Astrophysics Task Force

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Numerous USNDP institutions are pursuing projects that are beneficial for studies in nuclear astrophysics

These activities include work on both nuclear reactions & nuclear structure

USNDP Contributors to this report

- Argonne National Laboratory
- Los Alamos National Laboratory
- McMaster University
- Oak Ridge National Laboratory

Argonne National Laboratory

F. Kondev & C.J. Chiara

Studies of ^{186m}Re

$^{187}Re/^{187}Os$ clock cosmochronometer to "date" the r-process

- Work continues on elucidating the structure of levels above the $K^{\pi}=8+$ isomer ($T_{1/2}$~10^5y) using $^{186}W(d,2n)$ data; (n,2n) cross section measurements campaign at the TUNL facility – led by the TUNL Nuclear Data group (J. Kelley)

- evaluation of ^{187}Re half-life (with A. Mengoni, IAEA)

Studies of thermal equilibrium of ^{176}Lu via K-mixing

(with A. Champagne, V. Gintautas and R. Longland – UNC at Chapel Hill & TUNL) – arXiv:0804.0223v1 [nucl-th]

Argonne National Laboratory

F. Kondev & C. J. Chiara

Decay data needs for Astrophysics

- development of Argonne Total Absorption Gamma-ray Spectrometer to study Gamow-Teller strength distributions in neutron-rich nuclei along the r-process nucleosynthesis path
- compilation and evaluation of such data in the region of neutron-rich fission products

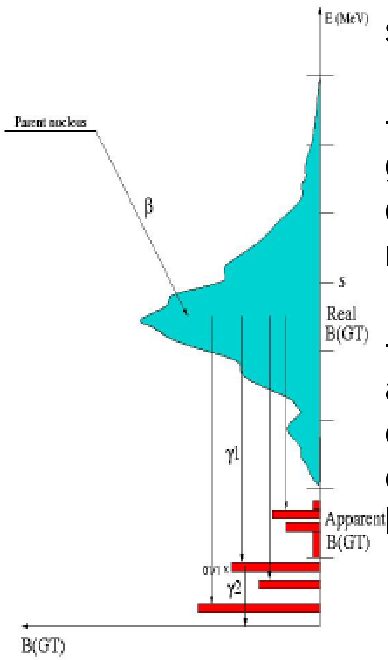
$$^{135}Sn : T_{1/2}^{\exp} = 530\,(20)\,ms$$

$$T_{1/2}^{calc} = 1833\ ms - QRPA\ (GT + ff)$$

$$T_{1/2}^{calc} = 8207\ ms - QRPA\ (GT)$$

K.L. Kratz et al., EPJ 2005

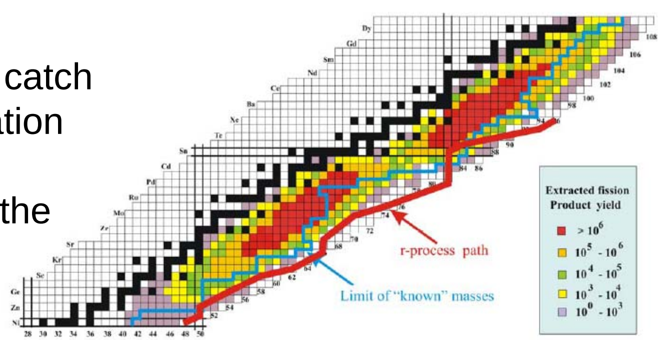
<u>Example</u>



- the large difference may be explained by decay into excited states [the blue region] and then subsequent gamma decays into lower lying states.

-if the lower lying states are detected but not the gamma rays into them, then it can appear as if the decay goes directly to the lower lying states, which will mess up the lifetime calculation.

- if you build a total absorption spectrometer, you catch all these gamma rays and then get a better indication of where the beta decays are going [in excitation energy], which then can give a better estimate of the lifetime.



