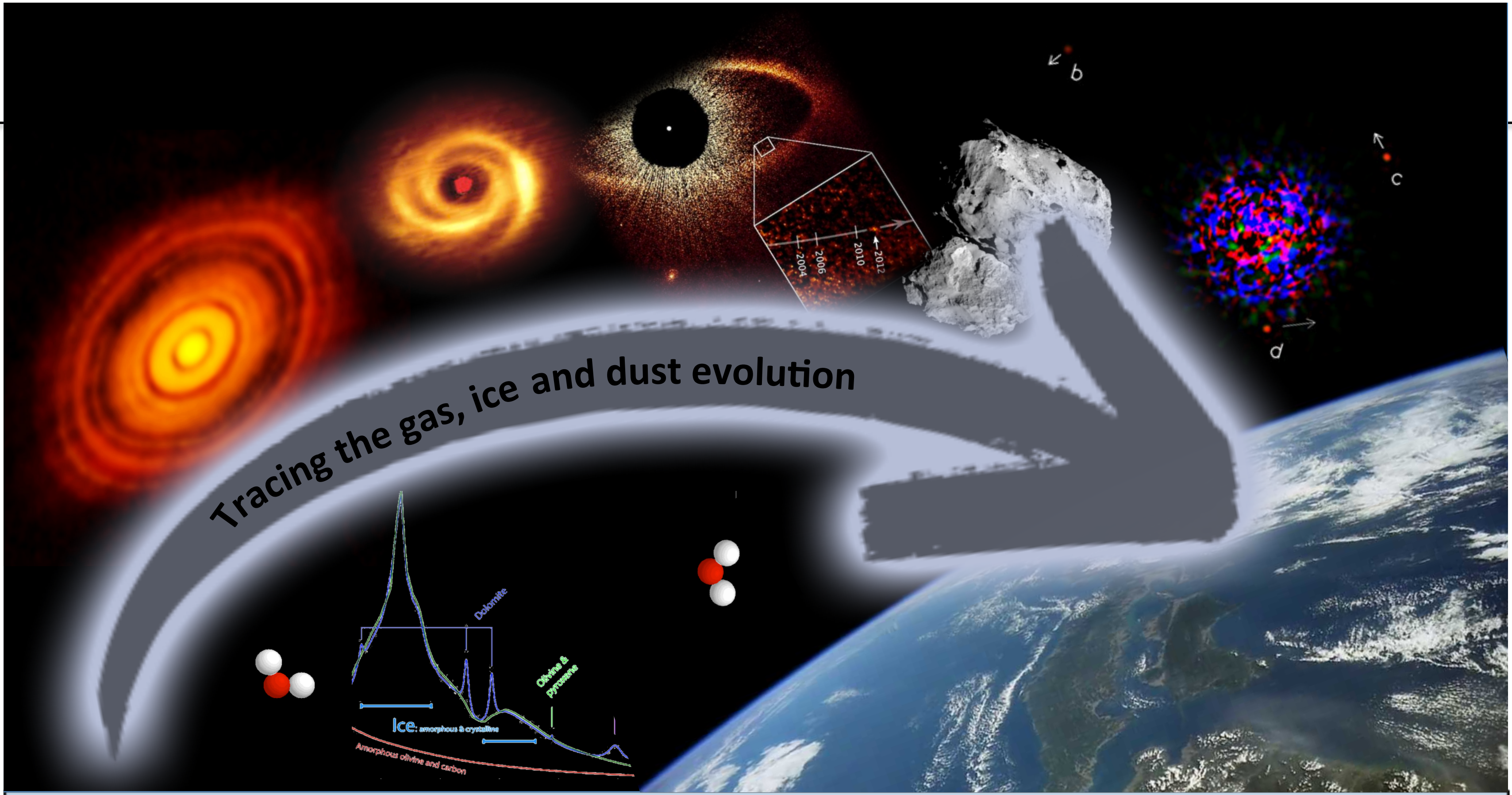
Protoplanetary disks

or

Tracing the gas, ice and dust evolution in planetary systems...

Inga Kamp, Marc Audard, on behalf of the SPFE team



1. How is water delivered to the planets?
2. How do solids evolve from pristine dust to differentiated bodies, and what is the link with our own Solar System?
3. When does the gas supply exhaust during the planet forming phase?
4. How does gas dissipation and photo-evaporation set the clock for planet formation?

Where SPICA makes an impact for PPDs

Unique SPICA capabilities:

simultaneous λ coverage 34-210 μm – HD & wide range of cooling lines (CO, H_2O)

far-IR water lines and water ice features @ 40 and 60 μm

line profiles w/o telluric contamination @12-18 μm (e.g. H_2, HD, [NeII], H_2O, R~30000)

Competition between now and 2028:

VLT/VISIR and CRIRES (now+, 2017?): N-, Q-band R~20000-30000, up to 5 μm R~100000 and AO **=> limited by AO & telluric corrections**

ground-based interferometers (e.g. MATISSE 2016) **=> complementary high spatial resolution, but low spectral resolution**

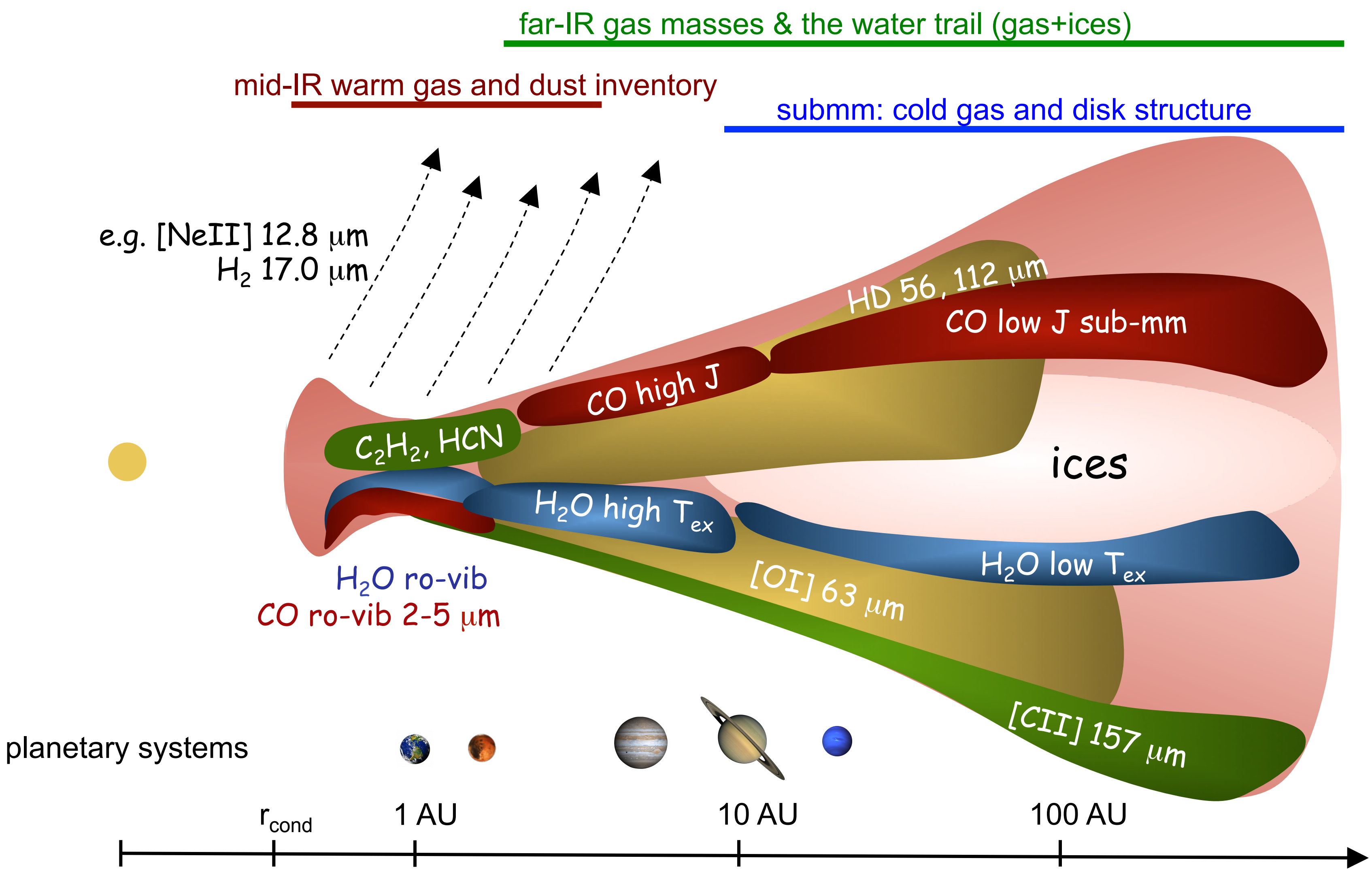
ALMA (now+) submm λ, heterodyne spectral resolution, AU spatial scale **=> complementary tracing cold (10-50K) material**

