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Star Formation and Young Clusters in Cygnus

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Abstract. The Great Cygnus Rift harbors numerous very active regions of current or recent star formation. In this part of the sky we look down a spiral arm, so regions from only a few hundred pc to several kpc are superposed. The North America and Pelican nebulae, parts of a single giant HII region, are the best known of the Cygnus regions of star formation and are located at a distance of only about 600 pc. Adjacent, but at a distance of about 1.7 kpc, is the Cygnus X region, a $\sim$10° complex of actively star forming molecular clouds and young clusters. The most massive of these clusters is the 3-4 Myr old Cyg OB2 association, containing several thousand OB stars and akin to the young globular clusters in the LMC. The rich populations of young low and high mass stars and protostars associated with the massive cloud complexes in Cygnus are largely unexplored and deserve systematic study.

1. The Great Cygnus Rift

The Milky Way runs through the length of the constellation Cygnus, and is bifurcated by a mass of dark clouds in the Galactic plane (e.g., Bochkarev & Sitnik 1985). This wealth of molecular material has formed numerous young stars of different masses and with a wide range of ages. The IRAS catalogue contains thousands of infrared sources towards the Great Cygnus Rift, some of which have the characteristic colors of young newborn stars.

A key problem in studying the various star forming regions of Cygnus is the uncertainty in their distances. When we look towards Cygnus, we appear to look down a spiral arm, with the resulting confusion of regions as near as several hundred parsec with others at 1-2 kpc and even well beyond. Kinematical distances in this region are very unreliable for distances up to $\sim$4 kpc because of the near-zero radial velocity gradient, smaller than the typical velocity dispersion of interstellar gas. Many distance estimates are therefore based on spectroscopic studies of stars, although such distance derivations are severely affected by the often high extinction in the region. We discuss distances to individual regions in the following sections, but the uncertainty of such determinations should be kept in mind.

The most commonly studied areas in Cygnus are the North America and Pelican Nebulae, both prominently visible a few degrees east of α Cygni, and the socalled Cygnus X region, a large $\sim$10 degree wide radio emission feature (Piddington & Minnett 1952) composed of numerous individual HII regions. Historically, these individual regions were together called Cygnus X, since at the time of discovery it was not possi-

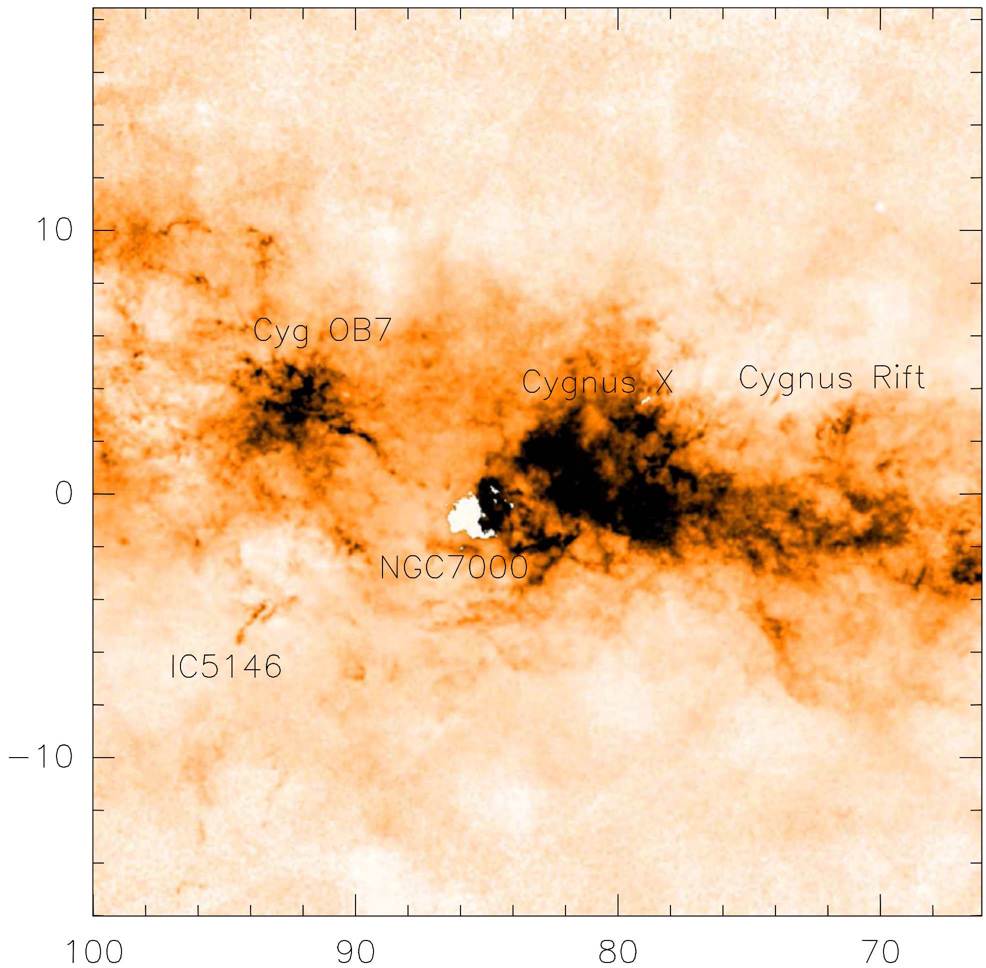

Figure 1. A map of visual extinction based on star counts in the Cygnus region. Dark regions represent high extinction. The X-axis is Galactic longitude, and the Y-axis is Galactic latitude. Based on data from Dobashi et al. (2005).

ble to spatially separate them. Piddington & Minnett just detected a large region with a thermal spectrum in their radio data and named this source Cygnus X in order to distinguish it from the well-known radio source Cyg A. (Cygnus X is thus *not* the name of an X-ray source as is sometimes assumed). Cygnus X is so bright that it is clearly seen as an enhancement in the pioneering radio skymaps of Reber (1944).

In the following we focus our discussion on the more important of these regions. It should be emphasized that a very large literature exists on the Cygnus region and the individual nebulae and clusters within it, so the literature cited here is representative rather than exhaustive. Also, there are so many interesting regions and individual objects in Cygnus that it is impossible to cover everything in a single chapter, so the discussion here inevitably is biased towards the authors' interests.

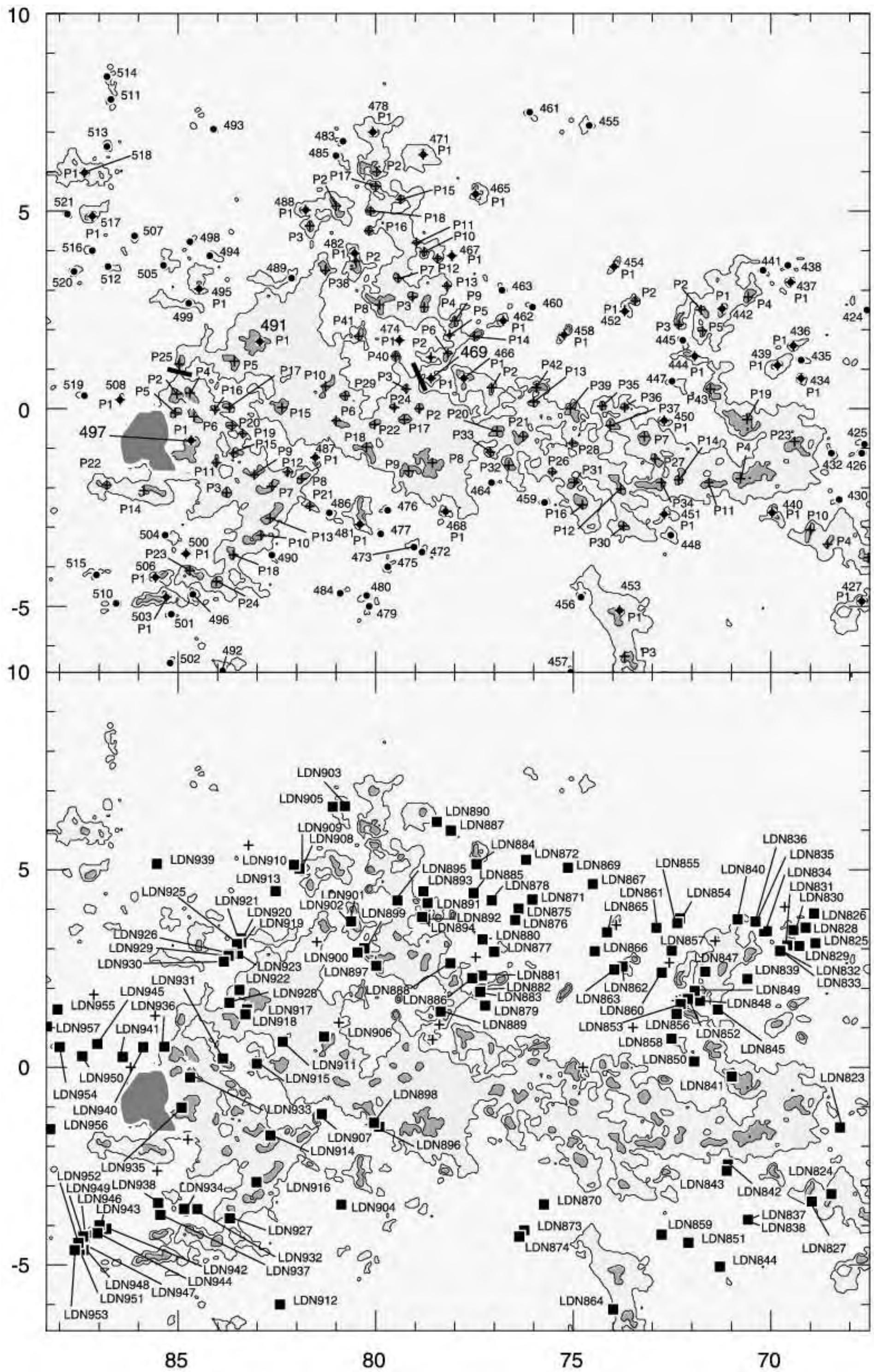

Figure 2. Cloud identifications in the central part of the Cygnus Rift. The upper panel refers to the TGU designations in the extinction atlas of Dobashi et al. (2005), and the lower panel indicates the nominal positions of the Lynds (1962) catalogue. Due to the poor coordinates for the Lynds clouds, it is not always obvious what cloud a number refers to. The axes are Galactic longitude and latitude. From Dobashi et al. (2005).

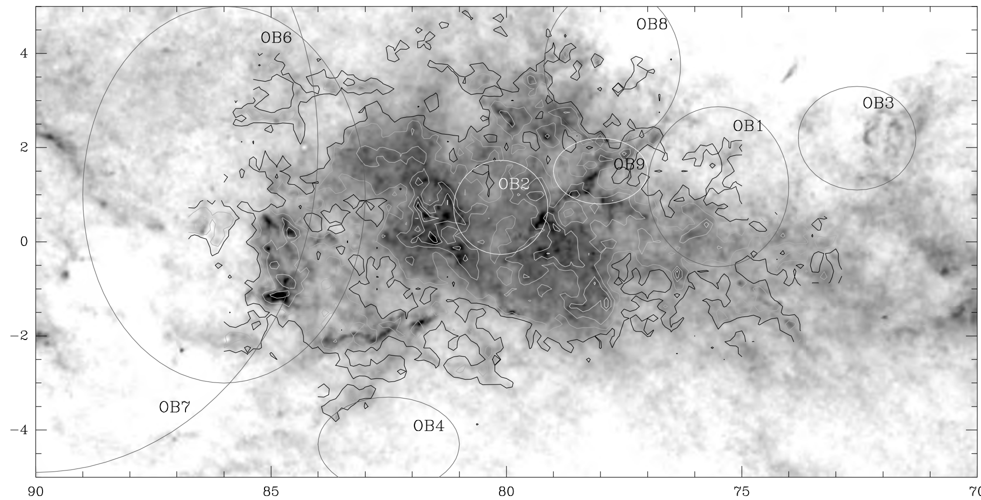

Figure 3. Visual extinction map (in Galactic coordinates) obtained from near-infrared 2MASS data expressed as visual extinction (Bontemps et al., 2008). A_v from 1 (white) to 32 (black) magnitudes. Overlaid are contours (20% to 100% of maximum intensity 39.7 K km s^{-1} in steps of 20%) of ^{12}CO 1→0 line integrated (–10 to 20 km s^{-1}) emission from the CfA survey. The grey ellipses represent the extent of the OB clusters (taken from Uyaniker et al. 2001).

Figure 1 shows the extinction from the main molecular cloud complexes in Cygnus based on the star count data by Dobashi et al. (2005). The figure shows the Galactic plane between longitudes 67° and 100°. The Great Cygnus Rift is most prominent to the right, and the 10 degree large Cygnus X region provides the highest extinction in the whole field. The North America nebula is indicated. At higher longitudes one finds the large cloud Kh 141 = TGU 541 associated with or in the line of sight towards the Cyg OB7 association. The small compact cloud which harbors the active star forming region IC 5146 (see the chapter in this book by Herbig & Reipurth) is at lower Galactic latitudes. Figure 2 shows the cloud identifications from the atlas by Dobashi et al. (2005) and the older designations by Lynds (1962).

A zoom into the central Cygnus region, comprising the North America and Pelican Nebulae and Cygnus X, is shown in Fig. 3. This extinction map was obtained from the reddening of J–H and H–K colors using 2MASS data (Bontemps et al. 2008) and correlates very well with contours of ^{12}CO J=1→0 emission from the CfA Columbia survey (Dame et al. 1987). The latter is the first large-scale millimeter transition survey of the Cygnus region (Cong 1977, Dame et al. 1987, Leung & Thaddeus 1992). Parts of Cygnus have been studied in CO or other molecular lines by Bally & Scoville (1980), Dame & Thaddeus (1985), Perault, Falgarone, & Puget (1985), Feldt & Wendker (1993), Dobashi et al. (1992, 1993, 1994, 1996), Schneider et al. (2006, 2007), and Simon et al. (2008) and will be discussed in Sections 2. and 3. The regions of highest column density are the Cygnus X region, forming two large complexes located at either side of Cyg OB2, and the North America/Pelican Nebula region. The various known OB associations in Cygnus (Humphreys 1978, Uyaniker et al. 2001) are indicated as well. The Cygnus Rift covers the whole Cygnus region with extinction up to a few A_v (Dickel & Wendker 1978) and has to be distinguished from the denser molecular clouds

Figure 4. This image, created by Jayanne English (U. of Manitoba) and Russ Taylor (U. of Calgary), shows the Cygnus X region as a composite plot using data from the Canadian Galactic Plane Survey (CGPS) and the Infrared Astronomical Satellite (IRAS). The field covers approximately from Galactic longitude 76° to 86° and Galactic latitude $-3.5°$ to $+5.5°$. The data have been colored such that synchrotron radiation appears as purplish-red (74 cm) and green (21 cm), and the IRAS bands in turquoise (60 μm) and 25 μm (blue). The bright circular clouds at the upper right and lower left are the Gamma Cygni (G78.2+2.1) and G84.2-0.8 supernova remnants. Red point-like sources are background radio galaxies and quasars. Courtesy the Canadian Galactic Plane Survey.

associated with OB clusters and located at different distances. Schneider et al. (2007) showed that CO emission due to the Cygnus Rift has high positive velocities (6–20 km s^{-1}) and a low column density. Piepenbrink & Wendker (1988) assume a distance of not more than 500-600 pc for the Rift.

The Cygnus region has been covered by a number of surveys at different wavelengths. The survey providing the highest angular resolution and coverage at the same time is the Canadian Galactic Plane Survey (CGPS, Taylor et al. 2003). Spectral line data of atomic hydrogen at 21 cm with a spatial resolution of $1'$ and continuum images at 1420 MHz ($1'$ resolution) and 408 MHz ($3.5'$ resolution) are available publicly. A composite picture (Fig. 4) released by the CGPS-team reveals the various features related to massive star formation in Cygnus. Blue-white compact nebulae indicate heated gas due to embedded, newly-formed stars, green emission is due to diffuse clouds of ionized gas and dark blue is from heated dust particles. At least two supernovae remnants are detected in the Cygnus X region. In the upper right corner, the remnant shell of Gamma Cygni (G78.2+2.1, e.g. Higgs et al. 1983, Prosch et al. 1996) is seen through its synchrotron radiation (rose) and in the lower left corner, the smaller source G84.2-0.8 (Uyaniker et al. 2003) is located close to the North America Nebula. Recently, Butt et al. (2003) detected a supernova-remnant-like structure in VLA 4.86 GHz data close to the center of Cyg OB2 and suggested that the very high energy (TeV-range) gamma-ray emission there may be due to a supernova remnant or cluster winds. Located further away from the Cygnus X region, the famous Veil nebula (NGC 6960, 6979, 6992, 6995 or G74.0-8.5) is part of one or even two supernova remnants known as the Cygnus Loop, located close to the star 52 Cygnus. The shattered stellar remains extend over several degrees.

Large scale surveys for Hα emission stars throughout Cygnus have been carried out by Coyne et al. (1974, 1975), McCarthy (1976), and Wisniewski & Coyne (1977). Some of these stars are likely to be young.

2. The North America and Pelican Nebulae

The North America Nebula, which was so named by Max Wolf (e.g., Wolf 1925), also known as NGC 7000, is the eastern part of the large HII region W80 (Westerhout 1958), whose northwestern portion is the Pelican Nebula (IC 5070). The North America Nebula and the Pelican Nebula are together also known as DR 27 (Downes & Rinehart 1966). This region has been recognized since the early days of astronomical photography (e.g., Duncan 1923, 1926), and numerous imaging studies exist (e.g., Morgan, Strömgren, & Johnson 1955). Radio continuum observations show that the two nebulae form a single large HII region about 3° in diameter bifurcated by the dense molecular cloud L935 (e.g., Wendker 1968, Wendker, Benz, & Baars 1983b). The overall extent and low density of the North America/Pelican Nebula complex indicate that W80 is an evolved HII region (Matthews & Goss 1980), and CO observations show that it is ringed by a complex and expanding network of molecular clouds (Bally & Scoville 1980). The North America and Pelican Nebulae each contain an association of T Tauri stars, providing evidence that star formation has occurred in the recent past (Herbig & Bell 1988). A small cluster and HII region, G84.0+0.8, on the western side of the Pelican Nebula is probably not associated with the W80 complex (Comerón et al. 2005).

