Physics at Felsenkeller: HEARTS project

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MU Days 2026
October 19, 2026

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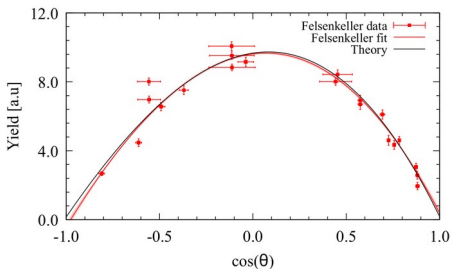
Nuclear astrophysics at Felsenkeller

Big Bang Nucleosynthesis

$^{2}H(p,\gamma)^{3}He$

New data from 0.3 – 2 MeV
Angular distribution data
Cross section data



Hydrogen Burning

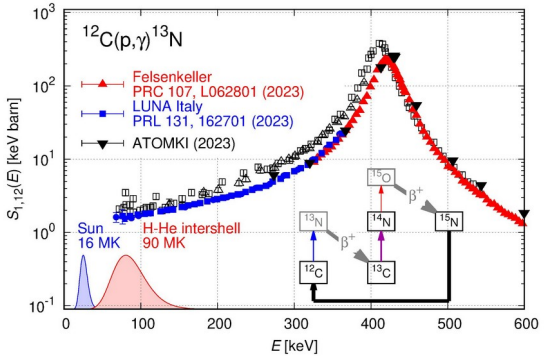
$^{3}He(\alpha,\gamma)^{7}Be$

$^{12}C(p,\gamma)^{13}N$

$^{13}C(p,\gamma)^{14}N$

Phys. Rev. C 111, 064611 (2025)

Phys. Rev. Lett. 131, 162701 (2023)



