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Can superheavy elements be formed in the r-process?

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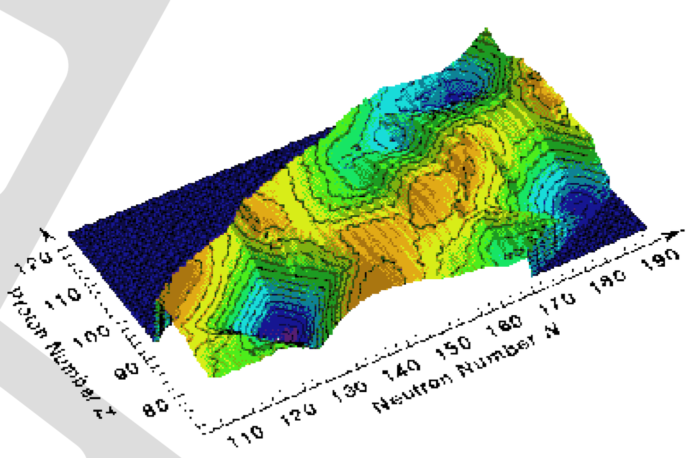
With the advent of up-to-date nuclear data and more accurate fission rates for actinium series[1], it becomes possible to consider the opportunity of nucleosynthesis prolongation and the formation of superheavy elements in the r-process (if neutron flow is sufficiently high).

We determine the r-process yields in the neutron star merger model[2], depending on calculation of the exploded matter composition. In this model, the r-process under high neutron density environment and big neutron-to-seed ratio (about few hundred neutrons by one seed nucleus) leads to a fast conversion of seed nuclei to actinium area, to fission via neutron-induced fission and recycling fission products as new seed nuclei.

The decay of newly formed isotopes near the region of superheavy elements goes on usually via α-decay, that gives an additional evidence in favor of high values of fission barriers of nuclei with neutron numbers close to 184. Only mass predictions on the basis of the ETFSi mass model[3] lead to high barriers and, as a result, to small fission rates for the isotopes from this region. Experimental data on decay modes[4] confirm the rates calculated on the basis of the ETFSi mass predictions.



The present calculations of nucleosynthesis show, that a nucleosynthesis wave, driven by the r-process, goes though the region of nuclei with 180 < N and N < 188 , where the fission rates are small; then some superheavy nuclei can be formed. The film frames on right side of poster show the movement of nucleosynthesis wave and changes of the r-process path together with nuclear yields (main figure); green colors are introduced to show the small yields for Z>100 and figure in bottom-right corner shows Y(A) for this area, and yellow-red colors and figure in top-left corner corresponds whole area and big yields. Alpha-decays were neglected, only β-delayed and neutron induced fission as well as β-decay and delayed fission were taken into account.

With the utilization of ETFSi mass and fission barrier predictions in the r-process model, superheavy elements (SHE) can be formed. Their yields strongly depend on a scenario and nuclear data predictions as well. A value of $\lg(Y_{SHE}/Y_U)$ at the end of the r-process is in range [-2, -18]. For current calculation it's about ~ -8 – -9, but for more accurate results, the fission rate calculations should be performed also for Z > 110 region. The formed superheavy elements has large β-decay[5] and alpha-decay and spontaneous fission[6] halflives. And now we are looking forward to new nuclear data for getting more precise results.

References

[1] I. V. Panov et al., Nuclear Physics A, 747, 633 (2005)

