

# Sh2-205: I. The surrounding interstellar medium

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## ABSTRACT

We investigate the distribution of the interstellar matter in the environs of the H II region Sh2-205, based on neutral hydrogen 21-cm line data and radio continuum images at 408 and 1420 MHz obtained from the CGPS,  $^{12}\text{CO}$  ( $J=1\rightarrow 0$ ) observations, high resolution *IRAS* data (*HIRES*), and MSX data.

Sh2-205 can be separated in three independent optical structures: SH 149.25–0.0, SH 148.83–0.67, and LBN 148.11–0.45. The three regions are detected both at 408 and 1420 MHz. The derived spectral indices show the thermal nature of SH 148.83–0.67 and LBN 148.11–0.45.

LBN 148.11–0.45 is a classical H II region surrounded by an H I shell. The associated neutral atomic and ionized masses are  $65\text{ M}_{\odot}$  and  $70\text{ M}_{\odot}$ , respectively. Dust and molecular gas ( $\approx 6 \times 10^4\text{ M}_{\odot}$ ) are found related to this ionized region. Particularly, a photodissociation region is detected at the interface between the ionized and molecular regions. If the proposed exciting star HD 24094 were an O8–O9 type star, as suggested by its near-infrared colors, its UV photon flux would be enough to explain the ionization of the nebula.

The optical, radio continuum, and 21-cm line data allow us to conclude that SH 148.83–0.67 is an interstellar bubble powered by the energetic action of HD 24431. The associated neutral atomic and ionized masses are  $180\text{ M}_{\odot}$  and  $300\text{ M}_{\odot}$ , respectively. The emission of SH 149.25–0.0 is too faint to derive the dust and gas parameters. An H I shell centered at  $(l, b) = (149^{\circ}0', -1^{\circ}30')$  was also identified. It correlates morphologically with molecular gas emission. The neutral atomic and molecular masses are  $1600\text{ M}_{\odot}$  and  $2.6 \times 10^4\text{ M}_{\odot}$ , respectively. The open cluster NGC 1444 is the most probable responsible for shaping this H I structure.

**Key words:** stars: individual: HD 24431, ALS 7793, and HD 24094 - ism: structure - ism: bubbles

## 1 INTRODUCTION

O-type stars emit a large amount of UV photons capable of ionizing the neutral atomic gas and photodissociating molecular material, creating H II regions (Osterbrock 1989) and photodissociation regions at the interface between the ionized and the molecular gas (Hollenbach & Tielens 1997). H II regions evolve from ultracompact to classical modifying the characteristics of their natal environment. They appear surrounded by neutral atomic and molecular gas, which generally constitute the remains of their natal clouds. Subsequent dynamical expansion favors the formation of dense low expanding neutral envelopes behind front shocks (Spitzer 1978) where conditions for stellar formation may be fulfilled.

Massive stars also lose mass at rates of  $10^{-6} - 10^{-7}\text{ M}_{\odot}\text{ yr}^{-1}$  with terminal velocities of  $1000 - 2000\text{ km s}^{-1}$  (Prinja et al. 1990; Chlebowski & Garmany 1991; Lamers & Leitherer 1993). Although clumpy stellar winds result in lower mass loss rates (Moffat & Puls 2003), the huge amount of mechanical energy released into the interstellar medium (ISM) through the stellar wind mechanism during the lifetime of a massive star is capable of creating stellar wind bubbles. An outer dense neutral shell will appear between the outer shock front and the ionization front if this last front is trapped within the expanding bubble (Weaver et al. 1977; Lamers & Cassinelli 1999).

The action of massive stars on their surrounding interstellar medium can be analyzed using radio continuum data, which allow us to know the characteristics of the ionized gas. Neutral hydrogen 21-cm line emission and molecular

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data allow us to investigate the distribution of the neutral atomic and molecular gas in the environs of the stars, while interstellar dust characteristics can be studied through its infrared emission.

Massive stars are the main source of energy injection into the interstellar medium in the Galaxy. This causes the re-distribution of interstellar material by photodynamical and photochemical processes. To improve theoretical scenarios, comprehensive observational studies are necessary. This is possible by achieving complete multiwavelength studies of H II regions and interstellar bubbles.

To contribute to the knowledge of the ISM and the processes that modify it, we are carrying out a systematic study of the kinematics and energetics of the ionized and neutral gas in the environs of massive stars. In this paper we specially analyze the H II region Sh2-205 in the region of Camelopardalis based on radio continuum, H I 21-cm line,  $^{12}\text{CO}$  line, and infrared data at several wavelengths.

## 2 THE H II REGIONS AND THEIR EXCITING STARS

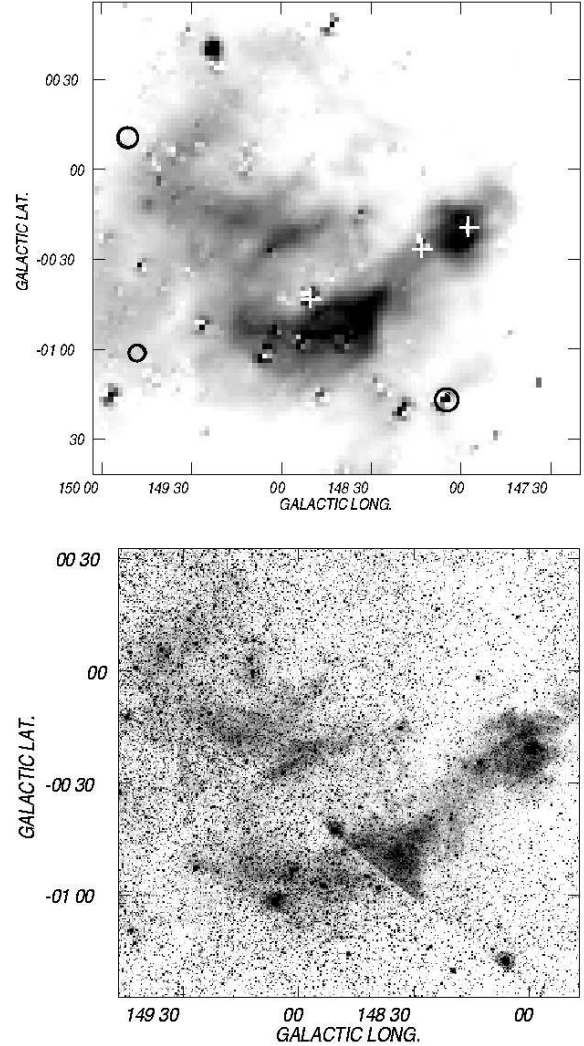
Figure 1 displays the VTSS and DSS-R images of a region of  $\approx 2^\circ \times 2^\circ$  centered at  $(l, b) = (148^\circ 40', -0^\circ 20')$ , showing the H II region Sh2-205 (Sharpless 1959) of about  $120'$  in size. The images reveal the presence of diffuse extended emission with two bright areas. One of them consists of an arc-like structure located at  $(l, b) = (148^\circ 45', -0^\circ 50')$ . The VTSS image shows that the edges of this arc are brighter than the inner region. Along with the fainter optical emission region detected at  $(l, b) \approx (149^\circ 0', -0^\circ 20')$ , the arc-like feature delineates an almost complete shell centered approximately at  $(l, b) = (148^\circ 50', -0^\circ 40')$ , of  $\approx 60'$  in diameter. From here on, this structure will be referred to as SH 148.83–0.67.

The exciting star of this H II region is the O-type star HD 24431 (Sharpless 1959), located at  $(l, b) = (148^\circ 50', -0^\circ 43')$ , projected close to the center of this structure. This star was classified as O9 IV–V by Hiltner & Johnson (1956) and as O9 III by Walborn (1973). Fabricius et al. (2002), based on Tycho2 data identifies this star as a double system.

Distance determinations for HD 24431 span the range between 710 and 1000 pc (Zdanavičius et al. 2001; Gies 1987; Garmany 1982; Humphreys 1978). Cruz-González et al. (1974) adopted a distance of 2.28 kpc, considering this star to be a member of  $\chi$  Persei. However, this open cluster is located at  $(l, b) = (135^\circ, -3^\circ 36')$ ,  $14^\circ$  far from HD 24431. This fact makes its relation to the cluster doubtful.

Table 1 lists the main photometric and astrometric parameters of HD 24431 taken from the literature. The star was related to Cam OB1  $(l, b) = [142^\circ, +2^\circ]$  of  $\approx 1.7 \times 10^\circ$  in size by Humphreys (1978) and Garmany (1982). Lyder (2001) carried out an extensive analysis of the optically identified Population I objects in the Cam OB1 region, deriving a distance of  $975 \pm 90$  pc for the OB association. This author, however, does not consider HD 24431 to be a member of Cam OB1. In what follows, we adopt a distance  $d = 1.0 \pm 0.2$  kpc for HD 24431, in agreement with previous determinations.

The other bright extended area shown in Fig. 1 is the conspicuous H II region centered at  $(l, b) = (148^\circ 5', -0^\circ 28')$ .



**Figure 1.** Optical images of the Sh2-205 H II region. *Top panel:* VTSS Continuum-corrected H $\alpha$  image. The positions of the stars HD 24431, ALS 7793, and HD 24094 are indicated by crosses. The locations of the open clusters NGC 1496, King 7 and NGC 1444 are marked by open circles. *Bottom panel:* DSS-R image of the region.

This region was catalogued as LBN 148.11–0.45 ( $43' \times 25'$  in size) by Lynds (1965), although it had originally been included in Sh2-205 by Sharpless (1959). Two B-type stars appear projected onto this region. One of them is ALS 7793  $(l, b) = [148^\circ 17', -0^\circ 26']$ , whose spectral type is B1 (Hiltner 1956). The star is situated onto the border of the H II region. The other star, HD 24094 (CY Cam,  $[l, b] = [147^\circ 58', -0^\circ 20']$ ), is seen projected near the center of LBN 148.11–0.45. Based on the Hipparchos catalogue, HD 24094 was identified as a slowly pulsating contact binary by Duerbeck (1997), its primary component being classified as a B8 star. The main parameters of these stars are listed in Table 1. No information about the distances to HD 24094 and ALS 7793 is available. As a working hypothesis, we adopt  $d = 1.0 \pm 0.2$  kpc.

