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Electron-capture supernovae – Thermonuclear explosion or gravitational collapse? The fate of sAGB stars on a knife's edge

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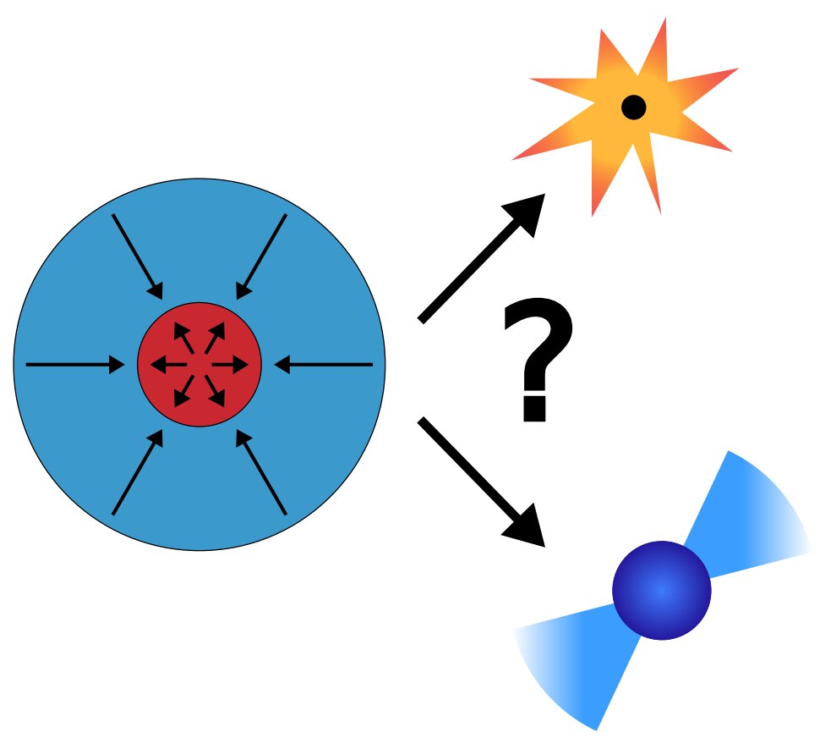
Abstract

New models of so-called electron-capture supernovae (ECSNe) suggest that while the full collapse of sAGB stars to a NS is still a possibility, the energy release by the electron-capture reactions can also trigger a thermonuclear runaway, initiating explosive thermonuclear burning in a “thermonuclear ECSN” (tECSN). Initial studies suggest that tECSNe could reproduce the solar abundances of so far problematic isotopes such as ^{48}Ca, ^{50}Ti, ^{54}Cr, together with ^{58}Fe, ^{64}Ni, ^{82}Se, and ^{86}Kr as well as several Zn-Zr isotopes, without introducing new tensions with the solar abundance distribution. In this work, we heavily expand on the existing tECSNe models, exploring a multitude of initial conditions and ignition geometries.

The results of our preliminary study suggest that the critical central density below which the collapse can be halted by thermonuclear burning is somewhere between $10.15 < \log \rho_{c,ini} < 10.3$ depending on the ignition geometry. We additionally provide details about the resulting ONeFe remnant properties, such as composition and kick velocity. These results will be used as an input for our 3D radiative transfer simulations, contributing the first-of-its-kind synthetic observables which will allow us to determine the feasibility of tECSNe as a realistic supernova scenario.

ECSNe in a nutshell

- Onset of electron-capture ^{20}Ne → ^{20}F → ^{20}O in a degenerate ONe core or WD
- Decay of ^{20}O increases temperature, triggering nuclear burning and an increasing electron-capture rate
- Loss of electron degeneracy pressure initiates gravitational collapse
- If flame becomes turbulent fast enough, burning can stop collapse
- Depending on outcome, scenario results either in formation of a neutron star or thermonuclear explosion leaving behind a bound remnant



Model setup

- 65/35% ONe WD with $9.875 < \log \rho_{c,ini} < 10.4$ and $Y_e \approx 0{,}4934$
- Ignition geometries with n = 1, 5, 50 individual ignition bubbles, off-set by r = 0, 100, 200 km
- All bubbles are placed randomly, but connected forming a single-spot ignition
- Model naming scheme: r_{offset}_n{# ignition bubbles}
- Simulation on a 512^3 grid using the LEAFS code

