A COLLISION BETWEEN THE LARGE AND SMALL MAGELLANIC CLOUDS 2×10^8 YEARS AGO

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ABSTRACT

A number of orbits are obtained for the Large and Small Magellanic Clouds (LMC and SMC) revolving around a model Galaxy with a massive halo. It is suggested that the SMC approached the LMC as close as 3 to 7 kpc about 200 million years ago, if these clouds have been in a binary state for the past 10^{10} years, and the Magellanic Stream (MS) is due to the gravitational interaction among the triple system of the Galaxy, LMC, and SMC.

1. PAST BINARY ORBITS OF THE LARGE AND SMALL MAGELLANIC CLOUDS

We search for the past binary orbit of the LMC and SMC in the gravitational potential ϕ_G of the flat rotation curve of constant velocity V_G,

$$\phi_G = - V_G^2 \ln r \, , \qquad (1)$$

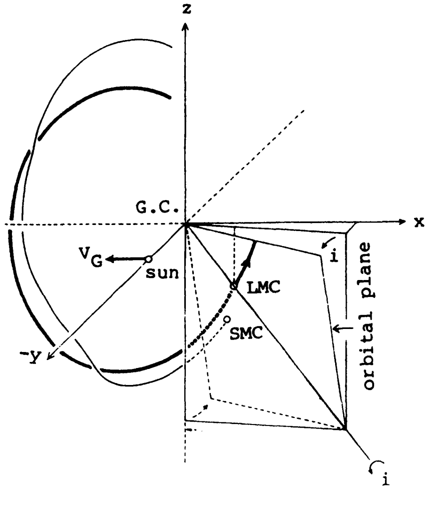

Figure 1. The geometrical relationship of the Galaxy, LMC, and SMC. The Galaxy rotates with the constant velocity V_G. The orbital plane of the Magellanic Clouds is inclined by the angle i.

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where r is the distance from the Galactic Centre (see Rubin et al. 1978; Blitz 1979). The geometrical relationship among the Galaxy, LMC and SMC, and some necessary parameters to be employed are given in Figure 1 and Tables 1 and 2. The quantities with suffixes G, L, and S refer to those associated with the Galaxy, LMC and SMC, respectively. When the superscript ^{0} is attached to the position vectors, $\mathfrak{r}_L$ and $\mathfrak{r}_S$, and the velocities, $\mathfrak{v}_L$ and $\mathfrak{v}_S$, they represent the respective values at t=0 (at present).

Table 1. Observed positions x, y, z and line-of-sight velocities of the LMC and SMC for various assumed values of $r_\odot$ and V_G*.

	$r_\odot$ = 10 kpc			$r_\odot$ = 9 kpc		
Position	$x^0_{L,S}$	$y^0_{L,S}$	$z^0_{L,S}$ (kpc)	$x^0_{L,S}$	$y^0_{L,S}$	$z^0_{L,S}$ (kpc)
LMC	42.9	-2.4	-28.3	42.9	-1.4	-28.3
SMC	37.4	14.3	-44.6	37.4	15.3	-44.6

	V_G = 230 km s^{-1}	250 km s^{-1}	280 km s^{-1}
	Line-of-sight velocity (km s^{-1})		
LMC	70	54	29
SMC	14	2	-16

* $r_\odot$ is the galactocentric distance of the Sun, V_G the velocity of the assumed flat rotation curve.

Table 2. Assumed masses for the LMC and SMC ($M_\odot$)

	V_G = 230 km s^{-1}	250 km s^{-1}	280 km s^{-1}
LMC	2×10^{10}	6.1×10^{9}	1.6×10^{10}
SMC	2×10^{9}	1.5×10^{9}	0.4×10^{10}

