Debris Disks: Now and the future

Wayne Holland (UK ATC, Edinburgh)

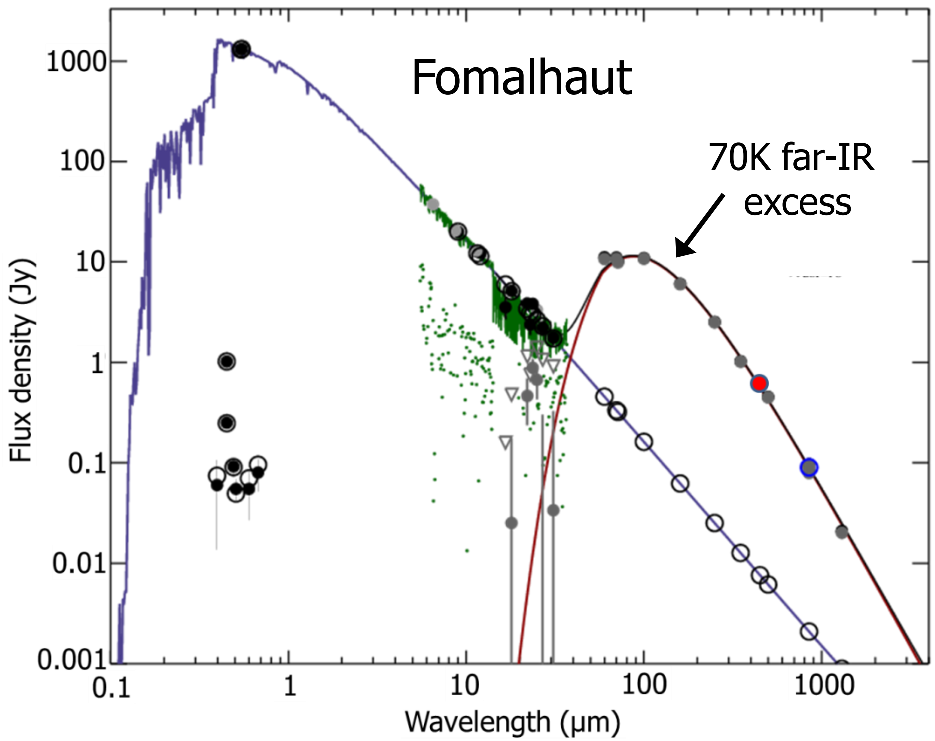
FISICA Science Workshop, Rome, 17th Feb 2014

Outline

- What are debris disks?
- Recent results: surveys
- Now and the near future: ALMA
- Future missions: sub-arcsec imaging in mid-IR
- Conclusions

Evidence for a disk?

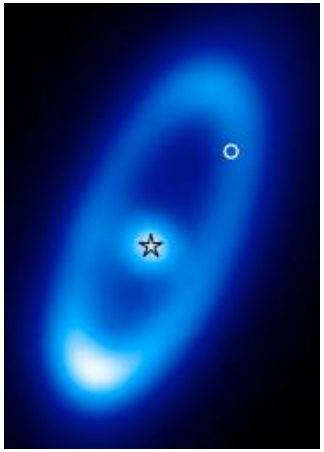
- Infrared emission from a star brighter than the photosphere (e.g. 70K excess for Fomalhaut)



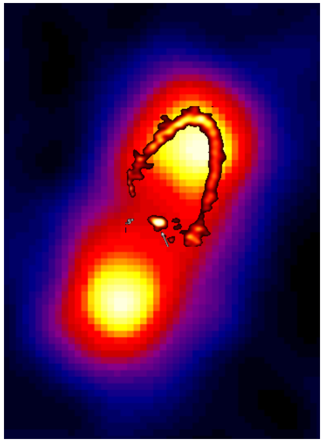
Observables

Optical
– scattered light
(Hubble)

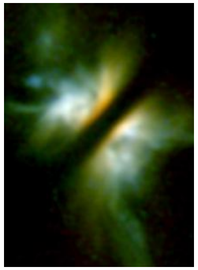
Far-IR
– dust emission
(*Herschel*/PACS)

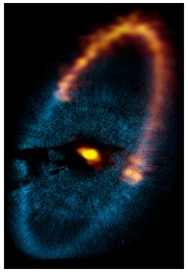


Submm
– dust emission
(JCMT/SCUBA-2
and ALMA)

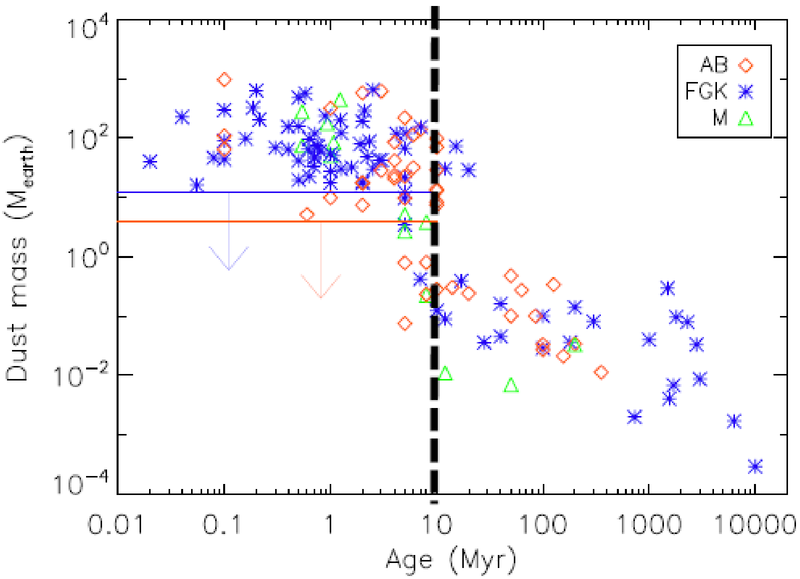


Descendant of proto-planetary disk





	Proto-planetary disk	Debris disk
Age	< 10 Myr	10 Myr – 10 Gyr
Optical depth	Optically thick	Optically thin
Dust mass	> 10 M_{Earth}	< 1 M_{Earth}
Gas mass	~100x dust mass	Very little (usually…)
Structure	Dust from 0.1 – 1000 AU	Confined to 30 – 100 AU ring
Dust origin	Primordial?	Secondary (short lifetime)

