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Low Mass Star Formation in the Taurus-Auriga Clouds

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Abstract. We review the history and structure of star formation in the Taurus-Auriga dark clouds. Our discussion includes a summary of the macroscopic cloud properties, the population of single and binary pre-main sequence stars, the properties of jets and outflows, and detailed summaries of selected individual objects. We include comprehensive tables of dark clouds, young stars, and jets in the clouds.

1. Overview

In October 1852, J. R. Hind 'noticed a very small nebulous looking object' roughly $18''$ west of a tenth magnitude star in Taurus. Over the next 15 years, the nebula slowly faded in brightness and in 1868 vanished completely from the view of the largest telescopes. O. Struve then found a new, smaller and fainter, nebulosity roughly $4'$ west of Hind's nebula. While trying to recover these nebulae, Burnham (1890, 1894) discovered a small elliptical nebula surrounding T Tau (Figure 1). Spectra of Hind's nebula revealed emission from either Hβ or [O III] λ5007, demonstrating that the nebula was gaseous as in novae and planetary nebulae. At about the same time, Knott (1891) reported 4 magnitude variability in the 'ruddy' star associated with these nebulae, T Tauri.

Despite the long history of interpreting variable nebulae (e.g., Herschel 1802, 1811), these discoveries generated little widespread interest. Among others, Ceraski (1906), Leavitt (1907), and Locke (1918) identified the unusual long-period variables RW Aur, UY Aur, RY Tau, and UX Tau on photographic plates. During the compilation of the HD catalog, Fleming (1912) noted T Tauri as a long period variable with an Ma? spectral type. Adams & Pease (1915) and Sanford (1920) later recorded higher quality spectra showing bright emission lines from H I and iron. A 5 1/2 hr spectrum taken with the $100''$ reflector revealed many iron absorption lines, characteristic of late-type stars.

In the 1940's, A. Joy compiled the first lists of 'T Tauri stars,' irregular variable stars associated with dark or bright nebulosity, with F5-G5 spectral types and low luminosity (Joy 1945, 1949; Herbig 1962). Intense searches for other T Tauri stars revealed

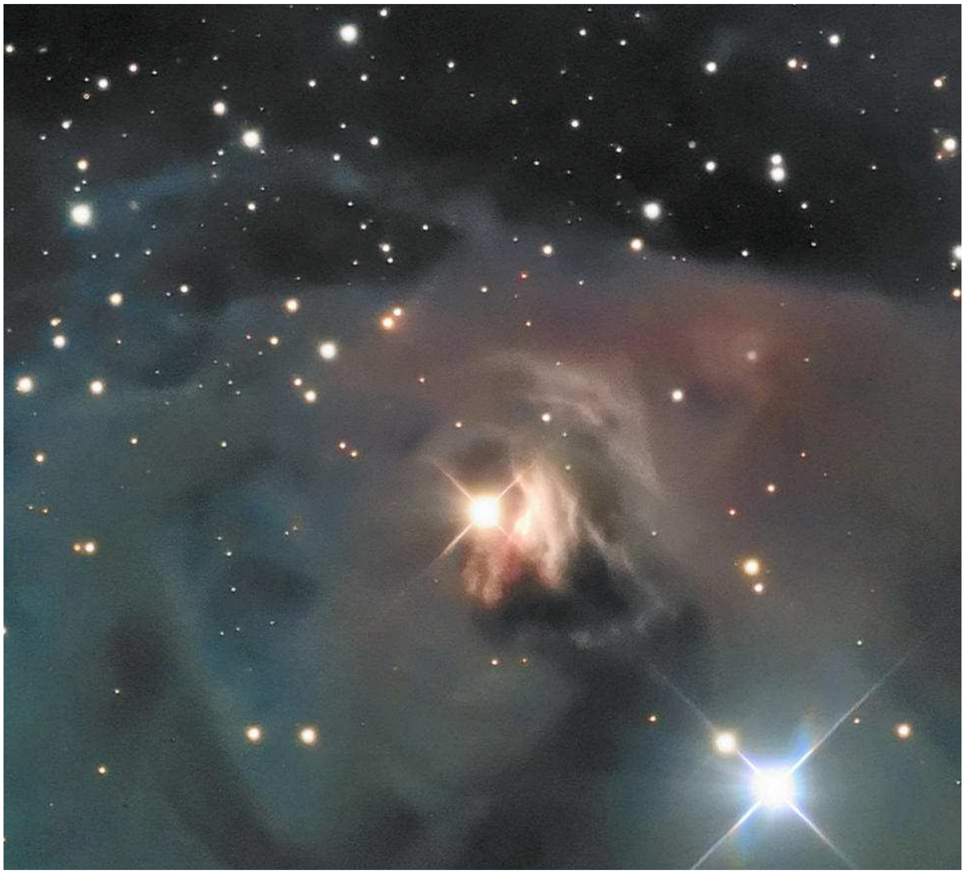

Figure 1. Optical image of T Tau and surroundings (courtesy D. Goldman). North is up and east is to the left. T Tau is the bright yellow star near the center. Barnard's nebula is visible as faint nebulosity immediately surrounding T Tau. Hind's nebula is the bright, arc-shaped cloud that covers some of the western pair of diffraction spikes from the T Tau image. Fainter nebulosity, mostly ionized gas powered by a weak ultraviolet radiation field, covers the rest of the image. Burnham (1894) and Barnard (1895) discuss the relationship between Burnham's nebula and the more distant Hind's and Struve's nebulae.

many stars associated with dark clouds and bright nebulae, including a class with A-type spectra (e.g. Herbig 1950a, 1960). Most of these stars were in loose groups, the T associations, or in dense clusters, the O associations (e.g., Herbig 1950b, 1957; Kholopov 1958; Dolidze & Arakelyan 1959). Because O stars have short lifetimes, both types of associations have to be composed of young stars, with ages of 10 Myr or less (Ambartsumian 1957). This realization – now 50 years old – initiated the study of star formation in dark clouds.

2. Cloud Structure

Shortly after the discovery of variability in T Tauri, Barnard began to photograph dark nebulae in the plane of the Milky Way (Barnard 1919, 1927). At the time Barnard

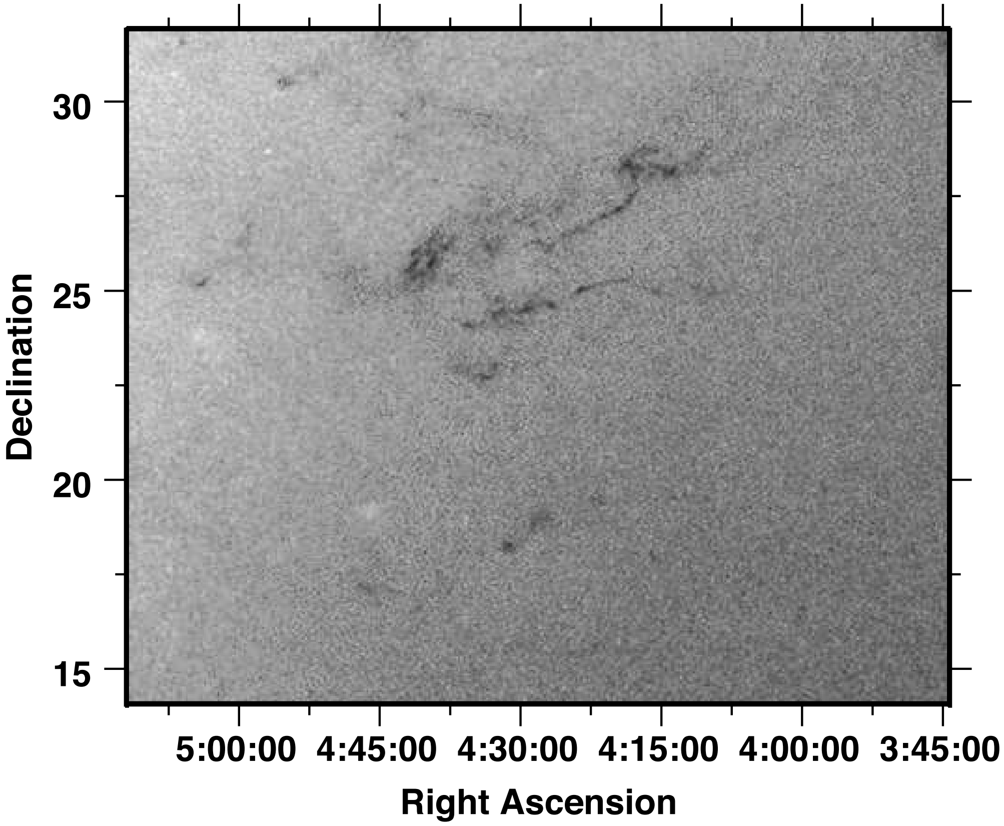

Figure 2. Star count map of the Taurus-Auriga dark clouds. This map was prepared for this paper from stars with J $\leq$ 16.5 in the 2MASS point source catalog downloaded from the IRSA archive. The intensity scale is proportional to the number of stars per square arcmin. The dark clouds are clearly visible as low density regions. Two small bright regions are the open clusters NGC 1647 (RA = $4^{h}46^{m}$, Dec = 19°) and NGC 1750/1758 (RA = $5^{h}04^{m}$, Dec = 24°).

began this program, it was still unclear whether dark nebulae were empty regions of the galaxy or patches of material that obscured background stars. These photographs showed convincingly that obscuring material is responsible for many dark clouds. In the B7 cloud, a partly luminous nebula 'seems to fit into a hole in the sky' (Barnard 1919). Barnard's photographs showed that many dark clouds were feebly nebulous, confirming impressions he gained from visual observations.

Barnard's first catalog of dark nebulae contains 182 objects. The Taurus-Auriga clouds comprise roughly a dozen of these dark regions and lie at a distance of 140–145 pc (Table 1; Elias 1978; Straižys & Meistas 1980; Meistas & Straižys 1981; Kenyon et al. 1994; Wichmann et al. 1998; Straižys et al. 2003; Loinard et al. 2005, 2007b; Torres et al. 2007). In B7, Barnard noted bright condensations and several small, round black spots with diameters of $5'$–$8'$. An irregular dark lane with a width of roughly $10'$ connects B7 to B22. He noted another dark lane arcing west of B18.

Deeper photographs and digital sky surveys provide the most dramatic images of the clouds (Figure 2; Table 2; Lynds 1962; Bok 1977; Dobashi et al. 2005). Barnard's

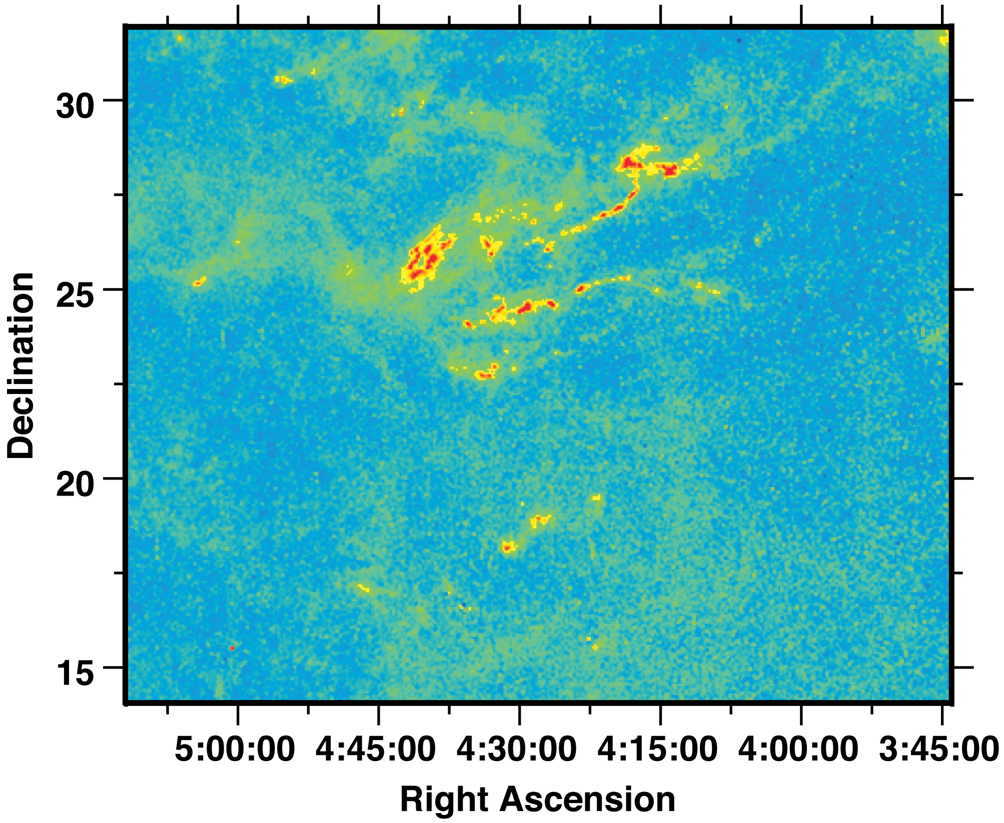

Figure 3. Map of the near-infrared color of stars in the Taurus-Auriga dark clouds. As in Figure 2, the map uses stars with J $\leq$ 16.5 from the 2MASS point source catalog. The intensity scale maps stars with J–H $<$ 0.5 into blue, stars with J–H = 0.5-1.25 into green, and stars with J-H $>$ 1.25 into red. The reddest stars lie in or behind the dark clouds. Other stars have neutral colors.

dark spots and sinuous dark lanes are clearly visible against the bright background of stars just south of the plane of the Milky Way. Ultraviolet images show a similar structure (Hurwitz 1994). Variations in the ultraviolet (UV) flux across the clouds and counts of stars in cells yield a good measure of the line-of-sight density in the cloud; counts in two or more colors allow estimates of the extinction (Straižys & Meistas 1980; Meistas & Straižys 1981; Cernicharo & Bachiller 1984; Cernicharo et al 1985; Cernicharo & Guélin 1987; Cambrésy 1999; Dobashi et al. 2005). Improved photometry from digital surveys like 2MASS and the digitized POSS (Dobashi et al. 2005) provide more quantitative estimates of the cloud density.

Stellar colors from 2MASS clearly demonstrate the two main features of dark clouds (Figure 3). Extinction by dust grains in the cloud reddens background stars (Trumpler 1930, 1934). In the optical, the ratio of total to selective extinction, $R_V = A_V/E_{B-V}$, where A_V is the visual extinction in magnitudes and E_{B-V} is the $B - V$ color excess, is a convenient way to compare the physical properties of dust grains among dark clouds (e.g., Cardelli et al. 1989; Mathis 1990). Most diffuse clouds have

Table 1. Barnard's Dark Nebulae in Taurus-Auriga

ID	α(2000)	δ(2000)	D ($'$)	ID	α(2000)	δ(2000)	D ($'$)
B7	4:17:25	+28:33		B209	4:12:23	+28:19	
B10	4:18:41	+28:16	8	B210	4:15:33	+25:03	
B14	4:39:59	+25:44	3	B211	4:17:12	+27:48	
B18	4:31:13	+24:21	60	B212	4:19:14	+25:18	
B19	4:33:00	+26:16	60	B213	4:21:10	+27:03	
B22	4:38:00	+26:03	120	B214	4:21:55	+28:32	5
B23	4:40:33	+29:52	5	B215	4:23:34	+25:02	
B24	4:42:53	+29:44	8	B216	4:23:59	+26:37	
B26	4:54:38	+30:37	5	B217	4:27:38	+26:07	
B27	4:55:08	+30:33	5	B218	4:28:09	+26:16	15
B28	4:55:52	+30:38	4	B219	4:34:00	+29:35	120
B29	5:06:23	+31:35	10	B220	4:41:30	+25:59	7
B207	4:04:35	+26:20		B221	4:44:00	+31:44	45
B208	4:11:32	+25:09		B222	5:08:23	+32:10	10

$R_V \approx$ 3.1; many dark clouds, including regions in Taurus-Auriga with $A_V > 3$, have $R_V \sim$ 3.5–5 (Cardelli et al. 1989; Mathis 1990; Whittet et al. 2001).

Figure 3 also shows that the reddest stars lie within the dark cloud. After correcting for extinction, many T Tauri stars have redder infrared (IR) colors than main sequence stars of similar spectral type (e.g., Mendoza 1966, 1968; Cohen 1973; Rydgren et al. 1976, 1982). These IR excesses demonstrate that the youngest stars are surrounded by dust grains with a large range in temperatures (Mendoza 1966, 1968; Glass & Penston 1974; Cohen & Kuhi 1979; Rydgren et al. 1982; Myers et al. 1987; Adams et al. 1987; Adams & Shu 1988; Kenyon & Hartmann 1987; Calvet et al. 1994; Kenyon & Hartmann 1995; Andrews & Williams 2005; Furlan et al. 2006). Images with *HST* and large ground-based optical/near-IR and radio telescopes reveal that this dust lies in a circumstellar disk or an infalling envelope (Burrows 1996; Lay et al. 1997; Dutrey et al. 1998; Duvert et al. 1998; Krist et al. 1998; Stapelfeldt et al. 1998a; Padgett et al. 1999; Monin & Bouvier 2000; Belloche et al. 2002; McCabe et al. 2002; Park & Kenyon 2002; Duchêne et al. 2003a; Schneider et al. 2003; Stapelfeldt et al. 2003; Krist et al. 2005; Kudo et al. 2008).

With no luminous O or B stars, the Taurus-Auriga dark clouds are mostly neutral and contain large amounts, 3–4 $\times$ 10^4 $M_\odot$, of molecular gas. Comprehensive surveys in ^{12}C^{16}O, ^{13}C^{16}O, and OH confirm the filamentary structure observed in the optical and near-IR (Duvert et al. 1986; Ungerechts & Thaddeus 1987; Kramer & Winnewisser 1991; Zhou et al. 1994; Abergel et al. 1994; Abergel et al. 1995; Onishi et al. 1996, 1998, 2002; Blitz & Williams 1997; Codella et al. 1997; Juvela et al. 1997; Goldsmith et al. 2008; Narayanan et al. 2008). Within these structures, the radio observations reveal dense clumps and cores of molecular gas with masses of 1–100 $M_\odot$. The higher density tracers ^{12}C^{17}O, ^{12}C^{18}O, CS, and NH$_3$ reveal structure within the cores, including evidence for turbulence on small scales (Benson et al. 1984; Benson & Myers 1989; Hayashi et al. 1994; Jijina et al. 1999).