JWST (2018-2023), R~3000, 5-28 μm **=> limited spectral resolution causing line confusion/blending**

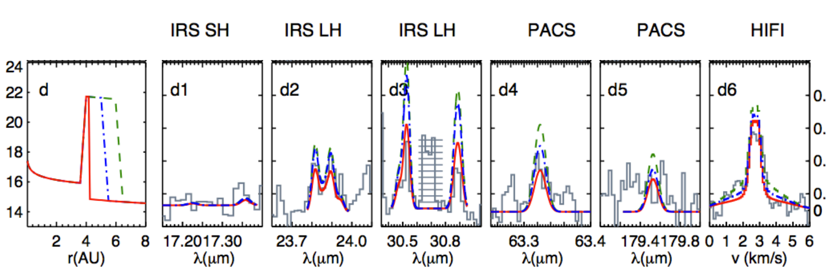
ELT/METIS (2024+), N(10μm)-band high spatial resolution (R<5000) **=> limited by AO & telluric corr., but very high sensitivity;** only L(3.5μm), M(4.7μm) have R~100000 !

MICHI (not approved yet) L, M, N, (Q-band) with R~120000, but transmission gap

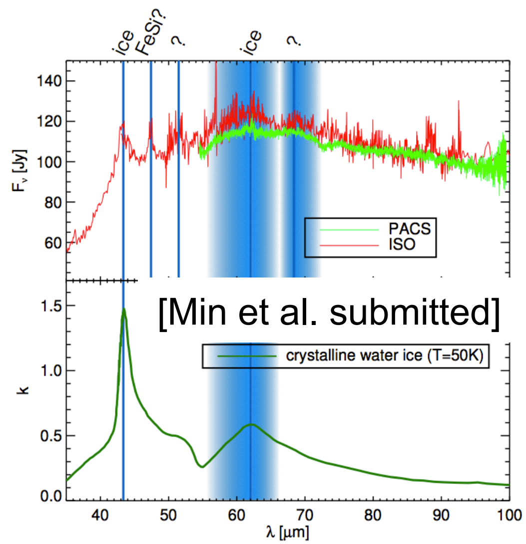
Observations of protoplanetary disks



How is water delivered to planets?

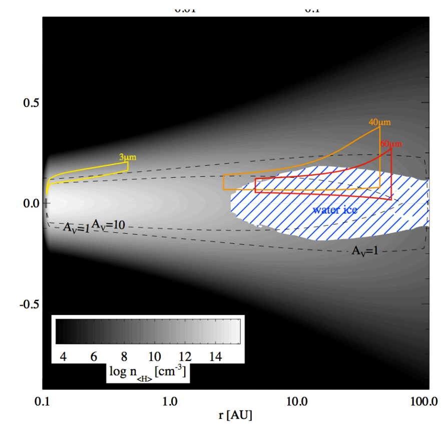


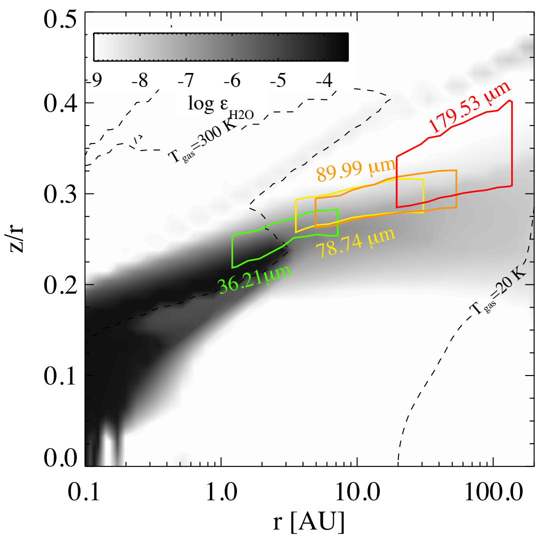
[Zhang, K. et al. 2013]



[Min et al. submitted]

thermal emission from water ice in a standard T Tauri disk





[FT Tau disk model: Garufi et al. 2014]

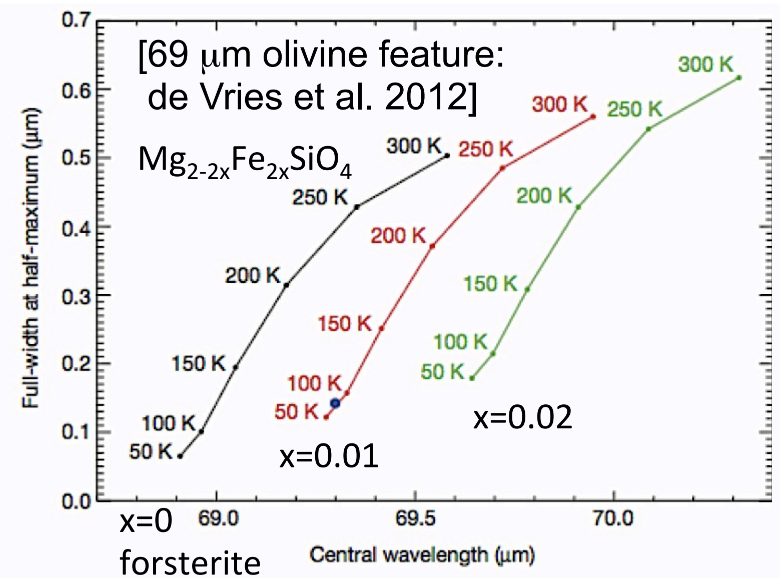
Science goals SMI/SAFARI:

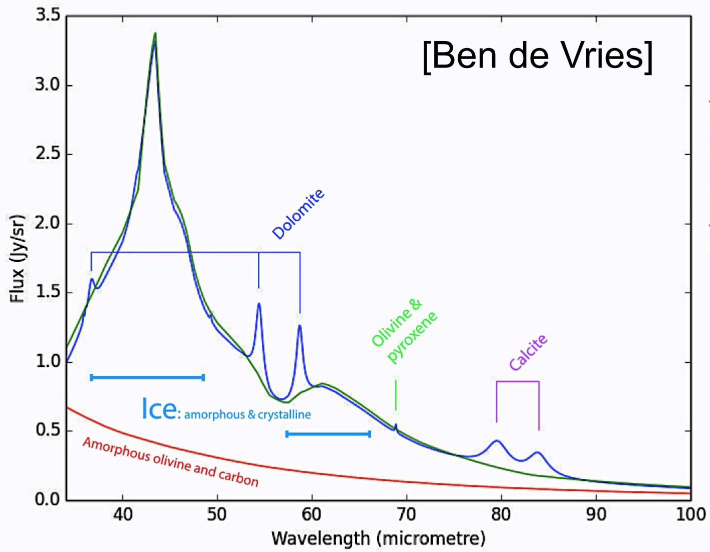
- trace the snow line with line fluxes (drop-out method)
- study the thermal history of ices during disk evolution

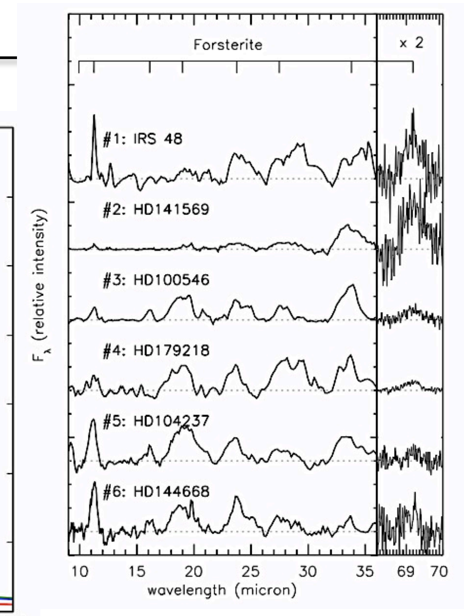
Uniqueness: ice features, broad λ coverage

Requirements: high line sens & spec resolution (push line/continuum), broad baseline stability (e.g. 55-80μm better than 10%), λ_{min}=30μm, careful design of λ split

How do solids evolve from pristine dust to differentiated bodies?







