# AGN dust model of 3CR sources

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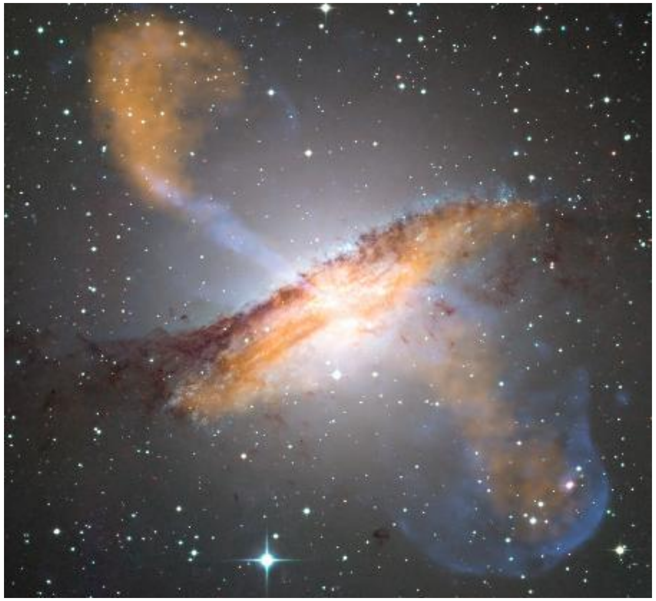
Endrik Krűgel, Christian Leipski

- MIR imaging & spectroscopy
- ISM dust model & PAH
- vectorized Monte Carlo model
- SED of a clumpy AGN torus



CenA (ESO)

# 1) Ground based MIR imaging

Nuclear activity in nearby galaxies

Surface brightness → AGN viz. starbursts

10m telescopes

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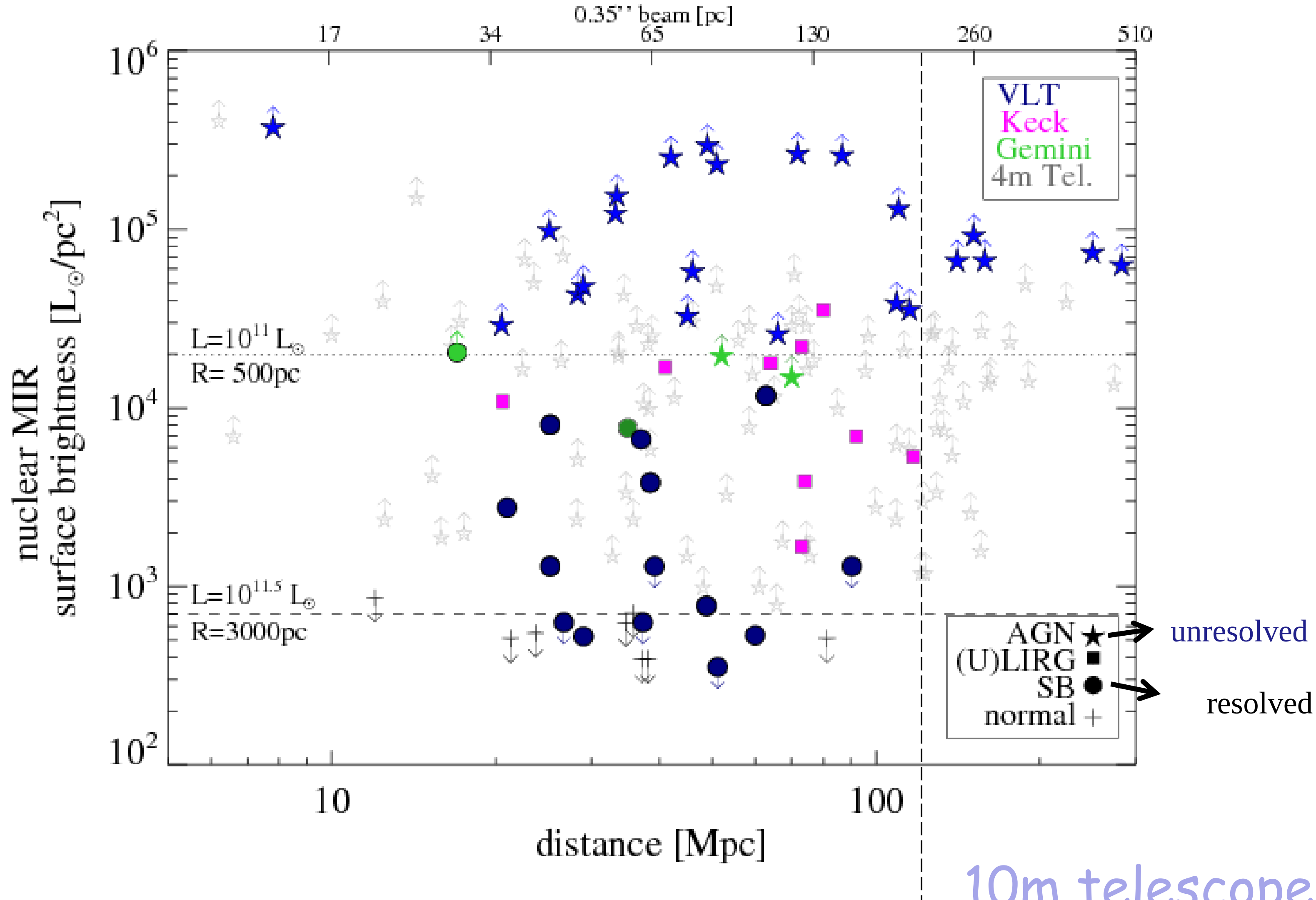


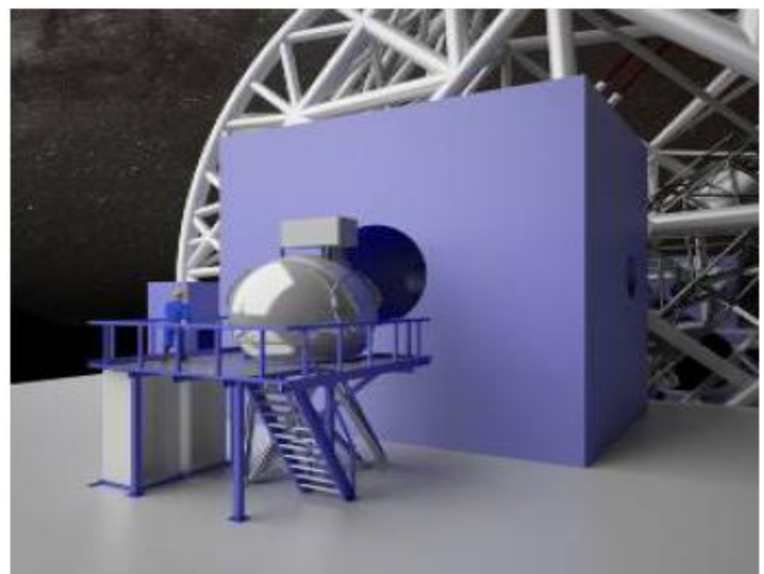

10m telescopes

Siebenmorgen et al. (2008)

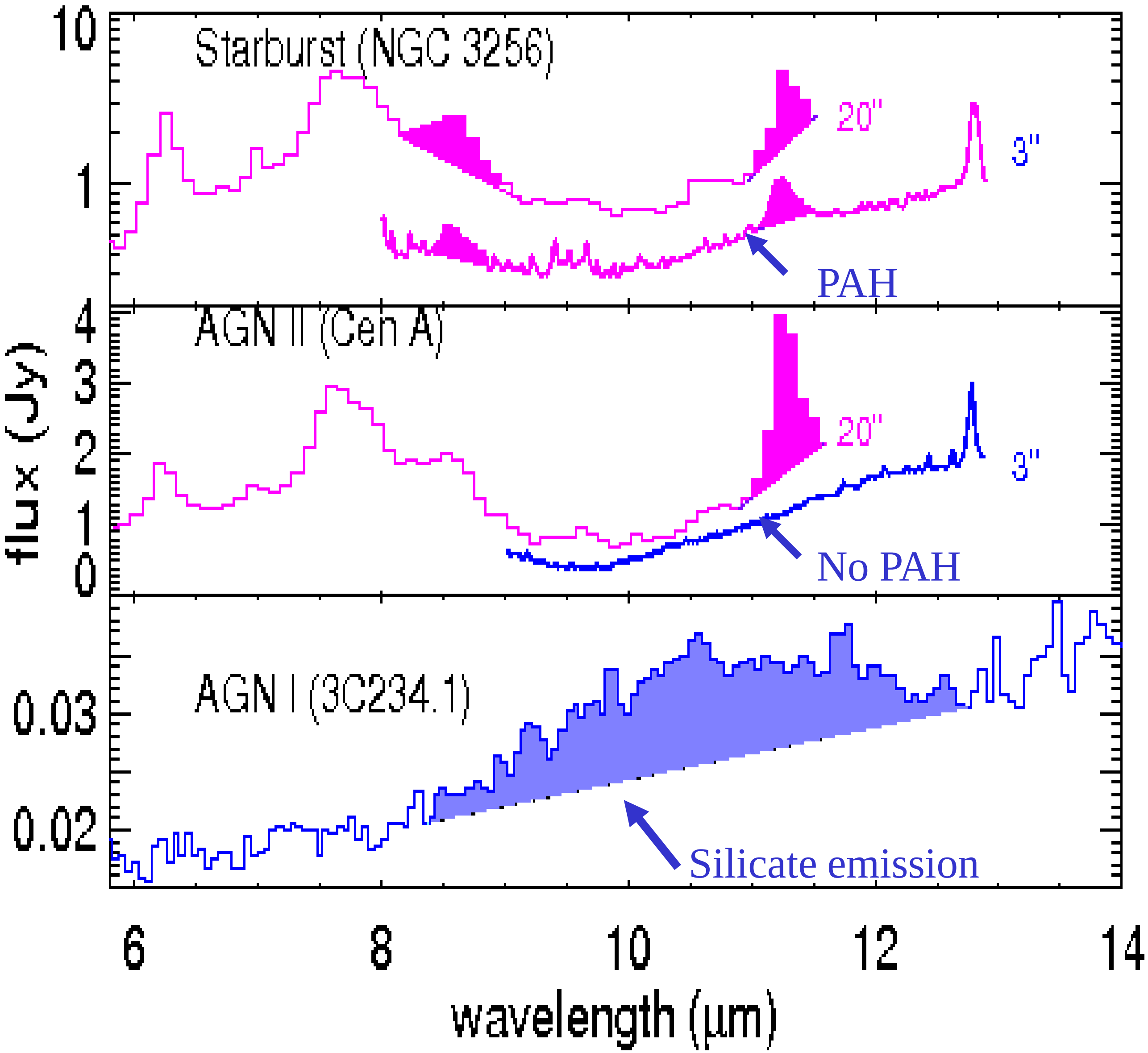
# ELT 42m

## MIR surface brightness diagnostics up to D ~ 500Mpc

METIS
Mid-infrared E-ELT Imager and Spectrograph



# 2) MIR spectroscopy




Siebenmorgen et al. (2004, 2005)

# 3) Spitzer photometry of 3CR sources

- powerfull AGN: 178MHz flux limited, isotropic sample

  23 quasars, 38 radio galaxies (Spitzer GTO: Fazio )
- $1 < z < 2.5 \rightarrow$ rest frame 1.6-10$\mu$m

Haas et al. (2008)

# 3) Spitzer photometry of 3CR sources

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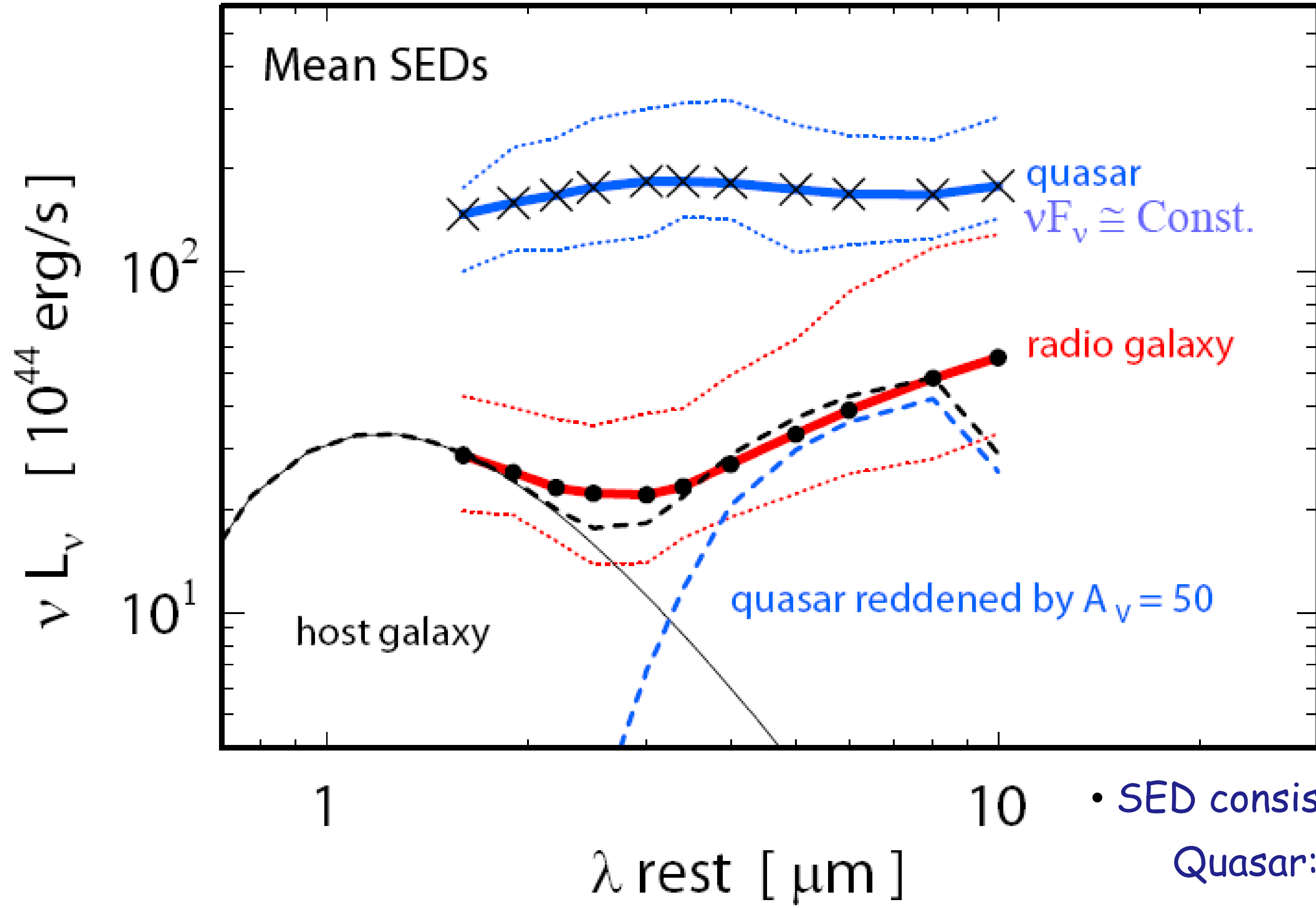
- 1 < z < 2.5 → rest frame 1.6-10μm




