Infrared portrait of the nearby massive star-forming region IRAS 09002-4732^{★,★★}

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Abstract. We present high-resolution near-infrared and mid-infrared imaging, mid-infrared spectroscopy and millimetre-wavelength continuum observations of the nearby massive star-forming complex IRAS 09002-4732. A rich cluster of young stars displaying near-infrared excess emission is detected. We identify the ionising source of the ultracompact H II region G268.42-0.85 and show that this star is the dominant heating and illuminating source of the region. Spectral type estimates based on different methods are consistent with a star of spectral type O9. The combination of the new observations with literature data allows us to set up the first structural model for the region. We argue that the ultracompact H II region is embedded in the rear side of the southern CS clump. Additionally, we detect several interesting objects. Among these objects are a network of dark dust filaments, an elongated, externally heated object with strong infrared excess inside the H II region and objects seen as silhouettes in the foreground of the large southern reflection nebula. The filamentary structures may play an important role in the star formation process.

Key words. stars: formation – stars: pre-main sequence – ISM: HII regions – ISM: individual objects: IRAS 09002-4732 – ISM: individual objects: G268.42-0.85 – infrared: ISM

1. Introduction

Young massive stars ($M > 8 M_{\odot}$) strongly influence the regions where they form. On the other hand, the formation of massive stars is determined by the conditions in the parental molecular cloud. Therefore, understanding massive star formation requires detailed studies of the youngest massive stars *and their environment*.

In this paper, we will study the bright far-infrared source IRAS 09002-4732 (RA: 09^h01^m54^s Dec: $-47^{\circ}43'59''$, J2000, $l = 268.419$ $b = -0.848$) as a prototype for a region of massive star formation. This region was selected because of its proximity, brightness and the available high-quality archival near-infrared data. IRAS 09002-4732 is located in the direction of the Vela Molecular Ridge, but a photometric study by Liseau et al. (1992) estimates a distance of about 700 pc. This would place the region closer to us than the Vela Molecular Ridge. Throughout this paper we assume the conservative

distance of 1.3 kpc which is consistent with the kinematic distance estimate provided by Wouterloot & Brand (1989), and which places this object in the Vela Molecular Ridge.

The first hints for massive star formation in the region of IRAS 09002-4732 came from an early detection of the strong radio source G268.42-0.85 (Manchester & Goss 1969) which was later classified as an ultra-compact H II region (UC H II). This source coincides with an extremely bright far-infrared source discovered by Furniss et al. (1975). The presence and strength of the $12.9 \mu\text{m}$ [NeII] line (Simpson & Rubin 1990), the radio flux (Walsh et al. 1998) and the high IRAS luminosity ($9 \times 10^4 L_{\odot}$ at a distance of 1.3 kpc, Ghosh et al. 2000) points to a spectral type of at least O9 if the ionising source is a single star. In addition to the luminosity, other signs of massive star formation such as water maser emission (Braz et al. 1989) and a massive molecular cloud core of $600 M_{\odot}$ (Zinchenko et al. 1995, at an assumed distance of 1.3 kpc) have also been detected in the region.

First evidence for the complexity of this massive star-forming region came from infrared images of the region obtained by Lenzen (1991). The images immediately revealed a very patchy distribution of matter. In addition, he found a cluster of near-infrared (NIR) sources with the reddest and strongest mid-infrared (MIR) object coinciding with the

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** Table 5 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/434/987>

Table 1. Log of the observations. The instruments and telescopes, filter names and central wavelengths, full width at half-maximum (*FWHM*) of point sources, final useful field of view, total integration times and the dates of the observations are given.

Instrument	Wavelength [μm]	<i>FWHM</i> [$''$]	Field of View	Integr. time [s]	Date
ISAAC UT1/VLT	1.2 (<i>J</i> s)	0.6''	4'25" $\times$ 4'25"	843.2	1st May 1999
ISAAC UT1/VLT	1.6 (<i>H</i>)	0.6''	4'25" $\times$ 4'25"	1757.8	1st May 1999
ISAAC UT1/VLT	2.2 (<i>K</i> s)	0.4''	4'25" $\times$ 4'25"	2636.7	10th April 1999
ISAAC UT1/VLT	3.78 (<i>L</i>)	0.5''	15" $\times$ 15"	237.6	1st June 2001
ISAAC UT1/VLT	4.07 (<i>Brα</i>)	0.6''	15" $\times$ 15"	431.2	1st June 2001
ISAAC UT1/VLT	4.66 (<i>M(nb)</i>)	0.5''	15" $\times$ 15"	415.8	1st June 2001
TIMM2/3.6 m	4.6 (<i>M</i>)	0.6''	40" $\times$ 40"	424	14th March 2001
TIMM2/3.6 m	11.9 (<i>N</i> 11.9)	0.8''	40" $\times$ 40"	807	14th March 2001
TIMM2/3.6 m	12.9 (<i>N</i> 12.9)	0.8''	40" $\times$ 40"	1451	14th March 2001
TIMM2/3.6 m	20 (<i>Q</i>)	1'4	40" $\times$ 40"	1008	14th March 2001
TIMM2/3.6 m	<i>N</i> -Spectr.	0.8''	3" $\times$ 60"	510	14th March 2001
SIMBA/SEST	1200	24''	9'3" $\times$ 15'	100	16th July 2003

radio position (G268.42-0.85). Using CS molecular line data, Lapinov et al. (1998) revealed the large-scale bipolar structure of the cloud.

The goal of this paper is to use multi-wavelength data from the near-infrared to the radio regime in order to develop a comprehensive picture of this region of massive star formation. To reach this goal, we use high-resolution data obtained with ISAAC at the VLT, imaging and spectroscopic TIMM2 mid-infrared data, and a SEST millimetre continuum map. Sensitive and high-resolution near-infrared observations are essential to address the stellar census and the structure of the nebulosity; the mid-infrared data are required to identify the main heating source of the intracluster dust.

In the following, we describe the observations and data reduction. Based on the new data, we discuss the morphology, stellar content, reflection nebulosities, the UC H II region, the ionising star and the spectral energy distribution (SED) of the region. Finally, we assemble a global structural picture of the region and summarize the main conclusions.

2. Observations and data reduction

The most important parameters of the near-infrared, mid-infrared, and millimetre observations presented in this paper are compiled in Table 1. In addition to these data, we will use archival MSX images and photometry (Egan et al. 1999), reprocessed IRAS fluxes (Ghosh et al. 2000), and centimetre-wavelength ATCA radio measurements (Walsh et al. 1998).

2.1. Near-infrared 1–2.2 μm imaging

We used *J*s, *H* and *K*s images taken with the ISAAC infrared camera at the UT1/VLT (ESO, Paranal Observatory) and retrieved from the ESO archive (courtesy L. Bronfman) to investigate the stellar content of the region around IRAS 09002-4732. The camera has been used at the SWI mode with a pixel size of $\sim 0''.15/\text{pixel}$. A mosaicing technique has been used to map a $4.25' \times 4.25'$ area centered on the IRAS

source 09002-4732. Along the edges (0.5') the mosaic is sparsely sampled. Every on-object frame was followed by an off-object frame with an offset of 30'' in both RA and Dec directions to provide background levels. To avoid the contamination of the sky frames by the extended nebulosity and stars, we combined the set of all images into a common sky frame. The combination was done by comparing the values of each pixel in every frame and taking the mean of the lowest 1/3 of them. This procedure effectively removed the imprints of any object brighter than the average sky background and, therefore, led to a homogeneous sky frame.

Additionally, the off-object frames have also been used to extend the available field of view. The detector integration time (DIT) was 1.7 s, i.e., the shortest possible exposure time to avoid saturation by bright stars. On each on-target position the 1.7 s exposure was repeated 62 times (NDIT) and averaged. Depending on the dithering pattern, some individual positions were consequently repeated, enhancing the signal-to-noise ratio (S/N) in the centre of the images.

