Interstellar medium around the HII region NGC3503

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Abstract

Dense molecular clouds are sites where mostly powerful OB stars are formed. Once OB stars are born, they emit the bulk of their radiation at wavelenghts shorter than the Lyman continuum limit (hν> 13.6 eV) ionizing the adjacent molecular gas and giving rise to a compact HII. The intense FUV fluxes dissociate the molecules and photoionize those heavy elements with ionization potentials lower than 13.6 eV. These regions called Photodissociated Regions (PDRs) may extend deep Av~ 5 – 10 mag. into the opaque clouds where the transition from H to H_2 and from C+ to CO occurs.

This study allow us to detect a molecular cloud in direction of the HII region NGC3503, which have as main stellar sources a number of B-type stars probably members of the open cluster Pismis 17. Mid and far IR counterparts of the HII region have been founded in the surroundings of NGC3503 as a product of the interstellar dust emission.

The interaction between the FUV photons of the B-type stars and the molecular material created PDRs around the HII region and at the edge of the molecular cloud, which together with the agreement between the expansion velocity of the ionized and molecular gas strongly suggests the expansion of the HII region in at the egde of the its parental molecular cloud.

The distribution of molecular and ionized gas, also seems to corroborate the presence of a *champagne flow* effect towards NGC 3503.

Introduction

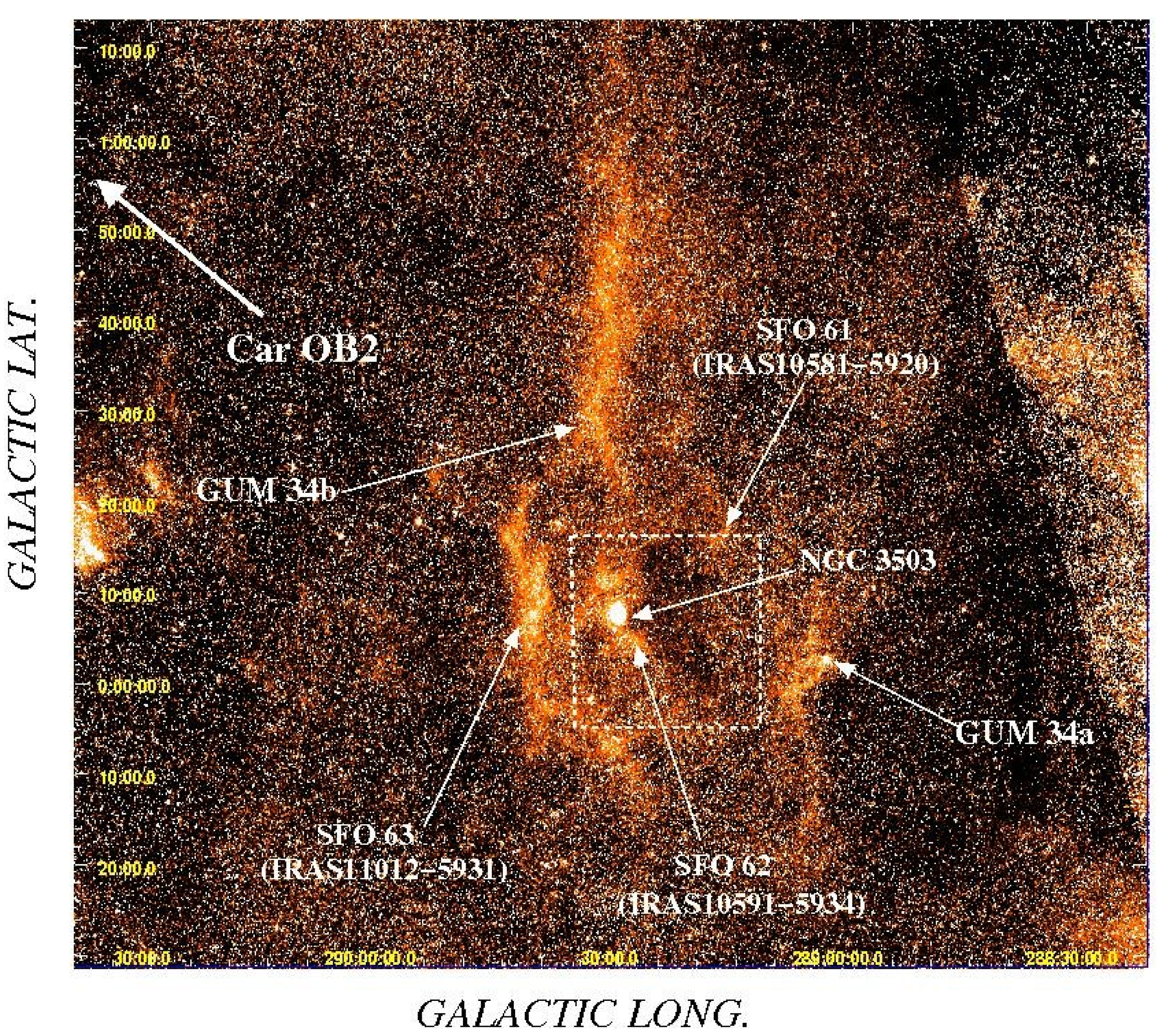

Figure 1: DSS2-red image of the gigantic HII region RCW 54. Our region of study is depicted by the dotted square

