# IR Spectra of Enstatite with Lattice Defects

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# Overview of crystallization experiments

1 $Mg_{1.1}Fe_{0.9}SiO_4$

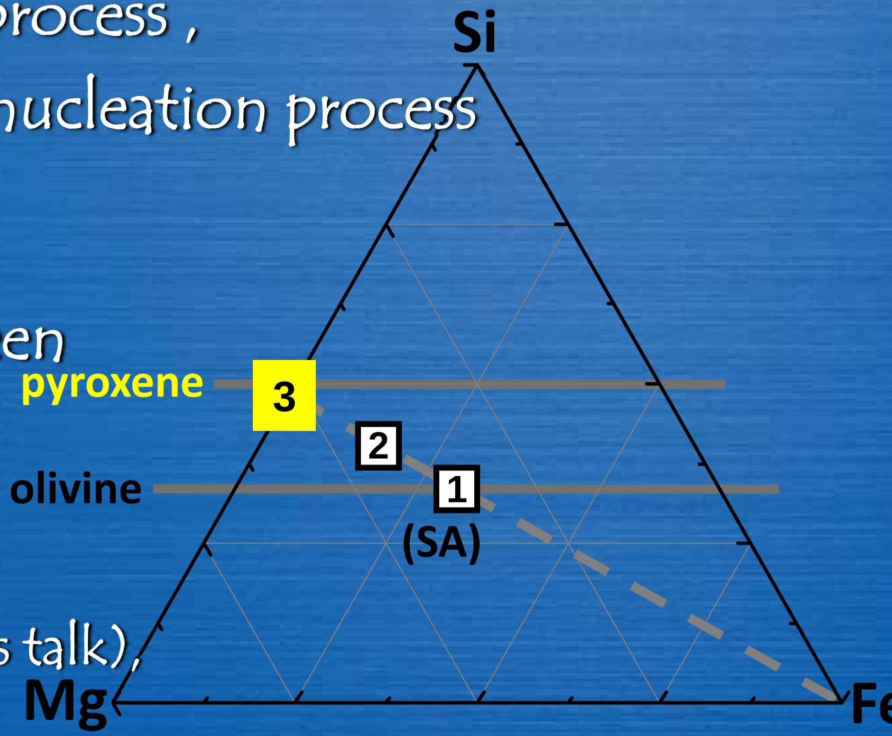
- Formulation of crystallization process ,
- Crystallization dependency on nucleation process

2 $Mg_{1.1}Fe_{0.4}SiO_{3.5}$

- Fractionation of Mg / Fe between crystal & amorphous phases

3 $Mg_{1.1}SiO_{3.1}$

- Activation energy(→Tsuchiyama's talk),
- Implication to observations



# 1 $Mg_{1.1}Fe_{0.9}SiO_4$ (Murata et al. 2007)

- Formulation of Crystallization

$C_{IR}$ : Degree of crystallization

$$\kappa_{im}=(1-C_{IR})\kappa_{as}+C_{IR}\kappa_{xt}$$

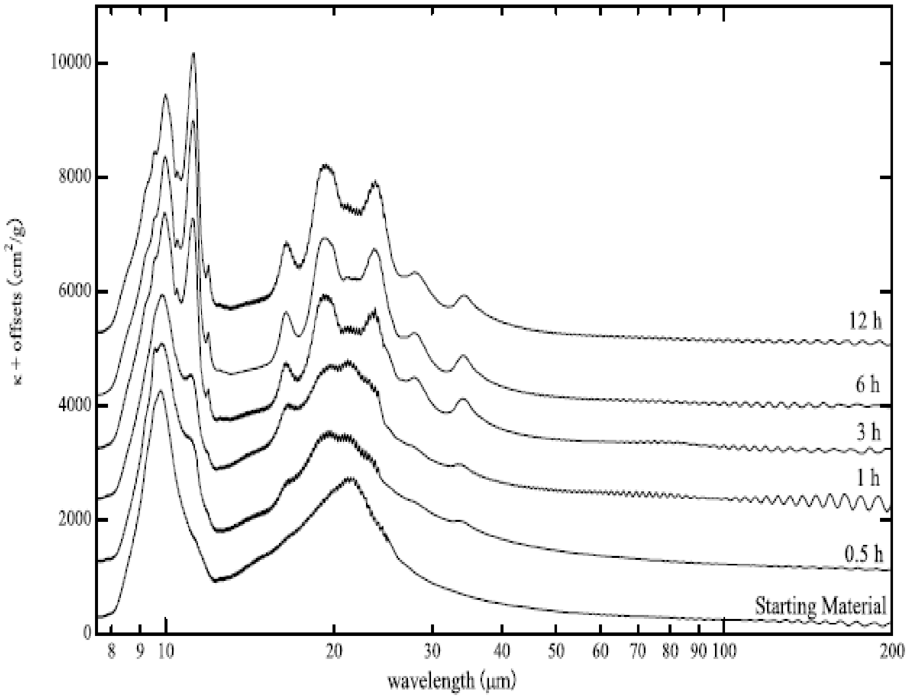



FIG. 7.—IR spectra of the samples heated at a constant temperature (680°C) for different durations.

# 1 $Mg_{1.1}Fe_{0.9}SiO_4$ (Murata et al. 2007)

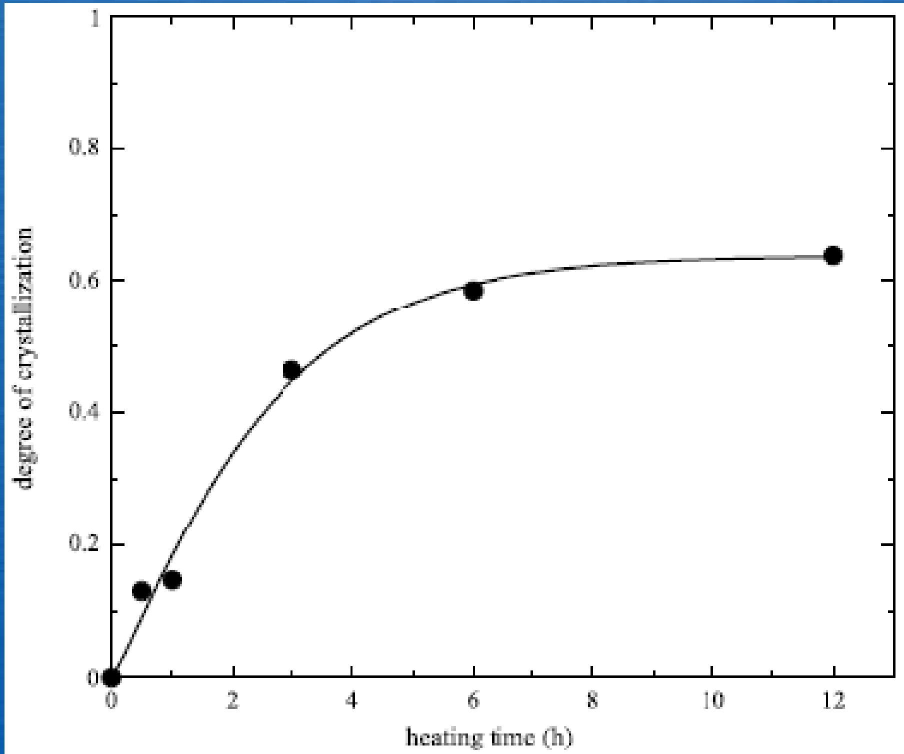
- Time evolution of crystallization

  JMA (Johnson-Mehl-Avrami) eq.

