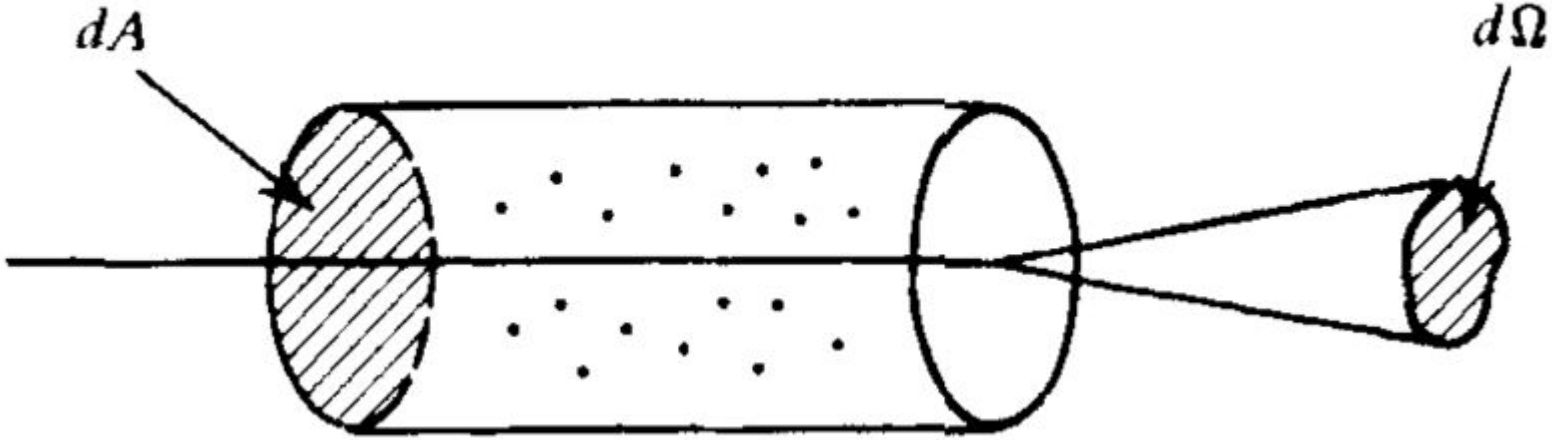
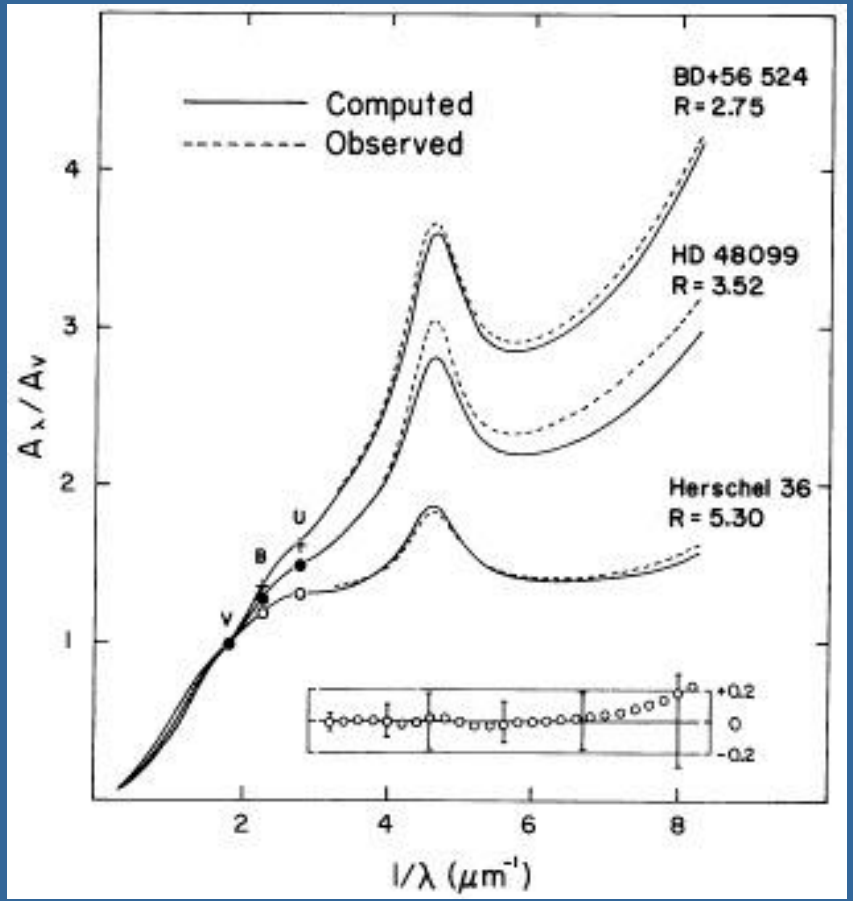
Introduction II

