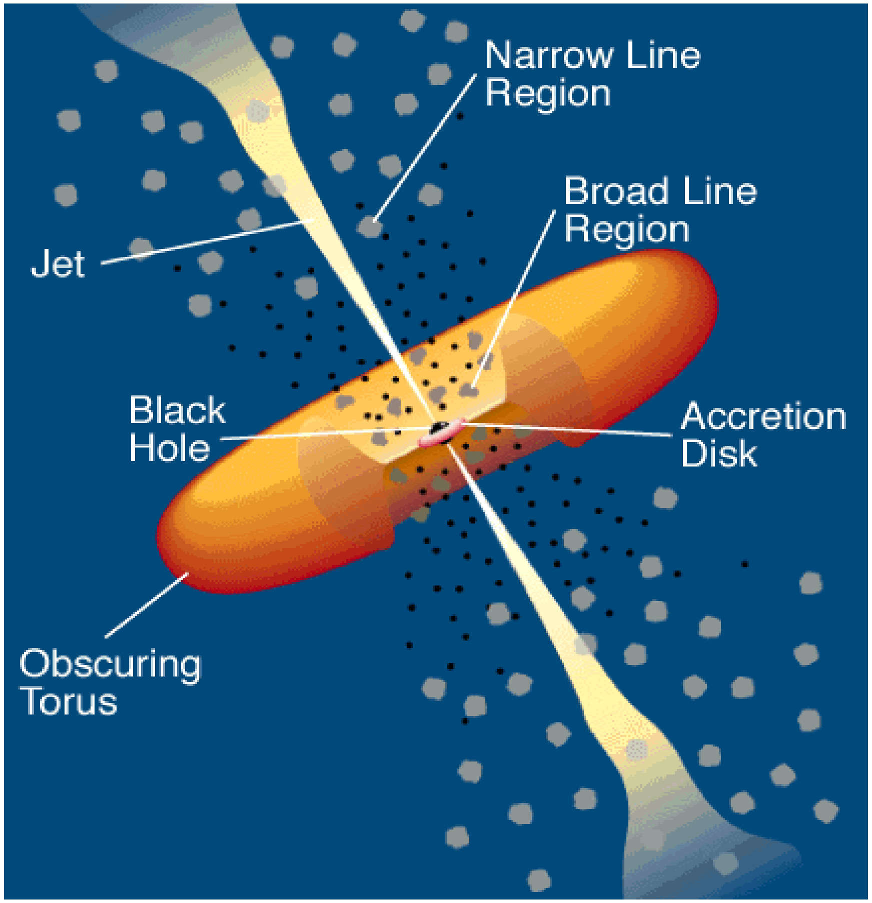
Radiative Processes in the Interstellar Medium

