Annu. Rev. Astron. Astrophys. 2004. 42:685–721
doi: 10.1146/annurev.astro.42.053102.134111

YOUNG STARS NEAR THE SUN

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Key Words stellar evolution, pre-main sequence, stellar kinematic groups, origins: stars and planetary systems

■ **Abstract** Until the late 1990s the rich Hyades and the sparse UMa clusters were the only coeval, comoving concentrations of stars known within 60 pc of Earth. Both are hundreds of millions of years old. Then beginning in the late 1990s the TW Hydrae Association, the Tucana/Horologium Association, the β Pictoris Moving Group, and the AB Doradus Moving Group were identified within ~60 pc of Earth, and the η Chamaeleontis cluster was found at 97 pc. These young groups (ages 8–50 Myr), along with other nearby, young stars, will enable imaging and spectroscopic studies of the origin and early evolution of planetary systems.

1. INTRODUCTION

Recent years have seen the resolution of two related and long-standing astronomical problems: (*a*) identification of unambiguous coeval moving groups as part of a proximate and youthful "Local Association" of stars and (*b*) identification of post T Tauri stars near the Sun. Infrared and submillimeter investigations of these stars promise to lead to a much better understanding of the origin and early evolution of planetary systems.

The study of moving groups of stars has a venerable history in astronomy. In the also venerable, nine-volume series *Stars and Stellar Systems* Eggen (1965a) briefly reviewed the history of the study of groups within a few hundred parsec of the Sun. According to Eggen, as early as 1869, R.A. Proctor published a paper in the *Proceedings of the Royal Society* (London) in which he noted not only stars in the vicinity of the Hyades cluster moving together through the Galaxy but also five comoving "Dipper" stars in Ursa Major. For nearly a century, these two groups were the only ones known near Earth; the former was associated with the rich Hyades (45 pc from Earth and ~600 Myrs old) and the latter with the sparse UMa nucleus (25 pc and ~300 Myrs).

Sharpless (1965), in a review paper that directly followed Eggen's, also referred to Proctor's early research, in particular an 1869 paper in *MNRAS*. Here Proctor introduced the model of "streams" of stars moving in the Galaxy. Sharpless discusses the concept of stellar associations and of star clusters following work of

V.A. Ambarzumian in the mid-twentieth century. A cluster has a density at least one order of magnitude greater than that of the field and is, thus, held together by the mutual attraction of its member stars. An association, on the other hand, has a stellar density considerably less than that of the field and undergoes relatively rapid tidal disruption, perhaps in a time of order a few times 10^7 years.

Here we refer to star clusters, associations, and moving groups, where the latter may be a stream of stars with common age and motion through the Milky Way and with no overdensity of stars discernable in any region.

In addition to the Hyades and UMa moving groups (the latter is also referred to as the Sirius group in honor of its brightest member as seen from Earth), in the 1960s Eggen introduced the idea of a Local Association of stars (e.g., Eggen 1961, 1965a,b). This association, also referred to as the Pleiades moving group, is envisioned to include bright B-type stars, stars in the Pleiades, the α Perseus and IC 2602 clusters, and stars in the Scorpio-Centaurus association. Although the space motions of proposed Local Association members are similar, their fairly wide range of ages ($\lesssim$100 Myrs) and widespread distribution around the Sun (sphere of diameter $\sim$300 pc) raise real questions as to whether it is constructive or illuminating, astronomically speaking, to lump them together into a single moving group.

Turning to the question of the existence of nearby post T Tauri stars, the concept of a T Tauri star was first introduced into astronomy in the mid-20th century by A.H. Joy (see Haro 1968, Bertout 1989). T Tauri stars have been considered numerous times in the *Annual Review of Astronomy and Astrophysics*; the review by Feigelson & Montmerle (1999), which focused on X-ray emission from young stellar objects, is especially germane to the present article.

The so-called classical T Tauri stars are typically very young (less than a few million years old) and associated with interstellar nebulosity. Excess emission above photospheric at near-, mid- and far-infrared (IR) wavelengths suggests the presence of substantial quantities of nearby heated dust particles in the form of a disk or envelope or both. Ultraviolet (UV) line and continuum emission at classical T Tauri stars indicates that, typically, they are actively accreting a portion of the surrounding gas and dust. But, by an age of $\sim$10 Myr, stellar optical activity is much reduced and near- and mid-IR excesses are very infrequent. In addition, no interstellar molecular clouds of any note exist within 100 pc of Earth. As a result, post T Tauri stars, with ages of tens of millions of years, have not been easy to find, although Herbig (1978) and Feigelson (1996) speculated that they ought to exist in the solar vicinity.

Observational investigations of our planetary system and theoretical studies indicate that giant planets form in $<$10 Myrs and Earth-like terrestrial planets in $\lesssim$30 Myrs. Thus, local, post T Tauri stars promise to reveal the story of the formation and early evolution of planetary systems.

A critical advance was the recognition that young stars are very strong X-ray emitters, with X-ray-to-bolometric luminosity ratios hundreds of times larger than that of an old star such as our Sun. Observations of young clusters (e.g., the rich Pleiades) by X-ray satellites, especially the Röntgen Satellite (ROSAT, launched 1990), showed that intense X-ray emission persists for of order 100 Myrs.

In its all-sky survey, ROSAT identified more than 100,000 X-ray sources at KeV energies (Voges et al. 1999, 2000). Subsequent studies (described below) make it clear that most young stars near the Sun are included in the ROSAT catalog.

A major problem has been to determine just which of more than 100,000 known X-ray sources are nearby, post T Tauri stars; the problem is multifold. Many objects in the Universe emit copiously at KeV energies for reasons other than being young nearby stars. Thus, to winnow such stars from the X-ray chaff (perhaps it is not fair to categorize objects like interacting binary stars and active galaxies as mere chaff!), signposts of youth that do not involve X-ray emission, proximity to molecular clouds, and infrared excesses are needed. Establishing reliable signposts of youth and investigating ∼100,000 stars (spectroscopically) for such signposts is a monumental task. In addition, youthful A- and early F-type stars are often not (detectable) X-ray emitters, even if they are very close to Earth and very young.

In practice then, systematically mining the ROSAT catalog and catalogs of nearby stars for post T Tauri stars in the solar vicinity requires development of methods that greatly reduce the number of X-ray emitting stars that must be observed spectroscopically with ground-based telescopes. The most successful of these techniques has involved considerations of Galactic space motions, thus connecting the two problems introduced in the opening paragraph of this review.

During the past few years four stellar groups that lie within 60 pc or so of the Sun and whose ages range between 8 and 50 million years have been discovered: the TW Hydrae Association, the β Pictoris moving group, the AB Doradus moving group, and the Tucana/Horologium Association. In addition, researchers have identified many other post T Tauri stars, not obviously part of these four groups, within 100 pc of the Sun, as well as the η Chamaeleontis Cluster, which is 97 pc away with likely age ∼8 Myr. This review is devoted to these nearby, young stars.

2. IDENTIFICATION OF NEARBY YOUNG STELLAR GROUPS

Why did it take so long for astronomers to identify the closest coeval associations of young stars? Because these groups are sparse and spread over large regions of the sky, usually there is no clustering whereby a stellar overdensity can be picked out against the background stars. Figure 1 illustrates the relative extent in the plane of the sky of the Pleiades cluster, the β Pictoris moving group, and Tucana/Horologium Association. Consequently, recent all-sky surveys in various wavebands have been crucial in enabling identification of commonality in space motions, distance from Earth, and age. In addition, most members of the newly identified associations listed in Tables 1–6 are located deep in the Southern Hemisphere even though most astronomers and telescopes are located in the Northern Hemisphere.

The realization that very young stars might be found far from interstellar molecular clouds probably had its genesis in early studies of the isolated variable

TABLE 1 Proposed TWA members

TWA No.	Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Multiplicity
21	TYC 8500-0697	10:13:14.8	−52:30:54	K3/4	9.8	(69)	
22	SSS 1017-5354	10:17:26.9	−53:54:27	M5	14.0	(22)	
6	TYC 7183-1477	10:18:28.8	−31:50:02	K7	12.0	(77)	
7	TYC 7190-2111	10:42:30.2	−33:40:17	M1	11.1	(38)	
1	TW Hya	11:01:52.0	−34:42:17	K7	10.8	56.4	
2	CD-29 8887	11:09:14.0	−30:01:39	M0.5	11.6	(52)	Binary
3	Hen 3-600	11:10:28.0	−37:31:53	M3	12.0	(42)	Triple
14		11:13:26.3	−45:23:43	M0	[a]	[a]	
12		11:21:05.5	−38:45:17	M2	13.6	(32)	
13	CD-34 7390	11:21:17.3	−34:46:47	M1	12.1	(38)	Binary
4	HD 98800	11:22:05.5	−24:46:38	K5	9.4	46.7	Quadruple
5	CD-33 7795	11:31:55.4	−34:36:28	M1.5	11.7	(50)	Triple
8	GSC 6659-1080	11:32:41.3	−26:51:55	M2	13.3	(21)	Binary
19	HD 102458	11:47:24.6	−49:53:04	G5	9.1	104.0	Binary
9	CD-36 7429	11:48:24.3	−37:28.49	K5	11.3	(81)	Binary
23	SSS 1207-3247	12:07:27.4	−32:47:00	M1	12.7	(37)	
24	TYC 8644-0802	12:09:41.9	−58:54:45	K3	10.3	(95)	
25	TYC 7760-0283	12:15:30.8	−39:48:42	M0	11.4	(44)	
15		12:34:20.6	−48:15:20	M2	14.0	(119)	Binary
16		12:34:56.4	−45:38:08	M1.5	12.3	(66)	Binary
10	GSC 7766-0743	12:35:04.4	−41:36:39	M2.5	12.7	(57)	
11	HR 4796	12:36:01.2	−39:52:10	A0	5.8	67.1	Binary
17		13:20:45.3	−46:11:38	K5	12.7	(133)	
18		13:21:37.2	−44:21:52	M0.5	12.9	(98)	

References: Kastner et al. (1997), Webb et al. (1999), Sterzik et al. (1999), Webb (2000), Zuckerman et al. (2001c), Song et al. (2002b, 2003), Torres et al. (2003), Neuhauser et al. (2003), Reid (2003), Weinberger et al. (2004).

[a] Spectrum in Zuckerman et al. (2001c) and apparent magnitudes in 2MASS, DENIS, and Weinberger et al. (2004) appear inconsistent.

–TWA 20 in Reid (2003) is likely a nonmember (Song et al. 2004b).

–Distances not in parenthesis are from the Hipparcos catalog; those in parenthesis are derived photometrically using Figure 2.

–Based on their large photometric distance, TWA 15 and 17 are probably members of the background LCC.

–TWA 5A is a very close binary (Macintosh et al. 2001, Brandecker et al. 2003).

–Gizis (2002) proposed two late-M-type, free-floating brown dwarf members, 2MASS 1207−3932 and 2MASS 1139−3159 (confirmed by Mohanty et al. 2003).

TABLE 2 Proposed β Pic members

Name	RA	DEC	Sp. Type	Vmag	Dist. (pc)	Note
	(2000)					
HR 9	00:06:50.1	−23:06:27	F2IV	6.2	39.1	
HIP 10679	02:17:24.7	+28:44:31	G2V	7.8	34.0	
HIP 10680	02:17:25.2	+28:44:43	F5V	7.0	39.4	
HIP 11437B	02:27:28.1	+30:58:41	M0	12.4	42.3	
HIP 11437	02:27:29.2	+30:58:25	K8	10.1	42.3	
HIP 12545	02:41:25.8	+05:59:19	M0	10.4	40.5	
51 Eri	04:37:36.1	−02:28:25	F0V	5.2	29.8	
GJ 3305	04:37:37.3	−02:29:28	M0.5	10.6	29.8	
HIP 23309	05:00:47.2	−57:15:26	M0.5	10.0	26.3	
HIP 23418	05:01:58.8	+09:59:00	M3V	11.5	32.1	Binary
HIP 25486	05:27:04.8	−11:54:04	F7	6.3	26.8	
β Pic	05:47:17.1	−51:03:59	A5V	3.9	19.3	
HIP 29964	06:18:28.4	−72:02:43	K6/7	9.8	38.5	
HIP 76629B	15:38:56.9	−57:42:18	M4.5	14.8	39.8	
HIP 76629	15:38:57.6	−57:42:26	K0V	8.1	39.8	
HR 6070	16:18:17.9	−28:36:51	A0	4.8	43.0	Nonmember?
HD 155555A	17:17:25.6	−66:57:03	G5IV	7.2	31.4	
HD 155555B	17:17:25.6	−66:57:03	K0IV/V	8.1	31.4	
HD 155555C	17:17:31.3	−66:57:00	M4.5	12.7	31.4	
HIP 88399	18:03:03.5	−51:38:54	F5V	7.0	46.9	
HR 6749	18:06:50.0	−43:25:29	A5V	5.7	43.9	Binary
HIP 92024	18:45:26.9	−64:52:16	A7	4.8	29.2	
CD-64 1208	18:45:37.0	−64:51:45	K7	9.5	29.2	
PZ Tel	18:53:05.8	−50:10:47	K0Vp	8.3	49.7	
HR 7329	19:22:51.2	−54:25:24	A0Vn	5.1	47.7	
HR 7329B	19:22:51.3	−54:25:29	M7/8V	20.0	47.7	
HIP 95270	19:22:58.9	−54:32:15	F5.5	7.0	50.6	
GJ 799B	20:41:51.1	−32:26:10	M4.5e	11.0	10.2	
GJ 799A	20:41:51.2	−32:26:07	M4.5e	11.0	10.2	
GJ 803	20:45:09.5	−31:20:27	M1e	8.8	9.9	
HD 199143	20:55:47.7	−17:06:51	F8V	7.3	47.7	Binary
BD-17 6128	20:56:02.7	−17:10:54	K7/M0	10.6	47.7	Binary
HIP 112312	22:44:57.9	−33:15:02	M4e	12.2	23.6	Binary?
HIP 112312B	22:45:00.0	−33:15:26	M4.5e	13.4	23.6	Binary?