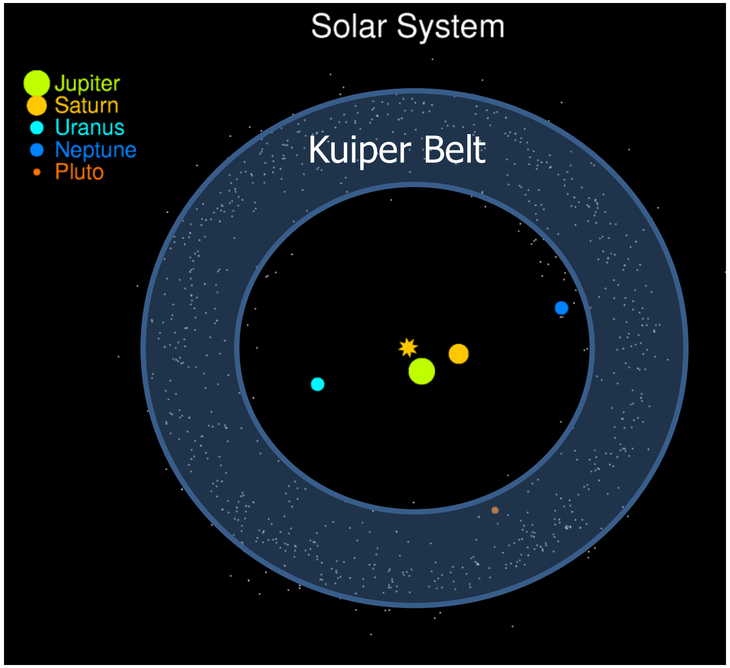


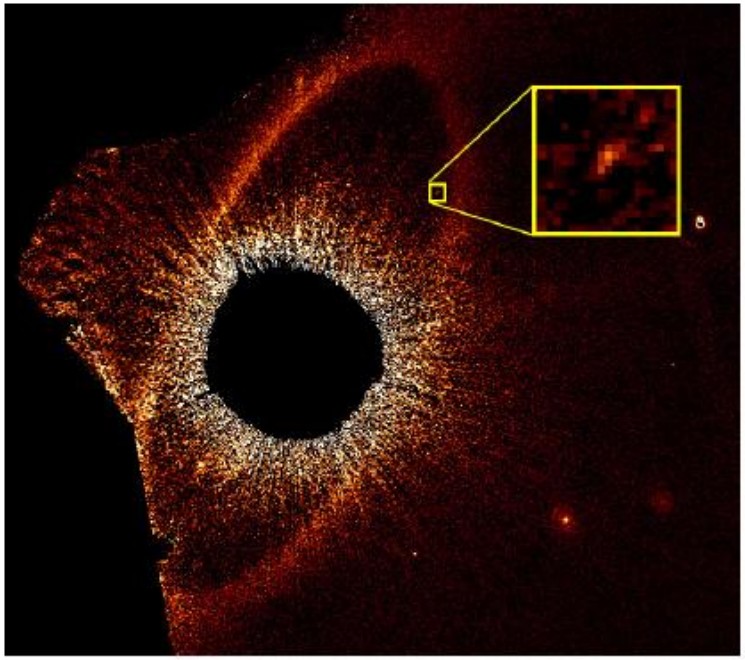
Onset of the debris phase

(Panić et al. 2013, MNRAS 435, 1037)

Debris disks and planets

• Structure provides indirect information on the architecture (and evolution) of a possible planetary system

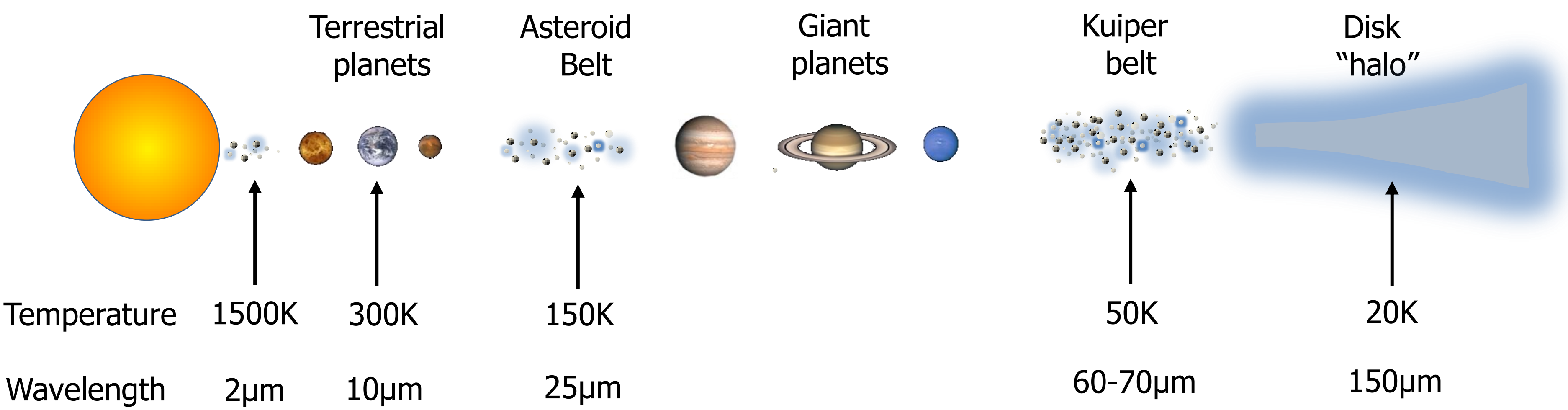




• Structure also can be used to predict and identify perturbers, such as planets

Observations probe different zones

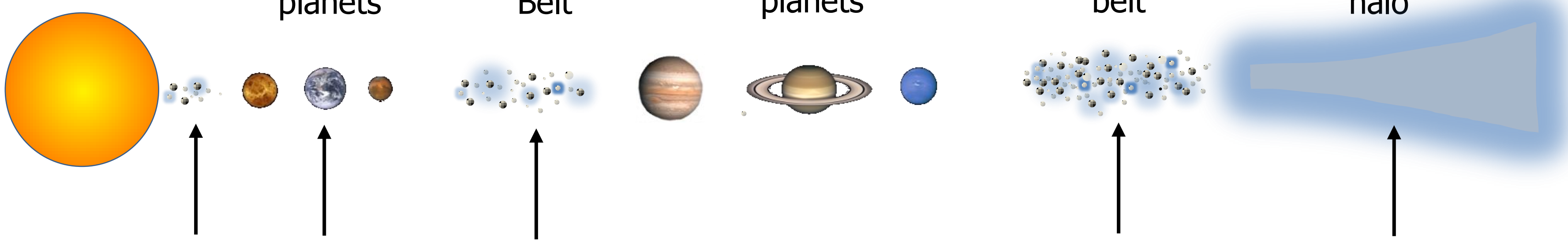
- Different wavelength observations probe multiple components of a disk



