Astrophysics Task Force

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

These activities include work on both nuclear reactions *and* nuclear structure

Recent Activities in

Compilations & Evaluations	ANL, LANL, McMaster, ORNL
Development of Evaluation, Processing, & Dissemination Tools	ORNL
Nuclear Theory	LANL

Compilations & Evaluations

ANL (F. Kondev)

- **Measured** and **Evaluated** levels in ^{186}Re that can modify the utilization of ^{187}Re - ^{187}Os abundances as a cosmochronometer to "date" the r-process

LANL (G. M. Hale)

- **R-matrix calculations** of p(n,γ) and ^{12}C(α,γ)^{16}O reactions which are important in many astrophysics studies

Compilations & Evaluations

McMaster (A. Chen)

- Focus on reactions involving **radioactive nuclei** important for **stellar explosions** - coupled to ISAC measurements
- * Reaction evaluations in progress: $^{13}N(p,\gamma)^{14}O$, $^{25}Al(p,\gamma)^{26}Si$, $^{18}Ne(\alpha,p)^{21}Na$, & $^{21}Na(p,\gamma)^{22}Mg$; others planned

ORNL (C. Nesaraja)

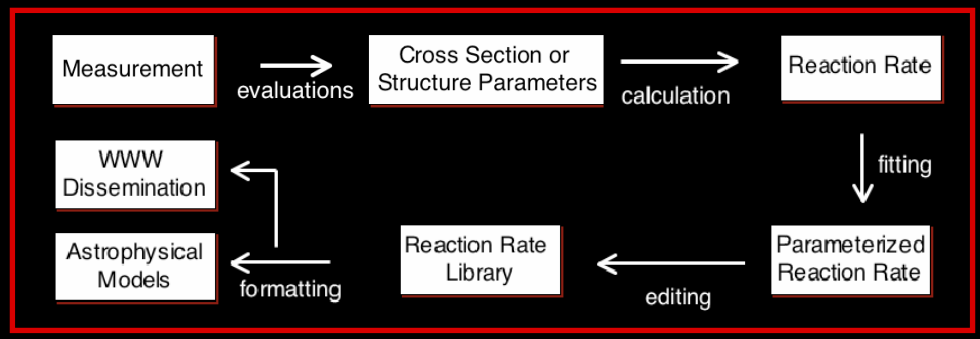
- Focus on reactions involving **radioactive nuclei** important for **stellar explosions** - coupled to HRIBF measurements
- * Reaction evaluations in progress: $^{18}F(p,\gamma)^{19}Ne$, $^{18}F(p,\alpha)^{15}O$, $^{30}P(p,\gamma)^{31}S$, $^{33}Cl(p,\gamma)^{34}Ar$ …

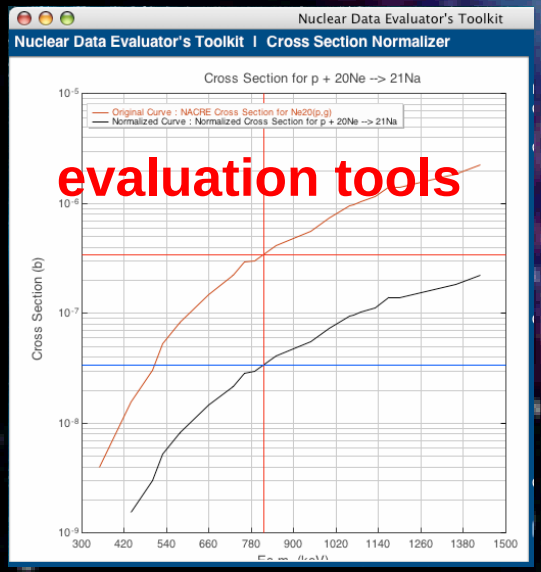
* All evaluations incorporating the **very latest experimental results**

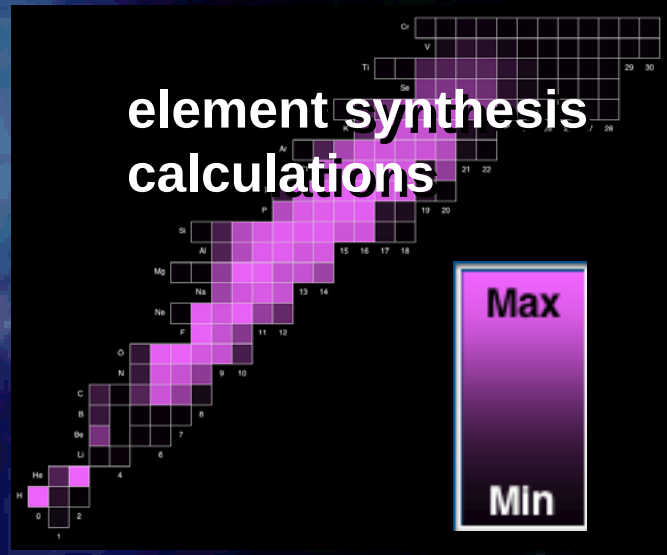
Results will be disseminated through **nucastrodata.org** & NNDC

Development of Evaluation, Processing, & Dissemination Tools

ORNL







Expansion of the **Computational Infrastructure for Nuclear Astrophysics** at nucastrodata.org to include nuclear mass models, reaction rate commenting, reaction flux animation, export of movie files, improved performance, and many other features

Nuclear Theory

LANL (T. Kawano)

- Calculation of $^{95}Zr(n,\gamma)^{96}Zr$ cross section

Important for heavy element synthesis in the slow neutron capture process in red giant stars

- Parameterization of Nuclear Level Density Systematics

(LANL - JAERI collaboration)

Important in calculations of reaction cross sections on unstable nuclei for use in r-process element synthesis

- Develop computer code for Direct Capture cross section calculations

Can help calculate rates on unmeasured reactions needed in astro simulations

Nuclear Theory

LANL (P. Moller)

- Calculation of fission barriers for 3000 nuclei with A>190

  Important for determining influence of fission on the r-process nuclei from the proton drip line to the neutron dripline

- Calculation of shape isomers (oblate/prolate, spherical/prolate…) for 7206 nuclei