[10, 20 and 69 μm features: Maaskant et al. 2015]

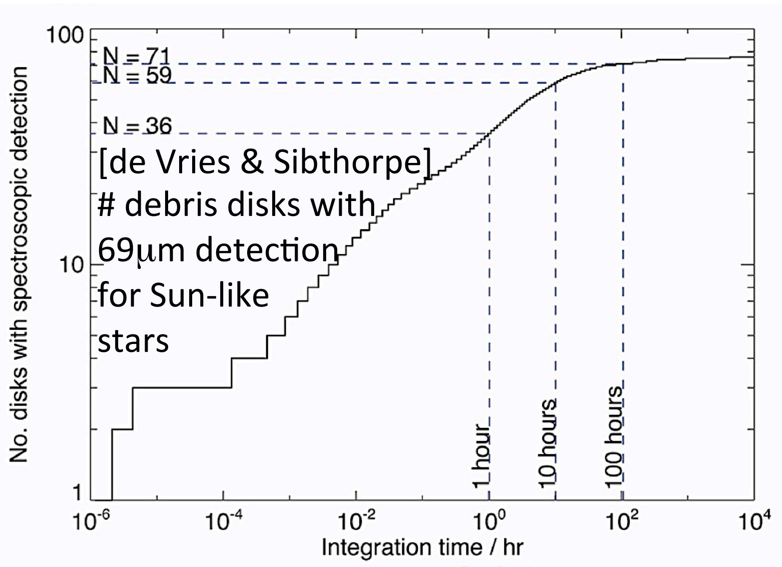
Science goals SAFARI/SMI:

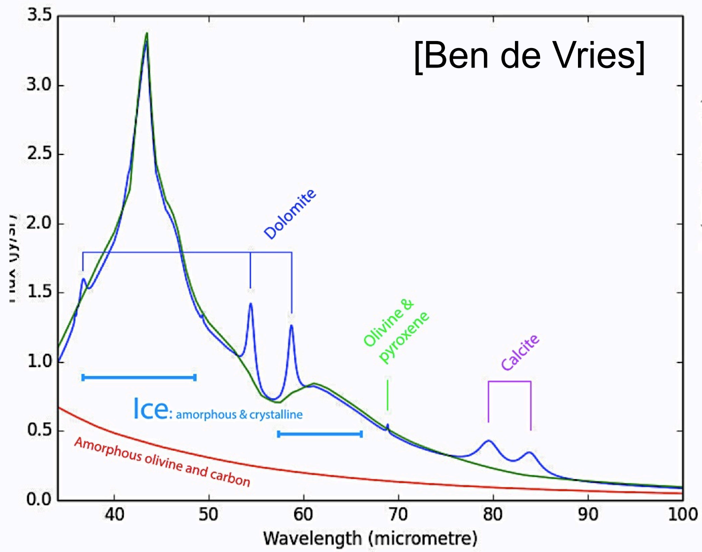
- determine evolution of composition (e.g. Fe/Mg) and lattice structure of grains

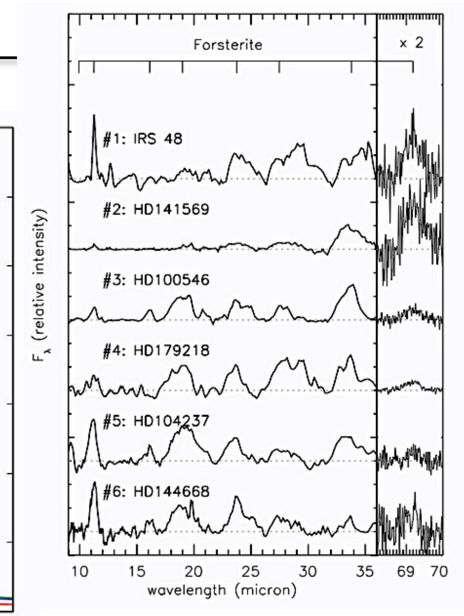
Uniqueness: features beyond 30μm (e.g. forsterite, calcite, dolomite, pyroxene)

Requirements: broad baseline stability (e.g. 55-80μm better than 10%), λ_{min}=30μm, careful design of λ split

How do solids evolve from pristine dust to differentiated bodies?







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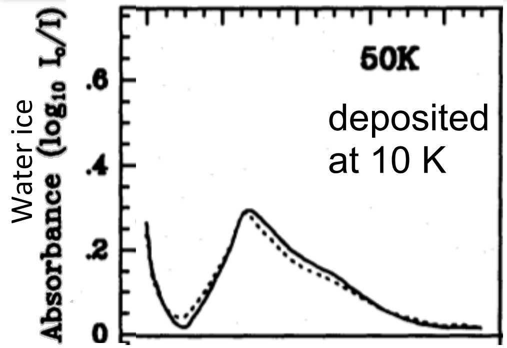
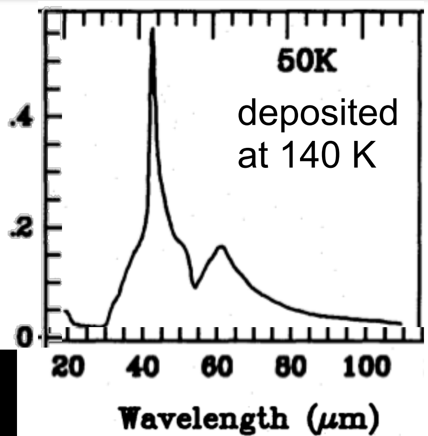
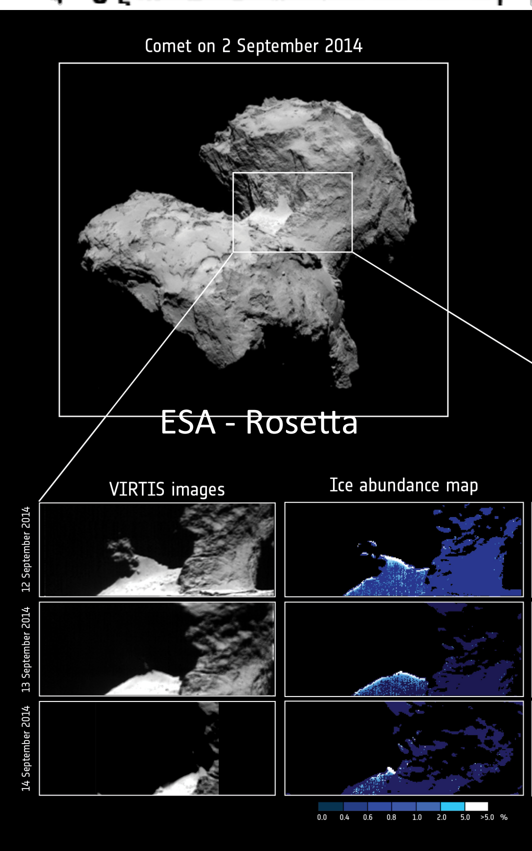
… and the link to the Solar System

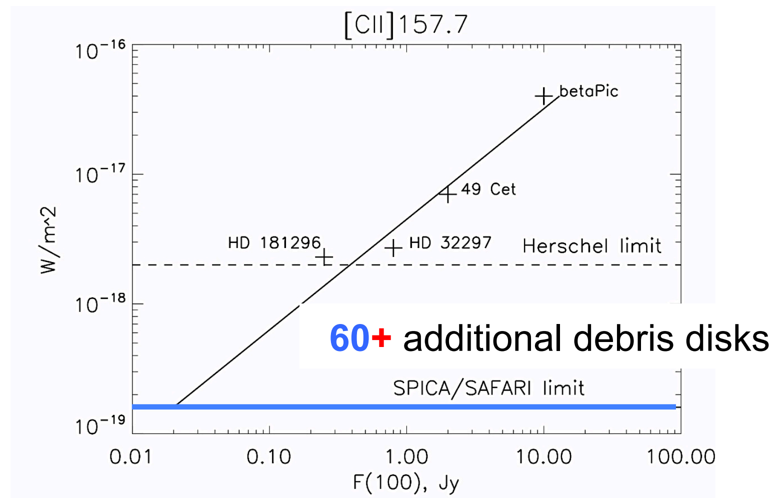




[Smith, R.G. et al. 1994]



[gas detections in debris disks: Goeran Olafsson]



