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NEWLY IDENTIFIED MAIN-SEQUENCE A STARS WITH CIRCUMSTELLAR DUST

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ABSTRACT

We have searched for stars with circumstellar (CS) dust using data from the *Infrared Astronomical Satellite* (*IRAS*) in two stellar samples: (I) all of the 62 A stars in Woolley's Catalogue of Stars within 25 Parsecs of the Sun (1970) and (II) 100 A stars in the Bright Star Catalogue with $4 \leq m_V \leq 5$ and $v \sin i \geq 100$ km s^{-1}. Our sample I represents an almost volume-limited sample, of which 29 stars have detections in three (12, 25, and 60 μm) or more *IRAS* bandpasses using the Faint Source Survey (FSS) data base and the new ADDSCAN/SCANPI software. We find 11 nearby A stars having [12] − [25] and [25] − [60] colors consistent with circumstellar dust. If this sample is representative of the Galaxy as a whole, more than 18% (11/62) of all A stars would have circumstellar dust. Among these 11 proto–planetary system candidates, five, namely, HD 29573 (A2 IV), HD 78045 (A2–A3 IV), HD 84121 (A3 IV), HD 159492 (A5 IV–V), and HD 193571 (A0 V) are reported for the first time. The analysis of sample II demonstrates that the use of the FSS data base indeed increases the likelihood of identifying A stars with CS dust fainter than $m_V = 4$. As a result, we find three more new dusty systems, HD 110411 (A0 V), HD 143894 (A0 IV), and HD 125473 (A3 V) in this sample. All eight of our newly identified dusty systems from both samples have Vega-like colors, which suggests that the IR emission of these systems is from warm dust similar to that seen for Vega (A0 V). So far, β Pictoris (A5 IV–V) is the only star within 25 pc of the Sun that displays IR colors indicative of both warm and cool dust. One interpretation is that the absence of cool dust in the vast majority of the systems implies that the dust disks of these stars are much less extended than that seen around β Pictoris. This is also consistent with the present negative results from attempts to image dust disks around other nearby stars directly.

Subject headings: circumstellar matter — infrared: stars — stars: early-type

1. INTRODUCTION

The discovery of excess infrared radiation, possibly indicating the presence of proto–planetary dust disks surrounding Vega, α PsA, and β Pic (Aumann et al. 1984), was one of the most important results of the *IRAS* mission. Subsequent direct CCD imaging of β Pic revealed a solar system–sized dust disk extending to at least 1100 AU (Smith & Terrile 1984). A simple picture of this system indicates a central star, encircled by an ionized gaseous inner disk and an outer dust disk. The spectroscopic UV detection of infalling and outflowing plasma surrounding β Pic suggested that the inner portions of the disk might be undergoing dynamical clearing (Kondo & Bruhweiler 1985; Lagrange et al. 1987; Bruhweiler, Kondo, & Grady 1991). To verify the link between the infalling plasma and the presence of a dust disk and to further determine the role of this linkage in the process of planetary system formation, one must search for and examine other proto–planetary system candidates. Although direct imagery provides a definitive identification of an extended solar system–sized dust disk, the β Pic disk is the only one detected by imagery to date. Attempts at imaging of more than 100 nearby stars have failed to detect any other circumstellar (CS) disk comparable to that of β Pic (Smith & Terrile 1987). However, one can still infer the presence of CS dust by the detection of IR excesses.

