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Young Stars and Molecular Clouds in the IC 5146 Region

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Abstract. IC 5146 is both a reflection nebula and an HII region surrounding the B0 V star BD+46° 3474. The region is relatively nearby at 1.2 kpc. It has attracted considerable attention, and has been studied at optical, infrared, millimeter, and radio wavelengths. A substantial population of young low-mass stars exists in the region. IC 5146 is located at the eastern end of a more than 1 degree long cloud filament, which harbors scattered star formation, including the FU Orionis star Elias 1-12 = V1735 Cyg.

1. History and Distance

IC 5146, whose name has become attached to many studies of the much larger region centered at about l = 94°, b = –5°, is a bright nebula illuminated by the B0 V star BD+46° 3474 (see Figure 1). It is central in a bulbous dark cloud at the end of a long ($\sim 1\overset{\circ}{.}5$) dark streamer extending to the northwest, where there is a dark cloud complex that includes the so-called 'Northern Streamer' (Figure 2). Optical observations have been concentrated on the immediate region of IC 5146 and the nebulous HAeBe star BD +46° 3471, about 10 arcmin to the east.

The IC 5146 nebula was identified by Wolf (1904), who also noted the presence of the long, dark cloud. Hubble (1922a,b) classified the nebula as continuous, whereas Minkowski (1947) listed the nebula as having Hα emission. Both are right, since IC 5146 is a transition case between a reflection nebula and an HII region.

Walker (1959) suggested a distance to IC 5146 of 1.0 kpc based on UBV photometry and spectra of four late-B stars (W35, W62, W64, W76). Elias (1978) added infrared photometry and assuming normal energy distributions derived a distance of 900±100 pc. Crampton & Fisher (1974) derived a distance of 960 pc for BD +46° 3474 alone. Using modern calibrations and improved normal colors and absolute magnitudes, Herbig & Dahm (2002) re-determined the distance to the early-type stars associated with IC 5146, and found them to range from 1.0 to 1.4 kpc. As a compromise value, Herbig & Dahm (2002) suggest a distance of 1.2 kpc, with an uncertainty of ±180 pc just from the intrinsic dispersion of the relation between absolute magnitude and luminosity, without taking other additional errors into account. Harvey et al. (2008) derived a photometric distance of 950±80 pc using the Orion Nebula Cluster as a calibrator. Clearly, the distance to IC 5146 is still somewhat uncertain.

A large number of studies and surveys at different wavelengths have been performed in IC 5146 and associated clouds, which will be discussed in the following.

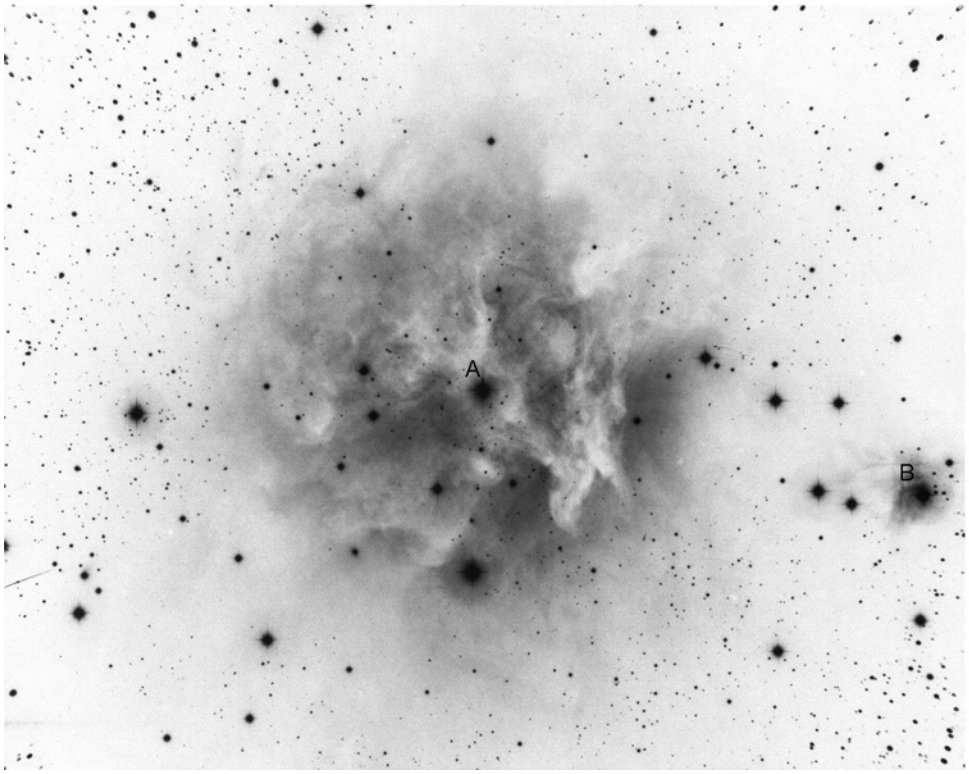

Figure 1. The IC 5146 region as seen in blue-violet light on a photographic exposure obtained by W. Baade with the 5 m Hale telescope. The area is about $20' \times 16'$, north is up and east is left. The star marked A is BD+46° 3474 and the one marked B is BD+46° 3471, both are young stars belonging to the cloud. From Herbig & Dahm (2002).

To facilitate a comparison between the areas surveyed in these studies, Figure 3 shows a Mercator projection of the entire region, outlining (approximately) the areas studied by various investigators; the identifications are explained below. The equinox is 2000 throughout. Figure 4 is a more detailed representation of the immediate region of IC 5146 in the same format as Figure 3. Boxes are identified as follows (solid line boxes indicate an optical or infrared investigation, dotted lines a molecular-line or radio continuum study):

Cambrésy: Extinction map from star counts done using the digitized USNO-PMM catalog (Cambrésy 1999).

Dobashi CO: ^{12}CO and ^{13}CO maps on $2'$ grid from Dobashi et al. (1992).

Elias 2 μm: Scan survey at H and K (to limiting K magnitude "fainter than +8"), at points spaced $45''$ in declination (Elias 1978).

Forte: UBVRI photographic photometry of about 1000 stars brighter than V = 20.5 (Forte & Orsatti 1984).

Herbig & Dahm 1: VRI photometry to about V = 22 in the area centered on BD +46° 3474; data are in Table 1 of Herbig & Dahm (2002). The position of that star is indicated by a black dot.

