ZN7090-2020f: Peculiar Ultra-Luminous Supernova

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Introduction

We present high cadence multi-band observations of young supernova ZN7090-2020f discovered by the Korean Microlensing Telescope Network Supernova Program in October 12, 2020. The observed light curves and the presence of hydrogen emission in the spectrum identify the source to be a Type IIL at red-shift $z = 0.0873$. The supernova appears to be more luminous than any other previously observed super-novae by ~ 1 magnitude.

Objectives

We aim to characterize and determine the progenitor and explosion parameters of supernova ZN7090. The preliminary spectrum taken of this source shows a broad Hα feature which indicates the presence of ionized hydrogen. This would suggest that the source is a Type II supernova. In addition, we will use the light curve morphology to further classify and inspect the amount of H in the progenitor as well as the powering mechanism.

Furthermore, we want to determine important progenitor and explosion parameters through analytical models provided through literature. In particular we will be focusing our attention in the model proposed by Sapir & Waxman (2017) [1] and Morag et al. [2].

Discovery & Observations

ZN7090 was first detected on 2020 October 12 at 14:44 UTC as part of the KMTNet Supernova Program. The KMTNet is a network of three 1.6m telescopes located in Chile, Africa, and Australia, providing 24 hr continuous sky survey. The Korean Supernova Program conducts high-cadence BVI monitoring of a sample of fields and focuses on studying early SNe and rapidly evolving transients.

We collected three spectrums for ZN7090 with the Gemini-South observatory during the early shock breakout phase, early, and late nebula phase.

Shock Breakout Model

The analytical model from Sapir & Waxman assumes that during the early stages of the shock breakout the plasma is fully ionized and thus the opacity κ, is nearly time and space independent. This assumption holds true for temperatures T $\geq 0.7\,$eV.

$$T_{\rm ph,RW} = 1.61[1.69]\left(\frac{v_{s*,8.5}^2 t_{\rm d}^2}{f_\rho M_0 \kappa_{0.34}}\right)^{\epsilon_1} \frac{R_{13}^{1/4}}{\kappa_{0.34}^{1/4}} t^{-1/2}\,\text{eV} \tag{1}$$

$$L_{\rm RW} = 2.0[2.1]\times 10^{42}\left(\frac{v_{s*,8.5}^2 t_{\rm d}^2}{f_\rho M_0 \kappa_{0.34}}\right)^{-\epsilon_2} \frac{v_{s*,8.5} R_{13}}{\kappa_{0.34}} \tag{2}$$

Where the pre-factors correspond to the different polytropic indices of the progenitor star with n = 3/2 [3] for convective and radiative effective envelopes respectively.

Furthermore the model proposed by Morag et al. is a numerical calibration and extension to the model proposed by Rabinak & Waxman. This model takes into account the transition from planar shock breakout to spherical self-similar motion of the ejecta.

$$L_{\rm C} = L_{\rm Planar} + L_{\rm SW} \tag{3}$$

Where $L_{\rm SW}$ is the supressed bolometric luminosity presented in Rabinak & Waxman 2017 and

$$L_{\rm Planar} = 2.974\times 10^{42}\frac{R_{13}^{0.462} v_{*,8.5}^{0.602}}{(f_\rho M_0 \kappa_{0.34})^{0.0643}} \frac{R_{13}^2}{\kappa_{0.34}} t_h^{-4/3} \tag{4}$$

And the new temperature expression is,

$$T_C = f_T \min[T_{\rm Planar}, T_{\rm ph,RW}] \tag{5}$$

Where $T_{\rm ph,RW}$ is given by eq.1 and $T_{\rm Planar}$ is,

$$T_{\rm Planar} = 6.937\frac{R_{13}^{0.1155} v_{*,8.5}^{0.1506}}{f_\rho^{0.01609} M_0^{0.01609} \kappa_{0.34}^{0.2661}} t_h^{-1/3}\,\text{eV} \tag{6}$$