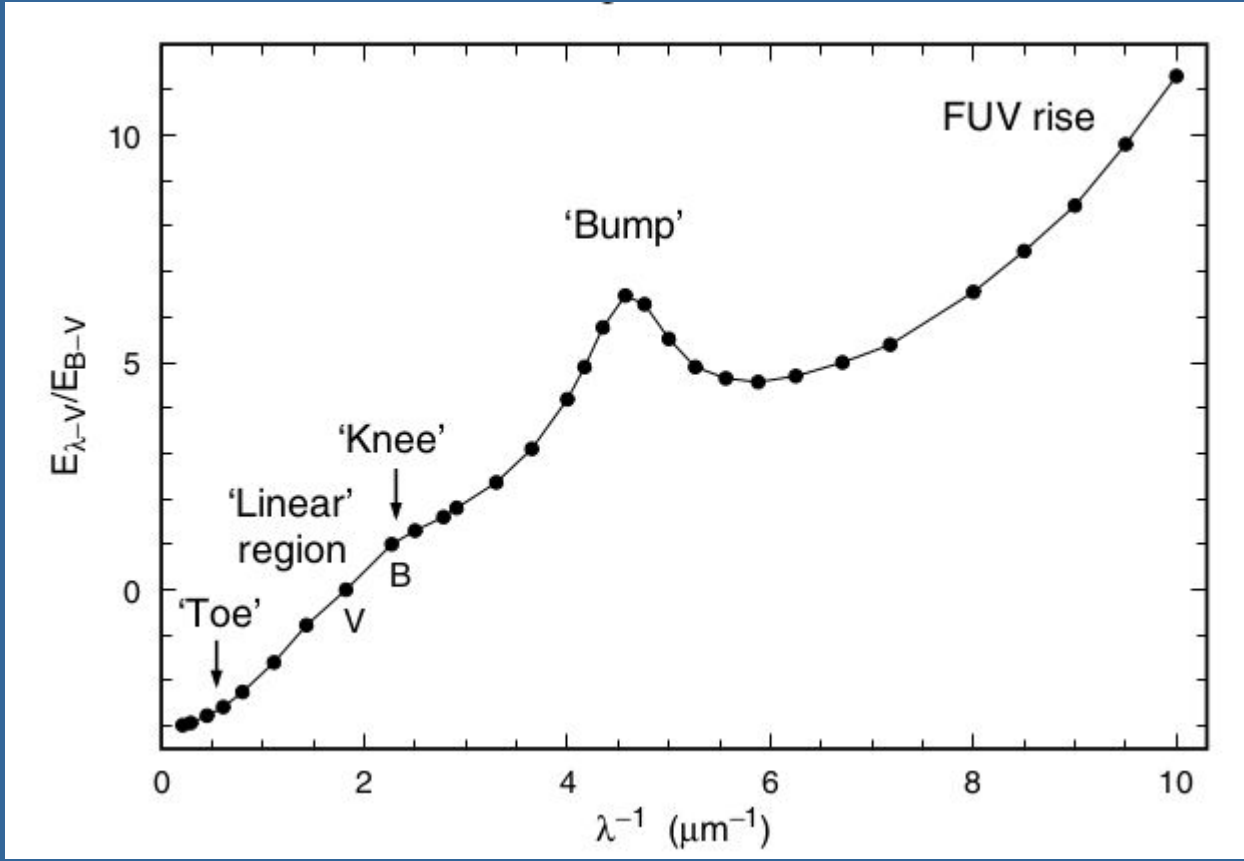
3 July 2023

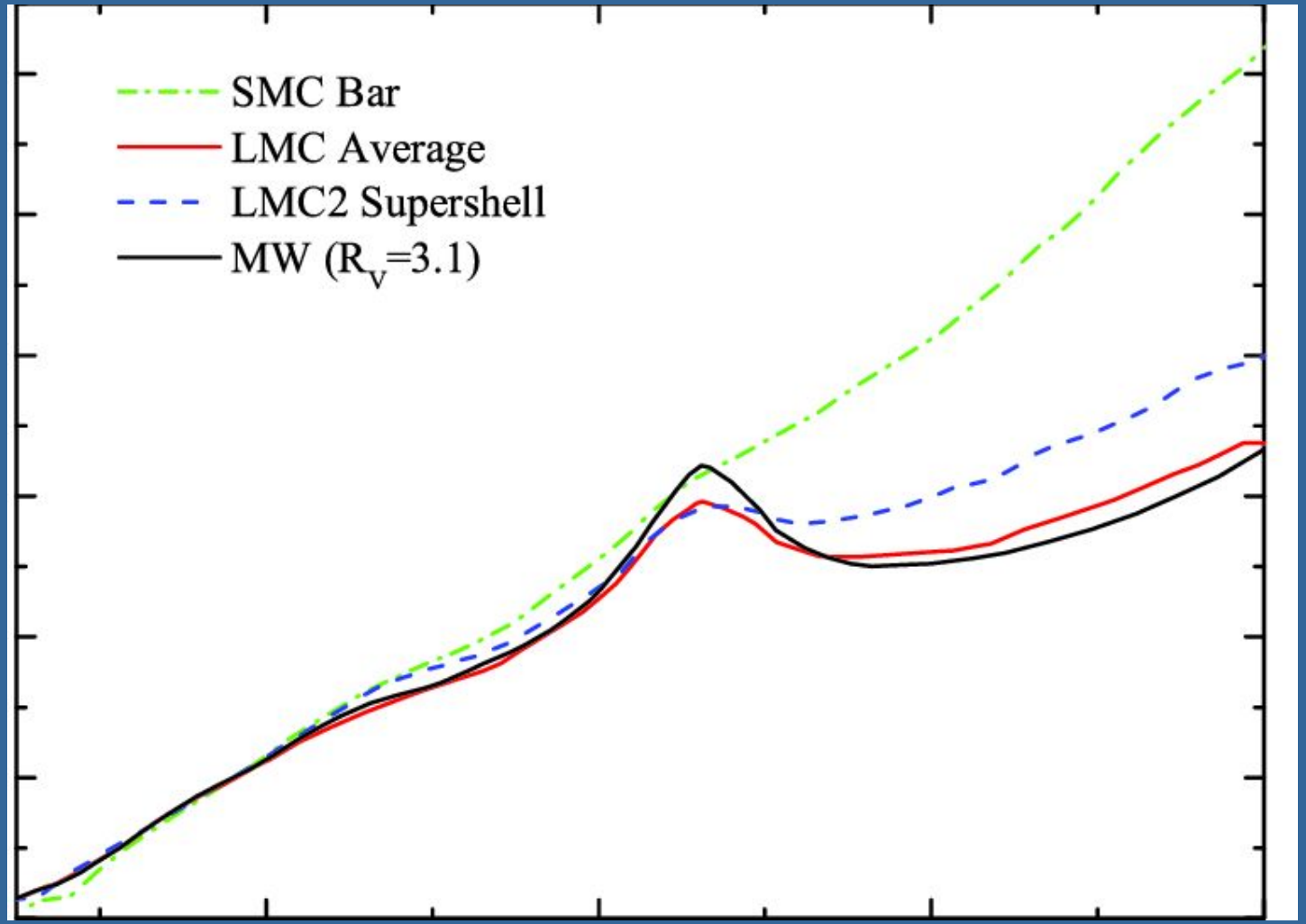
Ciska Kemper (ICE-CSIC / ICREA / IEEC)


dA
dΩ

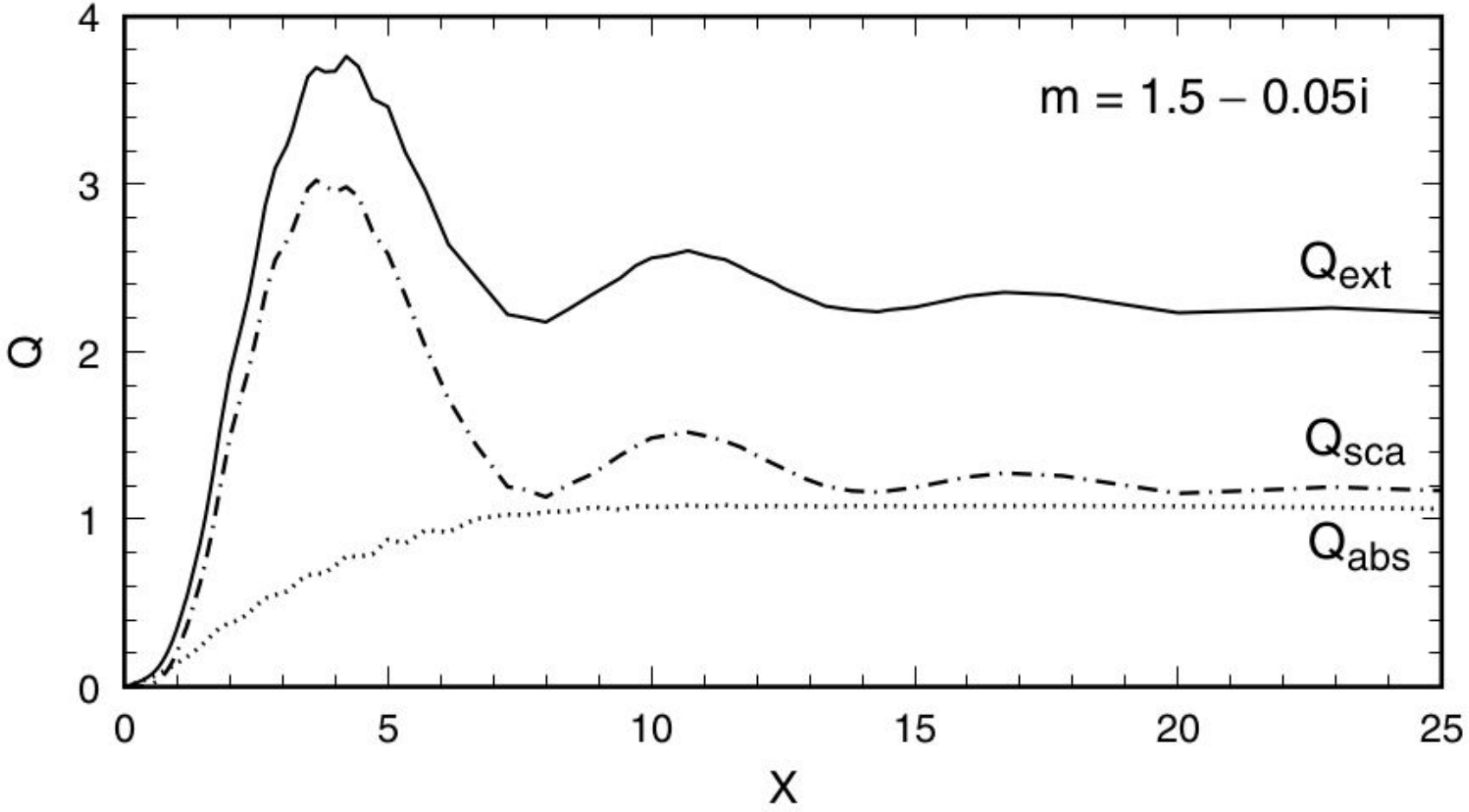


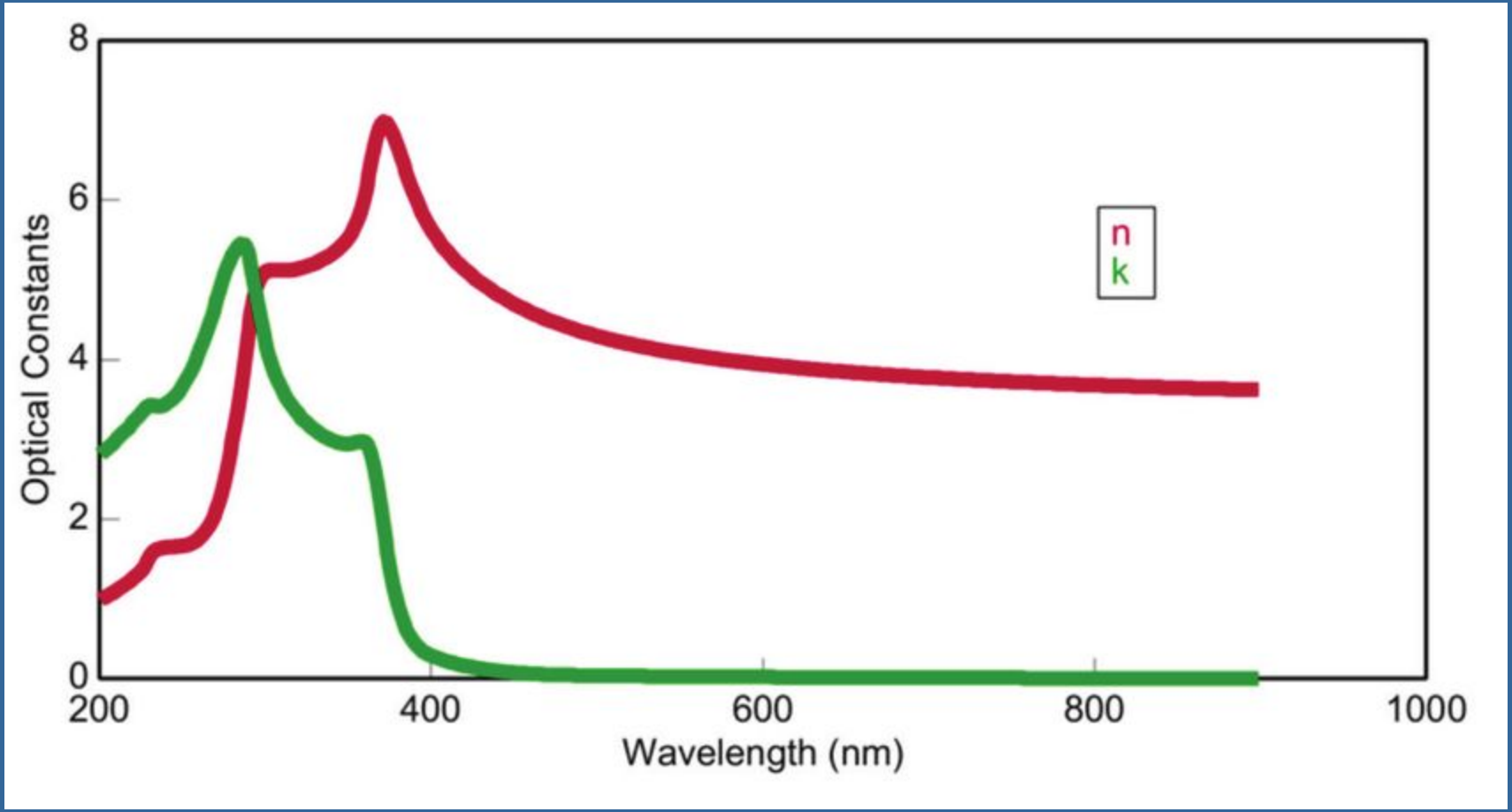
(Cardelli et al. 1989)