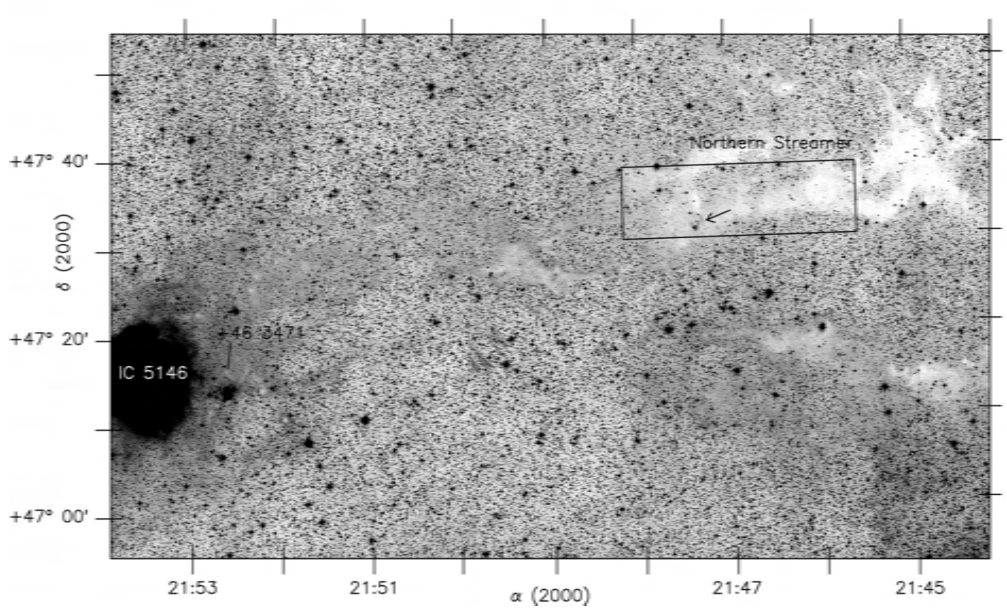

Figure 2. The IC 5146 region and associated clouds from red exposures of the Digital Sky Survey, extending from IC 5146 itself in the lower left to the "Northern Streamer"; the box encloses the smaller area studied by Lada, Alves, & Lada (1999) in some detail. A small arrow points to the FUor-type variable V1735 Cyg, discovered by Elias (1978) in the first near-IR investigation of the area.

Herbig & Dahm 2: VRI photometry in the area centered on BD +46° 3471; data are in Table 2 of Herbig & Dahm (2002). The position of that star is indicated by a black dot.
Israël 21 cm: 21 cm continuum map from Israël (1977).
Lada & Elmegreen: ^{12}CO and ^{13}CO map from Lada & Elmegreen (1979)
Lada CO 1994: JHK survey to about K = 13.8, and ^{13}CO, C^{18}O, CS molecular-line survey from Lada et al. (1994)
Lada 1999: Extinction map from H and K scans of the "Northern Streamer". The box shows the area surveyed in ^{13}CO from Lada et al. (1999)
Roger & Irwin: Line and continuum observations at 21 cm from Roger & Irwin (1982)
Sargent far-IR: 85 μm and 150 μm map from Sargent et al. (1981).
Wilking 2 μm: A small area surveyed to about K = 12.5 from Wilking et al. (1984)
Wilking 10 μm: Area surveyed at 10 μm, and to 20 μm in a smaller region from Wilking et al. (1984)

2. The Young Stellar Population in IC 5146

Walker (1959) used a combination of photoelectric and photographic photometry to identify about 20 variable stars in IC 5146 and a population of about 40 faint stars lying above the main sequence, suggesting that they are members of a population of young pre-main sequence stars. Herbig (1960a) carried out an objective-prism survey of the region, and identified about 20 emission-Hα stars surrounding BD+46° 3474 and BD+46° 3471.

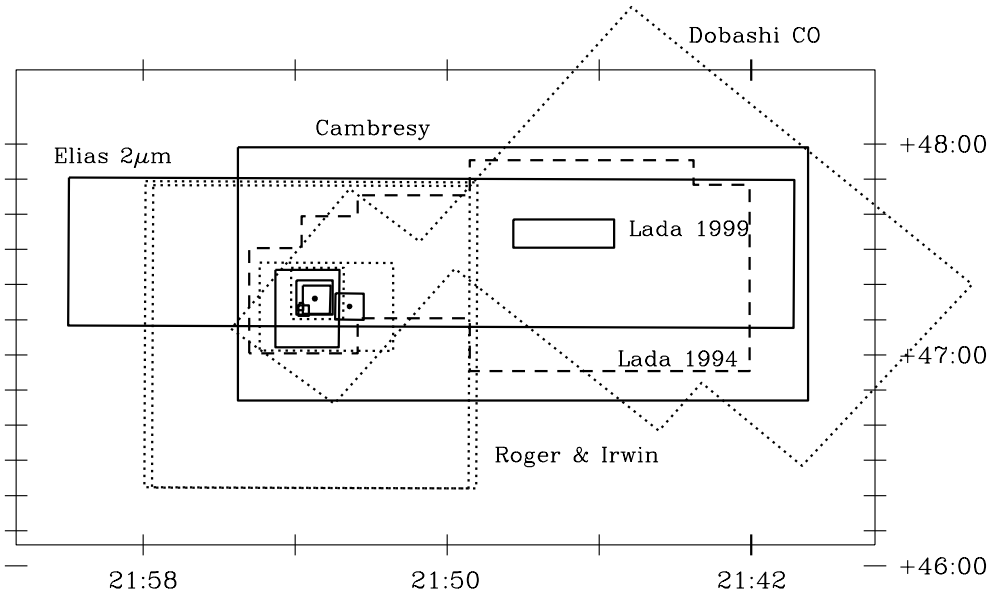

Figure 3. The relative positions of various large-scale surveys of the extended IC 5146 cloud complex in a Mercator projection. The coordinates of right ascension and declination are for equinox J2000. See text for details.

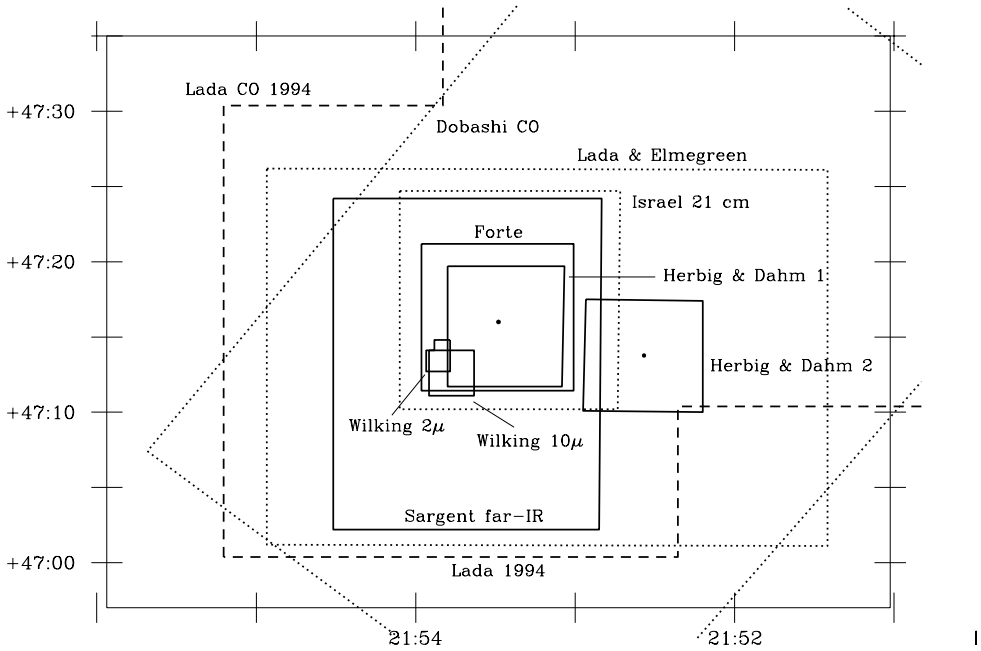

Figure 4. Similar to Figure 3, but for the inner region immediately around IC 5146.

