A STUDY OF DUST GRAIN FORMATION

A ROLE OF MINOR ELEMENTS

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Grain Formation Workshop

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Outline

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  - Spectra by meteorite
  - Questions
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- Objective
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Dust Grain

Dust grains play important role in many astronomical environments

Molecular clouds → maintain thermal balance

Planet formation → the building blocks of planetesimals

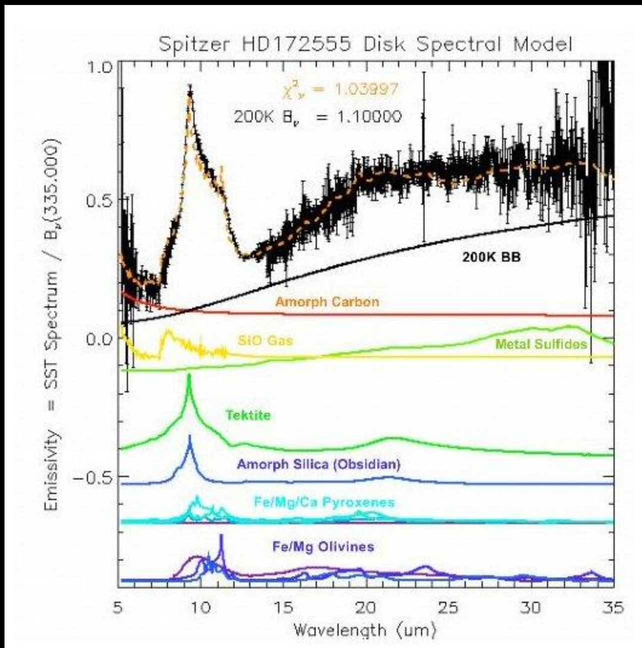
The study of interplanetary dust particles (IDPs) and meteorites reveals a large variety of dust grains

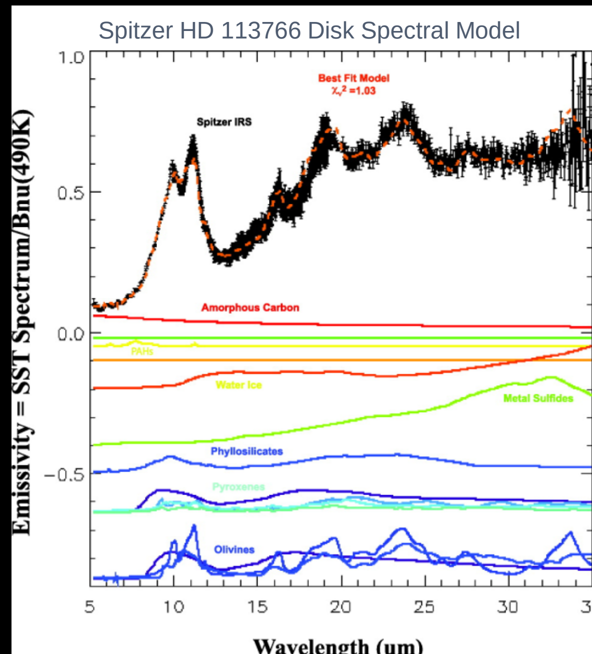
(e.g.) Carbonaceous Chondrite Allende (CV3)

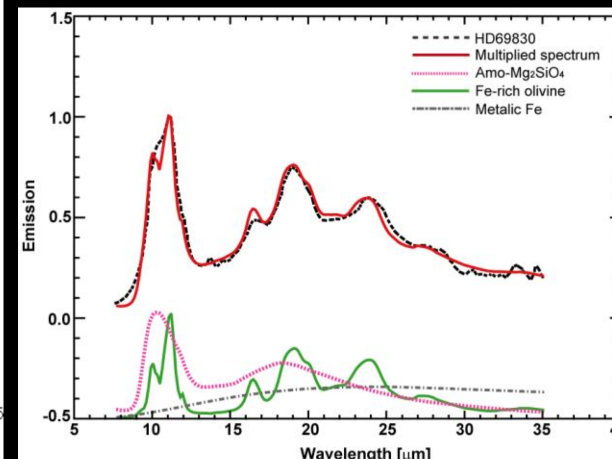
- Fe-rich olivine ($(Mg_{0.55}Fe_{0.45})_2SiO_4$)
- Hypersthene ($MgFeSiO_3$)
- Diopside ($MgCaSiO_3$)
- Pervoskite ($CaTiO_3$)
- Anorthite ($CaAl_2Si_2O_8$)
- Chromite ($FeCr_2O_4$)
- Melilite ($Ca_2Al_2SiO_7$)
- Ilmenite ($FeTiO_3$)
- Wollastonite ($CaSiO_3$)
- Corundum (Al_2O_3)
- Rutile (TiO_2)
- Tistarite (Ti_2O_3)
- Spinel ($MgAl_2O_4$)
- Phyllosilicates (talc, anthophyllite, …)
- Fullerene-like carbon …. more

(Jarosewich et al. 1987; Nagahara et al. 1987; Brearley 1996; Rubin 1997; Harris et al. 2000; Nozawa et al. 2009; Ma et al. 2010)

Observation







HD 172555 (A5 star)

- 40 % silica and tektite
- 35% olivines and pyroxenes

Lisse et al. 2009
Lisse et al. 2008

HD 113766 (F3/5 binary)

