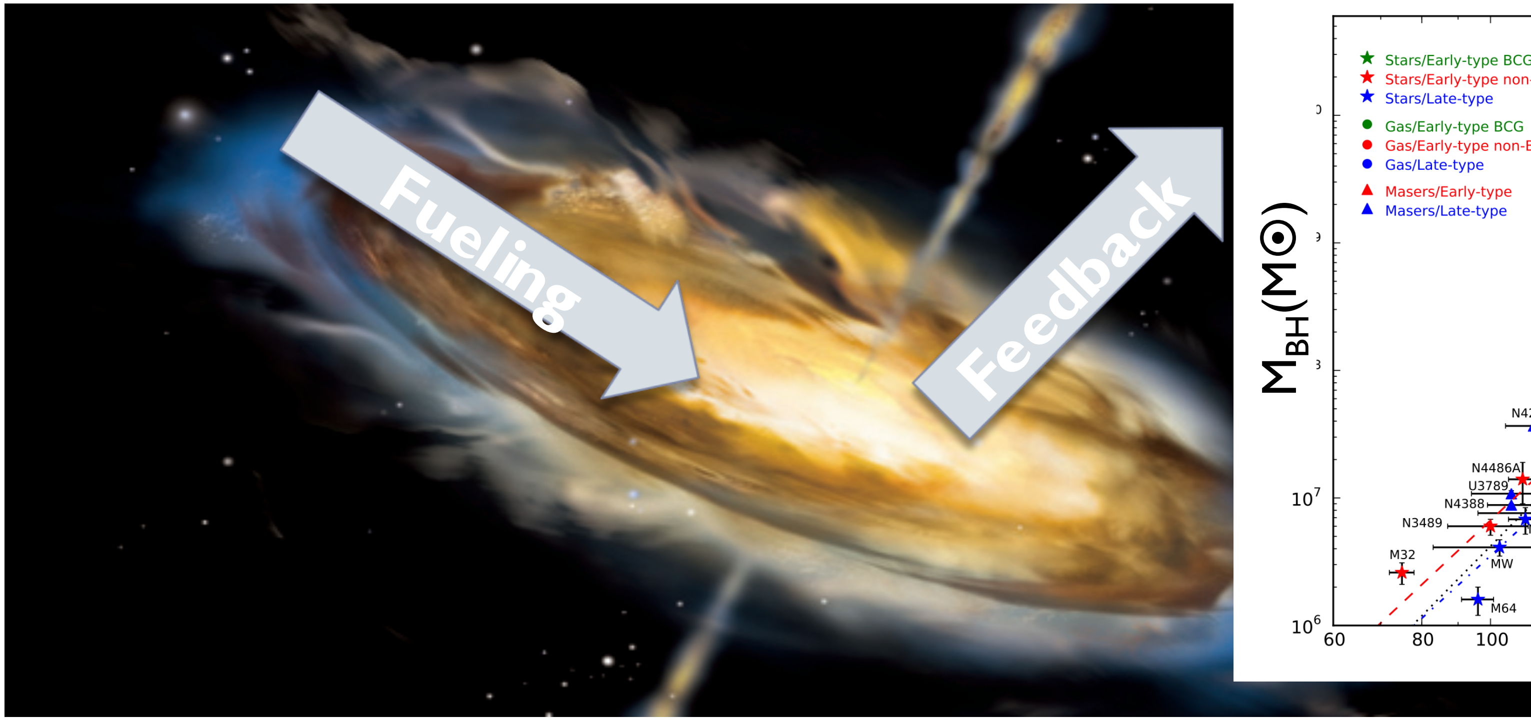
- Intermediate-mass SMBHs:
  - AO-based R>=8000 spectroscopy
  - mid-IR access for z>0.05 (the CO line)
- Very massive SMBHs:
  - Spatial resolution is the key
- Galaxies do not favor SMBHs:
  - M33, NGC205,
- Better calibrate the M-σ relation
  - More BH measurements from stellar dynamics, cross match with RM

SMBH demographics: over redshifts

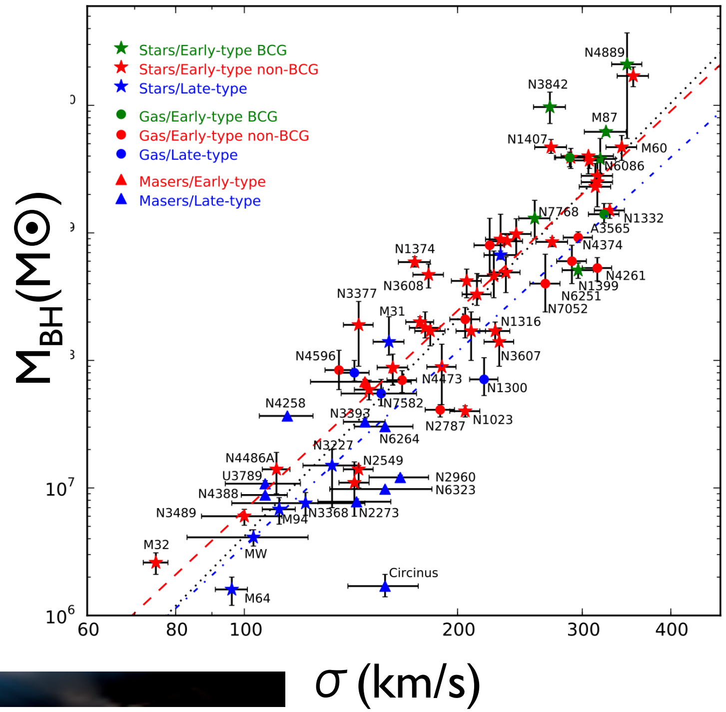
- Evolution of the LF of low & moderate-luminosity AGNs:
  - Large samples at high-z: AO-based multi-object spectrograph
- Finding 1st-generation quasars
  - IRMS
  - mid-IR spectroscopy in post-JWST era