Elias (1978) extended the search for young stars to the infrared and to the long dark cloud west of IC 5146. While the limiting magnitude of this early work was only K$\sim$8, and most of the objects found were field stars, Elias (1978) discovered a new FU Orionis object, Elias 1-12 = V1735 Cyg, which is discussed in more detail in Section 7.4. This object is not located in IC 5146 proper, but in the long dark tail extending to the west.

Sargent et al. (1981) and Wilking et al. (1984) made far-infrared maps of the IC 5146 region, and found that there is no evidence for any embedded massive stars, indeed the dust luminosity measured can be easily supplied by the main illuminating source BD+46° 3474. The IRAS sources towards the entire cloud complex containing IC 5146 are tabulated by Dobashi et al. (1992).

Forte & Orsatti (1984) provided photographic UBVRI photometry of more than 1000 stars brighter than V=20.5 mag around the IC 5146 complex. Based on a statistical analysis they conclude that the cluster contains some 110 stars with masses higher than 1.2 $M_{\odot}$.

Herbig & Dahm (2002) surveyed the IC 5146 region with CCD photometry in BVRI (to V = 22) and in JHK (to about K = 16.5). Additional grism images uncovered a total of more than 100 emission-Hα stars in two regions centered on BD+46° 3474 and BD+46° 3471. All emission-Hα stars in these regions are listed in Tables 1 and 2. A large number of pre-main sequence candidates were found in this study and are tabulated in the electronic version of the Herbig & Dahm (2002) paper.

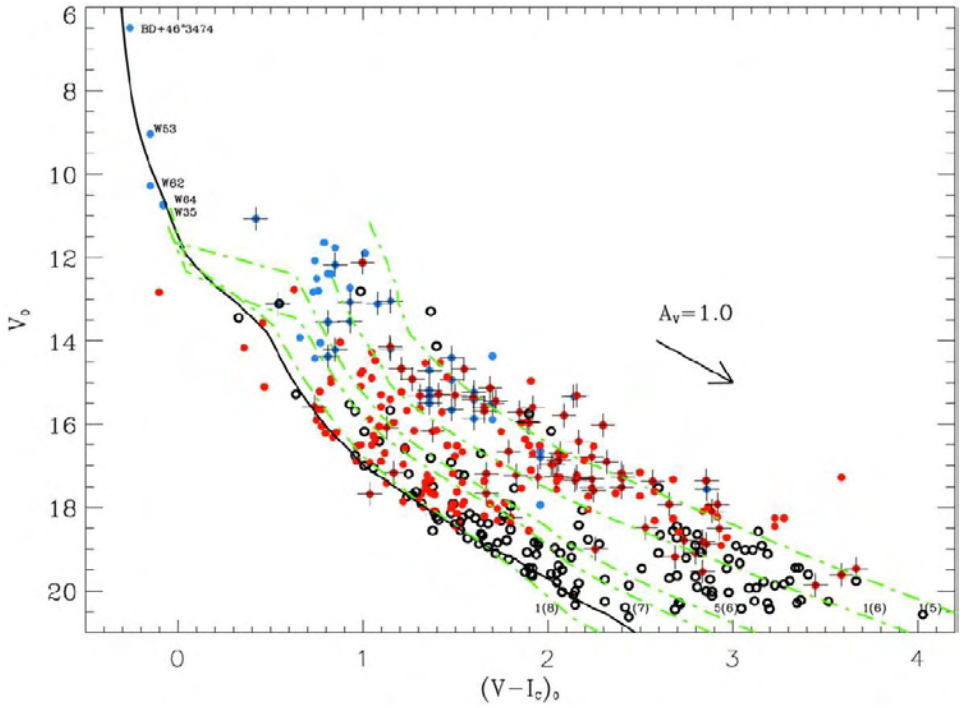

Figure 5. A color-magnitude V_0 vs. $(V–I)_0$ diagram of the IC 5146 cluster. Hα emitters with W(Hα) $>$ 10 Å are marked with crosses. For further details, see the original paper by Herbig & Dahm (2002).

The area is contaminated by a large number of foreground stars, but the distribution of just the Hα-emitters in the color magnitude diagram (Figure 5) suggests a median age of about 1.0 Myr for the cluster, with substantial dispersion. The shape of that dispersion depends upon the choice of isochrones (see Herbig & Dahm, their Fig. 11). The average extinction is about A_V = 3.0 mag.

From optical and radio radial velocities and the distribution of Hα emitters, Herbig & Dahm elaborated on a proposal by Roger & Irwin (1982) [see Sect. 4] namely that BD +46° 3474 formed rather recently near the front face of the cloud and evacuated a blister out of which dust and gas is streaming through a conical volume whose axis is inclined to the line of sight and is directed to the south-east. The Hα emitters are then regarded as an older population, now revealed by this cleaning-out process, that were previously concealed in that volume.

Most recently, Harvey et al. (2008) have performed an extensive study of the IC 5146 region including the long filamentary cloud using IRAC and MIPS onboard Spitzer. They identified more than 200 candidate young stellar objects using color-magnitude and color-color diagrams. They found an excellent correspondence with the population already identified by previous studies and additionally found many new objects, in particular towards the long streamer to the northwest. Figure 6 shows the distribution of the candidate objects from the Harvey et al. survey, which reveals three concentrations of pre-main sequence stars. The largest is the well known cluster towards IC 5146, and two other smaller groups are located to the northwest.

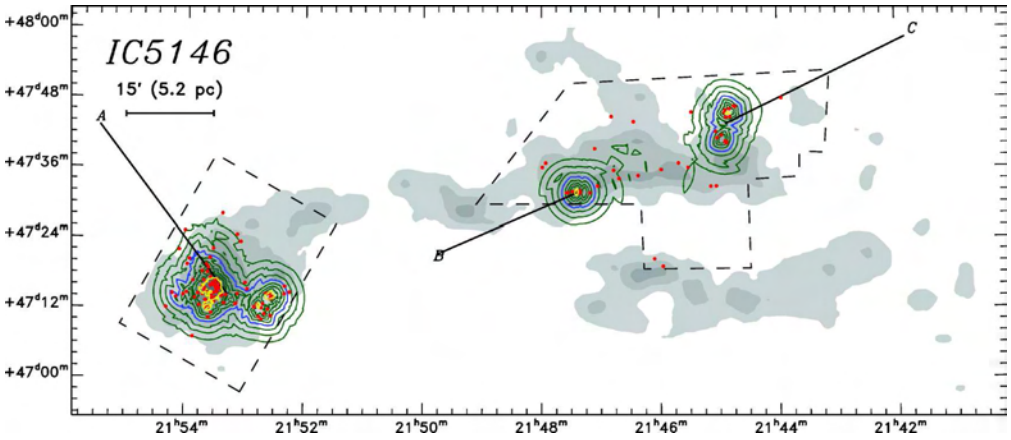

Figure 6. The young star candidates identified with five-band Spitzer photometry by Harvey et al. (2008) concentrate towards the IC 5146 cluster (A) and two more groups (B and C) in the cloud streamer to the northwest. From Harvey et al. (2008)

3. Cloud Identifications and Star Counts

In his paper 'On the dark markings of the sky, with a catalogue of 182 such objects', Barnard (1919) identifies a dark cloud, now known as B168, as follows: *This nebula is 10′ in diameter with over a dozen small stars of different magnitudes in it. There is no central condensation, nor does the nebula condense about any of the stars. There are some dark markings in it. The dark lane is 1.7° long and 9′ wide. See Lick Observatory Publications, 11, Plate 81.* Barnard here refers to the IC 5146 nebula and its associated long dark cloud.

