The total cross-section measurement for the reaction $^{37}Cl(\alpha,n)^{40}K$ using HeBGB detector

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Outline of the Talk

- Why
- How
- What
- Experimental Limitations
- Experimental Observations
- Future Plans


WHY

The Potassium Case

One of the most Prolific element on Earth!

Isotope	Atomic Mass	Abundance (%)
^{39}K	38.963	93.26
^{40}K	39.963	0.0117
^{41}K	40.961	6.73

STABLE

Radioactive

STABLE

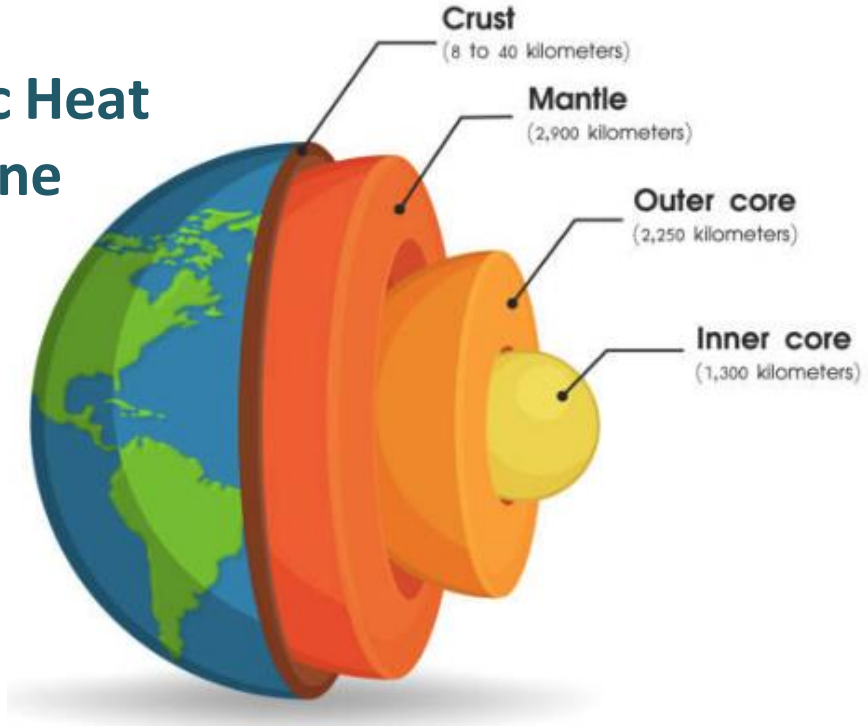
Half-life: 1.2 billion years

γ-rays from the decay of ^{40}K are detectable anywhere on Earth

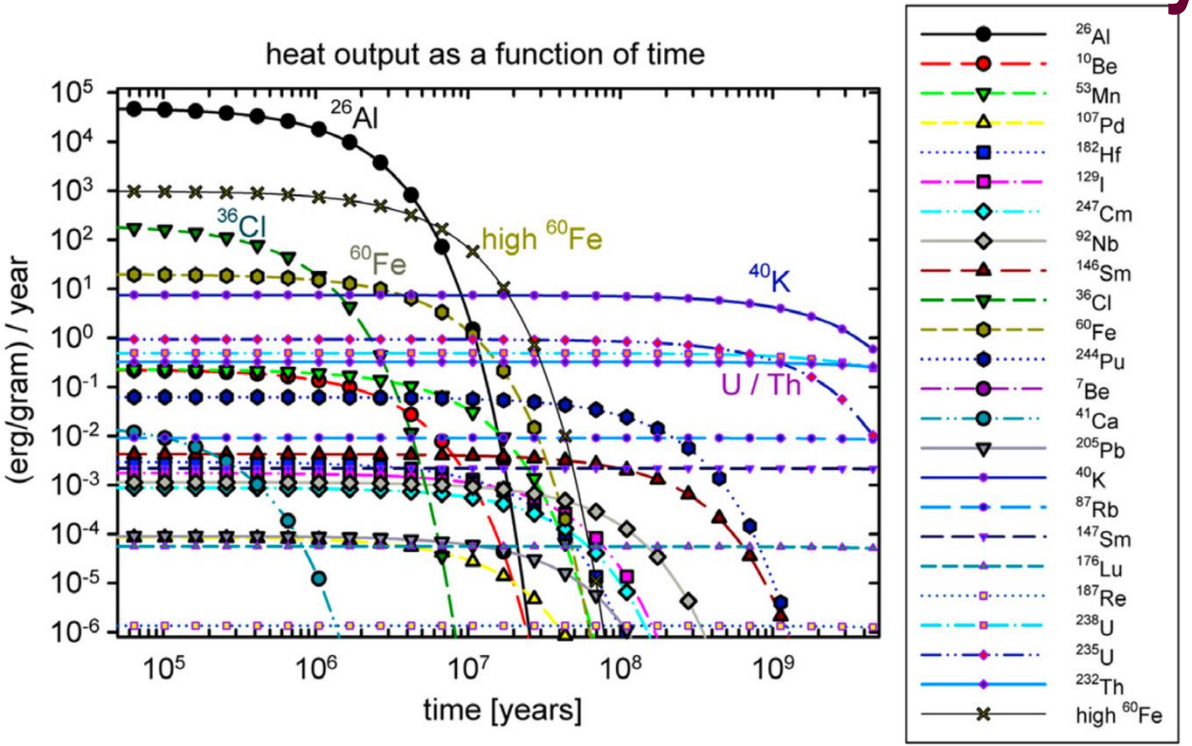
Comparable to age of Earth

Existence of Potassium Inside The Planet?

Gigantic Heat Engine



Existence of Potassium In The Solar System

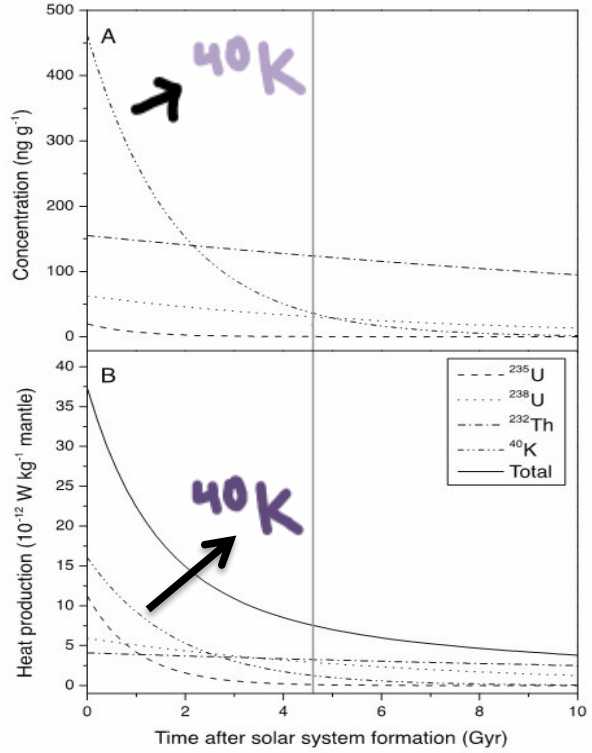


Lugaro et al., Progress in Particle and Nuclear Physics, 102 (2018)