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

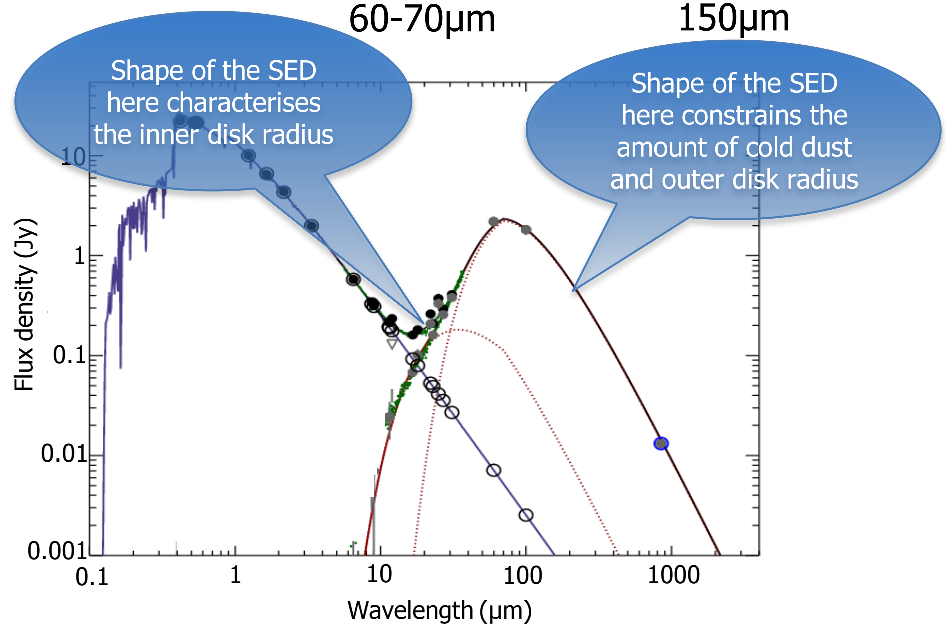
Observations probe different zones

- Different wavelength observations probe multiple components of a disk



		Terrestrial planets	Asteroid Belt	Giant planets	Kuiper belt	Disk "halo"
Temperature	1500K	300K	150K		50K	20K
Wavelength	2μm	10μm	25μm		60-70μm	150μm

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



Multi-wavelength surveys

Why carry out surveys of debris disks?

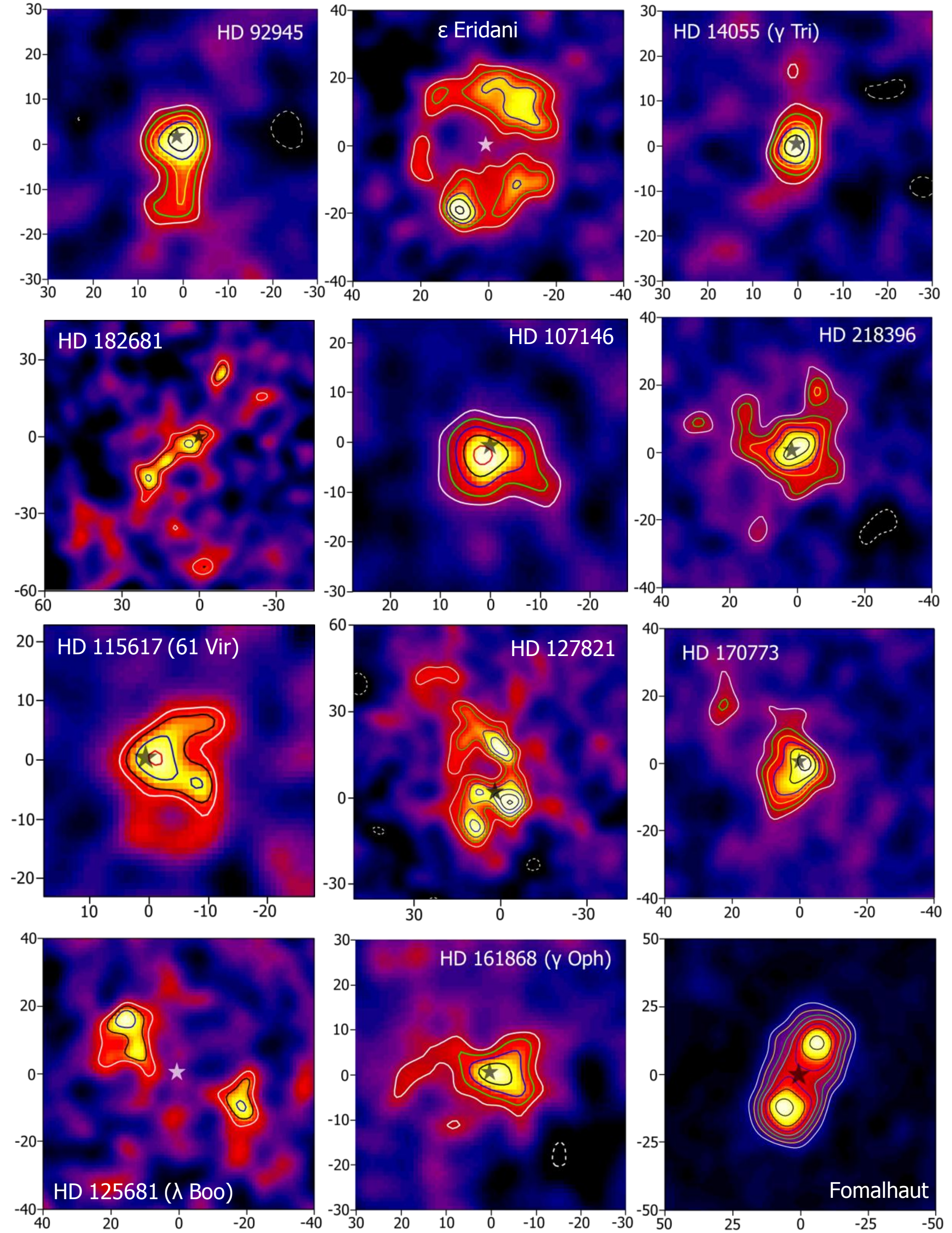
Statistics, resolved images, detection of gas and the possible discovery of new classes of object...

- IRAS, ISO, & SCUBA: photometry and "imaging" → early information on basic properties
- Spitzer: Surveys of A-stars → studying dust evolution
- *Herschel:* DUNES and DEBRIS → 50% of debris disks are resolved
- JCMT: SONS → cold and massive disks

Diversity of disks!

