Exploring the first generation of galaxies with Blue Waters and the James Web Space Telescope

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Manisha Gajbe (Blue Waters technical POC)
Bill Kramer and all of the Blue Waters team
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The Enzo and yt communities:
enzo-project.org
yt-project.org
Our goal:
Understanding the first generations of galaxy formation
Why is studying galaxy formation challenging?
Our simulation tool:

http://enzo-project.org

Our analysis/viz tool:

http://yt-project.org
Lots of results!


And much more to come!
Focus areas

The transition to metal-enriched star formation: Britton Smith*, John Wise*, BWO

Evolution of early galaxy populations: Hao Xu*, Pengfei Chen, Mike Norman, Kyungjin Ahn, BWO

* Ran the simulations
The transition to metal-enriched star formation

- **Small volume**: 0.5 Mpc/h box

- **Extremely high resolution**: 15 levels of AMR prior to explosion (0.029 pc comoving max); 30 after (~1 au comoving); ~0.19 M☉ gas, 0.92 M☉ dm mass resolution

- **Sophisticated physics**:  
  - Primordial gas + metal + dust chemistry & cooling  
  - **Radiation transport** for Pop III stars; core-collapse supernovae w/11.2 M☉ of metals

Smith et al. 2015 (submitted; arXiv:1504.07639)
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Metal mixing

Physical timescales

Smith et al. 2015 (submitted; arXiv:1504.07639)
Evolution of early galaxy populations

- **Large volume**: 40 Mpc box, refine on three separate ~300 Mpc$^3$ regions (overdense, average, low density)

- **High resolution**: Simulation at 12 levels of AMR (19 comoving pc), primordial + metal-enriched chemistry, Pop III and metal-enriched SF

- **Lots of galaxies**: 13,000 Pop III stars formed, ~3,000 halos > 10$^7$ M$_\odot$ (with star formation) by end of simulations

Xu et al. 2014, 15; Ahn et al. 2015; Chen et al. 2014; O’Shea et al. 2015
$z = 15$

**Normal**

**Rare peak**

**Void**

$10^{-26}$

$10^{-27}$

$z$ (Mpc) proper

$y$ (Mpc) proper
What’s in the “rare peak” region?

Projected Temperature
(scale: $10^3 - 3 \times 10^4$ K)

Projected Density
(scale: $3 \times 10^{-28} - 3 \times 10^{-24}$ g/cm$^3$)
Halo Mass \([M_\odot]\)

\[
\begin{align*}
z &= 18 \\
\end{align*}
\]

\[
\begin{align*}
\text{XRBs} & \quad \text{Xu et al. 2014, ApJ, 791, 110}
\end{align*}
\]
Luminosity function of early galaxies

Luminosity function of early galaxies

Luminosity function of early galaxies

Luminosity function of early galaxies

Density

Electron fraction
(ionizing radiation)
Simulation data as a community resource

- Simulation tool (Enzo) and analysis/viz tool (yt) are open-source community codes.
- We are making all of our datasets (and resulting data products) publicly available via the National Data Service and NDS Labs.
- These simulations were very expensive and will be a community resource for years to come!

Cutting-edge simulations have a long tail of utility!
Takeaways

• The transition between primordial and metal-enriched star formation is locally complex, and the outcome is strongly affected by the presence of dust.

• Multiple Pop III stellar remnants wind up in each high-sigma halo: X-ray binaries? SMBH progenitors?

• Star formation is inefficient (and sometimes suppressed entirely) in small, high-z galaxies - turnover in UV luminosity function predicted.

• This would have been undoable without a machine like Blue Waters: memory, interconnect, fast IO.