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Diffraction-Limited Imaging of HD 98800

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Abstract. Diffraction-limited images of HD 98800 A and B show that the IR luminosity excess originates around HD 98800 B. A 150 K dust disk around HD 98800 B, with an inner radius of $\sim$2 AU, an albedo of 0.3 and a total mass of 0.002 $M_\oplus$, spans a full height of 1.7 AU. The inner Ba$-$Bb binary is found to have an inclination of $\sim 58°$, probably coplanar with the disk, but not aligned with the outer A$-$B orbit. I suggest that the unusual properties of this system stem from complex dynamics related to the orientation of the dust and the stellar orbits.

1. Introduction

HD 98800, in the nearby TW Hya association, is interesting because of its very high fractional infrared (IR) luminosity and its complex multiplicity. In 1909, Innes identified it as a subarcsecond visual binary. Its IR properties were demonstrated by *IRAS* in the 1980's (Walker & Wolstencroft 1988; Garcia-Lario et al. 1990; Zuckerman & Becklin 1993). Torres et al. (1995) revealed that the components of the visual, currently $0.''8$ pair, HD 98800 A and B, are both spectroscopic binaries (SBs). Until *Hipparcos* found a distance of 47.6 pc to HD 98800 (Soderblom et al. 1998; Favata et al 1998), the pre$-$main-sequence age of this system was uncertain. Based on the precise distance and age, Tokovinin (1999) published imroved orbits for HD 98800 A$-$B. Further work over the last two years has shown the location of the dust in the system to be primarily around HD 98800 B, noted the absence of warm grains close to the central stars, and modelled the extent of the disk (Low et al. 1999; Gehrz et al. 1999; Koerner et al. 2000; Prato et al. 2001).

The wide HD 98800 A$-$B $\sim 0.''8$ pair has a projected separation of 38 AU at 47.6 pc. HD 98800 A is a single-lined SB with P=262 days. HD 98800 B, a double-lined SB with P=315 days, is associated with the IR excess. The eccentricities are large, 0.5 and 0.8, respectively, for A and B, and 0.3$-$0.6 for the wide orbit. The A$-$B inclination is $\sim 90°$ (Tokovinin 1999). In each SB the primaries are similar, underscoring the lack of dust around HD 98800 A and raising the question of whether the wide components are bound.

Prato et al. (2001) made a detailed study of the properties of HD 98800 A and B, and the dust around HD 98800 B, examining the dust's location and the interaction of the multiple components with the dust. I give a summary of these results and comment on the astrometry of the wide pair. A brief description of

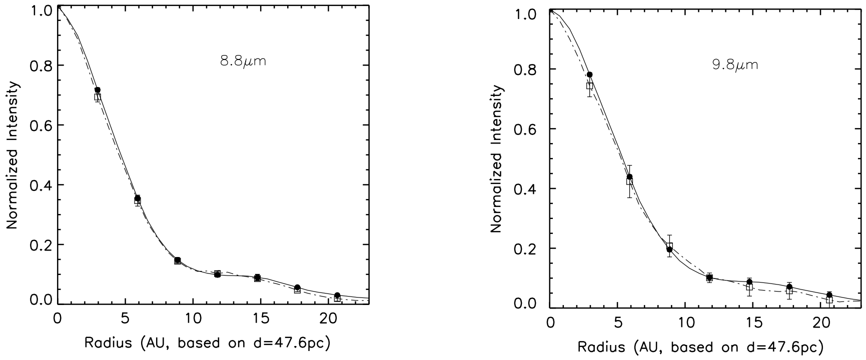

Figure 1. Azimuthally averaged profiles of HD 98800 A (dot-dash) and B (solid) at 8.8 and 9.8 μm.

the observations appears in §2. In §3 and §4 I present the results and discussion. §5 is a summary.

2. Observations

HD 98800 was observed using mid-IR imaging and near-IR adaptive optics at the Keck II 10 m telescope on 1998 May 10 and 1999 May 26, respectively, and with the near-IR speckle imaging system at the Keck I 10 m on 1996 January 4−6. The University of Florida mid-IR camera, OSCIR, provided four broad band and six narrow band observations from 2−18 μm. The adaptive optics system operated at 1.6 μm; speckle observations were obtained at 1.25, 1.56 and 2.20 μm (Matthews and Soifer 1994; Wizinowich et al. 2000). The resulting data were almost all diffraction-limited. A complete description of the observations, data reduction, and results appears in Prato et al. (2001).