The North America/Pelican region is located at a distance that has generally been estimated to be between about 500 pc to 1 kpc (Herbig 1958; Wendker 1968; Gieseking 1973; Goudis 1976; Goudis & Johnson 1978; Wendker, Benz, & Baars 1983b; Heske & Wendker 1985), although values as extreme as 200 pc and 2000 pc can also be found in the literature. More recent distance estimates place this region at the lower-end of this range. The currently most commonly adopted distance is 600 pc $\pm$50 pc, based largely on the work of Straizys et al. (1989), Straizys et al. (1993), Laugalys & Straizys (2002), and Laugalys et al. (2007), who used extensive multi-color photometry to determine color excesses, extinction and distances for hundreds of stars towards the North America/Pelican Nebula region. This distance is consistent with the relative paucity of stars in the foreground of the more opaque portions of the dark clouds associated with this

Figure 5. Between the North America Nebula and the Pelican Nebula lies the dark cloud L935 ('the Gulf of Mexico'), which is actively forming low mass stars. Image from the Digitized Sky Survey.

region. In a study of stars towards the obscuring cloud, L935, between the North America and Pelican Nebulae (Figure 5), Laugalys et al. (2006) found that extinction begins at a distance of 520$\pm$50 pc. Cersosimo et al. (2007) attempted to use Galactic rotation models to determine kinematic distances to various parts of W80, and found distances ranging from 0.7$\pm$0.5 kpc to 3.3 kpc, including regions unrelated to the W80 complex. In the following we assume a distance of 600 pc towards the North America/Pelican region.

2.1. Young Stars and Herbig-Haro Objects

The classical study of young low mass stars in the North America/Pelican Nebulae is the survey for Hα emission stars by Herbig (1958), who presents a list of 68 emission-line stars, including 4 that were found in the early surveys by Merrill & Burwell (1949, 1950). Herbig points out that in a region like Cygnus, where we are looking far down along a spiral arm, the Hα emission stars divide into two categories: Be stars which may be seen to large distances, and T Tauri stars, which are likely to be local to the North America/Pelican cloud complex. The stars discovered by Herbig (1958) are listed in

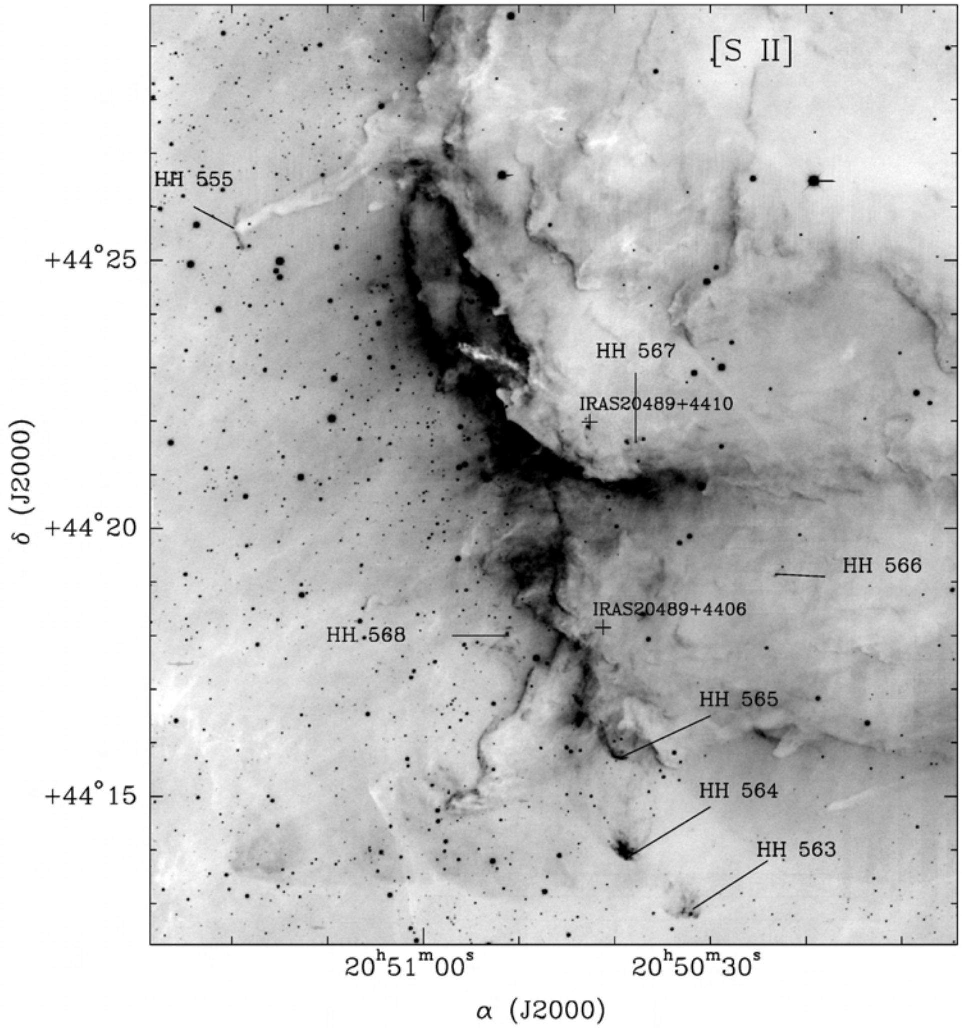

Figure 6. A bright-rimmed molecular cloud (part of IC 5067) located at the 'neck' of the Pelican Nebula is rich in Herbig-Haro flows. From Bally & Reipurth (2003).

Table 1; the brighter stars are likely Be stars, while the fainter ones represent a widespread population of T Tauri stars. The work of Herbig was followed by another survey by Welin (1973), who lists 141 Hα emission stars. However, a subsequent study by Gieseking & Schumann (1976) could only confirm a fraction of these stars as true Hα emitters. Further Hα emission stars were found by Tsvetkov (1975), Tsvetkov & Tsvetkova (1978), Marcy (1980), Melikian et al. (1987, 1996), Mendoza, Andrillat, & Rolland (1990), and Ogura, Sugitani, & Pickles (2002). Laugalys et al. (2006) did a photometric study of 430 stars towards the L935 cloud, which separates the North America Nebula from the Pelican Nebula, and suspected about 10% of them to be PMS stars. More recently, Armond et al. (2008) have found that the L935 cloud (Figure 5) does harbor a concentration of faint Hα emitters. In particular, Armond et al. (2008)

find that there is a small cluster of partly embedded low-mass pre-main sequence stars located around the previously identified LkHα 186-189 stars.

Table 1. Hα emission stars in the North America/Pelican Nebulae from Herbig (1958).

LkHα	α_{2000}	δ_{2000}	m_{pg}	LkHα	α_{2000}	δ_{2000}	m_{pg}
131	20 46 36.8	+43 44 35	13.5	163	20 51 58.8	+44 14 57	19
132	20 46 41.5	+43 46 48	16.0	164	20 51 59.2	+44 25 44	18.0
AS441[a]	20 46 45.6	+43 45 10	12.0	165	20 52 01.1	+44 28 42	18.5
133	20 46 49.2	+43 25 40	15.0	166	20 52 03.8	+44 37 29	17.0
AS442[a]	20 47 37.4	+43 47 25	11.5	167	20 52 04.7	+44 37 31	17.0
134	20 48 04.7	+43 47 26	12.0	168	20 52 06.1	+44 17 16	15.0
135	20 48 20.3	+43 39 49	11.5	169	20 52 07.6	+44 03 44	11.5
136	20 50 33.1	+44 15 39	19	MWC1032	20 52 09.6	+44 26 05	9.3
137	20 50 37.1	+44 18 25	17.0	170	20 52 12.8	+44 19 33	15.5v
138	20 50 37.0	+44 20 50	17	171	20 52 15.6	+44 28 11	19.0
139	20 50 40.4	+44 30 50	17.0	172	20 52 26.9	+44 17 07	16.0
140	20 50 45.0	+44 15 56	19	173	20 52 28.1	+44 03 31	18.5
141	20 50 52.7	+44 16 44	17.0	174	20 52 30.7	+44 20 12	18.5
142	20 50 53.9	+44 21 18	17	175	20 52 34.4	+44 17 41	18.5
143	20 50 53.9	+44 21 18	17	176	20 52 58.8	+44 15 04	12.5
144	20 50 55.7	+44 17 51	18.5	177	20 53 05.8	+44 42 37	18.5
145	20 50 58.8	+44 17 31	18.0	178	20 53 24.0	+43 54 18	17.0
146	20 51 01.6	+44 15 42	17.5	179	20 53 31.2	+44 23 27	17.0
147	20 51 02.8	+43 49 32	15.5	180	20 53 42.8	+44 03 49	18.5
148	20 51 03.4	+44 24 16	18.5	181	20 54 29.6	+44 45 28	18.5
149	20 51 04.7	+44 23 51	16.5	182	20 54 51.7	+45 15 06:	14:
150	20 51 15.2	+44 18 18	18.0	183	20 55 10.2	+45 03 03	12.0
151	20 51 15.7	+44 14 56	18.0	184	20 56 44.1	+44 04 14	17.0
152	20 51 16.6	+44 22 59	17.0	185	20 57 59.9	+43 53 26	17.0
153	20 51 21.1	+44 26 20	17.5	186	20 58 19.7	+43 53 55	18.0
154	20 51 22.8	+44 21 08	17.5	187	20 58 21.5	+43 53 45	18.5
155	20 51 26.8	+44 04 25	17.0	188	20 58 23.8	+43 53 11	15.0
156	20 51 27.0	+44 13 16	18.5	189	20 58 24.1	+43 53 54	17.5
157	20 51 32.8	+44 23 48	19v	190	20 58 53.7	+44 15 28	16.0
158	20 51 33.4	+44 26 37	17.5	191	20 59 05.8	+43 57 04	14
159	20 51 40.1	+44 33 15	19	192	20 59 17.3	+44 17 47	15.5
160	20 51 41.5	+44 15 06	19v	193	20 59 31.6	+44 35 45	14.5
161	20 51 42.0	+44 16 08	17.5	194	21 01 40.7	+44 19 44	14.0
162	20 51 42.2	+44 38 57	18.0	195	21 02 02.6	+43 30 46	16.5

[a] AS 441 and 442 are erroneously listed as LkHα 441 and 442 in SIMBAD.

Surveys have been made to find flare stars in the North America/Pelican Nebulae by Erastova & Tsvetkov (1974), Tsvetkov (1975, 1990), Tsvetkov & Tsvetkova (1978, 1990), Jankovics et al. (1980), Melikian (1983), and Chavushian, Tsvetkova, & Tsvetkov (1983).

Deep interference filter images of selected regions in the North America and Pelican Nebulae have revealed a number of Herbig-Haro flows, testifying to the presence

Table 2. Herbig-Haro Objects in the North America/Pelican Nebulae[a]

Object	α_{2000}	δ_{2000}	Comments
HH 555	20 51 19.6	44 25 36	Bipolar jet from tip of elephant trunk
HH 563	20 50 32.9	44 12 50	Bow most distant from I-front. Facing SW
HH 564	20 50 38.9	44 13 58	Brightest bow in Pelican. Facing S
HH 565	20 50 39.4	44 15 43	Large bow, near I-front. Facing S
HH 566	20 50 23.2	44 19 08	Knot in molecular cloud
HH 567	20 50 38.7	44 21 37	3 compact knots and faint knot, 1′ E of I-front
HH 568	20 50 51.1	44 18 02	Complex of [SII] knots in HII region
HH 569	20 50 29.5	44 03 40	Bright [SII] bow from isolated cloud
HH 570	20 51 22.8	44 04 30	[SII] jet at PA = 345°
–	20 51 18.4	44 06 24	Knot at N end of HH 570
–	20 51 23.8	44 03 44	Bow at I-front; S end of HH 570
HH 636	20 57 45.5	43 52 47	extends 1′ to S
HH 637	20 57 45.5	43 53 58	strong, knotty shape
HH 638	20 57 51.6	43 51 40	strong, knot shape
HH 639	20 57 55.5	43 50 15	strong bow-shock and larger fainter structure 1′ SE
HH 640	20 57 47.3	43 53 25	extends to E and W, 2′ wide
HH 641	20 57 52.7	43 54 02	other knot 7″ NW
HH 642	20 57 55.5	43 54 07	∼7″ wide
HH 643	20 57 56.5	43 52 52	∼7″ wide
HH 644	20 57 55.4	43 53 37	extends 30″ to NE
HH 645	20 57 59.6	43 54 07	extends to N and S, 40″ wide
HH 646	20 58 01.4	43 53 07	∼25″ wide
HH 647	20 58 02.3	43 54 09	weak, ∼20″ wide
HH 648	20 58 01.8	43 52 17	extends 3′ to NE
HH 649	20 58 12.5	43 53 03	extends 1′ to SW
HH 650	20 58 13.0	43 53 14	extends 1.′5 to S
HH 651	20 58 11.0	43 52 28	weak, 10″ long
HH 652	20 58 14.9	43 53 49	weak, other knot 14″ NE
HH 653	20 58 15.4	43 53 20	extends 17″ SE
HH 654	20 58 16.9	43 53 33	strong, stellar-like
HH 655	20 58 17.1	43 53 47	around star MKHα 11, 18″ wide
HH 656	20 58 18.6	43 53 11	extends 35″ to SE
HH 657	20 58 21.5	43 52 47	1.′3 long
HH 658	20 58 21.7	43 54 14	extends 36″ to NE
HH 659	20 58 21.9	43 53 54	extends 30″ to NE
HH 660	20 58 22.2	43 53 45	extends 10″ to NE
HH 661	20 58 27.9	43 53 25	extends 25″ to NE
HH 662	20 58 30.3	43 54 09	two knots, W and NE of star MKHα 31
HH 663	20 58 29.0	43 51 35	weak
HH 952	20 56 23.2	43 43 55	three weak knots, 2.′5 long across nebulous star
HH 953	20 56 41.6	43 48 39	very strong 24″ wide
HH 954	20 56 57.6	43 40 38	1.′2 SW from nebulous star
HH 955	20 58 14.3	43 46 13	triangular shape, 1.′5 SE from nebulous star
HH 956	20 57 02.8	43 41 46	knot near nebulous star
HH 957	20 58 26.5	43 54 00	weak jet-like 25″ long, W from star MKHα 28
HH 958	20 58 28.3	43 56 44	chain of four knots 1′ long

[a] HH 555–570 are from Bally & Reipurth (2003) and HH 636–663 and HH 952–958 are from Armond et al. (2008).

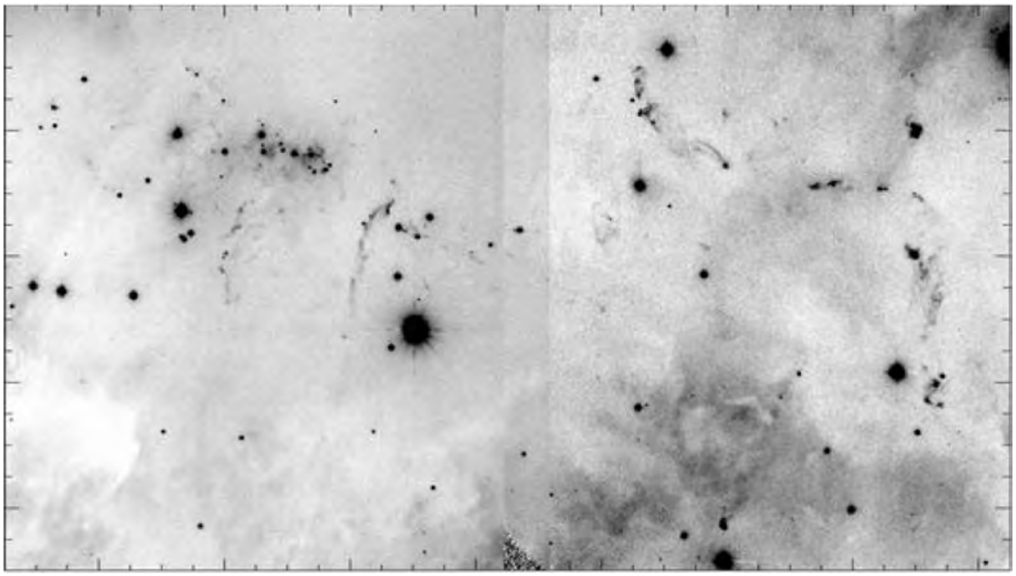

Figure 7. The north-eastern part of the L935 cloud between the North America and the Pelican Nebulae ("The Gulf of Mexico") contains numerous Herbig-Haro flows. From Armond et al. (2008).

of newborn stars in the associated clouds (Bally & Reipurth 2003). Table 2 lists the currently known HH flows in the region. These flows include a particularly interesting bipolar jet, HH 555, emerging from the tip of a major elephant trunk protruding into the Pelican Nebula from the adjacent molecular cloud (see Figure 6). Both beams of HH 555 bend towards the west, indicating deflection by a side-wind, probably caused by the expansion of the HII region. In a recent study of the L935 cloud (corresponding to the "Gulf of Mexico"), Armond et al. (2008) have found a major concentration of Herbig-Haro flows (Figure 7). Together with the many Hα emission stars also found by Armond et al., it demonstrates that the L935 cloud is a very active region of recent low-mass star formation.

Most recently, Stauffer et al. (2007) have reported on a major study of the North America and Pelican nebulae based on Spitzer data (IRAC 3-8 μm covering 5 deg^2 and MIPS 24-160 μm covering 6.2 deg^2) combined with BVI CCD images and 2MASS data. As a result they have found more than 700 sources with infrared excesses characteristic of YSOs (Guieu et al. 2008).

2.2. The Ionizing Source(s)

The identification of the source or sources of ionization for the North America and Pelican Nebulae has been attempted for 50 years, and seems only recently to have been resolved in a satisfactory manner. Osterbrock (1957) and Herbig (1958) presented early discussions of potential ionizing sources, and concluded that they would most likely be found as highly obscured stars behind the L935 cloud in the "Gulf of Mexico" region. This was further supported by the radio continuum observations of Matthews & Goss (1980), who found a number of ionized cloud rims, whose orientation points towards a location at the geometric center of W80 behind L935. Using deep I-band

Figure 8. The L935 cloud obscures the central region of the HII region of which the North America and Pelican nebulae form parts. The red dot marks the location behind the cloud of the ionizing source of the HII region, 2MASS J205551.25+435224.6, an O5V star identified by Comerón & Pasquali (2005). Image courtesy Robert Gendler.

images, Neckel, Harris, & Eiroa (1980) found a very red object, which is extremely bright in the near-infrared (L$\sim$2), and suggested this as the illuminating source of the W80 complex. However, further observations by Eiroa et al. (1983) showed it to be an evolved background star not related to W80. Bally & Scoville (1980) listed 11 infrared sources, among which the ionizing source(s) might be found. Wendker et al. (1983b) analyzed a 2695 MHz radio continuum map of the whole W80 cloud, and inferred the rather precise locations of 8 early type (O8 to B0) stars scattered throughout the ionized region. These stars are likely newly born and still ionize small cavities of gas in the surrounding dense molecular gas, thus contributing at least locally to the ionization of the region. Most recently, Comerón & Pasquali (2005) used the 2MASS catalogue with color selection criteria to identify 19 candidates behind the L935 cloud. Further near-infrared spectroscopy could exclude 18 of these objects. The remaining object, 2MASS J205551.25+435224.6, is a bright near-infrared object (K$\sim$5.0), and is also detectable in the optical (B$\sim$15.5, R$\sim$11.7). Optical spectroscopy reveals an O5V spectrum. Combined with optical/infrared photometry this indicates a star with about 9.6 magnitudes of visual extinction at a distance of 610 pc. The location is only 6 arcmin from the position inferred by Matthew & Goss (1980) from the orientation of bright rims, and it is star #10 among the candidate IR sources proposed by Bally & Scoville (1980). An O5V star produces three times as much ionizing flux as required by the radio continuum maps of W80, suggesting that this HII region is at least partly density-bounded. It is noteworthy that 2MASS J205551.25+435224.6 is surprisingly isolated, with no other stars of spectral type B2V or earlier located within 0.5°. Figure 8 shows the location of this source behind the L935 cloud. With Comerón & Pasquali's identification of 2MASS J205551.25+435224.6 as an obscured O5V star at the geometric center of the W80 complex, it appears that the long hunt for the ionizing star of the North America/Pelican Nebulae has finally succeeded.