Table 1.: Hα emission stars in the IC 5146 Region from Herbig & Dahm (2002).

Id[a]	W[b]	LkHα[c]	IHα	α_{2000}	δ_{2000}	V	R_C	J	W(Hα)[d]
17			104	21 53 8.45	+47 12 53.5	20.24	18.72		150.
18			105	21 53 8.64	+47 12 47.7	18.73	17.45		5.
21	22			21 53 9.06	+47 14 03.7	16.95	16.00		2.
32				21 53 11.38	+47 16 38.0	19.07	17.51	13.56	4.5
42			106	21 53 13.16	+47 18 28.4	19.10	17.95	14.90	76.
55	28			21 53 17.12	+47 17 18.4	17.00	15.93	13.34	1.5
66			107	21 53 18.49	+47 14 20.3	19.80	18.13	14.04	22.
67				21 53 18.52	+47 13 41.7	18.58	17.25	13.89	2.
77			108	21 53 19.61	+47 16 02.7	18.37	17.13	13.74	4. :
80			109	21 53 20.03	+47 18 11.4	19.16	17.75	14.16	4.
83	30	242		21 53 20.36	+47 12 58.0	18.08	16.56	13.63	300.
86			110	21 53 20.53	+47 14 56.6	22.20	20.58	15.66	55.
100				21 53 21.77	+47 13 33.0	18.39	17.12	13.94	1. :
108	31		111	21 53 22.49	+47 14 17.5	16.55	15.42	12.94	2.
111			112	21 53 22.72	+47 14 23.7	19.92	18.41	14.09	76.
113			113	21 53 22.84	+47 16 22.7	19.04	17.59	13.40	6.
116		243		21 53 23.06	+47 14 08.8	17.79	16.63	13.25	46.
120			114	21 53 23.39	+47 15 12.4	21.52	19.79	14.85	84.
124			115	21 53 23.69	+47 14 07.5	20.33	18.79	14.85	63. :
134			116	21 53 24.41	+47 16 35.0	19.98	18.38	14.10	5.
144				21 53 25.25	+47 14 57.6	18.04	16.71	13.31	2. :
148			117	21 53 25.82	+47 15 51.3	17.21	15.77	12.28	3.
154	36		118	21 53 26.40	+47 15 43.0	17.05	15.68	12.54	20.
159			119	21 53 26.70	+47 17 06.4	20.53	18.95	14.44	12.
160			120	21 53 26.70	+47 14 02.5	21.50	20.04	15.49	2. :
161			121	21 53 26.73	+47 17 44.6	21.83	20.22	15.34	14.
164			122	21 53 26.96	+47 14 13.5	19.51	17.99	13.43	10.
165			123	21 53 27.09	+47 16 57.8	17.57	16.05	12.08	2.
169		244		21 53 27.33	+47 14 50.5	18.96	17.48	13.57	em
170			124	21 53 27.49	+47 16 09.7	20.94	19.23	13.93	98.
171			125	21 53 27.51	+47 17 20.7		20.67	15.16	56. :
172	39			21 53 27.74	+47 15 11.5	16.83	15.69	12.68	6.
173			126	21 53 27.77	+47 15 22.8	18.98	17.40	13.82	8.
174			127	21 53 27.82	+47 15 42.0	18.33	16.68	12.42	16.
176			128	21 53 27.99	+47 13 45.2	19.43	18.00	13.78	53.
181			129	21 53 28.31	+47 16 48.3		21.51	17.70	em
182			130	21 53 28.38	+47 15 43.6	22.42	18.96	17.95	em
189			131	21 53 28.85	+47 16 53.0	20.37	18.44	13.13	13.
190	43		132	21 53 28.89	+47 16 13.5	18.80	16.90	12.05	60.
192			133	21 53 28.97	+47 15 30.3	19.18	17.93	14.36	em

a: Numbers from Herbig & Dahm (2002)

b: Numbers from Walker (1959)

c: Numbers from Herbig (1960a)

d: Hα equivalent width in Å; em = only emission, no continuum

Table 1.: Hα emission stars in the IC 5146 Region (continued)

Id[a]	W[b]	LkHα[c]	IHα	α_{2000}	δ_{2000}	V	R_C	J	W(Hα)[d]
196			134	21 53 29.22	+47 15 46.3	20.20	18.48	14.95	em
197			135	21 53 29.29	+47 15 14.8	20.67	19.16	13.88	24.:
205			136	21 53 29.84	+47 18 23.2	20.54	18.98	14.70	22.
209			137	21 53 30.30	+47 16 03.2	20.28	18.49	13.99	8. :
210	46	245		21 53 30.31	+47 13 13.8	15.11	14.07	11.42	32.
212			138	21 53 30.42	+47 16 53.5	19.88	18.21	14.09	15.
214			139	21 53 30.48	+47 13 11.1	15.14	13.98	13.39	3.
215			140	21 53 30.51	+47 14 44.0	17.84	16.50	13.41	24.
218			141	21 53 30.85	+47 16 06.2	21.80	19.06	14.21	em
225			142	21 53 31.38	+47 16 47.5	22.88	20.76	15.10	30.
228			143	21 53 31.74	+47 13 10.9	20.39	18.77	14.20	6.
229			144	21 53 31.80	+47 16 43.8	22.48	20.49	14.61	50.
231			145	21 53 31.84	+47 16 14.7	20.29	18.39	14.16	32.
234			146	21 53 31.93	+47 12 54.3	18.30	17.04	13.50	4.
236			147	21 53 32.09	+47 16 03.7	20.19	18.40	14.15	100.
237			148	21 53 32.16	+47 16 13.6	19.98	18.42	14.15	27.
243			149	21 53 32.91	+47 17 06.0	20.61	18.95	14.69	6. :
244			150	21 53 33.05	+47 15 22.7	20.69	19.47	16.51	115.
245			151	21 53 33.07	+47 14 39.1	21.25	19.54	15.37	117.
246			152	21 53 33.10	+47 16 18.9	22.55	20.68	14.81	27.
247	49		151	21 53 33.10	+47 16 09.1	16.23	14.99	12.19	1.5
249			153	21 53 33.24	+47 13 41.6	19.94	18.24	13.57	34.
252			154	21 53 33.76	+47 15 46.2	21.11	19.45	14.47	12.
256			155	21 53 34.10	+47 15 55.8	18.61	17.22	13.49	14.
257			156	21 53 34.11	+47 15 39.9	17.93	16.64	13.44	2.
261			157	21 53 34.14	+47 16 03.6	20.94		14.06	2. :
262			158	21 53 34.21	+47 16 04.2	20.27	18.60	14.08	10. :
270			159	21 53 34.76	+47 15 01.7	20.29	18.71	15.93	120. :
271			160	21 53 34.78	+47 14 00.7	18.33	17.03	13.90	13.
280			161	21 53 35.24	+47 16 22.8	18.70	17.21	13.71	1.5
288			162	21 53 35.89	+47 14 14.4	20.31	18.84	14.75	146. :
290			163	21 53 36.13	+47 17 06.4	18.15	16.62	12.91	9.
291		247		21 53 36.13	+47 18 36.0	18.27	16.95	13.78	16.
294			164	21 53 36.33	+47 13 42.6	20.18	18.99	15.70	200. :
308		248		21 53 38.21	+47 14 59.1	18.15	16.89	13.52	53.
310			165	21 53 38.40	+47 14 06.0	22.10	20.55	15.20	em
314			166	21 53 38.50	+47 12 31.1	19.71	18.14	14.26	18.
318			167	21 53 39.14	+47 15 00.1	22.01	20.54	15.78	em
320		249		21 53 39.47	+47 16 41.4	18.32	16.98	13.60	5.
321			168	21 53 39.49	+47 13 59.8	19.67	18.34	14.74	7.
325			169	21 53 39.99	+47 15 40.2	22.63	20.52	14.88	em

