

NEW MEMBERS OF THE SCORPIUS-CENTAURUS COMPLEX AND AGES OF ITS SUB-REGIONS

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ABSTRACT

We have spectroscopically identified ~ 100 G-, K-, and M-type members of the Scorpius-Centaurus complex. To deduce the age of these young stars we compare their Li $\lambda 6708$ absorption line strengths against those of stars in the TW Hydrae association and β Pictoris moving group. These line strengths indicate that Sco-Cen stars are younger than β Pic stars whose ages of ~ 12 Myr have previously been derived from a kinematic traceback analysis. Our derived age, ~ 10 Myr, for stars in the Lower Centaurus Crux and Upper Centaurus Lupus subgroups of ScoCen is younger than previously published ages based on the moving cluster method and upper main-sequence fitting. The discrepant ages are likely due to an incorrect (or lack of) cross-calibration between model-dependent and model-independent age-dating methods.

Key words: open clusters and associations: individual (Scorpius OB2, Lower Centaurus-Crux, Upper Centaurus-Lupus, Upper Scorpius) – stars: activity – stars: kinematics and dynamics – stars: pre-main sequence

Online-only material: color figures

1. INTRODUCTION

The Scorpius-Centaurus region (ScoCen) is the nearest (100–200 pc) massive star formation site to Earth. It consists of three subgroups (de Zeeuw et al. 1999): Upper Scorpius (US), Upper Centaurus Lupus (UCL), and Lower Centaurus Crux (LCC). Each of these sub-regions has a different location in the sky plane, different age, and different space motion. Therefore, ScoCen is the best site for studying a sequential star formation or triggered star formation phenomena. Furthermore, ScoCen holds the key to the origin of nearby young stellar groups (Zuckerman & Song 2004; Fernández et al. 2008), and due to its youth and proximity to Earth, a thorough membership determination can be made down to very low mass.

Using *Hipparcos* data, de Zeeuw et al. (1999) refined a list of Sco-Cen members containing many B- and A-type stars and relatively few F- and G-type stars. From the number of B- and A-type stars ($N \sim 300$), several thousand low-mass members were expected to exist. However, mainly due to the vast surface area of ScoCen in the projected sky plane (~ 2000 deg²) and its deep southern declination (80% of the region is below decl. = -40°), this region has been little studied. Compared to a similarly massive but more distant star formation site (e.g., the Orion region), the Sco-Cen complex has been barely investigated. No systematic search for low-mass members of ScoCen has been carried out with the exception of occasional small area pilot surveys (for example, Preibisch et al. 2001).

Mamajek et al. (2002) identified several dozen F- and G-type LCC and UCL members. Using a moving cluster method, they estimated secular parallaxes of new members, then derived ages (UCL 16 Myr and LCC 17 Myr) by plotting them on a Hertzsprung–Russell diagram (HRD) and comparing them with theoretical pre-main-sequence models. Recently, using a larger ($N = 138$) sample of F-type kinematic members from de Zeeuw et al. (1999), Pecaut et al. (2012) re-deduce old ages (16/17 Myr) for the UCL/LCC regions.

Using our ~ 100 spectroscopically confirmed G/K/M-type members of LCC/UCL (Table 1), we show that the LCC/UCL

age is more consistent with a younger age (~ 10 Myr). Because our age determination is anchored in the traceback age for the β Pic moving group and because kinematic traceback is the least model-dependent technique for deriving ages of young stars, we expect that an ~ 10 Myr age for LCC/UCL is most likely to be correct.

Ages of LCC and UCL are important in the interpretation of *Spitzer* and other data (e.g., Currie et al. 2008). For example, the high fraction ($>35\%$) of dusty disks (including several mid-IR excesses) around Sco-Cen F/G stars (Chen et al. 2005) applies to ~ 10 Myr old stars, rather than stars of nearly twice this age.

2. NEW MEMBERS

2.1. Observations

As part of an extensive search for young and nearby stars to Earth, $\lambda/\Delta\lambda \sim 4500$ spectra of candidate Sco-Cen members were obtained with the Double Beam Spectrograph (DBS) on the Nasmyth-A focus of the Australian National University's 2.3 m telescope. For many bright young stars confirmed from DBS spectra, we later obtained echelle spectra to obtain radial velocities. Candidate Sco-Cen members were selected over the Sco-Cen region (Figure 9 of de Zeeuw et al. 1999) from a correlation between X-ray (*ROSAT*; Voges et al. 1999, 2000) and kinematic catalogs (*Hipparcos*: Perryman et al. 1997; *Tycho-2*: Høg et al. 2000; SuperCOSMOS: Hambly et al. 2001). Then, we kept only X-ray bright stars ($\log L_X/L_{\text{bol}} \gtrsim 10^{-3.5}$) whose space motions are consistent with the nominal value of LCC ($UVW = -12, -13, -7$ km s⁻¹; de Zeeuw et al. 1999, details on space motion calculation are given below). Since most candidate members lack sufficient information to enable direct calculation of their *UVW* (distances to non-*Hipparcos* stars and radial velocities for almost all candidate members), we calculated *UVW* based on photometric distances using an ~ 10 Myr age and a range of radial velocities (-50 to $+50$ km s⁻¹). If an X-ray star can have a Sco-Cen-like *UVW* for some radial velocities within the above stated range, then we selected it as a candidate Sco-Cen member. Our chosen

