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An Investigation on the Morphological Structure of IC59: A New Type of Morphology of BRCs?

Jingqi Miao[1], Koji Sugitani[2], Glenn, J. White[3,4], Richard P. Nelson[5]

ABSTRACT

With references to recent observational results on the nebula IC59, we applied our previously developed Smoothed Particle Hydrodynamics (SPH) code which is based on Radiative Driven Implosion (RDI) model, to investigate the possible formation mechanism for the observed morphological structures of differently shaped BRCs. The simulation results confirmed the existence of the 4th type morphology of BRCs – type M BRC. We are able to find the necessary condition for the appearance of the type M BRC based on the fact that the simulated physical properties of the cloud are consistent with observations on IC59. More importantly, the prospect of RDI triggered star formation by RDI model in all of the observed type M BRCs is ruthlessly eliminated.

Subject headings: star: formation – ISM: evolution – ISM: HII regions – ISM: kinematics and dynamics – radiative transfer.

1. Introduction

Material at the star-facing surface of dense molecular clouds is intensively ionized by the ultraviolet (UV) radiation from nearby OB stars. The emission lines from recombination of electrons with ions create a bright rim surrounding the star facing surface of the molecular

[1]Centre for Astrophysics & Planetary Science, School of Physical Sciences, University of Kent, Canterbury, Kent CT2 7NR, UK, J.Miao@kent.ac.uk

[2]Institute of Natural Sciences, Nagoya City University, Mizuho-ku, Nagoya 467-8501, Japan

[3]Centre for Earth, Planetary, Space & Astronomical Research, The Open University, Walton Hall, Milton Keynes, MK7 6AA

[4]Space Physics Division, Space Science & Technology Division, CCLRC Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire, OX11 0QX, UK

[5]School of Mathematical Sciences, Queen Mary College, University of London, Mile End Road, London E1 4NS, UK

cloud. On the other hand, ionization heating drives a strong shock wave into the molecular cloud so that the compressed gas forms a condensed core behind the bright rim, which is the typical structural feature of a Bright Rimmed Cloud (BRC). The Formation of BRCs opens a window for our investigation on the physical processes involved in the interaction of UV photons with the gas particles in molecular clouds.

The variety of the morphology of BRCs has interested both astronomers and theoreticians since the last decade. Most of the observed BRCs could be categorized by three different morphologies dependent on the curvature of their bright rims: type A, B and C with an increased order of degree of the rim curvature (Sugitani et al 1991; Sugitani & Ogura 1994). The curved bright rims of type A, B and C BRCs are usually convex having the apex of its rim aligned with the center of the condensed core and the radial direction of the illuminating star as shown by the IC63 structure in both panels of Figure 1. Several theoretical models of the UV radiation effect on the dynamical evolution of molecular clouds have successfully re-produced the formation process of the above three types of BRCs (Lefloch & Lazareff 1994; Kessel-Deynet & Burkert 2000; Willams et al. 2001; Miao et al 2006, 2009), hence we have gained a basic understanding on the mechanism of the formation of BRCs with type A, B and C morphologies.

However, there is another interesting type cometary clouds, whose axial line is not aligned with but offset from the radial direction of the illuminating star by an angle θ (Osterbrock 1957), as shown by the right cap structure of the lower left object in the left panel of Figure 1. By a further inspection, one can find that the observed cometary structure is one of the two caps of a bigger cloud structure whose star facing surface is concave to the radial direction of the illuminating star as shown by the lower left structure in the left panel of Figure 1. Therefore the symmetrical line of any one of the two caps is neither aligned with the radial direction of the illuminating star, nor the condensed molecular core behind the concave rim as shown by the lower left object in the right panel of Figure 1. This type of cometary structure does not belong to any of the three previously defined morphological types. Quite a few known cometary clouds bear the same structural feature, e.g., the No. 8 source in IC 1396 (Osterbrock 1957) and SFO 80 in RCW 108 (Urquhart et al 2009). The H_α images of IC59 and IC63 in the same region are shown in Figure 1, which also describes an offset angle θ of the symmetrical line of IC59 from the radial direction of the illuminating star (for the time being we use the conventional name IC59 for the right cap structure only and later on we will redefine the structure range of IC59). The physical mechanism for the appearance of this type of morphology in molecular clouds, and its relation to the possibility of triggered star formation by RDI have not been fully understood.

Although the offset of the apex of IC59 from the radial direction of the illuminating star was tentatively explained as the projection effect of a three dimensional space onto a two dimensional observation plane (Blouin et al 1997; Karr et al 2005), the observed CO emission core from IC59 by Karr et al (2005), which usually traces the compressed dense molecular materials behind the apex of the bright rim of a BRC, does not seem to support this explanation. The CO emission core presented in the lower part structure in the right panel of Figure 1 reveals a dense core behind the concave rim, which is aligned with the radial direction of the illuminating star. If the offset angle of the apex of IC59 is a consequence of projection effect, the CO emission core should also be subject to the projection effect so that it should appear just behind the apex of the bright rim of the IC59, as the CO emission core in IC63 does, as shown in the upper cometary structure in the right panel of Figure 1. Since the center of the CO core in IC59 is aligned with the radial direction of γ CAS, it seems more likely that this type of morphological structure, i.e., a condensed molecular core behind the concave rim which has two apexes at its two sides, is developed during the evolutionary process of a molecular cloud by RDI mode, just as the formation of type A, B and C BRCs, whose morphology formation mechanism has been well understood through the theoretical simulations (Miao et al 2009). We would categorize this type of structure as type M morphology for its geometrical analogy.

