THE DISCOVERY OF NEW WARM DEBRIS DISKS AROUND F-TYPE STARS

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ABSTRACT

We report the discovery of four rare debris disks with warm excesses around F stars, significantly increasing the number of such systems known in the solar neighborhood. Three of the disks are consistent with the predictions of steady-state planetesimal disk evolution models. The oldest source, HD 169666, displays a dust fractional luminosity too high to be in a steady state and we suggest that this system recently underwent a transient event of dust production. In addition, two spectra of this star separated by approximately three years show silicate emission features, indicative of submicron- to micron-sized grains. We argue that such small grains would be rapidly depleted in these warm disks originated from blackbody grains, they would be located at a radius of 1–10 AU. Thus, in “solar-system terminology,” these disks are either similar to the main asteroid belt or are situated between the main belt and the Kuiper Belt. In these warm disks originated from blackbody grains, they would be located at a radius of 1–10 AU. Thus, in “solar-system terminology,” these disks are either similar to the main asteroid belt or are situated between the main belt and the Kuiper Belt.

1. INTRODUCTION

Many main-sequence stars exhibit excess emission at mid- to far infrared (IR) wavelengths, implying the existence of a ring or disk of circumstellar dust grains, which re-radiate the absorbed starlight at longer wavelengths. Due to mutual collisions, radiation pressure, and the Poynting–Robertson (PR) drag, the lifetime of the emitting dust grains is much shorter than the age of the star, and the dust particles are thought to be continuously replenished by the erosion of larger planetesimals (Backman & Fares 1993; Wyatt 2008). Thus, the existence of a dust “debris” disk implies the presence of a planetesimal belt around the star.

In most known debris disks around F-, G-, and K-type stars, the dust grains are relatively cold (50–90 K), similar in temperature to the dust located in the Kuiper Belt in our solar system (Carpenter et al. 2009). Interestingly, warm debris disks—where the emission (in $F_\nu$) peaks at $\lambda > 40$ µm, corresponding to $T_{\text{dust}} > 125$ K—are rare. If the IR emission in these warm disks originated from blackbody grains, they would be located at a radius of 1–10 AU. Thus, in “solar-system terminology,” these disks are either similar to the main asteroid belt or are situated between the main belt and the Kuiper Belt. So far ~20 warm debris disks have been discovered around FGK-type stars. Most of them encircle young stars that are often members of known young open clusters or moving groups typically located at larger (>100 pc) distances (Chen et al. 2005; Currie et al. 2007, 2008; Gorlova et al. 2007; Hines et al. 2006; Lisse et al. 2008; Rhee et al. 2008; Smith et al. 2008). In these young (<100 Myr) systems, the source of warm debris dust in the region of terrestrial planets may be an outwards propagating ring of planetesimal formation and/or the products of massive protoplanet collisions (Kenyon & Bromley 2004; Meyer et al. 2008). A smaller number of warm disks have been identified around older solar-type stars (Song et al. 2005; Beichman et al. 2005, 2006; Wyatt et al. 2005). All these old systems exhibit high fractional luminosity ($L_* / L_{\text{bol}} > 10^{-4}$) that cannot be explained with a steady-state asteroid belt evolution model, where the planetesimals are co-located with the warm dust. Instead, Wyatt et al. (2007) suggested that these systems are in a transient state. Recent collisions between large asteroids or the erosion/sublimation of planetesimals scattered from an outer reservoir into the inner regions due to a dynamical instability are proposed as the origin of the transient warm dust (Song et al. 2005; Wyatt et al. 2007). One can find possible analogous transient events also in the history of our solar system (Gomes et al. 2005; Nesvorný et al. 2003).

In our extensive program studying debris disks around 78 F-type stars (PID: 3401, 20707; A. Moór et al. 2009, in preparation), we identified four systems harboring warm disks. All four are new discoveries and are located relatively close to the Sun (<60 pc). Here we analyze their properties, discuss their possible origins, and speculate about the implications on the formation and evolution of dust in the inner region of planetary systems.

