Some recent theoretical developments devoted to the fission process

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* Some studies (not exhaustive)

* What did we learn ?

* What is still missing ? (my point of view)

Fission : a complex process

Many Nuclear properties involved:

* Shell effects
* deformations far from equilibrium
* large amplitude motion
* time evolution, dynamics
* Couplings between collective modes
* Couplings between collective and intrinsic excitations
* …
* nuclear force

Many Observables and data:
* fission fragment distributions (mass, charge, kinetic energy, …)
* fission fragment properties (deformation, polarization, spin …)
* cross sections
* fission life-time
* fission isomers
*   … fission barrier (through models)
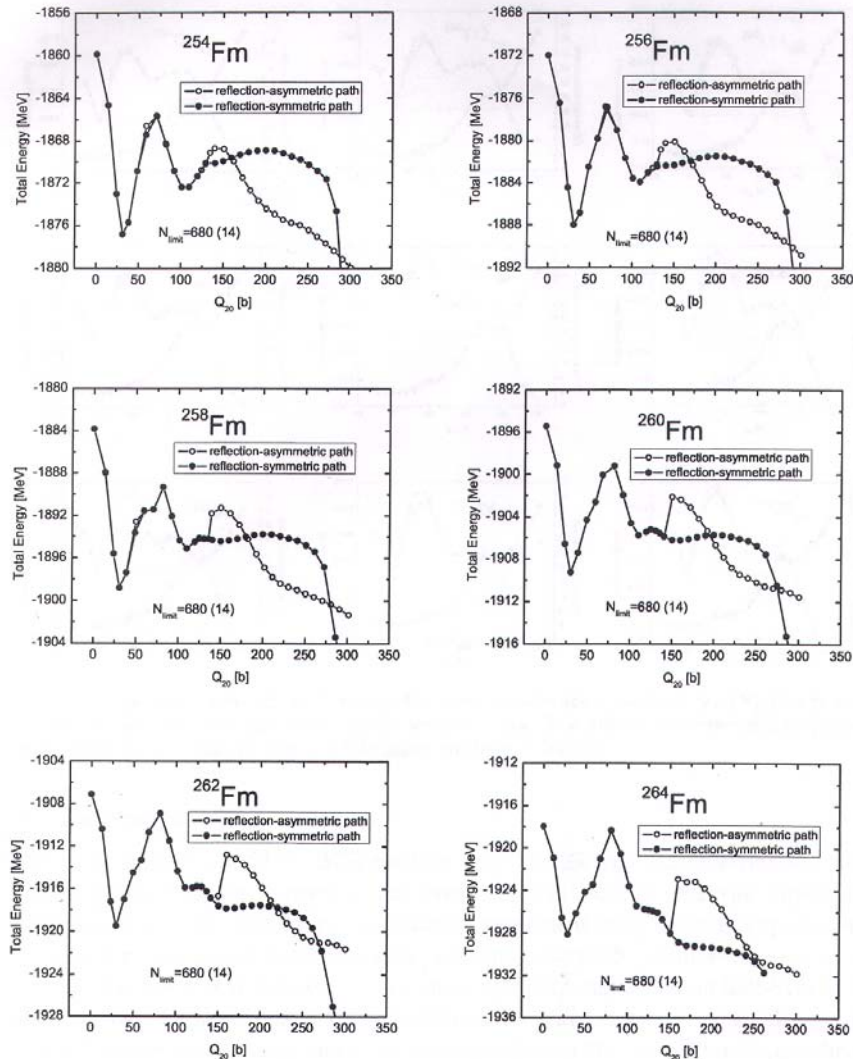
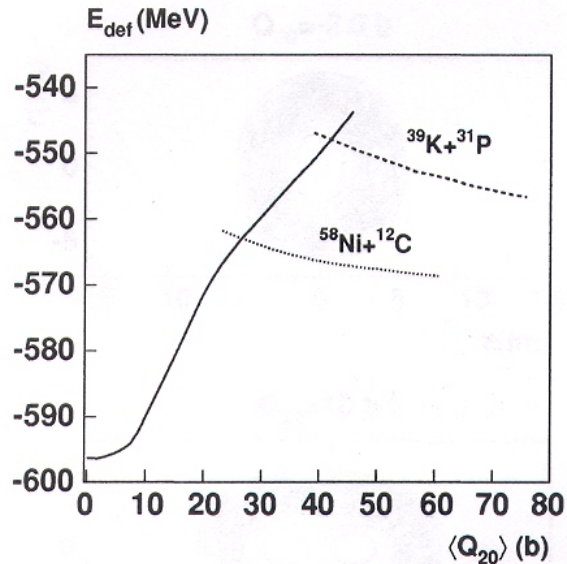**What do we learn:**

