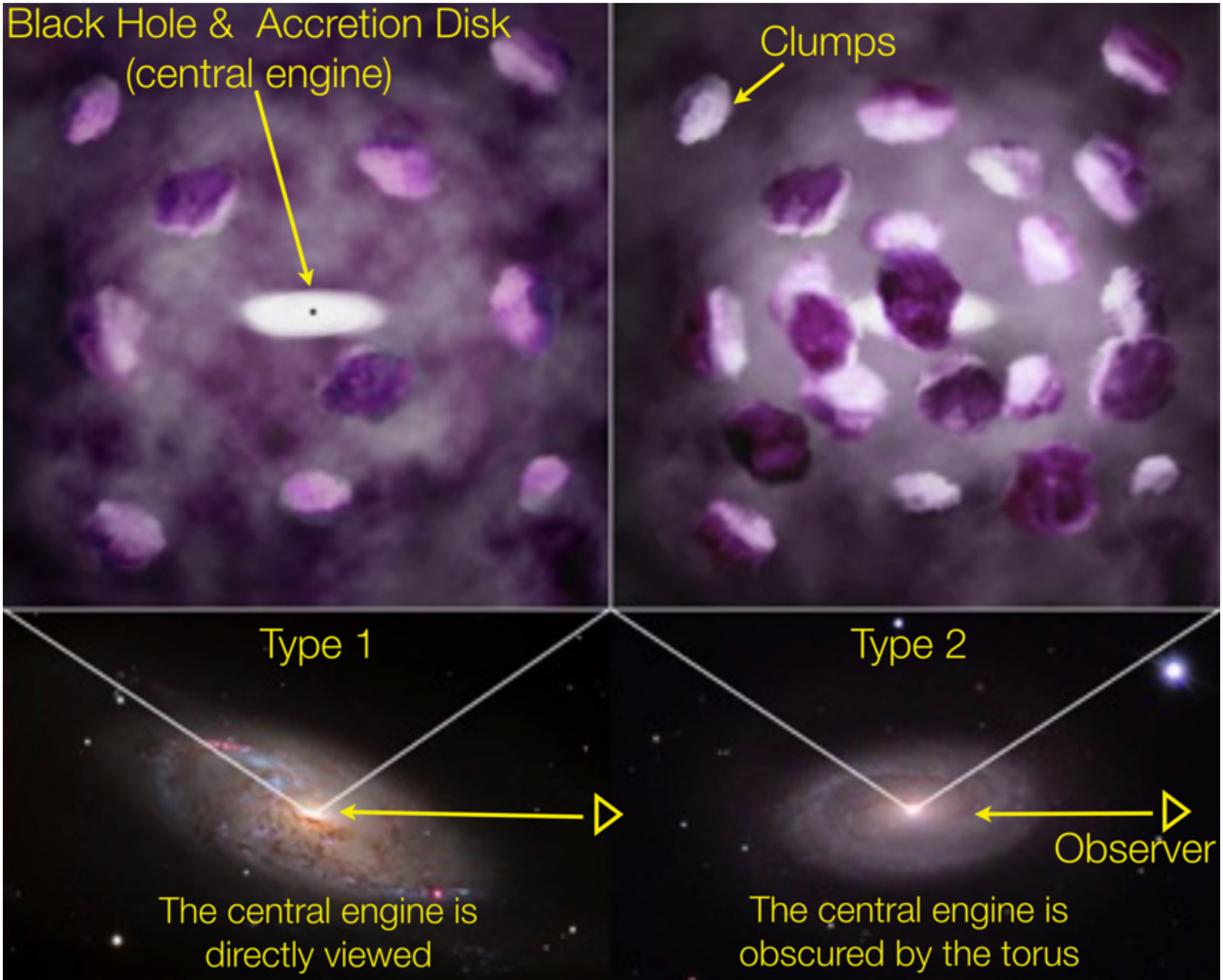
DUSTY TORUS IN ACTIVE GALACTIC NUCLEI: COMPOSITION & MORPHOLOGY

ENRIQUE LOPEZ RODRIGUEZ
Research Fellow
The University of Texas at Austin

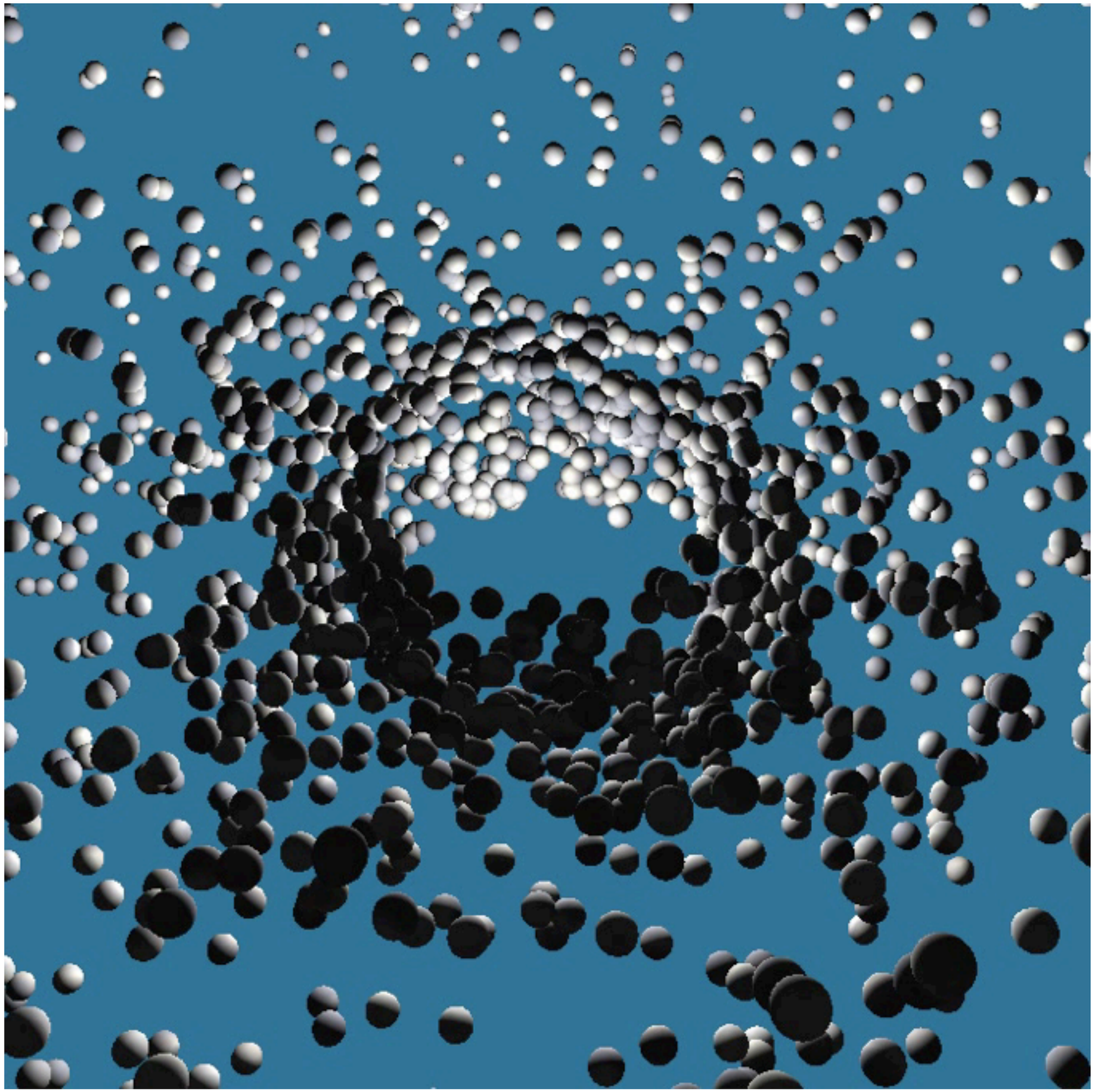
Collaborators:

Kohei Ichikawa (NAOJ, Japan)
Robert Nikutta (PUC, Chile)
Chris Packham (UT San Antonio, USA)
Nancy Levenson (Gemini Observatory, Chile)
Matt Malkan (UCLA, USA)
Lei Hao (SHAO, China)
Dharam Vir Lar (Pune University, India)

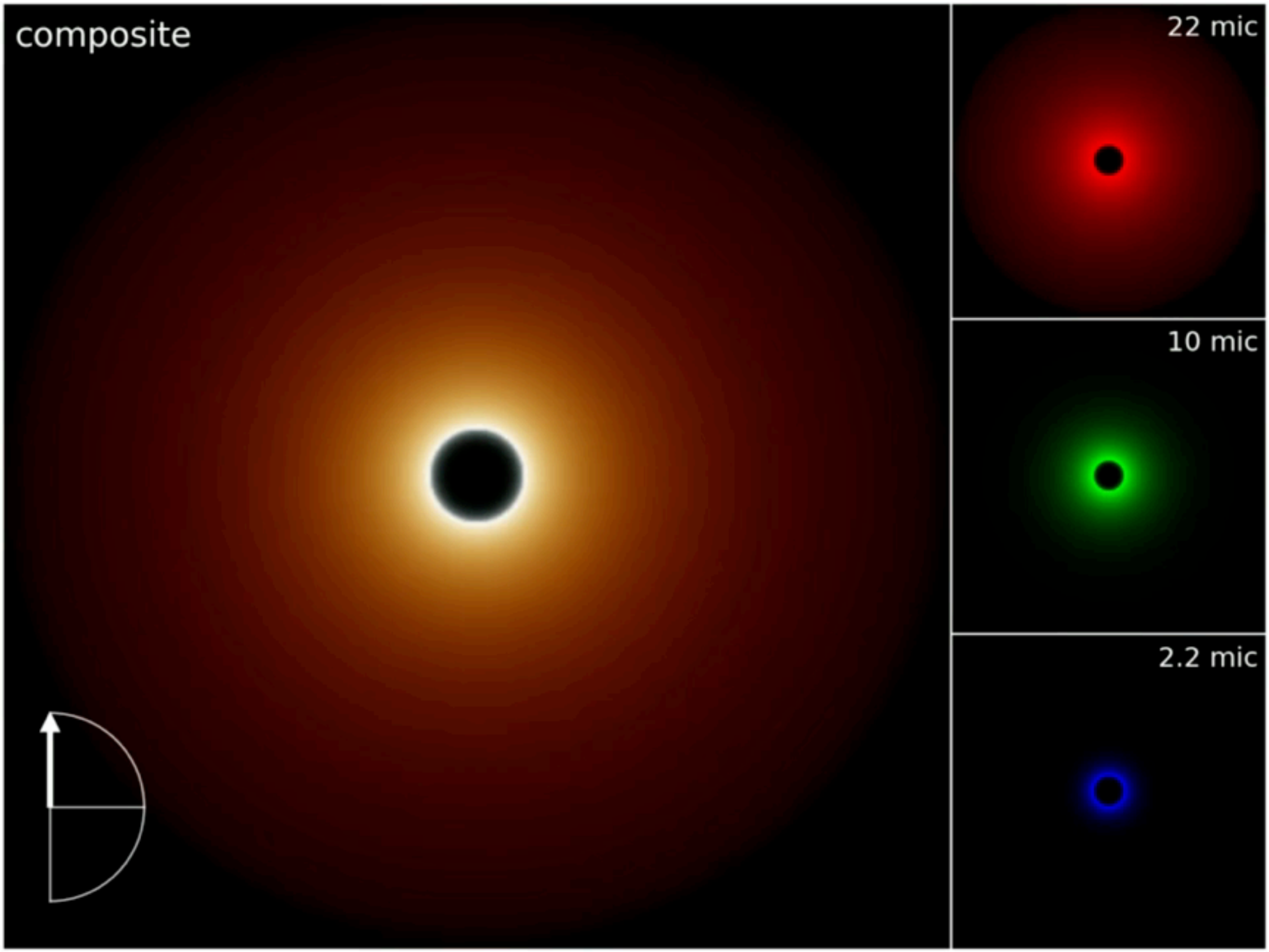
ACTIVE GALACTIC NUCLEI: THE DUSTY TORUS



THE DUSTY TORUS OF AGN: TORUS MORPHOLOGY



THE DUSTY TORUS OF AGN: TORUS EMISSION



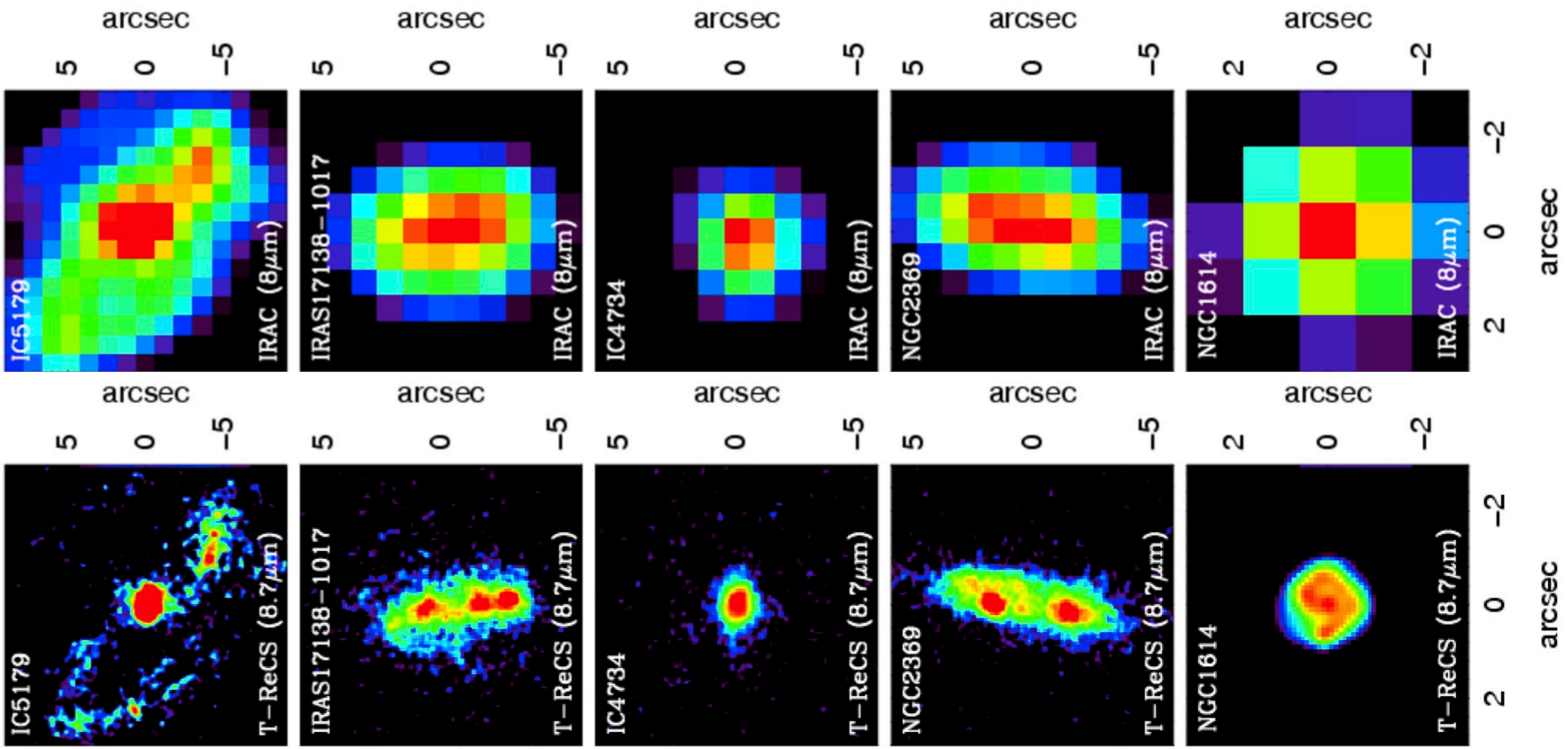
Torus models using CLUMPY (Nenkova et al. 2002, 2008a,b)

