Debris Disk Imaging

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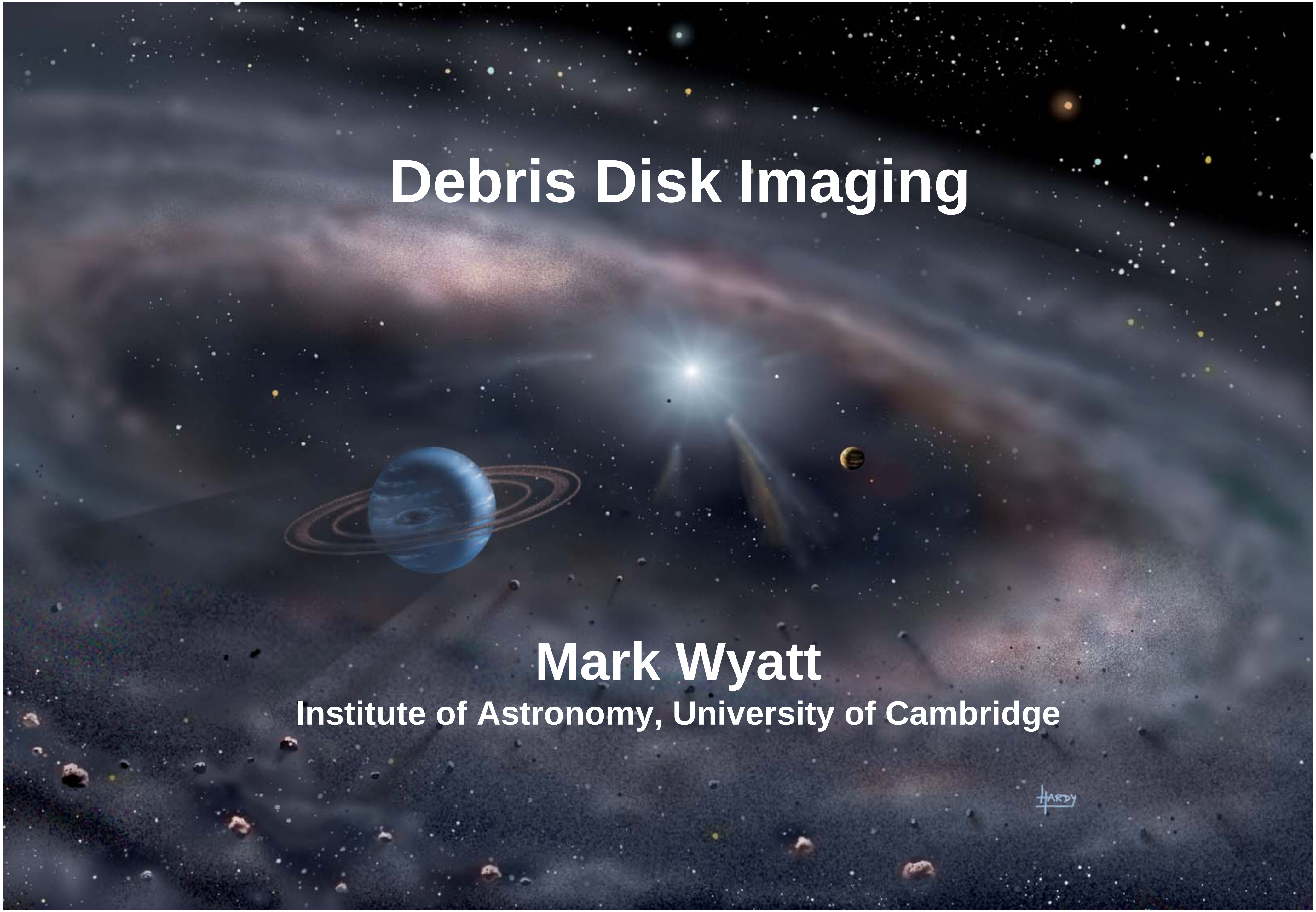
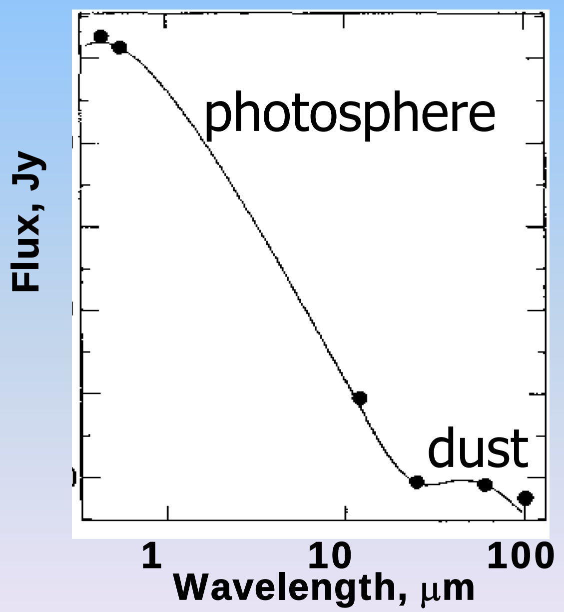
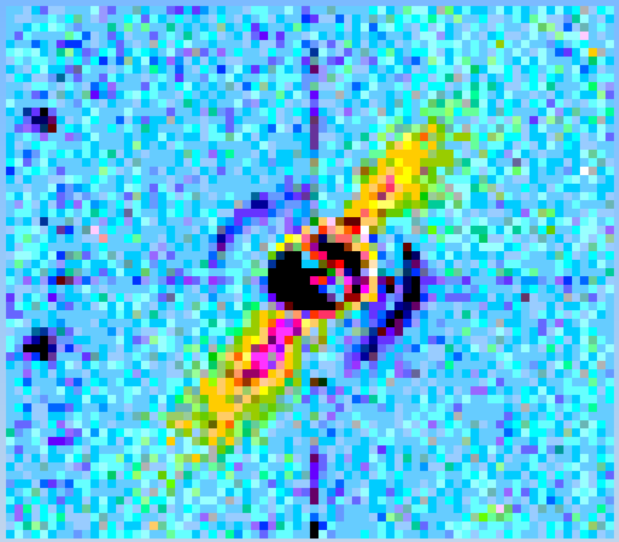


Debris disk history: discovery...

First extrasolar debris disk discovered around Vega using IRAS from the thermal emission of circumstellar dust

(Aumann et al. 1984)



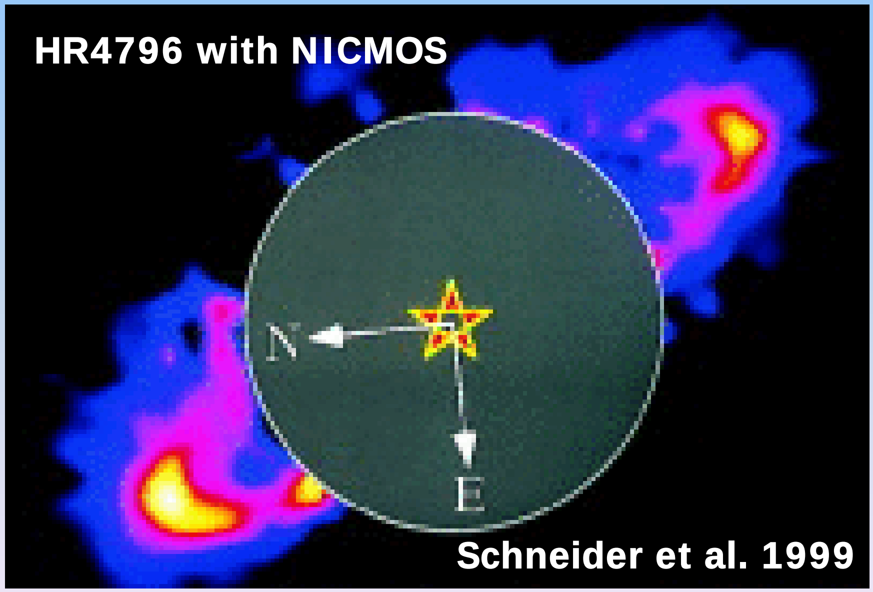


First image of a debris disk taken the same year of β Pictoris using ground-based optical coronagraphy

