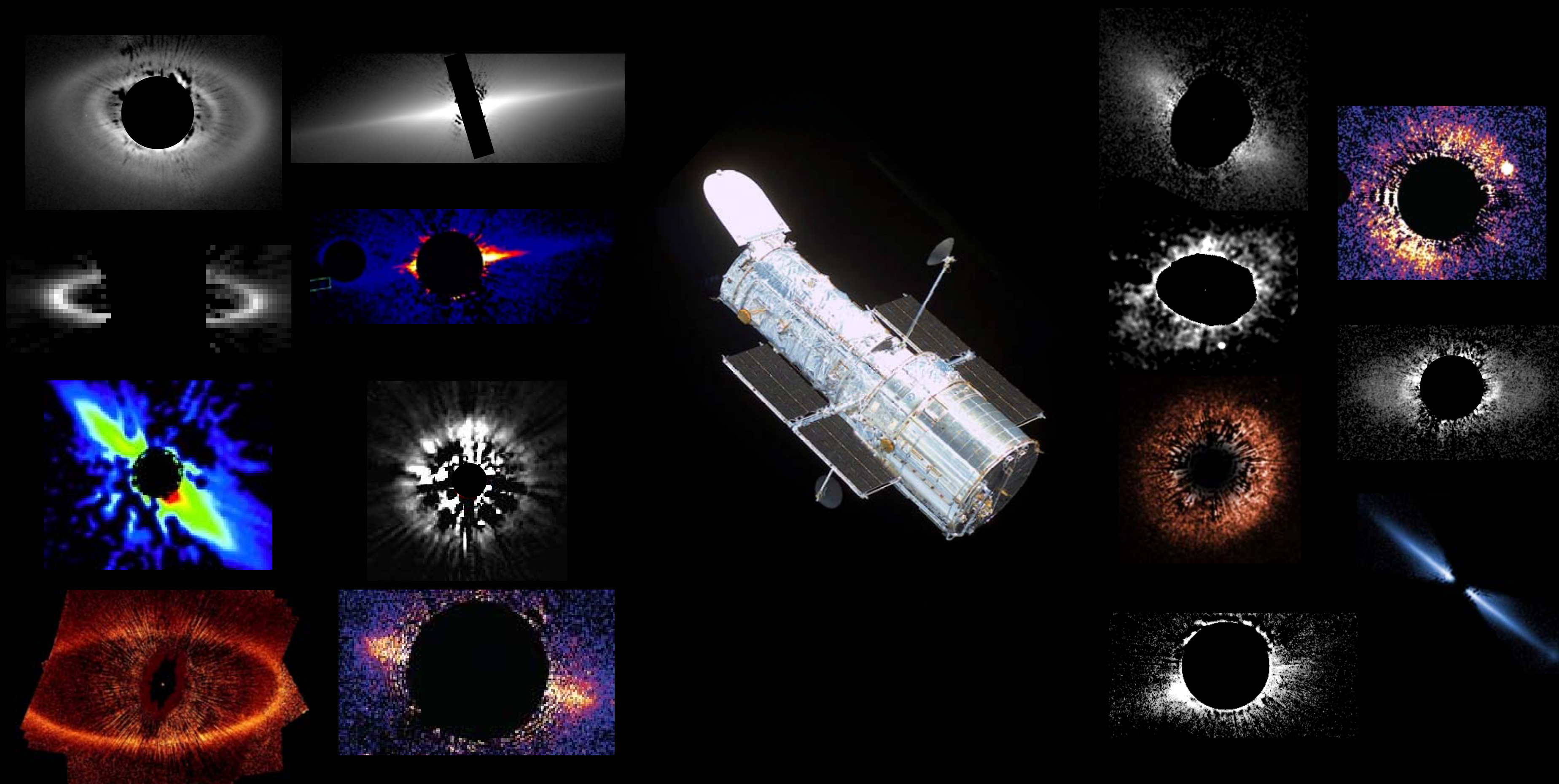
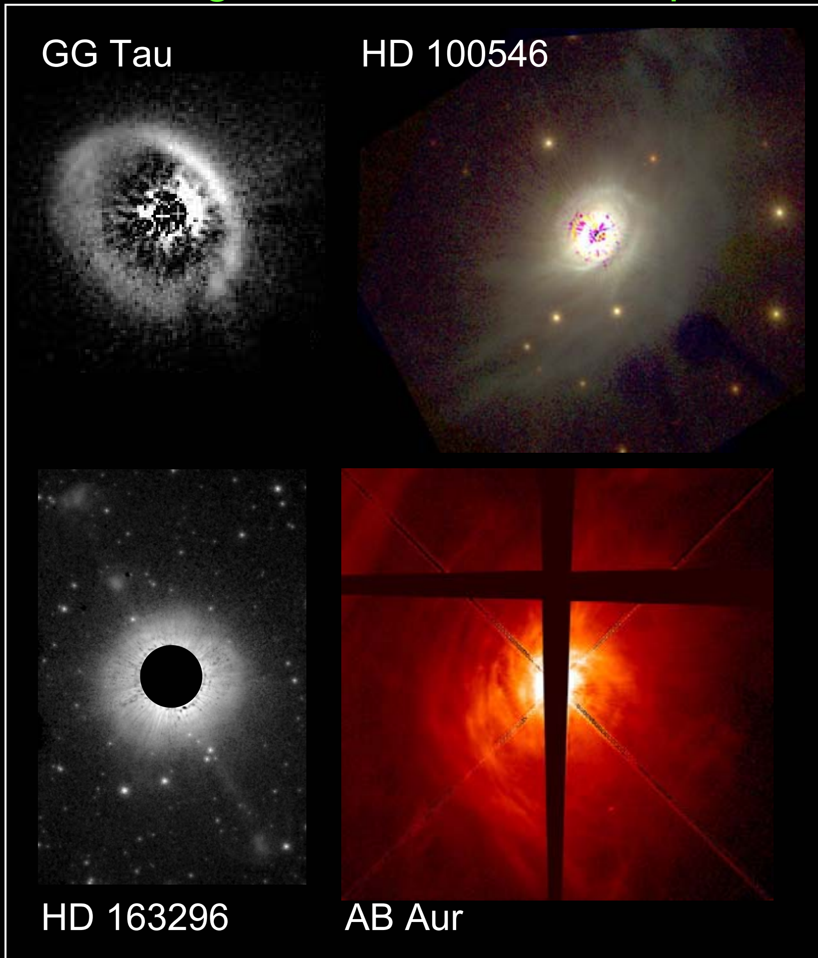
HST Coronagraphic Imaging of Debris Disks

John Krist (JPL & ACS Science Team)



Young Star Disks vs. Debris Disks

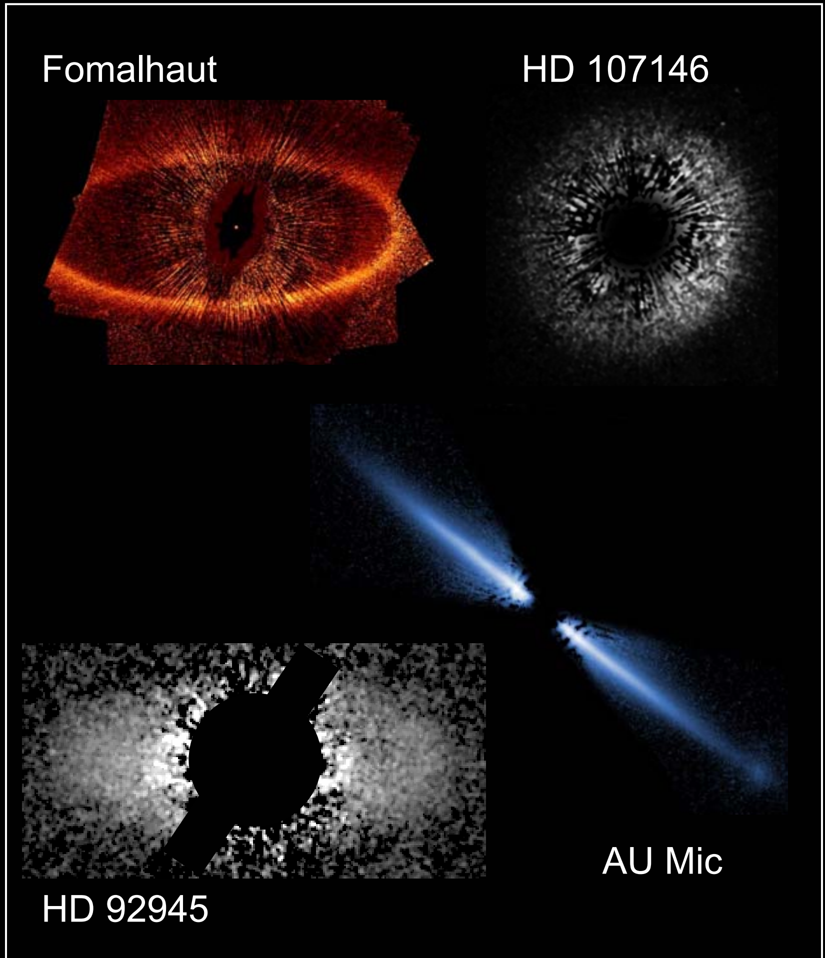
Young Star Disks & Envelopes



<~10 Myr, >M_{Jup}, Optically thick, Gas rich, Accreting

See talk by Grady

Debris Disks



>~10 Myr, <~M_{Earth}, Optically thin, Gas poor, Collisional debris

Observed Characteristics of Debris Disks

- $L_{dust}/L_{star} < 10^{-2}$
  - Beta Pic = ~2 x 10^{-3}
  - Fomalhaut = ~8 x 10^{-5}
- No significant extinction within disk (what you see is what there is)
- Low total brightness relative to star (e.g. Fomalhaut's integrated disk flux is 10^{-6} of the star's)
- Extended (Fomalhaut disk ~190 $arcsec^2$)

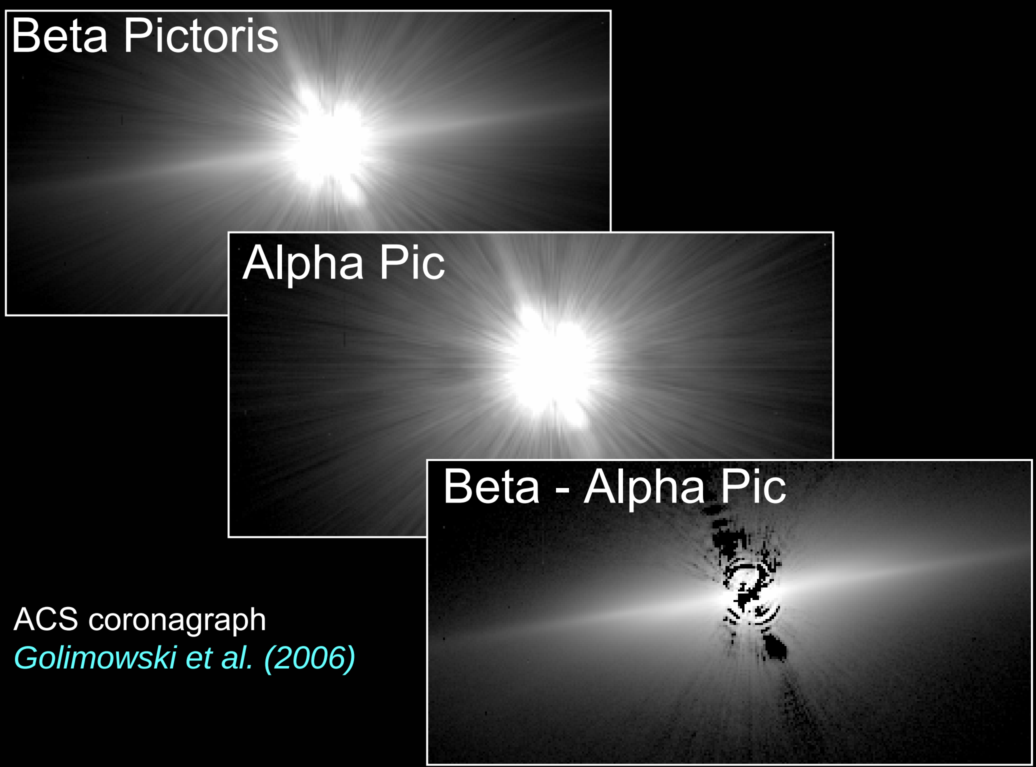
Why Use HST to Image Debris Disks?