Multiwavelength observations probe structure on the smallest scales within the Taurus-Auriga clouds. High angular resolution radio observations of molecular cloud cores detect infalling material and show that this gas is distinct from lower density gas

Table 2. Lynds' Dark Nebulae in Taurus-Auriga[1]

L	α(2000)	δ(2000)	l (deg)	b (deg)	Area (deg^2)	Opac[2]	Barnard[3]	TGU[4]
1484	4:03.1	29:08	165.72	−17.40	0.445	1		1121
1486	4:08.1	29:07	166.55	−16.64	0.480	1		1211
1489	4:04.7	26:28	167.96	−19.05	0.027	5		1144
1491	4:04.6	26:17	168.08	−19.20	0.004	5		1144
1495	4:18.1	27:37	169.27	−16.13	2.600	5	7,10,211,209,216	1211
1496	4:43.2	32:05	169.58	−09.08	0.710	3		1157
1497	4:27.1	28:36	169.92	−13.99	0.725	2		1158
1498	4:11.0	24:57	170.14	−19.11	0.118	5		1155
1499	4:10.5	24:47	170.18	−19.30	0.072	3		1155
1500	4:33.1	29:26	170.19	−12.46	0.972	3	219	1158
1501	4:15.0	25:07	170.68	−18.34	1.200	2		1180
1503	4:40.4	29:55	170.85	−10.95	0.008	5	23	1169
1504	4:41.2	29:55	170.97	−10.82	0.336	1		1169
1506	4:20.0	25:17	171.37	−17.40	0.334	6		1180
1507	4:43.2	29:45	171.38	−10.60	0.090	5	24	1169
1508	4:41.1	29:05	171.62	−11.36	0.183	3		1169
1511	4:20.0	24:47	171.75	−17.74	0.300	3		1173
1513	4:52.2	30:49	171.79	−08.41	0.057	4		1187
1514	4:42.6	29:05	171.83	−11.11	0.050	4		1169
1515	4:53.2	30:54	171.87	−08.19	0.147	3		1187
1517	4:55.2	30:34	172.40	−08.06	0.051	6	28,27,26	1187
1519	4:55.7	30:34	172.47	−07.98	0.063	4		1187
1520	4:44.1	28:25	172.57	−11.29	0.398	1		1190
1521	4:33.1	26:06	172.76	−14.66	4.100	4	22,19,14,220	1211
1522	5:07.2	32:03	172.79	−05.11	0.018	4	222	1193
1523	5:06.2	31:43	172.92	−05.48	0.017	6	29	1193
1524	4:28.0	24:36	173.16	−16.50	0.324	5	215,212,210	1198
1527	4:39.1	26:15	173.53	−13.53	0.010	6		1211
1528	4:37.1	25:46	173.63	−14.20	2.000	3		1211
1529	4:32.0	24:26	173.91	−15.92	0.223	5	18	1198
1531	4:32.0	24:19	174.00	−16.00	0.014	3		1198
1532	4:40.1	25:45	174.08	−13.68	0.112	4		1211
1533	4:36.2	24:55	174.18	−14.88	0.011	5		1210
1534	4:40.1	25:35	174.21	−13.79	0.870	5		1211
1535	4:35.5	23:54	174.87	−15.66	0.111	6		1198
1536	4:33.0	23:06	175.12	−16.62	1.500	4		1227
1537	4:51.1	26:25	175.15	−11.34	0.382	3		1211
1538	4:46.1	25:05	175.49	−13.06	3.000	4		1211
1539	4:56.1	26:34	175.72	−10.36	2.230	1		1228
1540	5:01.1	26:09	176.75	−09.73	0.282	4		1247
1541	4:44.0	22:45	177.07	−14.88	0.352	1		. . .
1542	5:01.1	25:34	177.22	−10.08	0.626	3		1247
1543	4:27.4	18:51	177.66	−20.35	0.090	5		1246
1544	5:04.1	25:14	177.91	−09.74	0.109	6		1247
1545	5:15.3	26:43	178.18	−06.82	0.052	3		1253
1546	4:28.9	18:26	178.25	−20.34	0.370	4		1246
1547	5:16.1	26:23	178.55	−06.86	0.049	5		1253
1548	5:16.1	26:13	178.69	−06.96	0.061	4		1253
1549	5:17.1	26:13	178.82	−06.78	0.079	4		1253
1551	4:31.4	18:06	178.92	−20.10	0.043	6		1246
1556	4:37.4	16:55	180.85	−19.71	0.050	5		1277
1558	4:45.9	17:05	182.02	−18.00	0.713	2		1295

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[1] This table is based on an updated version of the published catalog downloaded from the CDS.

[2] Opacity class from Lynds (1962)

[3] Barnard dark nebulae from Table 1.

[4] Dobashi et al. (2005) high resolution identification from the association file named 'hassoc.dat' and visual examination of Figure 18–5–6, which plots Lynds' IDs on the extinction maps.

in the molecular outflow (Ohashi et al. 1991; Barsony & Chandler 1993; Ohashi et al. 1996, 1997a,b; Chandler & Richer 2000; Hogerheijde & Sandell 2000; Hogerheijde 2001). In some cases, radio observations detect the orbital rotation of material in the disk surrounding the protostar (e.g., Sargent & Beckwith 1991; Kawabe et al. 1993; Terebey et al. 1993; Hayashi et al. 1993; Guilloteau & Dutrey 1994; Koerner & Sargent 1995; Mundy et al. 1996; Wilner et al. 1996; André et al. 1999; Belloche et al. 2002). In cores with young protostars, near-IR and optical imaging and polarimetric imaging reveal the structure of the disk and inner envelope, along with beautiful, often bipolar, reflection nebulae at the interface between the infalling gas and the bipolar outflow (Tamura et al. 1991; Kenyon et al. 1993b; Lucas & Roche 1996, 1997, 1998; Wood et al. 1996, 1998, 2001, 2002; Whitney et al. 1997; Hartmann et al. 1999; Padgett et al. 1999; Cotera et al. 2001).

Radio observations also probe the densest parts of the Taurus-Auriga clouds. In TMC-1/L1534, for example, high densities provide a good laboratory for the production of complex organic and inorganic molecules. In the last 25 years, detections of C_3O (Brown et al. 1985), HCN (Irvine & Schloerb 1984), HC_3N (Irvine & Schloerb 1984), HC_5N (Takano et al. 1990), $HC_{11}N$ (Bell & Matthews 1985), HCCNC (Kawaguchi et al. 1992), CH_2CN (Irvine et al. 1988), CH_3CN (Minh et al. 1993), H_2C_6 (Langer et al. 1997), C_3H_2 (Fossé et al. 2001), HDCS (Minowa et al. 1997; Kaifu et al. 2004), C_8H^- (Brünken et al. 2007), and other molecules show that cloud cores have a rich chemistry prior to the formation of circumstellar disks and planets.

Ices are an important part of dark cloud chemistry. Measurements of the absorption along the line-of-sight to field stars behind the dark cloud yields measures of ice abundances and an insight into the formation and evolution of grains and complex molecules within the cloud (Boogert et al. 2002; van Dishoeck 2004; Zasowski et al. 2007). In Taurus-Auriga, detections of H_2O (Whittet et al. 1988; Baratta & Strazzulla 1990; Smith et al. 1993) and CO_2 (Whittet et al. 2001; Bergin et al. 2005) show that water ice is the dominant constituent, with CO_2 roughly 25% as abundant as water ice. These observations demonstrate that there is an extinction threshold for ice absorption within dark clouds. The threshold varies from cloud to cloud, with $A_V \sim 3$ mag in Taurus-Auriga (Whittet et al. 1988) and $A_V \sim 12$ mag in Ophiuchus (Tanaka et al. 1990). Some observations show that the ice absorption varies along the line-of-sight to stars within the cloud, implying that the chemistry close to pre-main sequence stars is different than along more quiescent sightlines (Leinert et al. 2001).

3. Pre-Main Sequence Population

The Taurus-Auriga clouds have a rich population of pre-main sequence stars. Most T Tauri stars discovered before the 1980s are bright optical variables with G, K, or M spectral types and strong H I and Ca II emission lines (Joy 1945, 1949). In the last two decades, X-ray (Walter et al. 1987, 1988; Neuhäuser et al. 1995; Güdel et al. 2007a,b,c; Scelsi et al. 2007), optical (Herbig et al. 1986; Gómez et al. 1992, 1993; Briceño et al. 1993, 1997; Güdel et al. 2007a; Luhman 2006; Slesnick et al. 2006), near-IR (Gómez et al. 1994; Luhman & Rieke 1998; Luhman 2000, 2006; Luhman et al. 2006; Güdel et al. 2007a), far-IR (Beichman et al. 1986; Harris et al. 1988; Kenyon et al. 1990; Beichman et al. 1992; Güdel et al. 2007a), and radio (Bieging & Cohen 1985) surveys revealed three populations of young stars (Figure 4; Lada 1987; Adams et al. 1987; Adams & Shu 1988). Embedded sources, sometimes known as

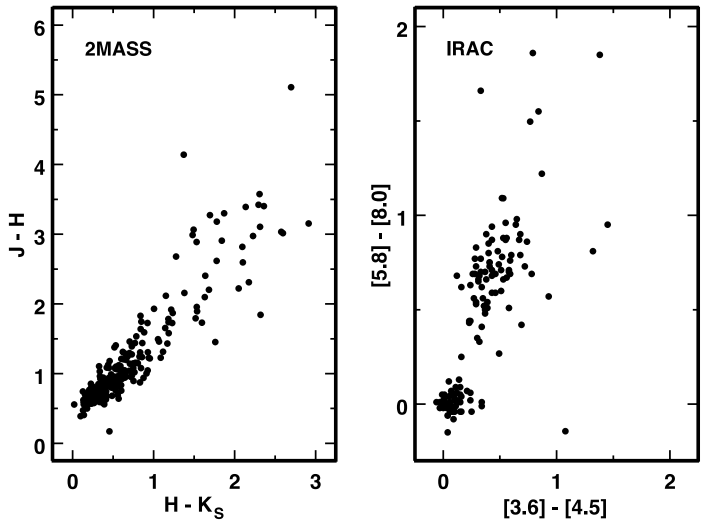

Figure 4. Infrared colors for Taurus-Auriga pre-main sequence stars. Left panel: data from the 2MASS all-sky survey; right panel: data from the IRAC camera on *Spitzer* (Luhman et al. 2006). Weak emission T Tauri stars have $H - K_s < 0.4$ and lie in a clump at $[3.6] - [4.5] \approx [5.8] - [8.0] \approx 0$ in the IRAC color-color plot. Classical T Tauri stars have $H - K_s <$ 1–1.5 and fall in a band with $[3.6] - [4.5]$ $\approx$ 0.5–1.0 and $[5.8] - [8.0] \approx$ 0.25–0.75. Embedded protostars have $H - K_s >$ 1.25–1.5, $[3.6] - [4.5] \geq 1$ and $[5.8] - [8.0] \geq 1$.

protostars, are optically invisible young stars with spectral energy distributions (SEDs) that peak at mid-IR to far-IR wavelengths. Classical T Tauri stars have strong emission lines and substantial IR or UV excesses. Weak emission T Tauri stars have weak or no emission lines and negligible excesses. These objects form a rough age sequence with protostars as the youngest stars and weak emission T Tauri stars as the oldest. Table 3 lists the current sample of young stars and brown dwarfs in Taurus-Auriga, using data for coordinates and photometry from the 2MASS all-sky survey (Nikolaev et al. 2000; Skrutskie et al. 2006), the USNO 1B atlas (Monet et al. 2003), and data from Cohen & Kuhi (1979), Beichman et al. (1986, 1992), Adams et al. (1990), Beckwith et al. (1990), Kenyon et al. (1990, 1993a, 1993b, 1994b, 1998), Gómez et al. (1992, 1993, 1994), Briceño et al. (1993, 1997, 1998, 1999, 2002), Kenyon & Hartmann (1995), Neuhäuser et al. (1995),Wichmann et al. (1996), Luhman & Rieke (1998), Bertout et al. (1999), Luhman (2000, 2004), Luhman et al. (2003, 2006), and Guieu et al. (2005, 2006).

The surface density of pre-main sequence stars closely follows the contours of the dark clouds. In the central portion of Taurus-Auriga (Figure 5), most pre-main sequence stars lie within the darkest clouds, B7/L1495 to the NW, B18, and B22. Other stars are projected along the narrow dark lanes that connect the larger clouds. A few stars are sprinkled at random across the cloud. Because they are often older, weak emission T Tauri stars are less concentrated in the dark cloud than classical T Tauri stars. Embedded protostars are most closely associated with cloud material.

Table 3.: Pre-main sequence stars in Taurus- Auriga

PMS	α(2000)	δ(2000)	B	R	K	PMS	α(2000)	δ(2000)	B	R	K
HBC 351	3:52:02.23	24:39:47.9	12.57	10.83	9.07	J04152409+2910434	4:15:24.10	29:10:43.5		18.95	12.36
HBC 352	3:54:29.50	32:03:01.3	10.56	10.70	9.58	J04153916+2818586	4:15:39.16	28:18:58.6	17.58	14.77	9.24
HBC 353	3:54:30.17	32:03:04.3			9.86	J04155799+2746175	4:15:57.99	27:46:17.5	18.60	16.80	10.52
HBC 354	3:54:35.56	25:37:11.1	12.79	11.23	11.10	J04161210+2756385	4:16:12.10	27:56:38.5	19.89	17.65	10.34
HBC 355	3:54:35.97	25:37:08.1	12.79	11.23	10.21	J04161885+2752155	4:16:18.86	27:52:15.5	20.58	18.64	11.35
HBC 356	4:03:13.95	25:52:59.7	13.95	12.35	10.16	LkCa 4	4:16:28.10	28:07:35.8	14.49	11.71	8.32
HBC 357	4:03:13.95	25:52:59.7	13.95	12.35	10.16	J04163048+3037053	4:16:30.48	30:37:05.3	19.88	18.06	12.62
HBC 358	4:03:49.30	26:10:52.0	15.57	13.50	9.46	J04163911+2858491	4:16:39.12	28:58:49.1	20.35	18.73	11.28
XEST06-006	4:03:49.97	26:20:38.2	20.36	17.83	12.34	CY Tau	4:17:33.72	28:20:46.8	15.15	12.50	8.60
HBC 359	4:03:50.84	26:10:53.1	15.10	13.12	9.53	LkCa 5	4:17:38.93	28:33:00.5	15.59	12.70	9.05
HBC 360	4:04:39.36	21:58:18.6	13.97	12.46	9.97	KPNO-10	4:17:49.55	28:13:31.8	18.36	16.14	10.79
HBC 361	4:04:39.84	21:58:21.5	0.00	12.70	10.10	V410 X-ray 1	4:17:49.65	28:29:36.2	17.26	14.22	9.08
IRAS04016+2610	4:04:43.22	26:18:54.5	20.35	16.50	9.84	V410 X-ray 3	4:18:07.96	28:26:03.6	19.62	16.92	10.45
HBC 362	4:05:30.87	21:51:10.6	14.73	13.43	10.06	J04181078+2519574	4:18:10.78	25:19:57.4	15.92	12.26	9.03
J04080782+2807280	4:08:07.82	28:07:28.1	18.32	14.97	11.39	V410 Anon 13	4:18:17.10	28:28:41.9	0.00	18.95	10.96
J04124858+2749563	4:12:48.58	27:49:56.3	17.21	15.97	11.68	HBC 372	4:18:21.47	16:58:47.0	14.32	13.50	10.46
LkCa 1	4:13:14.14	28:19:10.8	15.74	12.84	8.62	V410 Anon 24	4:18:22.39	28:24:37.5			10.73
Anon1	4:13:27.22	28:16:24.7	15.03	12.06	7.79	V410 Anon 25	4:18:29.09	28:26:19.1			9.94
IRAS04108+2803 A	4:13:53.28	28:11:23.3			10.37	KPNO-11	4:18:30.30	27:43:20.8	18.52	16.30	11.01
IRAS04108+2803 B	4:13:54.71	28:11:32.8			11.06	V410 Tau A	4:18:31.10	28:27:16.2	11.48	9.88	7.63
IRAS04108+2910	4:13:57.37	29:18:19.3	17.44	14.43	9.36	V410 Tau B	4:18:31.10	28:27:16.2	11.48	9.88	7.63
J04141188+2811535	4:14:11.88	28:11:53.5	18.47	17.36	11.64	V410 Tau C	4:18:31.10	28:27:16.2	11.48	9.88	7.63
V773 Tau A	4:14:12.91	28:12:12.4	11.39	9.97	6.21	DD Tau A	4:18:31.12	28:16:29.0	15.67	13.40	7.88
V773 Tau B	4:14:12.91	28:12:12.4	11.39	9.97	6.21	DD Tau B	4:18:31.12	28:16:29.0	15.67	13.40	7.88
FM Tau	4:14:13.58	28:12:49.2	15.57	13.14	8.76	CZ Tau A	4:18:31.58	28:16:58.5	16.27	14.50	9.36
FN Tau	4:14:14.58	28:27:58.0	16.30	13.48	8.19	CZ Tau B	4:18:31.58	28:16:58.5	16.27	14.50	9.36
CW Tau	4:14:17.00	28:10:57.8	14.84	11.75	7.13	IRAS04154+2823	4:18:32.03	28:31:15.3			10.27
CIDA-1	4:14:17.60	28:06:09.6	18.15	15.86	9.88	V410 X-ray 2	4:18:34.44	28:30:30.2			9.22
IRAS04113+2758	4:14:26.26	28:06:03.2	21.36	18.91	7.78	V410 X-ray 4	4:18:40.23	28:24:24.5			9.69
MHO2	4:14:26.40	28:05:59.7	21.36	18.91	7.80	V892 Tau	4:18:40.61	28:19:15.5	16.60	13.96	5.79
MHO3	4:14:30.55	28:05:14.7	20.24	16.84	8.24	LR1	4:18:41.33	28:27:25.0			11.05
FP Tau	4:14:47.30	26:46:26.4	14.81	12.13	8.87	V410 X-ray 7	4:18:42.50	28:18:49.8	0.00	18.49	9.26
XEST20-066	4:14:47.39	28:03:05.5	17.33	15.09	9.92	V410 Anon 20	4:18:45.05	28:20:52.8			11.93
CX Tau	4:14:47.86	26:48:11.0	15.18	12.63	8.81	Hubble4	4:18:47.03	28:20:07.3	13.34	11.93	7.29

Table 3.: Pre-main sequence stars in Taurus- Auriga (continued)

