Crystalline silicates in external galaxies

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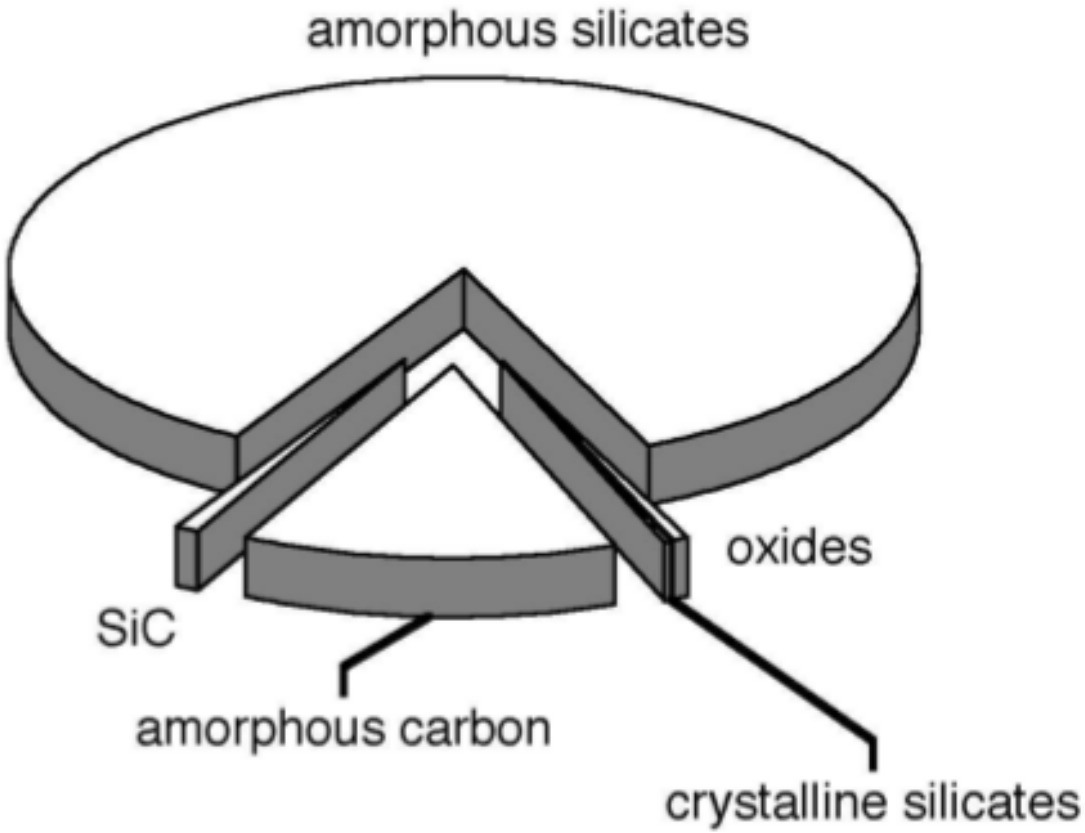
The composition of interstellar dust

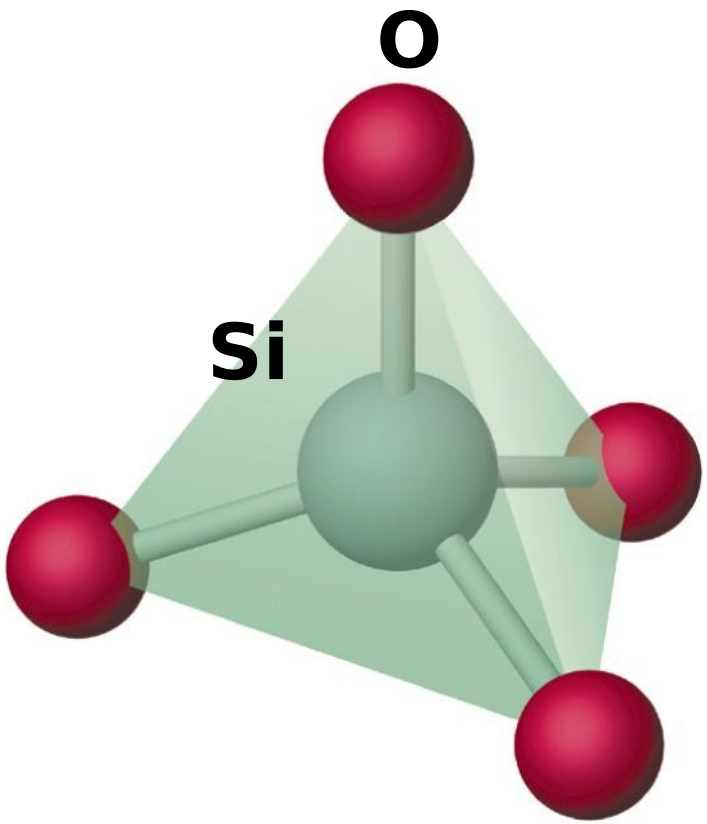


(Tielens et al. 2001)

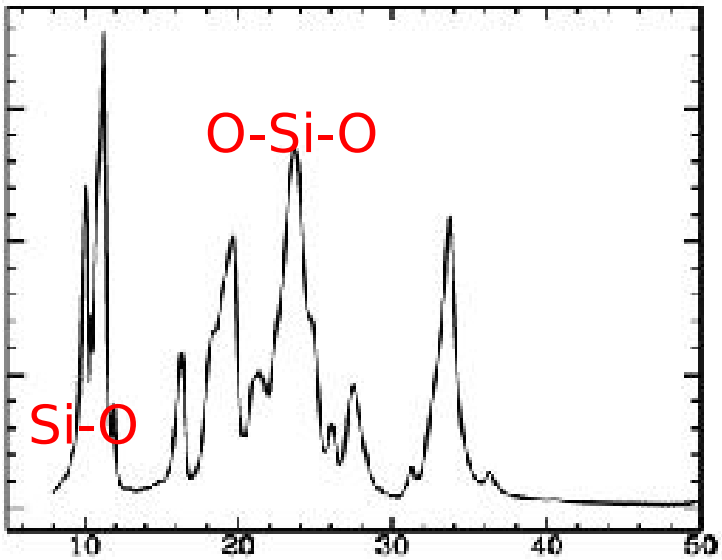
Silicates: the building blocks

- silicate anion
  SiO_4^{4-}

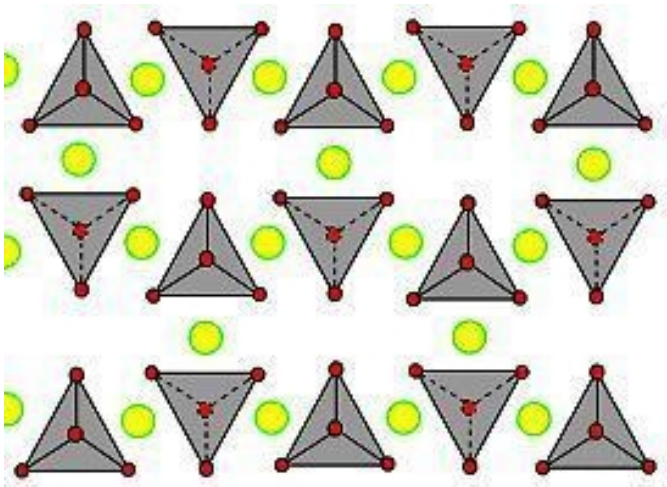
- Metal cation
  Mg^{2+}, Fe^{2+}, Ca^{2+}…



