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# NEW DEBRIS DISK CANDIDATES AROUND 49 NEARBY STARS

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## ABSTRACT

We present 49 new candidate debris disks that were detected around nearby stars with the *Spitzer Space Telescope* using the Multiband Imaging Photometer (MIPS) at 24 $\mu$m (MIPS24) and 70 $\mu$m (MIPS70). The survey sample was composed of stars within 25 pc of the Sun that were not previously observed by any other MIPS survey. Only stars with $V < 9$ were selected, corresponding to spectral types earlier than M0. MIPS24 integration times were chosen to detect the stellar photosphere at $10\sigma$ levels or better. MIPS70 observations were designed to detect excess infrared emission from any star in the MIPS70 sample with a disk as luminous as that around $\epsilon$ Eridani. The resulting sample included over 436 nearby stars that were observed with both MIPS24 and MIPS70, plus an additional 198 observed only with MIPS24. Debris disk candidates were defined as targets where excess emission was detected at $3\sigma$ levels or greater, and the ratio of observed flux density to expected photosphere emission was three standard deviations or more above the mean value for the sample. The detection rate implied by the resulting 29 MIPS24 candidates is 4.6%. A detection rate of 4.8% is implied by 21 MIPS70 candidates. The distribution of spectral types for stars identified as candidates resembles that of the general sample and yields strong evidence that debris-disk occurrence does not decrease for K dwarfs. Modeling of non-uniform sensitivity in the sample is required to interpret quantitative estimates of the overall detection frequency and will be presented in a future work.

*Key words:* circumstellar matter – infrared: stars – protoplanetary disks – solar neighborhood

## 1. INTRODUCTION

The infrared signature of nearby "debris disks" was first discovered with *IRAS* and identified with circumstellar dust grains around newly dubbed "Vega-type" stars of largely main-sequence age. Increasing evidence supports the early attribution of excess infrared emission to radiation from dust grains that are generated by collisions within a population of asteroid-like bodies or "planetesimals." The vastly improved sensitivity of the *Spitzer Space Telescope* has yielded a solid legacy of new disk detections and expanded our knowledge of their frequency of occurrence, especially for later spectral types. Unlike the *IRAS* all-sky survey, however, targeted surveys were necessary to obtain a complete census of debris disks in the solar neighborhood, and a global picture is just started to emerge from combined small-sample surveys.

Gautier et al. (2007) detected no excesses for stars within 5 pc of the Sun (largely M dwarfs), but Beichman et al. (2005) detected Multiband Imaging Photometer (MIPS) 70 $\mu$m (MIPS70) excess in 25% of a small sample of FGK dwarfs known to have one or more planets. Rieke et al. (2005) detected new infrared excesses in a MIPS 24 $\mu$m (MIPS24) survey of 76 A stars; comparison with stellar ages revealed prominent differences in debris-disk properties among similar-age stars and implied that circumstellar dust masses do not decrease monotonically with time. An expanded study of 160 A stars with both MIPS24 and MIPS70 by Su et al. (2006) yielded detection rates of 32% and 33%, respectively. Bryden et al. (2006) found a disk detection frequency of 1%–2% at 24 $\mu$m and 10% at 70 $\mu$m for a sample of 69 FGK stars, while Beichman et al. (2006) reported a MIPS70 detection rate of 13% ± 3% for a survey of 82 F, G, K, and a few M stars. Weak MIPS24 excesses in four of their targets with MIPS70 detections suggested a correlation. They detected no infrared excess emission in any of 38 targets with spectral types in the range K1–M6 and concluded that *Spitzer* detection rates decline with later spectral type. A survey of 69 A3–F8 binary systems yielded slightly higher detection rates than single-star surveys with MIPS24 and MIPS70 (Trilling et al. 2007), suggesting that binary companions do not inhibit planetesimal formation. Observations of over 200 F and G main-sequence stars by Trilling et al. (2008) yielded a MIPS24 detection rate of $4.2^{+2.0}_{-1.1}\%$ and $16.4^{+2.8}_{-2.9}\%$ for MIPS70. These seminal results comprise a discrete and sparse sampling of the immediate stellar neighborhood. To complete the picture, we recently carried out MIPS Cycle-3 observations of 634 nearby stars under Program 30490, "Completing the Census of Debris Disks Around Nearby Stars," as described below. Here we report candidate debris disks identified in this survey. Analysis of the complete sample will follow in a much longer manuscript.