PMS	$\alpha(2000)$	$\delta(2000)$	B	R	K
LkCa 3 A	4:14:47.97	27:52:34.6	13.98	11.35	7.42
LkCa 3 B	4:14:47.97	27:52:34.6	13.98	11.35	7.42
FO Tau A	4:14:49.28	28:12:30.5	16.97	13.79	8.12
FO Tau B	4:14:49.28	28:12:30.5	16.97	13.79	8.12
CIDA-2	4:15:05.15	28:08:46.2	17.12	14.52	9.09
KPNO-1	4:15:14.71	28:00:09.6			13.77
V410 X-ray 5a	4:19:01.97	28:22:33.2	21.28	18.48	10.15
FQ Tau A	4:19:12.81	28:29:33.0	16.81	14.33	9.31
FQ Tau B	4:19:12.81	28:29:33.0	16.81	14.33	9.31
BP Tau	4:19:15.83	29:06:26.9	13.00	13.38	7.74
V819 Tau	4:19:26.25	28:26:14.2	15.26	12.01	8.42
FR Tau	4:19:35.45	28:27:21.8	17.26	14.84	9.97
LkCa 7 A	4:19:41.27	27:49:48.4	14.23	11.76	8.26
LkCa 7 B	4:19:41.27	27:49:48.4	14.23	11.76	8.26
IRAS04166+2706	4:19:41.48	27:16:07.0			11.54
IRAS04169+2702	4:19:58.44	27:09:57.0			11.58
J04201611+2821325	4:20:16.11	28:21:32.5	20.56	18.42	12.55
J04202555+2700355	4:20:25.55	27:00:35.5	20.55	18.75	11.51
J04202583+2819237	4:20:25.83	28:19:23.7	20.40	18.02	11.72
J04202606+2804089	4:20:26.06	28:04:08.9	16.41	13.90	9.70
XEST16-045	4:20:39.18	27:17:31.7	18.15	16.22	9.56
J2-157	4:20:52.73	17:46:41.5	17.12	15.52	10.78
CFHT-19	4:21:07.95	27:02:20.4	0.00	18.85	10.54
J04210934+2750368	4:21:09.34	27:50:36.8	17.77	15.55	10.36
IRAS04181+2654 B	4:21:10.38	27:01:37.2			11.09
IRAS04181+2655	4:21:10.90	27:02:06.0			
IRAS04181+2654 A	4:21:11.46	27:01:09.4			10.34
J04213459+2701388	4:21:34.59	27:01:38.8	20.46	17.32	10.44
XEST21-026	4:21:40.13	28:14:22.4	18.15	16.22	11.03
IRAS04187+1927	4:21:43.23	19:34:13.3	16.99	14.86	8.02
CFHT-10	4:21:46.31	26:59:29.6			12.31
J04215450+2652315	4:21:54.51	26:52:31.5			13.90
DE Tau	4:21:55.63	27:55:06.0	14.98	11.89	7.80
RY Tau	4:21:57.40	28:26:35.5	10.73	9.62	5.39
KPNO-2	4:18:51.15	28:14:33.2	0.00	18.95	12.75
CoKu Tau/1	4:18:51.47	28:20:26.4	19.56	16.06	10.97
HBC 376	4:18:51.70	17:23:16.5	12.91	11.41	9.27
IRAS04158+2805	4:18:58.13	28:12:23.4	20.02	17.94	11.18
V410 X-ray 6	4:19:01.10	28:19:42.0	18.95	16.50	9.13
KPNO-12	4:19:01.26	28:02:48.7			14.93
XEST11-087	4:22:24.04	26:46:25.8	18.71	15.91	9.77
IRAS04196+2638	4:22:47.86	26:45:53.0	19.56	16.10	9.29
J04230607+2801194	4:23:06.07	28:01:19.4	20.20	16.98	11.20
IRAS04200+2759	4:23:07.76	28:05:57.3	17.71	16.66	10.41
J04231822+2641156	4:23:18.22	26:41:15.6	19.58	19.34	10.18
FU Tau	4:23:35.39	25:03:02.6	19.10	16.70	9.32
FT Tau	4:23:39.19	24:56:14.1	15.72	12.65	8.60
J04242090+2630511	4:24:20.90	26:30:51.1	20.34	18.73	12.43
CFHT-9	4:24:26.46	26:49:50.3	20.59	18.30	11.76
IRAS04216+2603	4:24:44.57	26:10:14.1	18.33	15.46	9.05
J1-4423	4:24:45.06	27:01:44.7	17.62	15.16	10.46
IP Tau	4:24:57.08	27:11:56.5	14.11	12.29	8.35
J1-4872 A	4:25:17.67	26:17:50.4	15.13	12.42	8.54
J1-4872 B	4:25:17.67	26:17:50.4	15.13	12.42	8.54
KPNO-3	4:26:29.39	26:24:13.7	19.89	19.02	12.08
FV Tau A	4:26:53.52	26:06:54.3	17.47	14.00	7.44
FV Tau B	4:26:53.52	26:06:54.3	17.47	14.00	7.44
FV Tau/c A	4:26:54.40	26:06:51.0	18.69	15.46	8.87
FV Tau/c B	4:26:54.40	26:06:51.0	18.69	15.46	8.87
IRAS04239+2436	4:26:56.29	24:43:35.3			9.99
KPNO-13	4:26:57.33	26:06:28.4	19.78	16.64	9.58
DG Tau B	4:27:02.66	26:05:30.4		19.39	
DF Tau A	4:27:02.80	25:42:22.3	12.96	13.34	6.73
DF Tau B	4:27:02.80	25:42:22.3	12.96	13.34	6.73
DG Tau	4:27:04.69	26:06:16.3	10.13	8.97	6.99
KPNO-4	4:27:27.99	26:12:05.2		19.70	13.28
CFHT-15	4:27:45.38	23:57:24.3			13.69
IRAS04248+2612	4:27:57.30	26:19:18.3	20.58	15.73	11.03

Table 3.: Pre-main sequence stars in Taurus- Auriga (continued)

PMS	$\alpha(2000)$	$\delta(2000)$	B	R	K	PMS	$\alpha(2000)$	$\delta(2000)$	B	R	K
HD283572	4:21:58.84	28:18:06.6	9.44	8.56	6.87	J04284263+2714039	4:28:42.63	27:14:03.9	17.51	16.81	10.46
T TauN	4:21:59.43	19:32:06.3	10.47	9.19	5.33	J04290068+2755033	4:29:00.68	27:55:03.3			12.85
T TauS	4:21:59.43	19:32:06.3	10.47	9.19	5.33	IRAS04260+2642	4:29:04.98	26:49:07.3	19.97	18.46	11.88
IRAS04191+1523	4:22:00.10	15:30:21.3			12.26	J1-507	4:29:20.71	26:33:40.6	16.08	13.56	8.79
H6-5 B	4:22:00.69	26:57:32.4			11.75	IRAS04263+2654	4:29:21.65	27:01:25.9		17.96	8.72
FS Tau A	4:22:02.17	26:57:30.4	13.78	11.33	8.18	GV Tau A	4:29:23.73	24:33:00.2	17.62	13.13	8.05
FS Tau B	4:22:02.17	26:57:30.4	13.78	11.33	8.18	GV Tau B	4:29:23.73	24:33:00.2	17.62	13.13	8.05
LkCa 21	4:22:03.13	28:25:38.9	15.32	12.45	8.45	IRAS04263+2426	4:29:24.11	24:32:57.7	20.54	15.36	10.57
J04221332+1934392	4:22:13.32	19:34:39.2	19.86	19.34	11.53	FW Tau C	4:29:29.71	26:16:53.2	17.47	14.65	9.39
XEST11-078	4:22:15.68	26:57:06.0	20.18	17.16	12.03	FW Tau A	4:29:29.71	26:16:53.2	17.47	14.65	9.39
CFHT-14	4:22:16.44	25:49:11.8	20.49	19.07	11.94	FW Tau B	4:29:29.71	26:16:53.2	17.47	14.65	9.39
CFHT-21	4:22:16.76	26:54:57.1	19.36	15.61	9.00	IRAS04264+2433	4:29:30.08	24:39:55.0		18.42	11.13
J04293606+2435556	4:29:36.06	24:35:55.6	18.32	16.17	8.66	J04320329+2528078	4:32:03.29	25:28:07.8	19.71	16.84	10.72
DH Tau A	4:29:41.55	26:32:58.2	14.96	12.09	8.18	L1551-51	4:32:09.27	17:57:22.8	13.83	11.13	12.15
DH Tau B	4:29:41.55	26:32:58.2	14.96	12.09	8.18	V827 Tau	4:32:14.56	18:20:14.7	14.35	11.39	8.23
DI Tau A	4:29:42.47	26:32:49.3	14.12	0.00	8.39	Haro 6-13	4:32:15.40	24:28:59.7	18.86	14.85	8.10
DI Tau B	4:29:42.47	26:32:49.3	14.12	0.00	8.39	V826 Tau A	4:32:15.83	18:01:38.7	14.23	11.28	8.25
KPNO-5	4:29:45.68	26:30:46.8	20.56	18.68	11.54	V826 Tau B	4:32:15.83	18:01:38.7	14.23	11.28	8.25
IQ Tau	4:29:51.56	26:06:44.8	15.60	12.14	7.78	MHO5	4:32:16.02	18:12:46.4	18.95	16.36	10.06
CFHT-20	4:29:59.50	24:33:07.8	20.52	17.15	9.81	CFHT-7	4:32:17.86	24:22:14.9	19.99	16.73	10.38
UX Tau C	4:30:03.99	18:13:49.3	12.04	10.30	7.55	V928 Tau A	4:32:18.85	24:22:27.1	15.59	12.87	8.11
UX Tau B	4:30:03.99	18:13:49.3	12.04	10.30	7.55	V928 Tau B	4:32:18.85	24:22:27.1	15.59	12.87	8.11
UX Tau A	4:30:03.99	18:13:49.3	12.04	10.30	7.55	MHO6	4:32:22.10	18:27:42.6	17.00	15.30	10.65
KPNO-6	4:30:07.24	26:08:20.7	0.00	19.42	13.69	J04322329+2403013	4:32:23.29	24:03:01.3	21.15	18.35	11.33
CFHT-16	4:30:23.65	23:59:12.9	18.14	15.37	13.70	J04322415+2251083	4:32:24.15	22:51:08.3	18.75	15.95	10.53
FX Tau A	4:30:29.61	24:26:45.0	15.01	12.71	7.92	MHO7	4:32:26.27	18:27:52.1	18.06	15.96	10.17
FX Tau B	4:30:29.61	24:26:45.0	15.01	12.71	7.92	GG Tau Ba	4:32:30.28	17:31:30.3			9.97
DK Tau A	4:30:44.25	26:01:24.4	14.17	11.08	7.10	GG Tau Bb	4:32:30.28	17:31:30.3			9.97
DK Tau B	4:30:44.25	26:01:24.4	14.17	11.08	7.10	GG Tau Aa	4:32:30.34	17:31:40.6	12.64	11.80	7.36
IRAS04278+2253	4:30:50.28	23:00:08.8	17.08	14.18	5.86	GG Tau Ab	4:32:30.34	17:31:40.6	12.64	11.80	7.36
ZZ Tau	4:30:51.37	24:42:22.2	15.82	13.31	8.44	FY Tau	4:32:30.58	24:19:57.2	17.37	13.79	8.05
ZZ Tau IRS	4:30:51.71	24:41:47.5	18.59	16.28	10.31	FZ Tau	4:32:31.76	24:20:02.9	17.11	13.85	7.35
KPNO-7	4:30:57.18	25:56:39.4	0.00	19.28	13.27	IRAS04295+2251	4:32:32.05	22:57:26.6	0.00	20.18	10.14
JH56	4:31:14.44	27:10:17.9	13.77	12.20	8.79	UZ Tau Ba	4:32:42.82	25:52:31.4	13.41	11.37	7.47

Table 3.: Pre-main sequence stars in Taurus- Auriga (continued)

PMS	α(2000)	δ(2000)	B	R	K
MHO9	4:31:15.94	18:20:07.2	17.66	15.16	10.30
J04311907+2335047	4:31:19.07	23:35:04.7		19.43	12.20
V927 Tau A	4:31:23.82	24:10:52.9	16.12	13.78	8.77
V927 Tau B	4:31:23.82	24:10:52.9	16.12	13.78	8.77
MHO4	4:31:24.06	18:00:21.5	20.31	17.50	
CFHT-13	4:31:26.69	27:03:18.8			13.45
L1551 IRS5	4:31:34.07	18:08:04.9	20.11	17.10	9.82
LkHα 358	4:31:36.13	18:13:43.2	19.40	16.50	9.69
HH30 IRS	4:31:37.50	18:12:24.4	19.48	16.77	14.24
HL Tau	4:31:38.43	18:13:57.6	14.20	10.63	7.41
XZ Tau A	4:31:40.07	18:13:57.1	16.11	13.56	7.29
XZ Tau B	4:31:40.07	18:13:57.1	16.11	13.56	7.29
L1551NE	4:31:44.44	18:08:31.5			11.41
HK Tau A	4:31:50.56	24:24:18.0	17.18	14.40	8.59
HK Tau B	4:31:50.56	24:24:18.0	17.18	14.40	8.59
V710 Tau A	4:31:57.70	18:21:37.0	14.95	12.70	8.69
V710 Tau B	4:31:57.70	18:21:37.0	14.95	12.70	8.69
J1-665	4:31:58.44	25:43:29.9	17.43	14.91	9.56
XEST17-036	4:33:26.21	22:45:29.3	20.47	17.49	9.92
GI Tau	4:33:34.05	24:21:17.0			7.89
GK Tau	4:33:34.56	24:21:05.8			7.47
IS Tau A	4:33:36.78	26:09:49.2	17.44	14.35	8.64
IS Tau B	4:33:36.78	26:09:49.2	17.44	14.35	8.64
DL Tau	4:33:39.06	25:20:38.2	13.81	11.52	7.96
DL Tau	4:33:39.06	25:20:38.2	13.81	11.52	7.96
HN Tau B	4:33:39.35	17:51:52.3	15.50	13.31	8.38
HN Tau A	4:33:39.35	17:51:52.3	15.50	13.31	8.38
J04333905+2227207	4:33:39.05	22:27:20.7	19.08	16.13	10.71
J04334291+2526470	4:33:42.91	25:26:47.0			13.33
J04334465+2615005	4:33:44.65	26:15:00.5	20.23	17.91	9.74
DM Tau	4:33:48.71	18:10:09.9	15.61	13.61	9.52
CI Tau	4:33:52.00	22:50:30.1	14.30	11.85	7.79
XEST17-059	4:33:52.52	22:56:26.9	17.31	14.78	9.11
J04335245p2612548	4:33:52.45	26:12:54.8			13.99
UZ Tau Bb	4:32:42.82	25:52:31.4	13.41	11.37	7.47
UZ Tau A	4:32:43.03	25:52:31.1	13.41	11.37	7.35
L1551-55	4:32:43.73	18:02:56.3	15.29	13.31	9.31
JH112	4:32:49.11	22:53:02.7	16.54	13.26	8.17
J04324938+2253082	4:32:49.38	22:53:08.2	20.15		9.20
CFHT-5	4:32:50.26	24:22:11.5			11.28
J04325119+1730092	4:32:51.19	17:30:09.2			13.55
MHO8	4:33:01.97	24:21:00.0	19.53	16.52	9.73
GH Tau A	4:33:06.22	24:09:33.9	14.57	11.63	7.79
GH Tau B	4:33:06.22	24:09:33.9	14.57	11.63	7.79
V807 Tau A	4:33:06.64	24:09:54.9	11.68	10.67	6.96
V807 Tau B	4:33:06.64	24:09:54.9	11.68	10.67	6.96
KPNO-14	4:33:07.81	26:16:06.6	20.60	18.70	10.27
CFHT-12	4:33:09.46	22:46:48.7		19.92	11.55
V830 Tau	4:33:10.03	24:33:43.3	13.33	10.95	8.42
IRAS04301+2608	4:33:14.36	26:14:23.5	0.00	19.26	12.48
IRAS04302+2247	4:33:16.50	22:53:20.4	0.00	18.04	11.72
IRAS04303+2240	4:33:19.07	22:46:34.2	20.39	16.22	7.67
KPNO-9	4:35:51.43	22:49:11.9			14.19
XEST08-047	4:35:52.09	22:55:03.9	18.56	15.85	9.81
HP Tau	4:35:52.77	22:54:23.1	0.00	0.00	7.62
XEST08-049	4:35:52.86	22:50:58.5	18.50	15.63	9.75
HP Tau/G3	4:35:53.49	22:54:08.9			8.80
HP Tau/G2	4:35:54.15	22:54:13.4	11.66	10.06	7.23
Haro 6-28 A	4:35:56.84	22:54:36.0	16.91	15.39	9.53
Haro 6-28 B	4:35:56.84	22:54:36.0	16.91	15.39	9.53
XEST09-042	4:35:58.92	22:38:35.3	13.90	11.44	8.37
J04361030+2159364	4:36:10.31	21:59:36.5		20.16	13.65
CFHT-2	4:36:10.38	22:59:56.0		19.17	13.75
LkCa 14	4:36:19.09	25:42:58.9	12.18	10.73	8.58
J04362151p2351165	4:36:21.51	23:51:16.5	18.91	17.43	12.24
CFHT-3	4:36:38.96	22:58:11.9		19.21	13.72
J04373705+2331080	4:37:37.05	23:31:08.0	20.23	17.91	15.44
ITG 1	4:37:56.70	25:46:22.9	19.14	17.45	12.70

Table 3.: Pre-main sequence stars in Taurus- Auriga (continued)

PMS	α(2000)	δ(2000)	B	R	K	PMS	α(2000)	δ(2000)	B	R	K
IT Tau B	4:33:54.70	26:13:27.5	15.95	13.06	7.86	ITG 2	4:38:00.83	25:58:57.2	20.41	18.16	10.10
IT Tau A	4:33:54.70	26:13:27.5	15.95	13.06	7.86	J04381486+2611399	4:38:14.86	26:11:39.9	19.84	19.45	12.98
J2-2041	4:33:55.46	18:38:39.0	16.44	14.47	9.61	GM Tau	4:38:21.34	26:09:13.7	18.39	16.16	10.63
JH108	4:34:10.99	22:51:44.5	16.68	13.90	9.43	DO Tau	4:38:28.58	26:10:49.4	14.61	12.12	7.30
CFHT-1	4:34:15.27	22:50:31.0			11.85	HV Tau A	4:38:35.28	26:10:38.6	15.02	11.88	7.91
HBC 407	4:34:18.03	18:30:06.6	14.44	13.00	9.90	HV Tau B	4:38:35.28	26:10:38.6	15.02	11.88	7.91
XEST08-003	4:34:56.93	22:58:35.8	16.00	13.46	9.27	HV Tau C	4:38:35.49	26:10:41.5	15.02	11.88	7.91
A A Tau	4:34:55.42	24:28:53.1	14.39	12.02	8.05	CFHT-6	4:39:03.96	25:44:26.4	19.99	18.92	11.37
J04345973+2807017	4:34:59.73	28:07:01.7	20.15	20.45	14.65	J04390525p2337450	4:39:05.25	23:37:45.0	17.30	14.55	11.55
CFHT-11	4:35:08.50	23:11:39.8	20.35	18.01	11.59	IRAS04361p2547	4:39:13.89	25:53:20.8			10.72
HO Tau	4:35:20.20	22:32:14.6	15.60	14.06	10.24	CIDA-13	4:39:15.86	30:32:07.4	17.81	15.76	11.83
FF Tau A	4:35:20.89	22:54:24.2	16.63	12.82	8.93	VY Tau A	4:39:17.41	22:47:53.3	14.70	13.03	8.96
FF Tau B	4:35:20.89	22:54:24.2	16.63	12.82	8.93	VY Tau B	4:39:17.41	22:47:53.3	14.70	13.03	8.96
HBC 412 A	4:35:24.10	17:51:41.0			9.10	LkCa 15	4:39:17.79	22:21:03.4	12.54	11.43	8.16
HBC 412 B	4:35:24.10	17:51:41.0			9.10	GN Tau A	4:39:20.90	25:45:02.1	17.34	13.76	8.06
DN Tau	4:35:27.37	24:14:58.9	13.20	11.44	8.02	GN Tau B	4:39:20.90	25:45:02.1	17.34	13.76	8.06
IRAS04325+2402	4:35:35.39	24:08:19.4			11.60	J04393364p2359212	4:39:33.64	23:59:21.1	18.28	15.72	10.28
CoKu Tau3 A	4:35:40.93	24:11:08.7	18.09	14.58	8.41	IRAS04365p2535	4:39:35.19	25:41:44.7			10.84
CoKu Tau3 B	4:35:40.93	24:11:08.7	18.09	14.58	8.41	ITG 15	4:39:44.88	26:01:52.7	20.34	16.62	8.95
KPNO-8	4:35:41.84	22:34:11.6	20.41	18.04	11.99	CFHT-4	4:39:47.48	26:01:40.7		19.09	10.33
XEST08-033	4:35:42.03	22:52:22.6	19.37	16.13	10.00	IRAS04368p2557	4:39:53.89	26:03:11.0			12.00
J04354526+2737130	4:35:45.26	27:37:13.1		19.43	13.71	IC 2087 IRS	4:39:55.74	25:45:02.0	0.00	19.15	6.28
HQ Tau	4:35:47.33	22:50:21.6	13.04	11.06	7.14	J04400067p2358211	4:40:00.67	23:58:21.1	19.45	17.35	11.48
KPNO-15	4:35:51.10	22:52:40.1	17.78	15.24	10.01	CFHT-17	4:40:01.74	25:56:29.2			10.76
IRAS04370+2559	4:40:08.14	26:05:26.54		19.30	9.10	DS Tau	4:47:48.59	29:25:11.2	11.67	11.00	8.04
J04403979+2519061	4:40:39.79	25:19:06.1	20.21	17.87	10.24	J04484189+1703374	4:48:41.90	17:03:37.4		19.64	12.49
JH223	4:40:49.50	25:51:19.1	16.62	14.26	9.49	UY Aur A	4:51:47.37	30:47:13.4	12.47	11.35	7.24
Haro 6-32	4:41:04.24	25:57:56.1	18.47	15.36	9.95	UY Aur B	4:51:47.37	30:47:13.4	12.47	11.35	7.24
IW Tau A	4:41:04.70	24:51:06.2	14.39	11.94	8.28	IRAS04489p3042	4:52:06.68	30:47:17.5			10.38
IW Tau B	4:41:04.70	24:51:06.2	14.39	11.94	8.28	St34	4:54:23.68	17:09:53.4	15.56	14.15	9.79
ITG 33 A	4:41:08.26	25:56:07.4	20.43	18.63	11.09	GM Aur	4:55:10.98	30:21:59.5	13.84	11.12	8.28
ITG 34	4:41:10.78	25:55:11.6		19.37	11.45	J04552333+3027366	4:55:23.33	30:27:36.6	0.00	18.63	11.97
IRAS04381p2540	4:41:12.67	25:46:35.4			11.54	LkCa 19	4:55:36.95	30:17:55.3	11.67	10.49	8.15
CoKu Tau/4	4:41:16.81	28:40:00.0	13.99	12.10	8.66	J04554046+3039057	4:55:40.46	30:39:05.7	19.07	17.08	11.77

