Dust and Ice in Protoplanetary Disks

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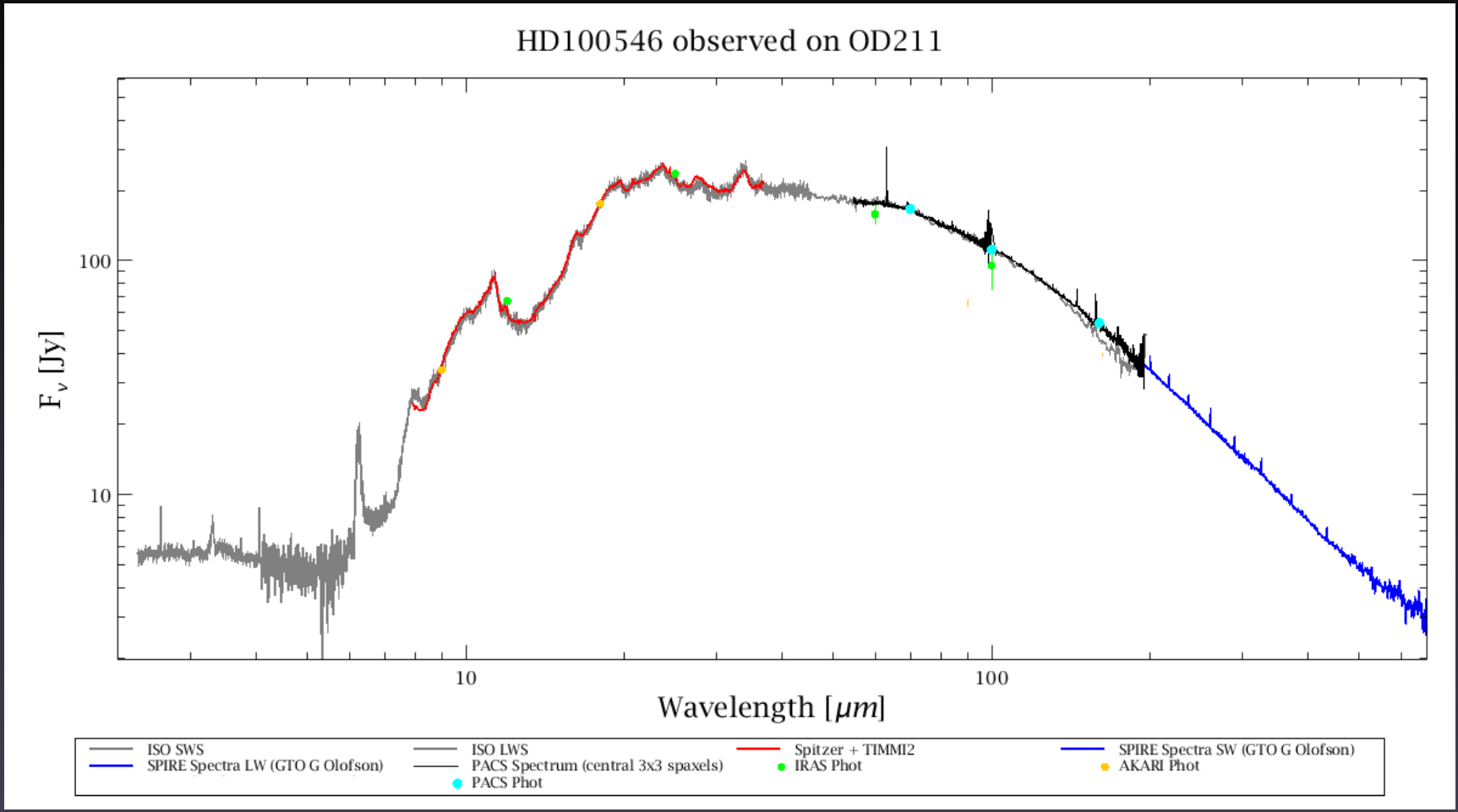
DIGIT TEAM

IDIGIT (Dust, Ice, and Gas in Time) Open Time Key Project

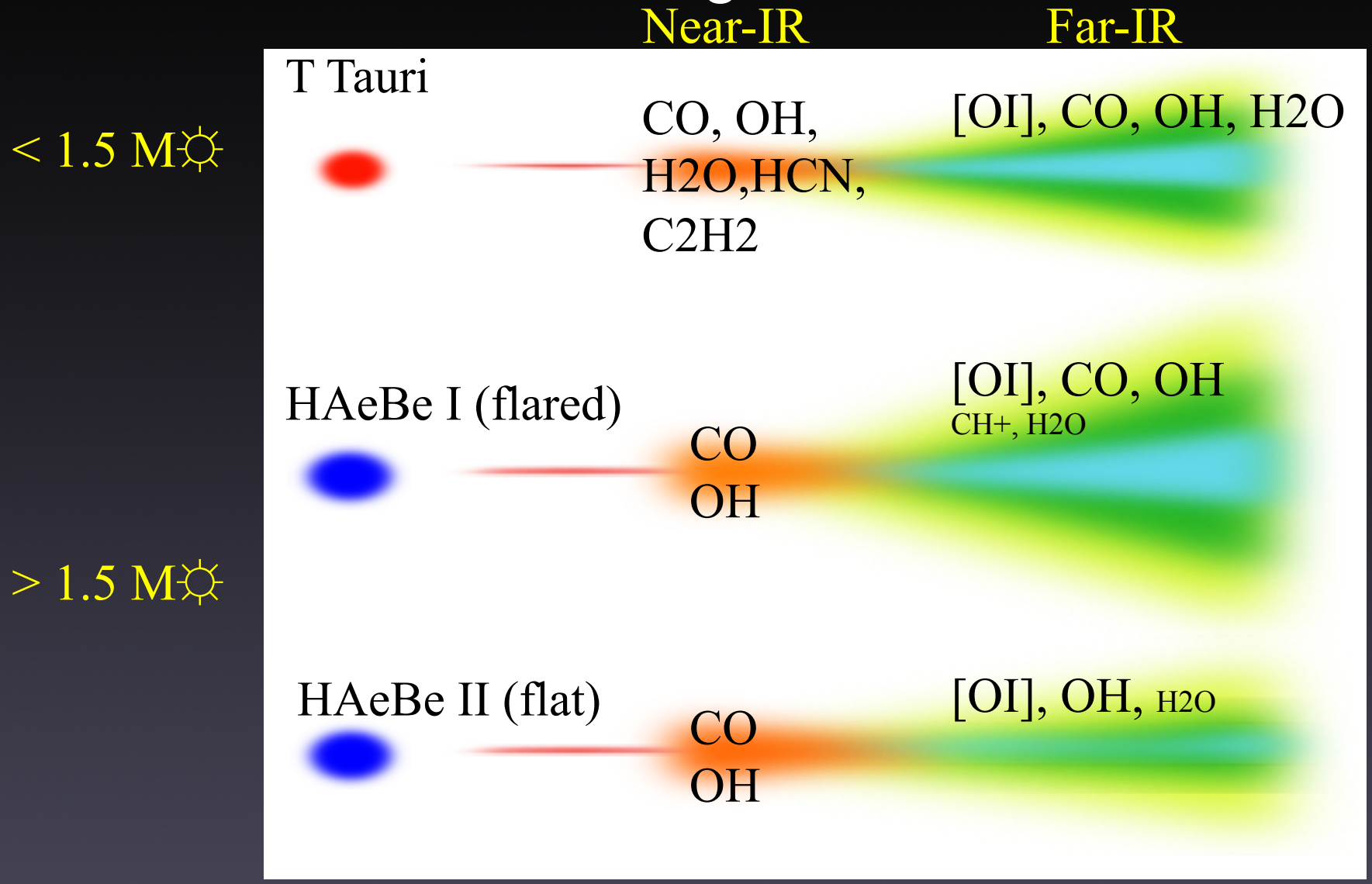
- 250 hrs + followup
- 31 embedded protostars (full spectral scans)
- 63 disk sources ranging from B to M in spectral type (intermediate and low mass), selected from nearby (a few x 100 pc) molecular clouds (Tau, Oph, Cha, Per, Ser, Lup)
- PACS spectroscopy (52-210 um), PACS photometry (WTTS only; 70, 100, 160 um)
- SPIRE photometry (WTTS only)
- HIFI spectroscopy on 557 GHz H2O
- Focus on evolution of chemical state during SF
- Spectral features of dust, ice, and gas
- OT2 Followup:
    - CO in protostars (PI: J. Green)
    - HIFI on CO J=16-15 (PI: L. Kristensen)
    - Serpens CO Line Map (PI: O. Dionatos)

