COSMOLOGY ON A MESH

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Abstract
An adaptive multi grid approach to simulating the formation of structure from collisionless dark matter is described. MLAPM (Multi-Level Adaptive Particle Mesh) is one of the most efficient serial codes available on the cosmological “market” today. As part of Swinburne University’s role in the development of the Square Kilometer Array, we are implementing hydrodynamics, feedback, and radiative transfer within the MLAPM adaptive mesh, in order to simulate baryonic processes relevant to the interstellar and intergalactic media at high redshift. We will outline our progress to date in applying the existing MLAPM to a study of the decay of satellite galaxies within massive host potentials.

MLAPM (Multi-Level Adaptive Particle Mesh) is a publicly available C-code\(^1\) for evolving a set of \(N\)-particles under their mutual gravity within a cosmological framework. The code solves Poisson’s equation on a hierarchy of nested grids; the entire computational volume is covered by one cubic domain grid, while refined regions are of arbitrary shape and adjusted to the actual density field at each major time-step in order to follow the real distribution of particles at all times. An example of MLAPM in action is shown in Figure 1. The left panel shows all parti-

\(^1\)http://astronomy.swin.edu.au/MLAPM/
cles in a slice of thickness $3h^{-1}\text{Mpc}$ through the simulation box. The right panel indicates the adaptive grids used with that 
particle distribution. In addition to this spatial refinement, an additional adaptive
time-stepping is implemented in the latest version of \textsc{MLAPM}. The time 
stepping is restricted so that we ensure that particles are advanced at 
least a pre-specified fraction of the cell in which it resides, but never 
more than half the cell spacing.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Particle distribution (left) vs. \textsc{MLAPM} adaptive grids (right)}
\end{figure}

\textsc{MLAPM} has proven to be one of the fastest single-CPU \textit{N}-body-codes 
on the market today (Knebe et al. 2001). We have begun an ambitious 
program of cosmological and galactic dynamical simulations using \textsc{MLAPM} 
- preliminary results on the latter are presented here.

The signatures of hierarchical galaxy formation are evident in the 
observed substructure seen in various phase-space projections of the Galactic 
halo. The clearest such signature is that of the spectacular stream of stars 
associated with the currently disrupting Sagittarius Dwarf Galaxy. 
Secondary streams have also been observed locally (Helmi et al. 1999) 
and in the halo of M31 (Ibata et al. 2001). Ibata et al have shown 
that such streams are extremely useful tools for constraining the shape 
of a halo’s gravitational potential well. In the case of the Milky Way, 
Ibata et al. concluded that our halo was necessarily very close to spherical 
(under the assumption of a static axisymmetric potential). We have 
adopted \textsc{MLAPM} to extend this analysis, but now are using live potentials.

Four low resolution ($128^3$ particles; $64h^{-1}\text{Mpc}$ box size) simulations 
were run initially, and ten halos selected sampling a range of triaxialities. These halos were then re-simulated at higher resolution ($512^3$ particles). 
The effective mass per particle was $10^6\text{M}_{\odot}$, with a force resolution 
of $1h^{-1}\text{kpc}$ in the dense regions. An adaptation of the Bound Density
Maxima (BDM, Klypin & Holtzman 1997) algorithm was used to identify and trace substructure evolution in these high resolution simulations. Our preliminary results show that triaxiality is a fleeting measure of the Galactic potential - the live potential and active substructure mitigates (somewhat) the usefulness of this measure. One simulated stream is highlighted here in Figure 2. A detailed analysis of the phase-space dissolution of these structures is currently underway.

![Figure 2 Disrupted satellite in halo potential](image)

We have begun implementing hydrodynamics within MLAPM, and aim to have a publicly available version of Hydro-MLAPM in 2004-2005. The existing grid structure will be used as a base for this implementation, as the grid provides a natural structure on which to solve the relevant equations.

**References**

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MLAPM is available at [http://astronomy.swin.edu.au/MLAPM/](http://astronomy.swin.edu.au/MLAPM/)