MIDI/VLTI AGN observations and clumpy tori statistics

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Questions

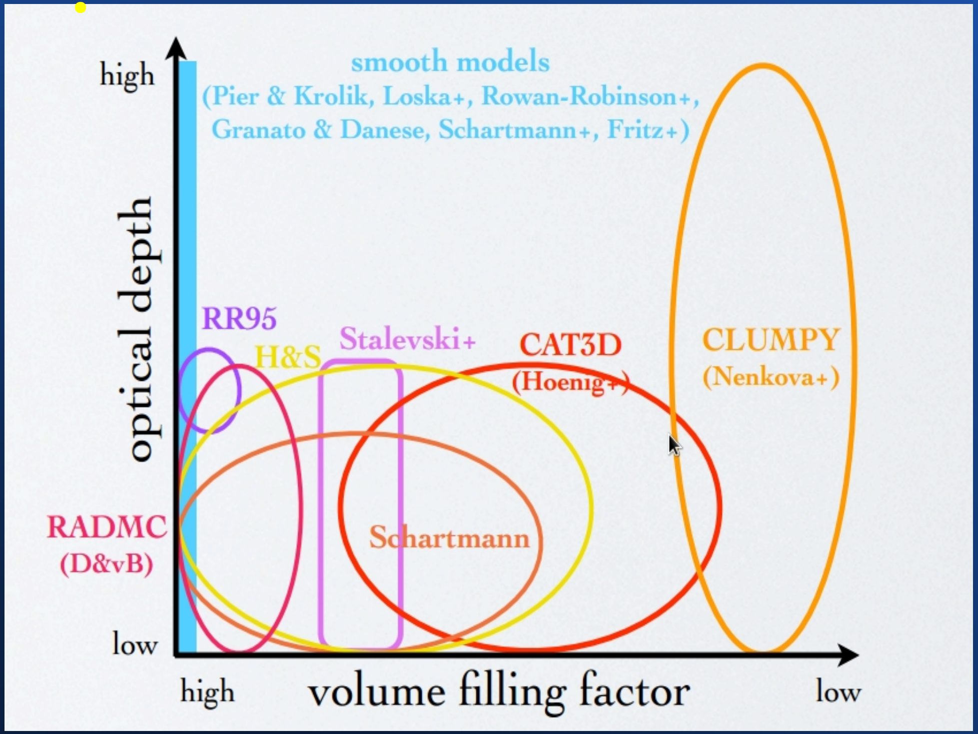
Can we reproduce a sample of MIR interferometric observations of dust tori using current models?

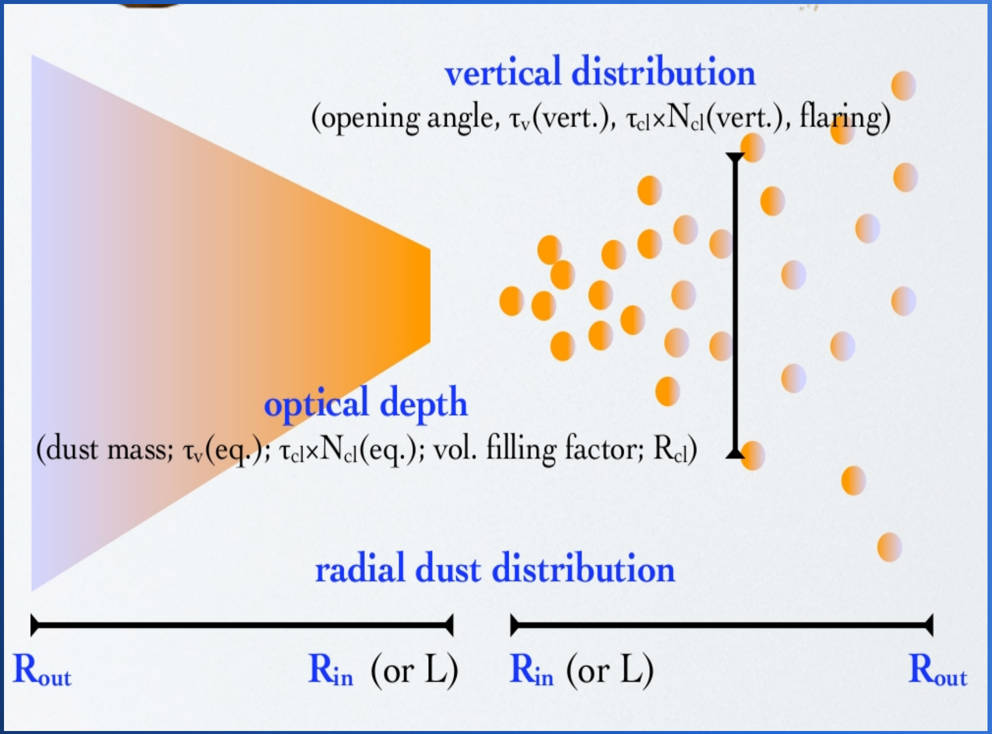
What is the structure of the dust torus ? Size, geometry, density profile.

