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FGK 22 μm excess stars in LAMOST DR2 stellar catalog

Chao-Jian Wu[1,2], Hong Wu[1,2], Kang Liu[3], Tan-Da Li[2], Ming Yang[1], Man-I Lam[1], Fan Yang[1], Yue Wu[1], Yong Zhang[4], Yong-Hui Hou[4] and Guang-Wei Li[1]

[1] Key Laboratory of Optical Astronomy, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China; *chjwu@bao.ac.cn*

[2] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China

[3] Department of Astronomy, Beijing Normal University, Beijing 100875, China

[4] Nanjing Institute of Astronomical Optics & Technology, National Astronomical Observatories, Chinese Academy of Sciences, Nanjing 210042, China

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Abstract Since the release of the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) catalog, we have had the opportunity to use the LAMOST DR2 stellar catalog and the WISE All-Sky Data Release catalog to search for 22 μm excess candidates. In this paper, we present 10 FGK candidates which show an excess in the infrared at 22 μm. All the 10 sources are newly identified 22 μm excess candidates. Of these 10 stars, five stars are F type and five stars are G type. The criterion for selecting candidates is $K_s - [22] \geq 0.387$. In addition, we present the spectral energy distributions covering wavelengths from the optical to mid-infrared band. Most of them show an obvious excess from the 12 μm band and three candidates even show excess from 3.4 μm. To characterize the amount of dust, we also estimate the fractional luminosity of 10 22 μm excess candidates.

Key words: infrared: planetary systems — stars: formation — planetary systems: protoplanetary disks

1 INTRODUCTION

More and more surveys (performed with the *Infrared Astronomical Satellite (IRAS)*, *Infrared Space Observatory (ISO)*, *Spitzer Space Telescope*, *Herschel*, *Wide-field Infrared Survey Explorer (WISE)*, etc.) have been conducted to search for infrared (IR) excess stars (especially systems with dust disks and exoplanets) since the first discovery of IR excess (known as a debris disk) around Vega in the 1980s (Aumann et al. 1984).

In fact, there are many reasons that can cause excess at the IR band (Wu et al. 2013). Protostars (Thompson 1982), their surrounding dust disks (Gorlova et al. 2004, 2006; Rhee et al. 2007; Hovhannisyan et al. 2009; Koerner et al. 2010; Wu et al. 2012), companion stars (like white dwarfs and M stars, white dwarfs and brown dwarfs or/and dust disks) (Debes et al. 2011), giant stars, a background galaxy, a background nebula, the interstellar medium and random foreground objects (Ribas et al. 2012) can all produce IR excess. In our study, we only focus on IR excess stars which are caused by protostars and their surrounding dust disks.

In previous work, there has not been a complete catalog of stars with a large amount of spectral information that can be used to search for IR excess stars. The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, also called the Guo Shou Jing Telescope, Cui et al. 2012) Data Release 2 (DR2) contains 4 136 482 spectra and it is the largest stellar spectral catalog available at present. Undoubtedly, it will provide us with unique insights into the population of IR excess stars. More details about the LAMOST data will be described in Section 2.1.

While searching for IR excess stars from the LAMOST Stellar Catalog, we also introduce the WISE All-Sky Data Release catalog (Wright et al. 2010, Wu et al. 2013). Some recent works about studying IR excess stars with *WISE* have been published. Rizzuto et al. (2012) presented an analysis of 829 *WISE* stars in the Sco-Cen OB2 association and observed that B-type stars have a smaller excess fraction than A and F-type stars. Luhman & Mamajek (2012) found ∼50 new transitional, evolved debris disk candidates from *Spitzer* and *WISE* data. Wu et al. (2013) focused on bright stars ($V_{\rm mag} \leq 10.27$) and searched more than 70 newly identified 22 μm excess stars. Vican & Schneider (2014) studied 2820 solar type stars and found 74 new stars with *WISE* excess at 22 μm. Patel et al. (2014) presented a sensitive search for *WISE W3* and *W4* excess candidates within 75 pc from the Sun and expanded the number of known cases with 10−30 μm excess to 379. Theissen & West (2014a,c,b) studied M dwarfs with *WISE* that show 12 and 22 μm excess.

