SUPERHEAVY NUCLEI: which regions of nuclear map are accessible in the nearest studies

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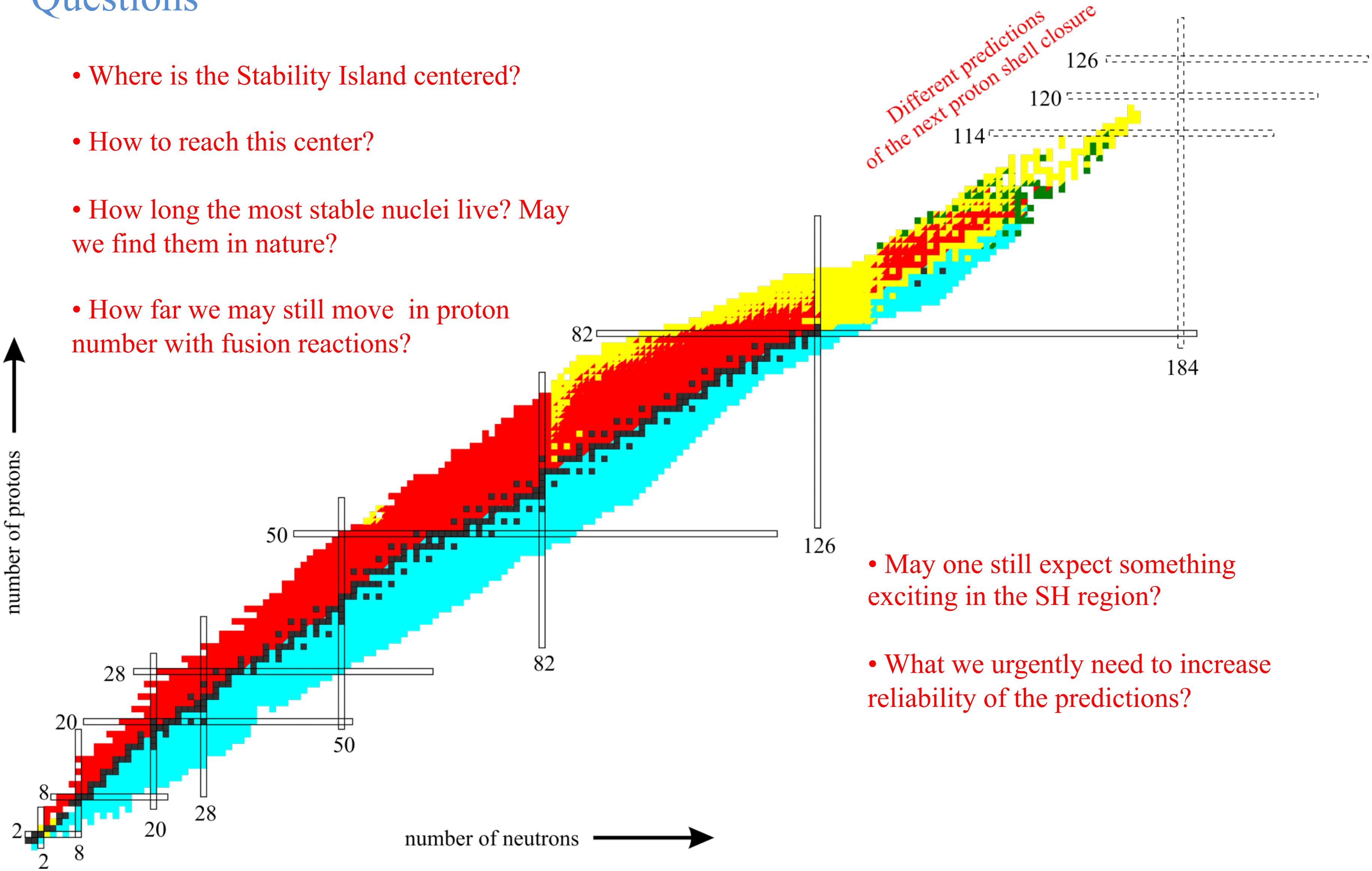
Questions

• Where is the Stability Island centered?

• How to reach this center?

• How long the most stable nuclei live? May we find them in nature?

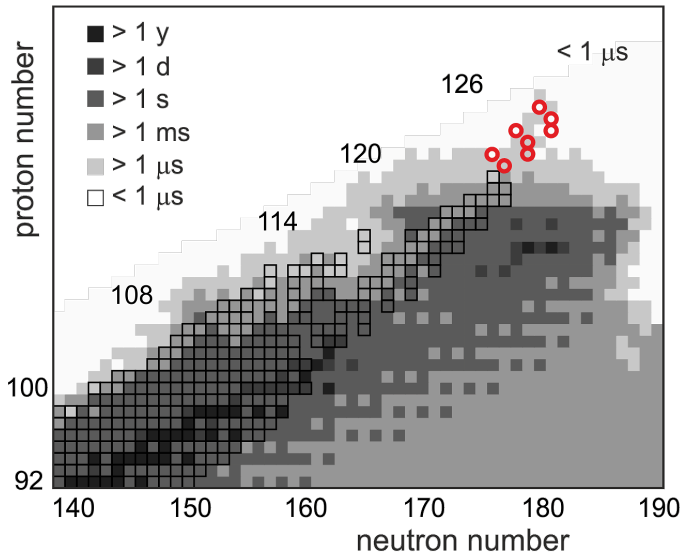
• How far we may still move in proton number with fusion reactions?

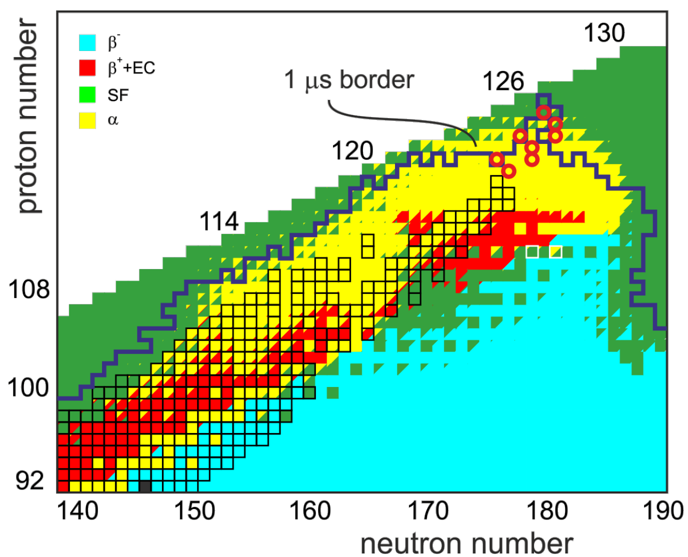


• May one still expect something exciting in the SH region?

• What we urgently need to increase reliability of the predictions?

