Handbook of Star Forming Regions Vol. II
Astronomical Society of the Pacific, © 2008
Bo Reipurth, ed.

The Young Cluster NGC 6604 and the Serpens OB2 Association

Bo Reipurth

Institute for Astronomy, University of Hawaii
640 N. Aohoku Place, Hilo, HI 96720, USA

Abstract. NGC 6604 is a young cluster in Serpens with an age of 4-5 Myr and at a distance of about 1.7 kpc. It forms the densest part of the wider Ser OB2 association, which contains about 100 OB stars. NGC 6604 lies about 65 pc above the Galactic plane, and has attracted special interest since it has produced a thermal chimney stretching 200 pc out of the plane. The combined effect of winds and radiation from the many OB stars has produced a rim of dense molecular material in which second-generation star formation is currently taking place.

1. Introduction

NGC 6604 is a young cluster, originally discovered by William Herschel in 1784 and listed as H VIII-15, and later catalogued by John Herschel as h3740. It is also listed as Cr 373 in the catalogue of Collinder (1931). It is located in a rich part of the Milky Way in the constellation Serpens, only about 1.5 degrees north of NGC 6611. The center of the cluster is at J2000: $18^h\ 18.0^m\ -12^\circ\ 14'$. The general region is seen in Figures 1 and 2.

2. The NGC 6604 Cluster - Distance and Age

Early distance estimates for NGC 6604 are uncertain and vary from 0.7 kpc to 4.4 kpc; they are listed in Alter et al. (1970) and are not considered further here. Moffat & Vogt (1975) obtained UBV and Hβ photometry of a dozen early-type stars in NGC 6604 and derived a distance of 1.64 kpc. Forbes & Dupuy (1978) obtained UBV photometry, partly photoelectric and partly photographic, of almost 100 stars towards NGC 6604, and derived a distance of 2.1$\pm$0.4 kpc. Barbon et al. (2000) obtained CCD photometry for 27 stars as well as some slitless spectra, and found a distance of 1.7 kpc. Finally, Kharchenko et al. (2005) used the Tycho-2 observations from the Hipparcos mission supplemented by existing data to derive a distance of 1.7 kpc. All recent distance determinations are thus consistent with a distance of 1.7 kpc, which is assumed in the following. At this distance, NGC 6604 is located at a galactocentric distance of 6.9 kpc, which places it on the outer boundary of the Carina-Sagittarius arm, about 65 pc above the Galactic plane.

NGC 6604 is a young cluster, Forbes & Dupuy (1978) find an age of 4.0$\pm$1.4 $\times$ 10^6 yr, Barbon et al. (2000) suggest an age of 5×10^6 yr, and Kharchenko et al. (2005) suggest 4.4 $\times$ 10^6 yr.

Figure 1. The large, diffuse HII region S54 is excited by the NGC 6604 cluster and other OB stars in the Serpens OB2 association. The cluster is located less than two degrees north of M16, seen towards the bottom of the figure. The field is about $2.4^\circ \times 3.3^\circ$. North is up and east is left. Courtesy Matt BenDaniel.

3. Members of NGC 6604

Essentially all studies of NGC 6604 so far have concentrated on its bright OB stars. The two best known are briefly discussed below.

The central star of NGC 6604 is HD 167971, an O8Ibf star which Humphreys (1978) lists among the visually most luminous known O stars in the Galaxy. It is an eclipsing binary with a 3 day period (e.g., van Genderen 1985 and references therein), and photometric and spectroscopic analyses demonstrate that it is a triple system with an eclipsing pair of two O5-8V stars together with a more distant very luminous O8I star (Leitherer et al. 1987, Davidge & Forbes 1988). X-ray data show a significant X-ray luminosity excess most likely due to colliding winds (De Becker et al. 2005), and radio observations reveal a long term variability possibly related to the orbit of the third star (Blomme et al. 2007).