We introduce the LAMOST survey, and describe the candidate selection criterion and source identification in Section 2. In Section 3, we analyze their IR properties and present their spectral energy distributions (SEDs). The conclusion and summary are presented in Section 4.

2 DATA

2.1 LAMOST Survey

LAMOST, which is a Wang-Su reflecting Schmidt telescope, is a new type of wide field telescope with a large aperture. The advantages of wide field and large aperture, combined with 4000 fibers (taking 4000 spectra in a single exposure), provide us with the opportunity to carry out the largest stellar and galactic survey to date (Zhao et al. 2012). The limiting magnitude is as faint as $r = 19$ at a resolution of $R = 1800$, which is equivalent to the design aim of $r = 20$ for the resolution $R = 500$.

To maximize the scientific potential of the facility, wide national participation and international collaboration have been emphasized. The survey has two major components: the LAMOST ExtraGAlactic Survey (LEGAS) and the LAMOST Experiment for Galactic Understanding and Exploration (LEGUE) survey of stellar structure in the Milky Way.

The first observations of the LAMOST regular survey began on 2012 September 28 (Luo et al. 2012), and were successfully finished on 2013 July 15. In total, over 1.2 million spectra of 689 square degrees with a signal to noise ratio (S/N) larger than 10 were obtained. The data set provided by LAMOST DR1, which include spectra of the pilot survey and spectra of the first year of the regular spectroscopic survey, has already been published for data users based in China and their international partners. The DR1 totally contains 2 204 860 spectra, including 717 660 spectra from the pilot survey and 1 487 200 spectra from the regular survey.

In the stellar catalog, there are 648 820 stars in the pilot survey and 1 295 586 stars in the first year spectroscopic survey. In addition, the stellar catalog contains the atmospheric parameters of 1 085 404 stars..

The second year of observations that were part of the LAMOST regular survey began in September, 2013 and concluded in July, 2014 under the joint effort of the entire staff based at the LAMOST center for operation and development. In total, over 1.3 million spectra with S/N larger than 10 were obtained during the past year, which demonstrates the advantages of LAMOST in spectral acquisition. The data set provided by LAMOST DR2 includes spectra of the pilot survey and spectra from the past two years of the regular spectroscopic survey. This data set has already been published for data users based in China and their international partners. DR2 totally contains 4 136 482 spectra, including 909 520 spectra from the pilot survey and 3 226 962 spectra from the regular survey. In addition, DR2 contains the atmospheric parameters of 2 207 788 stars, which is the largest catalog of stellar spectral parameters currently available.[1]

2.2 Data Selection

As described above, we mainly used the WISE All-Sky Data Release catalog and LAMOST DR2 stellar catalog to search for IR excess stars in this paper. Before doing the cross-match, we chose FGK stars from the LAMOST DR2 stellar catalog, because the FGK stars have more reliable photometric information. Then we entered the coordinates of the chosen FGK stars into the website for the WISE All-Sky Data Release catalog with a matching radius of $6''$ (Wu et al. 2013) and $cc_{\rm flags} = 0000$ (contamination and confusion flag), and 5511 stars were obtained.

S/N is an important index for photometric precision and it directly affects the selection accuracy of candidates. So, we deleted those sources with $\mathrm{S/N} \leq 15$ in the $W1$, $W2$, $W3$, $W4$, g and i bands from the 5511 sources; 2214 sources were left.

To reduce the effects of contamination by variable stars and bad pixels in the CCD, we considered the related index (var_flg and $w?flg$ Symbol? which indicate the $W1$, $W2$, $W3$ or $W4$ band) provided in the WISE All-Sky Data Release catalog. These indexes can help us select stars with much higher photometric accuracy. In this step, 2134 sources were obtained.

Moreover, there is another important index, saturation. In the WISE All-Sky Data Release catalog, saturation begins to occur for point sources brighter than $W1 \sim 8$, $W2 \sim 7$, $W3 \sim 4$ and $W4 \sim 0$ mag. By this criterion, there will be no saturated stars in our candidates. Lastly, we obtained 1120 stars (gray regions in Fig. 1).