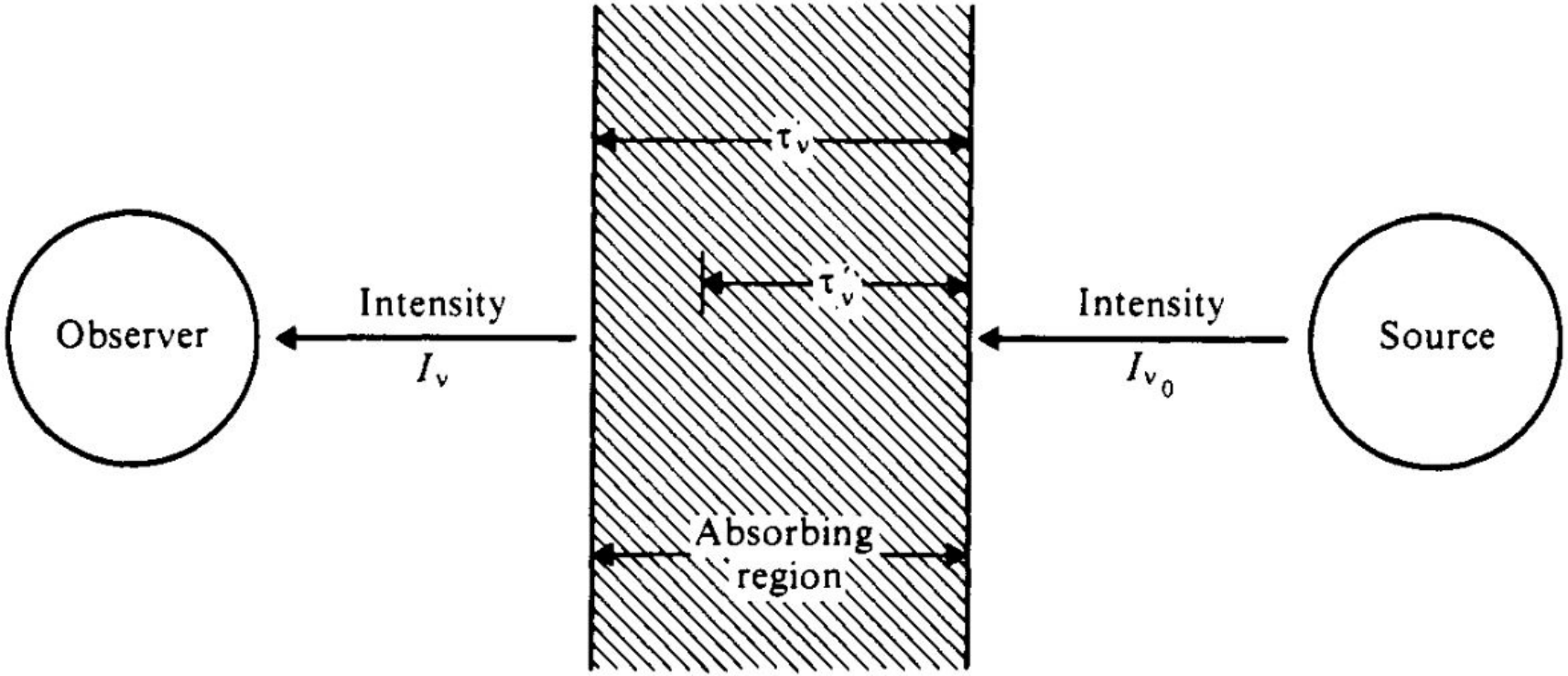

FUV rise
'Bump'
'Knee'
'Linear'
region
'Toe'
B
V
10
5
0
0
2
4
6
8
10
$E_{\lambda-V}/E_{B-V}$
λ^{-1} (μm^{-1})



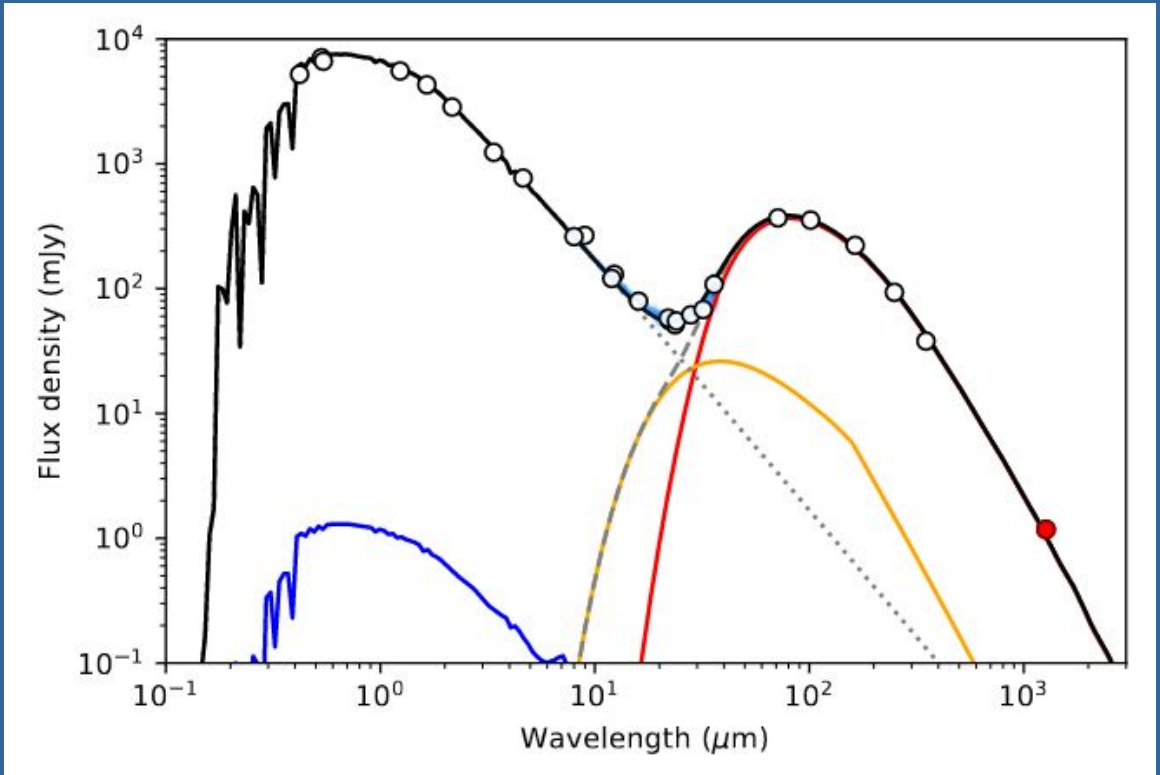
(Gordon et al. 2003)


