Possible Young Stellar Objects without Detectable CO Emission

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Abstract

Young stellar objects (YSOs) usually appear in molecular clouds as infrared objects associated with a molecular envelope. Wouterloot and Brand (1989, A&A 50.133.012) searched 1302 IRAS point sources with reliable fluxes at 25, 60, and 100 µm near to the galactic plane for 12CO(J = 1 − 0) emission; 1077 sources were detected. Among their far-infrared sources without detectable CO emission, we found that at least 18 objects are invisible at optical and near-infrared wavelengths. The infrared spectral indices between 2.2 µm and 25 µm correspond to those of class I YSOs, and the IRAS colors are similar to those of the usual YSOs. These peculiar far-infrared objects are highly concentrated around the galactic plane and the distances are estimated to be ∼1 kpc. Although their distribution is away from molecular clouds, some of them seem to be associated with large dark clouds or weak radio sources. These objects are possible YSOs with low CO abundance in the envelopes.

Key words: Stars: formation — Infrared: stars — Circumstellar matter — Young stellar objects: search

1. Introduction

Most of stars burstly form in molecular clouds. Low-mass stars are also born in globules that are dispersely distributed in spiral arms (e.g., Yun, Clemens 1994). Based on the spatial distribution, age distribution, and kinematics of T Tauri stars, Feigelson (1996) claims that dispersed T Tauri stars with various ages consist of components drifting outward from currently active sites of star formation in molecular clouds, and components formed in now-dissipated cloudlets in past molecular cloud complexes (see Neuhäuser 1997).

Young stellar objects (YSOs) grow in molecular cores up to the maximum luminosity phase while showing spectral energy distributions (SEDs) with a peak at the far-infrared (FIR) wavelength. The gas-to-dust mass ratio in molecular cores is considered to be similar to the interstellar value, because the core masses derived from the intensities of dust emission (e.g., Walker et al. 1990) are consistent with those derived from CO lines or other molecular lines (e.g., Casoli et al. 1986; Benson, Myers 1989; Wouterloot et al. 1989). In low-mass pre-main sequence stars, such as T Tauri stars, however, the envelope masses derived from the intensities of dust emission are larger than those derived from the CO line intensities (e.g., Dutrey et al. 1996); it has occurred at some stage from YSOs to pre-main sequence stage that CO molecules have been removed from the envelopes or locked up on grains or more complex molecules in the envelopes (e.g., Aikawa et al. 1997).

In this paper, we show the presence of 18 bright FIR objects peculiar in the sense that they are not detectable in the 12CO line, show the class I YSOs’ SEDs and are located away from molecular clouds. Section 2 describes the sample. In section 3 we consider infrared SED indices of the sample using data of IRAS and our near-infrared photometry, and show that the indices correspond to those of class I YSOs. In section 4 we discuss the IRAS colors, sky distribution, and luminosities of the sample. In section 5 we give a summary.

2. Sample

Wouterloot and Brand (1989) made a complete search for the 12CO(J = 1 − 0) line on 1302 IRAS point sources with reliable flux densities at 25, 60, and 100 µm (Joint IRAS Science Working Group 1988; IRAS PSC) and with characteristic FIR colors of YSOs in a zone of ℓ = 85° to 280° and b = −10° to 10° (we hereafter call those WB objects); their beam size and rms noise level were 43″ and 0.2–1.0 K for SEST observations, and 21″ and 0.7–1.5 K for IRAM observations, respectively. The velocity ranges of their 12CO observations are 220 km s⁻¹ with a central
velocity of 60 km s\(^{-1}\) for SEST observations, and 208 km s\(^{-1}\) with central velocities of \(-50\) to 20 km s\(^{-1}\) for IRAM observations. They detected CO emission on 1077 point sources (82.7\%), and no emission on another 223 sources. Wouterloot et al. (1990) considered that WB objects without detectable CO emission are extragalactic objects because of the homogeneous sky distribution in the surveyed region, in contrast with the distribution of WB objects with CO emission concentrated around the galactic plane. We examined the literature and optical images on Schmidt plates for all 223 WB objects without CO emission, and found that 132 are associated with optical objects, which are early-type stars, planetary nebulae, and galaxies. But the remaining 91 WB objects do not have any distinct optical counterparts at the positions of the IRAS point sources. The results are summarized in table 1.