CLUMPY TORUS SED

- Optically and geometrically thick, clumpy and dusty torus
- Scales of few parsecs
- We need to isolate the torus from:
  - Host galaxy, diffuse extended dust emission, star formation

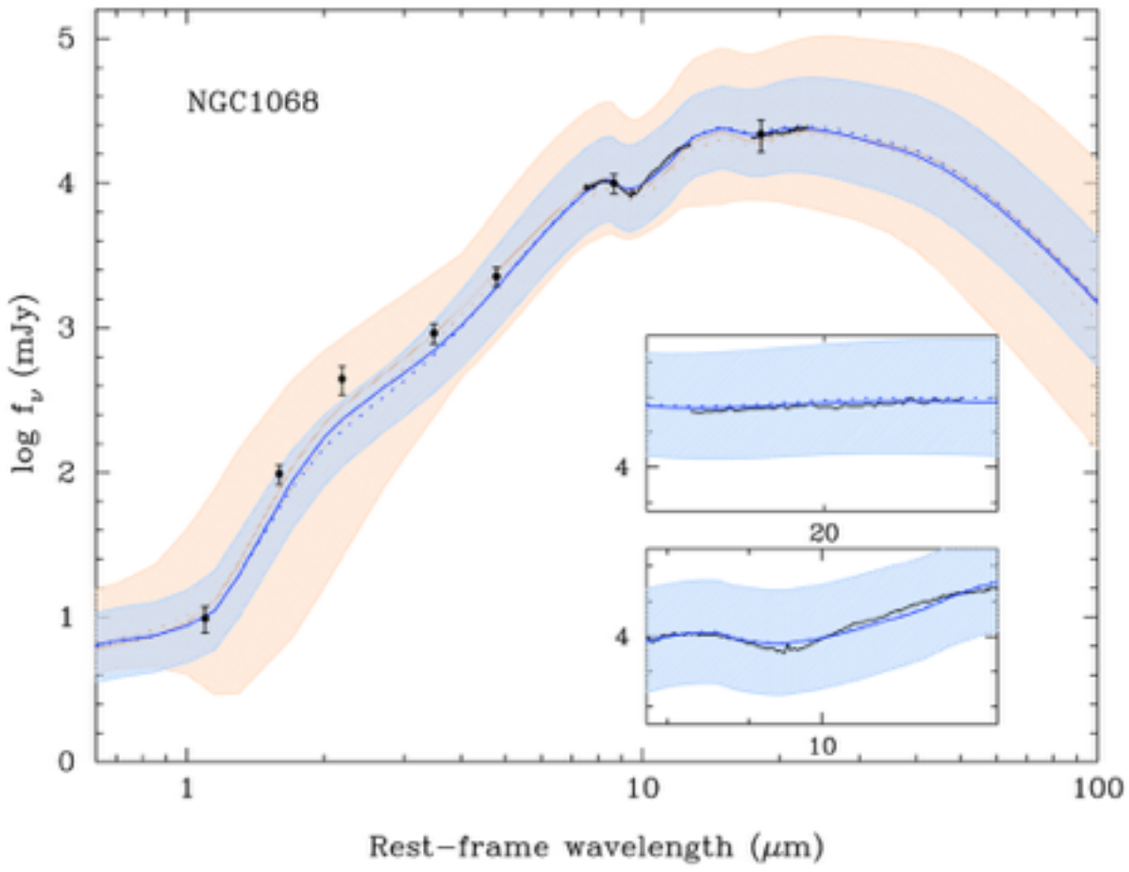
CLUMPY TORUS SED

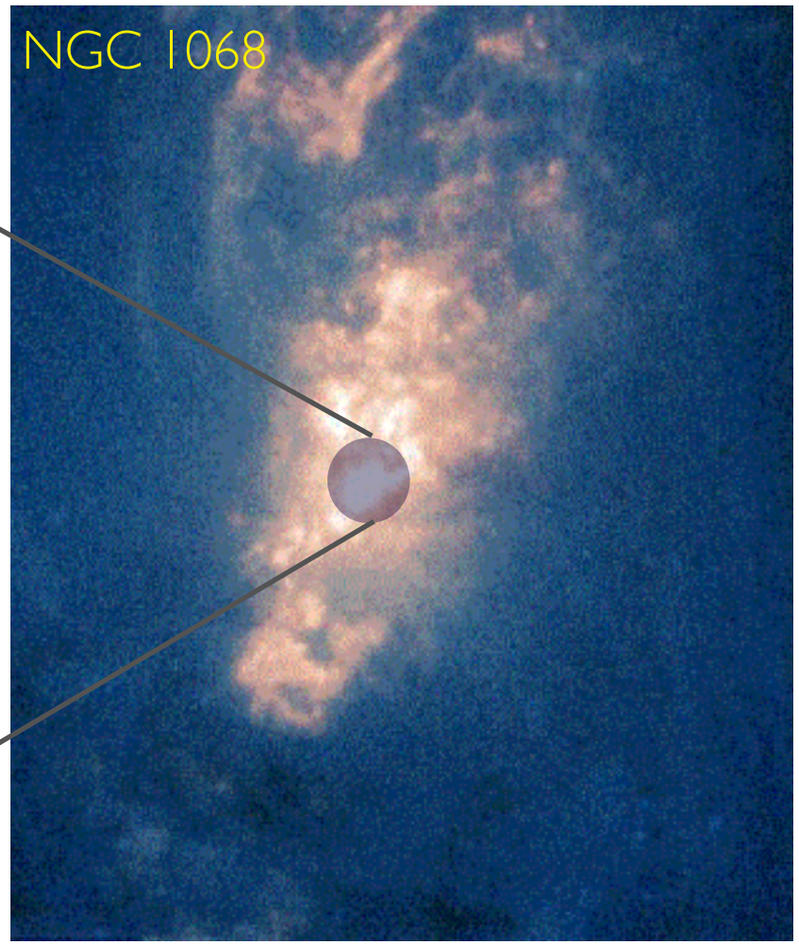
- Optically and geometrically thick, clumpy and dusty torus
- Scales of few parsecs
- We need to isolate the torus from:
  - Host galaxy, diffuse extended dust emission, star formation



CLUMPY TORUS SED

- The isolated emission from the nucleus using 10-m class telescopes can be reproduced using clumpy torus models.





Alonso-Herrero et al. (2011)

Torus models using CLUMPY (Nenkova et al. 2002, 2008a,b)