Since main-sequence A stars have lifetimes of order 10^9 yr or less, they probably exhibit many of the expected characteristics of a planetary system in an early evolutionary phase. The evolutionary lifetime of A stars roughly corresponds to the era of planet formation and subsequent "heavy bombardment" in our solar system. Also, A stars are numerous enough to furnish meaningful statistics and bright enough in both the UV and the optical range to permit follow-on spectroscopic studies. Previous surveys based on the *IRAS* Point Source Catalog (PSC) have resulted in the identification of 44 comparatively bright A stars with CS dust. Of these, 11 are within 25 pc of the Sun. However, several of these nearby detections are based on either marginal detections or upper limits (Sadakane & Nishida 1986). In this study we have used the *IRAS* Faint Source Survey data base and the ADDSCAN/SCANPI software available at the Infrared Processing and Analysis Center (IPAC) to search for systems with CS dust in our two samples: (I) all of the 62 A stars in Woolley's catalog (Woolley et al. 1970), which lie near the main sequence and are typically within 25 pc of the Sun, and (II) all A stars in the Bright Star Catalogue (Hoffleit & Jaschek 1982) with $4 \leq m_V \leq 5$ and $v \sin i \geq 100$ km s^{-1}. The use of the FSS data base and ADDSCAN/SCANPI processing (1) significantly increases the number of stars with detectable IR excesses, (2) improves the flux estimates for previously identified dusty systems with marginal detections at 60 μm, and (3) extends the *IRAS* detection limit down to 1 mag fainter.

2. *IRAS* DATA RETRIEVAL AND SOURCE IDENTIFICATION

In Table 1 we list all the data for the 62 A stars in sample I, including the projected rotational velocities ($v \sin i$), which provide information on how we view these stellar systems. Although these stars were selected from Woolley's Catalog of Stars within 25 Parsecs of the Sun, some appear to be beyond 25 pc. Based on the distances given in the Sky Catalogue