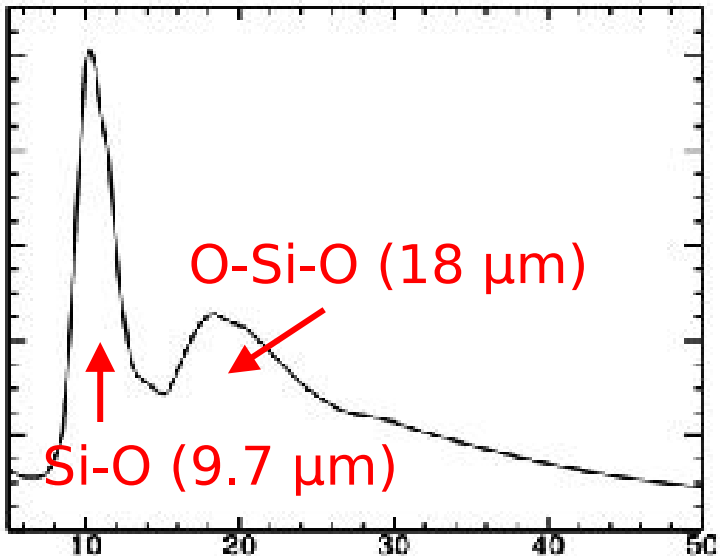
Crystalline



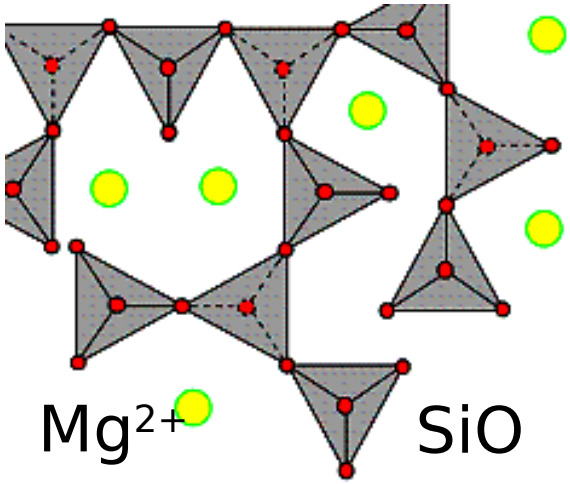
→Wavelength (μm)



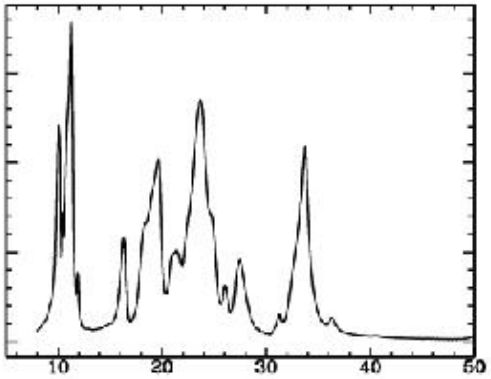
Amorphous

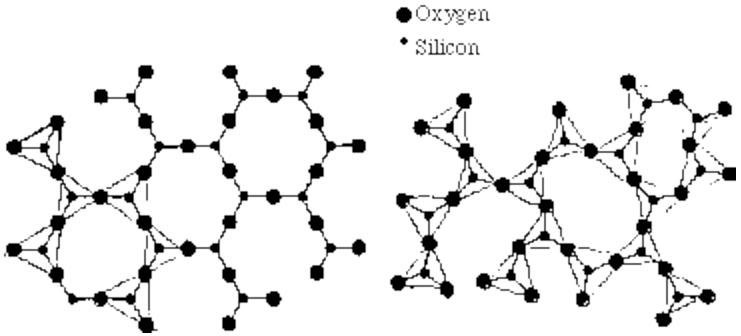


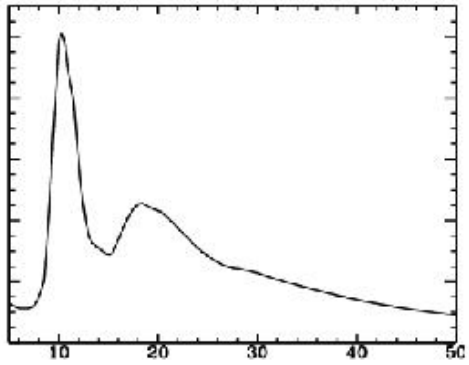
→Wavelength (μm)



Crystallinity of silicates





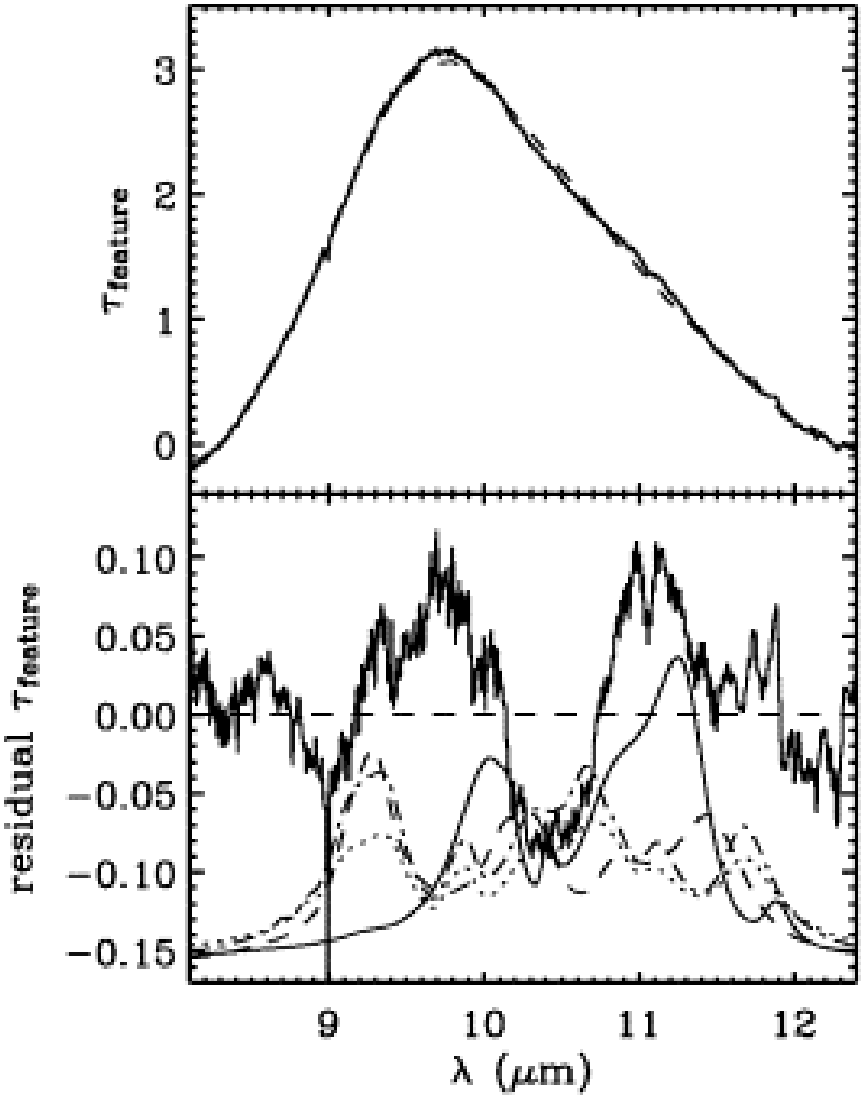


The glass temperature T_{glass} ~1000 K for silicates
(T_{evap} ~1500 K)

