Probing Nearby Planetary Systems by Debris Disk Imaging

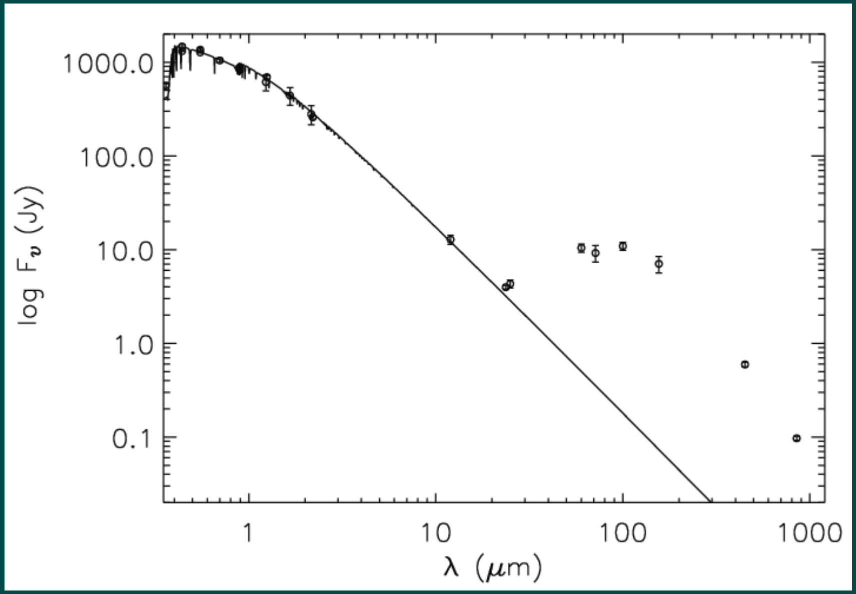
Karl Stapelfeldt
now at NASA Goddard

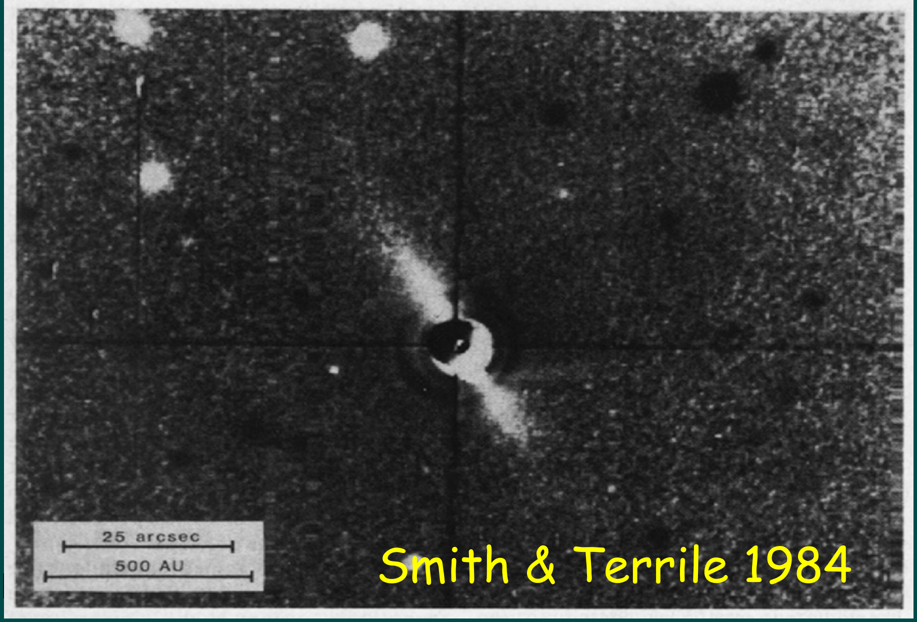
Plan for this talk

- Reminder on Debris disks
- Review the 5 resolved disk systems with known exoplanets: dynamical interactions
- Other resolved disks whose structures may reflect perturbing planets
  - See also Mike Fitzgerald's talk
  - See also posters by Torsten Löhne & Jenny Patience
- The future of Debris disk imaging

Extrasolar debris disks were discovered by their far-infrared excess: IRAS satellite, 1984

- Optically thin, gas-poor particle disks with optical depths from 30- 20,000 times Sun's "zodi"
- Disk masses very small, < few lunar masses. NOT protoplanetary disks.
- 10-100s of AU scales: Kuiper Belts
- Dust removal timescale much shorter than stellar ages: grains can't be primordial. Continuing replenishment of small particles from larger parent bodies is required.
- The best evidence for extrasolar planetary systems prior to 1995





Smith & Terrile 1984

19 Systems with both Planets and Debris Disks

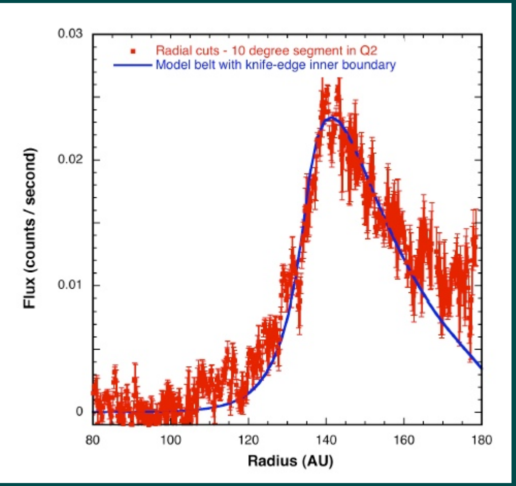
Star	Planet orbital semi-major axes (AU)	Outer planet Eccentricity	Approx. Disk Inner Radius	Disk Resolved ?
Fomalhaut	115	probably 0.11	133 AU	HST, Spitzer, submm
HR 8799	15, 24, 38, 68	?	95 AU	Spitzer
HD 69830	0.08, 0.19, 0.63	0.07	1.0 AU	
Epsilon Eridani	3.4	0.3-0.7 ??	2 AU, 35 AU	Spitzer, submm
Gl 581	0.03, 0.04, 0.07, 0.22	0.38	4 AU	
HD 142	1.0	0.37	> 28 AU	
HD 10647	2.0	0.1	~10 AU	HST, Spitzer, Herschel
HD 19994	1.4	0.3	> 7 AU	
HD 38529	0.12, 3.70	0.36	> 103 AU	
HD 50554	2.38	0.42	> 58 AU	
HD 52265	1.13	0.29	> 40 AU	
HD 82943	0.75, 1.19	0.22	> 65 AU	
61 Vir	0.05, 0.22, 0.48	0.35	4 AU	Herschel
70 Vir	0.48	0.4	> 5 AU	
HD 128311	1.10, 1.76	0.25	> 11 AU	
HD 150706	0.82	0.38	110 AU	
HD 178911 B	0.32	0.12	> 28 AU	
HD 202206	0.83, 2.55	0.27	> 50 AU	
HD 216435	2.56	0.07	> 13 AU	

