A FORMATION SCENARIO OF YOUNG STELLAR GROUPS IN THE REGION OF THE SCORPIO CENTAURUS OB ASSOCIATION

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ABSTRACT

The main objective of this work is to investigate the role played by Lower Centaurus Crux (LCC) and Upper Centaurus Lupus (UCL), both subcomponents of the Scorpio Centaurus OB association (Sco–Cen), in the formation of the groups β Pictoris, TW Hydrae, and the η Chamaeleontis cluster. The dynamical evolution of all the stellar groups involved and of the bubbles and shells blown by LCC and UCL are calculated, and followed from the past to the present. This leads to a formation scenario in which (1) the groups β Pictoris, TW Hydrae were formed in the wake of the shells created by LCC and UCL, (2) the young cluster η Chamaeleontis was born as a consequence of the collision of the shells of LCC and UCL, and (3) the formation of Upper Scorpius (US), the other main subcomponent of the Sco–Cen association, may have been started by the same process that created η Chamaeleontis.

Key words: open clusters and associations: individual (Sco–Cen OB Association, LCC, UCL, US, beta Pictoris, TW Hydrae, eta Chamaeleontis)

1. INTRODUCTION

The Scorpio Centaurus (Sco–Cen) OB association is one of the most important sites of recent star formation in the solar neighborhood. This association consists of three subgroups: Lower Centaurus Crux (LCC), Upper Centaurus Lupus (UCL), and Upper Scorpius (US) (Blauw 1964; de Zeeuw et al. 1999). According to their nuclear ages, determined considering both high and low mass stars, LCC and UCL are older with ages between 16 and 18 Myr (Sartori et al. 2003; Mamajek et al. 2002), while US is younger with an age of about 5 Myr (Preibisch & Zinnecker 1999; Preibisch & Mamajek 2008). It should be noted that Blaauw (1978, 1991), using an independent method of measuring ages based on stellar kinematics, found a similar result for US. This already characterizes US as an unbound stellar system.

The energetic output of massive stars in OB associations can significantly affect the interstellar medium (ISM). An interesting possible outcome of this interaction is the so-called triggered or assisted star formation as opposed to spontaneous. Not only isolated stars but entire groups of stars are thought to be formed by way of the triggered star formation mode. The creation of expanding bubbles and shells in the ISM by winds from massive hot stars and supernova (SN) explosions are key ingredients in triggered star formation. In fact, during the expansion the shell may become gravitationally unstable due to increased density resulting from the accumulation of swept-up gas and dust (Elmegreen & Lada 1977) or from the action of SN explosions in the associated bubble (McCray & Kafatos 1987). The instability fragments the shell leading to the formation of dense molecular clouds and eventually to the formation of star groups and clusters. Another possibility is that, during the expansion, shock fronts associated with shells may compress clouds existing in the ISM and ignite star formation. One interesting characteristic of triggered star formation is that it can propagate and form several star groups or associations. Increasing observational evidences of this mode of star formation in our Galaxy and in external nearby galaxies have been reported. Some investigations on this subject include: Thronson et al. (1985); Comeron et al. (1998); Cameron (2001); Oey et al. (2005); Deharveng et al. (2005); Zavagno et al. (2006); Lee & Chen (2007); Lee & Chen (2006); Chen et al. (2007); Carlson et al. (2007). Specifically for the Sco–Cen association, the interaction of the stars with the ISM and triggered star formation have been addressed by several authors: Weaver (1979); Cappa de Nicolau & Pöppel (1986); de Geus (1992). According to Preibisch & Zinnecker (1999) (see also Preibisch & Mamajek 2008), the narrow range of ages observed in US supports the view that the formation of this subgroup took place via the triggering mode. An SN exploding in UCL is assumed to be the triggering agent initiating the burst of star formation.

