Colliding interstellar bubbles in the direction of $l = 54^\circ$

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ABSTRACT

Context. Interstellar bubbles are structures in the interstellar medium with diameters of a few to tens of parsecs. Their progenitors are stellar winds, intense radiation of massive stars, or supernova explosions. Star formation and young stellar objects are commonly associated with these structures.

Aims. We compare IR observations of bubbles N115, N116 and N117 with atomic, molecular and ionized gas in this region. While determining the dynamical properties of the bubbles, we also look into their ambient environment to understand their formation in a wider context.

Methods. For finding bubbles in HI (VLA Galactic Plane Survey) and CO data (Galactic Ring Survey), we used their images from Galactic Legacy Infrared Mid-Plane Survey. We manually constructed masks based on the appearance of the bubbles in the IR images and applied it to the HI and CO data. We determined their kinematic distance, size, expansion velocity, mass, original density of the maternal cloud, age and energy input.

Results. We identified two systems of bubbles: the first, background system, is formed by large structures G053.9+0.2 and SNR G054.4-0.3 and the infrared bubble N116+117. The second, foreground system, includes the infrared bubble N115 and two large HI bubbles, which we discovered in the HI data. Both systems are independent, lying at different distances, but look similar. They are both formed by two large colliding bubbles with radii around 20–30 pc and ages of a few million years. A younger and smaller (~4 pc, less than a million years) infrared bubble lies at the position of the collision.

Conclusions. We found that both infrared bubbles N115 and N116+117 are associated with the collisions of larger and older bubbles. We propose, that such collisions increase the probability of further star formation, probably by squeezing the interstellar material, suggesting that it is an important mechanism for star formation.

Key words. ISM: bubbles – ISM: clouds – ISM: HII regions – ISM: supernova remnants

1. Introduction

1.1. Interstellar bubbles

The interstellar medium (ISM) in the Galaxy shows a rich variety of structures, including clumps, filaments and dense sheets. Some of the structures resemble envelopes and are known as shells or bubbles. Their (nearly) ubiquitous presence is the reason behind the term “the bubbling galactic disk” (Churchwell et al. 2006; Deharveng et al. 2010; Simpson et al. 2012), describing the state of the ISM. Progenitors of these bubbles, which are best observable in the infrared band, include stellar winds, intense radiation of massive stars, or supernova explosions. Basically all infrared (IR) bubbles are found near HII regions, CO clouds or other indicators of the recent or on-going star formation.

The walls delineating the IR bubbles are associated with sites of the new star formation, i.e. they contain objects younger than the predicted age of the bubble itself – many examples can be found in (Deharveng et al. 2010), suggesting triggered star formation. There are two basic mechanisms proposed to explain such triggering: Collect & Collapse (C&C) and Radiation Driven Implosion (RDI). In the first one, the interstellar medium is swept up into a dense cold layer and this layer gravitationally fragments and then forms stars. In the second scenario the shock front compresses existing cold clumps and thus initiates the star formation.

It is difficult to distinguish between these scenarios (see, e.g. Walch et al. 2015 for the discussion of these questions connected with the IR bubble RCW 120), and there is still the possibility that no real triggering is taking place, just shifting and relocation of material, which would also form stars without any external driver (see Dale et al. 2015 for a discussion about what triggering really means).

In this paper, we compare the IR observations of bubbles N115, N116 and N117 from Churchwell et al. 2006 with atomic (HI), molecular (CO) and ionized (radio continuum) gas in this region. We find two independent subsystems, which both look very much alike: colliding bubbles with the star formation taking place in the position of the collision. In the following section we first summarize what is known about the studied bubbles and then we describe the data and the methods of the analysis. Afterwards, we will describe each subsystem separately and calculate its properties. We conclude the paper with a brief discussion.

1.2. The region around infrared bubbles N115, N116 and N117

Infrared bubbles N115, N116 and N117 were identified by Churchwell et al. 2006. Radial velocities associated with these bubbles are $v_{LSR} = 24.0 \, \text{kms}^{-1}$ for N115 (Watson et al. 2010).
and \( v_{\text{LSR}} = 42.8 \, \text{km} \text{s}^{-1} \) for N117 (Watson et al. 2003\textsuperscript{1}), these velocities belong to the (molecular or ionized) gas associated with these bubbles.

