Discovery of exceptionally strong electron-capture transition sheds new light on the fate of intermediate-mass stars

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on behalf of

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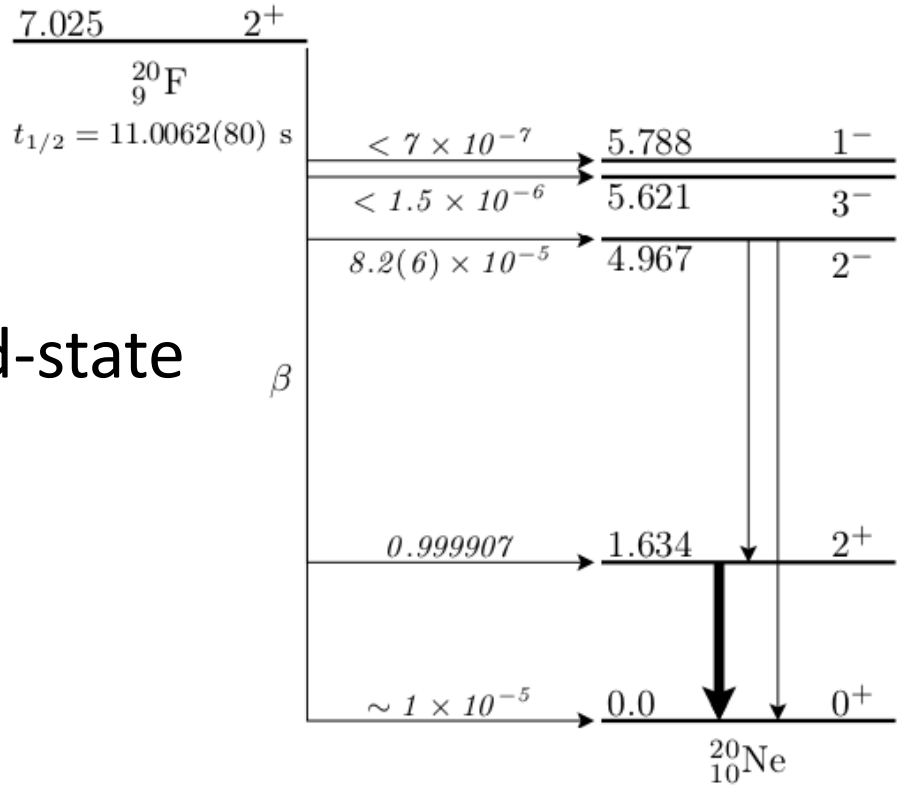
Brief overview

- First detection of ^{20}F decay to ^{20}Ne ground-state

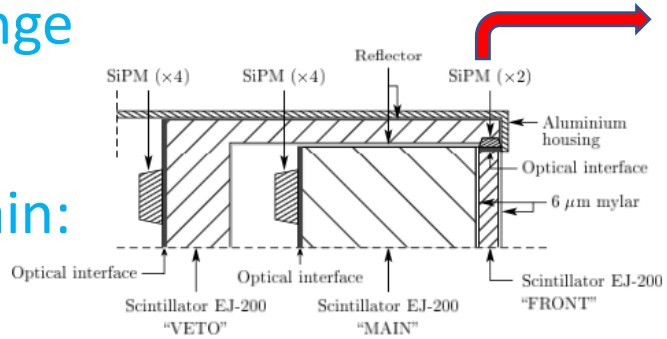


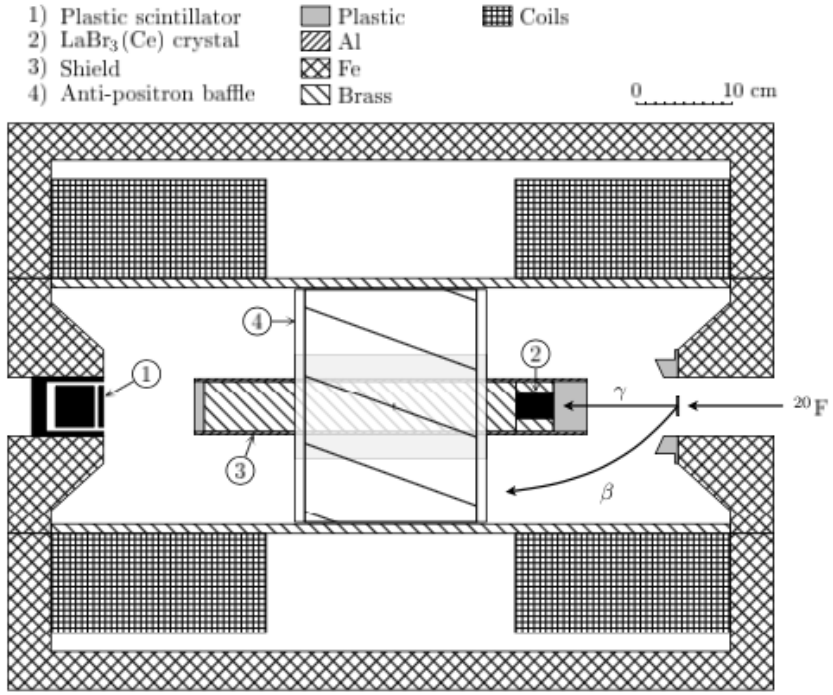
- Significant change of rate of stellar electron capture on ^{20}Ne