References: Barrado y Navascués et al. (1999b), Zuckerman et al. (2001a), Song et al. (2002a, 2003), Ortega et al. (2002, 2004), Neuhauser et al. (2003), Kaisler et al. (2004).

TABLE 3 Proposed Tucana/Horologium Association members

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Note
HIP 100751	20:25:38.9	−56:44:06	B2IV	1.9	56.2	Binary?
HIP 104308	21:07:51.2	−54:12:59	A5/6IV/V	6.7	66.4	
HIP 105388	21:20:49.9	−53:02:02	G5V	8.7	45.9	
HIP 105404	21:20:59.8	−52:28:39	K0V	8.9	46.0	Binary
HIP 107345	21:44:30.1	−60:58:38	M1	11.7	42.3	
HIP 107947	21:52:09.7	−62:03:08	F6V	7.2	45.1	
HIP 108195	21:55:11.3	−61:53:11	F1III	5.9	46.5	Binary?
HIP 108422	21:57:51.4	−68:12:49	G8V	8.9	54.9	
HIP 116748	23:39:39.4	−69:11:44	G5/8IV	8.2	46.2	Binary
HIP 118121	23:57:35.0	−64:17:53	A1V	5.0	48.7	Binary?
HIP 490	00:05:52.5	−41:45:10	G0V	7.5	40.2	
HIP 1113	00:13:52.8	−74:41:17	G6V	8.7	43.7	
HIP 1481	00:18:26.0	−63:28:39	F8/G0V	7.5	41.0	
HIP 1910	00:24:08.9	−62:11:04	M1	11.3	46.3	Binary
HIP 1993	00:25:14.6	−61:30:48	M1	11.3	37.5	[a]
HIP 2484	00:31:32.6	−62:57:29	B9V	4.4	42.8	Binary?
HIP 2487	00:31:33.4	−62:57:56	A2V	4.5	52.8	Binary
HIP 2578	00:32:43.8	−63:01:53	A0V	5.1	46.5	Binary?
HIP 2729	00:34:51.1	−61:54:58	K5V	9.6	45.9	
HIP 3556	00:45:28.1	−51:37:33	M3	11.9	38.5	
CPD-64 120	01:13:15.3	−64:11:35	K1Ve	10.2	(79)	
HD 8558	01:23:21.2	−57:28:50	G6V	8.5	49.3	
HD 9054	01:28:08.6	−52:38:19	K1V	9.4	37.1	
HIP 9141	01:57:48.9	−21:54:05	G3/5V	8.1	42.4	
HD 12894	02:04:35.0	−54:52:54	F2V	6.5	47.2	
HD 13183	02:07:18.0	−53:11:56	G5V	8.7	50.2	
HD 13246	02:07:26.0	−59:40:46	F8V	7.5	45.0	
CD-60 416	02:07:32.1	−59:40:21	K3/4	10.4	(48)	
HD 14228	02:16:30.6	−51:30:44	B8IV-V	3.5	47.5	Binary
GSC8056-0482	02:36:51.5	−52:03:04	M3Ve	12.1	(25)	[b]
HIP 12394	02:39:35.2	−68:16:01	B9III	4.1	47.0	
CD-53 544	02:41:46.8	−52:59:52	K6Ve	10.3	(28)	
GSC8491-1194	02:41:47.1	−52:59:30	M3Ve	12.2	(26)	

(*Continued*)

TABLE 3 (*Continued*)

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Note
GSC8497-0995	02:42:32.9	−57:39:37	K6Ve	11.0	(50)	c
HIP 15247	03:16:40.6	−03:31:49	F5	7.5	50.0	
HIP 16853	03:36:53.3	−49:57:29	G2V	7.6	41.7	
TYC 5882-1169	04:02:16.5	−15:21:30	K3/4	10.2	(63)	
HIP 21632	04:38:43.9	−27:02:02	G3V	8.5	54.7	
HIP 21965	04:43:17.2	−23:37:42	F2/3IV/V	7.1	58.2	
HIP 22295	04:48:05.0	−80:46:46	F7V	8.1	60.4	
HIP 24947	05:20:38.0	−39:45:18	F6V	7.4	45.6	
TYC 7600-0516	05:37:05.3	−39:32:27	K1	9.6	(63)	
TYC 7065-0879	05:42:34.3	−34:15:42	K4	11.2	(60)	
HIP 28036	05:55:43.2	−38:06:16	F6V	7.5	54.2	
HIP 30030	06:19:08.1	−03:26:20	G0	8.0	49.8	
HIP 30034	06:19:12.9	−58:03:16	K2V	9.1	45.5	
HIP 32235	06:43:46.2	−71:58:36	G6V	8.9	56.5	
HIP 32435	06:46:13.4	−83:59:30	F5V	7.5	57.3	
HIP 33737	07:00:30.5	−79:41:47	K3V	10.1	64.1	

References: Zuckerman & Webb (2000), Torres et al. (2000), Song et al. (2003), Neuhauser et al. (2003), Chauvin et al. (2003), Mamajek et al. (2004).

[a]Large Hipparcos parallax error.

[b]With EW(Li)=320 mÅ, GSC 8056-0482 is probably too young to be a Tuc/Hor member (see Song et al. 2004b).

[c]Questionable member (see Figures 3 and 4).

–Distances not in parenthesis are from the Hipparcos catalog; those in parenthesis are derived photometrically using Figure 2.

–HD 10144, 10269, 10472, & 20888 (not included in the table) are members suggested by Zuckerman et al. (2001b) whose membership status is uncertain.

–HIP 93815, 99803, 107649, and PPM 366328 are previously proposed members that are likely nonmembers.

–HIP 3556 may be a member (see Song et al. 2004b).

star TW Hya. The most detailed spectroscopic investigation was by Rucinski & Krautter (1983) who refer back to Herbig (1978) who, on the basis of his spectra, considered that TW Hya might be a post T Tauri star. The study by Rucinski & Krautter quite conclusively demonstrated the classical T Tauri nature of TW Hya. They argued that TW Hya was probably not a high-velocity escapee from some distant molecular cloud, but they did not have sufficient information to settle this issue of origins.

A few years later, de la Reza et al. (1989) and Gregorio-Hetem et al. (1992) carried out an optical spectroscopic survey of field stars with excess far-IR emission listed in the IRAS Point Source Catalog. They identified four T Tauri stars within

TABLE 4 Proposed η Cha members

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Note
J0836.2-7908	08:36:10.7	−79:08:18	M5.5	17.5	Binary?
GSC9402-921	08:36:56.2	−78:56:45	K4	10.6	Binary
J0838.9-7916	08:38:51.5	−79:16:14	M5	16.4	Binary?
η Cha	08:41:19.5	−78:57:48	B8	5.5	
J0841.5-7853	08:41:30.3	−78:53:06	M4	17.1	
J0841.6-7903	08:41:37.0	−79:03:30	M3	14.4	
HD 75505	08:41:44.8	−79:02:54	A1V	7.4	
GSC9403-1083	08:42:23.7	−79:04:03	K7	12.7	
J0842.5-7857	08:42:27.1	−78:57:48	M5	15.2	
GSC9403-288	08:42:38.8	−78:54:43	M2	14.1	
J0843.1-7904	08:43:07.2	−79:04:52	K3	10.8	Binary
RS Cha	08:43:12.2	−79:04:12	A7	6.1	Binary
J0843.3-7905	08:43:18.6	−79:05:18	M2	14.0	
J0844.2-7833	08:44:09.1	−78:33:46	M5.5	18.4	
J0844.3-7859	08:44:16.4	−78:59:08	M4	15.0	Binary
GSC9403-1279	08:44:31.9	−78:46:31	K7	12.5	
GSC9403-1016	08:47:01.7	−78:59:35	K4	11.1	
GSC9403-0389	08:47:56.8	−78:54:53	M2	13.2	Binary?

References: Mamajek et al. (1999), Lawson et al. (2002), Köhler & Petr-Gotzens (2002), Lyo et al. (2004), Song et al. (2004a).

–Distance from Earth to the cluster is 97 pc.

10 degrees of TW Hya although only HD 98800 and Hen 3-600 are IRAS sources; CoD −29 8887 and −33 7795 were serendipitous discoveries. Basing their conclusions on the presence of five T Tauri stars in this relatively small portion of the sky plane at fairly high galactic latitude (~25 degrees), Gregorio-Hetem et al. (1992) noted that TW Hya was not likely to be a “runaway” star and they considered the existence of a T Tauri association as more probable.

In the early 1990s, spectroscopic surveys for lithium in X-ray bright or chromospherically active, single, late-type stars was another fruitful avenue of approach in identifying young field stars (e.g., Pallavicini et al. 1992, Favata et al. 1993, 1995, Tagliaferri et al. 1994). Many nearby, activity-selected, stars have large lithium abundances, comparable with stars in young open clusters (e.g., the Pleiades) or even pre-main sequence T Tauri stars. Jeffries (1995) presented a prescient discussion of these early lithium investigations. On the basis of only a tiny fraction of the

TABLE 5 Proposed AB Dor members

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Note
PW And	00:18:20.8	+30:57:24	K2V	8.9	(28)	
HIP 3589	00:45:50.8	+54:58:41	F8V	7.6	48.5	Binary
HIP 5191	01:06:26.1	−14:17:46	K1V	9.5	50.0	?Binary
HIP 6276	01:20:32.2	−11:28:03	[G8]	8.4	35.1	
HIP 10272	02:12:15.3	+23:57:31	K1	7.7	32.3	?Binary
HIP 12635	02:42:20.9	+38:37:22	[K3.5]	10.2	49.6	[a]
HIP 12638	02:42:21.3	+38:37:08	G5	8.7	49.6	[a]
HIP 13027	02:47:27.4	+19:22:20	G0	7.5	32.6	Binary
HIP 14807	03:11:12.3	+22:25:24	[K6]	10.6	49.8	[b]
HIP 14809	03:11:13.8	+22:24:58	G5	8.5	49.8	[b]
HIP 16563	03:33:13.4	+46:15:28	[G5]	8.2	33.8	Binary
HIP 17695	03:47:23.2	−01:58:18	M3	11.6	16.3	
HIP 18859	04:02:36.7	−00:16:06	F5V	5.4	19.2	
HIP 19183	04:06:41.5	+01:41:03	F5	7.8	55.3	
HIP 25283	05:24:30.1	−38:58:10	[K7]	9.1	17.7	
AB Dor	05:28:44.8	−65:26:56	K1	6.9	14.9	Binary
HIP 26369	05:36:55.1	−47:57:48	[K7]	9.8	23.9	
HIP 26373	05:36:56.8	−47:57:53	K0V	8.0	23.9	
HIP 30314	06:22:31.0	−60:13:08	G1V	6.5	23.5	
GSC 8894-0426	06:25:55.9	−60:03:28	M2	11.7	(22)	
HIP 31711	06:38:00.4	−61:32:01	G1.5	6.2	21.7	Binary
HIP 31878	06:39:50.1	−61:28:42	[K7]	9.7	21.9	
HIP 36349	07:28:51.5	−30:14:47	[M3]	10.0	15.6	Binary
HIP 63742	13:03:49.8	−05:09:41	[K1]	7.7	22.1	
HIP 76768	15:40:28.4	−18:41:45	[K7]	10.2	42.6	?Binary
HIP 81084	16:33:41.7	−09:33:10	[M0.5]	11.3	31.9	?
HIP 82688	16:54:08.2	−04:20:24	G0	7.8	47.6	
HIP 86346	17:38:39.7	+61:14:16	M0	10.3	24.0	?
HIP 106231	21:31:01.6	+23:20:09	K8	9.2	25.1	
HIP 110526	22:23:28.9	+32:27:36	M3	10.7	16.0	Binary
HIP 113579	23:00:19.2	−26:09:12	G3V	7.5	32.1	?
HIP 113597	23:00:27.9	−26:18:41	[K8]	10.0	30.0	?Binary
HIP 114066	23:06:04.6	+63:55:35	[M1]	10.9	24.9	

(*Continued*)

TABLE 5 (*Continued*)

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Note
HIP 114530	23:11:52.0	−45:08:10	[G5]	8.8	50.5	?
HIP 115162	23:19:39.5	+42:15:10	[G4]	8.9	49.4	
HIP 118008	23:56:10.5	−39:03:07	K3V	8.2	22.1	?

References: Zuckerman et al. (2004a), Song et al. (2004b).

[a] Listed distance is a weighted mean of HIP 12635 and 12638 distances.

[b] Listed distance is a weighted mean of HIP 14807 and 14809 distances.

–Spectral types in brackets are based on $V-K$ color. Reasons for choosing $V-K$ in preference to SIMBAD listed spectral types may be found in the above references.

–Question mark in note column refers to questionable membership.

–Distances in parenthesis are derived photometrically using Figure 2.

