

INTERSTELLAR CLOUD MORPHOLOGIES AND THEIR ORIGINS

G.F. Gahm

Stockholm Observatory, S-133 36 Saltsjöbaden, Sweden

Received September 15, 1993.

Abstract. The morphologies of interstellar clouds are discussed in relation to the ideas of their origin. We overview work on the nearby (within about 1 kpc) large-scale structures of expanding, spherical shells, which fill a considerable fraction of the space. These features are related to winds from massive stars and supernova explosions, but some appear to have different origins. This interstellar “bubble pool” is a significant feature of the interstellar medium in terms of energetics, dynamics and star formation. We also briefly discuss filamentary molecular clouds. Certain phenomena may point to the presence of electric currents flowing in interstellar clouds and interacting with interstellar bubbles.

Key words: interstellar matter: bubbles, molecular clouds

1. Introduction

Similar to the clouds in our atmosphere, interstellar clouds appear in a variety of sizes and forms and with different types of substructures. The range in temperature, density, size and form is enormous. The origins of interstellar cloud features has been a long standing problem. The clouds are usually subject to both internal disturbances, such as molecular flows from star formation regions in the clouds, and external forces from radiation pressure and winds from stars in the environment, shockfronts moving through the interstellar medium or even global reorganizations of large volumes in space. It is not an easy task to extract the time evolution of such a cloud. The literature on various observational and theoretical aspects of individual or certain classes of clouds is so extensive that,

I suspect, very few persons are able to overview it in all details. I certainly do not belong to this group and the intention with the present article is to draw attention to some properties and selected questions (personal taste) concerning roundish bubble-like interstellar structures and to elongated, filamentary structures in molecular clouds in the Galaxy.

2. Interstellar bubbles

2.1. *The first detected bubbles*

More or less roundish bubbles of expanding ionized gas have been known for a long time from optical observations. Such are planetary nebulae (with the sizes of much less than 1 pc), regular H II regions, or Strömgren spheres, surrounding early-type stars (with the sizes from less than 1 pc to a few tens pc) and relatively “fresh” supernova remnants (SNR) like the Crab which has a diameter (optical) of about 4 pc. Some SNR of intermediate age were also recognized earlier, a well-known example being the Cygnus Loop with a diameter of 40 pc.

For almost all of these objects there is evidence of expansion. There is no doubt on why and how they originated or on the mechanisms for their expansion. The time-scales for the early evolution of these bubbles are fairly well established but depend on the details, such as density and structure of the surrounding interstellar medium. The expanding shells, especially the young SNR, have a dramatic effect on their surroundings. However, judging from the estimated number densities, the volume filling factors are small; less than 0.01 of the space at the galactic plane is occupied by these small bubbles.

Also, much larger, more or less spherical features in the local interstellar medium are known. One is the well-known Barnard's Loop (Barnard 1895), later shown to be a part of an expanding bubble with a diameter of 120 pc (Menon 1958). A very large arch of stars and H I was encountered in the Large Magellanic Cloud by Westerlund and Mathewson (1966) with a diameter of 500 pc. A similar structure (although not in all details) of similar size,

apparently expanding, was recognized in our local galactic environment. It is referred to as the Gould's Belt system of stars and neutral gas, which encloses the Sun, discussed, for instance, by Blaauw (1956), Lindblad (1967) and Olano and Pöppel (1987). The last decades of observations over practically all the electromagnetic spectrum have led to many discoveries of different types of bubble-like objects for which the origin and mechanisms of expansion are not always so easy to explain.

2.2. The bubble zoo

The word "bubbles" will be used here for anything named loops, shells, rings, long archs or curved filaments, holes, etc. and with forms that range from almost spherical to pronounced elliptical or even somewhat irregular shapes. These objects have been detected by their continuum X-ray (γ -ray) emission, far ultraviolet, optical continuum or line emission, far infrared dust emission, radio continuum or line emission. The range in size is impressive: from compact H II regions and planetary nebulae to entities that appear to have diameters of more than 1 kpc. For an excellent review on these superlarge structures, see Tenorio-Tagle and Bodenheimer (1988).

In many cases, a central object or an event can be associated with the bubble, as for the objects discussed in Section 2.1. Some bubbles of intermediate or large size surround OB associations. For several cases it is assumed that the shells are the result of one or several supernova explosions connected to the association. However, stellar winds and radiation pressure from early-type stars also have significant effects on the surroundings and can produce large bubbles during the lifetime of a star. As an example, it appears that λ Ori has produced a bubble of a size of 14 pc in this way (Zhang et al. 1989). An aging OB association will sweep up a considerable cavity before the first supernova ignites. These supernovae then expand into surroundings of very low density and are not decelerated much until the front reaches the interface between the windblown cavity and the denser surroundings. This morphology is seen in the far infrared (FIR) detected dust rings surrounding the recent supernova remnants, the Crab (Romani et al. 1990) and H 1538-32 (Gahm et al. 1990). For a middle-aged supernova remnant, like the Cygnus Loop, the size of the FIR bubble is equal to what is observed at

other wavelengths (Arendt et al. 1992). For the bubbles connected to OB associations, the total kinetic energy of the shell is vital for the interpretation of their origin. Yet the uncertainties are very large, and different authors often arrive at completely different conclusions on the origin, evolution and time-scales of these bubbles.

Another type of bubble appears to be the large FIR emission cavity surrounding the Pleiades. White and Bally (1993) suggest that the soft-ultraviolet radiation from the cluster pressurizes the surrounding medium through which the Pleiades are passing, forming a tunnel (wake) possibly through the action of photoelectric heating.

Even more intriguing are the bubbles for which, so far, no associated central object has been found. Our local interstellar medium (LISM) is an example of this, since the Sun travels in an irregularly shaped, hot and large cavity, which could be the result of one or several (?) supernova explosions that might have occurred some 10^7 years ago (for a review, see Cox and Reynolds 1987). One particular class of these objects was identified from the velocity scanning of H I profiles (Heiles 1976, 1979; Hu 1981). Of these, there is a subgroup of gigantic expanding bubbles, or supershells, with diameters up to 1.2 kpc, masses of $2 \cdot 10^7$ solar masses and kinetic energies of 10^{53} ergs, or 100 times larger than those available from a single supernova. However, there are also numerous shells of much smaller size, 10 to 50 pc. They show practically no relation to groups of OB stars or to any bubble detected at other frequencies. Also, their number densities are larger than those expected for SNRs of the same size. Large scale H α -mappings reveal another large emission regions (Sivan 1974, Reynolds et al. 1974). Another class of objects, for which the evolutionary history is uncertain, represents cavities surrounded by enhanced FIR emission engulfing ringlike regions of star formation (Schwartz 1987).