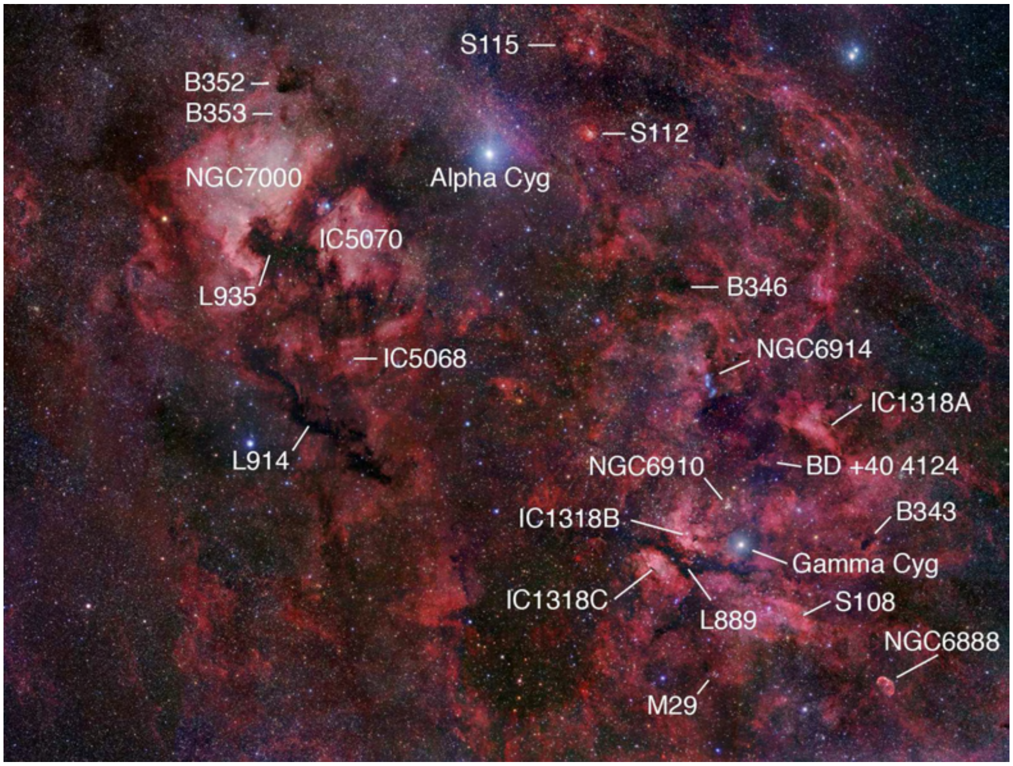

Figure 9. A red optical CCD image of the North America/Pelican and the Cygnus X region. The field is roughly $10° \times 13°$. North is up and east is left. Image courtesy Robert Gendler.

3. The Cygnus X region

Cygnus X is one of the brightest areas of the sky at all wavelengths and one of the richest known regions of star formation in the Galaxy. Figure 9 shows an optical wide-field CCD image of the Cygnus X region. The very high extinction as we see tangentially down along a spiral arm gives an appearance of a relatively calm area (Dickel & Wendker 1978). In reality this is a seething cauldron driven by thousands of OB stars and intense (massive) star formation activity. This is demonstrated by the existence of more than 40 massive protostars in regions such as DR21, DR21(OH), W75N, S106IR, and AFGL 2591, as well as embedded far-infrared sources in other regions (e.g., Campbell et al. 1980, Price et al. 1982). Also, recent Spitzer imaging (Hora et al. 2008) of the whole Cygnus X region, using the IRAC bands at 3.6, 4.5, 5.8, and 8 μm, and MIPS (24 and 70 μm), has revealed the full richness of this star formation region with thousands of young low mass stars and numerous high mass protostars. Figure 12 displays the 24 μm MIPS image.

A large number of radio surveys of this region exist, e.g. at 1390 MHz (Westerhout 1958), 5 GHz (Downes & Rinehart 1966), 408, 1420, and 4800 MHz (Wendker et al. 1984, 1991). Figure 10 shows the 1420 MHz Canadian Galactic Plane Survey (Taylor et al. 2003) at $1'$ angular resolution. More than 800 thermal continuum sources, i.e., HII regions, superimposed on a non-thermal background, are visible. The majority of the original sources DR4 to DR23 identified by Downes & Rinehart (1966) correspond to peak emission at this radio frequency (sometimes with slight shifts in position such as for DR9, DR10, DR11, DR13). However, a number of strong emission regions were not classified by Downes & Rinehart (1966) but they are found in other radio surveys (see references above) of the region. Among all the DR-sources, it is only DR7 that, most likely, is not linked to the Cygnus region. Molecular line data show molecular gas at a velocity that places DR7 in the Perseus arm, and Comerón & Torra (2001) determined a distance of $>$3.6 kpc. The radio image shows several supernova remnants (see, e.g., Uyaniker et al. 2001) including the well-studied source G78.2+2.1 (γ-Cygni), and an even larger number is required to explain the 'Cygnus Super-Bubble' (see Section 3.1.). Comerón & Torra (2001) identified near-infrared counterparts to compact HII regions in Cygnus X. The region has been surveyed for clusters by Dutra & Bica (2001), Le Duigou & Knödlseder (2002), and Bica, Bonatto, & Dutra (2003). The most important and influential feature in Cygnus X is the Cyg OB2 cluster (e.g., Reddish et al. 1966, Massey & Thompson 1991) near the center of the complex (see Sect. 3.2). Figure 11 shows the location of the most massive stars of Cyg OB2, whose intense UV radiation creates Photon Dominated Regions, visible in mid-IR emission at 8.3 μm observed with the Midcourse Space Experiment (MSX).

Humphreys (1978) divided the various OB stars in Cygnus into nine OB associations, listed with their approximate angular extents and distances in Table 3. Figures 3 and 13 outline the approximate locations of these OB associations. However, this early work was sensitive to extinction since obscured stars could not be included. Subsequently, Garmany & Stencel (1992) studied the OB associations incorporating point sources from the IRAS catalog. The distribution of bright 2MASS sources provides now a way to recognize compact (and therefore young) clusters of OB stars and to determine the stellar density of the brightest K-band sources (magnitude brighter than 13^m) by employing this extinction correction (see Bontemps et al. 2008 for details). Figure 13 shows the positions and sizes of 6 OB associations from the catalog of Uyaniker et al. (2001) overlaid on the MSX image together with contours of stellar density. It becomes obvious that Cyg OB2 at l = 80° is the richest and best defined association and corresponds well to its original definition by Humphreys (1978). Towards lower longitudes along the Galactic plane ($b\sim$0.5°), the stellar densities are still high but less consolidated. Mel'nik & Efremov (1995) proposed that OB1, OB8, and OB9 could actually be a single association centered at l = 76.8°, b = 1.4° at a distance of 1.4 kpc. Inside these associations, several concentrations have been recognized: NGC 6913 and IC4996 for Cyg OB1, and NGC 6910 for Cyg OB9. Altogether, however, only around

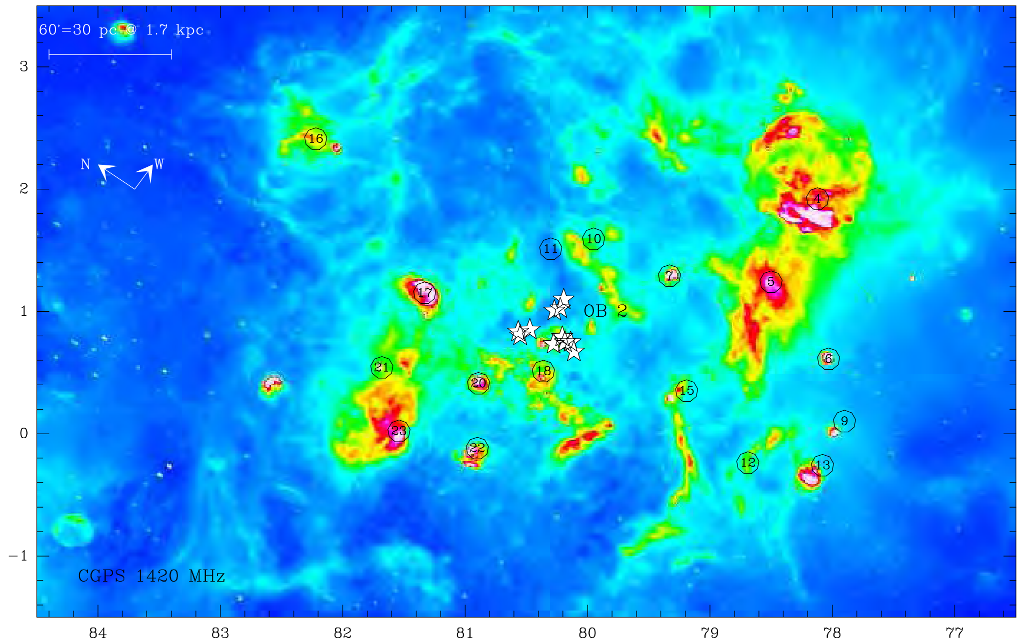

Figure 10. The Canadian Galactic Plane Survey (in Galactic coordinates) at 1420 MHz. Crosses indicate the positions of radio continuum sources (DR4 to DR23) as identified by Downes & Rinehart (1966). Asterisks indicate the most massive stars in the Cyg OB2 cluster.

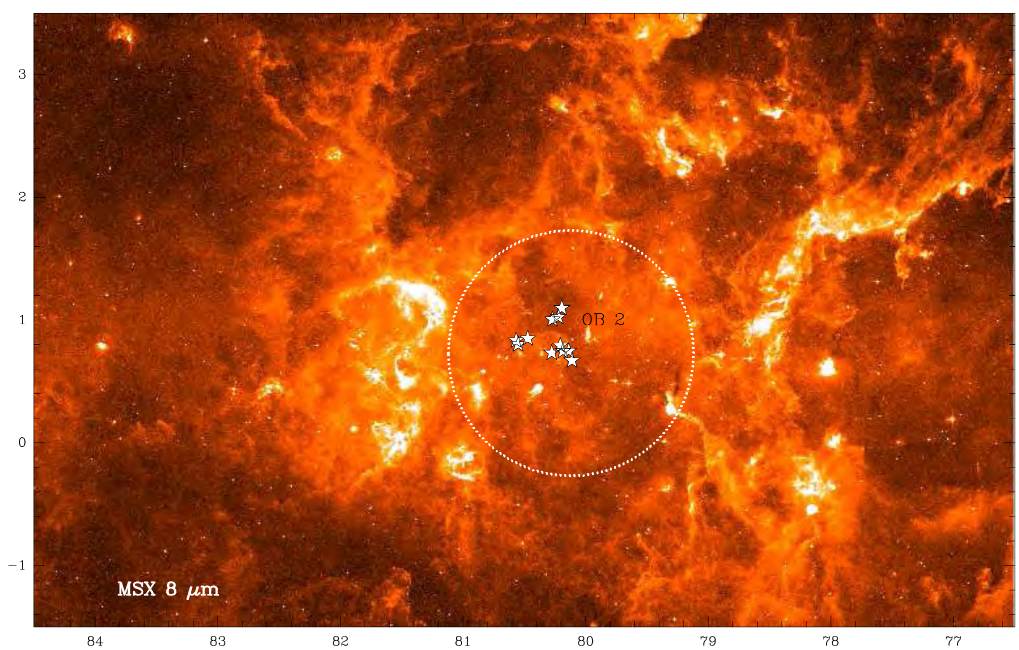

Figure 11. The Cygnus X region as seen at 8 μm by the MSX (in Galactic coordinates). Asterisks indicate the most massive members of the Cyg OB2 cluster and the dashed circle its extent. From Schneider et al. (2006).

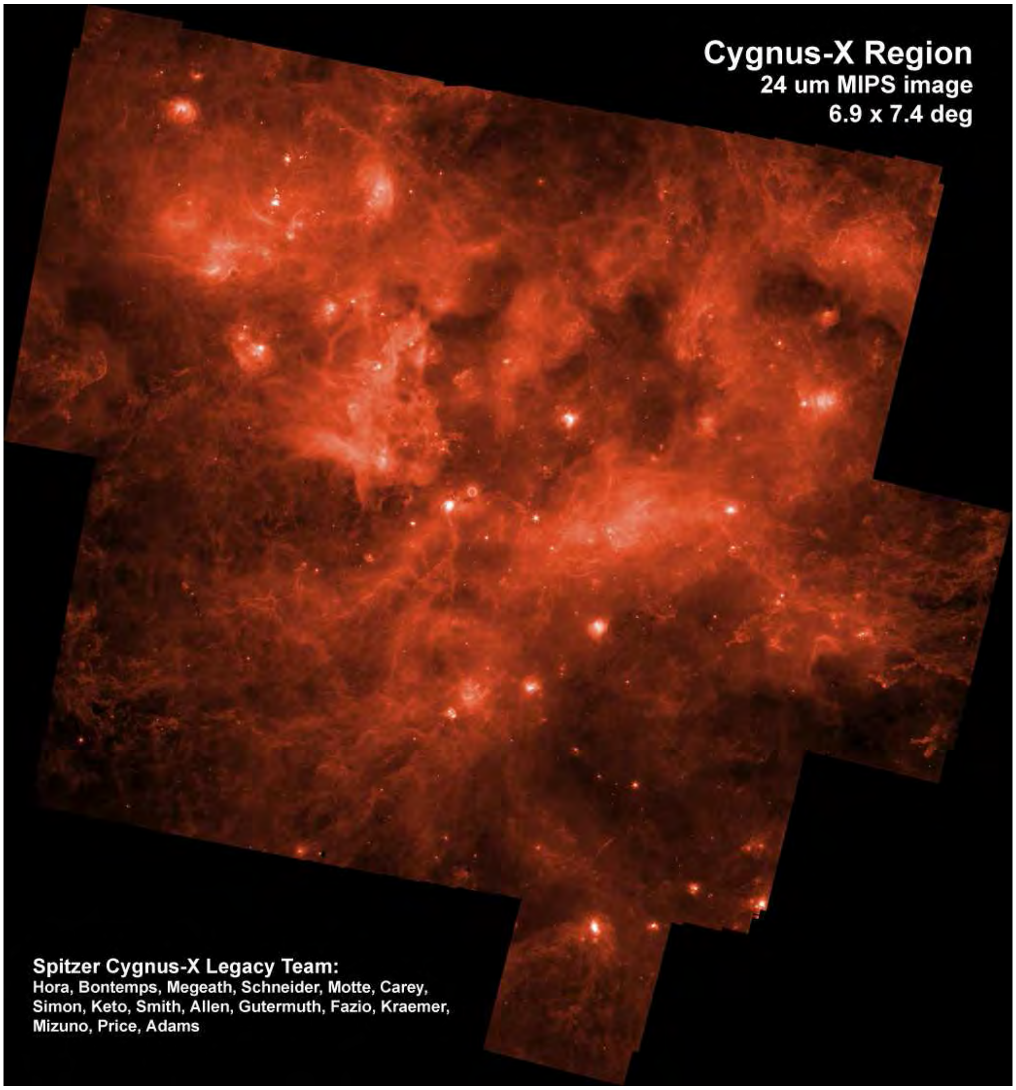

Figure 12. The Cygnus X region observed at 24 μm with MIPS on Spitzer. North is up and east is left. From Hora et al. (2008).

100 optical hot stars are known in OB1-8-9 (Mel'nik & Efremov 1995). In any case, it becomes obvious that the definition/classification of OB associations in the Cygnus X region needs to be revised.

Cygnus X also contains one of the most massive molecular cloud complexes of the nearby Galaxy. Figure 14 shows the distribution of molecular gas through the ^{13}CO 1$\rightarrow$0 line at 45$''$ resolution observed with the FCRAO (Simon et al. 2008). Schneider et al. (2006) derived a total mass of 3–4$\times 10^6$ M$_\odot$ for the Cygnus X molecular cloud complex based on a 2$'$ angular resolution ^{13}CO 2$\rightarrow$1 survey (Fig. 15) performed with KOSMA (Cologne observatory for submm-astronomy). Schneider et al. (2006, 2007) showed that the molecular clouds in Cygnus X form connected groups, and that the Cyg OB2 and OB1/9 associations directly heat the molecular material, implying that

Table 3. OB Associations in Cygnus. Adapted from Uyaniker et al. (2001).

Assoc.	l [°]	b [°]	Δl [°]	Δb [°]	dist[a] [kpc]	age[b] [Myr]
OB1	75.50	1.17	3.0	3.4	1.25-1.83	7.5
OB2	80.10	0.90	-	-	1.44-2.10	5.0
OB3	72.55	2.20	2.5	2.2	1.58-2.51	8.3
OB4	82.50	−4.30	3.0	2.0	1.0	[c]
OB5	67.10	2.10	5.8	9.6	1.61[c]	[c]
OB6	86.00	1.00	6.0	8.0	1.70[c]	[c]
OB7	90.00	2.05	12.0	13.9	0.74-0.80	13.0
OB8	77.75	3.75	2.9	3.3	2.19-2.32	3.0
OB9	78.00	1.50	2.0	1.4	1.17-1.20	8.0

[a] Distance interval in kpc as listed by Uyaniker et al. (2001), but see text for further discussion
[b] Age derived from HR diagram
[c] Very uncertain

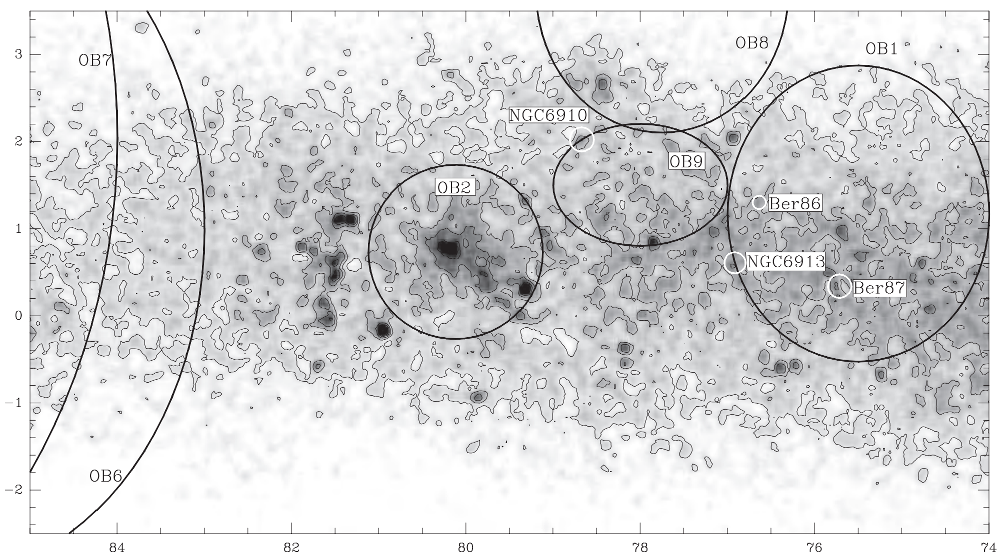

Figure 13. Contours of stellar densities brighter than K=13^m (Bontemps et al. 2008) in the Cygnus region (map in Galactic coordinates). The Cyg OB1, 2, 6, 7, 8, 9 associations are marked as ellipses and known stellar clusters are indicated.

the majority of objects seen in this region are located at the same distance, i.e., that of the OB1, 2, and 9 associations at $\sim$1.7 kpc. This is thus supporting the view of other authors (e.g., Véron 1965, McCutcheon & Shuter 1970, Landecker 1984) that Cygnus X can be understood simply as a large Strömgren sphere surrounding the Cyg OB2 and related associations. Schneider et al. (2006, 2007) also noted that the more diffuse emission at lower Galactic longitudes ('Cygnus X South') – compared to the more clearly defined filamentary structures seen in the DR21 region at higher longitudes ('Cygnus X North') – can be due to the fact that Cygnus X South is on the near side of Cyg OB2, and Cygnus X North on the far side. However, different evolutionary stages may also play a role.

