Laboratory Silicate Dust: Bridging the Gap between Cosmic Dust Experiments and Observations

Tushar Suhasaria

Max Planck Institute for Astronomy, Heidelberg

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The goal of laboratory studies

Dust evolution and optical properties

- Dust formation
- Dust processing (thermal annealing, UV, ions, X-rays, shocks)
- Determination of optical constants over broad wavelength range

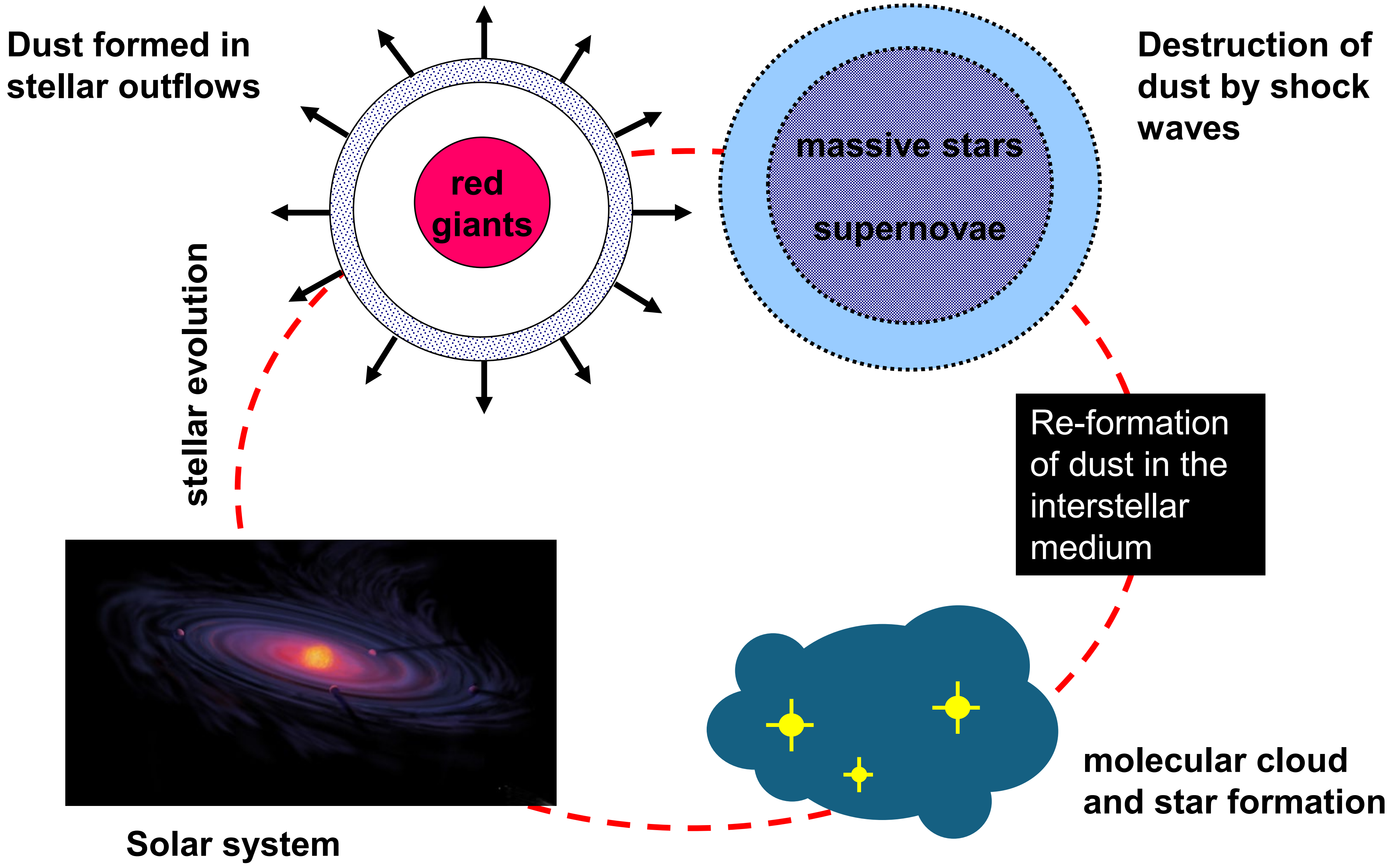
Surface chemistry

- Reactions on the surface of grains and in ices
- Catalytic effect on molecule formation
- Prebiotic chemistry

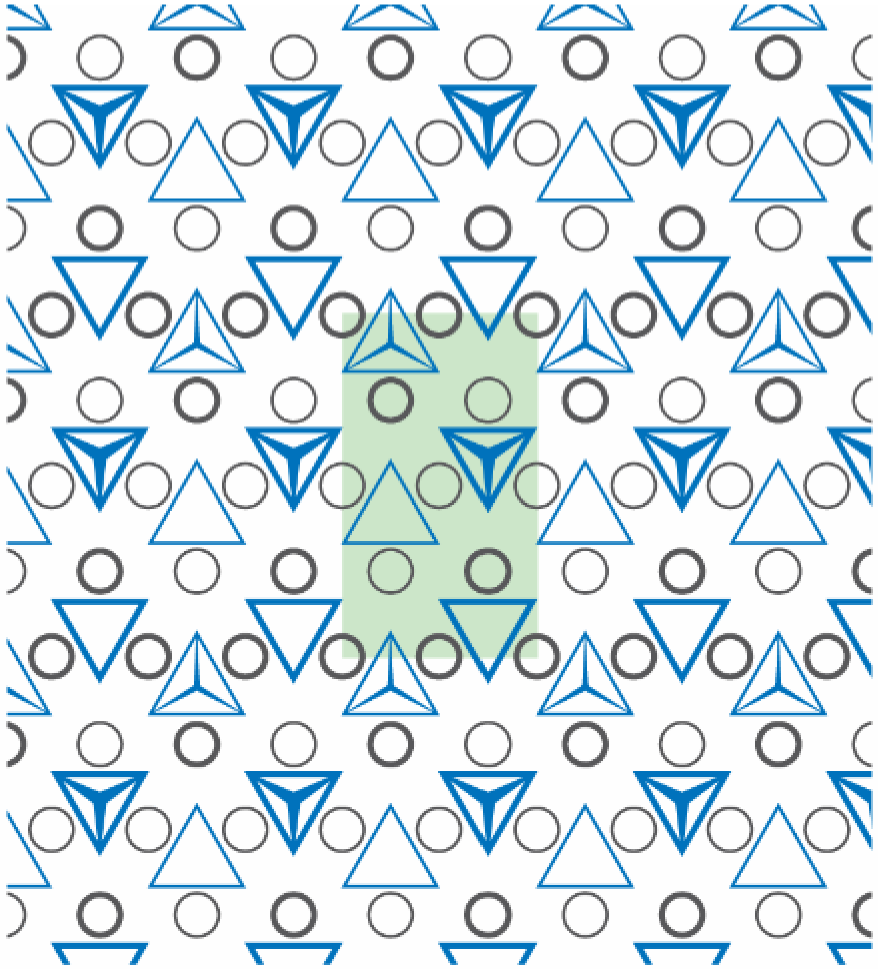
Planet formation

- Growth of grains to pebbles and planetesimals
  (see talk by Juergen Blum on dust aggregation)