- Impact on the final evolution of stars between 7-11 solar masses

The decay experiment

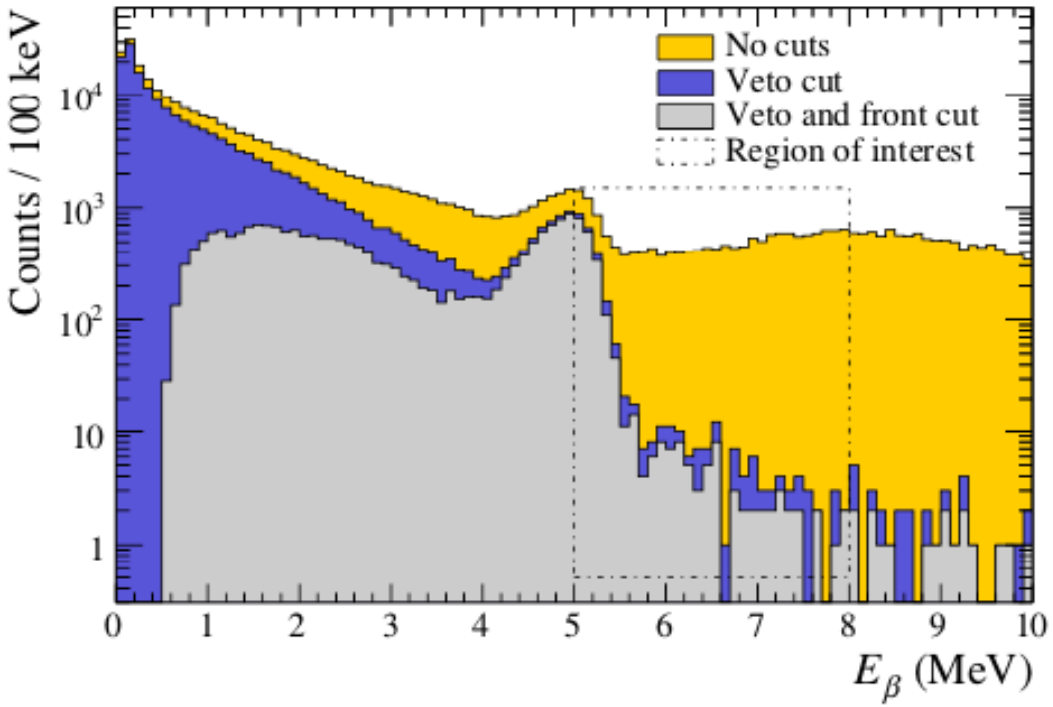
- Radioactive $^{20}F^{+}$ beam at IGISOL-4 / JYFL Accelerator Laboratory
  - (d,p) on BaF_2, ^{12}B (from B) for calibration
  - 30 kV transport, stopped in thin C foil
  - Intensity around 11 kHz
- Magnetic transporter
  - Selects momentum range
- Plastic-scintillator
  - 3 parts: veto, front, main:

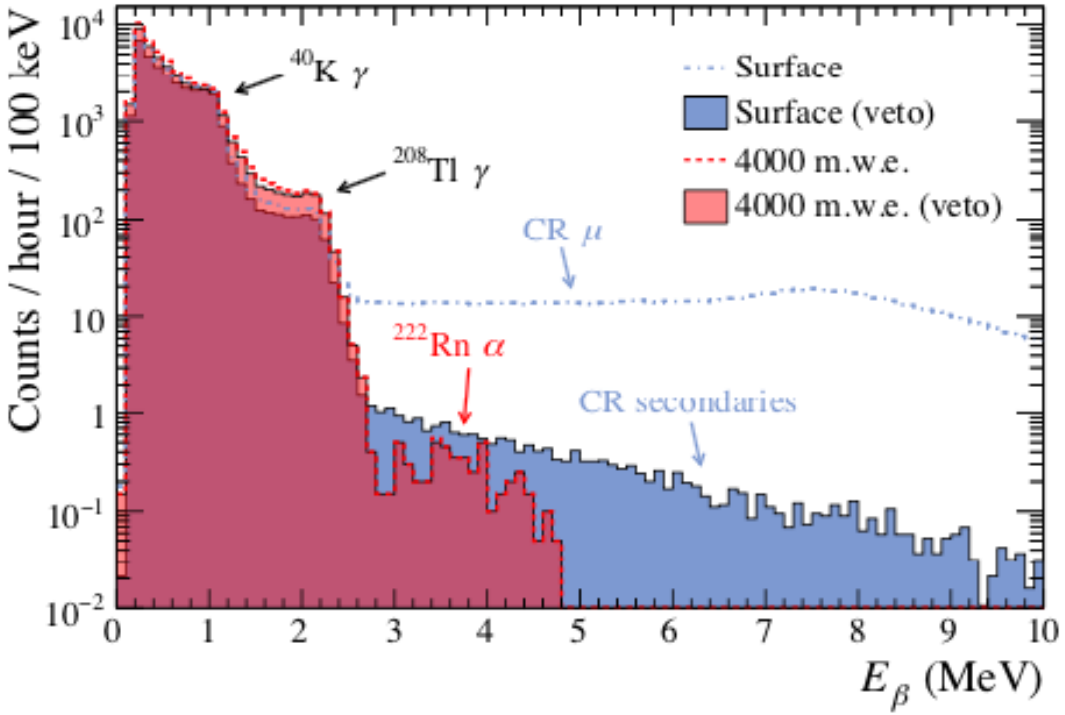




Recorded beta spectra

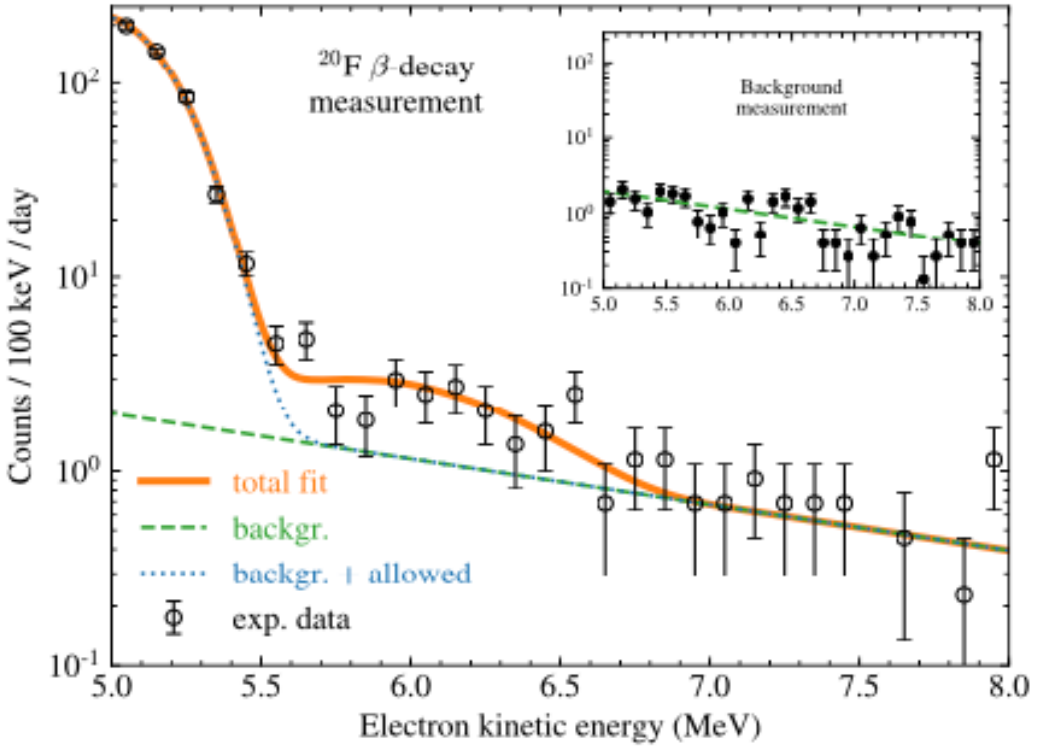
- At 67.7% max current - background (Pyhäsalmi mine)