The discussion on the origin and evolution of the observed bubbles will undoubtedly continue. Besides events connected to stellar evolution in the galactic disk, present ideas also include other scenarios, such as high velocity clouds splashing into the galactic disk from the halo (see references in Tenorio-Tagle and Bodenheimer 1988, Mirabel and Morras 1990, Comer and Torra 1992). The bubbles play a most dominant role in the interstellar medium, both energetically and by continuously changing the morphologies of interstellar clouds.

2.3. *The interstellar bubble pool*

We have a snapshot of a violently bubbling interstellar medium. New bubbles will form, expand and interfere with the other bubbles. Interstellar matter is shuffled back and forth, denser clouds build up from snowplow effects, clouds will collide with each other and form other entities, some bubbles in the outer parts of the disk will explode as champagne corks (in Tenorio-Tagles pictures) into the thinner halo medium, while other clouds entering from the halo will splash into the disk, some of these may form gigantic bubbles. The question is if there is a single quiescent volume of space left? Probably there are such regions, but it is not yet established whether one should look upon the interstellar disk as composed of a homogeneous layer of quiescent gas full of expanding bubbles, or as comprising pockets of quiescent gas squeezed between interacting bubbles.

In order to overview the situation, we have made an effort to make a compilation from the literature of what is believed to be roundish structures with diameters ≥ 10 pc (average of the major and minor axis) and for which some estimates of the distances have been made placing the object within 1 kpc. This work was presented first in the form of Master thesis by Shoshan (1992). The system developed by Shoshan for this catalogue is based on Hyper Card and Wingz. Each "card" contains information about the fundamental parameters for one bubble, and comments containing more details can be added. From this, any selection of parameters for listing or drawings can be made. In Table 1 we give a list of locations, velocity information and sizes of the bubbles compiled so far. Many bubbles have several names, whereas the others have no name. We have selected some of the designations, and more details can be found in the references (see last column) given at the bottom of the table. The name is followed by a comment indicating if the bubble is an H II region surrounding one or two OB stars (H II*), an OB association (Bubble OB), a SNR or it is not clearly related to any relevant central object (Bubble). Positions (α and δ in epoch 1950) are given followed by the distance from the Sun. Information on the central radial velocity (V_c) and expansion velocity (V_e) is given together with the diameter (our judgement from the literature data).

Table 1. Parameters for interstellar bubbles

Name	Type	l [°]	b [°]	α [h m]	δ [° ']	Dist. pc	V_c $\frac{\text{km}}{\text{s}}$	V_e $\frac{\text{km}}{\text{s}}$	D pc	Reference No.
S 27	H II*	6	24	16 34	-10 26	190	-15	?	28	2,3,16,24,32,66, 67
GS022+03-31	Bubble	22	3	18 17	-08 20	500	-31	16	40	3,22
Scu OB2	BubbleOB	25	-3	18 44	-08 28	730	?	?	128	7,13
GS036+01-21	Bubble	36	1	18 50	03 07	500	-21	10	40	3,22
HU 2C	Bubble	41	-31	20 52	-07 54	180	6	5	10	30
HU 1	Bubble	41	-13	19 48	01 12	425	-5	9	36	30
G41.9-4.1	SNR	42	-4	19 20	05 58	900	?	?	42	33
HU 2b	Bubble	42	-33	21 02	-07 42	170	5	7	24	30
HU 2	Bubble	44	-33	21 05	-06 13	170	1	14	24	30
HU 2a	Bubble	44	-35	21 12	-07 11	160	1	4	14	30
GS046-01+49	Bubble	46	-1	19 16	11 02	500	49	4	40	3,22
HU 3	Bubble	50	-30	21 03	00 02	185	4	10	16	30
GS057+03-11	Bubble	57	3	19 24	22 37	500	-11	4	40	3,22
GS063+04+13	Bubble	63	4	19 32	28 21	500	13	4	40	3,22
GS063-01-03	Bubble	63	-1	19 52	25 50	500	-3	4	20	3,22
HU 4	Bubble	68	-30	21 42	12 10	185	-5	7	10	30
HU 5	Bubble	68	-37	22 03	07 27	155	-5	7	27	30
Cygnus Loop	SNR	74	-9	20 49	30 28	770	33	116	40	33,57,61,70
HU 6	Bubble	76	16	21 20	27 04	335	1	15	23	30
HU 7	Bubble	77	-12	21 08	30 50	460	6	10	32	30
HU 8	Bubble	80	-12	21 17	32 17	440	6	10	19	30
Arch Cygnus	Bubble	80	-4	20 53	38 00	500	?	?	35	2,3
HU 24	Bubble	84	32	17 39	55 59	175	-6	5	13	30
W 80	BubbleOB	85	-1	20 53	43 45	900	0	5	45	3,46,55,71,72
GS087+03+19	Bubble	87	3	20 44	47 50	500	19	6	64	3,22
S 119	H II*	88	-4	21 16	43 45	720	?	1	34	16,24,44,65
GS88-04+17	Bubble	88	-4	21 18	43 53	500	19	3	64	3,22
HU 9	Bubble	88	-13	21 50	37 14	410	0	11	50	30
HB 21	SNR	89	5	20 44	50 28	800	0	25	24	49,51,52
HU 10	Bubble	91	-33	22 54	22 22	170	-7	8	24	30
10 Lac	H II*	97	-17	22 37	38 47	642	-10	?	50	2,32,67
Lac OB1	BubbleOB	98	-13	22 33	43 03	500	-10	?	44	3,32,58
S 129	H II*	99	8	21 14	59 45	950	-10	?	38	16,23,24
IC 1396	H II*	99	4	21 14	57 15	830	-3	?	40	16,23,24,46
Loop II	Bubble	100	-32	21 37	26 41	110	?	?	176	3,7,14,25,26,27, 36,37
HU 11	Bubble	103	-12	22 51	45 52	440	1	8	23	30
Cepheus Ring	BubbleOB	103	7	21 42	61 47	900	?	?	120	23
S 133	Bubble	103	9	21 27	63 52	900	?	?	20	3,23,24
Cep B1	BubbleOB	103	4	21 58	59 48	700	?	?	74	7,23
St 94	H II*	104	3	22 08	58 56	630	?	?	24	46,47
HU 25	Bubble	105	18	20 37	70 40	559	3	6	52	30
Cep OB3	BubbleOB	110	3	22 52	62 37	720	-5	35	112	17,18,24,38,48
S 155	BubbleOB	110	3	22 53	62 15	500	0	0	14	17,24,48
vdH	H II*	110	6	22 42	64 56	580	?	?	30	46
McD 32	H II*	111	5	22 55	64 64	1000	?	?	36	46
Ceph Flare	SNR	117	10	23 32	71 42	300	?	?	62	21,29