In this paper, we will explore the possibility of forming a BRC with a concave rim by RDI mechanism using our previously developed SPH (Smoothed Particle Hydrodynamic) code (Miao et al 2006, 2009), and discuss the connection between the appearance of type M BRC and triggered star formation within it. We will structure the paper in the following way: 1.Gather the structural and physical properties of IC59 and the illuminating star from available literature and our own observation; 2.Present the simulation results which reveals the formation of type M morphology in the evolutionary process of a molecular cloud by RDI mode; 3. Discuss the kinematics behind the formation of type M morphology in BRCs; 4. Discuss the possibility of RDI triggered star formation in type M BRCs; 5. Derive a conclusion for result of our investigation.

2. Physical properties of IC59 and γ CAS

As seen from Figure 1, IC59 is one of the pair nebulae in Sh 2-185 and is at a distance about 1.3 pc from the illuminating B0 IV star γ Cas, which is approximately 190 pc away from us. Our understanding on the physical properties of IC59 is gradually improved with the availability of the progressively advanced observing facilities. IC59 was once defined as a reflection nebula (Osterbrock 1957) for there was little molecular emission detected (Jansen et al 1994, 1995) especially when compared with that of its neighbor IC63 in the same region. Later the radio continuum and HI study by (Blouin et al 1997) revealed the existence of atomic hydrogen in IC59, which were produced through the dissociation of H_2, thus IC59 was taken as an emission nebula. The multiwavelength investigation on IC59 (Karr et al 2005) confirmed the presence of H_2 in IC59 and its similarity to IC63 in other spectrum features except that an ionization front (a bright rim) in IC59 was not clearly detected.

Recently we obtained Hα images with the Wide Field Grism Spectrograph 2 (Uehara et al. 1994) and Tektronix 2048 $\times$ 2048 CCD mounted on the University of Hawaii 2.2-m telescope on 2009 September 10 UT. It is seen from Figure 2 that around the star facing side of the nebula, a bright rim covers the east cap, the concave surface and the west cap. The brightest part of the rim is the concave part whose center is aligned with the radial direction of the star so that it receives stronger UV radiation than the surfaces around the two side-caps. Therefore it seems more reasonable to consider the two apexes and the concave part as one whole piece of the nebula structure and name it as IC59, rather than the east part only. We will use this new definition of IC59 in our following discussions. With the position of CO emission core in IC59 defined by Karr et al (2005) and the latest H_α image of IC59 we obtained, we believe that we have gathered enough evidence to ascertain that the newly defined IC59 structure should be a type of BRC structure with type M morphology, although which has never been investigated.

The geometrical and physical parameters we can collect from different literature's for the east cap of IC59 are as follows. The width of the cap $w \sim 0.18$ pc; length $l \sim 0.12$ pc (Osterbrock 1957) where the dimensions are defined by the convention for BRCs (Osterbrock 1957; Sugitani et al 1991; Sugitani & Ogura 1994); its column density is $3.4 \times 10^{17}\mathrm{cm}^{-2}$ (Karr et al 2005); the ionization flux at the star facing surface of IC59 is $F_{UV} = 5 \times 10^9\mathrm{cm}^{-2}\mathrm{s}^{-1}$, under the premise that γ Cas is a B0 star with a temperature 33,340 K (Vacca et al 1996; Karr et al 2005). An average temperature of the east cap of IC59 is estimated as $T = 590$ K (Karr et al 2005).

The above collected properties of IC59 are used as a guidence for the selection of an appropriate candidate from our simulation experiment in order for us to address the formation mechanism of type M BRC from an initially uniform molecular cloud. We run our SPH code (named as NEWcloud) for molecular clouds of different initial conditions. From the results obtained, we are able to reveal the possible origin and future evolution of IC59, and especially address the possibility of RDI triggered star formation within IC59 and other similar BRCs. It is our intention to focus on the formation mechanism of type M BRCs in this investigation, therefore the properties of IC63 is not included in our investigation, for which we will address its physical properties and evolutionary features in a separate paper in preparation.

3. Results and discussions

3.1. The formation of type M morphology

The SPH code we developed (Miao et al 2006, 2009) solves the compressible fluid dynamic equations, with inclusion of self-gravity of the cloud, the most important heating and cooling processes plus a chemical network of 12 basic chemical components in BRCs, which has been fully explained in our previous two papers and will not be repeated here. Interested readers could read the above two cited papers to know the details of the code. The radiation fields consists of an standard isotropic interstellar background radiation (with photon's energy between 6.4 and 13.6 eV)(Habing 1968) and a UV radiation field from nearby star (with photon's energy higher than the hydrogen ionizing energy of 13.6 eV). The cloud is initially situated at the center of a xyz coordinate and the UV radiation is set along $-z$ direction and incident on the surface of the upper hemisphere of the simulated cloud, with a constant energy flux F_{UV} specified in the last section.