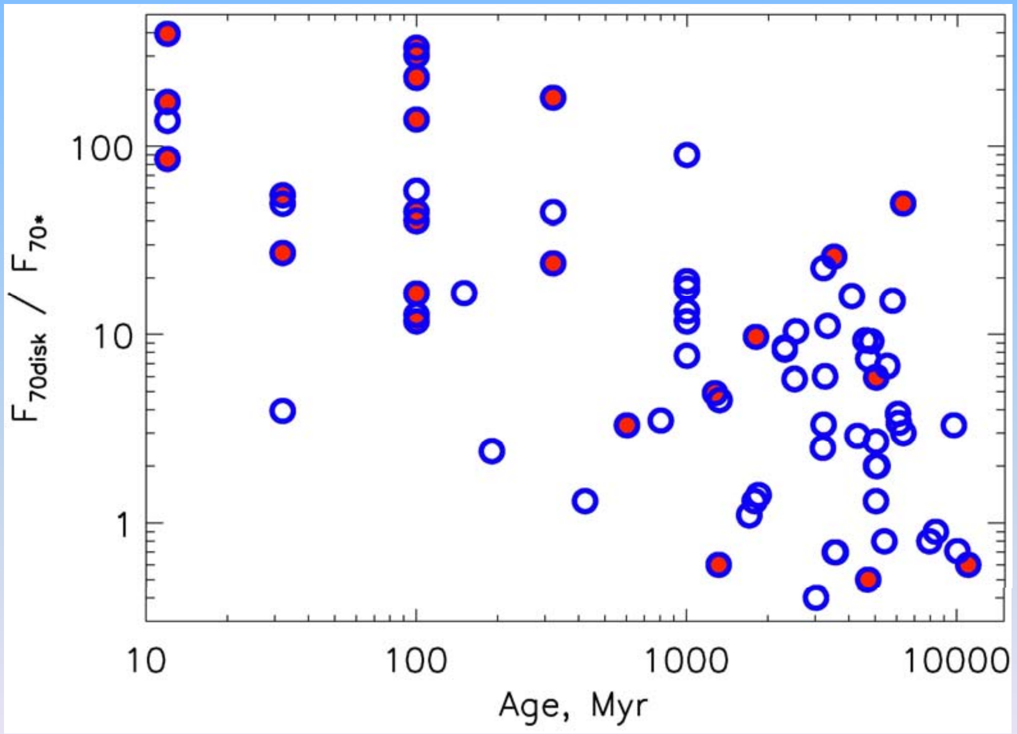
(Smith & Terrile 1984)

Debris disk history: ... to present day

Fourteen years later, imaging revealed 4 more resolved disks at near-IR (NICMOS), mid-IR (OSCIR), and sub-mm (SCUBA) wavelengths



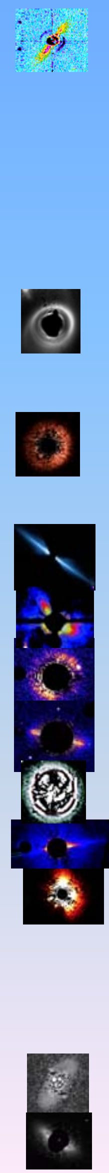
Now >300 debris disks known from thermal emission (more numerous and common than extrasolar planets), of which 20 have been imaged

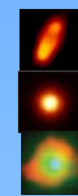
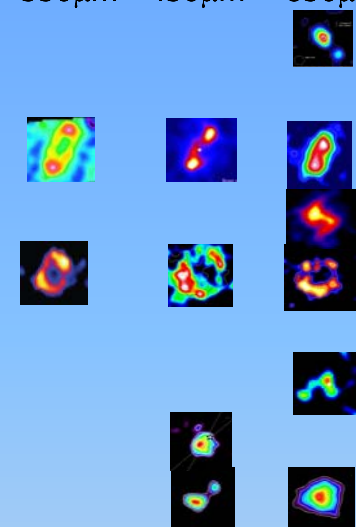
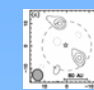


Evolution of disk brightness at 70μm for sun-like stars detected with Spitzer (Wyatt 2008)

Debris Disk Image Gallery

		HST?	Optical <1μm	NIR 1-5μm	Mid-IR 10–25μm	Far-IR 70–200μm	Submillimetre 350μm	450μm	850μm	Millimetre 1.3mm
1984	β Pictoris	ANSW								
1998	HR4796	NS								
1998	Fomalhaut	A								
1998	Vega									
1998	ε Eridani									
2000	HD141569	ANS								
2004	τ Ceti									
2004	HD107146	AN								
2005	η Corvi									
2005	AU Mic	AN								
2005	HD32297	N								
2006	HD53143	A								
2006	HD139664	A								
2006	HD181396	AN								
2007	HD15115	A								
2007	HD15745	A								
2007	HD61005	N								
2008	δ Vel									
2008	HD92945	A								
2008	HD10647	A								



+ACS images of HD207129, HD202917, AG Tri

HST is just getting into its stride

Why are images so scientifically valuable?

Disk Structure	Implication
Radius	Where are planetesimal belts at the end of planet formation?
Outer Edge	Stochastic evolution of small grains and dynamical excitation
Non-axisymmetries	Indirect detection of planets and discovery of new phenomena
Inner Edge	Constraining planet properties and comet population

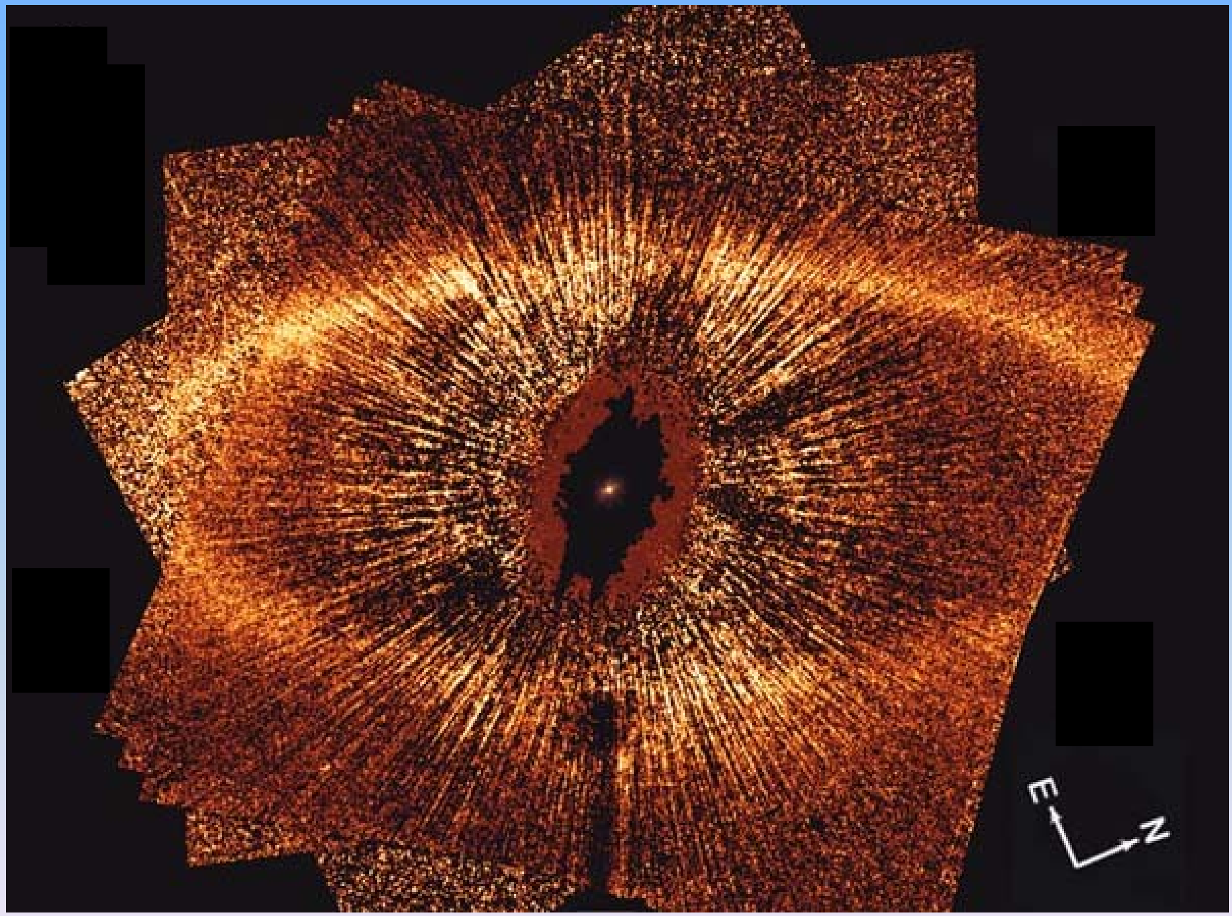
Debris disks show location of planetesimal belts

Debris disks are to first order rings of dust derived from a planetesimal belt analogous to the Kuiper belt

Knowing the location of planetesimal belts is vital for understanding the outcome of planet formation

