debris discs and the connection to exoplanets: a Herschel overview

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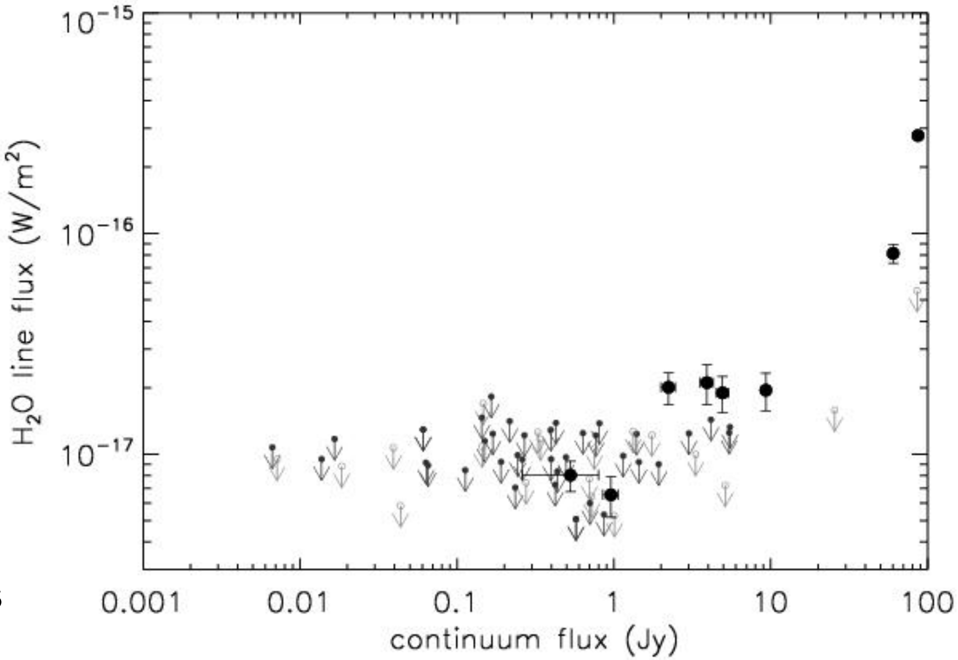
starting points

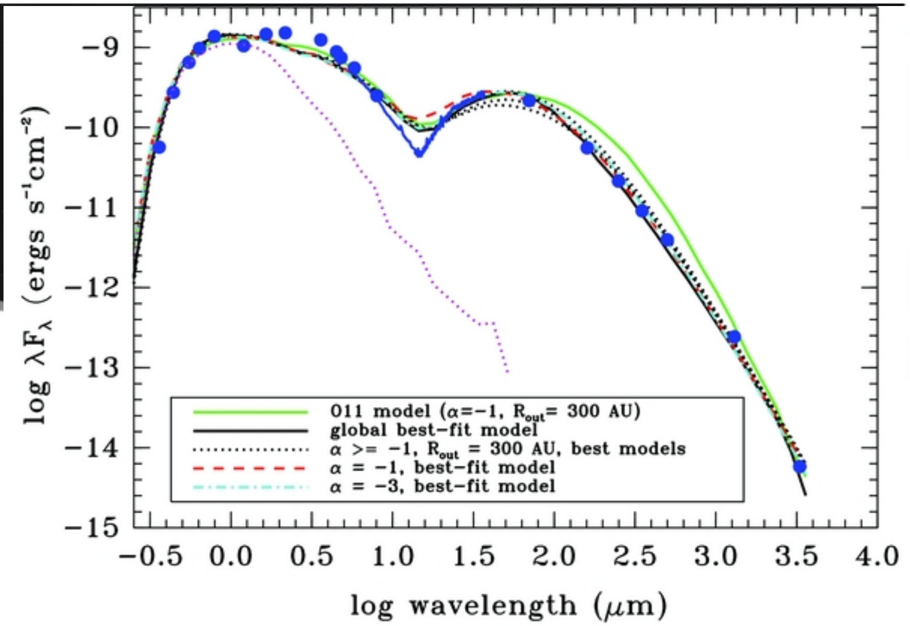
- GASPS survey tracks planet formation to ~30 Myr
  - epoch of assembling most of the Earth's mass
    - see remaining accretable dust, plus volatiles important for future life

- key is modelling
  - convert observables to masses of discs and chemical abundances

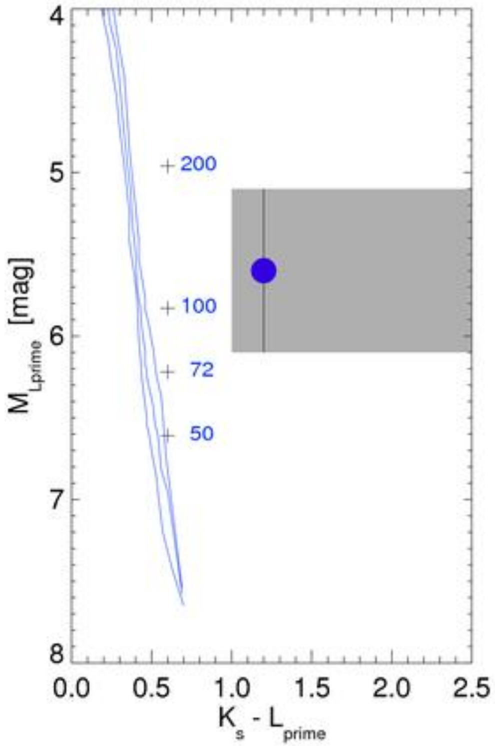
Riviere-Marichalar et al. (2011): detection of $8_{18} \rightarrow 7_{07}$ transition of ortho-water in ~1/4 of gas-rich discs



early-to-late transition



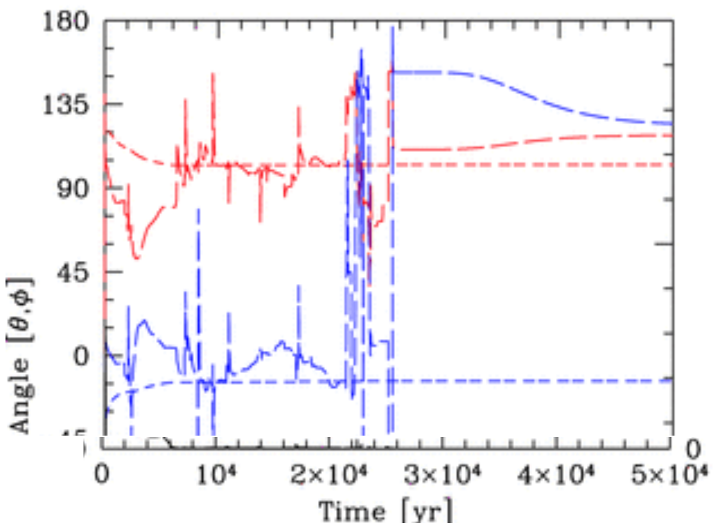
- from DIGIT, much work on transition discs, with cleared central regions - that may host planets?
  - NB transition is *not* a decline of dust mass… 'proto-planetary' dust accretes into larger bodies, then debris is generated by collisions among planetesimals



Cieza et al. (2011): at t ~ 7 Myr, T Cha has a very thin or tenuous dust ring at ≥10 AU; Huélamo et al. (2011) find a candidate companion at ~7 AU

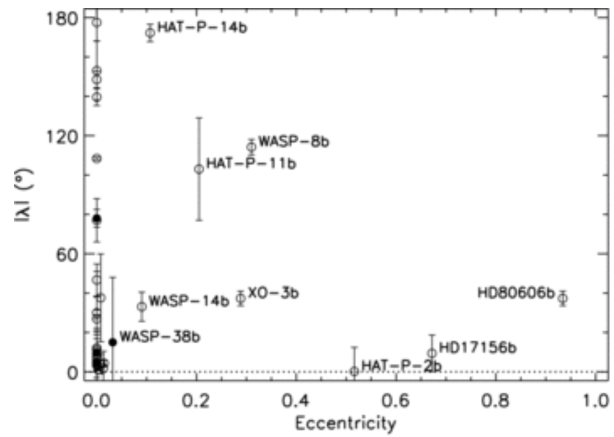
systematic or random processes?

