SFB 1245:
Nuclei: From fundamental Interactions to Structure and Stars

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Perspectives on SFB weak interactions in nuclei

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Electroweak transitions in nuclei

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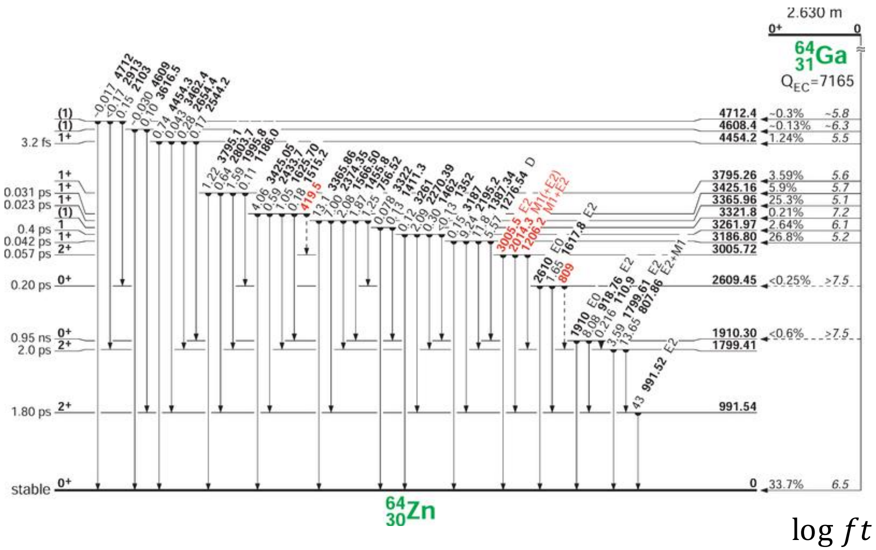
Beta decay: Gamow-Teller transitions

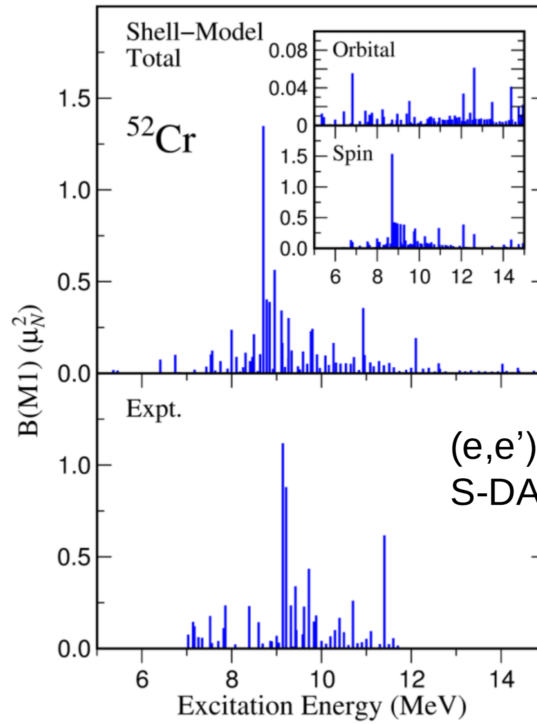


also measured by charge-exchange reactions.
Transition between initial and final state:

$$ft_{1/2} = \frac{K}{B(GT)}, \qquad K = 6147\ \text{s}$$

$$B(GT) = g_A^2 \frac{|\langle f \| \sum_k \boldsymbol{\sigma}^k \boldsymbol{t}_\pm^k \| i \rangle|^2}{(2J_i+1)}$$

Magnetic M1 transitions



(e,e')
S-DALINAC

$$B(M1) = \frac{|\langle f \| O(M1) \| i \rangle|^2}{(2J_i+1)} \mu_N^2$$

$$O(M1) = \sqrt{\frac{3}{4\pi}} \sum_k [g_l^k \boldsymbol{l}^k + \frac{1}{2} g_s^k \boldsymbol{\sigma}^k]$$