For example the radius may indicate the outer edge of the planetary system

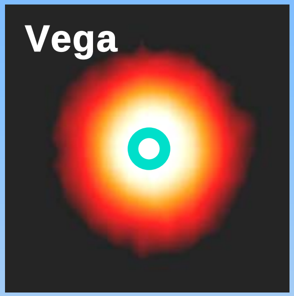
Fomalhaut, 133AU (Kalas et al. 2005)



Radius from dust temperature uncertain

Comparing dust location expected from 24μm-70μm colour temperature with that from imaging shows that disks are:

Bigger



Smaller

Just right (ish)

We can explain this because:

Radiation pressure

Multiple planetesimal belts/comets

But we cannot predict which apriori

Only way to break degeneracies is by imaging

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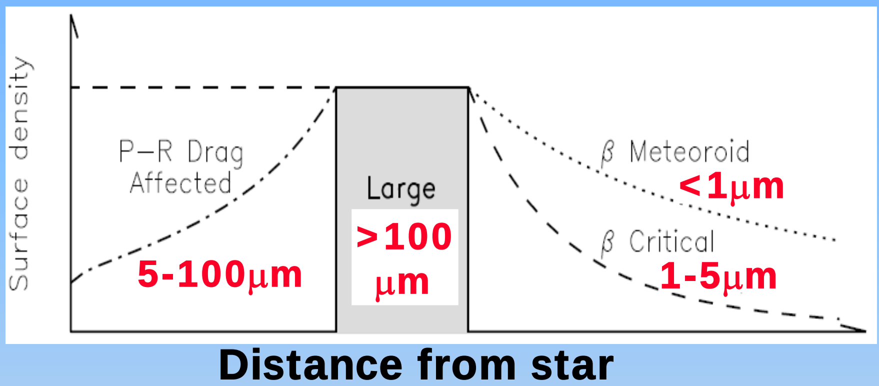
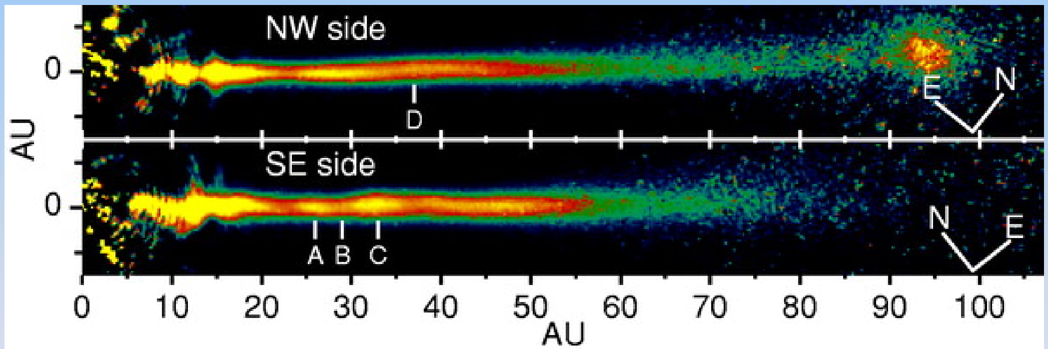
Unifying disk model

Significant advance of last few years has been to explain radial structures of broad debris disks as dust created in planetesimal belts

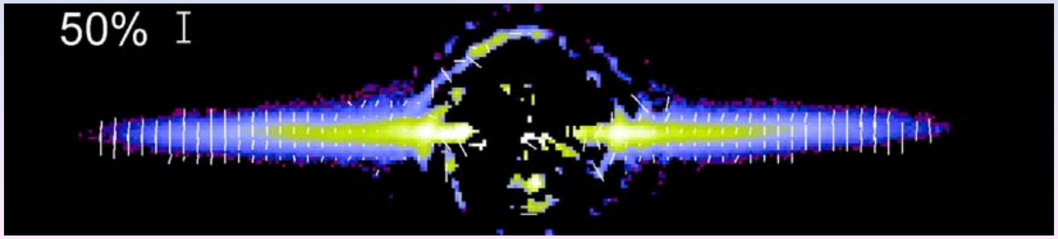


Extended disk comes from dust put onto eccentric or hyperbolic orbits (Wyatt et al. 1999)

For example, extended structure of AU Mic (Krist 2005) explained by dust created in a narrow belt at ~40AU (Augereau & Beust 2006; Strubbe & Chiang 2006)



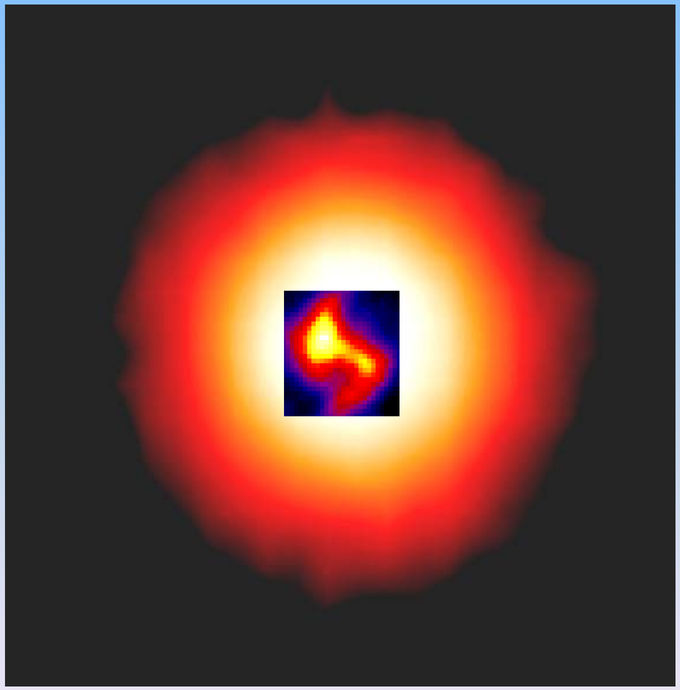
ACS polarisation images dominated by porous sub-micron grains (Graham et al. 2007) further supporting theory



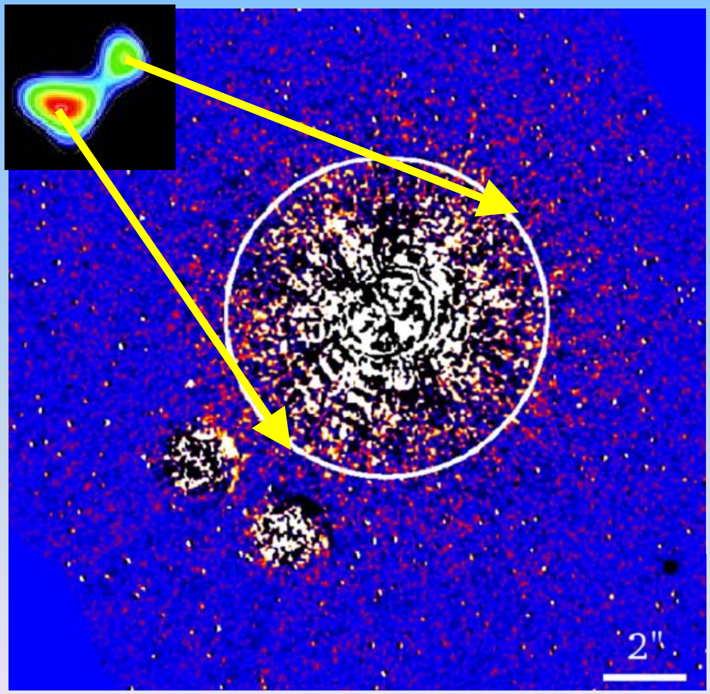
Stochastic evolution of small grains

While images can be explained they can't be predicted

Too many small grains seen around Vega implying a mass loss rate of $2M_{earth}$/Myr, which must be transient
(Su et al. 2005)