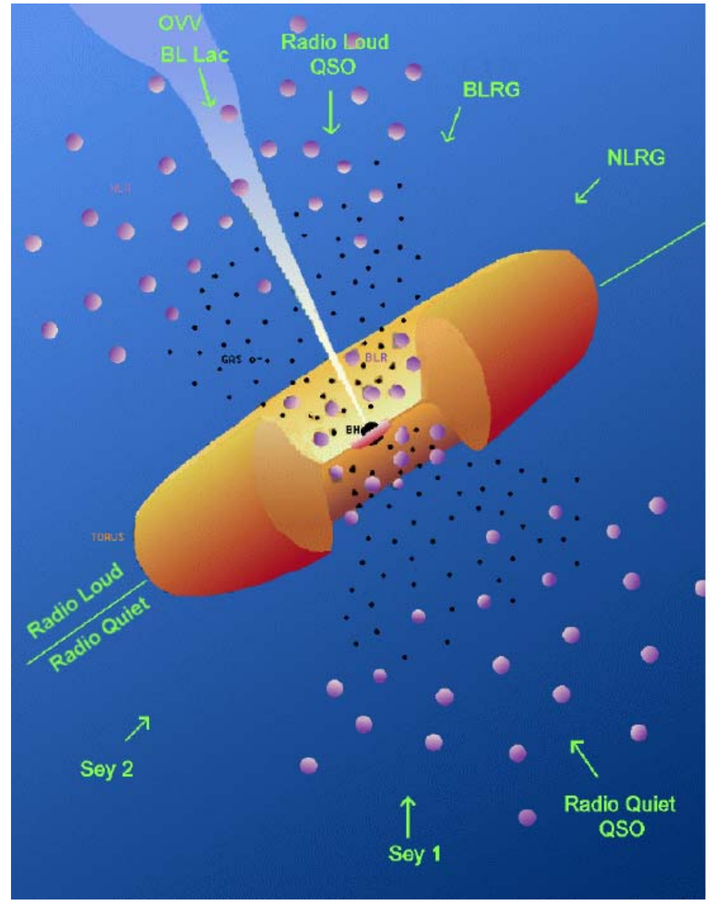
(V) IR from AGN

Moshe Elitzur
University of Kentucky

UNIVERSITY OF KENTUCKY

Unified Scheme for AGN



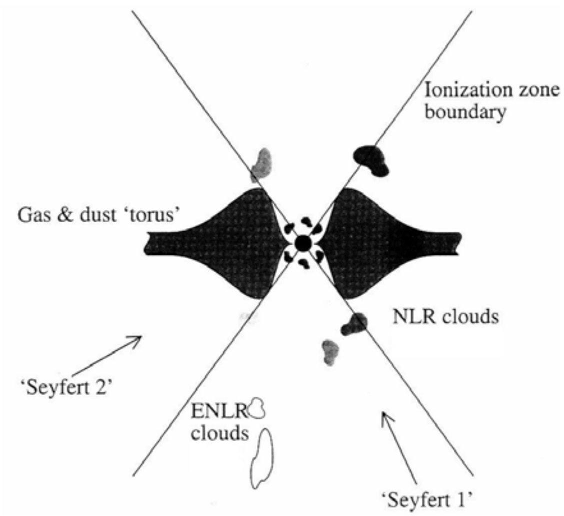


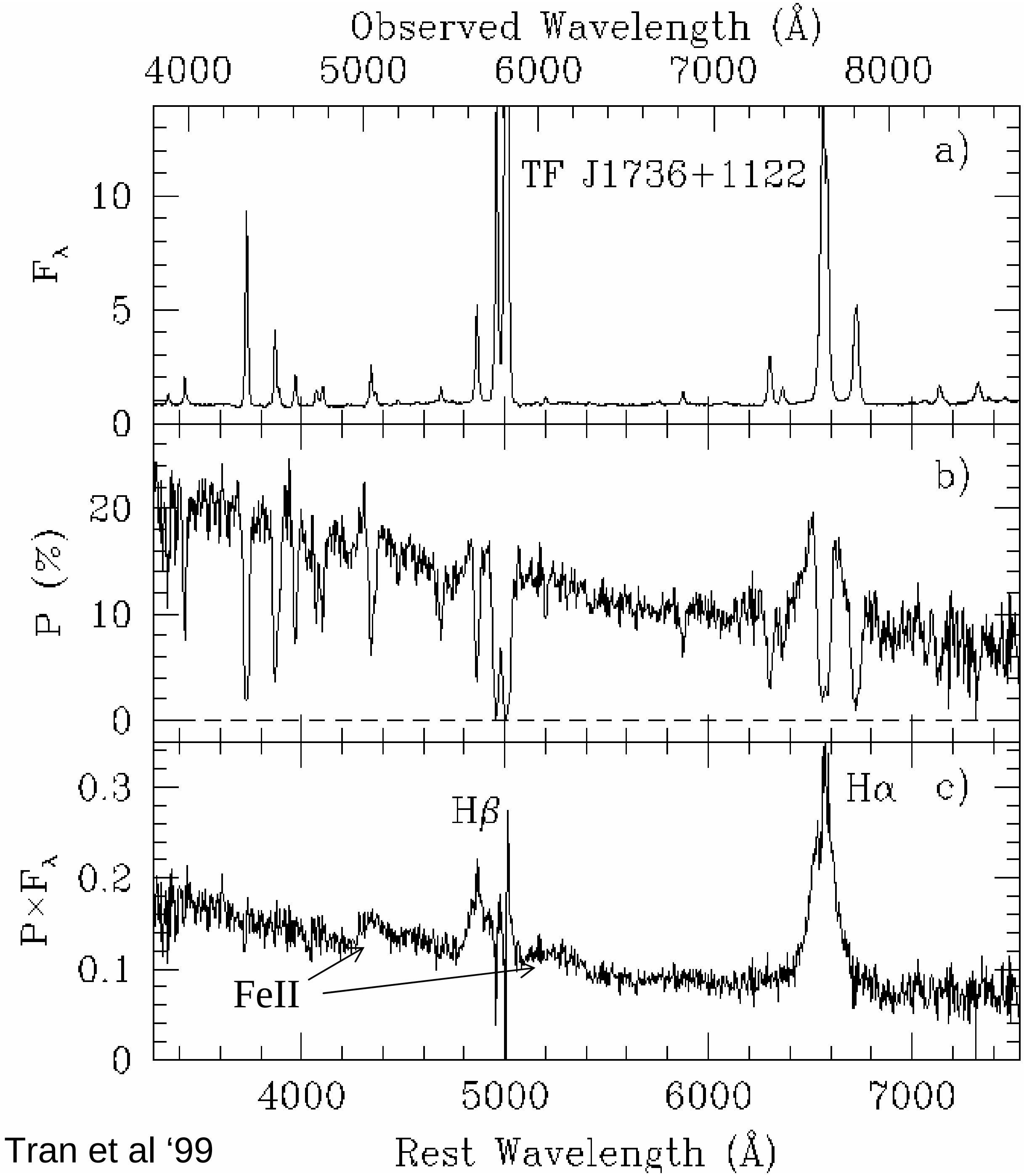
$M \sim 10^6 - 10^9\ M_\odot$

$R_s \sim 10^{11} - 10^{14}$ cm

Line Spectra

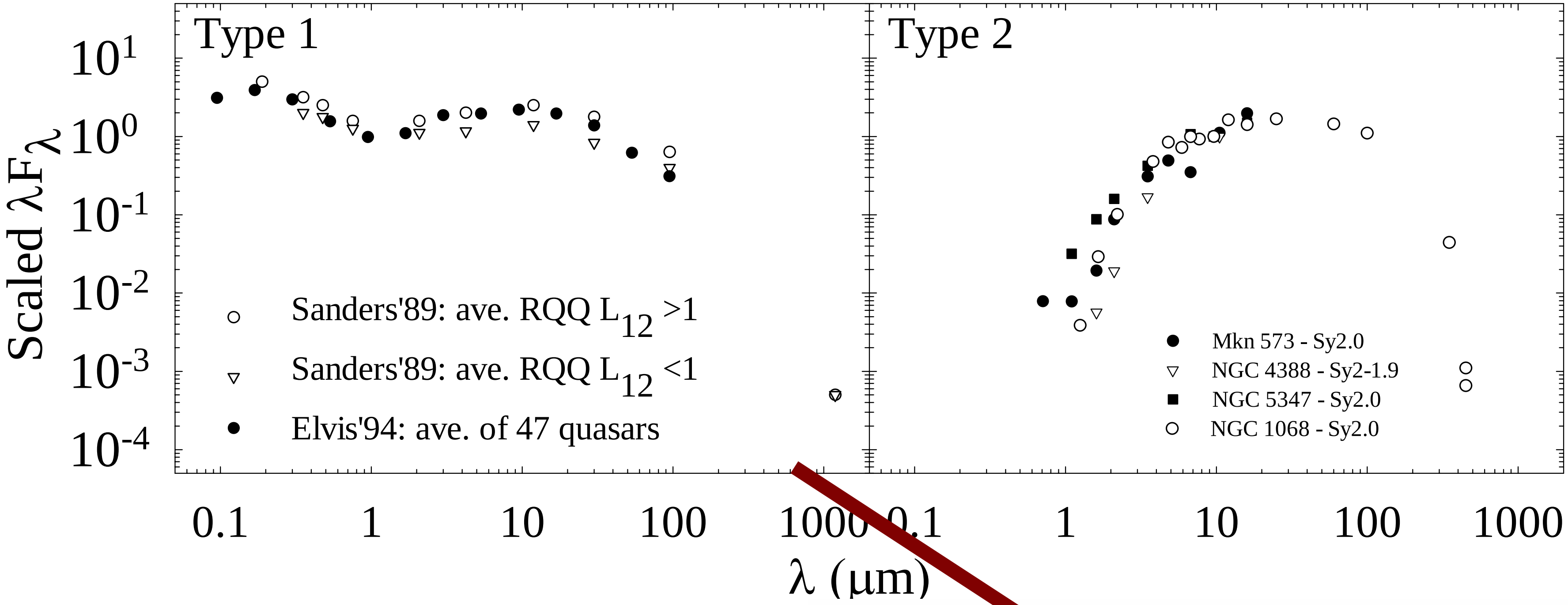
Type 2: Narrow Lines



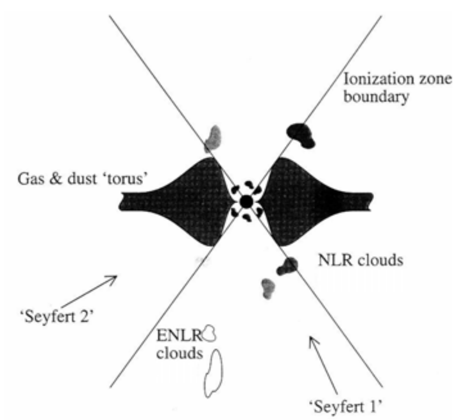


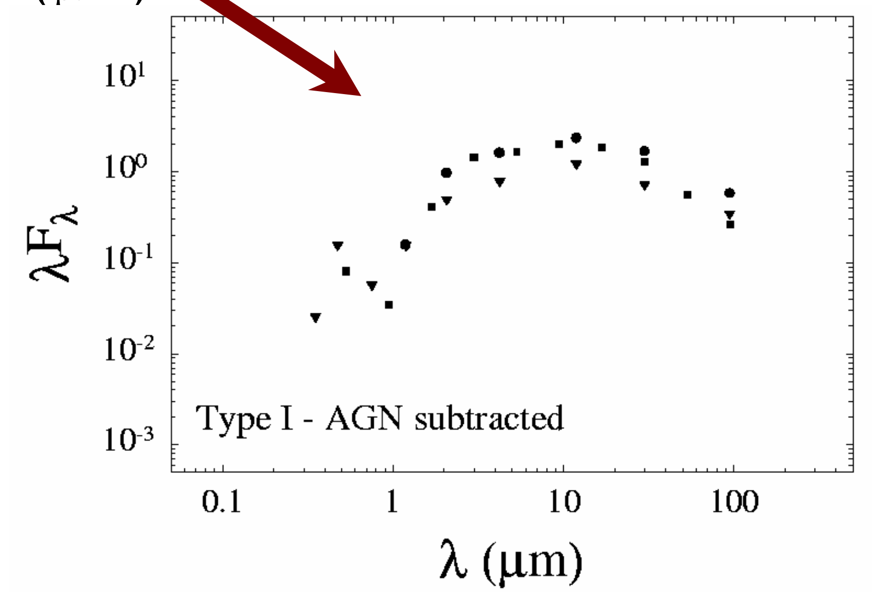
Type 1: Broad Lines

Tran et al '99



Unified Scheme – IR Successes



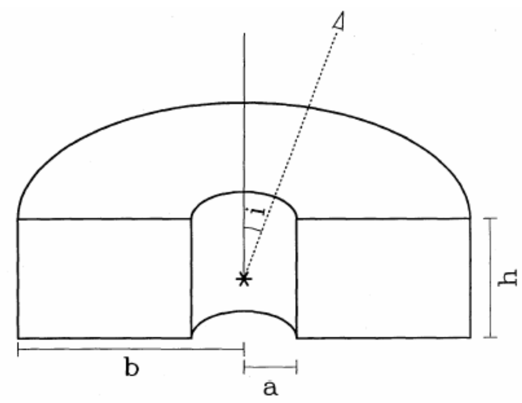


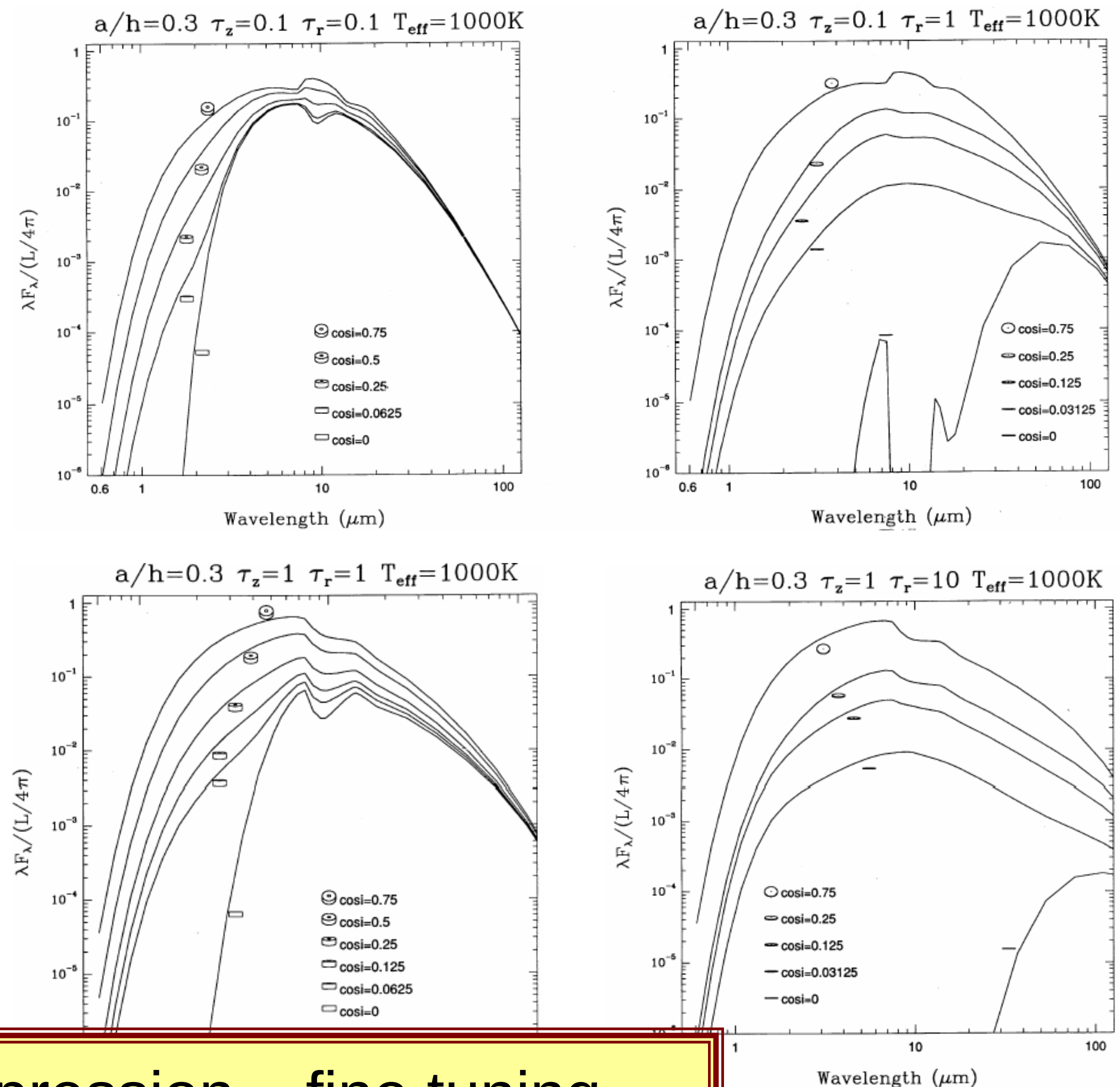
SED: I = AGN + II

Unified Scheme – IR Puzzles

- Huge column range (10^{22} – 10^{25} cm^{-2}) in x-rays, modest SED variation in IR
- 10μm absorption feature in type 2 never deep; depth uncorrelated with x-rays
- No 10μm feature in type 1

Pier & Krolik 92, 93:



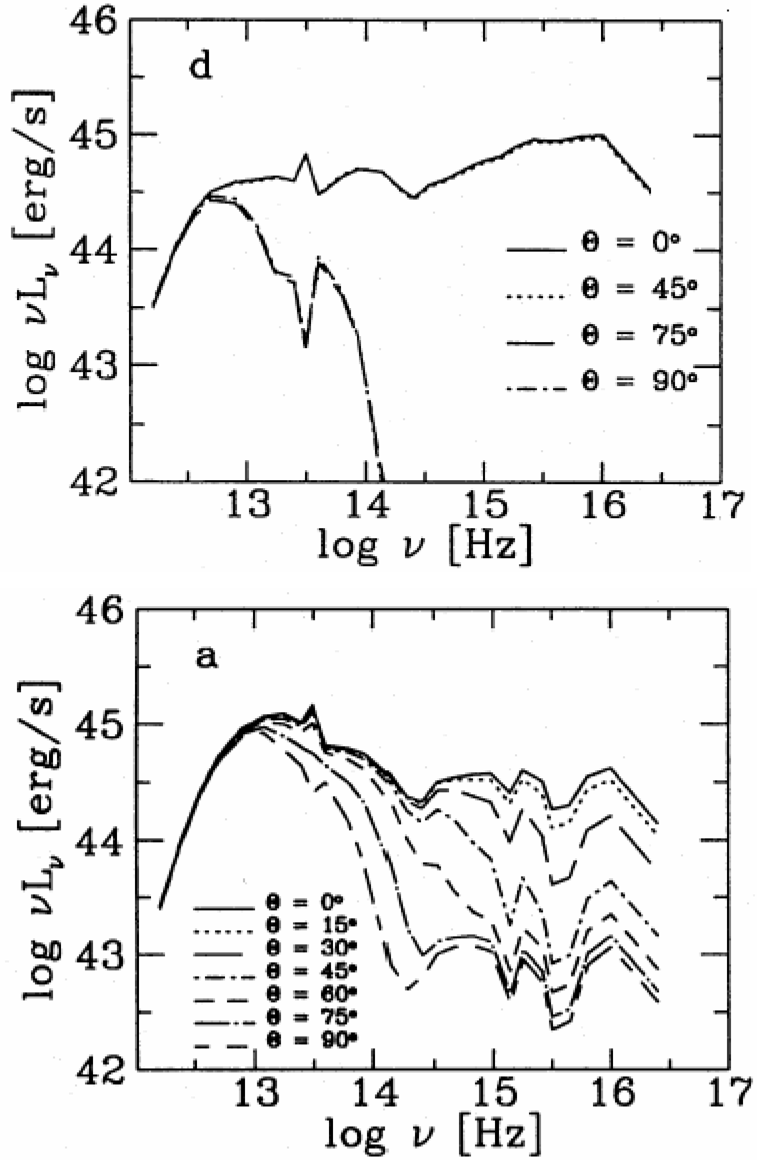


- Uniform density (although clumpy)
- No scattering

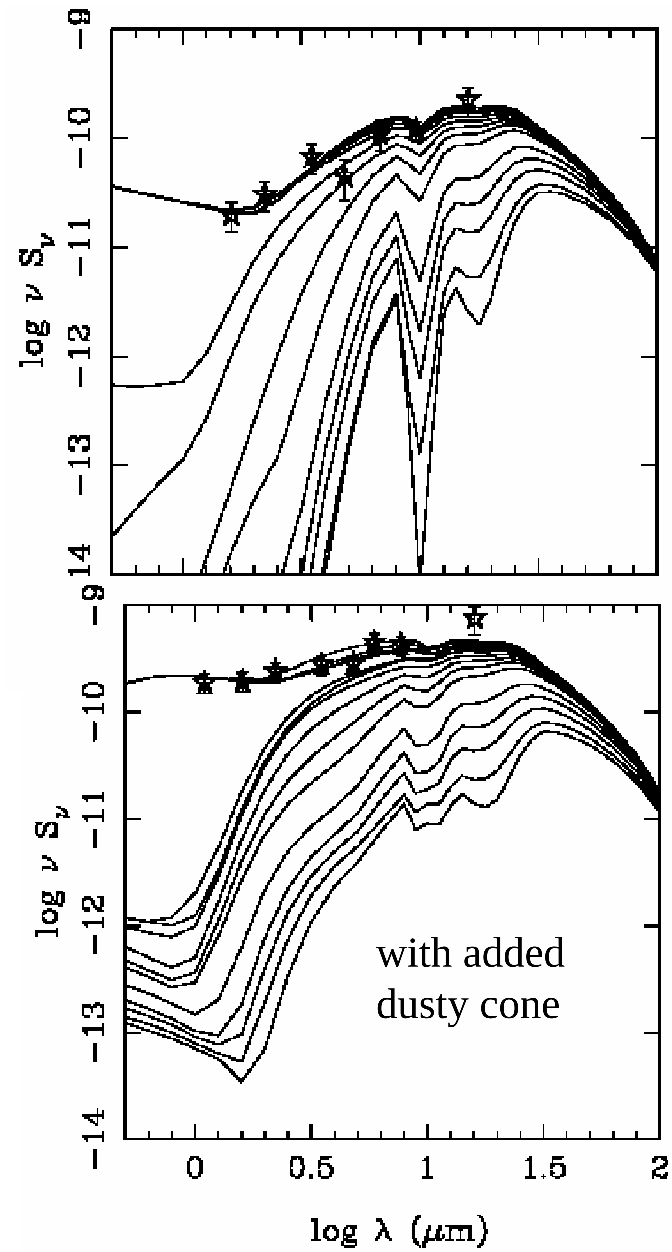
- 10μm emission suppression – fine tuning
- Extreme 10μm absorption – never observed
- Huge variation among SED's