a: Numbers from Herbig & Dahm (2002)

b: Numbers from Walker (1959)

c: Numbers from Herbig (1960a)

d: Hα equivalent width in Å; em = only emission, no continuum

Table 1.: Hα emission stars in the IC 5146 Region (continued)

Id[a]	W[b]	LkHα[c]	IHα	α_{2000}	δ_{2000}	V	R_C	J	W(Hα)[d]
326		250		21 53 40.03	+47 15 26.1	17.15	15.85	14.00	160.
330			170	21 53 40.44	+47 15 08.6	18.61	17.26	13.48	em
333	59		171	21 53 40.63	+47 16 49.4	18.46	17.03	12.90	37.
338			172	21 53 41.34	+47 18 08.7	20.36	18.92	14.66	26.
341		251		21 53 41.83	+47 17 50.3	17.69	16.29	12.85	45.
346	61	252		21 53 42.06	+47 15 53.3	16.79	15.64	12.79	52.
347			173	21 53 42.38	+47 14 00.9	21.89	20.33	15.22	em
348		253		21 53 42.46	+47 18 24.9	17.68	16.31	13.28	118.
367	66			21 53 45.21	+47 12 35.0	14.10	13.27		1.6
369	68	254		21 53 46.44	+47 14 35.8	17.42	16.11	12.71	44.

a: Numbers from Herbig & Dahm (2002)

b: Numbers from Walker (1959)

c: Numbers from Herbig (1960a)

d: Hα equivalent width in Å; em = only emission, no continuum

Table 2.: Hα emission stars around BD +46°3471 from Herbig & Dahm (2002).

Id[a]	W[b]	LkHα[c]	IHα	α_{2000}	δ_{2000}	V	R_C	J	W(Hα)[d]
407			174	21 52 14.54	+47 14 24.2	16.75	15.88		7
444			175	21 52 19.63	+47 14 38.3	19.49	18.01	13.34	103
497	1	235		21 52 30.76	+47 14 06.9	16.38	15.28	12.72	50
514	4	236		21 52 32.64	+47 13 46.6	15.70	14.74	12.20	28
516	5	237		21 52 32.78	+47 14 10.2	17.18	15.89	12.41	80
525			176	21 52 33.29	+47 10 50.9	19.86	18.43	14.17	170
535		238		21 52 34.57	+47 14 41.2	17.58	16.44	12.79	74
544			177	21 52 36.22	+47 11 56.7	19.73	18.25	13.79	6
547		239		21 52 36.59	+47 14 37.3	17.42	16.18	12.62	35
581			178	21 52 40.30	+47 12 13.5	18.93	18.07	13.98	4
588			179	21 52 41.28	+47 12 52.5	17.65	16.49	13.40	11
590			180	21 52 41.53	+47 10 25.8	20.34	18.89		6
595			181	21 52 42.31	+47 10 35.6	22.44	20.85		25
597		240		21 52 42.75	+47 12 09.5	18.30	17.01	13.67	125
616			182	21 52 45.48	+47 10 40.3	21.42	19.73		10
617				21 52 45.59	+47 12 13.3	23.10	21.28	16.59	
622	10		183	21 52 46.59	+47 12 50.5	16.00	15.01	12.63	2
646			184	21 52 49.60	+47 12 18.0	19.05	17.70		22
657			185	21 52 50.24	+47 12 20.9	18.71	17.58	14.13	33
677			186	21 52 52.12	+47 12 18.7	19.84	18.44		20

a: Numbers from Herbig & Dahm (2002)

b: Numbers from Walker (1959)

c: Numbers from Herbig (1960a)

d: Hα equivalent width in Å; em = only emission, no continuum

Star counts can provide excellent extinction maps. The first attempt to use this technique in the IC 5146 cloud was by Samson (1975). A large-scale visual extinction map of the entire IC 5146 cloud complex based on modern automated star counts is shown in Figure 7 based on the POSS R plates (Cambrésy 1999). The cloud surrounding IC 5146 is seen to the east, while two parallel streamers are visible to the west. These two streamers are dubbed the Northern Streamer and the Southern Streamer by Lada et al. (1994), and are referred to in this way in many subsequent papers.

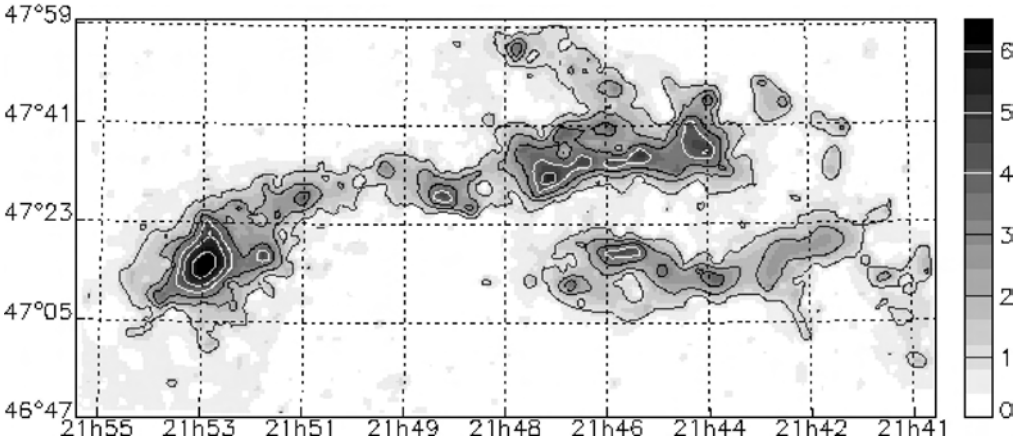

Figure 7. The entire dark cloud complex associated with IC 5146 is seen in this detailed map based on star counts. IC 5146 is located in the easternmost large cloud core. Iso-extinction contours are drawn, and the scale on the right indicates the visual extinction. Coordinates are J2000. From Cambrésy (1999).