## 2. OBSERVATIONS AND ANALYSIS

Our sample consists of all stars in the *Hipparcos* catalog located within 25 pc of the Sun with $V < 9$ (spectral types earlier than M0) and not yet listed in the *Spitzer* Reserved Object Catalog. These criteria produced a total sample of 634 targets that were observed with MIPS24. MIPS70 observations were carried out for a subset of these that exhibited sufficiently low-background emission at 70 $\mu$m. Background emission from cirrus and zodiacal dust at 70 $\mu$m was estimated using the *IRAS* Sky Survey as accessed by IRSKY Batch Inquiry System (IBIS;

Wheelock et al. 1993). A limit of 2 mJy for confusion due to background galaxies was taken from empirical analysis by Bryden et al. (2006). Cirrus and zodiacal background limits from IBIS were combined in quadrature with the background galaxy limit from Bryden et al. (2006) to estimate a total background sensitivity limit for each target. Sources were eliminated from the MIPS70 sample if they required integration times of greater than an hour according to sensitivity criteria described below. Approximately one third of the targets from the initial sample were eliminated in this way, largely due to background noise associated with their location in the galactic plane. The remaining 436 targets were observed with MIPS70, and all 634 were observed with MIPS24.

MIPS24 integration times were chosen to detect photosphere emission at the $10\sigma$ level. Cirrus emission and background galaxies precluded MIPS70 photosphere detection at that level for many of the more distant later-type sources. We aimed, instead, for sensitivity to disks such as that around the K2V star $\epsilon$ Eridani ($\epsilon$ Eri). *IRAS* measurements indicated that $\epsilon$ Eri radiates excess infrared emission at more than three times the photosphere level at 60 $\mu$m and would have been easily detected at the 25 pc distance of our most-distant targets. MIPS70 integration times were estimated for a $3\sigma$ detection of an $\epsilon$ Eri-like disk everywhere in our volume as per the *IRAS* 60 $\mu$m measurement. Subsequent *Spitzer* MIPS70 observations of $\epsilon$ Eri revealed a ninefold increase of excess over photosphere emission (Backman et al. 2009). Consequently, our survey probed disks with one third of $\epsilon$ Eri's 70 $\mu$m excess. Nevertheless, this criterion left many of our faintest sources undetected unless they had significant excess.

MIPS Basic Calibrated Data (BCD) frames were processed with MOPEX software to build Post-BCD mosaic images. Manual aperture photometry was carried out on sky-subtracted images using the *Global Astrometric Interferometer for Astrophysics* (*GAIA*) package. Aperture sizes for source emission were 13″ and 16″, respectively, for MIPS24 and MIPS70, and aperture corrections of 1.167 and 1.968 were applied. Background emission was measured in annuli with inner and outer radii of 20″ and 32″ for MIPS24 and with 18″ and 39″ for MIPS70. To identify excess infrared emission, overall flux densities were compared to expected photosphere levels.

The photospheric 24 $\mu$m flux was predicted by extrapolating from near infrared magnitudes with a $K_s - [24]$ color relation that was derived from ground-based photometry and *Spitzer* observations. $K_s$ values were taken from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 1997). For 24 $\mu$m fluxes, we assumed that the majority of our target stars had no 24 $\mu$m excess and used our own MIPS24 observations. MIPS24 magnitudes were generated as outlined by Rieke et al. (2008), assuming a zero-point magnitude flux of 7.17 Jy. $K_s - [24]$ was then calculated for each target and averaged over all targets within a spectral subtype. $K_s - [24]$ values varied from 0.009 to 0.05 over the spectral range, A0 to K5, and increased from 0.05 to 0.2 for subtypes between K5 and M0. MIPS70 photosphere values were estimated by extrapolating from the observed MIPS24 flux as described by Trilling et al. (2008).

