MODULO meeting

2 - 3 December 2010

Spectral Energy Distributions as probes of star formation in the distant Universe

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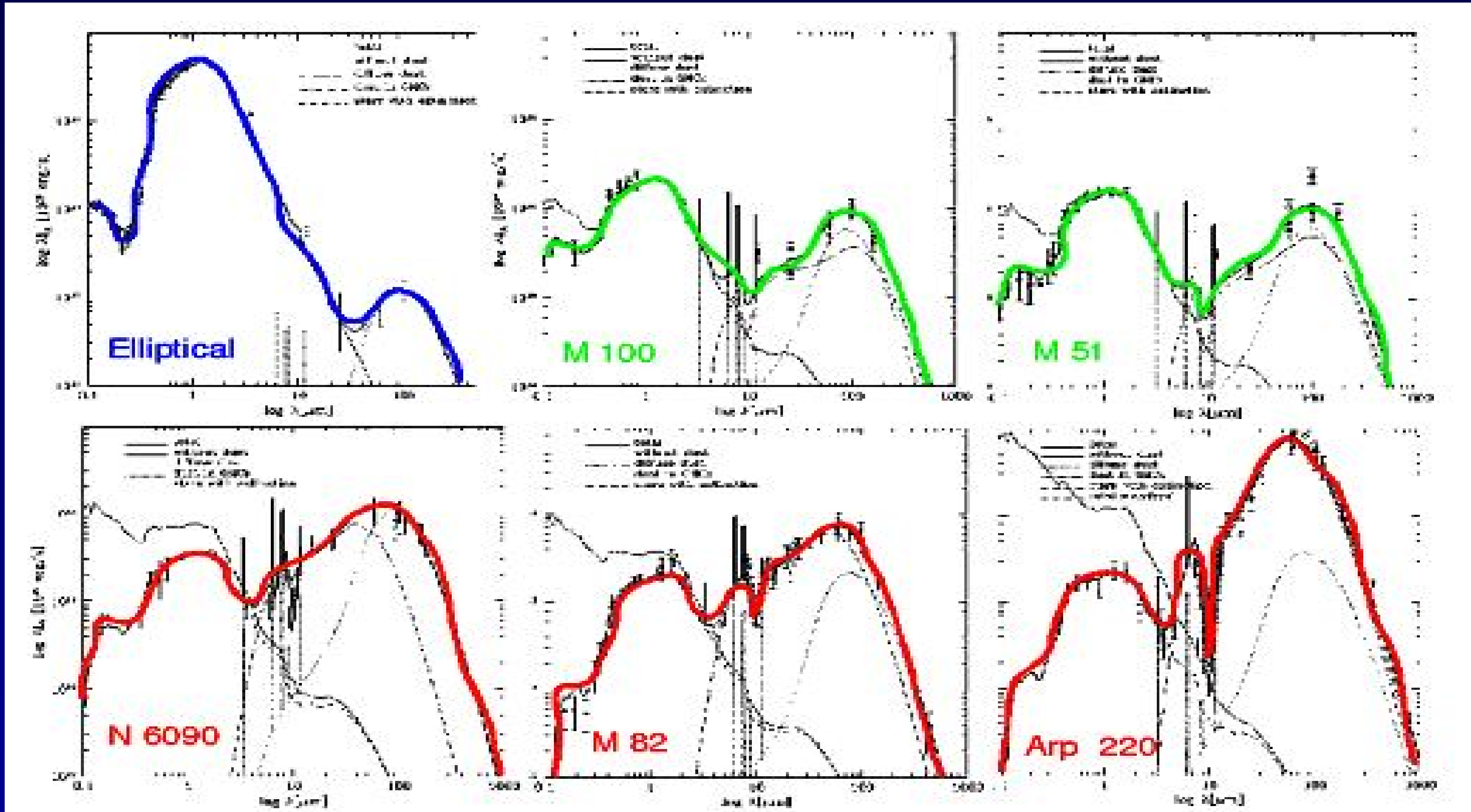
IRAS (1983), ISO (1995) and Spitzer (2003)

Have shown that:

1. ~75% of star formation in the universe is obscured by **DUST** (Chary & Elbaz 2001; Le Floc'h et al. 2005)
2. Half of energy and the most of the photons pervading the intergalactic space come from the **infrared (IR)** spectral region. The most luminous objects in the universe are also the most highly obscured (Hauser & Dwek 2001; Franceschini et al. 2008; Reddy et al. 2006)



Spectral Energy Distributions (SEDs) of a series of galaxies taken from Silva et al. (1998), shown from upper left to lower right as function of increasing dust opacity, luminosity, and Star Formation Rate (SFR).

- As galaxies host more star formation, dust opacities increases
- In galaxies with IR-dominated SED (NGC6090, M82, Arp220), the SFR is quite well correlated with L_{FIR}
  - → L_{FIR} is a powerful tracer of star formation
  - → the dust absorbs most of the ultraviolet (UV) radiation from the young hot stars and re-emits thermally it in the IR

→The IR SEDs are powerful tool to investigate star forming regions.

→Models of the IR SEDs of star-forming galaxies and starbursts vary in complexity, but the SEDs they predict are surprisingly similar

IR dust emission possesses scaling properties

Scaling properties of dust infrared emission

Dust infrared emission possesses general scaling properties that render the radiative transfer solution essentially ***scale-free***, even in arbitrary geometries (Rowan-Robinson, 1980; Ivezić & Elitzur, 1997; Chakrabarti & McKee, 2008)

Scaling properties of dust infrared emission

1) Spectral shape is the only relevant property of the heating radiation and the luminosity is never an input parameter; density and dimensions enter only through a single independent parameter, the overall dust optical depth, τ_V.

2) As long as τ_V stays the same , the system dimensions can be scaled up or down by an arbitrary factor without any effect on the radiative transfer problem.