Radio studies of the Sh2-205 H II region have been per-

**Table 1.** Photometric and astrometric results for HD 24431, ALS 7793, and HD 24094.

HD 24431					
$l$ [°]	$b$ [°]	Sp.T.	$V_r(\text{LSR})$ [kms $^{-1}$ ]	Distance [pc]	Ref.
148° 50'	−0° 43'	O9 IV-V <sup>1</sup>	−9.9± 2 <sup>3</sup>	957	4
		O9 III <sup>2</sup>		1000	3,5
				2280	6
ALS 7793					
$l$ [°]	$b$ [°]	Sp.T.	$m_v$ [mag]		
148° 17'	−0° 26'	B1 V <sup>1</sup>	11.1 <sup>1</sup>		
HD 24094 <sup>7</sup>					
$l$ [°]	$b$ [°]	Sp.T.	P [days]	B-V [mag]	
147° 58'	−0° 20'	B8 V	1.052	0.4	

Notes: 1: Hiltner & Johnson (1956); 2: Walborn (1973); 3: Humphreys (1978); 4: Zdanavičius et al. 2001; 5: Gies (1987); Garmany (1982); 6: Cruz-González et al. (1974); 7: Duerbeck (1997).

formed by several authors. Blitz, Fich & Stark (1982) detected a molecular component at  $-25 \pm 1 \text{ km s}^{-1}$  in their CO study of H II regions, pointing the telescope towards the position  $(l, b) = (148^\circ 50.4', -1^\circ 14.4')$ . Based on radio continuum data at 1400 MHz with an angular resolution of 10 arcmin, Felli & Churchwell (1972) found two radio sources. One of them, centered at  $(l, b) = (147^\circ 54', -0^\circ 24')$ , has a flux density of 7.4 Jy and is  $30.7 \times 22.7$  in size. This source spatially coincides with LBN 148.11–0.45. The other radio source was detected at  $(l, b) = (148^\circ 42', -0^\circ 7')$ , has a flux density of 0.2 Jy, and is  $14' \times 10.8$  in size. It appears projected onto a region almost free of optical emission.

No radial velocity information corresponding to the ionized gas in the bright regions is available. The only measurement comes from Fabry-Perot H $\alpha$  observations obtained by Fich, Dahl & Treffers (1990), who found a radial velocity of  $-16.8 \pm 0.3 \text{ km s}^{-1}$  observing towards the position  $(l, b) = (147^\circ 55.8', -0^\circ 3.46')$ .

In addition to the above mentioned optical features, a shell-like structure of faint diffuse optical emission is also detected centered at  $(l, b) = (149^\circ 15', 0^\circ)$  (from here on SH 149.25–0.00), spread over a circle of  $\sim 1^\circ$  in size. No stellar object seems to be related to this feature. This structure, together with the one probably related to HD 24431, were catalogued as LBN 149.02–00.13 by Lynds (1965).

The positions of the open clusters NGC 1496 at  $(l, b) = (149^\circ 51', +0^\circ 11')$ , NGC 1444 at  $(l, b) = (148^\circ 6', -1^\circ 18')$ , and King 7 at  $(l, b) = (149^\circ 46', -1^\circ 1')$  are indicated in the VTSS image. Their distances are 1.2 kpc (del Rio & Huestamendia 1988), 1.19 kpc (Lindoff 1968), and 2.2 kpc (Durgapal et al. 1997), respectively. Although they are seen projected close to the regions under study, their physical relation to the optical nebulae is doubtful.

**Table 2.** DRAO data: Observational Parameters.

Parameter	Value
H I	
Synthesized beam	$1.22 \times 0.97$
rms noise (single channel) [K]	1.0
Bandwidth [MHz]	1.0
Channel separation [ $\text{km s}^{-1}$ ]	0.82
Velocity resolution [ $\text{km s}^{-1}$ ]	1.3
Velocity range [ $\text{km s}^{-1}$ ]	−165, +45
1420 MHz	
Synthesized beam	$1.03 \times 0.96$
rms noise [K]	0.06
Bandwidth [MHz]	30.0
408 MHz	
Synthesized beam	$3.5 \times 2.8$
rms noise [K]	0.4
Bandwidth [MHz]	4.0

### 3 DATA SETS

Radio continuum images at 408 MHz and 1420 MHz, and 21-cm H I line emission data were taken from the Canadian Galactic Plane Survey (CGPS) observed with the DRAO Synthesis Telescope, in Penticton, Canada. The CGPS is a high resolution survey of atomic hydrogen and radio continuum emission from the Galaxy. The spectral line observations are presented as data-cubes with 272 spectral channels having a velocity resolution of  $1.3 \text{ km s}^{-1}$ . Table 2 presents the most important observational parameters of the DRAO data base (Taylor et al. 2003). Both the radio continuum images at 408 MHz and 1420 MHz, and H I line data cube were spatially smoothed to an angular resolution of  $\sim 2$  arcmin.

The radio continuum image at 2695 MHz, obtained using the Effelsberg 100-m telescope with an angular resolution of about 4.3 arcmin and an rms noise of 0.05 K (Fürst et al. 1990), was also analyzed.

Images in the mid and far infrared obtained with the MSX and IRAS satellites were used to investigate the dust emission distribution. The MSX data consist of images at  $8.3 \mu\text{m}$  (Band A),  $12.1 \mu\text{m}$  (Band C),  $14.7 \mu\text{m}$  (Band D), and  $21.3 \mu\text{m}$  (Band E), obtained with an angular resolution of  $18''.3$ . The IRAS (HIRES)<sup>1</sup> data include images at 12, 25, 60, and  $100 \mu\text{m}$  with angular resolutions in the range  $0.5$  to  $2.0$ . The IRAS images are included in the DRAO dataset.

<sup>12</sup>CO ( $J=1 \rightarrow 0$ ) data from Dame et al. (2001) were used to analyze the molecular gas distribution in the region. These data have an angular resolution of 7.5 arcmin, a velocity resolution of  $1.3 \text{ km s}^{-1}$ , and an rms noise of 0.05 K.

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## 4 THE GAS AND DUST DISTRIBUTIONS

### 4.1 The ionized gas

Figure 2 shows the radio continuum emission distributions at 408 MHz and 1420 MHz (upper panels), and overlays of the radio continuum emissions and the VTSS image (lower panels). The images at both frequencies show emission from LBN 148.11–0.45, and from the shell-like features at  $\sim(l, b) = (148^\circ 50', -0^\circ 40')$  and  $\sim(l, b) = (149^\circ 15', -0^\circ)$ .

The 1420 MHz radio continuum emission associated with LBN 148.11–0.45 is strong. It consists of an almost circular, centrally picked region, of  $\sim 30' \times 24'$  in size. The radio peak at  $\sim(l, b) = (147^\circ 59'.4, -0^\circ 25')$  does not coincide with the maximum in optical emission at  $\sim(l, b) = (147^\circ 58', -0^\circ 19')$ .

As regards SH 148.83–0.67 (related to HD 24431), the radio emission at 1420 MHz is smooth and very well defined, with the brighter optical region coincident with the highest radio continuum emission at  $\sim(l, b) = (148^\circ 30', -0^\circ 46')$ . The borders of the optical arc are brighter than the inner region, with the radio image displaying a rather uniform region instead. This radio emission extends towards the galactic plane, appearing as a diffuse and faint almost complete ring of  $13'$  in width, and  $60'$  in diameter, which correlates with the diffuse optical emission in the shell. Due to the lower angular resolution of the image at 408 MHz, the ring is not as well defined as at 1420 MHz. HD 24431 is seen projected onto the inner border of this ring, near one of the bright optical emission regions.

Diffuse radio continuum emission also correlates with SH 149.25–0.00. It is not clear if the two shell-like features, namely SH 149.25–0.0 and SH 148.83–0.67, are linked.

As a first step to derive the physical parameters of the extended radio structures, we have analyzed the small diameter sources projected onto and near the optical emission regions. Their galactic coordinates and derived flux densities measured at 1420 MHz and 408 MHz are listed in Table 3. Their spectral indices  $\alpha$  ( $S_\nu \propto \nu^\alpha$ ) derived using fluxes at these frequencies are shown in the fifth column. The sixth column indicates a previous reference to the sources. The derived spectral indices indicate that all but two sources are non-thermal in nature. These results are reinforced by the fact that all sources are identified as extragalactic sources in the *NASA Extragalactic Database* (NED). Two sources are particularly interesting. One of them, NRRF J035430.6+530759, is a galaxy. The other one, NVSS J035347+523208, has a steep spectral index ( $-2.27$ ), which could correspond to a pulsar. However, this source is not listed in pulsars' catalogues (see for example Taylor, Manchester & Lyne (1993)).

Flux densities at 2700 MHz, 1420 MHz, and 408 MHz for LBN 148.11–0.45 and SH 148.83–0.67, along with angular and linear sizes, are listed in Table 4. Flux densities corresponding to the small diameter non-thermal sources were subtracted from the measured fluxes at 1420 MHz, 408 MHz, and 2700 MHz for the two nebulae. The expected flux density of the non-thermal sources at 2700 MHz was estimated from the spectral index. The spectral indices derived using the resulting flux densities at 408, 1420, and 2700 MHz are listed in Table 4, indicating that the emission originates in thermal bremsstrahlung. We note that the emission at 2700 MHz is very low and may lead to a large uncertainty