$$C_{IR}=C_{\infty}\{1-\exp[-(t/\tau)^n]\}$$

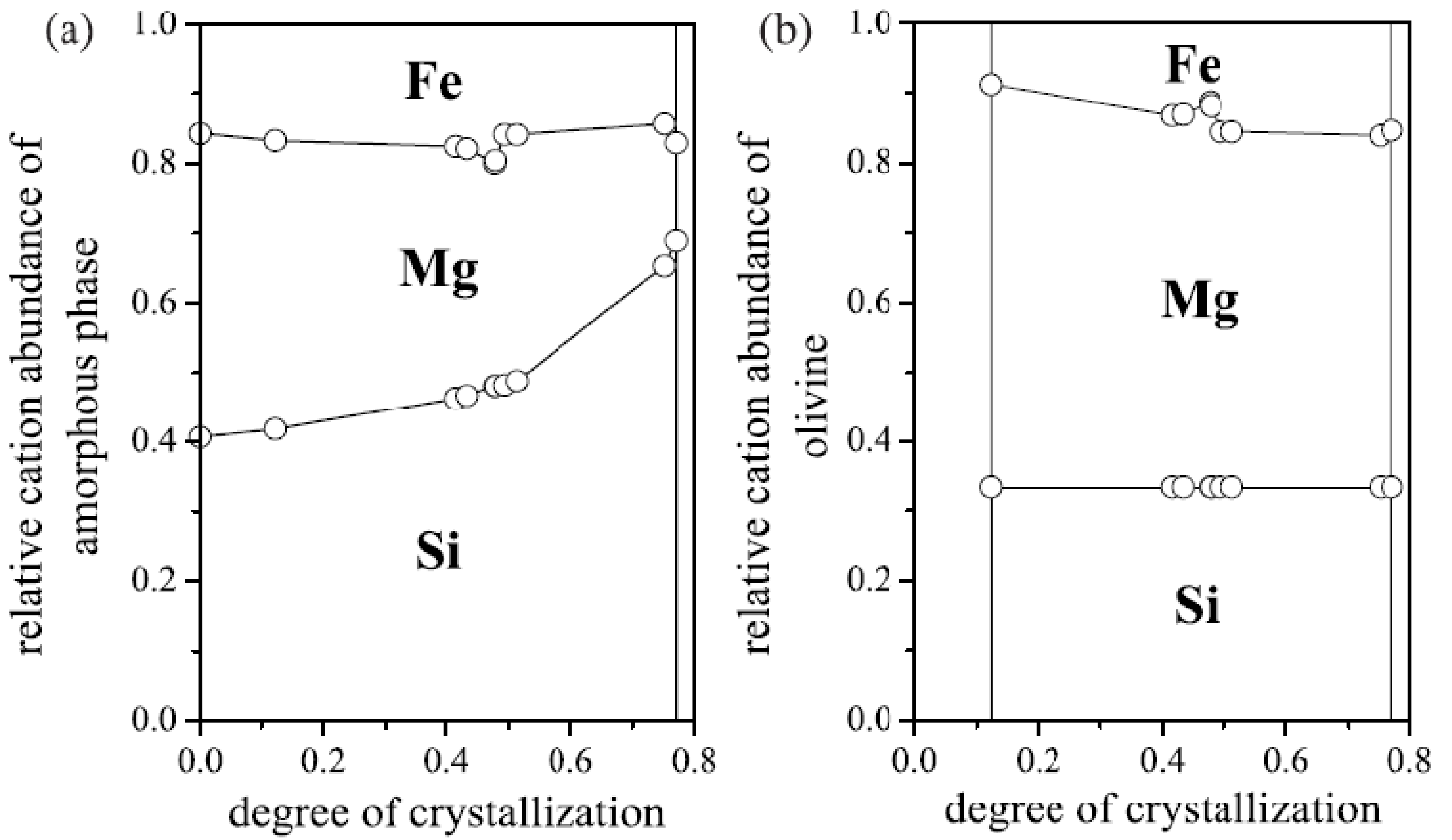
n=1.5 : constant number of nuclei

n=2.5 : constant nucleation rate

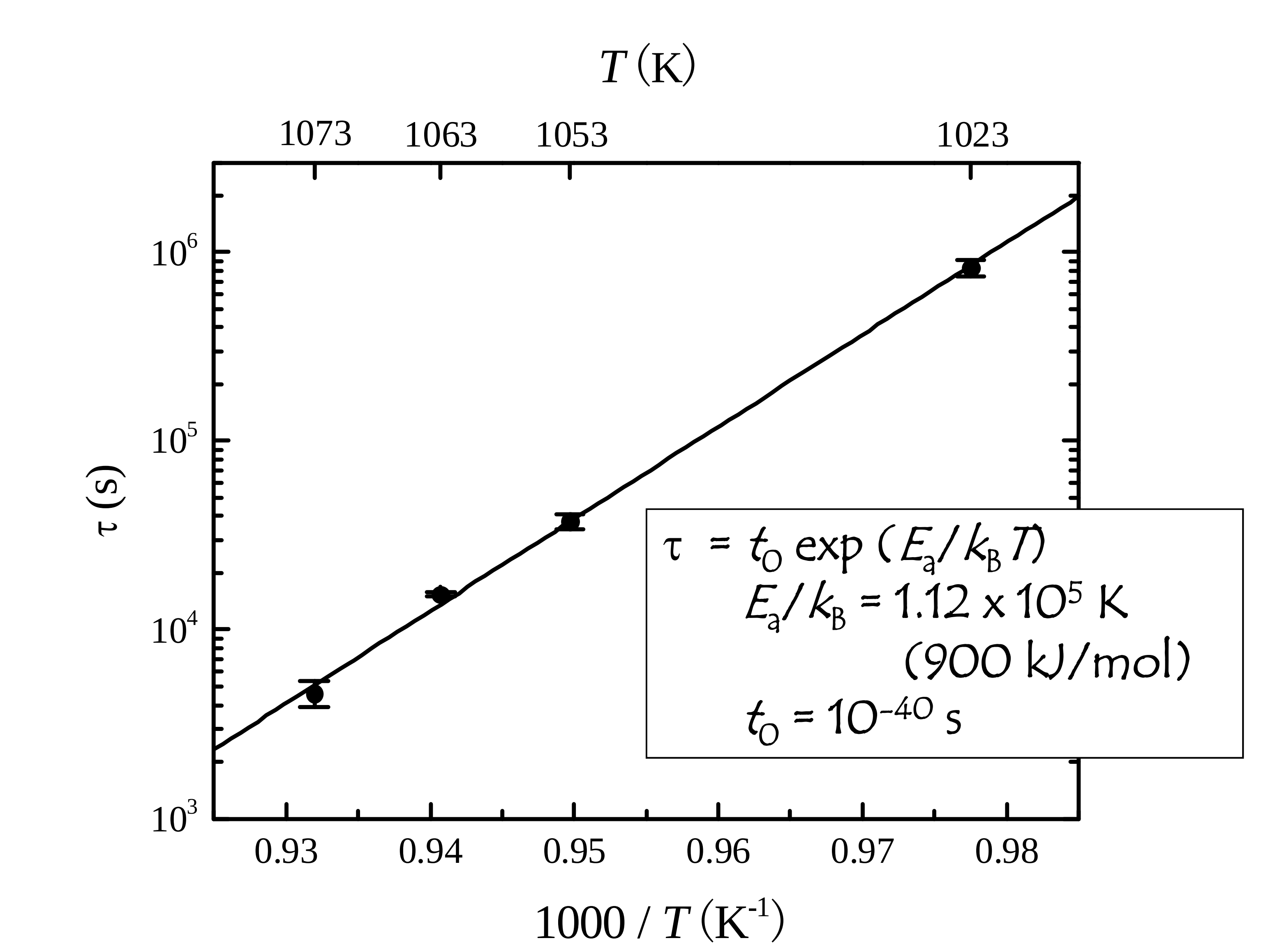


# 2 $Mg_{1.1}Fe_{0.4}SiO_{3.5}$ (Murata et al. 2009a)

## fractionation of Mg/Fe between crystal & amorphous phases



# 3 $Mg_{1.1}SiO_{3.1}$ (Murata et al. 2009b)



# 3 $Mg_{1.1}SiO_{3.1}$ (Murata et al. 2009c) Chondritic Enstatite with lattice defects

## Sample preparation

Amorphous silicate (Mg/Si = 1.07) with Si-alkoxide (TEOS) by Sol-Gel method

hydrolysis : $nSi(OR)_4 + 4nH_2O \rightarrow nSi(OH)_4 + 4nROH$

poly-condensation : $nSi(OH)_4 \rightarrow nSiO_2 + 2nH_2O$

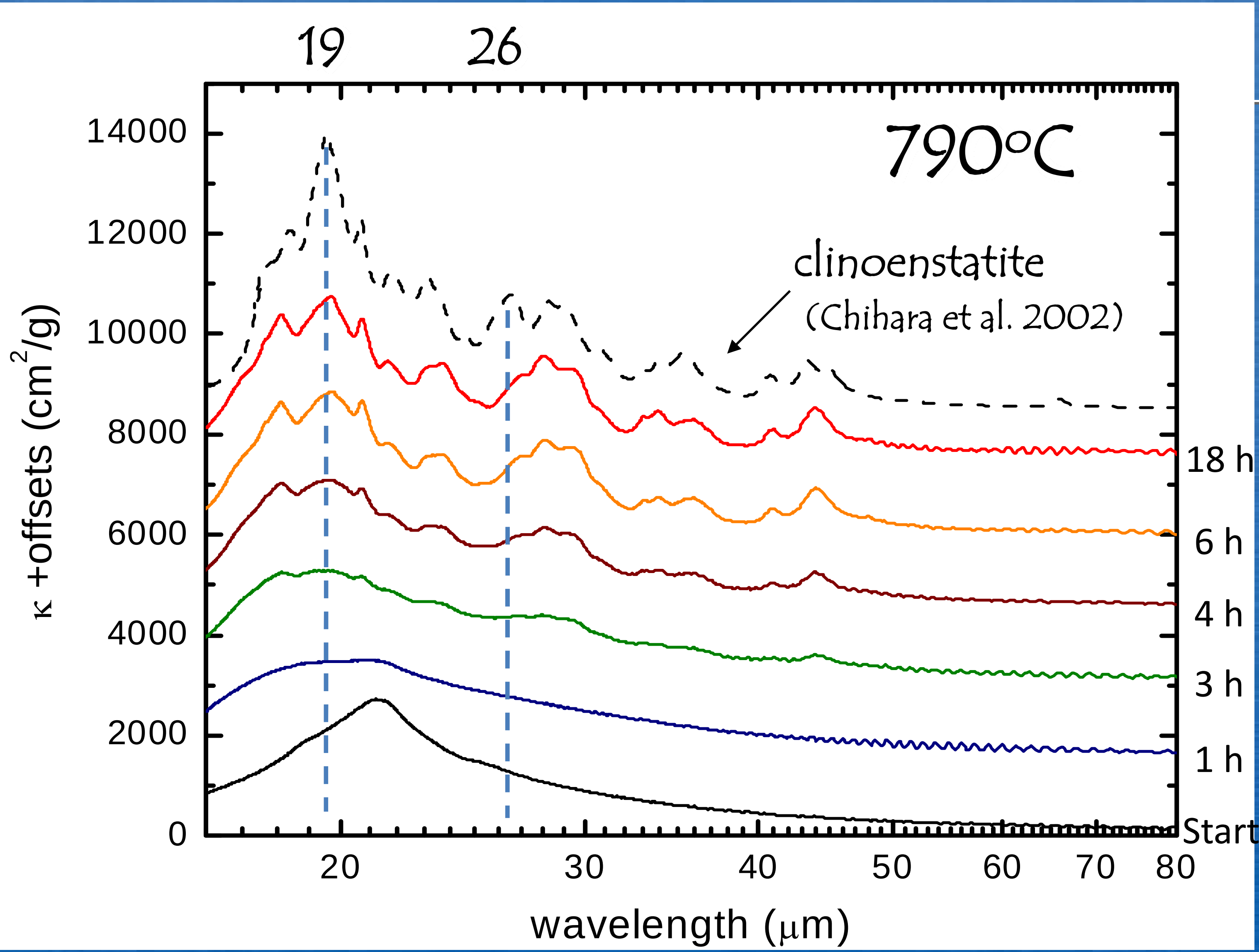
$nSi(OR)_4 + 2nH_2O \rightarrow nSiO_2 + 4nROH$