The method of selecting 22 μm excess stars was similar to our previous work (Wu et al. 2013). In this work, we gave the $K_s - [22]$ criterion by fitting the histogram of $K_s - [22]$ with a Gaussian function. Figure 2 shows the histogram of $K_s - [22]$. To reduce the bias introduced by the small number of matched catalog sources, we used a 4σ confidence threshold for all 1120 sources. That means the criterion used in this work was $K_s - [22] \geq \mu + 4\sigma = 0.387$. The $J - H$ vs. $K_s - [22]$ diagram can also help to reject those cases with incorrect spectral type by comparing with normal dwarf stars (the dashed line in Fig. 3). There are 64 sources with $K_s - [22] \geq 0.387$. To remove background contamination, we selected those cases with an *IRAS* 100 μm background level lower than 5 MJy sr^{-1} (Kennedy & Wyatt 2012; Wu et al. 2013). Then 54 sources were eliminated and 10 [22] μm excess candidates were finally obtained (red points in Fig. 1).

3 ANALYSIS AND RESULTS

3.1 Notes on Candidates

Table 1 shows the 10 selected IR excess candidates. The names of the 10 candidates are from the WISE All-Sky

[1] *www.lamost.org*

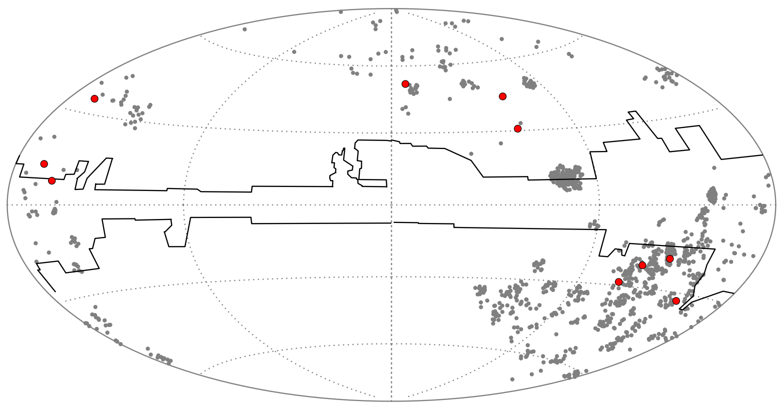

Fig. 1 Distribution of the 22 μm excess stars in a Galactic Aitoff projection. The red points are the 10 IR excess candidates and the gray points are the distribution of the matched sources from the LAMOST DR2 stellar catalog. The molecular cloud and the star formation region are located between the two black solid lines.

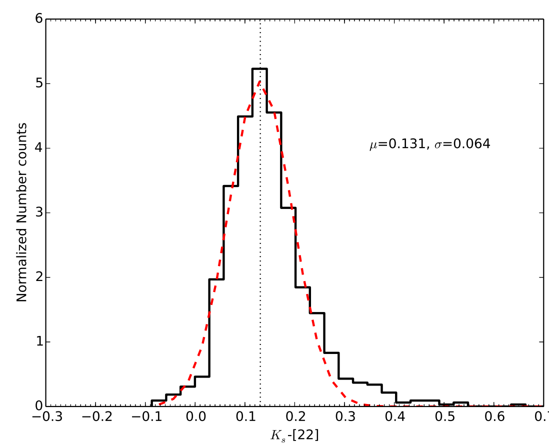

Fig. 2 Goodness of fit for all matched sources. The criterion is $K_s - [22]_{\mu m} \geq \mu + 4\sigma = 0.387$, which means that those with $K_s - [22]_{\mu m} \geq 0.387$ can be identified as 22 μm excess stars.

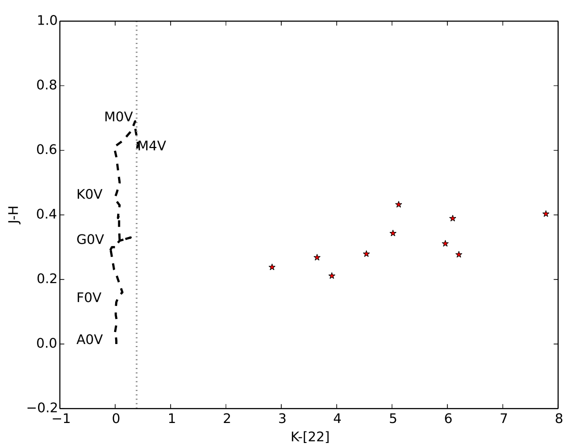

Fig. 3 Diagram of $J - H$ vs. $K_s - [22]$. The red star symbols show the distribution of FGK stars. Normal dwarf stars are plotted as a black dashed line and the corresponding spectral types are also labeled. The gray dotted line shows the criterion of the 22 μm excess candidates.