- see huge diversity of discs and planetary systems
  - some initial conditions must be random? e.g. angular momentum inherited from protostellar accretion phase
    - so e.g. 'what last fell in' and star-star encounters could lead to star/disc/planet misalignments



Bate et al. (2009)

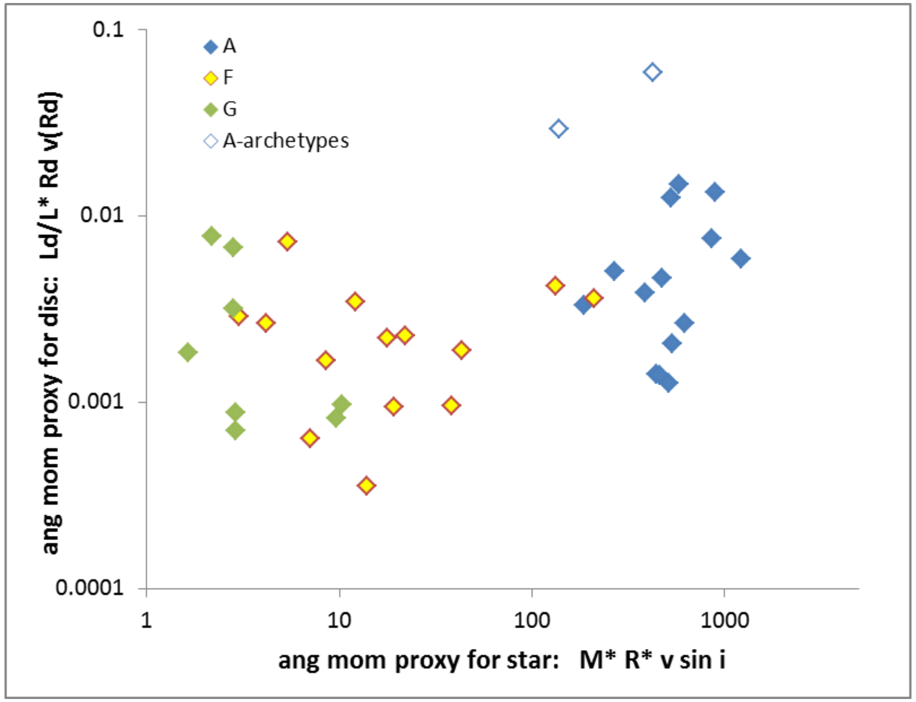
...as observed for transiting planets



Simpson et al. (2011)

key factors for evolution

- can try to identify these for a statistical ensemble
  - angular momentum example:
    - disc-braking of young star can relqte very much to properties of planetesimal belt (e.g. more ang. mom. in a 10 $M_\oplus$ belt at 50 AU than a 20 $M_\oplus$ planet inside 10 AU)



preliminary results from DEBRIS

debris surveys with Herschel

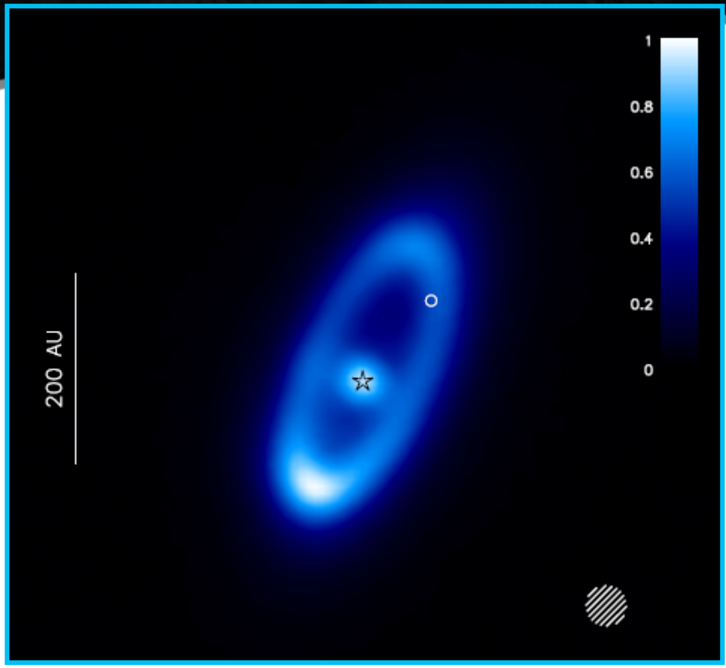
- GT (PI Göran Olofsson) – the archetypes
- DUNES (PI Carlos Eiroa) – large samples of nearby Sun-like stars
- DEBRIS (PI Brenda Matthews, + Jane Greaves) – unbiased completion of local volume

- range of approaches means few stars are missed
  - cf. with Spitzer, volume-complete late on (~2010)
  - DUNES and DEBRIS share stars for maximum effectiveness

methodologies

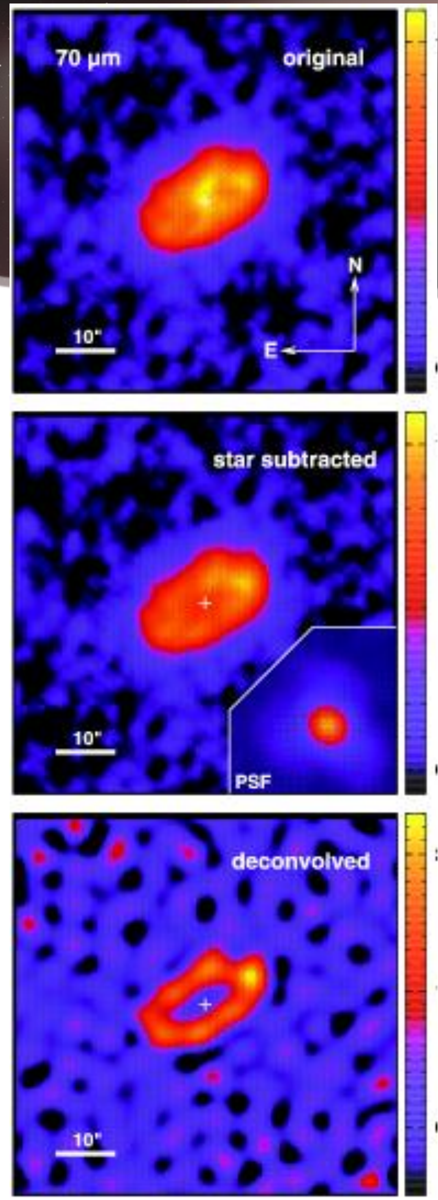
- DEBRIS and DUNES both use PACS plus SPIRE
  - omit only stars with high IR backgrounds
- DUNES is complete for d < 20 pc for FGK stars, extended to 25 pc for planet-hosts
  - depth scaled to detect photospheres at S/N = 5 at 100 μm; close to Kuiper Belt debris levels
- DEBRIS observes nearest ~90 stars of types A,F,G,K+M
  - constant depth at 100,160 μm to give unbiased view
  - hence late-type photospheres undetected, but can still discover massive and/or resolved discs