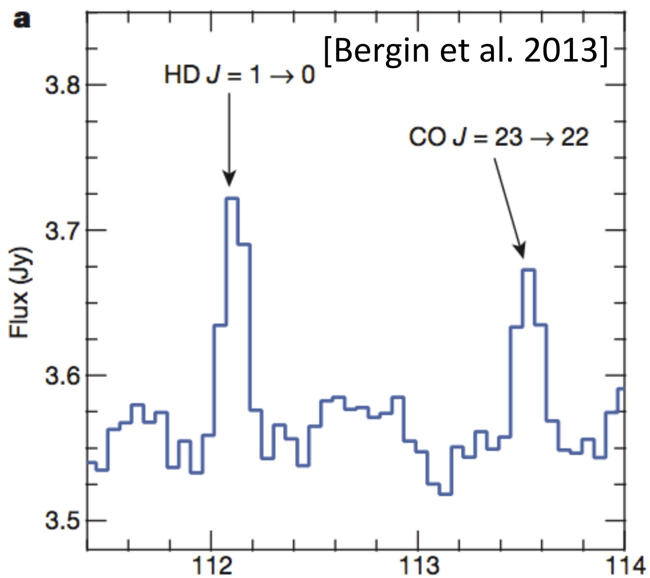
Science goals SMI/SAFARI:

- understand the nature of gas in debris disks (e.g. [FeII], [CII], [OI], water, OH, CO)
- study the thermal history of ices during disk evolution

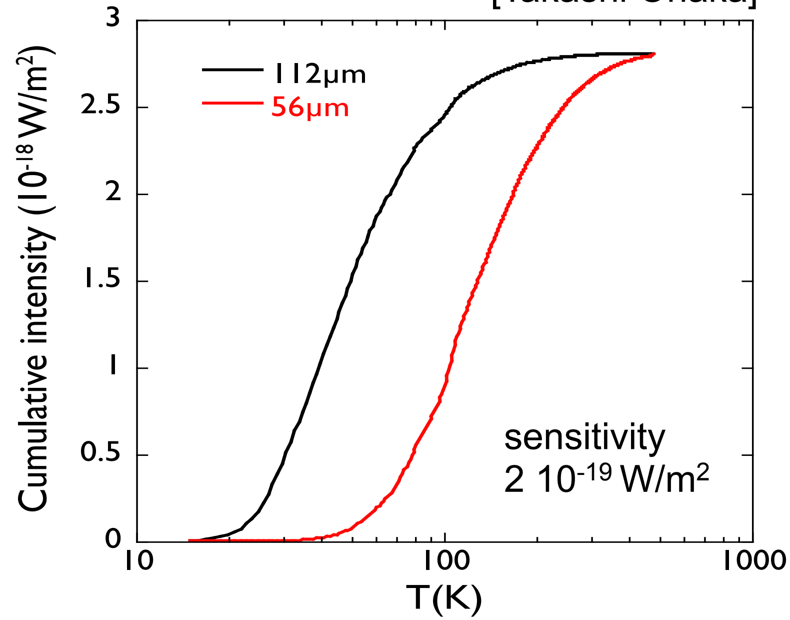
Uniqueness: ice features, full far-IR λ range

Requirements: broad baseline stability (e.g. 55-80μm better than 10%), λ_{min}=30μm, careful design of λ split

When does the gas supply exhaust during the planet formation phase?



[Takashi Onaka]

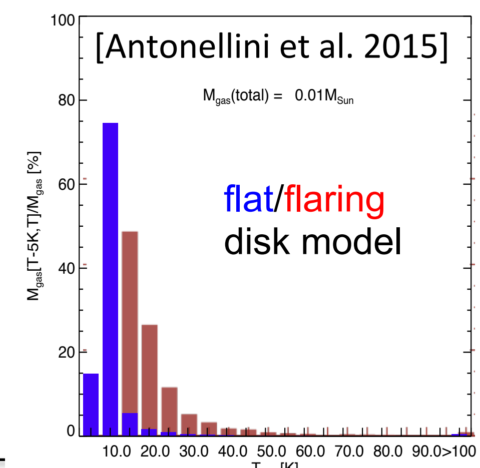


Science goals SMI/SAFARI:

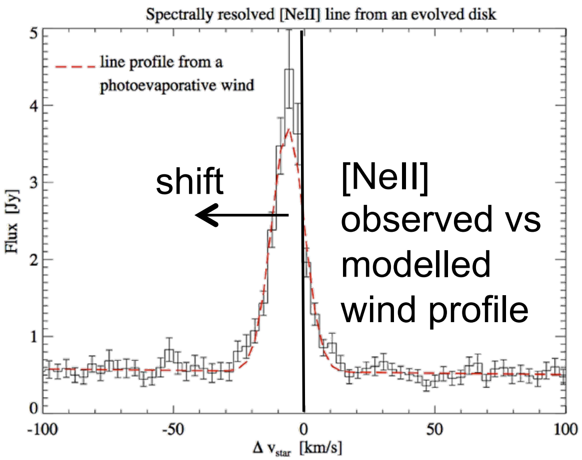
- direct disk gas mass evolution through HD

Uniqueness: several lines of HD probing a wide range of T_{gas} (50 - few 100 K)

Requirements: high line sensitivity, highest possible spectral resolution (push line/continuum)

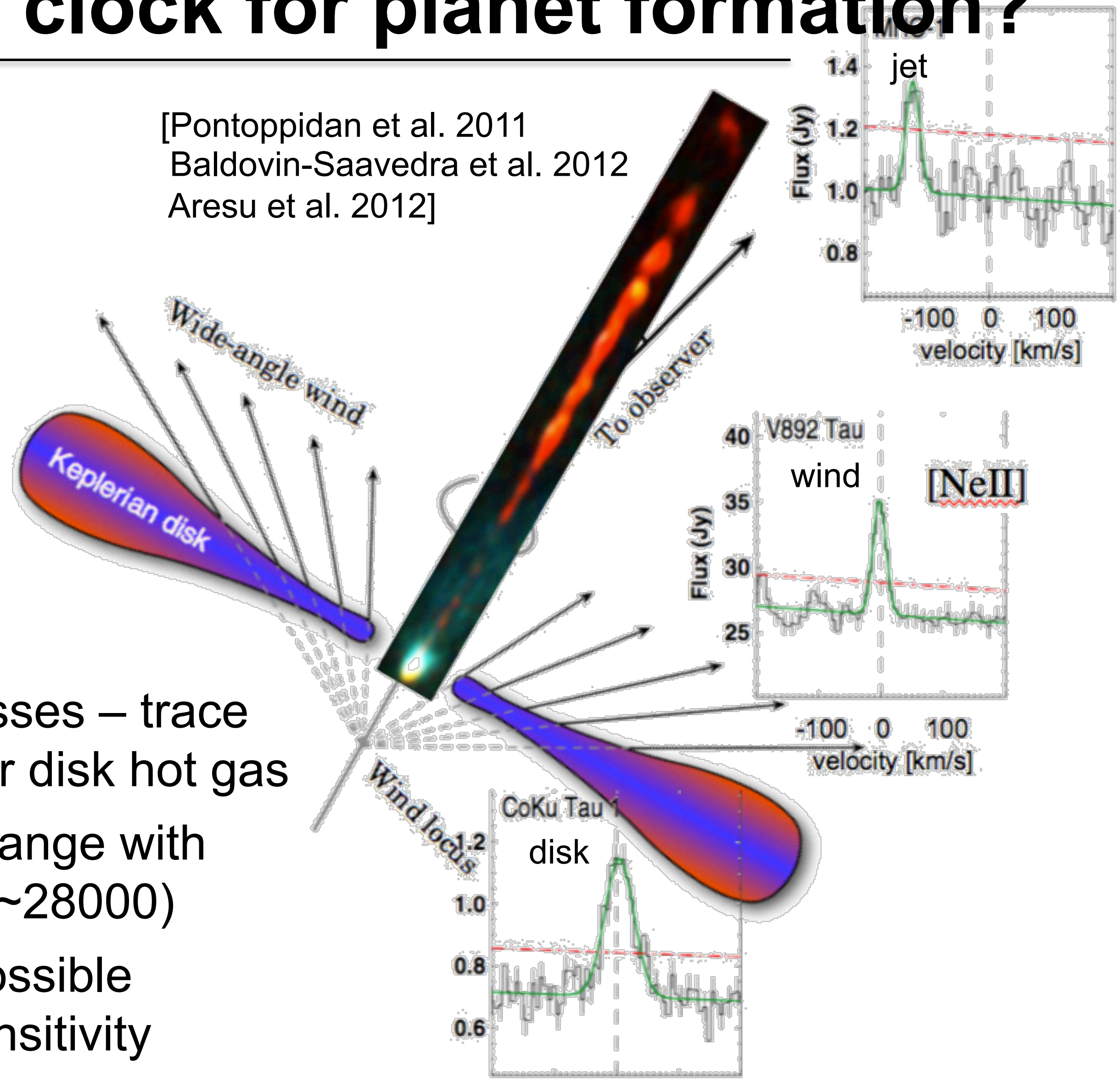


How does gas dissipation and photoevapo-ration set the clock for planet formation?