Helium Burning

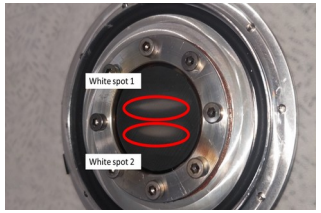
$^{15}N(\alpha,\gamma)^{19}F$

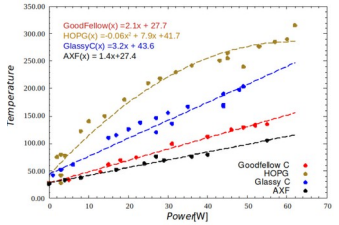
$^{14}N(\alpha,\gamma)^{18}F$

New gas jet target system for underground nuclear astrophysics

Master thesis: B. Poser, S. Goehler, F. Mayer

PhDs: P. Hempel, A. Yadav





Carbon Burning

$^{12}C+^{12}C$
Target tests
Particle detection

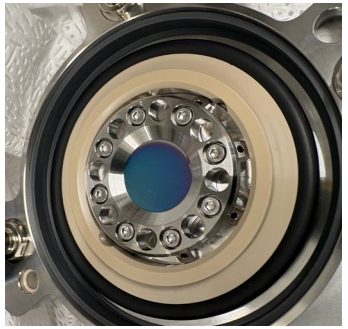
French collaboration
INFN collaboration

Explosive scenarios

$^{40}Ca(\alpha,\gamma)^{44}Ti$

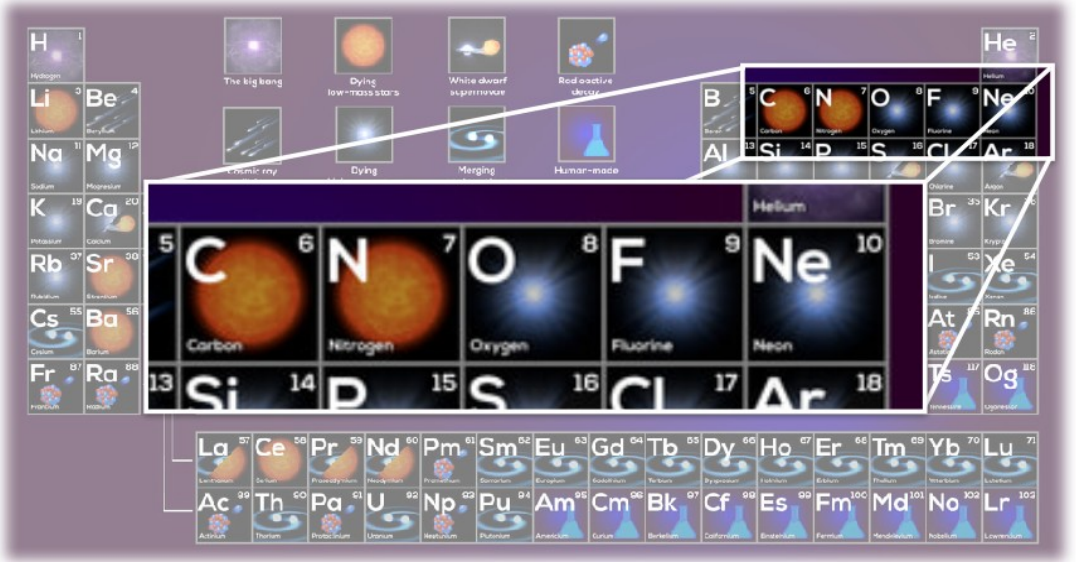
Ongoing

Master thesis: S. Werner

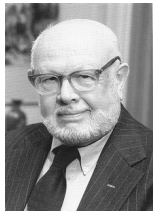


Stellar Helium burning

- **Temperature:** 0.1 – 0.4 GK
- Red Giant and Asymptotic Giant Branches stars,
- Massive stars
- Core-collapse supernova progenitors



➡ **Carbon to oxygen ratio**, hence, heavy-element production



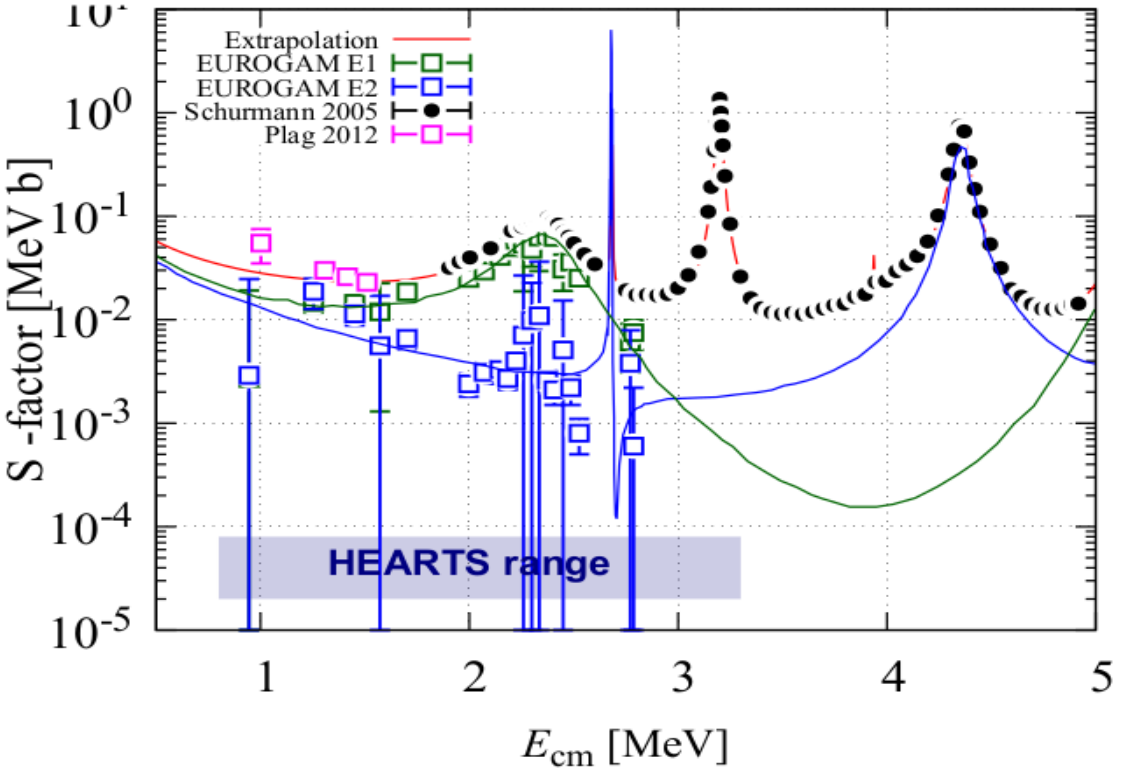
"The Holy Grail of Nuclear astrophysics: $^{12}C(\alpha, \gamma)^{16}O$ reaction"
William A. Fowler
1983 Nobel Prize in Physics