TABLE 6 Proposed members of the "Cha-Near" region

Name	RA (2000)	DEC (2000)	Sp. Type	Vmag	Dist. (pc)	Note
HIP 55746	11:25:18.1	−84:57:16	F5V	7.6	82.9	?
RXJ1137.4-7648	11:37:31.3	−76:47:59	—	—		? Binary
TYC 9238-0612	11:41:27.7	−73:47:03	G5	10.7		?
RXJ1147.7-7842	11:47:48.1	−78:41:52	—	—		
RXJ1150.4-7704	11:50:28.3	−77:04:38	K4	12.0		?
T Cha	11:57:13.7	−79:21:32	G8	11.9	66.4	HIP 58285
HIP 58400	11:58:28.3	−77:54:30	Kp	10.6	85.9	Binary
HIP 58410	11:58:35.4	−77:49:31	A7V	6.7	105.7	?
HIP 58490	11:59:42.4	−76:01:26	Kp	11.2	92.4	
HD 104467	12:01:39.1	−78:59:17	G5	8.6		
RXJ1202.8-7718	12:02:54.6	−77:18:38	M3	14.4		
RXJ1204.6-7731	12:04:36.2	−77:31:35	M2	13.8		
RXJ1207.7-7953	12:07:48.3	−79:52:42	M2/3	14.5		
HIP 59243	12:09:07.8	−78:46:53	A6III/IV	6.9	95.4	
RXJ1219.7-7404	12:19:43.7	−74:03:57	M0	13.1		
RXJ1220.4-7407	12:20:21.8	−74:07:39	M0	12.7		Binary
RXJ1239.3-7502	12:39:21.2	−75:02:39	K2	10.2		

References: Alcala et al. (1995), Covino et al. (1997), Terranegra et al. (1999), Teixeira et al. (2000), Mamajek et al. (2000), Köhler (2001), Zuckerman et al. (2004b).

–Distance from Earth to this region is ∼90 pc.

–Question marks refer to questionable membership.

data now available, Jeffries was able to tie the lithium-rich stars to Eggen's investigations of the nearby B-type stars and his concept of a young Local Association. Jeffries speculated on the origin and evolutionary state of these lithium-rich stars. But he recognized that the kinematic and lithium information available at that time was insufficient to discriminate between ages of a few tens to a few hundreds of millions of years. As long as the ages and Galactic motions of TW Hya and the X-ray active, lithium-rich stars remained uncertain, the ensemble of nearby, young stars would remain a hodgepodge of unknown overall status and history.

A few years later, around the time Neuhauser (1997) was reviewing "Low-mass pre-main sequence stars and their X-ray emission," Kastner et al. (1997) focused on the X-ray properties of the five T Tauri stars in the vicinity of TW Hya. Based on their very strong and similar X-ray fluxes and lithium 6708 Å absorption line strengths, Kastner et al. deduced that the five stars form a real physical association of age 20 ± 10 Myr. On the basis of theoretical models of pre-main sequence evolution, they derived distances to the five stars in the range 40 to 60 pc. At about the same time, measurements with the Hipparcos astrometric satellite yielded trigonometric distances of 56 ± 7 and 47 ± 6 pc for TW Hya and HD 98800, respectively.

Kastner et al. (1997) called the five stars the TW Hya Association (TWA) and concluded that it is likely the nearest region of recent star formation. They also presented millimeter wavelength spectroscopy of molecules in orbit around TW Hya itself and reaffirmed and solidified its special place—proximity to Earth and old age—relative to other classical T Tauri stars.

Taking a cue from the Kastner et al. (1997) paper, Webb et al. (1999) spectroscopically surveyed X-ray bright stellar ROSAT All-Sky Survey (RASS) sources in the vicinity of the TWA and, on the basis of strong lithium absorption and chromospheric activity, identified six more TWA member stars (some of which are multiple). Together, the Kastner and Webb results showed conclusively that TW Hya itself is not a high-velocity escapee from some more distant region of star formation. Rather it and its TWA companions formed ∼10 Myr ago in situ in a region now essentially devoid of interstellar molecular gas.

At about the same time, Mamajek et al. (1999) noticed that a few RASS sources in Chamaeleon were clumped together. They followed this up with a deep ROSAT high-resolution imager study and ground-based optical spectroscopy that revealed a young ($\lesssim$10 Myr) cluster only 97 pc from Earth. This η Cha cluster is, after the TWA, the closest grouping of T Tauri stars. Although the two groups contain roughly the same number of member stars (Tables 1 and 4), the linear diameter of η Cha is more than an order of magnitude smaller than that of the TWA.

While some researchers used the IRAS and ROSAT catalogs, other teams analyzed the Hipparcos catalog to search for previously unrecognized stellar associations. For example, Platais et al. (1998) undertook a "search for star clusters from the Hipparcos data" and listed basic data for five "very likely" new clusters and associations as well as 15 "possible" ones. They noted that at "distances less than 100 pc, the survey is incomplete as a result of the chosen search strategy." Of the

20 potential new groupings they list, the closest, which contains 11 members from Hipparcos, is 132 pc away.

Young stars are more likely than older stars to be far-IR excess sources (Habing et al. 2001, Spangler et al. 2001). Young stars are also more apt to be members of associations. Using these criteria, Zuckerman & Webb (2000) analyzed the Hipparcos catalog for stars with similar proper motions and distances from Earth located within a 6 deg radius of two dozen stars detected by IRAS at 60 μm wavelength. The result, following ground-based spectroscopy, was their discovery of the Tucana Association, ~45 pc from Earth and ~30 Myr old. Because the Tucana Association was discovered without any knowledge of its X-ray properties, Zuckerman & Webb (2000) showed that kinematics and optical spectroscopy, together, could be used to find substantial groups of coeval stars in the solar neighborhood.

At about the same time, Torres et al. (2000), relying on the RASS and ground-based spectroscopy, identified the Horologium Association. Their strategy was to observe stellar ROSAT sources in an area 20 degrees by 25 degrees centered on the high galactic latitude (−59 deg) active star EP Eri which they had previously classified as a T Tauri star. Because Horologium stars have the same space motions, age, distance from Earth, volume density, and range of spectral types as Tucana stars, it is appropriate to regard them as a single group (Table 3) (Zuckerman et al. 2001b).

IRAS discovered strong mid- and far-IR excess emission from the A-type star β Pictoris which Smith & Terrile (1984) revealed to be one of the most interesting stars in the Gliese catalog of nearby stars. An early suggestion that β Pic might be as young as 10 Myr (Jura et al. 1993) was difficult to accept because of the star's proximity to Earth (~20 pc) and apparent isolation in space. For years, the age of β Pic was disputed, with estimates ranging up to greater than 100 Myr.

To deduce the age of β Pic, Barrado y Navascués et al. (1999b) independently employed a kinematic approach similar to that used by Zuckerman & Webb (2000). Of an extensive list of stars searched, Barrado y Navascués et al. found that only the M-type stars GJ 799 and 803 had Galactic space motions in agreement with that of β Pic as well as sufficient X-ray activity to be plausibly youthful coeval counterparts. Placing the two M-type stars on theoretical pre-main sequence evolutionary tracks, they deduced an age of 20 ± 10 Myr for β Pic.

Most stars, especially relatively massive ones such as β Pic, form in clusters or associations containing dozens to hundreds of members. These associations dissociate with time, but if β Pic is indeed as young as 20 Myr, then it should have comoving, coeval companions in addition to GJ 799 and 803. Zuckerman et al. (2001a) considered ~22, 000 stars whose Galactic space motion UVW could be calculated from data available in the literature, a procedure often employed by Eggen. By only accepting stars with UVW components each within a few kilometers per second of those of β Pic and by demanding that a star have at least one strong signpost of extreme youth (see Section 3), they reduced the list of 22,000 to 18 star systems that they called the β Pictoris moving group. All 18 lie in the Southern Hemisphere, even though most of the 22,000 stars studied are located in the Northern Hemisphere.

In March 2001 researchers in this new and growing field gathered at NASA Ames Research Center at a workshop organized by Jayawardhana & Greene (2001). To date, this ASP Conference Series volume is the only existing summary of the field of young, nearby stars. It includes many papers on stars that are older and/or further from Earth than those discussed here.

3. AGE DIAGNOSTICS

To understand much of what is most interesting about a star—and any planetary system that might surround it—requires knowledge of its age. Unfortunately, age is one of the hardest stellar parameters to determine accurately. Although the existence of numerous young stars in the solar vicinity was realized a decade or so ago (Section 2), only in the past few years has real progress been made in establishing reliable ages; this advance is a consequence of the recognition of the associations and moving groups described in Tables 1–5.

Here we briefly describe the various age diagnostics appropriate for young stars. With only one or two exceptions, all diagnostics are statistical and not very quantitative. That is, they cannot be calibrated well in an absolute sense and are not to be overly trusted for any individual star, but rather only for an ensemble. Nonetheless, the totality of these (qualitative) indicators is very important in establishing reasonably precise stellar ages (see last paragraph of Section 3.1).

3.1. Evolutionary Tracks & Stellar Kinematics

The most quantitative technique for deducing the age of a young star uses its placement, along with theoretical pre-main sequence evolutionary tracks, on a color-magnitude diagram (CMD). Early applications of this technique often employed a plot of absolute visual magnitude (M_V) vs $V - I$ colors (e.g., Barrado y Navascués et al. 1999b, Zuckerman et al. 2001b). However, with publication of the 2MASS and DENIS catalogs which contain a wealth of accurate apparent K magnitudes, a more reliable plot is absolute K magnitude (M_K) vs $V - K$ color (Figure 2) (Song et al. 2003). The greater reliability of a $V - K$ CMD stems from the long color baseline which well separates different K- and M-type spectral subclasses. This separation provides protection against measurement errors and time variability in apparent V and/or K magnitudes.

The existence and recognition of young coeval groups (Tables 1–5) has increased the usefulness of these CMDs enormously and in various ways. Before discovery of these groups, the procedure for estimating the age of a K- or M-type star was to place it on a CMD and hope that the theoretical tracks could be trusted. Because (*a*) the tracks of the various theoreticians did not always agree, (*b*) transformation from color to effective temperature can be uncertain, and (*c*) there were no quantitative checks on accuracy, this was an unreliable procedure. In addition, this procedure is completely useless for deducing the age of an isolated G- or F-type star that is $\gtrsim$10 Myr old because by that age the star is effectively on the main sequence. Indeed, except for mid- and late-M types, by ~50 Myr, stars on a CMD are situated too close to the main sequence for evolutionary tracks to provide an accurate age diagnostic.

In contrast, when a group of late-type stars can be tied together kinematically (e.g., the β Pic moving group), then they will trace out a line on a CMD (Song et al. 2003) or Hertzsprung-Russell diagram (Zuckerman et al. 2001a). This line constrains the shape of the theoretical tracks at a given age and for given colors. The absolute age that corresponds to this line can be constrained and calibrated by kinematically tracing back the group members to a region of minimum size, presumably their birth place (Ortega et al. 2002, 2004; Song et al. 2003). For the β Pic moving group, the completely independent kinematic and evolutionary track ages agree at ~12 Myr.

In addition, when G- and F-type stars have UVW in common with pre-main sequence K- and M-type stars, along with other consistent age diagnostics (see below), then it is safe to assume that all four classes have the same age. This is the only method available to obtain accurate ages for young G- and F-type field stars.

However, an essential point is that kinematics, i.e., common space motion, is a necessary but not sufficient criterion to establish common age because many old stars have similar space motions to young stars. Thus, the age diagnostics listed below, although only qualitative, are essential and must be used in conjunction with kinematics.

3.2. Lithium Abundance

Lithium is "burned" as a star ages and photospheric lithium abundance can be used to estimate age. A huge amount of literature exists on lithium abundance measurements in all kinds of stars. Figure 3 illustrates equivalent width (EW) for the Li 6708 Å line across the HR diagram and as a function of age between a few Myr and ~100 Myr.

Lithium appears to be one of the best age indicators for young stars, but with some caveats. For example, there is little variation in the EW width of the 6708 Å line in F- and mid-G-type stars (colors between B-V = 0.4 and 0.7) up to the approximate age of the Pleiades (which is ~100 Myr, see Song et al. 2002a, Burke et al. 2004). We note that the strong "dip" in lithium abundance in F-type stars with temperatures ~6600 K, discovered in the mid-1980s by A.M. Boesgaard and M.J. Tripicco, does not develop significantly until post-Pleiades age.

For late-G- through mid-M-type stars, lithium EWs vary substantially over the time frame, 5 to 100 Myr, relevant for nearby young stars. However, the Li 6708 Å line has a spread in EW at a given age and mass (see, e.g., the Pleiades stars in Figure 3). Thus, this EW cannot generally be regarded as a precise age determinant.

Speculations as to what causes the spread include rotation rate, magnetic field, large photospheric spots, accretion, mass lost via a stellar wind, and time variability. These are considered, for example, by Jeffries (1999), Randich (2001), and Wilden et al. (2002).

Late-K and early-M-type stars deplete their lithium very rapidly (∼10 Myr) and the presence of a strong 6708 Å line can be used to flag the very youngest stars in the solar vicinity (e.g., TWA and η Cha members). Indeed, this line strength is the best way to distinguish late-type TWA members from members of the slightly older β Pic moving group for which the 6708 Å line is, usually, already substantially weaker (see Figure 3).

As one moves downward in mass from early-M-type toward late-M-type stars, lithium is not burned so rapidly and the 6708 Å line is strong in the 12 Myr old β Pic members of spectral class M4.5 (Song et al. 2002a, 2003). For older stars this boundary between low mass stars where lithium has been substationally depleted and even lower mass stars where it has not (i.e., the lithium depletion boundary) (see Section 5.1) moves to lower temperatures, so that by the age of the Pleiades, it resides at M6.5 (Stauffer et al. 1998). Thus, for spectral types between M4.5 and M6.5, lithium measurements can help to constrain a star's age between ∼12 and ∼100 Myr, but for stars (brown dwarfs) later than M6.5, lithium is of no use for age-dating in this age range.