There are two large radio objects in the vicinity of the bubbles: SNR G54.4-0.3 and a radio loop G053.9+0.2 (see Fig. 3, the left panel). SNR G54.4-0.3 was studied by Junkes et al. (1992a) and found to be associated with the CO gas at around \( v_{\text{LSR}} = 40.0 \, \text{km} \text{s}^{-1} \). The loop G053.9+0.2 was studied by Leahy et al. (2008) and was found to be related to an IR shell, which itself was connected to CO emission and HII regions with velocities around \( v_{\text{LSR}} = 40.0 \, \text{km} \text{s}^{-1} \). The CO and the HII regions in the vicinity of the loop G053.9+0.2 were extensively studied by Xu & Ju (2014) and the connection with IR bubbles N116 and N117 was explicitly claimed (see Fig. 1\textsuperscript{11} for their image of the region).

The pulsar wind nebula, connected with the SNR054.1+0.3 (Green 2009), is projected to the wall of the larger radio loop, but according to Leahy et al. (2008), is not physically associated with it, as it probably lies at a different radial velocity (53 \( \text{km} \text{s}^{-1} \)). This pulsar wind nebula is created by the young pulsar PSR J1930+1852 (the characteristic age of the pulsar is 2900 yr).

Fig. 1. A cartoon of the region surrounding G053.9+0.2 according to Xu & Ju (2014). N116+N117 connected to the radio loop G053.9+0.2 and the independent N115 and SNR G54.4-0.3.

Fig. 2. The example of a mask for a case of the bubble F (= IR bubble N115).

2. Data and methods

2.1. Data

For our study, we use the following surveys:

- Spitzer-GLIMPSE survey (Galactic Legacy Infrared Mid-Plane Survey Extraordinaire, Benjamin et al. 2003) with a pixel resolution of 1.2′′. We use the 8.0 \( \mu \text{m} \) filter.
- VGPS (VLA Galactic Plane Survey, Stil et al. 2006) for the HI and radio continuum data. The angular resolution is 1′, the channel width for HI is 1.2 km/s.
- GRS (Galactic Ring Survey, Jackson et al. 2006) for CO data. The angular resolution is 46′, the channel width is 0.2 km/s.

\textsuperscript{1} Watson et al. (2010) gives the \( v_{\text{LSR}} = 18.7 \, \text{km} \text{s}^{-1} \) for N117, but the cited value is not found in the given reference — as also noted by Xu & Ju (2014) — and therefore we disregard it.

We searched the surroundings of known IR bubbles N115, N116 and N117. N116 and N117 are listed separately in Churchwell et al. (2006) but based on their appearance and in accordance with HI, CO and radio continuum observations we consider them to be one physical entity (see also the discussion in Section 3.1). We manually constructed a mask (see the example in Fig. 2) based on the appearance of bubbles in the IR data (using the ds9 tool — Smithsonian Astrophysical Observatory (2000)) — basically a ring — and applied it to the HI and CO data. We searched for regions with significant contrast between the temperature of the ring and temperatures inside and outside the ring. We also applied masks, which were 25 percent wider or narrower than the original mask. However, the results did not differ significantly from each other. Such discovered regions were then inspected visually to confirm the connection between the infrared and HI or CO structures. Even though there are previous proposed connections between studied IR bubbles and the CO emission (see the subsection 1.2 in the Introduction), we do not use this a priori knowledge in our search to see, if we will come to the same conclusions. HI data, to our best knowledge, were not studied in the connection with these bubbles.

As another source of information about the distribution of the cold phase of the interstellar medium we use “BGPS clumps” from Dunham et al. (2011). These are sources detected in the Bolocam Galactic Plane Survey (1.1 mm), which are also detected in the \( NH_2 \) line by the Green Bank Telescope. Diameters of these structures lie in the range 33′′ and 5.9′′, but the objects in our studied region are smaller than 2.′1, which correspond to linear sizes between 0.3 pc and 3 pc for our assumed distances. These sizes lie in the interval of sizes given for clumps by Bergin & Tafalla (2007), i.e. objects smaller than clouds and larger than cores. That is why we adopt the name “BGPS clumps” for these tracers of the dense gas.

