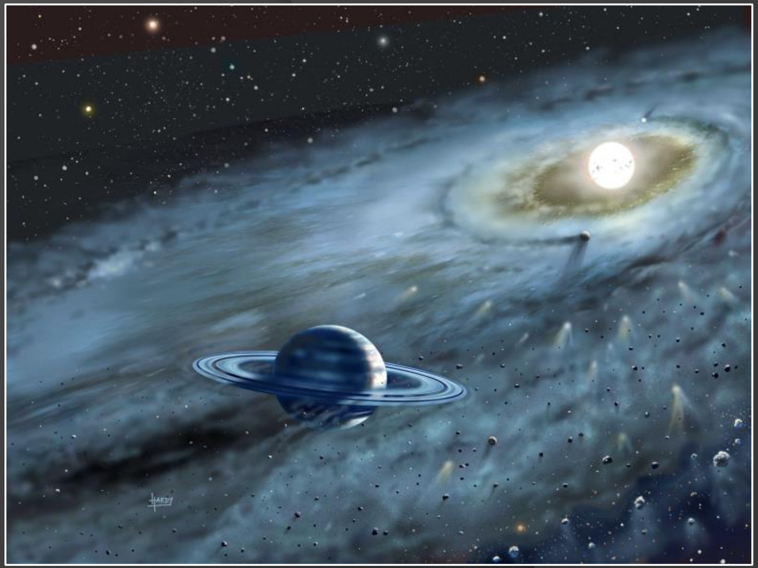
SPICA and debris disc spectroscopy



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What are debris discs?

Originally discovered by *IRAS* – excess IR emission from a main sequence star

- Detected in the optical → mm from scattered light to thermal emission of dust

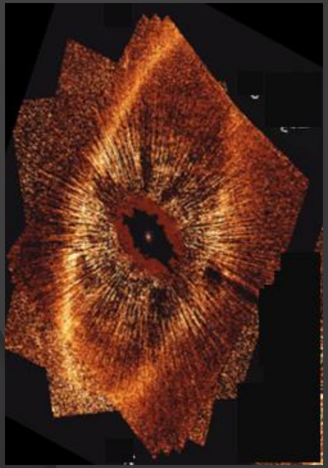
- Detection rates are ~20% with ~30 systems imaged in some detail

- Dust extent varies from a few 10's of AU to several hundred

- Implies the existence of larger bodies to replenish the material (e.g. planetesimals)

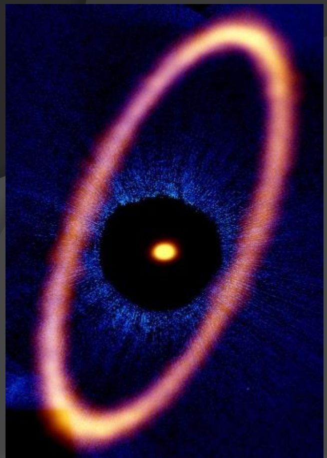
Observables

Optical
– scattered light
(*Hubble*)



Far-IR
– dust emission
(*Herschel*)

Submm
– dust emission
(ALMA)

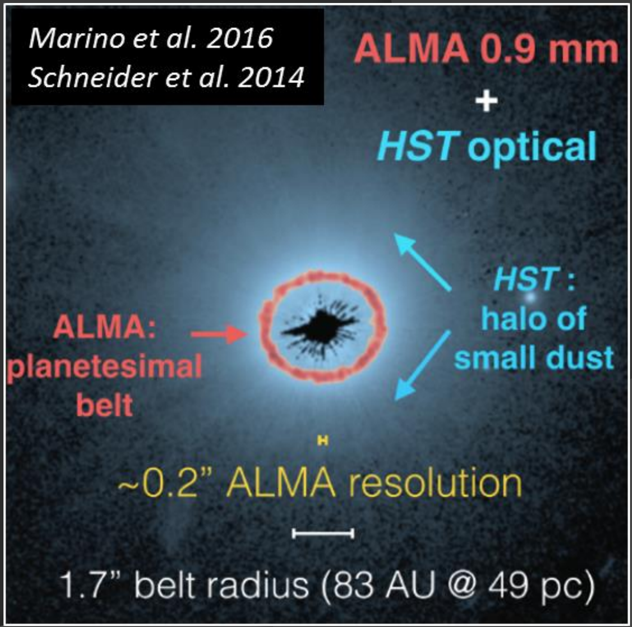


Recent work and implications

Recent surveys in the far-IR/submm:

- *Spitzer* studied the evolution of dust around luminous stars
- *Herschel* resolved almost half of the known discs
- Ground-based telescopes revealed cold and massive discs

+ now ALMA can **resolve** planetesimal belts…



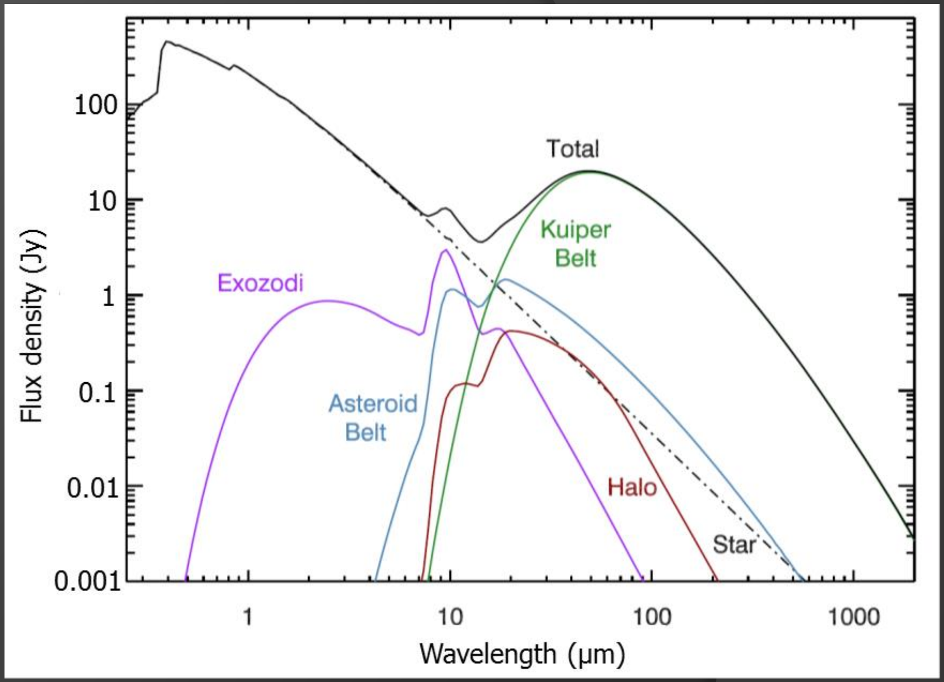
General picture emerging:

Studying debris discs is helping to understand the architecture (and possible evolution) of planetary systems

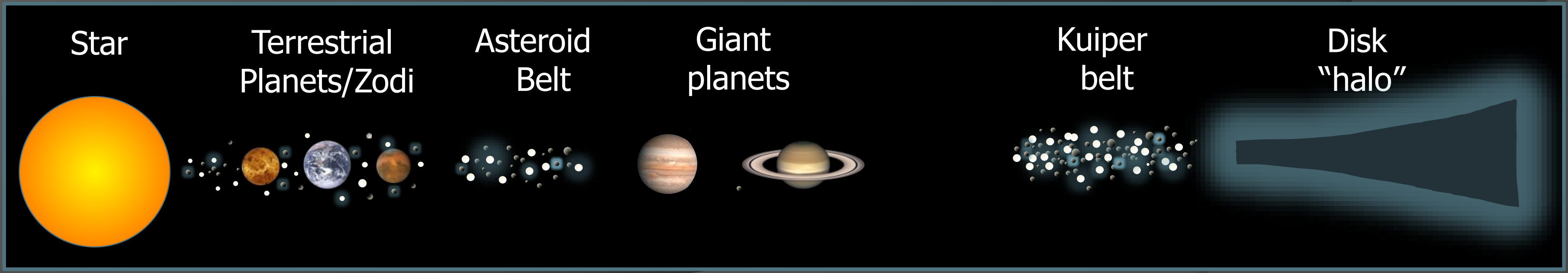
Architecture of planetary systems

- Different wavelengths can probe multiple components of a disc

If a single component dominates (such as a Kuiper belt) then multi-wavelength observations probe different grain sizes