Example: The Herbig Ae/Be star HD100546
complete spectral coverage with Herschel+ISO/Spitzer



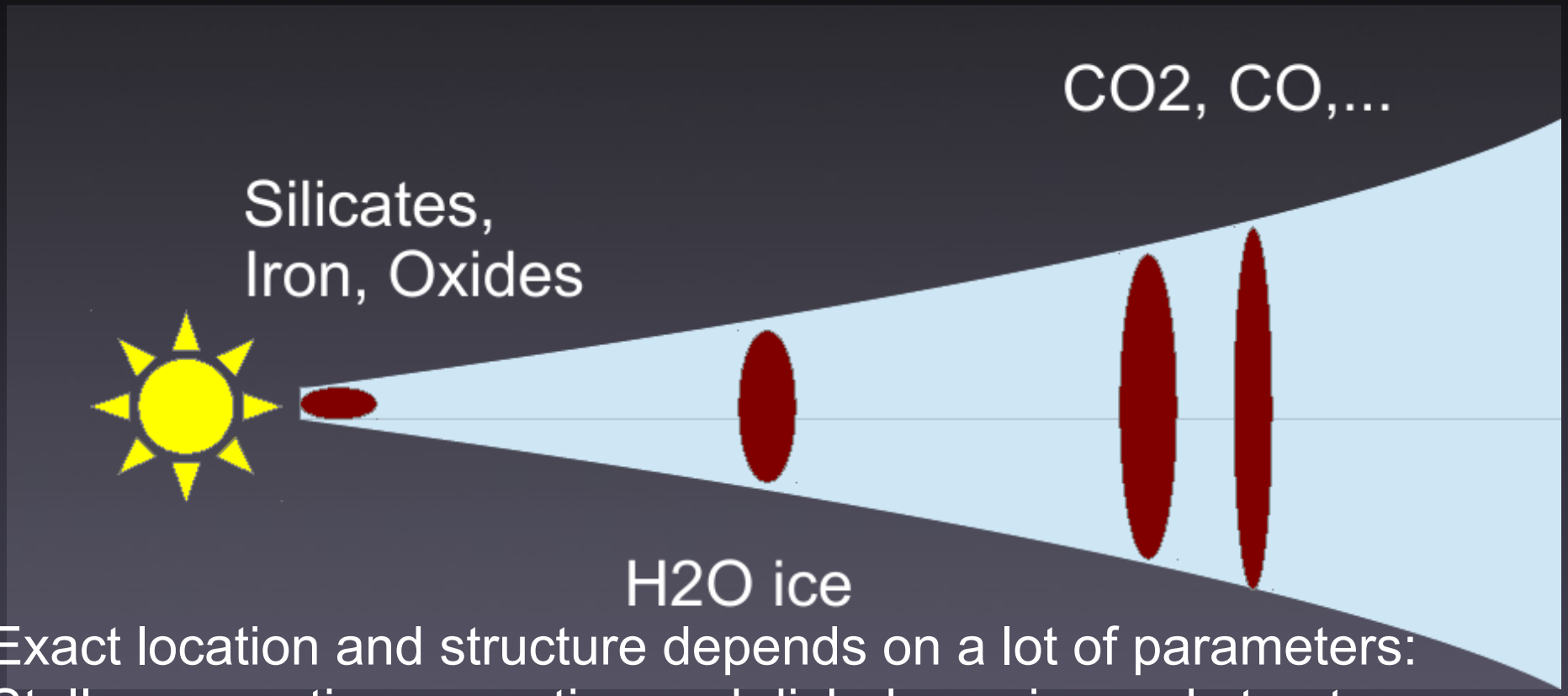
Bouwman et al in prep, see also Sturm et al 2010, 2013, van der Wiel et al in prep, Mulders et al 2011, Bouwman et al 2003, Malfait et al 1998, Min et al 2005, Juhasz et al 2010, Bruderer et al 2012

Not in this talk: DIGIT gas line studies of disks



Meeus et al 2013, Fedele et al 2012,2013, Salyk et al, in prep

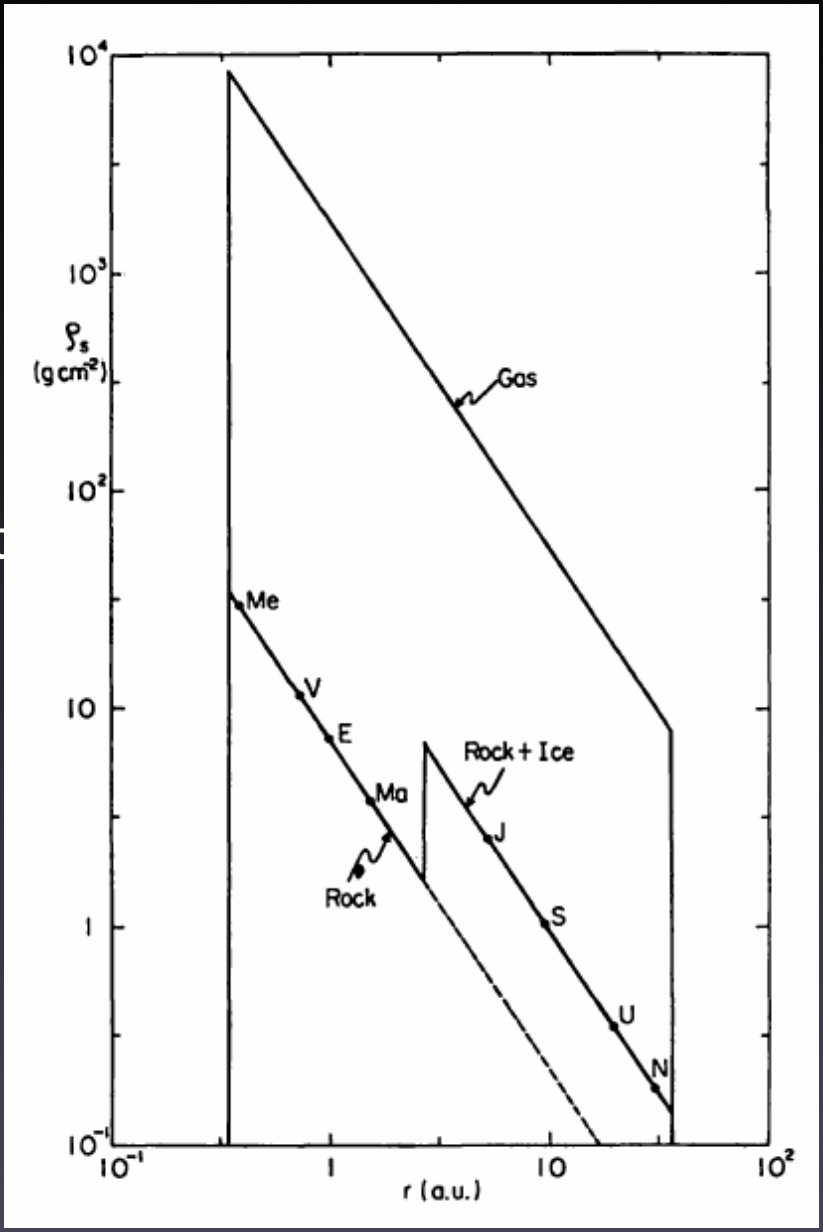
Dust condensation/evaporation zones



Exact location and structure depends on a lot of parameters: Stellar properties, accretion and disk dynamics and structure, shocks, grain properties.....and, and,and....

