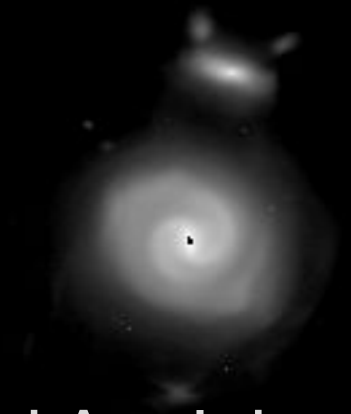
Looking Out for the Little Guy: A Comprehensive Study of Star Formation in Dwarf Galaxies



Elaad Applebaum

Rutgers University
Blue Waters Graduate Fellow

A Few Open Questions

- How big are the smallest galaxies (is there a “smallest” galaxy)?
- How many nearby galaxies are there?
- How do stars form from gas within galaxies?
- Why do galaxies stop forming new stars?
- Can we explain the diversity of galaxy properties we observe?
- …

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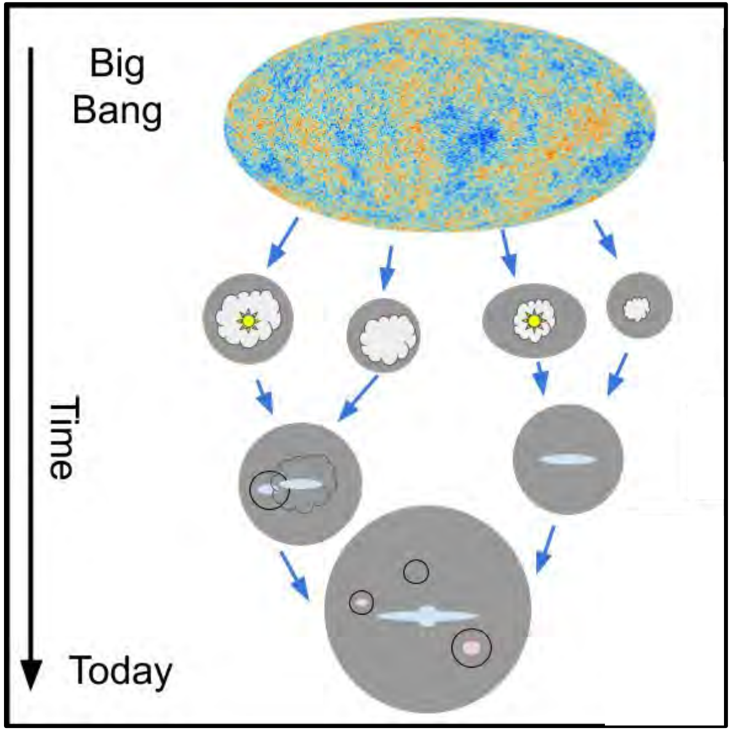
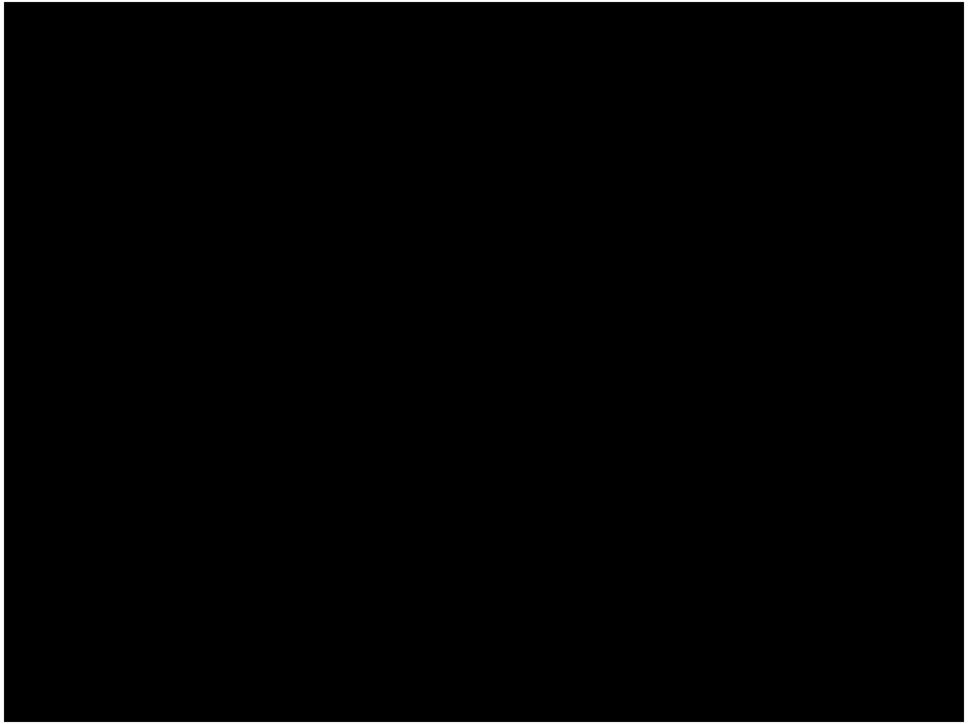
*And what conclusions can we safely draw from our simulations?