Table 1 (continued)

Name	Type	<i>l</i> [°]	<i>b</i> [°]	α [h m]	δ [° ']	Dist. pc	V_c $\frac{\text{km}}{\text{s}}$	V_e $\frac{\text{km}}{\text{s}}$	<i>D</i> pc	Reference No.
IRAS 118+2	Bubble	118	2	00 02	64 09	1000	?	?	86	38
W 1	BubbleOB	119	6	00 01	68 23	880	-13	?	46	1,16,24
Loop III	Bubble	125	16	01 26	77 57	150	?	?	260	3,7,14,36,37
GS130-29.5	SNR	130	23	04 24	81 59	460	-6	13	48	35
GS130+00+15	Bubble	130	0	01 48	61 47	500	15	6	126	3,22
HU 26a	Bubble	132	40	10 55	75 21	145	8	4	12	30
HU 26	Bubble	133	35	09 45	78 34	334	4	6	70	30
IC 1805	BubbleOB	135	1	02 28	61 34	1000	?	?	28	46
HU 26b	Bubble	143	40	09 38	69 12	145	6	7	11	30
Sivan 3	H II*	145	14	04 52	65 24	830	?	?	188	3,31,32,66
GS148-01+15	Bubble	148	-1	03 46	52 47	500	15	2	40	3,22
I Cam	BubbleOB	150	0	04 00	52 17	520	?	?	54	3,28,32
Local Bubble	Bubble	150	60	11 21	52 34	70	?	?	150	4,20,21
HU 12	Bubble	153	-36	02 29	20 46	155	-2	8	11	30
HU 27	Bubble	155	36	08 27	61 39	160	0	4	13	30
CTB 13	SNR	156	-1	04 24	47 00	900	?	?	47	34
HU 13	Bubble	160	-27	03 14	25 00	200	0	12	28	30
Cal Neb	H II*	160	-12	03 57	36 29	350	2	?	48	3,16,28,31,32,66,67
HU 28	Bubble	160	18	06 19	54 44	467	-6	6	45	30
Per OB3	BubbleOB	164	-13	04 09	33 19	350	?	?	92	3,7,28
GS165-21-04	Bubble	165	-21	03 45	26 49	720	-4	12	200	3,54
Pleiades	BubbleOB	166	-24	03 44	23 57	120	6	?	29	60
IRAS 173+1	BubbleOB	173	1	05 28	35 21	1000	?	?	44	38
G180.0-1.7	SNR	180	-2	05 35	28 00	900	?	?	48	33
GS183+01+35	Bubble	183	1	05 53	26 51	500	35	23	100	3,22
GS193-32+04	Bubble	193	-32	04 20	00 46	820	4	17	700	3,54
S 264	H II*	193	-12	05 28	11 36	460	10	8	56	7,10,11,16,66,67
Origem Loop	Bubble	195	0	06 15	16 22	1000	?	?	100	7,14,37
HU 20	Bubble	196	-42	03 53	-06 20	135	22	5	52	30
Eri Cavity	Bubble	198	-31	04 32	-02 17	400	?	23	210	39,69
Heiles Ring	Bubble	198	-40	04 01	-06 52	150	?	23	98	50
Ori OB1	BubbleOB	200	-25	04 57	00 46	470	?	?	246	3,28,32
Mon R1 Ring	Bubble	202	0	06 29	10 10	1000	0	8	54	47,53
GS203+02-11	Bubble	203	2	06 37	09 47	500	-11	8	39	3,22
Monegem ring	Bubble	203	11	07 10	13 50	300	?	?	156	26
HU 29	Bubble	203	17	07 33	16 22	405	-1	8	33	30
Mon OB1	BubbleOB	203	2	06 38	09 26	715	3	?	50	5,7,9,16,50
Ori Loop	BubbleOB	204	-12	05 49	02 18	430	5	?	150	15,16
Georgelin A	Bubble	204	0	06 34	07 59	570	4	?	30	16
GS205.5+0.2	SNR	206	0	06 35	06 44	700	?	?	51	33,34
Ori 1	BubbleOB	206	-19	05 28	-02 43	450	0	9	84	5,6,7,8,9,11,27
Mon 2	BubbleOB	206	0	06 36	06 12	800	?	?	42	2,7,12,34,55
Rosette	BubbleOB	207	-2	06 29	04 50	800	?	?	28	3,58
HU 16	Bubble	207	-18	05 35	-02 26	305	6	6	19	30
W 12	H II*	207	-17	05 38	-02 21	500	29	?	16	1,2,3,5,9,16
HU 17	Bubble	209	-23	05 18	-06 38	235	5	7	16	30

Table 1 (continued)