Evolution of Radiogenic Heating of Earth

Huge amounts of ^{40}K in early Earth

Dominated the heat production in early Earth



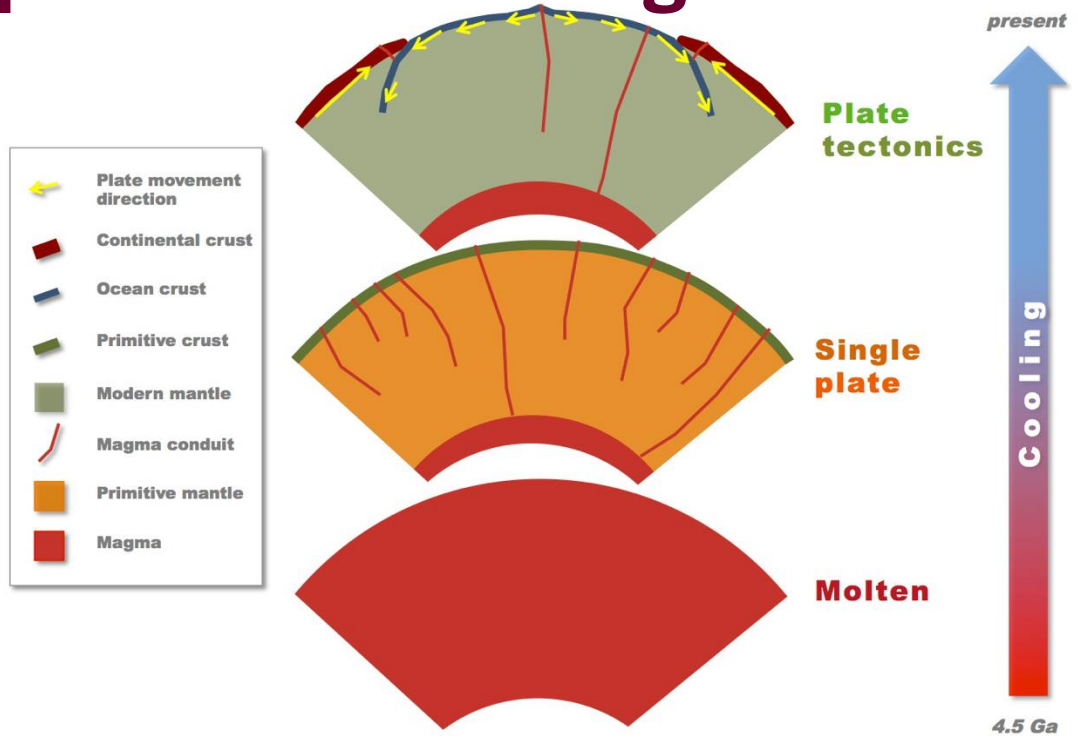
Currently responsible for 20% of total heat produced in mantle

Frank et al., Icarus (2015)

Importance of Radiogenic Heating

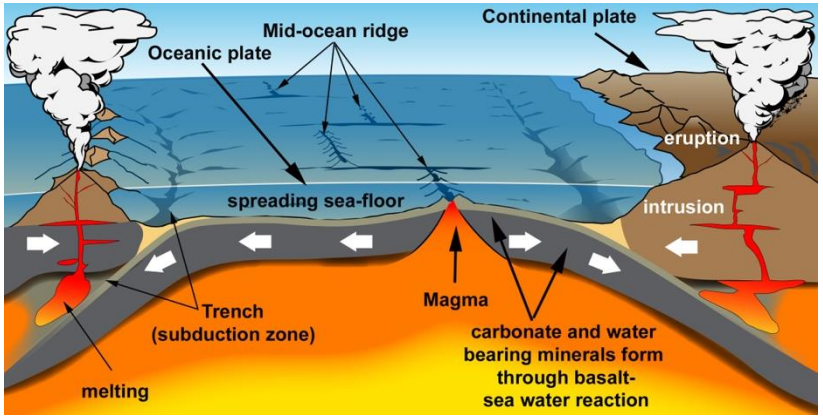
Radiogenic Heat production in Mantle is a key driver of rocky planet dynamics

