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The Circinus Star Forming Complex

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Abstract. The Circinus giant molecular cloud is a little explored region that deserves closer study owing to the many signs of vigorous low-mass star formation in the form of Hα emission stars, Herbig-Haro objects, molecular outflows, and embedded sources. The western part of the cloud complex has a filamentary structure with numerous cavities, indicating the effect of powerful molecular outflows. It is likely that the current strong star formation activity was triggered by a supernova explosion. Our present limited knowledge about this region is summarized, and several particularly interesting sources are discussed.

1. Introduction

The Circinus cloud complex is located toward *l* = 318°, *b* = –4° along a relatively extinction-free line of sight in the southern Milky Way. In right ascension and declination this corresponds to roughly 15^h and –63°. The total extent of the cloud complex as traced by its extinction is about 2° $\times$ 5°, and it forms an isolated giant molecular cloud beneath the Galactic plane. The location near α and β Centauri is indicated in Figure 1, adapted from the extinction atlas of Dobashi et al. (2005). The complex coincides with a large cloud seen in the Dame et al. (1987) CO survey at a velocity of –6 km s^{-1}. This region of the sky is remarkably little studied, in fact only the westernmost part of the Circinus complex, seen in Figure 2, has been studied in any detail. The dense core of this western part is denoted TGU 1978 P2 by Dobashi et al. (2005), and can be seen as a high extinction region in Figure 1 at *l* = 316.9°, *b* = –3.9°. Although it is more or less centrally located in the Circinus complex, in the following we denote the region seen in Figure 2 as Circinus-W, because it is the westernmost part of the high-extinction cloud structure in the Circinus complex. What is noteworthy about this western cloud region is the numerous cavities bounded by narrow dust filaments that fan away from the opaque core, indicating that the cloud has been subject to dozens of outflows powered by young stars in the recent past. This high level of simultaneous star formation activity led Bally et al. (1999) to suggest that a supernova may have blown up in the vicinity of the cloud, triggering a new generation of low-mass stars. This is supported by the shell-like morphology that is seen in Figure 2, and which extends on much larger scales, as is evident in the Dobashi extinction map in Figure 1.

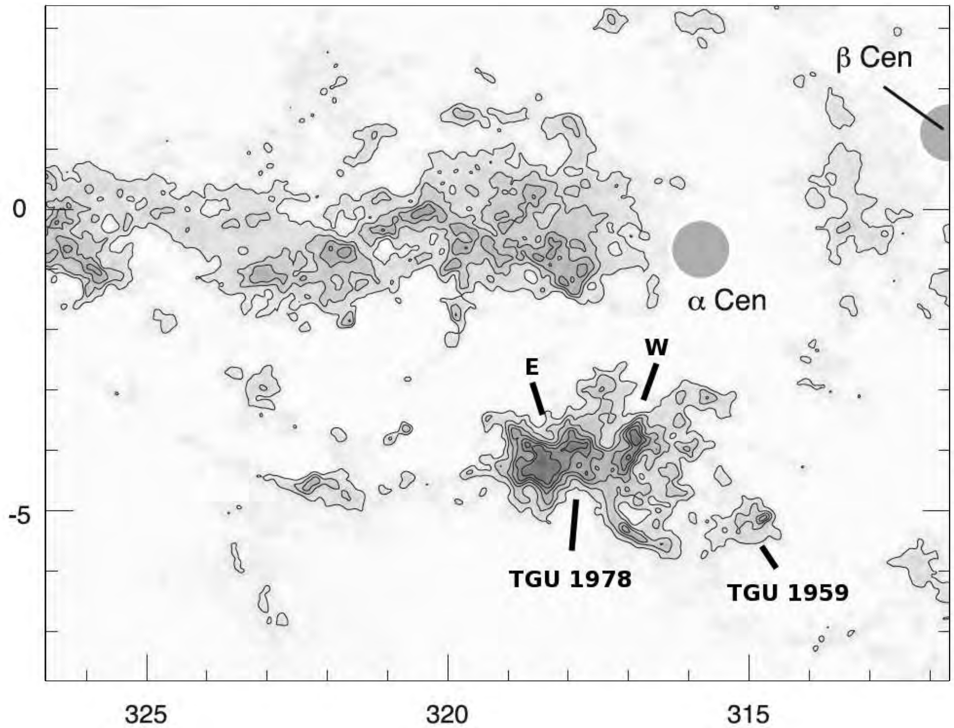

Figure 1. Extinction map of the giant Circinus cloud complex, denoted TGU 1978/1959, located close to α and β Cen and just beneath the Galactic plane. The cloud complex is also known as G317-4. The two highest-extinction regions of TGU 1978 are labeled Circinus-E and Circinus-W. Coordinates are Galactic. From Dobashi et al. (2005).