Galaxy Formation

- Most (~85%) matter is dark matter
- Initial density perturbations grow under the influence of gravity
- Gas condenses in dark matter “halos”, where it eventually forms the first galaxies
- Over time, halos accrete and merge, forming the systems we see today



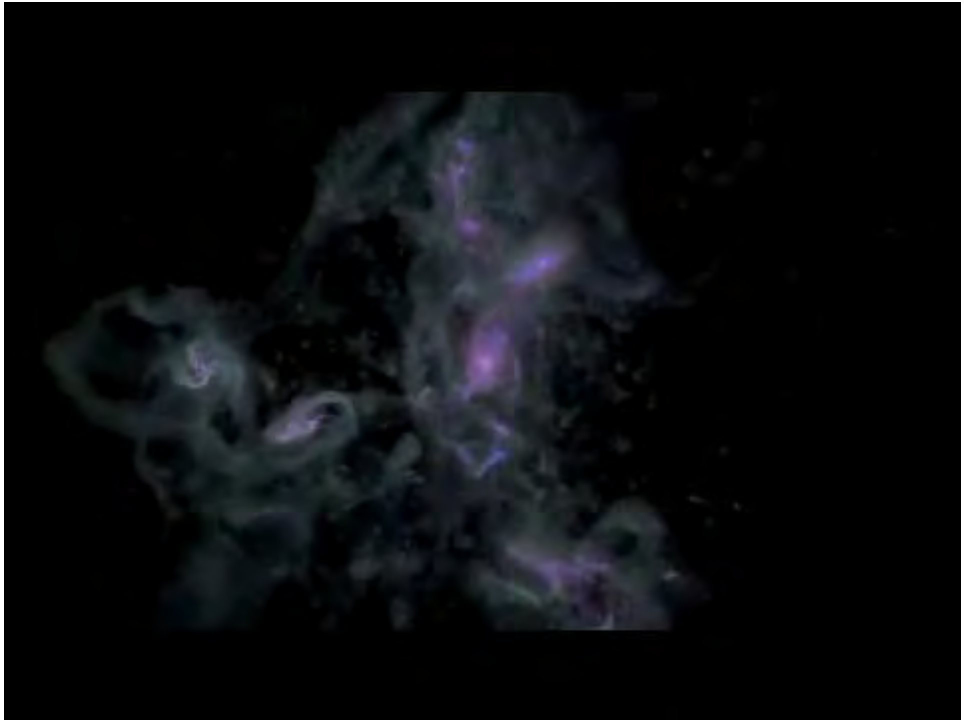
Galaxy Formation



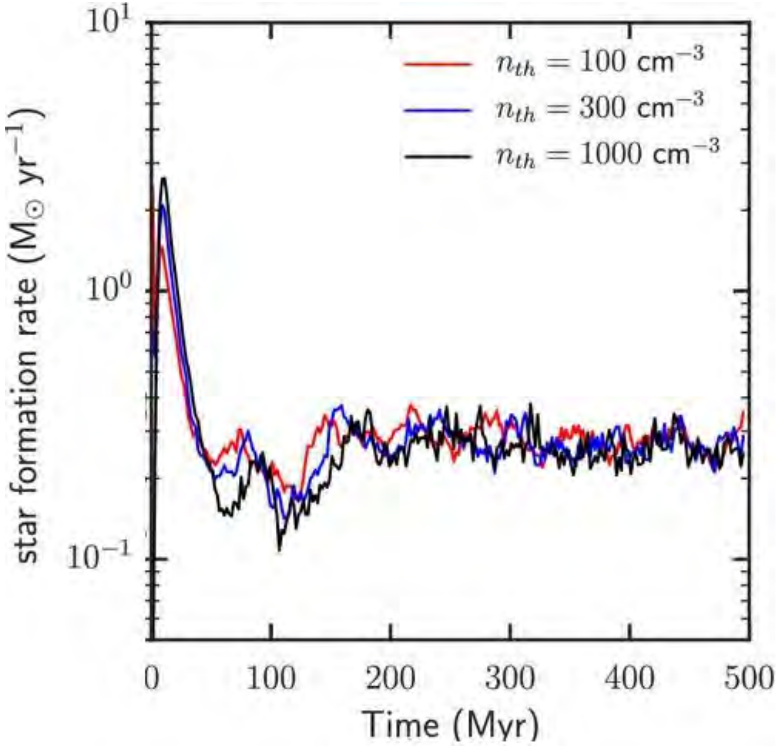
Credit: Via Lactea simulation
Diemand+ 2007

