SN 2023ixf – an average-energy explosion with circumstellar medium and a precursor

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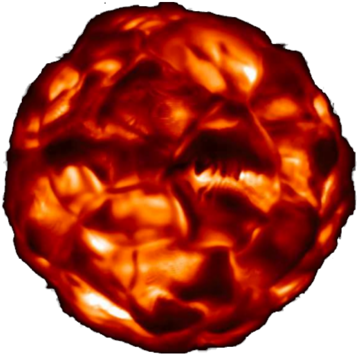
SN 2023ixf

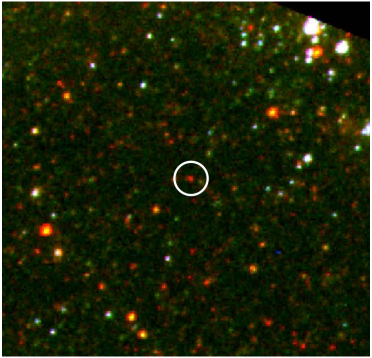
- Progenitor: Is there consensus?
- Circumstellar matter
- What happened before...

PROGENITOR



Chiavassa+2022

Progenitor Identification

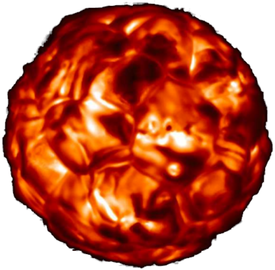


Kilpatrick+2023

$M_\odot$	
8-10	Pledger+2023
11	Kilpatrick+2023
12	Xiang+2024
9-14	Neustadt+2024
12-15	Van Dyk+2024
17	Jencson+2023
16-19	Niu+2023
18	Qin+2024
20	Soraisam+2023

Standard – Red Supergiant

Parameters of SN 2023ixf from RT/Spectra modelling



$M_\odot$	$R_\odot$	foe	
10	~ 500	**2–3**	Moriya+24
			Singh+24
12	~ 700	**1.2**	Bersten+24
12-17.5		**0.6-1.6**	Fang+24
15	500–900	**1–3**	Bostroem+23
			Jacobson-Galan+24
			Hiramatsu+23
			Martinez+24
		2–5	Teja+2023
18-22	~ 950	**0.5-0.7**	Hsu+2024

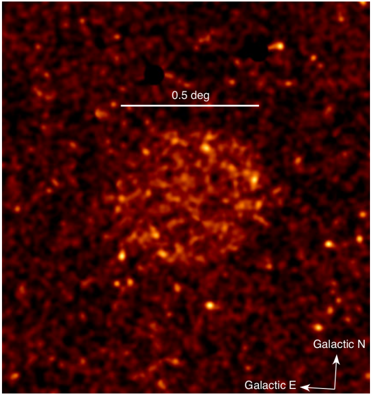
Chiavassa+2022

EXPLOSION ENERGY

Neutrino-driven core collapses
0.05 – 1.4 foe

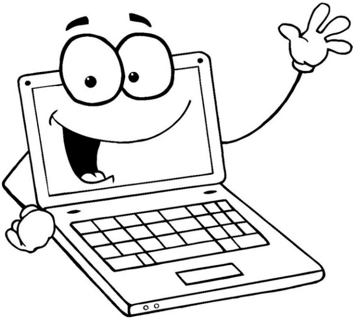
SN Remnants
0.45 – 0.75 foe

NOT 2-3-5 foe
for IIP



Khabibullin+2023

METHOD



Radiative-transfer code for SNe: **STELLA**

Blinnikov et al. 1993, 1995, 1998, 1999, 2000, 2004, 2006...