  Help understand structure of nuclei off stability for explosive burning in stars

- Calculation of log(ft) values for electron capture on excited states in (neutron-rich and stable) nuclei

  Help understand weak interactions that play a crucial role in the evolution and explosion of stars

  In collaboration with MSU

Summary

- Progress in understanding many **astrophysical phenomena requires improved nuclear data**

- Interesting, Important Astrophysics Projects involving
  - Structure & Reaction work
  - **Evaluations, Disseminations, Tool development, Nuclear Theory**
  - Multiple laboratories ANL, LANL, McMaster, ORNL

- **New computational infrastructure** at **nucastrodata.org** now online to incorporate this information into astro models

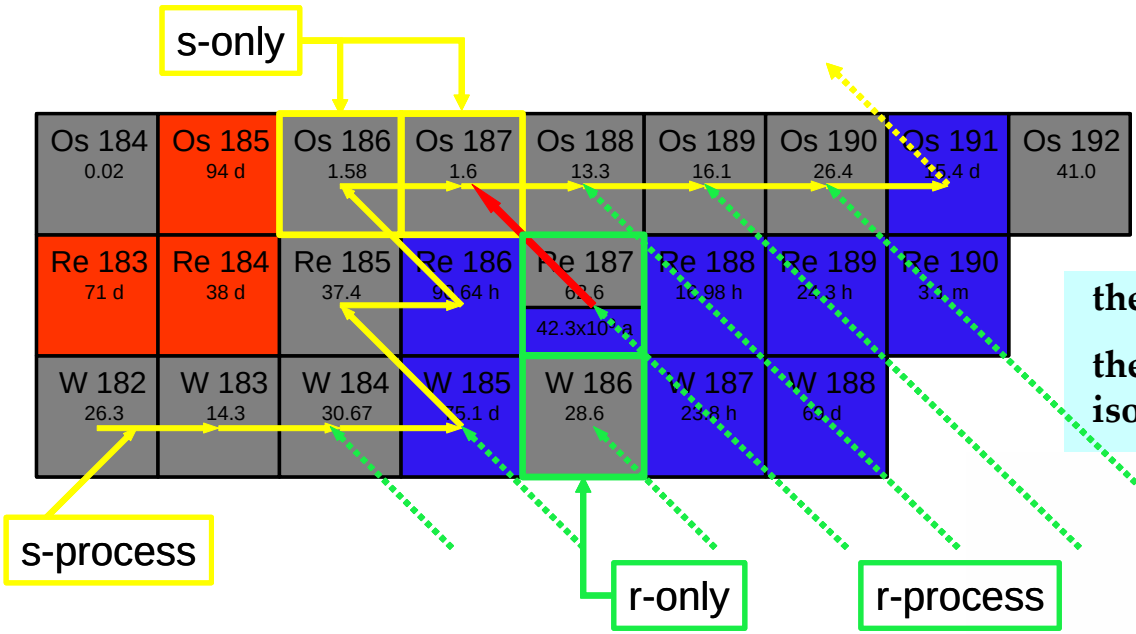
Supplemental Slide

ANL: Studies of ^{186}Re of relevance for astrophysics

F. Kondev

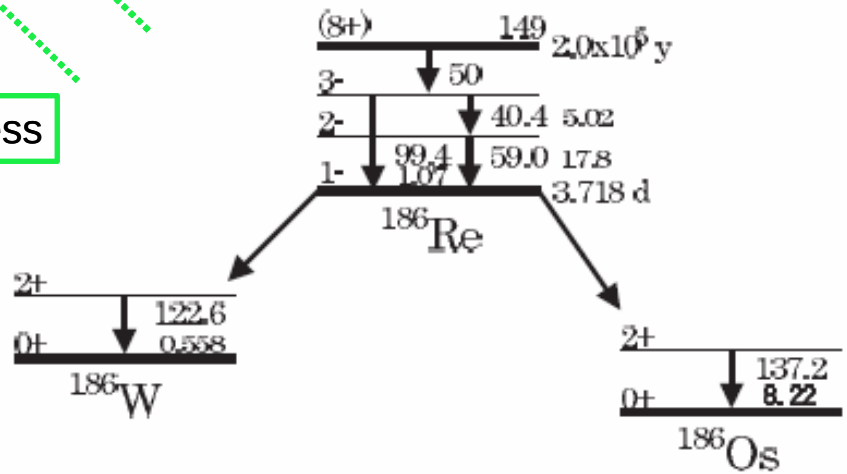
^{187}Re-^{187}Os cosmochronometer can be used to date the r-process

D.D. Clayton, Ap.J. 139 (1964) 637.



the existence of long-lived isomeric state

the production & destruction CS for the isomer are poorly known, but badly needed!



Activation Technique

- ✓ difficult owing to the long $T_{1/2}$
- ✓ $T_{1/2}$ - only one measurement without uncertainty

T. Hayakawa et al., Ap.J. 628 (2005) 533.

Using prompt γ–ray technique following n-capture, as recently demonstrated for ^{239}Pu(n,2n)^{238}Pu

L.A. Bernstein et al., Phys. Rev. C 65 (2003) 021601(R)

What is needed – detailed knowledge of the ^{186}Re levels above the isomer!

