Anomalies in the fission yields explained by memory effects in nuclear dynamics

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*) URL: http://www.khschmidts-nuclear-web.eu

Introduction

Transport properties of nuclear matter (viscosity and inertial mass) determine the dynamics of large-scale collective motion (e.g. fission).

- **Low viscosity:**
  under-damped motion, strong influence of inertia, memory, deviation from statistical equilibrium
- **Dominent viscosity:**
  over-damped motion, no influence of inertia, no memory, always in statistical equilibrium

> 50 years of intense experimental and theoretical efforts invested for determining the degree of damping.

Bender et al. (2020): Still no conclusive result.

Illustration, functioning of a gargoyle

Low viscosity of water and air:
Horizontal velocity preserved by inertia.

Honey would drop down vertically.

Dynamics with memory indicates influence of inertia!

Status of theory

Blocki et al., 1987 (wall- and window-formulae):
Strong one-body dissipation leads to over-damped motion. → dominant viscosity

Bulgac et al., 2020 (TDSLDA):
TDSLDA „justifies the assumption that the influence of inertia in fission dynamics is irrelevant“. → dominant viscosity

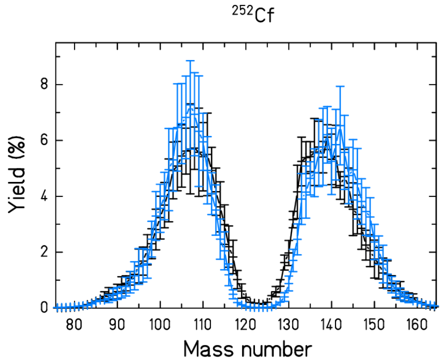
Griffin et al., 1985 and Pal et al., 1996
Concerns due to quantum effects and insufficient chaoticity → lower viscosity

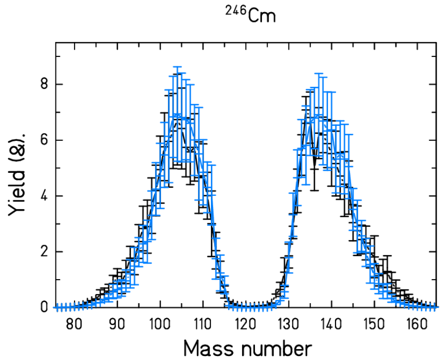
Status of experiment

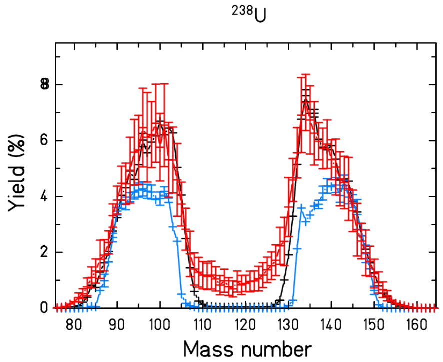
Success of scission-point models (Wilkins et al. 1972 and successors) and Brownian shape motion (Randrup et al. 2011):
Consistent with dominance of dissipation.

Dynamical Langevin approach (e.g. Mazurek et al. 2017):
Indications for influence of inertia from comparison of measured mass distributions with model calculations.

Anomaly in fission yields: („digged out“) Suppression of S1 mode in 238U(sf)







Mass distributions (Data from ENDF data tables, adjusted at A=90, mode S2.)

252Cf

Spontaneous fission

N-induced (En<2MeV)

N-induced (En = 14 MeV)