Illustrative SED for a debris disc (from Hughes et al. 2018)

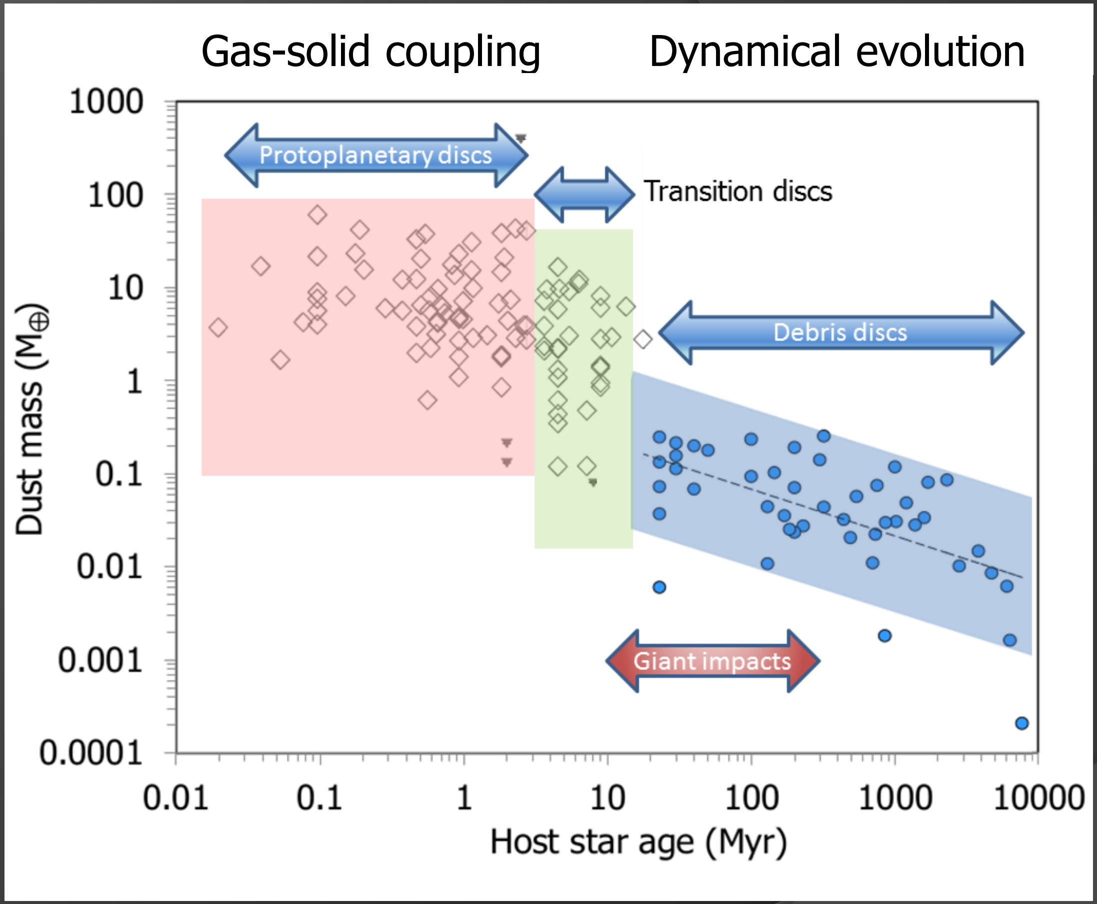


Schematic representation of the possible components of a planetary system

Evolution of debris discs

- Disc emission is expected to diminish over time – the reservoir of large planetesimals is depleted and the collisional timescales increase

- Younger stars tend to be distant – mass sensitivity is lower than for older, but closer stars (around which low mass discs are easier to detect)



Observational bias – mass sensitivity now improving for more distant protoplanetary discs, so decline in mass around 10Myr not as steep?

Questions for SPICA to address?