Sample of 110 nearby stars:

- Imaged new (cold) debris disks at 850µm
- 43/100 disks so far detected
- Many of the detected disks have been resolved
- Wide range of morphologies and typically a few times the size of KB in our Solar System (but more massive)



Key results so far (and issues…)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*

	A stars	F, G and K stars	M stars
Incidence	25-35%	3-20%	Very few!
Main wavelengths	2, 24, 70, 100μm	24, 70, 100, 160μm	24, 70, 100, 850μm

Su et al. 2006, ApJ 653, 675
Chen et al. 2011, ApJ 738, 122
Absil et al. 2013, A&A 555, 104
Thureau et al. 2014, *in prep*

Liu 2004, Science 305, 1442
Gautier et al. 2007, ApJ 667, 527
Lestrade et al. 2012, A&A 548, 86
Matthews et al. 2014, *in prep*

Hillenbrand et al. 2008, ApJ 677, 630
Carpenter et al. 2009, ApJS 181, 197
Eiroa et al. 2013, A&A 555, 11
Sibthorpe et al. 2014, *in prep*

Key results so far (and issues…)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*

Comparable to planet rate discovered by Kepler

	A stars	F, G and K stars	M stars
Incidence	25-35%	3-20%	Very few!
Main wavelengths	24, 24, 70, 100μm	24, 70, 100, 160μm	24, 70, 100, 850μm

Su et al. 2006, ApJ 653, 675
Chen et al. 2011, ApJ 738, 122
Absil et al. 2013, A&A 555, 104
Thureau et al. 2014, *in prep*

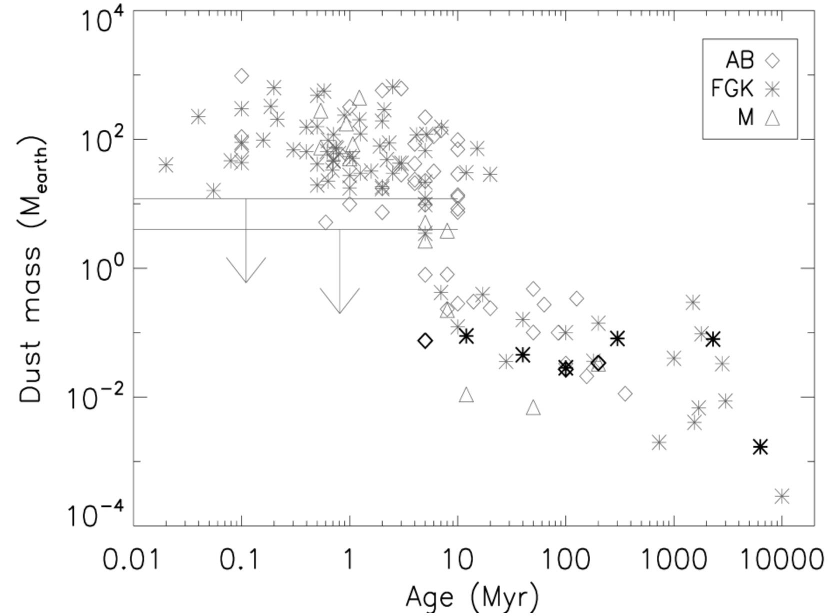
Liu 2004, Science 305, 1442
Gautier et al. 2007, ApJ 667, 527
Lestrade et al. 2012, A&A 548, 86
Matthews et al. 2014, *in prep*

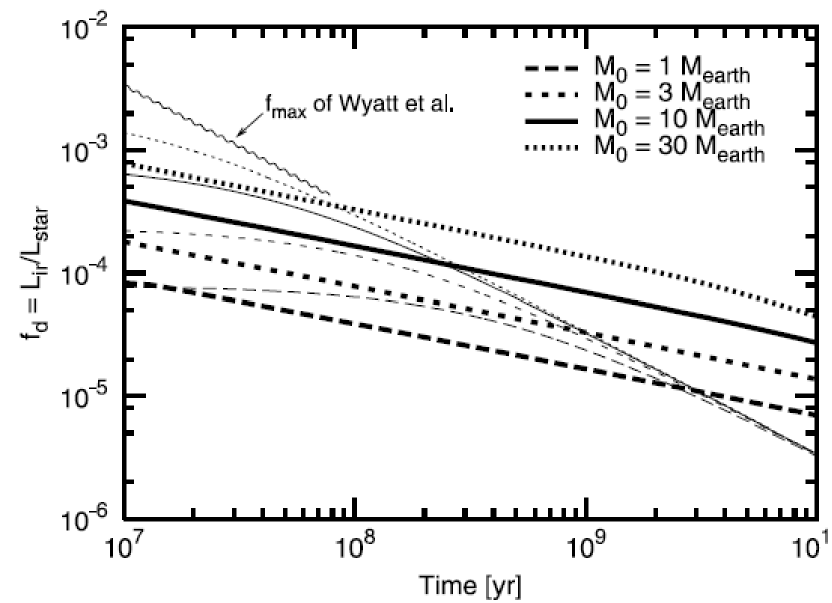
Hillenbrand et al. 2008, ApJ 677, 630
Carpenter et al. 2009, ApJS 181, 197
Eiroa et al. 2013, A&A 555, 11
Sibthorpe et al. 2014, *in prep*

Key results so far (and issues…)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*

- Evidence of declining disk mass and luminosity over time



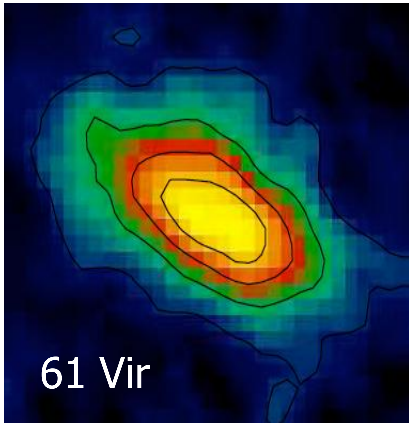


Wyatt et al. 2007, ApJ 663, 365

Key results so far (and issues…)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*

Wyatt et al. 2012, MNRAS 424, 1206



Nearest 60 G stars:

4/6 with low-mass planets have debris

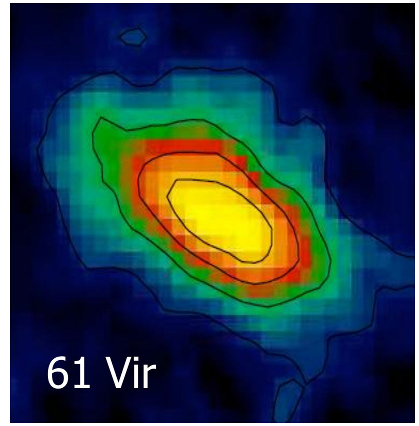
0/5 with high mass planets have debris

- Evidence of declining disk mass and luminosity over time

- Tentative correlation between low-mass planets and debris disks

Key results so far (and issues…)

