The final fate of the 8 - 10 solar mass star: Collapse into a neutron star or explode?

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Evolution of 8 - 10 solar mass stars

Formation of ONeMg core by the dredge-up of the helium layer

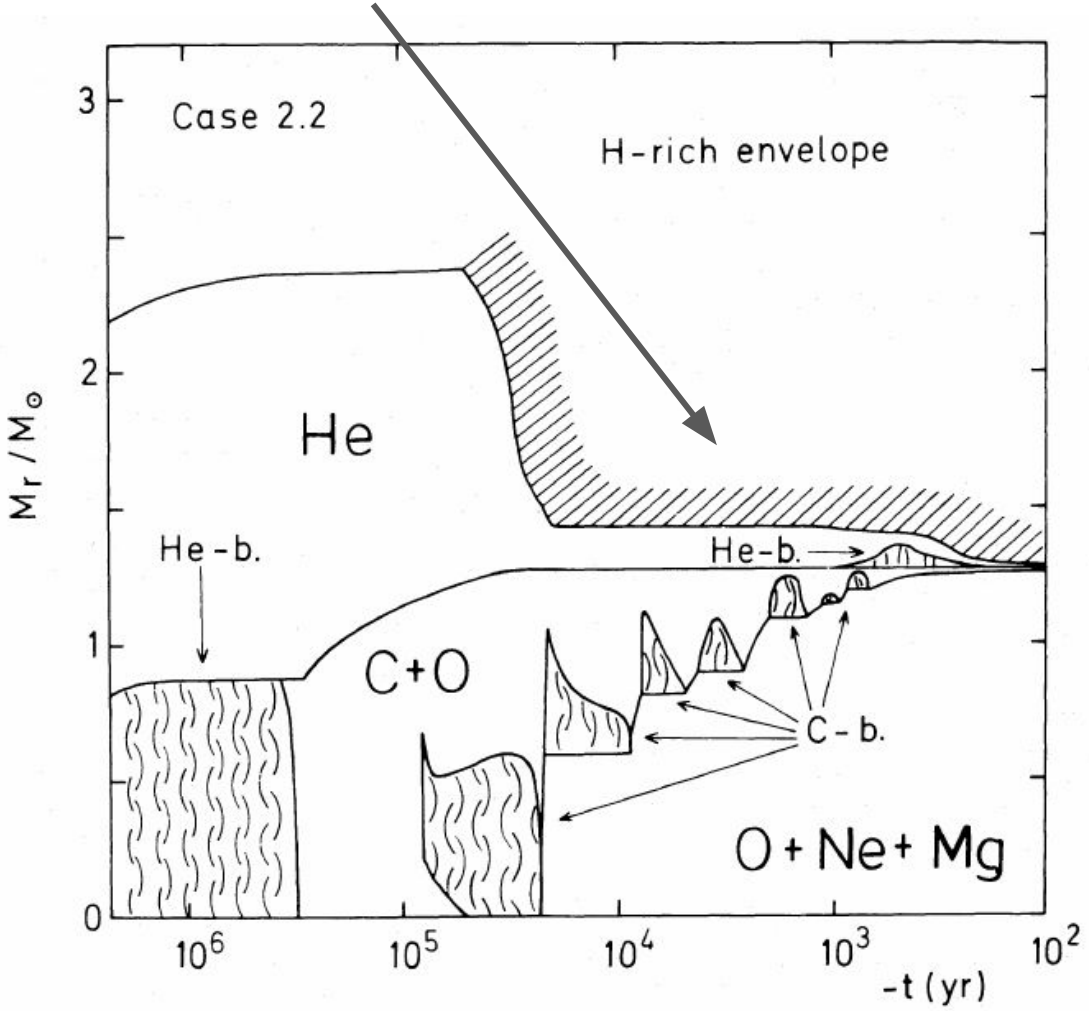
Extremely thin He layer

(Nomoto, 1987 ApJ)

Electron capture of

^{16}O and ^{20}Ne triggers

the 2nd contraction



Dependence of input physics

The final ONeMg core is sensitive to the flame properties

central density = $10^{9.95}$ g/cc

Turbulent flame → explosion

Laminar flame → collapse

(Nomoto et al., 1991 ApJ)

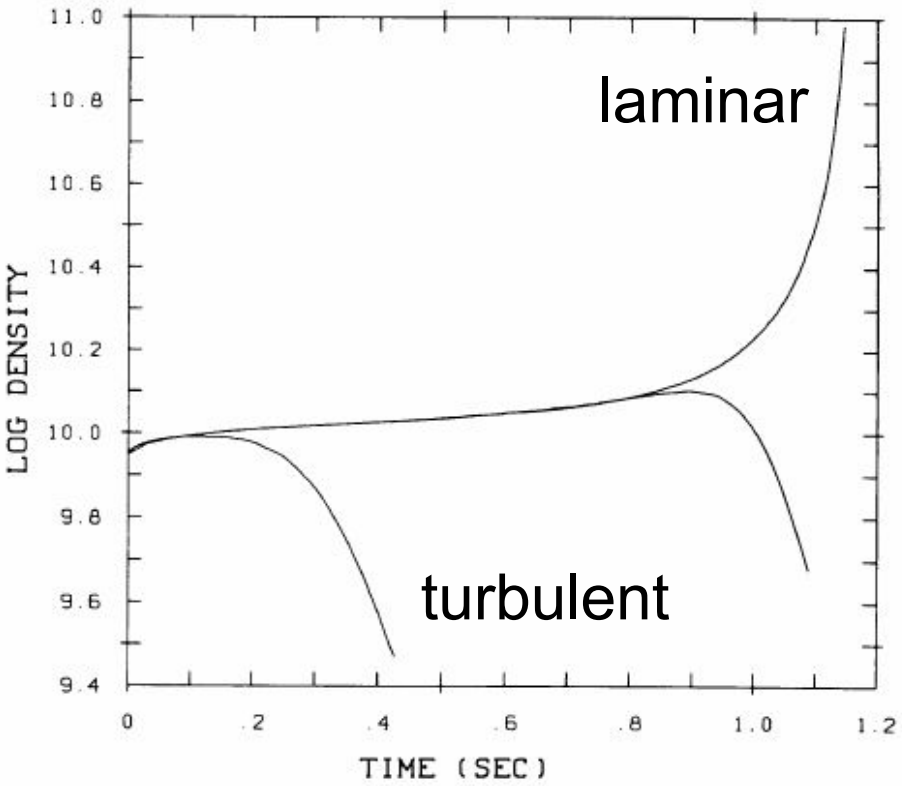


FIG. 1.—Change in the central density of the O + Ne + Mg white dwarfs following the propagation of the oxygen deflagration wave for three cases with l/min (H_p, r) = 1.4, 1.0, and 0.7. For the slowest case of $l/H_p = 0.7$, the central density (in units of g cm^{-3}) increases, i.e., the white dwarf undergoes collapse. Faster propagation induces an explosion of the white dwarf.