Name	Type	l [°]	b [°]	α [h m]	δ [° ']	Dist. pc	V_c $\frac{\text{km}}{\text{s}}$	V_e $\frac{\text{km}}{\text{s}}$	D pc	Reference No.
HU 18	Bubble	209	-26	05 09	-08 23	210	5	5	13	30
HU 30	Bubble	212	58	10 27	23 29	116	-1	3	10	30
GS215+06-13	Bubble	215	6	07 13	00 59	500	-13	6	40	3,22
HU 21	Bubble	217	-38	04 36	-19 13	150	5	4	10	30
S 296	BubbleOB	225	-2	07 03	-11 07	840	8	?	50	16,24
HU 22	Bubble	227	-14	06 23	-18 38	380	11	1	13	30
GS239+02+11	Bubble	239	2	07 47	-21 53	500	11	2	34	3,22
GS241-04-05	Bubble	241	-4	07 28	-26 36	500	-5	2	126	3,22
GS242-01+11	Bubble	242	-1	07 42	-26 00	500	11	?	64	3,22
Gum-Neb	BubbleOB	258	-2	08 19	-40 03	400	?	?	250	26,40,41,56
Vela OB2	BubbleOB	263	-7	08 11	-46 59	450	?	?	130	59
Vela SNR	SNR	264	-3	08 32	-45 35	500	?	?	36	33,34,62,63
Gum HI	Bubble	266	-3	08 44	-46 45	500	5	7	114	65,66
G 12a	H II*	269	-1	09 01	-48 29	250	9	?	86	16
HU 32	H II*?	273	42	11 18	-15 16	157	-4	6	21	30
HU 34	Bubble	287	39	11 56	-21 56	145	0	7	24	30
IRAS 295-1	BubbleOB	295	-1	11 38	-62 30	700	?	?	50	38
Georgelin B	H II*?	314	2	14 13	-59 02	850	-12	?	38	16
Loop IV	Bubble	315	49	13 21	-12 51	250	?	?	210	7,14,37
α Vir	H II*	316	51	12 23	-10 54	87	?	?	23	67
BBW 28802	H II*	321	-1	15 12	-58 38	1000	-6	?	28	16
Loop I	Bubble	329	18	14 56	-38 04	170	?	?	280	7,14,26,36,37, 40,45,64
Lupus Loop	SNR	330	15	15 09	-40 09	500	?	?	50	7,14,33,34,56
GG IRAS 1	Bubble	340	18	15 39	-32 08	340	?	?	85	42,43
GG IRAS 2	SNR	340	18	15 39	-32 08	340	?	?	22	42,43
BJM 11	BubbleOB	341	15	15 49	-33 46	170	?	?	11	69
HU 36	Bubble	345	23	15 42	-25 41	318	1	7	50	30
Sco OB2	BubbleOB	351	19	16 11	-24 19	170	?	?	35	69
S 7	BubbleOB	351	22	19 05	-46 19	170	?	?	17	69
Sivan 9	H II*	352	12	16 35	-28 40	182	?	?	68	2,3,31
RCW 129	H II*	352	14	16 31	-27 41	170	?	?	11	69
Sivan 10	BubbleOB	352	24	15 58	-20 10	174	?	?	78	31

References to Table 1

1. Landolt-Börnstein (1982), 2. Morgan et al. (1955), 3. G.F. Gahm (derivation of one or several quantities from literature data), 4. Welsh et al. (1990), 5. Habing and Israel (1979), 6. O'Dell et al. (1967), 7. Brand and Zealey (1975), 8. Ruprecht (1964), 9. Johnson (1964), 10. Zhang et al. (1989), 11. Wade (1958), 12. Morgan et al. (1965), 13. Rodgers et al. (1960), 14. Berkhuijsen (1973), 15. Georgelin (1971), 16. Georgelin and Georgelin (1970), 17. Simonson and van Someren Greve (1976), 18. Assousa et al. (1977), 19. Johnson (1955), 20. Cox and Reynolds (1987), 21. Y. Shoshan (derivation of one or several quantities from literature data), 22. Heiles (1979), 23. Kun et al. (1987), 24. Sharpless (1959), 25. Berkhuijsen et al. (1971), 26. Broten

et al. (1985), 27. Vallée (1982), 28. Allen (1973), 29. Grenier et al. (1989), 30. Hu (1981), 31. Sivan (1974), 32. Reynolds et al. (1974), 33. Clark and Caswell (1976), 34. Ilovaisky and Lequeux (1972), 35. Velden and Hirth (1982), 36. Spoelstra (1972), 37. Berkhuijsen (1973), 38. Schwartz (1987), 39. Vallée et al. (1988), 40. Franco (1990), 41. Chanot and Sivan (1983), 42. Gahm et al. (1990), 43. Riegler et al. (1980), 44. Wisotsky and Wendker (1989), 45. Colomb et al. (1980), 46. Pottasch (1956), 47. Kutner et al. (1979), 48. Felli et al. (1978), 49. Tatematsu (1990), 50. Heiles (1976), 51. Assousa and Erkes (1973), 52. Leahy (1987), 53. Weaver and Williams (1974), 54. Heiles (1984), 55. Neckel et al. (1980), 56. Leahy et al. (1991), 57. Raymond (1984), 58. Blitz (1993), 59. Sahu (1992), 60. White and Bally (1993), 61. Arendt et al. (1992), 62. Willmore et al. (1992), 63. Elliott et al. (1976), 64. Centurion and Vladilo (1991), 65. Wisotsky and Wendker (1989), 66. Dubner et al. (1992), 67. Shestakova et al. (1988), 68. Reynolds and Ogden (1982), 69. Baart et al. (1980), 70. Burrows et al. (1993)

Some of the objects are not well defined as bubbles and their distances are, in some cases, very uncertain. For instance, several of the H I rings discovered by Heiles (1979) were just put at 500 pc from kinematic indications. In this table we do not list more information of the type that dust-emitting shells and H II regions have different sizes, unless there is a considerable difference. We present this compilation as a first guide into observations of bubbles and with leading references. Also we want to draw attention to the picture (Fig. 1) that emerges from mappings of the bubbles in a projection onto the galactic plane. In Fig. 2 we show, as an example, the distributions of the bubbles in two cuts at different distances (z) from the galactic plane.

In brief, here are some of the conclusions drawn from this study:

(1) Several bubbles are not well defined and lack good distances. Classical photometric work can play an important role here to locate the dust fronts like it has been made for Loop I, for example, by Franco (1990). I would believe that the techniques used here in Lithuania, namely, the Vilnius photometric system, could be very useful in distance determinations of interstellar features (see, e.g., Černis, 1987, 1990). Stellar spectroscopy is also a useful tool – in the case of Loop I, see Centurion and Vladilo (1991).

(2) The surveys are subject to many selection effects (sky coverage, etc). The number density of the bubbles drops off by a factor of 4 beyond 600 pc, which means that far from all the bubbles within 1 kpc are discovered yet.

