TMT & The AGN Torus

Chris Packham
University of Texas at San Antonio

And contributions from
Kohei Ichikawa & Enrique Lopez Rodriguez

PHYSICS & ASTRONOMY
THE UNIVERSITY OF TEXAS AT SAN ANTONIO

Modeling on a WHIM

- Elvis (2000) developed a phenomenologically based model
  - Foundation is emission and absorption features in AGN spectra
  - Assumes a simple outflowing structure
- Model invokes a flow of warm highly ionized matter (WHIM) launched by the accretion disc
  - This approach was used by many, including Elitzur & Schlosman (2006) to account for the dusty torus

Cartoon of a WHIM

- Taken from Marin & Goosmann 2013

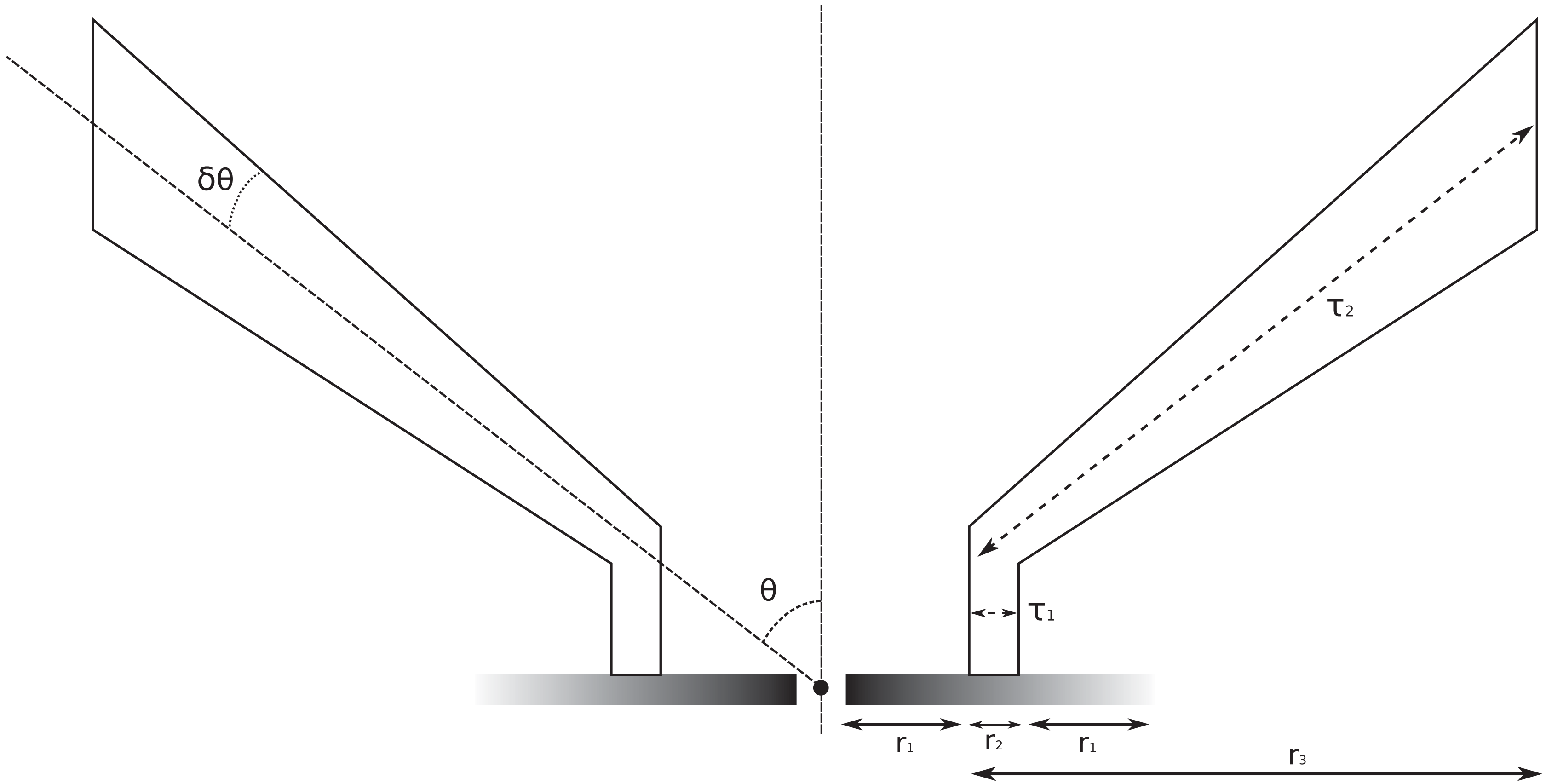
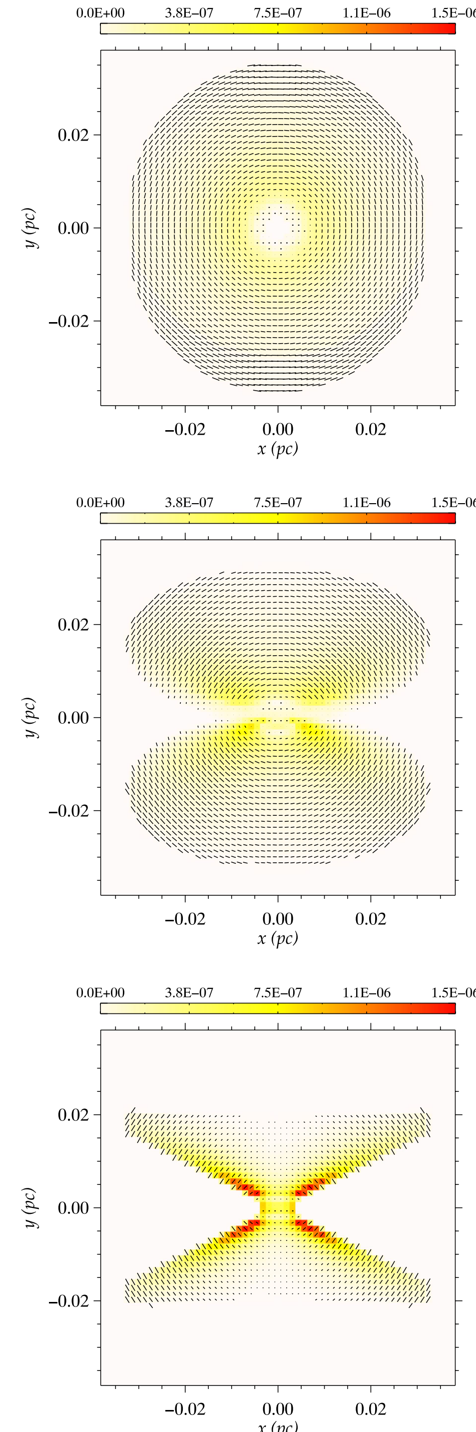


