FGK 22 μm excess stars in LAMOST DR2 stellar catalog

Chao-Jian Wu1,2, Hong Wu1,2, Kang Liu2, Tan-Da Li2, Ming Yang1, Man-I Lam1, Fan Yang1, Yue Wu1, Yong Zhang4, Yong-Hui Hou4 and Guang-Wei Li1

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 4136482 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 ($V_{mag} \leq 10.27$) 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 DR2 includes 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 first year spectroscopic survey. In addition, the stellar catalog contains the atmospheric parameters of 1 085 404 stars.

We 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

\footnote{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

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

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): $\sigma$log $g$ - Surface Gravity Uncertainty; Col. (7): $T_{\text{eff}}$ - Effective Temperature; Col. (8): $\sigma T_{\text{eff}}$ - Effective Temperature Uncertainty; Col. (9): [Fe/H] - Metallicity; Col. (10): $\sigma$[Fe/H] - Metallicity Uncertainty; Col. (11): $R_v$ - Heliocentric Radial Velocity; Col. (12): SPT - Spectral type; Col. (13): $f_d$ - Fractional Luminosity.
22 µm Excess Stars in LAMOST DR2

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 (\(J002623.58+403943.1\), \(J070240.89+114104.0\), \(J070904.25+202205.4\)), 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 $f_d (f_d = L_{IR}/L_\star = F_{IR}/F_\star)$ can be used to characterize the amount of dust, so we estimated $f_d$ in this paper. We assumed $\nu L_\nu$ to be the total IR luminosity $L_{IR}$ 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 $f_d$ mainly range from $10^{-4}$ to $10^{-3}$, and only the $f_d$ of J002623.58+403943.1 is larger than $10^{-2}$. It has been assumed that disks are confined to $f_d < 10^{-2}$. 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 $f_d$ 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 $\mu$m 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 $\mu$m 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 $\mu$m. There are three candidates that even show excess in 3.4 $\mu$m. Finally, we estimated the fractional luminosity $f_d$ for each candidate. There is one candidate that even has $f_d$ larger than $10^{-2}$.

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