Q1. Are there Kuiper and asteroid belts around most stars? ("How common is our Solar System architecture?") – exploit survey capability

Q2. Do discs exist around low luminosity stars? ("Are discs prevalent around M dwarfs where there is a known high incidence of terrestrial planets?") – exploit sensitivity

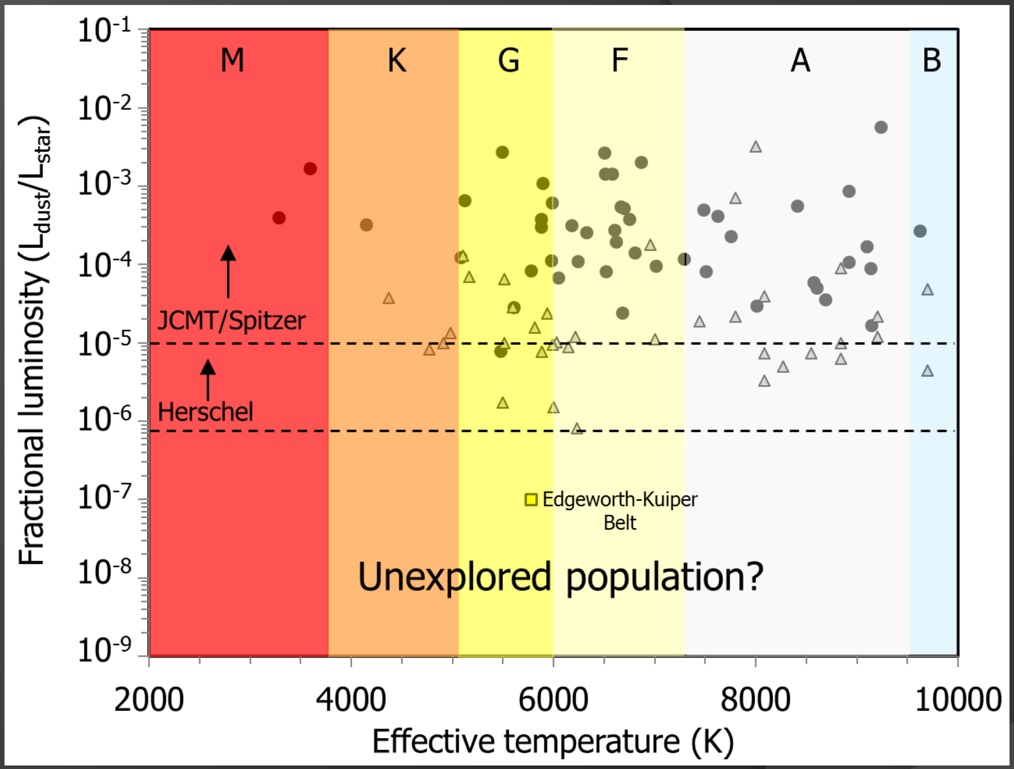
Q3. What role does atomic and molecular gas in the evolution of discs? ("Are there evaporating comets in these systems, which could have implications for terrestrial planet habitability?") – exploit spectroscopy

Q4. What is the composition of the disc material (mineralogy)? ("How did it originate and how does it evolve?") – exploit spectroscopy and (maybe) polarisation capabilities…

Do all stars have debris discs?

- Debris discs are faint so need very sensitive telescopes/instruments (e.g. M-stars within 100pc can be as faint as a few hundred µJy…)

- Must survey as many targets as possible (big sub-samples!)
  - Prevalence of planets
  - Spectral type
  - Age
  - Metallicity of star etc.