Table 1
Identified Members of Sco-Cen

No.	Name	R.A. (J2000)	Decl.	Dist. (pc)	<i>N</i>	Eq. Width		<i>V</i> (mag)	<i>V</i> − <i>K</i> (mag)	<i>B</i> − <i>V</i> (mag)	<i>f</i>	Rad. Vel. (km s ^{−1})	<i>(U, V, W)</i> (km s ^{−1})	Note
						Li	H α							
Lower Centaurus Crux														
1	SSS 1132-3019	11:32:18.38	−30:19:51.5	42	1	500	−6.7	14.20d	5.32	1.62	−3.51	−	−	phot dist=55, TWA 30
2	HIP 57524	11:47:24.58	−49:53:02.9	92	2	190	0.6	9.07	1.56	0.65	−3.29	13.4 ± 1.5	−6.4, −18.7, −5.0	phot dist=86, TWA 19A
3	HIP 57524 B	11:47:20.64	−49:53:04.2	92	1	330	−1.6	12.30d	4.13	1.52	−3.29	15.3 ± 3.2	−5.7, −20.4, −4.6	phot dist=63, TWA 19B
4	TYC 8631-0128	11:55:57.75	−52:54:00.8	107	3	360	0.1	11.00	2.61	1.06	−3.50	11.5 ± 1.5	−10.5, −18.5, −4.8	
5	SSS 1159-4510	11:59:27.87	−45:10:19.2	57	1	420	−4.6	14.54p	5.47	1.65	−2.92	−	−	
6	SSS 1205-5331	12:05:12.66	−53:31:23.1	102	1	270	−1.9	13.54d	4.23	1.53	−3.06	−	−	
7	HIP 58996	12:05:47.52	−51:00:12.1	110	1	240	0.9	8.89	1.58	0.66	−3.56	16.3 ± 2.5	−8.6, −24.0, −6.0	phot dist=78.0
8	SSS 1208-5850	12:08:20.60	−58:50:15.1	79	1	200	−3.4	15.35d	5.53	1.67	−3.08	−	−	
9	SSS 1210-4855	12:10:10.34	−48:55:45.9	104	1	360	−0.3	11.21p	2.79	1.14	−3.08	−	−	
10	TYC 8636-2515	12:12:35.79	−55:20:27.2	99	4	300	0.2	10.48	2.36	0.95	−3.22	14.7 ± 1.5	−6.1, −20.9, −6.7	
11	TYC 8978-3494	12:12:48.93	−62:30:31.9	63	1	350	0.4	11.77	3.81	1.38	−2.52	−	−	FS 623
12	TYC 8978-5124	12:13:57.02	−62:55:12.6	98	1	310	−0.2	11.40	3.01	1.28	−3.03	−	−	
13	TYC 8242-1324	12:14:34.12	−51:10:12.4	103	1	270	0.4	10.29	2.15	0.87	−3.35	−	−	
14	TYC 8242-1324B	12:14:31.88	−51:10:15.7	84	1	310	−0.5	13.57d	4.48	1.54	−3.35	−	−	
15	HIP 59716	12:14:50.76	−55:47:23.4	97	1	100	1.6	8.45	1.17	0.45	−3.54	13.0 ± 7.0	−8.1, −19.8, −4.6	phot dist=86
16	HIP 59721	12:14:52.35	−55:47:03.5	97	1	330	−0.7	9.77	2.26	0.79	−3.54	17.6 ± 1.7	−5.8, −23.6, −2.9	phot dist=76
17	TYC 8637-1558	12:16:01.20	−56:14:06.9	69	1	290	0.2	11.50	3.54	1.40	−2.99	−	−	broad lines
18	SSS 1216-5055	12:16:17.01	−50:55:26.3	105	1	150	−3.7	14.69d	4.83	1.57	−2.14	−	−	FS 625