Iwata et al. (1997) carried out near-infrared imaging observations of 55 objects among the 91 optically invisible WB objects without \(^{12}\)CO emission at the Okayama Astrophysical Observatory (OAO). As a result, 16 objects were found to be galaxies and possible galaxies, 4 objects are \(\text{H} \text{ii}\) regions and a possible \(\text{H} \text{ii}\) region, and 14 objects are stars, while 21 objects don’t show any counterparts, even in the \(J, H,\) and \(K‘\) bands. The 21 WB objects invisible at optical and near-infrared wavelengths and not detectable in \(^{12}\)CO(\(J = 1 \rightarrow 0\)) line were the sample of this study. We call those “peculiar FIR” objects. Iwata et al. (1997) claimed that these objects are mostly galactic objects because of the sky distribution along the galactic plane and the FIR colors colder than those of IRAS galaxies.

Figure 1 shows a relation of the 60 \(\mu\)m flux density in IRAS PSC versus the \(^{12}\)CO(\(J = 1 \rightarrow 0\)) line intensity for 21 peculiar FIR objects and 97 WB objects with \(^{12}\)CO emission existing at \(\ell = 85° \) to 105°. The CO intensities are the values of Wouterloot and Brand (1989); the single-line objects are preferentially adopted. For objects associated with multi-component CO lines we adopted a line if it is several times or more stronger than other components or it has some active features. For the peculiar FIR objects the upper limits are shown. We used the 97 WB objects shown by dots in figure 1 as a control sample, which are representatives of YSOs at around the maximum luminosity phase in molecular cores (Wouterloot et al. 1990). A correlation similar to that of the control sample is shown in Casoli et al. (1986). Figure 1 indicates that the peculiar FIR objects have relatively less strong 60 \(\mu\)m flux densities and extremely weak CO intensities among WB objects.

To ascertain the reality of the peculiar FIR objects, we requested the Infrared Processing Analysis Center (IPAC) for co-addition of the IRAS data. As results of the ADDSCAN-SCANPI programs, in which 6 to 21 scan data were co-added for each band of each object, more reliable flux densities were obtained for the four bands of all objects, except for a 12 \(\mu\)m flux density of IRAS 22044+5451 and an 100 \(\mu\)m flux density of IRAS 04375+5016.

Table 2 lists 21 peculiar FIR objects with respect to the number of Wouterloot and Brand (1989), IRAS name, galactic coordinate transformed from the equatorial coordinate of IRAS point source, flux densities at 12, 25, 60, and 100 \(\mu\)m quoted from IRAS PSC at the first line of each object and those of co-added data at the second line, three infrared colors calculated using the co-added data, infrared luminosity at 1 kpc (an assumed distance, described in subsection 4.2), and mode of our near-infrared observation. We computed the luminosity \(L_{IR}\) using an equation (Emerson 1988),

\[
L_{IR} = 0.31d^2(20.653f_{12} + 7.538f_{25} + 4.578f_{60} + 1.762f_{100})L_\odot, \tag{1}
\]

where \(f_\lambda\) is the co-added flux density in Jy and \(d\) is a distance in kpc.

### 3. Observations and Results

The near-infrared imaging observations were carried out at OAO on 1995 August and 1996 February using Okayama Astrophysical System for Infrared imaging and Spectroscopy (OASIS) with a detector NICMOS-3 equipped on the 1.88 m reflector (Yamashita et al. 1995). The FOV was \(4′ \times 4′\) and the pixel size was 0.97. The exposure times were 300 s, 150 s, and 225 s at the \(J, H,\) and \(K‘\) bands, respectively, for 18 objects, and 600 s at \(J\) or \(H\) bands for the other three objects (see table 2). The details of the observations and data reduction were shown in Iwata et al. (1997). Figure 2 shows the optical and near-infrared images of \(1′.2 \times 1′.2\) around the 21 objects. The optical images were made from Digitized Sky Surveys produced at the Space Telescope Science Institute based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain. At the positions of IRAS point sources which are indicated by the position uncertainty ellipses quoted in IRAS PSC, we could not find any distinct optical or near-infrared counterpart.