2.2. Determination of bubbles properties

Knowing the line-of-sight velocity of a bubble we compute its kinematic distance using the flat rotation curve (\( R_0 = 8.5 \, \text{kpc}, V_0 = 220 \, \text{km} \text{s}^{-1} \)).

We derive masses of its atomic and molecular component by using formulas from Rohlfs & Wilson (1996).

\textsuperscript{11} The neutral
hydrogen column density $N_{HI}$ is derived by:

$$N_{HI} = 1.8 \times 10^{18} \int T_h dv,$$

where $T_h$ is observed brightness temperature of the HI line.

The $^{13}$CO column density $N_{^{13}CO}$ is derived by:

$$N_{^{13}CO} = 2.6 \times 10^{14} \frac{T_{ex}}{1 - e^{-T_0/T_{ex}}} \int \tau(o) dv,$$

where $T_{ex}$ is the excitation temperature, which we assume to be 30 K, and $T_0$ for the frequency 110 GHz of the $^{13}$CO ($J = 1 - 0$) is 5.3 K. $\tau$ is the optical depth derived by the formula:

$$\tau = -\ln \left[1 - \frac{T_h}{T_0} \left(\frac{T_0}{T_{ex}} - 1\right)^{-1} - \left(\frac{T_0}{T_{exp}} - 1\right)^{-1}\right],$$

where $T_h$ is the observed brightness temperature of the CO line and $T_{CMB}$ is the cosmic microwave background temperature of 2.7 K. The GRS survey provides maps of the antenna temperature $T_A$, which has to be converted to the brightness temperature: $T_h = T_A / \eta_{MB}$, where $\eta_{MB} = 0.48$.

Using the sizes and column densities we calculate the original density of the medium, into which the bubble expanded. We give results for HI and CO separately.

Knowing the radius $r$ of the bubble and its expansion velocity $v_{exp}$ we can compute its age

$$t_{exp} = \alpha \frac{r}{v_{exp}},$$

where $\alpha = 3/5$ applies to bubbles created by a continuous supply of energy from an OB association and $\alpha = 2/5$ to bubbles created by one-time abrupt supernova explosion.

We estimate the total energy input $E_{tot}$ to create the bubble using the Chevalier’s formula:

$$E_{tot} = 5.3 \times 10^{43} \left(\frac{n}{\text{cm}^{-3}}\right)^{12} \left(\frac{r}{\text{pc}}\right)^{1.12} \left(\frac{v_{exp}}{\text{km/s}}\right)^{1.40},$$

where $n$ is the derived density in the vicinity of the bubble.

We compare our estimates of energies and ages with stellar models (Schaller et al. 1992) and try to derive the masses of the progenitor stars.

### 3. Results

Based on analysis of both the HI and CO data we find, in agreement with previous observations, that infrared bubbles N115 and N116+117 lie at different radial velocities and thus at different distances from us. The bubble N116+117, which has the radial velocity around $v_{rad} \approx 40$ km/s$^{-1}$, was assumed to be connected to a larger radio continuum bubble (Xu & Ju 2014). We confirm this and also believe, that it is in fact connected to both radio bubbles seen in this direction. We also find that the bubble N115 ($v_{rad} \approx 24$ km/s$^{-1}$) has two larger accompanying bubbles best visible in the HI gas.

The radial velocity of 40 km/s$^{-1}$ is close to the terminal velocity in the direction of $l = 54^\circ$ and therefore we place the N116+117 system at the tangential point corresponding to the distance of 5 kpc. The velocity 24 km/s$^{-1}$ has both the near and far kinematic distances. In accordance with most other authors (and also for reasons given below) we adopt the near distance as more appropriate. Therefore we call the system with the radial velocity of 40 km/s$^{-1}$, containing the infrared bubble N115, as the foreground system, and the system with the radial velocity of 40 km/s$^{-1}$ as the background system.

Table II gives an overview of the bubbles identified in the area, their positions and alternate names. Table II summarizes their dimensions, derived masses and densities (Eqs. 1 and 3), and energies involved in their creation (Eq. 5).