NGC 3503 is a 3' diameter, optically visible HII region located at (l,b)= 289º31',+0º07') (Dreyer & Sinnott, 1988) in the direction of RCW 54. RCW 54 is a gigantic HII region complex, ionized by the Car OB2 association and constituted by a number of minor HII regions (besides NGC 3503) namely: Gum 34a and Gum 34b (RCW 54b) located at (l,b)=(289º04',+0º05') and (l,b)=(289º36',+0º30'), respectively, Gum 35 (RCW 54a) (l,b)=(289º46',-009'), Gum 36 (RCW 54 d) (l,b)=(290º21',+1º37'), Gum 37 (RCW 54c) (l,b)=(290º37',+0º20'), and NGC 3572 (l,b)=(290º42', +0º12') (Rodgers at al. 1960). In Figure 1 we show the DSS2-red image of the brightest region of RCW 54, where some of the mentioned components are identified. The dashed square centered on the position of NGC 3503 depicts our further region of study.

NGC 3503 is considered to be member of the massive reflection nebulae association known as Car R1, which is placed at a distance of d = 2.88 kpc and is excited by a group of B-type stars (Herbs 1975, and references therein) and is thought to be related with three optical bright-rimmed cloud, (BRCs), identified by their SIMBAD name, as SFO 61, SFO 62, and SFO 63. (see Figure 1)

The aim of this work is to achieve a better understanding of the interaction between the ionized and molecular gas in the optical nebula NGC 3503. To this end, new 12CO (J=1-0) observations at 115 GHz of the nebula are analyzed. We compare these new observations with infrared and Hα line emission archival images. We complemented these observations with bibliographic data in order to perform a complete multifrequency analysis of the nebula.

Dust and ionized gas

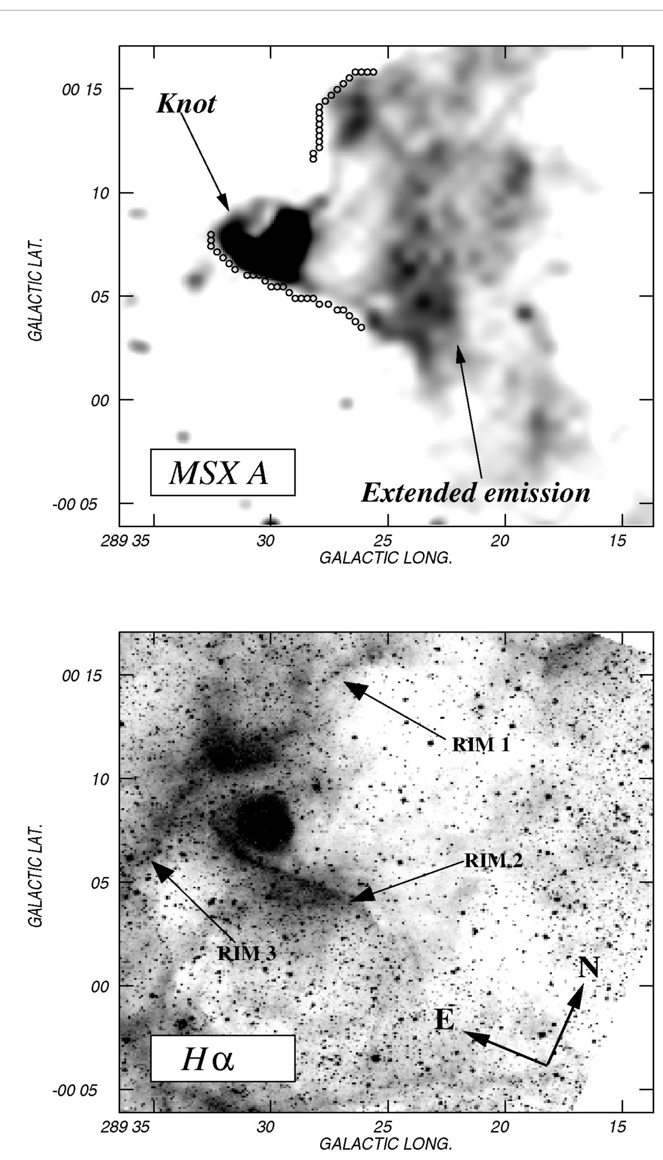

Figure 2: Upper panel: MSX band A emission map (8.13 microns) towards NGC 3503. The white circles represent the location of Rim1 and Rim 2 (see lower panel). Lower panel: Hα line emission map of the region obtained from the SuperCOSMOS survey (SHS)