Planet's Habitability Cool-Down

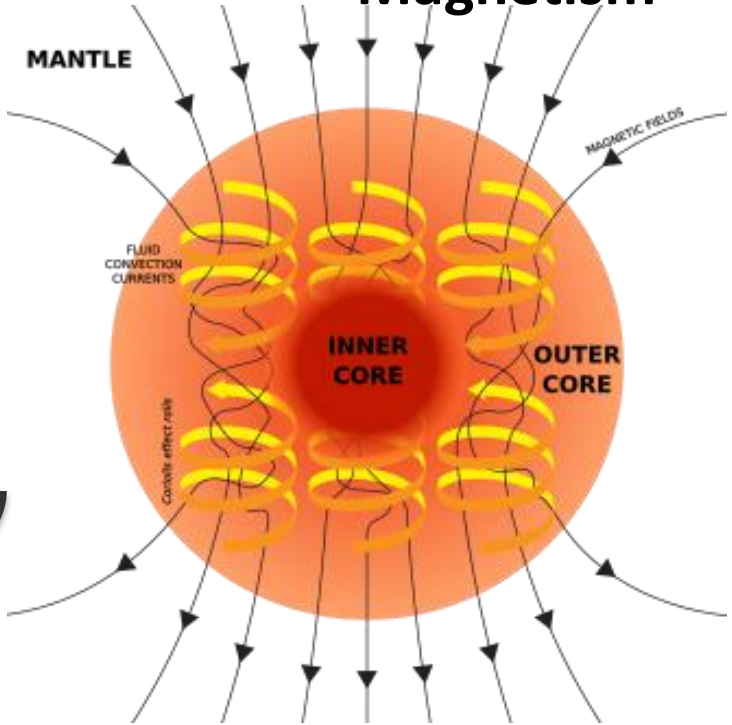


F. Nimmo eta l., Astro Jour Lett 903:L37 (2020)

Atmospheric-Evolution



Magnetism



CO_2 balance

Habitability

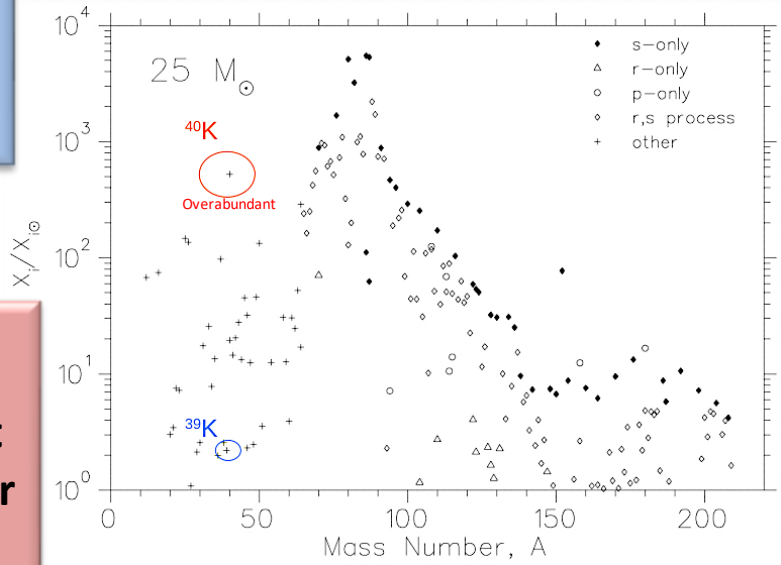
F. Nimmo eta l., Astro Jour Lett 903:L37 (2020)

HOW

How is ^{40}K produced?

s-Process Nucleosynthesis

$^{39}K(n,\gamma)^{40}K$



Type II Supernova

Rapid collapse and violent explosion of a massive star

$8M_{\odot} < M_{star} < 50M_{\odot}$

Oxygen burning under conditions of hydrostatic equilibrium

Explosive oxygen burning in Type II supernova

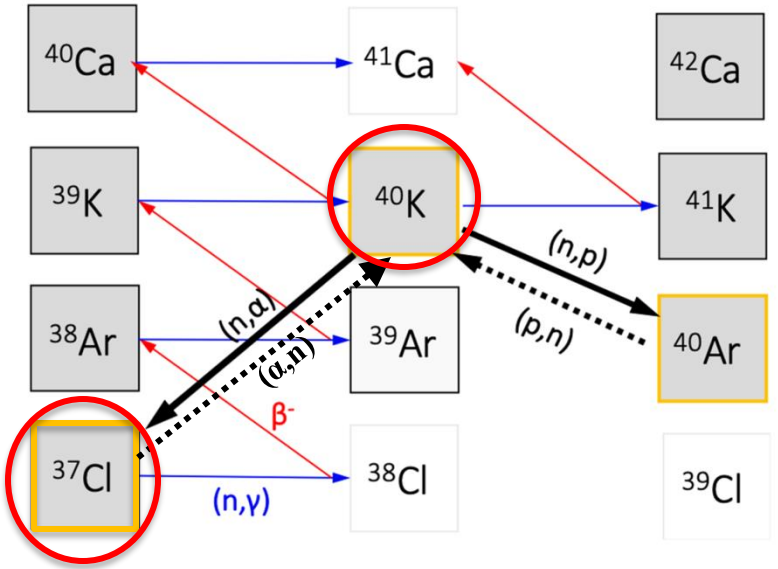
Explosive carbon burning in Stellar environments

$1.8 < T_9 < 2.9$

Timmes et al., AJS 98, 617 (1995)
The et al.
Samland, AJ 496, 155 (1998)