Perspectives of fusion reactions for SH (Z>118)





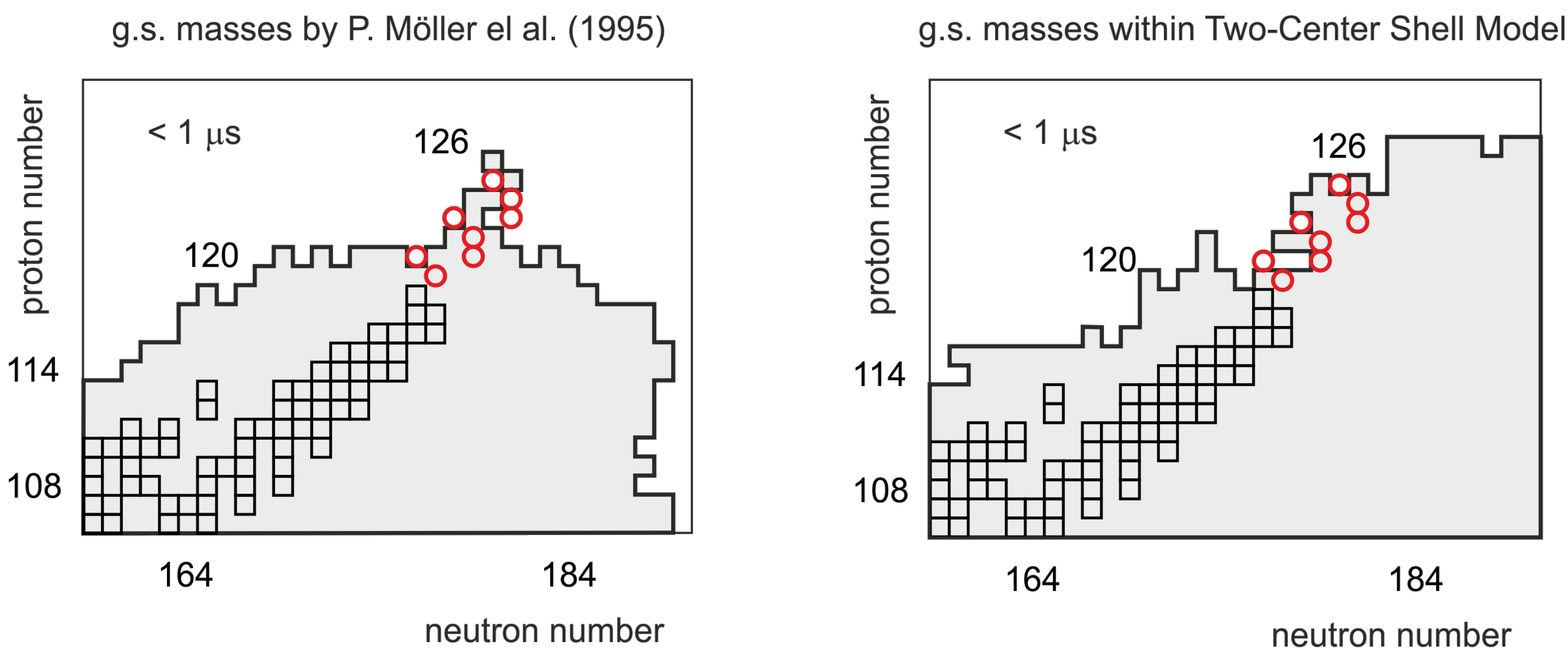
□ - ***known nuclei***

○ - *nuclei with* ***Z=119-124***
3n channel *of fusion-evaporation reactions:*

$$^{50}Ti + ^{249}Bk \rightarrow ^{296}119 + 3n$$
$$^{50}Ti + ^{249}Cf \rightarrow ^{296}120 + 3n$$
$$^{54}Cr + ^{248}Cm \rightarrow ^{299}120 + 3n$$
$$^{54}Cr + ^{249}Bk \rightarrow ^{300}121 + 3n$$
$$^{54}Cr + ^{249}Cf \rightarrow ^{300}122 + 3n$$
$$^{58}Fe + ^{248}Cm \rightarrow ^{303}122 + 3n$$
$$^{58}Fe + ^{249}Bk \rightarrow ^{304}123 + 3n$$
$$^{58}Fe + ^{249}Cf \rightarrow ^{304}124 + 3n$$

Superheavy nuclei with Z>120 could be hardly detected due to their short half-lives!

Perspectives of fusion reactions for SH (model dependence)



□ ***- known nuclei***

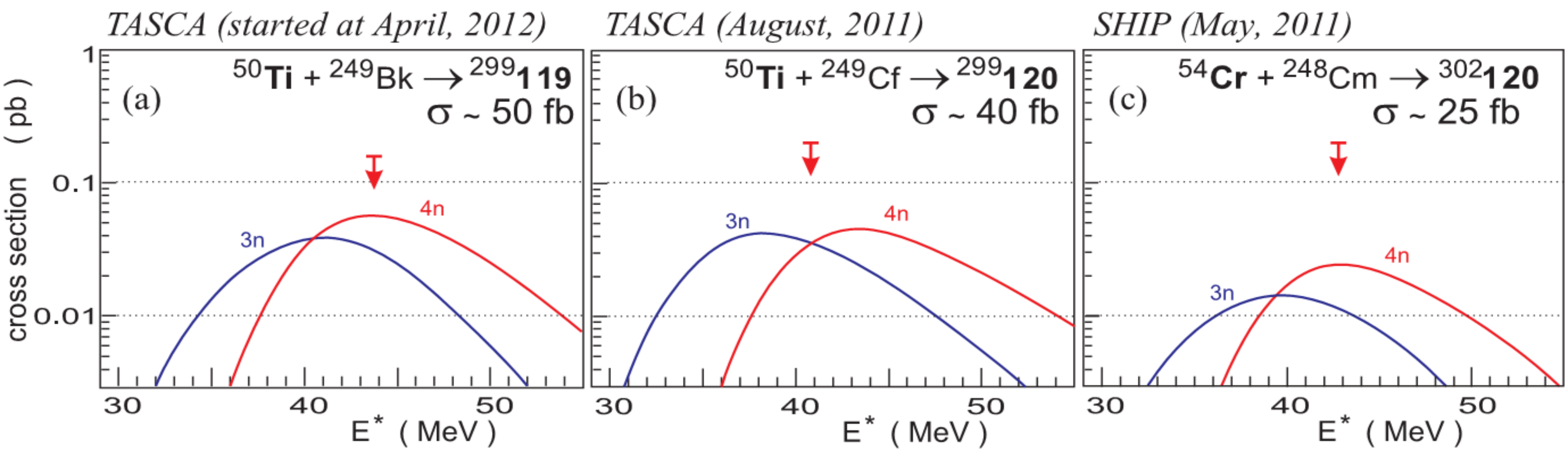
○ *- nuclei with **Z=119-124**, **3n channel** of the fusion reactions:*

$$^{50}Ti + ^{249}Bk, ^{249}Cf \quad \text{and} \quad ^{54}Cr, ^{58}Fe + ^{248}Cm, ^{249}Bk, ^{249}Cf$$

