Insights into planetary systems through JWST imaging of debris disks

Mark Wyatt

Institute of Astronomy, Cambridge

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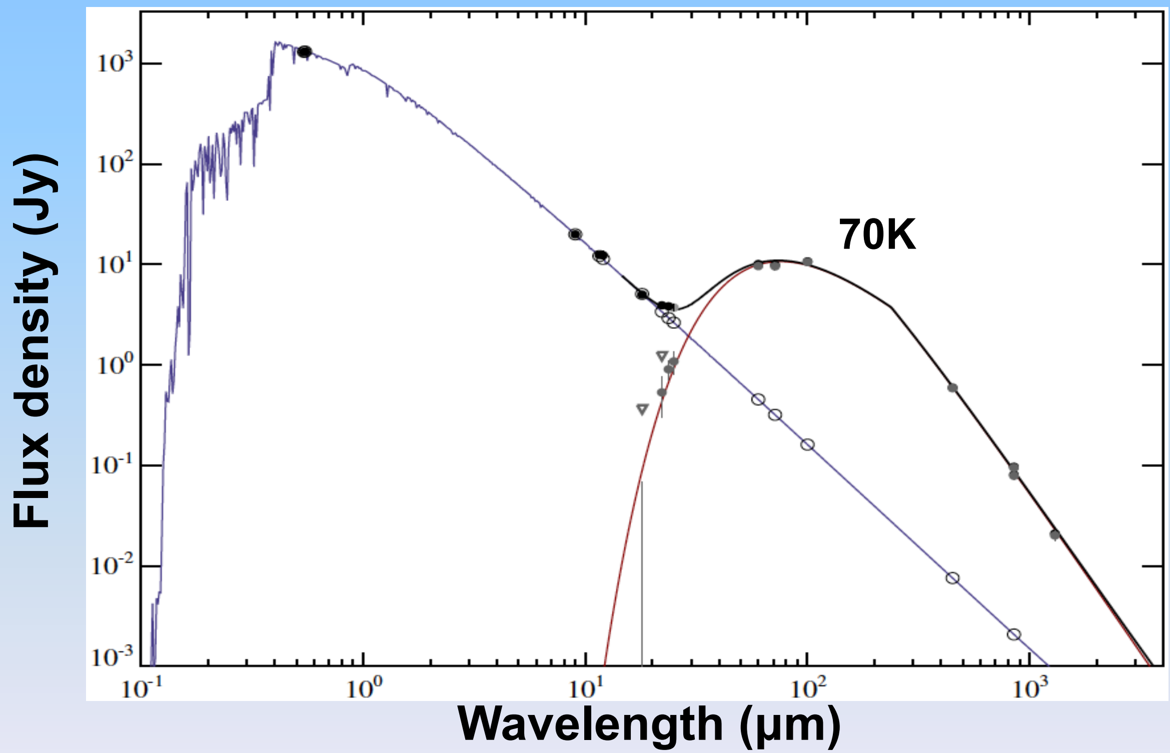
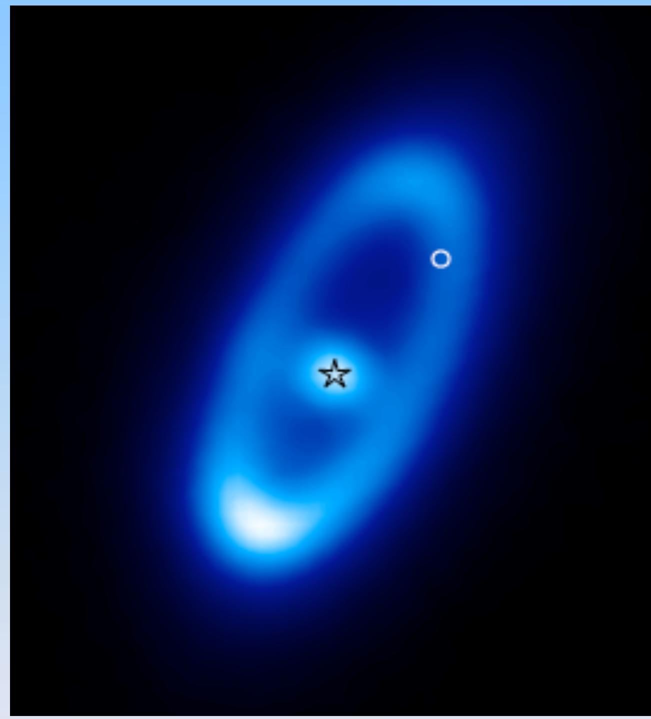
What is a debris disk?

Infrared emission of nearby main sequence stars above photosphere: e.g., Fomalhaut



DISCOVERY and STATISTICS

Imaging shows emission from 130AU dust ring (Acke et al. 2012)