Dobashi et al. (2005) have prepared an extinction map of the entire Galactic Plane, and have identified clouds and cloud cores. Figure 8 is from their atlas and shows a part of their Region 3-7 around IC 5146. The X-axis is Galactic latitude and the Y-axis is Galactic longitude. The left panel shows the clouds TGU 544, 545, 548, and 550 with associated cloud cores marked as P1, P2, etc. The right panel shows the same map with the nominal positions of the Lynds (1962) clouds in the region. Due to inaccuracies in the Lynds coordinates, the cloud identifications are in several cases uncertain. The TGU 550 cloud corresponds to Barnard's B168 cloud. The cloud core around IC 5146 is TGU 550 P3, and is also known as L1055. The Northern Streamer of Lada et al. (1994) is TGU 550 P1, P2, and P4, or L1035/1040/1042/1045, while the Southern Streamer is TGU 544/545/548, or L1010/1020/1030/1031.

4. The Ionized, the Atomic and the Molecular Gas

The early work on IC 5146 (aka S125, Sharpless 1959), starting with the first detection of radio continuum emission by Harris & Roberts (1960), focused on observations of the ionized gas and is summarized by Kuiper et al. (1976). More detailed observations have been done of HI at 21cm, mainly by Riegel (1967), Israël (1977), and Roger & Irwin (1982). The data support that BD+46° 3474 is the principal ionizing source in the region, without a need for another, more deeply embedded energy source. Roger & Irwin (1982) find that the total mass of HI associated with IC 5146 is about 445 ± 105 $M_{\odot}$ at their assumed distance of 960 pc. They combine their observations

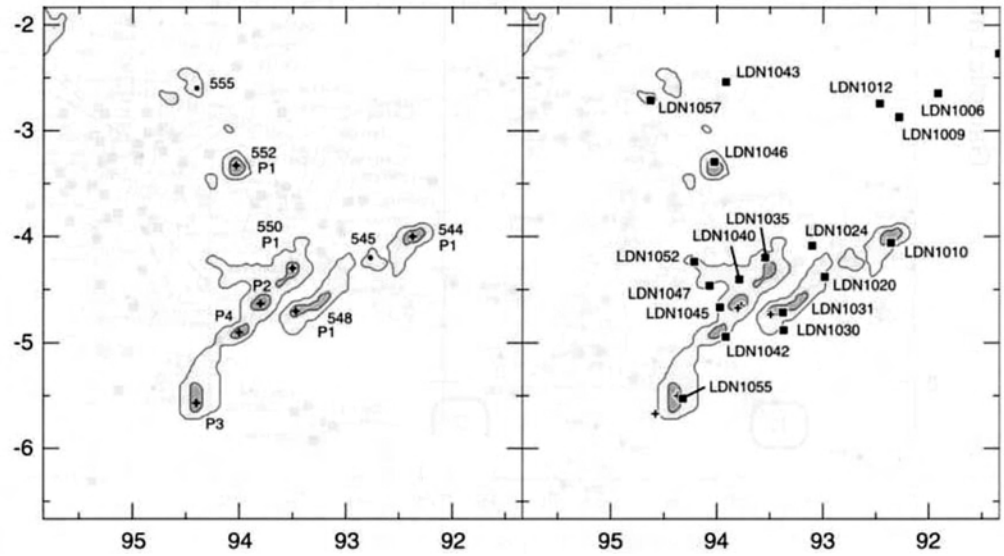

Figure 8. The dark clouds surrounding the IC 5146 region are identified in this extinction map from Dobashi et al. (2005), their region 3-7. The left map shows the new identifications of six clouds, TGU 544, 545, 548, 550, 552, and 555, with individual cores identified with P-numbers. The right map shows the Lynds (1962) identifications, with the nominal positions from the Lynds catalog marked with square boxes. The X- and Y-axes are in Galactic longitude and latitude, respectively.

of the ionized and neutral gas into a self-consistent model (Figure 9), with the ionizing source located 3 pc in front of the molecular cloud core and with the HII region opening up directly towards our line of sight. The age of the HI and HII regions is estimated to be about 10^5 yr, which is a factor of roughly 30 smaller than the estimated age of the cluster. At about half the present age of the HII region, the ionization on the near side of the cloud became complete, and the ionized gas then could stream outward with an observed velocity of about 5 km s^{-1} relative to the neutral gas, consistent with Fabry-Perot observations of the Hα line by Williamson (1970).

The molecular line observations of the IC 5146 region divide into two: those that focus on detailed studies of the area around IC 5146 itself, and larger-scale observations that probe the entire cloud complex. Lada & Elmegreen (1979) mapped the L1055 = TGU 550/P3 cloud region behind IC 5146 in ^{12}CO and found three cloud cores, with the HII region located between the three. McCutcheon, Roger, & Dickman (1982) have presented both ^{12}CO and ^{13}CO maps of the approximate same region with better sampling, and find a total mass of the three cores of about 440 $M_\odot$ (apparently assuming a distance of 960 pc).

Dobashi et al. (1992) made a large-scale map of a $\sim 3^\circ \times 2^\circ$ area with a $2'$ grid spacing covering the entire cloud complex seen in Figure 7 in both ^{12}CO and ^{13}CO. Assuming a distance of 1 kpc, they find a total mass of the complex of about 4500 $M_\odot$. Lada et al. (1994) present a higher resolution map of the same area in ^{13}CO, C^{18}O, and CS. Finally, Kramer et al. (1999) and Bergin et al. (2001) studied parts of the Northern Streamer in C^{18}O, C^{17}O, CS, and N_2H^+ and found evidence for a reduction of the abundance of CO and CS at high extinctions, presumably due to depletion of these molecules onto cold grain surfaces.

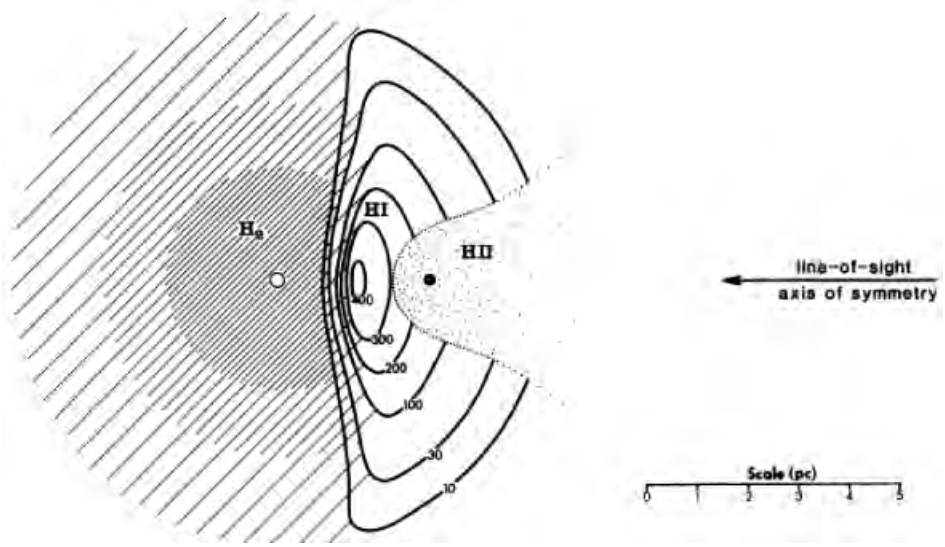

Figure 9. Based on their radio observations of the atomic and ionized gas in IC 5146, Roger & Irwin (1982) suggest a relative distribution of the HII region and the dissociated HI zone as indicated in this cross sectional view. The HII region opens up directly towards the observer. Contours of HI density are in units of cm^{-3}. The position of the exciting star BD +46° 3474 is marked by a filled circle.

