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IRAS * OBSERVATIONS OF MATTER AROUND NEARBY STARS†

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A systematic search of the *IRAS* point-source catalog has identified eight new nearby stars which are "Vega-like" in terms of their large 60-micron excess. This brings to twelve, of the set of 36 nearby dwarfs and subgiants which are bright enough to have *IRAS* catalog fluxes at 12, 25, and 60 microns, the total number of known Vega-like stars within 25 parsecs of the sun. Two significant effects distinguish these twelve stars from the 24 stars without 60-micron excess: The predominance of spectral type A and the absence of double stars in the Vega-like group. While both effects are intuitively consistent with the interpretation that the 60-micron excess radiation is due to a disk of protoplanetary material, suggesting an early phase in the evolution of a planetary system, this distribution can also be due to luminosity and brightness selection effects. A large fraction of the F, G, and K main-sequence stars, i.e., stars with longer main-sequence lifetimes than A stars, may thus also be surrounded by disks, but only the warmest of these disks are identifiable with high confidence in the *IRAS* catalog by their 60-micron excesses.

Key words: Vega–near stars–protoplanetary disk–*IRAS*

I. Introduction

The discovery of the far-infrared excess of α Lyrae (Aumann et al. 1984), interpreted as evidence of protoplanetary material, and the discovery of similar excesses in three other relatively nearby stars, ϵ Eridani, α Piscis Austrini, and β Pictoris (Gillett, Aumann, and Low 1984; Gillett et al. 1985) has raised the question about the frequency of this effect in stars in the solar neighborhood. The preliminary statistical analysis of the *IRAS* data base (Aumann 1984) indicated that a significant fraction of nearby stars showed evidence of cool infrared excess. In the following we present the results of a systematic search of the *IRAS* point-source catalog in order to identify additional Vega-like nearby stars and to test if the statistical distribution of spectral classes and double stars of Vega-like relative to normal stars might provide further insight into the physical conditions producing the 60-micron excess.

II. Search Method

For the purpose of this search we have characterized a point source in the *IRAS* catalog as "Vega-like" if it satisfied the following criteria:

(a) A high confidence position association with a known dwarf or subgiant within 25 parsecs.

(b) Catalog flux at 12, 25, and 60 microns.

(c) A statistically significant excess at 60 microns.

(d) Source spatial extent less than 90 arc sec at 60 microns.

The search for position associations between *IRAS* sources and nearby stars used the *Catalog of Nearby Stars* (Gliese 1969), which includes stars up to 22 parsecs from the sun, augmented with stars out to a distance of 25 parsecs from Woolley et al. (1970). These catalogs contain information on 1736 individual or multiple stars; i.e., multiple stars with the same nominal positions or within 15 arc sec are counted as one source, since the *IRAS* focal-plane resolution is inadequate to permit separate flux measurements of each component. The star positions were corrected for proper motion to epoch 1983.5.

III. Results

The search of the *IRAS* catalog yielded 756 position associations with nearby stars. Of these 756 stars, 504 are identified in the catalogs as subgiants or dwarfs and 267 of the 504 have *IRAS* catalog fluxes at 12 and 25 microns. Only 36 of these 504 stars have flux measurements at 12, 25, and 60 microns. The positions of 50% of the *IRAS* sources are within 10 arc sec of the associated nearby star. Associations further than 40 arc sec apart were rejected for the sake of reliability, although this cutoff is not well defined. Table I lists the right ascension and declination (epoch 1950) of the 36 *IRAS* sources identified by the search and the distance from the position of the associated star in units of arc minutes. This is followed by the galactic latitude, the Gliese number or Woolley number (prefix G and W, respectively), the name or DM number, the catalog spectral type, luminosity class, visual magnitude and the 2.2-micron magnitude where available (from Gezari, Schmitz, and Mead 1982). For stars where the K magnitude was not readily available, we have estimated it based on $(V-K)$ given by Johnson (1966) for main-sequence stars as a function of spectral type. Estimated K magnitudes are flagged with the letter E. Since we are dealing almost exclusively with A, F, and G stars, the K magnitude is sufficiently close to the expected 12-micron

