Excitation energy sorting in superfluid fission

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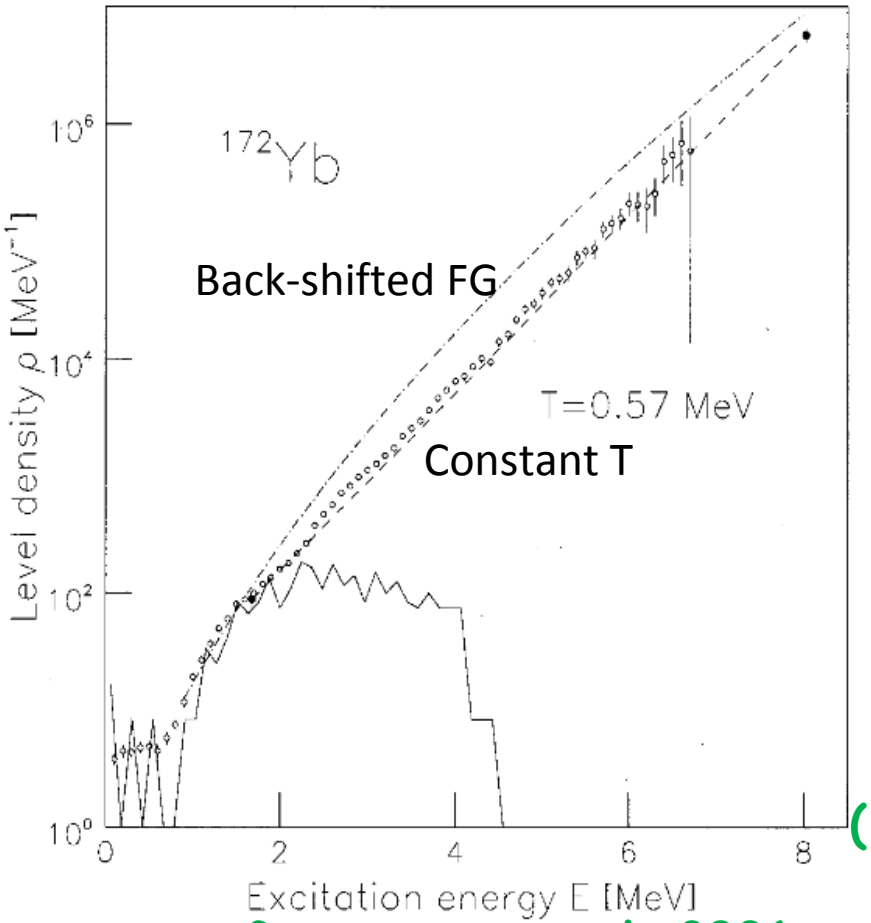
Constant temperature of nuclei



Guttormsen et al. 2001

Rather exact constant-temperature behaviour:

$$\rho(E^*) \propto \exp(E^*/T)$$

$$T = E^*/n_{eff} = \text{cte.}$$

Effect. Numb. of deg. of freedom

$$n_{eff} \propto E^*$$

(Melting of pairs)!

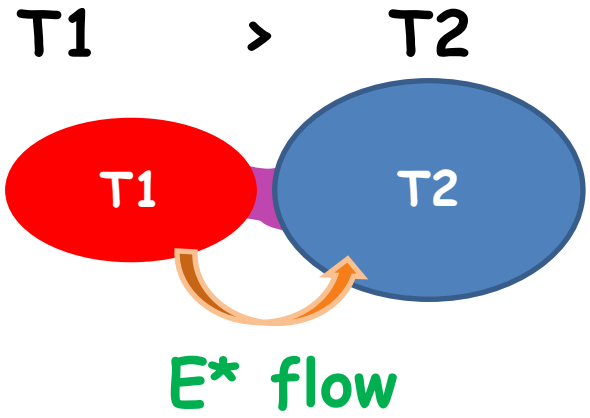
Constant temperature up to 20 MeV!!
(Voinov et al. PRC 79 (2009) 031301 (R))

T is specific for every nucleus:

$$T = A^{-2/3} \cdot \left(17.45 - 0.51 \cdot S + 0.051 \cdot S^2\right)$$

Empirical systematics by T. v Egidy et al. PRC 72 (2005) 044311

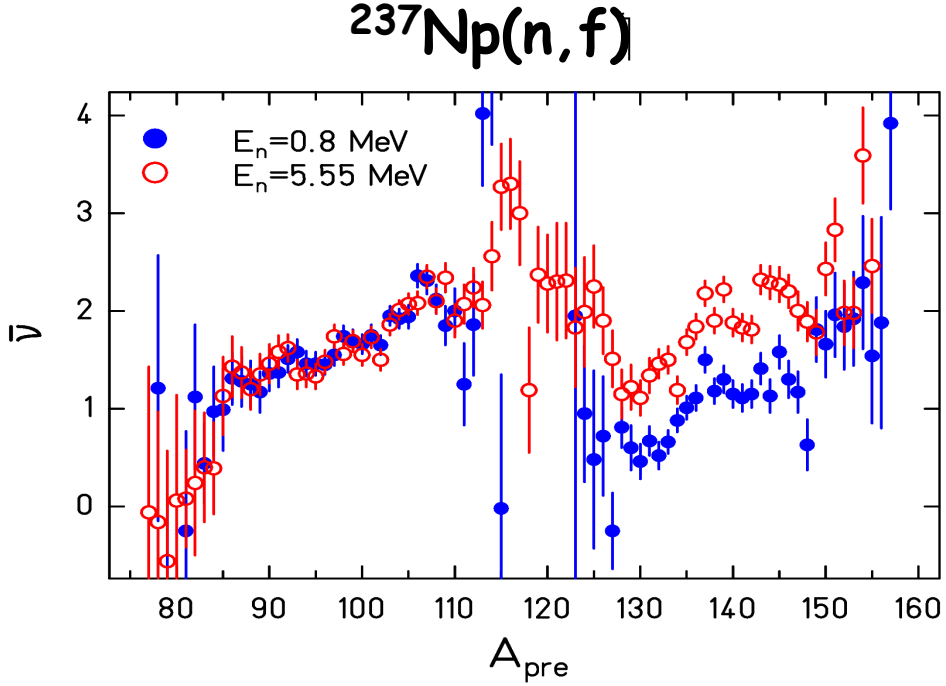
Two moderately excited nuclei in contact: Scission configuration



E* keeps flowing from the hot to the cold nucleus until the E* of the hot nucleus is completely exhausted!!!
-> Process of <u>excitation energy sorting</u>

<u>Unique!</u> All other objects in nature reach thermal equilibrium (T1=T2) before the hot object has exhausted all its heat

Neutron yields in fission: Signature of energy sorting



The additional energy of the neutron ends up in the heavy fragment only!!!

(Naqvi et al., PRC 34 (1986) 218)

Observation also found for ^{233}U, ^{238}U and proton-induced fission

Unexplained up to now because (Fermi-gas) level density not adapted to low E*!

Energy sorting and even-odd effect in fission

Finally, the system may eventually increase the excitation energy of the more excited nucleus by exchange of nucleons so that the fragment with zero excitation energy converts into a neighbouring **even-even nucleus** (energy gain up to 4 Δ)

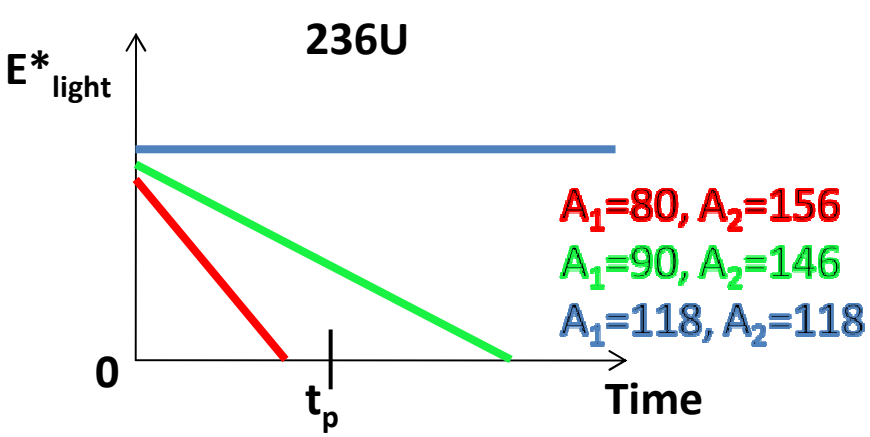
The "hotter" (generally lighter) fragment tends to be even-even!!!!!

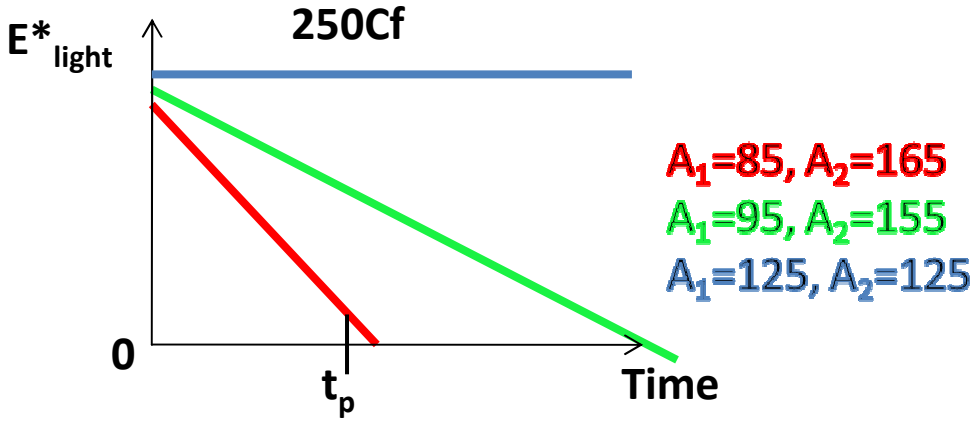
Energy sorting and even-odd (e-o) effect in fission

t→ time for E* transfer + time to transfer few protons to heavy fragment

Amount of E* to be transferred
$E^*_{light} \propto E^*_{total} = E^*_{fb} + E^*_{sad\text{-}sci}$