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



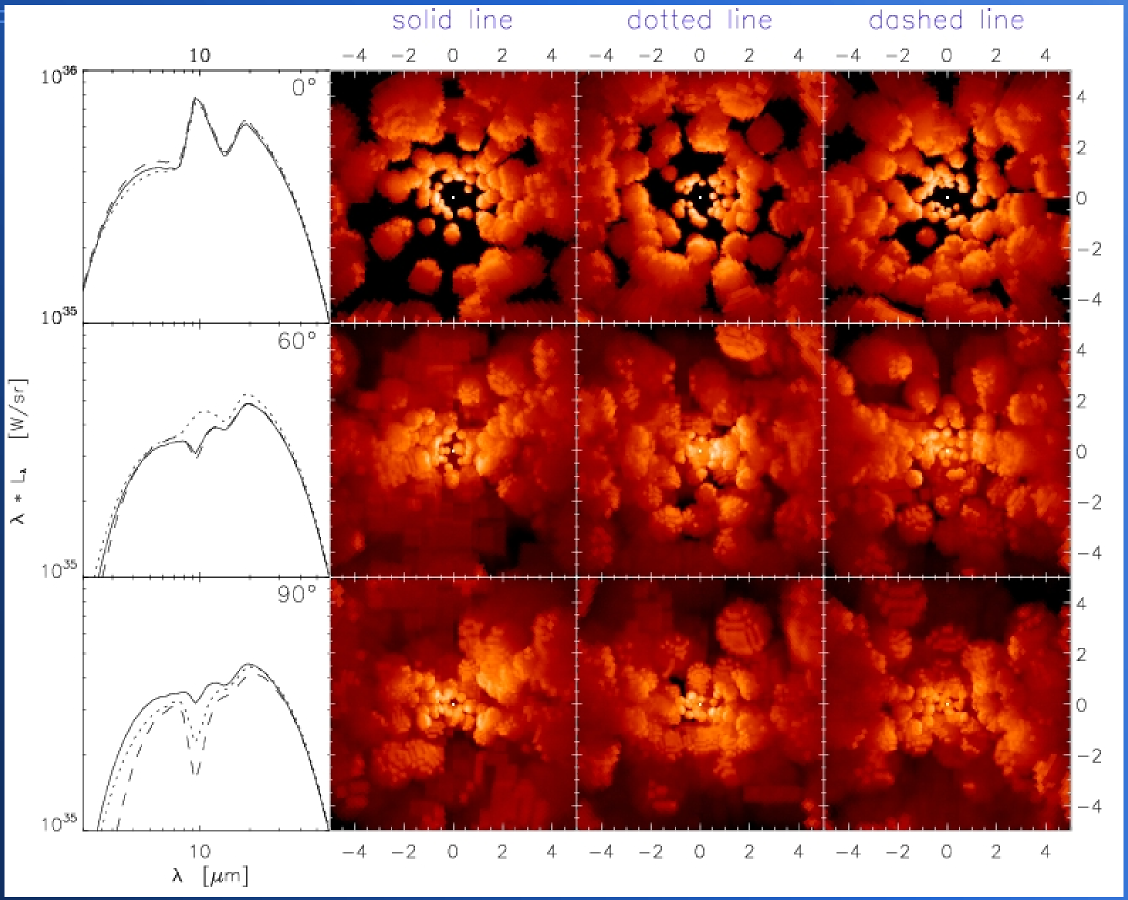


Hoenig, S. 2012

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.

inner radius of the torus	R_{in}	0.4 pc
outer radius of the torus	R_{out}	50 pc
half opening angle of the torus	θ_{open}	45°
total optical depth in equatorial plane	$\left\langle \tau_{9.7\,\mu\mathrm{m}}^{\mathrm{equ}} \right\rangle_{\phi}$	2.0
exponent of continuous density distribution	α	-0.5
number of grid cells in r direction		97
number of grid cells in θ direction		31
number of grid cells in ϕ direction		120
additional in clumpy model		
number of clumps	N_{clump}	400
exponent of clump size distribution	β	1.0
constant of clump size distribution	a_0	0.2 pc
optical depth of each clump	$\tau_{9.7\,\mu\mathrm{m}}^{\mathrm{clump}}$	0.38
average number of cells per clump		272



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

Schartmann et al.(2008)