Table 3.: Pre-main sequence stars in Taurus- Auriga (continued)

PMS	α(2000)	δ(2000)	B	R	K	PMS	α(2000)	δ(2000)	B	R	K
ITG 40	4:41:24.64	25:43:53.0			11.75	J04554535+3019389	4:55:45.35	30:19:38.9	17.64	15.49	10.46
IRAS04385+2550	4:41:38.82	25:56:26.5	18.84	15.54	9.65	AB Aur	4:55:45.82	30:33:04.3	7.13	7.03	4.23
J04414489+2301513	4:41:44.90	23:01:51.4		20.55	13.16	J04554757+3028077	4:55:47.57	30:28:07.7	17.26	15.17	9.98
J04414565+2301580	4:41:45.65	23:01:58.0	16.73	14.24	9.85	J04554801+3028050	4:55:48.01	30:28:05.5	20.47	16.66	12.15
J04414825+2534304	4:41:48.25	25:34:30.4	20.33	19.29	12.22	XEST26-052	4:55:48.20	30:30:16.0	17.67	15.80	10.95
LkHα 332/G2 A	4:42:05.48	25:22:56.2	15.55	11.99	8.23	J04554969+3019400	4:55:49.69	30:19:40.0	20.14	17.84	11.86
LkHα 332/G2 B	4:42:05.48	25:22:56.2	15.55	11.99	8.23	J04555288+3006523	4:55:52.89	30:06:52.3	17.87	15.80	10.73
LkHα 332/G1 A	4:42:07.32	25:23:03.2	13.80	9.84	7.95	XEST26-062	4:55:56.05	30:36:20.9	15.79	12.94	9.27
LkHα 332/G1 B	4:42:07.32	25:23:03.2	13.80	9.84	7.95	J04555636+3049374	4:55:56.37	30:49:37.5	18.32	16.17	11.09
V955 Tau A	4:42:07.77	25:23:11.8	14.90	0.00	9.43	SU Aur	4:55:59.38	30:34:01.5	9.88	8.83	5.99
V955 Tau B	4:42:07.77	25:23:11.8	14.90	0.00	9.43	HBC 427	4:56:02.01	30:21:03.7	12.08	10.67	8.13
CIDA-7	4:42:21.01	25:20:34.3	18.84	16.22	10.17	J04574903+3015195	4:57:49.03	30:15:19.5			11.48
DP Tau	4:42:37.69	25:15:37.4	16.71	14.03	8.76	V836 Tau	5:03:06.59	25:23:19.7	14.25	12.13	8.60
GO Tau	4:43:03.09	25:20:18.7	16.81	14.24	9.33	CIDA-8	5:04:41.39	25:09:54.4	17.11	14.64	9.60
CIDA-14	4:43:20.23	29:40:06.0	17.01	14.96	9.41	CIDA-9	5:05:22.86	25:31:31.2	17.04	14.09	11.16
IRAS04414+2506	4:44:27.13	25:12:16.4	19.27	17.00	10.76	CIDA-10	5:06:16.74	24:46:10.2	16.38	14.25	9.82
IRAS04428p2403	4:45:54.82	24:08:43.5	17.67	15.66	13.19	CIDA-11	5:06:23.32	24:32:19.9	15.49	13.82	9.46
RXJ04467+2459	4:46:42.59	24:59:03.1	18.29	15.85	15.58	RXJ05072+2437	5:07:12.07	24:37:16.4	14.32	12.07	9.30
DQ Tau	4:46:53.05	17:00:00.1	16.28	12.45	7.98	RW Aur A	5:07:49.53	30:24:05.0	10.62	10.06	7.02
Haro 6-37 A	4:46:58.97	17:02:38.1	14.93	12.69	7.31	RW Aur B	5:07:49.53	30:24:05.0	10.62	10.06	7.02
Haro 6-37 B	4:46:59.09	17:02:40.3	14.93	12.69	7.31	CIDA-12	5:07:56.56	25:00:19.6	15.63	14.26	10.40
DR Tau	4:47:06.20	16:58:42.8	12.08	10.68	6.87						

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[1] HP Tau and HP Tau/G3 are confused with reflection nebulosity on the USNO plates.

To the south, most pre-main sequence stars are in and around L1551. In addition to L1551 IRS5 (see below), the protostar L1551 NE and a few deeply embedded T Tauri stars (HL Tau, XZ Tau, and HH30 IRS) form a close group of pre-main sequence stars. A few stars lie in the larger but less dense L1556 cloud to the east, with only a few stars outside the main cloud boundaries (Figure 6).

Despite the filamentary structure of the dark clouds, the vast majority of young stars in Taurus-Auriga lie in several small groups (Table 4; Gómez et al. 1993; Simon 1997; Luhman 2006). Counting each group of stars within $20''$as one system, the median separation of young stellar systems is $\sim$ 0.3 pc, roughly a factor of 3 larger than the radius of a dense cloud core (Benson & Myers 1989). The typical group has 20–30 systems within a surface area of $\sim$ 1–3 pc^2 (see also Gómez et al. 1993). Current radial velocity and proper motion data are insufficient to infer whether any of these groups are bound.

Many pre-main sequence stars are in binary or multiple systems (Table 5; Leinert & Haas 1989; Haas et al. 1990; Simon et al. 1992, 1993, 1995, 2000; Ghez et al. 1993; Mathieu 1994; Richichi et al. 1994; Koresko et al. 1997; Köhler & Leinert 1998; White et al. 1999; Moriarty-Schieven et al. 2000; König et al. 2001; Woitas et al. 2001; Reipurth et al. 2002; Tamazian et al. 2002; Duchêne et al. 2003b, 2004, 2006; Kraus et al. 2006; Gramajo et al. 2007; Konopacky et al. 2007; Ireland & Kraus 2008). The binary frequency among this sample is comparable to or slightly larger than the field binary frequency. Although most binaries are pairs of weak emission T Tauri stars or classical T Tauri stars with bright emission lines, there are a few mixed pairs of weak and classical T Tauri stars. In most binaries and multiple systems, the stars are coeval, but there are some large age differences (e.g., Hartigan et al. 1994; Prato & Simon 1997; White & Ghez 2001; Hartigan & Kenyon 2003; Prato et al. 2003; Hillenbrand & White 2004). Further study is needed to see whether these differences are real, due to errors in the pre-main sequence evolutionary tracks, or the result of different accretion histories.

The large sample of pre-main sequence stars in Taurus-Auriga yields good tests of stellar evolution models. Kholopov (1951) and Herbig (1952) first showed that T Tauri stars lie 1–3 mag above the main sequence (Figure 7). Hayashi (1965, 1966) used stellar structure calculations to show that these stars are contracting to the main sequence along 'Hayashi tracks' with roughly constant effective temperature (see also Cohen & Kuhi 1979). Later elaborations of these models provide a better understanding of how pre-main sequence stars form and evolve (e.g. Baraffe et al. 1995, 2002; Siess & Forestini 1996; Siess et al. 1997, 1999; Tout et al. 1999; White et al. 1999; Hartmann 2002; Palla & Stahler 2002; Monin et al. 2005; Bertout et al. 2007).

Because dynamical masses for T Tauri stars have been rare, stellar evolution models are the best way to estimate masses and to measure the initial mass function (IMF) for young stars. In Taurus-Auriga, the large pre-main sequence population provides the standard IMF for a nearby young association with stellar ages of 1–10 Myr (Kenyon & Hartmann 1995; Itoh et al. 1996; Luhman 2004). The recent discovery of brown dwarfs extends the IMF to substellar masses (Briceño et al. 1993; Briceño et al. 2002; Luhman 2000, 2004, 2006; Martín et al. 2001; Guieu et al. 2006; Luhman et al. 2006).

From X-ray to radio wavelengths, T Tauri stars have impressive displays of periodic and random brightness variations. In the UV, optical, and near-IR, modulations due to hot and cold spots produce repeatable variations with periods of a few days to

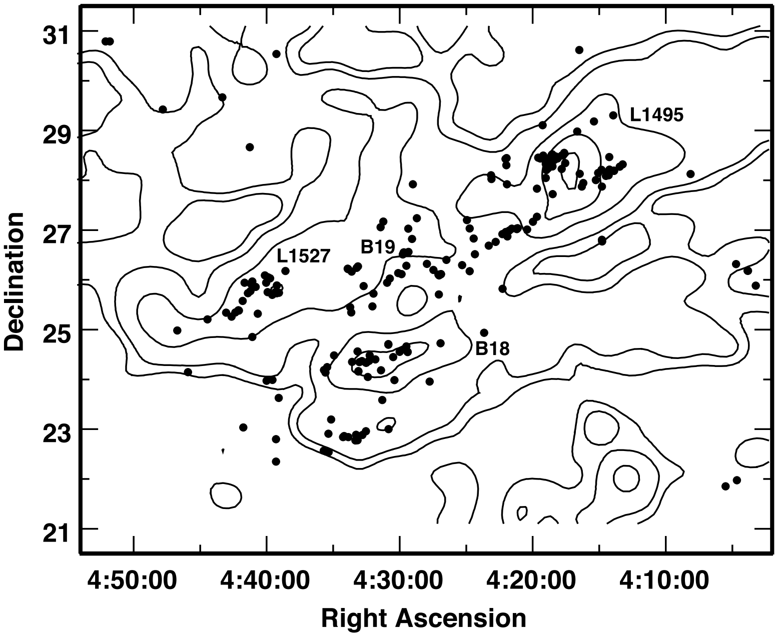

Figure 5. Sky map for the center of the Taurus-Auriga region in J2000 coordinates. Solid contours indicate CO column densities from Ungerechts & Thaddeus (1987); the levels are 3, 5, 10, 15, and 20 K km s^{-1}. Solid points indicate the positions of pre-main sequence stars from Table 3. Groups of young stars lie in L1495 (NW; RA = $4^h\ 12^m$–$4^h\ 20^m$, Dec = 27°–29°), B18/L1529 (center; RA = $4^h\ 24^m$–4^h 36, Dec = 23°–25°), B19/L1521 (center; RA = $4^h\ 24^m$–4^h 36, Dec = 25°–27°), and L1527-29, L1534-35 (E; RA = $4^h\ 36^m$–4^h 44, Dec = 24°–26°). Only a few young stars lie outside the densest molecular gas.

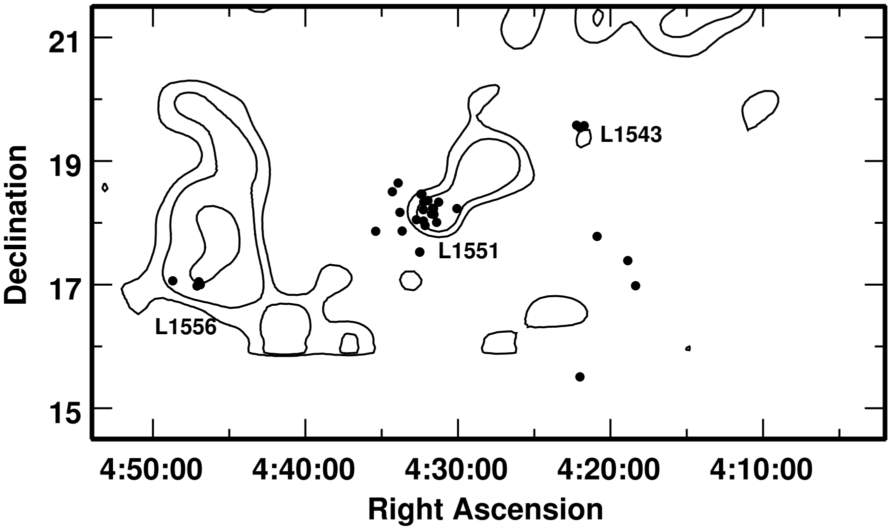

Figure 6. As in Figure 5 for the southern portion of the Taurus-Auriga region. Groups of young stars are heavily concentrated in the L1551 dark cloud (RA = $4^h\ 31^m$, Dec = 18°), with a few stars in L1543 (RA = $4^h\ 23^m$, Dec = 19°) and L1556 (RA = $4^h\ 46^m$, Dec = 17°).

Table 4. Groups of pre-main sequence stars in Taurus-Auriga

ID	α(2000)	δ(2000)	Dark Cloud	Density (pc^{-2})	Radius (pc)	Number
I	4:14:13	+28:10:50	B209	4.7	0.5	22
II	4:18:39	+28:23:55	L1495	7.2	0.5	34
III	4:40:17	+25:45:45	HCL2	2.0	0.9	30
IV	4:32:29	+24:23:00	L1529	1.3	1.1	25
V	4:34:40	+22:49:30	L1536	1.8	1.0	33
VI	4:31:47	+18:09:40	L1551	1.2	1.1	25

Table 5. Close binaries in Taurus-Auriga[1]

Binary	Sep ($''$)	δK (mag)	Binary	Sep ($''$)	δK (mag)
HBC 351	0.6	1.6	CFHT-7	0.2	0.4
HBC 356/357	2.0		V928 Tau	0.2	0.6
HBC 358	1.6	0.6	GG Tau A	0.3	0.5–1.2
V773 Tau AB	sb		GG Tau B	1.5	1.7–1.8
V773 Tau AB-C	0.1	1–2	UZ Tau W	0.4	0.5–1.1
LkCa 3	0.5	0.0	UZ Tau E	sb	
FO Tau	0.2	0.5	GH Tau	0.3	0.6
V410 Tau AB	0.1	2.0	V807 Tau	0.3	1.1
V410 Tau A-C	0.3	3.0	GK Tau	2.4	
DD Tau	0.6	0.7–0.9	IS Tau	0.2	2.6
CZ Tau	0.3	0.8	HN Tau	3.1	3.5
FQ Tau	0.8	0.1	IT Tau	2.5	1.6
LkCa 7	1.1	0.6	FF Tau	0.1	1.0
T Tau NS	0.7	2–6	HBC 412	0.7	0.0
T Tau S	0.1	0.5–3.0	CoKu Tau/3	2.0	1.9
FS Tau	0.3	2.3	HP Tau	0.1	2.3
J4872	3.0	0.8	HP Tau/G3	0.1	1.4
FV Tau	0.7	0.2	Haro 6-28	0.7	0.5
FV Tau/c	0.7	1.9	HV Tau Aa	0.1	0.6
IRAS04239+2436	0.3	0.5–1.0	HV Tau AB	4.0	3.8
DF Tau	0.1	0.4–0.9	IRAS04361+2547[3]	0.3	0.4
IRAS04248+2612[2]	4.6	4.6	VY Tau	0.7	1.5
J04284263+2714039	0.6	0.9	GN Tau	0.1	0.5
GV Tau	1.2	2.2	CFHT-17	0.6	1.5
IRAS04263+2426	1.3	1.1	J04403979+2519061	0.1	1.1
FW Tau	0.2	0.0	IW Tau	0.3	0.0
DH Tau A	2.3	6.8	CoKu Tau/4	0.1	0.2
DI Tau	0.1	2.3	IRAS04385+2550	18.9	3.2
UX Tau A-C	2.7	2.9	LkHα 332/G1	0.2	0.6
FX Tau	0.9	0.4	LkHα 332/G2	0.3	0.6
DK Tau	2.5	1.3	V955 Tau	0.3	1.6
ZZ Tau	0.1	0.9	Haro 6-37 Aa	0.3	2.5
V927 Tau	0.3	0.3	Haro 6-37 AB	2.7	0.9
XZ Tau	0.3	0.7	UY Aur	0.9	1.4
HK Tau	2.4	3.4	RW Aur A-BC	1.4	2.3
V826 Tau	sb		RW Aur B-C	0.1	4.0

[1] Spectroscopic (sb) and close binaries not resolved as distinct objects in 2MASS. Results are quoted to the nearest 0.1 arcsec (separations) and the nearest 0.1 mag (ΔK).

[2] 2MASS data show a K = 12.8 companion with a separation of 2.6$''$.

[3] Not resolved at L by Gramajo et al. (2007).

