

## ORBITAL DECAY AND ACCRETION OF M32 BY M31

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Received 1978 November 20; accepted 1979 January 16

## ABSTRACT

Tremaine has studied the effect of dynamical friction on the orbit of the Large Magellanic Cloud about our Galaxy to obtain an estimate of the rate of luminosity change of our Galaxy due to accretion of smaller companions. Tremaine did a rough estimate of the decay time of the M31 and M32 system using their relative radial velocity and projected positions on the sky. Recent computer simulations by Byrd of the gravitational effect of M32 on the disk of M31 have resulted in an estimate of the orbit and present position in space of M32 relative to M31; such an estimate permits a study like Tremaine's LMC work to be done for the M31-M32 system. We assumed a spherical halo model for M31 with a constant circular orbital velocity. Using different masses for M32, we find the decay time for M32 to be nearly inversely proportional to M32's mass, with accretion occurring in  $\sim 4 \times 10^8$  yr if M32's mass is  $3.6 \times 10^9 M_\odot$ , approximately the value obtained by Tremaine for a similar M32 mass. However, a recent M32 mass estimate of  $4.8 \times 10^8 M_\odot$  by Ford implies a much longer decay time of  $2.6 \times 10^9$  yr. This reduces by more than a factor of 8 the luminosity change of  $-0.05$  mag/ $10^9$  yr estimated by Tremaine for M31. Further work on the mass of M32 is needed to verify whether this great reduction is indeed the case.

*Subject headings:* galaxies: individual — stars: stellar dynamics

## I. INTRODUCTION

Tremaine (1976) has studied the effect of dynamical friction on the orbit of the Large Magellanic Cloud (LMC) about our Galaxy in order to determine the length of time required for the Magellanic Clouds to be disrupted by our Galaxy. The luminosity of large cluster galaxies may change by a similar accretion of smaller companions so that this process may be important in cosmological studies (Ostriker and Tremaine 1975; Gunn and Tinsley 1976).

In addition to the observed distance and radial velocity of the LMC, Tremaine (1976) had to know its tangential velocity. This was determined from studies of the tidal interaction of the Magellanic Clouds and our Galaxy (Toomre 1972). Tremaine also estimated a decay time for M32 to be accreted by M31 of  $\sim 3 \times 10^8$  yr. However, in this case only a very rough estimate could be made because only the radial velocity and projected distance of M32 relative to M31 were known; the line-of-sight position and the two components of the transverse velocity remained unknown. Since Tremaine did his estimate, computer simulations by Byrd (1976, 1978) of the tidal effect of M32 on the disk of M31 have resulted in estimates of the present line-of-sight position and transverse velocity components of M32 relative to M31. Ford, Jacoby, and Jenner (1978) have shown on the basis of reddening arguments that M32 is in front of M31, as predicted by the above computer simulations. The present paper uses the above estimates of the previously unknown position and velocity components for M32 to obtain an improved estimate of the decay time for M32.

## II. METHOD

Essentially the same procedure and assumptions as those used by Tremaine (1976) for the LMC are used in this investigation with appropriate modifications for the M31-M32 case. A spherical mass distribution for M31 is assumed such that the circular orbital velocity  $V$  is a constant of  $250 \text{ km s}^{-1}$ , matching 21 cm observations of M31 by Roberts and Whitehurst (1975). Such a spherical mass distribution is a reasonable approximation for orbital decay studies in our Galaxy and M31 (for discussions of this, see Tremaine 1976; Tremaine, Ostriker, and Spitzer 1975).

In Tremaine's model, the dynamical friction force per unit mass on M32 at a distance  $R$  from M31's nucleus is

$$-4\pi G^2 m \rho(R) \ln \Lambda \frac{[\phi(jv) - jv\phi'(jv)]}{v^2}, \quad (1)$$

where  $m$  is the mass of M32;

$$\rho(R) = V^2/(4\pi GR^2); \quad (2)$$

and

$$\Lambda = b_{\max}/b_{\min}, \quad (3)$$

where  $b_{\max}$  and  $b_{\min}$  specify the range of impact parameters considered for the stars belonging to M31. Following Tremaine, we choose  $R$  for  $b_{\max}$  with the condition that  $b_{\max}$  is never chosen to be less than  $b_{\min}$ . We must choose a value for  $b_{\min}$  based on the properties of M32. Using work by White (1976) showing that the proper choice of  $b_{\min}$  is 0.2 of the tidal radius of an elliptical galaxy or globular cluster,