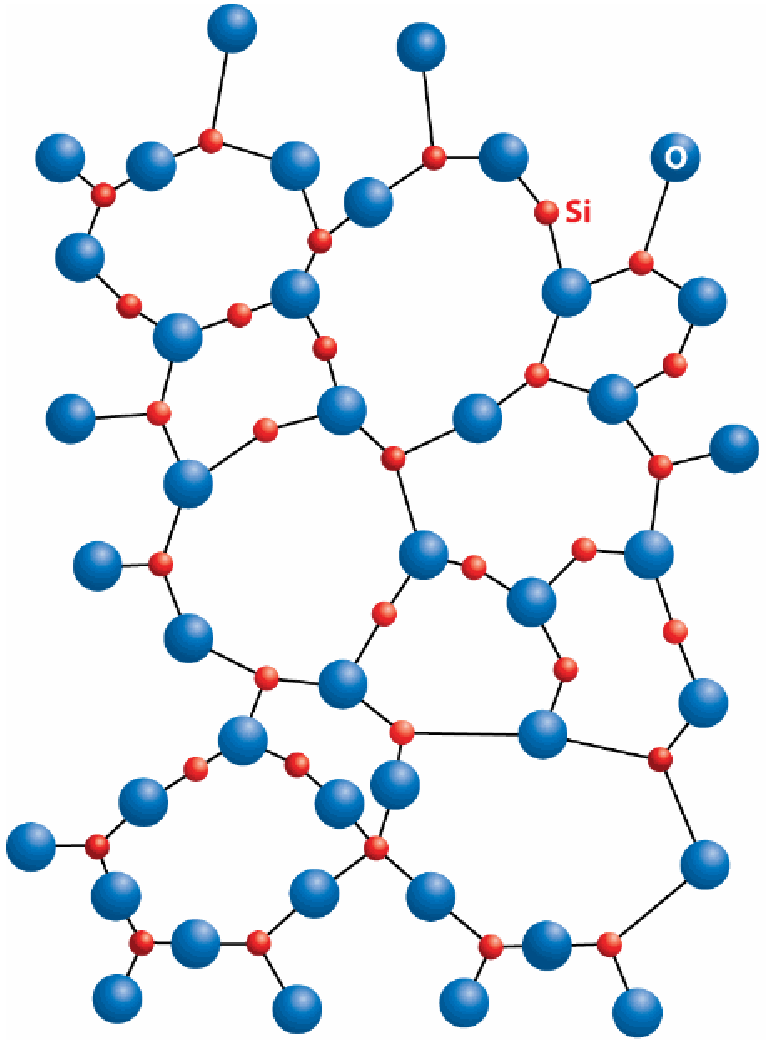
Cosmic dust cycle



Cosmic silicates



Olivines: Mg_2SiO_4-Fe_2SiO_4

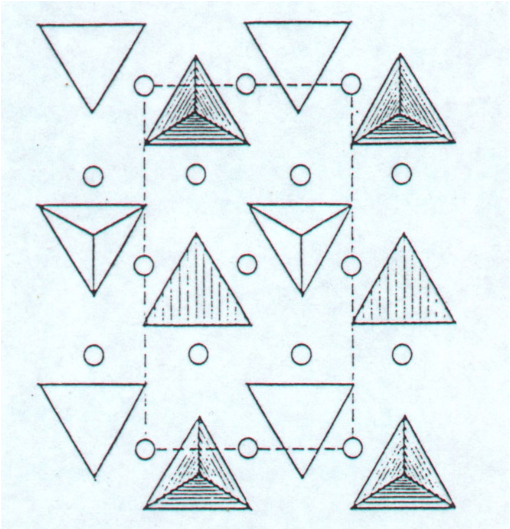


Amorphous SiO_2

Henning 2010, ARAA

Cosmic silicates

Olivines: Mg_2SiO_4-Fe_2SiO_4

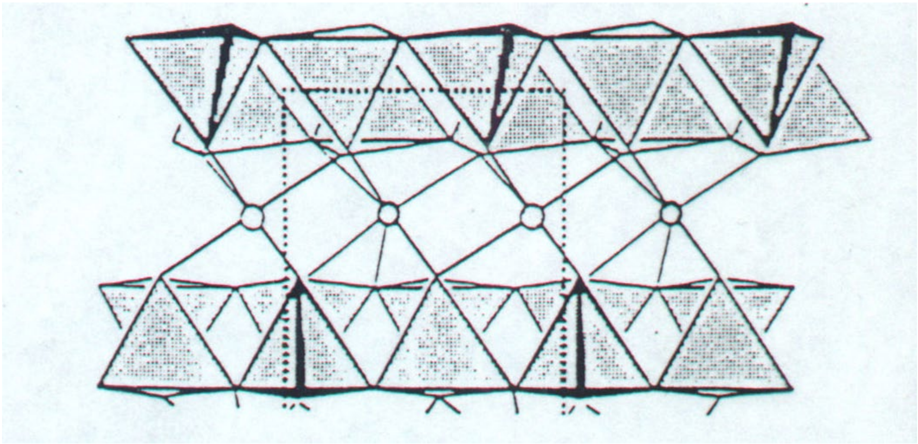


Neso silicates $[SiO_4]^{4-}$

Isolated tetrahedra

Forsterite: Mg_2SiO_4
Fayalite: Fe_2SiO_4

Pyroxenes: $MgSiO_3$-$FeSiO_3$



Ino silicates $[SiO_3]_\infty^{2-}$

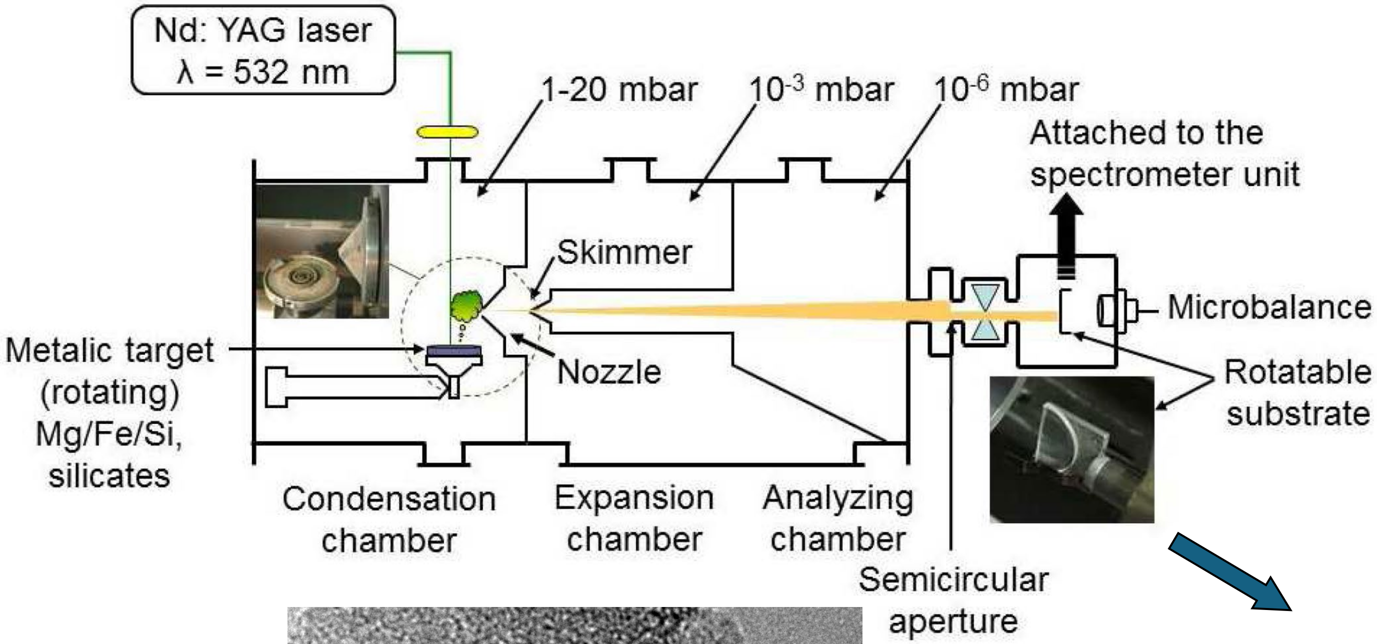
Chains of tetrahedra

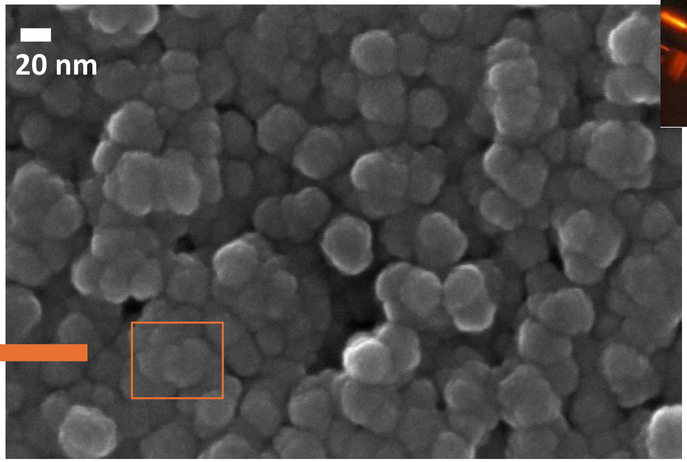
Enstatite: $MgSiO_3$
Ferrosilite: $FeSiO_3$

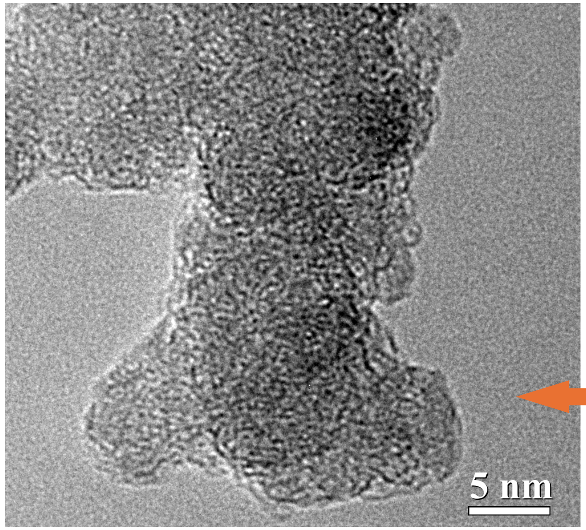
Henning+ 2005, IAUS

Gas-phase condensation studies

Laser ablation technique







Sabri+ 2013, ApJ

Liquid-phase studies

Sol-gel technique

Tetraethoxy
siloxane
+
Magnesium
methylate
in water+alchohol

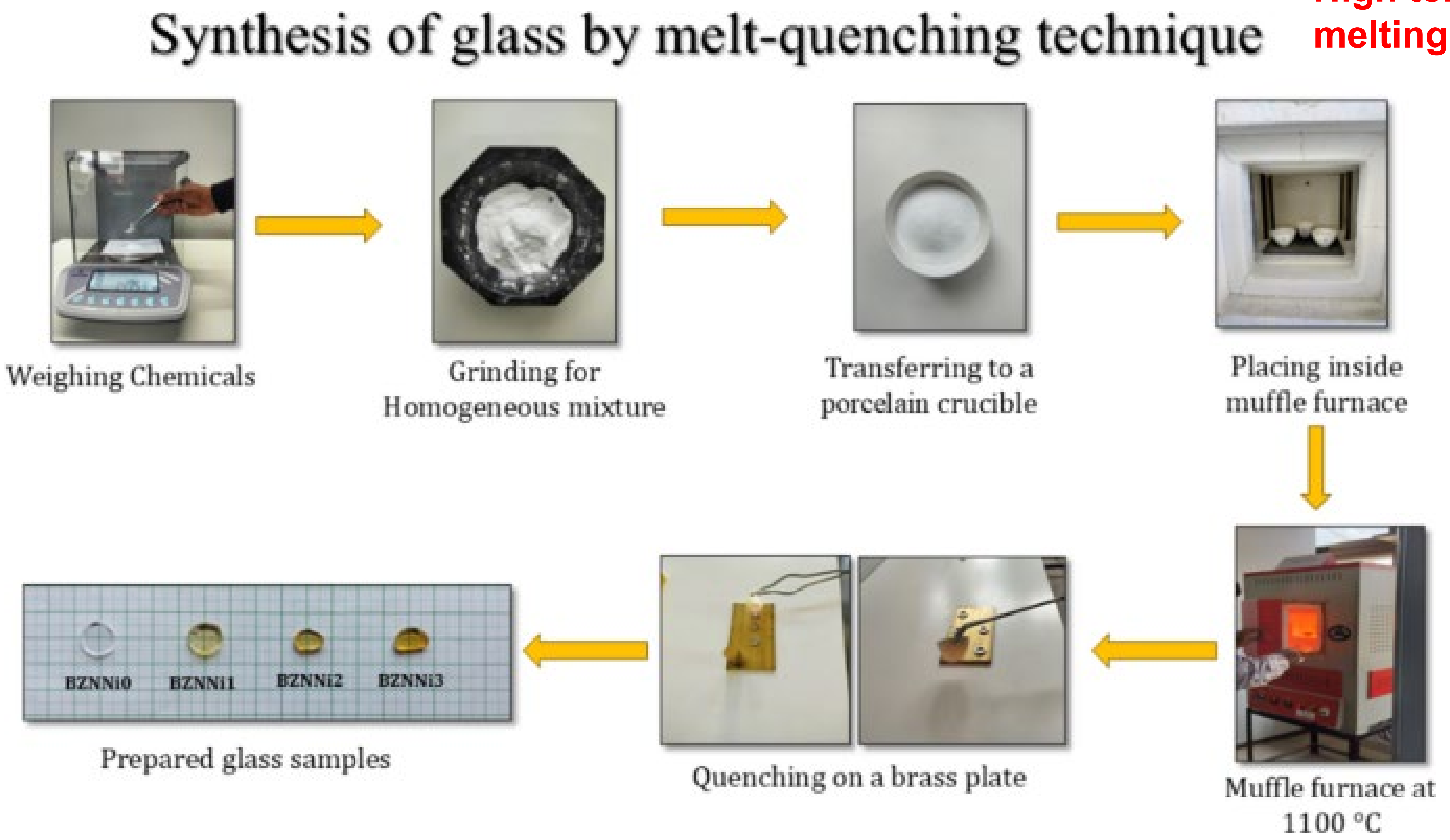
Silicon and
Magnesium
hydroxides

3D- Mg-Si network

Jaeger+2003

Glassy silicates

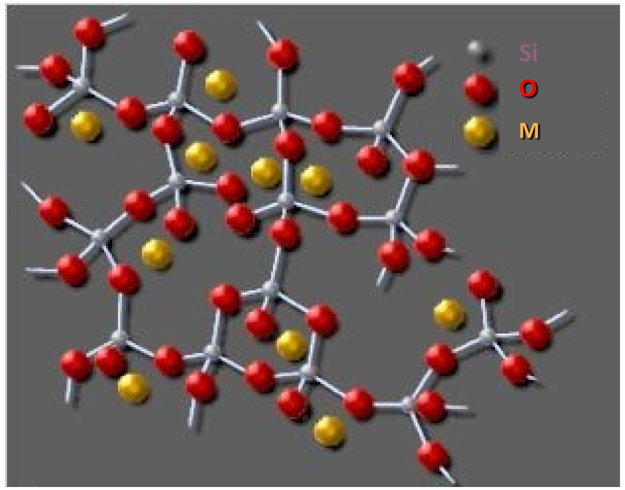
High temperature melting



Devaraja+ 2025, Scientific reports, dorschner+1995

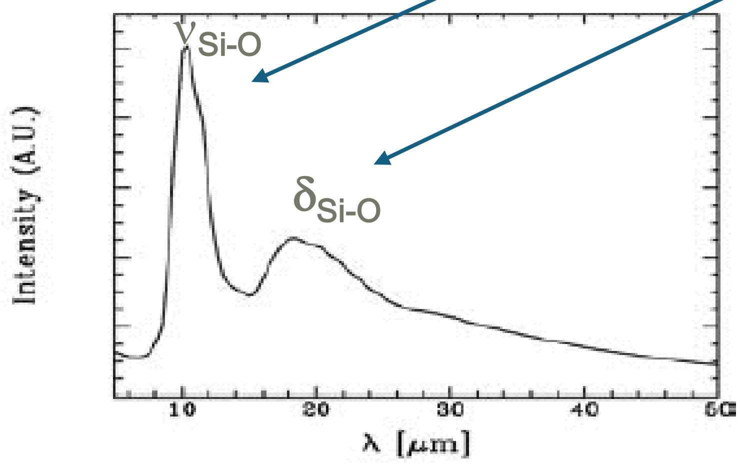
Optical properties: IR

structure



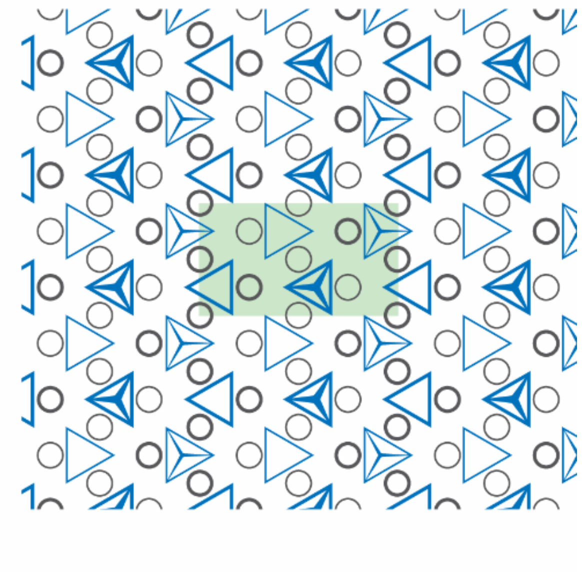
Si-O stretching (~10 μm)

