The Obscuring Dusty Structure of Active Galactic Nuclei as a Hydromagnetic Outflow Wind:

Mining their evolutionary history using a multi-wavelength polarimetric analysis

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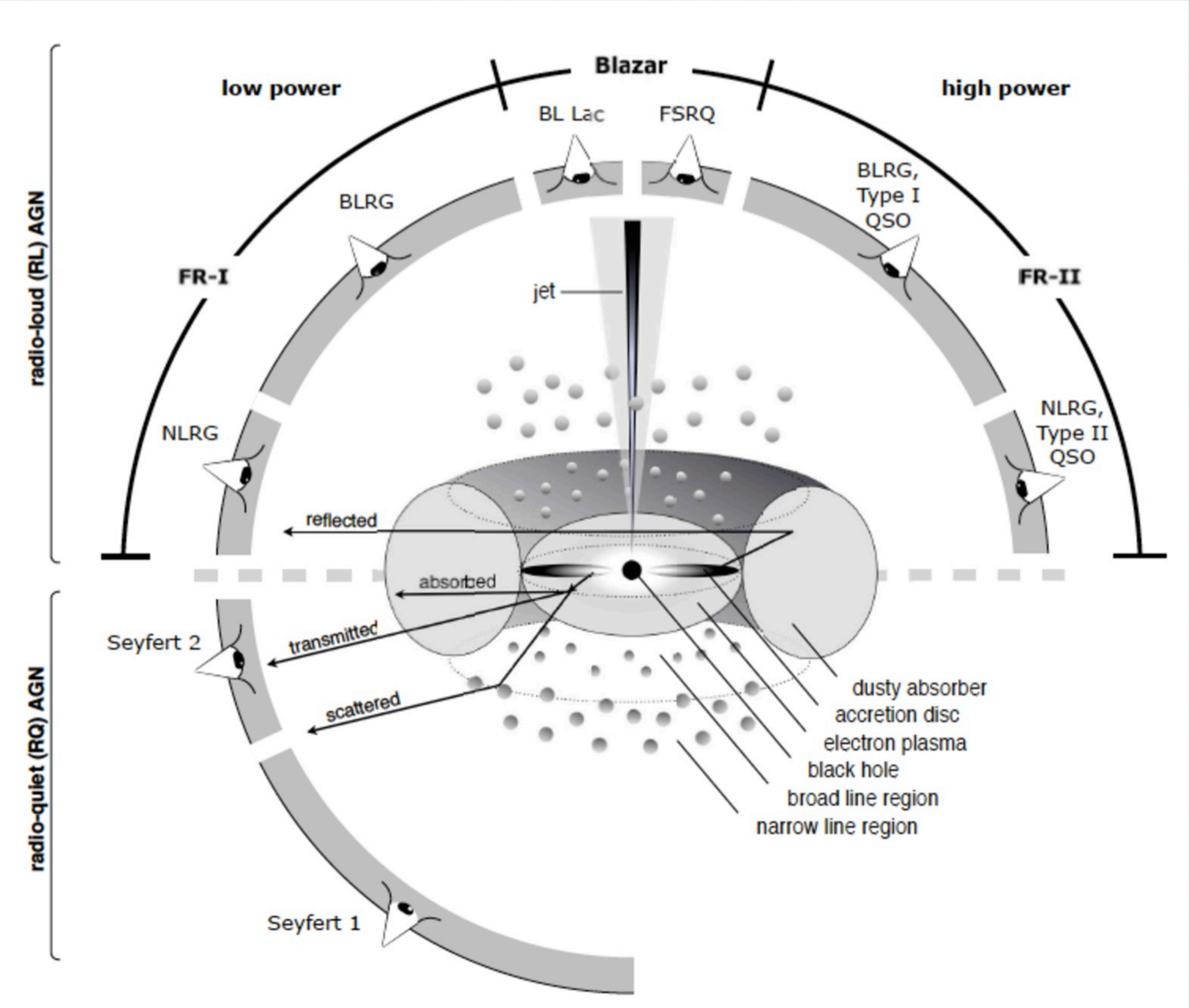
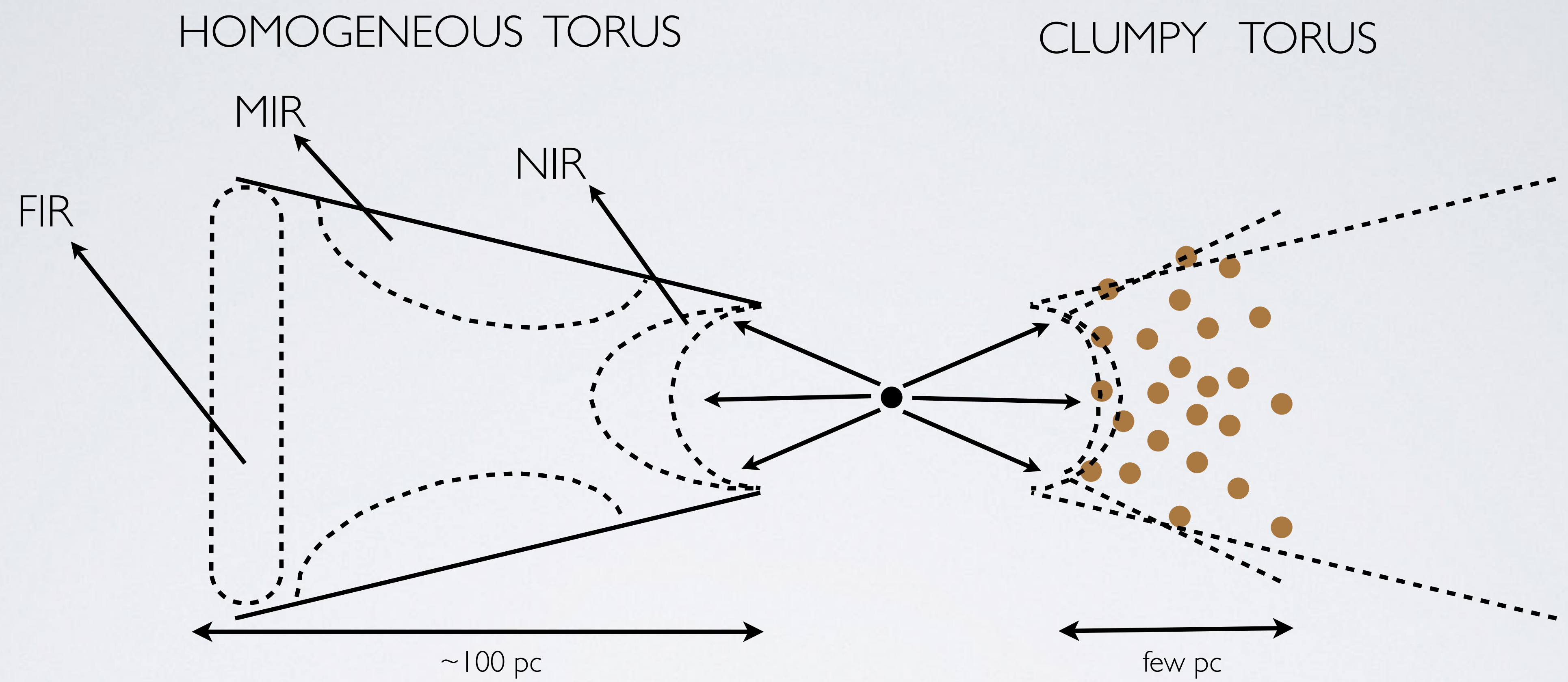
Active Galactic Nuclei



Beckman & Shrader (2012)

AGN Torus



Homogeneous

Homogeneous distribution of dust

~100 pc to reproduce wide apertures (>1") in MIR and FIR

Clumpy

Optically thick dusty clouds

~pc consistent with high-spatial resolution Near- and Mid-IR

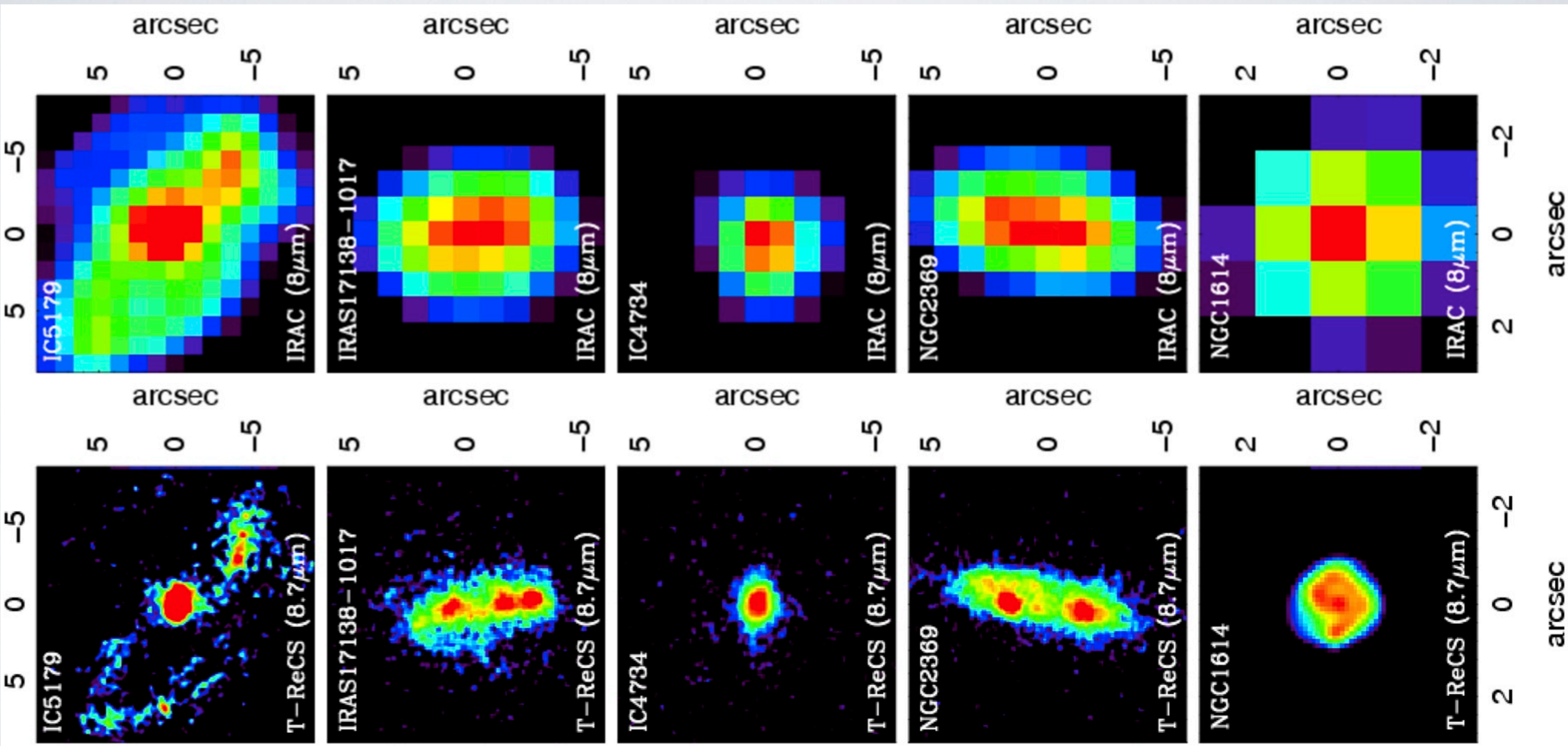
AGN Torus

Optically and geometrically thick, clumpy and dusty torus Nenkova et al. (2002,2008a,b)

Scales of a few parsecs Packham et al. (2002), Jaffe et al. (2004), Tristram et al. (2007), etc.

Isolate the torus from:
- Host galaxy
- Surrounding star formation

→ high-spatial resolution observations



Diaz-Santos (2009)

AGN Torus

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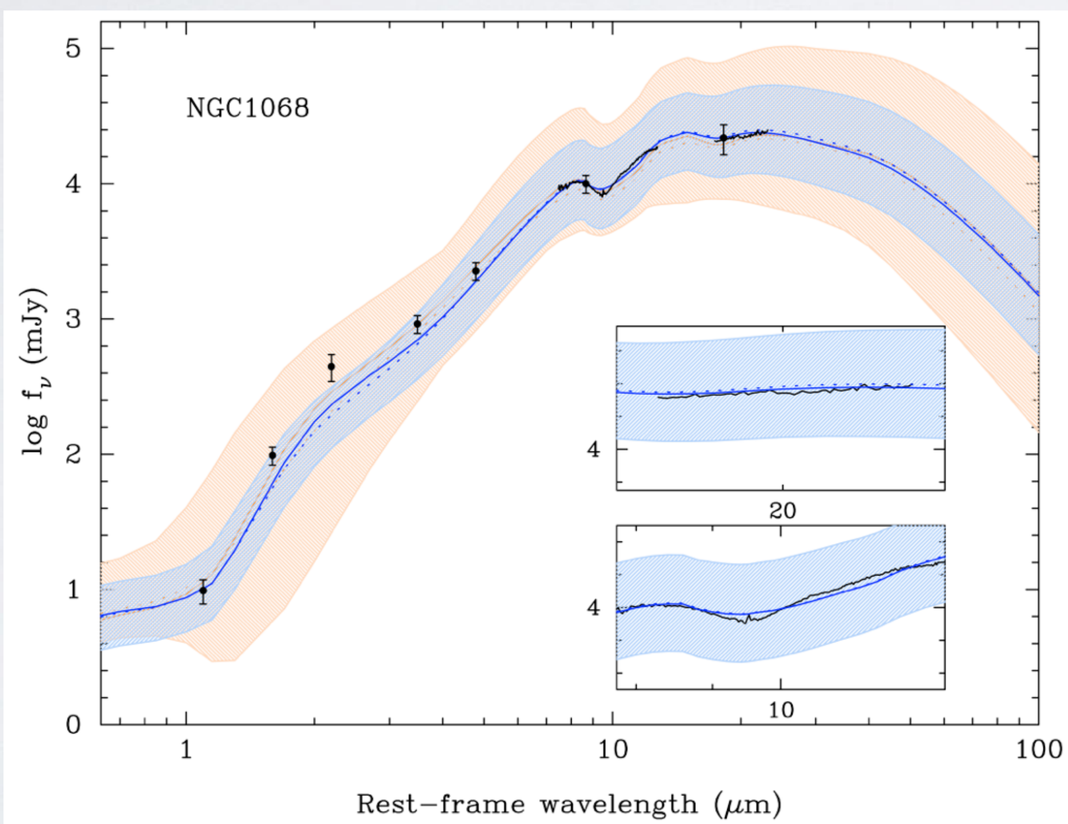
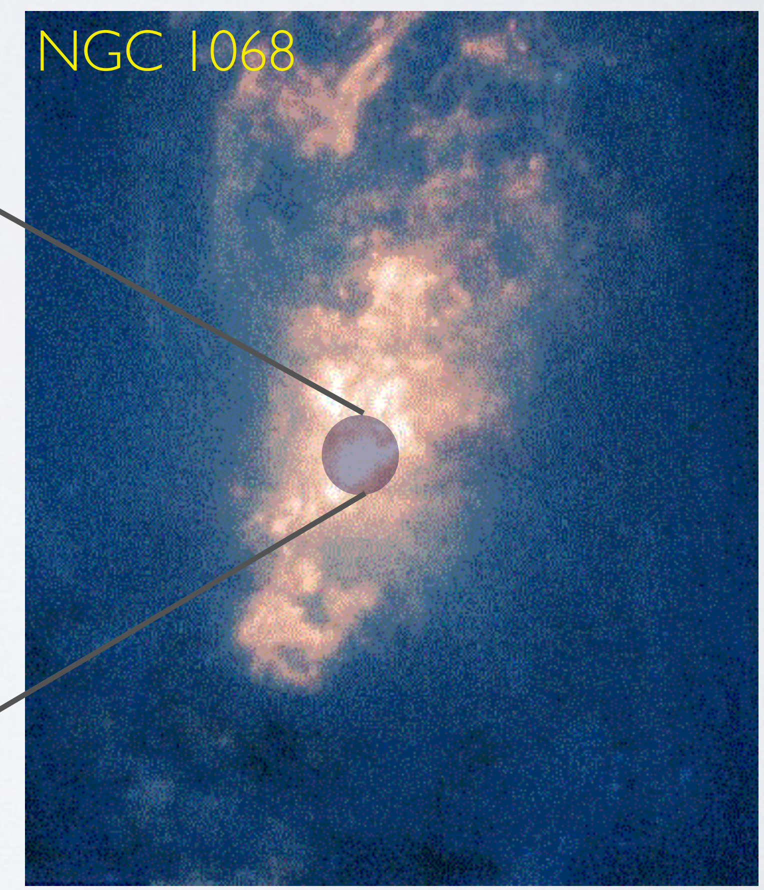


