Testing the Effect of Progenitor Metallicity on ^{56}Ni Mass and Constraining the Progenitor Scenarios in Type Ia Supernovae (Kim et al. 2025)

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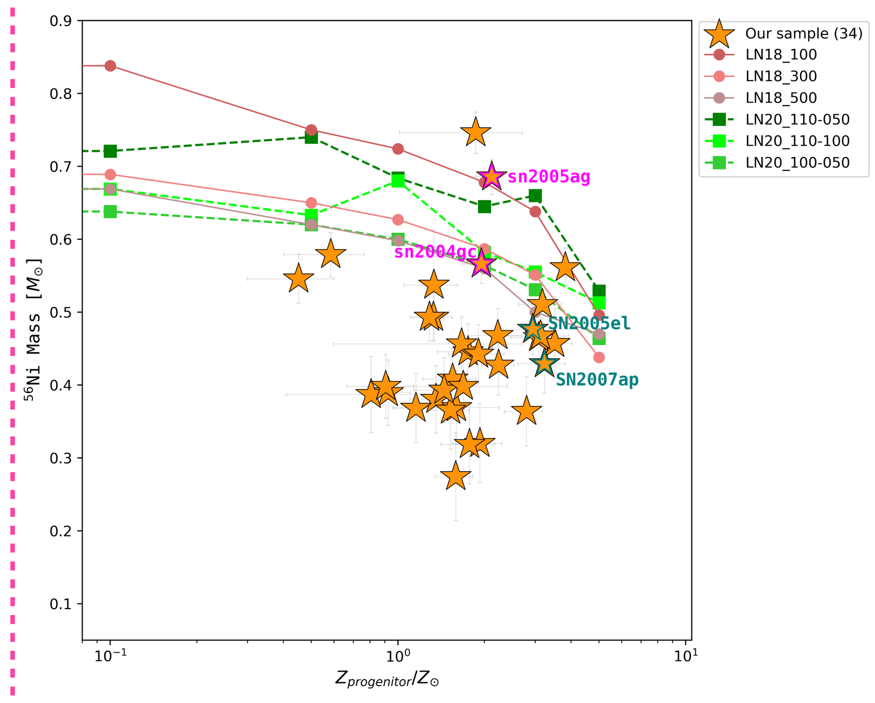
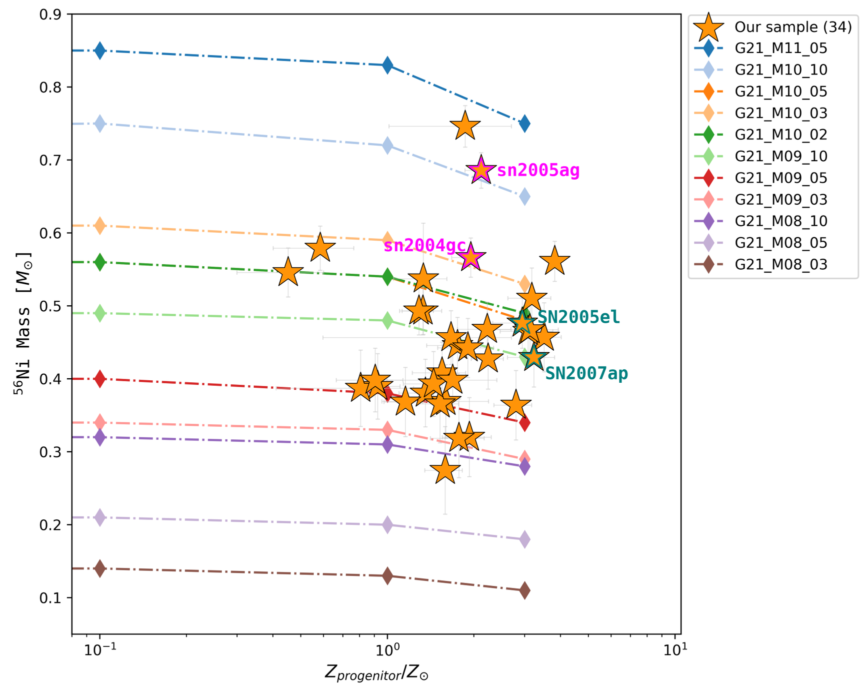
Abstract