(3) The number density also drops off rapidly with increasing galactic height. This, we believe, reflects a real drop-off of these,

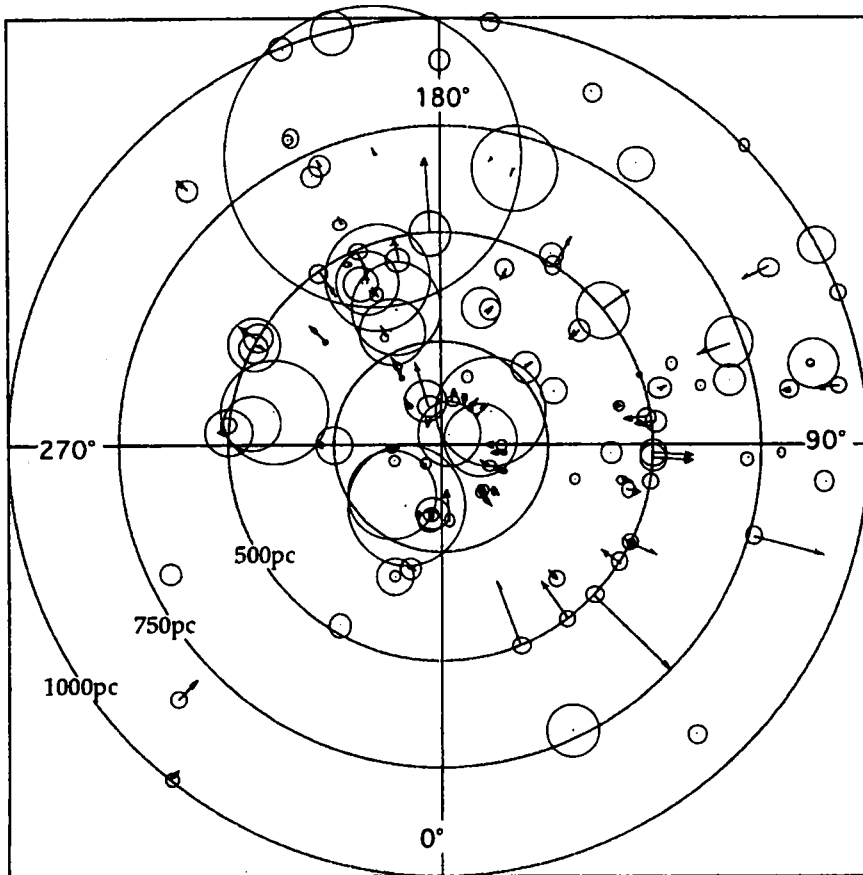


Fig. 1. Interstellar bubbles with diameters ≥ 10 pc and within 1 kpc projected on the galactic plane. The galactic center is in the direction "south" ($l = 0^\circ$) and the concentric circles outline the distance from the Sun. Each bubble is represented by a circle (even if the shapes normally are much more irregular). The central radial velocity is indicated by a vector; the scale is given in the 3rd quadrant. The Gould's Belt system is not plotted.

presumably, Population I-related objects, but selection effects operate also here.

(4) The volume filling factor of the bubbles is very large. If one includes the Gould's Belt system, roughly half of the space within 500 pc is occupied by the bubbles close to the galactic plane. We

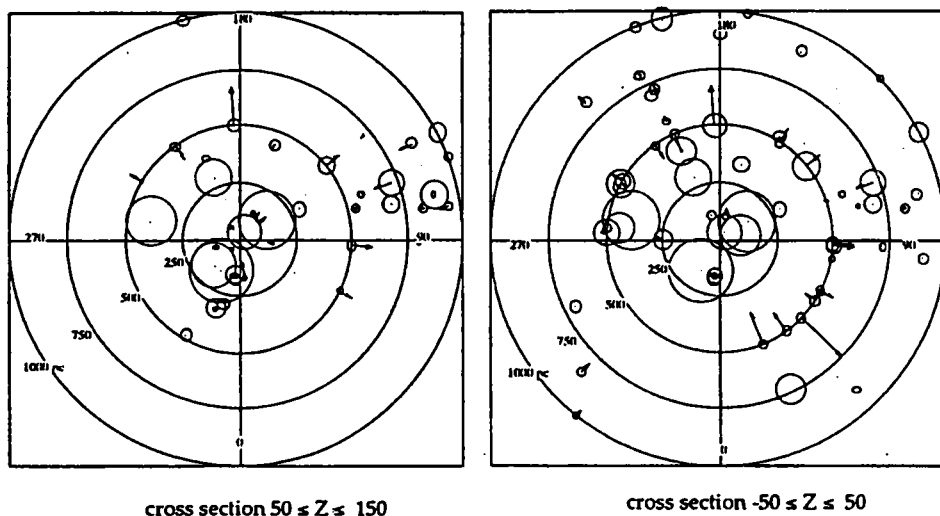


Fig. 2. Bubbles appearing in two layers, $-50 < z < 50$ pc and $50 < z < 150$ pc, parallel to the galactic plane. The symbols are as in Fig. 1. The number density of objects drops off rapidly with distance from the galactic plane.

have not included the vast supershell discussed by Verschuur (1993), which may represent a more global organization of matter in our environment.

(5) Some (but rather few) coincidences in position and approximate size were found between the bubbles discovered by different techniques, not noticed before.

(6) For a fraction of the objects, some estimate has been made on the central radial velocity. Several objects deviate considerably from the Population I galactic rotation. If these bubbles are related to Population I stellar evolution, then how can they achieve such large peculiar motions? We note that, according to Stone (1991), 46 % of O stars are runaway stars produced from supernova explosions in massive binaries. If we observed the progenitors to the shells, an explanation of the peculiar space motions could be found.

(7) Only a minority of the bubbles have well defined origins (SNR or relations to OB stars).