(II) SMBHs and galaxies

- How do SMBHs and galaxies exchange information:
  - Feeding and feedback

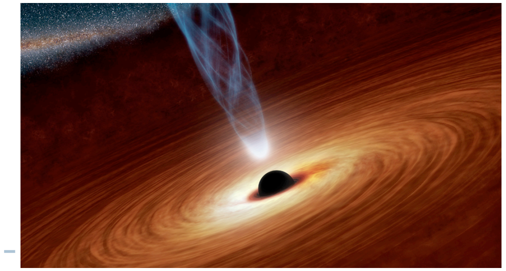


McConnell & Ma, 2013



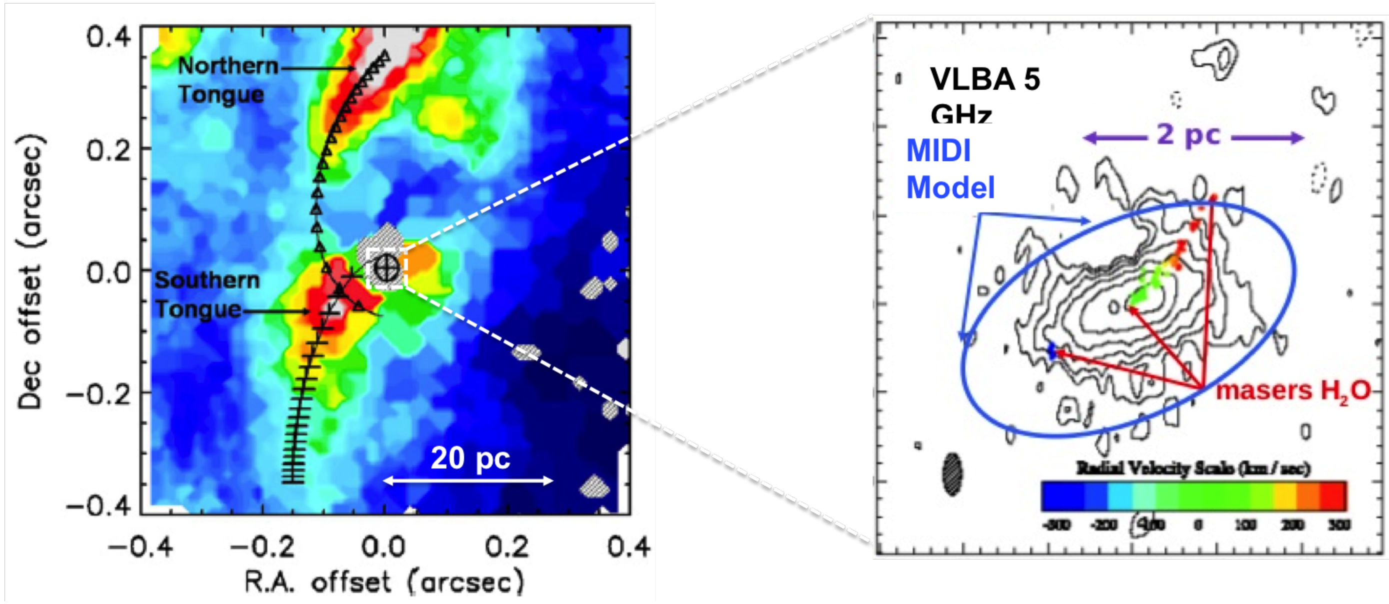
(II) SMBHs and galaxies

- **Feeding:**
  - Large-scale (>100pc):
    - Indirect probes (such as statistical studies) sometimes are quite controversial
    - Merging, galactic bars, spiral arms, oval structures, etc.
    - Great progress lately with large IFU surveys on 2-4m telescopes: directly trace the gas and stellar kinematics
  - Small-scale (<100pc):
    - Limited knowledge only for a small number of objects due to spatial resolution and great varieties of individual sources.
- **Feedback:**
  - Common, @various scales
  - Not sure how frequent it is, how strong, whether it will have effects on galaxy evolution



(II) SMBHs and galaxies

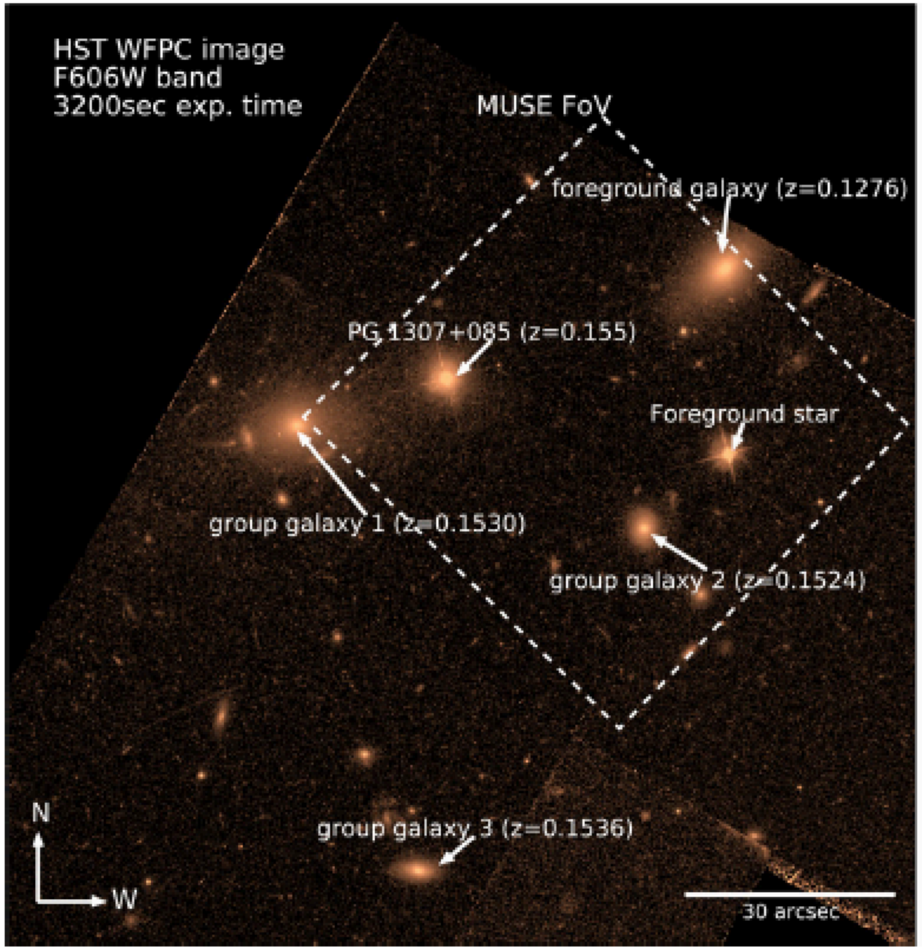
- TMT on Nearby AGNs (in much smaller scale):
  - Trace gas and star kinematics all the way to the torus:
    - Feeding, feedback, nuclear star-formation
  - These small-scale observations can be combined with larger-scale observations done with smaller telescopes.
- Trace gas infall and feedback at distant universe: where AGN activity is mostly active:
  - IR deployable multi IFUs