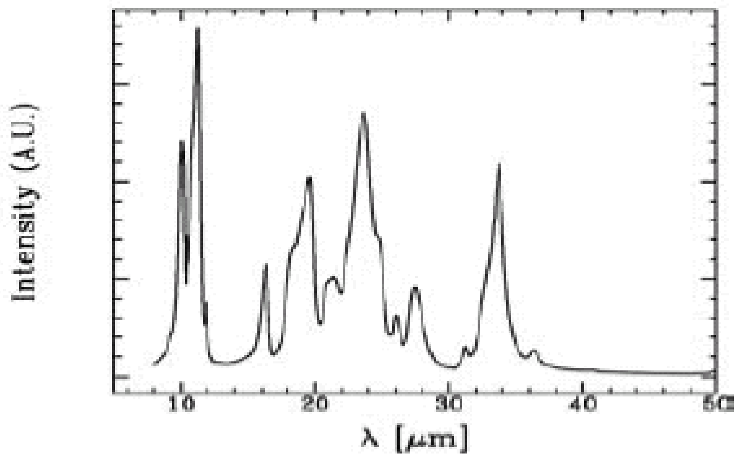
Si-O bending (~18 μm)/Mg-O stretch



amorphous Mg_xSiO_y

Broad features



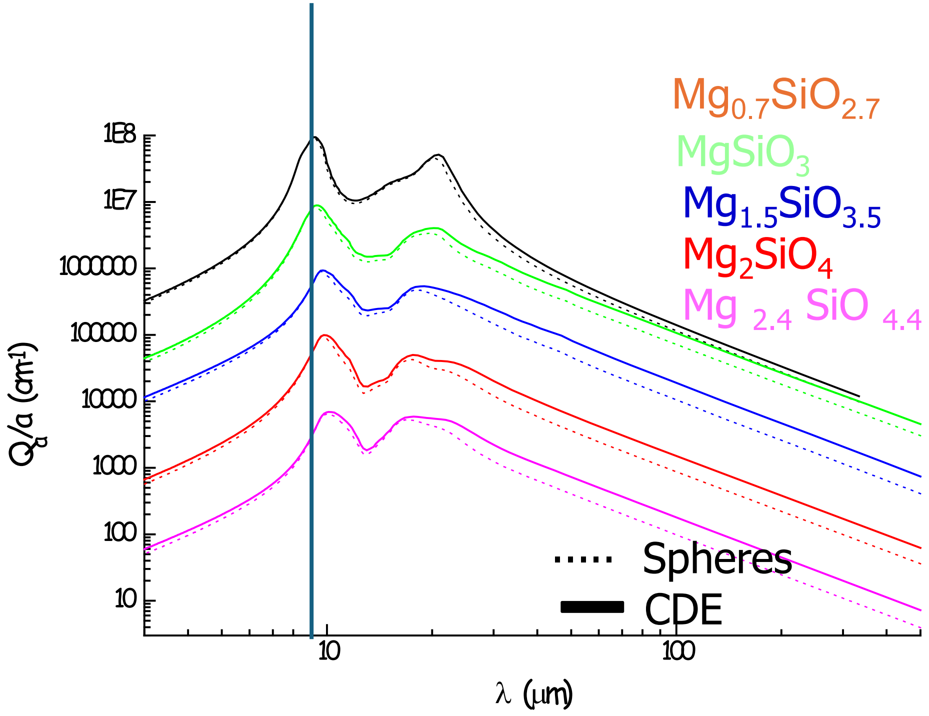


Olivine Mg_2SiO_4

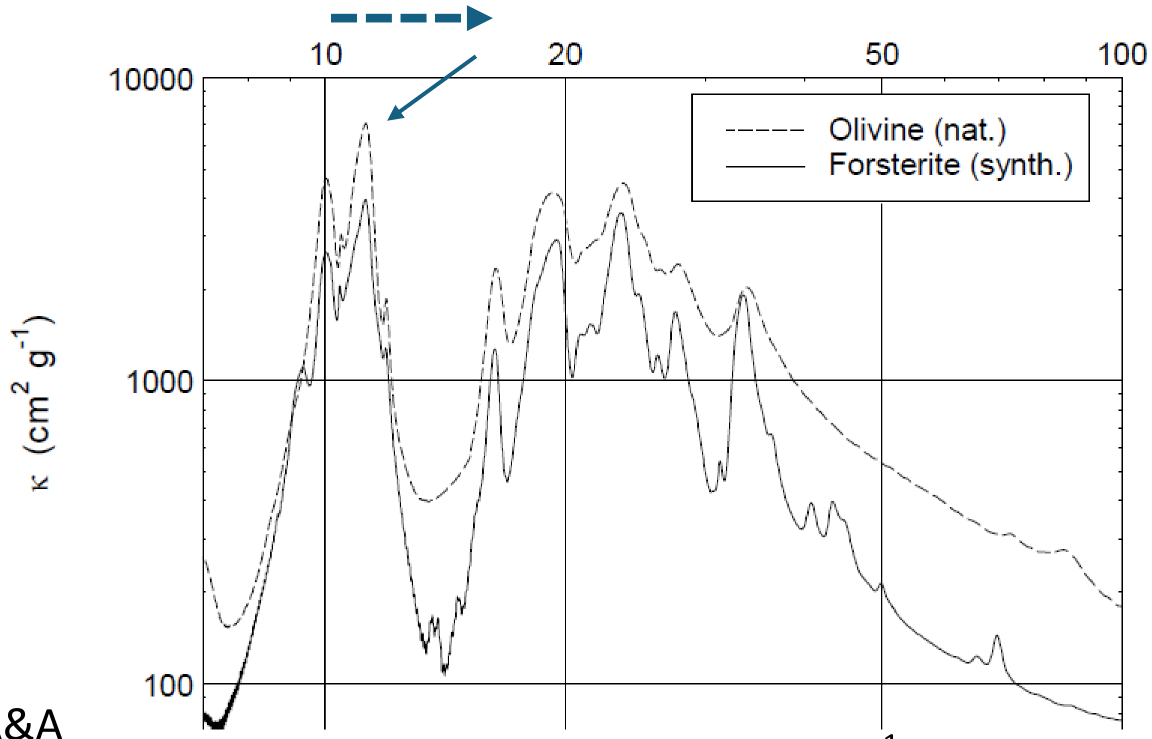
Sharp features

Optical properties: IR

composition



- ✓ relation between the polymerization degree of the SiO_4 units and the 10 and 20 μm band position
- ✓ Fe shifts the bands to longer wavelengths



- ✓ 9 μm – SiO_2
- ✓ 9.7 μm – $MgSiO_3$
- ✓ 10.25 μm – $Mg_{2.4}SiO_{4.4}$

https://www2.mpia-hd.mpg.de/HJPDOC/

Jäger+1998, 2003 A&A

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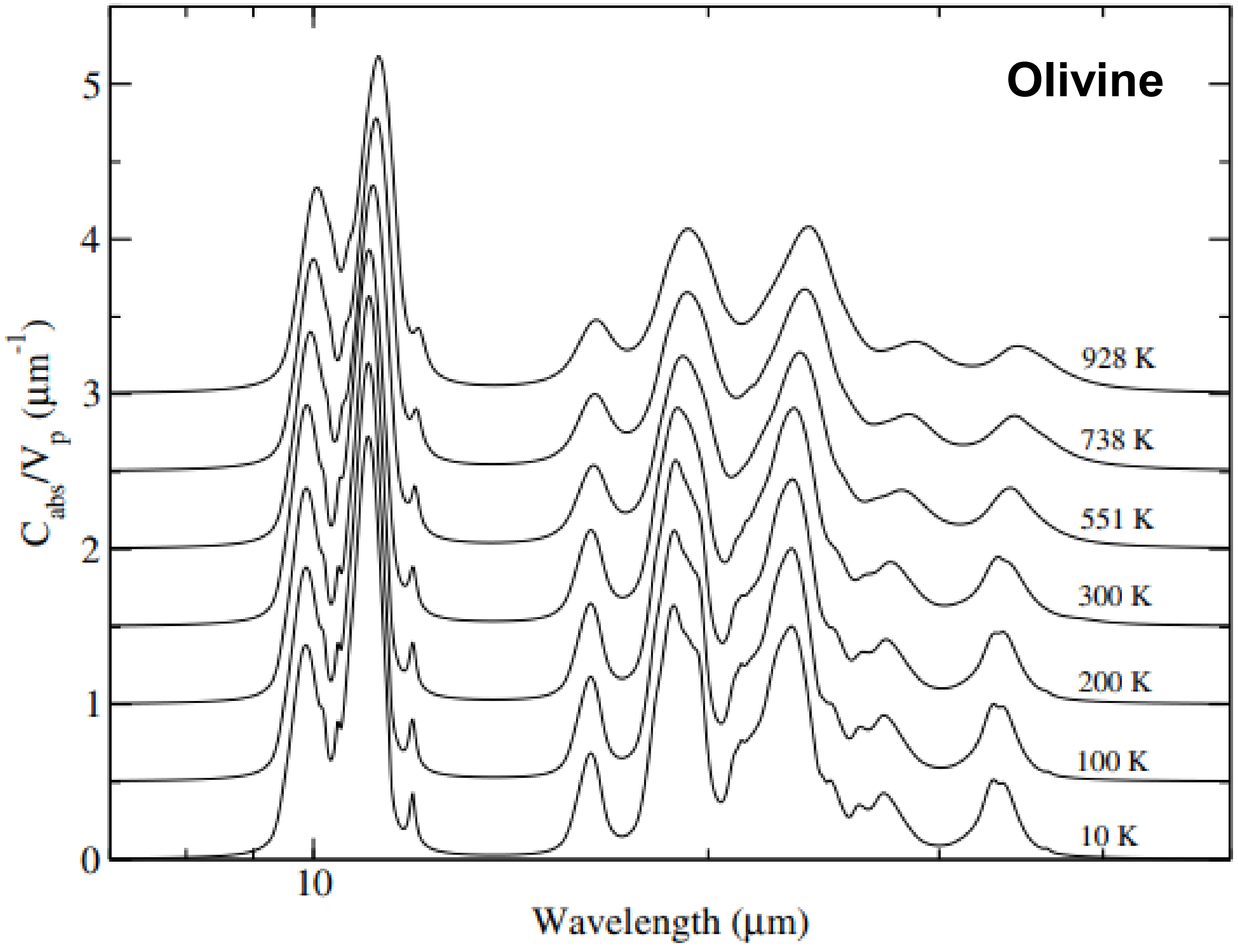
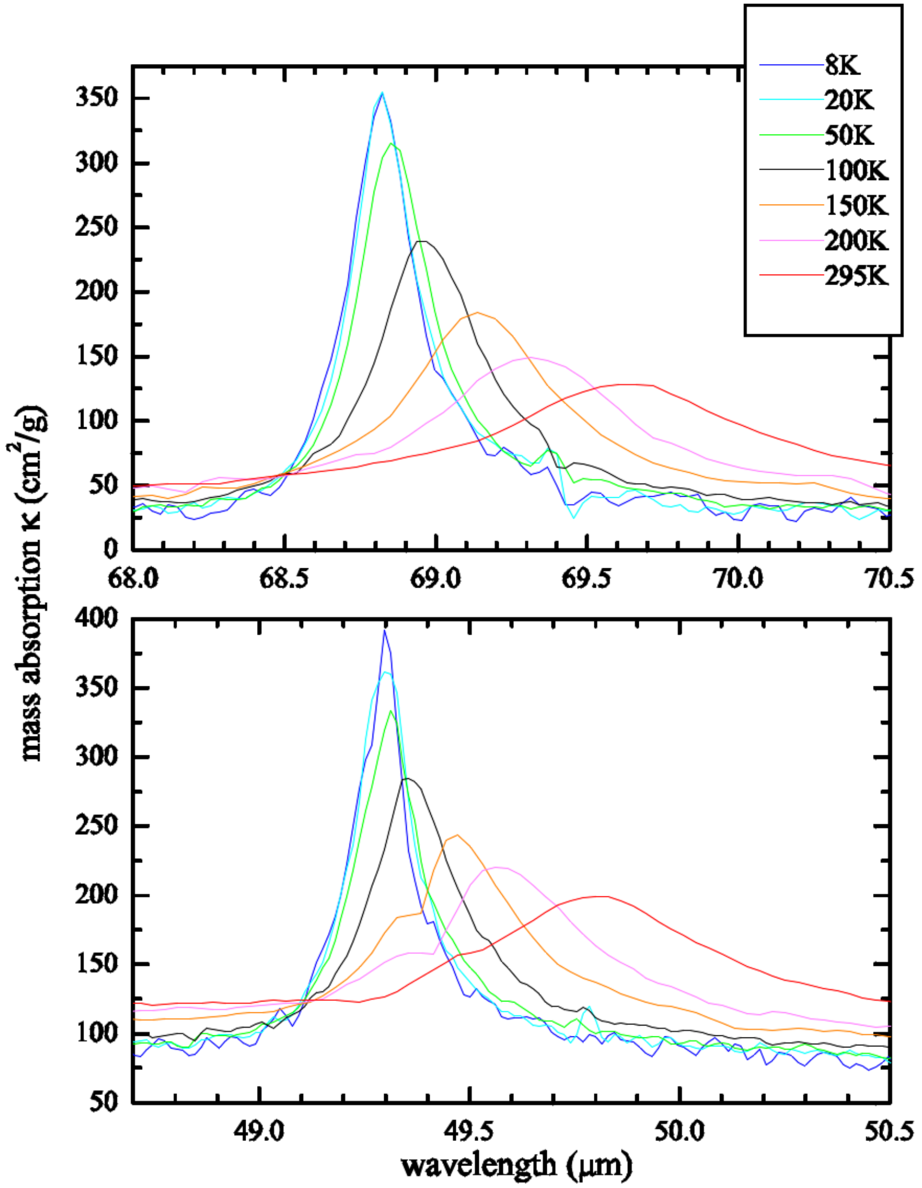
Optical properties: IR