Part of MESA

sorry... 1D

160,000 lines ... includes many Fe lines ... not much, but enough

IMPORTANT:

HYDRODYNAMICS CODE
$\longrightarrow$ SHOCKS

Input model: Modified 10 $\mathrm{M}_\odot$ progenitor Sukhbold+2016

Energy **0.7** foe

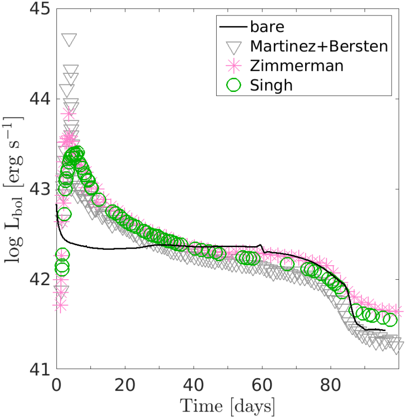
Ejecta mass **6** $\mathrm{M}_\odot$ 8.3

Radius 700 $\mathrm{R}_\odot$

Interpretation

Binary
Pulsations

CSM



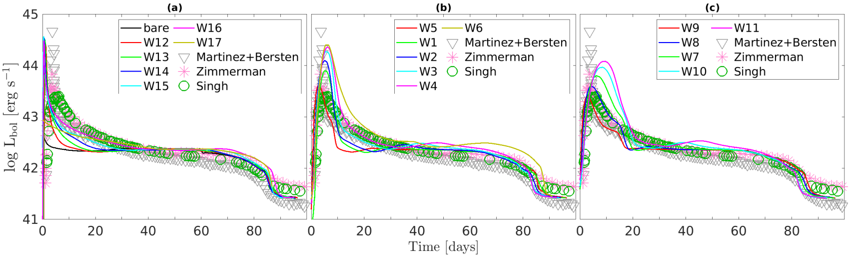
$$\log L \sim 2/3 \log R - 1/2 \log M - 0.8 \log E$$

$$\log t_{\mathrm{p}} \sim 1/6 \log R + 1/2 \log M - 1/6 \log E.$$

Popov 1993

RESULTS

Bolometric LCs



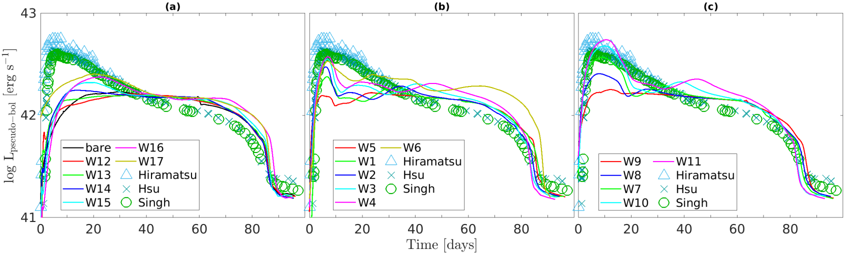
1.5×10^{14} cm $\quad 6 \times 10^{14}$ cm $\quad 10^{15}$ cm

$0.07\ \mathrm{M}_\odot \rightarrow 0.17\ \mathrm{M}_\odot \rightarrow 0.3\ \mathrm{M}_\odot \rightarrow 0.55\ \mathrm{M}_\odot \rightarrow 0.83\ \mathrm{M}_\odot \rightarrow 1.56\ \mathrm{M}_\odot$

Definitely not CSM 1.5×10^{14} cm: too steep rise

Not a high mass: $0.17\ \mathrm{M}_\odot$

Pseudo-Bolometric LCs



1.5×10^{14} cm $\quad$ 6×10^{14} cm $\quad$ 10^{15} cm

High CSM mass – 0.55-0.83 $M_\odot$ - preferable

Conclusion:

0.55-0.83 $M_\odot$ **CSM** extends to 10^{15} cm

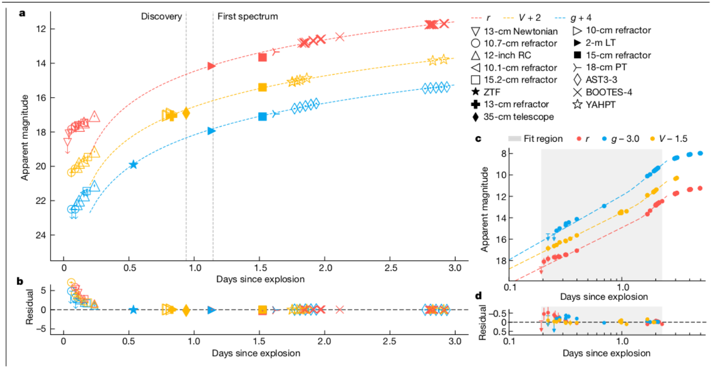
Origin:

Gravity waves driven by large-scale **convective plumes**

Pulsations

What happened before?..