Fomalhaut b

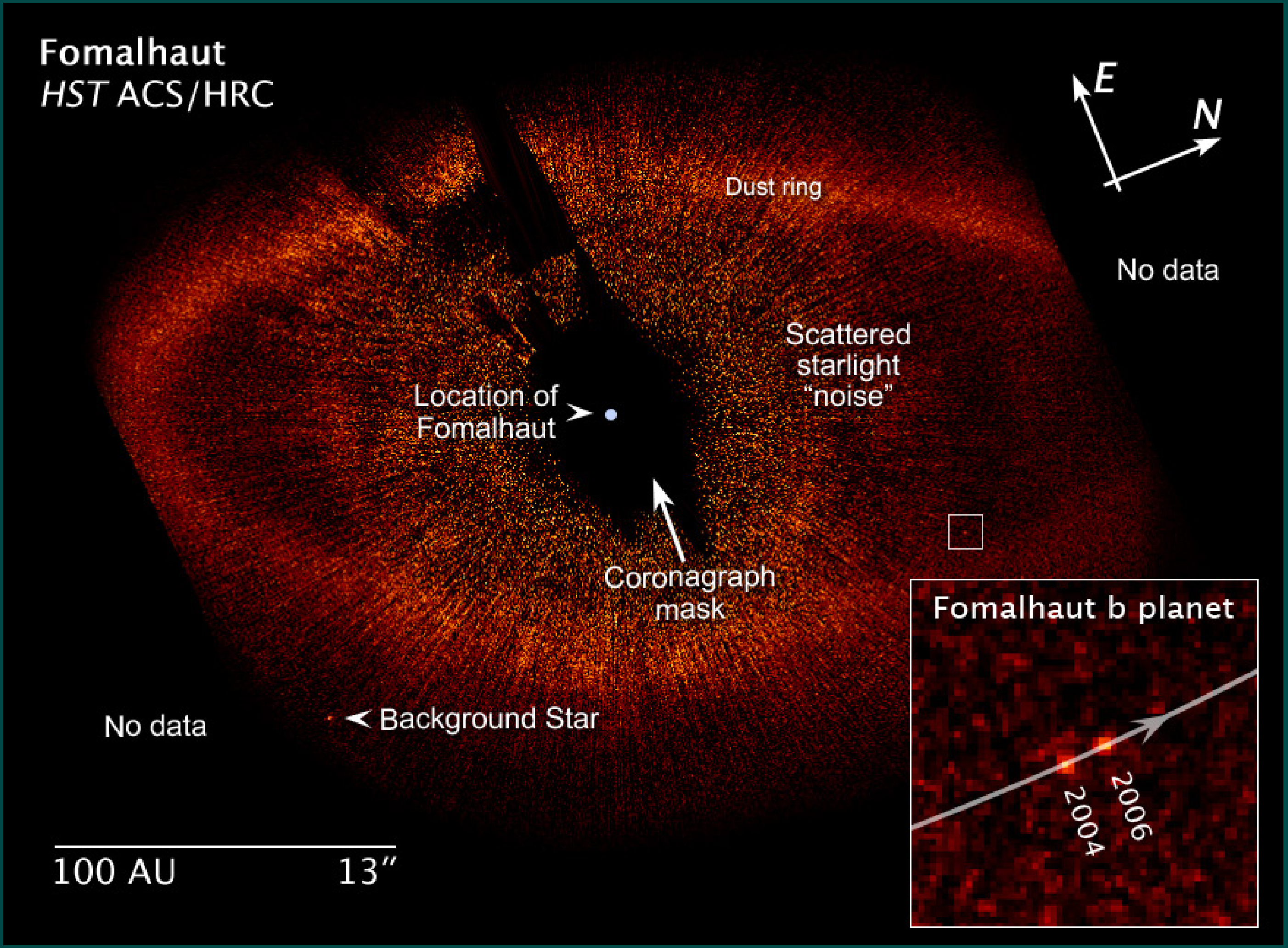
Kalas et al. 2005, 2008

Offset ring e=0.1, a= 133 AU

Radial cut shows sharp/sculpted ring inner edge

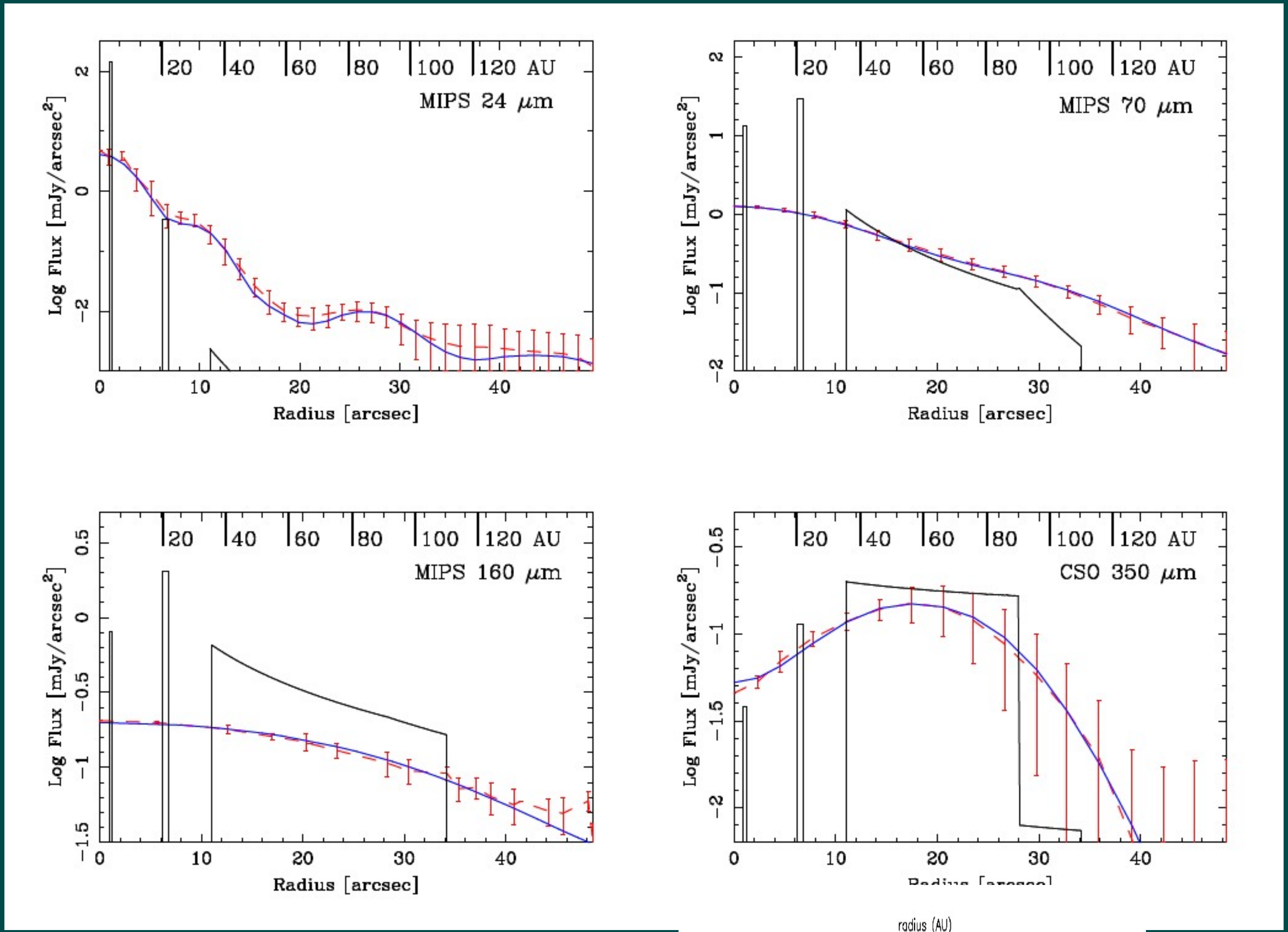


Planet seen at de-projected a=115 AU. Orbital motion parallel to ring inner edge; consistent with Kepler's law. Orbit confirmation pending



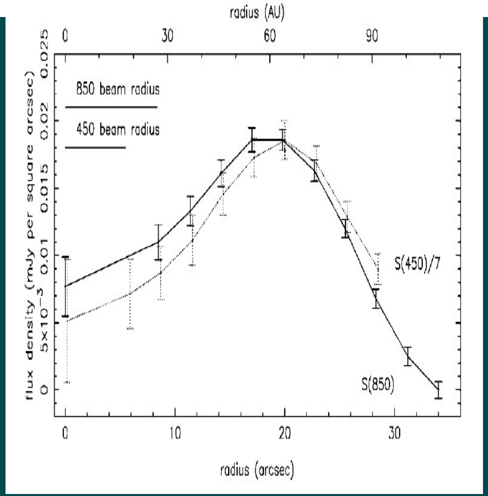
ε Eridani radial bright-ness profiles

Spitzer+CSO results from Backman et al. 2009.
Red dashed line & error bars show observations.
Black lines show model emission profiles before & after PSF convolution



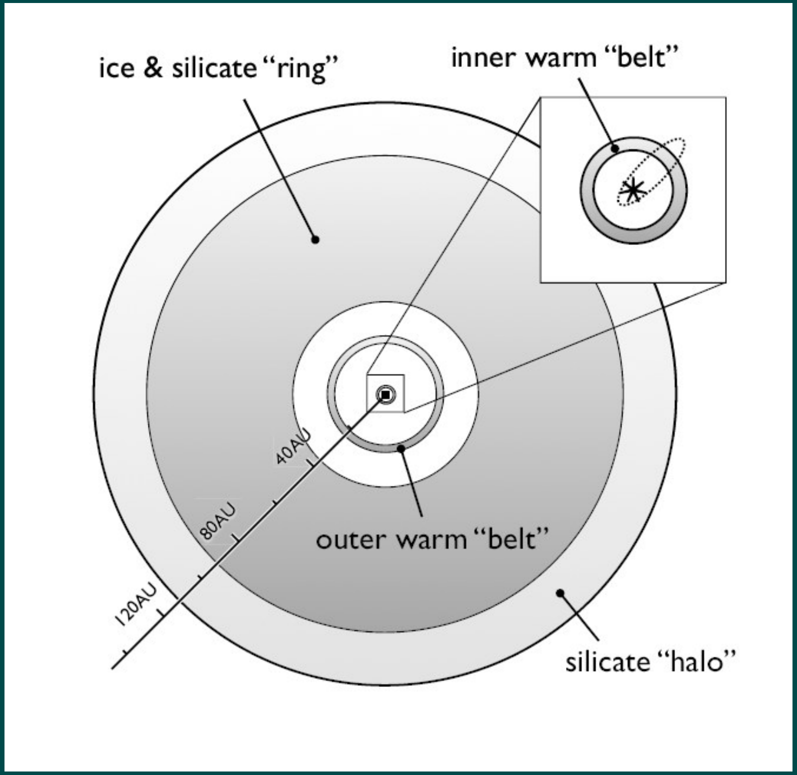
Separate inner belt, outer ring required by 24 and 350 μm profiles. Extended halo of outer ring required by 70, 160 μm profiles

Right: JCMT 450 & 850 μm profiles (Greaves et al, 2005)