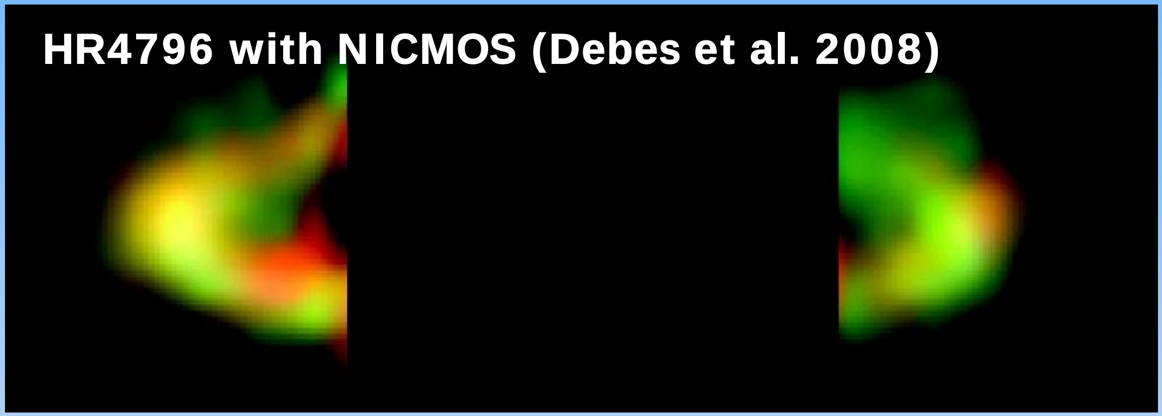
Too few small grains in disks like η Corvi that are bright in sub-mm but not detected by HST
(Wyatt, Clampin, Wisniewski et al. 2008)



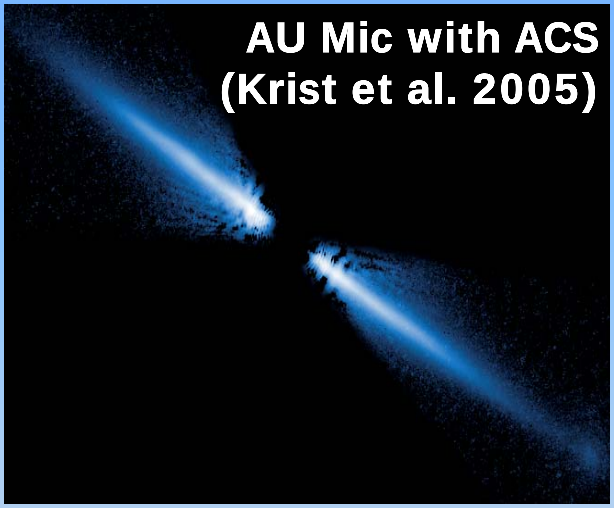
More images needed to understand what causes the diversity

Meaning of the outer edge

Why do some disks extend to large distance and others not?



Surface brightness $\propto r^{-7.5}$



Surface brightness $\propto r^{-3.5}$

Possibly related to disk stirring, with sharp edges from unstirred ($e<0.01$) disks (Thebault & Wu 2008)

Requires consistent analysis of large numbers of images along with studies of grain composition from multiwavelength and polarisation data

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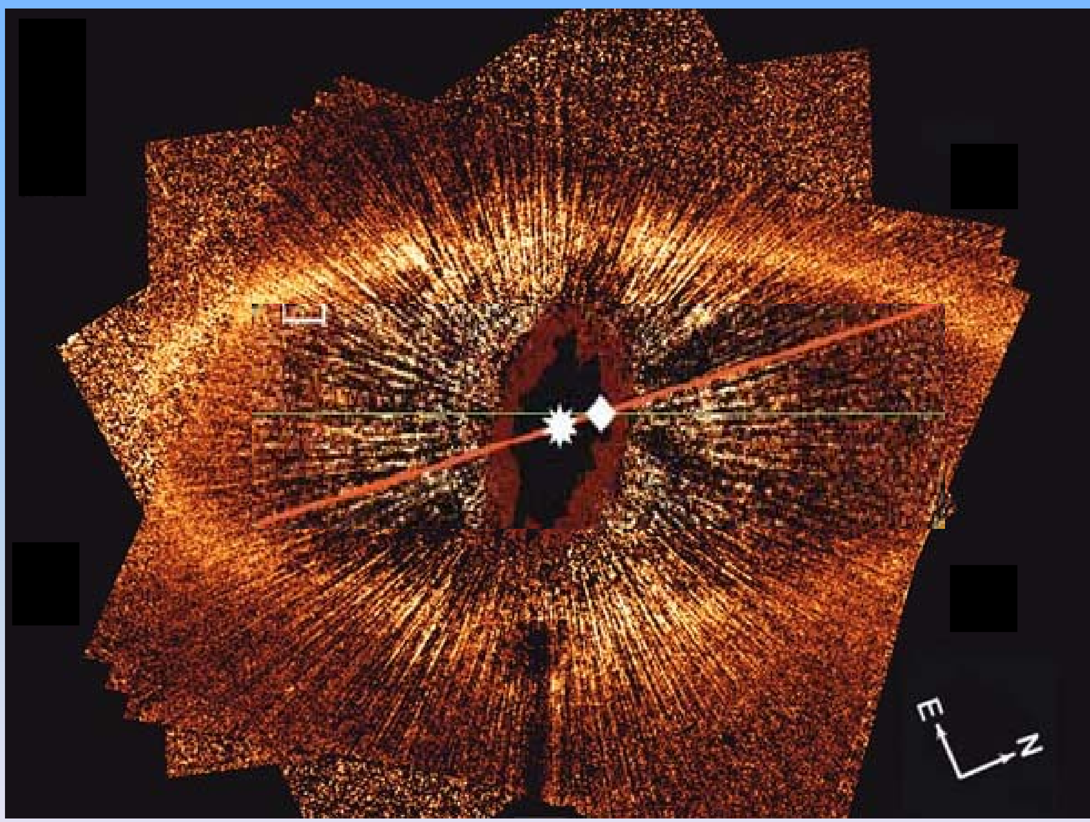
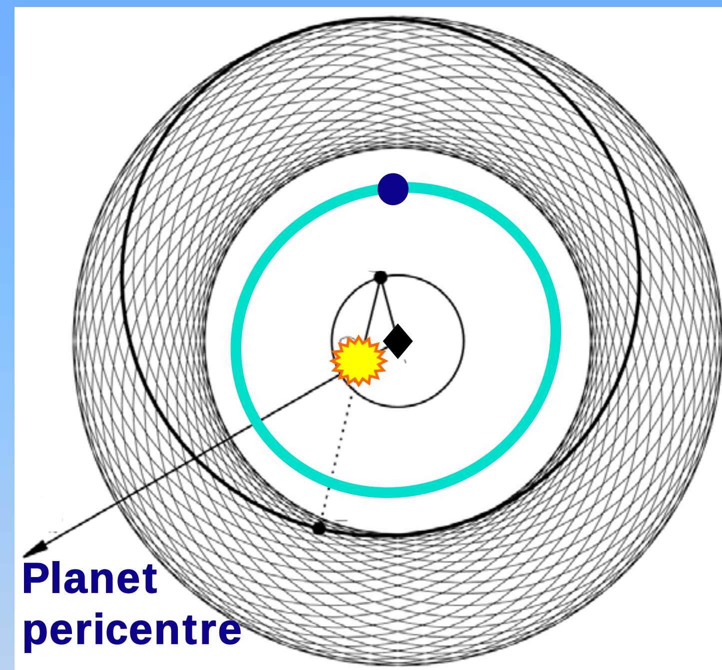
Offset centre of Fomalhaut disk

High resolution of ACS images (0.5AU) showed that Fomalhaut's 133AU ring is offset by 15AU from the star (Kalas et al. 2005)



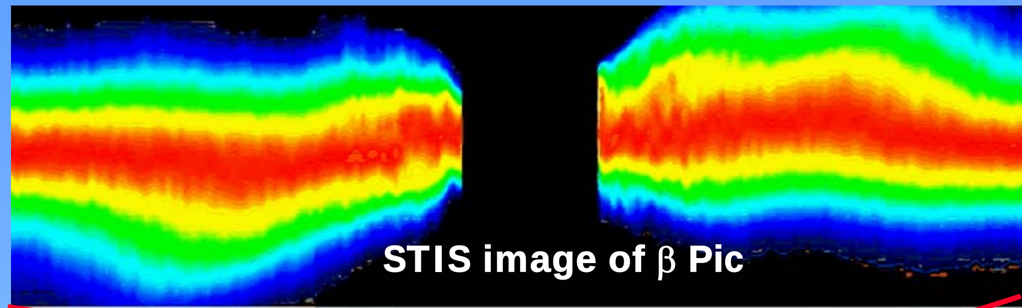


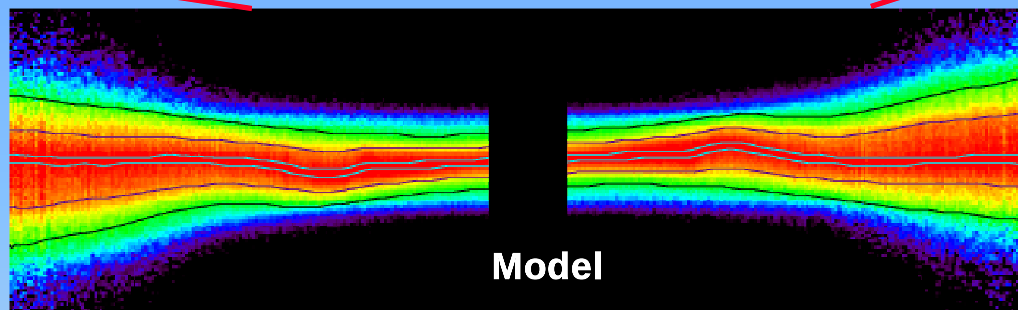
Such an offset predicted from planet on an eccentric orbit (Wyatt et al. 1999) implying a planet eccentricity of 0.11 in this case

More recent example of this phenomenon may be HD10647 (Stapelfeldt in prep.)

