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WISE Infrared Search for Young Stellar Objects Associated with Starless Cores

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Abstract

This study presents the results of an infrared search of young stellar objects (YSOs) associated with cores with high optical extinction and no associated infrared IRAS source. Four hundred YSO candidates were identified in the *WISE* photometric catalog based on the infrared excess attributed to the circumstellar materials and proto-planetary disks. One-hundred and forty-nine cores do not have YSO candidates. Whereas, 32 cores harbor only Class I candidates and 107 cores have Class II candidates. Ninety-one cores that were previously identified as starless cores, were found to contain YSOs. The ratio of the number of starless cores to the number of star-forming cores suggests that the typical timescale from molecular cloud core formation to the birth of a star is in the range of 0.5 - 1.4 Myr.

Keywords

Stars: Formation, ISM: Clouds, Infrared: Stars

1. Introduction

A starless core is a key astronomical object. An observational study of starless cores provides insights into the star formation process. A star is born in the core, which is the dense region of a molecular cloud. The ratio of the number of the starless cores to the number of the star-forming cores indicates a timescale from the formation of a molecular cloud core to the birth of a star, assuming that all the molecular cloud cores form a star. The observational study of starless cores also provides insights into the physical properties of an isolated core. A young stellar object (YSO) emanates an energetic outflow, which disturbs the physical condition of a molecular cloud. A starless core maintains the original condition of a quiescent molecular cloud core. Kandori *et al.* (2005) investigated physical properties of 10 Bok globules [1]. They found that their radial column density profiles are approximated by the Bonner-Ebert sphere model. The radial profiles of the star-forming globules were fitted by the model with the parameter indicating an unstable condition. On the other hand, the radial profiles of the starless globules were fitted by the model with the parameter that was close to the boundary between stable and unstable conditions. In addition, the observational study of starless cores provides insights into chemical processes in a dense, cold region. Chemical conditions are also changed by the YSO. The chemical process in a quiescent, dense, and cold region has been investigated in the starless cores.

Lee and Myers (1999) presented a comprehensive list of starless cores [2]. They made a map of optical extinction on the Digitized Sky Survey and identified 406 dense cores. The major—(a) and minor—(b) axes of the cores were measured. Subsequently, the geometric mean of the FWHM $(ab)^{0.5}$ of the core was calculated for each core. They searched for IRAS sources within a box twice the size of the geometric mean of the FWHM of the core. It was found that 306 cores did not have IRAS sources. These cores were classified as starless cores. Ninety-four cores have an IRAS source showing the spectral energy distribution signature of an embedded YSO. Six cores have a pre-main sequence star (PMS) only. Assuming that the age of an embedded YSO is 0.1 - 0.5 Myr, they estimated the timescale from the cloud core formation to the birth of the star to be 0.3 - 1.6 Myr.

However, IRAS sensitivity is not sufficient for detecting a sub-solar mass PMS at 150 pc. A low-mass YSO may be missed even if it is associated with the starless cores identified by Lee and Myers (1999) [2]. Consequently, more sensitive searches have then been conducted. Murphy and Myers (2003) conducted near-infrared (*J*-, *H*-, and *K*-bands) photometry of eight dense cores [3]. All cores do not have known PMSs, and most cores do not harbor IRAS sources. These were considered as candidates for the very earliest stage of low-mass star formation. However, they did not find objects with near-infrared excess.

Morita *et al.* (2006) discovered two classical T Tauri stars and one weak-line T Tauri star associated with the L 1014 dense core through optical broad-band photometry and long-slit spectroscopy [4]. The Spitzer Space Telescope also discovered a very faint infrared source, L 1014-IRS (Young *et al.* 2004) [5]. Thus, L 1014 is a star-forming core, although it was previously classified as a starless core (Lee and Myers 1999) [2].

A deeply embedded YSO is very faint in optical and near-infrared wavelengths shorter than 2 μm. This study searched for YSOs associated with starless and star-forming cores at the wavelengths of 3.4 μm, 4.6 μm, and 12 μm (*W*1-, *W*2-, and *W*3-bands) by using the Wide-field Infrared Survey Explorer (*WISE*) photometric catalog.

2. Dataset

We investigated infrared sources in the ALLWISE photometric catalog for the 288 cores listed in Lee and Myers (1999) [2], whose major-axis, minor-axis, and distance are known. The searched area for each core is an elliptical centered on the core center. Its semi-major and semi-minor axes are twice those of the core, respectively.

We selected the *WISE* sources whose photometric signal to noise ratios are larger than 5 in the *W*1-, *W*2-, and *W*3-bands. We eliminated the sources if the contamination and confusion flag was "D" (diffraction spike), "P" (short-term latent image), "H" (scattered light halo), or "O" (optical ghost). Further, we also removed the objects with a saturation value greater than 0.05 in the *W*1-, *W*2-, or *W*3-bands.

Class I and Class II candidates were selected on the color-color diagram. We applied the selection method proposed by Fischer *et al.* (2016) [6].

3. Results

Figure 1 shows the color-color diagram of the *WISE* sources detected in the [LM 99] 69 region. In this diagram, we identified 2 and 6 Class I and Class II candidates, respectively. We detected 132 and 268 Class I and Class II candidates from 139 cores, respectively (Table 1).

We classified 288 cores into 3 types. One is the starless core, which is a molecular cloud core without any associated YSO candidates. We identified 149 cores for this type (Table 2). Second is the molecular cloud core with associated Class I candidates only. We identified 32 cores for this type. Here, the cores with both Class I and Class II candidates are not classified into this type. Third is the molecular cloud core with associated Class II candidates. We identified 107 such cores. The cores with both Class I candidates and Class II candidates are classified into this type. Ninety-one cores that were previously identified as the starless core were found to harbor Class I and/or Class II candidates.

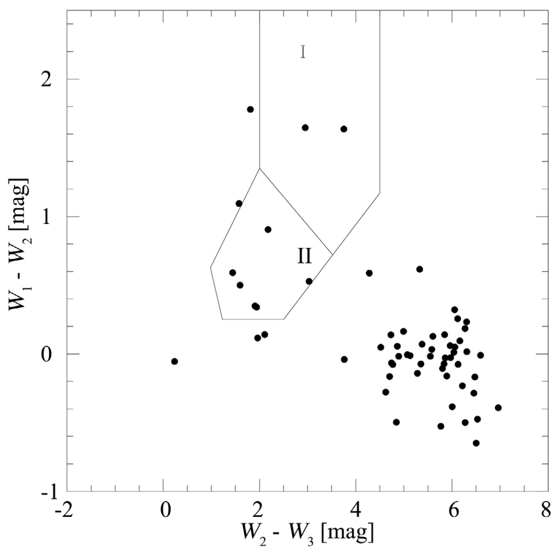

Figure 1. Color-color diagram of *WISE* point sources in the [LM 99] 69 region. Sources plotted in the region labeled as I are identified as Class I candidates. Sources in the region II are Class II candidates. Other sources are identified as field stars.

Table 1. *WISE* point sources associated with the optically selected cores. The letters in the parentheses following the core name indicate the core classification in Lee and Myers (1999) [2]. N: starless core, I: core with an embedded YSO, II: core with a PMS.