Alonso-Herrero et al. (2011)



Clumpy torus model reproduces well the observations

AGN Torus

Optically and geometrically thick, clumpy and dusty torus Nenkova et al. (2002,2008a,b)

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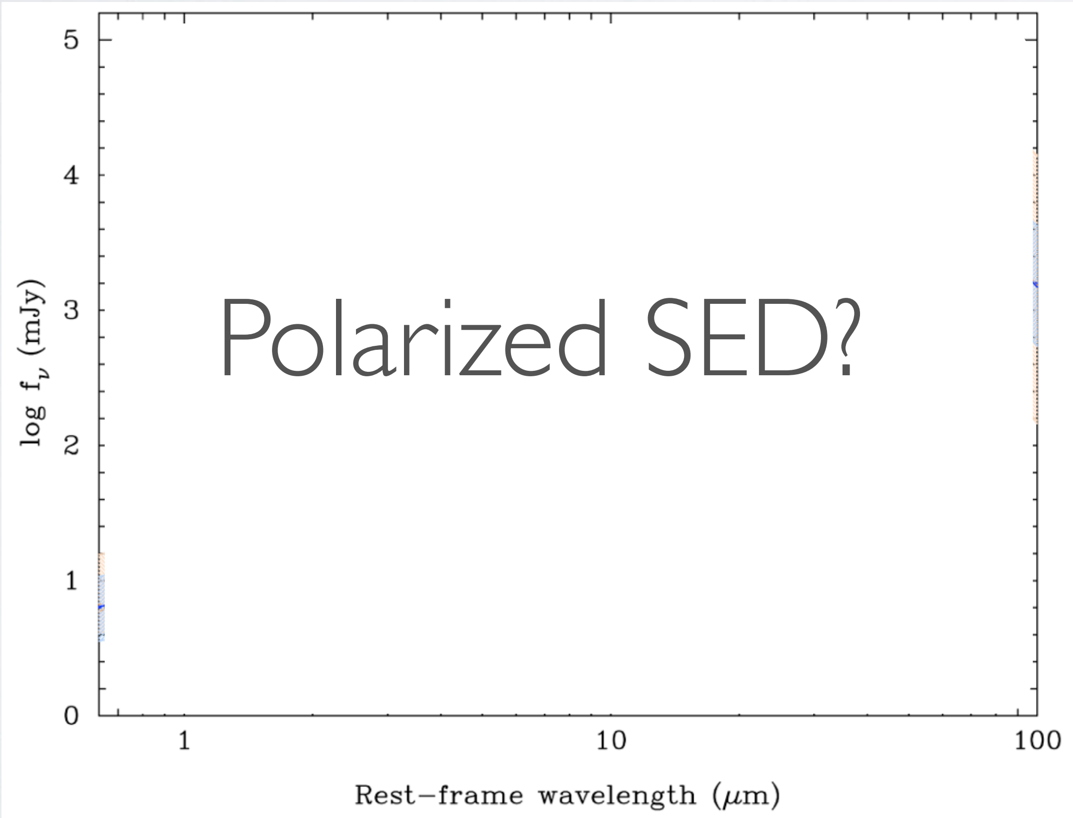
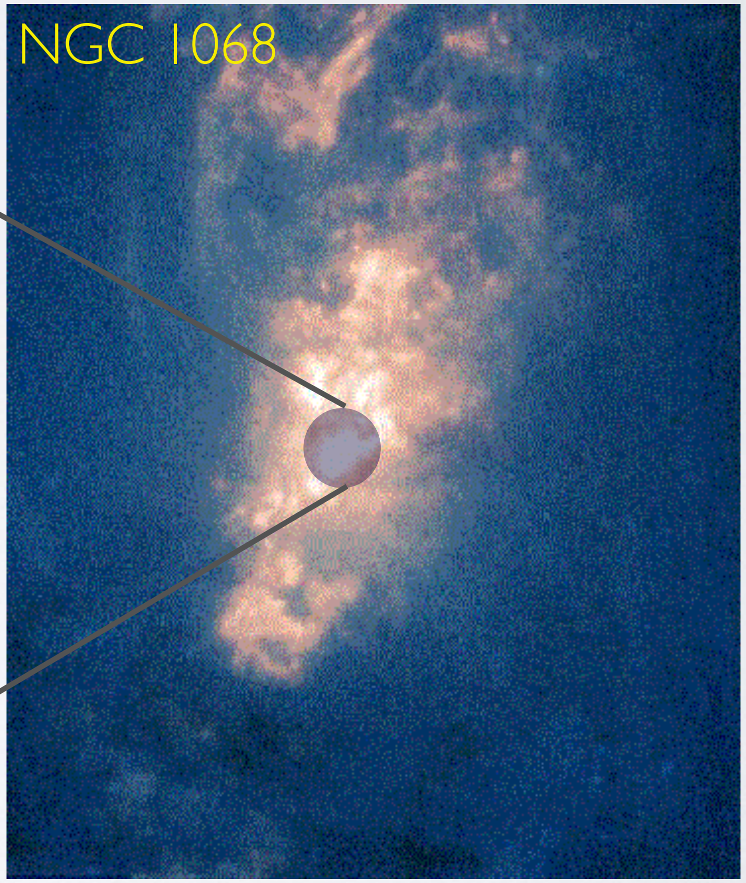
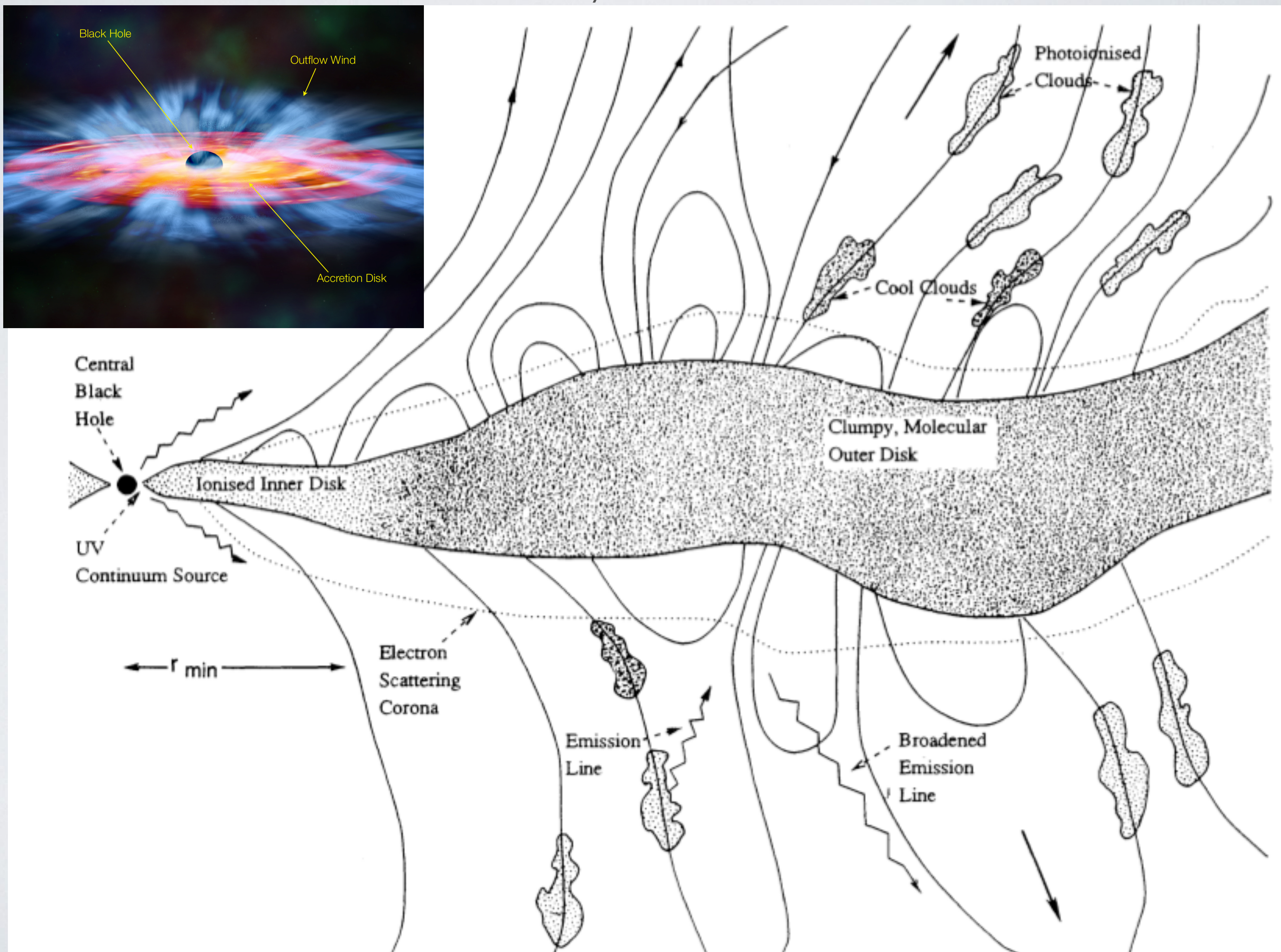




Hydromagnetic Outflow Wind

Torus is a particular region of an outflow wind, where optically thick and dusty clouds are formed

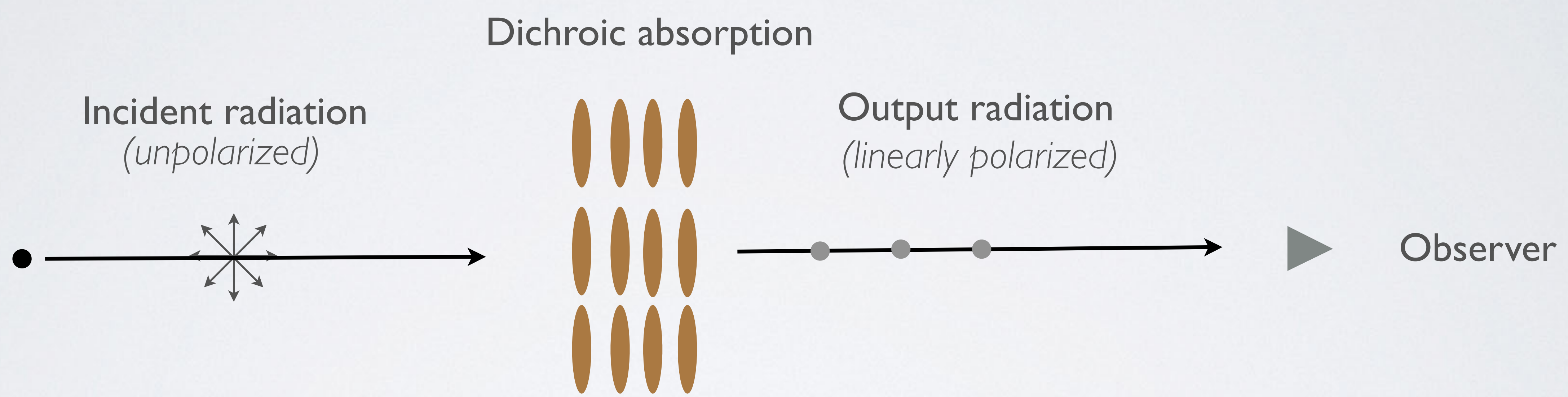


Emmering et al. (1992)

Mechanism of Polarization

Dichroism: produced by the absorption/emission of the electromagnetic wave components by dust grains

Non-spherical dust grains produce a differential level of absorption



Magnetic fields can induce a preferential orientation of dust grains

Origin of the Torus

Is the obscuring dusty structure of AGN created by a hydromagnetic outflow wind?