In the following, we discuss some of the most interesting regions in Cygnus X.

3.1. The Cygnus Super-Bubble

The combined effects of stellar winds from massive stars and supernova explosions can produce large cavities filled with hot ($\sim$10^6 K) low-density ($\sim$10^{-3} cm^{-3}) gas (e.g., McKee & Ostriker 1977), called 'super-bubbles'. Very large expanding super-bubbles (reaching a size scale comparable to the thickness of the Galactic disk) break out of the Galactic plane and thus couple halo gas with the disk both chemically and dynamically. In the Milky Way, only a few such bubbles have been identified. One of those is the

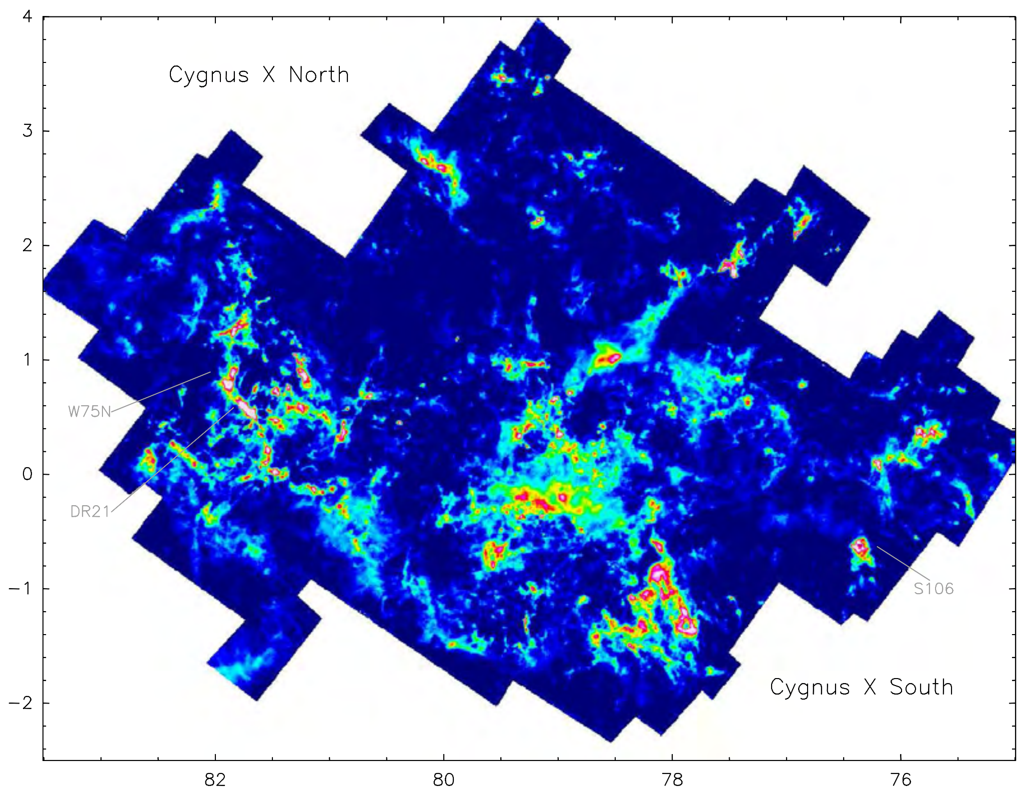

Figure 14. A 35 square degree ^{13}CO 1-0 map (in Galactic coordinates) of line integrated emission towards the Cygnus X region obtained at the FCRAO (Simon et al. 2008).

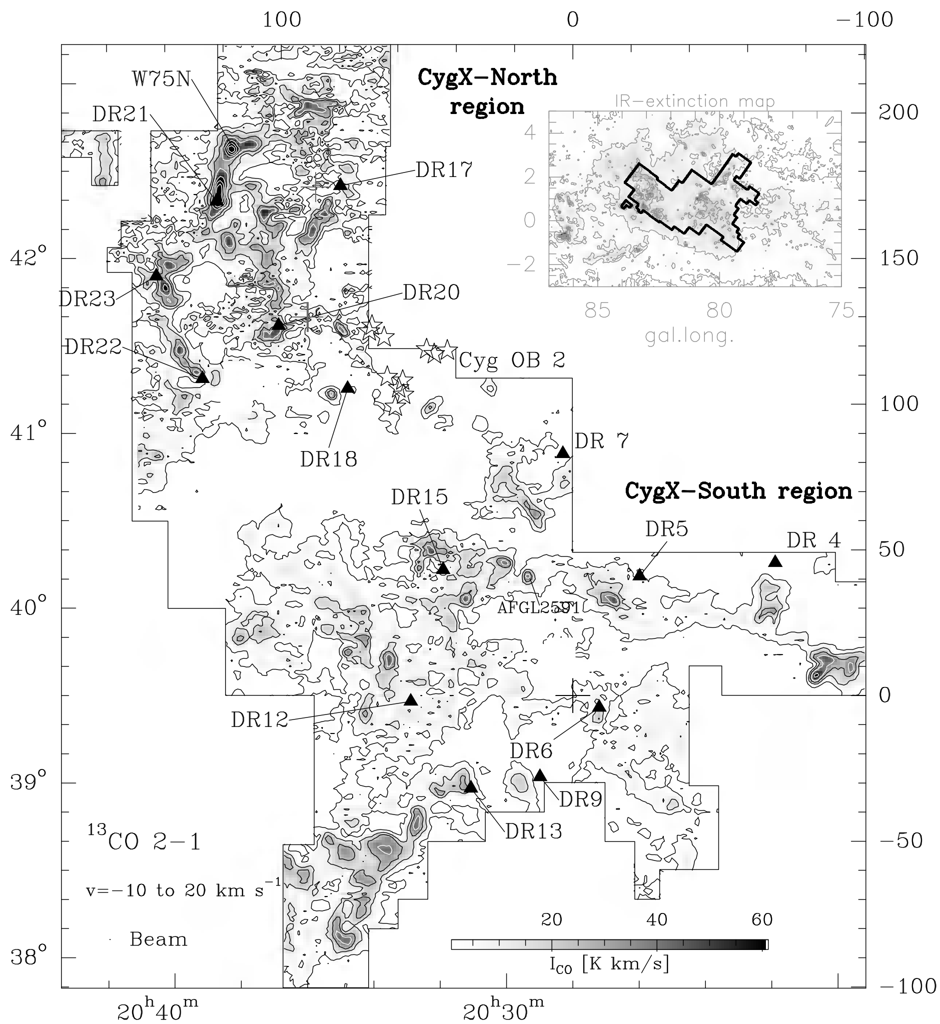

Figure 15. ^{13}CO 2→1 emission from Cygnus X as observed with KOSMA (Schneider et al. 2006). Contour lines start at 9σ (3σ=0.35 K km s^{-1}). The map is in RA/DEC (J2000). Black triangles mark the position of radio sources, and asterisks show the brightest members of Cygnus OB2. The dashed circle outlines the approximate extent of the OB2 cluster (Uyaniker et al. 2001). In the upper right corner, the extinction map from Fig. 3 is reproduced and indicates the ^{13}CO 2→1 mapping region.

'Cygnus Super-Bubble', an extended (18°×13°), strong, soft-X-ray emission region approximately centered on Cyg OB2, and first detected by Cash et al. (1980). A detailed discussion of the Cygnus Super-Bubble is given by Bochkarev & Sitnik (1985). Support of the super-bubble scenario was provided by the fact that the Cygnus region contains up to nine OB associations with Cyg OB2 as the most massive one in the Galaxy, and that Cygnus is the strongest emission feature in COMPTEL 1.809 MeV data of the radioactive decay of the ^{26}Al line (e.g., Plüschke et al. 2002). Comerón &

Torra (1994) considered the onset of gravitational instabilities in the dense shell surrounding an expanding super-bubble in order to explain the anomalous stellar proper motions measured in the Cygnus Super-Bubble (Comerón et al. 1993, 1998). A multi-wavelength study of Uyaniker et al. (2001), however, arrived at the conclusion that the Cygnus Super-Bubble is not a physical unit but results from a projection effect due to the emission from several features along the line-of-sight.

3.2. The Cygnus OB2 Association

An excellent overview of the Cyg OB2 complex and its many studies at various wavelengths has been presented by Knödlseder (2003), and the reader is referred to this source for more details than can be presented here.

The Cyg OB2 association was discovered by Münch & Morgan (1953), and further OB stars were found by Morgan et al. (1954a,b) and Schulte (1956a,b, 1958). When analyzing spectra of these stars, Johnson & Morgan (1954) realized the very high extinction towards the stars. The first large-scale study of Cyg OB2 was performed by Reddish et al. (1966), who identified about 300 OB star members. The distance to Cyg OB2 has been estimated by Torres-Dodgen et al. (1991) and Massey & Thompson (1991), who both agree on a value of 1.7 kpc, a distance that is now generally accepted for the region, although Hanson (2003) argue for a slightly smaller distance of about 1.5 kpc. An age of 3-4 Myr has been estimated for Cyg OB2 (e.g., Torres-Dodgen et al. 1991; Knödlseder et al. 2002). A recent survey for early A-stars in Cyg OB2 using the IPHAS (INT/WFC Photometric Hα survey of the Northern Galactic Plane) data by Drew et al. (2008) identified $\sim$200 A-stars, which is consistent with an age of 5 Myr for a distance of 1.7 kpc or 7 Myr if the distance is 1.5 kpc. In another IPHAS survey, Vink et al. (2008) have found over 50 strong Hα emission stars towards and south of Cyg OB2, many of which appear to be T Tauri stars.

In a more recent near-infrared statistical study, Knödlseder (2000) found that Cyg OB2 is a spherically symmetric association with a diameter of $\sim$2° and a half light radius of 13′, the latter corresponding to 6.4 pc at a distance of 1.7 kpc (see Figure 16). From infrared color-magnitude diagrams he estimated the number of OB stars to be approximately 2600$\pm$400, of which a hundred or more are O stars. This is among the largest groupings of O stars presently known in our Galaxy. The total mass of Cyg OB2 may be 4-10$\times$10^4 M$_\odot$. The implication is that Cyg OB2 may contain up to 100,000 low-mass T Tauri stars. Table 4 summarizes the results of Knödlseder (2000). The extinction A$_V$ towards Cyg OB2 varies from 5^m to 20^m, which accounts for early underestimations of its size and richness. A recent spectroscopic study by Comerón et al. (2002) identifies about 100 O stars or stars having evolved from O stars, in agreement with the Knödlseder (2000) study. Hanson (2003) obtained optical MK classification spectra of 14 of these massive stars. The view that Cyg OB2 may be a young globular cluster, similar to those found in the LMC, is gaining support (Reddish et al. 1966; Knödlseder 2000; Comerón et al. 2002). However, the central stellar mass density (within 0.5 pc) of OB2 is of the order of 2400 M$_\odot$/pc^3 (Bontemps et al. 2008), which is still only half of the Arches cluster or a quarter of NGC 3603, and Hanson (2003) argue that the mass of Cyg OB2, while still impressive, is overestimated by inclusion of non-members.

The extent of Cyg OB2 has been under some discussion. In a new study, Comerón et al. (2008) investigated the possible existence of an extended halo of early-type stars around Cyg OB2 using near-infrared imaging to identify a magnitude-limited sample,

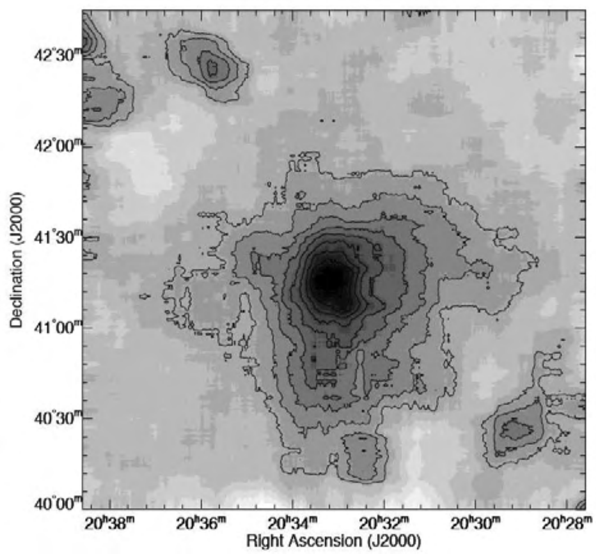

Figure 16. The stellar density distribution of the Cyg OB2 association derived from the 2MASS catalogue. Isodensity contours are in 10% steps of the peak density. From Knödlseder (2000).

followed by infrared spectroscopy. The study dismisses the case for a large extent of Cyg OB2 much beyond the boundaries of its central condensation. Many early-type stars are found that are not associated with any known structure. This pervasive field population suggests that massive star formation in the whole Cygnus region has proceeded for a long time.

Table 4. Properties of Cyg OB2. From Knödlseder (2000).

Center (J2000)	$20^h33^m10^s$, +41°12′
Diameter	$\sim$2° ($\sim$60 pc)
Half light radius	13′ (6.4 pc)
Core radius r_c	29′$\pm$5′ (14$\pm$2 pc)
Tidal radius r_t	93′$\pm$20′ (46$\pm$10 pc)
Members earlier F3V	8600$\pm$1300
OB star members	2600$\pm$400
O star members	120$\pm$20
Total stellar mass	(4-10)$\times 10^4$ $M_\odot$
Central mass density ρ_o	40-150 $M_\odot$ pc^{-3}
IMF slope Γ	-1.6 ± 0.1

A number of surveys have been made towards the Cyg OB2 association. A low-dispersion spectroscopic survey in search of early-type stars was conducted by Parthasarathy & Jain (1995). The region has been studied using the IRAS maps, and a number of point sources have been detected, which are either embedded early-type stars or young stellar objects (e.g., Odenwald 1989; Parthasarathy et al. 1992; Odenwald & Schwartz 1993). The Cyg OB2 region has been surveyed at radio frequencies in search of hot, massive stars by many groups, including Wendker (1984) at 4800 MHz, Zoonematkermani et al. (1990) at 1400 MHz, Wendker, Higgs, & Landecker (1991) at 408 and 1430 MHz, Taylor et al. (1996) at 327 MHz, Taylor et al. (2003) at 408 and 1420 MHz, and Setia Gunawan et al. (2003) at 1400 and 350 MHz. Various X-ray studies have been performed, with Einstein (Harnden et al. 1979), with ROSAT (Waldron et al. 1998; Mukherjee et al. 2003), with ASCA (Kitamoto & Mukai 1996), with XMM-Newton (Rauw et al. 2005, De Becker et al. 2006), and with Chandra (Albacete Colombo et al. 2007a,b). Gamma-ray observations have been carried out with COMPTEL by del Rio et al. (1996), with EGRET by Chen et al. (1996), with INTEGRAL by Knödlseder et al. (2004) and De Becker et al. (2007), with HEGRA by Aharonian et al. (2002), and with Milagro by Abdo et al. (2007a), among others.

Recently, Aharonian et al. (2005) analysed the existing data on the TeV source J2032+4130 close to the center of Cyg OB2. Butt et al. (2003) and Butt (2007) suggest that the origin of these highly energetic γ-rays are supersonic winds of charged particles from a subgroup of massive stars in Cyg OB2. The plasma motions, i.e. turbulence, created in that way accelerate particles to TeV energies that interact with the ambient gas. Martí et al. (2007) report on deep radio maps towards the TeV source, and Horns et al. (2007) present XMM-Newton observations around the source, and identify an extended X-ray emission region around J2032+4130. Butt et al. (2008) showed that there is probably a physical relation between the TeV source and one of the molecular clouds associated with Cyg OB2.

Some of the stars in Cyg OB2 are quite remarkable. The association includes several of the most luminous stars known in our Galaxy, including #12 (the numbering is from Schulte 1958), which has $M_V \sim -10$, although its high extinction ($A_V \sim 10^m$) makes it visually unimpressive (Souza & Lutz 1980). #8 contains a trapezium system with four O stars, including the massive colliding-wind binary #8A (De Becker et al. 2004), #5 is a massive eclipsing contact binary (Bohannan & Conti 1976; Rauw et al. 1999), #9 is a long-period massive binary (Nazé et al. 2008), and #7 and #22A belong to the extreme class of O3 stars (Walborn 1973; Walborn et al. 2002). It is noteworthy that Cyg OB2 harbors 3 members of the category of non-thermal emitting O-type stars (#5, #8A, and #9), see De Becker (2007). A number of spectroscopic and eclipsing binaries are known among the massive stars in Cyg OB2 (e.g., Kiminki, McSwain, & Kobulnicky 2008). The peculiar star MWC 349A is a massive Be star, either a pre-main sequence star (Meyer et al. 2002) or a more evolved Be supergiant (White & Becker 1985). Comerón & Pasquali (2007) detected a massive runaway star, dynamically ejected by Cyg OB2. This star is of spectral type O4If and is one of the three most massive runaway stars known. Though a recent radial velocity survey of Kiminki et al. (2007) did not identify any other runaway stars, Comerón & Pasquali (2007) estimate that at least 10 more should eventually be discovered.

The Cyg OB2 association contains molecular clouds with embedded luminous infrared sources, providing evidence of still ongoing star formation (e.g., Odenwald 1989, Dobashi et al. 1994). An example of such a case is the source IRAS 20343+4129, which has been studied in some detail. It is an ultracompact HII region with a luminosity of $\sim$5,500 $L_\odot$ (Miralles et al. 1994) associated with DR 18. In a 1.2 mm continuum survey, Beuther et al. (2002a) found three compact sources, which are associated with a dense cloud core (Schneider et al. 2006) and a massive molecular outflow (Beuther et al. 2002b).

3.3. The DR 21/W75N Complex

The W75 complex (Westerhout 1958) is a large radio emission region that comprises DR21 and DR21(OH) (which is not a radio source and is sometimes called W75S(OH)) to the south, and the W75N region to the north (see Fig. 17 and 18).

