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

Not in this talk: DIGIT gas line studies of disks

T Tauri
< 1.5 M☉
CO, OH, [OI], CO, OH, H2O
H2O, HCN, C2H2

HAeBe I (flared)
[OI], CO, OH
CO, CH+, H2O
OH

HAeBe II (flat)
> 1.5 M☉
[OI], OH, H2O
CO, OH

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
The 69 micron Forsterite feature

Sturm 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.
Influence of the temperature and iron content on the 69 micron Forsterite feature

Sturm et al 2013
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 then cooling (outward transportation).
IHD100546: Giant planet opening a gap in the disk?

Bouwman et al. 2003
Location of the Forsterite in HD100546

2D 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
Example of possible parent body processing: Hydrosilicates in the disk of the Herbig Ae/Be stars HD142527 with ISO

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

(Malfait et al. 1999)
Herschel: No hydro-silicates in HD142527

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

No 100 micron feature

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

(Malfait et al 1999)
DIGIT result III: Water ice or how to characterize 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 (~140K) 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.