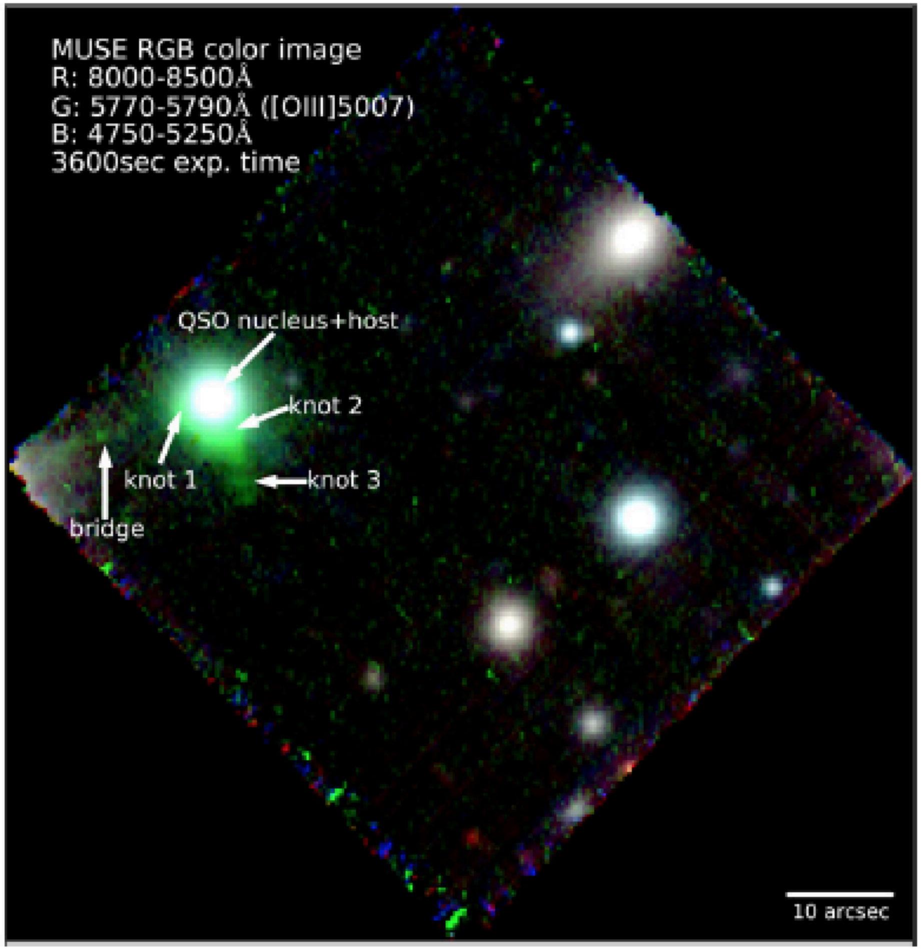


NGC1068: Muller-Sanchez et al. 2009

(II) SMBHs and galaxies

- Host galaxies and environment of bright QSOs



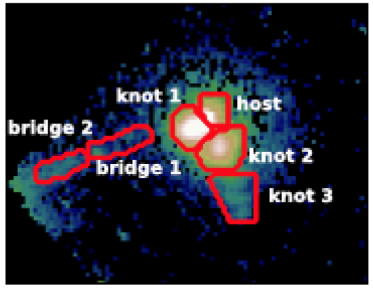


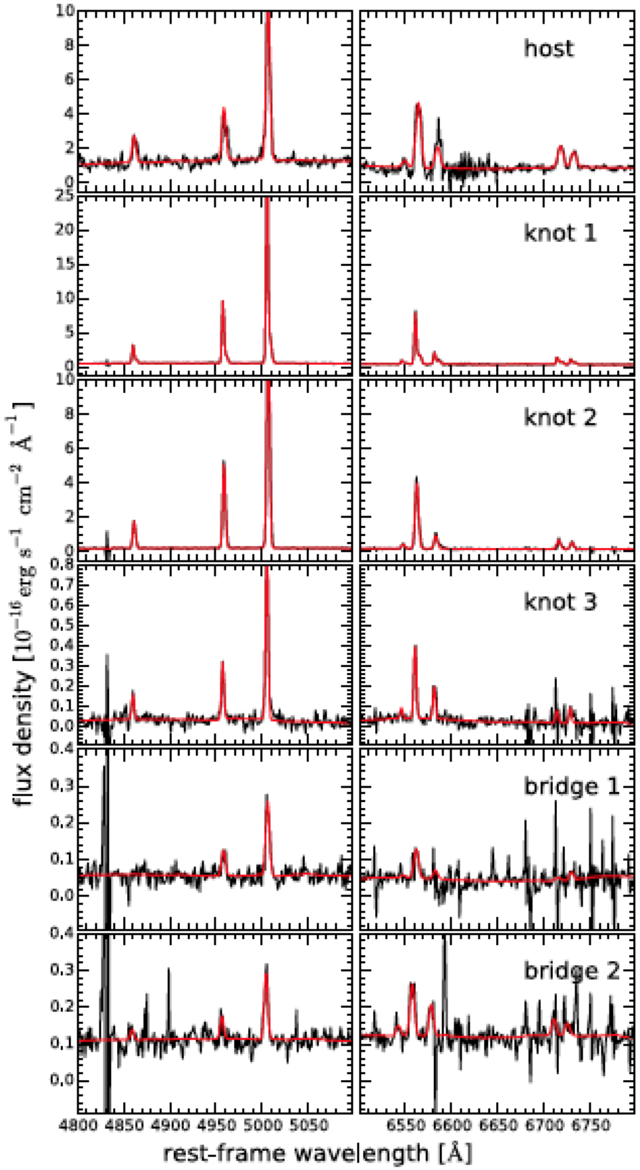
Husemann et al., 2016

(II) SMBHs and galaxies

- Gas kinematics
- Morphology
- Metallicity

- Wide-field optical/IR IFU
  - Like MUSE on VLT, or KCWI on Keck
  - Low-surface brightness studies:
    - Hanny's Voorwerp





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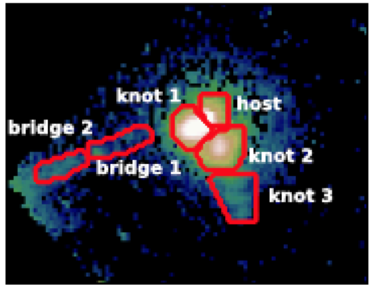

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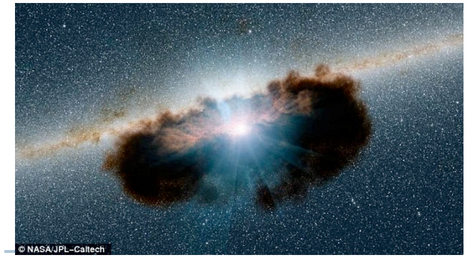
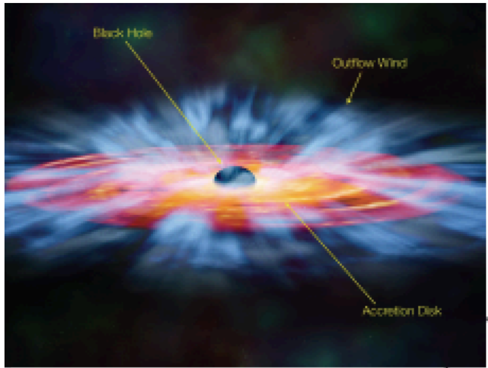
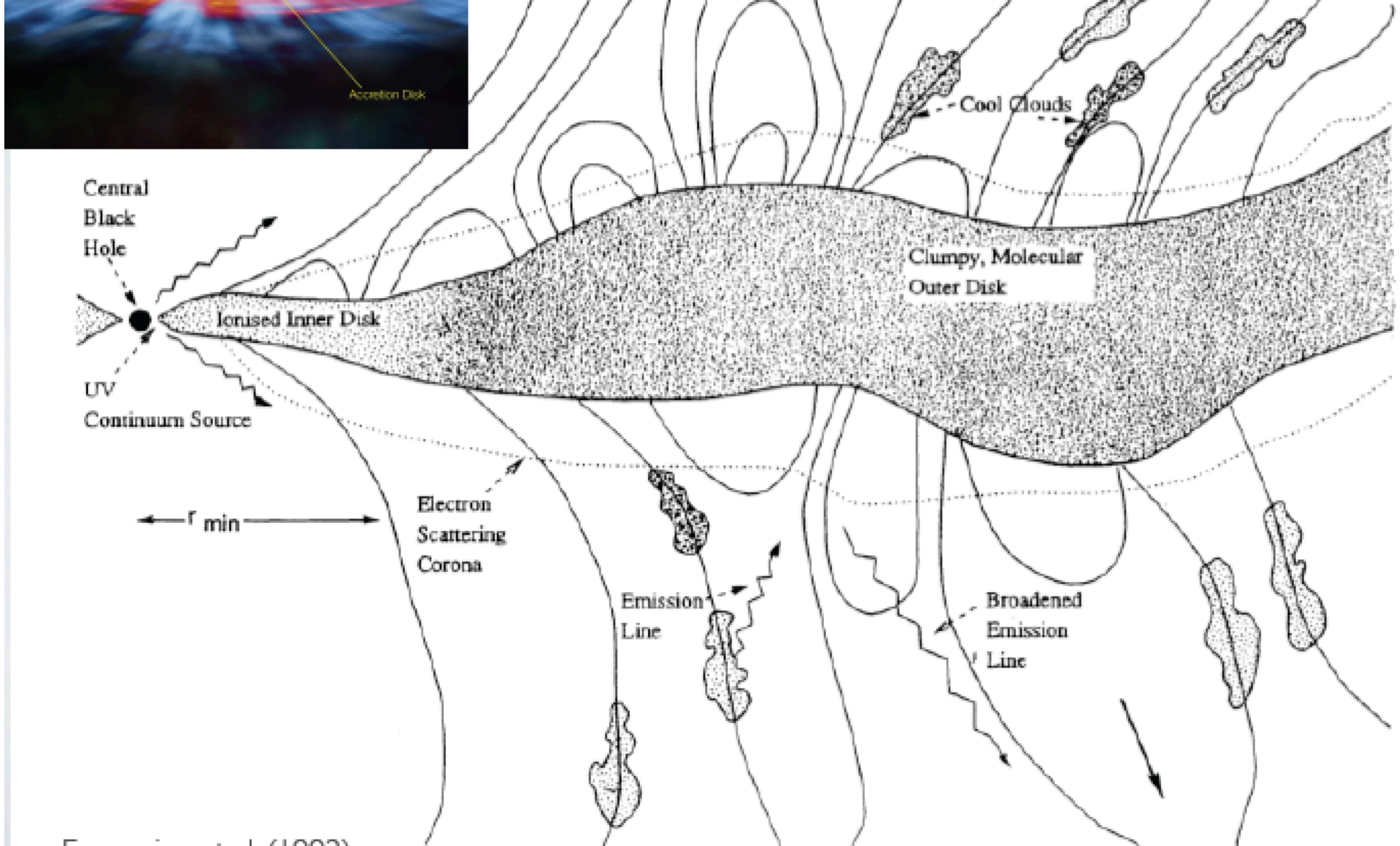