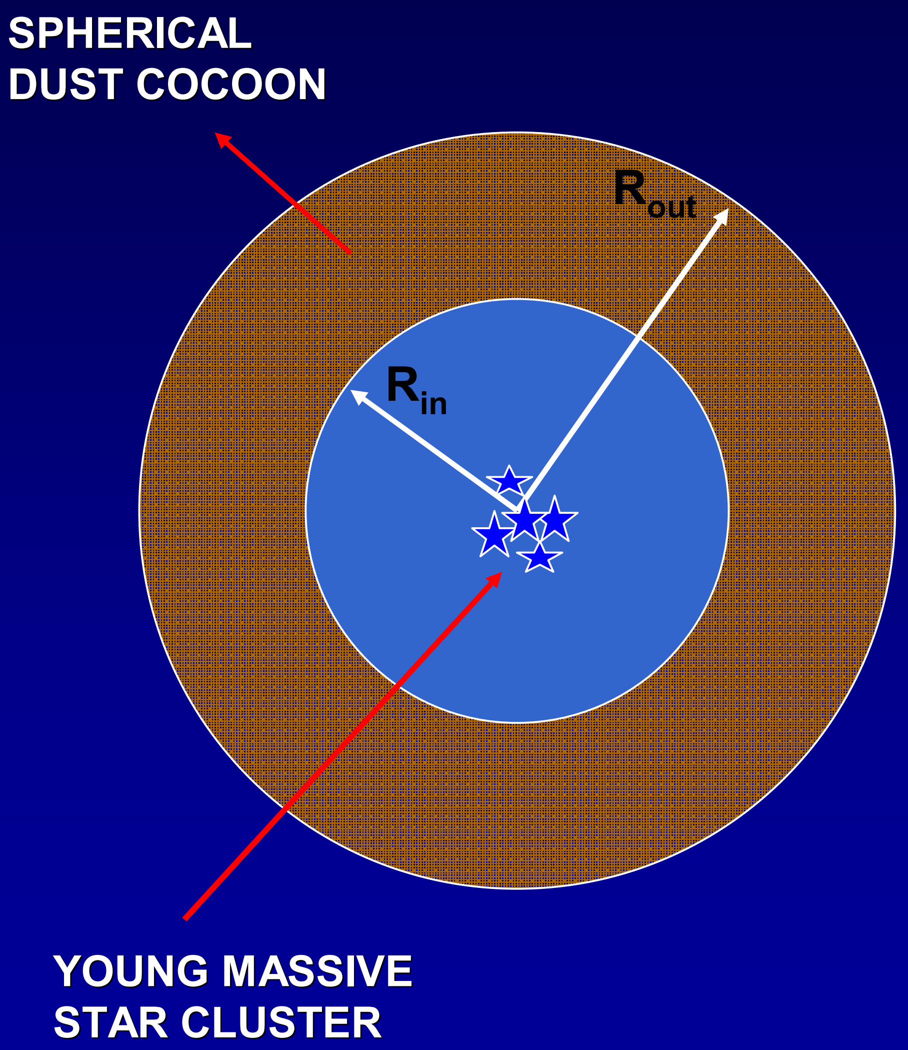
3) Scaling properties enable a systematic approach to modelling and classification of IR spectra, and reduce the number of independent input parameters

DUSTY

DUSTY (Ivezić & Elitzur, 1997) is a code which solves the radiative transfer problem in dusty environment exploiting scaling properties of dust infrared emission,

and has already been used with success to model both local unobscured and dusty starbursts over a wide range of metallicities, and different samples of high redshift galaxy populations.

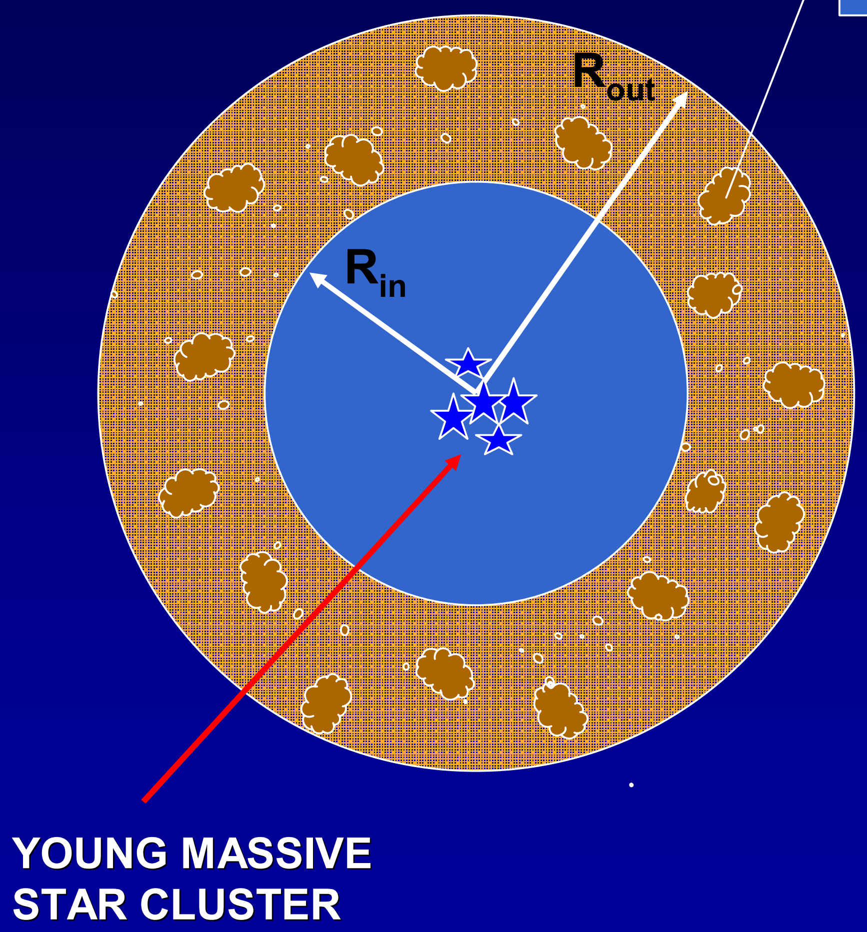
How DUSTY works?



INPUT PARAMETERS:

- $Y = (R_{out} - R_{in}) / R_{in}$
- $T_{in} = T_{dust}\,(R_{in})$
- p, power-law density distribution index
- spectral shape of the heating radiation

How DUSTY works?



https://newton.pa.uky.edu/~clumpyweb/

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- $T_{in} = T_{dust} (R_{in})$
- p, power-law density distribution index
- spectral shape of the heating radiation

What shapes the SED?