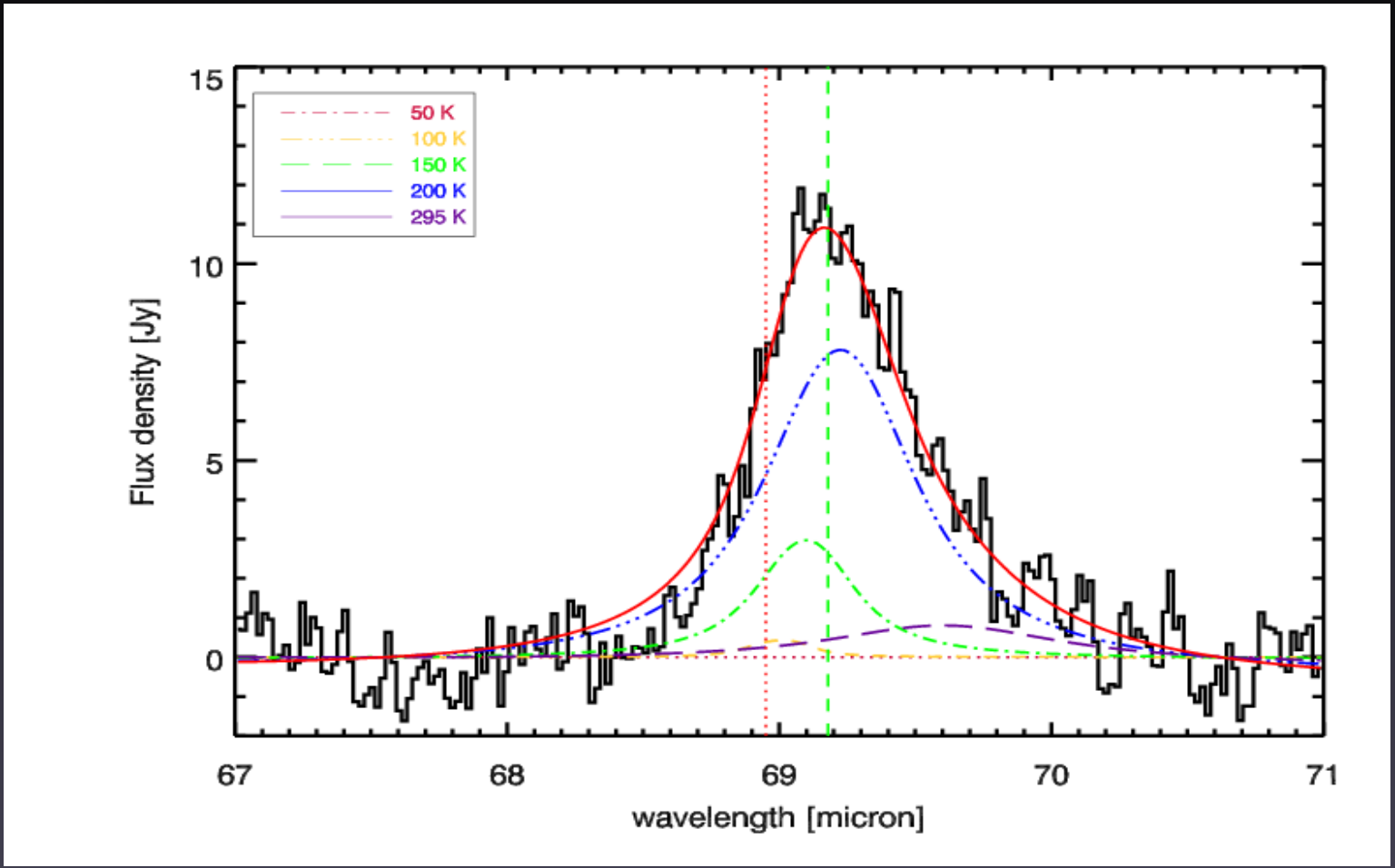
The Snow Line

- Original idea by Hayashi et al 1981
- Enhanced density of solid material
- Favorable for grain growth and planet
- formation.



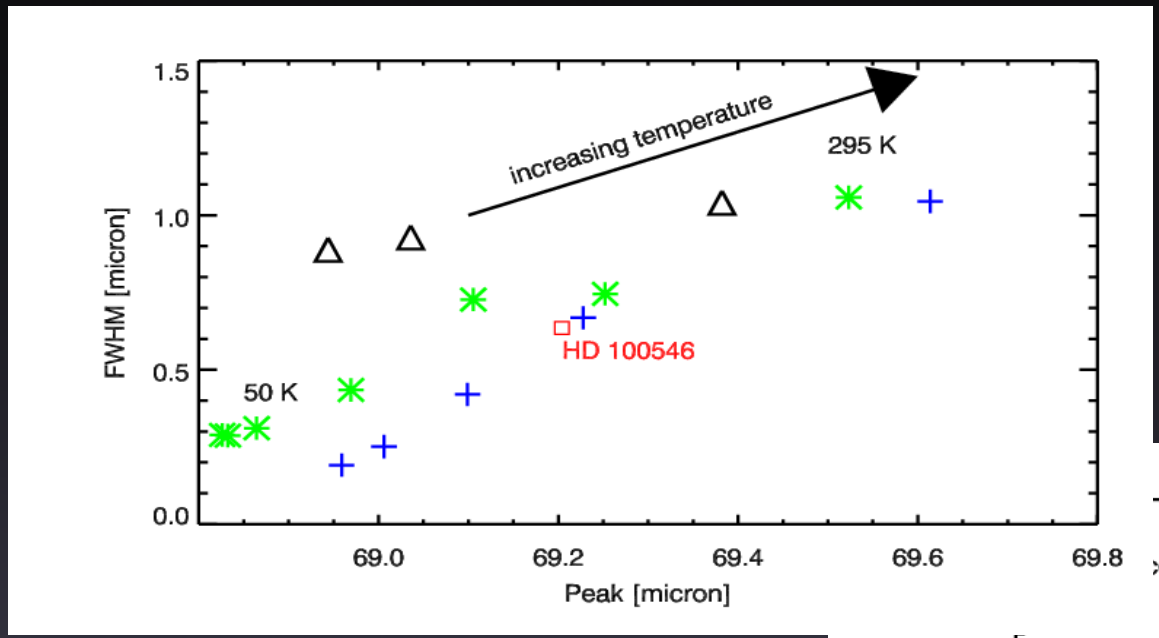
DIGIT Results I: Silicate processing

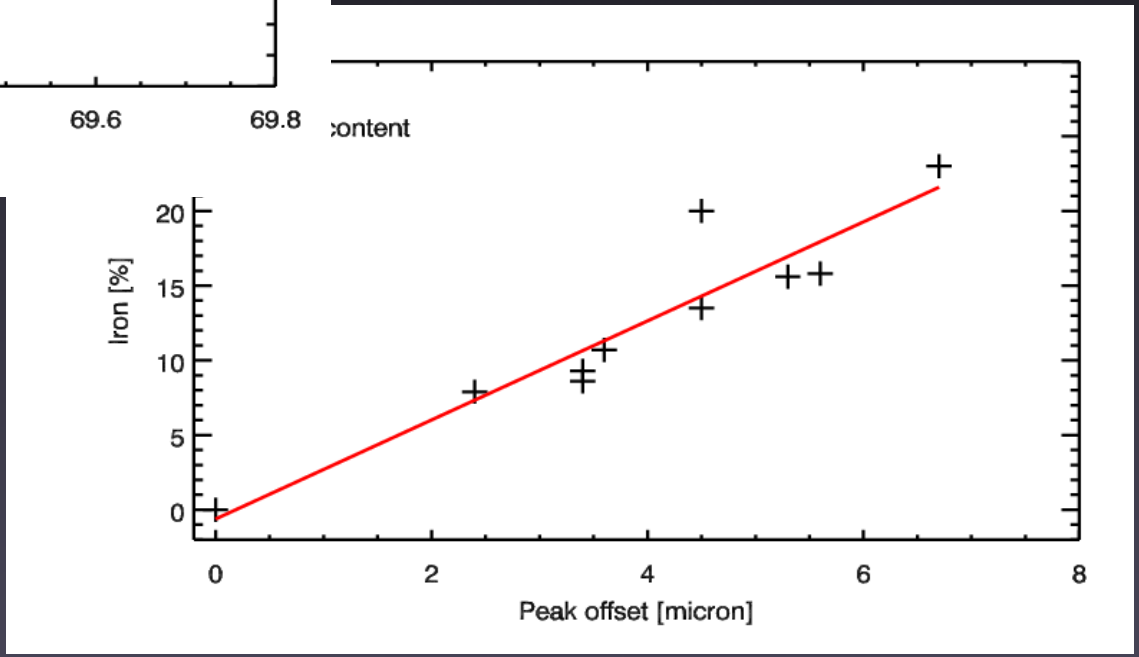
IThe 69 micron Forsterite feature



ISturm et al 2010, 2013, see also posters P34 by Blommaert et al and IP38 by de Vries et al for evolved stars and debris disks.