image highlights

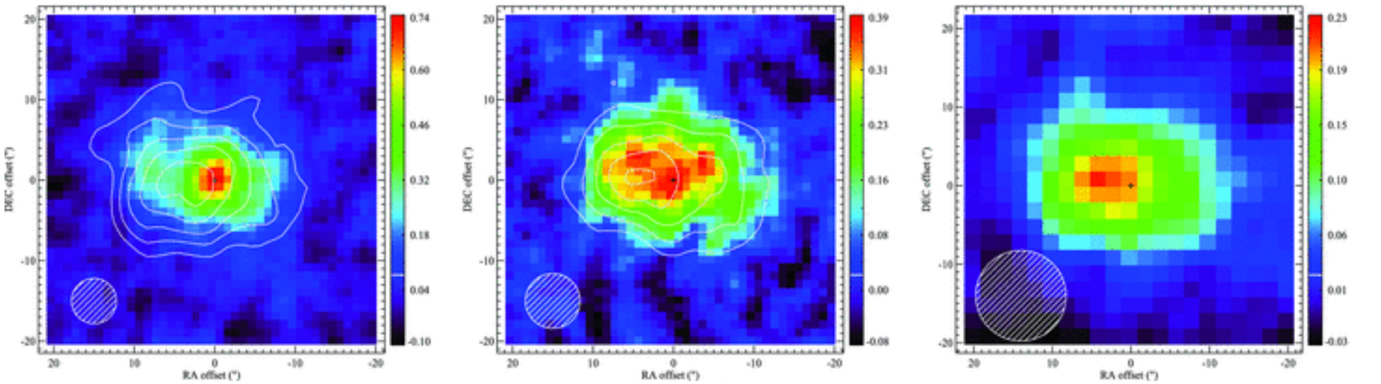


70 μm image of Fomalhaut (GT, Bram Acke)

HD 207129 (DUNES, Jonathan Marshall)

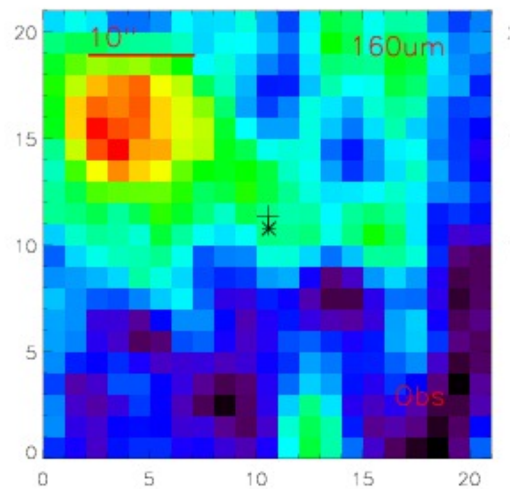


99 Her at 70, 100, 160 μm (DEBRIS, Grant Kennedy)

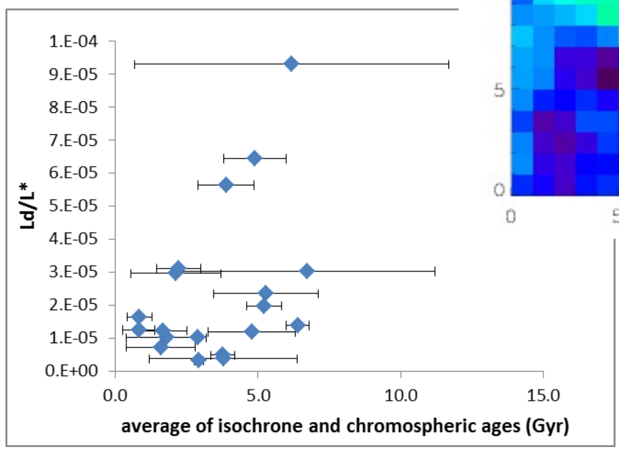


challenges

- observational:
  - identification of background objects (distant galaxies)
  - subtraction of the stellar photosphere to few-% precision
    - if these are wrong, candidate debris discs could be false, or wrong conclusions drawn about disc structure

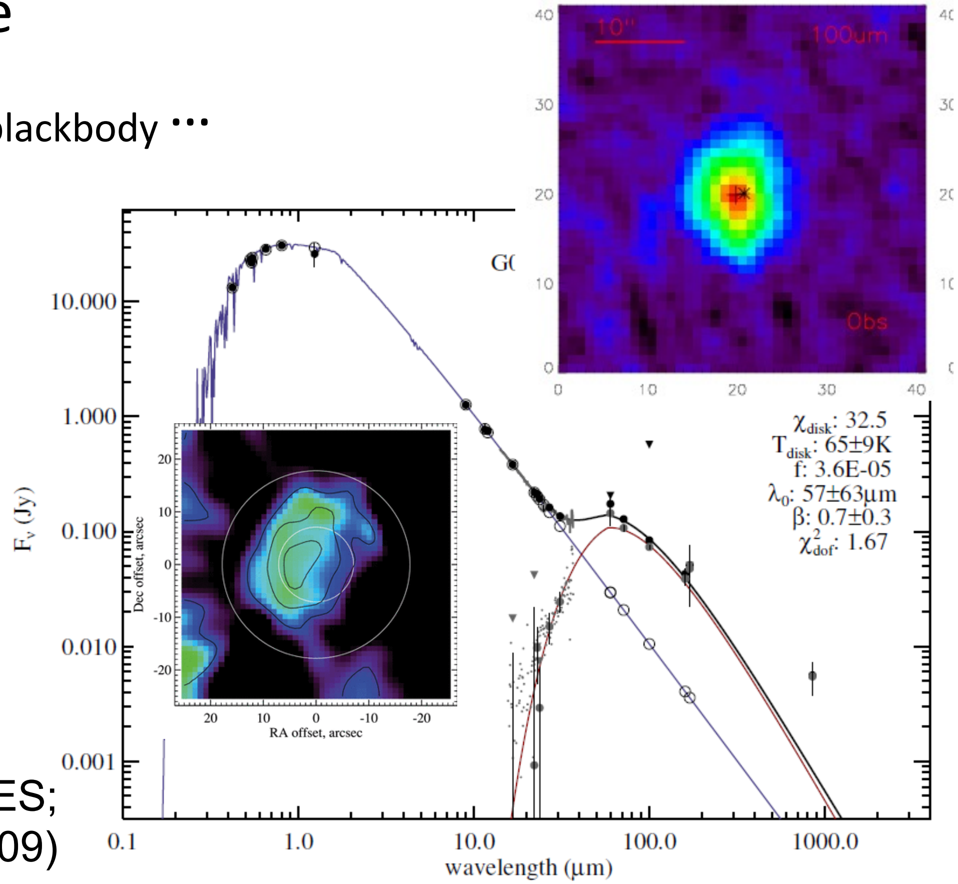


- interpretation:
  - e.g. for evolution, need good stellar ages
  - e.g. find *all* planet-hosts