Uniform density Models

Granato & Danese '94 – flared disks:



Efstathiou & Rowan-Robinson '95 – tapered disks:

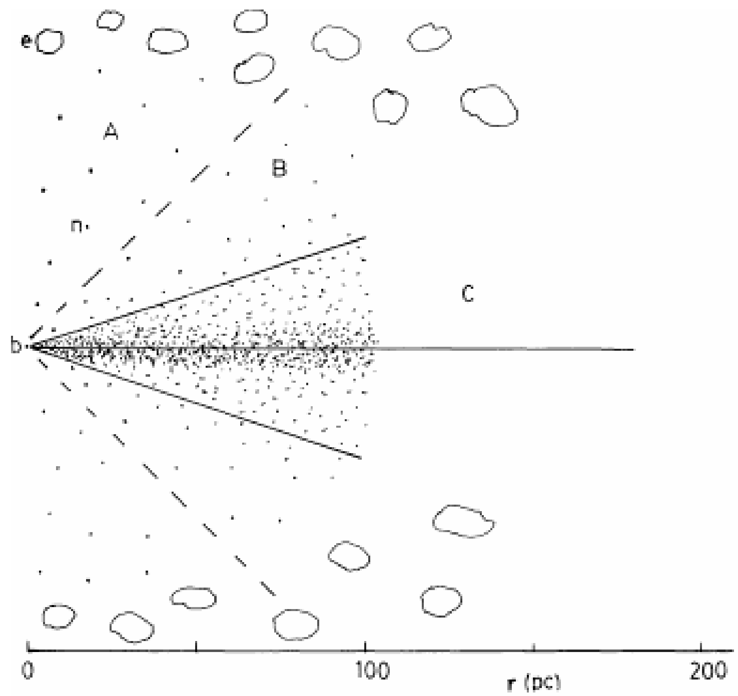


IR Puzzles

Rowan-Robinson, ApJ 1995

Nenkova, Ivezic & Elitzur, ApJ 570, L9, 2002

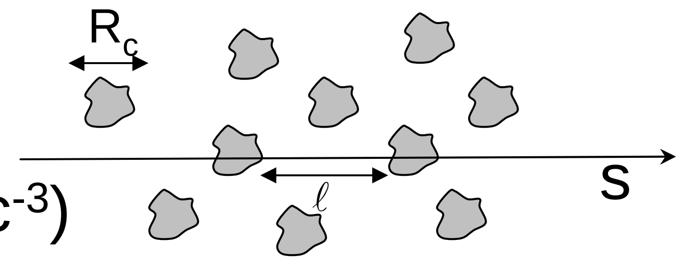
Clumps ?! / !!!



Clumpy Medium

filling factor: $\phi = n_c V_c << 1$

n_c (pc^{-3})



$\phi = n_c A_c R_c = R_c/\ell << 1$

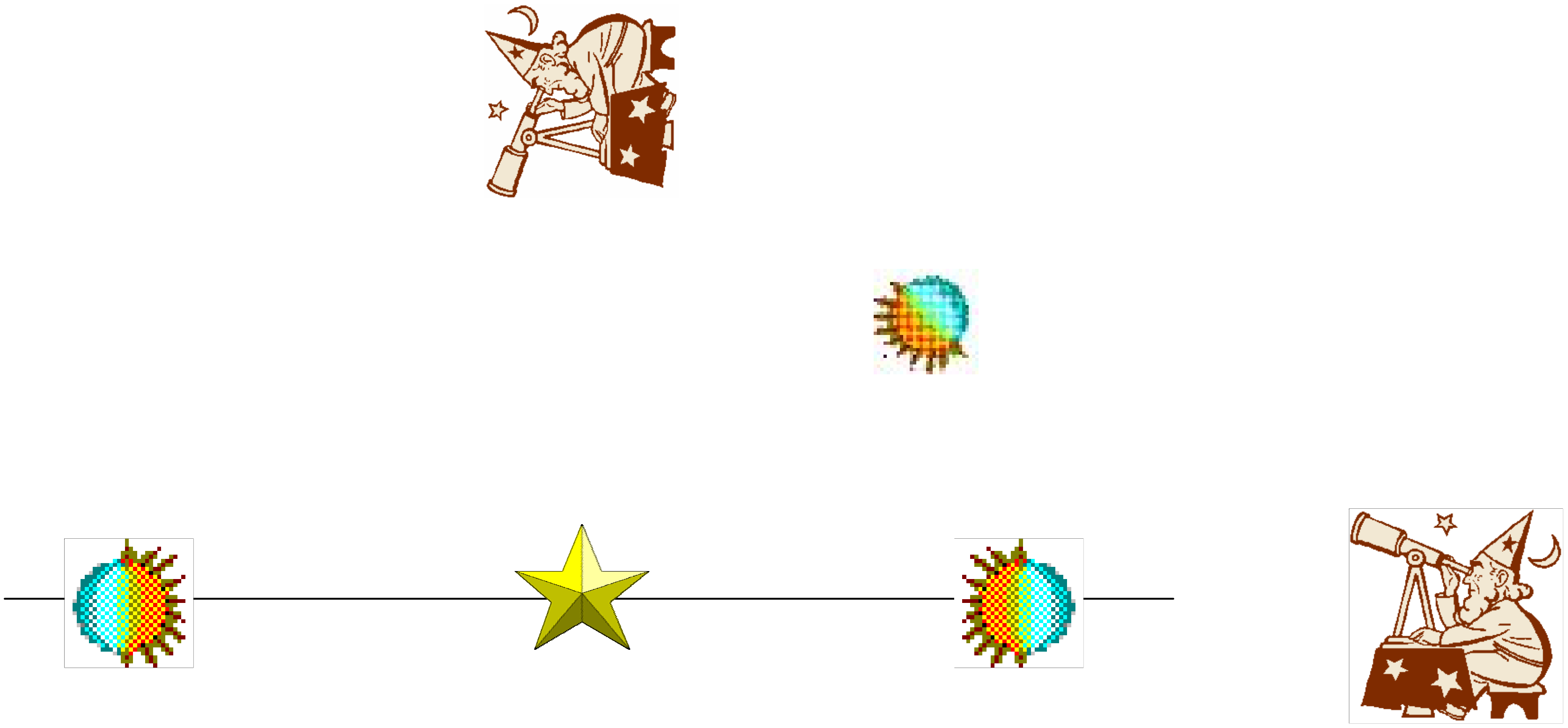
segment ds: $dN(s) = \frac{ds}{\ell(s)}$

emission: $S_{c\lambda} dN(s)$

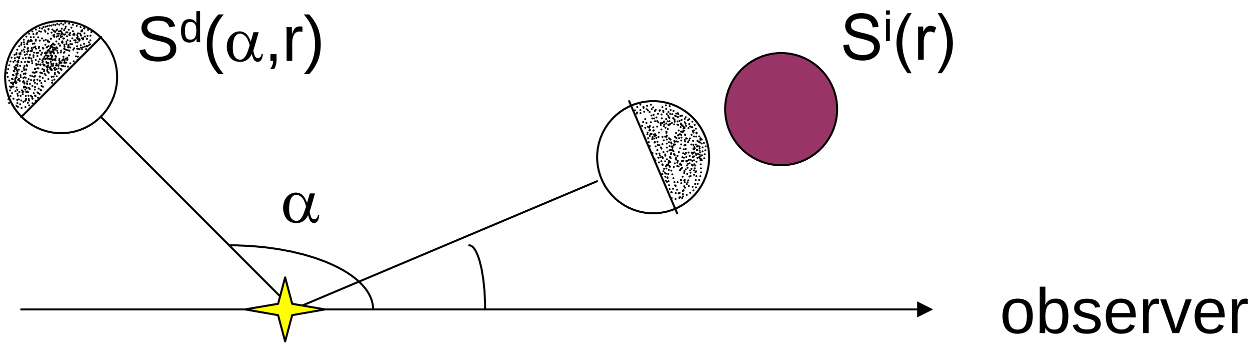
Natta & Panagia 84: $P_{esc} = e^{-t}$; $t = N(s)(1 - e^{-\tau})$

$$I_{C\lambda} = \int e^{-t} S_{c\lambda} dN(s)$$

Clump Emission - Anisotropy



Direct & Indirect Heating

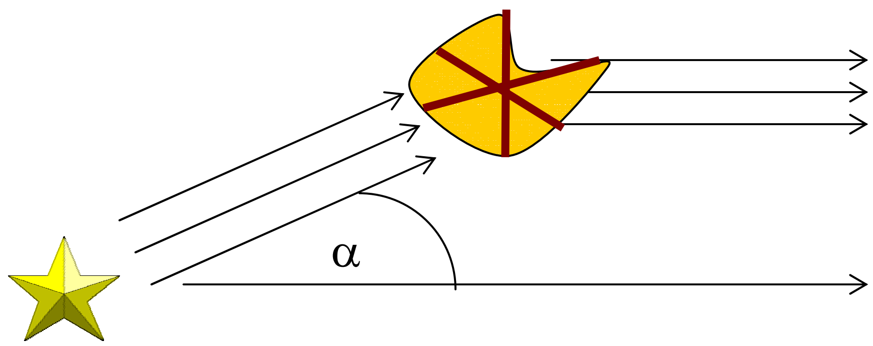


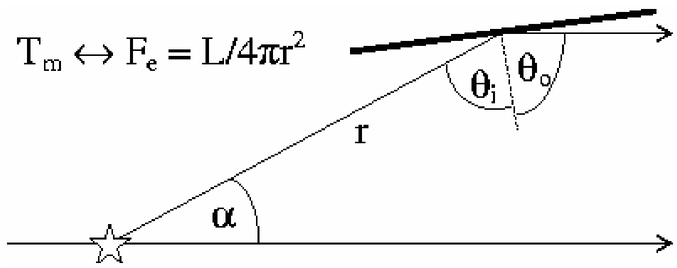
Composite source function:

$$S_c(\alpha,r) = p\,S^d(\alpha,r) + (1 - p)\,S^i(r)$$

$$p(r) = e^{-N(r)}$$

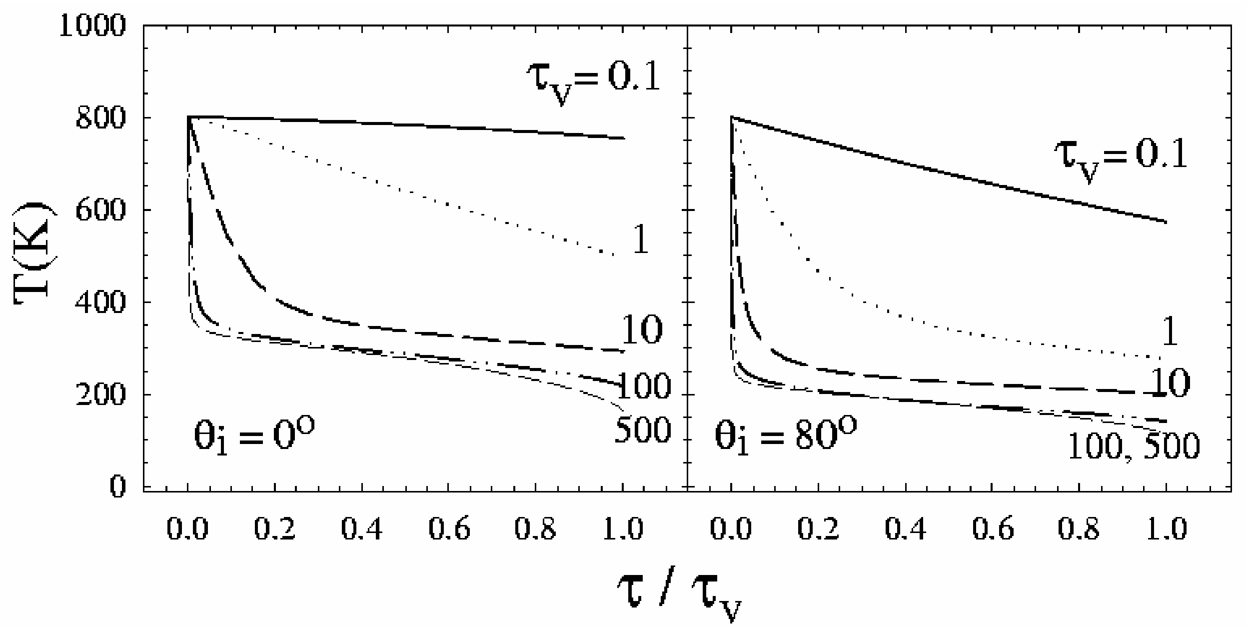
Clump modeling





Solutions by DUSTY http://www.pa.uky.edu/~moshe/dusty/

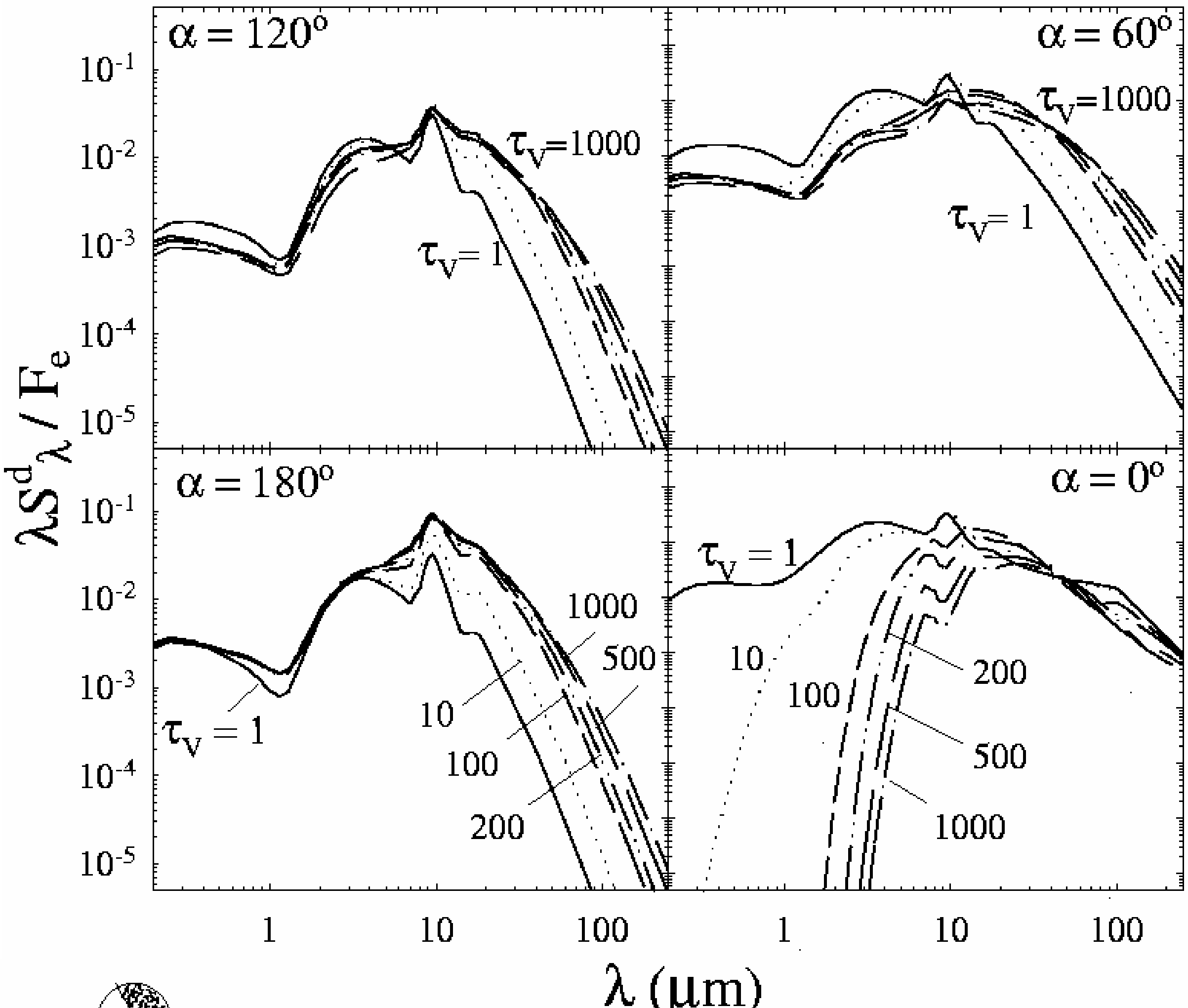
Slab Temperature Profile

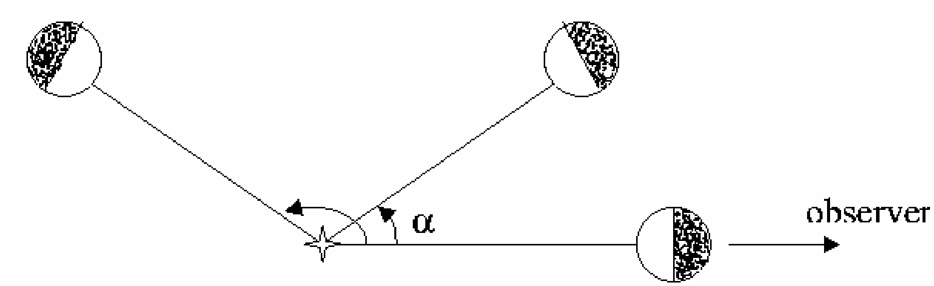


- Increase τ_V:
  - Temperature of cool material is flat
  - Temperature profile saturates

Clump emission

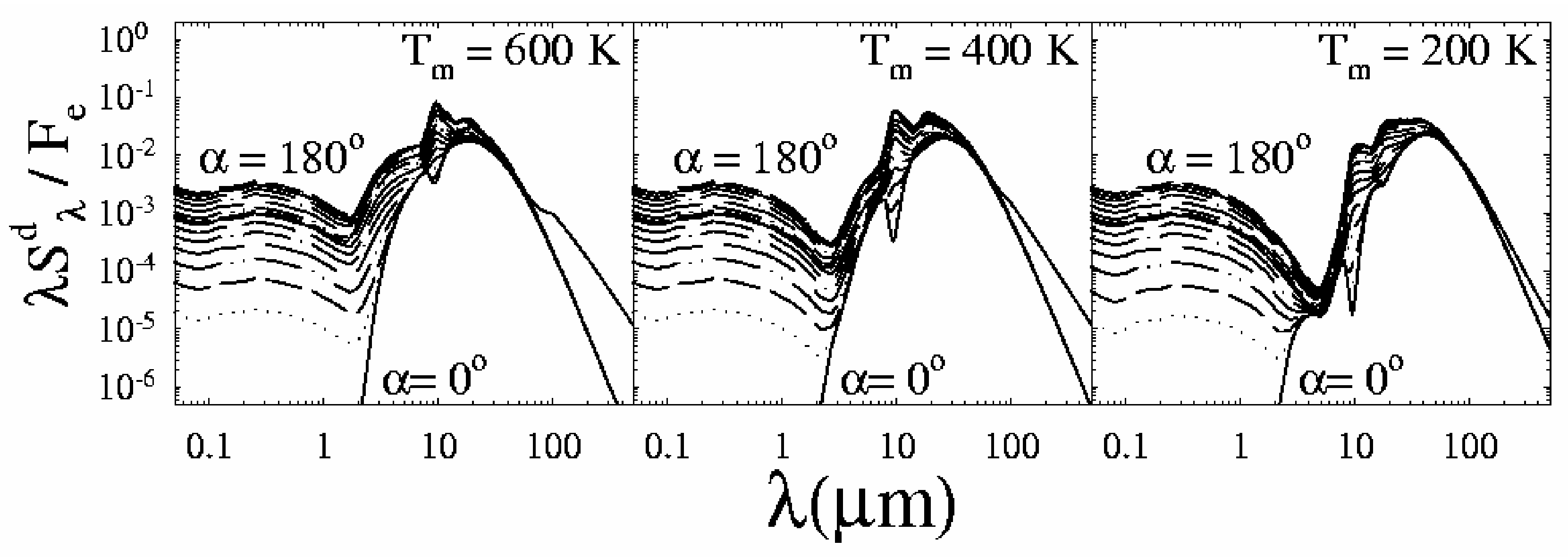
T_m = 800 K

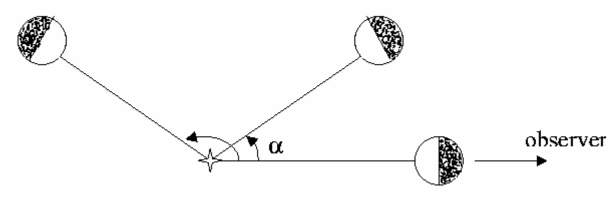




τ independence!!!

Clump emission, τ_V = 100





Limited 10μm depth!!!

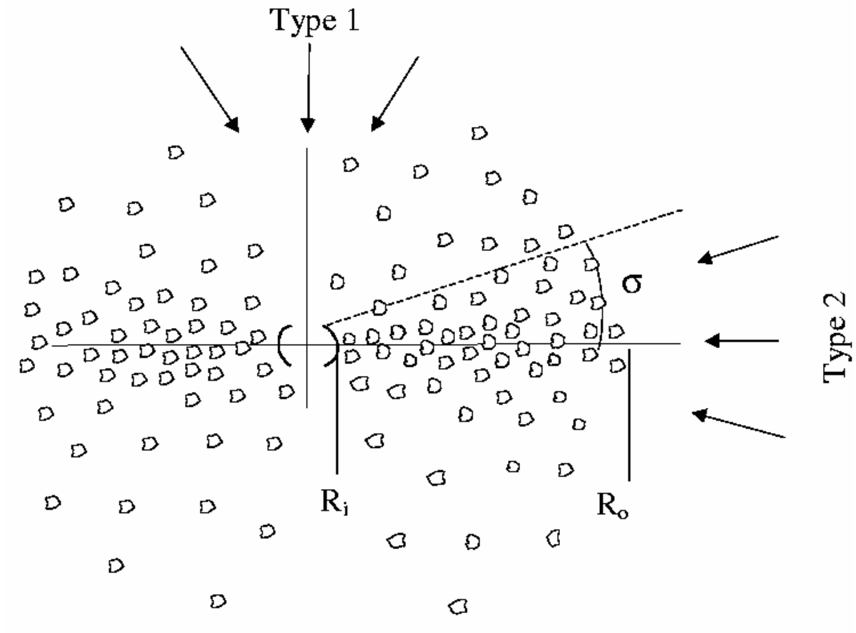
Unified Scheme – IR Puzzles

Clumpiness!!!