* Need of having a code that breaks all the symmetries example: HF+BCS code HFODD (v.2.8i) for Skyrme force

* Shell effects well reproduced for the heavy systems (ex: bimodal fission)

Example Hartree-Fock-BCS +Sly4 + seniority pairing force taken from :
A. Staszczak, J. Dobaczewski and W. Nazarewicz Int. J. Mod. Phys. E14 (2005) 395

E_{def} (MeV)

^{39}K + ^{31}P

^{58}Ni + ^{12}C

$\langle Q_{20} \rangle$ (b)

	Th.	Exp. (in MeV)
$B_f(^{58}Ni)$	34.7	25.28 ($\pm$0.8)
$B_f(^{39}K)$	44.9	35.09 ($\pm$0.8)

What did we learn :

* good shell effects

* probing surface terms in the nuclear energy density functional

Example Hartree-Fock-BCS +SkM*+ seniority pairing force taken from :
L. Bonneau and P. Quentin PRC72 (2005) 014311

Very asymmetric fission
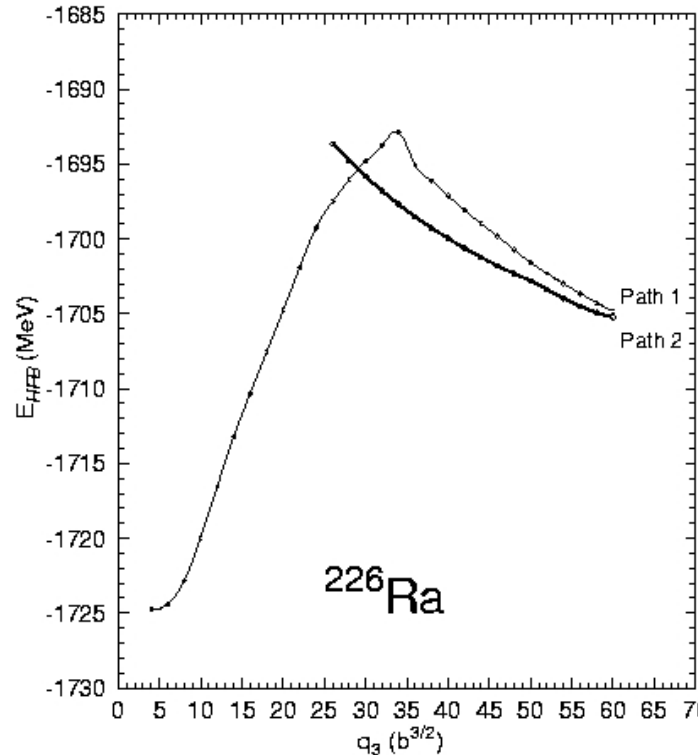
Cluster emission of ^{14}C:
T $_{1/2}$=8.8 10^{22} s (exp 1.58 10^{21} s)