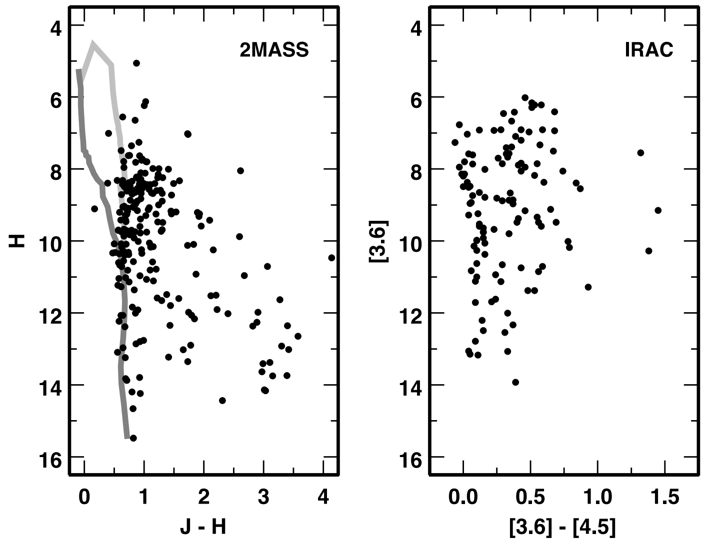

Figure 7. Infrared color-magnitude diagram for Taurus-Auriga pre-main sequence stars. *Left panel:* Data from 2MASS. TTS lie above and to the right of the ZAMS (dark gray line) and the 1 Myr isochrone (light gray line) from Siess et al. (2000). *Right panel:* Data from IRAC. Most TTS have large color excesses relative to the few TTS that lie close to the 1 Myr isochrone.

almost two weeks (Bouvier et al. 1988, 1992, 1993; Bouvier & Bertout 1989; Audard et al. 2007; Stelzer et al. 2007). Random changes in brightness occur on timescales of days to years (Rydgren et al. 1984a; Herbst et al. 1994; Johns & Basri 1995; Grosso et al. 2007a). In X-rays and radio emission, occasional large flares erupt with frequencies similar to those observed in the Sun, but with luminosities several orders of magnitude larger (O'Neal et al. 1990; Phillips et al. 1993, 1996; Feigelson et al. 1994; Chiang et al. 1996; Carkner et al. 1996, 1997, 1998; Giardino et al. 2006; Audard et al. 2007).

In addition to their variability and strong emission lines, many T Tauri stars have considerable UV continuum emission compared to a main sequence stellar photosphere with the same spectral type (Herbig 1958, 1960, 1977; Varsavsky 1960; Smak 1964; Rydgren et al. 1976). Because this 'veiling' is an extra source of continuum emission, it fills in stellar absorption lines. Together with analyses of IR excesses, measurements of stellar veiling have led to detailed accretion disk models and fairly robust estimates of accretion rates from the disk onto the star (Rydgren et al. 1984b; Rucinski 1985; Kenyon & Hartmann 1987, 1990; Bertout et al. 1988; Basri & Bertout 1989; Bertout 1989; Hartmann & Kenyon 1990; Hartigan et al. 1991; Gullbring et al. 1998; Johns-Krull et al. 2000; Johns-Krull & Valenti 2001; Hartigan & Kenyon 2003; Edwards et al. 2006).

Robust measurements of continuum veiling and rotational modulation of T Tauri stars prompted magnetospheric accretion models, where the stellar magnetic field truncates the disk at 3–5 stellar radii and channels the accretion flow onto magnetic hotspots, which rotate with the stellar photosphere (Königl 1991; Calvet & Hartmann 1992; Edwards et al. 1993, 1994; Clarke et al. 1995; Kenyon et al. 1996; Mahdavi & Kenyon 1998; Muzerolle et al. 1998, 2003; Gullbring et al. 2000; Bouvier et al. 1999; Oliveira et al. 2000; Beristain et al. 2001; Bouvier et al. 2003; Symington et al.

2005; Eisner et al. 2005; O'Sullivan et al. 2005). Magnetic field measurements provide some support for this picture (Basri et al. 1992; Johns-Krull et al. 1999, 2004). This picture also provides physical mechanisms to power stellar jets and Herbig Haro flows (Shu et al. 1994; Kudoh & Shibata 1997; Hirose et al. 1997; Soker & Regev 2003; Krasnopolsky et al. 2003), and to understand the distribution and evolution of rotational periods (Collier Cameron & Campbell 1993; Yi 1994, 1995; Allain et al. 1996; Krishnamurthi et al. 1997; Stassun & Terndrup 2003; Broeg et al. 2006; Grosso et al. 2007b).

4. Herbig-Haro Flows and Molecular Outflows

In the 1950's, Herbig (1951) and Haro (1952, 1953) discovered bright knots of nebulosity in several star-forming regions. Besides intense H I emission lines, the knots showed strong emission from [S II] $\lambda\lambda$4068, 4076, 6717, 6731; [O I] $\lambda\lambda$6300, 6363; and [O II] $\lambda\lambda$3726, 3729. Sensitive spectra also revealed weak emission from Ca II and [Fe II]. Although early observations made a clear association of these 'Herbig-Haro' (HH) objects with young stars in Taurus-Auriga and other molecular clouds (Haro 1953; Herbig 1974; Schwartz 1975; Elias 1978), modern data demonstrate that HH objects, jets, and outflows are an important – perhaps necessary – part of low mass star formation (e.g., Mundt & Fried 1983; Mundt et al. 1984; Strom et al. 1986; Bally et al. 2007).

Table 6 lists the currently known jets and HH flows in Taurus-Auriga. Most jets have been discovered using the optical [O I], Hα, [N II] $\lambda\lambda$ 6548, 6583, and [S II] $\lambda\lambda$ 6717, 6731 emission lines (e.g., Gómez et al. 1997; Devine et al 1999a, 1999b). In regions of large extinction, near-IR transitions of H_2 and [Fe II] are also important (Davis et al. 2002, 2003). Sensitive imaging surveys covering most of the clouds have detected flows associated with the most deeply embedded young stars (e.g., L1551 IRS5, L1527 IRS, and IRAS04248+2612) and optically visible T Tauri stars with clear evidence for a circumstellar disk (e.g., T Tau, DG Tau, and RW Aur). Despite sensitive searches, there are no weak emission T Tauri stars with an HH outflow or a jet. Thus, these surveys suggest a clear link between accretion and outflows.

Figure 8 illustrates some of the amazing variety of jets among Taurus-Auriga young stars. In HH 30 and other jet sources, the jets typically have opening angles of roughly 5 degrees and linear dimensions ranging from a few tens of AU to about 0.2 pc (e.g., Kepner et al. 1993; Ray et al. 1996; Burrows et al. 1996; Krist et al. 1997, 1999; Lavalley et al. 1997; Fridlund & Liseau 1998; Stapelfeldt et al. 1999, 2003; Dougados et al. 2000; Woitas et al. 2002a,b, 2005; Bacciotti et al. 2002; Pyo et al. 2003, 2005; Coffey et al. 2004a, b; Hartigan et al. 2004; Fridlund et al. 2005; McGroarty et al. 2007). When resolved, the lateral dimensions are $\sim$ 10–20 AU. Jets come in two broad classes, nebulous knots of HH objects arranged like 'beads on a string' and continuous narrow jets. Few jets are perfectly straight. Many jets curve slightly, while others have a wavy or sinusoidal shape. This morphology may indicate that the source of the jet wobbles, precesses, or is part of a binary system. Both classes have a bipolar (or sometimes unipolar) morphology, with the jet or HH object lying roughly along the apparent rotation axis of the circumstellar disk surrounding the T Tauri star.

Some jets and HH objects have impressive bow shocks, arc-shaped nebulae formed as ejected material plows through the molecular cloud. In XZ Tau, *HST* data show a clear expansion of the bubble-like structure surrounding the HH knots (Krist et al.

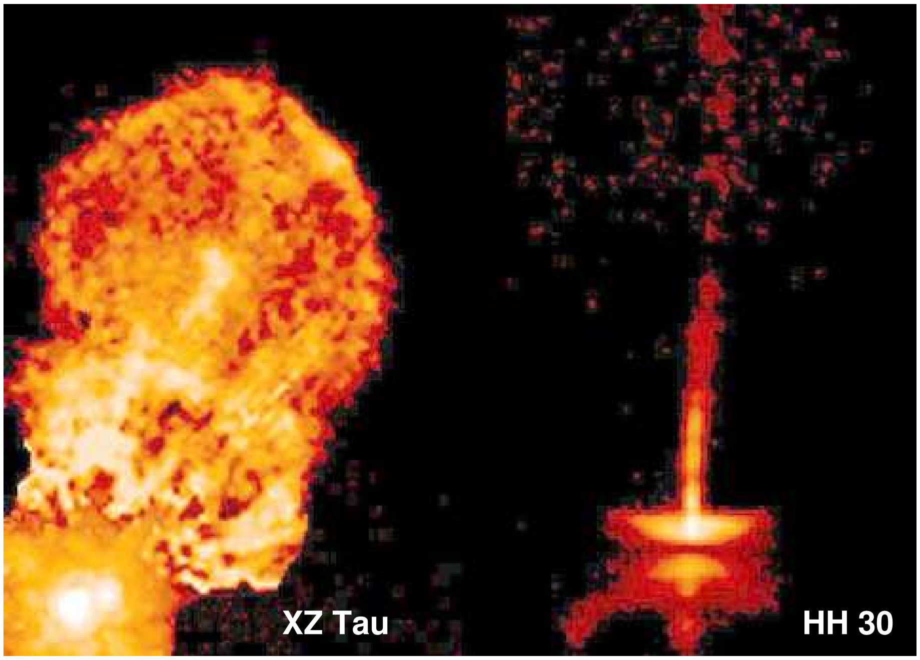

Figure 8. HST WFPC2/F675W images of XZ Tau (Krist et al. 1999) and HH 30 (Burrows et al. 1996). The F675W filter includes the [S II] $\lambda\lambda$6717,6731, Hα λ6563, and [O I] λ6300 lines. The XZ Tau bubble extends for 800–900 AU from the central binary. The HH 30 jet has a length of 1300–1400 AU from the disk midplane.

1999). Often, the HH objects also show a clear proper motion away from the central young star (e.g., Cudworth & Herbig 1979). The expansion velocities derived from the proper motions, $\sim$ a few hundred km s^{-1}, typically agree with expansion velocities derived from the profiles of the [O I] and [S II] emission lines (e.g., Gómez de Castro 1993; Hirth et al. 1994a, 1994b, 1997; Böhm & Solf 1994; Bacciotti et al. 1996; Eislöffel & Mundt 1998; Solf & Böhm 1999; Takami et al. 2002; Sun et al. 2003).

Many HH flows are associated with reflection nebulae. In L1551 IRS5 and many other jets, impressive reflection nebulae surround the jet, suggesting that the jet flows through a cavity in the surrounding molecular gas. Other TTS have bowl-shaped or C-shaped reflection nebulae. In HH 30 (Fig. 8), the beautiful bipolar jet is associated with a bipolar bowl-shaped nebula almost perfectly bisected by a dark band of obscuring material. This image closely resembles the predicted images of illuminated disks observed edge-on (Whitney & Hartmann 1992, 1993); the upper half of the nebula is the near side of the disk, while the lower half is the far side of the disk.

In addition to large-scale jets, discoveries of 'microjets' in DG Tau (Kepner et al. 1993) and RW Aur (Bacciotti et al. 1996) provide important details on the structure and evolution of outflows from young stars. In DG Tau, images with high spatial resolution show several knots lying inside an expanding bow shock, with structure similar to XZ Tau but on scales of 1–2 arcsec instead of 5–10 arcsec (Lavalley et al. 1997; Lavalley-Fouquet et al. 2000; Bacciotti et al. 2000; Dougados et al. 2000; Takami et al. 2002, 2004; Pyo et al. 2003; Güdel et al. 2005, 2008). Small wiggles in the jet and the spacing and apparent trajectory of the knots suggest a precessing outflow source with recurrent ejections on timescales $\sim$ 8 yr. Sophisticated models show that a precessing jet accounts for the excitation, kinematics, and morphology of the emission lines (Raga et al. 2001; Cerqueira & de Gouveia Dal Pino 2004; Massaglia et al. 2005).

On the largest scales, continued improvement of large-format optical CCD and infrared HgCdTe and InSb cameras enable amazing detections of beautiful new jets and many faint and distant components of known jets and HH objects (e.g., Eiroa et al. 1994; Alten et al. 1997; Gómez et al. 1997; Lucas & Roche 1998; Eislöffel & Mundt 1998; Aspin & Reipurth 2000; Magakian et al. 2002; McGroarty et al 2007). Imaging of giant HH flows often reveals quasi-periodically spaced ejections with impressive point symmetry (e.g., Reipurth et al. 1997, 2000; Devine et al 1999a, 1999b; Sun et al. 2003; McGroarty & Ray 2004; Wang et al. 2004). In IRAS 04248+2612, the sinusoidal outflow trajectory resembles the structure in DG Tau, suggesting that precessing jets may explain the basic geometry of most jets (Gómez et al. 1997). Because this source is a known binary (Padgett et al. 1999), binary motion might also produce a sinusoidal outflow.

The young stars in Taurus-Auriga also drive impressive large-scale mm and cm outflows. After Snell et al. (1980) discovered the bipolar CO outflow in L1551 IRS5, high velocity molecular gas was observed around many T Tauri stars (Edwards & Snell 1982; Kutner et al. 1982; Bally & Lada 1983; Heyer et al. 1987; Moriarty-Schieven et al. 1987, 1992, 1995; Moriarty-Schieven & Wannier 1991; Myers et al. 1988; Moriarty-Schieven & Snell 1988; Terebey et al. 1989; Fukui 1989, e.g.,). At about the same time, Cohen et al. (1982) detected large-scale ionized outflows associated with 4 young stars in Taurus-Auriga. Larger surveys with the VLA continued to reveal ionized outflows associated with other T Tauri stars, while more sensitive, high resolution observations revealed the fine details of the outflows (e.g., Rodríguez & Cantó 1983; Bieging et al. 1984; Schwartz et al. 1986; Rodríguez 1994).

Modern radio observations concentrate on resolving small-scale structures within the outflow, deriving the orientation of the outflow relative to the disk and optical jet, and measuring the physical parameters and chemistry of the outflow. In Taurus-Auriga, the projected lengths, $\sim$ 0.1–1 pc, and velocities, $\sim$ 10–100 km s^{-1}, roughly span the range observed in HH objects and collimated jets (Bachiller & Tafalla 1999; Richer et al. 2000; Arce & Goodman 2001). Outflow rates, $\sim 10^{-6}\ M_\odot$ yr^{-1} or less, are also similar to those derived from optical and near-IR data and comfortably less than the typical inflow rates within the molecular cloud (Bontemps et al. 1996). The radio data show that the molecular outflows are much cooler, $\sim$ 20–100 K, than optical jets, as expected for molecular gas. These regions have a rich chemistry, with an impressive array of charged and neutral molecules (e.g., Hogerheijde et al. 1998; Spinoglio et al. 2000)

While most protostars in Taurus-Auriga drive large-scale molecular outflows (Table 6; Heyer et al. 1987; Terebey et al. 1989; Moriarty-Schieven & Wannier 1991), only one protostar – 04166+2706 – drives a well-collimated, high velocity, bipolar molecular outflow ('molecular jet'; Tafalla et al. 2004). This system is similar to other molecular jets in Ophiuchus and Perseus, with an outflow velocity of at least 50 km s^{-1} and a high degree of symmetry between the blue-shifted and red-shifted material. Because this system has weak optical [S II] emission (Gómez et al. 1997), deeper optical and near-IR images might reveal a well-collimated optical jet associated with the molecular gas.

Table 6.: Herbig Haro Flows in Taurus-Auriga

HH	Other ID	α(2000)	δ(2000)	Driving Source	Description	CO Outflow?	References
362		4:04:23.0	26:20:41	04016+2610?	small knots	yes	1,2,3,4,5
361		4:04:34.9	26:21:44	04016+2610?	small knots		1,2
360		4:04:43.0	26:19:00	04016+2610?	small knots		1,2
701		4:12:16.4	28:50:15		knots		6
829		4:14:03.0	28:25:36	CW Tau	knot		7
828		4:14:10.3	28:14:54	CW Tau	knot		7
827		4:14:15.1	28:03:55	CW Tau	knot		7
220	CW Tau jet	4:14:16.9	28:10:59	CW Tau	bipolar jet		7,8,9,10,11
826		4:14:17.8	28:10:40	CW Tau	knot		7
	DD Tau A jet			DD Tau A	[O II] jet		11
156	CoKu Tau-1 jet	4:18 51.5	28:20:28	CoKu Tau-1	bipolar jet		12,13
390		4:19 40.8	27:15:53	04166+2706?	small knots	yes	2,14
391		4:19 56.3	27:09:26	04169+2702?	small knots/HH jet?	yes	2,5,14
392		4:20 54.3	26:59:52	04181+2655/54?	small knots	yes	2,5,14
355		4:21:43.6	19:50:42	T Tauri S	bipolar HH jet		15,16
155	HH 1555	4:21:57.1	19:32:07	T Tauri	bipolar jet	yes	5,13,16,17,18,19,20,21,22,23,24,25,26,27,28
998		4:21:57.8	28:26:35.9	RY Tauri	small knots/bipolar jet		30
255	Burnham's Nebula	4:21:59.4	19:31:56	T Tauri S	HH jet		16,18,19,29
157	Haro 6-5B jet	4:22:00.9	26:57:38	Haro 6-5B(FS Tau B)	HH jet		13,31,32,33,34,35
276		4:22:07.3	26:57:26		HH jet		13,32
300	HH 300 [FeII] jet	4:25:23.0	24:23:20	04239+2436	HH jet/bow-shock shape knots	yes	2,5,15,36,37,38
702		4:26:35.6	25:57:55		knots		6
	DF Tau jet			DF Tau	[O II] jet		11
838		4:26:56.4	26:05:58	DG Tau B?	knot		7
159	DG Tau B jet	4:27:02.0	26:05:42	DG Tau B	jet		7,13,39,40,41
836		4:27:13.5	26:04:16	DG Tau B	knot		7
839		4:27:43.8	26:04:35	DG Tau B?	knot		7
837		4:27:44.8	26:00:49	DG Tau B	knot		7
158	DG Tau jet	4:27:04.6	26:06:16	DG Tau	bipolar jet		7,10,13,31,38,39,40,42,43,44
830		4:27:37.3	26:12:27	DG Tau	knot		7
31		4:28:18.4	26:17:41	04248+2612	jet/knots	yes	2,5,32,45
410		4:28:13.0	24:19:02	Haro 6-10 IR comp	bright knots/bow shock		46
184	Haro 6-10/HH	4:29:23.6	24:33:01	Haro 6-10 IR comp	compact knot		2,31,46,47,48
	Haro 6-10 jet	4:29:24.4	24:33:02	Haro 6-10	small bipolar jet	yes	4,25,46,49,50,28
412		4:29:47.9	24:37:10	Haro 6-10 IR comp	diffuse emission		46
411		4:30:16.9	24:42:42	Haro 6-10 IR comp	Hα filament		46
414		4:29:30.3	24:39:54	04264+2433	bipolar jet		46
413		4:29:53.0	24:38:12	04264+2433	bow-shock		46
393		4:30:50.6	24:41:25	ZZ Tau?	small knot	yes	2,50

Table 6.: Herbig Haro Flows in Taurus-Auriga (continued)