The distance to the Circinus cloud complex is poorly known. Herbst (1975) suggested a distance of 1260 pc. However, Neckel & Klare (1980) studied the extinction towards this line of sight, and found a minor but abrupt increase of extinction at a distance of about 170 pc, and a larger jump in A_V of 2.0 mag somewhere between 600 and 900 pc. Franco (1990) studied the extinction in an adjacent area, and found a similar distribution. In the only major study of this region, Bally et al. (1999) adopted a distance of 700 pc, noting that it may be uncertain by almost a factor 1.5. At this distance the entire cloud complex mapped by Dame et al. (1987) has a mass of 4.7×10^4 $M_\odot$.

Apparently the first evidence of recent star formation in the Circinus complex was found by van den Bergh & Herbst (1975), who identified two nebulous stars, vBH 65a and 65b, associated with the western cloud region, and by Herbst (1975), who noted the presence of a small group of stars with reflection nebulae which he called Cir R2.

2. Hα Emission Stars

An objective prism survey for Hα emission stars in the Circinus complex has been carried out by Mikami & Ogura (1994). The area surveyed is shown in Fig. 3, together

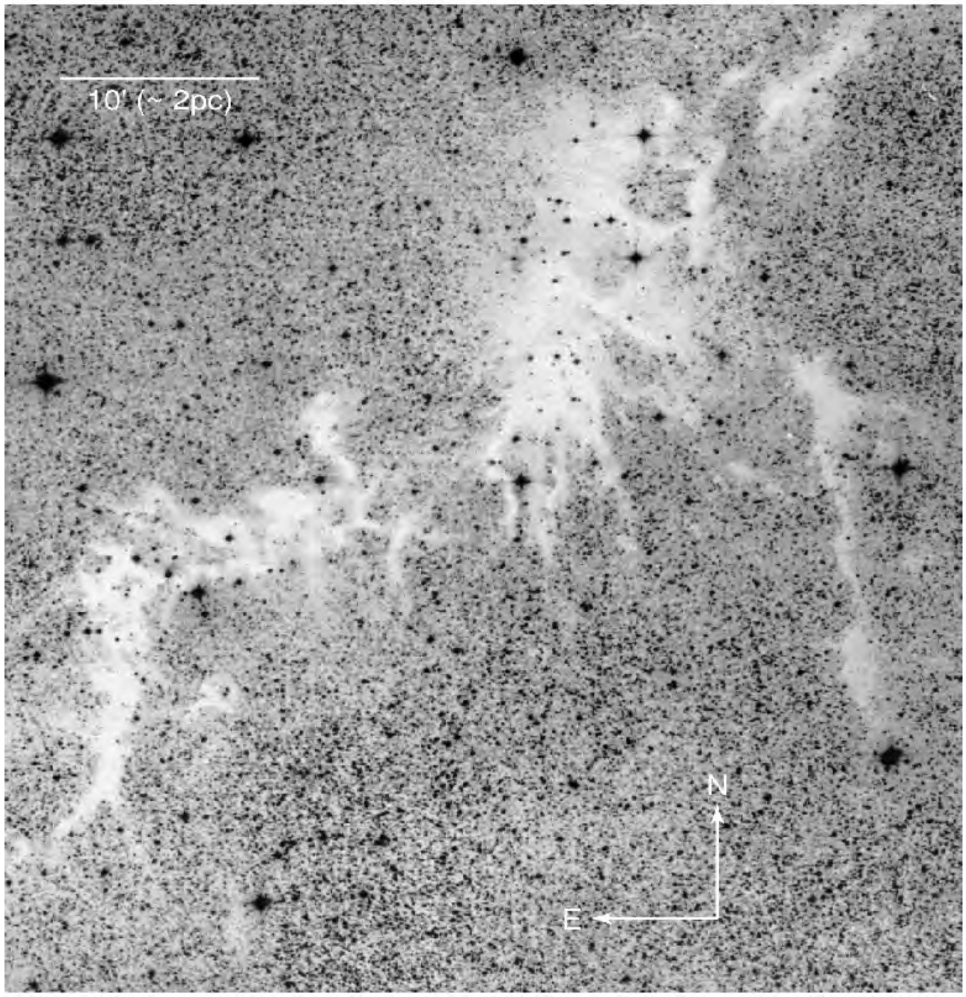

Figure 2. The cloud complex Circinus-W as seen on an R-band ESO Schmidt photograph. It is evidently highly structured and has high extinction. The area shown is approximately 48 arcminutes on each side. From Bally et al. (1999).