Position of 1 μs border in proton-rich region is nearly model-independent

Beyond ^{48}Ca: ^{50}Ti and ^{54}Cr induced fusion reactions

Ti beam: Cr beam:

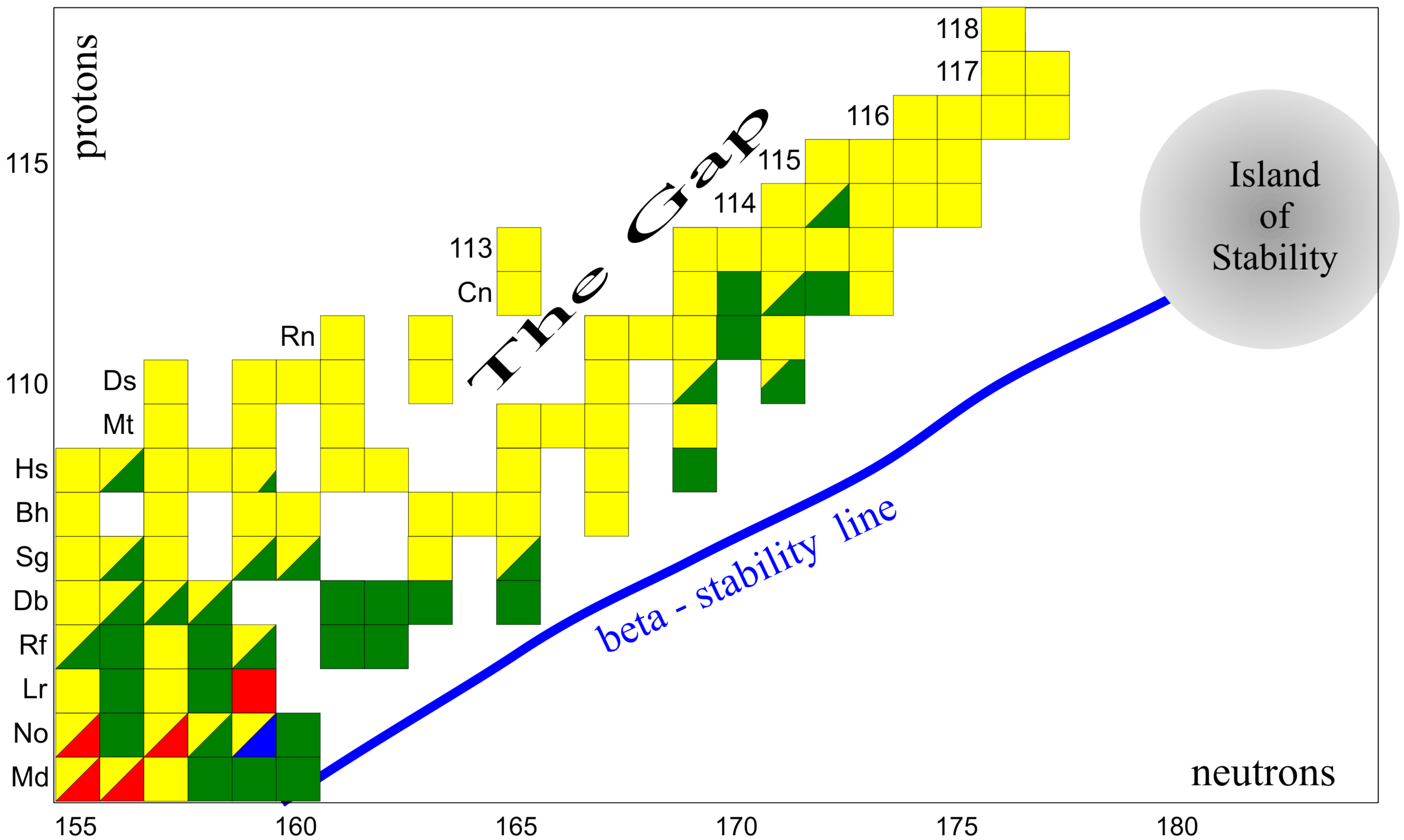


factor $\frac{1}{20}$ as compared to ^{48}Ca

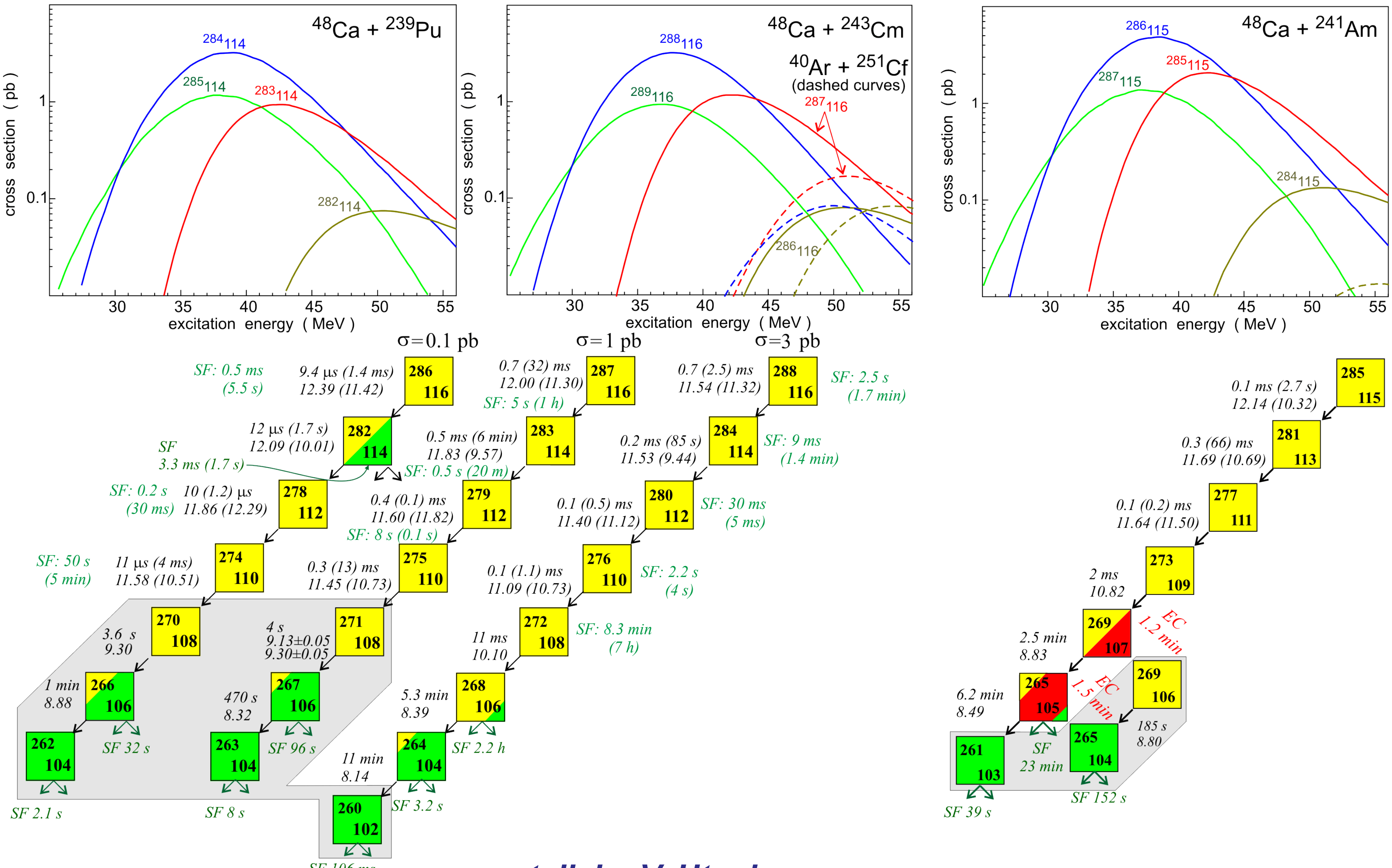
Predictions by V. Zagrebaev, et. al, 2007