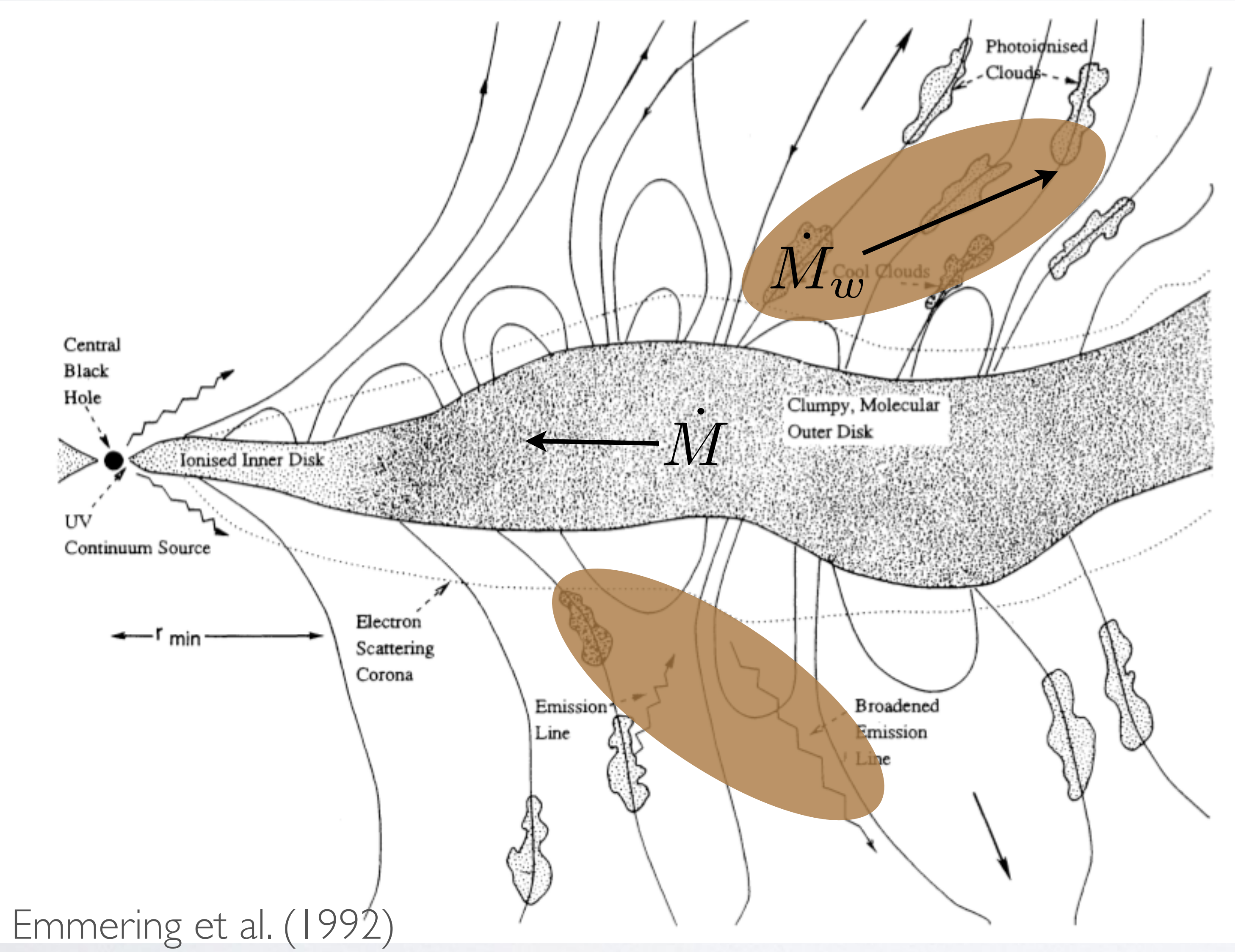
Within the magnetohydrodynamical framework,

The magnetic field can induce a preferential orientation of dust grains in the torus that can give rise to a measurable degree of polarization

a) How does the outflow wind move away from the central engine and create the torus?
b) What is the relationship of the inflow/outflow mass rates at the inner and outer edge of the torus?
c) How large is the torus under the influence of the hydromagnetic outflow wind?

Torus of NGC 1068 as a Hydromagnetic Wind

Kinematics of the clumps using the thermal and magnetic pressure equipartition in the midplane of the torus, as well as the hydromagnetic wind model by Elitzur & Schulman (2006).



Mass inflow rate at 0.4 pc:

- Only for those clumps showing dichroic absorption at 2.2 um:

$$\dot{M}_{cl} \leq 8 \times 10^{-3}\ M_{\odot}\ yr^{-1}$$

- From bolometric luminosity:

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

Mass outflow rate at 0.4 pc:

- Only for those clumps showing dichroic absorption at 2.2 um:

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

Mass of the torus of NGC 1068:

- Using Clumpy torus models: (Alonso-Herrero et al. 2011)

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

The torus can be created in a timescale of $t_w = M_{torus}/\dot{M}_w \geq 10^5 yr$

Rotational velocity of the clumps $\leq 1228\ km\ s^{-1}$

Assuming clumps in a Keplerian orbit, torus is created in ~100 Keplerian orbits

- Typical Seyfert galaxies are ~10^{10} yr old

Lopez-Rodriguez et al. (2015)

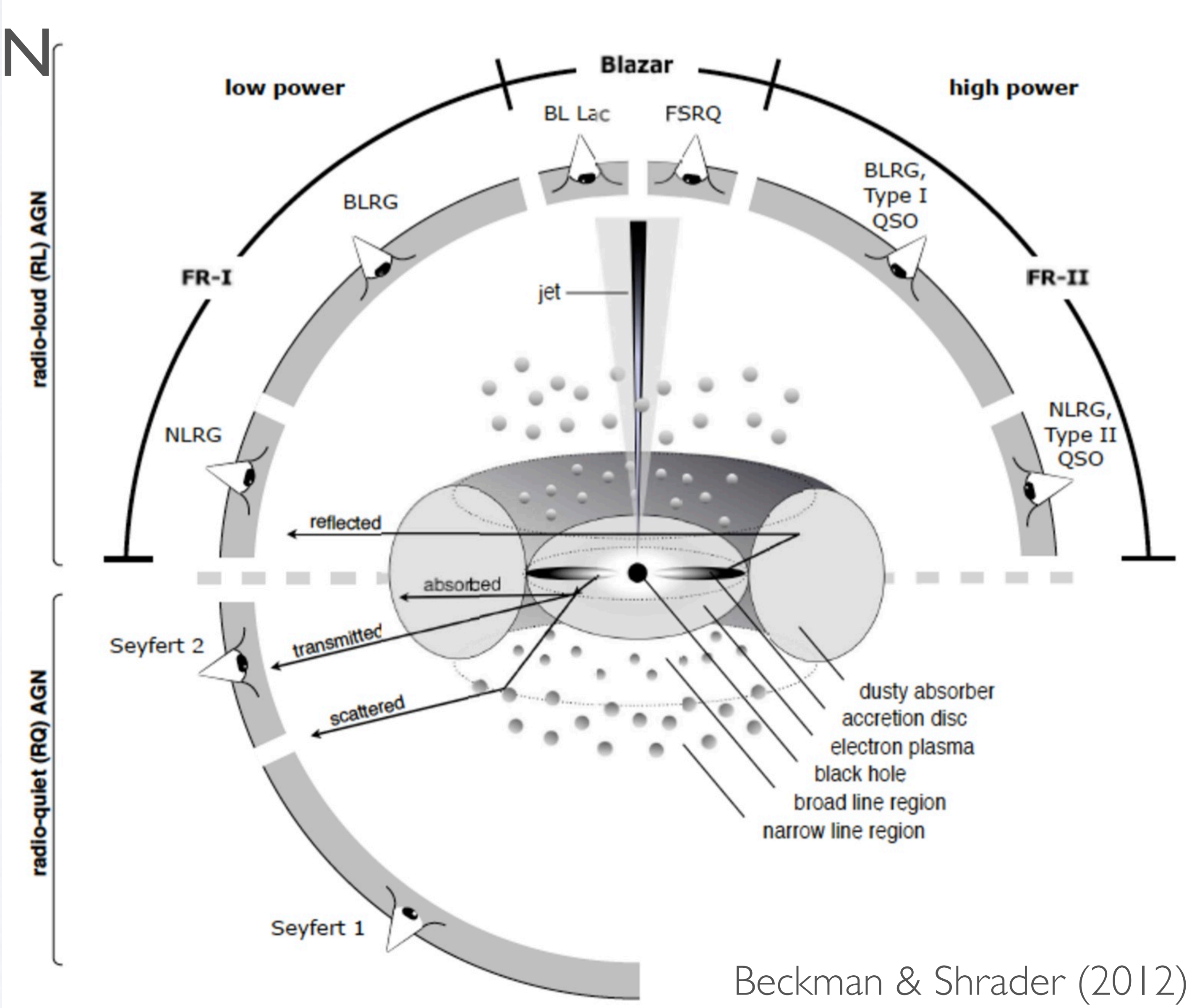
Why Polarimetry?

Polarimetry & AGN

Scattering can arise from:
- Broad emission line region
- Narrow emission line region
- Torus?

Dichroic emission/absorption can arise from:
- Aligned dust in the torus
- Aligned dust around the AGN

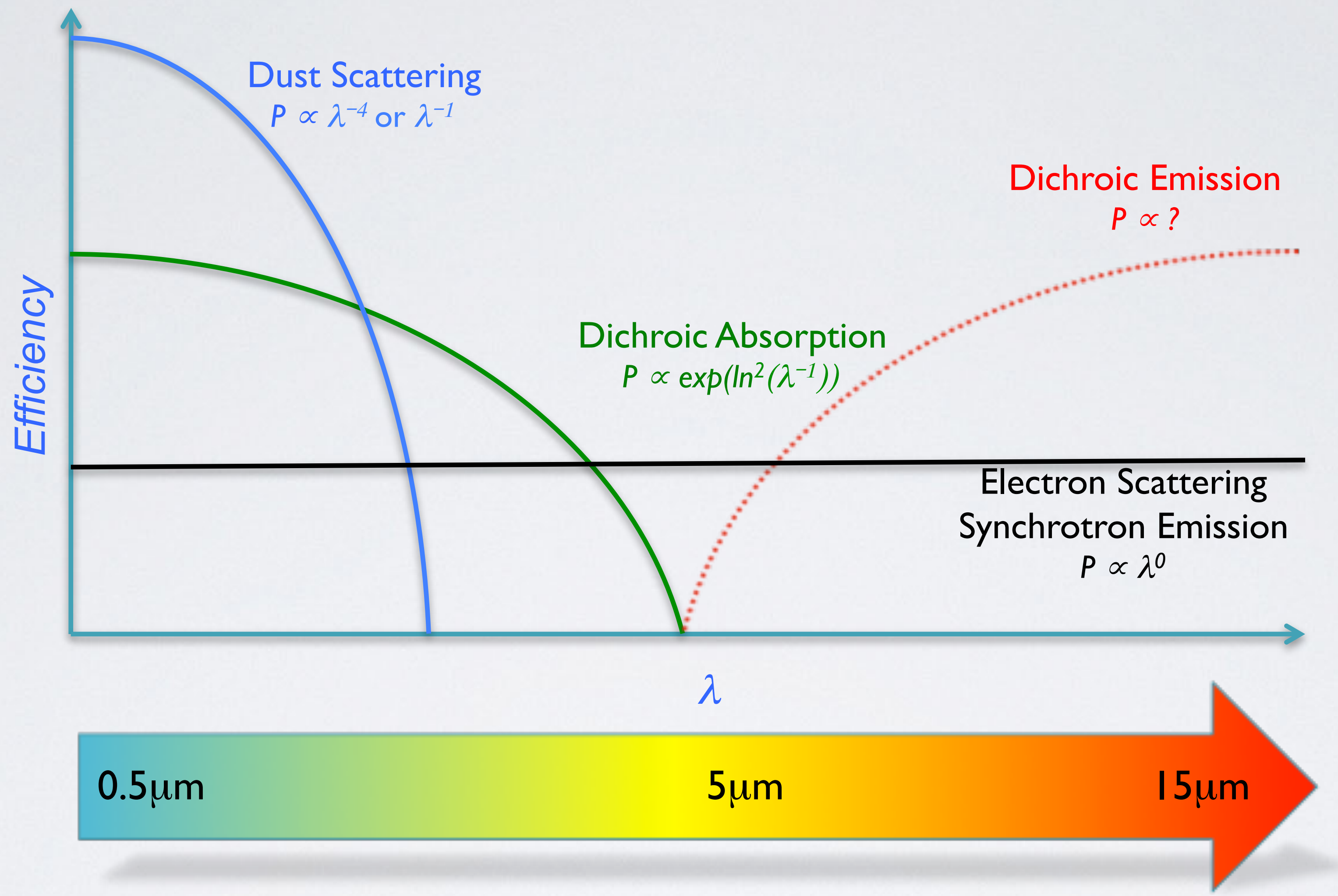
Synchrotron emission can arise from:
- Jets



Beckman & Shrader (2012)

Polarized SED

Illustrative Only

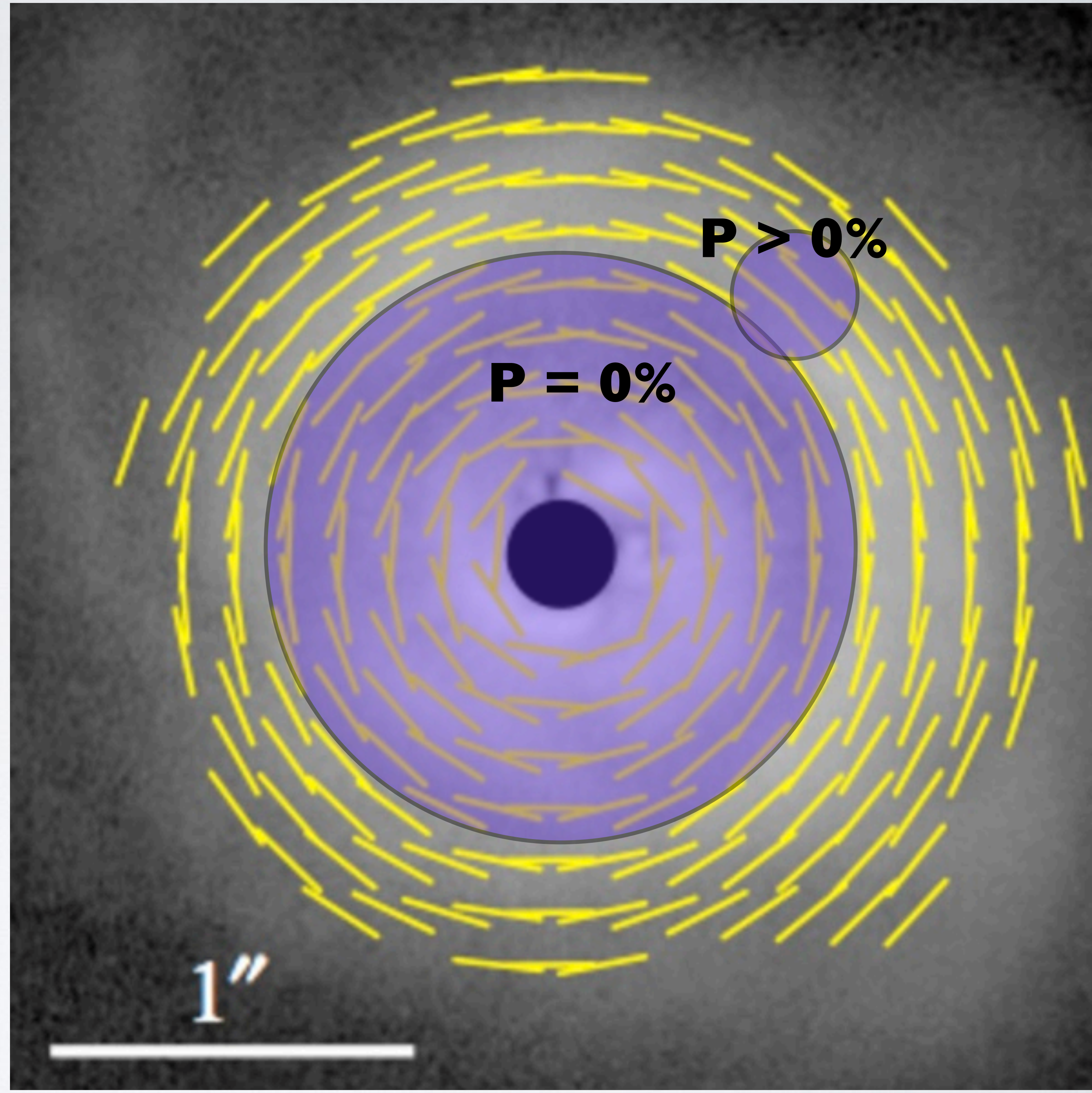


Multi-wavelength polarimetry studies are crucial to identify the mechanisms of polarization