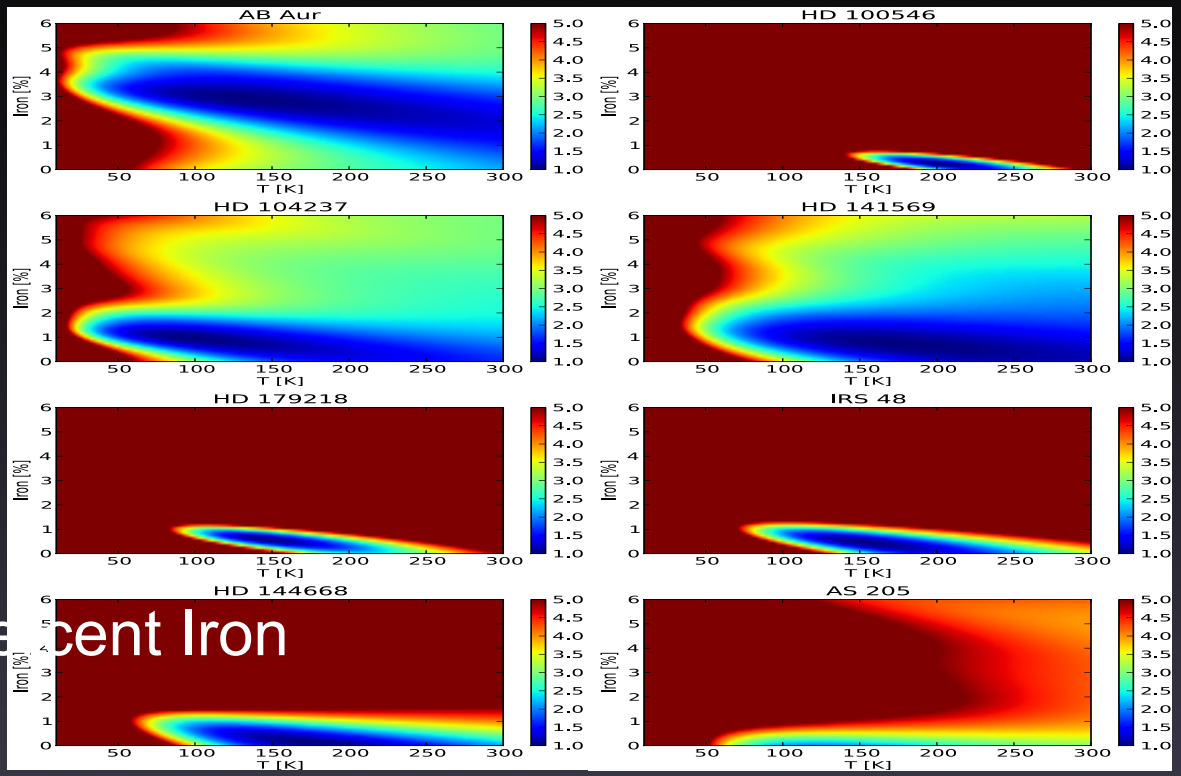
IInfluence of the temperature and iron content lon the 69 micron Forsterite feature





ISturm et al 2013

Fits in Fe - T plane



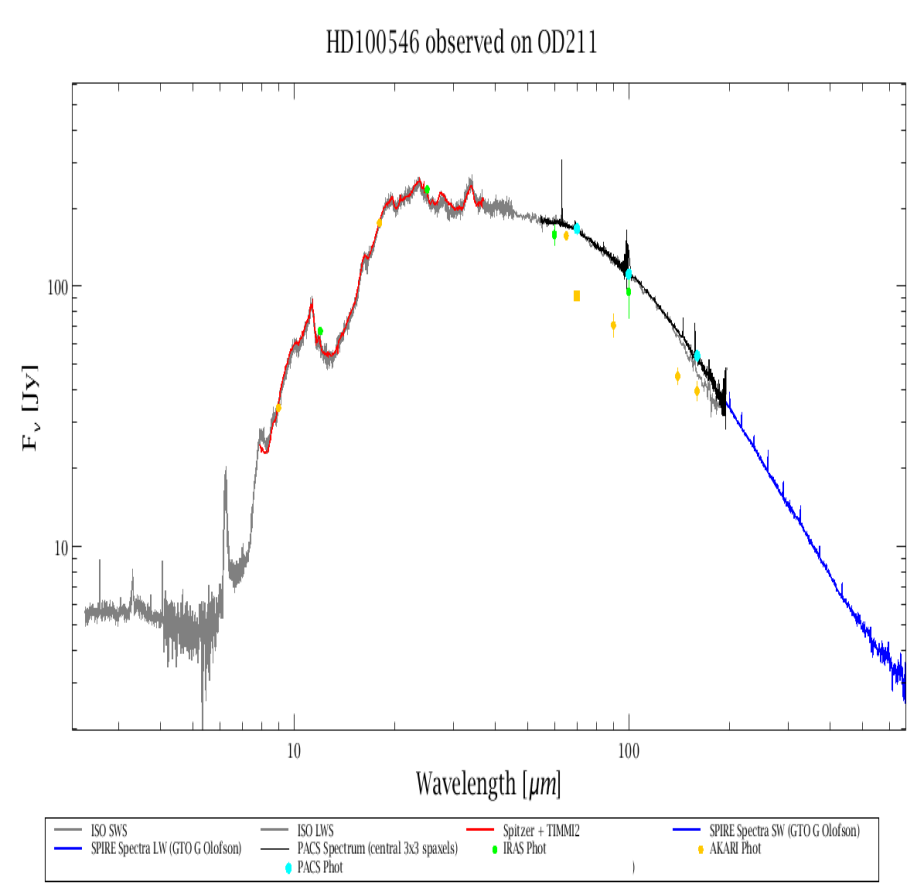
B. Sturm et al. 2013

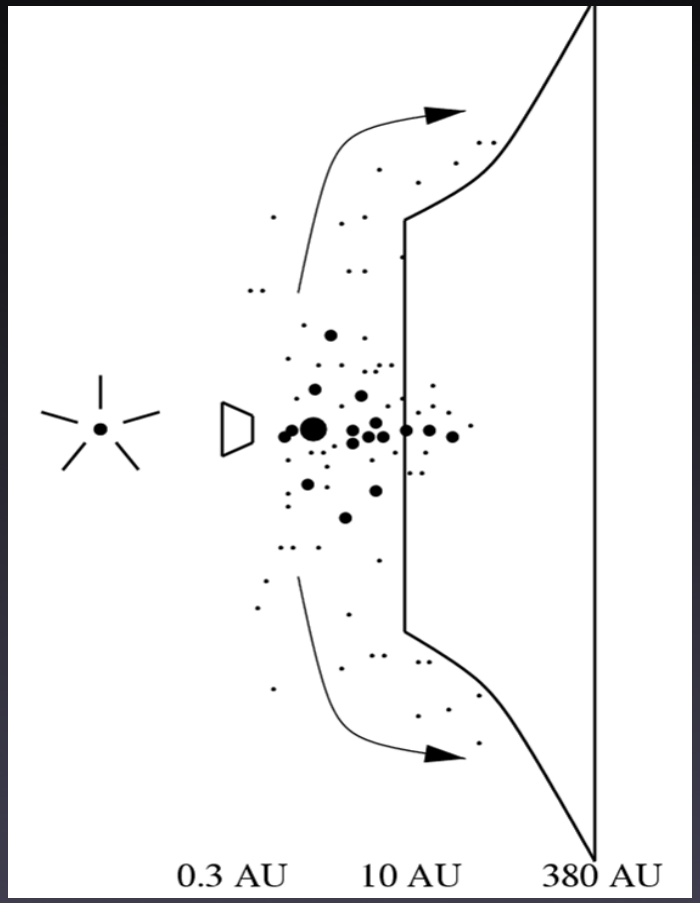
Percent Iron

Dust Temperature

8 out of 32 systems show forsterite band. Most require very low (< 1%) Fe content and a range of possible temperatures (100-300 K) which is consistent with high (1500K) temperature formation and than cooling (outward transportation).