outputs

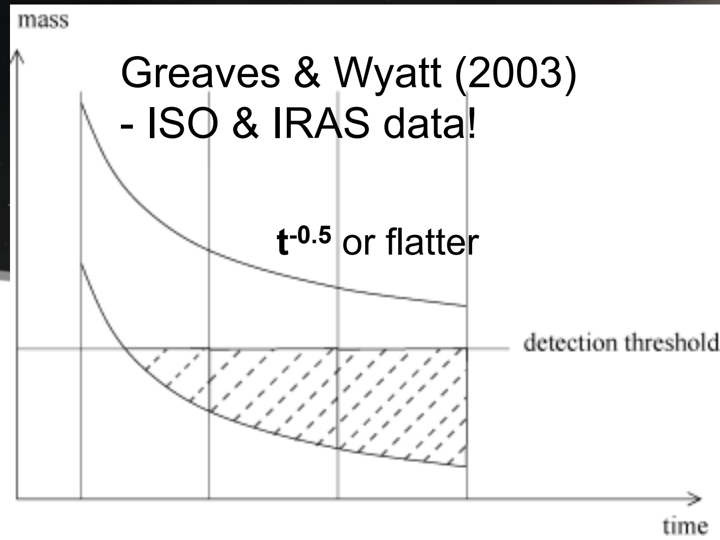
- wealth of information from resolved images & SEDs
  - fit T_{dust}, r_{disc}, spectral slope
  - find L_{dust}/L_{star}, M_{disc}, $r_{disc}/r_{blackbody}$ …
  - hence links to evolution, planet, star companions, Solar System…
- NB new submm surveys
  - fitting for cooler discs
  - SONS with SCUBA-2 at 850,450 μm (2012+)

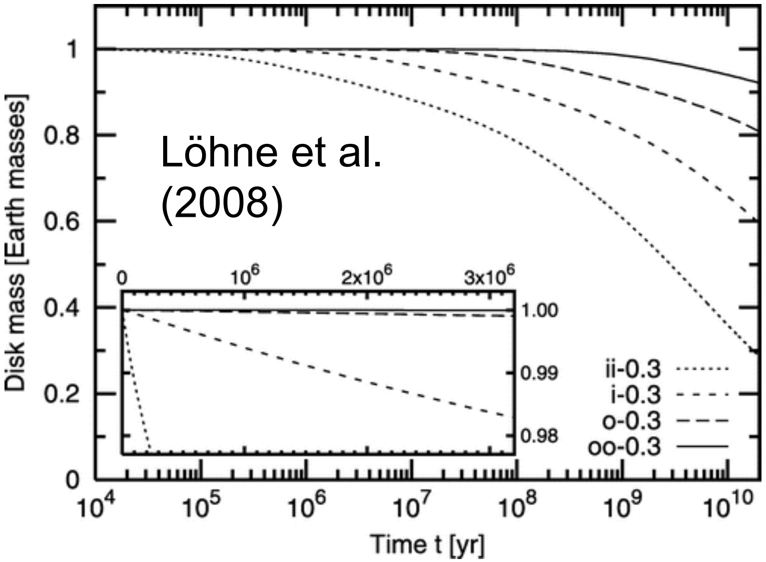


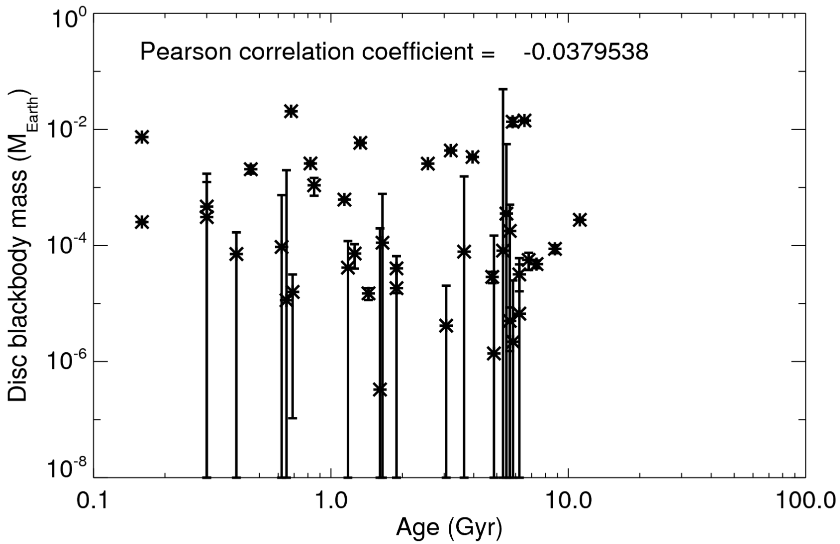
G-star HIP 22263 (PACS data from DUNES; SCUBA image from Greaves et al. 2009)

disc evolution

- for Sun-like stars, t_{evol} comparable to $t_{main\ sequence}$?
  - as in models of grinding down of planetesimal belt



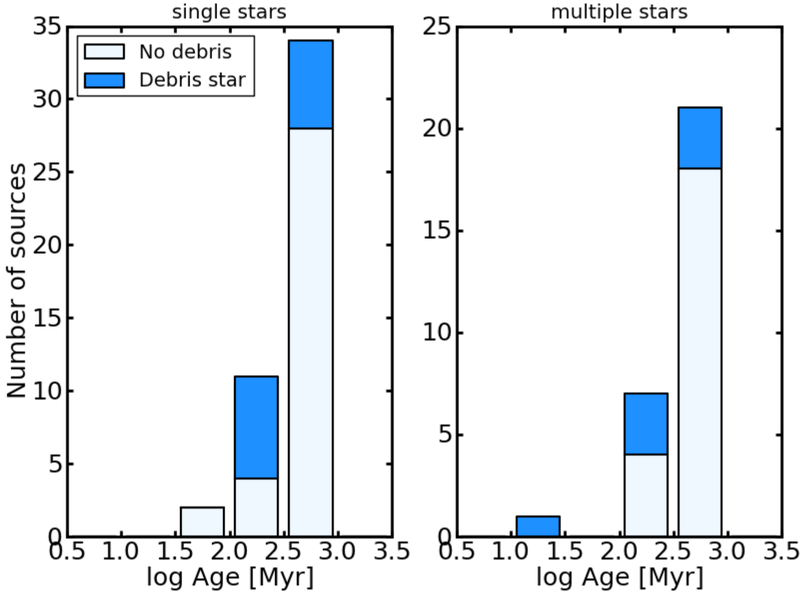


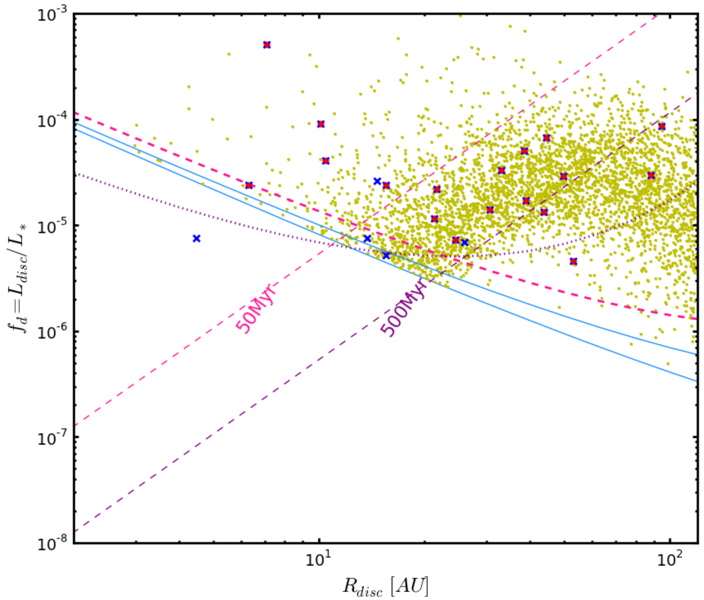


results from DEBRIS (Bruce Sibthorpe)