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Quenching electroweak transitions

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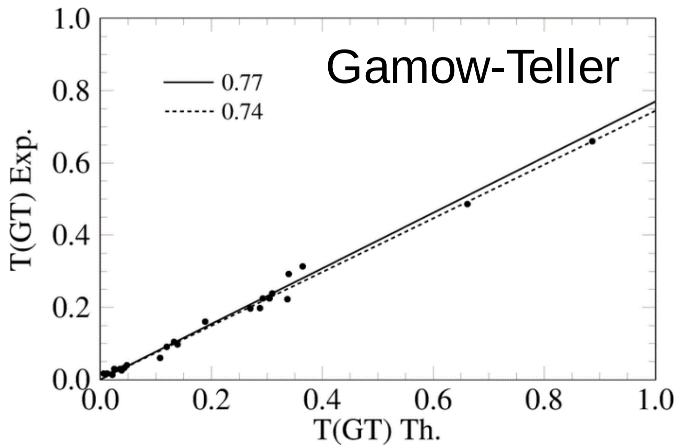
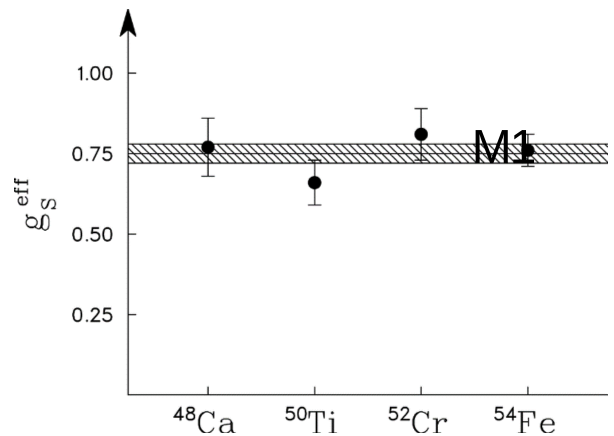
Comparison between shell model $0\hbar\omega$ calculations and data

Martínez-Pinedo *et al*., PRC (1996)



von Neumann-Cosel *et al*., PLB (1998)

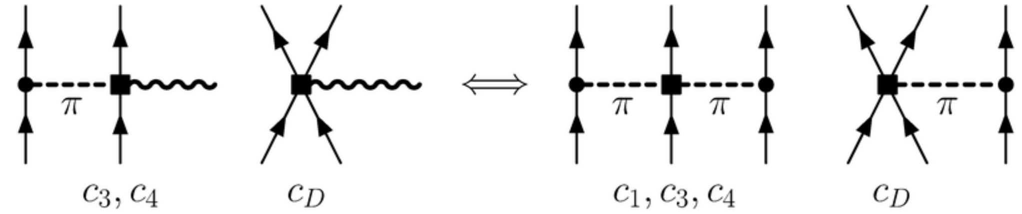


What is the origin of quenching and its momentum dependence?

- Many-body correlations → extension of model space, ab initio calculations
- Two-body currents → going beyond leading order contributions to the electroweak current