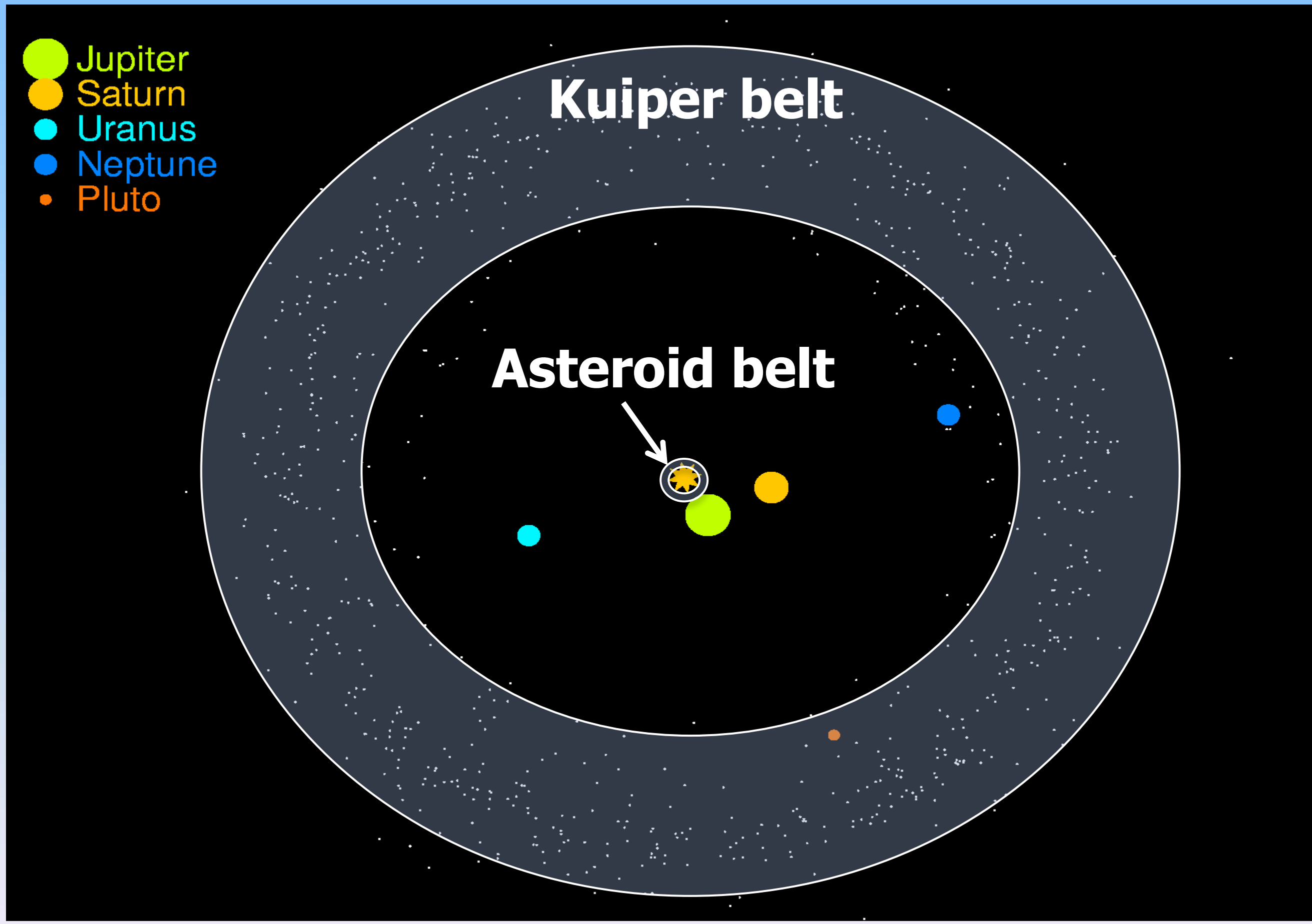


DETAILED CHARACTERISATION

Debris disks are components of planetary systems

Planetesimal belts are analogous to the Kuiper belt and Asteroid belt

Disk structure is indicative of the architecture of the planetary system

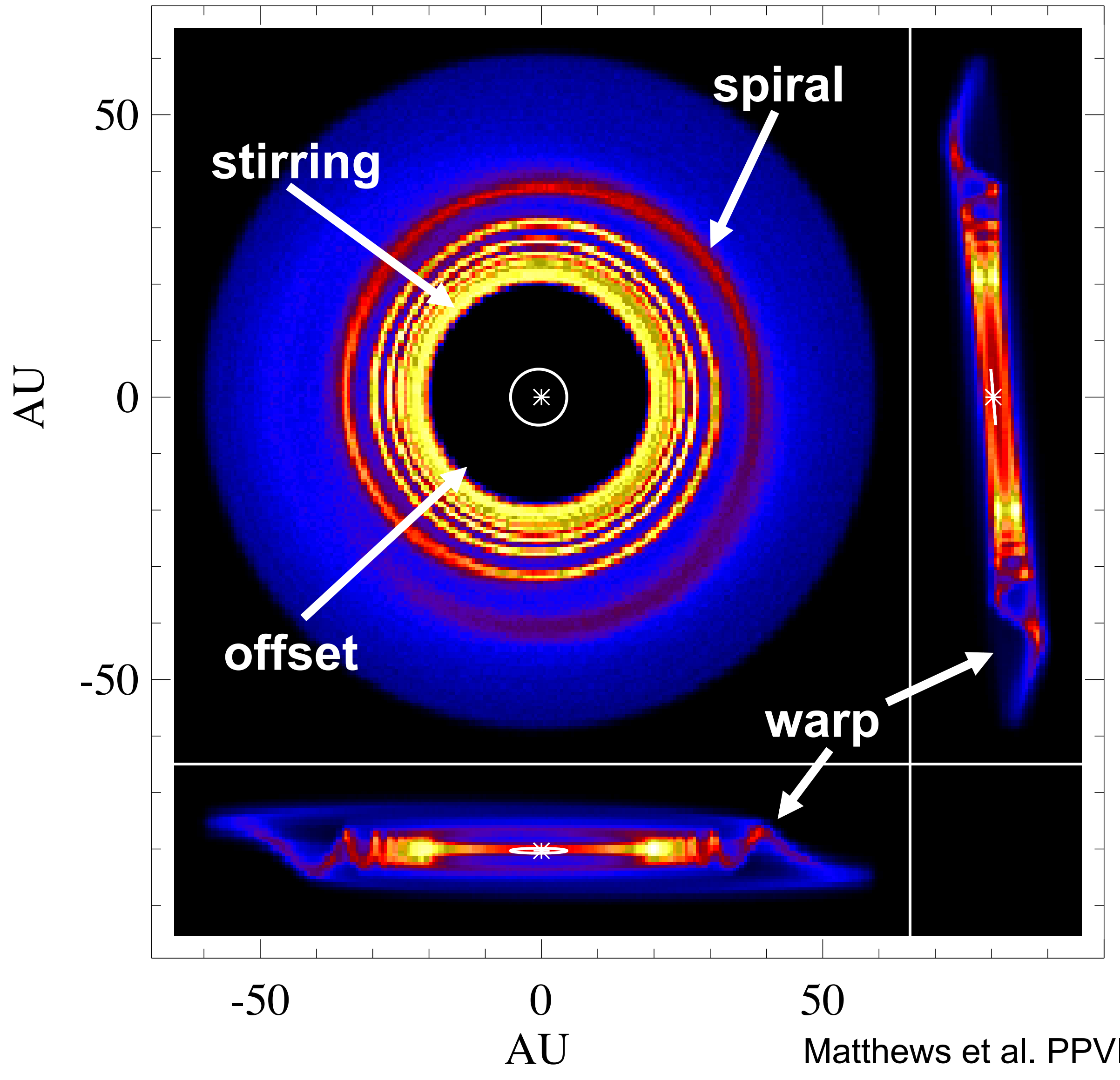


Planets inevitably affect disk structure

Planet:
1M_{jup}
5AU
e=0.1
I=5°

Disk:
20-60AU

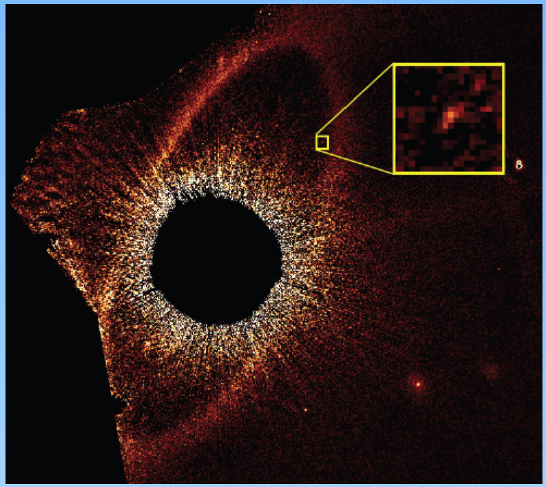
Time:
100Myr
after
formation



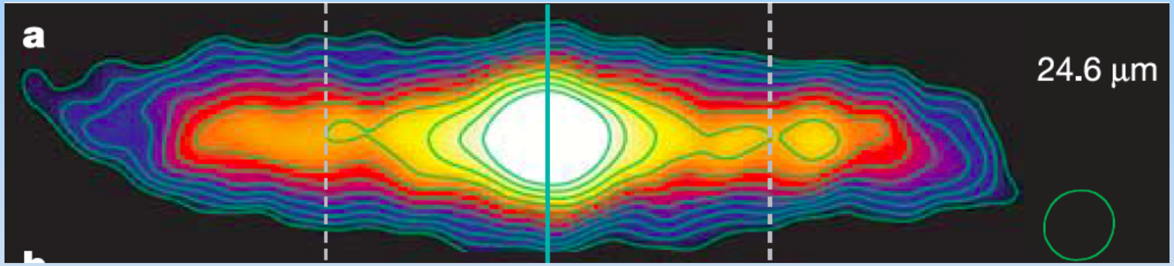
Matthews et al. PPVI

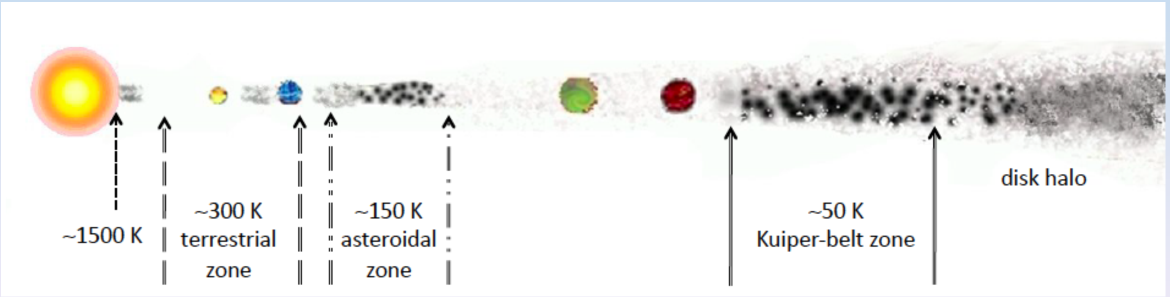
JWST contribution to debris disk science

(1) Scattered light coronagraphic imaging of structure in extrasolar Kuiper belts