with cloud designations from Hartley et al. (1986) and the location of 47 Hα emission line stars. The positions of these stars are listed in Table 1 (omitted are stars with uncertain Hα emission).

Centrally located in the Circinus-W cloud, and just 22″ east of the Hα emission star MOHα 10 one finds a cometary nebula, listed as vBH 65a in the catalogue of van den Bergh & Herbst (1975), see Figure 4. The nebula opens up from the embedded source IRAS 14568–6304 (see Table 2), which is located in a N-S oriented dense filament of gas and dust. The source drives a bipolar molecular outflow oriented E-W and labeled Flow F by Bally et al. (1999). In the middle of the cometary reflection nebula one finds a small bow shock, HH 139 (Reipurth 1999). Perrin & Sivan (1993) studied the spectrum of the reflection nebula, and speculated that it was illuminated by the neighboring star MOHα 10 which, however, one can exclude because an embedded source is located at the apex of the nebula (Scarrott et al. 1994).

Table 1. Hα emission stars in the Circinus cloud from Mikami & Ogura (1994)[a].

MOHα	α_{2000}	δ_{2000}	$I^b_{H\alpha}$	MOHα	α_{2000}	δ_{2000}	$I^b_{H\alpha}$
1	14 58 43.6	–62 53 41	4	26	15 14 36.9	–62 44 54	4
2	15 59 13.7	–63 00 04	3	29	15 14 43.2	–62 45 21	4
4	15 00 29.4	–63 09 45	3	30	15 14 52.9	–62 48 01	3
5	15 00 30.9	–63 06 52	4	32	15 15 23.9	–62 47 38	1
6	15 00 41.9	–63 11 10	1	33	15 15 27.3	–62 43 11	2
7	15 00 48.8	–63 05 37	4	34	15 15 34.9	–62 42 28	2
10	15 00 56.3	–63 16 55	3	35	15 15 42.4	–62 45 43	2
12	15 03 09.5	–63 24 27	1	36	15 15 50.2	–62 40 19	3
13	15 03 24.0	–63 22 59	5	37	15 16 04.1	–62 49 10	1
15	15 04 41.5	–64 07 13	2	38	15 16 16.4	–62 39 43	2
16	15 10 20.7	–62 40 03	4	39	15 16 27.3	–62 13 37	4
18	15 12 34.3	–62 45 19	2	42	15 16 50.8	–62 20 11	3
19	15 13 34.9	–62 22 51	1	43	15 17 20.6	–62 39 57	2
20	15 13 48.7	–62 25 03	4	44	15 17 59.6	–62 18 18	4
22	15 14 15.2	–62 36 52	1	46	15 18 20.0	–62 42 47	1

a: Objects in Hα intensity category 0 (uncertain emission) have not been included in this table.

b: Hα intensity ranging from 1 (weak) to 5 (strong).

A particularly interesting star in Circinus-W is vBH 65b. This is a Herbig Ae/Be star, also known as HBC 596, with a rich emission line spectrum somewhat resembling V380 Ori (Gahm & Malmort 1980). It was discovered as an Hα emission line star by Sanduleak & Stephenson (1973), who thought it might be a symbiotic star (their object no. 44). Other spectroscopy is reported by Allen (1978), by Manchado et al. (1990), who noted strong P Cygni profiles in the Balmer lines, and by Pereira et al. (2003). The star is bright optically (V∼12.7), is variable (with the name DG Cir), and was detected by IRAS (source 14592–6311, see Table 2), and is associated with a weak variable H_2O maser (Scalise et al. 1981). It was detected in X-rays with the ROSAT satellite (Carkner et al. 1998). vBH 65b is associated with a prominent reflection nebula, see Figure 5, and is surrounded by a little cluster of Herbig-Haro objects, HH 140-143 (Ray & Eislöffel 1994). The star drives a bipolar molecular outflow, denoted as Flow D by Bally et al. (1999).