Figure 1. Schematic view of the structure proposed by Elvis (2000) and implemented in the STOKES model. The outflow arises vertically from the accreting disc and is bent outward by radiation pressure along a 60° direction relative to the model symmetry axis. The half-opening angle of the wind extension is 3°. The radial optical depths of the wind base and of the outflowing material are set to be τ_1 and τ_2, respectively.

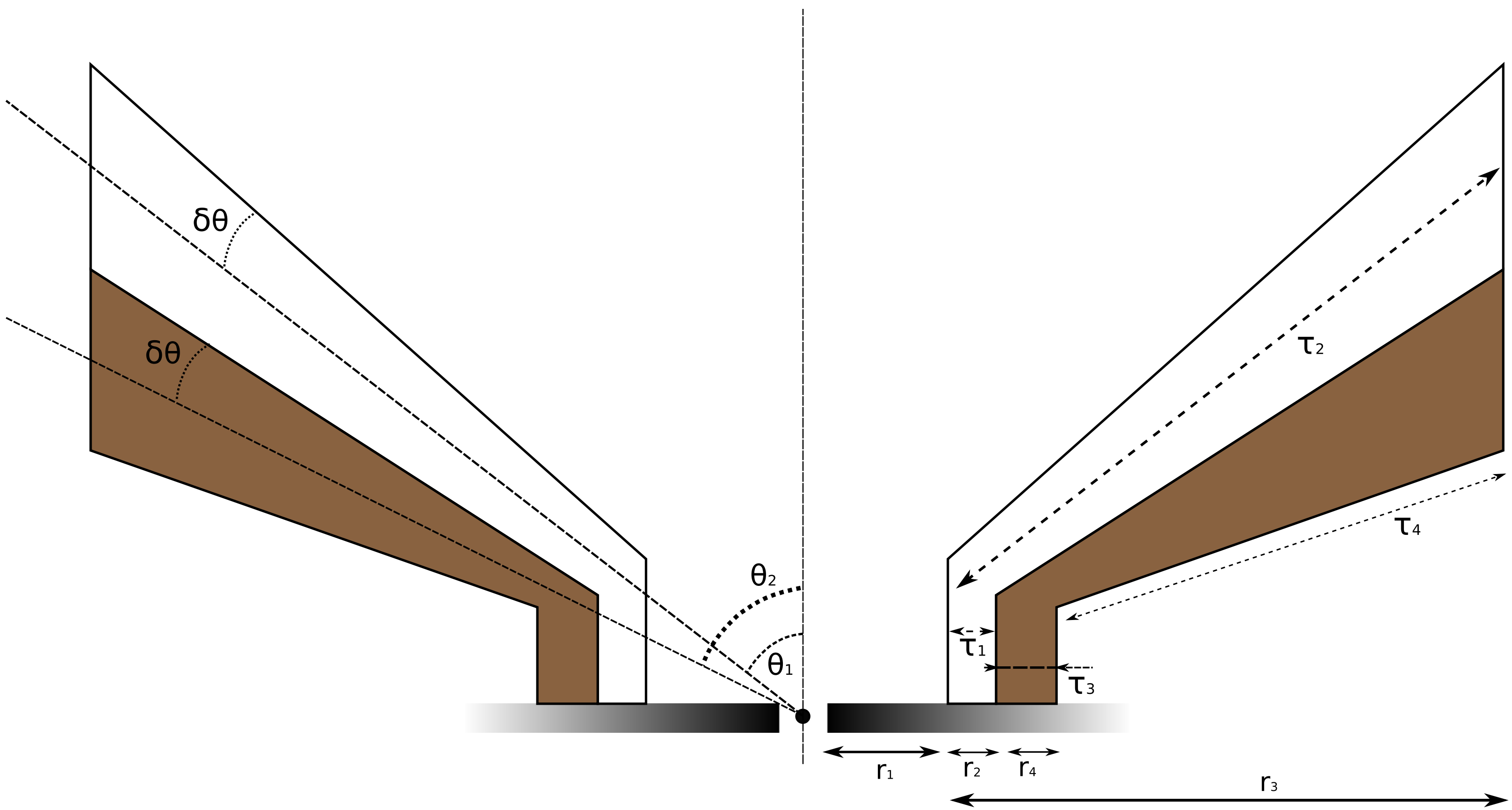
Polarization Maps

- Assuming an electron filled scattering outflow at UV/Optical, maps of polarized flux and degree of polarization
- Such simple models underestimate the observed polarization and the PA is wrong for Type-2 sources



An Improved Model

- Two phased media, dust is enshrouded by the WHIM

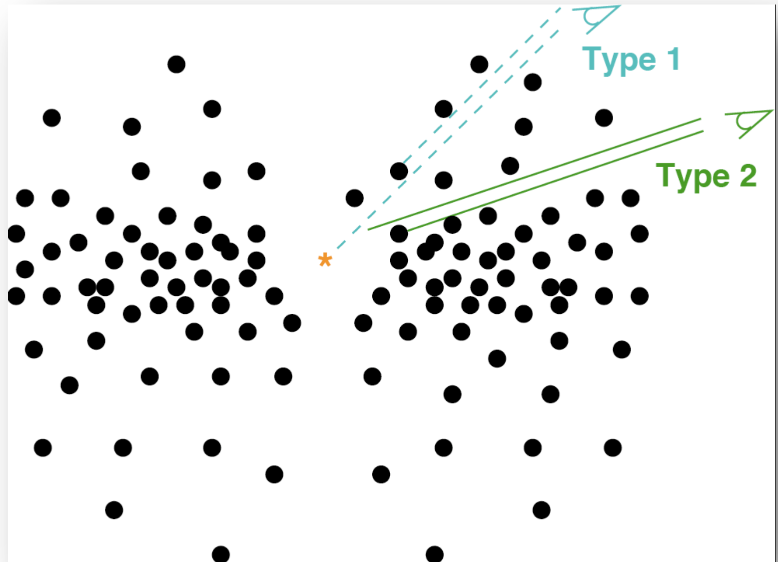


Models & Observations

- Model well matches previously observed data
- Best fit where $\theta = 45^{\circ}$ and $\delta\theta = 3^{\circ}$–10°, and moderate optical depths of the dust with $1 < \tau_{dust} \leq 4$
- Elitzur & Schlosman 2006 suggests that outflow will shut down at some level of accretion
  - Used M87 as a test case
  - Seems likely that morphology will depend significantly on the luminosity/accretion rate