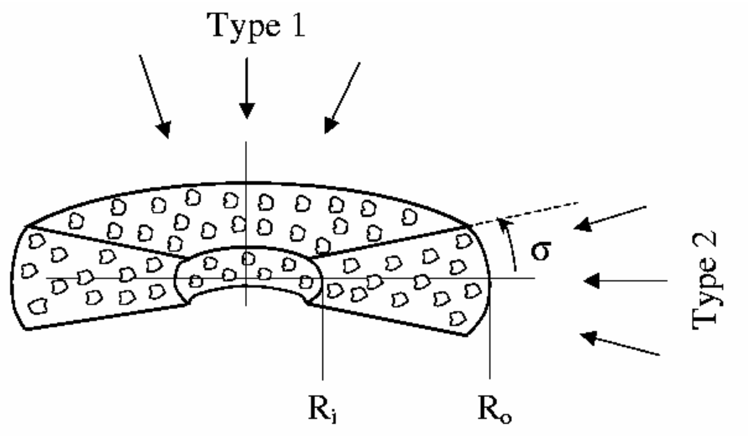
- Huge column range (10^{22} – 10^{25} cm^{-2}) in x-rays, modest SED variation in IR
- 10μm absorption feature in type 2 never deep; depth uncorrelated with x-rays
- No 10μm feature in type 1

AGN Modeling:

Gaussian edge



sharp edge



$N_T(\beta) = N_T(0)\ \exp(-\beta^2/\sigma^2)$

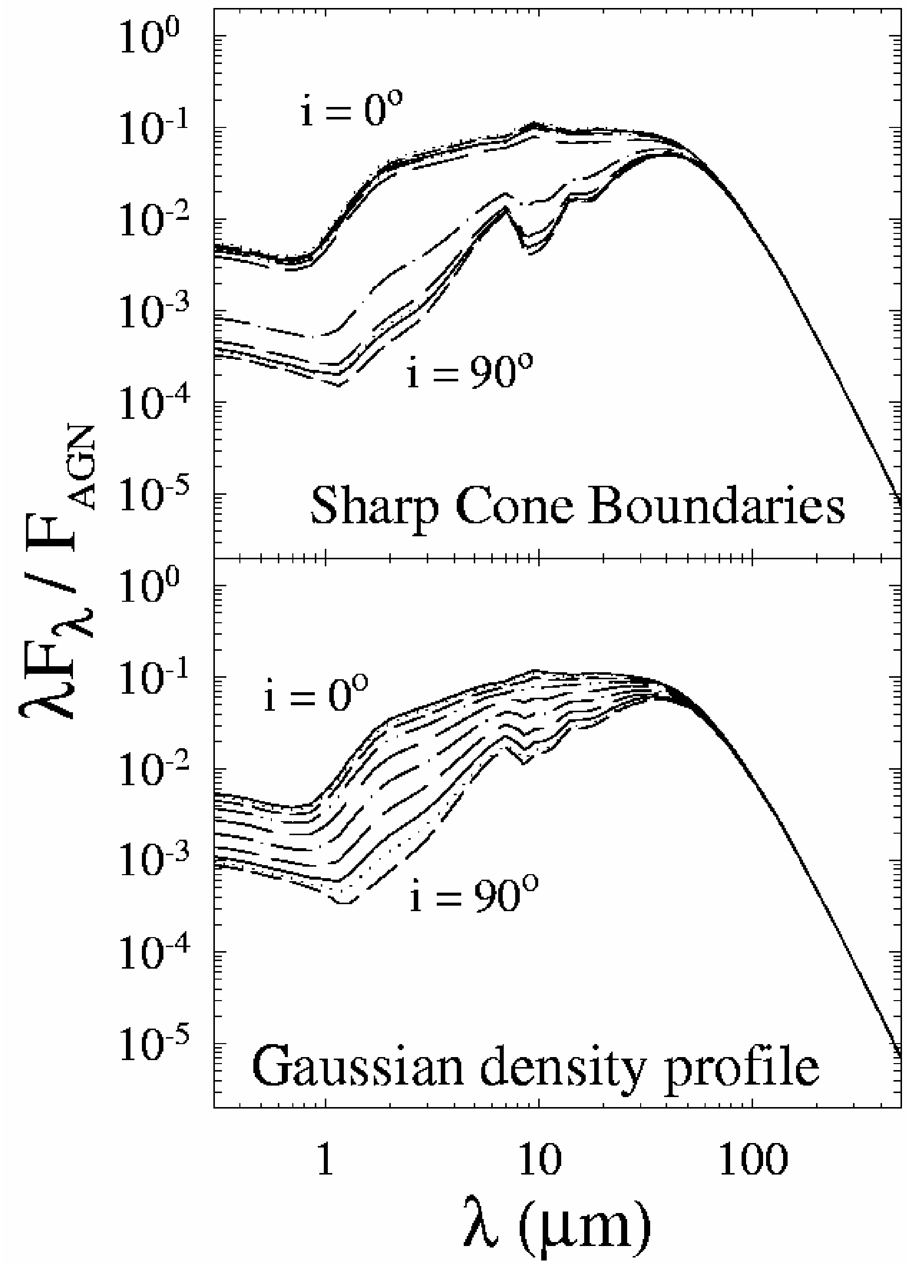
$T_{mi} = 1500\ \text{K} \quad (R_i = 0.85\text{pc}\ L^{1/2}_{12}), \quad Y = R_o/R_i\,, \quad \sigma$

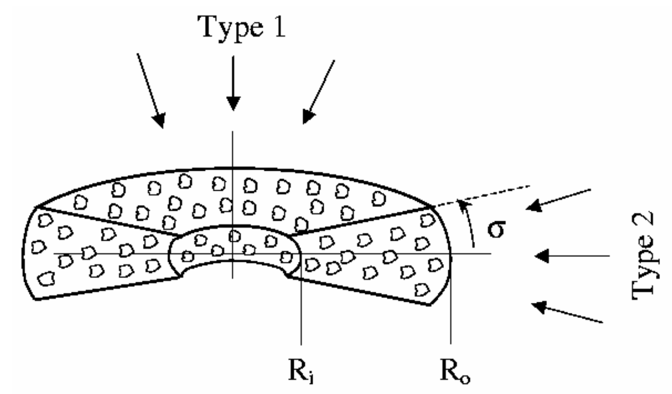
τ_V

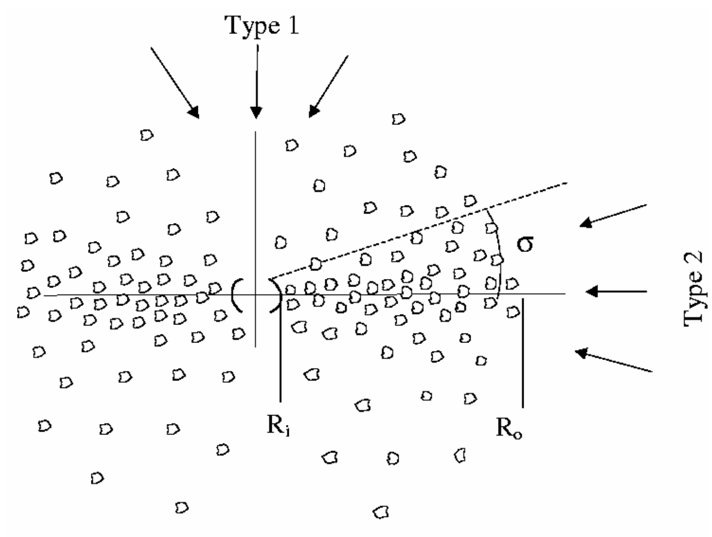
$\ell \propto r^q$: $\quad q, \quad N_T = \int_{R_i}^{R_o} \frac{dr}{\ell}$

