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

K. Riisager (Aarhus University)
on behalf of
Oliver S. Kirsebom (Aarhus University, Dalhousie University)
**Brief overview**

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

<table>
<thead>
<tr>
<th>$^{20}\text{F}$</th>
<th>$^{20}\text{Ne}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{1/2} = 11.0062(80)$ s</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversion Rate</th>
<th>Energy (MeV)</th>
<th>Quantum State</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 7 \times 10^{-7}$</td>
<td>5.788</td>
<td>$1^-$</td>
</tr>
<tr>
<td>$&lt; 1.5 \times 10^{-6}$</td>
<td>5.621</td>
<td>$3^-$</td>
</tr>
<tr>
<td>$8.2(6) \times 10^{-5}$</td>
<td>4.967</td>
<td>$2^-$</td>
</tr>
</tbody>
</table>

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

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

• Radioactive $^{20}\text{F}^+$ beam at IGISOL-4 / JYFL Accelerator Laboratory
  • $(d,p)$ on $\text{BaF}_2$, $^{12}\text{B}$ (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

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: $(0.41 \pm 0.08 \pm 0.07) \times 10^{-5}$

- $\log(ft) = 10.89(11)$, 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 $^{20}\text{Ne}$

- 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 $^{20}\text{Ne}$ ground state.
Brief results of stellar modelling

• New gs rate: electron capture on $^{20}\text{Ne}$ 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 $^{20}\text{Ne}$ and $^{20}\text{F}$. 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 ($10^{-7} \text{ M}_\odot \text{ yr}^{-1}$).
Contributors to the work

**arXiv:1805.08149**

**arXiv:1905.09407**

*Contributors to the work*

**Measurement of the $2^+ \to 0^+$ ground-state transition in the $\beta$ decay of $^{20}$F**


**arXiv:1905.09407**

*Contributors to the work*

**Discovery of exceptionally strong nuclear transition sheds new light on the fate of intermediate-mass stars**


**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 JA. Finally, HOUF and KR helped with the data analysis.