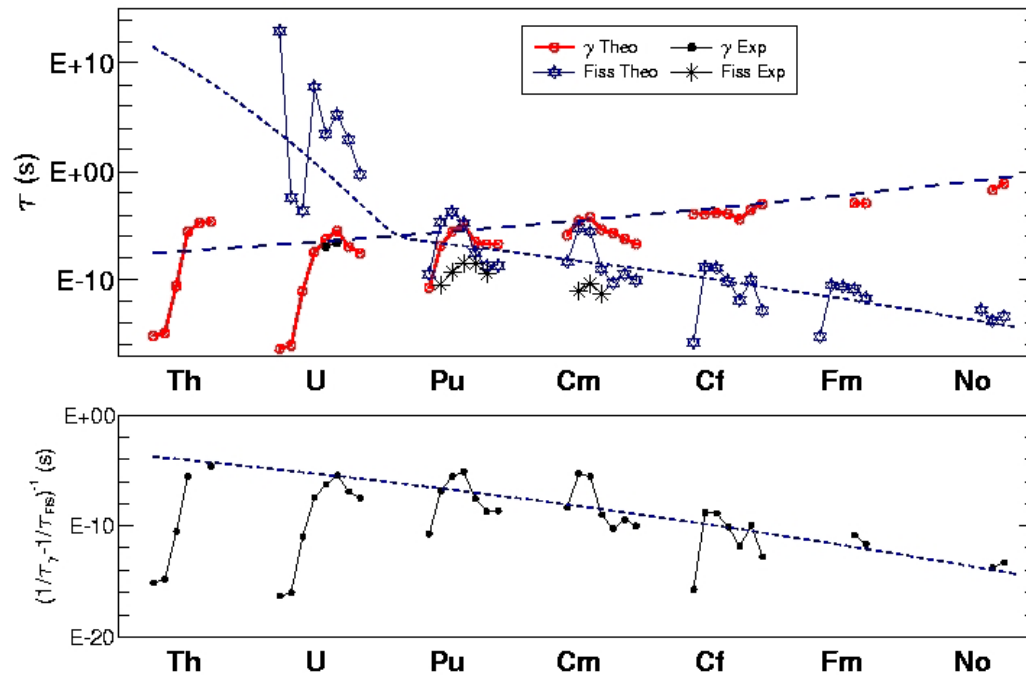and ^{20}O:
T $_{1/2}$=2.7 10^{21} s (not seen exp.)

Question :

      * Is very asymmetric fission equivalent to light particle emission ?

Example Hartree-Fock-Bogoliubov +D1S force :
L. Egido, L. Robledo proceeding "Cadarache 2005" AIP to be published

What do we learn :

•Microscopic fission barriers in heavy nuclei can be introduced in reaction models (see also S. Goriely et al.) (prediction/accuracy)
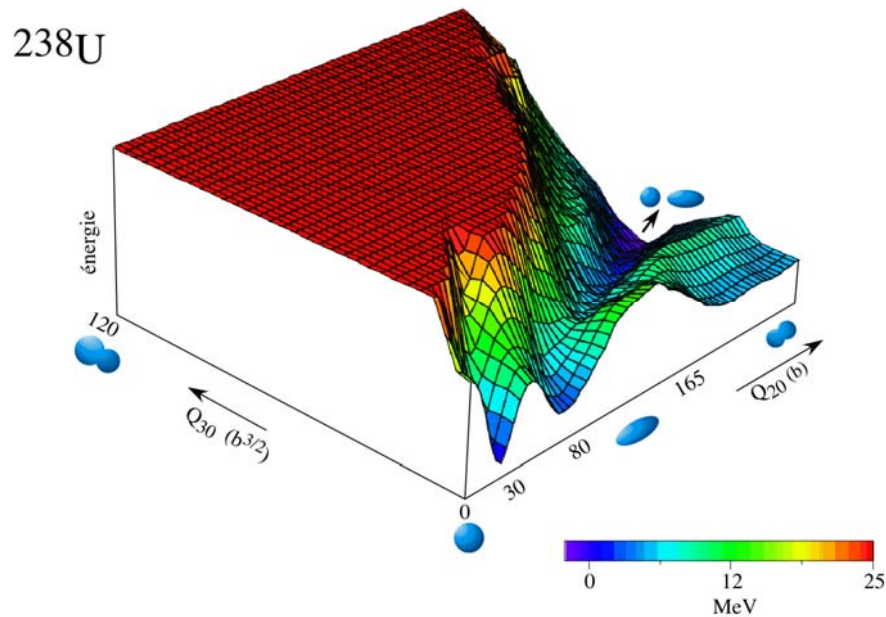
Example Hartree-Fock-Bogoliubov calculation + D1S force taken from :
M. Girod, J. Libert, J.P. Delaroche and H. Goutte to be published

Fission barriers

What can be improved ?

(if we want to introduce the calculated barriers in reaction model)

* How to define a fission barrier ?
  The lowest energy path ?

* How to connect the different valleys (discontinuities)

* Fission barriers for odd nuclei (see Robledo et al) ? Spin conservation ?
  What about parity for asymmetric shapes ?