19	TYC 8986-0497	12:16:30.10	−67:11:47.7	72	3	430	−0.2	11.10	3.25	1.39	−3.19	7.0 ± 5.0	−6.8, −11.5, −5.5	
20	TYC 9231-1185	12:16:40.31	−70:07:36.1	92	1	325	0.0	10.73	2.64	1.07	−3.49	−	−	
21	TYC 8641-2187	12:18:58.05	−57:37:19.1	68	4	340	−0.1	9.87	2.50	1.01	−3.22	−	−	broad lines
22	TYC 8983-0098	12:19:21.68	−64:54:10.3	66	4	340	0.2	10.12	2.72	1.11	−3.21	15.0 ± 1.5	−2.3, −18.3, −5.5	
23	SSS 1219-5018	12:19:59.38	−50:18:38.1	165	1	260	−1.0	12.89p	3.24	1.38	−2.85	−	−	2MASS binary?, ~2'' 5 NS
24	TYC 8983-0795	12:20:54.56	−64:57:24.2	98	1	400	−0.9	10.39	2.31	0.93	−3.53	−	−	
25	TYC 8983-0564	12:21:30.84	−64:03:52.7	56	1	380	−0.8	10.83	3.42	1.40	−3.33	−	−	
26	TYC 8238-1462	12:21:55.69	−49:46:12.4	99	2	355	−0.4	10.02	2.01	0.83	−3.42	13.8 ± 2.4	−7.4, −21.5, −5.3	
27	TYC 8234-2856	12:22:04.32	−48:41:24.8	101	1	340	0.5	10.51	2.35	0.94	−3.23	13.1 ± 2.3	−5.1, −19.2, −4.0	
28	SSS 1222-5739	12:22:28.84	−57:39:12.2	81	1	240	−4.3	14.59d	5.09	1.59	−2.81	−	−	
29	SSS 1222-6020	12:22:39.93	−60:20:24.4	106	1	140	−3.0	15.09d	5.04	1.58	−2.76	−	−	
30	SSS 1223-5540	12:23:14.33	−55:40:16.1	78	1	130	−11.0	14.85d	5.27	1.60	−2.47	−	−	FS 632
31	TYC 8983-0854	12:23:47.54	−64:02:54.9	101	1	375	−0.7	10.79	2.55	1.03	−3.41	−	−	
32	TYC 8979-1997	12:27:16.63	−62:39:14.2	91	1	375	0.0	10.90	2.78	1.13	−3.15	−	−	
33	TYC 8979-1683	12:28:25.44	−63:20:58.6	73	3	260	0.6	9.33	2.00	0.83	−2.91	13.9 ± 1.9	−3.0, −17.9, −5.1	
34	TYC 8654-2791	12:33:33.85	−57:14:06.6	101	1	345	0.0	10.89	2.62	1.07	−3.23	−	−	
35	TYC 8992-0605	12:36:39.02	−63:44:43.4	68	3	410	0.3	9.88	2.51	1.01	−3.38	−	−	
36	TYC 8646-0166	12:36:59.00	−54:12:17.9	104	1	290	0.6	10.40	2.22	0.89	−3.36	−	−	
37	TYC 8658-1264	12:38:35.60	−59:16:43.8	123	1	380	−0.6	11.62	2.83	1.15	−3.10	−	−	
38	SSS 1244-6902	12:44:14.57	−69:02:35.4	79	1	520	−3.3	13.34d	4.43	1.54	−2.64	−	−	FS 645
39	TYC 8992-0420	12:44:34.85	−63:31:46.1	79	2	390	−0.9	10.79	2.91	1.20	−3.05	−	−	
40	TYC 8647-0324	12:45:48.85	−54:10:58.3	127	1	340	−0.2	11.28	2.54	1.03	−3.23	−	−	