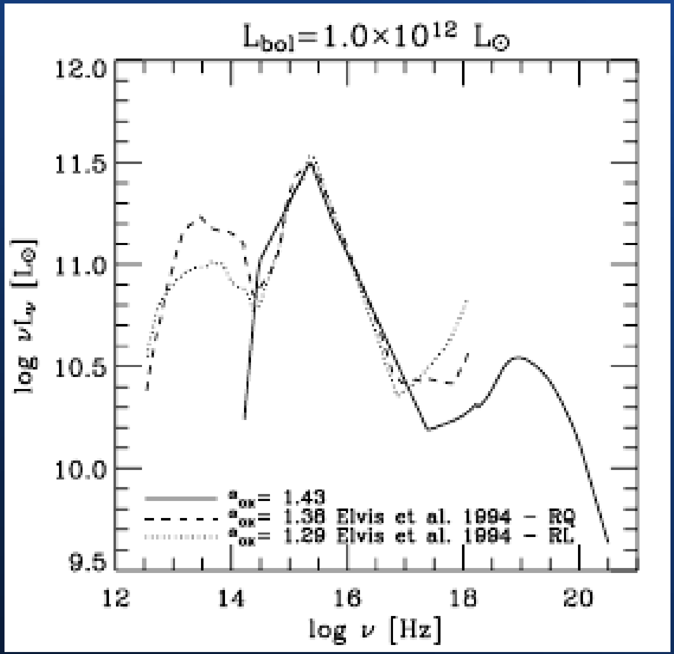
AGN MIDI DATA

	Name	RA [h m s]	Dec [° ′ ″]	Type (1)
1	I Zw 1	00 53 35.1	+12 41 34	NL Sy 1
2	NGC 424	01 11 27.6	−38 05 00	Sy 1h
3	NGC 1068	02 42 40.7	−00 00 48	Sy 1h
4	NGC 1365	03 33 36.4	−36 08 25	Sy 1.8
5	IRAS 05189−2524	05 21 01.7	−25 21 45	Sy 1h
6	H 0557−385	05 58 02.1	−38 20 04	Sy 1.2
7	IRAS 09149−6206	09 16 09.4	−62 19 30	Sy 1
8	MCG−05−23−16	09 47 40.2	−30 56 54	Sy 1i
9	Mrk 1239	09 52 19.1	−01 36 43	NL Sy 1
10	NGC 3281	10 31 52.1	−34 51 13	Sy 2
11	NGC 3783	11 39 01.8	−37 44 19	Sy 1.5
12	NGC 4151	12 10 32.6	+39 24 21	Sy 1.5
13	3C 273	12 29 06.7	+02 03 08	Sy 1.0
14	NGC 4507	12 35 36.6	−39 54 33	Sy 1h
15	NGC 4593	12 39 39.4	−05 20 39	Sy 1.0
16	ESO 323−77	13 06 26.1	−40 24 52	Sy 1.2
17	Centaurus A	13 25 26.6	−43 01 09	?
18	IRAS 13349+2438	13 37 18.7	+24 23 03	NL Sy 1
19	IC 4329 A	13 49 19.3	−30 18 34	Sy 1.2
20	Circinus	14 13 09.9	−65 20 21	Sy 1h
21	NGC 5506	14 13 15.0	−03 12 27	Sy 1i
22	NGC 5995	15 48 25.0	−13 45 28	Sy 1.9
23	NGC 7469	23 03 15.6	+08 52 26	Sy 1.5

- 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



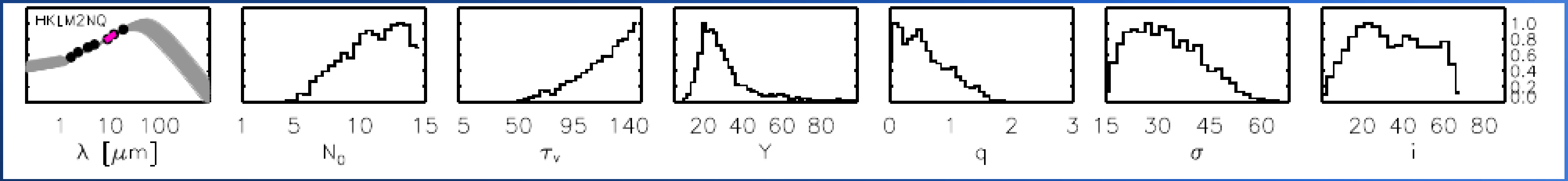
Marconi et al (2009)

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

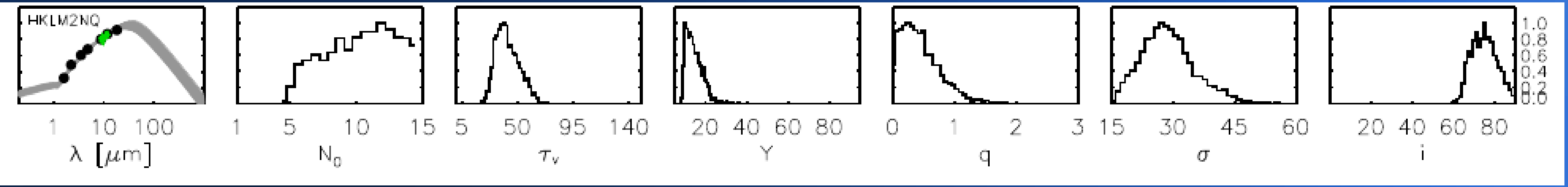
$$BL_m = BL_{AGN} \left(\frac{D_m}{D_s}\right)\left(\frac{L_s}{L_m}\right)^{0.5}$$

- 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)



Average Type I



Average Type II

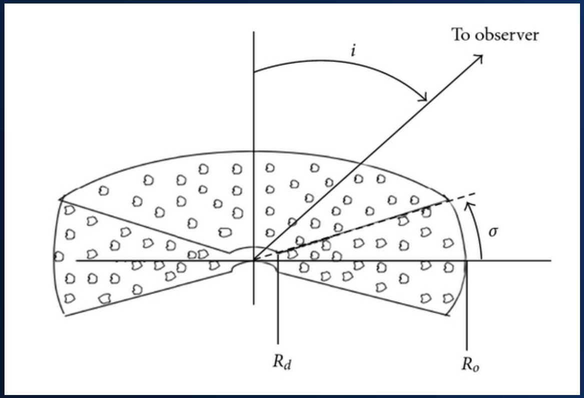
Ramos Almeida et al (2014)

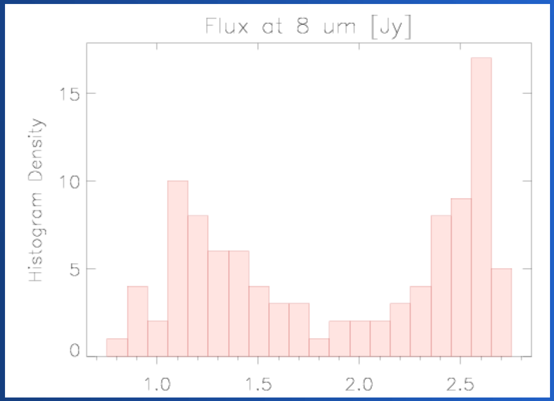
- No direct fit of the spectrum of each source. Validate models from a statistical point of view
- Include in analysis posible degeneration of model due to uncertainty of inclination and position angle.
- Randomness in clouds distribution can create differences for models with same parameters.