The simulated cloud is initially situated in a warm and defuse interstellar medium, which is assumed to compose primarily of atomic hydrogen with $n(\mathrm{HI}) = 10$ cm^{-3} and $T = 100$ K (Nelson & Langer 1999; Miao et al 2006). The molecular cloud is of an initial temperature of 60 K, mass of 2 $M_\odot$ and a radius of 1.4 pc (corresponding to an initial number density $n_i(\mathrm{H_2}) = 3.48$ cm $^{-3}$, which is within the observed range of volume densities of star forming molecular clouds (Heiner et al 2008)) In all of the simulations presented in the following, 20,000 particles are used.

The hydrogen number density profile in the up-left panel in Figure 3 shows that 0.47 My after the radiation fields were switched on, the initially spherical cloud evolved into a type A BRC having its front surface (star facing side) squashed from a hemispherical surface and a maximum density of 30 cm^{-3} was achieved at the head of the upper hemisphere as a consequence of UV radiation induced shock propogation into the cloud, whose physical implications have been fully understood (Bertoldi 1989; Lefloch & Lazareff 1994; Kessel-Deynet & Burkert 2000; Willams et al. 2001; Miao et al 2009). The up-middle and -right panels show that the front surface of the cloud gets more squashed at $t = 0.62$ My and then become very flat at $t = 0.82$ My, whilst a more and more condensed core appeared with a centre density of 136 cm^{-3} at t = 0.83 My. When $t = 1.01$ My, the front surface of the cloud started to become concave to the radial direction of the star which is above the cloud at positive z axis. A further condensed core formed behind the concave surface and had a centre density of 1127 cm^{-3}. The degree of concavity of the front surface got enhanced at $t = 1.11$ My. It is seen from the bottom-middle panel in Figure 3, that the morphology of the cloud structure is very similar to the observed morphology of IC59 as shown in both panels in Figure 2, i.e., a concave surface whose center is aligned with z axis (the radial direction of the star), is in between two caps whose geometrical symmetrical line is offset an angle from the z axis. Thus a type M BRC has formed and the centre density of the core behind the concave part of the rim is 807 cm^{-3} which is less denser than that at $t = 1.01$ My.

It is obviously seen that the core behind the concave surface expanded in volume from $t = 1.01$ to $t = 1.11$ My, therefore the centre density of the core decreased. The bottom right panel in Figure 3 shows that the whole structure retained a type M morphology but further expanded at $t = 1.24$ My and the centre density of the core further decreased to 581 cm^{-3}. Further simulation sequences after $t = 1.24$ tells the whole structure contines expansion and finally expands away as large piece of very defused cloud at $t = 1.7$ My.

Taking any one of two caps in the formed type M BRC at $t = 1.11$ My as an example, we can estimate its average column density and then compare it with the observational data. We take the east cap structure in the middle-bottom panel of Figure 3 as the corresponding structure previously defined as IC59 by astronomers. Simulation result revealed that the structure of the east cap has a mass of 3×10^{-4} $M_\odot$. If we assume the mass distributes uniformly in a cap of a sphere of height 0.13 pc and radius 0.10 pc according to the simulated dimension, which is very close to the measurement (0.12, 0.09) pc by Osterbrock (1957), a minimum value of the column density $N = 2.2 \times 10^{17}$ cm^{-2} is derived which is consistent with the observed value of 3.4×10^{17} cm^{-2}(Karr et al 2005). The result for the west cap is similar to the east cap.

3.2. Kinematics for the formation of type M BRCs

A qualitative analysis on the kinematics of the evolution of the cloud would reveal a physical picture for the formation of type M BRC. The cloud is not strongly bound by self-gravity since it has an initial Jeans number α (the ratio of the gravitational to the thermal energies) of 0.025 which is far from the value of 1, the necessary condition for a molecular cloud to be unstable to gravitational collapse. After the initial stage of the evolution , the head of the front hemisphere of the cloud is modestly compressed at $t = 0.62$ My so that the gravitational center of the cloud has moved to the head of the upper hemisphere as shown in the up-middle panel in Figure 3. The gas particles at the apex and off-apex points on the surface of the upper hemisphere have approximately similar gravitational acceleration, hence similar radial velocity V_G as illustrated in Figure 4 by the solid arrowed lines. One the other hand, the UV radiation induced shock velocity $V_s'(\theta)$ (by the dot arrowed lines in Figure 4) at the point $(R, \theta$) on the front surface is given by (Bertoldi 1989; Lefloch & Lazareff 1994),

$$V_s'(\theta) = V_s(0)(cos(\theta))^{1/4} \quad (1)$$

where θ is the angle of a surface point from z axis and $0 \leq \theta \leq \pi/2$ for all of positions at the front surface of the upper hemisphere of the cloud; $V_s(0)$ is the shock velocity at the apex $r = R, \theta = 0$ and $V_s(0) \sim [F_{UV}/n]^{1/2}$ with n being the number density of the site (Bertoldi 1989).

For the molecular cloud we simulated, because of its very low initial density, the shock velocity $V_s(0)$ is one order of magnitude higher and the radial velocity V_G is much lower than that in those clouds in which type A, B and C BRCs formed with a high probability of triggered star formation in their shocked cores (Miao et al 2009). Therefore the total velocity V_T' (by the dot-dash arrowed lines in Figure 4) of a gas particle at the front surface forms a very small angle δ from the direction of V_s' as shown by Figure 4, so that V_T' is actually dominated by the component V_S' which is dependent on the angular distance θ of the position from z axis. Consequently V_T' is determined by θ and will decrease with θ. Now it is clear that the gas particles at the apex of the front surface have the highest total velocity $V_T = V_T'(0)$ whose direction is aligned with $-z$ axis as shown by Figure 4. After some period of time, the gas particles at or close to the apex of the front surface are in advance of the particles at two sides of the apex along $-z$ axis, which results in formation of a concave surface on the star facing side of the molecular cloud as shown by the lower left, middle and right panels in Figure 3.