Table 1
(Continued)

No.	Name	R.A. (J2000)	Decl.	Dist. (pc)	N	Eq. Width		V (mag)	V - K (mag)	B - V (mag)	f	Rad. Vel. (km s ⁻¹)	(U, V, W) (km s ⁻¹)	Note
						Li	H α							
41	TYC 9228-1355	12:47:21.99	-68:08:40.0	86	1	425	-0.5	10.88	2.85	1.16	-3.50	-	-	
42	SSS 1247-5050	12:47:35.99	-50:50:51.9	107	1	140	-4.7	14.98d	4.97	1.58	-2.98	-	-	
43	TYC 8651-0442	12:47:48.27	-54:31:30.6	75	1	460	-2.2	11.47	3.42	1.40	-3.06	-	-	
44	TYC 7783-1908	12:48:07.82	-44:39:16.6	76	1	260	0.0	9.73	2.22	0.89	-3.11	-	-	
45	TYC 8257-1545	12:50:51.44	-51:56:35.4	109	1	450	-2.1	11.68	3.05	1.30	-3.35	-	-	2MASS binary? ~3" EW
46	SSS 1251-5253	12:51:05.57	-52:53:12.1	102	1	395	-1.1	12.39d	3.57	1.41	-2.87	-	-	FS 650
47	SSS 1251-5630	12:51:12.46	-56:30:46.8	70	1	460	-2.1	13.24d	4.51	1.54	-3.17	-	-	
48	SSS 1252-5615	12:52:00.60	-56:15:57.7	93	1	340	-4.7	14.52d	4.87	1.57	-2.71	-	-	
49	SSS 1252-5553	12:52:14.72	-55:53:37.2	109	1	360	-1.7	12.54d	3.57	1.41	-3.12	-	-	FS 652
50	SSS 1255-5355	12:55:55.95	-53:55:31.1	99	1	315	-4.4	14.50d	4.80	1.56	-2.90	-	-	
51	TYC 9245-0535	12:56:08.35	-69:26:53.9	68	1	430	-1.9	11.63	3.64	1.41	-2.66	-	-	FS 655
52	TYC 8989-0583	12:56:09.46	-61:27:25.3	68	3	260	-0.1	9.45	2.19	0.88	-2.93	10.5 \pm 3.0	-8.3, -18.3, -4.1	
53	TYC 9245-0617	12:58:25.65	-70:28:49.0	75	3	350	0.0	9.92	2.38	0.95	-3.32	11.1 \pm 1.5	-7.3, -17.1, -7.5	
54	SSS 1259-6808	12:59:35.74	-68:08:01.0	59	1	540	-6.3	14.56d	5.44	1.65	-1.90	-	-	FS 658
55	TYC 8648-0446	13:01:50.70	-53:04:58.3	136	1	290	0.2	11.09	2.30	0.92	-3.28	-	-	
56	TYC 8993-0409	13:02:47.06	-62:13:58.9	88	1	315	0.8	10.18	2.33	0.93	-3.25	-	-	2MASS binary ~9" NE
57	TYC 9242-0290	13:14:01.15	-68:46:38.5	106	1	360	-0.4	11.27	2.81	1.14	-3.27	-	-	SB2?
58	TYC 8259-0689	13:14:23.86	-50:54:01.8	99	1	250	0.5	10.40	2.30	0.92	-2.97	-	-	
59	TYC 8674-2317	13:21:20.30	-59:03:44.0	73	2	430	-1.2	10.82	3.04	1.30	-3.50	15.5 \pm 1.8	-1.3, -20.8, -4.4	
60	HIP 65423	13:24:35.15	-55:57:24.0	124	1	220	0.9	9.59	1.51	0.63	-3.51	8.1 \pm 2.1	-8.9, -17.9, -4.3	phot dist=106.2
61	TYC 8256-1840	13:27:05.98	-48:56:17.9	77	1	350	-0.6	10.69	2.88	1.18	-3.12	-	-	
62	TYC 7796-2110	13:34:31.92	-42:09:30.5	93	1	315	-0.9	10.70	2.61	1.06	-3.10	-	-	
63	TYC 7796-1788	13:37:57.32	-41:34:41.7	91	1	275	0.6	10.08	2.20	0.88	-3.20	-	-	
64	TYC 7800-0858	13:38:05.99	-43:44:56.3	114	1	310	0.0	11.14	2.60	1.06	-3.49	-	-	
65	TYC 7796-0286	13:38:49.37	-42:37:23.4	138	1	320	0.1	11.36	2.47	0.99	-3.64	-	-	
66	TYC 8261-1690	13:40:25.56	-46:33:51.3	102	2	340	-1.5	11.38	2.94	1.23	-2.79	10.1 \pm 1.9	-2.1, -17.0, -2.7	
67	TYC 8266-2914	13:44:24.45	-47:06:33.9	93	4	310	0.5	10.50	2.47	0.99	-3.47	-	-	
68	TYC 9012-1005	13:44:42.84	-63:47:49.2	70	4	370	-0.4	10.88	3.14	1.37	-3.16	18.0 \pm 1.0	-1.2, -24.0, -4.1	SB?
69	TYC 8274-0030	13:45:56.02	-52:22:25.3	114	1	340	-0.1	11.34	2.75	1.12	-2.98	-	-	
70	TYC 8267-2879	13:54:42.13	-48:20:57.6	129	1	260	0.0	11.07	2.37	0.95	-3.24	-	-	
71	TYC 8271-0864	13:56:34.69	-49:07:14.5	136	4	310	-0.2	11.14	2.33	0.93	-3.10	5.6 \pm 1.7	-11.8, -20.7, -4.3	
Upper Centaurus Lupus														
72	TYC 7818-0504	14:30:13.56	-43:50:09.7	72	1	340	-0.7	10.46	2.82	1.15	-2.80	-	-	
73	SSS 1450-3458	14:50:34.04	-34:58:56.1	116	2	370	-0.7	12.10p	3.22	1.38	-3.12	1.3 \pm 1.6	-	No proper motion data
74	TYC 7325-0465	15:24:32.37	-36:52:02.5	154	1	340	0.2	10.87	1.94	0.81	-3.41	4.0 \pm 1.5	-5.0, -23.3, -4.6	
75	SSS 1533-3917	15:33:40.48	-39:17:47.7	62	2	280	-7.9	14.22u	5.20	1.60	-3.51	-2.0 \pm 5.0	-12.9, -34.7, -23.0	
76	SSS 1539-3451	15:39:46.38	-34:51:02.6	83	1	385	-0.2	12.89d	4.12	1.52	-3.02	-	-	
77	HIP 77199	15:45:47.65	-30:20:54.9	40	3	400	-0.8	9.37	2.91	1.20	-3.03	-5.7 \pm 1.5	-10.1, -20.2, -7.4	phot dist=17.4 (binary?)
78	TYC 6782-0900	15:47:07.49	-25:19:46.4	92	1	450	-0.4	11.00	2.83	1.15	-3.04	-4.5 \pm 1.5	-8.2, -22.6, -5.8	
79	TYC 7328-1706	15:49:02.72	-31:02:53.6	121	1	350	-0.1	10.85	2.30	0.92	-3.28	-9.9 \pm 3.5	-13.9, -14.8, -4.9	