Heating at 790℃ → Crystallized Enstatite

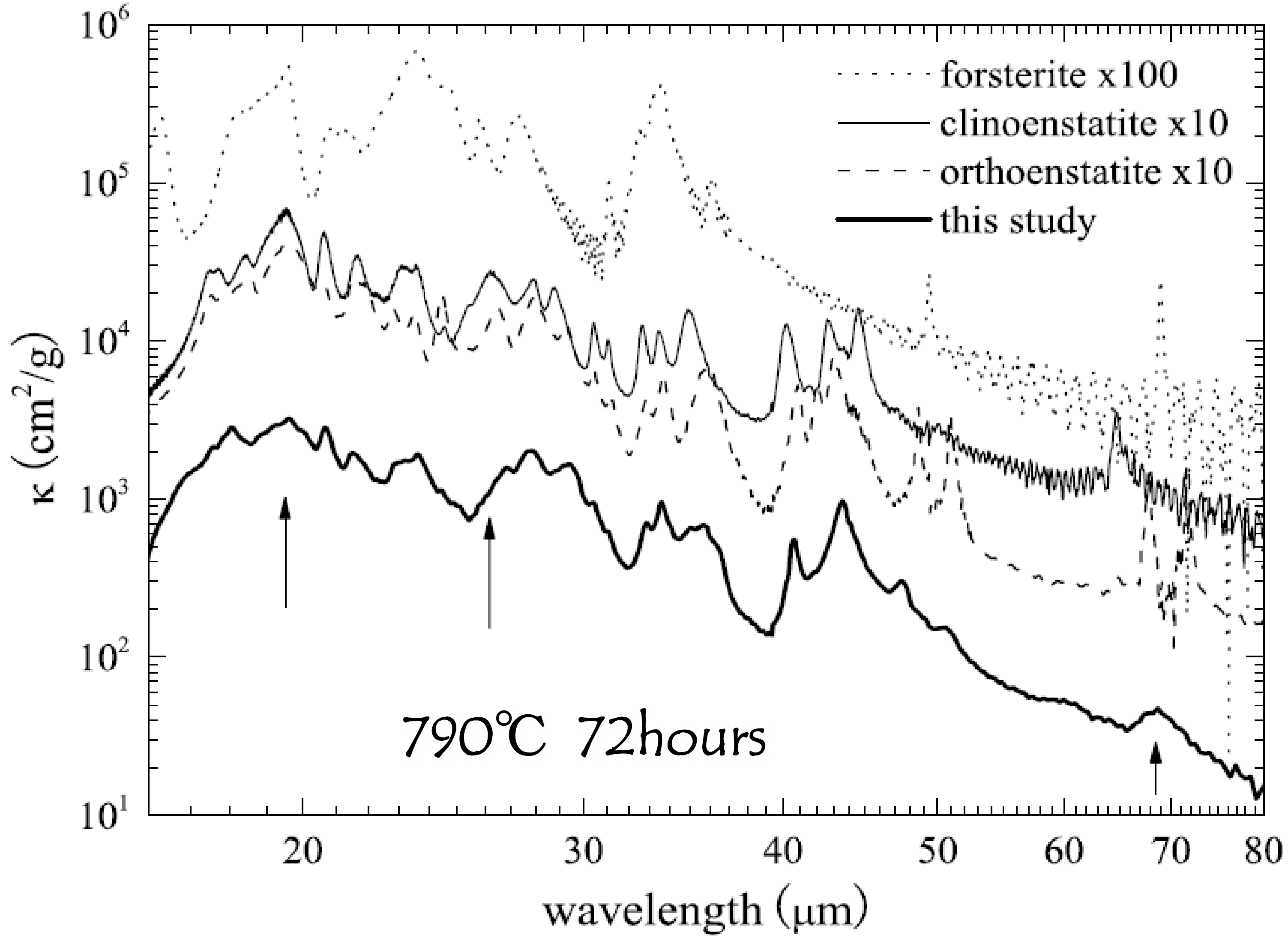
# Advantages of Sol-Gel method

- Very promising method to produce functional glass materials in industrial fields !
  - Homogeneity within the molecular scale
  - Required temperature is low
  - Molding is possible
  - Extremely porous → chemically active

