МАССОВОЕ РАСПРЕДЕЛЕНИЕ ПРОДУКТОВ ДЕЛЕНИЯ И НУКЛЕОСИНТЕЗ ТЯЖЕЛЫХ ЯДЕР.

FISSION FRAFMENTS DISTRIBUTION AND HEAVY ELEMENTS NUCLEOSYNTHESIS

Panov I.V.

NIC Kurchatov Institute – ITEP
ФТО КЯФК НИЦ "Курчатовский институт"

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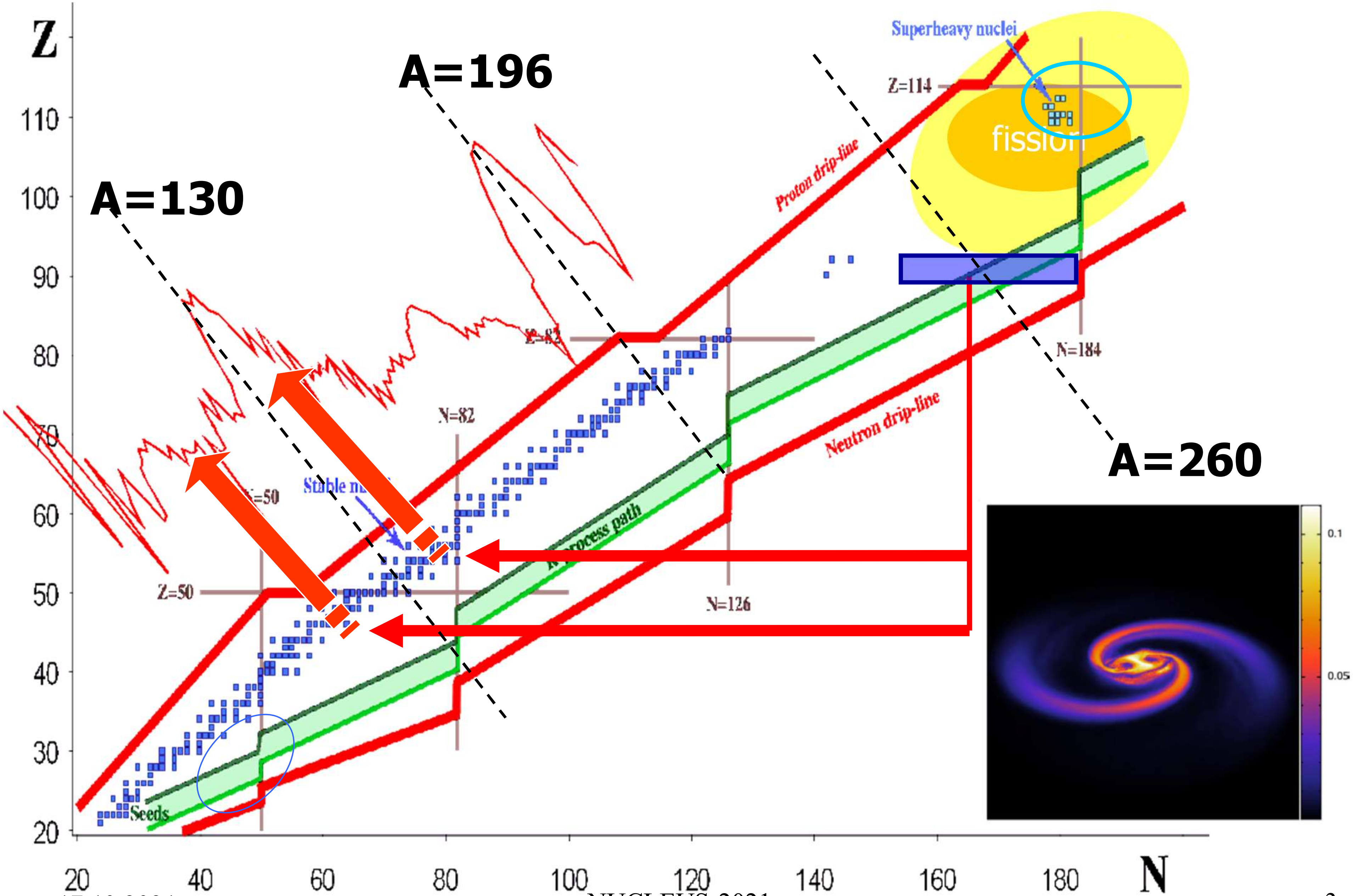
- Introduction, motivation
- Fission and fission fragments distribution
- r-process modelling and heavy nuclei in NSM-scenario
- Conclusions: discussion and opportunities

The discovery of neutron star merger process and simultaneous observation of heavy elements registered for the first time in 2017 confirms the theoretical findings that neutron star merger scenario for the close binary is the main site for the r-process passing.