On Clumpy Models

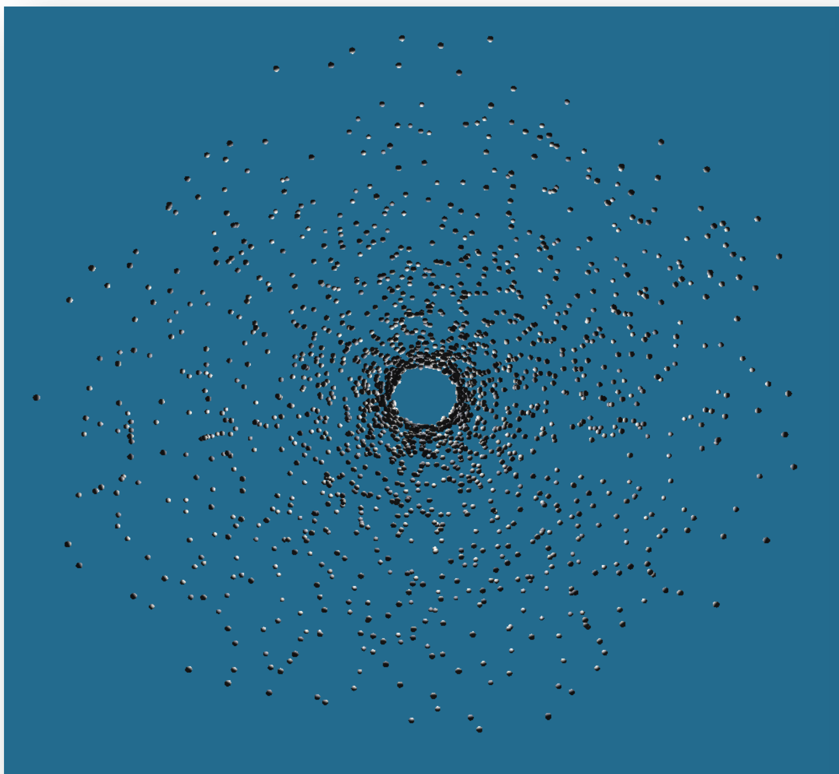
Clumpy Torus Model



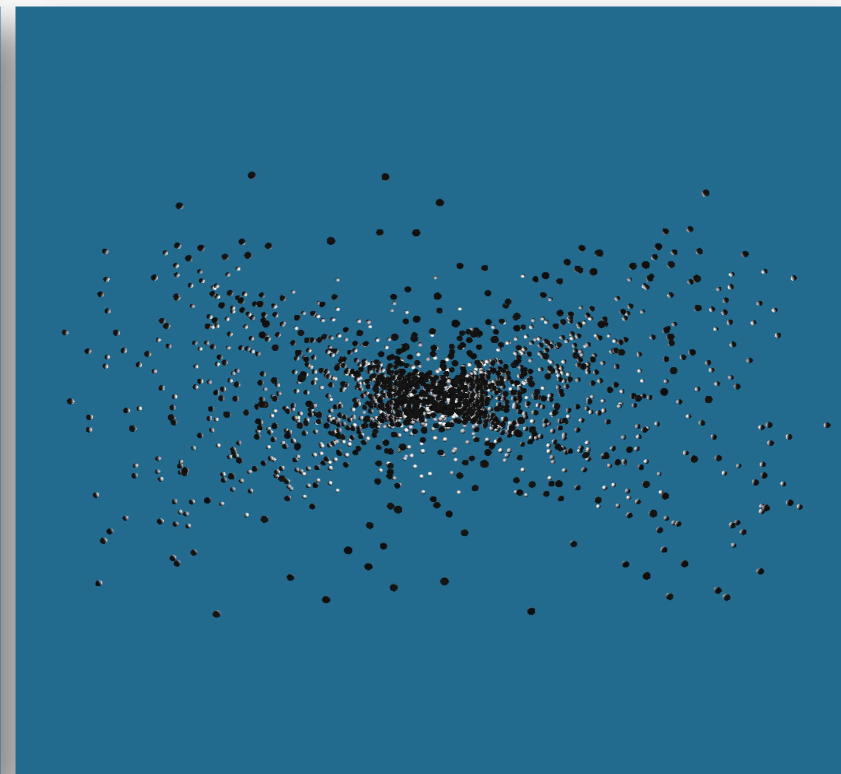
- Clumpy torus model of Nenkova et al. (2002)
  - Clouds follow power law distribution
  - Clouds concentrated in equatorial plane
  - Distributed with scale height σ
  - τ_v of each cloud = 40-100+ Av
  - Type 2 number of clouds along pencil-beam line of sight ~8

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

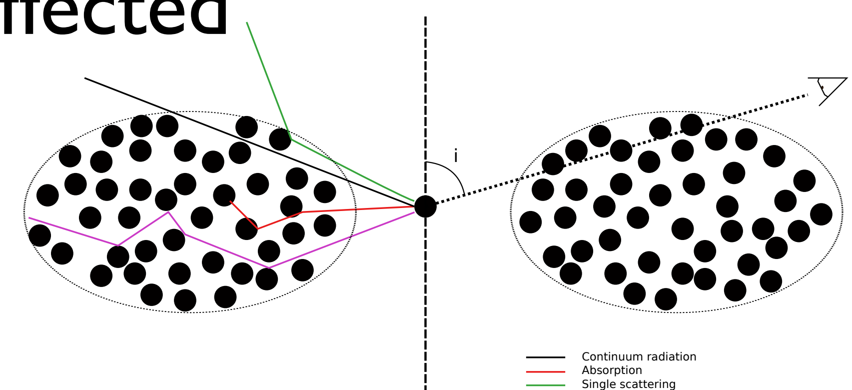
Major Limitations of (some) of the Clumpy Models

