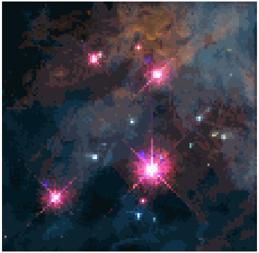

Reaction modeling and evaluation for astrophysics

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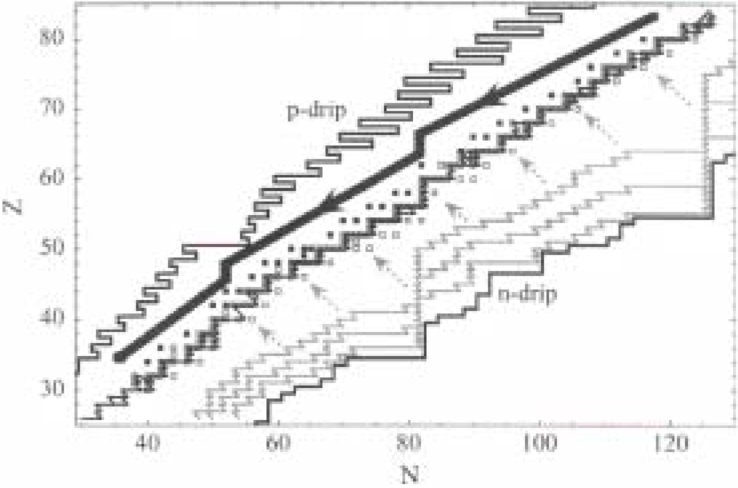
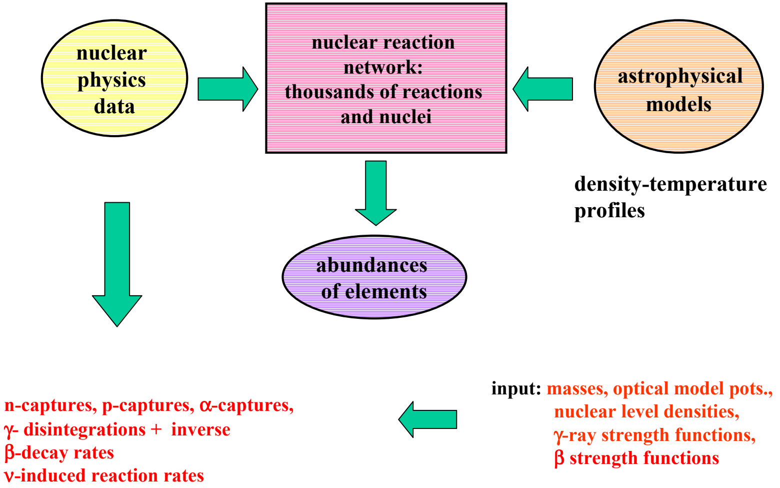
CSEWG Workshop, 3-7 Nov. 2003


p-drip
n-drip
Z
N
30
40
50
60
70
80
40
60
80
100
120

Nuclear astrophysics



GLOBAL models for Large-Scale Calculations

Nuclear Astrophysics Data

BRUSLIB: the Brussels Nuclear Library for Astrophysics Applications

- NACRE: The European Nuclear Astrophysics Compilation of Reaction Rates (A<30)

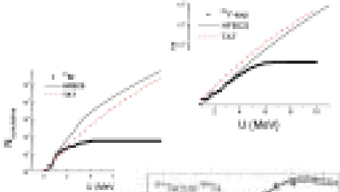
  - Nuclear level densities – (energy and spin dependence)
  - Hauser-Feshbach rates – (n-, p-, α-captures)
  - b-decay properties - (β-decay properties)
  - Masses – nuclear structure (deformations,charge radii,masses,fission barriers)
  - Partition functions – (Nuclear Partition Functions)

