BASIC PROPERTIES OF DEBRIS DISKS AROUND NEARBY YOUNG BROWN DWARF CANDIDATES

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ABSTRACT

In this paper, we present our study of basic properties of debris disks around nearby young brown dwarf candidates. Using archival data, we constructed spectral energy distributions of these candidates to determine basic properties such as mass, temperature and emissivity index of dust of debris disks around them. Our study might provide us with important implications for the theory of planet formation around brown dwarfs.

***Keywords*:** planetary systems, debris disks, brown dwarfs.

TÓM TẮT

Những tính chất của đĩa tàn dư xung quanh các ứng cử viên sao lùn nâu trẻ trong vùng lân cận Mặt Trời

Trong bài báo này, chúng tôi trình bày nghiên cứu của chúng tôi về một số tính chất của đĩa tàn dư xung quanh các ứng viên sao lùn nâu trẻ trong vùng lân cận Mặt Trời. Sử dụng các cơ sở dữ liệu có sẵn, chúng tôi xây dựng phổ phân bố năng lượng của các ứng viên này để ước tính khối lượng, nhiệt độ và chỉ số phát xạ của bụi của đĩa tàn dư xung quanh chúng. Nghiên cứu của chúng tôi sẽ cung cấp các chỉ dẫn quan trọng cho lí thuyết hình thành hành tinh xung quanh các sao lùn nâu.

Từ khóa: hệ thống hành tinh, đĩa tàn dư, sao lùn nâu.

1. Introduction

Brown dwarfs (BDs) are sub-stellar objects whose masses are from 13 to 75 M_J (1 $M_J = 1.898\times10^{27}$kg: Jupiter mass). BDs are not massive enough to sustain hydrogen-burning reactions in their cores, but they are still massive enough to burn deuterium. According to theoretical models, BDs with masses above 60 M_J also destroy lithium in their cores. Thus, all BDs with masses ranging from 13 to 60 M_J will preserve primordial lithium. Because BDs are fully convective, the preserved lithium therefore can be detected in their atmosphere. In the regime of very low temperature (i.e., ultracool dwarfs), the lithium is detectable as a resonance absorption line Li I at wavelength 6708 Å.

Most Sun-like stars are born with protoplanetary disks where the process of planet formation occurs. Most these stars have lost their protoplanetary disks by 6 Myr [10]. Disks that are made of planetesimals left over the process of planet formation are

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so-called debris disks. In debris disks, dust is continuously generated by collisions and evaporation of planetesimals. These disks have been found around many Sun-like stars. The detection of dust emission (i.e, debris disks) indicates the presence of larger bodies around a star. Therefore, the detection of debris disks implies the presence of planets.

Up to date, debris disks have been found around A, F, G and K stars. However, for M dwarfs, there are only 4 early-M dwarfs with debris disk detected so far. They are GJ 182 (M0.5), GJ 842.2 (M0.5), AU Mic (M1) and GJ 581 (M3) [5, 6, 7]. For the case of late-M (later than M5-M6) and BDs, no debris disks have been detected so far.

In this paper, we present a sample of nearby (distances ≤ 30 parsecs) late-M and BDs for a search for debris disks. We then show our modeling of their spectral energy distributions (SEDs) in order to determine basic properties of dust in debris disks such as mass, temperature and emissivity index. Finally, we use our SED modeling to estimate a possible range of flux from dust emission from these targets at sub-mm wavelengths. These estimates values of flux will be useful for incoming observations.

Section 2 describes our sample. Section 3 presents our SED modeling. In Section 4, we estimate the range of continuum flux at submillimeter wavelengths using our SED modeling and discuss the modeling. Section 5 summarizes our results.

2. Sample

We selected 5 nearby (distances ≤ 30 parsecs) late-M dwarfs with spectral types later than M5 (Table 1). These candidates were discovered from the DENIS survey (see [9] and references therein). The lithium absorption line at 6708 Å has been detected in these late-M dwarfs. One should note that at very young ages, some early M dwarfs (M0-M4) still have lithium not because they are BDs but because either their cores have not yet reached the critical temperature for burning lithium or there has not been sufficent time for completely depleting lithium in these M dwarfs. However, late-M dwarfs with temperatures below 2,700 K (M7 or later) that shows lithium must be substellar [2]. Therefore, the presence of lithium in our late-M dwarfs indicates that targets 1, 2 and 3 are young BDs. Targets 4, 5 that have spectral types M6.5 and M5.0, respectively, are young BD candidates and lie very close to the substellar boundary.

Since these targets are young, thus they are hotter than older BDs. Therefore, the thermal emission of dust (heated by the central star) in debris disks around these objects are more significant than that from older BDs. This makes them excellent targets for searching for debris disks.