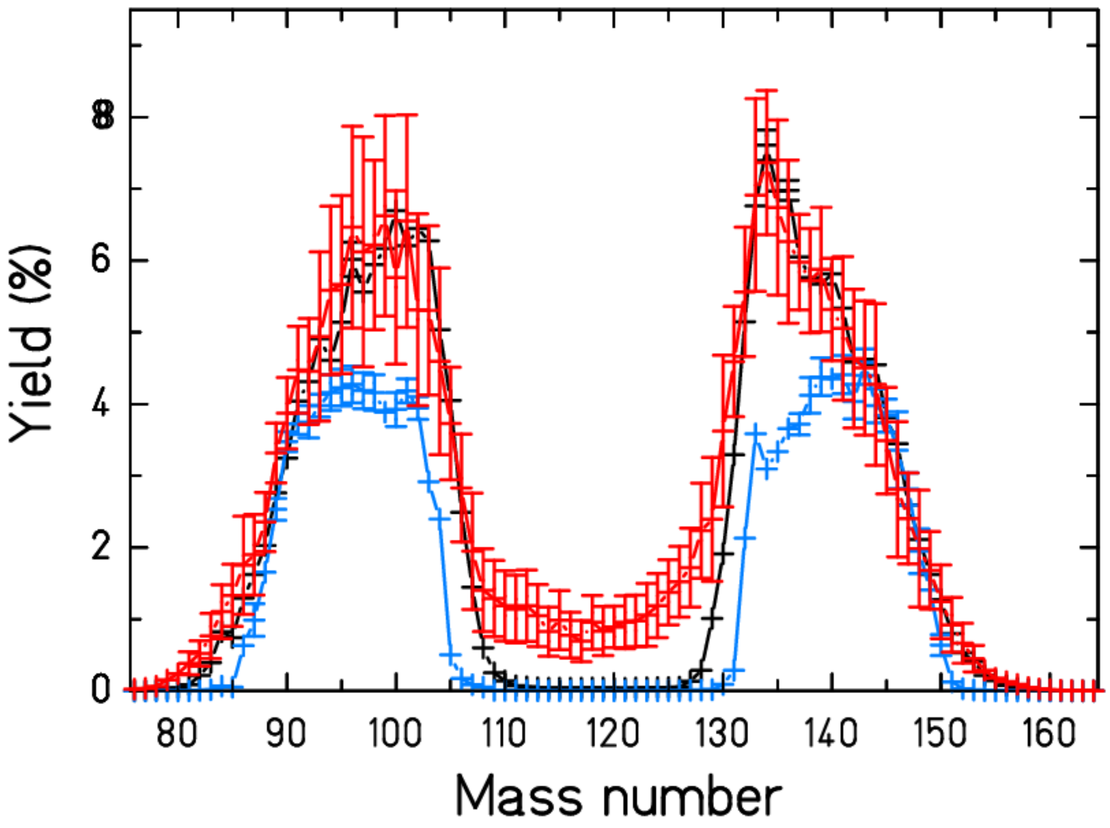
245Cm

238U

238U(sf): Fragments near 132Sn are suppressed.

This is the most drastic case.
Many others in light actinides, also at higher E*!

Detailed view on 238U



Spontaneous fission

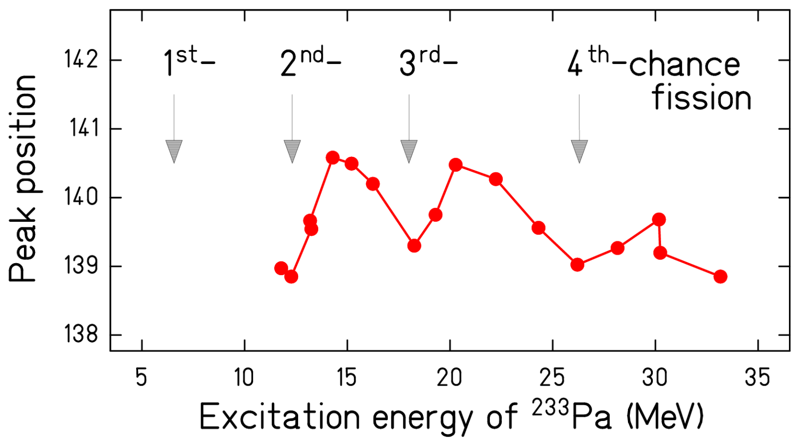
N-induced (En<2MeV)

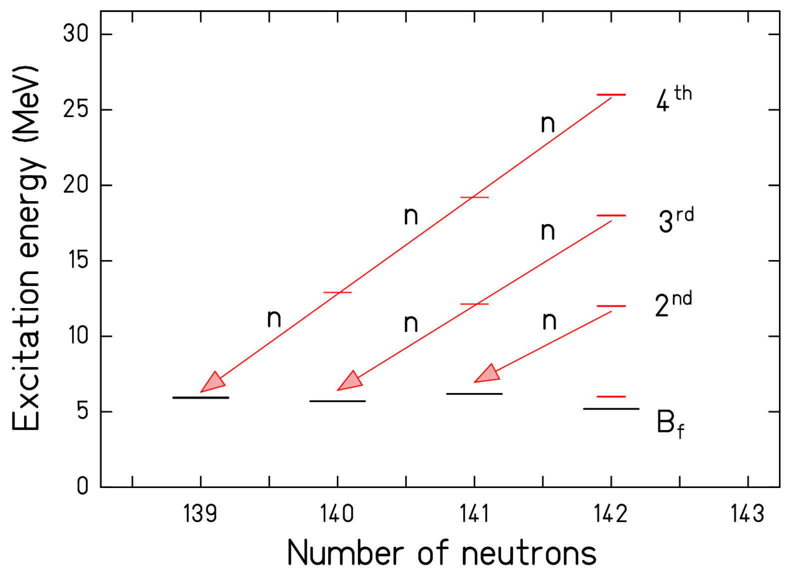
N-induced (En = 14 MeV)