Supplemental Slide

ANL: Studies of ^{186}Re of relevance for astrophysics

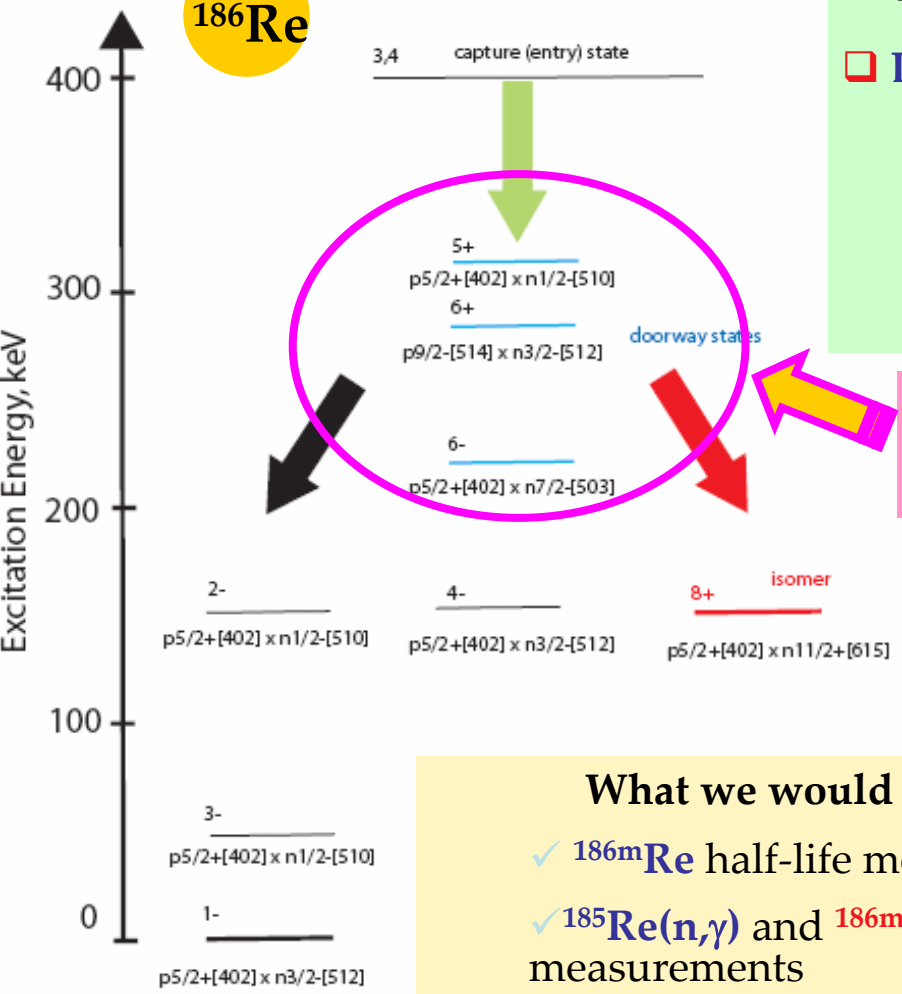
F. Kondev

New Measurements

- using ^{186}W(d,2n) at ANU & γ–ray coin. technique
- DC beam & CAESAR array – 9 CSS Ge & 2 LEPS
  - ✓excitation functions from 12 MeV to 18 MeV
  - ✓γ–γ coin. at 12 MeV (near the barrier) – only a few channels are open – identification of ^{186}Re
  - ✓γ–γ coin. at 14 MeV to enhance population of the isomer

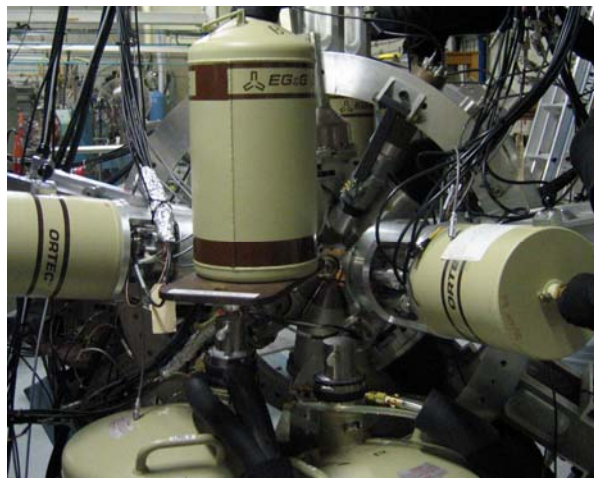
"doorway" states above the isomer have been discovered and characterized!

Deformed shell-model calculations



What we would like to do next?

- ✓ ^{186m}Re half-life measurements
- ✓ ^{185}Re(n,γ) and ^{186m}Re(n,γ) cross-section measurements