- Large, high-resolution field
- Wide wavelength coverage (0.2 - 2.5 μm)
- Only choice for high-res imaging in the visible
- Stability over time
  - Residual diffracted & scattered light pattern is very stable compared to ground-based scopes and can be subtracted out using PSF subtraction (reference PSF or roll subtraction)

HST PSF Subtraction

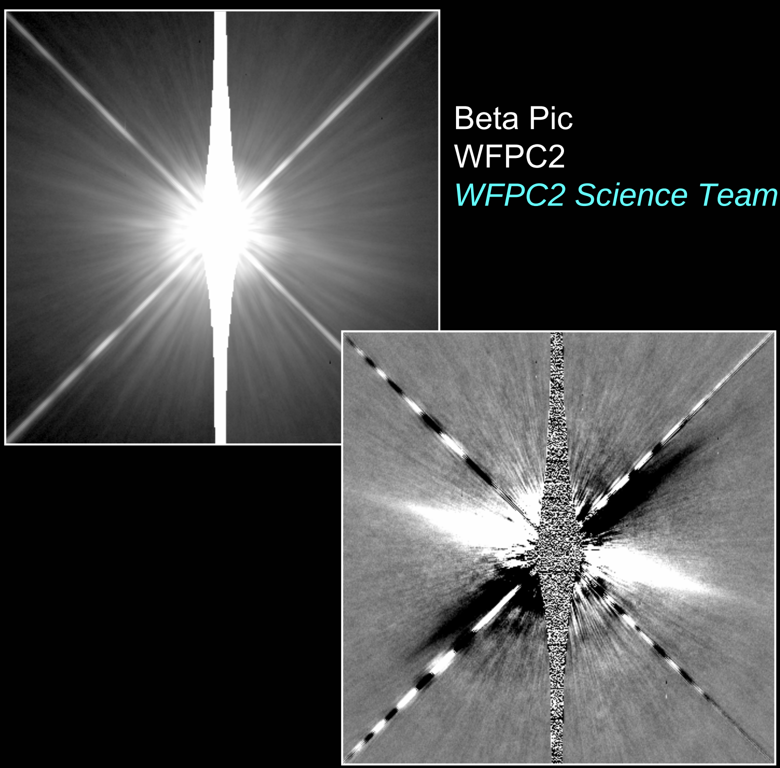
The stability of HST allows diffracted and scattered light to be subtracted

Reference PSF Subtraction



ACS coronagraph
Golimowski et al. (2006)

Roll Subtraction

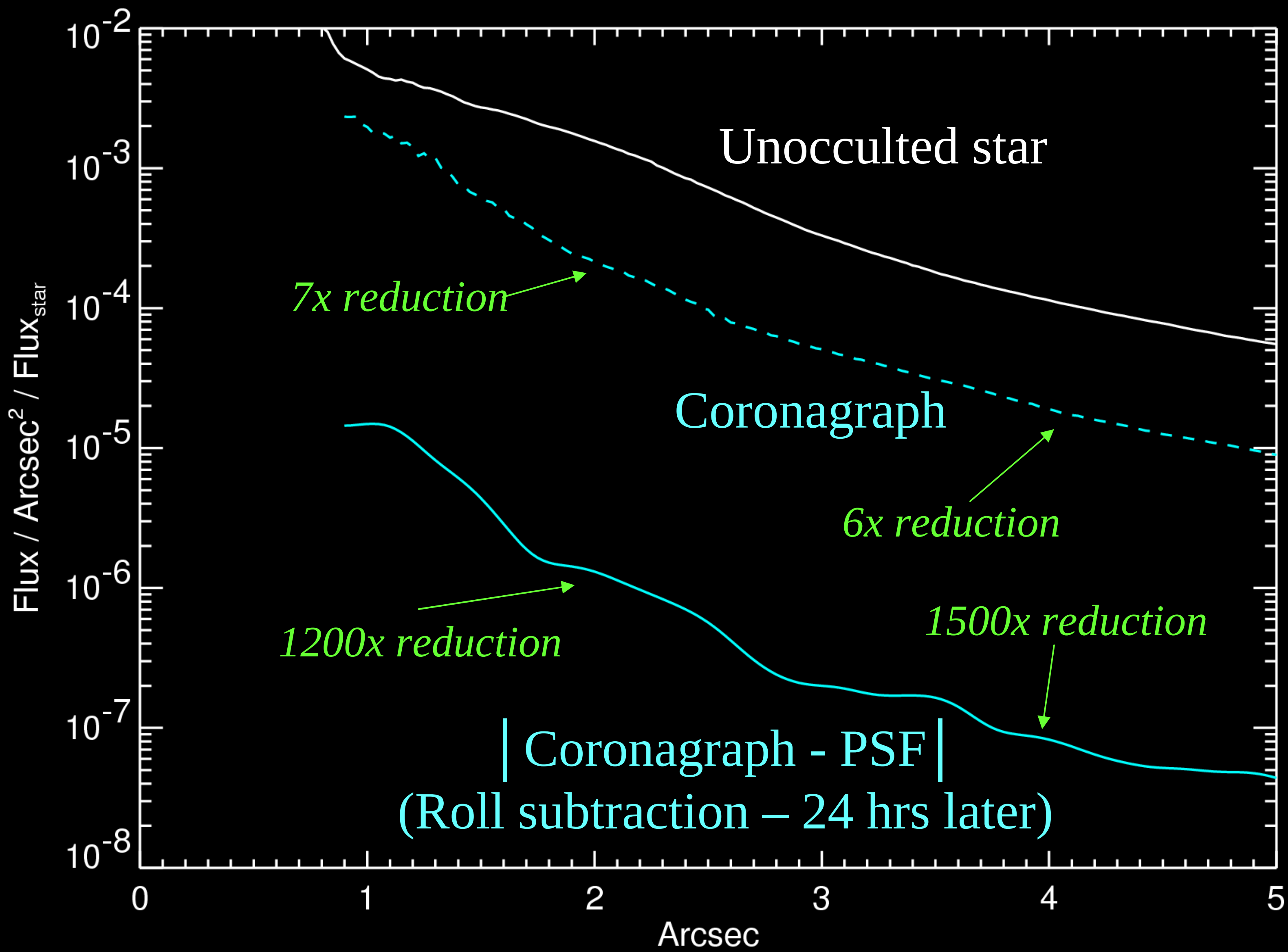


Beta Pic
WFPC2
WFPC2 Science Team

HST Coronagraphs

Camera	Bandpass	Practical Inner Radius	Advantages & Disadvantages
NICMOS	0.9 – 2.5 μm	~0.5”	Filters & polarizers
			Still working
			Misaligned Lyot stop
STIS	0.2 – 1.0 μm	~0.5”	No filters
			Incomplete Lyot stop
			Dead
ACS	0.2 – 1.0 μm	~1”	Filters & polarizers
			Full Lyot stop
			Large occulters
			Dead

ACS PSF Mean Brightness Profiles (V)



Debris Disks Seen in Scattered Light

Name	Spec Type	Distance (pc)	Disk Seen in Scattered Light with
HD 141569A	A0	99	NICMOS, STIS, ACS, ~Ground (Palomar)
HR 4796	A0	67	NICMOS, STIS, Ground
HD 32297	A0	112	NICMOS, Ground
Fomalhaut	A3	8	ACS
Beta Pic	A5	19	Ground, WFPC2, NICMOS, STIS, ACS
HD 15115	F2	45	ACS, Ground
HD 181327	F5	51	ACS, NICMOS
HD 139664	F5	18	ACS
HD 10647	F9	17	ACS
HD 207129	G0	16	ACS
HD 107146	G2	29	ACS, NICMOS
HD 61005	G4	35	NICMOS (see Hines talk)
HD 202917	G5	46	ACS
HD 53143	K1	18	ACS
HD 92945	K1	22	ACS
AG Tri	K8	43	ACS (Ardila et al.)
AU Mic	M1	10	Ground, ACS, NICMOS

www.circumstellardisks.org

Catalog of Resolved Circumstellar Disks

Last updated: May 30 2007; maintained by Caer McCabe (JPL)

- What's new...
- Description of Catalog
- Contributing to the database
- Search the catalog

Total number of disks: 100 (Pre-Main Sequence disks: 85, Debris Disks: 15)

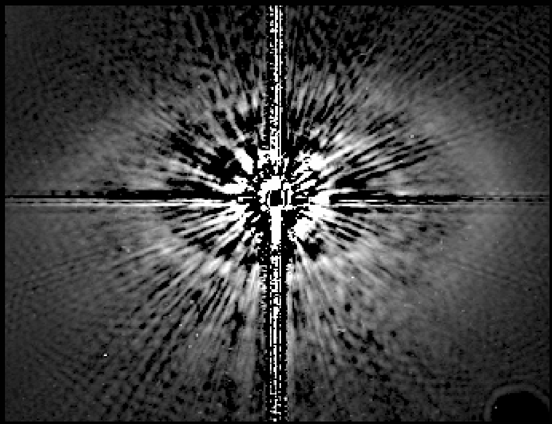
Object	SpTy	Category	Distance (pc)	R band (mag)	Disk Diameter (")	Disk Diameter (AU)	Inclination	How well Resolved	At ref. wavelength (micron)
2MASSI1628137-243139		TT	140	17.7	4.3	602	86	10.8	2.1
49 Cet	A1	Hae	61	5.6	0.8	48		3.9	10
AA Tau	M0	TT	140	11.8	1.34	187	75	1.0	2000
AB Aur	A0e	Hae	144	7.1	18	2592	21.5	367.4	0.57
AS 209	K5	TT	140	10.4	3.1	434	56	0.9	1300.39
ASR 41		TT	316		20	6320	80	97.0	2.2
AU Mic	M1	MS	9.94	8.9	29.25	290	90	567.2	0.6
BD +31 643	B5	Hae	330	8.7	40	13200	5	28.6	0.65
Beta Pic	A5	MS	19.28	3.9	26	501	90	504.2	0.6
BP Tau	K7	TT	140	11.1	1.5	210	30	1.5	1300.39
CB 26		YSO	140		5.5	770	88	42.4	2.2
CI Tau	K7	TT	140	12.3	2	280		0.7	2700
CoKu Tau 1	M0	TT	140	16.8	6.4	896		46.5	1.6
CQ Tau	F2	TT	100	8.9	2.9	290	33	2.5	20.5
CRBR 2422.8-3423		YSO	140		1.5	210	70	4.3	2.2
CY Tau	M1	TT	140	12.5	3.8	532	30	2.5	1300.39
DG Tau	K6	TT	140	11.4	0.61	85		0.8	2700
DG Tau B		TT	140		3.93	550	75	28.6	1.6
DL Tau	K7	TT	140	11.8	7.4	1036	35	5.7	1300.39
DM Tau	M1	TT	140	12.1	11.4	1596	32	0.0	1300.39

See poster by McCabe

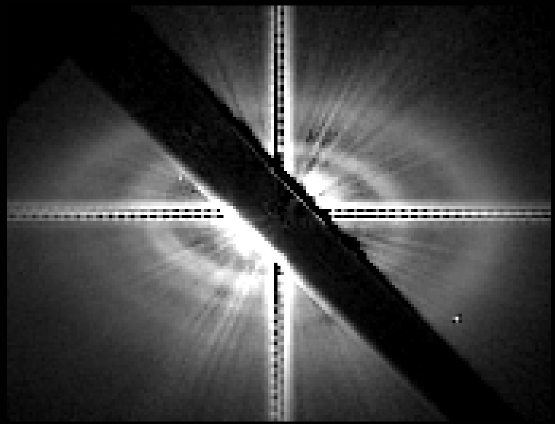
HD 141569a

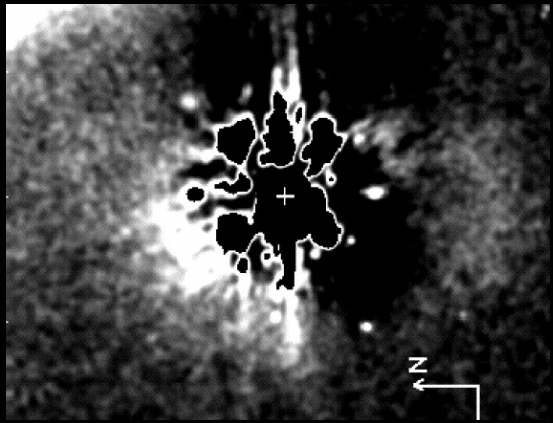
A0V (Herbig Ae), 99 pc, ~5 Myr, $L_d/L_*=8 \times 10^{-3}$

ACS Direct (V)



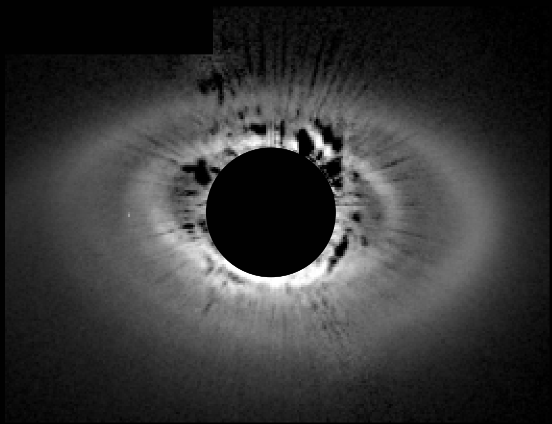
STIS Coronagraph (U→I)



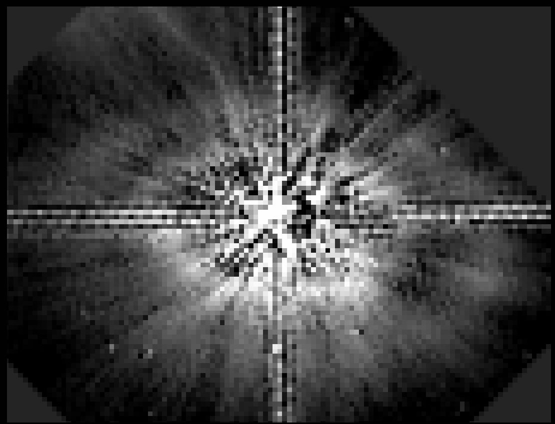


Palomar AO Coronagraph (2.2 μm)

Boccaletti et al. (2003)



ACS Coronagraph (V)



NICMOS Coronagraph (J)

HST subtractions by Krist.

