[10.13] An HST/NICMOS Coronagraphic Imaging Survey of Protoplanetary and Debris Disks Through the Epochs of Planet-Building

Glenn Schneider and the HST/GO 10177 Team

CONTACT: Glenn Schneider, Steward Observatory, 933 North Cherry Avenue, University of Arizona Tucson, Arizona 85721 USA, gschneider@as.arizona.edu, http://nicmosis.as.arizona.edu:8000, 520-621-5865 The GO/10177 TEAM: G. Schneider, K. Stapelfeldt, D. Padgett, C. Grady, M. Silverstone, D. Hines, A. Cotera, M. Clampin, D. Wilner, J. Krist, C-F McCabe, J. Kim, F. Menard, T. Henning, B. Stecklum, S. Wolf

Introduction: During HST Cycle 13 we conducted a highly sensitive 52-target NICMOS coronagraphic circumstellar disk imaging survey. Our survey provides: (a) critically needed high resolution scattered-light imagery of protoplanetary and debris disks to assist in discriminating between proposed evolutionary scenarios in the epochs of planet-building, (b) a legacy of cataloged disk morphologies for interpreting mid- and far-IR SEDs (e.g., Spitzer) and (c) reliable, spatially resolved, photometry and flux density limits for non-detections. Our high-contrast scattered-light imagery yields, directly, the spatial distribution of the grains for disks detected within the sensitivity limits of our survey and which cannot be uniquely inferred from (longer-wavelength) spectral energy distributions alone. Asymmetries (e.g., warps, gaps, arc, spirals, rings, axial anisotropies, etc.) in the spatial distributions of dusty debris in evolved disks provide evidence for unseen co-orbital planetary-mass companions through their dynamical interactions with the disk grains. Spatially resolved flux-density limits for non-detections provide constraints to break degeneracies in possible disk geometries and compositions which are otherwise coupled in SED models of thermally emissive disks. We provide an overview of our survey, highlighted with observational results from both our YSO and debris disk targets.

Young Stellar Object (YSO) Sample. A < 10 Myr sample of 26 optically-thick YSO disk candidates:18 T Tauri (d < 150 pc) stars of spectral types G-M, with mm continuum excesses and/or intrinsically high optical polarizations; 8 A-F (d < 200 pc), including 4 Herbig AeBe stars with thermal IR and/or mm emission well above their photospheric levels. Several of these YSO disks were previously detected with HST in the optical: (WFPC-2: GO Tau, DoAr 25, Sz 82, Haro 6-33; STIS: AA Tau, DM Tau, DL Tau), with possible detections about three others (CW Tau, CY Tau, RNO 91) and two (LK Ca 15 and HD 169142) with ground based simultaneous dual-beam polarimetry in the near-IR.

Targets highlighted in green are discussed in this or neighboring posters (10.12, 10.14)

STAR	H	d pc	Sp	Target Selection Comments
AA TAU	8.5	~140	M0	CO Detection rmax = 2.2", STIS Detection with jet
BP TAU	8.2	53	K5	CO rmax 0.8" [SDG00], Undetected: WFPC2
CI TAU	8.4	~140	G	CO rmax 1.5", Undetected: WFPC2 & STIS
CQ TAU	7.1	100	F2	CO & mm emission r<0.6" [MS00], Undetected: STIS
CW TAU	8.2	~140	K5	CO rmax 1.6", Disk Undetected: WFPC2 & STIS, jet maged with STIS
CY TAU	9.0	~140	M2	CO disk rmax 1.9" [SDG00], STIS HH knots
DL TAU	*8.7*	*~140*	*G*	*CO disk rmax 3.7" [SDG00], STIS & WFPC2 see jet*
DM TAU	*9.8*	*~140*	*K5*	*CO disk rmax 5.7" [SDG00], STIS: Ring-like disk r=2"*
DOAR 25	*8.4*	*~140*	*K7*	*Disk Detected: WFPC2 rmax = 1.1" & Ground Pol.*
DQ TAU	9.5	~140	M0	Spec. Binary. CO @ 1.5", Undetected WFPC-2
GO TAU	*9.8*	*~140*	*K5*	*WFPC-2 Scattered Light to rmax = 1.5", CO detection*
HARO-6 33 10.1		*~140*	*C*	*WFPC-2 Scattered Light Disk/Envenlope, GB Jet @ 3"*
HD 36112	6.6	204	A2	
HD 135344	8.6	~140	A0	
HD 142666	6.7	~140	A8	
HD 150193	6.2	151	A1	
HD 163296	7.2	122	A3	STIS & ACS: Scattered Light Disk rmax = 3.2" [GR00]
HD 169142	*6.9*	*~140*	*A7*	*See poster 10.14 (AAS.1014)*
HD 179218	6.6	240	B9	
LKCA 15	8.6	~140	K5	CO disk rmax=4.0" [SDG00], Undetected: STIS & WFPC2, Ground-based dual-beam polarimetric detection
MWC 480	9.9	131	Be	CO disk rmax 3.9" [MKS97], Undetected: WFPC2 & STIS
RNO 91	*9.6*	*125*		*Star obscured @ 0.8_m, WFPC-2 nebulosity & dust lane*
RY TAU	6.1	136	F8	WFPC-2: Outflow cavity & Jet
SZ 82	*8.1*	*~140*	*M2*	*Disk Detected: WFPC2 rmax = 2"*
UZ TAU E	8.1	~140	M2	Spec Binary. CO disk [SDG00], Undetected: WFPC2
V1121 OPH	7.4	95	K5	CO Disk @ 2.1" [KS95], Undetected: WFPC2 & STIS