In order to investigate which parameters characterizes which part of the SED shape, I considered a hypothetic star forming region consist of a young massive star cluster surrounded by a spherical dust cocoon.
In this region I fixed:

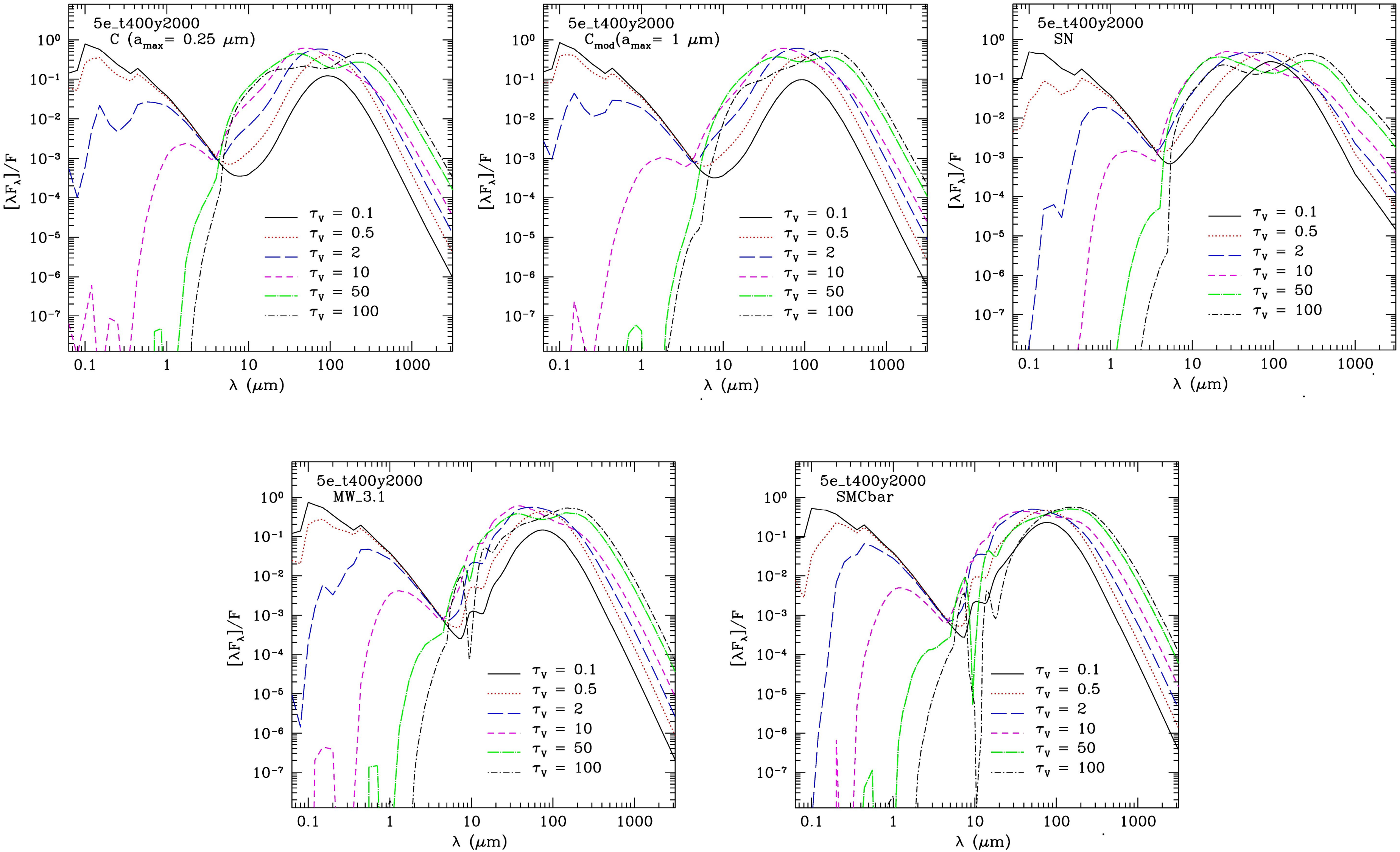
- **Geometry** of dust cocoon :
  T_{in} = 400 K, Y = 2000, p = 0 (uniform density distribution)

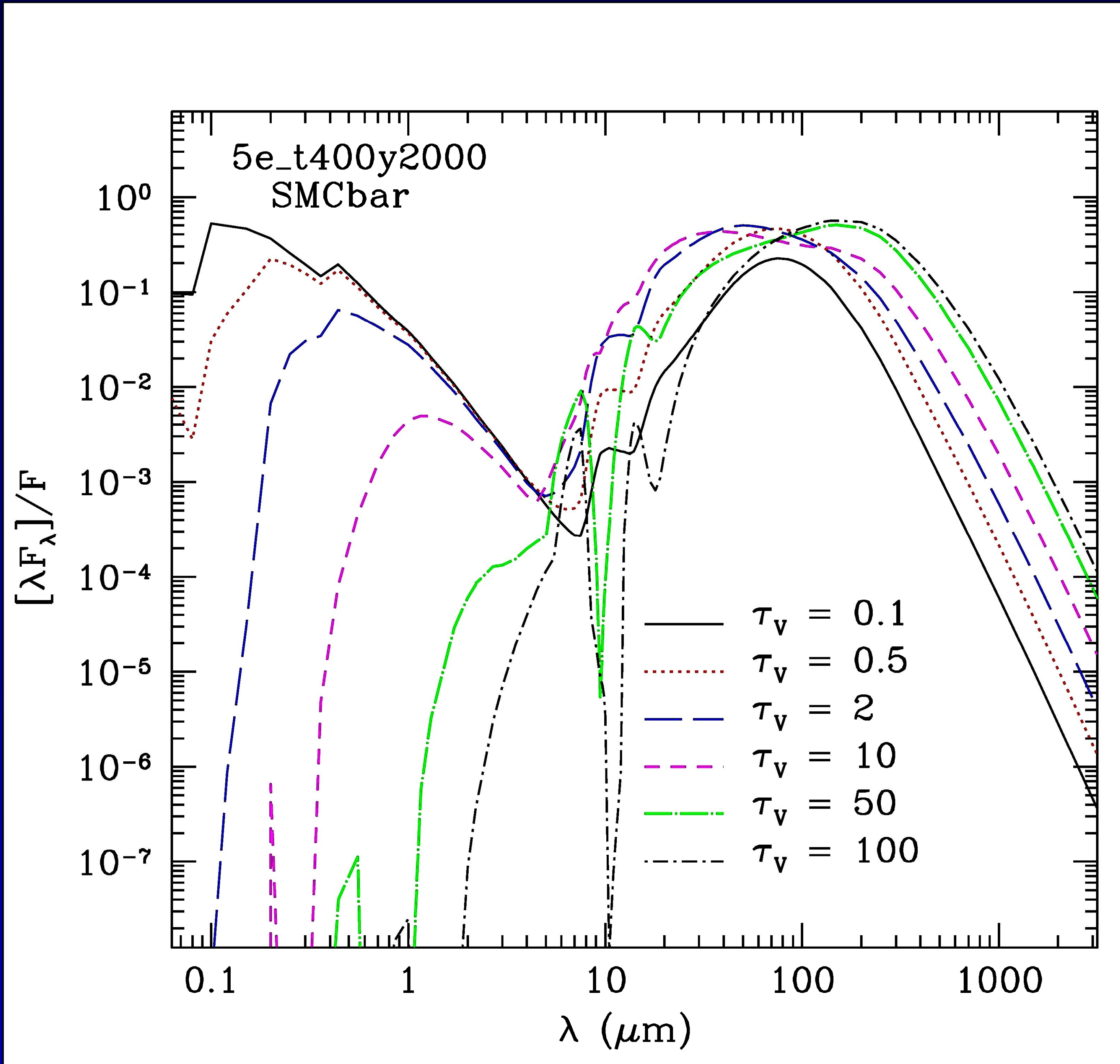
- **Age** and **metallicity** of stellar population:
  5 Myr and Z = 0.05 $Z_{\odot}$ (SED from Starburst99-Leitherer et al. 1999, *http://www.stsci.edu/science/starburst99/*)