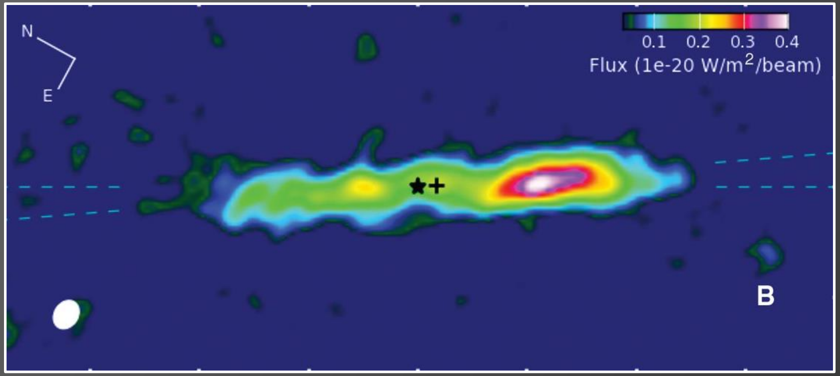


- It is quite possible that **ALL** stars have a debris disc at some level (below current detection thresholds…)

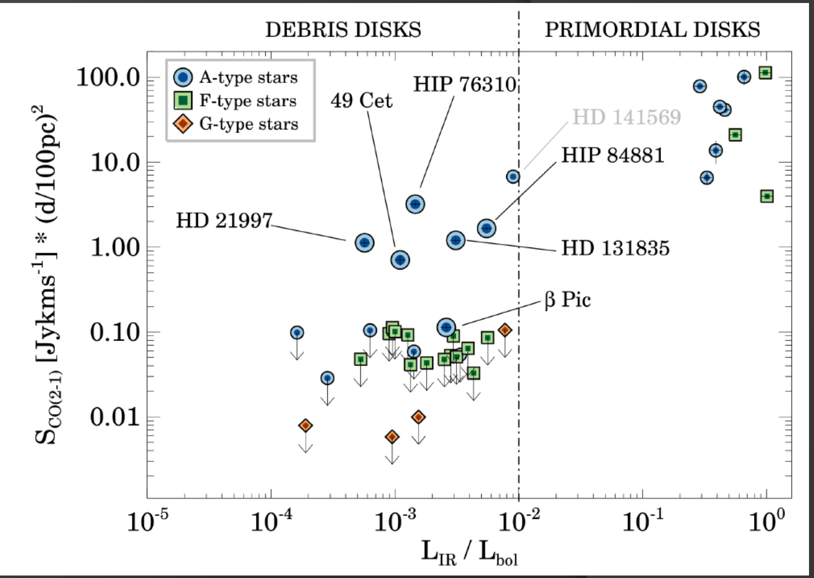
Gas in debris discs

- Debris discs are generally described as “gas-poor”, particularly compared to the earlier protoplanetary phase

- CO is relatively common, but unlikely to affect the dust dynamics or planet forming potential



CO(3-2) line emission from β Pic (Dent et al. 2014)



Integrated $^{12}CO(2\text{-}1)$ fluxes vs. fractional luminosities based on ALMA data (from Attila Moór)

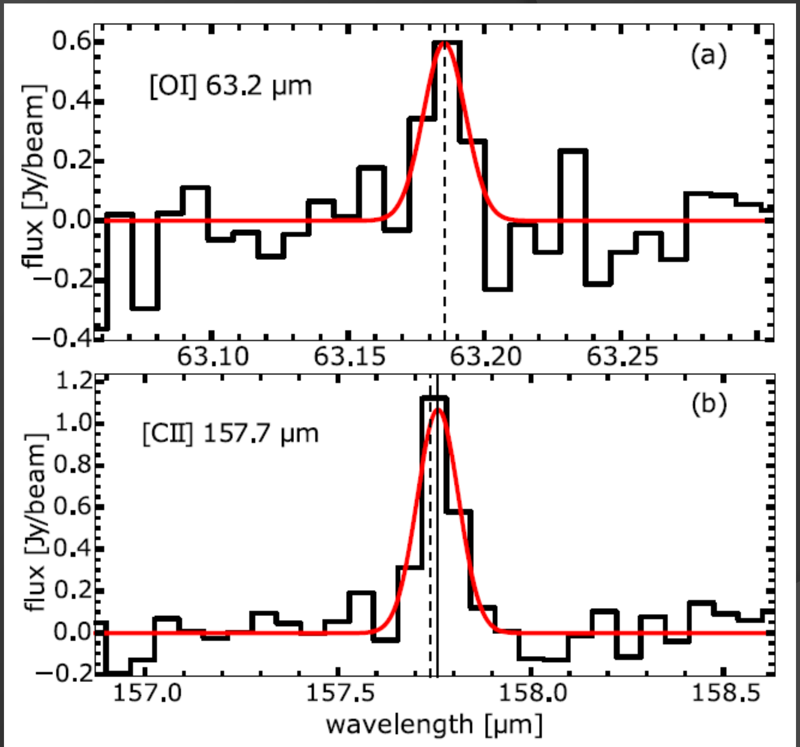
- Origin and evolution of the gas; Does the CO originate from a narrow ring of comets that could affect the habitability of any terrestrial planets in a system (but need R of 10^6…)