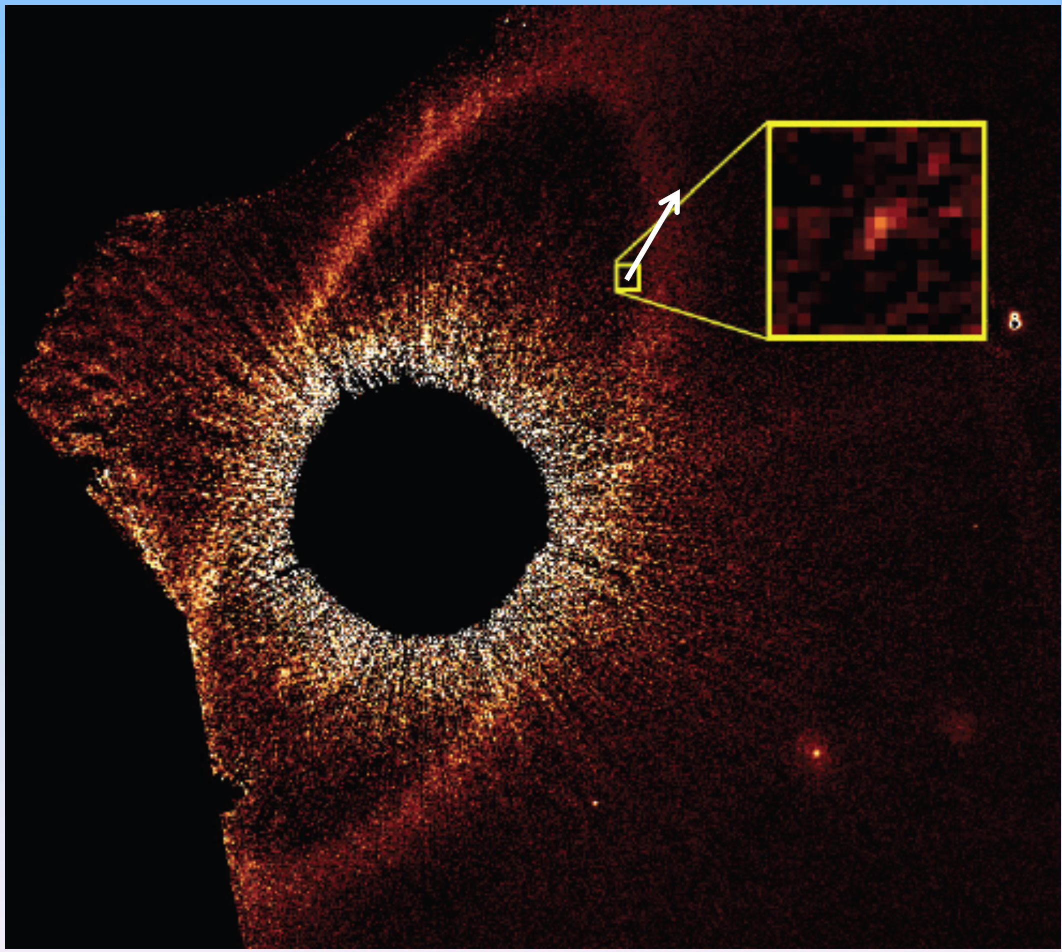
(2) Mid-IR (coronagraphic) imaging of structure in extrasolar Kuiper belts and mid-planetary system planetesimal belts





(3) TBD…

(1) Scattered light coronagraphic imaging of structure in extrasolar Kuiper belts

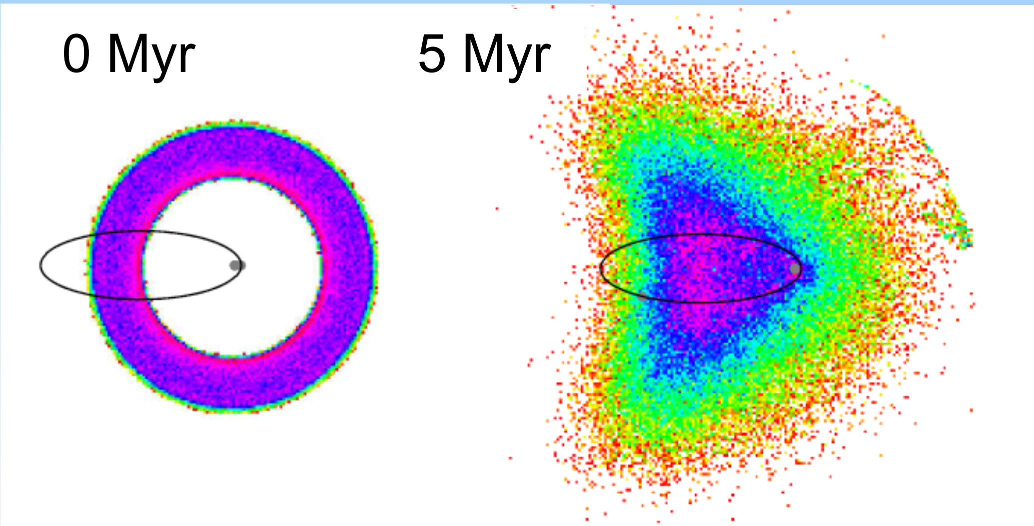


HST images show detailed structure of Fomalhaut's disk (Kalas et al. 2013): eccentricity, sharp inner edge, azimuthal gap

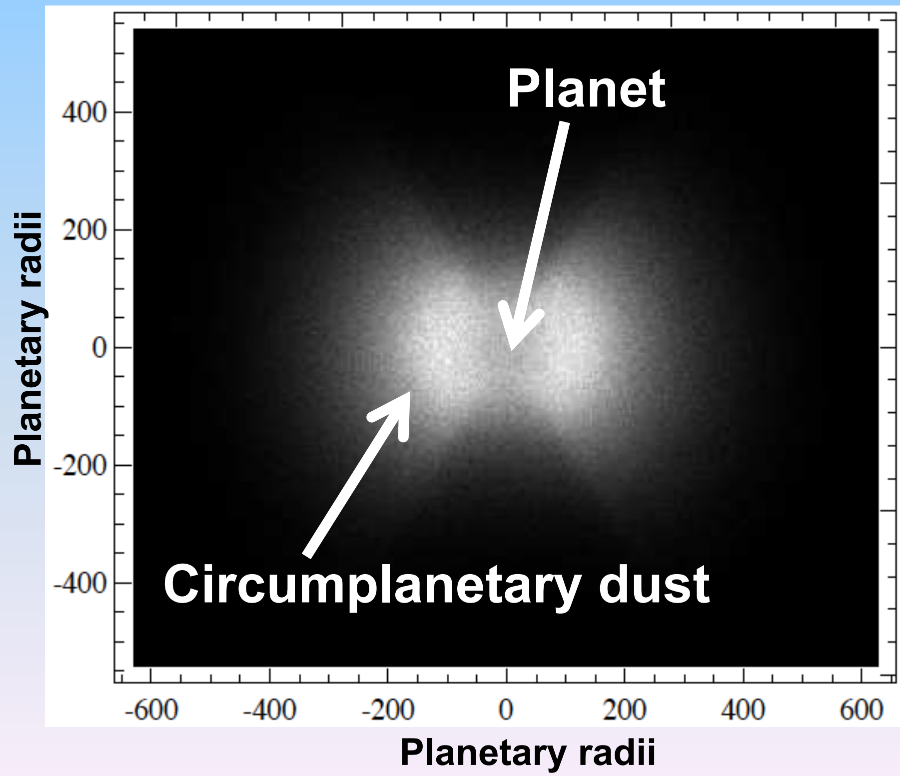
Also a planet (Fom-b) orbiting not along the inner edge, but on highly elliptical orbit

Debris disks are planet signposts, and provide constraints on planets

Debris disk coherence sets tight constraints on the Fom-b: either it's very low mass, or was put on its belt-crossing orbit very recently (Beust et al. 2013)

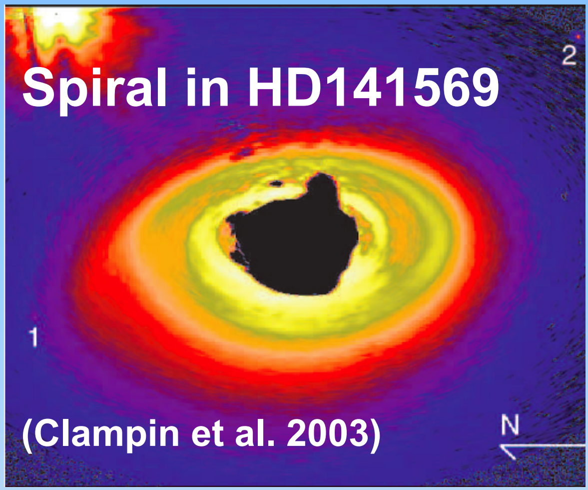


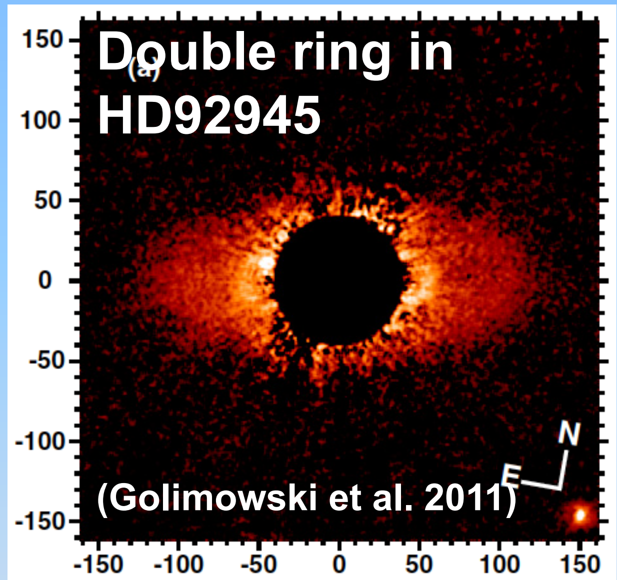
Best explanation: ~$M_{Neptune}$ and a cloud of irregular satellites around it (Kennedy & Wyatt 2011; Tamayo 2014; Kenyon & Bromley 2015)