[Pascucci et al. 2012]

[Pontoppidan et al. 2011
Baldovin-Saavedra et al. 2012
Aresu et al. 2012]



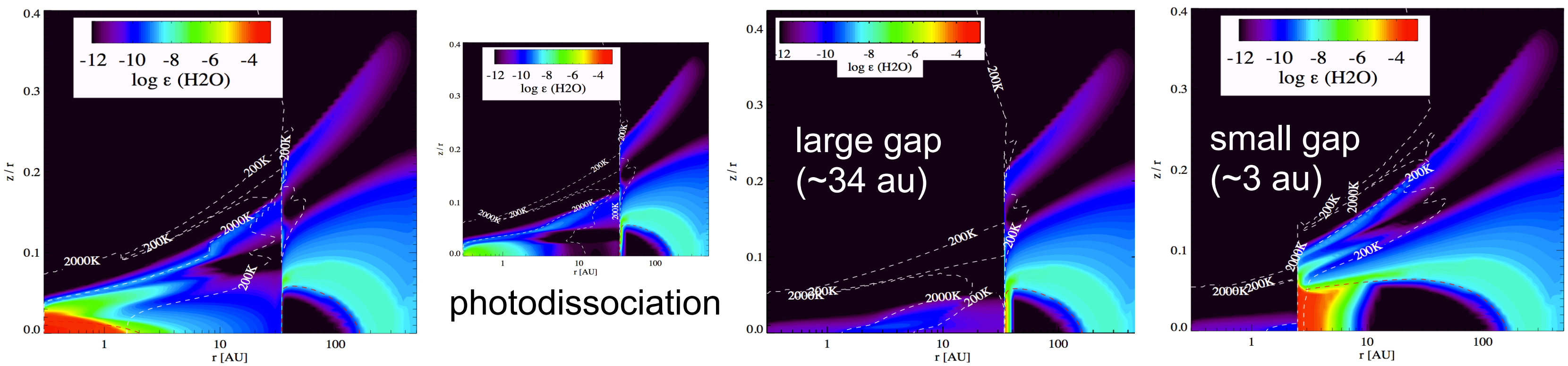
Science goals SMI:

- gas disk dispersal processes – trace directly launching of inner disk hot gas

Uniqueness: 12-18μm λ range with high spectral resolution (R~28000)

Requirements: highest possible spectral resolution, line sensitivity

How does gas dissipation and photoevaporation set the clock for planet formation?



inner water reservoir =>
strong broad mid-IR water lines

new water vapor reservoir at the inner rim of the outer disk =>
strong narrow mid-IR water lines

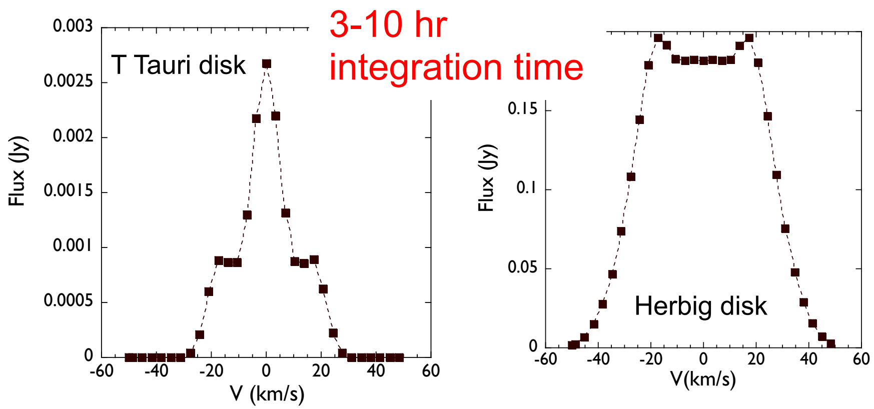
[Kamp, van den Born, Hein Bertelsen in prep]

Science goals SMI:

- gas disk dispersal processes – trace gap opening in inner disks (planets?)

Uniqueness: 12-18μm λ range with high spectral resolution (R~28000)

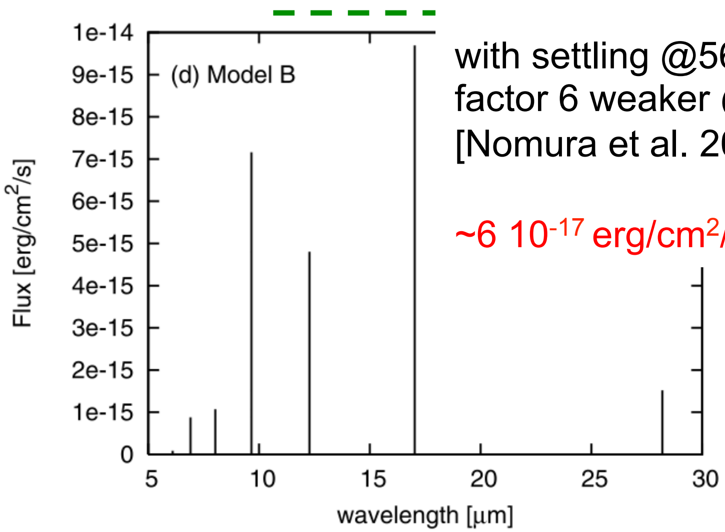
Requirements: highest possible spectral resolution, line sensitivity



17.8 μm water line profile by T. Onaka based on disk models from [Notsu, Nomura et al. 2016a,b]

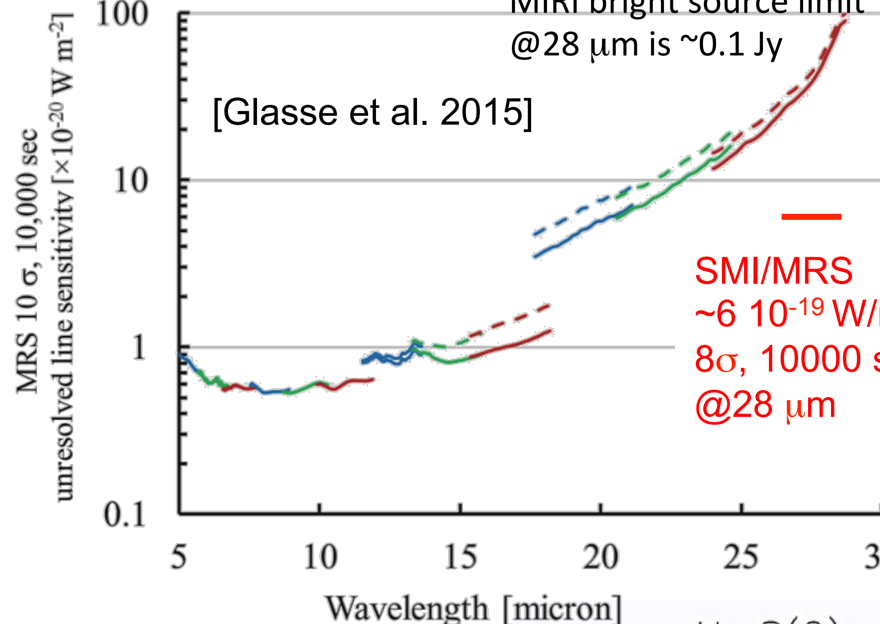
How does gas dissipation and photoevapo-ration set the clock for planet formation?