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TABLE I

DWARFS AND SUBGIANTS WITHIN 25 PARSEC WITH IRAS FLUX AT 12, 25 AND 60 MICRONS

	RA (1950)	DEC	B II	DEL	NUMBER	NAME	CLASS	MV	[K]	[12]	[25]	[60]	[100]	K -[12]	[12] -[25]	[12] -[60]
	0: 6:32	58 52.3	-3.27	0.03	8.0	BET CAS	F2IV	2.27	1.48	1.34	1.28	0.49	-3.55U	0.14	0.06	0.85
	0:23:32	-77 31.9	-39.78	0.05	19.0	BET HYI	G1IV	2.79	1.32	1.30	1.26	1.25	-0.82U	0.02	0.04	0.05
	1:22:32	59 58.4	-2.35	0.15	58.1	DEL CAS	A5V	2.68	2.37	2.27	2.28	1.41M	-2.75U	0.10	-0.01	0.86
	1:41:40	-16 11.6	-73.44	0.13	71.0	TAU CET	G8V	3.50	1.65	1.56	1.59	1.21	-1.11U	0.09	-0.03	0.35
*	2:42:44	-18 47.1	-62.54	0.50	111.0	TAU(1) ERI	F6V	4.46	3.32	3.32	2.89	-0.30M	-2.53M	0.00	0.43	3.62
	3: 9:57	-29 10.6	-59.03	0.04	127.0A	ALF FOR	F8IV	3.95	2.51	2.47	2.46	1.54M	-0.82U	0.04	0.01	0.93
*	3:30:32	- 9 37.6	-49.05	0.11	144.0	EPS ERI	K2V	3.73	1.65	1.56	1.37	-0.07	-1.47	0.09	0.19	1.63
	3:40:50	- 9 55.5	-46.00	0.03	150.0	DEL ERI	K0IV	3.54	1.45	1.34	1.36	1.20M	-0.82U	0.11	-0.02	0.14
	3:43:35	-64 57.7	-43.54	0.05	154.2	BET RET	K0IV	3.84	2.01E	1.16	1.12	1.12	-0.95U	0.85	0.04	0.04
*	4:14:43	-51 36.6	-44.76	0.04	167.1	GAM DOR	F0V	4.24	3.45E	3.46	3.31	1.40M	-0.82U	-0.01	0.15	2.06
*	5:14:15	79 10.7	22.65	0.05	196.0	DM+79 169	F6V	5.04	3.97E	3.86	3.73M	1.50M	-0.82U	0.11	0.13	2.36
*	5:46: 5	-51 4.9	-30.61	0.10	219.0	BET PIC	A5V	3.85	3.47	2.66	0.04	-2.75	-3.41	0.81	2.62	5.41
	6:34:30	-19 12.7	-11.79	0.09	239.1	NU CMA	K1V	3.92	1.61	1.54	1.52	1.34M	-0.82U	0.07	0.02	0.20
	6:42:55	-16 39.5	-8.88	0.16	244.0A	ALF CMA	A1V	-1.46	-1.35	-1.38	-1.39	-1.24	-1.74	0.03	0.01	-0.14
	7:31:24	31 59.9	22.48	0.01	278.0A	ALF GEM	A1V	1.95	1.46	1.49	1.52	1.36	-0.82U	-0.03	-0.03	0.13
	7:36:38	5 20.7	13.02	0.13	280.0A	ALF CMI	F5V	0.37	-0.65	-0.74	-0.53	-0.73	-0.82U	0.09	-0.21	-0.01
	8:43:19	-54 31.5	-7.37	0.12	321.3A	DEL VEL	A0V	2.02	2.05E	1.72	1.68	0.98	-3.14U	0.33	0.04	0.74