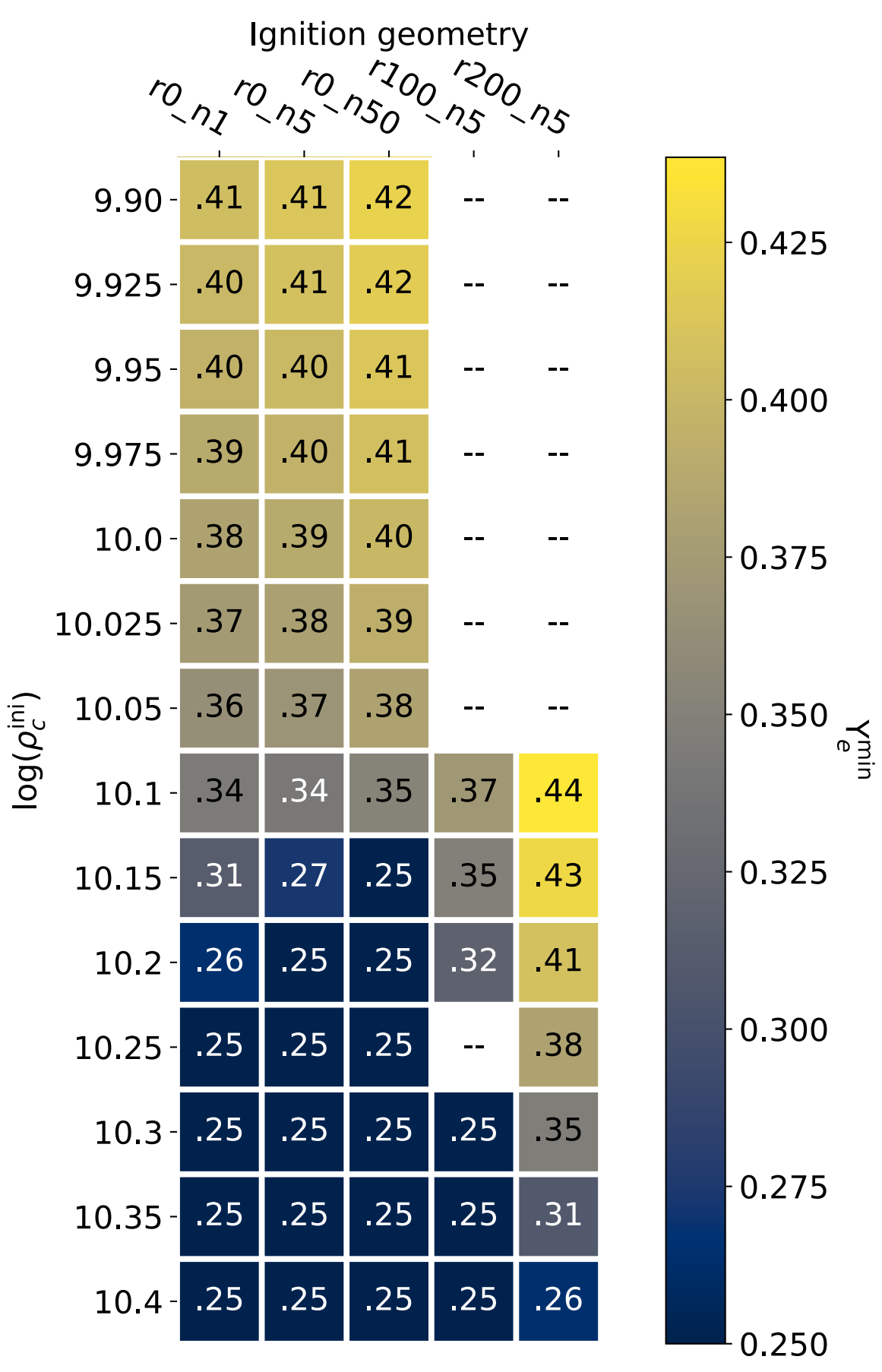
PRELIMINARY RESULTS

Many of the results here are still under investigation and may change until publication