3.3. Other fingerprints of the simulated cloud

Figure 5 displays a sequence of formation of a CO core behind the concave surface. Simulation data reveals that the fractional concentration X_{CO} varied with the centre density of the compressed core since CO is a very important ingredient for tracing the dense gas in a molecular cloud. From $t = 0.47$ to 1.01 My, the centre concentration of X_{CO} in the compressed core increased from 1.55×10^{-11} to 7.9×10^{-7} and then decreased to 2.2 $\times 10^{-7}$ at $t = 1.11$ My, to 3.08 $\times 10^{-8}$ at $t = 1.24$ My. The variation of the CO fraction reflects the change of the centre density in the cloud structure over the whole evolutionary sequence. The position of the CO core at $t = 1.11$ My is very similar to the observed one as shown in IC59 structure in lower part of the right panel of Figure 1 (Karr et al 2005).

In order to investigate the thermal properties of the caps, the east cap was chosen for keeping a consistency with the column density estimation in the last section. Figure 6 presents a temperature distribution of the east cap within a slice of $\Delta y = 0.056$ pc centered at $y = 0$. Because of the low initial density of the cloud (3.48 cm^{-3}), ionizing flux easily penetrates into the cloud structure and gas particles in the cap are heated dominantly by ionizing hydrogen atoms. The average temperature over a region of $0.43 < x < 0.63$ pc, $-2.08 < z < -1.95$ pc is 520 K, which is comparable with the value of 590 K estimated by Karr et al (2005), while the average temperature in the core behind the concave rim is only 65 K due to its higher density (807 cm^{-3}) than that in the cap structure ($\tilde{4}0$ cm^{-3}). The dimension of the region with such a temperature distribution is also consistent with that was determined by Osterbrock (1957) for the dimensions of the east cap: a diameter of 0.18 pc and height of 0.12 pc. Beyond the front surface of the east cap, the temperature reaches 10^4, typical to HII region. Around the front surface of the east cap, recombination of electrons with hydrogen ions creates the bright rim as shown in Figure 2, although dimmer than that around the concave part of the rim, where the ionisation/recombination are most active.

3.4. The structure formation and the fate of IC59

Taking the consistent results derived from our simulation for the column density, the position of CO core, the dimension and mean temperature of the east cap with that from observations, we could confidentlly construct a whole evolutionary pictrue for the formation of the whole structure of IC59: An initially uniform and spherical molecular cloud evolved into a type M BRC after being exposed to the ionizing radiation from the nearby star γCAS for 1.11 My; the observed cap structure is one of its two caps formed at the above specified time, where there is no condensed cores inside due to its high temperature state (520 K); the whole structure will expand away after t = 1.7 My.

centre of the cap Therefore no IRAS point sources should be observed in both of caps' structures. Our simulation results strongly support the comment made by Karr et al (2005) on the the nature of the previously reported IRAS point source inside the east cap, i.e., 'the spuriously detected IRAS point source inside is merely an unresolved dust feature'. From the simulation result, we conclude that there is no prospect for triggered star formation in the whole structure of IC59 at all. We will address a general criteria in the next subsection for the prospect of RDI triggered star formation in type M BRCs.

3.5. Formation of type M BRC and trigger star formation

In order to find the physical conditions for the formation of type M BRCs and its relation to the possibility of triggered star formation, we firstly define the initial position of our simulated molecular cloud in Lefloch's two-parameter space, the ionization parameter Δ and recombination parameter Γ which are expressed in the following forms (Lefloch & Lazareff 1994):

$$\Delta = \frac{n_i}{n_0} = f_1(R, F_{UV}, c_i, n_0) \tag{2}$$

$$\Gamma = \frac{\eta \alpha_B n_i R}{c_i} = f_2(R, F_{UV}, c_i, n_0) \tag{3}$$

where n_i and n_0 is the initial densities of ionized and neutral hydrogen atoms respectively; c_i is the isothermal sound speed in the ionized gas; $\eta \approx 0.2$ is a parameter to describe the effective thickness of the recombination layer around the molecular cloud; α_B is the effective recombination coefficient under the the assumption of 'on the spot' approximation (Dyson & Williams 1997); R is the initial radius of the cloud; f_1 and f_2 are two functions of the R, F_{UV}, c_i and n_0. This two dimensional parameter space was divided into five different regions depending on the prospects of the evolution of molecular clouds under the effect of UV radiation. According to lefloch's RDI modeling without inclusion of the self-gravity of the system, the clouds in region I ($\frac{\Gamma}{\Delta} \leq 1.4 \times 10^{-2}$) and II ($\Delta < 10^{-2} - 10^{-3}$) are too trivial to discuss because the effect of the ionization is too weak to produce any noticeable dynamical effects; clouds in region III (defined as $\Delta > 2$) is entirely photo-ionized by an R-weak ionization front and there is no possibility for RDI triggered star formation. Recent investigation based on a SPH code developed by the authors of this paper has proved that the lower boundary of region III should be shifted to $\Delta > 23$ as the result of inclusion of the self-gravity of the cloud in the our code (Miao et al 2009). Classifications of Region IV and V are not very relevant to the clouds we are interested in this work, therefore will not be described here.