	9:12:39	-69 30.6	-14.41	0.04	339.2	BET CAR	A1IV	1.67	1.53	1.52	1.53	1.43M	-0.82U	0.01	-0.01	0.09
*	10:58:50	56 39.1	54.80	0.10	W9343	BET UMA	A0V	2.40	2.35	2.33	2.08	0.94	-0.82U	0.02	0.25	1.39
*	11:46:28	14 51.1	70.80	0.24	448.0	BET LEO	A3V	2.14	1.90	1.90	1.62	0.32	-0.82U	0.00	0.28	1.58
	13:53:14	-54 27.6	6.98	0.06	534.1	DM-54 5466	G8V	6.00	4.37E	3.95	3.77M	1.13M	-3.32U	0.42	0.18	2.82
	14:35:54	-60 37.4	-0.69	0.03	559.0A	ALF CEN	G2V	-0.01	-1.51	-1.86	-1.84	-1.65	-6.11U	0.35	-0.02	-0.21
*	15:32:34	26 52.9	53.77	0.00	W9524	ALF CRB	A0V	2.2	2.21	2.10	1.83	0.80	-0.82U	0.11	0.27	1.30
	15:37:44	-44 30.0	8.43	0.04	594.0	DM-44 10310	F5V	4.63	3.56E	3.61	2.82	0.94	-1.73U	-0.05	0.79	2.67
*	15:54:10	15 48.6	45.7	0.34	603.0	GAM SER	F6V	3.86	2.65	2.54	2.60	1.44	-0.82U	0.11	-0.06	1.10
	16:39:22	31 41.7	40.29	0.10	635.0A	ZET HER	G0IV	2.89	1.27	1.20	1.17	1.12M	-0.79U	0.07	0.03	0.08
	17:12: 9	-38 32.4	-0.11	0.25	662.0A*	DM-38 11686	G3IV	6.66	5.19E	2.59	0.61	-1.86	-6.87U	2.60	1.98	4.45
	17:44:29	27 44.5	25.62	0.04	695.0A	MU HER	G5IV	3.42	1.70	1.66	1.66	1.57M	-0.82U	0.04	0	0.09
*	18:35:15	38 44.3	19.24	0.14	721.0	ALF LYR	A0V	0.03	0.00	-0.04	-0.17	-1.95	-3.00	0.04	0.13	1.91
	19:48:21	8 44.3	-8.90	0.08	768.0	ALF AQL	A7V	0.76	0.20	0.21	0.16	0.25	-0.94U	-0.01	0.05	-0.04
	19:52:51	6 16.6	-11.09	0.17	771.0A	BET AQL	G8IV	3.72	1.61	1.62	1.58	1.41M	-0.79U	-0.01	0.04	0.21
	20:44:17	61 39.1	11.64	0.09	807.0	ETA CEP	K0IV	3.43	1.22	1.10	1.14	0.83	-2.32U	0.12	-0.04	0.27
*	21:45: 1	-47 32.1	-49.10	0.07	838.0	DM-47 13928	G2V	5.58	4.14E	4.24	3.59M	1.63M	-0.82U	-0.10	0.65	2.61
*	22:54:54	-29 53.4	-64.91	0.06	881.0	ALF PSA	A3V	1.16	0.99	0.86	0.72	-1.89	-3.40	0.13	0.14	2.75
	23:28:57	58 52.9	-2.13	0.59	895.4	DM+58 2605	K0V	6.75	4.92E	4.70	3.59M	0.62M	-4.07U	0.22	1.11	4.08
	23:37:16	77 21.3	15.31	0.03	903.0	GAM CEP	K1IV	3.21	0.89	0.72	0.77	0.79	-0.88U	0.17	-0.05	-0.07