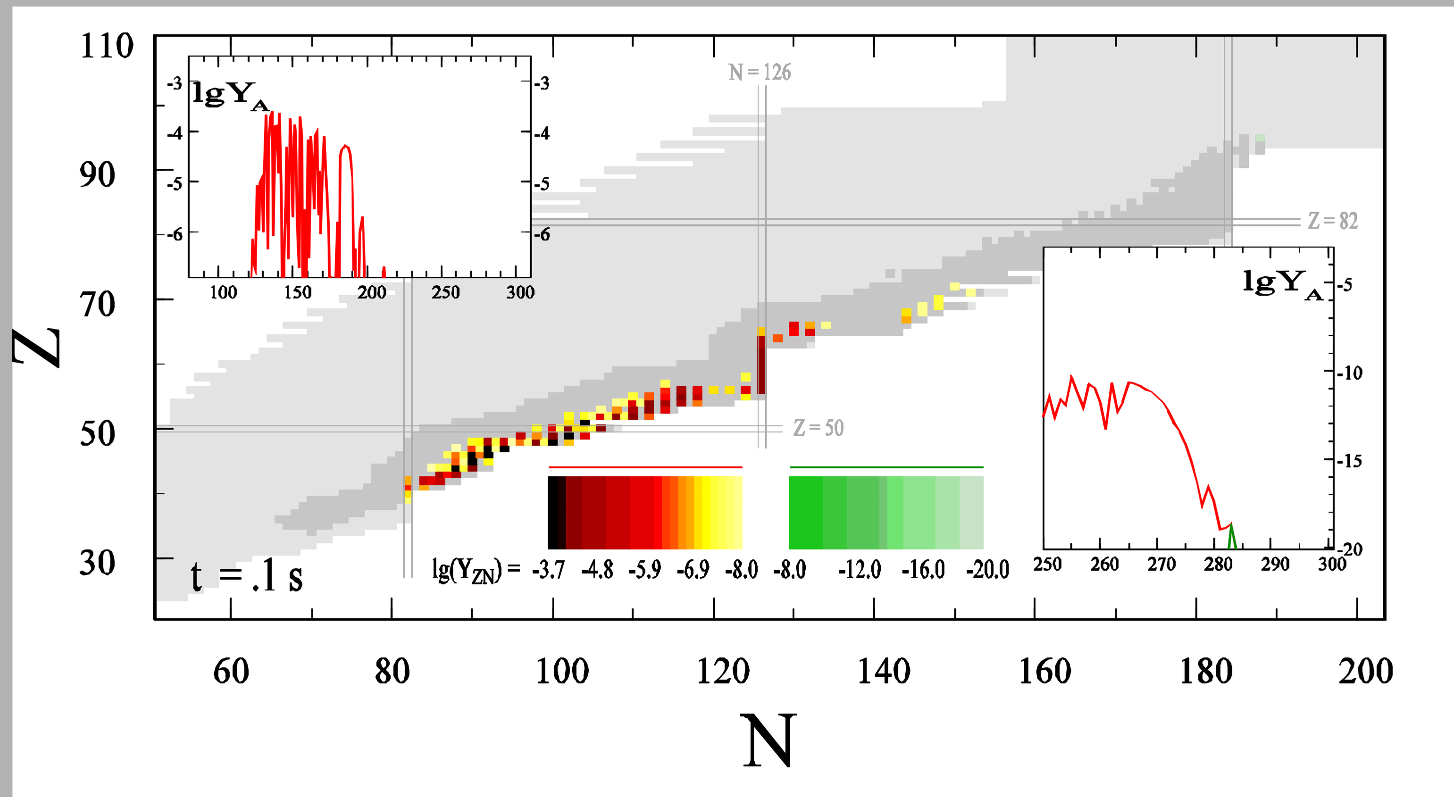
[2] S. Rosswog, M. Liebendörfer, F.-K. Thielemann et al., Astronomy and Astrophysics, 341, 499 (1999)

[3] A. Mamdouh et al., Nuclear Physics A, 679, 337 (2001)