Gas in debris discs

- Absorption spectroscopy revealed volatile-rich gas in a variety of atomic tracers, but limited to discs seen edge-on (e.g. β Pic)

- Atomic gas in emission is independent of disc orientation

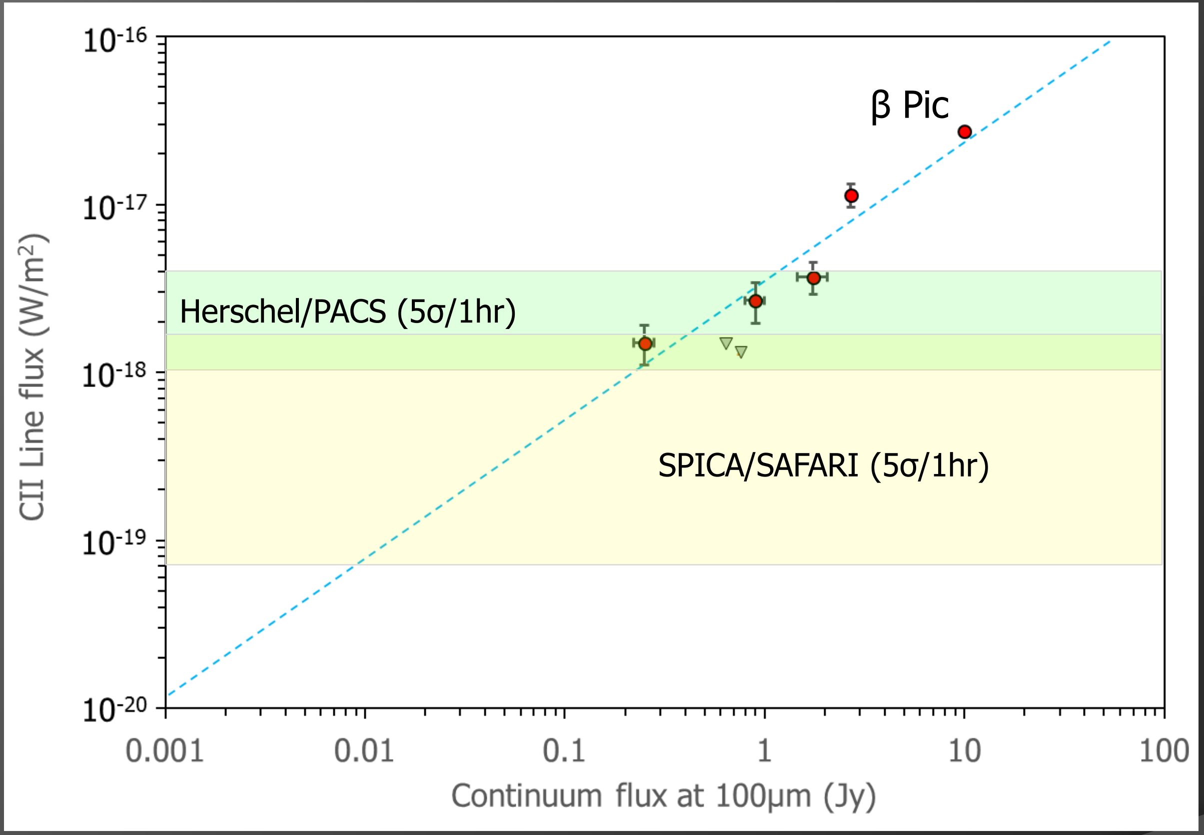
- Herschel/GASPS programme detected gas (OI and CII) around five young A stars with known debris discs (ages in the range 5–40 Myr)