Several young stellar associations mainly composed of pre-main sequence stars like β Pictoris (BPMG) (Barrado y Navascués et al. 1999; Zuckerman et al. 2001; Ortega et al. 2002, 2004), TW Hydrae (TWA) (de la Reza et al. 1989; Kastner et al. 1997; Webb et al. 1999; Reid 2003; Mamajek 2005; de la Reza et al. 2006), and the compact young cluster η Chamaeleontis (η Cha) (Mamajek et al. 1999, 2000; Jilinski et al. 2005) are closely related to the Sco–Cen OB association. The purpose of this work is to investigate this relation with the aim to explore the part taken by LCC and UCL in the formation of the BPMG, TWA, η Cha, and also US. In principle this can shed light on the question of the way, or ways, these stellar systems were formed. The approach we adopt is based on the calculation of the past three-dimensional orbits of all the systems involved. We also compute the evolution of the shells associated with the bubbles created by the subcomponents LCC and UCL. The expectation is that a formation scenario of the groups the BPMG, TWA and of η Cha can be obtained by following their temporal evolution combined with the evolution of LCC, UCL and the shells of these Sco–Cen subcomponents. We expect that this scenario will help us answer to several general questions concerning this problem: what was the formation mode of the loose unbound associations the BPMG, TWA and of the compact cluster η Cha? Were these systems originated in the shells formed by the bubbles blown by LCC and UCL? Or did the birth of these stellar groups occur exterior to the shells? Finally, had the formation of US something to do with this process? A related point concerns the role played...
by the SNe that certainly existed in LCC and UCL. Did the formation of the groups take place as a consequence of the direct action of SNe on the shells? Or was this action more indirect by contributing to the formation of the bubbles and shells? All these questions are important and, obviously, one cannot hope to obtain detailed answers to all of them by only using stellar and shell dynamics. Nonetheless, this approach can provide a valuable general picture of star formation in the region of the Sco–Cen association.

2. THE METHOD

The methodology of calculating the stellar three-dimensional past evolution of young associations has been employed by us in previous works (Ortega et al. 2002, 2004; Jilinski et al. 2005 and de la Reza et al. 2006) to get estimates of their ages and places of origin. This is realized by backward integration of the orbits of all the stars of the groups taking into account the (modeled) gravitational potential of the Galaxy. The region of first maximum concentration of the orbits (confinement) we consider to be the birthplace of the stellar group; the time interval, from today, we consider to be the age of the group. A more detailed analysis of the orbit confinement region leads to a star distribution pattern at birth that can be considered as a representation of the density distribution in the natal cloud. One example is the BPMG, whose dynamical age of 11.2 Myr can serve as calibrator for other pre-main sequence systems which lack age determination but have similar youth features. This can be of importance, for instance, in the investigation of the temporal evolution of associated protoplanetary disks. Apart from getting age estimates, this method is very efficient in detecting intruding stars. This method can also be used to look for new, potential, members of a group on the basis of the confinement of their past orbits in the previously determined formation region of the group. Furthermore, the confinement must take place at the previously determined age of the group under investigation. This condition is far more stringent than the simple comparison of the present-day kinematics. As an example, using this technique and a compilation, brought together by us containing more than 30,000 stars with Hipparcos entries and radial velocity measurements, we were able to pick five new potential members of the BPMG. They are included in Table 1 where we briefly comment on them. To confirm, or reject, the membership of these systems to the BPMG, further properties, typical of the group, should be investigated. In Table 2 we list the stars which likely are related to the BPMG. Although they are not in the confinement region of the BPMG, they are spatially in its neighborhood at the age of the BPMG. They may have formed not in-group but in a more isolated fashion. To these systems we ascribe the same age of the BPMG. Table 3 contains the stars which very probably have no relation to the BPMG because their orbits take them far away from this group. They can be considered as interlopers.

A similar exercise realized for TWA with an age of 8.3 Myr did not give any additional potential members, probably because of the small number of stars with full kinematic data in the association.

The existence of two modes of star formation, in-group and isolated, seems to be quite common in associations, as in the Orion complex (Lee & Chen 2006) for example. Can we identify some formation mechanism capable of giving origin to these modes? In the following, we shall present a formation scenario in which such a mechanism could exist.

### Table 1

| HIP     | HIP     | HIP     | HIP     | HIP     |
|---------|---------|---------|---------|---------|
| 560     | 21547   | 27321   | 92024   | 92680   |
| 103311  | 10680   | 11437A  | 84586   | 12545   |
| 14361   | 23200⁴  | 23309⁶  | 25486   | 9927³   |
| BD −17 6128 | 105441² | 102409  | 88399   | 102141 |

#### Notes.

This table contains stars whose three-dimensional orbits confine at the age of 11.2 Myr forming a group. The symbols a, b, c, d, e refer to five new potential members.

³ Poorly known F5V star.

⁴ Well known M type star V1005 Ori which independently has been recognized as a member of the BPMG by Torres et al. (2006).

² This star has been independently proposed by Torres et al. (2006) as a member of the BPMG.