Temperature



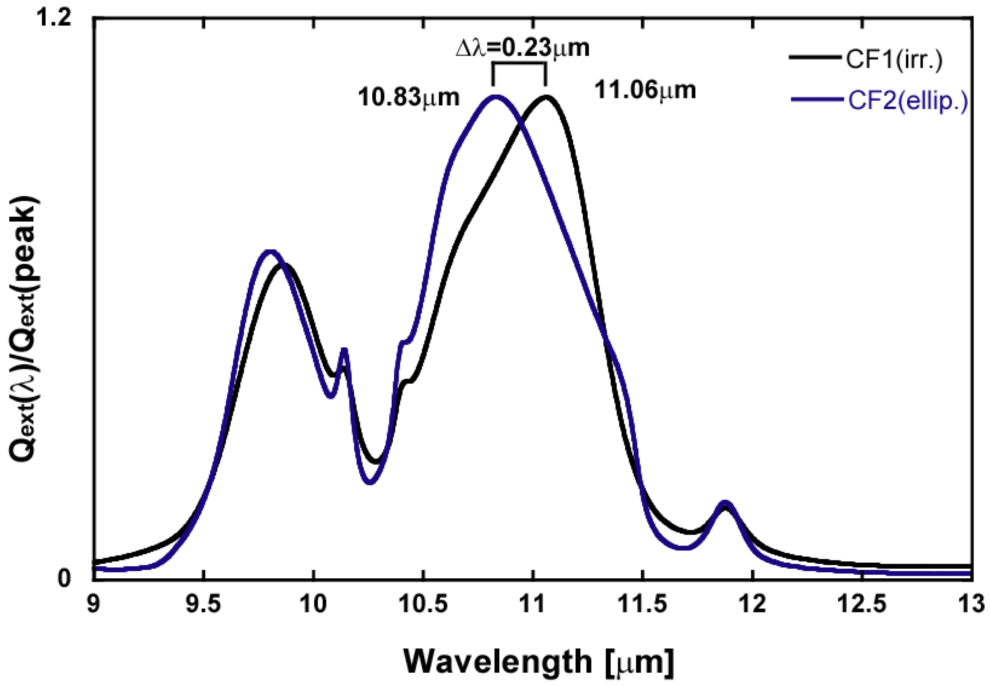
Absorption coefficient spectra

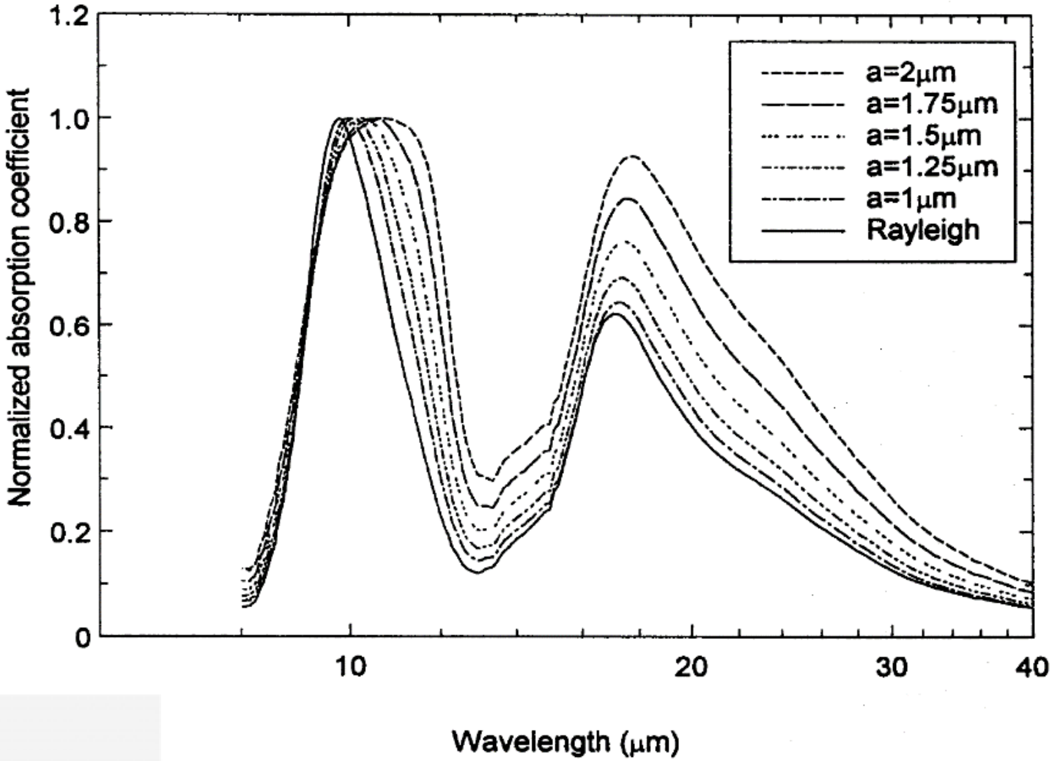


Zeidler+2015 ApJ, Koike+2006 A&A

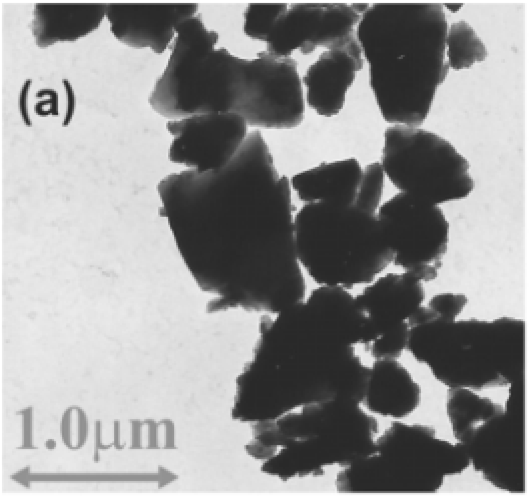
Optical properties: IR

Shape & Size

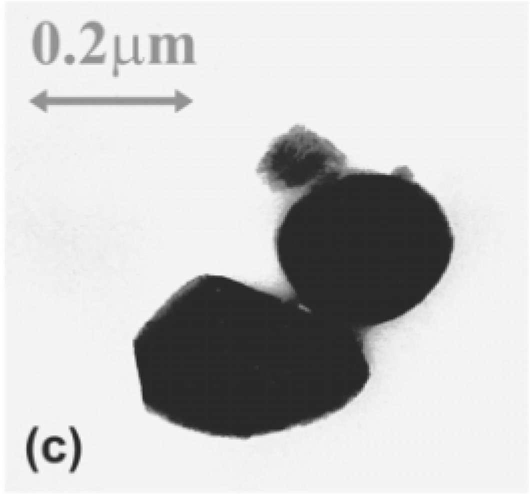




Irregular Shapes



Ellipsoidal Shape



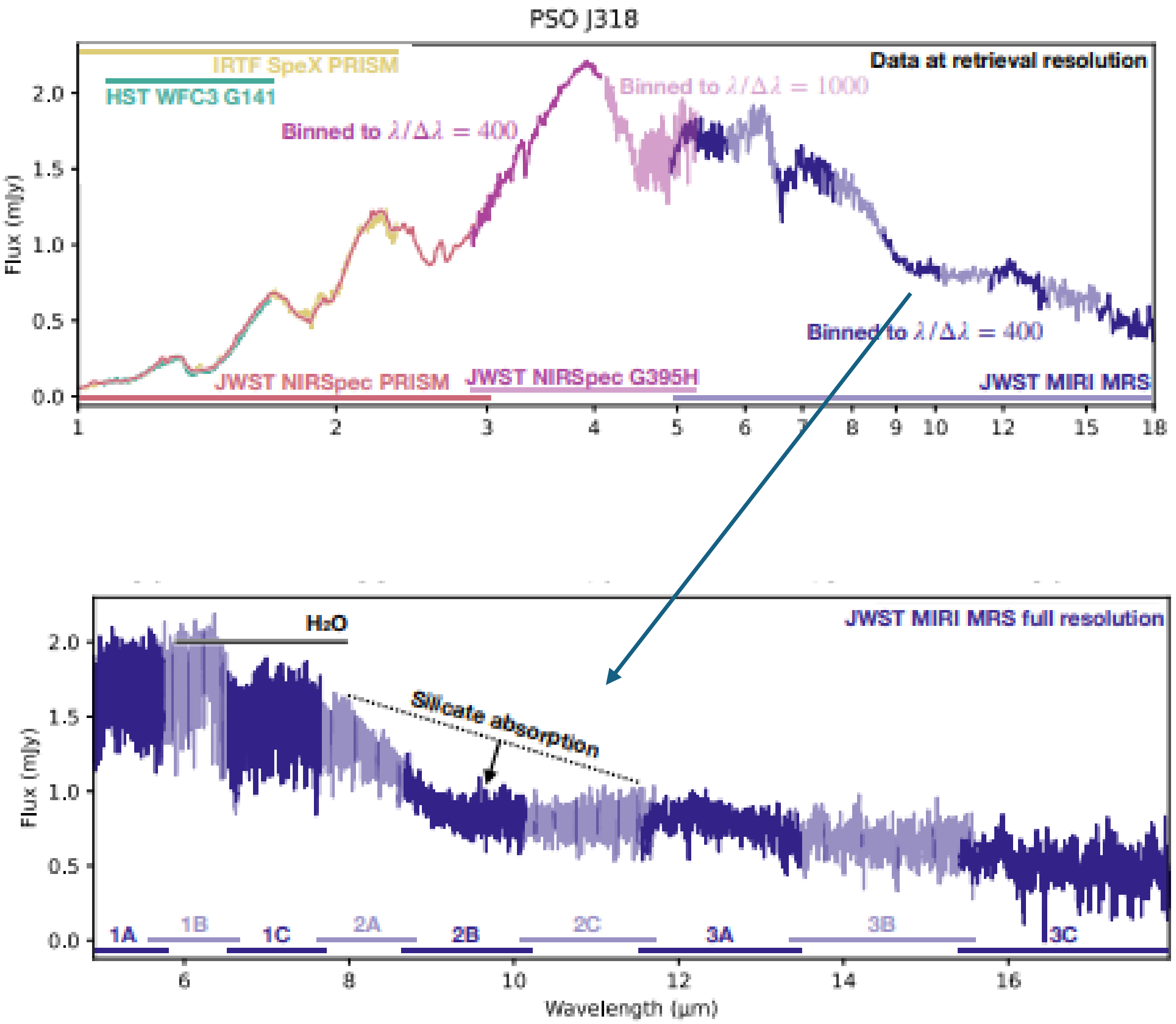
Dorschner+1995

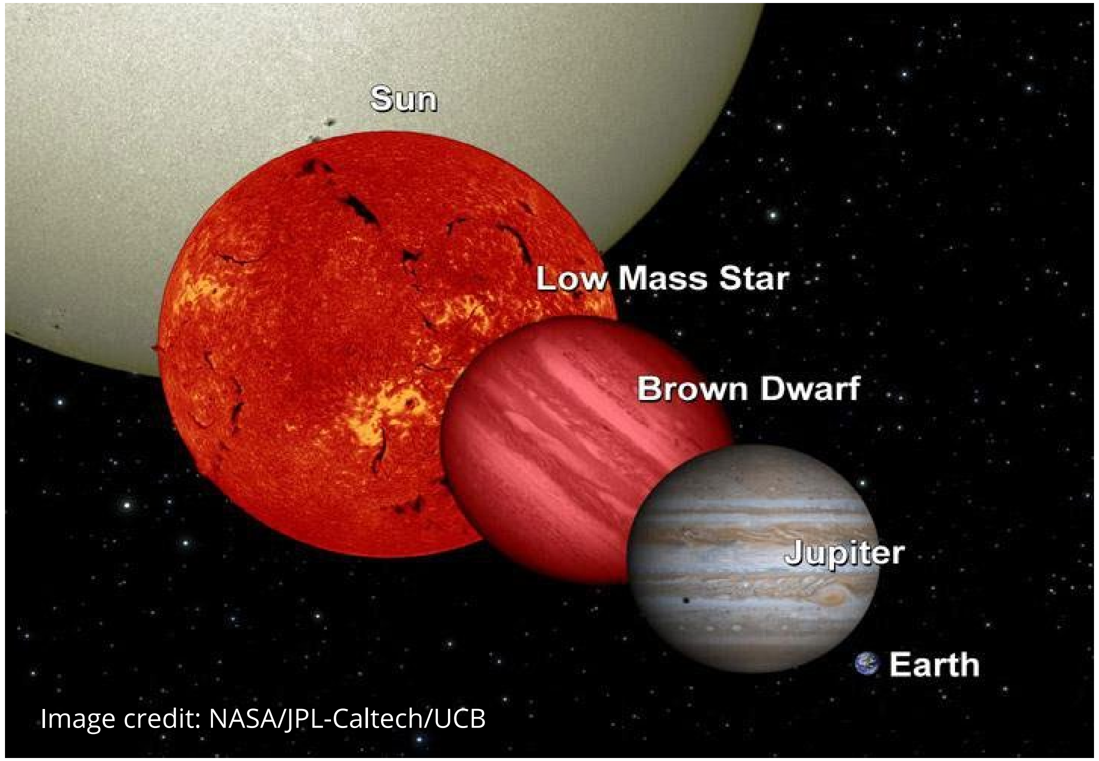
Tamanai+2006

Summary and take-home messages

- Careful about silicate nomenclature
- Different ways of preparing silicate dusts