HD 168112 is another prominent member of the NGC 6604 cluster. It is an O5.5IIIf star with nonthermal radio emission from shocks and strong X-ray emission,

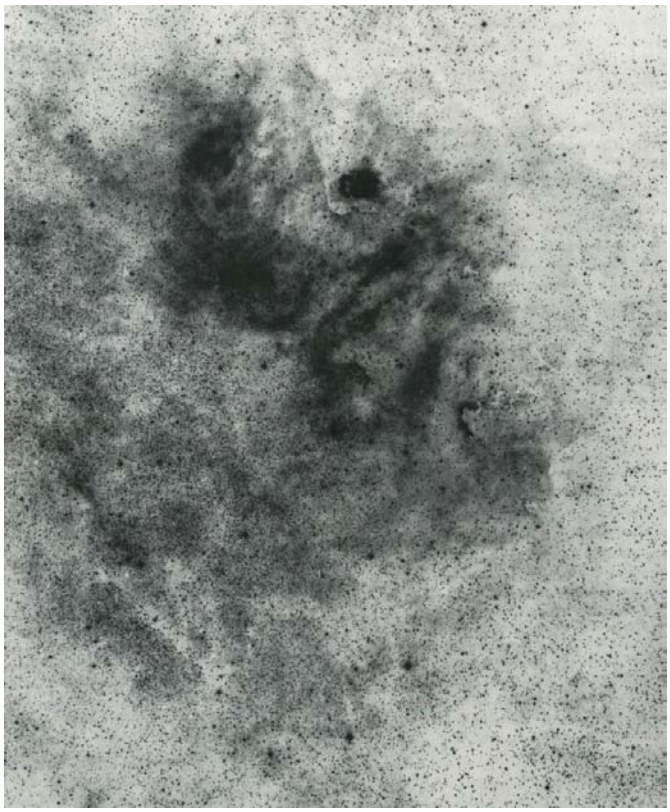

Figure 2. The young cluster NGC 6604 and the central part of its surrounding HII region S54 and molecular cloud complex TGU 179. The field is about $1.5^\circ \times 1.8^\circ$. North is up and east is left. From the red Palomar Sky Survey.

which is best understood if the star is a binary with wind-wind collisions (De Becker et al. 2004, Blomme et al. 2005). There is, however, no photometric or spectroscopic evidence for binarity.

In their study, Forbes & Dupuy (1978) noted a number of faint stars above the ZAMS, some of which also appeared to be variable. They speculated that these stars could be young low-mass members of the cluster. In their XMM-Newton study towards NGC 6604, De Becker et al. (2005) noted several X-ray sources with properties consistent with them being low-mass pre-main sequence stars. A detailed study of the NGC 6604 region is required to identify the young low-mass population of the cluster.

4. The Atomic and Molecular Gas and a Thermal Chimney

The various photometric studies of the cluster members (see Section 2) agree that there is a rather large extinction of around $A_V \sim 3$ magnitudes towards NGC 6604. Optical images show a major molecular cloud partly surrounding NGC 6604 to the north and west and partly behind the cluster (see Figure 2). This large complex is listed as TGU 179 in the catalogue of Dobashi et al. (2005), and is shown in their atlas as a gi-