Emission lines from β Pic (Brandeker et al. 2016)

Potential of SAFARI: atomic gas

- SPICA/SAFARI would have the sensitivity and resolving power to probe hundreds of new candidates



CII line flux plotted against 100μm continuum for a number of young debris disc systems (including two upper limits in CII detection)

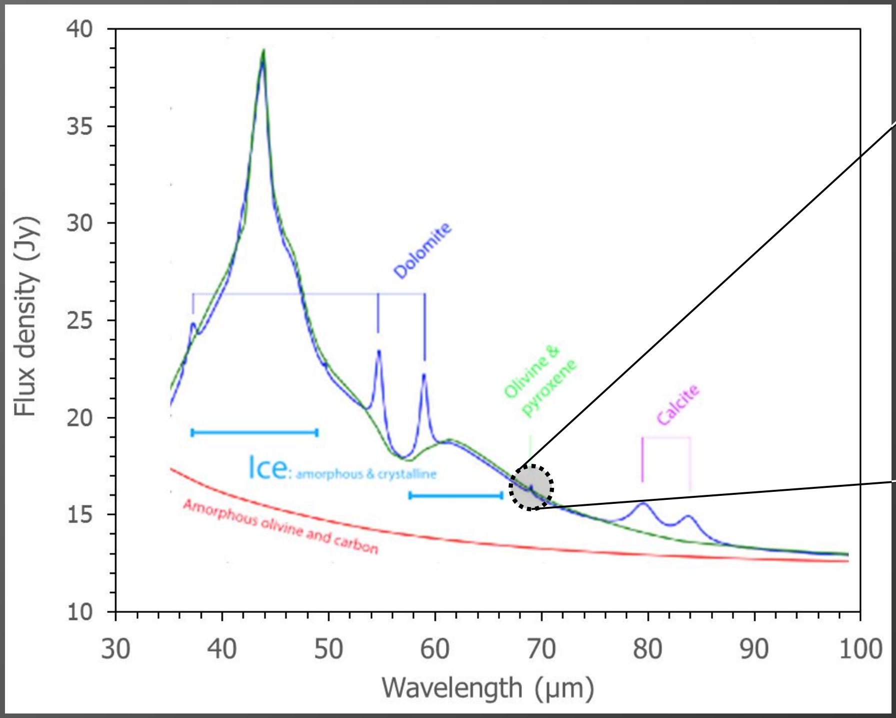
(data taken from Dent et al. 2013, Moor et al. 2014, Thi et al. 2014, Greaves et al. 2016, Roberge et al. 2018)

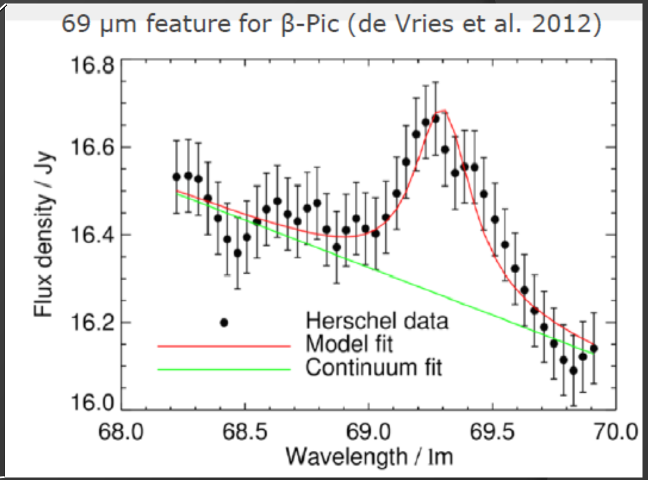
- Lots of other (gas) tracers accessible (e.g. OI, OH, H_2O, SiII…)

Mineralogy of debris discs

- Dust composition is dominated by silicates with smaller amounts of refractories and ices – much like the dust in the Solar System…