- Structure of amorphous silicates not well defined
- Optical properties depends on the **composition, structure, temperature, size, and shape** of grains
- **https://www2.mpia-hd.mpg.de/HJPDOC/**
- (see poster by Hanako Enomoto on optical constants for amorphous silicates)

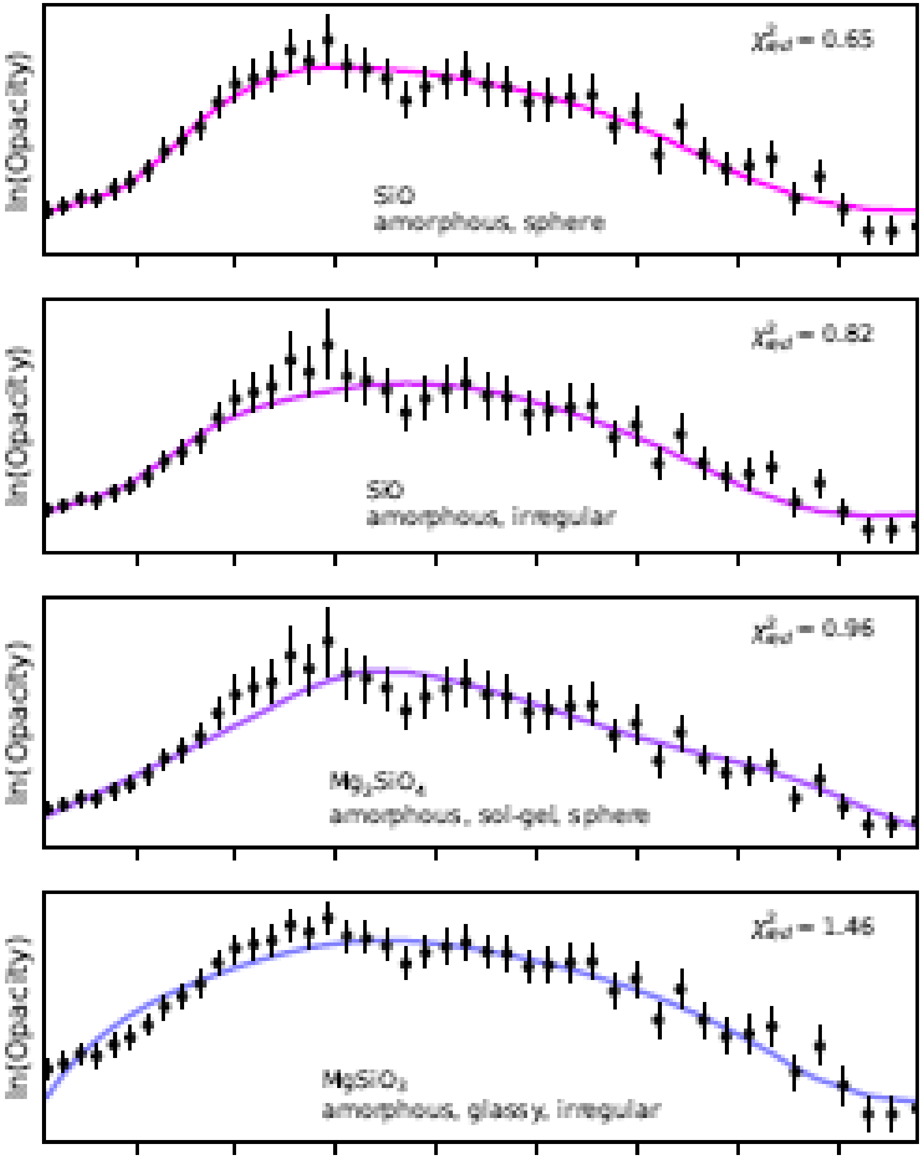
Silicate clouds in Brown dwarfs/Rogue planets





Mollière+ 2025, A&A

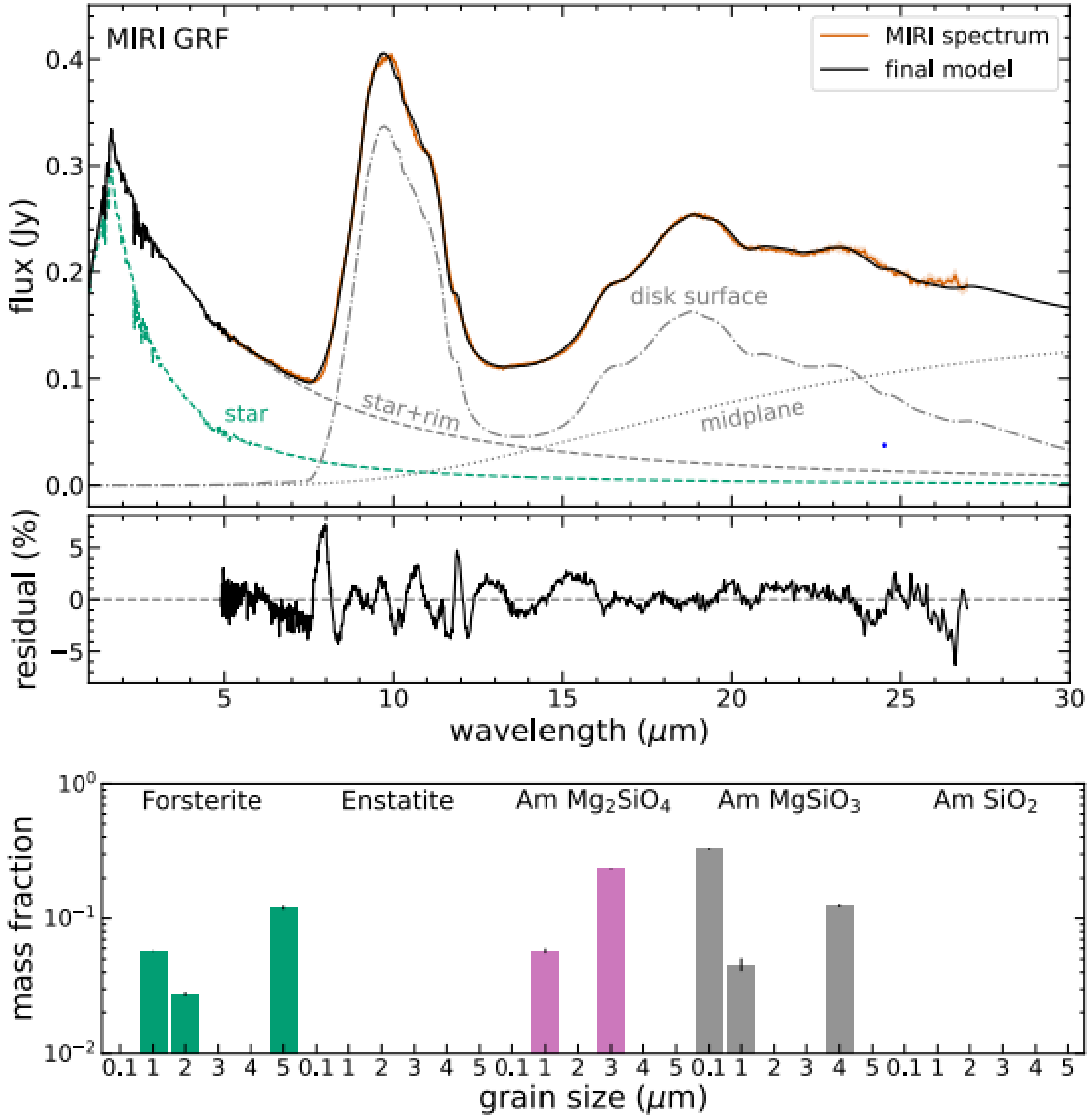
Silicate clouds in Brown dwarfs/Rogue planets



$$\ln[\kappa(\nu)] \approx -\frac{\ln[T_{\mathrm{bright}}(\nu)]}{\nabla} + \mathrm{cst}$$