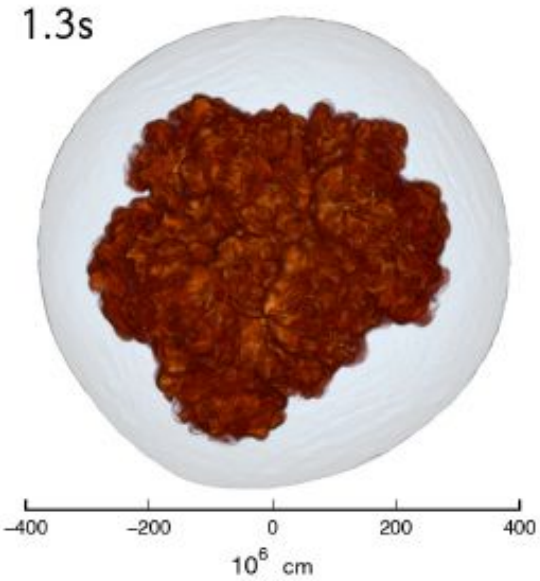
Multi-dimensional simulations

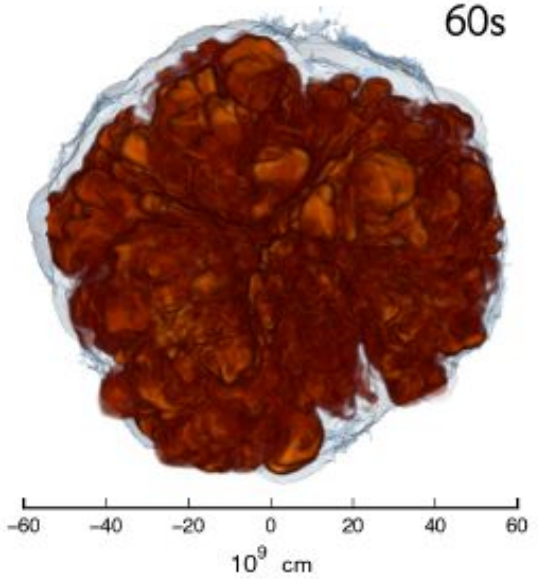
The first multi-dimensional model

studying the impact of microphysics

(Jones et al., A&A 2016)

The electron screening in the equation of state determines the ejecta mass, thus the final remnant mass





id.	res.	[a] $\log_{10}\rho_c^{ini}$ ($g\ cm^{-3}$)	[b] CC (Y/N)	[c] M_{rem} ($M_\odot$)	[a] M_{rem}^{re} ($M_\odot$)	[e] M_{ej} ($M_\odot$)	[f] M_{ej}^{re} ($M_\odot$)	[g] $\langle Y_{e,rem}\rangle$	[n] M_{Ch}^{eff} ($M_\odot$)
J01	256^3	9.95	N	0.631	0.171	0.768	0.233	0.491	1.379
J02	256^3	9.95	Y	1.291	0.226	0.104	0.025	0.493	1.392

Neutron star statistics

Two groups of NS

(Schwab et al., 2010 ApJ)

Group 1: Lower NS mass, smaller natal kicks

Group 2: Higher NS mass, higher natal kicks

Connections to ECSN?