$T_{cond} > T_{glass}$: atoms in mineral are mobile, crystallization may occur

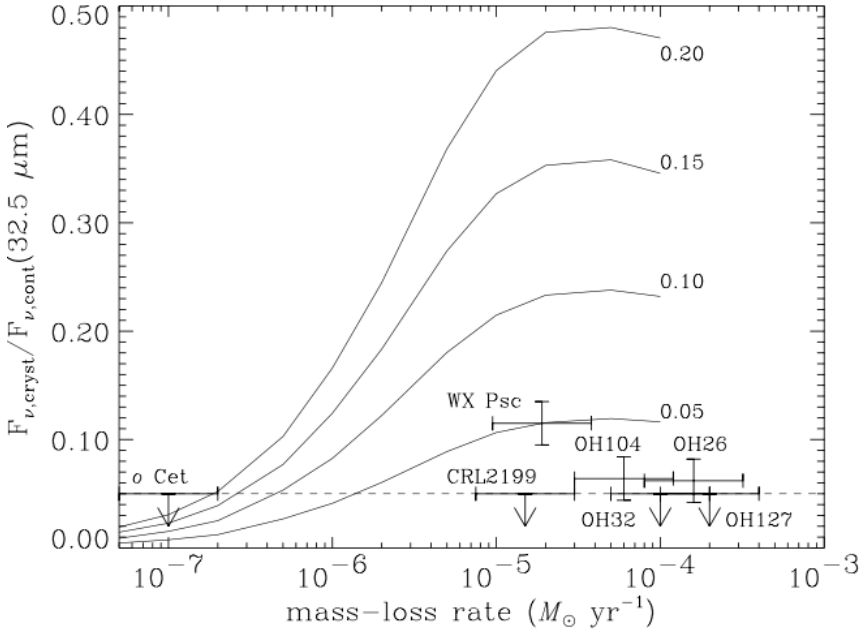
$T_{cond} < T_{glass}$: immediate freeze out → amorphous silicate

No crystalline silicates in the ISM of the Milky Way

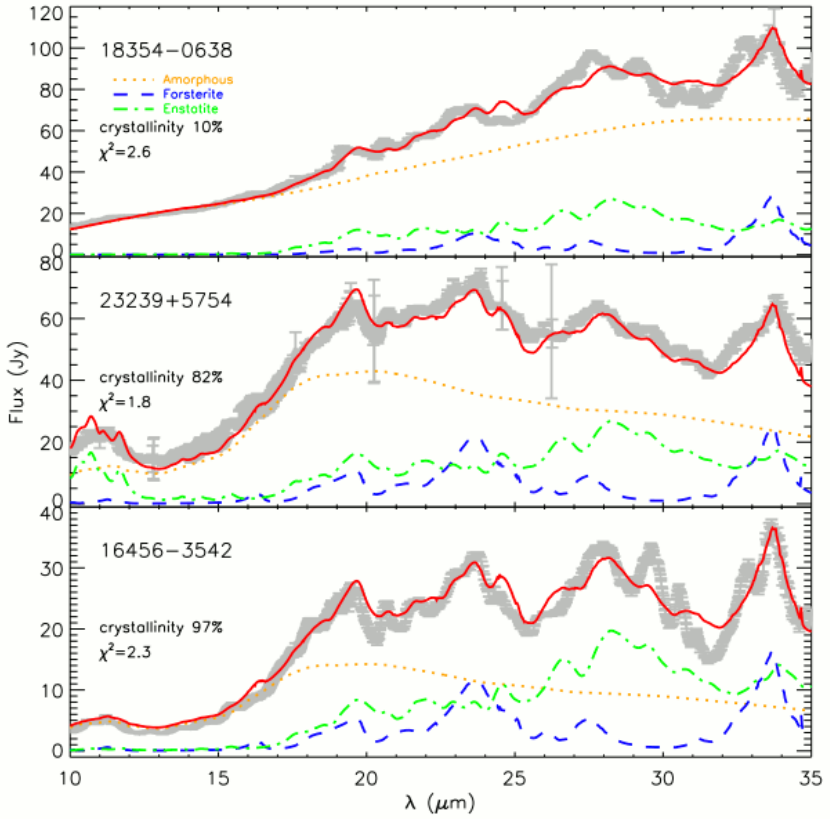


(Kemper et al. 2004)

AGB stars produce crystalline silicates



(Kemper et al. 2001)



typical crystallinity ~10%, but as high as ~90%

(Jiang et al. 2013)

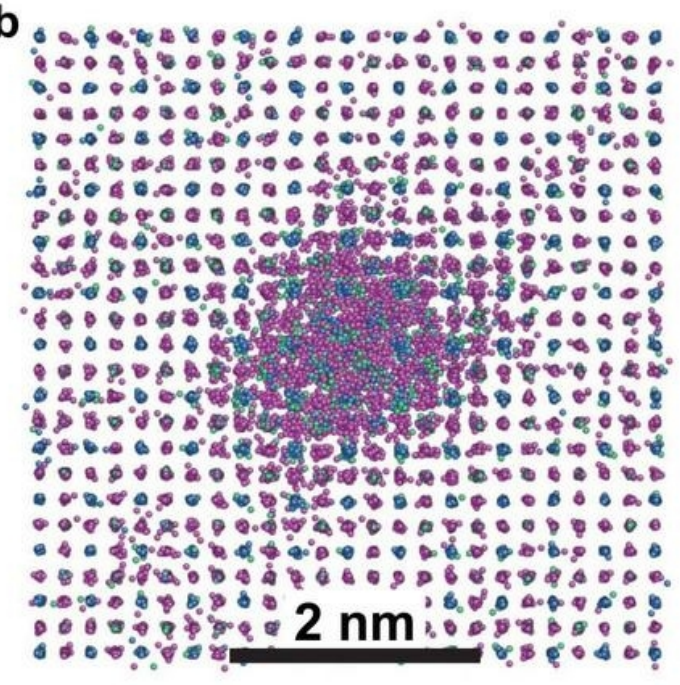
amorphization in ISM needs to be explained with CR hits