#### 3.1. Background system

The background system, centered around the IR bubble N116+117 at the radial velocity of $\sim 40$ km/s$^{-1}$, lies at the distance of approximately 5 kpc. For the purposes of the description we will name the larger bubbles of this system as A and B, and the smaller bubble (which is coincident with the IR bubble N116+117) as C. The diameter of the small bubble C in Figures (and its typical size in all studied spectral regions) is 5', diameters of A and B are 39' and 45', respectively. In linear dimensions it corresponds to 7 pc (C) and 56 or 65 pc (A and B).

In the infrared emission (8µm) the small bubble C is described by Churchill et al. (2006) as two bipolar bubbles, one incomplete (N116) and one closed (N117), see Fig. 3 the right part. Also the larger bubble A is observable in this spectral region as an incomplete ring surrounding a region devoid of any extended emission (see Fig. 3, the upper panel the left part; the brightest emission in the wall of A rightward from C does not belong to this system, it is N115 and belongs to the foreground system). The bubble B has no clear counterpart in the IR region.

All three bubbles are visible in the radio continuum image. C is the brightest one, with the radio continuum filling the interior of the infrared structure. A is visible as the closed irregular ring. B forms the incomplete but well defined spherical ring (Fig. 3, the second panel, in the left part).

The bubble best visible in the HI emission is small C. It is a small hole, which is filled by the radio continuum emission (Fig. 3, the right half). The hole is surrounded by a fragmented denser wall. If the structure expands at all, its expansion velocity is small, around 4 km/s$^{-1}$. Bubbles A and B are not visible, or at least not visible with a sufficient credibility. The region is complex and full of arcs, loops and holes, and therefore one can.
Fig. 3. The multiwavelength image of the background system (left: the total system, right: the small central region. Positions of bubbles A (upper right), B (lower left) and C (small in the middle) are overlaid. The HI is summed over the velocity interval: $38.9 \, \text{kms}^{-1} < v_{\text{LSR}} < 42.2 \, \text{kms}^{-1}$ (left) and $39.8 \, \text{kms}^{-1} < v_{\text{LSR}} < 42.2 \, \text{kms}^{-1}$ (right), the CO over the interval: $38.6 \, \text{kms}^{-1} < v_{\text{LSR}} < 41.6 \, \text{kms}^{-1}$ (left) and $38.4 \, \text{kms}^{-1} < v_{\text{LSR}} < 41.8 \, \text{kms}^{-1}$ (right). Crosses in the CO pictures belong to the BGPS clumps found at the corresponding velocity intervals.
from the HI measurements, which means, that this number is $n$ (around $10^3$).

Using Eqs. 1-5 we calculate masses of individual bubbles.

### 3.1.1. Properties of bubbles A, B and C

Gas in bubbles A and B is ionized by O stars and partly traced by the CO spectrum. Bubble C has two components: a larger, compact bubble and a smaller bubble, which is coincident with the IR bubble. These bubbles (A and B) are seen as rings of the warm ionized gas. The bubbles probably interact with the neutral gas around $\sim$2.1 kpc. Looking at the 3rd panels of Fig. 5 we see, that the radial velocity of bubble B, lies at the distance of approximately 2.1 kpc, is high (2 Myr for A and 0.5 Myr for C). We do not measure the expansion velocity of B, if we take the value from Park et al. (2013) we get the age of 0.3 Myr. This age is too young for the bubble B to be able to create the small bubble C by the collision with the bubble A. However, from the Park et al. (2013) it seems plausible, that this supernova evolves inside the stellar wind bubble (and still resides inside it) and therefore the older stellar bubble is the one, which collides with the bubble A.

All calculated values can be found in the Table 2. Energies involved in the creation of bubbles A and B are quite high ($\sim 4 \times 10^{50}$ erg for A and $\sim 2.6 \times 10^{51}$ erg for B). This is not surprising for the bubble B, which is the supernova remnant, but even the bubble A is quite energetic. It could be an old supernova remnant (Leahy et al. 2008), but the needed energy could be supplied by stars, but either a very massive star or several less massive would be needed. The bubble C is much less energetic and it can be easily powered by the stellar wind of a star, which is able to ionize its surrounding.