The molecular filament containing DR21 and DR21(OH) is among the most massive star forming regions of our Galaxy, but because of the very high extinction in this direction (up to $A_V \sim 50$–150 mag) it is observable only at infrared and radio wavelengths. A wealth of studies have been performed in these regions, and only a few selected references are given here. The distance to DR 21 is uncertain, with suggested values ranging from 1.5 to 3 kpc (e.g., Campbell et al. 1982; Piepenbrink & Wendker 1988; Odenwald & Schwartz 1993; Schneider et al. 2007).

DR 21 is compact (about $30'' \times 30''$) and extremely bright in the radio continuum (e.g., Wendker 1984), and Harris (1973), Roelfsema et al (1989), and Cyganowski et al. (2003) have identified a group of radio continuum peaks labeled A - F, whose free-free emission indicate the presence of luminous O stars, although no near-infrared counterparts were found by Hanson, Luhman, & Rieke (2002). The radio source DR 21 is embedded in a N-S oriented molecular cloud ridge that stretches over $\sim 15'$ (Dickel et al. 1978, Wilson & Mauersberger 1990; Wilson et al. 1995; Vallée & Fiege 2006; Jakob et al. 2007, Motte et al. 2007). Figure 17 shows this filamentary cloud in different molecular line tracers (Schneider et al. 2008) and in 1.2 mm continuum (Motte et al. 2007) together with the source definitions given in Chandler et al. (1993). The maser source DR21(OH) (Norris et al. 1982) indicates the presence of high-mass YSOs. Some far-infrared sources further north were detected by Harvey et al. (1986) and were called,

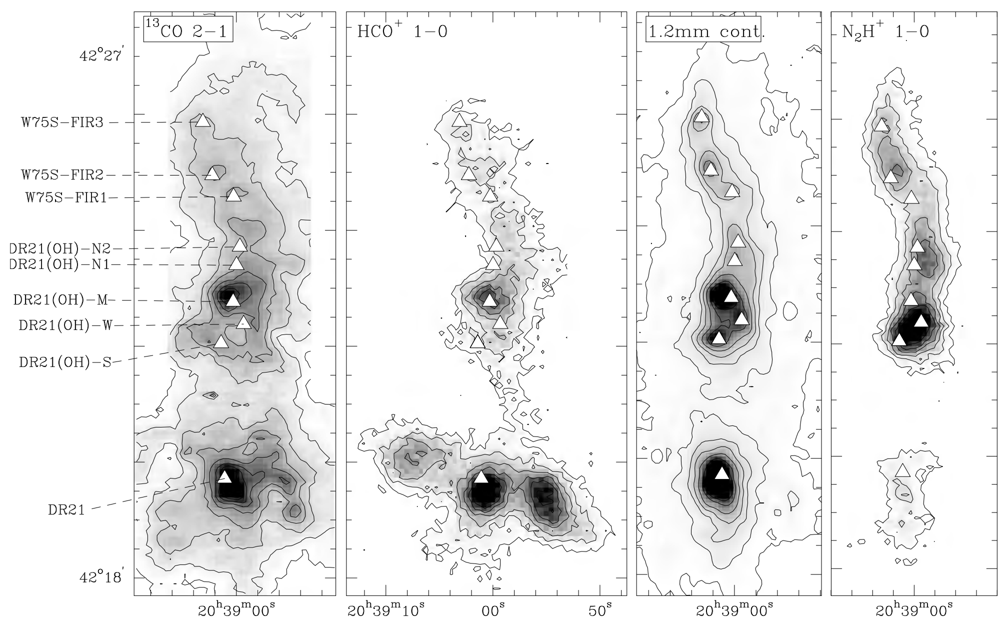

Figure 17. The molecular ridge containing DR21 and DR21(OH) seen in the lines of ^{13}CO 2→1, HCO^+ 1→0, and N_2H^+ 1→0 (Schneider et al. 2008), and in 1.2 mm continuum (Motte et al. 2007). The map is in RA/DEC (J2000), and triangles indicate continuum sources.

confusingly, W75S FIR1–3. The maps of ^{13}CO 2→1 and N_2H^+ 1→0 emission and the continuum map show that all sources are embedded in dense cores.

The HCO^+ 1→0 map in Figure 17 shows a remarkable outflow, centered on DR 21, oriented roughly along an E-W axis. It is detected in CO and other molecular millimeter transitions (Fisher et al. 1985; Garden et al. 1991b; Garden & Carlstrom 1992; Russell et al. 1992), and shows up in molecular hydrogen emission (Garden et al. 1991a, Davis & Smith 1996; Fernandes, Brand, & Burton 1997, Davis et al. 2007, Jakob et al. 2007). Smith et al. (2006) suggest that an accreting O8 ZAMS star is responsible for the DR 21 outflow. Figure 18 shows a recent H_2 image (Davis et al.

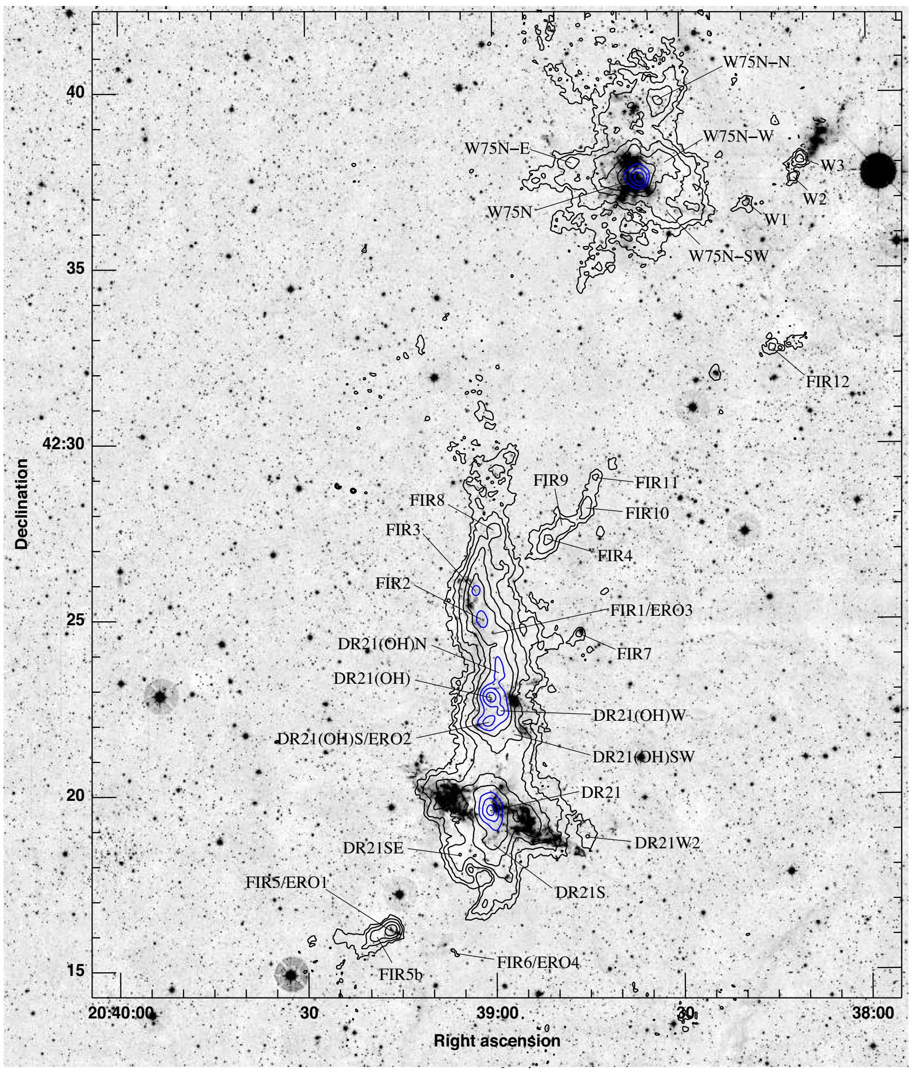

Figure 18. The DR 21/W75N complex. An H_2 image from the UKIRT WFCAM has superimposed contours of 850 μm emission from SCUBA. A number of H_2 flows are seen emanating from the cold cores, in particular the major flow from DR 21. From Davis et al. (2007).

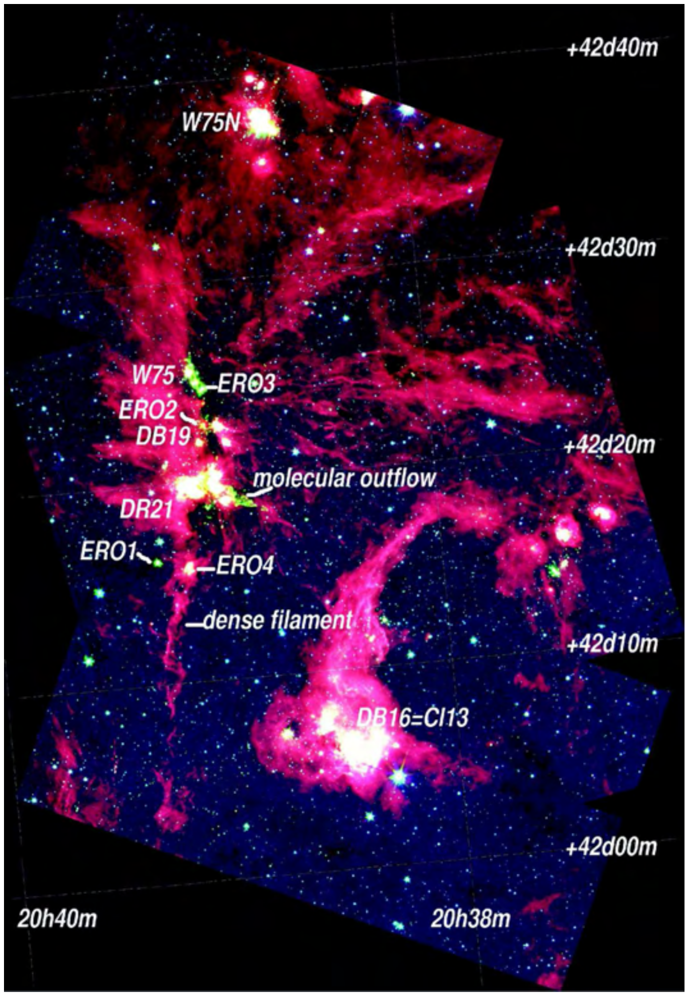

Figure 19. Co-added IRAC 3.6, 4.5, and 8.0 μm images from *Spitzer* reveal the great complexity of the DR 21 region. DB 16 and 19 are clusters from Dutra & Bica (2001), and four extremely red objects (ERO) are indicated. The sensitivity and resolution of these *Spitzer* images allow the detection of young low-mass stars. From Marston et al. (2004).

2007) in which at least 50 individual outflows, driven by embedded low-mass stars, are identified. The most prominent flow in this image remains the one from DR 21. Cruz-Gonzalez et al. (2007) study the velocity structure of this H_2 outflow in detail.

The DR 21 region has been observed at far-infrared wavelengths by Harvey et al. (1986), Lane et al. (1990), and Colomé et al. (1995), and in the sub-millimeter and millimeter continuum by Richardson, Sandell, & Krisciunas (1989), Chandler et al. (1993), Vallée & Fiege (2006), and Motte et al. (2007). All these studies reveal a chain of dusty, dense cores along the ridge. Some of them are high mass protostars, driving powerful SiO outflows (Motte et al. 2007).

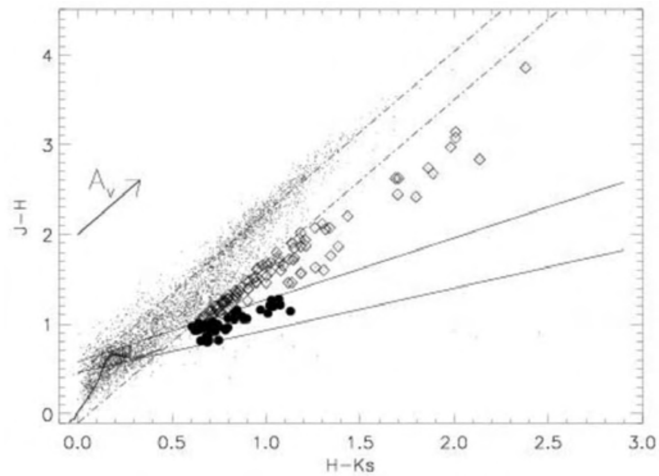

Figure 20. A 2MASS color-color diagram covering the region shown in Fig. 19. The majority of sources fall within reddening lines projected from the loci of dwarfs and giants, but open diamonds indicate likely young stellar objects, and filled circles indicate possible T Tauri stars. From Marston et al. (2004).

A real break-through in our view of this region came with the recent *Spitzer* observations of the DR 21/W75N field with IRAC at 3.6, 4.5, and 8.0 μm and at 24 and 70 μm by Marston et al. (2004). Figure 19 shows the Spitzer co-added IRAC images, revealing the enormous complexity of the region. Remarkable are the long filaments stretching across a few parsecs and converging to a center that includes the DR21/DR21(OH) region. Kumar et al. (2007) find that star formation occurs within these filaments. A color-color diagram from 2MASS data of the same region is shown in Fig. 20, indicating the presence of numerous young stellar objects and T Tauri stars. Four of the 2MASS sources are extremely red objects (ERO), and they are marked in Fig. 20. With these *Spitzer* data, we are beginning to probe the enormously rich populaton of young low-mass stars in the region.

The W75N region is known as a massive star forming region located 15′ north of DR21 (Fig. 18). Haschick et al. (2004) identified three regions of ionized gas at a resolution of 1.5″: W75N(A), W75N(B), and W75N(C) and Shepherd (2001) detected at least 3 mm-continuum sources (MM1–MM3) that were also seen in CH_3CN (Watson et al. 2002). In W75N(B)/MM1, three cm-continuum sources were resolved with the VLA (Torrelles et al. 1997). One of these sources powers a parsec-scale CO outflow (Davis et al. 1998, Shepherd et al. 2003, 2004). Persi et al. (2006) used groundbased mid-infrared images and Spitzer IRAC images to identify a young cluster of at least 25 members around W75N(B). W75N is also famous for its OH and H_2O maser sources (see Fish & Reid 2007 and references therein) and is seen nowadays as a B-star cluster forming region (see Shepherd et al. 2004 for a review on the region).

3.4. The IC 1318 Region, NGC 6910 Cluster, and BD+40°4124 Complex

The HII region IC 1318 consists of three components, *a*, *b*, and *c* that are seen in the optical image in Figure 9. Only a brief summary of some of the work done on this

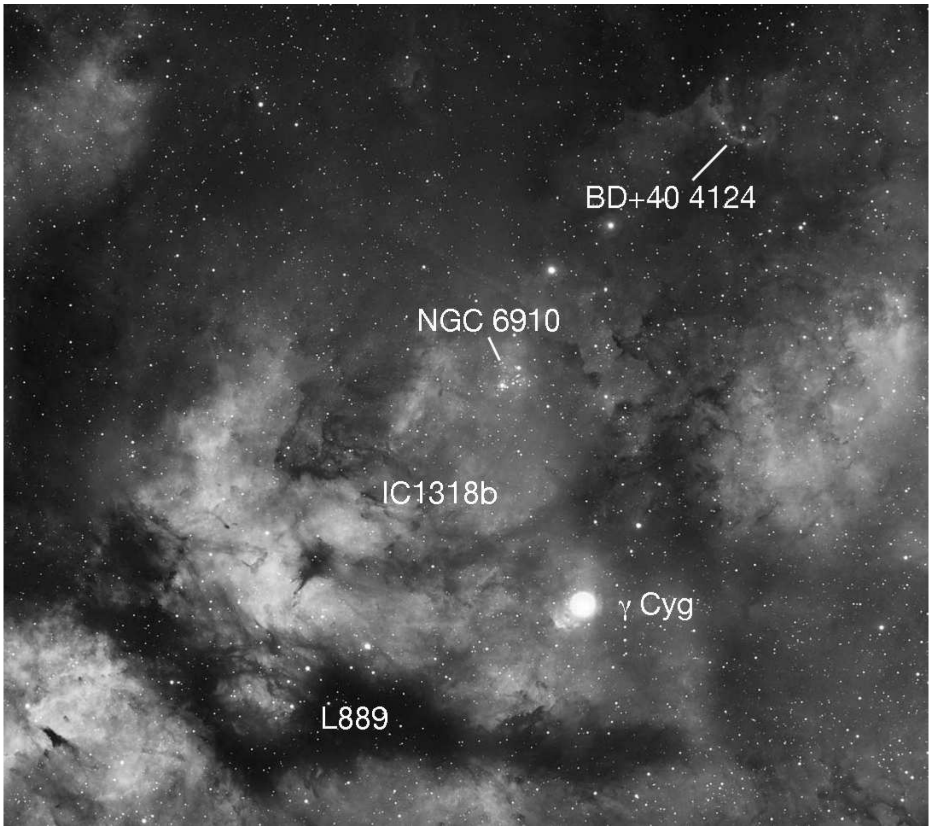

Figure 21. The young cluster NGC 6910 is located near the middle of the HII region IC 1318 b. The well known Herbig Ae/Be star BD+40°4124 is to the upper right. Image courtesy Matthew T. Russell.

region will be presented here. The IC 1318 b/c regions are part of a single, giant HII region prominent in the radio domain (Baars & Wendker 1981) and bifurcated by a massive, highly structured, dust lane (Dickel, Seacord, & Gottesman 1977; Wendker, Schramm, & Dieckvoss 1983a), which is known as Lynds 889 (see Figures 21 and 22). The distance to IC 1318 b/c has been estimated at about 1.5 kpc (Dickel, Wendker, & Bieritz 1969). A possible ionizing source of IC 1318 b/c was found by Arkhipova & Lozinskaya (1978) and was classified as an O9V star by Appenzeller & Wendker (1980). Odenwald & Schwartz (1993) studied the stellar content of Cygnus X using IRAS data, and Wendker et al. (1991) present a catalog of compact radio sources. Their source ECX 6-15, also known as DR 6, lies in the dark lane L889 between IC 1318 b and *c*. It was studied in the far-infrared and in the radio continuum by Campbell et al. (1981) and Odenwald et al. (1986). Comerón & Torra (2001) studied this region in the near-infrared, and found a compact cluster of red sources. Clearly, the study of star formation in this region has just begun.