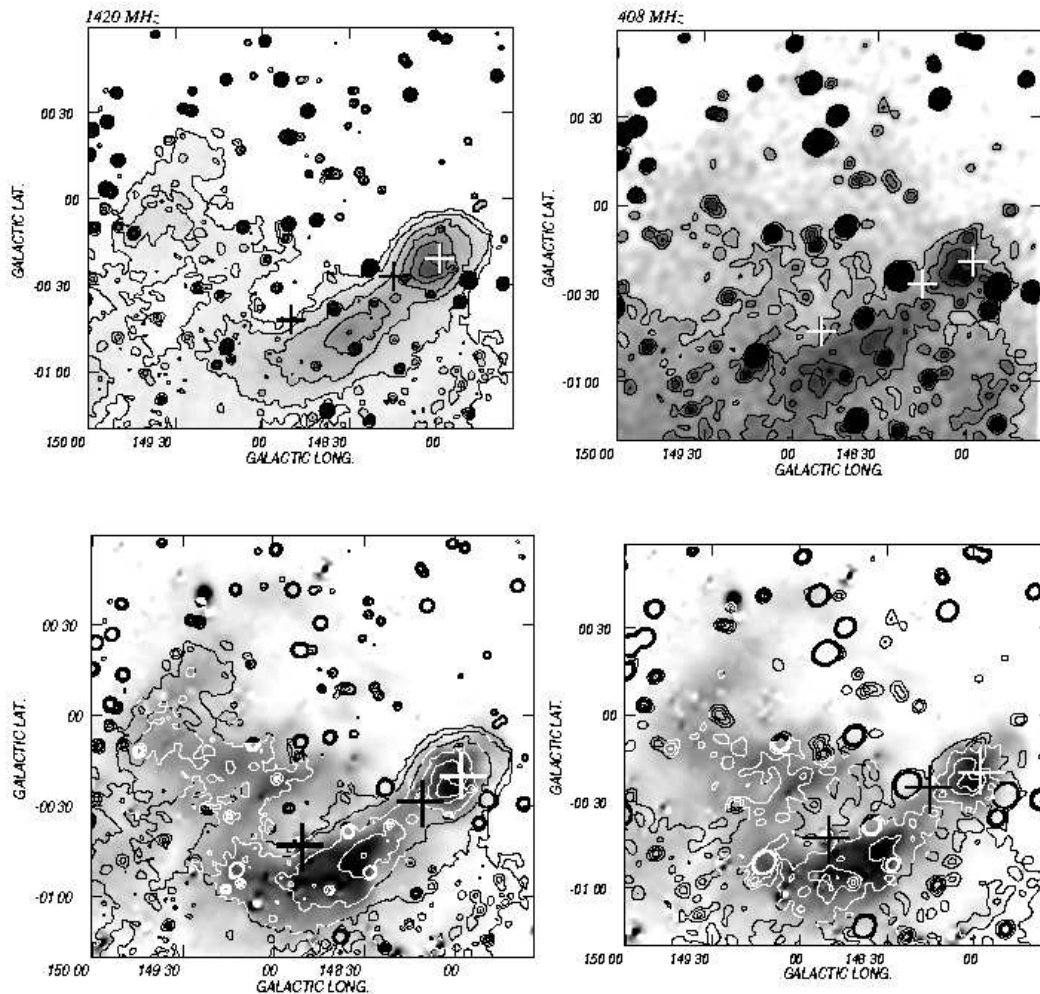
**Table 4.** Physical parameters of H II regions.

SH 148.83–0.67	
Related star	HD 24431
Size (')	$60 \times 54$
Adopted distance (kpc)	$1.0 \pm 0.2$
Size (pc)	$17.5 \times 15.7$
Radius (pc)	8.3
$S_{1420}$ (Jy)	$7.2 \pm 0.2$
$S_{408}$ (Jy)	$6 \pm 0.3$
$S_{2700}$ (Jy)	$3.7 \pm 1.8$
$\alpha$	$-0.20 \pm 0.12$
$T_e$ (K)	$8000 \pm 2000$
EM ( $pc\ cm^{-6}$ )	$520 \pm 120$
$f = 1$	
$n_e$ ( $cm^{-3}$ )	$6 \pm 1$
$M_i$ ( $M_\odot$ )	$420 \pm 170$
$f = 0.1\text{--}0.3$	
$n_e$ ( $cm^{-3}$ )	$15 \pm 4$
$M_i$ ( $M_\odot$ )	$180 \pm 90$
LBN 148.11–0.45	
Related stars	HD 24094, ALS 7793
Size (')	$30 \times 24$
Adopted distance (kpc)	$1.0 \pm 0.2$
Size (pc)	$8.7 \times 7.0$
Radius (pc)	3.9
$S_{1420}$ (Jy)	$3.2 \pm 0.1$
$S_{408}$ (Jy)	$1.90 \pm 0.07$
$S_{2700}$ (Jy)	$2.3 \pm 1$
$\alpha$	$+0.13 \pm 0.1$
$T_e$ (K)	10000
EM ( $pc\ cm^{-6}$ )	$1000 \pm 160$
$f = 1$	
$n_e$ ( $cm^{-3}$ )	$12 \pm 1$
$M_i$ ( $M_\odot$ )	$70 \pm 25$

in the estimate of the spectral index. By including the flux densities at 408 and 1420 MHz only, the spectral index results  $\alpha = +0.14 \pm 0.02$  for SH 148.83–0.67 and  $+0.4 \pm 0.04$  for LBN 148.11–0.45, also compatible with thermal nature. Thus, the derived spectral indices show that the sources are thermal in nature.

The physical parameters of the H II regions, namely, emission measure  $EM$ , electron density  $n_e$ , and ionized mass  $M_i$ , were obtained using the expressions by Mezger & Henderson (1967) and correspond to a filling factor  $f = 1$ . For the case of SH 148.83–0.67, a more realistic volume filling factor was estimated considering a shell-structure with inner radius  $R_{in}$  and outer radius  $R_{ou}$ . Both radii were measured using the radio continuum map at 1420 MHz, taking into account the contour level of 5.15 K ( $\equiv 85\ \sigma$ ) (see Fig. 2). The values  $28'$  and  $13'$  were obtained for  $R_{ou}$  and  $R_{in}$ , respectively. For the adopted distance,  $d = 1$  kpc,  $R_{ou} = 8.2$  pc and  $R_{in} = 3.8$  pc. Assuming that 10–30 per cent of the shell surface is occupied by plasma, the derived volume filling factor is in the range 0.1–0.3.

The assumed electron temperature is  $10^4$  K for the case of LBN 148.11–0.45, and values in the range  $(0.6\text{--}1.0) \times 10^4$  K were used for SH 148.83–0.67. The derived ionized masses were multiplied by 1.27 to take into



**Figure 2.** Radio continuum images at 1420 MHz and 408 MHz. *Top left panel:* Image at 1420 MHz. Contour levels are from 5.2 to 6.1 K in steps of 0.2 K. *Top right panel:* Image at 408 MHz. Contour levels are from 53 to 61 K in steps of 2 K. *Bottom left panel:* Overlay of the 1420 MHz image (contours) and the VTSS image. *Bottom right panel:* Overlay of the 408 MHz image (contours) and the VTSS image.

account singly ionized Helium (Goss & Lozinskaya 1995). The results are listed in Table 4. Uncertainties in masses and electron densities come mainly from the distance uncertainty. For the case of LBN 148.11–00.45, the central radio peak suggests  $f = 1$ .

#### 4.2 Dust emission distribution

Figure 3 illustrates the infrared emission distribution in the area under study. The top left panel displays the emission at  $60\mu\text{m}$  in contours and grayscale, while the top right panel shows an overlay of the infrared emission at  $60\mu\text{m}$  (grayscale) and the radio continuum emission at 1420 MHz (contours).

The emission distribution in the far infrared differs from the radio continuum emission. Strong emission comes from LBN 148.11–00.45. Arc-shaped extended emission at  $60\mu\text{m}$  strikingly surrounds the border of the H II region towards larger galactic longitudes and separates this region from SH 148.83–0.67.

Two small emission regions are easily distinguished in LBN 148.11–00.45. One of them is a relatively extended feature coincident with the stellar position. This  $60\mu\text{m}$  maximum is shifted 5 arcmin from the maximum at 1420 MHz. The other infrared region is detected towards  $(l, b) = (148^\circ 0', -0^\circ 10')$ . Its position is coincident with the small diameter source NVSS J035327+533601, detected in the radio continuum and suspected to be an extragalactic source.

Faint diffuse infrared emission also overlaps part of SH 148.83–0.67. This weak feature coincides with the arc-like structure seen at 1420 MHz and at optical wavelengths (see Fig. 2). No far infrared emission is identified near  $(l, b) = (149^\circ 00', -0^\circ 20')$ , where faint optical emission belonging to SH 148.83–0.67 was detected.

The image at  $100\mu\text{m}$  is not shown here since the emission distribution is similar to that at  $60\mu\text{m}$ .

The bottom right panel of Fig. 3 shows an overlay of the infrared emission at  $8.3\mu\text{m}$  (Band A of MSX satellite) (grayscale) and the infrared emission at  $60\mu\text{m}$  (contours).

**Table 3.** Small diameter sources projected onto the region.

Position $l$ [°] $b$ [°]		$S_{1420}$ [mJy]	$S_{408}$ [mJy]	$\alpha$	Source designation
sources seen onto LBN 148.11–0.45					
147° 49′	−0° 28′	503 ± 0.93	1038 ± 18	−0.58 ± 0.03	NVSS J035125+532828
147° 52′	−0° 35′	80 ± 0.92	167 ± 17	−0.59 ± 0.17	NVSS J035107+532041
147° 54′	−0° 25′	13.3 ± 0.91	14 ± 10	−0.03 ± 1.25	NVSS J035205+532753
148° 02′	−0° 33′	19.9 ± 0.89	39 ± 21	−0.54 ± 0.92	NVSS J035210+531621
148° 11′	−0° 28′	21.2 ± 0.84	60 ± 32	−0.8 ± 0.2	NVSS J035320+531453
147° 59′	−0° 11′	13 ± 0.9	45 ± 27	−1.0 ± 0.2	NVSS J035327+533601
sources seen onto SH 148.83–0.67					
148° 23′	−0° 24′	405.4 ± 1.5	1288 ± 19	−0.92 ± 0.02	NRRF J035430.6+530759
148° 35′	−0° 39′	59.2 ± 1.6	177 ± 20	−0.88 ± 0.16	6C B035049.0+524145
148° 37′	−0° 37′	17.8 ± 1.5	149 ± 62	−1.7 ± 0.6	NVSS J035337+530130
148° 28′	−0° 52′	70.9 ± 1.6	81 ± 19	−0.12 ± 0.38	87GB 034917.6+523604
148° 22′	−0° 47′	9.2 ± 1.8	17 ± 8	−0.48 ± 0.57	NVSS J035256+525159
148° 16′	−0° 58′	24.9 ± 1.6	14 ± 5	+0.47 ± 0.51	NVSS J035651+521521
149° 12′	−0° 51′	20.4 ± 1.5	419 ± 19	−0.57 ± 0.074	87GB 035303.4+520859
148° 51′	−0° 09′	123.4 ± 1.5	not resolved		87GB 035414.7+525443
148° 52′	−0° 14′	5.06 ± 0.32	18 ± 5	−1.01 ± 0.34	NVSS J035748+525933
148° 59′	−0° 21′	15.7 ± 1.5	35 ± 18	−0.64 ± 0.2	NVSS J035751+524924
148° 41′	−0° 58′	1.94 ± 0.25	33 ± 16	−2.27 ± 0.68	NVSS J035347+523208
148° 13′	−0° 59′	30.3 ± 1.9	30 ± 7	+0.01 ± 0.36	NVSS J035115+525046

Notes:

Col. 6: References found in NED catalogue: 6C: Hales, Baldwin & Warner (1988), NVSS: Condon et al. (1998), 87GB: Gregory & Condon (1991), NRRF: Newberg et al. (1999)

The bottom left panel shows an overlay of the infrared emission at 8.3  $\mu\text{m}$  (*grayscale*) and the radio continuum emission at 1420 MHz (*contours*). The image at 8.3  $\mu\text{m}$  reveals an arc-shaped feature, 5′ in width, which delineates the border of the H II region towards larger galactic longitudes and lower galactic latitudes, and coincides with a similar feature seen at 60  $\mu\text{m}$ . No emission in the MSX band A is detected close to HD 24431. Very likely, the image at 8.3  $\mu\text{m}$  shows radiation from polycyclic aromatic hydrocarbons (*PAHs*), which can survive in the neutral gas around H II regions (Hollenbach & Tielens 1997), but not inside the ionized regions. Thus, this emission traces a PDR lying in the outskirts of LBN 148.11–0.45.