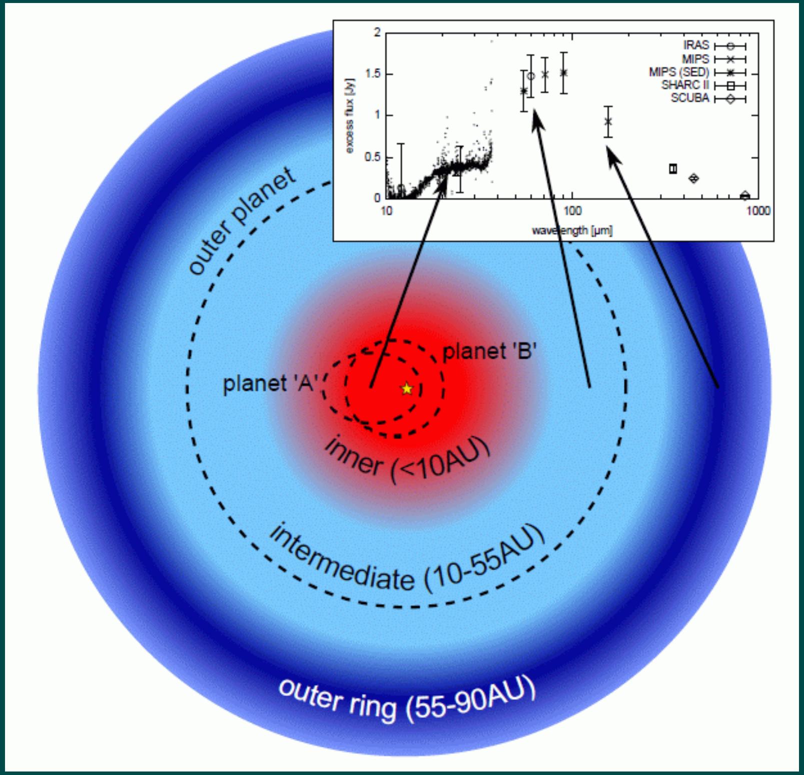


Scenarios for the ε Eri debris system

Backman et al. 2009



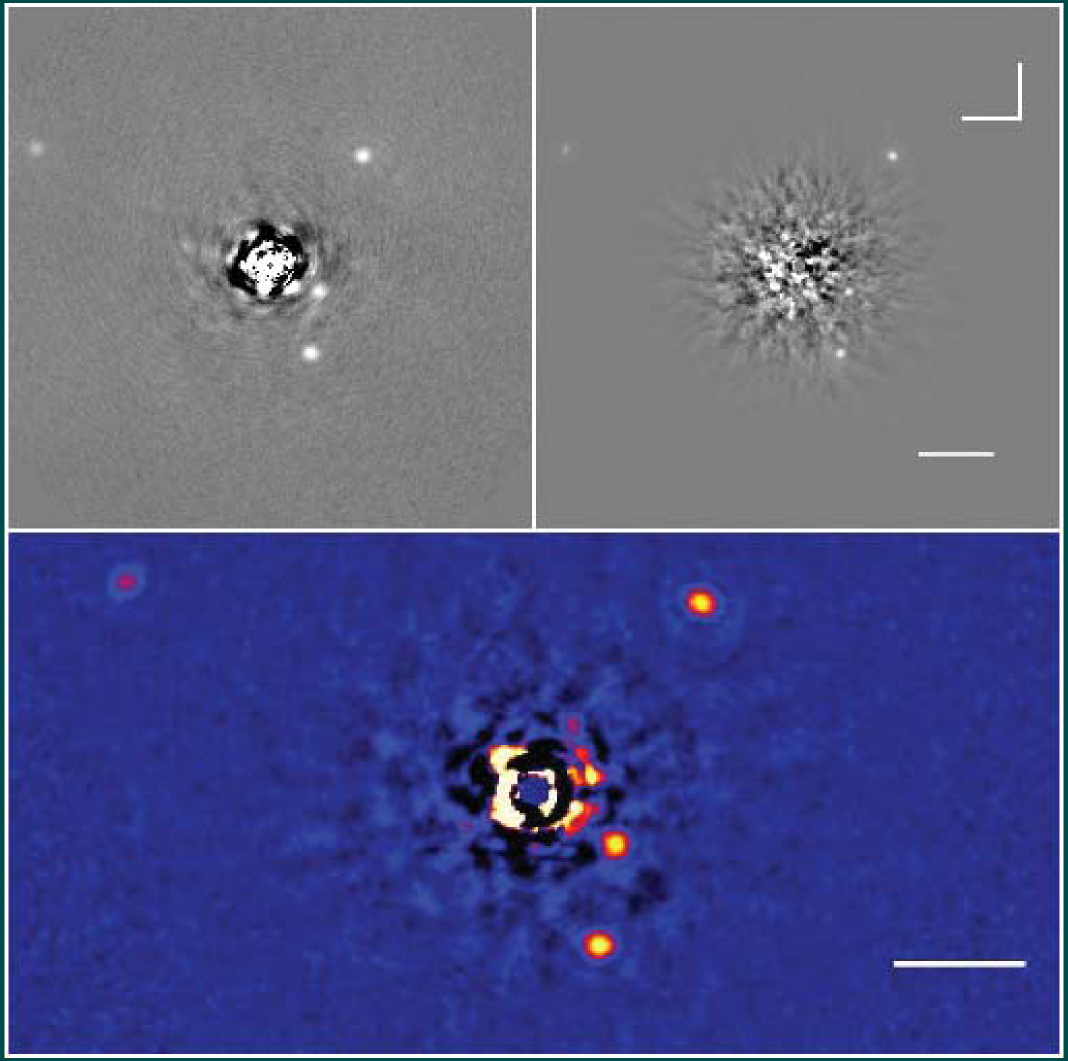
Reidemeister et al. 2011



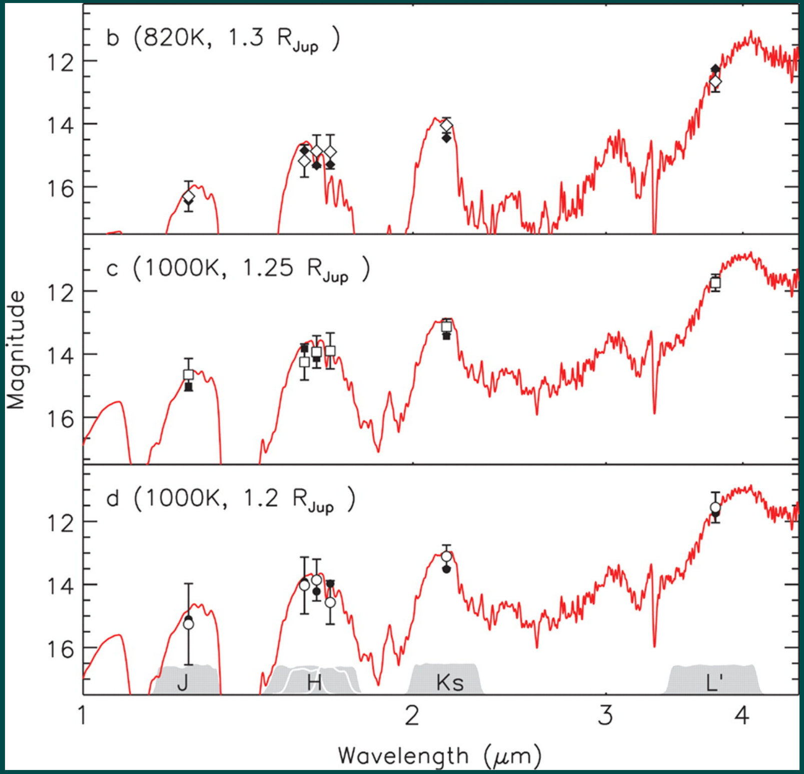
- Outer dust belt corresponds to resolved submillimeter ring, 55-90 AU region
- RV planet ε Eri b (a= 3.4 AU): e= 0.7 (Benedict et al. 2006), or 0.25 (Butler et al. 2006)
- Warm Inner dust modeled as discrete belts (2-3 AU, 20 AU) or continuous inflow from outer ring. Belt of parent bodies at 2-3 AU not compatible with planet e= 0.7 (Brogi et al. 2009).

Four planets orbiting HR 8799

Marois et al. 2008. 2010



A0 star at 40 pc distance
Young system age 60 Myrs
Spectra of outer 3 below



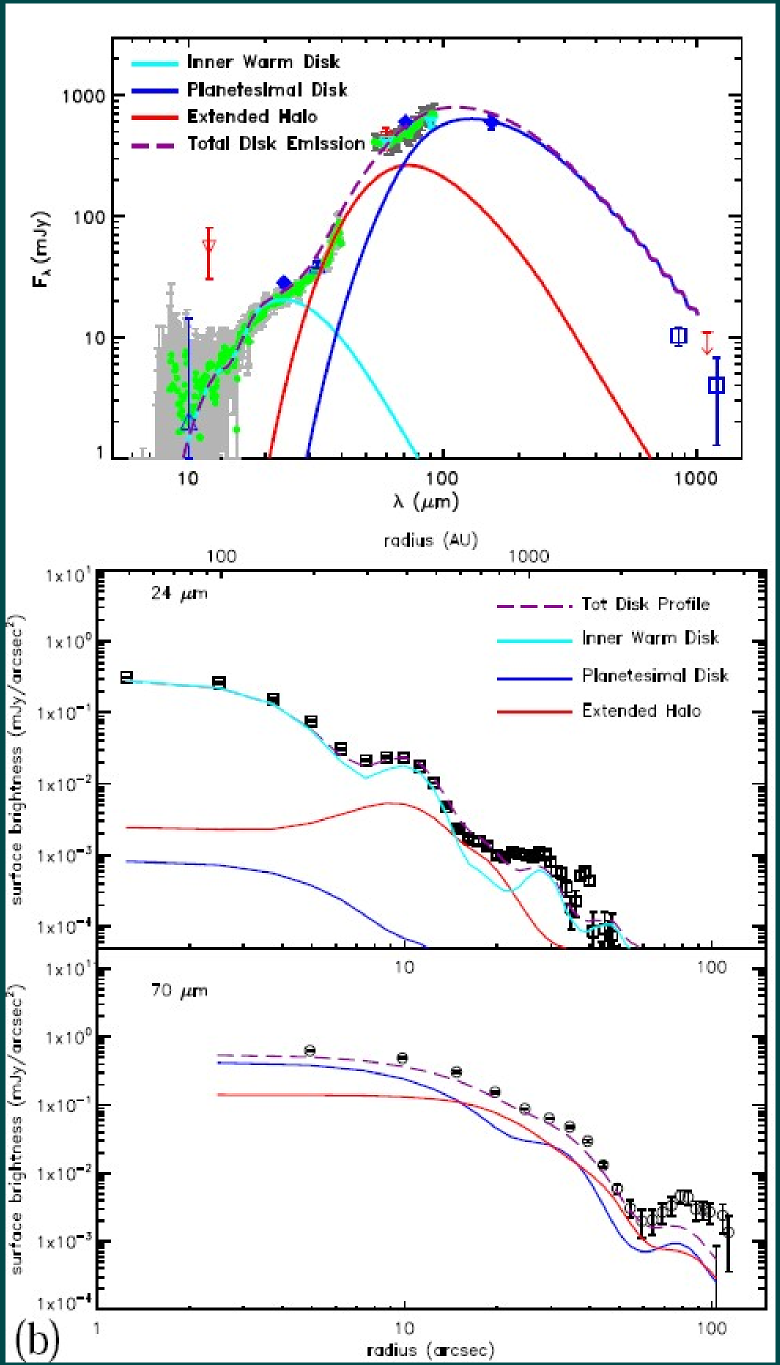
Properties of the HR 8799 debris disk

Su et al. 2009;

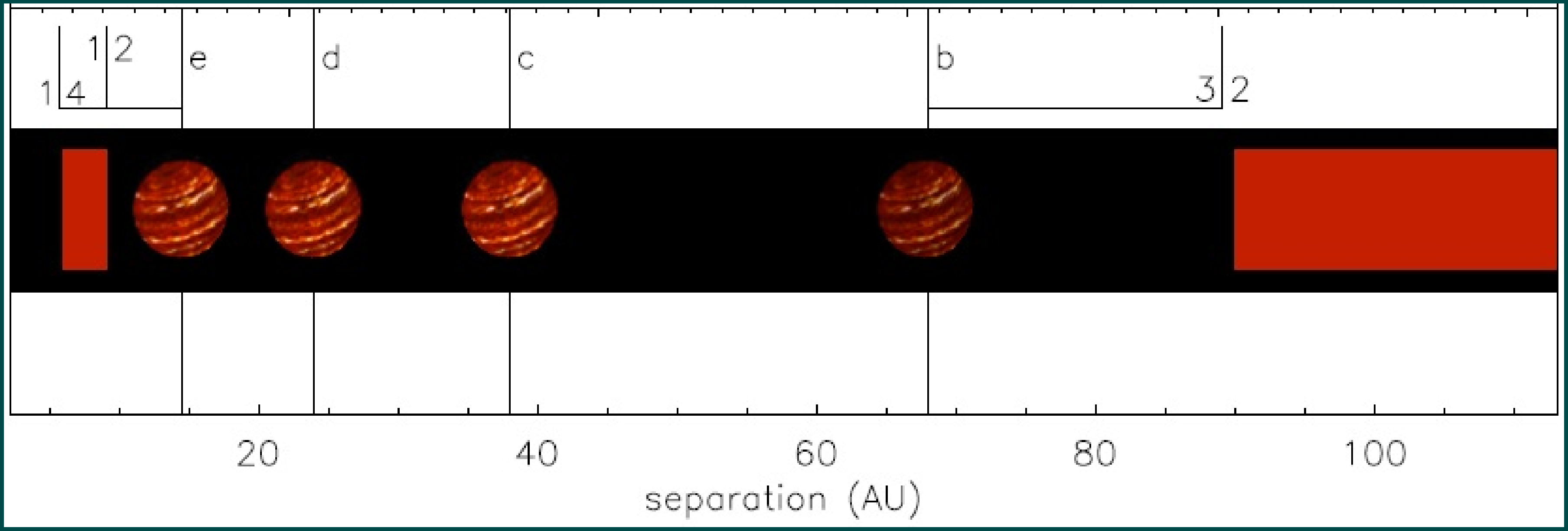
(see also Chen et al. 2009, Reidemeister et al. 2009)

- Inner warm disk belt r= 6-15 AU, 1-5 µm grains
- Planetesimal parent belt between r= 90-300? AU, grainsizes 10-1000 µm
- Halo extending from r= 300?-1000 AU with small 1-10 µm grains
- Halo has 50% of disk infrared luminosity

see Patience et al. poster – evidence for outer disk asymmetry ?