(III) Structures of AGNs

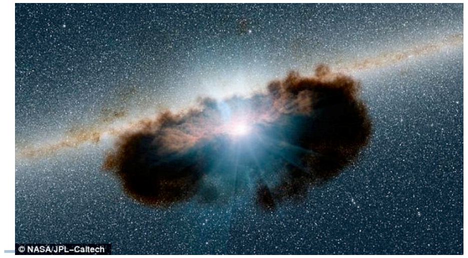
- Torus



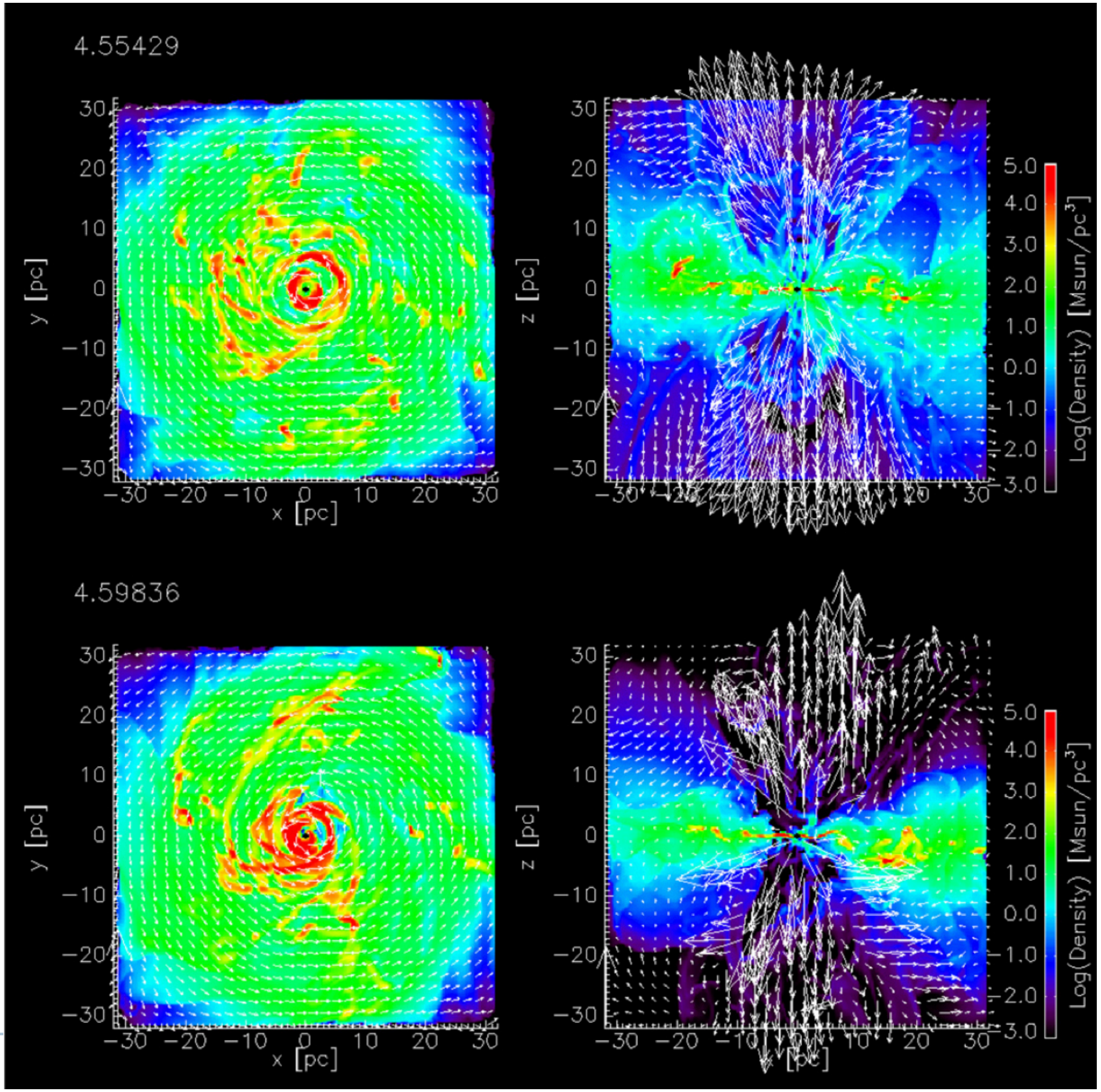


Emmering et al. (1992)

(III) Structures of AGNs: torus

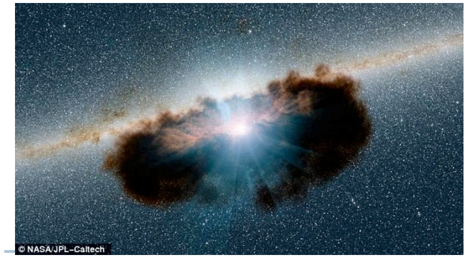


- Radiative-driven fountain
- Torus is dusty



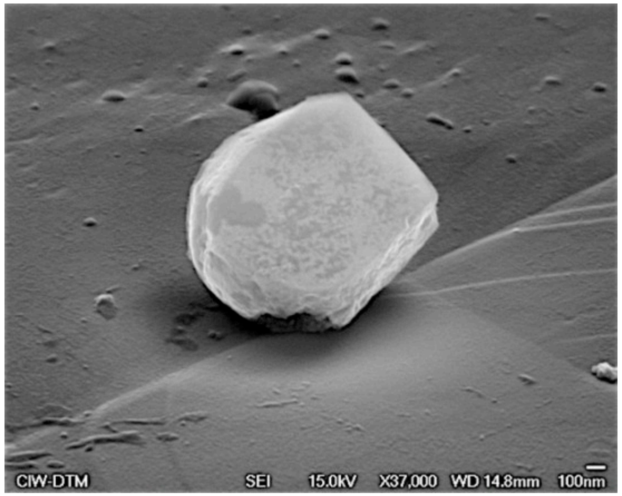
Wada et al., 2012

(III) Structures of AGNs: torus



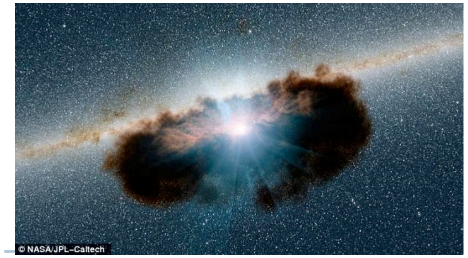
- Dust is a great thing
  - Dust remembers,