- Disk incidences are reasonably well measured by *Spitzer* and *Herschel*



Wyatt et al. 2012, MNRAS 424, 1206

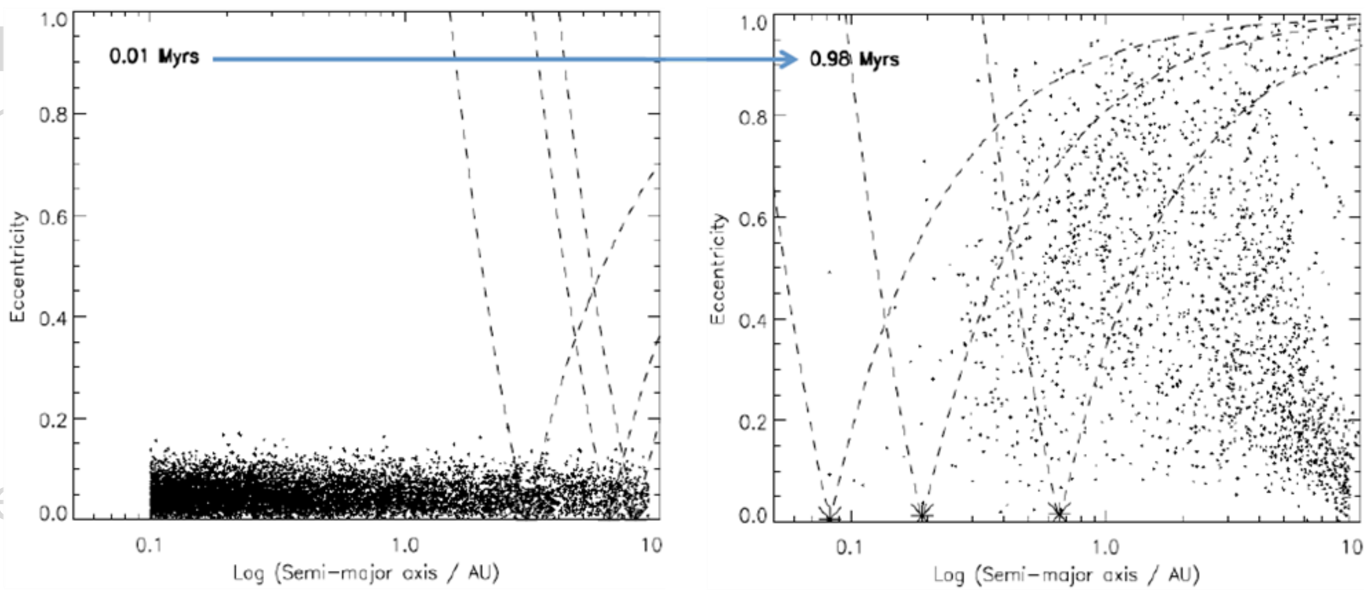
Nearest 60 G stars:

4/6 with low-mass planets have debris

0/5 with high-mass planets have debris

- Evidence of d
mass and lumi

- Tentative cor
low-mass plan
disks

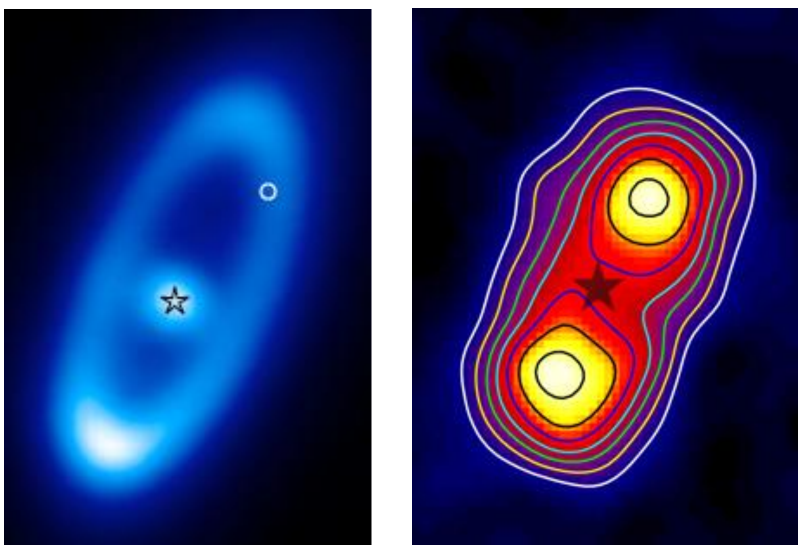


Planets start off at 5-10 AU and migrate inwards → many planetesimals end up beyond the outermost planet in a dynamically stable system

Payne et al. 2009, MNRAS 393, 1219

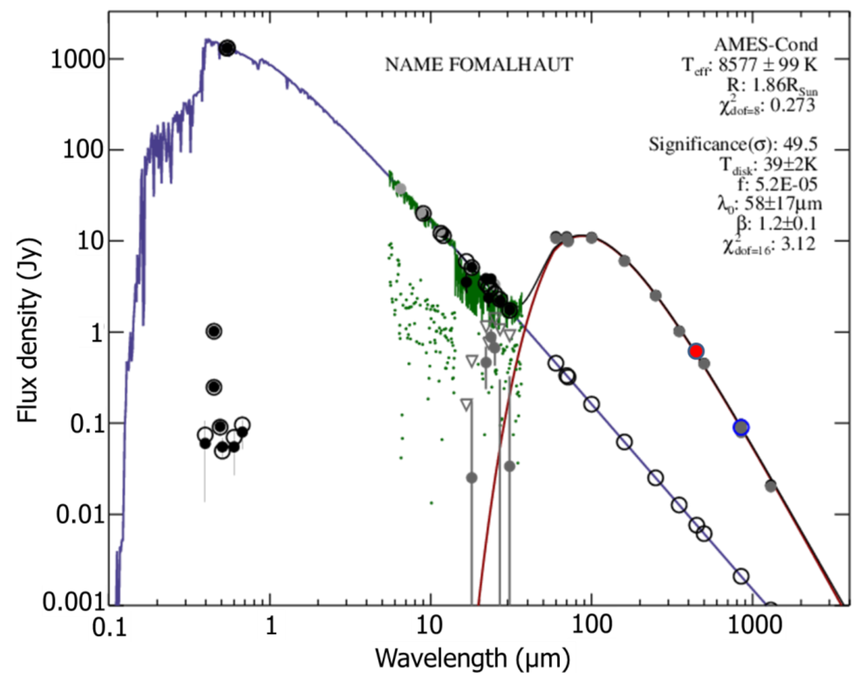
Key results so far (and issues…)