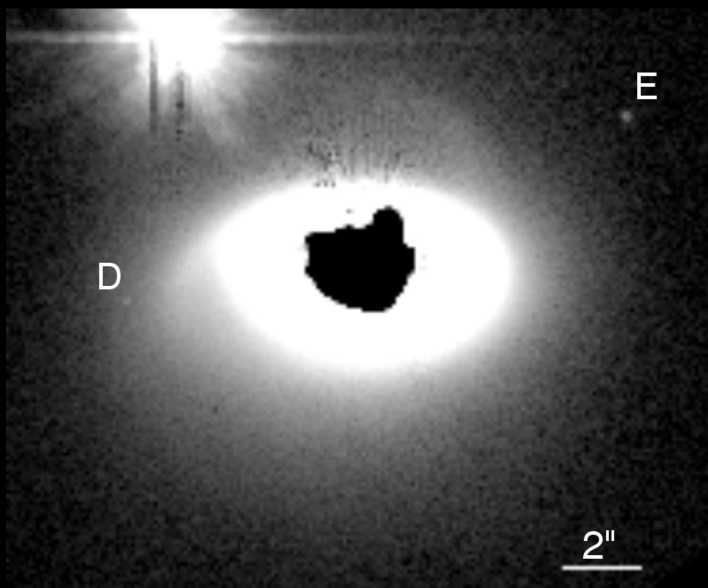
ACS results in Clampin et al. (2003)

NICMOS results in Weinberger et al. (1999), Augereau et al. (1999)

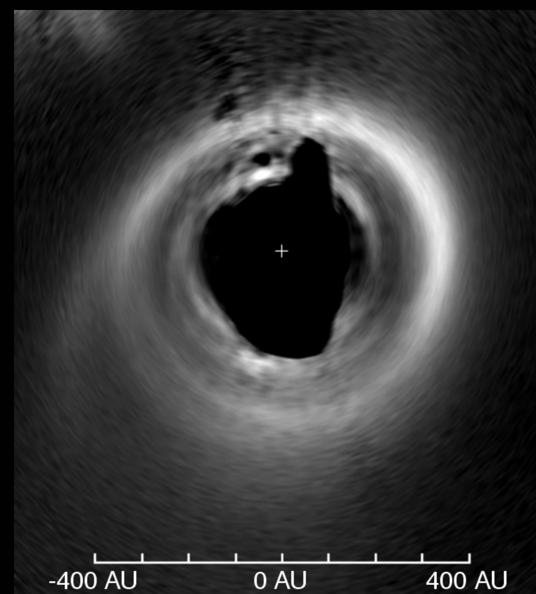
STIS results in Mouillet et al. (2001)

HD 141569a: ACS Observations

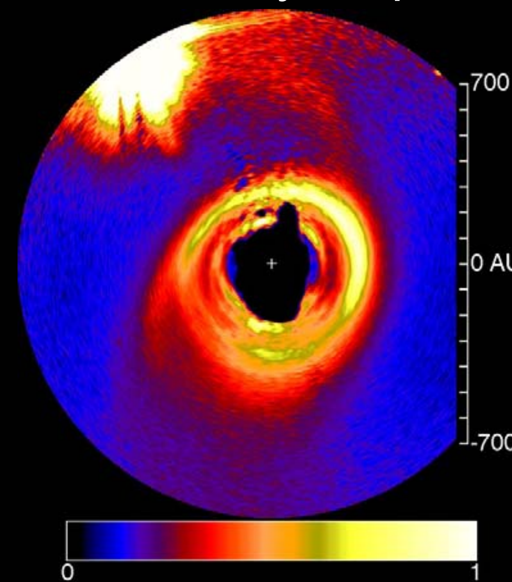
Hard stretch



Deprojected Density Map



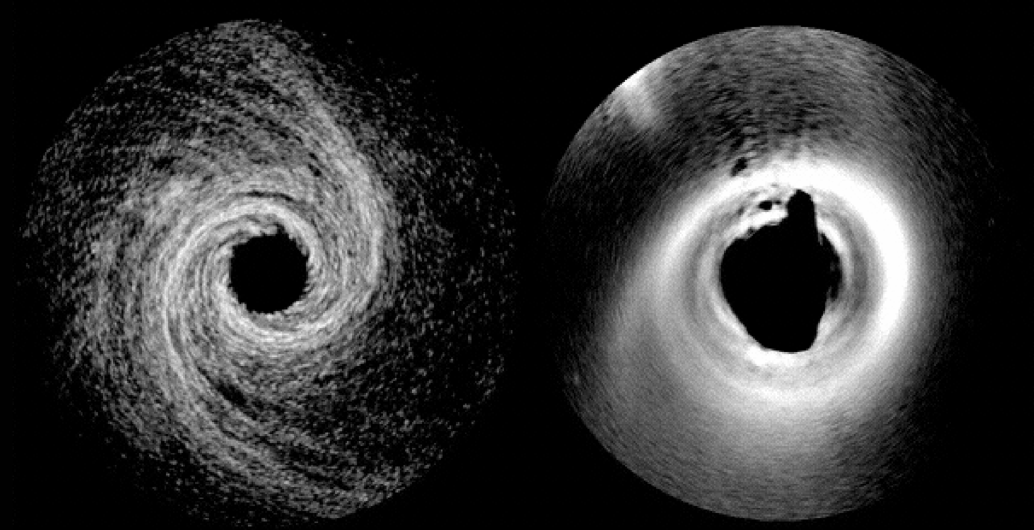
Deprojected Density Map



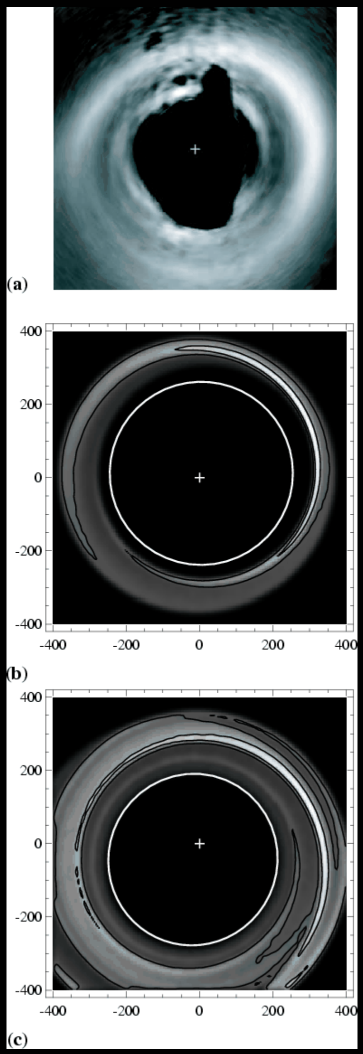
Disk is red relative to star.
g = ~0.2

ACS science results in Clampin et al. (2003)

HD 141569a: Dynamical Modeling



Ardila et al. (2005):
Recent fly-by of nearby binary created large spirals,
while a large planet created tight spirals & inner clearing;
gas drag needed to slow the blow-out of dust

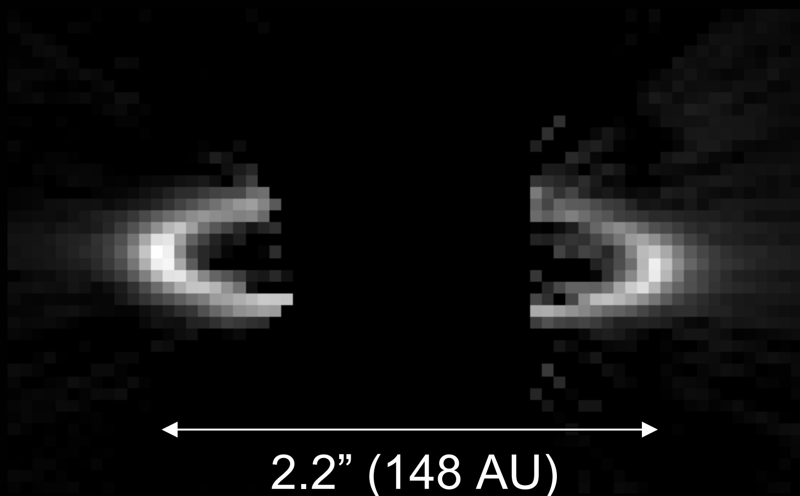


Wyatt (2005)

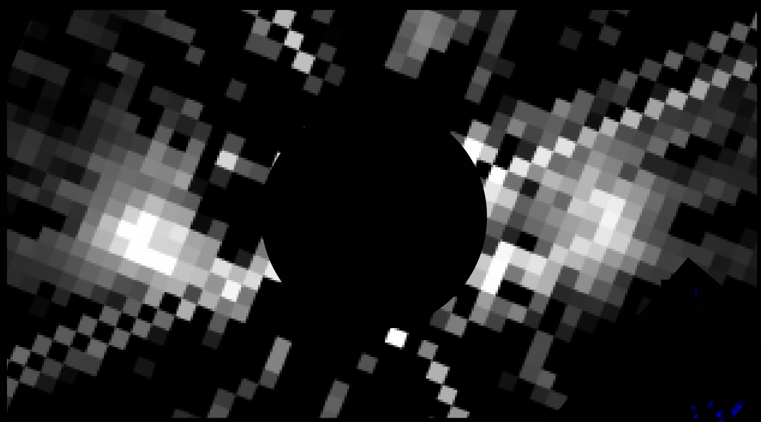
HR 4796

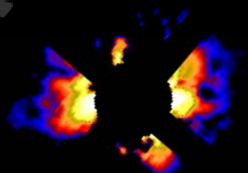
A0V, 67 pc, ~8 Myr, $L_d/L_* = 5 \times 10^{-3}$, with nearby M star

STIS (0.2 – 1 μm)



NICMOS (J band)





Ground K'
Augereau et al. (1999)

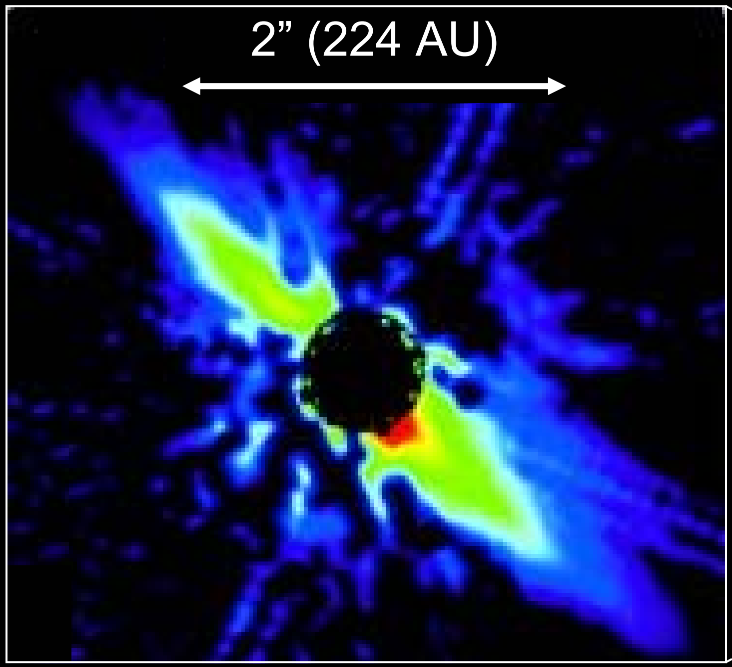
Disk is red relative to star.
Brightness asymmetries possibly due to influence of companion star.
Sharp inner edge.
May be nearly optically thick in radial direction.

