Evolution of the Small Galaxy Population

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Outline

- Scientific background (Why it matters)
- Need for high resolution (Key Challenges)
- Project goals (Why Blue Waters)
- Charm++ and ChaNGa (Key Challenges)
- Preliminary results (Accomplishments)
- Work from the PAID program
- STEM education/training (Broader Impacts)
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
  – Supernovae/stellar winds/radiation regulate star formation
  – Mitigate issues with poor resolution (overcooling)
  – Tune to match present day stellar populations
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
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
Charm Nbody GrAvity solver

- Massively parallel SPH
- SNe feedback creating realistic outflows
- SF linked to shielded gas
- SMBHs
- Optimized SF parameters
Overlap of Phases
Scaling to .5M cores

![Graph showing scaling to .5M cores](image-url)
Clustered/Multistep Challenges

- Load/particle imbalance
- Communication imbalance
- Fixed costs:
  - Domain Decomposition
  - Load balancing
  - Tree build
Load Variance
ORB Load Balancing
Multistep speedups for 2 billion clustered particles
The Vulcan

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

Faint galaxies reionize the Universe

Anderson et al 2016

![Graph showing reionization of the Universe with redshift and ionization rate](Image)
Faint galaxies reionize the Universe

Anderson et al 2016
Scatter in Stellar Mass/Luminosity

Ferah Munshi, in prep.
Black hole/AGN feedback

• Supernova feedback doesn't suppress star formation in massive galaxies
  – Modeling of more energetic feedback required

• Components of AGN modeling:
  – Seed (1e6 Msun) BH form in dense, low metallicity gas
  – BH grow from accreting gas, and release energy into the surrounding gas (Active Galactic Nuclei)
  – BH in merging galaxies sink to the center and merge (LIGO, eLISA)
Tremmel et al 2016

\[ \frac{M_*}{M_{\text{vir}}} \]

\[ 10^{-1} \]

\[ 10^{-2} \]

\[ 10^{-3} \]

\[ 10^{11} \]

\[ 10^{12} \]

\[ 10^{13} \]

- Romulus25, \( z = 0.25 \)
- Kravtsov+ 14, \( z < 0.1 \)
- Moster+ 13, \( z = 0.25 \)
Black Hole Dynamics

![Graph showing distance from halo center over time with different colors representing different conditions: No Corr., Dyn. Fricht., and Advection. The x-axis represents time in Gyr, and the y-axis represents distance from the halo center in parsecs (pc).]
PAID: ChaNGa GPU Scaling

- ChaNGa has a preliminary GPU implementation
- Goals of PAID:
  - Tesla → Kepler optimization
  - SMP optimization
  - Multistep Optimization
  - Load balancing
- Personnel:
  - Simon Garcia de Gonzalo, NCSA
  - Michael Robson, Harshitha Menon, PPL UIUC
  - Peng Wang, Tom Gibbs (NVIDIA)
PAID GPU Progress

- 2X speed up of main gravity kernel; 1.4X speedup of 2\textsuperscript{nd} gravity kernel
  - Interwarp communication
  - Caching of multipole data
  - Higher GPU occupancy
  - Overall speedup of 60%

- SMP queuing of GPU requests
  - Reduced memory use, allowing more host threads
  - GPU memory management still an issue
Broader Impacts: Pre-Majors and Supercomputing

- UW Pre-Major in Astronomy Program:
  - Engage underrepresented populations in research early
  - Establish a cohort
  - Plug major leak in the STEM education pipeline

- Simulation data analysis is ideal for this research
  - Science and images are compelling
  - Similarity to Astronomical data reduction
Zoe Deford
Joshua Smith
(UW Freshman)
Simulated Images
Take Aways

• Scaling is necessary, but hard
  – Need all the help we can get
• “Break through” results are unexpected
• “Simulated observations” enable broad impact
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