The young cluster NGC 6910 is located in the outskirts of IC 1318 b, see Figure 23. The precise relation between the cluster and the HII region is unclear. The cluster location is within the Cygnus OB9 association, a region of about 30 × 40 pc con-

Figure 22. The molecular cloud L889 which obscures the central part of the HII region IC1318 is highly structured and has been sculpted by the presence of massive OB stars in the region. The image is approximately 50 $\times$ 50 arcmin, with north up and east left. Image courtesy Johannes Schedler.

taining numerous massive young stars. The NGC 6910 cluster was discovered in 1786 by William Herschel, and photometric studies of the cluster members have been presented by Becker & Stock (1949), Tifft (1958), Hoag et al. (1961), Crawford, Barnes, & Hill (1977), Shevchenko, Ibragimov, & Chernysheva (1991a), Vansevicius (1992), Delgado & Alfaro (2000), Peña et al. (2001), and Kolaczkowski et al. (2004). A number of distance determinations have been performed, and Shevchenko et al. (1991a) list the various values, which tend to cluster around 1500 pc. However, the extinction to NGC 6910 is high and apparently anomalous, so distances are sensitive to the particular R-value adopted. Shevchenko et al. (1991a) favors a distance of 1 kpc, assuming R = 3.4, but show how the distance changes to 1.5 kpc if a value of 2.5 is adopted, as in several earlier studies. In subsequent studies, Vansevicius (1992) finds a distance of 1530 pc and an age of less than 7 Myr, and Delgado & Alfaro (2000) suggest a distance of 1740 pc and an age of about 6.8 Myr. The ten brightest members of the cluster have spectral types between O9 and B2, including the probable member HD 194279, a B1.5 Ia supergiant star. Delgado & Alfaro (2000) identify a dozen faint, probable pre-main sequence members of NGC 6910 with spectral types between A and G. Kolaczkowski et al. (2004) searched for variable stars in NGC 6910. Melikian & Shevchenko (1990) surveyed the general region around NGC 6910 for Hα emission stars, and Kubát et al. (2007) studied the Hα emission line in some of these stars.

Figure 23. The young NGC 6910 cluster in the Cyg OB9 association. The figure is about 25$\times$25 arcmin. Image courtesy Johannes Schedler.

To the northwest of NGC 6910, one finds a small cometary globule, which hosts a clustering of young stars (see Figures 21 and 24). Herbig (1960) first drew attention to this region, and identified the two Herbig Ae/Be stars BD+40°4124 = V1685 Cyg = HBC 689 = MWC 340 (B2V) and LkHα 224 = V1686 Cyg = HBC 690 (B5V), together with the peculiar young binary LkHα 225 = V1318 Cyg consisting of two components, LkHα 225N and S, separated by 5 arcsec. The stars are very young, surrounded by circumstellar material, and display optical variability (Cohen 1972, Strom et al. 1972, Shevchenko et al. 1991a), and form the center of a small cluster of lower-mass partially embedded young stars (Hillenbrand et al. 1995). The LkHα 225 binary was studied at infrared and sub-millimeter wavelengths by Aspin, Sandell, & Weintraub (1994), who found the southern source to have a bolometric luminosity of about 1600 $L_{\odot}$, suggesting

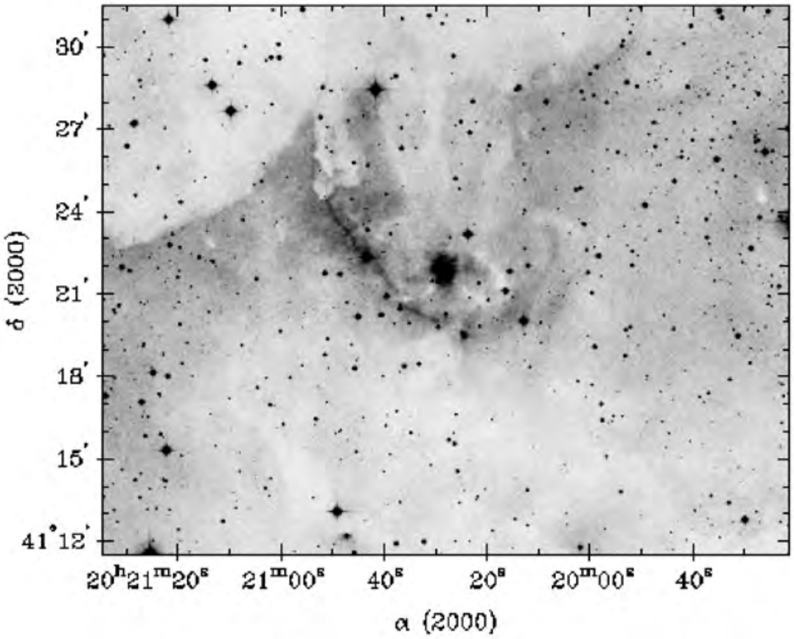

Figure 24. The region around the nebulous Herbig Ae/Be star BD +40°4124 and its PMS cluster, as seen on the red Digitized Sky Survey. The young cluster is embedded in a cometary globule.

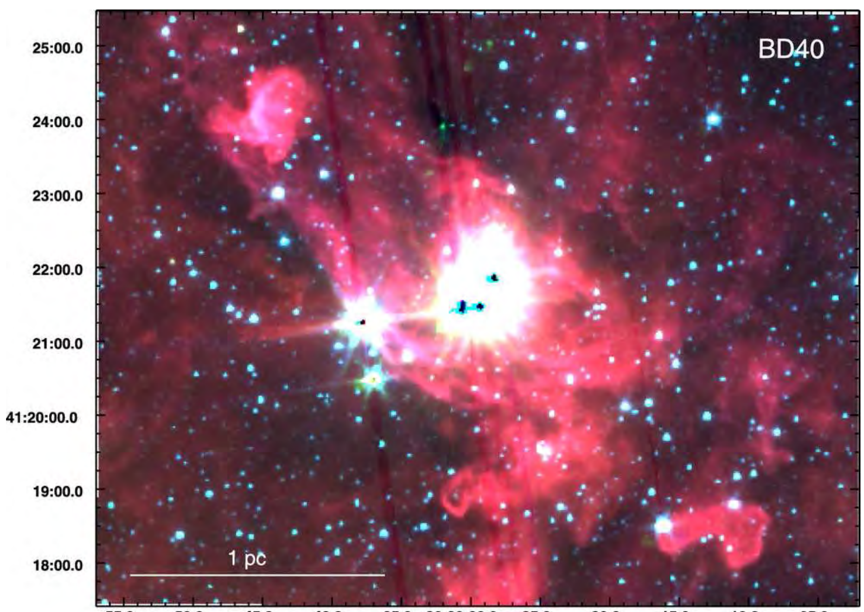

Figure 25. The region around the two Herbig Ae/Be stars BD +40°4124 and LkHα 224 = V1686 Cyg, as well as the peculiar binary LkHα 225 = V1318 Cyg as seen in a multi-band Spitzer image (3.6 μm is blue, 4.5 μm is green, and 8.0 μm is red). From Wang & Looney (2007).

that it is another newly formed Herbig Ae/Be star. Infrared spectra of both components show no absorption lines, making spectral classification difficult (Davies et al. 2001). The group of Herbig Ae/Be stars were studied with ISO, and found to be associated with molecular hydrogen emission, related to shocks in the region (Wesselius et al. 1996, van den Ancker et al. 2000). A luminous, deeply embedded sub-millimeter source has been detected 1 arcsec northeast of LkHα 225S by Looney et al. (2006), which coincides with a water maser (Palla & Prusti 1993, Marvel 2005) and compact shocked H_2 emission (Davies et al. 2001), and which is apparently driving a molecular outflow (Palla et al. 1995, Matthews et al. 2007). Millimeter observations of the cluster region in a variety of transitions have been reported by Loren (1977), Cantó et al. (1984), Fuente et al. (1990), Palla et al. (1995), and Looney et al. (2006), which demonstrate that a massive core is centered on the deeply embedded sub-millimeter source next to LkHα 225S, while the other Herbig Ae/Be stars are located near its edge. Wang & Looney (2007) have detected 134 candidate PMS stars using Spitzer in the field seen in Figure 25. Star formation is obviously an ongoing process in this very active region.

3.5. IC 4996, NGC 6913 and Ber 86 and 87 in the Cygnus OB1 Association

The open cluster IC 4996 is found in the center of the Cygnus OB1 association in a region of Cygnus with many young stars and active star formation about 40 pc above the Galactic plane and is located at the position $20^h16^m32^s$, $+37°38'$ (J2000). The cluster was first described in detail by Bellamy (1904). Photometric observations have been provided by many observers, for a detailed listing of references, see Alfaro et al. (1985). The distance to the cluster has been estimated to be variously 1670 pc (Purgathofer 1961), 1775 pc (Becker & Fenkart 1971), 1930 pc (Alfaro et al. 1985), 1620 pc (Vansevicius et al. 1996), 2400 pc (Delgado et al. 1998), 1732 pc (Kharchenko et al. 2005), and 2300 pc (Bhavya et al. 2007), among other studies. The large and spotted extinction towards the cluster helps to explain the large range of these values, but it seems fairly certain that the cluster is less than 2 kpc away. The age of the cluster has been determined in several investigations, yielding 7.5 Myr (Alfaro et al. 1985), 9 Myr (Vansevicius et al. 1996), 7.5 Myr (Delgado et al. 1998), and 6.3 Myr (Kharchenko et al. 2005). Spectral types for many cluster stars are given by Mermilliod (1976). A number of variable stars have been identified in IC 4996 (Alfaro et al. 1985, Delgado et al. 1985, Pietrzynski 1996). Efforts have been made to detect pre-main sequence stars in IC 4996, Delgado et al. (1998) found a number of PMS candidates through a photometric study, and these stars were further studied spectroscopically by Delgado et al. (1999), who noted that the majority are likely Herbig Ae/Be stars and hot T Tauri stars. Zwintz & Weiss (2006) found two δ Scuti-type pulsating pre-main sequence stars in IC 4996. HD 193007 is the brightest star in IC 4996 and is a multiple system (e.g., Trumpler 1952, Echevarria et al. 1979). Several eclipsing binaries are known in the cluster (Zakirov 1999).

NGC 6913 (M29) is found within the boundaries of the Cyg OB1 association (Figure 26). Despite it being a Messier object, it is relatively poorly studied, with wide discrepancies among the various analyses, which is likely due to contamination by non-members and to significant and varying extinction towards the cluster stars. Photometric or spectroscopic studies are presented by Becker & Stock (1950), Morgan & Harris (1956), Tifft (1958), Hoag et al. (1961), Walker & Hodge (1968), Crawford et al. (1977), Joshi et al. (1983), and Massey et al. (1995). Sanders (1973) attempted a membership analysis based on astrometry. Early determinations of the cluster dis-

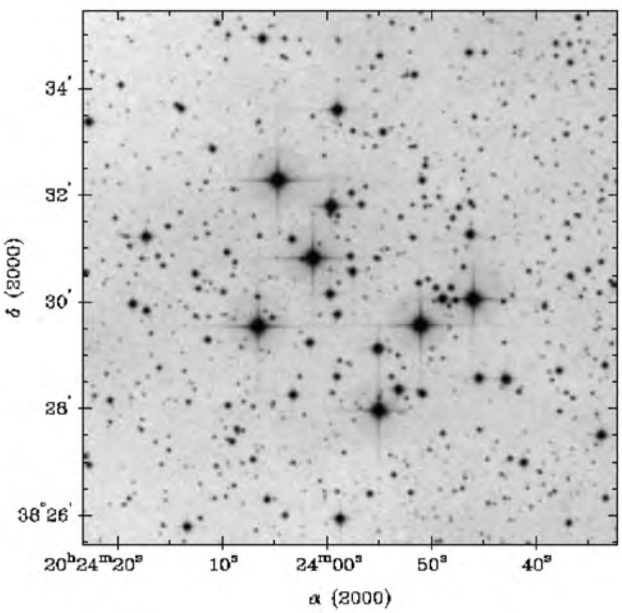

Figure 26. The young cluster NGC 6913 = M29. Red image from the Digitized Sky Survey.

tance range from 1.1 kpc (Hoag et al. 1961) to 2.2 kpc (Morgan & Harris 1956). The more recent study of Joshi et al. (1983) suggests a distance of about 1.5 kpc, making its membership in Cyg OB1 likely, whereas Massey et al. (1995) determine a distance of 2.2 kpc. In contrast, Wang & Hu (2000) did spectral classification of 100 cluster members which they combined with previous photometry to derive a distance of 1.1 kpc. Age estimates range from 0.3-1.75 Myr by Joshi et al. (1983) to 10 Myr by Lyngå (1987). The study of Wang & Hu (2000) demonstrates that the extinction across the cluster shows major variations. Several eclipsing binaries were studied by Boeche et al. (2004). In summary, while there is no doubt that the NGC 6913 cluster is quite young, its association with Cyg OB1 remains controversial.

Berkeley 86 is a small cluster originally discovered by Setteducati & Weaver (1962). Sanduleak (1974) realized that it contains O stars and thus is young. The photometry of Forbes (1981) suggested a distance of 1.7 kpc. Bhavya et al. (2007) derived a distance of 1585$\pm$160 pc. The famous Wolf-Rayet binary V444 Cyg appears to be a member of the cluster (Lundström & Stenholm 1984, Forbes et al. 1992). An age of 2-3 Myr was suggested by Massey et al. (1995) and about 6 Myr by Deeg & Ninkov (1996). Using Strömgren photometry, Delgado et al. (1997) estimate an age of 8$\pm$5 Myr. Bhavya et al. (2007) suggest that star formation started at a low level about 5 Myr ago, but that vigorous star formation has been occurring during the last 1 Myr. Vallenari et al. (1999) identify candidate PMS stars in the cluster using near-infrared photometry. It is generally assumed that Ber 86 is a part of the Cyg OB1 association.

Another young cluster found in the direction of Cyg OB1 is Berkeley 87, also known as Dolidze 7 or C 2019+372. The principal study of this cluster is by Turner & Forbes (1982), who find about 100 brighter members within a 5 pc radius, and suggest

Table 5. Open Clusters towards the Cyg OB1 Association[a]

Cluster	α_{2000}	δ_{2000}	l	b
IC 4996	20 16.5	+37 38	75.35	+1.31
NGC 6913	20 23.9	+38 31	76.92	+0.61
Ber 86	20 20.2	+38 41	76.64	+0.30
Ber 87	20 21.7	+37 22	75.72	+0.30

[a] Positions are from Simbad.

a distance of about 950 pc and a very young age of 1-2 Myr. However, Bhavya et al. (2007) derive a distance of 1445±145 pc, making it more likely to be a member of Cyg OB1. The cluster is heavily reddened, and it appears that it is associated with a large molecular cloud in which star formation is still taking place (e.g., Dent et al. 1988). A spectrophotometric study by Polcaro et al. (1991a) has shown that most of the known members are OB stars. The cluster contains the rare WO-type star Sand 5 = ST 3 = WR 142 (e.g., Polcaro et al. 1997). Attention has recently focused on Ber 87 following the discovery from the Milagro gamma-ray observatory of TeV radiation from the direction of the cluster (Abdo et al. 2007b), which may arise from acceleration of particles in shocks driven by Wolf-Rayet stars (Bednarek 2007).

The Crescent nebula (NGC 6888, seen in the south-west corner of Fig. 9) is located in the outskirts of the Cyg OB1 association. It has a distinct shape that is due to an expanding outer shell of the massive Wolf-Rayet star HD 192163 (Moore et al. 2000).

The Cygnus OB1 association extends over about $4^\circ \times 3.5^\circ$ and in addition to the clusters mentioned above it contains a number of scattered O stars (e.g., Garmany & Stencel 1992). The collective effect of stellar winds and supernova explosions have combined to have a significant impact on the environment of this association. Brand & Zealey (1975) found an almost complete ring of Hα emission about 4° in diameter centered within the Cyg OB1 association. Lozinskaya & Sitnik (1988) showed that there are several hierarchical shells in the Cyg OB1 association, and Lozinskaya et al. (1997, 1998) studied their kinematics. Using IRAS Skyflux images, Saken et al. (1992) found a $2^\circ \times 5^\circ$ region deficient of infrared emission, which they modeled as a 1 Myr old bubble. Further kinematical studies have established supersonic velocity differences within the Cyg OB1 superbubble of over 100 km s^{-1} (e.g., St-Louis & Smith 1991, Dewdney & Lozinskaya 1994, Spangler & Cordes 1998).

4. NGC 6914

Figure 27 shows the region of NGC 6914, which displays three prominent reflection nebulae. NGC 6914, first noticed in 1881 by Jean Marie Edouard Stephan, is the northernmost of the three, and Hubble (1922) and Collins (1937) called the middle one for NGC 6914a and the southernmost for NGC 6914b (confusingly, Cederblad 1946 and Witt & Schild 1986 use the opposite terminology), and the entire complex is commonly known as the NGC 6914 region. Subsequently, van den Bergh (1966) published his large catalog of reflection nebulae, and here the southernmost nebula is known as vdB 131 and the middle nebula vdB 132, designations that are now commonly used for these two nebulae. The illuminating source of vdB 131 is BD +41°3731 (HBC 693),

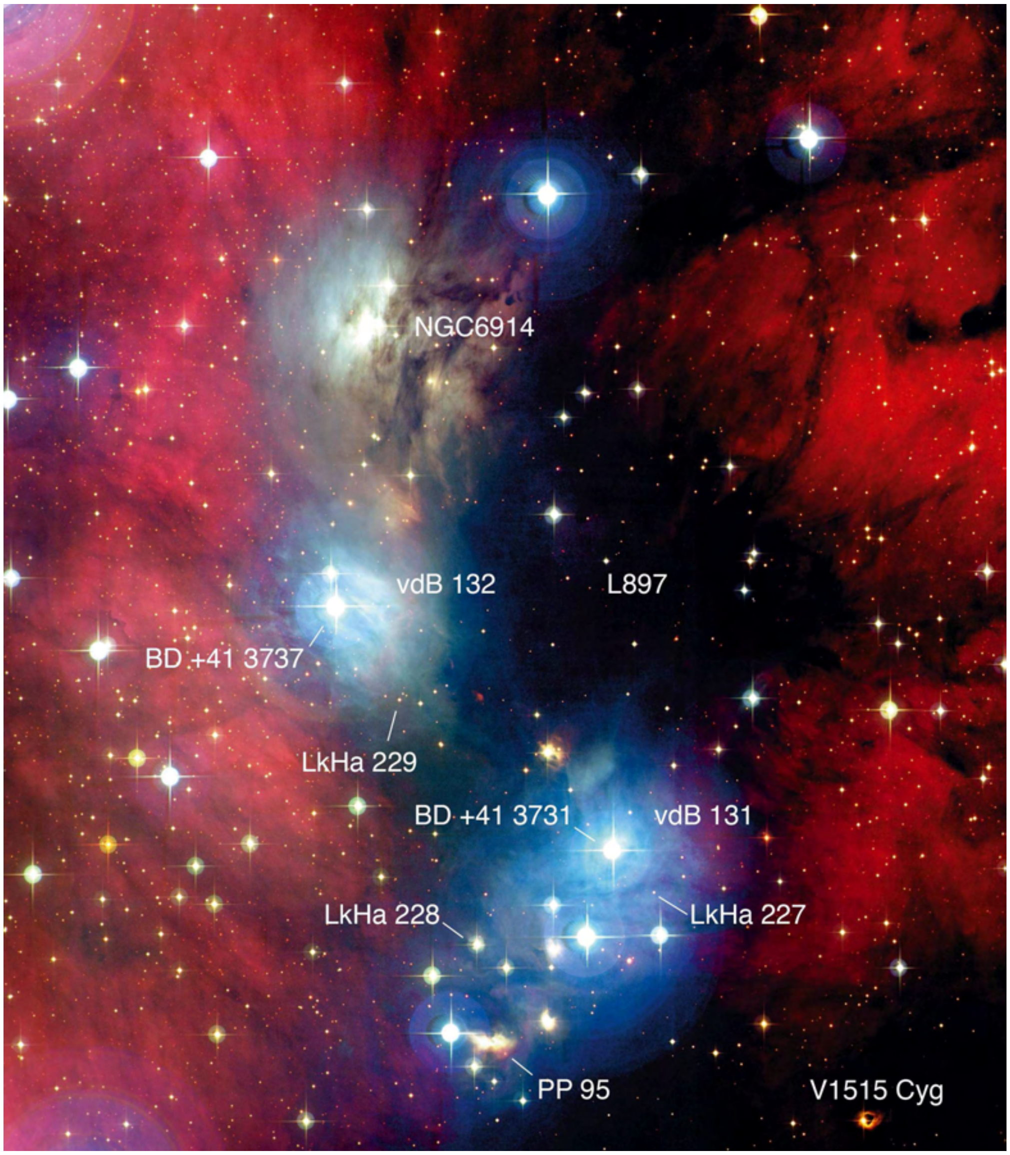

Figure 27. The reflection nebula NGC 6914 contrasts with the surrounding HII region. The associated molecular cloud is actively forming stars. The nebulous star in the lower right corner is the FUor V1515 Cyg. CFHT image courtesy Jean-Charles Cuillandre.

a Herbig Ae/Be star of spectral type B3 (Herbig 1960). The illuminator of vdB 132 is BD +41°3737, another B3 star (Racine 1968).