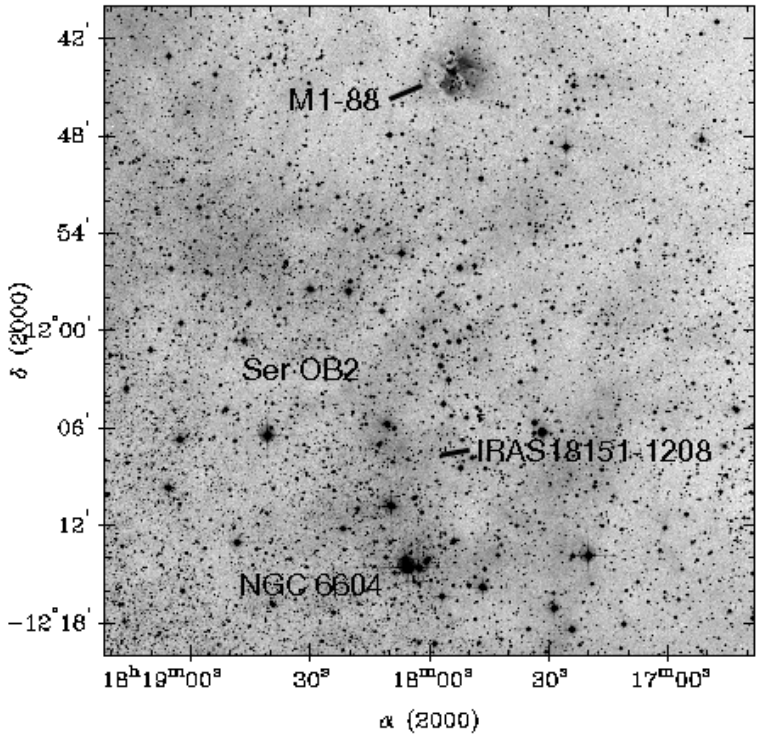

Figure 3. The young cluster NGC 6604 is seen at the bottom of this image, together with some of the OB stars in the wider Serpens OB2 association. To the north is the second-generation cluster within the HII region M1-88 = Gum 85. From the red Digitized Sky Survey.

ant molecular cloud with an extent of about $2^\circ \times 4^\circ$. The large extinction towards the cluster may suggest that part of the TGU 179 cloud complex is intersecting our line of sight to the cluster.

The massive stars of the Ser OB2 association ionize a major HII region, variously known as S54 (Sharpless 1953), W35 (Westerhout 1958), and RCW 167 (Rodgers, Campbell, & Whiteoak 1960). The ionized and neutral gas found in the region has the same velocity, and there may be a larger connection between S54 and the neighboring M16 and M17 regions (Sharpless 1953, Georgelin, Georgelin, & Roux 1973, Heiles et al. 1996). Reifenstein et al. (1970) observed S54 in H109α recombination line emission and found a very large HII region 2 degrees across. Felli & Churchwell (1972) observed S54 at 1400 MHz and detected a complex HII region more than a degree across.

Using multifrequency radio continuum observations, Müller, Reif, & Reich (1987) discovered a major thermal chimney extending from NGC 6604 and Ser OB2 out of the Galactic plane (Figure 4). It has dimensions of roughly 20 pc by 200 pc, has a mean electron temperature of $T_e \sim 4000$ K, and a continuous decrease of mean electron density from N_e of about 15 cm^{-3} near S54 to 1-2 cm^{-3} in its most distant parts. Similar chimneys have been found elsewhere in the Galaxy (e.g., Heiles 1984, Heiles

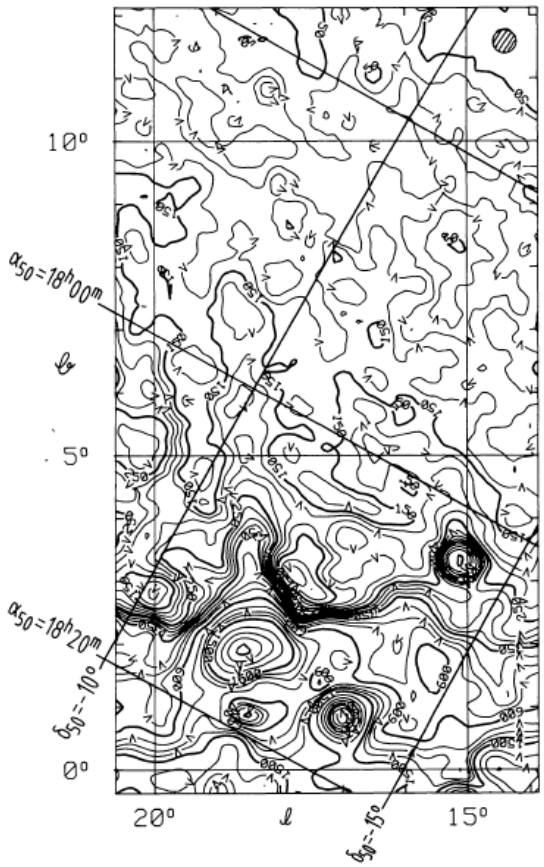

Figure 4. A 2720 MHz radio continuum map shows a thermal spur emanating from the HII region S54. The thermal spur extends at $l \sim 18.5°$ from $b = 2.5°$ to $b = 8°$. From Müller et al. (1987).

et al. 1996) and in other galaxies. Further radio recombination line observations of this chimney are discussed by Azcarate & Cersosimo (1996) and Heiles et al. (1996). In a study of the Ser OB2 association, Forbes (2000) determined that the known OB stars in the association are capable of providing the kinetic energy and number of ionizing photons required to form the chimney.