- An improvement in angular resolution is key to understanding disk structure



Images give inclination and position angle

Spectral energy distribution
Fit for T_{dust}, r_{disk} and spectral slope

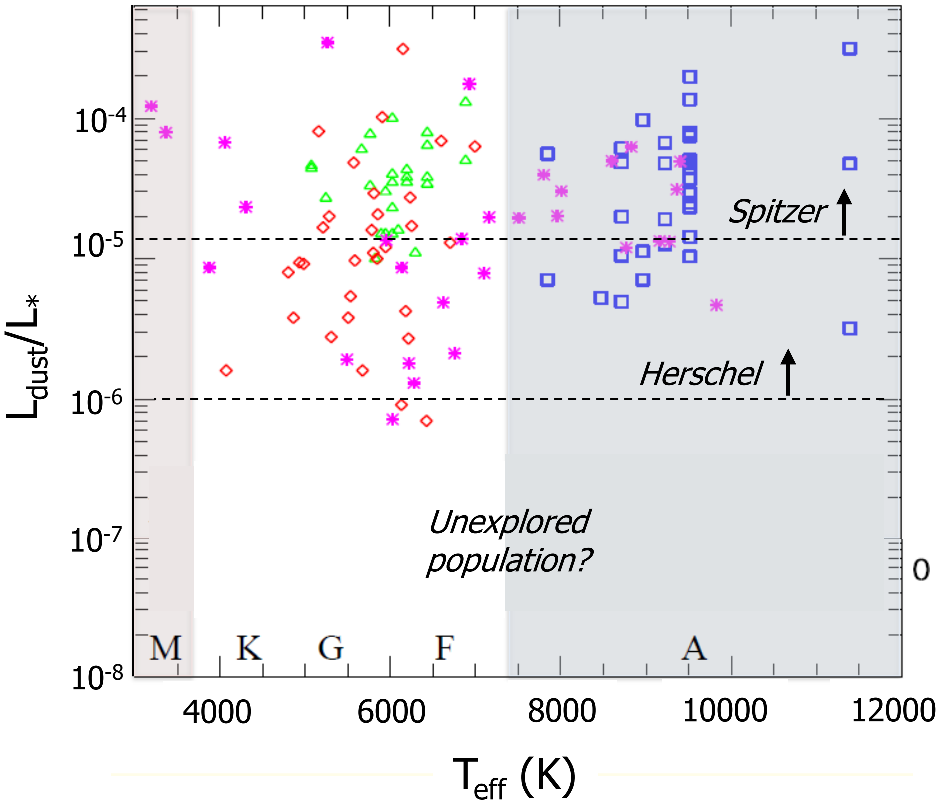


Can derive other physical parameters such as dust luminosity and mass, and information about dust grain sizes and composition.

Key results so far (and issues…)

- An improvement in angular resolution is key to understanding disk structure

- Debris disks are faint



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

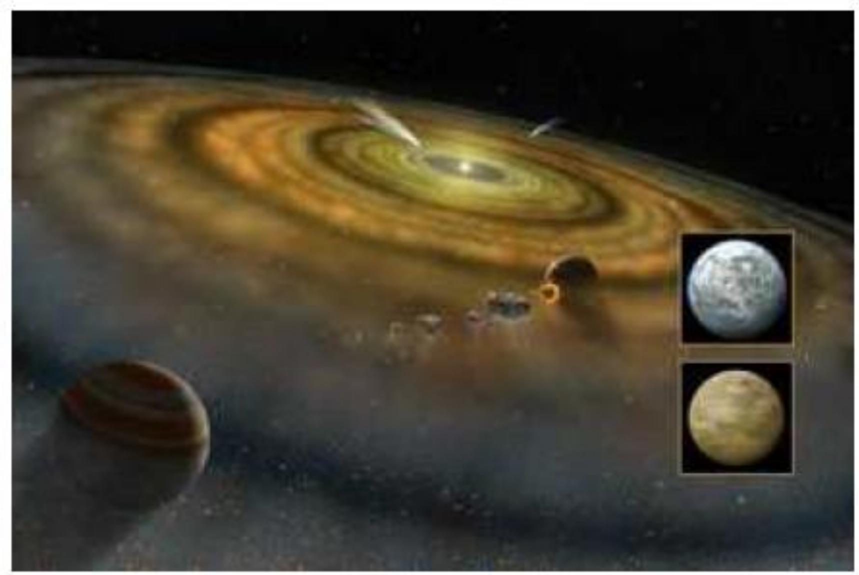
Key results so far (and issues…)

- An improvement in angular resolution is key to understanding disk structure

- Debris disks are faint

- Warmer inner regions of exo-systems – Asteroid Belt analogs?

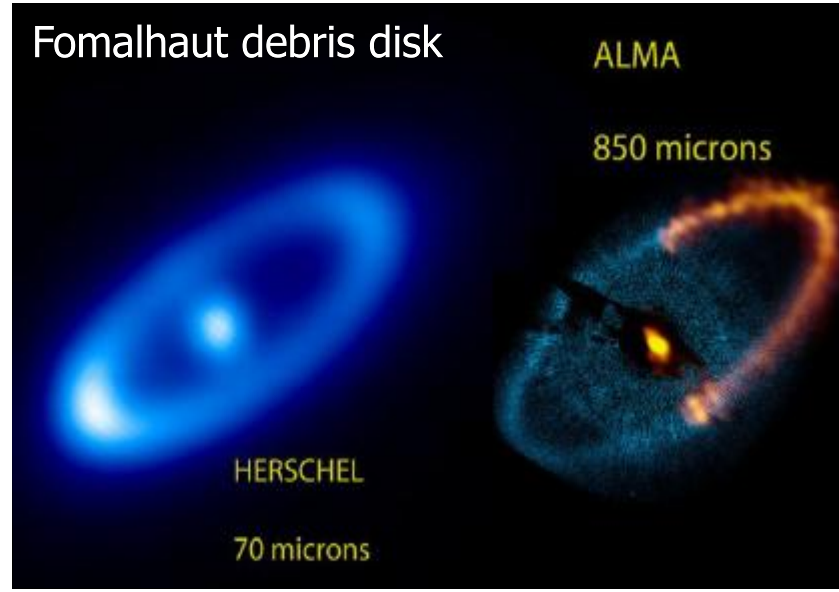
Lack of both sensitivity and resolution to study the warmer inner regions – probing the realm of terrestrial planets and the "habitable zone"



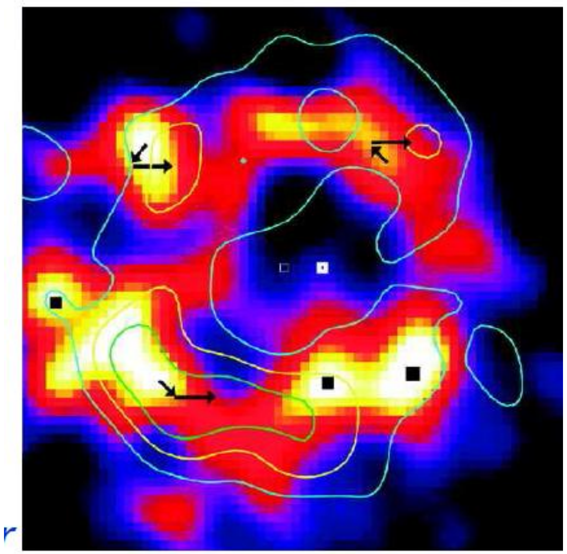
Key roles for ALMA

- Resolving disks is key to understanding the underlying structure of debris disks