5. Infrared Extinction and Dust Emission Studies

Lada et al. (1994) pioneered the use of infrared array cameras to study extinction through dark clouds by imaging the main section of the Northern Streamer (TGU 550 P1 and P2). By determining near-infrared color excess from JHK photometry for thousands of stars and combining with certain aspects of star counting they were able to map the dust column density to much higher extinction values than is possible with optical observations. In a follow-up study, Lada, Alves, & Lada (1999) examined a smaller section of the area previously observed, but with higher sensitivity, yielding a higher spatial resolution of the extinction map. The extinction measurements were compared to millimeter maps of the same area with the same angular resolution (see the previous section), among other things demonstrating that while $C^{18}O$ and CS emission varies roughly linearly with extinction, ^{13}CO emission saturates at cloud depths between 5-8 mag of visual extinction.

An additional result of the star counts is an independent estimate of the distance to the Northern Streamer. This distance is usually assumed to be the same as for the B-stars in IC 5146. By comparing the number of foreground stars (stars with no or little infrared excess) with predicted numbers from models of Galactic structure, Lada, Alves, & Lada (1999) found that the Northern Streamer is at a distance of about 460 pc. This is obviously a controversial result, since the Northern Streamer not only appears to be structurally connected to the IC 5146 cloud region, but the global velocity field of the CO emission changes smoothly from IC 5146 to the Northern Streamer (Dobashi et al. 1992, 2001). Clearly this contradiction needs to be resolved at some point.

Studies of submillimeter dust emission have been made in the Northern Streamer by Kramer et al. (1998, 2003) and agree well with the abovementioned dust extinction maps. By comparing SCUBA maps at 850 and 450 μm, they derive a map of the dust temperature, which shows significant temperature gradients, with temperatures of $\sim$20 K in the outskirts and between the cores, down to $\sim$10 K in the cores themselves. Their results are consistent with models that predict an increase of the 850 μm opacity in the cores due to grain coagulation and the formation of ices on the grain surfaces.

Samson (1976) studied the polarization towards 245 stars in the direction of IC 5146. The polarization vectors show a very complex pattern, suggesting that the magnetic field and associated aligned dust grains is very disturbed in this region.

6. Molecular Outflows

Molecular outflows were detected through pointed observations around the FUor V1735 Cyg and the HAeBe star BD+46° 3471 by Levreault (1983, 1988). Subsequently, Dobashi et al. (1993) found four molecular outflows around selected IRAS sources in the densest cores of the Northern Streamer (cores now known as TGU 550 P1 and P2). In a subsequent study, Dobashi et al. (2001) re-observed all six known IRAS sources in TGU 550 P1 and P2 with higher spatial resolution and better sensitivity, and found that all six (including Elias 1-12) drive molecular outflows.

7. Individual Objects of Interest

7.1. BD+46° 3474

This is the exciting star of IC 5146, and obviously a very young object, but high-resolution spectroscopy by Herbig & Dahm (2002) showed no sign of the line emission or P Cyg structure conventionally associated with HAeBe stars. It is apparently a normal B0 V with unusually narrow absorption lines. It is a close ($0\farcs9$) visual binary, but there is no evidence of velocity variation. The star is elongated and nonstellar in Spitzer IRAC and MIPS images, but the IRAC fluxes are consistent with no excess emission above the photosphere (Harvey et al. 2008).

7.2. BD+46° 3471

This is a slightly variable, classic HAeBe star (Herbig 1960b), and possibly an X-ray source (Zinnecker & Preibisch 1994). It illuminates a small reflection nebulosity, has two faint companions (one of which is an Hα emitter) and is centered in a small cluster of emission-Hα stars. There are also three faint HH objects nearby, discovered by Goodrich (1993). The complex spectrum of BD +46° 3471 has been described by earlier HAeBe investigators (references in Herbig & Dahm): there is a rotationally-broadened (about $v \sin i$ = 180 km s^{-1}) late B- or early A-type absorption spectrum plus emission lines of H and ionized metals.

7.3. IHα 130 and IHα 141

Two of the objects studied by Herbig & Dahm (2002) have unusual spectra, both showing forbidden emission line spectra resembling those of Herbig-Haro objects, but superposed on strong stellar continua and with additional emission lines found in certain

T Tauri stars. IHα 141 is slightly extended, and a long-slit spectrum shows velocities at about +200 km s^{-1} out to 1.″5 to the southeast, and at about -200 km s^{-1} out to 2.″2 to the northwest. Undoubtedly the star is driving a high-velocity bipolar micro-jet, now known as HH 898. Both stars are located very close to the bright star BD+46° 3474.

7.4. V1735 Cyg = Elias 1-12

This star, also known as HBC 733, was first recognized as a new FU Orionis variable by Elias (1978). The date of eruption is not known, but the time range has been narrowed to between 1957 and 1965 (Rodríguez et al. 1990). The star has become fainter with time at near-infrared wavelengths (Ábrahám et al. 2004). V1735 Cyg drives a molecular outflow (Levreault 1983, 1988, Evans et al. 1994, Dobashi et al. 2001) and is associated with a dense cloud core (Benson & Myers 1989). Sub-millimeter observations are presented by Weintraub, Sandell, & Duncan (1989, 1991), and Sandell & Weintraub (2001) discovered a bright embedded sub-millimeter source, V1735 Cyg SM1, about 20 arcsec northeast of the FUor (Fig. 10) and almost coincident with the source IRAS 21454+4718, which is therefore not related to the FUor. SM1 is too deeply embedded to be detected in the near-infrared, but an infrared reflection nebula is seen at its location (e.g., Hodapp 1994, Connelley et al. 2007). SM1 is most likely responsible for part of the molecular outflow towards the FUor. V1735 Cyg was detected in the 2 and 1.3 cm radio continuum by Rodríguez et al. (1990) and Rodríguez & Hartmann (1992), indicating the presence of free-free emission from an ionized outflow. Interestingly, the SM1 source was not detected. Near-infrared low-resolution spectra are presented by Sato et al. (1992) and Greene & Lada (1996), mid-infrared spectroscopy