The cloud we simulated above (termed as cloud A in the following) has $\Gamma = 21$ and $\Delta = 57$, so that its initial location in Lefloch's two-parameter space is in region III ($\Delta > 23$), which means that there should be no prospect for triggered star formation in a cloud of an initial mass of 2 $M_\odot$ and a radius of 1.4 pc, while $F_{UV} = 5 \times 10^9$ cm^{-2}s^{-1}. The simulation result presented in the last section on the future evolution of the IC59 is consistent with the predicted prospect of the BRCs by the modifiled Lefloch's 2-dimensional parameter space model.

In order to show that type M BRC is indeed one of morphologies resulted from UV radiation effect and type M BRC formation in cloud A is not by chance, we made further exploration to a few more molecular clouds of different initial physical conditions. We further found another two molecular clouds (termed as B, C clouds in the following) which would develop type M BRCs and finally expand and split into pieces as cloud A does. We listed their initial physical properties in Table 1 with the calculated values of ionization/recombination parameters. It is clearly seen that their initial physical status make them all locate in region III. Following the way we did our exploration, we can, in principle, found infinite number of molecular clouds with different physical conditions and under different strength of UV radiations, which would form a type M BRC by RDI mode. Although we are not able to prove that all of the molecular clouds located in region III in Lefloch's two-parameter space will form type M BRCs, we can at least conclude that an initial location in region III in the Δ/Γ parameter space is a necessary condition for a molecular cloud to develop a type M BRC morphology, i.e, a molecular cloud has to be in a very high initial ionization state, as the definition of Region III described. Furthermore it is also true that the triggered star formation by RDI mode is not possibly to occur in all of type M BRCs observed, which may form a good guidance for astronomers who are looking for the sign of triggered star formation in different BRCs.

4. Conclusion

Based on our latest observation and numeriacl simulation results to the nebula IC59 in Sh-158, we conclude that the observed cap structure (so called IC59 in Sh-158) is actually one of the two caps of a type M BRC which is a transient morphology from type A morphology to a full expansion, which is developed over the evolution of a molecular cloud of an initial mass of 2 $M_\odot$ and a initial radius of 1.4 pc, under the effect of UV radiation from nearby star γ CAS. The molecular cloud is at a very high initial ionization state in the ionization flash region III in Lefloch's two dimensional parameter space. Comparison of the simulated physical properties of the type M BRC with the observations on IC59 structure tells that the observed IC59 has been exposed to the ionizing radiation from γ CAS for about 1.11 My. Simulation result predicts that the observed IC59 structure will continue expanding and finally split into pieces after another 0.59 My. The future evolution of IC59 revealed by numerical result is consistent with the analytical conclusion on the evolutionary prospect of a molecular cloud located in region III in the two-parameter space defined by Lefloch & Lazareff (1994), i.e., all of the molecular clouds with their initial status in region III will be finally evaporated with no prospect for triggered star formation at all.

Further investigation found more molecular clouds of different initial conditions could evolved into a type M BRC after a type A morphology was developed through RDI mode.

However these molecular clouds share a common character, i.e., no matter how different their initial masses or radii, their initial conditions make them all locate initially in region III in Lefloch's two parameter space. Therefore we are able to define a necessary condition for a molecular cloud to develop a type M BRC based on the analytical results (Lefloch & Lazareff 1994) and our numerical simulations: the molecular cloud should have the initial physical conditions that make it an initial state in region III in Lefloch's two-parameter space.

Although the formation of type M BRC may not account for all of the obseerved offsets of the apexes of BRCs to the radial directions of their illuminating stars, our simulation results reveal that if there are two caps connected by a concave front surface in an observed BRC structure and the concave part is centrally aligned with the radial direction of the star, then the offset of the apex of the observed caps' structure to the radial direction of the star may be caused by the formation of a type M BRC. In a seperated paper, we will address some other reasons which could possibly cause the offset of the apex of a single structure BRC to the radial direction of the illuminating star. More importantly, the presented simulation results in this paper reveal that triggered star formation will not occur in the observed type M BRC, neither in its cap structures nor behind the concave front surface.

The above results based on our simulations strongly support the argument made by Karr et al (2005) on the nature of the structure of IC59: the previously detected potential example of triggered star formation is spurious and the observed IRAS source(s) in IC59 is merely an unresolved dust feature.