Destruction of ^{40}K

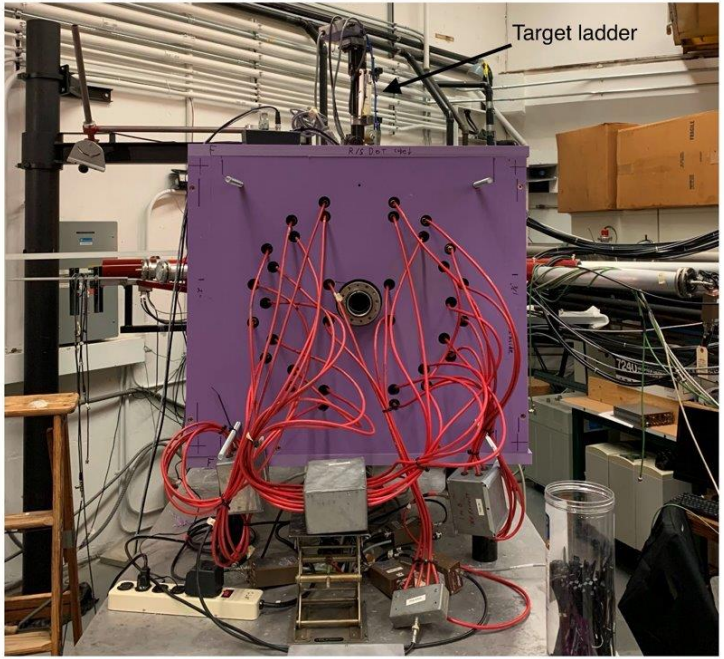
- Destroyed by $^{40}K(n,\alpha)^{37}Cl$ or $^{40}K(n, p)^{40}Ar$
- Easier to measure (p,n) and (α,n) and deduce (n,p) and (n,α)
- **<u>No experimental data for (n,α) destruction channel</u>**



R.D. Hoffmann et al.
P. Gastis et al.

Experimental Setup

- α-beam from 4.5 MV Tandem Pelletron at Edwards Laboratory, Ohio University.
- HeBGB is a 4π-polyethelyene-moderated detector
- 16 ^{3}He and 18 BF_3 proportional counters arranged into three concentric rings (4,14, and 16).

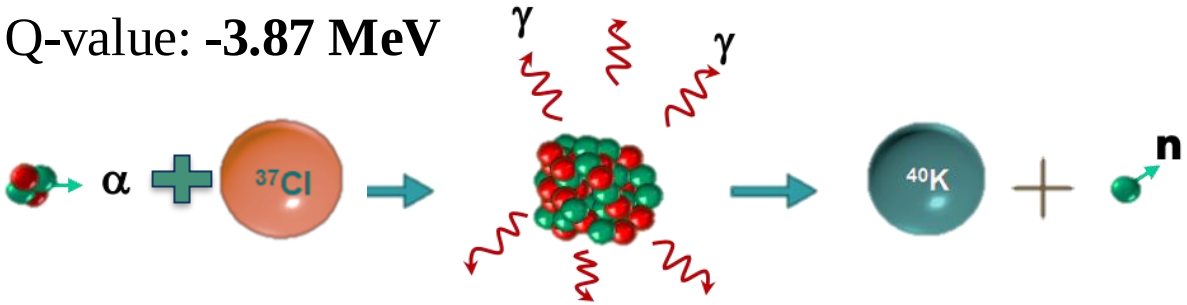


WHAT

The Reaction!!