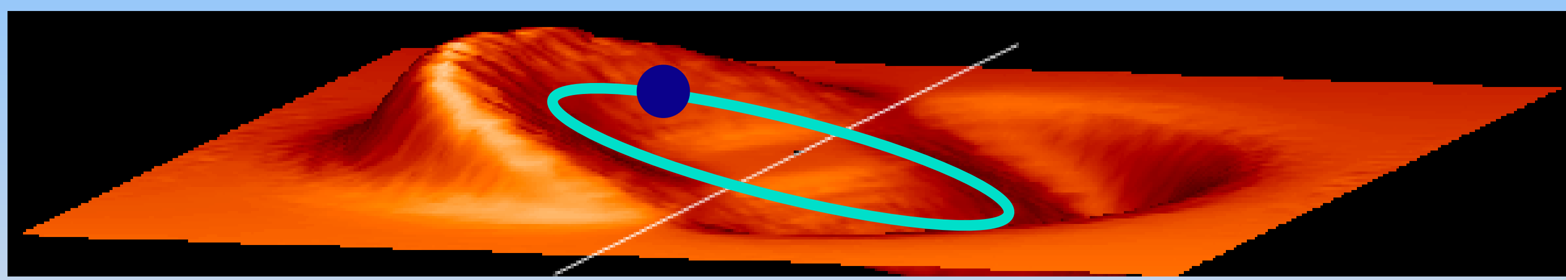
Warp in β Pic disk

STIS shows a 3° warp in β Pic disk (Heap et al. 2000)

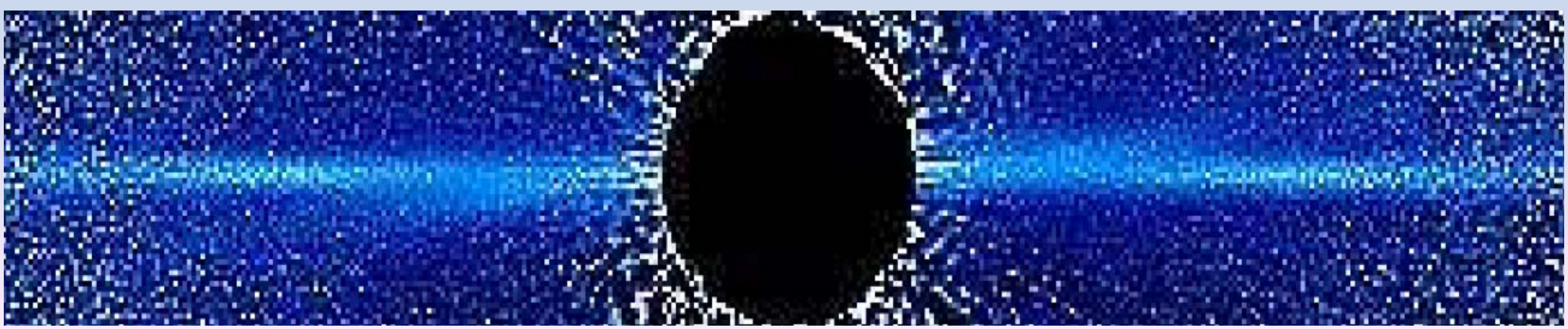




Explained by 1-2$M_{jupiter}$ planet at 10AU inclined 3^0 to disk mid-plane; warp at 70AU by 20Myr (Augereau et al. 2001)

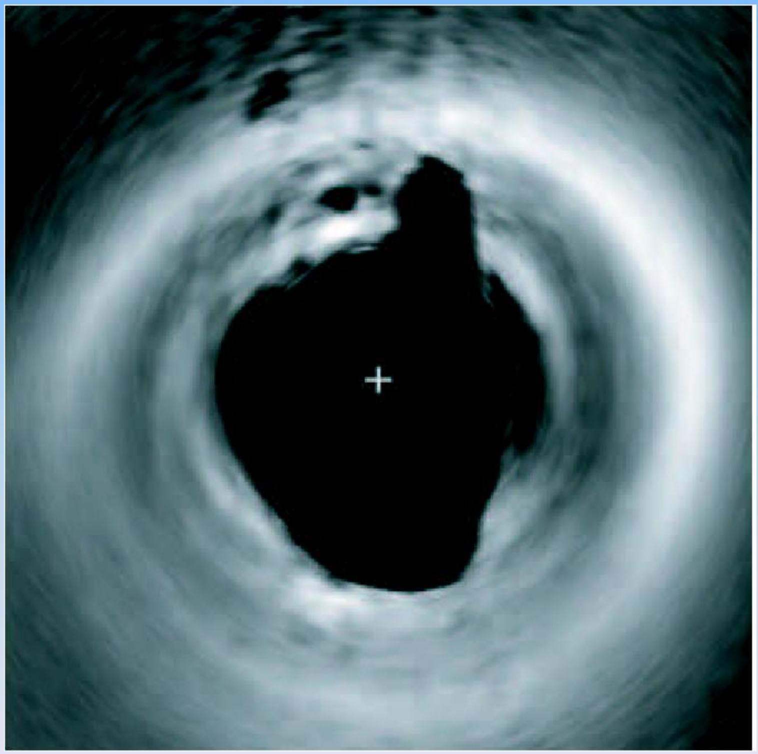


Latest ACS image shows warp is two disks (Golimowski et al. 2006)

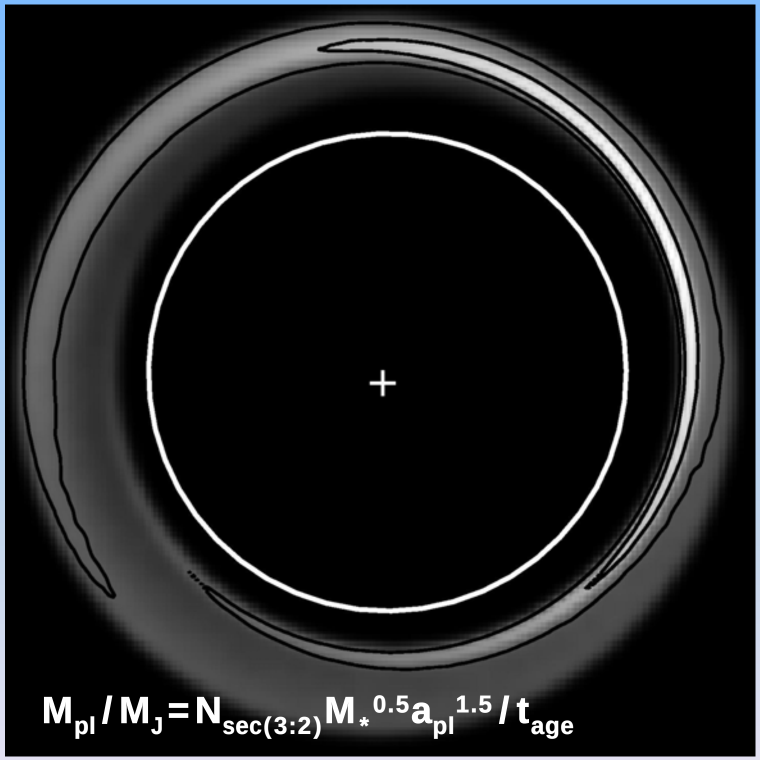


Spiral Structure in the HD141569 Disk

ACS image of 5Myr HD141569 shows dense rings at 200 and 325 AU with tightly wound spiral structure (Clampin et al. 2003)