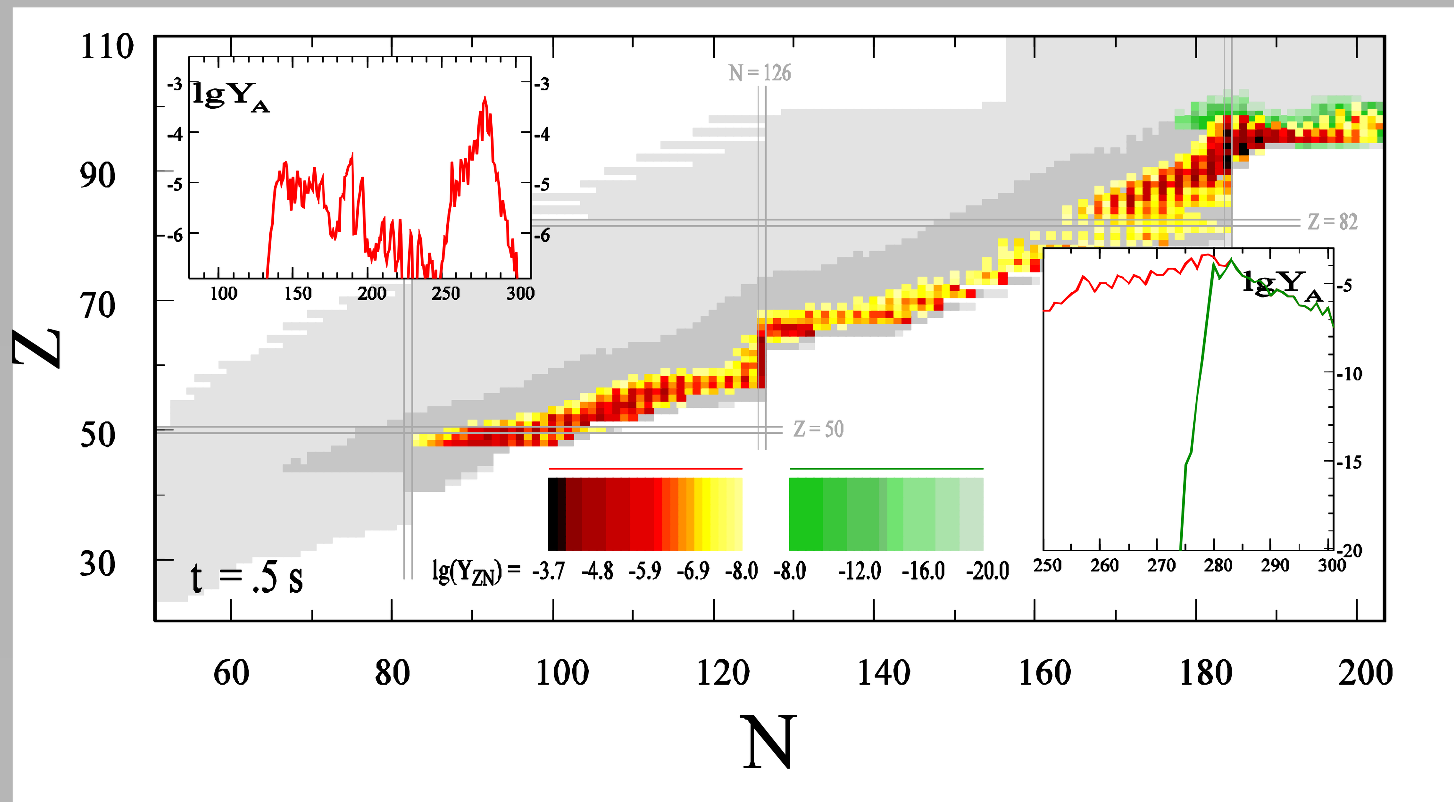
[4] Yu. Oganessian, Journal of Physics G: Nuclear and Particle Physics, 34, 165 (2007)

[5] P. Möller, B. Pfeiffer and K.-L. Kratz, Physical Review C, 55802-1-17, 67 (2003)

