Silicates in the β Pictoris Debris Disk

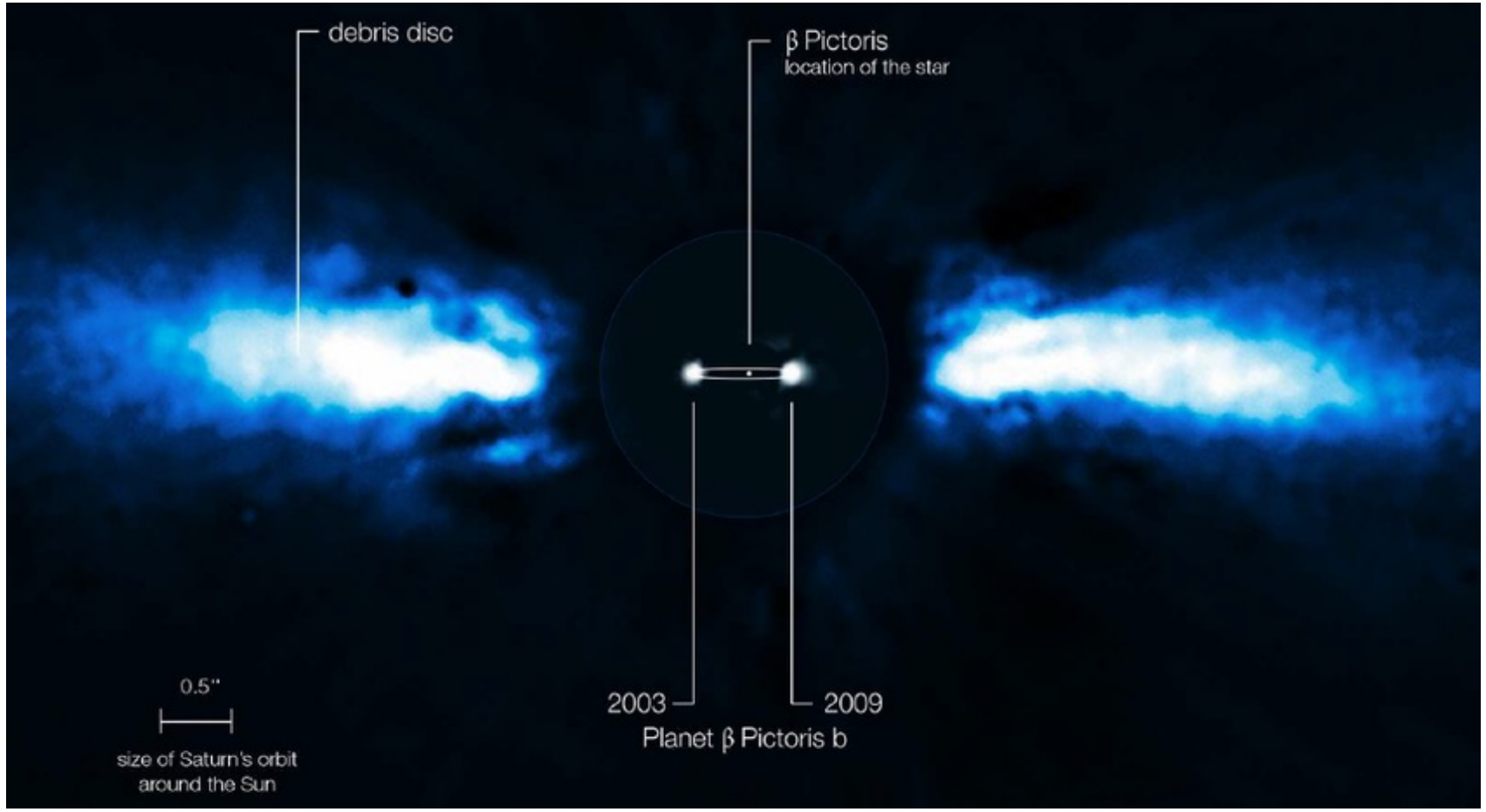
Cicero X. Lu[1], **Christine H. Chen**[1, 2], B. A. Sargent[1, 2], Dan M. Watson[3], Carey M. Lisse[4], Mike Sitko [6,7], Joel D. Green[2], Tushar Mittal[5], Isabel Rebollido[2], Dean C. Hines[2], Michael Werner [8], Karl R. Stapelfeldt [8]

[1] Johns Hopkins University, [2] Space Telescope Science Institute, [3] University of Rochester, [4] Johns Hopkins University Applied Physics Laboratory, [5] Massachusetts Institute of Technology, [6] University of Cincinnati, [7] Space Science Institute, [8] Jet Propulsion Laboratory

Talk Outline

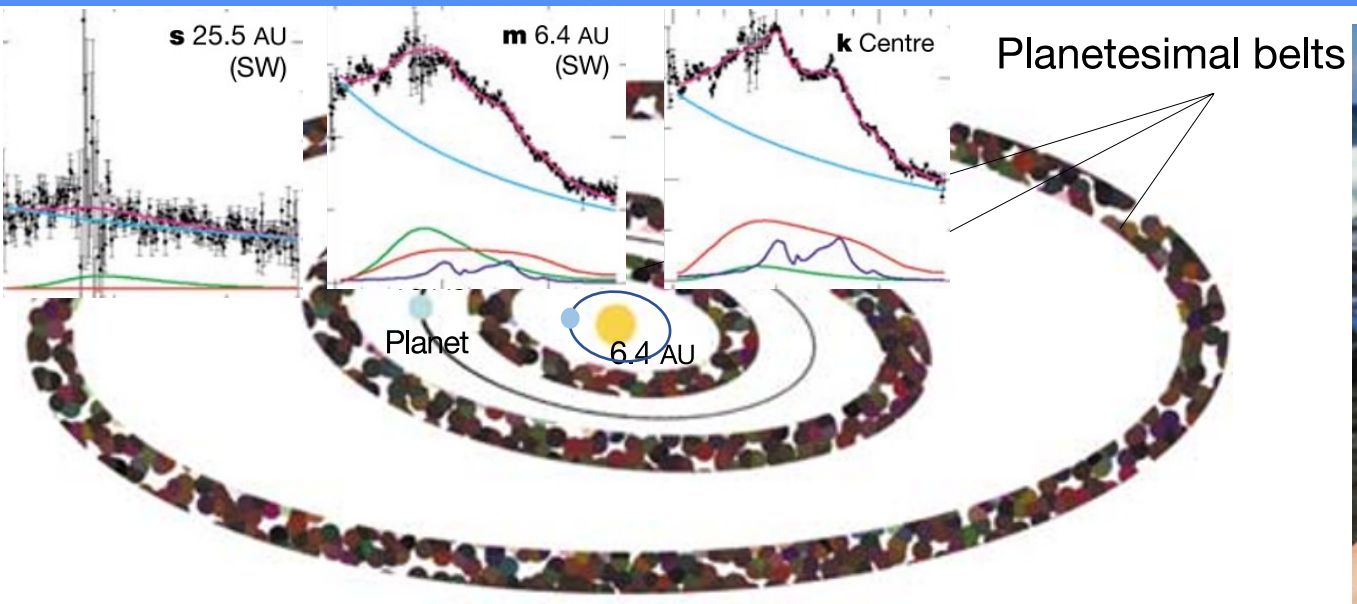
- New extraction of βpic Spitzer IRS spectrum
- Discovery of 18 and 23 μm features
- Spectral fitting of silicate features
- Trends as a function of stellocentric distance:
  - Grain shape
  - Fe abundance
  - Crystallinity