Nearby or early-type target stars with $K_s < 4$ were bright enough to exceed the 2MASS saturation limit and had correspondingly greater uncertainties in color-derived photosphere estimates if 2MASS values were used. For these, we used Phoenix/NextGen model fitting to measurements in the literature, including Johnson $B$, $V$, 2MASS $J$, $H$, $K_s$ (Hauschildt et al. 1999), and the *IRAS* 12 $\mu$m flux. Model fluxes for each *Spitzer* band were computed by multiplying the Phoenix/NextGen model with the MIPS filter function before scaling and fitting (Hauschildt et al. 1999; Rieke et al. 2004). SEDFIT software (J. Rhee & I. Song 2007, private communication) was modified to carry out model fitting and estimate both MIPS24 and MIPS70 photospheric values.

As illustrated in Figures 1 and 2 of Beichman et al. (2005) for MIPS24 and MIPS70, respectively, the distributions of observed-to-predicted photosphere ratios were fitted as a Gaussian function to check the method and extract a conservative estimate of the uncertainty in the photospheric estimation process. Ratios near unity are expected for a sample of stars where very few display excess infrared emission. MIPS24 ratios peaked sharply at 0.99 with $\sigma = 0.04$. MIPS70 values peaked at 1.09 with $\sigma = 0.28$.

To identify debris-disk candidates, we selected targets with infrared excess at $3\sigma$ levels or higher, i.e., $\chi_\lambda = (F_\lambda - F\mathrm{phot}_\lambda)/\sigma_\lambda > 3$. The uncertainty was calculated as $\sigma_\lambda = \sqrt{(\sigma_{\lambda,\mathrm{systematic}})^2 + (F_\lambda/(\mathrm{S/N}))^2}$, where systematic errors included both a calibration error and $K_s$ band photometric uncertainty. For MIPS24 observations at high signal-to-noise ratio (S/N) the error is dominated by uncertainties in calibration and photosphere estimation, and was estimated to be 6%. At 70 $\mu$m, the error in flux density is a combination of calibration uncertainty and background noise. We assume systematic errors in the 70 $\mu$m values of 15% of the observed flux. In addition to this, background noise was estimated from each of the images and folded into the total 70 $\mu$m uncertainty calculation.

## 3. RESULTS AND DISCUSSION

Out of 634 targets observed with MIPS24, 29 met our criteria for identification as debris-disk candidates. Definitive identification of a debris-disk origin for the infrared excess emission will require follow-up observations. Candidates are listed by *Hipparcos* catalog number in Table 1 together with the spectral types and distances to the target stars as well as MIPS24 flux density, estimated photosphere emission, flux/photosphere ratio, the S/N of the observations, and the S/N of the excess emission, $\chi_{24}$. Candidates comprise 4.6% of the sample with excess emission that ranges from 20% to 60% of photosphere values. Two thirds of both the overall targets surveyed and those on the candidate list have spectral types K and later, indicating no decrease in detection frequency with later spectral type.

Plavchan et al. (2009) pointed out that an M dwarf spectroscopic binary companion to a K dwarf primary will produce an apparent MIPS24 excess at the 10% level. Six of the candidates in Table 1 are known to be spectroscopic binaries. They all have MIPS24 excesses greater than 20% and relative spectral types that would produce a diminished effect compared to that mentioned by Plavchan et al. (2009). Several close binaries do have K and M spectral types for the primary and secondary, however. We calculate that their companions contribute less than 10% of the measured $K - 24$ color and cannot be considered as a sole source of an artifactual excess.