Disk/planet arrangement in the HR 8799 system

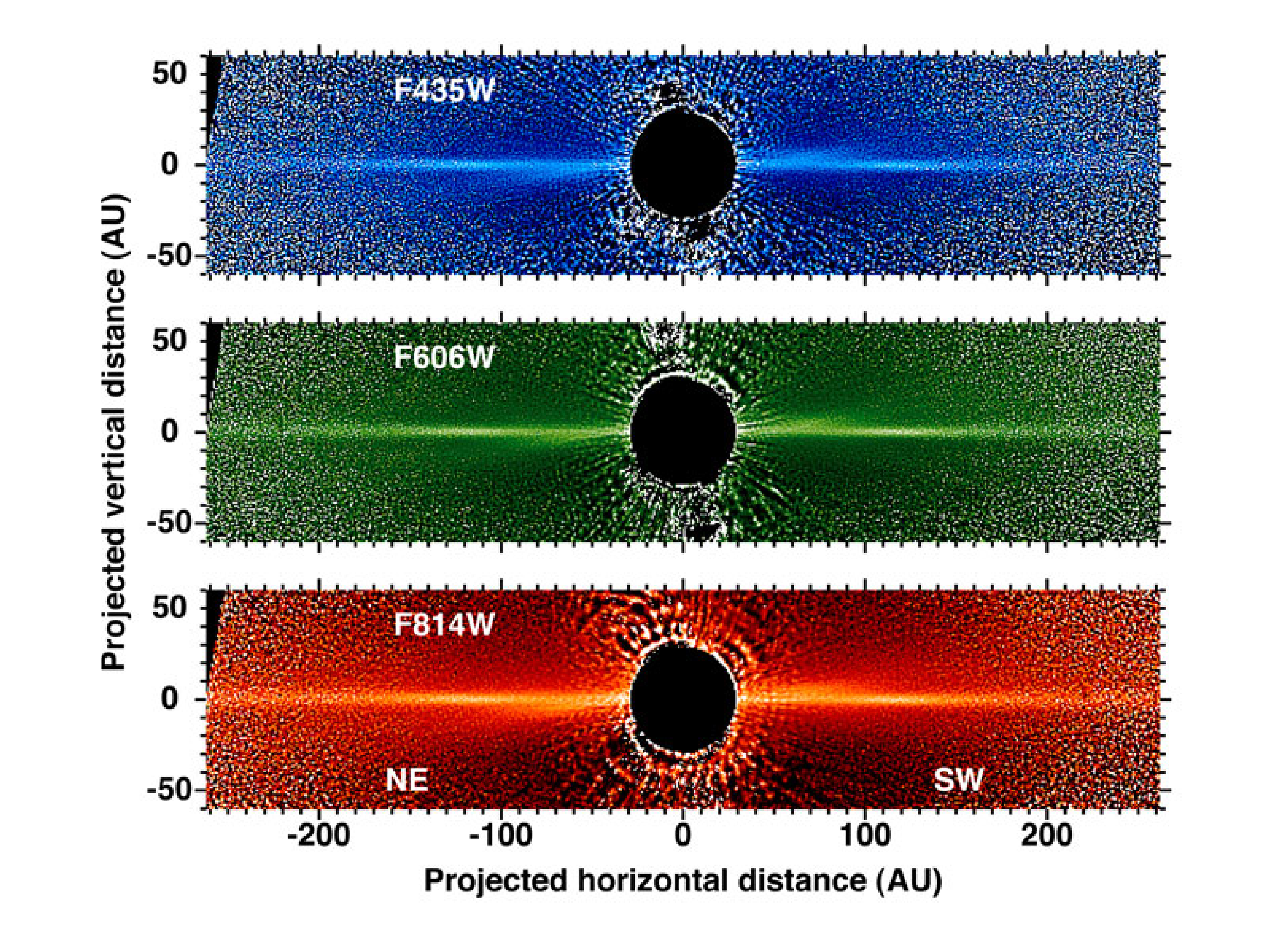


- Planet e found in the gap between inner belt and planet d
- Suggestion that belt edges may be located at major resonances