The reduction of the frames and the composition of the mosaic images were performed by an IDL pipeline (Stecklum et al. 2003). After reducing the individual frames, applying the standard dark current, flat field and bad pixel corrections, the field distortion was also corrected following the polynomial transformation given in the ISAAC reduction recipe at the ESO web site http://www.eso.org/instruments/isaac/problems_tips.html. Since the flat field correction was not reliable along the edges of the chip, the outermost lines and columns were ignored.

After the assembly of the mosaic, aperture and PSF photometry was performed on the *J*s, *H* and *K*s band images, using the DAOPHOT package of IRAF. Due to the strongly varying background nebulosity and the densely populated innermost regions, the point spread function (PSF) photometry proved to be the most suitable method for measuring the stellar fluxes. The detection levels were fine-tuned and carefully checked to optimize the result.

The PSF was constructed from the best 25 star profiles, where no saturation, chip edge or neighboring star could be seen. During the PSF photometry, the PSF was scaled to the profile of each star; the scaling factor depends linearly on the brightness of the individual sources. Following the PSF photometry of the three frames, the identified stars were cross-checked between the different filters. In order to exclude misidentifications, the maximum allowed shift of a star in the different filters must not exceed the full width at half maximum of the PSF. The number of stars measured in all three bands amounts to 268. The brightness of the faintest objects identified as stars were 19.5, 18.4 and 17.0 mag in J_s , H and K_s , respectively. We take these values as the limiting magnitudes of the observations.

The flux calibration was based on the ESO standard star FS19 (Casali & Hawarden 1992) in the J_s and H band and on the standard star S875-C (Persson et al. 1998) in the K_s band. The standard star images were processed using the same pipeline settings as for the science frames. To increase the accuracy of the calibration, aperture photometry was applied to the standard stars and this value was transferred to the PSF photometry of the science frames using an aperture correction. The aperture correction was established by comparing the aperture and PSF photometry for at least 5 stars on each science frame.

The statistical error of the photometry (i.e. fit error of the PSF) is better than 0.1 mag for the majority of the stars; however, the strong fluctuations of the nebulosity throughout the field influence the local photometric accuracy. Since the standard calibration process provided by ESO placed the standard stars far in time from the science objects, the error of the absolute photometry can be somewhat higher than 0.1 mag.

The composed mosaic has been compared to the US Naval Observatory Catalog (Monet et al. 2003) and an astrometrical reference frame has been established using 8 stars, which are present both on the images and in the Catalog. The achieved positional accuracy is typically better than 0.5".

2.2. Near-Infrared 3–5 μm imaging

To investigate the warm dust around the UC H II region G 268.42-0.85 region, we carried out imaging at wavelengths between 3 and 5 μm with the ISAAC infrared camera at the UT1/VLT (ESO, Paranal Observatory). We applied the LWI camera mode with a pixel scale of 0".071/pixel using three filters: L , narrow band 4.07(nb) centered on the Br α line and narrow band $M(nb)$. The central wavelengths/widths are as follows: 3.78/0.58, 4.07/0.08 and 4.66/0.10 μm , respectively. A 15" chopping throw in N-S direction was applied.

During the reduction process bad pixel filtering, flat field correction and simple shift-and-add beam combination have been used. Due to the presence of extended emission, the too small chopping throw made large parts of the images useless. In the following, we only consider the direct vicinity (15" $\times$ 15") of the UC H II region G268.42-0.85 which is by far the brightest object in the image and thus can be regarded as undisturbed by the imperfect background subtraction.

For flux calibration we used the standard star HR 5494, which was observed with identical DIT times. However, this star does not have previous flux measurements in the Br α filter nor in the M -band. The flux densities for these wavelengths are based on a blackbody extrapolation. This method, however, is less reliable for the determination of the emission line flux.

To inspect the distribution of the Br α line emission the subtraction of the continuum from the Br α images is necessary. Because no narrow-band continuum image at wavelengths close to the Br α filter was taken, we composed the continuum image by interpolating between the L and $M(nb)$ filters and scaled this image to the appropriate level. The scaling was based on two sources which we – based on their broad-band fluxes – assumed to be stellar and thus exhibiting no line emission. Finally, the counts of the interpolated continuum image were scaled to equal the counts measured from the stellar sources in the Br α images. Thus, a subtraction of the two frames canceled out all pure continuum sources. Detailed inspection of the residuals proved that our strategy was working, even though the accuracy is not as good as what could have been achieved by using a narrow-band continuum filter.

2.3. Mid-infrared imaging

The thermal infrared images were acquired during our guaranteed time program on the TIMMI2 camera at the 3.6 m ESO telescope. The object was observed in the filters M (4.30–4.99 μm), $N11.9$ (10.61–12.50 μm), $N12.9$ (11.54–12.98 μm), and $Q + Si$ (19 μm –atmospheric cut-off). Both the north-south chopping throw and the east-west nodding throw were selected to be 40" in all filters. In addition, a 11.9 μm measurement was performed with 18.5" chopping throws and 20" nodding throws. The pixel size was 0.2"/pixels for the 11.9, 12.9 μm and the Q filters and 0.3"/pixels for the M -band observations.

During the reduction process the video frames were summed, neglecting the first three frames after each repositioning to eliminate image distortions from the vibration of the secondary mirror. A sigma-filtering process was used to remove the bad pixels. Thereafter the positive and negative beams have been extracted and combined. To avoid any overlap between the negative and positive beams of the extended source, subimages with the dimensions of the chopping/nodding throws were extracted. The ESO standard stars HD 81797 and HD 123139 have been used as flux calibrators. The calibration of the 20 μm science frame was not possible because the standard star was not present in the calibration images. The 1σ sensitivity limits – estimated from the background's standard deviation – for the M , 11.9 μm and 12.9 μm images are 35 mJy, 18 mJy and 21 mJy, respectively.

2.4. The N-band spectrum

Spectroscopy of IRAS 09002–4732 between 8.5 and 11.5 μm was performed with TIMMI2 with a nominal spectral resolution of 120. Since the 10 μm grism was not yet available for these observations, the 20 μm grism had to be used in

Fig. 1. *Left panel:* 1.2 mm SIMBA/SEST contours overlaid on the grayscale ISAAC K_s -band image. The contour levels correspond to (5, 10, 20, 40, 60, 80, 110) $\times$ 46 mJy/beam. The inverted gray scale ISAAC K_s image shows the stellar population and the short-wavelength nebulosity. *Right Panel:* high sensitivity MSX 8.28 μ m contours, showing an extended, continuous distribution of warm dust in the star-forming region. The contours mark 5, 10, 50, 100, 150, 250, 300 σ levels; the MSX point source flux is 30.74 Jy. The square marks the radio position of the UC H II region G268.42-0.85, while the ellipse indicates the positional error ellipse of the IRAS point source 09002-4732. The MSX A-band images are probably influenced by PAH emission and this explains the offset between the IRAS- and MSX-peaks.

second order. Unfortunately, the 12.9 μ m [NeII] line was not covered by the spectrum. The slit of 3'' width was oriented north-south and centered on the mid-infrared peak. A chopper throw of 10'' was applied. The star Sirius served as spectroscopic standard star. The spectrum was calibrated using the atmospheric opacity derived from the standard star observation and the ISO SWS full scan spectrum of Sirius retrieved from the ISO archive. For the data reduction we used the TIMMI2 pipeline by Siebenmorgen et al. (2004). The final effective spectral resolving power of the TIMMI2 observations is $R \approx 170$.

2.5. SIMBA 1.2-mm mapping

The 1.2 mm continuum observations were carried out with the 37-channel bolometer array SIMBA (Nyman et al. 2001) at the SEST on La Silla, Chile. SIMBA is a hexagonal array in which the HPBW of a single element is about 24'' and the separation between elements on the sky is 44''. The observations were made using a fast-mapping technique without a wobbling secondary (Weferling et al. 2002). The raw data were reduced with the MOPSI mapping software package developed by R. Zylka (IRAM, Grenoble, France), using a deconvolution algorithm to remove the contribution of the electronics arising from the fast-mapping observing mode. Maps of Uranus were taken to check the flux calibration of the resulting data. To correct for the atmospheric opacity, skydips were performed every 2–3 h. Despite the occurrence of some thin clouds, the observing conditions were good which is reflected in zenith opacity values of 0.16–0.18. The pointing was checked roughly every two hours and proved to be better than 6''. The combination

of three maps with sizes of 560'' $\times$ 900'' resulted in a residual noise of about 46 mJy/beam (rms).