Out of 436 MIPS70 observations, only 145 stars were detected at $3\sigma$ levels or greater. Of these, 21 stars yielded evidence of candidate debris disks and are listed in Table 2. Target and observational properties are given as in Table 1, together with an additional column as described below. As for MIPS24 observations, the distribution of spectral types is in agreement

**Table 1**

Measured and Predicted Flux Densities (MIPS24)

| HIP | *SpT* | Distance (pc) | $F_{\rm MIPS24}$ (mJy) | $F_*$ (mJy) | $F_{\rm MIPS24}/F_*$ | S/N | $\chi_{24}$ |
|---|---|---|---|---|---|---|---|
| 169 | K5V | 15.96 | 46.97 | 34.95 | 1.34 | 33.49 | 4.96 |
| 171[a] | G5Vb | 12.46 | 215.53 | 175.34 | 1.23 | 71.89 | 4.69 |
| 3588 | K7V | 16.06 | 87.89 | 59.61 | 1.47 | 45.97 | 7.46 |
| 3810[a] | F8V | 23.96 | 212.35 | 168.02 | 1.26 | 71.52 | 5.25 |
| 5336[a] | G5Vb | 7.66 | 343.01 | 279.78 | 1.23 | 90.75 | 4.25 |
| 12623[a] | F9V | 24.76 | 259.75 | 214.49 | 1.21 | 79.01 | 3.97 |
| 13642 | G5V | 22.96 | 63.45 | 48.17 | 1.32 | 39.12 | 4.90 |
| 17750 | M1.5V | 17.46 | 25.38 | 16.00 | 1.59 | 24.68 | 6.33 |
| 21770 | F2V | 20.16 | 276.63 | 228.00 | 1.21 | 81.28 | 4.02 |
| 24783 | K7V | 20.36 | 34.60 | 26.55 | 1.30 | 28.78 | 4.27 |
| 36827 | K2V | 24.86 | 35.63 | 28.05 | 1.27 | 28.94 | 3.91 |
| 44295 | K4V | 18.36 | 52.99 | 32.19 | 1.65 | 35.52 | 7.76 |
| 54952 | K5V | 14.76 | 77.87 | 62.20 | 1.25 | 43.36 | 4.20 |
| 58345 | K5V | 10.26 | 139.11 | 112.94 | 1.23 | 57.86 | 4.14 |
| 58576 | G9IV | 12.96 | 214.13 | 172.15 | 1.24 | 71.77 | 4.43 |
| 72848[a] | K2V | 11.56 | 200.82 | 133.19 | 1.51 | 69.33 | 7.58 |
| 73633 | K3V | 24.36 | 32.05 | 26.55 | 1.21 | 27.66 | 3.09 |
| 74975 | F8III-IV | 24.76 | 234.84 | 190.40 | 1.23 | 75.07 | 4.29 |
| 77952 | F2III | 12.36 | 1256.26 | 947.00 | 1.33 | 173.49 | 5.81 |
| 78734 | K8Vk | 23.36 | 20.91 | 17.00 | 1.23 | 22.56 | 3.06 |
| 79492 | G8V | 24.46 | 82.53 | 60.57 | 1.36 | 43.57 | 5.56 |
| 83101 | K5V | 19.16 | 54.37 | 45.10 | 1.21 | 36.45 | 3.40 |
| 85561 | K5V | 18.26 | 23.95 | 19.60 | 1.22 | 33.42 | 3.52 |
| 86282 | K5V[b] | 22.16 | 33.42 | 22.20 | 1.51 | 28.15 | 6.10 |
| 99316 | K0V | 24.36 | 51.07 | 40.47 | 1.26 | 34.91 | 4.08 |
| 101150 | K5V | 23.16 | 26.33 | 20.30 | 1.30 | 25.25 | 3.97 |
| 102488 | K0III | 22.16 | 5678.52 | 3770.00 | 1.51 | 368.49 | 7.99 |
| 104239 | K1V | 17.66 | 87.26 | 70.78 | 1.23 | 45.64 | 3.99 |
| 117712[a] | K3V | 10.86 | 212.55 | 157.08 | 1.35 | 71.24 | 5.89 |

**Notes.**

[a] Spectroscopic binary.

[b] Spectral type estimated from $T_{\rm eff} = 4400$ K.