I computed SEDs models using several dust families which differs for size distribution and chemical composition:

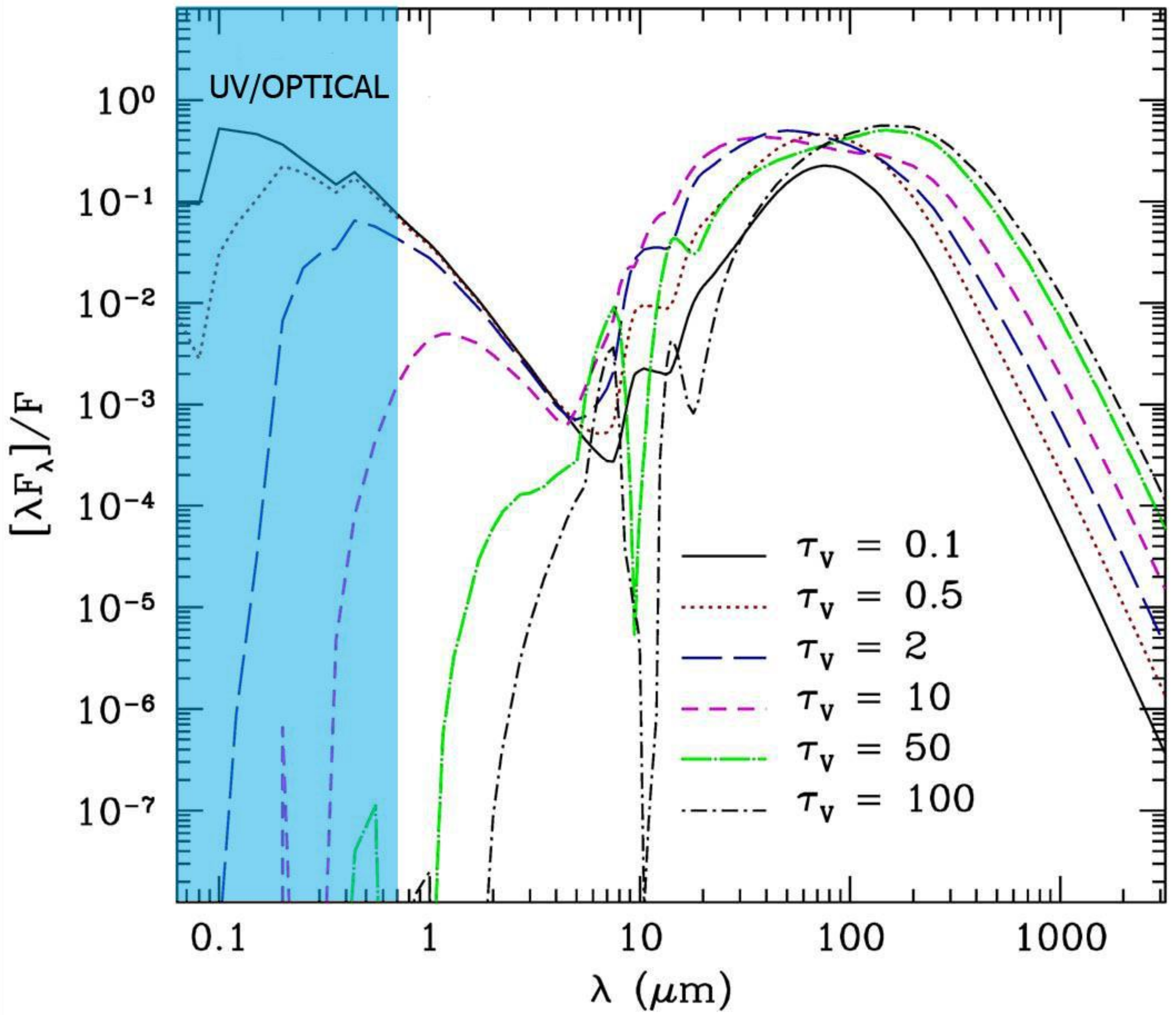
- Draine (2003) for Milky Way (R_V =3.1)
- Weingartner & Draine (2001) for SMC bar dust
- Simone Bianchi’s supernova dust (Bianchi & Schneider 2007)
- Only carbonaceous grains with 0.005 μm ≤ a ≤ 0.25 μm
- Only carbonaceous grains with 0.005 μm ≤ a ≤ 1.0 μm