WISE name	R. A. (2000) [deg]	Dec. (2000) [deg]	*W*1 [mag]	*W*2 [mag]	*W*3 [mag]	class
[LM99] 8 (N)						
J034819.55 + 325449.4	57.0815	32.9137	15.73	13.72	11.07	I
J034818.90 + 325436.7	57.0788	32.9102	15.88	14.93	11.51	I
[LM99] 11 (N)						
J041757.81 + 283647.5	64.4909	28.6132	14.34	13.88	11.04	II
[LM99] 12 (I)						
J041834.44 + 283029.9	64.6435	28.5083	8.65	8.01	6.77	II
J041835.58 + 283025.5	64.6483	28.5071	12.64	12.14	10.23	II
J041817.11 + 282841.6	64.5713	28.4782	10.51	9.81	8.00	II
J041812.82 + 283217.0	64.5534	28.5381	15.19	14.50	11.05	II
J041841.50 + 283500.6	64.6729	28.5835	13.95	12.71	9.93	I
J041831.09 + 283931.5	64.6296	28.6588	16.11	14.96	11.19	I
[LM99] 15 (I)						
J042335.40 + 250302.4	65.8975	25.0507	8.60	7.82	6.07	II
J042219.00 + 251404.3	65.5792	25.2345	14.82	13.47	10.60	I
[LM99] 22 (N)						
J042757.32 + 261918.0	66.9888	26.3217	9.71	8.59	5.47	I
[LM99] 24 (N)						
J042827.41 + 265127.2	67.1142	26.8576	15.16	13.52	10.22	I
J042823.04 + 264933.8	67.0960	26.8261	14.20	12.96	9.73	I
[LM99] 25 (N)						
J042947.36 + 541110.8	67.4473	54.1864	14.21	13.77	11.05	II
J043012.92 + 541357.9	67.5539	54.2328	11.02	10.46	7.55	II
J042926.32 + 540711.0	67.3597	54.1197	16.64	15.43	11.50	I
J042837.60 + 541347.2	67.1567	54.2298	15.14	14.20	10.95	I
[LM99] 26 (I)						
J042932.09 + 243059.4	67.3837	24.5165	11.06	9.22	6.32	I
[LM99] 28 (I)						
J042930.18 + 243932.8	67.3758	24.6591	10.56	10.27	8.88	II
J042936.06 + 243555.4	67.4003	24.5987	8.26	7.73	6.42	II
J042940.65 + 243726.0	67.4194	24.6239	16.68	15.10	11.12	I

Continued

[LM99] 29 (N)						
J042921.65 + 270125.6	67.3402	27.0238	8.26	7.59	5.80	II
[LM99] 31 (I)						
J042959.51 + 243307.5	67.4980	24.5521	9.12	8.48	6.87	II
J042932.09 + 243059.4	67.3837	24.5165	11.06	9.22	6.32	I
J042936.06 + 243555.4	67.4003	24.5987	8.26	7.73	6.42	II
J042940.65 + 243726.0	67.4194	24.6239	16.68	15.10	11.12	I
[LM99] 32 (N)						
J042959.51 + 243307.5	67.4980	24.5521	9.12	8.48	6.87	II
J042932.09 + 243059.4	67.3837	24.5165	11.06	9.22	6.32	I
[LM99] 35 (I)						
J043150.57 + 242417.5	67.9607	24.4049	7.82	7.37	5.53	II
[LM99] 36 (N)						
J043142.52 + 180818.1	67.9272	18.1384	13.48	12.31	9.52	I
J043142.70 + 180832.5	67.9279	18.1424	13.50	12.32	9.51	I
[LM99] 37 (I)						
J043138.45 + 243812.7	67.9102	24.6369	14.67	13.50	10.87	I
[LM99] 40 (N)						
J043244.65 + 225821.0	68.1861	22.9725	16.09	15.01	11.18	I
[LM99] 43 (N)						
J043309.46 + 224648.4	68.2894	22.7801	11.03	10.52	9.40	II
J043319.15 + 224751.9	68.3298	22.7978	15.94	14.87	11.00	I
[LM99] 45 (I)						
J043535.40 + 240819.5	68.8975	24.1388	9.82	8.70	6.41	II
[LM99] 47 (I)						
J043814.88 + 261139.8	69.5620	26.1944	11.08	10.03	7.90	II
J043751.48 + 261759.9	69.4645	26.3000	14.91	14.32	11.16	II
[LM99] 49 (I)						
J043903.95 + 254426.1	69.7665	25.7406	10.98	10.39	8.36	II
[LM99] 51 (I)						
J044125.72 + 254349.3	70.3572	25.7304	14.29	12.25	9.24	I
J044144.47 + 254421.9	70.4353	25.7394	12.60	12.32	10.99	II
J044112.69 + 254634.9	70.3029	25.7764	9.82	7.64	4.89	I
J044110.79 + 255511.3	70.2950	25.9198	10.96	10.26	8.34	II
J044049.50 + 255119.0	70.2063	25.8553	8.94	8.47	7.10	II

Continued

			[LM99] 52 (I)			
J044122.82 + 255825.9	70.3451	25.9739	15.26	14.57	11.22	II
J044148.47 + 255945.5	70.4520	25.9960	14.05	13.58	10.91	II
J044138.17 + 260520.6	70.4090	26.0891	15.39	13.96	10.85	I
J044138.83 + 255626.6	70.4118	25.9407	8.18	7.37	4.58	II
J044104.72 + 255949.2	70.2697	25.9970	13.82	12.76	9.33	I
			[LM99] 62 (N)			
J050349.61 + 251653.8	75.9567	25.2816	14.69	13.51	10.56	I
			[LM99] 65 (N)			
J050441.39 + 250954.3	76.1725	25.1651	9.22	8.79	7.28	II
			[LM99] 69 (N)			
J053207.29 + 123046.1	83.0304	12.5128	13.20	12.29	10.11	II
J053208.91 + 123019.2	83.0371	12.5054	13.57	13.04	10.01	II
J053206.40 + 122922.1	83.0267	12.4895	10.47	10.13	8.19	II
J053201.37 + 123323.0	83.0057	12.5564	14.79	13.14	10.19	I
J053211.92 + 122941.9	83.0497	12.4950	13.21	11.57	7.82	I
J053206.20 + 122824.0	83.0259	12.4734	12.11	11.52	10.08	II
J053200.53 + 123415.1	83.0022	12.5709	12.34	11.99	10.09	II
J053149.11 + 123200.2	82.9547	12.5334	8.51	8.01	6.41	II
			[LM99] 70 (N)			
J054436.61 + 091101.0	86.1526	9.1836	13.07	11.38	8.55	I
J054430.29 + 090930.2	86.1262	9.1584	15.32	14.14	11.06	I
J054429.95 + 090856.6	86.1248	9.1491	10.56	8.22	5.82	I
J054438.39 + 090841.7	86.1600	9.1449	10.99	9.96	8.36	II
J054436.99 + 091320.0	86.1541	9.2222	10.91	10.45	8.60	II
			[LM99] 77 (I)			
J060744.74 − 053433.7	91.9364	−5.5761	16.07	13.54	9.93	I
J060744.26 − 052933.7	91.9344	−5.4927	9.97	9.02	6.90	II
			[LM99] 83 (N)			
J073057.55 − 465611.1	112.7398	−46.9364	11.13	10.56	8.43	II
			[LM99] 84 (N)			
J080534.98 − 390855.3	121.3958	−39.1487	14.21	13.04	10.57	I
J080534.83 − 390915.3	121.3951	−39.1543	14.98	13.82	10.55	I
J080533.03 − 390924.7	121.3877	−39.1569	12.90	11.63	8.68	I
J080533.82 − 390926.1	121.3909	−39.1573	13.17	12.22	8.91	I
J080525.90 − 390905.5	121.3579	−39.1515	11.97	11.05	8.47	II