⁶ Also independently proposed by Moor et al. (2006) as a member of the BPMG.

The formation region of the group. Furthermore, the confinement of their past orbits in the previously determined formation region of the group. The existence of two modes of star formation, in-group and isolated, seems to be quite common in associations, as in the Orion complex (Lee & Chen 2006) for example. Can we identify some formation mechanism capable of giving origin to these modes? In the following, we shall present a formation scenario in which such a mechanism could exist.

### Table 2

| HIP     | HIP     | HIP     |
|---------|---------|---------|
| 23418AB | 29964   | 95270   |

#### Note.

The stars in this table do not confine but are spatially related to the BPMG at the age of 11.2 Myr.

### Table 3

| HIP     | HIP     | HIP     | HIP     |
|---------|---------|---------|---------|
| 10679   | 79881   | 88726   | 95261   |

Stellar and shell kinematics have been used to study the velocity distribution of stars in expanding shells (Moreno et al. 1999) and also as a tracer of triggered star formation (Comeron et al. 1998; Comeron 2001). In the next section, we shall investigate the evolution of stars and shells in the region of the Sco–Cen OB association. A distinctive feature of our work is that we take into account the temporal evolution of structures from the past to the present.

3. DYNAMICAL EVOLUTION OF THE STAR GROUPS AND SHELLS

In Figures 1, 2, 3 we show the past positions of the stellar groups the BPMG, TWA and η Cha at the epochs of their formation as obtained by us in previous works (Ortega et al. 2002, 2004; Jilinski et al. 2005; de la Reza et al. 2006) using the method mentioned in the previous section. In these figures the axes X, Y, Z are positive oriented in the directions of the Galactic center, the Galactic rotation, and above the Galactic plane, respectively. The positions of the stellar subcomponents LCC and UCL are also shown in these figures. A common and intriguing aspect of these plots is the location, at birth, of the BPMG and TWA behind LCC and UCL, while η Cha shows a somewhat different relative configuration (Ortega et al. 2006). What is the origin of such groups’ disposition? Is it possible to find a formation scenario compatible with such a disposition? To investigate this question we consider the evolution of the bubbles and shells originated by LCC and UCL in addition to their stellar components.

The bubbles are blown by the combined action of the winds of hot stars and SNe. To compute the effective resulting “mechanical luminosity” we use the contribution of stellar winds and the number of expected SNe in LCC and UCL found by de Geus (1992) and take 18 Myr as a mean age for both
Figure 1. LSR positions of LCC, UCL, and the BPMG group at the age of −11.2 Myr in the (X, Y) plane (a) and in the (Y, Z) plane (b). The symbols representing the stars are used to mark roughly the shape of each group.

subcomponents. In the case of an association it is necessary to take into consideration the fact that the creation of a common bubble enclosing all the stars is not a point, instantaneous process, but one extended in space and time. Every star of the association, mainly the hot ones, is contributing to this process. A common shock for the whole association can be said to have formed when all the stars of the association turn out to be within it. This fixes the initial radius $R_i$ and the initial time $t_i$ for the expansion of the shock. The mass of the ambient medium will be swept up by the common shock thereafter for $t > t_i$, and we assume that this takes place in a uniform ISM of number density $100 \text{ cm}^{-3}$ and molecular weight 2.8. To follow the time evolution of the shells created by the UCL and LCC we integrate numerically the system of equations given by Castor et al. (1975):

$$\frac{d}{dt} \left(\frac{4}{3} \cdot \pi \cdot R^3 \cdot \rho_0 \cdot \frac{dR}{dt}\right) = 4 \cdot \pi \cdot R^2 \cdot P$$

$$\frac{dE}{dt} = \mathcal{L} - P \cdot \frac{d}{dt} \left(\frac{4}{3} \cdot \pi \cdot R^3\right)$$

$$E = 2 \cdot \pi \cdot R^3 \cdot P$$

where $R$ is the radius, $P$ is the pressure exerted on the shell by the hot bubble of thermal energy $E$, $\rho_0$ is the ISM density, and $\mathcal{L}$ is the “mechanical luminosity;” that is, the rate at which the energy is generated in the bubble.