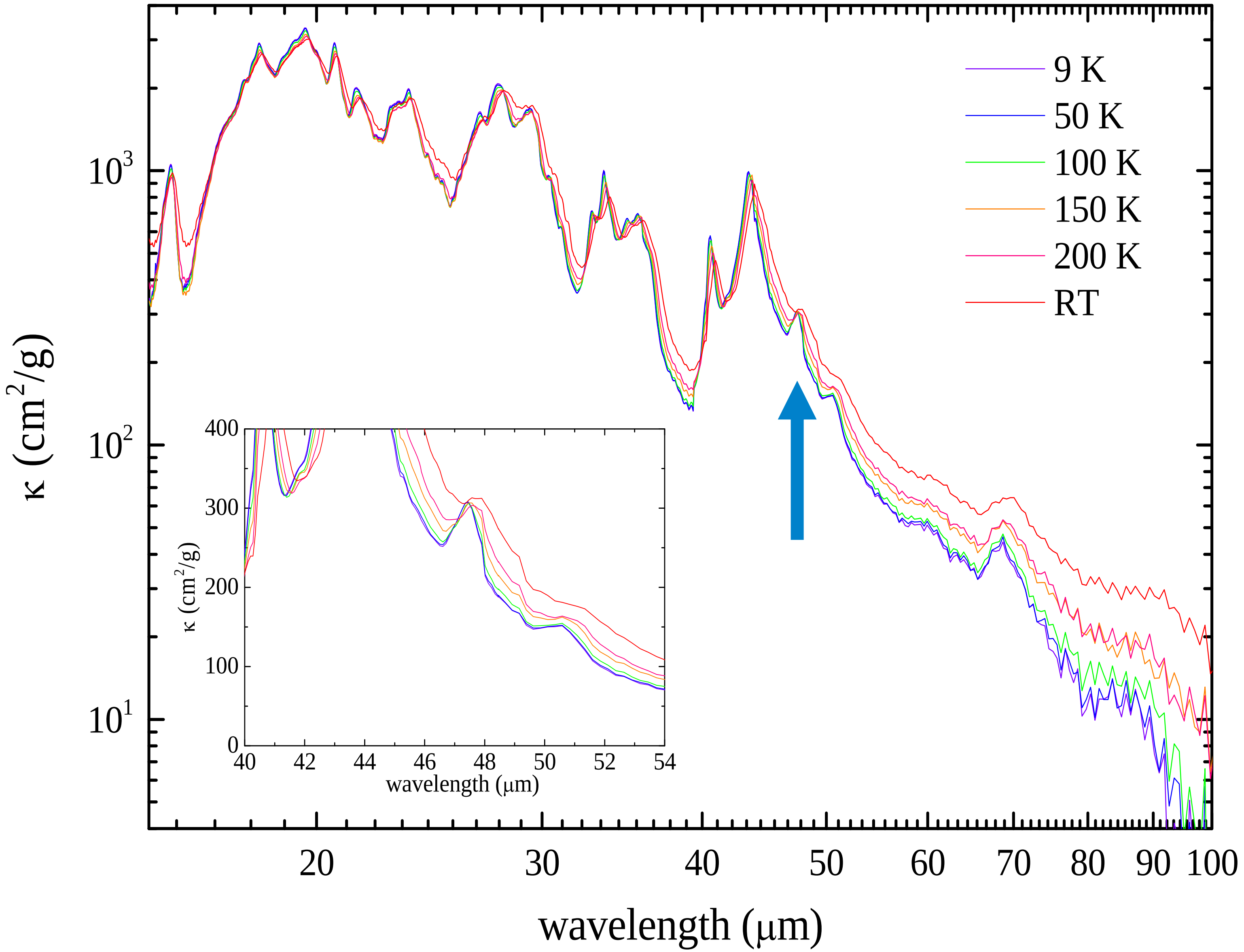
# Time evolution of crystallization



# Spectra at room temperature & comparison with single crystals

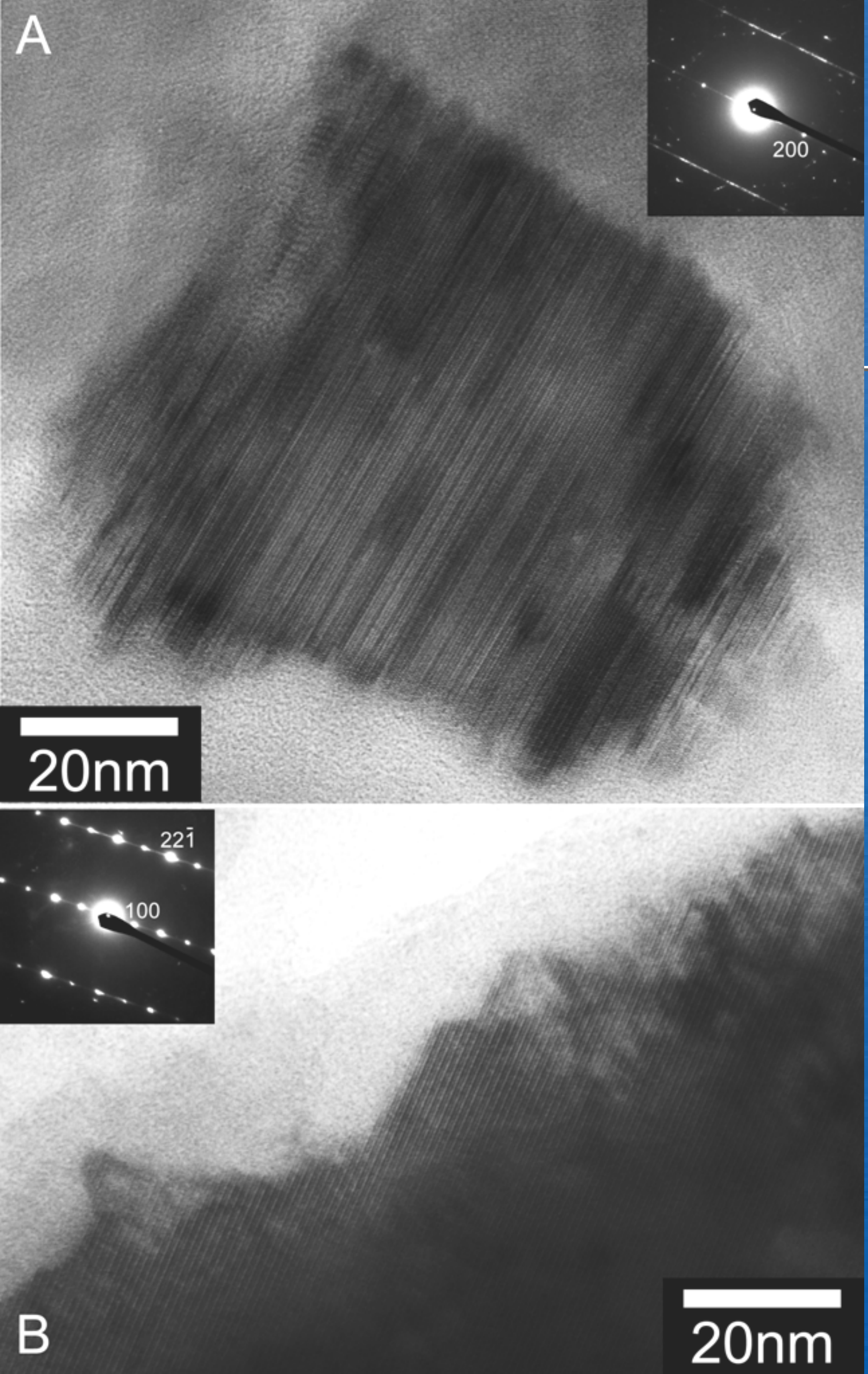


# Spectra at lower temperature



# Summary of spectral features

- Far-IR features are different from both of ortho- and clino- enstatite.
- some peak strengths are weaker than those of single crystals (19, 26 micron)
- at lower temperature prominent feature appear at 48 micron
- Broad 69um feature