- Unambiguous identification of dust trapped in resonances with a planet

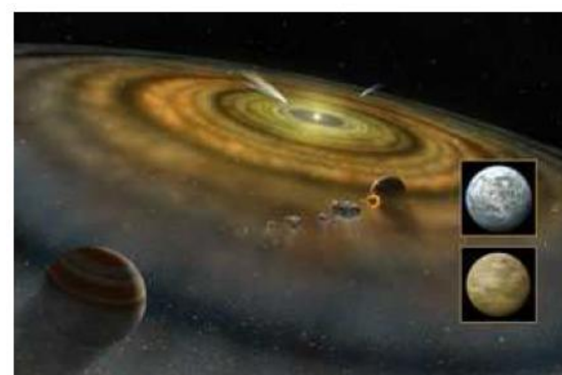


Acke et al. 2012, AAp 540, A125; Kalas et al. 2013, ApJ 775, 56



- Sensitivity to detect perturbations within disks on short timescales
e.g. rotation of ε Eridani clumps in 1 month!

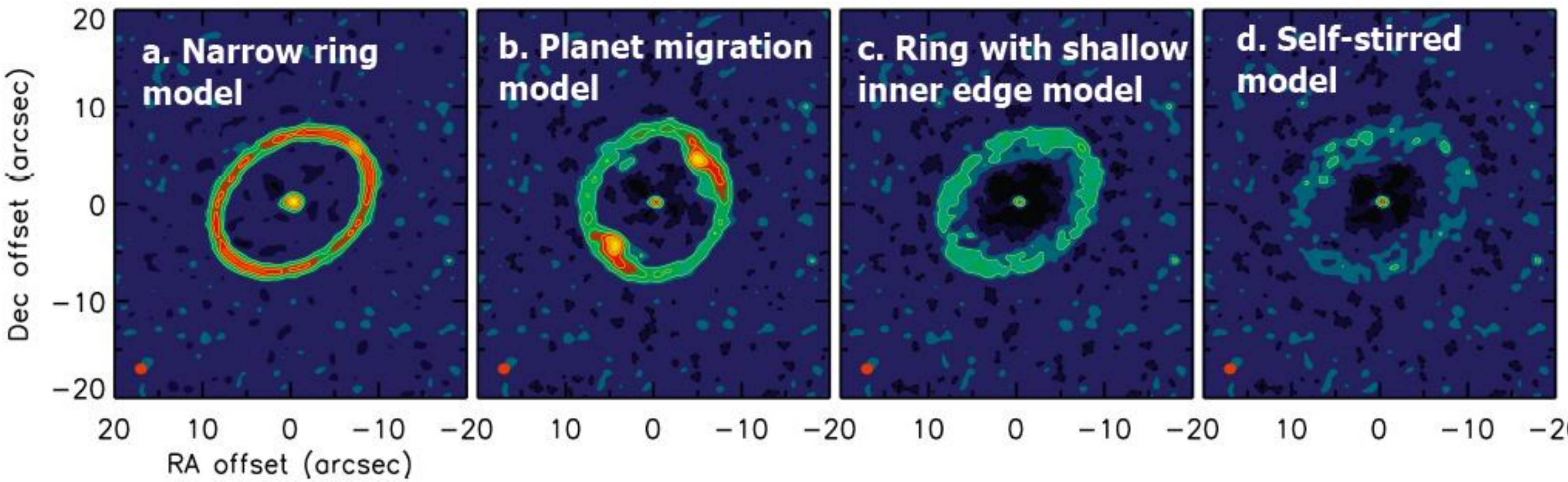
ε Eridani dust ring
(Greaves et al. 2005, ApJ 619, L187)



…But deep spectroscopy will be important to study comet collisions that should produce H_20 and CO

The role of ALMA

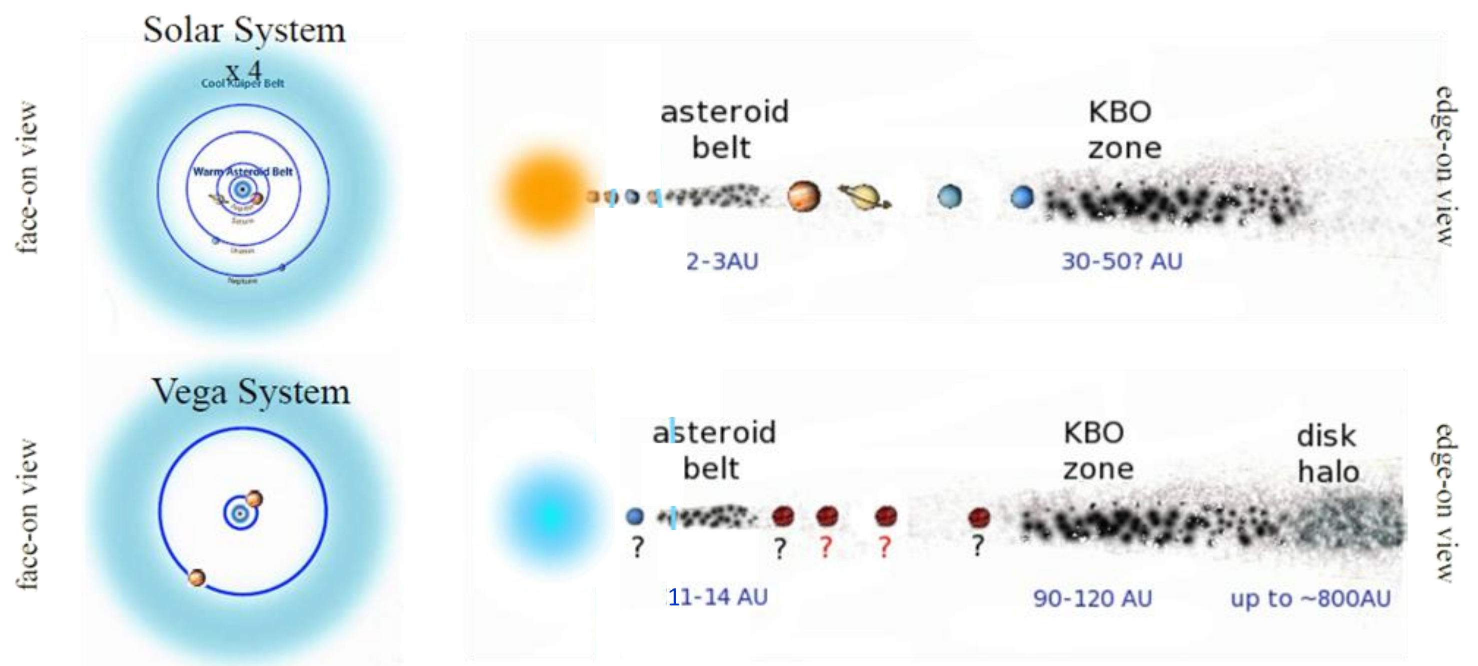
- Distinguish between models that have VERY different implications for the structure and evolution of a planetary system