5. The Ser OB2 Association

Voroncov (1951), Markarian (1952), and Morgan, Whitford, & Code (1953) drew attention to a loose group of OB stars in Serpens, which the latter called II Ser, and of which NGC 6604 forms the densest part. The most complete listing of association members is given by Humphreys (1978), who introduced the modern designation Ser OB2. Humphreys suggested a distance of about 2 kpc, while Davidge & Forbes (1988) suggested about 1.7±0.5 kpc. Kaltcheva & Kuntchev (1994) presented *uvbyβ* photometry for seven stars in the association. Forbes (2000) has presented a major study of the massive star population of the Serpens OB2 association, using UBVRI

photometry and MK spectral types. He finds that the association contains over 100 OB stars at a distance of 1.9±0.3 kpc, consistent with the distance of 1.7 kpc adopted for the NGC 6604 cluster (see Section 2). Given that Ser OB2 is located about 65 pc above the Galactic plane, it is unlikely that many field OB stars have been included in this study.

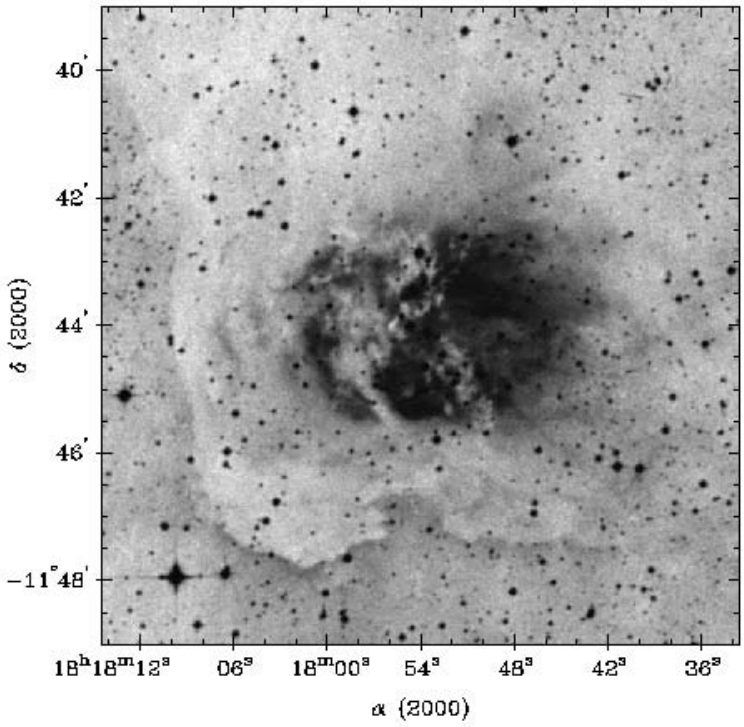

Figure 5. Star formation is taking place in the molecular cloud rim surrounding the NGC 6604 cluster. In this image, the nebula M1-88 is seen within a cometary globule where a loose infrared cluster of massive young stars has recently formed. From the red Digitized Sky Survey.

