Star Formation in the Large Magellanic Cloud(Proceedings of Japan-France Seminar on Chemical Evolution of Galaxies with Active Star Formation)

著者	FUJIMOTO Mitsuaki
journal or publication title	The science reports of the Tohoku University. Ser. 8, Physics and astronomy
volume	7
number	3
page range	313-319
year	1987-03-20
URL	http://hdl.handle.net/10097/25617

Proceedings of Japan-France Seminar on Chemical Evolution of Galaxies

Star Formation in the Large Magellanic Cloud

Mitsuaki FUJIMOTO
Department of Physics, Nagoya University
Nagoya 464, Japan

The Large and the Small Magellanic Clouds (LMC and SMC) made close encounters some 10^8 years ago on their binary orbits around the Galaxy. The LMC and SMC perturbed each other seriously to enhance their star formation. The present paper applies a cloud model for interstellar gas and numerically estimate the past star formation rate at the galaxy collision.

Keywords: The Magellanic Clouds, the Magellanic Stream, star formation, tidal interaction.

§ 1. Close Encounters between the LMC and the SMC

In a series of papers[1,2,3], the past orbits of the LMC and SMC have been searched for under the condition that these two irregular galaxies have been in a gravitationally bound state for the past 10^{10} years and revolved around the Galaxy with a massive halo of flat rotation curve over 100 kpc of the galactic center. They could reproduce the Magellanic Stream of hydrogen gas which extends along a great circle from the SMC, passing by the South Galactic Pole and reaching $l=90^\circ$ and $b=-30^\circ$[4,5]. The high-negative radial velocity of the Magellanic Stream is also reproduced only when the Galaxy is massive with 7×10^{11} $M_\odot$ in its 100 kpc radius.

In an extensive search for the binary orbits of the LMC and SMC[1,2], it is found that these two galaxies made about 2×10^8 years ago a close encounter of impact parameter of 2～5 kpc (figure 1). Since this collision is found to occur in almost all cases of computed binary orbits of the LMC and SMC, we conclude that it is a realistic past event. In fact, the SMC with smaller mass was more disturbed tidaly than the LMC with larger mass[1] at the last collision and it is now torn into half[6].

As in figure 1, the last second and third collisions are found also at $t\sim-10^9$ years in many cases of our numerical computastions, although the collision

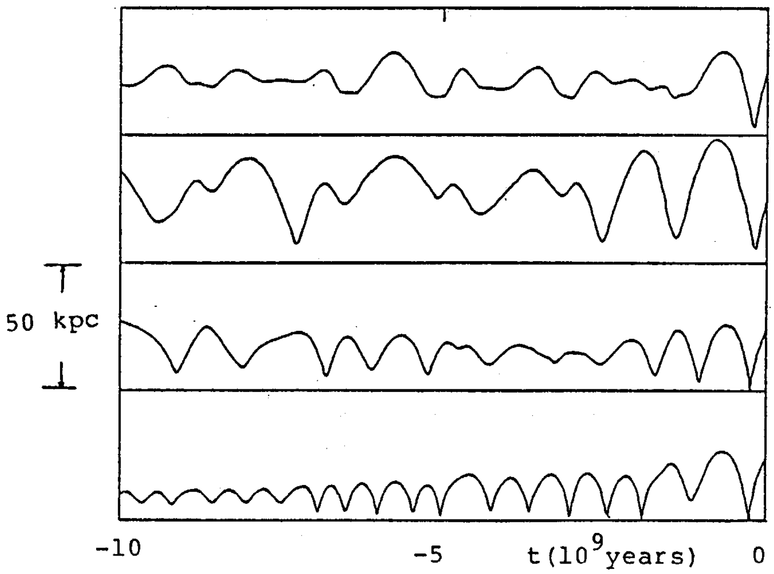

Fig. 1. Four examples of the computed time variations of the LMC-SMC separation. The abscissae are time in year whose negative values indicate the past measured from the present. The close encounters are found at $t=-2x10^{8}$ yesrs in almost all cases and the last second ones are at some $t\sim-10^{9}$ years.

parameters and epoch are not determined so uniquely as in the latest one at $t=-2x10^{8}$ years.