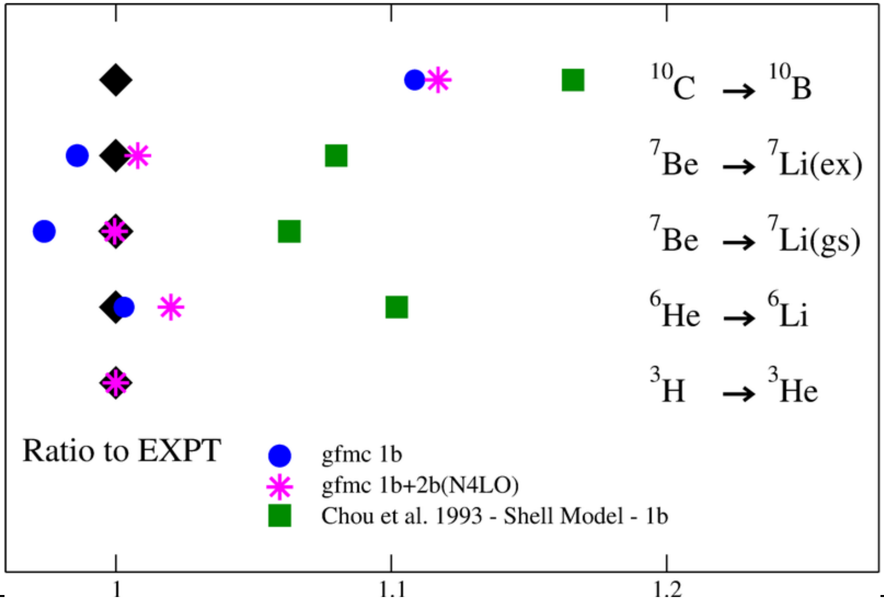
Two body currents

Chiral EFT provides consistent description of nuclear forces and currents



Park *et al.*, PRC (2003)
Pastore *et al*., PRC (2009)
Kölling *et al.*, PRC (2011)
Baroni *et al.*, PRC (2016)
Krebs *et al*, Ann. Phys. (2016)

Impact in light nuclei
Pastore et al, PRC 97, 022501 (2018)



Addressing the origin of quenching requires:

- Extension to heavier sd and pf shell nuclei. Systematic study of GT and M1 transitions
- Study forbidden transitions and electromagnetic analogs. Test of the momentum dependence predicted by two-body currents

Connections

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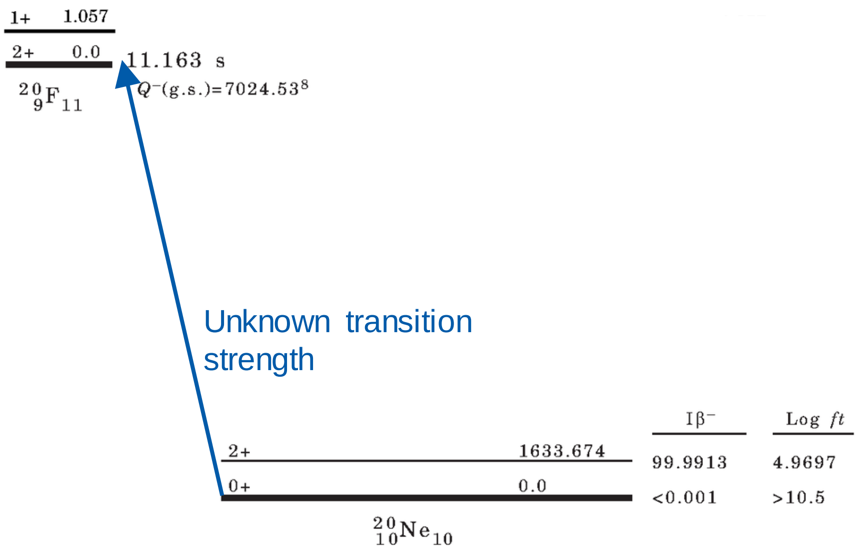
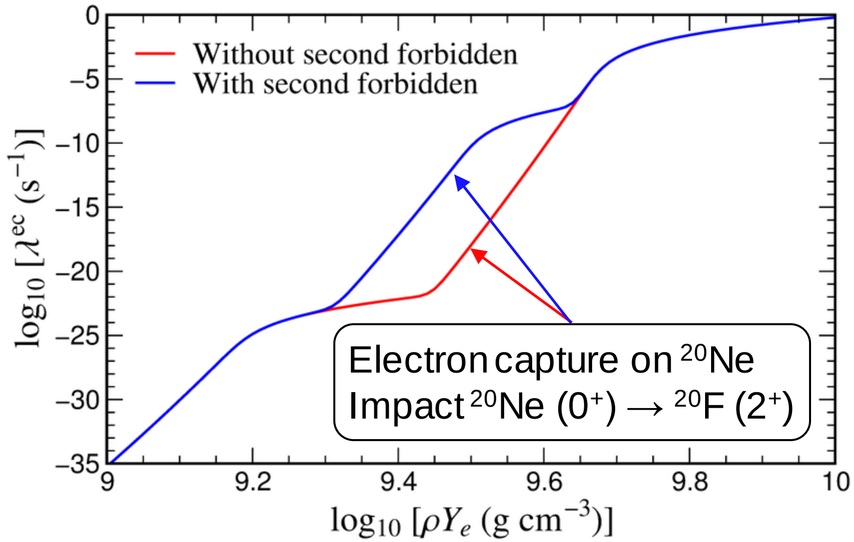
A better understanding of the weak interaction is required for:

- Beta-decay of r-process nuclei
  - Nucleosynthesis
  - Electromagnetic transients from mergers
- Electron capture and neutrino processes in stars.
  - supernova explosion mechanism
  - nucleosynthesis.
- Matrix elements for fundamental interactions
  - neutrinoless double beta-decay
  - dark matter detection:

Electron capture on ^{20}Ne





- Second-forbidden transition between ground state of ^{20}F and ^{20}Ne was suggested to impact the electron capture rate on ^{20}Ne
- Implications for the evolution of intermediate mass stars?

Weak processes and stellar evolution

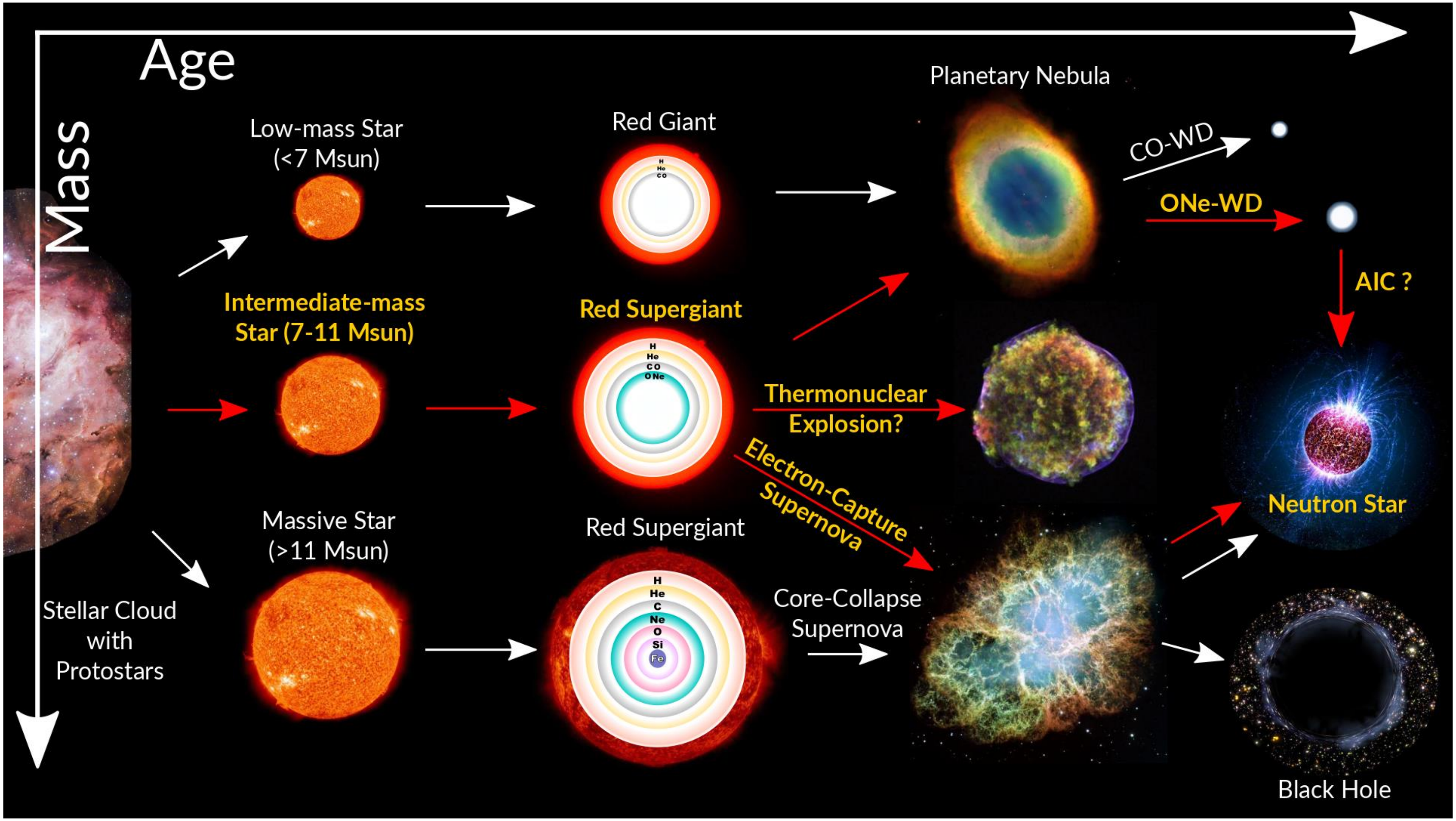
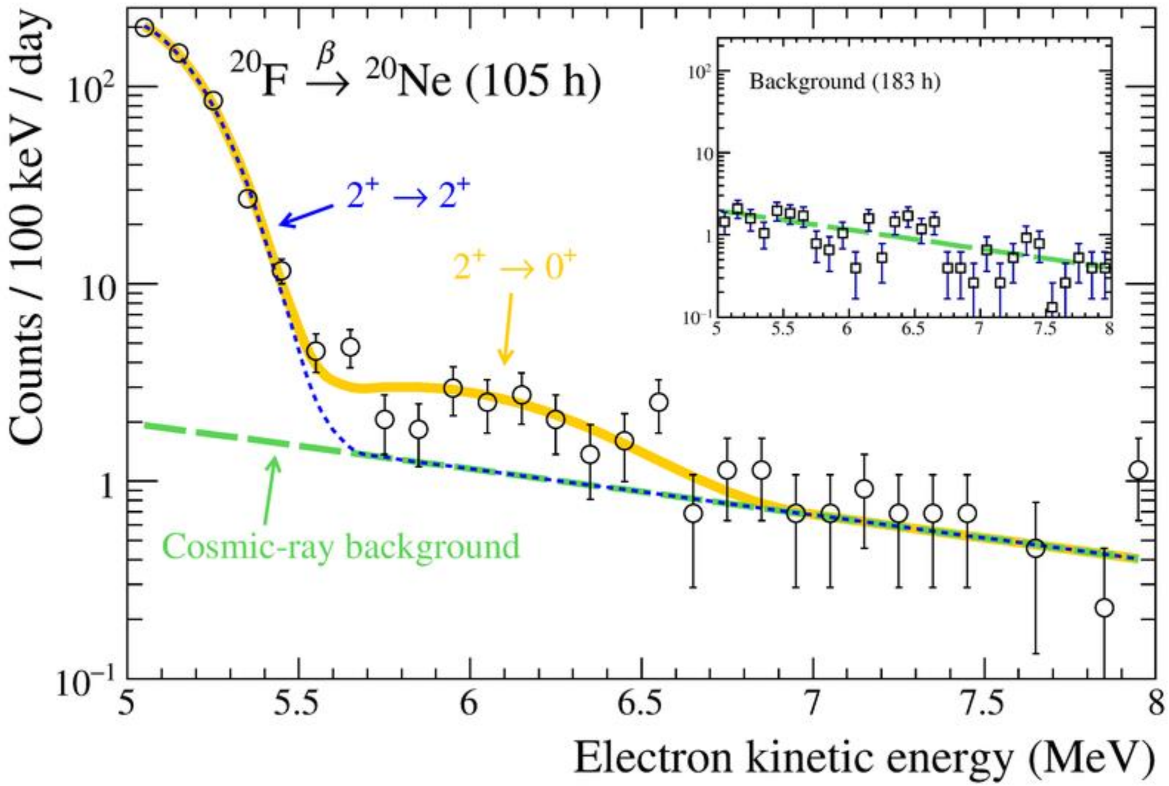