Reipurth & Zinnecker (1993) found an Hα emission star, ESO Hα 283, that is a visual binary with 2.1″ separation. In a subsequent study, Correia et al. (2006) found that the binary has a third component forming a non-hierarchical triple system.

3. Embedded Sources, Herbig-Haro Flows, and Molecular Outflows

Bally et al. (1999) carried out a millimeter study of the Circinus-W molecular cloud. In that context they extracted the IRAS sources found towards the cloud, and they are listed in Table 2. Many of these sources are associated with outflow activity, in the form of molecular outflows (Figure 6 and Table 2), or as Herbig-Haro flows. The first HH objects in the Circinus cloud were found by Reipurth & Graham (1988), these are HH 76 and 77. Cohen (1990) discussed potential energy sources for these two objects. Further HH objects were subsequently found by Ray & Eislöffel (1994) and by Reipurth

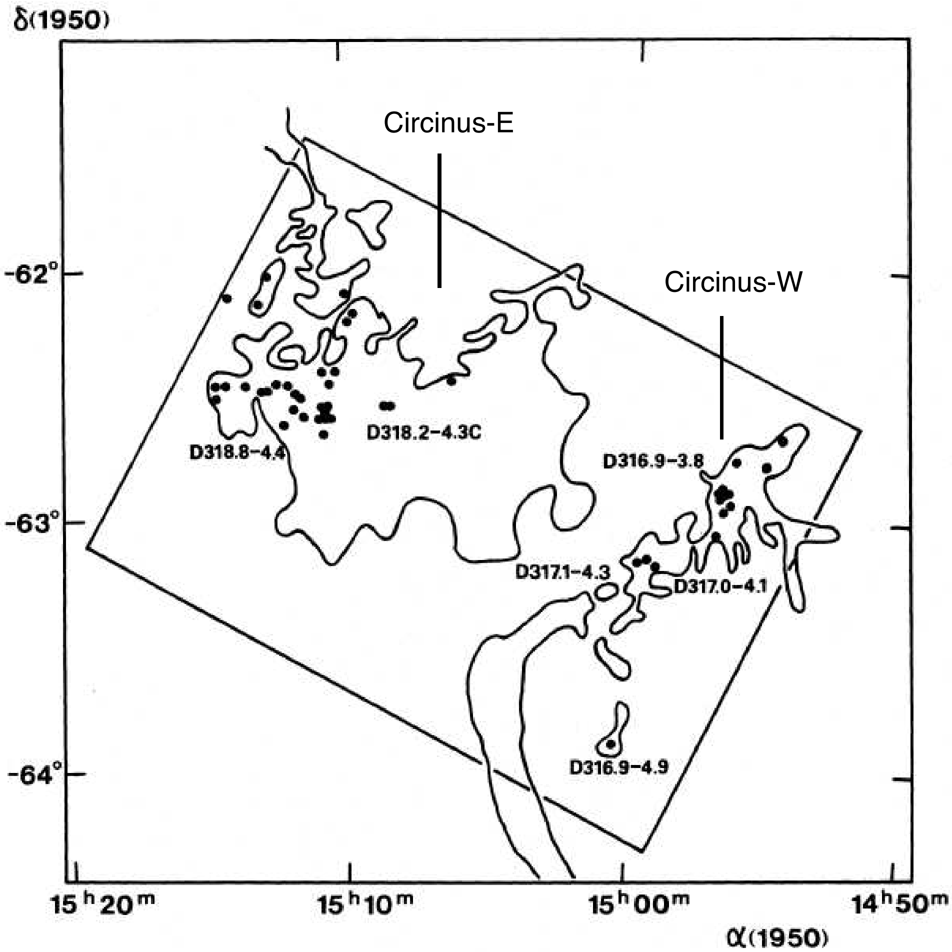

Figure 3. A sketch of the main cloud components of the Circinus complex. The rectangular box indicates the area surveyed for Hα emission stars by Mikami & Ogura (1994). Cloud designations are from Hartley et al. (1986). The Circinus-W cloud is seen at the right edge of the figure. From Mikami & Ogura (1994).

(1999), see Table 3. A deep widefield Hα and [SII] survey has been carried out of the Circinus-W cloud, revealing a multitude of new HH flows (Reipurth, Walawender, Bally, in preparation).