τ_V effect

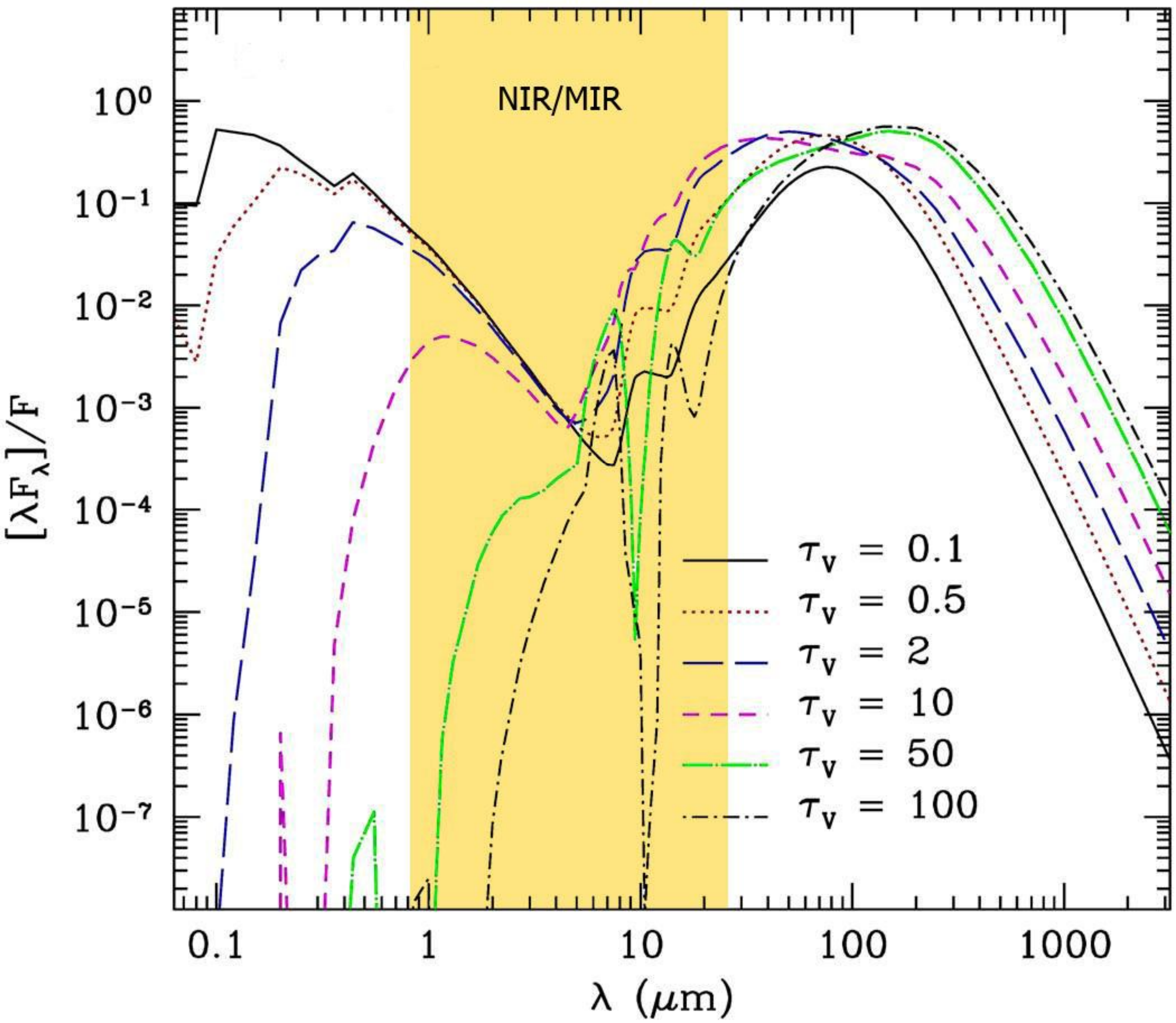

5e_t400y2000
C (a_max= 0.25 μm)
5e_t400y2000
C_mod(a_max= 1 μm)
5e_t400y2000
SN
5e_t400y2000
MW_3.1
5e_t400y2000
SMCbar
[λF_λ]/F
λ (μm)
τ_V = 0.1
τ_V = 0.5
τ_V = 2
τ_V = 10
τ_V = 50
τ_V = 100

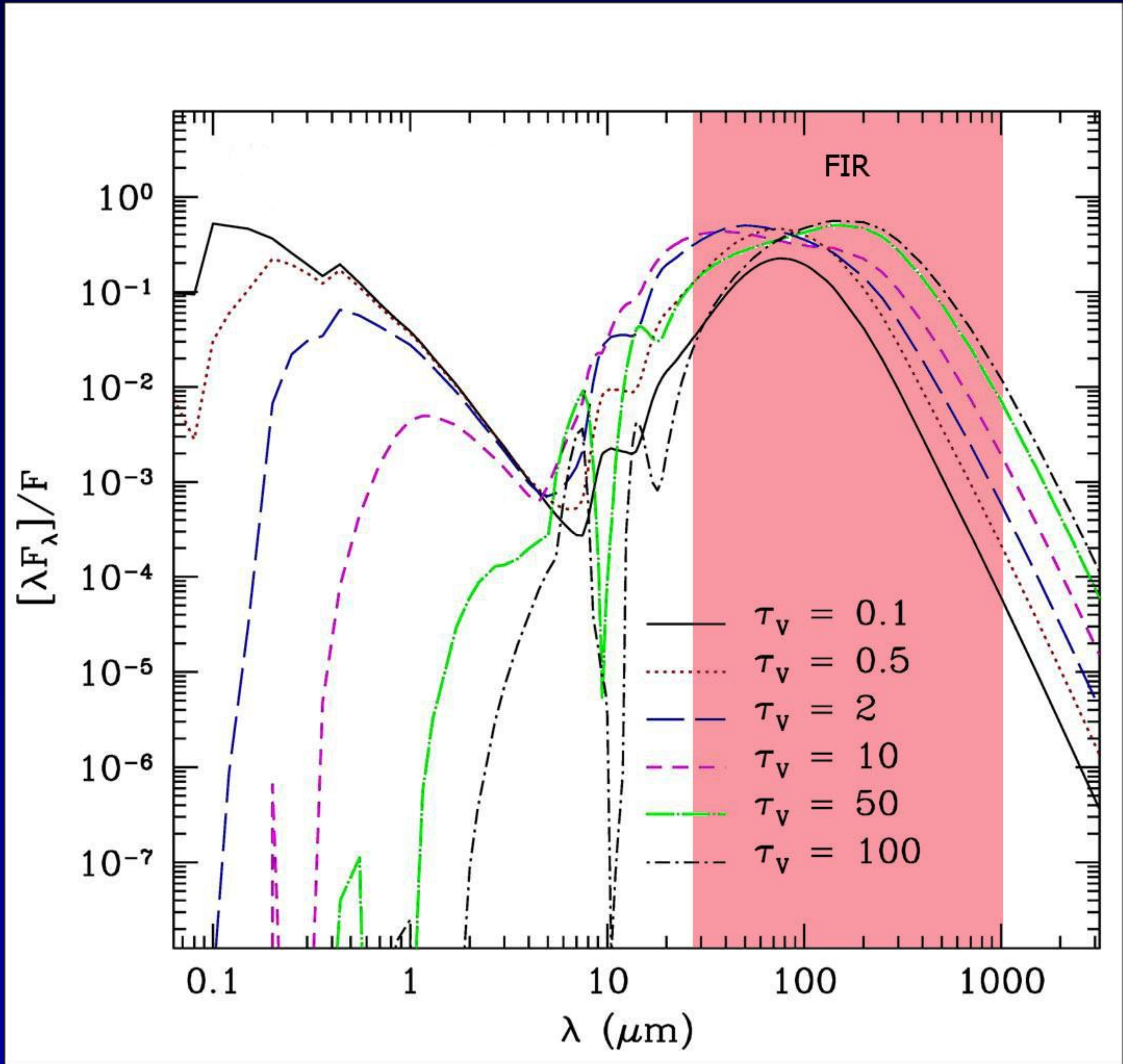


5e_t400y2000
SMCbar
$[\lambda F_\lambda]/F$
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.1
1
10
100
1000
λ (μm)
τ_V = 0.1
τ_V = 0.5
τ_V = 2
τ_V = 10
τ_V = 50
τ_V = 100