Subtractions by Krist (no additional cleaning or smoothing).
NICMOS science results in *Schneider et al. (1999)*

HD 32297

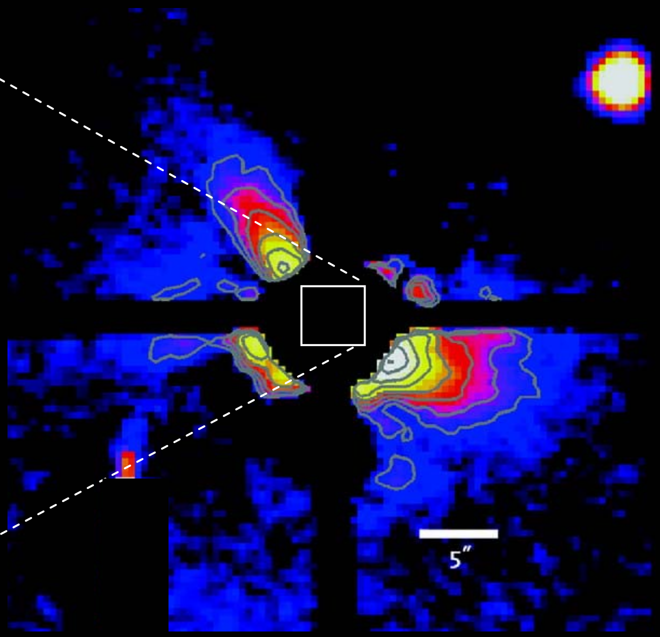
A0V, 112 pc, $L_d/L_* = 3 \times 10^{-3}$

NICMOS (J band)



Schneider et al. (2005)

Ground (R band)



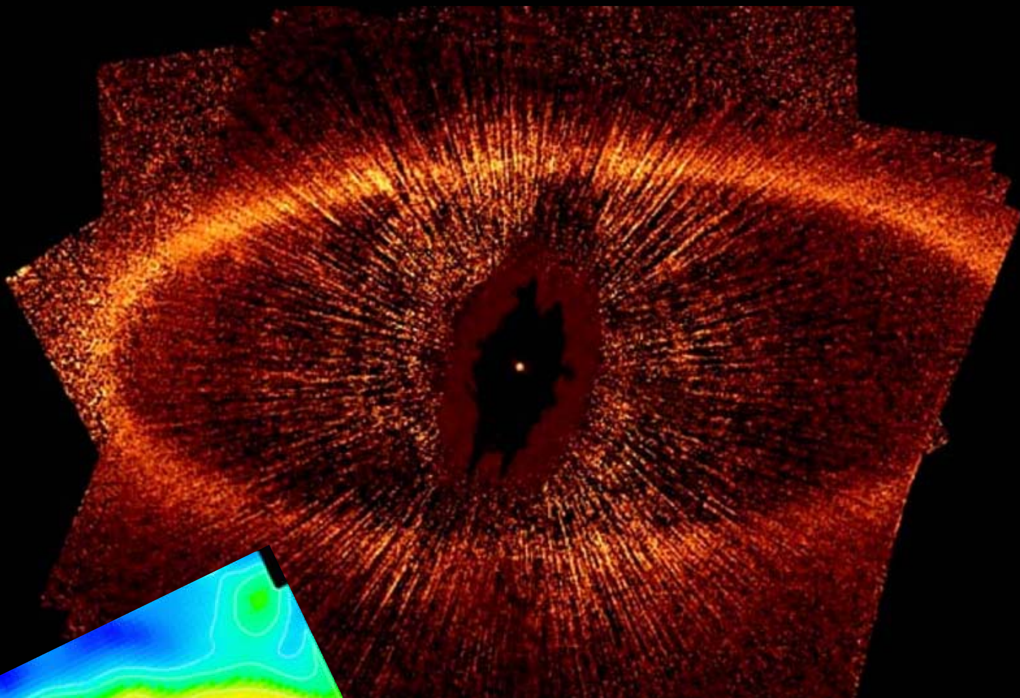
Kalas (2005)

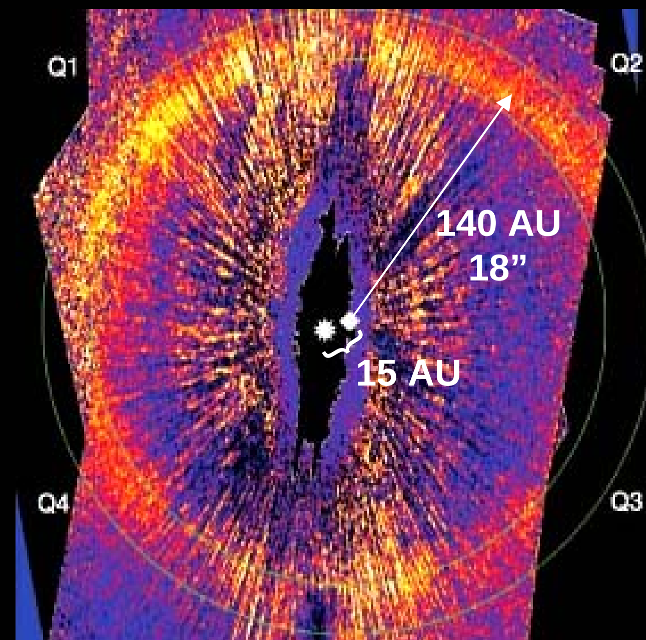
Inclination ~10 deg
Disk *might* be blue.
~0.004 of starlight scattered by disk.

Fomalhaut

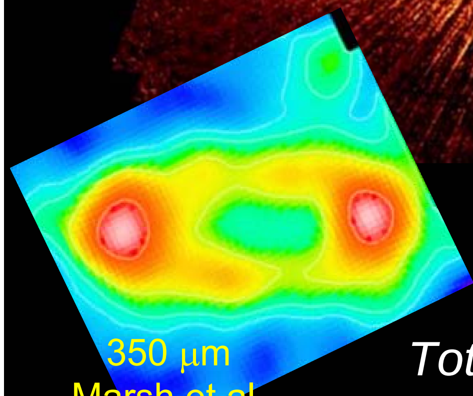
A3V, 8 pc, ~200 Myr, $L_d/L_* = 8 \times 10^{-5}$

ACS (Wide V band)





Deprojected



350 µm
Marsh et al.
(2005)

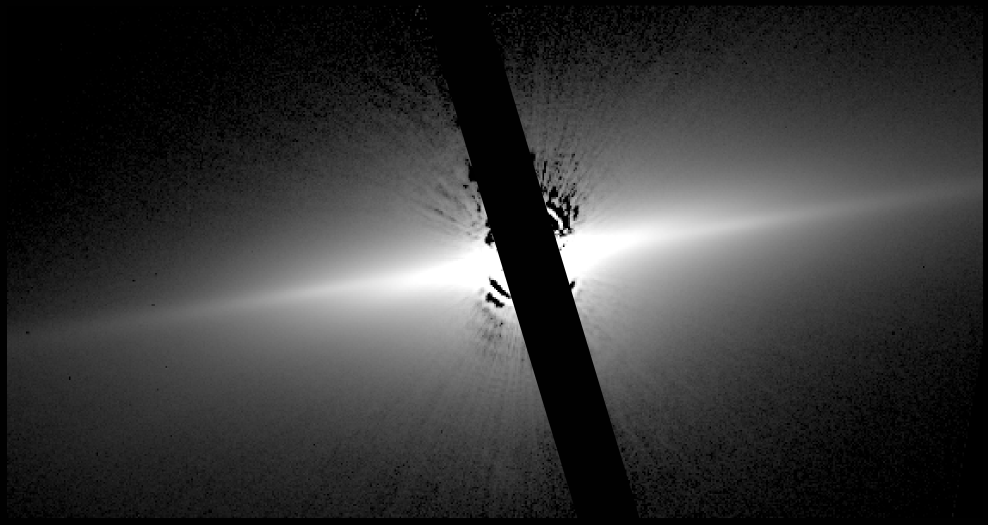
Kalas, Graham, & Clampin (2005)

Total light from disk is 10^{-6} *of the star’s.*
Mean surface brightness = 22 mag arcsec^{-2}.
Moderate forward scattering (g ~ 0.2)
Quillen (2006) suggests a Neptune-Saturn mass planet at r = 119 AU

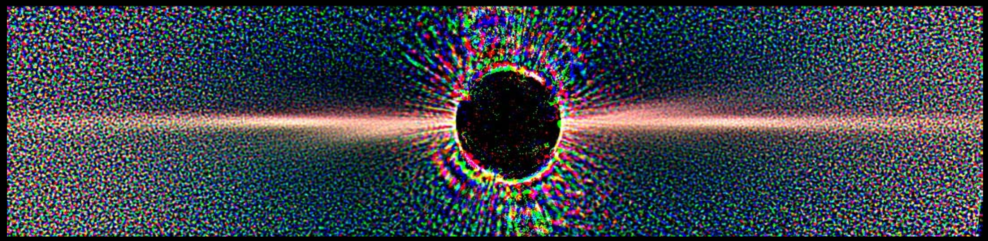
Beta Pic

A5V, 19 pc, 12-20 Myr, $L_d/L_* = 3 \times 10^{-3}$

ACS (Wide V band)



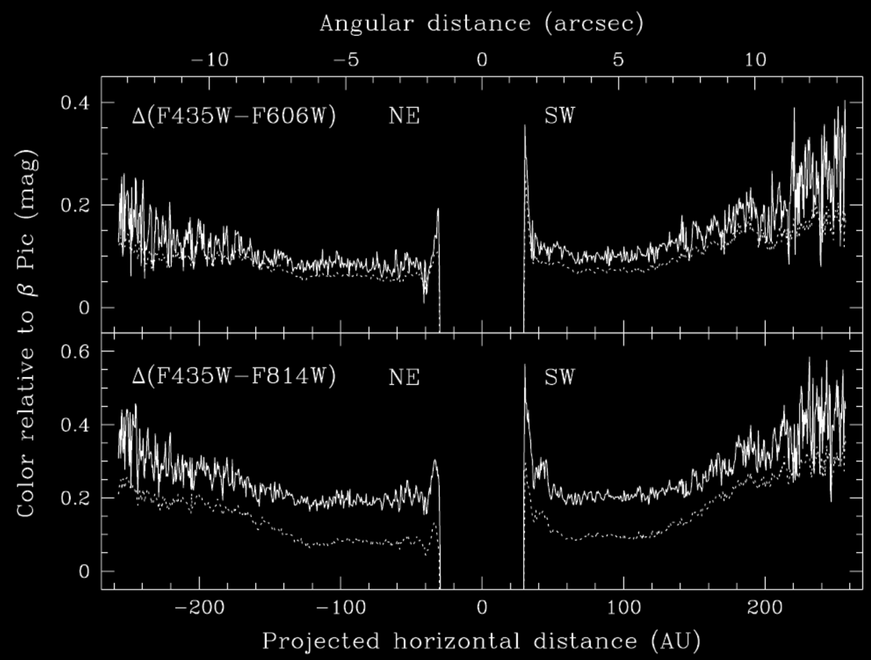
29” (550 AU)

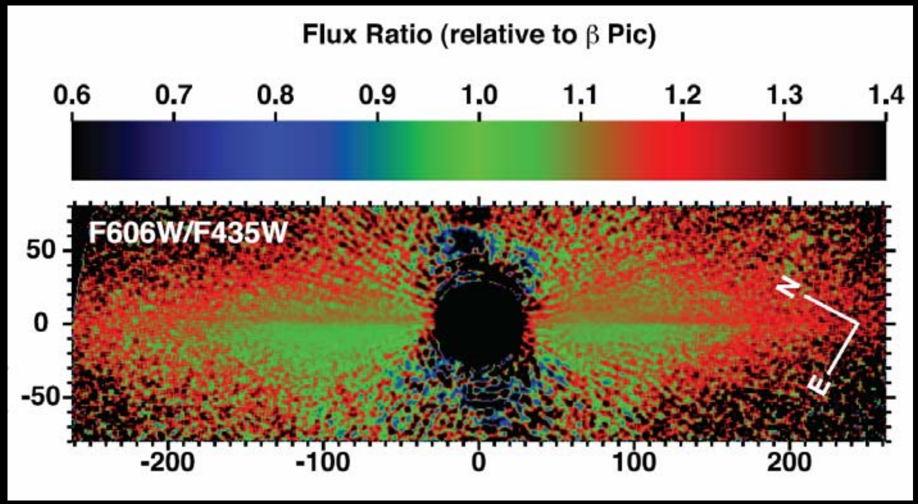


Deconvolved

Golimowski et al. (2006)

Beta Pic Colors





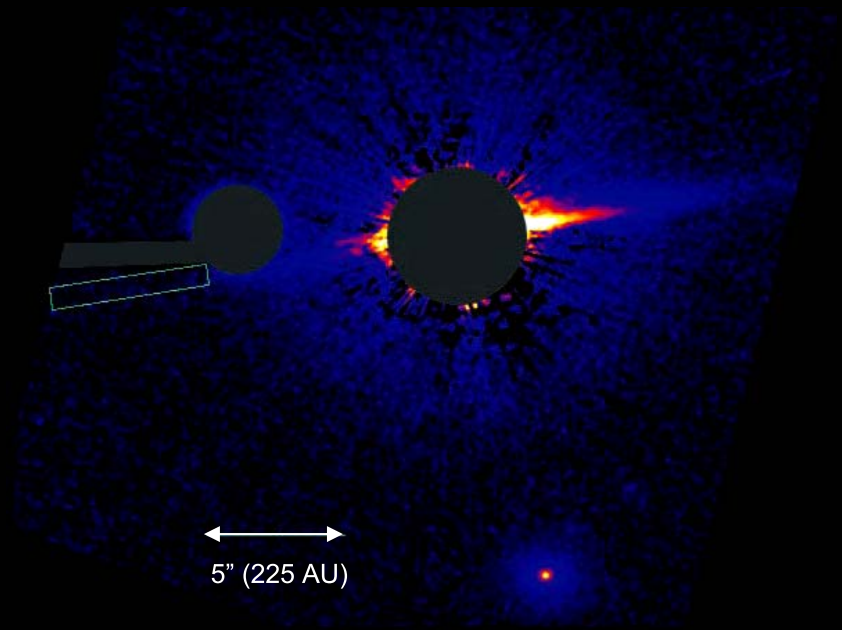
Right/Left & Top/Bottom disk color asymmetries.
Disk is red and gets redder with increasing radius.

