HST High-Contrast Imaging of Circumstellar Disks with Optical/Near-IR Coronagraphy. G. Schneider[1], M. D. Silverstone[1], D. C. Hines[2], A. S. Cotera[3], C. A. Grady[4], K. R. Stapelfeldt[5], D. L. Padgett[6], F. Menard[7], S. Wolf[8], B. Stecklum[9], [1]Steward Observatory, 933 N. Cherry Ave., University of Arizona, Tucson, Arizona, 85721, USA (gschneider@as.arizona.edu), [2]Space Science Institute, NM Office, 7409 Pawnee Creek Tr. NE, Albuquerque, NM, 87113, USA, [3]SETI Institute, 515 N. Whisman, Mountainview, CA, 93035 USA, [4]Eureka Scientific and Goddard Space Flight Center, Code 667 NASA/GSFC, Greenbelt, MD 20771USA, [5]Jet Propulsion Laboratory, 4800 Oak Grove Dr., MS 183-900, Pasadena, CA 91109, [6]Caltech, Spitzer Science Center, Mail Code 220-6, Pasadena, CA 91125, [7]Laboratoire d'Astrophysique, Observatoire de Grenoble, CNRS/UJF UMR 5571, France, [8]Max-Planck-Institut fuer Astronomie, Koenigstuhl 17, 69117 Heidelberg, Germany, [9]Thuringer Landessternwarte Tautenburg, Sternwarte 5, D - 07778 Tautenburg, Germany.

Introduction: Probing circumstellar environments with spatially resolved imaging of their constituent materials irradiated by, and scattering, central starlight has been observationally challenging. Both the intrinsically high contrast ratios and small spatial scales of such regions have rendered their study extremely difficult even with the most aggressive ground-based observing techniques. The *Hubble Space Telescope* (*HST*) uniquely provides high spatial resolution at optical and near-IR wavelengths, extreme image (point spread function) stability, and high contrast coronagraphic imagery. These technical attributes are simultaneously exploited to study the circumstellar environments of potentially planet-forming disks. High contrast images of circumstellar disks, provided by the enabling capabilities of *HST*, are being used to probe the posited evolutionary epochs of grain-growth, disk formation (and dissipation), and planet-building.

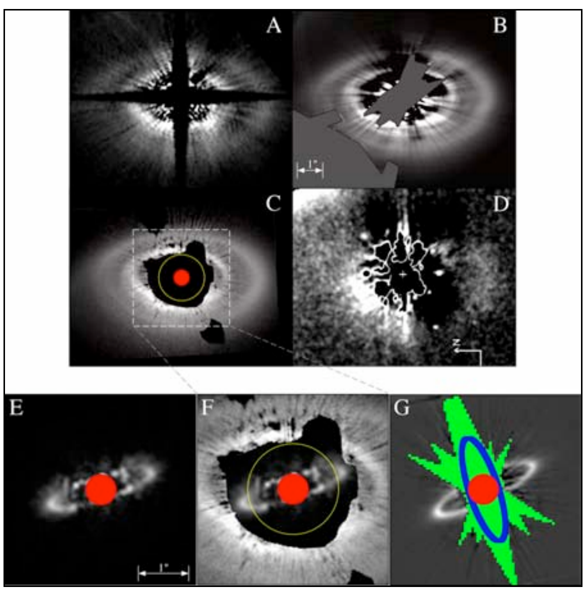

Figure 1. HST coronagraphic imagery of dusty circumstellar disks. Top: 400 AU radius circumstellar disk of ~ 5 Myr Herbig AeBe star HD 141569A. (A) NICMOS [1], (B) STIS [2], (C) ACS [3], (D) ground-based PALAO [4]. Bottom: 70 AU radius debris ring around ~ 8 Myr A0V star HD 4796A. (E) NICMOS [5], (F) Compared to inner region of (C) at same angular scale, (G) STIS[6].

HST Capabilities: Direct, and PSF-subtracted imagery, of reflection nebulae and envelopes associated with younger sources are critically augmented with high-contrast coronagraphy in HST's NICMOS, STIS, and ACS instruments revealing the detailed structures of and within both optically thick and thin circumstellar disks (see Figures 1 and 2).