Dust heated emission counterpart of NGC 3503 was searched using mid-infrared distribution images at 8.28, 12.13, 14.65, and 21.3 microns (MSX band A, C, D, and E, respectively). The Band A bandwidth include the emission bands at 7.7 and 8.6 microns, attributed to the emission of PAH, which are good tracers of UV-irradiated PDRs. The emission distribution image at this frequency is shown in the top panel of Figure 2. This figure reveals a bright nebular knot located at (l,b)=(289º30',0º7'), coincident with the location of the optical nebula NGC 3503. At lower galactic longitudes (l < 289º27'), a relative strong extended emission feature is also observed, spanning the entire range of galactic latitude and subtended by prominent bright edges at l > 289º23' . These features are indicated in Figure 2 as “Knot” and “Extended emission”, respectively.

Aimed to investigate the distribution of the ionized gas in the surroundings of NGC 3503, the Hα emission line distribution was analyzed. In the bottom panel of Figure 2, we show the Hα line emission map obtained from SHS. An intense feature of about 2' in size, stands out at (l,b)=(289º 30',0º07') at the location of the infrared “Knot”. About 2' at northeastern, another bright structure is noticed at (l,b)~(289º32',00º11') which has no infrared counterpart emission. Two regions of strong optical absorption are noticeable. The large one is observed in a region between 289º18' < l < 289º28' and 0º03' < b < 0º15', and is bounded by notorious enhacements in the Hα emission, labeled in Figure 2 as Rim1 and Rim2. The small one is located at (l,b) ~(289º35',0º00') and is bounded towards its interior border by a bright rim of Hα emission labeled as Rim3.

The location, shape and size of the intense Hα structure placed at (l,b)=(289º30',0º07') strongly suggests that the emissions observed in Hα and 8.28 microns (Knot) come from the same component, and represent the optical and dust emission counterparts of the nebula NGC 3503, respectively. The shape of the infrared (Extended emission) resembles remarkably the larger region of high optical absorption, which very likely indicates the presence of a molecular cloud in which dust heating emission process are taking place. The proximity of Rim1, Rim2, and Rim3 to high optical obscured regions may suggest some degree of ionization at the edge of a molecular cloud, which may also indicate the presence of PDRs. Rim1 and Rim2 are highly coincident with the edges of the “Extended emission” observed at about l > 289º23', which gives an additional support for the PDR hypothesis. In Figure 2 (upper panel) we indicated the position of Rim1 and Rim2 with white circles.

Databases

Intermediate angular resolution (2.7 '), medium sensitivity, and high-velocity resolution (0.055 km s-1) CO (J=1 – 0) data from the 4-m NANTEN millimeter-wave telescope of Nagoya University were used. At the time the authors carried out the observations (April 2001) this telescope was installed at Las Campanas Observatory, Chile. The data were gathered using the position switching mode. The integration time per point was 16s resulting in an rms noise of ~0.3 K. Narrow-band Hα data retrieved from Super Cosmos Hα Survey (SHS) (Parker et al. 2005) was used while Mid and Far IR data retrieved from the Midcurse Space Experiment (MSX) (Price et al. 2001), Spitzer-IRAC image at 4.5 and 8.0 mu, and IRAS images at 60 and 100 mu, respectively, were used.

Comparison between optical and molecular emission

In Figure 3 we show the spatial distribution of CO in the velocity ranges from -29 to -20 km/s, -17 to -15 km/s, and 14 to 24 km/s. For the sake of clarity these molecular components are referred, as component 1, component 2, and component 3, respectively. To facilitate the comparison with the ionized gas, the right panels of Figure 3 show the overlay of the molecular gas (contours) with the Hα line emission (grey scale).

Aimed to identify the molecular gas associated with NGC 3503, we investigated the physical properties of component 1, component 2, and component 3. Results are presented in Table 1. According the inferred values of kinematical distances (d κ) and masses, we concluded that component 1 and component 2 are physically related with NGC 3503

Though the spatial resolution of NANTEN observations is not high enough to carry out a detailed kinematical analysis, we searched for evidence revealing the presence of expanding motions in the molecular gas of component 1 that could expose an interaction between the ionized and molecular gas in NGC 3503. In Figure 4 we show a series of images of CO spanning the velocity range of -27.4 to -23.4 km/s. Every image represents a mean of the CO emission (contours) over a velocity interval of 1 km/s superimposed on the MSX band A emission (greyscale).

	component 1	component 2	component 3
$\bar{V}$ $(km\ s^{-1})$	−24.7	−16.6	19.3
d_K (kpc)	2.9	2.9	8.1
$I_{^{12}CO}$ $(K\ kms^{-1})$	9.9	1.9	7.7
Ω $(10^{-5}\ ster)$	2.1	0.3	2.7
N_{H_2} $(10^{21}\ cm^{-2})$	1.9 ± 0.3	0.4 ± 0.1	1.5 ± 0.2
$M_{tot\ H_2}$ $(10^3\ M_\odot)$	7.6 ± 4.5	0.2 ± 0.1	57.6 ± 34.5
A_v (mag)	2.0	0.4	1.6