3. Results

In this section we present first the overall morphology and the stellar content of the star-forming region, then the intracluster material, and finally the properties of the UC H II region.

3.1. Global morphology of the star-forming region

We used the infrared observations, ranging from 1.2 μ m to 20 μ m, the 8.64 GHz radio continuum observations of Walsh et al. (1998), our 1.2 mm SEST map as well as CS $J = 7-6$ line measurements by Lapinov et al. (1998) to analyze the structure of the star-forming region IRAS 09002-4732. Figures 1 and 2 summarize the global features of this region.

The near-infrared images of the region show a large number of red stars surrounded by a large nebula (cf. Fig. 1). A dark lane extending in east-west direction cuts across the nebula, creating the impression of bipolarity. The thermal dust emission in the MSX 8.28 μ m (A-band) resembles the K_s -band morphology. However, the distribution of the 8.28 μ m flux does not show any multiple or bipolar structure as does the K_s -band image. This fact could be understood if the prominent dark lane and several other dark patches in the K_s image are introduced by filaments of dense, warm dust in front of the roughly homogeneous nebulosity.

The MSX 8.28 μ m filter also includes emission bands of interstellar PAH molecules that are often widely distributed. The MSX 21.34 μ m band, however, is not known to include strong PAH features. The similar appearance of the 8.28 μ m

Fig. 2. MEM deconvolved CS $J = 7-6$ contours (vel. channel 2.75 km s^{-1} , Lapinov et al. 1998) overlaid over the central region of the inverted K_s -band ISAAC image. The CS $J = 7-6$ line transition shows two clumps with only a small line-of-sight velocity difference. The gray scale K_s -image suggests that the SE clump is located in front of the cluster while the NW clump is located behind the embedded stars. The squares mark stars with NIR excess larger than 0.1 mag. The large rectangle marks the approximate field of view of the CS observations, while the thin contours mark the free-free emission morphology (Walsh et al. 1998).

and $21.34 \mu\text{m}$ band images of IRAS 09002-4732 indicates that the overall morphology of the large-scale MIR emission is not *dominated* by the emission from PAH molecules and hence traces mainly the warm dust. Slight shifts ($\sim 5''$ – $15''$) are present between the MSX peaks and the position of the centimetre radio peak, which we mainly attribute to the combined influence of the extinction and PAH emission.

The 1.2-mm SIMBA map (Fig. 1) shows a moderately resolved region of strong emission. The emitting region has an elliptical shape with the major axis oriented in north-NW–south-SE direction similar to what has been measured in the CS (2–1) line by Zinchenko et al. (1995). The emission mainly covers the middle and northwestern part of the dark lane seen in the NIR as well as the southern lobe of the MIR emission. The peak emission at 1.2 mm is located in the southern lobe and is slightly displaced ($13.5''$) from the location of the IRAS peak. Assuming the emission at 1.2 mm wavelength to be optically thin thermal dust radiation and using the canonical gas/dust mass ratio of 100, we can obtain the total mass M of the region:

$$M = \frac{S_\nu D^2}{\kappa_m \times B_\nu(\nu, T_d)}.$$

Here, S_ν is the flux density, D is the distance, T_d the dust temperature and κ_m the mass absorption coefficient per gram

gas. With a value for T_d of 80 K (see Sect. 3.5) and κ_m of $0.01 \text{ cm}^2 \text{ g}^{-1}$ (Ossenkopf & Henning 1994) we obtain a total mass of about $100 M_\odot$ which is significantly lower than the $600 M_\odot$ derived from CS $J = 2-1$ observations (Zinchenko et al. 1995). A variety of factors can contribute to this discrepancy, including the dust-to-gas mass ratio, the uncertainty in the mass absorption coefficient, and the CS abundance. To put the high mass estimate of Zinchenko et al. (1995) into perspective we note that Pirogov et al. (2003) derived a total virial mass of $138 M_\odot$ from $\text{N}_2\text{H}^+(1-0)$ observations.

In the case that the millimetre emission is not purely thermal but has a non-negligible contribution from free-free emission, the relation above might overestimate the actual mass. Assuming a spectral index for optically thin free-free emission of $F_\nu(\nu) \propto \nu^{-0.1}$ and extrapolating from the 5 GHz fluxes of Caswell & Haynes (1987) we estimate a free-free contribution of about 3 Jy at 1.2 mm, compared to the 17 Jy total flux. Given the large uncertainties involved, however, we do not correct our mass estimate for this possible effect.

These large-scale observations also show that the main heating source of the dust is located in the southern lobe. In fact, the most massive star(s), indicated by the presence of an UCH II region, is located close to both the MSX and the SIMBA peak emission (see Fig. 1).

Figure 2 shows the Maximum Entropy Method (MEM) deconvolved CS $J = 7-6$ contours which trace relatively warm and dense gas. Two nearly equal-mass clumps which have only a small line-of-sight velocity difference (Lapinov et al. 1998) are seen here. The southern clump coincides with the extinction lane outlined in the overlaid K_s band image. The lack of stars in this region points to the fact that this extinguishing structure is located in front of the stellar cluster. In contrast, the northern CS clump does not appear as an extinction structure in the NIR map, indicating a location behind the stellar cluster.

All the millimetre line and continuum data have a rather coarse resolution of $\sim 24''$. In contrast, the *JsHKs* composite image (see Fig. 3) provides a picture of the region with subarc-second resolution. It immediately shows the inhomogeneous extinction structure around IRAS 09002-4732. We will discuss this structure in more detail in the next section.

3.2. Structures on smaller scales

3.2.1. Reflection nebulosity

South-west of the UC H II region G268.42-0.85 the optical/near-infrared emission is dominated by blue scattered light. This reflection nebulosity was first identified as Bran 222 by Brand et al. (1986) and has a size of roughly $1' \times 1'$. To find the source that illuminates this nebula, we plotted the observed *Js*-band surface brightness versus the distance from the UC H II region G268.42-0.85 in Fig. 4. Here the surface brightness was integrated over $1'' \times 1''$ squares and background-corrected. The positions for measuring the surface brightness were selected manually to minimize the contamination by extinction, stars or foreground filaments. Figure 4 clearly shows an increasing surface brightness towards the UC H II region G268.42-0.85 with a best-fit radial slope of $R^{-1.4 \pm 0.2}$. This fact

Fig. 3. False-colour composite image from the near-infrared observations. The K_s band image is coded in red, H in green and J_s in blue.

demonstrates that the source of the scattered light lies close to the location of the UC H II region. An unambiguous identification of the illuminating source could be provided by polarimetric observations using adaptive optics (see, e.g., Henning et al. 2002).

3.2.2. Dark filaments and globules

Numerous dense dust structures are visible as dark silhouettes in front of the bright surface of the reflection nebula.

Our high-resolution NIR image (see Fig. 3) gives a stunning view of the dust content of the region, proving that a significant amount of the dust is concentrated in string-like filaments, criss-crossing the face of the cluster. We outline their positions in Fig. 5 with five of the most interesting filaments tagged as S1 to S5. The designation was only chosen to guide the reader. These filaments were selected with the following criteria in mind: continuous, elongated areas of high extinction with sharp, well-defined borders. Filaments S1, S2 and S5 are

Table 2. Catalogue of the dark globules and their estimated properties. Their assigned number, H -band surface brightness difference inside and outside of the globule, the derived extinction, approximate dimensions and axis ratio together with additional notes are given. For their location and orientation see Fig. 5.