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TABLE 1

62 Program A Stars in Sample I

HD	SIMBAD[a] Spectral Type	BSC[b] Spectral Type	V	d[c] (pc)	$v \sin i$ (km s^{-1})	F_ν (12 μm) (Jy)	F_ν (25 μm) (Jy)	F_ν (60 μm) (Jy)	$V-[12]$	$[12]-[25]$	$[25]-[60]$	Dusty[d]
39060 (β Pic)[e]	A5 V	A5 V	3.80	24	139	3.43	9.06	19.74	1.68	2.48	2.65	Yes
172167 (Vega)[e]	A0 V	A0 V	0.03	8.1	15	41.49	11.03	9.54	0.09	0.3	1.78	Yes
216956 (α PSA)[e]	A3 V	A3 V	1.16	6.7	100	18.16	4.72	9.46	0.31	0.34	2.72	Yes
2262	A7 V	A7 V	3.90	19	219	1.56	0.42	L[f]	0.40	...	...	...
3003[g]	A0 V	A0 V	5.08	13	84	0.44	0.33	L	0.55	...	...	...
4150	A0 IV	A0 IV	4.36	71	96	0.75	0.19	L	0.04	...	...	...
11636	A5 V	A5 V	2.64	14	79	4.77	1.15	0.20	0.32	0.04	0.05	No
13709[h]	B9 V	B9 V	5.29	27	...	0.41	0.12	L	0.37	...	...	...
15008	A3 V	A3 V	4.10	35	163	1.01	0.28	L	0.13	...	...	...
16970	A3 V	A3 V	3.47	23	183	2.17	0.47	0.06*	0.26	−0.1	−0.29	No
18978	A4 V	A4 IV	4.10	23	144	1.40	0.36	L	0.47	...	...	...
28527	A6 IV	A6 IV	4.80	24	71	0.74	0.20	L	0.49	...	...	...
29573	A0 V	A2 IV	5.01	12	43	0.60	0.10	0.12*	0.34	−0.11	2.2	Yes†
33111	A3 III	A3 III	2.79	28	179	4.61	1.11	0.21	0.43	0.05	0.14	No
37507	A4 V	A4 V	4.80	57	170	1.40	1.02	L	1.44	...	...	...
38678	A2 V	A3 V	3.60	24	202	2.28	1.19	L	0.77	...	...	...
48915	A1 V	A1 V	−1.47	2.7	13	144.46	31.86	5.05	−0.12	−0.03	−0.04	No
50241[i]	A7 IV	A7 IV	3.30	16	205	3.85	1.01	0.15	0.77	0.1	−0.14	No
56405[g]	A1 V	A3 V	5.46	63	152	0.28	L	L	(0.05)**	...	...	...
56537	A3 V	A3 V	3.57	25	154	2.05	0.54	0.12*	0.36	0.15	0.3	No
60178/60179	A2 V/A1 V	A2 V/A1 V	1.58	14	30/14	10.24	2.39	0.41	0.07	0.25	0.07	No
70060	A7 III	A7 III	4.40	62	129	1.16	0.35	L	0.62	...	...	...
74956	A1 V	A1 V	1.95	21	40	8.29	1.96	0.7	0.22	0.12	0.83	No
76644	A7 V	A7 IV	3.10	15	151	3.65	0.88	0.28	0.49	0.12	0.69	No
78045	A2.5 IV	A2–A3 IVm	4.00	24	45	1.33	0.34	0.15	0.31	0.21	1.05	Yes†
80007	A2 IV	A2 IV	1.70	26	133	9.87	2.26	0.33	0.15	−0.02	−0.14	No
84121	A3 IV	A3 IV	5.32	12	39	0.50	0.19	0.35	0.71	0.63	3.23	Yes†
87696	A7 V	A7 V	4.48	26	148	1.2	0.30	L	0.67	...	...	...
89822	A0 sp	A0 psisr	4.90	11	15	0.4	L	L	(−0.13)**	...	...	...
95418	A1 V	A1 V	2.37	19	39	4.72	1.41	0.56	0.11	0.32	0.92	Yes
97277	A1 V	A2 III	4.48	72	58	0.75	0.20	L	0.18	...	...	...
97603	A4 V	A4 V	2.56	16	181	[j]	[j]	[j]	[j]	...	...	...
102590[k]	F0 V	F0 V	5.9	46	...	0.33	L	L	(0.66)**	...	...	...
102647	A3 V	A3 V	2.14	12	121	6.97	2.37	1.10	0.35	0.45	1.07	Yes
103632	A0 V	A0 V	5.17	51	74	0.31	L	L	(−0.13)**	...	...	...
106591	A3 V	A3 V	3.31	20	177	2.44	0.57	L	0.25	...	...	...
111968	A7 III	A7 III	4.30	57	81	1.41	0.37	L	0.68	...	...	...
115892	A2 V	A2 V	2.70	16	85	3.56	0.9	0.23	0.08	0.13	0.45	No
125161	A9 V	A9 V	4.80	28	137	0.80	0.21	L	0.57	...	...	...
130841	A3 IV	A3 IV	2.75	22	84	4.7	1.13	0.12*	0.41	−0.02	−0.53	No
135379	A3 V	A3 V	4.07	22	59	1.61	0.42	[j]	0.59	...	...	...
139006	A0 V	A0 V	2.21	24	133	5.81	1.70	0.77	0.16	0.33	1.07	Yes
155125	A2.5 V	A2 V	2.43	18	26	5.12	1.09	0.24	0.15	−0.03	0.31	No
157792	A3 m	A3 m	4.17	25	59	1.65	0.47	L	0.75	...	...	...
159561	A5 III	A5 III	2.10	19	219	9.32	2.15	0.32	0.49	−0.01	−0.12	No
159492	A5 IV–V	A5 IV–V	5.24	31	48	0.48	0.26	0.22	0.69	0.89	1.7	Yes†
165777	A4 IV	A4 IVs	3.70	28	80	1.75	0.39	L	0.27	...	...	...
187642	A7 V	A7 V	0.77	5.1	242	34.33	8.13	1.24	0.58	0.02	−0.10	No
188899	A3 IV	A3 IV	5.02	71	102	0.48	0.15	L	0.30	...	...	...
193571	A2 V	A0 V	5.59	45	...	0.25	0.14	0.15	0.34	0.93	1.97	Yes†
200499	A5 V	A5 V	4.84	12	71	0.71	0.15	L	0.43	...	...	...
201184	A0 V	A0 V	5.28	86	199	L	L	[j]	[j]	...	...	...
202730	A5 V	A5 V	4.40	28	178	1.18	0.34	L	0.62	...	...	...
203280	A7 IV	A7 V	2.44	14	246	7.13	1.73	L	0.55	...	...	...
207098	A IIIm	Am V	2.87	15	87	6.47	1.51	0.25	0.87	0	0	No
210418	A2 V	A2 V	3.50	25	117	2.05	0.45	L	0.25	...	...	...
212061	A0 V	A0 V	3.84	28	57	0.97	0.13	L	−0.23	...	...	...
215789	A3 V	A3 V	3.49	25	236	2.18	0.52	L	0.32	...	...	...
216336	A0 III	A0 III	4.50	59	55	0.64	L	L	(−0.02)**	...	...	...
217782	A3 V	A3 Vn	5.10	21	190	0.44	L	L	(0.18)**	...	...	...
218640[g]	G6/G8 III	G2 IV + A2	4.69	13	...	[j]	[j]	[j]	[j]	...	...	...