**Table 2**

Measured and Predicted Flux Densities (MIPS70)

| HIP | *SpT* | Distance (pc) | $F_{\rm MIPS70}$ (mJy) | $F_*$ (mJy) | $F_{\rm MIPS70}/F_*$ | S/N | $\chi_{70}$ | $f_d$ |
|---|---|---|---|---|---|---|---|---|
| 1368 | K7 | 14.99 | 27.88 | 5.15 | 5.41 | 5.23 | 3.35 | $1.1 \times 10^{-4}$ |
| 1499 | G0V | 23.44 | 64.45 | 8.61 | 7.48 | 8.66 | 4.58 | $7.1 \times 10^{-5}$ |
| 1598 | G0 | 24.84 | 44.75 | 5.35 | 8.37 | 7.37 | 4.35 | $6.6 \times 10^{-5}$ |
| 4148 | K3V | 14.08 | 30.25 | 8.77 | 3.45 | 5.48 | 3.01 | $3.8 \times 10^{-5}$ |
| 8497 | F3III | 23.61 | 61.79 | 25.62 | 2.41 | 8.11 | 3.01 | $6.7 \times 10^{-6}$ |
| 17439 | K0V | 16.23 | 83.30 | 8.45 | 9.85 | 10.05 | 4.99 | $1.1 \times 10^{-4}$ |
| 19893 | F4III | 20.30 | 157.37 | 35.63 | 4.42 | 13.59 | 4.63 | $1.6 \times 10^{-5}$ |
| 25775 | M0 | 19.39 | 28.22 | 2.74 | 10.30 | 5.91 | 3.99 | $2.4 \times 10^{-4}$ |
| 30503 | G2IV | 22.04 | 110.75 | 8.93 | 12.40 | 11.12 | 5.26 | $1.0 \times 10^{-4}$ |
| 32919 | K2 | 18.83 | 23.59 | 3.67 | 6.42 | 4.62 | 3.21 | $1.2 \times 10^{-4}$ |
| 36827 | K2V | 24.80 | 45.63 | 3.09 | 14.79 | 6.77 | 4.43 | $1.9 \times 10^{-4}$ |
| 43534 | K5 | 16.49 | 27.11 | 3.35 | 8.09 | 5.19 | 3.59 | $1.6 \times 10^{-4}$ |
| 50384 | F8Vbw | 22.72 | 42.93 | 13.01 | 3.30 | 6.99 | 3.36 | $1.9 \times 10^{-5}$ |
| 58451 | K2V | 20.82 | 47.95 | 4.53 | 10.58 | 7.81 | 4.59 | $1.5 \times 10^{-4}$ |
| 66781 | K0IV-V | 23.74 | 26.24 | 3.88 | 6.76 | 5.72 | 3.70 | $7.1 \times 10^{-5}$ |
| 72387 | M2V | 24.24 | 16.91 | 2.14 | 7.90 | 4.35 | 3.18 | $1.6 \times 10^{-4}$ |
| 88745 | F7V | 23.61 | 100.07 | 42.66 | 2.23 | 10.60 | 3.12 | $1.5 \times 10^{-5}$ |
| 105184 | G2V | 23.79 | 106.27 | 6.25 | 17.01 | 11.31 | 5.41 | $1.4 \times 10^{-4}$ |
| 108028 | K0 | 23.98 | 42.66 | 3.20 | 13.33 | 7.34 | 4.57 | $1.9 \times 10^{-4}$ |
| 112190 | K0 | 21.52 | 22.37 | 3.88 | 5.76 | 5.35 | 3.45 | $7.4 \times 10^{-5}$ |
| 117779 | K5 | 22.41 | 20.57 | 2.45 | 8.38 | 5.01 | 3.53 | $1.9 \times 10^{-4}$ |

with that for the general sample. In the overall sample (436 stars), 70% of the targets had spectral types K and later. The detected sample (145 stars) was biased in favor of early types, however, so less than half were K or later. Nevertheless, almost two thirds (62%) of the MIPS70 debris-disk candidates have spectral types K and later.