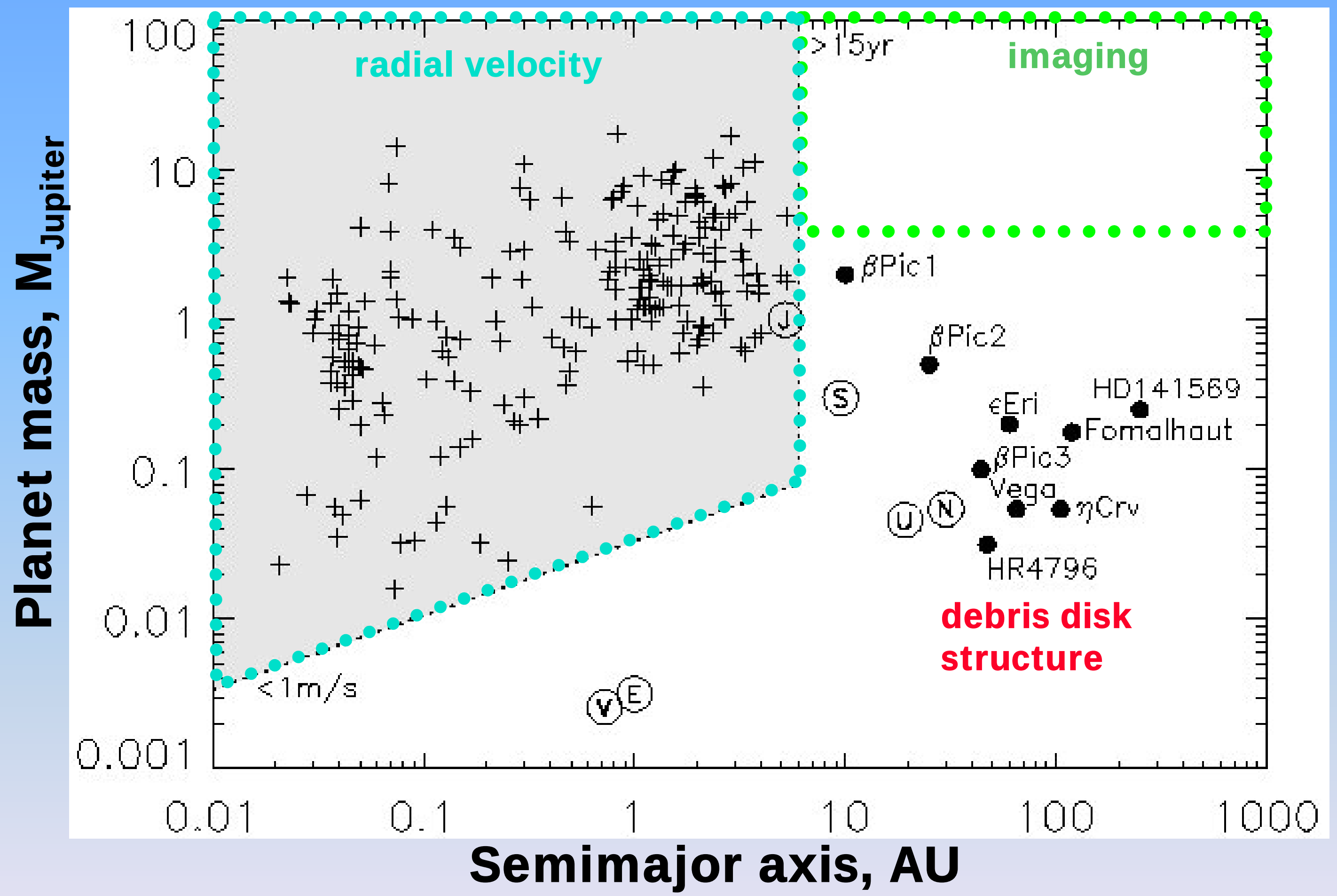


The spiral at 325AU explained by $0.2M_{Jupiter}$ at 250AU with e=0.05 (Wyatt 2005)



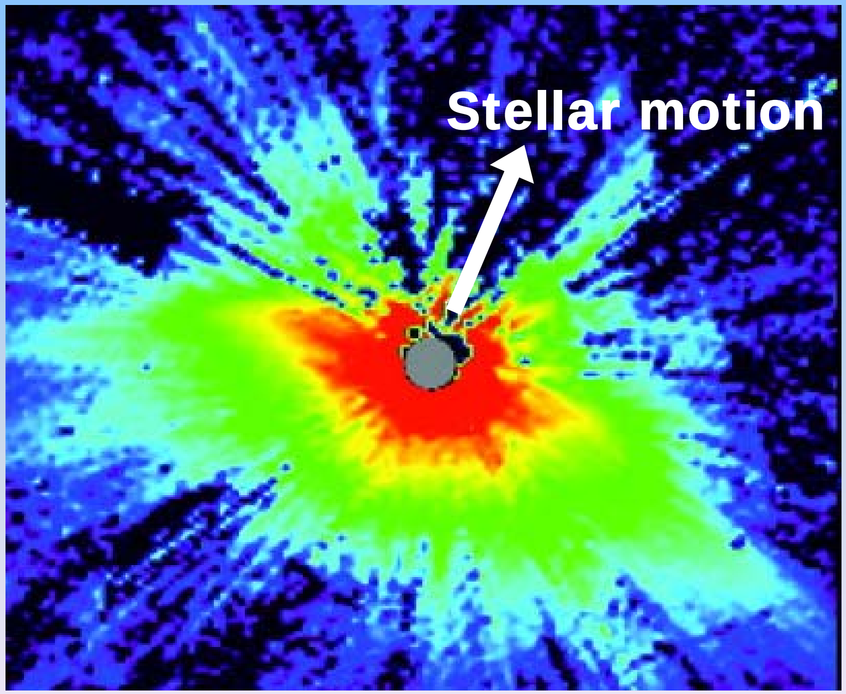
Exoplanet parameter space

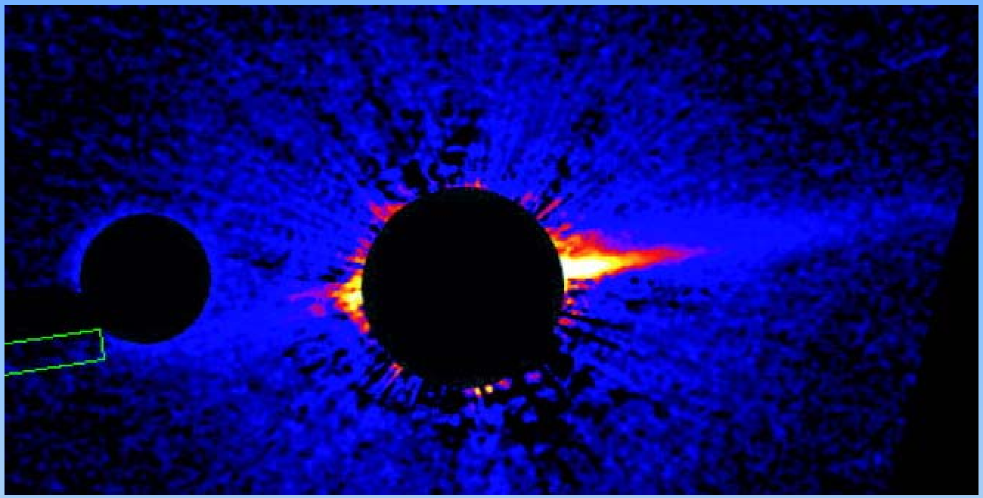
Debris disks open up the parameter space in which it is possible to infer information about their planetary system, so that Neptune-analogs are accessible
(Wyatt 2008)



Asymmetric surprises

The "moth" disk of HD61005 seems to be interacting with the interstellar medium (Hines et al. 2007) but at 35pc this star should be within the local bubble





The extreme brightness asymmetry in the "blue needle" disk of HD15115 is reminiscent of that expected following a stellar encounter, but encounters should be rare (Kalas et al. 2007)

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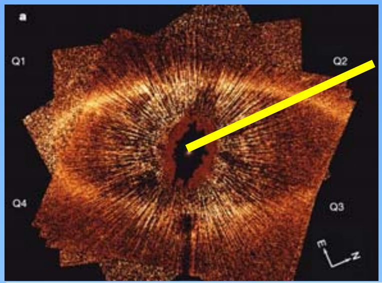
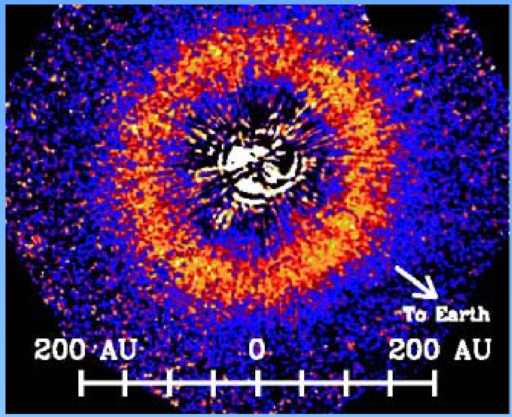
The inner disk edge frontier