Beta Pic is an archetypal debris disk



ESO / A.- M. Lagrange, Composite

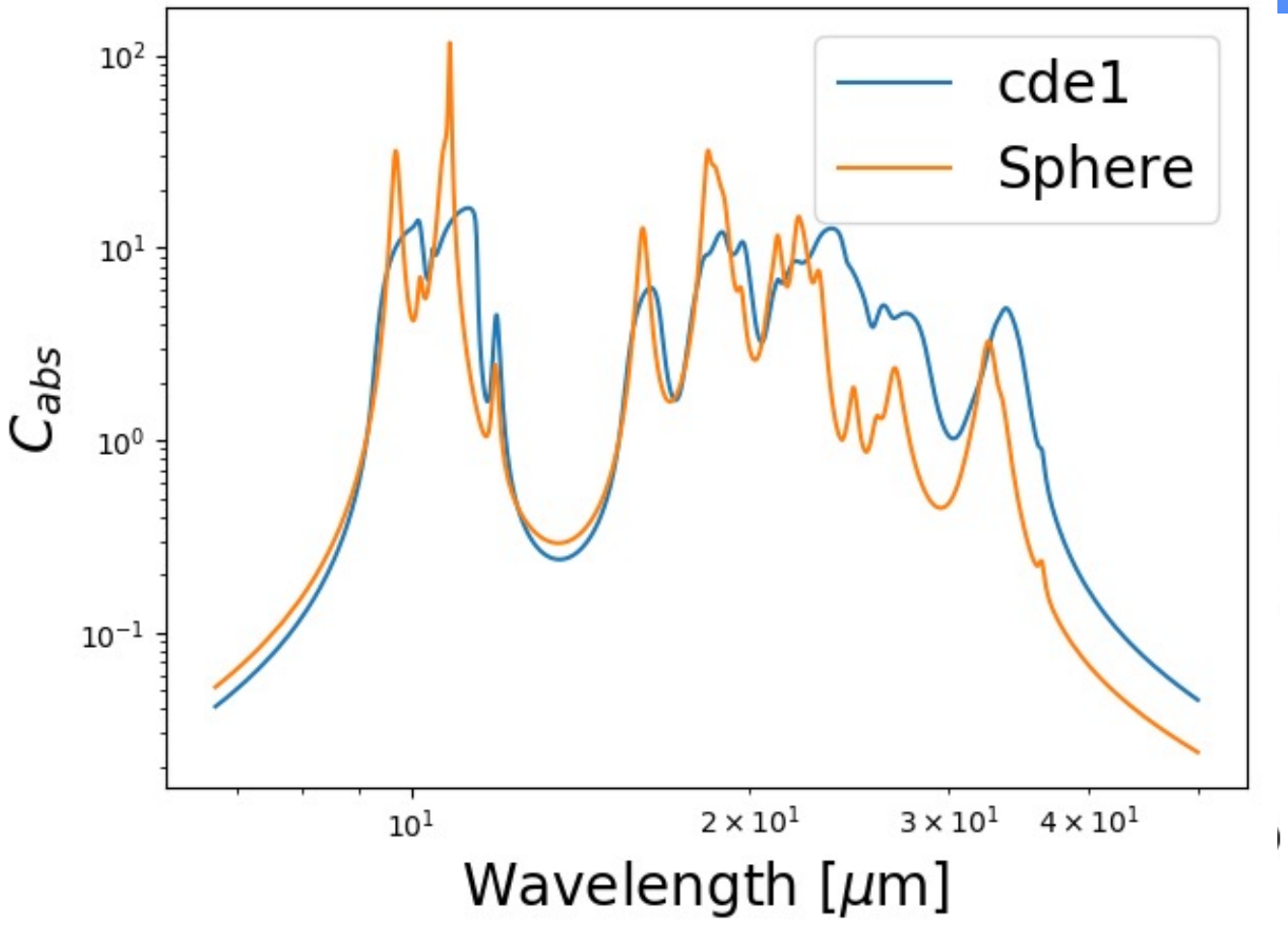
Probing mineralogy in the βPic disk



- Subaru/COMICS 10 μm features reveal a crystalline silicate gradient in the βPic disk, but is limited by sky thermal background to 10 μm emission features.
- Spitzer is sensitive out to 35 μm. Do we see a crystalline gradient to a larger extent?
- Are the forsterite grain emitting at the Spitzer IRS wavelength range also Mg-rich?

Okamoto et al. 2005; de Vries et al. 2012;

Effects of Grain Stoichiometry, Temperature and Shape on Spectral features



T_{grain}

Higher Temp shift peaks to longer λ

Fe/Mg ratio

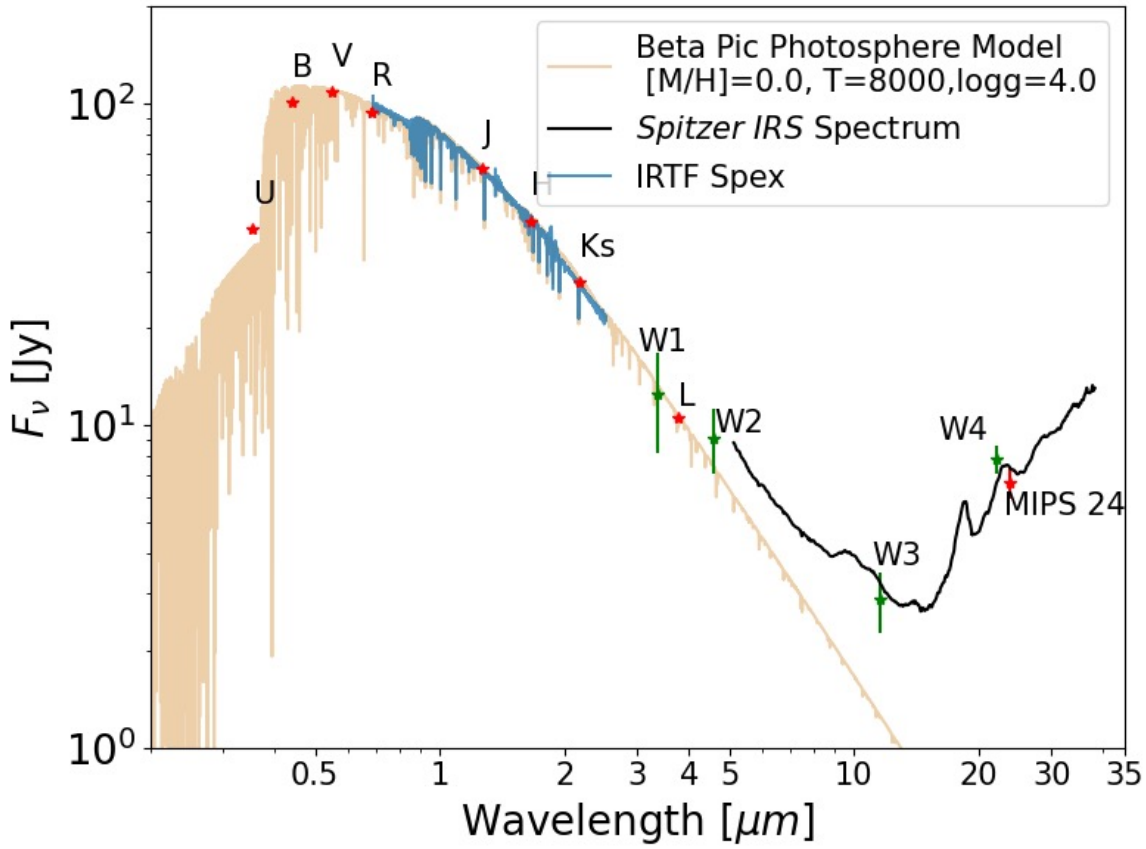
Inclusion of Fe in silicates broadens the features