Galaxy Formation

- Gravity + hydrodynamics
- Initially dark matter and gas, then stars form
- Star formation, supernovae, mass and radiation from massive stars all modeled as “sub-grid” recipes



Laissez Faire Galaxies?



- Galaxy "self-regulation" obscures the underlying mechanisms of star formation and feedback

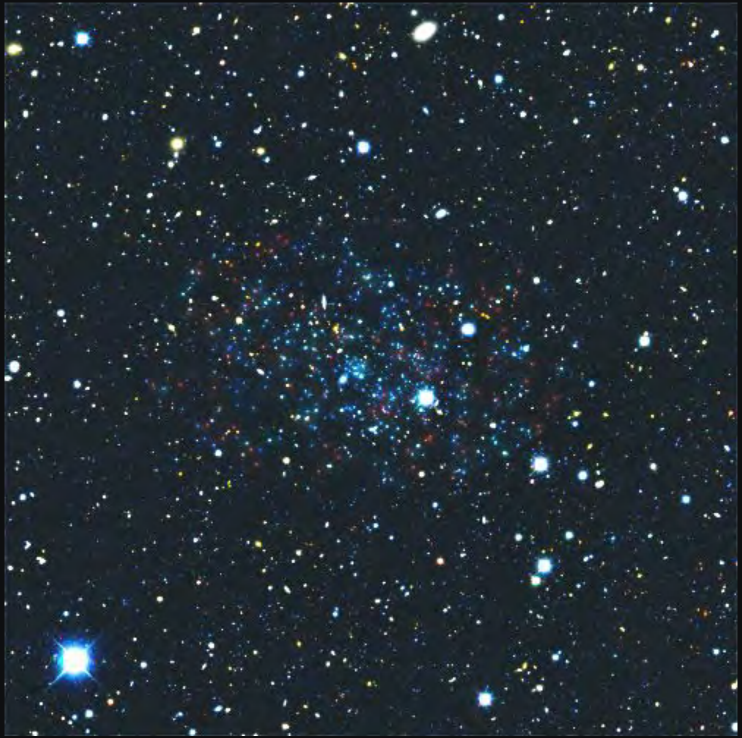
- Constraining the details requires studying a regime that cannot self-regulate