$\tau_V = 60$, $Y = 100$, $\sigma = 45^o$, $N_T = 5$, $q = 1$

Geometry effect



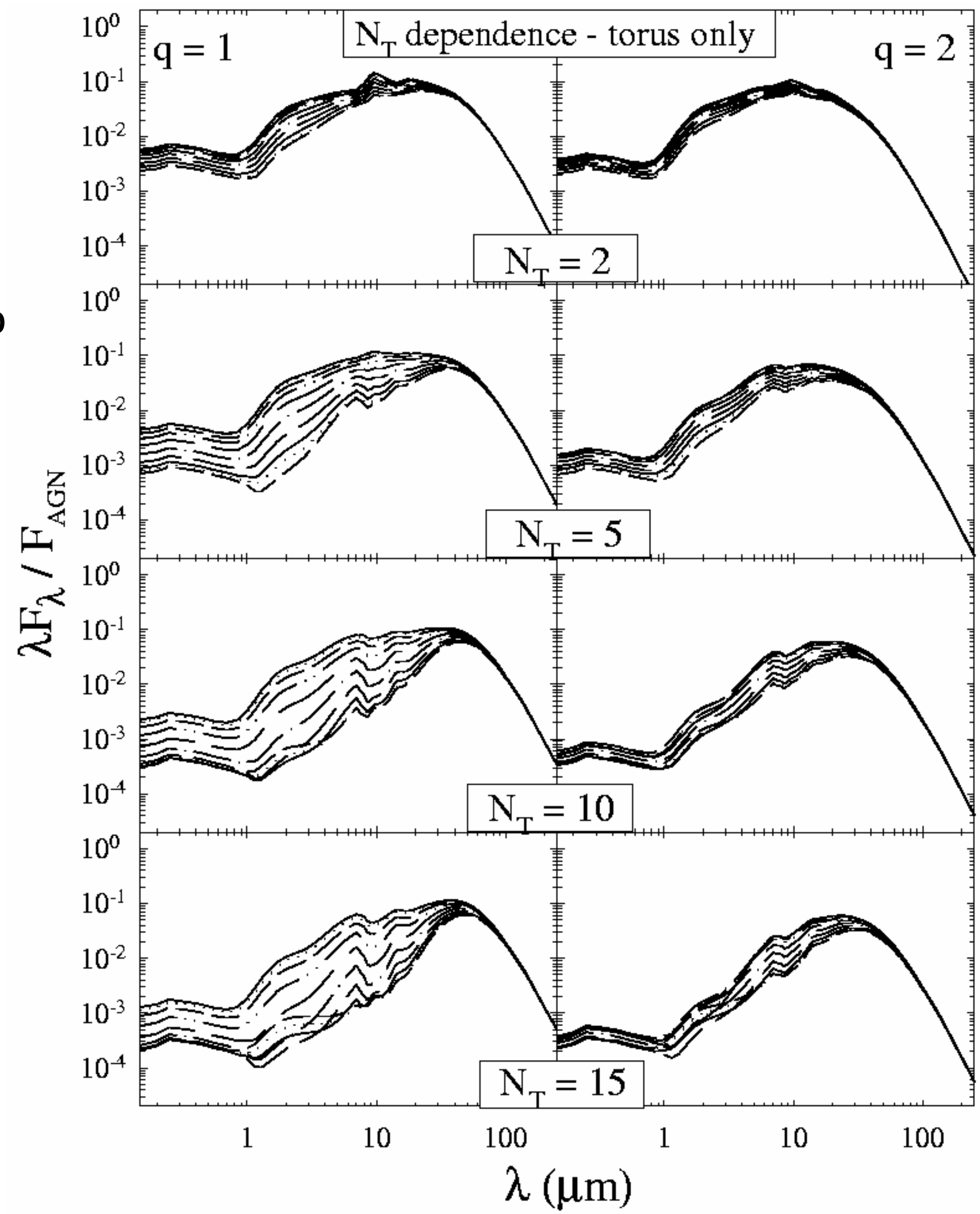




of clouds effect

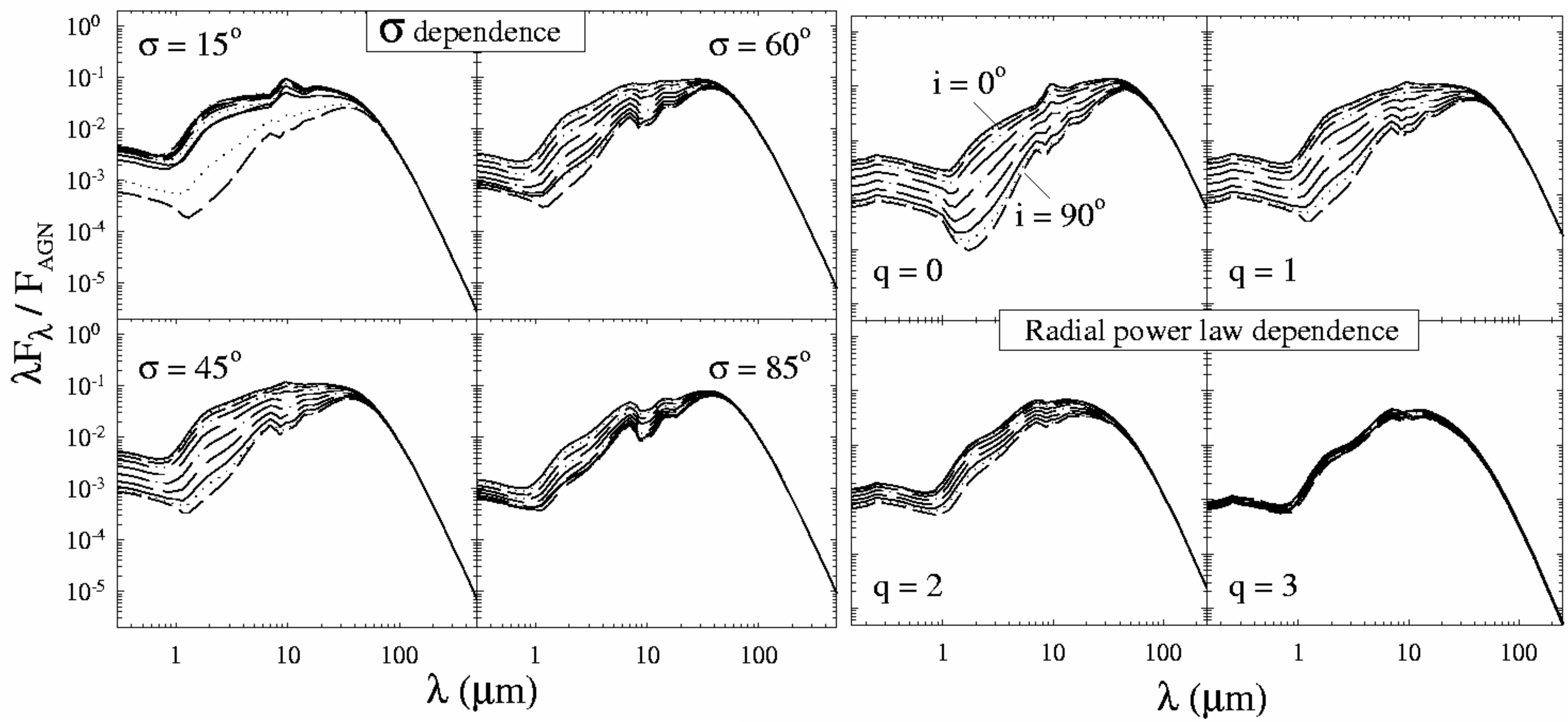
τ_V = 60, Y = 100, σ = 45º

i = 0 – 90º, 10º steps



Angular and radial parameters

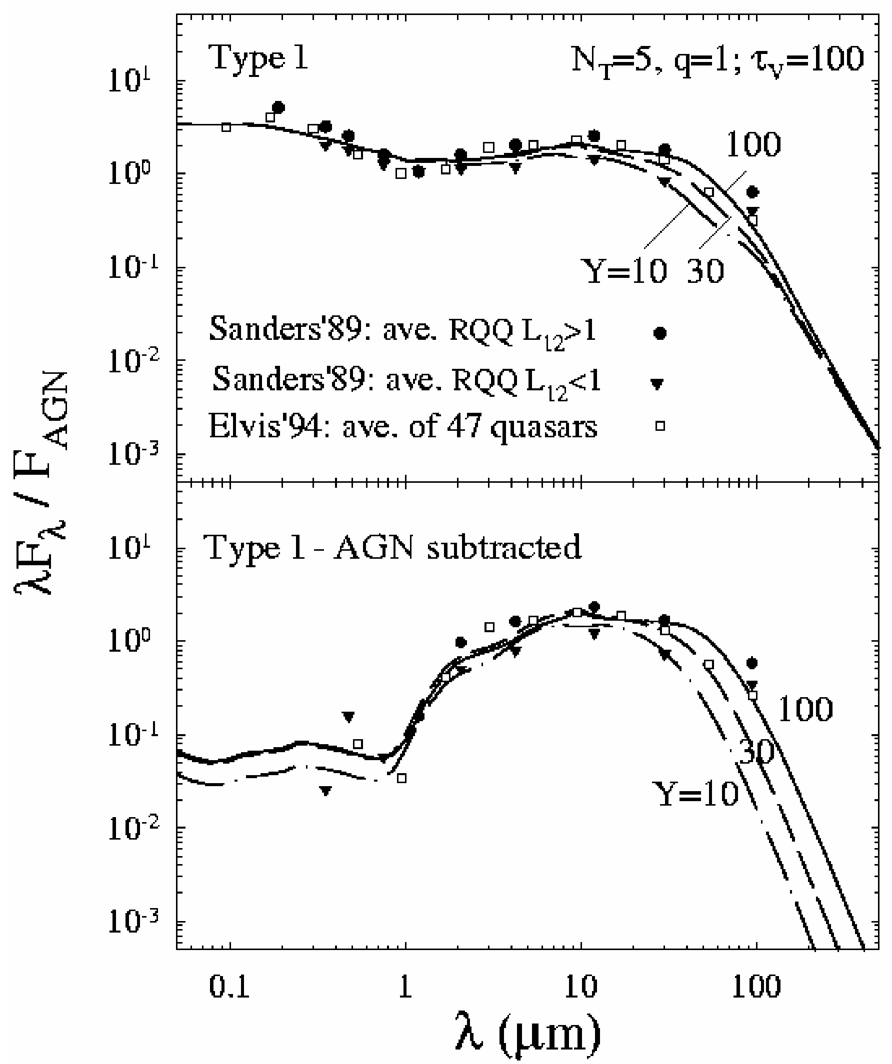
(torus only)



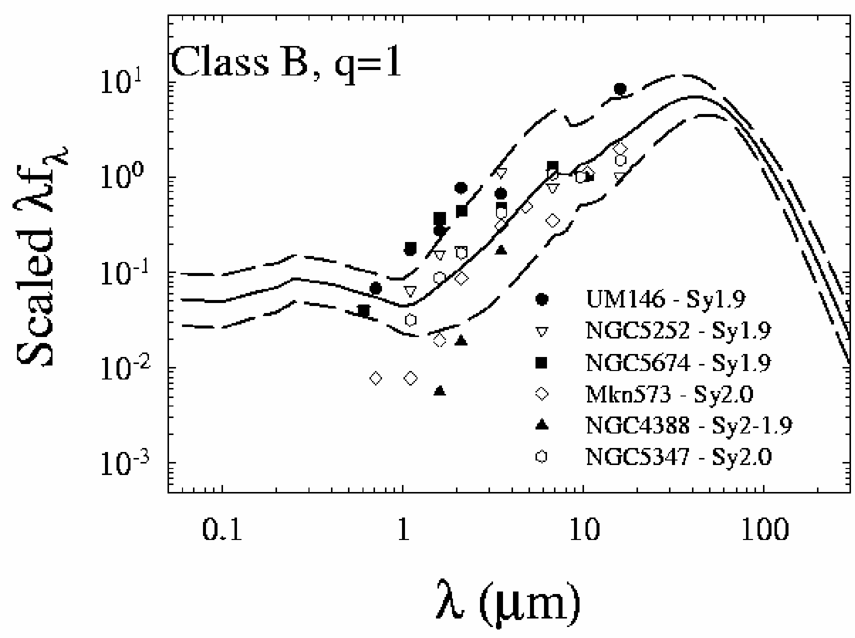
Anisotropic obscuration but isotropic emission? (Lutz et al ‘04)

Comparison with Observations

Average Type 1 spectra



Type 2 sources



$$F_{AGN} = \frac{L}{4\pi D^2}$$

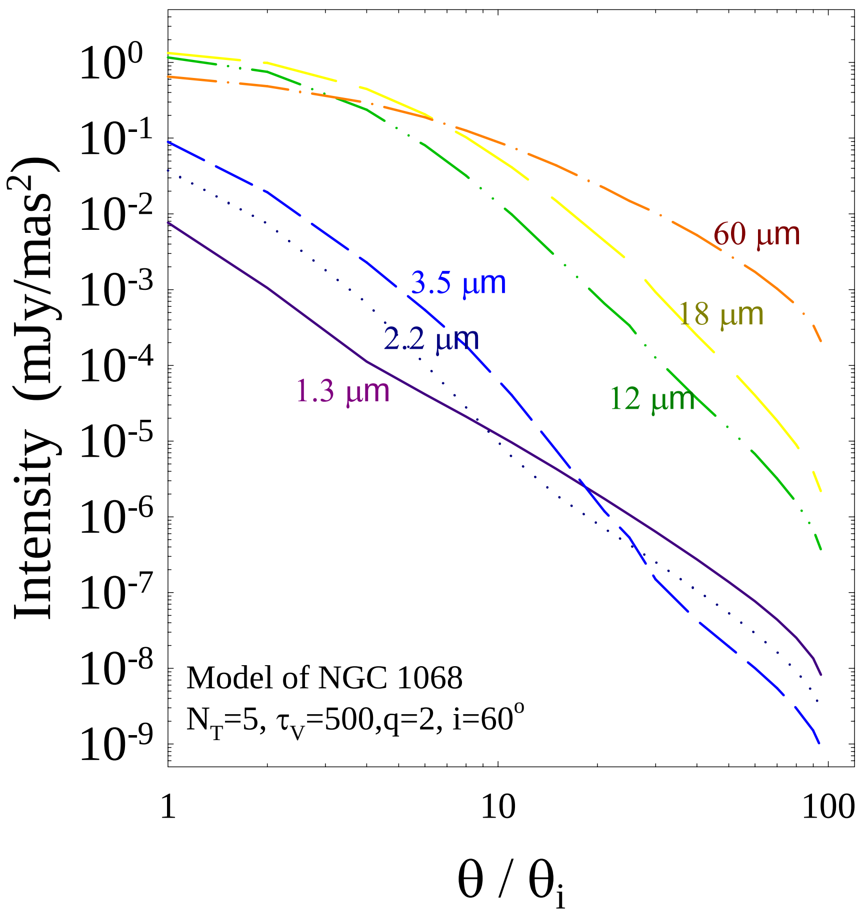
Determine F_{AGN} for type 2!

Parameter Range:

- $\sigma = 30° – 60°$
- $\tau_V = 40 – 120$
- $N_T = 5 – 10$ clouds
- $q = 1 – 2$
- $R_o/L^{½}_{12} = 10 – 100$ pc

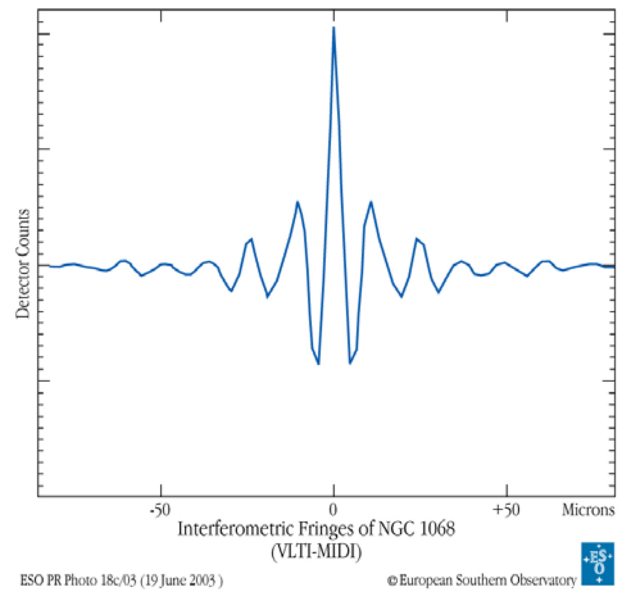
Standard Galactic ISM Dust!