3.3. Rotation Rate & Stellar Activity

Stars spin-down as they age. Thus, large $v \sin i$ (rapid rotation) can be used as an age indicator. But because stars are born with a wide range of initial rotation rates, and because $\sin i$ is usually unknown, $v \sin i$ is, at best, a rough, qualitative age diagnostic. However, this rapid (differential) rotation in the presence of an outer stellar convection zone generates large regions of magnetic spots. Rotational modulation of large starspots generates optical photometric variability of 0.1 magnitudes or so; this is often seen in young stars (e.g., Lawson et al. 2001, Shobbrook et al. 2004). These spots, in turn, generate activity that manifests itself as X-ray (Figure 4) and Hα (Figure 5) emission. Pizzolato et al. (2003) presented the results of a study of the relationship between coronal X-ray emission and stellar rotation in a sample of 259 main sequence stars with $B - V$ in the range 0.5 to 2.0. Cutispoto et al. (2003) studied 110 late-F- and G-type stars selected for their large rotational velocity and they plotted lithium abundance vs. X-ray luminosity and both quantities vs. $v \sin i$.

Kastner et al. (1997) considered X-ray activity (L_x/L_{bol}) for K5 to M3 stars between the ages of 10^6 yr and that of the Sun. There appears to be a slight increase, on average, in L_x/L_{bol} as stars age from 10 to 100 Myr. But the differences are not sufficient, given the wide spread in L_x/L_{bol} at any given age in this range, to use this ratio to determine a precise age for a star younger than ∼100 Myr. The same may be said for the ROSAT X-ray hardness ratios HR1 and HR2 (Kastner et al. 2003).

Over a restricted range of spectral types, Hα and other optical emission lines can provide a somewhat more precise measure of age than can X-ray luminosity. For example, for mid- and late-K types (B-V $\sim$ 1.1), Hα in emission, probably indicates a star of age <50 Myr (Figure 5). Emission lines from neutral sodium at 5890 and 5896 Å and from neutral helium at 5876 and 6678 Å are gone already for early M-type stars at an age of ~12 Myr, but these lines can appear in spectral types later than ~M3 (Song et al. 2003).

3.4. Location on an A-Star Color-Magnitude Diagram

Jura et al. (1998) plotted ~1000 A-type stars in the Yale Bright Star Catalog with $m_v < 6.5$ and within 100 pc of the Sun according to Hipparcus data on an M_V vs. $B - V$ CMD. They discovered the luminosity corresponding to the zero-age main sequence (ZAMS) for A-type stars. This ZAMS is shown even more clearly on the CMD produced by Lowrance et al. (2000; reproduced as figure 5 in Zuckerman 2001). Although ZAMS ($\lesssim$10 Myr) A-type stars populate the very bottom of this diagram, some Pleiades age stars are also found there. Thus, even though this diagram is a very useful indicator of youth, the location of a star on it should not be overinterpreted.

3.5. Large Fractional Dust Luminosity

Far-IR observations of main-sequence stars in young clusters and in the field indicate that as stars age they are on average orbited by increasingly fewer dust particles (Habing et al. 2001, Spangler et al. 2001). Defining τ as the total energy emitted by orbiting dust grains divided by the bolometric luminosity of a star makes τ a measure of the fraction of UV and visible light emitted by a star that is absorbed by the dust. If $\tau \gtrsim 0.001$, then a star is probably not older than ~100 Myr (Spangler et al. 2001; figure 8 in Zuckerman 2001). Zuckerman & Song (2004) used all techniques described in Section 3 to derive ages for a sample of 58 dusty stars, most from Silverstone (2000), within 100 pc of the Sun. The youngest and closest of these are excellent targets for adaptive optics and HST/NICMOS imaging searches for cooling massive planets (see Section 7.2).

4. SPECTROSCOPIC SURVEYS FOR NEARBY YOUNG STARS

Surveys devoted to identifying members of young kinematic groups within ~60 pc of Earth are listed in the notes beneath Tables 1, 2, 3, and 5. If one defines "young" and "nearby" as $\lesssim$ 50 Myr old and $\lesssim$ 60 pc from the Sun, respectively, we may ask: What fraction of all such stars, irrespective of their kinematic status, have been identified in existing surveys?

Early surveys for lithium in active field stars are listed Section 2 (Pallavicini et al. 1992; Favata et al. 1993, 1995; Tagliaferri et al. 1994; Jeffries 1995). A few other early references are listed in Jeffries (1995). Montes et al. (2001a,b) report the early stages of their still ongoing study of moderately young stellar kinematic groups; only the Local Association contains a significant number of stars as young as 50 Myr. Their extensive sample was selected from a wide range of sources; most included stars are in the Hipparcos catalog and have accurate radial velocities. They divide the stars according to calculated UVWs into the Local Association (Pleiades moving group; UVW = −12, −21, −11), IC 2391 supercluster (UVW = −21, −16, −9), Ursa Major group (Sirius supercluster; UVW = + 14, +1, −9), Hyades supercluster (UVW = −40, −17, −3), and Castor moving group (UVW = −11, −8, −10) where the idea of a supercluster dates back to O.J. Eggen. See Montes et al. 2001a and Soderblom & Mayor 1993 for discussions and reference to many of the original papers by Eggen.)

As mentioned above, it is not possible to assign an age to a young star strictly on the basis of its kinematics because of the background of numerous old stars in the solar neighborhood (Song et al. 2002b). In this review and in almost all papers we reference, UVW are defined with respect to the Sun. Montes et al. use a "right-handed" coordinate system, with U positive toward the Galactic Center, V positive in the direction of Galactic rotation, and W positive toward the north Galactic pole.

In a second paper, Montes et al. (2001b) measured activity and lithium abundance in 14 stars taken from the much larger sample in Montes et al. (2001a). Further measurements and analysis are forthcoming (D. Montes, private communication).

Cutispoto et al. (2002) selected 129, fast-rotating, late-F- and G-type stars brighter than V $\sim$ 8.6 from a CORAVEL survey. They measured lithium EW, radial velocity, and $v \sin i$, and tabulate these along with RASS X-ray fluxes. Sixty-two percent of their sample are binaries. Of the single stars, they consider at least 9 to be pre-main sequence or on the ZAMS.

Wichmann et al. (2003) cross-correlated the RASS and the TYCHO catalog to define a sample of 748 stars they observed spectroscopically. Their stars have $B - V > 0.54$ (F8 and later-type) and TYCHO parallaxes larger than 3.5 times their uncertainty (σ). Because of the apparent brightness limit of the TYCHO catalog ($V \sim 11$ mag), the sample is biased toward earlier-type stars; it included 257 K-type stars, but only 24 M stars. Most of the stars are closer than 50 pc from the Sun; the average distance is ~30 pc. On the basis of measurements of lithium EW, UVW, and $v \sin i$, they found ~10 stars that they judged to be younger than the Pleiades and another ~70 with ages comparable to that of the Pleiades.

The largest of the spectroscopic surveys has been conducted by Song et al. (2004b) who measured ~1200 stars (most of which lie within ~60 pc of the Sun) for lithium, Hα, radial velocity, and $v \sin i$. Their choice of targets relied heavily on kinematic considerations. They assumed that almost all young stars would have UVW such that each component would be within ~10 km/s of the average UVW of Eggen's Local Association (see Jeffries 1995), i.e., these UVW will fall within the "good box" shown in Figure 6. The box sides in UVW space as measured in kilometers per second are: 0 to −15, −10 to −34, and +3 to −20,

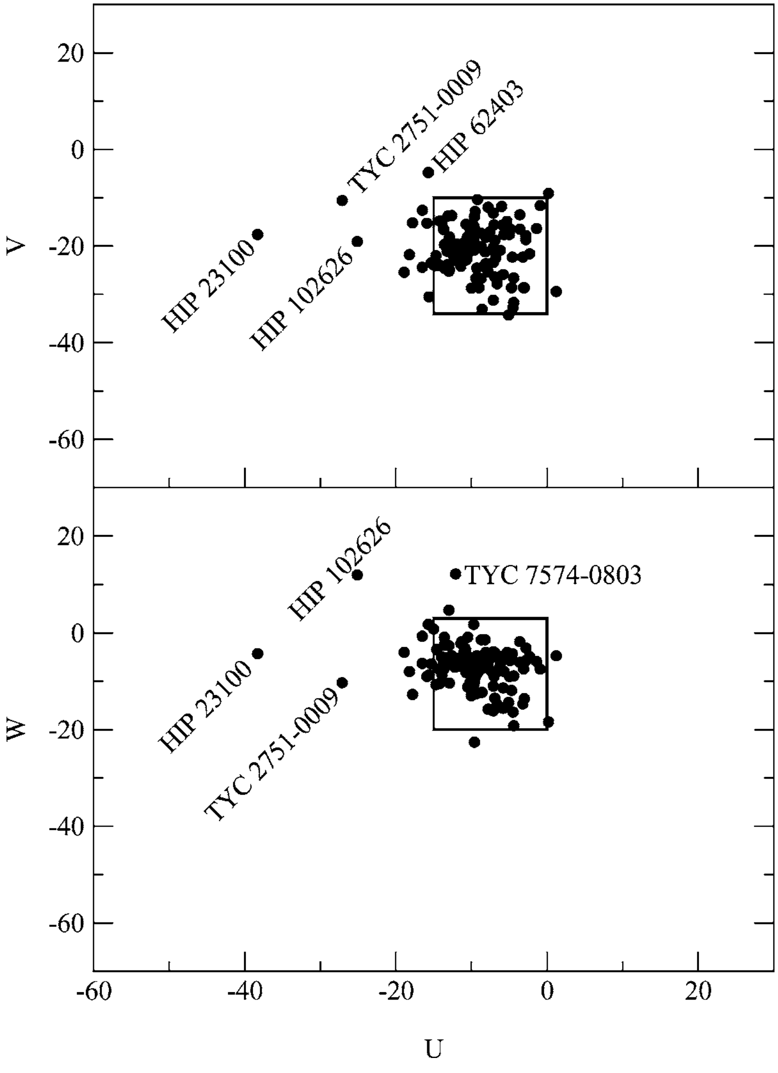

Figure 6 Galactic UVW velocities of young stars identified by Song et al. (2004b). Small boxes indicate the "good UVW box" mentioned in the text.

respectively. UVW for some kinematic groups mentioned in this review are listed in Table 7.

Calculation of UVW requires knowledge of six stellar parameters: right ascension, declination, proper motion in right ascension, proper motion in declination, distance from the Sun, and radial velocity. For a Hipparcos star with known radial velocity it is straightforward to calculate UVW to determine if that star's motion lies in the good UVW box. When such motion was found, Song et al. (2004b)

TABLE 7 Galactic space motions

Group Name	UVW (km/sec)	Age (Myr)
Hyades Cluster	−40, −17, −3	600
Ursa Majoris Moving Group	+14, +1, −9	300
Pleiades Moving Group	−12, −21, −11	∼100
TW Hydrae Association	−11, −18, −5	8
Tucana/Horologium	−11, −21, 0	30
β Pictoris Moving Group	−11, −16, −9	12
AB Dor Moving Group	−8, −27, −14	50
η Cha Cluster	−12, −19, −10	8
Cha-Near	−11, −16, −8	10?

UVW are defined with respect to the Sun, with U positive toward the Galactic Center, V positive in the direction of Galactic rotation, and W positive toward the north Galactic pole.

observed the star spectroscopically. Unfortunately, ∼80% of Hipparcos stars do not have measured radial velocities. For each of these stars, Song et al. (2004b) calculated the UVWs that correspond to a range of heliocentric radial velocities, from −80 to +80 km/s, to see if any radial velocity would yield a UVW in the good box. Not surprisingly, most Hipparcos stars cannot have UVW in the good box, regardless of their radial velocity. As a result, and by using a distance cutoff ∼70 pc from the Sun, Song et al. (2004b) were able to reduce a total pool of 118322 Hipparcos stars to ∼2000. Furthermore, since their spectroscopy indicated that Hipparcos stars of late-F through early-M type that are within 70 pc but are not RASS sources are very unlikely to be young (i.e., <100 Myr old), Song et al. (2004b) were able to reduce the pool further by eliminating most of these non-RASS stars. In total, they observed ∼650 Hipparcos stars, all with the possibility that their actual UVW falls in the good box.

Song et al. (2004b) used similar techniques to winnow down the much larger TYCHO and SuperCosmos (Hambly et al. 2001) catalogs to manageable numbers of target stars. Radial velocities for almost all non-Hipparcos stars in these catalogs are unknown; in addition, quality trigonometric parallaxes do not exist. Thus Song et al. (2004b) assumed an age (typically ∼30 Myr), used theoretical pre-main sequence evolutionary tracks in conjunction with observed brightnesses, and calculated photometric parallaxes. Prospective UVWs were calculated over the range of radial velocities from −80 to +80 km/s. Because of the great size of these catalogs, an additional constraint, an RASS source within 60″ of a star, was imposed so as to produce spectroscopic target lists of manageable size. In total, Song et al. (2004b) observed ∼350 Tycho and ∼200 SuperCosmos stars with UVW possibly falling in the good box. Essentially all these stars were of K or M type.

By combining results from all the surveys mentioned in this section, Song et al. (2004b) generated a list of ~200 stars that they estimate to be within ~60 pc of the Sun and $\lesssim$50 Myr old. Many of these stars are listed in Tables 1, 2, 3, and 5. Additional plausible kinematic groups are considered in Song et al. (2004b). Virtually all such nearby, young stars with UVW in the good box and of spectral type late-K and earlier should have been identified. An exception could be a few young stars that are anomalously faint X-ray sources and, thus, do not appear in the RASS.

Early M-type stars lacking accurate distances present a special problem. By the age of the β Pic moving group (~12 Myr), lithium in an early M-type star is usually already depleted. For such stars not in the β Pic, AB Dor, or Tucana/Horologium kinematic groups, there is no good way to distinguish age in the range 12–100 Myr on the basis of the lithium 6708 Å absorption feature. Age determinations require accurate trogonometric parallaxes and placement on a Hertzsprung-Russell diagram. Young field stars of spectral type mid-M and later are sufficiently faint such that they may not appear in the TYCHO catalog and may have been missed by Song et al. (2004b) in the astrometrically and photometrically less precise SuperCosmos catalog. So the abundance of such stars within 60 pc of the Sun remains to be determined.