Globule ID	$H_{\text{out}} - H_{\text{in}}$ [$\times 10^{-5}$ Jy/arcsec 2]	Extinction [H -mag/arcsec 2]	Dimensions “ $\times$ ”	Axis ratio	Note
G1	4.0	2.4	4.2×1.6	2.6	
G2	2.16	1.3	3.5×1.5	2.3	
G3	9.3	3.5	2.6×1.0	2.6	
G4	3.8	>3.7	2.9×0.9	3.2	
G5	8.6	2.8	2.6×0.9	2.9	
G6	17.3	>1.6	3.8×1.7	2.2	
G7	6.1	>4.0	4.0×2.8	1.4	
G8	4.6	>3.8	3.9×0.8	4.9	
G9	10.0	>4.6	6.5×3.0	2.2	
G10	13.3	2.3	3.3×1.2	2.8	
G11	5.0	>4.0	5.0×2.2	2.3	Larger?
G12	7.3	1.5	2.6×1.4	1.9	
G13	7.4	3.3	3.3×1.4	2.4	
G14	4.5	3.2	5.9×2.6	2.3	Double?
G15	28.2	3.2	4.9×1.6	3.0

Fig. 4. J -band surface brightness of the reflection nebula versus the distance from the UC H II region G268.42-0.85 plotted on a logarithmic scale. The best fit gives an $R^{-1.4 \pm 0.2}$ dependence.

remarkably confined and their typical length/diameter ratio is of the order of 40.

A closer inspection of the NIR surface brightness of the filaments shows strongly varying optical depths along their extent. We observed small ($<5''$) regions of increased extinction *inside* the dark filaments that we interpret as arising from dense globules (see Fig. 3).

After identifying the objects on the colour composite image (Fig. 3), Fig. 5 outlines the positions of 15 globules identified in the inner part of the star-forming region. Table 2 gives an overview of their estimated properties. The extinction values given here have been derived from the comparison of the surface brightness values inside and outside (averaged at three locations) of the globule. We note that the objective characterization of such dark, diffuse objects is rather difficult; their list is certainly incomplete and the values given in Table 2 should be

taken with caution. Therefore, we have not made an attempt to derive further parameters such as column densities or masses. This remains a task for follow-up projects, possibly using millimetre interferometry.

While most of the dark globules are located inside the filaments and should be considered as part of the overall structure of cold dust, we also see some isolated, compact ($d < 2''$) objects as faint silhouettes against the foreground of the evenly illuminated southern reflection nebula (an example is IS2, compare Figs. 3 and 5). In addition, we find a very faint bright-rimmed object (IS1) which looks more similar to a proplyd (see Fig. 6). Although these small (<1300 AU) and dense isolated objects are similar in appearance to those identified as proplyds in Orion, some important differences have to be noted. The resolution and sensitivity of our current data set does not allow the detection of silhouette structures at scales of the typical Orion proplyds (~ 100 AU), but only of significantly larger structures (~ 700 AU). Although proplyds of this size are not unheard of (see, e.g. McCaughrean & O'Dell 1996; Bally et al. 1995), current evidence does not allow a final conclusion concerning the nature of these objects. High-resolution narrow-band imaging of the region would be necessary to find more of these silhouettes and to explore their nature.

Although the existence of the isolated globules IS1 and IS2 has been confirmed in the individual J , H and K s band mosaics obtained with different dithering patterns, we cannot completely exclude the possibility that they are artifacts from the imperfect sky subtraction.

The remarkably long and confined dark filaments in IRAS 09002-4732 are very similar in appearance to the *globular filaments* observed in the field, i.e. not associated to any star-forming region (Schneider & Elmegreen 1979). Similar, but larger-scale filamentary structures also seem to be

Fig. 5. Outlines of the filamentary structure of extinguishing material seen in the NIR images. The solid lines trace the general structure, while the dashed lines indicate the dark filaments (S1-S5). The dense globules inside the filaments are indicated with hatched ellipses and designated as G1-G15. The two circles (IS1 and IS2) mark two isolated silhouette objects.

characteristic to the distribution of both the molecular gas and young stellar objects in the Taurus star-forming region (Hartmann 2002, and references therein). Although the detailed comparison of these filamentary structures of different ages and environments is outside of the scope of this work, we note some interesting points.

The density of the globules/filaments drops in the southern lobe of the reflection nebula, which as shown in Sect. 3.2.1 is directly influenced by the massive star ionising

the UC H II region G268.42-0.85. Therefore, we speculate that the massive star could have destroyed these structures, while the undisturbed northern filaments could be filaments of the same nature as those identified in the Taurus star-forming region. Such filaments with “embedded cores” are also predicted by simulations of turbulent fragmenting cloud cores (see, e.g. Klessen & Burkert 2001).

The most interesting question concerning these filaments might be their origin. Do they represent an early stage of

Fig. 6. Unsharp-masked magnified field from Fig. 5 showing the objects IS1 and IS2.

collapsing cloud material or are they confined and shaped by the influence of the newly born young stars? If the globules embedded in the filaments are indeed collapsing, these chains of protostars could provide the next generation of young stars in the region similar to the situation observed in the Taurus star-forming region (Hartmann 2002). If this were true, the lack of filaments in the southern lobe probably provides an important insight into how massive stars can influence the initial mass function.

3.3. Stellar population of the star-forming region

We identify about 1100 stars in the vicinity of the IRAS source 09002-4732 in our ISAAC *Ks*-band mosaic image over a field of $4.25' \times 4.25'$ (see Fig. 7). 268 of these stars have photometry in all three near-infrared (*Js*, *H* and *Ks*) filters. In Table 5 (available only at the CDS) we give the coordinates, photometry and photometric errors for these stars.

A comparison of our limiting magnitudes to the 1 Myr-old pre-main sequence isochrones of Baraffe et al. (1998) shows that – assuming an extinction of $A_{Ks} = 1$ mag and a distance of 1.3 kpc – our sensitivity is sufficient to detect stars with masses down to the stellar/substellar limit in the *Ks*-band. The sensitivity limit (expressed in solar masses) is worse for the dimmer main-sequence stars, where our *Ks*-band imaging reaches the $\sim 0.5 M_{\odot}$ limit (Bessell & Brett 1988; Lang 1991).

We plot the colours of all stars with reliable NIR photometry in Fig. 8. The NIR colours of most of the stars in the diagram are consistent with the colours of heavily reddened main-sequence stars, i.e., they lie in the reddening lane.

The infrared colour excess $E(H - K)$ of most stars range from 0.2 to 2.0 mag, corresponding to visual extinctions between $A_V \approx 3.0$ and 30 mag (Mathis 1990). The upper value reflects our sensitivity in the *Js*-band, while the lower one is most likely given by the foreground extinction.

A large fraction of the stars display infrared excess emission in the NIR bands, i.e. they lie below the reddening

Fig. 7. *Ks*-band inverted gray scale image. Crosses mark the 1106 stars identified in the *Ks* band, while boxes denoted those with identified infrared excess emission.

Fig. 8. Colour-colour diagram of the stellar population around IRAS 09002-4732. The colour index ($J_s - H$) is plotted against the ($H - K_s$) index. The connected crosses indicate the colours of unreddened main sequence stars (Bessell & Brett 1988; Wegner 1994). Single crosses show the observed colours, while the asterisks represent stars with NIR excess larger than 0.1 mag. The dashed lines enclose the possible colours of reddened main sequence stars. The solid line represents the T Tauri locus (Meyer et al. 1997). The mean error is plotted in the figure legend.

lane (see, Fig. 8). We identify 63 stars displaying significant (>0.1 mag) NIR excess emission, indicating their youth and pre-main sequence (PMS) nature (see, e.g. Lada & Adams 1992; or Li et al. 1997). Although the different types of young stellar objects (T Tauri stars, Herbig Ae/Be stars, Class I,

Fig. 9. Near-infrared colour-magnitude diagram of the same stellar population as in Fig. 8. The symbols are identical to those used in Fig. 8. The assumed distance of the zero age main sequence stars is 1.3 kpc. Individual error bars are shown on each object, some of which are smaller than the actual symbols.

etc.) have characteristic positions in the colour-colour diagram, these groups are not distinct. Therefore the classification of these sources based only on $J_s - H$ and $H - K_s$ band colours is not possible (see Lada & Adams 1992). Additional information on the luminosity of these objects is obtainable from their apparent magnitudes, but their unknown distances and reddening makes their more precise classifications ambiguous.