Continued

		[LM99] 89 (I)				
J081712.43 − 395409.2	124.3018	−39.9026	11.49	10.78	8.18	II
J081704.49 − 395507.4	124.2687	−39.9187	9.78	8.27	4.76	I
		[LM99] 90 (N)				
J081711.19 − 395016.4	124.2967	−39.8379	11.12	10.43	8.56	II
		[LM99] 93 (I)				
J082537.39 − 510121.8	126.4058	−51.0227	15.34	13.38	10.80	I
J082543.78 − 510035.1	126.4324	−51.0098	9.99	7.19	3.88	I
		[LM99] 98 (N)				
J092214.48 − 454631.3	140.5604	−45.7754	12.05	10.78	7.45	I
J092213.53 − 454545.4	140.5564	−45.7626	11.88	11.12	9.48	II
J092210.92 − 454559.4	140.5455	−45.7665	10.13	9.47	7.04	II
		[LM99] 100 (N)				
J092850.20 − 513637.3	142.2092	−51.6104	10.70	9.83	7.85	II
J092851.11 − 513624.6	142.2130	−51.6068	12.96	12.70	10.82	II
J092851.29 − 513658.8	142.2137	−51.6163	10.57	9.72	7.88	II
J092844.62 − 513438.4	142.1859	−51.5773	11.78	10.92	8.37	II
		[LM99] 102 (N)				
J105707.42 − 770436.4	164.2809	−77.0768	14.55	14.09	11.88	II
J105701.44 − 770736.2	164.2560	−77.1267	15.13	14.47	11.89	II
J105713.43 − 770800.0	164.3060	−77.1333	16.09	14.81	11.46	I
		[LM99] 104 (N)				
J110256.80 − 774008.9	165.7367	−77.6691	16.22	15.38	11.79	I
J110129.02 − 774359.5	165.3710	−77.7332	11.95	11.10	7.83	I
J110051.54 − 774511.1	165.2148	−77.7531	15.24	14.58	11.93	II
J110355.17 − 773740.3	165.9799	−77.6279	15.47	14.82	11.56	II
		[LM99] 108 (I)				
J120131.79 − 650525.2	180.3825	−65.0903	9.98	9.18	7.30	II
		[LM99] 111 (N)				
J122905.98 − 711326.3	187.2749	−71.2240	15.50	14.87	11.59	II
		[LM99] 114 (N)				
J123235.66 − 634319.6	188.1486	−63.7221	10.95	10.13	7.94	II
		[LM99] 119 (N)				
J124814.65 − 770010.2	192.0611	−77.0029	15.08	13.87	10.80	I
J124817.46 − 770155.1	192.0728	−77.0320	14.34	13.91	11.33	II

Continued

[LM99] 120 (I)						
J125342.78 − 771511.6	193.4283	−77.2532	10.81	9.34	6.42	I
J125317.08 − 771637.0	193.3212	−77.2770	15.61	15.04	11.92	II
J125139.59 − 771640.2	192.9150	−77.2778	15.74	14.97	11.36	I
[LM99] 121 (N)						
J125752.91 − 771329.8	194.4705	−77.2250	16.40	15.15	11.54	I
J125909.24 − 771454.2	194.7885	−77.2484	16.47	15.45	11.88	I
J125806.71 − 770909.5	194.5280	−77.1527	11.91	11.07	9.13	II
J125730.49 − 771005.6	194.3770	−77.1682	15.02	14.17	11.25	II
[LM99] 122 (N)						
J130058.78 − 771448.0	195.2449	−77.2467	13.89	13.26	11.37	II
J125948.16 − 771233.1	194.9507	−77.2092	15.49	14.79	11.53	II
[LM99] 123 (I)						
J130058.78 − 771448.0	195.2449	−77.2467	13.89	13.26	11.37	II
J130055.25 − 771022.3	195.2302	−77.1729	8.41	7.77	5.56	II
J130053.31 − 770908.9	195.2221	−77.1525	8.55	7.97	6.43	II
[LM99] 129 (I)						
J130728.01 − 770024.0	196.8667	−77.0067	14.23	13.26	10.90	II
[LM99] 133 (I)						
J153930.08 − 344611.8	234.8754	−34.7700	12.56	12.10	10.54	II
[LM99] 141 (I)						
J154506.33 − 341738.1	236.2764	−34.2939	11.22	10.22	7.98	II
J154508.86 − 341733.6	236.2869	−34.2927	8.88	8.04	6.33	II
J154517.40 − 341828.4	236.3225	−34.3079	8.52	7.86	6.51	II
J154457.87 − 342339.4	236.2412	−34.3943	11.90	11.60	9.85	II
[LM99] 142 (N)						
J154520.10 − 341046.5	236.3338	−34.1796	15.04	13.97	10.94	I
[LM99] 143 (N)						
J154518.50 − 342124.7	236.3271	−34.3569	10.15	9.51	7.54	II
[LM99] 144 (N)						
J154532.02 − 342525.7	236.3834	−34.4238	15.17	13.91	11.37	I
J154518.50 − 342124.7	236.3271	−34.3569	10.15	9.51	7.54	II
J154525.84 − 342039.7	236.3577	−34.3444	16.26	15.12	11.59	I
J154525.60 − 342909.1	236.3567	−34.4859	16.02	14.67	10.51	I

Continued

			[LM99] 145 (N)			
J154618.66 − 351000.3	236.5778	−35.1668	15.57	14.29	11.35	I
J154700.59 − 351647.1	236.7525	−35.2798	15.84	14.50	11.23	I
			[LM99] 146 (I)			
J154756.93 − 351434.9	236.9872	−35.2430	7.56	6.72	4.70	II
J154806.22 − 351548.5	237.0259	−35.2635	9.16	8.74	7.12	II
			[LM99] 147 (N)			
J155327.64 − 043040.0	238.3652	−4.5111	16.38	15.07	11.51	I
J155320.28 − 043004.5	238.3345	−4.5013	15.46	14.58	11.24	I
			[LM99] 148 (N)			
J155343.47 − 025232.3	238.4312	−2.8757	15.00	14.18	10.80	I
			[LM99] 151 (N)			
J155829.99 − 423510.1	239.6250	−42.5862	12.79	12.22	9.46	II
J155746.47 − 423548.8	239.4437	−42.5969	9.02	8.38	6.10	II
			[LM99] 154 (N)			
J155954.95 − 420150.8	239.9790	−42.0308	13.48	13.21	11.24	II
J160023.23 − 415422.3	240.0968	−41.9062	15.19	14.48	11.53	II
J160026.11 − 415355.5	240.1088	−41.8988	10.46	10.05	8.14	II
J160210.44 − 420158.3	240.5435	−42.0329	14.53	13.81	10.70	II
			[LM99] 155 (N)			
J160202.64 − 415255.8	240.5110	−41.8822	15.40	13.88	11.22	I
J160202.64 − 415255.8	240.5110	−41.8822	15.40	13.88	11.22	I
			[LM99] 158 (N)			
J160633.02 − 455559.7	241.6376	−45.9333	10.64	10.18	8.13	II
			[LM99] 159 (N)			
J160801.76 − 391231.6	242.0074	−39.2088	13.22	12.80	10.02	II
			[LM99] 168 (N)			
J161347.62 − 435828.3	243.4484	−43.9746	14.73	13.66	10.63	I
			[LM99] 169 (N)			
J161739.06 − 373416.5	244.4128	−37.5713	15.82	14.31	11.29	I
			[LM99] 170 (N)			
J162446.45 − 395615.1	246.1935	−39.9375	9.19	8.59	7.53	II
			[LM99] 174 (N)			
J162908.22 − 241547.0	247.2843	−24.2631	10.68	10.24	8.51	II
J162924.93 − 241342.6	247.3539	−24.2285	11.44	11.12	9.93	II