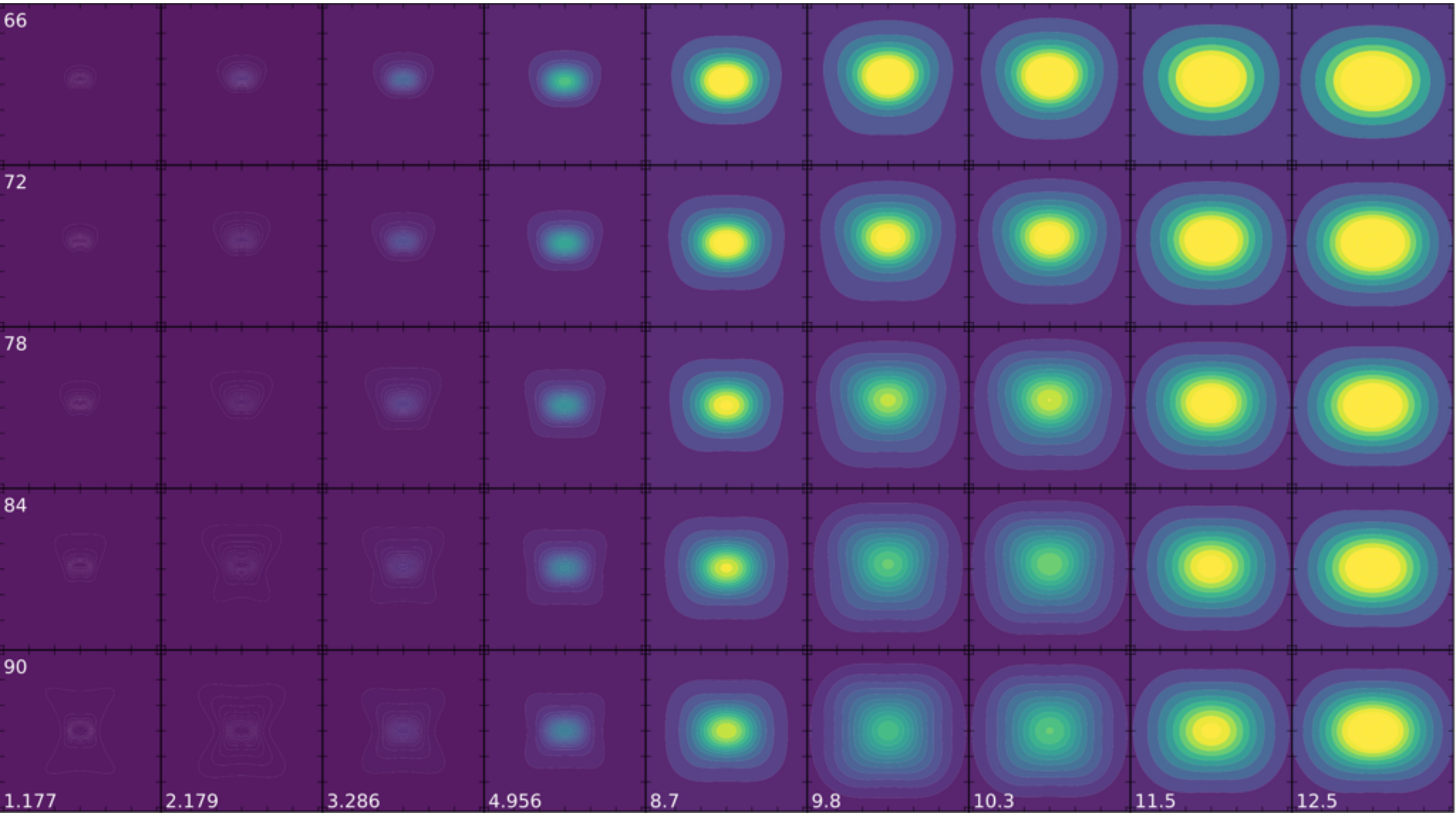
The dusty torus is investigated through two different approaches:

1) THE MORPHOLOGY AND COMPOSITION OF THE DUSTY TORUS THROUGH DIRECT IMAGING AND SPECTROSCOPY

2) THE TORUS AS A MHD DUSTY WIND: ORIGIN AND EVOLUTION OF THE DUSTY TORUS

DUSTY TORUS IS RESOLVED USING 30-M CLASS TELESCOPES

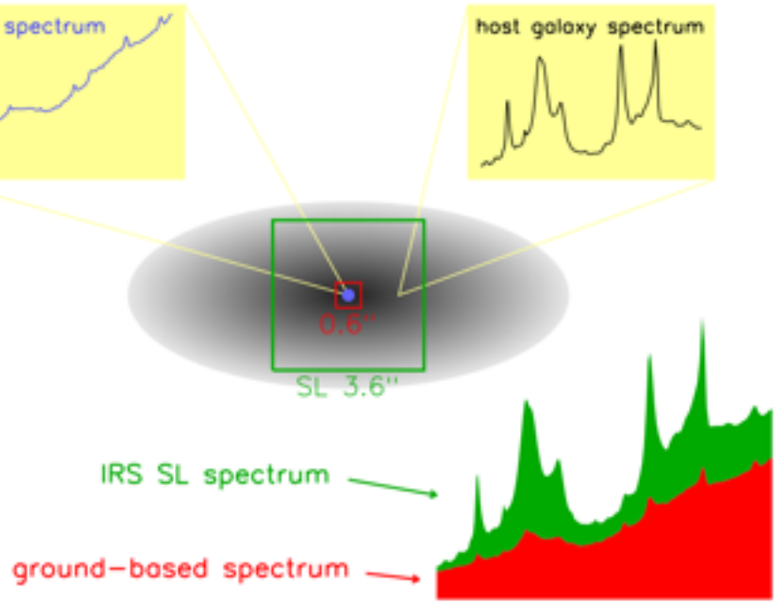
- CLUMPY torus model outputs at IR wavelengths
- Models were convoluted with the PSF of a 30-m class telescope.