  gas forget
- Detect in mid-IR

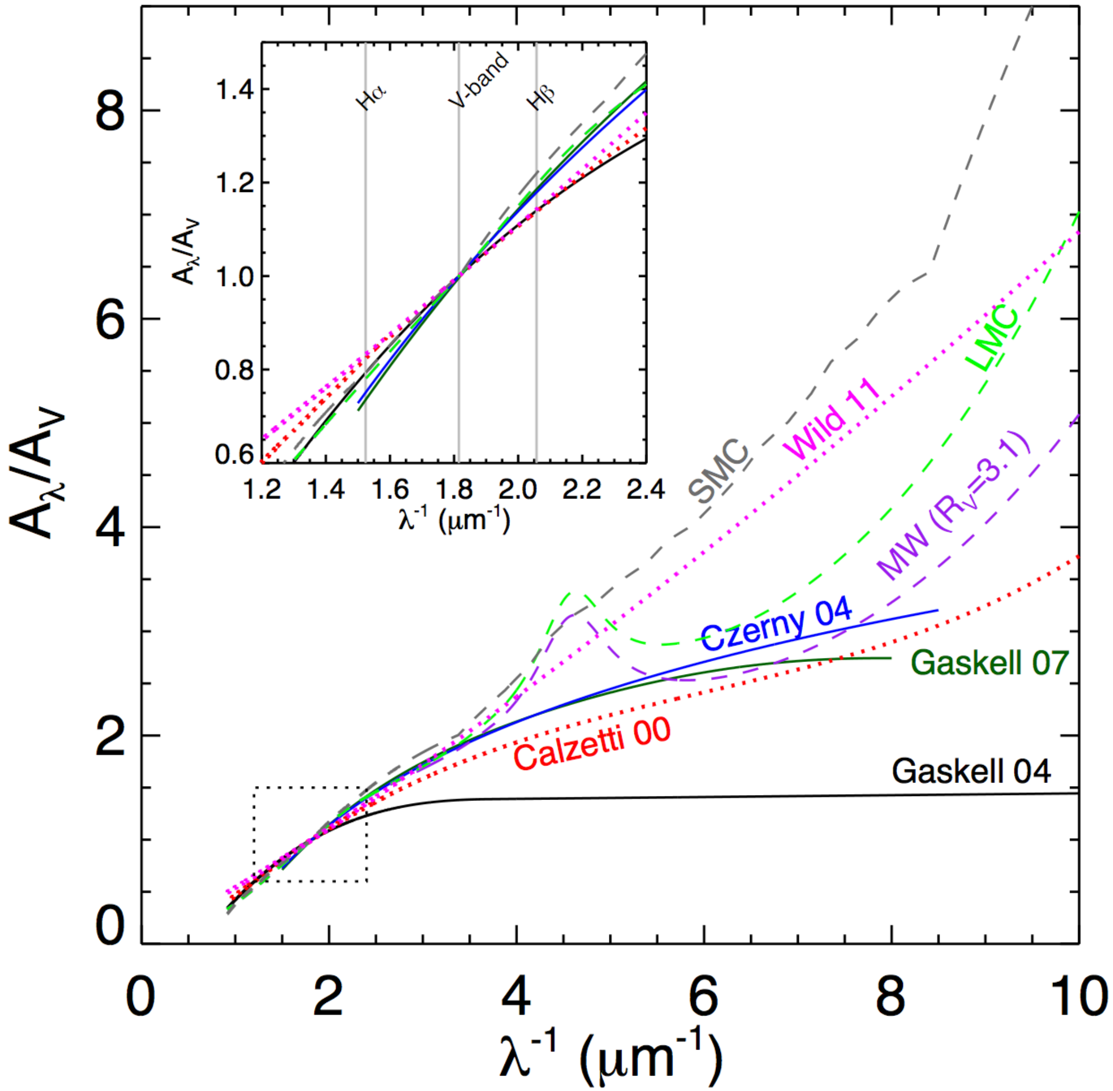


Electron microscope image of dust from interstellar space

(III) Structures of AGNs: torus

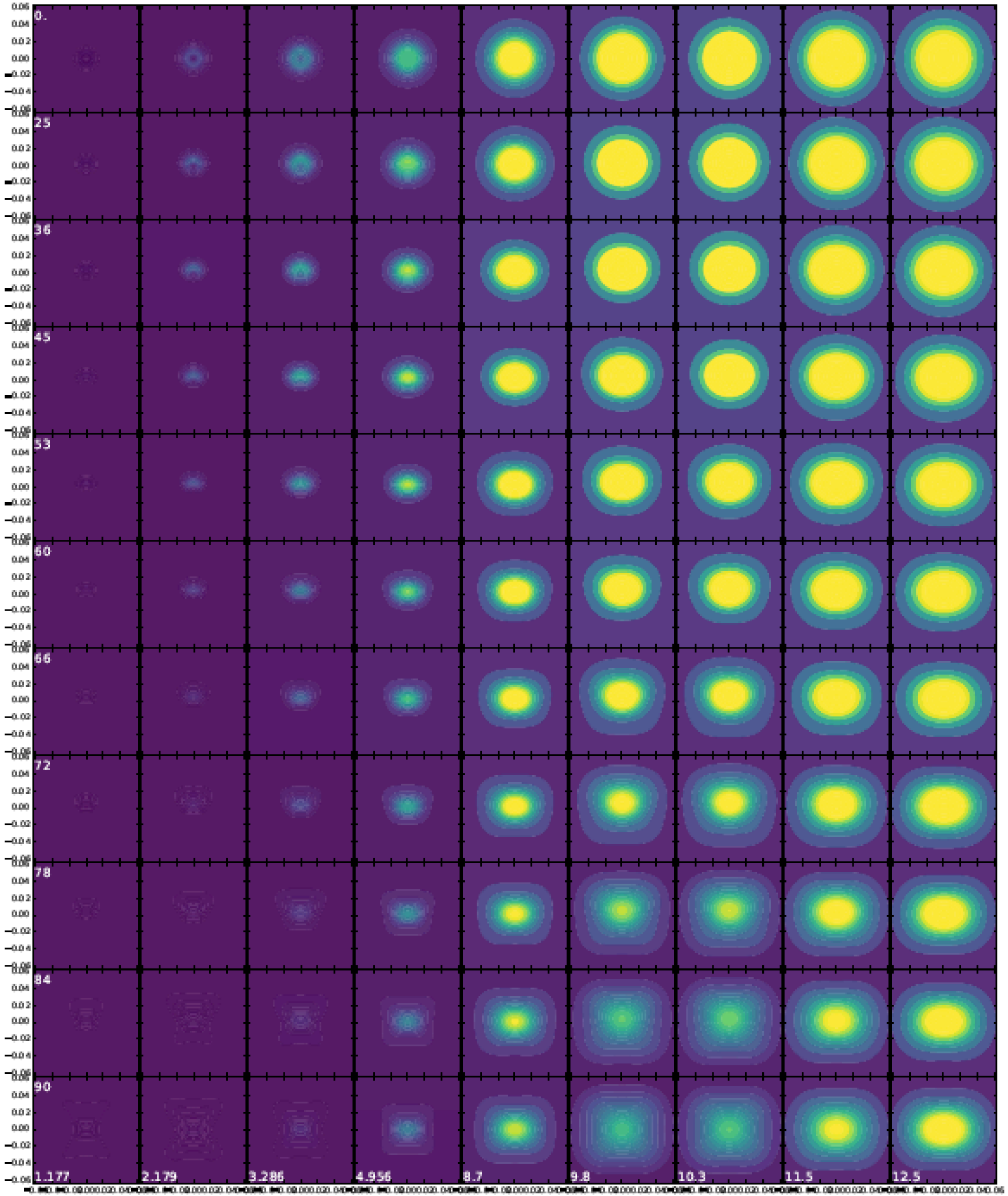


- We know very little about dust in AGNs
- TMT vs. JWST:
  - spatial resolution
  - IR, particularly mid-IR