In order to better understand the effects of extinction we also show the NIR colour-magnitude diagram in Fig. 9. The symbols used here are identical to those used in the colour-colour diagram. This diagram compares the stars' apparent magnitudes and colours with those of zero age main sequence stars located at a distance of 1.3 kpc. The strong reddening of the stellar population in IRAS 09002-4732 is again evident.

The fact, however, that the IRAS 09002-4732 region is located only 0.85° above the galactic plane makes contamination from unrelated stars likely. Based on our data set firmly discriminating cluster members from unrelated objects is not possible. Still, by investigating the reddening distribution of the stars a robust clue for clustering can be found. In Fig. 10 we plot the $E(J_s - K_s)$ indices versus the number of stars in the given bins for both the full population and the infrared excess stars. We expect the associated stars to have roughly similar reddening. Indeed, the distribution of the full population shows two significant peaks at $E(J_s - K_s) = 1.6$ mag and $E(J_s - K_s) = 2.7$ mag. No stars have $E(J_s - K_s) < 1.0$ mag clearly indicating the extent of the foreground extinction, and about 30 stars have $E(J_s - K_s) \approx 1.5$ mag. At these reddening values no significant number of infrared excess stars is present, suggesting that the stellar population with $1 \text{ mag} < E(J_s - K_s) < 2 \text{ mag}$ is not young.

The highest peak in both populations, however, is seen between $2.2 \text{ mag} < E(J_s - K_s) < 3.5 \text{ mag}$ allowing two immediate conclusions. First, the bulk of the stars in our field have

Fig. 10. The distribution of the stellar detections as a function of colour. The dashed line traces the histogram of stellar detections in all three near-infrared bands, while the solid line shows the distribution of stars with identified infrared excess emission. The reddening shows a well-defined peak at $J_s - K_s \approx 2.7$ for both stellar populations, and a peak at $J_s - K_s \approx 1.6$ for the main-sequence stars.

Fig. 11. K_s -band stellar density derived from stellar counts in concentric annuli around the UC H II region G268.42-0.85.

reddening values in this range or above; second, at least $\sim 23\%$ of these stars have infrared excess emission and are thus young. Note that the declining tail of the second peak (i.e. at $E(J_s - K_s) > 3 \text{ mag}$) is partly due to our J_s -band detection limit.

Although the above analysis does not offer a conclusive proof of membership for any individual star, the existence of a reddened, young cluster is obvious. The celestial positions of the stars with known NIR excess emission are shown in Figs. 2 and 7. Although these stars appear to form two loose associations in front of the northern reflection lobe and in the south-west part of the region, we stress that this distribution is likely to be caused by extinction.

To make one step further and show that the stars are also clustered around the massive star we plot in Fig. 11 the stellar density in K_s -band as a function of distance from the UC H II region G268.42-0.85. We used concentric annuli with width of $7.5''$ to integrate the stars identified in Sect. 2.1. The number of stars in each annulus has been divided by the area of the annulus in arcsec^2 to derive the apparent stellar density.

The outer diameter of the area investigated with this method was about $3.3'$, excluding the incompletely covered and noisy peripheral areas of our NIR mosaic. An increase in stellar density towards the UC H II region G268.42-0.85 is obvious from the plot, with a strong rise in the central $20''$. This increase further argues for a clustering of the stars in the vicinity of the IRAS source 09002-4732.

Assuming that all PMS stars belong to the cluster around IRAS 09002-4732 it is worthwhile to compare their number to the similar values in the well-known young stellar cluster in Orion. Hillenbrand (1997) finds ~ 440 stars in the O-M1 spectral type range (in the inner $2.5 \text{ pc} \times 2.5 \text{ pc}$ of the Orion cluster). Our images show in a field about three times smaller ($\sim 1.6 \text{ pc} \times 1.6 \text{ pc}$) about eight times less young stars (~ 63) in about the same spectral type range. Several factors such as membership, completeness, disk lifetimes and cluster ages, as well as the massive and highly varying extinction, may strongly influence this comparison.

3.4. The UC H II region

In the following we discuss the infrared morphology of the UC H II region, its spectral energy distribution (SED) and investigate the spectral type and luminosity of the ionising star.

3.4.1. Morphology of the UC H II region

The direct vicinity of a newly born massive star is one of the most hostile stellar environments. The intense ultraviolet radiation and stellar wind rapidly deplete the dust particles, dissolve accretion disks and protostellar sources as seen in the case of the Orion Trapezium (O'Dell 2001), M 16 (Hester et al. 1996) or M 8 (Stecklum et al. 1998). However, these processes also render visible many otherwise invisible low-mass objects and structures. The question of the existence of photoevaporating disks around massive stars is of central importance, since this could support evidence for the disk accretion being possible even for massive stellar objects (see, e.g., Yorke & Sonnhalter 2002). Furthermore, the study of the photoevaporating objects can constrain the timescale of the H II region's evolution and its low-mass stellar content. Answering these questions requires multi-wavelength, high-resolution deep imaging.

Our images cover the wavelength range between 1 and $20 \mu\text{m}$, giving a detailed look into the stellar content and the circumstellar material. Figure 12 shows the region centered on the radio continuum peak in bands centered at $2.2 \mu\text{m}$ (K_s), $3.78 \mu\text{m}$ (L), $4.07 \mu\text{m}$ ($\text{Br}\alpha$), $4.66 \mu\text{m}$ (M), $11.9 \mu\text{m}$ ($N11.9$), $12.9 \mu\text{m}$ ($N12.9$), with the radio continuum intensity overlaid as contour lines. More than 15 objects are seen in the $20'' \times 20''$ field of view of the images, 9 of them detected in more than one of the filters between H to Q . The J_s -band data was not considered here because the strong background nebulosity overshines the individual objects. In the following we discuss these 9 objects, assigned with letters A–I. For the nomenclature and locations see Fig. 12 and for the summary of the fluxes we refer to Table 3.

Source A: located $1.7''$ east and $9.57''$ south of source D. This source remains unresolved in all our images, pointing to a diameter of less than 700 AU.

Source B: $2.7''$ east, $6.5''$ south of D. Very red ($H - K_s > 2.8 \text{ mag}$) point source, undetected shortward of $2.2 \mu\text{m}$.

Source C: $1.1''$ east, $1.1''$ south of D. Only present in J_s , H and K_s images. Extended source, most probably reflection nebula. It is brighter in H and K_s than in J_s . This nebula lies in the direction, in which the UC H II region has its strongest decline in intensity and smallest extension (measured from its peak), as well as the direction of increasing CS density (Lapinov et al. 1998, see Fig. 2).

Source D: This NIR peak is coinciding with the radio peak G268.42-0.85 within our astrometric accuracy and therefore is expected to be the NIR counterpart of the most massive star. The peak is not separable from the background nebulosity in J_s , while in H and K_s it appears as a point source surrounded by a fainter halo. In L -, $\text{Br}\alpha$ - and M -band the source has a faint halo extending mainly the north-west direction with an extension of up to $5''$ in the M -band. Its emission is increasing towards longer wavelengths. Longwards of $3 \mu\text{m}$ this thermal emission dominates the region. Source D gets even stronger at $11.9 \mu\text{m}$. It is extended in our images with $\sim 5''$ extension in the north-south direction and $\sim 2.5''$ in the east-west direction. The spectral energy distribution and the spectral type of the underlying source is analyzed in Sect. 3.5.

Source E: $1.2''$ east, $1.6''$ north of D; a very red object, elongated in L - and $M(\text{nb})$ -bands. Its dimensions in L -band are $0.8'' \times 0.5''$. The positions of the K_s -, L - and M -band peaks of source E are not coinciding, but are slightly shifted: the shorter the wavelength is, the closer the peak lies to source D, the ionising source of the region. This shows that the part pointing towards the massive star is the hottest, suggesting the importance of external heating for this clump.