### 3.2. Foreground system

The foreground system, centered around the IR bubble N115 at the radial velocity of $\sim 24$ km s$^{-1}$, lies at the distance of approximately 2.1 kpc. Looking at the 3rd panels of Fig. 5 we see, that it contains not only the small central bubble, but also two larger ones. We name the larger bubbles of this system as D and E, and the smaller bubble (which is coincident with the IR bubble N115) as F. The diameter of the small bubble F in Figures (and its typical size in all studied spectral regions) is 13°, diameters of D and E (more precisely, geometrical means of their axes) are 13° and 0°, respectively. For the near kinematic distance, which is our adopted distance, these values correspond to 8 pc (F), 46 pc (D) and 34 pc (E). At the far kinematic distance (8 kpc) sizes of the larger bubbles D and E would be around 140 pc. Such values are comparable to the thickness of the HI disk.

### Table 1. Measured properties of the studied bubbles: positions, radial velocities and diameters, together with wavelengths, where the bubble is nicely seen or where it was previously detected and described. ‘B’ and ‘F’ stands for the background or foreground system.

| Name       | $l$ [deg] | $b$ [deg] | $v_0$ [km/s] | $d$ [arcmin] | Prominent data | System            | Alternative name |
|------------|-----------|-----------|--------------|--------------|----------------|------------------|-----------------|
| Bubble A   | 53.385    | +0.180    | 41.4         | 39           | radio continuum | B                | Leahy’s large-scale bubble |
| Bubble B   | 54.498    | -0.303    | 40.0         | 45           | radio continuum | B                | SNR G54.4-00.3   |
| Bubble C   | 54.089    | -0.087    | 40.0         | 5            | IR emission     | B                | N116 & N117     |
| Bubble D   | 53.821    | +0.302    | 25.0         | 78           | HI line         | F                | -               |
| Bubble E   | 53.257    | -0.419    | 24.9         | 54           | HI line         | F                | -               |
| Bubble F   | 53.556    | -0.014    | 24.1         | 13           | IR emission     | F                | N115            |

### Table 2. Properties of identified bubbles. R is the mean radius, $v_{\text{exp}}$ is the expansion velocity, $M_{\text{HI}}$ is the mass of the bubble in HI, $M_{\text{H}_2}$ is the molecular mass from, $n$ is the density of the medium into which the bubble was expanding (derived from HI and CO), $E$ is the energy needed to create the bubble. The bubble B is the special case: its expansion velocity does not come from our measurements and its age is likely to be higher (see the Section 3.1.1).

| Bubble | $R$ [pc] | $v_{\text{exp}}$ [km/s] | $M_{\text{HI}}$ [M$_\odot$] | $M_{\text{H}_2}$ [M$_\odot$] | $n_{\text{HI}}$ [cm$^{-3}$] | $n_{\text{H}_2}$ [cm$^{-3}$] | $E$ [$10^{50}$ erg] | age [Myr] |
|--------|---------|--------------------------|-------------------------------|-------------------------------|----------------------------|--------------------------|------------------|-----------|
| A      | 28      | 7                        | 2.4$\times 10^4$             | 1.4$\times 10^3$             | 13                        | 31                       | 4.0              | 2.7       |
| B      | 32      | 50                       | 1.2$\times 10^4$             | 1.4$\times 10^3$             | 3.4                       | 19                       | 26.0             | 3.0       |
| C      | 4       | 4                        | 3.60                      | 3.4$\times 10^4$             | 160                      | 7.5$\times 10^5$          | > 0.028           | 0.5       |
| D      | 23      | 5                        | 2.4$\times 10^3$             | 5.6$\times 10^4$             | 1.8                       | 20                       | 0.19             | 3.6       |
| E      | 17      | 6                        | 2.1$\times 10^3$             | 3.0$\times 10^4$             | 3.9                       | 26                       | 0.21             | 2.3       |
| F      | 4       | 4                        | 130                       | 1.5$\times 10^4$             | 23                       | 1.3$\times 10^5$          | > 0.008           | 0.6       |
Fig. 5. The multiwavelength image of the foreground system (left: the total system, right: the small central region). Positions of bubbles D (upper left), E (lower right) and F (small in the middle) are overlaid. The HI is summed over the velocity interval: $23.3 \kms < v_{LSR} < 24.9 \kms$ (left) and $23.3 \kms < v_{LSR} < 24.1 \kms$ (right), the CO over the interval: $23.8 \kms < v_{LSR} < 25.0 \kms$ and $23.9 \kms < v_{LSR} < 24.8 \kms$. Crosses in the CO pictures belong to the BGPS clumps found at the corresponding velocity intervals.
in the infrared and radio continuum data, is another IR bubble, the bubble E (Fig. 5). Along the wall of the bubble D and also along the upper part of the bubble MWP1G053179+001558. According to Bronfman et al. (1996) and Anderson et al. (2009) it lies at the radial velocity $6.6 \text{ km s}^{-1} \leq v_{\text{rad}} \leq 8.3 \text{ km s}^{-1}$ and therefore does not belong to our foreground system (and also not to the background system).