Figure from Heiko Möller

Experimental measurement

Kirsebom et al, arXiv:1805.08149, JYFL Accelerator Laboratory, Jyväskylä,

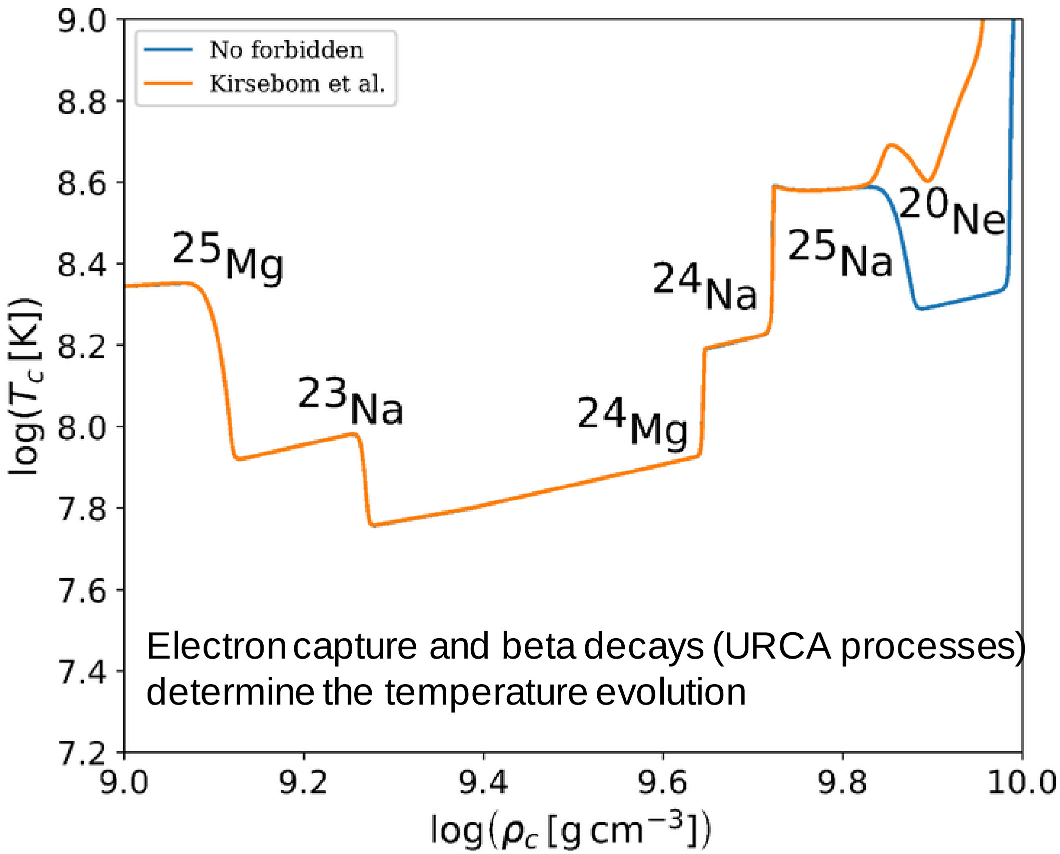


$\log\ ft = 10.47(11)$ $\quad B = 2.08 \times 10^{-7}$ for ^{20}F decay

Compared with $\log ft = 13.58(3)$ $\quad B = 1.6 \times 10^{-10}$ for ^{36}Cl decay