Polarimetry & High-Spatial Resolution

Integrated polarization = 0%
- Crossed (unresolved) polarization vectors add to null (zero)

High-spatial resolution polarimetric observations
P > 0%

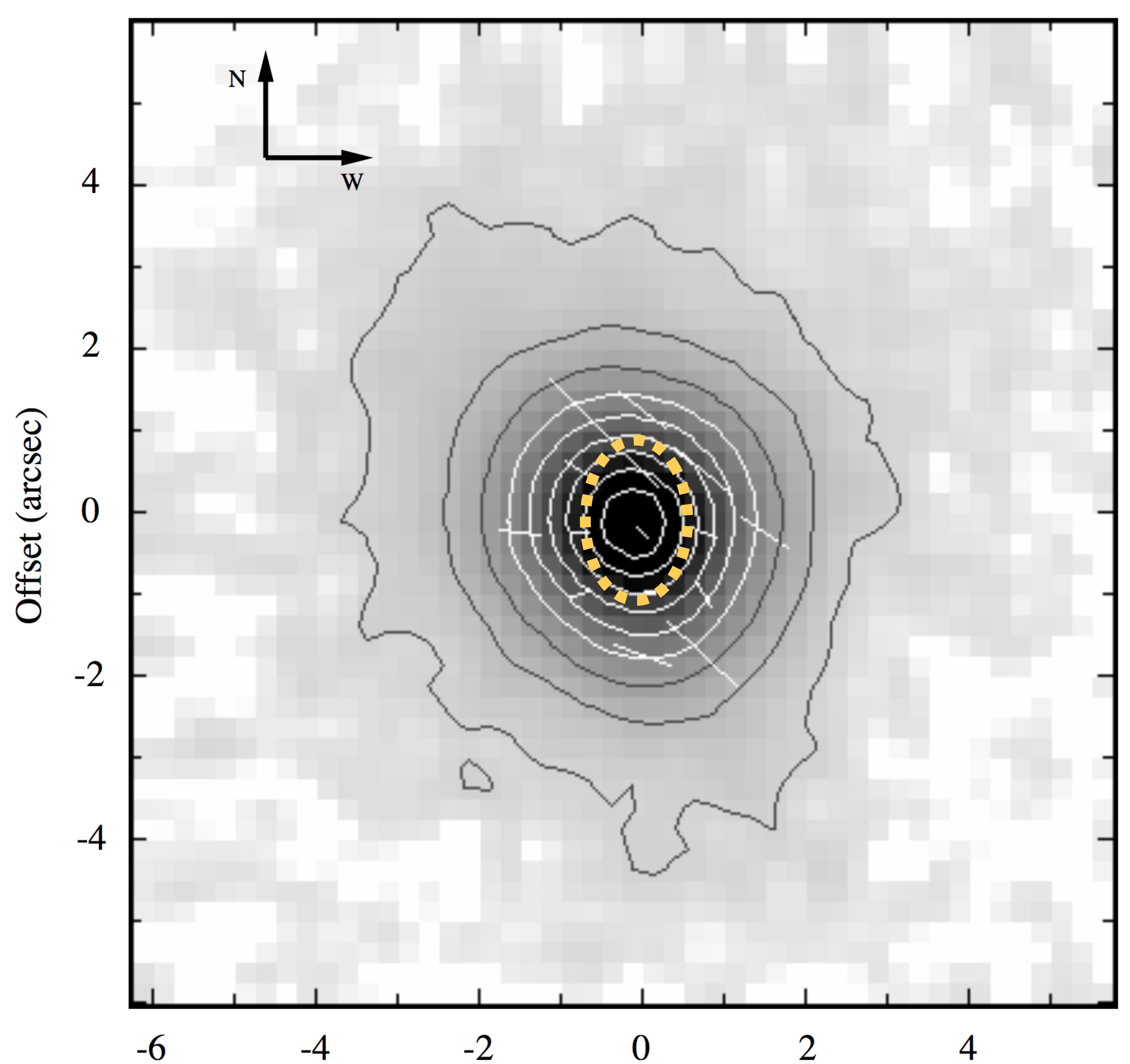


Hashimoto et al. (2011)

High-spatial resolution observations are crucial to obtain sensitive polarimetric measurements

Mid-Infrared Polarimetry & AGN

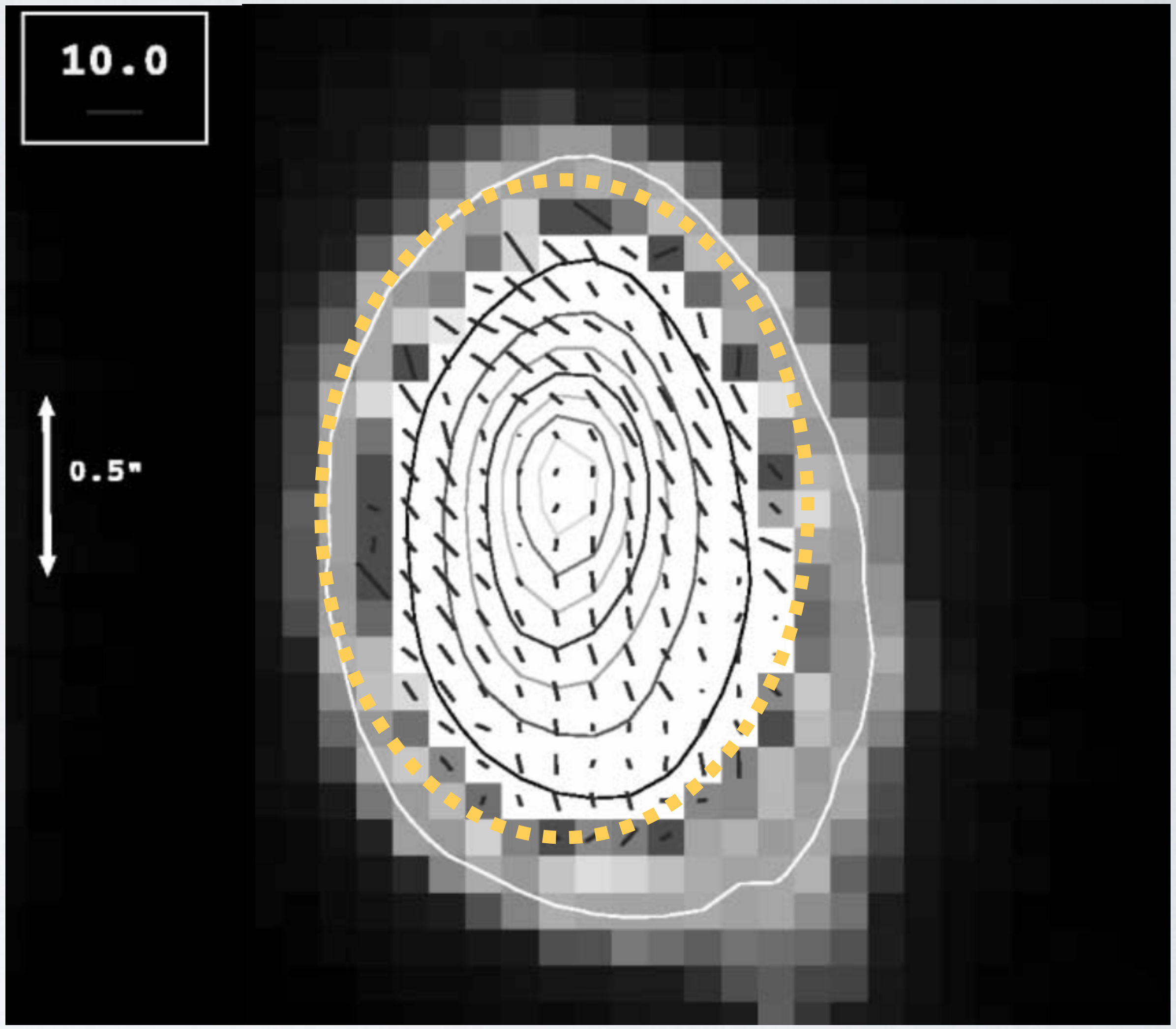
NGC 1068 in the 90's



Lumsden et al. (1999)

3.9-m Anglo-Australian Telescope
N-band (10 um window)
0.6" resolution

NGC 1068 in the early 2000's

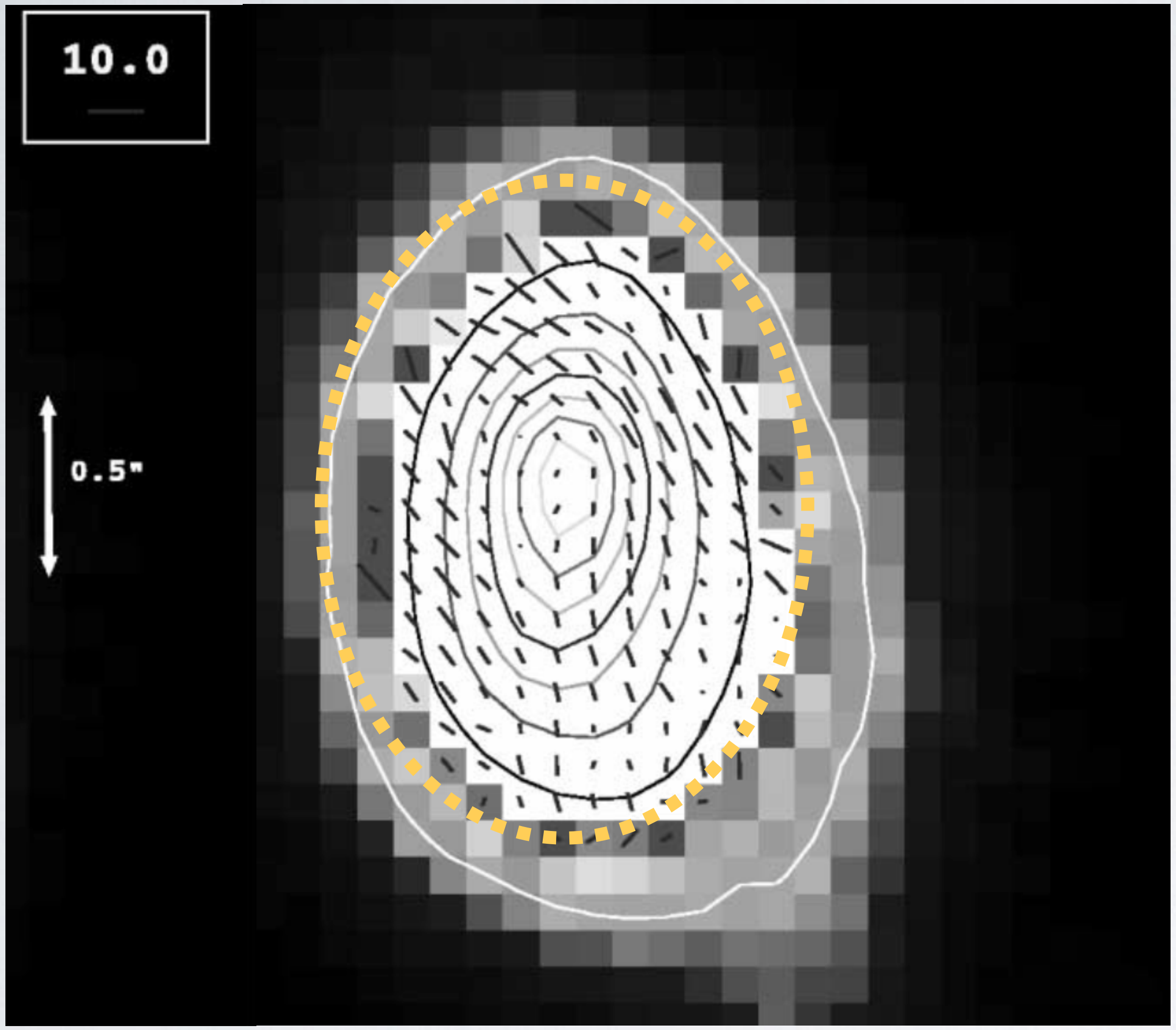


Packham et al. (2007)

8.1-m Gemini North
9.7 um filter
0.3" resolution

Mid-Infrared Polarimetry & AGN

NGC 1068 in the early 2000's



Packham et al. (2007)