§ 2. Star Formation Enhanced at the LMC-SMC Collision

In order to see the past star formation in the Magellanic Clouds, we employ a cloud model for interstellar gas in the gravitationally interacting galaxies[7,8]. This model mimicks interstellar gas of clumpy structure like that consisting of molecular clouds and giant molecular clouds in our Galaxy. Stars are assumed to form stochastically at a certain rate in each cloud and at a higher rate in a condensed region due to the collision and coalescence of clouds. After stars are formed, these clouds are assumed to disperse in random directions and to move under the gravitational potentials of the Galaxy, the LMC and SMC until they make a next collision with a cloud or/and clouds. Consumption of gas into stars is not considered, or the total mass of interstellar gas is assumed to remain unchanged.

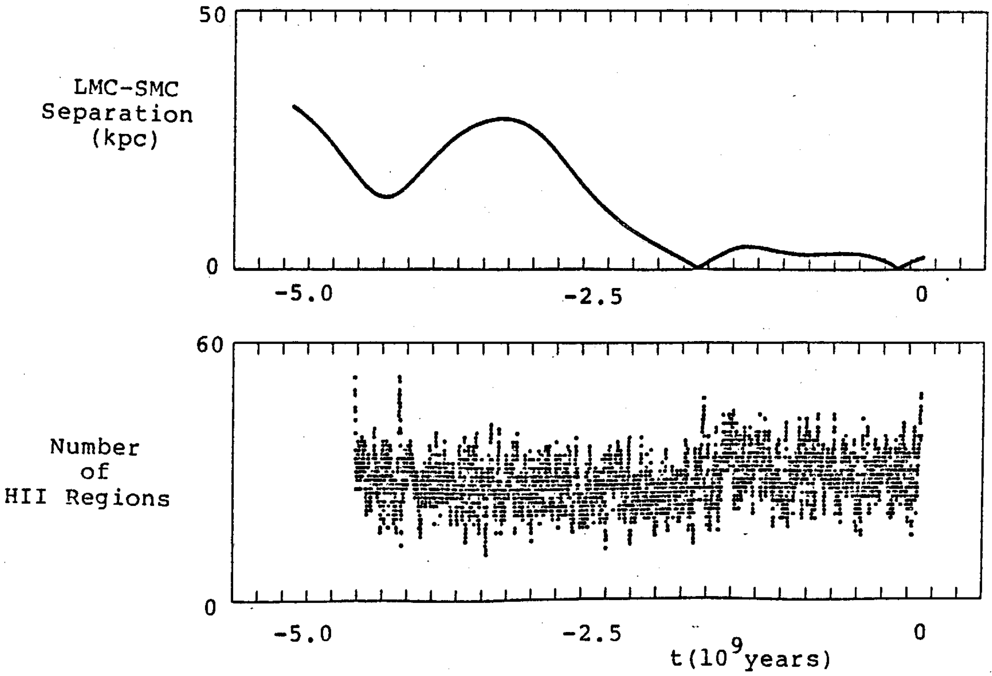

Fig. 2. Time variations of the LMC-SMC separation and of the number of HII regions. The abscissa is the same as in figure 1.

Figure 2 shows the variations of the LMC-SMC separation (upper) and of the number of HII regions in the LMC (lower) against the time with negative numbers in year measured toward the past. The unit of the ordinate in the lower diagram is arbitrary. The vertical spreads in the number of HII regions are due to short-period fluctuations of the stochastic star formation. We can observe that star formation is enhanced by 10 to 20 percents at $t=-2\times10^{8}$ and -2×10^{9} years when the LMC and SMC encountered closely. Figure 3 displays a face-on distribution of HII regions in the model LMC at $t= -2\times10^{8}$ years. The widely dispersed and locally condensed distributions of HII regions resemble the actual ones in the LMC, although the total number of HII regions in the model is arbitrary. Particularly the former is characteristic of the tidal disturbance which is stronger at the outer part of the disk.

We have employed 1000 clouds for our model interstellar gas. Since the number of cloud-collisions per unit time is proportional to the square of the cloud number, we can fit the number of our model HII regions to that counted in the LMC by increasing the employed number by a factor, say, of 2 to 3 (see figure 4).