- SED consistent with unification:

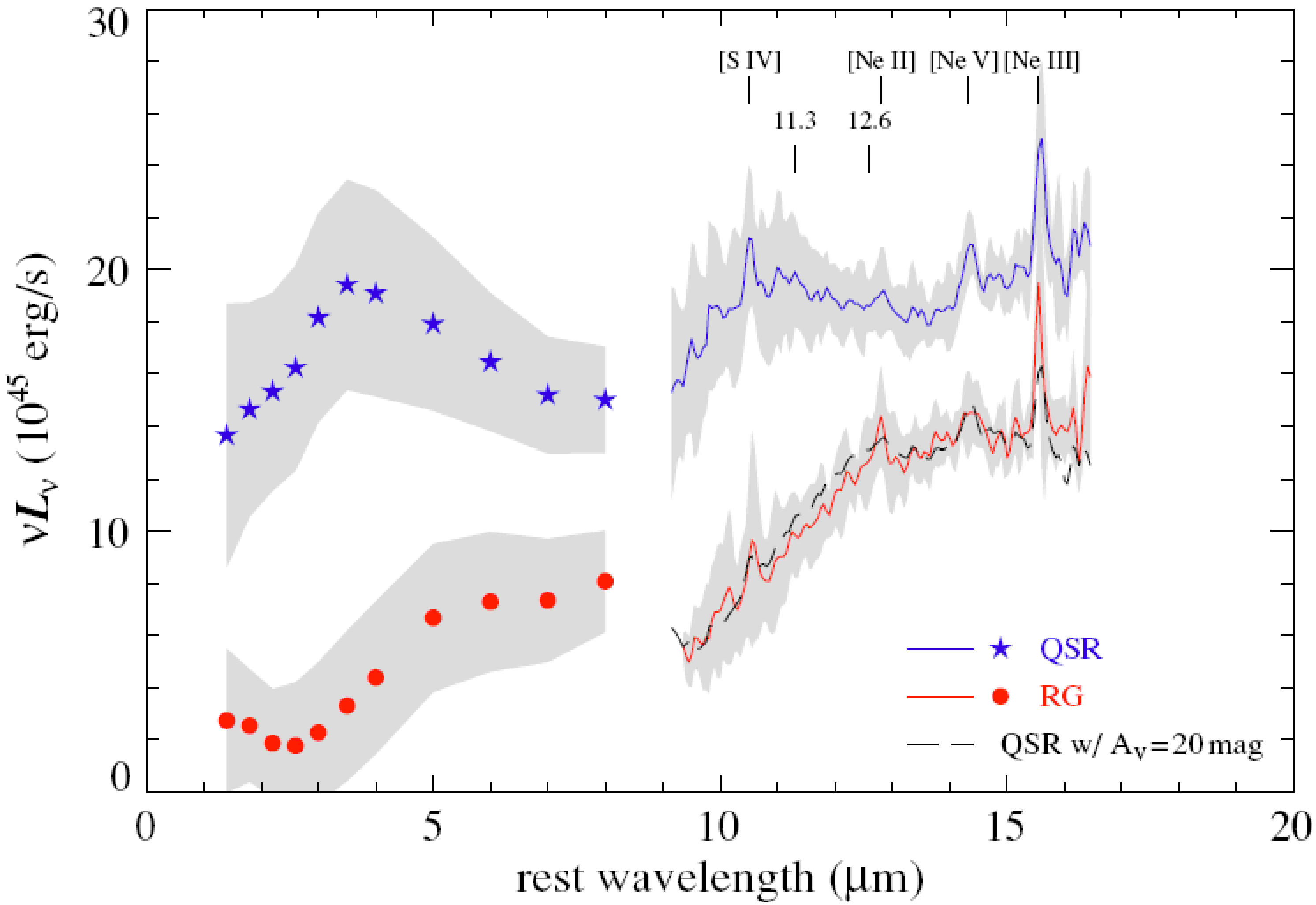
  Quasar: ~flat

  RG: reddened quasar + host
- 24μm surveys biased to type I

Haas et al. (2008)

# 4) Spitzer spectroscopy of 3CR sources

mean SED normalised to 178 MHz luminosity




Quasar (11) ~ flat

- no PAH

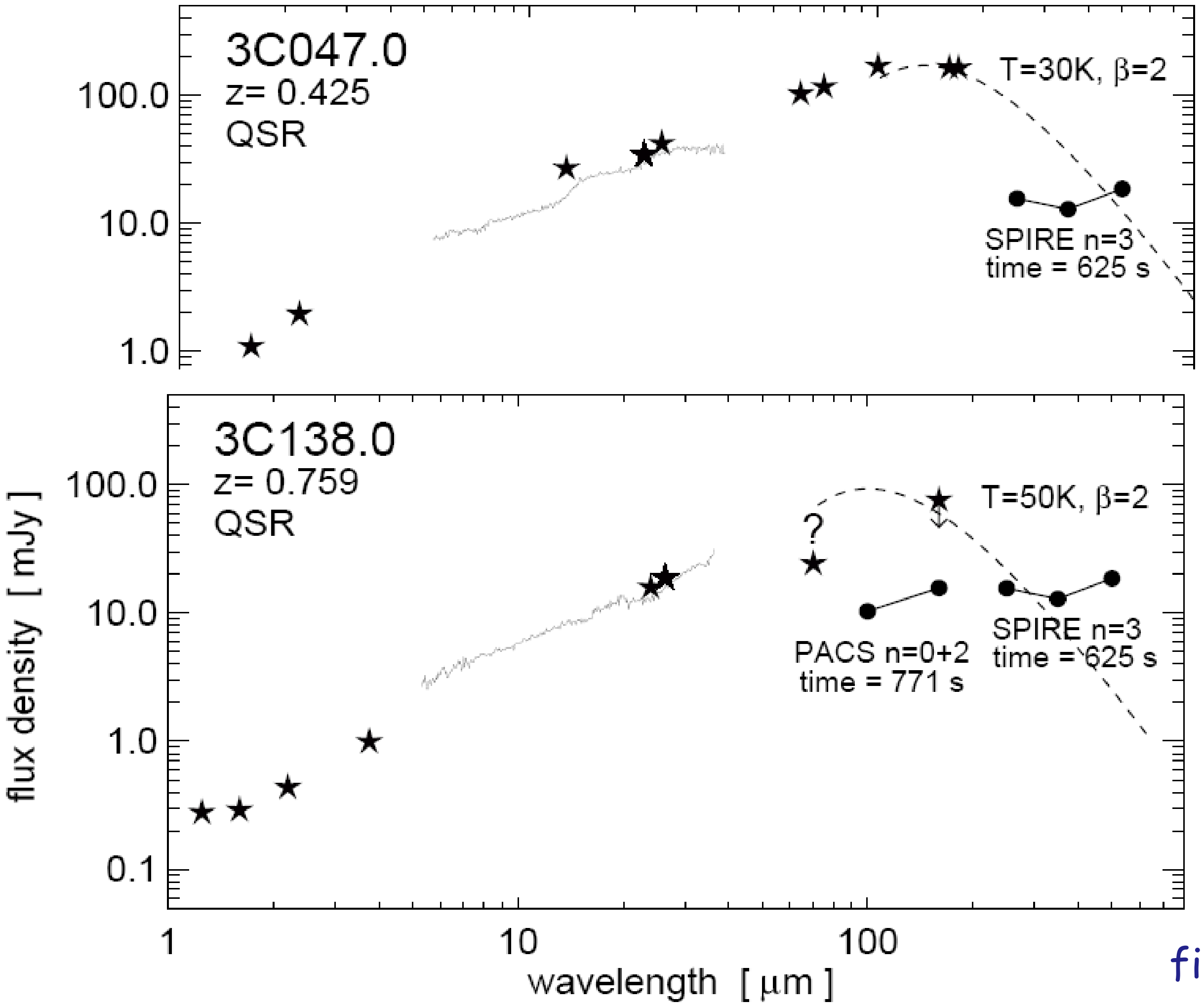
RG (9): reddened quasar + host

similar emission line ratios

Leipski et al. (2010)

# 5) Herschel observations of 3CR sources

## at z<1 (proposed by Haas + 19 CoIs)

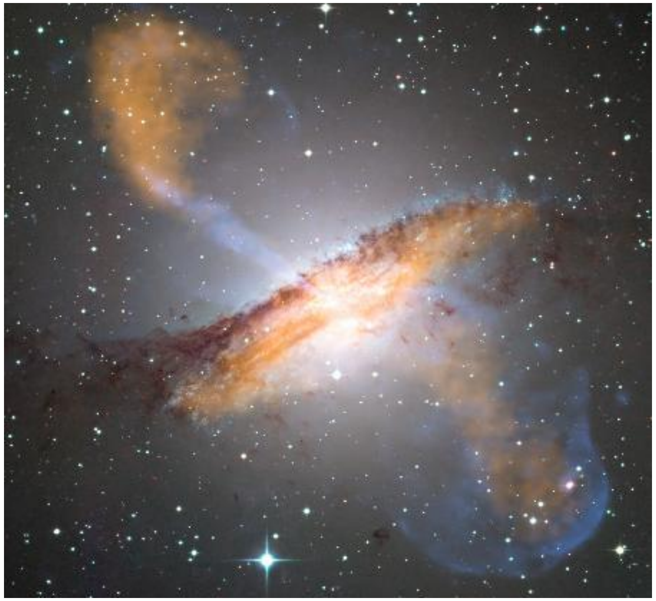



filling the gap between

Spitzer + SCUBA/MAMBO

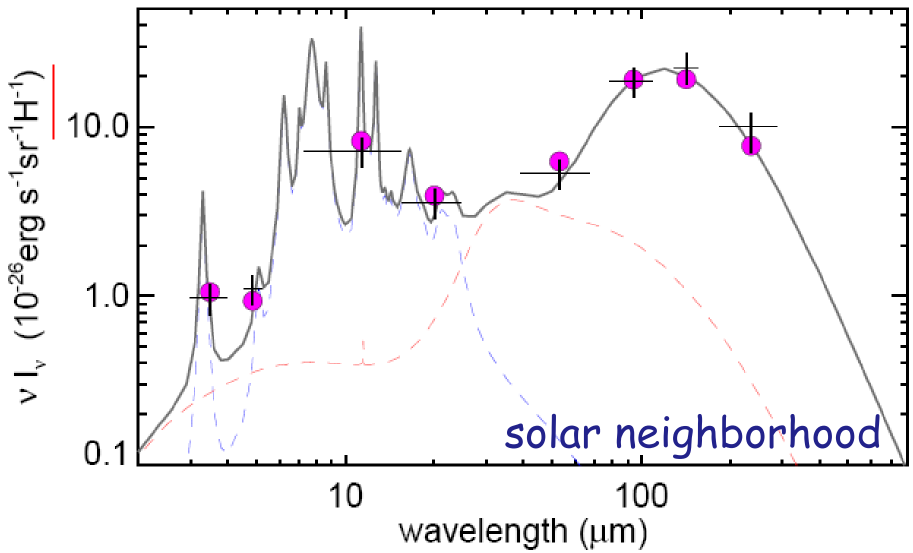
# 3D Monte Carlo radiative transfer models

1) ISM dust model
2) PAH: SB emission & AGN destruction
3) MC model
4) clumpy AGN torus models



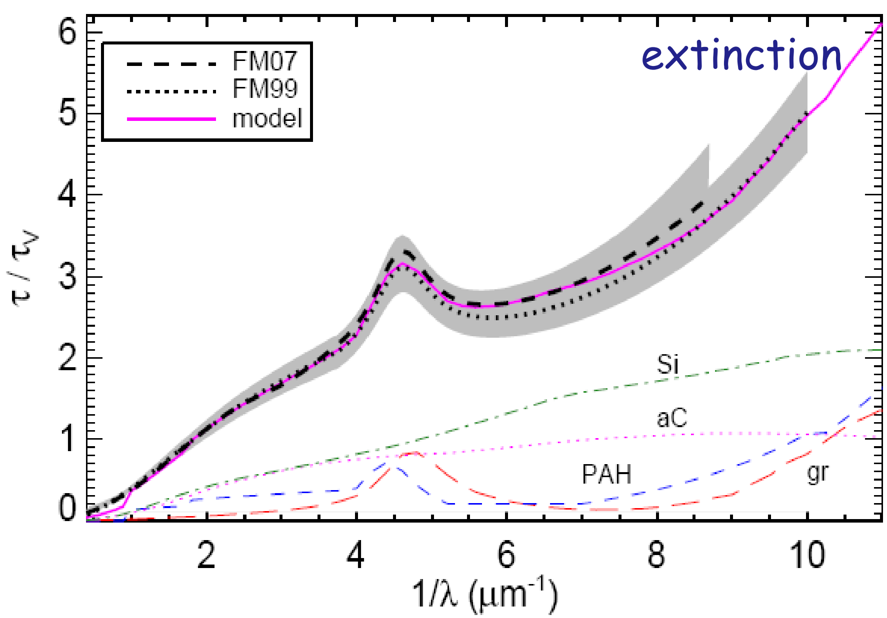
CenA (ESO)

# 1) ISM dust 2010




Abundances [X/H in ppm]:

31Si + 150aC + 50gr + 30PAH



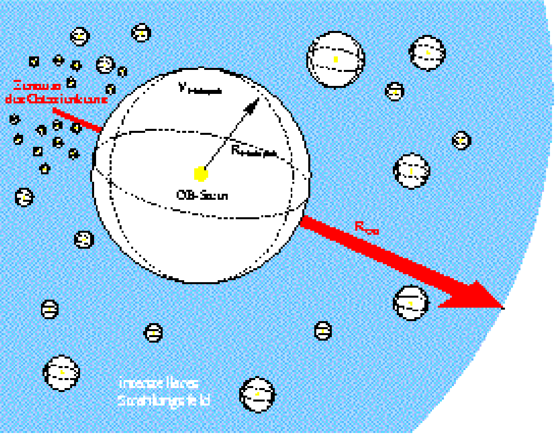

Si + aC : 60Å < a <0.2-0.3μm ~ $a^{-3.5}$

Graphite : 5Å < a < 80 Å ~$a^{-3.5}$

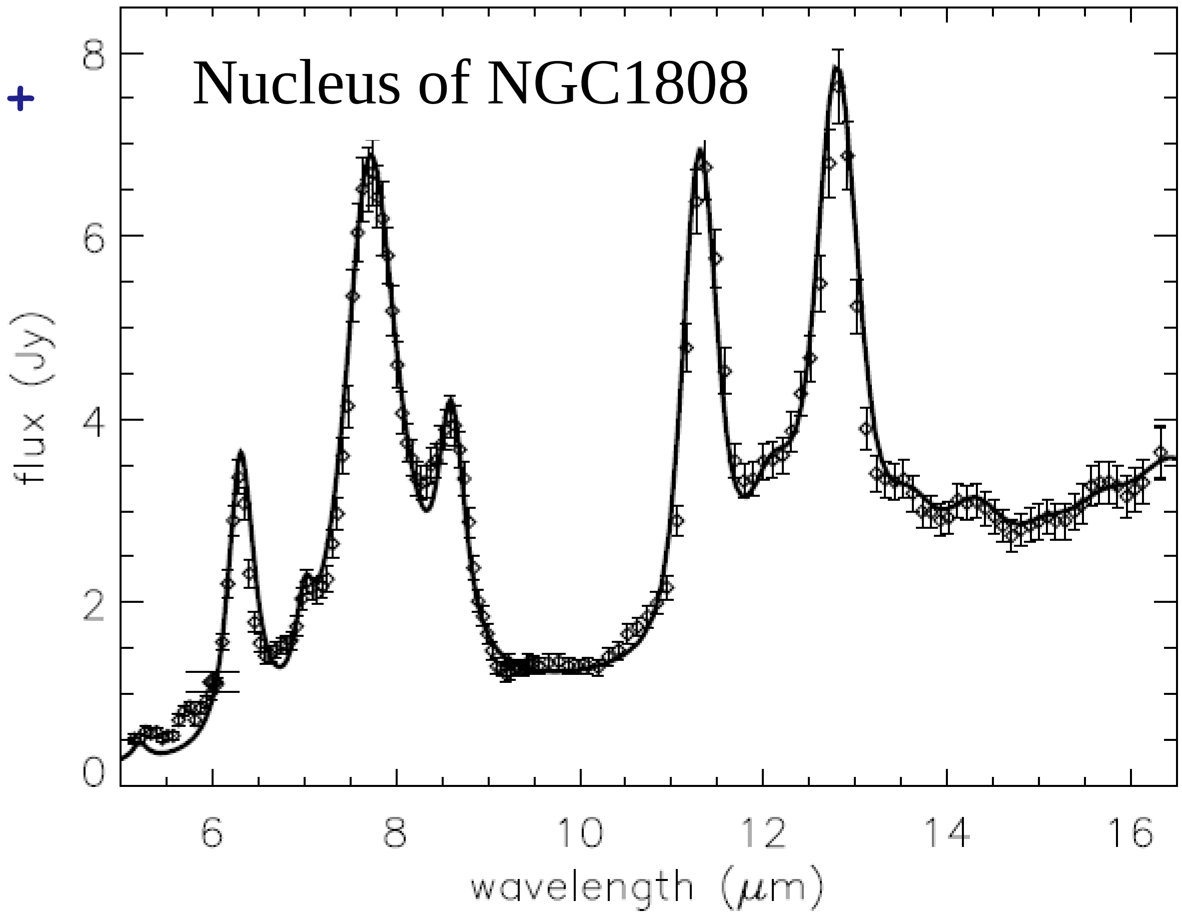
PAH : 30 C + 200 C

# 2) PAH emission

## Radiative transfer in the nuclei of star bursts

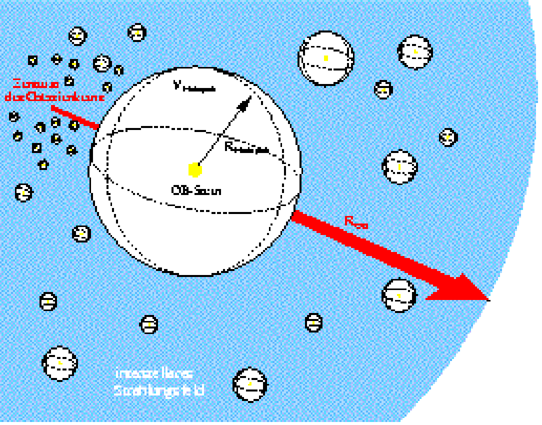


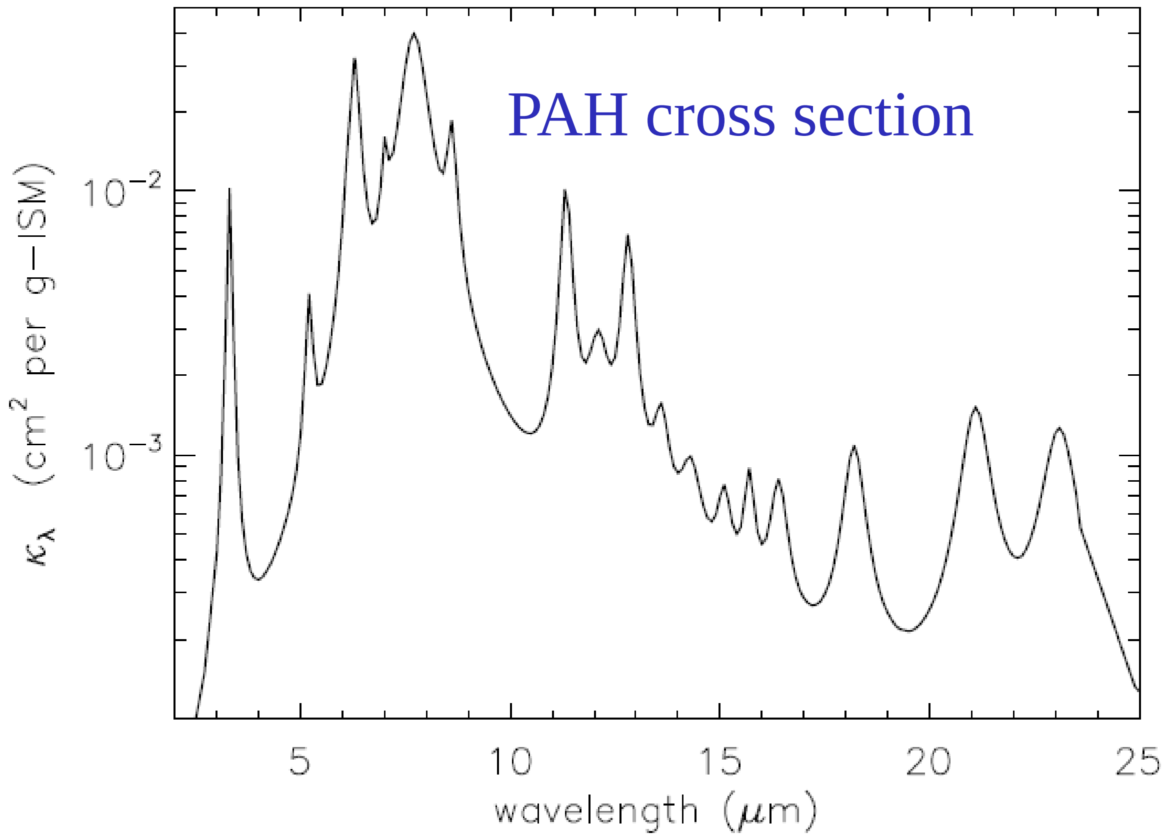
Distribution of stars + "Hot spots"




Tutokov & Krűgel(1978); Siebenmorgen et al. (2001)

# 2) PAH emission
## Radiative transfer in the nuclei of star bursts

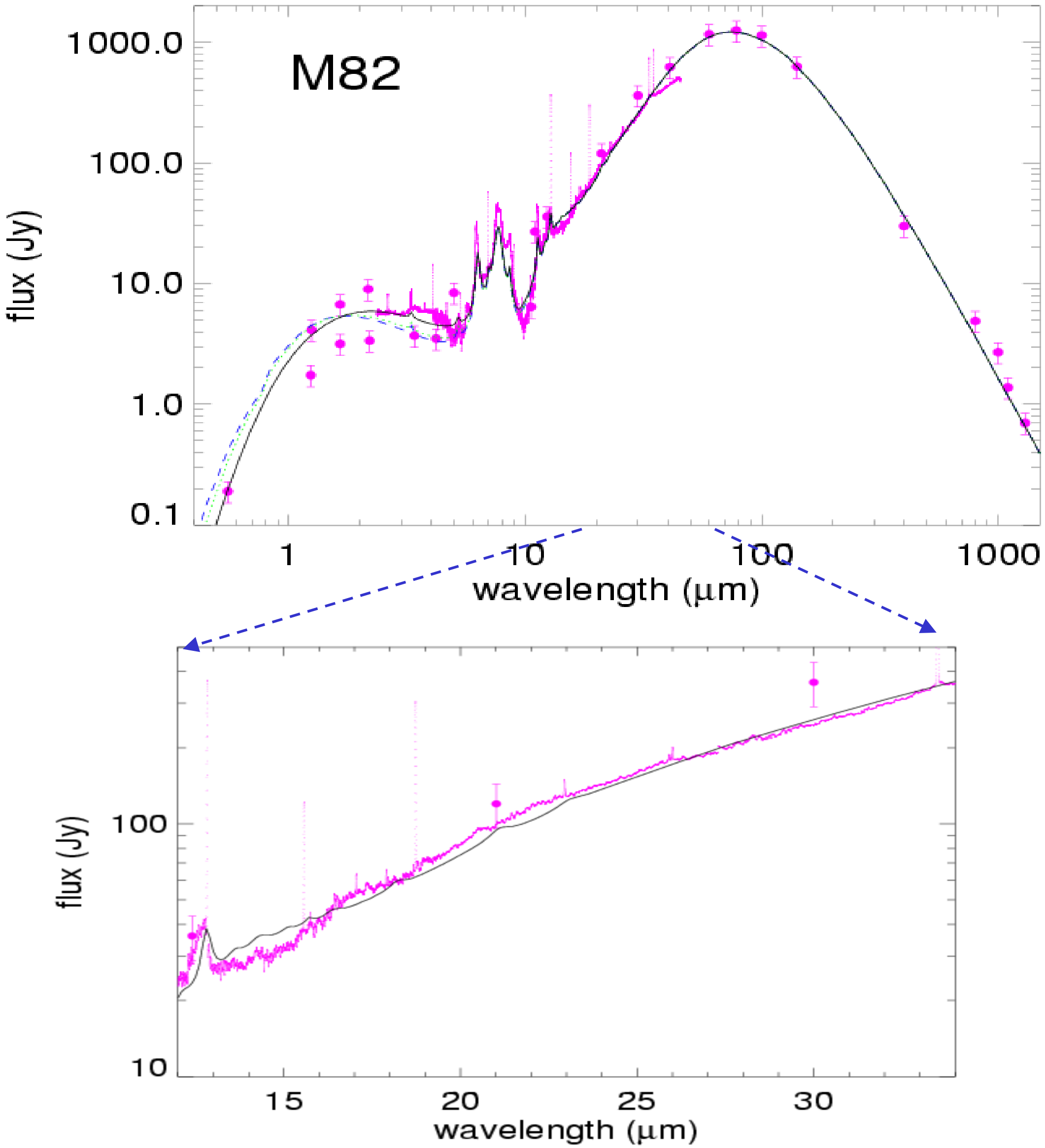





Siebenmorgen et al. (2001), Draine & Li (2007); Tielens (2008)

# SED library for SB

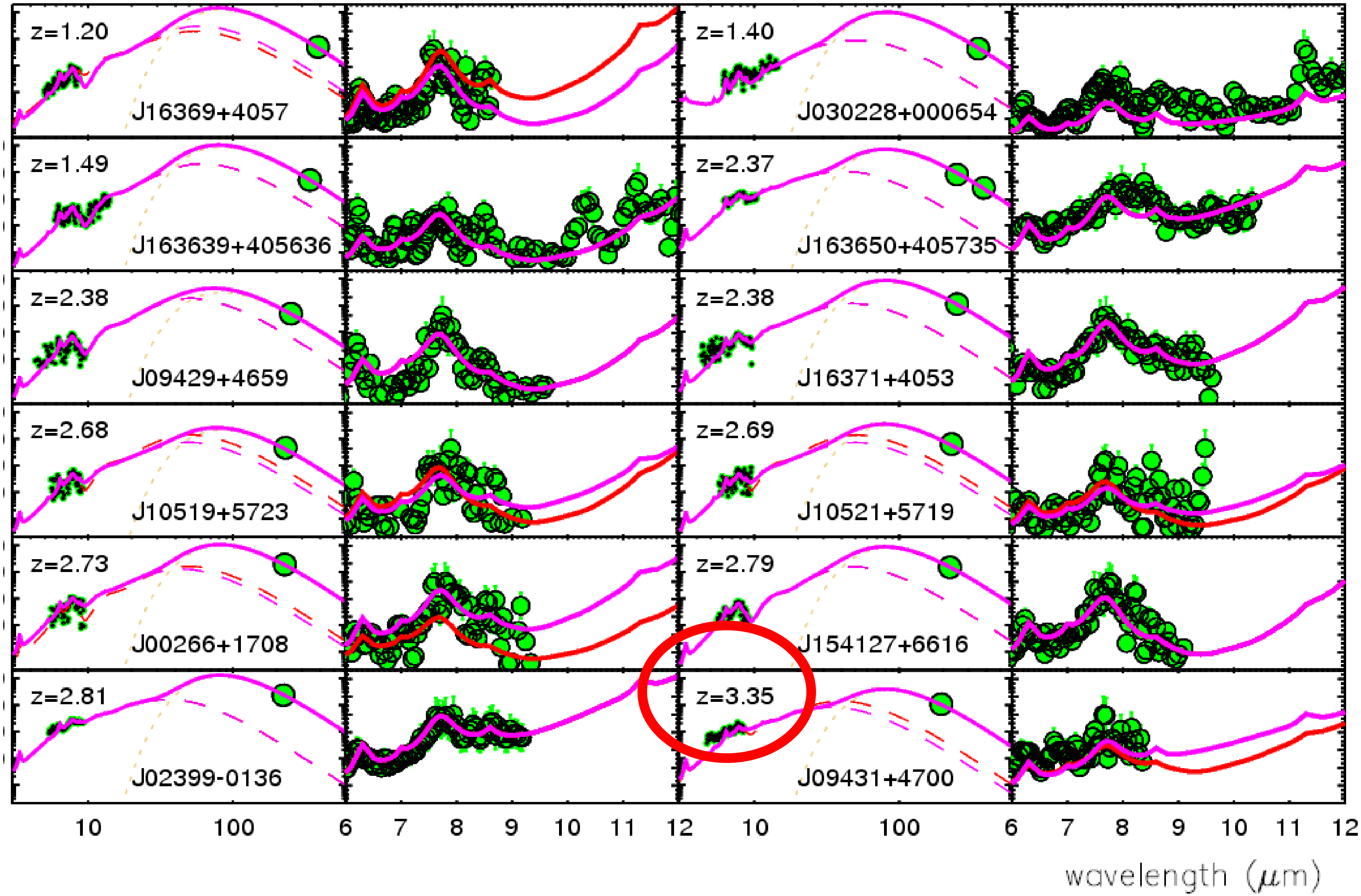
www.eso.org/~rsiebenm



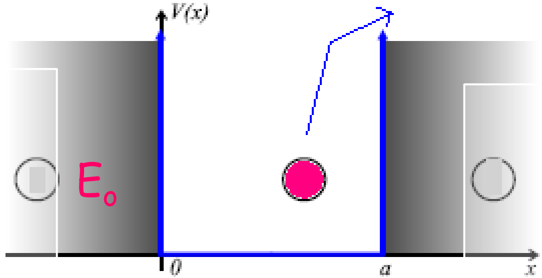

- luminosity
- size
- mass

Siebenmorgen et al. (2007)