We integrate backward the equations of motion of the LMC and SMC,

$$d^2\mathfrak{r}_L/dt^2 = \partial\phi(\ \mathfrak{r}_L\ )/\partial\mathfrak{r}_L + \partial\phi(\ \mathfrak{r}_L - \mathfrak{r}_S\ )/\partial\mathfrak{r}_L + \mathfrak{F}_L\ , \qquad (2)$$

and

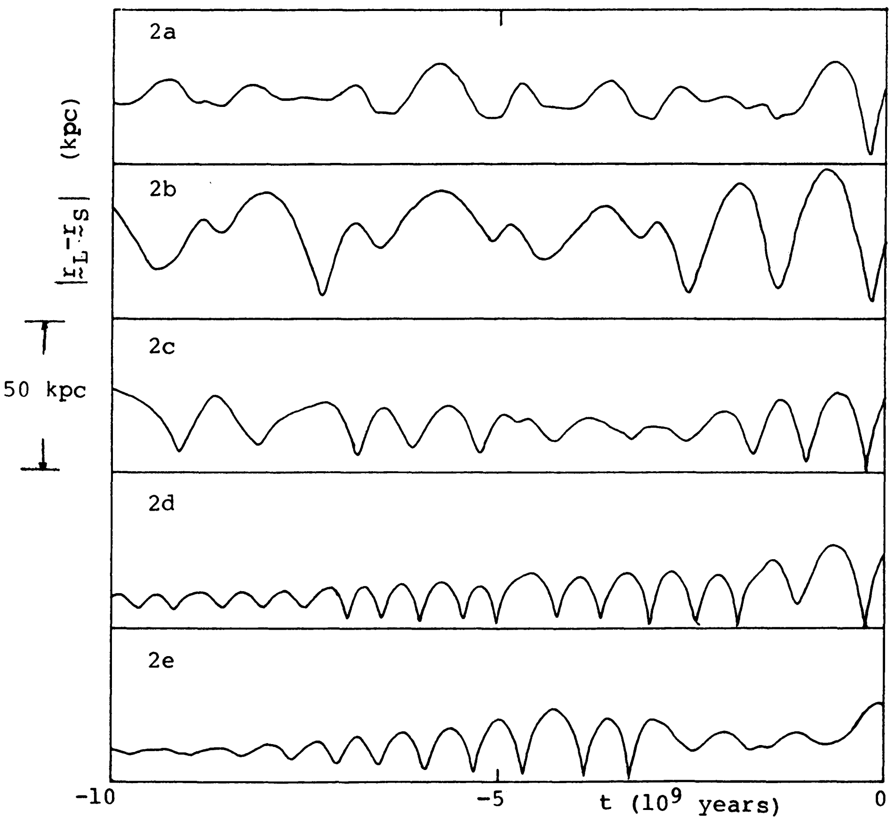
$$d^2\mathfrak{r}_S/dt^2 = \partial\phi(\ \mathfrak{r}_S\ )/\partial\mathfrak{r}_S + \partial\phi(\ \mathfrak{r}_S - \mathfrak{r}_L\ )/\partial\mathfrak{r}_S + \mathfrak{F}_S\ , \qquad (3)$$

with the initial (present) positions, $\mathfrak{r}^0_{L,S}$, given in Table 1 and various assumed velocities, $\mathfrak{v}^0_{L,S}$, whose line-of-sight components must be, however, identical with the observed values in Table 1. The dynamical frictions (Chandrasekhar 1942) on the LMC and SMC, $\mathfrak{F}_{L,S}$, caused by the dark halo (Tremaine 1976; Murai and Fujimoto 1980) are included in the calculation.

Figures 2a to 2e show some of our binary orbits in the form of $|\mathfrak{r}_L - \mathfrak{r}_S|\ (\lesssim D)$, enduring for the past 10^{10} years, where D denotes the perigalactic distance of the LMC orbit. We find easily that $|\mathbf{x}_L - \mathbf{x}_S|$ became temporarily as small as a few kpc at $t=-2\times10^8$ years, so the SMC made a close encounter with the LMC about 200 million years ago.