Transition from explosion to collapse

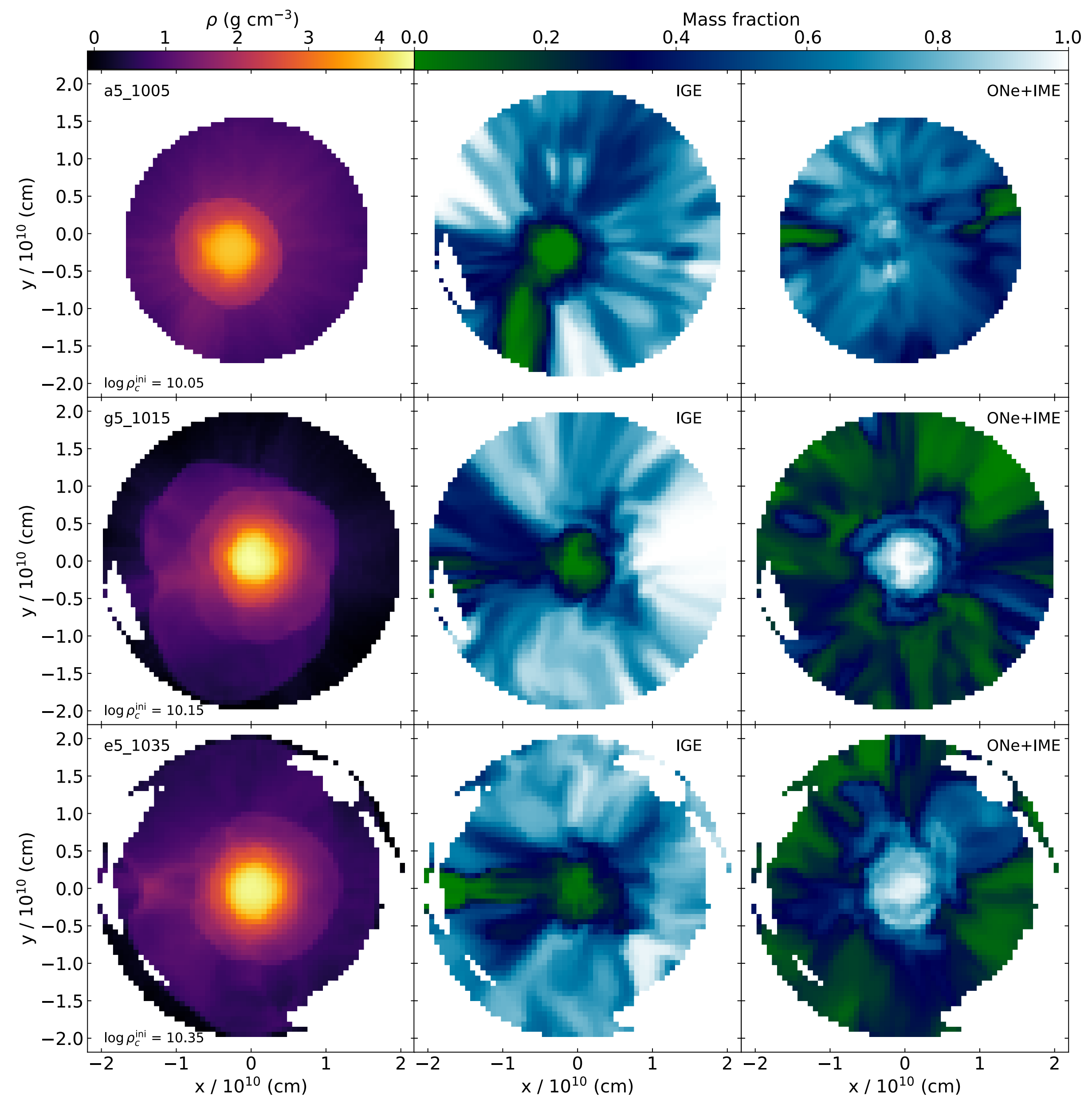
- Simulations that reach $Y_{e,min} = 0.25$ are considered to collapse
- No sharp transition density, rather a smooth transition depending on ignition geometry and central density
- Outcome heavily depends on how quick turbulent flame speed becomes faster than laminar flame speed
- Offcenter ignitions support higher central densities due to rapid pressure reduction on core

(Note: Simulations marked - - were excluded or showed some numerical issues)



