Thermonuclear electron-capture supernovae – New production sites completing the solar inventory of isotopes?

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ECSNe in a Nutshell

Progenitors:

- Isolated star: Degenerate ONe core inside an extended H envelope
- Binary star: Stripped ONe core with stable He burning
- WD in binary system: ONe WD stably accreting from companion

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Onset of electron capture:

$^{20}\mathrm{Ne} \rightarrow {}^{20}\mathrm{F} \rightarrow {}^{20}\mathrm{O}$

- Energy release triggers nuclear burning
- Loss of electron degeneracy pressure initiates collapse

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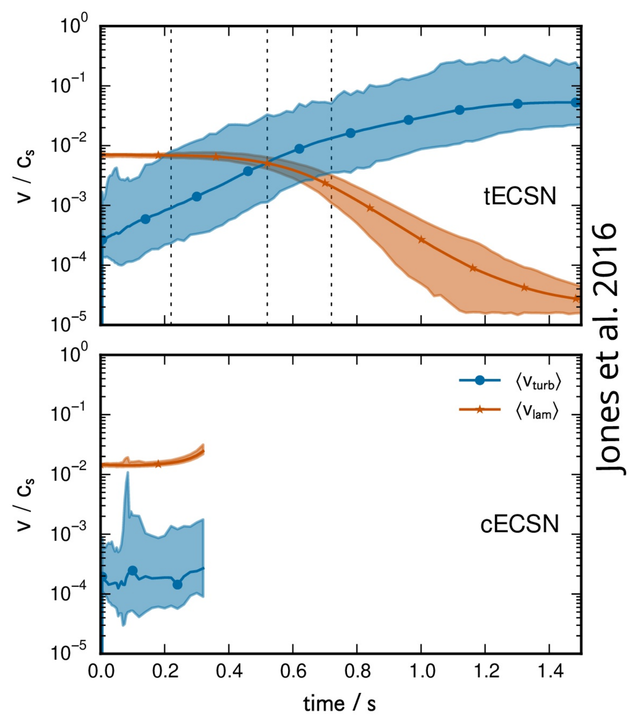
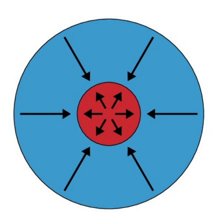
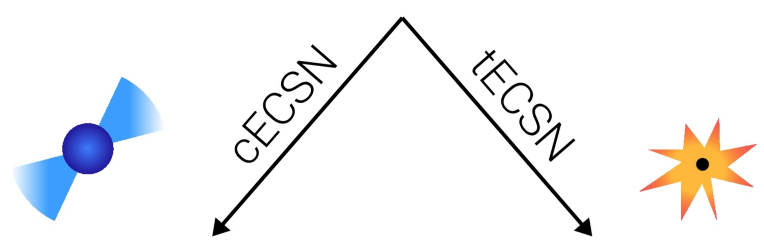


Collapse vs. explosion:



- Nuclear burning counteracts gravitational collapse
- Energy release depends on turbulence of flame
- If flame becomes turbulent fast enough, burning can stop collapse