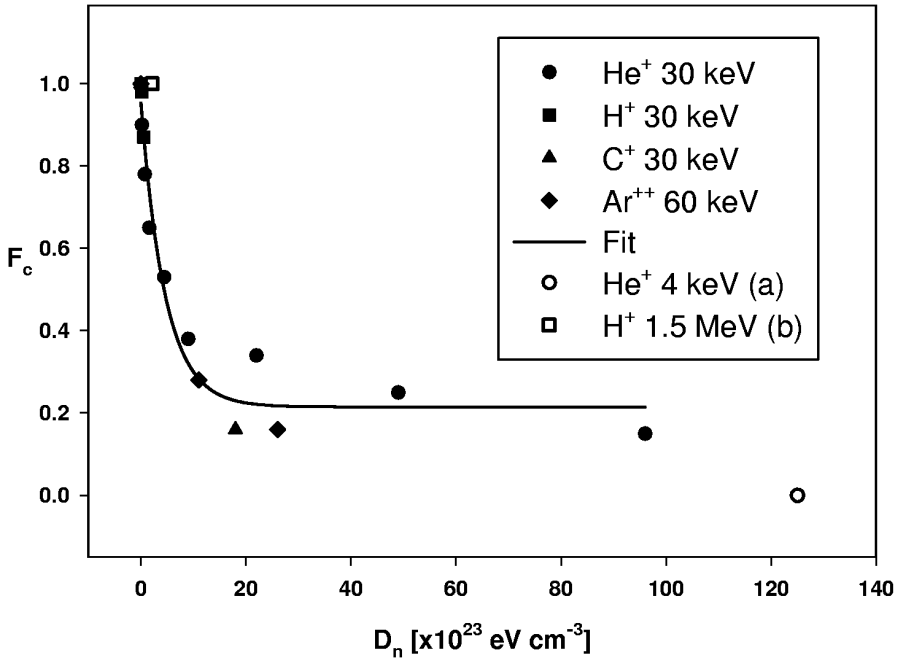
amorphization time scale few tens Myr

Amorphization of silicates

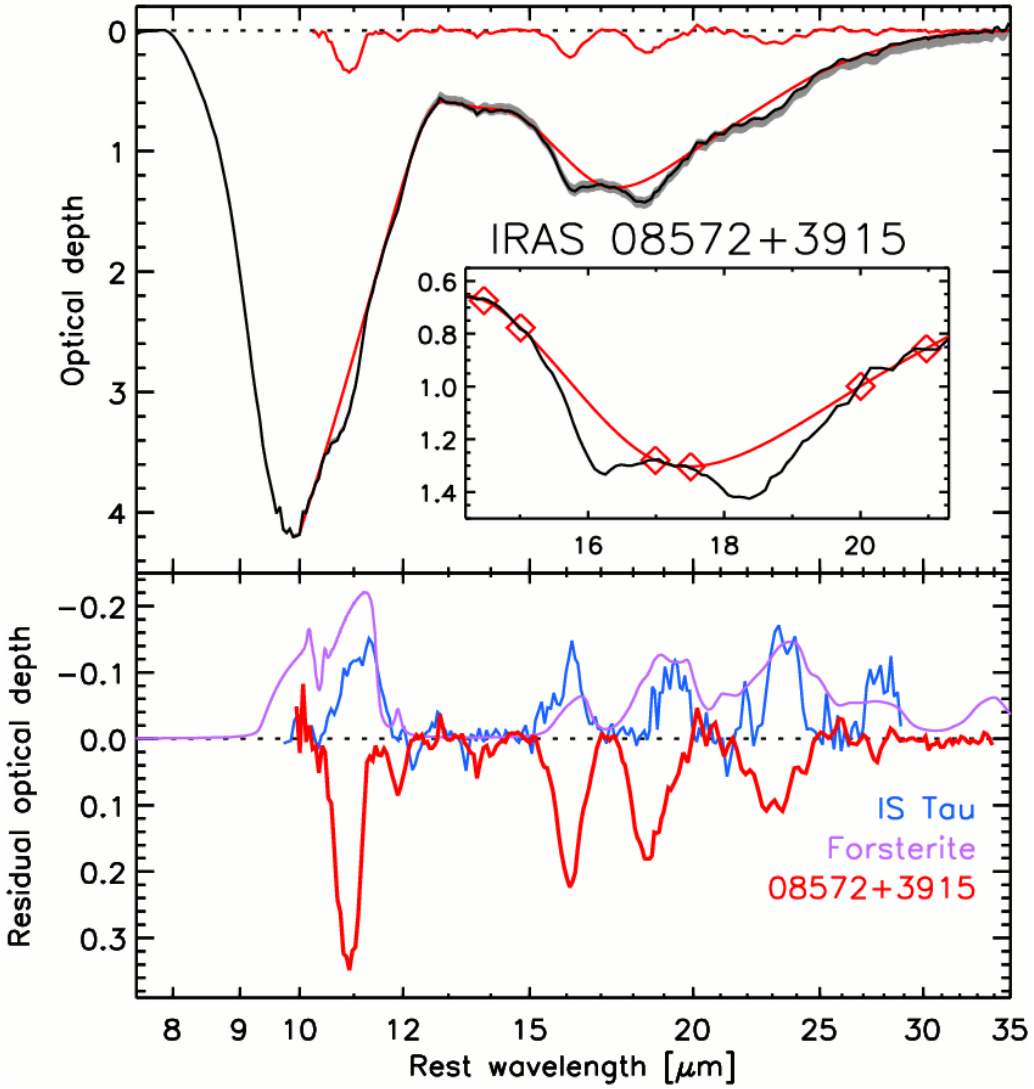
Upon cooling, crystalline silicates retain their structure

Amorphization is non-thermal:





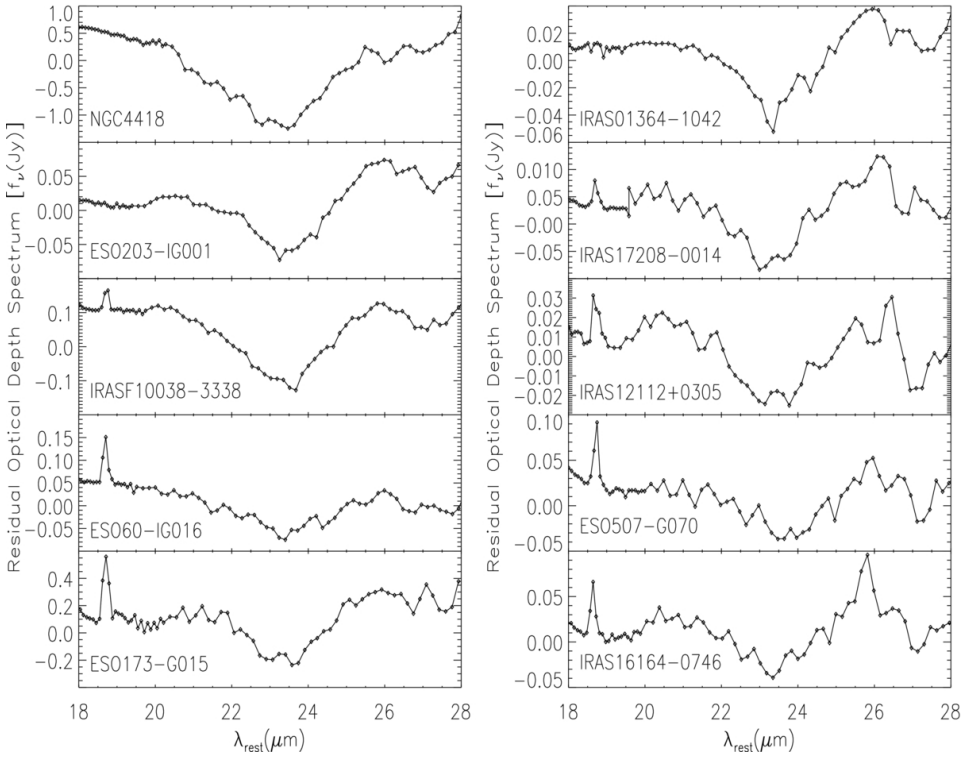
~12/77 starburst galaxies have silicate crystallinities of 6-13%

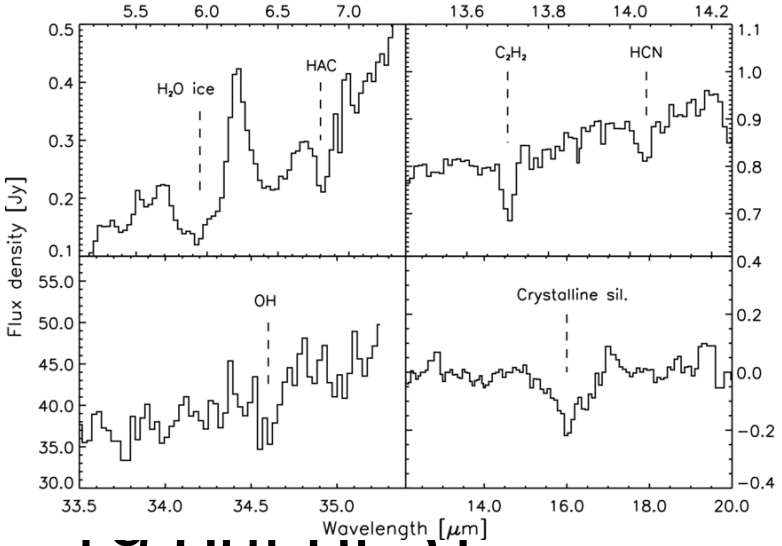


(Spoon et al. 2006)