An embedded source of particular interest is IRAS 14564–6254. It is located in a massive cloud core in the northernmost part of Circinus-W, in the direction of the nebulous Hα emission star MOHα 5. A major molecular outflow, Flow A, was detected emanating from the IRAS source by Bally et al. (1999). A 1300 μm map by Reipurth, Nyman, Chini (1996) revealed a cluster of four cold sources, Cir-MMS 1-4, located towards the IRAS source (Figure 7). This compact aggregate extends over about 0.15 pc. There is a measurable displacement between the IRAS source and the peak of the 1300 μm emission, suggesting that we see sources in different stages of evolution.

Figure 4. CCD image through an Hα filter of the cometary nebula vBH 65a and its associated jet HH 139. The star immediately to the west of vBH 65a is the emission line star MOHα 10. From Reipurth, Walawender, Bally (in preparation).

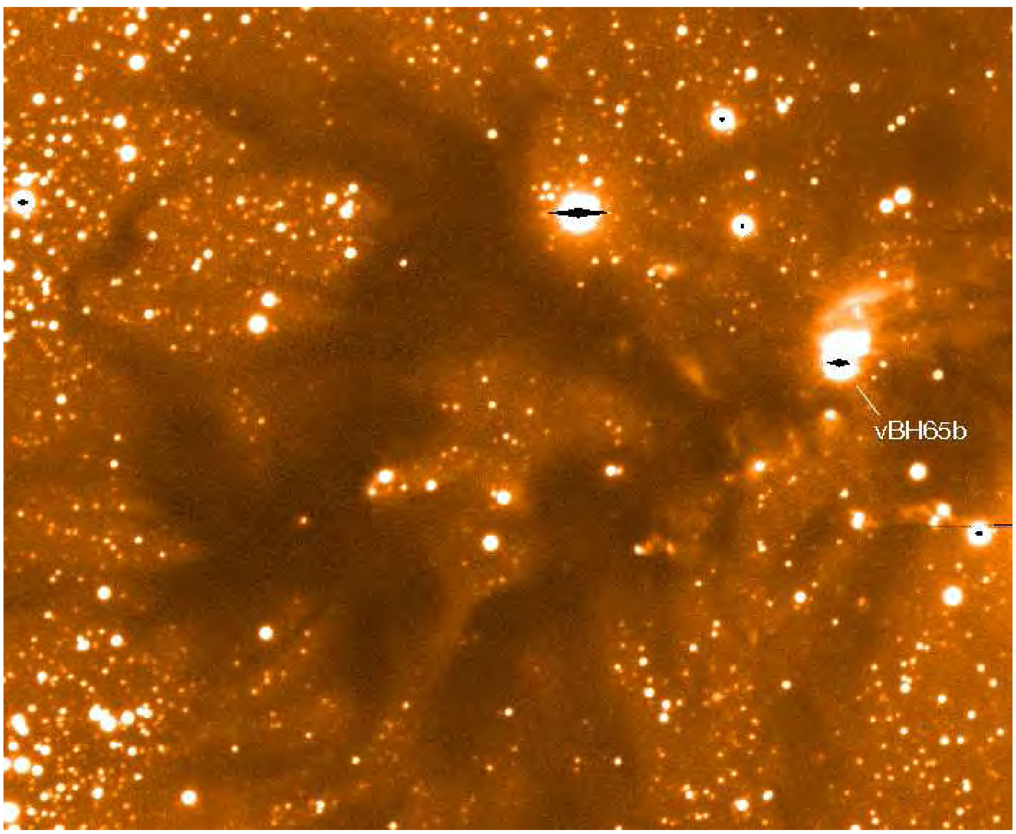

Figure 5. CCD image through an Hα filter of the Herbig Ae/Be star vBH 65b and the numerous HH flows surrounding it. The molecular cloud has been torn apart by many molecular outflows. From Reipurth, Walawender, Bally (in preparation).