Perhaps substantial numbers of nearby stars that are younger than the Pleiades have UVW that do not fall within the good box? We think this unlikely for at least two reasons. First, Song et al. (2004b) found that very few stars in their sample with UVW not in the good box are this young. Second, the large sample observed by Wichmann et al. (2003), which was drawn from a nearby X-ray-selected population with no kinematic constraints, yielded only a handful of stars they (and we) deem to be younger than the Pleiades. In effect, a large fraction of nearby stars in the RASS are not especially young (see also Makarov 2003).

5. ASTROPHYSICS OF YOUNG STARS

5.1. Lithium Depletion

Gravitationally contracting low-mass ($\lesssim$0.35 $M_\odot$) stars are fully convective until they reach the main sequence. As the contraction proceeds the core temperature rises; when it reaches ~3×10^6 K, lithium depletion proceeds via the ^{7}Li(p,α)^{4}He reaction. This process is very temperature sensitive, so once lithium burning begins, it consumes all available lithium quickly ($\lesssim$10 Myr). Stars of solar mass or greater develop radiative cores early in their evolution, resulting in separation of the convective outer layers from the much hotter inner regions. As long as the temperature at the base of the convective layer is less than the lithium-burning temperature, surface lithium can be preserved for a long time. This accounts for the very modest reductions in equivalent width of the Li 6708 Å line for the F- and G-type stars at ages up to 100 Myr (Figure 3). On the very low mass side, it takes time for the central temperature to rise above the lithium-burning temperature, so the lowest mass M-type stars retain their lithium for a long time; the lower the star's mass is, the longer it retains its lithium. Indeed below ~0.065 $M_\odot$ the central temperature of brown dwarfs never becomes hot enough for lithium to burn.

At a given time, the onset of lithium burning at the low-mass end is a very sensitive function of stellar mass; only a small difference in mass (hence brightness) can result in appearance or disappearance of a Li 6708 Å absorption feature (Bildsten et al. 1997, Ventura et al. 1998, Basri 2000). This sudden change over a very small stellar mass range is called the Lithium Depletion Edge (or Boundary) (LDB) and its location (luminosity) has been used to estimate ages of a handful of open clusters (Basri et al. 1996; Stauffer et al. 1998, 1999; Barrado y Navascués et al. 1999a; Oliveira et al. 2003; Burke et al. 2004). However, open cluster ages estimated from this LDB method are all ~50% larger than model turn-off ages for upper-main sequence stars with zero convective overshoot. A convective overshoot model that increases the main sequence lifetime of high-mass stars can reconcile these age differences. However, the physical basis, and, thus, quantitative implications of such overshoot models are ill constrained.

Song et al. (2002a) discovered a pre-main sequence binary with almost equal brightness, GJ 871.1 A&B, where the secondary shows a strong Li 6708 Å feature even though no such feature is seen in the primary. Using GJ 871.1 data, they suggested that, if the likely age of the binary is correct (~12 Myr), then lithium burning faster than predicted by the theoretical models is required to match the lithium content, color, and brightness of both binary components. If so, this could reduce the LDB open-cluster age scale and reconcile it with upper-main sequence turn-off ages with zero convective overshoot. Regardless, this binary suggests that contemporary pre-main sequence evolutionary tracks and lithium burning timescales are not self consistent.

5.2. Abnormal Colors of Young K/M Stars

Pleiades K-stars fall nearly 0.5 mag below the ZAMS on an M_V versus $B - V$ color-magnitude diagram (Jones 1972) whereas no such difference appears in an M_V versus $V - I_C$ CMD (Stauffer et al. 2003). On the contrary, on an M_V versus $V - K$ CMD, the locus of ~100 Myr old Pleiades K-stars lies slightly above the one defined by ~600 Myr old Praesepe K-stars (see Figure 7). These abnormal colors of Pleiades K-stars (mainly due to excess B-band emission and weak K-band excess emission) can be explained by spottedness induced by rapid stellar rotation, including both warm and cold spots with surface-filling factors $\gtrsim 50\%$ among young stars (Stauffer et al. 2003). Staffer et al. (2003) also suggested that for stars younger than the Pleiades the same effect may be seen at earlier spectral type. In fact, blue $B - V$ color for a given $V - I$ color appears among a few stars in the Taurus-Auriga region studied by Kenyon & Hartmann (1995). Multicolor photometric monitoring of young stars mentioned in this review will provide further information about this effect.

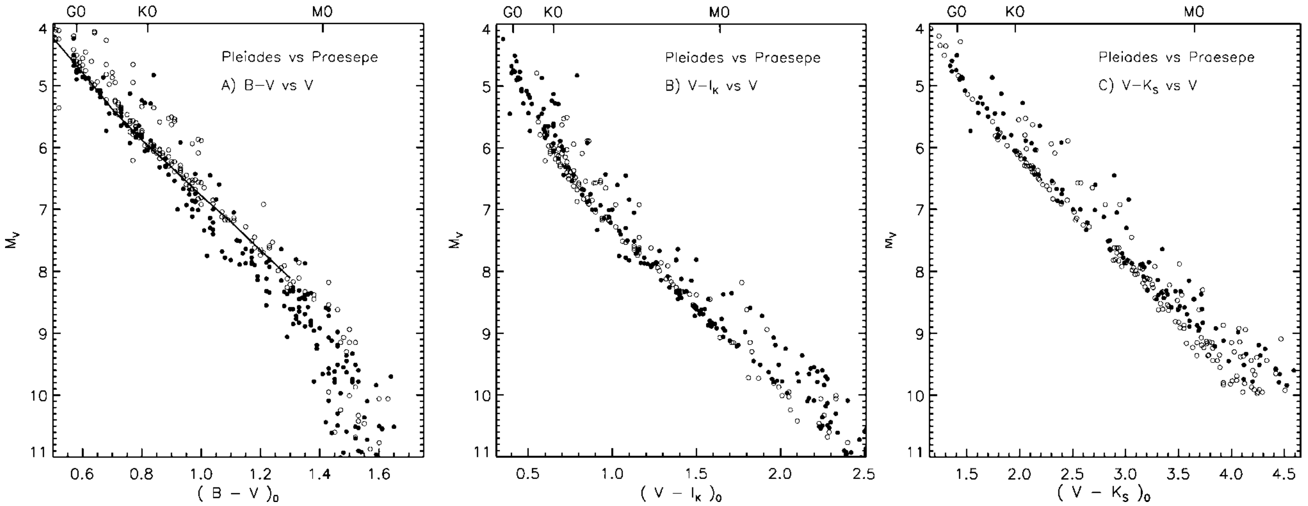

Figure 7 Abnormal colors of Pleiades K-dwarfs from Stauffer et al. (2003). Pleiades (*filled circles*) and Praesepe (*open circles*) members are overplotted for comparison. There is no obvious difference between the two clusters in the $V - I$ plane, but Pleiades stars are bluer in $B - V$ and are redder in the $V - K$ plane. Stauffer et al. explained this as excess emission at B and K bands for young K dwarfs. For younger stars, such as those mentioned in this review, this color abnormality may be present among earlier spectral types.

5.3. X-Ray Emission

Kastner and collaborators (Kastner et al. 2003 and references therein) have been most active in analyzing X-ray emission from stars in the age range of interest in this review. They summarize the history and significance of such emission in a single paragraph:

> "Over the past two decades beginning with Einstein and continuing through the most recent observations by the Chandra X-ray Observatory and the X-ray Multi-Mirror Mission (XMM), X-ray observatories have produced an increasingly detailed and comprehensive census of X-ray sources in star formation regions. These observations have firmly established the presence of strong X-ray emission as one of the defining characteristics of stellar youth (Feigelson & Montmerle 1999). Moreover, high-energy emission from young stars is central to many seemingly disparate aspects of star and planet formation, from the chemical evolution of dark clouds to formation of chondrules found in meteoritic inclusions."

For stars with convective surface layers, coronal activity due to strong magnetic fields is regarded as the principal source of X-ray emission. But for classical T Tauri stars such as TW Hya, Kastner et al. (2002) proposed that accretion of material from disk to star could be responsible for a majority of the X-ray activity (see Section 7.1.1). X-ray emission spectra can yield clues regarding the evolving properties of young stars and their surrounding disks. Kastner et al. (2003) analyze ROSAT Position Sensitive Proportional Counter data for many of the stars in Tables 1–3, for Taurus dark cloud T Tauri stars, for Hyades members, and for main sequence dwarfs in the field. They found that the intrinsic X-ray spectrum of a star of spectral type F or later softens with age. But it remains unclear whether this trend can be attributed to age-dependent changes in the intrinsic X-ray spectra, to a decrease in the column density of circumstellar gas (e.g., in residual protoplanetary disks), or to the diminishing contributions of star-disk interactions to X-ray emission.

5.4. Mass Loss from the Young Sun

The problem of a faint young Sun has been around for many years (see, e.g., Sackmann & Boothroyd 2003, Kasting & Catling 2003). Evidence for liquid water on the early Earth and Mars seems likely, perhaps even compelling. Yet a faint Sun—one unable to raise the surface temperature of these planets above the freezing point of water—is predicted by all conventional models of stellar evolution. The conventional way around this conundrum has been to assume large atmospheric greenhouse effects on both planets when they were young. But, especially for Mars, this solution is far from convincing.

An alternative possibility, one potentially able to solve the liquid-water problem simultaneously for both planets, is that the Sun was slightly more massive at its origin than it is now. Measurements of $\sim$10 stars of solar mass suggest that mass-loss rates decline as a star ages (Gaidos et al. 2000, Wood et al. 2002). These and other observational constraints, including the depletion of solar lithium, seem to restrict the maximum permissible initial mass of our Sun to ∼1.07 solar masses (Sackmann & Boothroyd 2003) which could be sufficient to produce liquid water on Mars 3.8 Gyr ago.

All stars observed by Gaidos et al. (2000) and Wood et al. (2002) are substantially older than the stars discussed here. Sackmann & Boothroyd (2003) remarked that "measurements of mass-loss rates from more young stars" are "urgently needed." Observations of stars of approximately solar mass in the β Pic, AB Dor, and Tucana/Horologium Associations, as well as very young field stars not obviously belonging to a moving group (Song et al. 2004b), would be worthwhile to help elucidate the faint young Sun problem.

5.5. Emission Lines

Emission lines of non-hydrogen elements, e.g., HeI, OI, CaII, Na D, seen among classical T Tauri stars have been used as an indicator of extreme youth. In the magnetic accretion model, these emission lines are thought to be from near footprints of magnetically controlled accretion funnel flows (Muzerrolle et al. 1998) or from both funnel flows and hot winds (Beristain et al. 2001). The He I lines are especially useful because of their diagnostic power due to high-excitation potential that narrowly restricts the region in which they can form (Beristain et al. 2001). Generally, these lines are composite with a narrow (FWHM $<$ 50 km/sec) and a broad component ($>$50 km/sec).

However, these non-hydrogren emission lines are seldomly seen among weak-lined (post) T Tauri stars in the age range of 10–30 Myr. A few post T Tauri stars with He I emission lines have been identified among young stars (Song et al. 2004b), but only for spectral types ∼M2 or later. This behavior is similar to the onset of Hα emission in young stellar clusters. The earliest spectral type where the Hα line is seen in emission is correlated with cluster age, i.e., the younger the cluster is, the earlier is the spectral type that displays Hα emission.

Among η Cha members, three of late-spectral type show non-hydrogen emission lines [RECX9 (W.A. Lawson, private communication), J0843.3−7905 (Lawson et al. 2002), and J0844.2−7833 (Song et al. 2004a)]. RECX5 and J0841.5−7853 also show a hint of such emission lines. Based on JHK and/or $K - L$ colors, all five stars have infrared color excesses indicating a disk (Lyo et al. 2003) consistent with results on classical T Tauri stars (e.g., Batalha et al. 1996). Broad Hα emission profiles imply that the disk material is being accreted onto the stars (Lawson et al. 2004).

At ages of 10−30 Myr, $\lesssim$10% of stars with spectral type earlier than mid-K have Hα in emission, whereas almost all M stars do (Song et al. 2004b). This behavior appears similar to that of non-hydrogen emission lines that are more prevalent among low mass stars. The exclusive appearance of non-hydrogen emission lines among the latest spectral-type stars may indicate a prolonged duration of accretion around low mass stars. An interesting study will be one that looks systematically for non-hydrogen emission lines in ∼30 Myr old open clusters such as IC 2602.

6. ORIGINS OF NEARBY YOUNG STARS

The nearest site of massive star formation, the Sco-Cen region (ScoCen), is more than 100 pc from Earth. Considering that many young stars are within 60 pc of Earth, the origin of such stars is a subject of some interest. There is no sign of a molecular cloud close to Earth, say within 100 pc, that could readily explain the origin of these young stars as in-situ star formation similar to typical sites such as Taurus/Auriga and ScoCen.

An important clue to the origin of nearby young stars may be the fact that they exist mostly in the Southern Hemisphere. Most likely this Southern prevalence is related to recent massive star formation in ScoCen that consists of three subregions, each distinguishable by different sky positions, age, and kinematics. The closest of the three sub-regions is Lower Centaurus-Crux (LCC) with an estimated distance of ~120 pc (de Zeeuw et al. 1999). The TWA and the north west part of LCC overlap each other in the sky plane and TWA/LCC stars in the overlapped region have similar space motion (Song et al. 2003). The age of LCC is thought to be 10–15 Myr (de Geus et al. 1989), but use of different methods results in a somewhat older age (15–25 Myr; Mamajek et al. 2002). Traceback of members of the β Pic moving group indicates an age of ~12 Myr (Ortega et al. 2002, Song et al. 2003). TWA stars are clearly younger because they lie above β Pic stars in the CMD (Figure 2) and because their lithium abundance is greater than that of β Pic members (Figure 3). Thus, TWA stars are as young or younger than the youngest stars in LCC. Along the line of sight, TWA members appear to extend from ~30 pc all the way to the LCC distance (Table 1) (Song et al. 2003). TWA is probably the forefront edge of LCC.