Belt shepherded by planets	Outward migrating planet at inner edge	Late heavy bombardment	Planets still growing in outer regions

Sub-arcsec observations in the mid/far-IR

- Explore the warmer inner regions, but also have the range to characterise systems with multiple dust belts



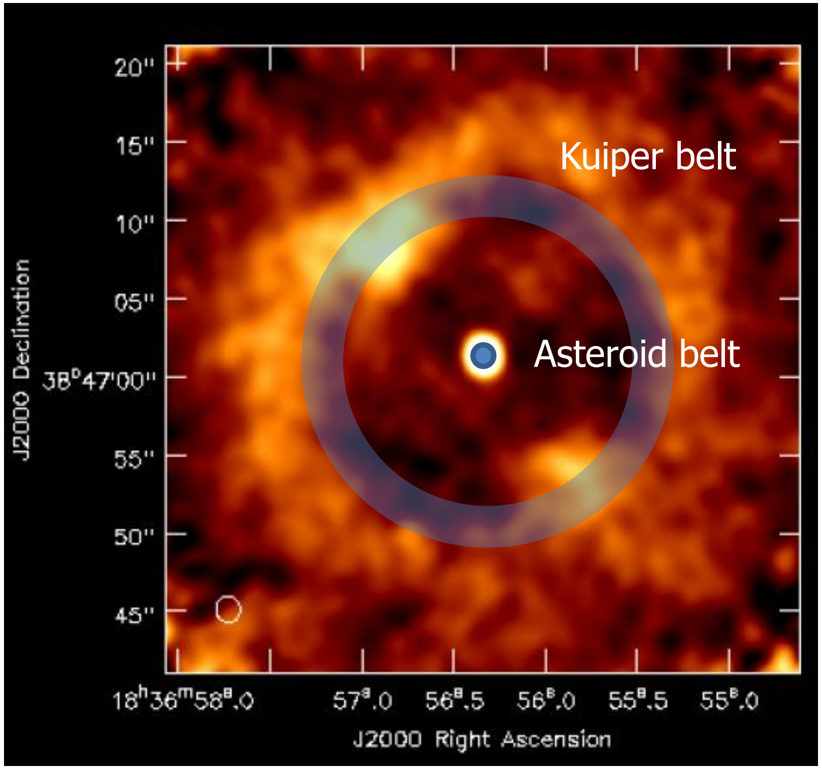
- Would have information on zodiacal and asteroid belt dust – regions that could affect the evolution of habitable planets

Sub-arcsec observations in the mid/far-IR

- What are the requirements?

The angular resolution to resolve structure in Kuiper and asteroidal belts around other stars.

For example, an asteroid belt at 10 pc has a diameter of ~1 arcsec – so a facility like FIRI at 40μm would be perfect.



Simulation of the Vega disk with 1″ resolution (Rob Reid)

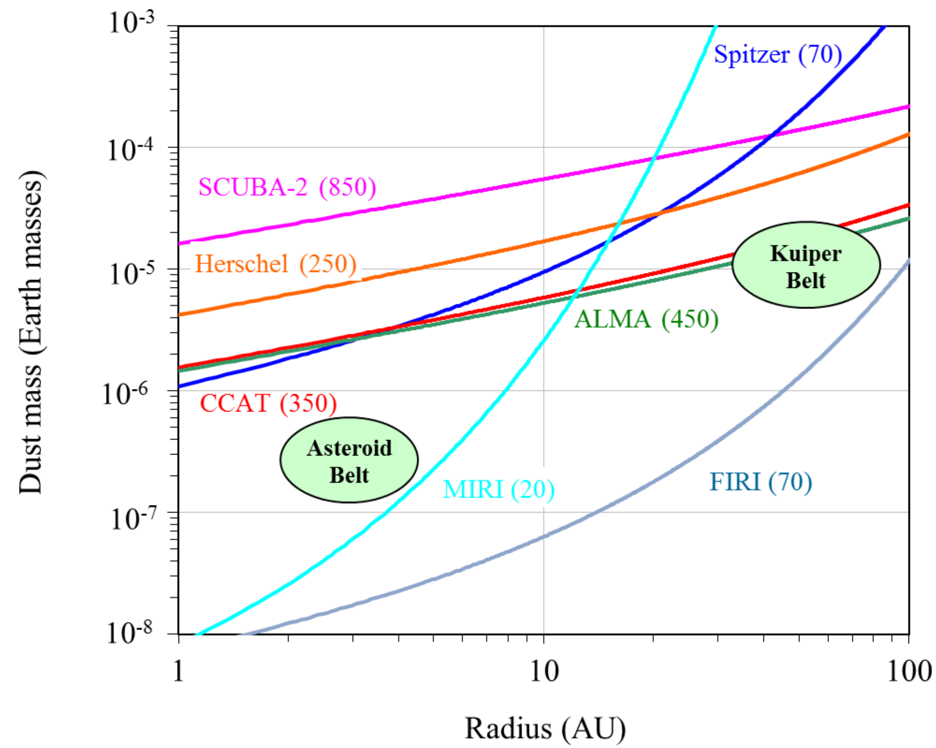
FIRI (100m baseline)	30μm	40	100	200
FWHM beam (arcsec)	0.07	0.1	0.25	0.5

Sub-arcsec observations in the mid/far-IR

- What are the requirements?

Sensitivity to reach very low dust mass levels.

A facility such as FIRI will be able to measure the equivalent of both our Kuiper and Asteroid Belts around nearby stars



The dust mass sensitivity (5-σ, 10-hr) as a function of radius from the star (distance of 10pc) for a selection of current and new facilities. The mass sensitivity is for unresolved sources.

Also:

Line-rich wavebands (covered by the 30-300μm range – OI at 63μm, for example)

Perhaps even a coronograph for the brightest, nearby stars... (or at least very good control of the PSF)

Summary

- Studying debris disks provides a unique insight into the evolution of a planetary system

- Observations have increased enormously over the past decade

- Theory needs to address issues such as the main mechanism that stirs debris disks (planets, planetesimals or both?)

- Recent results suggest a positive correlation between debris disks and planets; however, whether dusty debris implies a planetary system must exist remains an open question.

- ALMA and JWST in the near future and FIRI downstream will be important for taking this research to the next level

Acknowledgements

I would like to thanks the following people for providing input and comments on this presentation:

Jane Greaves
Brenda Matthews
Mark Wyatt
Rob Reid

And members of the SONS and DEBRIS survey teams.