Probably these elements are the last ones which will be synthesized in the nearest future

The gap in SH mass area must be filled somehow

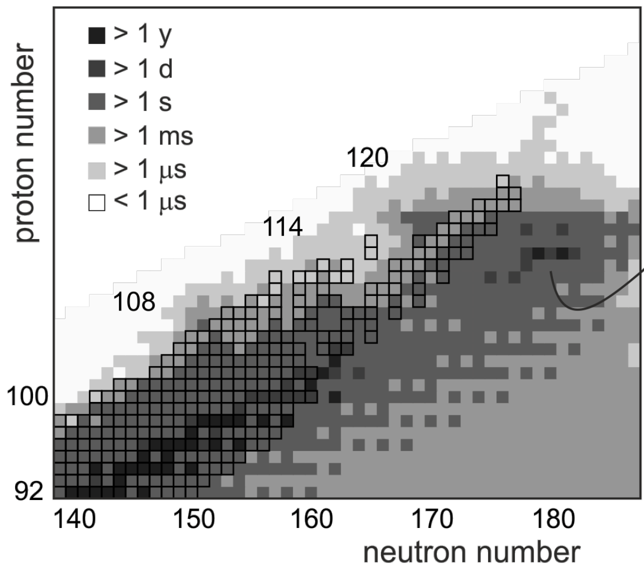


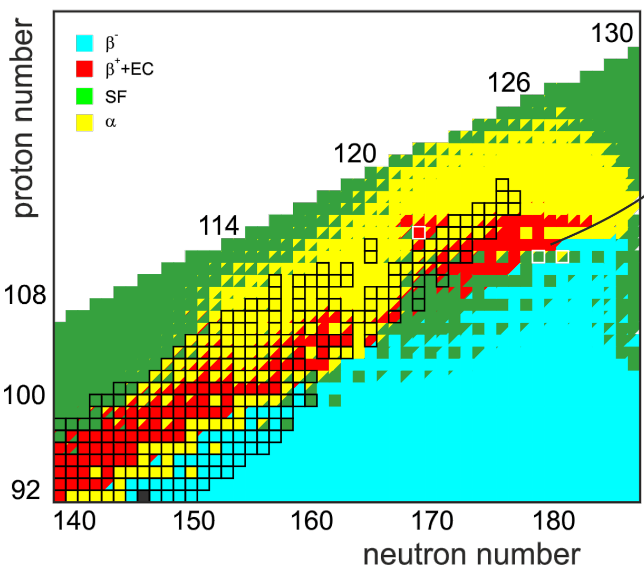
Cross sections are high enough to perform experiments at available facilities just now (already started in Dubna…)



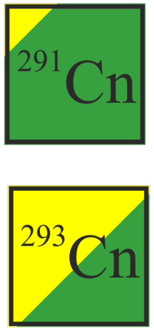
see talk by V. Utenkov

Center of the Stability Island. Search of SH in Nature





with g.s. masses by *P. Möller et al. (1995)*



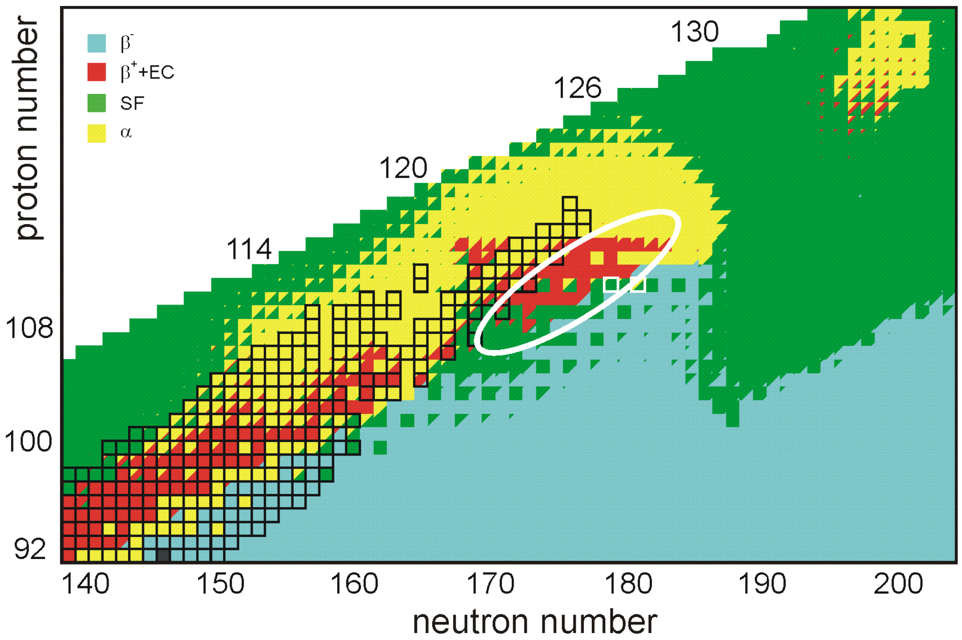
The most stable are **β-stable** isotopes of the element **112** with half-life ~ **100 years** *(with Möller g.s. masses)*