2. OBSERVATIONS AND DATA REDUCTION

The four stars, HD 13246, HD 53842, HD 152598, and HD 169666, were selected for our program because of earlier hints for IR excess from IRAS and/or their membership in young moving groups. HD 13246 and HD 53842 belong to the Tucana–Horologium moving group (Zuckerman & Song 2004) implying an age of ~30 Myr. Age indicators, such as lithium abundances and X-ray luminosities, further support this age. The galactic motion of HD 152598 ($U = -10.7$, $V = -22.6$, $W = -4.0$ km s$^{-1}$) as well as its galactic position are consistent with those of the “b3” subgroup of the Local Association, implying an age of 0.21 ± 0.07 Gyr (Asiain et al. 1999). Both its fractional X-ray luminosity ($ROSAT$ J165258.2+314203, $\log{(L_*/L_{\text{bol}})} \sim -5.63$) and the equivalent width of the lithium 6708 Å feature (43 ± 8 mÅ from spectra available in the Elodie archive; Mouttaka et al. 2004) support this age. In the case of HD 169666 isochrone fitting yields...
2.1^{+0.2}_{-0.4} Gyr (Holmberg et al. 2007). Its location in the HRD indicates that this star is already leaving the main sequence, supporting the conclusion of the isochrone dating. HD 169666 coincides with ROSAT J181909.0+713054, whose X-ray luminosity is \( \log(L_x/L_{bol}) \sim -5.67 \). We note that this value is not inconsistent with the measured \( \log(L_x/L_{bol}) \) values of stars with similar \( B-V \) color indices in the 1.9 Gyr old NGC 752 open cluster (Daniel et al. 1994; Giardino et al. 2008), giving support to the isochrone age determination. The key properties of the four stars are listed in Table 1.

### 2.1. Spitzer Observations and Data Reduction

Mid- and far-IR images were obtained using the MIPS instrument (Rieke et al. 2004) in small-field photometry mode. All four objects were measured at 24 and 70 \( \mu \)m, while two of them were also observed at 160 \( \mu \)m. In addition, low-resolution spectra (\( R = 70-120 \)) were obtained for each source using the Infrared Spectrograph (IRS; Houck et al. 2004). All these observations belong to our program PID 20707 except the IRS spectrum of HD 13246, which was taken from the Spitzer Archive (PID: 241, PI: C. Chen). In order to improve the signal-to-noise ratio and search for possible variability, we performed follow-up IRS measurements for HD 13246 and HD 169666, obtained 41 and 35 months after the first epochs, respectively (PID: 50538, PI: Á. Kóspál).

**MIPS:** We started the data processing with the BCD files (pipeline version S16.1). Additional corrections, including flat field and a background matching at 24 \( \mu \)m, were performed using MOPEX (Makovoz & Marleau 2005). At 70 \( \mu \)m column mean subtraction and time filtering were applied following Gordon et al. (2007). BCD data were co-added with the MOPEX software. Output mosaics had pixels with sizes of 2\('\prime\prime\). At 70\( \mu\)m, we obtained 41 and 35 months after the first epochs, respectively

| Source ID | Stellar Properties | Disk Properties |
|-----------|--------------------|-----------------|
|           | \( V \) (mag) | SpT | \( D \) (pc) | \( T_{eff} \) (K) | \( L_* \) \( (L_\odot) \) | \( M_* \) \( (M_\odot) \) | \( \log g \) (cm s\(^{-1}\)) | \[Fe/H\] | Age (Myr) | \( T_{dust} \) (K) | \( R_{dust} \) (AU) | \( t \) (10\(^{-4}\)) | \( f_{max} \) (10\(^{-4}\)) |
| HD 13246\(^a\) | 7.50 | F8V | 44.2 | 6140 | 1.55 | 1.06 | 4.4 | -0.17 | \sim -30 | 166 \pm 18 | 3.5 \pm 0.9 | 1.7 | 0.8 |
| HD 53842 | 7.46 | F5V | 56.0 | 6430 | 2.6 | 1.20 | 4.3 | -0.16 | \sim -30 | 151 \pm 24 | 5.4 \pm 1.4 | 0.53 | 1.5 |
| HD 152598\(^b\) | 5.34 | F0V | 29.2 | 7100 | 4.8 | 1.43 | 4.3 | -0.21 | 210 \pm 70 | 135 \pm 11 | 9.3 \pm 1.5 | 0.35 | 0.5 |
| HD 169666 | 6.68 | F5 | 53.2 | 6540 | 4.7 | 1.35 | 4.1 | -0.04 | 2100+200 | 198 \pm 13 | 4.2 \pm 0.6 | 1.84 | 0.008 |

*Notes.*

\(^a\) HD 13246 has a late-type (K5) companion, CD-60 416 (HD 13246B), with a separation of \( \sim 52'' \) on the sky.