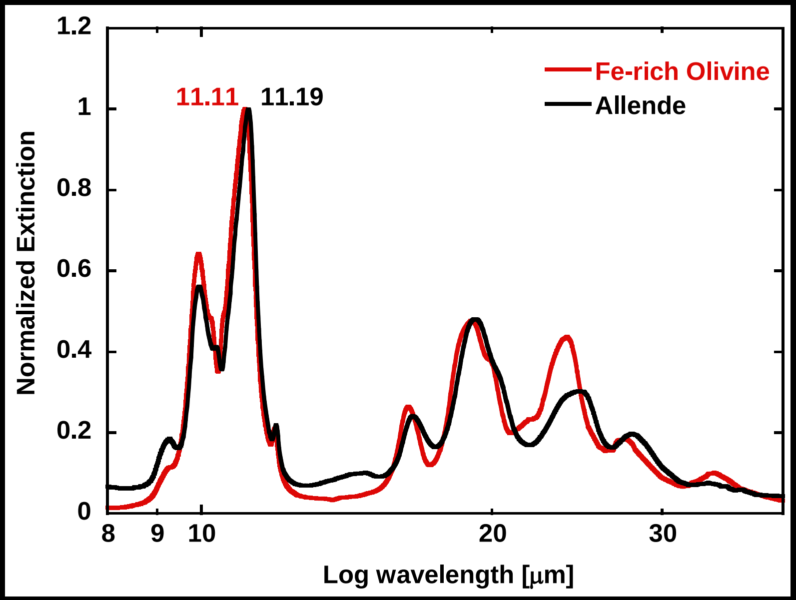
- 29 % olivines, 14 % pyroxenes, 12 % amorphous silicate
- 21 % FeS, 12 % ice
- Warm asteroidal dust (T=450K) at 1.8 AU
- Icy dust at 4-9 and 30-80 AU

HD69830 (K0V)

- Beichman et al. (2005): Spitzer IRS
- T(dust) ~ 400K
- M(dust) ~ 1000 zodi

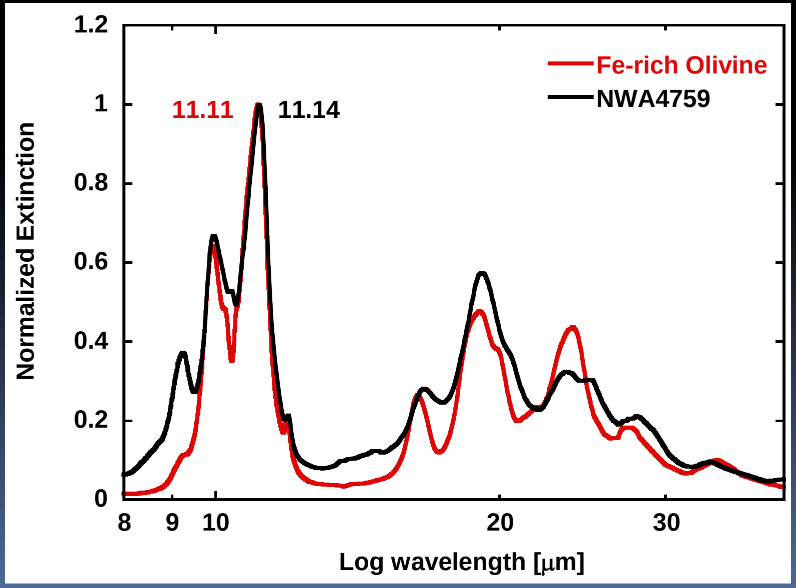
Tamanai & Mutschke 2010

Spectra obtained by meteorites



Carbonaceous Chondrite
Allende
CV3

- Fe-rich olivine from Sri Lanka (Fo_{80})
- Ferrous olivine in Allende is Fo_{56-65} (Johnson et al. 1990)



Carbonaceous Chondrite
NWA 4759
CV3

Tamanai et al. in prep.