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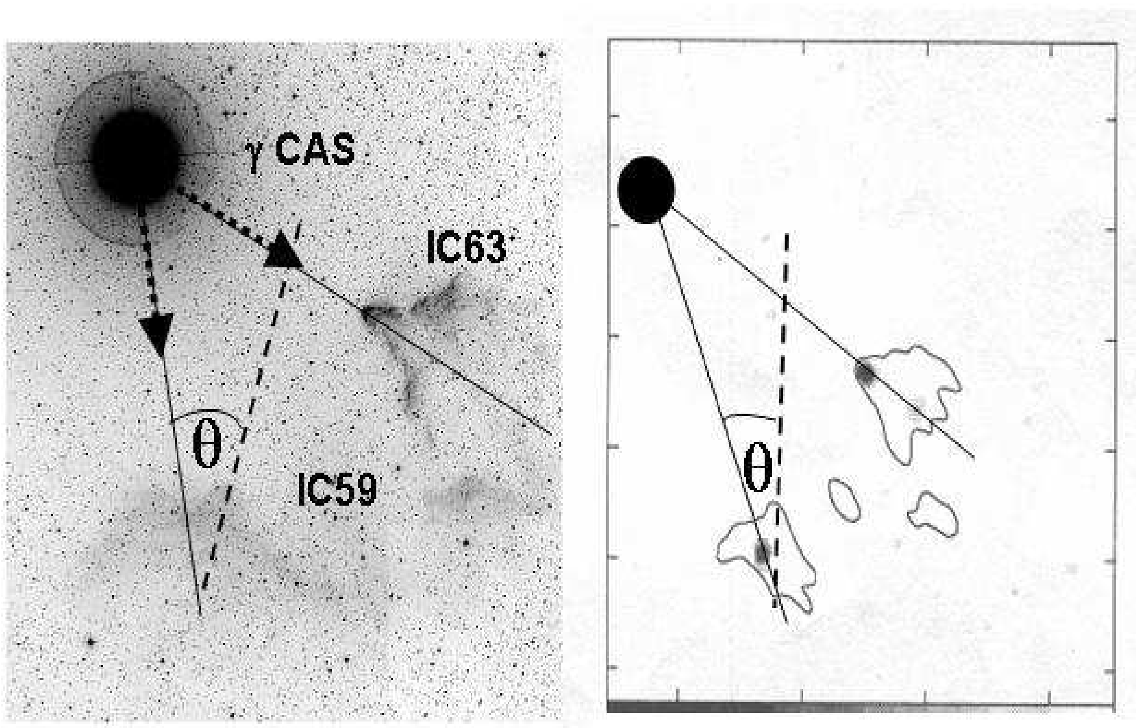

Fig. 1.— A geometrical picture of Sh-158 with both IC59 and IC63 surrounds the illuminating star γ CAS. On the left is theH_α images for IC63 and IC59 and one right is position of the detected CO emission cores in both clouds Karr et al (2005).

Fig. 2.— Hα image of IC59 overlaid with CO emissions. The area of the image is ∼11.5′ × 11.5′. South is at the top, West to the left. Arrows indicate the directions of UV light from γ Cas. The pixel scale is $0''.34$ pixel^{-1}, providing a field of view of 11.5′ × 11.5′. Three 180 s exposures dithered by 5″ were taken with H_α narrow band filter. Dome flat fielding was applied and a combined image was obtained with these three images. The CO contours is derived by suming up 5 channels of V(LSR) = -0.839798, -0.0272369, 0.785339, 1.59790 and 2.41046 km/s. The central LSR velocity of the integrated intensity map is about 0.8 km/s and the contour interval is 1 K km/s.