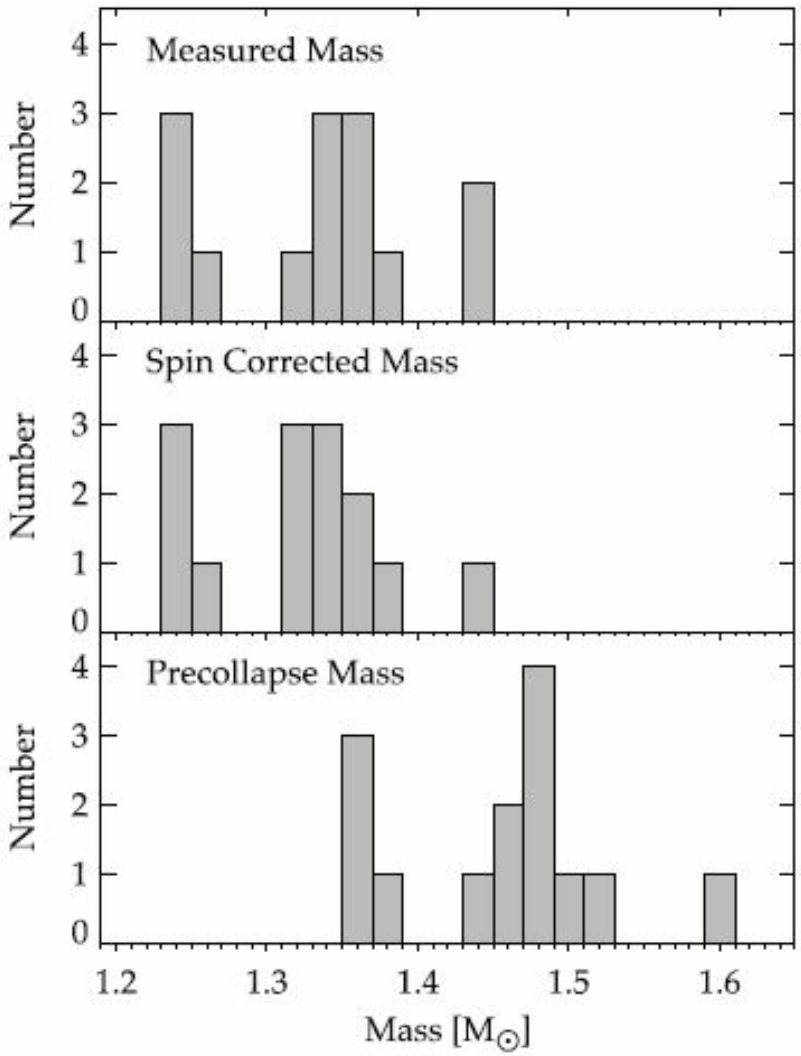


Figure 1. Mass histograms for the sample of 14 neutron stars. Top panel: the measured (gravitational) masses of the neutron stars. Middle panel: the masses of the neutron stars corrected for accretion as discussed in the text. Bottom panel: the pre-collapse (baryonic) masses of the neutron stars, based on one particular illustrative neutron-star equation of state.

Motivations

What is the final fate of the main-sequence star with 8-10 solar mass?

Explosion? Collapse?

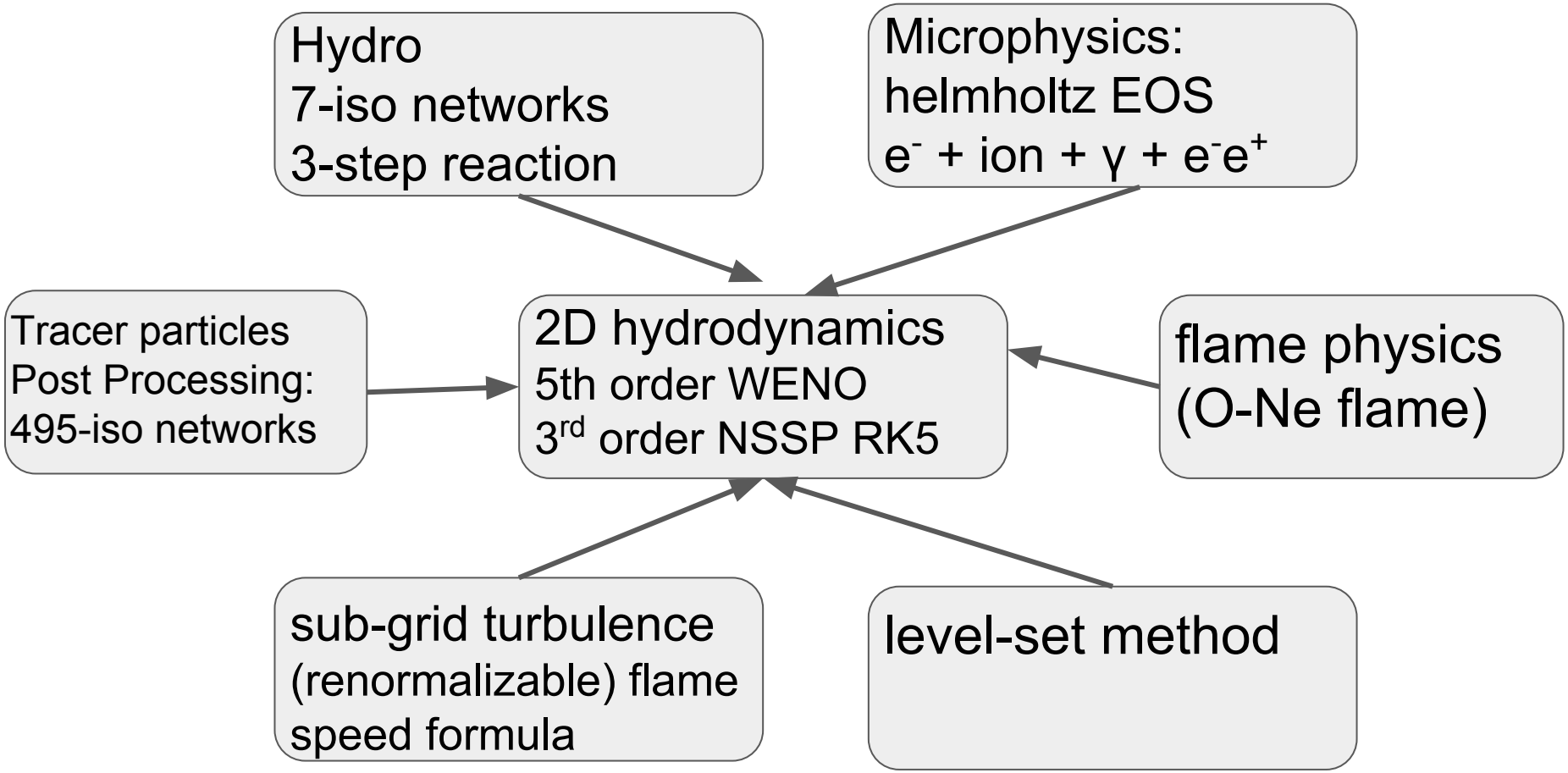
Is it associated with the candidate of electron-capture supernova?

What determines its fate?

Its microphysics? Its flame structure? Its density?