Star formation history of the LMC is known from colour-magnitude diagram and luminosity functions. According to a recent paper[9], we can follow the epoch of enhanced star formation up to $\sim10^{8}$ and $\sim10^{9}$ years ago. These past two epochs coincide well with those at which we have predicted that the LMC and SMC encountered very closely and interstellar gas was strongly stirred.

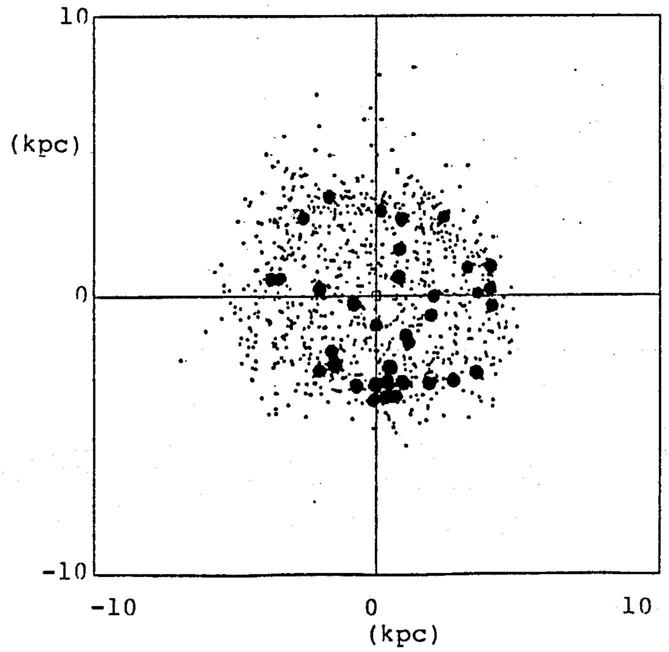

Fig. 3. A computed distribution of HII regions in the LMC. Dotts indicate molecular clouds and lager filled circles HII regions.

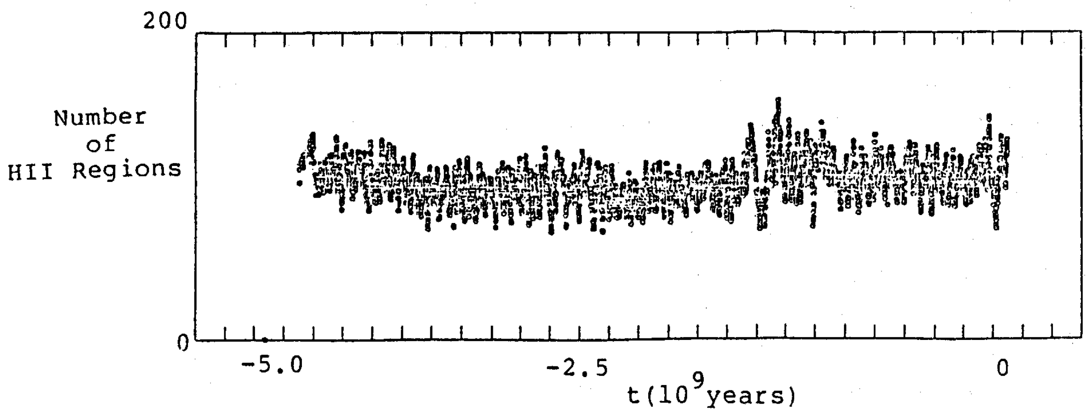

Fig. 4. Same as the lower diagram in figure 2 but the number of test clouds is 2000. Compare the unit of the ordinate with that in figure 2.

Figures 4 and 5 are given in order to see the parameter dependence of our results[8]. Figure 3 shows the time variation of the number of HII regions for 2000 clouds in the model LMC. It is approximately four times larger than that in figure 2 where we have applied 1000 clouds. The enhancement of the stellar formation rate remains ten to twenty percents, the same as before. The observational fact that the star formation enhancement at $t \sim -10^9$ years is higher than at $t \sim -10^8$ years[9] is reproduced in figure 4. Figure 5 is the same as figures 2 to 4 but the masses of the LMC and SMC have been taken very conservatively as