Tracing positions of currently known β Pic members back in time indicates that at its birth the β Pic group was very close to ScoCen (Mamajek & Feigelson 2001; Ortega et al. 2002, 2004; Song et al. 2003). The compact star cluster 97 pc from Earth, η Cha (Table 4), located slightly west of LCC may be related to ScoCen (Mamajek et al. 2000, 2002). In addition, there exist a handful of young stellar groups in the forefront regions of ScoCen; ϵ Cha cluster (Feigelson et al. 2004), "Cha-Near" region (Table 6) (Zuckerman et al. 2004b), and β Crux cluster (Alcala et al. 2002). Positions and relative sizes of these Southern clusters are plotted in Figure 8. Extrapolating from these, one may deduce that most nearby young stars of age $\lesssim$15 Myr are related to ScoCen. Then one can ask: what could have caused this large-scale star formation (~200 pc) over a timescale corresponding to the age range (~30 Myr) found in the "greater" ScoCen region?

To answer, let us examine the ScoCen region in more detail. Although ScoCen is the massive star formation site closest to Earth, we have only limited information about it because of its vast area in the projected sky plane; its spatial scale is $\gtrsim$200 pc with a total mass $\sim 10^{3-4}$ $M_{\odot}$. Currently known membership is good down to only early G-type (de Zeeuw et al. 1999).

The passage of a Galactic spiral arm can naturally explain such large-scale star formation. In this scenario, ~60 Myr ago, the Carina arm passed through a region that is now the solar neighborhood and triggered massive star formation (Elmergreen 1992, 1993). Sartori et al. (2003) argue that alignments of molecular clouds and young stellar groups including the ScoCen, Ophiucus, Lupus, and Chamaeleon regions, which are all in the anti-galactic rotation direction, can easily be explained by the passage of a Galactic spiral arm. Alternatively, the interstellar medium is full of turbulence which continuously creates and destroys regions of enhanced density at various scales. In their numerical simulation, Hartman et al. (2001) demonstrate that in a few tens of millions of years an interstellar cloud a few hundred parsec in size can be created. In this scenario, large-scale turbulent flows in the diffuse interstellar medium rapidly form filamentary molecular clouds that extend over a scale of a few hundred parsec in which a small branch ($\sim$50 pc) gives birth to nearby stellar groups such as those discussed in this review. A large filamentary cloud is analogous to ScoCen, and small stellar aggregations generated from small branches are analogous to young stellar groups.

Extrapolating from the mass function of currently known ScoCen members (de Zeeuw et al. 1999), one expects to see at least a handful of O stars in the whole ScoCen region. However, there is no O-type star in ScoCen even though two dozen or so B0-2 stars exist. This implies that there were a few O-type stars that blew up as supernovae. These supernovae explosions could have (*a*) contributed to the dispersal of small star-forming molecular clouds and (*b*) triggered new star formation in their neighborhood. Although we do not see direct evidence of such explosions, there may exist indirect evidence such as the local, low-density, bubble in the solar neighborhood (e.g., Maiz-Apellaniz 2001) and the expanding shell structures surrounding ScoCen (de Geus 1992). Indeed, triggered star formation of small stellar groups through a supernova explosion in ScoCen is a popular scenario today (Mamajek & Feigelson 2001, Sartori et al. 2003, Ortega et al. 2004).

Although we may not know exactly how star formation in ScoCen began, a physical relation between nearby, young stellar groups and ScoCen is evident. Unless the ScoCen mass function is very different from those of other star-forming regions, there must have been a handful of supernova explosions that triggered and later dispersed the maternal clouds of the young nearby groups. Small stellar groups formed in the expanding shell of supernova shock waves or in branches of turbulence-induced filamentary molecular clouds can explain small differences in space motion between young nearby stellar groups and ScoCen.

7. ORIGIN OF PLANETARY SYSTEMS

To introduce this section we cannot do better than to quote the first paragraph from Calvet et al. (2002): "The discovery of extrasolar planets has opened up a new era in the study of planetary systems. While many important clues to the processes of planet formation can be obtained from studies of older systems, the best tests of formation scenarios will require the direct detection of actively planet-forming systems."

Members of the coeval groups in Tables 1, 2, 3, and 5 are prime targets for direct imaging searches for cooling planets and circumstellar dusty disks because of their youth (8–50 Myr) and proximity to the Sun ($\lesssim$60 pc). In fact, many members do possess substellar companions (e.g., TWA 5 and HR 7329) (Lowrance et al. 1999, 2000) or prominent protoplanetary/debris disks (e.g., β Pic, TW Hya, AU Mic, HR 4796A, HD 98800, Hen3-600). The age range of these groups overlaps important epochs of planet formation, gas-giant formation in $\lesssim$10 Myr and terrestrial planet formation in $\lesssim$30 Myr. The latter timescale has been determined for Earth from chronometry using the hafnium-tungsten system via precise measurements of tungsten isotopes in meteorites (Jacobsen 2003, Kasting & Catling 2003 and references therein). Thus, the ensemble of planets and disks found around the stars in Tables 1–6 should provide crucial, perhaps unique, information about the formation and early evolution of planetary systems, including our own.

7.1. Dusty Circumstellar Disks

Planets form from dust and gas in circumstellar disks and giant-planet formation must be rapid because little dust and gas remains after a few million years (Zuckerman et al. 1995, Lecavelier des Etangs et al. 2001, Haisch et al. 2001, Richter et al. 2002, Sheret et al. 2003, Weinberger et al. 2004; but see also Lyo et al. 2003). What remains uncertain is whether giant-planet formation involves a disk instability, i.e., gravitational collapse, or core formation followed by the gravitational attraction of a hydrogen and helium envelope (e.g., Lunine & Boss 2003) or both.

Studies of dust around young stars through the end of 2000 are reviewed by Zuckerman (2001) and Lagrange et al. (2000). Zuckerman noted that, with a few exceptions such as TW Hya, evidence for dust (from IR emission) or for gas (from accretion signatures or radio molecular emission) was lacking for most stars in the age range represented by stars in Tables 1–5. Subsequent studies (see references listed in the notes to Tables 1–4) are consistent with the notion that by the time most stars reach an age ~10 Myr, there is little evidence of dust particles and gas. However, given the (limited) sensitivities of IRAS and ISO, the possibility that late-type 10–30 Myr old stars are much dustier than the Sun remains open. Below, we focus on developments since 2001 on a few key stars, anticipating that Spitzer and SOFIA will soon greatly expand this field.

7.1.1. TW Hya As we mentioned in Section 2, the recognition that TW Hya (K7) is an isolated T Tauri star far from any interstellar molecular cloud was the first hint that very young stars might be found quite close to the Sun. TW Hya, which is probably both the oldest and the closest classical T Tauri star known, has become one of the most studied of all T Tauri stars (see, e.g., Zuckerman 2001). In recent years, TW Hya has been investigated at radio (van Zadelhoff et al. 2001, van Dishoeck et al. 2003, Wilner et al. 2003), near-infrared (Weinberger et al. 2002, Bary et al. 2003, Apai et al. 2004), optical (Alencar & Batalha 2002, Batalha et al. 2002), far-UV (Herczeg et al. 2002), and X-ray (Kastner et al. 2002) wavelengths.

As of mid-2004, dusty disks at eight "Vega-like" stars—ϵ Eri, Vega, Fomalhaut, AU Mic, β Pic, HD 141569, HR 4796, TW Hya—have been imaged at one or more wavelengths. Excepting TW Hya (Weinberger et al. 2002 and references therein) and AU Mic (Kalas et al. 2004), all show pronounced spatial structure that could be generated by the gravitational field of a planet (see Zuckerman & Song 2004 and references therein as well as discussion of HD 141569 in Section 7.1.2). HST NICMOS coronagraphic images of scattered light from TW Hya at 1.1 and 1.6 μm reveal a rather featureless face-on disk that is seen from 20 to 230 AU. The scattering profile indicates that the disk is flared, not geometrically flat.

Accretion of disk material onto TW Hya is deduced from Hα and UV continuum emission at a rate of $\lesssim 10^{-8}\ M_{\odot}$ per year (Alencar & Batalha 2002, Batalha et al. 2002) or a rate $\lesssim 10^{-9}\ M_{\odot}$ per year (Muzerolle et al. 2000). Accretion is perhaps also indicated from the 1.5–2.5 Å high resolution X-ray emission spectrum obtained with Chandra/HETGS by Kastner et al. (2002). They argue that the observed X-rays are more likely produced in an accretion shock at the bottom of a funnel connecting the inner part of the circumstellar disk to the star rather than via coronal activity which seems to dominate the X-ray emission of HD 98800, a multiple TWA member not experiencing significant levels of accretion (Muzerolle et al. 2000, Kastner et al. 2004; see also Kastner et al. 2003).

In any event, TW Hya is a strong source of X-ray emission which may be an underlying energy source that excites H_2 seen in emission in the $v = 1 \rightarrow 0$, S(1) line at 2.12 μm (Bary et al. 2003). Also, H_2 fluorescent UV emission in Lyman band transitions has been seen by HST/STIS, but in this case the excited electronic state is pumped mainly by H_2 transitions coincident with Lyα (Herczeg et al. 2002). A model of the H_2 fluorescence suggests that the emitting molecules reside in a warm ($\sim$2500 K) surface layer of the disk within $\sim$2 AU of TW Hya (Herczeg et al. 2004).

High energy radiation can modify the disk chemistry, which promises to be quite rich when synthesized with the next generation of radio interferometers. A modest suite of molecules (CO, HCN, HCO^+, CN), including some with multiple isotopic species, has already been detected from the TW Hya disk (Kastner et al. 1997, van Zadelhoff et al. 2001, Bergin et al. 2003, Wilner et al. 2003, van Dishoeck et al. 2003). Still, models remain poorly constrained and more sensitive instruments with excellent spatial resolution (e.g., ALMA) will be required before the secrets hidden in TW Hya's dusty disk are clearly revealed.

Notwithstanding numerous investigations, the rotation period of TW Hya remains uncertain, perhaps in part owing to its nearly pole-on orientation. A recent study yielded a period of 4.4 days on the basis of a periodogram analysis of ultraviolet veiling and of photometry of the photosphere (Batalha et al. 2002).

Positioning a classical T Tauri star on an HR diagram is rendered difficult by accretion-generated excess continuum flux. TW Hya well illustrates this problem. Batalha et al. (2002) deveiled the star and, with models by Baraffe et al. (1998), derived an age of 30 Myr. But placement on an HR diagram (Figure 2) of naked T Tauri stars in the TWA relative to those in the β Pic moving group, whose age can be calibrated by trace back (Ortega et al. 2002), combined with the very strong lithium 6708 Å lines in TW Hya and all other late-type TWA members, shows that TW Hya must be much younger than 30 Myr. This example illustrates how knowledge that a star is a member of a coeval association can be critical in establishing important stellar parameters.

7.1.2. HD 141569 In contrast to TW Hya's rather bland disk, the 500 AU radius disk around the closest Herbig Ae star HD 141569 displays a variety of structure that has been imaged in scattered light with three coronagraphic cameras on HST: NICMOS at 1.1 and 1.6 μm (Augereau et al. 1999, Weinberger et al. 1999), STIS over a wide band of optical colors centered at 5850 Å (Mouillet et al. 2001, Augereau & Papaloizou 2004), and ACS at B,V,I (Clampin et al. 2003). The resolution of the ACS images is as good as ~50 mas, which is 5 to 10 times better than the approximately diffraction limited images obtained with the OSCIR and MIRLIN mid-IR (10–20 μm) cameras on the Keck telescope (Fisher et al. 2000, Marsh et al. 2002).

Notwithstanding the superior HST resolution, the mid-IR images show a compact, slightly resolved, region of one arc-second radius which is equal to 100 AU whereas the HST images are insensitive to dust close to HD 141569 because such dust is covered by the coronagraphic spot. Instead, the HST images reveal light scattered out to 500 AU. This could be the tidal truncation radius of the disk expected as a consequence of nearby companions B and C, depending on the physical separation of A and BC (Artymowicz & Lubow 1994, Li & Lunine 2003).

The wealth of disk structure and the presence of two M-star companions (Weinberger et al. 2000) make this ~5 Myr old dusty disk a challenge to analyze. In addition, the dynamical behavior of dust particles can be complicated by gas-dust coupling resulting from gas present out to ~100 AU (Zuckerman et al. 1995, Takeuchi & Artymowicz 2001). The complex images (Figure 9) have been analyzed (Marsh et al. 2002, Augereau & Papaloizou 2004, Clampin et al. 2003), and the consensus appears to be that the gravitational field of companion BC is the primary generator of structure in the disk although the possibility of a planet in the gap in the disk ~250 AU from HD 141569 remains.

With the imaging observations as a constraint, Li & Lunine (2003) analyzed the mid-IR to submillimeter emission (SED) from the disk. Their model consists of porous aggregates of either unadulterated or heavily processed interstellar materials mixed with a population of polycyclic aromatic hydrocarbons (PAHs). To match the observed SED with the model requires some dust particles of a few Angstroms in radius which are rapidly expelled by radiation pressure (the drag due to the gas also needs to be considered). Thus, Li & Lunine postulated that particles smaller than ~10 μm must be resupplied via frequent collisions of planetesimals. They courageously predict, on the basis of their models, what Spitzer imaging and spectroscopy will reveal about the HD 141569 disk. The model of Augereau & Papaloizou (2004) focuses more on simulating the complex disk images and less on the SED. Augereau & Papaloizou also concluded that small, short-lived grains are abundant and probably are produced by high collisional activity.