Microscopic Models

- **masses**

HF-BCS 2001 (738 keV)
HFB 2002 (660 keV)

using Skyrme-type + δ-pairing force fitted to 2000 masses



- **nuclear level densities**

HF-BCS 2001

g.s. deformation:renormalized to low-lying states and s-neutron spacings

- **γ-strengths**

HF-QRPA 2002 (300 keV)

using Skyrme force+spherical QRPA HF-BCS and HFB method

- **optical model potentials**

N: Jeukenne etal., 1977
Bauge etal., 2001

nuclear matter+effective M3Y force+LDA fitted to extended data base

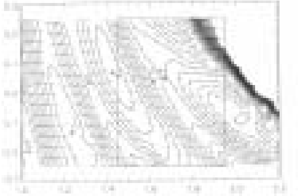
α: Demetriou etal., 2002

double-folding real part + Fermi-type energy-dependent imaginary

- **fission barriers**

ETFSI 2001
HFB 2003

3-dimensional energy surface {Q,O,H} + flooding method



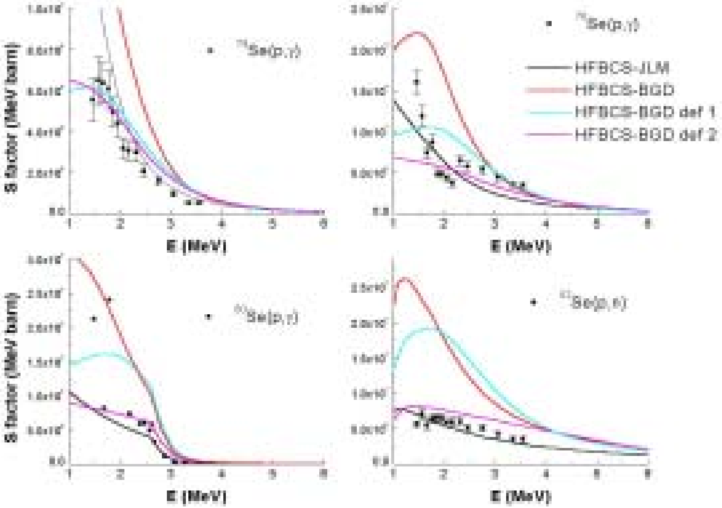
- **β-decay strengths**

ETFSI-cQRPA

694 spherical and slightly deformed short-lived nuclei from Fe to U

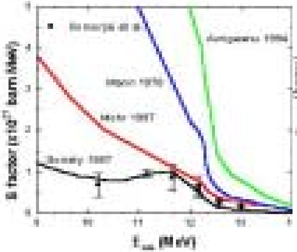
Nucleon Optical Model Potential

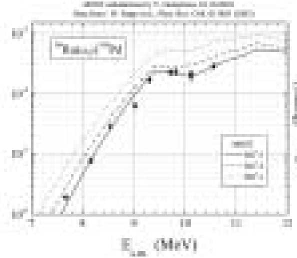
- Bauge, Delaroche, Girod, PRC 64 (2001) – up to 200 MeV
  JLM + Improved LDA + $(\lambda_V(E), \lambda_W(E), \lambda_{V1}(E), \lambda_{W1}(E))$

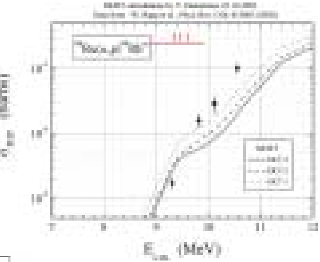


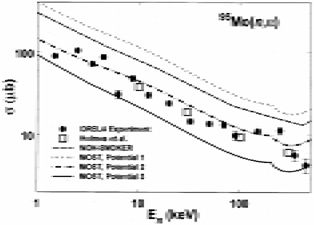
α- Optical Model Potential

- Real part : Double- folding (Kobos et al. 1984)
- Imaginary part W: Woods-Saxon $W = W(E) / (1+\exp(r-r_W)/a_W)$
  Fermi-type energy dependence $W(E) = J_0/(1+\exp(E^* - E)/a^*)$









Fission

- fission barriers (flooding method on PES)

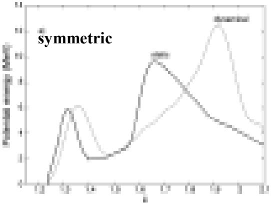
(large scale calculations) **ETFSI (SkSC4 force)**
- → mass tables (Aboussir etal 1995; RIPL2 2002)
- → fission barriers (Mamdouh etal 2001; RIPL2 2002)

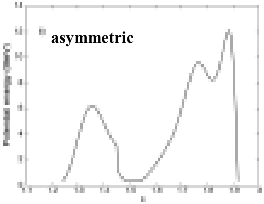
new

HFB (BSk8 force)
+ particle-number projection
- → mass tables (2000 nuclei, rms=660 keV, Goriely etal 2002)
- → fission barriers (Samyn etal 2003)