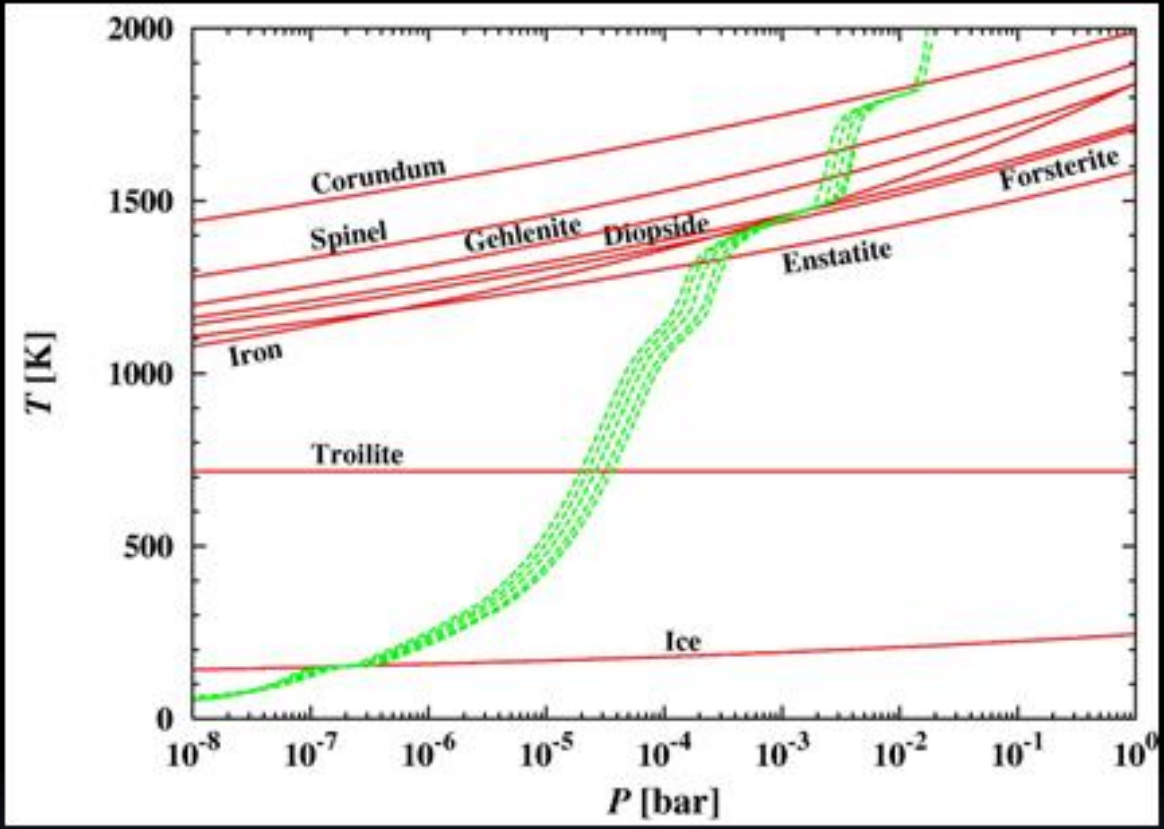
Questions

Questions with respect to dust formation and evolution processes

How dust grains have undergone chemical and physical metamorphosis and evolved during the chemical transformation in different environments???

Q1 What is the highest temperature condensation material?
Q2 How does silicate dust formation take place?
Q3 How much silicates are formed?
Q4 Does silicate formation start by surface growth on the high temperature condensates such as spinel and corundum or directly from a gas phase?

Cont. Model Calculation



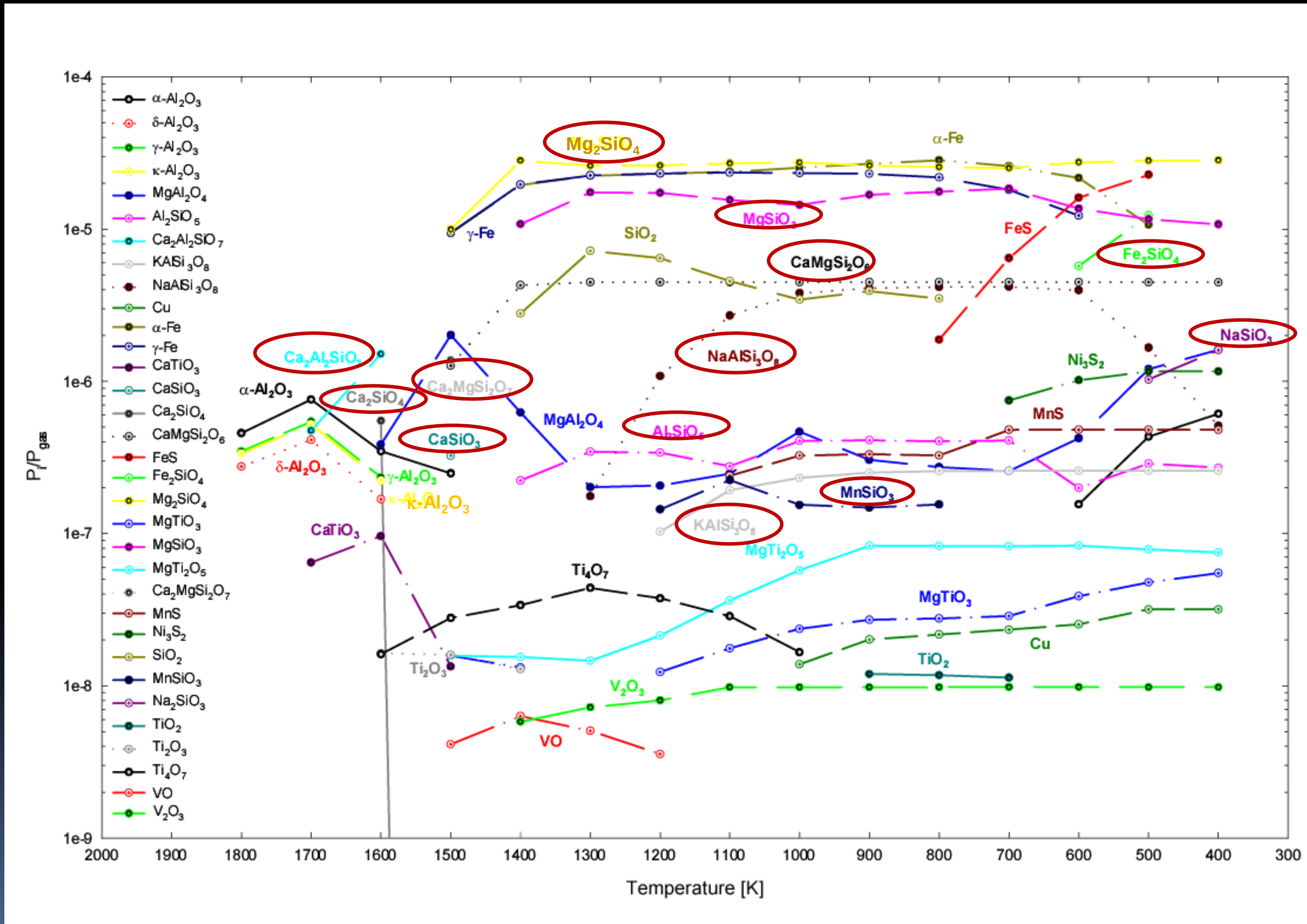
Corundum (Al_2O_3)
Spinel ($MgAl_2O_4$)
Gehlenite ($Ca_2Al_2SiO_7$)
Diopside ($CaMgSi_2O_6$)
Forsterite (Mg_2SiO_4)
Enstatite ($MgSiO_3$)
Troilite (FeS)