UV/OPTICAL
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
$[\lambda F_\lambda]/F$
0.1
1
10
100
1000
λ (μm)
τ_V = 0.1
τ_V = 0.5
τ_V = 2
τ_V = 10
τ_V = 50
τ_V = 100


NIR/MIR
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
$[\lambda F_\lambda]/F$
0.1
1
10
100
1000
λ (μm)
τ_V = 0.1
τ_V = 0.5
τ_V = 2
τ_V = 10
τ_V = 50
τ_V = 100


FIR
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
$[\lambda F_\lambda]/F$
0.1
1
10
100
1000
λ (μm)
τ_V = 0.1
τ_V = 0.5
τ_V = 2
τ_V = 10
τ_V = 50
τ_V = 100

How can models best fit to data?

DUSTY models depend on several parameters:

- Y, T_{in}, p, τ_V, dust properties

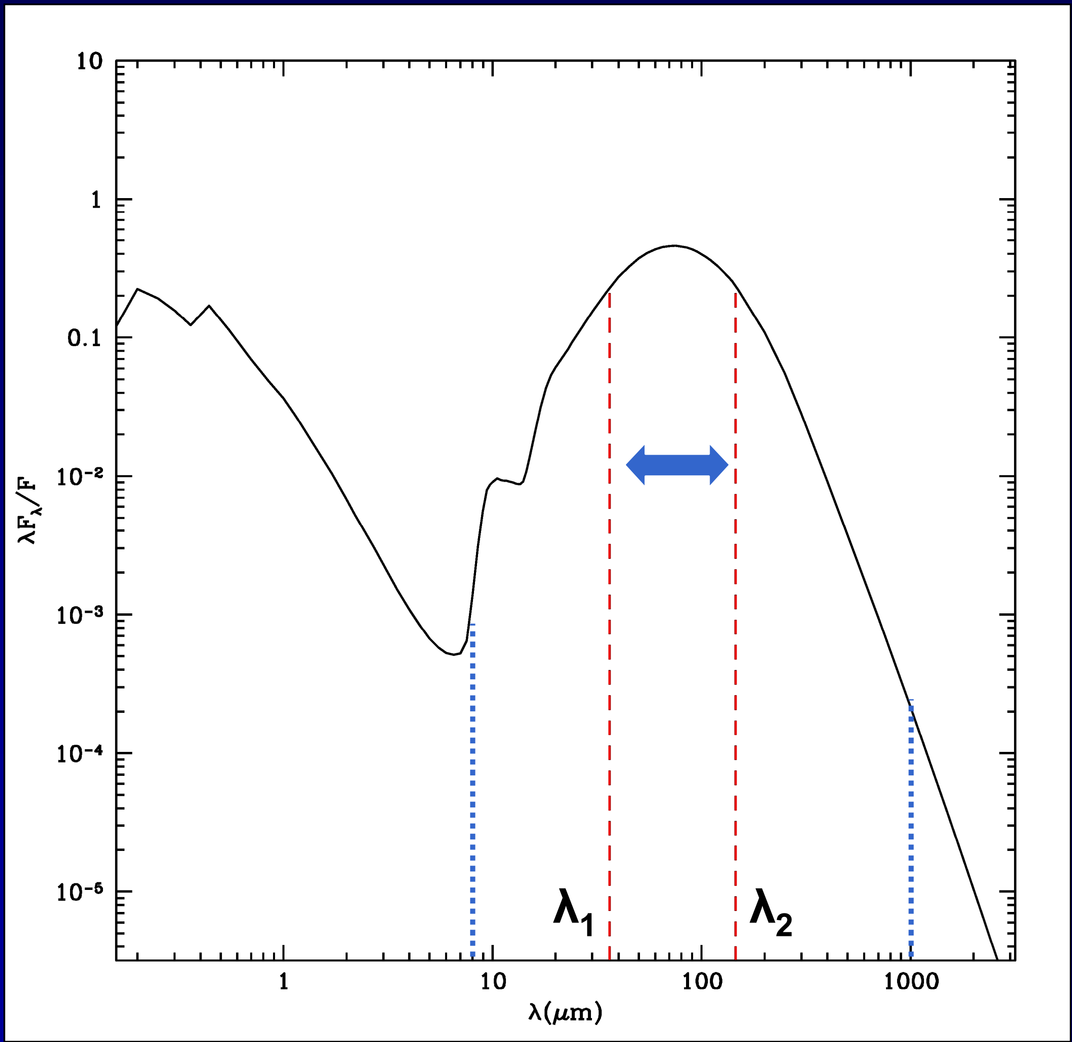
How can we find best-fit model for each observed SED?

Parametrization of SED

- Searching for parameters which correlate with geometry and optical depth of the system, computable directly from models but especially from observations.

- Creating different categories of SED models to simplify their comparison with observations.

Simple tool for the analysis of SED



$$halfsum = \lambda_2 - \lambda_1$$

where

$$\lambda_1 \mid \int_{8\,\mu m}^{\lambda_1} (F_\lambda \lambda / \lambda) d\lambda = \frac{1}{4} totsum$$

$$\lambda_2 \mid \int_{\lambda_2}^{1000\,\mu m} (F_\lambda \lambda / F) d\lambda = \frac{1}{4} totsum$$