disc evolution

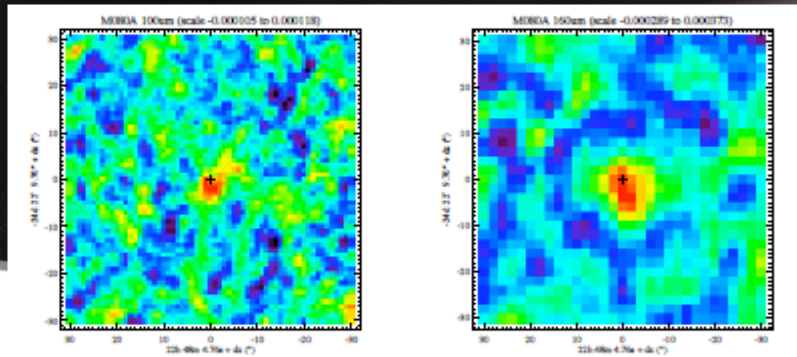
- evolution is more marked for A-stars
  - dynamical time shorter for higher M_* and same r_{disc}; appears many A-discs have r < 50 AU and so fade over t_{ms}



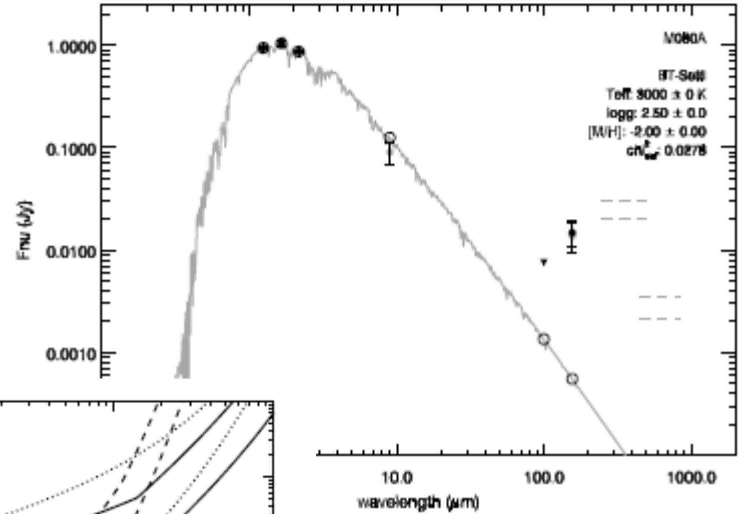


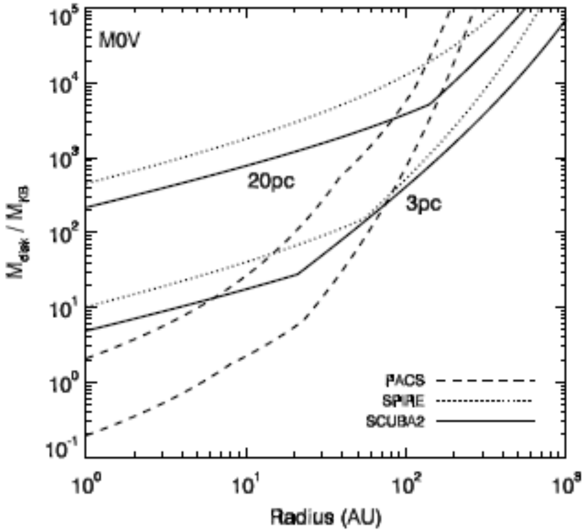
DEBRIS results and comparison to evolving model population for A-stars (Nathalie Thureau)

disc evolution



- few M-star debris disc detections
  - but limited to quite massive discs for low T_{star} ... also no discs detected in a SPIRE mini-survey of nearest 20 M-stars
  - in contrast to many planetary systems being found!





links to planets

- previously, little connection of presence or brightness of debris with planets in system
  - now hints that *low-mass* planets connected to debris?
    - DEBRIS/DUNES estimate: 5/24 discs in 'Jupiter'-hosting FGKM systems but 6/13 for 'Neptunes'
  - illustrates breakthroughs possible with robustly sized samples of stars

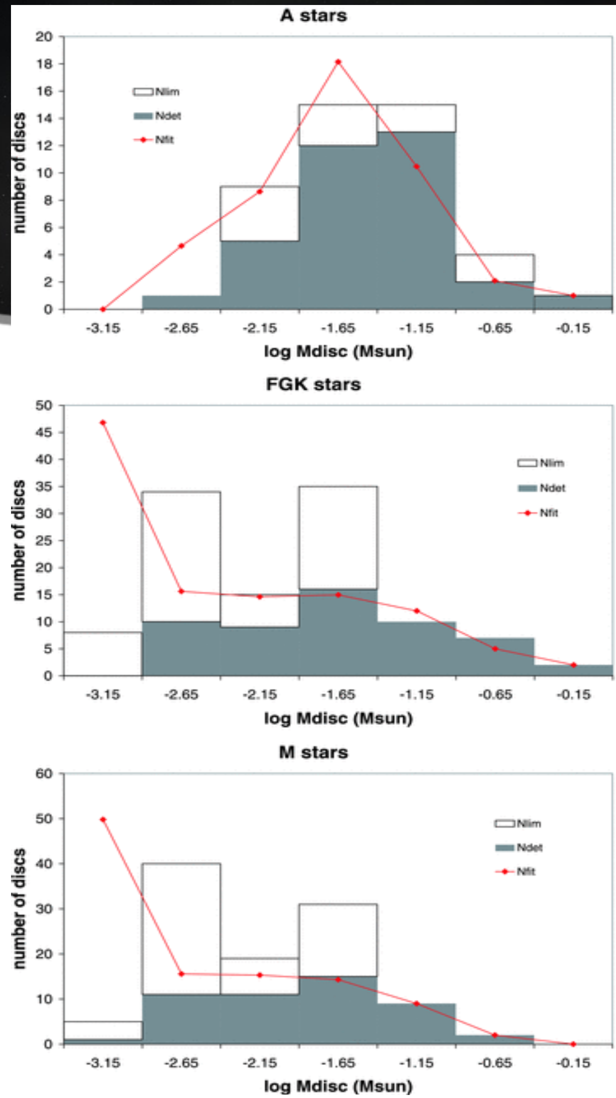
Table 1: DUNES statistics

Sp. type	F	G	K	Total
Sample	28	53	52	133
Observed	26	51	49	126
Non-excess	17	37	38	92
Excess (New)	9 (2)	14 (6)	11 (5)	34 (13)
"Peculiar"	2	2	4	
Resolved	4 (3)	8 (4)	4 (2)	12 (9)
Excess+planet	2 (2)	7 (1)	2 (1)	11 (4)

Lebreton et al. (2011)

outcome predictions

- natural consequence in models where initial mass reservoir of solids dictates how fast planets and planetesimals grow
  - can map masses in proto-planetary discs correctly onto ‘massive’ and ‘low mass’ outcomes, for different stellar types