Pressure vs. temperature variation in the mid-plane of the solar nebula at 2×10^5 yr, 5×10^5 yr and 1, 2, 3×10^6 yr (dashed green lines, from left to right). Full red lines are stability limits of abundant minerals and (water) ice. (The model calculation of the evolution of an accretion disk around a star with $1M_{\odot}$ by H.-P. Gail.)

Model Calculation for Dust Grains

Dust condensation models → Theoretical approaches

The abundances of condensates as a function of T for a single gas pressure ($P_{gas}=10^4$ dyne/cm^2)



Equation of state calculations (more details in Allard et al. 2001 & Ferguson et al. 2005)

(Ferguson, J.W., private communication: PHOENIX)

Objective

Investigating the optical properties of chemical compounds which contain minor elements (Ca, Na, Ti, Li, Al) in order to clarify dust grain evolution (chemical pathway)

⇩

Yardstick experiments

⇩

Back up the condensation experiments

e.g. Pyroxene ($XYSi_2O_6$)
Possible cations → Mn, Cr, Al, Na, Li, Y
A rare pyroxene → "the mineralogy of meteorites with isotopic anomalies" in discussions (Cowley 1995)

Target Species

Al-compounds

Al_2SiO_5 (Kyanite)

Al_2O_3 (corundum) + SiO_2 (quartz) → Al_2SiO_5 (kyanite)

Al_2TiO_5 (Titanate) (Tamanai et al. 2009)

Al, Li, Na-compounds

$LiAlSi_2O_6$ (Spodumene)

$NaAlSi_2O_6$ (Jadeite)

$NaAlSi_2O_6$ (jedeite) + SiO_2 (quartz) ↔ $NaAlSi_3O_8$ (albite)