6. Ongoing Star Formation

Minkowski (1946) drew attention to a small nebula, M1-88, located half a degree north of the NGC 6604 cluster (see Figure 3). An enlargement from the red Digitized Sky Survey shows that the nebulosity is located within a cometary globule in the molecular cloud that rims the NGC 6604 cluster (Figure 5). M1-88 is listed as Gum 85 in the catalogue of Gum (1955) where it is included as the brightest part of the large S54 HII region. Jorden et al. (1976) discovered a group of infrared sources associated with M1-88. Bica et al. (2003) searched the Galactic plane for new embedded young clusters using the 2MASS catalogue, and found the same loose cluster, BDS03-9, centered on M1-88. From the location and morphology of the cometary cloud, it appears that M1-88 is a case of second-generation star formation triggered by the NGC 6604 cluster and perhaps also the Ser OB2 association. Virtually nothing is known about the M1-88

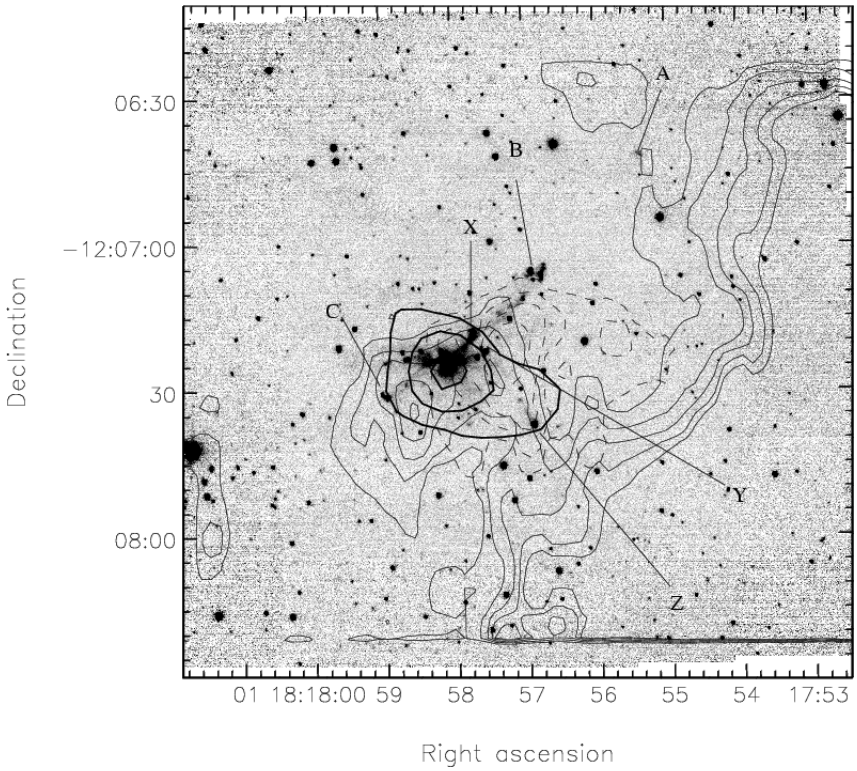

Figure 6. A 2.12 μm narrow-band image of IRAS 18151-1208 with CO J=2-1 line and 1.2 mm continuum emission superimposed as contours (from Beuther et al. 2002a,b): 1.2 mm data are plotted with thick, full contours; blue-shifted CO with thin, full contours and red-shifted CO with thin, dashed contours. The H_2 knots marked B and C represent the endpoints of one collimated bipolar flow, and Y and Z another one. From Davis et al. (2004).

object, apart from a few serendipitous observations. For example, M1-88 is detected in the radio recombination line survey of Lockman (1989) (his object G18.686+1.965) with a velocity of v_{lsr} = 26.6 km/sec. Likewise, it was listed (as J1817−1144) in the 4850 MHz survey by Griffith et al. (1994).

A number of IRAS sources with infrared colors and fluxes consistent with them being high luminosity pre-main sequence stars are found in the TGU 179 cloud complex. Forbes (2000) has compiled a selection of 9 such sources, which are listed in Table 1 together with their fluxes from the IRAS Point Source Catalogue. IRAS 18151−1208 and 18151−1134 were studied in more detail by McCutcheon et al. (1991), who suggested that they are embedded early B stars. IRAS 18123−1203 and 18141−1156 were studied by Wilking et al. (1989), and Wood & Churchwell (1989) found that IRAS 18146−1148 could be an ultracompact HII region. IRAS 18151−1208 is the most luminous of the young objects listed in Table 1 and has been observed at a variety of wavelengths. Bronfman, Nyman, & May (1996) found a dense core towards the source but despite its colors typical of ultra-compact HII regions, Sridharan et al. (2002) did not detect the source in the radio continuum. High velocity gas and both H_2O and CH_3OH