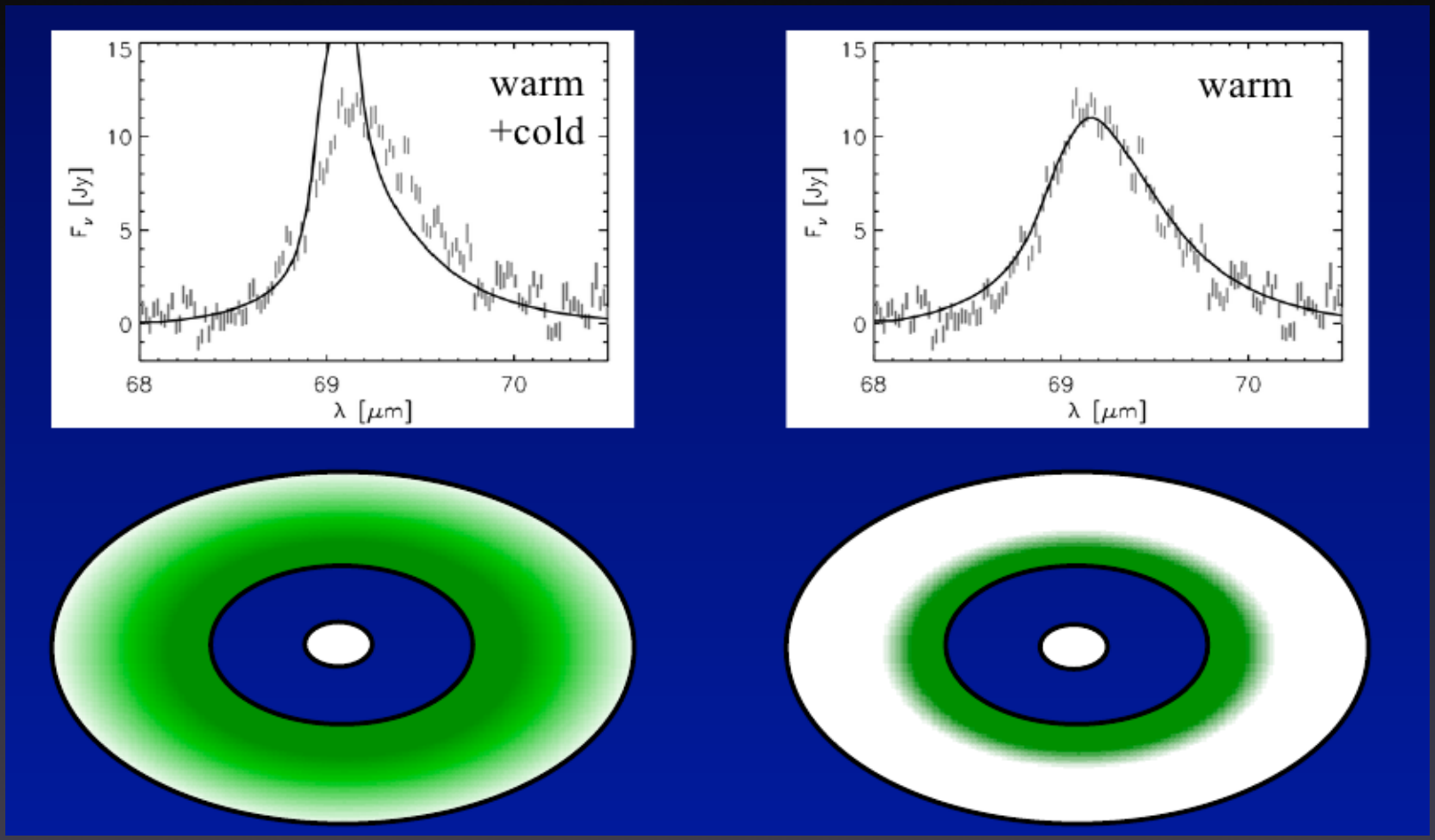
IHD100546: Giant planet opening a gap in the disk?





lBouwman et al. 2003

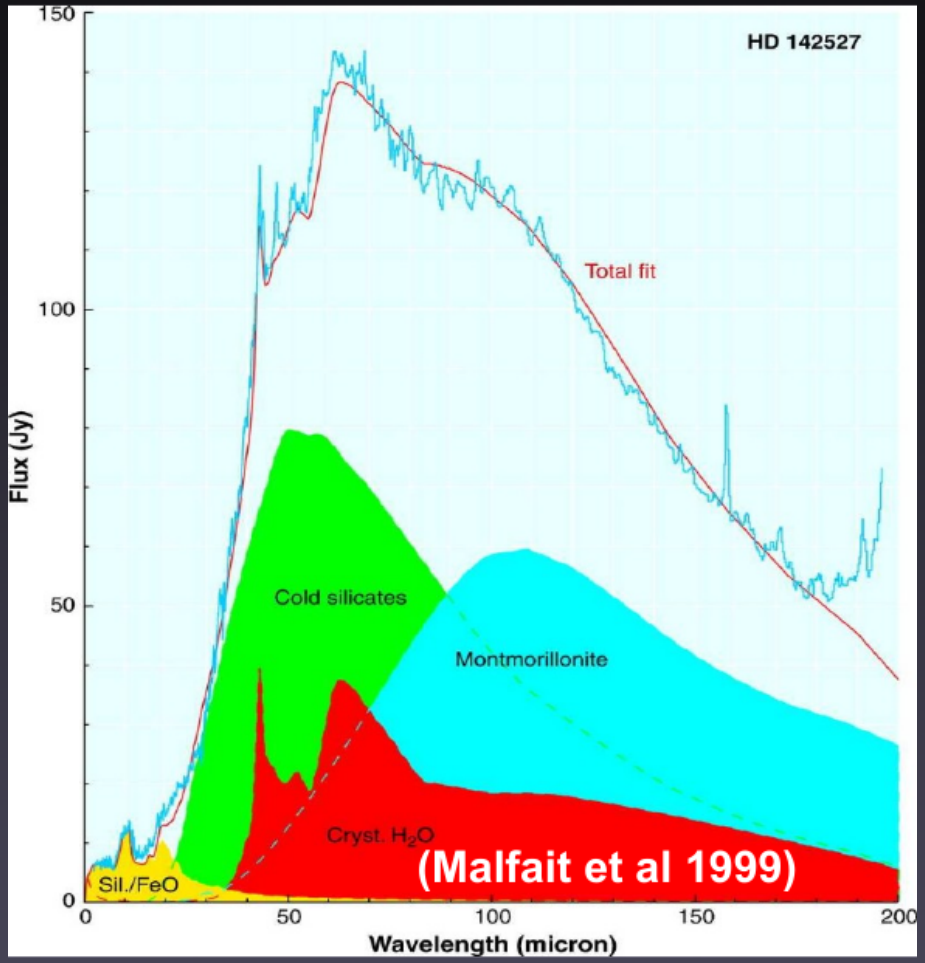
lLocation of the Forsterite in HD100546



I2D RT: forsterite located close to disk wall (13-20 AU). Low total mass (0.5-0.8%), but strong features. This results suggest an origin related to the formation of the disk gap (Mulders et al. 2011)