NVSS J035327+533601 also has a bright counterpart at 8.3  $\mu\text{m}$ . No significant emission at 8.3  $\mu\text{m}$  is detected in the rest of the area. We note that band E is free of emission in the whole area.

The IRAS (HIRES) image at 12  $\mu\text{m}$  (not shown here) presents the same spatial distribution as the 8.3  $\mu\text{m}$  image, since the filter responses of A and 12  $\mu\text{m}$  bands are similar (Egan 1996). These bands are detecting dust with the same physical conditions.

Table 5 lists flux densities at 60  $\mu\text{m}$  and 100  $\mu\text{m}$ , dust temperatures, and dust masses associated with LBN 148.11–0.45 and SH 148.83–0.67. The parameter  $n$  is related to the dust absorption efficiency ( $\kappa_\nu \propto \nu^n$ ). The dust temperature was estimated for  $n$  in the range 1 to 2. The infrared emission related to LBN 148.11–0.45 was split in three regions to obtain the physical parameters of the associated dust. The first region involves the infrared emission which correlates with the central part of the H II re-

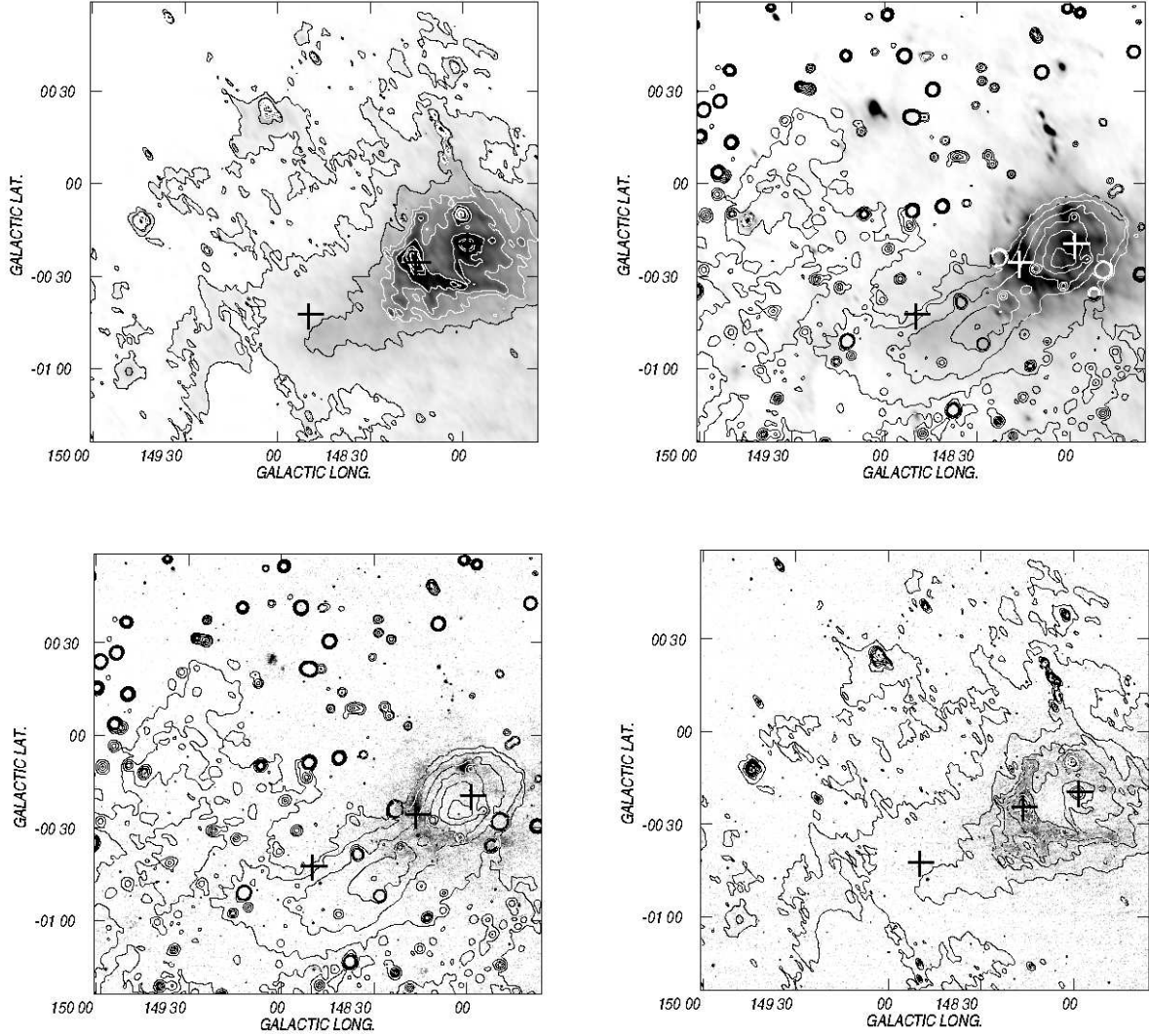
gion (a), the second one is the arc-shaped structure (b), and the third one is the extended emission coincident with NVSS J035327+533601 (c). Region (d) corresponds to the H II region as a whole. Uncertainties in listed dust masses originate in the adopted distance error and in different infrared background **emissions**. No significant difference in dust color temperature is apparent among the different sections of LBN 148.11–0.45. Derived dust temperatures for SH 148.83–0.67 and LBN 148.11–0.45 are typical for H II regions.

### 4.3 The H I gas emission distribution

To find possible H I structures associated with the ionized regions, the H I data cube was carefully examined within the velocity range from −165 to +45  $\text{km s}^{-1}$  (all velocities in this paper are with respect to the LSR).

The average H I spectrum corresponding to a region of  $2^\circ \times 2^\circ$  in size centered at  $(l, b) = (148^\circ 29', -0^\circ 19')$  is displayed in Fig. 4 to facilitate visualization of the large scale characteristics of the H I in the area. The H I profile shows the presence of significant emission covering the velocity range from −80 to +10  $\text{km s}^{-1}$ . Three main H I components can be distinguished. According to circular galactic rotation models (Brand & Blitz 1993), components centered at +4  $\text{km s}^{-1}$ , −32  $\text{km s}^{-1}$  and −56  $\text{km s}^{-1}$  should be located at kinematical distances  $\lesssim 1$  kpc,  $4 \pm 1$  kpc and  $9 \pm 2$  kpc, respectively. These features are probably related to emission from the local and the Perseus spiral arms (Georgelin & Georgelin 1976).

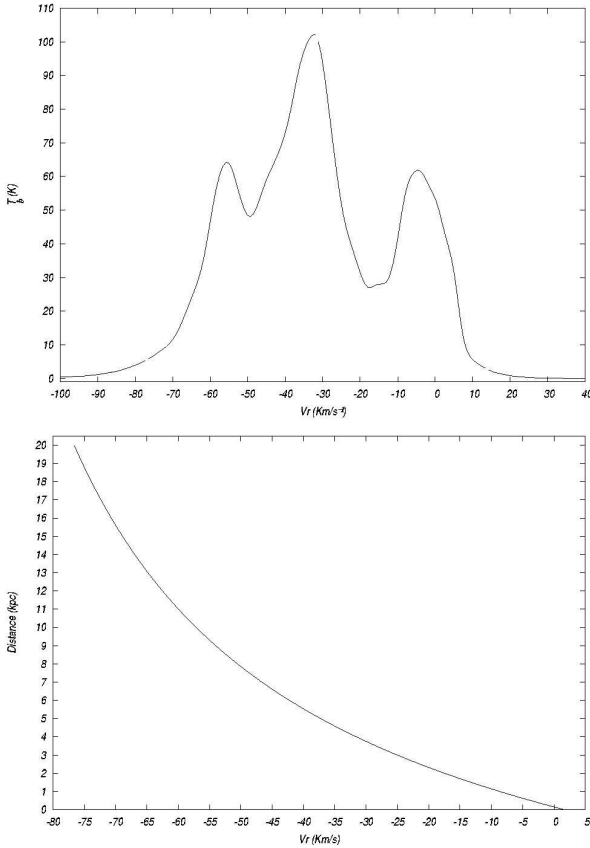
The H I profile presents a minimum at  $\approx -15 \text{ km s}^{-1}$ .



**Figure 3.** *Upper left panel:* Image at  $60\ \mu\text{m}$  in grayscale and contour lines. Contour lines are 10, 15, 20, 25, 35, 50, 60, 100, and  $140\ \text{MJY}\ \text{ster}^{-1}$ . Grayscale is from  $9.00$  to  $40.00\ \text{MJY}\ \text{ster}^{-1}$ . *Upper right panel:* Overlay of the  $60\ \mu\text{m}$  image (grayscale) and  $1420\ \text{MHz}$  emission (contours). Contour levels are from  $5.2$  to  $6.1\ \text{K}$  in steps of  $0.1\ \text{K}$ . *Bottom left panel:*  $1420\ \text{MHz}$  emission (contours) superposed onto the  $8.3\ \mu\text{m}$  image (grayscale). Grayscale corresponds to  $600 \times 10^{-9}$  to  $1400 \times 10^{-9}\ \text{W m}^{-2}\ \text{ster}^{-1}$ . *Bottom right panel:* Overlay of the  $8.3\ \mu\text{m}$  image (grayscale) and  $60\ \mu\text{m}$  emission (contours). The crosses mark the positions of HD 24431, ALS 7793, and HD 24094.