Method

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

- Project a model on sky for different inclinations and position angles (images).

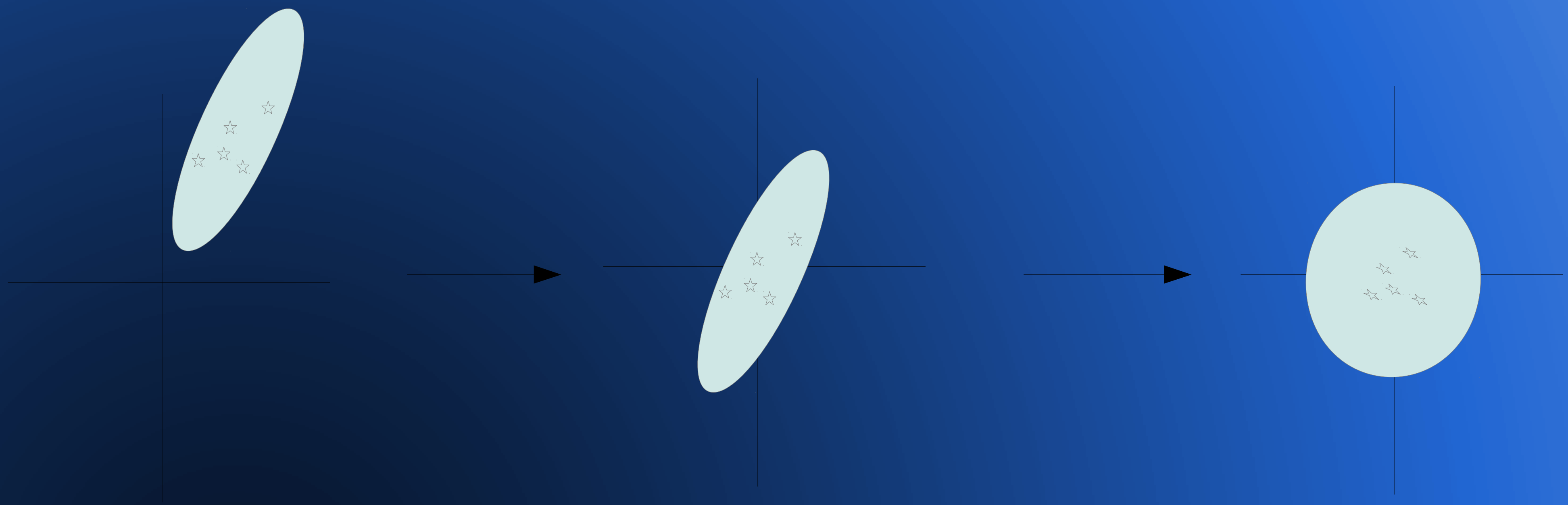
- 



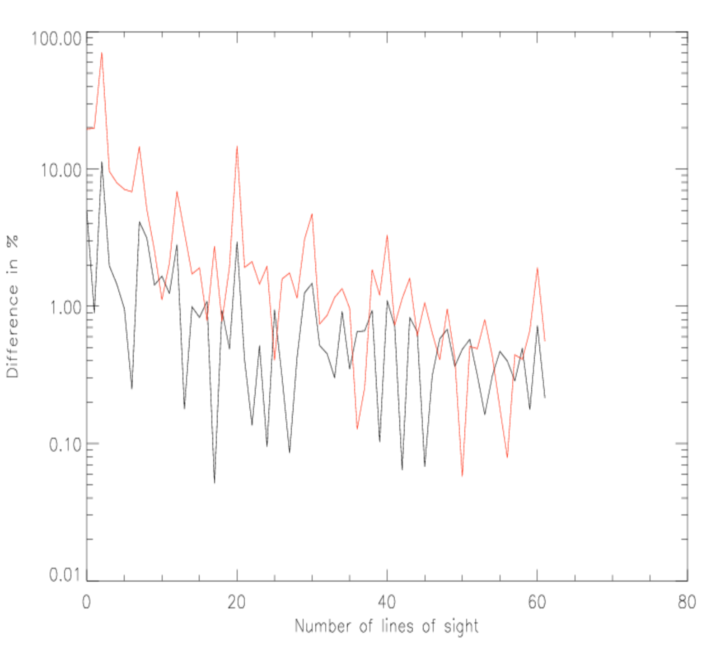
- Rescale the fluxes and baselines of the real sources acording to previous relations. Simulate observations with rescaled baselines for all sources.

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

- Apply transformations to simulated distributions so that final distribution has a dispersion equal to one and zero mean. Apply same transformations to real observations.
- Apply a chi-square test to compare both distributions.