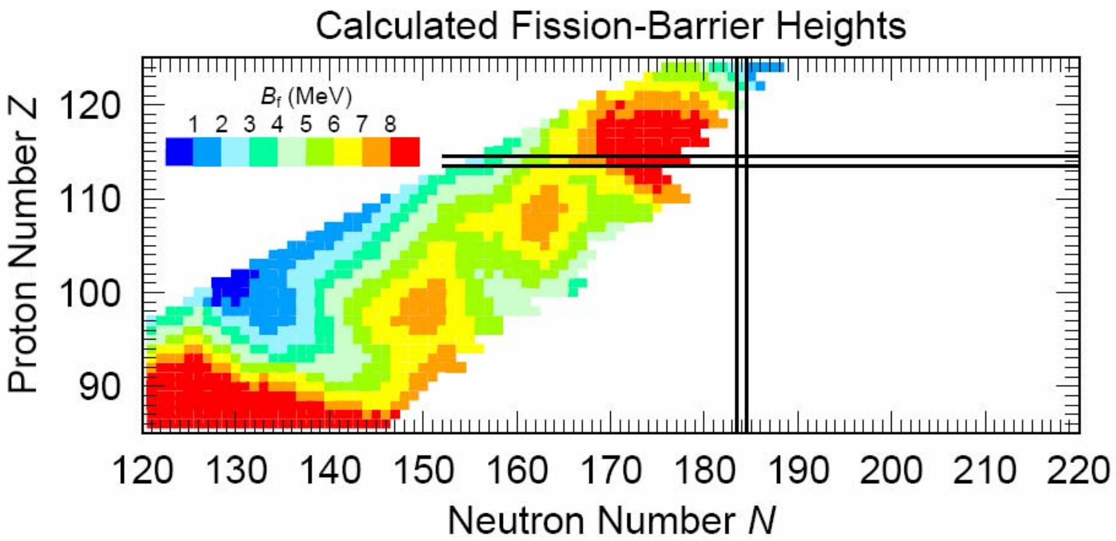
Los Alamos National Laboratory

P. Möller

Calculation of Fission Barrier of Heavy Elements

To model many astrophysical scenarios; for example to model the end of the rapid neutron-capture process (r-process) in which many heavy elements are formed in stars, it is necessary to know fission-barrier heights of a large number of nuclei. When a neutron is captured in the r-process it is energetically possible for the nucleus to fission if the neutron binding energy of the compound system is larger than the fission-barrier height.

www.lanl.gov/orgs/adtsc/publications/nw_highlights_2007/ch10/10_6moller.pdf



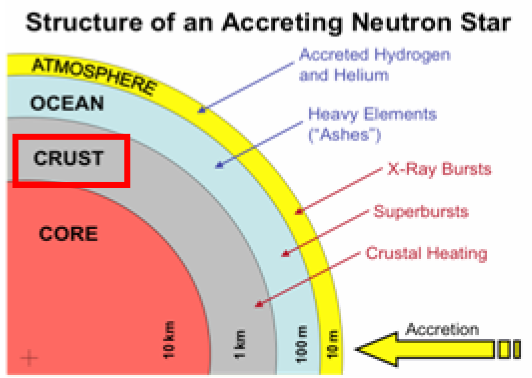
- Fission Barriers of 5254 nuclei calculated for elements between 170<A<330
- Several different parameterizations were used.
- e.g. 5D parameterization and for each nucleus, the energy is calculated for 5 000 000 different nuclear shapes

Results will be made available at http://t16web.lanl.gov/Moller/abstracts.html

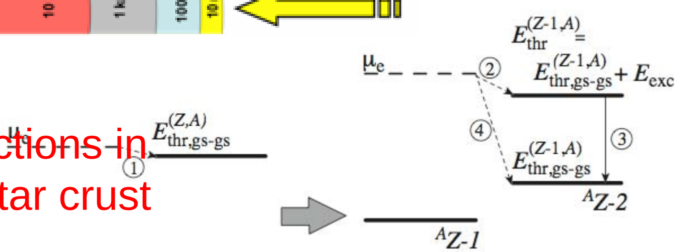
Los Alamos National Laboratory

S.Gupta

Improved Weak Rates lead to New Description of Neutron Star Crust Composition



weak reactions in neutron star crust



8 Gupta et al.

decays to excited states important

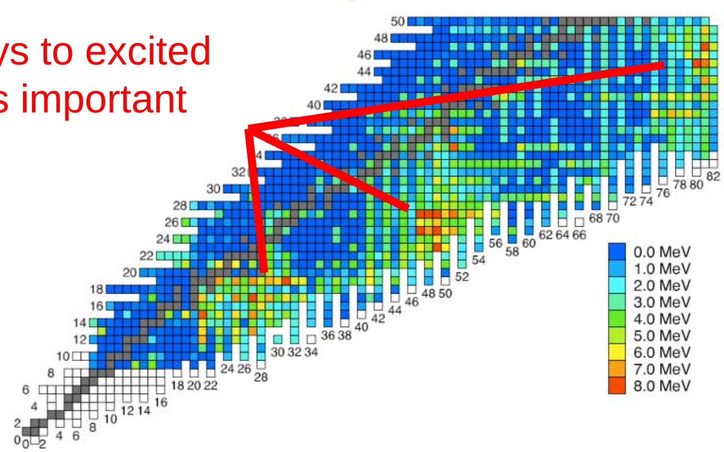


FIG. 6.— For each parent nucleus we show the excitation energy of the dominant state in the daughter nucleus populated by electron capture. Electron capture sequences passing through regions with high excitation energies in the daughter will result in increased heat deposition.