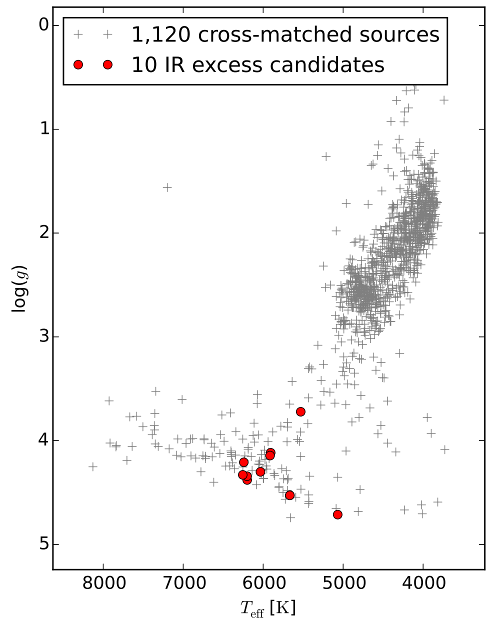

Fig. 4 H-R Diagram of 22 μm excess stars. Gray + symbols are the more than 1000 selected sources from the LAMOST DR2 catalog. Red points are the 10 candidates that show IR excess, and nine of them are obviously main sequence stars.

Table 1 10 Mid-IR Excess Stars from the LAMOST DR2 Stellar Catalog

ID (LAMOST) (1)	RA (J2000) (2)	Dec (J2000) (3)	K_s-[22] (mag) (4)	log g (5)	e_log g (6)	$T_{\rm eff}$ (K) (7)	e_$T_{\rm eff}$ (8)	[Fe/H] (9)	e_[Fe/H] (10)	R_v (11)	SPT (12)	$f_{\rm d}$ (13)
J000153.53+330250.0	0.4730602	33.0472467	5.017	4.527	0.518	5666.7	224.52	0.004	0.242	14.02	G6	2.3e–3
J002623.58+403943.1	6.5982554	40.6619950	7.779	4.117	0.622	5905.99	222.03	−0.228	0.237	−58.37	G2	3.5e–2
J012825.91+432504.2	22.1079984	43.4178478	3.913	4.209	0.485	6242.06	159.5	−0.146	0.165	−39.14	F6	4.2e–4
J023430.10+243831.9	38.625456	24.6422148	5.120	4.713	0.331	5068.22	83.28	−0.006	0.116	−3.16	G9	2.1e–3
J070240.89+114104.0	105.6703877	11.6844692	6.207	4.379	0.481	6199.84	176.02	−0.011	0.175	−13.49	F2	9.0e–3
J070904.25+202205.4	107.2677215	20.3681877	6.096	3.722	0.739	5530.51	183.66	−0.596	0.233	46.47	G3	8.9e–3
J083820.18+283823.0	129.5841041	28.6397304	2.833	4.343	0.420	6201.13	86.15	−0.175	0.101	31.7	F7	2.1e–4
J151031.26+072454.1	227.6302529	7.415044	3.646	4.301	0.470	6034.04	110.4	−0.4	0.136	11.88	F7	3.9e–4
J162412.18+385720.8	246.0507688	38.9558047	5.962	4.33	0.480	6255.22	206.16	−0.364	0.237	−61.45	F5	3.5e–3
J173214.60+360622.1	263.0608529	36.106158	4.537	4.144	0.548	5914.00	143.17	0.159	0.136	−49.44	G3	1.1e–3

Notes: Column (1): Names of candidates; Cols. (2)−(3): Coordinates of candidates; Col. (4): K_s-[22] - Criterion of selecting 22 μm excess; Col. (5): $\log g$ - Surface Gravity; Col. (6): e_$\log g$ - Surface Gravity Uncertainty; Col. (7): $T_{\rm eff}$ - Effective Temperature; Col. (8): e_$T_{\rm eff}$ - Effective Temperature Uncertainty; Col. (9): [Fe/H] - Metallicity; Col. (10): e_[Fe/H] - Metallicity Uncertainty; Col. (11): R_v - Heliocentric Radial Velocity; Col. (12): SPT - Spectral type; Col. (13): $f_{\rm d}$ - Fractional Luminosity.