Temperature difference T1-T2





$t \sim E^*_{total}/(T1-T2)$
- T1-T2 ↑ with mass asymmetry
- E^*_{total} ↑ A of fiss. nucleus or Coulomb parameter

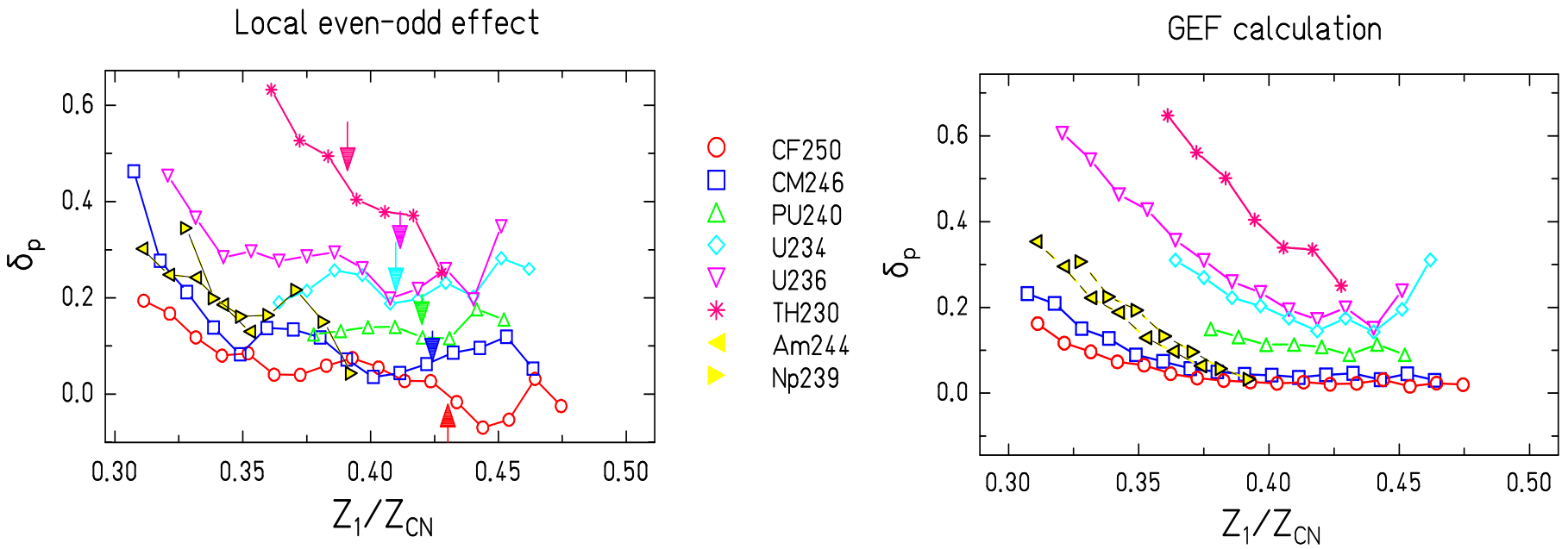
t_p→time at which the exchange of protons through the neck is very much hindered

If $t > t_p$, no even-odd effect is possible !!!

- ✓**e-o effect sets in at a certain asymmetry**
  - **which ↑ with A of fiss. nucleus**
  - **which ↑ with E* of fiss. nucleus**
- ✓**Equal description for even-Z and odd-Z fissioning nuclei**

Comparison with experimental data

Experiment



(Thermal neutron-induced fission, Lohengrin)

- ✓The e-o effect increases with asymmetry
- ✓The lighter the nucleus the smaller the threshold asymmetry
- ✓Similar behavior of even-Z and odd-Z fissioning nuclei
- ✓General trends nicely reproduced with GEF code (Talk K.-H. Schmidt)
- ✓No data to test variation of threshold asymmetry with E*

Conclusions

✓The scission configuration offers a unique opportunity to observe the behavior of two nuclei in the superfluid regime set in contact:
The hot fragment transfers all its E* to the cold one → **Excitation energy sorting!!!**

✓Energy sorting → **Clearly reflected by number of prompt neutrons vs. A**
An increase of E* translates into an increase of υ for the heavy fragment only .
This observation remained unexplained up to now!!!

✓Energy sorting **explains the dependence of the e-o effect with asymmetry and with the A of the fiss. nucleus**:
e-o effect sets in at a threshold asymmetry that ↑ with A and E* of fiss. nucleus

✓**Need for more experimental data** on prompt neutrons and e-o effect

More information:

K.H. Schmidt and B. Jurado accepted for publication in Phys. Rev. Lett.
GEF web site (www.cenbg.in2p3.fr/GEF) (Talk K.-H. Schmidt)