- For accurate NS Crust modeling - require EC and (EC,xn) rates on > 2000 nuclei
- New calculations [Peter Moller, LANL] of these rates for thousands of nuclei in the Neutron Star Crust
- Involves solving the Schrödinger Equation for the nuclear wave function in a *deformed 3D single-particle potential* (Folded-Yukawa) …crucial to determine the low-lying B(GT+) strengths correctly for astrophysical weak rates
- New Nuclear Input used for first calculation [S. Gupta, LANL] of large reaction network (1575 isotopes) in Neutron Star Crust with realistic initial composition and new (EC,xn) rates
- Nucleosynthesis pathway very different from single-species network which did not use EC to excited states and only had neutron emissions from g.s.
- can influence heating of neutron star crust -- gamma rays from decay of excited states deposit energy locally in crust [neutrinos carry it off]
- this can influence ignition of superbursts in the crust

McMaster University

A. Chen & C. Ouellet

Evaluation of Reactions for Nuclear Astrophysics

- Two reactions evaluated relevant to nuclear astrophysics: $^{40}Ca(\alpha,\gamma)^{44}Ti$ and $^{21}Na(p,\gamma)^{22}Mg$

- both evaluations closely tied to McMaster research in nuclear astrophysics [Alan Chen]

- rates submitted using the ORNL's Computational Infrastructure for Nuclear Astrophysics at **nucastrodata.org**

- both new rates represent an improvement over existing datasets

^{40}Ca(a,γ)^{44}Ti Evaluation

McMaster University
Inspiring Innovation and Discovery

- This reaction is critical to the production of radioactive ^{44}Ti in supernova during the alpha-rich freezout phase

- ^{44}Ti is one of the very few important radionuclides which can be detected in space [e.g., Cas A supernova remnant] - allows for an absolute supernova yield of nucleosynthesis

- Longstanding controversy over Cas A: calculations greatly underpredict the observed ^{44}Ti using the measured ^{40}Ca(a,γ)^{44}Ti reaction rate

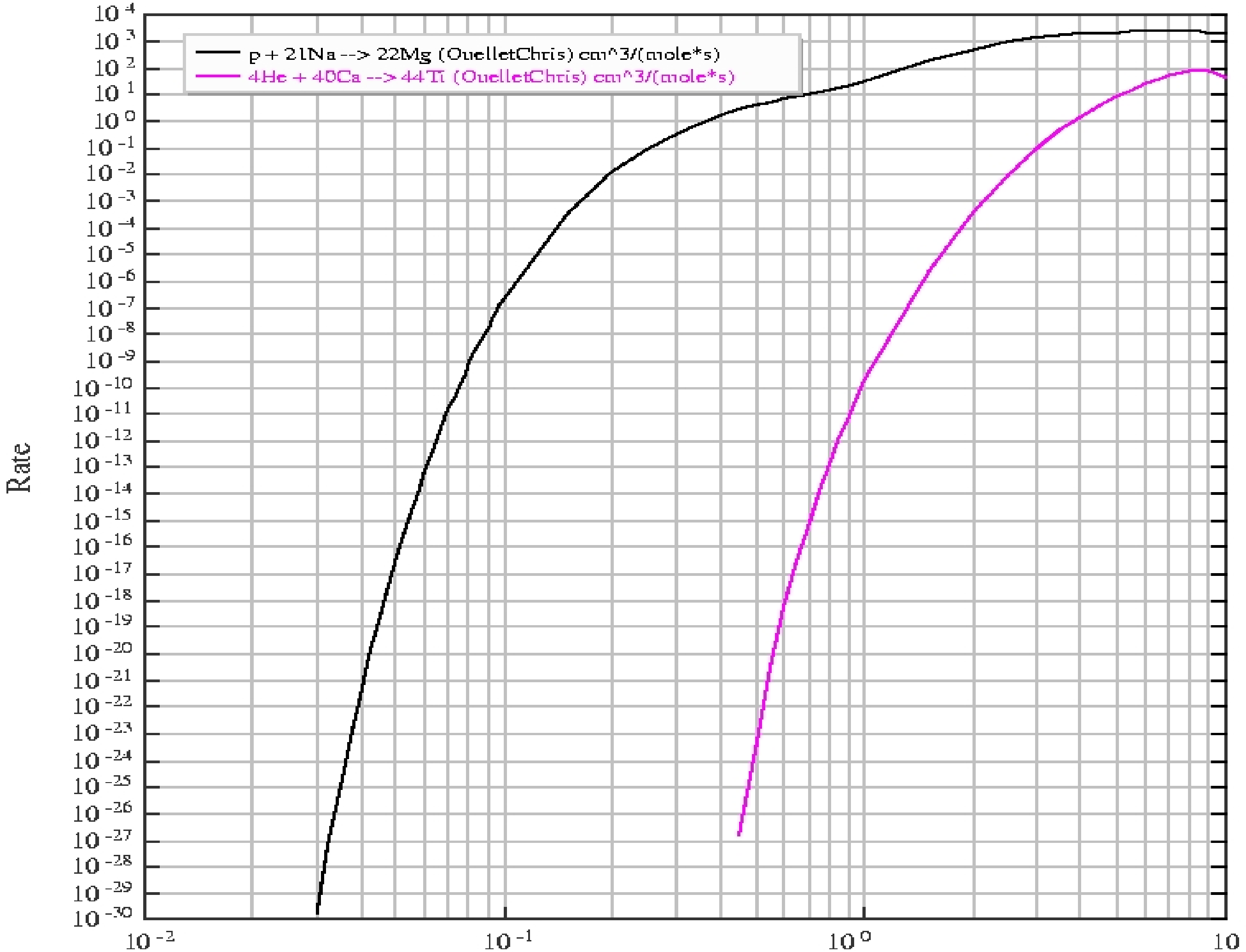
- Need a new rate combining all previous work:
  - early (1976-1981) γ-ray measurements for resonance strengths
  - Isreali (+Argonne) AMS technique (2001-2006) discovered greatly enhanced yield compared to earlier studies
  - Measurement at ISAC / DRAGON (2007) data found many previously unresolved resonances