Data Release catalog. From the values of $K_s - [22]$ listed in Table 1 we can see that all the 10 candidates obviously show excess in 22 μm. $\log g$, $T_{\rm eff}$, [Fe/H], R_v and spectral type are the stellar parameters provided by LAMOST DR2. The fractional luminosity $f_{\rm d}$, which is defined as the ratio of integrated IR excess of the disk to bolometric luminosity of the star, is also estimated for each candidate. More details can be seen in Section 3.4.

Compared with a database (like SIMBAD) and previous work, they are all newly identified 22 μm excess candidates. The spectral type of the 10 candidates ranges from F2 to G9.

3.2 Hertzsprung-Russell Diagram

Generally, research related to debris disks or IR excess stars focuses on main sequence stars. However, there is still some work on giant stars with IR excess (Jones 2008; Groenewegen 2012). The stellar parameters provided in LAMOST DR2 can help us to separate main sequence stars from giants. Figure 4 shows the temperature $T_{\rm eff}$ versus $\log(g)$ in a Hertzsprung-Russell (H-R) diagram.

From Figure 4 we can see that nine sources are obviously main sequence stars. Among the 10 candidates, five stars are F type stars and five are G type stars. They are all Sun-like stars and their properties are listed in Table 1.

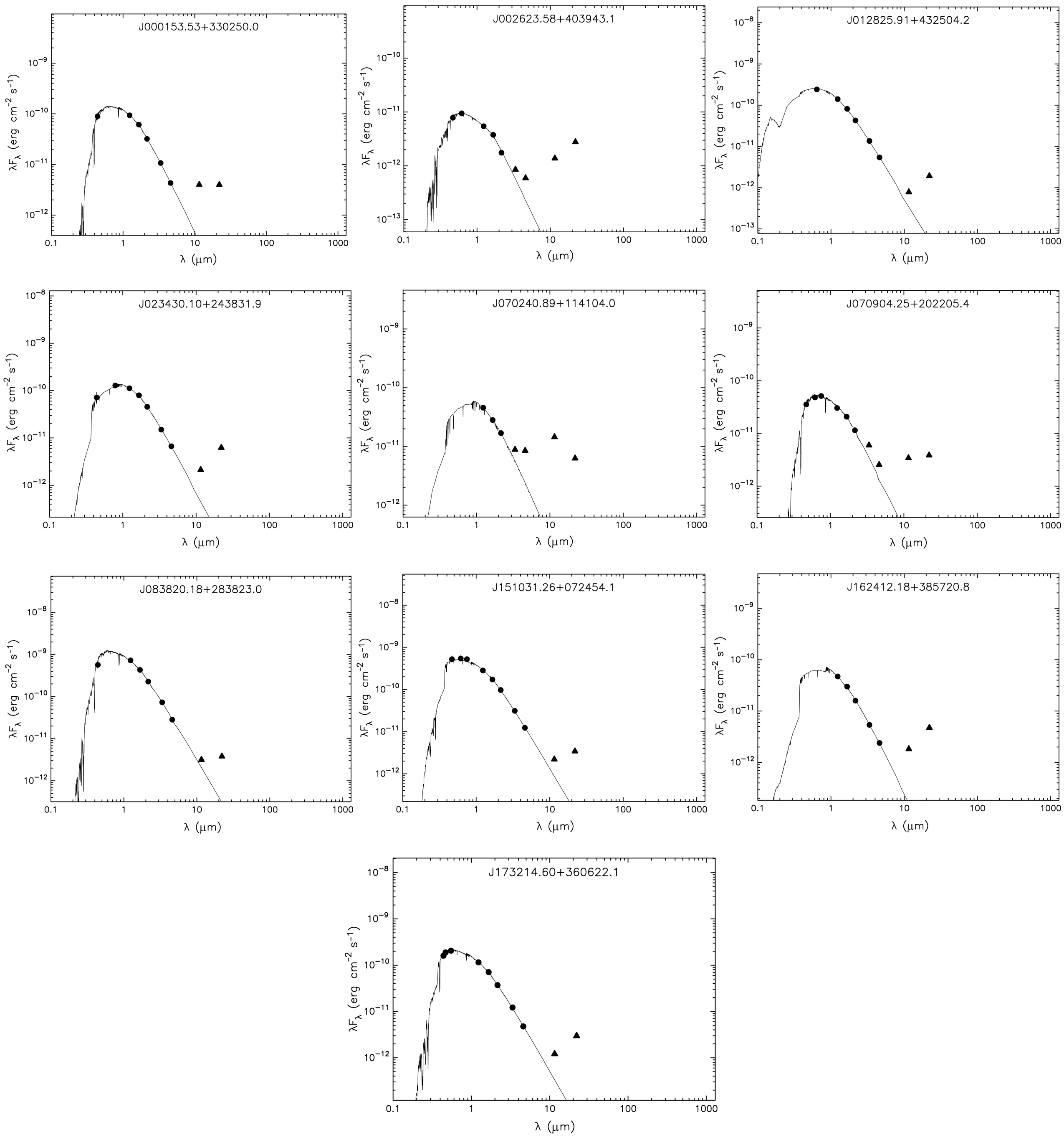

Fig. 5 SEDs of the 10 candidates. They all show excess in the 12 μm band. There are three candidates that even show obvious excess in the 3.4 μm band.

3.3 Spectral Energy Distribution

Figure 5 shows the SEDs of 10 selected IR excess candidates. All these SEDs are fitted by using the optical band information provided by LAMOST DR2, the near IR band (J, H, K, $W1$, $W2$, $W3$ and $W4$) provided by 2MASS and *WISE*. The fitted stellar parameters are consistent with those given by LAMOST (Table 1) (Robitaille et al. 2007; Kurucz 1979). All the candidates show an obvious excess at 22 μm ($W4$), even at the 12 μm band (Fig. 5). The upward triangular symbols represent mean flux excess compared to black body radiation. Some even show excess in the 3.4 μm band (J002623.58+403943.1, J070240.89+114104.0 and J070904.25+202205.4), which indicates that they are surrounded by hotter dust than other candidates. Since there is no photometric information in the longer band, we do not know the peak of the IR excess and cannot determine the shape of disks around candidates.