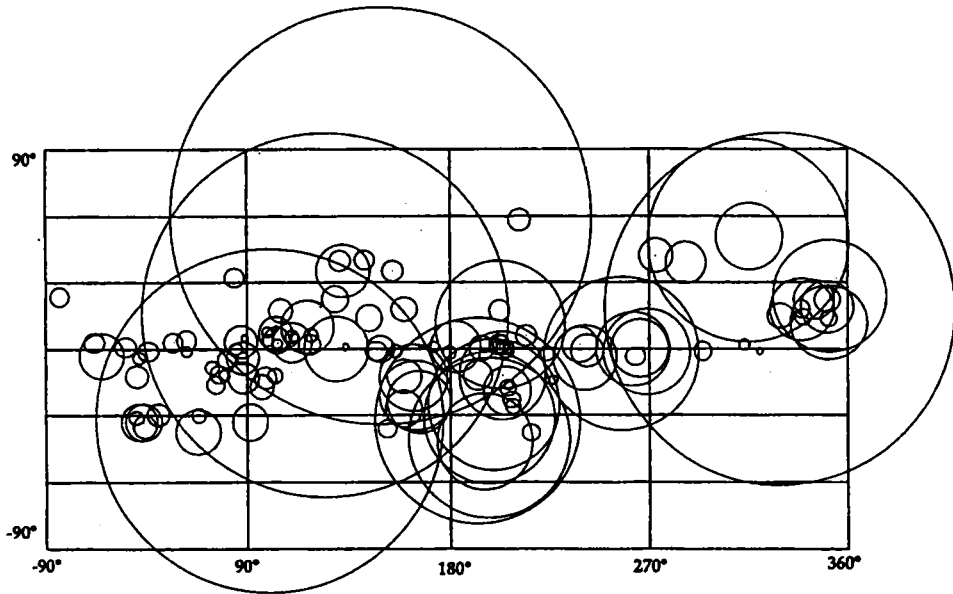


Fig. 3. All bubbles within 1 kpc plotted with their angular sizes on a sky map in coordinates of l and b . The bubbles do not show any pronounced correlation in positions with the Gould's Belt. Practically all directions lead to a bubble.

Finally, we present in Fig. 3 a plot of all bubbles projected on the sky. The Gould's Belt system distribution is not a striking feature in this plot. As it can be seen, the bubbles within 1 kpc occupy practically the whole sky. *When you go out on a clear night, you "see" bubbles everywhere.*

3. Filamentary molecular clouds

Another characteristic entity encountered in the interstellar medium is a molecular cloud. A characteristic feature observed among molecular clouds is a filament. Like the bubbles, there is a class of filaments, the worms, of a very large size (see, e.g., Koo et al. 1992, Verschuur 1991). It is apparent that when a new step is taken towards higher spatial resolution, then new substructures can be resolved. A giant molecular cloud complex, such as the one in Orion, is threaded by thick filaments (Bally et al. 1987), but on a much

smaller scale, the arcsecond and even subarcsecond fine-structures, thin filaments or cells have been resolved (Yusef-Zadeh 1990, Hester et al. 1991). Similar small substructures have been discovered also in the Rosette nebula (Block et al. 1992) and L 1551 (Liseau and Fridlund 1993). The nearby dark clouds, as catalogued by Lynds (1962), have very different shapes from roundish diffuse structures to elongated filamentary and/or clumpy structures. I would like to close this discussion with some very brief remarks on the filamentary forms that we see in the nearby clouds of small or intermediate mass.

3.1. Filamentary forms and magnetic field orientations

Elongated filamentary forms represent a very common feature of the molecular clouds. These structures can be remarkably straight over 0.1 pc, as is the case for the thin dust complex surrounding the Pleiades and for which Arny (1977) suggested that it is a consequence of the radiation pressure from stellar light much in the same way as the wind-blown sand on the beach. Other clouds show extremely complex structures with wispy and clumpy substructures. In the calculations by Woodward (1976) such “elephant trunks” can form through the interaction of shockfronts on clouds. It has been speculated that the extended filaments rooted in the more roundish core of the ρ Oph complex are the result of the passage of the Loop I bubble front (see, e.g., de Geus 1992). Close to this complex is the cloud complex L 204 with extended sinusoidal filaments, at locations parallel to each other. Shock interaction from the Loop I front could be called upon also in this case, but one suggestion has been that the run-away star ζ Oph pushed the less massive parts of the filaments away by a radiation pressure when it passed closer to the filaments (McCutcheon et al. 1986). A completely different view will be presented in Section 3.2. Helical features are seen in many clouds, for example in the Sandqvist 187–188 complex (the Norma “sword”; see picture taken and treated by H.-E. Schuster, G. Pizarro and C. Madsen and published by Reipurth 1988). In the Norma “sword” there are locations of star formation and outflows. Such interior sources of mechanical energy also help to reshape the clouds and can form the “elephant trunks”. Helical features in the Orion complex have been discussed by, e.g., Uchida et al. (1991), but here axial and helical magnetic fields have been called upon as a basic underlying feature (see, e.g., Hanawa et al. 1993). By a certain technique of filtering the IRAS images, Mattila (1993) has isolated

an extended serpentine-like filament in Chameleon (Cha III), but its origin remains unknown. Many filaments are inside or outline of the interstellar bubbles of the type discussed above. It is natural to believe that their morphology is partly related to previous events in the environment. Cloud-cloud collisions may occur, resulting in that new entities may appear. For a recent review on the local interstellar environment, see Bally et al. (1991).

From radio data and by measuring the linear polarization in the light of background stars, we can hope to get an outline of the strength and orientation of the magnetic field in the clouds. For several cloud complexes, rather detailed information on the field pattern has been obtained. For a recent review on these topics the reader is referred to Heiles et al. (1993) and references therein. Usually there is a gross preferential direction of the electric vector over entire filaments. However, in some clouds the orientation is along the major axis of the clouds, and in others the main orientation is perpendicular to the cloud axis (see, e.g., Myers and Goodman 1991). There are also filaments where at certain locations the electric vector flips about 90 degrees relative to the main direction and some filaments show a pronounced bimodal distribution over an angle with approximately a 90 degree separation (see, e.g., Goodman et al. 1990). This could be related to the general direction of the field in the area where the cloud is situated (see Moneti et al. 1984), or it is an intrinsic property of the clouds.

For the clouds with the magnetic field perpendicular to the axis, it was natural, some decades ago, to discuss a cloud collapse along the magnetic field lines and the resulting pancake forms which we happen to see edge-on. The evidence is now that the medium contains little of flat clouds but rather that the filaments are tube-like.

The discussion of the origin and evolution of filamentary structures in molecular clouds includes a number of possible mechanisms. We will, however, point to one mechanism that could be of importance in the evolution of interstellar filaments and which is usually overlooked.

3.2. The importance of electric currents in interstellar clouds

According to the picture drawn in the present article, we are living in dramatic interstellar surroundings. The expanding bubbles will no doubt have large effects on the surrounding medium of molecular and *magnetic* clouds. Certainly, more energetic bubbles

will sweep up the surrounding material and also produce expanding magnetic structures. Instabilities will produce filamentary structures already on the surface of the bubble, and the Cygnus Loop is an example of this. Much older bubbles can pass the molecular clouds with less dramatic effects, but compressions and shockwave produced filaments can result and one would expect, for instance, initiation of waves, like the Alfvén waves, in the clouds.