# SMG at high z

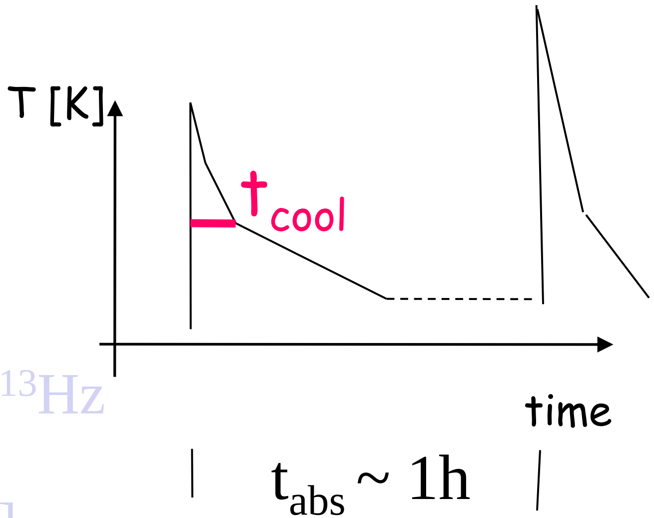



Efstathiou & Siebenmorgen (2009)




# 2) PAH destruction

## Unimolecular dissociation



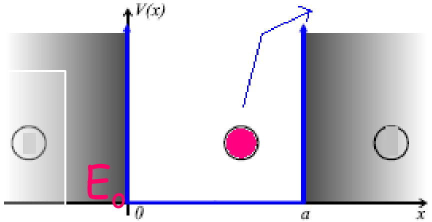

**Arrhenius form:**

$t_{dis} \sim \exp(E_o/kT) / \nu_0 \quad \ll t_{cool} \sim 1s$

$T_{min} = E_o/k \ln(\nu_0) \sim 2000K; \quad E_o \sim 5eV; \quad \nu_0 = 10^{13}Hz$

$\Delta E = 3N_c\, kT_{min} \sim 0.1\, N_c \cdot E_b \Rightarrow N_c < 2\, \Delta E / [eV]$ (PAH unstable)

Tielens (2005) ; Micelotta et al. (2010) ; Siebenmorgen & Krűgel (2010)

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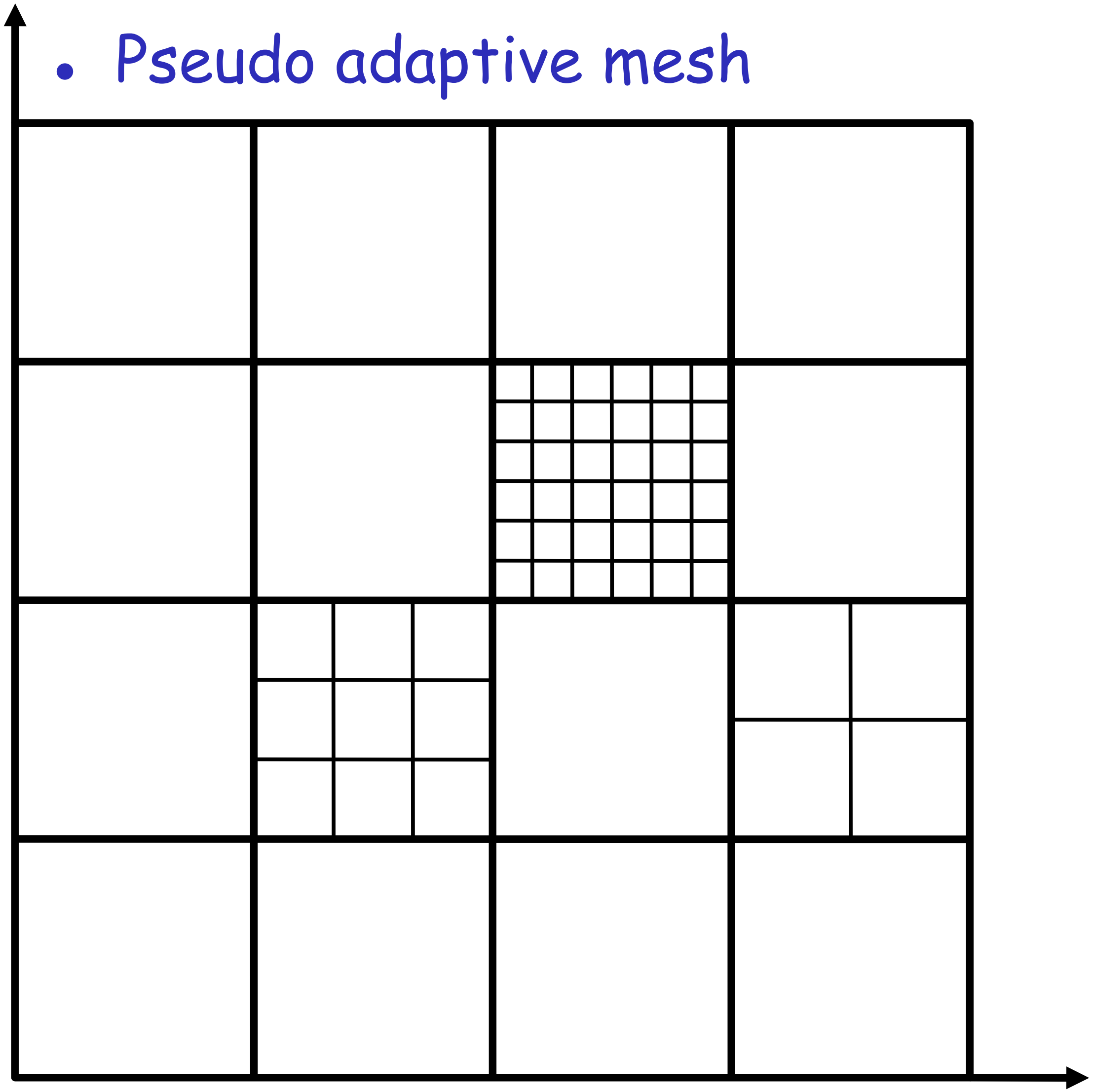
(PAH unstable)

1) single **hard** photon : independent of distance
2) many **soft** photons : ~inner torus

Tielens (2005) ; Micelotta et al. (2010) ; Siebenmorgen & Krűgel (2010)

# 3) Monte Carlo

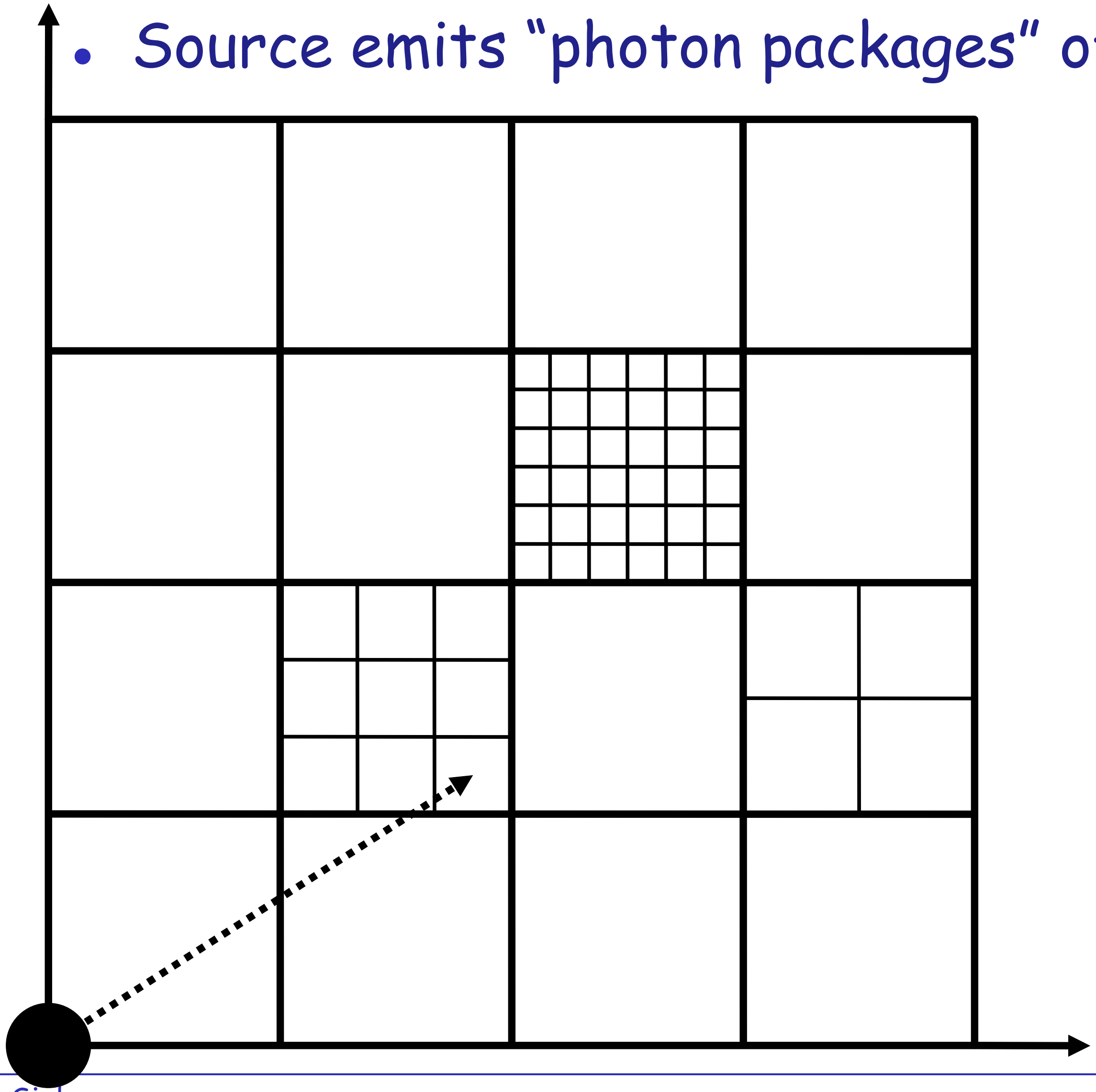
- **Arbitrary dust distribution**
- Pseudo adaptive mesh



1. geometry

Krűgel (2006)