238U

Data from ENDF data tables

233Pa, mean heavy fragment mass





Fission of the CN 233Pa, induced by protons.

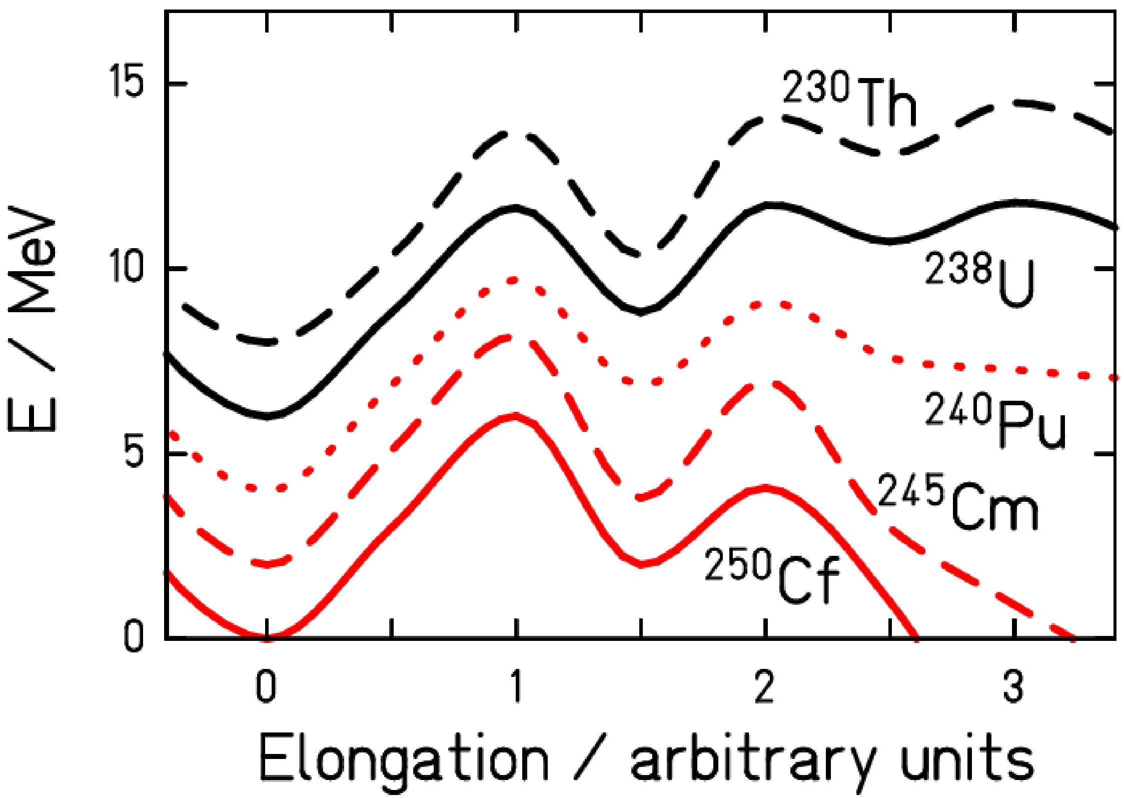
Data from Berriman et al.

Shift of heavy mass peak to larger asymmetry at the onset of higher-chance fission.

Information on E* dependence of the suppression effect.