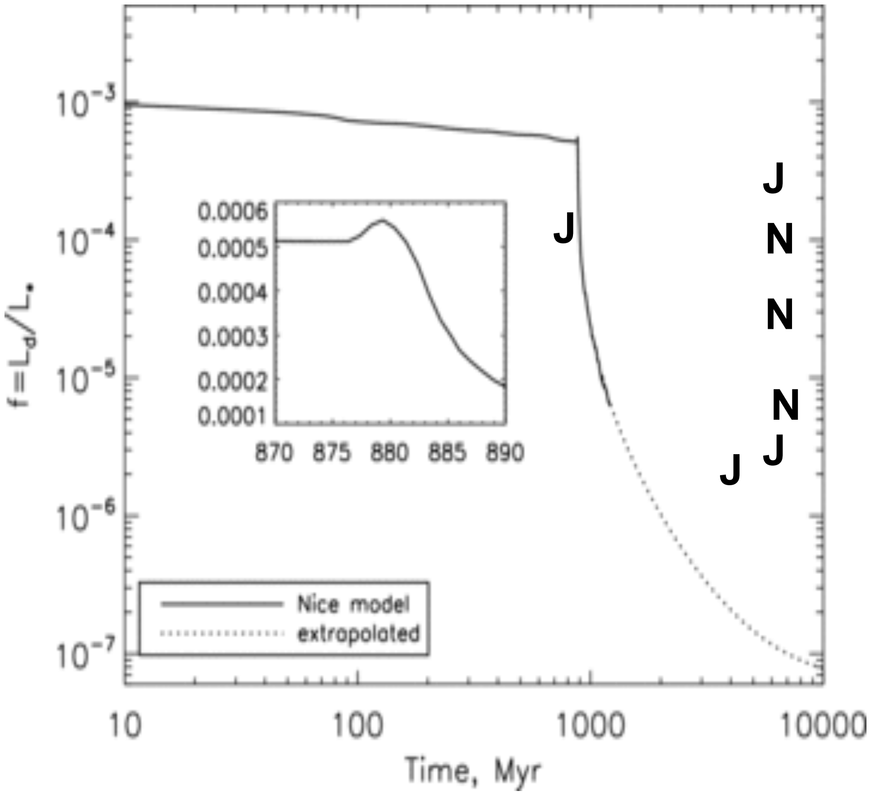


Spectral type	Max M_{disc} (M_{Jup})	Min [Fe/H] (planet)	Min M_{solids} ($M_{\oplus}$, for planet)	Min M_{disc} (M_{Jup}, at [Fe/H] = 0)	f(planet) per cent Predicted	f(planet) per cent Observed	f(debris) per cent Predicted	f(debris) per cent Observed
FGK	600	−0.7	400	120	8 ± 3	8.5 ± 1.0	–	19 ± 3
A	150*	−0.36	200	60	20 ± 7	20 ± 3	55 ± 11	70 ± 11
M	270	−0.12	650	200	1.9 ± 1.3	3.3 ± 1.5	14 ± 4	<7 (∼2)

Greaves (2010)

comparison to Solar System

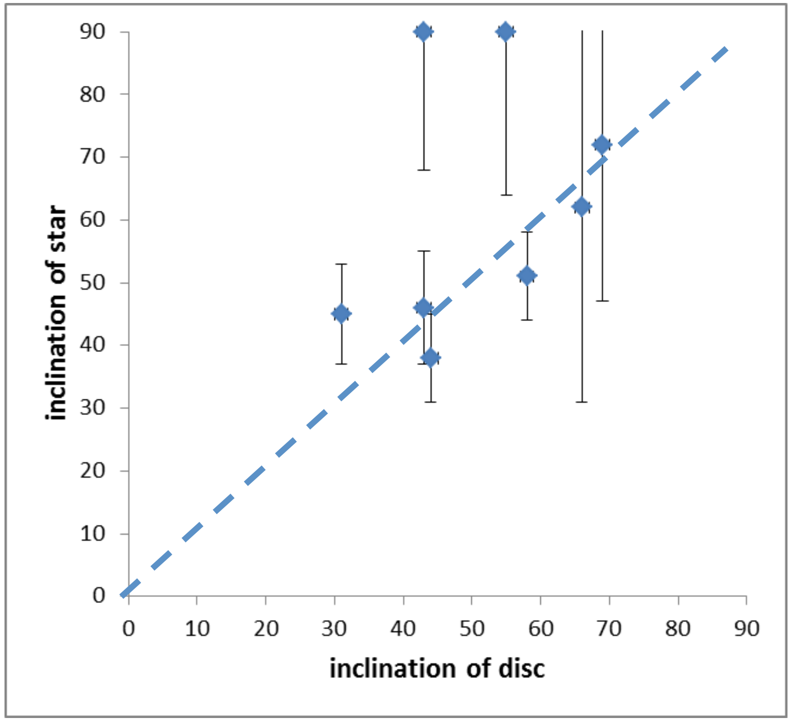
- primordial Kuiper Belt must have been much more massive… appears it was cleared out during giant planet migration
  - now see planetary systems with far more debris at far later ages than Late Heavy Bombardment (~0.8 Gyr)
  - implies catastrophic planetary hits?



Booth et al. (2009); overlaid **J** and **N** from DEBRIS/DUNES results

disc-star interaction

- precision of PACS images allows fitting of inclinations
  - hence test of alignment of rotation axes of star and disc, where (P, v sin i, R_*) accurately known
- appears that (unlike case of close-in planets) rotation axes of debris discs are well aligned with their host stars

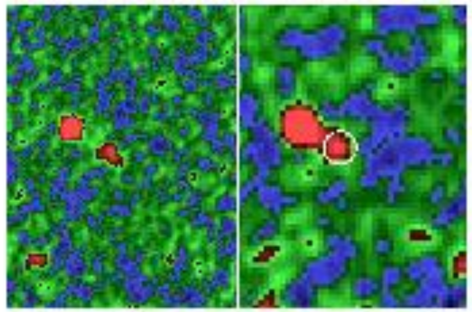


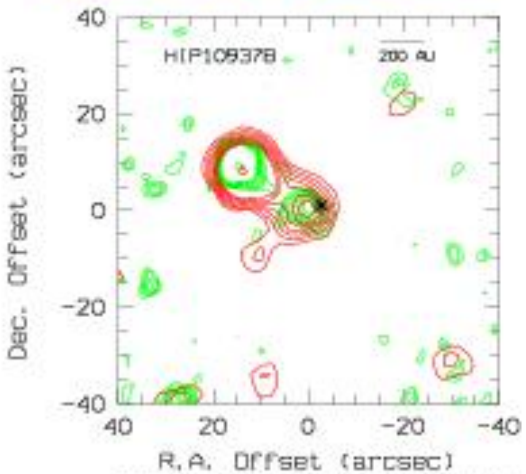
Greaves, Eiroa et all. (in prep.)