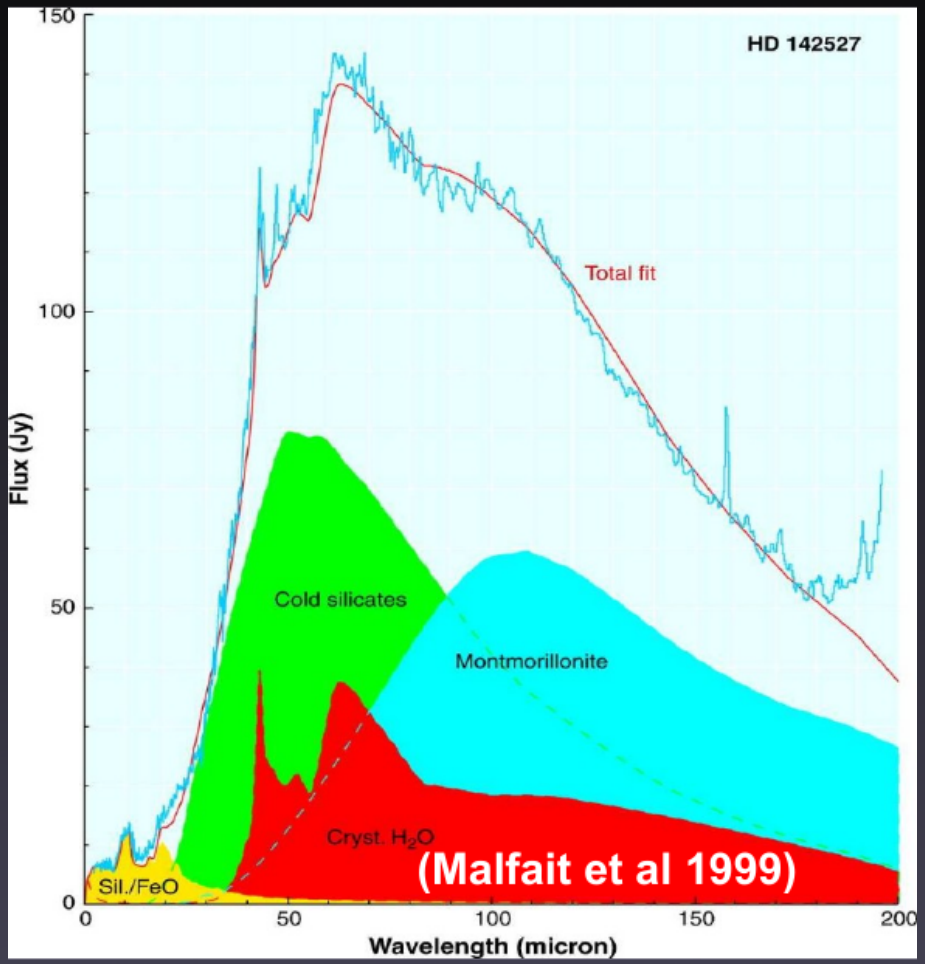
DIGIT result II: parent body processing of silicates

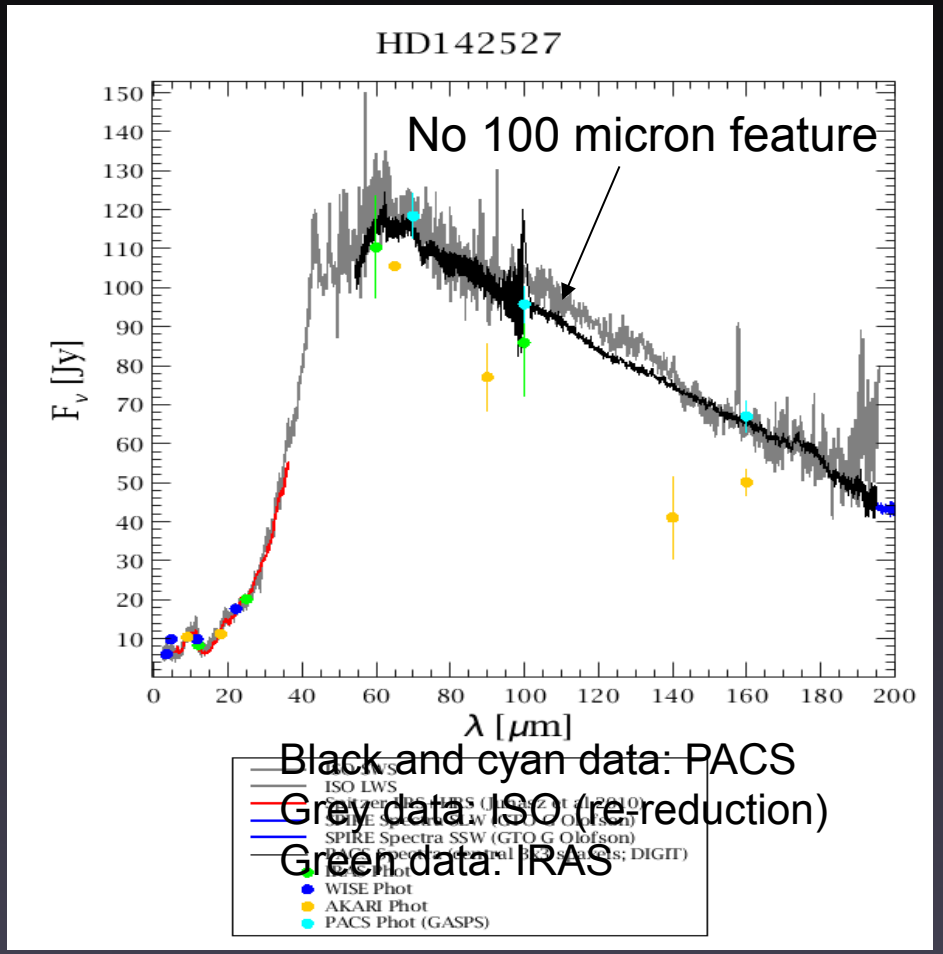
lExample of possible parent body processing: lhydrosilicates in the disk of the Herbig Ae lstars HD142527 with ISO



lNote: Hydrosilicates need liquid water in parent body to form, thus detecting hydrated silicates is indirect prove of larger (differentiated) objects present in the protoplanetary disk.