Opacities **brightness temp**

Dust mineralogy and processing in PDS 70 disk



Amorphous silicates are dominant dust species in the environment and is Mg-rich

observations over a period of 2 epochs to see the processing by following dust size and crystallinity

Yao+ 2025, SCPMA, Jang+2024, A&A

Processing of silicate dust

ions

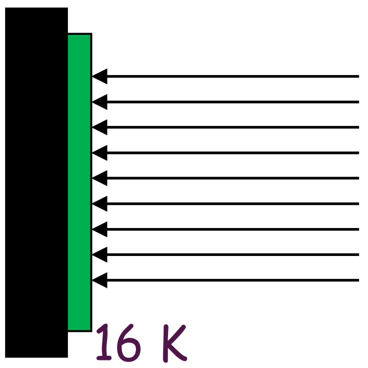
- the silicate matrix shows a depletion of Fe and Mg relative to Si

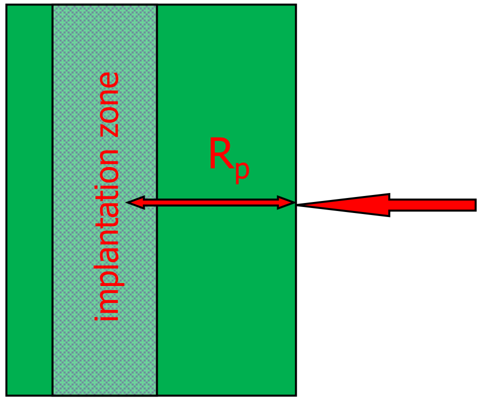
Fe/Si =0.6; Mg/Si =0.96

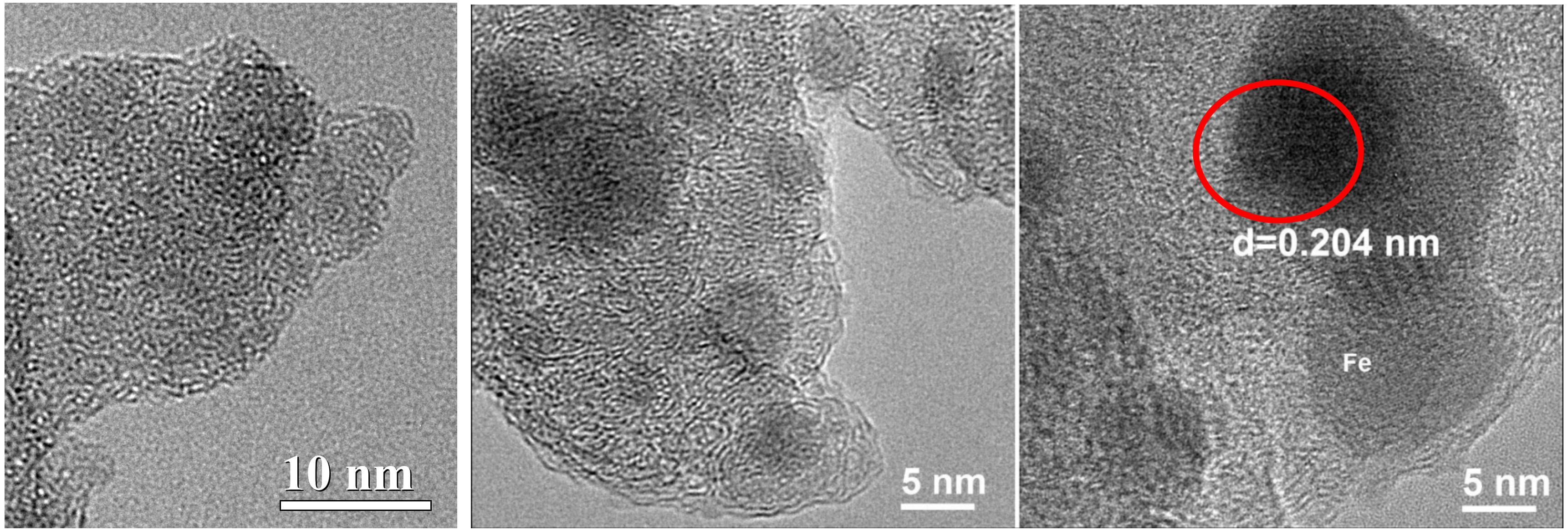
$4H^+ + 2O^{2-} \rightarrow 2H_2^0 + O_2$
$2Fe^{2+} + 2O^{2-} \rightarrow 2Fe^0 + O_2$

O_2 is sputtered and Fe is reduced

10 keV H^+ (1×10^{17} ions cm^{-2})







Jäger+2016

Processing of silicate dust

temperature

- By thermal annealing, amorphous silicates converted to crystalline at relatively high temperature

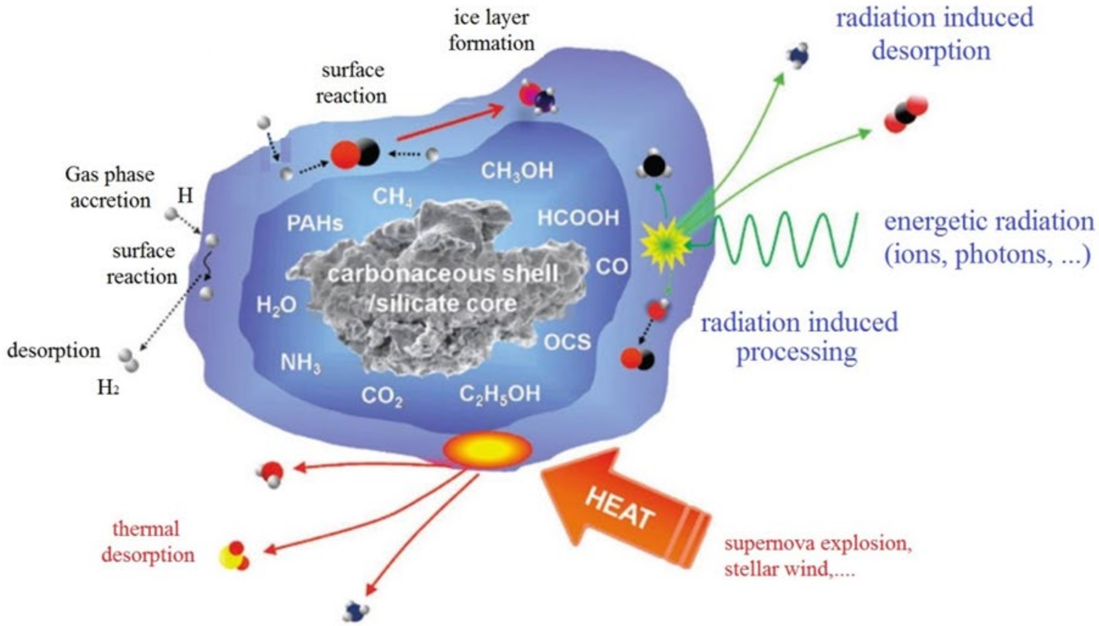
- Annealing temperature can change due to composition of silicates

e.g. faster in presence of OH^- and Fe^{2+}

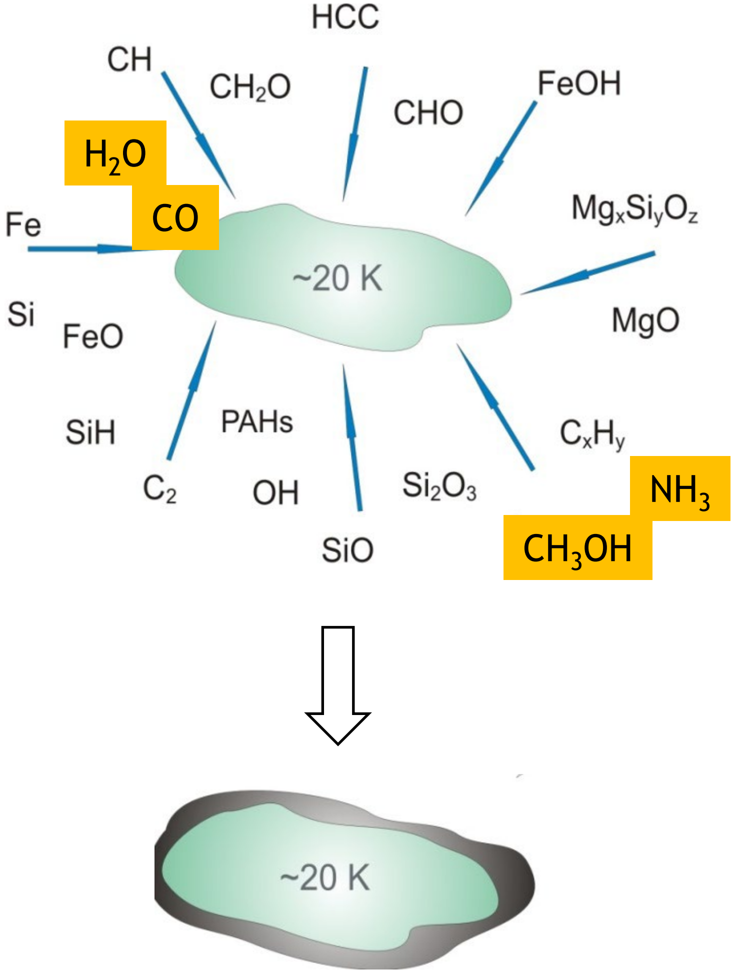
(see poster by Kate Su on highly processed silicate dust)