	B_{inner} (Mev)	B_{outer}(sym) (MeV)	B_{outer}(asym) (Mev)
^{240}Pu	5.9 (5.8)	9.6	5.9 (5.45)
^{246}Cm	6.0 (6.0)	7.5	5.3 (4.8)
^{252}Cf	6.7 (5.3)	6.2	4.4 (3.5)

- spontaneous fission
  - **dynamical calculations** (WKB+least action principle)





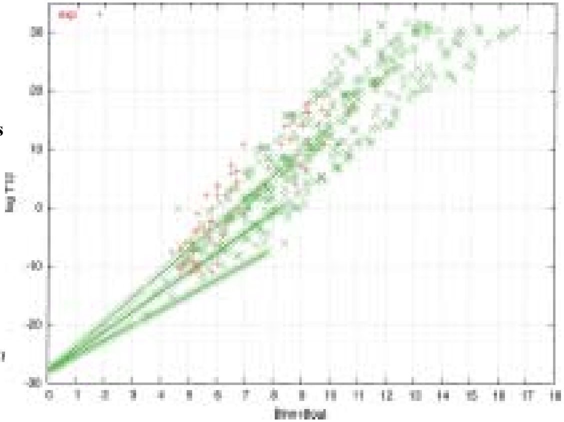
^{240}Pu	B_{inner} (MeV)	B_{outer} (MeV)	T_{sf} (yr)
sym.	6.2	12.4	$1.9\cdot10^{15}$
asym.	6.2	9.5	$7.8\cdot10^{13}$
HW	5.9	5.9	$2\cdot10^{14}$

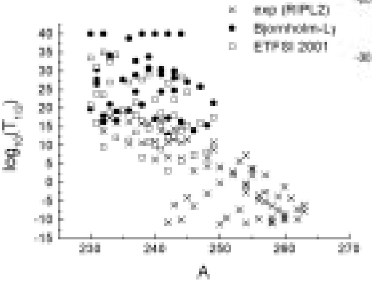
- large-scale calculations of SF $T_{1/2}$

Hill-Wheeler formula+

ETFSI barrier heights+

Bjornholm & Lynn ’80 barrier widths

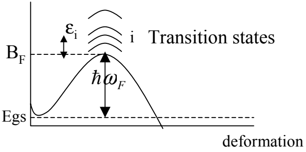




■ n-induced reaction rates

T_f : fission transmission coefficient

1. single-humped barrier B_F : $E_x = E_{inc}+S_N$



- **Hill-Wheeler formula**

$$T^J{}_F = \sum_{i=1} \frac{1}{1+\exp\left\{\frac{2\pi}{\hbar\omega_F}(E_x - B_F - \varepsilon_i)\right\}} + \int \rho^F(\varepsilon,J) \frac{1}{1+\exp\left\{\frac{2\pi}{\hbar\omega_F}(E_x - B_F - \varepsilon)\right\}} d\varepsilon$$

transition states i : where exp.data exist (RIPL2) !!!

2. double-humped barrier (A,B) $\quad T_{eff} = \frac{T_A T_B}{T_A + T_B}$

3. **subbarrier effects**: $E_x < \max(B_A, B_B)$
   - **picket fence model** (Lynn & Back 74)

$$\frac{T_F}{T_{tot}} = \left\{1 + \left(\frac{T_n + T_\gamma}{T_{eff}}\right)^2 + 2\left(\frac{T_n + T_\gamma}{T_{eff}}\right)\coth\left[\frac{1}{2}(T_A + T_B)\right]\right\}^{-1/2}$$

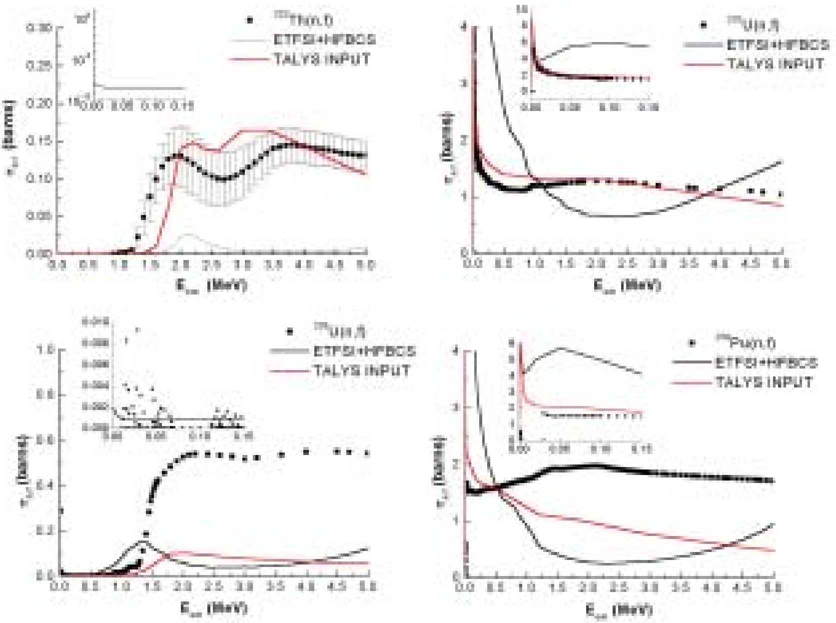
ETFSI 2001 (RIPL2) ⬅ $B_{A,B}$ **: barrier heights**