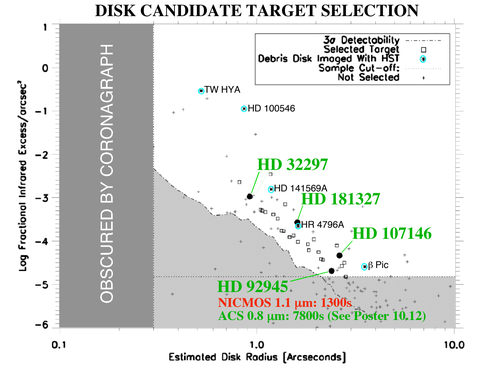
KS95: Koerner & Sargent 1995; GR00: Grady et al 2000; MS00: Mannings & Sargent 2000; SDG00: Simon, Dutrey & Guilloteau 2000; MKS97: Mannings, Koerner & Sargent 1997

Debris Disk Candidate Sample. A > 10 Myr sample of 26 optically thin dust-dominated debris disk candidates (d < 150 pc), A0–K2 main sequence stars, with IRAS far-IR excesses†, $L_{ir} / L_{*} > 3 \times 10^{-4}$, unconfused by background nebulosity at $b > 10°$. Our selection criteria were predicated, in part, by results from earlier NICMOS disk surveys, and were designed to maximize the likelihood of imaging spatially resolved circumstellar disks.

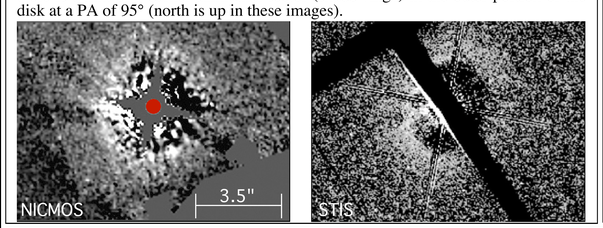
STAR	J	d pc	Sp	Lir/L*	
HD 15745	6.7	64	F0	1.8e-3	
HD 22128	6.9	142	A5	1.6e-3	
HD 30447	7.2	78	F3	5.4e-4	
HD 32297	*7.7*	*112*	*A0*	*2.8e-3*	*ApJ 639 L227*
HD 34739	8.4	122	F7	1.8e-3	
HD 35841	8.2	145	F3	9.7e-4	
HD 38207	7.7	130	F2	7.9e-4	
HD 39944	8.4	104	G1	1.5e-2	
HD 72390	8.1	111	F7	1.9e-3	
HD 83870	6.7	68	G5	5.4e-4	
HD 92945	*6.3*	*22*	*K1*	*3.7e-4*	*AAS 207.1012*
HD 95146	8.1	149	F3	1.7e-3	
HD 105781	8.9	109	G3	4.8e-3	
HD 107146	*5.9*	*29*	*G2*	*1.0e-3*	*ApJ 517 L174*
HD 124718	7.6	61	G5	1.0e-3	
HD 143840	7.0	99	F1	1.3e-3	
HD 164249	6.2	47	F5	7.6e-4	
HD 181327	*6.2*	*51*	*F5.5*	*2.2e-3*	*ApJ submitted*
HD 185053	7.6	51	F5.5	4.3e-3	
HD 204366	8.4	102	G0	1.8e-3	
HD 204942	7.3	81	F7	6.5e-4	
HD 211231	6.6	122	F0	6.1e-4	
HD 220750	7.0	148	A0	8.8e-4	
HD 221853	6.6	71	F0	3.8e-4	
SAO 84773	7.0	29	K2	1.0e-3	
SAO 93101	6.4	68	K0	7.4e-4	