8.1-m Gemini North
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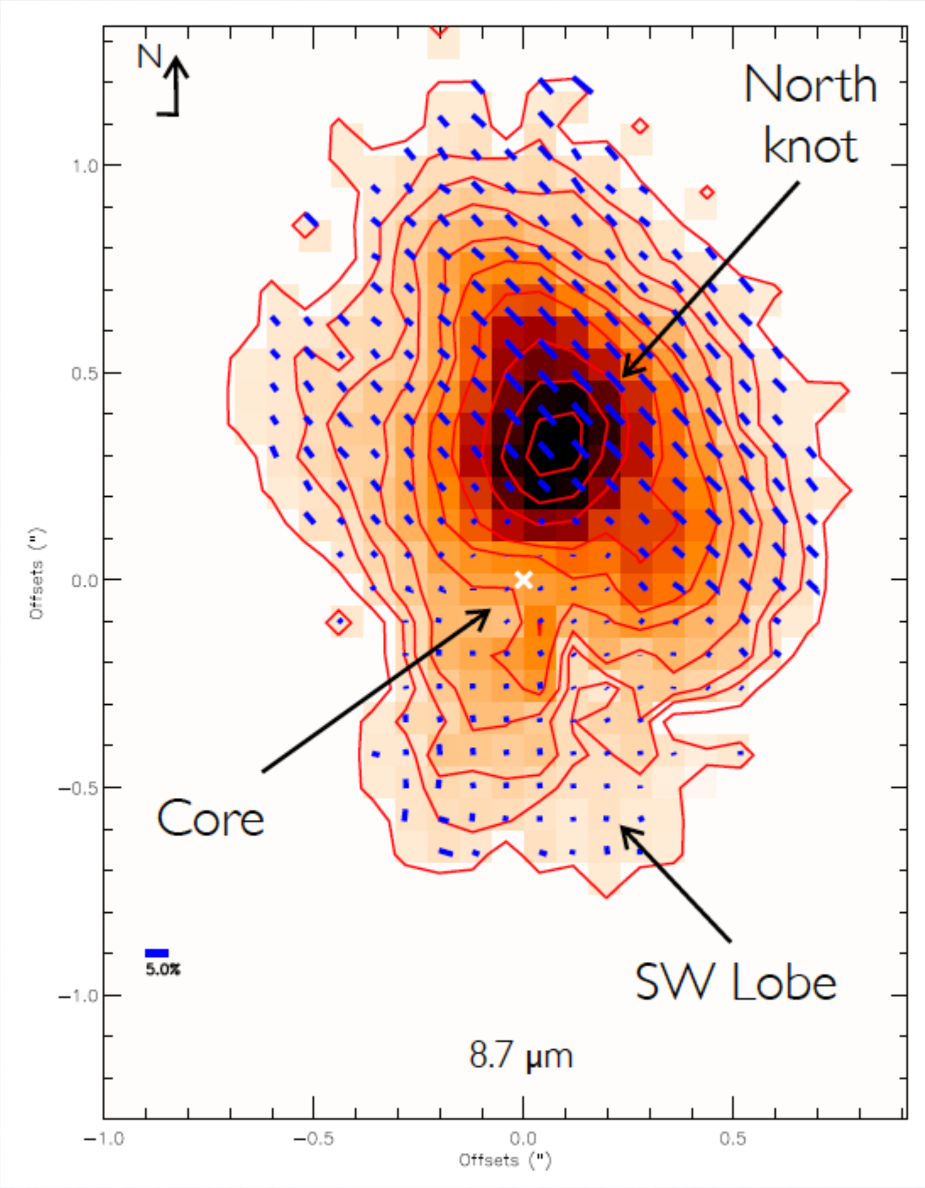
0.3" resolution

NGC 1068 Today



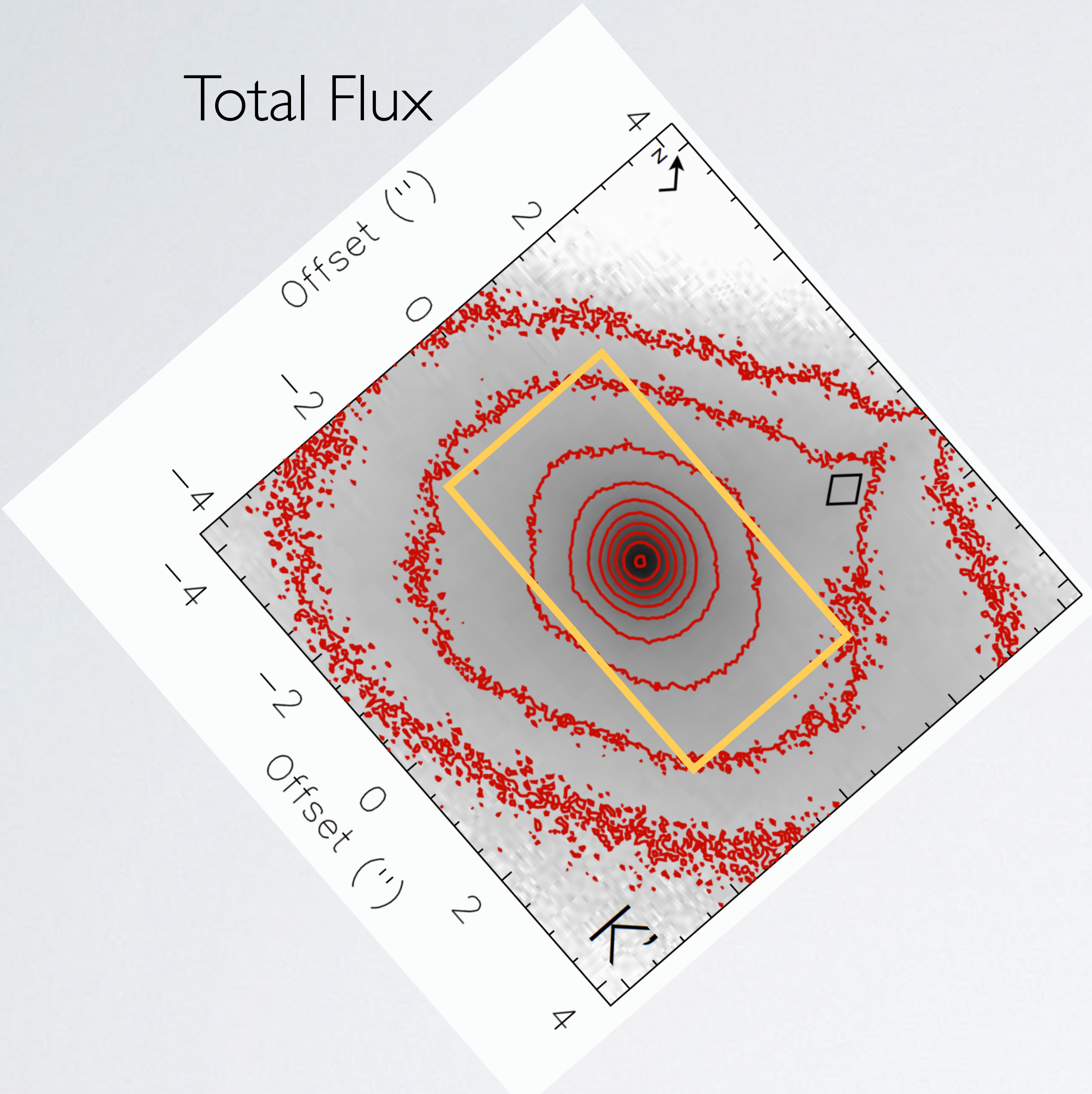
Lopez-Rodriguez et al. (2015b, in preparation)