The NGC 6914 region is located at a distance of about 1000 pc according to Racine (1968) and Shevchenko et al. (1991a). It thus appears to be a foreground feature to the Cygnus X region at about 1.7 kpc. A number of young stars are found in the region, the best known is the FUor V1515 Cyg (see Sect. 7.2.). Herbig (1960) noted three

Hα emission stars, LkHα 227, 228, and 229 (see Fig. 27). A small reflection nebula, PP 95, was noted by Parsamian & Petrossian (1979), and Aspin & Reipurth (2000) found a large HH object, HH 475, near PP 95. Two luminous IRAS sources, IRAS 20226+4206 and 20227+4154, are in the same region, both are Class I sources, and at least IRAS 20227+4154 drives a molecular outflow (Odenwald & Schwartz 1993). The whole region deserves closer scrutiny.

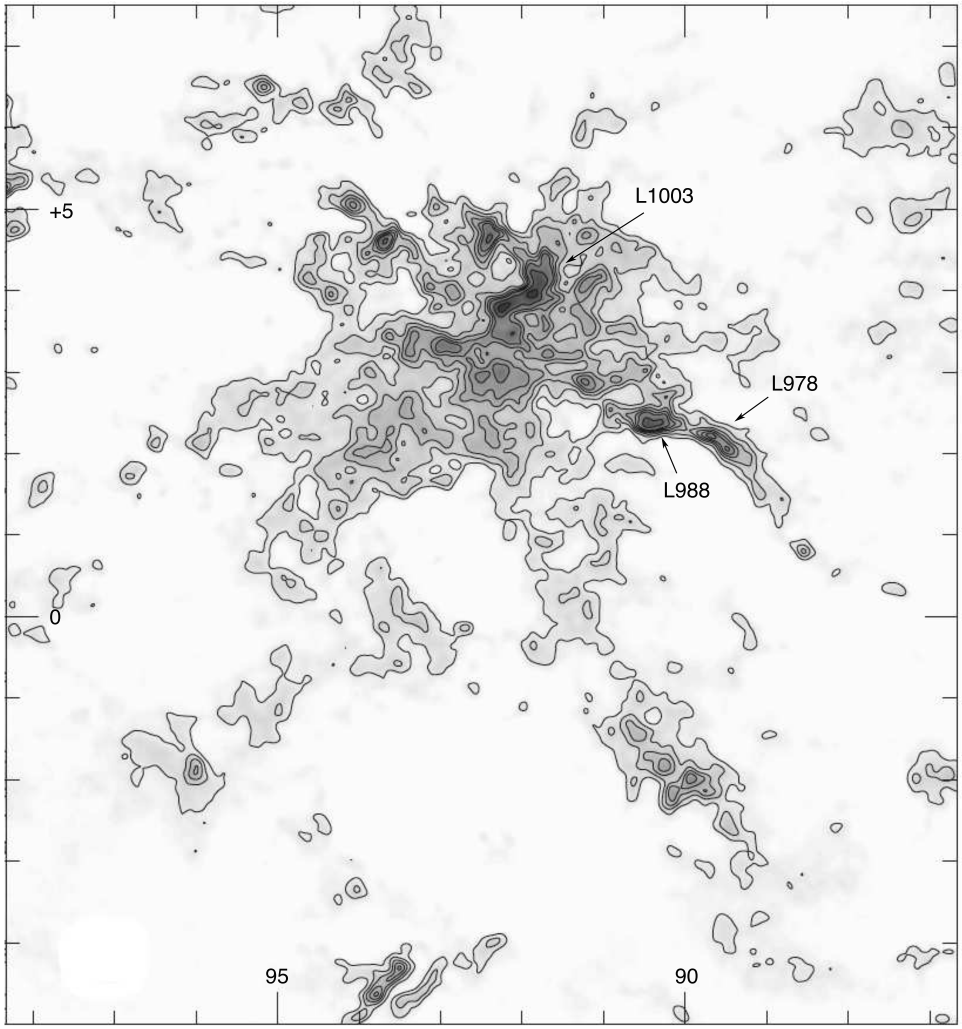

Figure 28. The large cloud complex Kh 141 (Khavtassi 1960) or TGU 541 (Dobashi et al. 2005) is also known as "the Northern Coalsack". It is associated with the Cyg OB7 association. The figure shows an extinction map of about 11.6° $\times$ 12.5°. The figure is oriented in Galactic longitude vs. latitude, (86.7° $< l <$ 98.3° and $-5° < b <$ +7.5°). From Dobashi et al. (2005).

5. Cygnus OB7 and Star Formation in L988 and L1003

The Cyg OB7 region is the nearest of the nine generally recognized Cygnus OB associations. Based on observations of Hiltner (1956), Schmidt (1958) derived a distance of about 740 pc, and this or a distance of 800 pc are generally adopted for the Cyg OB7 region. Further massive members of the association were identified by Schmidt-Kaler (1961), Ruprecht (1966), and Humphreys (1978). The Hipparcos study of the region did not improve on the distance determination (de Zeeuw et al. 1999).

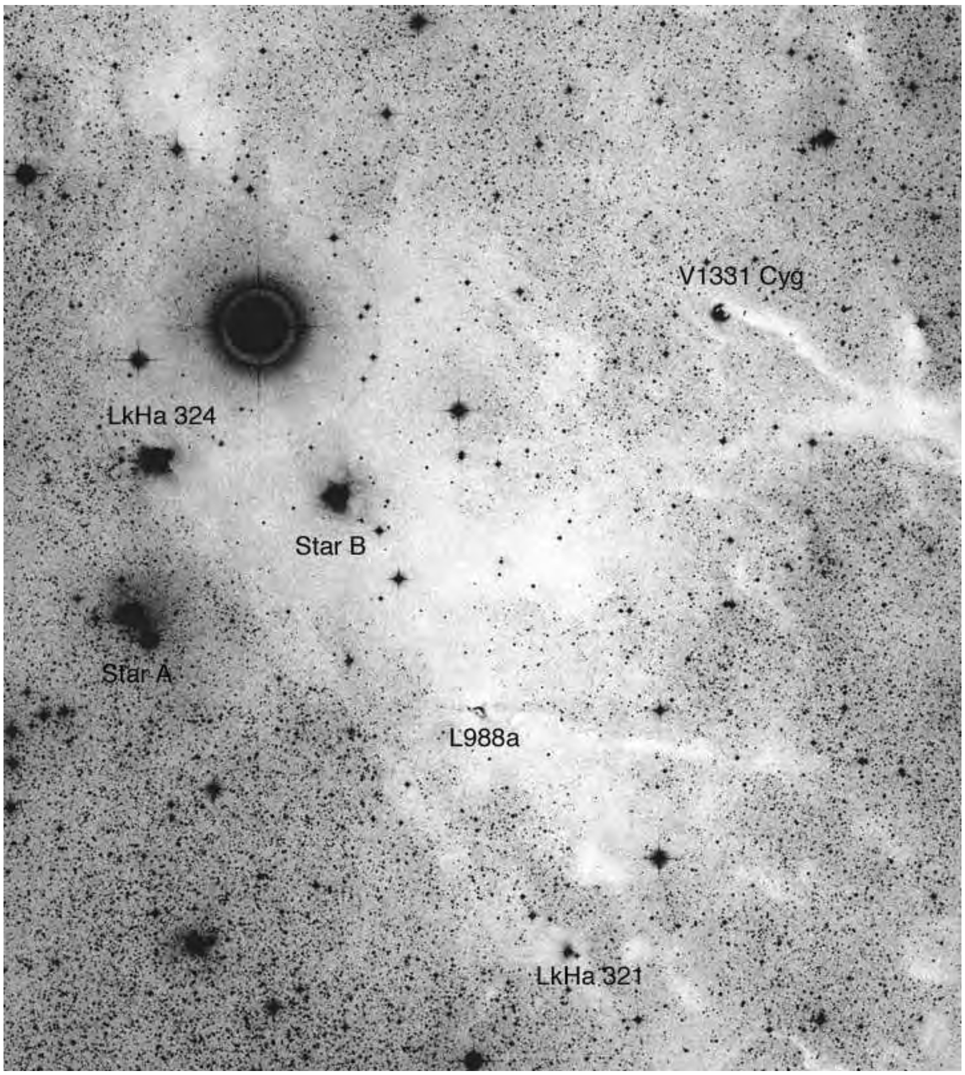

Figure 29. The Lynds 988 cloud as seen on the red Digitized Sky Survey. The field is about 45×55 arcminutes. Individual stars are identified. Star A and B refer to stars discussed by Herbig & Dahm (2006).

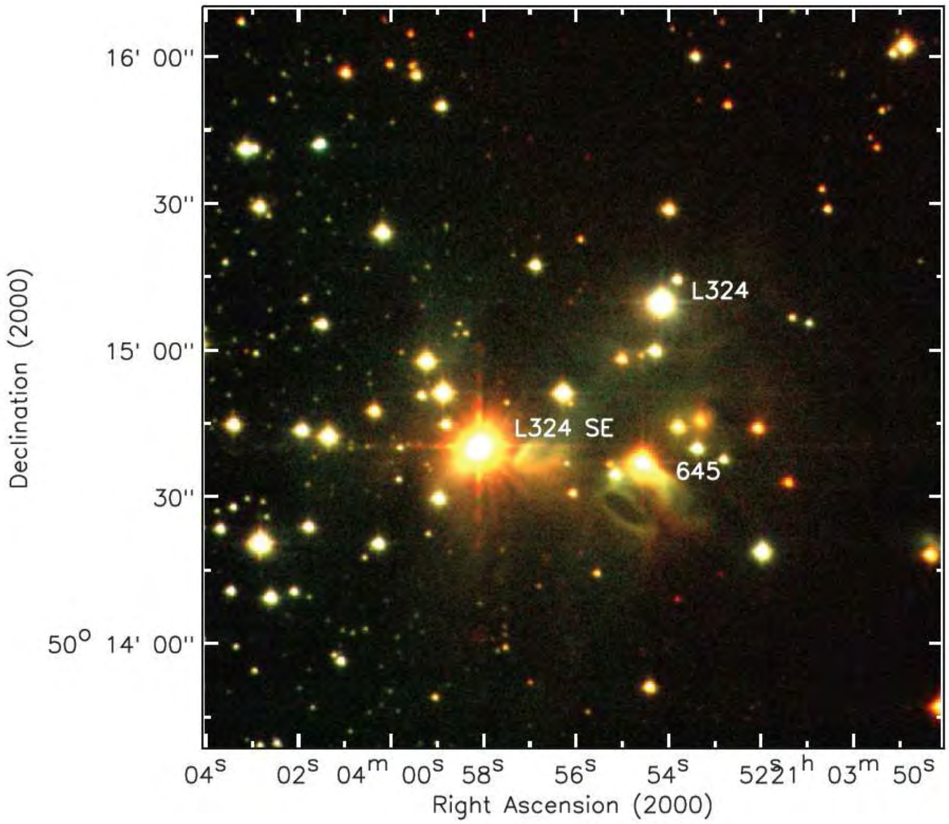

Figure 30. The partly embedded cluster around the Herbig Ae/Be star LkHα 324 at the eastern edge of the L988 cloud. The cluster is also sometimes called the L988e cluster. The bright star LkHα 324SE is a probable Herbig Ae/Be star. The nebulous star IHα 645 is prominent at IR wavelengths, but highly extincted in the optical. JHK mosaic from Herbig & Dahm (2006).

A large number of IRAS sources have been identified as potential young stars in this general direction of Cygnus (Dobashi, Bernard, & Fukui 1996). An outflow and disk was found around the embedded massive young star GH2O 092.67+03.07 by Bernard, Dobashi, & Momose (1999). A number of nebulous stars, Herbig-Haro objects and Hα emission stars have been found in the cloud complexes in this area of Cygnus (e.g., Cohen 1980; Herbig & Bell 1988, Devine, Reipurth, Bally 1997; Movsessian et al. 2003; Melikian & Karapetian 2003).

A major cloud complex is seen towards the direction of the Cyg OB7 region, it is known as Kh 141 (Khavtassi 1960), or TGU 541 (Dobashi et al. 2005), and is sometimes called "The Northern Coalsack" see Figure 28. It has been suggested to be lying in the foreground at a distance of only about 400 pc (Simonson & van Someren Greve 1976), but others suggest a direct connection with Cyg OB7, and thus a distance of closer to 800 pc. The extinction and HI content of the cloud complex was studied by Saito et al. (1981). The highest extinction regions in Kh 141 are L988 (TGU 541 P2), L978 (sometimes called L977, TGU 541 P7), and L1003 (TGU 541 P1) (Dobashi et

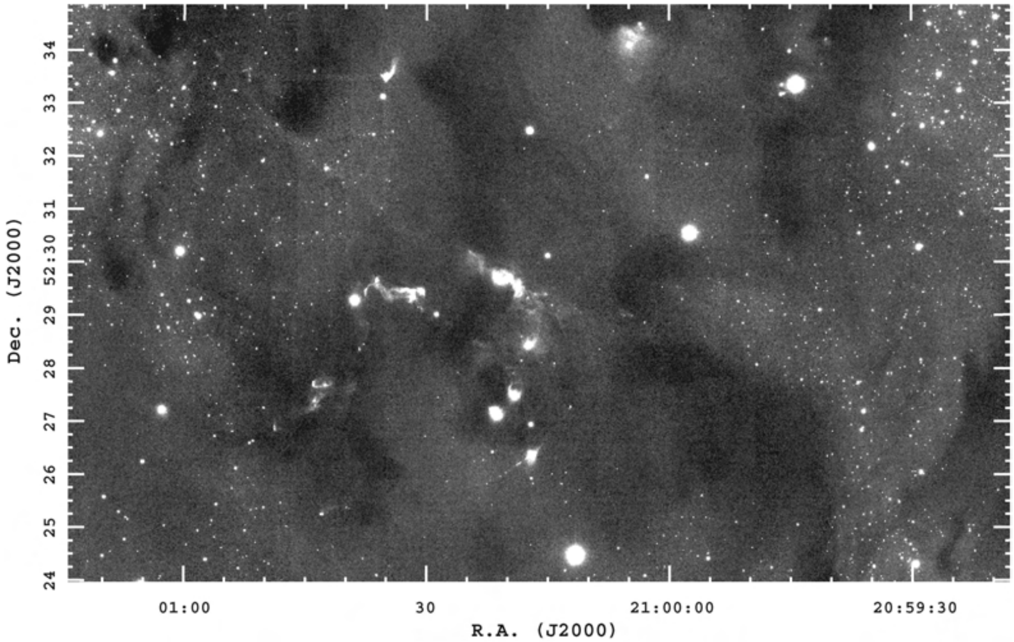

Figure 31. The central part of the L1003 cloud with numerous Herbig-Haro flows, reflection nebulae, and nebulous young stars is seen in this Hα CCD image obtained at the Subaru 8m telescope. Courtesy Colin Aspin.

al. 2005, see Figure 28). Chavarria-K. (1981) and Chavarria-K. & de Lara (1981) determined a distance of 700 pc and 780 pc, respectively, to two nebulous stars in L988 marked A and B in Figure 29. Shevchenko et al. (1991b) observed a large number of stars in the region and concluded that the extinction rises sharply at a distance of 550 pc. In reviewing the various values, Herbig & Dahm (2006) adopted the compromise distance of 600 pc to L988. Alves et al. (1998) studied the L978 cloud (they called it L977), which is very close to L988, and found a distance of 500$\pm$100 pc.

The two principal regions of high extinction in Kh 141, the L988 cloud and the L1003 cloud, are both actively forming stars.

The L988 cloud, see Figure 29, harbors three bright Hα emission stars, V1331 Cyg (see Sect. 7.3.), LkHα 321, and LkHα 324 (see Figure 29), in addition to two little-studied nebulous stars (marked A and B in Figure 29 following the nomenclature of Herbig & Dahm 2006). Finally, a small nebula is visible at the location of the molecular outflow L988a, one of several identified in this cloud by Clark (1986), see also Staude & Elsässer (1993) and Hodapp (1994). In a detailed optical/infrared study, Herbig & Dahm (2006) finds that LkHα 324 and the neighboring partly embedded star LkHα 324-SE, both probable Herbig Ae/Be stars, are surrounded by a cluster of at least 60 Hα emitters, see Figure 30. Allen et al. (2008) used further near-infrared and Spitzer images to study the exposed and the embedded parts of this cluster. Millimeter studies show that the cluster is partly embedded in a large dense cloud core (Ridge et al. 2003, Allen et al. 2008). In a widefield imaging study of L988, Walawender, Reipurth, & Bally (2008) found a large number of Herbig-Haro objects, including a major parsec-scale flow.

The L1003 cloud first attracted attention when Cohen (1980) discovered a red and nebulous object, RNO 127, that later was found to be a bright Herbig-Haro object, HH 448 (Melikian & Karapetian 2001, 2003). The cloud contains several IRAS sources and numerous HH objects, see Figure 31 (Devine et al. 1997, Movsessian et al. 2003). Of particular interest is the presence of a new FUor in this cloud (Movsessian et al. 2003, 2006).

The Bok globule B362 is located at l = 92.7°, b = –0.1° just south of the main part of the Kh 141 cloud complex and is probably associated with it. Ogura & Hasegawa (1983) surveyed the region and found several Hα emission stars around the globule. About 10 arcmin south of B362 one finds the even smaller L1014 cloud (e.g., Crapsi et al. 2005), which has attracted some interest in recent years because of the detection of an embedded, low-luminosity, mid-infrared and radio continuum source (Young et al. 2004, Shirley et al. 2007) illuminating a reflection nebula and driving a molecular outflow (Huard et al. 2006, Bourke et al. 2005). Assuming a kinematically derived distance of 200 pc, the embedded source could be a proto-brown dwarf. However, as pointed out by Morita et al. (2006) (who noted several Hα emission stars near L1014), the cloud is likely to be more distant. If associated with the Kh 141 complex and the Cyg OB7 association at $\sim$800 pc, the luminosity is no longer unusually low.