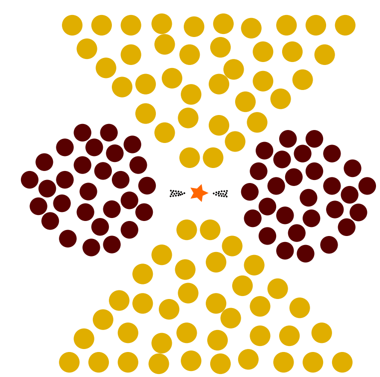
- Physical dimension of the clumps very poorly constrained
  - Eclipse monitoring at x-ray could be key
- Degenerate parameters
- No inter-clump material

- Large numbers of quality data points need to advance the field

Clumpy Torus Polarization Modeling

- Marin et al. 2015 recently modeled radiative transfer models of the torus at UV/optical
  - Clumps are assumed to be of constant density
- Scattering probability changes with the filling factor and hence the polarization will be affected

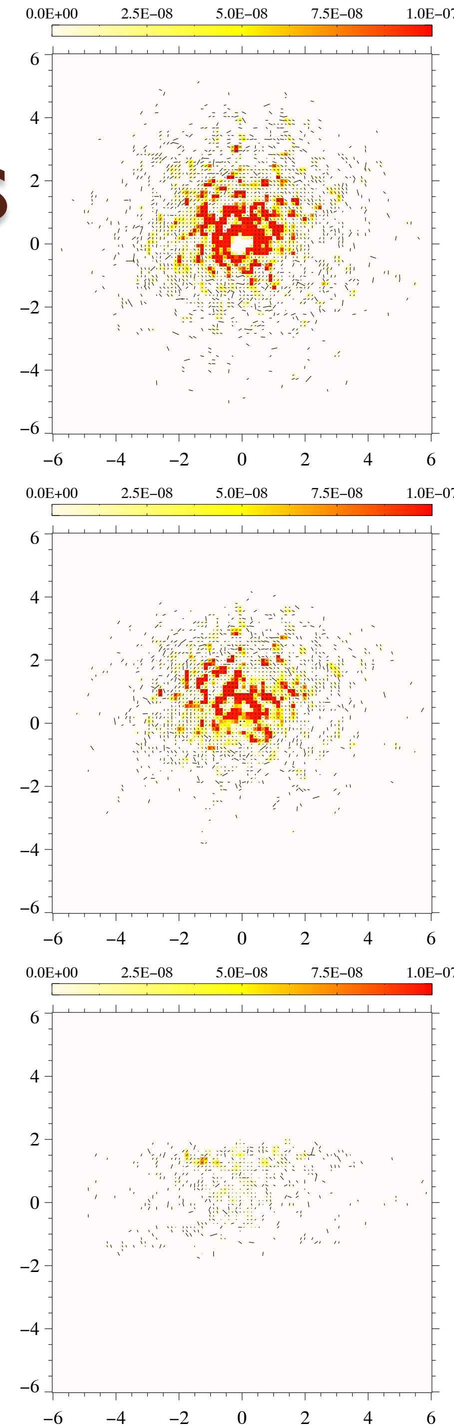




AGN model

Model Polarization Maps

- Polarized flux with overlaid polarization vectors
  - Top is face-on, middle at 45 deg, bottom edge on
- Face-on view shows far more polarized flux
  - Individual knots of emission up to 2.5pc from central engine
  - As expected, edge on view shows very little polarized flux
- Type 1 shows up to 2% polarization, λ invariant
- Type 2 shows as high as 40%, λ invariant



Differences Between Homogenous & Clumpy Models

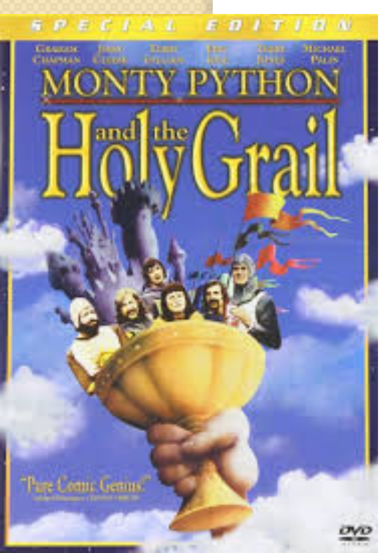
- Extended clumpy tori (>10's of PC) polarization is low (≤2%)
  - When the observer's line of sight passes through the central part of the torus, polarization increases up to a level of 40% and switches PA
- This behavior is similar to homogenous torus models, with one exception
  - Homogenous torus models produce significantly lower polarization at intermediate and edge-on orientations
- The torus is very much better modeled with compact yet fragmented tori with an opening angle $\theta \geq 45^\circ$