Jäger+2003, Brucato+1999, Fabian+2000

Interstellar Dust Condensation

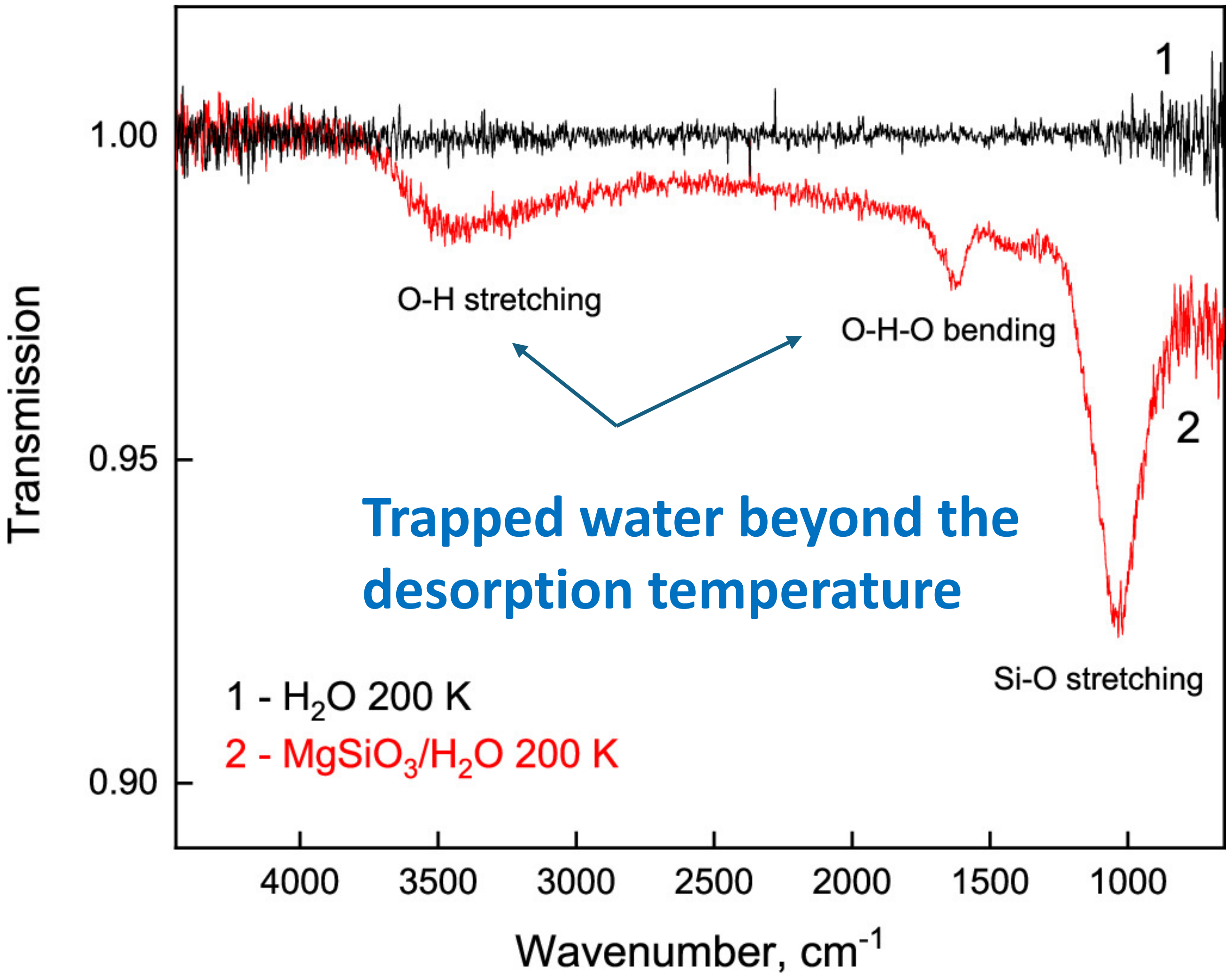


Adapted from Burke and Brown 2010

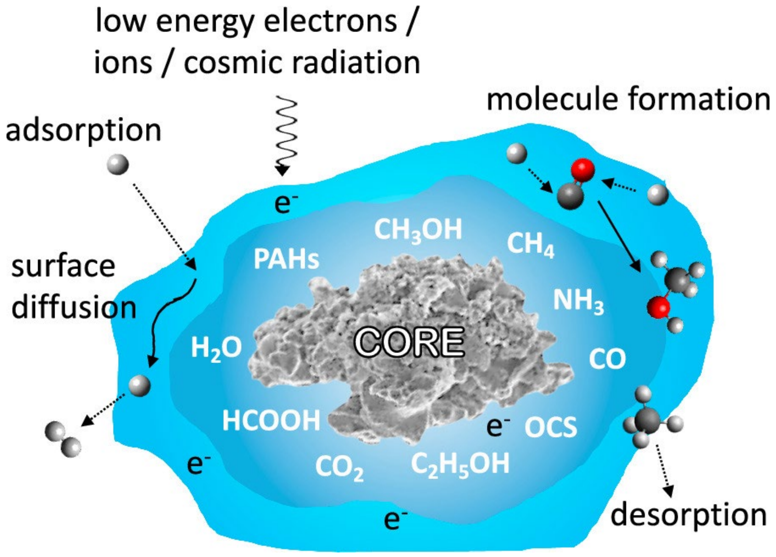


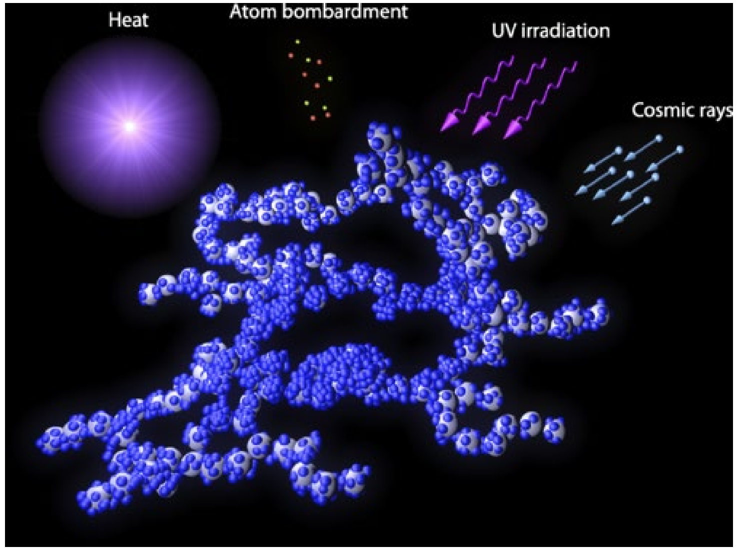
Re-formation of dust in the ISM and in disks at low temperature and densities?

Trapping by silicates



Trapped water beyond the desorption temperature

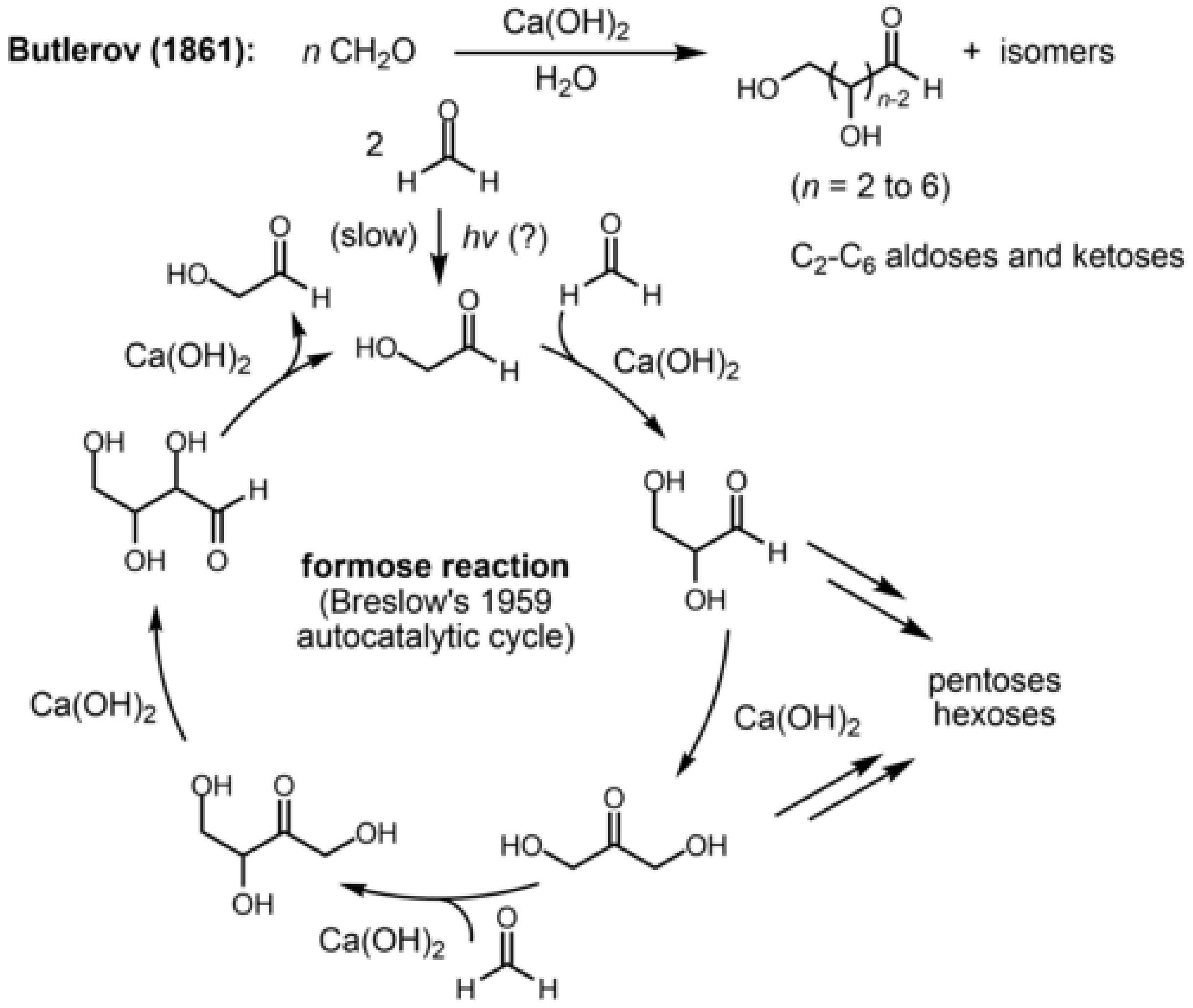




(see poster by Aki Takigawa water ice meets silicate dust)