Table 1. Pre-Main Sequence Candidates in TGU 179 (from Forbes 2000)

IRAS	α_{2000}	δ_{2000}	12^a	25^a	60^a	100^a
18117−1225	18 14 30.8	–12 24 48	1.27	1.21	9.24:	L
18136−1201	18 16 27.8	–12 00 49	3.14:	5.64	52.48:	L
18137−1237	18 16 36.6	–12 36 11	1.73	1.49	11.46:	L
18146−1148	18 17 28.0	–11 47 22	4.90:	23.63:	189.05	L
18151−1208	18 17 57.1	–12 07 22	19.03	98.60	890.64	1890.90
18151−1134	18 17 57.0	–11 33 28	7.73:	7.85	170.57	636.08
18174−1246	18 20 14.4	–12 44 49	2.29	5.56	12.65:	L
18174−1148	18 20 15.5	–11 46 52	8.07	13.54	22.70:	141.80:
18166−1128	18 19 23.7	–11 27 27	4.39	3.78	23.58	L
18123−1203	18 15 07.3	–12 02 42	3.19:	6.63	164.75:	463.23:
18141−1156	18 16 56.0	–11 54 54	6.49	7.09	210.15:	1137.69:

a: Wavelengths in microns, fluxes in Jy.

masers have been detected towards the source (Beuther et al. 2002a,b). Most recently, Davis et al. (2004) found two highly collimated bipolar molecular hydrogen jets near the IRAS source (see Figure 6), together with evidence for an embedded cluster with infrared excess stars.

Since the pre-main sequence contraction times for all these IRAS sources is much shorter than the age of the visible stars in the Ser OB2 association, it is evident that massive star formation continues to take place in the TGU 179 complex.

Acknowledgements. I thank the referee Douglas Forbes for a careful reading of the manuscript, and Matt BenDaniel for use of Figure 1. The use of the Digitized Sky Surveys through the Canadian Astronomy Data Centre is gratefully acknowledged. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope. This research has made use of NASA's Astrophysics Data System, and of the SIMBAD database, operated at CDS, Strasbourg, France. BR was supported by the NASA Astrobiology Institute under Cooperative Agreement No. NNA04CC08A and by the NSF through grants AST-0507784 and AST-0407005.

References

Alter, G., Balazs, B., & Ruprecht, J. 1970, *Catalogue of Star Clusters and Associations*, Akademiai Kiado, Budapest

Azcárate, I.N. & Cersosimo, J.C. 1996, Astrophys. Spa. Sci., 235, 141

Barbon, R., Carraro, G., Munari, U., Zwitter, T., & Tomasella, L. 2000, A&A Suppl., 144, 451

Beuther, H., Schilke, P., Sridharan, T. K., Menten, K. M., Walmsley, C. M., & Wyrowski, F. 2002a, A&A, 383, 892

Beuther, H., Walsh, A., Schilke, P., Sridharan, T. K., Menten, K. M., & Wyrowski, F. 2002b, A&A, 390, 289

Bica, E., Dutra, C.M., Soares, J., & Barbuy, B. 2003, A&A, 404, 223

Blomme, R., Van Loo, S., De Becker, M., Rauw, G., Runacres, M.C., Setia Gunawan, D.Y.A., & Chapman, J.M. 2005, A&A, 436, 1033

Blomme, R., De Becker, M., Runacres, M.C., Van Loo, S., & Setia Gunawan, D.Y.A. 2007, A&A, 464, 701