$\log(\rho_c^{ini})$	r0_n1	r0_n5	r0_n50	r100_n5	r200_n5
9.90	.41	.41	.42	--	--
9.925	.40	.41	.42	--	--
9.95	.40	.40	.41	--	--
9.975	.39	.40	.41	--	--
10.0	.38	.39	.40	--	--
10.025	.37	.38	.39	--	--
10.05	.36	.37	.38	--	--
10.1	.34	.34	.35	.37	.44
10.15	.31	.27	.25	.35	.43
10.2	.26	.25	.25	.32	.41
10.25	.25	.25	.25	--	.38
10.3	.25	.25	.25	.25	.35
10.35	.25	.25	.25	.25	.31
10.4	.25	.25	.25	.25	.26

Bound remnant structure



- Bound proto-remnants left behind by most of the exploding models
- Dense ONe core at the center, mixed with intermediate mass elements (e.g. Si)
- Low density ash consisting of iron-group elements around the core which will fall onto remnant surface
- Neutron poor ($Y_e \approx 0.5$) inner core with a neutron rich ($Y_e \approx 0.4$) outer layer

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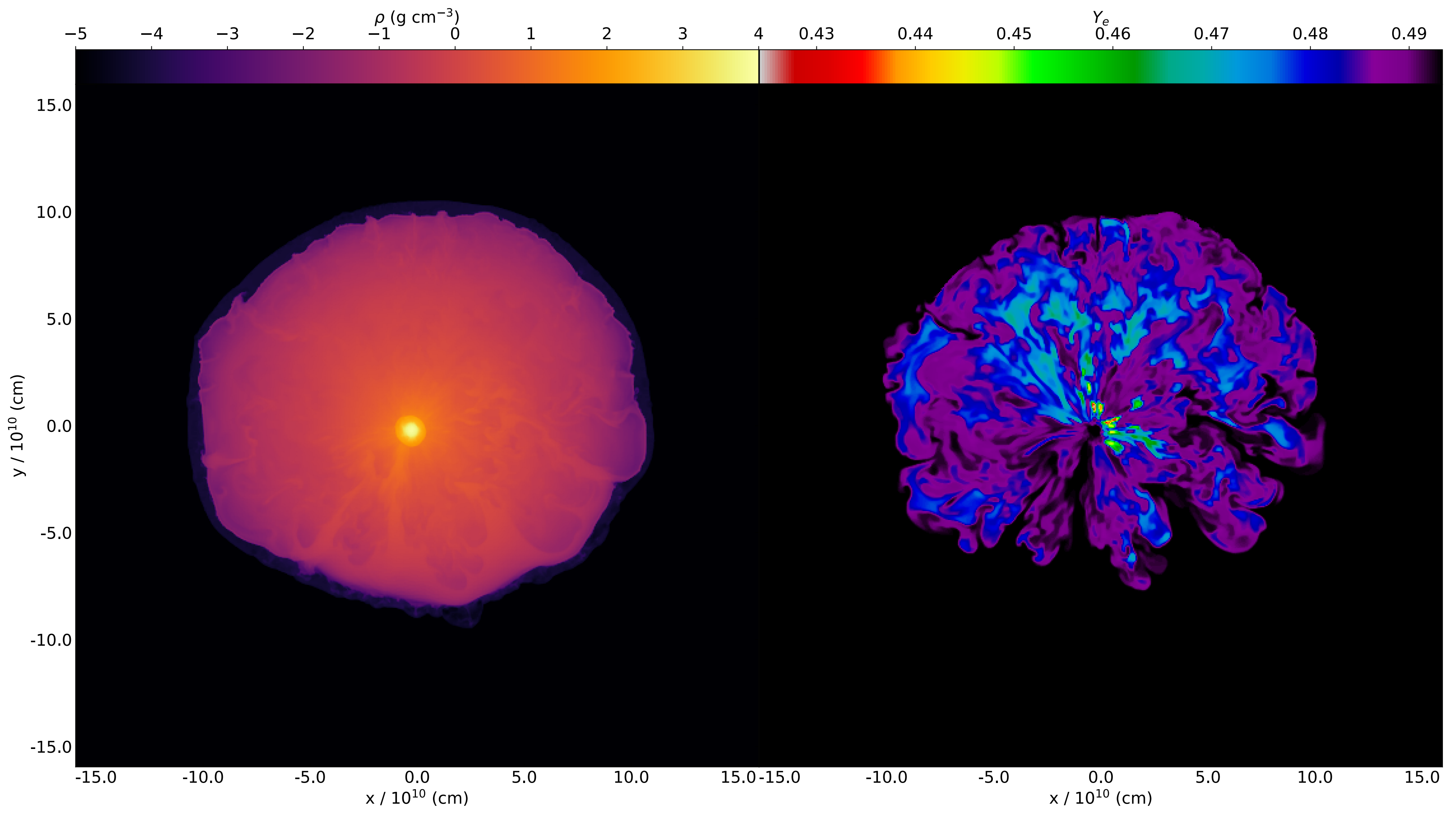
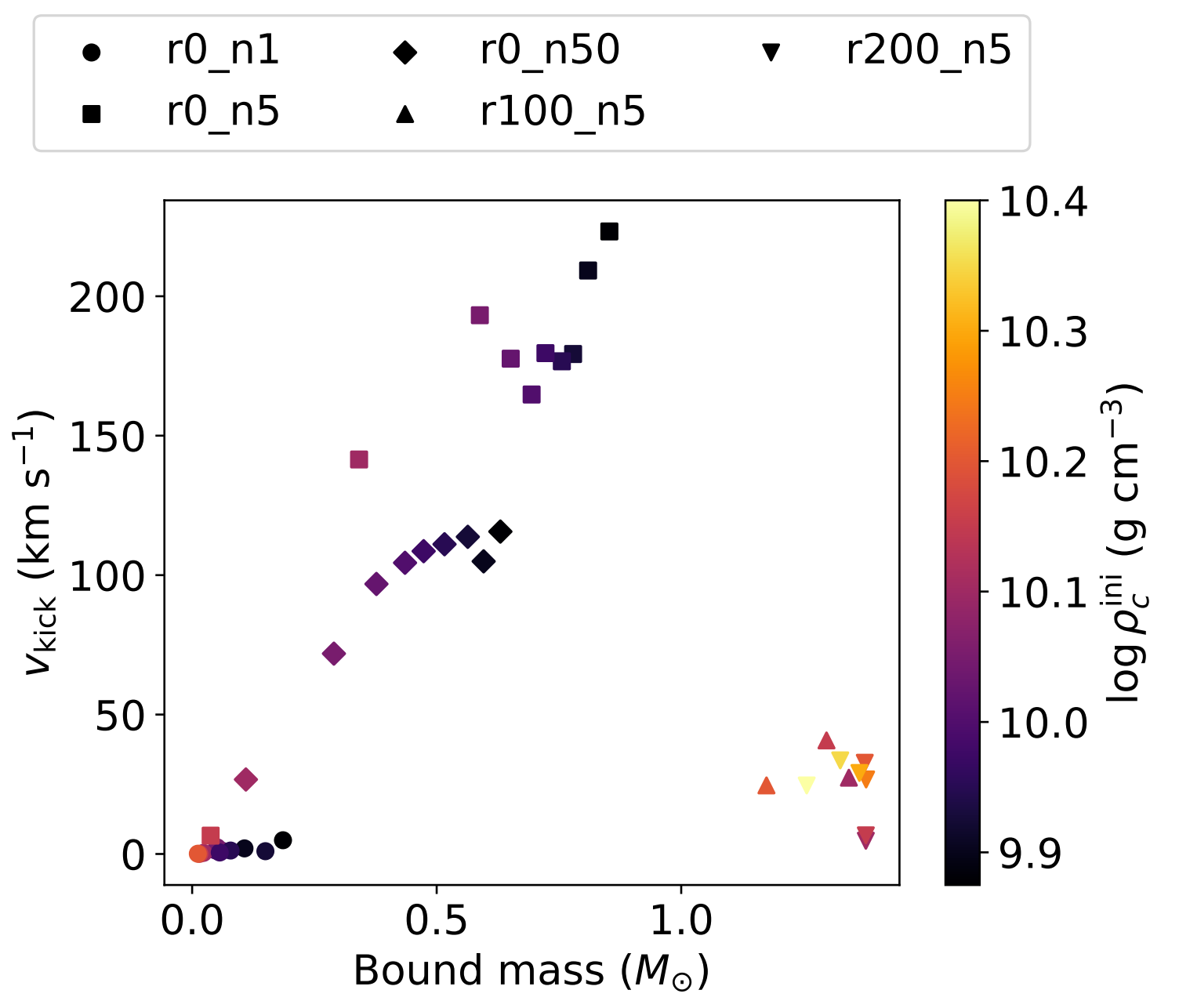
Ejecta structure