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[LM99] 181 (I)						
J163226.95 − 242633.6	248.1123	−24.4427	13.86	13.29	10.94	II
J163221.03 − 242829.0	248.0877	−24.4747	15.45	12.59	10.48	I
J163213.16 − 242938.8	248.0549	−24.4941	14.72	13.68	10.12	I
[LM99] 182 (N)						
J163301.17 − 234324.6	248.2549	−23.7235	16.27	14.53	10.92	I
J163129.22 − 240431.2	247.8718	−24.0754	10.26	9.09	6.61	I
J163133.82 − 240446.9	247.8910	−24.0797	8.54	7.57	4.97	II
J163135.89 − 240352.8	247.8995	−24.0647	13.52	12.81	10.30	II
J163144.57 − 240213.2	247.9357	−24.0370	8.90	8.01	6.18	II
J163107.82 − 240555.3	247.7826	−24.0987	15.73	14.39	10.57	I
J163346.41 − 233922.7	248.4434	−23.6563	13.62	13.11	11.03	II
J163102.38 − 240843.4	247.7599	−24.1454	10.30	9.79	8.26	II
[LM99] 183 (N)						
J163301.17 − 234324.6	248.2549	−23.7235	16.27	14.53	10.92	I
J163245.68 − 234337.8	248.1903	−23.7272	14.90	14.26	11.04	II
J163129.22 − 240431.2	247.8718	−24.0754	10.26	9.09	6.61	I
J163133.82 − 240446.9	247.8910	−24.0797	8.54	7.57	4.97	II
J163135.89 − 240352.8	247.8995	−24.0647	13.52	12.81	10.30	II
J163144.57 − 240213.2	247.9357	−24.0370	8.90	8.01	6.18	II
J163107.82 − 240555.3	247.7826	−24.0987	15.73	14.39	10.57	I
J163346.41 − 233922.7	248.4434	−23.6563	13.62	13.11	11.03	II
J163102.38 − 240843.4	247.7599	−24.1454	10.30	9.79	8.26	II
[LM99] 184 (N)						
J163337.56 − 244645.2	248.4065	−24.7792	15.61	14.40	10.86	I
J163255.86 − 244652.5	248.2328	−24.7813	16.53	15.23	11.08	I
[LM99] 186 (I)						
J163413.91 − 450144.4	248.5580	−45.0290	12.35	12.00	9.45	II
J163403.89 − 445817.5	248.5162	−44.9715	10.76	10.25	7.99	II
[LM99] 187 (N)						
J163409.28 − 232828.4	248.5387	−23.4746	14.69	14.11	10.97	II
J163301.17 − 234324.6	248.2549	−23.7235	16.27	14.53	10.92	I
J163245.68 − 234337.8	248.1903	−23.7272	14.90	14.26	11.04	II
J163129.22 − 240431.2	247.8718	−24.0754	10.26	9.09	6.61	I
J163133.82 − 240446.9	247.8910	−24.0797	8.54	7.57	4.97	II
J163135.89 − 240352.8	247.8995	−24.0647	13.52	12.81	10.30	II
J163144.57 − 240213.2	247.9357	−24.0370	8.90	8.01	6.18	II
J163346.41 − 233922.7	248.4434	−23.6563	13.62	13.11	11.03	II

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[LM99] 189 (N)						
J163406.58 − 154938.8	248.5274	−15.8275	13.88	13.23	10.17	II
J163441.57 − 154505.1	248.6732	−15.7514	15.55	13.94	11.01	I
J163306.90 − 155852.0	248.2788	−15.9811	15.01	13.78	11.00	I
J163303.17 − 155850.6	248.2632	−15.9807	15.07	14.18	11.25	II
[LM99] 190 (I)						
J163429.12 − 154455.3	248.6214	−15.7487	15.13	14.04	10.89	I
J163408.05 − 160611.5	248.5335	−16.1032	14.58	13.45	10.28	I
[LM99] 192 (I)						
J163441.57 − 154505.1	248.6732	−15.7514	15.55	13.94	11.01	I
J163433.07 − 155543.7	248.6378	−15.9288	14.95	14.19	11.19	II
[LM99] 195 (N)						
J163748.09 − 352922.7	249.4504	−35.4897	9.43	8.89	6.03	II
[LM99] 199 (N)						
J164613.86 − 460052.8	251.5578	−46.0147	10.60	10.26	8.41	II
J164607.87 − 460128.1	251.5328	−46.0245	9.89	9.50	8.24	II
J164626.77 − 460014.0	251.6116	−46.0039	9.56	9.18	7.79	II
J164633.23 − 460022.0	251.6385	−46.0061	7.92	7.56	6.29	II
J164633.12 − 460047.8	251.6380	−46.0133	9.53	9.26	7.28	II
[LM99] 200 (N)						
J164648.66 − 442844.6	251.7028	−44.4791	9.39	9.06	7.17	II
[LM99] 201 (N)						
J164626.69 − 140328.5	251.6112	−14.0579	14.82	13.09	9.79	I
[LM99] 203 (I)						
J164714.09 − 093135.9	251.8087	−9.5266	14.23	13.34	11.01	II
J164726.73 − 093136.3	251.8614	−9.5268	15.29	14.43	11.19	I
J164714.28 − 094226.6	251.8095	−9.7074	13.08	12.78	11.28	II
[LM99] 213 (I)						
J164923.41 − 141055.9	252.3476	−14.1822	13.21	12.88	11.48	II
J164918.92 − 141305.0	252.3289	−14.2181	14.52	13.09	10.14	I
[LM99] 216 (N)						
J165004.91 − 175810.8	252.5205	−17.9697	14.58	13.23	10.44	I
[LM99] 217 (N)						
J165019.86 − 180721.9	252.5828	−18.1228	14.40	13.57	10.55	II
[LM99] 218 (N)						
J165019.86 − 180721.9	252.5828	−18.1228	14.40	13.57	10.55	II