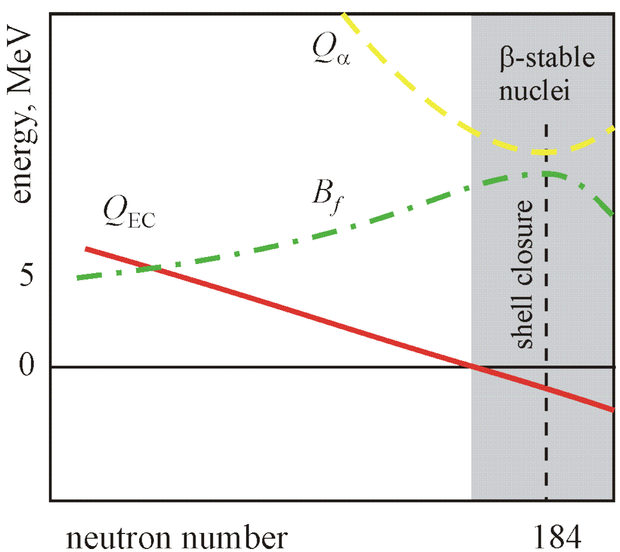
half-life ~ **1000 years** *(with TCSM g.s. masses)*

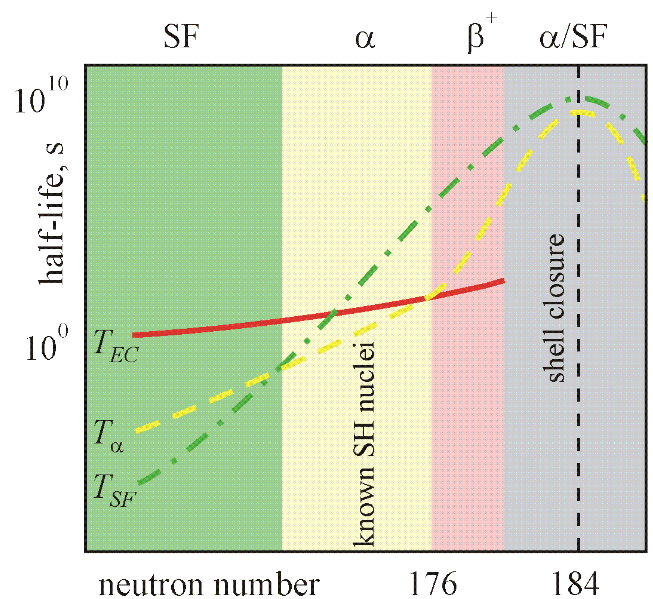
Search of superheavy nuclei in nature may be performed in cosmic rays.

Under terrestrial conditions a measurable amount of superheavies is unlikely to exist.

Decay modes in the vicinity of Stability Island

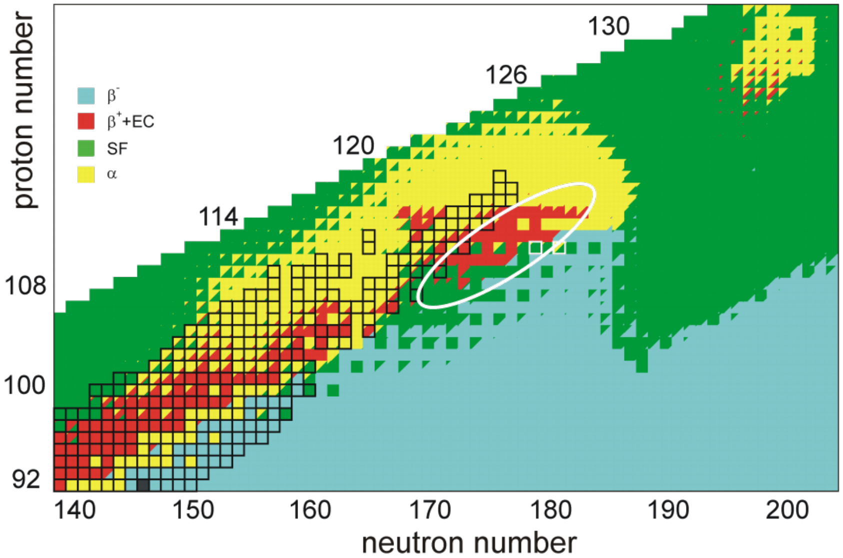




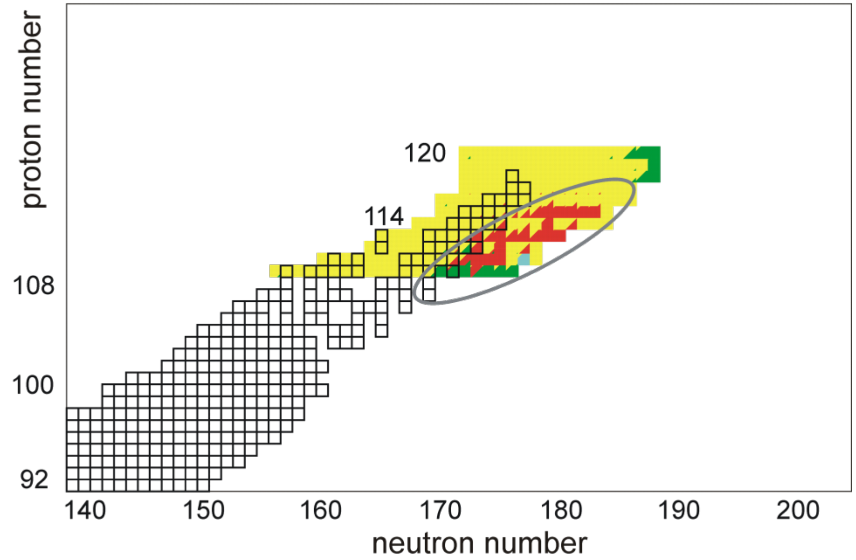


EC – model dependence

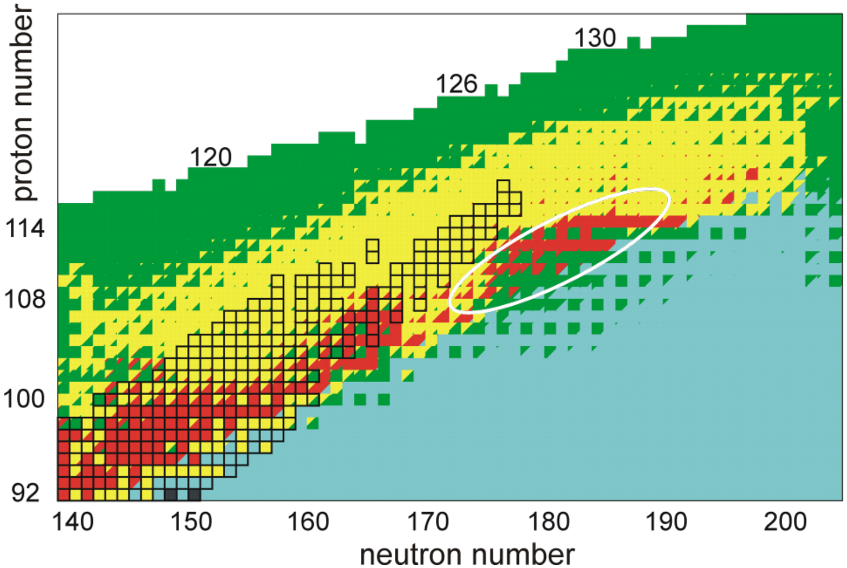
g.s. masses by *P. Möller et al. (1995)*



