Finding the First Cosmic Explosions

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From Stars to Massive Stars, Apr 9, 2016
Probing the Properties of The First Stars with SNe

• direct detection of Pop III stars not possible now or even with 30 – 40 m class telescopes

• might get lucky and catch the lensed H II region of a Pop III star, but need a magnification \( \mu > 300 \) (Rydberg et al. 2013)

• stellar archaeology: hunting for the ashes of the first SNe in ancient, dim metal-poor stars

• direct detection of Pop III SNe in the NIR
  -- build up a rough IMF by binning transients by explosion type
  -- constrain cosmic star formation rates by counting transients
PI SN Explosion (Chen et al. 2014a)
Los Alamos Supernova Light Curve Project

Frey, Even, Whalen et al. 2013 ApJS, 204, 16

- model final pre-SN structure of star with Kepler, MESA, GENEVA or some other stellar evolution code
- simulate explosion in the Los Alamos RAGE rad hydro code
- post process RAGE profiles with SPECTRUM code to compute spectra and light curves
- use the LANL OPLIB database of atomic opacities to get absorption / emission lines
• PI and PPI SNe will be visible to JWST and 30 – 40 m telescopes at $z \sim 15 - 30$

• CC SNe and explosions of compact progenitors will be visible at $z \sim 10 - 15$
• JWST and the ELTs have high sensitivities that can capture PI SNe at any epoch, but their narrow fields of view may not encounter many events

• they will also only detect CC SNe out to $z \sim 10 - 15$, the era of the first galaxies, not first light

• the Pop III IMF cannot be constrained with PI SNe alone

• so will these telescopes play any role in revealing the properties of the first stars?
Detecting Ancient SNe at $5 < z < 20$
with Dedicated Cluster Lens Surveys
Whalen et al. 2016, in prep

J0717
Cluster Surveys of High Redshift SNe with JWST

CLASH SN detection rates

Frontier Fields SN detection rates
WFIRST could detect large numbers of Pop III PI SNe at $z = 10 - 15$, which may be their optimum redshift for detection due to Lyman-Werner UV backgrounds.

- all sky NIR survey mission
- 5.04 deg$^2$ Deep SN Survey: AB mag 29.3 H, J band sensitivity
Constraining the Pop III IMF and SFRs with WFIRST

• future wide fields like the 5.04 deg$^2$ WFIRST Deep SN survey could enclose "tens of thousands" of cluster lenses

• these lenses could boost flux from background transients at $z \sim 15 – 20$ above the 29.3 AB mag limit of the survey in the NIR

• if so, WFIRST might capture hundreds or thousands of Pop III CC SNe at this epoch

• together with PI SNe, which need no magnification, these transients could constrain the Pop III IMF

• they could also probe cosmic SFRs down to the least optimistic values predicted by simulations
Supermassive Pop III Stars

• thought to form in at the centers of hot, dead protogalaxies in strong Lyman-Werner backgrounds at $z \sim 15 – 20$

• they form under accretion rates of 0.01 – 10 solar masses / yr

• most are thought to reach masses of 75,000 – 350,000 solar masses and then collapse directly to black holes via the GR instability

• a few may explode, with energies of $10^{55}$ erg, or 10,000 Type Ia SNe (Whalen et al. 2013; Chen et al. 2015)

• almost certainly required to explain the existence of $10^9$ solar mass BHs at $z \sim 7$
CR7: a possible site of Pop III SMS formation
Preliminary Results

Woods et al. 2016, in prep
Hammerle et al. 2016, in prep

• Kepler non-rotating SMS models: $0.01 - 10 \, M_{\text{sun}}/\text{yr}$

• final masses of 75,000 to 320,000 $M_{\text{sun}}$

• maximum mass at $\sim 1 \, M_{\text{sun}}/\text{yr}$

• stars are not fully convective – both convective and radiative zones

• stars that accrete at $\sim 3 \, M_{\text{sun}} / \text{yr}$ explode rather than collapse
Supermassive Pop III SNe: the Most Energetic SNe in the Universe


- may herald the births of SMBH seeds
- $10^{55}$ erg thermonuclear SNe
- 55,000 solar masses
- visible at any redshift to both JWST and WFIRST
The Supernova that Destroyed a Protogalaxy