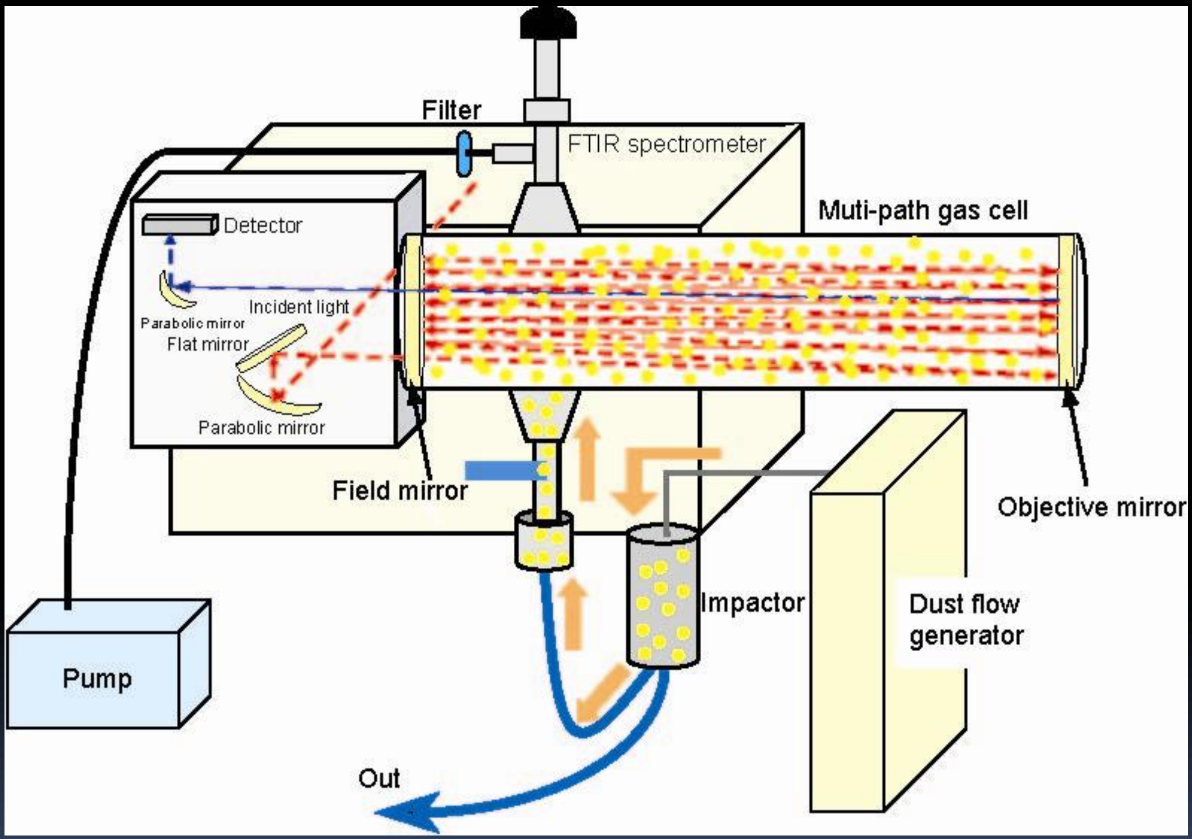
Kyanite

Spodumene

Jadeite

Experimental Setup

Aerosol Spectroscopy

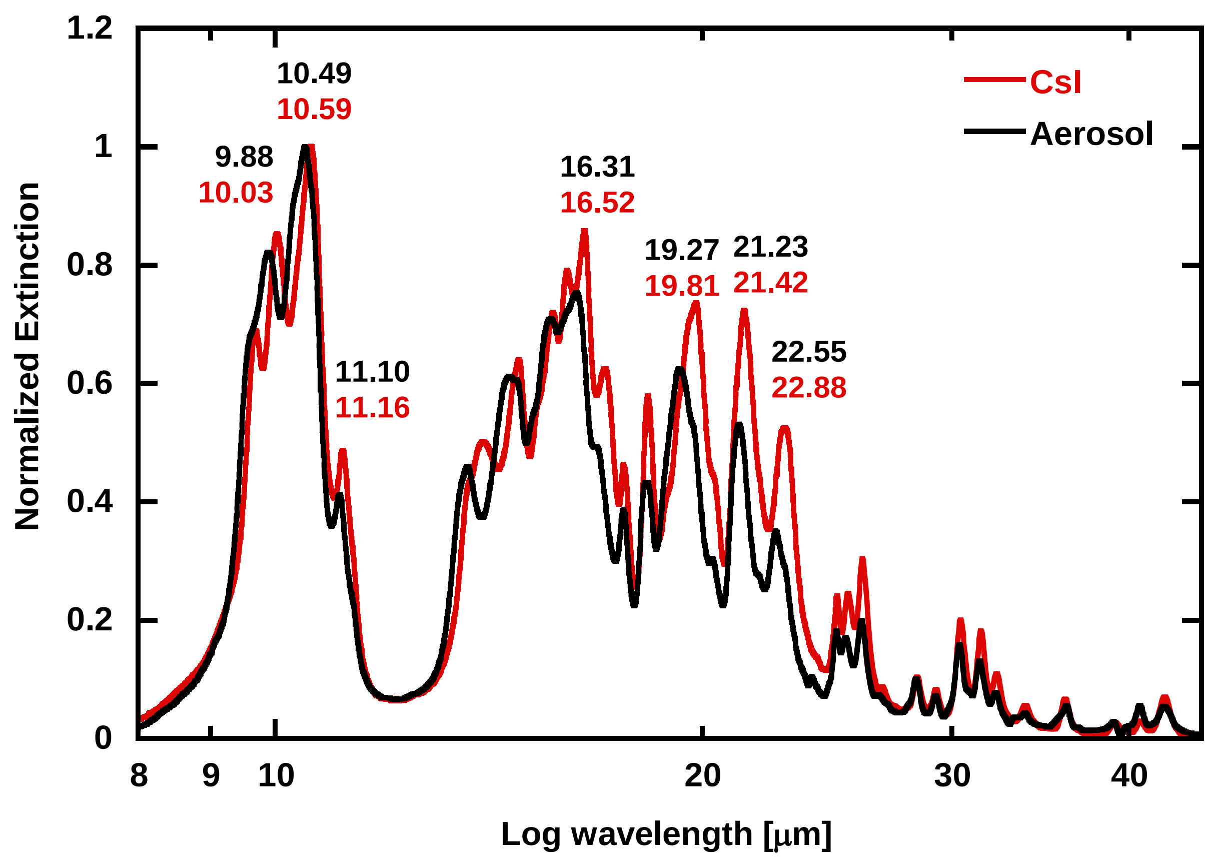


- Particle size: <1μm
- N_2-gas
- Path length: ~18m
- Wavelength range: 2-50 μm
- Sampling: Polyester capillary pore membrane filters

Tamanai et al. 2006, 2009, 2010

Al-compounds

Al_2SiO_5 (Kyanite)