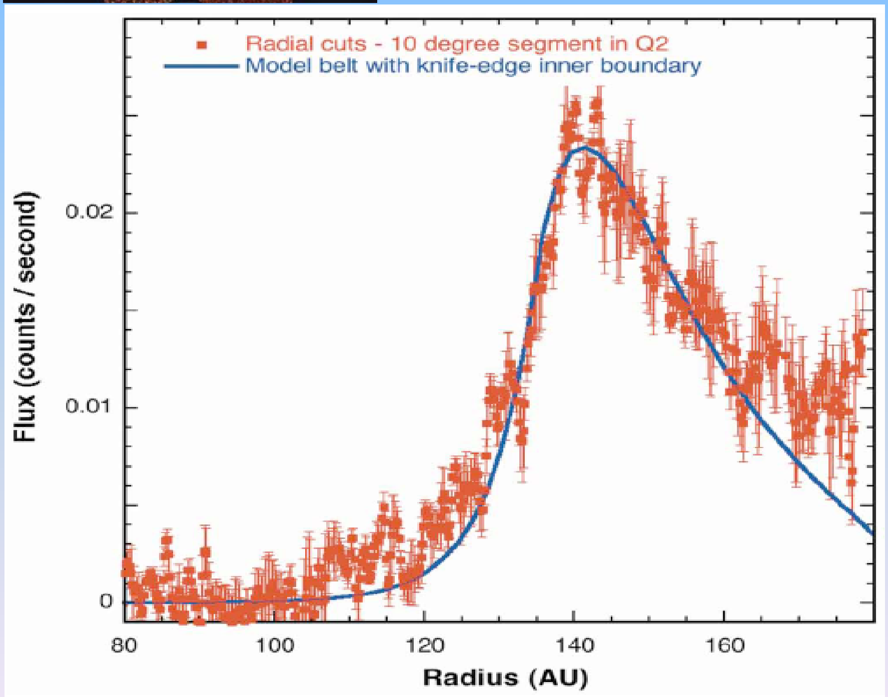
Inner edge slopes are diverse too!

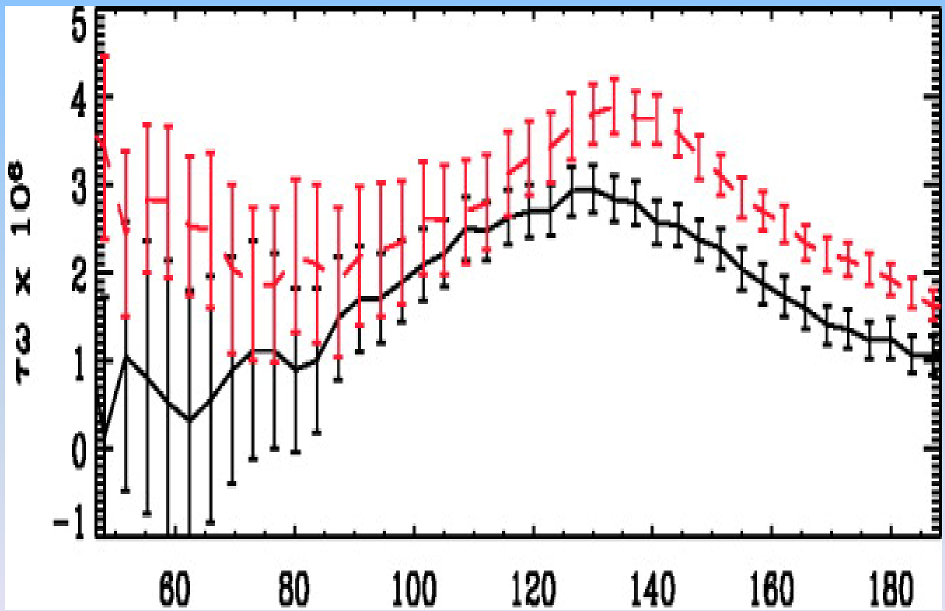


Fomalhaut's is steep (Kalas et al. 2005)

HD107146's is shallow (Ardial et al. 2004)





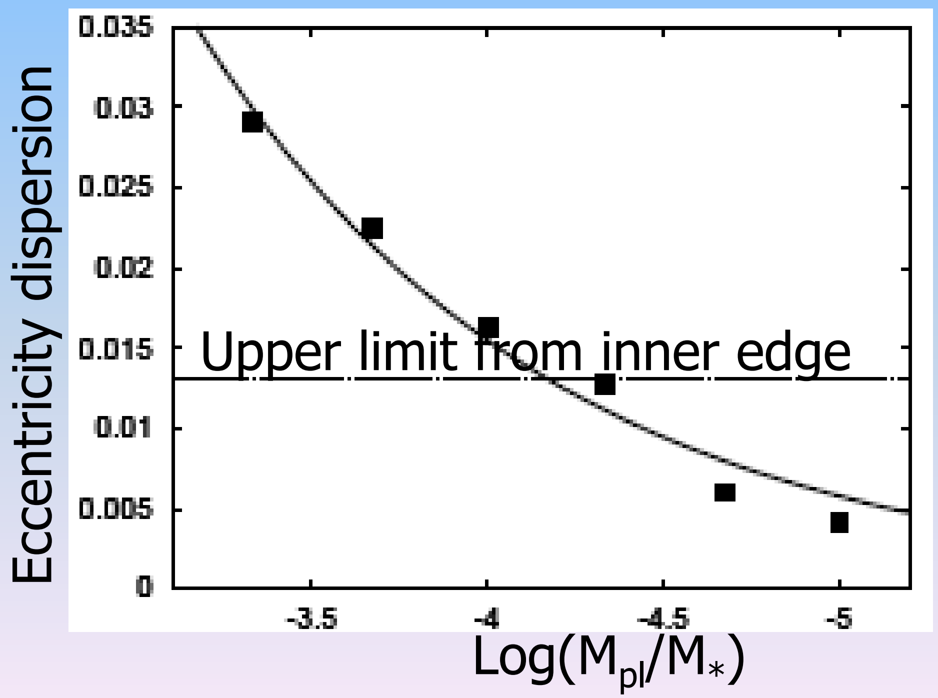


The potential of high resolution studies possible with HST is just being realised

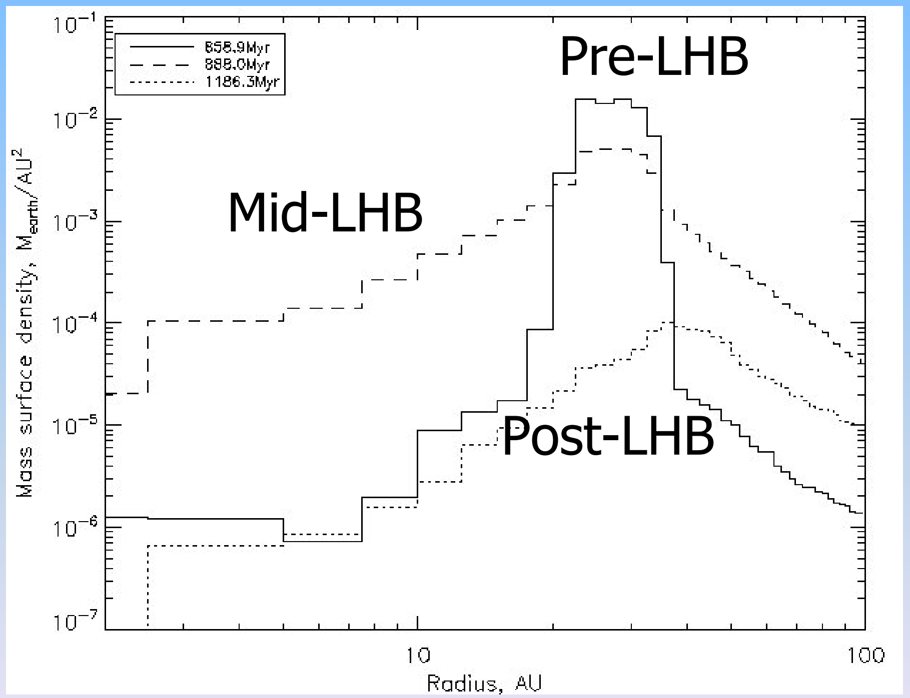
Origin of inner edge?