Physics model

Mechanism: Turbulent deflagration model

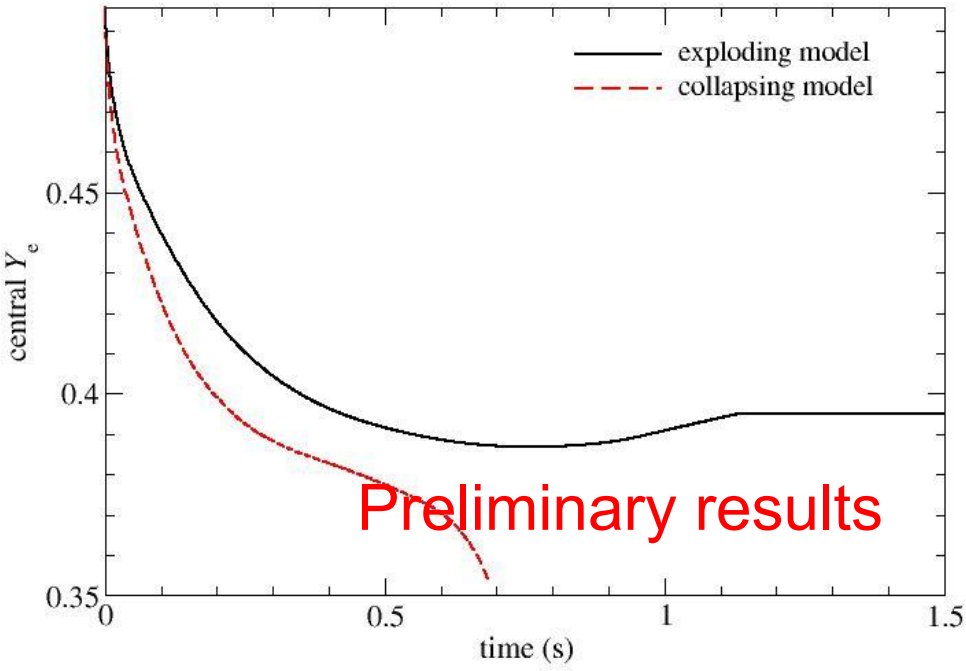


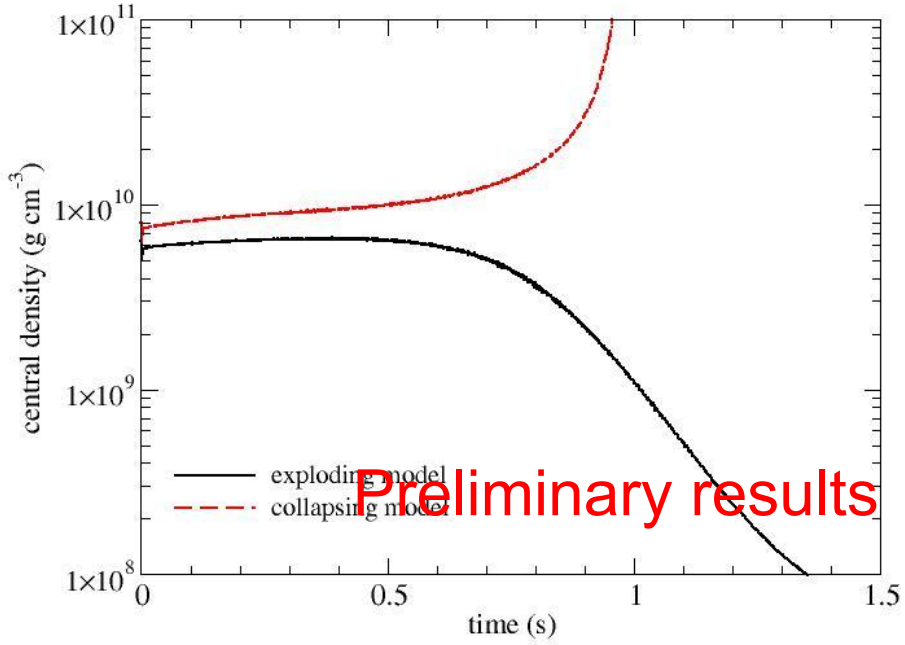
Typical models

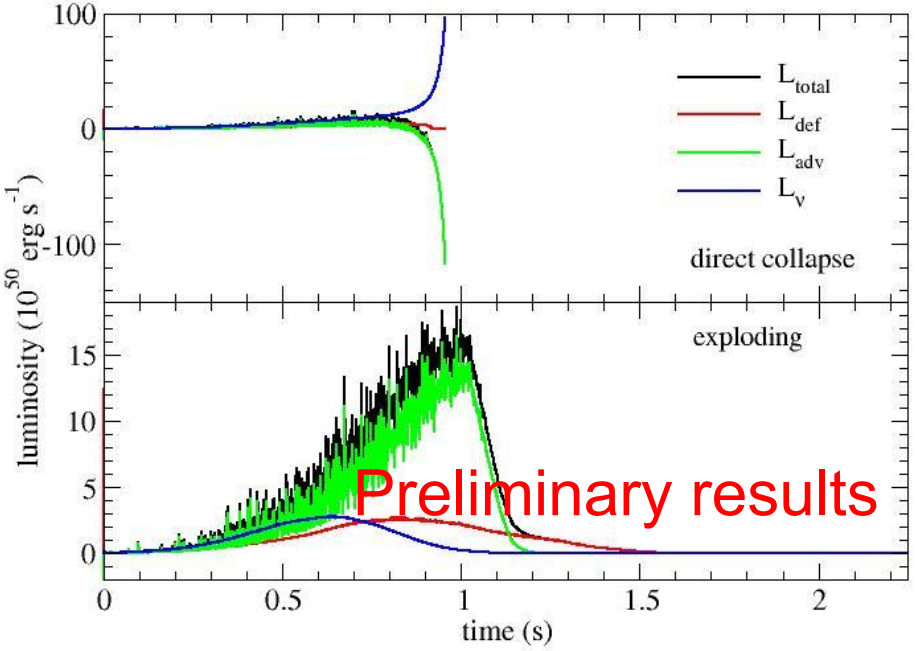
Compare two models