Table 1. *Physical parameters of the 5 late-M dwarfs*

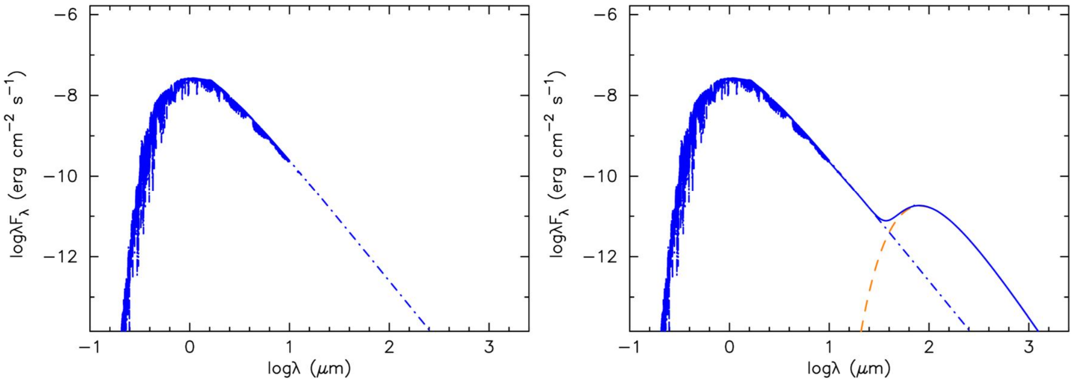
Target	**Distance** (pc)	**Spectral Type**	**Temperature (K)**	**Reference**
1	12.8	M7.0	2430	[3], [8]
2	8.9	M7.5	2400	[3], [9]
3	12.1	M8.0	2270	[3], [9]
4	19.5	M6.5	2580	[3], [8]
5	21.5	M5.0	2720	[3], [8]

3. Modeling of Spectral Energy Distribution

3.1. Spectral Energy Distribution

The SED of a star is the diagram of the energy emitted by the star as a function of wavelengths. The SED of a star is very similar to that of a black body. If a star has a debris disk, its SED will show up an extra emission because the dust in the debris disk is heated by the central star and reradiates the energy mainly from far-infrared (far-IR) to submillimeter (sub-mm) wavelengths. Therefore, the SED is an important tool for detecting and studying basic properties of debris disks around stars.

Figure 1.a shows an example of the SED of a star without a debris disk. The emission from the star is very similar to that of a black body. Since the temperature of the star is very high, thus most of light is produced at short wavelengths (i.e., optical and near-IR regions). In the case of Figure 1.b, it illustrates the SED of a star with a debris disk. The SED shows a little extra emission from dust in the debris disk coming out in the far-IR and sub-mm region. This far-IR and sub-mm excess is detectable.



a) Star without a debris disk *b) Star with a debris disk*

Figure 1. *SEDs of a star without (panel a) and with a debris disk (panel b). The blue dash-dotted line represents the theoretical stellar spectrum (i.e. stellar emission) of the star. If the star has a debris disk, the orange dashed-line shows the extra emission from dust in the debris disk, which is similar to the emission of a modified black body*

3.2. SEDs of the targets

In this section, we assume that all our five BD candidates have debris disks, we then construct the SEDs of these targets to determine basic parameters of dust in the debris disks. Since the far-IR and sub-mm emission of each target is from the BD candidate itself and the dust in its debris disk, the SED of each target therefore consists of an SED of a black body for the central object and an SED of a modified black body for the dust (see Figure 1.b as an example).

First, to construct the SEDs of BD candidates, we have collected archival data at near-IR (J, H & K_s bands of 2MASS) and IR wavelengths (band 1, 2 & 3 of WISE). We then fitted these data with NextGen model atmospheres for very low-mass (VLM) stars and BDs [1].

Second, to construct the SEDs of dust in the debris disks of BD candidates we use the following equation (see also [5]):

$$M_{dust} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_d)} \quad (1)$$

where M_{dust} is the dust mass, F_ν is the continuum flux of dust at observed frequency ν, d is the distance to the target, κ_ν is the dust opacity coefficient that changes with frequency ν following a power law of index β, and $B_\nu(T_d)$ is the Planck function at dust temperature T_d.

If we have fluxes at observed far-IR and sub-mm wavelengths, we could determine basic parameters T_d, M_{dust} and β of dust. Their values are derived from the best fit by searching these parameters minimizing χ^2. Dust temperature T_d is typically in the range of 10 - 80 K, dust mass of 0.01 - 1 $M_\oplus$ (1 $M_\oplus = 5.972\times10^{24}$ kg: the Earth mass) [4] and dust emissivity index β of 0.1 - 2.0.

In our case, we need to estimate expected fluxes at sub-mm wavelengths by assuming a possible range of mass of dust based on the previous detections of debris disks around early-M dwarfs. We defer this to Section 4.

3.3. Testing of the SED modeling

We also tested our SED modeling. We used our modeling to estimate the dust masses of previously detected debris disks around three early-M dwarfs (Au Mic, GJ 182 and GJ 842.2) [6, 7]. Their debris disks were detected at 850 μm with JCMT/SCUBA Telescope.