Truncation by a planet causes slope to be affected by mass of planet
(Quillen 2006)

Planet: a_{pl}=119AU, e_{pl}=0.1, M_{pl}<M_{Saturn}



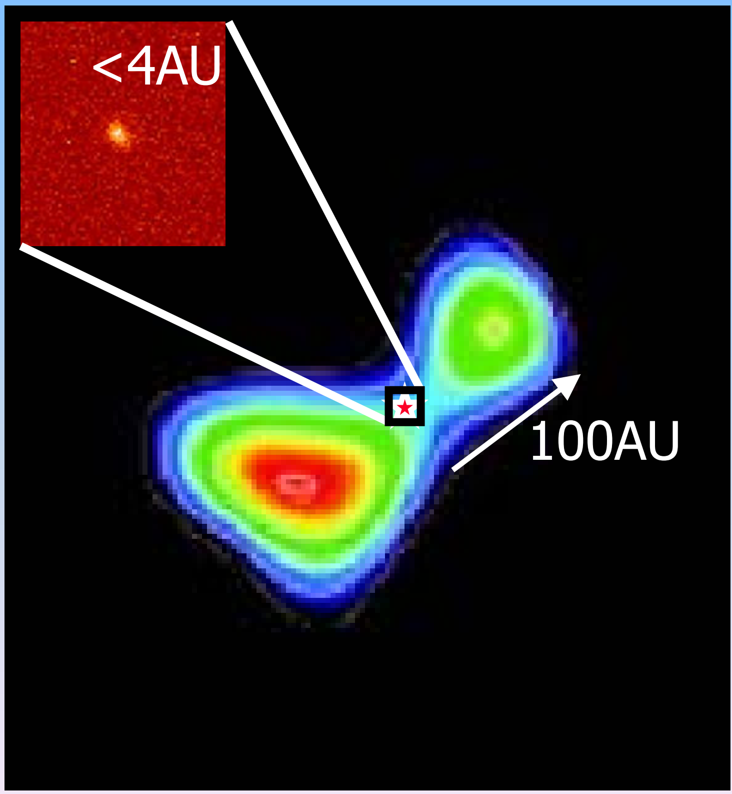
Dynamical state and planet distribution affects distribution of comets

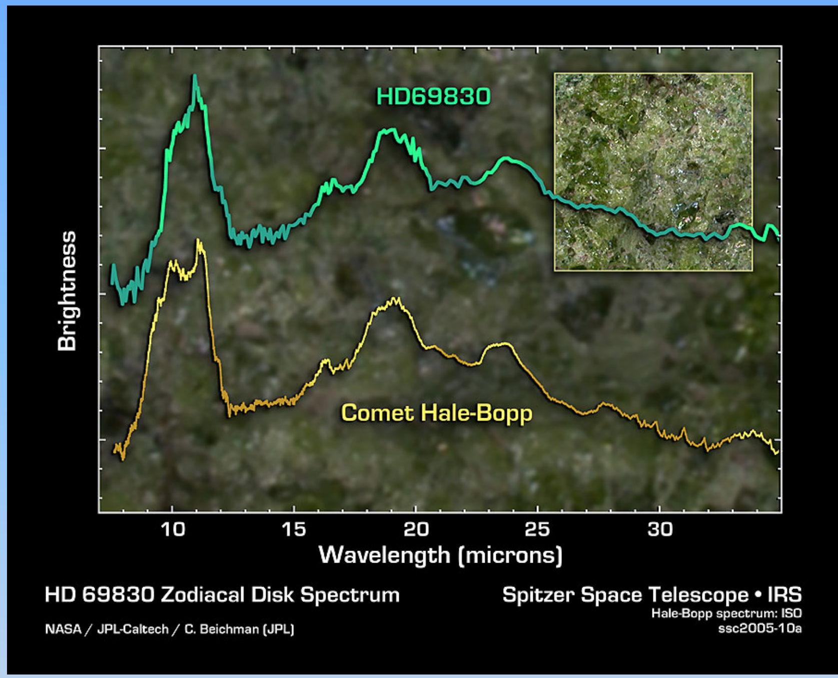


Distribution of solar system comets
(Booth, Wyatt, Morbidelli et al., in prep.)

Probing extrasolar comets...

It is thought that comets may be scattered in from an outer planetesimal belt in systems like η Corvi (Wyatt et al. 2005; Smith, Wyatt & Dent 2008)





Dust around HD69830 also looks cometary (Beichman et al. 2005; Lisse et al. 2007)

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Has HST exhausted resolvable disks?

Maybe?

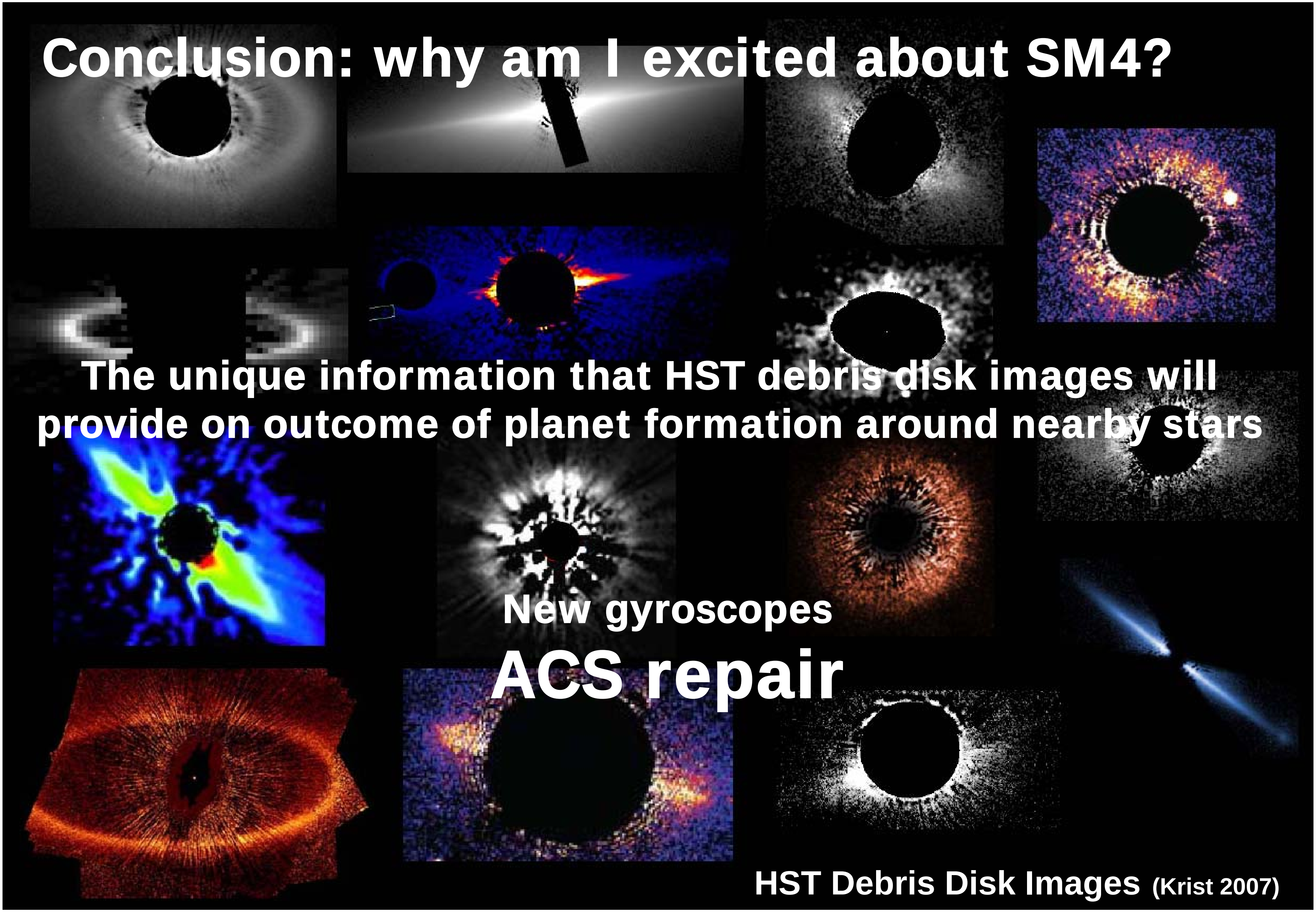
- 90 known IRAS disks observed with 15% successful image rate

No

- Demise of ACS was before Spitzer-surveys completed, and NICMOS still returning images for Spitzer disks, so new candidates resolvable
- SCUBA2 legacy- and Herschel key- programmes of nearest 500 stars (2008-2010) will discover many disks

Also

- More detailed study of known disks
    - grain composition from colours, polarisation
    - information on unseen planets/stochasticity/etc


Conclusion: why am I excited about SM4?
The unique information that HST debris disk images will provide on outcome of planet formation around nearby stars
New gyroscopes
ACS repair
HST Debris Disk Images (Krist 2007)