(III) Structures

- IRIS and MICHI



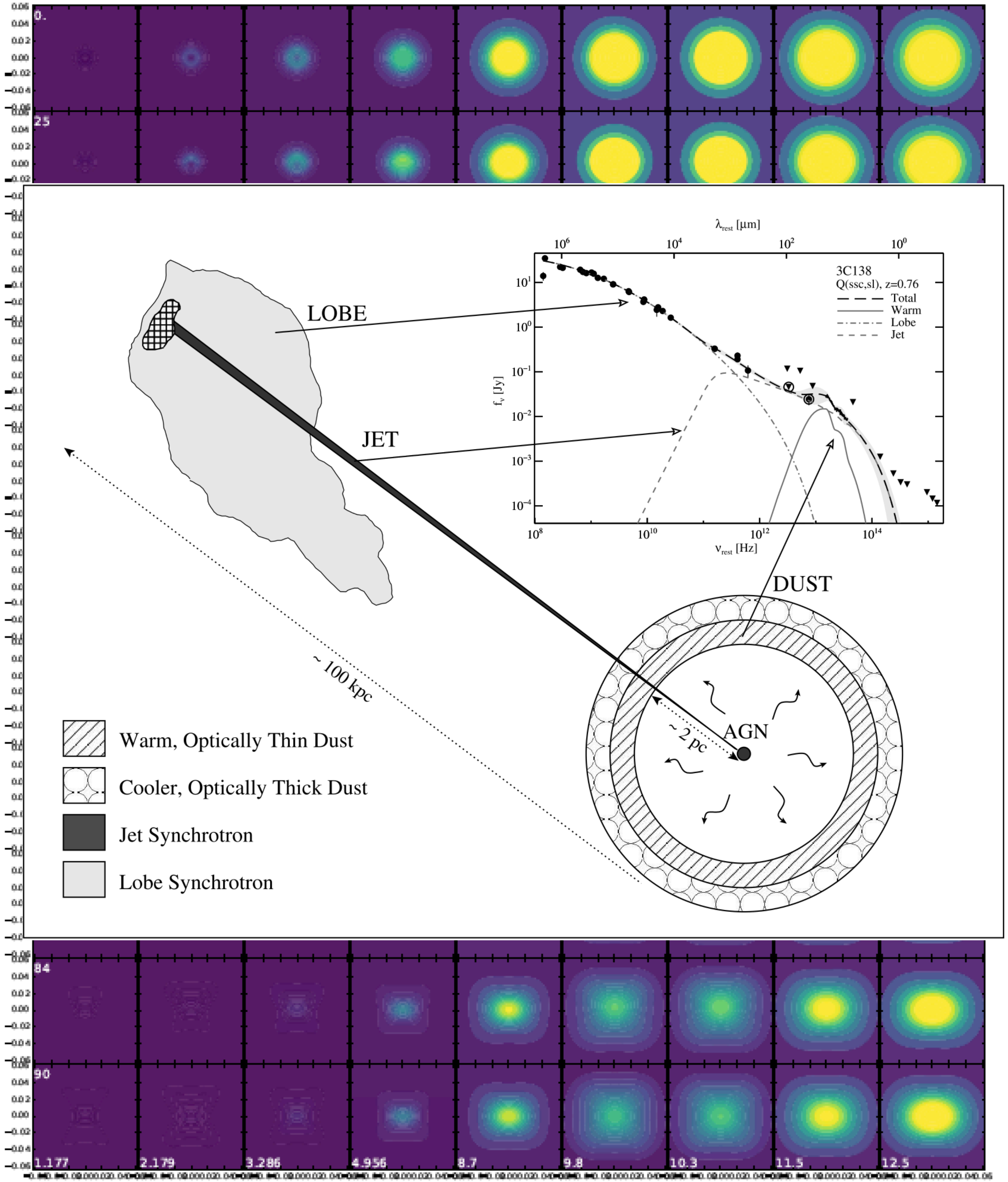
IRIS and MICHI simulated imaging observations of a generic clumpy torus model @ 14Mpc

(III) Structures

- IRIS and MICHI

Dust temperature structure

IRIS and MICHI simulated imaging observations of a generic clumpy torus model @ 14Mpc



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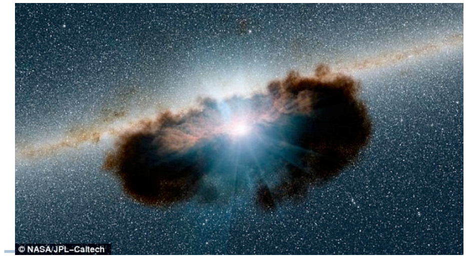
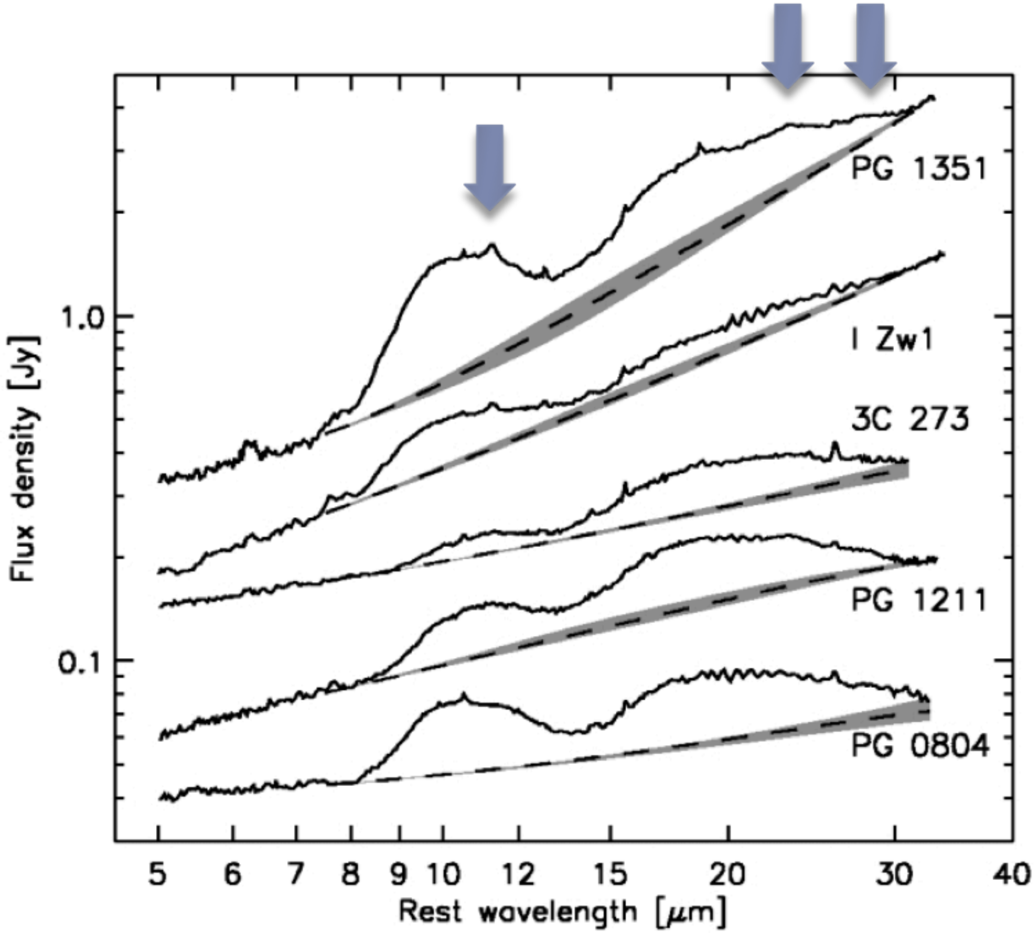


- mid-IR spectroscopy: powerful
- Silicate feature at 10um:
  - Peak shift, strength, shape
  - Special features