Lir/L*: Excess luminosity ratio computed from IRAS 25 + 60 μm PSC or FSC Flux Densities

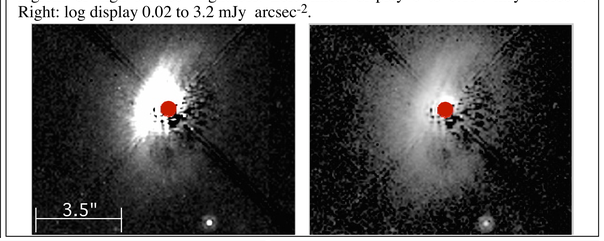
DISK CANDIDATE TARGET SELECTION



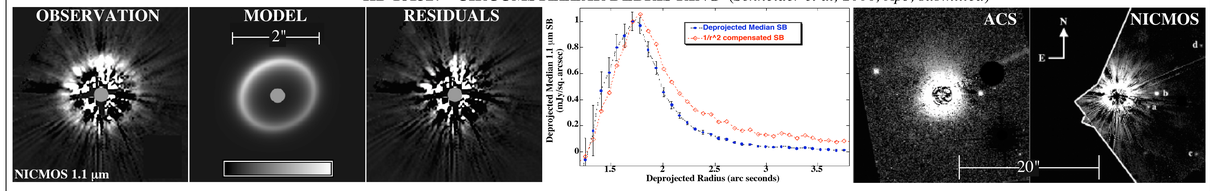
DM Tauri: A faint disk (peak surface brightness ~ 17 μJy arcsec^{-2}) seen around DM Tau (K5, H=9.8) at 1.6 μm with NICMOS (left) was also detected in the optical with STIS (right) as previously reported by Grady. The disk appears to be inclined appx 37° from the line-of-sight. The interior of the disk, to a distance of ~ 1.8" (240 AU), appears relatively dark (cleared?), though with a brightening toward east. A "bright" ring, at ~ 320 AU, is hemispherically asymmetric in surface brightness, and there is a hint of a darker azimuthal sector (shadowing?) in the outer portion of the disk at a PA of 95° (north is up in these images).



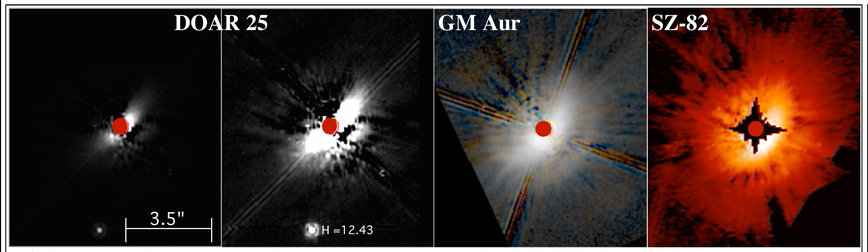
GO Tauri (K5V, H=9.8)**.** NICMOS PSF-subtracted cornonagraphy shows that the morphology of the GO Tau disk is similar to GM Tau, but slightly more inclined. The disk also exhibits a much stronger brightness asymmetry along the minor axis. The dark zone in the GO Tau disk extends to ~ 2.4" (290 AU). The disk semimajor axis is ~ 4.5" (540 AU). Striated structures (above the disk midplane) are seen the regions of high surface brightness. Left: linear display 0 to 0.134 mJy arcsec^{-2}. Right: log display 0.02 to 3.2 mJy arcsec^{-2}.