\(^b\) HD 152598 is identified as a binary system in the CCDM catalog (Dommanget & Nys 2002). However, according to the NOMAD catalog, the proper motion of the proposed companion (CCDM J16530+3142B) deviates significantly from the proper motion of HD 152598, implying that a physical connection between these stars is unlikely.

#### Table 1

| Source ID | P24 | F24 | P70 | F70 | P160 | F160 |
|-----------|-----|-----|-----|-----|------|------|
| HD 13246 | 23.4 | 46.2 \pm 1.9 | 2.6 | 20.1 \pm 3.3 | 0.5 | <60.6 |
| HD 53842 | 21.2 | 30.1 \pm 1.3 | 2.3 | <27.5 | 0.5 | <123.2 |
| HD 152598 | 106.5 | 134.8 \pm 5.5 | 11.6 | 44.3 \pm 5.0 | ... | ... |
| HD 169666 | 40.2 | 89.2 \pm 3.7 | 4.4 | 21.8 \pm 4.0 | ... | ... |

*Notes.* Predicted (P24, P70, P160) and measured (F24, F70, F160) flux density values given in mJy. The final uncertainties were computed by adding quadratically the individual internal errors and the absolute calibration uncertainties. Following the MIPS Data Handbook, we adopted 4% and 7% calibration uncertainty at 24 and 70 \( \mu \)m. For sources not detected at a specific wavelength, upper limits were computed as the flux measured in the source aperture + 3\( \sigma \) (all measured fluxes were positive).

#### 3. RESULTS

#### 3.1. Spectral Energy Distributions and Infrared Excesses

We compared the spectral energy distribution of each star by combining IR fluxes from the IRS and MIPS observations with published optical and near-IR photometric data (Hipparcos, Tycho2, 2MASS catalogs). In Figure 1 we present the IR data, as well as stellar photospheric predictions obtained by fitting an ATLAS9 atmosphere model (Castelli & Kurucz 2003) to the optical and near-IR measurements. Metallicity data from Holmberg et al. (2007) and computed surface gravity values, used as inputs to the fits, are listed in Table 1. Since from distance estimates based on Hipparcos parallax data (van Leeuwen 2007) all our stars lie in the Local Bubble (Lallement et al. 2003), we assumed the extinction to be negligible. The fitted effective temperatures are included in Table 1. Predicted photospheric fluxes for the MIPS bands are listed in Table 2. All our sources exhibit significant (>3\( \sigma \)) excess over the predicted photosphere at 24 \( \mu \)m. At 70 \( \mu \)m HD 53842 was not detected, while the measured fluxes of the three other sources were found to be in excess.
Figure 1. Spectral energy distribution of the four F-type stars harboring warm debris disks. In the cases of HD 13246 and HD 169666, IRS spectrum of the first epochs from 2005 were plotted.

The IRS spectra show that the excesses are present even at shorter wavelength as they begin to depart from the expected photosphere at ∼9, 14, 14, and 8 μm in the case of HD 13246, HD 53842, HD 152598, and HD 169666, respectively.

3.2. Spectral Features in the IRS Spectra

Figure 2 presents the IRS spectrum of HD 169666. Several broad spectral features at around 11.3, 16.4, 23.7, 27.5, and 33.8 μm can be recognized. For comparison we plotted the spectrum of HD 69830 and comet Hale-Bopp, which also exhibit features at similar wavelengths (Beichman et al. 2005; Crovisier et al. 1997). These peaks, especially the 11.3 μm one, can be attributed to forsterite (Koike et al. 2003; Jäger et al. 1998), indicating the presence of micron-sized silicate grains in the disk of HD 169666. The spectra of HD 13246, HD 53842, and HD 152598 do not show any spectral features exceeding the noise. The lack of features in these disks may imply the depletion of small grains.

3.3. Search for Variability

We compared the two spectra of HD 169666 obtained at different epochs. Both the continuum level and the spectral features were found to be remarkably unchanged. The flux differences were typically in the order of 1%–2% over the whole spectral range. A similar comparison for HD 13246 showed more pronounced differences especially between 10 and 20 μm. However, these two measurements were processed with different pipeline versions, namely with S15.3 and S18.1. We performed an analysis of four calibration measurements of η¹ Dor processed with the same pipeline versions as HD 13246. The results indicated that the differences observed at HD 13246 could be explained by systematic calibration effects related to the two pipeline versions. Thus, we conclude that no significant spectral change can be detected in our measurements.