- Iron-group element rich outer ejecta layer with bound ONe remnant at the center
- Highly asymmetric ejecta structure, especially regarding their composition
- Strong dependence on ignition geometry and central density

Bound remnant properties

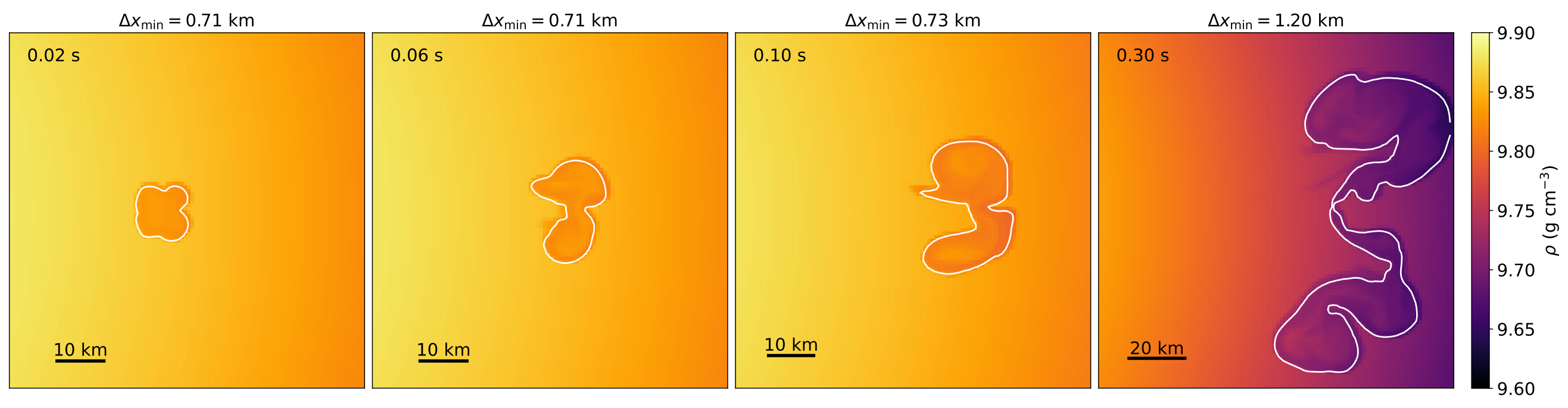
	$\log \rho_{c,ini}$	M_{bound} ($M_\odot$)	v_{kick} (km s^{-1})	M_{IGE} ($M_\odot$)	M_{IME} ($M_\odot$)
r0_n5	9.9	0.81	209.24	0.16	0.014
	9.95	0.76	176.68	0.15	0.013
	10.05	0.59	193.20	0.11	0.008
r0_n50	9.9	0.60	104.93	0.12	0.012
	9.95	0.52	111.07	0.10	0.010
	10.05	0.29	71.84	0.06	0.004
r100_n5	10.15	1.30	40.72	0.24	0.015
	10.2	1.17	24.60	0.24	0.014
r200_n5	10.2	1.38	32.70	0.11	0.008
	10.3	1.36	29.04	0.22	0.017



- Large dispersion of natal kick velocities v_{kick}
- Kick velocity strongly connected to flame evolution, less to central density
- For centrally ignited models, buoyant rise of initial flame in direction of asymmetry causes large kick
- Offcenter models burn around core, ejecting less mass leading to small kick velocities
- Higher central density decreases bound remnant mass due to rise time of flame

(Note: Quantities given here are only upper limits/ approximations due to limitations of the simulations)

What's next?



- High resolution study with a focus on ignition geometries
- Detailed nuclear post-processing
- First-of-its-kind radiative transfer simulations of tECSNe

Find the poster here:

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