Central evolution ONe core

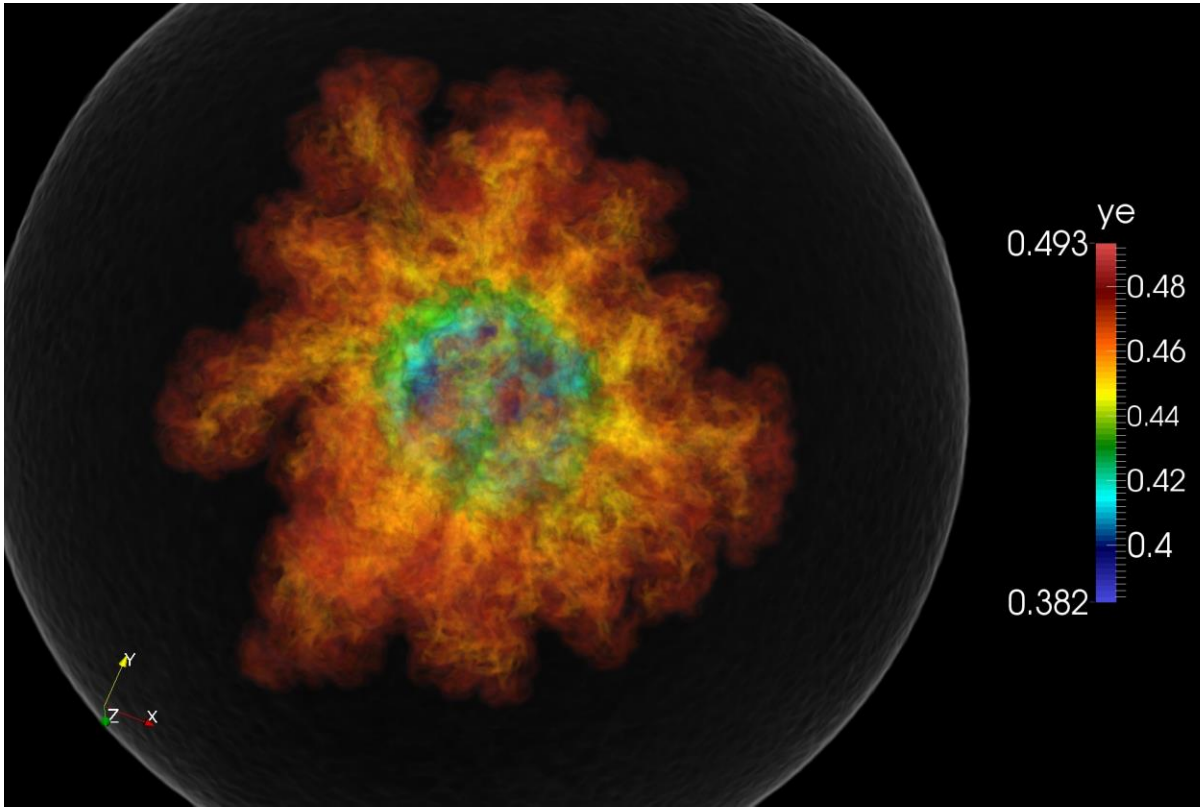
Evolution central temperature and density (Dag Fahlin Strömberg using MESA)



Onset of oxygen ignition shifted to a lower densities favoring thermonuclear explosion

Simulation thermonuclear explosion

3D Thermonuclear simulation by Samuel Jones and Friedrich Röpke



Remnant mass
0.3 $M_\odot$

Ejected mass
1.1 $M_\odot$

Thermonuclear explosion (Electron Capture Ignited Supernova Explosion) is the most common outcome for intermediate star evolution.
Previously assumed they will collapse and explode as core-collapse supernova

Project goals (B1)

- Advance electroweak currents based on chiral EFT to ab initio calculations of light to medium-mass nuclei (A02, A04)
- Develop systematic understanding of electroweak transitions addressing the role of many-body correlations and two-body currents
- Explore momentum-transfer dependence of one- and two-body currents, predicted by chiral dynamics (B02)
- Describe neutrino-matter interactions for use in core-collapse supernovae simulations (B06) consistent with equation of state (EOS) (B05)
- Transport the insights to the description of matrix elements for fundamental symmetries (B03)