m = 1.5 – 0.05i
Q
X
Q_ext
Q_sca
Q_abs
0
1
2
3
4
0
5
10
15
20
25


8
6
4
2
0
Optical Constants
200
400
600
800
1000
Wavelength (nm)
n
k

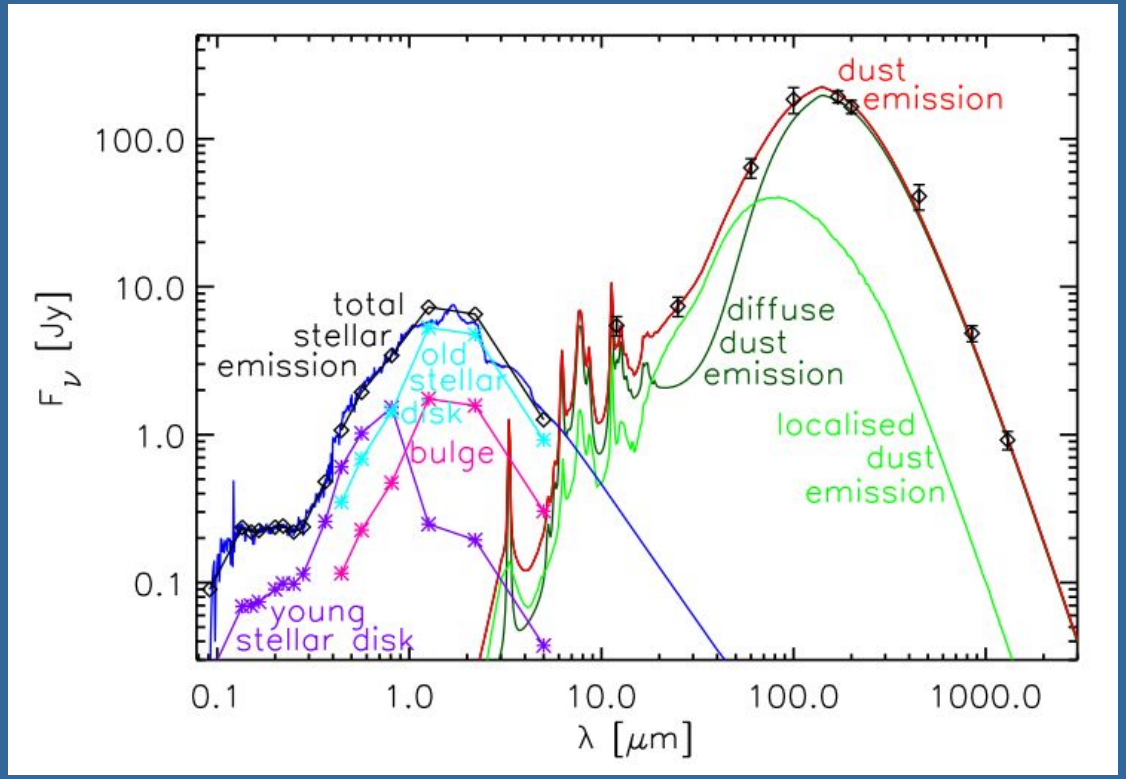

Observer
Intensity
I_ν
τ_ν
τ'_ν
Absorbing region
Intensity
I_{ν_0}
Source

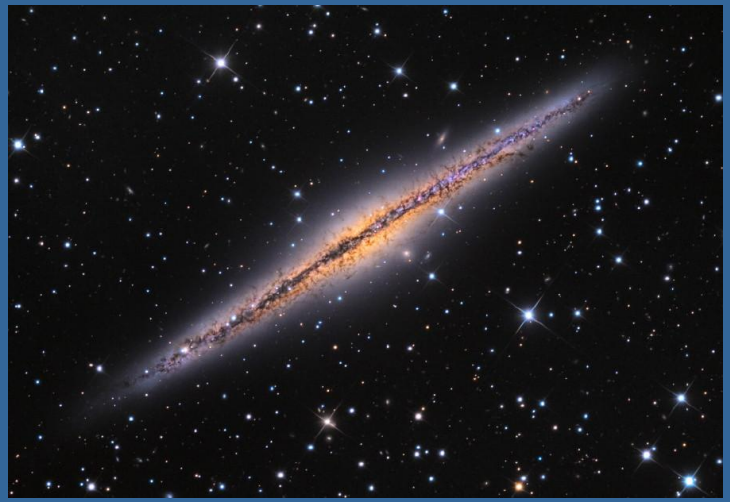
Thermal dust emission



HD 16743 (Marshall et al. 2023)

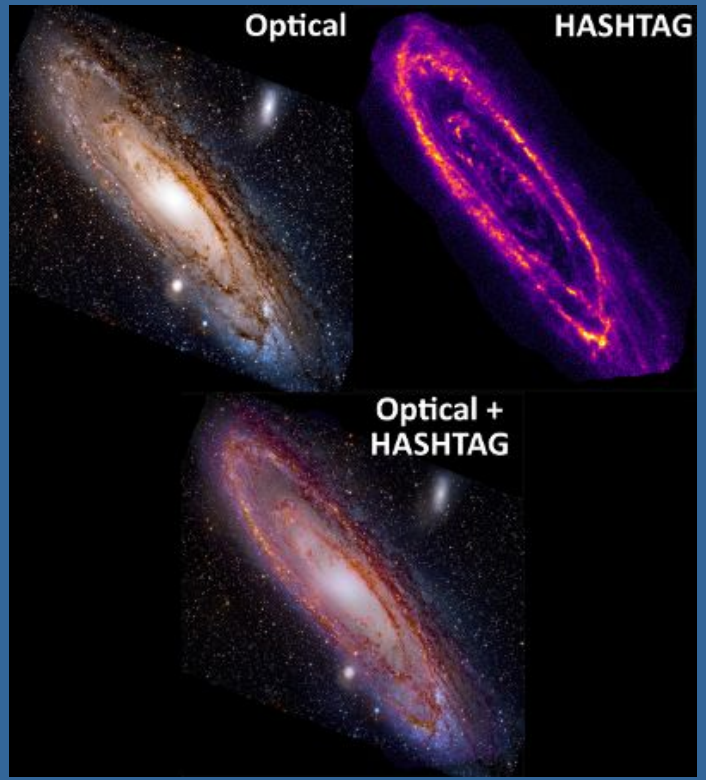
Thermal dust emission



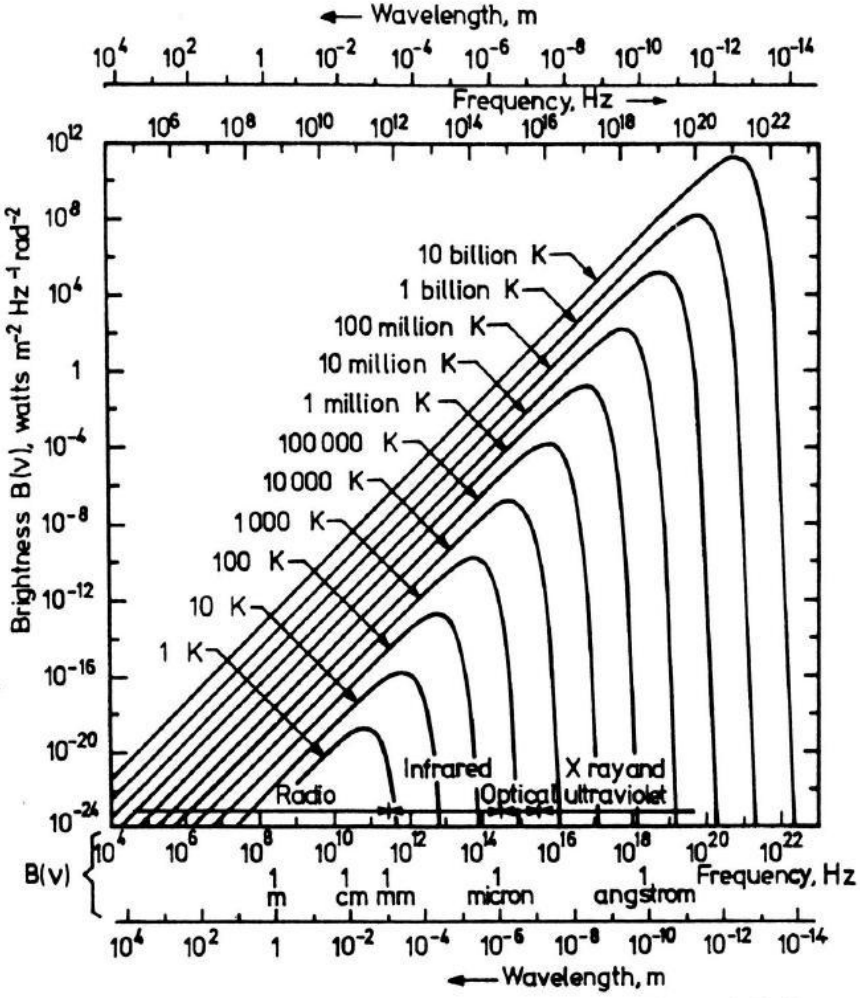


NGC 891 (Popescu et al. 2011)

Thermal dust emission



Andromeda (Smith et al. 2021)


Wavelength, m
Frequency, Hz
Brightness B(ν), watts m⁻² Hz⁻¹ rad⁻²
10 billion K
1 billion K
100 million K
10 million K
1 million K
100 000 K
10 000 K
1 000 K
100 K
10 K
1 K
Radio
Infrared
Optical
X ray and ultraviolet
B(ν)
1 m
1 cm
1 mm
1 micron
1 angstrom
Frequency, Hz
Wavelength, m

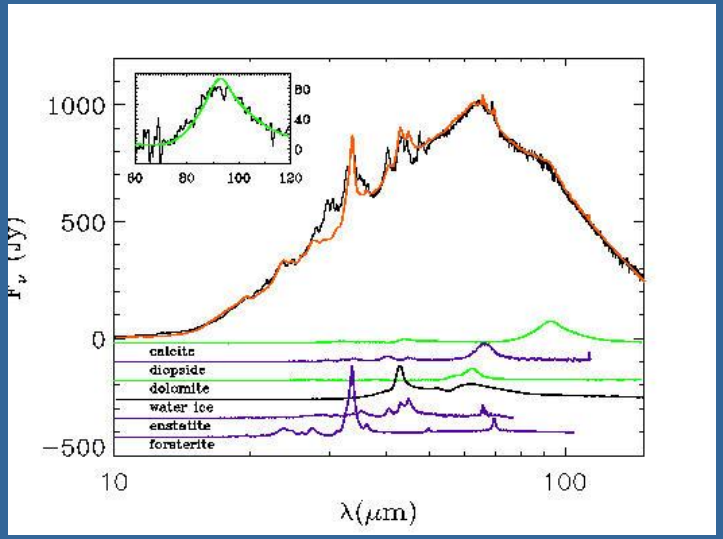
Dust components in the ISM

Amorphous olivine	$(Fe,Mg)_2SiO_4$
Amorphous pyroxene	$(Fe,Mg)SiO_3$
Metallic iron	Fe
Enstatite	$MgSiO_3$
Forsterite	Mg_2SiO_4
Diopside	$(Ca,Mg)SiO_3$
Hydrous silicates	silicate + H_2O
Carbonates	$(Ca,Mg)CO_3$
Silica	SiO_2
Spinel	$MgAl_2O_4$
Iron-magnesium oxide	$Mg_{(0.1)}Fe_{(0.9)}O$
Corundum	Al_2O_3

Pyrite, pyrrhotite	$Fe_{1-x}S$
Troilite	FeS
Silicon carbide	SiC
Amorphous carbon	C
Graphite	C
Polycyclic Aromatic Hydrocarbons	
Magnesium sulfide	MgS

Various ices	H_2O, CO_2, CO, CH_4, CH_3OH

Fit to spectrum of NGC 6302



(Kemper et al. 2002)

T = 30-60 K
am. olivine: 94%
forsterite: >4.0%
enstatite: >1.1%
water ice: 0.72%
diopside: 0.56%
calcite: 0.26%
dolomite: 0.16%

Extending wavelength coverage

- Towards short wavelengths
  - Extend with similar materials, for example forsterite is extended with amorphous olivine
  - Further shortwards: oscillator description as in Bohren & Huffman
- Towards long wavelengths:
  - Extinction is usually extended with a $\lambda^{-\omega}$ power law, with $\omega = 1 - 2$, depending on grain properties
  - Effect on FIR slope of spectrum