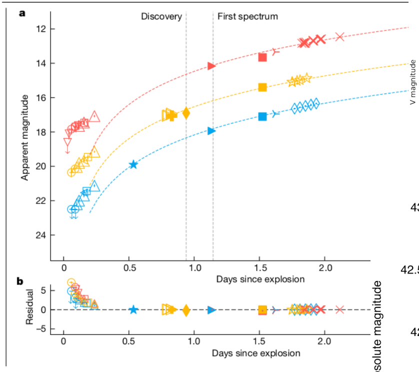
What happened before?..

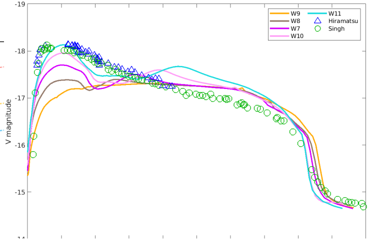


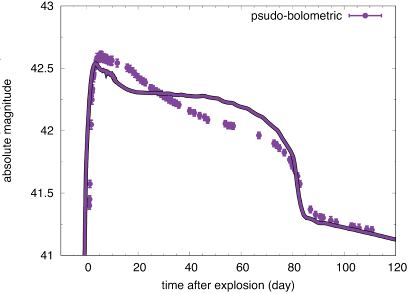
Can it be called "Early-phase flux excess"?

Li+2024

What happened before?..







What powers the early-phase flux excess?

<u>Compact CSM</u> W17

0.7 foe

$\rightarrow$ 1.56 $M_\odot$

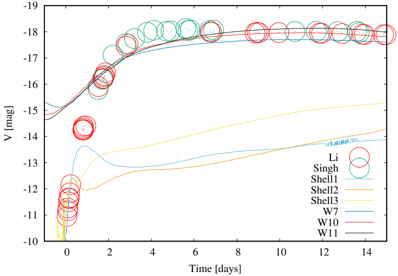
$\rightarrow$ affects plateau

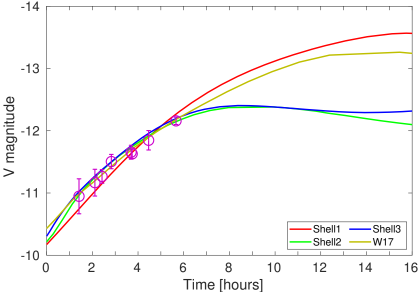
<u>Shell-models</u>

0.5-1 $M_\odot$ 0.01 foe

$R_{in} = 700\ R_\odot$

800, 900, 1000 $R_\odot$



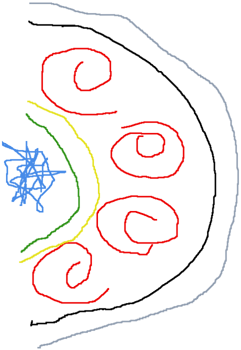


Interpretation

Uncorrelated
Resonance

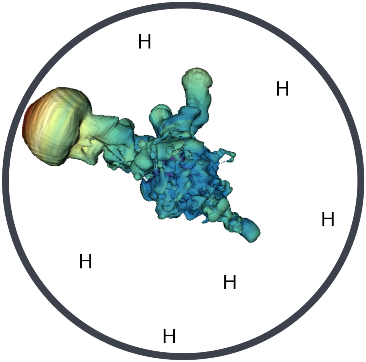
Stochastic processes

driven by convection



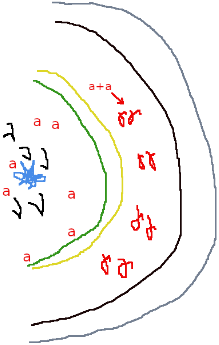
Interpretation

Correlated "Asymmetry"



Intrinsically
Asymmetric
Explosion

Correlated "Exotic"