Bronfman, L., Nyman, L.-Aa., & May, J. 1996, A&A Suppl., 115, 81
Codella, C., Palumbo, G.G.C., Pareschi, G., Scappini, F., Caselli, P., & Attolini, M.R. 1995, MNRAS, 276, 57
Conti, P. S., Ebbets, D., Massey, P., & Niemela, V. S. 1980, ApJ, 238, 184
Davidge, T.J. & Forbes, D. 1988, MNRAS, 235, 797
Davis, C.J, Varricatt, W.P., Todd, S.P., & Howat, S.K.R. 2004, A&A, 425, 981
De Becker, M., Rauw, G., Blomme, R., Waldron, W. L., Sana, H., Pittard, J. M., Eenens, P., Stevens, I. R., Runacres, M. C., Van Loo, S., & Pollock, A. M. T. 2004, A&A, 420, 1061
De Becker, M., Rauw, G., Blomme, R., Pittard, J.M., Stevens, I.R., & Runacres, M.C. 2005, A&A, 437, 1029
Dobashi, K., Uehara, H., Kandori, R., Sakurai, T., Kaiden, T., Umemoto, T., & Sato, F. 2005, PASJ, 57, No. SP1, S1
Felli, M. & Churchwell, E. 1972, A&A Suppl., 5, 369
Forbes, D. 2000, AJ, 120, 2594
Forbes, D. & DuPuy, D.L. 1978, AJ, 83, 266
Georgelin, Y.M., Georgelin, Y.P., & Roux, S. 1973, A&A, 25, 337
Griffith, M.R., Wright, A.E., Burke, B.F., & Ekers, R.D. 1994, ApJS, 90, 179
Gum, C.S. 1955, Mem. R. Astron. Soc., 67, 155
Heiles, C. 1984, ApJS, 55, 585
Heiles, C., Reach, W.T., & Koo, B.-C. 1996, ApJ, 466, 191
Humphreys, R.M. 1978, ApJS, 38, 309
Jorden, P.R., MacGregor, A.D., Selby, M.J., & Whitelock, P.A. 1976, MNRAS, 174, 1P
Kaltcheva, N. & Kuntchev, P. 1994, Astrophys. Spa. Sci., 222, 39
Kharchenko, N.V., Piskunov, A.E., Röser, S., Schilbach, E., & Scholz, R.-D. 2005, A&A, 438, 1163
Leitherer, C., Forbes, D., Gilmore, A. C., Hearnshaw, J., Klare, G., Krautter, J., Mandel, H., Stahl, O., Strupat, W., Wolf, B., Zickgraf, F.-J., & Zirbel, E. 1987, A&A, 185, 121
Lockman, F.J. 1989, ApJS, 71, 469
Markarian, B.E. 1952, Proc. Armenian SSR Acad. Sci., 15, 11
McCutcheon, W.H., Dewdney, P.E., Purton, C.R., & Sato, T. 1991, AJ, 101, 1435
McSwain, M.V. & Gies, D.R. 2005, ApJS, 161, 118
Minkowski, R. 1946, PASP, 58, 344
Moffat, A.F.J. & Vogt, N. 1975, A&A Suppl., 20, 155
Morgan, W.W., Whitford, A.E., & Code, A.D. 1953, ApJ, 118, 318
Müller, P., Reif, K., & Reich, W. 1987, A&A, 183, 327
Reifenstein, E.C., Wilson, T.L., Burke, B.F., Mezger, P.G., & Altenhoff, W.F. 1970, A&A, 4, 357
Rodgers, A.W., Campbell, C.T., & Whiteoak, J.B. 1960, MNRAS, 121, 103
Sharpless, S. 1953, ApJ, 118, 362
Sridharan, T.K., Beuther, H., Schilke, P., Menten, K.M., & Wyrowski, F. 2002, ApJ, 566, 931
van der Walt, D.J., Gaylard, M.J., & MacLeod, G.C. 1995, A&A Suppl., 110, 81
van Genderen, A.M. 1985, IBVS, No. 2760
Voroncov, B. 1951, AZh, 28, 391
Westerhout, G. 1958, Bull. Astron. Inst. Netherlands, 14, 215
Wilking, B.A., Mundy, L.G., Blackwell, J.H., & Howe, J.E. 1989, ApJ, 345, 257
Wood, D.O.S. & Churchwell, E. 1989, ApJ, 340, 265