3. Results

3.1. Images

The angular resolution of the data ranges from $0.''03$ at 1.25 μm to $0.''46$ at 18.2 μm. The HD 98800 A and B components are easily distinguished except at 18.2 μm where of HD 98800 A is detected at 3 σ. The dust appears to be entirely associated with HD 98800 B, consistent with Koerner et al. (2000). Figure 1 shows typical azimuthally averaged profiles of HD 98800 A and B; no resolved structure is seen. Simple star + disk models yield a 3 σ upper limit of ~2 AU to the radius of the mid-IR excess. A 1 σ upper limit on the 1.65 μm reflected light of <10%, combined with the IR fractional luminosity of $0.2L_B$ (Zuckerman & Becklin 1993), indicates a grain albedo of <0.3.

In Figure 3 of Torres et al. (1995), the authors show the projected values for the change in declination of the HD 98800 A−B pair for gravitationally bound

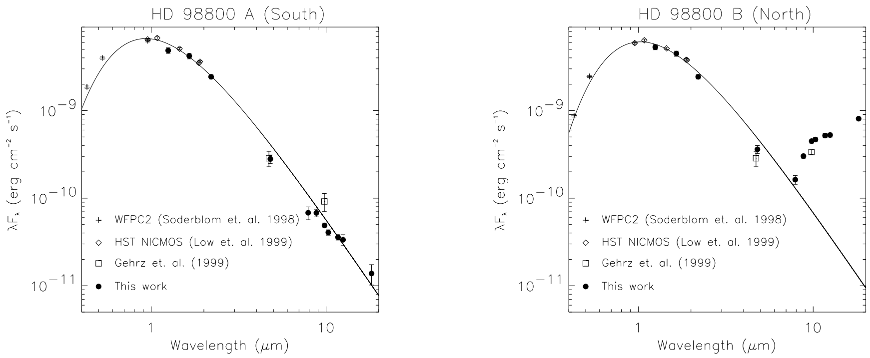

Figure 2. Spectral energy distributions for HD 98800 A and B. Black body spectral fits are shown for reference.

and unbound motion. Measurements of the HD 98800 A and B positions in five of the mid-IR bands give $\Delta\delta = 0.''79 \pm 0.''01$ for the observations made on 1998 May 10. This is consistent with a bound system.

3.2. Spectral Energy Distributions

Spectral energy distributions (SEDs) created from the near- and mid-IR data described here, in addition to data from the literature, appear in Figure 2. Comparison of the SEDs at 0.43−4.80 μm with *HST* SYNPHOT Kurucz atmospheric models provided estimates of stellar temperatures and luminosities for HD 98800 A and B (Table 1). Positions of the stars on the HR diagram are useful for the determination of coevality and masses. Since HD 98800 A is a single-lined SB in which the primary dominates, the Aa component is assigned the temperature and luminosity given in Table 1. Soderblom et al. (1998) give $T_{Ba} = 4250$ K and $T_{Bb} = 3700$ K, and Torres et al. (1995) estimate the Ba/Bb luminosity ratio. With L_B from Table 1, $L_{Ba} = 0.21$ and $L_{Bb} = 0.36$. HD 98800 Aa, Ba and Bb all have ages of $\sim 10^7$ years on the tracks of Baraffe et al. (1998). Component masses appear in Table 1; combining these with the mass functions from Torres et al. (1995) yields an estimate of 58° for the inclination of the Ba−Bb pair (Figure 3).

Table 1. Table 1: Derived Stellar Parameters

Component	T_{Kurucz} (K)	L_{Kurucz} ($L_\odot$)	M ($M_\odot$)
A (South)	4500±250	0.71±0.14	1.1±0.1[a]
B (North)	4000±250	0.58±0.11	1.6±0.1[b]

[a] Primary only.

[b] $M_{Ba} \sim 0.93$ and $M_{Bb} \sim 0.64$ $M_\odot$.