Solid state features

For silicates we will illustrate the following:
- Mineralogy, preferably based on several features
- Lattice structure: crystalline or amorphous
- Exact chemical composition (Fe-content)
- Grain shape & grain size
- Ice layers and other impurities
- Change in intrinsic shape of features due to temperature: only marginally explored

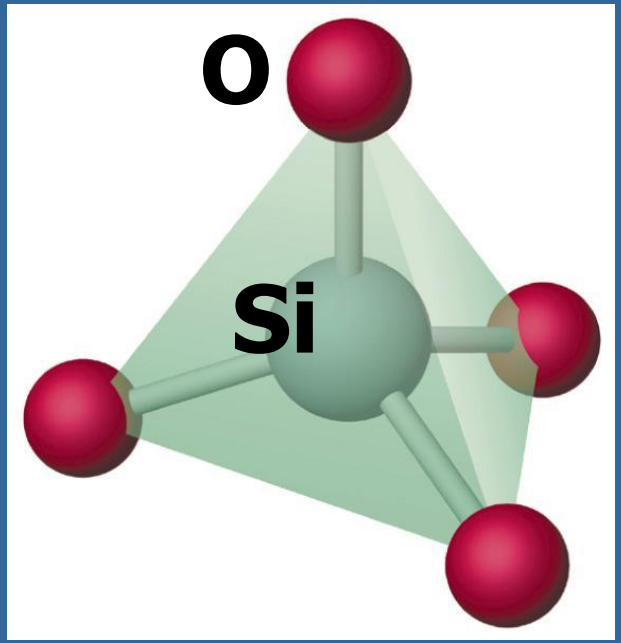
Silicates: the building blocks

silicate anion

SiO_4^{4-}

Metal cation

Mg^{2+}, Fe^{2+}, Ca^{2+}…

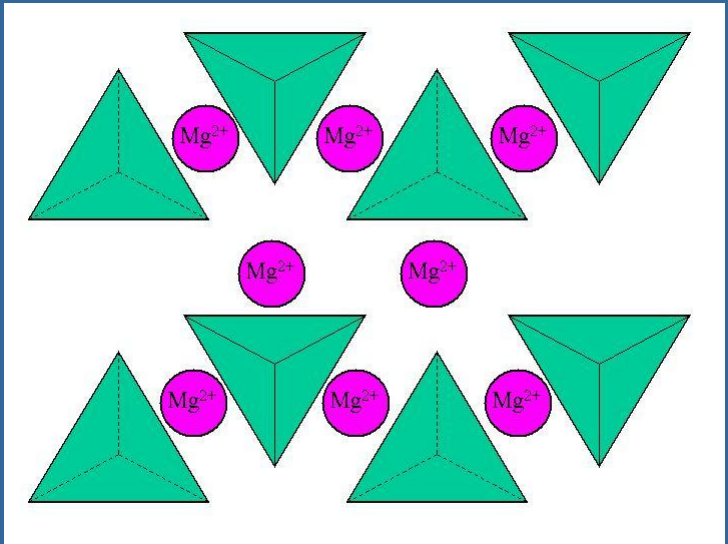


Olivine

$Fe_{2x}Mg_{2(1-x)}SiO_4$

$x=0 \rightarrow Mg_2SiO_4$

forsterite

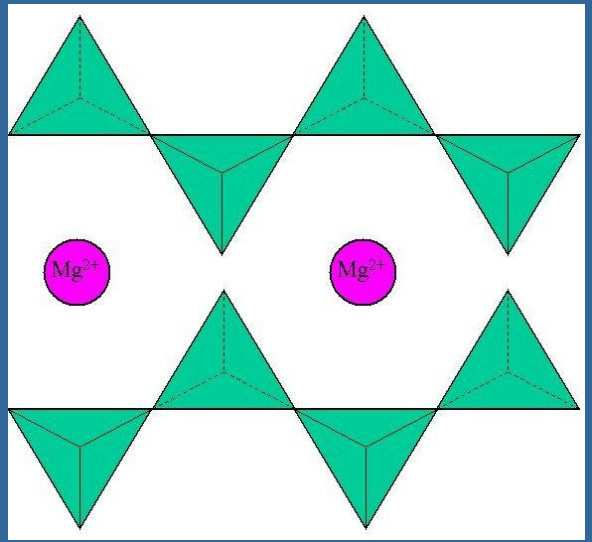


Pyroxene

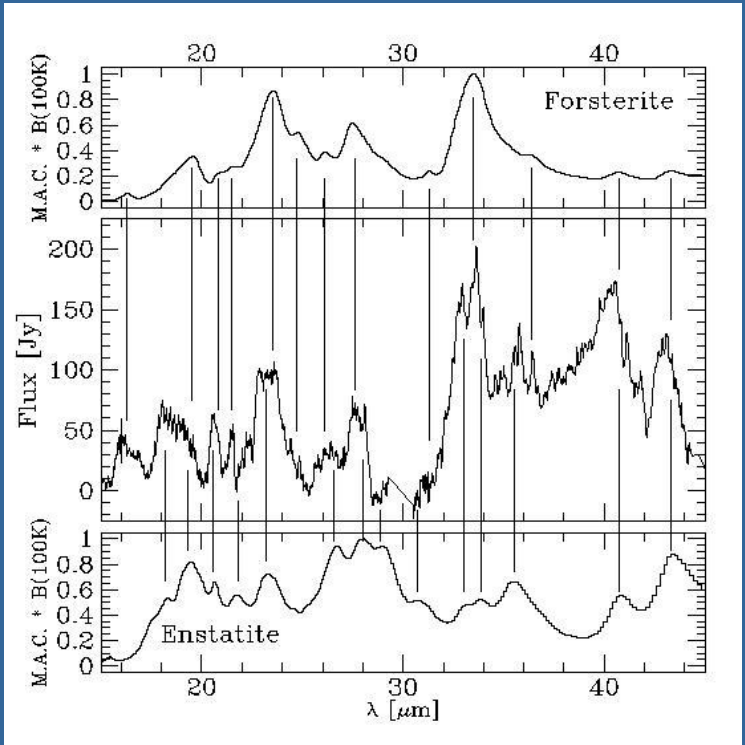
$Fe_xMg_{1-x}SiO_3$

$x=0 \rightarrow MgSiO_3$

enstatite

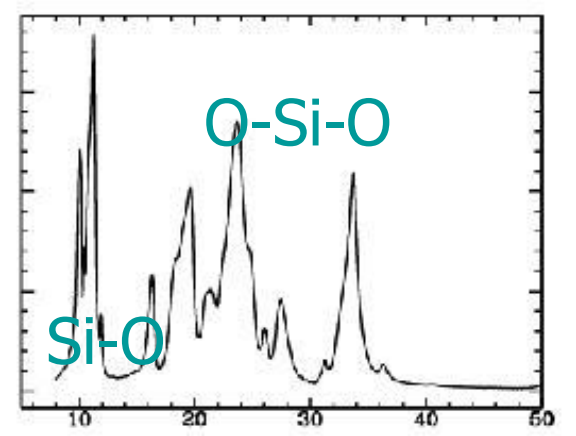


Mineralogy

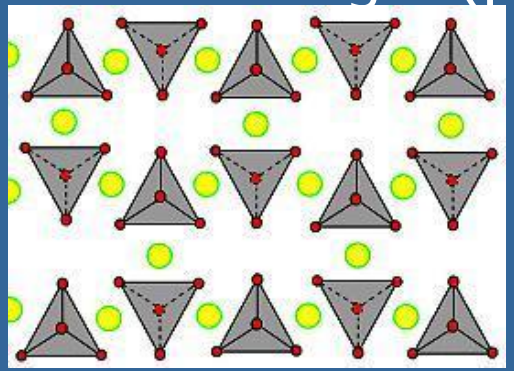


(Jaeger et al. 1998)

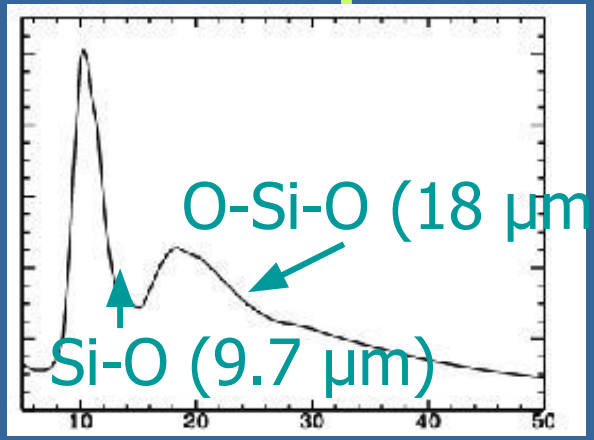
Crystalline



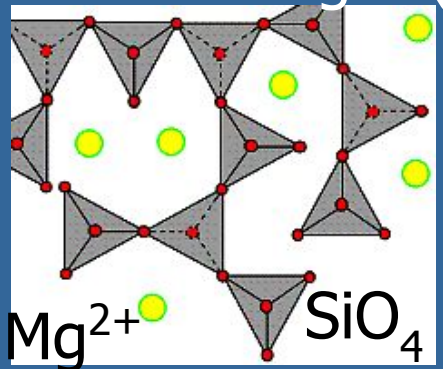
→Wavelength (μm)