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[LM99] 224 (I)						
J165555.54 − 155555.7	253.9814	−15.9322	14.91	13.82	10.24	I
J165551.43 − 160326.3	253.9643	−16.0573	16.30	14.94	11.09	I
J165616.54 − 160210.5	254.0689	−16.0363	9.54	7.36	4.24	I
J165535.48 − 155216.3	253.8978	−15.8712	14.12	13.78	11.38	II
J165605.91 − 160402.3	254.0246	−16.0673	16.33	14.48	11.00	I
[LM99] 226 (I)						
J165715.03 − 160647.3	254.3126	−16.1132	14.25	12.90	10.11	I
[LM99] 229 (II)						
J171603.21 − 205656.2	259.0134	−20.9490	10.00	8.32	5.20	I
J171611.73 − 205754.3	259.0489	−20.9651	9.75	9.35	7.56	II
J171558.00 − 205606.9	258.9917	−20.9353	14.67	14.05	11.37	II
J171555.95 − 205601.2	258.9831	−20.9337	9.06	8.18	5.84	II
J171555.67 − 205603.0	258.9820	−20.9342	8.88	8.36	6.14	II
J171613.11 − 205428.7	259.0546	−20.9080	9.01	8.49	6.68	II
[LM99] 232 (N)						
J171941.26 − 265532.1	259.9219	−26.9256	12.69	10.89	7.21	I
[LM99] 233 (N)						
J172153.75 − 265959.2	260.4740	−26.9998	12.33	11.98	9.82	II
[LM99] 242 (N)						
J175314.22 − 082553.3	268.3093	−8.4315	11.68	10.48	7.82	I
J175313.55 − 082542.1	268.3065	−8.4284	13.47	13.19	11.16	II
[LM99] 245 (N)						
J175829.68 − 053820.0	269.6237	−5.6389	14.91	14.07	11.10	II
[LM99] 257 (N)						
J181617.36 − 023241.1	274.0723	−2.5448	10.97	10.03	8.04	II
[LM99] 260 (N)						
J181712.02 − 081536.6	274.3001	−8.2602	9.79	9.43	8.13	II
J181729.47 − 080201.7	274.3728	−8.0338	13.90	13.14	10.38	II
[LM99] 261 (N)						
J181712.02 − 081536.6	274.3001	−8.2602	9.79	9.43	8.13	II
[LM99] 262 (N)						
J181712.02 − 081536.6	274.3001	−8.2602	9.79	9.43	8.13	II
[LM99] 264 (N)						
J181729.47 − 080201.7	274.3728	−8.0338	13.90	13.14	10.38	II
J181712.02 − 081536.6	274.3001	−8.2602	9.79	9.43	8.13	II

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			[LM99] 266 (N)			
J181938.55 − 060305.7	274.9107	−6.0516	14.42	13.27	10.41	I
			[LM99] 271 (I)			
J182559.53 − 114743.0	276.4980	−11.7953	7.62	7.00	5.90	II
J182559.26 − 115046.0	276.4969	−11.8461	9.70	9.38	7.18	II
J182554.35 − 115221.5	276.4765	−11.8727	12.12	9.38	5.24	I
J182553.81 − 115236.0	276.4742	−11.8767	11.97	9.33	6.77	I
J182557.14 − 115217.8	276.4881	−11.8716	7.76	7.01	5.13	II
J182554.97 − 115301.8	276.4791	−11.8838	9.12	8.79	7.22	II
J182609.28 − 114659.1	276.5387	−11.7831	9.43	9.04	7.44	II
J182603.62 − 114243.3	276.5151	−11.7120	7.93	7.03	5.44	II
			[LM99] 272 (N)			
J182745.21 − 101335.8	276.9384	−10.2266	9.69	9.04	7.71	II
J182734.24 − 101334.6	276.8927	−10.2263	8.54	8.24	6.92	II
			[LM99] 275 (N)			
J183233.93 − 085707.3	278.1414	−8.9520	11.12	10.54	8.21	II
J183234.89 − 085513.8	278.1454	−8.9205	9.58	8.98	6.75	II
J183231.29 − 085902.4	278.1304	−8.9840	9.66	8.93	7.69	II
J183225.29 − 085836.6	278.1054	−8.9769	11.24	10.91	8.29	II
J183240.42 − 085746.5	278.1684	−8.9629	10.31	9.95	8.55	II
J183236.07 − 085442.7	278.1503	−8.9119	10.15	9.79	7.39	II
J183221.33 − 085805.1	278.0889	−8.9681	10.33	10.06	8.36	II
J183237.48 − 085421.0	278.1562	−8.9059	9.63	9.18	7.72	II
			[LM99] 276 (N)			
J183250.19 − 091403.2	278.2092	−9.2342	9.61	9.13	8.00	II
J183236.74 − 091319.7	278.1531	−9.2221	10.45	10.19	8.27	II
J183241.57 − 091537.1	278.1732	−9.2603	11.32	10.92	8.48	II
J183256.94 − 090943.8	278.2373	−9.1622	11.47	10.80	8.23	II
J183233.50 − 091014.3	278.1396	−9.1707	10.22	9.78	7.56	II
J183253.86 − 090857.9	278.2244	−9.1494	11.13	10.86	8.90	II
J183241.38 − 091619.0	278.1724	−9.2720	10.48	10.22	8.85	II
J183301.96 − 091038.3	278.2582	−9.1773	10.47	10.18	8.16	II
J183304.24 − 091322.5	278.2677	−9.2229	10.90	10.49	8.85	II

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			[LM99] 278 (N)			
J183250.19 − 091403.2	278.2092	−9.2342	9.61	9.13	8.00	II
J183304.24 − 091322.5	278.2677	−9.2229	10.90	10.49	8.85	II
J183304.15 − 091650.6	278.2673	−9.2807	9.44	9.05	7.37	II
J183309.95 − 091358.5	278.2915	−9.2329	10.94	10.31	8.43	II
J183310.14 − 091341.5	278.2923	−9.2282	10.48	10.22	7.76	II
J183241.57 − 091537.1	278.1732	−9.2603	11.32	10.92	8.48	II
J183311.58 − 091617.7	278.2983	−9.2716	11.06	10.61	8.34	II
J183312.50 − 091318.5	278.3021	−9.2218	10.79	10.14	8.13	II
J183241.38 − 091619.0	278.1724	−9.2720	10.48	10.22	8.85	II
J183301.96 − 091038.3	278.2582	−9.1773	10.47	10.18	8.16	II
J183313.20 − 091254.1	278.3050	−9.2150	10.27	9.74	8.26	II
J183256.94 − 090943.8	278.2373	−9.1622	11.47	10.80	8.23	II
			[LM99] 282 (N)			
J183927.36 − 063638.8	279.8640	−6.6108	9.79	9.51	7.08	II
			[LM99] 285 (N)			
J184922.51 − 050147.0	282.3438	−5.0297	12.42	12.07	10.73	II
J184931.25 − 045701.5	282.3802	−4.9504	11.21	10.62	9.43	II
			[LM99] 286 (N)			
J185001.01 − 044841.9	282.5042	−4.8117	13.04	12.77	10.64	II
J184959.33 − 044559.1	282.4972	−4.7664	10.59	9.73	7.85	II
J185012.41 − 044053.0	282.5517	−4.6814	10.76	10.44	9.08	II
J185005.01 − 043255.9	282.5209	−4.5489	12.31	11.87	9.11	II
			[LM99] 287 (N)			
J185012.41 − 044053.0	282.5517	−4.6814	10.76	10.44	9.08	II
J184959.33 − 044559.1	282.4972	−4.7664	10.59	9.73	7.85	II
J185005.01 − 043255.9	282.5209	−4.5489	12.31	11.87	9.11	II
J185001.01 − 044841.9	282.5042	−4.8117	13.04	12.77	10.64	II
			[LM99] 290 (I)			
J190622.32 − 065436.6	286.5930	−6.9102	13.46	12.70	11.12	II
J190617.36 − 065340.1	286.5724	−6.8945	13.54	12.91	10.60	II
J190616.14 − 065332.1	286.5673	−6.8923	9.16	7.94	5.64	II
J190613.26 − 065312.8	286.5553	−6.8869	13.98	12.16	9.39	I
J190626.86 − 065508.8	286.6119	−6.9191	8.51	7.20	4.66	I
J190610.48 − 065212.6	286.5437	−6.8702	11.44	10.55	8.95	II
J190621.71 − 065812.1	286.5905	−6.9700	11.61	11.18	9.39	II
J190629.06 − 065857.1	286.6211	−6.9825	15.57	14.42	10.57	I