- Source emits "photon packages" of equal energy

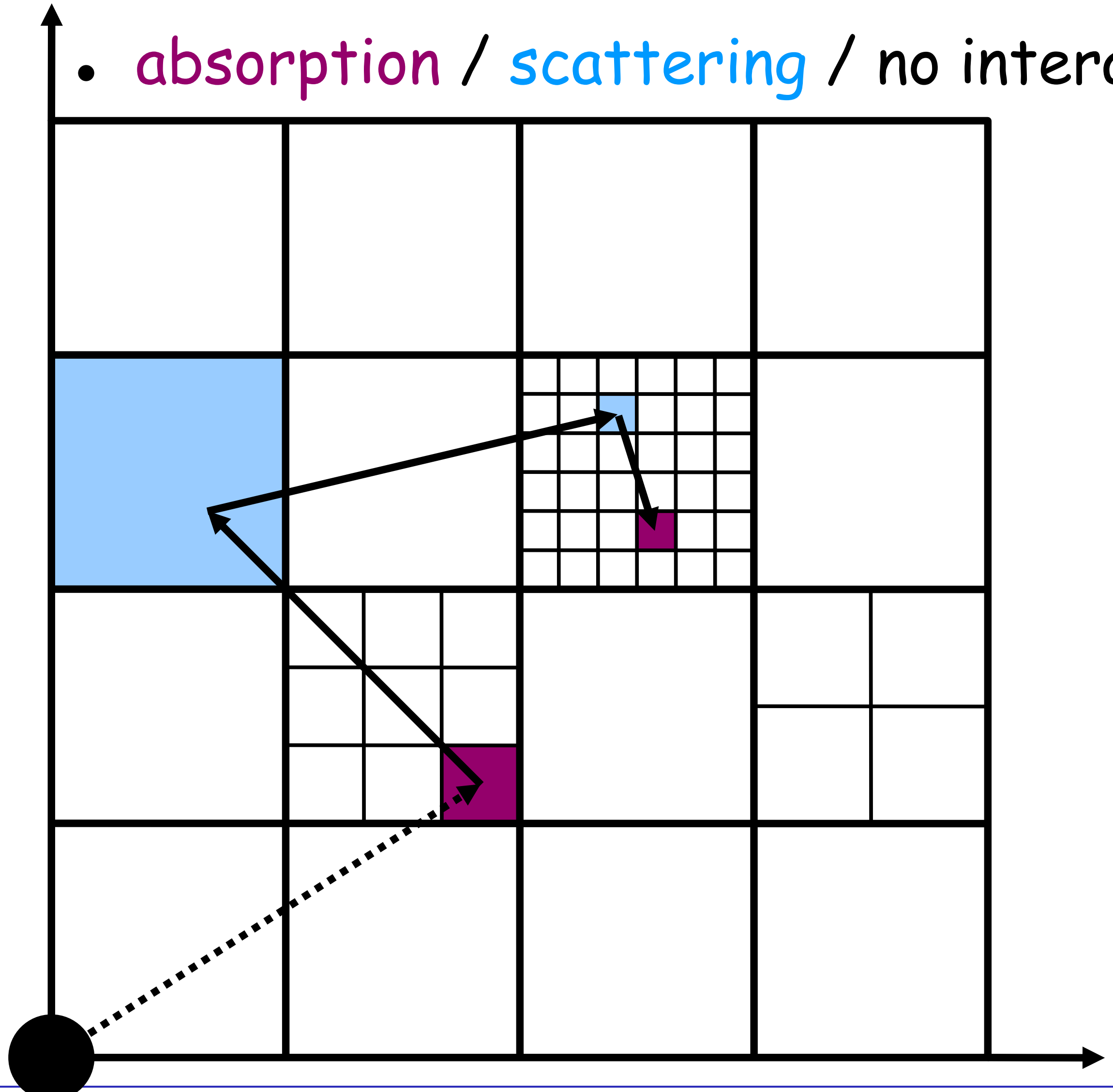


1. geometry
2. source

# Monte Carlo

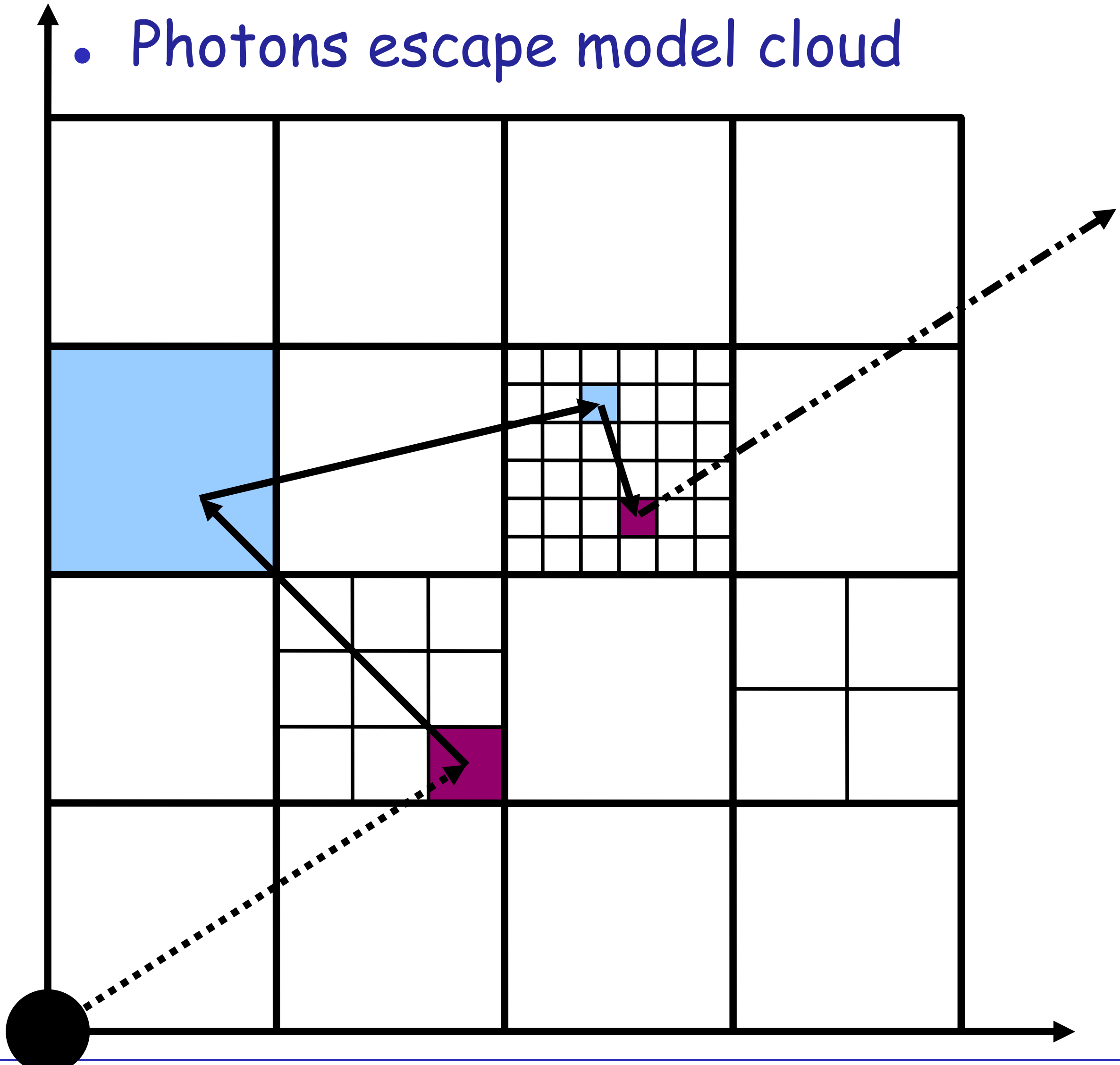
$\tau = -\ln(\zeta)$

- absorption / scattering / no interaction



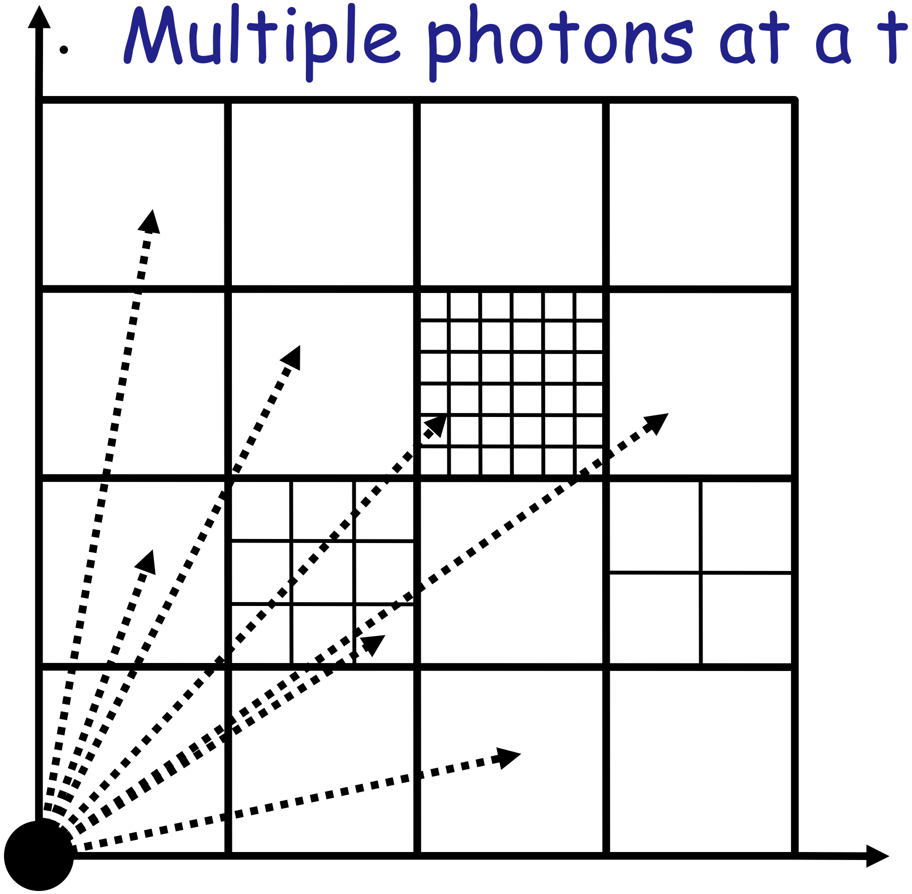
1. geometry
2. source
3. inter-action
4. dust temperature

- Photons escape model cloud



1. geometry
2. source
3. inter-action
4. temperature
5. detection

- Multiple photons at a time:



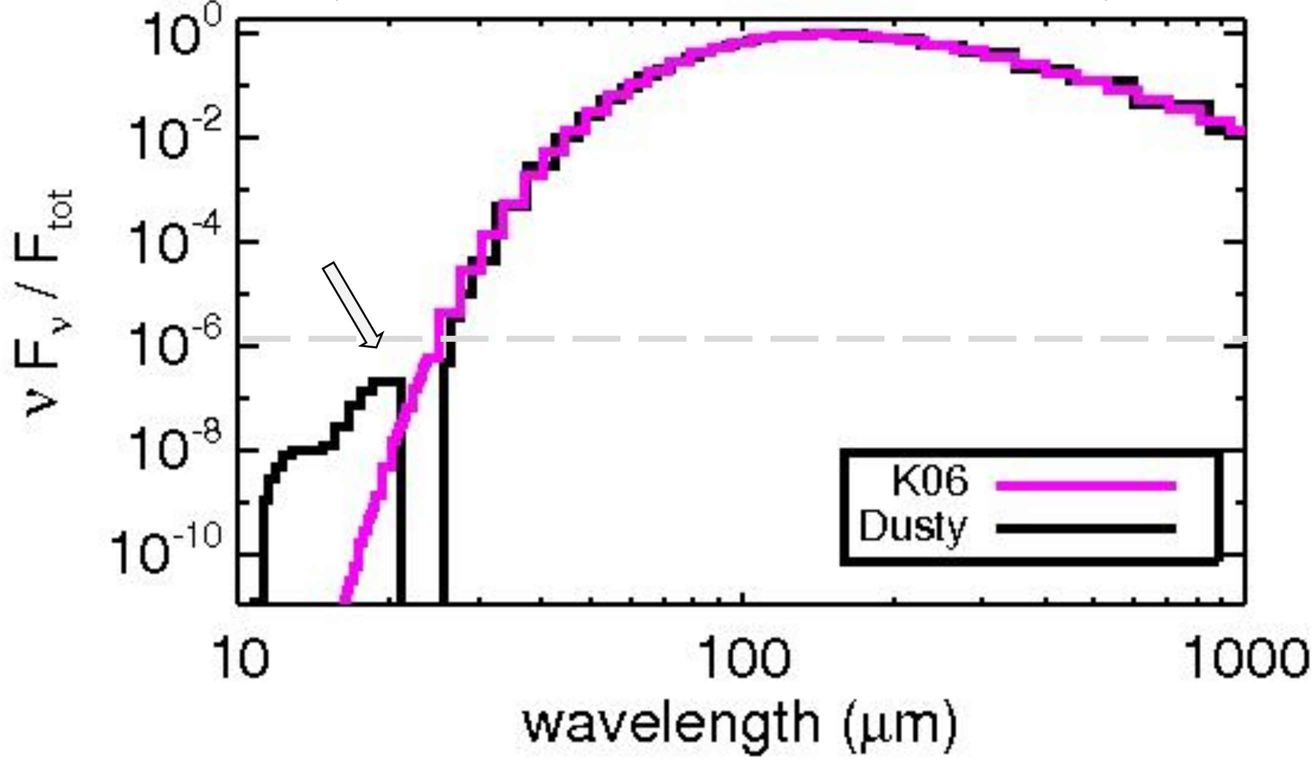
Challenges

- Cell locked when hit by photon
- Parallel random number generator (Mersene Twister)
- Computer games ⟹ Graphical Processing Units (CUDA)

Heymann (2010, PhD)

# Comparison of 2 ray tracing codes

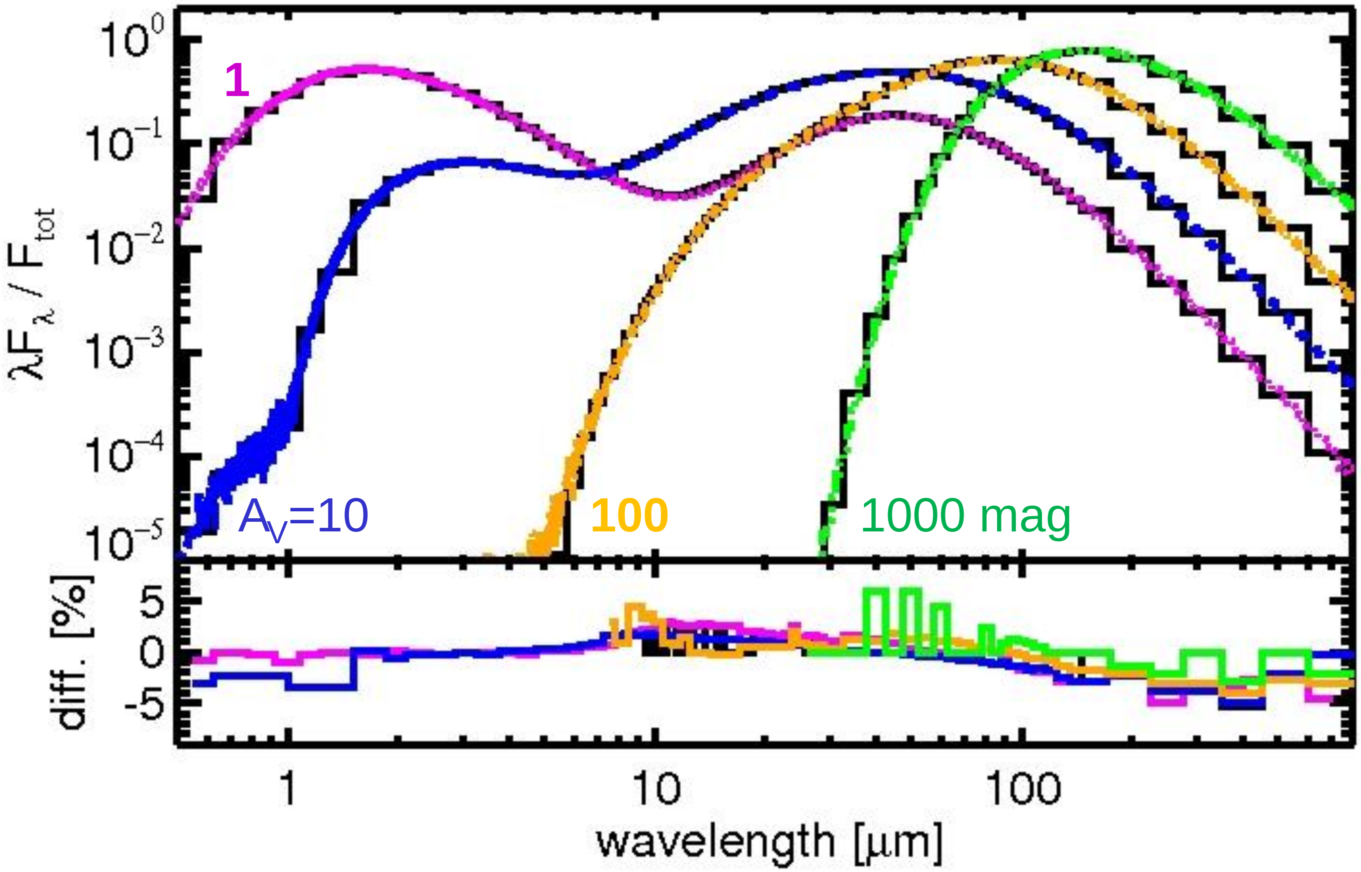
Dust sphere: $A_V$ = 1000mag, heated by star