Amorphous



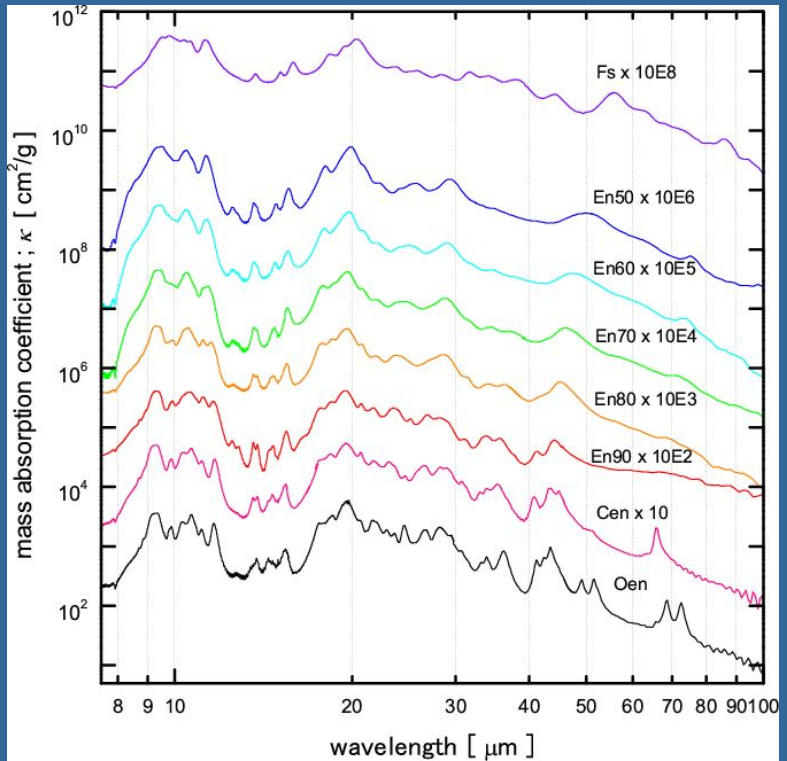
→Wavelength (μm)

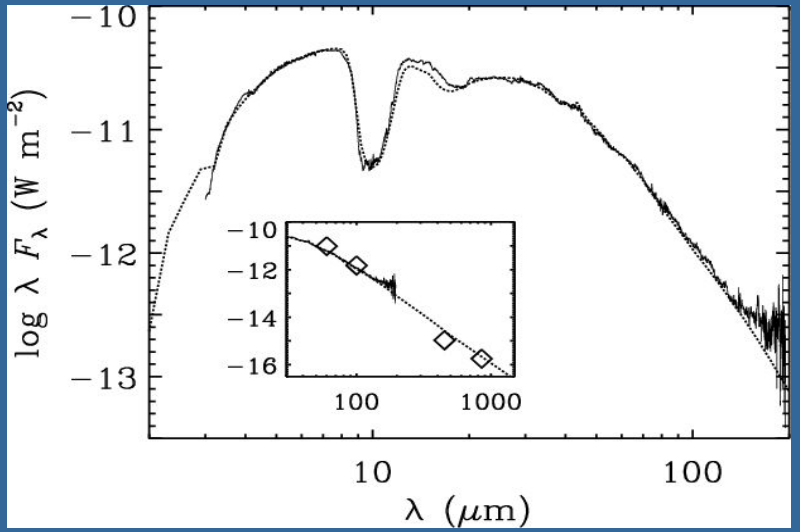


Fe-content

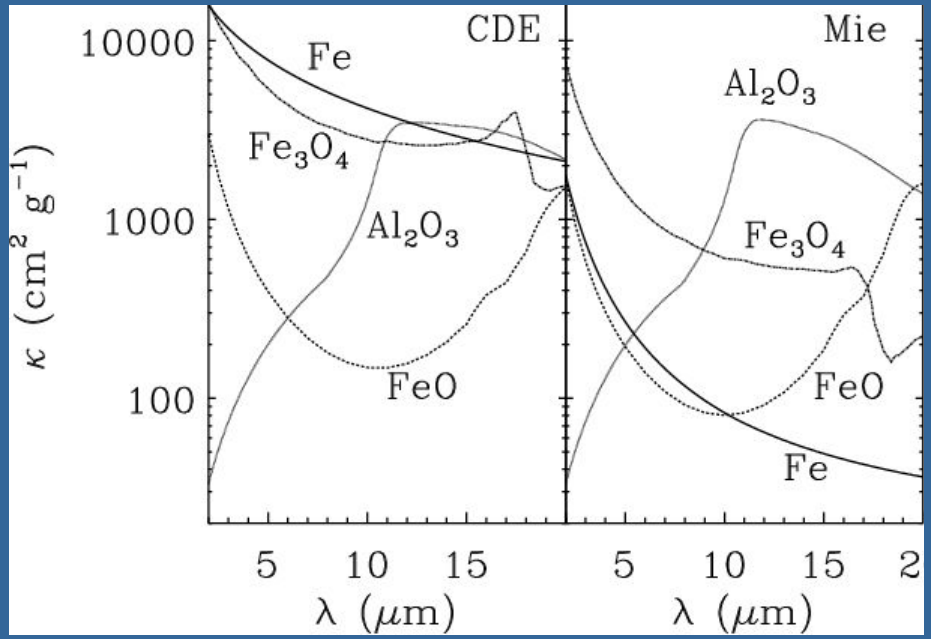
Interstellar vs. parent body processing

(Chihara et al. 2002)





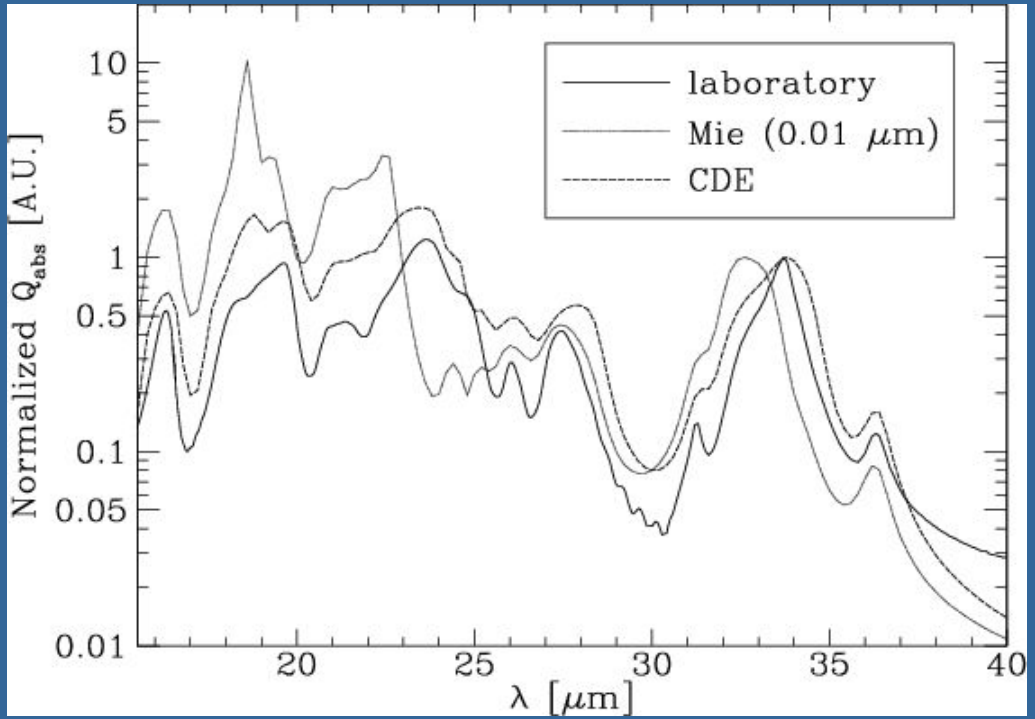
(Kemper et al. 2002)



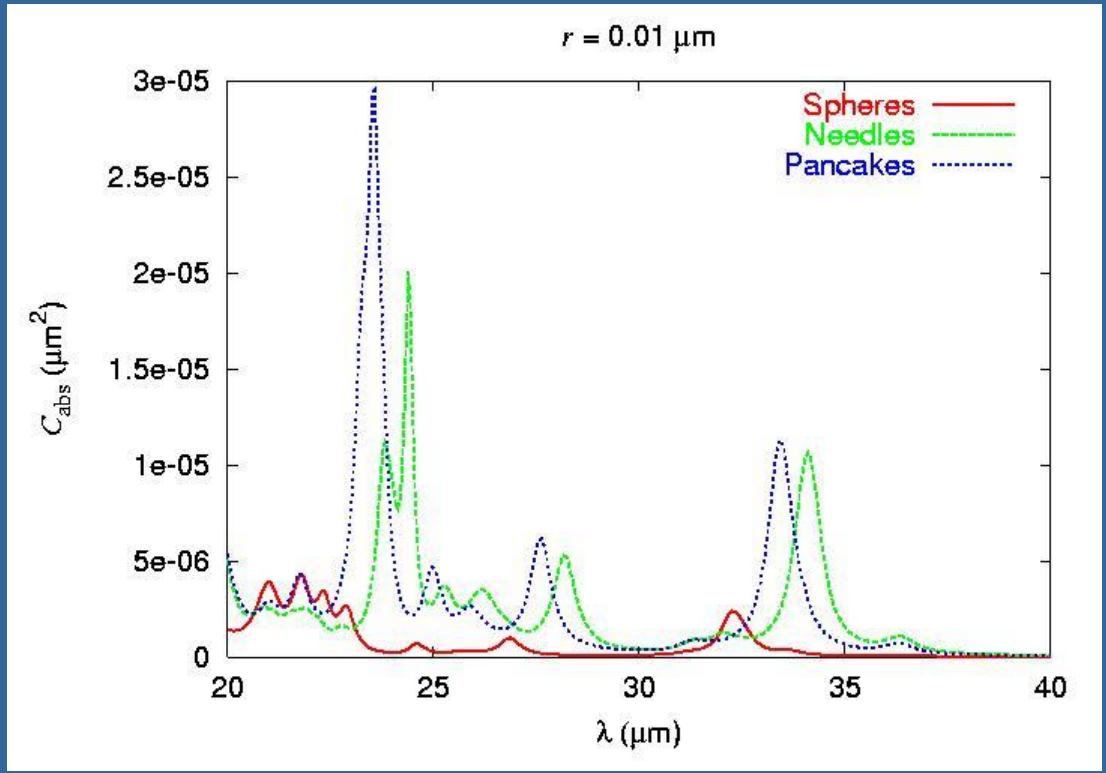
Mie: spherical grains

CDE: continuous distribution of ellipsoids, non-spherical

Mie vs. CDE vs. laboratory



forsterite


r = 0.01 μm
Spheres
Needles
Pancakes
3e-05
2.5e-05
2e-05
1.5e-05
1e-05
5e-06
0
20
25
30
35
40
λ (μm)
C_{abs} (μm^2)