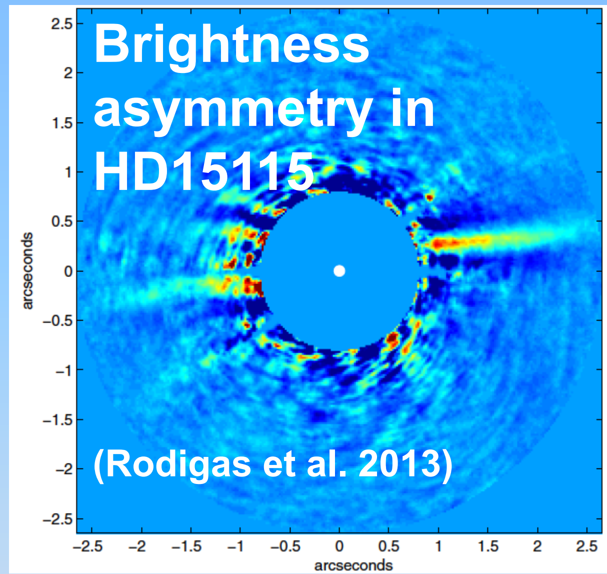


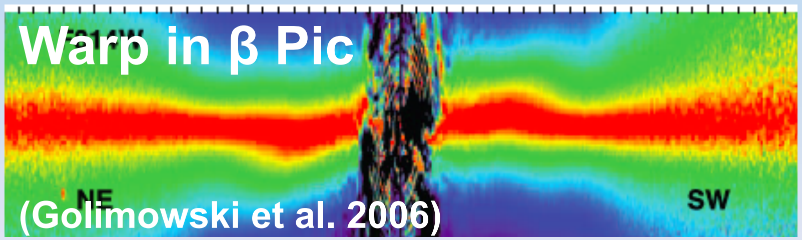
NIRCAM imaging of disk structure

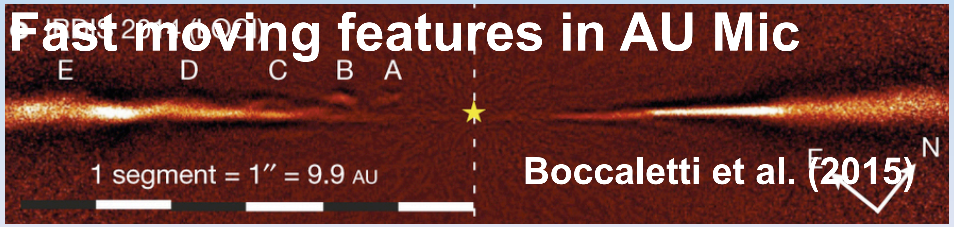
Will improve on what can currently be done from the ground and with HST





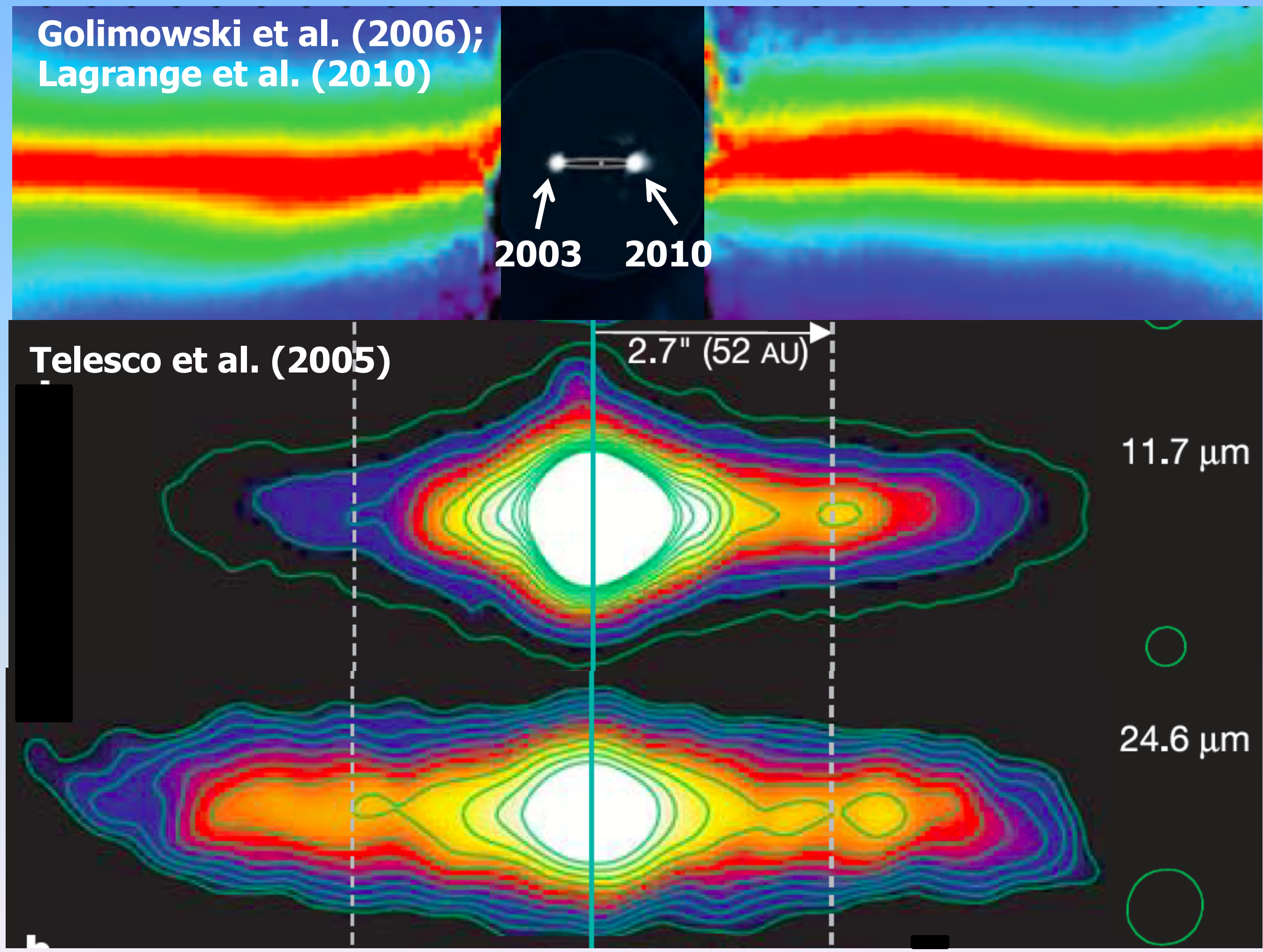






- Deeper means fainter (less extreme, older) disks can be imaged?
- Multiwavelength information
- Simultaneous imaging of planets interacting with disks

(2) Mid-IR imaging of structure in extrasolar Kuiper belts



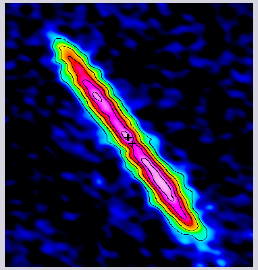
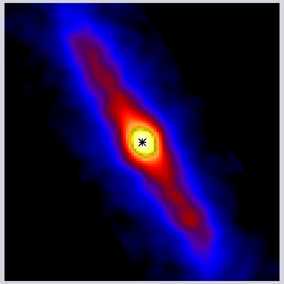
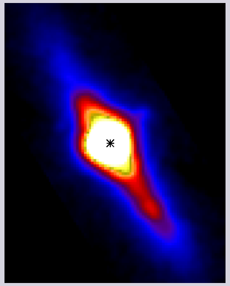
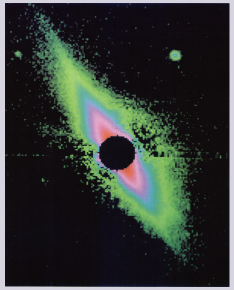
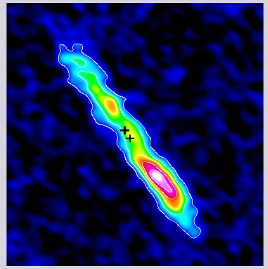
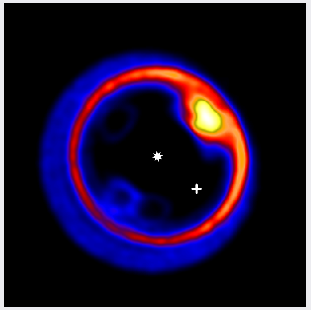
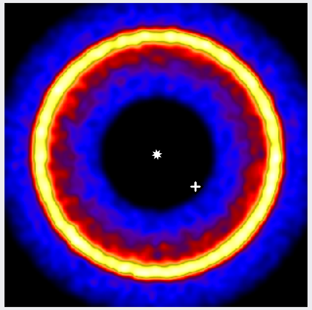
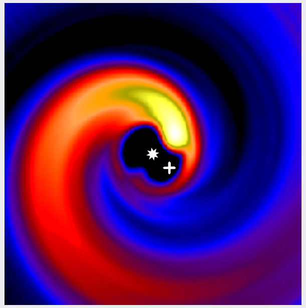
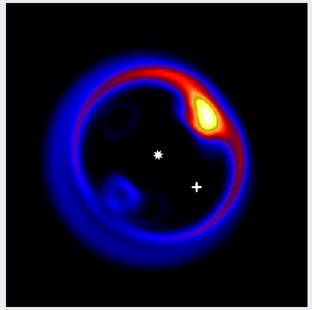
Scattered light warp at 80AU in β Pic explained by a misaligned ~$9M_{Jupiter}$ planet at 8AU