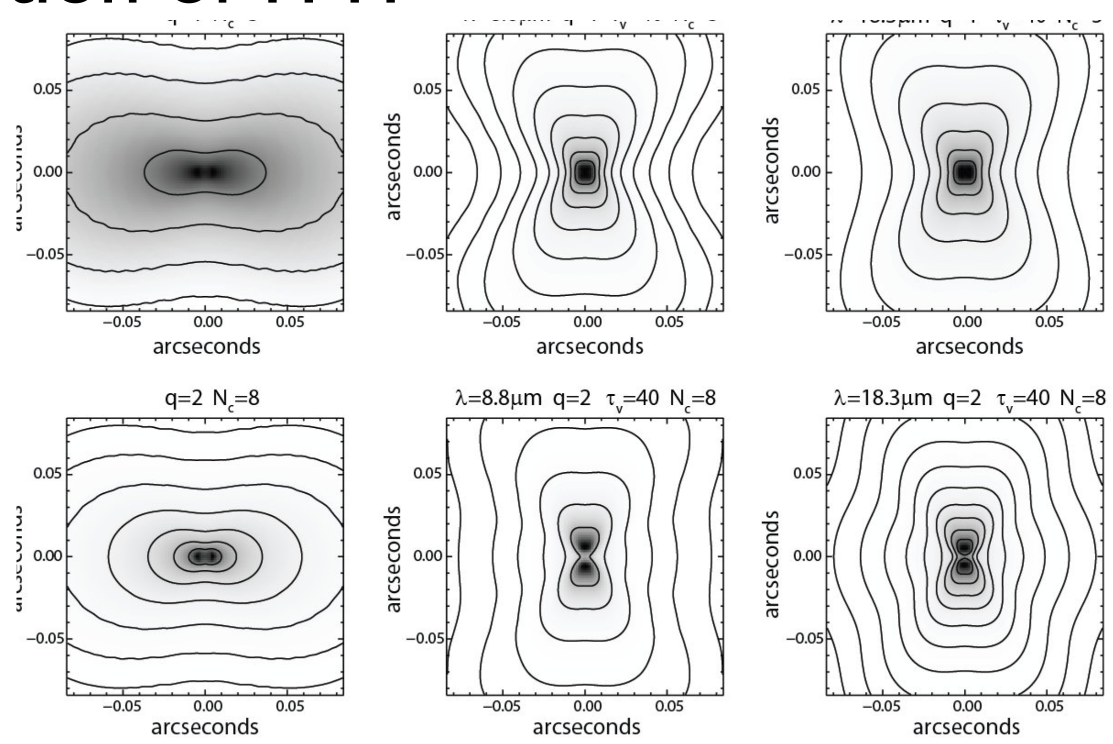
Dust in AGN

- Many assume (including me) that dust MIR emission is mostly from the torus
- Reemission from the torus peaking at MIR wavelengths
  - A standard approach for years
- So can we see the torus with the TMT?

Torus of Cen A

- Models using Nenkova clumpy torus of Cen A (Radomski et al 2006) shown below) at 8 and 18um (top, bottom respectively)
- Near resolution of TMT
- Models need to be updated



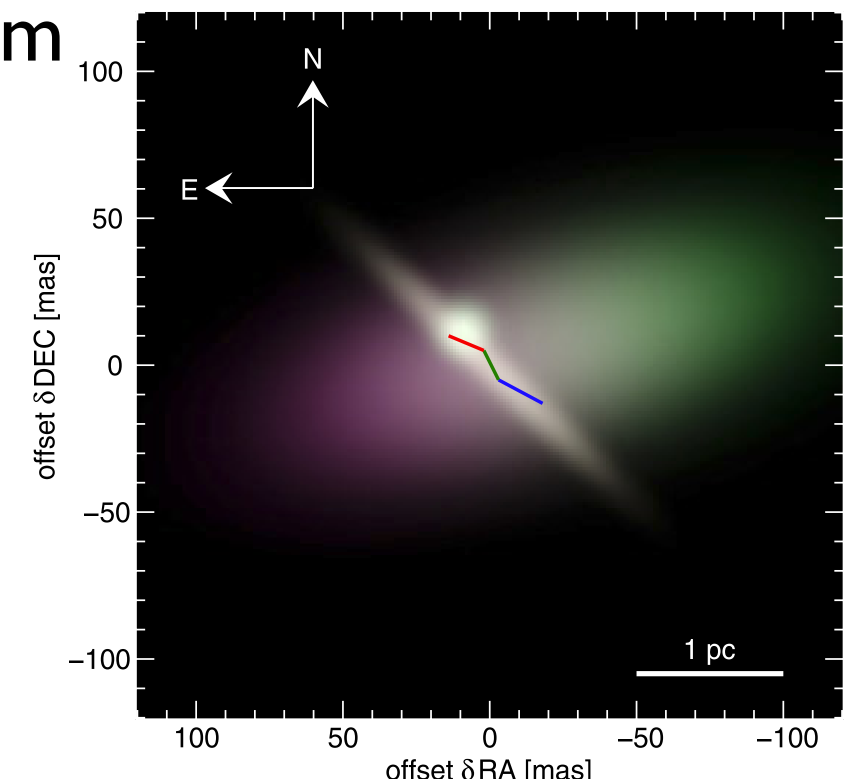


ALMA?