During the observations we observed three photometric standard stars, HD 44612, BD +0°1694, and HD 105601 (Elias et al. 1982); their \(K\) magnitudes are 7.040, 4.585, and 6.685, respectively. For a detection limit of \(S/N = 10\), we obtained the limiting magnitudes to be \(K‘ = 14.3\) to 15.2 for 225 s exposure, where the range of magnitudes was due to the different sky conditions. The magnitude difference of the OASIS \(K‘\) band (2.16 \(\mu\)m) and \(K\) band (2.19 \(\mu\)m) is less than 0.03 mag in the rms value for more than 50 stars (Okumura et al. 1999, in preparation). For a similar photometric system, Wainscoat and Cowie...
(1992) derived $K' - K=0$ to 0.08 mag for 18 stars. We assume the OASIS $K'$ magnitude to be equivalent to the $K$ magnitude. The 18 peculiar FIR objects from WB 70 to WB 584 listed in table 2 are less bright than $K = 14.3$. We thus adopt $K = 13.7$ as the upper limit for the 18 peculiar FIR objects, assuming an interstellar extinction less than $0.06$ at the $K$ band, i.e., $A_V < 5.6$ (Mathis 1990).

The $K$ magnitude is transformed to flux density $f_K$ in Jy, following Bessell and Brett (1988); i.e.,

$$\log f_K = 0.4(13 - K) - 2.38. \quad (2)$$

Equation (2) yields $\log f_K = -2.66$ and $\log(\nu f)_K = 11.47$ for $K = 13.7$. The upper limit of $\log(\nu f)_K = 11.47$ is less than $\log(\nu f)_{25}$ at 25 $\mu$m for all of the 18 peculiar FIR objects, which are $\log(\nu f)_{25} = 13.08 + \log(f_{25}) > 12.3$ for their values of $f_{25} > 0.2$ Jy, as shown in table 2. YSOs are classified by the spectral index, $\alpha = -d \log(\nu f)_\nu/d \log \nu$, between 2.2 $\mu$m and 25 $\mu$m. Lada (1987) defined class I YSOs to be objects with $\alpha_{2.2,25} > 0$, and class II YSOs to be $-2 < \alpha_{2.2,25} < 0$. Class I YSOs are usually invisible at optical wavelengths because of heavy obscuration by dense molecular clouds, and they are considered to be at an early stage of stellar evolution. Typical class II YSOs are T Tauri stars. All of the 18 peculiar FIR objects have positive $\alpha$-indices corresponding to class I YSOs. For the remaining three objects (WB 628, WB 901, and WB 1001), we can not give $\alpha_{2.2,25}$. Although the exposure times at the $J$ and $H$ bands for these objects were longer than those for the other 18 objects, we found no counterpart within the position uncertainty ellipses of the IRAS point sources. In the following discussion we include these objects in the peculiar FIR objects.

The $\alpha$-indices of all of the peculiar FIR objects are also positive between $\lambda = 25$ $\mu$m and 60 $\mu$m, where $\alpha_{25,60} = 2.63 \log(\nu f_{60}/f_{25}) - 1$ (see table 2). But the values of $\alpha_{12,25} = 3.137 \log(\nu f_{25}/f_{12}) - 1$ are negative for 12 peculiar FIR objects with $\log(f_{25}/f_{12}) < 0.32$ (see table 2). This means that more than half of the peculiar FIR objects have a second peak at between 2.2 $\mu$m and 25 $\mu$m.