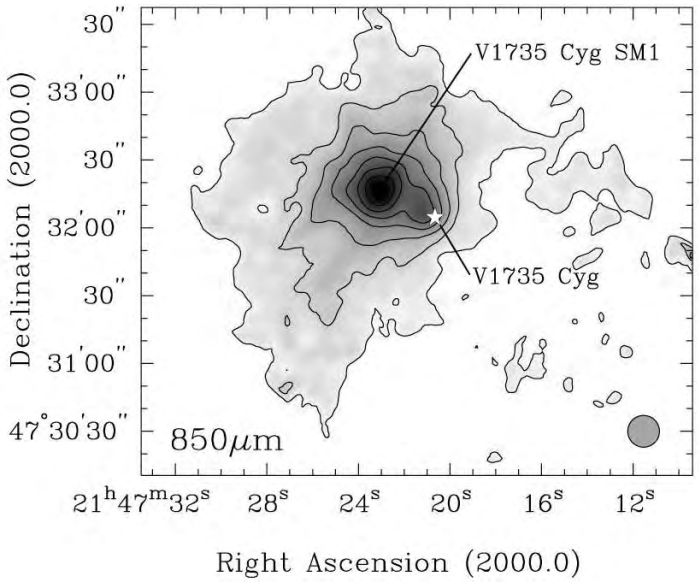

Figure 10. An 850 μm deconvolved map of the V1735 Cyg region with a resolution of 14 arcsec. The main source is not V1735 Cyg, but an embedded source to the northeast. From Sandell & Weintraub (2001).

is discussed by Hanner et al. (1998), and far-infrared spectra were obtained by Lorenzetti et al. (2000). Harvey et al. (2008) analyzed Spitzer data of the IC 5146 region, and list V1735 Cyg as their YSO #31; the submm source is also detected and is YSO #34, nearly as bright at 70 μm as V1735 Cyg.

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References

Ábrahám, P., Kóspál, A., Csizmadia, Sz., Kun, M., Moor, A., & Prusti, T. 2004, A&A, 428, 89
Barnard, E.E. 1919, ApJ, 49, 1
Benson, P.J. & Myers, P.C. 1989, ApJS, 71, 89
Bergin, E.A., Ciardi, D.R., Lada, C.J., Alves, J., & Lada, E.A. 2001, ApJ, 557, 209
Cambrésy, L. 1999, A&A, 345, 965
Connelley, M.S., Reipurth, B., & Tokunaga, A.T. 2007, AJ, 133, 1528
Couteau, P. 1987, A&AS, 67, 13
Crampton, D. & Fisher, W.A. 1974, Publ. DAO, 14, 283
Dobashi,K., Yonekura, Y., Mizuno, A. & Fukui, Y. 1992, AJ, 104, 1525
Dobashi, K., Onishi, T., Iwata, T., Nagahama, T., Patel, N., Nimesh, Snell, R.L., & Fukui, Y. 1993, AJ, 105, 1487
Dobashi, K., Yonekura, Y., & Hayashi, Y. 2001, PASJ, 53, 811
Dobashi, K., Uehura, H., Kandori, R., Sakurai, T., Kaiden, M., Umemoto, T., & Sato, F. 2005, PASJ, 57, S1
Elias, J.H. 1978, ApJ, 223, 859
Evans, N.J., Balkum, S., Levreault, R.M., Hartmann, L., & Kenyon, S. 1994, ApJ, 424, 793
Forte, J.C. & Orsatti, A.M. 1984, ApJS, 56, 211
Goodrich, R.W. 1993, ApJS, 86, 499
Greene, T.P. & Lada, C.J. 1996, AJ, 112, 2184
Hanner, M.S., Brooke, T.Y., & Tokunaga, A.T. 1998, ApJ, 502, 871
Harris, D.E. & Roberts, J.A. 1960, PASP, 72, 237
Harvey, P.M., Huard, T.L., Jørgensen, J., Gutermuth, R.A., Mamajek, E.E. et al. 2008, ApJ, 680, 495
Herbig, G.H. 1960a, ApJ, 131, 516
Herbig, G.H. 1960b, ApJS, 4, 337
Herbig, G.H. & Dahm, S.E. 2002, AJ, 123, 304
Hodapp, K.W. 1994, ApJS, 94, 615
Hubble, E.P. 1922a, ApJ, 56, 162
Hubble, E.P. 1922b, ApJ, 56, 400
Israël, F.P. 1977, A&A, 60, 233
Kramer, C., Alves, J., Lada, C.J., Lada, E.A., Sievers, A., Ungerechts, H., & Walmsley, M. 1998, A&A, 329, L33
Kramer, C., Alves, J., Lada, C.J., Lada, E.A., Sievers, A., Ungerechts, & Walmsley, C.M. 1999, A&A, 342, 257
Kramer, C., Richer, J., Mookerjea, B., Alves, J., & Lada, C. 2003, A&A, 399, 1073
Kuiper, T.B.H., Knapp, G.R., & Rodriguez Kuiper, E.N. 1976, A&A, 48, 475
Lada, C.J. & Elmegreen, B.G. 1979, AJ, 84, 336
Lada, C.J., Lada, E.A., Clemens, D.P. & Bally, J. 1994, ApJ, 429, 694
Lada, C.J., Alves, J. & Lada, E.A. 1999, ApJ, 512, 250
Levreault, R.M. 1983, ApJ, 265, 855

Levreault, R.M. 1988, ApJS, 67, 283
Lorenzetti, D., Giannini, T., Nisini, B., Benedettini, M., Creech-Eakman, M. et al. 2000, A&A, 357, 1035
Lynds, B.T. 1962, ApJS, 7, 1
McCutcheon, W.H., Roger, R.S, & Dickman, R.L. 1982, ApJ, 256, 139
Minkowski, R. 1947, PASP, 59, 257
Riegel, K.W. 1967, ApJ, 148, 87
Rodríguez, L.F., Hartmann, L.W., & Chavira, E. 1990, PASP, 102, 1413
Rodríguez, L.F. & Hartmann, L.W. 1992, Rev. Mex. Astron. Astrofis., 24, 135
Roger, R.S. & Irwin, J.A. 1982, ApJ, 256, 127
Samson, W.B. 1975, Ap&SS, 34, 377
Samson, W.B. 1976, Ap&SS, 44, 217
Sandell, G. & Weintraub, D.A. 2001, ApJS, 134, 115
Sargent, A.I., van Duinen, R.J., Fridlund, C.V.M., Nordh, H.L. & Aalders, J.W.G. 1981, ApJ, 249, 607
Sato, S., Okita, K., Yamashita, T., Mizutani, K., Shiba, H., Kobayashi, Y., & Takami, H. 1992, ApJ, 398, 273
Sharpless, S. 1959, ApJS, 4, 257
Walker, M.F. 1959, ApJ, 130, 57
Weintraub, D.A., Sandell, G., & Duncan, W.D. 1989, ApJ, 340, L69
Weintraub, D.A., Sandell, G., & Duncan, W.D. 1991, ApJ, 382, 270
Wilking, B.A., Harvey, P.M. & Joy, M. 1984, AJ, 89, 496
Williamson, R.A. 1970, Ap&SS, 6, 45
Wolf, M. 1904, MNRAS, 64, 838
Zinnecker, H. & Preibisch, Th. 1994, A&A, 292, 152