"For his theoretical and experimental studies of the nuclear reactions of importance in the formation of the chemical elements in the universe"a

HEARTS objectives

$^{12}C(\alpha,\gamma)^{16}O$ reaction

The rate of the **$^{12}C(\alpha,\gamma)^{16}O$** nuclear reaction ("Holy Grail") remains **highly uncertain**



What we have:
30% uncertainty

What we need:
10% uncertainty

HEARTS will

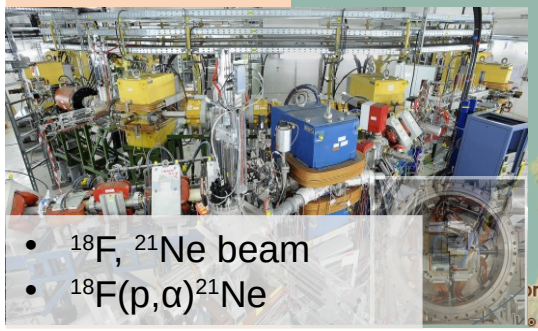
- $^{12}C(\alpha,\gamma)^{16}O$ angular distribution and cross-section
- Measure and reduce the reaction rate uncertainties, for α-induced reaction on N, O, F ^{25}Mg isotopes
- Combine different facilities, and tools (one astro postdoc in the team)

