The Destruction of Cosmological Minihalos by Primordial Supernovae: Triggered Star Formation?

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Daniel Whalen
X-2, LANL

Bob Van Veelen
Utrecht

Michael Norman
UCSD

Brian O’Shea
T-6, LANL
A Cosmological Halo \( z \sim 20 \)

\( \sim 200 \text{ pc} \)
Properties of the First Stars

• thought to be very massive (100 - 500 solar masses) due to inefficient H$_2$ cooling

• form in isolation (one per halo)

• $T_{\text{surface}} \sim 100,000$ K

• *extremely* luminous sources of ionizing and LW photons ($> 10^{50}$ photons s$^{-1}$)

• 2 - 3 Myr lifetimes

Transformation of the Halo

ZAMS

End of Main Sequence
What a Primordial Supernova Does to a Halo I: H II Region

- the remnant collides with the dense H II region shell and later grows to half the radius of the H II region
- metals preferentially permeate voids
- neither metals nor gas return to the halo in less than a merger time (~ 20 Myr)

Star Formation is Postponed!

What a Primordial Supernova Does to a Halo II: Neutral Halo

It Fizzles!


- temperatures skyrocket to $10^9$ K at the center of the halo
- the hot, ionized, dense center emits intense bremsstrahlung x-rays
- the core radiates away the energy of the blast before it can sweep up its own mass in the halo
Recipe for an Accurate Primordial Supernova

- initialize blast with kinetic rather than thermal energy
- couple primordial chemistry to hydrodynamics with adaptive hierarchical timesteps
- implement metals and metal-line cooling
- use moving Eulerian grid to resolve flows from 0.0005 pc to 1 kpc
- include the dark matter potential of the halo

ZEUS-MP 1D Primordial Supernova: 9 Models

• Halos: $6.9 \times 10^5$, $2.1 \times 10^6$, and $1.2 \times 10^7$ solar masses

• Stars: 25, 40, and 200 solar masses (Type II, hypernova, and pair-instability supernovae)

• Stage 1: illuminate each halo for the lifetime of its star

• Stage 2: set off the blast and evolve the remnant for 7 Myr
4 SN Remnant Stages in H II Regions

- $t < 10$ yr: free-expansion shock
- $30$ yr $< t < 2400$ yr: reverse shock
- $19.8$ kyr $< t < 420$ kyr: collision with shell / radiative phase
- $t > 2$ Myr: dispersal of the halo
Reverse Shock

Collision with the Shell
4 SN Remnant Stages in Neutral Halos

- $t < 1 \text{ yr}$: free-expansion shock
- $t < 20 \text{ yr}$: early radiative phase
- $100 \text{ yr} < t < 5000 \text{ yr}$: late radiative phase
- $t > 1 \text{ Myr}$: fallback
Late Radiative Phase

Fallback
Enormous, Episodic Infall Rates During Fallback
Observational Signatures of Primordial Supernovae
Halo Destruction Efficiency

SN Energy ($10^{20}$ erg) vs Halo Mass (Solar Masses)

- $10^1$: E,D, P,D, N,F
- $10^2$: E,D, P,D
- $10^3$: E,D

Legend:
- E: Efficient
- D: Destruction
- P: Partial
- N: None
- F: Failure
Conclusions

• if a primordial star dies in a supernova, it will destroy any cosmological halo $< 10^7$ solar masses

• supernovae in neutral halos do not fizzle--they seriously damage but do not destroy the halo

• primordial SN in H II regions may trigger a second, prompt generation of low-mass stars that are unbound from the halo

• blasts in neutral halos result in violent fallback, potentially fueling the growth of SMBH seeds and forming a cluster of low-mass stars