* Symmetry breaking effects during fission and restauration

* Angular momentum dependence

Potential energy surfaces and fission fragment properties

Two-dimensional potential energy surface (constraints on elongation and asymmetry)
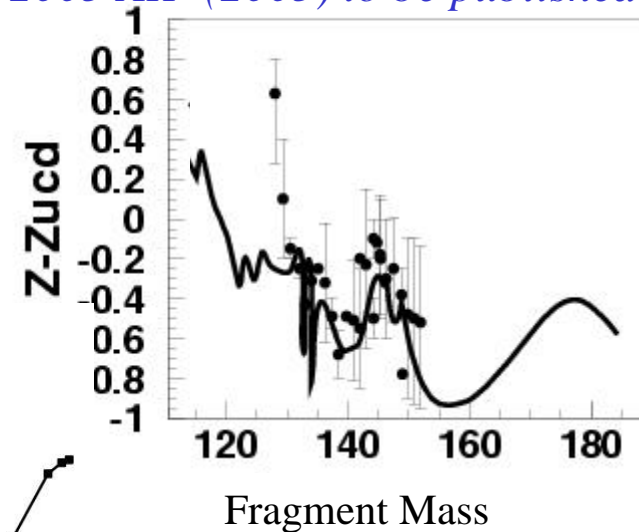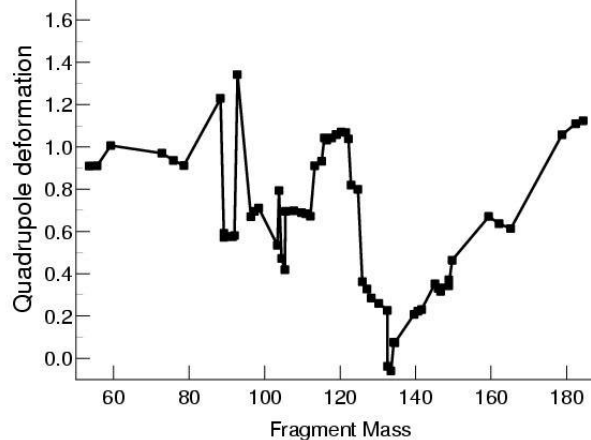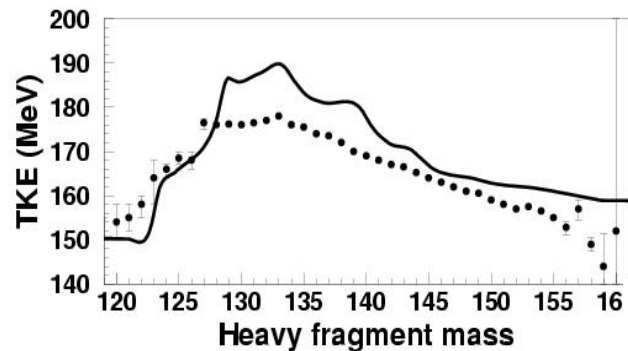
Determination of the scission line

Calculation of many nuclear properties

Example Hartree-Fock-Bogoliubov +D1S force taken from :
H. Goutte, P. Casoli, J.-F. Berger Nucl. Phys. A734 (2004) 217.

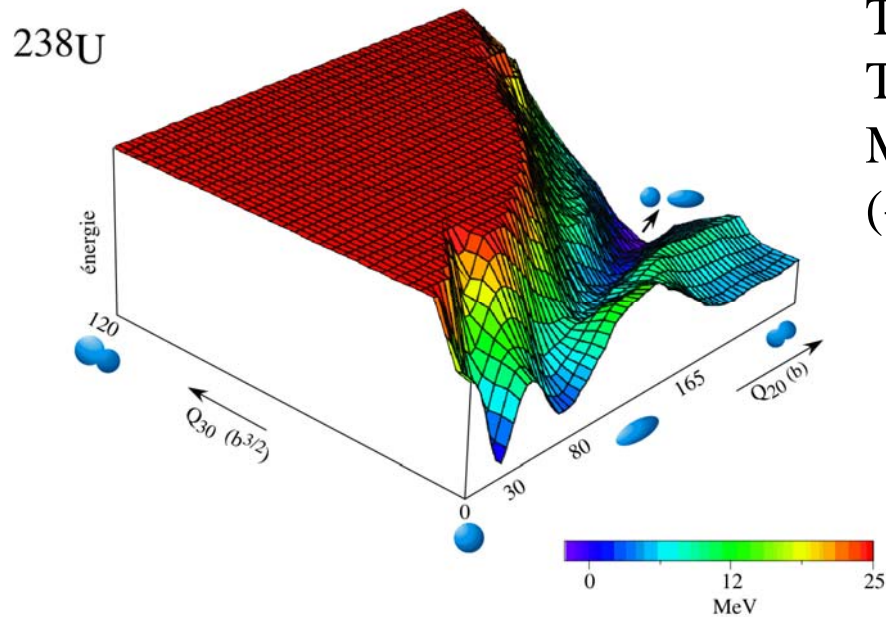**Potential energy surfaces and fission fragment properties**