HH	Other ID	α(2000)	δ(2000)	Driving Source	Description	CO Outflow?	References
256	GH 1	4:30:53.2	17:59:07	L1551 IRS 5,HH 30 IRS?	small faint knots		51,52,53
257	GNG 17	4:31:00.7	18:00:42	L1551 IRS 5	faint knot		52
258	GH 2-8	4:31:04.8	18:03:32	L1551 IRS 5	faint knots		51
260	GNG 1	4:31:27.0	18:06:55	L1551 IRS 5	faint knot		52,54
261	SH 219/220	4:31:30.0	18:06:53	L1551 IRS 5	knots		51,52,55,56
154	L1551 IRS5 jet	4:31:33.8	18:08:02	L1551 IRS 5	short jet	yes	5,24,26,27,32,34,38,39,51,52,54,55,57,58,59 60,61,62,63,64,65,66,67,68,69,70,71
264	GNG 4	4:31:18.4	18:06:16	L1551 IRS 5?	knots		51,52,54,55
262	GH 9/10	4:32:01.1	18:11:24	L1551 IRS 5,L1551 NE?	faint knots		51,52,53,56
28		4:31:07.0	18:03:23	L1551 NE	bright bow shock		32,45,51,52,53,54,55,72,73
29		4:31:27.0	18:06:23	L1551 NE	bright bow shock		32,45,51,52,53,54,55,72,73
454		4:31:42.7	18:08:19	L1551 NE	bipolar HH jet	yes	53,74
259	SH 229 group	4:31:14.1	18:04:02	L1551 NE?	knots/HH jet		51,52,53,55,56
286		4:32:41.7	18:16:36	L1551 NE?,L1551 IRS 5?	knot		53
265	GNG 25	4:31:14.9	18:11:59		knot		52,53
263	SH 214, GNG 3	4:31:23.4	18:07:48	HH 30 IRS?	small knots		51,52,54,55
30		4:31:37.6	18:12:26	HH 30 IRS	bipolar jet		34,35,40,45,51,53,75,76,77,78,79,80,81,82,83,84
150	HL Tau jet	4:31:38.5	18:13:59	HL Tau	bipolar jet	yes	22,23,24,35,75,76,77,79,84,85,86,87,88
153	HL Tau Hα jet	4:31:39.4	18:13:39	HL Tau	Hα jet,[S II]knot		75,76
151	HL Tau VLA 1 jet	4:31:39.6	18:14:08	HL Tau VLA	bipolar jet		32,34,35,40,75,76,89
266	GNG 24	4:31:52.3	18:16:50	HL Tau?	knot		52,77,84
152	XZ Tau jet	4:31:40.1	18:13:58	XZ Tau	bipolar jet		32,48,75,76,87,90
	Haro 6-13 Hα jet			Haro 6-13	unipolar jet		32
319	Haro 6-19	4:32:41.1	24:21:46	FY Tau?,FZ Tau?	knots		6,91,92
	UZ Tau E jet			UZ Tau E	[O I],[N II],[SII] jet		11,48
394		4:33:12.3	22:55:10	04302+2247?	HH knots	yes	2,5,15
467		4:33:32.9	24:20:27	GK Tau	knot/extended emission		20
466		4:33:35.4	24:21:32	GK Tau	knots		20
468		4:33:37.6	24:21:43	GK Tau	diffuse knot		20
	HN Tau jet			HN Tau	[O I],[N II],[SII] jet		11,48
434		4:34:13.2	23:09:29	04325+2402(L1535)?	knots	yes	3,5,93,94,95
435		4:34:15.1	23:08:08	04325+2402(L1535)?	bow shock	yes	5,93
436		4:34:20.3	23:08:40	04325+2402(L1535)?	elongated knot		93
703		4:35:01.9	23:38:58		nebula		6
230	DO Tau jet	4:38:28.6	26:10:50	DO Tau	bipolar knots		7,9,48
833	HV Tau C jet	4:38:44.0	26:14:42	HV Tau	[O I],[SII] jet		7,41,96,97
834		4:39:05.9	26:03:23	HV Tau?	knot		5
832		4:39:02.0	26:12:21	DO Tau	knot		7
831		4:39:13.2	26:13:48	DO Tau	knot		7

Table 6.: Herbig Haro Flows in Taurus-Auriga (continued)

HH	Other ID	α(2000)	δ(2000)	Driving Source	Description	CO Outflow?	References
704		4:38:45.1	25:18:14		knots/nebulae		6
705		4:39:06.7	26:20:30		nebula		6
706		4:39:11.4	25:27:19		nebula		6
192		4:39:47.7	26:03:27	04368+2557?	small knot	yes	4,5,14,95,98,99
395		4:40:08.7	25:46:44	04369+2539(IC 2087)	small knots	yes	2,22,28,94
408		4:41:38.9	25:56:26	Haro 6-33	bipolar knots		100
231	DP Tau jet	4:42:37.6	25:15:38	DP Tau	bipolar HH jet		9,13,48,101
386	UY Aur jet	4:51:47.3	30:47:15	UY Aur	bipolar microjet		47,48
835		5:07:30.4	30:27:11	RW Aur	knot		7
229	RW Aur jet	5:07:49.5	30:24:07	RW Aur	bipolar HH jet		7,10,38,47,48,101,102,103,104,105,106,107

References: 1- Alten et al. (1997); 2- Gómez et al. (1997); 3- Myers et al. (1988); 4- Terebey et al. (1989); 5- Moriarty-Schieven et al. (1992); 6- Sun et al. (2003); 7- McGroarty & Ray (2004); 8- Gómez de Castro (1993); 9- Hirth et al. (1994a); 10- Dougados et al. (2000); 11- Hartigan et al. (2004); 12- Movsesyan & Magakyan (1990); 13- Eislöffel & Mundt (1998); 14- Bontemps et al. (1996); 15- Reipurth et al. (1997); 16- Solf & Böhm (1999); 17- Schwartz (1975); 18- Bührke et al. (1986); 19- Böhm & Solf (1994); 20- Aspin & Reipurth (2000); 21- Knapp et al. (1977); 22- Edwards & Snell (1982); 23- Calvet et al. (1983); 24- Lada (1985); 25- Levreault et al. (1988); 26- Cabrit & Bertout (1992); 27- Moriarty-Schieven et al. (1987); 28- Larionov et al. (1999); 29- Burnham (1894); 30- St-Onge & Bastien (2008); 31- Mundt et al. (1984); 32- Strom et al. (1986); 33- Woitas et al. (2002a); 34 - Krist et al. (1998); 35- Mundt et al. (1991); 36- Reipurth et al. (2000); 37- Arce & Goodman (2001); 38- Davis et al. (2003); 39- Mundt & Fried (1983); 40- Mundt et al. (1987); 41- Lavalley et al. (1997); 42- Kepner et al. (1993); 43- Bacciotti et al. (2000); 44- Bacciotti et al. (2002); 45- Herbig (1974); 46- Devine et al. (1999a); 47- Elias (1978); 48- Hirth et al. (1997); 49- Edwards & Snell (1984); 50- Fukui (1989); 51- Graham & Heyer (1990); 52- Garnavich et al. (1992); 53- Devine et al. (1999b); 54- Davis et al. (1995); 55- Stocke et al. (1988); 56- Rodríguez et al. (1989); 57- Fridlund & Liseau (1994); 58- Fridlund & Liseau (1998); 59- Neckel & Staude (1987); 60- Campbell et al. (1988); 61- Yamashita & Tamura (1992); 62- Liseau et al. (2005); 63- Fridlund et al. (2005); 64- Snell et al. (1980); 65- Bally & Lada (1983); 66- Moriarty-Schieven & Snell (1988); 67- Fridlund & White (1989); 68- Moriarty-Schieven & Wannier (1991); 69- Rodríguez et al. (1995); 70- Momose et al. (1998); 71- Fridlund & Knee (1993); 72- Fridlund et al. (1993); 73- Cudworth & Herbig (1979); 74- Moriarty-Schieven et al. (1995); 75- Mundt et al. (1988); 76- Mundt et al. (1990); 77- López et al. (1995); 78- Burrows (1996); 79- Ray et al. (1996); 80- Stapelfeldt et al. (1996); 81- Brugel et al. (1981); 82- Cohen & Schmidt (1981); 83- Raga et al. (1997); 84- López et al. (1996); 85- Stapelfeldt et al. (1995); 86- Bacciotti & Eislöffel (1999); 87- Torrelles et al. (1987); 88- Monin et al. (1996); 89- Cohen & Jones (1987); 90- Krist et al. (1997); 91- Haro (1953); 92- Magakian et al. (2002); 93- Wang et al. (2001); 94- Heyer et al. (1987); 95- Tamura et al. (1996); 96- Woitas & Leinert (1998); 97- Stassun & Terndrup (2003) 98- Eiroa et al. (1994); 99- Chandler et al. (1996); 100- Stapelfeldt et al. (1999); 101- Mundt & Eislöffel (1998); 102- Hirth et al. (1994b); 103- Bacciotti et al. (1996); 104- Woitas et al. (2002b); 105- López-Martín et al. (2003); 106- Coffey et al. (2004); 107- Woitas et al. (2005)

Table 7. Molecular Outflows without Detected Jets/HH Objects in Taurus-Auriga

ID Description	Other ID CO Outflow?	α(2000) References	δ(2000)	References
04191+1523		4:21:58.8	15:30:20	1,2,3,4,5,6,7
04361+2547	TMR 1	4:39:13.9	25:53:21	8,9,10
04365+2535	TMC 1A	4:39:35.0	25:41:45	9,10,11,12,13
04381+2540		4:41:12.5	25:46:37	9,10,11,12
TMC 2A		4:31:55.9	24:32:49	1,14
L1529	TMC 2	4:32:44.7	24:25:13	1,15,16
L1642		4:35:02.8	14:13:57	17

1- Larionov et al. (1999); 2- Fukui (1989); 3- André et al. (1999); 4- Lee et al. (2002); 5- Belloche et al. (2002); 6- Takakuwa et al. (2003); 7- Lee et al. (2005); 8- Terebey et al. (1990); 9- Moriarty-Schieven et al. (1992); 10- Bontemps et al. (1996); 11- Terebey et al. (1989); 12- Chandler et al. (1996); 13- Tamura et al. (1996); 14- Myers et al. (1988); 15- Lichten (1982); 16- Lada (1985) 17- Liljeström et al. (1989)

5. Individual Objects of Interest

5.1. T Tauri

T Tauri is synonymous with young stars. In addition to serving as the prototype of low mass, young variable stars, T Tau has inspired a festival for young filmmakers and countless images of space art. Lying in rich nebulosity in the most southern of the Taurus-Auriga dark clouds (Stapelfeldt et al. 1998b), T Tauri has an embedded companion (T Tau S; Dyck et al. 1982; Schwartz et al. 1984) and a bright optical jet (Figure 9; Schwartz 1975; Bührke et al. 1986; Gorham et al. 1992; Eislöffel & Mundt 1998).

T Tauri has an amazing, 150 yr history of brightness variations (e.g., Baxendell et al. 1916; Rydgren et al. 1984a; Herbst et al. 1994). The bright optical star, T Tau N, has a K-type spectrum and fluctuates between V = 9 and V = 14 on timescales of months to years (Beck & Simon 2001). There is also a small (0.01–0.03 mag) periodic variation in the light curve due to stellar rotation (Herbst et al. 1986). Roughly 100–200 AU away, T Tau S is a close binary composed of an intermediate mass star, $\sim$ 2.1 $M_{\odot}$, and a lower mass pre-main sequence star with a mass of $\sim$ 0.8 $M_{\odot}$ (Koresko 2000; Duchêne et al. 2002, 2005; Furlan et al. 2003; Beck et al. 2004; Johnston et al. 2004; Tamazian 2004; Duchêne et al. 2006; Mayama et al. 2006; Köhler et al. 2008; Skemer et al. 2008). During 1985–1993, the more massive component of T Tau S brightened by more than two magnitudes in the IR and then faded (Ghez et al. 1991; Kobayashi et al. 1994; Simon et al. 1996; Beck & Simon 2001; Beck et al. 2004). This behavior is reminiscent of FU Ori eruptions (Hartmann & Kenyon 1996).

Multiwavelength observations of the nebulosity reveal a complicated structure (Saucedo et al. 2003; Mayama et al. 2006). The elliptical Burnham's nebula surrounds T Tau and has an extent of a few arcsec. Hind's nebula (NGC 1555) is an arc-shaped reflection nebula 45$''$ to the west; Struve's small nebula (NGC 1554) is 4$'$ west (Burnham 1890; Barnard 1895; Curtis 1915; Herbig 1950a). Recent IR, optical, and UV

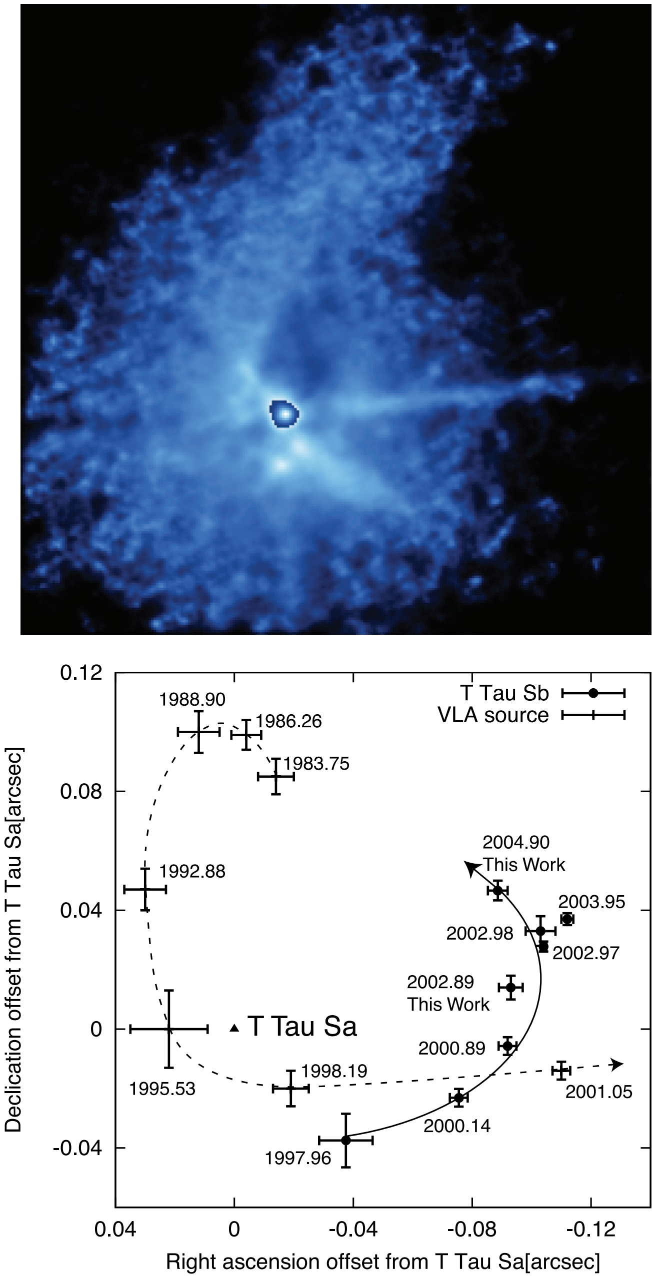

Figure 9. The T Tauri binary. *Upper panel:* 10″x 10″ optical image (C. & F. Roddier). T Tau N is the saturated point source surrounded by a dark halo. T Tau S is the fuzzy source due south. At PA = 315° from T Tau, the slightly elongated blob is a bright radio source (Ray et al. 1997). Two collimated jets appear to emanate from T Tau N, one with PA $\approx 45°$ and 225° and another with PA $\approx 270°$. The bright spike at PA $\approx 270°$ points to Hind's nebula, $\sim 45''$ to the west. *Lower panel:* Motion of the T Tau S binary from Mayama et al. (2006). T Tau Sa and T Tau Sb appear to form a bound pair; the VLA source is probably not bound to this pair (see also Köhler et al. 2008).

data show a patchy structure, with an optical extinction of roughly 1-2 mag to T Tau N and $\sim$ 15–40 mag to T Tau S (Kobayashi et al. 1997; van den Ancker et al. 1999; Beck et al. 2001; Saucedo et al. 2003). Although early spectra hinted at emission lines in Burnham's nebula, Herbig (1950a) first showed convincingly that the lines are intrinsic to the nebula. Deeper optical spectra extended this study and demonstrated the lines are formed in shocked gas (Solf et al. 1988; Böhm & Solf 1994; van den Ancker et al. 1999).

Both T Tau N and T Tau S are bright radio sources (Schwartz et al. 1984, 1986; Ray et al. 1997) and drive powerful stellar winds (Johnston et al. 2003, 2004; Loinard et al. 2007a; Beck et al. 2008). T Tau S also has a fairly bright H_2O maser (Furuya et al. 2003). A third bright radio source roughly midway between the two stars is visible as a fuzzy blob in the optical image (Figure 9). A bright nonthermal radio source associated with T Tau S provides an excellent distance estimate of 147.6 ± 0.6 pc (Loinard et al. 2005, 2007b). This emission probes the structure of the magnetosphere and inner disk around the brighter component of the T Tau S binary (Loinard et al. 2007a).

Both T Tau N and T Tau S eject jets. The jet in T Tau N was first detected on photographs from the 1940s and 1950s (Herbig 1950a). Many spectroscopic and imaging studies identify shocked gas along the well-collimated jet (Schwartz 1974, 1975; Böhm & Solf 1994, 1999; Burnham 1894; Eislöffel & Mundt 1998; Walter et al. 2003). The brightest part of this jet lies along PA $\approx 270^\circ$ and extends for at least $30''$, which is $\sim$ 5000 AU at 140 pc. A much fainter counter-jet lies along PA $\approx 90^\circ$. The kinematics of this weak flow are consistent with kinematics of the brighter western jet (Böhm & Solf 1999).

T Tau S drives a remarkable jet (Reipurth et al. 1997; Walter et al. 2003). Close to the star, a broad, multicomponent bipolar jet (HH 255) lies along an axis with PA $\approx 0^\circ \pm 30^\circ$(Solf et al. 1988). The jet has a length of several arcsec, with a blueshifted southern lobe and a redshifted northern lobe (Böhm & Solf 1994, 1997, 1999; Quirrenbach & Zinnecker 1997). At much larger distances, Reipurth et al. (1997) identified a 'giant' HH flow (HH 355) with similar kinematics. For a distance of 140 pc, the HH 355 bipolar flow has a projected length of 1.6 pc.

Circumstellar disks play an important role in the geometry of the jets. T Tau S has an extensive dusty disk with a mass of $\sim$ 0.04 $M_\odot$ (Hogerheijde et al. 1997b; Akeson et al. 1998; Walter et al. 2003). Material from this disk probably drives the T Tau S jet and the large molecular outflow (Edwards & Snell 1982; Levreault et al. 1988; Moriarty-Schieven et al. 1992). In T Tau N, 3D radiative transfer calculations suggest that the rotational axis of the dusty disk is tilted by $\sim 20^\circ$ relative to the rotational axis in T Tau S (Wood et al. 2001; Akeson et al. 2002, 2005).

5.2. L1551 IRS 5

L1551 IRS5 is the iconic bipolar outflow source. Although Sharpless (1959) originally identified it as an H II region, Strom et al. (1974, 1976) showed that the object is a very red young star illuminating a reflection nebula. More sensitive, multi-wavelength data demonstrate that the 0.5–1 pc long outflow has several components. Bright optical and near-IR jets are surrounded by a well-collimated molecular outflow embedded in a magnificent reflection nebula (Snell et al. 1980; Snell & Schloerb 1985; Snell et al. 1985; Draper et al. 1985; Scarrott 1988). The flow contains many HH objects and is a primary testing ground for theories of jet formation and evolution.