Brightness Profiles (I)



$\theta_i = R_i/15\,\text{Mpc} \approx 0.02''$

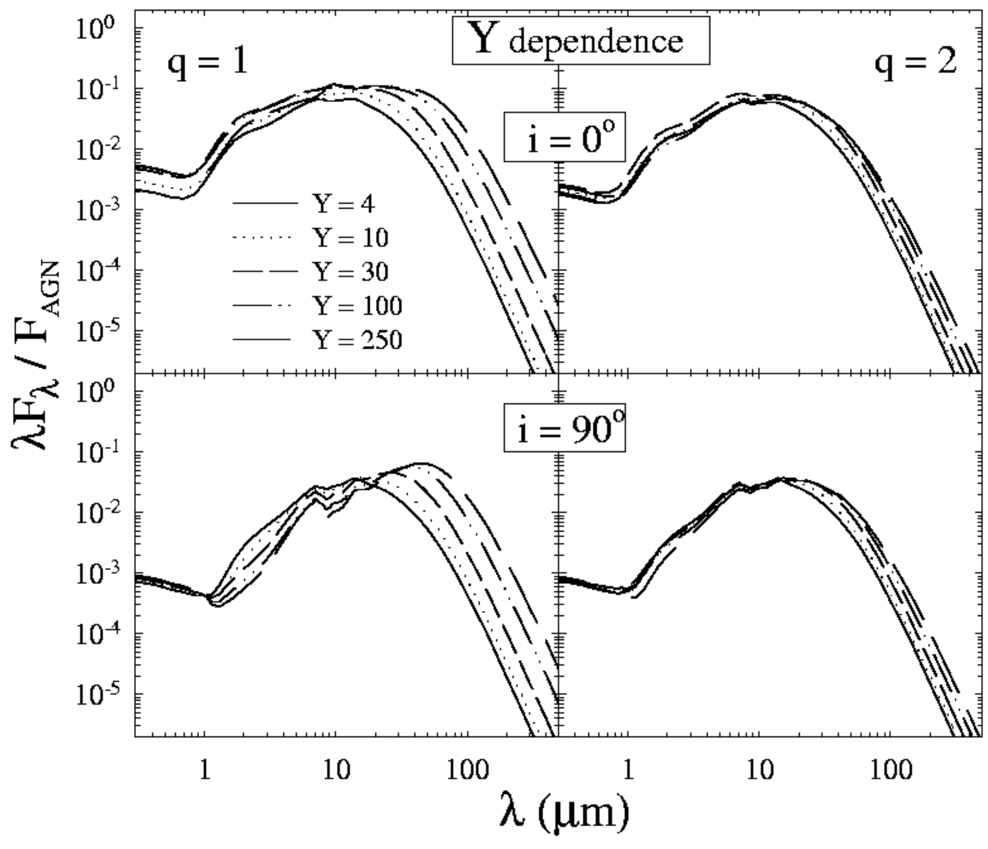
VLTI – milliarcsec J-band!



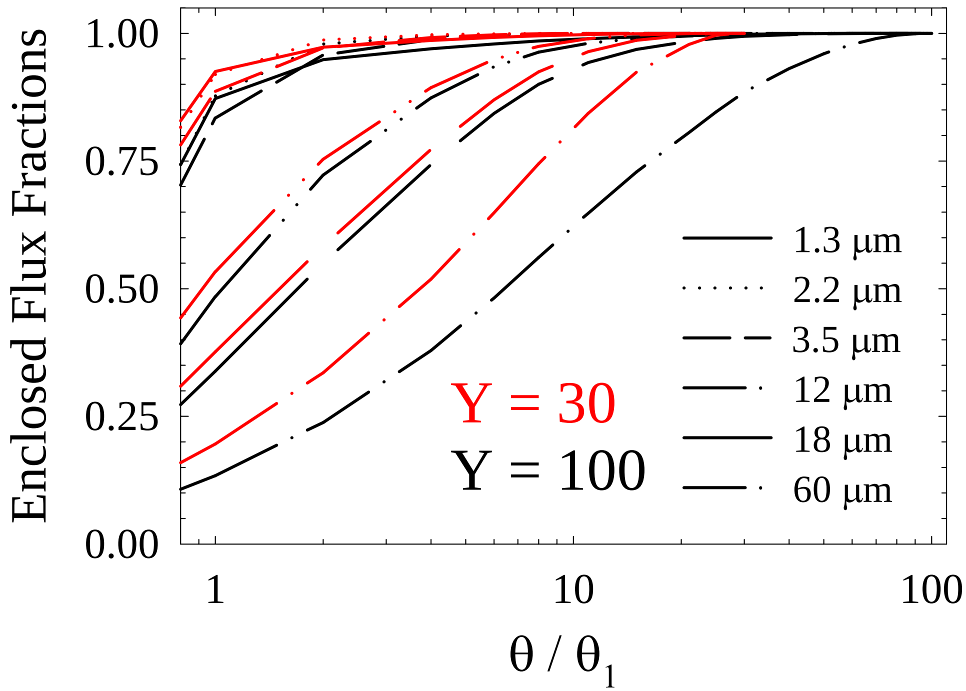
“structures on scales of approximately 0.03 arcsec”

Jaffe et al ‘04

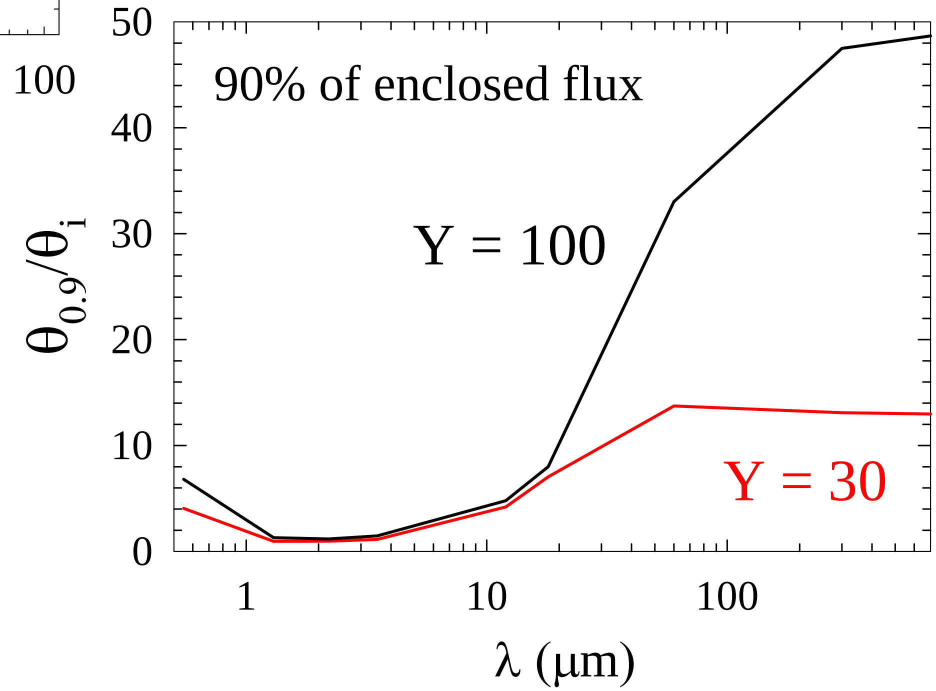
Torus Outer Radius



$R_i = 0.85\text{pc}\ L^{½}_{12} \quad Y = R_o/R_i$



It's a point source!

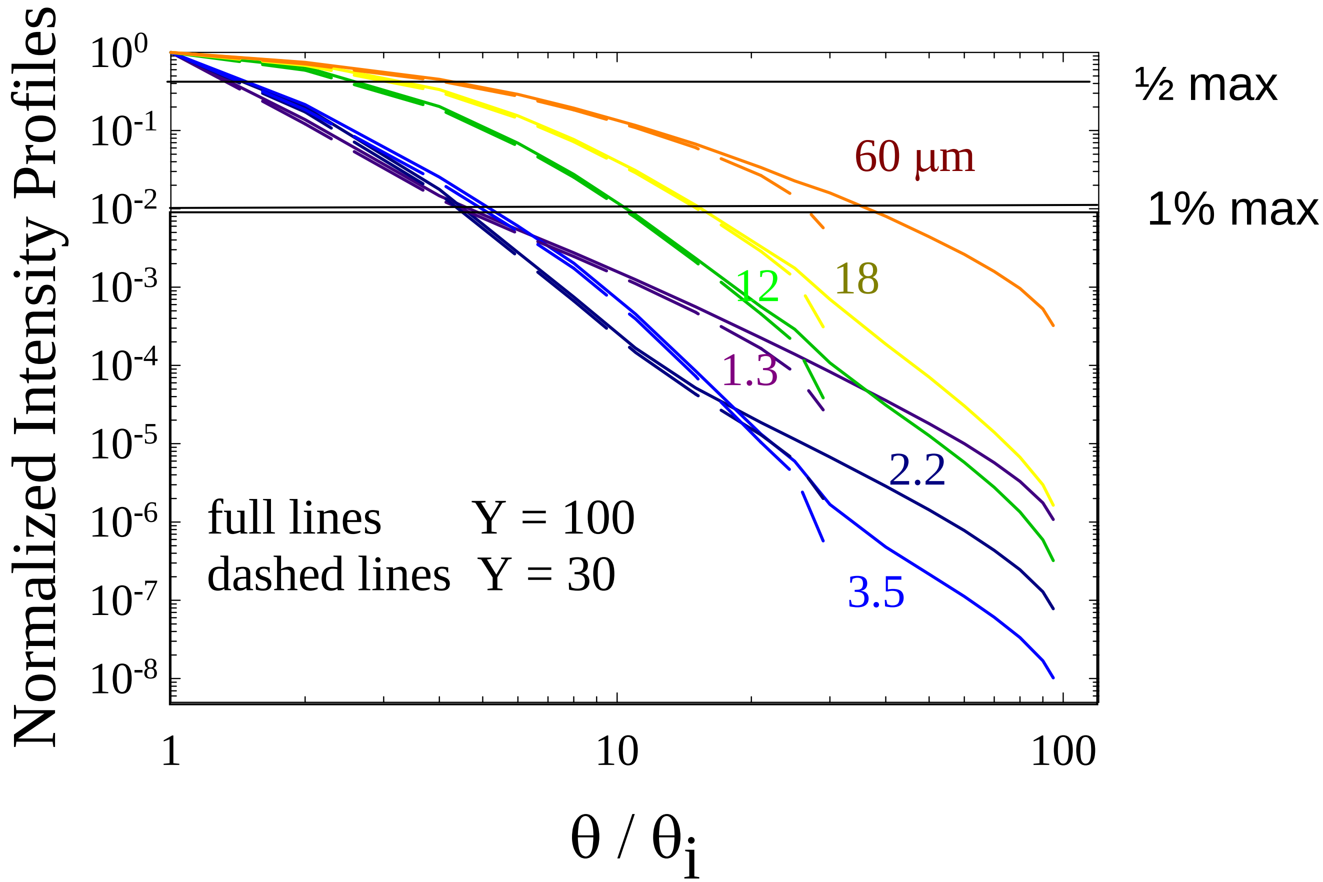


NGC 1068:

$$R_i = 0.85\,\text{pc} \cdot L_{12}^{1/2} \approx 1.2\,\text{pc}$$

$$\theta_i = \frac{R_i}{15\,\text{Mpc}} \approx 0.02''$$

Brightness Profiles (II)