Table 2. IRAS Sources towards the Circinus-W cloud (from Bally et al. 1999)

IRAS	α_{1950}	δ_{1950}	$F^a_{12\mu m}$	$F^a_{25\mu m}$	$F^a_{60\mu m}$	$F^a_{100\mu m}$	Flows
14544-6242	14 54 27.3	–62 42 53	0.48	0.34L	2.79L	15.77L	
14544-6252	14 54 28.4	–62 52 11	1.44	0.92	2.36L	39.36L	
14547-6302	14 54 44.0	–63 02 02	1.73	0.86	2.25L	33.86L	
14551-6248	14 55 10.2	–62 48 14	0.40L	0.64	0.88	38.90L	
14556-6259	14 55 38.4	–62 59 34	0.67	0.24	2.55L	32.57L	
14556-6302	14 55 39.9	–63 02 38	1.02	0.81	1.07L	20.46L	
14562-6248	14 56 12.7	–62 48 03	0.25L	1.64	5.26	94.03L	G
14563-6250	14 56 18.5	–62 50 02	0.74	2.48	5.69L	94.03L	E
14563-6301	14 56 18.6	–63 01 42	1.46	4.08	13.50	25.66	B+C
14564-6258	14 56 25.0	–62 58 38	0.41	1.09	13.50L	94.03L	C
14564-6254	14 56 28.9	–62 54 57	1.38	7.13	48.63	94.03	A
14568-6304[b]	14 56 51.6	–63 04 59	5.04	9.30	19.02	20.59	F
14569-6242	14 56 54.3	–62 42 35	1.98	0.50	2.34L	33.13L	
14576-6312	14 57 36.6	–63 12 22	0.28L	0.25L	1.37L	14.42	
14576-6251	14 57 37.0	–62 51 11	1.59	0.71	2.23L	18.93L	
14580-6303	14 58 04.9	–63 03 36	0.28L	1.04	1.68	20.83L	I
14582-6305	14 58 13.7	–63 05 15	0.81	0.33L	3.27L	26.92L	
14583-6329	14 58 21.2	–63 29 35	1.22	2.69	0.70	41.63L	
14585-6300	14 58 32.5	–63 00 27	0.34L	0.70L	1.89	48.71L	
14591-6238	14 59 10.7	–62 38 53	0.40	0.27	4.29L	37.30L	
14592-6311[c]	14 59 17.1	–63 11 20	2.77	5.96	10.54	11.37	D
14593-6254	14 59 21.3	–62 54 43	0.27L	0.37L	2.23	19.23	
14596-6320	14 59 37.4	–63 20 05	0.32L	0.29	4.02	16.03	H

a: The letter ”L” appearing after a quoted flux limit implies that the value is an upper limit.

b: vBH 65a

c: vBH 65b

Table 3. Herbig-Haro objects in the Circinus cloud

Object	α_{2000}	δ_{2000}	Ref.
76	15 00 38.7	–63 04 13	Reipurth & Graham (1988)
77	15 00 49.0	–63 07 46	Reipurth & Graham (1988)
139	15 00 58.3	–63 16 51	Reipurth (1999)
140	15 03 23.4	–63 22 50	Ray & Eislöffel (1994)
141	15 03 23.1	–63 23 54	Ray & Eislöffel (1994)
142	15 03 25.7	–63 22 25	Ray & Eislöffel (1994)
143	15 03 27.9	–63 23 36	Ray & Eislöffel (1994)