Note.—Four stars (HD 16970, HD 29573, HD 56537, and HD 130841) have 60 μm detections (marked by asterisks) below 0.15 Jy, with S/N ratios 3, 5, 4, and 3, respectively. In the $V-[12]$ column, a double asterisk means that no 25 μm detections are available, so a 10,000 K blackbody is assumed for the 12 μm magnitudes color correction.

[a] Spectral type based on SIMBAD data base of the Strasbourg, France, Astronomical Data Center.

[b] Spectral type listed in the Bright Star Catalogue.

[c] d = distance listed in the Sky Catalog 2000.0.

[d] Entries marked with a dagger are newly identified.

[e] Proto–planetary system candidate.

[f] L = upper limit.

[g] Listed as A2 in Woolley's catalog.

[h] Listed as A2 V in Woolley's catalog.

[i] Listed as A5 V in Woolley's catalog.

[j] No detection.

[k] Listed as A7 V in Woolley's catalog.

TABLE 2

STATISTICS OF *IRAS* IR DETECTIONS FOR SAMPLE I
62 A STARS WITHIN 25 pc OF THE SUN

IRAS Bandpass (μm)	PSC Detection	FSS Detection	ADDSCAN/SCANPI Detection
12........	52 (84%)	59 (95%)	59 (95%)
25........	36 (58%)	50 (81%)	54 (87%)
60........	11 (18%)	14 (23%)	29 (47%)
100........	4 (6%)	3 (5%)	8 (13%)

2000.0 (Hirshfeld & Sinnott 1982), 36% of our sample stars are beyond 25 pc; however, the parallaxes listed in the Bright Star Catalogue indicate that only 11% of the stars are more distant than 25 pc.

We have searched the *IRAS* FSS data base for IR sources within a few arcseconds of the nominal coordinates of each of our program stars. For an unambiguous IR source identification, we must minimize confusion from neighboring stellar and extragalactic sources, as well as infrared cirrus. Thus, we have carefully inspected the *IRAS* flux data and bibliographic information from both SIMBAD and the NASA/IPAC extragalactic data base to ensure that the *IRAS* source "position match" could be confidently attributed to the A star. Questionable identifications were not a problem for any star in our sample. Usually, galaxies can be identified in the *IRAS* PSC by requiring (1) that there be a detection at 60 μm and (2) that the flux density in this band exceed the *IRAS* flux or flux limit at 12 μm (Soifer et al. 1984). However, any star with an extended, multitemperature dust disk such as β Pic also satisfies these galaxy criteria. In these circumstances, the data must be examined carefully.

Source confusion with the low-temperature IR emission of the IR cirrus can also be minimized. In general, IR cirrus is concentrated near the Galactic plane, and its emission can be seen in all four *IRAS* bands, peaking at 60–100 μm, while stellar sources are seldom detected at 100 μm. Each IR detection has been carefully examined for possible cirrus contamination by scrutinizing both the location of the IR source on cirrus maps generated by IPAC and the source's observed IR flux distribution.