Targets in Table 2 are independent from those listed in Table 1 with the exception of a single K2V star, HIP 36827. A simplistic detection rate derived from the MIPS70 observed sample, $21/436 = 4.8\%$, is lower than that of other surveys and probably reflects the influence of low sensitivity for distant faint targets. A rate derived only from objects detected at $3\sigma$ levels, $21/145 = 14.5\%$ is closer to results reported elsewhere in the literature. A better estimate of the detection rate requires modeling of the variable sensitivity for the entire sample with estimates of the upper limits of detection for infrared excess. This will be presented in a future manuscript together with *Spitzer* results for all 634 stars (S. Kim et al. 2010, in preparation).

MIPS70 excesses can be expressed as a lower limit to the fraction of stellar infrared luminosity that is absorbed and re-radiated by an optically thin debris disk, under the assumption that excess emission comes from a distribution of grains radiating as a 50 K blackbody with peak emission near 70 $\mu$m. Values of this expression, $f_d \sim L_{\rm IR}/L_{\rm star}$, are listed in the final column to Table 2 and range from $6.7 \times 10^{-6}$ to $2.4 \times 10^{-4}$. For comparison, $f_d \approx 9.7 \times 10^{-5}$ for $\epsilon$ Eri (Backman & Paresce 1993). Twelve of the targets listed in Table 1 have lower-limit values of $f_d$ greater than this, suggesting that debris disks as massive as that around $\epsilon$ Eri are present at the 3% level or greater.

Tables 1 and 2 tally a total of 49 debris-disk candidates, since only one target is common to both lists. HIP 36827 exhibits excess infrared emission with flux densities of 7.6 mJy and 42.5 mJy at MIPS24 and MIPS70, respectively. The color temperature implied by these values is $T_{\rm col} = 80$ K with an implied distance of 8 AU for blackbody grains orbiting the K2 primary star.

The paucity of candidates with excess detected at both 24 and 70 $\mu$m supports the idea of independent reservoirs of dust grains, a warm one that belongs to an inner planetary region and a colder "exo-Kuiper" Belt. Incongruence between targets in Tables 1 and 2 indicate that the presence of dust grains is unrelated between the regions. This notion accords well with the idea that the most massive debris disks are the result of larger collisions that occur periodically in time and independently between asteroidal and Kuiper Belt regions. The large number of giant stars in the MIPS24 sample may suggest an alternate explanation, such as the presence of a dust shell (see Jones 2008 and references therein). Refined understanding of dust source regions will require multi-wavelength observations at high angular resolution, as has been carried out for $\epsilon$ Eri (e.g., Backman et al. 2009).

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## REFERENCES

Backman, D., & Paresce, F. 1993, in Protostars and Planets III, ed. E. H. Levy & J. I. Lunine (Tucson, AZ: Univ. Arizona Press), 1253
Backman, D., et al. 2009, ApJ, 690, 1522
Beichman, C. A., et al. 2005, ApJ, 622, 116
Beichman, C. A., et al. 2006, ApJ, 652, 1674
Bryden, G., et al. 2006, ApJ, 636, 1098
Gautier, T. N., et al. 2007, ApJ, 667, 527
Hauschildt, P. H., Allard, F., & Baron, E. 1999, ApJ, 512, 377
Jones, M. H. 2008, MNRAS, 387, 845
Plavchan, P., et al. 2009, ApJ, 698, 1068
Rieke, G. H., et al. 2004, ApJS, 154, 25
Rieke, G. H., et al. 2005, ApJ, 620, 1010
Rieke, G. H., et al. 2008, AJ, 135, 2245
Skrutskie, M. F., et al. 1997, in The Impact of Large Scale Near-IR Sky Surveys, ed. F. Garzon et al. (Kluwer: Dordrecht), 25
Su, K. Y. L., et al. 2006, ApJ, 653, 675
Trilling, D. E., et al. 2007, ApJ, 658, 1289
Trilling, D. E., et al. 2008, ApJ, 674, 1086
Wheelock, S., et al. 1993, http://irsa.ipac.caltech.edu/IRASdocs/issa.exp.sup/index.html