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

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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
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
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

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**Star formation, supernovae, stellar mass loss $\ll$ 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

https://nbody.shop

Menon+ 2015, Wadsley+ 2017
Model Comparisons

Star Formation Models:

- “Metal Cooling (MC)”
  - Density threshold ($100 \text{ m}_H \text{ cm}^{-3}$) in cold ($<10^4 \text{ K}$) gas

- “Molecular Hydrogen ($\text{H}_2$)”
  - Requires sufficient $\text{H}_2$ gas to form stars
  - Tracks non-equilibrium $\text{H}_2$ 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
Results Far From the Milky Way

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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*
Acknowledgments

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