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A MODEL FOR THE FORMATION AND EVOLUTION OF COSMOLOGICAL HALOS

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RESUMEN

Estudiamos el colapso y la evolución de los halos de materia oscura que resultan de la inestabilidad gravitacional y de la fragmentacion de "crepas" cosmológicas. Estos halos se parecen a los formados por el agrupamiento jerárquico en un universo CDM. Nuestros halos se encuentran aproximadamente en equilibrio virial y son casi isotérmicos, como en las simulaciones CDM. Sus perfiles de densidad en evolución y su historia de acreción de masa son muy similares a los reportados recientemente en simulaciones de N-cuerpos de CDM. Por ello, concluimos que estas propiedades son un resultado genérico de la formación por inestabilidad gravitacional, y no están limitadas a condiciones iniciales de agrupamiento jerárquico o de ruido gaussiano al azar.

ABSTRACT

We study the collapse and evolution of dark matter halos that result from the gravitational instability and fragmentation of cosmological pancakes. Such halos resemble those formed by hierarchical clustering in a CDM universe. Our halos are in approximate virial equilibrium and roughly isothermal, as in CDM simulations. Their evolving density profiles and mass accretion history are very similar to those reported recently in N-body simulations of CDM. We therefore conclude that these properties are a generic result of formation by gravitational instability and are not limited to hierarchical clustering or Gaussian-random-noise initial conditions.

Key Words: **COSMOLOGY: THEORY — DARK MATTER — GALAXIES: FORMATION — GALAXIES: KINEMATICS AND DYNAMICS — LARGE-SCALE STRUCTURE OF UNIVERSE**

1. HALO FORMATION VIA PANCAKE INSTABILITY

Test-bed Model: Cosmological pancakes – modelled as single plane-wave density fluctuations – are gravitationally unstable; density perturbations transverse to the direction of pancake collapse cause the pancake to fragment (Valinia *et al.* 1997). When a pancake is perturbed by two transverse density modes with wave-vectors in the plane of pancake collapse, a quasi-spherical halo forms at the intersection of two filaments in the pancake plane. This halo closely resembles those formed by hierarchical clustering from initial conditions in a CDM universe.

ASPH/P3M Simulations: Two simulations were run of the formation of a dark matter halo by pancake instability for use as a test-bed model for halo formation, with 64^3 DM particles, both with and without 64^3 gas particles. The primary pancake collapses (i.e. first forms accretion shocks and caustics) at a scale factor a_c. By $a/a_c = 3$, a well-defined pancake-filament-halo structure appears (Fig. 1).

2. HALO PROFILES & EQUILIBRIUM

Density Profile: By $a/a_c = 3$, the DM halo (simulated with and without gas) has a spherically-averaged density profile close to the fit by NFW to N-body simulations of halos formed by hierarchical clustering in CDM (Fig. 2).

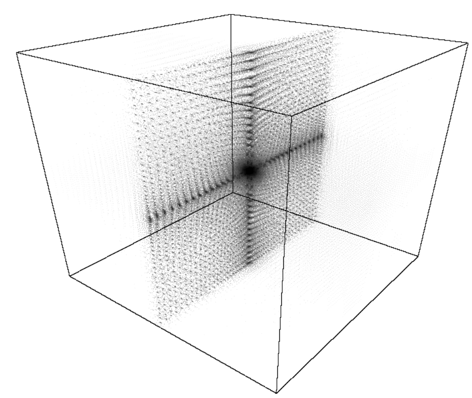

Fig. 1. Dark matter particles at $a/a_c = 3$.

Jeans Equilibrium & Anisotropy: After $a/a_c = 3$, the halo is close to equilibrium, according to the Jeans equation in spherical symmetry, and is close to isothermal. Hereafter, we shall consider the halo to form at $a_0 \equiv 3a_c$. The velocity distribution is somewhat more anisotropic than found in simulations of CDM, $0.2 < \beta < 0.8$, whereas the CDM simulations give $0.0 < \beta_{CDM} < 0.6$, where $\beta = 1 - \langle v_t^2 \rangle / (2\langle v_r^2 \rangle)$.