3.4. Modeling the Observed Infrared Excess

We assume that the detected IR excess originates from optically thin dust confined into a circumstellar ring. The excess above the predicted photosphere was fitted by a single-temperature blackbody (as, e.g., Wyatt et al. 2005; Rhee et al. 2008). For the fitting process, the IRS spectra were robustly averaged in five bins centered at 8, 13, 18, 24, and 32 μm (the last bin was not used in the case of HD 169666 because of the presence of a relatively strong feature). For HD 13246 and HD 169666, where two IRS spectra are available, we used the earlier ones because they were obtained closer in time to the MIPS observations. An iterative method was used to compute and apply color corrections for the MIPS data (see Moór et al. 2006). The derived dust temperatures (T_dust) are listed in Table 1 and the best-fitting models are overplotted in Figure 1.

Assuming that the emitting grains act like a blackbody, we estimated the ring radius using the following formula (Backman & Paresce 1993):

$$ R_{dust} = \left( \frac{L_{\star}}{L_{\odot}} \right)^{0.5} \left( \frac{278 \, K}{T_{dust}} \right)^2. $$

The fractional dust luminosities of the four systems were calculated as $f_d = L_{dust}/L_{bol}$ and are in the range of 0.3–1.8 × 10^{-4}. The derived disk properties are listed in Table 1. Note that using the second epoch spectra for HD 13246 and HD 169666, the fitted disk parameters are not altered significantly.

4. DISCUSSION

4.1. Comparison with Steady-State Evolutionary Models

In all four systems the inferred radii of dust rings correspond to the region of the asteroid belt and the gas giants in our solar
system. A comparison of the PR and the collision timescales for our dust rings (Equations (14) and (15) in Backman & Paresce 1993) implies that the grain evolution is dominated by collisions. The derived short lifetimes with respect to the ages of the stars demonstrate the second generation (“debris”) nature of the dust grains, and indicates the presence of planetesimals co-located with the dust rings. Wyatt et al. (2007) used an analytical steady-state model to study the collisional evolution of planetesimal belts and argue that at any given age there is a maximum disk mass and fractional luminosity, since initially more massive disks consume their mass faster. We computed the maximum fractional luminosity value \( f_{\text{max}} \) for each system taking into account its properties as listed in Table 1 and using Equation (20) in Wyatt et al. (2007), also adopting their fixed model parameters (belt width: \( dr/r = 0.5 \); planetesimal strength: \( Q_p = 200 \) J kg\(^{-1}\); planetesimal eccentricity: \( e = 0.05 \); diameter of largest planetesimal in cascade: \( D_c = 2000 \) km). Comparing these values with the calculated fractional luminosities, we find that the disk properties of HD 13246, HD 53842, and HD 152598 are consistent with a steady-state evolutionary scenario within the uncertainties of the model. In contrast, in the case of HD 169666, a ratio of \( f/f_{\text{max}} > 100 \) implies a high dust content around this old star, inconsistent with a steady-state model.

4.2. Origin of Debris Dust in Individual Systems

HD 13246 and HD 53842 belong to the Tuc-Hor association, implying an approximate age of 30 Myr. In such young stars, the disks are thought to be the sites of intense planet formation. In regions where the growing size of the largest planetesimals reach \( \sim 2000 \) km, these protoplanets stir their surroundings leading to catastrophic collisions among the left-over planetesimals. A collisional cascade begins and produces large amounts of debris dust. Since the formation of giant planetesimals takes longer at larger radii, the site of debris production propagates outwards with time (Kenyon & Bromley 2002, 2004).

Using the evolutionary model of Kenyon & Bromley (2004) we calculated the radius of such a ring for an age of 30 Myr, as a function of initial disk surface density. We found that the 3.5–5 AU radii derived for our disks can be explained by disk surface density of \( \Sigma < 0.3 \Sigma_{\text{MMSN}} \), where \( \Sigma_{\text{MMSN}} \) is the surface density of the minimum solar mass nebula. This parameter implies a relatively low initial disk mass provided that the disk is really in this evolutionary phase. After this peak the average dust production drops, but there may be episodic spikes due to individual collisions between left-over rocky protoplanets. If the dust rings around HD 13246 and HD 53842 represent these later phases of the evolution, the initial surface density could have been higher.

HD 152598 is older than the previous two stars, and at its age of 0.21 Gyr most likely represent a later evolutionary phase, when dust grains are already generated by colliding minor bodies in a steady planetesimal ring.