VISIR sensitivity ~1.5 10^{-14} erg/cm²/s [Carmona et al. 2008]



with settling @56 pc
factor 6 weaker @140pc
[Nomura et al. 2008]

~6 10^{-17} erg/cm²/s



MIRI bright source limit
@28 μm is ~0.1 Jy

[Glasse et al. 2015]

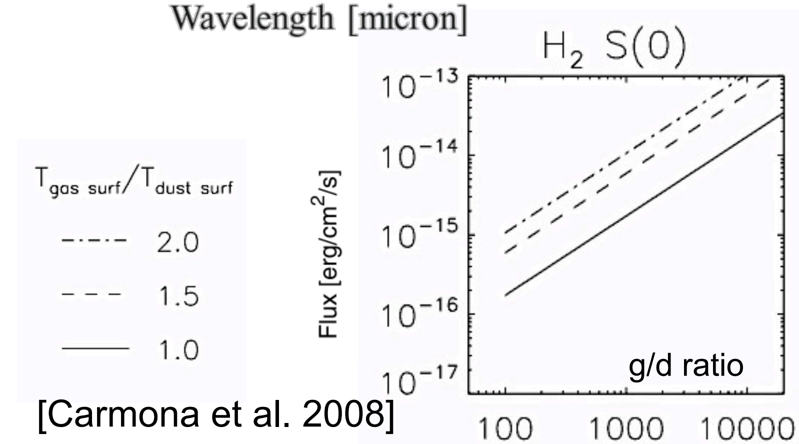
SMI/MRS
~6 10^{-19} W/m²
8σ, 10000 s
@28 μm

Science goals SMI:

- gas disk dispersal processes – trace directly launching of inner disk hot gas

Uniqueness: MRS sensitivity @28μm H_2 S(0) – JWST/MIRI sensitivity drop

Requirements: highest possible spectral resolution, line sensitivity



[Carmona et al. 2008]

Summary

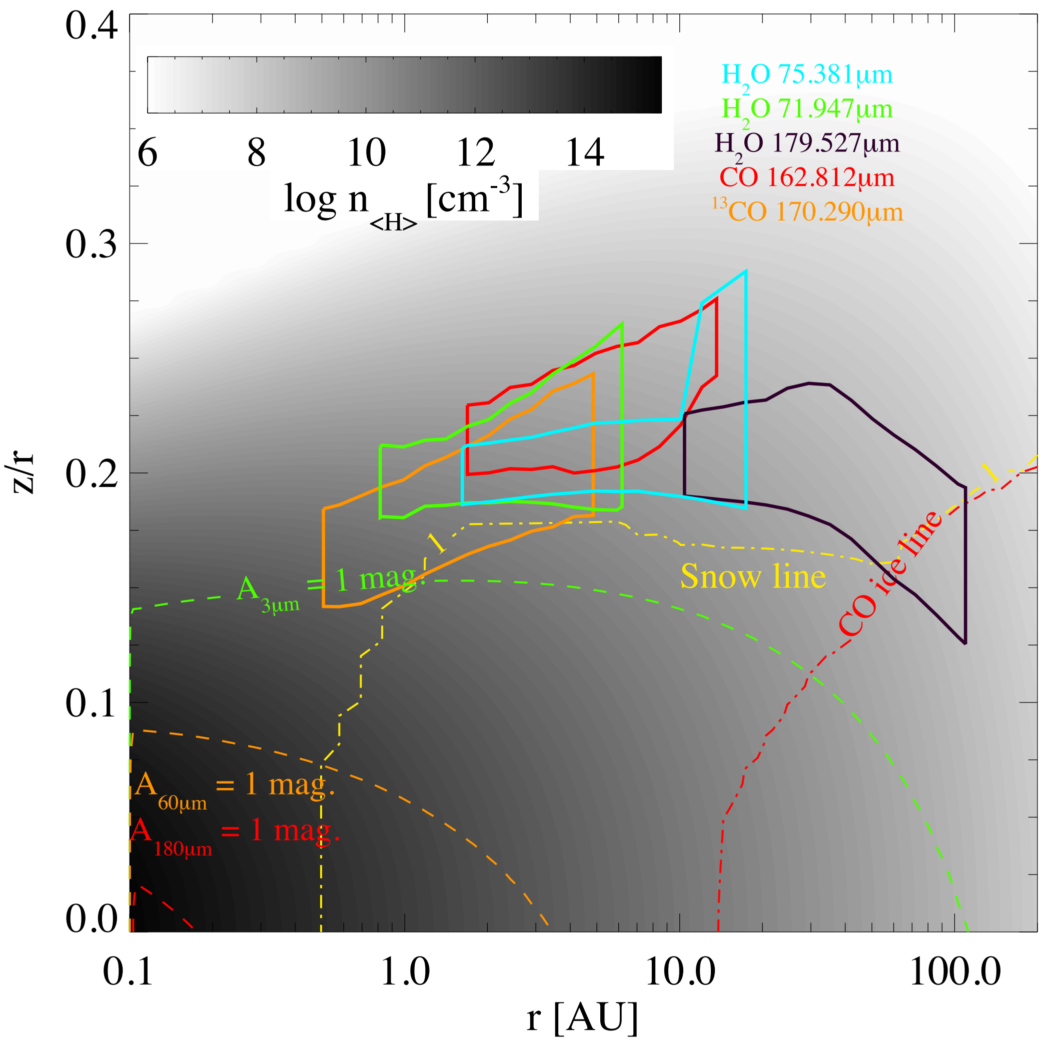
Planetary Systems key unique science:

- HD, water vapour+ice, CO-ladder (including isotopes), mineralogy
- "global" PPD evolution (tracing the entire disk)
- close missing link between debris disks and KBOs

From this, SPICA will answer the following questions:

1. How is water delivered to the planets?
2. How do solids evolve from pristine dust to differentiated bodies, and what is the link with our own Solar System?
3. When does the gas supply exhaust during the planet forming phase?
4. How does gas dissipation and photo-evaporation set the clock for planet formation?

SPICA's discovery space

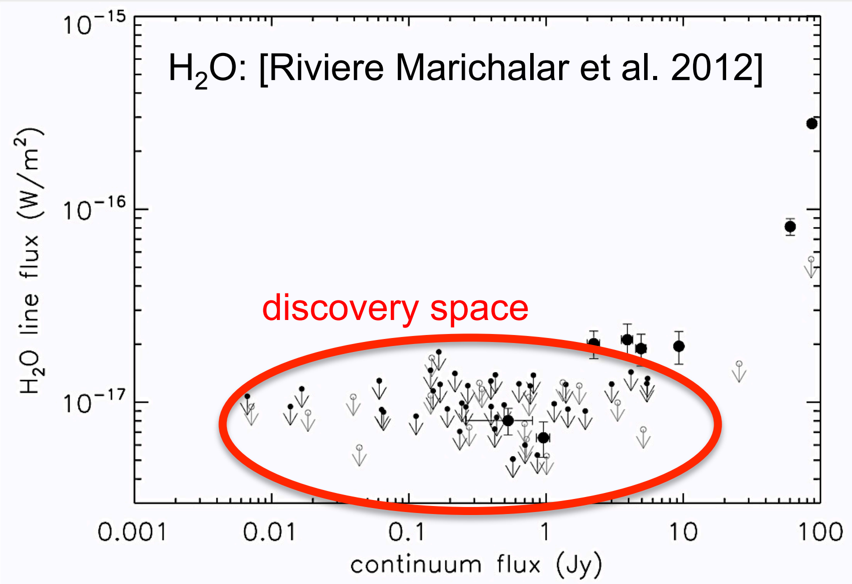


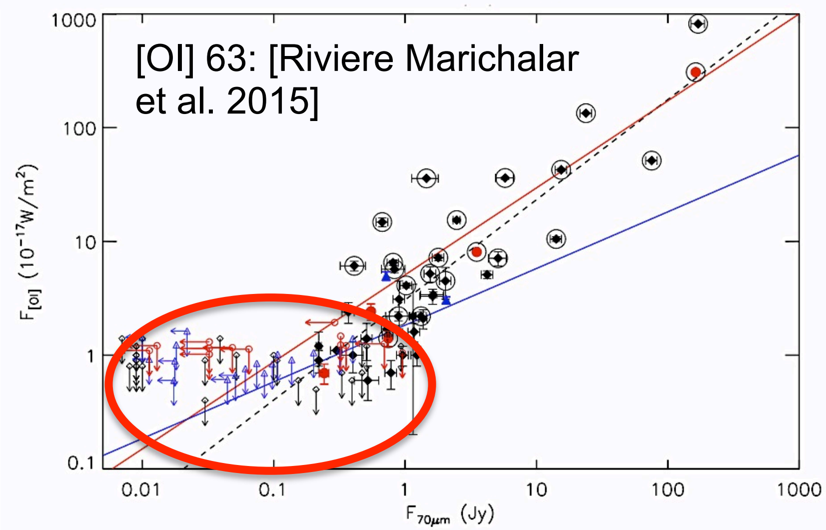
T Tauri disk model

$M_{disk} = 0.01\ M_{Sun}$

[Antonellini et al. 2015]