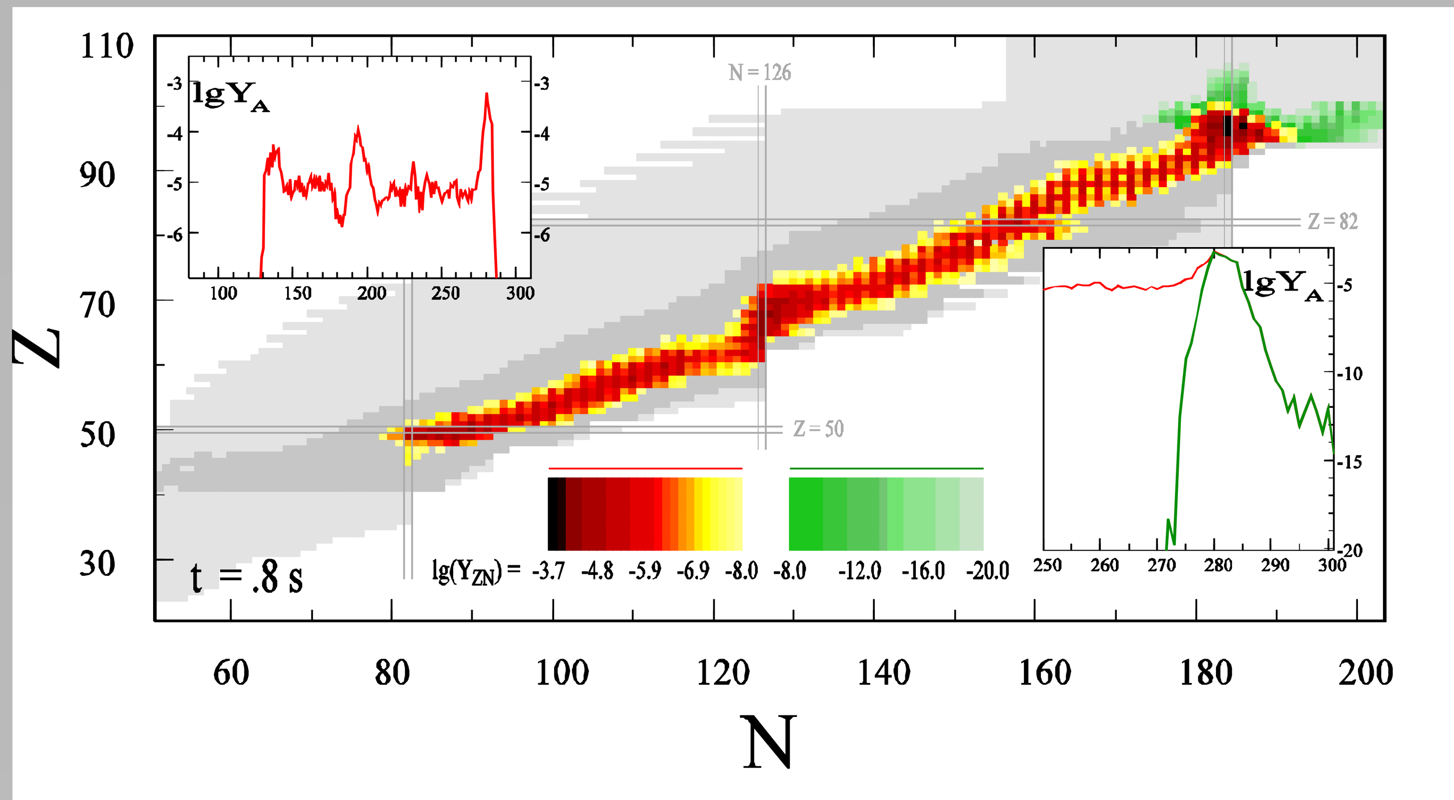
[6] R. Smolanczuk, Physical Review C, 812, 56 (1997)