Herschel: No hydro-silicates in HD142527



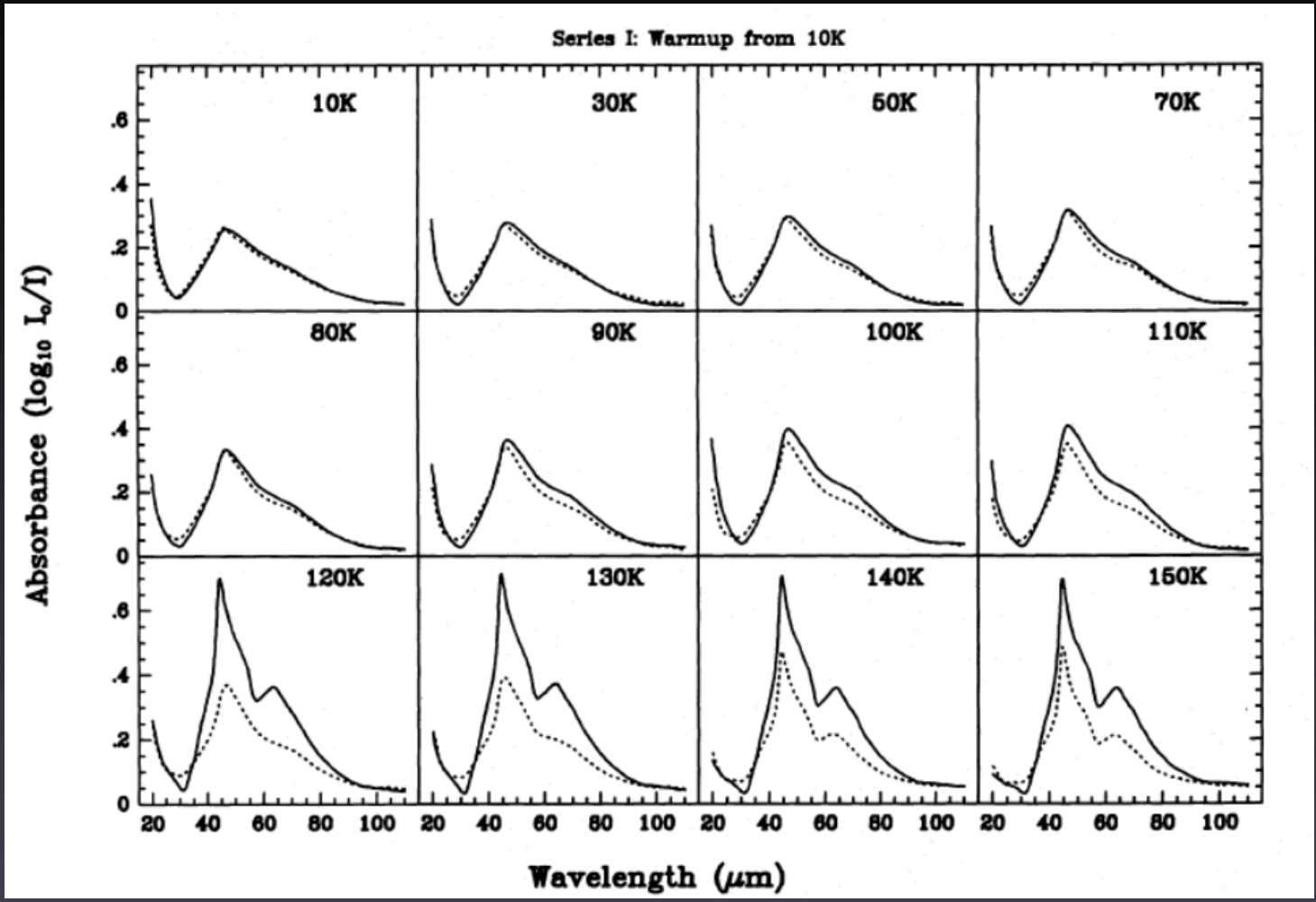


Black and cyan data: PACS
Grey data: ISO (re-reduction)
Green data: IRAS

Malfait et al 1999, M. Min et al in prep

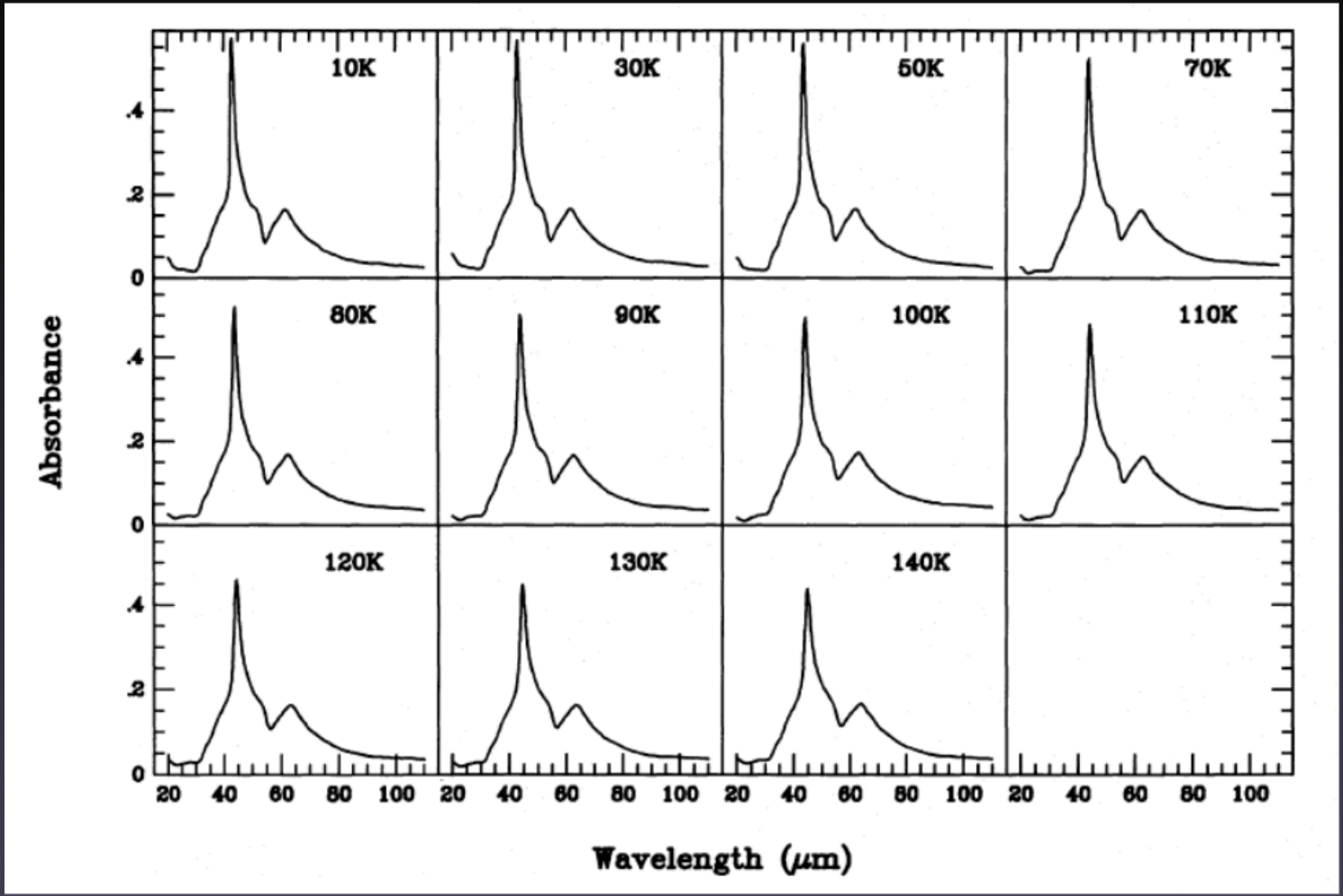
DIGIT result III: Water ice or how to characteriz the snow line.

