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HST Observations of Dusty Disks in the TW Hya Association

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Abstract. The fortuitous proximity of the TW Hya association (TWA) enables spatially resolved studies of the distribution and physical characteristics of the dust/debris in the circumstellar environment of its roughly coeval $<$ 10 Myr members. Space-based high spatial resolution, high contrast imaging via coronagraphy with the Hubble Space Telescope's NICMOS and STIS instruments is providing morphological and photometric information on the cold dust component of the disks around these stars with unprecedented detail. Multi-wavelength observations are required to reveal the critical circumstellar processes associated with planetary system formation and disk evolution. Here we discuss HST near-IR and optical observations of three previously-identified members of the TWA (TW Hya itself, HR 4796A, and HD 98800A/B) which contribute to our understanding of those processes.

1. Introduction

The approximately twenty stellar systems currently identified as members of the loose association of stars named for the cTTS archetypical member TW Hya (Zuckerman et al. 2001) represents the nearest site of recent star formation to the Earth. With canonical distances of $\sim$ 55 pc. and ages of typically 5–10 Myr the TWA members provide a post-natal collection of objects to test the current competing theories of star, disk, and planetary system formation, evolution and interaction. The number of nearby young stars recognized in this, and other newly-identified and possibly spatially contiguous (though likely somewhat older) associations of Horologium, η Chameleontis, Tucana and MBM-12 continue to grow as these regions are surveyed and studied from the X-ray to the optical. The TWA though, remains the closest and youngest of these regions of recent star formation.

The expectation for imaging cold dust in the environments of the TWA stars in the near-IR was high given the IRAS excesses of a number of its members. Indeed in 1998 a NICMOS coronagraphic survey of a subset of the then-known TWA members imaged and resolved dusty disks about TW Hya and HR 4796A. The warm dust component about HD 98800B seen in the mid-IR (Gehrz et al. 1998; Koerner et al. 2000) was not detected in the near-IR. This negative detection, combined with high precision multi-band photometry of the stellar components, greatly constrained the systemic dust parameters.

The youth and proximity of the TWA members also made them prime targets for searching for brown dwarf and planetary companions by direct imaging as discussed by Lowrance 2001. That survey lead to the identification (and subsequent confirmation) of the brown dwarf companion to CD -33°7795 (Lowrance et al. 1999), and an extrasolar giant planet companion *candidate* to ROSAT 116 (Schneider et al. 2000). While the number of TWA members observed with NICMOS was small, the fraction of those thus-far observed with HST posessing disks and sub-stellar companions (or companion candidates) was not. Anisotropies in the brightness distributions of these and other disks observed with NICMOS (eg., HD 141569; Weinberger et al. 1999) are suggestive (though not conclusive) of dynamical interactions with unseen planetary perturbers (Schneider 2001). This suggests that the incidence of formative extrasolar planetary systems, in relatively sparse and dispersed regions like TWA, may be quite common. Follow-up STIS coronagraphic and spectroscopic observations of the NICMOS TWA targets are in progress, and we discuss some of those disk observations here.