Table 1
(Continued)

No.	Name	R.A. (J2000)	Decl.	Dist. (pc)	<i>N</i>	Eq. Width		<i>V</i> (mag)	<i>V</i> − <i>K</i> (mag)	<i>B</i> − <i>V</i> (mag)	<i>f</i>	Rad. Vel. (km s ^{−1})	<i>(U, V, W)</i> (km s ^{−1})	Note
						Li	H α							
80	TYC 7846-1538	15:53:27.32	−42:16:00.2	51	3	190	0.8	7.86	1.52	0.64	−3.45	−0.2 ± 3.5	−6.9, −16.6, −5.4	
81	TYC 7846-0833	15:56:44.01	−42:42:29.9	78	1	495	−1.9	11.88	3.61	1.41	−3.10	−	−	
82	HIP 78345	15:59:49.53	−36:28:27.5	65	1	425	−0.3	11.00	2.97	1.25	−3.20	−0.3 ± 1.2	−3.4, −13.4, −7.7	phot dist=79.0
83	SSS 1603-4018	16:03:05.46	−40:18:25.8	−	1	310	−60.5	−	−	−	−	−	−	EX Lup
84	SSS 1606-2036	16:06:31.70	−20:36:23.2	70	1	450	−1.3	13.47d	4.64	1.55	−3.04	−	−	FS 810
85	TYC 7349-2447	16:35:22.41	−33:28:52.2	72	1	415	−0.8	11.66	3.58	1.41	−2.94	−	−	
86	SSS 1639-3920	16:39:47.32	−39:20:40.5	99	1	440	−2.0	14.08d	4.56	1.55	−2.39	−	−	FS 844
87	SSS 1652-3359	16:52:10.87	−33:59:33.3	86	2	325	−1.1	11.98d	3.56	1.40	−3.08	−	−	
Upper Scorpius and Young Stars in the Vicinity														
88	TYC 6801-0186	16:14:59.19	−27:50:22.7	130	1	355	0.2	10.98	2.29	0.92	−3.33	−2.0 ± 1.5	−3.6, −16.6, −6.1	
89	TYC 6798-0544	16:25:19.26	−24:26:52.5	87	1	400	1.1	10.06	2.26	0.91	−3.50	−2.4 ± 1.5	−3.6, −13.7, −1.9	
90	TYC 7344-0788	16:26:57.65	−30:32:27.7	98	2	440	−0.5	11.68	3.19	1.38	−3.09	−4.2 ± 1.6	−	
91	TYC 7344-0788B	16:26:57.00	−30:32:23.3	94	2	425	−1.0	12.46d	3.72	1.43	−3.09	−	−	
92	TYC 6816-0234	17:13:32.84	−26:02:06.9	101	1	350	0.6	10.14	2.08	0.85	−3.17	−7.0 ± 5.0	−6.9, −19.5, −4.2	
93	TYC 6820-0223	17:15:03.62	−27:49:39.4	59	1	580	−2.3	10.56	3.18	1.38	−3.15	−1.1 ± 1.8	−0.9, −10.6, −6.8	
94	HIP 84642	17:18:14.71	−60:27:26.7	59	3	185	0.6	9.51	1.98	0.82	−3.42	0.6 ± 1.2	−14.3, −26.4, −1.0 [‡]	phot dist=65.3
95	SSS 1719-4615	17:19:42.09	−46:15:26.5	35	2	520	−10.2	12.93p	5.17	1.59	−3.25	−	−	Wack3672, Flare star,
96	SSS 1724-3914	17:24:53.51	−39:14:43.8	128	2	275	0.0	11.88p	2.94	1.23	−3.46	−3.2 ± 1.9	−12.6, −42.1, −32.4	
97	TYC 8728-2262	17:29:55.08	−54:15:48.1	72	2	310	0.2	9.54	2.18	0.88	−3.21	−0.5 ± 3.7	−9.8, −17.2, −8.9	
98	TYC 5672-0216	17:37:46.48	−13:14:45.6	45	3	260	−0.8	10.11	3.27	1.39	−2.56	−	−	FS 903
99	HIP 86598	17:41:49.04	−50:43:27.5	72	2	190	0.9	8.33	1.34	0.51	−3.65	1.7 ± 1.7	−7.0, −19.4, −10.5	phot dist=71.3
100	TYC 8742-2065	17:48:33.74	−53:06:42.9	55	3	260	0.4	8.99	2.21	0.89	−3.15	−0.2 ± 1.5	−6.2, −12.0, −5.9	
101	SSS 1751-4854	17:51:34.16	−48:54:55.4	54	2	290	−3.8	13.14d	4.76	1.56	−2.93	−	−	
102	SSS 1814-3246	18:14:22.09	−32:46:10.8	71	1	125	−1.6	12.79p	4.25	1.53	−2.65	−	−	
103	SSS 1818-3710	18:18:35.44	−37:10:11.5	60	2	330	−7.1	14.65d	5.70	1.71	−3.02	−	−	
104	TYC 7408-0054	18:50:44.47	−31:47:46.8	50	2	425	−1.6	11.31	3.85	1.47	−3.09	−3.0 ± 6.0	−4.1, −16.3, −8.6	

Notes.

For non-*Hipparcos* stars, distances are photometrically estimated based on an empirical ~ 10 Myr isochrone on a $V - K$ versus M_K diagram (e.g., Figure 2 of Zuckerman & Song 2004). A typical uncertainty is about 30%. Column “*N*” indicates the number of independent measurements (listed EW values for Li and H α are average of *N* measurements). Equivalent widths for Li $\lambda 6708$ and H α are in mÅ and Å, respectively. “−” sign indicates emission. Suffix “d” after *V* indicates photometric data from DENIS. Suffix “p” after *V* indicates our own *V*-band photometry + 2MASS *K*. Suffix “u” after *V* indicates USNO *R*_{mag} + 2MASS *K*. No suffix after *V* means *V*_{mag} come from either *Hipparcos* or *Tycho-2* and *K* from 2MASS. *B* − *V* colors are interpolated from *V* − *K* values using Kenyon & Hartmann (1995). X-ray data are from *ROSAT* All Sky Survey (Voges et al. 1999, 2000) and $f \equiv \log L_X/L_{\text{bol}}$. For binaries, X-ray counts are divided according to each star’s optical brightness. HIP 60913 may be a member (good kinematics and Li=215 mÅ) with low X-ray luminosity ($\log L_X/L_{\text{bol}} = -4.34$). HIP 76063 may be a member (A-type star located on zero-age main sequence; Zuckerman & Song 2004).

[‡]Based on *UVW*, HIP 84642 may instead be a Tucana/HorA member (Table 7 of Zuckerman & Song 2004). “FS” designation indicates an X-ray variable star (Fuhrmeister & Schmitt 2003). Some (~ 30) stars listed in the above table were previously identified by Mamajek et al. (2002).