2. A VERY POSSIBLE COLLISION BETWEEN THE LMC AND SMC OF 2×10^8 YEARS AGO

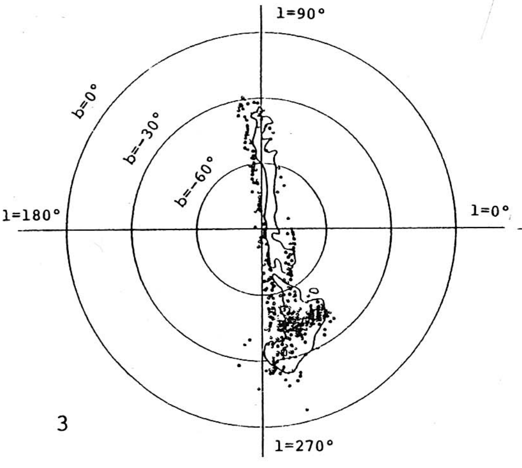
We have chosen systematically a set of initial velocity values $\mathbf{v}_S^0$ for integrating equations (2) and (3). The result can be summarized in the form of a "capture window" in $\mathbf{v}_S^0$-space; inside this window the initial (present) velocity guarantees the bound state of the SMC and the LMC for 10^{10} years (Fujimoto and Sofue 1976, 1977; Murai and Fujimoto 1980). Five binary orbits are given in figures 2a to 2e in order to show in how many cases the last collision occurred in our computed orbits for $\mathbf{v}_S^0$ in the capture window. In fact only rarely are realized such orbits as in Figure 2e where the last collision did not occur.



Figures 2a to 2e. The time variation of $|\mathbf{x}_L - \mathbf{x}_S|$ for various initial velocities. The collision is found at $t = -2\times10^8$ years (2a to 2d). The main parameters are: $M_L = 2\times10^{10}\ M_\odot$, $M_S = M_L\times10^{-1}$, $i = 0^0$, $D = 50$ kpc and $V_G = 250$ km s^{-1}.

3. THE MAGELLANIC STREAM AND THE BINARY ORBIT OF THE LMC AND SMC

We now examine whether these binary orbits may be responsible for the Magellanic Stream (MS) in the time-dependent gravitational potential due to the Galaxy, LMC and SMC. We conduct the particle simulation developed by Toomre and Toomre (1972), and show two typical results in Figures 3 and 4 as projected onto the plane of sky and superimposed on the MS. It is found that the binary orbit which went through the last collision can reproduce the MS (Figure 3), whereas that without the collision cannot do it (Figure 4). Since this tendency holds for other parameters in Tables 1 and 2 (except for $V_G = 280$ km s^{-1}), we consider that our collision of 200 million years ago is a very possible event between the LMC and SMC.



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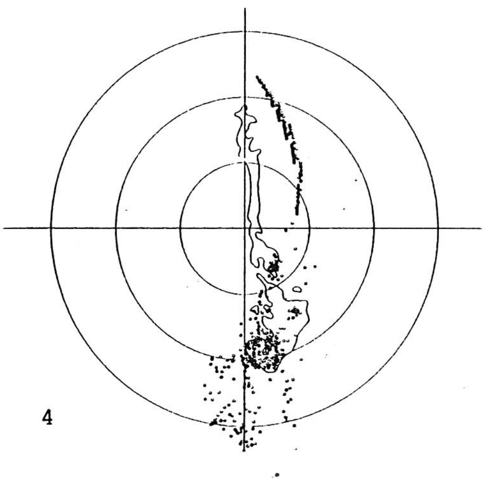
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Figures 3 and 4. The Magellanic Stream (outline, Mathewson et al. 1974), and the particle distributions for the orbits in Figures 2a and 2e.

Finally we refer to the spatial distributions of the neutral hydrogen gas (Hindman et al. 1963), the plane of optical polarization of bright stars (Mathewson and Ford 1970; Schmidt 1969, 1976), and Hα emission (Johnson et al. 1982) in the Magellanic Clouds. They are observed along the LMC-SMC line, as if the SMC has stretched the common magnetized hydrogen gas as it departs from the LMC after the collision.

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DISCUSSION

H. van Woerden: Does your work imply that the Magellanic Stream is a tidal tail formed in the collision of the Large and Small Magellanic Clouds? If so, why is the Magellanic Stream at right angles to the galactic plane?

Fujimoto: No, the Magellanic Stream is due to the tidal interaction between the LMC and SMC in the past ~2×10^9 years. The collision is a very recent dynamical event, in which the Magellanic Clouds would be much perturbed. The Magellanic Stream may be in the orbital plane of the Magellanic Clouds, which is perpendicular to the galactic plane, or the orbital plane is perpendicular to the line joining the Sun and the Galactic Centre.

On the lakes - front to back and left to right: Van Driel and Schwering, Judy Young and Seiden, Chanda Jog and Fujimoto, Anneke van Albada and Okuda, Mieke Oort, Kormendy, Oort (standing). LZ

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