RevMexAA (Serie de Conferencias), **17**, 24–25 (2003)

THE PHASE-SPACE STRUCTURE OF CDM HALOS AND DARK-MATTER DIRECT DETECTION EXPERIMENTS

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RESUMEN

A continuación presentamos algunos resultados sobre el análisis de una simulación numérica de la formación de un cúmulo de galaxies en un universo ΛCDM. Luego de reducir la escala de la simulación a la de una galaxia del tipo de la Vía Láctea, determinamos la cantidad de subestructura remanente del proceso de formación del halo, y cómo esta afectará la señal en experimentos de detección directa de partículas de materia oscura.

ABSTRACT

Here we discuss some results from a high-resolution simulation of the formation of a cluster of galaxies in a ΛCDM cosmology, which we scale down to a Milky Way size halo. We focus mostly on quantifying how much substructure is left over from the inhomogeneous growth of the halo, and how it may affect the signal in experiments aimed at detecting the dark matter particles directly.

Key Words: **DARK-MATTER**

1. WHAT IS THE NATURE OF DARK-MATTER?

Dark-matter is the dominant mass component of galaxies and large-scale structures in the Universe. It thus has become a key ingredient in theories of structure formation, and in particular of the currently popular hierarchical paradigm. But what is the dark-matter really made of? Several candidates have been proposed by particle physics, which include axions and weakly interacting particles (WIMPs) such as the lightest supersymmetric particle: the neutralino. WIMPs can be detected in the laboratory through elastic scattering on nuclei. The idea is to determine the count rate over recoil energy above a given (detector) background level. The experimental situation has been improving rapidly over the past years, with large-scale collaborations such as DAMA, Edelweiss and CDMS starting to probe interesting regions of parameter space (see Bergström 2000).

The differential direct detection rate for WIMPs in a given material (per unit detector mass) is

$$\frac{dR}{dQ} = \frac{\rho_0}{M_\chi} \int d^3v f(\mathbf{v}) v \frac{d\sigma}{dQ} \qquad (1)$$

where Q is the energy deposited in the detector and $d\sigma/dQ$ is the differential cross section for WIMP elastic scattering with the target nucleus (Jungman, Kamionkowski & Griest 1996). Here the WIMPs have mass M_χ, a local density ρ_0 and a velocity distribution function $f(\mathbf{v})$. Thus, the count rate depends on the velocity distribution of dark-matter particles near the Earth. To understand the signal and optimize the searches it is imperative to have a reasonable guess of the velocity distribution.

2. THE PHASE-SPACE STRUCTURE OF A CDM HALO

In a hierarchical universe, the build-up of dark halos through mergers and accretion of smaller subunits implies that the latter will leave substructure in the phase-space of the final object. The key question is whether this substructure will be directly or indirectly observable, and thus affect $f(\mathbf{v})$. We expect less than 1% of the fraction of mass to be in bound subhalos going through the Solar neighborhood at the present day (Helmi, White & Springel 2002a). Most of the mass in the Solar neighborhood is in the form of streams of particles, whose origin can be traced back to the different mergers the Galaxy has experienced in its lifetime. Streams manifest themselves as peaks in $f(\mathbf{v})$. Clearly it is crucial to know whether $f(\mathbf{v})$ in the vicinity of the Sun is dominated by a few of these peaks, or whether their number is so large that it is close to Gaussian.

In Figure 1 we show the growth of mass in the "Solar Neighborhood" and that of the whole galaxy halo (solid and dashed curves, respectively). We note that all the mergers that contributed a substantial amount of mass to the "Solar neighborhood" took place quite early. Mergers at late times contributed a relatively large amount of mass to the galaxy halo, but deposited most of this mass in the outer regions

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Galaxy Evolution: Theory and Observations (Cozumel, Quintana Roo, México, 8-12 April 2002)
Editors: Vladimir Avila-Reese, Claudio Firmani, Carlos S. Frenk & Christine Allen