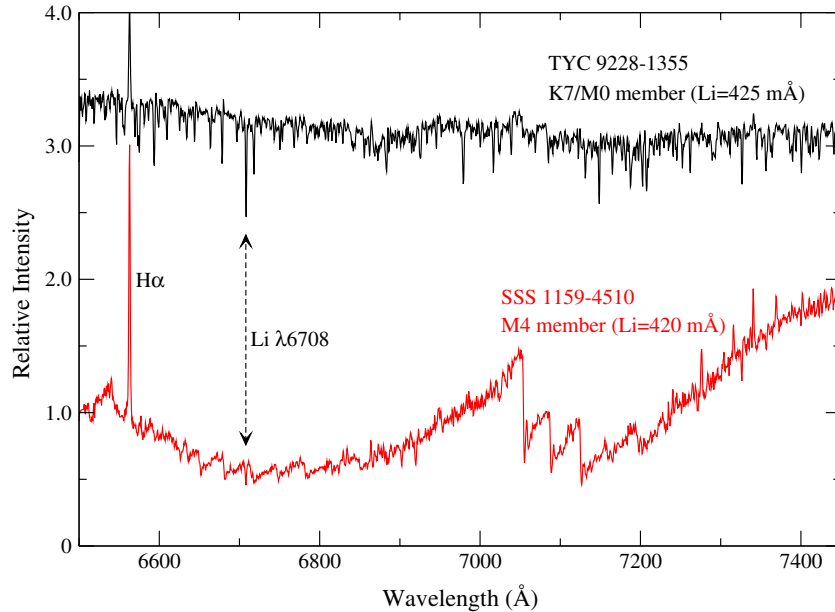


Figure 1. Representative spectra of newly identified Sco-Cen members.
(A color version of this figure is available in the online journal.)

radial velocity range is large enough to cover nearly all Sco-Cen members because a typical speed ($\equiv \sqrt{U^2 + V^2 + W^2}$) of Sco-Cen stars is less than 30 km s^{-1} , requiring that their radial velocities be smaller than this total speed. The use of young age in the photometric distance estimate does not affect the candidate selection much because of our rather generous *UVW* range ($\pm 5 \text{ km s}^{-1}$ in each component).

All spectra were reduced with IRAF following a standard procedure (bad pixel and cosmic ray removal, flat fielding, source extraction, telluric correction, etc.). Typical spectra have ~ 5000 counts pixel^{-1} in the vicinity of 6700 \AA . Equivalent widths (EWs) of Li I $\lambda 6708$ and H α together with their $V - K$ colors and X-ray information are listed in Table 1. We used $V - K$ colors (see footnotes of Table 1 for sources of V and K magnitudes) as spectral type proxies because $V - K$ separates K- and M-type subclasses nicely and the long color baseline is less susceptible to measurement errors and time variabilities compared to other broadband colors (e.g., $B - V$). Two typical spectra are displayed in Figure 1.

2.2. Refinement of LCC and UCL Ages

To estimate ages of LCC and UCL from our spectra, in Figure 2 we compare their Li $\lambda 6708$ absorption strengths against those of other young stellar groups with well-known ages on an EW(Li) versus $V - K$ plot. Because Table 1 contains US stars that are thought to be ~ 5 Myr old, we plot LCC/UCL stars and US stars with different symbols in Figure 2. Ages of the TW Hydrae Association (~ 8 Myr) and the β Pictoris Moving Group (~ 12 Myr) are well established and calibrated against contemporary theoretical pre-main-sequence evolutionary models by plotting their members on a color-magnitude diagram (CMD) along with theoretical models. An essentially model-independent age of the β Pictoris moving group was obtained by tracing positions of its members backward in time (Ortega et al. 2002; Song et al. 2003). Members of this unbound stellar group should have been confined in the smallest volume at its birth; a kinematic age of ~ 12 Myr obtained from this method agrees well with current stellar evolution models. Similarly, a

kinematic age of TWA is estimated to be 8.3 ± 0.8 Myr (de la Reza et al. 2006).

As is evident in Figure 2, overall lithium absorption strengths of LCC/UCL stars fall between those of the TWA and the β Pictoris moving group. Therefore, a likely age of LCC/UCL is ~ 10 Myr. Reddening toward the LCC/UCL region ($A_J = 0.00\text{--}0.35$ mag; Mamajek et al. 2002) does not change the relative ordering of Li $\lambda 6708$ strength distribution among TWA, LCC/UCL, and β Pictoris Moving Group members. In fact, dereddening will make most LCC/UCL stars appear younger (i.e., moving LCC/UCL stars leftward in Figure 2) because reddening toward the TWA and the β Pictoris Moving Group is almost negligible. For this reason, we do not consider the effect of reddening in this paper.

Current theoretical stellar evolutionary models (e.g., Baraffe et al. 1998) predict near complete depletion of lithium (down to the 1%–2% level) among M1/2 stars ($V - K \sim 4.0$) within 16 Myr, but we do not see such depletion of lithium among early M-type LCC/UCL stars (i.e., $V - K \sim 4.0$) in Figure 2. In addition, lithium depletion rates predicted in current evolutionary models appear to be slower than what is observed (e.g., Song et al. 2002) which further strengthens the preceding statement. As demonstrated in Figure 2, LCC/UCL members are younger than β Pictoris moving group members. Therefore, the LCC/UCL cannot be as old as 16 Myr.

Due to our target selection criterion based on *ROSAT* all-sky X-ray detection, our Table 1 LCC stars are systematically closer than stars considered by Mamajek et al. (2002). Therefore, it is conceivable that our LCC/UCL stars (close to Earth) are ~ 10 Myr old while more distant LCC/UCL stars surveyed by Mamajek et al. (2002) could be 17/16 Myr old. Supporting this conjecture, although based on small number statistics, Lawson & Crause (2005) photometrically measure the median rotational period of TWA 1–13 (4.7 days) to be longer than the median value of TWA 14–19 (0.7 days) which they interpret as an age difference between these two groups, TWA 1–13 being younger than TWA 14–19. To investigate the possibility of age dependence on distance for our low-mass stars, we divided the LCC/UCL stars of Table 1 into two groups (distance ≤ 95 pc

