The Effect of Tidal Fields on the Shapes and Kinematics of Dark Halos

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Dark halos form from the collapse of density perturbations layed down in the early universe. The collapse of a density perturbation to form a dark halo is strongly influenced by the tidal shear created by evolving structure in the local neighborhood. Tidal torques act during the collapse (Hoyle 1949; Peebles 1969; White 1984) since the tidal field couples very effectively to the perturbations which are filled with substructure and more generally triaxial (Bardeen et al. 1986). Tidal torques are the source of angular momentum in dark halos and galaxies as well as being influential in the development of the structure of dark halos.

We have carried out a series of N–body simulations to investigate the effect of tidal shear on the structure and kinematics of dark halos (Dubinski 1992). We simulate the collapse of density perturbations using a tree code as described in Dubinski & Carlberg (1991). Density peaks are selected from a random realization of a CDM density field and used as the initial conditions for N-body simulations. We use an experimental approach to examine the effects of tidal shear on collapse. The cosmological tidal field is treated as an external time dependent potential whose strength and orientation can be varied freely. We examine the effects of the tidal field with two experiments. In the first experiment we simulate a sample of 14 dark halos from the collapse of density peaks in the presence of a 1σ tidal field. In the second experiment, we use the same initial conditions though the tidal field is turned off allowing an experimental control for comparison to highlight the influence of tidal shear on the development of the structure and kinematics of the dark halos.

A comparison of the dark halos from the two experiments reveals the profound effect of tidal shear on the structure. The shape distribution of dark halos depends strongly on the strength and orientation of the tidal shear field. Dark halos which collapse without a tidal field are very flat ($c/a \sim 0.5$) and almost exclusively prolate. This tendency towards a prolate morphology probably results from the propensity of prolate density peaks in the initial conditions though may be partially due to the radial orbit instability (Merritt & Aguilar 1985). When we introduce a cosmological tidal field, the halos still are very flat though a variety of morphologies are apparent with roughly an even split between oblate and prolate forms. The shapes of the resulting dark halos are completely uncorrelated with the shapes of initial density peaks.

We also studied the kinematics in the two experiments using measurements of the angular momentum, the velocity ellipsoids, streaming motions and tumbling of the dark halos. Most of the angular momentum is in the form of streaming motions with tumbling motions having periods exceeding 4 Gyrs. The total angular momentum is coherently aligned and distributed roughly as $J(r) \propto r^2$. The angular momentum vector tends to align with the minor axis of the triaxial dark halos as observed previously by other investigators (Warren et al. 1991; Barnes & Efstathiou 1987). The alignment of the angular momentum vector probably has a primordial origin. During the expansion phase, the tidal torque vector tends to align with an axis perpendicular to the major axis of the given triaxial density peak. This effect apparently imprints a spin about the minor axis on dark halos. The origin of the tendency for the small misalignment angle between the rotation vector and the apparent minor axis in elliptical galaxies is probably due to the same effect (Franx et al. 1992) The tangential accelerations arising from tidal torques are comparable to the radial accelerations of the collapsing peaks. Orbits can acquire significant amounts of angular momentum from torques which produce isotropic velocity ellipsoids. In contrast, the velocity ellipsoids of the dark halos which collapse when neglecting the tidal field develop radially anisotropic velocity ellipsoids similar to those seen in cold collapse simulations (e.g., van Albada 1982).

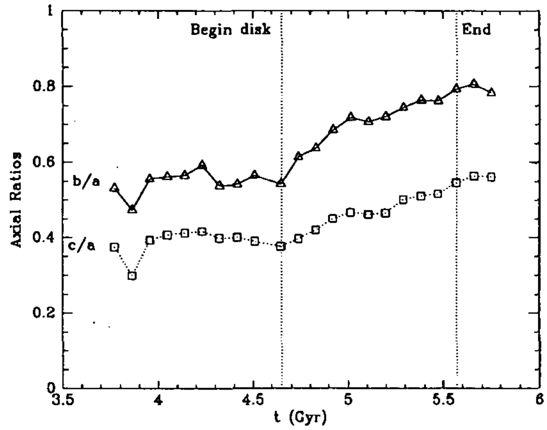

FIG. 1.–Axial ratio profiles for a dark halo. A disk potential scaled appropriately to represent a typical galaxy grows to it full mass in 1 Gyr. The halo transforms from a nearly prolate shape to an oblate one.

The dark halos produced in these simulations are extremely flat ($c/a \sim 0.5$) and often prolate especially in their centers. A disk embedded in a very flat prolate halo with its spin aligned with the minor axis should dramatically reflect the shape of the halo in its structure and kinematics. These extreme halos should result in disk galaxies which are ovally distorted with significant noncircular velocity deviations in their rotation curves (Franx and de Zeeuw 1991; Kuijken and Tremaine 1991) Some analyses suggest that such extremely flat dark halos (at least flat in the plane of disks) are not allowed by the observations (Franx and de Zeeuw 1991). A possible solution to this problem may come from the process of baryonic feedback on the evolution of the shape and density of the dark halo. As the baryons sink into the center of the dark halo to form a disk, the growing axisymmetric potential of a disk can modify the shape of the dark halo. Box orbits in the prolate potential (for example) may gradually be change into loop orbits in response to the oblate potential of the disk. We examined this process using a simulation of a dark halo with a growing potential. We grow a disk potential (Miyamoto–Nagai potential) in the center of an initially virialized dark halo which is nearly prolate. The shape of the dark halo changes slowly from an initially prolate object with $c/a = b/a = 0.5$ to a more oblate object. The halo remains flat with $c/a = 0.5$ but becomes considerably more oblate with $b/a = 0.8$ (Fig. 1). The dark halos surrounding disk galaxies are likely more oblate than dissipationless dark halo simulations would suggest.

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