Marois et al. 2010

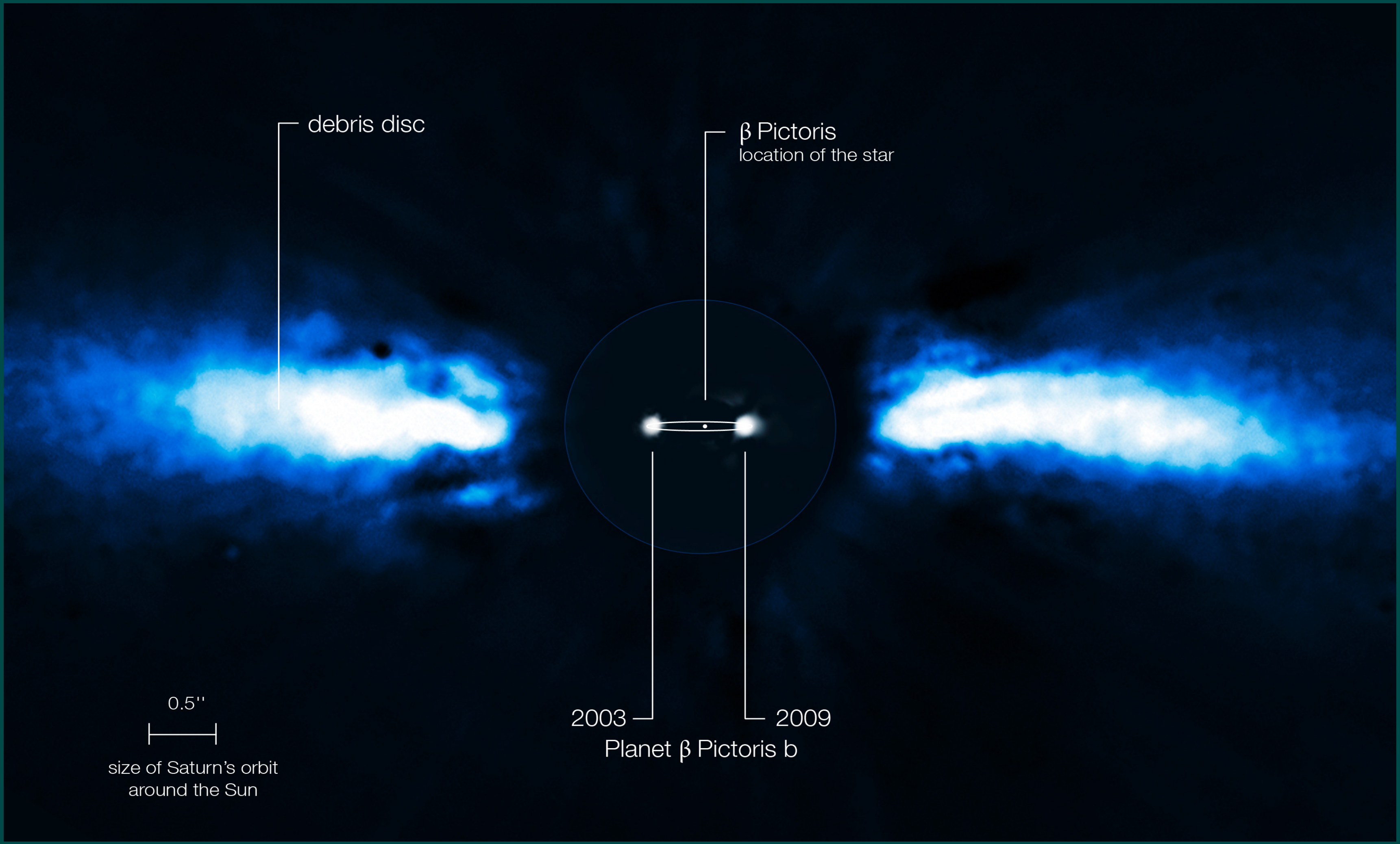
β Pictoris warped inner disk

HST coronagraphy Golimowski et al. 2006



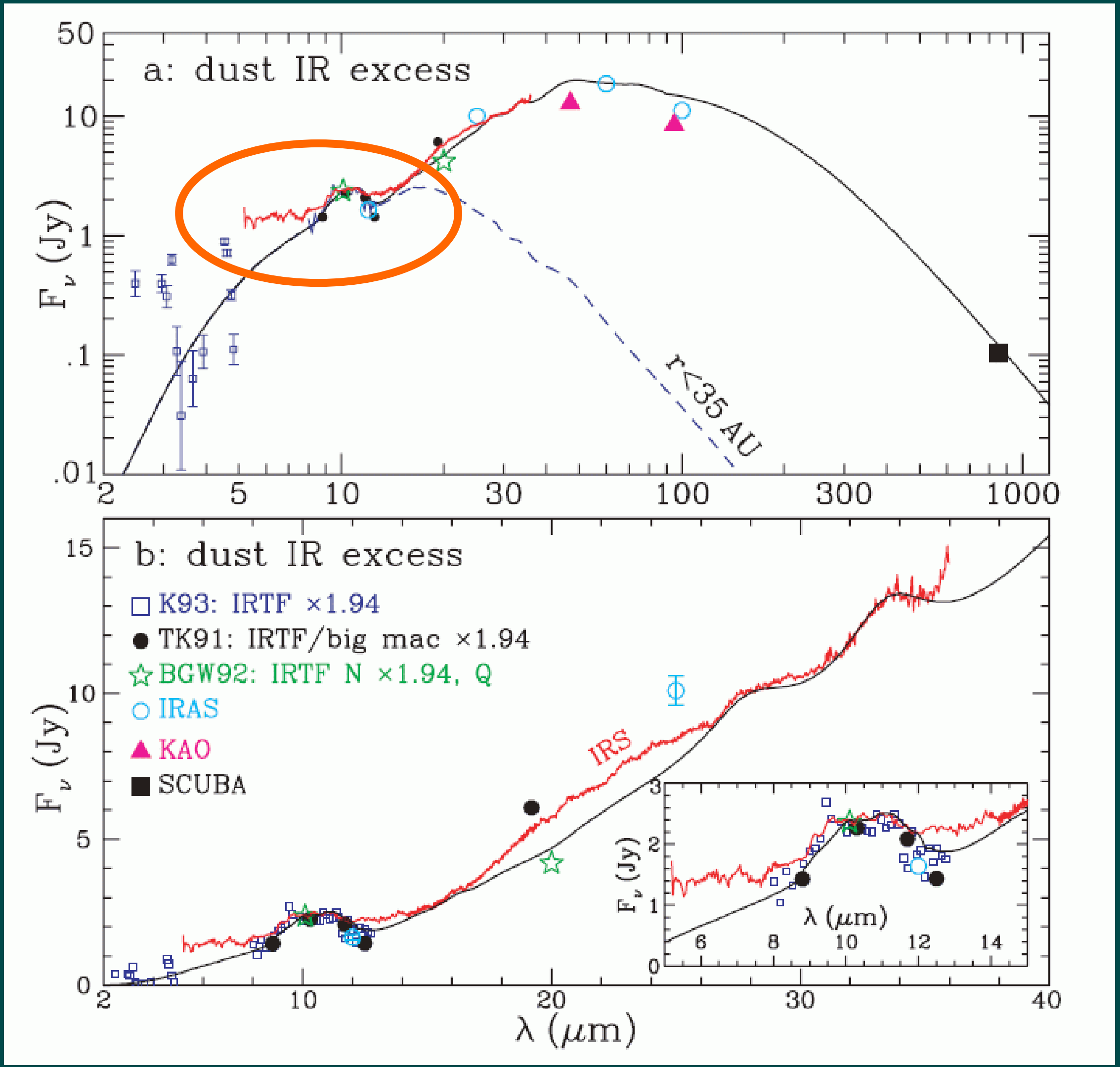
Planet beta Pictoris b confirmed

a~ 8AU, Lagrange et al. 2010.   Orbit determination pending



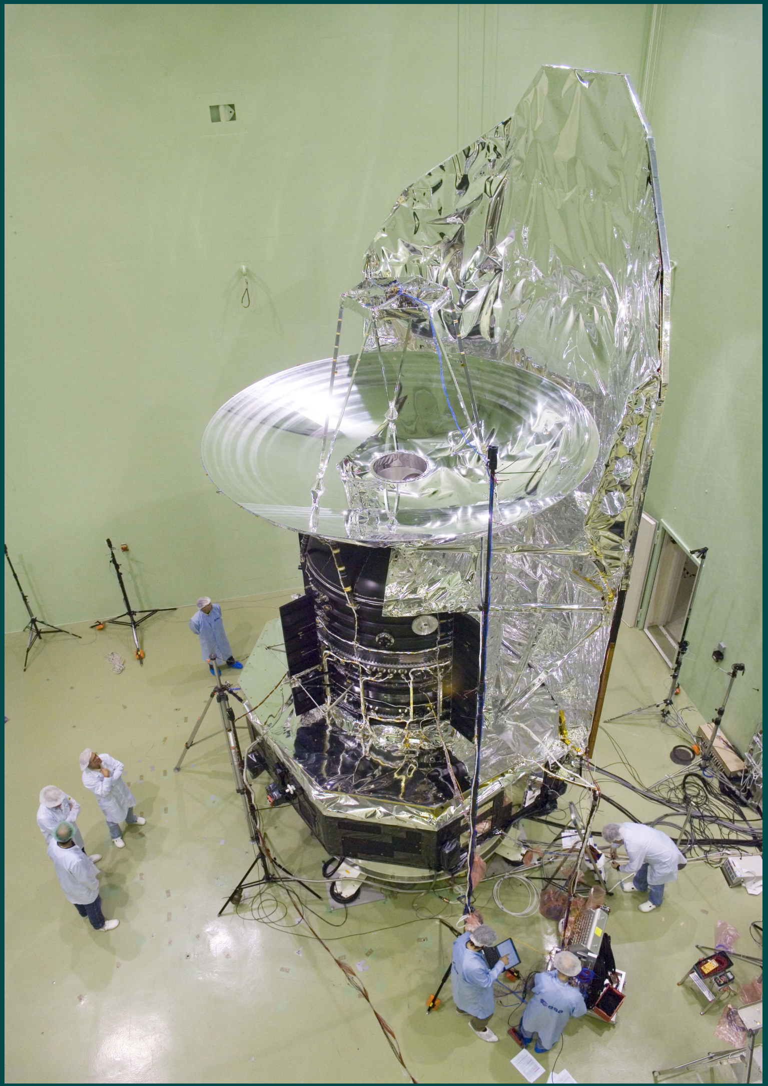
What is the dust configuration near β Pic b ?

- Spitzer/IRS results of Chen et al. (2007)
- Dust excess emission seen down to λ= 5μm
- Silicate emission indicates minimum grainsize ~1 μm.
- Modeled as continuous disk 0.2 < r < 2000 AU, peak density at 100 AU – spans the planet's orbit.
- Can a disk model with a dust-free region near the planet be fit to the infrared excess SED ?



The newest debris disk imager: Europe's Herschel Space Observatory

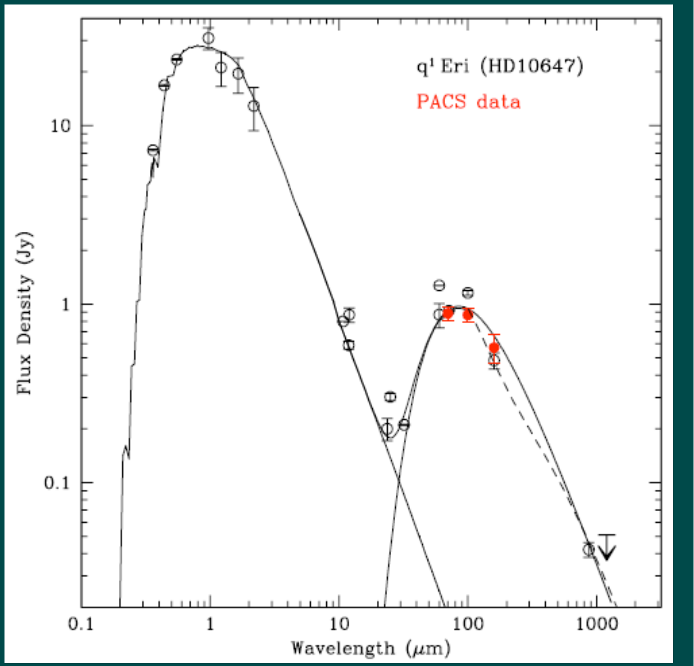
- 3.5 meter primary mirror
- 70 μm imaging resolution 4x sharper than Spitzer; resolving central holes & disk asymmetries
- Sensitivity to lower levels of L_{IR}/L_{star} at 100 & 160 μm
- 500 nearby targets have been surveyed by the DUNES and DEBRIS key programmes
- see also Löhne talk Friday



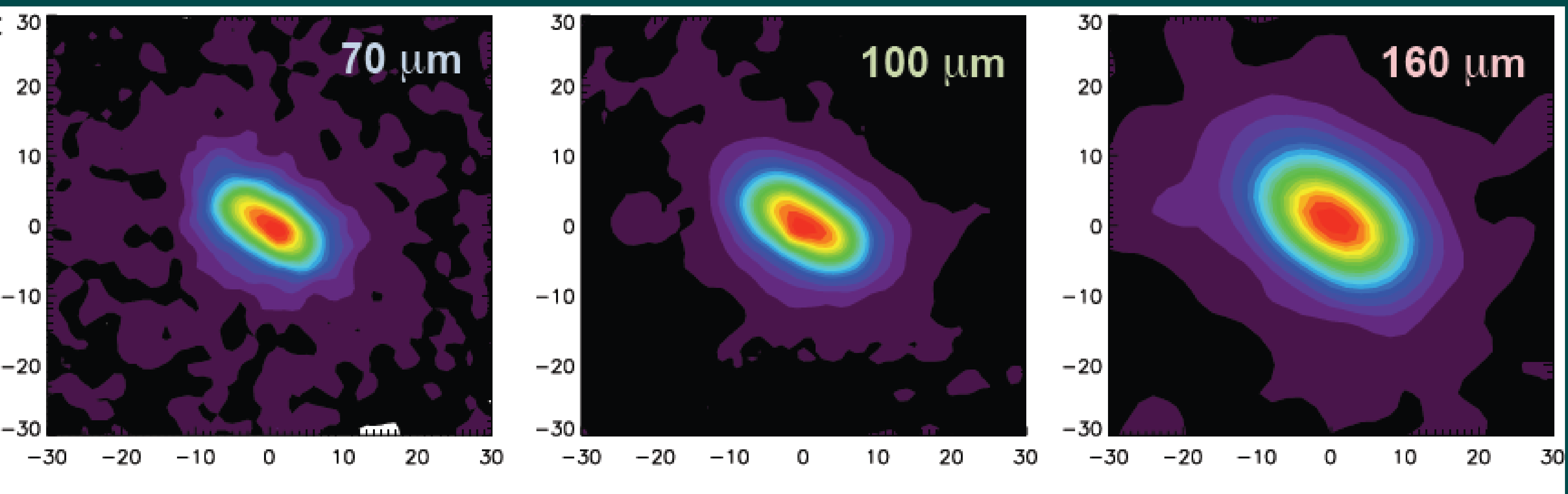
q^1 Eri: resolved disk

F9V star, d=17.35 pc, 1.2 $L_\odot$,
Age ~ 2 Gyr, <u>0.9 M_J planet at 2 AU</u>
Known disk resolved:
- 85 AU inner radius for 60 K dust ring
- ring width > 40 AU
- i ~ 73° (assuming circular shape)