Golimowski et al. (2006)

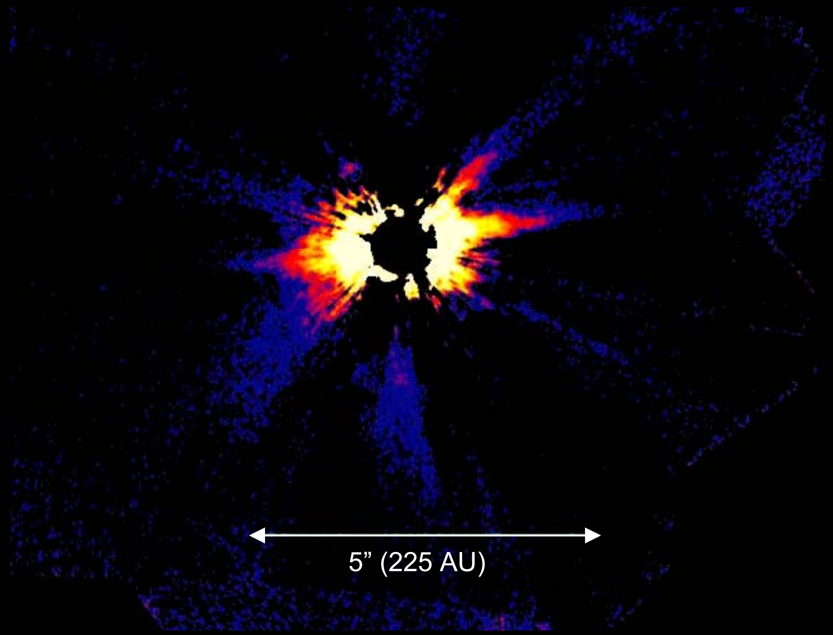
HD 15115

F2V, 45 pc, ~12 Myr?, $L_d/L_* = \sim 5 \times 10^{-4}$

ACS (Wide V band)



Keck (H band)



Kalas et al. (2007)

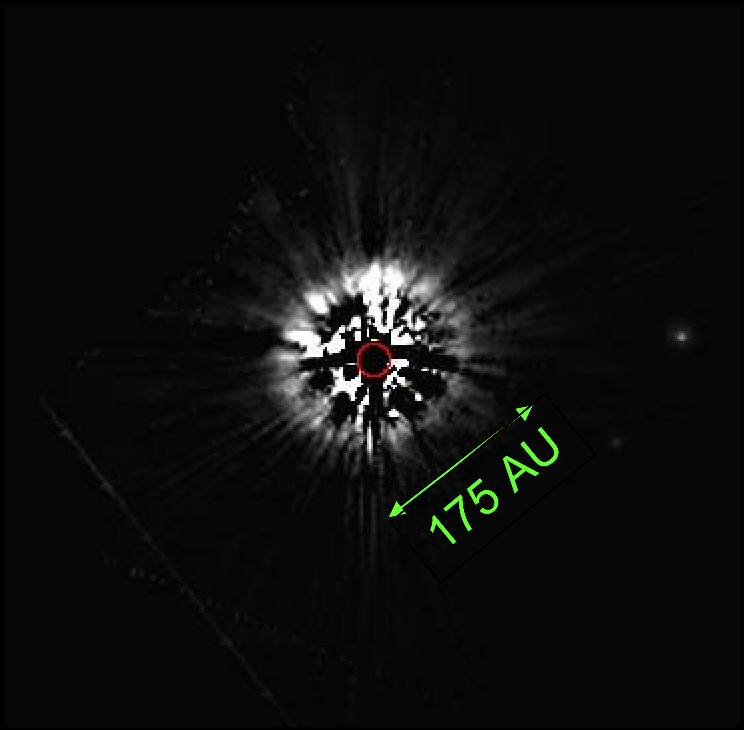
Possible fly-by candidate identified
Disk is blue relative to star based on V-H colors, and becomes more blue at larger radii

See poster by Kalas at this conference

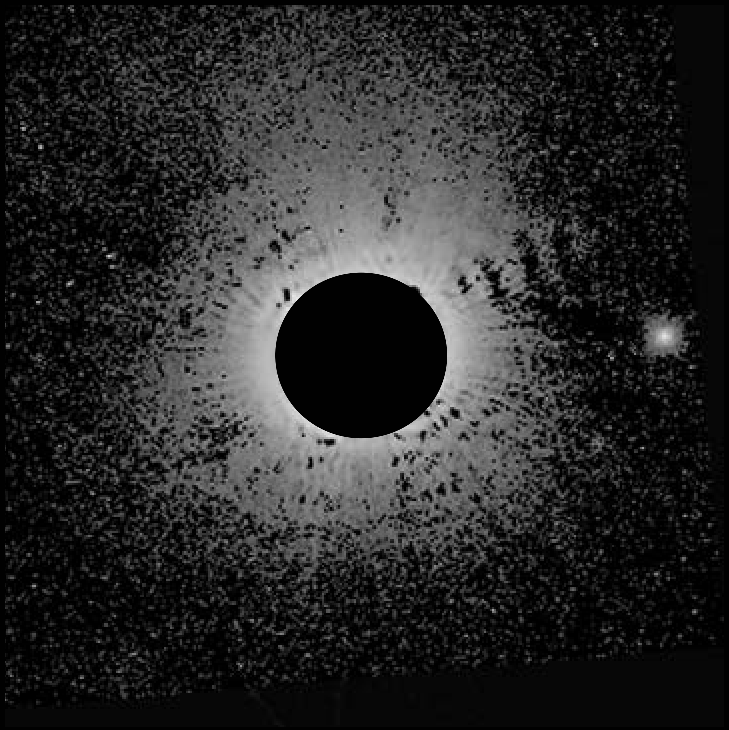
HD 181327

F5V, 51 pc, 12 Myr, $L_d/L_*=2 \times 10^{-3}$

NICMOS (J)



ACS (Wide V band)



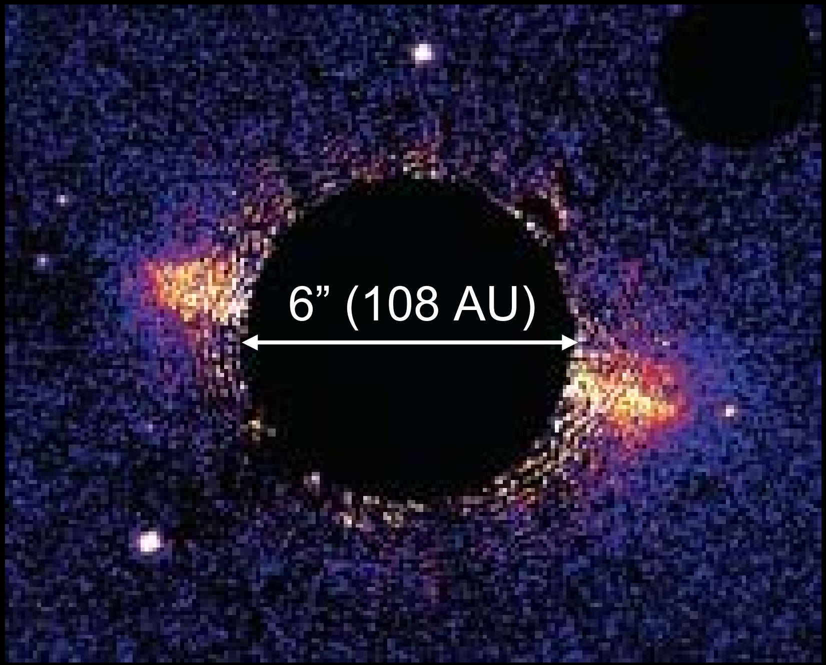
Disk is red.
g = 0.3

Schneider et al. (2006)

HD 139664

F5V, 18 pc, 100-1000 Myr, $L_d/L_*=1 \times 10^{-4}$

ACS (Wide V band)

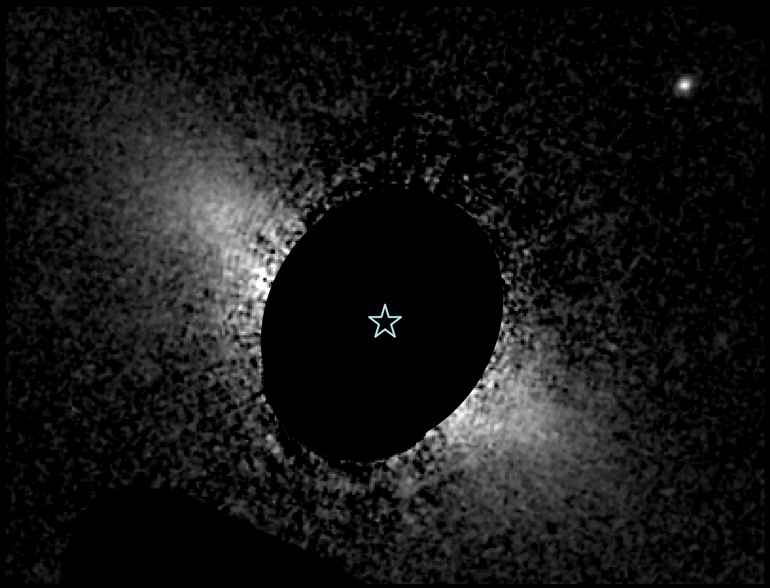


Kalas et al. (2006)

HD 10647(HR 506)

F9V, 17 pc, 0.3-7 Gyr, $L_d/L_*=3 \times 10^{-4}$

ACS (Wide V band)



350 AU (20”)

Has R-V planet: a = 2 AU, M*sin*i = 0.91 M_{Jup}

Stapelfeldt et al. (in prep)

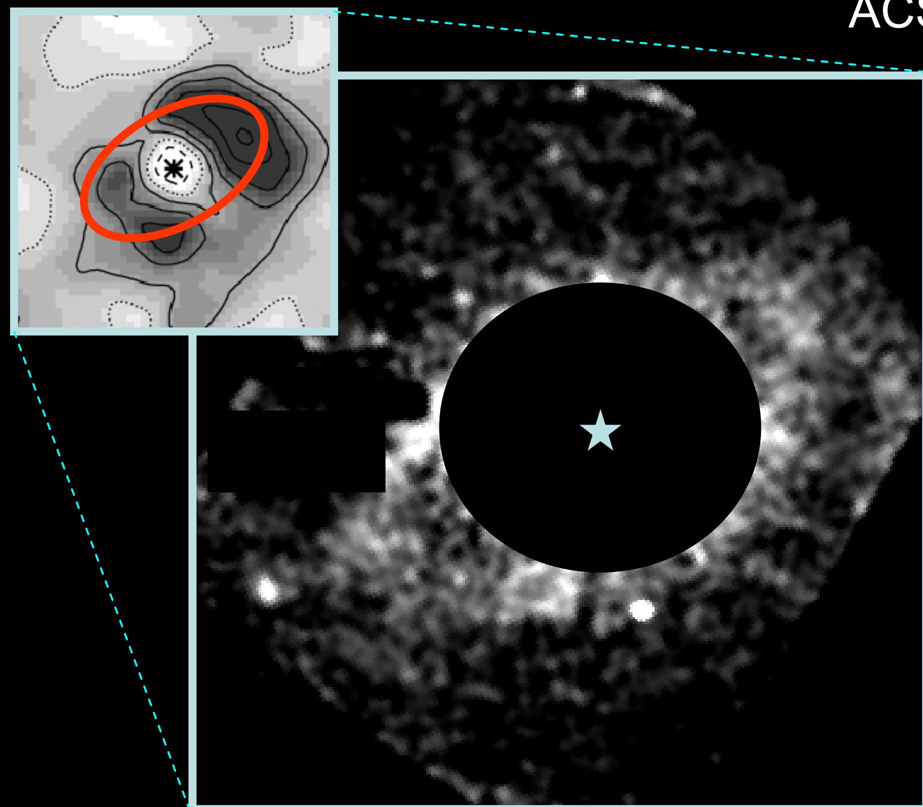
See poster by Stapelfeldt et al. at this conference.