$\rho_c = 10^{9.95}, 10^{9.975}$ g cm^{-3}

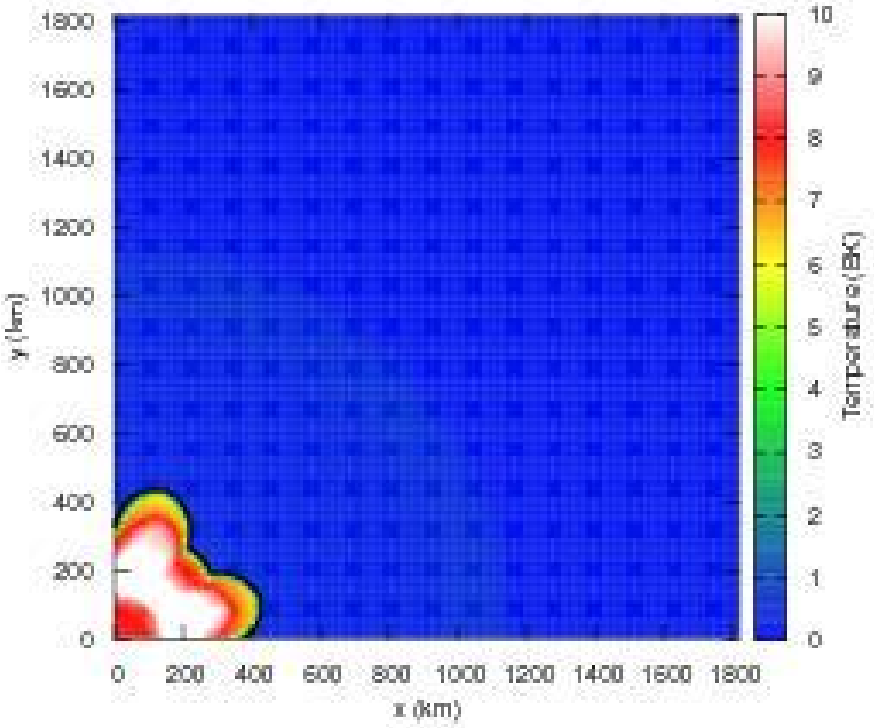
The details of ONeMg core are important



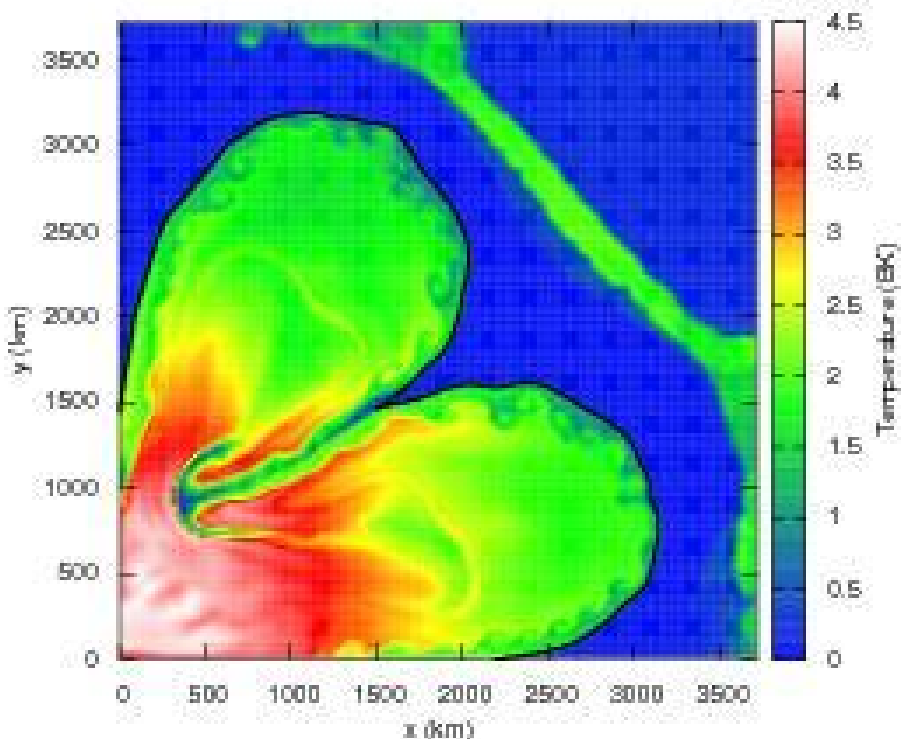




Flame structure (collapse/explode)