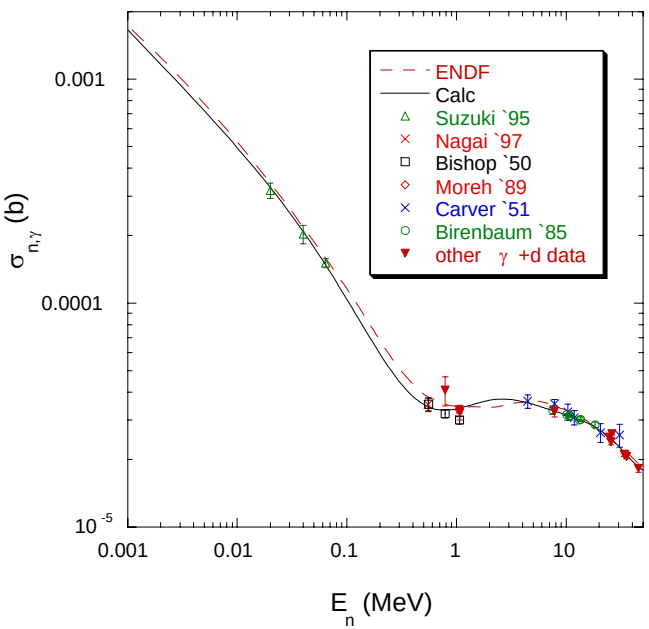


Supplemental Slide

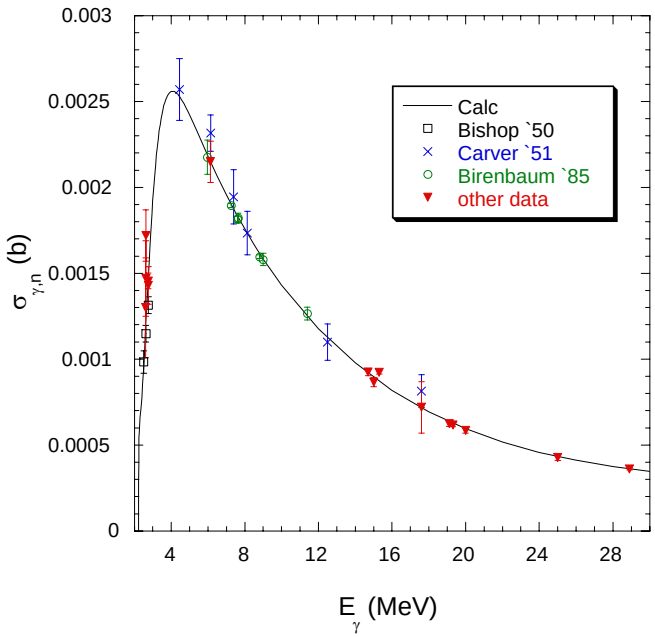
G.M. Hale

LANL: n-p Capture Evaluation

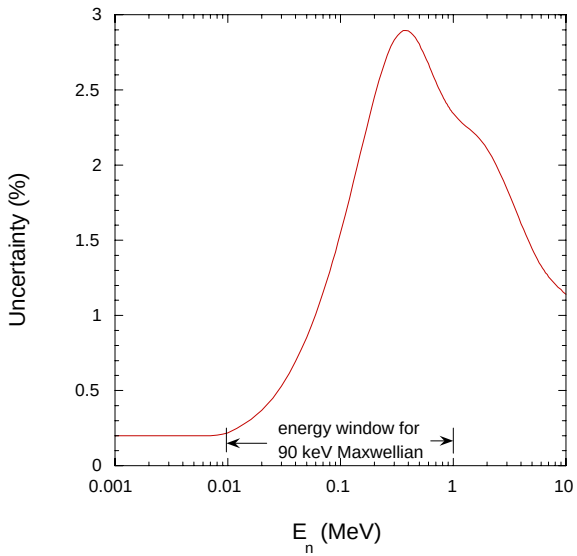
p(n,γ)d Cross Section



d(γ,n)p Cross Section



n-p Capture



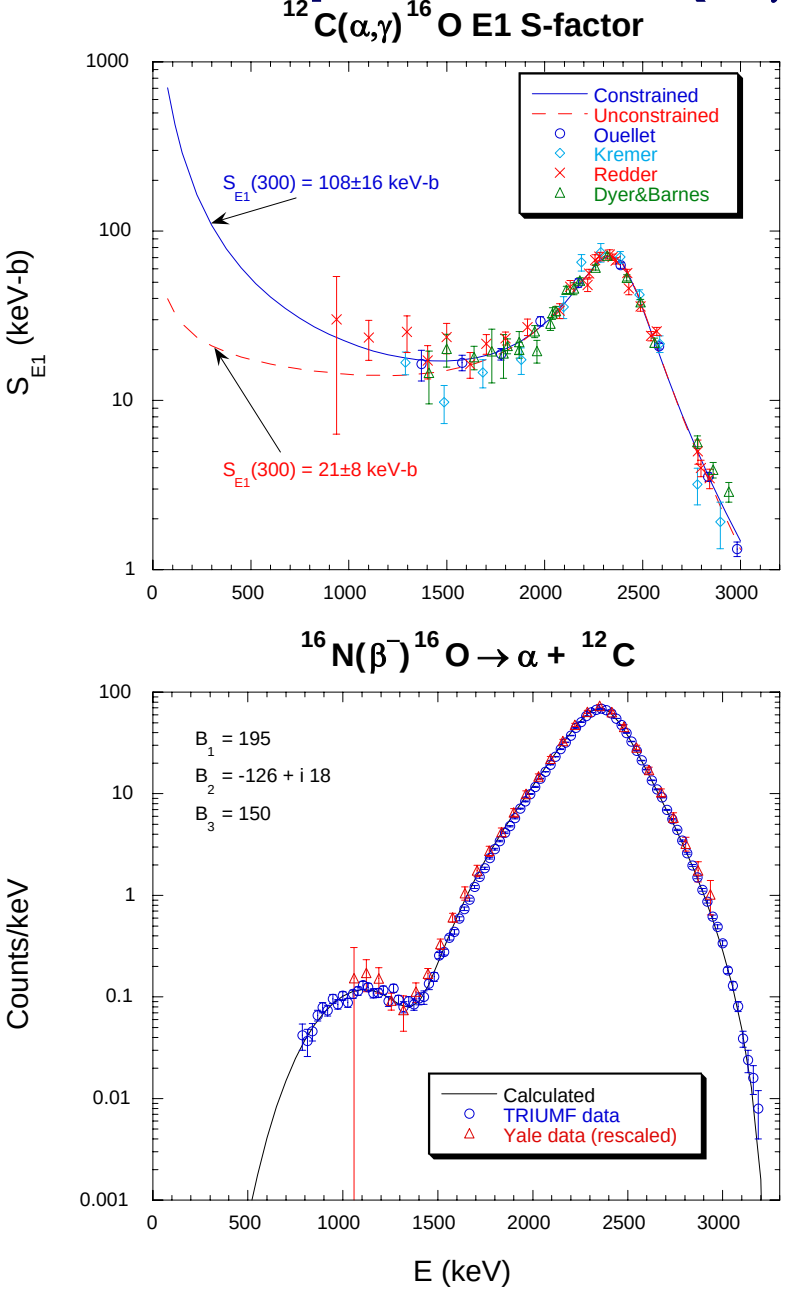
Data are shown above both as $p(n,\gamma)$ and $d(\gamma,n)$.

Calculated uncertainty for $p(n,\gamma)$ is shown at the left.

Supplemental Slide

LANL: Update of $^{12}C(\alpha,\gamma)^{16}O$ Analysis

G.M. Hale



- Uses new photon-channel prescription
- Includes elastic scattering data of Plaga, E1 capture data
- Unconstrained: $\gamma_{1\gamma}$ fixed in -45 keV level by $\Gamma_{1\gamma}$ = 0.05485 eV.
- Constrained: $|\gamma_{1\alpha}|$ fixed in -45 keV level by $C^2 = (4.33 \pm 0.84) \times 10^{28}$ fm^{-1} measured by Brune et al. [PRL **83**, 4025 (1999)]
-
- Spectrum from the β-delayed α-decay of ^{16}N looks reasonable; height of first maximum determines the combination $B_1|\gamma_{1\alpha}|$.