4. Discussion

4.1. Features of the Peculiar FIR Objects

Figures 3 and 4 show IRAS color-color diagrams for the peculiar FIR objects, the control sample, which are usual YSOs, and cirrus. The cirrus colors indicated by the open circles were measured by Boulanger and Perault (1988) in 8 nearby molecular clouds, and the filled circle stands for the FIR color of warm cirrus in the H I cloud at high galactic latitude (Boulanger et al. 1985). Clemens et al. (1991) measured the infrared colors of 248 globules and small molecular clouds, and obtained the mean values and dispersions to be $\log(f_{100}/f_{60}) = 0.70 \pm 0.20$, $\log(f_{60}/f_{25}) = 0.68 \pm 0.34$, and $\log(f_{25}/f_{12}) = 0.01 \pm 0.30$; these are similar to the colors of cirrus described in Boulanger and Perault (1988). Clemens et al. interpreted the infrared emission of globules to be cirrus. We find in figures 3 and 4 that the IRAS colors of the peculiar FIR objects resemble those of the usual YSOs rather than the colors of cirrus, except for the warm cirrus. Among the visually known WB objects without a detectable $^{12}$CO line, there are early-type stars, and their number is as many as about half of the galaxies, as shown in table 1. In table 3, such 11 early-type stars with reliable 12 $\mu$m flux densities are given. The seven stars from B5 to A2 are possibly associated with IRAS point sources having $f_{60} \approx 2$ Jy to 12 Jy, which are similar values to those of the peculiar FIR objects. The visual magnitudes are 5 to 9 mag, and thus the $K$ magnitudes are brighter than 9 mag (Bessell, Brett 1988). In order to make apparent $K$ magnitudes of these stars be less than 13 mag due to extinction, the extinction value should be greater than $A_V \approx 37$ (Mathis 1990), which is unusually large interstellar extinction. The latitude distributions differ between these stars and the peculiar FIR objects. The three B0 or OB stars listed in table 3 are also associated with IRAS point sources with $f_{60} \approx 36$ Jy to 56 Jy; the values are one order of magnitude larger than the typical values of the peculiar FIR objects. Putting these stars at distances three-times further than the present distances, we may obtain $m_v \approx 11.5$ to 13 and $K > 12$. If there is an additional interstellar extinction of $A_V > 7^m$, we may find no object on these positions at visual and $K$ bands for detection limits of $m_v = 19$ and $K = 13$. Such large interstellar extinctions are only caused by the presence of molecular clouds in the line of sight. But the peculiar FIR objects do not have detectable CO emission. We rule out the possibility that the peculiar FIR objects mostly correspond to obscured early-type stars with an FIR emitting envelope. Galaxies have IRAS colors similar to those of YSOs in a range of $\log(f_{60}/f_{25}) = 0.6 - 1.2$ and $\log(f_{100}/f_{60}) = 0.0 - 0.6$ (e.g., Sauvage, Thuan 1994). It is still possible that a few of the peculiar FIR objects are obscured galaxies with intrinsically low surface brightness.

4.2. Distances and Luminosities of the Peculiar FIR Objects

About half of the 21 peculiar FIR objects are located within $b = 2^\circ$ and 90% are within $4^\circ$ (see table 2). This concentration toward the galactic plane is higher compared with that of globules by Clemens and Barvainis (1988), who found the extent of the globules in $b$ to be $10^\circ$ to $12^\circ$. This suggests that the distances to the peculiar FIR objects are further than the typical distances of dark globules, $\sim 600$ pc (Clemens, Barvainis 1988). If
we take ±4° as the extent in b of the peculiar FIR objects and 87 pc as the layer thickness, the same as that of molecular gas within 1 kpc by Dame et al. (1987), the typical distances of the peculiar FIR objects are ~ 1.2 kpc. Note that the angular scale height of the ultra-compact H II regions is 0′6, which corresponds to ~90 pc at the distance of the galactic center (Wood, Churchwell 1989).

For an assumed distance of 1 kpc, the peculiar FIR objects have luminosities of ~4 L⊙ to 96 L⊙ (see table 2), which correspond to the highest values of YSOs in the Taurus–Auriga and Ophiucus regions (Kenyon et al. 1990). The peculiar FIR objects should have internal energy sources, and they seem to have intermediate YSO luminosities.

The beam size, 21′′, of Wouterloot and Brand’s (1989) observations at IRAM for the 19 objects, except for WB 901 and WB 1001, corresponds to about 0.1d pc, where d is an assumed distance in kpc, and is comparable to or smaller than the typical CO core sizes at distances of d < 3 kpc. Thus, the weak CO intensities of the peculiar FIR objects are not caused by dilution effects.

4.3. Location of the Peculiar FIR Objects

The cirrus 2 flags (CIRR2) in IRAS PSC indicate a ratio of the cirrus flux, FC to source flux at 100 µm, FS:

\[ \text{CIRR2} = \frac{(8/3) \log(F_C/F_S) + (19/3)}{1} \]  

(3)

The distributions of the cirrus 2 flags are shown in table 4 for the control sample and the peculiar FIR objects; the peculiar FIR objects have flags by two grades higher than the control sample. The difference almost corresponds to the different 100 µm intensities between the peculiar FIR objects and the control sample (see figures 1 and 3); the cirrus intensities are not stronger around the peculiar FIR objects compared with the locations of the control sample.