Source F: $3.4''$ west, $1.7''$ south of D; red ($H - K_s = 3.8 \text{ mag}$) point source.

Source G: large, extended nebulosity close to the western edge of region shown in Fig. 12. It is very bright in the J_s , H and K_s -band, while its intensity drops rapidly towards the longer wavelengths. We note, that the warm dust is extending westward from source D, but the structure visible at $11.9 \mu\text{m}$ and $12.9 \mu\text{m}$ bands has different size and morphology than nebulosity G.

Source H: $5.4''$ north, $2.0''$ west of source D; very red ($K_s - L > 6.1 \text{ mag}$) source, undetected in K_s -, but strong in L - and M -band.

Source I: $\sim 0.5''$ north, $\sim 1''$ west of source D; an unresolved, very red ($K_s - L = 7.4 \text{ mag}$) source, which is strong in the L - and $M(\text{nb})$ -bands.

The continuum-subtracted $\text{Br}\alpha$ image traces well the nebulosity around the object D and indicates the presence of ionised emission from the sources D and E (see Fig. 12).

Based on these observations we draw the following conclusions:

1. *The neighbourhood of the massive star:* the direct environment of the star ionising the UC H II region is not

Fig. 12. The morphology of the UC H II region G268.45-0.85 as seen in $2.2 \mu\text{m}$ (*Ks*), $3.78 \mu\text{m}$ (*L*), $4.66 \mu\text{m}$ (*M*), $4.07 \mu\text{m}$ (*Brα*), $11.9 \mu\text{m}$ (*N11.9*) and $12.9 \mu\text{m}$ (*N12.9*) images. The overlaid contours are 8.64 GHz radio continuum measurements from Walsh et al. (1998). The objects of particular interest are marked with letters from A–I. The resolution of the images are as follows $d(Ks) \approx 0.44'' = 600 \text{ AU}$, $d(L) \approx 0.45'' = 590 \text{ AU}$, $d(4.07 \mu\text{m}) \approx 0.6'' = 780 \text{ AU}$, $d(M) \approx 0.47'' = 610 \text{ AU}$, $d(11.9 \mu\text{m}, 12.9 \mu\text{m}) \sim 0.8'' = 1040 \text{ AU}$.

Table 3. Summary of the observed fluxes of objects in the vicinity of the UC H II region G268.42-0.85. Only objects that are detected in more than one band are given; for the nomenclature, see Fig. 12. Due to the extended nebulosity the objects can not be distinguished in the *Js*-band and therefore no fluxes in this band are provided here. At wavelengths longwards of the *M*-band only object D is visible. Photometry on object G is omitted in this table because the object lacks definable boundaries and extends outside the image. ^a – See Table 4 for the complete list of measurements.

ID	$1.6 \mu\text{m}$ (<i>H</i>) [mJy]	$2.2 \mu\text{m}$ (<i>Ks</i>) [mJy]	$3.78 \mu\text{m}$ (<i>L</i>) [mJy]	$4.07 \mu\text{m}$ (<i>Brα</i>) [mJy]	$4.66 \mu\text{m}$ (<i>M</i>) [mJy]	$11.9 \mu\text{m}$ (<i>N</i>) [mJy]	Note
A	1.4	4.7	7	4	4	–	
B	–	0.33	10	13	8	–	Reflection?
C	1.9	1.5	–	–	–	–	
D ^a	0.113	14.8	530	1175	952	10520	UC H II
E	–	0.95	70	167	126	–	Red, elongated
F	0.12	2.4	34	8	47	–	
H	–	–	12	37	29	–	
I	–	–	40	82	89	–	

devoid of stars; we identify more than 15 sources in the multi-wavelength images, many of them presumably being stellar sources with infrared excess emission. The most massive star’s infrared counterpart has also been identified as Source D. This source dominates the infrared images at wavelengths longward of $3 \mu\text{m}$, while its emission is rapidly decreasing towards shorter wavelengths due to the high extinction.

2. *Reflection Nebulae*: at shorter wavelengths ($1\text{--}2 \mu\text{m}$) our images are dominated by large, extended nebulosities, such as sources G and C. These sources quickly fade away with increasing wavelengths and show increasing surface brightness gradients towards source D. We interpret them as

reflection nebulae. The actual shape of these sources is defined both by the geometry of the scattering material and the extinction.

3. *Other Sources*: sources A, B and F also appear in the *L*- and *M*-band images. These sources are most likely stellar sources with significant *L*- and *M*-band excess, suggesting recent or ongoing star formation close to the UC H II region. The elongated, externally heated source E can either be a photoevaporating dust clump or an elephant trunk, similar in nature but much smaller in size than those seen in M 16. Its stellar content is unknown. Source H can be interpreted as a warm dust cocoon, only visible at 3 and $5 \mu\text{m}$. The following simple argument demonstrates that source H

Table 4. Summary of the observed fluxes and errors of the UC H II region G268.42-0.85. As the error of the NIR photometry, we give the statistical error of the PSF fit. The last but one column indicates if the given flux density was included in the SED fitting (see Sect. 3.5). Notes: ^a PSF-Fit; ^b filter centered on Br α ; ^c narrow-band filter; ^d flux standard star not detected, only lower limit can be given. References: ¹ this paper; ² Egan et al. (1999); ³ Ghosh et al. (2000); ⁴ Walsh et al. (1998).

Wavelength μm	Flux [Jy]	Error	Photometric aperture Radius ["]	Instrument	SED Fit?	Note Ref.
1.6	1.1×10^{-4}	$\pm 12\%$	1.02 ^a	ISAAC SWI	No	¹
2.2	1.5×10^{-2}	$+3.5\%$ -2%	1.02 ^a	ISAAC SWI	No	¹
3.78	0.53	$\approx 8\%$	4.6	ISAAC LWI	No	¹
4.09	1.175	$\approx 11\%$	4.6	ISAAC LWI	No	^{1, b}
4.66	0.95	$\approx 8\%$	4.6	ISAAC LWI	No	^{1, c}
11.9	10.52	$\approx 10\%$	4.6	TIMMI2	No	¹
12.9	10.7	$\approx 10\%$	5.5	TIMMI2	No	¹
20	>29.5	–	0.8	TIMMI2	No	^{1, d}
8.28	30.74	$\pm 5\%$	PSF-Fit	MSX A	No	²
12	203	$\pm 9\%$	90	IRAS	No	³
12.13	103.3	$\pm 3\%$	PSF-Fit	MSX C	Yes	²
14.65	188.8	$\pm 4\%$	PSF-Fit	MSX D	Yes	²
21.34	1301	$\pm 6\%$	PSF-Fit	MSX E	Yes	²
25	2577	$\pm 4\%$	90	IRAS	No	³
60	13611	$\pm 8\%$	90	IRAS	Yes	³
100	14057	$\pm 8\%$	90	IRAS	Yes	³
148	9127	–	90	TIFR	Yes	³
209	4753	–	90	TIFR	Yes	³
1.2 mm	17.0	$\pm 20\%$	60	SEST	Yes	¹
3.5 cm	2.67	$\pm 10\%$	5	ATCA	No	^{1, 4}

Fig. 13. TIMMI2 N -band spectrum of the UC H II region G268.42-0.85. The spectrum shows broad and deep silicate absorption feature with forbidden line emission from [ArIII] and [SIV]. The structures around $9.6 \mu\text{m}$ and $11.3 \mu\text{m}$ are probably artifacts, partly due to imperfect cancellation of the telluric ozone bands.

is probably internally heated: the equilibrium temperature of a spherical dust particle with absorptivity/emissivity of unity heated by an O7 star – the highest luminosity estimate for source D, the worst case scenario – at a projected distance of source H from source D, is at most 80 K. Because the flux of source H peaks in the 3–5 μm regime, its effective temperature is as high as ~ 700 K, requiring an internal heating source.