**Table 5.** Parameters of the interstellar dust associated with LBN 148.11–0.45 and SH 148.83–0.67.

H II region	$S_{60\ \mu\text{m}}$ (Jy)	$S_{100\ \mu\text{m}}$ (Jy)	$T_d$ (K) ( $n=1.0\text{--}2.0$ )	$M_d$ ( $M_\odot$ )	
				$n=1.0$	$n=2.0$
LBN 148.11–0.45 (a)	680	1410	$32 \pm 3$	$0.2 \pm 0.1$	$0.8 \pm 0.3$
LBN 148.11–0.45 (b)	910	2470	$29 \pm 3$	$0.6 \pm 0.3$	$2.0 \pm 0.9$
LBN 148.11–0.45 (c)	260	740	$29 \pm 3$	$0.2 \pm 0.1$	$0.6 \pm 0.3$
LBN 148.11–0.45 (d)	$2900 \pm 100$	$8100 \pm 300$	$29 \pm 3$	$0.4 \pm 0.2$	$1.5 \pm 0.6$
SH 148.83–0.67	$620 \pm 180$	$1750 \pm 450$	$29 \pm 3$	$2.0 \pm 0.8$	$7.0 \pm 3.0$



**Figure 4.** *Top panel:* Average H I profile within a region of  $2^\circ \times 2^\circ$  in size, centered at  $(l, b) = (148^\circ 29', -0^\circ 19')$ . *Bottom panel:* Kinematical distance vs. Radial velocity plot derived from the analytical fit to the rotation curve by Brand & Blitz (1993).

The circular galactic rotation model predicts a kinematical distance of  $\approx 1.6 \pm 0.8$  kpc for gas at this velocity, compatible with distance estimates for HD 24431 (see Table 1). In order to look for cavities and holes that may be associated with HD 24431 and HD 24094 we have meticulously inspected the velocity interval  $[+6, -50]$   $\text{km s}^{-1}$ .

Figure 5 shows the H I emission within the velocity interval  $+1.6$  to  $-31.6$   $\text{km s}^{-1}$  in steps of  $3.3$   $\text{km s}^{-1}$ . Each image is the average of four consecutive H I maps. In order to facilitate the display of the images, a constant background, equal to the mean value of each image within a box of  $2^\circ \times 2^\circ$  in size centered at  $(l, b) = (148^\circ 29', -0^\circ 19')$  was subtracted from every map. The H I gas distribution is quite complex and, as a consequence, the identification of the neutral gas associated with the ionized regions is hard to establish. We will discuss each case separately, along with an H I shell centered at  $(l, b) = (149^\circ 0', -1^\circ 30')$ .

#### 4.3.1 H I gas related to LBN 148.11–0.45

An inspection of Fig. 5 shows that H I gas related to LBN 148.11–0.45 is detected within the velocity range from  $+1.6$  to  $-15.1$   $\text{km s}^{-1}$ . At  $+1.6$   $\text{km s}^{-1}$ , a region of enhanced H I emission is seen partially coincident with the H II region. This feature consists of a faint elongated H I cloud centered at  $(l, b) = (148^\circ 10', -0^\circ 15')$  that extends 30 arcmin at a

position angle of  $\approx 45^\circ$ . Within the velocity interval from  $-1.6$  to  $-5.2$   $\text{km s}^{-1}$ , H I gas is clearly seen surrounding the H II region near  $(l, b) \approx (148^\circ 15', -0^\circ 15')$ . In the velocity range from  $-5.2$  to  $-11.8$   $\text{km s}^{-1}$ , a patchy envelope encircles the H II region almost completely. At  $\approx -8.5$   $\text{km s}^{-1}$ , the brightest section of the H I structure surrounds the H II region towards  $b \sim -0^\circ 40'$ . The envelope is hardly identifiable at  $v \lesssim -15.0$   $\text{km s}^{-1}$ . At  $v \approx -22.0$   $\text{km s}^{-1}$ , HD 24094 and ALS 7793 are seen projected onto a bright H I filament that runs along a position angle of  $\approx 30^\circ$  across the area.

Figure 6 shows the H I emission in the velocity range from  $-1.5$  to  $-11.8$   $\text{km s}^{-1}$  (left panel), and an overlay of the 1420 MHz continuum emission and the H I image (right panel). H I gas most probably related to LBN 148.11–0.45 is clearly seen in the left panel, where the H I envelope is identified. We believe that the H I gas that encompasses LBN 148.11–0.45 represents an atomic gas shell associated with the ionized region. H I gas projected onto the central part of the H II region, which is detected within the velocity interval  $+1.5$  to  $-5.2$   $\text{km s}^{-1}$ , may represent part of the receding cap of the envelope.

#### 4.3.2 H I gas related to SH 148.83–0.67 and SH 149.25–0.0

Identification of neutral atomic gas related to these features is particularly difficult.

Figure 5 shows a low emission region surrounded by an almost complete shell centered at  $(l, b) = (148^\circ 50', -0^\circ 35')$ , which can be identified in the velocity range from  $-22.0$  to  $-32.0$   $\text{km s}^{-1}$ .

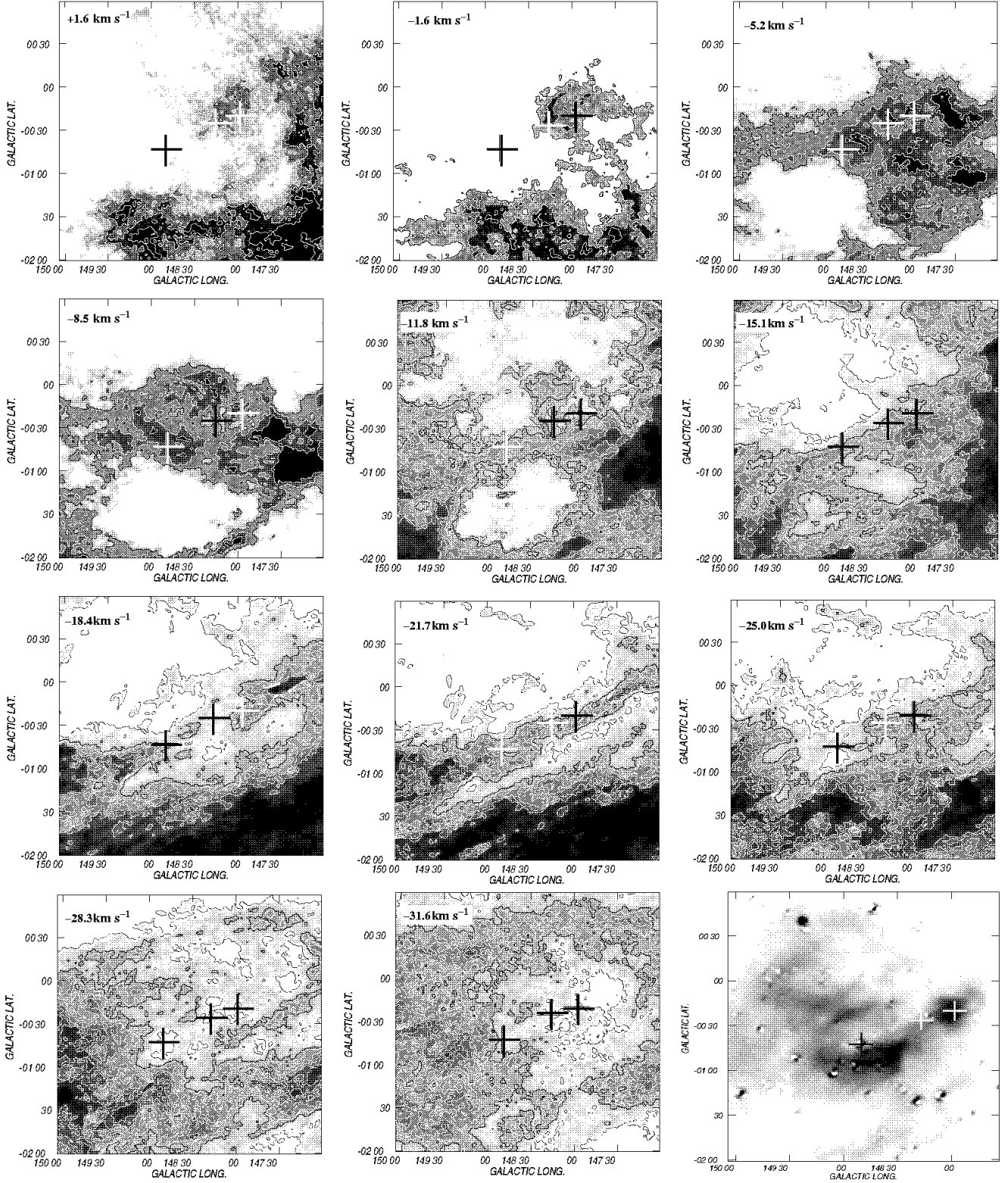
Figure 7 shows the H I emission averaged in the velocity range from  $-25.0$  to  $-28.0$   $\text{km s}^{-1}$ , where this feature is better defined. The cavity and the outer shell,  $1.8 \times 1.3$  in size, are shown in the left panel. The borders of the cavity are defined by the contour line corresponding to 70 K at  $b \leq -0^\circ 30'$  and by the contour line of 60 K at  $b \geq -0^\circ 30'$ . The right panel, which displays a superposition of the H I and optical images, reveals that the optical arc-like feature at  $(l, b) = (148^\circ 45', -0^\circ 50')$  appears projected onto the cavity. The faint optical emission at  $(l, b) = (149^\circ, -0^\circ 20')$  is seen within the cavity. The comparison between the H I and optical emission suggests that this H I shell is related to SH 148.83–0.67.

A bright H I filament running along the complete interval of galactic longitudes at a position angle of  $30^\circ$  can be easily distinguished at  $\approx -22.0$   $\text{km s}^{-1}$  (Fig. 5), with HD 24431 projected onto the H I filament. Thin H I areas surround the bright knots seen in the optical image near  $(l, b) = (148^\circ 40', -0^\circ 45')$  suggesting that H I gas at this velocity interacts with the nebula.