Maximum-Likelihood-Estimation on Early Light Curve

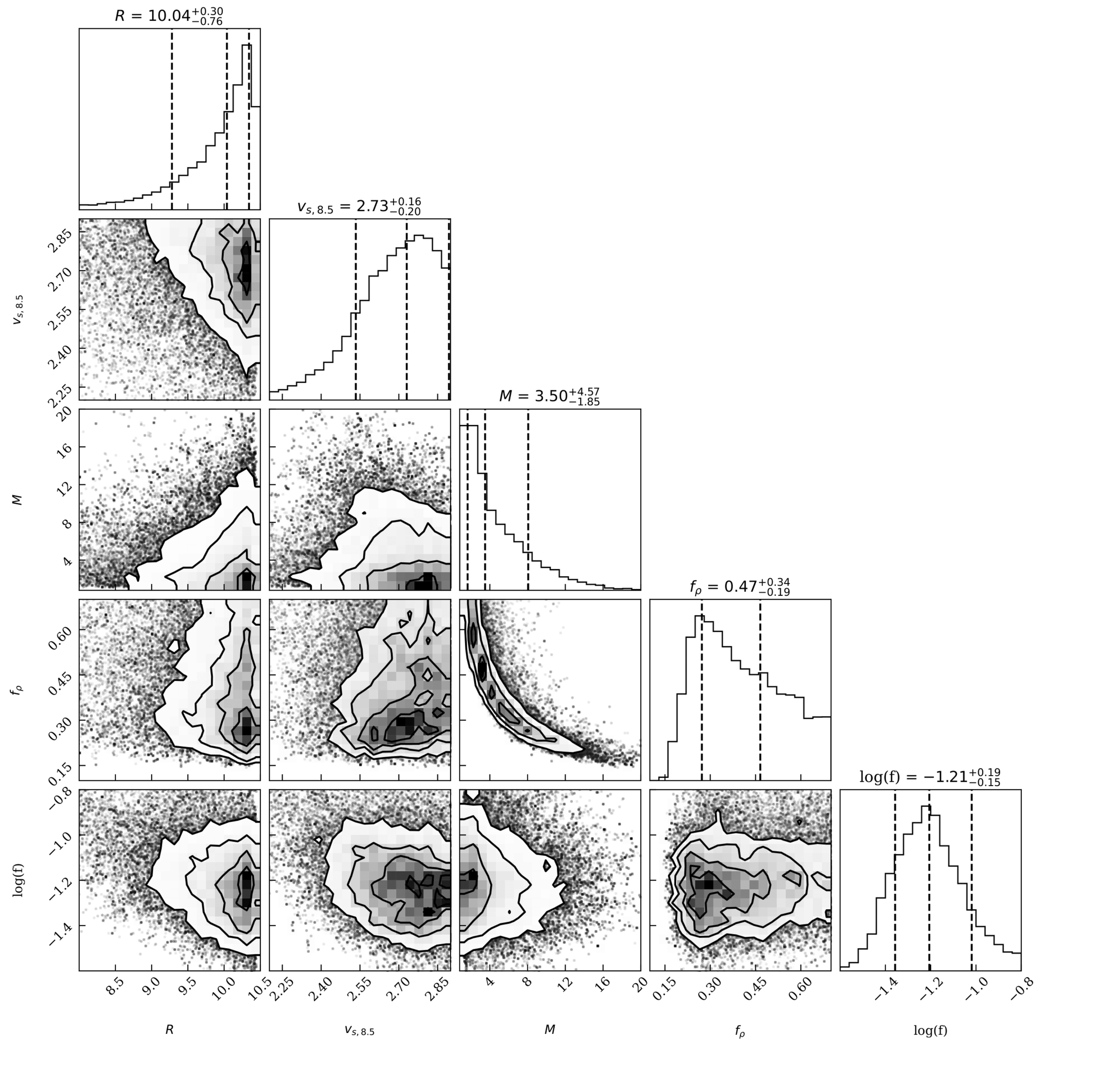

Figure 1: MLE corner plot for progenitor and explosion parameters proposed by [2]