magnitude of the stellar photosphere. The next four columns in Table I contain the *IRAS* magnitude of the source at 12, 25, 60, and 100 microns. Fluxes listed as medium quality in the *IRAS* catalog are flagged with the letter M and upper limits at 100 microns are flagged with the letter U. The zero point of the *IRAS* magnitude system at any wavelength is defined as the flux from a 10,000 K blackbody, subtending a solid angle of 1.57×10^{-16} sterad. For the *IRAS* effective wavelengths, zero magnitude corresponds to 28.3, 65.73, 1.19, and 0.43 Jy at 12, 25, 60, and 100 microns, respectively (*IRAS Catalog Explanatory Supplement*, 1984, p.VI-20). The last three columns in Table I give the $K-[12]$, $[12]-[25]$, and $[12]-[60]$ magnitude differences.

The stars listed in Table I are position associations with point sources in the *IRAS* catalog. In order to make these associations more reliable, we have carried out two additional steps: A check for potential source confusion and a check of the photometry of sources with the medium flux quality. While we expect the size of the region emitting the 60-micron excess to be extended, we would not expect any evidence of extent from survey data. The angular diameter of a source has to be of the order of 90 arc sec or more at 60 microns before it can be identified as extended, based on survey data, while the size of the 60-micron emitting region in the case of Vega was only about 23 arc sec (Aumann et al. 1984), measured using special observations. None of the 36 sources listed in Table I show indications of being extended at the 90-arc-sec level.

A. *Potential Source Confusion*

The fact that an *IRAS* source has fluxes listed at 12, 25, and 60 microns and its position lies within 40 arc sec of a nearby star makes it very likely, but does not assure that the 60-micron source, the 12- and 25-micron source, and the star are physically associated with each other. This is due to the fact that the *IRAS* beam is large, 0.75×4.2 arc min at 12 and 25 microns and 1.5×4.3 arc min at 60 microns, resulting in some likelihood of source confusion and erroneous position merging of unrelated sources.

The hypothesis that the 12- and 25-micron fluxes are due to the photosphere of the star can be tested by comparing the expected photospheric flux with the observed flux. With two exceptions, to be discussed below, the $K-[12]$ color index listed in Table I is a fraction of a magnitude, indicating that the stellar photospheres contribute the bulk of the 12-micron flux.

Excess flux at 60 micron could be due to a cold background source. Since the nearby stars are essentially uniformly distributed, the most likely source of confusion for sources sufficiently far away from the galactic plane would be background galaxies. Inspection of the raw data for each source indicated that the centroids of the sources of the 60-micron radiation coincided with the 12- and 25-micron sources, i.e., the stellar photospheres, to within an error box of 40×120 arc sec. The density of galaxies with a flux of more than 0.5 Jy, the 60-micron completeness cutoff (*IRAS* Catalog Supplement, VIII-9), is 0.65 per square degree (Rowan-Robinson et al. 1985). The probability of a spurious association is thus 2.4×10^{-4}, i.e., the probability, that one of the 267 sources with 12- and 25-micron photospheric flux has an excess 60-micron flux due to a background galaxy, is less than 10%. This argument is not valid within a few degrees of the galactic plane, where the probability of source confusion is much higher. Rather than rejecting sources within some arbitrary distance from the galactic plane, we have included them in Table I, but the flux of sources within 10° of the galactic plane has to be interpreted with considerable caution. For example, the association between the *IRAS* source with the large $[12]-[25]$ and $[12]-[60]$ excess and G662.0A, is questionable, even though it has high quality catalog fluxes and lies within 15 arc sec of the *IRAS* source: It lies at -0.1 degree galactic latitude. Inspection of the raw data of the *IRAS* source associated with G321.3, which has a high-quality 60-micron flux but is only 7° from the galactic plane, indicated the presence of another source of almost equal flux in the beam which was not resolved by the survey processing. Based on this inspection, the 60-micron flux associated with G321.3 was decreased by 0.6 magnitude. In only four sources (α Lyr, α PsA, β Pic, and ϵ Eri, ref. cit.) has the coincidence of the centroid of the 60-micron source been measured to be within 5 arc sec of the stellar photosphere. These measurements were done using additional observations, not survey data. All four sources are well above the galactic plane.