A. Sobiczewski et al. (2003) + R. Smolanczuk (1997)



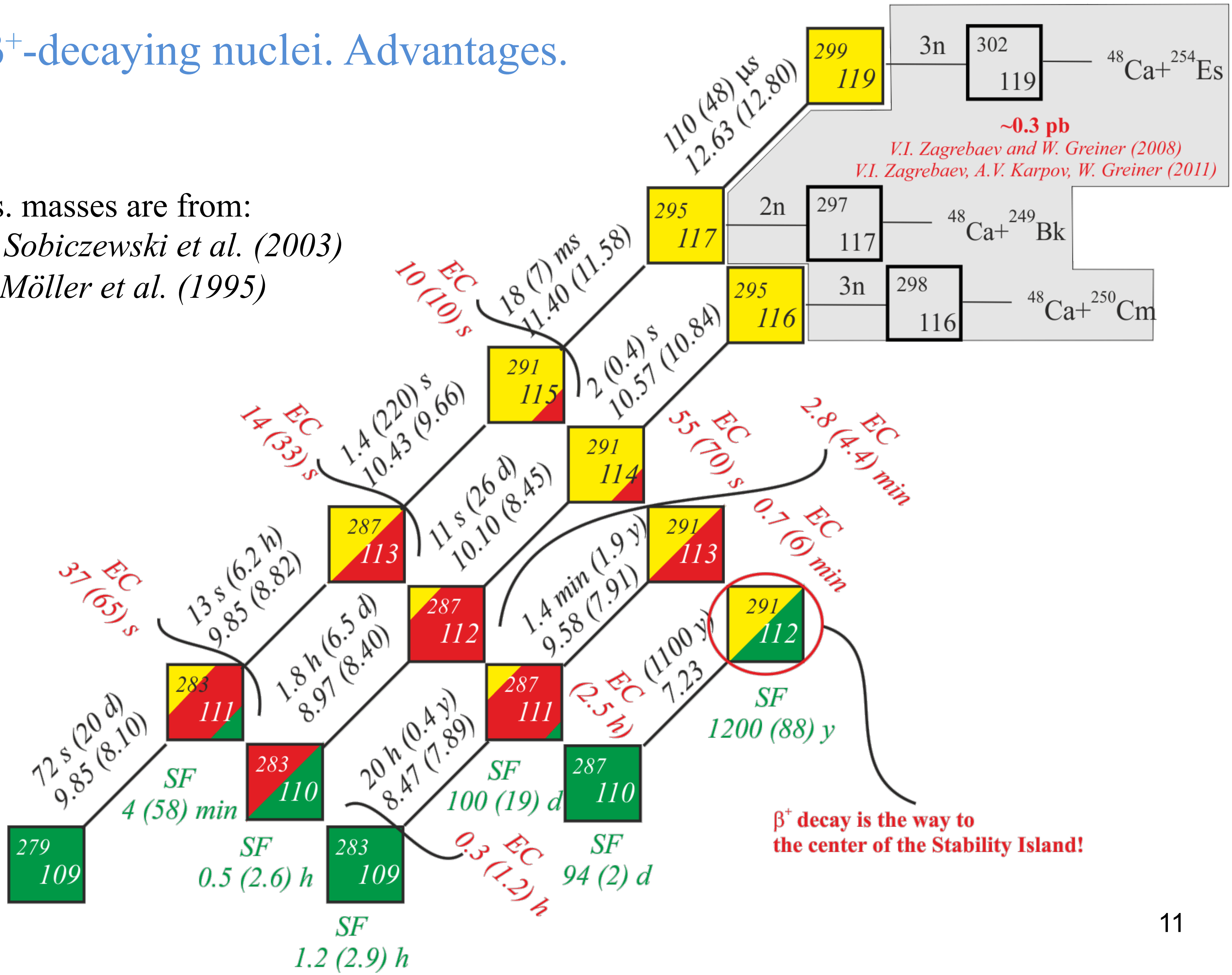
g.s. masses within Two-Center Shell Model *Y. Martinez et al. (2011)*



The predicted EC region appears independently of the mass formula used.

β^+-decaying nuclei. Advantages.

g.s. masses are from:
A. Sobiczewski et al. (2003)
P. Möller et al. (1995)



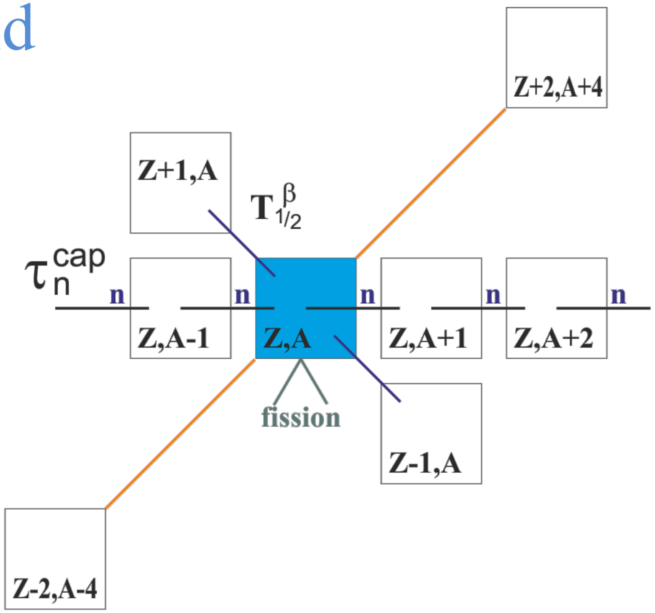
Nucleosynthesis in processes of slow and rapid neutron capture