6.1×10^{9} and 1.5×10^{9} $M_\odot$, respectively. We cannot find any star formation enhancement directly related to the close encounters between the LMC and SMC. The fluctuations in time-scale of some 10^{8} years are due primarily to the stochastic process applied in our star formation model. The computational search for the past orbits of the Magellanic Clouds[1] suggests that the closest distance between the LMC and SMC at $t\sim-10^{8}$ years and -10^{9} years are larger in general compared with that in the case that the masses of the LMC and the SMC are 2×10^{10} $M_\odot$ and 2×10^{9} $M_\odot$. It is also to be noted that the relative velocity of the SMC to the LMC is 250 km s^{-1} at the closest approach, fairly larger than the typical rotation velocity of gas in the LMC. These three dynamical facts—the smaller mass of the SMC, the lager impact parameter and the high relative velocity—seem to weaken the tidal disturbance in the LMC.

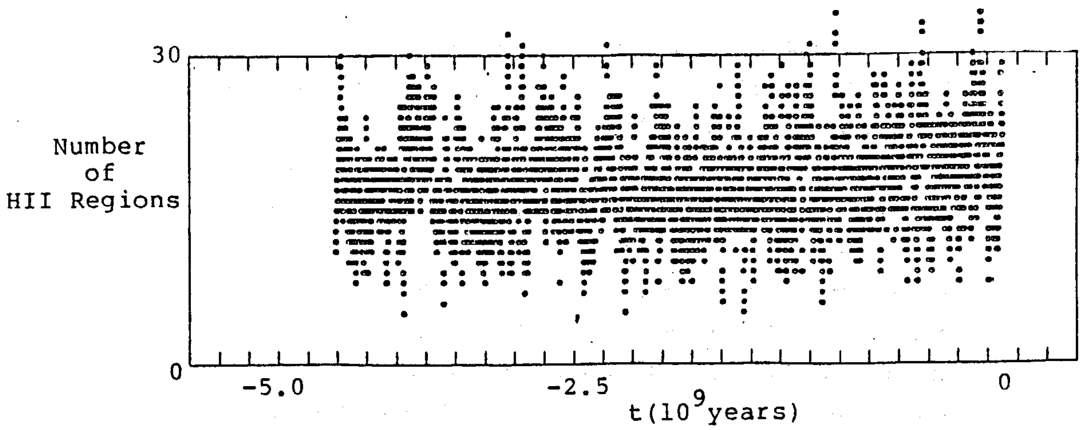

Fig. 5. Same as the lower diagram of figure 2, but the masses of the LMC and SMC are taken as 6.1×10^{9} and 1.5×10^{9} $M_\odot$, respectively.

§ 3. Conclusions

We have applied a star formation model to the LMC tidally interacting with the SMC and the Galaxy[7,8]. Star-formation enhancements in the LMC observed some 10^{8} and 10^{9} years ago[9] are reproduced, if the LMC and SMC made close encounters at these past epochs as predicted in the tidal theory of the Magellanic Stream[1,2,3]. In view of a recent study that the SMC is now stretched along the line-of-sight and being torn off into half[6], the past close approaches of the LMC and SMC are considered very realistic events and, therefore, the observed star-formation enhancements in the LMC are explained in terms of the dynamical interaction among the Galaxy, the LMC and the SMC. Results are summarized graphyically in figure 6.