B. *Verification of the Flux*

Four of the 36 sources identified by the search have medium-quality catalog fluxes at 25 microns, 16 have medium-quality 60-micron fluxes. In order to increase the confidence in the medium-quality flux measurements we have coadded the survey data for all 36 sources. Coadding typically increases the effective survey sensitivity by about one stellar magnitude. While a detailed analysis of the coadding process will be given elsewhere (Kopan et al. 1986), we briefly need to discuss the distinction between the flux listed in the *IRAS* survey catalog and flux measured by coadding the survey data. During the ten-month lifetime of the *IRAS*, each position on the sky was typically scanned ten to twelve times by detectors in each wavelength band (Explanatory Supplement p. III-9). The flux of sources listed in the catalog was obtained by separately detecting the sources on each scan with a threshold detector, measuring the flux, and then using essentially the noise-weighted average of the n measurements above threshold as a best estimate of the true flux (Explanatory Supplement p.V-55). For catalog sources with medium quality fluxes, detections did not occur on all n possible scans and the resulting average is biased toward detections boosted above the threshold by noise. In the coaddition process the time-sampled data from each detector, which during the survey passed over the known position of a source, are added together into an inertial reference grid centered on the source coordinate. These coadded data, with the noise potentially decreased by the square-root of 12, are then used to make an improved estimate of the source flux. For three of the 16 sources with medium-quality catalog 60-micron flux, coadding indicated that the sources were fainter by 0.7 to 1.0 magnitude. For the remaining sources coadding produced less than 0.3 magnitude of change, which we consider at this point to be insignificant.

IV. Discussion

With the qualifications discussed above, we assume in the following discussion that all 36 position associations with nearby stars are physical associations. Figures 1 and 2 show the [12] − [25] color index and the [12] − [60] color index versus [12] for the 36 nearby stars listed in Table I. Selected stars in the figures are identified by their Gliese or Woolley numbers. For the four sources which required a correction to the photometry we have plotted an arrow from the catalog color (given in Table I) to the corrected color.

Figure 1 shows that, with the exception of two sources, the 36 stars show little anomalous [12] − [25] magnitude difference. Of the four previously announced sources, α Lyr (G721), α PsA (G881), ϵ Eri (G144), and β Pic (G219), only the latter is conspicuous in terms of its large [12] − [25] excess. It is interesting to note that recently a circumstellar disk has been observed around this star using a stellar coronagraph (Smith and Terrile 1984). The other conspicuous source is G662.OA, a G3 dwarf ($m_v = 6.66$), with a close companion ($m_v = 6.8$) at a distance of 0″.1. We have already indicated that this association is questionable because of the proximity of the galactic plane.

Inspection of Figure 2 indicates that 23 of the 36 stars have less than 0.35 excess between [12] and [60], while twelve stars have [12] − [60] > 1.1. If we define a [12] − [60] excess of more than 1.0 as significant for sources further than 10° from the galactic plane, we have a reasonably clean division between stars with and without excess. We refer to the twelve stars with [12] − [60] > 1 as Vega-like. These stars are identified in Table I by asterisks and are plotted in Figures 1 and 2 with filled-in symbols. The two most pronounced effects which distinguish these twelve Vega-like stars from the 24 stars in our sample without significant excess are the predominance of A and F spectral types and the absence of double stars in the Vega-like group. In the following we analyze brightness, luminosity, catalog completeness, and color-threshold selection effects which may contribute to this distribution and show that our observations are consistent with the assumption that the 60-micron excess is due to cold material distributed in a ring or toroid about the central star, suggestive of a proto-planetary disk.

The overabundance of A and F stars, compared to the known distribution of spectral classes in the near stars and the fact that of the twelve stars identified as Vega-like six are spectral type A, four are spectral type F, and only one each are spectral type G and K, would at first glance suggest an effect common to relatively young stars, if the known main-sequence lifetime is used as a rough indicator of age. Table II shows the spectral class distribution of all 504 dwarfs or subgiants detected by *IRAS* at [12] < 5, the distribution of the 36 stars from Table I and the number of stars detected with [12] − [60] > 1 as a function