It follows from Maxwell's equation that a change in magnetic field morphology must be related to production of electric currents in the clouds. It is also envisioned that the whole galaxy acts as a dynamo (see, e.g., Krause 1987, Fujimoto 1987) and that electric currents flow through the interstellar medium, and one can speculate that such current systems can be tunneled into filaments and become enhanced during their compression. The effects of such current systems can be large and produce a variety of instabilities as found from both theoretical and laboratory experiments (see, e.g., Alfvén and Fälthammar 1963). The emphasis has been put on the magnetic fields and not on the electric currents in the astronomical literature, except for solar physics, but already Woltjer (1958) called upon the currents to explain the forms of certain emission filaments in the Crab. The possibility that magnetic clouds could be subject to pinching was discussed already by Bruce (1963) and Alfvén and Carlqvist (1978). One instability pattern, which could be of importance, is the Bennett pinch (see, e.g., Spitzer 1956) developed later into a more general form by Carlqvist (1988) by including gravitational and centrifugal forces, besides the original electromagnetic forces and kinetic pressure. This model has been used to trace the conditions in the two cloud complexes mentioned above, namely L 204 and the Norma "sword", by Carlqvist and Gahm (1992). Magnetic fields with both toroidal and axial components were considered. Axial currents of a few times 10^{13} A are necessary for the clouds to be in equilibrium, but the fractional density of electrons required is very low due to the large dimensions of the filaments. Furthermore, the electron velocities necessary to carry the large currents are of the order of 10^{-2} to 10^{-5} m s⁻¹, thus being much smaller than the thermal velocities in the clouds.

The postulated presence of electric currents in the interstellar medium can have a very large influence on molecular clouds on the macro-scale but rather small effects on the micro-scale. With toroidal+axial magnetic field structures, there is no difficulty to envision how sinusoidal and even helical structures could develop

from electromagnetic instabilities in the tube-like filaments. And finally, Carlqvist and Kristen (1993) have recently demonstrated that bimodal polarization patterns quite naturally result in interstellar clouds with a wound-up (coaxial cable type) toroidal+axial magnetic field.

References

- Alfvén H., Carlqvist P. 1978, *Ap&SS*, 55, 487
Alfvén H., Fälthammar C.-G. 1963, *Cosmical Electrodynamics*, Clarendon Press, Oxford, p. 120
Allen C.W. 1973, *Astrophysical Quantities*, 3rd edition, Athlone Press, London
Arendt R.G., Dwek E., Leisawitz D. 1992, *ApJ*, 400, 562
Army T. 1977, *ApJ*, 217, 83
Assousa G.E., Herbst W., Turner K.C. 1977, *ApJ*, 218, L13
Assousa G.E., Erkes J.W. 1973, *AJ*, 78, 885
Baart E.E., de Jager G., Mountfort P.I. 1980, *A&A*, 92, 156
Bally J., Langer W.D., Wilson R.W., Stark A.A. 1987, *ApJ*, 312, L45
Bally J., Langer W.D., Wilson R.W., Stark A.A., Pound M.W. 1991, *IAU Symp.* 147, p. 11
Barnard E.E. 1895, *Pop. Astron*, 2, 151
Berkhuijsen E.M. 1973, *A&A*, 24, 143
Berkhuijsen E.M., Haslam C.G.T., Salter C.J. 1971, *A&A*, 14, 252
Blaauw A. 1956, 123, 408
Blitz L. 1993, in *Protostars and Planets III*, eds. E.H. Levy and J.I. Lunine, Univ. Arizona Press, p. 125
Block D.L., Dyson J.E., Madsen C. 1992, *ApJ*, 390, L13
Brand P.W.J.L., Zealey W.J. 1975, *A&A*, 38, 363
Brotén N.W., MacLeod J.M., Vallée J.P. 1985, *Astrophys. Lett*, 24, 165
Bruce C.E.R. 1963, *J. Inst. Elec. Eng.*, 9, 259
Burrows D.N., Singh K.P., Nousek J.A., Garmire G.P., Good J. 1993, *ApJ*, 406, 97
Carlqvist P. 1988, *Ap&SS*, 144, 73
Carlqvist P., Gahm G.F. 1992, *IEE Trans. Plasma Sci.*, 20, 867
Carlqvist P., Kristen H. 1993, private communication
Centurion M., Vladilo G. 1991, *ApJ*, 372, 494
Černis K. 1987, *Ap&SS*, 133, 355
Černis K. 1990, *Ap&SS*, 166, 315
Chanot A., Sivan J.P. 1983, *A&A*, 121, 19
Clark D.H., Caswell J.L. 1976, *MNRAS*, 174, 267

- Colomb F.R., Pöppel W.G.L., Heiles C. 1980, *A&AS*, 40, 47
- Comeron F., Torra J. 1992, *A&A*, 261, 94
- Cox D.P., Reynolds R.J. 1987, *ARA&A*, 25, 303
- de Geuz E.J. 1992, *A&A*, 262, 258
- Dubner G., Giacani E., Cappa de Nicolau C., Reynoso E. 1992, *A&AS*, 96, 505
- Elliott K.H., Goudis C., Meaburn J. 1976, *MNRAS*, 175, 605
- Felli M., Tofani G., Harten R.H., Panagia N. 1978, *A&A*, 69, 199
- Franco G.A.P. 1990, *A&A*, 227, 499
- Fujimoto M. 1987, in *Interstellar Magnetic Fields (Proc. of a Workshop, Tegernsee, Germany)*, eds. R. Beck and R. Gräve, Springer, p. 23
- Gahm G.F., Gebeyehu M., Lindgren M., Magnusson P., Modigh P., Nordh H.L. 1990, *A&A*, 228, 477
- Georgelin Y. P., Georgelin Y. M. 1970, *A&A*, 6, 349
- Georgelin Y.P. 1971, *A&A*, 11, 414
- Goodman A.A., Bastien P., Myers P.C., Ménard F. 1990, *ApJ*, 359, 363
- Grenier I.A., Lebrun F., Arnaud M., Dame T.M., Thaddeus P. 1989, *ApJ*, 347, 231
- Habing H.J., Israel F.P. 1979, *ARA&A*, 17, 345
- Heiles C. 1976, *ApJ*, 208, L137
- Heiles C. 1979, *ApJ*, 229, 533
- Heiles C. 1984, *ApJS*, 55, 585
- Heiles C., Goodman A.A., McKee C.F. 1993, in *Protostars and Planets, III*, eds. E.H. Levy and J.I. Lunine, Univ. Arizona Press, p. 279
- Hester J.J. et al. 1991, *ApJ*, 369, L75
- Hu E.H. 1981, *ApJ*, 248, 119
- Ilovaisky S.A., Lequeux J. 1972, *A&A*, 20, 347
- Johnson H.M. 1955, *ApJ*, 121, 604
- Johnson H.M. 1964, *Trans. IAU*, 12 B, 446
- Koo B.-C., Heiles C., Reach W.T. 1992, *ApJ*, 390, 108
- Krause F. 1987, in *Interstellar Magnetic Fields (Proc. of a Workshop, Tegernsee, Germany)*, eds. R. Beck and R. Gräve, Springer, p. 8
- Kun M., Balazs G., Toth I. 1987, *Ap&SS*, 134, 211
- Kutner M.L., Dickman R.L., Tucker K.D., Machnik D.E. 1979, *ApJ*, 232, 724
- Landolt-Börnstein 1982, *Astronomy and Astrophysics*, Vol. 2, VIc, Springer-Verlag
- Leahy D.A. 1987, *MNRAS*, 228, 907
- Leahy D.A., Nousek J., Hamilton A.J.S. 1991, *ApJ*, 374, 218
- Lindblad P.O. 1967, *Bull. Astron. Inst. Netherlands*, 19, 34
- Liseau R., Fridlund M. 1993, *A&A*, in press