- Dwarf and ultra-faint dwarf galaxies

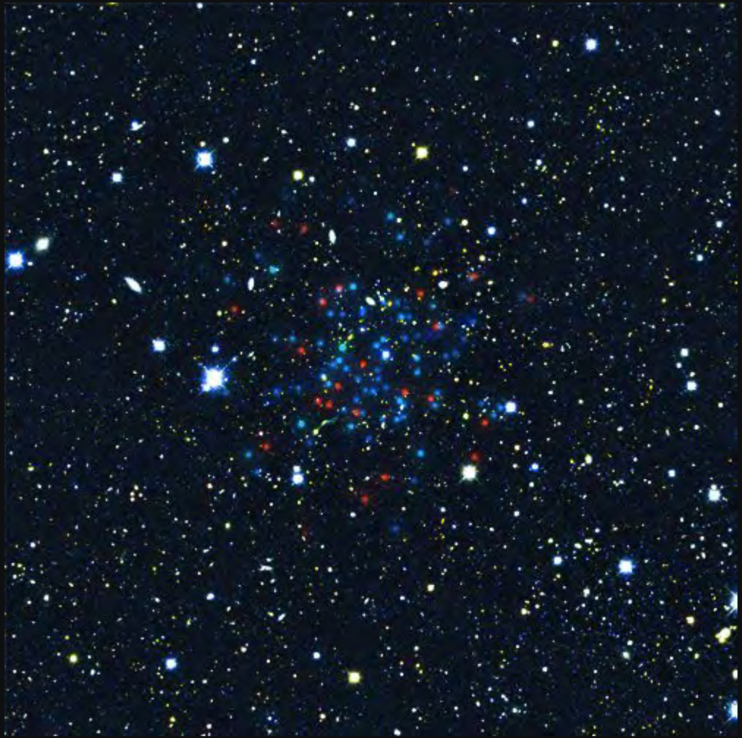
Benincasa+ 2016

M100
(Distance ~ 50 Mly)

Credit: ESO



Eridanus II
(Distance ~ 1 Mly)



Horologium I
(Distance ~ 300 kly)

Credit: V. Belokurov, S. Koposov (IoA, Cambridge)

Recap

We want to study very small galaxies, in large enough numbers to draw conclusions about different star formation models, in a fully cosmological context

↓

We need very high-resolution, cosmological hydrodynamic simulations

Why We Need Blue Waters

Scale → ↓	Small	Big
Spatial	10s of ly (Hydrodynamics and gravity resolutions)	>10^8 ly (gravitational torques and forces)
Temporal	100s of yr (force calculations)	>10^{10} yr (age of Universe)

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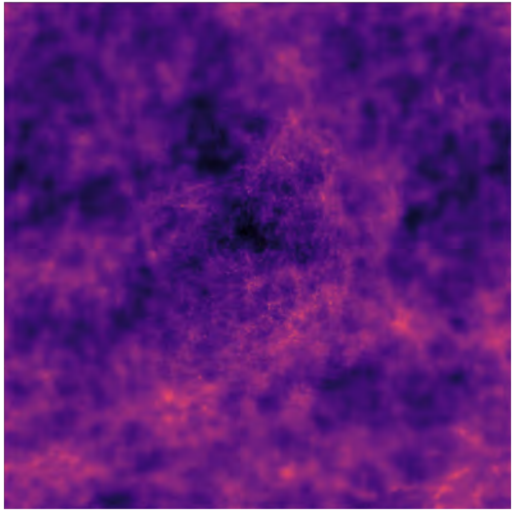
Star formation, supernovae, stellar mass loss << resolution

ChaNGa: A Modern Cosmological SPH Code

- Includes the SPH methods and physics modules of GASOLINE2
- Uses CHARM++ runtime system
- Designed for scalability on massive parallel systems like Blue Waters



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Menon+ 2015, Wadsley+ 2017

Model Comparisons

Star Formation Models:

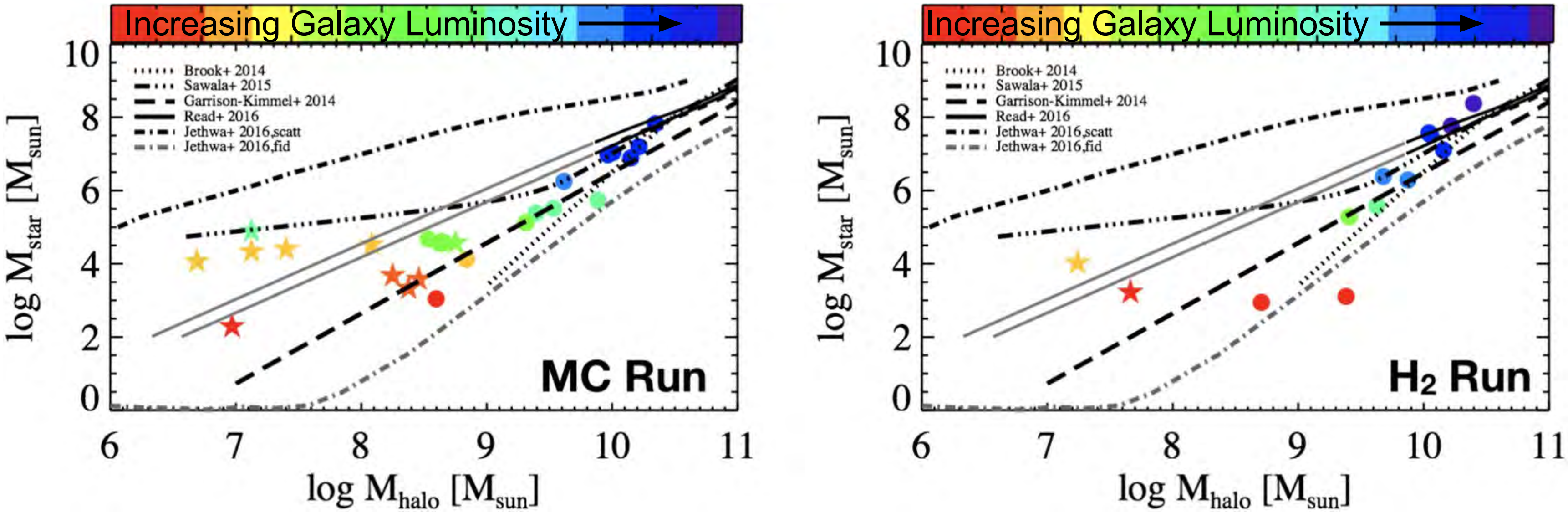
- "Metal Cooling (MC)"
  - Density threshold (100 m_H cm^{-3}) in cold (<10^4 K) gas
- "Molecular Hydrogen (H_2)"
  - Requires sufficient H_2 gas to form stars
  - Tracks non-equilibrium H_2 abundance
  - Pushes star formation to higher densities in un-enriched gas

Environments:

- Far from the Milky Way (>15 Mlyr from Milky Way, in an "isolated" environment)
- Near (analogous to) the Milky Way
  - At cutting-edge resolution!
    - 87 parsec gravitational softening, 11 pc hydro smoothing
    - 994 Msun initial star particle mass
    - 3310 (17900) initial gas (dark matter) particle mass