Hao et al., 2005

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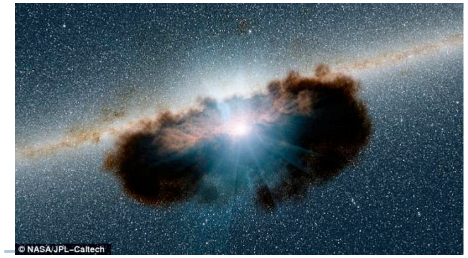
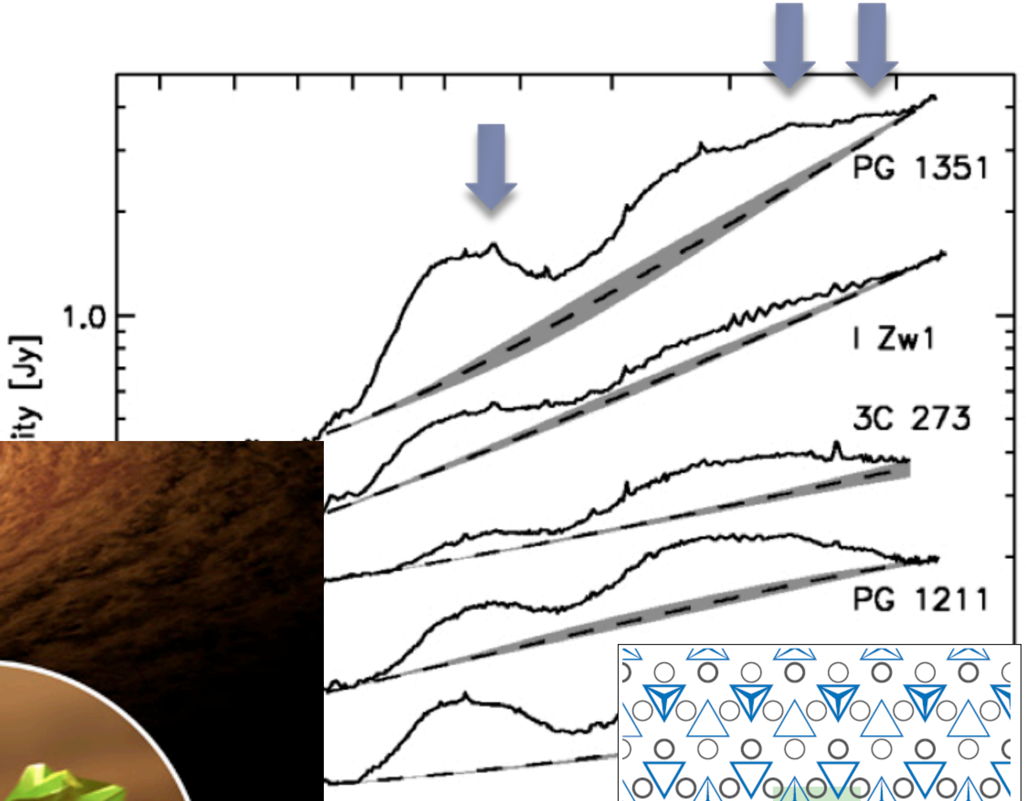
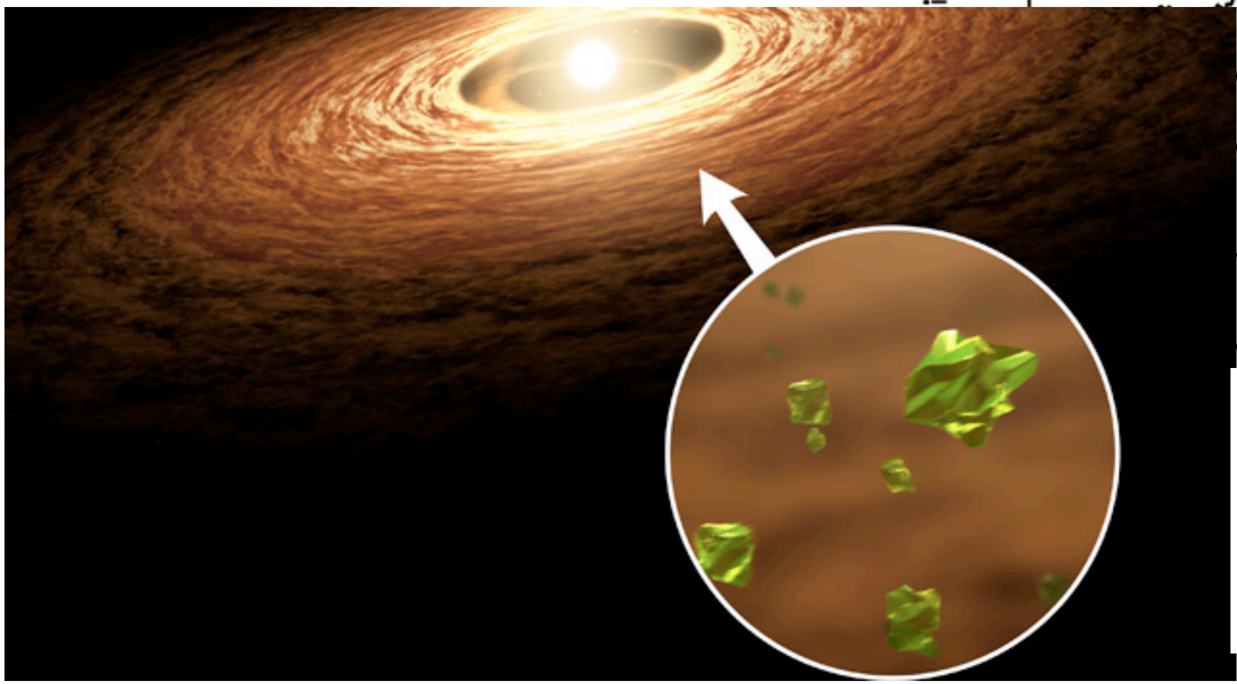
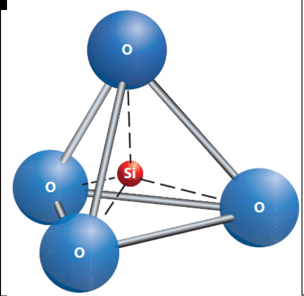
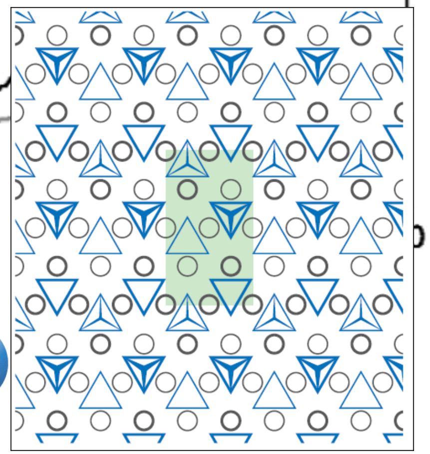


- mid-IR spectroscopy: powerful
- Silicate feature at 10um:
  - Peak shift, strength, shape
  - Special features
    - Crystallized silicate: fresh from stove (wind)