10.4-m GTC/CanariCam
8.7 um filter
0.3" resolution

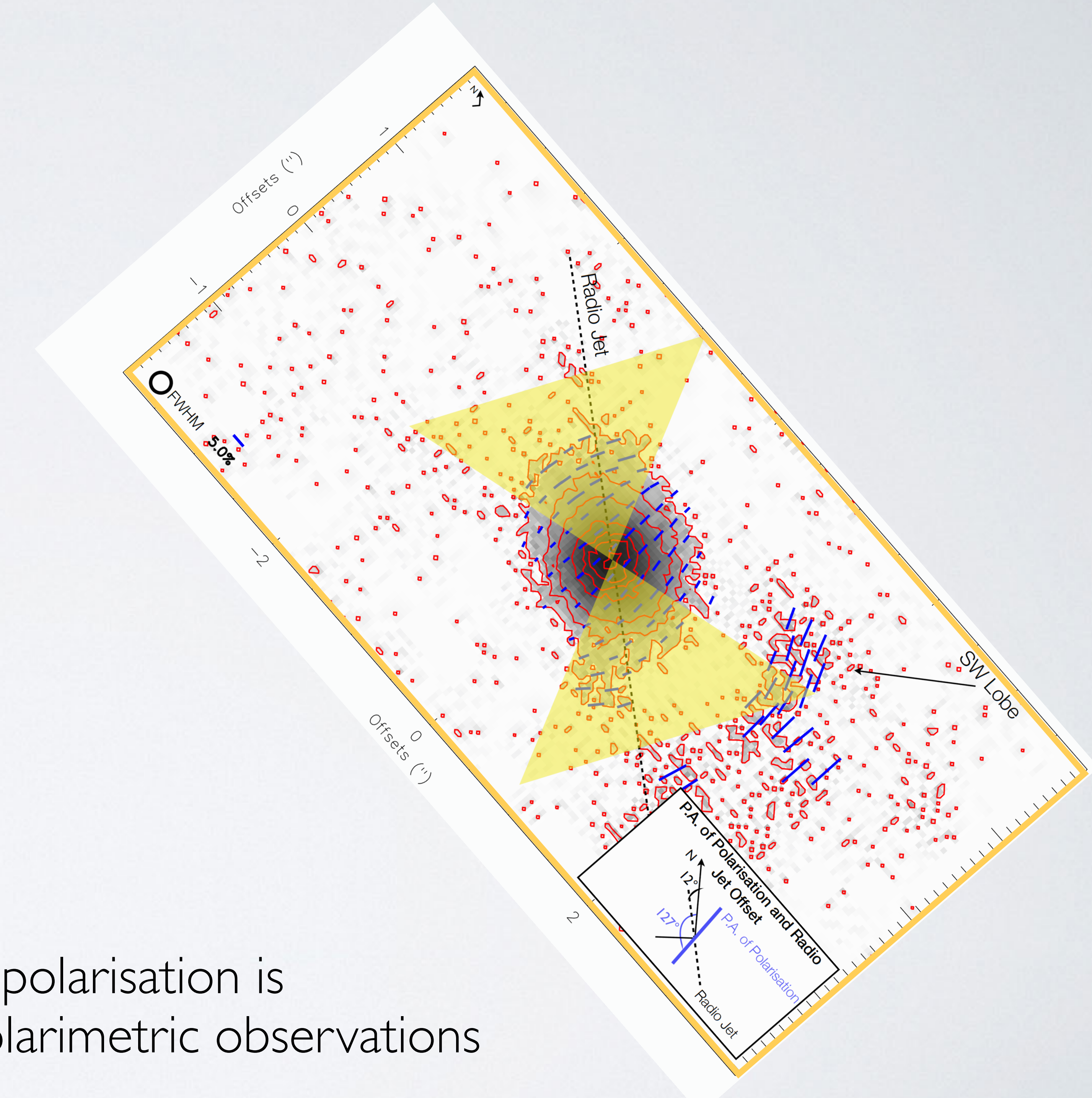
Contrast enhanced using polarimetry

MMT-Pol observations at 2.2 um with AO on the 6.5-m MMT

Total Flux



Polarized Flux

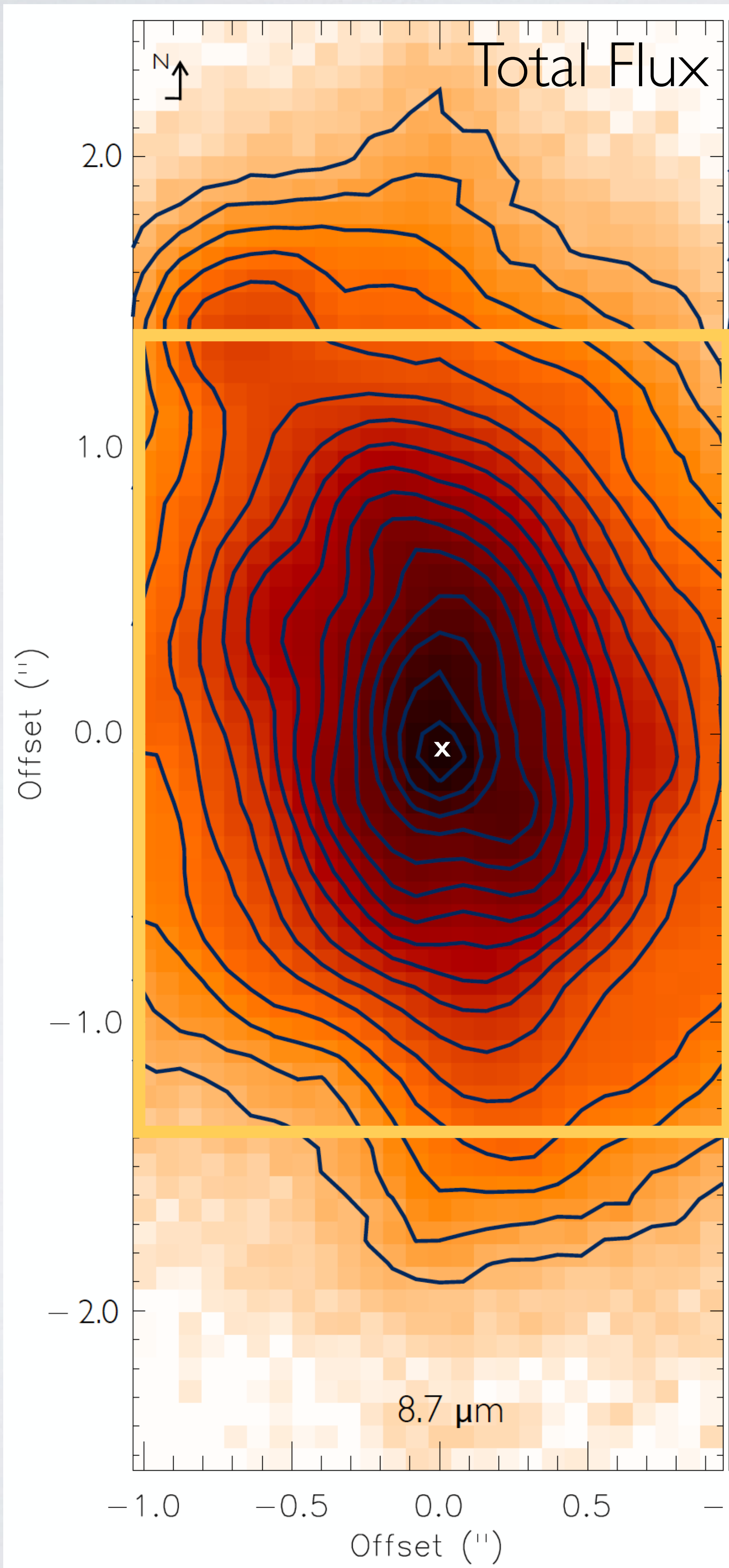


Unpolarized polarisation is
'removed' from the polarimetric observations

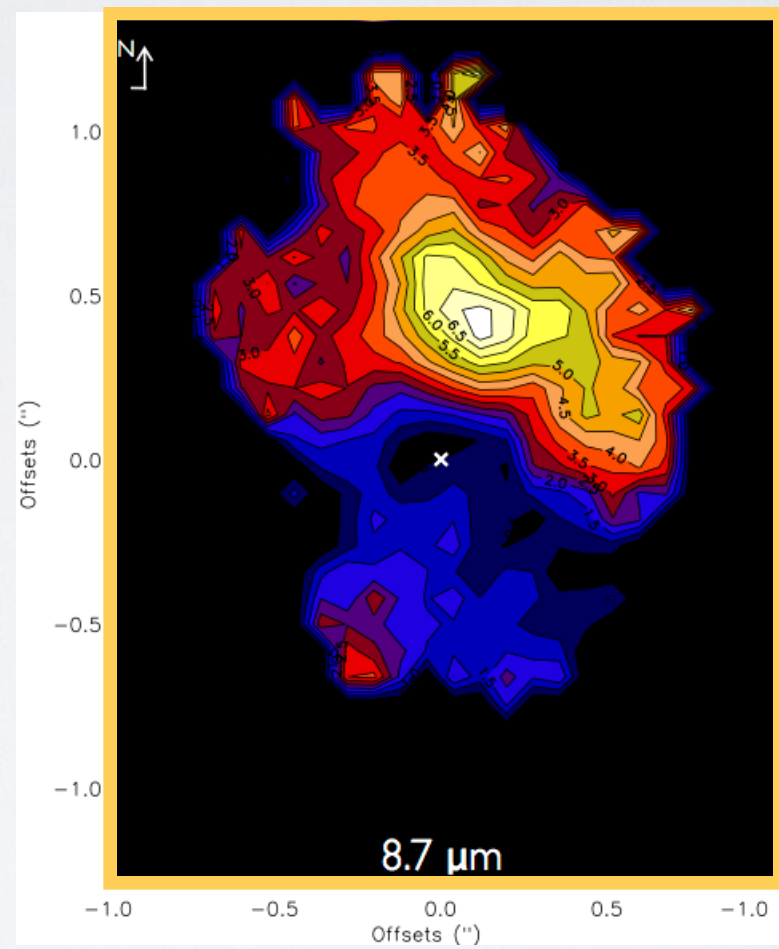
Lopez-Rodriguez et al. (2015a)

Contrast enhanced using polarimetry

CanariCam polarimetric MIR observations on the 10.4-m GTC, Spain



Degree of polarization



Unpolarized polarisation is
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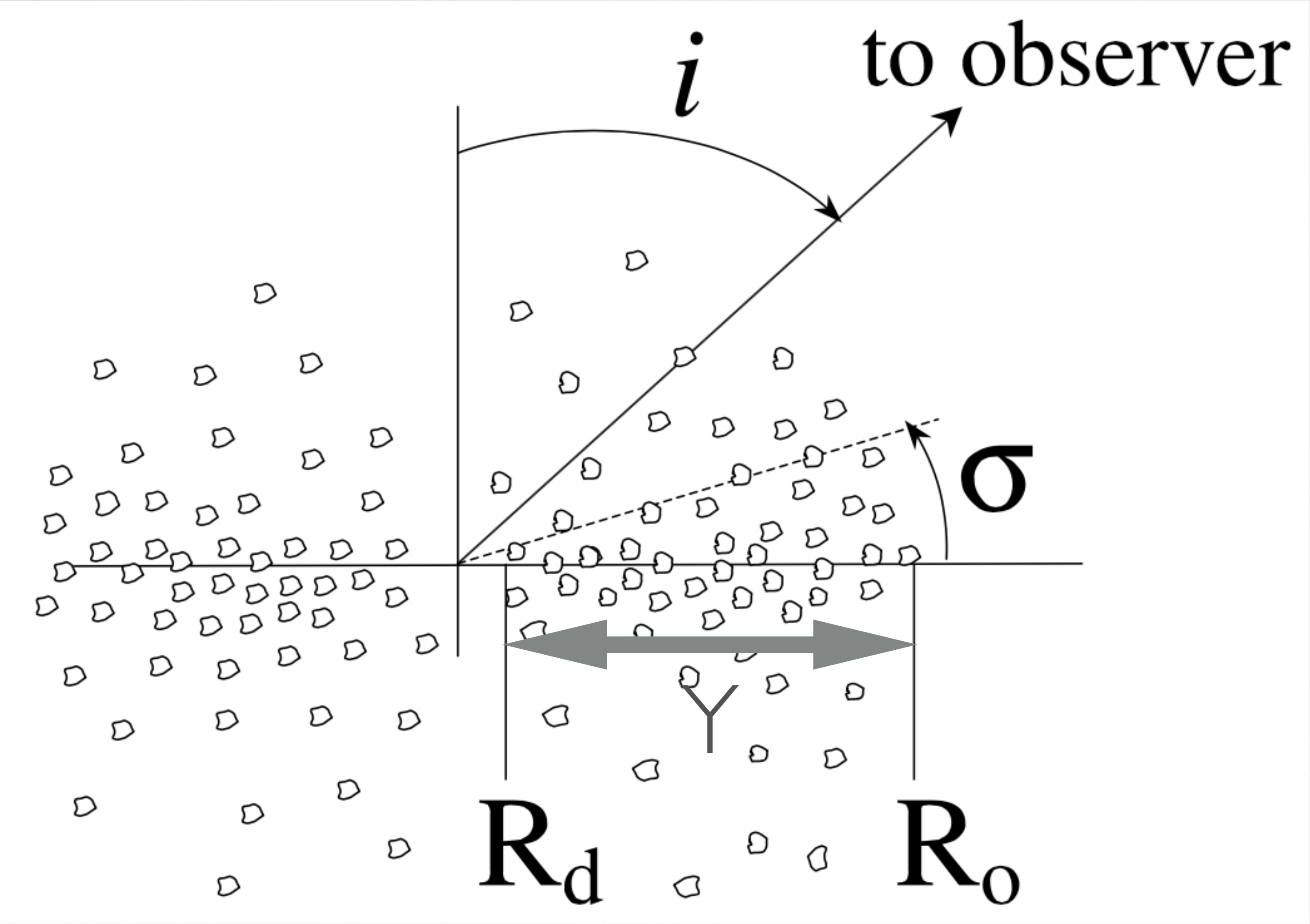
Lopez-Rodriguez et al. (2015b, in preparation)

Simulated Observations of the Torus of NGC 1068 with TMT

CLUMPY torus model

CLUMPY can produce images of the torus based on the fitting outputs

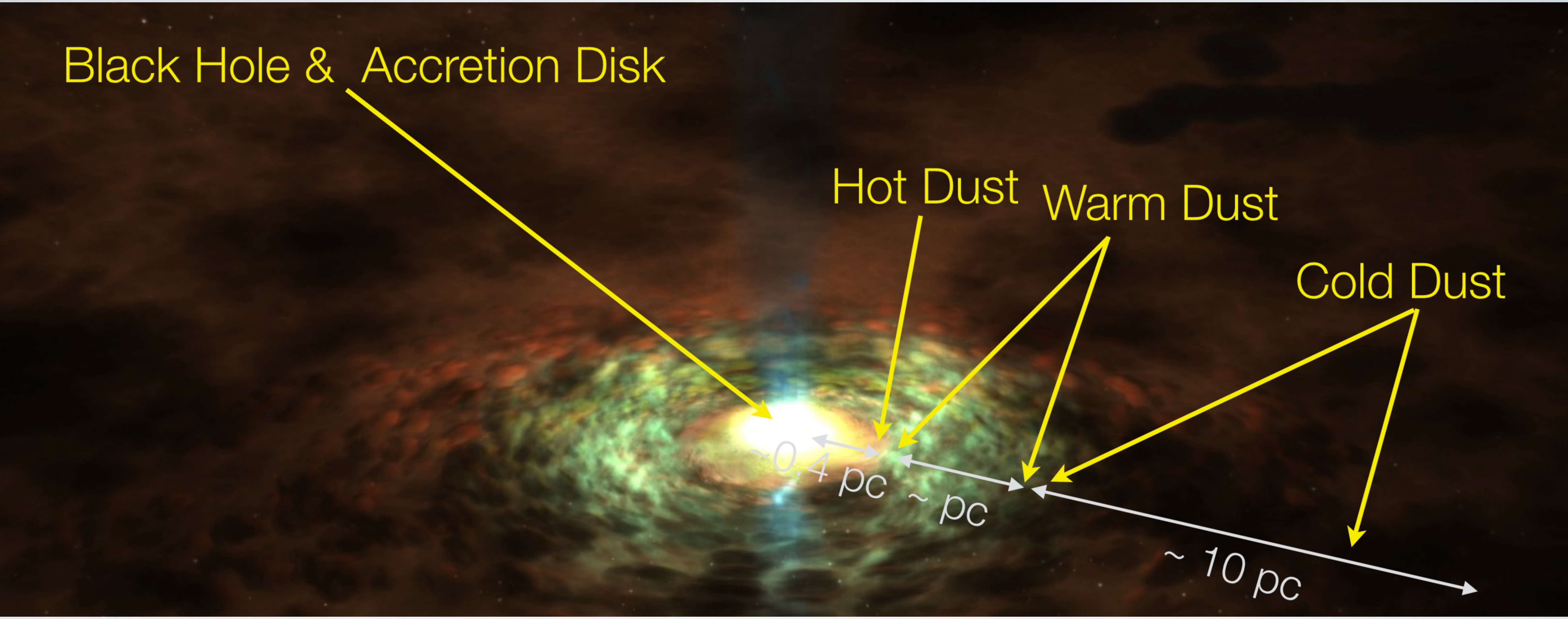
- Thanks Robert Nikutta for helping on this task!



clumpy.org

Parameter	Abbreviation	Interval
Width of the angular distribution of clouds	σ	[15°, 75°]
Radial extent of the torus	Y	[5, 100]
Number of clouds along the radial equatorial direction	N_0	[1, 15]
Power-law index of the radial density profile	q	[0, 3]
Inclination angle of the torus	i	[0°, 90°]
Optical depth per single cloud	τ_V	[5, 150]

Multi-wavelength analysis



Hot Dust: Dust at the inner edge of the torus with temperatures of 800-1500K

Observations: NIR (1-5 um)

Warm Dust: Dust at temperatures of 100-500 K

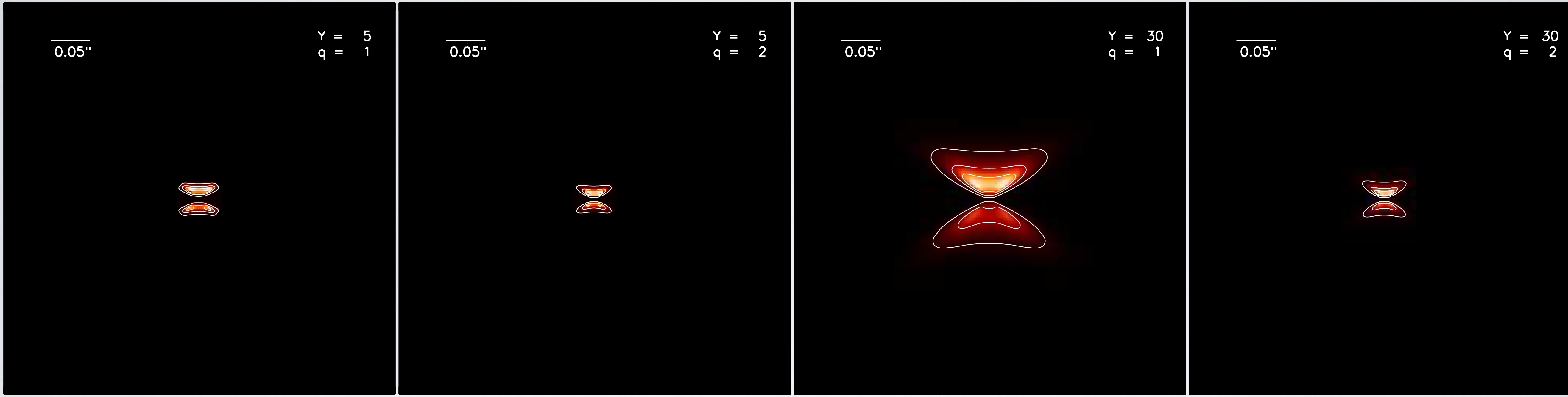
Observations: MIR (7-20 um)

Cold Dust: Dust at the outer edge of the torus with temperatures < 100 K

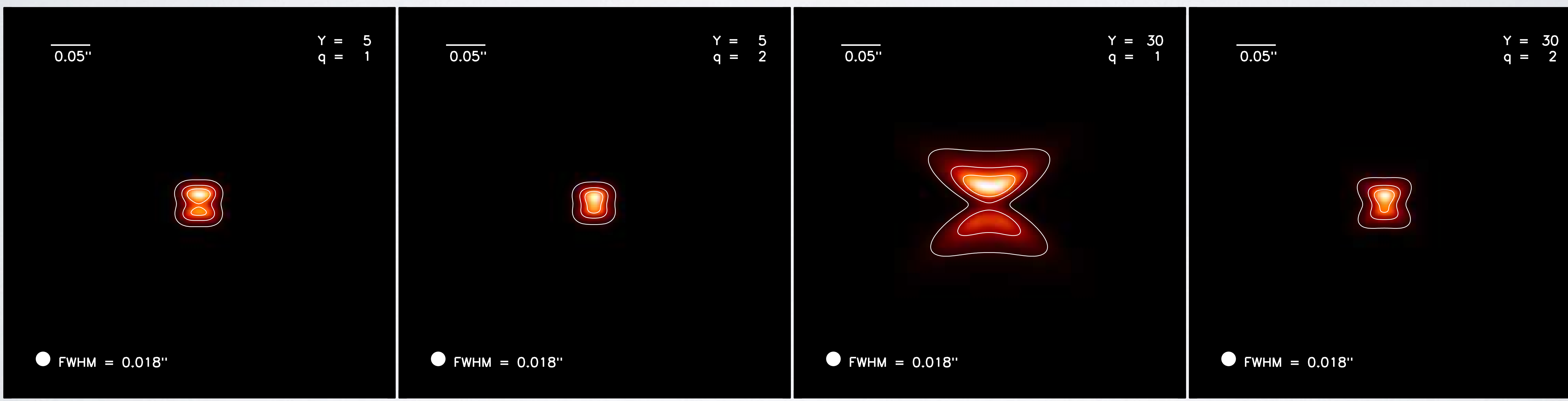
Observations: mm (ALMA)