Crystalline silicates in starburst galaxies

6% out of 244 (U)LIRGs *(Stierwalt et al. 2014)*

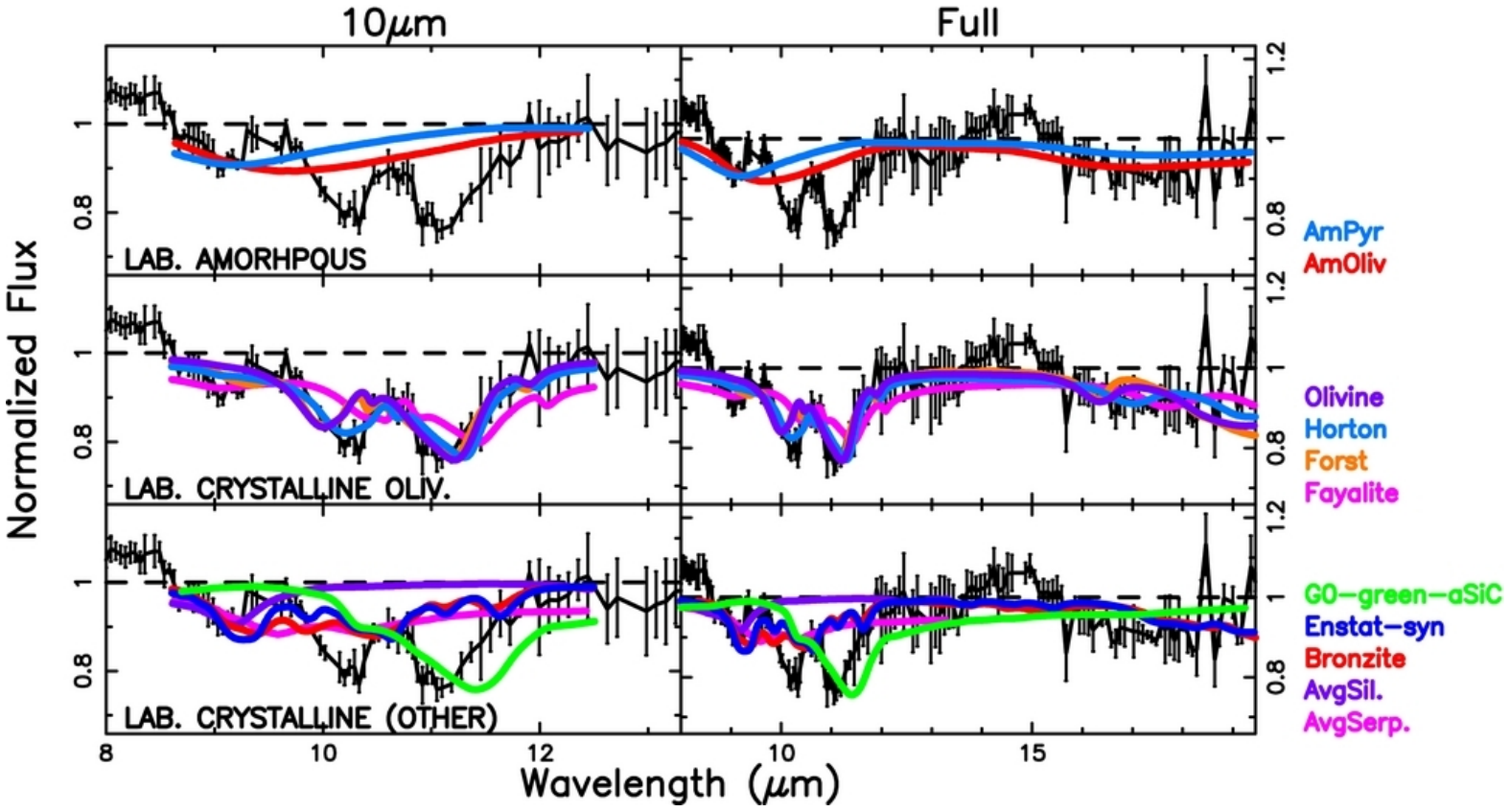




19 out of 31 OH megamaser galaxies *(Willet et al. 2011)*

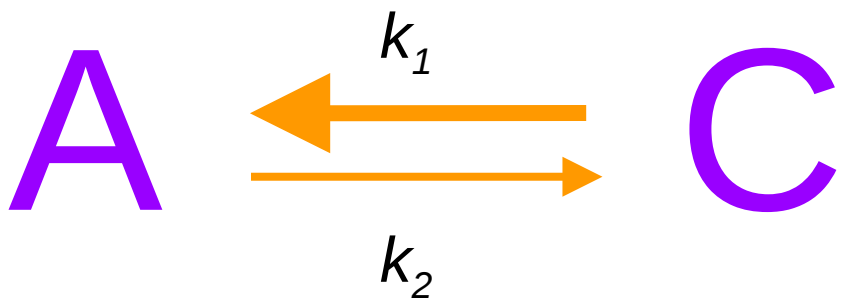
Crystallinity not determined!

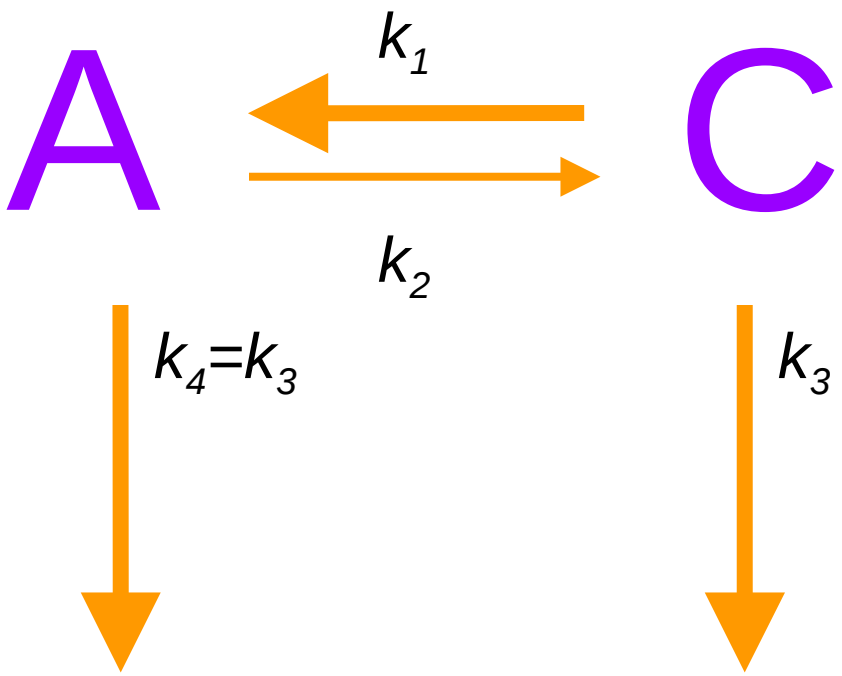
Quasar foreground absorber (Damped Lyα system) has a crystallinity of 95%