(Augereau et al. 2001; Lagrange et al. 2010)

Mid-IR (8-18μm) images show a clump at 52AU in the SW

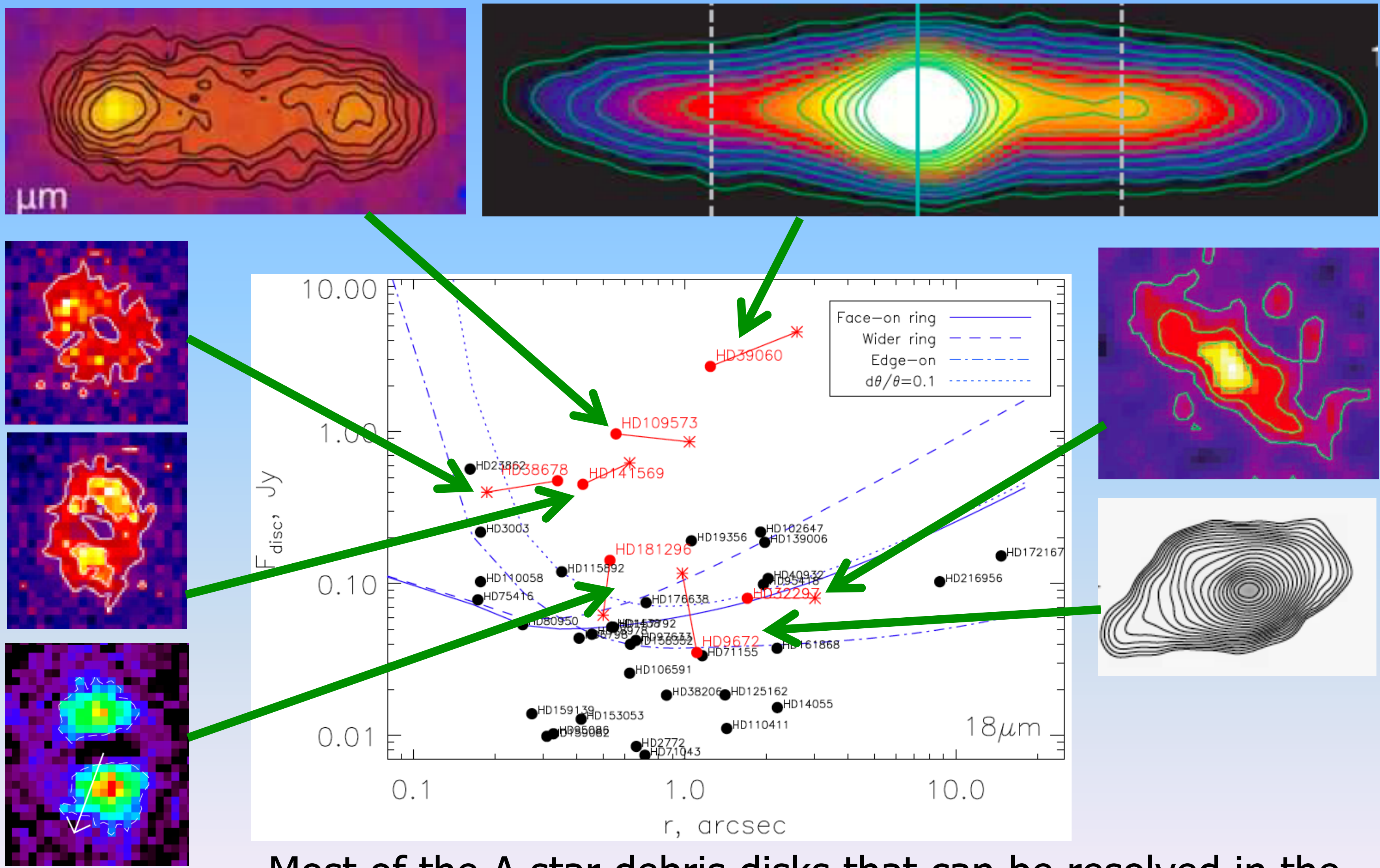
But that clump is absent at 25μm

Multi-wavelength imaging is key to interpretation

	Sub-mm continuum (planetesimals)	Mid-IR (small but bound dust)	Scattered light and short mid-IR (small unbound dust)	CO (short-lived gas)
Observed β Pic			 	
Model (face-on)				

Clump (and different structure at different wavelengths) explained by a $>M_{Neptune}$ planet which migrated out to ~60AU trapping planetesimals into its mean motion resonances (Wyatt 2006)

Ground-based mid-IR imaging is hard (sensitivity)

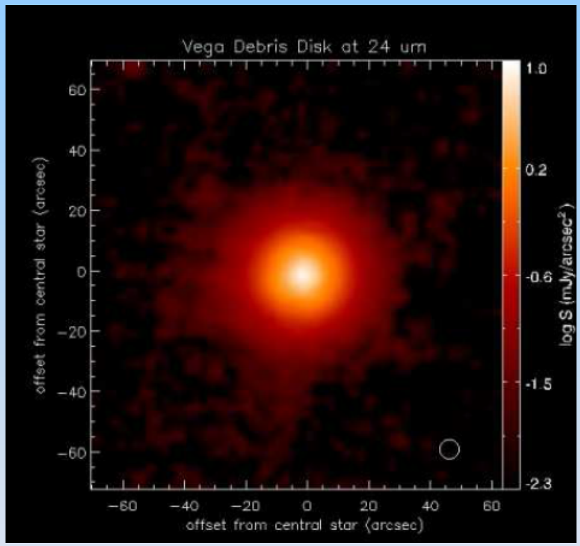


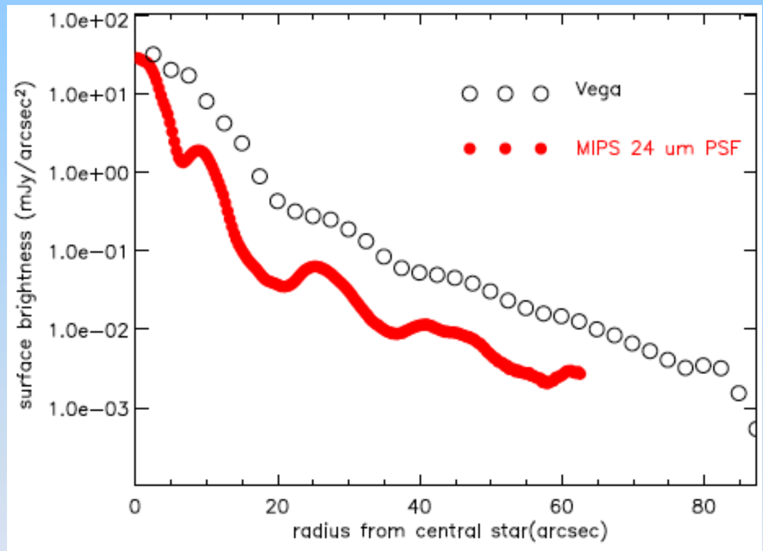
Most of the A star debris disks that can be resolved in the mid-IR from the ground have been imaged (Smith & Wyatt 2010)

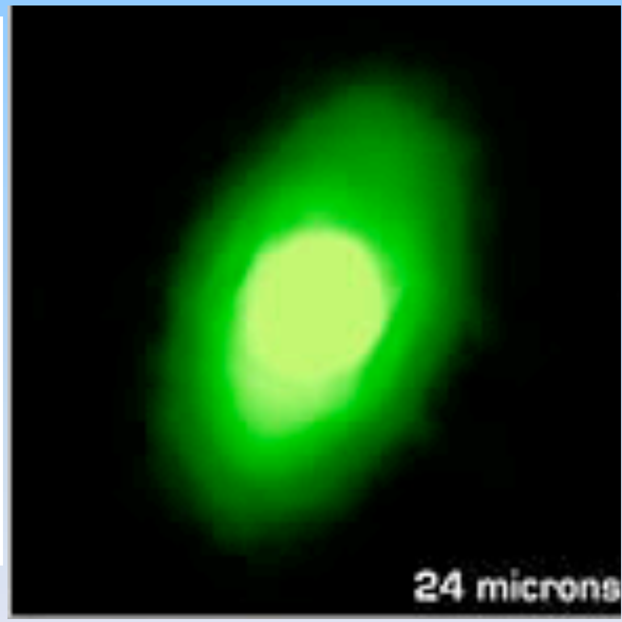
Space-based imaging also hard (resolution)