$\hbar\omega_{A,B}$ **: barrier widths** ➡ **Bjornholm & Lynn (1980)**

$\rho^F(\varepsilon,J)$: density of transition states at saddle-point deformation

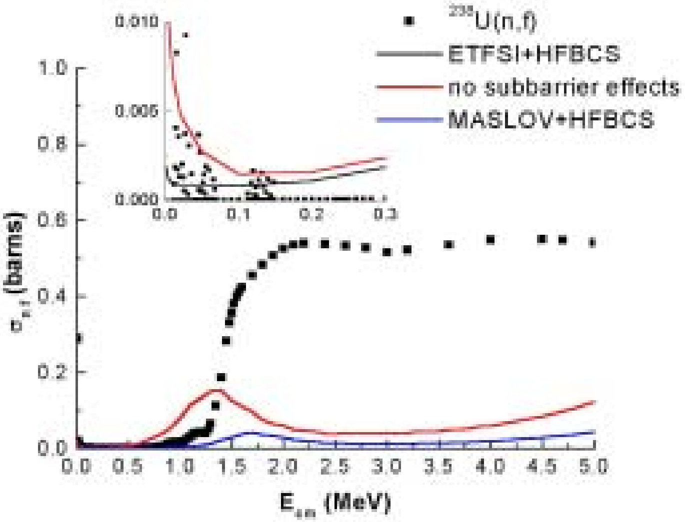
⬇

s.p. level scheme at saddle-point deformation from constrained HF-BCS
no damping of collective states (RIPL2)
consistent with g.s. densities



ETFSI+HFBCS
TALYS INPUT
(MeV)
(barns)

sensitivity to barrier heights+subbarrier effects



astrophysical applications : r-process

- relevant nuclei: A> 209 and up to n-dripline

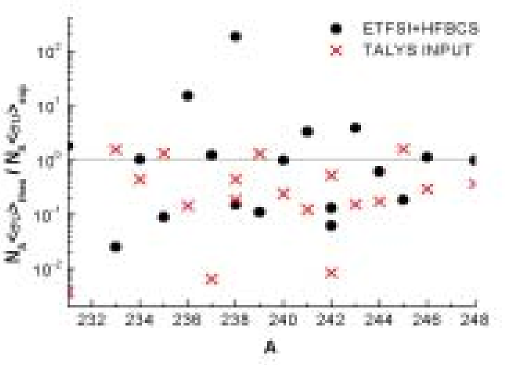
  → global predictions of (n,f) cross sections

- relevant temperature : T ≅ 1.5-2 x10^9 K or energies 100-150 keV

  → relevant quantities: Maxwellian averaged cross sections $N_A<\sigma\upsilon>$ at T

  → Comparison for **actinides:** experimental data (EXFOR)

  TALYS input (Maslov barriers +Gilbert-Cameron NLD)



rms = 8.4

rms = 11.1

Present & Future Work on Microscopic Models for astrophysical applications

- **nuclear structure** : investigation of various Skyrme forces (effective mass, contact pairing force) with the aim of reproducing masses and fission barriers

- **optical model pots**: improvement of global microscopic OMPs by including deformation
  test E-dependence of global α-optical potentials

- **nuclear level densities**: at saddle-point deformations obviously need to be revisited
  impact of *vibrational enhancement+rotational enhanement+ pairing force* are currently under study

- **fission properties**: obtain barrier widths as well as barrier heights from potential energy surfaces
  extend *dynamical* approach to large-scale calculations

- **beta-decay**: include deformation in QRPA calculations

NEEDS: more and more accurate and reliable data