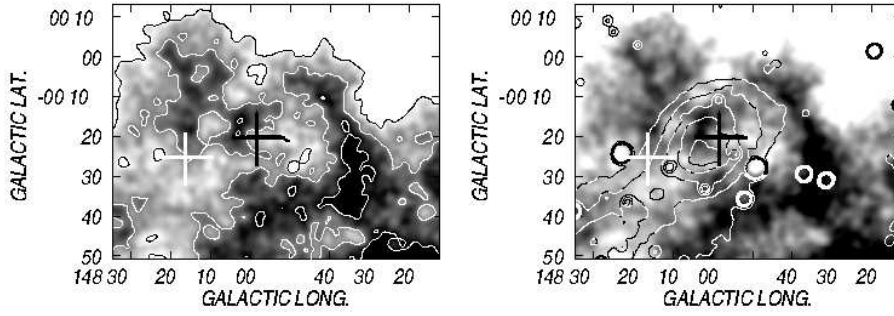
For a systemic velocity of  $\approx -27$   $\text{km s}^{-1}$ , the circular galactic rotation model (see Fig. 4) predicts a kinematical distance of  $\approx 3.3 \pm 0.8$  kpc, assuming a velocity dispersion of  $6$   $\text{km s}^{-1}$ . The derived distance is larger than spectrophotometric distance estimates for HD 24431 (see Table 1). Based on the spectrophotometric distance to this star, we adopt  $d = 1.0 \pm 0.2$  kpc as the distance to SH 148.83–0.67 and the surrounding H I shell.

Other H I structure in the area is centered at  $(l, b) = (149^\circ 15', +0^\circ 25')$  at  $v = -15.1$   $\text{km s}^{-1}$ , of  $\approx 60'$  in size. The structure can be followed within a velocity range from  $-12.0$  to  $-18.4$   $\text{km s}^{-1}$ . At  $\approx -15$   $\text{km s}^{-1}$ , this feature

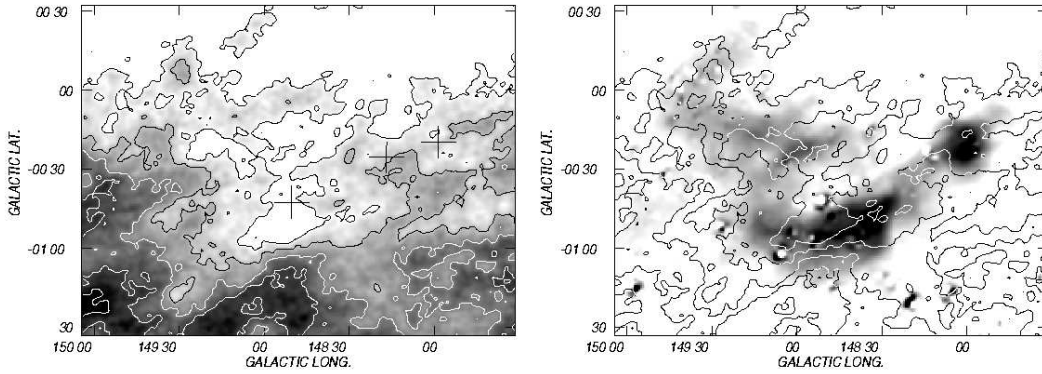




**Figure 5.** H I emission distribution in the velocity range from  $+1.6$  to  $-31.6 \text{ km s}^{-1}$ . The crosses mark the positions of HD 24431, ALS 7793, and HD 24094. The central velocity of each map is indicated in its upper left corner. Contour levels for maps within the velocity interval  $[+1.6, -11.8] \text{ km s}^{-1}$  are from 4 to 16 K in steps of 4 K. Contour levels for maps within the velocity interval  $[-15.1, -31.6] \text{ km s}^{-1}$  are from -8 to 16 K in steps of 4 K. The grayscale for maps having velocities of  $+1.6 \text{ km s}^{-1}$  and  $-1.6 \text{ km s}^{-1}$  are from 0 K to 10 K. The grayscale for the rest of the maps is from -10 K to 30 K. The optical image of Sh2-205 is shown in the bottom right corner. Darker regions mean brighter areas.



**Figure 6.** *Upper panel:* H I emission distribution towards LBN 148.11–0.45 within the velocity range  $-1.5$  to  $-11.4$   $\text{km s}^{-1}$ . The crosses indicate the positions of ALS 7793 and HD 24094. The grayscale is from 60 to 70 K. Contour levels are from 60 to 75 in steps of 5 K. *Lower panel:* Overlay of the H I emission shown in the left panel (grayscale) and the radio continuum image at 1420 MHz (contour lines). Contour levels are from 5.3 to 6.1 K in steps of 0.2 K. Darker regions mean brighter areas.



**Figure 7.** *Left panel:* H I emission distribution for the structure probably related to SH 148.83–0.67 within the velocity range  $-25.0$  to  $-28.0$   $\text{km s}^{-1}$ . The grayscale is from 60 to 100 K. The contour levels are 60 to 100 K in steps of 10 K. The cross symbols indicate the positions of HD 24431, ALS 773, and HD 24094. *Right panel:* Overlay of the H I emission distribution (contour lines) and the VTSS image (grayscale). Darker regions mean brighter areas.

presents its largest angular size, and its borders are better defined than at other velocities (Fig. 8, *upper panel*). For gas at this velocity, the analytical fit by Brand & Blitz (1993) predicts a kinematical distance  $d = 1.8 \pm 0.8$  kpc. The comparison with the radio continuum emission at 1420 MHz reveals that the weak radio emission at  $(l, b) = (149^\circ 15', +0^\circ 20')$ , related to SH 149.25–0.00, is seen projected onto the innermost part of the cavity, suggesting that the H I structure is linked to it.

#### 4.3.3 An H I shell centered at $(l, b) = (149^\circ 0', -1^\circ 30')$

The analysis of the H I emission allows identification of an H I structure within the velocity range  $-5.2$  to  $-15.1$   $\text{km s}^{-1}$ , centered at  $(l, b) = (149^\circ 0', -1^\circ 30')$ , with a systemic velocity of  $\approx -12$   $\text{km s}^{-1}$ . The open cluster NGC 1444, at a distance of 1.2 kpc (see Section 1), is placed near the border of the H I hole. The kinematical distance of the shell is compatible with the optical distance to the cluster. The structure is  $\approx 2.2 \times 1.5$  in size and is shown in the lower panel of Fig. 8.

#### 4.3.4 Physical parameters of the H I structures

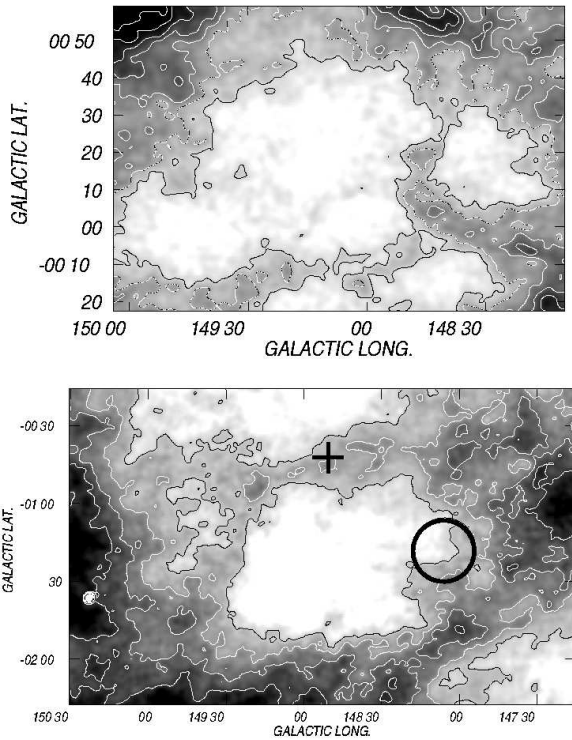
Table 6 lists the main data of the neutral atomic structures identified in the region: the  $(l, b)$  centroid of the H I shells, the velocity interval spanned by the structures, the systemic and expansion velocities, and the kinematical and adopted distances. The expansion velocity was estimated from the velocity range spanned by the H I feature as  $(v_2 - v_1) / 2 + 1.0$ . The size of the H I structures was derived from the position of the maxima in the shells. The radius  $R_s$ , is defined as half the geometric mean of the axes of the H I structure. The neutral atomic mass corresponds to the mass excess in the shell. It was obtained within a circle of radius  $R_e$ , assuming that the gas is optically thin, and includes a He abundance of 10 per cent. The neutral atomic mass associated with the H I shell probably linked to SH 149.25–0.00 is difficult to establish.

#### 4.4 The molecular gas emission distribution

The analysis of the  $^{12}\text{CO}$  emission distribution in the region shows the presence of molecular gas associated with LBN 148.11–0.45 within the velocity range from  $-0.65$  to  $-11.1$   $\text{km s}^{-1}$ . Figure 9 (upper left panel) shows an overlay of the  $^{12}\text{CO}$  emission distribution within the

**Table 6.** Parameters of H I and  $^{12}\text{CO}$  structures.

Related ionized regions	LBN 148.11–0.45	SH 148.83–0.67	–	Sh 149.25–0.0
<b>Neutral H I shells</b>				
( $l, b$ ) centroid	147°55′, –0°20′	148°50′, –0°35′	149°0′, –1°30′	149°15′, +0°25′
Velocity interval $v_1, v_2$ (km s $^{-1}$ )	+1.6, –18.0	–22, –32	–5, –15	–20, –12
Systemic velocity (km s $^{-1}$ )	–9 ± 1	–27 ± 1	–12 ± 1	–15 ± 1
$V_{exp}$ (km s $^{-1}$ )	11	7	7	6
Kinematical distance $d$ (kpc)	1.3	3.3	1.5	1.8
Adopted distance (kpc)	1.0 ± 0.2	1 ± 0.2	1.0 ± 0.2	1.0 ± 0.2
Size of the H I structure ( $r_1 \times r_2$ ) (′)	51 × 49	105 × 80	129 × 90	60 × 60
Size of the H I structure ( $r_1 \times r_2$ ) (pc)	15 × 14	31 × 23	38 × 26	17 × 17
Radius $R_s$ (pc)	7.2	13.4	15.7	8.5
$R_e$ (′)	25	27	56	–
Neutral atomic mass ( $M_\odot$ )	65 ± 25	300 ± 120	1600 ± 640	–
<b>Molecular gas</b>				
Velocity interval $v_1, v_2$ (km s $^{-1}$ )	–0.65, –11.1	–	–0.65, –11.1	–
$W_{\text{CO}}$ (K km s $^{-1}$ )	41	–	9	–
Mean $\text{H}_2$ column density ( $10^{21}$ mol $_{\text{H}_2}$ cm $^{-2}$ )	8 ± 0.8	–	2 ± 0.2	–
Mass ( $10^4 \times M_\odot$ )	6.0 ± 3.0	–	2.6 ± 1.3	–
Ambient density (cm $^{-3}$ )	~ 800	~ 2	~ 70	–



**Figure 8.** *Upper panel:* H I emission distribution for the neutral atomic gas structure probably related to SH 149.25–0.0 within the velocity range –13.4 to –16.7 km s $^{-1}$ . The grayscale is 15 to 45 K. The contour levels are 10, and from 20 to 50 K in steps of 5 K. *Lower panel:* H I emission distribution within the velocity interval from –3.1 to –17.1 km s $^{-1}$  showing the H I structure at ( $l, b$ ) = (149°0′, –1°30′). The contour levels are from 50 to 65 K in steps of 5 K. The positions of HD 24431 and NGC 1444 are indicated by a cross symbol and a circle, respectively. Darker regions mean brighter areas.

velocity range [–3.2, –4.5] km s $^{-1}$  (contours) and the infrared emission at 60  $\mu\text{m}$  (grayscale). The molecular cloud at  $l = (148^\circ 25')$  delineates strikingly well the border of the PDR detected at 8.3  $\mu\text{m}$ . Note that this CO cloud encompasses the brightest H I emission arc detected at  $v = -1.6$  km s $^{-1}$  (Fig. 5), suggesting that the thin H I filament can originate in the photodissociation of the molecular gas.