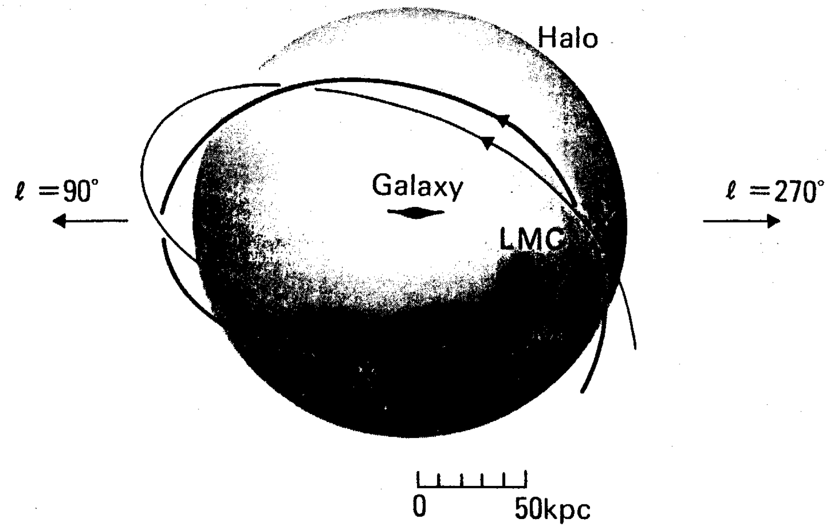

Fig. 6. A graphical summary of the dynamics of the Galaxy, the LMC and SMC. The binary orbits of the LMC and SMC are given for the past $2x10^9$ years. The orbital plane is approximately perpendicular to the line joining the present position of the sun and the Galactic center, or the direction l=0 and b=0. A massive halo of the Galaxy and the Magellanic Stream are given. The close encounters between the LMC and SMC are indicated by the crosses at which star formation is enhanced by ten to twenty percents. The SMC is stretched along the line-of-sight and being splitted into two pieces.

The present work was in part supported by the Scientific Research Fund of the Ministry of Education, Science, and Culture under Grant No.60540156 in 1985 and 1986.

References

1) T. Murai and M. Fujimoto: Publ. Astron. Soc. Japan **32** (1980) 581.
2) M. Fujimoto and T. Murai: Structure and Evolution of the Magellanic Clouds (1984, IAU Symposium 108), ed. S. van den Berg and K. S. de Boer (Reidel), 115.
3) M. Fujimoto and T. Murai: The Milky Way Galaxy (1985, IAU Symposium 106), ed. H. van Woerden, R. J. Allen and W. B. Burton (Reidel), 471.
4) P. Wannier and G. T. Wrixon: Astrophy. J. **173** (1972) L119.
5) D. S. Mathewson, U. N. Cleary and J. D. Murray: Astrophys. J. **190** (1974) 291.

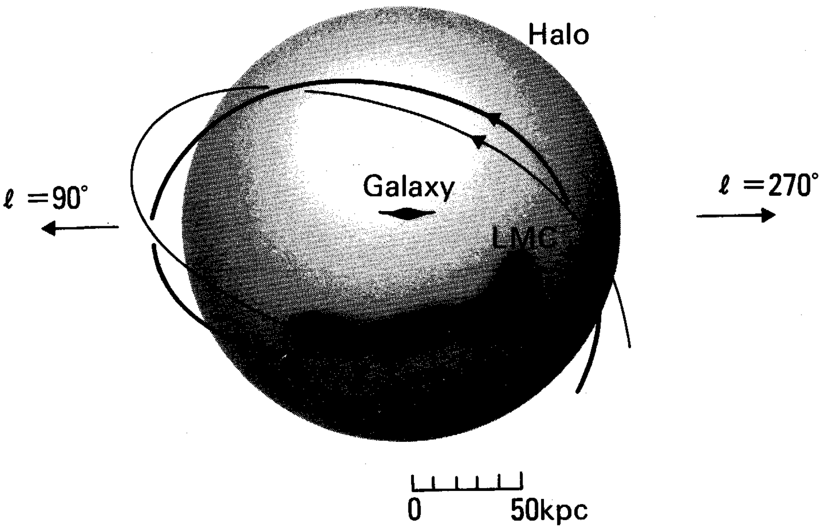

Fig. 6. A graphical summary of the dynamics of the Galaxy, the LMC and SMC. The binary orbits of the LMC and SMC are given for the past 2×10^{9} years. The orbital plane is approximately perpendicular to the line joining the present position of the sun and the Galactic center, or the direction l=0 and b=0. A massive halo of the Galaxy and the Magellanic Stream are given. The close encounters between the LMC and SMC are indicated by the crosses at which star formation is enhanced by ten to twenty percents. The SMC is stretched along the line-of-sight and being splitted into two pieces.

6) D. S. Mathewson and V. L. Ford: Structure and Evolution of the Magellanic Clouds (1984, IAU Symposium 108), ed. S. van den Berg and K. S. de Boer (Reidel), 125.
7) M. Noguchi and S. Ishibashi: Mon. Not. R. astr. Soc. **219** (1986) 305.
8) M. Noguchi, T. Murai and M. Fujimoto: in preparation (1987).
9) L. L. Stryker: Structure and Evolution of the Magellanic Clouds (1984, IAU Symposium 108), ed. S. van den Berg and K. S. de Boer (Reidel), 79.