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		[LM99] 291 (N)				
J190757.78 − 035307.5	286.9908	−3.8854	13.46	13.17	11.20	II
J190822.25 − 040124.5	287.0927	−4.0235	14.38	13.56	10.62	II
J190731.97 − 041115.4	286.8832	−4.1876	15.19	14.36	11.11	II
J190808.90 − 033755.3	287.0371	−3.6321	11.38	10.18	7.66	I
		[LM99] 295 (N)				
J191959.72 + 195743.8	289.9989	19.9622	9.21	8.64	7.11	II
		[LM99] 297 (I)				
J192014.94 + 113540.0	290.0623	11.5945	9.54	8.09	5.31	I
		[LM99] 300 (I)				
J192057.00 + 233137.6	290.2375	23.5271	12.77	11.56	8.89	I
		[LM99] 308 (N)				
J192130.09 + 123028.3	290.3754	12.5079	11.45	11.01	9.34	II
		[LM99] 322 (I)				
J192626.65 + 235705.2	291.6111	23.9515	12.30	11.63	9.47	II
		[LM99] 323 (N)				
J192635.22 + 235728.3	291.6468	23.9579	11.11	10.50	8.22	II
J192632.84 + 235732.2	291.6369	23.9590	8.85	8.25	6.42	II
J192632.85 + 235745.7	291.6369	23.9627	11.96	9.95	7.63	I
		[LM99] 324 (N)				
J192845.12 + 233358.5	292.1880	23.5663	13.60	12.89	10.41	II
		[LM99] 330 (N)				
J194624.09 + 190246.6	296.6004	19.0463	12.13	11.32	9.23	II
		[LM99] 331 (N)				
J201319.04 + 400945.0	303.3294	40.1625	12.80	12.48	11.08	II
		[LM99] 333 (I)				
J203720.42 + 574416.7	309.3351	57.7380	13.36	10.19	7.75	I
		[LM99] 334 (I)				
J203711.72 + 574749.9	309.2989	57.7972	12.55	10.82	8.16	I
		[LM99] 339 (N)				
J204104.53 + 572751.5	310.2689	57.4643	14.04	12.98	10.17	I
		[LM99] 340 (N)				
J204045.60 + 672052.1	310.1900	67.3478	15.47	14.68	12.03	II
J204046.53 + 672200.2	310.1939	67.3667	15.32	14.49	11.99	II
J204049.95 + 672212.7	310.2081	67.3702	15.86	15.40	12.49	II
J204039.60 + 672257.4	310.1650	67.3826	18.00	16.49	12.06	I
J204056.66 + 672304.9	310.2361	67.3847	14.02	13.04	9.53	I

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[LM99] 344 (N)						
J204028.42 + 671647.5	310.1184	67.2799	15.65	14.96	12.04	II
[LM99] 345 (N)						
J204328.94 + 675300.9	310.8706	67.8836	16.60	15.29	12.00	I
J204346.59 + 675127.0	310.9441	67.8575	15.93	15.29	12.12	II
[LM99] 350 (N)						
J204952.01 + 601554.3	312.4667	60.2651	11.80	10.49	7.92	I
[LM99] 351 (I)						
J205129.83 + 601838.4	312.8743	60.3107	15.15	11.87	8.33	I
[LM99] 356 (N)						
J210055.70 + 492035.8	315.2321	49.3433	13.30	12.62	10.59	II
J210054.81 + 492136.2	315.2284	49.3601	11.88	11.29	9.66	II
[LM99] 358 (I)						
J210020.65 + 681316.7	315.0861	68.2213	12.09	9.70	7.53	I
J210022.18 + 681259.0	315.0924	68.2164	11.60	9.09	7.03	I
J210028.92 + 681302.2	315.1205	68.2173	10.59	9.64	8.01	II
J210032.09 + 681247.5	315.1337	68.2132	8.71	8.14	6.69	II
[LM99] 359 (N)						
J210149.99 + 674718.0	315.4583	67.7884	16.24	15.44	11.91	I
J210130.73 + 674503.0	315.3780	67.7508	14.73	13.12	10.26	I
J210202.70 + 674947.4	315.5113	67.8299	15.54	14.77	11.39	II
J210143.65 + 675026.7	315.4319	67.8408	10.48	9.91	8.34	II
[LM99] 360 (I)						
J210221.21 + 675420.1	315.5884	67.9056	11.39	9.11	6.93	I
[LM99] 362 (N)						
J210803.63 + 561731.2	317.0152	56.2920	9.39	8.70	6.43	II
J210806.18 + 561714.1	317.0258	56.2873	10.03	9.26	7.50	II
J210823.31 + 561942.3	317.0971	56.3284	15.85	14.73	11.62	I
J210753.61 + 561732.7	316.9734	56.2924	14.38	13.08	10.05	I
[LM99] 363 (I)						
J211221.99 + 472444.6	318.0916	47.4124	10.39	9.35	6.69	II
J211218.86 + 472506.4	318.0786	47.4185	9.76	8.34	5.82	I
J211216.73 + 472340.9	318.0697	47.3947	15.66	14.27	11.23	I
J211225.09 + 472633.5	318.1046	47.4427	13.73	13.47	11.29	II
J211212.25 + 472407.4	318.0511	47.4021	11.45	10.69	8.81	II

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J211213.10 + 472313.0	318.0546	47.3870	12.93	12.00	10.24	II
J211222.34 + 472729.6	318.0931	47.4582	14.71	13.94	11.15	II
J211246.25 + 472526.6	318.1927	47.4241	12.71	12.17	9.98	II
J211228.58 + 471840.9	318.1191	47.3114	13.92	13.66	11.19	II
J211158.44 + 472036.8	317.9935	47.3436	14.11	13.07	10.32	II
J211307.16 + 472003.3	318.2799	47.3343	14.04	13.77	11.35	II
J211314.77 + 471852.6	318.3116	47.3146	13.72	13.06	10.38	II
J211238.40 + 473435.9	318.1600	47.5766	15.46	13.80	10.97	I
J211243.43 + 471403.6	318.1810	47.2343	14.17	13.91	11.56	II
[LM99] 364 (I)						
J211228.58 + 471840.9	318.1191	47.3114	13.92	13.66	11.19	II
J211307.16 + 472003.3	318.2799	47.3343	14.04	13.77	11.35	II
J211216.73 + 472340.9	318.0697	47.3947	15.66	14.27	11.23	I
J211213.10 + 472313.0	318.0546	47.3870	12.93	12.00	10.24	II
J211221.99 + 472444.6	318.0916	47.4124	10.39	9.35	6.69	II
J211243.43 + 471403.6	318.1810	47.2343	14.17	13.91	11.56	II
J211246.25 + 472526.6	318.1927	47.4241	12.71	12.17	9.98	II
J211314.77 + 471852.6	318.3116	47.3146	13.72	13.06	10.38	II
J211212.25 + 472407.4	318.0511	47.4021	11.45	10.69	8.81	II
J211218.86 + 472506.4	318.0786	47.4185	9.76	8.34	5.82	I
J211158.44 + 472036.8	317.9935	47.3436	14.11	13.07	10.32	II
J211225.09 + 472633.5	318.1046	47.4427	13.73	13.47	11.29	II
J211222.34 + 472729.6	318.0931	47.4582	14.71	13.94	11.15	II
J211314.18 + 471401.7	318.3091	47.2338	14.48	13.32	11.49	II
[LM99] 374 (N)						
J212352.46 + 500814.0	320.9686	50.1372	11.91	11.10	8.03	II
J212350.70 + 500827.7	320.9613	50.1410	12.41	12.12	9.84	II
J212352.49 + 500754.0	320.9687	50.1317	9.43	8.71	6.89	II
J212350.18 + 500818.1	320.9591	50.1384	10.69	9.90	7.69	II
[LM99] 378 (N)						
J214038.77 + 574741.5	325.1615	57.7949	13.80	13.41	10.99	II
J214022.71 + 574623.9	325.0947	57.7733	11.05	10.71	8.86	II
J214031.52 + 574944.2	325.1313	57.8290	13.70	13.32	11.63	II