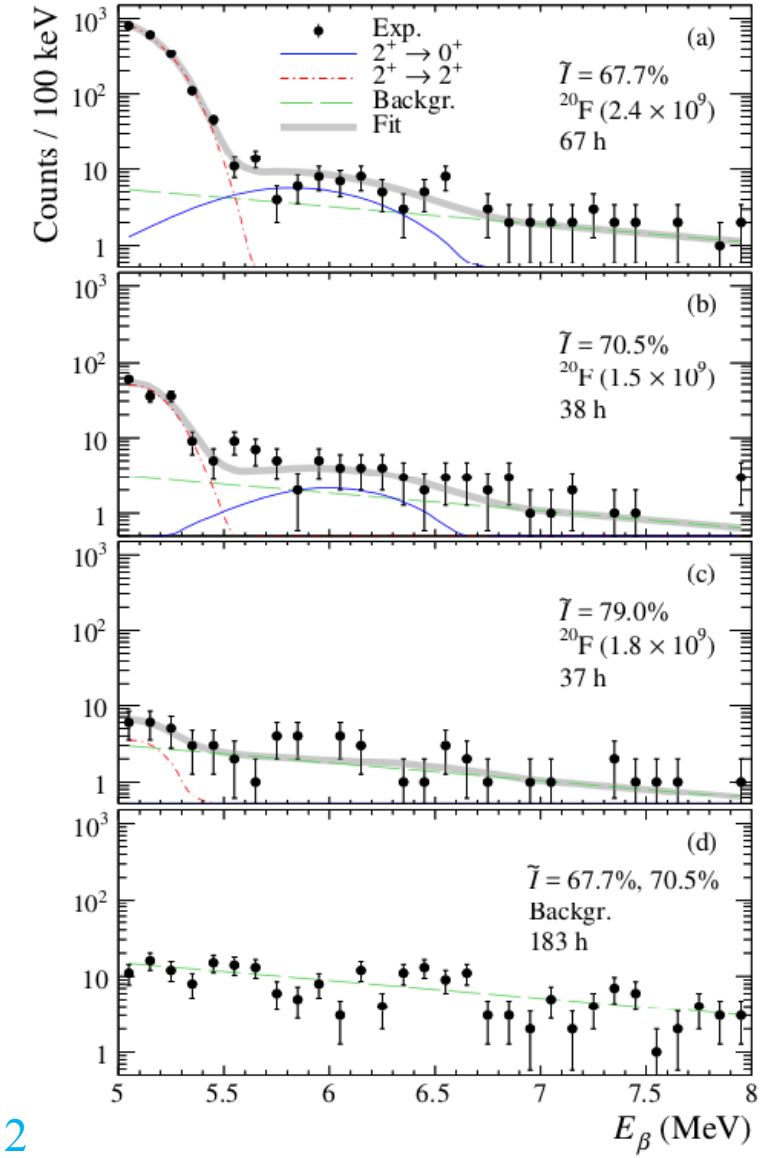




Veto cut = no signal in Veto Front cut = deposited energy 0.65-1.60 MeV in Front

Fit to beta spectra





RoI

Out of RoI

Above RoI

Background

Maximum likelihood fit - - $\chi^2/N = 133.6/112$

Ground state transition ^{20}F to ^{20}Ne

- Calibrations cross-checked with ^{12}B, ^{207}Bi … validated with GEANT4
- Branching ratio: (0.41 +- 0.08 +- 0.07) 10^{-5}
- log(ft) = 10.89(11), strong second-forbidden non-unique transition
- Several shell-model calculations (IM-SRG, CCEI, USDB) agree within a factor of 2

Deduced electron-capture rate on ^{20}Ne

- Intermediate-mass starts after C burning = degenerate O-Ne core
- Electron-capture rates:

  Increase due to gs transition

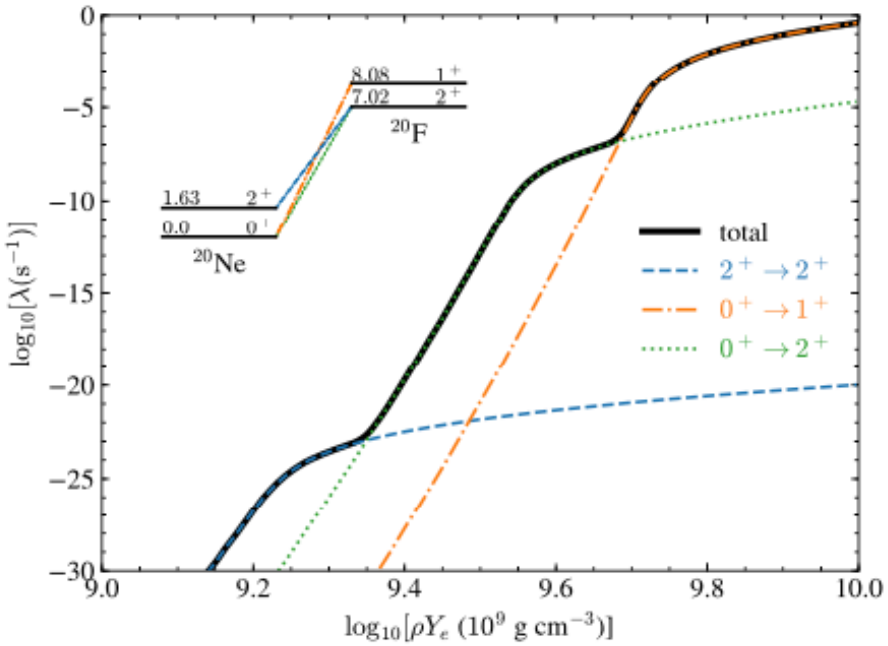


FIG. 2. Astrophysical electron-capture rate as a function of density for a temperature of $T = 0.4$ GK and an electron fraction of $Y_e = 0.5$. A simplified level scheme shows the main transitions with the nuclear levels labeled by their spin-parity and energy in MeV relative to the ^{20}Ne ground state.

Brief results of stellar modelling

- New gs rate: electron capture on ^{20}Ne proceeds at lower densities

Simulations:

thermonuclear explosion

rather than

gravitational collapse

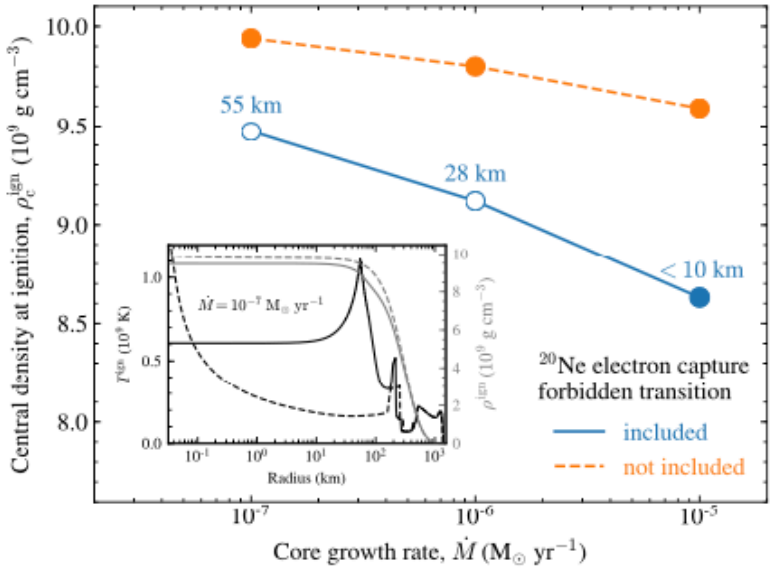


FIG. 3. Central ignition density vs. growth rate for a contracting, degenerate ONe core, with and without the forbidden transition between the ground states of ^{20}Ne and ^{20}F. Filled circles denote cases in which oxygen ignition occurs centrally, while empty circles denote off-center ignition at the indicated radius. The panel shows temperature and density profiles at the time of ignition for the low growth rate (10^{-7} M$_\odot$ yr^{-1}).

Contributors to the work

arXiv:1805.08149

Measurement of the $2^+ \rightarrow 0^+$ ground-state transition in the β decay of ^{20}F

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Author Contributions The project was born out of discussions between KL, GMP and HOUF. OSK led the experiment, analyzed the data and wrote the paper together with SJ, DFS, GMP, KL and FR; all authors were involved in the project and commented on the paper. DFS and HM performed the MESA simulations. SJ performed the LEAFS simulations with assistance from STO. The electron-capture rates were calculated by DFS, GMP, KL, AI and BAB. The experiment was carried out by OSK, MH, AK and SRA under the supervision of WHT and with assistance from TE, AJ, IM, HP and JÄ. Finally, HOUF and KR helped with the data analysis.

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