Potapov+ 2024, ApJ

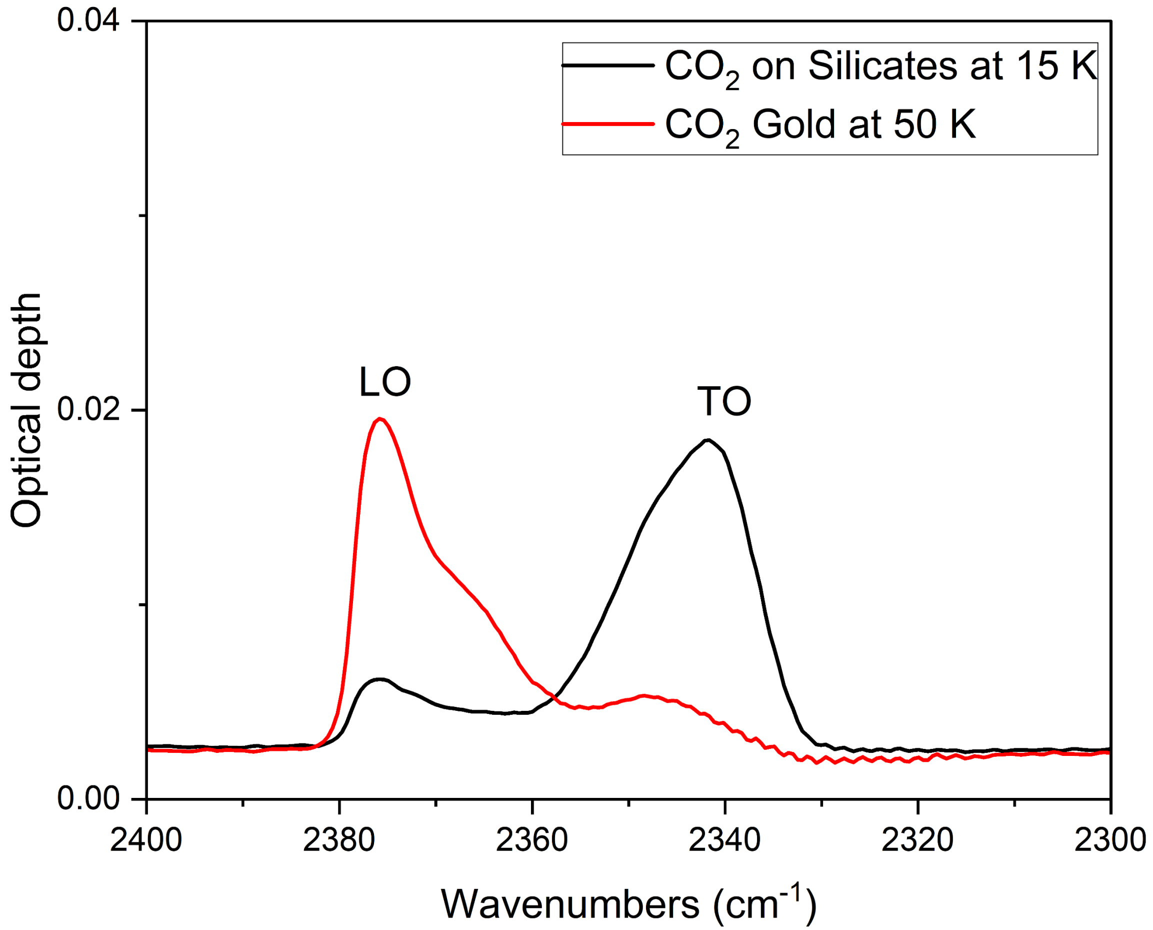
Catalytic effect by silicates

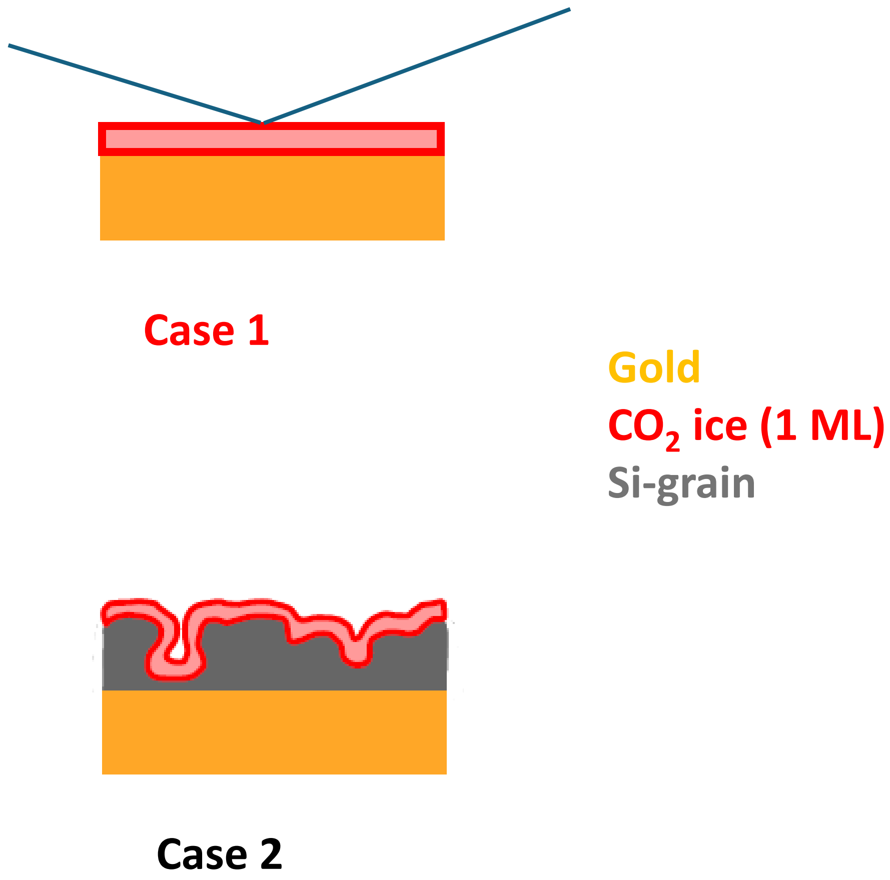


- ➢ Ability to stabilize enediol by Mg^{2+} of olivine stochiometry silicates in aqueous environment

Vinogradoff+ 2024, Earth Planet Science Letters

Effect of underlying grains on IR profile

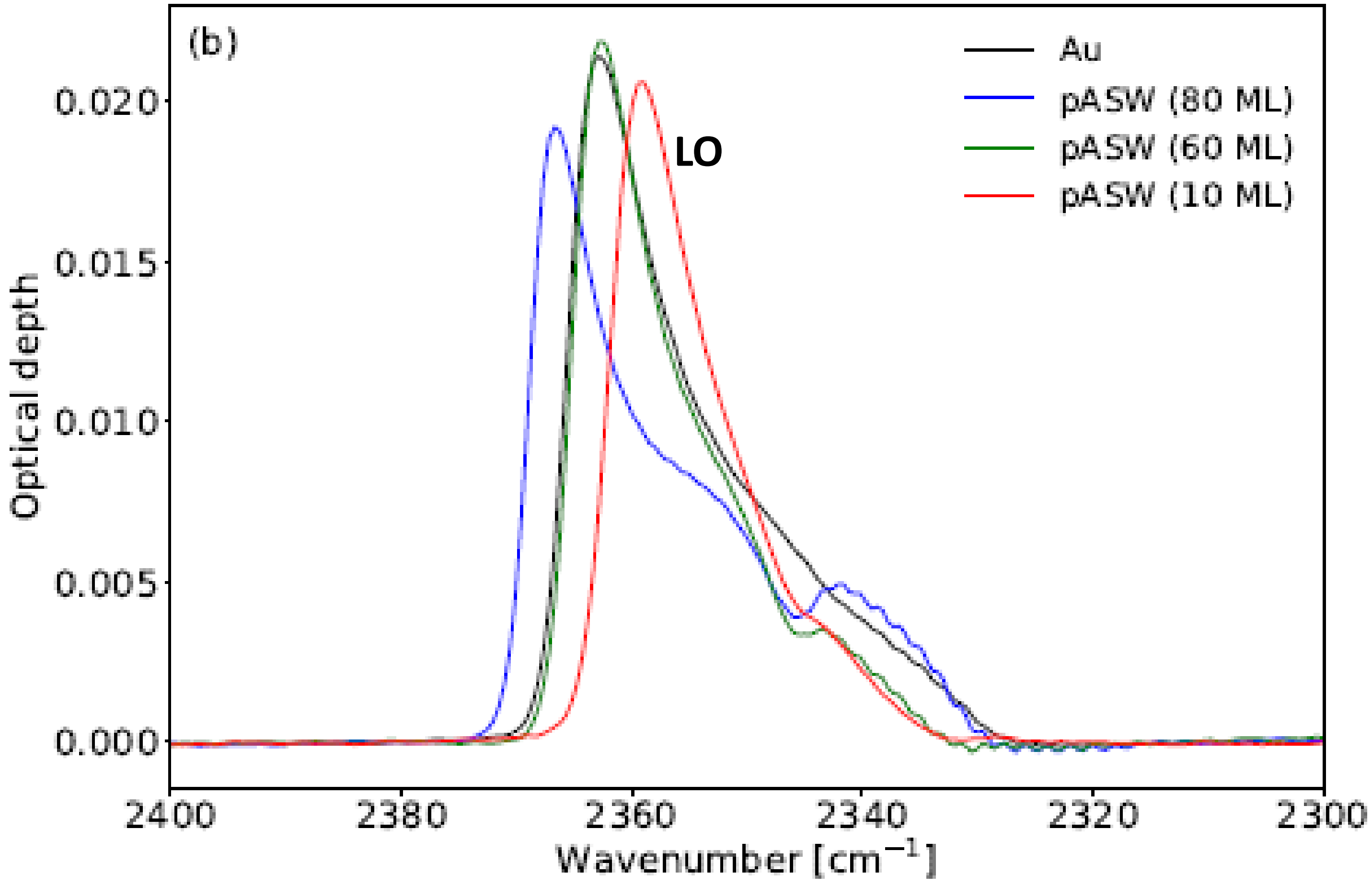


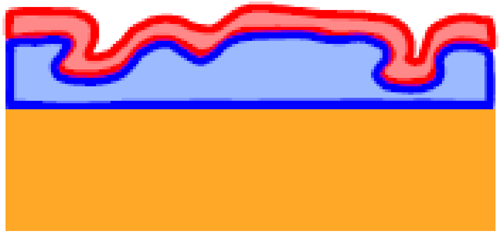


Suhasaria et al. 2025, ApJL
Berreman 1963, Phys. Rev.

Does the grain composition/thickness influences the spectral behaviour?

Effect of water ice





Gold
CO_2 ice
Amorphous water

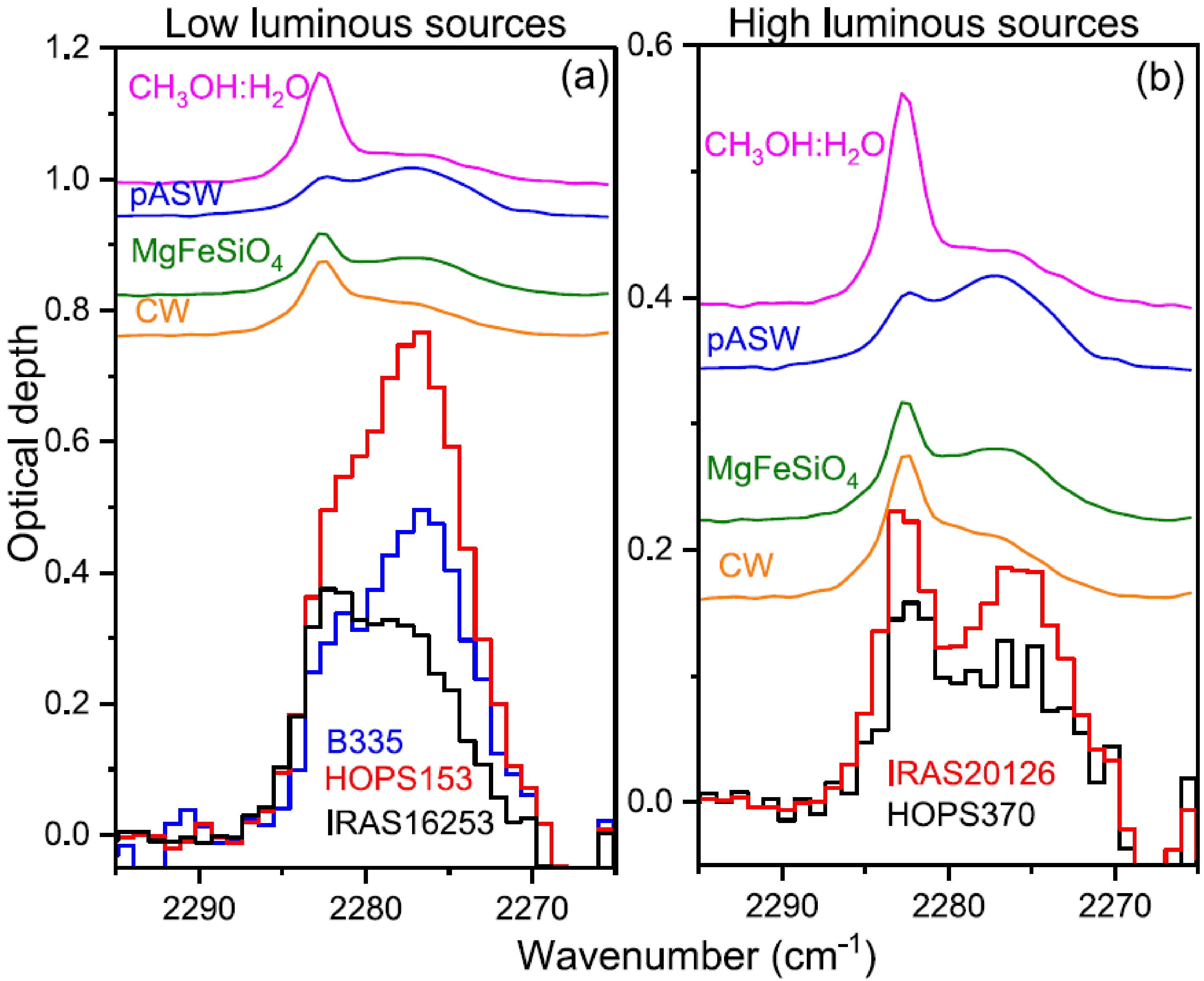
Suhasaria et al. 2025, ApJL

No relaxation of metal surface selection rule!

See my poster

Comparison with JWST observations

$^{13}CO_2$ stretch



Suhasaria et al. 2025, ApJL

Conclusions

- processing leads to the reduction of Fe in silicates and increase in absorptivity in NIR
- play a role in surface chemistry as it can trap water
- can influence the IR spectra of CO_2
- silicates mineral can act as catalyst for prebiotic chemistry but the effect is poorly understood
- we need to look at the impact of different grains on molecule spectroscopy using JWST

Acknowledgement

erc Advanced Grant

NanoSpace

Thank you for your attention!