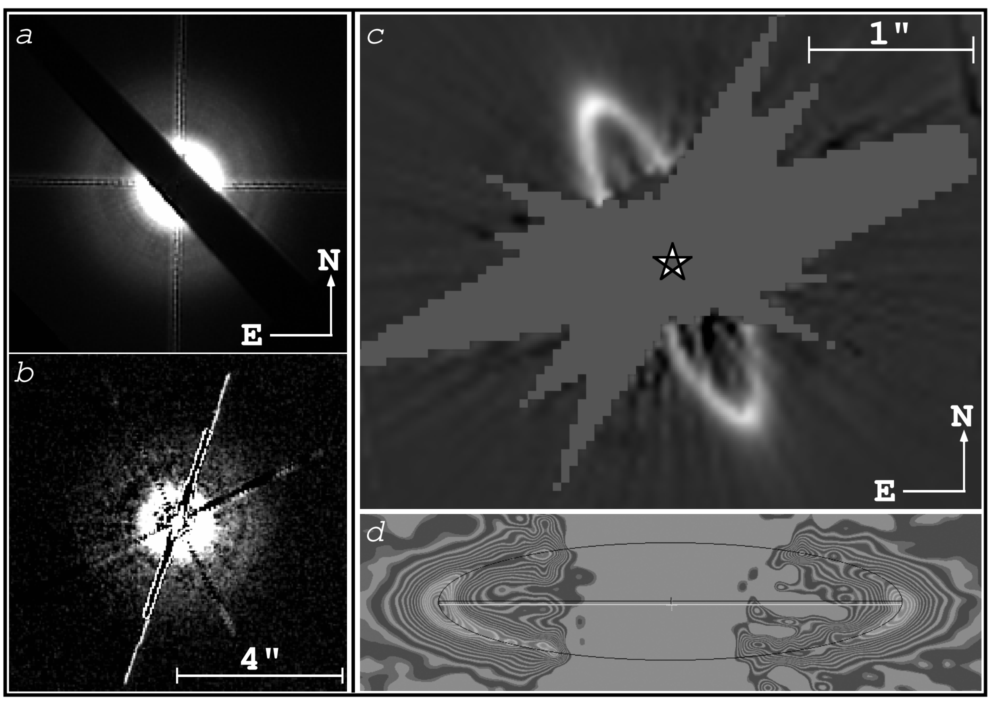

Figure 1. Optical HST imaging of TWA circumstellar disks. TW Hya - panels a & b (STIS and WFPC-2, respectively); HR 4796A - STIS image (panel c) and isophotal contour map (panel d).

2. TW Hya (TWA 1)

TW Hya is a classical, isolated, K7Ve T-Tauri star (Ruckinsk & Krautter 1983), exhibiting typical cTTS signatures of optical variability, and H_α and UV excesses. A significant far-IR excess was noted from IRAS observations with $L_{\rm disk}/L_\star \sim 0.3$, and continuum emission in the sub-millimeter was detected by Weintraub et al. (1989). The dusty circumstellar disk about this $\sim$ 6 Myr PMS star has a significant amount of remnant molecular gas as evidenced by CO emission (Zuckerman, Forveille & Kastner 1995).

Optical/near-IR observations of TW Hya revealed an optically-thick, pole-on disk seen in WFPC-2 (Krist et al. 2000) and NICMOS (Weinberger et al. 2001) images to a radius of $\sim$ 4" (200 AU) with a characteristic power-law fall-off of $r^{-2.6\pm0.1}$ from $\sim$ 40–120AU, though small departures are seen at $\sim 1\farcs5$. We have now observed the scattered light disk at higher S/N (than WFPC-2) and greater spatial resolution (than NICMOS) with STIS and find a very similar morphology. The surface brightness profile may be reproduced by a face-on flared disk with a central hole. The disk appears to be spectrally gray over five HST broad photometric bands while ground-based mid-IR spectroscopy shows amorphous silicate emission from a spatially unresolved source (Weinberger et al. (2001)). The disk colors and shape of the mid-IR spectrum are indicative of a population of grains which have grown from a primordial population.

The higher spatial resolution afforded by the optical observations (Figure 1a & b) reveal an arc-like depression in the disk surface brightness, azimuthally confined to only one sector of the disk (centered at a PA of $\sim 260°$). This may implicate the existence of an undetected planetary mass co-orbital body.

3. HR 4796A (TWA 11A)

A significant amount of circumstellar dust about the Vega-like star HR 4796A was inferred by Jura (1991) from its IRAS excess, with $L_{\rm disk}/L_{\star} \sim 5 \times 10^{-3}$, approximately twice that of β Pictoris. Jura et al. (1995) noted that their earlier-determined dust temperature of $\sim$ 110K indicated a lack of material at radii less than $\sim$ 40 AU, and grain sizes $> 3\mu$m were required to remain gravitationaly bound between 40 and 200 AU. Independent mid-IR imaging by Koerner et al. (1998) and Jayawardhana et al. (1998) spatially resolved an inclined disk. An inner depleted region was evident in 20.8μm images and reproduced by a model suggesting i $\sim 72°$, $r_{\rm inner} \sim$ 55 AU, and $r_{\rm outer} \sim$ 80 AU, analogous to a Kupier belt-like dust ring. Schneider et al. (1999) confirmed and further constrained the systemic parameters from high resolution ($\sim 0\farcs1$) 1.1 and 1.6μm NICMOS coronagraphy wherein the near-IR scattered flux agreed well with absorption in the visible and re-radiation in the mid-IR. The well-resolved NICMOS images clearly showed a narrowly confined ring-like circumstellar disk with ansal brightnesses differeing by $\sim$ 10–15%, and possibly enhanced scattering toward the presumed-forward azimuthal sectors. Similar ansal brightness asymmetries were also seen by Telesco et al. (2000) in deep 10.8 and 18.2 μm OSCIR images.