Consistency



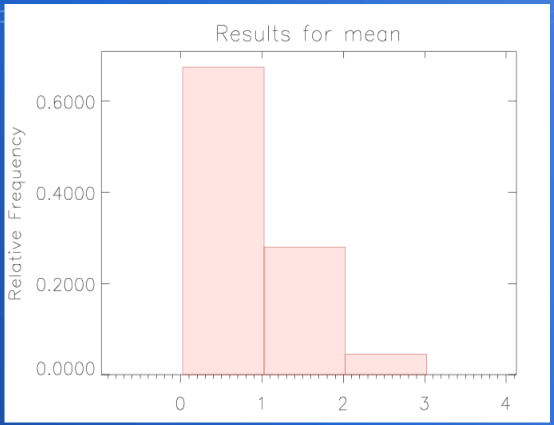
Convergence of distribution

Consistency test

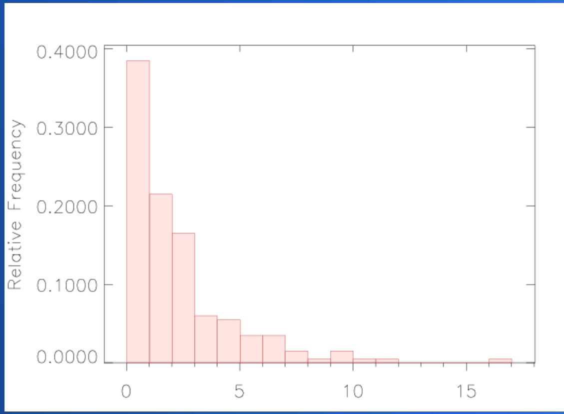
200 simulated experiments.

Artificial baselines.

Model with same parameters but different randomness of clumps.