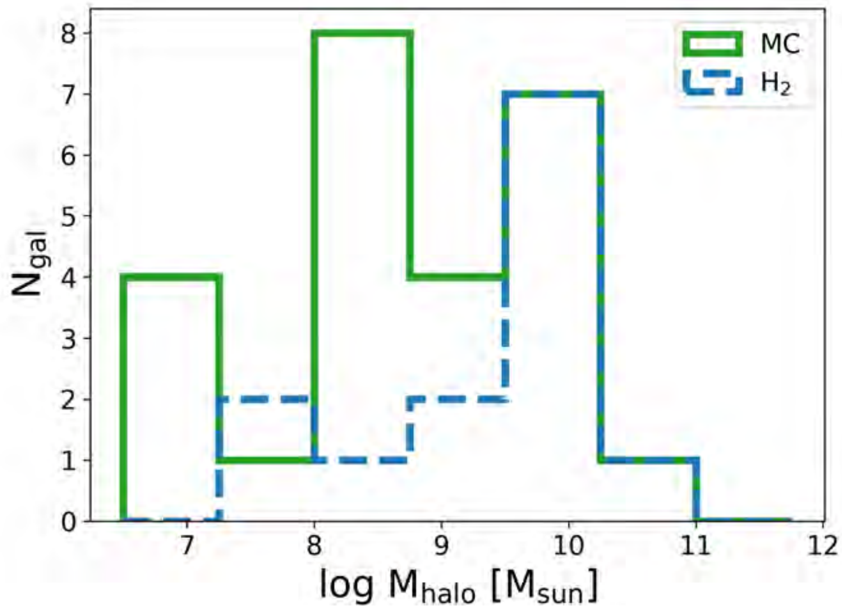
See also, e.g., Agertz+ 2019

Results Far From the Milky Way



Munshi...EA..+ 2019

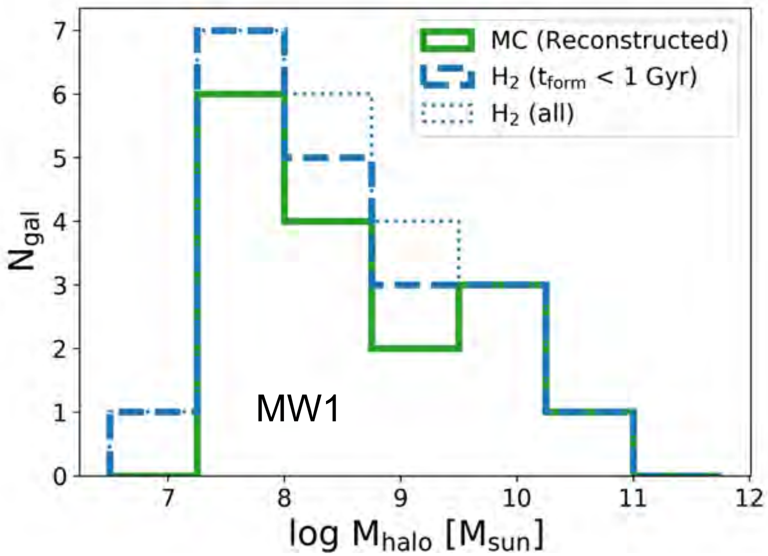
Results Far From the Milky Way

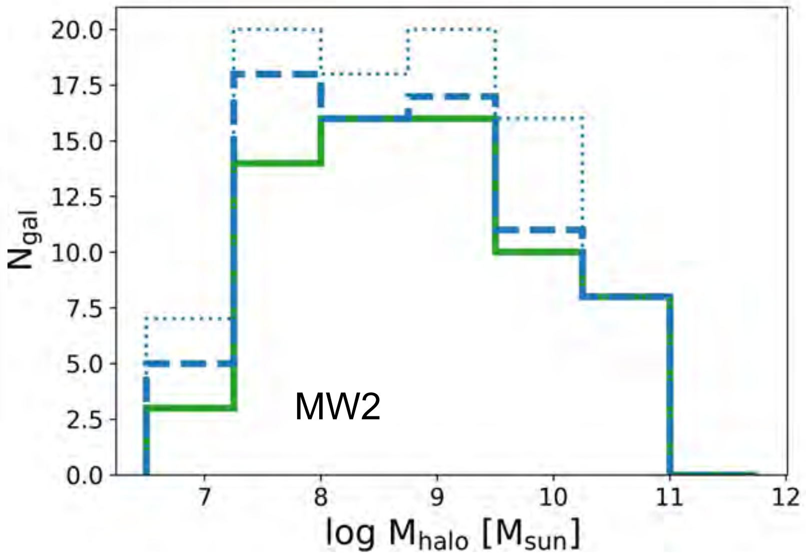


Applebaum+ *in prep*

Results Near the Milky Way

Surprisingly, there is little difference between star formation models!





Applebaum+ *in prep*

Summary

- Cosmological hydrodynamic simulations are probing for the first time analogs to the faintest known galaxies
- At low enough halo masses, self-regulation breaks down, and we can test the assumptions used in cosmological simulations
- In environments far from the Milky Way, we have shown that different star formation criteria lead to diverging results
- Near the Milky Way, the denser environment leads to converged galaxy counts and locations. *Caution is needed when interpreting nearby observations using simulations of isolated environments*

applebaum@physics.rutgers.edu emapple https://nbody.shop

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applebaum@physics.rutgers.edu

emapple

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