Mid-IR observations need not be constrained by use of a coronagraph and, hence, can probe regions close to HD 141569. Brittain et al. (2003) detected CO 4.7 μm fundamental ro-vibrational lines in emission. The CO linewidths constrain the inner diameter of the emitting region, whereas the spatially unresolved extent constrains the outer diameter. As a result, conclusions of Brittain et al. apply between ~17 and 50 AU from HD 141569, a region of great interest for planet formation. Their spectra show that, while not all the gas has been removed, the amount presently available is too small to form a Jovian mass planet, and, also, much smaller than the mass of gas found ~100 AU from the star by Zuckerman et al. (1995). Brittain et al. (2003) are insensitive to this more distant gas because the cold CO molecules are not excited out of the ground vibrational state.

7.1.3. β Pictoris β Pic (A5V) has been one of the most intensely investigated stars in the sky (e.g., reviews by Artymowicz 1997, Vidal-Madjar et al. 1998, Lagrange et al. 2000, Zuckerman 2001). Particular focus has been given to its prominent edge-on disk extending out to ~1000 AU. Although researchers have derived the fundamental stellar parameters of β Pic itself, the star has attracted little interest because main sequence A5-type stars are not expected to be chromospherically active. According to the conventional theory of stellar evolution, such stars possess, at most, very thin outer convection zones unable to sustain magnetic activity (e.g., Simon et al. 2002). Moreover, chromospheric emission lines had never been detected in spectroscopic data accumulated for years, supporting the idea that β Pic is not active. In this context, then, the discovery of broad emission lines from the highly ionized species C III and O VI with the Far Ultraviolet Spectroscopic Explorer (FUSE) (Deleuil et al. 2001) came as quite a surprise.

Only collisional processes can produce these ions; the stellar far-UV flux from β Pic is much too weak to so ionize a significant fraction of C and O atoms. Previously, variable absorption features from lower-energy ionic states had been interpreted in terms of star-grazing comets in the Falling Evaporating Bodies (FEB) scenario (see below). However, the FEB framework appears unable to explain the C III and O VI data (Deleuil et al. 2001, Bouret et al. 2002). Rather, to account for the observations, these researchers prefer a chromosphere-like model with a thin region close to the stellar photosphere heated to a few times 10^5 K in combination with a weak wind flowing off the disk at small angles with respect to the disk plane. They suggest that this surprising activity in a mid-A-type star dies away as the star ages, much like the decay of activity in sun-like stars. Using future far-UV observations of young A-type stars in the solar vicinity, researchers may be able to isolate the relative importance, in generation of the lines detected by Deleuil et al. (2001), of spectral class, age, and the presence or absence of a substantial debris disk.

The energy required to explain the non-thermal ionization discovered by FUSE might be supplied by pulsations of the sort discovered by Koen et al. (2003). Although β Pic has a radiative photosphere, pulsational energy might be converted to thermal energy, perhaps through the mediation of a magnetic field, thus explaining the existence of a chromosphere. If this suggestion is correct, then the presence of far-UV emission lines in A-type stars should correlate with the presence of detectable pulsations.

In any event, the much-studied absorption spectrum of β Pic remains quite unusual. Hempel & Schmitt (2003) searched for variable Ca II K-line absorption in eight other A-type stars, some of which possess surrounding dust disks. Short-term variations (timescales ranging from hours to days) seen in β Pic are not seen in any other star. A few stars in the sample do show long-term variations (timescale measured in years).

Turning to β Pic's extensive surrounding disk, recent papers have focused on one of three areas: (*a*) the FEB model, (*b*) the structure of the dusty disk, and (*c*) the gaseous content of the disk. Karmann et al. (2001), Thebault & Beust (2001), and Karmann et al. (2003) have considered the flux of FEBs onto β Pic, the need to invoke the gravitational influence of a massive planet, and the physics and chemistry of the sublimation of the volatile and refractory components of the FEBs.

Thebault et al. (2003) investigated connections between the FEB phenomenon and the production and size distribution of dust particles in the disk within $\sim$10 AU of β Pic. Structure at this size scale is resolvable at mid-IR wavelengths on the largest ground-based telescopes (Wahhaj et al. 2003, Weinberger et al. 2003). Disk structure can be probed closer to the star, 10–20 AU, with mid-IR imaging than with scattered-light imaging, even with HST, because of the more favorable disk-to-star brightness ratio in the mid-IR. The structure out to 100 AU and beyond, derived from thermal-IR emission at 10 and 18 μm and reflected optical light, is complex (e.g., see references in Weinberger et al. 2003). Augereau et al. (2001) model the grain properties and conclude that plantesimals, "parent bodies" for the dust, are located between 20 and 150 AU with a peak at $\sim$110 AU.

Weinberger et al. (2003) obtained spatially resolved spectroscopy that revealed evidence for amorphous and crystalline silicates within $\sim$20 AU of β Pic. Honda et al. (2003) found evidence for crystalline silicates around Hen 3–600A, an M-type star in the TWA. By an age of $\sim$10 Myr only a few stars have detectable mid-IR emission of any sort, so the presence of crystalline silicates at two of them suggests that these minerals are readily produced in young, evolving circumstellar disks. Honda et al. provide a discussion of specific minerals and possible connections with the origin of our own solar system.

Holland et al. (1998) reported an 850-μm source quite far from the star ($\sim$650 AU), located approximately in the disk plane. Whether this source is physically related to β Pic has been unclear (Zuckerman 2001). Liseau et al. (2003) mapped the β Pic region at 1.2 mm wavelength with angular resolution inferior to that available to Holland et al. (1998). A 450 μm image also exists, but is not yet fully reduced (W. Holland, personal communication). The submillimeter spectral index of the 650 AU source between 0.45 and 1.2 mm as well as a physical association with β Pic remain uncertain.

Finally, there is the controversial question of the existence of substantial amounts of H_2 gas in the disk. The detection of pure rotational transitions of H_2 by the Infrared Space Observatory (ISO) (Thi et al. 2001) is unlikely on the basis of observations of electronic transitions with FUSE (Lecavelier des Etangs et al. 2001).

Ground-based observations of pure rotational transitions of H_2 by Richter et al. (2002) and Sheret et al. (2003) cast general doubt on the reliability of the ISO observations of Thi et al.

Optical emission lines reveal Fe, Na, Ca, Ni, Ti and Cr atoms and ions along the disk and show that the southwest arm is revolving toward us and the northeast arm is receding (Olofsson et al. 2001, Brandeker et al. 2004). Along the SW arm the Na I D lines are detected, with ~15 AU resolution, from 13 to 323 AU.

Chen & Kamp (2004) used the Far Ultraviolet Spectroscopic Explorer (FUSE) and the Space Telescope Imaging Spectrograph (STIS) to obtain spectra of HR 4796A, an AO-type member of the TWA (Table 1). HR 4796 is about as dusty as and slightly younger than β Pic. Chen & Kamp searched for but failed to detect circumstellar absorption in transitions of CII, OI, ZnII, Lyman series H_2, and CO(A-X). Their model for HR 4796's dusty circumstellar ring indicates insufficient hydrogen in either molecular or atomic form to presently support the formation of a planet of Jovian mass.

7.2. Substellar Companions

The most exciting aspect of nearby, young stars discussed in this review may be that they will enable future astronomers, through very high spatial resolution observations, to view the full spectrum of planetary system formation during the tens of millions of years following star formation and over the range of spectral types from A to M. Jovian-mass planets, located not too close to these stars, will be easiest to resolve. But eventually, even forming terrestrial planets should be discernable. This knowledge will be gained from study of these stars or not at all because, for all practical purposes, no other stars are suitable. Currently, near-IR adaptive optics on the largest telescopes or the NICMOS camera on HST may be used to detect self-luminous planets of a few Jupiter masses with semi-major axes of tens of astronomical units around many of the stars in Tables 1, 2, 3, and 5.

As of mid-2004, of all the stars in Tables 1–6, only two brown dwarf companions are known with certainty: TWA 5B (Lowrance et al. 1999, Webb et al. 1999) and HR 7329B (Lowrance et al. 2000). Initially Lowrance et al. placed HR 7329 in the Tucana Association, but it is much more likely a member of the β Pic moving group (which was not really known at the time the Lowrance paper was written.) Another likely brown dwarf is a companion to GSC 8047-0232 (Chauvin et al. 2004, Neuhäuser & Guenther 2004). Each of the three brown dwarfs have very late M-type spectra and masses ~30 times that of Jupiter.

8. OUTLOOK

Future research on young stars near the Sun will follow at least two major paths. One will be identification of the faintest main sequence, and possibly substellar, "youngsters." Current efforts are limited by brightness cutoffs in all-sky optical and X-ray catalogs and by lack of accurate proper motions for and distances to faint stellar objects. The other path will be increasingly sensitive ground- and space-based investigations of the vicinity of stars listed in Tables 1–6 and in Song et al. (2004b), beginning with Spitzer and SOFIA. Eventually, such studies will reveal, in detail, how planetary systems form.

ACKNOWLEDGMENTS

We thank our colleague Dr. Michael Bessell for his important contributions to our joint research which has been supported in part by NASA's Astrobiology Institute and by a NASA grant to UCLA.

The *Annual Review of Astronomy and Astrophysics* is online at http://astro.annualreviews.org

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NOTE ADDED IN PROOF

The following references have been added to the review:

Apai D, Pascussi I, Brandner W, Henning Th, Lenzen R, et al. 2004. *Astron. Astrophys.* 415:671–76

Brandeker A, Liseau R, Olofsson G, Fridlund M. 2004. *Astron. Astrophys.* 413:681–91

Neuhäuser R, Guenther EW. 2004. *Astron. Astrophys.* In press

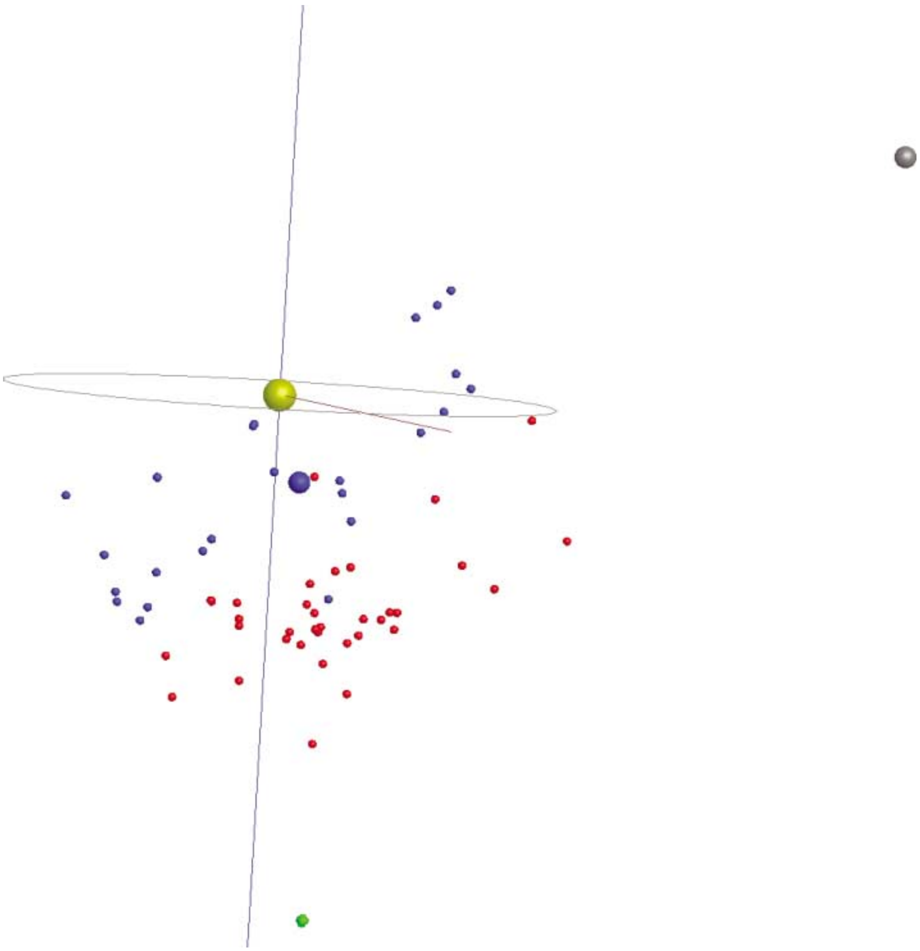

Figure 1 Widespread distribution of members of the β Pic and Tucana/Horologium Associations contrasted with the more distant and much more spatially concentrated Pleiades (*gray dot*) and η Cha (*green dot*) clusters, shown approximately to scale. The oval represents a distance of 50 pc from the Sun (*yellow ball*). Note the concentration to deep in the Southern Hemisphere. The large blue dot is β Pic. Blue dots represent β Pic members, and red dots represent Tucana/Horologium Association members.

