N93-26780

GAS DISTRIBUTION AND STARBURSTS IN SHELL GALAXIES

MELINDA L. WEIL & LARS HERNQUIST
Board of Studies in Astronomy & Astrophysics
University of California, Santa Cruz
Santa Cruz, California 95064

Detailed maps of most elliptical galaxies reveal that, whereas the greatest part of their luminous mass originates from a smooth distribution with a surface brightness approximated by a de Vaucouleurs law, a small percentage of their light is contributed by low surface brightness distortions termed "fine structures" (e.g. Seitzer and Schweizer 1990). The sharp-edged features called "shells" are successfully reproduced by merger and infall models involving accretion from less massive companions (e.g. Quinn 1984, Hernquist and Quinn 1988). In this context, dwarf spheroidal and compact disk galaxies are likely progenitors of these stellar phenomena. However, it is probable that the sources of shell-forming material also contain significant amounts of gas. This component may play an important role in constraining the formation and evolution of shell galaxies.

To investigate the effects of the gaseous component, we have performed numerical simulations to study the tidal disruption of dwarf galaxies containing both gas and stars by more massive primaries, and the evolution of the ensuing debris. The calculations were performed with a hybrid N-body/hydrodynamics code (Hernquist & Katz 1989). Collisionless matter is evolved using a conventional N-body technique and gas is treated using smoothed particle hydrodynamics in which self-gravitating fluid elements are represented as particles evolving according to Lagrangian hydrodynamic equations. An isothermal equation of state is employed so the gas remains at a temperature 10^4K. Owing to the large mass ratio between the primary and companion, the primary is modeled as a rigid potential and the self-gravity of both galaxies is neglected. The potentials of both the primary and companion are represented by an analytic model which mimics the mass distribution in elliptical galaxies (Hernquist 1990). The primary mass and scale length are both unity; the stellar component of the disk companion has a mass 0.1 and scale length 0.7 while the gas component has a mass 0.01 and the same scale length as the stars. Scaled to values appropriate for large ellipticals, a dimensionless time unit corresponds to a physical time $\sim 4 \times 10^6$ years. Initially, particles evolve in the time-varying field provided by solving the two-body problem consisting of the primary and secondary; after the the separation between the two galaxies is smaller than a prescribed radius, the companion is disrupted and particles evolve in the lone potential well of the primary.

The top row of Figure 1 shows an example of the evolution of a stellar disk accreted by a more massive spherical galaxy. In this simulation, the encounter was precisely radial and the plane of the disk coincided with the orbit plane. During its passage through the center of the primary the disk was destroyed by the tidal forces acting on it. The oscillations of particles with a range of binding energies through the primary potential leads to an enhancement in density at the turning points where the particle velocities are relatively low. After further evolution, a characteristic pattern of sharp-edged features develops, resembling those seen in shell galaxies.

The bottom row of Figure 1 shows the distribution of disk gas at the same times as the stars. Following the disruption of the companion, gas particles, like the stars, begin to oscillate back and forth in the potential of the primary. However, in addition to the gravitational forces which act on all particles, the gas is subject to local hydrodynamic accelerations arising from pressure gradients and shocks. Within a short time, the gaseous and stellar debris are effectively segregated. Because the gas is subject to self-interaction, shocks developed as oppositely-directed gas flows encounter one another and dissipate the orbital kinetic energy of the gas. Most of the gas still bound to the primary settles into a compact disk, which is somewhat smaller than the initial disk and spins in the same direction as it.

Additional models (not shown) demonstrate that the qualitative features of the results here are not altered by variations in orbital geometry (Weil & Hernquist 1992). If the orbit is not precisely radial, stars and gas are again segregated, but, instead of a nuclear disk, the gas forms a compact ring near the center of the primary. If the disk is tilted with respect to the orbital plane, shells again form from stars and gas collects either into a disk or ring, but the gas structure is tilted with respect to the orbit plane.

The segregation and subsequent independent evolution of stars and gas has a number of implications for our understanding of fine structures in galaxies. As indicated by Figure 1, it is expected that little gas will be found near shells Thus, shells should not exhibit significant rates of star formation but should age as would an isolated stellar population and become redder with time. In contrast, it seems quite plausible that star formation will be boosted in the nuclear disks and rings formed during accretion events. This suggests that a population of stars will be produced near the center of the primary that will be distinct from that of its main body. Several recent observations support this contention. A significant fraction of shell galaxies ($\sim 20\%$) in the Malin & Carter (1983) catalog contain nuclear concentrations of A stars, indicative of recent star formation (Carter et al. 1988). The galaxy Markarian 717 displays a starburst nucleus and shells (Taniguchi et al. 1990). Our results may also be relevant to the interpretation of observations of NGC 1275, an elliptical which possesses shells and a central population of bright, blue point sources which have characteristics similar to those of young globular clusters (Holtzmann et al. 1992). These sources lie in a ring around the center of the elliptical, with a distribution and size comparable to that of the gaseous remnants in our non-radial encounter models.