- Lynds B.T. ApJS, 7, 1
- Mattila K. 1993, private communication
- Matthews H.E., Goss W.M. 1980, A&A, 88, 267
- McCutcheon W.H., Vrba F., Dickman R.L., Clemens D.P. 1986, ApJ, 309, 619
- Menon T.K. 1958, ApJ, 127, 28
- Minkowski R. 1958, Rev. Mod. Ph., 30, 1048
- Mirabel I.F., Morras R. 1990, ApJ, 356, 130
- Moneti A., Pipher J.L., Helfer H.L., McMillan R.S., Perry M.L. 1984, ApJ, 282, 508
- Morgan W.W., Hiltner W.A., Neff J.S., Garrison R., Osterbrock D.E. 1965, ApJ, 142, 974
- Morgan W.W., Strömgren B., Johnson H.M. 1955, ApJ, 121, 611
- Myers P.C., Goodman A.A. 1991, ApJ, 373, 509
- Neckel Th., Harris A.W., Eiroa C. 1980, A&A, 92, L9
- O'Dell C.R., York D.G., Henize K. G. 1967, ApJ, 150, 835
- Olano C.A., Pöppel W.G.L. 1987, A&A, 179, 202
- Pottasch S. 1956, Bull. Astron. Inst. Netherlands, 13, 77
- Raymond J.C. 1984, ARA&A, 22, 75
- Reipurth B. 1988, ESO Messenger, No. 52, 27
- Reynolds R.J., Ogden P.M. 1982, AJ, 87, 306
- Reynolds R.J., Roesler F.L., Scherb F. 1974, ApJ, 192, L53
- Riegler G. R., Agrawal P. C., Gull S.F. 1980, ApJ, 235, L71
- Rodgers A.W., Campell C.T., Whiteoak J.B., Bailey H.H., Hunt V.O. 1960, An atlas of Ha emission in the southern Milky Way, Mount Stromlo Obs.
- Romani R.W., Reach W.T., Koo B.C., Heiles C. 1990, ApJ, 349, L51
- Ruprecht J. 1964, Trans. IAU, 12B, 336
- Sahu M.S. 1992, PhD thesis, Univ. Gronningen
- Schwartz P.R. 1987, ApJ, 320, 258
- Sharpless S. 1959, ApJS, 4, 257
- Shestakova L.I., Kuttyrev A.S., Ataev A.Sh. 1988, AZh Lett., 14, 60
- Shoshan Y. 1992, The Galactic Bubble Pool, Master thesis, Stockholm Observatory and Royal Inst. Technology, Stockholm
- Simonson S.C., van Someren Greve H.W. 1976, A&A, 49, 343
- Sivan J.P. 1974, A&AS, 16, 163
- Spitzer L. Jr. 1956, Physics of Fully Ionized Gases, Intersci. Publ., New York, p. 41
- Spoelstra T.A.Th. 1972, A&A, 21, 171
- Tatematsu K., Fukui Y., Landecker T.L., Roger R.S. 1990, A&A, 237, 189
- Tenorio-Tagle G., Bodenheimer P. 1988, ARA&A, 26, 145

- Tomoyuki H., Nakamura F., Matsumoto T., Nakano T., Tatematsu K., Umemoto T., Kameya O., Hirano N., Hasegawa T., Kaifu N., Yamamoto S. 1993, *ApJ*, 404, L83
- Uchida Y., Fukui Y., Minoshima Y., Mizuni A., Iwata T., Takaba H. 1991, *Nature*, 349, 141
- Vallée J.P., MacLeod J.M., Broten N.W. 1988, *A&A*, 196, 255
- Vallée J.P. 1982, *ApJ*, 261, L55
- Velden L., Hirth W. 1982, *A&A*, 113, 340
- Verschuur G.L. 1991, *Ap&SS*, 185, 137
- Verschuur G.L. 1993, *ApJ*, 409, 205
- Wade C. 1958, *Rev. Mod. Phys.*, 30, 946
- Weaver H., Williams D.R.W. 1974, *A&AS*, 17, 1
- Welsh B.Y., Vedder P.W., Vallerger J.V. 1990, *ApJ*, 358, 473
- Wendker H. 1968, *Z. f. Astrophys.*, 68, 368
- Westerlund B.E., Mathewson D.S. 1966, *MNRAS*, 131, 371
- White R.E., Bally J. 1993, *ApJ*, 409, 234
- Willmore A.P., Eyles C.J., Skinner G.K., Watt M.P. 1992, *MNRAS*, 254, 139
- Wisotzky L., Wendker H.J. 1989, *A&A*, 221, 311
- Woltjer L. 1976, *Bull. Astron. Inst. Netherlands*, 14, 39
- Woodward P.R. 1976, *ApJ*, 207, 484
- Yussef-Zadeh F. 1990, *ApJ*, 361, L19
- Zhang C.Y., Laureijs R.J., Chlewicki G., Clark F.O., Wesselius P.R. 1989, *A&A*, 218, 231