Supplemental Slide

McMaster: Evaluations for Astrophysics

- Personnel: A. Chen (McMaster faculty)
  J. Pearson (postdoc, part-time)

- Reactions evaluated: $^{25}Al(p,\gamma)^{26}Si$ and $^{13}N(p,\gamma)^{14}O$

  - Additional ongoing evaluations: $^{21}Na(p,\gamma)^{22}Mg$ and $^{18}Ne(\alpha,p)^{21}Na$

  - Planned evaluations: $^{26}Al(p,\gamma)^{27}Si$ (new data in 2005 from TRIUMF-ISAC)
    $^{40}Ca(\alpha,\gamma)^{44}Ti$ (new data in 2005 from TRIUMF-ISAC)

  - New reaction rates will be disseminated through the new ORNL computational infrastructure at www. nucastrodata.org.

Supplemental Slide

McMaster: Evaluation of the $^{25}Al(p,\gamma)^{26}Si$ reaction rate

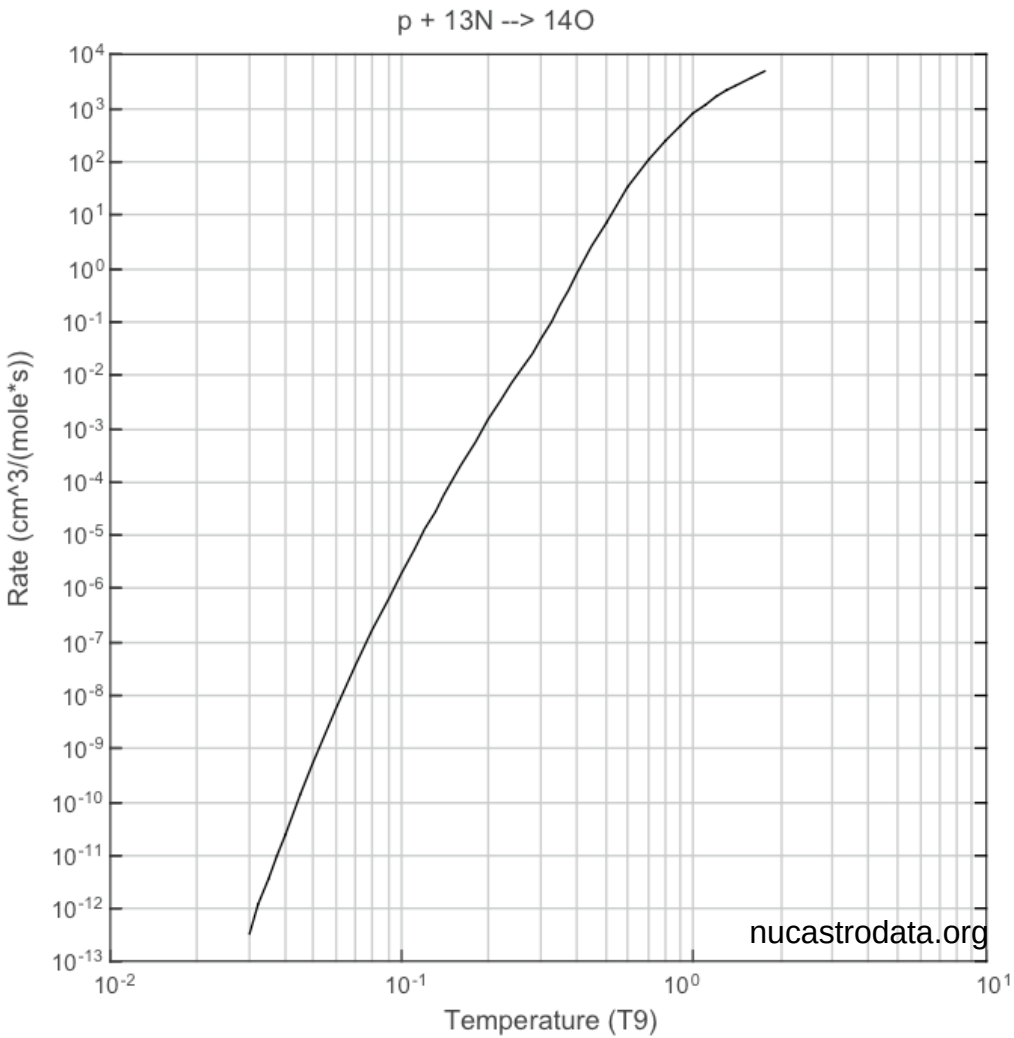
A. Chen

- Critical rate in the production of galactic ^{26}Al in nova explosions.
- Incorporated recent data from various transfer reaction studies (e.g., (p,t) at ORNL, (^{3}He,^{6}He) at Yale University, and (^{3}He,n) at Ohio University).
- **Evaluation will continue** as new results on this reaction become available from TRIUMF-ISAC and other laboratories, including a planned direct measurement of the cross section at ISAC.

Supplemental Slide

McMaster: Evaluation of the $^{13}N(p,\gamma)^{14}O$ reaction rate

A. Chen



- Important in the breakout from the CNO cycles to the Hot-CNO cycles in novae and X-ray bursts.