Example Hartree-Fock-Bogoliubov +D1S force taken from :
H. Goutte, P. Casoli, J.-F. Berger, proceeding Cadarache 2005 AIP (2005) to be published

Fragment Mass

What do we learn :

* Not only the most probable fragmentation but the whole distributions are well-reproduced :→ good properties of the N-N force
(see also P. Quentin et al spin of the fragments)

238U

Time evolution in the fission channel based on
The Time dependent Generator Coordinate
Method
(+Gaussian Overlap Approximation)

Calculation of the flux along the scission line
→ Fission yields

Example Hartree-Fock-Bogoliubov +D1S force taken from :
H. Goutte, P. Casoli, J.-F. Berger Nucl. Phys. A734 (2004) 217.

« 1D »
« DYNAMICAL »
WAHL
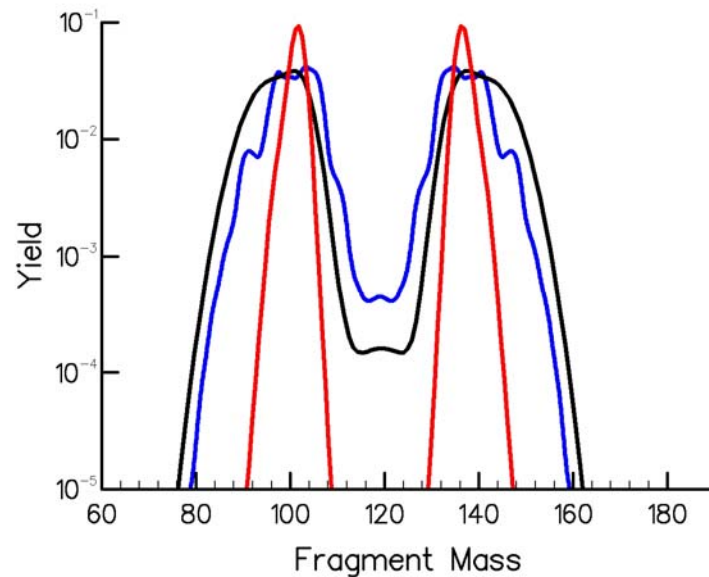
What do we learn?

* Dynamical effects are responsible for the large widths of the mass distributions,

• the initial condition of the fissioning system influences the symmetric fission yield

• No parameters -> predictions possible

Example Hartree-Fock-Bogoliubov +D1S force taken from :
H. Goutte, P. Casoli, J.-F. Berger, D. Gogny PRC71 (2005) 024316.

Potential energy surfaces

What can be improved :

* what is the number of pertinent degrees of freedom ?
(5D Micro-macro potential energy surface by P. Moller)
(related to the fissioning system or to the fragments?)

* how to reduce a N-dimensional problem to a one dimensional one
(fission barriers for reaction models) ?

Fission dynamics

What can be improved :

       * coupling between collective and intrinsic degrees of freedom

       * high energy fission …

Thanks to all the experimentalists for the new data they provide.

Most of these studies are motivated by their results
(see K. H. Schmidt et al. Nucl. Phys. A)

See Proposal to the INTC Committee   n_TOF-Ph2:
     Fission cross section
     Fission-Fragments angular distributions
     Fission-fragments yields
     …

Astrophysical implications :
      neutrino-induced fission
      fission of N-rich nuclei