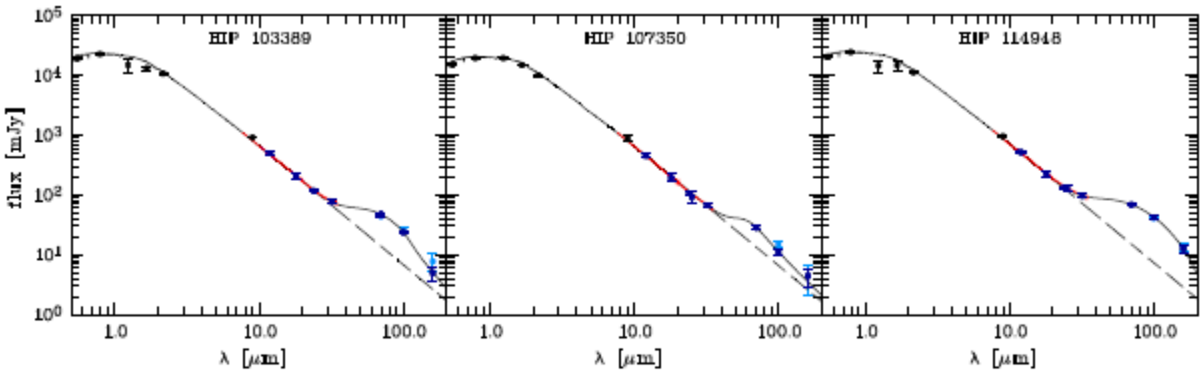
new parameter spaces

- cold, faint debris discs
  - T_{dust} ~ 20 K or less, L_{dust}/L_{star} ~ 10^{-6}
- dust with steep spectral index
  … linked phenomena?

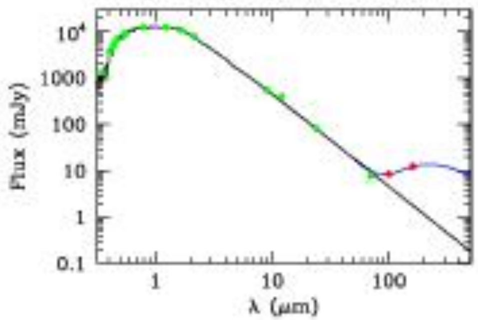
→ talk by A. Krivov (DUNES)







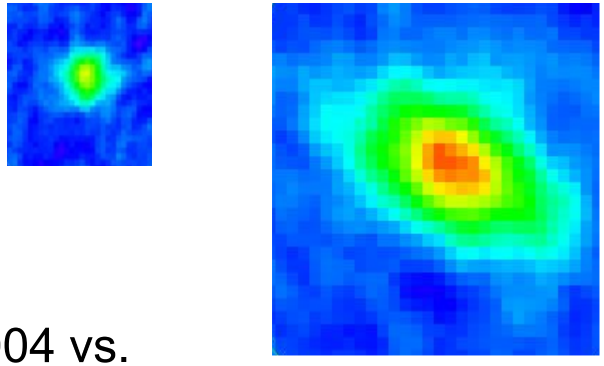
Ertel et al. (2012)



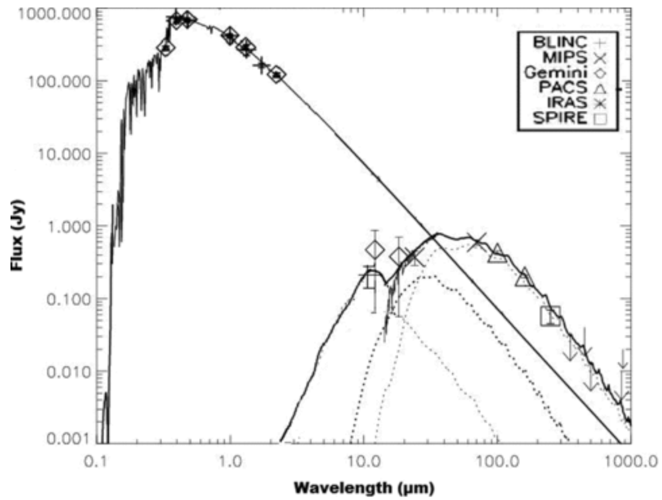
Eiroa et al. (2011)

new parameter spaces

- small debris discs
  - resolved for the first time below the size of the Kuiper Belt
- multiple dust belts
  - e.g. β Leo: up to 3 debris belts
  - better analogues to the asteroid & comet belts of the Solar System



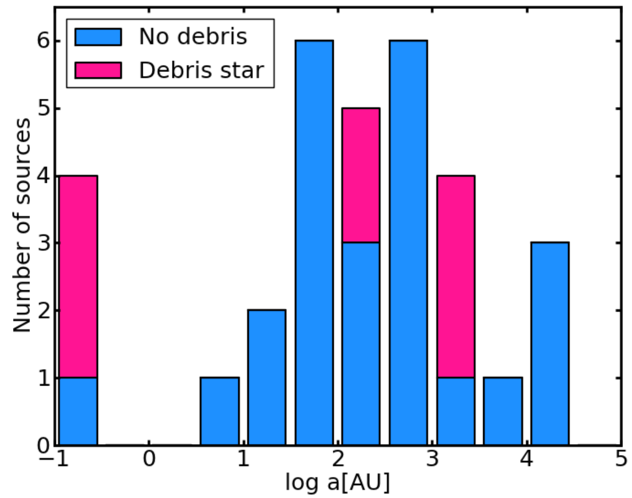
K004 vs.
G008 (Kuiper Belt-sized)



Churcher et al. (2011)

‘predictors’ of debris

- unbiased statistics from DEBRIS suggest:
  - incidence of discs is ~1/4 for any spectral type AFGK
    - *not* e.g. higher for A-stars
  - stellar age weakly correlated
    - evolution is *slow*
    - only noticeable for A-stars?
  - binarity is important, presumably for dynamical stability



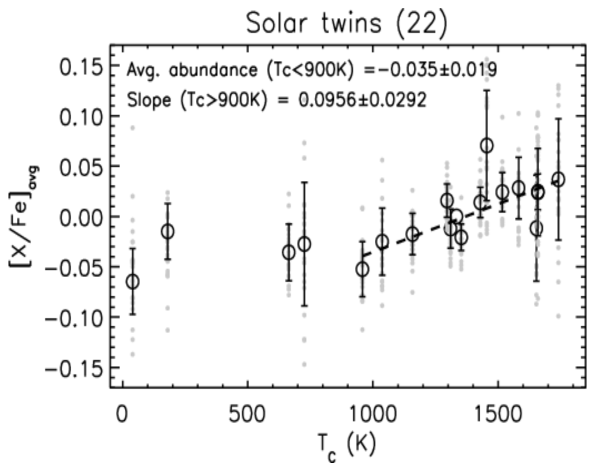
    - planetesimals survive best in close or wide binaries
  - hosting a planet is not strongly correlated with debris
    - but (esp. low-mass) planets and debris discs do co-exist

solar twins

- but, *very* Sun-like stars do show some trends?
  - among DUNES/DEBRIS 'solar twins', old ones undusty:

G006	t ~0.3 Gyr	T_{disc} = 18 K	$R_{100} \approx 1.40$
G013	t ~1.5 Gyr	T_{disc} = 144 K	$R_{100} \approx 1.02$
G036	t ~0.3 Gyr	T_{disc} = 115 K	$R_{100} \approx 2.11$
G048	t ~8 Gyr	no disc	$R_{100} \approx 1.05$
G080	t ~0.3 Gyr	T_{disc} = 88 K	$R_{100} \approx 3.13$
G120	t ~7 Gyr	no disc	$R_{100} \approx 0.92$
Sun	t =4.5 Gyr	T_{disc} ~ 40 K	R_{100} ~1.05?