After subtraction the Kurucz model atmosphere fit from the SED of HD 98800 B, a 150 K black body remains. A distinct 10 μm feature reveals silicate grains. Given L_B, for stability against radiation pressure, a silicate grain must have a radius >0.07 μm. However, for grains to show a silicate feature, r_g must

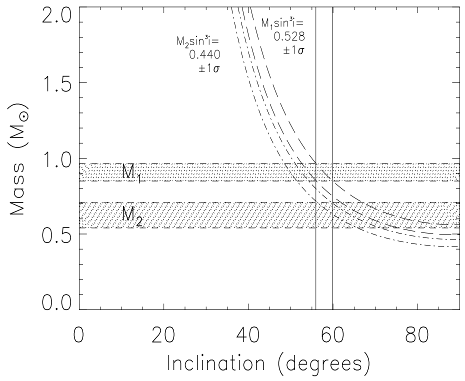

Figure 3. The inclination of the Ba−Bb SB, $\sim 58°$, estimated from the intersection of the mass functions (curved dot-dash and dash lines, Torres et al. 1995) and the stellar masses inferred from models (Baraffe et al. 1998).

be <few μm. The Poynting-Robertson (P-R) lifetime of an $r_g = 2$ μm silicate grain is 29,000 years. If the dust is as old as the stars, some process, such as collisions between larger objects, must replenish the grain population. With a mass absorption coefficient of 1000 g/cm^2, the lower limit of the silicate dust mass is 0.002 $M_\oplus$.

4. Discussion

The HD 98800 B dust equilibrium radius, based on the properties of Ba, Bb and the IR excess, is $\sim$2.4 AU. The theoretical criterion of Artymowicz & Lubow (1994) for stability of the inner radius of a tidally truncated circumbinary disk, $0.5a(1{+}e){+}a$, where a is the semimajor axis and e is the eccentricity of the stellar orbit, gives a radius of $\sim$2 AU for the dust. In §3, a simple model to the observations indicated that the dust is at a radius of 2 AU. Thus, three independent methods result in a similar value for the the dust radius, suggesting that the mid-IR excess arises in a relatively narrow region.

For the dust luminosity to be consistent with a grain albedo of 0.3, a large fraction of the stellar light must intercept the dust. This may be achieved by invoking a thick or flared disk geometry with a total height of 1.7 AU. Reflected light from a flared disk around HD 98800 B would not necessarily be detected even in the shortest wavelength images since the total reflected light is typically orders of magnitude less than that of the star (e.g. Weinberger et al. 2001).

Assuming that the dust in HD 98800 B is coplanar with the orbit of the central SB (S. Lubow, priv. comm. 2000), then the inclination of the dust disk is also 58°. Since the inclination of the wider A−B orbit is nearly edge on, the dust surrounding HD 98800 B could be more readily perturbed during periastron passages of HD 98800 A than expected in a coplanar system.

I propose a model for HD 98800 B in which dynamical perturbations are responsible for maintaining the geometry of the dust. The inner SB clears a gap of $\sim$2 AU in radius and the outer binary, HD 98800 A, not only sets an upper limit to the outer radius, $\sim$1/3 the periastron distance or $\sim$10 AU, but also is responsible for perturbing HD 98800 B's disk. The most puzzling aspect of this system is that HD 98800 B is associated with such an unusual excess while no dust has been detected around HD 98800 A. If the HD 98800 B disk precesses, periastron encounters with HD 98800 A which alternate between perpendicular and parallel orientations, depending on the longitude of periastron passage, may have destroyed a primordial disk around A. The 300−400 year period of HD 98800 A−B (Tokovinin 1999) provides ample opportunity for perturbations of HD 98800 B's disk by A's periastron passages, stimulating collisions between particles, resupplying the silicate grains against P-R drag, and maintaining a large disk height.

5. Summary

Diffraction-limited images of the quadruple system HD 98800 show that the northern component, HD 98800 B, is the source of the unresolved IR excess, arising in a dust disk around the central SB. The dust is characterized by an inner gap of radius 2 AU, an albedo of 0.3, and a height of ∼1.7 AU. Silicate grains with a total mass of 0.002 $M_\oplus$, must be resupplied against depletion by P-R drag. The outer limit for the dust radius is ∼10 AU, imposed by the orbit of HD 98800 A. The inclination of the HD 98800 Ba−Bb binary, 58°, is probably shared by the dust disk. Thus, the HD 98800 A−B orbit, ∼90°, and HD 98800 B's disk are not coplanar, inducing complex dynamical interactions in the system. The mid-IR data, obtained in 1998, yield $\Delta\delta = 0.''79 \pm 0.''01$, consistent with HD 98800 A and B being gravitationally bound.

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