Warm excess suggests dust extends inward to within ~10 AU of the star



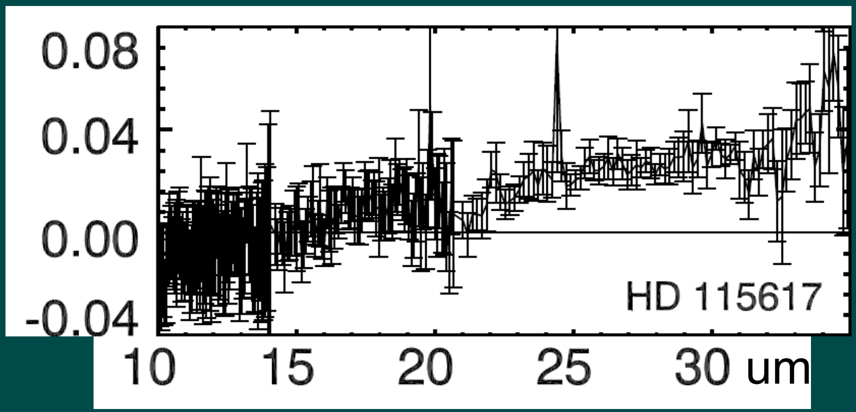
Liseau et al. 2010



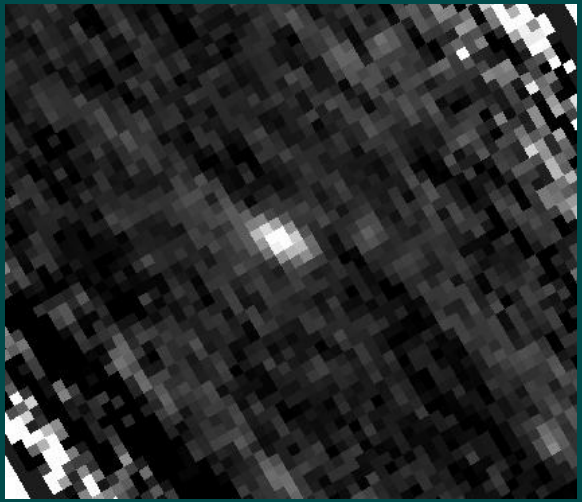
61 Vir
(Vogt et al. 2010)

61 Vir Infrared Excess

Lawler et al. 2009

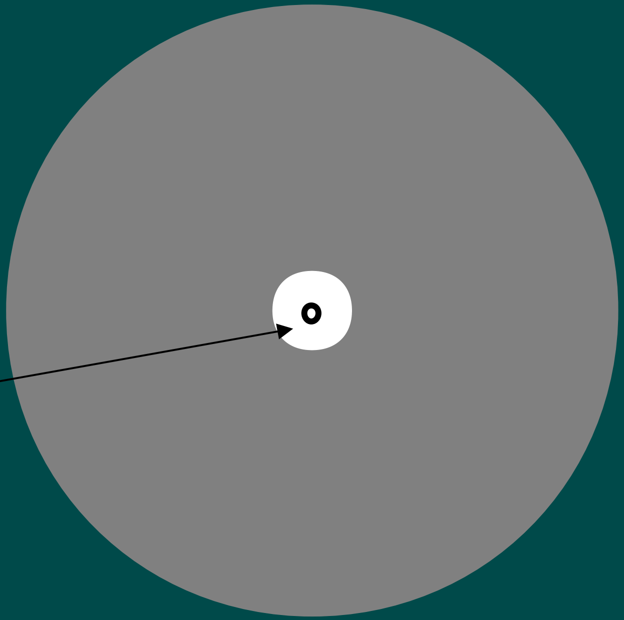


Spitzer infrared excess spectrum

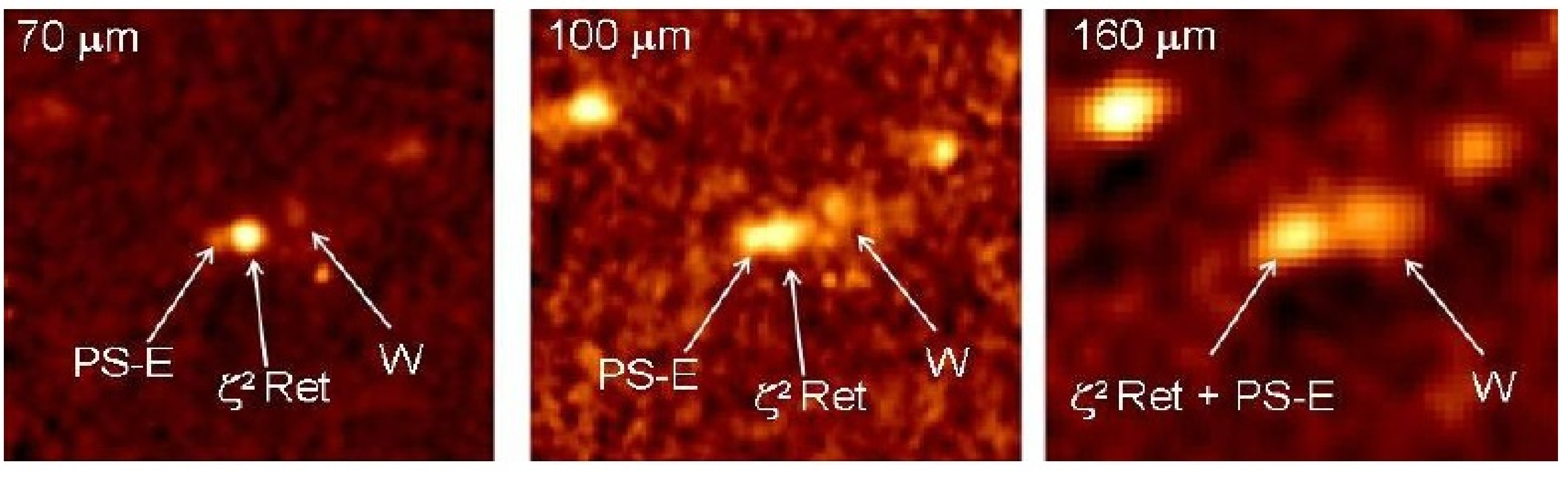


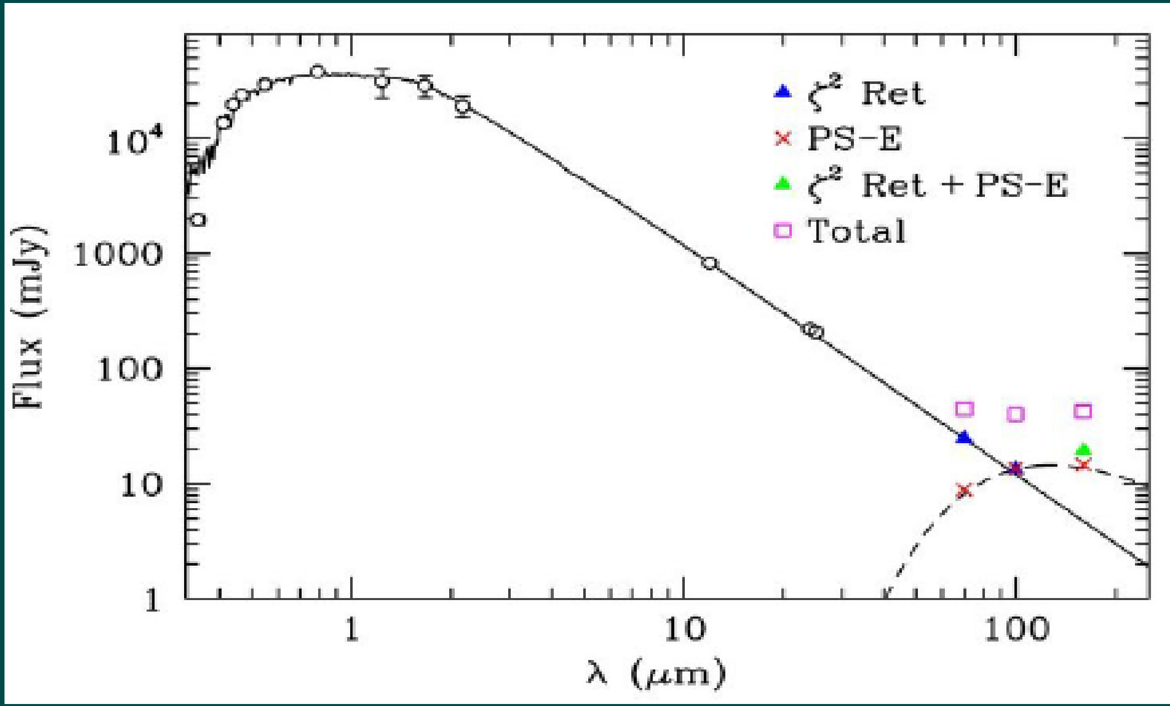
Left:
Herschel 70 µm image showing source extended to ~50 AU radius (c/o DEBRIS consortium)

- Debris disk ! At 8.5 pc, the 5th closest one to the Sun
- ~20x as much cool material as our Kuiper Belt
- Dust model temps 47-120 K
- Dust-free gap interior to 4 AU; Suggests room for additional planets in the 0.5-4 AU region



ζ^2 Ret: new resolved disk ?