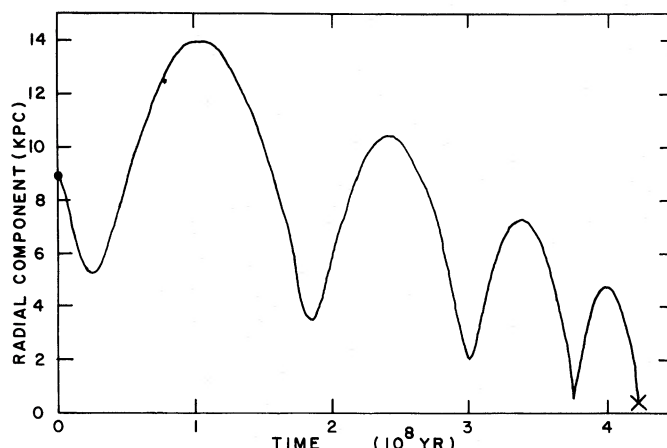


FIG. 1.—Radial component of the orbit of a high-mass M32 about M31 versus time. The present position is marked by a dot. The point of disruption is marked by a cross. The mass of M32 is assumed to be  $3.14 \times 10^9 M_{\odot}$ .

we choose a  $b_{\min} = 0.4$  kpc since M32's tidal radius is about 2 kpc (King 1962). In formula (1),  $v$  is the speed of M32 relative to M31 and  $\phi$  is the error function, where  $j = 1/V$ .

The future behavior of M32 in its orbit was simulated using an  $n$ -body program based on that of Aarseth (1971) on the University of Alabama UNIVAC 1110 computer. The force law assumed for M31 was  $V^2/R$ . The drag force in formula (1) was included opposite to the direction of M32's motion for extrapolation forward in time. Finally, the distance dependence for M32's gravitational force was assumed to be  $0.04 (1 - ae^{-br})/r^2$ , where  $a = 0.6056$  and  $b = 0.47958$  for  $r$  in kpc (Byrd 1977). This formula was obtained using King's (1962) formula for density versus radius of spherical stellar systems for the case of M32.

In regard to the validity of the above approach and the validity of the drag formula, White (1978) has compared results using the drag formula to a more realistic (but more time-consuming) full  $n$ -body simulation of the merging of a small, concentrated galaxy with an extended, more massive galaxy. White finds that the drag formula gives an adequate descrip-

tion of the orbital decay. The final program used in the present study was checked for error by changing the input parameters to match the case for the LMC and our Galaxy and then duplicating Tremaine's (1976) results.

Unfortunately, since Tremaine did his study, considerable uncertainty has emerged about one parameter in the model, the mass of M32. Mass estimates for M32 vary from  $4.8 \times 10^8 M_{\odot}$  (Ford 1978) to  $3.6 \times 10^9 M_{\odot}$  (Burbidge, Burbidge, and Fish 1961; King 1961; Sargent *et al.* 1977). The mass of M32 in formula (1) determines the force per unit mass and thus affects the decay time. Because of the disagreement, the model simulations were done 3 times assuming different masses for M32 of  $3.14 \times 10^9 M_{\odot}$ ,  $1.57 \times 10^9 M_{\odot}$ , and  $4.3 \times 10^8 M_{\odot}$ . The results of these simulations were used to construct a graph of decay time for any mass within the range of the simulations.

### III. ORBITAL DECAY RESULTS

Figures 1 and 2 show the model results for a high-mass M32 and a low-mass M32, respectively.

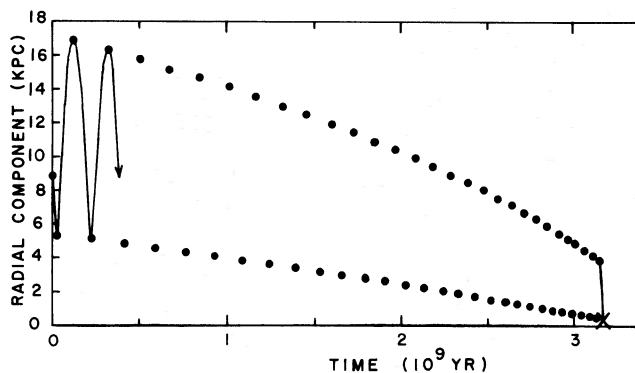


FIG. 2.—Radial component of the orbit of a low-mass M32 about M31 versus time. The present position and succeeding perigalacticon and apogalacticon positions are marked by dots. The point of disruption is marked by a cross. The mass of M32 is assumed to be  $4.3 \times 10^8 M_{\odot}$ .