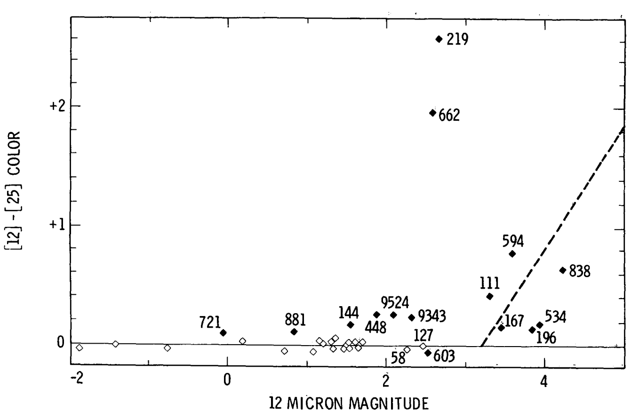

FIG. 1–The [12] − [25] color index as function of 12-micron magnitude for all dwarfs and subgiants within 25 parsecs, which have catalog fluxes at 12, 25, and 60 microns. The stars represented by solid dots have more than one magnitude of the [12] − [60] color index. The dashed line represents the 99% catalog completeness boundary for 25-micron sources.

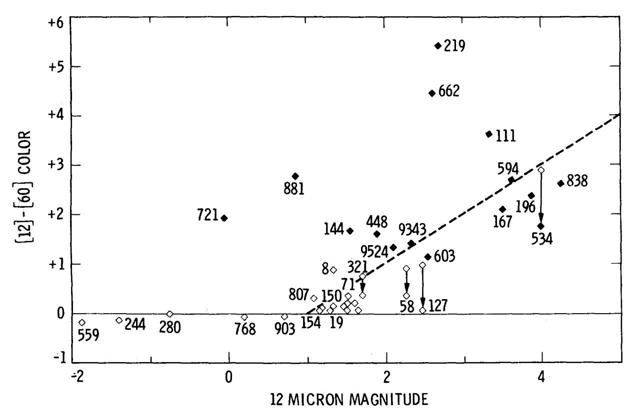

FIG. 2–The [12] − [60] color index as function of 12-micron magnitude for all dwarfs and subgiants within 25 parsecs, which have catalog fluxes at 12, 25, and 60 microns. The stars represented by solid dots have more than one magnitude of the [12] − [60] color index. The dashed line represents the 99% catalog completeness boundary for 60-micron sources. The arrows on four sources reflect the downward revision of the flux after coadding or raw detector data inspection as discussed in the text.

TABLE II

Spectral Classification of All Dwarfs and Subgiants Within 25 Parsecs Listed in the IRAS Catalog

	B	A	F	G	K	M
504 SOURCES WITH [12] < 5	4	43	133	163	126	3
36 SOURCES WITH CATALOG [60]	0	12	8	9	7	0
12 SOURCES WITH [12]-[60]>1	0	6	4	1	1	0

TABLE III

Spectral Classifications of Dwarfs and Subgiants Within 25 Parsecs Listed in the IRAS Catalog with [12] < 2

	B	A	F	G	K	M
34 SOURCES WITH [12] < 2	2	9	5	10	8	0
23 SOURCES [12]<2 AND CATALOG [60]	0	8	2	7	6	0
4 SOURCES WITH [12]-[60]>1	0	3	0	0	1	0

of spectral type. From Table II we conclude that between 14% (6 of 43) to 50% (6 of 12) of all A stars and between 3% to 50% of all F stars, but less than 1% of the G and K stars would be expected to show Vega-like excess at 60 microns.