The analytical model of Timmes et al. (2003) found that the intrinsic variation in the initial metallicity of the Type Ia supernova (SN Ia) progenitor stars (*Zprogenitor*) translates into a 25% variation in the ^{56}Ni mass synthesized and, therefore, ~0.2 mag difference in the observed peak luminosity of SNe Ia. Previous observational studies used the currently-observed global gas-phase metallicity of host galaxies, instead of *Zprogenitor* used in the model, and showed a higher scatter in the ^{56}Ni mass measurements compared to the model prediction. In this poster, I will present our results based on the *Zprogenitor* of 34 normal SNe Ia. To cover the observed ^{56}Ni mass range, we employ recent SN Ia explosion models with various configurations. In particular, **we find that comparing our sample with SN Ia explosion models on the *Zprogenitor*-^{56}Ni mass diagram allows us to constrain the progenitor scenarios, such as white dwarf mass and explosion mechanism**.

3.1. Constraining SN Ia progenitors on the $Z_{progenitor}$–^{56}Ni mass diagram





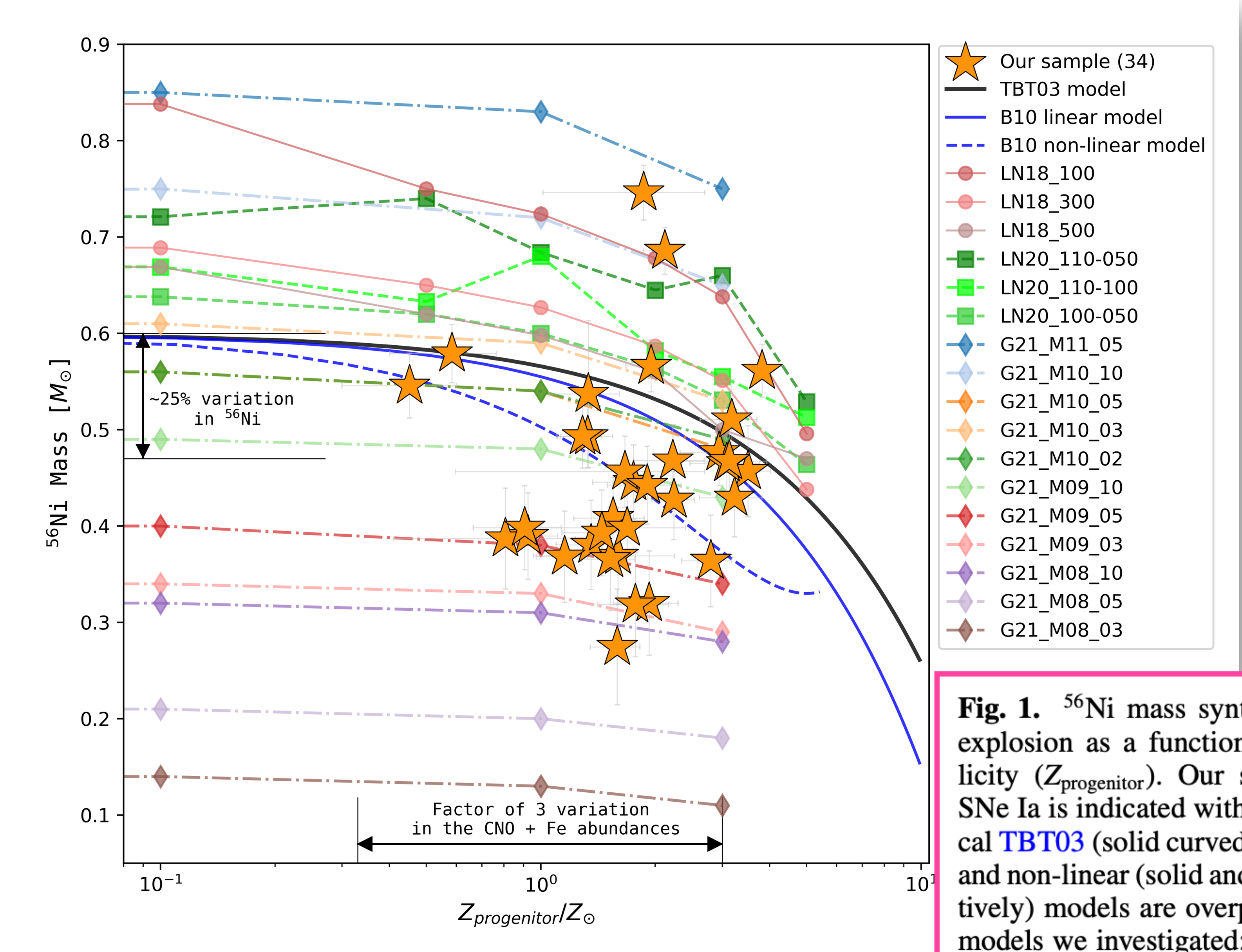