YSOs leave its parent molecular cores with time, and the offset distances may become up to 1 pc for bright YSOs (e.g., Kenyon et al. 1990; Clark 1991). The peculiar FIR objects may have its parent molecular cores in the neighborhood. Dobashi et al. (1994) made a 13CO(J = 1 − 0) survey at a region of ℓ = 80° to 104° and b = −7° to 10°5 with 2′7 angular resolution and 8′ grid spacing; they detected emission lines >1.2 K km s−1 at 2191 positions, or 9% of the observed points. Yonekura et al. (1997) made a successive 13CO survey in the region ℓ = 100° to 130° and b = −10°5 to 20° with a same beam size and a same grid spacing as Dobashi et al. (1994). Although there are 15 peculiar FIR objects among the regions of these two surveys, none of them are associated with the molecular clouds. The peculiar FIR objects at other regions are also not located on any molecular clouds detected by Dame et al. (1987). At ℓ < 140°, 7 of the 17 peculiar FIR objects are located on or near to large Lynds dark clouds; these are WB 92 vs. Lynds 1083, WB 151 and 153 vs. Lynds 1107, WB 274 vs. Lynds 1238, WB 302 vs. Lynds 1264, and WB 425 and 428 vs. Lynds 1373 (Lynds 1962). These imply that the peculiar FIR objects tend to be associated with large dark clouds, or to be located at distances further than the large dark clouds. Yun and Clemens (1995) found 22 YSOs with near-infrared counterparts in globules and classified them into 10 class I objects and 12 class II objects. Their class I YSOs have K = 9.8 to 13.9 and the luminosities at assumed distance of 600 pc are similar to those of the peculiar FIR objects. There is, however, an outstanding difference that Yun and Clemens’ class I YSOs almost have CO outflows (Yun, Clemens 1994), in contrast with the weak CO emissions of the peculiar FIR objects.

Four peculiar FIR objects (WB 72, 92, 127, and 157) are located near to radio sources with 18 − 39 mJy at λ ≃ 6 cm (Gregory et al. 1996); the separations between the FIR and radio sources are 39″ to 108″. None of the peculiar FIR objects are on the X-ray point sources detected by ROSAT (Voges et al. 1994).

5. Summary

We found the presence of unusual IRAS point sources in the sense that they are bright at 25, 60, and 100 µm but invisible at optical and near-infrared wavelengths as well as in the 12CO line. At least 18 such objects have α-indices between 2.2 and 25 µm, corresponding to class I YSOs. The IRAS colors are similar to those of the usual YSOs; in detail, about half of them have a second peak at between 2.2 µm and 25 µm and the largest log(f100/f60) values of YSOs. Although the peculiar FIR objects avoid molecular clouds, seven objects are located near to large dark clouds, and four are near to radio sources. The distances are induced to be around 1 kpc, implying that they are mostly YSOs with intermediate luminosities and low CO abundance in the envelopes.

Further observations of these objects in molecular lines and millimeter continuum are needed to clarify their nature.

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Table 1. Optical counterparts of IRAS point sources not associated with the $^{12}$CO line in Wouterloot and Brand’s (1989) search.

| Optical object         | Number | Reference                                                                 |
|------------------------|--------|---------------------------------------------------------------------------|
| star                   | 41     | SAO Star Catalog (1966), Wackering (1970), Mermilliod, Mermilliod (1994) |
| galaxy                 | 79     | Nilson (1973), Yamada et al. (1993), Takata et al. (1994), Nakanishi et al. (1997) |
| planetary nebula       | 12     | Acker et al. (1992)                                                       |
| unknown                | 91     |                                                                           |

* The number of galaxies with known redshifts is 65 among them.