Representative spectrum of the mineral content of a circumstellar disc



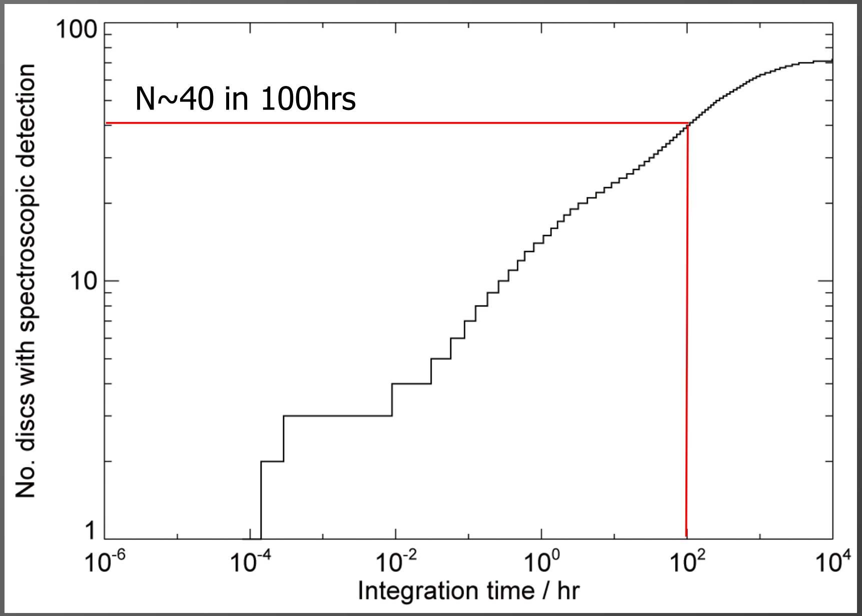


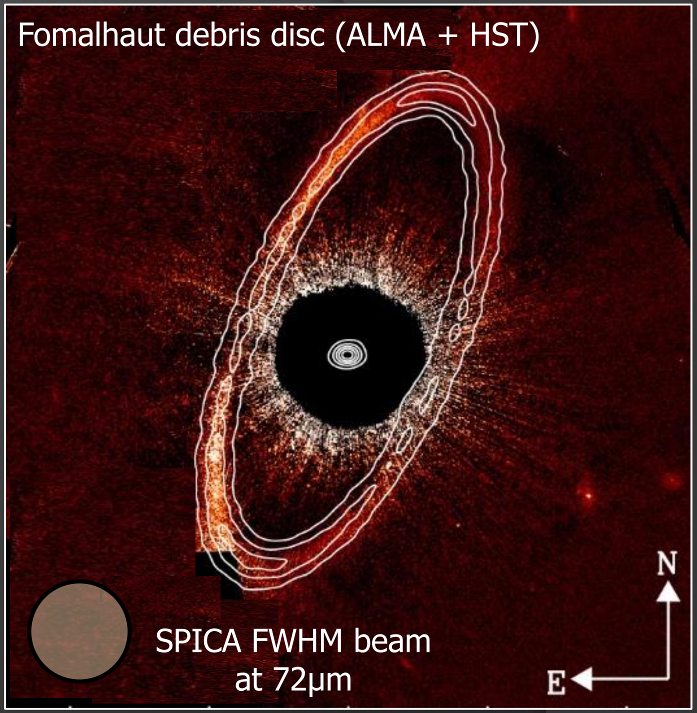
A great diagnostic of the composition and temperature of the crystalline olivine (forsterite)

- The width and wavelength position of the 69µm band are especially sensitive to the grain temperature and Mg/Fe ratio

Potential of SAFARI: mineralogy

Predicted number of discs with Forsterite detections with SPICA/SAFARI as a function of survey time (Sibthorpe & de Vries)





- Detect mineral features, such as forsterite, around tens of disc systems
- Trace the variability of mineral content as a function of disc radius for nearby systems (snow line)

Spectropolarimetry would be interesting if minerals are in aligned grains…

Summary

SPICA will help address some of the key questions, including that of the uniqueness (or otherwise) of our Solar System.

In terms of spectroscopy, SPICA will:

- Explore the nature of atomic gas and the role it plays in the evolution of debris discs
- Detect the presence (and trace the evolution) of water ice ("snow line") in debris discs around mature stars
- Detect minerals such as olivine in up to 100 discs (unique contribution as most will be too faint for SOFIA)