NGC 1068: Simulated TMT observations

CLUMPY torus model output at 2.2 um (K band)



Convolved with a PSF of 0.018'' at 2.2 um (simulated TMT observations)

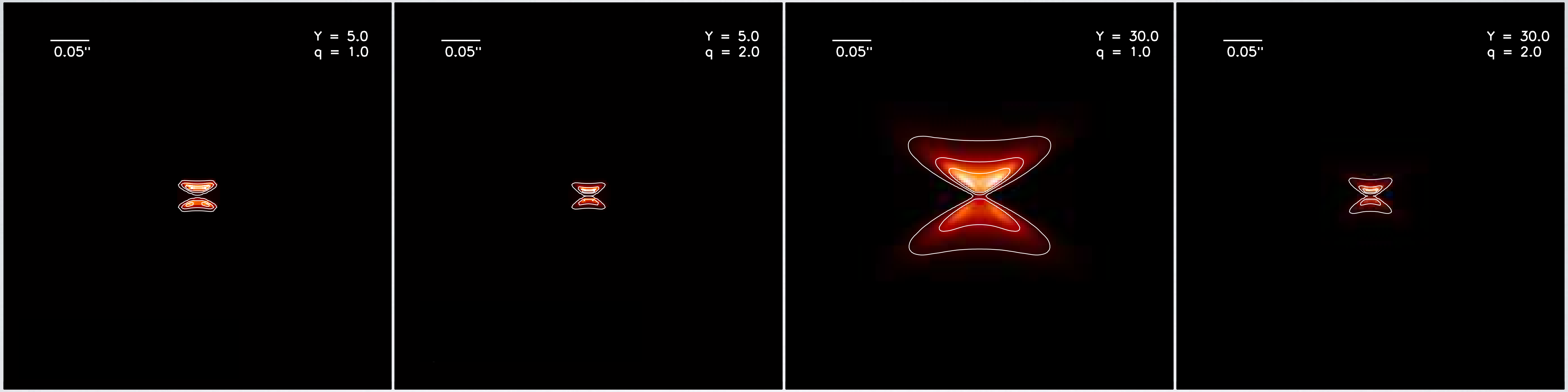


In all cases:

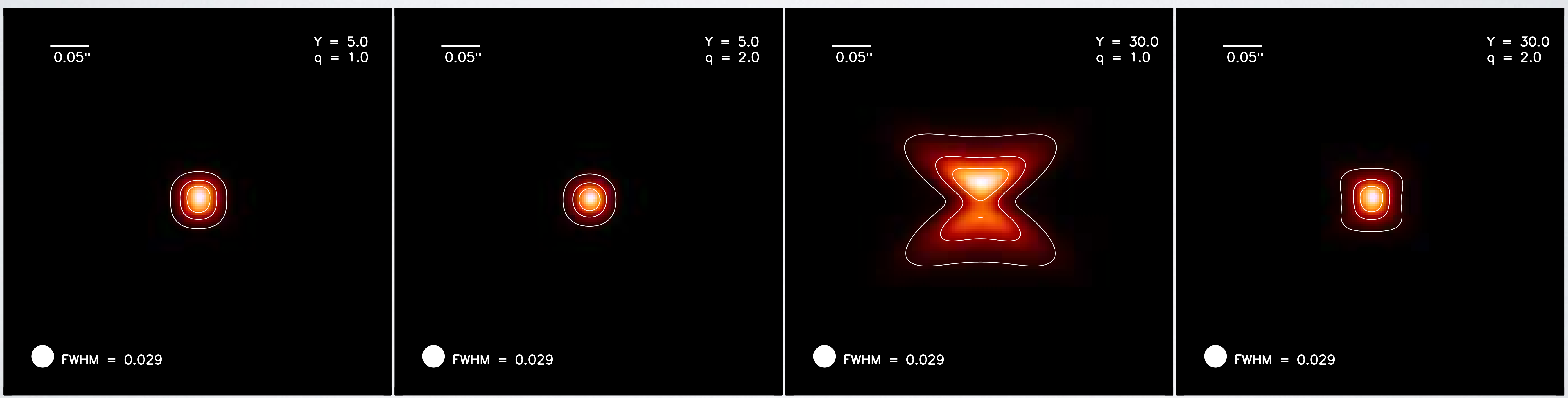
The torus of NGC 1068 at 2.2 um is resolved with TMT

NGC 1068: Simulated TMT observations

CLUMPY torus model output at 3.45 um (L band)



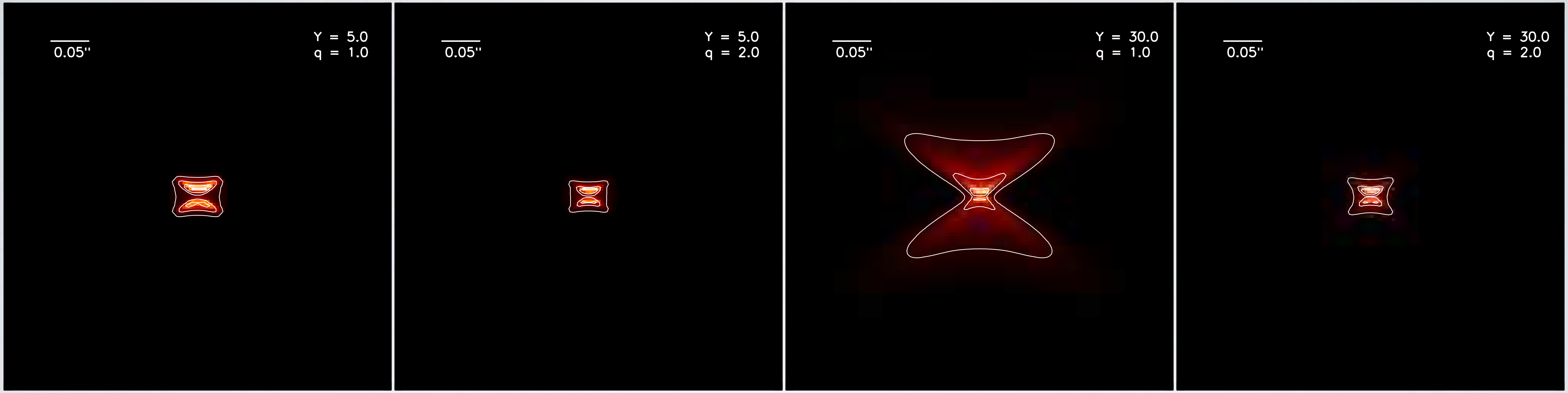
Convolved with a PSF of 0.029'' at 3.45 um (simulated TMT observations)



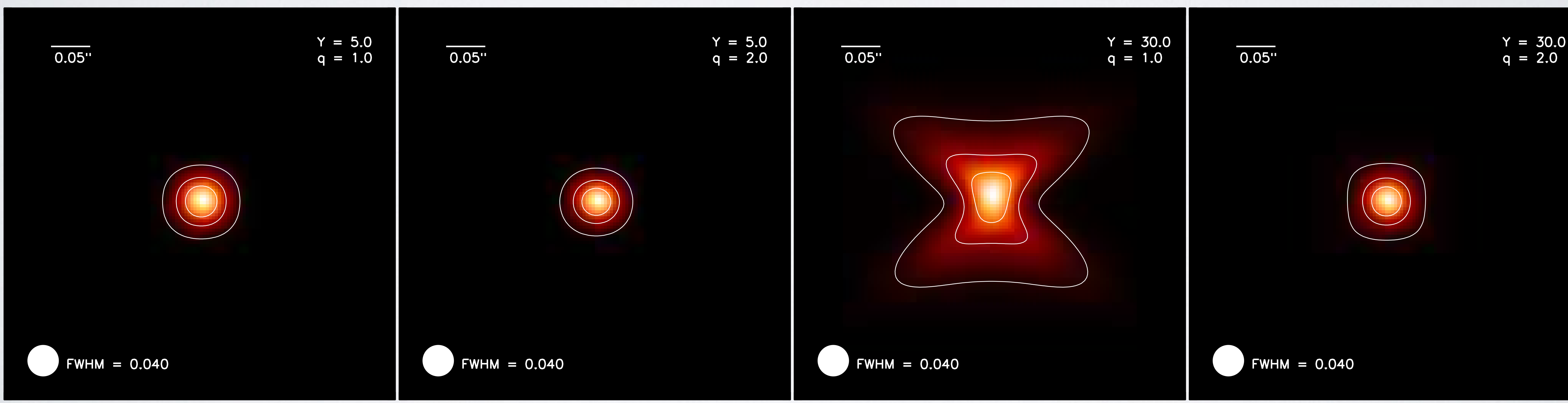
The torus of NGC 1068 at 8.7 um is resolved

NGC 1068: Simulated TMT observations

CLUMPY torus model output at 4.75 um (M band)



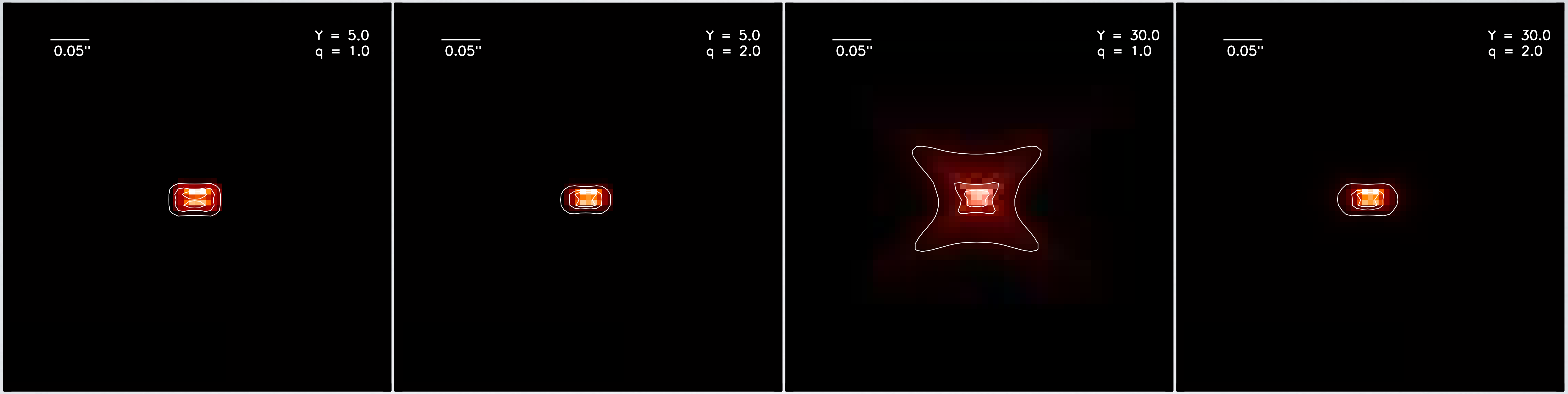
Convolved with a PSF of 0.040'' at 4.75 um (simulated TMT observations)



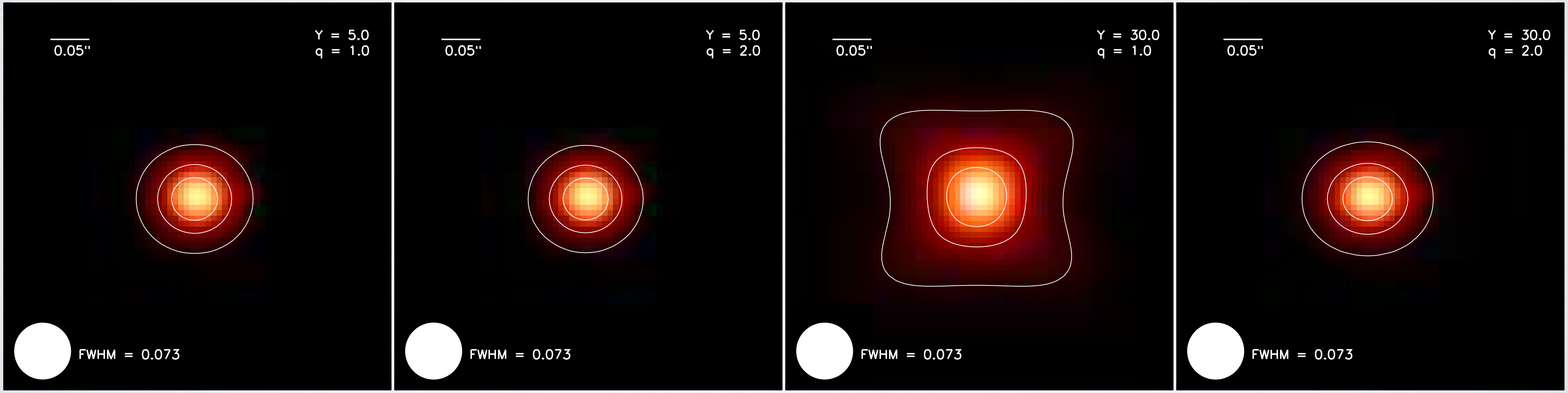
Only the most extended configuration of the torus of NGC 1068 at 8.7 um is resolved

NGC 1068: Simulated TMT observations

CLUMPY torus model output at 8.7 um



Convolved with a PSF of 0.073'' at 8.7 um (simulated TMT observations)



Only the most extended configuration of the torus of NGC 1068 at 8.7 um is resolved

