Evolution of the Small Galaxy Population

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Galaxy formation: can this...
... turn into this?
Modeling Star Formation: it's hard

- Gravitational Instabilities
- Magnetic Fields
- Radiative Transfer
- Molecular/Dust Chemistry
- Driven at large scales: differential rotation
- Driven at small scales: Supernovae and Stellar Winds
- Scales unresolvable in cosmological simulations
Resolution and Subgrid Models

- Maximize Simulation Resolution
  - Capture tidal torques/accretion history (20+ Mpc)
  - Adapt resolution to galaxy (sub-Kpc)
- Capture Star Formation in a sub-grid model
  - Stars form in high density environments
  - Supernova/stellar winds/radiation regulate star formation
  - Mitigate issues with poor resolution (overcooling)
Star Formation and Dark Matter

- Initial orbit
  - Dark matter particle
  - Dense, star-forming gas
- Gas driven away from centre
  - Gravitational force insufficient
  - Particle migrates outwards
- Gas cools & flows back in
- Final orbit
  - Force returns to original strength
    - ... but is weaker at large distances, so the particle cannot be pulled back to its old orbit.

Process can repeat. Analytic arguments and simulations show effect accumulates with each episode.
Inner Profile Slopes vs Mass

Governato, Zolotov et al. 2012
Blue Waters: High Redshift Galaxies

- 25 Mpc Volume
- Few million particles/galaxy
- Goals:
  - Models to compare with HST Frontier fields
  - Physical properties of high z galaxies and connection to the present day
Cosmo25

- 2 billion particles
- (25 Mpc)^3
- Forces ~ 350pc
- SPH ~ 40 pc
- 100s of galaxies
- 5 TB dataset
Luminosity Function: Faint end slope

Fit Schechter Function at bright end and project to dimmer magnitudes

Faint end essential to assessing the impact of galaxies on the reionization of the universe

Better constraint on galaxy contribution to reionization
Charm++

- C++-based parallel runtime system
  - Composed of a set of globally-visible parallel objects that interact
  - The objects interact by asynchronously invoking methods on each other
- Charm++ runtime
  - Manages the parallel objects and (re)maps them to processes
  - Provides scheduling, load balancing, and a host of other features, requiring little user intervention
ChaNGa: Charm Nbody GrAvity solver

Massively parallel SPH+nbody code, including:

- SNe feedback creating realistic outflows
- H2 based star formation
- SMBH formation, growth, and energy feedback
- Optimized parameters regulating star formation
Overlap of Phases
Scaling to .5M cores
Clustered/Multisteppeing Challenges

- Load/particle imbalance
- Communication imbalance
- Fixed costs:
  - Domain Decomposition
  - Load balancing
  - Tree build
Load Variance
Load distributions
Intra-node work balancing
Multistep speedups for 2 billion clustered particles
Multistep speedups for 2 billion clustered particles
# Future Simulations

<table>
<thead>
<tr>
<th></th>
<th><strong>First Stage</strong></th>
<th><strong>Near Future</strong></th>
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<tbody>
<tr>
<td><strong>Timeline</strong></td>
<td>February 2014</td>
<td>Summer 2014</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>$(25 \text{ Mpc})^3$</td>
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<tr>
<td><strong>Nparticles</strong></td>
<td>2 billion</td>
<td>25 billion</td>
</tr>
<tr>
<td><strong>Duration in z</strong></td>
<td>100-4</td>
<td>100-0</td>
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<tr>
<td><strong>Force Resolution</strong></td>
<td>350 pc</td>
<td>175 pc</td>
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<tr>
<td><strong>Morphologies</strong></td>
<td>$5e10 M_{\text{tot}} (1e9 M_*)$</td>
<td>$5e9 M_{\text{tot}}$</td>
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<tr>
<td><strong>Size</strong></td>
<td>5 TB</td>
<td>500 TB</td>
</tr>
<tr>
<td><strong>Extra Physics</strong></td>
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<td>Black hole feedback</td>
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<td>H2 regulated star formation</td>
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Future Results

Predict faint end slope of LF

Measure escape fraction $f(z, M, sfr, Z)$

Morphologies of $\sim 100$ (1000) systems in Vulcan (Enterprise)

Evolution of SFR-M.-Z relation

Law+ 2013