3. IDENTIFICATION OF CIRCUMSTELLAR DUST SYSTEMS

We have searched for detectable *IRAS* emission at 12, 25, and 60 μm from stars in our two samples. In sample I, the 62 A stars from Woolley's catalog, 11 stars (18%) are detected in three or more *IRAS* bandpasses based on the PSC. If the FSS data base data are considered, the number of stars with detections in three or more bandpasses increases to 14, or 23% of the sample. If we further use the ADDSCAN/SCANPI software, we significantly increase the number of detections primarily at 25 and 60 μm (we require a signal-to-noise ratio $S/N \geq 3.0$ and a template correlation coefficient larger than 0.9), i.e., more than doubling the number of stars suitable for searching for CS dust (see Table 2).

When converting the monochromatic *IRAS* fluxes to broadband magnitudes, a color correction is needed to account for changes in the effective bandpass wavelength as a function of the color (i.e., temperature) of the source. Some previous studies of CS material around A stars have assumed that the stellar photosphere dominates the IR flux distribution, where a 10,000 K blackbody is assumed (Walters, Cote, & Aumann 1987) for the stellar photospheric IR flux distribution. However, our experience with the multitemperature dusty system β Pic has shown that while this assumption is applicable at 12 μm (emission from warm dust close to the star), it is not a good assumption at 60 or 100 μm (emission from the cold dust). Therefore, we have followed the color correction scheme outlined in the FSS Explanatory Supplement (Moshir et al. 1989) instead. This approach yields systematic changes in the magnitudes, which are largest at 12 μm but smaller at 25 and 60 μm. Although the actual choice of color correction does not affect the identification of systems with IR excesses, it is likely to be important in the interpretation of all systems, particularly those with IR excesses dominated by free-free emission.

A dusty system cannot be identified based on its 12 μm excess only. This is due to uncertainties in both the calibration of the *IRAS* 12 μm data and the intrinsic stellar photospheric flux. Usually, dusty systems have strong IR excesses beyond 12 μm, but we cannot identify a dusty system based only on its 25 μm IR excess either, because the observed 25 μm excess can also be produced by free-free emission from plasma in a stellar wind or in the CS gas "shell." However, free-free emission is negligible at 60 μm, so any IR excess in this bandpass can confidently be ascribed to dust (see Fig. 3 in Cheng, Grady, & Bruhweiler 1991). Thus, to ensure identification of dusty systems, we need to examine 60 μm IR excess in combination with that at 12 and 25 μm.

We can identify dusty systems based on their [12], [25], and [60] magnitudes. Since simple calculations show that the intrinsic flux distributions of stars of different spectral types all provide $[12] - [25]$ colors close to zero, we infer the presence of CS dust, if it has a $[12] - [25]$ color more than 0.25 mag. Furthermore, a dusty system should have a significant IR excess at 60 μm. Therefore, stars with $[25] - [60] \geq 1.5$ are considered unambiguously dusty, whereas stars with $[25] - [60] \approx 1.0$ represent borderline detections for the presence of CS dust. Applying these criteria, we identify 11 nearby A stars in sample I (see Table 1) as dusty systems. The location of each star in the color-color diagram (see Fig. 1) allows us to determine whether these systems more resemble Vega or β Pic in terms of their dust temperature characteristics.

4. CONCLUSION

Since circumstellar disks may offer clues to the process of planet formation, it is important to find out the frequency with which these disks occur. Previous results for the youngest pre–main-sequence stars (Strom et al. 1989) show ~60% to have disks. Also, several groups (Aumann 1985; Sadakane & Nishida 1986; Cote 1987; Backman & Gillett 1987; Walker & Wolstencroft 1988; Colin & Francesco 1989; Cheng et al. 1991) have searched for main-sequence stars with far-IR excesses comparable to those of Vega or β Pic. Aumann (1984) concludes that about 18% of *all* nearby main-sequence stars show IR excesses, if the stellar flux distributions are representative of "normal" main-sequence dwarfs, on which the IR excesses are based.