Therefore, we need observations in far-IR in the future for confirmation.

3.4 Fractional Luminosity

The fractional luminosity $f_{\rm d}$ ($f_{\rm d} = L_{\rm IR}/L_* = F_{\rm IR}/F_*$) can be used to characterize the amount of dust, so we estimated $f_{\rm d}$ in this paper. We assumed νL_ν to be the total IR luminosity $L_{\rm IR}$ because of the absence of longer bands that are available from *WISE*. Details of the method can be seen in Wu et al. (2013).

The fractional luminosities of 10 candidates are listed in Table 1. All the values of $f_{\rm d}$ mainly range from 10^{-4} to 10^{-3}, and only the $f_{\rm d}$ of J002623.58+403943.1 is larger than 10^{-2}. It has been argued that debris disks are confined to $f_{\rm d} < 10^{-2}$. J002623.58+403943.1 probably contains a significant amount of gas (Artymowicz 1996; Wu et al. 2012). It is worth verifying this in future work. There is no consensus on the relation between $f_{\rm d}$ and ages (Wu et al. 2013), so we cannot conclude whether these candidates are young or old.

4 SUMMARY

In this work, we use the LAMOST DR2 stellar catalog and WISE All-Sky Data Release catalog to search for 22 μm excess candidates. The searching method used in this paper is a $J-H$ vs $K_s-[22]$ diagram (Wu et al. 2013). Then we obtain 10 high-precision candidates with 22 μm excess. Each candidate presented here can be studied further with higher angular resolution IR imaging or IR spectroscopy. Among the 10 candidates, five are F type stars and five are G type stars. We also provide the SEDs for all the candidates covering wavelengths from optical to mid-IR bands. From the SEDs, we find that all of the 10 candidates show obvious excess in 12 μm. There are three candidates that even show excess in 3.4 μm. Finally, we estimated the fractional luminosity $f_{\rm d}$ for each candidate. There is one candidate that even has $f_{\rm d}$ larger than 10^{-2}.

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