Shape

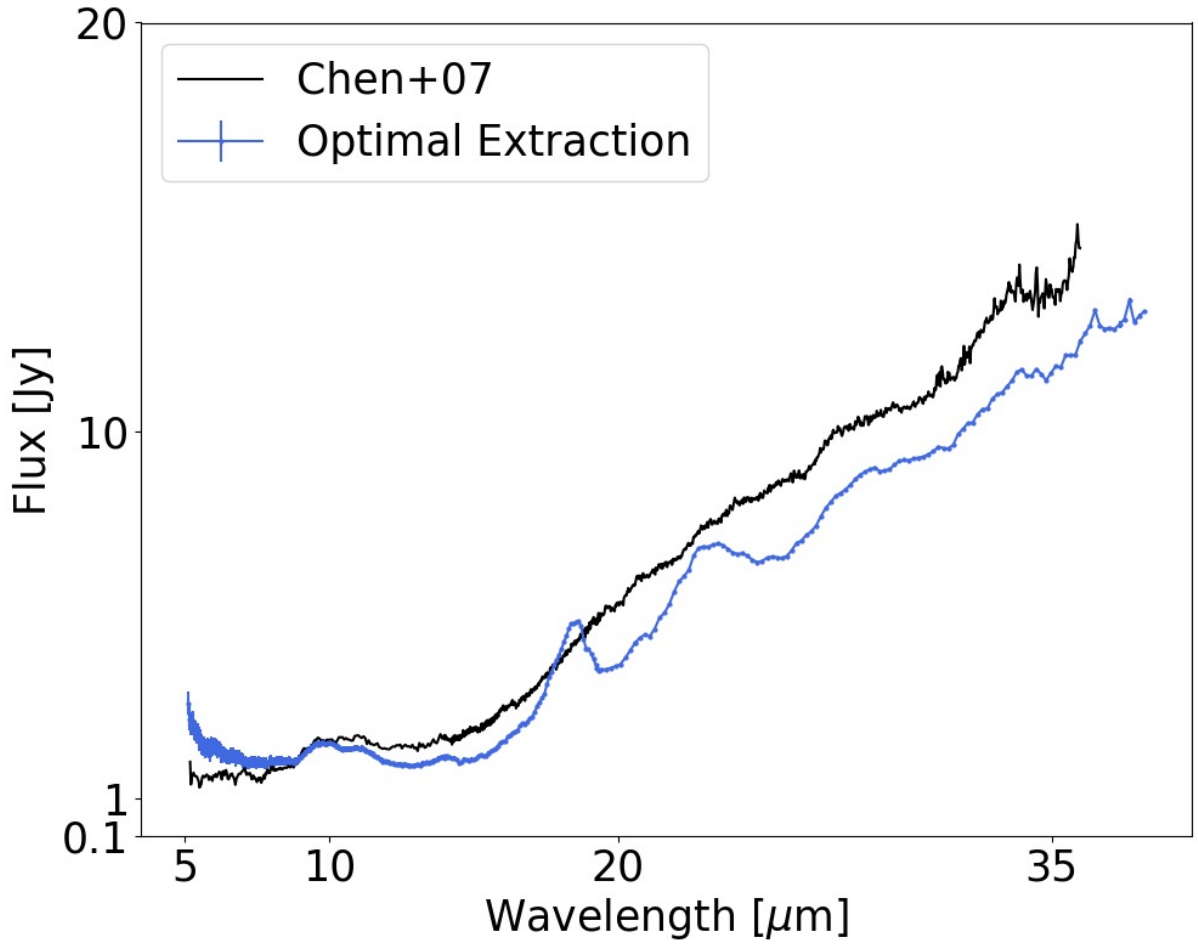
Grain Shape changes spectral shapes.

SED analysis reveals weak 3-5 μm Excess

First, we model stellar photosphere with a newly observed IRTF Spex spectra and photometry.