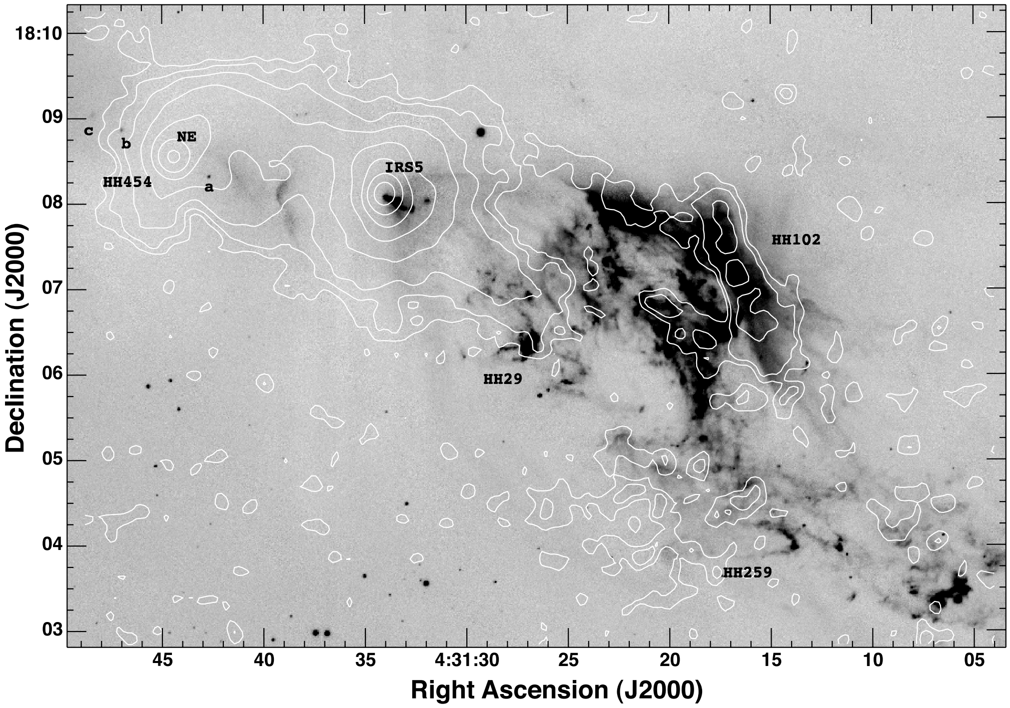

Figure 10. [S II] image of L1551 IRS5 with contours of 850 μm emission overlaid (Moriarty-Schieven et al. 2006). The contour levels are 0.02, 0.04, 0.08, 0.16, 0.32, 0.64, 1.28, and 2.56 Jy beam^{-1}.

A relatively inconspicuous close binary drives the outflows in L1551 IRS5 (Bieging & Cohen 1985; Looney et al. 1997; Rodríguez et al. 1998; Rodríguez et al. 2003). The binary has a projected separation of 45 AU, yielding a rough orbital period of 300 yr. Both stars are bright radio sources at mm and cm wavelengths, with thermal emission from circumstellar disks and free-free emission from the jets and stellar winds. The disks lie in an extended envelope that dominates the far-IR and submm flux (Beichman & Harris 1981; Davidson & Jaffe 1984; Emerson et al. 1984; Edwards et al. 1986). The spectral energy distribution of scattered optical and near-IR light and thermal far-IR and submm flux indicate that the extended envelope is falling into the central object at a rate $\sim$ 3–10 $\times 10^{-6} M_{\odot} \mathrm{yr}^{-1}$ (e.g. Kenyon et al. 1993a; Butner et al. 1994; Whitney et al. 1997; Osorio et al. 2003; Gramajo et al. 2007).

The structure of the IRS5 jet is remarkable (Figure 10). The flow consists of a short jet (HH 154) and numerous faint knots and bow shocks (HH 28, HH 29, HH 256, HH 257, HH 259, HH 260, HH 261, HH 262, HH 264, HH 265, HH 286, and HH 454; Mundt & Fried 1983; Strom et al. 1986; Stocke et al. 1988; Graham & Heyer 1990; Garnavich et al. 1992; Davis et al. 1995; Hodapp & Ladd 1995; Krist et al. 1998; López et al. 1998). Both binary components appear to drive outflows, which interact and merge to form the majestic large-scale outflow structure (Fridlund & Liseau 1998; Devine et al. 1999b; Hartigan et al. 2000; Rodríguez et al. 2003). Some knots and bow shocks are associated with the nearby young stars L1551NE and HH30 IRS (Herbig 1974; Emerson et al. 1984; Strom et al. 1986; Graham & Heyer 1990; Garnavich et al. 1992; Devine et al. 1999b). Because there are at least three interacting HH flows, the kinematics of the region is complicated, with some indication for twisted jets and other distortions (Neckel & Staude 1987; Campbell et al. 1988; Stocke et al. 1988; Yamashita & Tamura 1992; Fridlund & Liseau 1994, 1998; Itoh et al. 2000; Fridlund et al. 2005; Liseau et al. 2005). The HH objects require several velocity components ranging from slow speeds of tens of km s^{-1} up to velocities of 300 or more km s^{-1} (Stocke et al. 1988; Hartigan et al. 2000; Reipurth et al. 2000; Favata et al. 2002; Pyo et al. 2002, 2005; Bally et al. 2003; Davis et al. 2003).

In addition to the jet, L1551 IRS5 has a large-scale molecular outflow (Snell et al. 1980; Bally & Lada 1983; Moriarty-Schieven et al. 1987; Sargent et al. 1988; Pound & Bally 1991; Moriarty-Schieven et al. 1992; Fridlund & Knee 1993; Bachiller et al. 1994; Fuller et al. 1995; Ladd et al. 1995; Plambeck & Snell 1995; Yokogawa et al. 2003). The outflow is clumpy, with significant small-scale structure, and a fast component in H I (Giovanardi et al. 2000). The outflow rate of $\sim 10^{-5}$ $M_{\odot}$ yr^{-1} is comparable to the infall rate (Ohashi et al. 1996; Saito et al. 1996). Many of the small-scale features are associated with similar structures in the jet and the HH objects. As in the optical HH objects, the molecular gas shows evidence for shocks, including X-ray emission (Rudolph 1992; Barsony et al. 1993; Favata et al. 2002; Bally et al. 2003).

The jet is embedded in an impressive infalling cloud of molecular gas (Lay et al. 1994; Ohashi et al. 1996; Saito et al. 1996; Momose et al. 1998; Takakuwa et al. 2004). The kinematics of the gas indicates infalling material with a central mass of $\sim$ 0.1–0.15 $M_{\odot}$, consistent with the mass estimate derived from the optical luminosity (Kenyon 1999) but much smaller than estimated from the binary orbit, $\sim$ 1.2 $M_{\odot}$ (Rodríguez et al. 2003). The infall rate is $\sim 5 \times 10^{-6}$ $M_{\odot}$ yr^{-1}, consistent with rates derived from the spectral energy distribution.

A striking reflection nebula yields additional information about the central object, the outflowing jet, and the infalling gas. Optical spectra indicate that at least one component of the central binary is an FU Ori object (Mundt et al. 1985; Carr et al. 1987; Stocke et al. 1988; Sandell & Weintraub 2001). Near-IR data show that this component is variable on short timescales (Liu et al. 1996). The nebulae is highly polarized, $p \sim$ 15%–20% at JHK, with vectors perpendicular to the outflow axis (Lucas & Roche 1996; Whitney et al. 1997). These data demonstrate that the nebula marks the boundary of a cavity produced where the jet flows out through the collapsing cloud.

L1551 IRS5 provides excellent tests for numerical models of star formation. In the current picture, gas in a molecular cloud core collapses into a star + disk system, where the central star slowly grows from material transported inward by the disk. Calculations of the collapse yield predicted images and spectral energy distributions for comparison with observations (e.g., Adams & Shu 1986; Adams et al. 1987; Adams & Shu 1988). In L1551 IRS5, models with a flattened infalling envelope surrounding a pair of circumstellar disks account for the images, polarization maps, and spectral energy distribution (Strom et al. 1985; Butner et al. 1991; Keene & Masson 1990; Kenyon et al. 1993a,b; White et al. 2000; Osorio et al. 2003).

5.3. RW Aurigae

Discovered as an irregular variable (Ceraski 1906) with an optical companion at a separation of 1.5 arcsec (Joy & van Biesbroeck 1944; Ghez et al. 1993, 1997; White & Ghez 2001), RW Aur may be a spectroscopic binary (Gahm et al. 1999; Petrov et al. 2001). In addition to the strong red continuum of a typical T Tauri star, the

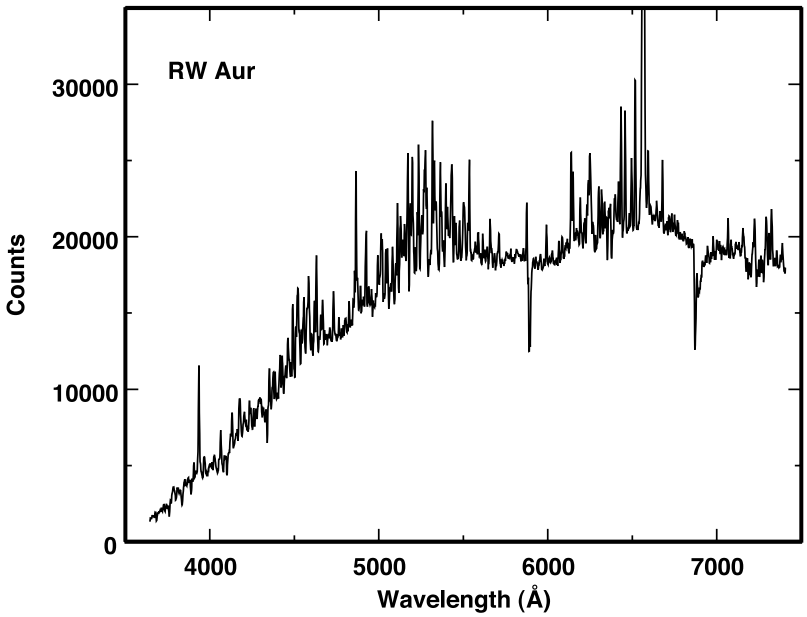

Figure 11. Optical spectrum of RW Aurigae from Kenyon et al. (1998). The spectrum shows a strong red continuum from a late-type star along with a weak blue continuum and strong emission lines from a hotter, optically thick source. Aside from the strong H I Balmer lines, the spectrum contains emission from [O I], [S II], Fe II, and [Fe II].

system has a strong UV continuum, hundreds of strong emission lines, and a prominent near-IR excess (Joy 1945; Herbig 1945; Mendoza 1966; Glass & Penston 1974; Shanin 1979). Because absorption lines from the underlying star are difficult to detect on most spectra, RW Aur and other T Tauri stars with similar spectra are often called ‘continuum + emission’ stars.

RW Aur is among the most active T Tauri stars. The optical continuum and strong line spectrum (Figure 11) vary irregularly on timescales of hours to months; there is a small amplitude variation with an underlying periodicity of 2.6–2.8 days (Herbig 1945; Gahm 1970; Appenzeller et al. 1983; Ivanova 1993; Gahm et al. 1999; Petrov et al. 2001). As the system brightens, the optical and near-IR colors become bluer; as the system fades, the colors become redder. Together with analyses of the optical spectrum, this behavior indicates a high accretion rate from the disk onto the central star.

The spectrum of RW Aurigae is distinct from most T Tauri stars. At low resolution, the absorption lines are almost completely veiled by a strong, blue continuum and many emission lines. At higher spectral resolution, the line ratios of temperature sensitive absorption lines imply a K7 or M0 spectral type, much cooler than the middle G spectral type estimated from early spectra (Hartigan et al. 1989, 1991). In the UV, a strong Balmer continuum demonstrates that dense gas with a temperature of roughly 10,000 K produces the blue excess (Imhoff & Giampapa 1980; Errico et al. 2000). Strong line emission from [C IV] and H_2 indicates a wide range of temperatures.

RW Aur also has a remarkable bipolar jet (HH 229; Bacciotti et al. 1996; Woitas et al. 2002b, 2005; López-Martín et al. 2003; Gómez de Castro & Verdugo 2003; Alencar et al. 2005; Pyo et al. 2006; Beck et al. 2008). The data indicate a well-collimated outflow from a small inner region of the disk, with variations on timescales of months to years. The jet may rotate close to the star, with high velocities in the C III] and Si III] lines suggestive of a rotating belt or ring close to the star[1]. At larger distances, the blue and red lobes of the outflow appear to have different helicities, as predicted by MHD theories. It is not clear whether changes in the jet are associated with fluctuations in the brightness of the underlying star and disk. With some evidence for a 20 yr period in the outflow rate, searches for similar timescales in the optical source might provide additional tests of jet models.

The structure of molecular gas around RW Aur is also interesting. RW Aur A lies within a small molecular disk (40–60 AU radius; disk mass $\sim 3 \times 10^{-4}$, Andrews & Williams 2005) in Keplerian rotation about the central star and oriented perpendicular to the bipolar jet (Cabrit et al. 2006). RW Aur B is within an asymmetric clump of gas connected to the RW Aur A disk by a 600 AU arm of material between the two stars. Cabrit et al. (2006) interpret this arm of gas as a tidal tail resulting from the orbital interaction of RW Aur A and B.

5.4. RY Tauri

RY Tau is embedded in an impressive reflection nebula (Herbig 1961; Petrov et al. 1999). The central star and the nebula are variable on hour to year timescales. Although emission lines from the nebula have been observed on several occasions, recent observations demonstrate a $31''(\sim$ 4500 AU) jet in Hα (St-Onge & Bastien 2008, see also Gómez de Castro & Verdugo 2007). The orientation of the jet on the sky is roughly perpendicular to the plane of the disk derived from polarization measurements. The young dynamical age of the jet system, short timescale optical variability, and strong intercombination emission lines suggest that this system might yield interesting clues concerning the structure of jets and the inner accretion disk (see also Schegerer et al. 2008).

The continuum and emission lines in RY Tau vary on timescales of hours to months with no obvious periodicity (Figure 12; Dragomiretskaia & Tsessevich 1971; Zajtseva et al. 1974; Zajtseva & Kurochkin 1980; Zajtseva 1982; Zajtseva et al. 1985; Herbst & Stine 1984; Holtzman et al. 1986; Ismailov & Rustamov 1987; Chugainov et al. 1991; Vrba et al. 1993; Beck & Simon 2001). On long timescales, the star usually becomes bluer when brighter and redder when fainter. Although the equivalent width of the Hα emission line often increases as the star fades, the absolute Hα flux declines. When the star is faint, large flares on hour timescales are common. The flares have blue colors, which requires a hot source. Occasionally, the star becomes bluer when it brightens and redder when it fades, indicating that variable extinction along the line of sight causes some fluctuations.

RY Tau is polarized, $p \sim 2\%$–3%, with variations on timescales similar to the fluctuations in the optical continuum level (Vardanian 1964; Efimov 1980; Bastien 1982). The magnitude of the polarization shows that the nebula partially obscures the central star. From high quality spectropolarimetry, Vink et al. (2003) suggest that much of the Hα emission is scattered off a rotating circumstellar disk (see also Koerner & Sargent 1995).

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[1] Coffey et al. (2007) describe evidence for rotation in the micro-jet of DG Tau.

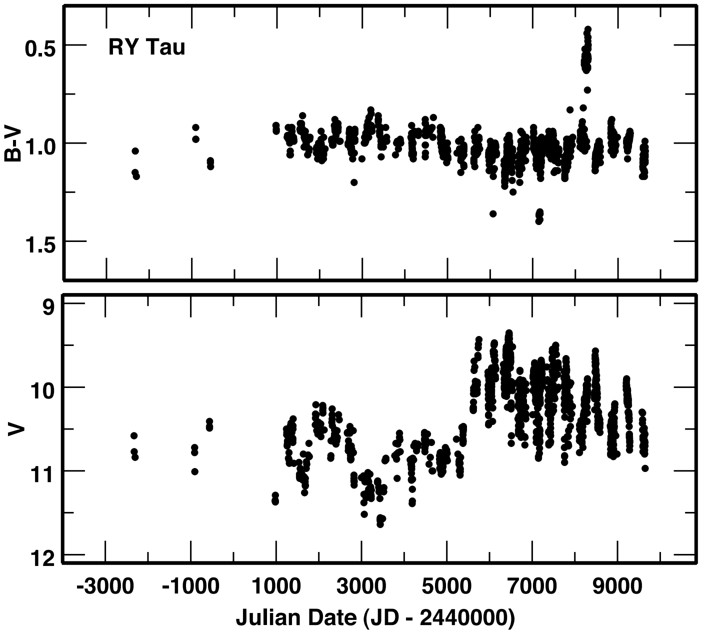

Figure 12. Optical light curve of RY Tauri using data from the literature (Herbst et al. 1994). The brightness and color vary irregularly on various timescales.

5.5. DR Tauri

DR Tauri is another 'continuum + emission' T Tauri star with a rich emission line spectrum. It is a member of the small group of 'EXors,' T Tauri stars that have brightened by 2–4 mag and remained bright for months to decades (Herbig 1989). As in most T Tauri stars, there is a strong UV excess from Balmer continuum emission and a large IR excess from material in the disk (Guenther & Hessman 1993; Kenyon et al. 1994; Skrutskie et al. 1996; Hessman & Guenther 1997).

The recent outburst of DR Tau is the slowest-developing of the EXor class. Prior to 1960, the star maintained B $\approx$ 14 for $\sim$ 30 yr (Chavarria-K. 1979; Götz 1980a,b; Kurochkin 1980). From 1960–80, the star brightened by $\sim$ 3.5 mag. As the system brightened, the colors became bluer. Since 1980, the star has remained bright with no evidence for fading as in some FUors.

The spectrum of DR Tau is highly variable. The emission lines and blue continuum have night to night variations of 0.5 mag and smaller variations on hour timescales (Bertout et al. 1977; Krautter & Bastian 1980; Kolotilov 1987; Appenzeller et al. 1988; Guenther & Hessman 1993; Kenyon et al. 1994; Hessman & Guenther 1997). There is some evidence for 5 day and 10 day periodicities in the continuum and the lines. These variations may reflect the underlying stellar rotation period. The IR continuum also varies (Kenyon et al. 1994; Skrutskie et al. 1996), suggesting strong correlations in activity between the hot source and the cool source.

Because the variations in the lines and continuum are so well-correlated, DR Tau is one of the best examples of magnetospheric accretion among T Tauri stars (Guenther & Hessman 1993; Kenyon et al. 1994; Hessman & Guenther 1997; Smith et al. 1997, 1999; Beristain et al. 1998; Mahdavi & Kenyon 1998). In this picture, a circumstellar disk produces the strong IR excess; changes in disk luminosity produce variations in the magnitude of the excess. A strong magnetic field truncates the disk several stellar radii above the stellar photosphere and channels material onto the star. Material in the stream is heated from roughly 1000 K (the temperature of the inner disk) to roughly 10,000 K. Shocked gas where the stream hits the star produces a wide range of emission lines. The large tilt of the magnetic axis with respect to the rotation axis produces variations in the UV continuum and line emission, including the apparent occultation of material in the stream or in the shock as these structures rotate behind the stellar photosphere.