Spitzer imaged a few disks at 24μm like Vega (Su et al. 2005)

And Fomalhaut (Stapelfeldt 2004)



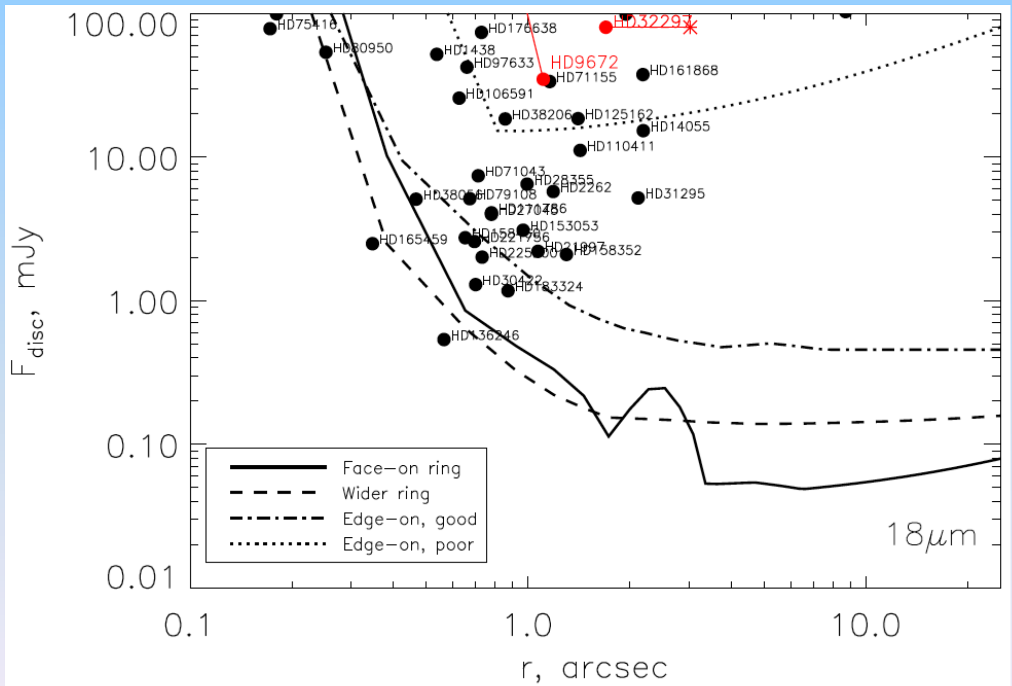


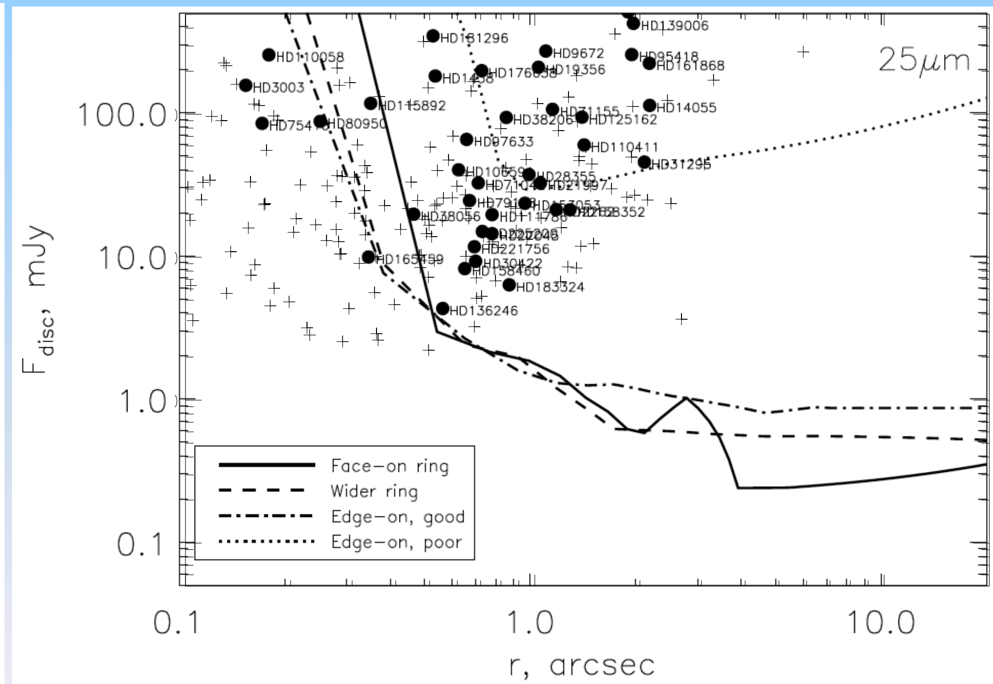


But relatively few disks were resolved

Imaging with MIRI will be very productive

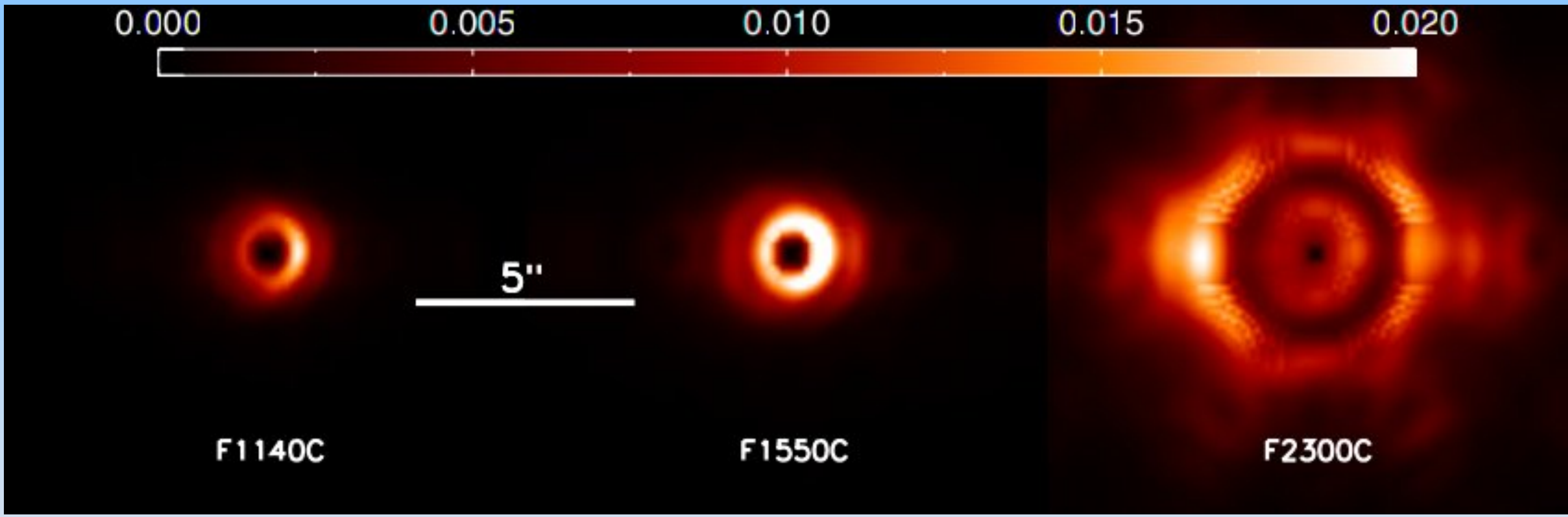
Almost all of the known debris disks around A stars will be imageable with MIRI (Smith & Wyatt 2010)





Example: imaging of giant impact debris

Simulated MIRI images of debris from Ceres-sized break-up at 6au
0.01-0.1Myr post-impact (Kral et al. 2015)