HD 181327 - CIRCUMSTELLAR DEBRIS RING (*Schneider et al, 2006, ApJ, submitted*)

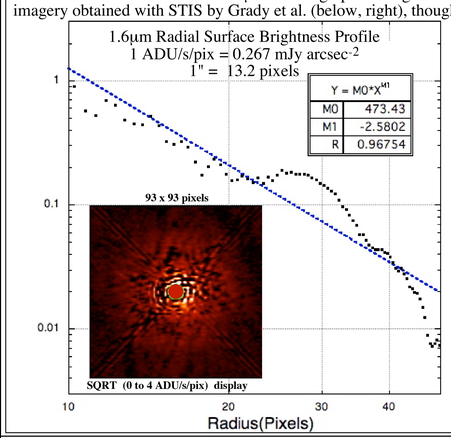


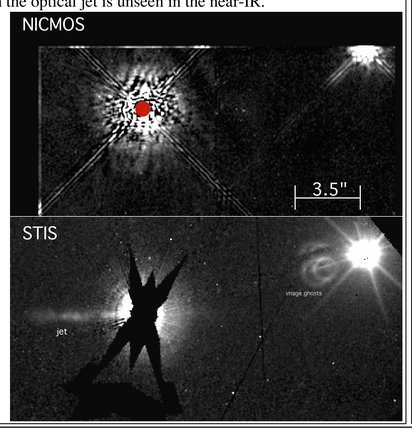
NICMOS PSF-subtracted coronagraphic observations of HD 181327, a member of the ~ 12 Myr β Pic moving group, reveal a ring-like disk of circumstellar debris seen in 1.1 μm light scattered by the disk grains, surrounded by a diffuse outer scattering region of low surface brightness (SB). The annular disk is inclined by 31.7° ± 1.6° from face on with the disk major axis PA at 152° ± 2°. The total 1.1 μm flux density of the light scattered by the disk (at 1.2" < r < 5") of 9.6 mJy ± 0.8 mJy is 0.17% ± 0.015% of the starlight. Seventy percent of the light from the scattering grains is confined in a 36 AU wide annulus centered on the peak of the radial SB profile 86.3 AU ± 3.9 AU from the star with an azimuthally medianed SB at that distance of 1.00 ± 0.07 mJy arcsec^{-2}. The ring is bilaterally symmetric, with strong directionally preferential scattering well represented by a Henyey-Greenstein scattering phase function with g = 0.30 ± 0.03. No photocentric offset is seen in the ring relative to the position of the central star. A low surface brightness diffuse halo is seen in the NICMOS image to a distance of ~ 4". Deeper 0.6 μm ACS PSF-subtracted coronagraphic observations reveal a faint (V ~ 21.5 mag arcsec^{-2}) outer nebulosity from 4" < r < 9", asymmetrically brighter to the North of the star. Modeling the disk we infer a maximum vertical scale height of 4-8 AU at the 87.6 AU radius of maximum surface density. The model also predicts a total maximum mass ~ 4 M_{Moon} of collisionally replenished grains with a minimum grain size of ~ 1 μm.

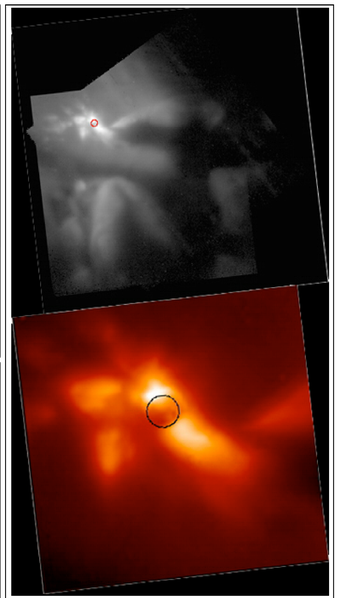


Left: The circumstellar disk about the T Tauri star and X-ray source DOAR 25 (K7V, H = 8.4; ROXR1 23) in the ρ Oph star forming region was imaged with NICMOS 1.6μm PSF-subtracted coronagraphy. The r = 2.7" DOAR 25 disk, (left: 0 to 5.3 mJy arcsec^{-2}; adjacent: 0 to 0.53 mJy arcsec^{-2}), is similar to the less-inclined GM Aur disk (middle right; NICMOS 1.1 and 1.6 μm two color image; Schneider et al 2003). The dark DOAR disk mid-plane, 0.7" from the star and the "lower" scattering surface of the disk are seen below and to the right of the star. Right: A strikingly similar morphology is seen in the disk of the weak-lined T-Tauri star SZ-82 (IM Lup) in the NICMOS 1.6μm PSF-subtracted coronagraphic image.