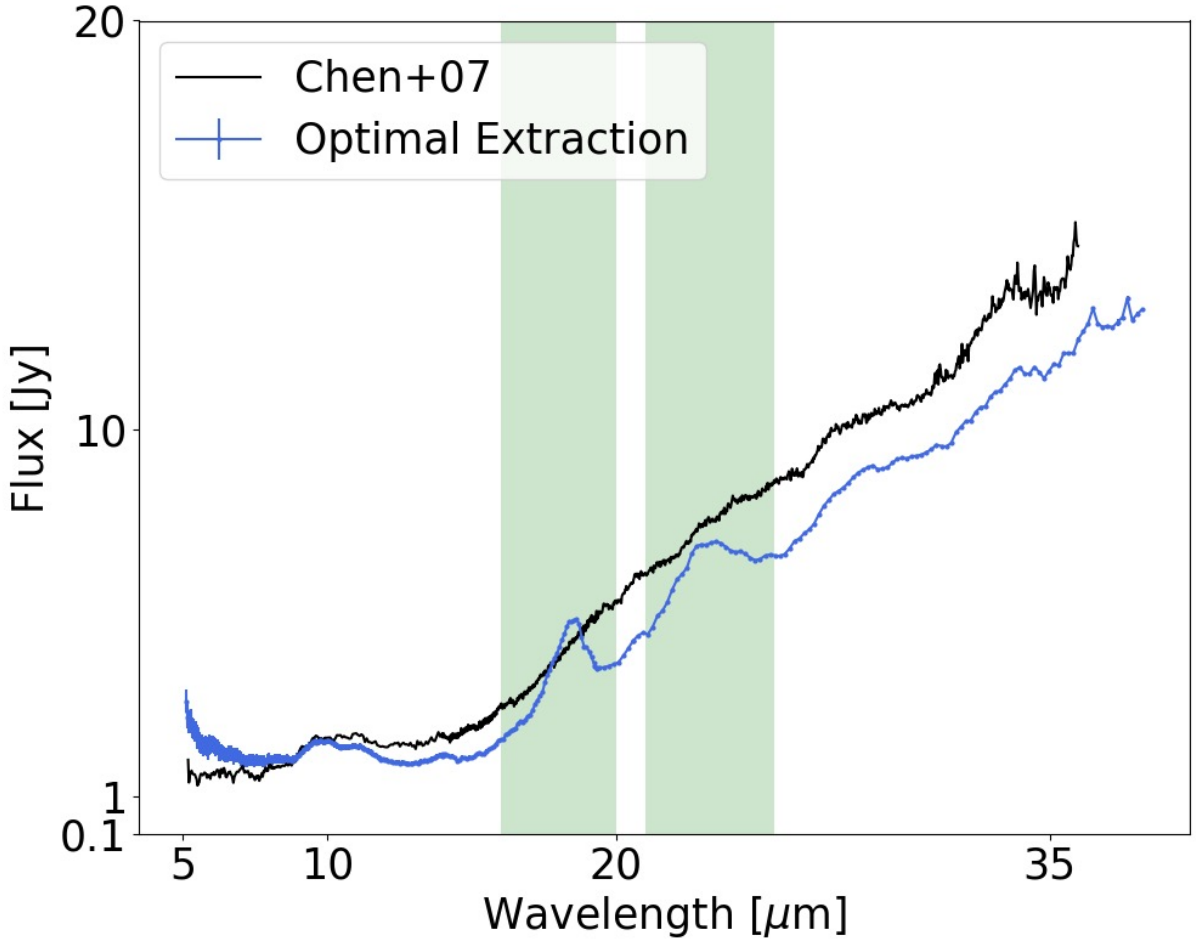


Discovery of new 18 and 23 μm Silicate features with Advanced Optimal Extraction

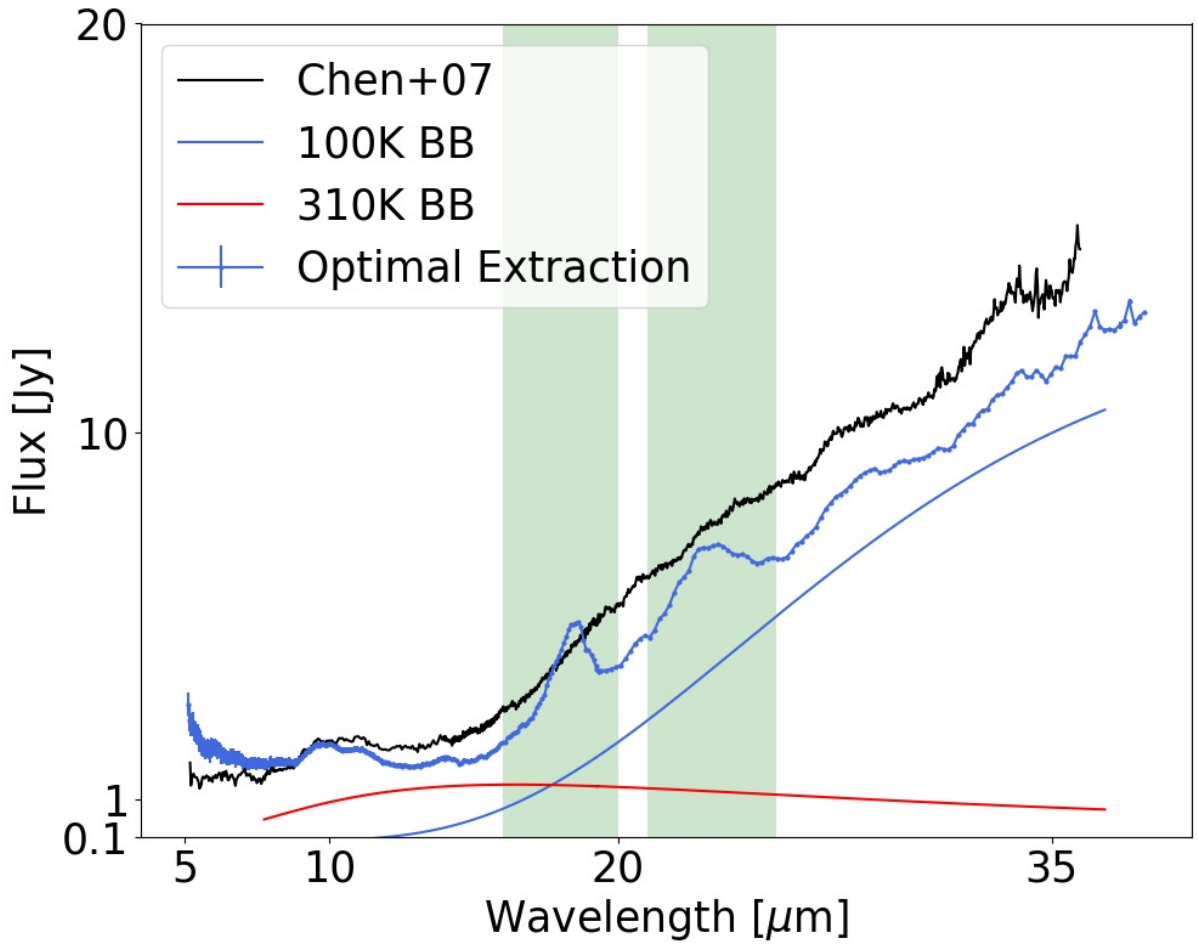


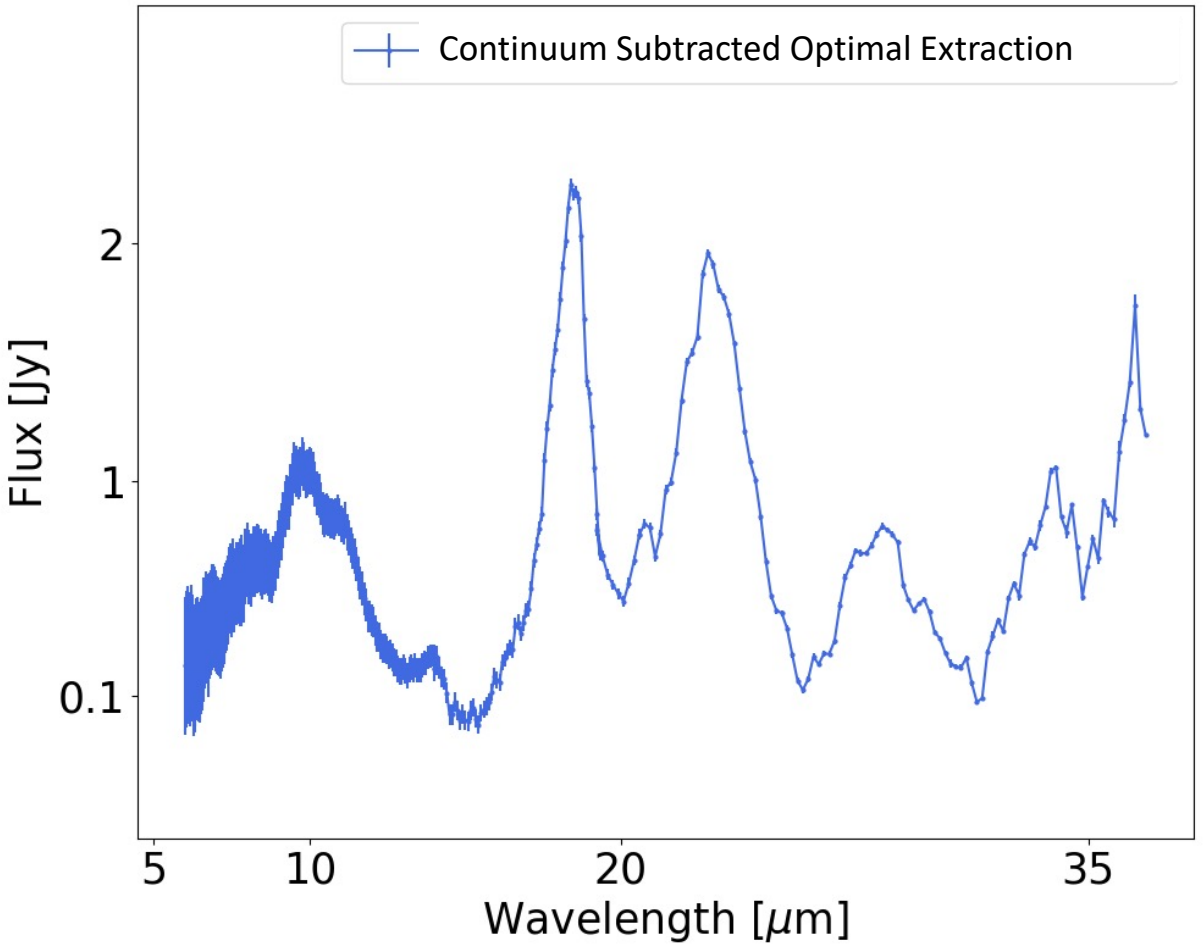
- The spectrum (This work) is extracted with the Advanced Optimal Extraction which weights every pixel by its SNR (Lebouteiller+10).
- Chen+07 spectrum uses a full-slit extraction.