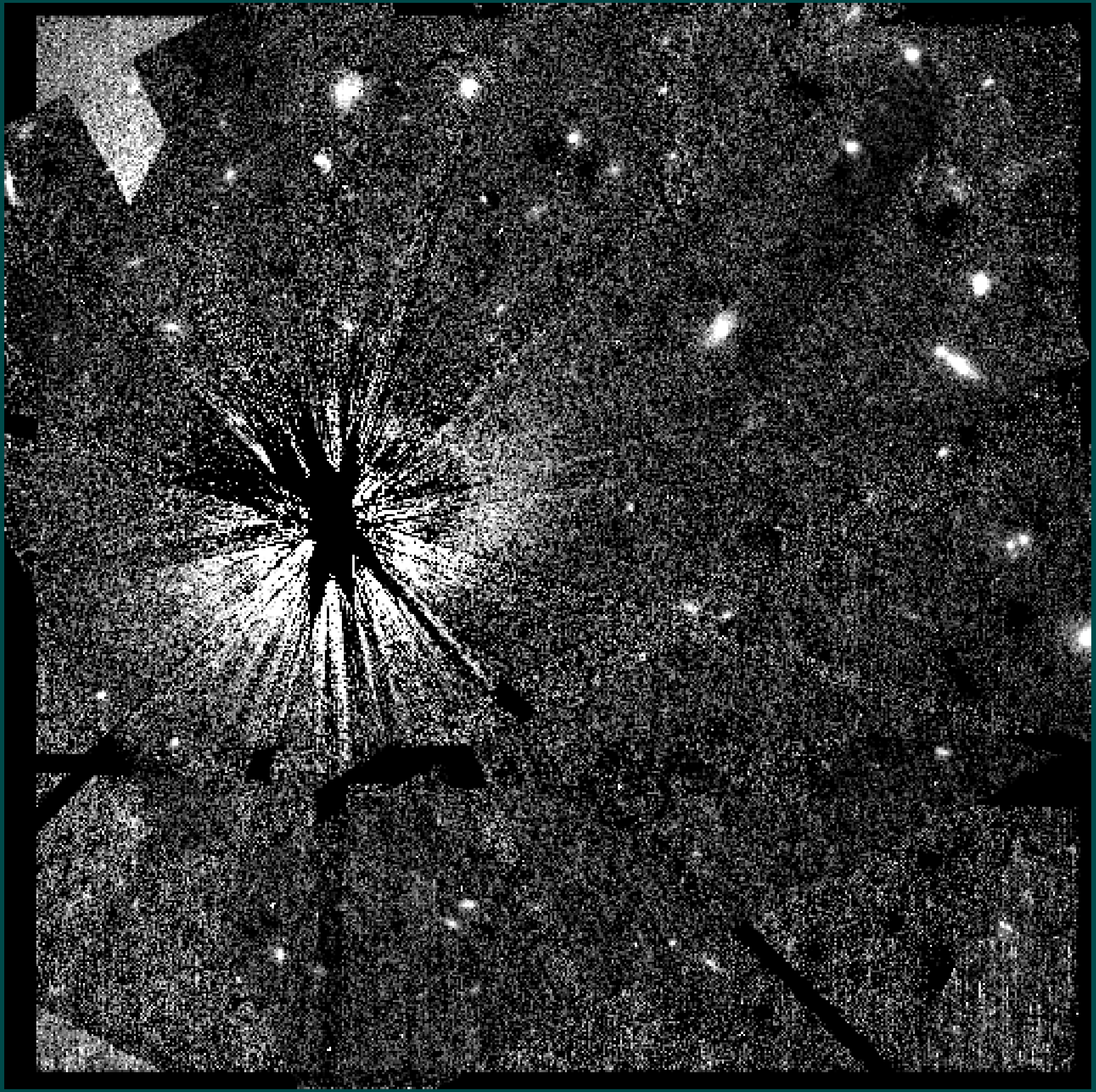


G2 star $L_{dust}/L_* \sim 10^{-6}$

Dust in 40-55 AU region

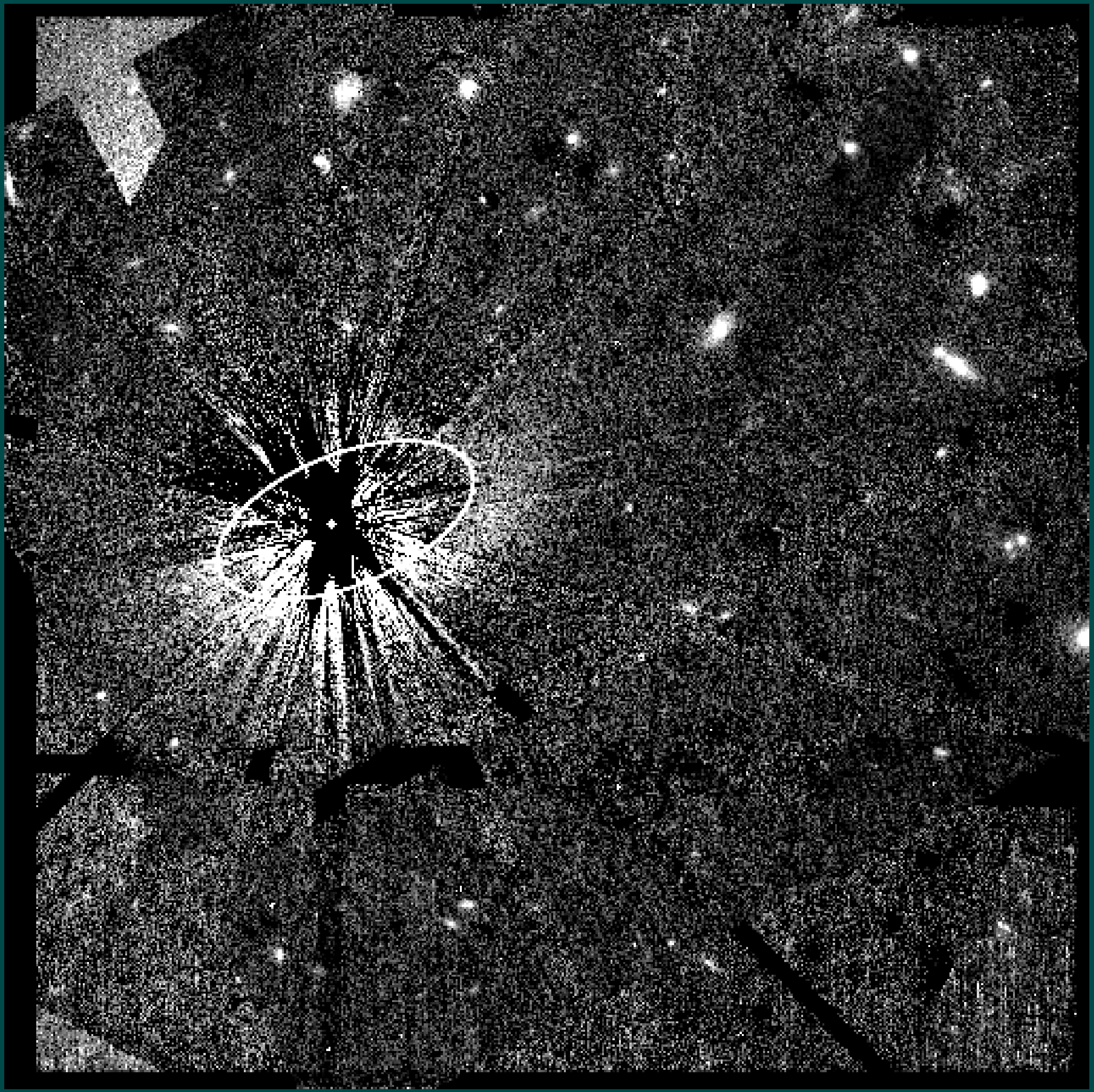
Eiroa et al. 2010

New HST scattered light detection of circumstellar debris ring (Krist et al. 2012)



- Found around nearby solar-type star with Spitzer 70 um excess
- Wide ring with cleared central region ~160 AU in radius.
- Sharp ring inner edge ?

Evidence for eccentric/offset ring



- Ellipse fitting to ring inner edge finds center is offset 16 AU from stellar position: e= 0.1
- Inclination 61˚
- Very similar to Fomalhaut ring, but at even larger orbital distance
- Perturbing planet search may be difficult: system age is ~1 Gyr

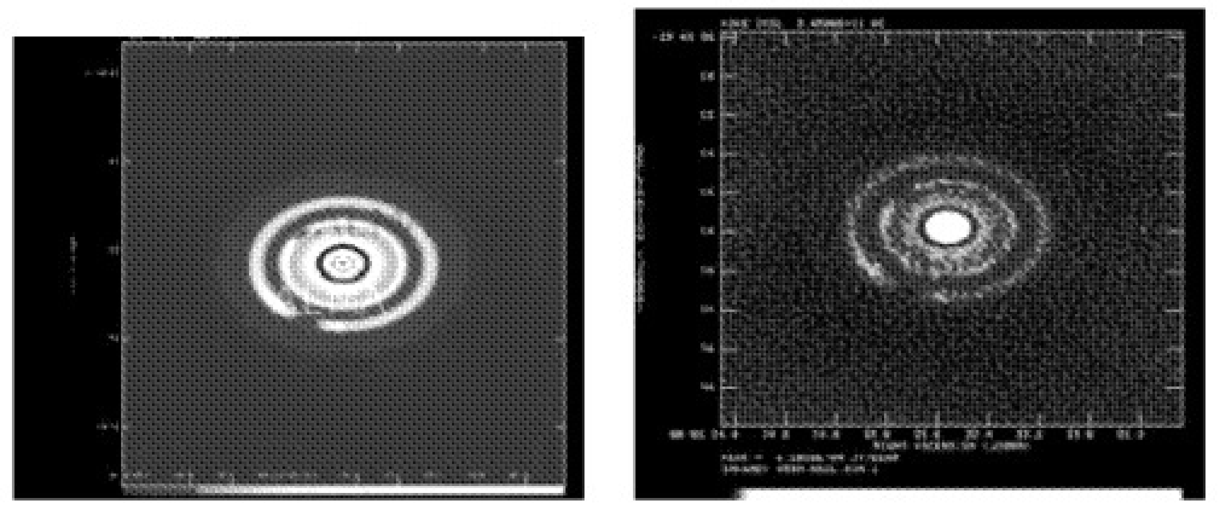
Inventory of Resolved Debris Disks

(23 objects with at least 1 refereed publication)

Star Name	Spec Type	Lir/Lstar	Scattered Light ground	Scattered Light space	Thermal IR ground	Far-IR space	Mm/submm
HD 141569A	B9	8.0E-03	Y	Y	Y	N	Y
HD 32297	A0	3.0E-03	Y	Y	Y		Y
HD 181327	F5	2.0E-03		Y	Y		Y
HD 61005	G8	2.0E-03	Y	Y			Y
HD 15745	F2	2.0E-03		Y			
beta Pic	A5	2.0E-03	Y	Y	Y	Y	Y
HR 4796A	A0	1.0E-03	Y	Y	Y	N	
HD 107146	G2	1.0E-03		Y		Y	Y
49 Ceti	A1	9.0E-04		N	Y	Y	Y
HD 92945	K1	6.0E-04		Y			
HD 15115	F2	5.0E-04		Y			
AU Mic	M0	5.0E-04	Y	Y	N	?	N
HD 53143	K1	3.0E-04		Y			
HD 10647	F9	3.0E-04	N	Y		Y	Y
HD 139664	F5	1.0E-04		Y		Y	
HR 8799	A5	1.0E-04	N	N		Y	
HD 207129	G0	1.0E-04		Y	N	Y	
eps Eri	K2	1.0E-04	N	N	N	Y	Y
gamma Oph	A0	9.0E-05		N		Y	N
Fomalhaut	A3	8.0E-05	N	Y	N	Y	Y
eta Corvi	F2	3.0E-05		N	Y	Y	Y
Vega	A0	2.0E-05	N	N	N	Y	Y
tau Ceti	G8	1.0E-05		N		N	Y

ALMA submm continuum imaging

Wooten, Mangum & Holdaway 2004



Only a handful of debris disk systems are bright enough in the submm for this sort of mapping

Left: Model disk image at 850 μm, 125 AU radius, d=15 pc, (about ¼ surface brightness of Fomalhaut disk)