HD 207129

G0V, 16 pc, ~6 Gyr, $L_d/L_*=1 \times 10^{-4}$

Spitzer 70 μm
Bryden et al. (2007)

ACS (Wide V band)



Smoothed,
4x4 Binned

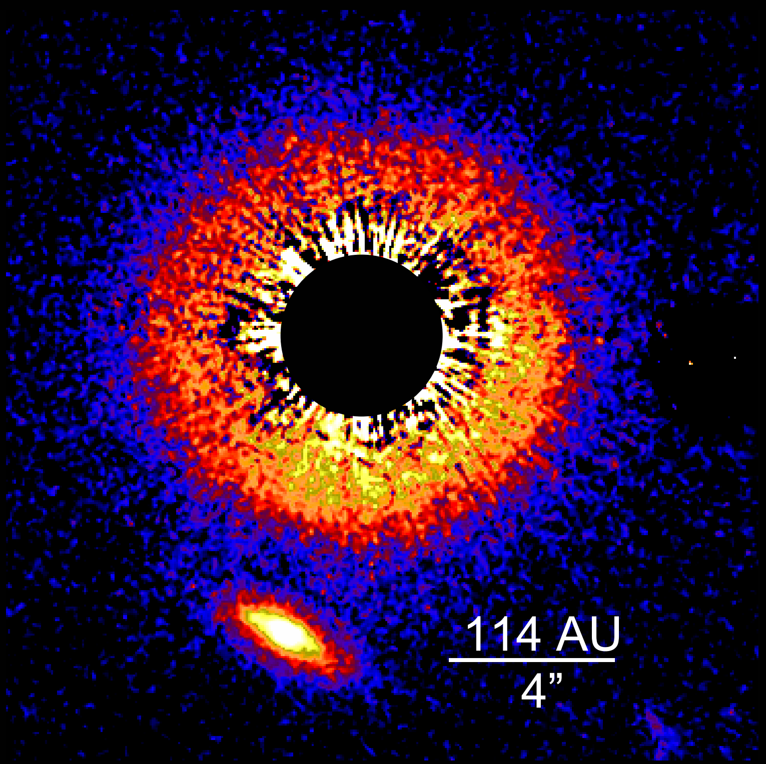
- *Seen only in roll subtractions*
- *Faintest disk yet seen*
  V = 24 mag / arcsec^2

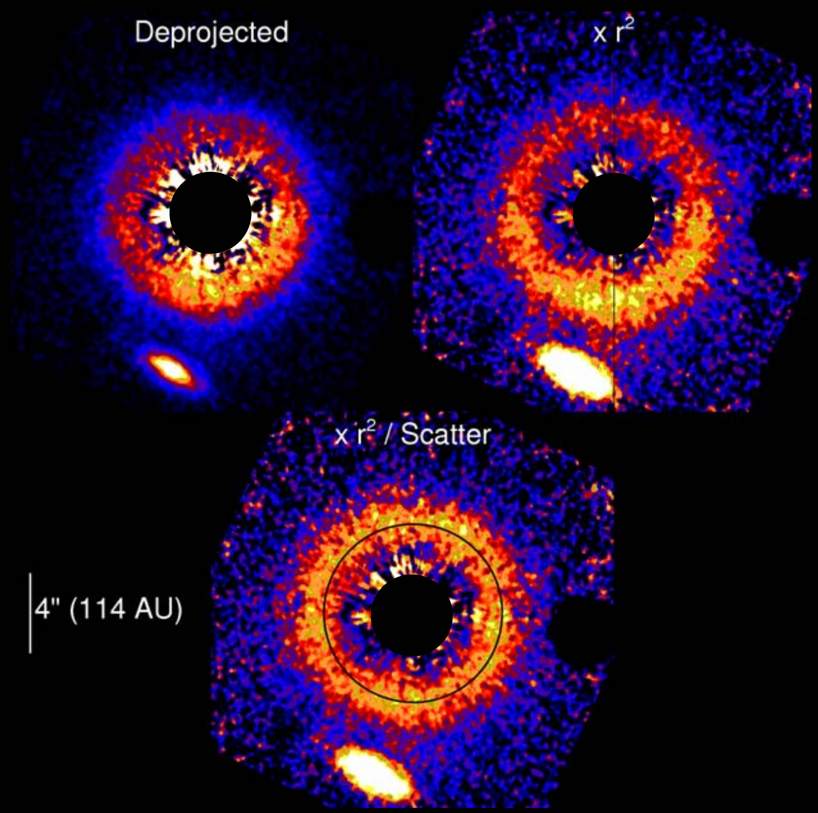
Krist et al. (2007)

HD 107146

G2V, 29 pc, 30-250 Myr, L_d/L_*=1 x 10^{-3}

ACS (Wide V band)





Ardila et al. (2004)

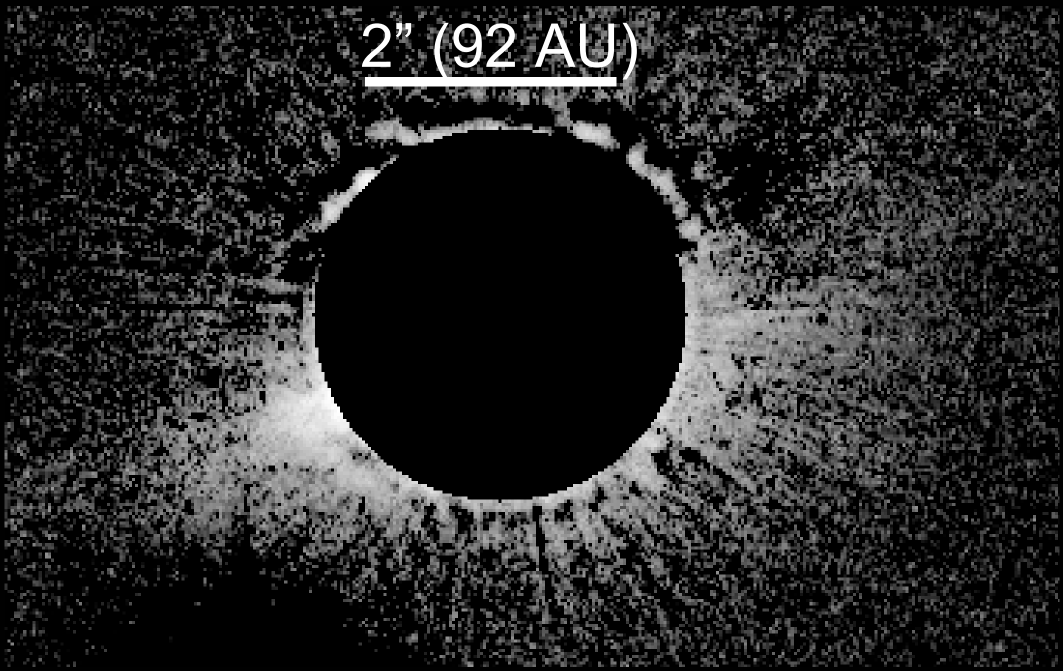
g = 0.2 – 0.3
Slightly red relative to star

See talk by Metchev on modeling of this disk.

HD 202917

G5V, 46 pc, 30 Myr, $L_d/L_*=3 \times 10^{-4}$

ACS (Wide V band)

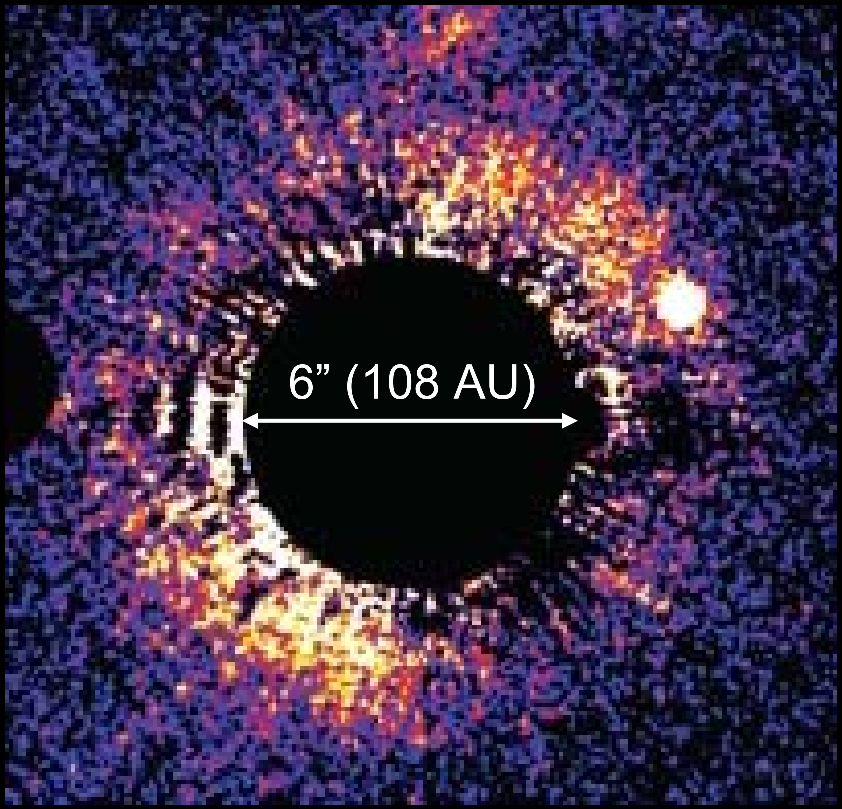


ACS Science Team

HD 53143

K1V, ~1 Gyr, 18 pc, $L_d/L_*=3 \times 10^{-4}$

ACS (Wide V band)

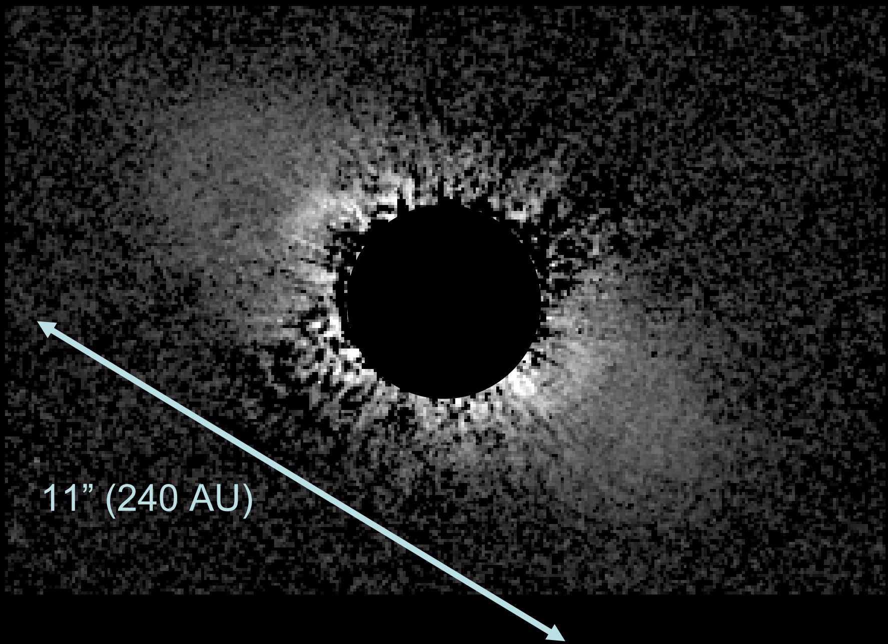


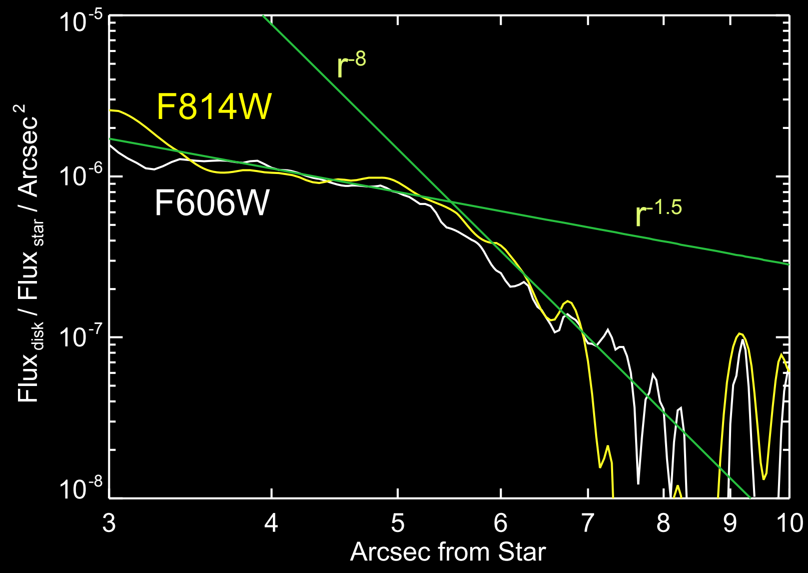
Kalas et al. (2006)

HD 92945

K1V, 22 pc, ~100 Myr, L_d/L_*=8 x 10^{-4}

ACS (Wide V band)