Discovery of new 18 and 23 μm Silicate features with Advanced Optimal Extraction

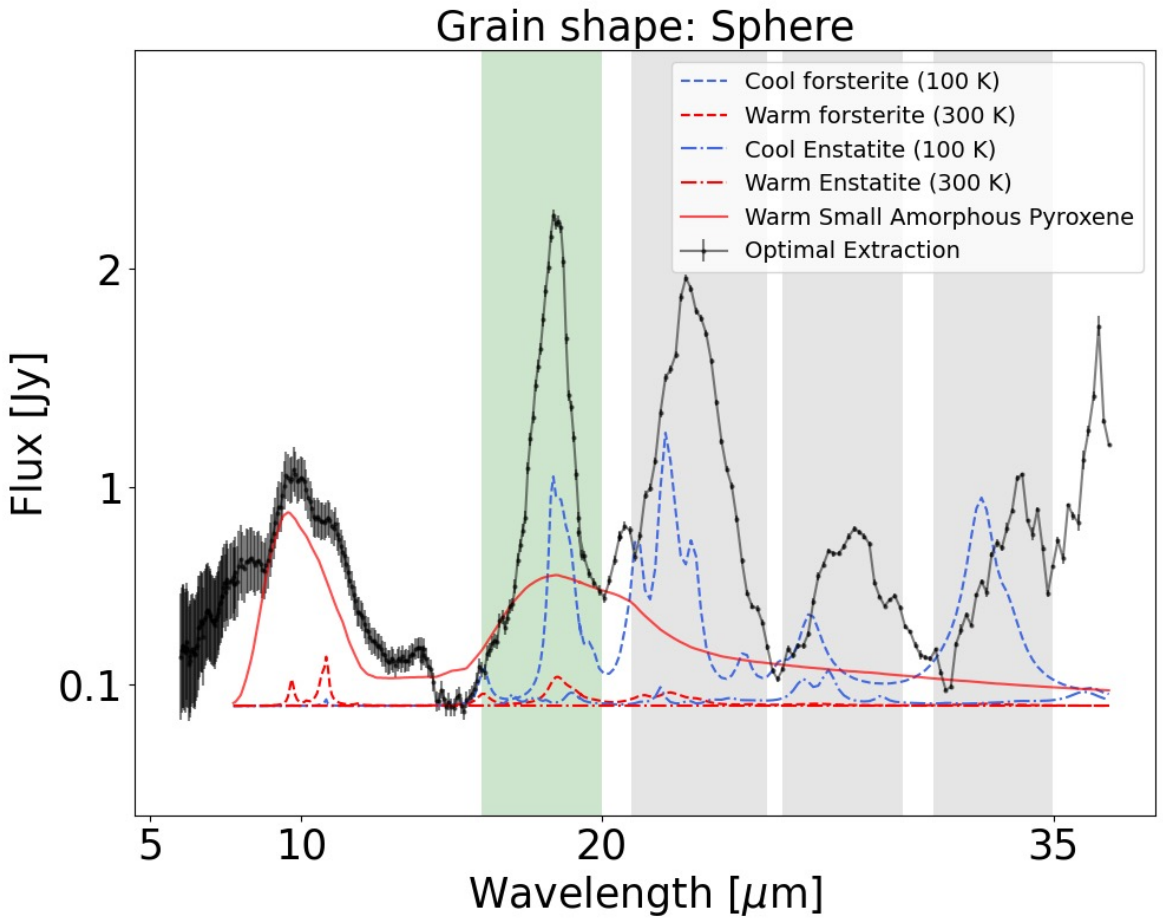


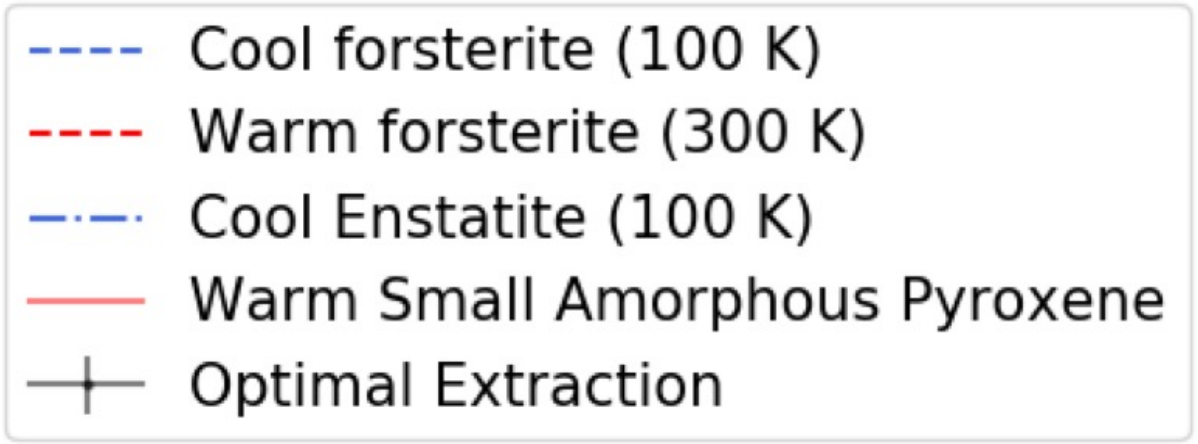
Discovery of new 18 and 23 μm Silicate features with Advanced Optimal Extraction