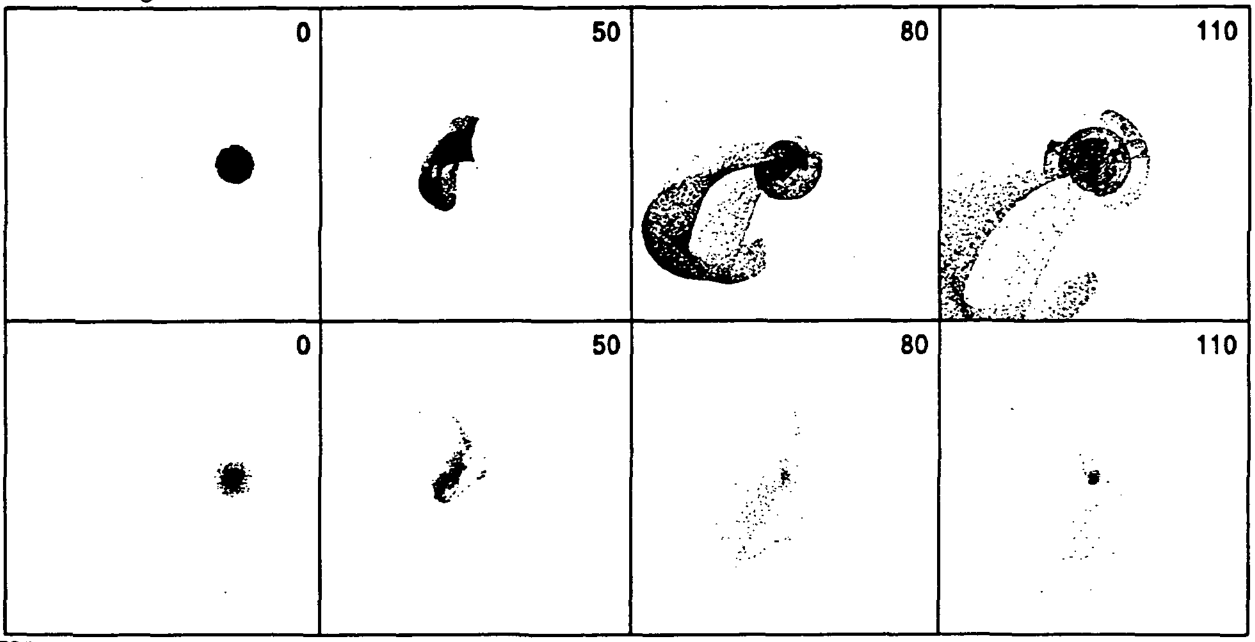

FIG. 1. Top row: Stellar component of radial encounter between a disk companion of mass 0.1 and scale length 0.7 and a spherical primary with mass and scale length equal to unity. Bottom row: Gas component with disk mass 0.01. Initial separation of the two galaxies is 10 primary scale lengths. All frames show x-y spatial projection, measure 40 length units per edge, and display dimensionless time in the upper right-hand corner.

REFERENCES

Carter, D., Prieur, J.L., Wilkinson, A., Sparks, W.B. & Malin, D.F. 1988, MNRaS 235, 813.

Hernquist, L. 1990, ApJ 356, 359.

Hernquist, L. & Katz, N. 1989, ApJS 70, 419.

Hernquist, L. & Quinn P.J. 1988, ApJ 331, 682.

Holtzmann, J.A., Faber, S.M., Shaya, E.J., Lauer, T.R., Groth, E.J., Hunter, D.A., Baum, W.A., Ewald, S.P., Hester, J.J.,Light, R.M., Lynds, C.R., O'Neil, E.J. & Westphal, J.A. 1992, Lowell Observatory preprint.

Malin, D.F. & Carter, D. 1983, ApJ 274, 534.

Quinn, P.J. 1984, ApJ 279, 596.

Seitzer, P. & Schweizer, F. 1990, in Dynamics and Interactions of Galaxies, ed. R. Wielen, Springer-Verlag, Berlin, 270.

Taniguchi, Y., Ichikawa, S., Hamabe, M., Yamagata, T. & Iye, M. 1990, A&A 233, 385.

Weil, M.L. & Hernquist, L. 1992, ApJ, submitted.