Table 1: Main physical properties of the molecular components founded towards NGC 3503

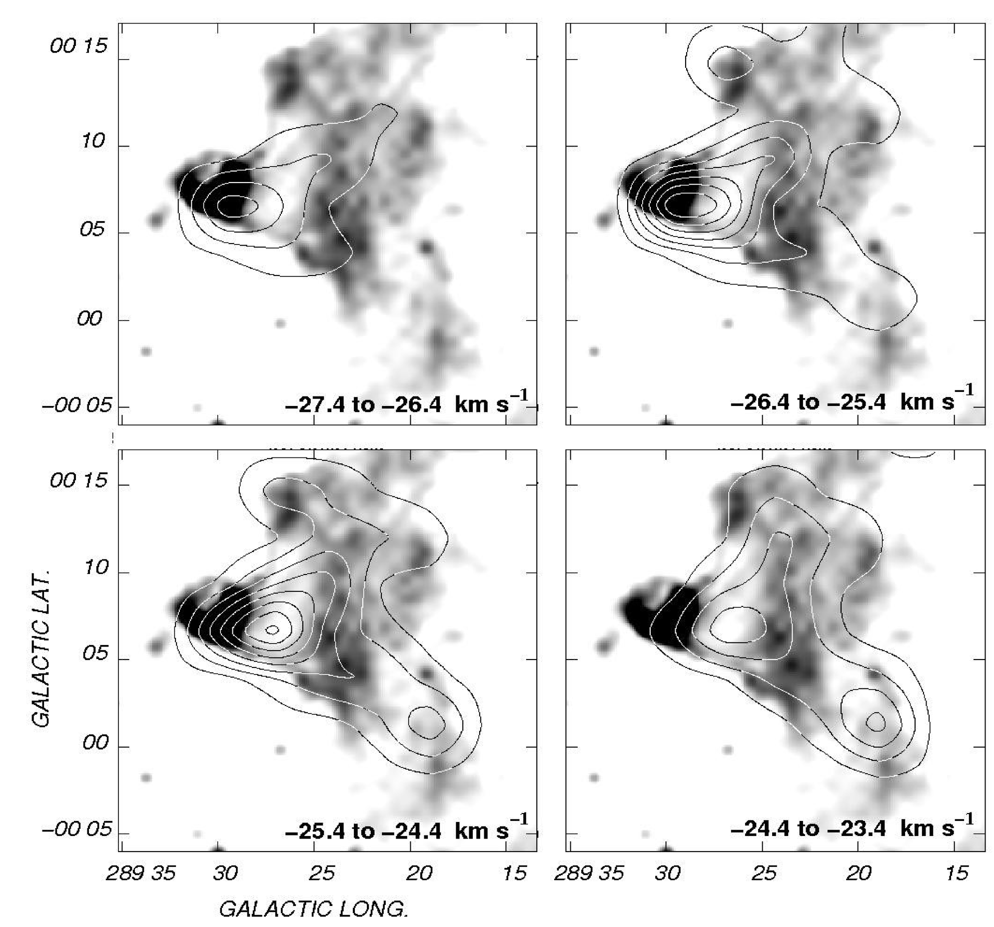

Figure 4 : Overlay of the mean CO emission (contours) in the velocity range from -27.4 to -23.4 km/s and the MSX band A emission (grey scale). Every image represents the CO distribution averaged in a velocity interval of 1 km/s. The velocity interval is indicated in the bottom right corner of each image