$^{41}K^*$

Q-value: **-3.87 MeV**



$4.25\ \text{MeV} < E_{lab} < 5.80\ \text{MeV}$

Reaction Channels open at Experimental Energies

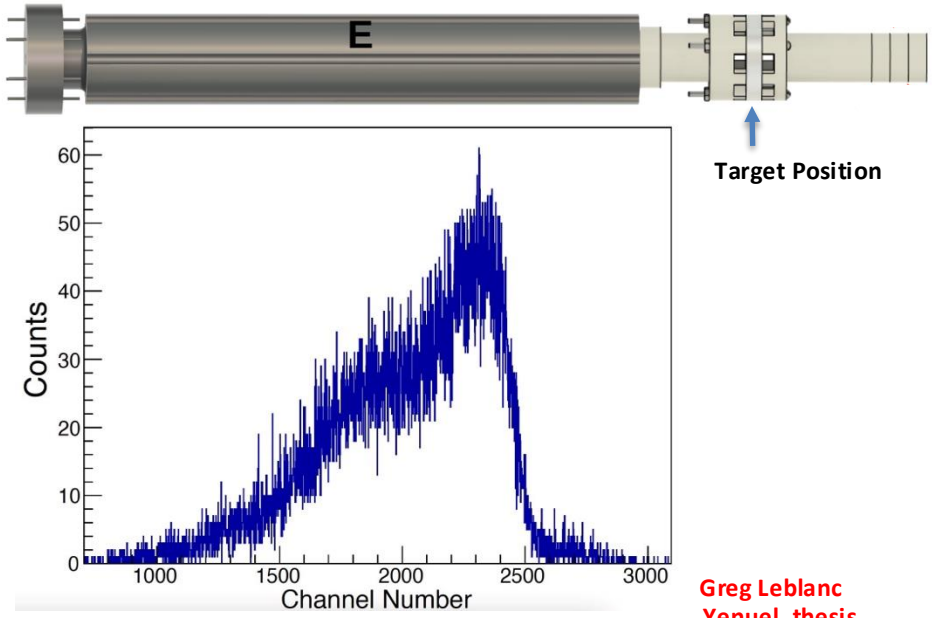
$^{37}Cl + \alpha$

(E_{lab} = 6000 keV)

Reaction Products	Q-Value (keV)	Threshold (keV)
$^{41}K + \gamma$	6222.91 *6*	0
$^{37}Cl + \alpha$	0	0
$^{40}Ar + p$	-1585.71 *5*	1745.50 *6*
$^{40}K + NN$	-3872.46 *8*	4262.68 *9*

Neutrons from HeBGB

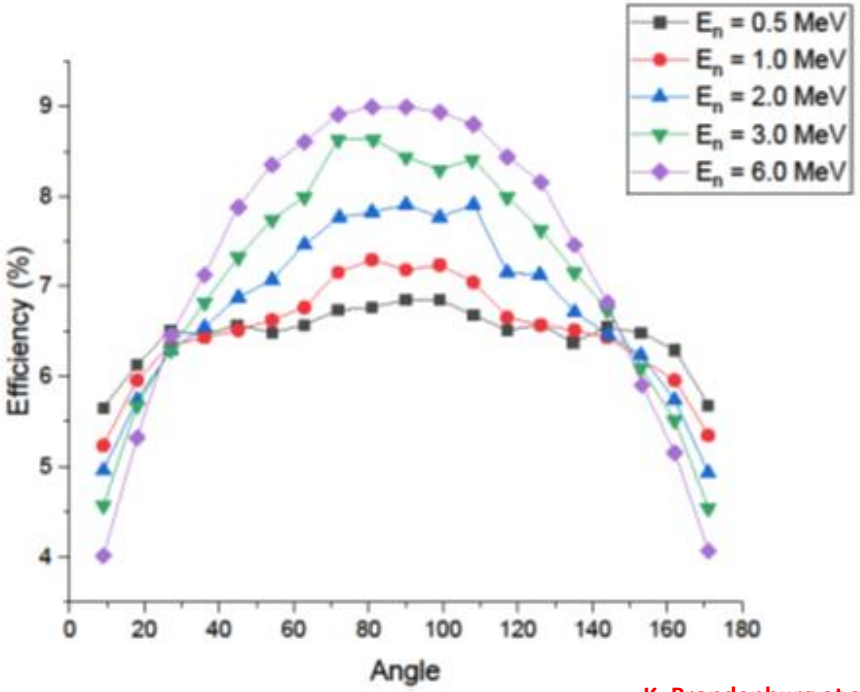
- To ensure that α-beam impinges only the target, HeBGB housed solid targets via a target insert mechanism.
- Neutrons produced by the $^{37}Cl(\alpha,n)^{40}K$ reaction are scattered by the polyethylene moderator and then detected via the $^{10}B(n,\alpha)^{7}Li$ and $^{3}He(n,p)^{3}H$ reactions.
- The integrated neutron counts from the pulse height spectra from each pre-amplifer signal provide information about angle-integrated yield.
- The yield from all the pre-amplifier signals is summed to obtain total neutron counts.