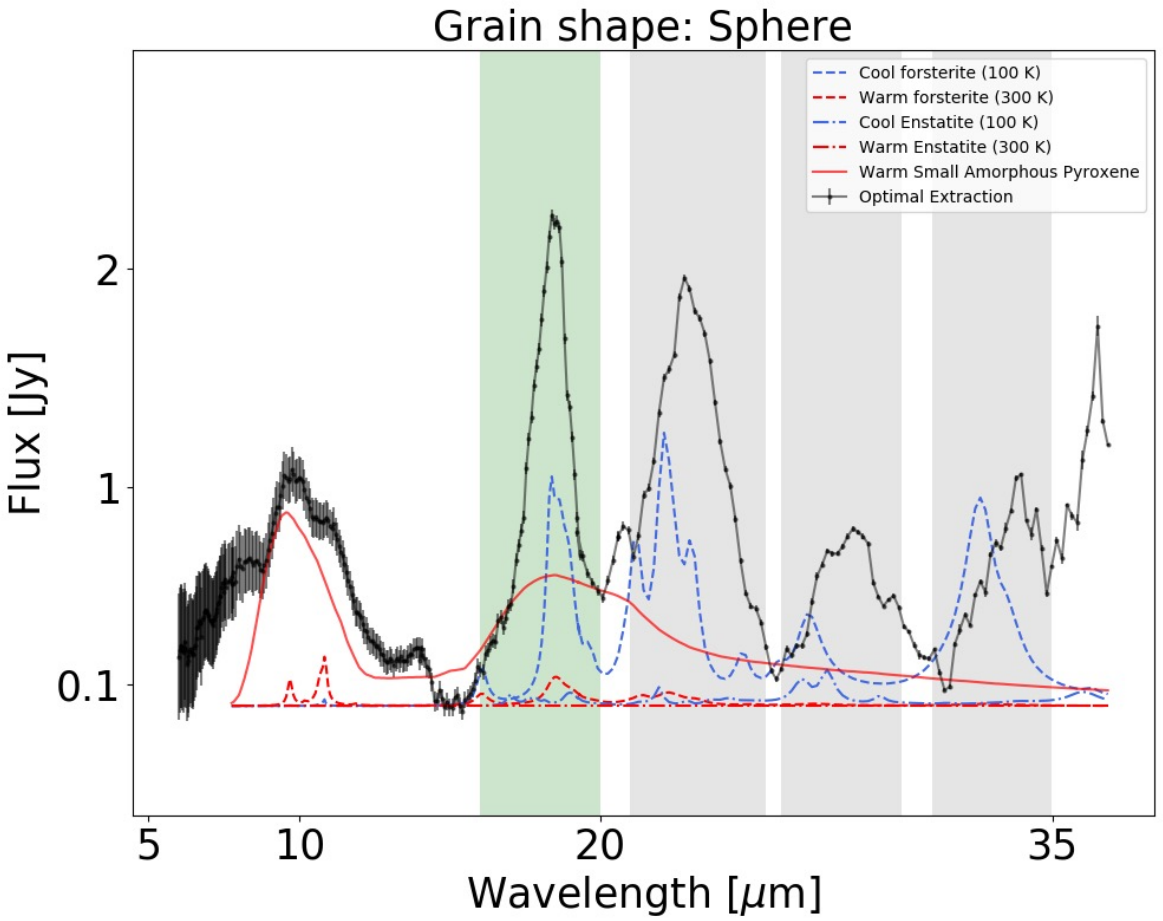


Modeling spectrum -- Grain Temperatures



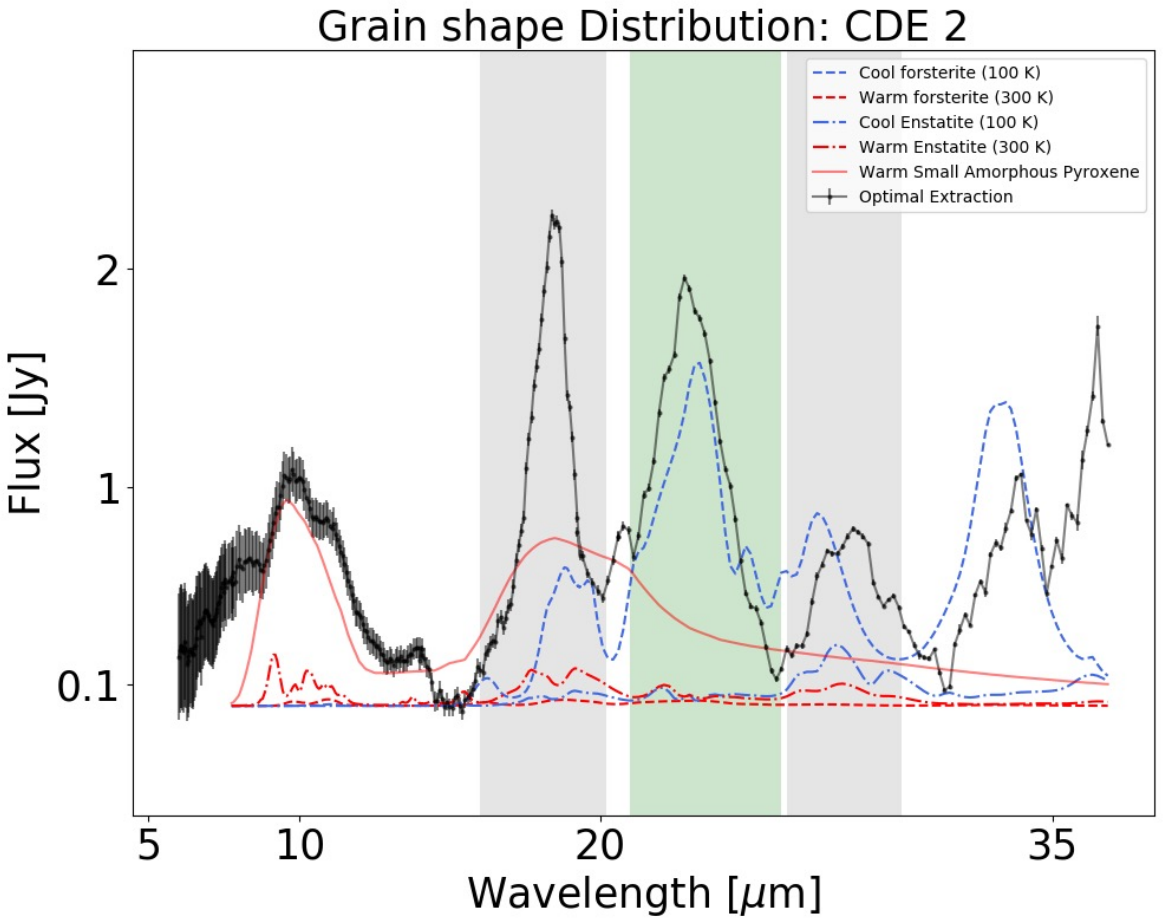


Modeling spectrum – Stoichiometry (Mg-to-Fe ratio) & Grain shape distribution

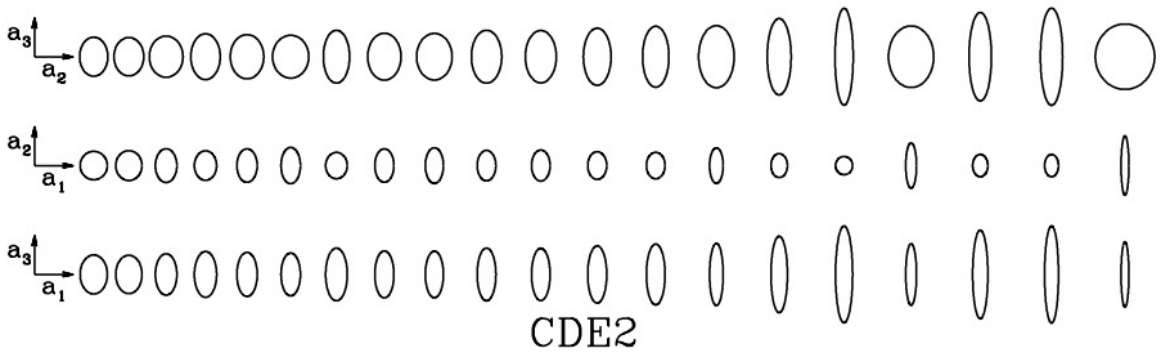


- The 18 μm band is well-fitted by a 98.9 percent Mg-rich forsterite
- Such Mg-rich silicates grain composition shows that the parent bodies - planetesimals - are primitive and unprocessed, similar to the comets seen in the Kuiper belt in the solar system.

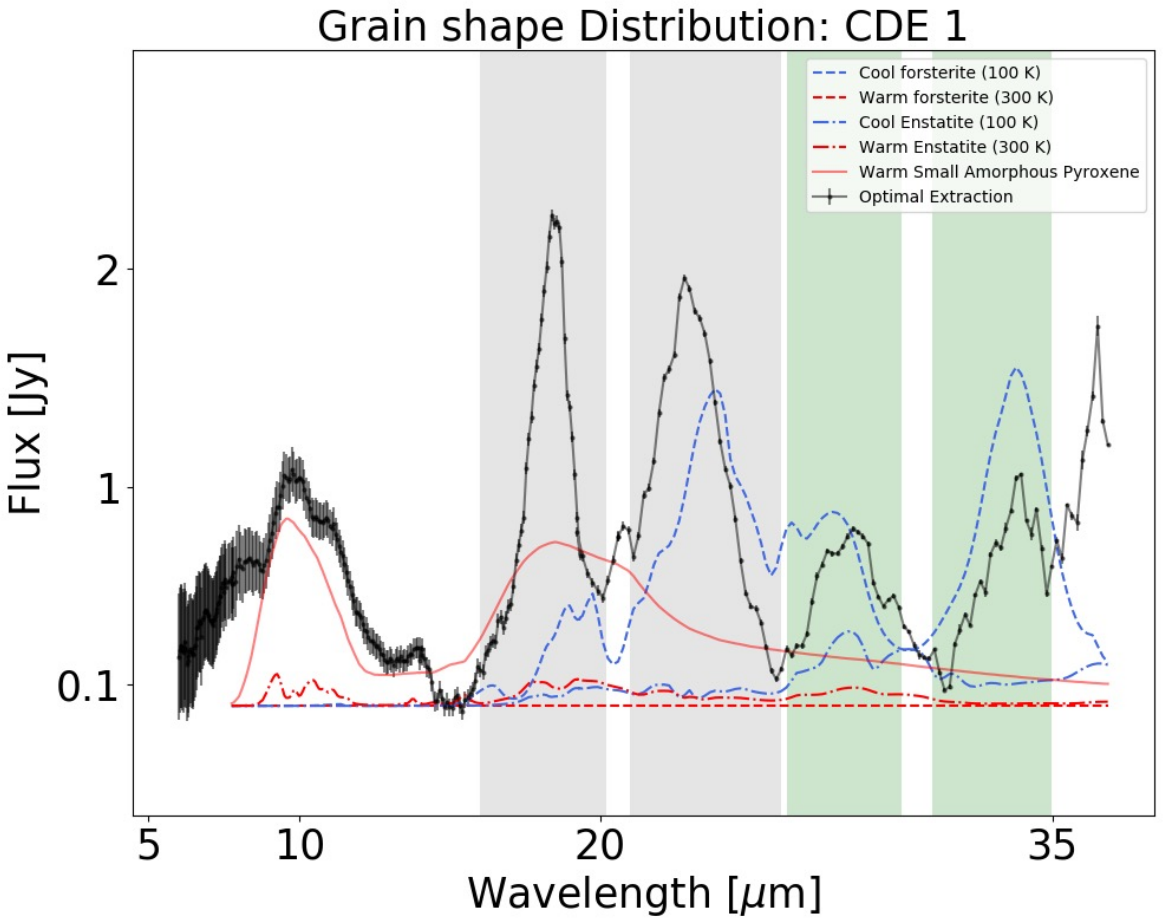
Modeling spectrum – Stoichiometry (Mg-to-Fe ratio) & Grain shape distribution