The values computed from our SED modeling based on the flux at 850 μm are in excellent agreement with the previously measured values (see Table 2). For GJ 182, the dust mass is greater than 0.026 $M_\oplus$, which is estimated only from the 850 μm flux, because there is possibly an additional dust component as discussed in [6].

Table 2. *Dust masses estimated from our modeling for 3 early-M dwarfs with previously detected debris disks*

Star	**SpT**	**Age** (Myr)	**Disk mass ($M_\oplus$)**		**Reference**
			This paper	*Literature*	
AU Mic	M1	12	0.012	0.011	[6]
GJ 182	M0.5	50	> 0.026	> 0.026	[6]
GJ 842.2	M0.5	20 – 200	0.37	0.35	[7]

4. Estimate of a possible range of flux from dust emission at sub-mm wavelengths

Debris disks (i.e., dust emission) could be detected at far-IR and sub-mm wavelengths with several instruments such as CSO/SHARC, Herschel/SPIRE, JCMT/SCUBA. At these wavelengths, debris disks are much brighter than their host stars. Therefore, to search for and study debris disks around our targets, we need to observe our targets at far-IR or sub-mm wavelengths. Among the available instruments, SCUBA-2 of the JCMT telescope that offers observations at 450 μm and 850 μm is an excellent instrument for our study.

However, for any observations we need to estimate the integration time, which is in short the time requested to point the telescope towards a target. In order to calculate the integration time for the observations of our targets, we need to estimate a possible range of fluxes at observed wavelengths. The possible range of fluxes could be estimated from the expected range of dust mass of debris disks around our targets.

Since there are only 4 early-M dwarfs with debris disks detected so far: AU Mic (M1, 12 Myr) with dust mass M_{dust} = 0.01 $M_\oplus$; GJ 182 (M0.5, 50 Myr) with M_{dust} > 0.026 $M_\oplus$ [6]; GJ 842.2 (M0.5, 20-200 Myr) with M_{dust} = 0.35 $M_\oplus$ and GJ 581 (M3, 2-8 Gyr) with M_{dust} = 0.16 $M_\oplus$ [7, 8]. There is therefore no obvious correlation between the dust mass and the spectral type (i.e., the stellar mass) for M dwarfs. We thus assume that the dust mass of our late-M dwarfs is in the range from 0.01 $M_\oplus$ to 0.4 $M_\oplus$ based on these detections. Then we construct the SEDs of all our targets as described in Section 3.2. At a given dust mass, the best fit gives T_d = 40 K and β = 0.8 for all our targets. Figure 2 represents an SED of one of our targets with M_{dust} = 0.05 $M_\oplus$. One should also note that dust opacity coefficient κ_ν of 1.7 $cm^2.g^{-1}$ is assumed at 850 μm.

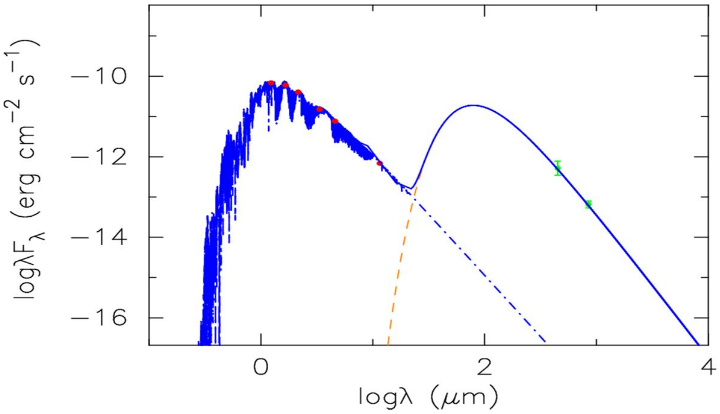


Figure 2. *An SED of one of our targets. The blue dash-dotted line represents the theoretical stellar spectrum that fits data from VIZIER (solid red circles). The dashed orange line shows the modified black body with* $M_{dust} = 0.05\ M_\oplus$, $T_d = 40$ K *and* $\beta = 0.8$. *Two solid green circles show expected fluxes at sub-mm wavelengths 450 μm and 850 μm.*

Table 2 lists our estimate of a possible range of fluxes at 450 µm and 850 µm for each target corresponding to an expected range of dust mass of 0.01 - 0.4 $M_\oplus$. These estimated values of fluxes at sub-mm wavelengths could be used to calculate the integration time for any observations in the near future with SCUBA-2/JCMT.

Table 2. *A possible flux range at 450 μm and 850 μm for 5 late-M dwarfs*

Target	**Flux_450 (mJy)**	**Flux_850 (mJy)**
1	39 - 1541	8 - 319
2	80 - 3188	17 - 661
3	43 - 1725	9 - 358
4	17 - 664	3 - 138
5	14 - 546	3 - 113

5. Summary

In this paper, we present our SED modeling of debris disks around nearby young brown dwarf candidates. This tool is useful for estimating fluxes at observed far-IR and sub-mm wavelengths for any observations in the near future. Once the fluxes are measured, this tool could also be used to determine basic parameters of dust in debris disks around our young brown dwarfs.

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