Herschel vs SPICA sensitivities





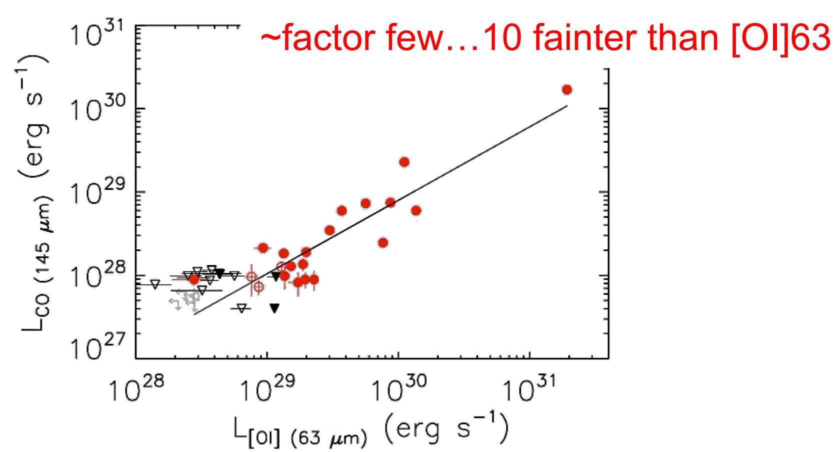
not corrected to same exp time and 5σ
factor 30 improvement at short λ faint sources

New SAFARI factsheet:

10 Jy continuum:
LW: 6 10^{-19}; SW: 1.5 10^{-18} W/m^2

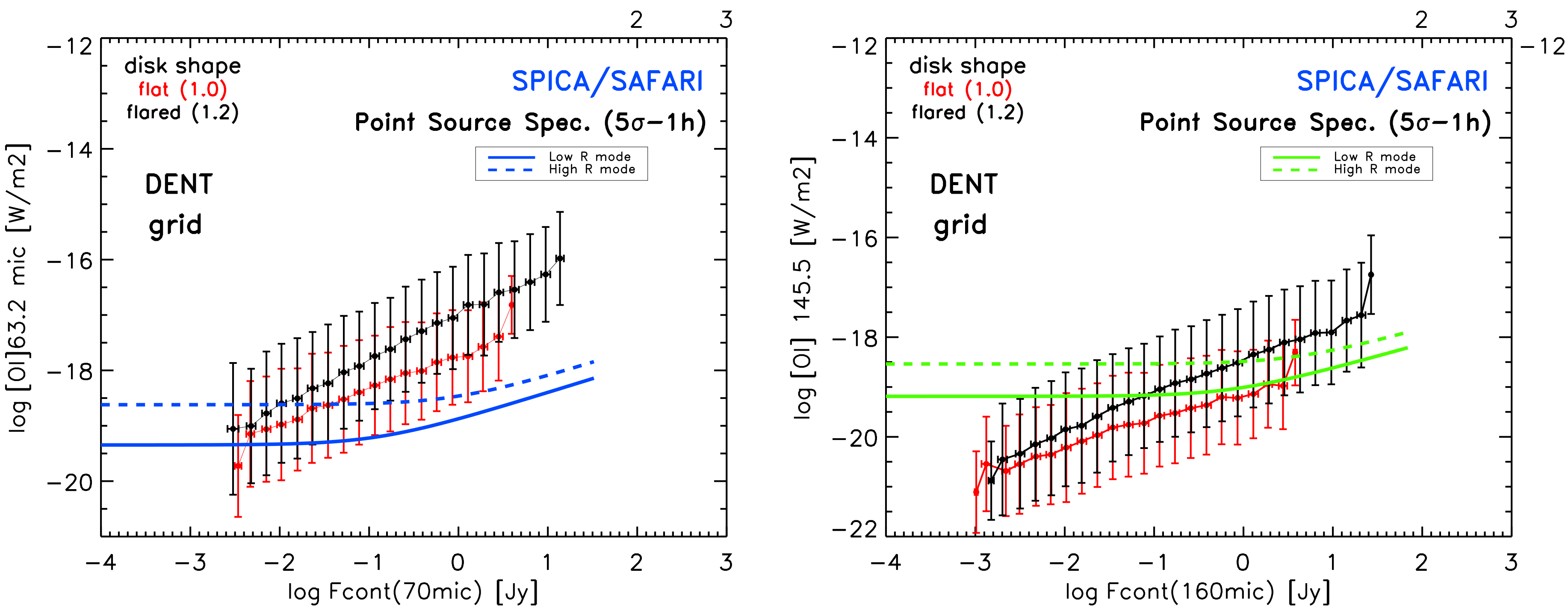
0.1 Jy continuum:
LW: 2.9 10^{-19}; SW: 2.5 10^{-19} W/m^2

[CO 18-17: Alonso Martinez in prep.]



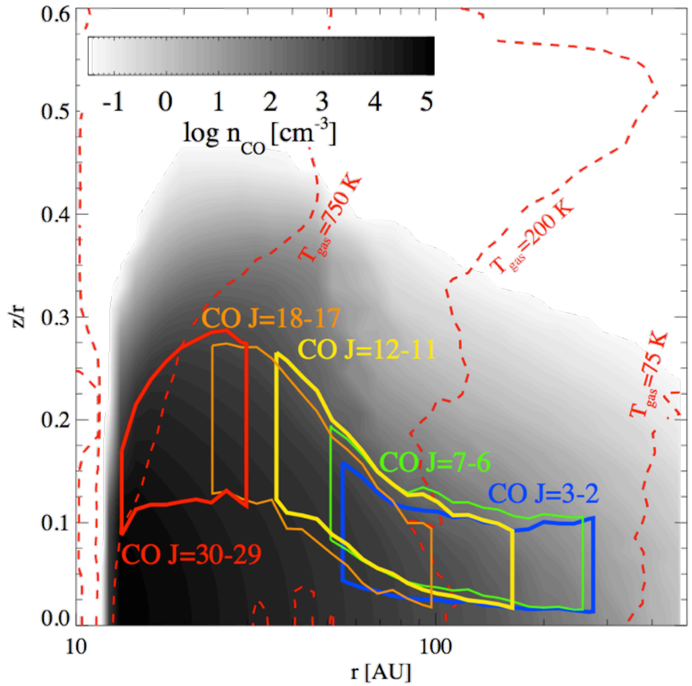
DENT disk model grid & SPICA sensitivities

[Vicente et al. in prep.]

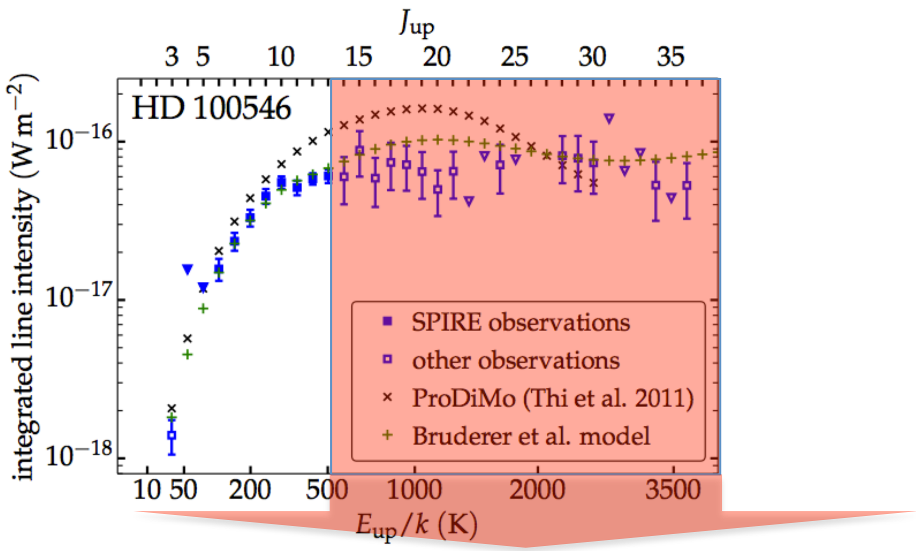


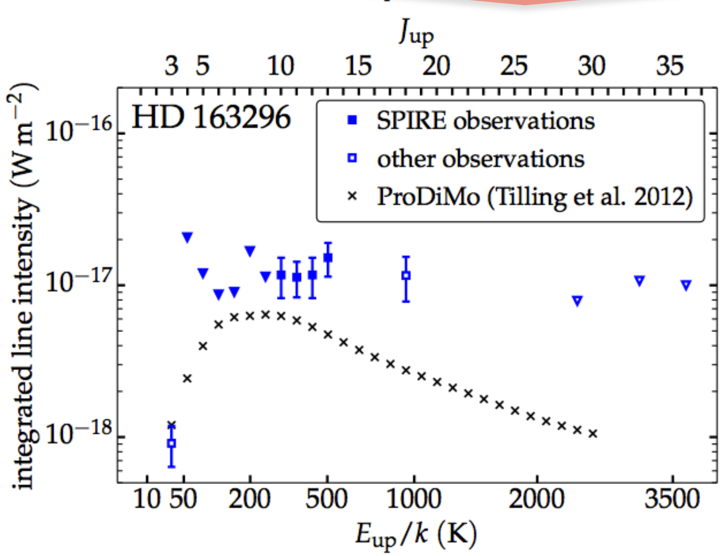
[OI] 63 and 145 μm fine structure line predictions