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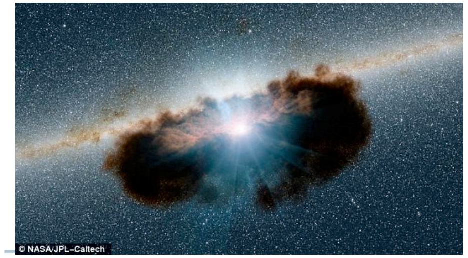
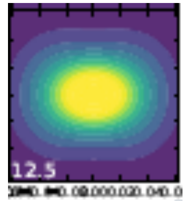
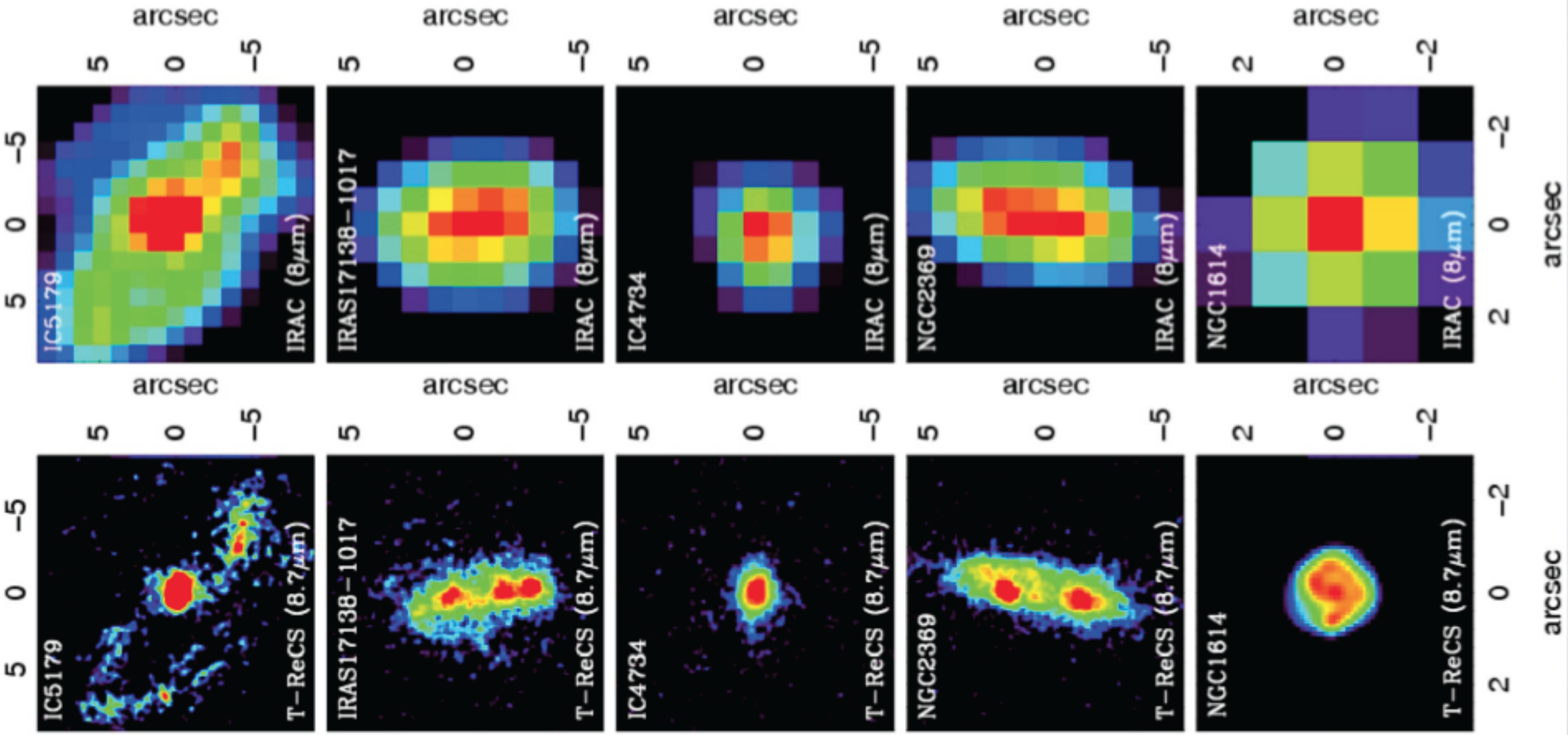


- Dust mineralogy
- JWST vs. TMT





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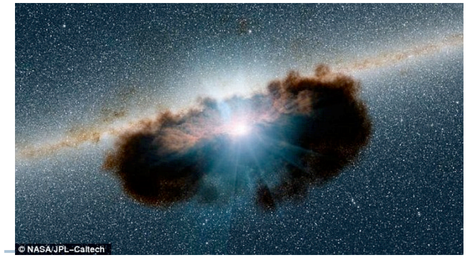
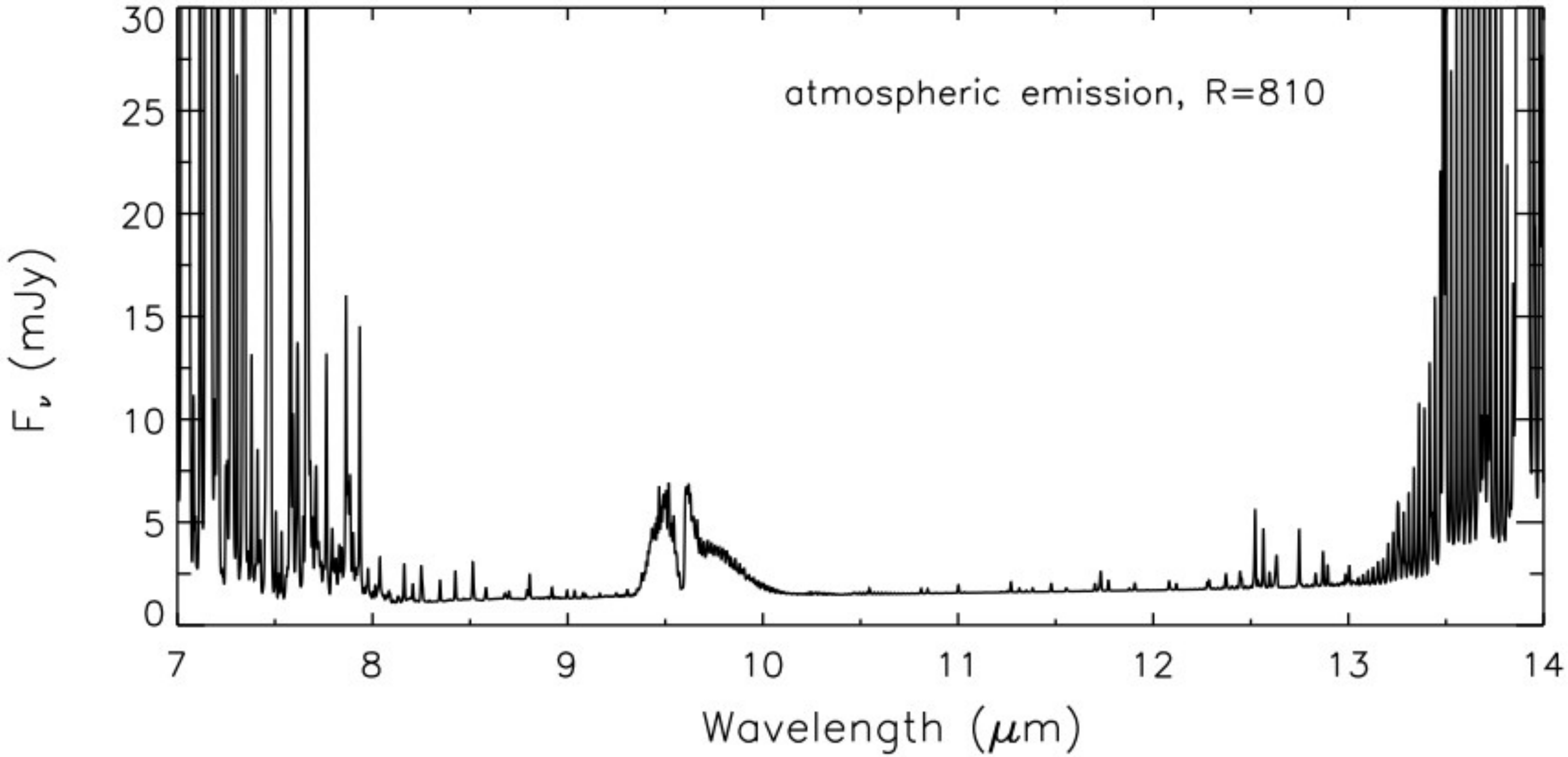


- MICHI: 5sigma, 1 hour integration, ~2mJy at 10 μ m with R=600
- Suggest lower R set (R~100) to increase the sensitivity



Summary

- Sciences:
  - SMBHs
    - Milky way and M31
    - SMBH demographics, broader mass ranges and redshift ranges; better calibrations
  - SMBHs and galaxies:
    - Feeding and feedback of AGN
    - Quasar host and environment studies
    - AGN and nuclear starformation
  - Structures of AGNs:
    - Torus: mid-IR imaging and spectroscopy from TMT will be powerful
    - Accretion disk (variability)
    - Broad-line region, kinematics
    - Narrow-line region, kinematics

Summary: 2nd-generation instruments

- AO-based multi deployable IFU:
  - Galactic center
  - AGN feeding and feedback at high-z
- AO-based multi object spectragraph
  - Luminosity function and its evolution for low-L AGNs
- Wide-FOV optical IFU, low-surface-brightness sensitive
  - Quasar host galaxies and environments
  - Quasar ionization echo
  - Extended narrow-line region
  - Large-scale faint inflow and outflow
- Mid-IR imaging and spectroscopy
  - Direct imaging and dust mineralogy studies of AGN torus.
- High-resolution IR spectroscopy:
  - Chemical elements of resolved stars in Galactic center, M31 and globular clusters
  - kinematics of the narrow-line region