Fig. 14. Spectral energy distribution of the G268.42-0.85 UC H II region. Crosses mark observations which were used for fitting the SED, squares denote data that are neglected in this regard (see Table 4). The source is modeled as a modified black body with 0.014 pc radius, 80 K temperature and a dust emissivity of $\epsilon_\nu \sim \nu^{2.1 \pm 0.4}$. Error bars are included according to the values given in Table 4 but remain tiny due to the logarithmic scaling of the plot.

3.5. Spectral energy distribution of the UC H II region

In this section we estimate the extinction towards the UC H II region from the N -band spectrum, summarize the available photometry and discuss the spectral energy distribution of the region.

The N -band spectrum shown in Fig. 13 displays a strong $9.7\ \mu\text{m}$ silicate feature in absorption as well as the sharp forbidden emission lines of [ArIII] and [SIV]. The shape and the depth of the silicate absorption feature is characteristic of the absorbing foreground dust. We followed the simple approach described by Pascucci et al. (2004) to fit the feature by a synthetic absorption profile. This procedure results in a hydrogen column density (atomic and molecular) of $N_{\text{H}} = 3.7 \times 10^{22}\ \text{cm}^{-2}$, which corresponds to a visual extinction of about $A_{\text{V}} \approx 19.5$ mag using the Weingartner & Draine (2001) $R = 3.1$ Milky Way extinction law. The estimated dust colour temperature is about $T_{\text{C}} \approx 220 \pm 3$ K.

In Table 4 we compiled the flux densities obtained both from our measurements and from the literature. The wavelengths, instruments and apertures as well as the corresponding references are indicated here. Based on these observational data, in Fig. 14 we show the spectral energy distribution of the UC H II region. We included here the results of several satellite and balloon missions: the MSX satellite provided data at $8.3\ \mu\text{m}$, $12.1\ \mu\text{m}$, $14.7\ \mu\text{m}$, and $21.3\ \mu\text{m}$. The TIFR balloon experiment observed our source at $148\ \mu\text{m}$ and $209\ \mu\text{m}$ (Ghosh et al. 2000). The same authors also reexamined the IRAS HIRES images, and we use their revised fluxes for the $60\ \mu\text{m}$ and $100\ \mu\text{m}$ data points. Furthermore, we included our ISAAC and TIMMI2 measurements between $1\text{--}13\ \mu\text{m}$ and our new SIMBA $1.2\ \text{mm}$ data point.

The SED follows well the main characteristics of UC H II regions (see, e.g., Henning et al. 1990; Churchwell 1991): a steep rise of thermal dust emission in the mid- and far-infrared with a peak between 60 and $100\ \mu\text{m}$, and a decline of the millimetre dust emission with decreasing optical depth ($100\text{--}3000\ \mu\text{m}$). Although in the case of IRAS 09002-4732 the millimetre regime is poorly sampled, the infrared part is quite well constrained.

Since the data plotted in Fig. 14 have been taken by different instruments with different beam sizes, some flux differences are inevitable. Observations with large beams – such as IRAS or TIFR – are not directly comparable to high-resolution data. A good example for this effect is the large difference around $10\ \mu\text{m}$ in the high-resolution TIMMI2 and the coarser MSX-photometry. However, the fluxes at different beam sizes often include additional spatial information and are important for constraining radiative transfer models.

We fitted the data with a modified Planck curve with frequency-dependent dust emissivity as a free fitting parameter along with the temperature and two scaling factors:

$$F_{\nu} = \Omega B_{\nu}(\nu, T) (1 - e^{-\tau}),$$

with $\tau = \tau_0 (\frac{\nu}{\nu_0})^{\beta}$. Here, F_{ν} are the observed flux densities, T is the temperature, Ω is the solid angle subtended by the source, $B_{\nu}(\nu, T)$ is the Planck function, τ_{ν} is the optical depth. The parameters Ω , T , τ_0 and β are fitted. The actual fitting procedure was carried out using the logarithmic quantities.

Only data derived from large-beam measurements were used for the fit to assure a more or less homogenized sample (see Col. 6 of Table 4). This is also shown in Fig. 14, where crosses mark the data we have used for fitting and squares show data we have neglected. We have not used the MSX A-band

data at $8.3\ \mu\text{m}$ because this band is known to be affected by PAH emission. These aggregates are often susceptible to so-called quantum heating and do not necessarily attain an equilibrium temperature. As is evident in the plot, the $8.3\ \mu\text{m}$ point shows excess emission and is thus far above the expected level.

The best-fitting temperature is 80 ± 10 K, the best-fitting radius is $0.014\ \text{pc}$ and τ_0 is 3.2 ± 1.4 at a wavelength of $250\ \mu\text{m}$. The power-law approximation for the frequency behaviour of the dust emissivity resulted in $\epsilon_{\nu} \sim \nu^{2.1 \pm 0.4}$. Thus, the exponent is near to the canonical value of 2.0 for interstellar grains (e.g. Draine & Lee 1984). The modified Planck curve fits the used data quite well. Obviously, the fit cannot account for the flux levels of the L and M band data ($3\text{--}5\ \mu\text{m}$). In these bands strong infrared excess emission was measured, which we interpret as a trace of hot circumstellar material very near to the central heating source.

The bolometric luminosity we infer from our SED fit is $\sim 8 \times 10^4 L_{\odot}$ at an assumed distance of $1.3\ \text{kpc}$. The bolometric luminosity and the spectral type estimate will be discussed in Sect. 3.6.

A somewhat less well-defined SED has been modeled recently by Ghosh et al. (2000), using a self-consistent radiative transfer model that included the angular sizes at different wavelengths, radio continuum data as well as dust composition and grain size distribution. Their best fitting spherically symmetric model, assuming a distance of $1.4\ \text{kpc}$, predicts a single O7 ZAMS star as heating source, providing a bolometric luminosity of $10^5 L_{\odot}$ to the region. Scaling their result to the $1.3\ \text{kpc}$ distance used in our paper results in $\sim 9 \times 10^4 L_{\odot}$, coinciding well with our own estimate.

3.6. The ionising star of the UC H II region

As shown in Figs. 1 and 4 the mid-infrared and the millimetre emission, as well as the reflection nebosity, peak at the location of the UC H II region. Thus, the heating and illumination of the IRAS 09002-4732 star-forming region is dominated by the same single source or compact cluster which ionises the UC H II region G268.42-0.85 region. The fact that no other locations of radio continuum emission were reported in the region supports the assumption that the most massive young star(s) in the region is (are) located at G268.42-0.85.

This UC H II region is one of the few cases where the NIR and MIR counterpart of the ionising source can be clearly identified (source D in Sect. 3.4.1). Because this counterpart remains unresolved even at a spatial resolution of $\approx 700\ \text{AU}$ in the H and K_s filters, discriminating between a compact multiple system of massive stars and a single source requires interferometric or spectroscopic observations. For the purposes of this work we assume that the ionising source is a single massive star.

In the following we use the flux density of the free-free emission to derive a lower limit for the ionising star's luminosity. The number of Lyman continuum photons (N'_{c}) necessary to maintain the ionisation of the nebula is:

$$N'_{\text{c}} \geq 8.04 \times 10^{46} T_{\text{e}}^{-0.85} U^3,$$

Fig. 15. Simple sketch of the structure of the star-forming region IRAS 09002-4732. The likely relative line-of-sight positions are mainly deduced from the extinction pattern and different geometrical considerations as described in Sect. 4.1. The observer's direction is marked by an eye symbol.

where T_e is the electron temperature and U is the ionisation parameter (see, e.g. Kurtz et al. 1994). Following their arguments the ionisation parameter can be calculated as

$$U = rn_e^{2/3} = 4.553 \left[\frac{1}{a(\nu, T_e)} \left(\frac{\nu}{\text{GHz}} \right)^{0.1} \left(\frac{T_e}{\text{K}} \right)^{0.35} \left(\frac{S_\nu}{\text{Jy}} \right) \left(\frac{D}{\text{kpc}} \right)^2 \right]^{1/3},$$

where r is the radius, n_e is the rms electron density, ν is the frequency of the observations, T_e is the electron temperature, S_ν is the flux density and D is the distance. The term $a(\nu, T_e)$ is tabulated by Mezger & Henderson (1967) with values close to 1. Corresponding to the 8.64 GHz frequency of the ATCA observations of Walsh et al. (1998), we adopted the value of 0.95.