ν-driven shock – 0.6 d
axions (BSM) – 28 mins
axion-driven shock precedes

Conclusions about SN 2023ixf nature

Progenitor and CSM

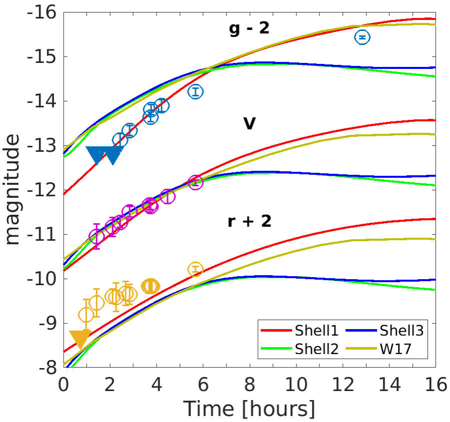
- Explosion 0.7 foe
- Greatly reduced envelope
- Binary interaction
- CSM: 0.55-0.83 $M_\odot$ 10^{15} cm

The first 5 hours

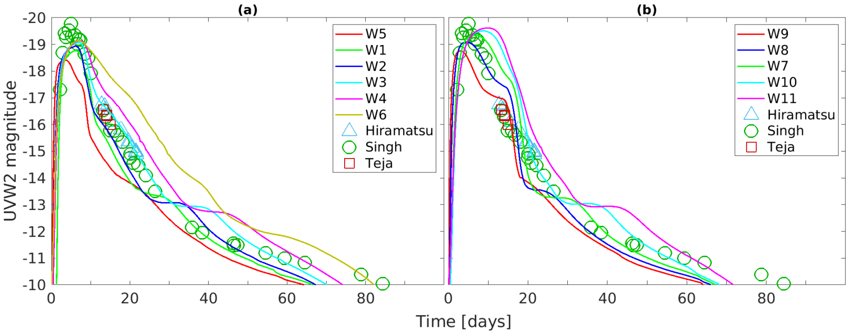
- Compact CSM not preferable
- Shell-ejection preferable
- Beyond Standard Model?

Additional figures

The early-phase flux excess

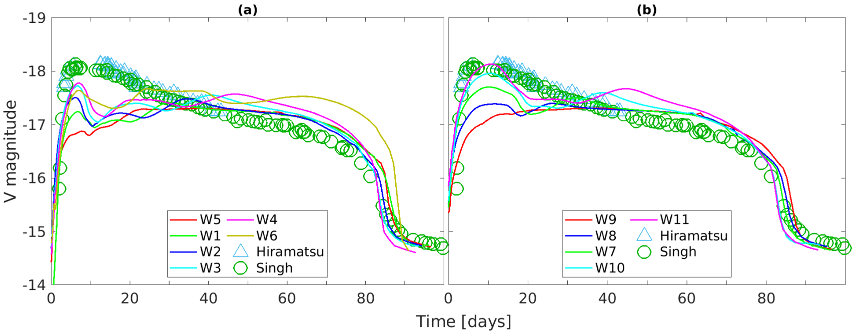


Broad-band LCs: UVW2



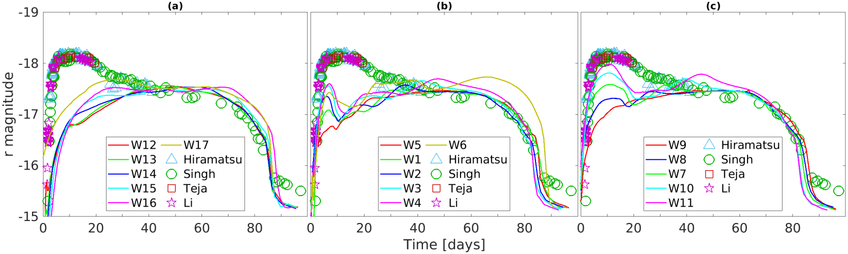
6×10^{14} cm $\qquad 10^{15}$ cm

Broad-band LCs: V



6×10^{14} cm $\quad$ 10^{15} cm

Broad-band LCs: r



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Pulsations (Talk by Philipp Podsiadlowski)

Photospheric velocity