Table 2. IRAS data of the point sources invisible at optical and near-infrared wavelengths and having no detectable $^{12}$CO line.

| WB No. | IRAS name     | ℓ (°) | b (°) | $f_{12}$ (Jy) | $f_{25}$ (Jy) | $f_{60}$ (Jy) | $f_{100}$ (Jy) | log of $f_{100}/f_{60}$ | $f_{60}/f_{25}$ | $L_{IR}^* (L_{⊙})$ | NIR obs. |
|--------|---------------|-------|-------|---------------|---------------|---------------|---------------|----------------------|---------------|-------------------|----------|
| 70     | 21188+5517    | 96.05 | 4.06  | 0.49          | 0.49          | 10.38         | 43.63         | 1.0                  | 1.28          | 0.70              | 48       |
| 72     | 21199+4949    | 92.32 | 0.06  | 0.25          | 0.30          | 1.30          | 7.70          | 1.2                  | 0.03          | 0.24              | 25       |
| 92     | 21306+5532    | 97.45 | 3.09  | 0.73          | 2.48          | 8.79          | 15.41         | 1.34                 | 0.76          | 0.24              | 25       |
| 117    | 21422+5625    | 99.24 | 2.67  | 0.36          | 0.59          | 6.63          | 38.02         | 0.06                 | 1.05          | 0.76              | 35       |
| 119    | 21426+5732    | 99.92 | 3.38  | 0.51          | 0.59          | 6.63          | 38.02         | 0.06                 | 1.05          | 0.76              | 35       |
| 127    | 21472+5642    | 99.95 | 2.44  | 0.22          | 0.39          | 5.22          | 15.73         | 0.25                 | 1.13          | 0.48              | 18       |
| 151    | 22035+5442    | 100.56| −0.54 | 0.11          | 0.27          | 4.01          | 8.63          | 0.39                 | 1.17          | 0.33              | 12       |
| 153    | 22044+5451    | 100.74| −0.49 | 0.25          | 0.26          | 1.49          | 6.97          | —                   | 0.76          | 0.67              | 7        |
| 157    | 22096+5725    | 102.81| 1.19  | 0.25          | 0.40          | 7.70          | 25.57         | 0.23                 | 1.24          | 0.50              | 31       |
| 168    | 22169+5316    | 101.37| −2.83 | 0.30          | 0.51          | 8.96          | 28.61         | 0.23                 | 1.24          | 0.50              | 31       |
| 246    | 23055+5913    | 110.10| −0.77 | 0.26          | 0.40          | 8.67          | 27.07         | 0.65                 | 0.70          | 0.33              | 4        |
| 260    | 23122+5758    | 110.45| −2.25 | 0.34          | 0.71          | 6.95          | 30.83         | 0.60                 | 0.99          | 0.65              | 29       |
| 272    | 23190+5637    | 110.83| −3.84 | 0.25          | 0.50          | 1.65          | 3.02          | 0.59                 | 0.59          | 0.18              | 23       |
| 274    | 23217+6028    | 112.45| −0.33 | 0.37          | 0.53          | 4.26          | 14.79         | 0.76                 | 0.82          | 0.62              | 18       |
| 302    | 23504+6802    | 117.55| 6.07  | 0.26          | 0.52          | 5.49          | 13.65         | 0.76                 | 0.82          | 0.62              | 18       |
| 425    | 02264+6034    | 134.70| 0.20  | 0.44          | 0.63          | 12.96         | 50.79         | 0.25                 | 1.19          | 0.60              | 59       |
| 428    | 02309+6034    | 135.21| 0.41  | 0.59          | 0.96          | 9.59          | 29.53         | 0.23                 | 0.98          | 0.50              | 43       |
| 584    | 04375+5016    | 155.50| 2.65  | 0.31          | 0.47          | 4.54          | 8.57          | 0.47                 | 0.47          | 0.53              | —        |
| 628    | 05183+3323    | 173.43| −1.86 | 0.66          | 1.02          | 14.70         | 44.07         | 0.07                 | 0.09          | 0.50              | 10: 1    |
| 901    | 06486-0110    | 214.02| −0.61 | 0.48          | 0.54          | 5.88          | 23.50         | 0.55                 | 0.61          | 0.54              | 28: 27   |
| 1001   | 07272-1909    | 234.31| −0.68 | 0.25          | 0.28          | 2.31          | 8.87          | 0.30                 | 0.37          | 0.28              | 13: J    |