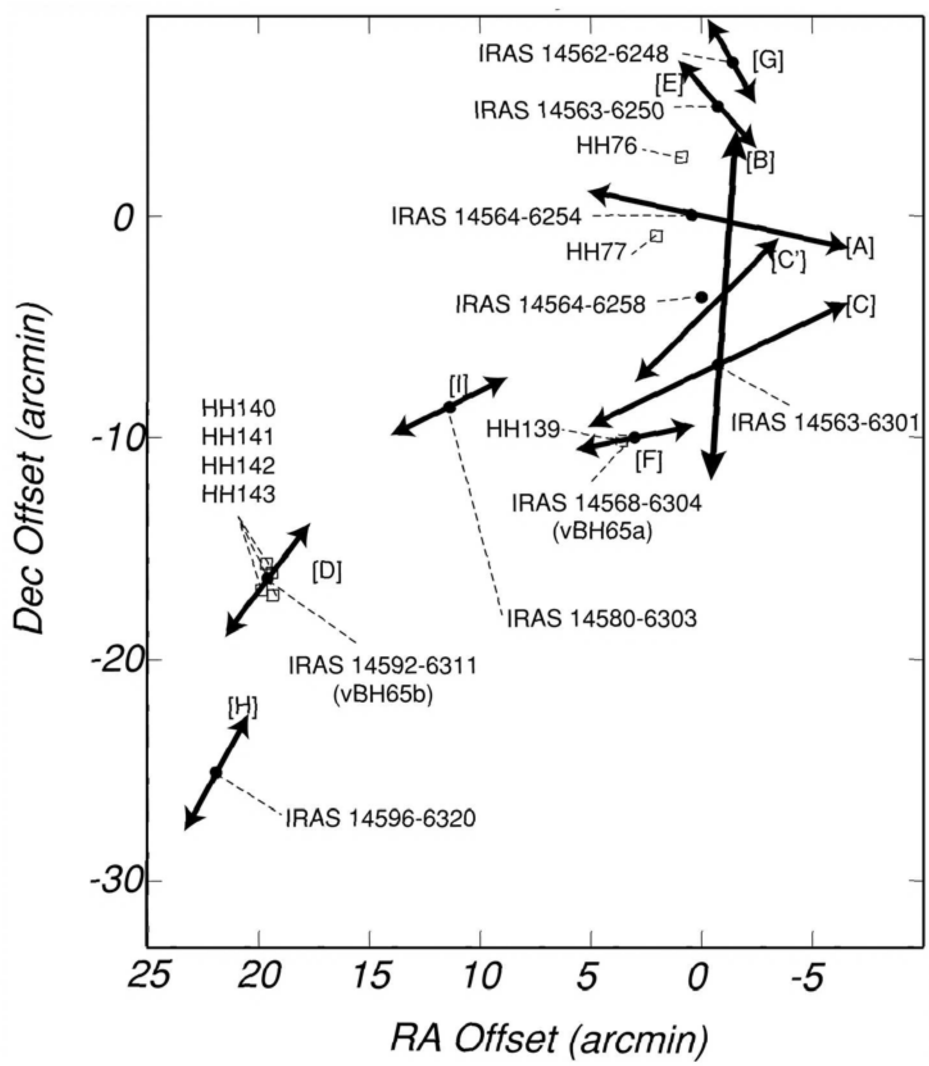

Figure 6. A finder chart showing the location of CO outflows in the western part of the Circinus complex. From Bally et al. (1999).

4. Future Work

The Circinus cloud complex is one of the last major star forming regions at a relatively close distance which has not been the subject of detailed studies. The eastern half of the Circinus complex has barely been studied at radio wavelengths, apart from a detection in the Galactic plane survey of Dame et al. (1987). The distance is highly uncertain, and it would be very valuable if an attempt was made to improve it by means of the radio parallax of the maser associated with vBH 65b using VLBI techniques. Additionally, further research is needed to identify the possible source (supernova, massive star wind, or source of UV irradiation) that may have triggered the active star formation in this cloud. Circinus-W abounds in newborn stars and outflow phenomena, and the

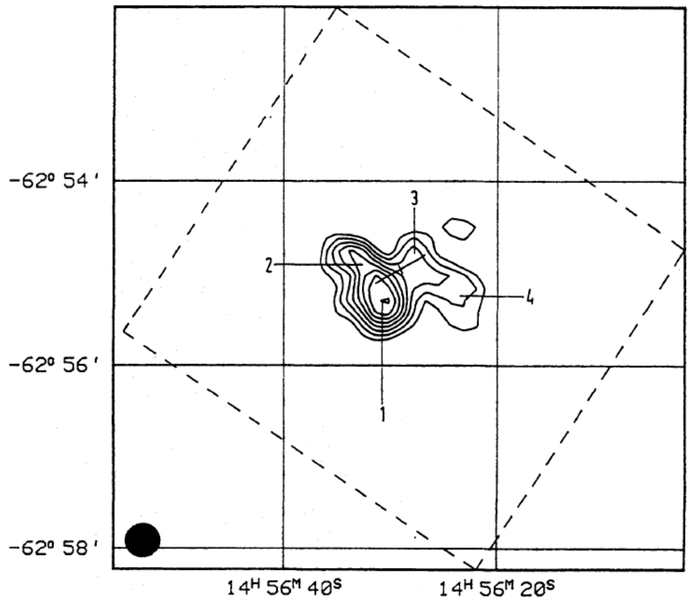

Figure 7. A 1300 μm map of the embedded multiple source Cir-MMS1 (IRAS 14564–6254). The dashed line box indicates the area mapped. (From Reipurth, Nyman, Chini 1996).

microburst of star formation witnessed in this cloud appears to be a southern equivalent to the NGC 1333 region (see the chapter by Walawender et al. in Volume I) and clearly deserves further detailed study.

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