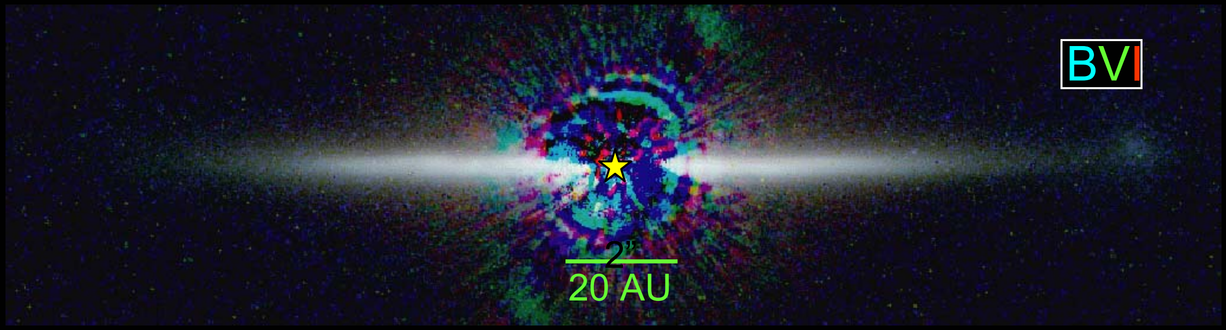
Golimowski et al. (in prep)

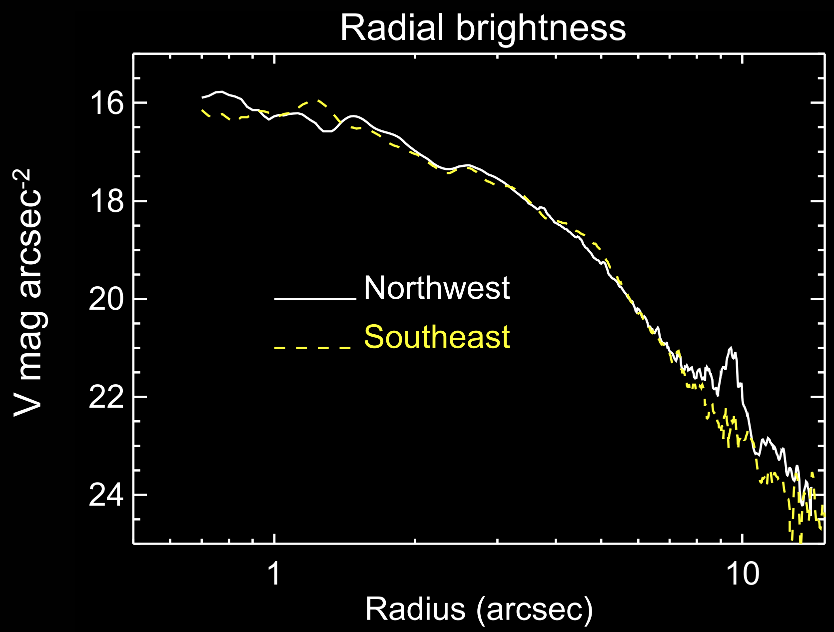
See poster by Golimowski et al. at this conference

AU Mic

M1V, 10 pc, 12 Myr, $L_d/L_*=4 \times 10^{-4}$

ACS (B,V,I)

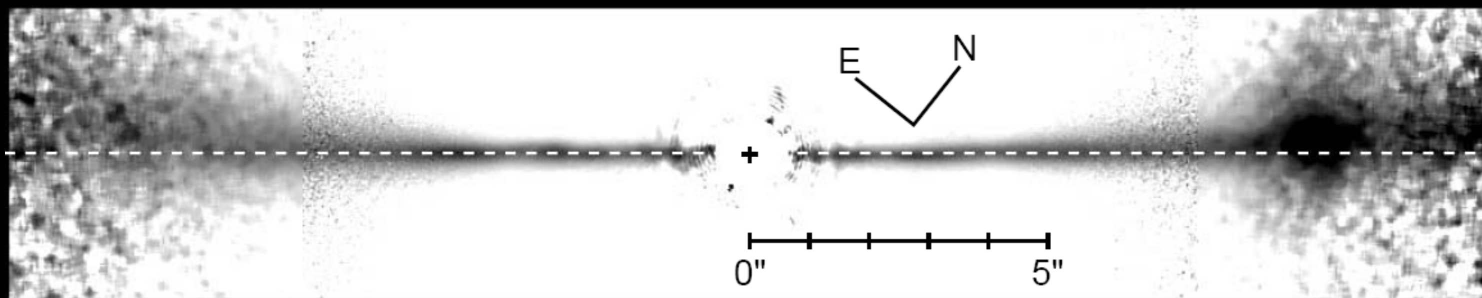


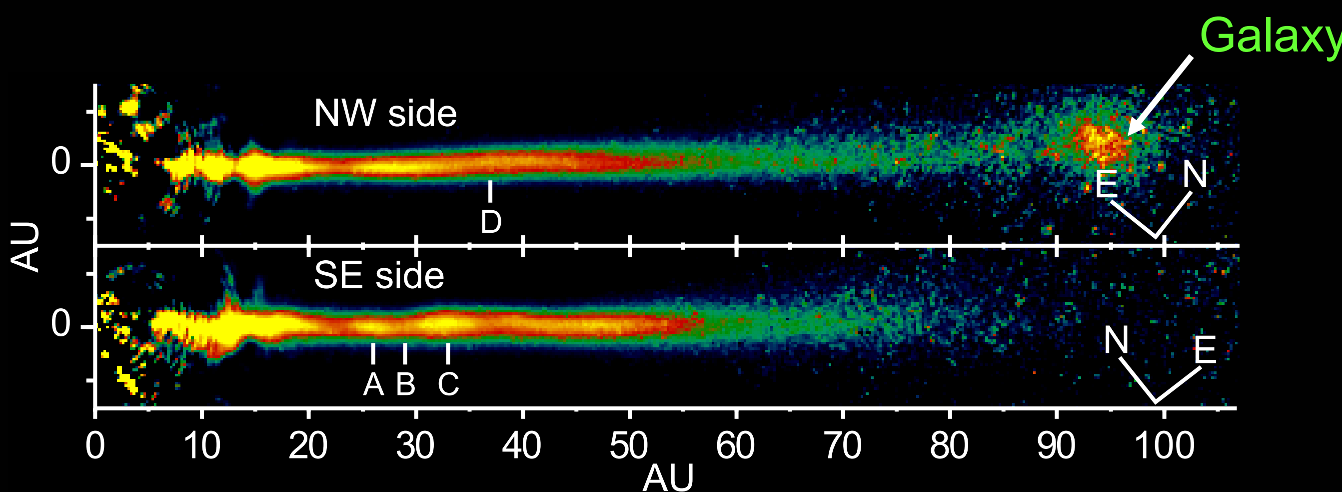


Krist et al. (2005)

AU Mic

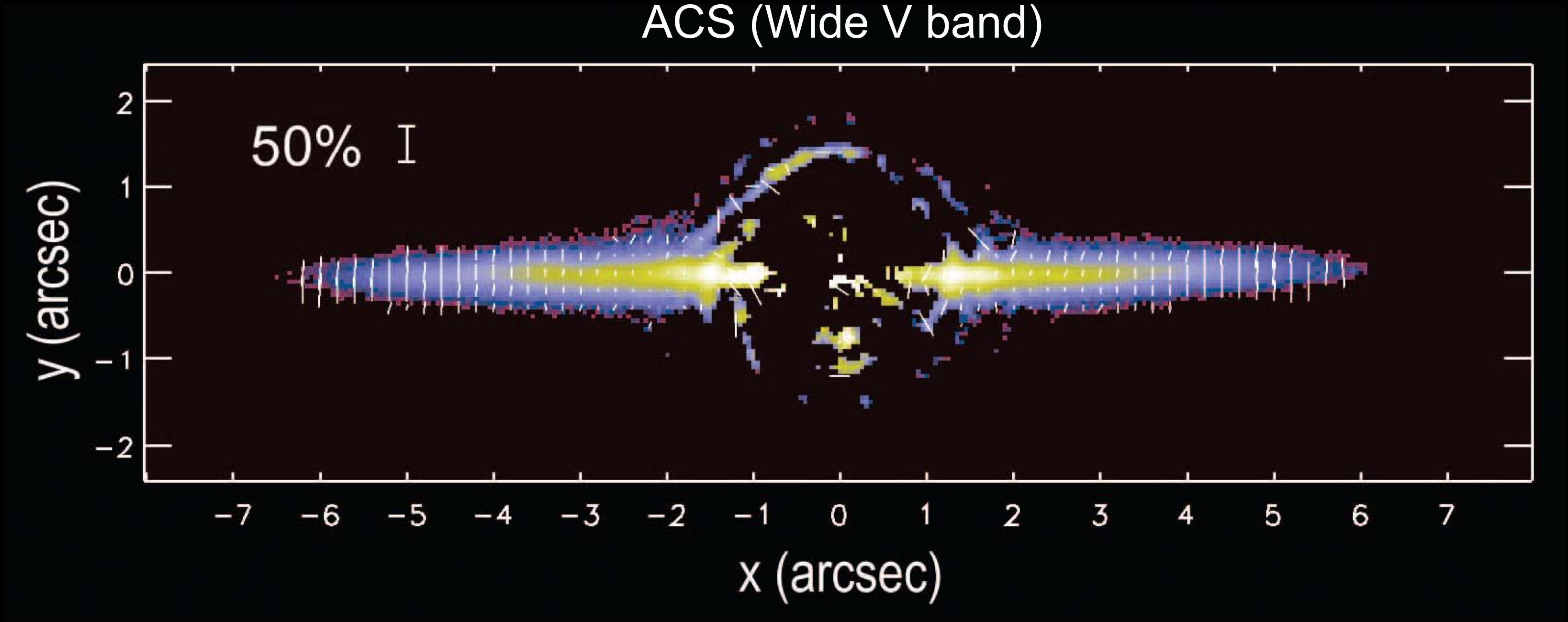
ACS (Wide V band)





Krist et al. (2005)

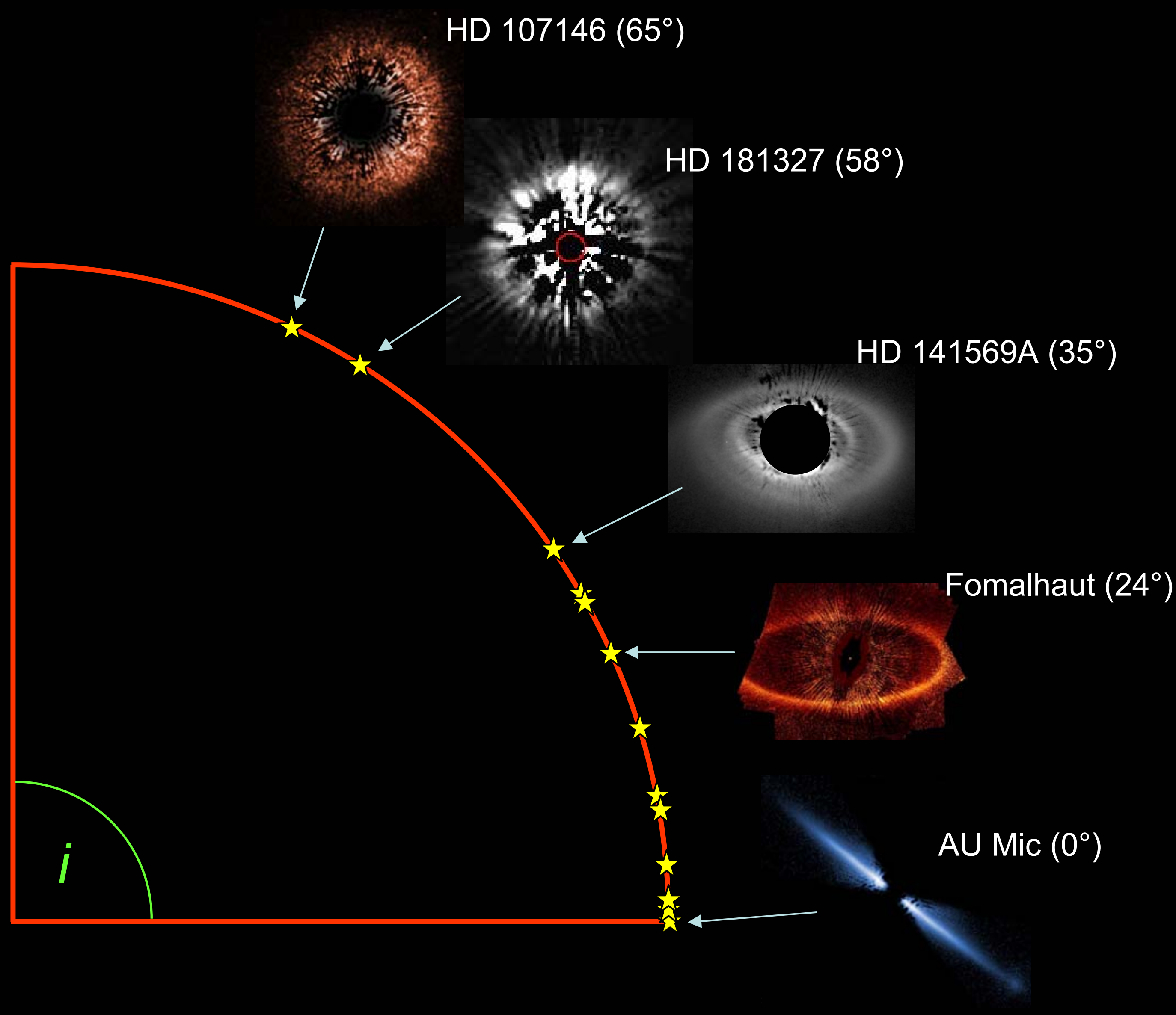
AU Mic Polarization



Graham, Kalas, & Matthews (2007)