- ALMA of course has superior resolution, but observes cooler dust
  - Likely associated with dust in the galaxy/torus interface?
  - Maybe it won't produce the breakthrough we need in this area

MIR Interferometry

- Tristram et al (2014) suggest the MIR flux from Circinus arises from (a) torus dust and (b) dust in the funnel
- 80% of MIR flux from dust in the funnel?
- Achieved after model fitting of the interferometric results



If True…

- Are the clumpy model fits still correct?
  - If 80% of the MIR flux is from the funnel, what can we say about the AGN fits?
  - But does the MIR flux really trace well the dust?
- But if so much dust in the cones (funnel), how is flux still so energizing downstream?
- We need the TMT to improve our local understanding of the torus at high spatial resolution, extending to more distant AGN, and then connecting to JWST high sensitivity observations
  - MATISSE on VLT (interferometry) could produce breakthroughs in this area, but flux limited

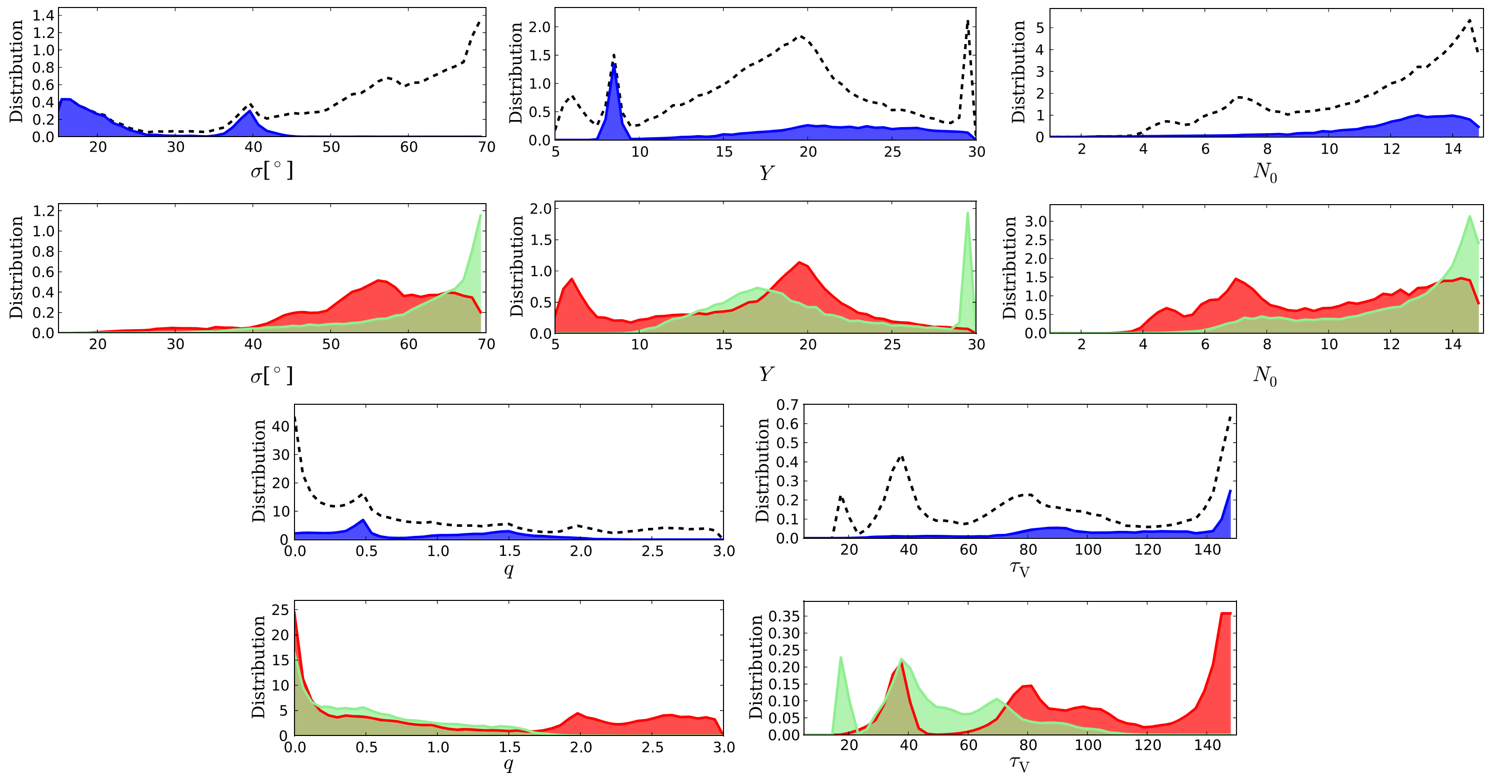
One Example

- Of surveys of torus properties
- Just an example, more to come based a GTC-based survey a few of us in this room are engaged in