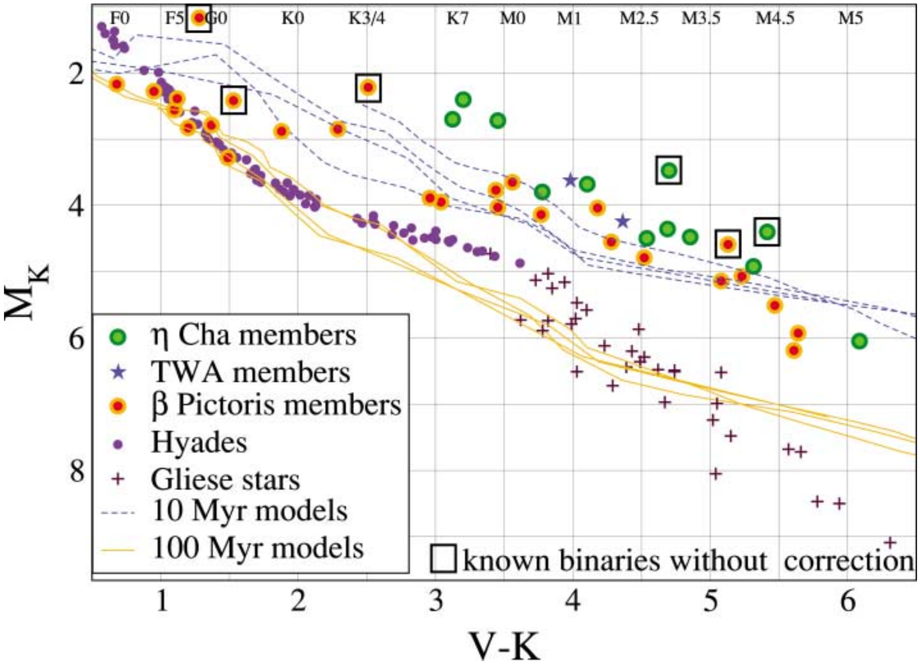

Figure 2 Absolute *K* magnitude versus $V - K$ color of main sequence and pre-main sequence stars. All plotted stars have Hipparcos measured distances. Isochrones from solar-metallicity evolutionary models from four research groups (see Song et al. 2003) are plotted at 10 and 100 Myr. To determine the location of old main sequence stars, 600-Myr-old Hyades members and late-type Gliese stars with well-determined distances are plotted (see figure 2 in Song et al. 2003 for additional details).

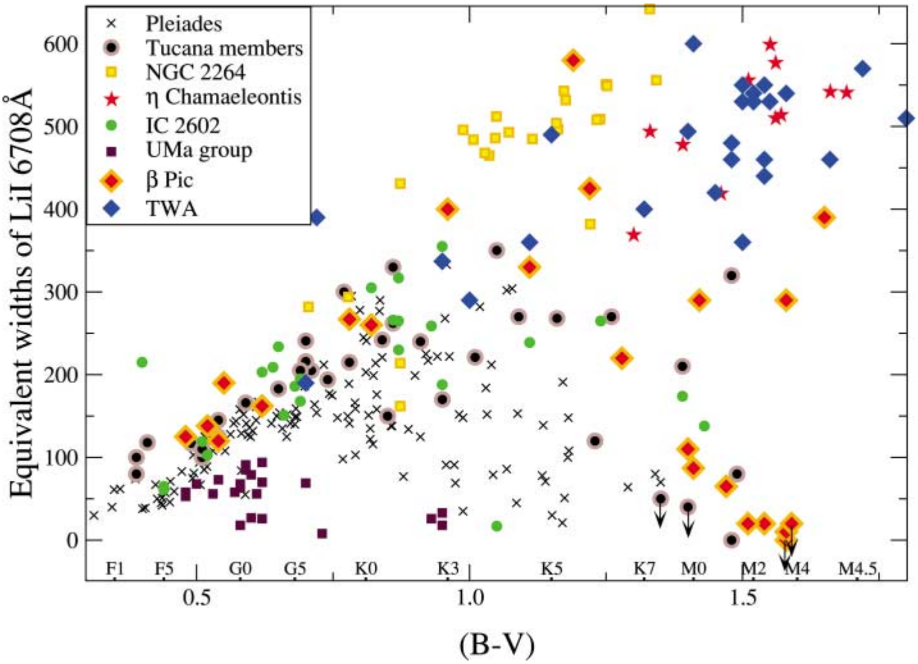

Figure 3 Equivalent width of Li I 6707.76 Å as a function of $B - V$. Displayed equivalent widths are not corrected for possible contamination by Fe I 6707.44 Å, and measurement uncertainty of equivalent widths is ~20 mÅ. Cluster ages are as follows: NGC 2264 (<5 Myr), IC 2602 (~30 Myr), Pleiades (~100 Myr). For ~M3 stars in the β Pic moving group lithium is burning in a timescale shorter than the ~12 Myr stellar age. For slightly later–type stars (M4.5) lithium is only partially burned. "Tucana members" refers to Table 3. GSC8497-0995 is the K6 Tucana star plotted with equivalent width = 120.

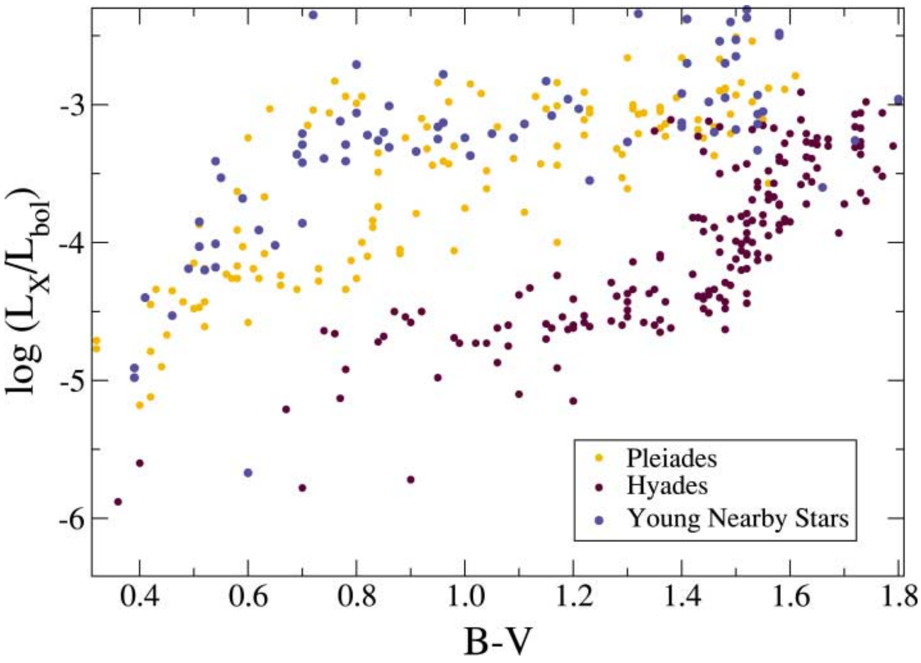

Figure 4 Ratio of X-ray to bolometric luminosity as a function of $B - V$. Young K- and M-type stars often have saturated X-ray activity ($L_x/L_{bol} \sim 10^{-3}$). The young star plotted at B-V = 1.23 and $L_x/L_{bol} = -3.56$ is GSC8497-0995 (see Table 3).

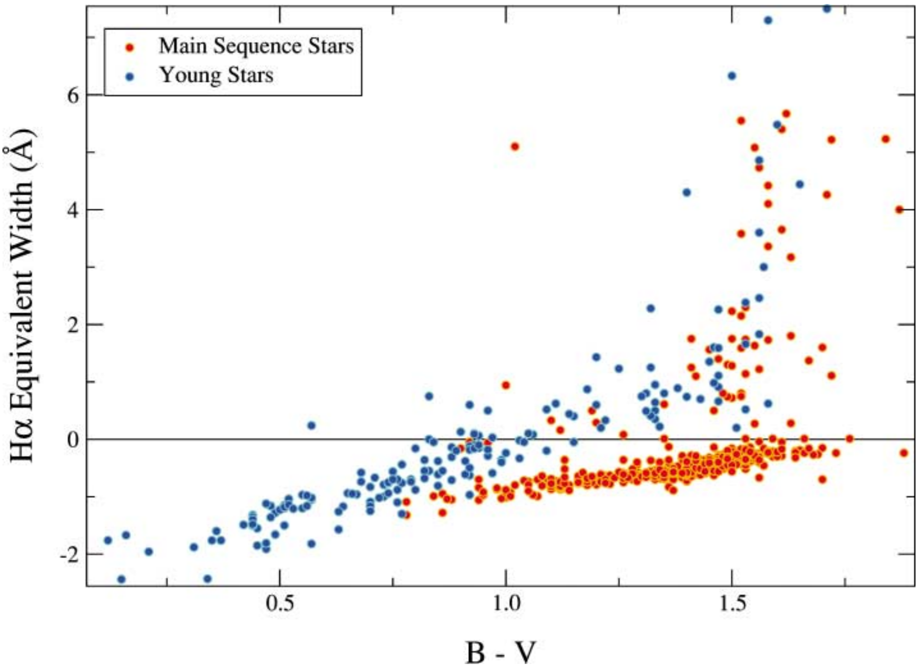

Figure 5 Hα equivalent width distribution of young stars (from Song et al. 2004b) and main sequence stars (from Panagi & Mathioudakis 1993).

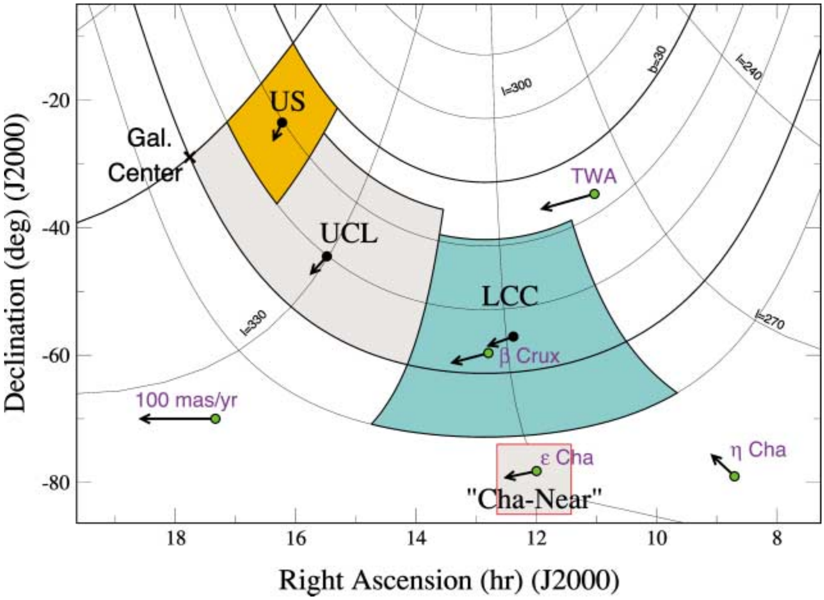

Figure 8 Young stellar associations in the deep Southern Hemiphere are plotted with their proper motion vectors.

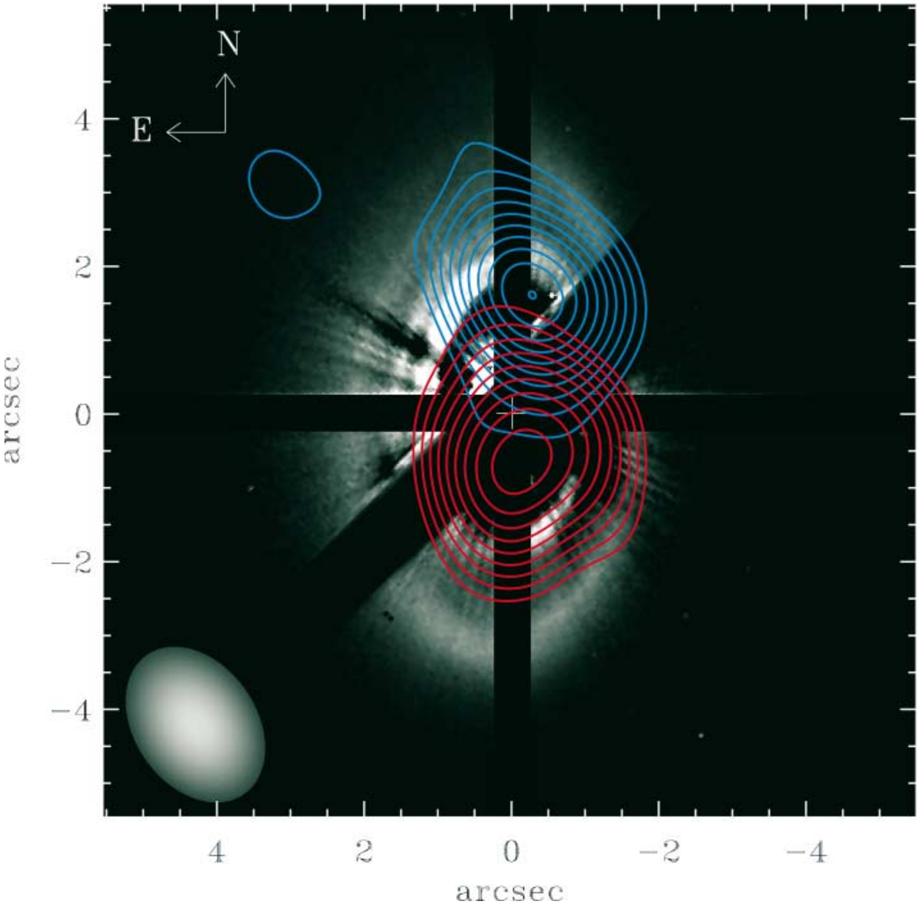

Figure 9 Map of ^{12}CO $J = 2 \rightarrow 1$ emission at HD 141569 obtained with the IRAM Plateau de Bure Interferometer overlayed on a coronagraphic image obtained with HST/STIS (Mouillet et al. 2001, Augereau et al. 2004). The blue and red contours are for $V_{\mathrm{helio}} = -5.27$ and -10.10 km/sec, respectively. The $2.''3 \times 1.''65$ IRAM beam size is indicated on the lower left corner. One arc second corresponds to 100 AU.

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Volume 42, 2004

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ERRATA

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