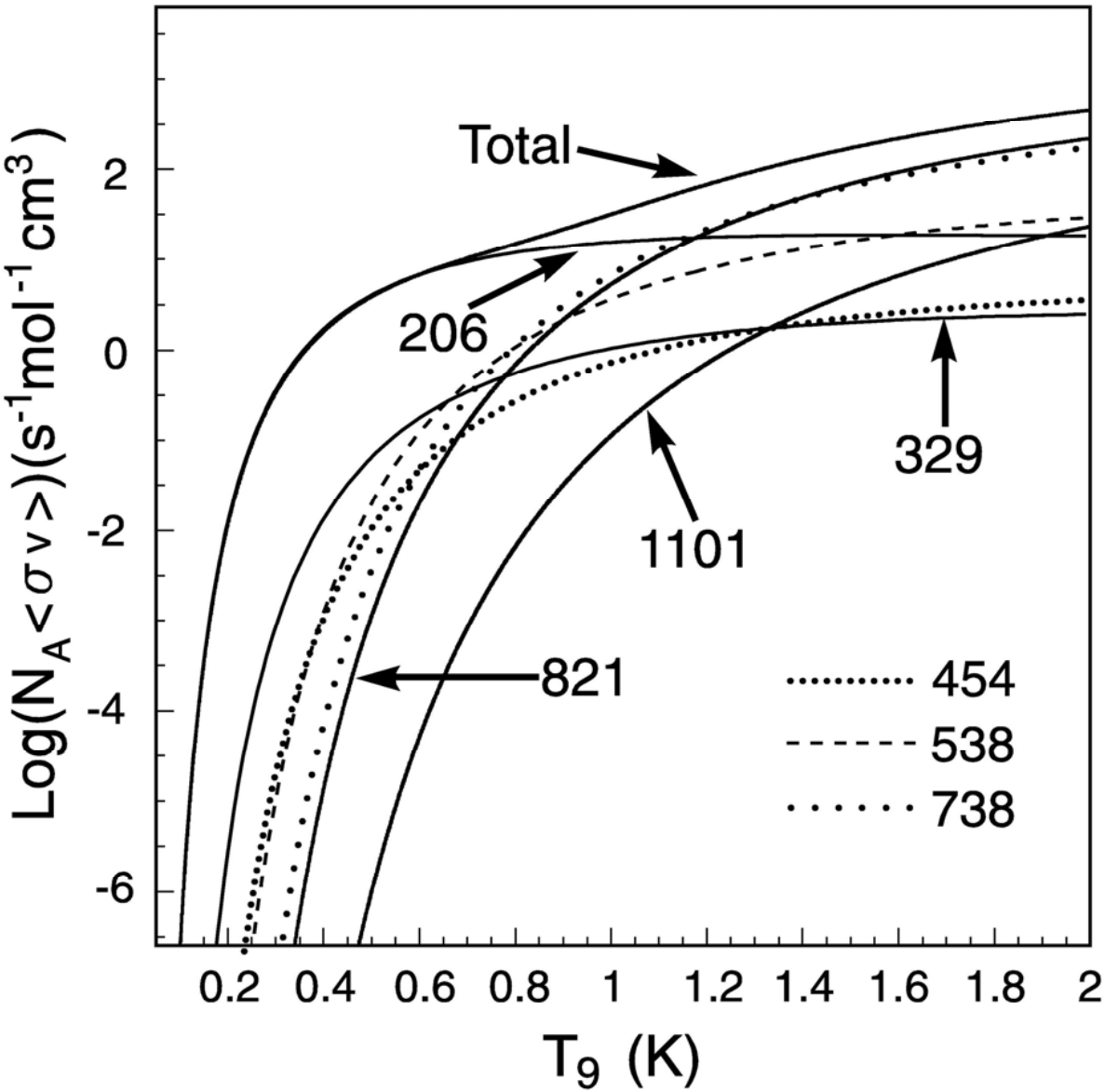
- Incorporated all data on this reaction to date.

- New direct measurement of the reaction rate is planned at TRIUMF-ISAC.

Supplemental Slide

McMaster: Evaluation of the $^{21}Na(p,\gamma)^{22}Mg$ reaction rate

A. Chen



$^{21}Na(p,\gamma)^{22}Mg$ reaction rate based on recent ISAC results (D'Auria et al. PRC 2004)

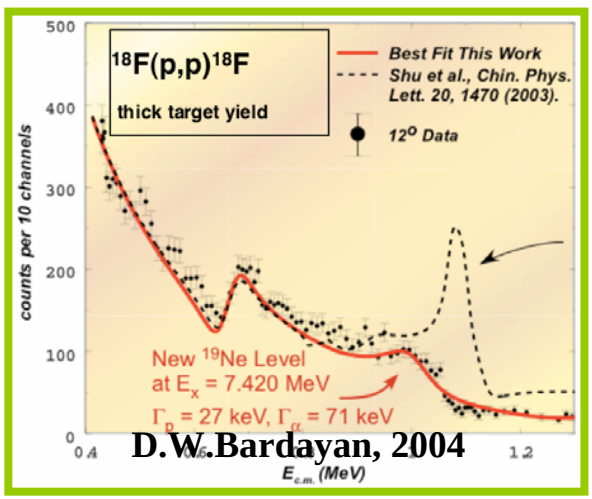
Resonance energies in keV

Supplemental Slide

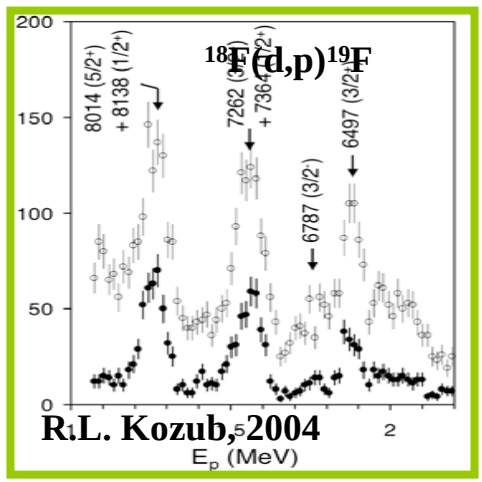
ORNL : Evaluation of $^{18}F(p,\alpha)^{15}O$ & $^{18}F(p,\gamma)^{19}Ne$

C. Nesaraja

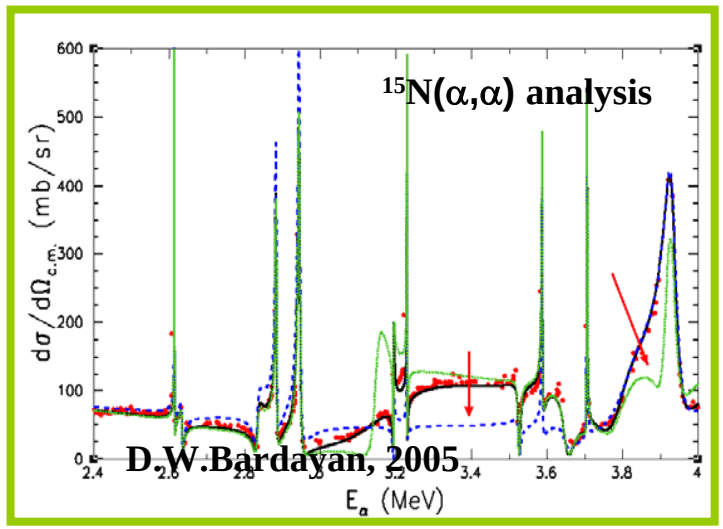
- Important for novae & X-ray bursts
- Many experiments performed with radioactive beams require new evaluations
- New evaluation of ^{19}F levels from the legacy of $^{15}N(\alpha,\alpha)$ data