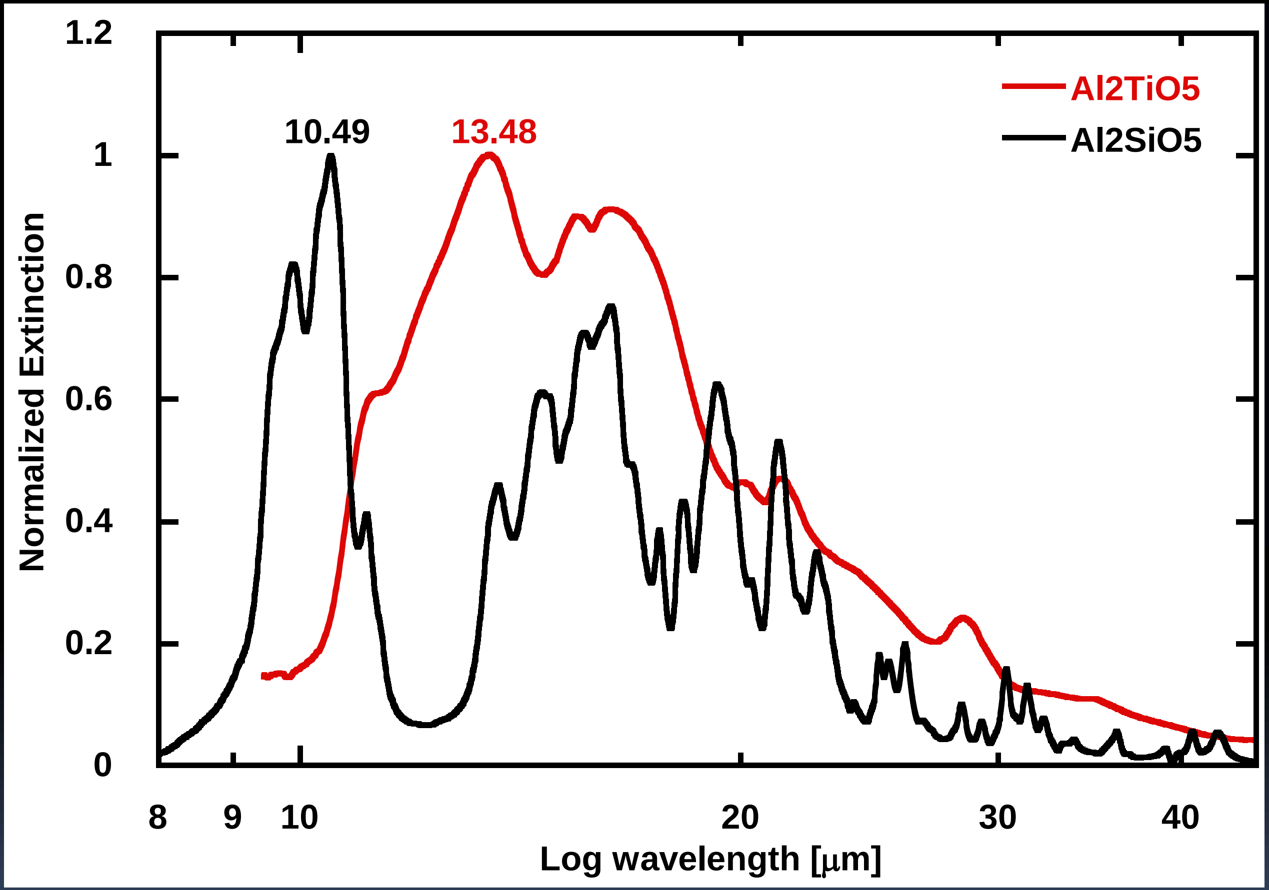


- ✓ Red-shift (CsI spectrum)
- ✓ Disparity in these spectra
  Possible reasons:
  - Suspended particles
  - Segregated well in the CsI pellet
  - Containing larger aggregates in the aerosol experiment

Si-O vibrations:
9.88, 10.49, 11.10, 13.66, 22.55 µm

Al-O vibrations:
14.64 – 22 µm

Al_2SiO_5 (Kyanite) vs. Al_2TiO_5 (Tialite)