Benchmark = 'Dusty' code (Iveciz et al. 1999):

unphysical at faint flux levels

# MC versus benchmark




Sphere

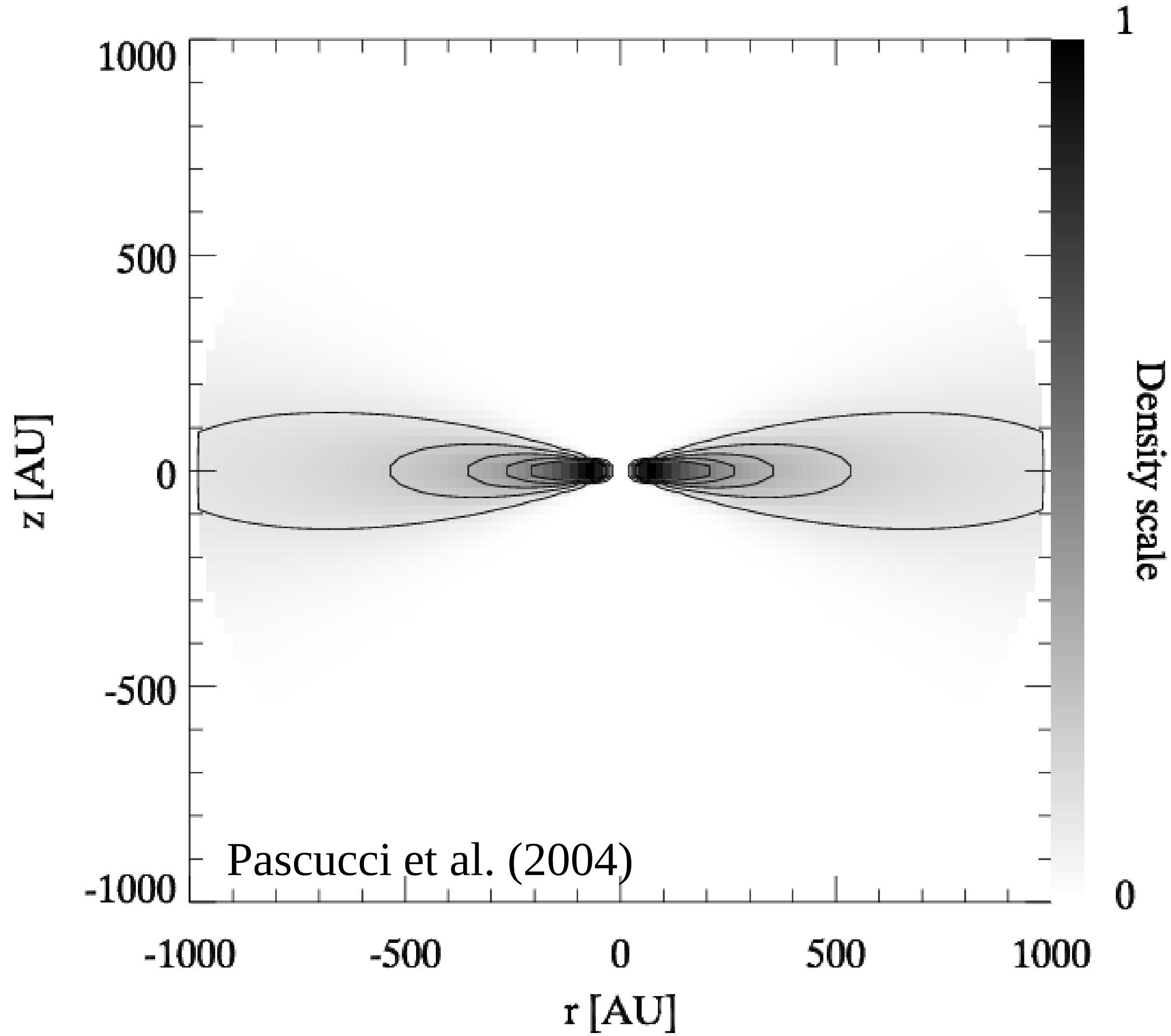
$T_* = 2500K$

$\rho(r)$ = const.

~5% for $\tau \rightarrow 0$

# MC methods

| Method | Parallelization | Advantage | Time<br>Benchmark sphere τ~1000) |
|---|---|---|---|
| Lucy | YES<br>(but floating) | Optical thin | >1h |
| Bjorkman & Wood | Partly<br>(not independent) | No iteration | 5min |
| our | YES | GPU | <1min |




**Disk:**

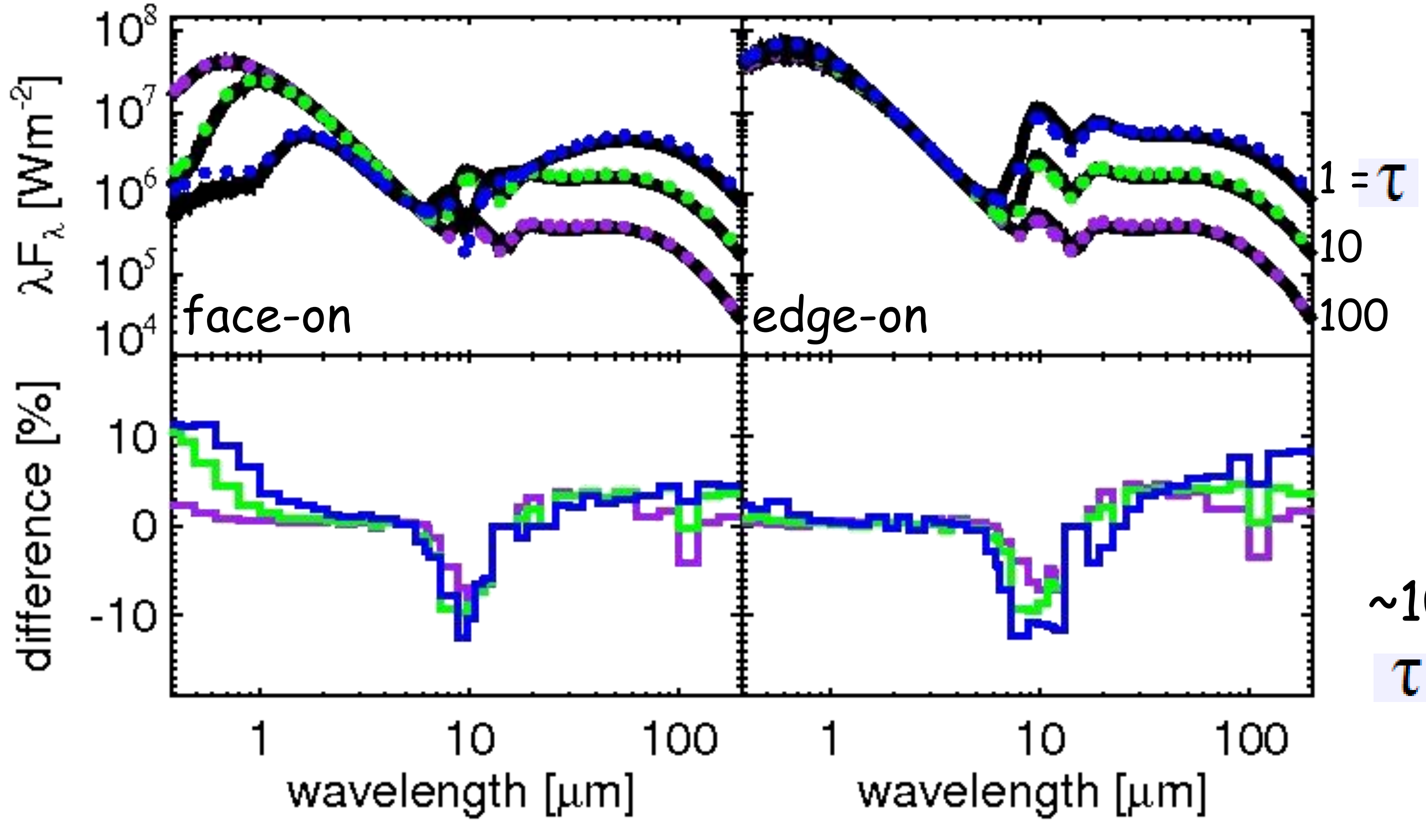
$T_* = 5800K$

$L_* = L_{sun}$

ρ(r) : hydro static equilibrium

(Chiang & Goldreich 1997)

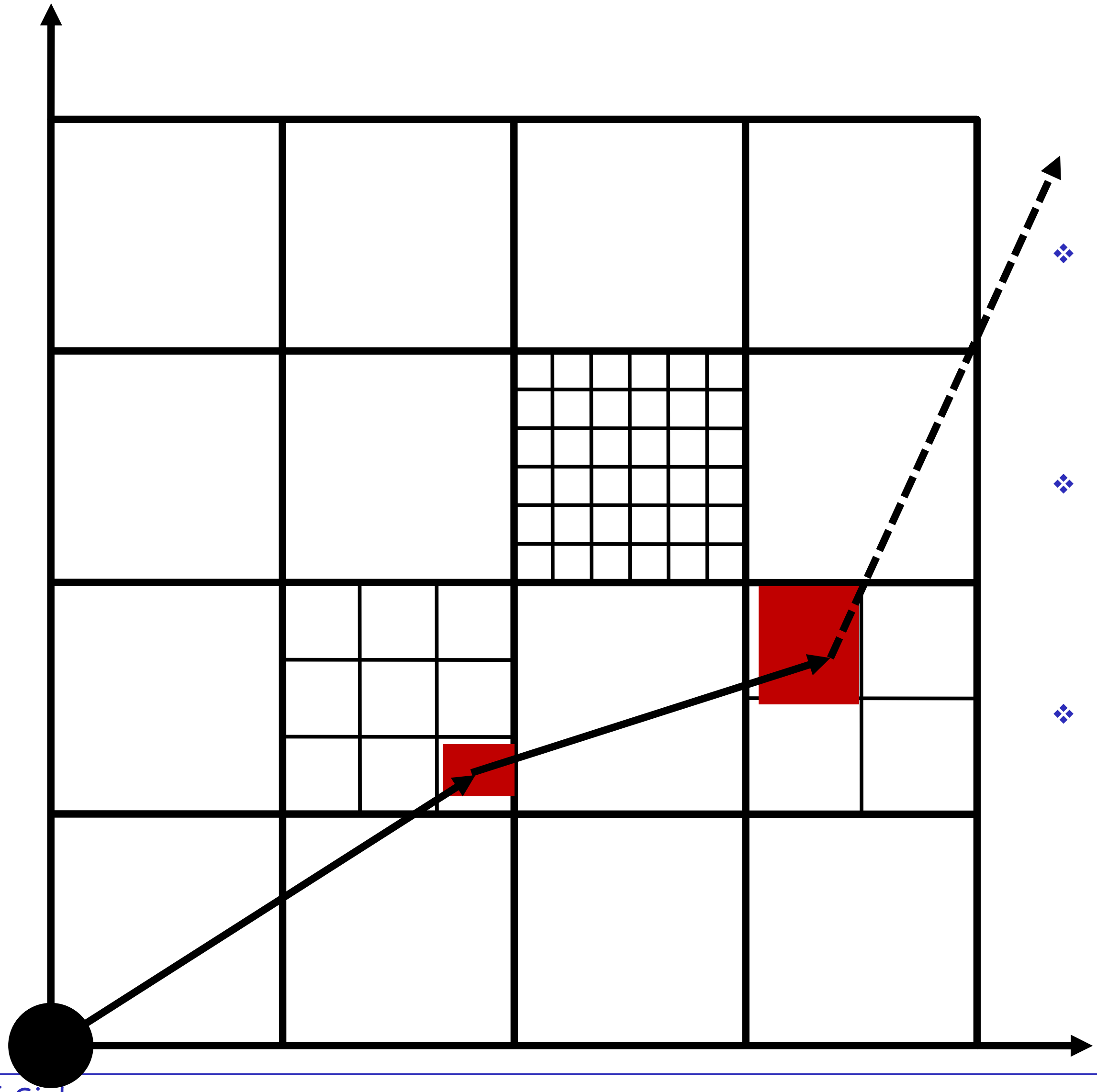
# 2D benchmark




~10% for

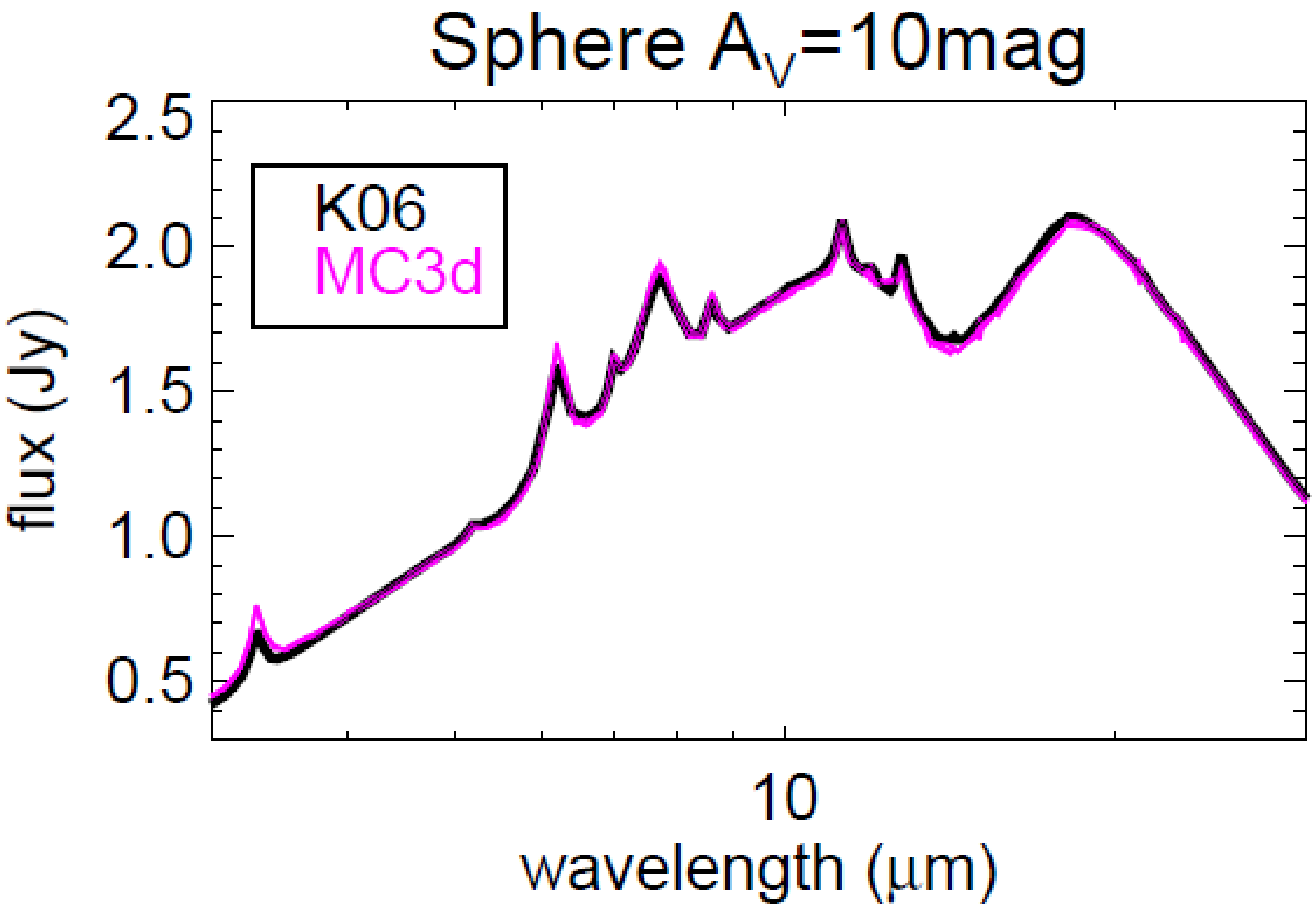
$\tau \longrightarrow 0$

# Monte Carlo + PAH



- store PAH absorption events of each cell
- compute PAH emission
- neglect PAH self absorption

