Radiative Feedback and the Low Efficiency of Star Formation in Cosmological Simulations

Daniel Ceverino (UAM, Madrid)

Anatoly Klypin, Elizabeth Klimek, Sebastian Trujillo-Gomez, Christopher Churchill (NMSU);
Joel Primack (UCSC), Avishai Dekel (HUJI)

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Low efficiency of galaxy formation on low-mass halos at high-redshift

- Abundance matching
- Conditional luminosity modeling
- Stellar fractions lower than 1% for $M_h \approx 10^{11}$ Ms at $z=3$

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Low efficiency of galaxy formation on low-mass halos at high-redshift

- Star formation and galaxy formation is a rather inefficient process in $M_h \approx 10^{11}$ Ms halos at any redshift

Which physical process drives this low efficiency?

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Galaxy formation simulations done with ART


- **Gas Cooling, Star Formation, Stellar Feedback** (Ceverino & Klypin 2009; Ceverino, Dekel and Bournaud 2010)
  - Cooling below $10^4$ K (minimum temperature of 300 K).
  - Thermal feedback + runaway stars.

- **Radiative Feedback** (Ceverino et al. 2013, ArXiv 1307.0943)

- **Zoom-in simulations: 15-30 pc resolution**
Radiative feedback

Rosette Nebula

40 pc

No Supernova explosion yet
Stellar winds
Thermal pressure
Radiation pressure from ionizing photons

Typical resolution of our zoom-in, cosmological simulation: ~ 20 pc
- At low column densities

\[ P_{\text{rad}} \propto (1 - \exp(-\tau)) \]

- Optically thin

- No effect from radiation pressure
• At high column densities

• Add pressure

\[ P_{\text{rad}} = \frac{L}{R^2 c} \]

\[ L = M \ast \Gamma \]

\[ \Gamma = \text{cte for 5 Myr} \]

For column densities \( >10^{21} \text{ cm}^{-2} \)

No free parameters
Photoionization & photoheating

Cloudy models

Sutherland & Dopita 93
VELAs

- ~35 zoom-in simulations
- 15-30 pc reso
- \( M_{DM} = 8 \times 10^4 \) Ms
- \( M_* = 10^3 \) Ms
- \( z = 1-3 \)

\( 10^{11} \) Ms/h < \( M_H \) < \( 10^{12} \) Ms/h

\( V_{c\_max} = 100-200 \) km/s
Low Star Formation Efficiency

- Radiation pressure reduces SFR and stellar mass by a factor ~3
- $\frac{M_{\text{star}}}{M_h} = 0.7\%$
- SFR $\sim 1$ Ms/yr

For $M_h \sim 10^{11}$ Ms at $z \sim 3$
Gas distributions

Without radiation pressure

With radiation pressure

Gas face-on

Gas edge-on

20 kpc
Stars face-on

Without radiation pressure

With radiation pressure

20 kpc
\[ V_c = \left( \frac{GM(R)}{R} \right)^{1/2} \]
Phase Diagrams

Without radiation pressure

With radiation pressure

Density

Density
Summary

• The low efficiency of star formation in low-mass halos at high redshift is driven by radiation pressure
• Radiation pressure controls the high-density tail of the density distribution
• Results are stable against model variations
• Photoionization and photoheating can prevent cooling in the log(T)=4-4.5 range
The End