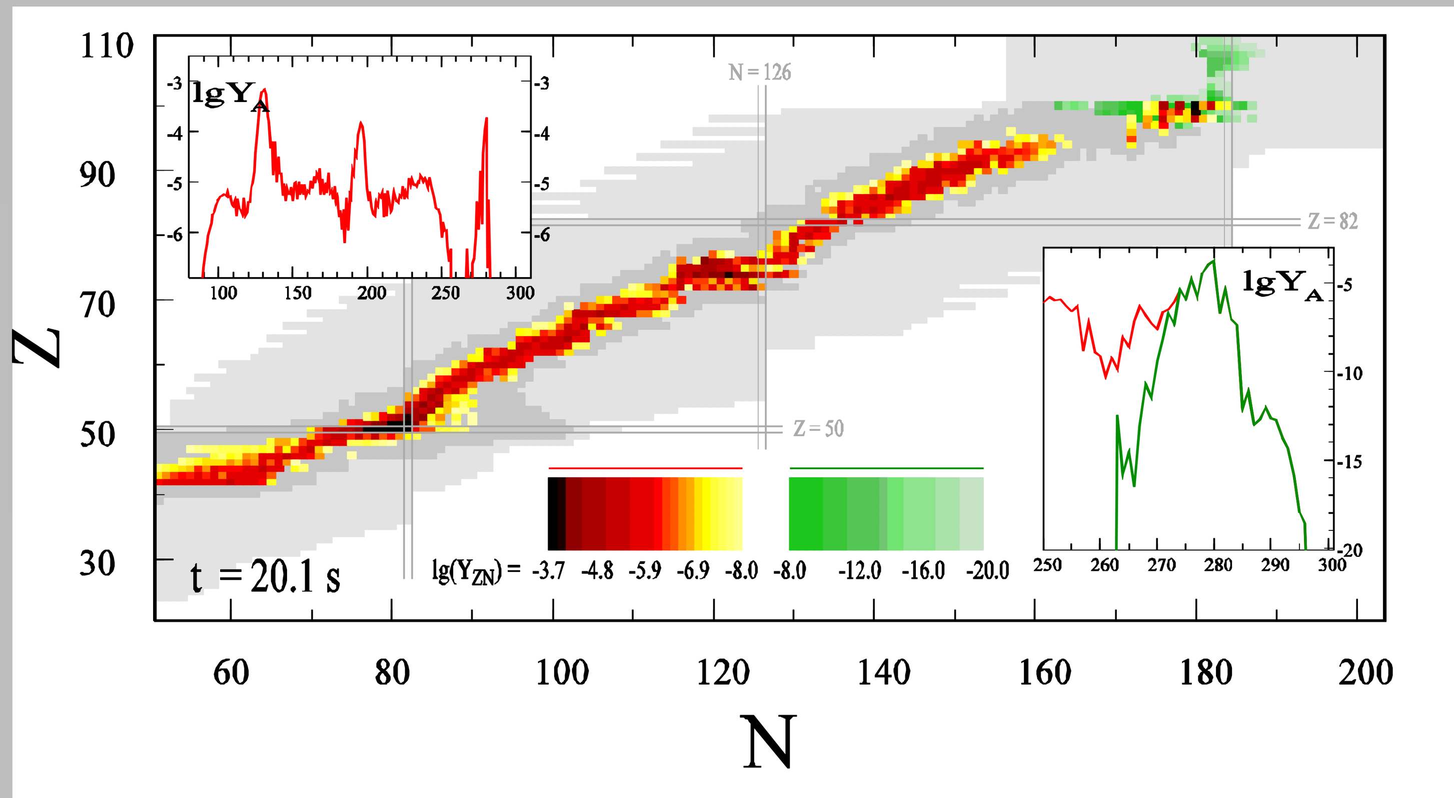
• Beginning of the r-process.
Nuclei due to capture of neutrons and beta-decay reach the transuranium area and break down.