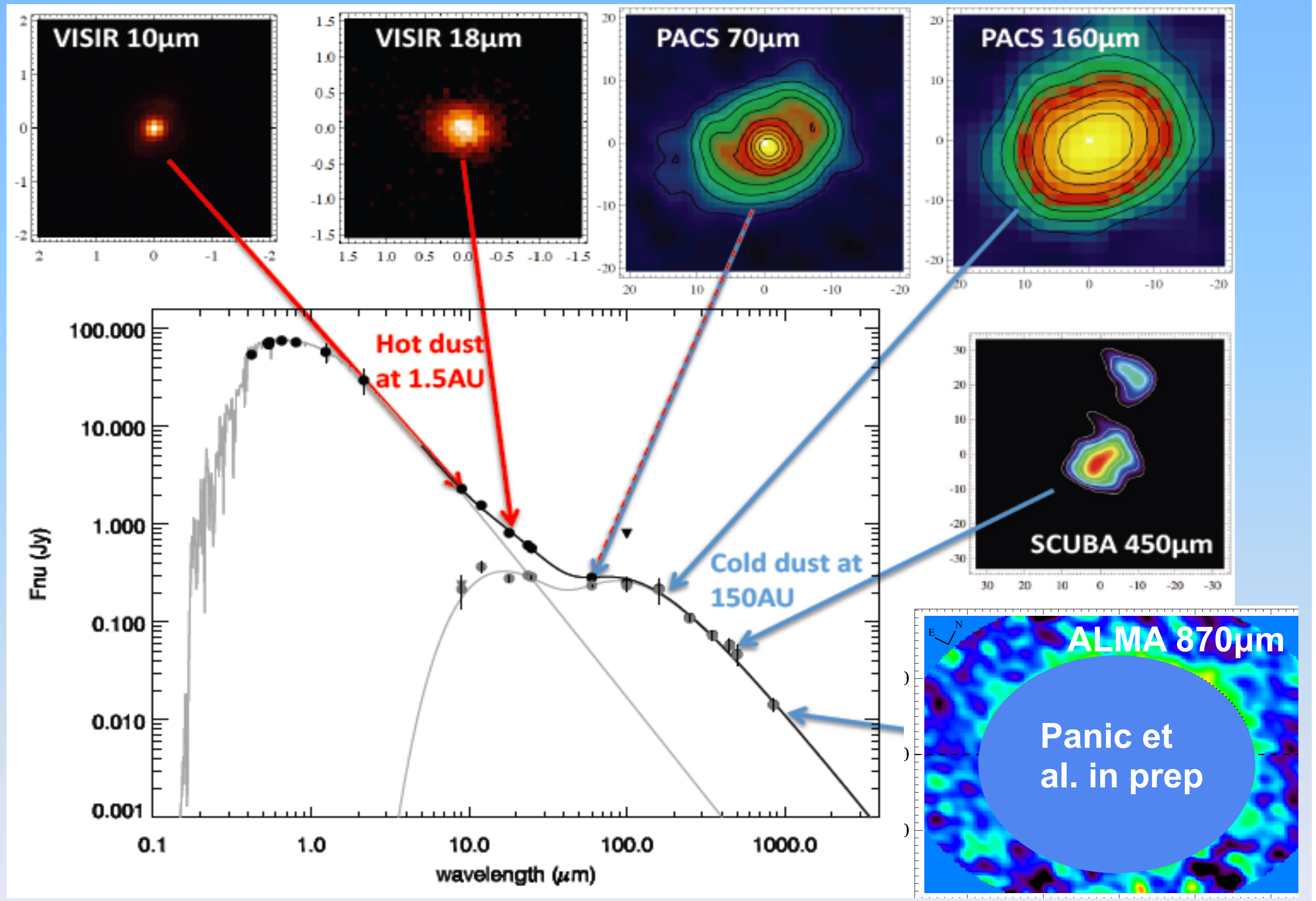
Debris is asymmetric, since all orbits pass through collision point, easily detectable by MIRI at 11-15μm

Lyot mask obscures impact site, but reveals asymmetry on opposite side from small grains

Mid-planetary system dust

Debris disk holes not always empty (Su et al. 2013); e.g., η Corvi (right) is a 1Gyr F star with 150au Kuiper belt (Wyatt et al. 2005; Duchêne et al., in prep) and 1.5au dust (Smith, Wyatt & Haniff 2009)

Origin of hot dust could be in mid-planetary system belts (like the asteroid belt), but could be cometary, and regardless is telling of planetary system

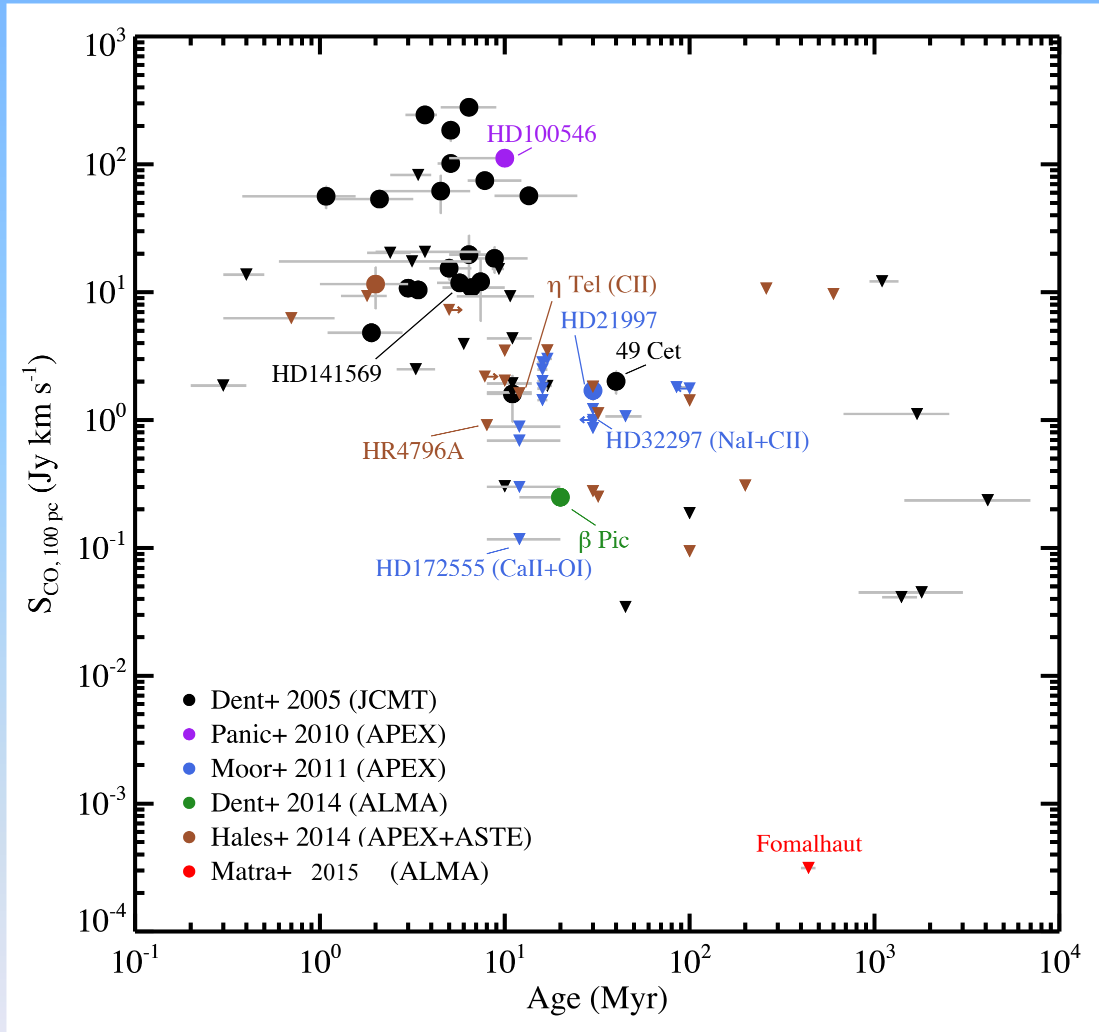


Dust at intermediate distances, if present, is most readily imaged at 10-25μm

3.1 Evolution of circumstellar gas

Searches for CO show usually not detected in debris disks suggesting significant depletion in gas (as well as dust) after proto-planetary disk dispersal

But there are some debris disks with CO detections, others with CII or OI



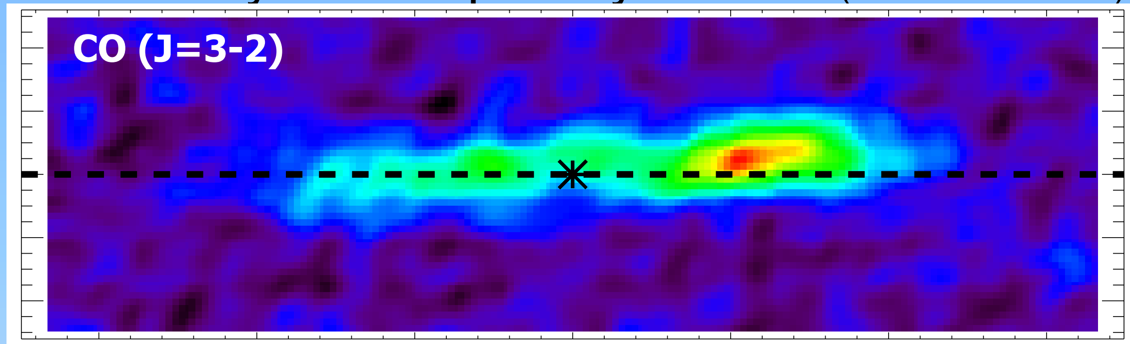
Origin of DD gas: remnant of protoplanetary disk or secondary (break-up of icy planetesimals)?