HEARTS facilities

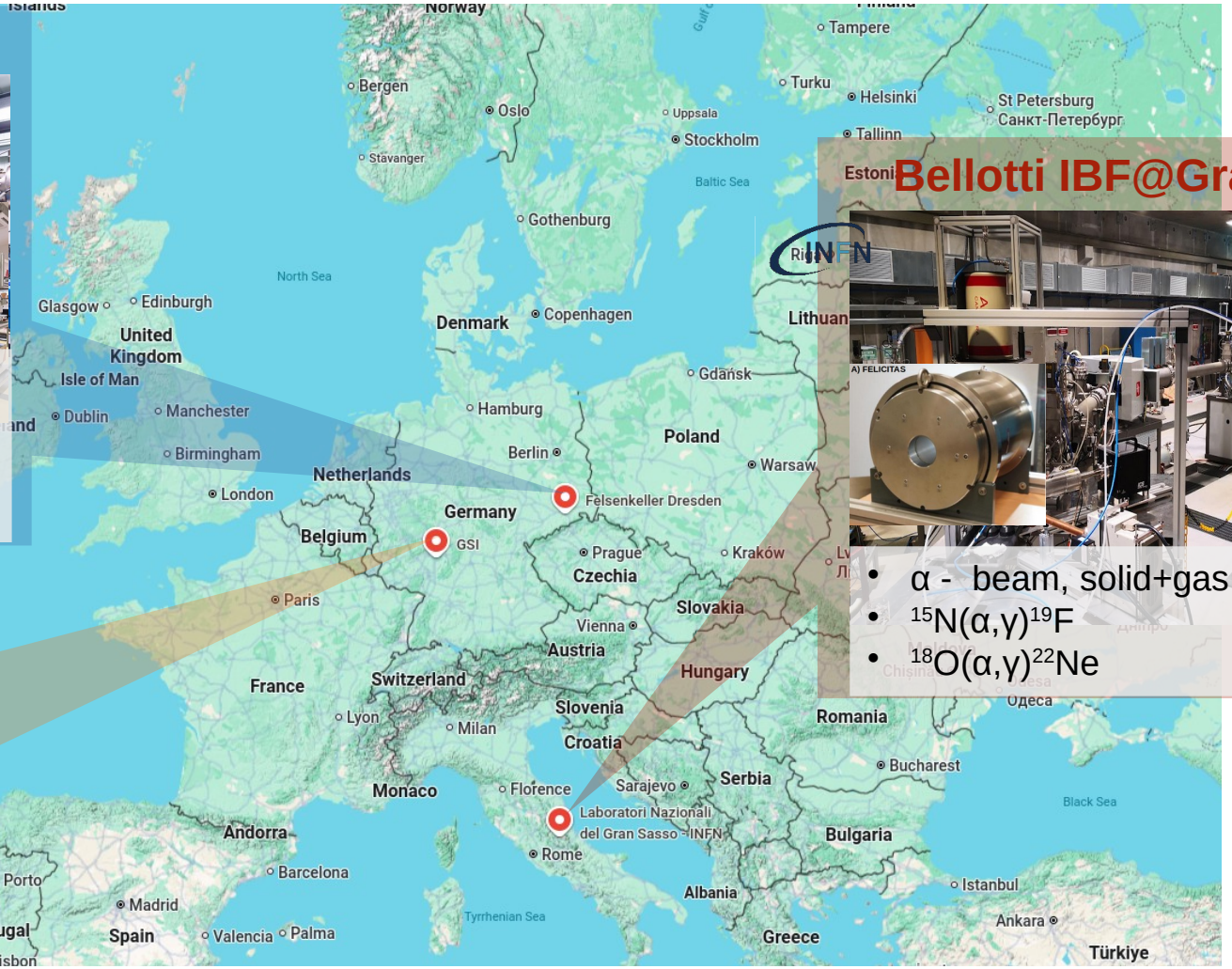
Felsenkeller@HZDR

- α, ^{12}C beams
- solid+ gas-jet target
- ^{12}C(α,γ)^{16}O
- ^{25}Mg(α,n)^{28}Si

