Computational Adaptive Mesh Refinement

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Overview

* Astrophysics is a highly multi-scale problem!
* Sophisticated physics needed on all scales
* Eulerian methods with large dynamical range in space and time are possible with embedded meshes
* With appropriate on-the-fly criteria, meshes can be embedded adaptively
* Extreme dynamic range now possible
Multi-Scale Physical Problems

* Primordial stars have formation efficiency of 0.03%!
* Galaxies shaped by stars, star clusters, merger history
* Must be able to adequately resolve large scale structure and small scale in order to develop next-generation subgrid models!
<table>
<thead>
<tr>
<th></th>
<th>Size</th>
<th>Relative Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Universe</td>
<td>$1.3 \times 10^{23}$ km</td>
<td>1.00</td>
</tr>
<tr>
<td>Galaxy Cluster</td>
<td>$3 \times 10^{19}$ km</td>
<td>$2 \times 10^{-4}$</td>
</tr>
<tr>
<td>Galaxy</td>
<td>$6 \times 10^{17}$ km</td>
<td>$5 \times 10^{-6}$</td>
</tr>
<tr>
<td>Star Cluster</td>
<td>$2 \times 10^{15}$ km</td>
<td>$2 \times 10^{-8}$</td>
</tr>
<tr>
<td>Star</td>
<td>700,000 km</td>
<td>$5 \times 10^{-18}$</td>
</tr>
<tr>
<td>Earth</td>
<td>6,000 km</td>
<td>$5 \times 10^{-20}$</td>
</tr>
<tr>
<td>Us</td>
<td>0.002 km</td>
<td>$1.5 \times 10^{-26}$</td>
</tr>
</tbody>
</table>
Physics Necessary

* Radiative cooling
* Ionization physics
* Background radiation
* Multi-species fluids
* Extensible to new subgrid models
Adaptive Mesh Refinement

* Higher-order hydrodynamic schemes
* Interpolate to higher resolution
* Correct fluxes of conserved quantities across boundaries
Adaptive Mesh Refinement

log dynamic range

1995  1997  1999  2001  2006
Codes Available

* Diversity of codes:
  – Enzo (SLAC, UCSD, Colorado, Columbia)
  – Orion (LBL, LLNL, Princeton, UCSC)
  – ART (UChicago, Fermilab)
  – Chombo (LBL)

* Enzo code:
  – Wide use in cosmology
  – Freely distributed, community developed
  – Patch-based AMR
  – Piecewise Parabolic Mesh hydro reconstruction
  – 12-species chemistry network
Simulational Domain

* Primordial star formation
* Galaxy formation
* Large-scale structure
* Present-day star formation
Computational Domain Expanding

* Modern simulations run on hundreds if not thousands of processors
* Computational infrastructure at SLAC supports large-scale simulations
* Studying formation of large scale structure with all attendant physics (galaxy feedback, cosmic rays, chemistry, star formation) is nearer than ever
* Galaxy catalogs, simulated observations, lensing studies