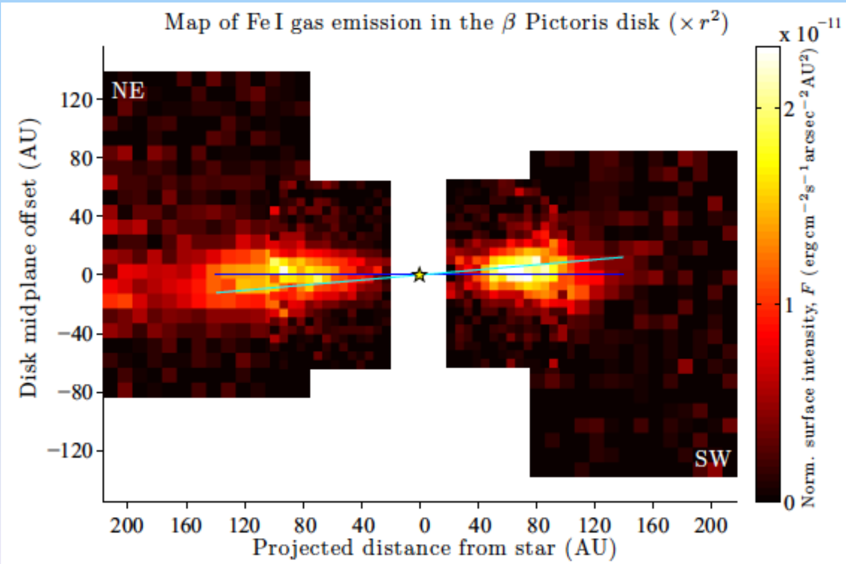
3.1 JWST: Imaging gas in debris disks

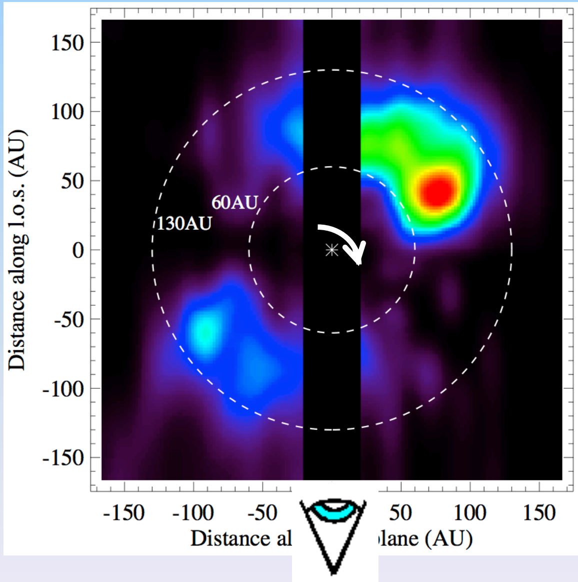
Mapping of gas within debris disks is already possible:

VLT/FLAMES/GIRAFFE
IFU of metallic ions in β Pic
(Nilsson et al. 2012)

ALMA imaging of CO in β Pic shows gas is created by break-up of icy comets (Dent et al. 2014)





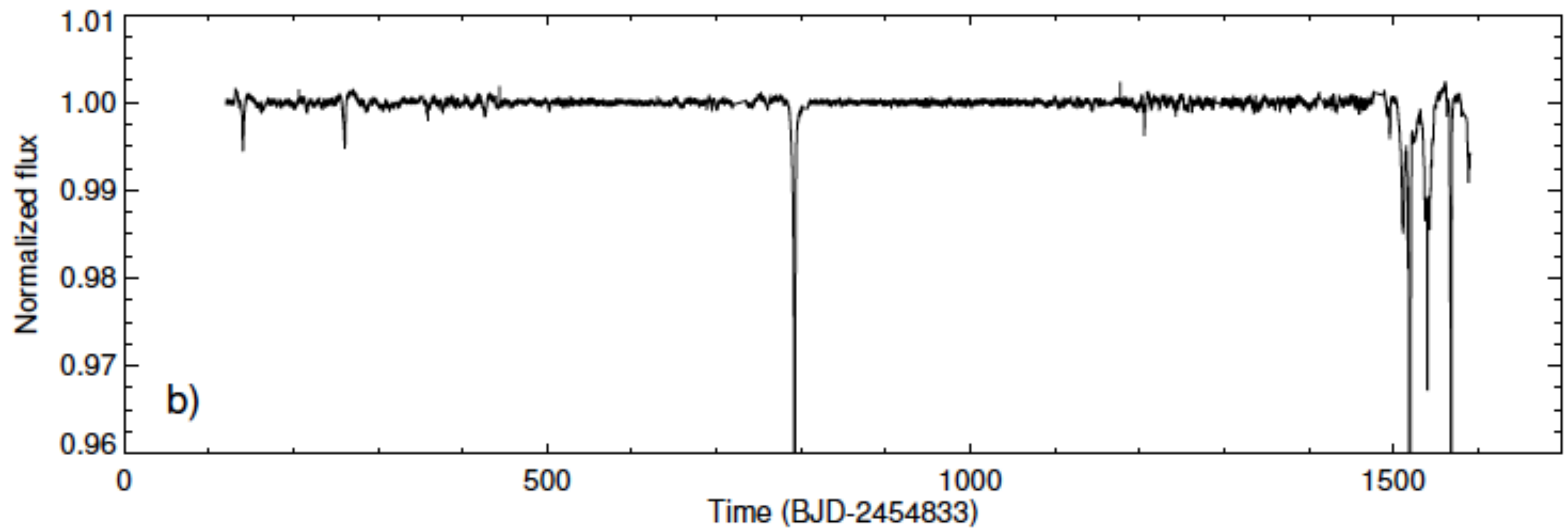


Velocity information allows deprojection of gas distribution

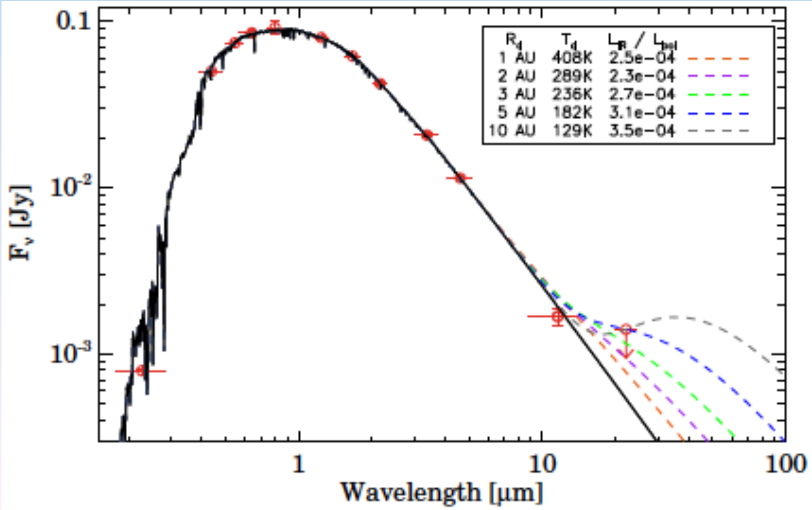
Searches for OH as photodissociation product of water, look for H_2O lines, H_2 to see remnant of protoplanetary disk? Fe, S, Si?

3.2 Exocomets

KIC8462852 shows aperiodic dips as large as 20% loss in flux best explained by exocomet family (Boyajian et al. 2015)



JWST can detect and characterise the thermal emission expected from such comets



What will the field be like in 3 years?

- Already have all far-IR info from Spitzer and Herschel
- ALMA follow-up imaging of some targets will be complete
- ALMA discoveries of gas will have grown
- Lots of SPHERE/GPI disks imaged, increasing the number of scattered light images and extrasolar planets

Conclusions

Debris disks provide unique constraints on both the current architecture of extrasolar planetary systems and their formation and evolution

JWST will:

- **image extrasolar Kuiper belts and perturbing planets in scattered light**
- **image extrasolar Kuiper belts and mid-planetary system belts in mid-IR**
- **search for gas/exocomets in debris disks?**