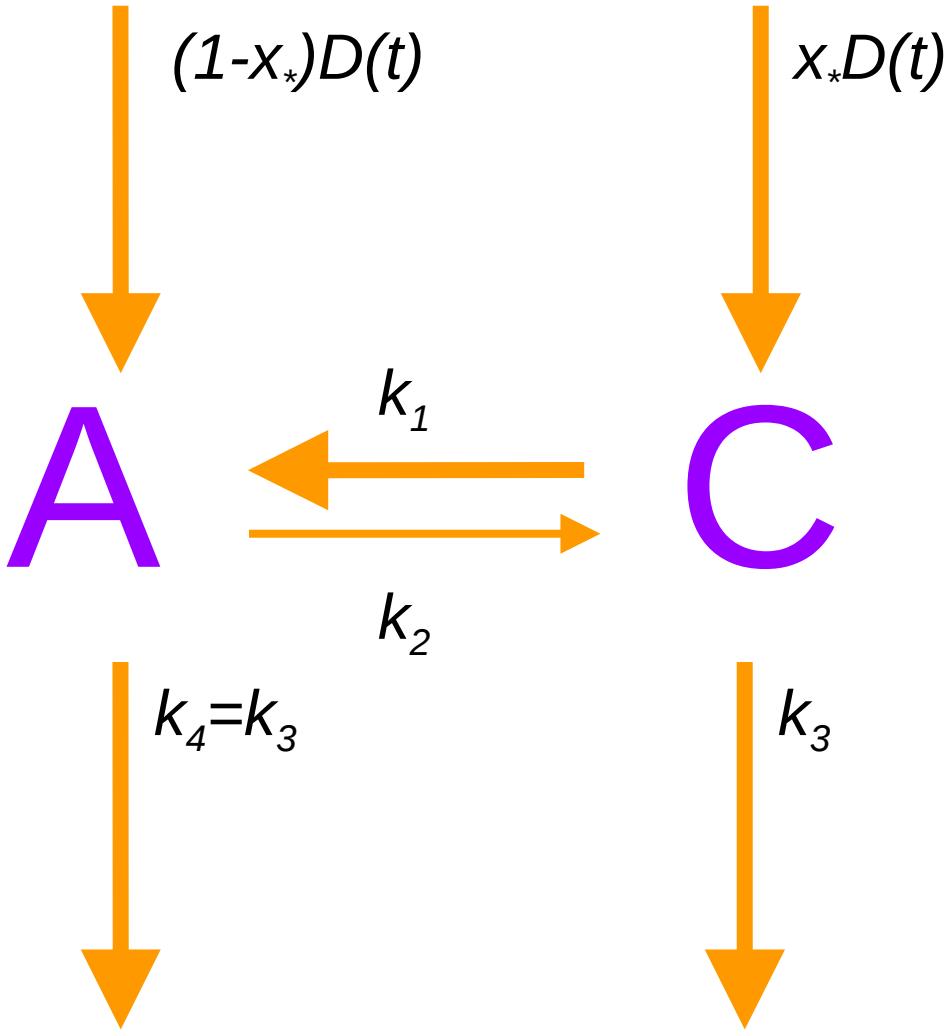


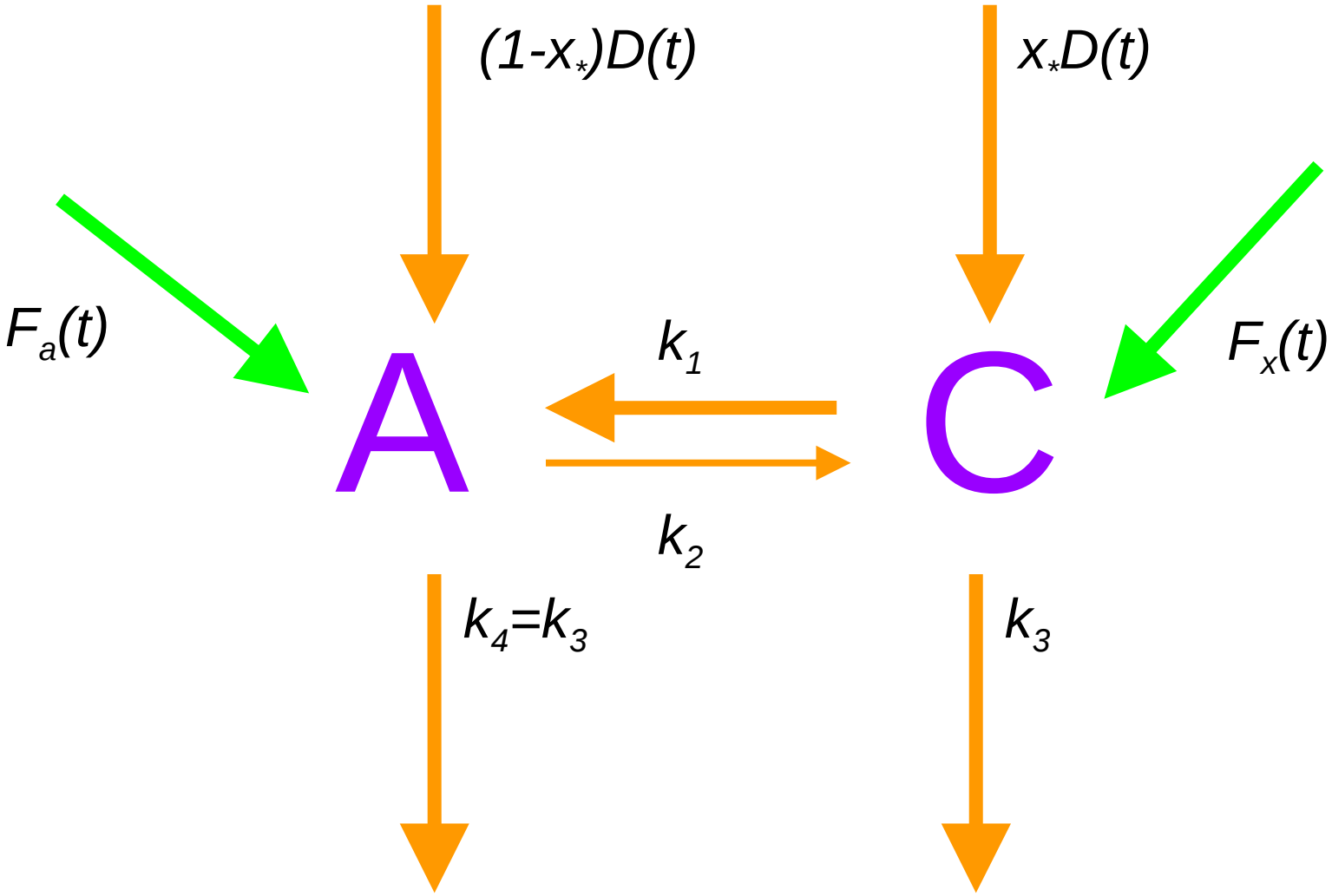
(Aller et al. 2012)

