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Finding Ancient Supernovae at $5 < z < 12$ with Frontier Fields

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Abstract. Supernovae are important probes of the properties of stars at high redshifts because they can be detected at early epochs and their masses can be inferred from their light curves. Direct detection of the first cosmic explosions in the universe will only be possible with JWST, WFIRST and the next generation of extremely large telescopes. But strong gravitational lensing by massive clusters, like those in the Frontier Fields, could reveal supernovae at slightly lower redshifts now by magnifying their flux by factors of 10 or more. We find that Frontier Fields will likely discover dozens of core-collapse supernovae at $5 < z < 12$. Future surveys of cluster lenses similar in scope to Frontier Fields by JWST might find hundreds of these events out to $z \sim 15$ - 17. Besides revealing the masses of early stars, these ancient supernovae could also constrain cosmic star formation rates in the era of first galaxy formation.

Keywords. early universe – galaxies: high-redshift – galaxies: clusters: general – gravitational lensing – large-scale structure of universe – stars: early-type – supernovae: general

1. Introduction

With the advent of the *James Webb Space Telescope* (*JWST*) and the next generation of 30 m class telescopes, it will soon be possible to detect SNe at the edge of the observable universe at $z \sim 10$ - 20 and use them to probe the earliest stellar populations (Whalen *et al.* 2008; 2013a,b,c,d,e,f; Whalen *et al.* 2014a,b; de Souza *et al.* 2013;2014). But SNe could be discovered in surveys at $z > 5$ now. In principle, strong lensing by massive galaxy clusters at $z \lesssim 1$ could boost flux from SNe by factors of 20 or more and allow them to be detected at $z \gtrsim 10$ by HST (Whalen *et al.* 2013g).

We have computed the number of SNe expected to be found in the Frontier Fields (FF) survey at $z > 5$. First, we construct magnification maps, μ, as a function of redshift for each cluster in FF from its κ and γ maps, which are taken from Zitrin *et al.* 2015. Then we calculate the volume that is lensed to a given μ by a small patch on the map with that magnification, $dA(\mu, z)$, and sum the dV to compute the total volume of space, $\mathrm{d}V(z, \mu)$, lensed to this μ at z_i by the cluster. We then convolve these lensed volumes with cosmic star formation rates (SFRs) from observations and simulations to calculate the number of SNe enclosed by the lensing volume $\mathrm{d}V(z, \mu)$ whose flux is boosted by a factor μ or more at redshift z over the time $\mathrm{d}t$ in the observer frame:

$$\mathrm{d}N(z, \mu) \;=\; \mathrm{SFR}\,(1+z)\,\frac{1\ \mathrm{SN}}{100\ M_\odot}\,\mathrm{d}V(z, \mu)\frac{\mathrm{d}t}{1+z}. \tag{1.1}$$

To obtain the total number of SNe above a given redshift, $N(> z)$, we integrate $\mathrm{d}N(z, \mu)$ over all z above that redshift and all μ above the minimum magnification needed to detect the event at each redshift.

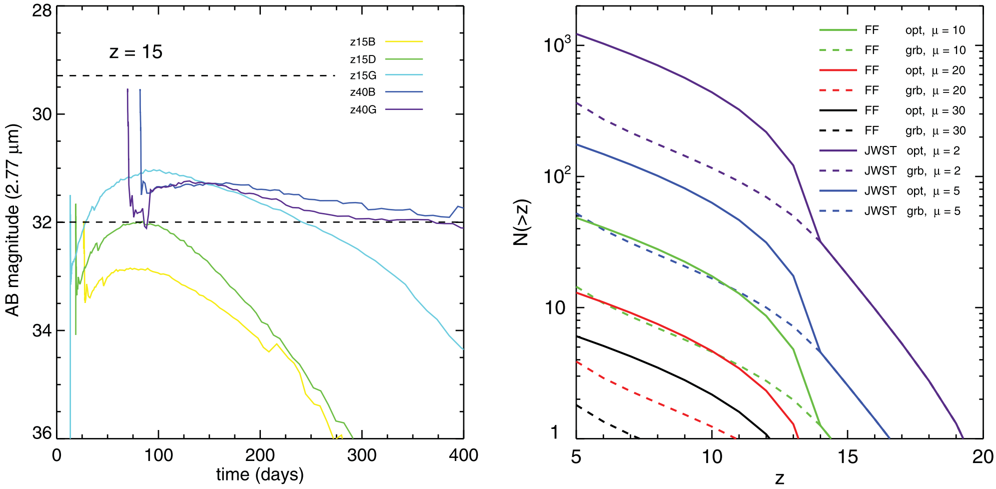

Figure 1. Left panel: 15 - 40 $M_\odot$ Pop III CC SN NIR light curves at $z = 15$. The two dashed lines are FF and JWST photometry limits at AB mag 29.3 and 32, respectively. Right panel: cumulative SN rates down to redshift z.

Light curves for Pop III core-collapse SNe and detection rates are shown in Fig. 1. FF could find dozens of SNe at $5 < z < 12$, and future surveys of these clusters by JWST might find hundreds of SNe out to $z \sim 15$ - 17. Such detections will probe the properties of stars and their formation rates in the era of first galaxy formation.

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