$$totsum = \int_{8\,\mu m}^{1000\,\mu m} (F_\lambda \lambda / F) dF$$

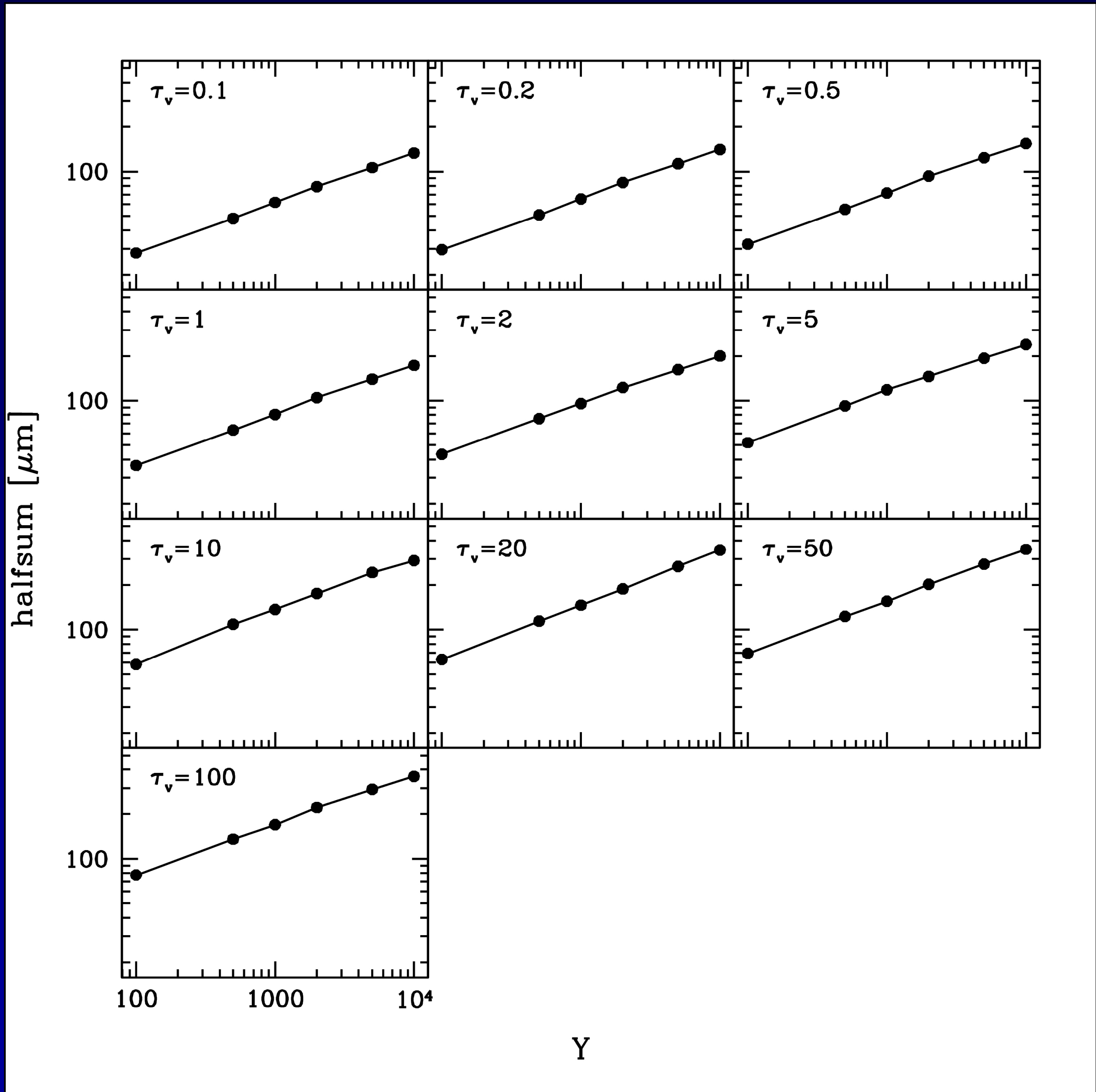
Simple tool for the analysis of SED

I produced 300 models with the following features:

- $100 \leq Y \leq 10000$
- $300\ K \leq T_{in} \leq 800\ K$
- $p = 0$ (uniform density distribution)
- $0.1 \leq \tau_V \leq 100$
- SMC bar dust (Weingartner & Draine, 2001)
- Age = 5 Myr, $Z = 0.05\ Z_\odot$

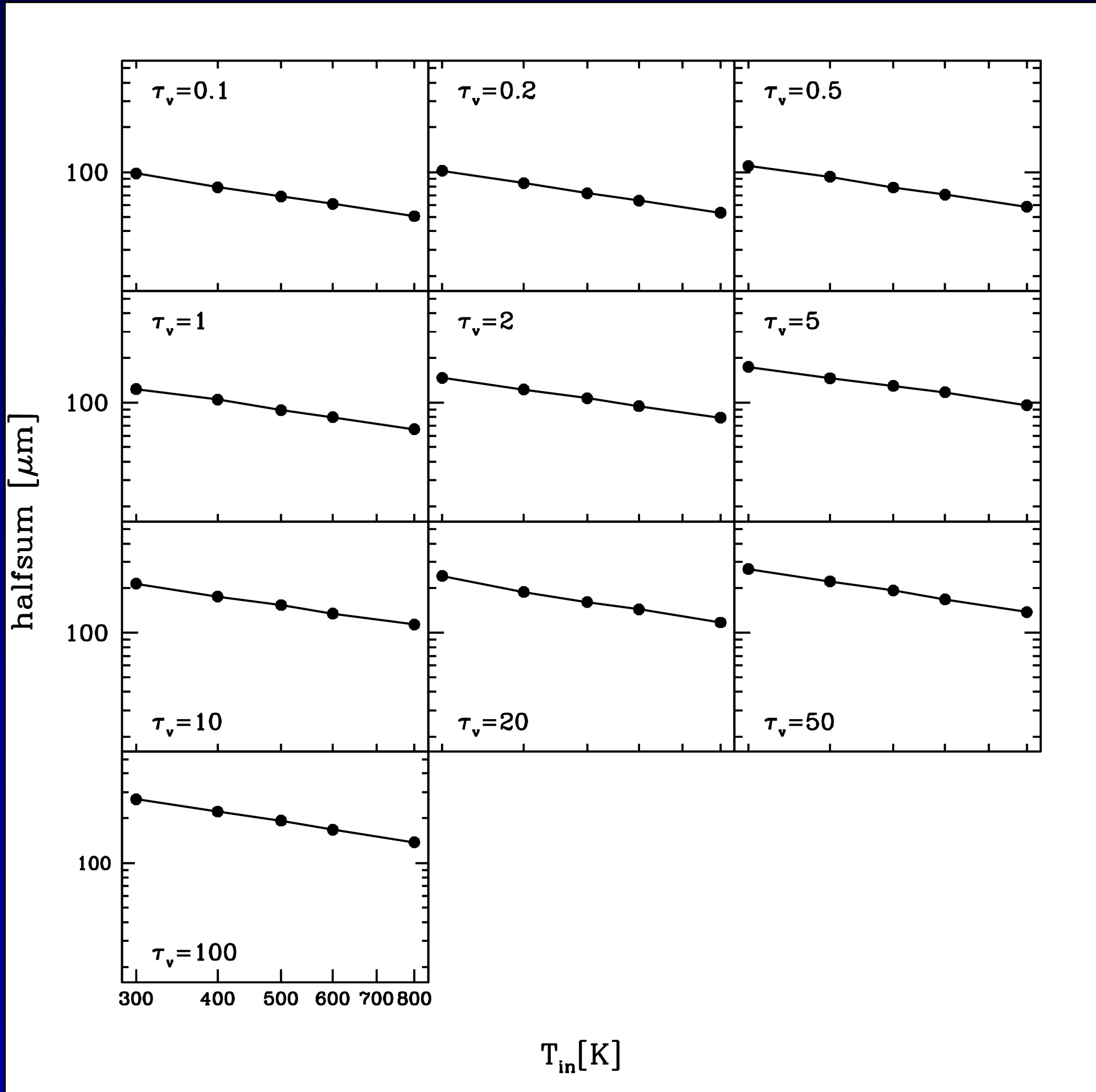
I calculated *halfsum* for each model and I related it with geometry (Y and T_{in}) and τ_V