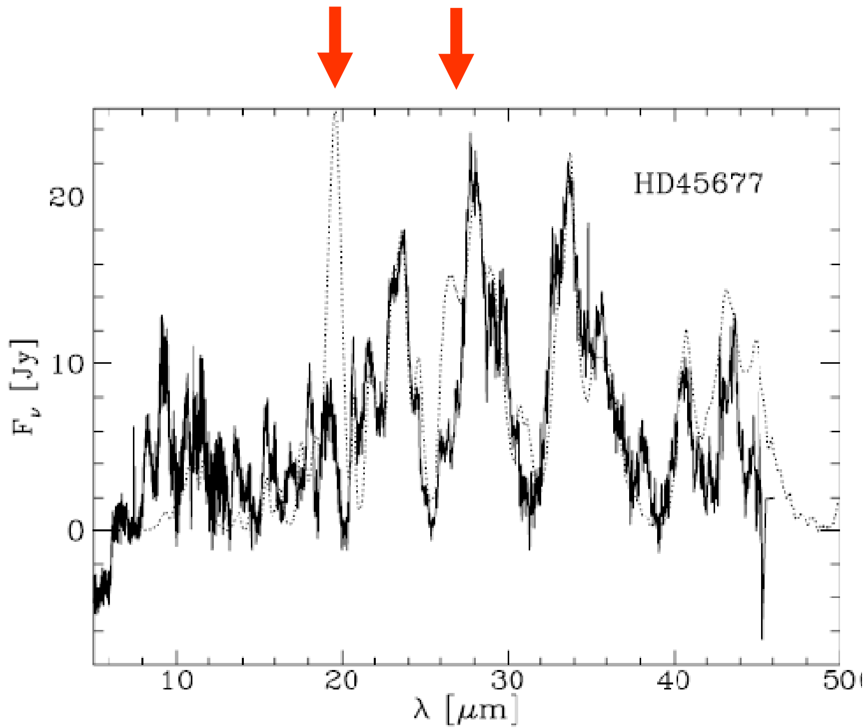



**A** crystallized enstatite from sol-gel material

stacking faults along to (100) direction

**B** clinoenstatite single crystal

# Implication to observations



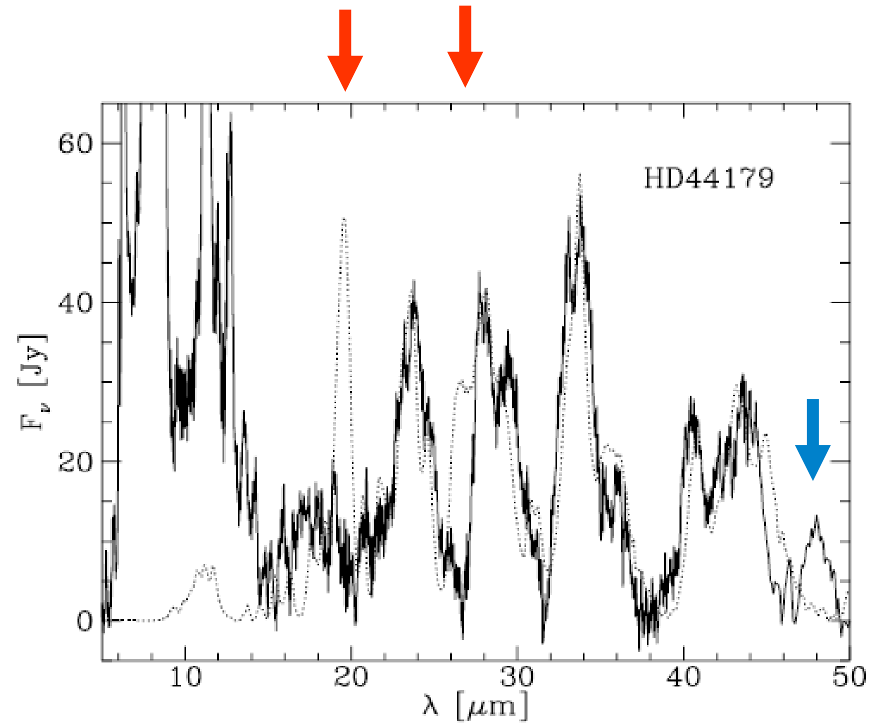




**Fig. 10.** A fit (dotted line) to the continuum and amorphous silicate subtracted spectrum (solid line) of HD 45677. $T_f$ = 140 K and $T_e$ = 140 K.

**Fig. 13.** A fit (dotted line) to the continuum subtracted spectrum (solid line) of HD 44179. $T_f$ = 135 K and $T_e$ = 135 K. Below 15 μm the spectrum is dominated by PAH features.

F.J.Molster et al. 2002

# Previous suggestion on 48 um unidentified feature

Ferrarotti et al. (2000) proposed that FeSi may be possible carrier of the unidentified the 48 μm feature under a peculiar abundance condition.

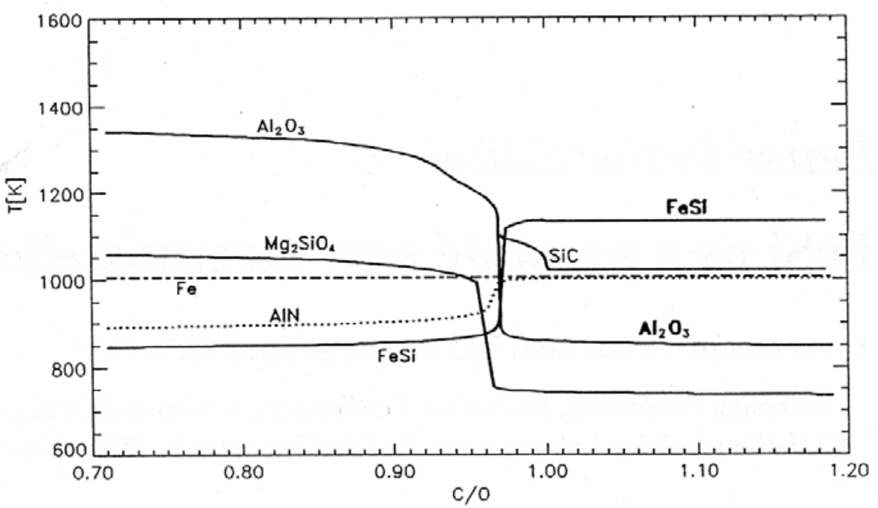



**Fig. 1.** Stability limits of condensates of some of the most abundant elements for varying C/O abundance ratio. The pressure is fixed at $P = 10^{-4}\,\mathrm{dyn\,cm^{-2}}$.

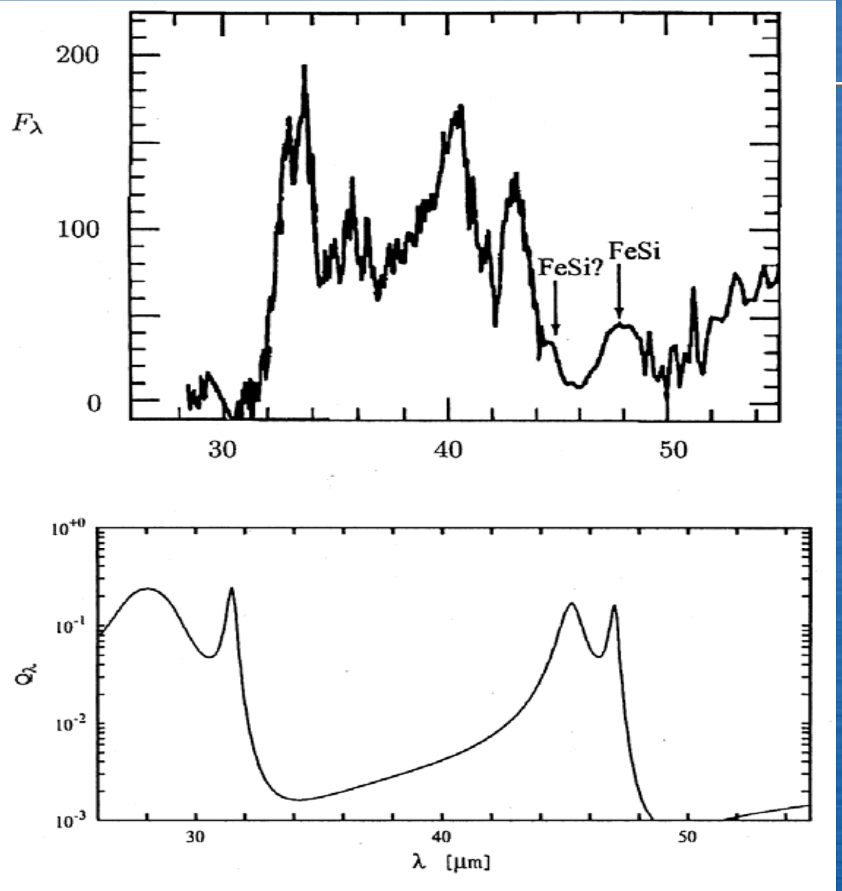



**Fig. 4.** *Upper Part:* Spectrum of AFGL 4106 (taken from Molster et al. 1999) in the far infrared wavelength region $28 \lesssim \lambda \lesssim 54\,\mu$m. The strong bands are due to forsterite and enstatite. *Lower part:* Absorption efficiency $Q_\lambda$ of FeSi grains with $0.1\,\mu$m radius at $T_{\rm dust} = 120\,$K. A broad distribution of grain radii would broaden the absorption bands.