A quantitative interpretation of Table II has to take into account the fact that the *IRAS* catalog is complete at a level four magnitudes fainter at 12 microns than at 60 microns. (*IRAS* catalog completeness if above 0.99 for [12] < +5.0, [25] < +3.2, and [60] < 1.0, (Catalog Supplement, p.VIII-9).) Within 0.5 magnitude fainter than these limits the completeness decreases to near 1%, (Rowan-Robinson et al. 1985). The extrapolation from the observed fraction of Vega-like stars in any spectral class to the true fraction of all nearby stars which would be expected to be Vega-like is thus heavily biased by brightness selection effects. In order to obtain a better estimate of brightness selection effects we consider only those 34 of the 504 subgiants and dwarfs with [12] < 2.0. Twenty-two of these 34 stars are listed in Table I, i.e., have 12, 25, and 60 magnitudes. The remaining twelve are fainter than [60] = +1, i.e., they have [12] − [60] < 1 and are therefore by our definition not Vega-like. No Vega-like stars will have been missed in this set of 34 stars due to the catalog completeness cutoff at [60] = 1.0. Table III gives the spectral class distribution of these 34 stars and, for each spectral class, the count of stars with more than one magnitude of excess at 60 microns. Only four of the 34 stars have significant excess by our definition. Of these four stars, three are spectral class A, constituting 30% of the A stars in the [12] < 2 group. None of the two B, five F, and ten G stars and only one of eight K dwarfs with [12] < 2, the K2 dwarf ϵ Eri is on the Vega-like list.

From the fact that large 60-micron excess is observed less frequently in F, G, and K stars than in A stars one cannot conclude that the physical phenomenon causing the excess is common in stars with short main-sequence lifetimes, i.e., presumably young, but is much less frequent in stars with lower luminosity and presumably on the average older stars. If we interpret the 60-micron excess as evidence for a ring or disk of material, similar to that deduced in the case of Vega, we need to ask the following question: Is it possible that a large fraction of all main-sequence stars have similar disks, but *IRAS* can detect only the hottest of these disks, i.e., disks with the smallest diameter and/or those surrounding the more luminous main-sequence stars. In order to analyze this question, we assume that the excess from the Vega-like stars can be fitted to first order with a simple disk model. We then test if disks of comparable physical dimensions and optical depths as those detected around the A stars could be detected by *IRAS* if a solar-type star was at the center instead of an A star. The model consists of a ring of radius D of large particles (i.e., unity emissivity), at temperature T, in thermal equilibrium with the central star and effective radiating area C, i.e., the ring is actually an optically thin disk with a hole at the center. We calculate the color temperature of the ring from the 25- and 60-micron measurements, after subtracting the photospheric contribution. This color temperature is then used to deduce the effective solid angle of the ring and its effective radiating area C, since the ring diameter is fixed by the temperature and the luminosity of the central star. Table IV summarizes the results for each of the Vega-like stars. For the stellar luminosities we used typical values from Allen (1976). The calculation of the radius D assumes unity emissivity. The parameter $\tau = C/\pi D^2$ is a rough measure of the optical depth of the disk. The quality of the model is tested by checking how well the predicted 12-micron flux fits the observations. The model gives a satisfactory fit for the eleven of the twelve Vega-like stars which show little excess at 12 microns, but underestimates the 12-micron magnitude of β Pic by 0.8 magnitude. Typical values of τ range from 10^{-4} to 10^{-3}, resulting

TABLE IV

Calculated Parameters for Large-Particle Ring Models

Name	Star S	Star LO	CALCULATED SINGLE RING PARAMETERS T[K]	[SR] *10^{14}	EFF. AREA [AU^2]	RADIUS [AU]	TAU *10^3
TAU(1)ERI	F	2	71	30	2.25	22	1.5
EPS ERI	K	0.25	106	6	0.026	3.5	0.67
GAM DOR	F	6	77	4	0.46	32	0.14
DM+79 169	F	2	81	3.5	0.50	17	0.055
BET PIC	A	20	106	90	8.9	31	3.3
BET UMA	A	80	120	1.4	0.20	48	0.028
BET LEO	A	30	111	4	0.28	35	0.072
ALF CRB	A	80	141	1.0	0.24	35	0.062
GAM SER	F	2	76	3	0.18	19	0.16
ALF LYR	A	80	84	80	2.1	99	0.068
DM-47 13928	G	1	105	1.5	0.11	7.1	0.71
ALF PSA	A	30	75	110	2.03	76	0.11

in minimal effect on the photospheric emission in the visible. Typical disk temperatures for A and F stars are in the 70K to 100K range. The disk radii corresponding to thermal equilibrium for unit emissivity are of the order of 50 AU for A stars and somewhat smaller, 20 AU for F stars. The disk temperatures of the G star (G838) and the K star (ϵ Eri) are near the top end temperature range observed for the A and F stars, in spite of their much lower luminosity.