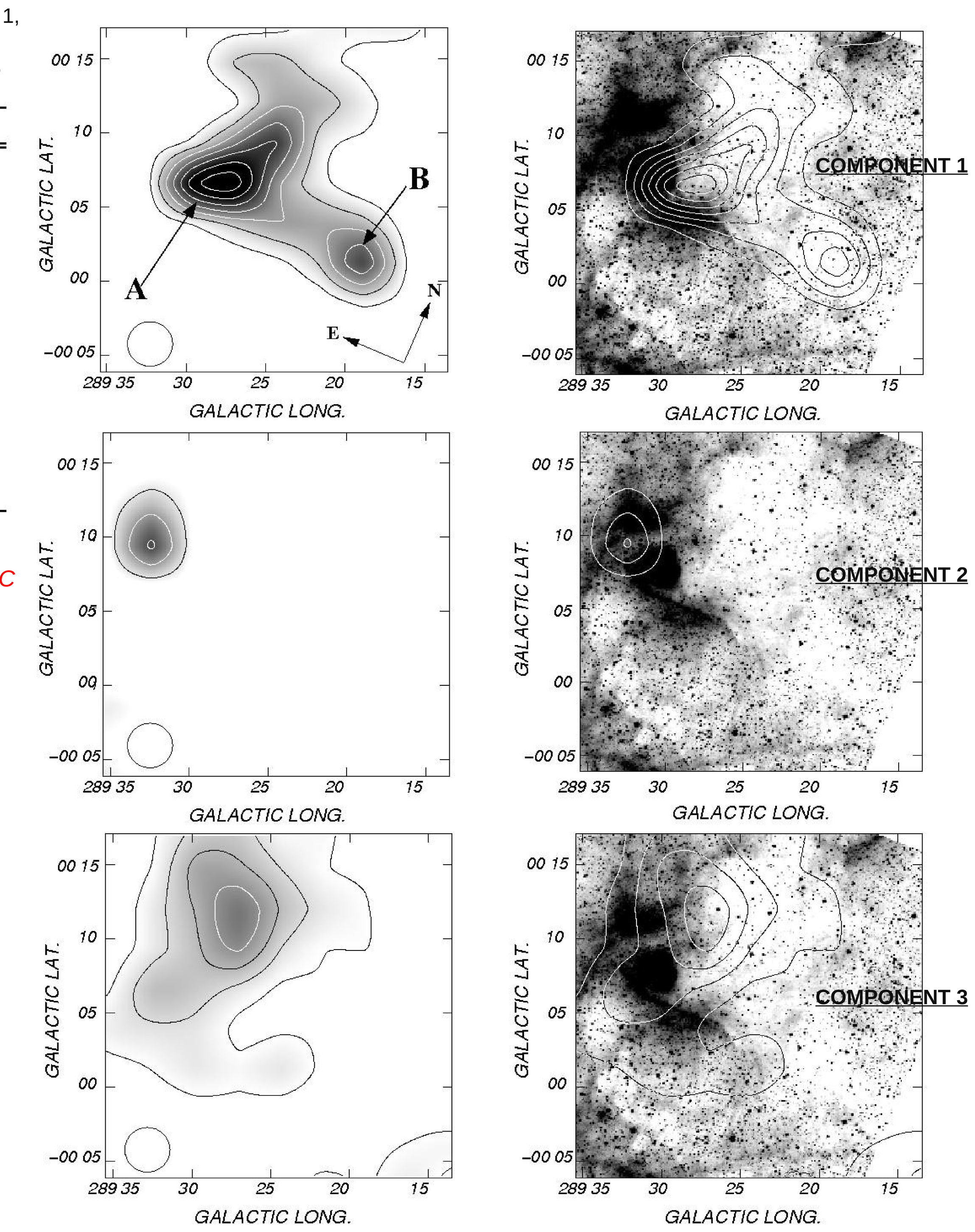

Figure 3: Molecular components founded towards NGC 3503.

In the velocity range from -27.4 to -25.4 km/s the CO emission of clump A peaks at (l,b)=(289º29',0º06') and its position is almost coincident with the intense MSX counterpart of NGC 3503 (Knot). To lower negative velocities its center is slightly displaced to lower galactic longitudes. The maximum displacement is observed in the velocity interval from -24.4 to -23.4 km/s. At this velocity interval the CO emission of clump A peaks at (l,b)=(289º26',0º06'). Therefore, there is molecular gas belonging to the clump A spatially concentrated at different velocities. Therefore, a velocity gradient of about ~2 km/s is detected in the molecular gas towards NGC 3503, which can be interpreted as expansion motions. Considering projection effects, a velocity expansion of the molecular gas as high as 7 km/s can be deduced. This expansion velocity is in good agreement with the expansion velocity range inferred for the ionized gas (2 – 8 km/s) (see Discussion and conclusions)