- *ACS R band coronagraphic imaging polarimetry*
- *Peak polarization of 41% indicates single scattering by sub-micron size particles*
- *Consistent with highly porous, micron-sized dust aggregates*

Scattered-Light Debris Disk Inclinations

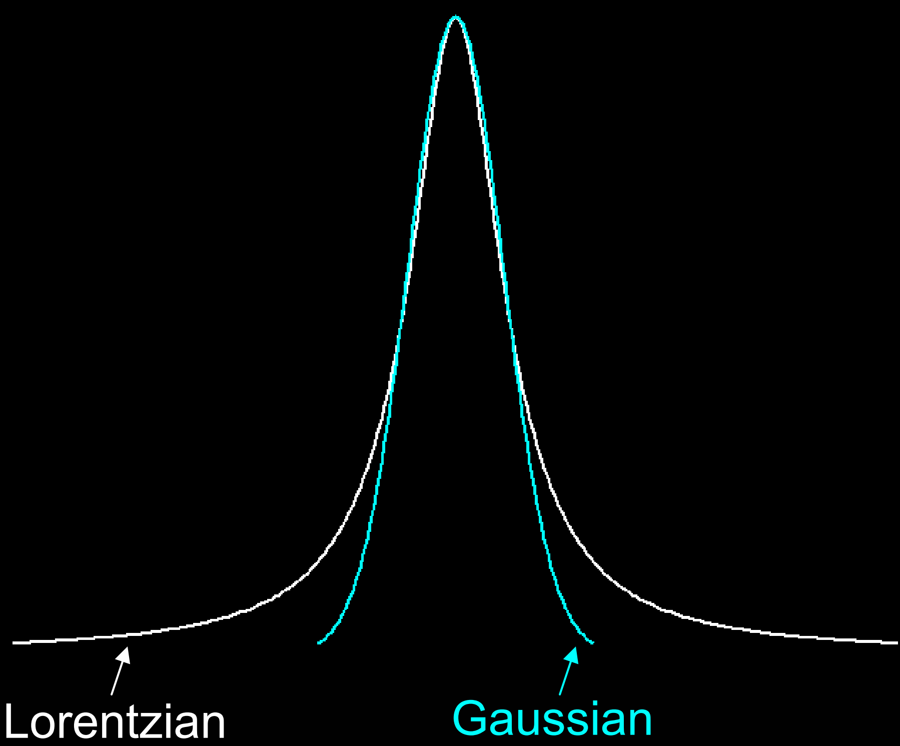


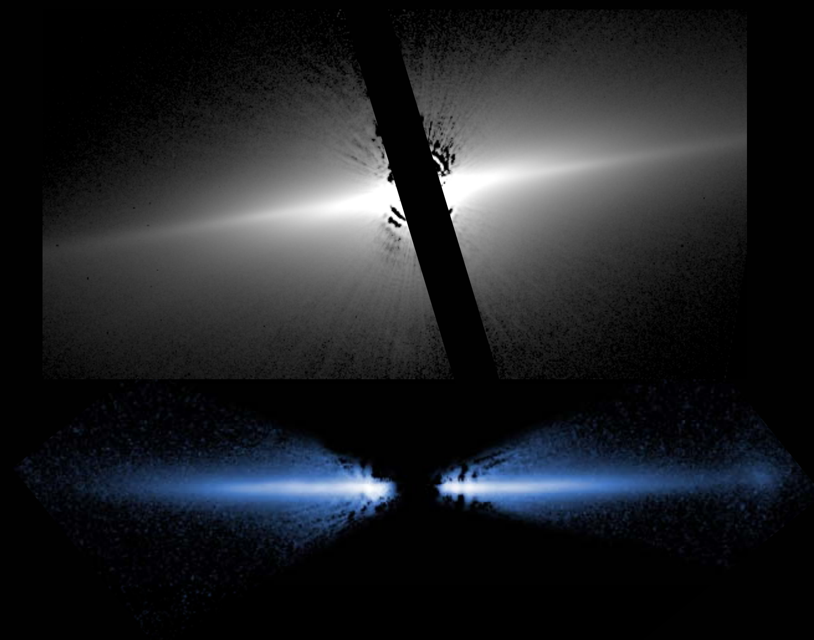
Disk Vertical Profiles

At r = 30 AU:

Beta Pic FWHM_{vert} = 12 AU

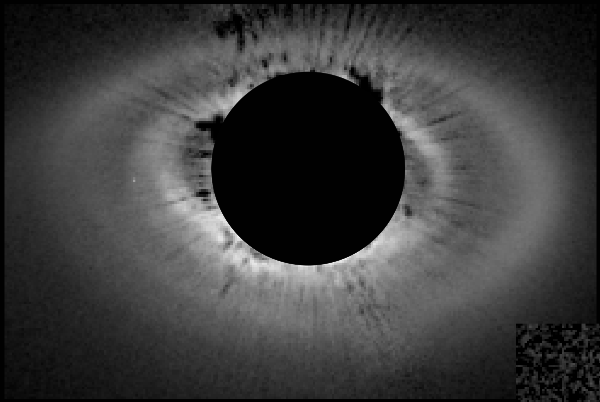
AU Mic FWHM_{vert} = 2 AU



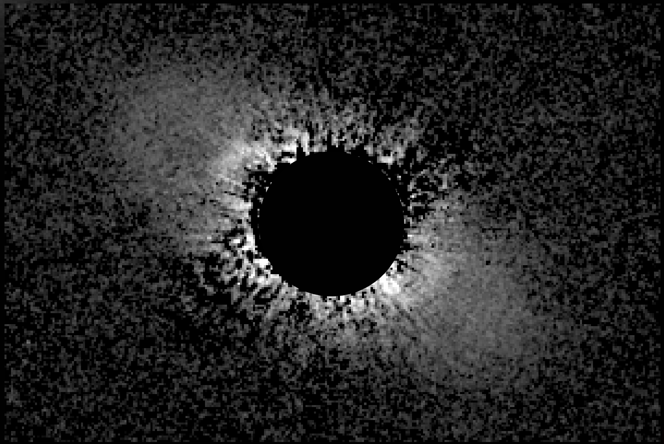


Beta Pic & AU Mic have Lorentzian vertical profiles.

Fractional Disk Luminosities (L_d/L_{star})



8×10^{-3}
HD 141569a

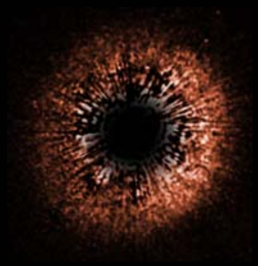


8×10^{-4}
HD 92945

~800x more than solar zodi → 8×10^{-5}
Fomalhaut

Known Colors of Debris Disks

Relative to Star



Red

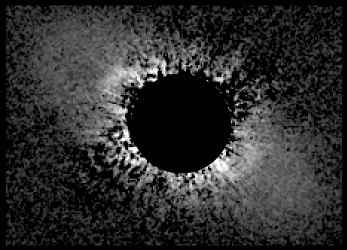
HD 141569A

HD 4796A

Beta Pic

HD 181327

HD 107146



Neutral

HD 92945

Blue

HD 32297 (?)

HD 15115

AU Mic

One disk color by itself doesn't mean a whole lot

See talk by Debes

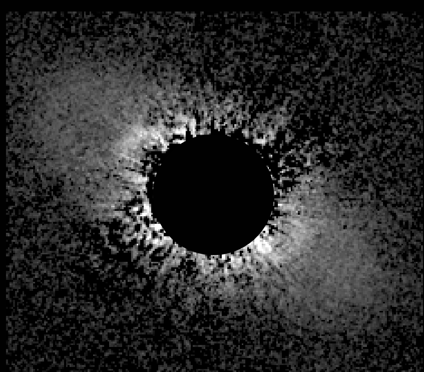
Degree of Forward Scattering

$g = 0$ Isotropic

$g = 1$ Full forward scattering

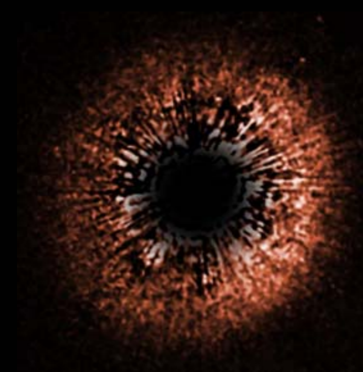
$g = -1$ Full backward scattering

g = 0



g = 0.2

g = 0.3

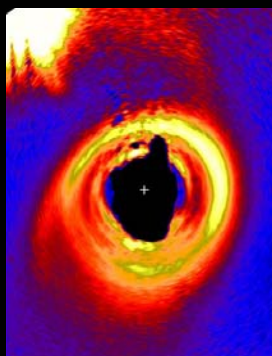


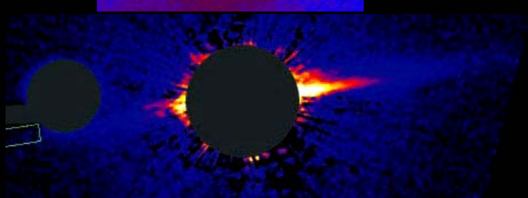
g = 0.4 (0.7?)

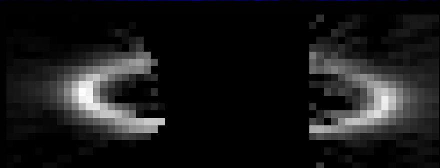
By itself, degree of forward scattering doesn’t say a whole lot

Signs of Stellar & Planetary Encounters?

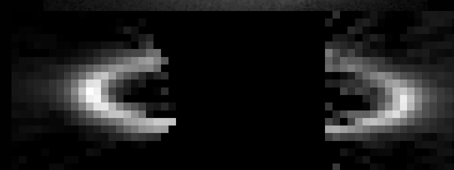
Stellar Encounters

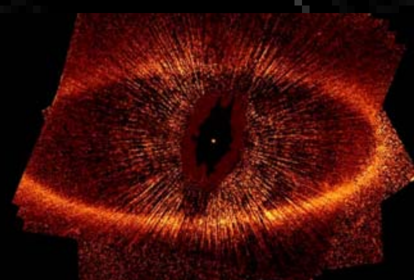




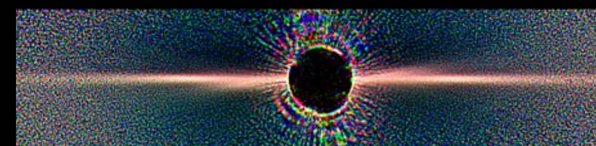


Clearings, Rings





Secondary disks, Warps



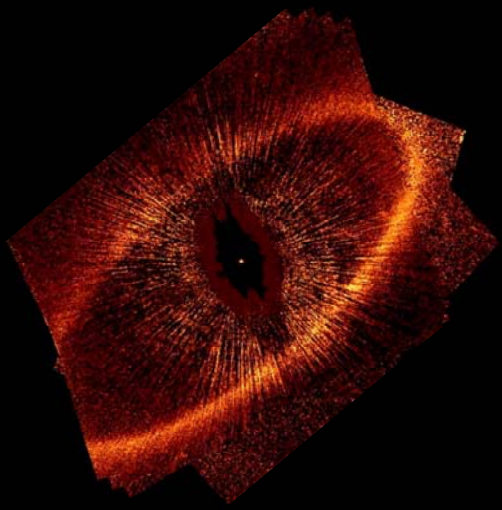
HST Rules! (for debris disks)

Of the debris disks that have been imaged in scattered light:

- ~70% have been reliably seen only with HST

- ~40% have been seen only with ACS

Non-detections for ~90 debris disk candidates (15% success rate)



The Future

- NICMOS is still operational
- Only a couple of debris disk programs in Cycle 16
- STIS might be repaired in next servicing mission, maybe ACS/WFC, but ACS/HRC (which contains the coronagraph) is uncertain
- No coronagraph on new WFC3 camera
- At the bottom-of-the-barrel for IRAS-derived candidates; Spitzer is providing new targets, especially for solar & later type stars
- JWST coronagraphs will probably have lower contrast than ACS or STIS ones