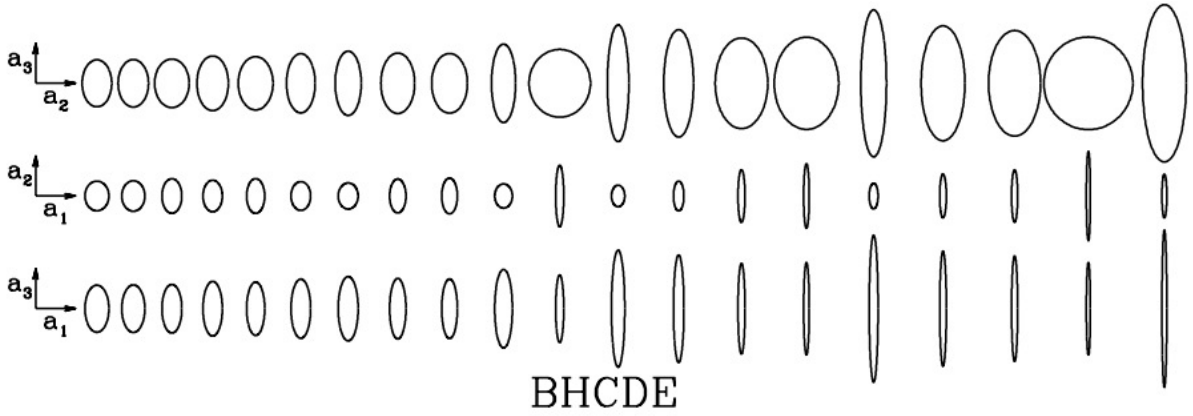
- The 23 μm feature is best fitted with CDE2.
- CDE stands for continuous distribution of ellipsoids.
- The grain shapes include oblates and prolates.



Grains are increasingly irregular as a function of wavelength.

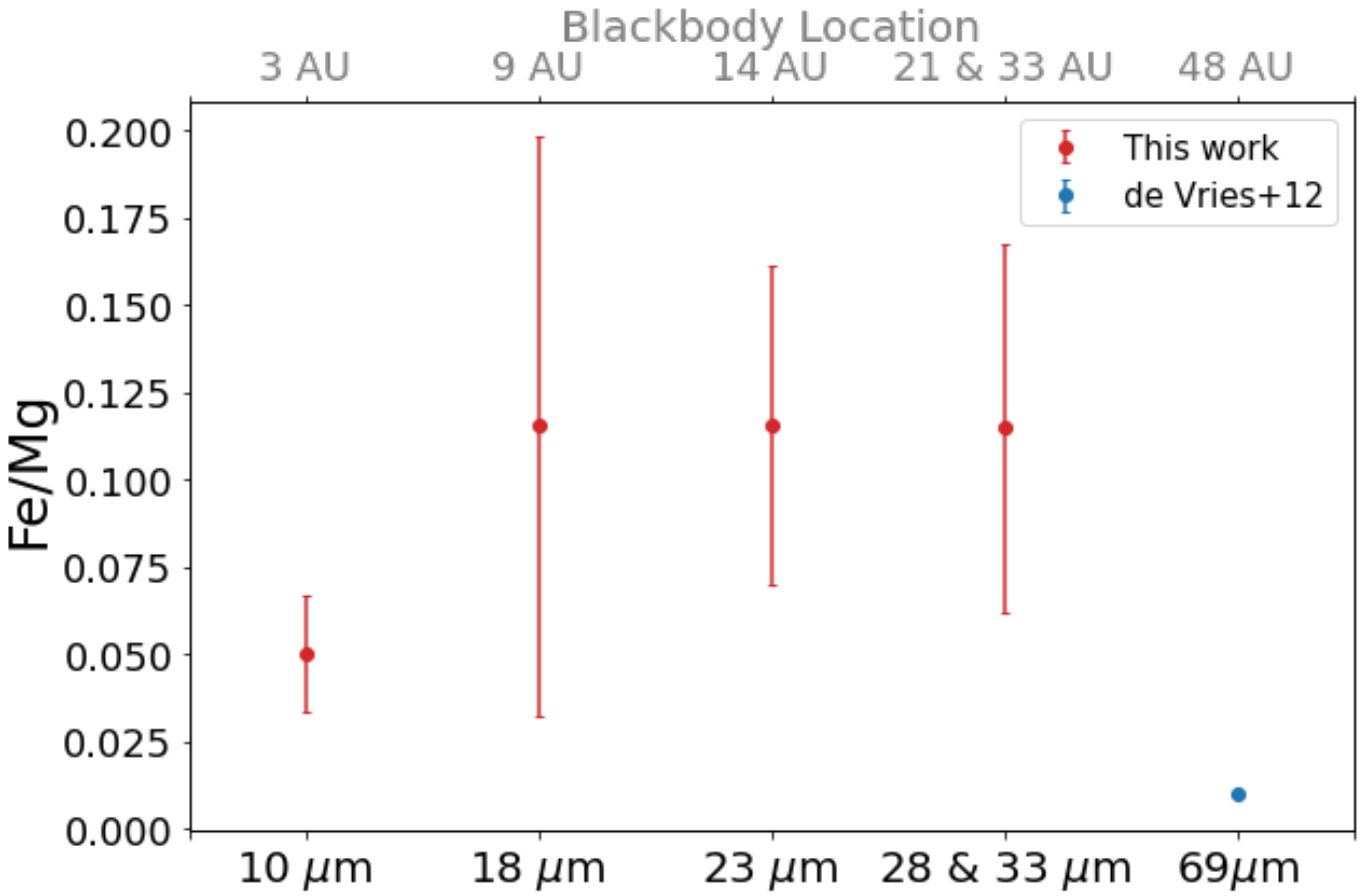


- 28 & 35 μm feature is best fitted with CDE1 particle shape distribution.
- The spectral features requires even more extreme grain shapes such as needles and plates.