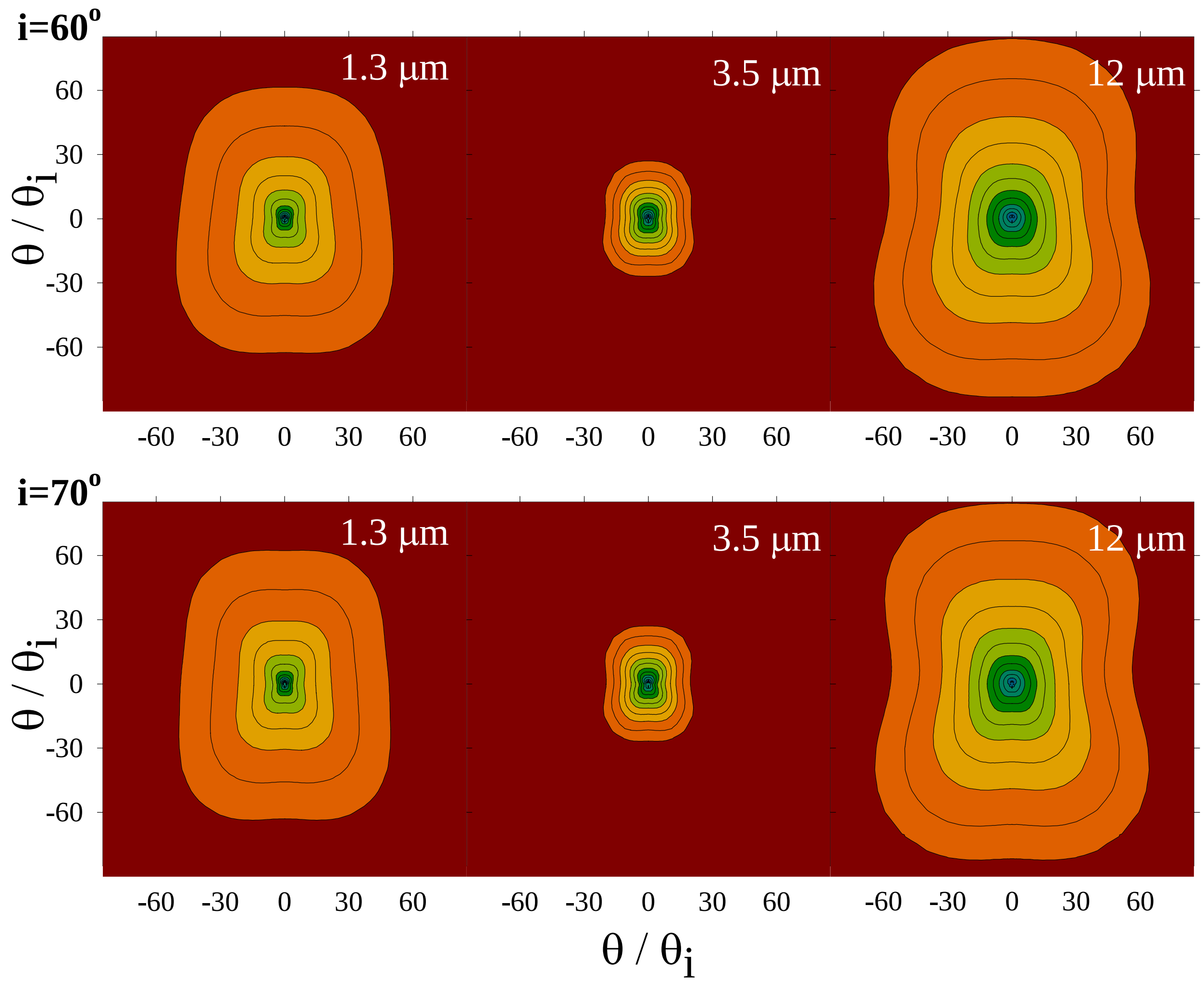
$\theta_i \approx 0.02''$

Inner parts are indistinguishable!

ALMA – ?

Herschel (6” at 100 μm) ?

Brightness Contours down to 10^{-6} of peak



Sample cloud realization

$q = 1$, $N_T = 5$, $Y = 100$, $\tau_V = 100$

ϕ irrelevant when $\phi << 1$!

(R_c irrelevant when $R_c << \ell$)

<u>assume</u>: $\phi = 0.1$, $L_{12} = 1$

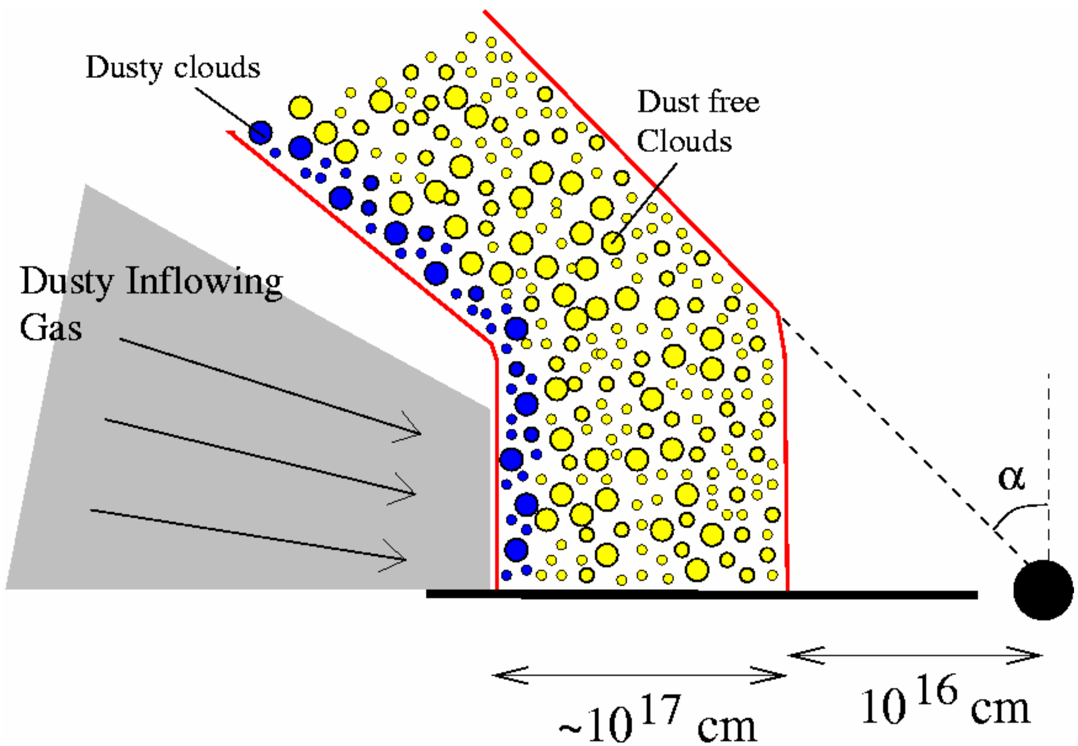
	R_i	R_o
r (pc)	1	100
R_c (pc)	0.1	9
n (cm^{-3})	$3 \cdot 10^5$	$3 \cdot 10^3$

X-ray variability

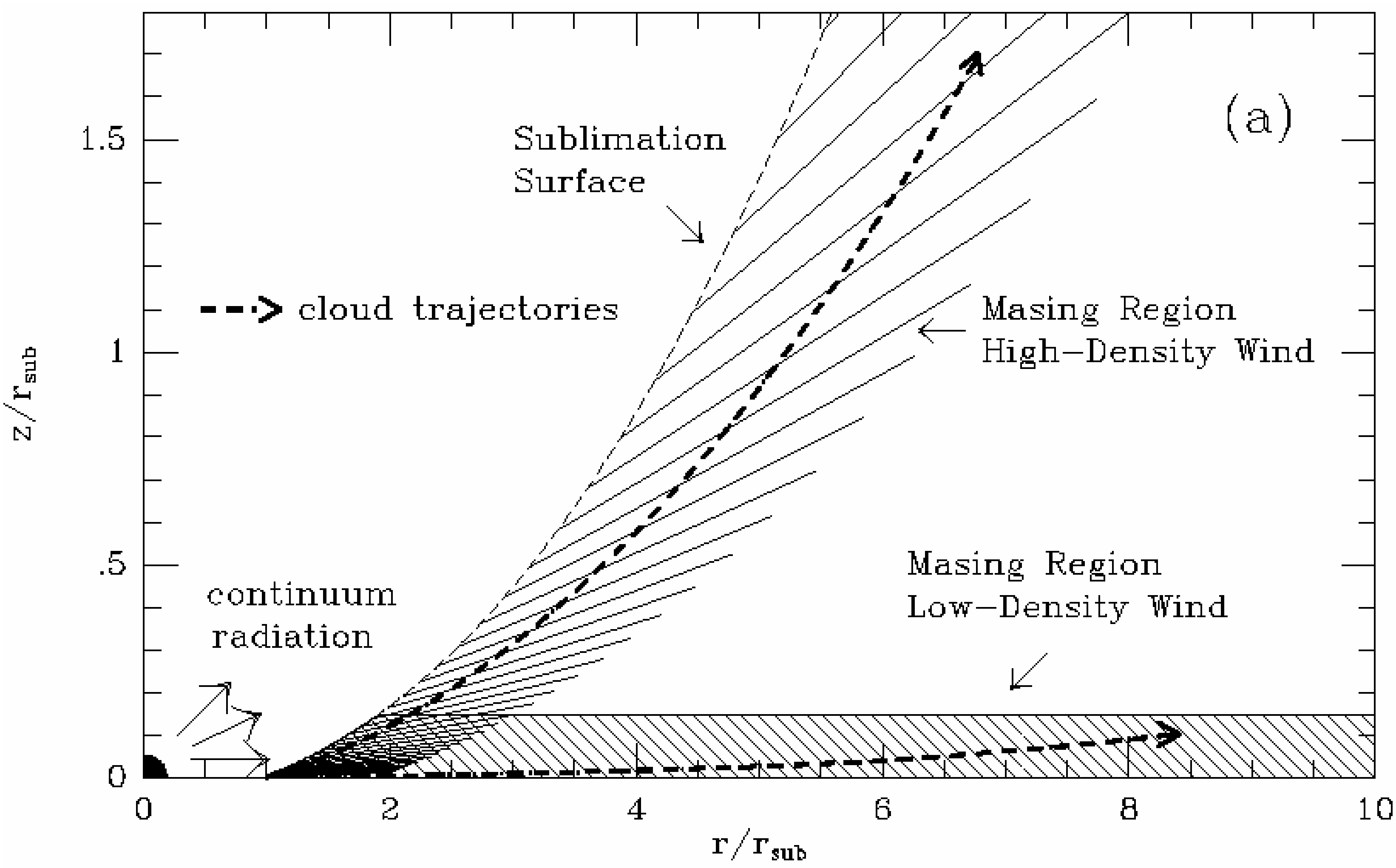
Risaliti, Elvis & Nicastro 2002

time scales ~ months – 20 years

radial distances ~ 0.1 pc – 10 pc



Disk winds?

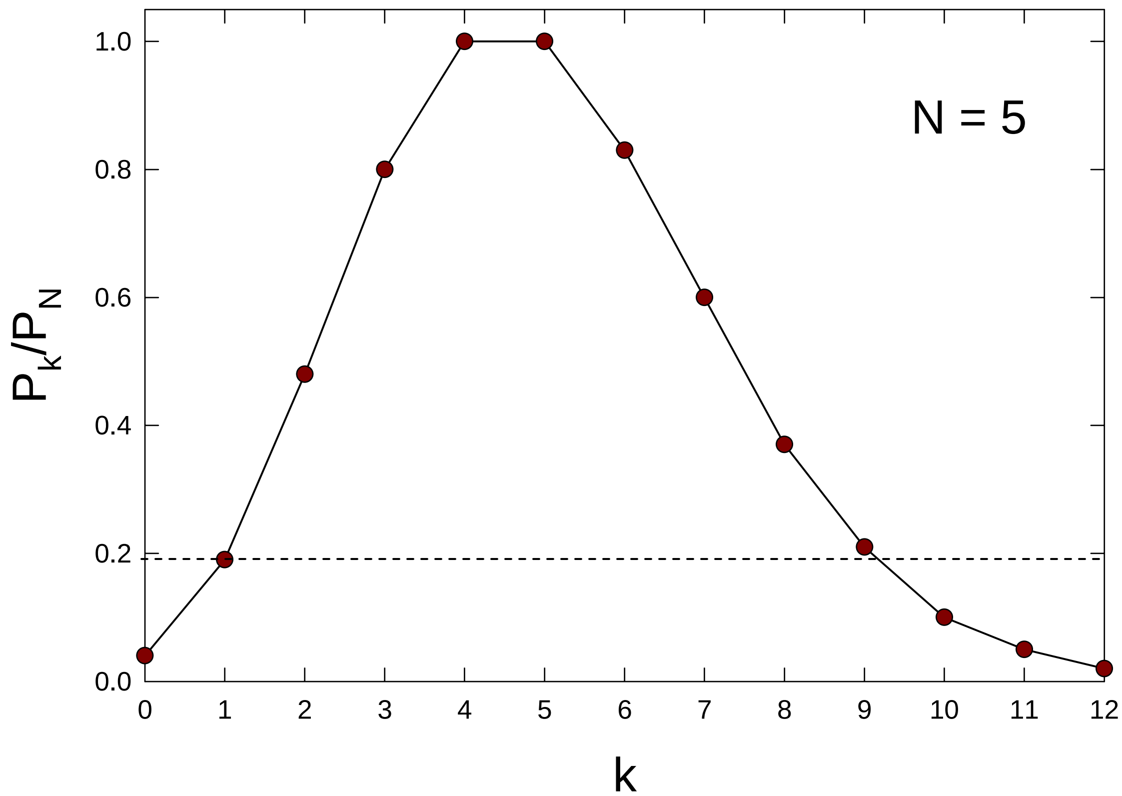


Kartje, Konigl & Elitzur 1999

Poisson Probability

$P_k \propto N^k/k!$

$P_5 = 18\%$



Clumpy Tori

- IR emission – average over many los
- x-ray absorption – single los
- type 1 vs 2 – probability
- flips between type 1 $\leftrightarrow$ 2
- Seyfert 1.x – intercloud medium?
- molecular lines – kinematics