The radial distance of M32 from M31's center versus time is shown. Each graph shows the inward and outward orbital motion of M32 versus time. We will assume M32 to be accreted by M31 when its minimum distance from M31 is equal to  $b_{\text{min}}$  (0.4 kpc). At this distance the tidal radius will be only a few tenths of a kpc, much smaller than the present value of 2 kpc. A significant fraction of M32's mass will thus be removed tidally, beginning M32's destruction and adding another mechanism of orbital energy absorption beyond the scope of this model. Also, at this distance M32 will be about to enter the core of M31 and should orbit rapidly toward the center (Tremaine *et al.*).

As can be seen in Figures 1 and 2, the range in estimated masses results in a correspondingly wide range in decay times, from the short  $4.2 \times 10^8$  yr for the high-mass M32 ( $3.14 \times 10^9 M_{\odot}$ ) to the very long  $3.2 \times 10^9$  yr for the low-mass M32 ( $4.3 \times 10^8 M_{\odot}$ ).

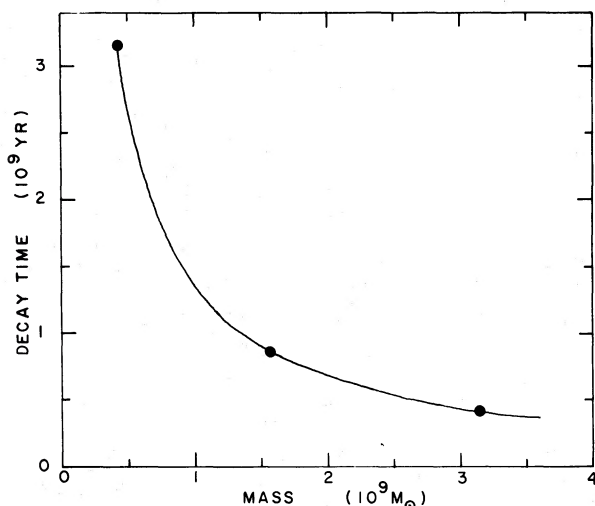


FIG. 3.—Decay time versus assumed mass for M32 in its orbit about M31.

The first estimate of decay time is quite close to the rough estimate Tremaine obtained using a similar mass for M32. Another model was run with a mass between these two extremes of  $1.57 \times 10^9 M_{\odot}$ . Figure 3 shows the decay times versus M32 mass from these simulations as points. The decay time varies nearly inversely with mass. This is shown as a line in Figure 3 so that the decay time can be read off for intermediate values of the mass.

#### IV. CONCLUSION

Which mass value and decay time in Figure 3 should one believe to be real? The smallest and also most recent mass of  $4.8 \times 10^8 M_{\odot}$  (Ford 1978) was calculated from radial velocities and positions of planetary nebulae in M32. The larger mass values for M32 have been obtained using spectroscopic velocity dispersions of the central regions of M32. As discussed by Sargent *et al.* (1977), published estimates obtained from such velocity dispersions with different methods of analysis have disagreed with one another. There are more fundamental possibilities for error in such mass estimates, as discussed by King (1961) and Sargent *et al.* (1977), because the spectrum is obtained only of M32's bright core.

We can thus conclude that, in light of these computer simulations and a new determination of M32's mass, Tremaine's (1976) rough estimate of  $3 \times 10^8$  yr for M32's decay time must be increased. The decay time may be as long as  $2.6 \times 10^9$  yr for a  $4.8 \times 10^8 M_{\odot}$  M32. For the M31-M32 system, the  $dM_B/dt = -0.05$  mag/ $10^9$  yr estimated by Tremaine (1976) may be too large by as much as a factor of 8. Certainly, more work is needed on determining M32's mass so that this local example of a process that may be very important cosmologically can be better understood.

The author thanks S. J. Aarseth and an anonymous referee for suggesting this investigation. This work was supported by the University of Alabama Research Grants Committee, Project 956.

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