CO ladder and radial temperature gradient



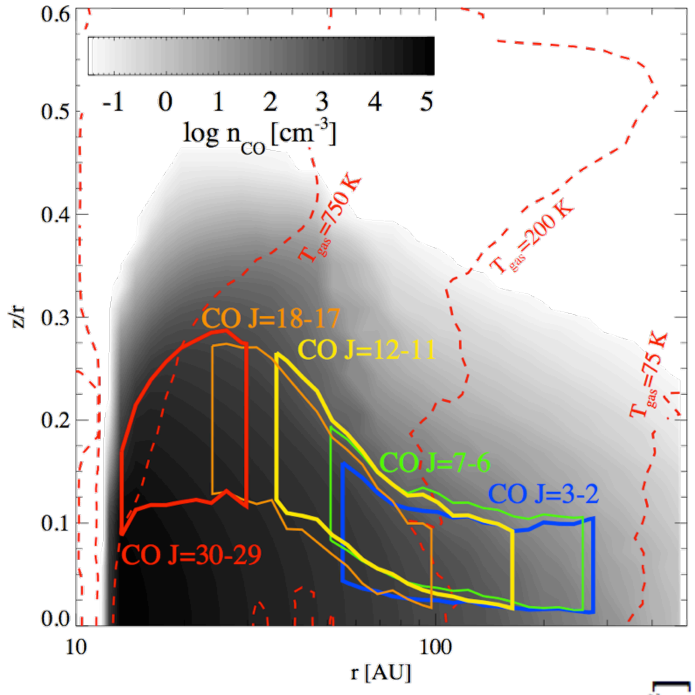
[van der Wiel et al. 2014]





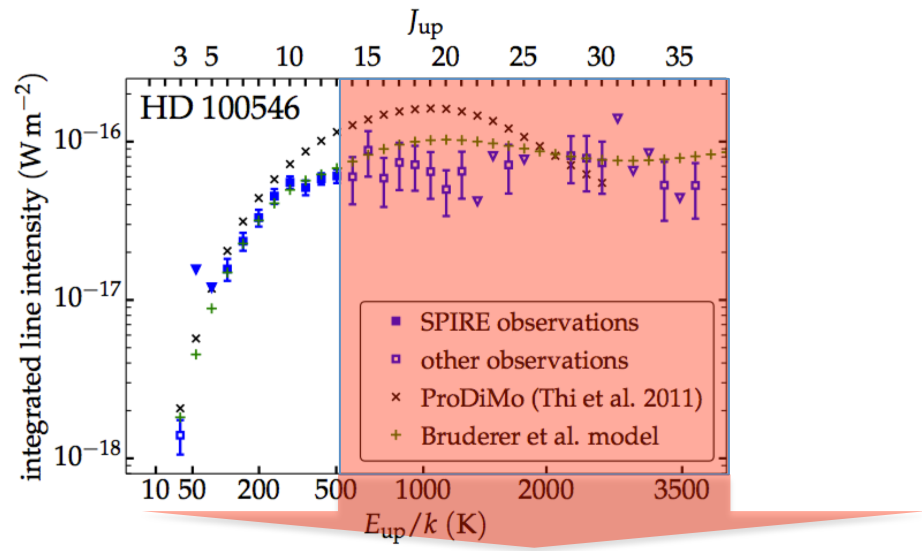
SAFARI sensitivity => feasible also for ^{13}CO ladder – expanding to vertical temperature information – and to T Tauri disks – DENT grid for theory study?

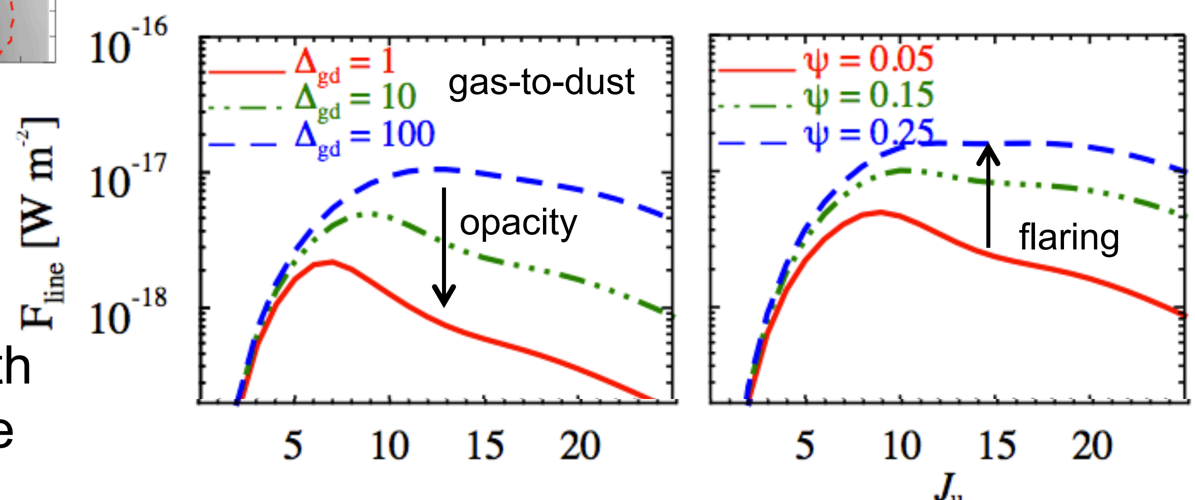
CO ladder and radial temperature gradient



[van der Wiel et al. 2014]

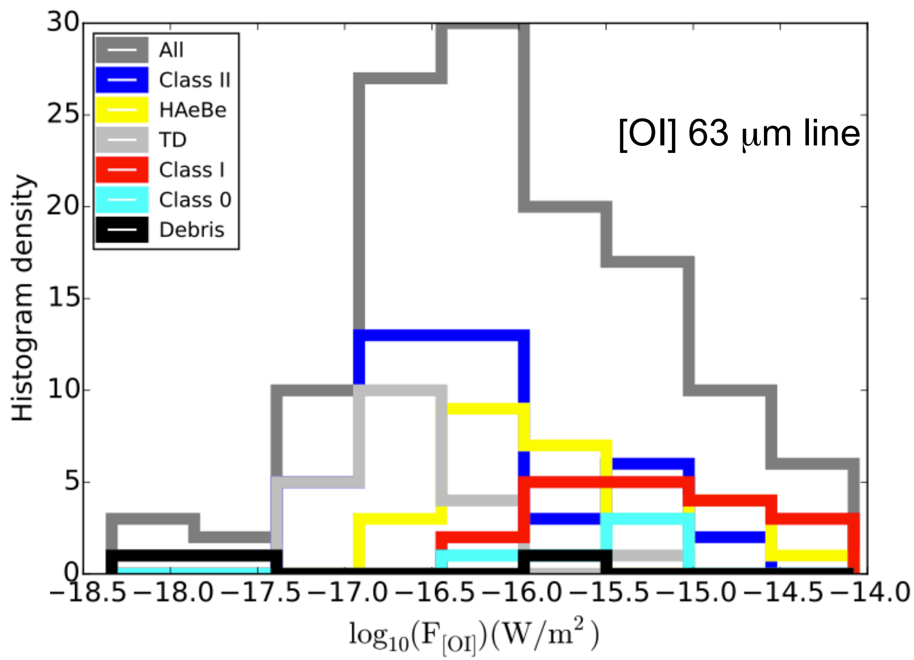
The CO ladder changes notably in shape and strength with the flaring angle and the gas-to-dust mass ratio





[Fedele et al. submitted]

Herschel vs SPICA samples



[279 YSO's from archive reprocessed: Riviere Marichalar submitted]