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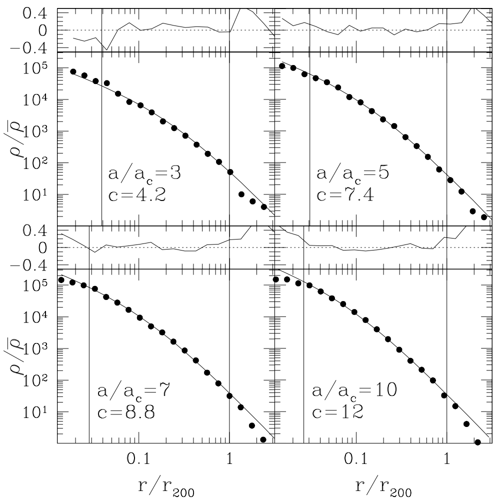

Fig. 2. Density profiles: spherically-averaged simulation of DM no gas (dots), best-fit NFW profiles (solid curves), at $a/a_c = 3$, 5, 7, 10; fractional deviations from NFW, $(\rho_{\rm NFW} - \rho)/\rho_{\rm NFW}$, above.

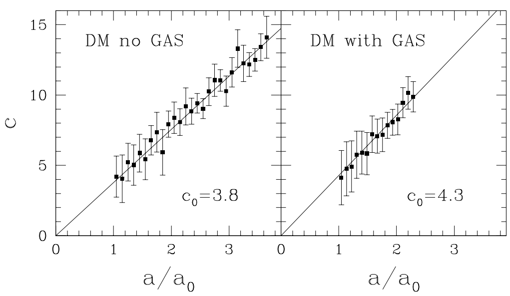

Fig. 3. Concentration parameter vs. scale factor.

3. EVOLUTION

Concentration Parameter: The concentration parameter of the best-fitting NFW density profile at each epoch evolves linearly with scale factor (Fig. 3). For $a > a_0$, after the halo formation epoch, we find $c \simeq 4(a/a_0)$, almost identical to that reported by Wechsler *et al.* (2002) for N-body simulations of CDM halos.

Mass Growth Rate: For $2 < a/a_c < 3$, M_{200} (mass within r_{200}) grows rapidly, while for $3 < a/a_c < 7$, $M_{200} \propto a$, consistent with self-similar spherical infall (Bertschinger 1985). For $a/a_c > 7$, growth flattens due to finite mass supply. This mass history closely resembles that for CDM halos found by Wechsler *et al.* (2002) (Fig. 4).

Self-Similar Infall: The radial velocity profile, mass, and radius are consistent with self-similar

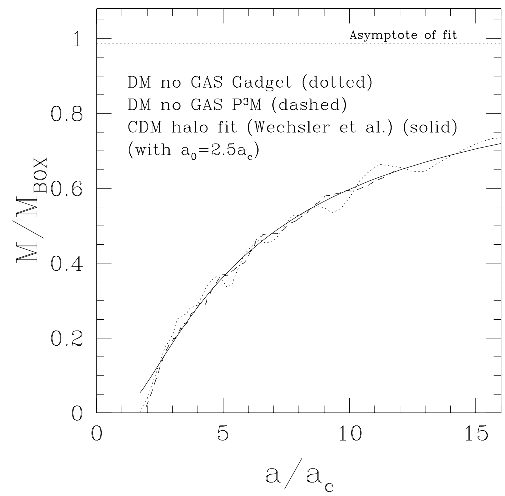

Fig. 4. Halo mass vs. scale factor. "Gadget" curve used code of Springel *et al.* (2001) to simulate same problem.

infall for $3 < a/a_c < 7$, with $\lambda_{200}/\lambda_c \simeq 0.8$, where $\lambda_{200} = r_{200}/r_{ta}$, r_{ta} is the time-varying turnaround radius, and λ_c is the radius of the outermost caustic in the self-similar solution.

Virial Ratio: The virial ratio $2T/|W|$ just after virialization is ~ 1.35, close to that of the N-body results for CDM halos, as predicted by the TIS model and consistent with the value expected for a virialized halo in which mass infall contributes an effective surface pressure. Thereafter, the virial ratio evolves towards the value expected for an isolated halo, $2T/|W| \sim 1$, as the mass infall rate declines.

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