Continued

[LM99] 384 (I)						
J214626.67 + 471706.9	326.6112	47.2853	9.99	9.23	7.57	II
J214629.01 + 471826.5	326.6209	47.3074	11.23	10.67	9.17	II
J214633.73 + 471830.4	326.6406	47.3085	11.53	10.45	8.47	II
J214632.07 + 471850.3	326.6336	47.3140	10.54	9.86	8.37	II
J214620.65 + 471739.9	326.5861	47.2944	12.87	12.03	9.94	II
J214620.51 + 471648.0	326.5855	47.2800	12.50	12.14	10.80	II
J214641.79 + 471632.7	326.6742	47.2758	11.89	11.38	8.98	II
J214614.39 + 471831.2	326.5600	47.3087	10.53	9.68	7.19	II
J214640.31 + 471527.8	326.6680	47.2577	13.84	13.30	11.47	II
J214618.14 + 471526.4	326.5756	47.2573	11.10	10.29	8.14	II
J214603.52 + 471910.1	326.5147	47.3195	13.24	12.38	10.50	II
J214557.12 + 471931.4	326.4880	47.3254	12.29	11.61	10.29	II
[LM99] 390 (N)						
J221602.78 + 732400.6	334.0116	73.4002	15.65	14.87	11.83	II
J221559.65 + 732428.0	333.9986	73.4078	13.91	13.42	11.45	II
J221610.78 + 732408.4	334.0450	73.4024	13.90	12.29	9.57	I
J221644.41 + 732518.7	334.1850	73.4219	11.52	11.11	9.71	II
[LM99] 392 (I)						
J222802.91 + 690116.8	337.0121	69.0213	8.99	6.98	4.36	I
J222814.96 + 685930.6	337.0624	68.9918	15.10	14.24	11.32	II
J222831.97 + 690045.8	337.1332	69.0127	15.47	15.02	12.09	II
J222824.68 + 690508.4	337.1029	69.0857	15.41	14.27	11.58	I
[LM99] 393 (N)						
J222735.65 + 751451.0	336.8986	75.2475	15.88	15.01	11.92	II
[LM99] 395 (I)						
J223050.66 + 751301.2	337.7111	75.2170	14.17	13.76	11.48	II
J223031.28 + 751254.4	337.6303	75.2151	16.88	15.75	11.70	I
J223054.39 + 751454.8	337.7267	75.2486	16.51	14.69	11.71	I
J223025.94 + 751036.1	337.6081	75.1767	14.92	13.05	11.03	I
J223025.41 + 750955.6	337.6059	75.1655	13.00	12.67	11.43	II
J223031.63 + 751537.9	337.6318	75.2605	14.96	13.09	10.93	I
J222959.54 + 751404.2	337.4981	75.2345	11.31	9.85	7.11	I
J223135.55 + 750844.4	337.8982	75.1457	14.73	13.90	10.82	II
J223040.50 + 751753.2	337.6688	75.2981	17.11	15.17	11.56	I

Continued

J222933.39 + 751316.2	337.3891	75.2212	13.89	11.42	8.53	I
J223044.46 + 751802.5	337.6853	75.3007	17.09	16.05	11.87	I
J223040.00 + 751804.6	337.6667	75.3013	17.12	15.33	11.38	I
[LM99] 397 (N)						
J223747.99 + 751028.1	339.4500	75.1745	15.36	14.71	11.58	II
J223808.76 + 751213.9	339.5365	75.2039	12.89	12.41	10.59	II
J223811.60 + 751214.6	339.5484	75.2041	11.30	10.61	8.27	II
J223818.71 + 751153.7	339.5780	75.1983	8.27	7.56	5.48	II
J223814.20 + 751223.2	339.5592	75.2065	12.36	12.09	10.64	II
J223820.94 + 751300.9	339.5873	75.2169	16.98	15.11	11.88	I
J223829.62 + 751426.6	339.6234	75.2407	11.50	10.95	8.93	II
[LM99] 401 (I)						
J232546.38 + 741738.7	351.4433	74.2941	12.22	9.13	5.86	I

Table 2. Starless cores. The numbers indicate the core number labeled in Lee and Myers (1999) [2].

4, 7, 9[a], 10, 13, 18, 21[b], 23, 27, 33, 38, 41, 42, 44, 46, 48, 50, 53, 54, 55, 56, 57, 58, 59, 60, 61, 63, 66, 67, 68, 71, 72[c], 73, 74, 82, 85, 86, 87, 95, 96, 97, 99, 106, 107, 109, 110, 113, 115, 116, 117, 118, 124, 125, 126, 128, 131[d], 134, 136, 137, 140, 149, 150[e], 152, 153, 156, 160, 164, 175, 176, 177[f], 180, 185[g], 193, 194, 196, 197, 198, 202, 204, 205, 206, 207[h], 208, 209[i], 210, 211[j], 212, 215, 220, 221, 222, 223, 225, 227, 228, 230, 231, 234[k], 235, 236, 237, 243, 244, 246, 247, 248, 254, 255, 256, 258, 259, 265, 267, 273, 277, 280, 281, 288, 289, 292, 293, 294, 296, 298, 301, 302, 305, 310, 311, 312, 313, 314, 315, 316, 321, 325, 326[l], 332[m], 341, 346, 348, 349, 355, 361, 365, 373, 375, 381, 382, 383, 402

a: Lee and Myers (1999) listed IRAS 04005 + 5647 as an associated embedded YSO; however, it is classified as a field star in this study. b: Lee and Myers (1999) [2] listed IRAS 04248 + 2612 as an associated embedded YSO; however, it is located outside the searched region in this study. c: Lee and Myers (1999) [2] listed IRAS 05522 + 0146 as an associated embedded YSO; however, it is located outside the searched region in this study. d: Lee and Myers (1999) [2] listed IRAS 14,451 − 6502 as an associated embedded YSO; however, it is classified as a field star in this study. e: Lee and Myers (1999) [2] listed IRAS 15,534 − 3740 as an associated embedded YSO; however, it is saturated in the $W1$-band. f: Lee and Myers (1999) [2] listed IRAS 16,285 − 2355 as an associated embedded YSO; however, it is saturated in the $W1$-band. g: Lee and Myers (1999) [2] listed IRAS 16,305 − 2425 as an associated embedded YSO; however, it is a low-S/N in the $W3$-band. h: Lee and Myers (1999) [2] listed IRAS 16,451 − 0953 as an associated embedded YSO; however, it is a low-S/N in the $W2$- and $W3$-band. i: Lee and Myers (1999) [2] listed IRAS 16,451 − 1045 as an associated embedded YSO; however, it is a low-S/N in the $W2$- and $W3$-band. j: Lee and Myers (1999) [2] listed IRAS 16,455 − 1405 as an associated embedded YSO; however, it is saturated in the $W1$-band. k: Lee and Myers (1999) [2] listed IRAS 17,193 − 2705 as an associated embedded YSO; however, it is identified as a planetary nebula (Henize 1967) [10]. l: Lee and Myers (1999) [2] listed IRAS 19345 + 0727 as an associated embedded YSO; however, it is classified as a field star in this study. m: Lee and Myers (1999) [2] listed IRAS 20353 + 6742 as an associated embedded YSO; however, it is classified as a field star in this study.