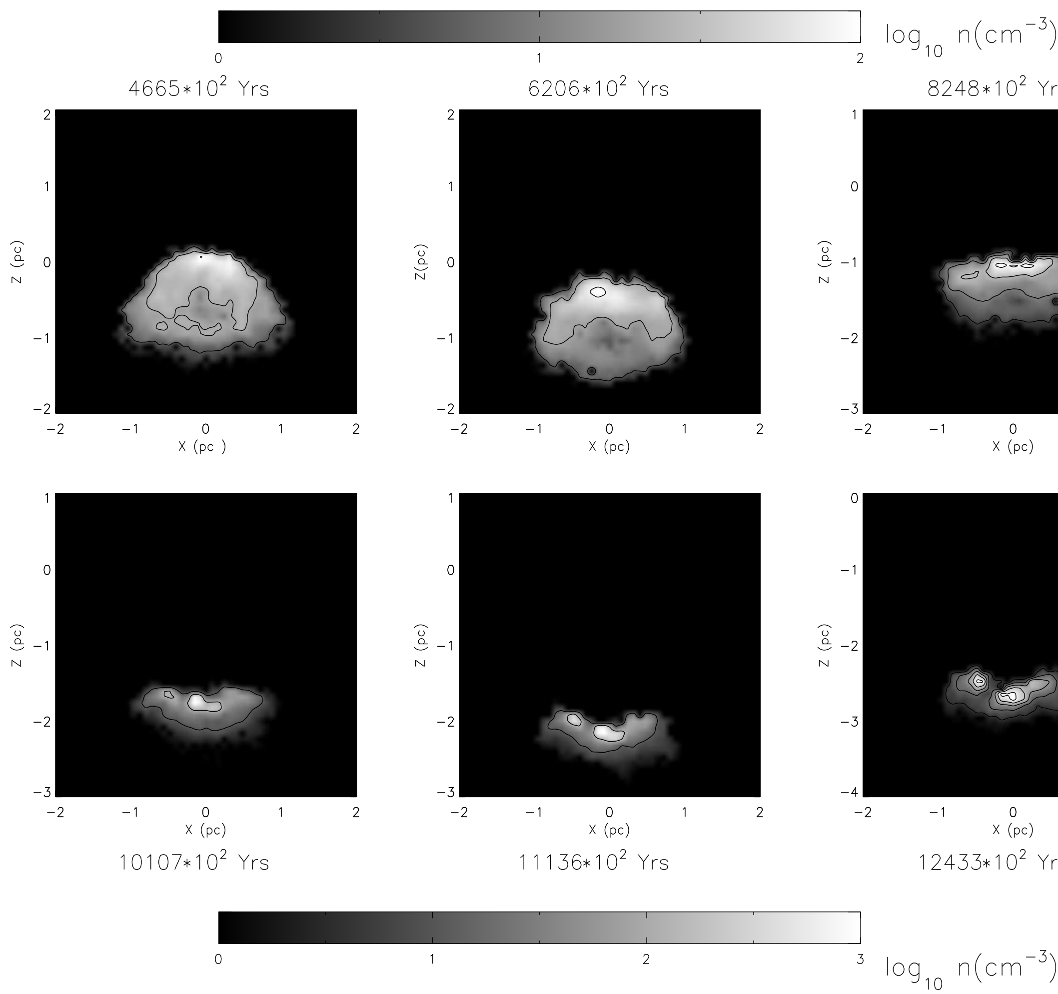

Fig. 3.— The evolutionary sequence of an uniform molecular cloud with an initial mass of 2 $M_\odot$ and radius of 1.4 pc under the effect of UV radiation field with an ionising photon flux of $5 \times 10^9 \mathrm{cm}^{-3}$. The UV radiation is along the $-z$ direction from the above of the cloud. The images and contours are both for number density of hydrogen atoms within the slice of $\Delta y = 0.056pc$ centered at $y = 0$. A scale on the numbersity is shown on the gray bars.

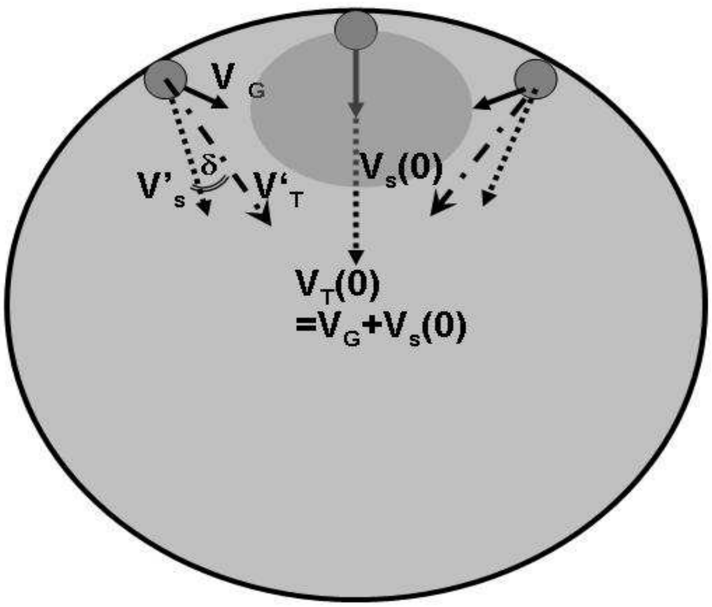

Fig. 4.— The diagram of velocities of the gas particles at the apex and off-apex point on the front surface of the BRC in our simulation.