Photodissociated regions

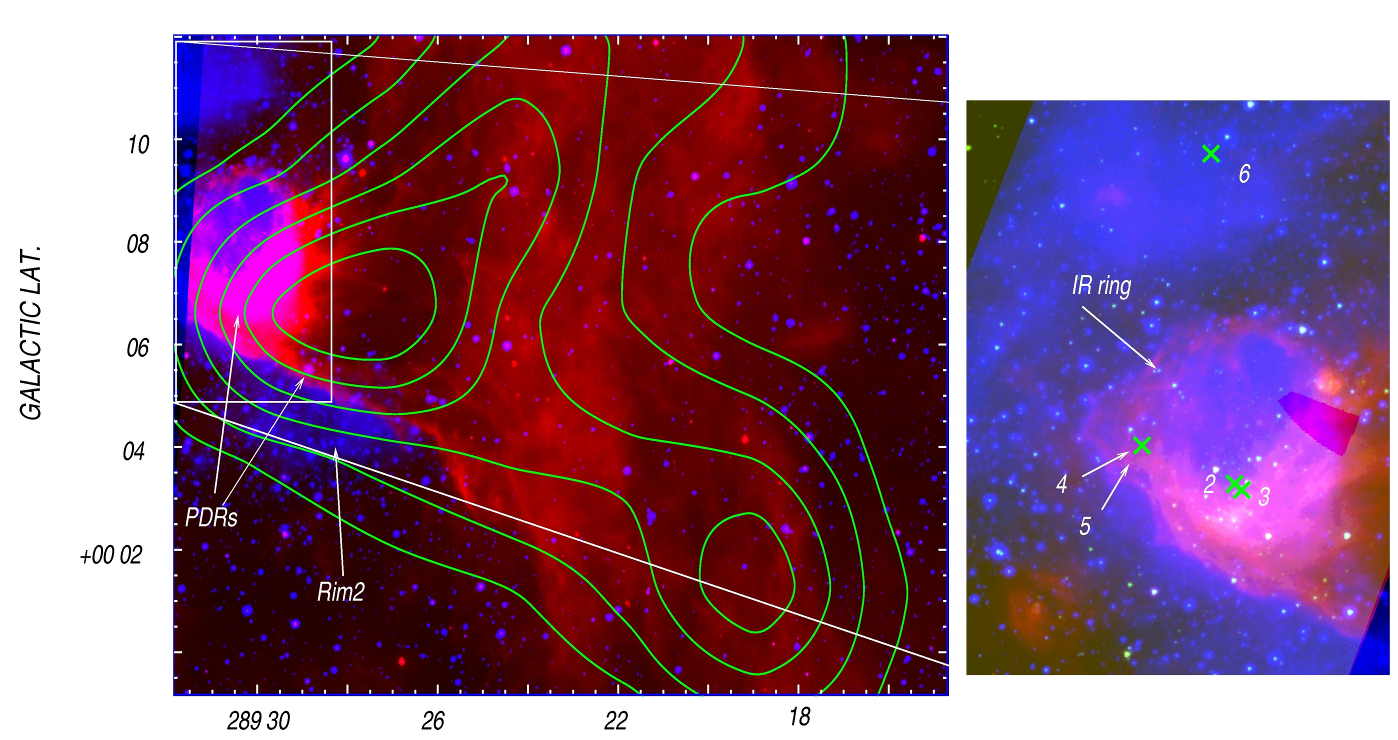

Figure 5: (Left panel): Superposition between optical (blue) and mid-IR (IRAC 8.0 microns band)(red) emission distributions, with the green contours of the CO emission of component 1. (Right panel): Overlapping of IRAC 8.0 microns (red) and 4.5 microns bands (green), and optical image (blue) of the HII region NGC 3503. The green crosses indicate the B-type stars which are at the same distance of the HII region.

The study of interactions between FUV radiation and molecular cloud gas is very important in understanding the molecular cloud evolution and the subsequent star formation in molecular clouds. A sign of interaction between the ionized and molecular gas are the PDRs. One of the most important components of these such regions are the PAHs which are good tracers of B-type stars, which dominate the galactic stellar energy budget (Peeters et al. 2004)

In order to look for stellar sources of FUV photons, we made a search of stars in the neighbourhood of the HII region. The results are listed in Table 2

ID	l	b	V	(B-V)	Av	SpT	d (kpc)	L($L_\odot$)	Cross.Ref.
1	289.50	+0.12	11.4$^{(g)}$	0.2$^{(g)}$	1.5 ± 0.3$^{(g)}$	B2 V$^{(g)}$	2.9 ± 0.8$^{(g)}$	5.7×10^3	NGC 3503-1
2	289.50	+0.13	10.5$^{(g)}$	0.2$^{(g)}$	2.1 ± 0,6$^{(g)}$	B0 V$^{(g)}$	2.9 ± 0.9$^{(g)}$	5.2×10^4	NGC 3503-2, PISMIS 1$^{(h)}$
3	289.51	+0.12	11.4$^{(g)}$	0.2$^{(g)}$	1.6 ± 0.2$^{(g)}$	B2 V$^{(g)}$	2.8 ± 0.7$^{(g)}$	5.7×10^3	NGC-3503-3, PISMIS 2$^{(h)}$
4	289.51	+0.12	11.4$^{(g)}$	0.2$^{(g)}$	1.6 ± 0.1$^{(g)}$	B2 V$^{(g)}$	2.8 ± 0.6$^{(g)}$	5.7×10^3	NGC 3503-4, CPD-59 2945s
5	289.51	+0.12	13.7$^{(h)}$	0.4$^{(h)}$	—	—	—	—	PISMIS 7
6	289.51	+0.12	12.9$^{(h)}$	1.4$^{(h)}$	—	—	—	—	PISMIS 9
7	289.51	+0.20	10.4$^{(d)}$	0.2$^{(d)}$	1.5 ± 0.5	B1 V$^{(d)}$	2.7 ± 0.8	1.6×10^4	CP-592951
8	289.50	+0.13	10.5$^{(b)}$	0.2$^{(b)}$	1.6 ± 0.5	B0 Ve$^{(b)}$	3.6 ± 0,9	5.2×10^4	ALS 16024, CD-59 3483
9	289.53	+0.13	11.4$^{(b)}$	0.2$^{(b)}$	1.4 ± 0.4	B2 Ve$^{(b)}$	3.1 ± 0.6	5.7×10^3	ALS 16027
10	289.60	+0.10	8.7 $^{(d)}$	—	—	B5 V$^{(d)}$	—	8.3×10^2	CP-592956
11	289.60	+0.22	9.6 $^{(f)}$	0.2$^{(f)}$	1.6 ± 0.5	B0 V$^{(f)}$	2.6 ± 0.6	5.2×10^4	CP-592961
12	289.61	+0.21	9.6$^{(c)}$	0.2$^{(c)}$	1.3 ± 0.4	B2 II$^{(c)}$	4.1 ± 0.8	1.7×10^4	HD 305845
			9.7$^{(e)}$	0.1$^{(e)}$	0.9 ± 0.3	B2 II$^{(e)}$	5.2 ± 0.8		