In sample I we have used the *IRAS* $[12] - [25]$ versus $[25] - [60]$ color-color diagram to identify the dusty systems unambiguously. According to our results, the percentage of nearby A stars with detectable IR excess has been increased largely by the use of the FSS data base and ADDSCAN/SCANPI processing. Specifically, we have found that more than 18% of the A stars in the solar neighborhood display

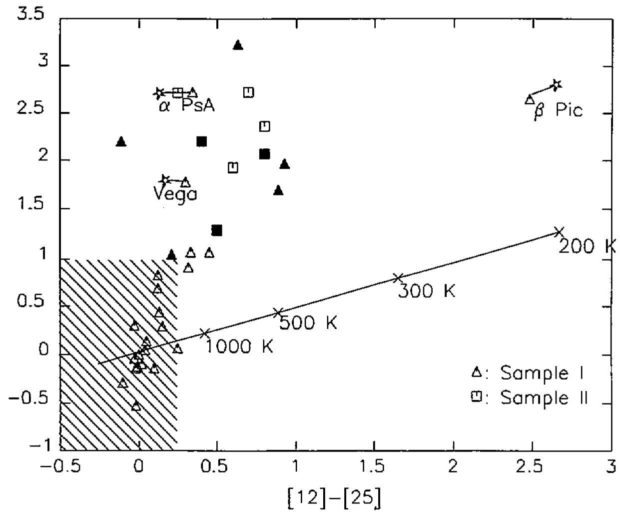

FIG. 1.—Infrared color-color diagram. Triangles represent 28 nearby A stars from our first sample. The five newly identified dusty A stars in this sample are shown with filled triangles. The effect on the colors of two different color corrections for the three proto–planetary system candidates β Pic, Vega, and α PsA is shown (*open triangles*: color correction based on *IRAS* flux ratios; *stars*: color correction based on 10^4 K blackbody distribution). Squares represent seven A stars identified from our second sample as having CS dust. Three newly identified dusty A stars in this group are shown with filled squares. The solid line indicates a single-temperature blackbody with values of temperature indicated. Stars without circumstellar dust disks occupy the shaded region.

Vega-like infrared colors. This is also true for our five newly identified systems: HD 29573, HD 78045, HD 84121, HD 159492, and HD 193571 (see Fig. 1). The identification of these five Vega-like systems, all fainter than $m_V = 4.0$, is due to the increasing sensitivity of the co-added *IRAS* data. Since most of them have very low rotational velocities, we are probably viewing their disks nearly pole-on, and direct CCD imaging of these dust disks may therefore be impossible.

Consequently, we include sample II to demonstrate that the use of the FSS data base indeed increases the likelihood of identifying new dusty systems fainter than $m_V = 4$. Since one of our major goals is to study the CS gas in the newly identified dusty systems with follow-up UV and optical spectroscopic observations, the $v \sin i \geq 100$ km s^{-1} restriction is imposed. Our analysis of this sample is based upon the FSS data only, without the use of ADDSCAN/SCANPI software. Our results show that 10% (10/100) of the stars have FSS detections in at least three *IRAS* bandpasses. Based on our identifying criteria, we find that (7%) stars are unambiguously dusty and have IR colors similar to Vega (see Fig. 1). Among them, three are newly identified, namely, HD 110411 (A0 V, $d = 63$ pc, $[12] - [25] = 0.8$, $[25] - [60] = 2.07$), HD 125473 (A0 IV, $d = 65$ pc, $[12] - [25] = 0.5$, $[25] - [60] = 1.29$), and HD 143894 (A3 V, $d = 42$ pc, $[12] - [25] = 0.4$, $[25] - [60] = 2.2$). If analogies can be made to sample I, use of the ADDSCAN/SCANPI software should double the total number of detections. We stress that the total number of detections in this sample represents a lower limit. A more extensive analysis of this sample is in progress.

As Figure 1 shows, we find no A stars with IR colors that resemble those of β Pic. This may suggest that β Pic is atypical and all the other nearby A stars which display IR excesses possess much smaller, less extended dust disks than β Pic (1100 AU). This interpretation would also explain the null detection for direct CCD imaging of dust disks except for β Pic. Certainly, a smaller disk close to the star would be relatively warm. This implies that the disk of β Pic might have been formed by a different process from that for other identified dusty systems, or that the β Pic disk is in a different evolutionary phase.

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