# Comparison with previous templates

HD44179

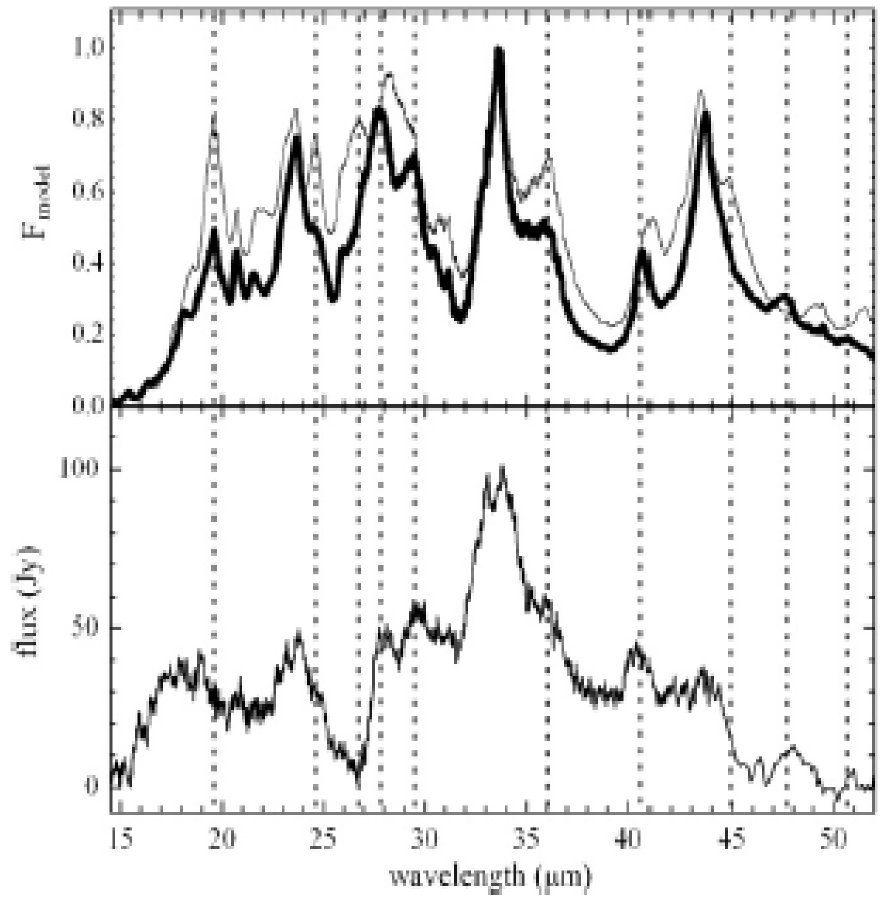



**Figure 4.** Comparison of the continuum-subtracted spectrum of HD 44179 with the model (1) (SCE + forsterite, thin line) and (2) (HAS + forsterite, thick line) multiplied by the Planck function of 150 K and normalized to 1.