(Vitense et al. 2010)

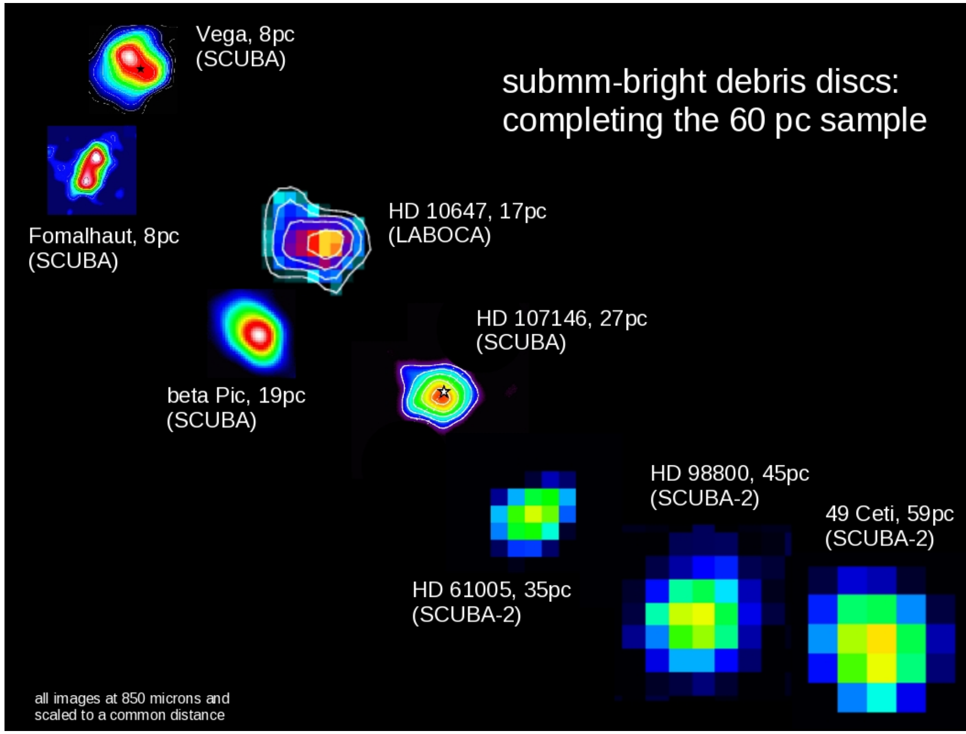


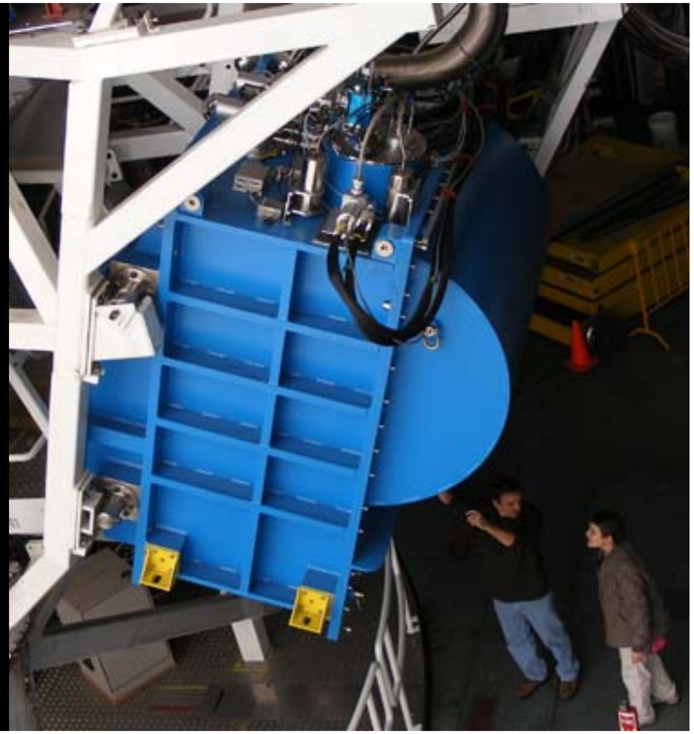
Ramírez et al. (2009): low $T_{condense}$ elements are depleted in solar twins ??

- no clear link to planets, but note 51 Peg (G048) also undusty

future observations

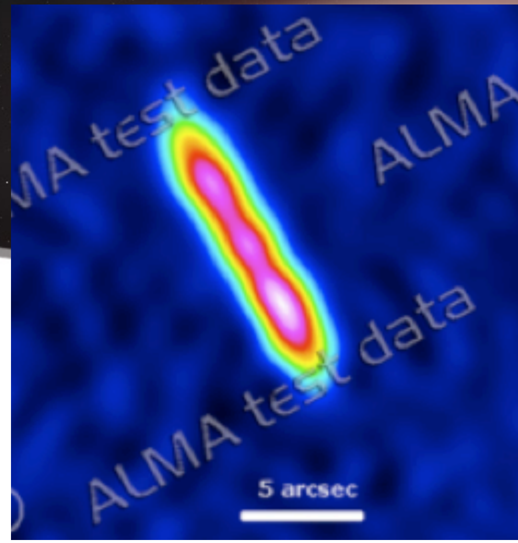
- SPIRE is giving insights to cool discs… can follow up at higher resolution with SCUBA-2 (450,850 μm: 8,15″)



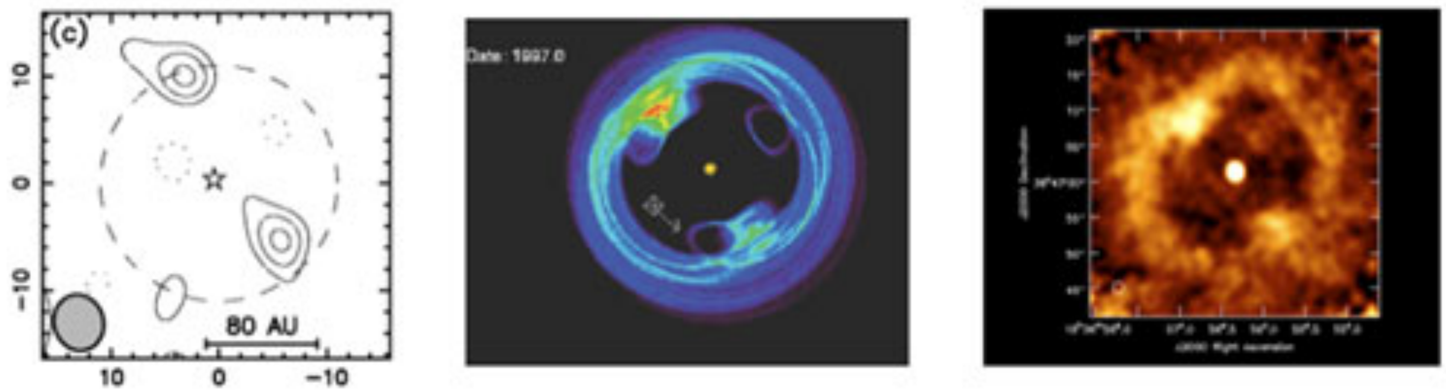


Science Verification images from SCUBA-2 at 850 μm for SONS, Jan 2012

the future - now



- ALMA is just starting to image debris discs… soon will be able to examine scales and structures for archetypes and more! … from the populations uncovered by Herschel



Three views of the Vega debris disk. Left: IRAM image (Wilner 2002). Center: Wyatt model (2003). Right: Simulation of Wyatt model as observed by ALMA (Reid 2008).