Using standard AIPS routines, we estimated the total flux density to be 2.67 Jy at 8.64 GHz from the radio interferometric data of Walsh et al. (1998). With the assumptions of 8000 K electron temperature and a distance of 1.3 kpc we derived a Lyman-continuum flux of $N'_e = 5.0 \times 10^{47} \text{ s}^{-1}$.

Based on this estimate, the spectral type of the ionising star has to be at least B0 (Panagia 1973; Schaerer & de Koter 1997). However, this estimate gives only a lower limit for the following three reasons: First, the interferometric observations are insensitive to the extended halo and thus underestimate the total flux. Second, a considerable fraction of the Lyman-continuum photons are absorbed by dust inside the UC H II region (see, e.g., Sect. 3.4.1; Mezger et al. 1974; Feldt et al. 1998). Third, the interpretation of the radio fluxes in terms of spectral types of the exciting star(s) is not straightforward. It sensitively depends on the level of sophistication of the underlying stellar models. Recent investigations of O star models demonstrate that considerable shifts in the calibration of the effective stellar temperature can occur when accounting for the combined effects of line and wind blanketing (e.g. Martins et al. 2002). Thus, these models predict a lower number of Lyman continuum photons from the star than the earlier models.

Simpson & Rubin (1990) used a similar method to calculate the Lyman-continuum photons from the radio flux of Caswell & Haynes (1987) with an assumed distance of 1.5 kpc. The deduced value of $N'_e = 7.1 \times 10^{47}$ photons/s corresponds to a spectral type of at least O9.5 and is in good agreement with our previous estimate.

Lenzen (1991) fits the spectro-photometric intensity distribution with an O7 ZAMS star heating an optically thick dust cocoon assuming a distance of 1.8 kpc. Transforming this estimate to the distance of 1.3 kpc used in this work would predict a spectral type between O7 to O8. This is probably due to the fact that Lenzen (1991) based his estimate on the IRAS fluxes, which has been recently found to be overestimated (Ghosh et al. 2000).

Because the heating of the region is dominated by the ionising source of the UC H II region, the bolometric luminosity of the star-forming region can also be used to assess the spectral type of this star. In Sect. 3.5 we found the bolometric luminosity derived from the SED to be $\sim 8 \times 10^4 L_\odot$ at the assumed distance of 1.3 kpc, indicating a spectral type O9V, consistent with what we found from the radio continuum data. This bolometric luminosity thus argues again for a star of a spectral type not later than O9. If the central object were a compact cluster, then the O9 spectral type estimate would be valid for its most massive star because the most massive star always dominates the luminosity of such small clusters.

Thus, the radio continuum measurements, infrared and bolometric luminosity estimates give a coherent picture for the spectral type of the ionising star as being O9 with an estimated accuracy of 1 subclass.

4. Global picture and summary

4.1. Geometric model – completing the puzzle

In this section, we summarize what we have learned about the individual components of the star-forming region and develop

a coherent structural model. Figure 15 illustrates the basic concept of this model.

Hundreds of stars have been identified in the region of IRAS 09002-4732. We find at least 60 young pre-main sequence stars, evidence for recent star-formation. The stellar density increases towards the location of the UC H II region G268.42-0.85. It is worthwhile to compare the stellar cluster with the positions and extensions of the two dense molecular clumps observed in CS by Lapinov et al. (1998) and shown in Fig. 2. While the north-western clump has no obvious effect on the stars, at the position of the south-eastern clump, high reddening and extinction is present. This implies that the former clump is in the background of the cluster, while the latter is in front of it. Still, both of them should belong to the same complex since the CS maps show a loose connection between the foreground and background clumps. The presence of large masses of dust and dense molecular gas ($M > 600 M_{\odot}$, Zinchenko et al. 1995) suggests that the star-formation process has not yet had time to fully disperse the natal molecular cloud and there is still material left for further star formation.

The UC H II region is detected close to the edge of the southern CS clump with all objects in its environment being very red. This suggests that the UC H II region is not in front of the clump. Furthermore, as shown in Sect. 3.2.1, the star ionising the UC H II region is also causing the southern reflection nebulosity. This, in turn, shows that (even the visible) light can escape backwards from the UC H II region, thus its likely location is at the rear of the molecular clump or behind it. However, the fact that the morphology of the UC H II region is cometary and is compressed roughly towards the CS clump implies that it is not behind the southern CS clump but partly embedded in its rear wall. Furthermore, the halo of the cometary UC H II region extends westward, roughly pointing toward the brightest spot of the southern reflection nebula, suggesting that most of the light escapes in the same direction in which the hot gas expands – apparently away from the centre of the CS clump, towards decreasing density. The location and the morphology of the ionised gas suggests that the UC H II region G268.42-0.85 is most likely a champagne flow type region (Wood & Churchwell 1989). It seems probable that the NIR-bright object G in Fig. 12 is the reflection of light that shines out from the CS clump through this opening.

Thus, the southern reflection nebulosity acts as a screen reflecting the light of the most massive star, which is almost completely hidden behind a dense molecular clump.

The dark dust filaments must be in the foreground of the northern reflection nebula, in a position where no light from the massive star can illuminate their sides facing us. Apparently the southern reflection nebula has a lower number of such filaments – it is tempting to assume that this is due to the influence of the massive star.

The birth of the massive young star or compact cluster in G268.42-0.85 had a fundamental impact on the whole star-forming region, by re-arranging its illumination and temperature distribution.

4.2. Open questions

Although the basic steps have been performed to understand this region, many more questions are still to be answered by future sensitive high-resolution observations. These are:

Are the filaments left-overs from the contraction of the dust cloud? If so, can this filamentary structure also be seen in the distribution of the young stellar sources? Are the globules in the filaments an early stage of protostellar objects? Does the distribution of young stellar objects or protostars follow the filamentary structure? Does the UC H II region move at supersonic speeds through the dust clump or do they have a common radial velocity? Are the elongated red objects around the massive star stellar objects with circumstellar material or externally heated and evaporating starless clumps? Is the most massive star single or multiple?

4.3. Conclusions

In this paper we provide the first global view of star formation around the IRAS point source 09002-4732. Our high-resolution, multi-wavelength (1–20 μm) data provide a detailed insight into the distribution and nature of the young stellar objects as well as into the morphology of the thermal dust emission. We described the large-scale morphology of the star-forming region, the associated young stellar cluster, and silhouettes of filaments and globular structures. We analyzed the most massive object and its surrounding, embedded in an UC H II region. The most important conclusions of the current work are the following:

- An embedded cluster of young pre-main sequence stars exhibiting NIR excess is identified. The overall stellar density shows an increase towards the UC H II region.
- The foreground extinction is estimated to be $A_V \simeq 4$ mag, while the bulk of the cluster stars show extinctions of $A_V \simeq 11$ mag or larger.
- We unambiguously identified the location of the star (or compact cluster) ionising the UC H II region. Different methods are presented to assess its spectral type, which we found to be consistent with a spectral type of $\sim\text{O9}$.
- We showed that the heating and illumination of the star-forming region is dominated by the ionising source(s) of the UC H II region G268.42-0.85. This object is presumably the most massive young star in this star-forming region.
- The first structural model for the star-forming region is proposed: The UC H II region G268.42-0.85 is located at the rear side of a dense molecular clump, consistent with the champagne flow configuration. The massive star's light is reflected back from the southern reflection nebula.
- We identified numerous objects inside and in the direct vicinity of the UC H II region at sub-arcsecond resolution. We showed that some of these objects are reflections, some are young stellar objects with NIR excess, while in some cases the external heating by the ionising star is dominant.
- In the foreground of the reflection nebula's southern lobe a number of dark, high-extinction globular filaments were identified with localized enhancement of the extinction.

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