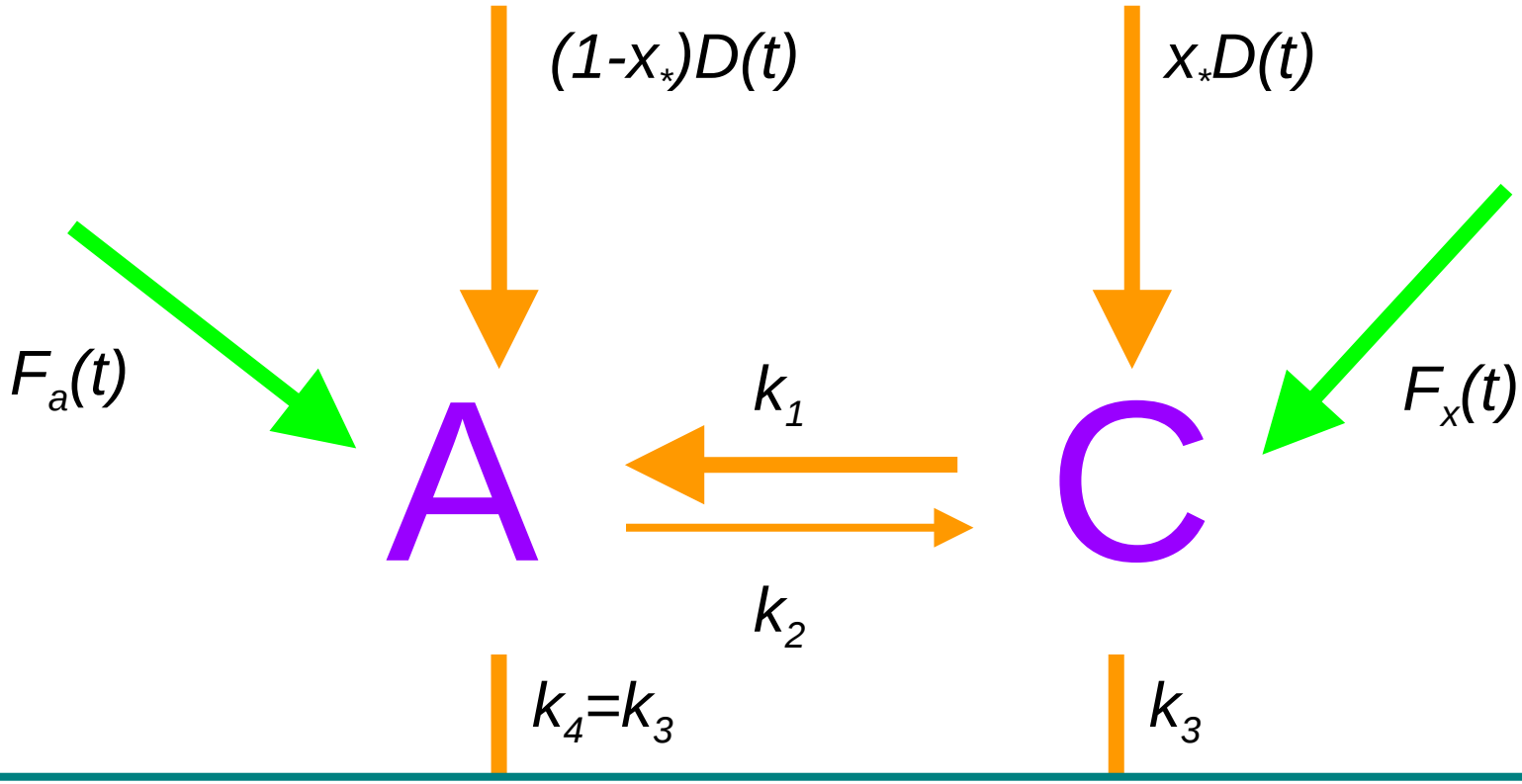
A C


A
k_1
C
k_2

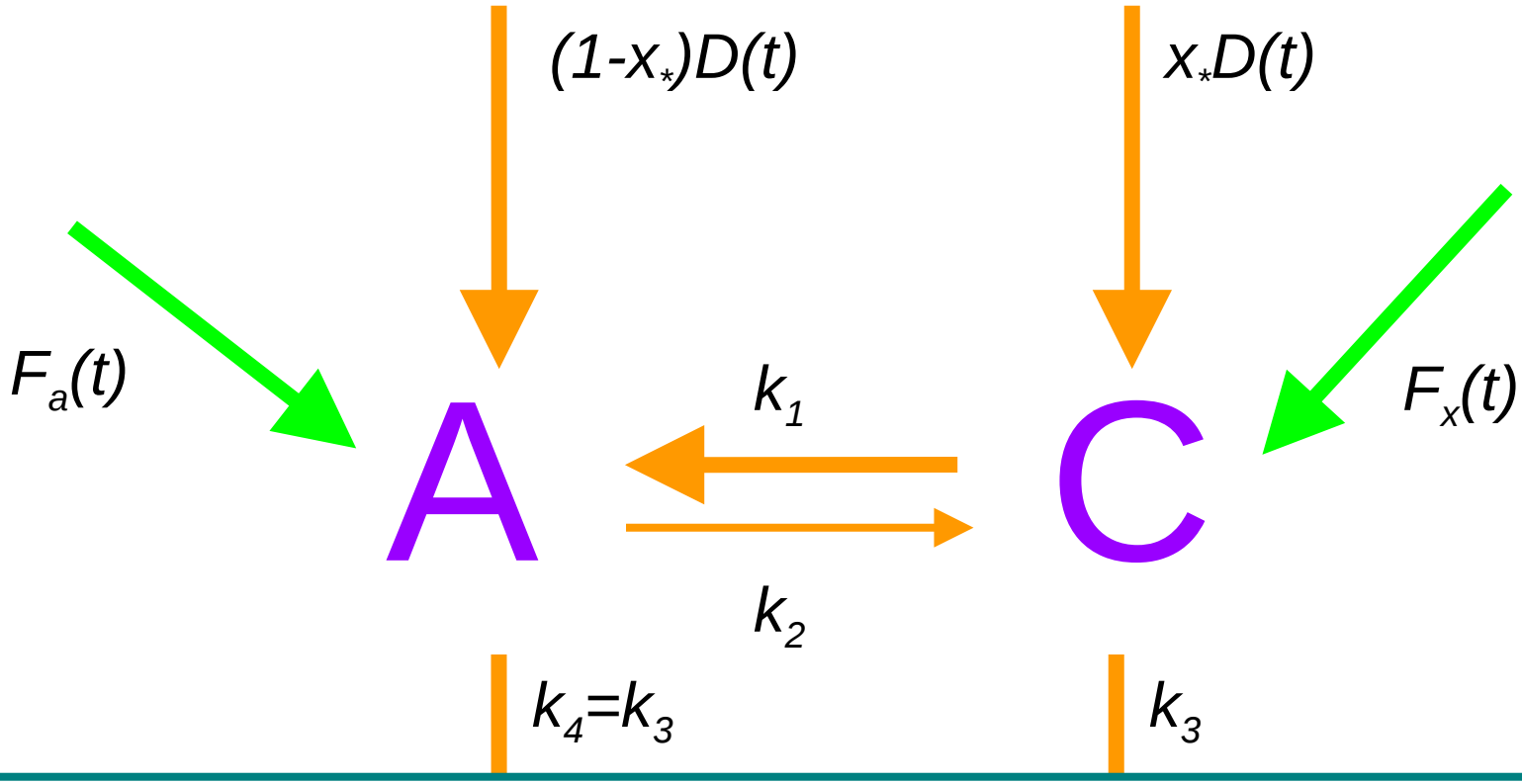

A
C
k_1
k_2
$k_4=k_3$
k_3


(1-x*)D(t)
x*D(t)
A
C
k1
k2
k4=k3
k3

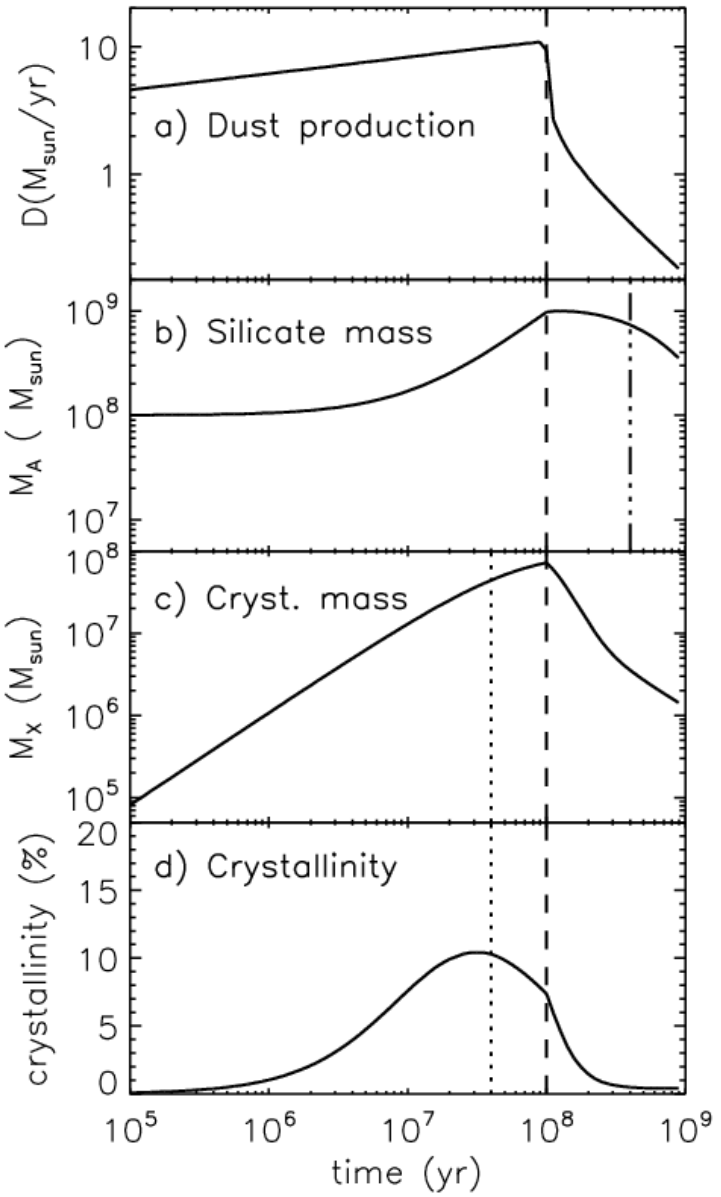

(1-x*)D(t)
x*D(t)
Fa(t)
Fx(t)
A
C
k1
k2
k4=k3
k3



$$\begin{cases} \frac{dM_{\mathrm{X}}}{dt} = x_* D(t) - k_1 M_{\mathrm{X}} + k_2 M_{\mathrm{A}} - k_3 M_{\mathrm{X}} + F_x(t) \\ \frac{dM_{\mathrm{A}}}{dt} = (1 - x_*) D(t) + k_1 M_{\mathrm{X}} - k_2 M_{\mathrm{A}} - k_4 M_{\mathrm{A}} + F_a(t) \end{cases}$$



$$\begin{cases} \frac{dM_X}{dt} = x_* D(t) - k_1 M_X + k_2 M_A - k_3 M_X + F_x(t) \\ \frac{dM_A}{dt} = (1 - x_*) D(t) + k_1 M_X - k_2 M_A - k_3 M_A + F_a(t) \end{cases}$$