Values for the initial thermal and kinetic energies were calculated from the solution of Weaver et al. (1977; see also Mac Low & McCray 1988). Making use of the initial mass of the shell computed as $M_i = \frac{4}{3} \cdot \pi \cdot R_i^3 \cdot \rho_0$, we determine a value for the initial velocity of the shell. Solutions for the expansion of the shells can be computed with and without the contribution of the SNs to the mechanical luminosity. In both cases, we take $R_i = 15 \text{ pc}$ as the initial radius and start the integration at the initial time $t_i = 5 \text{ Myr}$.

4. THE FORMATION OF THE STELLAR GROUPS

Figure 4(a) shows the solutions for the shells of UCL and LCC without the contributions of the SNs. From this figure we see that although there is a certain approach between the shells, they do not come into contact.

Table 4 lists and Figure 4(b) shows the details of the solution (the radii and velocities of the UCL and LCC shells) for the case where both, stellar winds and SNs, contribute to the mechanical energy supplied to the bubbles. As in the previous case, the shells
gradually approach each other but now, about 9 Myr, they have met together starting the process of interaction between them (Figure 7). In the narrowing process of the approaching shells a supersonic flow is expected to arise in the funnel created by them. We identify the flow so formed as a physical mechanism which could be responsible for the formation of the BPMG and TWA (Figures 5 and 6). In the case of TWA an additional trigger can be present besides the pressure field originated by the funneling of the shells: in fact, a Mach shock is expected to arise as a result of the shells collision (Figure 7). Such mechanisms can explain quite naturally why the stellar groups the BPMG and TWA were born in the wake of LCC and UCL. They can also explain the formation of isolated star systems, as is the case in the neighborhood of the BPMG.

Shells collisions have been proposed by Chernin et al. (1995) as a mechanism of violent star formation. Characteristic of this process is the appearance of two reflected shocks which, dragging material from the region of collision, move to the internal areas of the bubbles giving rise to the formation of “champagne flows.” In Figure 8 we show the position of the

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**Figure 3.** LSR positions of LCC, UCL, the BPMG group, TWA and η Cha cluster at the age of −6.7 Myr in the (X, Y) plane (a) and in the (Y, Z) plane (b). The symbols representing the stars are the same as in Figure 1.

**Figure 4.** Time evolution of the LCC and UCL shells. The left panel shows the shells evolution without the SNs contributions. The right shows the shells evolution with the contribution of the stellar winds and SNs. The ordinate is the time interval in Myr from today as in Table 4. The zero point of the distance scale corresponds to the mid-point between the stellar centroids of UCL and LCC at each epoch. Each curve displays the time evolution of the shortest distance from that mid-point to the corresponding shell. The crossing point corresponds to the epoch of the shells collision.

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**Table 4**

| Time (Myr) | \(R_{\text{LCC}}\) (pc) | \(V_{\text{LCC}}\) (kms\(^{-1}\)) | \(M_{\text{LCC}}\) \(\times 10^5\) \(M_\odot\) | \(R_{\text{UCL}}\) (pc) | \(V_{\text{UCL}}\) (kms\(^{-1}\)) | \(M_{\text{UCL}}\) \(\times 10^5\) \(M_\odot\) |
|------------|----------------|-----------------|-----------------|----------------|----------------|-----------------|
| −13        | 15.0           | 13.2            | 0.98            | 15.0           | 18.6           | 0.98            |
| −12        | 22.0           | 4.2             | 1.36            | 23.6           | 4.8            | 1.67            |
| −11        | 25.4           | 2.7             | 1.43            | 28.0           | 3.0            | 1.87            |
| −10        | 27.8           | 2.1             | 1.36            | 30.1           | 2.3            | 1.77            |
| −9         | 29.7           | 1.7             | 1.28            | 32.3           | 1.9            | 1.67            |

\[\sum M = 6.41\]

\[\sum M = 7.96\]

**Notes.**

Timescale presents time interval from today.

\(R_{\text{LCC}}\) and \(R_{\text{UCL}}\) show the radii of the LCC and UCL bubbles.

\(V_{\text{LCC}}\) and \(V_{\text{UCL}}\) show the velocities of shell’s expansions.

\(M_{\text{LCC}}\) and \(M_{\text{UCL}}\) show mass, initial plus swept-up, in the shells expansion.

Values of \(\sum M\) present the total masses accumulated during the shells expansion.
Figure 5. LCC and UCL positions projected onto the plane XY shown at birth of the BPMG age. The positions and sizes of the LCC and UCL shells are also shown. The lines between the shells schematically show the flow created by the compression. The symbols representing the stars as in Figure 1.