CRYRING@GSI



- ^{18}F, ^{21}Ne beam
- ^{18}F(p,α)^{21}Ne

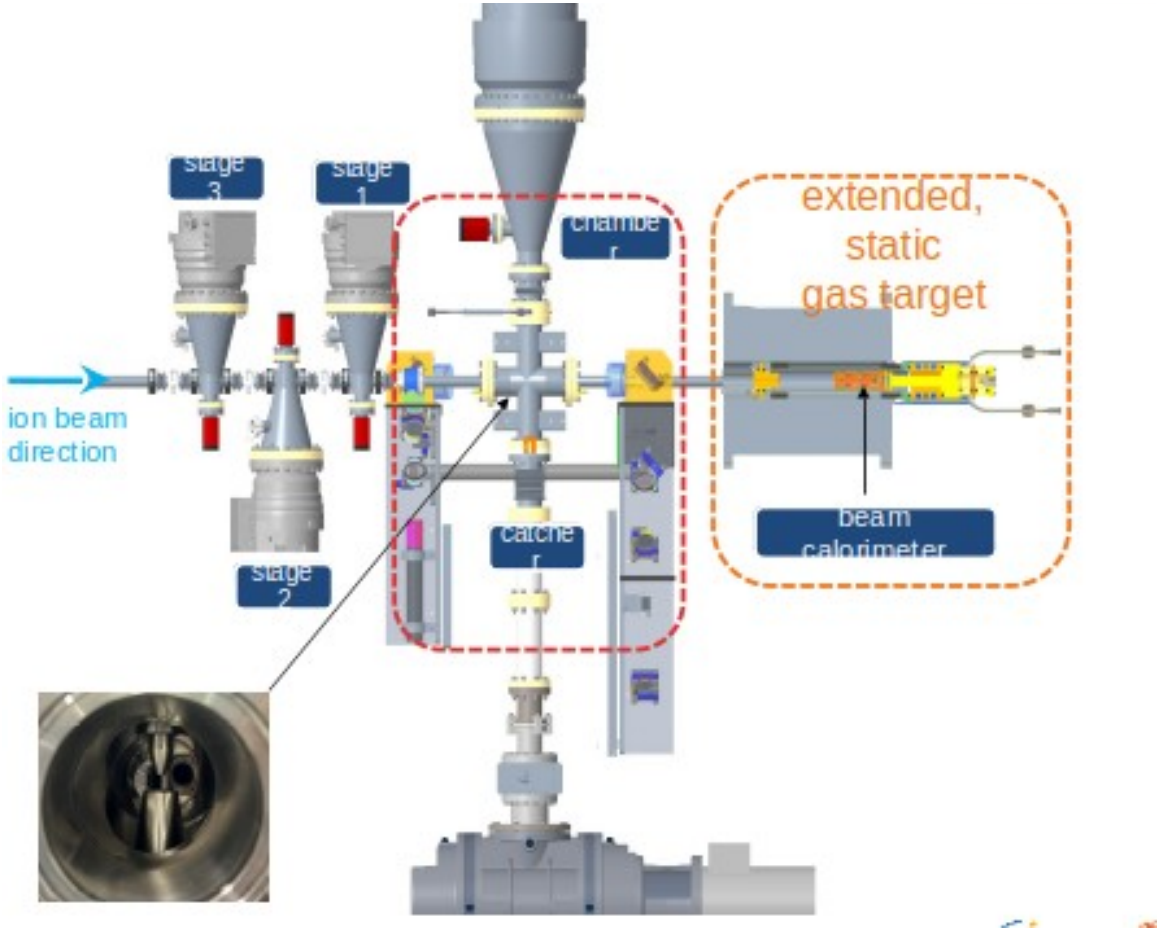


Bellotti IBF@Gran Sasso

- α - beam, solid+gas target
- ^{15}N(α,γ)^{19}F
- ^{18}O(α,γ)^{22}Ne

α- induced on Nitrogen

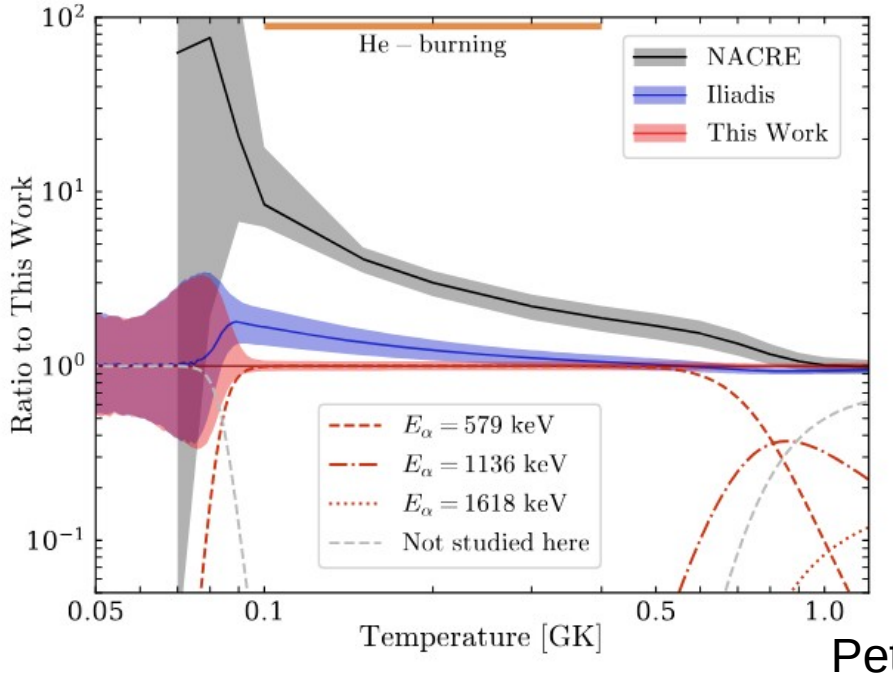
Felsenkeller gas-jet target



Nucl. Inst. Meth. A 1082, 171034 (2025)

A. Yadav PhD project

$^{14}N(\alpha,\gamma)^{18}F$: commissioning and first science case



PRL,, Under review (2026)

$^{15}N(\alpha,\gamma)^{19}F$ case

- High energy data under analysis
- Low energy campaign at IBF (2027)

Peter Hempel

Maria Lukyanova

Summary

- Felsenkeller facility has explored several science cases in less than five years and has developed the first jet target in underground lab **opening the floor to many new science cases**
- LUNANOVA and HEARTS project will provide precise nuclear reaction for **hydrogen** and **helium** burning phases of stars.
- HEARTS combines three different facilities (Felsenkeller, CRYRING, IBF-LNGS)
- First science cases and experimental preparation are ongoing

Felsenkeller team