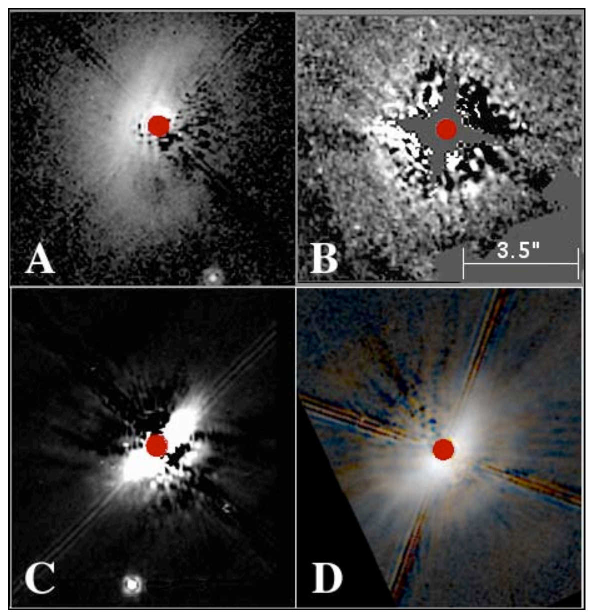

Figure 2. HST/NICMOS coronagraphy of (~ 1 Myr) T-Tauri star disks: (A) GO Tau, (B) DM Tau, (C) DOAR 25 [7] and (D) GM Aur [8] (all shown at the same angular scale).

Collectively, the HST coronagraphs: (a) probe material as close as 0.3" from occulted stars, (b) provide spatial resolutions of ~ 50 mas in the optical, (c) enable panchromatic studies in the wavelength regime from ~ 0.4 to 2.0 microns, (d) are sensitive to circumstellar material with scattering fractions of a few time 10^{-5} of the total starlight at a distance of ~ 1" from the central stars, (e) in optically thin (e.g., debris) disks at ~ 10 Myr are capable of detecting co-orbital objects of $\gtrsim$ 2 Jupiter masses at distances > 1" from the central stars in the near-IR.

Grain Properties: Scattered-light imagery of circumstellar disks directly provides the spatial distribution of the constituent grains, which cannot be uniquely inferred from (longer-wavelength) spectral energy distributions (SEDs) alone. This information can be used to break the degeneracies in disk geometries and compositions intrinsic to SED-driven models of disk properties. Together, spatially resolved imagery and SEDs of evolved circumstellar disks, inform on their global structures and on the distribution and physical properties of the circumstellar grains (e.g., [8]).

Disk Structures & Planetary Dynamics: Anisotropies (e.g., warps, gaps, arc, spirals, rings, 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 (e.g., see Figure 3).

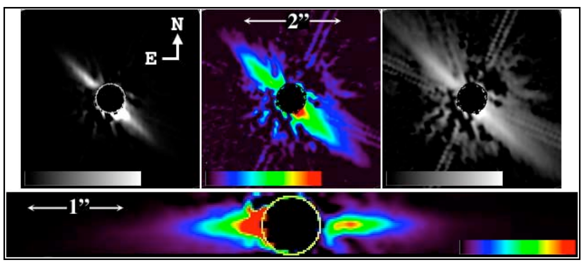

Figure 3. Brightness asymmetries in the recently discovered circumstellar disk of HD 32297 (A0V) (possibly of comparable age to HR 4796A and β Pictoris, ~ 10 My) may implicate the existence of a planetary perturber [9], as noted for other disks of circumstellar debris.

HST/GO 10177 Survey: We are conducting a highly sensitive circumstellar disk imaging survey, using HST/NICMOS coronagraphy at 1.6 µm, to provide critically needed imagery. Our sample of 52 stars spans spectral types A–M and crosses the evolutionary epochs of planet building. Our disk targets fall into two broad categories segregated, primarily, by age:

(1) *Young Stellar Object (YSO) Sample.* A < 10 Myr sample of 26 optically-thick YSO disk candidates with 18 T Tauri (d < 150 pc) stars of spectral types G–M, selected by their millimeter continuum excesses and/or intrinsically high optical polarizations, and 8 A–F stars (d < 200 pc), including 4 Herbig AeBe stars, with thermal IR and/or millimeter 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 differential polarimetry in the near-IR.

(2). Debris Disk Candidate Sample. A $\gtrsim$ 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 (thermal emission > stellar photospheric level, f = LIR/L_* > 3 x 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. Null detections set quantitative constraints in the determination of grain properties.

Recent Results from HST: We review the technical capabilities of HST high contrast coronagraphy that have further advanced the field of circumstellar disk evolution and the investigation of the disk/planet connection. We illustrate the science enabled by these capabilities with recent examples of newly acquired debris and protoplanetary disk images from our HST/GO 10177 circumstellar disk survey program.

References: [1] Weinberger A. J. et al. (1999) *ApJL*, *525*, L53-L56. [2] Schneider G. and Silverstone M. (2003) *ASPC*, *291*, 69-76. [3] Clampin M. et al (2003) *AJ*, *126*, 385-392. [4] Boccaletti A. et al. (2003) *ApJ*, *585*, 494-501. [5] Schneider G. et al. (1999) *ApJL*, *513*, 127-131. [6] Schneider G. (2001) *BAAS*, *904*, 911. [7] Schneider et al. (2005) *AAS CCCVI*, Abstract #35.09. [8] Schneider G. et al. (2003) *ApJ*, *125*, 1467-1479. [9] Schneider G. et al. (2005) *ApJL*, *629*, L117-L120.