D.W.Bardayan, 2004



R.L. Kozub, 2004



D.W.Bardayan, 2005

Supplemental Slide

C. Nesaraja

Detailed nuclear structure information for ^{19}Ne
~ 30 levels between E_x= 6.411 -8.100 MeV

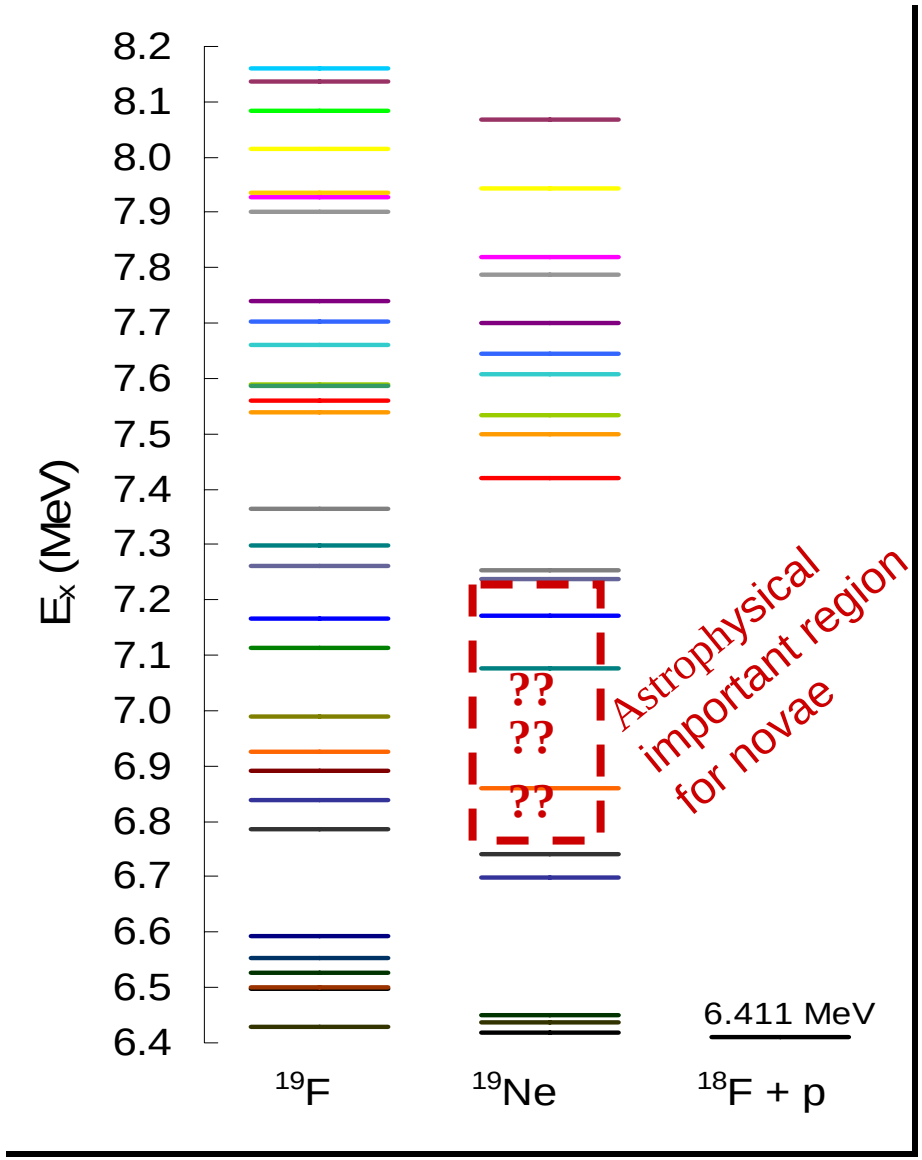
Excitation energies for missing levels
(scaled using Thomas-Ehrman shift calculations)

spin and parity assignments
(angular momentum transfer or J^{π} of mirror nuclei)

Partial gamma widths $\Gamma\gamma$
(corrected for phase space &
reduced transition probability
for $\Gamma\gamma$ of mirror nuclei)

Partial proton widths Γp
(spectroscopic factor and using a diffuse surface potential or by direct measurements)

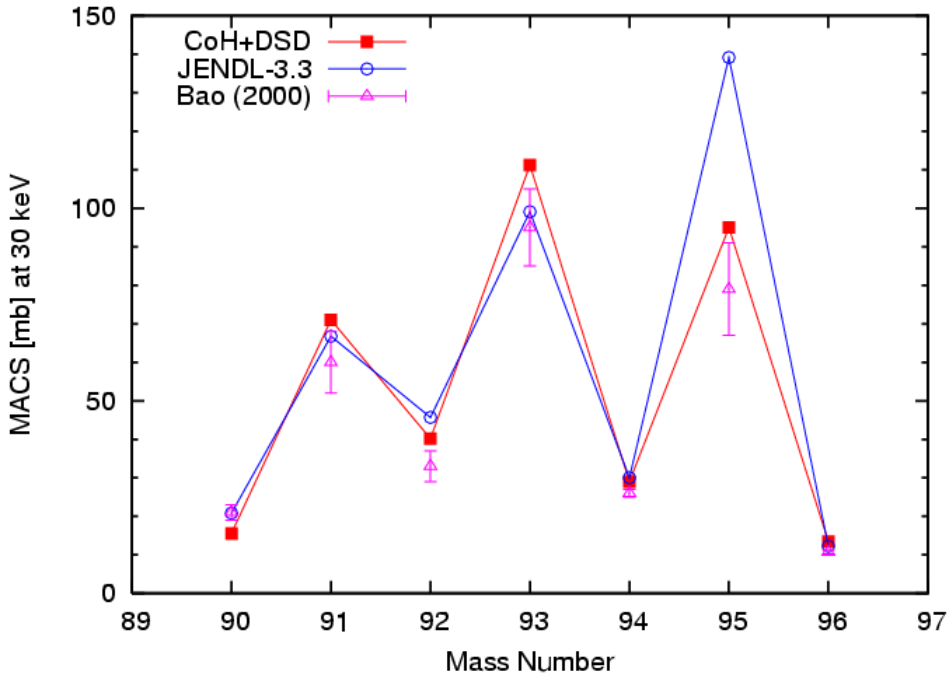
Partial alpha widths $\Gamma\alpha$
(assuming analog states have same reduced widths & correcting for the Coulomb barrier penetration)