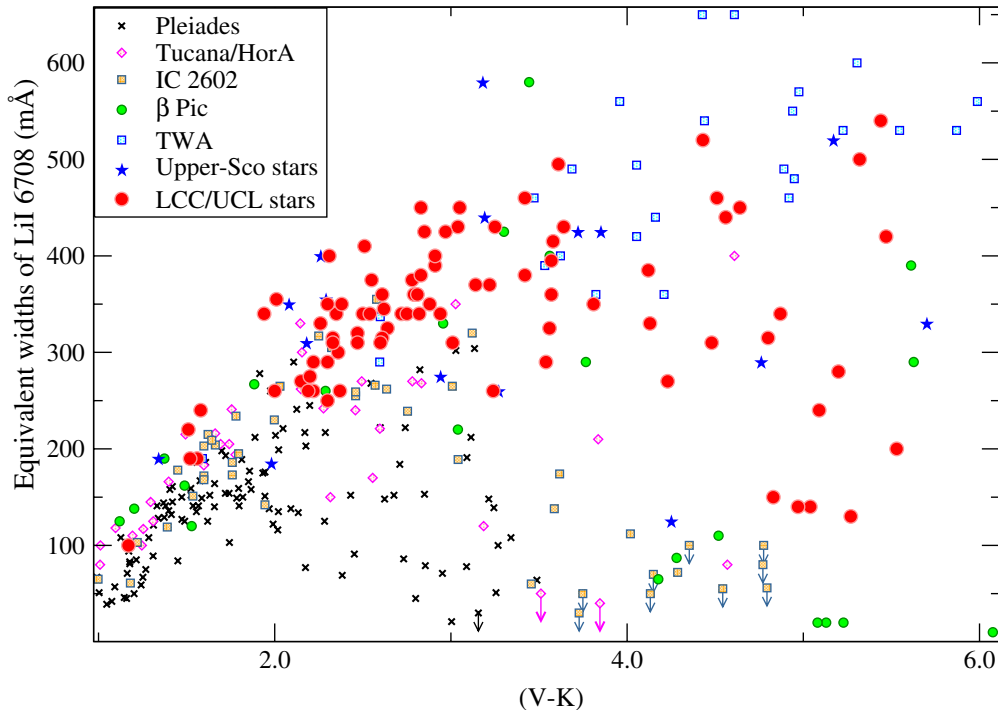


Figure 2. Li $\lambda 6708$ equivalent widths of LCC and UCL stars. Tucana/HorA and IC 2602 stars are generally considered to be ~ 30 Myr old. (A color version of this figure is available in the online journal.)

[$N = 46$] and distance > 95 pc [$N = 41$]) and compared their Li absorption strengths. Stars in these two bins show almost identical Li $\lambda 6708$ absorption strength distribution, hence we believe that the whole LCC/UCL group is ~ 10 Myr old. Furthermore, TWA 14–19 all show very strong Li $\lambda 6708$ absorption strengths that are consistent with LCC stars in Table 1. Nonetheless, whether there is a radial age spread toward the direction of LCC/UCL or not, from Figure 2 alone, G/K/M-type members of LCC/UCL are younger than ~ 12 Myr old. Also, since the original discovery of TWA, many more members have been identified to date. These newly discovered members are generally more distant than original TWA members. As a result, the apparent clear distinction in distance between original TWA members and LCC members is disappearing. The current set of age-dating methods cannot readily discern ~ 8 Myr old stars from ~ 10 Myr ones. Based on several common characteristics (similar ages, similar positions on the projected sky plane, similar space motions) and the weakening gap in distance between TWA and LCC, we believe that TWA is likely a near edge of a larger population of stars (i.e., LCC). As more sensitive data become available in future, namely next generation parallax measurements, one may find that the distribution of ~ 10 Myr old stars extends from TWA to all the way to LCC.

We note that we base our age estimate on Li-strong stars in the relative age dating of TWA, LCC/UCL, and β Pictoris moving group members. One might therefore question whether the possible existence and non-inclusion of Li-weak *true* members might vitiate the validity of such a comparison. Currently, in the absence of accurate trigonometric parallax, there is no effective way to identify Li-depleted members of young dispersed moving groups. This means that the same possible bias introduced by including only Li-strong members exists equally in the TWA, LCC/UCL, and the β Pictoris Moving Group. Therefore, comparing the upper envelopes of Li $\lambda 6708$

strength distributions among young stellar groups should be a perfectly valid method of relative age dating.

2.3. Comparison between HRD and CMD/Li Ages

Among several commonly used age-dating methods—position on a CMD or HRD, stellar rotation, Li $\lambda 6708$ absorption strength, X-ray brightness, $H\alpha$ emission strength, Galactic space motion, Ca II HK index, IR excess emission—the CMD, HRD, and Li methods can provide quantitative age estimates for stars in the 5–30 Myr age range. We already demonstrate the Li age in the previous section. Using the CMD/HRD age-dating method requires a precise distance to a star, and eight stars in Table 1 have measured trigonometric parallaxes from *Hipparcos* (van Leeuwen 2007). Using the transformation scheme from colors to effective temperatures and bolometric correction values from Mamajek et al. (2002), we plot four LCC/UCL *Hipparcos* stars on an HRD (Figure 3, left panel). *Hipparcos* stars from Table 1 sit on the theoretical 20 Myr isochrone from Siess et al. (2000), at first glance apparently in support of an age of ~ 20 Myr as deduced by Mamajek et al. (2002). However, as may be seen, various F-type β Pictoris moving group members sit on the ~ 30 Myr isochrone which is inconsistent with the age of the group (~ 12 Myr). It implies an age calibration problem between these two age-dating methods similar to the case of inconsistent ages from Ca II HK and Li ages (Song et al. 2004).