Fig. 1. ^{56}Ni mass synthesized during the SN Ia explosion as a function of the progenitor metallicity ($Z_{progenitor}$). Our sample of the 34 normal SNe Ia is indicated with orange stars. The analytical TBT03 (solid curved black line) and B10 linear and non-linear (solid and dashed blue lines, respectively) models are overplotted with various SN Ia models we investigated: 3 LN18 near-M_{ch} models (circles with solid lines), 3 LN20 sub-M_{ch} models (squares with dashed lines), and 11 G21 sub-M_{ch} models (diamonds with dash-dotted lines).

Table 2. Summary of the SN Ia progenitors.

SN	Model Name [used in the present work]	Model	Mechanism	M_{WD} $[M_\odot]$	M_{core} $[M_\odot]$	M_{shell}/M_{He} $[M_\odot]$	$Z_{progenitor}$ $[Z_\odot]$
2007ap	G21_M09_10	Sub-M_{ch}	DD	1.00	0.9	0.1	3
2005ag	LN18_100	Near-M_{ch}	DDT	1.33	–	–	2
	G21_M10_10	Sub-M_{ch}	DD	1.10	1.0	0.1	1–3
2005el	G21_M10_05	Sub-M_{ch}	DD	1.05	1.0	0.05	3
	LN18_500	Near-M_{ch}	DDT	1.39	–	–	3
2004gc	LN18_500	Near-M_{ch}	DDT	1.39	–	–	1
	LN20_100-050	Sub-M_{ch}	DD	1.00	0.95	0.05	1
	G21_M10_03	Sub-M_{ch}	DD	1.03	1.0	0.03	1–3

3.2. ^{56}Ni mass as a function of [Fe/H] and [α/Fe]

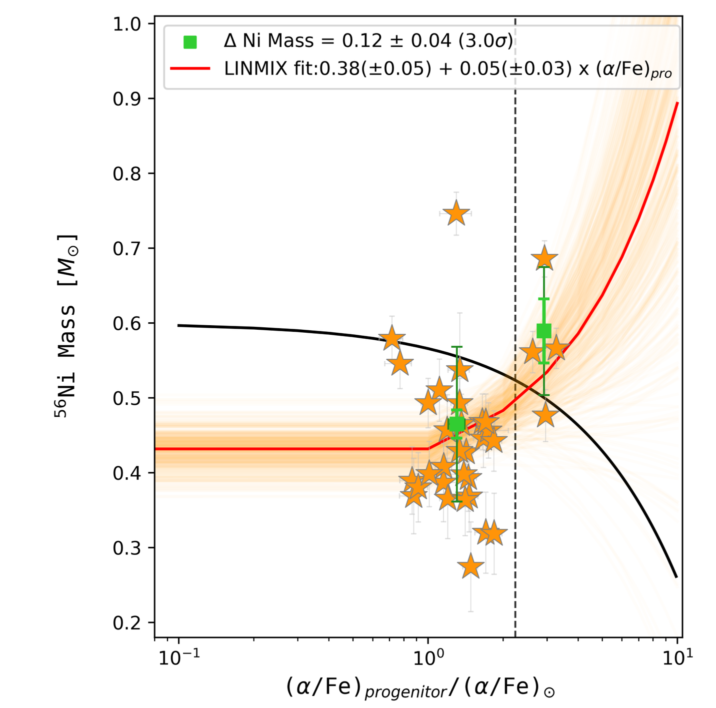


Table 3. Weighted-means of ^{56}Ni mass and Hubble residuals in the different env

