MIDI/VLTI AGN observations and clumpy tori statistics

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Questions

Can we reproduce a sample of MIR interferometric observations of dust tori using current models?

What is the structure of the dust torus? Size, geometry, density profile.

Do Seyfert Type I and Type II share general properties? Standard model valid?

Fueling of the Active Nuclei? What role does the torus of gas and dust play in this?
Torus Models

Hoenig, S. 2012
Schartmann clumpy tori (2008)

- 3D radiative transfer
- Multiple dust species
- Edge-shaped disk with random clouds.
- RADMC3D for radiative transfer.
- Inner radius determined by Sublimation temperature.

\[
\rho_{\text{cont}}(r, \theta, \phi) = \rho_0 \left( \frac{r}{1 \text{ pc}} \right)^\alpha
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner radius of the torus</td>
<td>0.4 pc</td>
</tr>
<tr>
<td>Outer radius of the torus</td>
<td>50 pc</td>
</tr>
<tr>
<td>Half opening angle of the torus</td>
<td>45°</td>
</tr>
<tr>
<td>Total optical depth in equatorial plane</td>
<td>(\langle \tau_{9.7 \mu m} \rangle_{\phi} )</td>
</tr>
<tr>
<td>Exponent of continuous density distribution</td>
<td>-0.5</td>
</tr>
<tr>
<td>Number of grid cells in (r) direction</td>
<td>97</td>
</tr>
<tr>
<td>Number of grid cells in (\theta) direction</td>
<td>31</td>
</tr>
<tr>
<td>Number of grid cells in (\phi) direction</td>
<td>120</td>
</tr>
</tbody>
</table>

**additional in clumpy model**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of clumps</td>
<td>400</td>
</tr>
<tr>
<td>Exponent of clump size distribution</td>
<td>(\beta) = 1.0</td>
</tr>
<tr>
<td>Constant of clump size distribution</td>
<td>(a_0) = 0.2 pc</td>
</tr>
<tr>
<td>Optical depth of each clump</td>
<td>(\tau_{\text{clump}}^{9.7 \mu m}) = 0.38</td>
</tr>
<tr>
<td>Average number of cells per clump</td>
<td>272</td>
</tr>
</tbody>
</table>
AGN MIDI DATA

- Data from the Large Program (LP) from Burtscher et al. (2013).
- We exclude Centaurus A, 3C 273 and NGC 1068.
- 20 sources to compare, with at least 3 baselines available.
- Currently we only take values for correlated fluxes at 8.5, 10. , 11.5 um.
- We use only correlated fluxes. No single dish flux.
Normalization

- Hard-xray luminosity 14-195 KeV not absorbed by the dust tori. If 14-195 KeV luminosity not available we use 2-10 KeV luminosity.

- Assume a constant ratio between the hard-xray luminosity and luminosity from the accretion disk. (ratio ~ 10)

\[ \nu F_\nu = \nu f_\nu \left( \frac{D_s}{D_m} \right)^2 \left( \frac{L_m}{L_s} \right) \]

\[ BL_m = BL_{AGN} \left( \frac{D_m}{D_s} \right) \left( \frac{L_s}{L_m} \right)^{0.5} \]

Marconi et al (2009)
• No direct fit of the spectrum of each source. Validate models from a statistical point of view

• Include in analysis possible degeneration of model due to uncertainty of inclination and position angle.

• Randomness in clouds distribution can create differences for models with same parameters.
Method

• For each source we create a n-dimensional vector containing correlated fluxes at the available (u,v) points and required wavelengths. \( N = (\text{number of } (u,v) \text{ points}) \times (\text{number of wavelengths}) \).

• Project a model on sky for different inclinations and position angles (images).
1. Rescale the fluxes and baselines of the real sources according to previous relations. Simulate observations with rescaled baselines for all sources.

2. Compute distribution of simulated fluxes and include Gaussian distributions to model uncertainties.

3. Apply transformations to simulated distributions so that final distribution has a dispersion equal to one and zero mean. Apply same transformations to real observations.

4. Apply a chi-square test to compare both distributions.
Consistency

Consistency test
200 simulated experiments.
Artificial baselines.
Model with same parameters but different randomness of clumps.

Convergence of distribution

Chi square for the mean and variance
Preliminary results

Rout = 50 pc

Filling factor = 15 %

Filling factor = 30 %
Preliminary results

Rout = 25 pc

Filling factor = 15 %

Filling factor = 30 %
Seyfert type 1
Different properties or missed good parameters?
Spectral shape

Total flux from model

Observed AGN
Correlated fluxes + Chromatic phases

Rout = 25 pc

Filling factor = 15 %

Filling factor = 30 %

[Graph showing mean optical depth at equator vs density slope for Type II with different filling factors]
Things to do

- Investigate more deeply for probable models to reproduce Type I sources.
- Estimate effect of uncertainties due to X-ray Luminosity normalization.
- Compare AGN interferometric observations with other radiative models.
- Include other wavelengths and/or SED.
Thank you for your attention