The whole region towards Cyg OB7 deserves further detailed study at infrared wavelengths and in X-rays.

6. NGC 6871, Byurakan 2, and the Cyg OB3 Association

The Cyg OB3 association is spread across about 3.5° $\times$ 1.5° in the western part of the Cygnus Rift. It has not been studied in great detail, the most complete lists of association members are those of Humphreys (1978) and Garmany & Stencel (1992), who suggest distances of 2.3 kpc and 1.7 kpc, respectively. Massey et al. (1995) performed UBV CCD photometry of 1955 stars towards Cyg OB3 and find a distance of 2.1 kpc. The earliest association member is an O4 star HD 190429A. The cluster NGC 6871 is generally presumed to be a nucleus in the Cyg OB3 association. The cluster was first noted in 1825 by Friedrich Georg Wilhelm von Struve, and has since been the subject of many studies, those based on photographic material are today mostly of historical interest (e.g., Riggs 1944, Purgathofer 1961, Bogdanovic 1973). The cluster is dominated by two bright multiple stars, but is otherwise not very obvious due to the high density of background stars. The earliest type member of the cluster is the O6.5III star HD 190864. The distance to NGC 6871 has been in some dispute. Among the more detailed studies, Cohen (1969) used Hβ photometry of ten OB stars to find 1.9 kpc, Crawford et al. (1974) used uvbyβ photometry of 24 members and suggest 2.0 kpc, while Reiman (1989) used uvby photometry to study 21 members and favor 2.4 kpc. Overall, NGC 6871 and the Cyg OB3 association is probably located at a distance of roughly 2 kpc. The age determinations of the cluster are rather discrepant, e.g., 12 Myr (Reiman 1989), 2-5 Myr (Massey et al. 1995), and 8-12 Myr (Southworth et al. 2004), the latter is based on the eclipsing B0-type binary V453 Cyg. A number of variable stars have been found in NGC 6871, including several eclipsing binaries (e.g., Delgado et al. 1984, Southworth et al. 2004). Emission line stars have been found towards NGC 6871 (Bernabei & Polcaro 2001, Balog & Kenyon 2002), the latter of these studies found 44 emission line stars, 24 of which are likely cluster members, partly Be stars and partly weak-line T Tauri stars.

Table 6. Open Clusters towards the Cyg OB3 Association[a]

Cluster	α_{2000}	δ_{2000}	l	b
NGC 6871	20 06.0	+35 47	72.65	+2.05
Byurakan 1	20 07.5	+35 42	72.75	+1.75
Byurakan 2	20 09.2	+35 29	72.75	+1.35
NGC 6883	20 11.3	+35 50	73.28	+1.18

[a] Positions are from Simbad.

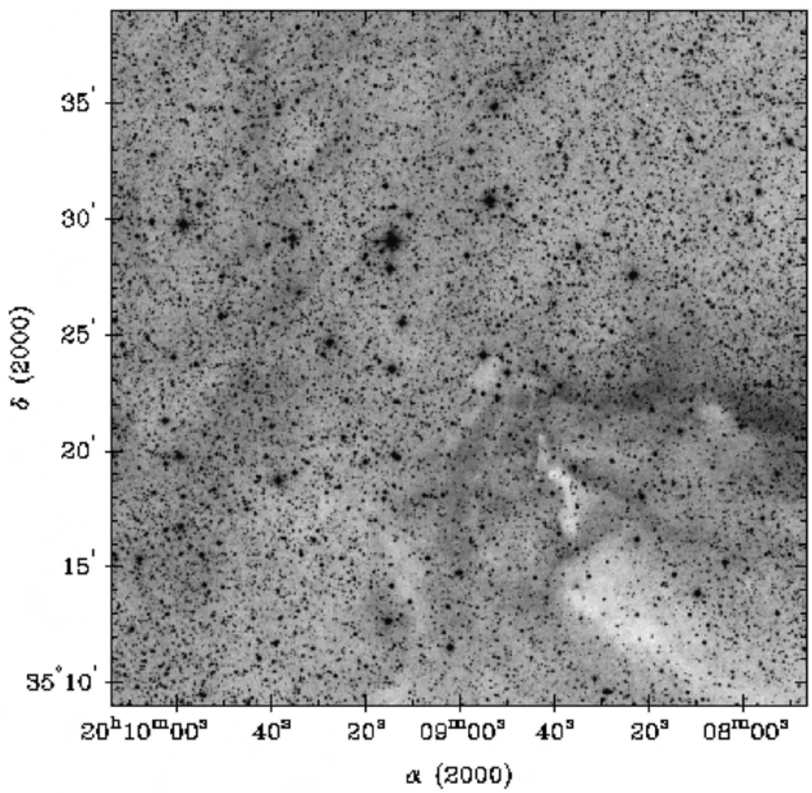

Figure 32. The young loose cluster Byurakan 2 and the nearby cometary clouds (L856 = TGU 444). The cluster appears to be part of the Cyg OB3 association. Image from the red DSS survey.

Another cluster that appears to be associated with Cyg OB3 is Byurakan 2 (see Fig. 32). It is located near the tip of a cometary cloud complex known as L856 or TGU 444 (Dobashi et al. 2005), and it appears that the young stars are responsible for sculpting the cloud complex. The central bright star of Byurakan 2 is HD 191566, a B0.5IV star (V$\sim$7.7) in a double system. The cluster was studied by Dupuy & Zukauskas (1976), who found a diameter of about 19 arcmin, an absorption of $A_V\sim$3.3, a distance of 1445$\pm$133 pc, and an age of less than 10^7 yr. Most recently, Bhavya et al.

(2007) used the existing optical data combined with 2MASS data to derive a distance of 1739±175 pc, and an age in the range 0.5 - 5 Myr.

Two other little-known clusters are found within Cyg OB3, they are Byurakan 1 and NGC 6883, both of which are difficult to discern on sky surveys because of the richness of the background star fields. No dedicated studies have been made of either cluster.

7. Individual Objects of Particular Interest

In the following we discuss a number of young sources towards Cygnus which have been the focus of detailed studies. These stars are only a small selection of the many very interesting sources in this direction.

7.1. V1057 Cyg

The young star LkHα 190 (HBC 300, V1057 Cyg) was a faint irregular variable with Hα in emission (Herbig 1958) until it underwent a major FUor eruption in 1969 (Welin 1973), brightening by about 5.5 magnitudes (Herbig 1977), see Fig. 33. It is located towards the center of the North America nebula, and is thus likely to be located at a distance of about 600 pc (Laugalys & Straizys 2002). Numerous photometric studies have subsequently been made in the optical (e.g., Mendoza 1971, Gieseking 1974, Landolt 1977, Kolotilov 1990, Ibragimov 1997, Kopatskaya et al. 2002) and in the infrared (e.g., Cohen & Woolf 1971, Simon et al. 1972a,b, Simon 1975, Simon & Joyce 1988). Spectroscopically the star went from an advanced T Tauri type emission spectrum with no absorption lines (Herbig & Harlan 1971) to a pure absorption line spectrum with F-G type supergiant features and strong P Cygni wings at Hα and the Sodium doublet (Herbig 1977). Many further spectroscopic studies have been performed, including

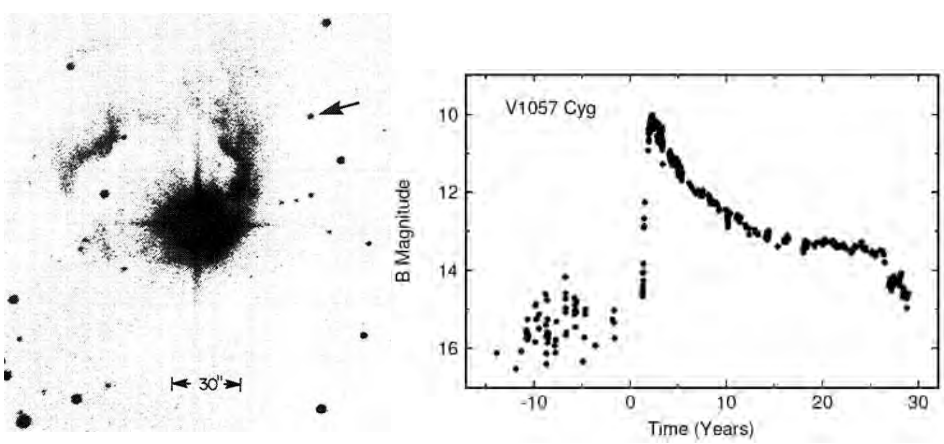

Figure 33. *Left:* The FUor V1057 Cyg was near maximum brightness surrounded by a large, bright reflection nebula, as seen in this red photograph. The faint adjacent star at the arrow is variable. From Duncan, Harlan, & Herbig (1981). *Right:* Optical lightcurve of V1057 Cyg from 1955 to 1998, from Kolotilov & Kenyon (1997).

Schwartz & Snow (1972), Grasdalen (1973), Chalonge et al. (1982), Kolotilov (1983b), Hartmann & Kenyon (1987), Welty et al. (1990,1992), Petrov et al. (1998), Rustamov (2001), and Herbig, Petrov, & Duemmler (2003). A 1720 MHz OH maser was detected in association with V1057 Cyg in 1973 (Lo & Bechis 1973,1974, Elitzur 1976) and another outburst was detected again in 1979 (Andersson et al. 1979, Winnberg et al. 1981). These masers may result from interaction between expanding shells and circumstellar material a few hundred AU from the star. The FUor phenomenon can be understood either as a major disk accretion event (Kenyon et al. 1988) or as a rapidly rotating star near the edge of stability (Herbig et al. 2003).

7.2. V1515 Cyg

V1515 Cyg (HBC 692, IRAS 20220+4202) is an FU Orionis-type object discovered by Herbig (1977) in the dark cloud complex L897 associated with the NGC 6914 region, seen in Figure 27. Although V1515 Cyg shares the characteristic spectral features of FU Ori and V1057 Cyg, in contrast to these two stars it has had a much slower rise to maximum brightness, with a rise time of a decade or longer. Photometric studies of V1515 Cyg include Landolt (1977), Gottlieb & Liller (1978), Kolotilov & Petrov (1983), Ibragimov & Shevchenko (1990), and Ibragimov (1997). In a more detailed optical/infrared spectroscopic study, Kenyon et al. (1991) have shown that V1515 Cyg displays many features in common with other FUors, including a variation of spectral type with wavelength and strong CO band head absorption.

7.3. V1331 Cyg

V1331 Cyg (LkHα 120, HBC 302, IRAS 20595+5009) is a peculiar T Tauri star surrounded by a curved reflection nebula (see Figs. 29 and 34). The star has been extensively studied in the optical by, among others, Kuhi (1964), Chavarria-K. (1981), Kolotilov (1983a), Mundt (1984), Shevchenko et al. (1991b), Ivanova (1994), Hamann

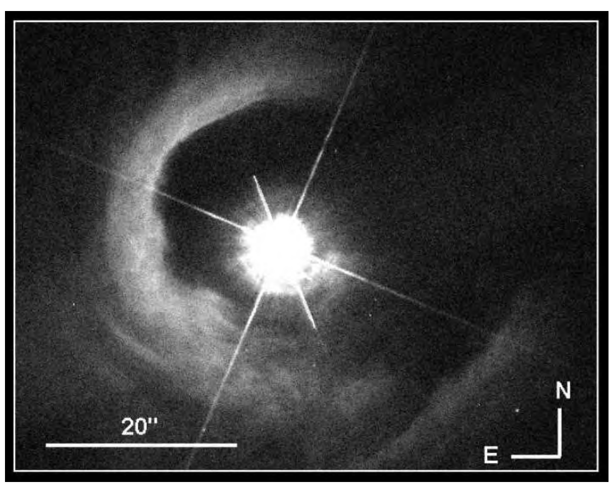

Figure 34. The rich emission-line T Tauri star V1331 Cyg displays a highly structured circumstellar environment, as seen in a red WFPC2/HST image. From Quanz et al. (2007).

(1994), and Quanz et al.(2007). Infrared CO spectra, displaying prominent emission in the first-overtone CO bands, are shown by Biscaya et al. (1997). Weintraub, Sandell, Duncan (1991) present 450 - 1300 μm photometry. Henning et al. (1998) present a 1300 μm map. McMuldroch, Sargent, Blake (1993) use aperture synthesis ^{13}CO and continuum observations to detect a disk and circumstellar envelope, as well as a molecular outflow, also studied by Levreault (1988). Mundt & Eislöffel (1998) present interference filter CCD images with which they discovered a 3 arcmin long HH flow, HH 389, emanating to the south from V1331 Cyg. Terquem et al. (1999) discuss precession of the HH jet axis due to a possible binary nature of the source. Shevchenko et al. (1991b) suggest a distance of 550 pc to V1331 Cyg. Hojaev (1999) finds that V1331 Cyg is associated with a compact group of young stars. Occasionally V1331 Cyg is related to FUors with the hazy term “pre-FUor”, but there is no credible basis to connect the star to the FUor phenomenon.

7.4. IRAS 20126+4104

The luminous source IRAS 20126+4104 is located in a small globule facing away from the Cyg OB2 cluster, and this association indicates a distance of 1.7 kpc. The source has a luminosity of roughly 10^4 $L_\odot$, most of which is likely produced by accretion towards an early B-type star. A major, bipolar molecular outflow is seen to emanate from the source in a north-south direction (Wilking et al. 1990, Cesaroni et al. 2005, Lebrón et al. 2006), see Fig. 35, and associated with molecular hydrogen knots (Ayala et al. 1998, Shepherd et al. 2000, Caratti o Garatti et al. 2008). The molecular outflow may be driven by an ionized jet detected in the radio continuum (Hofner et al. 1999), and with evidence from SMA interferometric millimeter observations of a history of precession (Su et al. 2007). The central source is lying in a hot dense core and is surrounded by a collapsing disk in Keplerian rotation (Cesaroni et al. 1997, 1999, Zhang et al. 1998). Numerous water maser spots have been detected around IRAS 20126+4104, and multi-epoch VLBI observations show that they are accelerating away from a common origin at the protostar, seemingly moving along the surface of a conical jet (Moscadelli et al. 2000, 2005, Trinidad et al. 2005, Lekht et al. 2007). OH and CH_3OH masers are consistent with Keplerian rotation around a central mass of $\sim$5 $M_\odot$ (Edris et al. 2005). Deep near-infrared imaging suggests that IRAS 20126+4104 may have a fainter companion with a separation of $\sim$1000 AU (Sridharan et al. 2005).

7.5. AFGL 2591

The massive embedded protostar AFGL 2591 (IRAS 20275+4001) is located in a cometary cloud pointing towards the center of the Cyg OB2 cluster, and is therefore likely to be at a distance of $\sim$1.7 kpc (Schneider et al. 2006), but adopted distances in the literature vary a great deal. A massive molecular outflow is driven by this source (Bally & Lada 1983, Lada et al. 1984, Mitchell et al. 1992, Hasegawa & Mitchell 1995), and Poetzel et al. (1992) found a group of Herbig-Haro objects, HH 166, associated with the source. The outflow activity is also seen as near-infrared H_2 knots (Tamura & Yamashita 1992). Interferometric observations have revealed two prominent sources with a separation of about 6 arcsec (Brown 1974, Simon et al. 1981, van der Tak et al. 1999), of which the NW component corresponds to a near-infrared source surrounded by an outflow cavity seen in near-infrared reflected light (e.g., Tamura et al. 1991, Minchin et al. 1991, Preibisch et al. 2003), see Figure 36. Other fainter sources also surround these two sources in a small cluster (e.g., Trinidad et al. 2003). A large number of H_2O

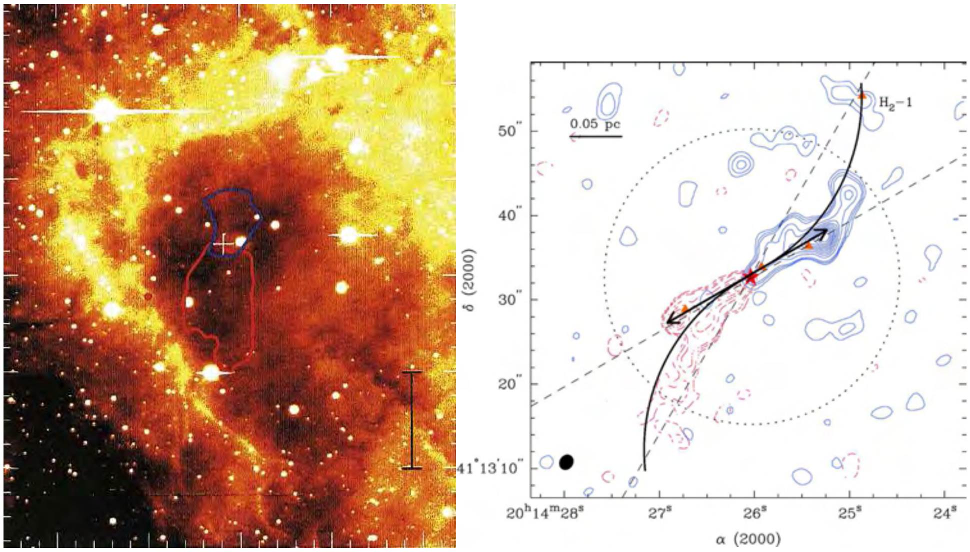

Figure 35. *Left*: The luminous source IRAS 20126+4104 is embedded in a small globule with a bright rim facing away from the Cyg OB2 association. The blue and red CO contours of a molecular outflow are superposed on an Hα image. The scale bar is 0.5 pc long and the field is about 4×6 arcmin. From Shepherd et al. (2000). *Right*: The molecular outflow emanating from IRAS 20126+4104, as observed with the SMA in the CO (3-2) transition. The dotted circle represents the primary beam of the SMA observations. The synthesized beam is indicated in the lower left corner. From Su et al. (2007).

Figure 36. The AFGL 2591 source as seen in a near-infrared J,H,K image. Courtesy Colin Aspin and Gemini Observatory.

maser spots have been found around AFGL 2591 by Tofani et al. (1995) and Trinidad et al. (2003). AFGL 2591 is probably an early B-star surrounded by a large, massive envelope with a total extinction $A_V \sim$100 mag. The chemistry triggered by irradiation of the protostar in the hot inner envelope has attracted increasing attention, see Benz et al. (2007) and references therein.

8. Concluding Remarks

The star forming regions in Cygnus contain hundreds of thousands of young stars and are among the most active regions of star birth in our Galaxy. The account presented here is of necessity limited to the more well known regions, but there are many other regions in Cygnus that offer excellent opportunities to study little known young stars and clusters deserving of closer examination. Also, this review is limited to regions within about 2 kpc, but Cygnus contains numerous important regions at larger distances. In addition to targetted observations of specific regions, it would be particularly valuable to carry out large scale, systematic surveys for Hα emission stars, infrared excess sources, and X-ray sources in the Cygnus clouds.

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