In Figure 3, bottom panel, we plot eight *Hipparcos* Table 1 stars on a $V - K$ versus M_K diagram (i.e., model-independent) along with an empirical 10 Myr isochrone from Zuckerman et al. (2004) and several dozen ~ 30 Myr old stars from Tucana-Horologium Association and IC 2602. A useful comparison would be plotting ~ 20 Myr old F/G-type stars but there are no such suitable stars with reliably determined ages in the solar neighborhood. As shown in the CMD, all eight *Hipparcos* LCC/UCL stars are located on or above the 10 Myr isochrone as defined by η Cha, TWA, and the β Pictoris moving group

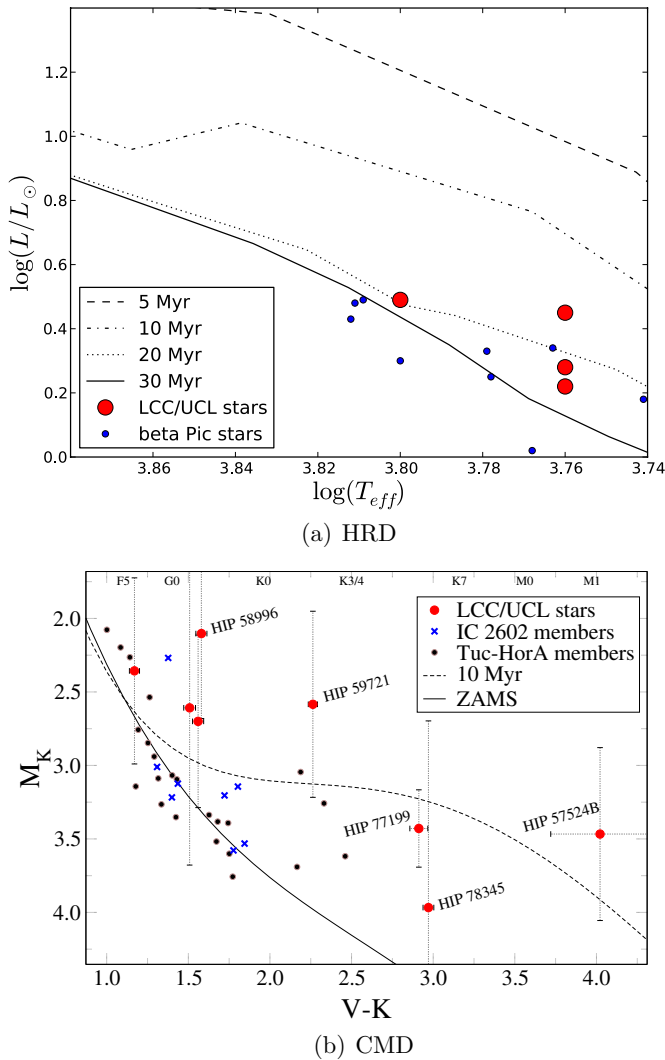


Figure 3. Top: LCC/UCL stars plotted on a HRD along with theoretical isochrones from Siess et al. (2000). Several F-type β Pictoris moving group (BPMG) members are located around the ~ 30 Myr theoretical isochrone while the trusted age of the BPMG is based on various techniques that all point to an age of ~ 12 Myr. This implies a significant systematic discrepancy between HRD ages and ages obtained by other methods. Bottom: same LCC/UCL *Hipparcos* stars plotted on a CMD which does not involve any theoretical models. When compared to empirical ~ 10 Myr isochrones (from η Cha, TWA, and BPMG members) and other slightly older (~ 30 Myr) stars from Tucana-HorA and IC 2602, LCC/UCL stars appear to be ~ 10 Myr in the observational domain. Distances are obtained from the reanalyzed *Hipparcos* data (van Leeuwen 2007). The distance to HIP 59721 is adapted from its comoving companion (HIP 59716; $\pi = 10.36 \pm 1.31 \text{ mas yr}^{-1}$) due to the large error ($\pi = 7.56 \pm 5.84 \text{ mas yr}^{-1}$) for HIP 59721. For IC 2602, $(m - M)_0 = 5.95$ was used following Stauffer et al. (1997).

(A color version of this figure is available in the online journal.)

(see Zuckerman et al. 2004 for more details on the 10 Myr empirical isochrone). This is a corroborant demonstration that LCC/UCL stars are as young as stars in η Cha, TWA, and β Pictoris moving group, and the claimed older age of LCC/UCL is likely due either to a lack or incorrect calibration of HRD

ages against empirical ages. Likewise, the relatively old age for the Upper-Sco region recently deduced by Pecaution et al. (2012) requires additional scrutiny because it is based on the same HRD age-dating method.

3. SUMMARY

We spectroscopically identified ~ 100 G/K/M-type Sco-Cen members, mostly LCC and UCL members, that show strong Li $\lambda 6708$ absorption and/or $H\alpha$ emission features. Comparison of Li absorption strengths against those of other young stellar groups on a $V - K$ versus lithium strength diagram indicates that the age of LCC/UCL is ~ 10 Myr. Specifically, LCC/UCL stars must be younger than stars in the β Pictoris moving group whose age of 12 Myr has been derived previously from kinematic traceback analysis. Based on plots of LCC/UCL *Hipparcos* stars in CMDs and HRDs, we find that ages derived from the HRD are systematically older than CMD and Li ages; the HRD ages are model-dependent whereas CMD and Li ages are primarily empirically anchored. This difference can explain the discrepancy between our young age and previously claimed older ages of UCL/LCC. Because of the importance of accurate ages in many astrophysical phenomena, a thorough cross-calibration of various age-dating methods for young stars is in urgent need.

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