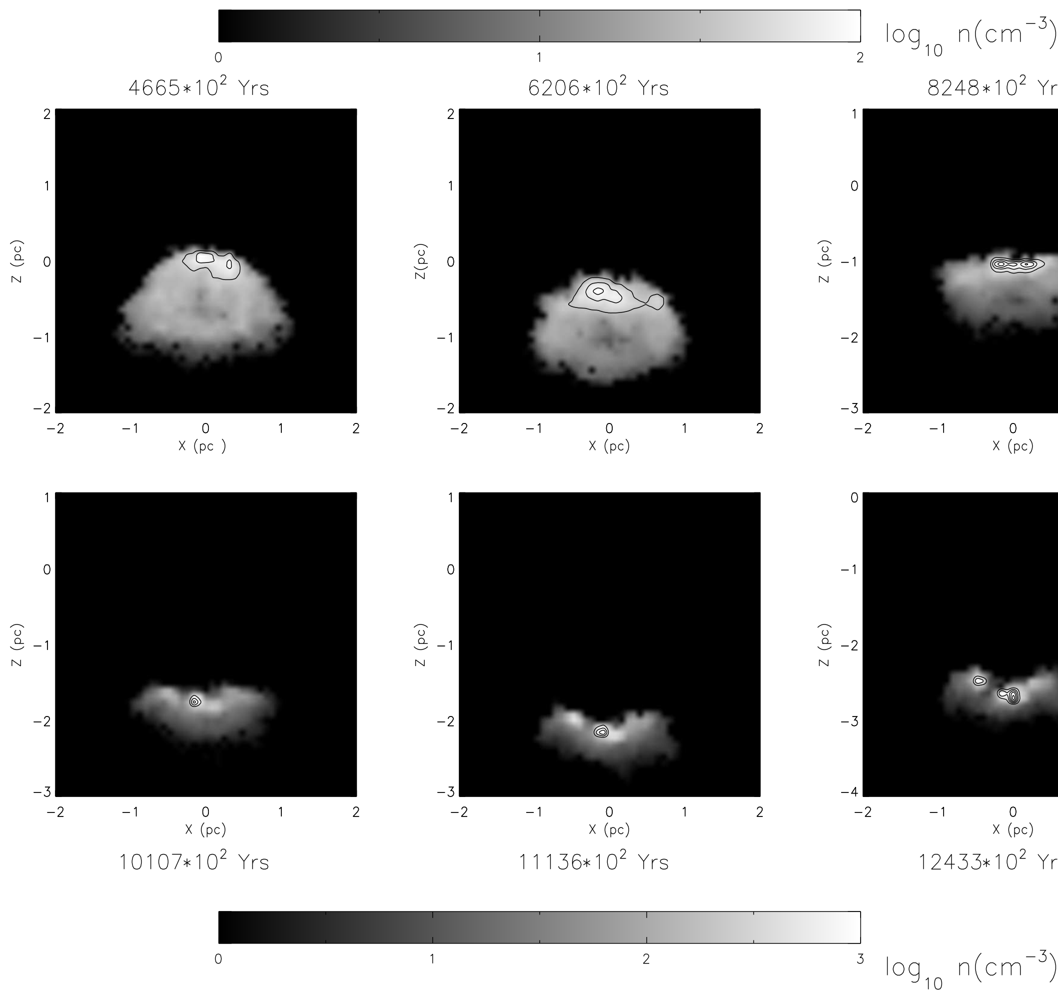

Fig. 5.— The evolution of the fraction of CO molecules is shown by the contours which is overlaid the number density images of the gas particles within the slice of $\Delta y = 0.056pc$ centered at $y = 0$. A scale on the number density images is shown on the gray bars.

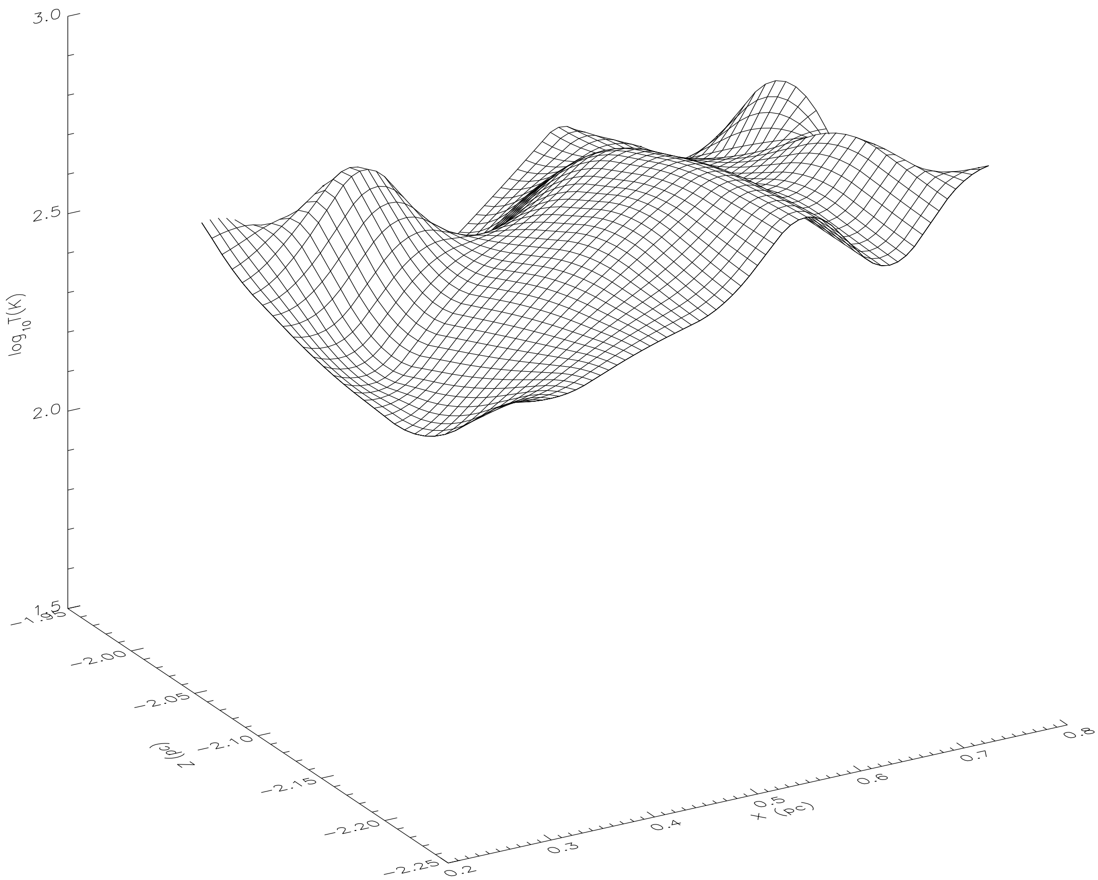

Fig. 6.— The temperature distribution of the east-cap of IC59 (within the slice of $\Delta y = 0.056pc$ centered at $y = 0$) at $t = 1.11$ My.

Table 1. Parameters of clouds which form type M BRC

Cloud	Δ	Γ	$n_0(cm^{-3})$	R(pc)	Mass($M_\odot$)	Region
A	57	21	3.48	1.4	2	III
B	52	18	4.37	1.03	1	III
C	35	13	8.8	0.56	0.4	III