n_0 is the neutron flux

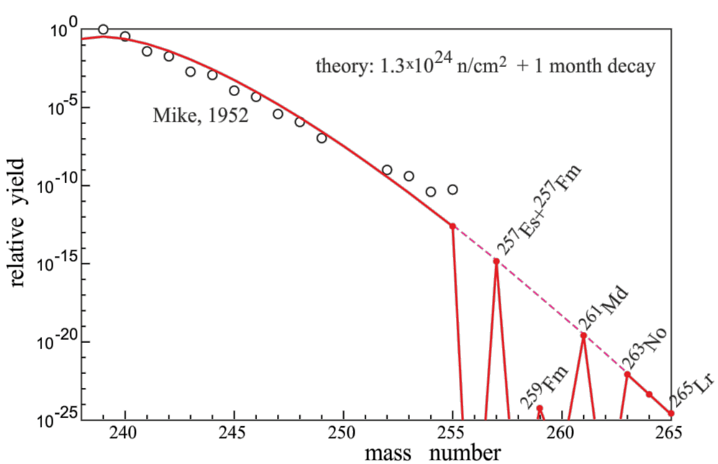
time of neutron capture

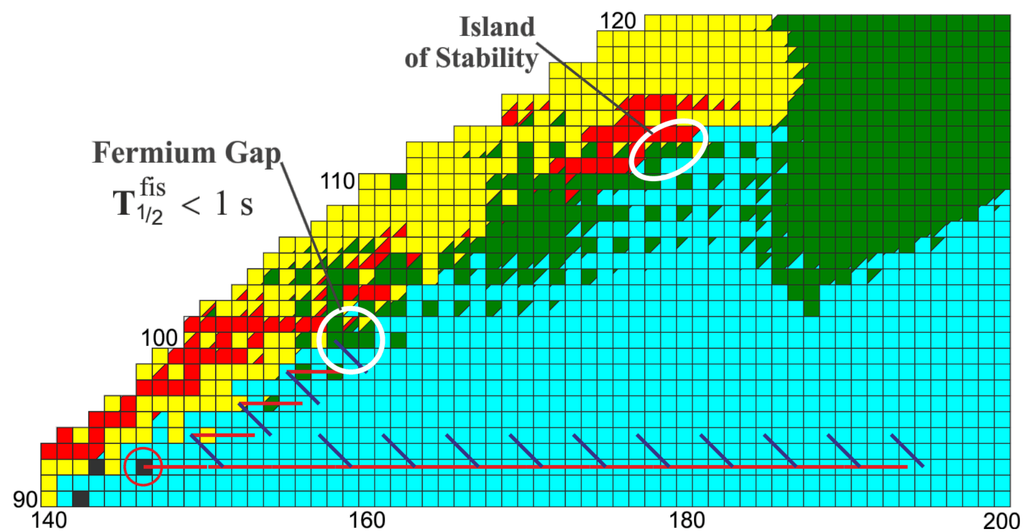
$$\tau_n^{cap} = \frac{1}{n_0 \times \sigma(n,\gamma)}$$

$$(Z,A) \rightarrow (Z,A+1) \text{ if } T_{1/2} > \tau_n^{cap}$$



$$\frac{dN_{ZA}}{dt} = N_{ZA\text{-}1}\, n_0\, \sigma^{n\gamma}_{ZA\text{-}1} - N_{ZA}\, n_0\, \sigma^{n\gamma}_{ZA} - N_{ZA} \frac{\ln 2}{T^{\beta}_{ZA}} - N_{ZA} \frac{\ln 2}{T^{\alpha}_{ZA}} - N_{ZA} \frac{\ln 2}{T^{fis}_{ZA}} + N_{Z\text{-}1A} \frac{\ln 2}{T^{\beta}_{Z\text{-}1A}} + N_{Z+2A+4} \frac{\ln 2}{T^{\alpha}_{Z+2A+4}}$$