MWC922

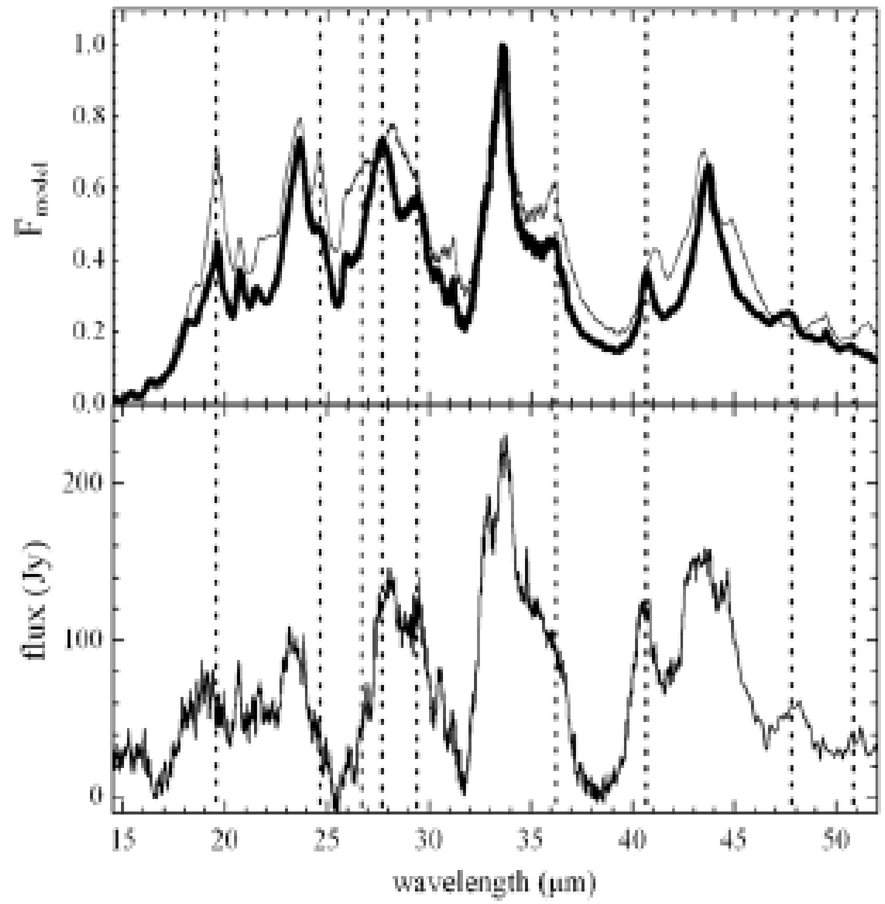
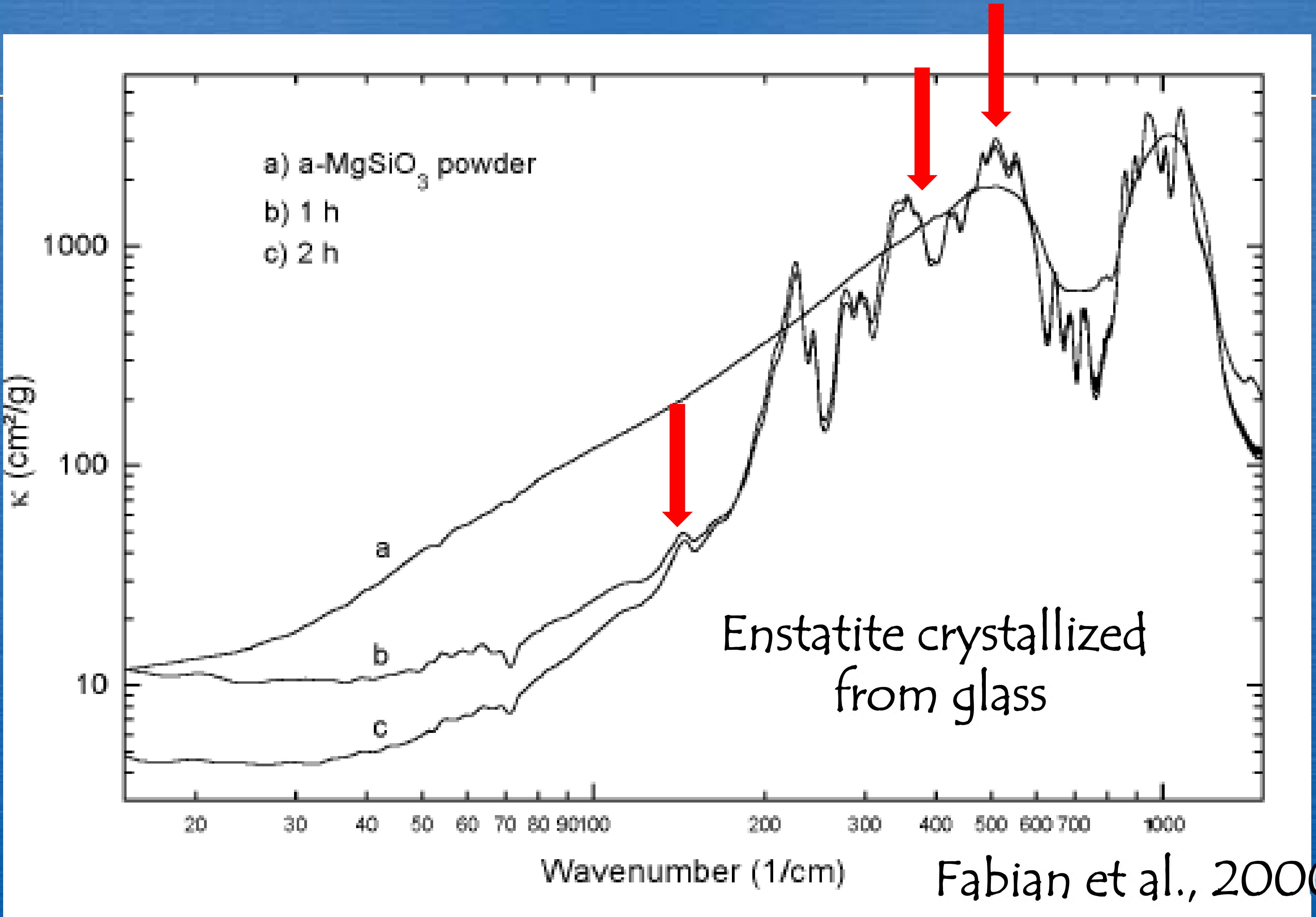
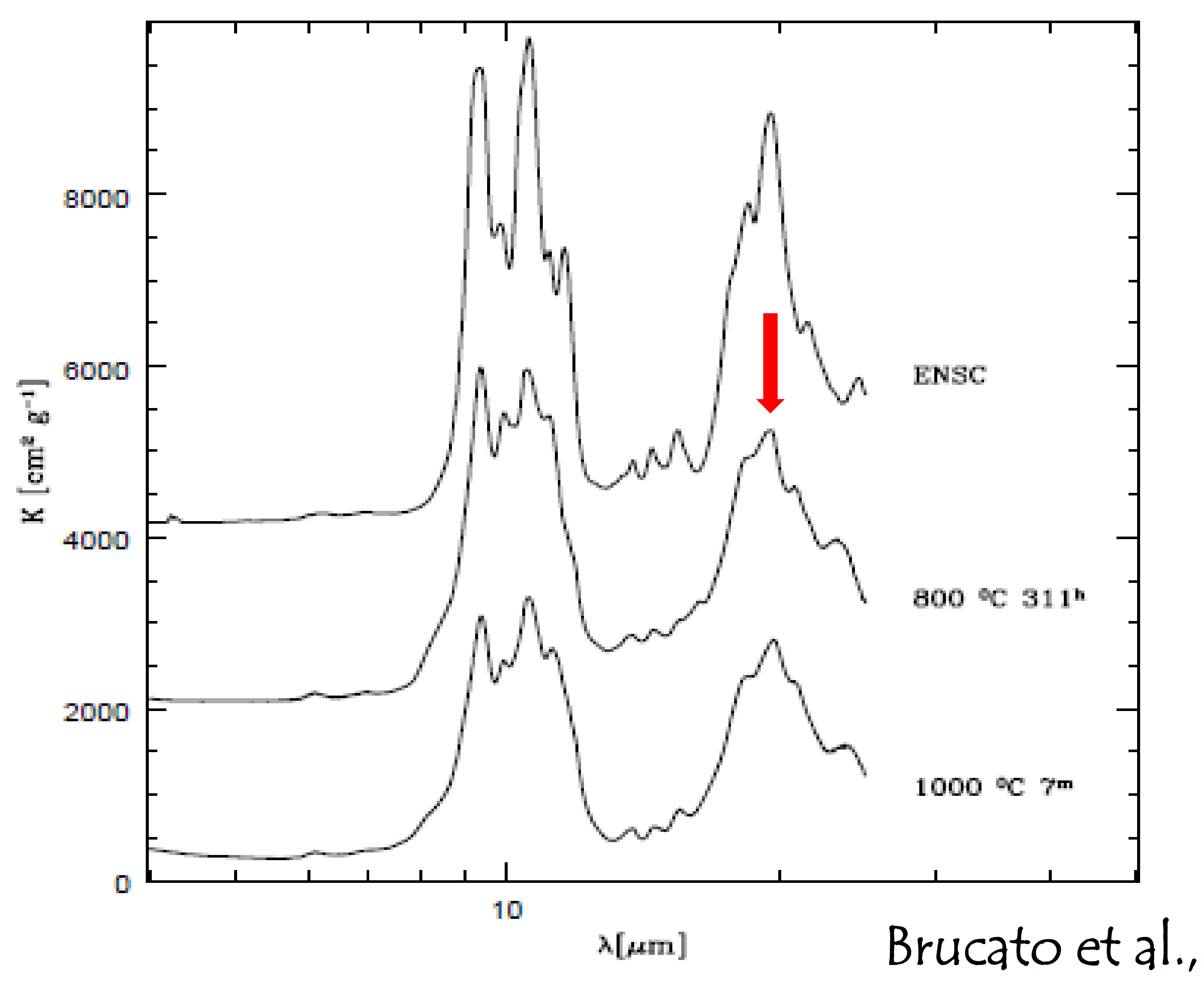



**Figure 5.** Comparison of the continuum-subtracted spectrum of MWC 922 with the model (1) (SCE + forsterite, thin line) and (2) (HAS + forsterite, thick line) multiplied by the Planck function of 150 K and normalized to 1.

# Traces of similar features in previous studies




Fabian et al., 2000




Brucato et al., 1999

# Conclusion

- IR spectrum of the sample shows different features from those of single crystals (in particular at 19, 26, 48 & 69 um)
- Lattice defects (stacking faults) is thought to be the cause of the spectral discrepancies

↓

- Existence of enstatite with lattice defects is suggested in circumstellar environment.