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Bolometric light-curve modeling reveals extremely high ejecta masses in SLSNe-I

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INTRODUCTION – Preparation for modeling

Data: ZTF g and r light curves of 98 SLSNe-I exploded between 2018 and 2024
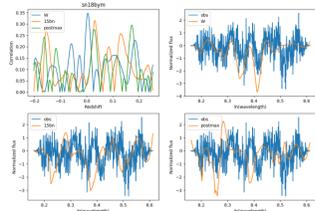
Bolometric light–curve calculations:
Following the method of Chen et al. (2023) from the g and r light curves:
$\log(L_{bolo}/L_{gr}) = -1.093x^3 + 1.244x^2 - 0.261x + 0.410$

Velocity estimates:
They are crucial for reliable ejecta mass (M_{ej}) estimates. Out of the sample, 56 SLSNe had available spectra. The ejecta velocity of all other objects was fitted between 8000 and 30000 km/s during modeling.

The method presented in Könyves-Tóth & Vinkó (2021) was applied. It is based on the combination of the spectrum modeling with SYN++ and the cross correlation.
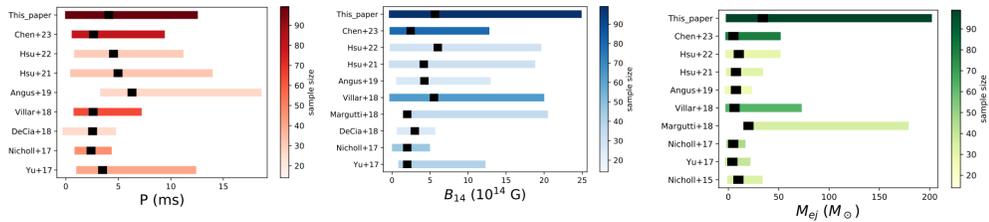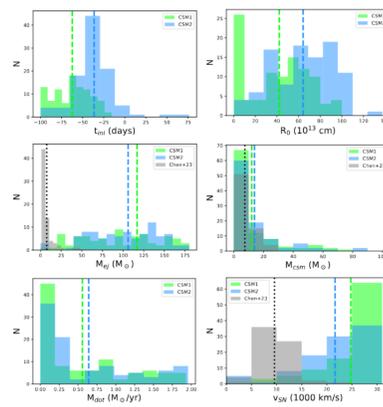
Results: $5711 < v_{ej} < 30002$, average: 14707 km

METHOD – Modeling using the Minim code

Megnetar model:
 Basic assumption: $\kappa = 0.2$ cm²/g

$$P_{10} = (2 \cdot 10^{50}[\text{erg/s}]/E_p)^{1/2}; \quad B_{14} = (1.3 P_{10}^2/t_{p,yr})^{1/2} \quad M_{ej} = \frac{\beta c}{2\kappa} v_{SN} t_{diff}^2$$

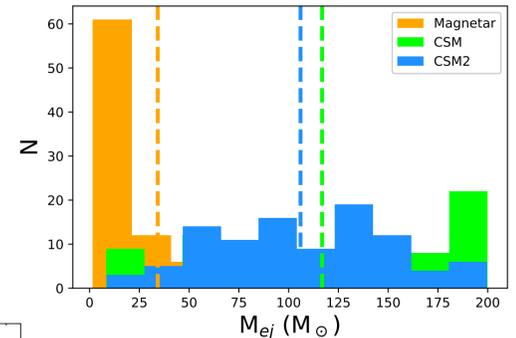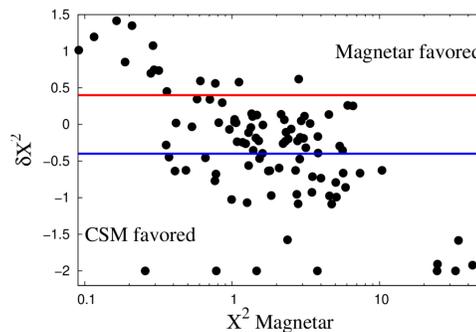| Parameter	Unit	Input bounds	Mean
t_{ini}	days	$[-100 : 0]$	-45.06 ± 2.27
R_0	10^{13} cm	$[0.1 : 10]$	4.43 ± 0.26
E_p	10^{51} erg	$[0.1 : 100]$	2.64 ± 0.40
t_{diff}	days	$[5 : 300]$	78.79 ± 7.04
t_p	days	$[1 : 100]$	12.45 ± 1.33
v_{SN}	1000 km s^{-1}	$[8 : 30]$/fixed	15.01 ± 0.58
P_{10}	10 ms	calculated	0.41 ± 0.02
B_{14}	10^{14} G	calculated	5.65 ± 0.43
M_{ej}	$M_\odot$	calculated	34.26 ± 4.67
χ^2			3.6787 ± 0.7021

CSM models: CSM (s=0) and CSM2/CSMW (s=2)
 Basic assumptions:
• $x_0 = 0.1$: the fractional radius of the constant density core within the ejecta.
• $n = 12$: the power-law exponent of the density in the outer part of the ejecta.
• $\kappa = 0.2$ (cm²/g): the electron scattering opacity.
• $s = 0$ (in case of CSM model) and 2 (in case of CSM2 model): the CSM density power-law exponent.
• $v_{wind} = 10$ (km/s): the mass-loss wind velocity.
• $d = 0$: the density exponent in the core.

Param	Unit	Bounds	Mean CSM	Mean CSM 2
t_{ini}	days	$[0 : -100]$	-62.35 ± 2.21	-36.40 ± 2.43
R_0	10^{13} cm	$[0.1 : 100]$	42.13 ± 2.82	64.15 ± 2.77
M_{ej}	$M_\odot$	$[1 : 200]$	116.82 ± 5.97	105.99 ± 4.50
M_{CSM}	$M_\odot$	$[0 : 100]$	12.06 ± 1.74	13.90 ± 1.67
M_{dot}	$M_\odot$/yr	$[0.0001 : 2]$	0.56 ± 0.06	0.64 ± 0.06
v_{SN}	1000 km s^{-1}	$[8 : 30]$	24.78 ± 0.62	21.64 ± 0.69
χ^2			1.7437 ± 0.1251	1.8829 ± 0.1923

CSM+Ni hybrid model wasn't applied because it increases the degree of freedom, and doesn't change the results of M_{ej} significantly.

DISCUSSION – Comparison with others

Megnetar model: results were compared to 8 studieis in the literature

Every output parameter is in agreement with the literature with the exception of M_{ej}, which was found to be significantly larger in this study, compared to others.

CSM models: results were compared to Chen et al. (2023b)

The CSM masses of Chen et al. (2023b) are slightly lower, while their M_{ej} values are significantly lower compared to our results.

M_{ej} (magnetar) vs M_{ej} (CSM) vs M_{ej} (CSM2)

Favored models based on χ^2 values:
- Magnetar: 14 SLSNe-I
- CSM: 39 SLSNe-I
- Both: 45 SLSNe-I

CONCLUSION

Our ejecta masses were found to be significantly larger compared to other studies.
Possible causes: **a) larger ejecta velocities** **b) different κ** **c) different parameter bounds** **d) different priors**
The overall picture of SLSNe did not change: they are the explosions of the most massive stars.

FURTHER INFORMATION