Greg Leblanc
Yenuel, thesis

HeBGB offers us…

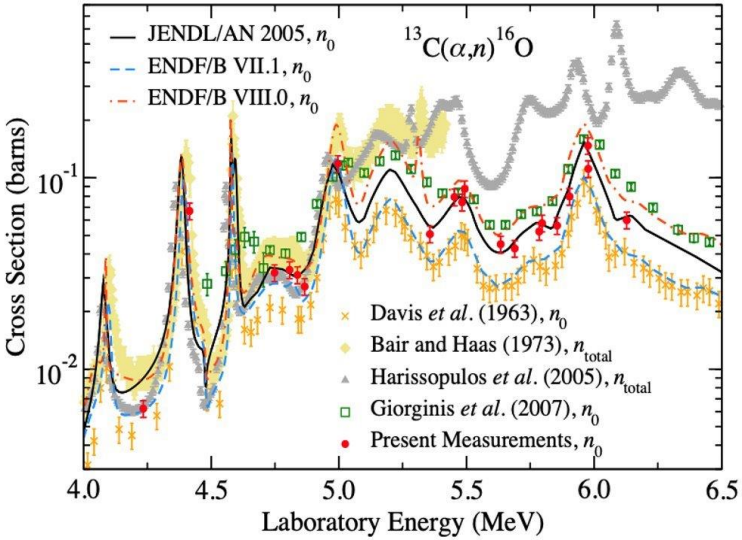
- A near-constant neutron detection efficiency of (7.5 ± 1.2)% over the energy range 0.01 MeV – 9.00 MeV.
- Removes significant source of systematic uncertainty in (α,n) cross section measurements.



K. Brandenburg et al.

Experimental Limitations

- Background measurements carried out with no target present in the target insert at the same experimental energies.
- The carbon cross-section from supplemental data was used to calculate cross-sections at energies of interest for background data.



K. Brandenburg et al.

The Statistical Model

Ingredients of a Hauser-Feshbach Calculation

- Optical Potentials
- Energy dependence of level densities
- J dependence of level densities
- Distribution of level densities

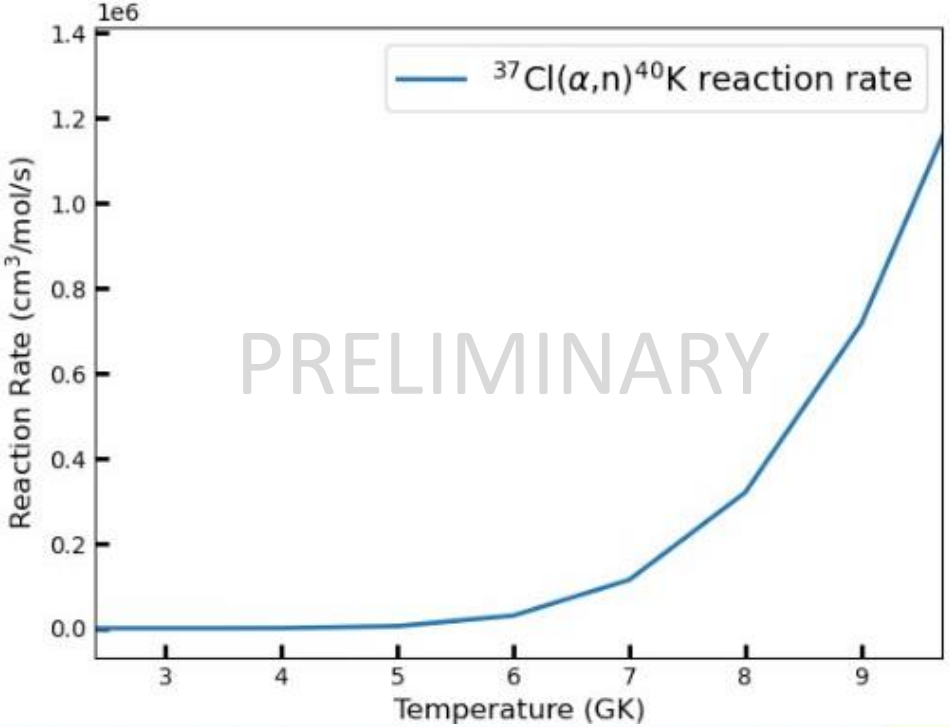
...

...

In practice, many adjustable parameters in the models.

- For n,p or n,a cross sections the **optical potentials are key**.

Reaction Rate



Future Plans

- Fine tune statistical model parameters to obtain a better fit.
- Constrain astrophysical reaction rate for the $^{40}K(n,\alpha)^{37}Cl$ reaction.
  - Using the **optimized potential values** which explains the experimental data for direct reaction.
  - Using **detailed balance**, we will extract the reaction rate for the destruction of ^{40}K via $^{40}K(n,\alpha)^{37}Cl$.
- Experimentally constraining relevant reaction channels responsible for the destruction of ^{40}K → Improved accuracy of astrophysical models for stellar evolution

List of Collaborators

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Thank You!

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