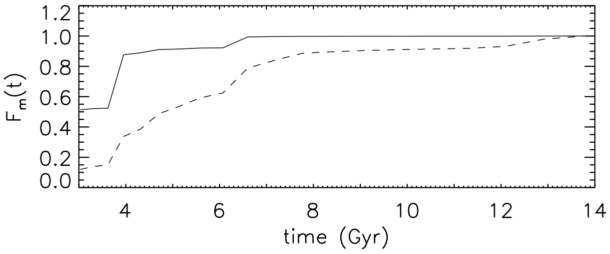

Fig. 1. Mass growth of the halo in time. Note that 85% of the mass in the Solar neighborhood was already in place 10 Gyr ago (solid curve). For the whole galaxy halo (dashed curve), this did not happen until 6 Gyr ago.

of the galaxy. Particles accreted in the past Gyr, do not account for more than about 10^{-3} of the total present number of particles near the Sun. The influence of streams from such recently accreted material on the $f(\mathbf{v})$ near the Sun will thus be relatively small, and may dominate only the high energy tail of the distribution function.

In Figure 2 we plot the velocities of particles inside a cube of 2 kpc on a side, located in the "vicinity of the Sun". We identify with different colors and symbols particles that belonged to the same halo at $z = 2.4$. In this box there are 474 particles which come from 39 different halos; but only 3 contribute with more than ten particles. We do not expect all particles of the same color to be clustered in a single massive stream, since each individual halo is predicted to have given rise to many streams in the Solar neighborhood (Helmi, White & Springel 2002b).

A larger volume of 4 kpc on a side allows us to increase the number of particles by roughly a factor of 8. In Figure 3 we show the velocities of particles located in such a box in the "vicinity of the Sun". Their velocity distribution is relatively smooth, but that is not the case for the highest energy particles. particles The 1% fastest moving particles (highlighted in gray) are strongly clumped, and their velocity distribution is highly anisotropic.

3. DISCUSSION

Our results indicate that direct detection experiments may safely assume that the velocity distribution of dark-matter particles in the Solar neighborhood is well represented by a multivariate Gaussian. We find that none of the streams present in any of the volumes at the Sun's location dominate the local distribution. The mean density of an individual

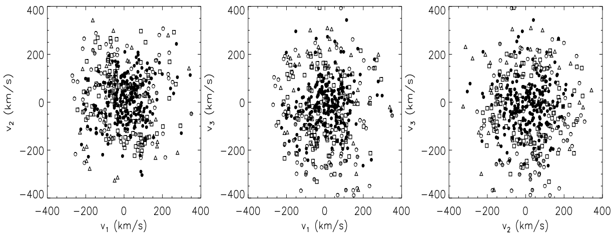

Fig. 2. The velocities of particles located in a box of 2 kpc on a side on the "Solar" circle. The different colors and symbols are used here to indicate particles originating in the same halo identified 11 Gyr ago. Open circles correspond to particles from halos which do not contribute substantially to this volume. Black filled circles are particles from the main progenitor identified at this redshift, open triangles correspond to "field" particles, squares and light gray circles to the second and third most massive halo identified at this time, respectively.

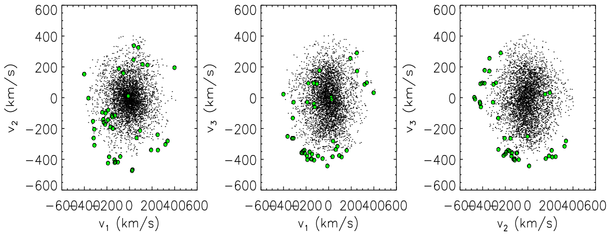

Fig. 3. Velocity distribution of particles located in a box of 4 kpc on a side on "Solar" circle. We highlighted the 1% fastest moving particles.

stream is typically 0.3% that of the local dark-matter distribution. These small values are due to the fact that most of the streams in the inner galaxy come from a few massive halos that merged at high redshift to build up the object we see today. Experiments sensitive to the direction of motion of the incident particles could exploit the anisotropy of the most energetic particles to discover a direct indication of the hierarchical growth of our Galaxy's halo.

Acknowledgments. Thanks to Volker Springel and Simon White for an enjoyable collaboration that gave rise to the work presented here.

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