(the right panel of Fig. 3)	N_{SN}	^{56}Ni mass $[M_\odot]$
$(\alpha/Fe)_{progenitor}$-rich	4	0.59 ± 0.04
$(\alpha/Fe)_{progenitor}$-poor	30	0.47 ± 0.02
Difference		0.12 ± 0.04 (3.0σ)

Role of *a/Fe* in the SN Ia explosion?

2. Method

2.1. Sample

We used 34 total metallicity of the birth environments of the normal SN Ia progenitor stars determined by Kim et al. 2024b, considering that those are *Zprogenitor*.

2.2. Estimating $Z_{progenitor}$

K24 employed YEPS as their main results, as discussed by Kang et al. (2020). Accordingly, we also used [Fe/H] and [α/Fe] estimated from the YEPS model. Thus, to determine the total metallicity (Z), we adopted the conversion among Z, [Fe/H], and [α/Fe] from the YEPS model paper Chung et al. (2013) (see their Section 2.2),

$$\log\left(\frac{Z}{Z_\odot}\right) = [Z/H] = [\mathrm{Fe/H}] + 0.723\,[\alpha/\mathrm{Fe}]\,. \qquad (5)$$

2.3. Estimating the ^{56}Ni mass

The ^{56}Ni mass that is synthesized during the SN Ia explosion can be inferred from the SN Ia bolometric luminosity and its rise time using Arnett's rule (Arnett 1979, 1982). Scalzo et al. (2019) determined the ^{56}Ni mass from the SN Ia bolometric light curve and then provided a fitting formula in terms of the SALT2 light-curve shape parameter x_1,

$$^{56}\mathrm{Ni\ mass} = (0.659 \pm 0.023) + (0.136 \pm 0.019)x_1 \qquad (6)$$

We employed this equation to obtain the ^{56}Ni mass from SALT2 x_1 for our sample.
To estimate an uncertainty for each value, we used the Python package `uncertainties`[2].

2.4. Hydrodynamic simulations of SN Ia explosion models

Table 1. SN Ia explosion models we used.

Ref.	Model	Mechanism	Model Name [used in the present work]	ρ_c $[10^8\ \mathrm{g\,cm^{-3}}]$	M_{WD} $[M_\odot]$	M_{He} $[M_\odot]$	$Z_{progenitor}$ $[Z_\odot]$
LN18	Near-M_{ch}	DDT	LN18_100	10	1.33	–	0, 0.1, 0.5, 1, 2, 3, 5
			LN18_300	30	1.38	–	
			LN18_500	50	1.39	–	
LN20	Sub-M_{ch}	DD	LN20_110-100	0.62	1.10	0.10	0, 0.1, 0.5, 1, 2, 3, 5
			LN20_110-050	0.62	1.10	0.05	
			LN20_100-050	0.32	1.00	0.05	

Ref.	Model	Mechanism	Model Name [used in the present work]	ρ_c $[10^8\ \mathrm{g\,cm^{-3}}]$	M_{core} $[M_\odot]$	M_{shell} $[M_\odot]$	$Z_{progenitor}$ $[Z_\odot]$
G21	Sub-M_{ch}	DD	G21_M11_*XX*	–	1.1	0.05	0.001, 0.1, 1, 3
			G21_M10_*XX*	–	1.0	0.02, 0.03, 0.05, 0.1	
			G21_M09_*XX*	–	0.9	0.03, 0.05, 0.1	
			G21_M08_*XX*	–	0.8	0.03, 0.05, 0.1	

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