Connection with tripple-humped barrier

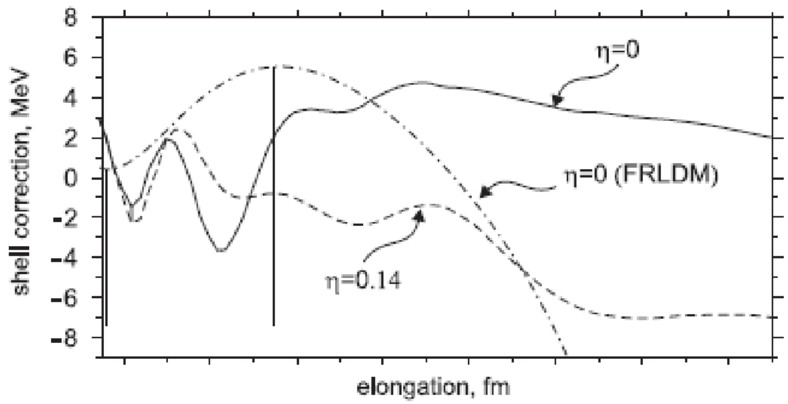
Potential energy on the fission path (schematic)



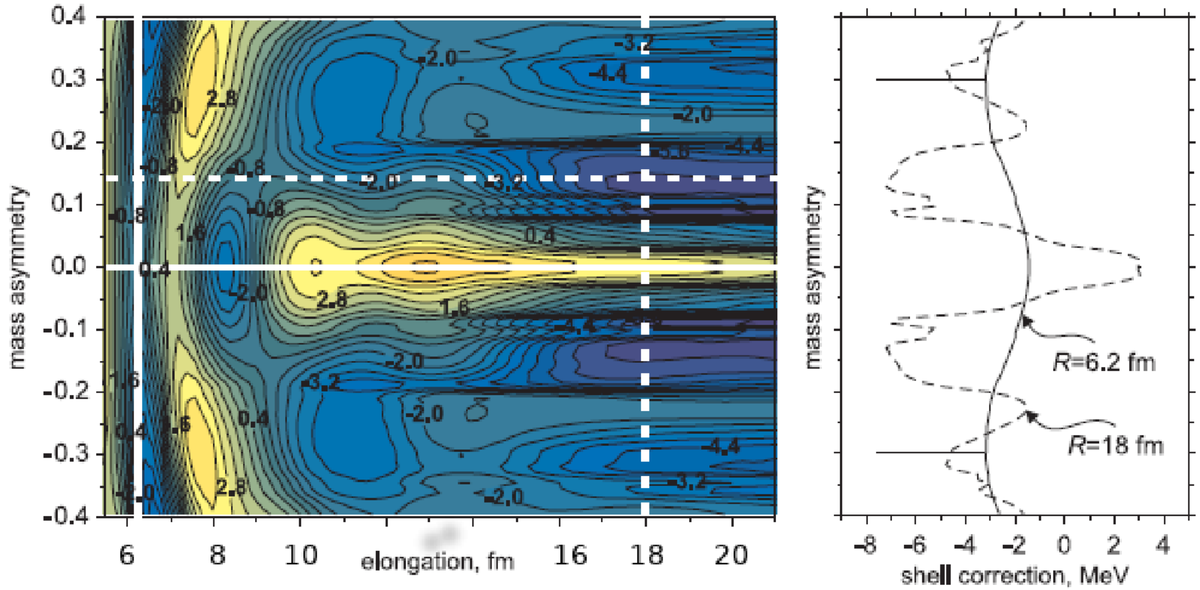
Third barrier is high for light actinides.

Known since the 1970th from the „thorium anomaly“ in fission probabilities and angular distributions.

2-dim potential-energy (mic-mac model)



Calculation by Karpov et al.



Potential in mass asymmetry is similar at the second and the third barrier, but may differ a bit.

Suppression appears, when the system must tunnel through third barrier.

Our hypothesis

In 238U and lighter actinides:
At sufficiently low E*, mass distribution corresponds to potential at third barrier, because influence of tunneling is strong.

At high E*, mass distribution corresponds to potential at second barrier, because influence of phase space alone is too weak to wipe out the memory of the second barrier.

Heavier nuclei:
Mass distribution corresponds to potential at second barrier for all E*.

Conclusion

In all actinides, the system remembers and keeps the mass asymmetry of the 2nd barrier.

Exception: When the system is obliged to pass the 3rd barrier by tunneling, the memory of the system is erased.

In conflict with the assumption of statistical equilibrium along the fission path.

The anomalies in the fission yields (digged out from existing data and overlooked up to now) provide proof for the influence of inertia and impose new constraints on theory!