Polarized Broad Emission Lines

- Why do not all Sy2 show scattered BLR?
- Based on the objects in a survey my collaborators and I are involved with, we can divide our objects to:
  - Sy1 (Type 1)
  - Sy 2 with polarized broad emission lines (HBLR)
  - Sy 2 with no (or thus far undetectable) published broad emission lines (NHBLR)
  - Ichikawa et al 2015

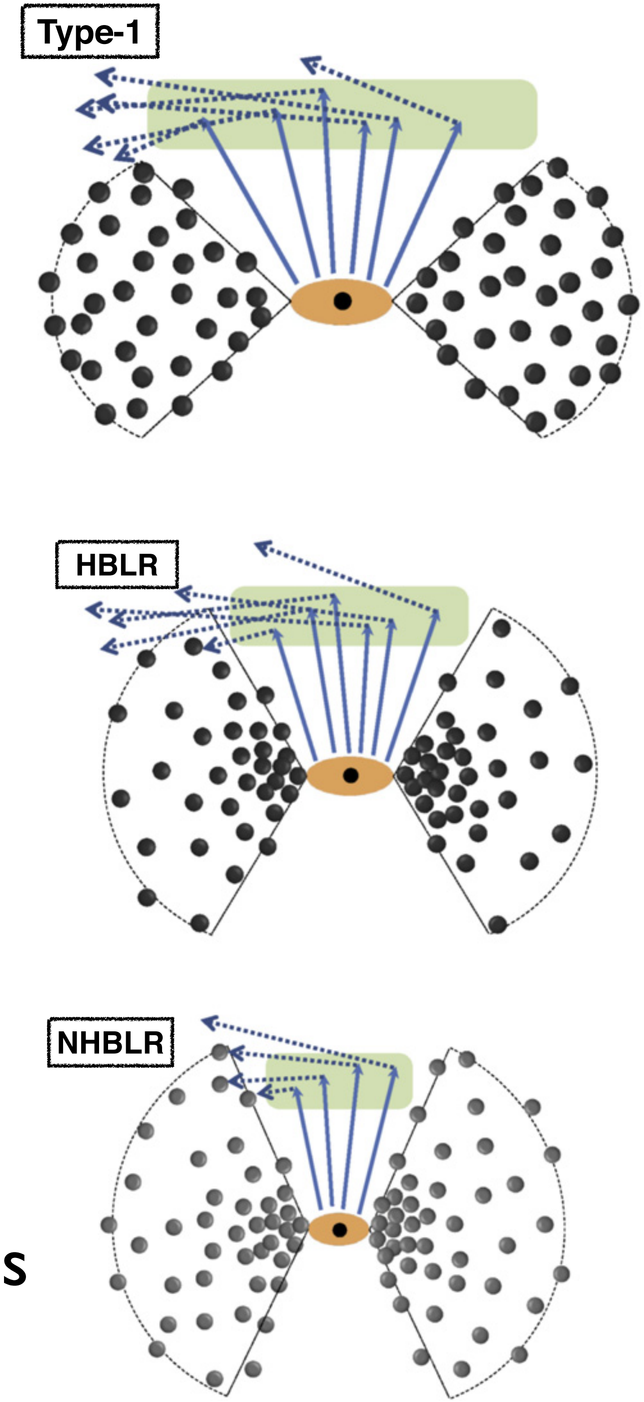
Small Survey Size (21 AGN) Results



- σ = torus scale height
- Y = torus radial thickness
- N_0 = number of clouds along an equatorial ray
- q = clump distribution (compact vs. extended torus)
- τ_v = optical depth of each cloud

Torus Structural Changes?

- Should be confirmed via a bigger survey these suggest that the torus size and structure changes between HBLR and NHBLR objects
- HBLR objects have a smaller covering fraction, larger opening angle, and material is more concentrated to the inner torus as compared to NHBLR objects
- Thus NHBLR would be less likely to scatter radiation into our LoS, and polarized flux less likely to be observed



TMT Observations

- Need more and at high spatial resolution to continue this work
  - JWST spatial resolution insufficient to make big progress

1. Could we progress to see evolution of torus structure vs. z?
2. What is the nature of the torus material and its connection with the ISM of the host galaxy?
3. How do the properties, such as, geometry and optical depth, of the torus depend on the AGN luminosity and/or activity class?
4. Do the dust properties (composition, grain size) change with the AGN luminosity/type?
5. What is the role of nuclear (< 100 pc) starbursts in feeding and/or obscuring AGNs?
6. Low luminosity AGN with no tori (naked AGN)

TMT Synergies

- Clear connections to ALMA and JWST
- Connection to other science cases of Msigma relationship?
- Future of torus research could be ‘coherence’ with outflows, if torus is an outflow region
  - Highly related to accretion rate, mass, Edington, etc. ?

Instrument Needs

- Really want 1-13um high spatial resolution imaging and low spectral resolution (few 100)