CO emission seen towards the central part of the H II region LBN 148.11–0.45 is likely placed behind the ionized region.

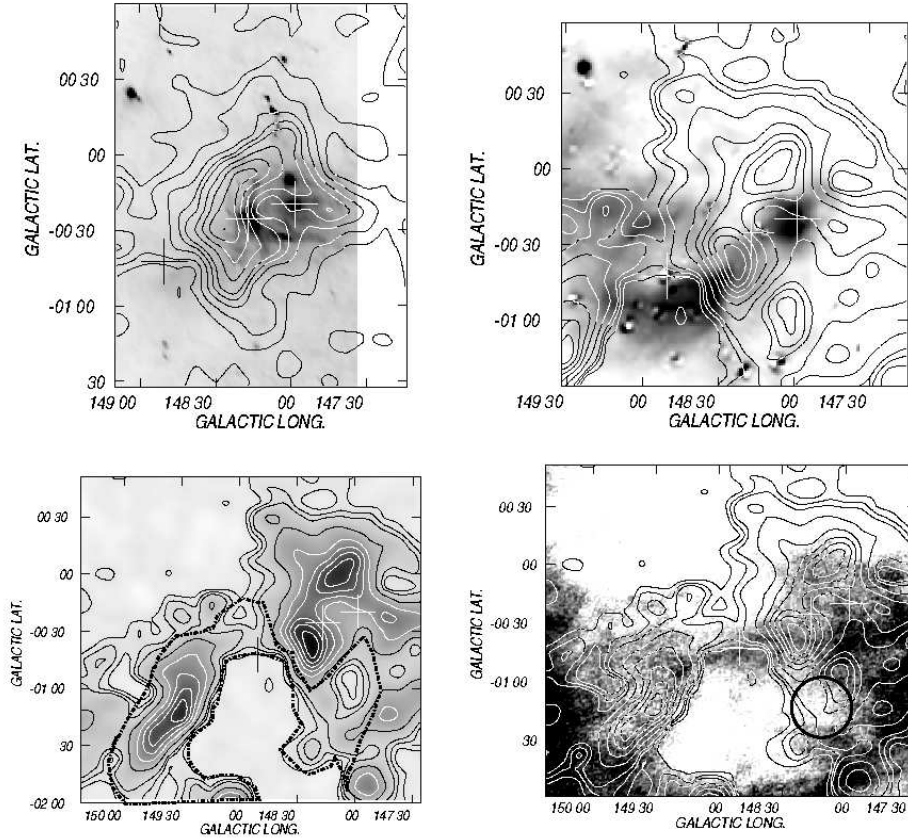
The upper right panel of Fig. 9 shows the  $^{12}\text{CO}$  emission distribution in the velocity range [–0.65, –11] km s $^{-1}$  overimposed onto the VTSS image.  $^{12}\text{CO}$  gas emission at ( $l, b$ ) = (148°25′, –0°40′) coincides with the faint optical emission region which separates the optically bright regions SH 148.83–0.67 and LBN 148.11–0.45. The slight distortion in the molecular clump at ( $l, b$ ) = (148°25′, –0°40′) following the border of SH 148.83–0.67, and the morphological correlation among the optical, radio continuum, and  $^{12}\text{CO}$  emissions indicates that the molecular gas is interacting with the ionized material.

The bottom panels of Fig. 9 show the  $^{12}\text{CO}$  emission within the velocity interval –3.1 to –17.1 km s $^{-1}$  and a superposition of the CO and H I gas distributions in the region of the H I shell centered at ( $l, b$ ) = (149°0′, –1°30′). The morphological correspondence between the H I and CO emissions reveals that this H I shell has a clear molecular counterpart.

The open cluster NGC 1444, marked in Fig. 9 by a circle, is seen projected close to the border of the CO and H I emission rings.

Towards the region under study, identification of molecular structures related to the ionized regions is easier than recognition of the associated H I structures, as can be expected bearing in mind confusion effects in the line of sight.

Table 6 summarizes the physical parameters of the molecular clouds associated with the ionized and neutral regions. The  $\text{H}_2$  column density ( $N_{\text{H}_2}$ ) was derived



**Figure 9.**  $^{12}\text{CO}$  emission distribution. *Upper left panel:* Overlay of the integrated  $^{12}\text{CO}$  emission in the velocity range from  $-3.2$  to  $-4.5$   $\text{km s}^{-1}$  (contour lines) and the  $60\ \mu\text{m}$  image (grayscale). Contours levels are  $0.15$  ( $\equiv 3\sigma$ ),  $0.5$ ,  $1$ ,  $1.5$  K, from  $2$  to  $6$  K in steps of  $1$  K, and from  $6$  to  $16$  K in steps of  $2$  K. *Upper right panel:*  $^{12}\text{CO}$  emission integrated in the velocity interval  $[-0.65, -11.1]$   $\text{km s}^{-1}$  superposed onto the VTSS  $\text{H}\alpha$  image (grayscale). *Bottom left panel:*  $^{12}\text{CO}$  emission integrated in the velocity interval  $[-0.65, -11.1]$   $\text{km s}^{-1}$ . The molecular mass was derived within the area marked out by the dash-dot line. *Bottom right panel:* Overlay the  $^{12}\text{CO}$  emission and the  $\text{H I}$  emission distributions within the velocity range from  $-3.1$   $\text{km s}^{-1}$  to  $-17.1$   $\text{km s}^{-1}$  (grayscale). The contour levels indicated in the lower panels are the same that are displayed in the upper right panel. The positions of HD 24431, ALS 7793, and HD 24094 are indicated by crosses.

from the  $^{12}\text{CO}$  data, taking into account the empirical relation between the integrated emission  $W_{\text{CO}} (= \int T dv)$  and  $N_{\text{H}_2}$ . We adopted  $N_{\text{H}_2} = (1.9 \pm 0.3) \times W_{\text{CO}} \times 10^{20} \text{ cm}^{-2} (\text{K km s}^{-1})^{-1}$ , obtained from  $\gamma$ -ray studies of molecular clouds in the Cepheus Flare (Digel et al. 1996; Denier & Lebrun 1990). To derive the molecular mass associated with LBN 148.11–0.45 we took into account the region enclosed by the contour level of  $1.5$  K centered at  $(l, b) = (148^\circ 10', -0^\circ 20')$ . For the case of the molecular mass associated with the  $\text{H I}$  shell centered at  $(l, b) = (149^\circ 0', -1^\circ 30')$ , we considered the region enclosed by the dash-dot line (Fig. 9). Errors in the derived molecular masses arise in uncertainties in distance and in  $N_{\text{H}_2}$ .

The ambient density was derived by distributing the ionized, neutral atomic and molecular masses over a sphere of radius  $R_e$ . For the case of LBN 148.11–0.45,  $R_e = 31'$  ( $\equiv 9$  pc), which corresponds to the region showing  $\text{CO}$  emission.

The comparison between the low neutral atomic mass related to LBN 148.11–0.45 and the associated molecular mass suggests that the  $\text{H I}$  mass originated in the photodis-

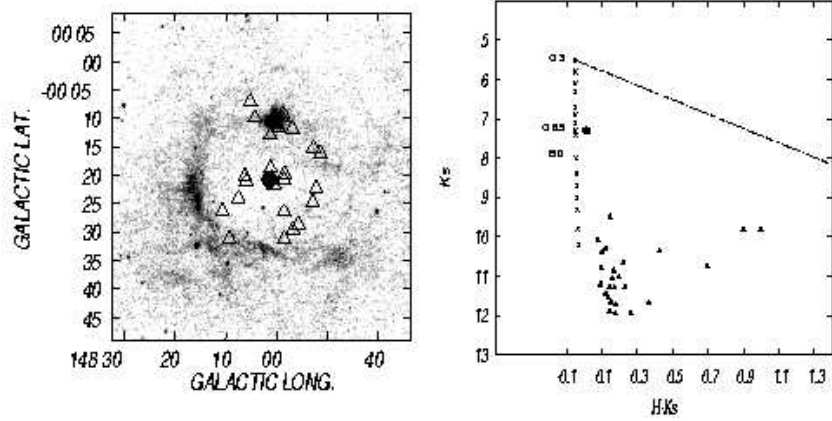
sociation of the molecular gas. This region is clearly evolving in a highly dense ambient medium.

## 5 THE ORIGIN OF THE STRUCTURES

### 5.1 SH 148.83–0.67

We can estimate the number of UV photons  $N_{\text{Ly}-c}$  ( $\text{s}^{-1}$ ) necessary to ionized the gas in the  $\text{H II}$  region from the radio continuum results and compare our estimate with the UV photon flux emitted by the exciting star,  $N_*$ , as derived from stellar atmosphere models. From the expression for the Stromgren's sphere (see Spitzer 1978), and adopting a radius of  $8.3$  pc for the  $\text{H II}$  region SH 148.83–0.67 and the electron density listed in Table 4 corresponding to  $f = 1$ , we derived  $\log N_{\text{Ly}-c} = 47.9$ .