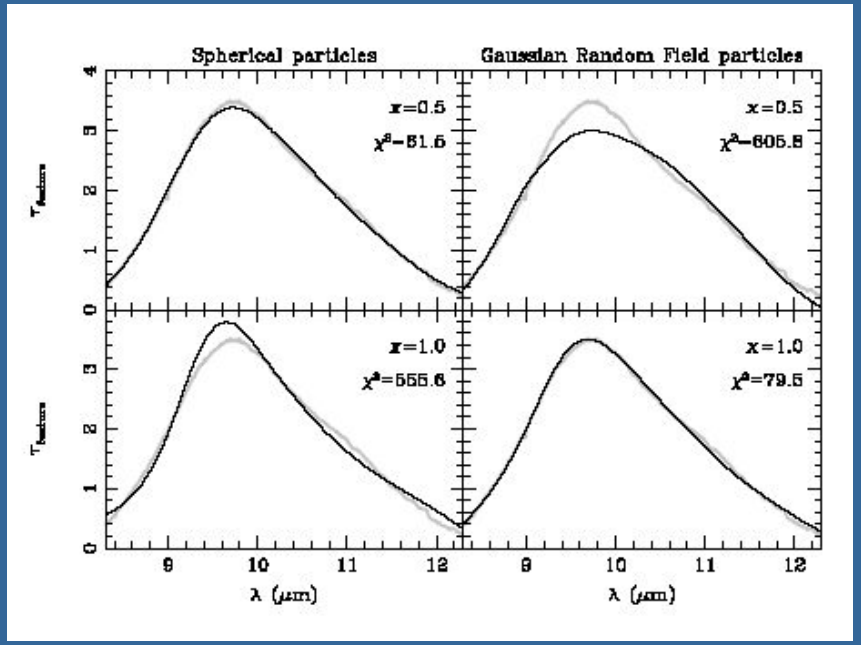
Grain shape & composition

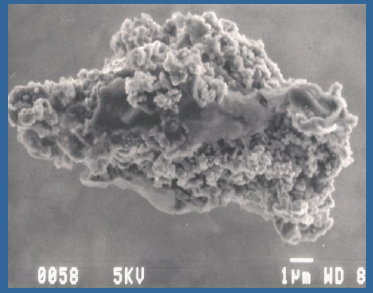
Spherical Non- spherical

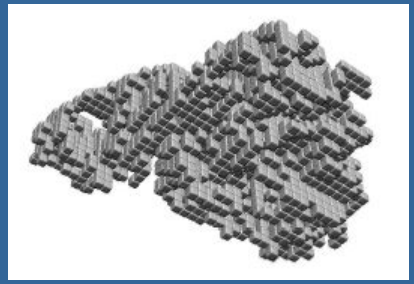
$MgFeSiO_4$

Mg_2SiO_4

(Min et al. 2007)



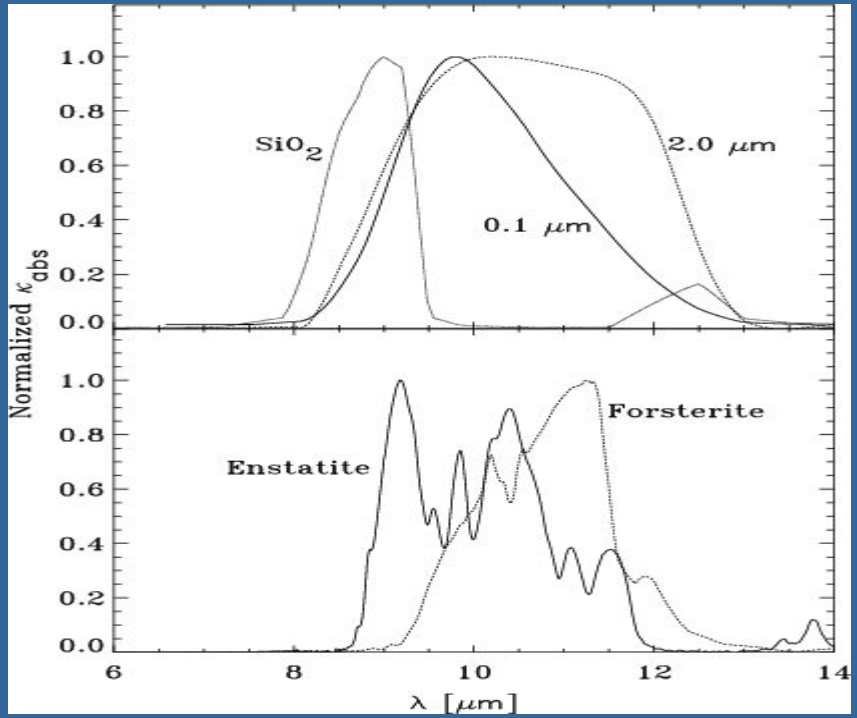


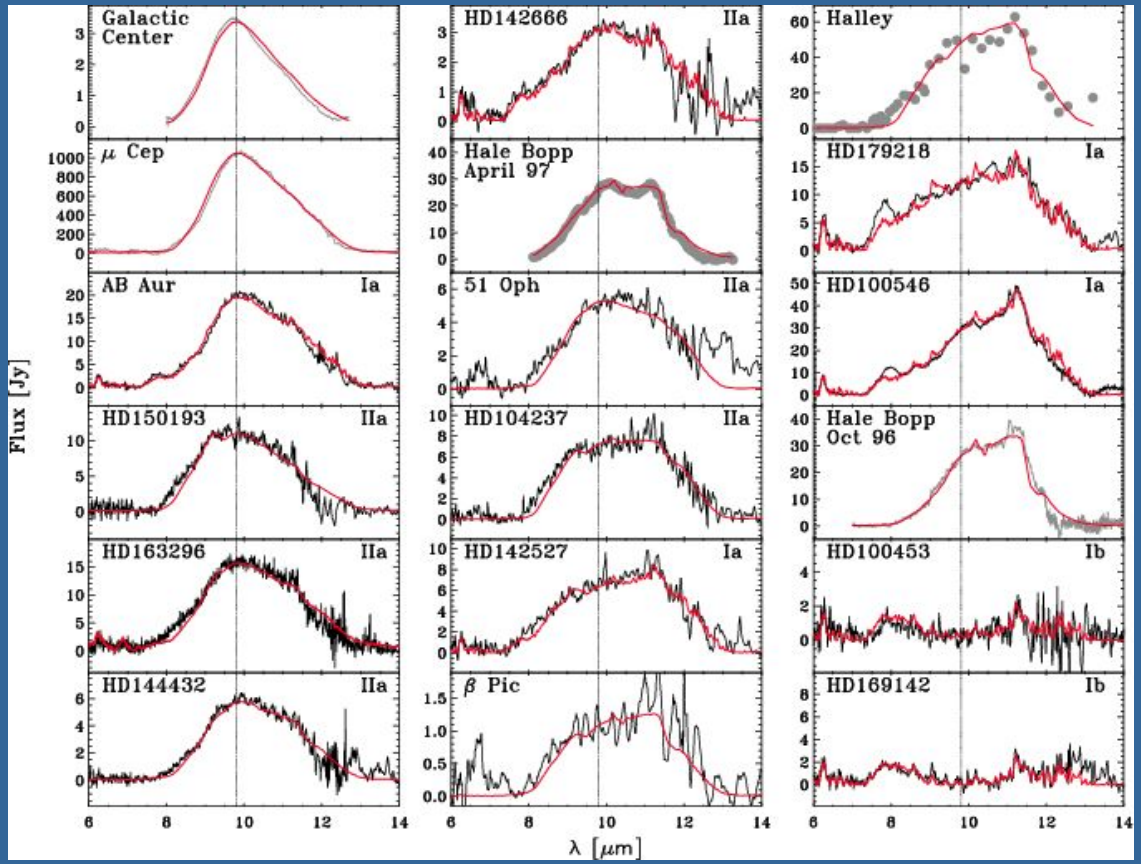


Grain size

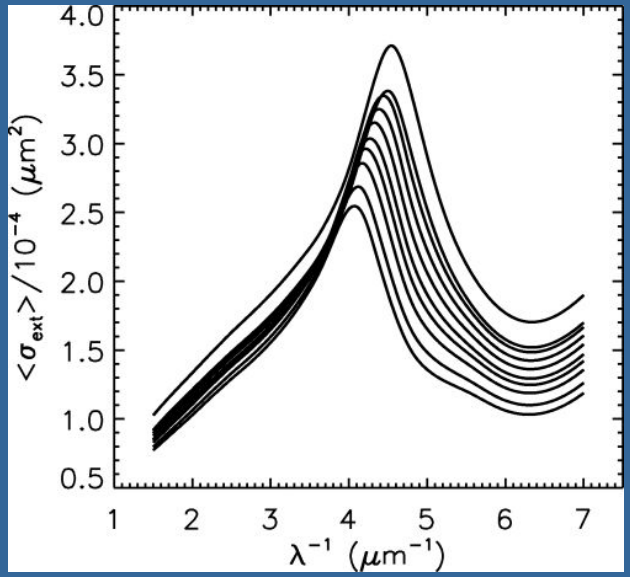
Average grain size distribution in the ISM: 0.005-0.25 micron *(Mathis et al. 1977)*