HD 169666 is a new member of a distinguished, small group of FGK-type stars harboring warm debris disks of unusually high fractional luminosity. Only a handful of such systems have been identified so far: BD+20 307, HD 23514, HD 69830, HD 72905, and \( \eta \) Corvi (Song et al. 2005; Rhee et al. 2008; Beichman et al. 2005, 2006; Wyatt et al. 2005). The peculiar brightness of these disks is usually explained by an episodic increase in dust production (Wyatt et al. 2007). It is also a common property of HD 169666 and most other members of this group that they are old (\( > 300 \) Myr) and their mid-IR spectra exhibit spectral features attributed to small silicate dust grains. Such small grains move and evolve primarily under the influence of radiation pressure and collisions.

In order to draw a picture on the dust evolution, we computed the maximum size of dust grains blown out of the HD 169666 system due to the radiation pressure. Approximating the absorption+scattering cross section by the geometric cross section and adopting a density of 2.5 g cm\(^{-3}\) and an albedo of 0.1, we found a “blowout-size” of 1.6 \( \mu \)m (Burns et al. 1979). Under the influence of radiation pressure alone these small grains would be removed very fast; first-order estimates of the grain removal from the mid-IR emitting region \( T > 130 \) K suggest typical timescales of a few months to a year. With the most prominent opacity source removed so rapidly, significant changes in the mid-IR spectral features are to be expected on similarly
short timescales. However, the mid-IR spectrum of HD 169666 showed no significant variations in the course of three years. The constant flux levels of the spectral features indicate that small grains are continuously replenished on timescales of a few years or less. The existence of warm—small or large—dust in this system covers an even longer interval. Convolving our IRS spectrum with 25 \( \mu \)m filter profile of IRAS (Beichman et al. 1988) and comparing this synthetic flux value of 112 mJy with the IRAS measurement in 1983 (101 ± 13 mJy; Moshir et al. 1989), we could not see any variation within the measurement uncertainties. This finding suggests that the transient phase of HD 169666 lasts at least for a quarter of a century. It is an open question whether the small grain production is active also on this longer timescale. Nevertheless, the fact that most old transient systems (see above) exhibit spectral features might suggest that small grains are present, and their production mechanism is active over a significant fraction of the transient phase. Because no multi-epoch measurements exist for the other five warm disks, possible variations of the spectral features cannot be excluded. Details of the variability depend on the actual mechanism of small grain replenishment in the system.

Three possible mechanisms have been put forward to explain the origin of dust in systems like HD 169666. First, breakup of a large planetesimal similar to the event leading to the birth of the Veritas asteroid family (Nesvorný et al. 2003). The probability of such an event, however, is relatively low at an age of \( \sim 2 \) Gyr (Wyatt et al. 2007). Second, dust may originate from the continuous evaporation of a super-comet as proposed for the case of HD 69830 (Beichman et al. 2005). The dust temperature in the disk of HD 169666 exceeds 110 K, the sublimation temperature of comets, consistently with this scenario. The third mechanism would be that the observed high fractional luminosity of these disks may be the result of an event similar to the Late Heavy Bombardment (Wyatt et al. 2007). Modeling the expected brightness and spectral evolution of transient disks around older stars in the three scenarios and comparing them with multi-epoch observations may help to identify the processes responsible for replenishing the observed massive dust belts in these extrasolar planetary systems.

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REFERENCES

Apai, D., Pascucci, I., Bouwman, J., Natta, A., Henning, T., & Dullemond, C. P. 2005, Science, 310, 834

Asiain, R., Figueras, F., Torra, J., & Chen, B. 1999, A&A, 341, 427

Backman, D. E., & Paresce, F. 1993, in Protostars and Planets III, ed. E. H. Levy & J. I. Lunine (Tucson, AZ: Univ. Arizona Press), 1253

Beichman, C. A., Neugebauer, G., Habing, H. J., Clegg, P. E., & Chester, T. J. (ed.) 1988, IRAS Explanatory Supplement (Washington, DC: US Govt Printing Office)

Beichman, C. A., et al. 2005, ApJ, 626, 1061

Beichman, C. A., et al. 2006, ApJ, 639, 1166

Bouwman, J., Lawson, W. A., Dominik, C., Feigelson, E. D., Henning, T., Tielens, A. G. G. M., & Waters, L. B. F. M. 2006, ApJ, 653, L57