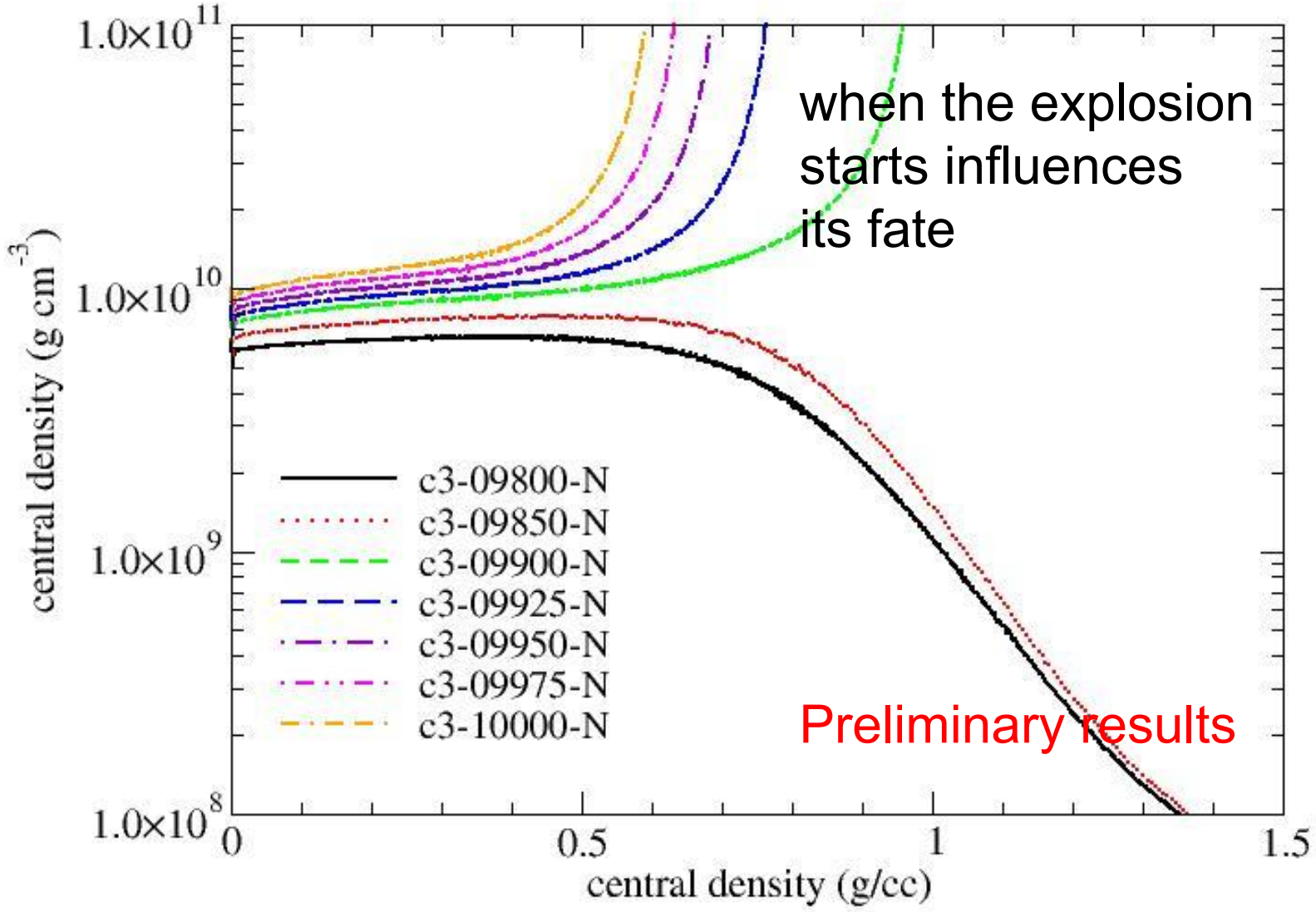


Collapsing model

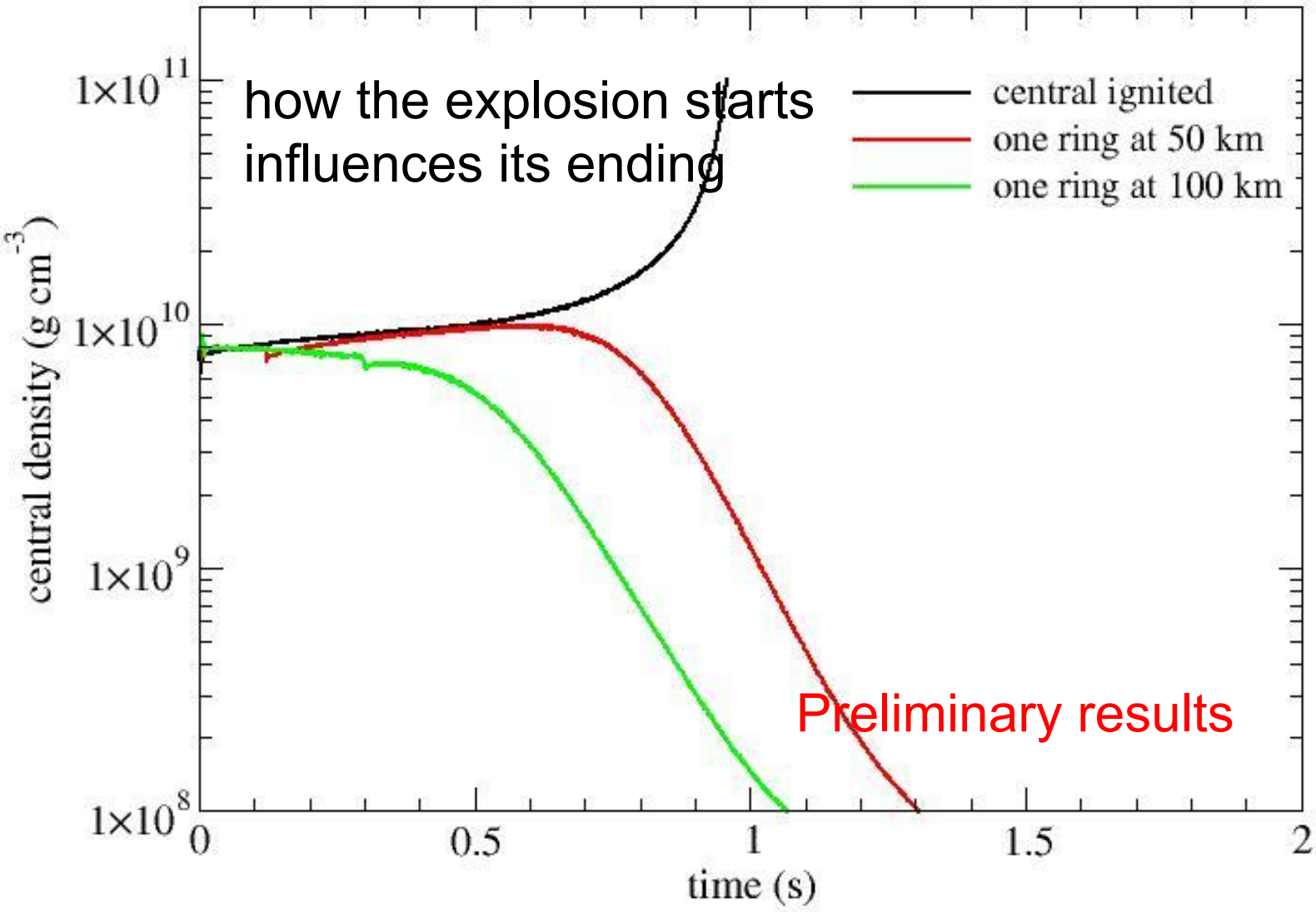


Exploding model

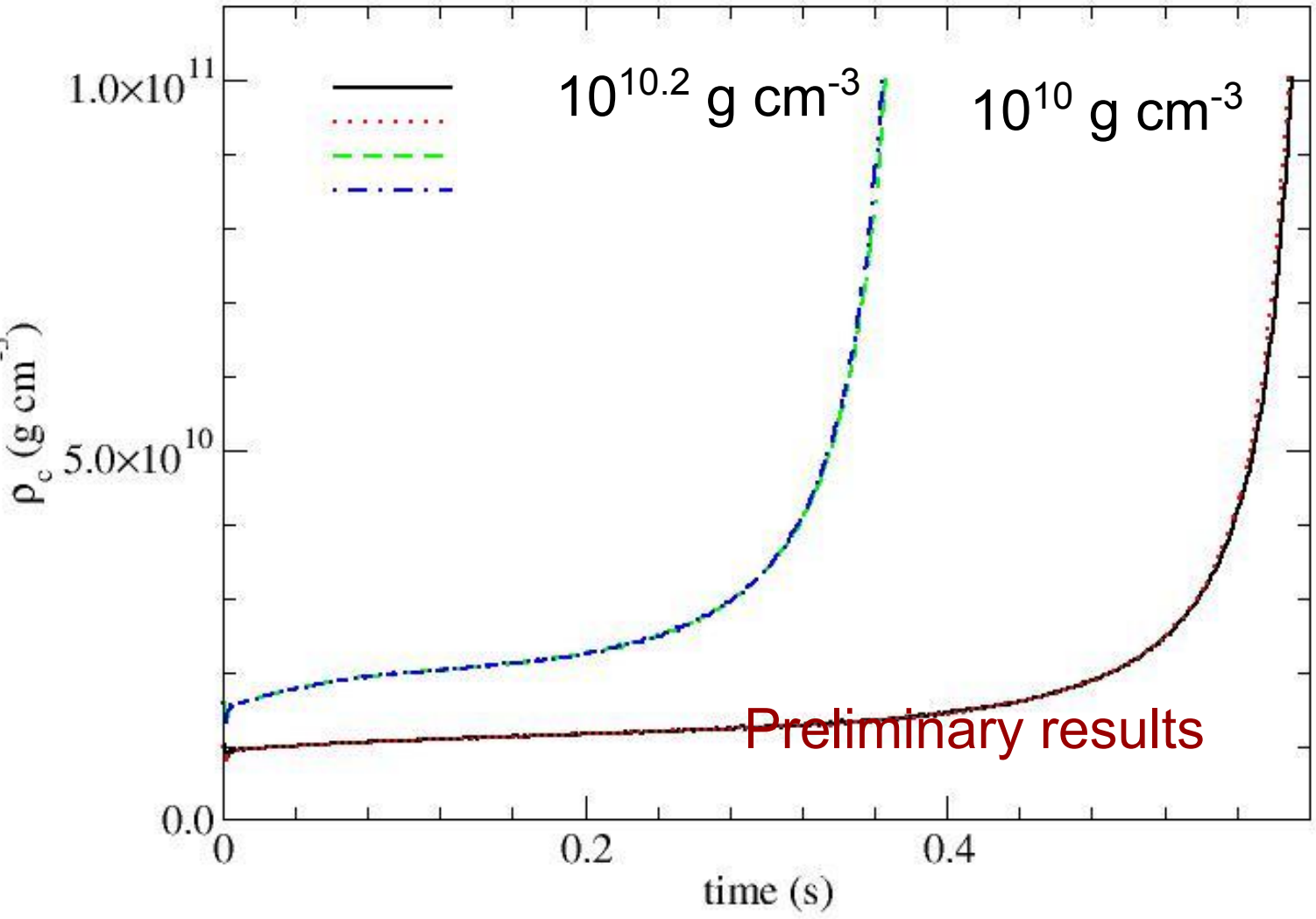
Sensitivity test of central density (with central flame)



Sensitivity test of flame structure ($10^{9.95}$ g cm^{-3})



Sensitivity test of relativistic effects



Summary of collapse

Flame structure	Initial burn mass (solar mass)	With relativity?	Collapse density ($\log_{10}$ [g cm^{-3}])