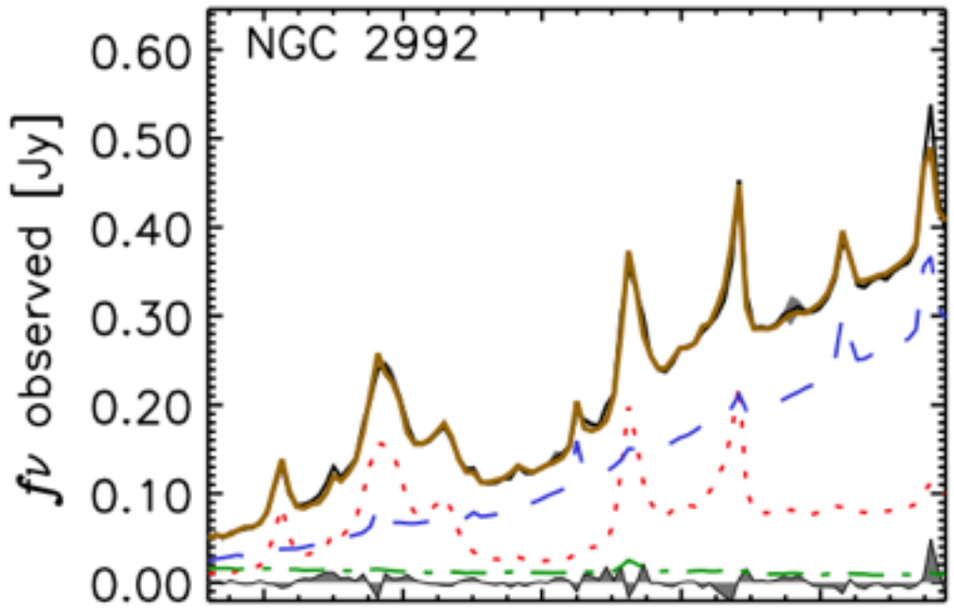


Lopez-Rodriguez, Ichikawa & Nikutta

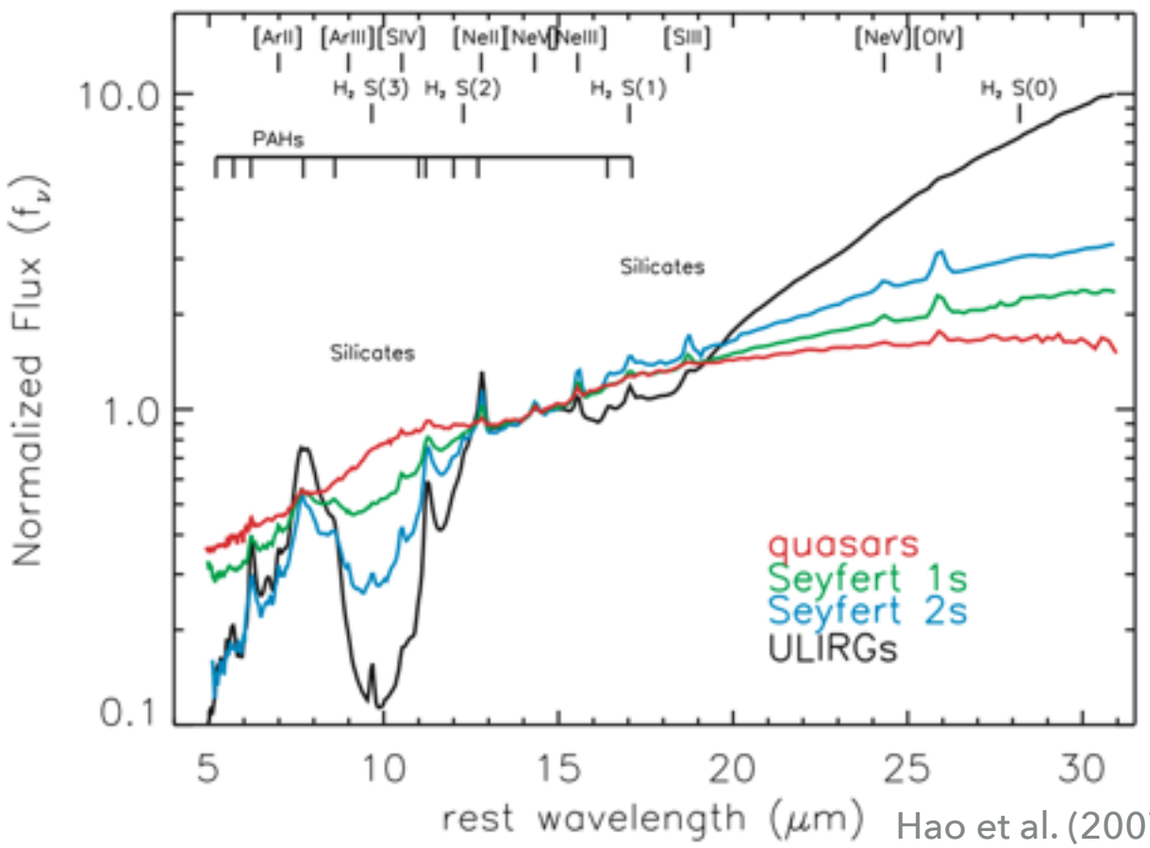
DUSTY TORUS CAN BE ISOLATED AND ITS COMPOSITION STUDIED

- Spitzer and ground-based spectroscopy are contaminated by host galaxy, extended diffuse dust emission, star formation regions





Hernan-Caballero et al. (2015)



Hao et al. (2007)

INSTRUMENTAL REQUIREMENTS

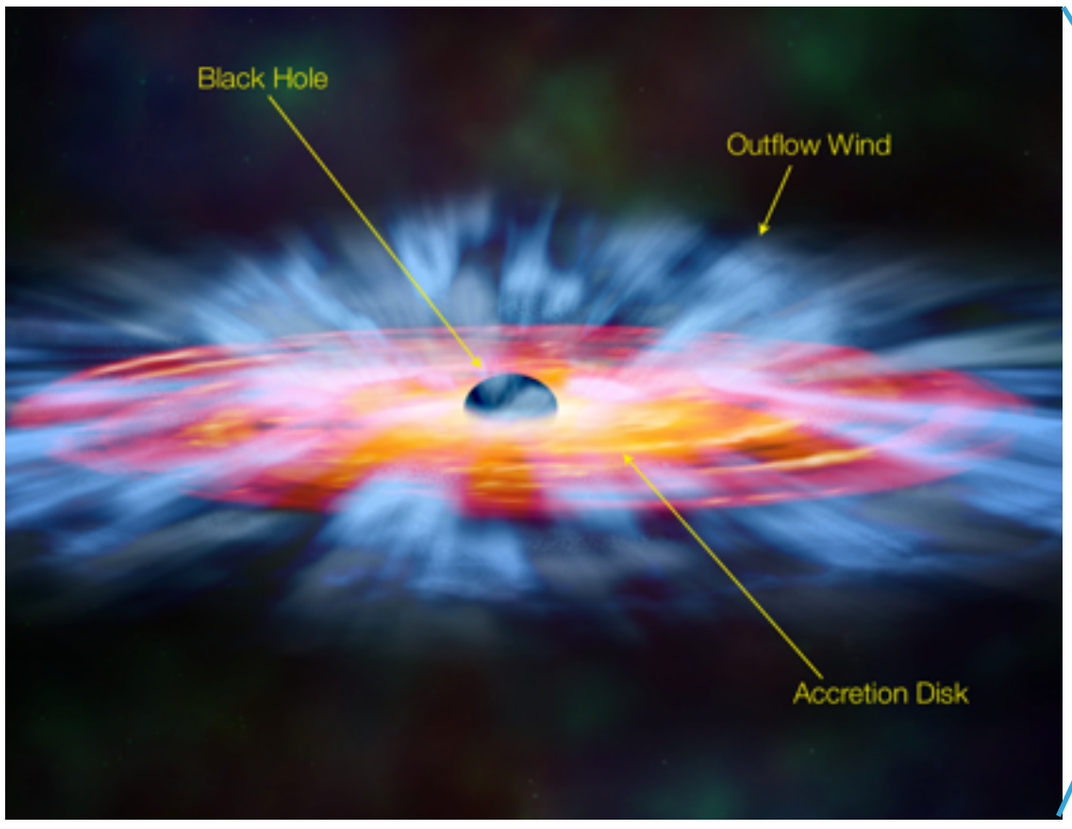
- 1-13 um imaging and spectroscopic modes
- High-strehl (>80%) diffraction-limited resolution observations, AO is necessary
- Imaging sensitivities <1 mJy, spectroscopic sensitivity ~1 mJy
  - 5-sigma, 1hr on-source
- Spectral resolution R~100-600
- Dry place with low PWV.
- Sample selection: flux-limited, nearby (<200 Mpc) and well-studied, sample of ~40 AGN

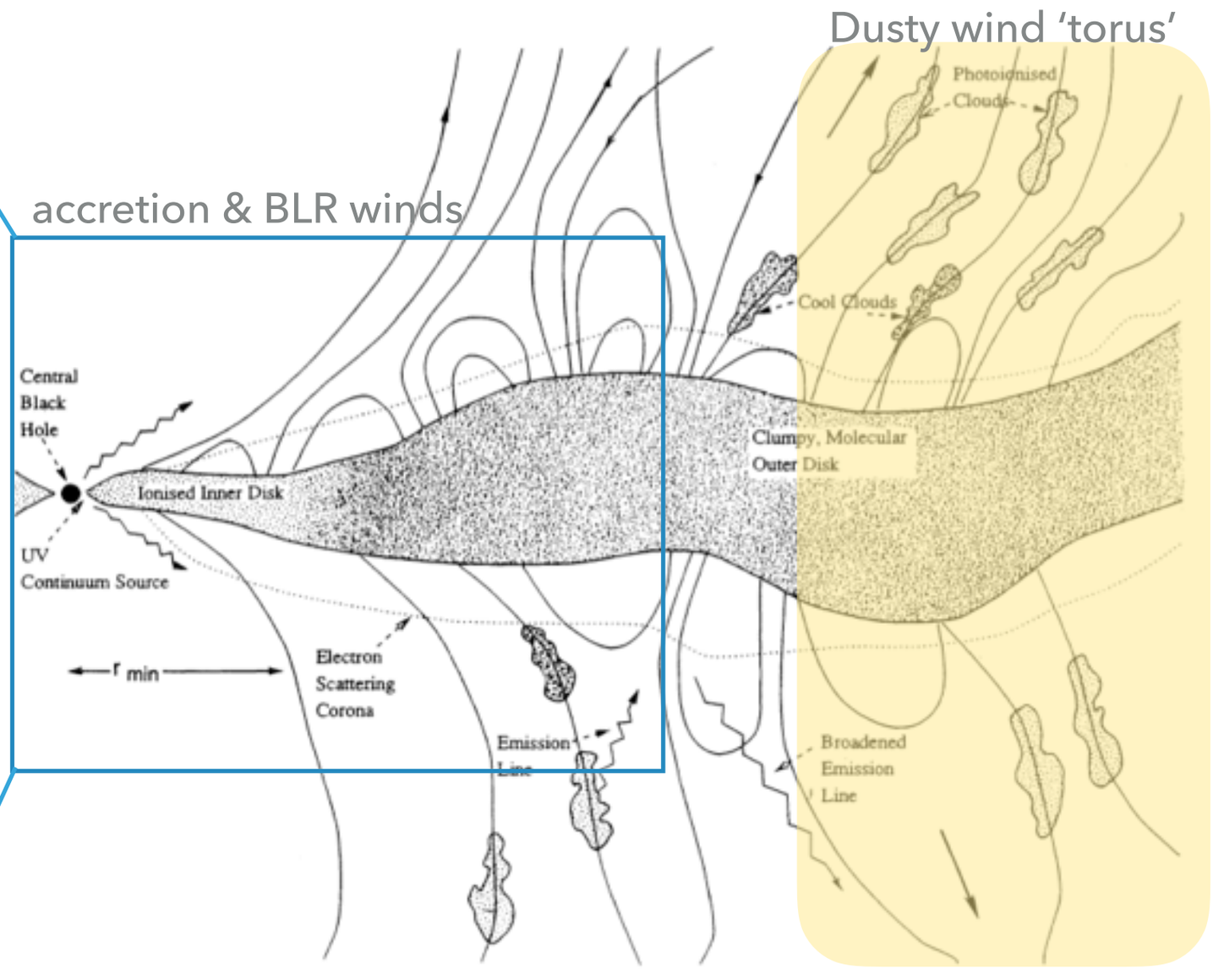
- First generation instruments:
  - IRIS can be used to study the hot-dust of the torus in the 1-3 um wavelength range.