Following Smith et al. (2002) and Martins et al. (2005), the number of Lyman continuum photons emitted by an O9 III star is in the range  $\log N_* = 47.9 - 48.4$ , indicating that HD 24431 can maintain SH 148.83–0.67 ionized if a small amount of interstellar dust is related to the structure (Inoue 2001). Indeed, the lack of infrared emission related to



**Figure 10.** *Left panel:* Spatial distribution of the main sequence star candidates from the 2MASS PSC (triangles) superposed onto the image at  $8.3\ \mu\text{m}$  of LBN 148.11–0.45. *Right panel:* Near-Infrared Color-Magnitude diagram of the main sequence star candidates shown in left panel. The sources are represented by triangles. The position of the main sequence is shown by crosses. We have adopted a distance of 1.0 kpc. The dashed line represents the reddening curve for an O3 star. The filled circle indicates the position of HD 24094 in both panels.

this H II region suggests that little interstellar dust is present (see also Table 5).

To investigate whether the ring-like structure originated in the action of the stellar winds of HD 24431 on the surrounding gas, we will estimate the energy conversion efficiency,  $\epsilon$ , defined as the ratio between the kinetic energy  $E_k$  in the shell and the mechanical energy supplied by the stellar wind  $E_w$ .

To evaluate the kinetic energy in the expanding shell,  $E_k = 0.5 M V_{exp}^2$ , we consider that the ionized, H I, and molecular gas expand at  $V_{exp}$ . The kinetic energy results to be  $E_k = 2.3 \times 10^{47}$  erg.

A rough estimate of the stellar wind energy of HD 24431, can be obtained adopting a mass loss rate  $\dot{M} = 1 \times 10^{-7} M_{\odot} \text{ yr}^{-1}$  (Chlebowski & Garmany 1991) and a terminal velocity  $V_w = 2000 \text{ km s}^{-1}$  (Prinja et al. 1990). We assume that this wind blew during at least the dynamical age of the bubble,  $t_d = 0.55 R_s / V_{exp}$  (McCray 1983). For the values listed in Table 6,  $t = 1.1 \times 10^6$  yr. The lifetime in the main sequence can be considered as an upper limit to this time. From Schaller et al. (1992),  $t = 4.0 \times 10^6$  yr. For  $t = (1.1 - 4.0) \times 10^6$  yr, we estimate  $E_w = 0.5 \dot{M} V_w^2 t = (5-16) \times 10^{48}$  erg.

The parameter  $\epsilon = 0.015 - 0.05$ , similar to values derived for other interstellar bubbles (Cappa et al. 2003), indicating that SH 148.83–0.67 probably originated in the stellar winds of the O9 III star.

## 5.2 LBN 148.11–0.45

Adopting the radius and electron density derived for this region from Table 4, we estimate that the UV photon flux necessary to ionize the gas is  $\log N_{Ly-c} = 47.7$ . Clearly this UV photon flux is higher than that provided by HD 24094 (B8V) and ALS 7793 (B1V) star. To look for additional sources of ionizing photons associated with the H II region, we investigated the presence of main sequence O-type stars which may contribute to the ionization of the H II region by using the 2MASS data base. We identified the main sequence

candidates based on the position of the sources in the color-magnitude (CMD) and color-color (CMD) diagrams according to the  $q$  parameter. Following Hanson et al. (1997), the parameter  $q$  is defined as:

$$q = (J - H) - 1.83 \times (H - K_s) \quad (1)$$

Main sequence stars have  $q$ -values in the range  $-0.15$  to  $0.10$ . Using this selection criteria, we found 28 candidates to be main sequence stars in the region of LBN 148.11–0.45. Fig. 10 shows the spatial distribution of these sources superposed onto the image at  $8.3\ \mu\text{m}$ , and the CMD. Most of the sources have  $K_s$ -magnitudes greater than 10 mag, suggesting that they are foreground late-type stars (later than B1 V). HD 24094, indicated in Fig. 10 as a filled circle, has values  $(H-K_s, K_s) = (0.023, 7.35)$ , corresponding to an O-type star (O8.5 or O9) with  $A_v = 10$  mag, different from the B-type star determination by Duerbeck (1997). Were HD 24094 an O8.5 V – O9 V star, it would supply an UV photon flux  $N_* = 1 \times 10^{48} \text{ s}^{-1}$  (Martins et al. 2001), enough to explain the ionization of the H II region. Spectroscopic data are needed to confirm this point.

Note that a number of B-type star candidates are projected onto NVSS J035327+533601.

We can roughly estimate the age of the H II region LBN 148.11–0.45 from the expression (12-20) by Spitzer (1978), which considers the expansion of an H II region with time. The radius of the H II region at the beginning of the expansion phase,  $R_i$ , can be derived from the expression for the Strongem’s sphere, adopting an electron density equal to the ambient density (see Table 6) and  $\log N_{Ly-c} = 47.7$ . For  $R_i = 0.35$  pc and adopting the present radius  $R_i = 7.2$  pc, the age of the H II region is  $4 \times 10^6$  yr.

## 5.3 Shell centered at (l,b) = (149°0′, −1°30′)

The question that raises is whether this neutral gas structure is physically related to NGC 1444. The estimated age of this cluster is in the range  $(25-41) \times 10^6$  yr (Lynga 1983, 1987). The spectral type of its earliest star is B2 (Lynga 1983) and

four blue stragglers were found to be related to it (Ahumada & Lapasset 1995). Leisawitz (1990) carried out a molecular survey around open clusters and found molecular clouds within the velocity range  $[-0.4, -26] \text{ km s}^{-1}$  probably associated with NGC 1444. Clouds labelled by Leisawitz (1990) as I and E centered at  $(l, b) = (149^\circ 12', -0^\circ 24')$  and  $(l, b) = (149^\circ 36', -1^\circ 6')$  with mean radial velocities of  $-4.5$  and  $-8.1 \text{ km s}^{-1}$ , respectively, coincide in position and velocity with the CO ring shown in Fig. 9. No other OB stars projected onto the cavity were found in the literature. The origin of this shell is still an open question.

## 6 SUMMARY

We have examined the interstellar medium in the surroundings of Sh2-205. We based our study on radio continuum data at 408 and 1420 MHz, and 21-cm H I line emission data belonging to the Canadian Galactic Plane Survey,  $^{12}\text{CO}$  from the survey by Dame et al. (2001), IRAS (HIRES) and MSX data.

The main findings can be summed up as follows:

1. Sh2-205 can be separated in three independent structures called: SH 149.25–0.00, SH 148.83–0.67, and LBN 148.11–0.45. To obtain the physical properties of these optical nebulae we have adopted a distance of  $1.0 \pm 0.2 \text{ kpc}$ .

2. We conclude that SH 148.83–0.67 is an interstellar bubble powered by the energetic winds of HD 24431. Low infrared emission is detected in this region. The H I shell related to SH 148.83–0.67 is identified in the velocity range from  $-22$  to  $-32 \text{ km s}^{-1}$ . It is  $31 \times 23 \text{ pc}$  in size and expands at  $6 \text{ km s}^{-1}$ . The electron density and the associated ionized mass are  $15 \pm 4 \text{ cm}^{-3}$  and  $180 \pm 90 \text{ M}_\odot$ , respectively, adopting a filling factor  $f = 1$ . The associated neutral atomic mass is  $65 \text{ M}_\odot$ .

3. LBN 148.11–0.45 is a classical H II region. The optical, mid- and far- infrared emissions reveal that dust and gas are well mixed in this region. The dust temperature is  $\approx 29 \text{ K}$ , typical of H II regions. Molecular gas within the velocity range  $[-0.65, -11.1] \text{ km s}^{-1}$  is found to be associated with the H II region. We estimated a molecular mass of  $60 \times 10^3 \text{ M}_\odot$ . The distribution of the emission in the MSX band A encircles the H II region and correlates with the molecular emission, indicating the presence of a PDR. Neutral atomic gas in the velocity range  $[+1.6, -18.0] \text{ km s}^{-1}$  is related to LBN 148.11–0.45. H I gas with velocities in the range from  $+1.6$  to  $-5.2 \text{ km s}^{-1}$  is seen projected onto the central part of the H II region, which may represent part of the receding cap of the envelope. The H I structure is  $15 \text{ pc} \times 14 \text{ pc}$  in size and expands at about  $9 \text{ km s}^{-1}$ . The associated neutral atomic mass is  $300 \text{ M}_\odot$ . The electron density and ionized mass are  $12 \pm 1 \text{ cm}^{-3}$  and  $70 \pm 25 \text{ M}_\odot$ , respectively. The H II region is evolving in a dense interstellar medium. We estimate that the H II region has been expanding for  $4 \times 10^6 \text{ yr}$ .

The ionizing source of LBN 148.11–0.45 remains uncertain. The earliest spectral type stars seen in projection onto this region are ALS 7793 (B1 V) and HD 24094. Duerbeck (1997) determined a B8 V spectral type for HD 24094. However, results from the 2MASS point source catalogue showing main sequence stars in the area of the nebula suggest that HD 24094 is an O8.5 – O9 star. A star with this spec-

tral type would provide the necessary UV photon flux to keep the H II region ionized. High quality spectroscopic data are needed to elucidate this point.

4. An H I structure within the velocity range  $-5.2$  to  $-15.1 \text{ km s}^{-1}$  was identified centered at  $(l, b) = (149^\circ 0', -1^\circ 30')$ . This shell correlates morphologically with molecular gas emission detected in the velocity range from  $-0.65$  to  $-11.1 \text{ km s}^{-1}$ . The neutral and molecular mass are  $1600 \text{ M}_\odot$  and  $20 \times 10^3 \text{ M}_\odot$ , respectively. Possible progenitors of this structure are the stellar members of NGC 1444.

5. An H I shell was also found possibly associated with SH 149.25–0.00. The neutral atomic structure is expanding at  $6 \text{ km s}^{-1}$  and is about  $17 \text{ pc}$  in size. The radio continuum emission is too faint to allow us to determine the physical properties of this nebula. No early type stars were found responsible for the ionization and expansion of SH 149.25–0.00 in the literature.

6. A relatively large number of main sequence candidates were found in the region of LBN 148.11–0.45 by making use of the 2MASS point source catalogue. Particularly interesting are the main sequence candidates projected onto NVSS J035327+533601 at  $(l, b) = (148^\circ 0', -0^\circ 10')$ .

Finally, the presence of a photodissociation region at the interface between the molecular material and the ionized gas in LBN 148.11–0.45, strikingly bordering the ionized region, is suggestive of the existence of regions of active stellar formation. This suggestion is reinforced by the high density medium where the H II region is evolving.

The observed scenario favors the conditions for the *collect and collapse* process (Elmegreen 2000), as was found by Deharveng et al. (2003) for Sh2-104. In a forthcoming paper, we analyze the stellar formation activity in the area.

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