The whole foreground system is well visible in the HI emission (see Fig. 5). The bubble D is a hole in the HI distribution in this region, i.e. it shows only the region devoid of HI but no prominent walls except where it interacts with E (and where F is located). The bubble E shows, on the contrary, a nice partial wall, or arc, in its lower part.

The brightest CO emission is connected to the small bubble F (see Fig. 5 and also Fig. 7). The HI spectrum of the bubble F (the foreground system) is shown in Fig. 6. For the spectrum through the center of the bubble F, the HI spectrum of the bubble E was strong enough to push the gas, but not strong enough to completely dissolve it (see Ehrerová & Palouš 2016 for the analysis, how do properties of CO clouds change with the position of clouds inside and outside HI shells). Bubbles F and E contain cold molecular clumps (BGPS clumps $\equiv$ crosses in the lowest panels in Fig. 5). The picture which we see in this foreground system resembles the background one: two larger, and therefore probably older, colliding bubbles, with the region of the very recent star formation located in the interacting zone. This zone is the center of activity of the system and is best observable in all studied wavelengths. Unlike in the previously described case, the interacting bubbles seem to be less energetic, as they are not connected to a substantial degree with the ionized gas. This is confirmed by the estimates (Table 2). Ages of interacting bubbles A, B, D and E are similar, but D and E are an order of magnitude less energetic than A.

### 3.3. Progenitors of bubbles

One (B) of six studied bubbles is a supernova remnant, one (A) might also be one and the rest are created by stellar winds.

The underlying picture for both systems, the background and the foreground, needs the coeval and cospatial existence of two or more massive stars, which is indicative of the presence of the young cluster. From Morales et al. (2013) we have selected young (< 100 Myr) clusters in the area: Teutsch 42, [BDS2003] 12 and 156, G3CC 69 and 70. Their positions are shown in the Fig. 8 (together with the schematic positions of bubbles) and given in Table 3. From the spatial distribution it looks like that [BDS2003] 12 is connected to the bubble F (IR bubble N115), [BDS2003] 156 to the bubble C (N116+117), Teutsch 42 to either bubble A or D. G3CC 69 and 70 might be connected to the infrared bubble MWP1G053179+001558 which does not belong to any of our studied systems. Radial velocities given in Morales et al. (2013) and cited in Table 3 belong to the gas associated with the clusters.

[BDS2003] 156 and 12 are both young clusters still embedded in the gas and dust envelopes (Morales et al. 2013). Their radial velocities correspond to the radial velocities of the bubbles, which the clusters seem to lie in. They have age of about 100 Myr. The first connec-

but we see (Fig. 5, left) that the bubbles are both located inside the disk and are not influenced by the density gradient in the vertical direction. That is the other reason, apart from wanting to be on a safe, lower energetics, side, why we prefer the near kinematic distance. In the infrared emission ($8 \mu$m) the only clearly visible object is the small bubble F (the IR bubble N115). Churchwell et al. (2006) describes it as a closed ring (see Fig. 3, the upper panel at the right side). A very faint IR emission might be connected to the right-lower wall of the bubble D.