- Second generation instruments:
  - MICHI, at LMN bands, is crucial to achieve the goals of this project.

THE DUSTY ENVIRONMENT OF NGC 1068 AS A DUSTY WIND

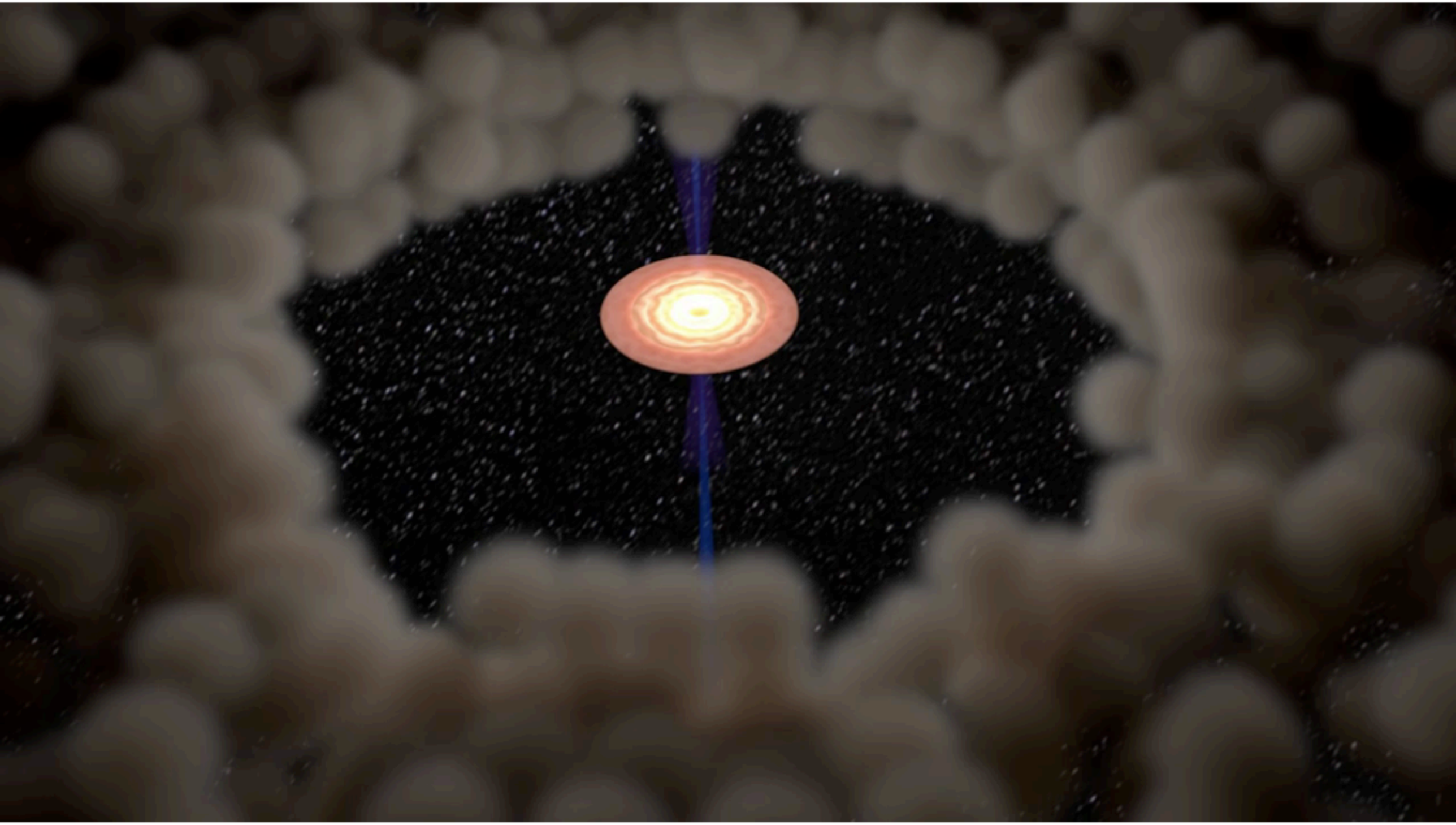
From a MHD framework: the obscuring dusty environment is a particular region of a dusty wind, where optically thick and dusty clouds are formed.





Emmering et al. (1992)