Figure 6. Same as in Figure 5 but at the time of the shells collision. The overlapping of the shells is a projection effect. The symbols representing the stars as in Figure 1.

η Cha cluster at the time of its birth, 6.7 Myr ago, determined previously by us (Jilinski et al. 2005); η Cha is at the shell of LCC and by this time the “champagne flow” has advanced into the LCC bubble. We identify the “champagne flow” in this region as the mechanism triggering the formation of the η Cha cluster.

Another interesting point refers to the reflected shock which surged into the bubble of UCL in a direction symmetric relative to the first one. In Figure 9 we show the situation at −5 Myr, the age of US formation (Preibisch & Zinnecker 1999; Preibisch & Mamajek 2008). At this time point US is in the shell of UCL. The configuration is such that the “champagne flow” created by the reflected shock should have interacted with the shell of UCL igniting the burst of star formation which may have given origin to the US subcomponent.

5. DISCUSSION AND CONCLUSIONS

In the Introduction we posed some questions concerning the origin of young stellar groups in the region of the Sco–Cen OB association and wondered whether using stellar and shell dynamics, considered in their time evolution, would give us clues to tackle those questions. We found that this approach leads to a picture in which quite different physical mechanisms capable of inducing star formation can occur. According to this picture, the unbound groups the BPMG and TWA were born in regions of the medium between LCC and UCL, the source of overpressure being the flow generated by the approaching shells of these subcomponents and the Mach shock arisen after the shells have come together. On the other hand, the formation of the compact cluster η Cha took place quite differently, the trigger being one of the energetic “champagne flows” arising as a result of the collision of the shells of LCC and UCL. Are such formative differences reflected in the observed properties of the BPMG, TWA, and η Cha? This seems in fact to be the case.

Table 5 contains and Figures 10, 11, and 12 show the velocity components of the stellar groups the BPMG, TWA, and η Cha.
Figure 9. As in Figure 8, but at −5.0 Myr, the age of US subcomponent. The place of this subcomponent is shown. This location was determined on the basis of its three-dimensional orbit. As in Figure 6 the projection on the plane XY shifts the three-dimensional position of US slightly into the bubble. The symbols representing the stars as in Figure 1.

Table 5
Space Velocity Components (in km s\(^{-1}\)) Relative to the Local Standard of Rest at the Formation Epochs of the BPMG at −11.2 Myr, of TWA at −8.3 Myr and of the \(\eta\) Cha Cluster at −6.7 Myr

| Name    | \(U\) | \(V\) | \(W\) | Age (Myr) |
|---------|-------|-------|-------|-----------|
| LCC     | 2.8   | −11.9 | 1.4   | −6.7      |
| UCL     | 4.6   | −13.1 | 2.1   |           |
| \(\eta\) Cha | 1.1   | −13.1 | −2.8  |           |
| LCC     | 2.8   | −12.2 | 1.5   | −8.3      |
| UCL     | 4.3   | −13.6 | 2.2   |           |
| TWA     | 1.2   | −12.4 | 1.0   |           |
| LCC     | 2.9   | −13.1 | 1.6   | −11.2     |
| UCL     | 4.1   | −14.8 | 2.4   |           |
| BPMG    | 0.3   | −11.5 | −2.5  |           |

relative to the local standard of rest (LSR) at the epochs of their formation. The velocity components of LCC and UCL are also included. All the groups have \(V_z\) components negative, that is, contrary to the Galactic rotation. This reflects the peculiar motion of the gas complex. At the same time, all the groups have \(V_x\) components positive (the direction to the Galactic center), that is, in the course of time they will lose rotational support until the Galactic rotation takes over. How does the situation at these epochs look relative to the average motion of LCC and UCL? Table 6 and Figure 13 present the velocity components of the BPMG, TWA and \(\eta\) Cha in this reference system at the times of their formation. We see that the BPMG has the largest positive \(V_z\) component, equal to 2.4 km s\(^{-1}\). This is consistent with the proposed mechanism of gas flux produced by compression and also explains why the BPMG is farther away from LCC. On the other hand, the \(V_z\) component of TWA is also positive but significantly smaller than that of the BPMG which is consistent with the final stage of compression resulting from the shell collision 9 Myr ago. Finally, the \(V_z\) component of \(\eta\) Cha is negative and quite small, whereas its \(V_x\) component is larger and, in the Galactic anticenter direction, consistent with a triggering action due to the “champagne flow.” The sequence shown by Figure 13 strongly suggests the occurrence of one process, involving several triggering mechanisms, taking place during the temporal evolution of the Sco–Sen subcomponents LCC and UCL.