Consistency for the mean

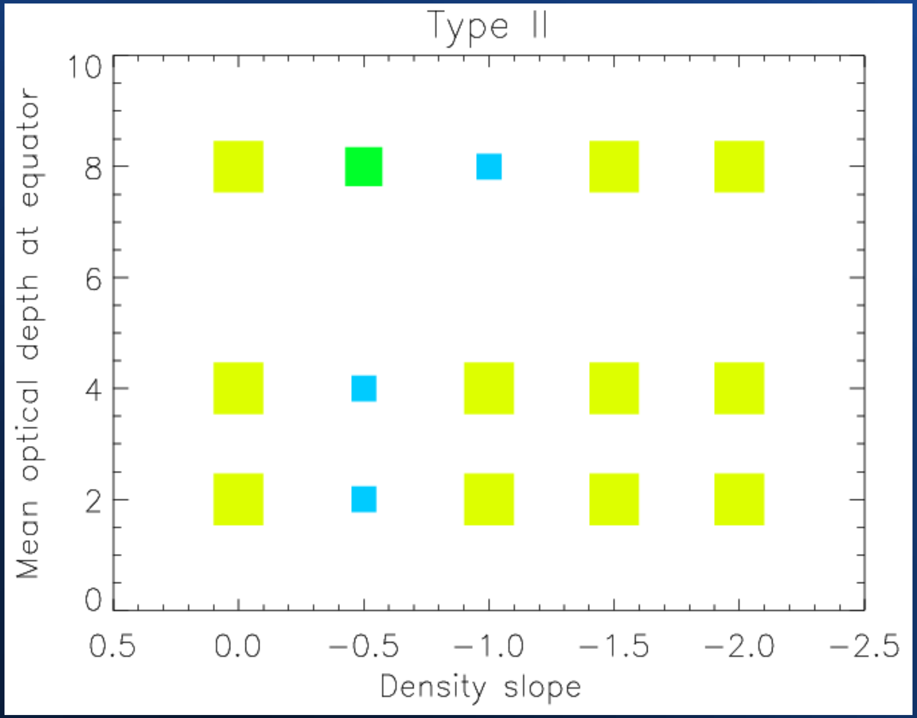


Chi square for the mean and variance

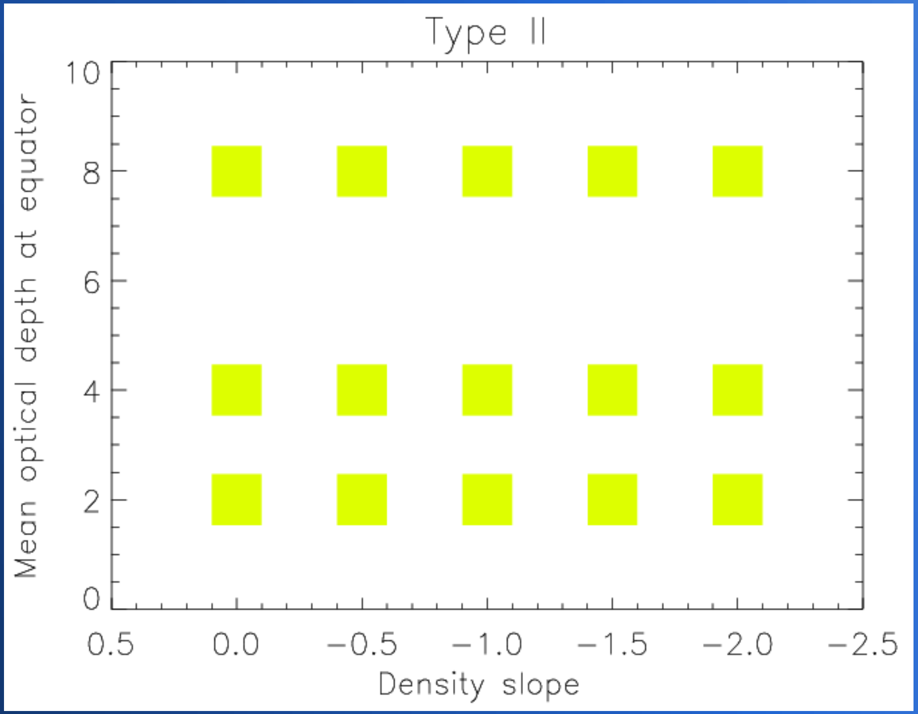
Preliminary results

Rout = 50 pc

Filling factor = 15 %



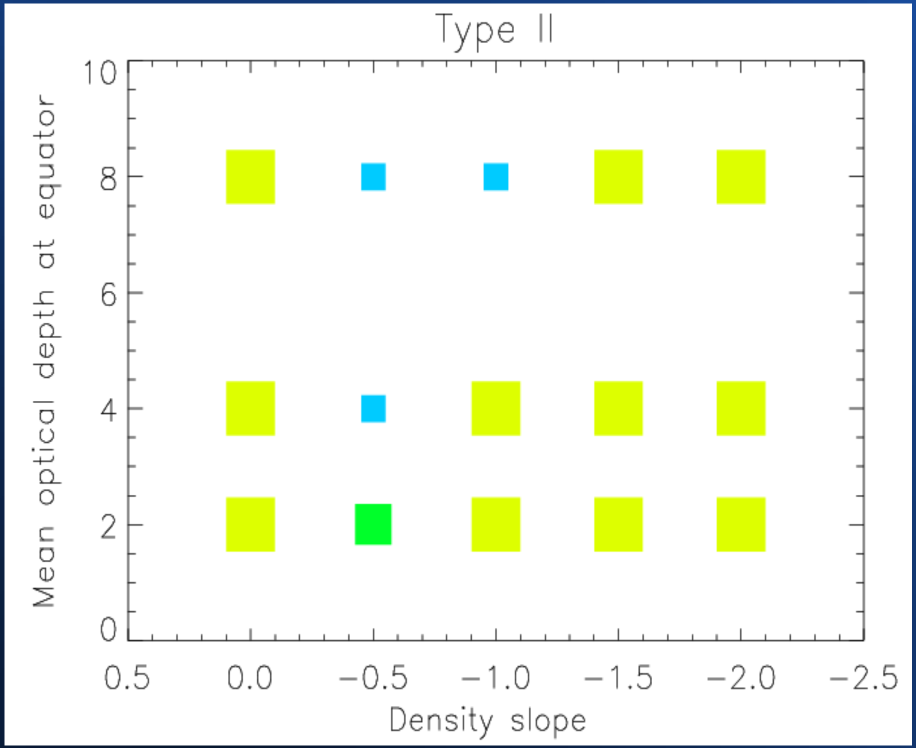
Filling factor = 30 %