Centrally ignited	8.56×10^{-4}	No	9.900
Centrally ignited	6.67×10^{-3}	No	9.925
Centrally ignited	4.80×10^{-2}	No	9.975
Centrally ignited	8.56×10^{-4}	Yes	9.900
Bubble x1	1.39×10^{-3}	No	9.925
Bubble x1	2.59×10^{-3}	No	9.975
Bubble x1	2.59×10^{-3}	Yes	9.975
Bubble x5	1.04×10^{-2}	No	9.975
Bubble x5	1.04×10^{-2}	Yes	9.975

Conclusion

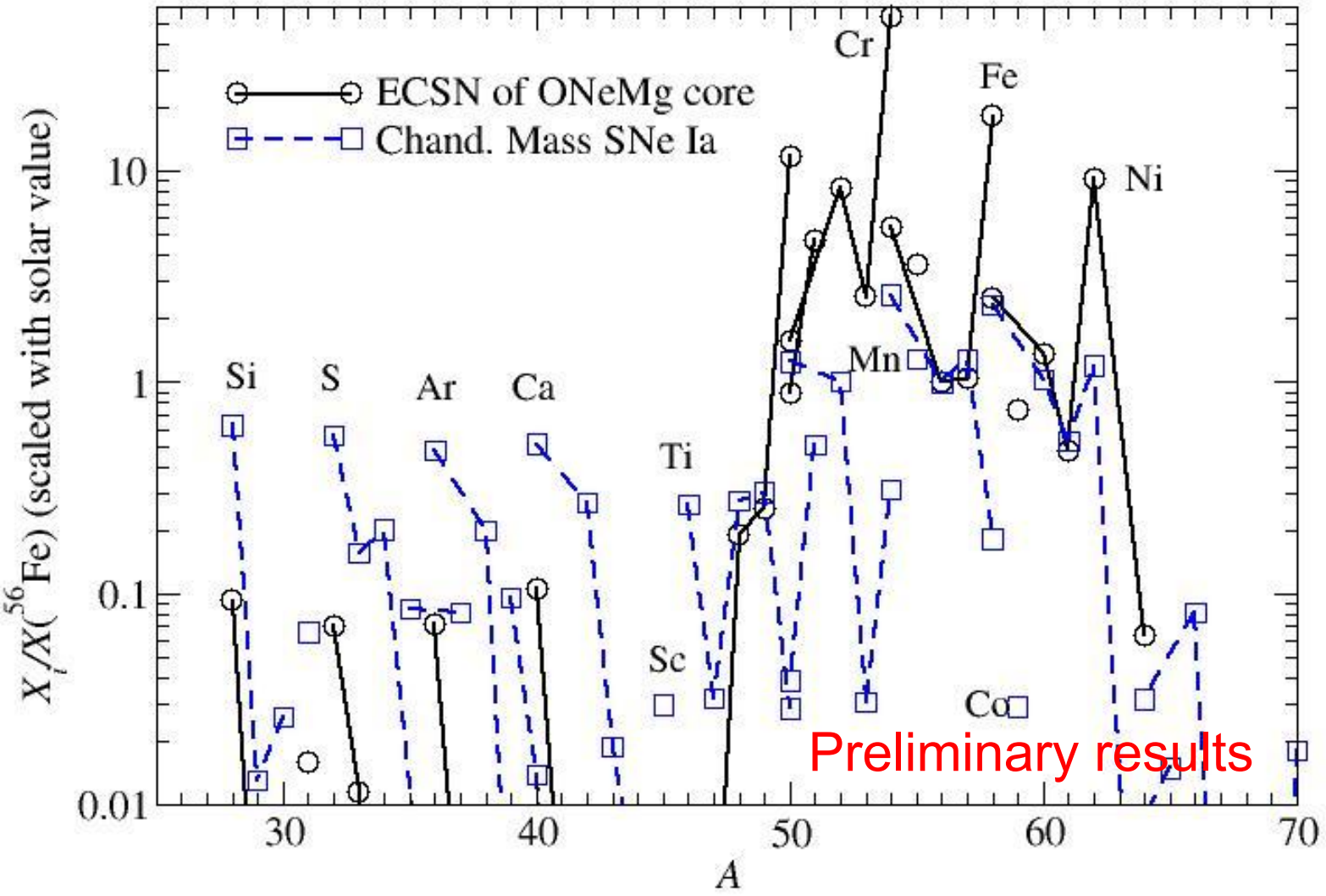
We studied the deflagration phase of ONeMg core