(a) Lynga & Wramdemark, 1973; (b) Herbst, 1975; (c) Klare & Neckel, 1977; (d) Buscombe & Foster, 1999; (e) Hog et al., 2000; (f) Buscombe & Foster, 1995; (g) Pinheiro et al., 2010; (h) WEBDA

Table 2 : Information about the stars searched in the region of NGC 3503

Figure 5 shows a superposition between optical (blue) and mid-IR (IRAC 8.0 μm band)(red) emission distributions, with the green contours of the ^{12}CO emission over a region that include the molecular clumps A and B. The morphological correlation between the ionized gas and molecular cloud is evident at the edge of clump A, where the optical Rim2 and the HII region are projected. It is evident how the distribution of PAH delineate the high intense Rim2 from (l,b)~(289º29', +0º4') to (l,b)~(289º32', +0º7'), and border the molecular clump A which exhibits the maximum emission at a low mid-IR emission region. Unless we can not detect any star related with the optical Rim 2, the morphological distribution is in agreement with a PDR.

Taking into account the spectrophotometrical distances of the B-type stars 2, 3, 4, and 5, which are projected inside the HII region, and its correlation with the kinematical distance of the CO data, it is suggested as main ionizing responsibles of the HII region these B-type stars.

A PDRs towards the HII region is detected, supported by the presence of four B2V and two B0V-type stars, according with its spectrophotometric distances (labeled as 2 to 7 in the first column of Table }) related with NGC 3503. To focuss in the morphological analysis, we display a zoom of this region at the right panel of Fig. 5. In this case, we overlapped the images at 4.5 and 8.0 microns (green and red, respectively), with the optical emission distribution (blue).The IRAC 4.5 microns band contains both H2 (v=0-0, S(9,10,11)) lines and CO (v=1-0) bandheads, which may be excited by shocks..

Discussion and conclusions

We can estimate an upper limit for the age of NGC3503 considering that the main exciting stars are two B0V and four B2V type stars. The main-sequence lifetime for a B2V star is greater than 4.0 Myr (Schaeller et al. 1992). On the other hand, a lower limit to the age can be estimated considering the sound crossing time, R/v_s, where v_s is the sound speed in the ionized gas (13 km/s) and R is the radius of the HII region.

For NGC 3503, the corresponding lower limit is about 0.1 Myr. As a different approach, the age of the HII region can be inferred using the simple model described by Dyson & Williams (1997) for an expanding ionized region in a uniform medium. The expansion of an HII region is highly dependent on the density of the surrounding gas. As a rough estimate, the original ambient density can be obtained by distributing the total mass related to the structure (ionized and dust) over an sphere of 1.5 +/- 0.3 pc in radius. In the case of molecular mass, we consider that a 40 % of the clump A can be related with the HII region. We determine an ambient density of about 3800 cm 3. Under these conditions, we can infer that the HII region has been expanding during ~ 0.2 Myr. This range for the dynamical age, together with the age limits estimated above, suggests that the age of NGC 3503 could be between 0.1 and 4.0 Myr. Using the same simple model, the expansion velocity of the HII region can be inferred. Considering the limits in the age of the HII region, we obtained a range in V_{exp} in the range 2 - 8 km/s.

We calculate whether the six B-type stars in NGC 3503 can provide the energy to ionize the gas. In all cases, they passed through an O9.5V type stage, according with Schaller et al. (1992). Taking into account these two evolutionary phases, they generate a total UV photon flux of log N* 48.0. Considering that a fraction of FUV of the stellar energy has been absorbed by PAHs (about 5 %, Allamandola et al. 1989) and dust grains (lower that 50 %, Draine 2010), the effective FUV used to ionized the interstellar gas is greather than log N_{FUV} ~ 48.7. By comparing N_{FUV} with the UV photons used to ionize the gas, log N_{Lym-c} ~ 47.3, we can suggest that the four B-type stars can maintain the HII region ionized.