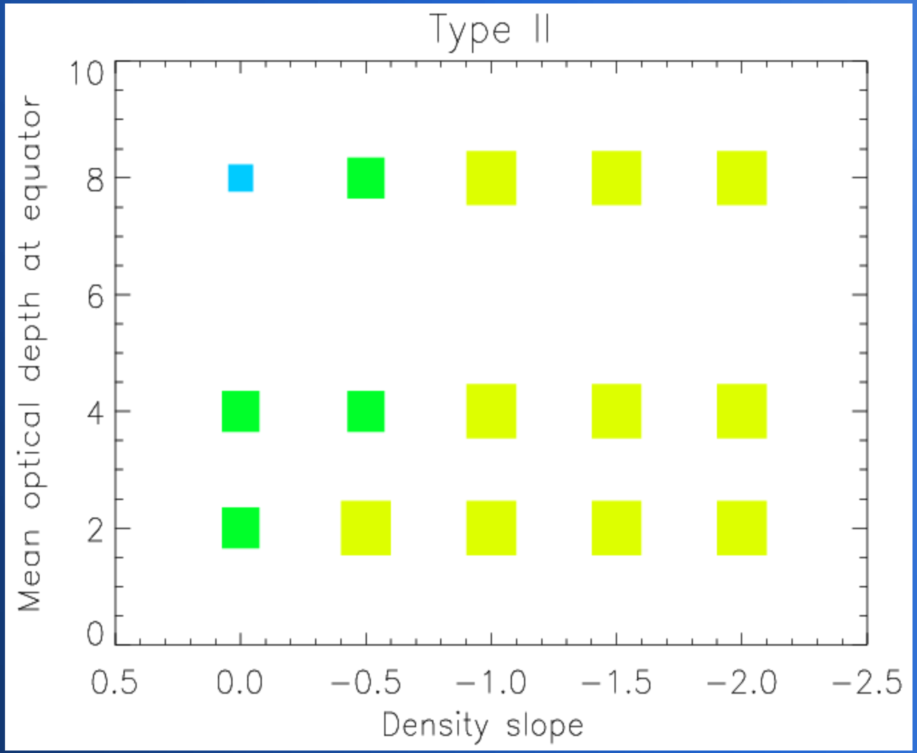
Preliminary results

Rout = 25 pc

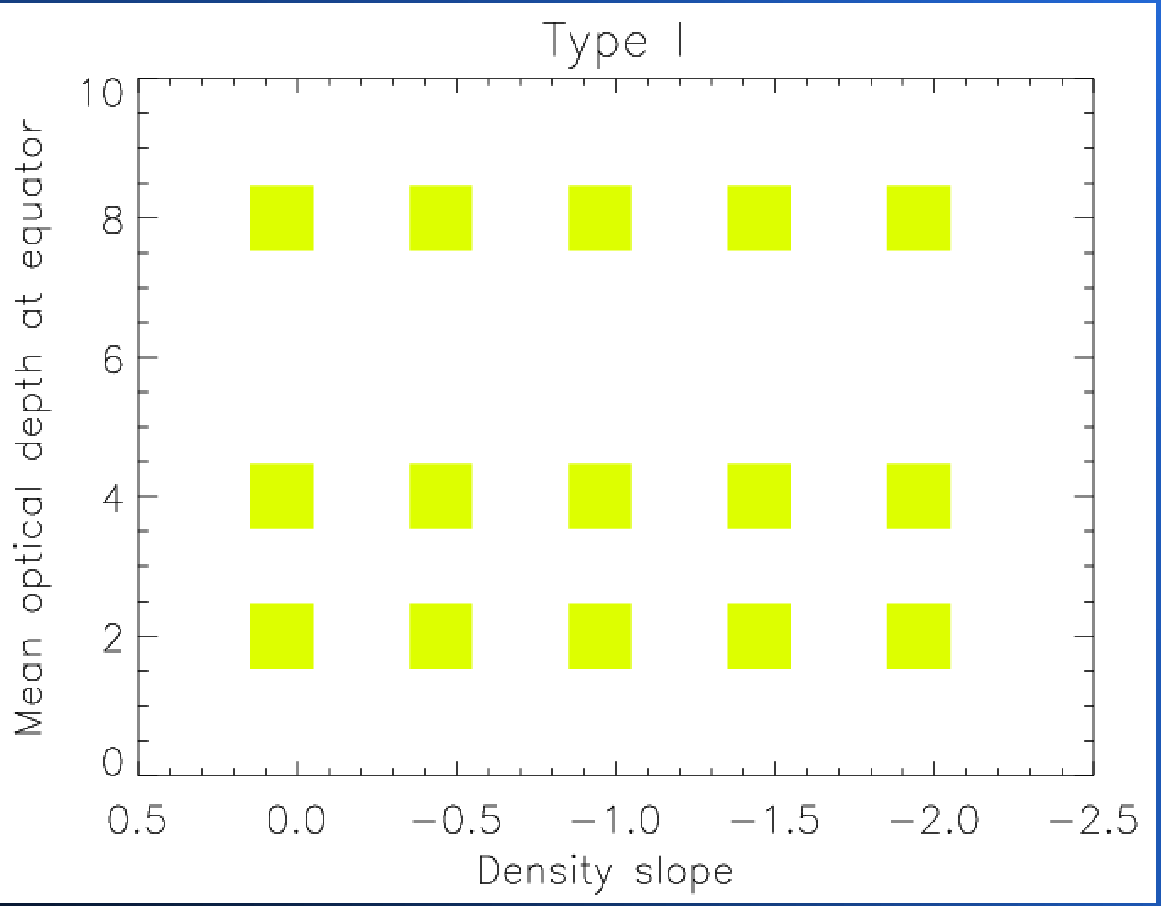
Filling factor = 15 %



Filling factor = 30 %

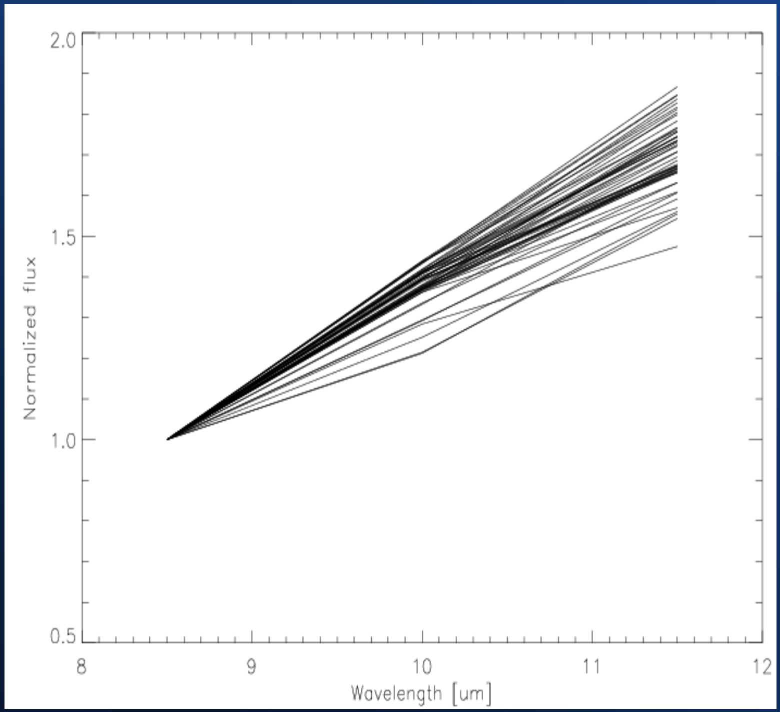


Seyfert type 1
Different properties or missed good parameters?