We surveyed the model parameters

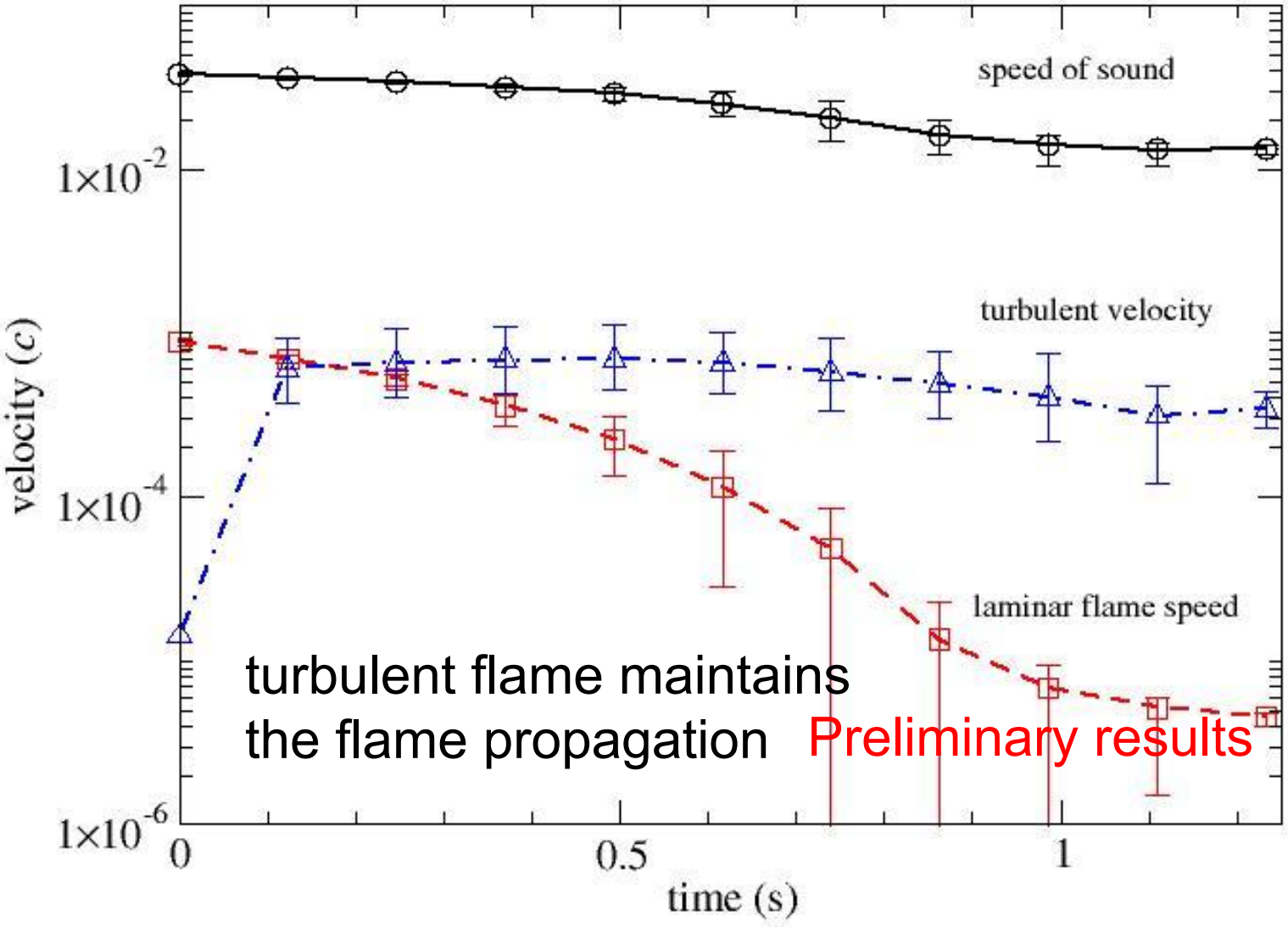
- Density
- Flame structure
- Relativistic effects

In general, an ONeMg core with a central density $\gtrsim 10^{9.95}$ g cm^{-3} can collapse into a neutron star, thus contributing to the lower-mass branch of NS

Appendix: What happens to the exploding model?



Appendix: Flame speed against time



turbulent flame maintains
the flame propagation

Preliminary results

Global criteria in determining collapse condition