Comparison with a Al_2TiO_5 spectrum

Ti-O stretching
13.48 µm

Al-O vibrations:
11 – 13.5 µm
22.2 µm

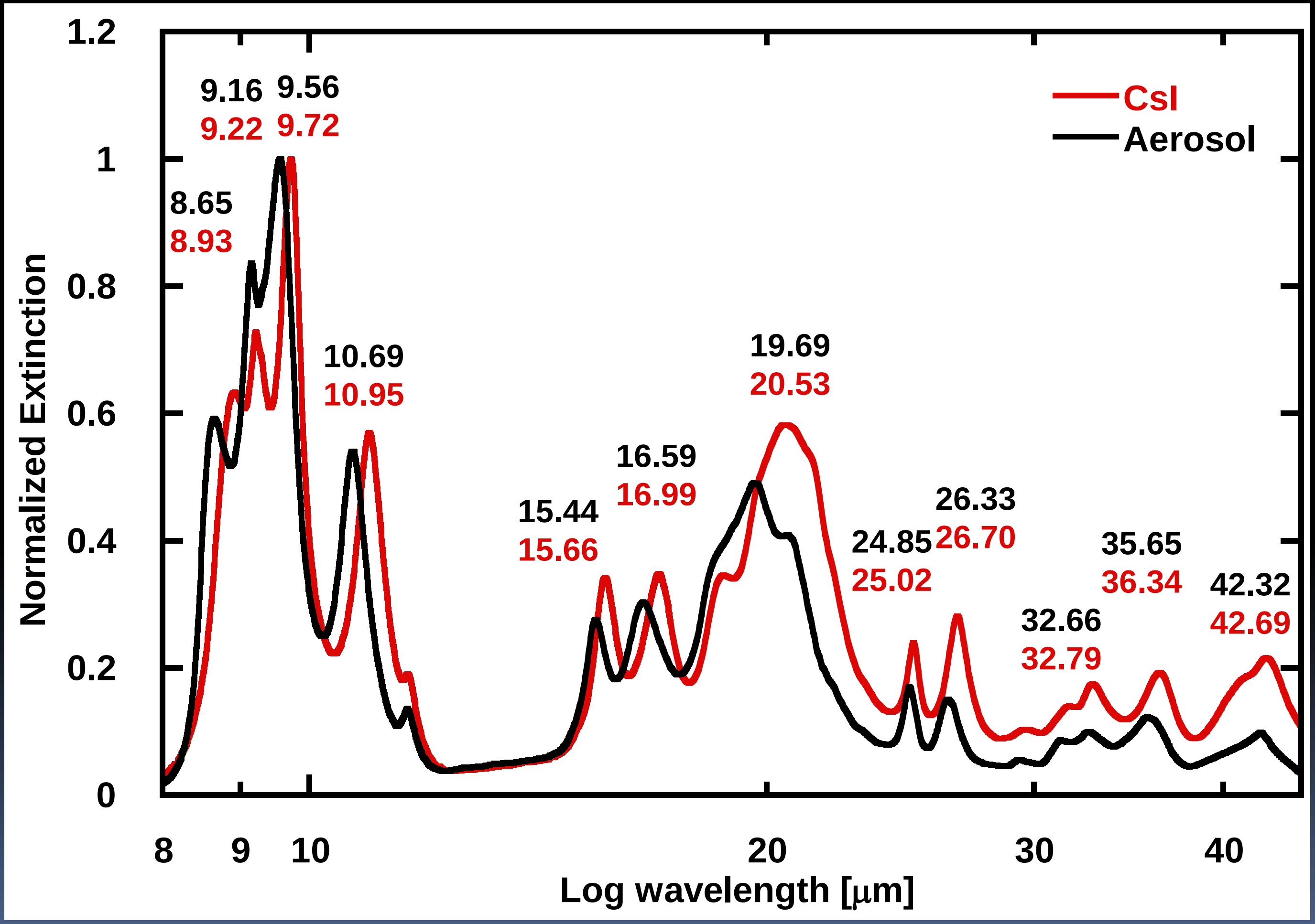
Pseudobrookite structure

X_2YO_5 (X, Y: Fe^{2+}, Fe^{3+}, Mg, Al, Ti, Si)

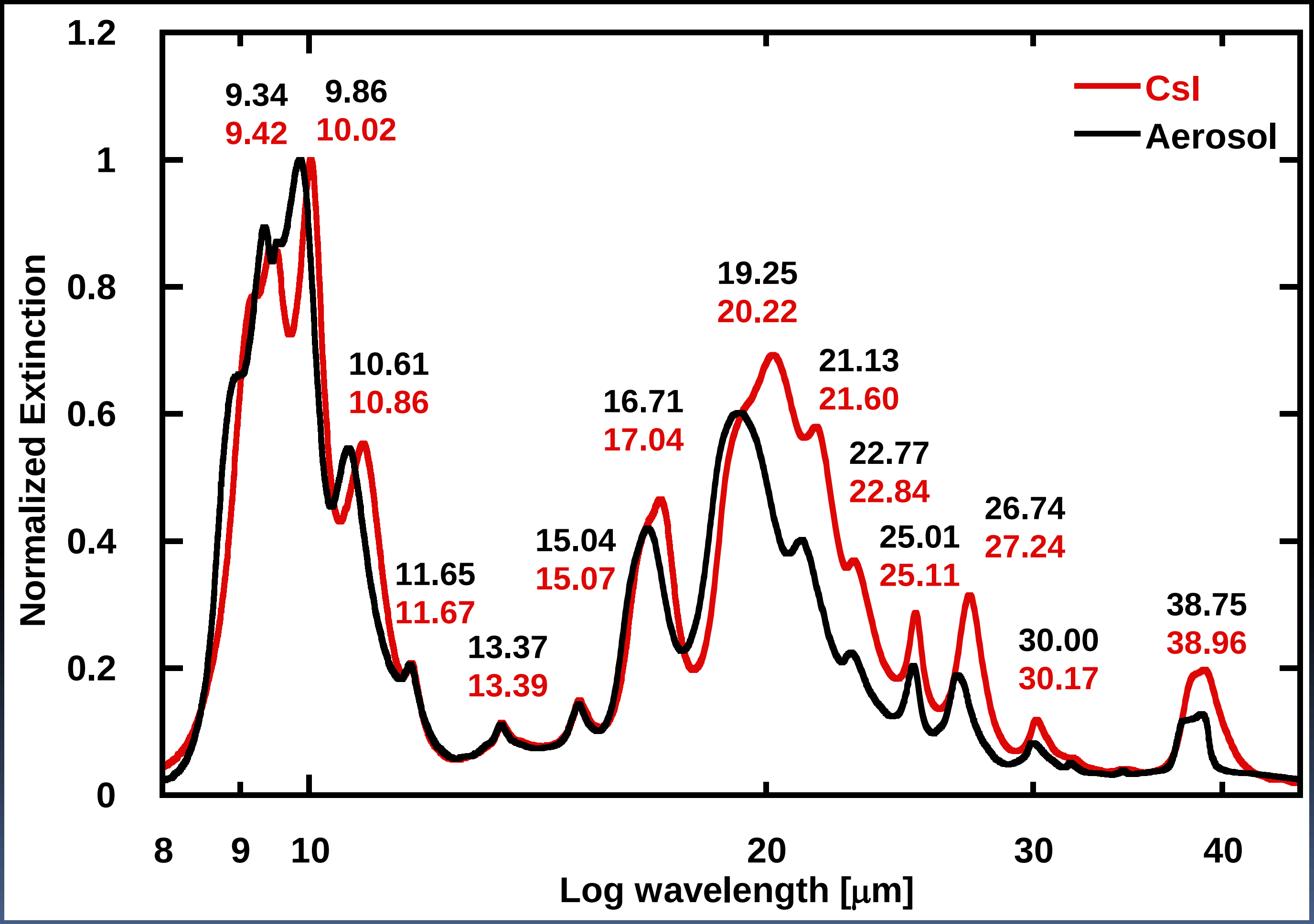
(http://ruby.colorado.edu/~smyth/min/armalcolite.html)