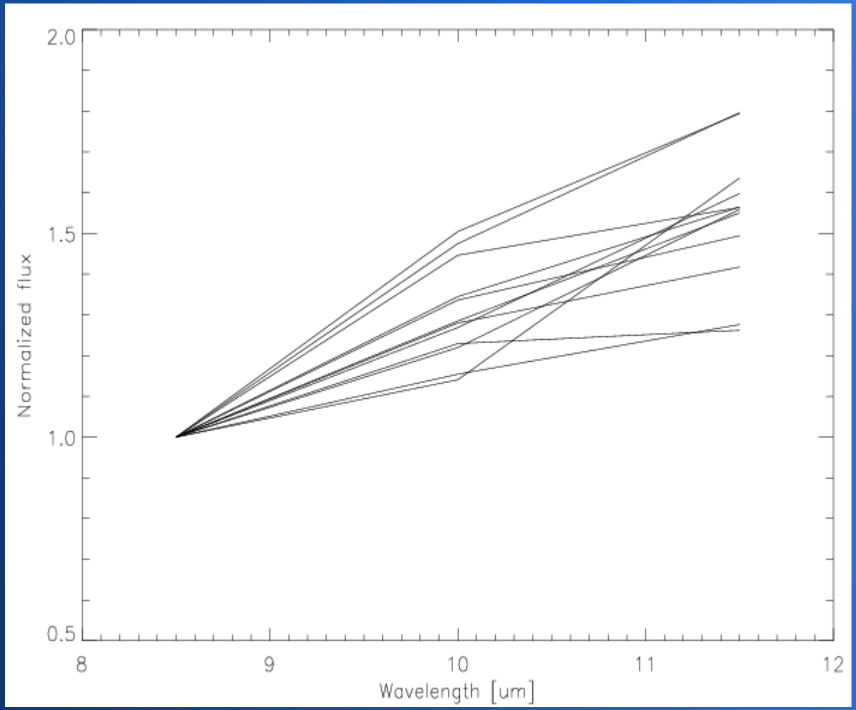


Spectral shape

Total flux from model



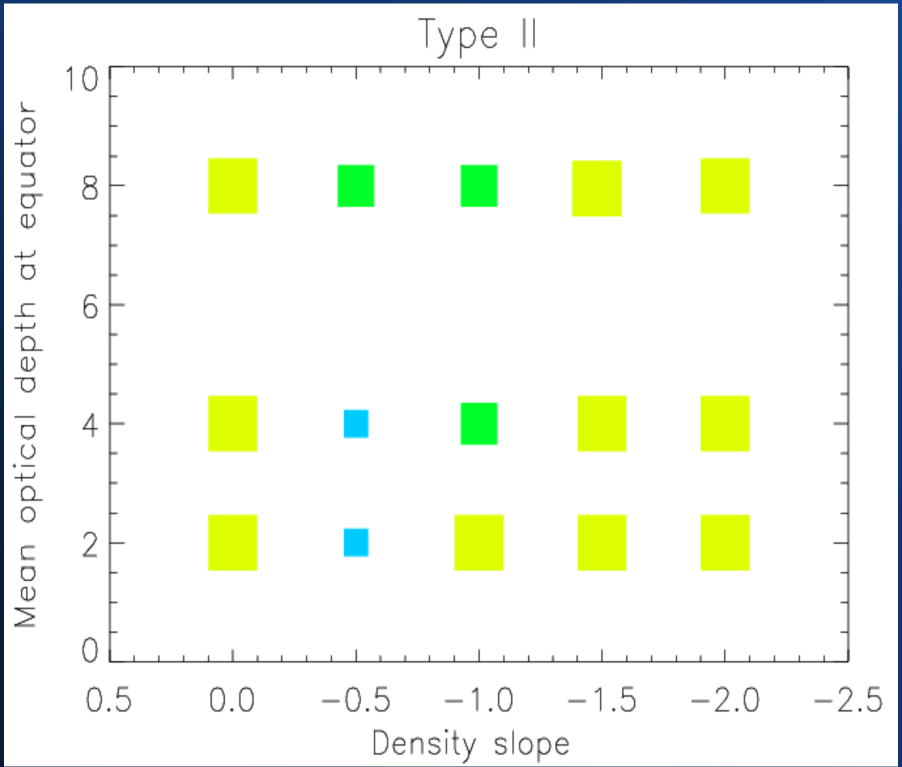
Observed AGN



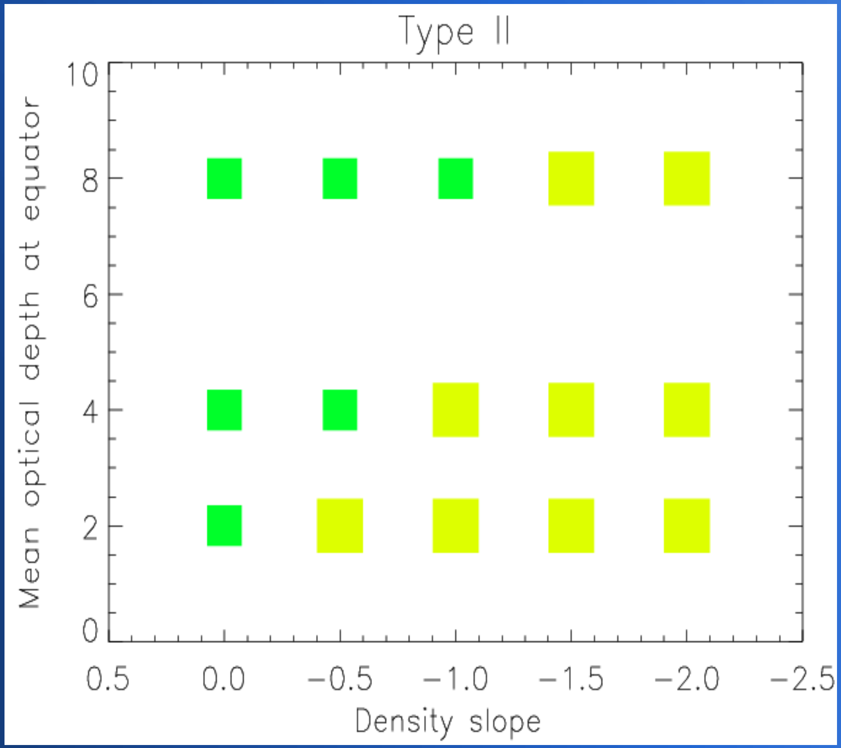
Correlated fluxes + Chromatic phases

Rout = 25 pc

Filling factor = 15 %



Filling factor = 30 %



Things to do

- Investigate more deeply for probable models to reproduce Type I sources.
- Estime 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