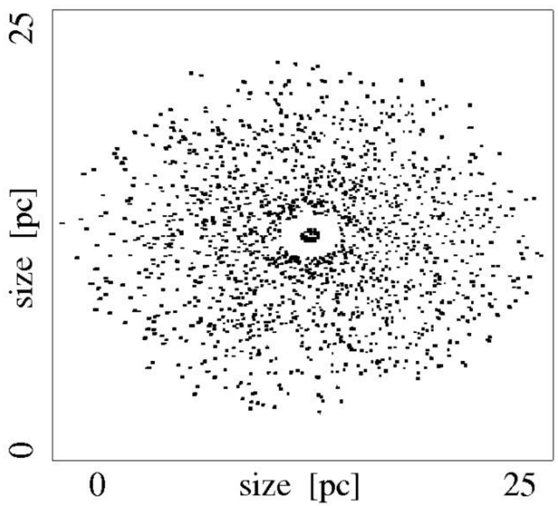
# Monte Carlo + PAH



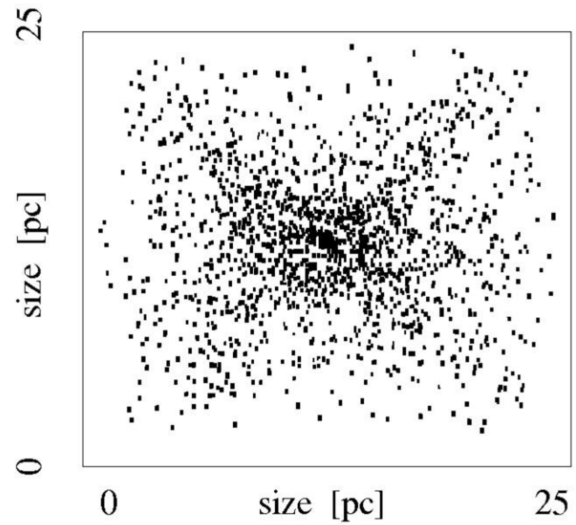
# 4) clumpy AGN torus

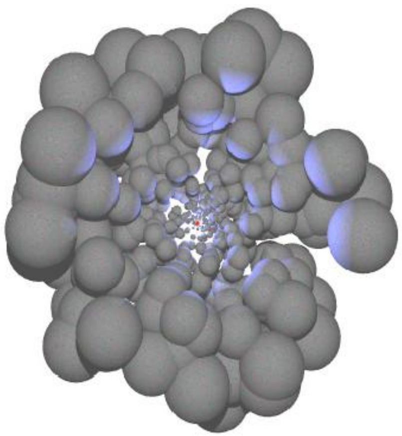
## - density structure

face-on




edge-on



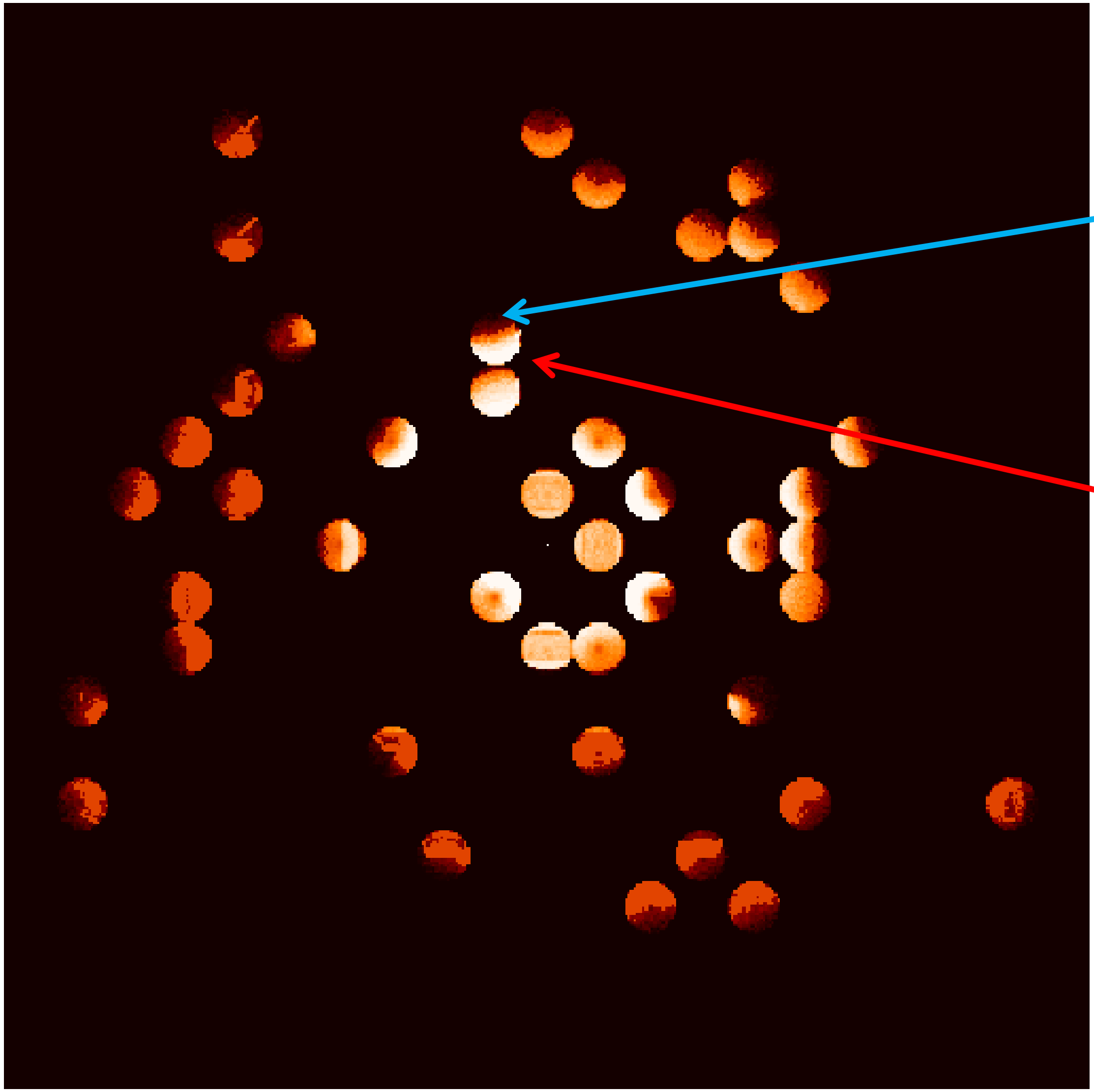



3D models: Heymann (PhD) Schartmann et al. (2008)

MIDI: Tristram (2007)

Statistical model: Nenkova et al.(2002, 2008)

# Shadows caused by clump structure

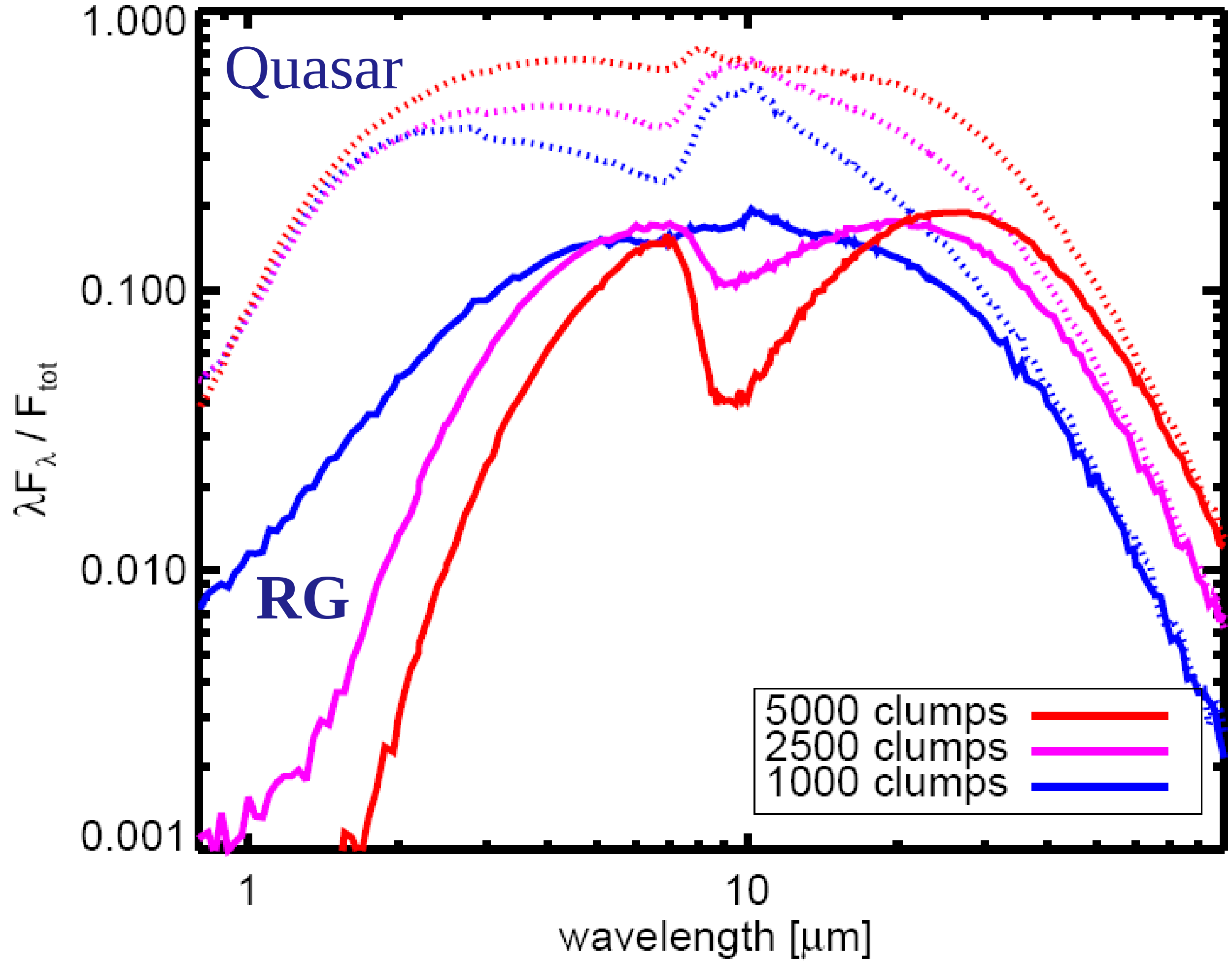


dark side: cold

bright side: hot

10µm emission
face-on

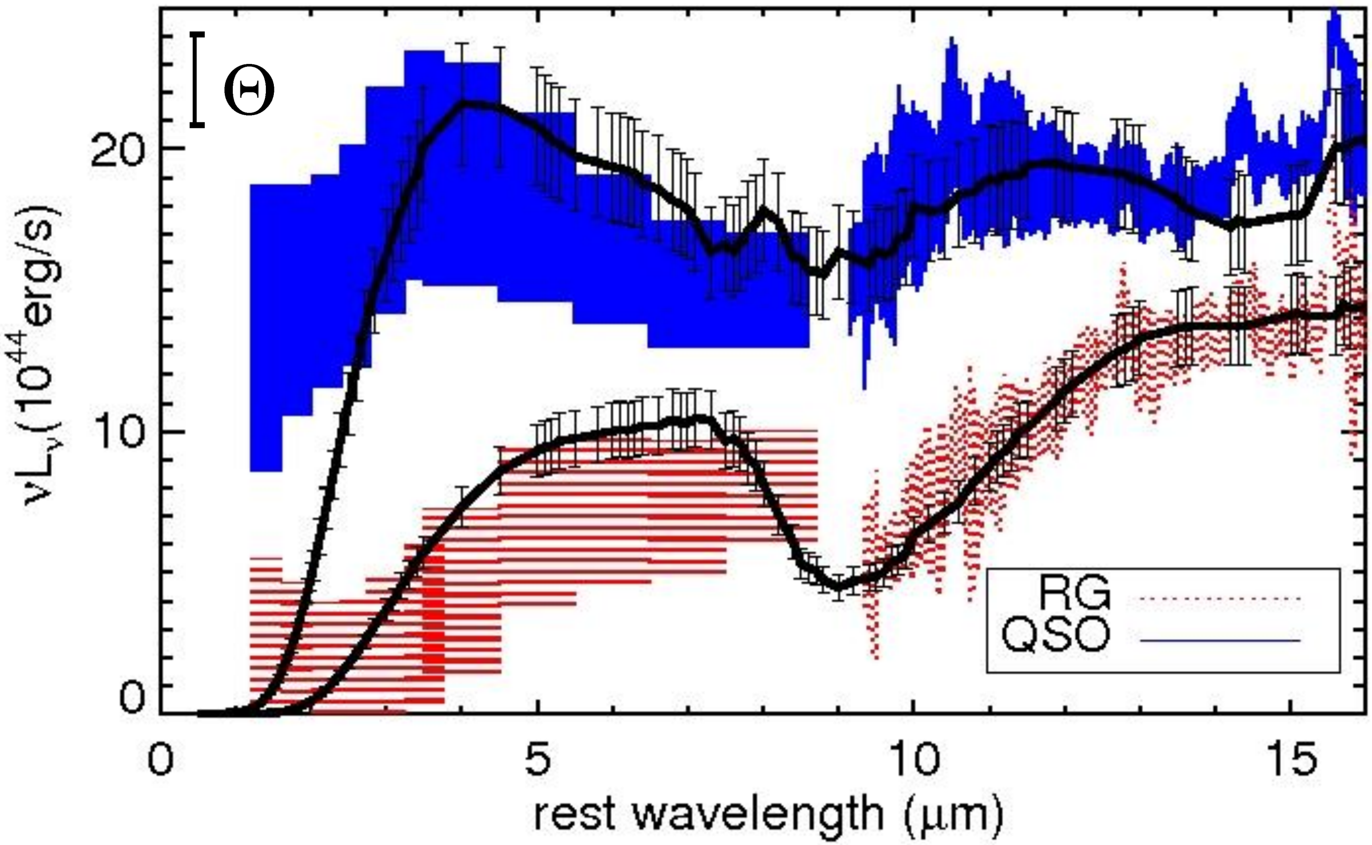
# Number of clouds ↔ SED of AGN



# Mean SED of 3CR sources

| | |
|---|---|
| $N_{clump}$ | 5 000 |
| $L_{AGN}$ | $10^{11} L_\odot$ |
| $D_{AGN}$ | $10^9$pc |
| $s_x \times s_y \times s_z$ | 25pc×25pc×12.5pc |
| $\tau_V$ | $\sim 100$ |
| $M_{Dust}$ | $10^3 M_\odot$ |