halfsum vs Y

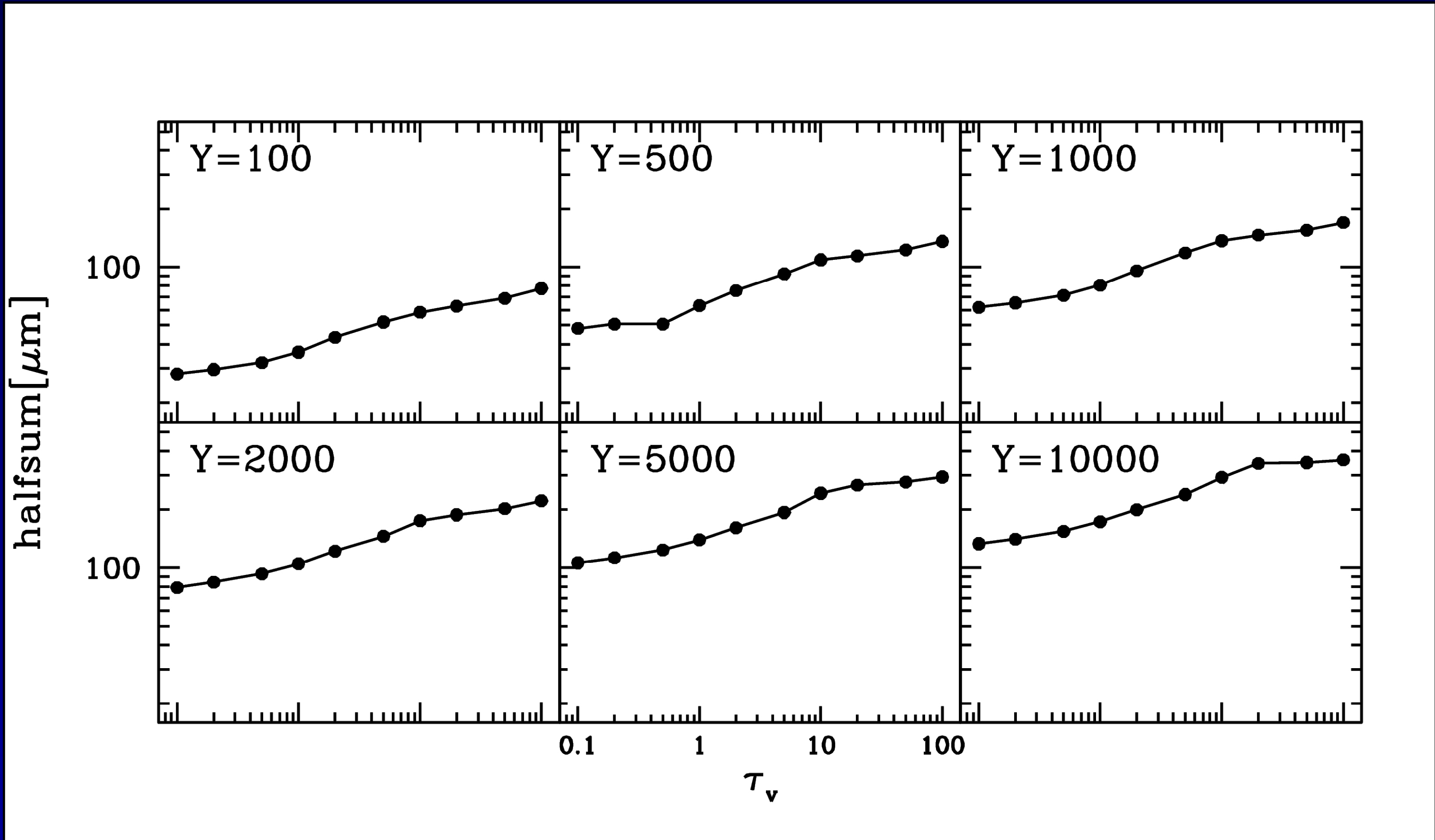


τ_v=0.1
τ_v=0.2
τ_v=0.5
τ_v=1
τ_v=2
τ_v=5
τ_v=10
τ_v=20
τ_v=50
τ_v=100
100
halfsum [μm]
100
1000
10^4
Y

halfsum vs T_{in}



halfsum vs τ_V



Work in progress

Creating a comprehensive library of the DUSTY models varying

1. $50\ K \leq T_{in} \leq 850\ K$, with $\Delta T_{in} = 50\ K$
2. $10 \leq Y \leq 50000$
3. p = 0, 0.2, 0.3, 0.5, 1, 2
4. $0.1 \leq \tau_V \leq 100$
5. Single – age stellar population from Starburst99 with: instantaneous burst, Salpeter IMF (α=2.35) 1Myr $\leq$ age 10 Myr $\leq$, $0.05\ Z_{\odot} \leq Z \leq 1.0\ Z_{\odot}$

Where Y and τ_V roughly vary logarithmically

Future work

- Models generated by DUSTY, will be combined with CLUMPY (*https://newton.pa.uky.edu/~clumpyweb/)*, an algorithm able to handle the problem of radiative transfer in inhomogeneous environments.

- Developing a method based on Principal Component Analysis (PCA) to searching for best-fit models.

- Developing a realistic algorithm to include stochastic emission from PAHs (Polycyclic Aromatic Hydrocarbons) in SED models.

Thanks for your attention!