In Figure 14 we show the situation at the epoch 13 Myr ago, when the common shell was formed and the region where the BPMG would be formed at about 11 Myr ago. It can be wondered whether such 2 Myr time intervals would be sufficient to produce the necessary compression of the medium between LCC and UCL to induce the formation of the BPMG. Couldn’t a different, additional more powerful triggering mechanism be involved in the formation of that stellar group? An SN event occurring in LCC prior to the formation of the common shell, for example? Note that this would also be consistent with the dynamical constraints and would not contradict Figure 13. Such a possibility was investigated by us in a previous work.
Figure 11. As in Figure 10 but for TWA.

Figure 12. As in Figure 10 but for the η Cha.

Figure 13. Space velocity components of the BPMG, TWA and η Cha cluster relative to the average motion of LCC and UCL at the epochs of their formation: −11.2 Myr, −8.3 Myr, and −6.7 Myr, respectively.

(Ortega et al. 2004) where an attempt was made to identify the probable SN responsible for the formation of the BPMG. Unfortunately, large uncertainties in the radial velocity of the suspected runaway star made this attempt inconclusive. Better radial velocities are needed in order to get reliable three-dimensional orbits of runaway stars.

Aside from the bound nature of η Cha, further differences have been reported in the literature. Moraux et al. (2007), for
example, emphasize its very compact configuration, the absence of wide binaries and mass segregation in this young cluster. All these features point to a violent formation of η Cha. Interestingly, the position of the US subcomponent in the shell of UCL 5 Myr ago follows from our past orbits calculations of US using the present positions and velocities of its stars, and also from the modeled evolutions of the shells. It is worth noting that the formation of US in the shell of UCL may have been triggered by the “champagne flow” arising from the collision of the shells of LCC and UCL.

It should be stressed that the ambient mean number density of 100 cm$^{-3}$ used in the calculations is not arbitrary because it must satisfy dynamical constraints set by the orbits of the stellar groups and the evolution of the shells.

How does the mass swept up by the shells with the mass observed today in the region of the Sco–Cen association? The masses of the shells up to $-9.0$ Myr, the time when they collided, given by our solutions are $6.4 \times 10^5 M_\odot$ for LCC and $8.0 \times 10^5 M_\odot$ for UCL (see Table 4). This gives a total mass of $1.4 \times 10^6 M_\odot$, consistent with the value of about $10^6 M_\odot$ quoted by Weaver (1979). We compare this value with the mass seen today in the adjacent regions of LCC and UCL. For the H I loops surrounding today the subcomponents LCC, UCL and US, de Geus (1992) found a mass of $4.8 \times 10^5 M_\odot$. In addition to this, there is mass in the form of molecular clouds. In Figure 15, constructed using the catalog of Dutra & Bica (2002), we show the present-day situation. One identifies molecular gas aggregates such as the Chamaeleontis clouds, the Lupus clouds, the Ophiuchus complex, the Coma Australis molecular cloud, and others. According to Table 1 of Ballesteros-Paredes & Hartmann (2007), the mass in these molecular clouds amounts to $0.8 \times 10^5 M_\odot$, which, added to the previous $4.8 \times 10^5 M_\odot$ H I mass found by de Geus (1992), gives a mass of $5.6 \times 10^5 M_\odot$. In addition to this, the Aquila Rift molecular cloud, with a mass of $2.7 \times 10^5 M_\odot$, has been often genetically related to the Sco–Cen association (for example, Straižys et al. 2003). Then the overall identifiable mass in the region will be $8.3 \times 10^5 M_\odot$. If we do not include in this value the mass $1 \times 10^5 M_\odot$ for the LCC H I loop found by de Geus (1992), the resulting value $7.3 \times 10^5 M_\odot$ is consistent with the mass associated with the UCL shell. As regards LCC, quite a lot of mass would remain unidentifiable today and the scenario here proposed would be indicating that a sizeable quantity of mass has been leaving the system during the last 5–6 Myr, most probably in the direction of the Galactic anticenter (as suggested by Figures 8 and 9), a low density region in which the Sun is located at present. In this respect, it is pertinent to note that de Geus (1992) in his analysis of the present-day situation found no evidence of expanding gas associated with the LCC subcomponent.

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