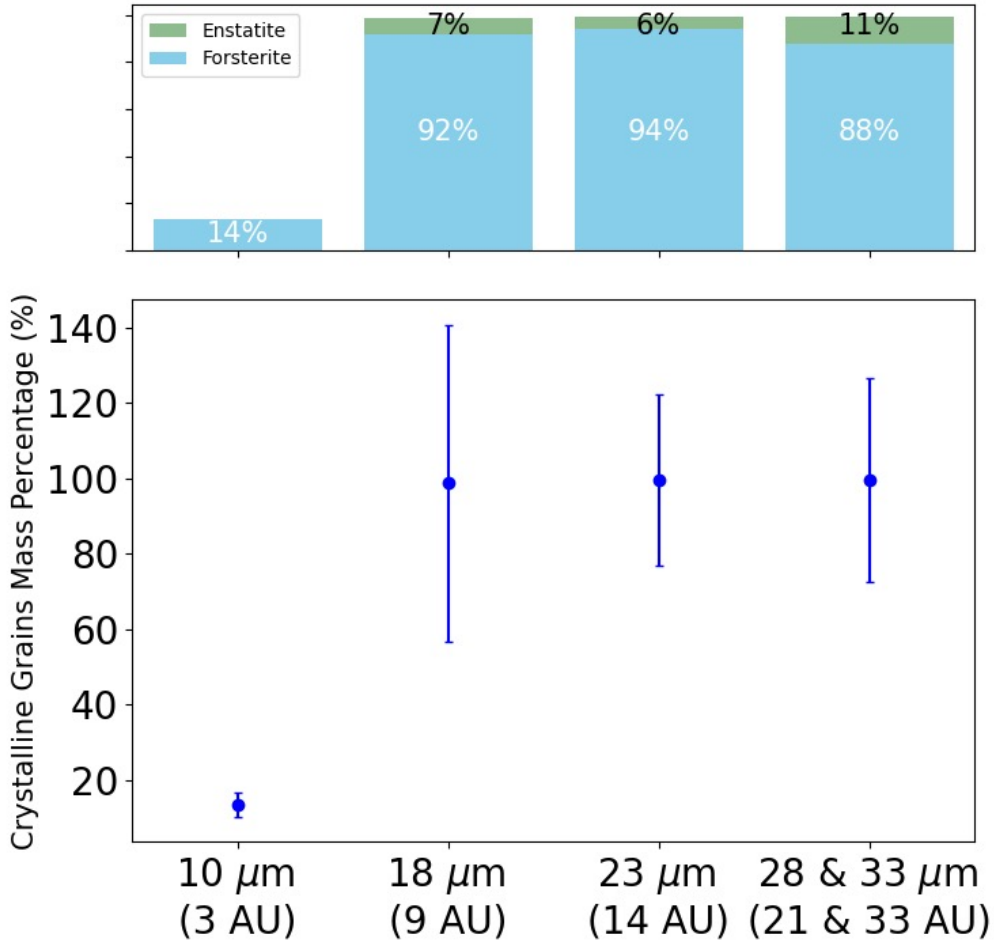
Fe abundance decreases a function of the stellocentric distance in the disk.

- Fe requires a higher condensation temperature than Mg.
- The inclusion of Fe in silicates is more commons in regions close to star where planetesimal collision velocity are higher than the outskirt of the disk.
- Water (liquid) might facilitate the production of Fe-rich silicates (Wood 2020).



Crystalline grain fraction increases as a function of stellocentric distance

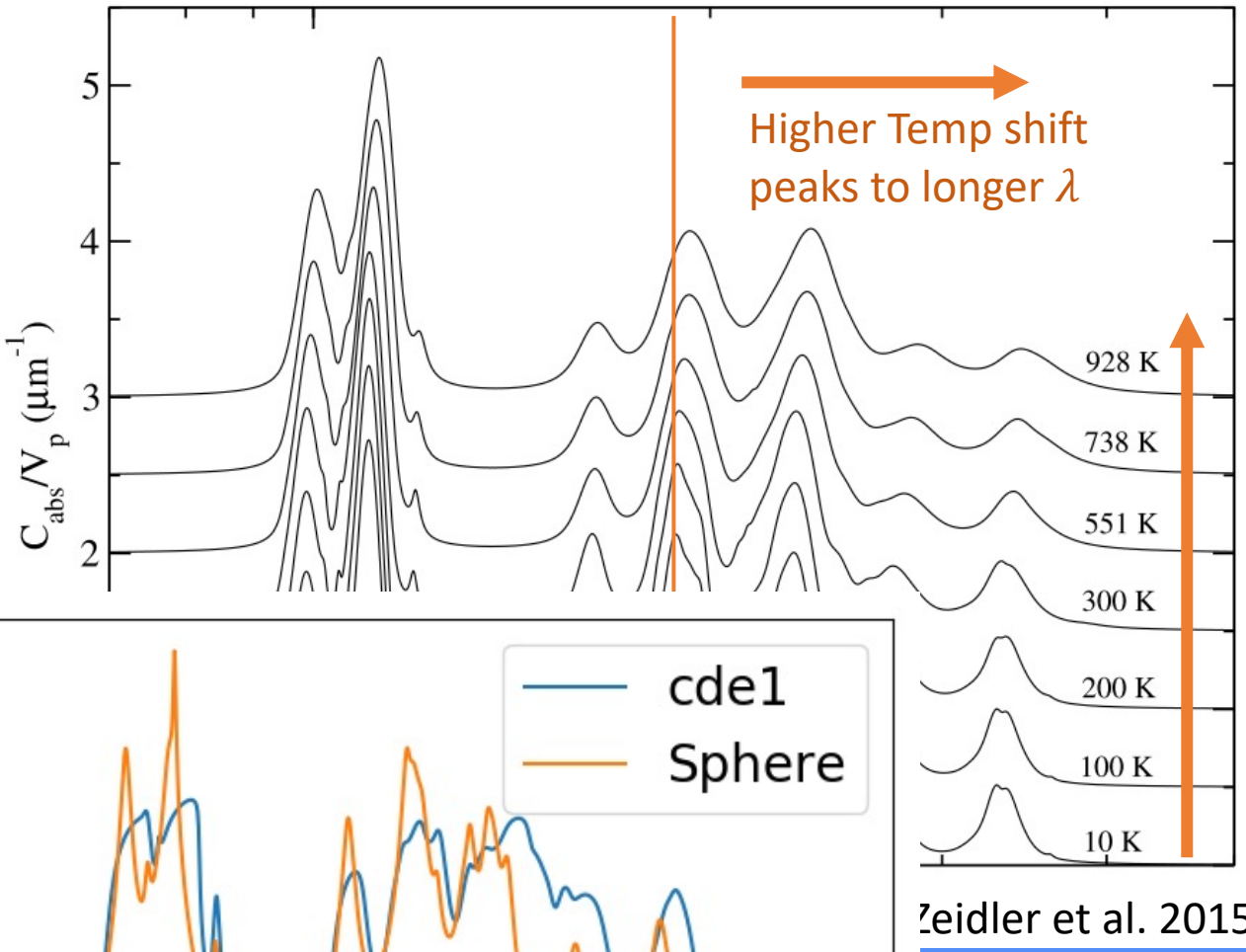
- The Spitzer observation suggests that the crystalline fraction increases as the distance increases.
- The Subaru/COMICS spectra shows the crystalline grain are centered towards the star (Okamoto+05).
- Beam size is 10 times bigger for Spitzer compared to Subaru. The beam size different might be a cause.



Summary

- The disk contains cool (100 K) and warm (300K) dust population from spectral modeling.
- SED analysis shows evidence of a weak 3-5 micron excess.
- The Mg-rich stoichiometry from newly discovered 18 μm feature indicates that the both cool and warm planetesimals are primitive and unprocessed, similar to Kuiper Belt objects.
- The grain shape, Fe abundance and crystallinity changes as a function of wavelength.
- Future work:
  - Study the dust grain properties at the CO clump location to understand the origin of CO clump
  - JWST MIRI will study the disk at higher angular resolution

Effects of Grain Stoichiometry, Temperature and Shape on Spectral features



Zeidler et al. 2015

Inclusion of Fe in silicates broadens the features

Grain Shape changes spectral shapes.