The bubble F is also seen in the radio continuum image. Not very bright emission comes from the interior of the bubble. There might be small and faint regions of the ionized gas along the wall of the bubble D and also along the upper part of the bubble E (Fig. 5).

An object at coordinates $l = 53.19^\circ$, $b = 0.16^\circ$, visible both in the infrared and radio continuum data, is another IR bubble,
Table 3. Young clusters in the studied area.

| Name       | $l$ [deg] | $b$ [deg] | $v_{lsr}$ [km/s] | age [Myr] | Type            |
|------------|-----------|-----------|------------------|-----------|-----------------|
| G3CC 69    | 53.147    | 0.071     | 22.0             |           | embedded        |
| G3CC 70    | 53.237    | 0.056     | 23.9             |           | partially emb.  |
| BDS2003 12 | 53.622    | 0.039     | 23.7             |           | embedded        |
| Teutsch 42 | 53.771    | 0.164     | 37.7             | 3         | exposed, assoc. |
| BDS2003 156| 54.084    | -0.069    | 39.9             |           | embedded        |

Fig. 8. A schematic picture of the two systems, background (smaller red one) and foreground (larger blue one) with young clusters and pulsars in the area.

Fig. 9. A cartoon of the region with all previously known and newly identified bubbles. There are two systems: a foreground system (larger bubbles D and E and a small bubble F connected to the IR bubble N115); and the background system (bubbles A = radio loop GS053.9+0.2, B = SNR G054.4-0.3 and small C = N116+117).

4. Discussion

Both the foreground and the background system look similar. They are formed by two bubbles with radii around 20–30 pc and ages of a few million years which collide. A younger and smaller (∼ 4 pc, less than a million years old) bubble lies at the position of the collision. While this small bubble is best seen in the infrared data, it is much better visible at all studied wavelengths (IR, radio continuum, HI, CO) than the larger structures. Fig. 9 shows our
new, more complicated image of the area, where the interacting bubbles are depicted.

Average densities of the ISM, both corresponding to HI and CO, are higher for the smaller shells. For the bubbles with radii around 20 pc, the densities are several \( \text{H} \text{ cm}^{-3} \) for HI and several 10 \( \text{H} \text{ cm}^{-3} \) for CO. For the smaller bubbles the density is (10-20) times higher for HI and 100 times higher for CO. This is likely the result of the star formation taking place in the densest parts of the ISM, and as the structure created by the massive, energy-releasing star, grows, the ISM becomes less and less dense.

These two systems, though they are similar, differ especially in the amount of energy involved in their creation. The background system, the one in the vicinity of the IR bubble N116+117, is more energetic. Bubble B is known a supernova remnant (Green 2009). Bubble A might also be one: our energy estimates are high enough to be consistent with this hypothesis. But it could also be a more energetic stellar-wind blown bubble. Other bubbles, i.e. the IR bubbles connected to N116+117 and to N115, and the whole foreground system, are probably created by stellar winds or ionizing radiation of massive stars. Energetic requirements, estimated by the Eq. 5 of most of the structures can be fulfilled by one massive star. In the future, these bubbles either merge and create larger structures (if the energy supply is sufficient), or they will soon disappear into undetectability and blend with the surrounding.

There are some young clusters in this area. At least two of them are connected to the studied bubbles: [BDS2003] 156 to a small bubble C (= N116+117) and [BDS2003] 12 to small F (= N 115). Teutsch 42 might be the progenitor of the bubble A (= IR loop GS053.9+0.2). The connection of our studied systems to two young clusters G3CC 69 and 70 and to three young pulsars (J1927+1856, J1929+1844, J1930+1852) in the area is unclear.

4.1. Colliding systems

Perhaps our most interesting finding is that both infrared bubbles (N115 and N1167+117) are associated with collisions of larger and older bubbles. While we do not claim, that all IR bubbles are created by collisions, these events must be important in promoting star formation. We therefore propose, that such collision increase the probability of further star formation, probably by squeezing the material and increasing its density.

In addition to the C&C or RDI scenarios, the collision driven “Collect & Collide” triggered star formation process should also be considered.

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