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SIMULATIONS OF THE INTERACTING MAGELLANIC SYSTEM

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ABSTRACT

The Galaxy and the Large and Small Magellanic Clouds (LMC and SMC respectively) form a triple system of mutually interacting galaxies. We have carried out a set of N-body simulations on the gravitational interaction of the SMC with the Galaxy and the LMC in order to model prominent features such as the Magellanic Stream, the inter-Cloud Bridge, and the large depth of the SMC which are thought to be products of the tidal interactions among the members of this system.

Key Words : Magellanic Clouds, methods:numerical, galaxies:interactions

I. MODEL

This paper summarizes significant results obtained from recent numerical modeling of the Magellanic Clouds system conducted by Gardiner and his co-workers (see Gardiner & Noguchi 1996, Gardiner *et al.* 1994). The basic model of the Galaxy-Magellanic Clouds system was derived from the work of Murai & Fujimoto (1980). A Galaxy with an extended massive halo was employed, characterized by a rigid potential of form $\phi_G(r) = V_0 \log r$, where V_0 is the circular velocity at the LSR and taken to be 220 kms^{-1}. The LMC was also represented as a rigid spherical potential, with a Plummer-type form. The SMC was constituted as a self-gravitating system of 15,000 collisionless particles with a disk-halo mass ratio of unity.

The past orbits of the Magellanic Clouds were obtained by performing test particle modeling of the Magellanic Stream and inter-Cloud bridge (Gardiner *et al.* 1994). The resultant computed orbits were used to calculate the gravitational forces due to the Galaxy and the LMC acting on the self-gravitating assembly of particles constituting the SMC. In addition, each particle was subjected to the combined force of all the other SMC particles computed according to the tree code algorithm (Barnes & Hut 1986).

II. RESULTS

A stable equilibrium model of the SMC in isolation was first generated, producing a flat disk with a bar about 5 kpc long and a spherical halo supported by random motions. A suite of simulations were then carried out in which the SMC particle system was evolved from $T = -2$ Gyr ago until the present ($T = 0$). Different initial configurations for the SMC were tested by varying the spatial orientation of the SMC disk plane and the initial position angle of the bar. The simulation which best matched the observed appearance of the Magellanic Stream and the geometrical structure of the SMC was chosen for extended analysis and comparison with observational data.

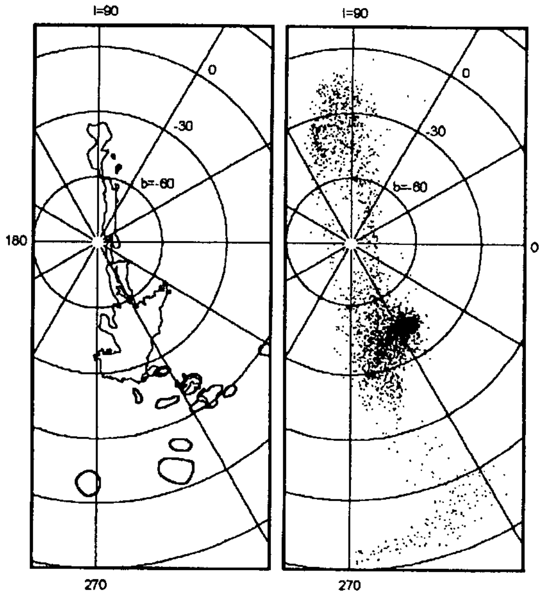

Fig. 1.— Simulation of the Magellanic Stream. The neutral hydrogen distribution (left panel) and the distribution of disk particles in the best model (right panel) are shown projected onto the sky plane.

(a) The Magellanic Stream

The Magellanic Stream is generally understood to be a tidal feature produced as a result of gravitational interaction between the Magellanic Clouds and the Galaxy. Our model for the Magellanic Stream is the first to employ particles with self-gravity and is essentially a refinement of the original Murai & Fujimoto (1980) picture.

According to the simulation, the Magellanic Stream is a tidal tail drawn out from the Magellanic Clouds when they were near perigalacticon about 1.5 Gyr ago. It consists mostly of SMC material, and the simulation gives a total mass of $\sim 2 \times 10^8 M_\odot$, comparable to observational estimates. In agreement with observations, the simulated Stream emerges from the inter-Cloud region near the SMC (see Fig.1). The velocity profile of the Magellanic Stream has also been well reproduced, successfully realizing the large negative velocities ($\sim -200\mathrm{kms}^{-1}$) seen at the northern tip of the Stream. The simulation produces a leading arm or bridge ahead of the Magellanic Clouds. This feature mimicks the distribution of clumps of H I on the opposite side of the Clouds to the Stream (see Fig.1).

(b) The SMC

The simulation indicates that the present geometry of the SMC is strongly influenced by the generation of a bridge-tail structure originating in the relatively recent close encounter between the Magellanic Clouds occurring about 0.2 Gyr ago, when the LMC and SMC centers were separated by 7 kpc.

The simulation reproduces the overall distribution of matter in the vicinity of the Magellanic Clouds, with the particle distribution from the SMC exhibiting extensions to the north (the start of the Magellanic Stream) and to the east (the inter-Cloud region). The 3D spatial orientation of the simulated SMC bar was shown to match that derived from its observed projection on the sky plane and the structure in depth shown by Cepheid variable observations (Caldwell & Coulson 1986). Analysis of the halo component of the simulation indicated that large line-of-sight depths are produced in the north-eastern part of the SMC by superposition of the halo bridge and tail structures. This suggests that the origin of the extended line-of-sight depth ($\sim$ 20 kpc) exhibited by intermediate-aged HB/clump stars in the north-eastern outer parts of the SMC (Hatzidimitriou & Hawkins 1989) is due to the LMC-SMC tidal interaction.

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