Given the age of HR 4796A of $\sim$ 8 Myr (as inferred from a presumed coeval M-dwarf companion at a projected distance of $\sim$ 500 AU), the much shorter time scales for dust clearing by Poynting-Robertson drag and radiation pressure blow-out implies dust confinement and/or replenishment. The NICMOS colors suggest a mean particle size of at least a few microns and thus dust likely of debris origin (and not trapped interstellar dust) replenished through the collisional erosion of planetesimals. The confinement of the dust grains could be accomplished by dynamical interactions with one or more unseen bodies, though the M-dwarf companion can serve to truncate the outer disk.

New higher-resolution STIS coronagraphic observations (Figure 1c) further constrain and better define the systemic parameters. The ansal brightness asymmetries noted in the NICMOS observations are easily seen in the STIS imagery (Figure 1d) and may be explained by an anisotropic azimuthal distribution of the debris particles, perhaps due to the influence of a gravitational perturber. The additional color information provided by these observations, and an axisymmetric brightness profile w.r.t. the minor axis (likely due to directionally enhanced scattering) will further constrain the nature of the disk particles.

4. HD 98800AB (TWA 4AB)

HD 98800AB is quadruple system with two "similar" PMS dwarfs (K5V and M0V from unblended STIS optical spectroscopy) which contains one of the brightest debris systems found by IRAS. The two visible components (A & B) are currently separated by $0\farcs8$ (38AU), so they are easily resolved at all HST wavelengths. Each component has a low-mass spectroscopic companion separated by $\sim$ 1AU with respective periods of 262 and 315 days (Torres et al. (1995)). From 4.7 and 9.8 μm observations, Gehrz et al. (1998) demonstrated that the debris system is centered on the B component. Approximately 20% of the B component luminosity is emitted in a nearly isothermal 164$\pm$5K SED from the mid-IR to the submillimeter. No near-IR flux excess above the photospheric level was seen in high-precision NICMOS photometric imaging by Low et al. (1999), nor from NICMOS coronagraphy (Schneider 2001). From this they suggested a grain albedo of < 0.3, $\mathrm{B}_{\mathrm{scattered:total}}$ light $< 6\%$, and a radially confined debris band (r $\sim$ 4.5AU) subtending no more than 20% of the sky as seen from the B stars. Such a system may be similar to the planetary debris system around the Sun as it may have appeared at a few million years after its formation. Both Koerner et al. (2000) and Prato et al. (2001) confirmed the circumbinary disk about the B spectroscopic pair, upon which a silicate feature is imposed, and suggest systemic geometries and properties similar to those inferred by Low et al. (1999). The HD 98800B debris system bears resemblance to the Zodiacal bands in our own solar system, and could have resulted from the failed formation of a terrestrial planet.

5. Summary

The diversity of disk structures and properties in the NICMOS-surveyed far-IR excess stars is striking. The morphology of the HR 4796A debris ring is virtually identical from 0.5 to 20μm. This is in stark contrast to the cold dust component of the much larger disk around the non-TWA source HD 141569A, a star of very similar age, mass, and spectral type. The HD 141569A disk exhibits a complex near-IR radial morphology with a bright outer ring and annular trough (Weinberger et al. 1999), both external to the central region of resolved thermal emission (Marsh et al. 2001). Perhaps HD 141569A represents an "intermediate" case between HR 4796A and the optically-thick comparatively gas-rich disk about TW Hya. The HD 98800 disk grains are circumbinary only to the B spectroscopic pair of this quadruple system. The periodic closest encounters of HD 98800 A and B in their long-period highly-elliptical orbit (Tokovinen

1999) are complicated by the dynamics of the low-mass spectroscopic companions and undoubtedly influence the spatial distribution and stability of the dust. In each of these systems stellar companions are likely to affect the evolution and morphologies of their disks. And, in the spatially-resolved disks, the radial anisotropies and azimuthal asymmetries in the brightness distributions bespeak the possibility of yet-unseen planetary-mass companions. Scheduling constraints precluded the observation of a fourth previously-known far-IR excess source and T Tauri binary, Hen 3-600, in the NICMOS survey, though the detection of thermal emission from a dust disk is suggested by Jayawardhana et al. (1999). One can only posit what this system may actually look like. Clearly, many more spatially resolved images of the cold components of dusty disks are needed in the quest to further our understanding of the evolution of the environments which may give rise to extrasolar planetary systems.

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