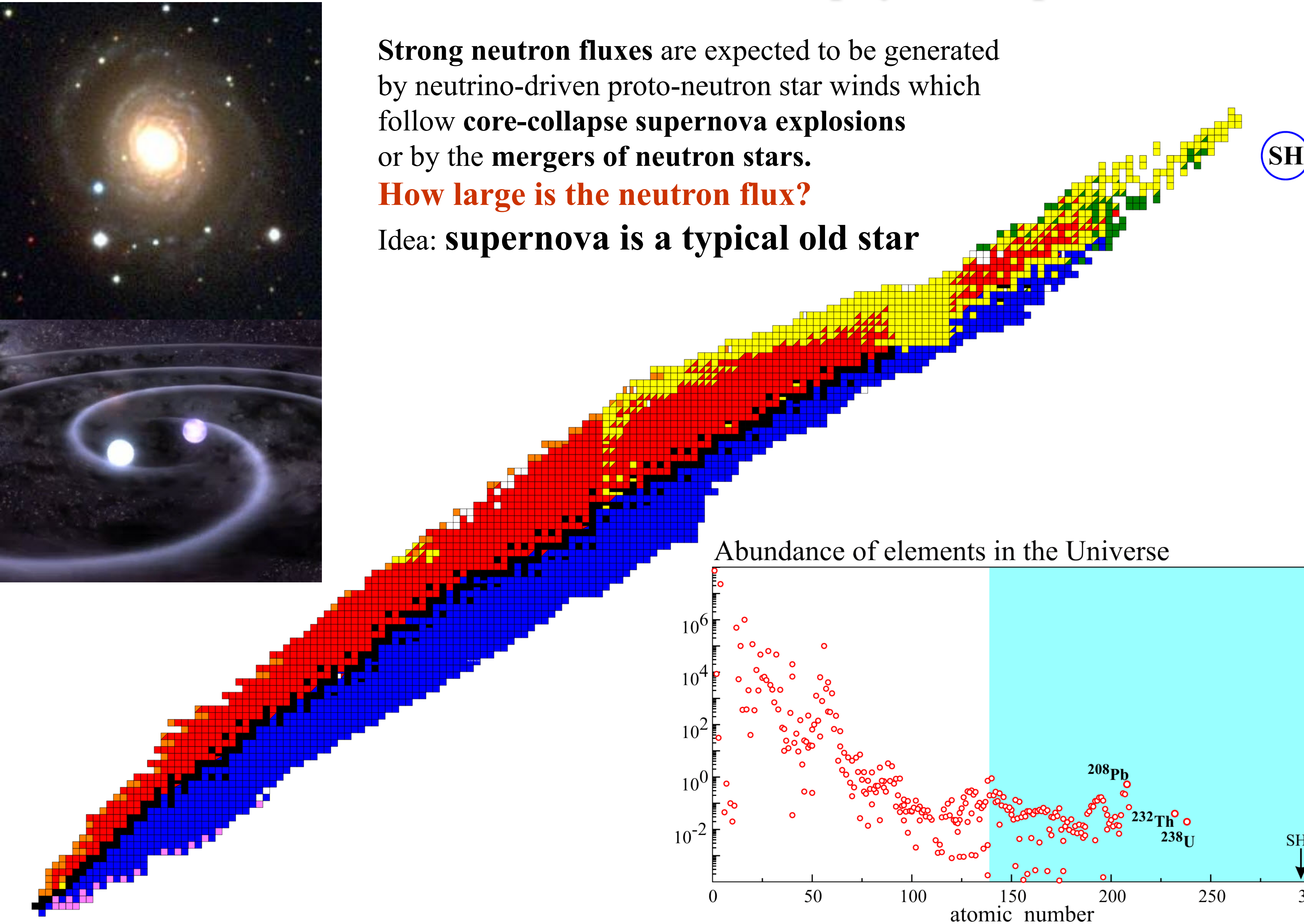


Formation of SH elements in astrophysical r-process

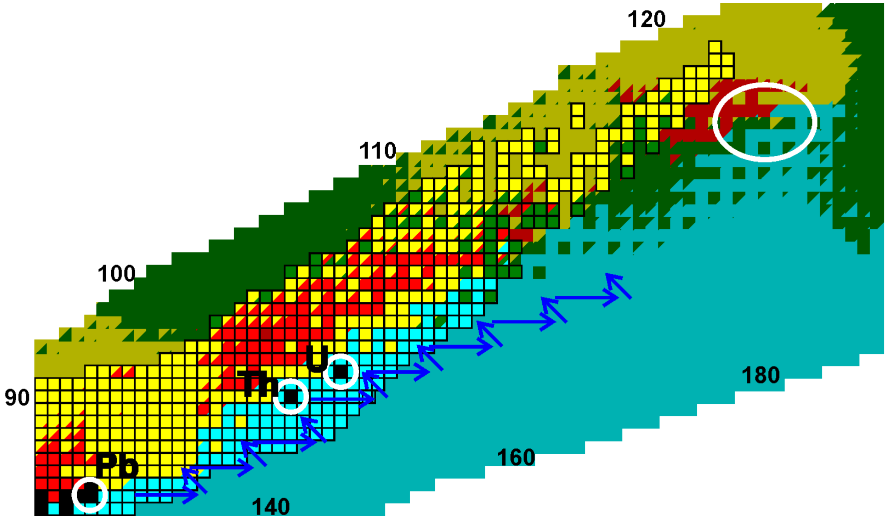
Strong neutron fluxes are expected to be generated by neutrino-driven proto-neutron star winds which follow **core-collapse supernova explosions** or by the **mergers of neutron stars.**

How large is the neutron flux?

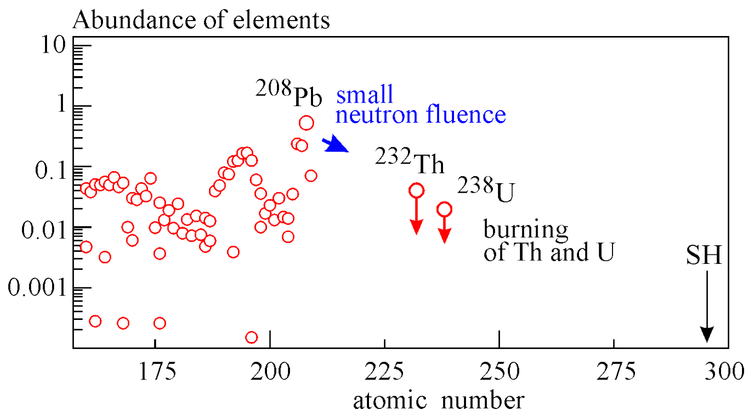
Idea: **supernova is a typical old star**

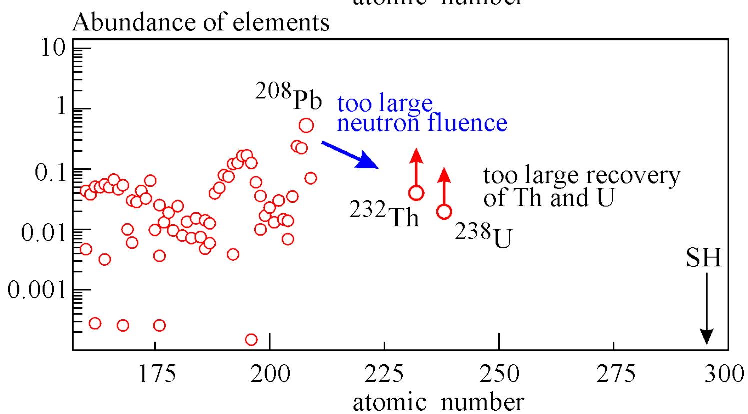


Formation of SH elements in astrophysical r-process

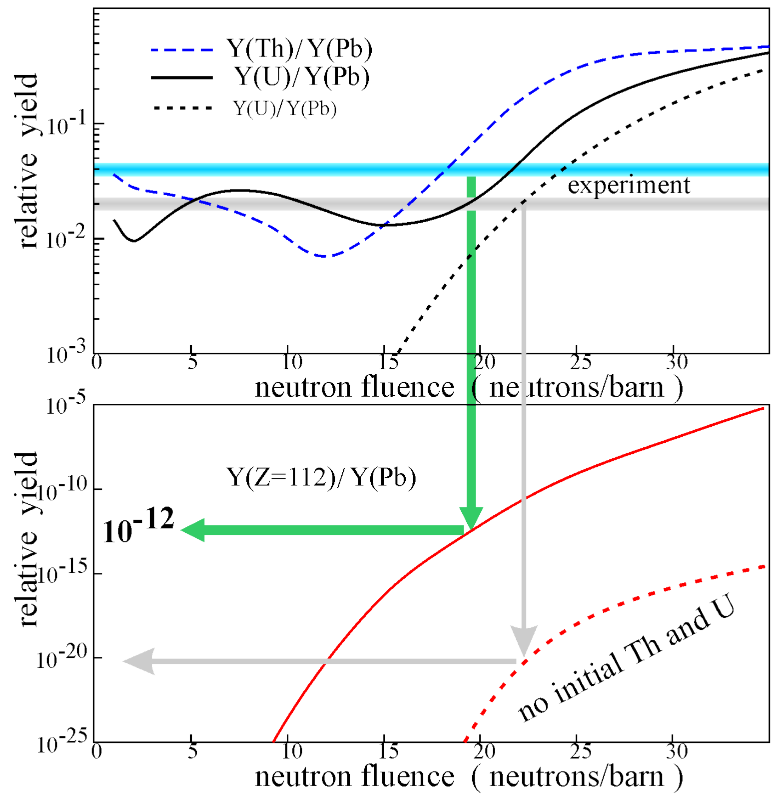


In the course of neutron irradiation initial Th and U material are depleted transforming to heavier elements and going to fission, while more abundant Pb and lighter stable elements enrich Th and U.





Unknown total neutron fluence is adjusted in such a way that the ratios **Th/Pb and U/Pb keep their experimental values.**



Conclusions

- **At existing experimental facilities the synthesis and detection of nuclei with *Z*>120 produced in fusion reactions may be difficult due to their short half-lives (shorter than 1μs) and low production cross sections.**

- **The ordinary fusion reactions could be used for the production of new isotopes of SH elements. The gap of unknown SH nuclei, located between the isotopes which were produced earlier in the "cold" and "hot" fusion reactions, could be filled in fusion reactions of ^{48}Ca with available lighter isotopes of Pu, Am and Cm.**

- **An existence of EC-decaying isotopes of elements with 111<*Z*<115 (located to the right of those synthesized in ^{48}Ca fusion reactions) is a chance to synthesize neutron-rich SH nuclei and to reach the center of the island of stability (predicted for β-stable Copernicium isotopes).**

- **Production of long-living SH nuclei in the astrophysical *r* process looks not so much pessimistic: relative yield of SH / Pb is about 10^{-12}.**

Our ability of predictions in superheavy mass area