Water Ice Opacities: From Cold to Warm



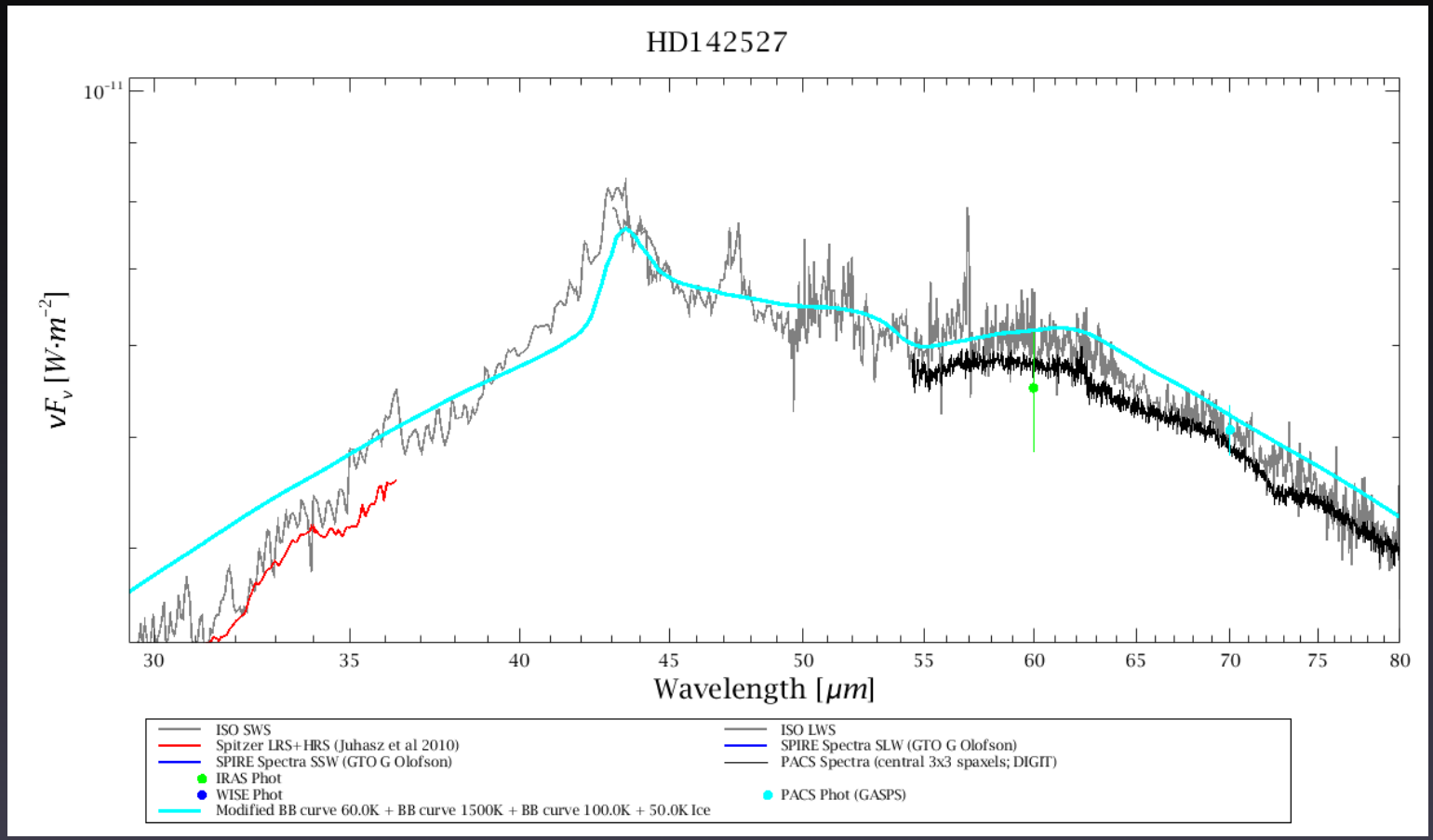
Smith et al 1994

Water Ice Opacities: From Warm to Cold



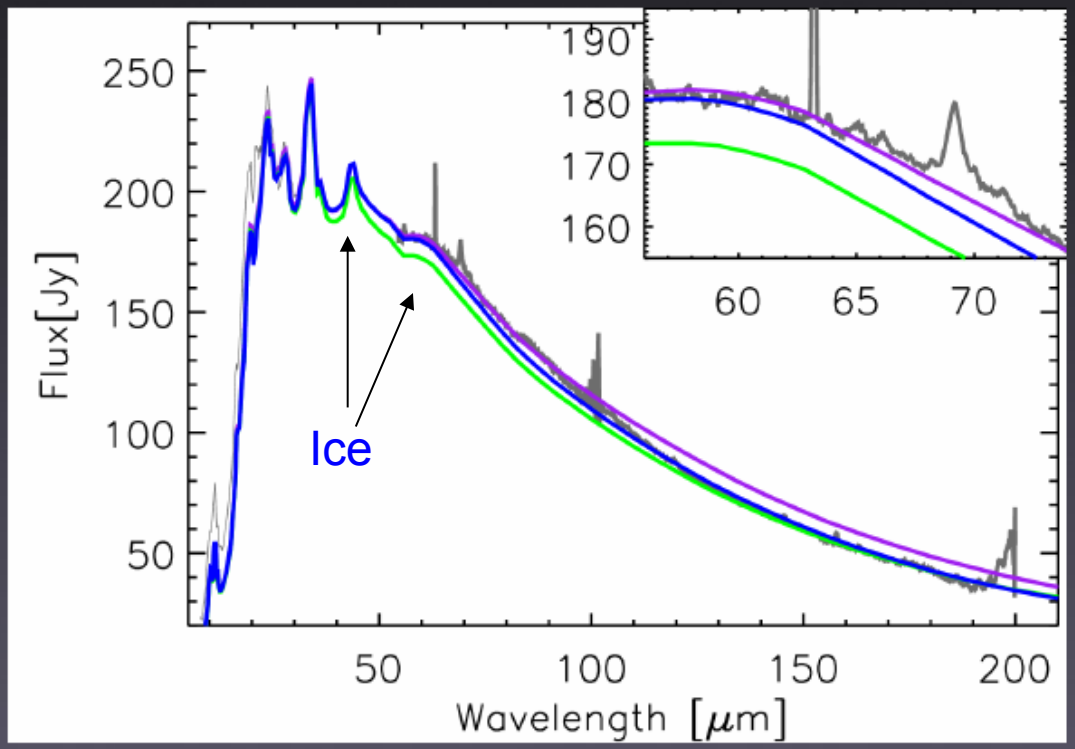
Smith et al 1994

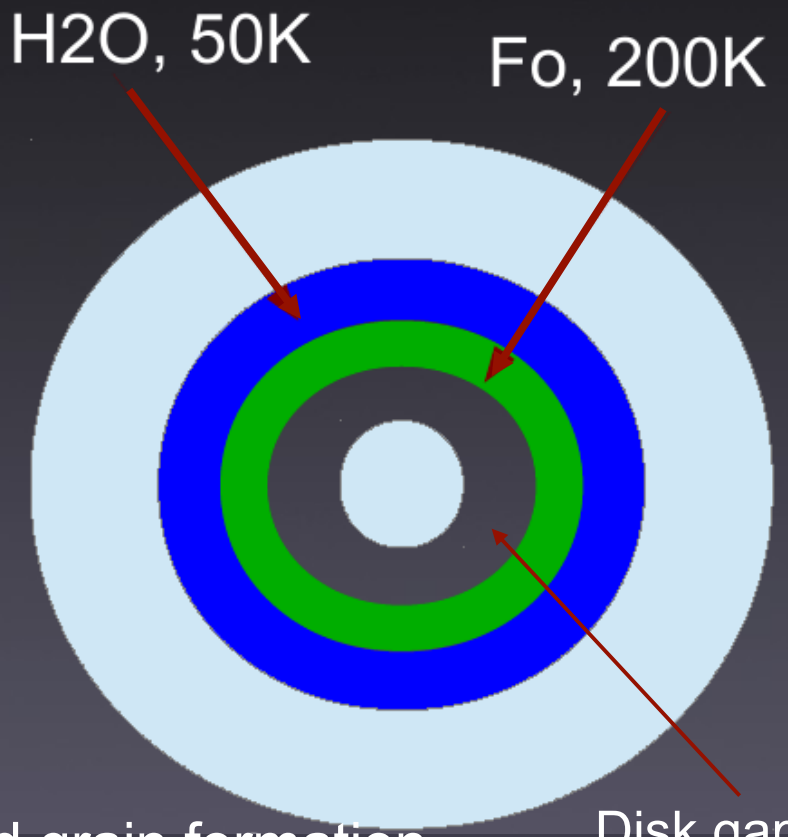
The Ice bands in the spectrum of HD142527



Ice consistent with crystalline water ice formed at the condensation temperature (~140
and than cooled down to ~40-50K, Min et al in prep.

Modeling of the Silicate and Ice features





-Consistent with transient disk heating and grain formation near outer edge of the disk gap: Disk-Planet interaction?

-Need only few percent in mass of H2O ice crystals.

-Work in progress: No amorphous ice? Grain size? Mantels?

Conclusions

Herschel observations + Spitzer/ISO can characterize the condensation zones in protoplanetary disks.

Detection of Far-IR silicate band of forsterite in 25% of the systems in the DIGIT disk sample. Silicates consistent with high temperature gas-phase condensation. Need of radial mixing of local transient heating (disk-planet interaction).

No evidence for Hydrosilicates

First time a characterization of the snow line is possible. Ice bands and gas phase water detected in several disks, analysis in progress.