DL Tau (GV:e; H = 8.68) appears to have a nearly circularly symmetric scattered light disk at extending to r ~ 3.5" as seen in NICMOS PSF-subtracted 1.6 μm coronagraphic images. This morphology generally agrees with earlier corongraphic imagery obtained with STIS by Grady et al. (below, right), though the optical jet is unseen in the near-IR.

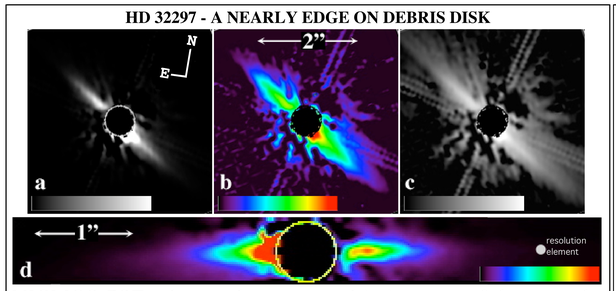






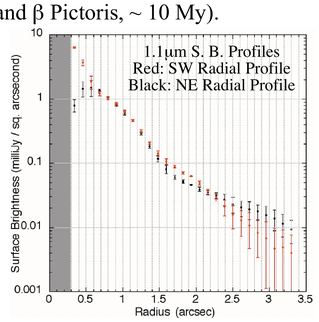
RNO 21 (IRAS 16316-1540; H = 9.6, d = 125 pc) is an embeded (and optically obscured) T-Tauri star in the Ophiuchus L43 cloud. The class II source (L ~ 2.7 L(sun), M ~ 0.5 M(sun)) and surrounding nebulosity, recently discussed by Lee & Ho 2005 (ApJ, 624, 841), is shown above in a NICMOS 1.6 μm two-orientation combined coronagraphic image without PSF-subtraction. Top panel: 27"x27". Bottom panel: 5.5" x 5.5". The source, in the late stages of star formation, exhibits 450 μm — 3.6 cm continuum emission, a CO outflow, and shocked H_2 emission.

HD 32297 - A NEARLY EDGE ON DEBRIS DISK



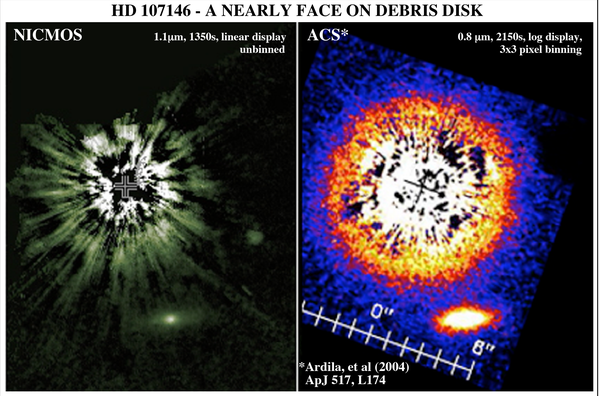
NICMOS PSF-subtracted coronagraphic imagery of the recently discovered circumstellar disk of **HD 32297*** (A0V) (possibly of comparable age to HR 4796A and β Pictoris, ~ 10 My).

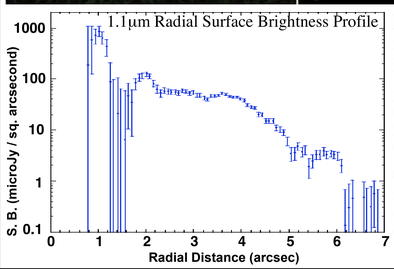
Radial surface brightness asymmetries along NE and SW "halves" of the HD 32297 disk major axis may implicate the existence of a planetary perturber modifying the azimuthal distribution of circumstellar scattering grains. (Region in gray obscured by the NICMOS coronagraph.)



***Schneider G., et al. (2005) ApJ, 639, L227**

HD 107146 - A NEARLY FACE ON DEBRIS DISK





NICMOS and ACS* two-roll combined PSF-subtracted coronagraphic images, and 1.1 μm (NICMOS) radial SB profile, of a nearly face-on debris disk, r ~ 150 AU, about the 30-250 Myr Sun-like star **HD 107146**. (*see poster 10.12)

This display paper (#10.13), presented at the 207th meeting of the American Astronomical Society (Washington, D. C., 09 January 2006) may be downloaded from: http://nicmosis.as.arizona.edu:8000/POSTERS/AAS_JAN_2006_GO10177.pdf

This work is based on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program 10177. Support for program 10177 was provided by NASA through a grant from the Space Telescope Science Institute.