Supplemental Slide

LANL: Nuclear Theory

T. Kawano



Calculation of $^{95}Zr(n,\gamma)^{96}Zr$ cross section based on new experimental data for $^{90,91,92,94}Zr$ and systematics of nuclear model parameters (with R. Reifarth & F. Herwig of LANL)

Important for heavy element synthesis in the slow neutron capture process in red giant stars

Supplemental Slide

LANL: Nuclear Theory

T. Kawano

Parameterization of phenomenological Nuclear Level Density using shell & pairing energies of KTUY05 mass formula
(LANL - JAERI collaboration)

- Important in calculations of reaction cross sections on unstable nuclei for use in r-process element synthesis

Develop computer code for Direct Capture cross section calculations

- Using DSD theory with Hartree-Fock BCS calculations for bound state wave functions
- Can help calculate rates on unmeasured reactions needed in astro simulations

Supplemental Slide

LANL: Nuclear Theory

P. Moller

Calculation of fission barriers for 3000 nuclei with A>190

Important for determining influence of fission on the r-process

nuclei from the proton drip line to the neutron dripline

use a 5 dimensional 3 quadratic surface parameterization of nuclear shapes

goals: determine optimum saddle point for each nucleus and, later, complete potential structure

developed highly automated procedures to interpret the widely-varying calculated surfaces.

Calculations are set up as 15 production jobs (different regions of the N/Z plane), each takes ~10 days with 30 500MHz computers

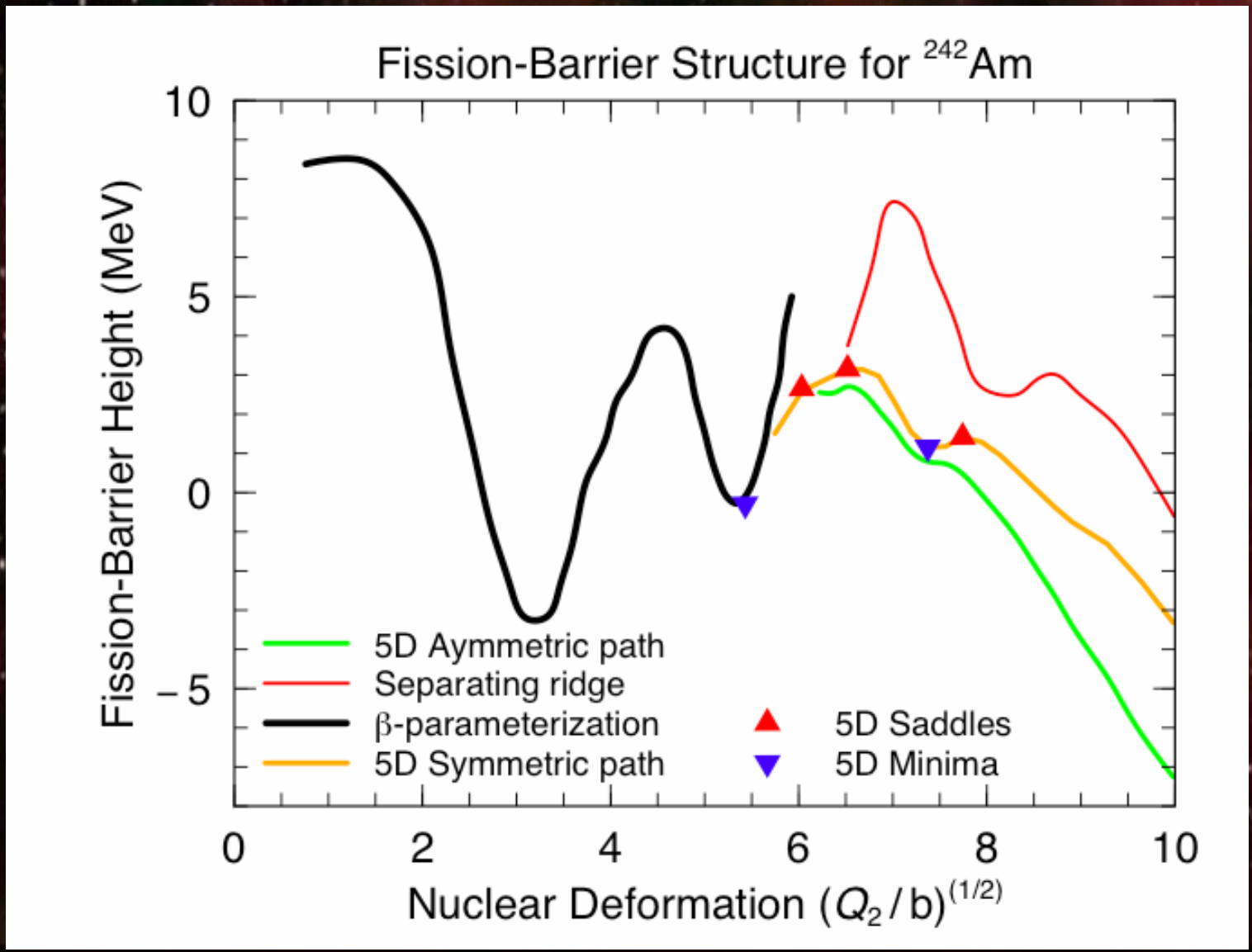
Exciting result: for U and Pu there is a region of low fission barriers (around 4 MeV) around A=260

Supplemental Slide

LANL: Nuclear Theory

P. Moller

Calculation of fission barriers for 3000 nuclei with A>190



LANL: Nuclear Theory

P. Moller

Calculation of shape isomers (oblate/prolate, spherical/prolate…) for 7206 nuclei

Help understand structure of nuclei off stability for explosive burning in stars

Develop classification of shapes and shape-isomer types (oblate-prolate, triple…) for global N/Z plots

Will compare to experimental data and will publish in ATNDT