Al, Li, Na-compounds

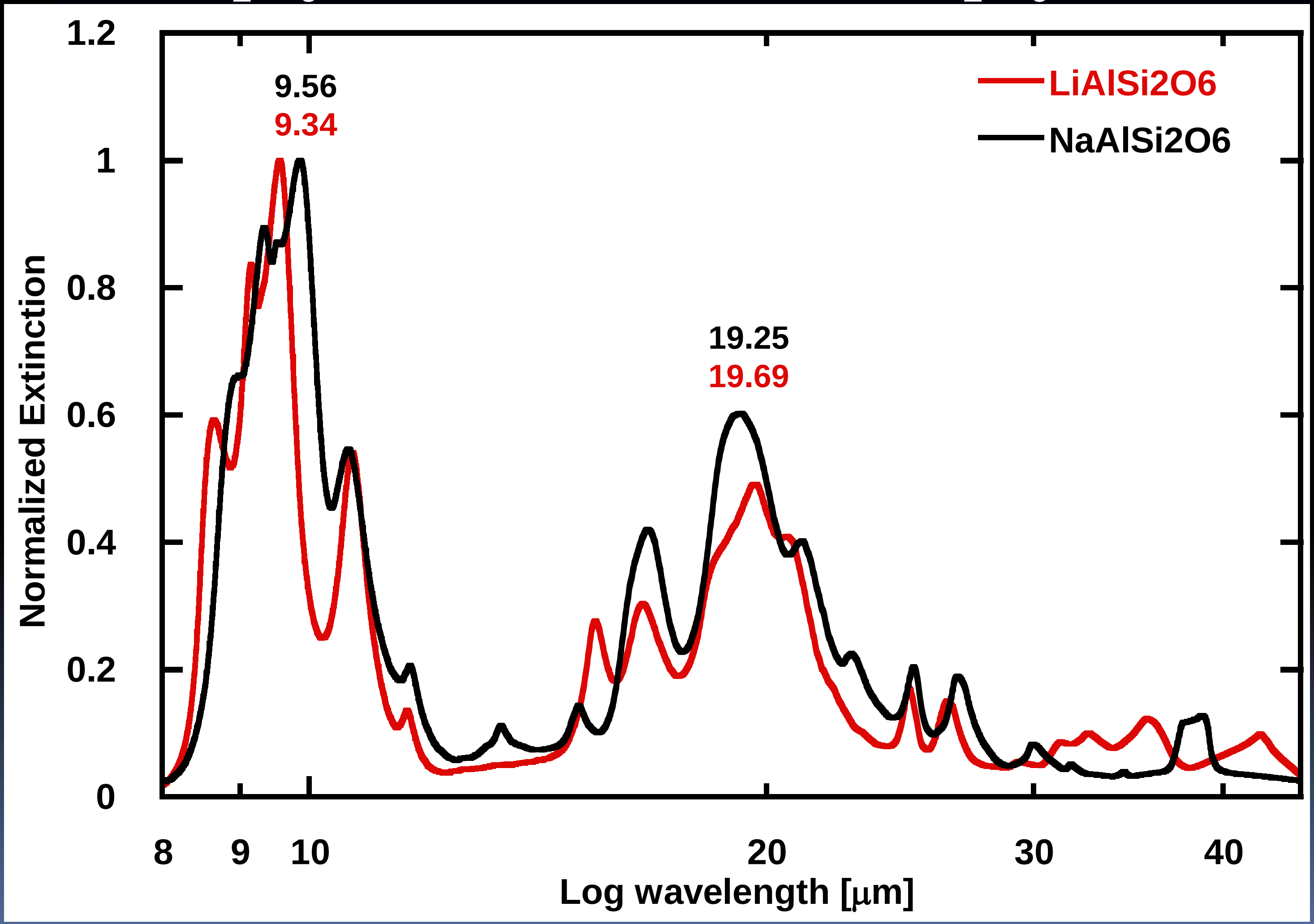
$LiAlSi_2O_6$ (spodumene)



$NaAlSi_2O_6$ (Jadeite)



$LiAlSi_2O_6$ (Spodumene) vs. $NaAlSi_2O_6$ (Jadeite)



Summary

- Performed the mid-IR extinction measurements of chemical compounds containing minor elements for benchmark use

  --- Al_2SiO_5 (kyanite)
  --- $LiAlSi_2O_6$ (spodumene)
  --- $NaAlSi_2O_6$ (jadeite)

Outlook

- Taking into account of minor elements in condensation experiments
- Investigation of particle morphology
  --- Separating each morphological effect (size, shape, agglomeration) and measuring the absorption spectra

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