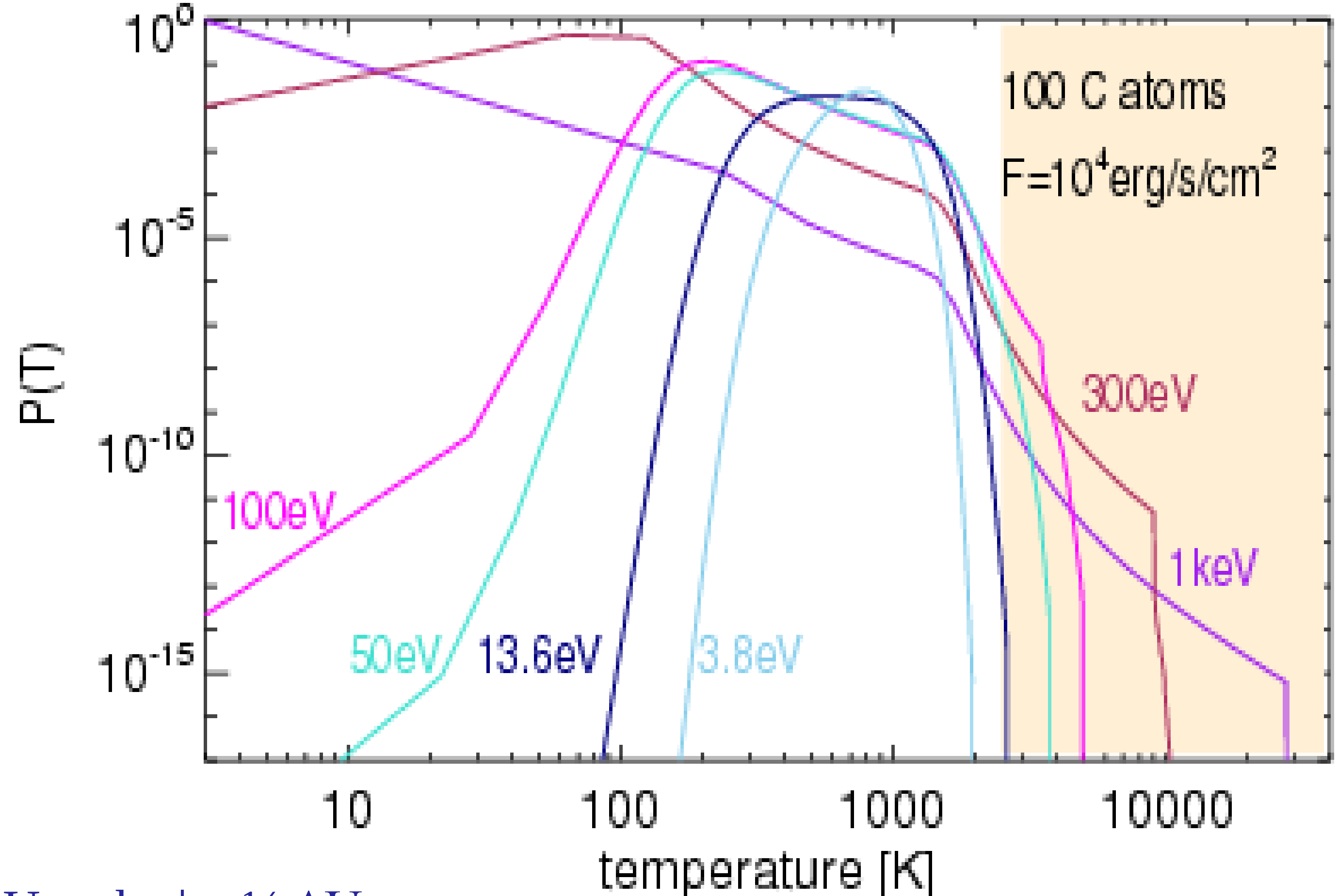
Data: Haas et al (2008), Leipski et al. (2010)



# Conclusion

- MIR observations consistent with unified scheme.
- Dust model of the diffuse ISM for extinction and emission. PAH destruction by hard photons.
- Monte Carlo dust radiative transfer model including PAH using vectorised computing technology.
- Clumpy AGN torus model consistent with SED of 3CR sources.

# PAH in a mono-energetic heating bath




if $| U_f - U_i - h\nu | < \frac{1}{2} \Delta U_f$ :

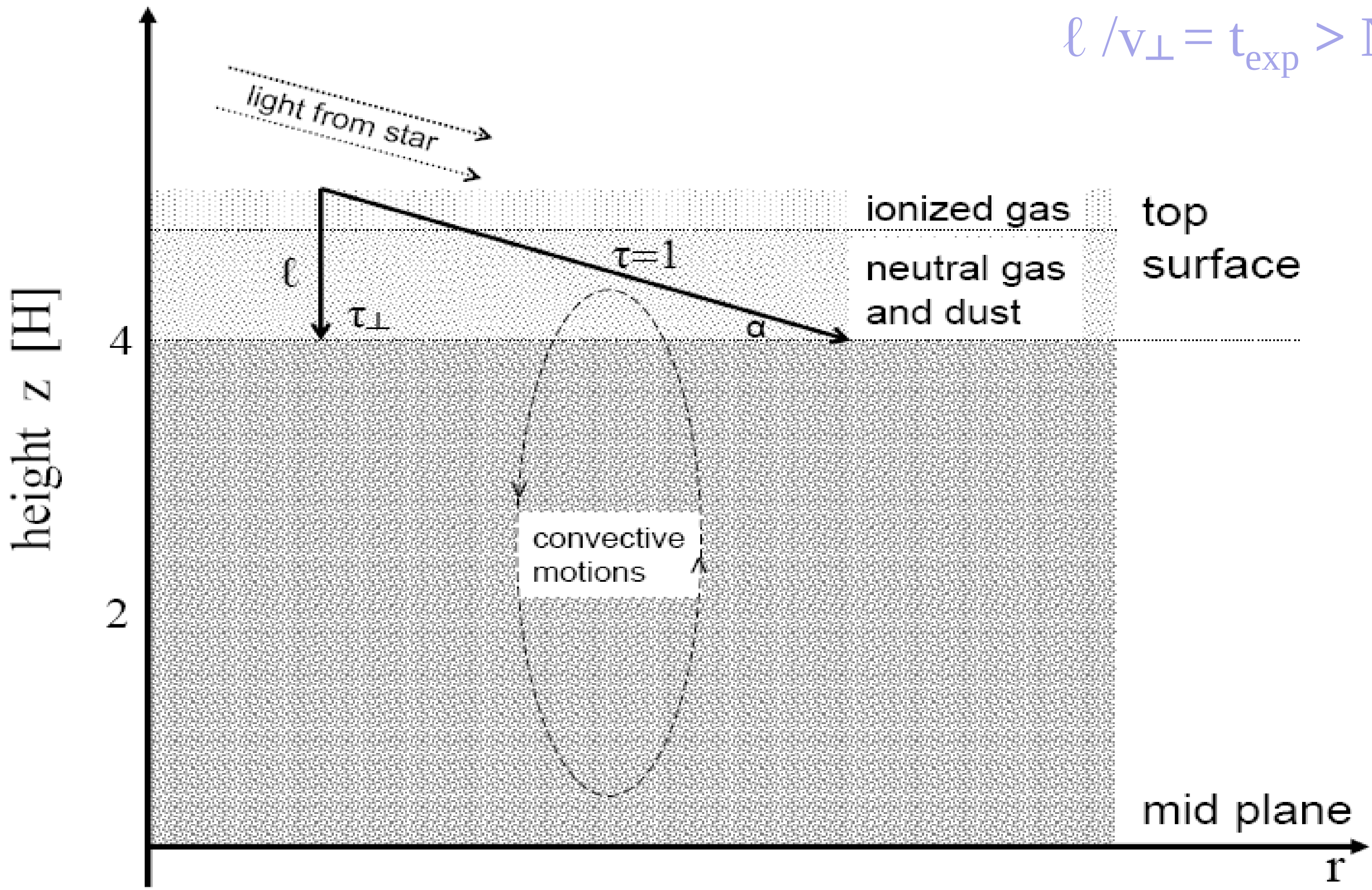
$A_{fi} = K_\nu F_\nu / h\nu$

Siebenmorgen & Krűgel (2010)

# PAH replenishment

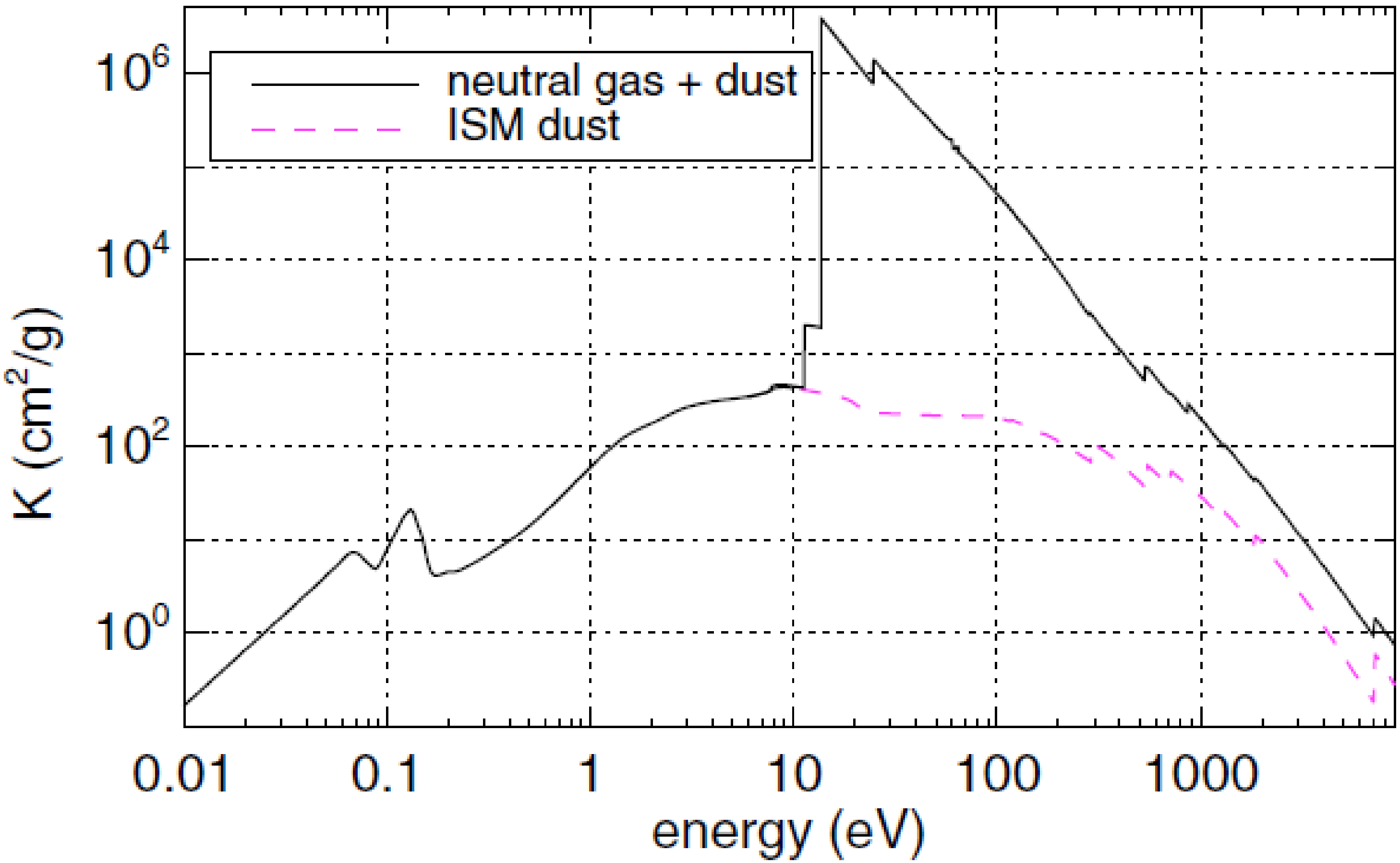
## Vertical mixing in torus?

$\ell / v_{\perp} = t_{exp} > N_C \, t_{abs}$

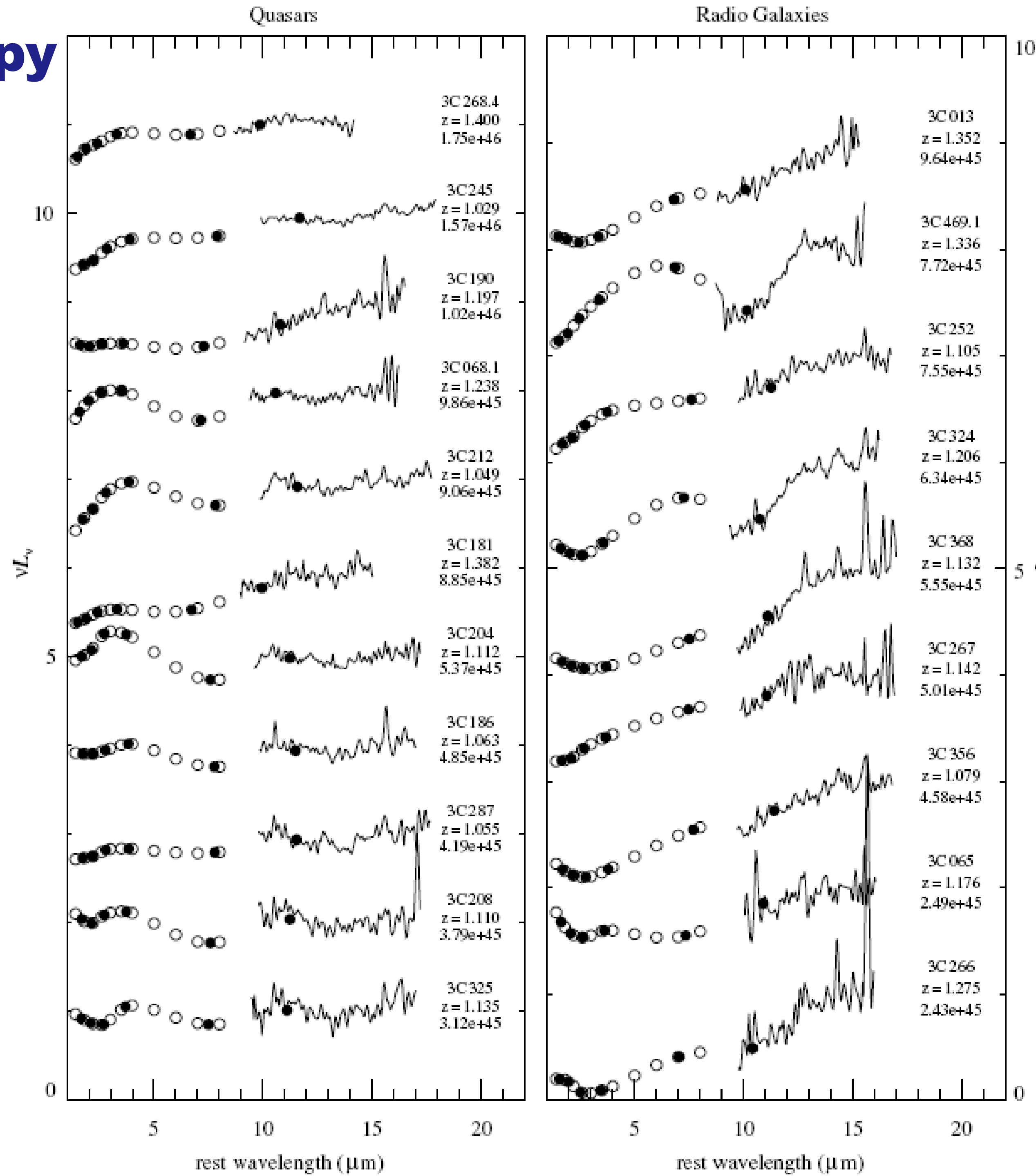



Siebenmorgen & Krügel (2010)

# AGN and hard photons
## (EUV, soft X-ray)



# 4) IRS spectroscopy of 3CR sources

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- similar emission line ratios
- no PAH

Leipski et al. (2010)