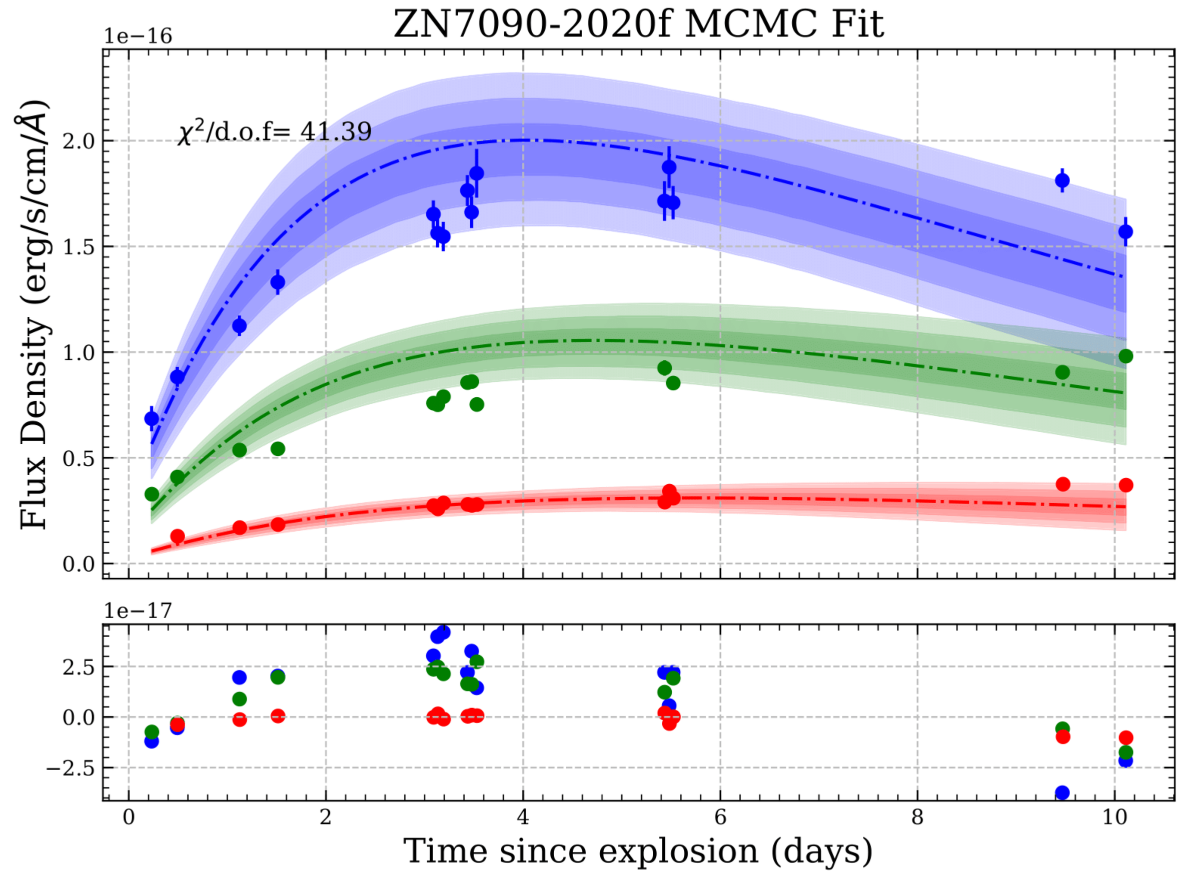

Figure 2: Simultaneous Markov-Chain Monte Carlo fitting to BVi spectral flux density light curves to ZN7090. Dashed-dotted line indicates the model with the highest likelihood parameters. Confidence bands indicate indicate 1,2 and 3 sigma level significance for each band

Progenitor Parameters

To simulate a pseudo-bolometric light curve we performed a Markov-Chain Monte Carlo simultaneous fit on the monochromatic fluxes. We set the following priors to the fitting routines; $R \in [200\,{\rm R}_\odot, 1500\,{\rm R}_\odot]$, $v_{s*,8.5} \in [0.5, 3.0]$, $M \in [2, 25]$, $f_\rho \in [\sqrt{1/3}, \sqrt{10}]$. The 'likeliness' used for the MCMC is the log likelihood function.

Parameter	Median	H.L	1σ Conf.
R	1458	1498	[1393, 1489]
$v_{s*,8.5}$	2.69	2.62	[2.54, 2.85]
M	9.44	17.80	[3.38, 18.81]
f_ρ	0.24	0.17	[0.169, 0.453]

The progenitor and explosion parameters suggest that the progenitor star was a red super giant with a massive core.

Discussion

The parameters presented in the Progenitor Paramters sections indicate a ultra-energetic ejecta with an energy of $E_{\rm ej} = 21.0^{+12.4}_{-12.3}$ foe. This value is greater than average Type II SNe ejecta energy by a factor of ten. In the BVi light curves of ZN7090 we see that the peak B and V band absolute magnitudes are ≈ -19, this makes ZN7090-2020f brighter than most Type II CCSNe by a one magnitude. So it could be that the results from MLE are influenced by this ultra-high luminosity. Further inspection on the early photometry needs to be carried out in order to be confident on the validity of our results.

This overestimate could be cause by not correcting for host galaxy extinction, which in principle would affect the BV bands more than the i band. We can use the NaI doublets emission lines (5889 and 5895 .), as tracers to find host galaxy extinction

Ongoing Research

Given our current finidings we belive ZN090-2020f belongs to a classification of supernova called Super-luminous Supernovae (SLSNe). This class of supernova have been rarely seen in literature and their explosion/powering mechanisms are not well understood. It's been observe that several of these type of supernova are H deficient which often leads them to be classified as Type Ic, however, the spectrums for ZN7090 indicate the presence of ionized H which does not agree with the current features of SLSNe.

References

[1] Nir Sapir and Eli Waxman. UV/optical emission from the expanding envelopes of type II supernovae. *The Astrophysical Journal*, 838(2):130, apr 2017.

[2] Jonathan Morag, Nir Sapir, and Eli Waxman. Shock cooling emission from explosions of red super-giants: I. a numerically calibrated analytic model. *Monthly Notices of the Royal Astronomical Society*, mar 2023.