Although a jet has not been discovered in DR Tau, the line profiles show evidence for accretion and outflow (Appenzeller et al. 1980; Alencar et al. 2001; Ardila et al. 2002). Deep narrow-band images might reveal whether the system has a jet.

5.6. HL Tauri

HL Tauri is a remarkable T Tauri star in a complex region of star formation. In the early 1980's, near-IR and mid-IR observations suggested an edge-on circumstellar disk surrounding a highly variable T Tauri star (Cohen 1983; Grasdalen et al. 1984; Beckwith et al. 1986). High resolution radio observations supported this interpretation; later observations indicated the disk lies at the center of a large-scale molecular inflow and outflow (Sargent & Beckwith 1987; Beckwith et al. 1989; Grasdalen et al. 1989; Monin et al. 1989; Sargent & Beckwith 1991; Rodríguez et al. 1992; Hayashi et al. 1993; Lay et al. 1994, 1997; Cabrit et al. 1996; Wilner et al. 1996; Brittain et al. 2005). The disk is geometrically flared and massive, with a radial temperature gradient close to that predicted by theory.

HL Tau is heavily embedded within an impressive C-shaped reflection nebula (Figure 13; Stapelfeldt et al. 1995; Weintraub et al. 1995; Close et al. 1997; Welch et al. 2000). On large scales, this nebula merges with nebulosity surrounding XZ Tau. In HL Tau, the star and the nebula are variable and highly polarized, indicating that the star is observed only in reflected light (Weintraub et al. 1995; Liu et al. 1996; Whitney et al. 1997; Lucas et al. 2004). Optical and near-IR spectra show a heavily veiled, K7-M0 spectral type, with strong emission from H I and various metallic lines (e.g., Cohen & Kuhi 1979; Carr 1989, 1990; Kenyon & Hartmann 1995; Kenyon et al. 1998).

In addition to the nebula, HL Tau drives a bright optical jet (HH 150) and an energetic molecular outflow (Mundt & Fried 1983; Cohen & Jones 1987; Torrelles et al. 1987; Mundt et al. 1987, 1988, 1990; Magakyan et al. 1989; Rodríguez et al. 1994; Monin et al. 1996; Mundy et al. 1996; López et al. 1995, 1996). This region has additional outflows from HH30 IRS, XZ Tau, and the optically invisible object HL Tau VLA-1 northeast of HL Tau (Mundt et al. 1987, 1988, 1991; Movsessian et al. 2007), which has complicated interpretations of the jet structure and driving mechanism. The nearby late-type T Tauri star LkHα 358 does not appear to drive an outflow, but deeper images might reveal more structure in this fascinating region.

Close to the star, there is a well-collimated micro-jet in [Fe II] with clear bipolar morphology (Pyo et al. 2006; Takami et al. 2007). Both components of the micro-jet lie within bubbles of H_2 emission (see also Beck et al. 2008). The length of the micro-jet, $\sim$ 150 AU, is comparable to the diameter of the bubble. The NE H_2 bubble lies within the scattered light emission in Figure 13). The much fainter SW component may lie within a much fainter bubble with similar structure.

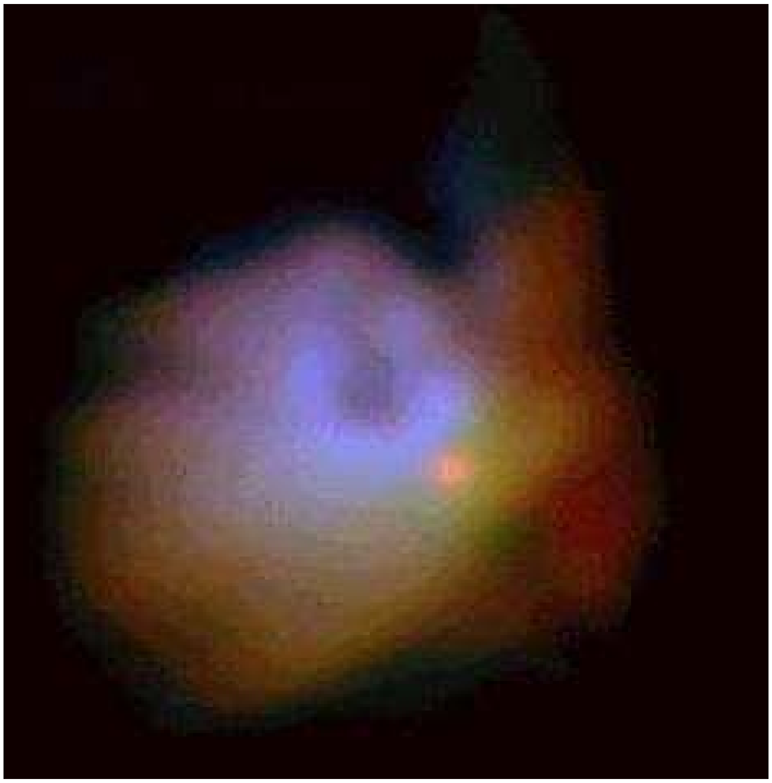

Figure 13. Image of HL Tauri in the I, J, and H filters from Close et al. (1997). The image is roughly $6''$ on a side. Blue colors (I) trace material close to the outflow cavity; green colors (J) trace material in the disk and infalling envelope; red colors (H) trace scattered emission from the star and highly reddened light in the disk.

5.7. Haro 6-10

Haro 6-10 is a relatively nondescript young binary star driving a remarkable giant HH flow. After Haro (1953) discovered the Haro 6-10 emission knot, Elias (1978) detected a bright source with an IR excess at the base of a small fan-shaped nebula. The central binary has a separation of $\sim$ 1.2 arcsec (Leinert & Haas 1989; Menard et al. 1993; Koresko et al. 1999; White & Ghez 2001; Duchêne et al. 2004). The primary (Haro 6-10 S) has a late spectral type (Goodrich 1986; Carr 1990; Herbst et al. 1995) and may be a binary (Reipurth et al. 2004); the secondary (Haro 6-10 N) may be a continuum + emission star. The system also has a large far-IR excess and lies embedded in a dense envelope in a small ammonia core (Anglada et al. 1989; Sato et al. 1990). Haro 6-10 N appears to produce most of the far-IR excess.

The Haro 6-10 outflow consists of several small jets, a few HH knots, and a giant outflow with a length of 1.6 pc (Strom et al. 1986; Devine et al. 1999a; Movsessian & Magakian 1999; Reipurth et al. 2004). The original HH 184 is composed of a small set of knots subtending a wide opening angle. These knots are probably part of two independent flows ejected by each component of the binary. On small scales, Haro 6-10 S drives an optical jet (Movsessian & Magakian 1999) and a compact radio jet (Reipurth et al. 2004). On large scales, HH 410 and HH 411 mark the ends of the outflow. A few other knots, including HH 412, lie between the binary and the end of the outflow (Devine et al. 1999a).

Haro 6-10 is also an active mm and submm radio source. The system has a large-scale molecular outflow that is roughly aligned along the direction of the optical outflow (Terebey et al. 1989; Devine et al. 1999a; Stojimirović et al. 2007). Strong extended submm continuum emission from Haro 6-10 lies perpendicular to the outflow direction (Chandler et al. 1998; Motte & André 2001). There is some indication that the extended envelope is still infalling into the disk of Haro 6-10 (Chandler et al. 1998).

Like T Tau and L1551 IRS5, the Haro 6-10 binary varies significantly at near-IR wavelengths (Leinert et al. 2001). Some of the variations – including changes in the equivalent width of the 3.1 μm ice absorption band – are consistent with fluctuations in the line-of-sight extinction. However, some variations are probably associated with the binary components. Long-term monitoring of near-IR variability in the brightest Taurus-Auriga sources would provide a context for interpreting the variations in the more famous sources such as T Tau, L1551 IRS5, and Haro 6-10.

5.8. IC 2087

Located in the so-called Taurus Molecular Ring (TMR; e.g., Schloerb & Snell 1984; Cernicharo & Guélin 1987; Terebey et al. 1990; Tóth et al. 2004), IC 2087 is a small, bright reflection nebula (Hodapp 1994) embedded in a dense ammonia core associated with L1534 (Benson & Myers 1989), see Fig. 14. The bow-shaped nebula surrounds a very red T Tauri star (IC 2087 IRS; Allen 1972; Elias 1978), associated with a molecular outflow (Heyer et al. 1987). The source is a bright IRAS source, with a Class II mid-IR to far-IR spectral energy distribution (Beichman et al. 1986; Harris et al. 1988; Berrilli et al. 1989). Although initial work assigned an early B spectral type to the star, more recent spectra and the integrated luminosity suggest a highly reddened K4 PMS star (Kenyon & Hartmann 1995; White & Hillenbrand 2004). The K4 spectrum is heavily veiled, with strong Hα and Ca II emission but no obvious forbidden lines.

In addition to driving the molecular outflow, the central TTS is linked to two HH knots well outside the main body of the reflection nebula (HH 395A and HH 395B; Gómez et al. 1997). The knots are bright in [S II] but are not visible in H_2. A line connecting the two knots points back to a small indentation in the highly polarized reflection nebula ($\sim$ 2%–4% at JHK; Tamura & Sato 1989; Whitney et al. 1997) and the bright IR source.

The line-of-sight towards IC 2087 has been a popular laboratory for studying ice formation in molecular clouds (e.g. Sato et al. 1990; Tielens et al. 1991; Chiar et al. 1995; Brooke et al. 1996; Bowey et al. 1998; Teixeira & Emerson 1999; Shuping et al. 2001). As in other regions of Taurus-Auriga, H_2O ices and CO/CO_2 ices are detected along various sightlines through the cloud. The data indicate that the optical depth towards the TTS is larger than the optical depth through the cloud, which requires additional absorbing material along the sightline to the IR source.

5.9. VY Tau

VY Tau is an exceptional PMS star in the Taurus-Auriga dark clouds. The star is a close binary with a projected angular separation of 0.66” and approximate component masses of 0.6 $M_\odot$ and 0.25 $M_\odot$ (e.g., White & Ghez 2001; Woitas et al. 2001). The primary star has an M0 spectral type and is not veiled (Hartmann & Kenyon 1990;

Figure 14. Optical image of IC 2087 and surroundings (courtesy Thomas V. Davis). The image is roughly 1 degree on a side; north is up and east is to the left. A heavily reddened T Tauri star (IC 2087 IRS) and HH 395 lie within the bright reflection nebula at the center of this image. The dark areas are regions of high extinction within the B22 and L1527 dark clouds. Several protostars – IRAS04361+2547, IRAS04365+2535, and L1527 IRS – and at least one HH object – HH 192 – lie within the small dark clouds north and west of IC 2087. The bright pair of nebulous stars in the SE corner is a small group of binary T Tauri stars (V955 Tau, LkHα 332/G1, and LkHα 332/G2). The bright set of nebulous stars in the NW corner is another group of T Tauri stars (DO Tau, GM Tau, and the HV Tau triple system). These stars power several HH objects, including HH 230 and HH 831–834. Other fainter T Tauri stars and HH objects are scattered across the field.

Shiba et al. 1993; Valenti et al. 1993). The system has no IR excess and is not a mm source (Kenyon & Hartmann 1995; Osterloh & Beckwith 1995). However, the system is a bright X-ray source (Neuhäuser et al. 1995), with a modest rotational velocity of ~ 10 km s^{-1} (Hartmann & Stauffer 1989).

Unusual optical variability and spectroscopic activity distinguish VY Tau from other classical and weak-emission T Tauri stars (Meinunger 1969, 1971, 1980; Herbig 1977, 1990; Herbst et al. 1983; Stone 1983; Rydgren et al. 1984a). During decade-long periods of inactivity, the star is relatively faint, B $\approx$ 15, and the M0 absorption spectrum is conspicuous. The star then displays a fairly prominent 5.37 day period in its optical light curve, which is consistent with its expected radius and rotational velocity (Bouvier et al. 1995). During occasional active periods of 1–2 yr, the star brightens to B = 11-12 and develops an impressive emission spectrum with bright, low excitation lines from Fe I, Si I, Mg I. Although higher excitation lines from Fe II and the H I Balmer series are often present, they are weak. Both sets of features seem to vary at roughly constant equivalent width as the star varies between B = 11–14.

Herbig (1990) discussed several possible interpretations for the origin of the activity in VY Tau. With the discovery of a close companion, the two binary hypotheses currently seem most worthy of further study. If the fainter component of the system is surrounded by an optically thick ring or disk of dust, active periods might occur when the optical depth in the dust declined. Although close approaches of the two stars might induce active periods, the wide separation – $\sim$ 90 AU – probably precludes activity cycles with recurrence times of 1–2 decades. If deep mid-IR and submm studies of this system detect evidence for emission from a dusty ring or disk, detailed study of this emission might reveal clues to the origin of the amazing line spectrum.

5.10. L1527 IRS

Lying within a dense ammonia core (Benson & Myers 1989), L1527 IRS is the most deeply embedded protostellar source in the Taurus-Auriga dark clouds (e.g. Kenyon et al. 1990, 1993a,b; André et al. 1993; Kenyon & Hartmann 1995; Chini et al. 2001; Whitney et al. 1997; Hartmann et al. 2005; Furlan et al. 2008). Several groups have classified this system as a Class 0 source, implying that it lies at an earlier evolutionary stage than typical Class I sources (e.g., André et al. 1993; Chini et al. 2001). Detection of C_4H^- and other carbon-chain molecules suggests the nebula has interesting chemistry (Sakai et al. 2007; Agúndez et al. 2008; Sakai et al. 2008a,b,c; Hassel et al. 2008). Despite its relatively low luminosity of $\sim$ 1 $L_\odot$, the central young binary star drives a wide-angle molecular outflow, illuminates an enormous variable, bipolar reflection nebula, and powers a fascinating set of HH objects, HH 192.

At optical and near-IR wavelengths, L1527 IRS displays an almost perfectly symmetric bipolar reflection nebula with an angular size of more than 1 arcmin (Figure 15; Kenyon et al. 1993b; Eiroa et al. 1994; Tamura et al. 1996; Whitney et al. 1997). The eastern lobe of the nebula is much brighter than the western lobe and is highly polarized, with $p_K \sim 40\%$ to 60%. This lobe shows strong evidence for a large-scale outflow, with strong Hα, [O I], and [S II] emission lines on optical spectra (Eiroa et al. 1994; Kenyon et al. 1998) and two amorphous [S II] knots (HH 192A and HH 192B) on deep images (Gómez et al. 1997). A single small HH object (HH 192 C) lies several arcmin west of the reflection nebula. Deeper images on larger telescopes might detect additional optical jet emission from the western lobe of the nebula.

In addition to the HH objects, the bipolar nebula marks an impressive molecular outflow which lies perpendicular to an extended envelope of infalling gas (Myers et al. 1995; Fuller et al. 1996; Zhou et al. 1996; Bontemps et al. 1996; Tamura et al. 1996; Hogerheijde et al. 1997a, 1998; Chini et al. 2001; Loinard et al. 2002; Reipurth et al. 2004). The outflow lies in the plane of the sky and has a large opening angle of $\sim$ 50°. A binary cm radio source coincides with the position of the central, bright IRAS source (04368+2557); this region powers one or two outflows observed at cm and mm wavelengths as well as the optical HH objects.

As with many of the Class I sources in Taurus-Auriga, the evolutionary status of the L1527 IRS protostar in unclear. The massive infalling envelope, $\sim$ 0.5–1 $M_\odot$, and relatively low luminosity imply a very young central star with only a small fraction of

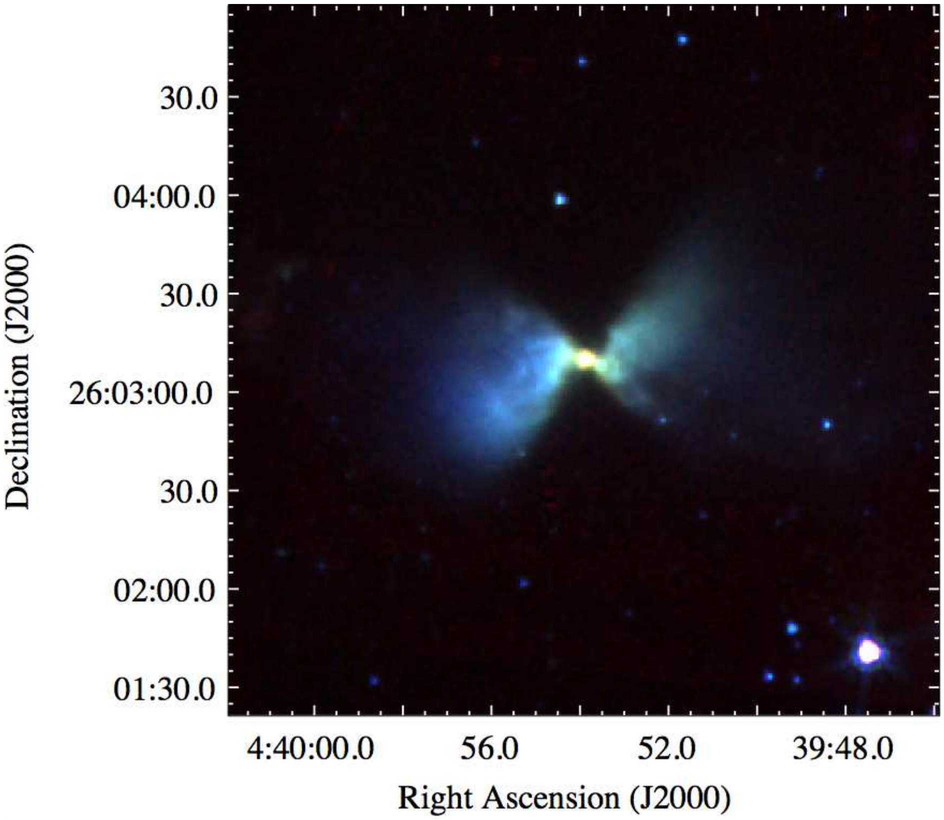

Figure 15. Spitzer image of L1527 IRS in the [3.6], [4.5], and [5.8] filters from the Taurus Legacy program (see Güdel et al. 2007a). Blue light ([3.6]) traces scattered light far away from the central protostar; green light ([4.5]) and red light ([5.8]) traces scattered light from material closer and closer to the protostar.

its 'final' stellar mass (Class 0 source). The geometry of the molecular outflow and the bipolar reflection nebula suggests that the central source lies embedded in an extended edge-on disk. Extinction from the disk and the infalling envelope produce the very red SED of the IRAS source (Kenyon et al. 1993a; Whitney et al. 1997; Andrews & Williams 2005); scattering from the outflow cavities produces the blue images and SED at IRAC wavelengths (Whitney et al. 2003, Robitaille et al. 2007; Tobin et al. 2008). This geometry complicates direct measurements of the luminosity and the evolutionary status of the central young star.

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