Collapse and formation of a neutron star

Thermonuclear explosion leaving behind a bound remnant

Ejecta of tECSNe

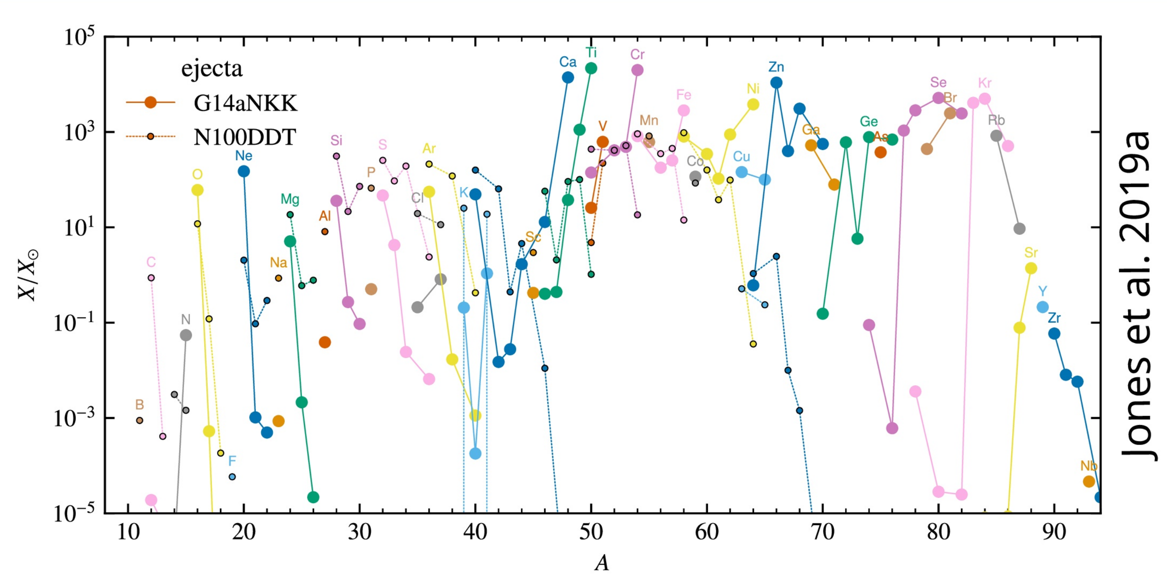


Figure: Overabundance of stable isotopes in the ejecta of a tECSN simulation (G14aNKK) after decaying for 0.32 Gyr. DDT simulation N100DDT from Seitenzahl et al. (2013) is plotted for comparison (decayed to 2 Gyr).

- Nuclear postprocessing using a derivative of the NuGrid reaction network (Pignatari et al. 2016, Jones et al. 2019c) covering **5213** isotopes
- Results similar to high-density CO deflagration simulations by Woosley (1997):
  - Deficit of C
  - Ejection of large amounts of O and Ne
  - Presence of large quantities of trans-iron elements from Zn to Rb
  - Significant overproduction of ^{48}Ca, ^{50}Ti and ^{54}Cr
- In contrast to high-density CO cores, high density ONe cores are supported by stellar evolution

⇒ tECSNe could replace high-density CO deflagrations as production sites of ^{48}Ca

Hydrodynamic Simulations

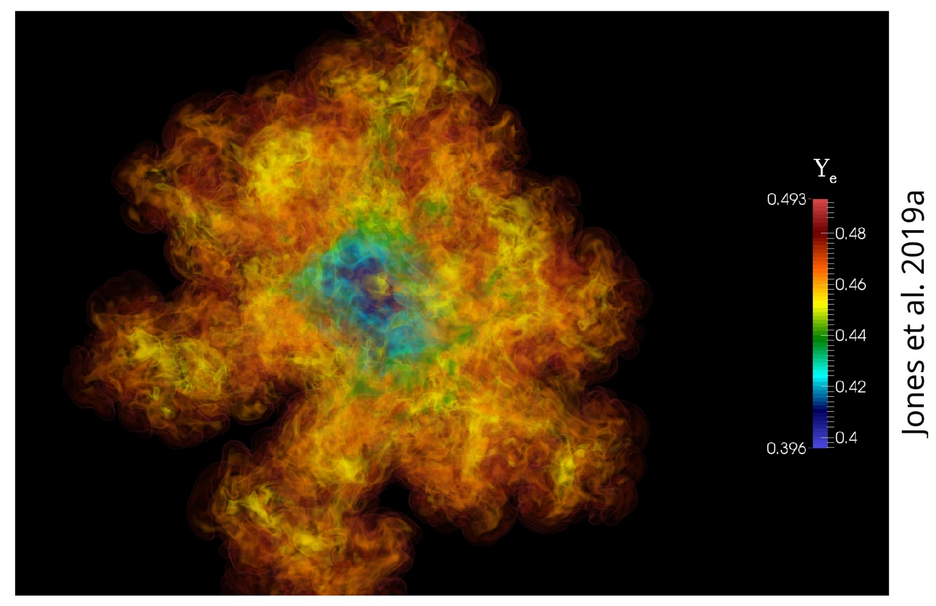


Figure: Volume rendering showing the spatial distribution of the electron fraction Y_e in the deflagration ashes of a ONe deflagration in a tECSN simulation.