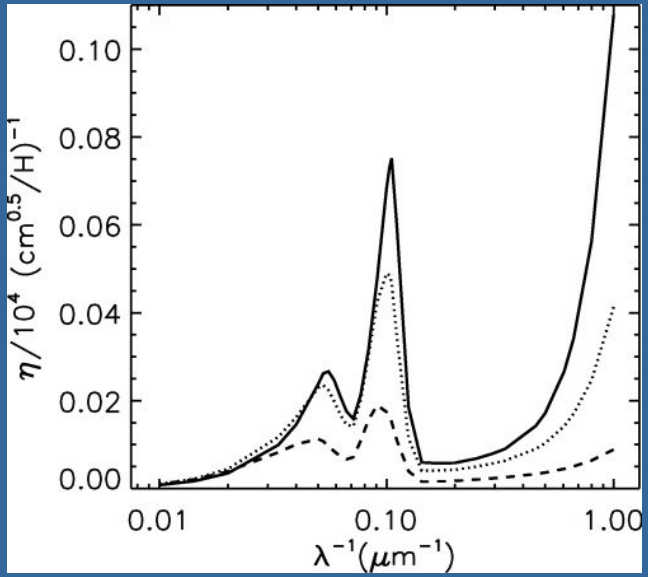
(Bouwman et al. 2001)




Galactic Center
HD142666 IIa
Halley
μ Cep
Hale Bopp April 97
HD179218 Ia
AB Aur Ia
51 Oph IIa
HD100546 Ia
HD150193 IIa
HD104237 IIa
Hale Bopp Oct 96
HD163296 IIa
HD142527 Ia
HD100453 Ib
HD144432 IIa
β Pic
HD169142 Ib
Flux [Jy]
λ [μm]

Impurities

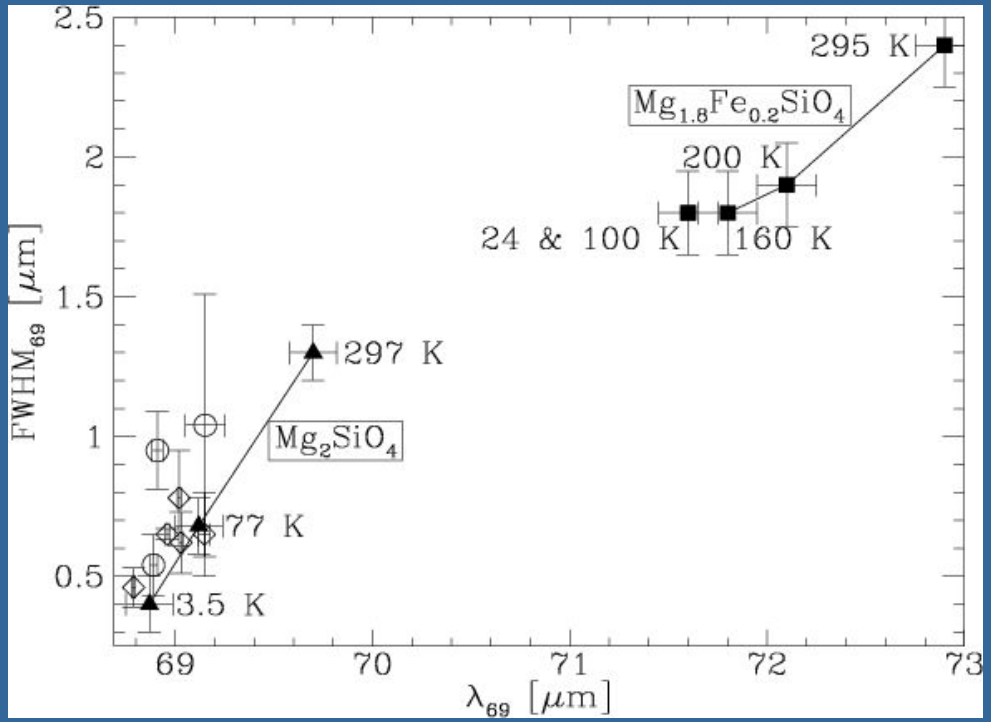




Porous graphite: Increasing porosity from top to bottom *(Iati et al. 2001)*

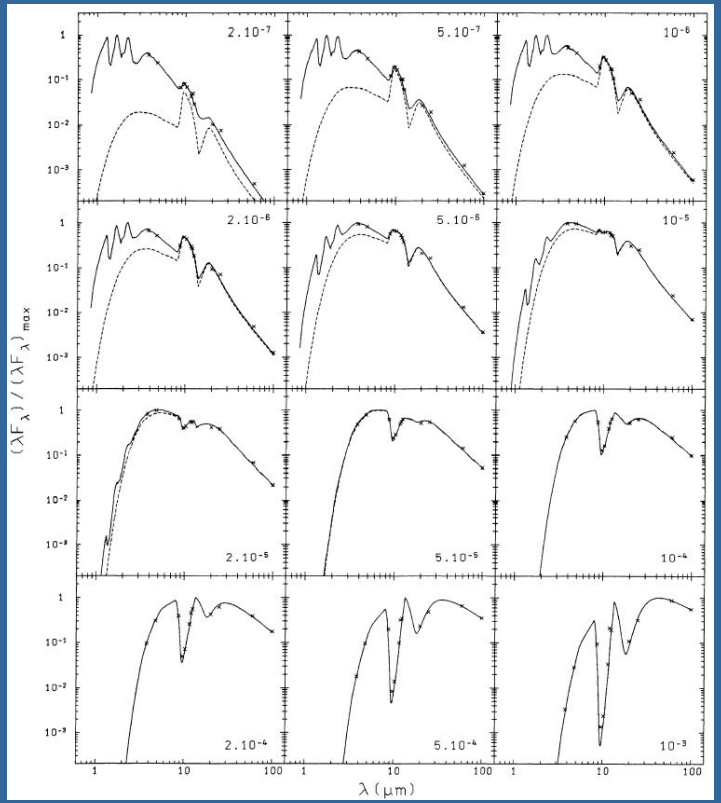
Silicates: Increasing porosity from top to bottom *(Iati et al. 2001)*

Temperature



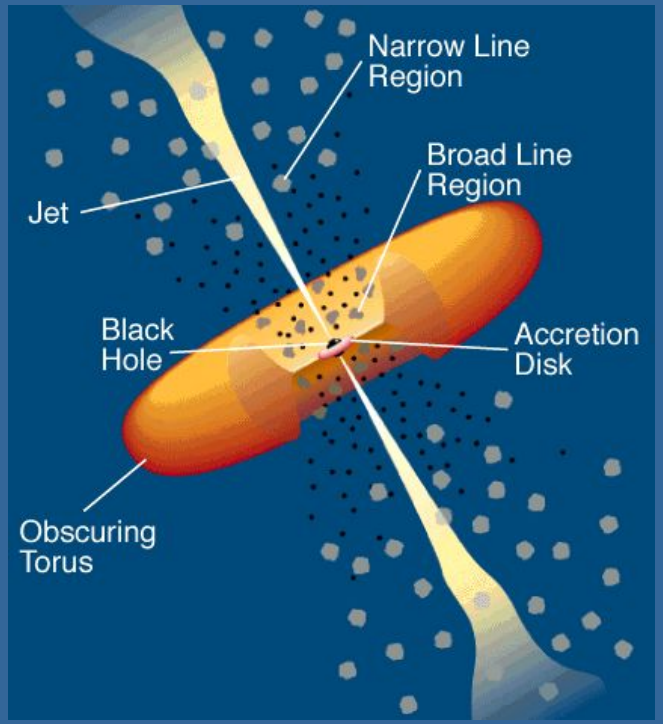
(Molster et al. 2002)

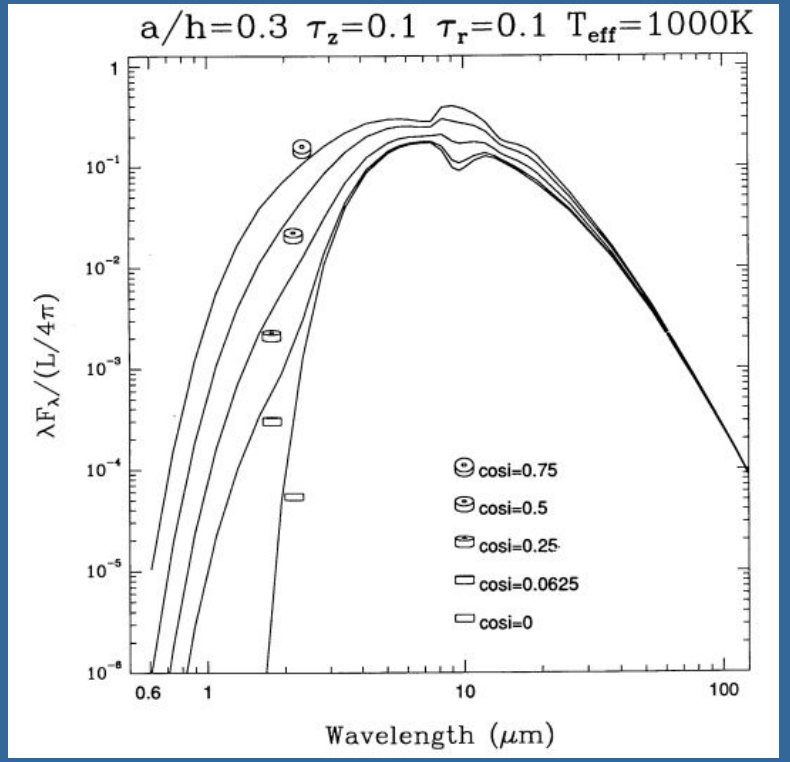
Dust radiative transfer models



(Bedijn 1987)

Dust radiative transfer models





(Pier & Krolik 1992)