If we now assume that the disk parameters deduced for the A stars are typical and independent of luminosity, we can estimate if disks around solar-type stars could be identified from their 60-micron excess in the *IRAS* catalog. Table V gives the calculated [12] − [25] and [12] − [60] excess if the stars at the centers of the disk modeled for the five Vega-like A stars were replaced by stars of one solar luminosity. We have not used β Pic for this argument because of the unsatisfactory fit of the simple disk model to the data at 12 microns, as mentioned above. It can be seen that the [12] − [60] micron excess predicted by the model exceeds the one-magnitude threshold in none of the five Vega-like G stars, although it is close in two cases. We conclude that even if everyone of the 15 F and G stars with [12] < 2 had a ring with physical parameters bounded by those deduced for the five A stars, we would expect to be able to detect fewer than one in five, i.e., three of 15 with more than one magnitude of 60-micron excess. The fact that none of 15 F and G stars with [12] < 2 were detected with Vega-like excess leads to the conclusion that our data are consistent with 30% of all F and G main-sequence stars having Vega-like disks, but only the most extreme cases are sufficiently hot to be detectable by *IRAS*.

Next to the prominence of A stars in the Vega-like list is the conspicuous absence of double stars. While ten of the 36 stars in Table I are identified in the near star catalogs as members of multiple-star systems, none of the twelve stars identified as Vega-like are. However, only three of twelve A stars listed in Table I are double stars. Since we concluded that about 30% of all A stars show excess, we would have expected only one Vega-like spectral type A double star instead of none. In addition, as discussed above, we would have expected less than one in five F and G stars, single or double, to be identified as Vega-like from survey data. The statistical probability of expecting less than one source and finding none does not justify a claim of an anticorrelation between Vega-like stars and double stars.

TABLE V

Calculated [12]-[25] and [12]-[60] Color Indices If the Star at the Center of the Rings of Five Vega-Like A Stars Was Replaced by a G2 Star

RING PARAM.	[12]-[25]	[12]-[60]
G2 ALF LYR	0	0.25
G2 ALF PSA	0	0.87
G2 ALF CRB	0	0.58
G2 BET UMA	0	0.38
G2 BET LEO	0.01	0.86

The simple ring model provides a relatively self-consistent interpretation of the observed distribution of spectral classes and double stars with and without Vega-like 60-micron excess. This strengthens the hypothesis that large 60-micron excess in any main-sequence star can by itself be interpreted to first order as evidence of protoplanetary material, even without a direct measurement of the angular source extent at 60 microns, which was available only in the case of Vega, α PsA, and β Pic. However, a more definitive argument in favor of protoplanetary material around nearby stars cannot be made without supportive data from other wavelengths and, for statistical purposes, a significantly longer list of Vega-like sources than are available at present.

V. Conclusions

A systematic search of the *IRAS* point-source catalog has identified eight new nearby stars which are "Vega-like" in terms of their large 60-micron excess. This brings to twelve the total number of known Vega-like stars within 25 parsecs of the sun, from the set of 36 nearby dwarfs and subgiants which are bright enough to have *IRAS* catalog fluxes at 12, 25, and 60 microns. Two significant effects distinguish these twelve stars from the 24 stars without 60-micron excess: The predominance of spectral type A and the absence of double stars in the Vega-like group. While both effects are intuitively consistent with the interpretation that the 60-micron-excess radiation is due to a disk or ring of protoplanetary material, suggesting an early phase in the evolution of a planetary system, the same distribution can be produced by luminosity and brightness selection effects. A large fraction of the F, G, and K main-sequence stars, i.e., stars with longer main-sequence lifetimes than A stars, may thus also be surrounded by disks, but only the warmest of these disks are identifiable with high confidence in the *IRAS* catalog by their 60-micron excesses.

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