- 3D level-set simulations of ONe cores using LEAFS
- Timmes EoS (Timmes & Arnett 1999), Coulomb corrections through formulation of Potekhin & Chabrier (2002) where considered.
- Some simulations **collapse**, others end as **thermonuclear explosions** depending on the central ignition density
- In non-collapsing models Y_e^{min} does not drop below ~ 0.4.
- If flame does not become turbulent fast enough, energy release cannot reverse collapse; Y_e will continue to decrease
- Including Coulomb corrections makes the flame take longer to become dominated by turbulence

Galactic Chemical Evolution (GCE) with tECSNe

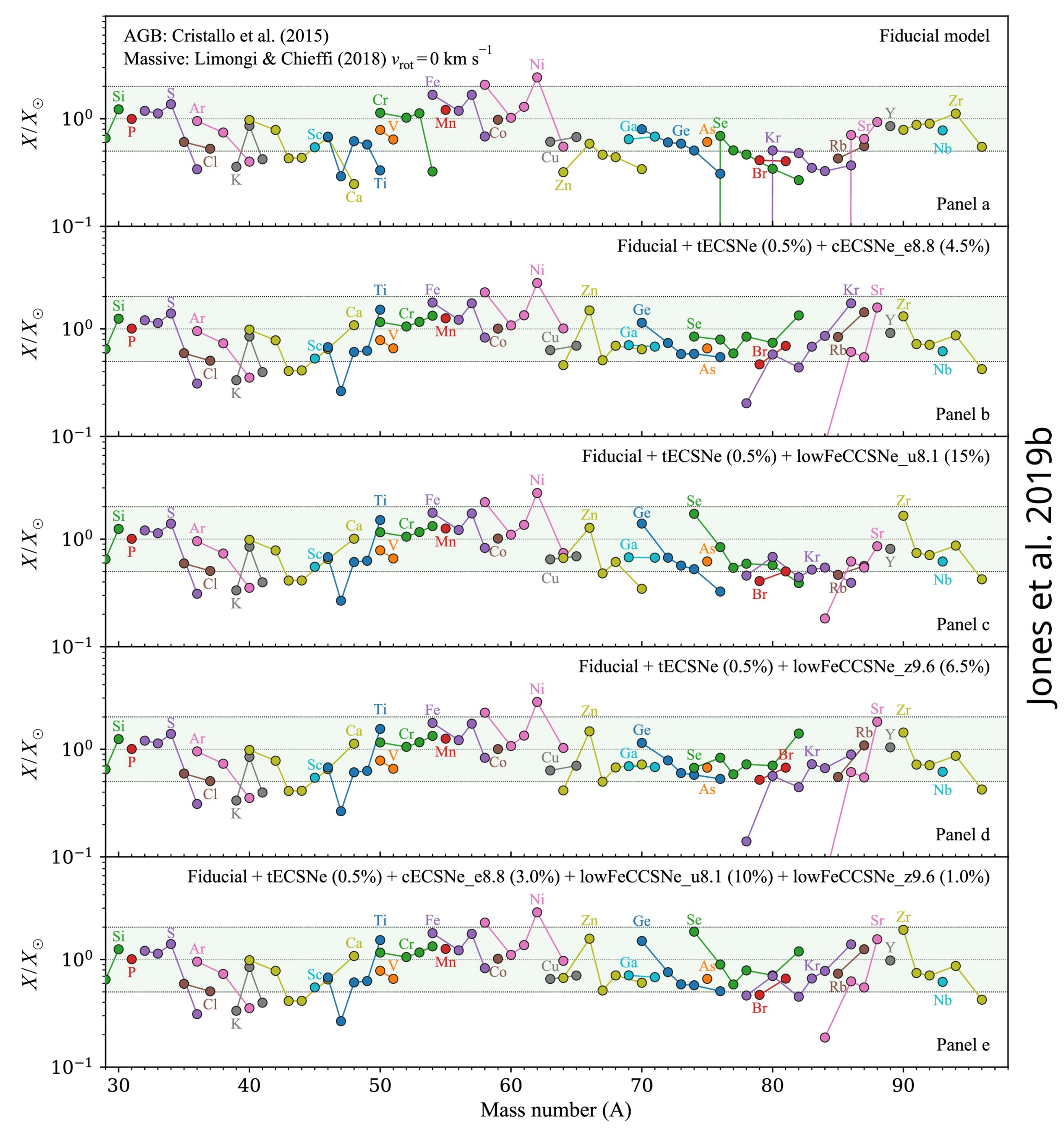


Figure: Galaxy model composition relative to solar when the sun forms.

- tECSNe are needed to match solar abundance of ^{48}Ca
- A complement of cECSNe is required for production of Zn-Zr range of elements
- cECSNe could potentially be replaced by low-mass Fe CCSNe (→ new progenitors for **low-kick neutron stars** would be needed!)

⇒ A mix of tECSNe, cECSNe and low-mass Fe CCSNe does not produce tension with solar abundances in GCE!

Do tECSNe exist in nature?

So far, no synthetic observables of tECSNe exist, allowing for a match to astronomical data.

⇒ The next step: Generation of high quality synthetic observables using tools such as ARTIS and TARDIS.

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