4. Discussion

For the star-forming cores, Lee and Myers (1999) [2] listed the associated IRAS sources. Among them, 16 IRAS sources were identified as Class I candidates, and 5 as Class II candidates in our study. Six sources were identified as field stars. Further, 22 sources were saturated mostly in the *W*1-band. Eleven sources were low S/N mainly in the *W*3-band. Two sources possessed the contamination and confusion flag, and five sources were located outside the searched region. Based on these discrepancies in the source identification, 13 cores previously classified as star-forming cores were reclassified as starless cores in this study (**Table 2**).

The associated *WISE* sources are thought to be very low-mass objects. For example, the *J*-band apparent magnitudes of the Class II sources associated with [LM 99] 10 are approximately 16 mag, which corresponds to absolute magnitudes of approximately 10 mag. Based on the evolutionary track of Baraffe *et al.* (2003) [7], a 0.005 $M_\odot$ object has 10th absolute magnitude in the *J*-band at 1 Myr old. Because 400 YSO candidates were found in 141 cores, each core has 3 YSO candidates on average. Assuming that the average mass of the core is ~1 $M_\odot$ (e.g., Dunham *et al.*, 2016 [8]; Tokuda *et al.*, 2019 [9]), the star formation efficiency is obtained as low as 1%.

Extremely low-mass YSOs and deeply embedded YSOs may not be detected even with WISE. A portion of the starless cores classified in this study may indeed have YSOs. We detected 132 and 268 Class I and Class 2 candidates, respectively. The number of Class II sources should be 10 times that of the Class I sources if stars form constantly. This is because the age of a Class II source is 10 times that of a Class I source. The small number of the detected Class II candidates indicates the shallow detection limit for the Class II source even using the *WISE* photometric catalog. Another interpretation for the deficit in the Class II sources is based on the proper motion of the YSOs. Esplin and Luhman (2019) showed that YSOs associated with the Taurus molecular cloud have a dispersion of proper motion as large as ~10 mas/yr [11]. The distances of the nearest cores in this study are similar to that of the Taurus molecular cloud. Thus, a Class I source born in the nearest core spreads out as ~17′ in 10^5 yr and a Class II source spreads out as ~2.8˚ in 10^6 yr. Because the size of the cores in this study is only a few arcminutes, we may miss the scattered YSOs, particularly the Class II sources associated with the nearby cores. If this is the case, the ratio of the number of Class II sources to that of the Class I sources (hereafter, the Class ratio) is low for the nearby cores. We investigated this detection bias by dividing the star-forming cores into three groups according to their distance (**Table 3**). The Class ratio is low for the cores in the distant group, compared to the cores in the medium distance group. The apparent sizes of the cores in the distant group are, on average, smaller than those of the cores in the other groups. Many Class II sources scattered from the distant cores may not be detected in this study, resulting in the low Class ratio for the distant cores. The average apparent sizes are comparable for the cores in the nearby and medium distance groups; however,

Table 3. Ratio of the number of Class II candidates to that of the Class I candidates associated with the star-forming cores. *a* and *b* represent the average semi-major and semi-minor axes, respectively.

distance	*n* (cores)	*a*	*b*	$\frac{n(\text{Class II})}{n(\text{Class I})}$
$d < 170$ pc	48	11.0′	4.0′	1.24
170 pc < d < 300 pc	52	9.4′	4.0′	3.12
$d > 300$ pc	39	5.5′	2.7′	2.19

the Class ratio is low for the nearby group. We consider that a portion of the Class II sources associated with the nearby cores may be located outside the searched region, resulting in the low Class ratio for the nearby cores. Thus, completeness in this study may be different for the Class I and Class II sources owing to their proper motion.

Lee and Myers (1999) [2] recognized that the sizes of the star-forming cores are larger than those of the starless cores, while they did not find significant differences in the distances and aspect ratios between these two types of cores. However, we did not find any differences in size, distance, and aspect ratio. Because both starless and star-forming cores have a large variety, we took the sigma clipping average for these parameters. We calculated the average and standard deviation of the parameters, and subsequently removed the values beyond ±3 sigma from the average. We iterated this procedure until there were no more values to remove. The projected areas were 0.024 ± 0.018 pc^2 and 0.066 ± 0.043 pc^2 for the starless cores and star-forming cores, respectively. Further, the distances were 195 ± 56 pc and 215 ± 82 pc, and the aspect ratios were 1.99 ± 0.61 and 2.09 ± 0.74 for the starless cores and star-forming cores, respectively. As evident, the differences between all the parameters for the starless and star-forming cores are not significant.

The ratio of the number of starless cores to that of the star-forming cores suggests the timescale from the formation of the cloud core to the birth of the star. We estimated this timescale to be 0.5 Myr from the ratio of the number of starless cores (149) to that of the cores with Class I candidates only (32), assuming that the age of a Class I source is 0.1 Myr. Otherwise, the timescale was estimated to be 1.4 Myr when considering the ratio of the number of the starless cores (149) to that of the cores with Class II candidates (107), assuming the age of a Class II source as 1 Myr. Lee and Myers (1999) [2] found 306 starless cores and 94 cores with embedded YSOs. The embedded YSO corresponds to a Class 0 or Class I source. Assuming 0.1 - 0.5 Myr for the age of the embedded YSO, they estimated the typical lifetime of the starless cores to be 0.3 - 1.6 Myr. This value is consistent with the timescale derived in this study. On the other hand, they detected only six PMSs. However, because the age of a Class II source is 10 times that of a Class I source, the number of Class II sources should be 10 times that of the Class I sources, assuming a constant star formation rate. Thus, the small number of PMSs implies a shallow detection limit of IRAS for a PMS.

We claim that the timescale of low-mass star formation in a core is approximately 1 Myr. Shu (1977) considered the gravitational collapse of an isolated core, and derived the collapse timescale of 1 Myr [12]. Whereas, Palla and Galli (1997) considered ambipolar diffusion during the collapse of a core, and then derived a collapse timescale of several tens of Myr [13]. Our statistics are consistent with the collapse timescale presented by Shu (1977) [12].

Kim *et al.* (2010) examined the association of infrared dark cloud cores with YSOs [14]. They used the Spitzer GLIMPSE, MSX, and IRAS point source catalogs. The infrared dark clouds are as massive as 10^2 - 10^4 $M_\odot$ and are considered to be the forming site of a massive star. They identified YSO candidates for 1072 cores, while 8102 cores had no YSO candidates. Based on the ratio of these numbers and the typical lifetime of a high-mass embedded YSO of 10^3 - 10^4 yr, they suggested that the cores spend 10^4 - 10^5 years to form high-mass stars. This value is shorter than the timescale estimated in this study. Thus, the lifetime of massive starless cores may be shorter than that of low-mass starless cores.

5. Conclusion

We searched for infrared sources associated with the molecular cloud cores listed in Lee and Myers (1999) [2], by using the *WISE* photometric catalog. One hundred and forty-nine cores do not have associated sources and are starless cores. Further, 32 cores have only Class I candidates, and 197 cores have Class II candidates. The estimated timescale from the core formation to the birth of a star is approximately 1 Myr. This is consistent with the gravitational collapse model of a core.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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