Bouwman, J., et al. 2008, ApJ, 683, 479

Burns, J. A., Lamy, P. L., & Soter, S. 1979, Icarus, 40, 1

Carpenter, J. M., et al. 2009, ApJS, 181, 197

Castelli, F., & Kurucz, R. L. 2003, Modelling of Stellar Atmospheres, ed. N. Piskunov, W. W. Weiss, & D. F. Gray (San Francisco, CA: ASP), 210, 20P

Chen, C. H., et al. 2005, ApJ, 634, 1372

Crovisier, J., Leech, K., Bockelee-Morvan, D., Brooke, T. Y., Hanner, M. S., Altieri, B., Keller, H. U., & Lettlouch, E. 1997, Science, 275, 1904

Currie, T., Kenyon, S. J., Rieke, G., Balog, Z., & Bromley, B. C. 2007, ApJ, 663, L105

Currie, T., Plavechan, P., & Kenyon, S. J. 2008, ApJ, 688, 597

Daniel, S. A., Latham, D. W., Mathieu, R. D., & Tworog, B. A. 1994, PASP, 106, 281

Dommanget, J., & Nys, O. 2002, Obs. Travaux, 54, 5

Giardino, G., Pillitteri, I., Favata, F., & Milca, G. 2008, A&A, 490, 113

Gomes, R., Levison, H. F., Tsiganis, K., & Morbidelli, A. 2005, Nature, 435, 466

Gordon, K. D., et al. 2007, PASP, 119, 1019

Gorlova, N., et al. 2007, ApJ, 670, 516

Higdon, S. J. U., et al. 2004, PASP, 116, 975

Hines, D. C., et al. 2006, ApJ, 638, 1070

Holmberg, J., Nordström, B., & Andersen, J. 2007, A&A, 475, 519

Houck, J. R., et al. 2004, ApJS, 154, 18

Jagers, C., Melster, F. J., Dorschner, J., Henning, Th., Mutschke, H., & Waters, L. B. F. M. 1998, A&A, 339, 904

Kenyon, S. J., & Bromley, B. C. 2002, ApJ, 577, L35

Kenyon, S. J., & Bromley, B. C. 2004, ApJ, 602, L133

Koike, C., Chihara, H., Tschiyama, A., Suto, H., Sogawa, H., & Okuda, H. 2003, A&A, 399, 1101

Lallement, R., Welsh, B. Y., Vergely, J. L., Crifo, F., & Sfeir, D. 2003, A&A, 411, 447

Lisse, C., Chen, C., Wyatt, M. C., & Morlock, A. 2008, ApJ, 673, 1106

Makovoz, D., & Marleau, F. 2005, PASP, 117, 1113

Meyer, M. R., et al. 2006, PASP, 118, 1690

Meyer, M. R., et al. 2008, ApJ, 673, L181

Moór, A., Abrahám, P., Derekas, A., Kiss, C., Kiss, L. L., Apai, D., Grady, C., & Henning, T. 2006, ApJ, 644, 525

Moshir, M., et al. 1989, Explanatory Supplement to the IRAS Faint Source Survey (Pasadena, CA: JPL)

Moultaka, J., Ilovaisky, S. A., Prugniel, P., & Soubiran, C. 2004, PASP, 116, 693

Nesvorný, D., Bottke, W. F., Levison, H. F., & Dones, L. 2003, ApJ, 591, 486

Pascucci, I., Apai, D., Hardegree-Ullman, E. E., Kim, J. S., Meyer, M. R., & Bouwman, J. 2008, ApJ, 673, 477

Rhee, J. H., Song, I., & Zuckerman, B. 2008, ApJ, 675, 777

Rieke, G. H., et al. 2004, ApJS, 154, 25

Smith, R., Wyatt, M. C., & Dent, W. R. F. 2008, A&A, 485, 897

Song, I., Zuckerman, B., Weinerberger, A. J., & Becklin, E. E. 2005, Nature, 436, 363

van Leeuwen, F. 2007, A&A, 474, 653

Wyatt, M. C. 2008, ARA&A, 46, 339

Wyatt, M. C., Greaves, J. S., Dent, W. R. F., & Coulson, I. M. 2005, ApJ, 620, 492

Wyatt, M. C., Smith, R., Greaves, J. S., Beichman, C. A., Bryden, G., & Lisse, C. M. 2007, ApJ, 658, 569

Zuckerman, B., & Song, I. 2004, ARA&A, 42, 685