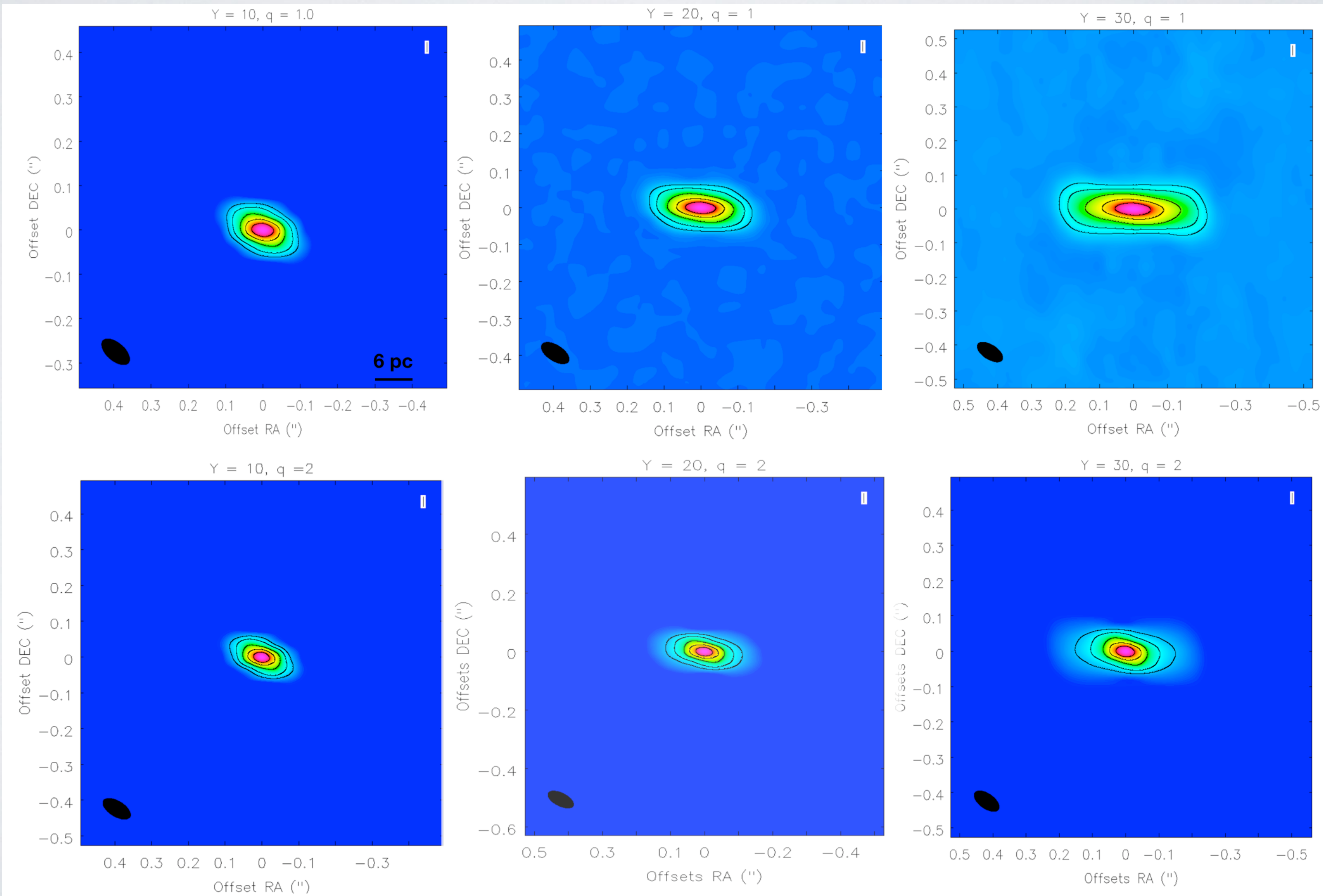
Now it is when I use the word ‘synergy’…

ALMA Polarimetry

Configuration: Band 7 (350 GHz), beam size 0.034”

Simulations:

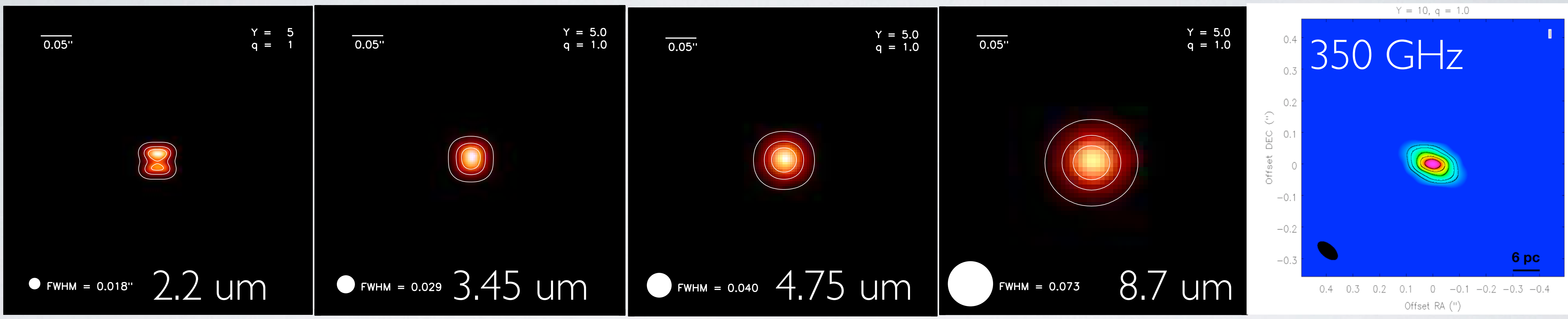
CLUMPY torus model output at 350 GHz + CASA Simulation



Simulated Observations

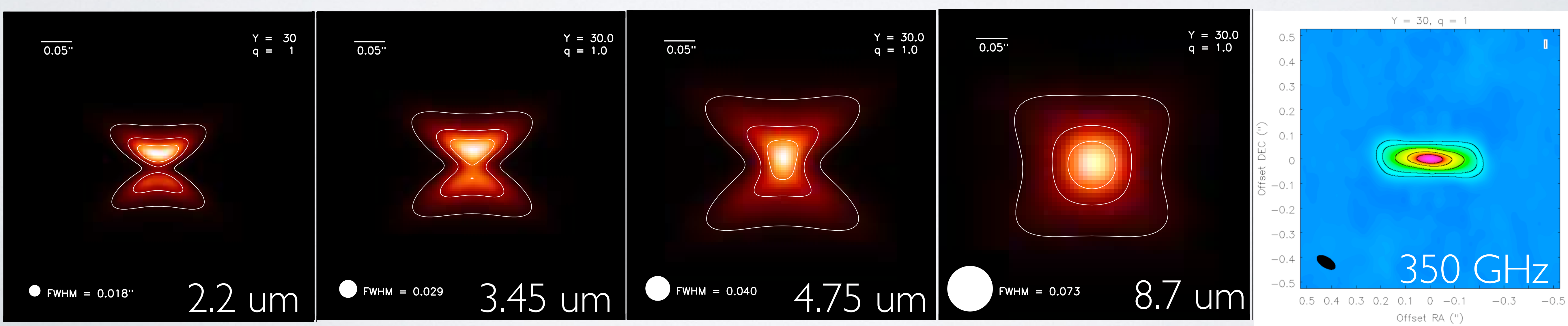
Pessimistic Case: The torus is partially-resolved at 2.2-3.45 um and 350 GHz

This case will imply the torus to be very compact ~pc. However, SOFIA observations of 10 AGN suggest a torus to be more extended with Y~10-20 (Fuller, Lopez-Rodriguez, Packham et al. 2015, in preparation)



Optimistic Case: The torus is resolved at all wavelengths

This case will imply the torus to be extended to ~10 pc



Multi-wavelength analysis: TMT & ALMA

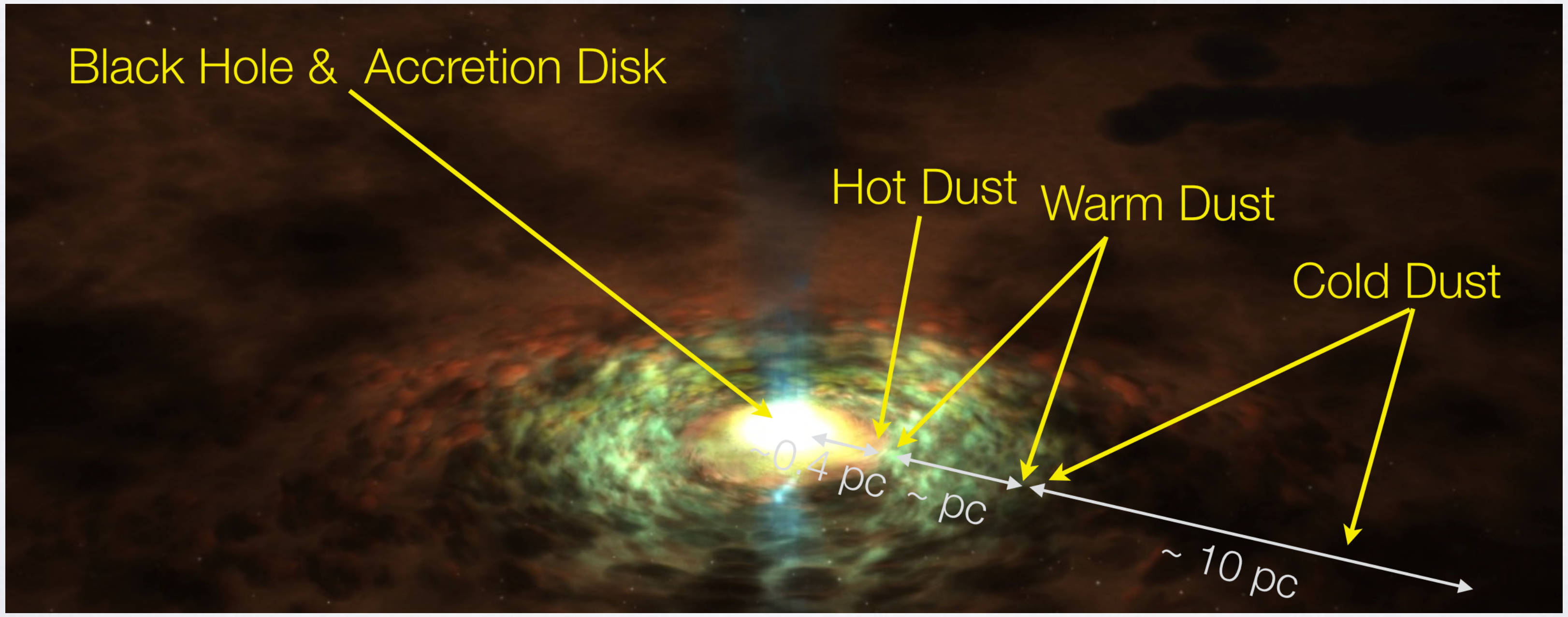
a) How does the outflow wind move away from the central engine and create the torus?
b) What is the relationship of the inflow/outflow mass rates at the inner and outer edge of the torus?
c) How large is the torus under the influence of the hydromagnetic outflow wind?

Assuming a torus with ~10-20 pc diameter, then:

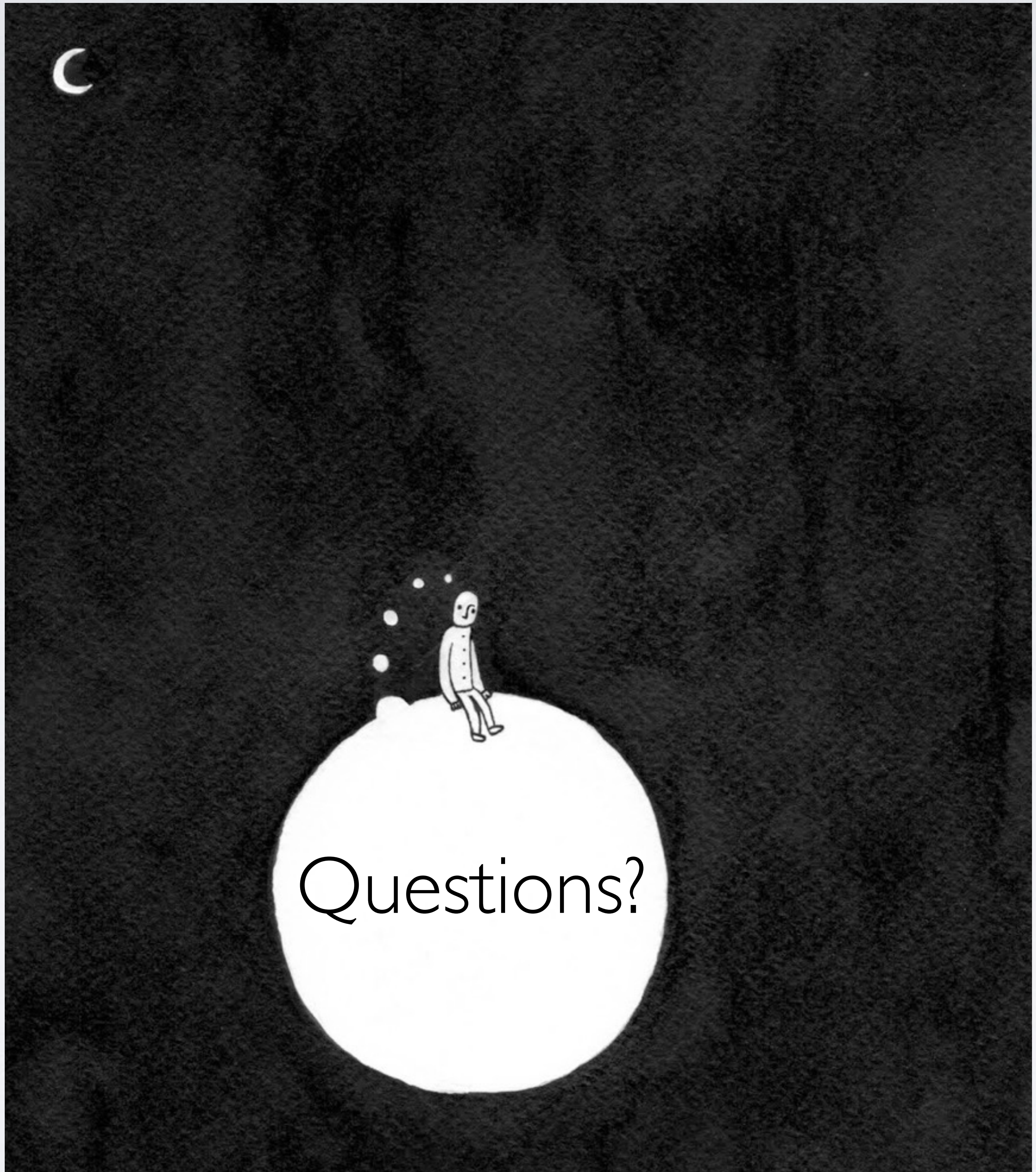
- Torus is resolved up to D ~ 30 Mpc at 2.2 um
- Representative sample of 20-30 AGN

Topographic map of the magnetic field from the inner to the 'outer' edge of the torus

1) Study of the origin of the clumpy and dusty obscuring structure
2) Evolution and kinematics of the clumps from a MHD framework
3) Put constraints in MHD models from observations



Thank you!



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