Right: Simulation of 4 hour ALMA observation, 0.4″ synthesized beam

ALMA early science projects just selected last week

There is a large unexplored parameter space for debris disk scattered light imaging

Bryden et al. 2009

Only 2% of nearby stars have debris disks bright enough for current high contrast imaging systems

Two paths to future progress on resolved disks:

1. Identify more bright disks
2. Improve the contrast/sensitivity of disk imagers

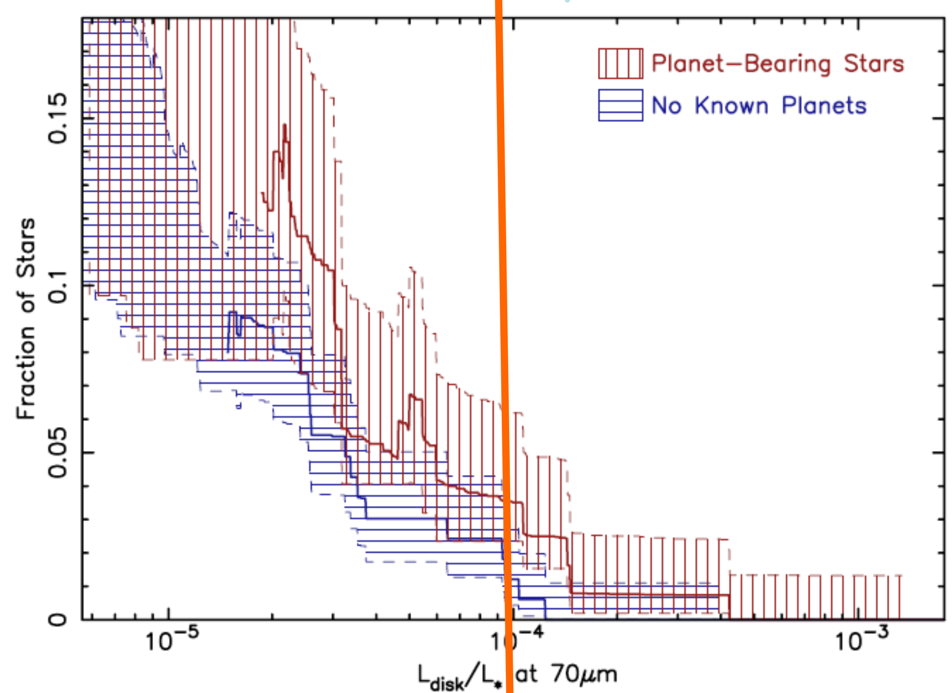
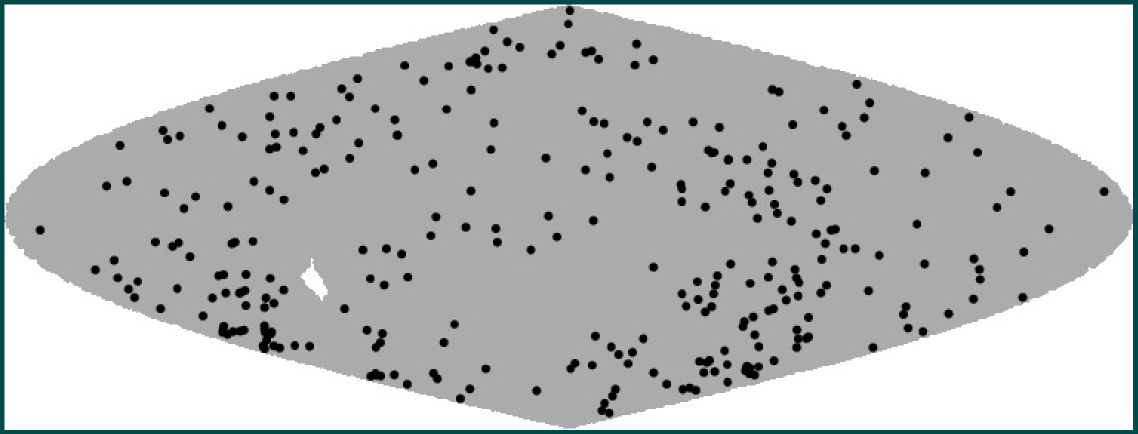
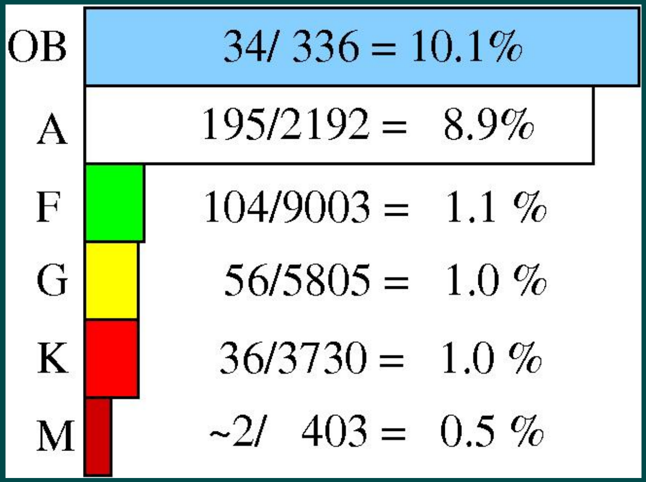


Figure 3. Cumulative fraction of stars with 70 μm excess as a function of disk luminosity for the planet and non-planet samples. As in Figure 1, the dust's fractional luminosity, $L_{dust}/L_\star$, is derived from the strength of the 70 μm emission relative to the stellar photosphere (Equation (2)). For both the planet and non-planet samples, dust disks with $L_{dust}/L_\star > 10^{-4}$ are rare, with $L_{dust}/L_\star \approx 10^{-5}$ disks detected much more frequently. The 1σ uncertainties in the underlying distributions of $L_{dust}/L_\star$ are indicated by the shaded regions. While the dust around planet-bearing stars is nominally brighter than for the non-planet stars (i.e., the red line lies above the blue line), the difference is not statistically significant.

WISE all-sky survey finds field stars with warm excess

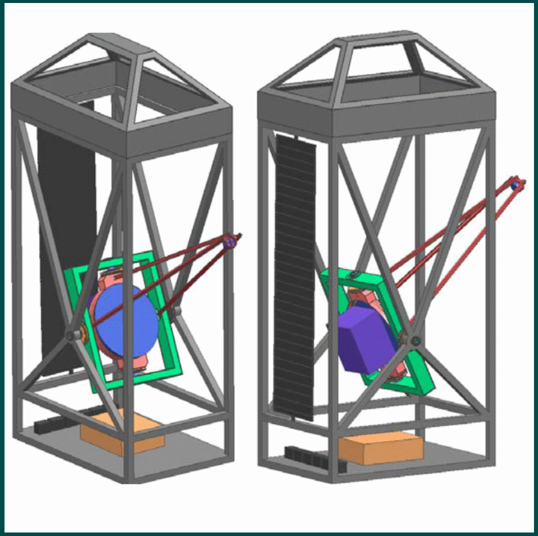
- ~400 Hipparcos main sequence stars within 120 pc show 22 um excess > 0.25 mag (see Padgett poster)
- Warm excess sources likely young – exoplanet imaging targets
- Below left: sky distribution of excess sources.
- Below right: 22 um excess frequency vs. spectral type

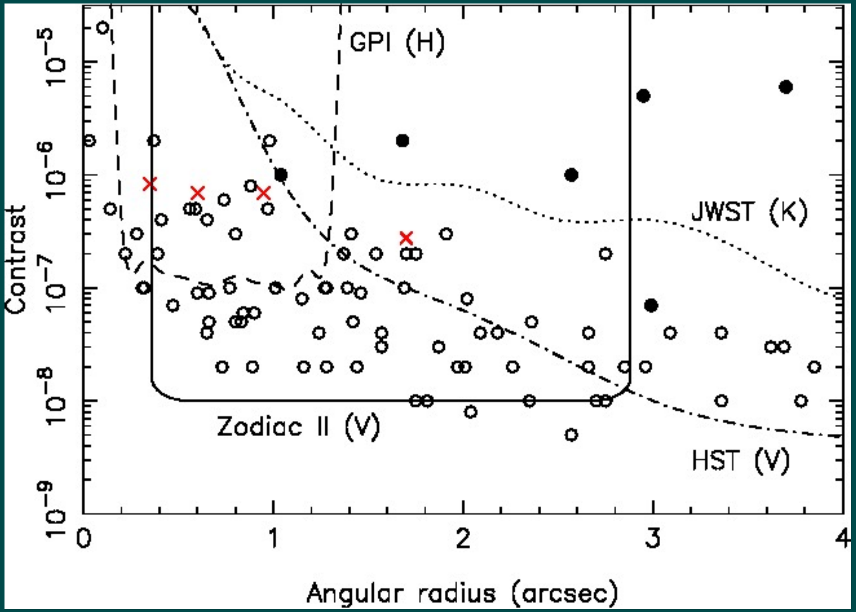




Possible next step in coronagraphy : Zodiac II balloon telescope (Traub et al.)

- Image debris disks to 10^{-8} contrast
- Optical wavelengths 0.5-0.9 um
- If selected, 1st flight would be FY 2016





Track disk imaging at
http://circumstellardisks.org

Catalog of Resolved Circumstellar Disks - Mozilla Firefox

File Edit View History Bookmarks Tools Help

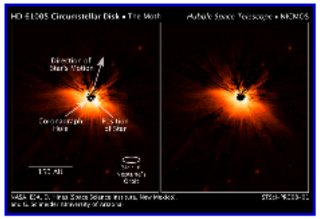
http://circumstellardisks.org/

PRESTO Spitzer JPL Intranet Wikipedia Webdisks ADS Simbad LAsat CUsat

Catalog of Resolved...

Catalog of Resolved Circumstellar Disks

Last updated: Aug 26 2011; created by Caer McCabe;
maintained by Karl Stapelfeldt, with assistance from Carlotta Pham



Total number of disks: 160 (Pre-Main Sequence disks: 128, Debris Disks: 32)

Object	SpTy	Category	Distance (pc)	R band (mag)	Disk Diameter (")	Disk Diameter (AU)	Inclination	How well Resolved	At ref. wavelength (micron)
2MASSI J1628137-243139		TT	140	17.7	4.3	602	86	10.8	2.1
49 Cet	A1	Hae	61	5.6	0.8	48		3.9	10
AA Tau	M0	TT	140	11.8	1.34	187	75	1.0	2000
AB Aur	A0e	Hae	144	7.1	18	2592	22	367.4	0.57
AS 205A	K0	TT	125	11.9	0.4	50	25	0.7	880

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