* For an assumed distance of 1 kpc.
†: the exposure time was 300 s at J-band, 150 s at H-band, and 225 s at $K'$-band. H: the exposure time was 600 s at H-band. J: the exposure time was 600 s at J-band.
Table 3. IRAS point sources without CO emission and associated with known stars.

| WB No. | IRAS name       | $\ell$  | $b$  | $f_{12}$ (Jy) | $f_{25}$ (Jy) | $f_{60}$ (Jy) | $f_{100}$ (Jy) | Star       | Sep.* | Ref.  |
|--------|-----------------|---------|------|---------------|---------------|---------------|---------------|------------|-------|-------|
| 17     | 20556+4806      | 88.34   | 1.80 | 0.35          | 0.91          | 9.75          | 27.05         | 050280     | 6''   | 1     |
| 164    | 22150+6109      | 105.49  | 3.89 | 0.35          | 1.92          | 36.71         | 78.53         | Em. star 11B | 2''   | 2     |
| 167    | 22162+5539      | 102.60  | −0.78| 0.70          | 2.49          | 36.64         | 93.46         | B0 10.4    | 15''  | 3     |
| 207    | 22444+5853      | 107.51  | 0.00 | 0.43          | 1.57          | 14.38         | 33.75         | Em. star   | 35''  | 2     |
| 454    | 02495+6414      | 135.64  | 4.64 | 0.40          | 1.15          | 11.77         | 26.01         | 012493     | 9''   | 1     |
| 575    | 04331+5211      | 153.62  | 3.40 | 0.23          | 0.46          | 2.95          | 7.62          | 024716     | 22''  | 1     |
| 600    | 05017+2639      | 176.80  | −8.71| 0.43          | 0.69          | 2.48          | 6.59          | 076945     | 7''   | 1     |
| 645    | 05247+3422      | 173.37  | −0.20| 1.66          | 5.03          | 56.89         | 135.78        | 058067     | 64''  | 1     |
| 655    | 05293+1701      | 188.50  | −8.89| 0.43          | 1.23          | 3.74          | 4.06          | 094630     | 4''   | 1     |
| 893    | 06467−1505      | 226.21  | −7.38| 0.43          | 1.62          | 4.60          | 5.68          | 151962     | 15''  | 1     |
| 1177   | 08428−3657      | 258.27  | 3.52 | 0.26          | 0.88          | 5.05          | 9.21          | 199573     | 64''  | 1     |

* The separations given in IRAS PSC.
† 1: Star Catalog (SAO 1966), 2: Wackering (1970), and 3: Mermilliod and Mermilliod (1994).

Table 4. Distribution of IRAS cirrus 2 flags for the control sample and the peculiar FIR objects.

| Flag ......................... | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | total |
|----------------------------|---|---|---|---|---|---|---|---|---|------|
| Control sample ............ | 1 | 3 | 20| 21| 28| 19| 4 | 1 | 0  | 97   |
| Peculiar objects .......... | 0 | 0 | 1 | 1 | 2 | 6 | 7 | 3 | 1  | 21   |
Fig. 1. IRAS 60 µm flux density (Jy) versus the $^{12}$CO($J = 1 - 0$) line intensity (K) for IRAS point sources obtained by Wouterloot and Brand (1989). The dots indicate 97 objects with $^{12}$CO emission. The crosses indicate 21 objects, the CO intensities of which are the upper limits in the Wouterloot and Brand observations. The 21 objects are also invisible in the optical and near-infrared wavelengths.
Fig. 2. Sample images at optical and near-infrared wavelengths around peculiar FIR objects. The optical images were made from the Digitized Sky Survey and the near-infrared images were taken at OAO by using OASIS; the 18 near-infrared images, except for last three, are at the $K'$ band, and for IRAS 05183+3323 it is at the $H$ band, and for the last two at the $J$ band. The FOV is $1.2' \times 1.2'$. The ellipses are the position uncertainty ellipses taken from IRAS PSC.
Fig. 3. IRAS color–color diagram of the peculiar FIR objects (crosses), the control sample (dots), and cirrus (open and filled circles). $f_\lambda$ is the IRAS flux density at $\lambda$ $\mu$m.
Fig. 4. Same as figure 3, but for the colors of $\log(f_{60}/f_{25})$ versus $\log(f_{25}/f_{12})$. 
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