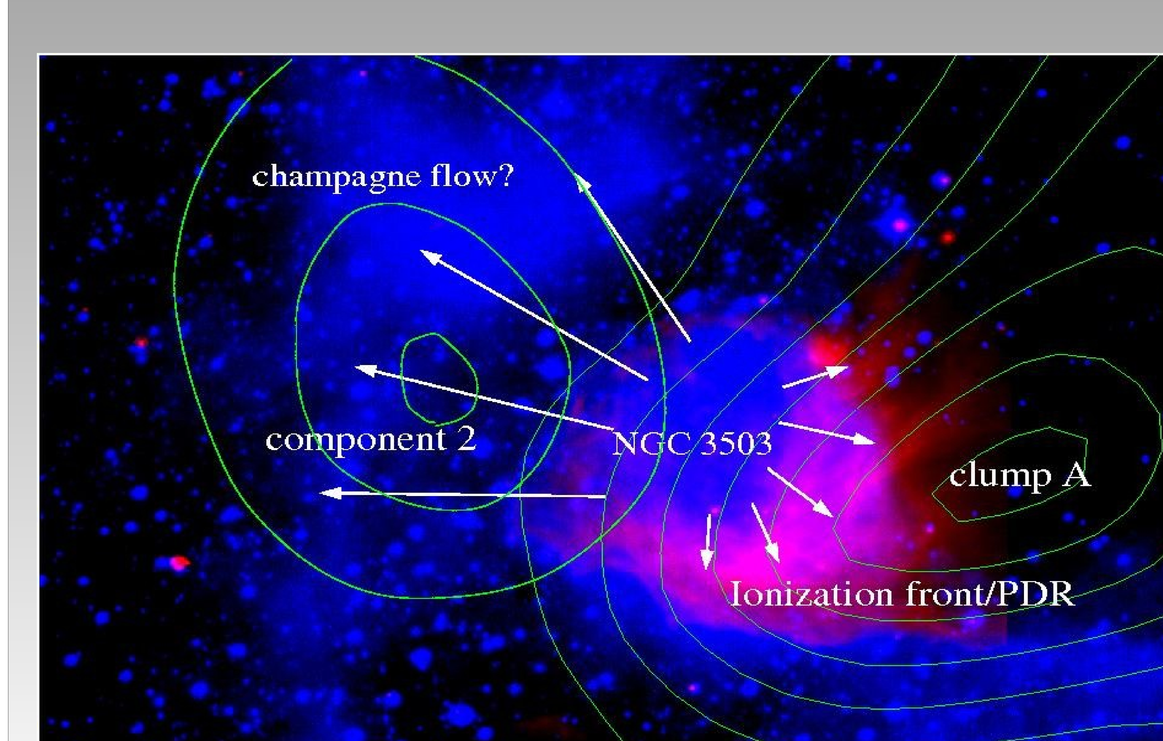

Figure 6: Proposed scenario for the interstellar medium around NGC 3503

It is readily noticeable from Figure 3 that the peak of the CO emission of component 1 (clump A) is shifted westwards from the position of the brightest nebular emission (NGC 3503). The shifted position of clump A strongly suggests that the optical emission corresponding to NGC 3503 could be produced as a result of photoevaporation process owing to the internal UV field, which seems to be taking place on the periphery of the parental molecular cloud. The explained morphology resembles the classical scenario of the *Champagne flows* effect, which propose that an expanding HII region placed at the edge of a molecular cloud breaks free into the ambient releasing streams of ionised gas and possibly molecular gas. The Hα emission distribution observed towards NGC 3503 and the location and velocity of component 2 seem to corroborate this scenario.

In Figure 5 we present a descriptive sketch of the proposed scenario for the ISM around NGC 3503. The position of clump A behind the ionization front may indicate that this feature represents the molecular gas that is been ionized by the internal UV field and also accelerated due to the expansion of the HII region (indicated by dotted white arrows). Taking into consideration the characteristics of the molecular data, it is very likely that the molecular emission in direction to the center of NGC 3503 could be as a result of a low spatial resolution. In this context, it is our understanding that the UV field of NGC 3503 has disrupted the molecular gas of clump A in its low density side, and has released the high-pressured ionized gas (the Hα structure placed at (l,b)~(289º32',+0º11', and possibly the Rim3) into the ambient as a typical *Champagne flow* effect. We also indicated in Figure 6 the position of component 2. The peak emission position of this molecular component is observed near the released ionized gas, and its mean velocity is shifted by ~ --8 km/s with respect to the velocity of component 1. This strongly suggests that component 2 could be molecular gas which has been impelled by the ionized gas after breaking free from the parental molecular cloud.

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