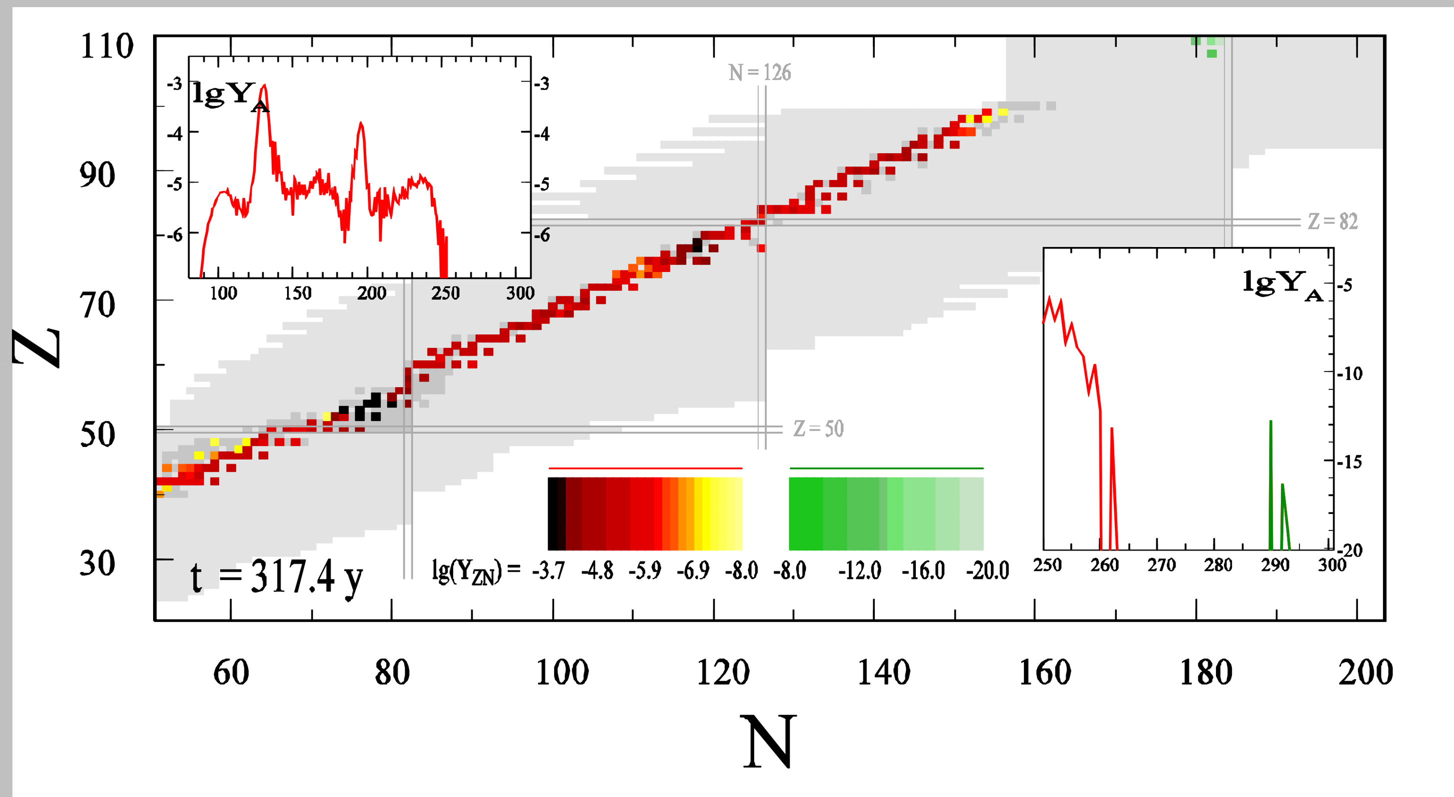
• Cycling of the r-process.
Fissioned nuclei are drawned into r-process again and reach transuranium area anew.



• Ending of the r-process.
Neutron density decreases and $N_A\langle\sigma\upsilon\rangle_{n,\gamma} \sim \lambda_\beta$ therefore nuclei reach superheavy area.



Nuclei penetration into superheavy area through "neck" in spontaneous and alfa-decay fission region.



• Superheavy nuclei formation