- Now combined to give new rate from 1 – 7 GK

$^{21}Na(p,\gamma)^{22}Mg$ Evaluation

McMaster University
Inspiring Innovation and Discovery

- This reaction is very important in explosive hydrogen burning that occurs in novae and X-ray bursts as it impacts the abundance of ^{21}Na
- ^{21}Na like ^{44}Ti is also one of a handful of very important radionuclides which can be detected in space – but the decay of ^{22}Na has not yet been observed in space
- Many potential explanations proposed, including (2007) electron screening in the hot plasma environment to modify the reaction rate formalism … *or perhaps a new rate evaluation*
- Similar to the $^{40}Ca(\alpha,\gamma)^{44}Ti$ evaluation direct methods of measuring resonance strengths were favored in the evaluation
- Rate is dominated by two proton resonances, one at 206 keV which dominates Nova temperatures (~0.1 GK) and one at 825 keV which dominates above 1.1 GK


p + 21Na --> 22Mg (OuelletChris) cm^3/(mole*s)
4He + 40Ca --> 44Ti (OuelletChris) cm^3/(mole*s)
Rate
10 -2
10 -1
10 0
10 1

Oak Ridge National Laboratory
M.S. Smith & C.D. Nesaraja

Close Coupling of Measurements & Evaluation Projects

Reactions of Interest (all measured at ORNL)

$^{17}F(p,\gamma)^{18}Ne$ - nova and X-ray bursts
- resonance strength for astrophysically important 3^+ state in ^{18}Ne

$^{15}N(d,p)^{16}N$ - $^{15}N(n,\gamma)^{16}N$ important nucleosynthesis calculations in AGB stars
- spectroscopic factor
- cross sections extracted for the population of low lying states in ^{16}N

$^{31}P(p,\alpha)^{28}Si$ - influence of this reaction on the cyclic process in the Si-P mass range
- preliminary results for the resonance strengths

Level Assessments are in Progress

Software Data Projects

- Computational Insfrastructure for Nuclear Astrophysics (nucastrodata.org)

Streamline reaction rate evaluation activities with new Rate Evaluation Toolkit

New **online repository for sharing files**

Expanded and fitted KADONIS rates – now available in library and available to all

- Nuclear masses (nuclearmasses.org)

Launched to aid research in nuclear masses and to help facilitate a proposed new effort in nuclear mass evaluations

SHARE and **ACCESS** work with scientific community (experimentalist, theorist, evaluators)

VISUALIZE, ANALYZE & COMPARE mass datasets