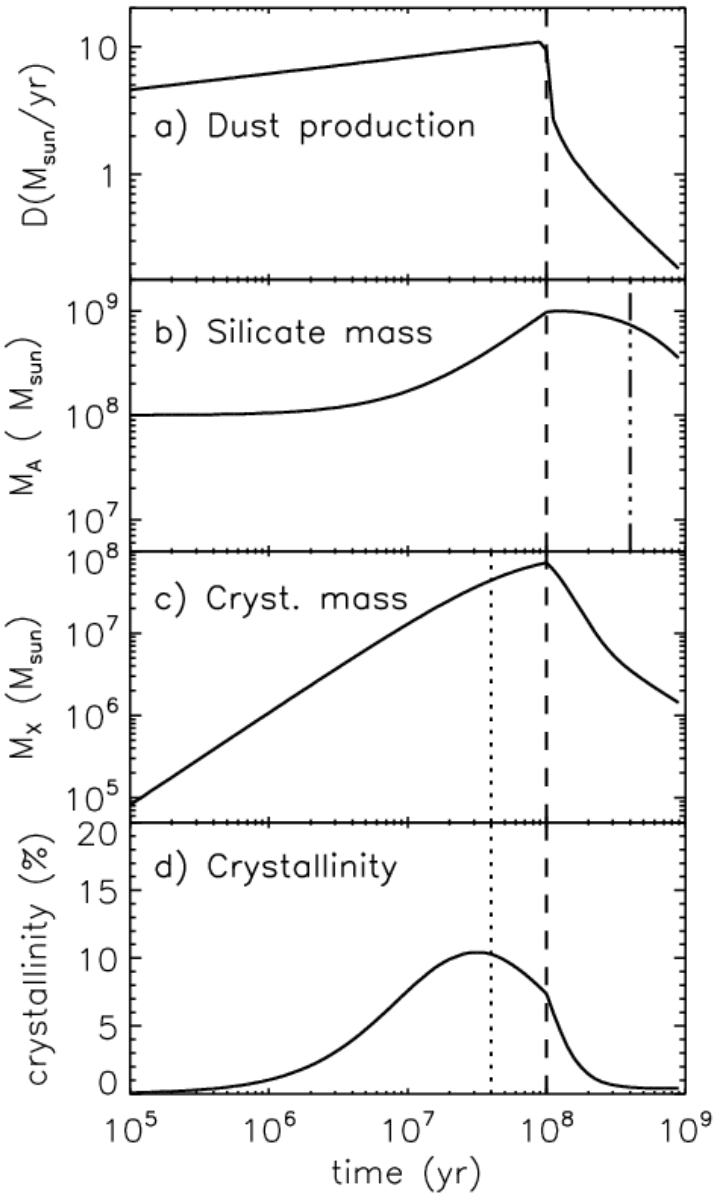


(Kemper et al. 2011)

Results

- Initial silicate mass:
- 10^8 $M_\odot$
- SFR: 1000 $M_\odot$ yr^{-1}
- x* = 0.2
- Dust-to-gas ratio:
- 0.01 for SNe

⇒ crystallinity ~10 %



(Kemper et al. 2011)

Results

- Initial silicate mass:
- 10^8 $M_\odot$ → low
- SFR: 1000 $M_\odot$ yr^{-1} → high
- x* = 0.2 → high
- Dust-to-gas ratio:
- 0.01 for SNe → high

⇒ crystallinity ~10 %

Detecting crystalline silicates in external galaxies

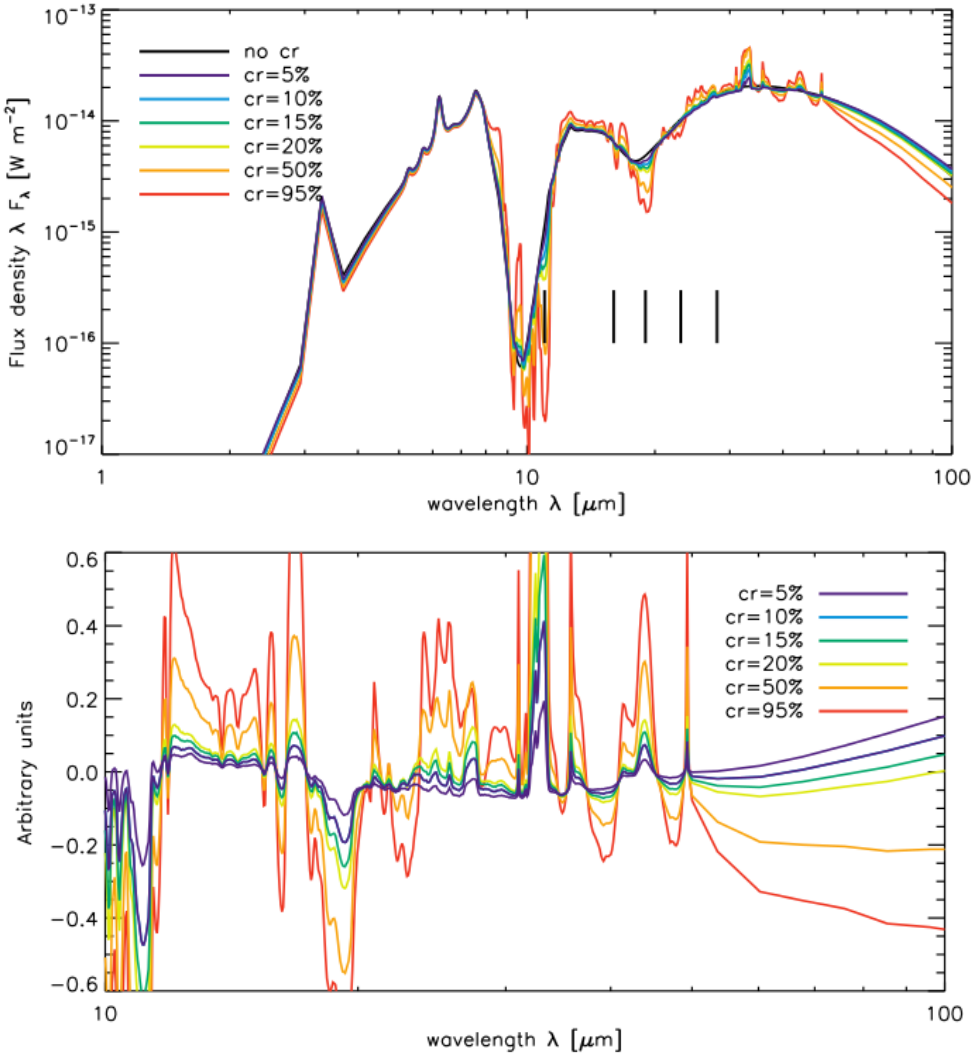
SPICA: $\lambda > 20$ μm, $R > 300$-1000
JWST: $\lambda < 28$ μm, $R \sim 3000$

Spitzer archival data: $\lambda = 5$-40 μm; $R \sim 120$-600

Are amorphous ISM silicates the norm?

What are the properties of galaxies showing crystallinity?

Detecting crystallinity of silicates with SPICA



dust mixture:
silicates, graphite, PAHs
R~300

Result:
10-20% above continuum

Detecting crystalline silicates in external galaxies

Using diagnostic plots (under development), we can determine the crystalline fraction of silicates for every galaxy for which a spectral information from ~8-70 μm is obtained.
R ~300 is fine, and we can even get results from lower resolutions (Spitzer-IRS SL/LL)

Are amorphous ISM silicates the norm?

What are the properties of galaxies showing crystallinity?

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