How to slow down star formation in dwarf galaxies

John Forbes (University of CA, Santa Cruz)
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with Mark Krumholz, Nathan Goldbaum, Avishai Dekel
Outline

• Dwarf galaxies are inefficient at forming stars

• The most popular way to explain this is with strong feedback from SNe.
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- The most popular way to explain this is with strong feedback from SNe.
- We are running simulations with well-resolved SNe feedback to verify or reject this scenario.
- We find that grain photoelectric heating has a much stronger effect(!)
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What is a galaxy?

Outflows

Gas

Stars
Dwarf galaxies are bad at their jobs

Behroozi+ (2013a,b) model
Three possibilities

Outflows

Gas

Stars
Three possibilities

Outflows

Gas

Stars
Three possibilities

Outflows

Gas

Stars
Three possible explanations

- **Option 1: Ejective** Feedback:
  - Radiative: e.g. Murray+ (2005), Hopkins+ (2012), FIRE
  - Prescriptive: Dave+ (2008,…), Illustris, SAMs

- **Option 2: Preventative** Feedback:
  - e.g. Cantalupo (2010), Lu, Mo and Wechsler (2015)

- **Option 3: “Parking Lot”** Feedback
  - e.g. Krumholz & Dekel (2013)
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Option 1: Remove the gas

FIRE
Muratov+ (2015)
Theorists are divided

Schroetter+ (2015)
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The Simulations

• **Big questions:** Are dwarfs in or out of equilibrium? I.e., is there dramatic ejective feedback? Why have dwarf galaxies formed so few stars?

• **Testing ground:**
  
  • Halo Mass $\sim 10^{10} \, M_\odot$
  
  • Large predicted mass loading factors
  
  • Small sizes -> computational affordability
The Simulations

- AMR hydrodynamics and gravity with Enzo
- Detailed SNe Feedback + Stellar winds, HII regions
- Grackle cooling to 10 K, UVB, Photoelectric heating
- Non-cosmological
- Maximum resolution between 2.5 pc and 10 pc
- Effective mass resolution $\sim 10 \, M_\odot$ / cell at SF threshold
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Photoelectric Heating

8-13.6 eV
non-ionizing
Photoelectric Heating

\[ g \propto F_{\text{FUV}} \ Z \ n_H \ \left[ \text{erg/s/cm}^3 \right] \]
Photoelectric Heating

\[ \Gamma_{\text{p.e.}} = \frac{G}{n_H} \propto F_{\text{FUV}} Z \ [\text{erg/s}] \]

Movie available:
https://www.dropbox.com/s/pfdk3i120p98yr4/m10r402_ProjectionDensJeans.gif?dl=0
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Photoelectric heating alone suppresses SFR by 10+

Simulation Time

50 Myr

200 Myr

SFR

No feedback
SNe, no PE
PE, no SNe
PE + SNe
No Photoelectric Heating

Gas Surface Density

Jeans Unstable Gas

Newly formed stars

Movie available: https://www.dropbox.com/s/pfdk3l120p98yr4/m10r402_ProjectionDensJeans.gif?dl=0
Photoelectric Heating + SNe

Gas Surface Density

Jeans Unstable Gas

Newly formed stars

Movie available:
https://www.dropbox.com/s/rol1euwpjrq3l/m10r431_ProjectionDensJeans.gif?dl=0
Photoelectric Heating shuts down SF in large swathes

Movie available: https://www.dropbox.com/s/f4vlmlkq2rgyyvn/m10r431_ProjectionDensJeans_slomo.gif?dl=0
What about the SNe?!

(Are they even on?)

![Graph showing SFR over simulation time](image)

- No feedback
- SNe, no PE
- PE, no SNe
- PE + SNe

Simulation Time

SFR

No feedback
SNe. no PE
PE. no SNe
PE + SNe

Simulation Time
SNe determine morphology
SNe determine the mass loading factor

log10 outflow/SFR

Simulation Time

No feedback
SNe. no PE
PE. no SNe
PE + SNe
Summary

- Dwarf galaxies are inefficient at forming stars.
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- We are running simulations with well-resolved SNe feedback to verify or reject this scenario.

  • **Photoelectric heating sets the depletion time in dwarf galaxies.**
  
  • **Supernovae set the outflow rates in dwarf galaxies, but have remarkably little effect on the SF Law.**