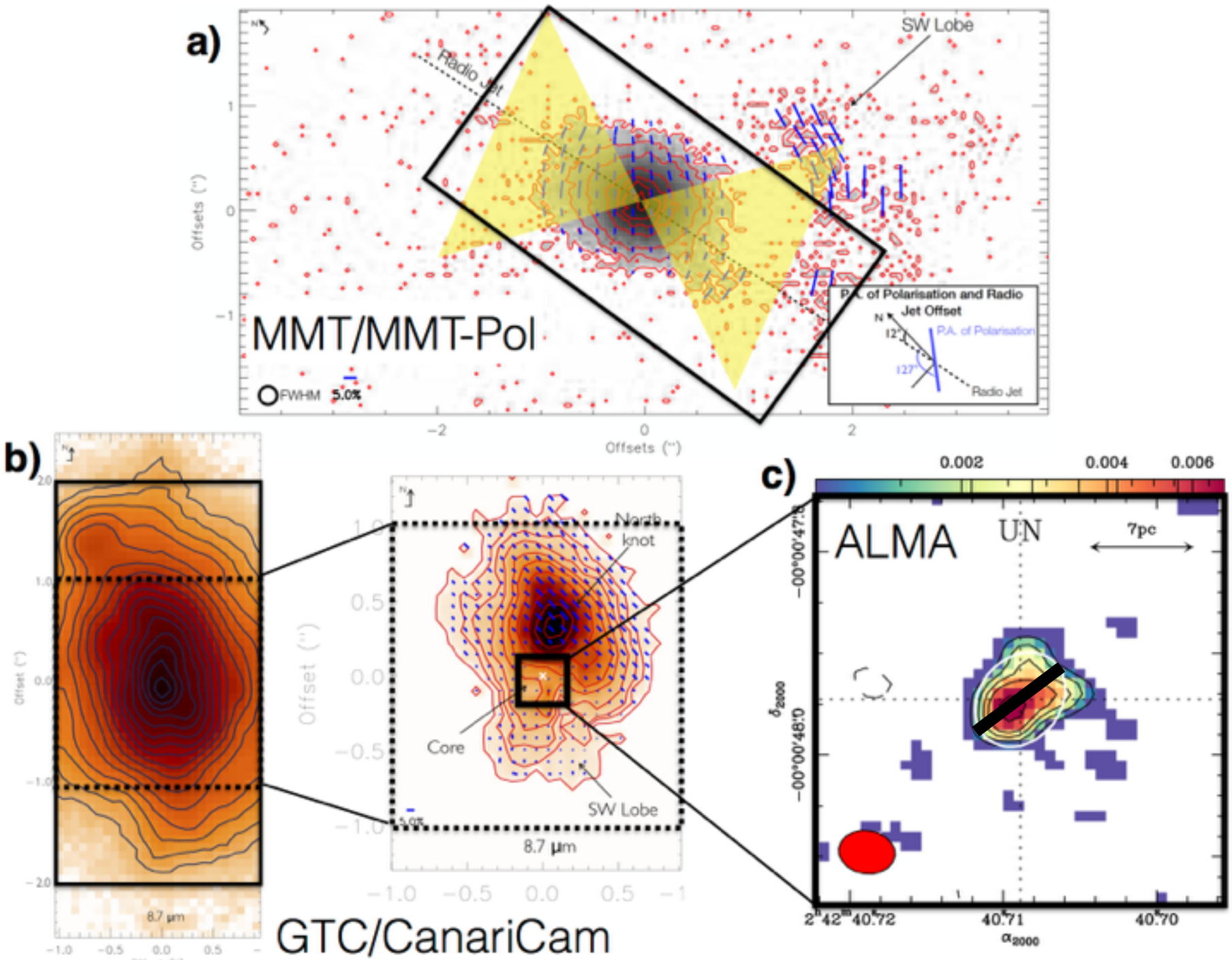
THE DUSTY TORUS OF AGN: DUSTY WINDS



Credit: Stalevski, M.

ALMA resolved the dusty torus of NGC 1068 (Garcia-Burillo et al. 2016)

Our P.A. of polarization is spatially coincident with the long-axis of the torus into the plane of the sky.



Lopez-Rodriguez et al. (2015,2016b), Garcia-Burillo et al. (2016)

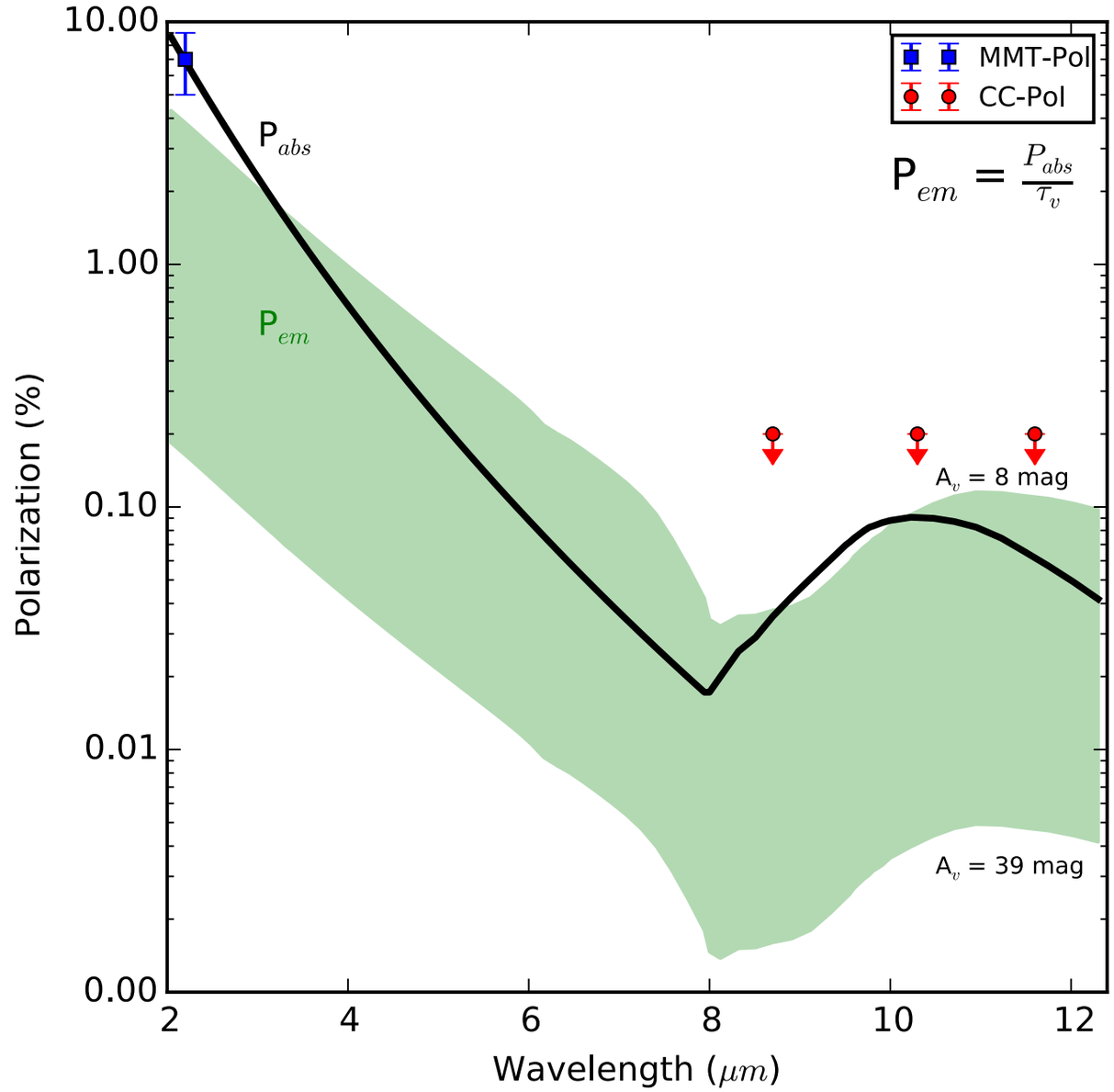
NGC1068 POLARIZATION: A POLARIZED CORE DOMINATED BY DICHROISM

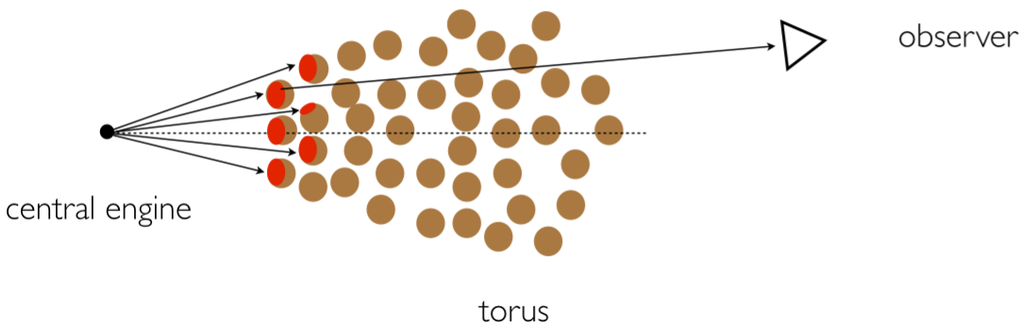
At 2.2 um:

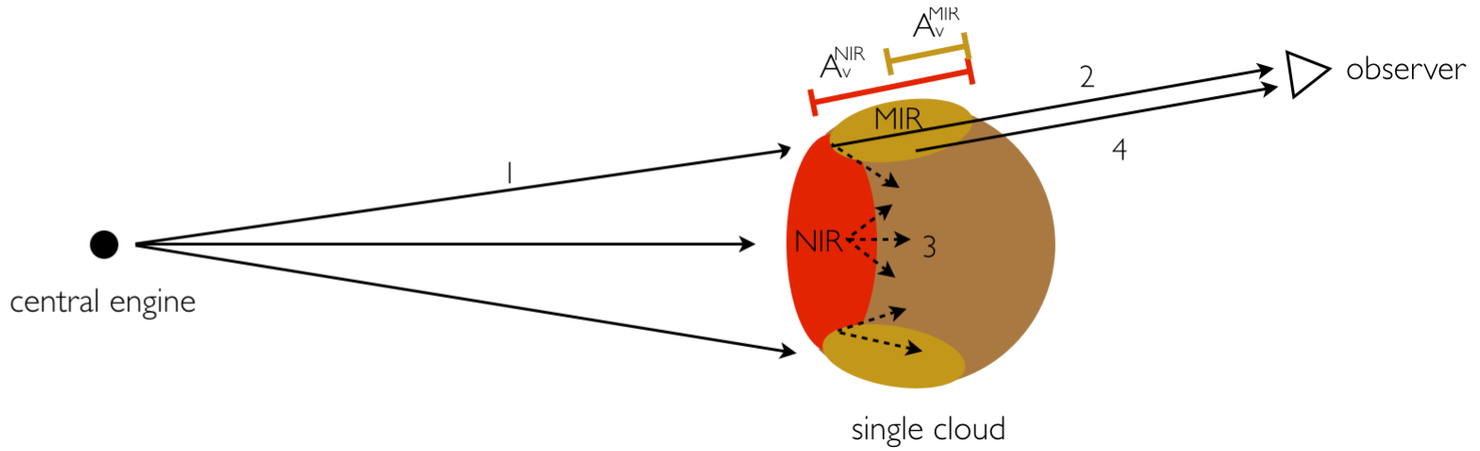
- Polarization arises from magnetically aligned dust grains located in the inner edge of the torus.

In the 10 um window:

- Expected polarization is ~0.1% for silicate-type dust grains
- Dust grains located at the lower-density outer-layers of the clumps with A_v > 8 mag



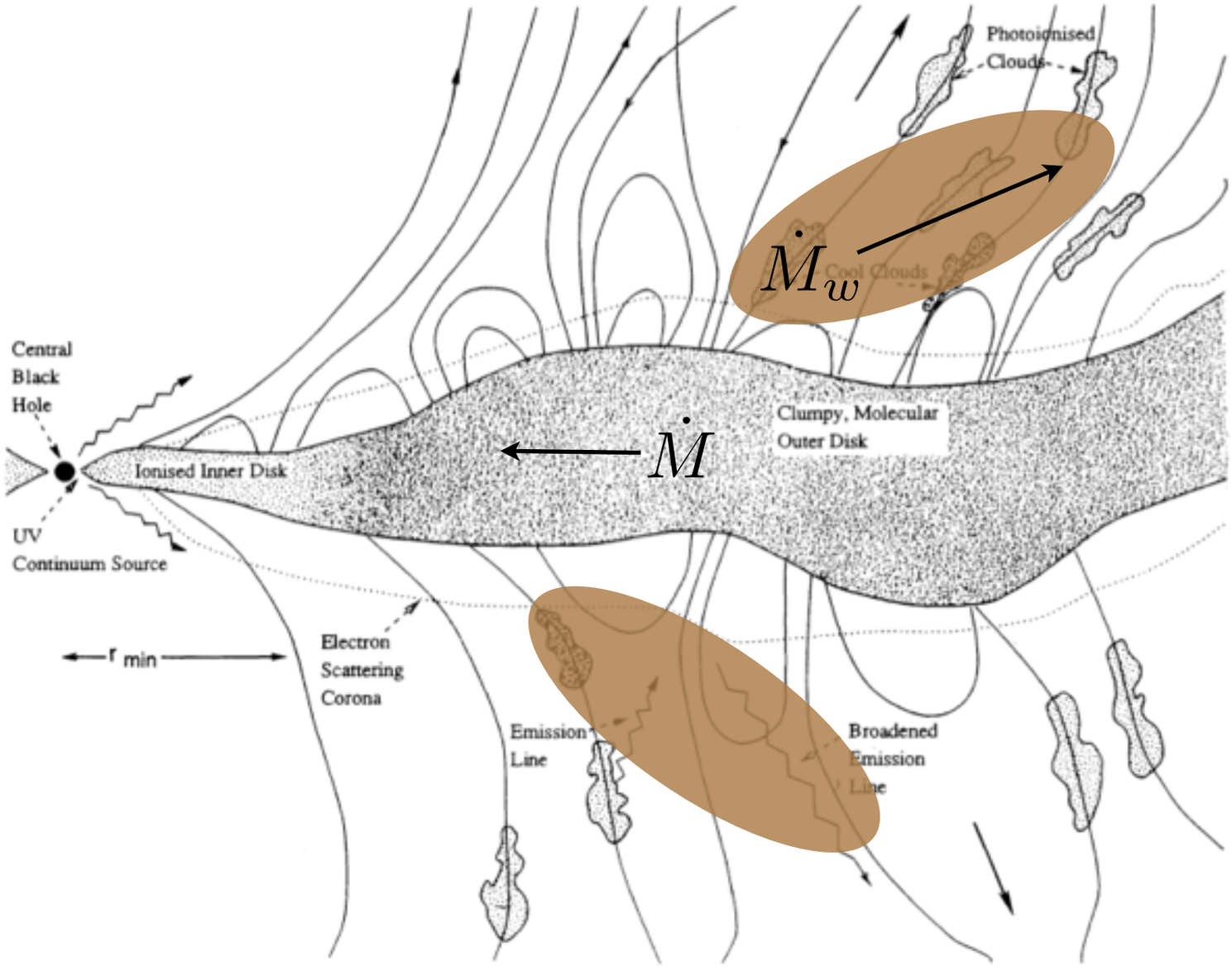




Lopez-Rodriguez et al. (2016b)

Dusty Wind

- We characterized the magnetic field strength and geometry using IR (1-13 um) polarimetric observations.
- These results are then used in simple analytical solutions of the MHD wind model to obtain:
  - 1) the *mass accretion inflow and outflow* for those clumps showing dichroic polarization
  - 2) *timescales* of the *creation and evolution* of the dusty environment in NGC 1068.
  - 3) the *rotational velocities* of the clumps.



Mass inflow rate at 0.4 pc:

$$\dot{M} = 0.18\ M_\odot\ yr^{-1}$$

Mass outflow rate at 0.4 pc:

$$\dot{M}_w \leq 0.17\ M_\odot\ yr^{-1}$$

Mass of the torus:

$$M_{torus} = 6.73^{+1.08}_{-1.74} \times 10^4\ M_\odot$$

Timescale to create the torus:

$$t_w = M_{torus}/\dot{M}_w \geq 10^5 yr$$

Rotational velocity of the clumps:

$$\leq 1228\ km\ s^{-1}$$

Lopez-Rodriguez et al. (2015)

INSTRUMENTAL REQUIREMENTS

Polarization is a vector quantity rather than a scalar quantity:

- High-spatial resolution is needed: Well, we will have a 30-m telescope!
- Wide-wavelength range is crucial: MICHI can offer a 3-13 um wavelength coverage.

- 3-13 um imaging and spectroscopic **polarimetric** models
- High-strehl (>80%) diffraction-limited resolution observations
- Imaging sensitivities <1 mJy, spectroscopic sensitivity ~1 mJy
  - 5-sigma, 1hr on-source
- Spectral resolution R~100-600
- Sample selection: flux-limited, nearby and well-studied in imaging and spectroscopy, sample of ~20 AGN

- Second generation instruments:
  - MICHI with LMN bands in polarimetric mode will open a new window of scientific discoveries.
    - Not only in AGN but also in dust composition, supernovae, molecular clouds, atmospheres in exoplanets, magnetic fields in galaxies, molecular clouds, YSO, ...


Thank you