Fission in such a scenario became one of the main reaction channel for the heavy nuclei formation due to involvement of fission products into the r-process as secondary seed nuclei. In such a scenario the role of fission products mass distribution became very important for the creation of second peak on the abundance curve. More over, the agreement of predicted abundances of second peak heavy nuclei with observations is the test for theoretical models of fission fragment mass distribution.

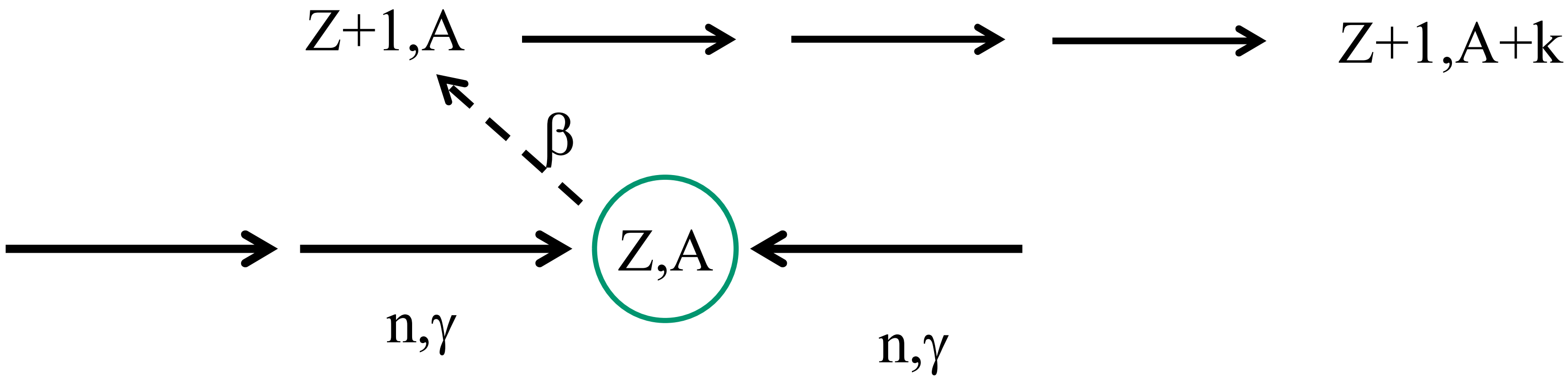
In the present report we considered the fission fragment mass distributions, based on present [1] and Kodama-Takahashi [2] models, and have researched the dependence of predicted value of chemical elements abundances on the fission fragments mass distribution models used. The role of symmetric and asymmetric mass distributions of fission products as well the multiplicity of fission neutrons were considered. 1. Panov, Korneev, Thielemann, Astronomy Letters. 2008. 2.Kodama, Takahashi, Nucl. Phys. A. 1975.

Nuclear map and r-process path



Nuclear data for the r-process: n/seeds >100

$$\lambda_{n\gamma} >> \lambda_\beta$$



- **mass-excess predictions**
- **(n,γ)- cross-sections** (neutron rates)
- **Beta-decay-rates** $\lambda_\beta \sim \ln 2/T_{1/2}$
- and $P_{\beta in}$
- Fission: (n,f), βdf, sf, FFD, …
- Other data …

THE ROLE OF FISSION IN NEUTRON STAR MERGERS AND ITS IMPACT ON THE r-PROCESS PEAKS

M. Eichler[1], A. Arcones[2,3], A. Kelic[3], O. Korobkin[4], K. Langanke[2,3], T. Marketin[5], G. Martinez-Pinedo[2,3], I. Panov[1,6], T. Rauscher[1,7], S. Rosswog[4], C. Winteler[8], N. T. Zinner[9], and F.-K. Thielemann[1] AJ, 808:30 (13pp), 2015

1 University of Basel, Basel, Switzerland;

2 Institut für Kernphysik, Technische Universität, Darmstadt, Germany;

3 GSI GmbH, Darmstadt, Germany;

4 The Oskar Klein Centre, Stockholm University, Stockholm, Sweden;

5 University of Zagreb, Zagreb, Croatia;

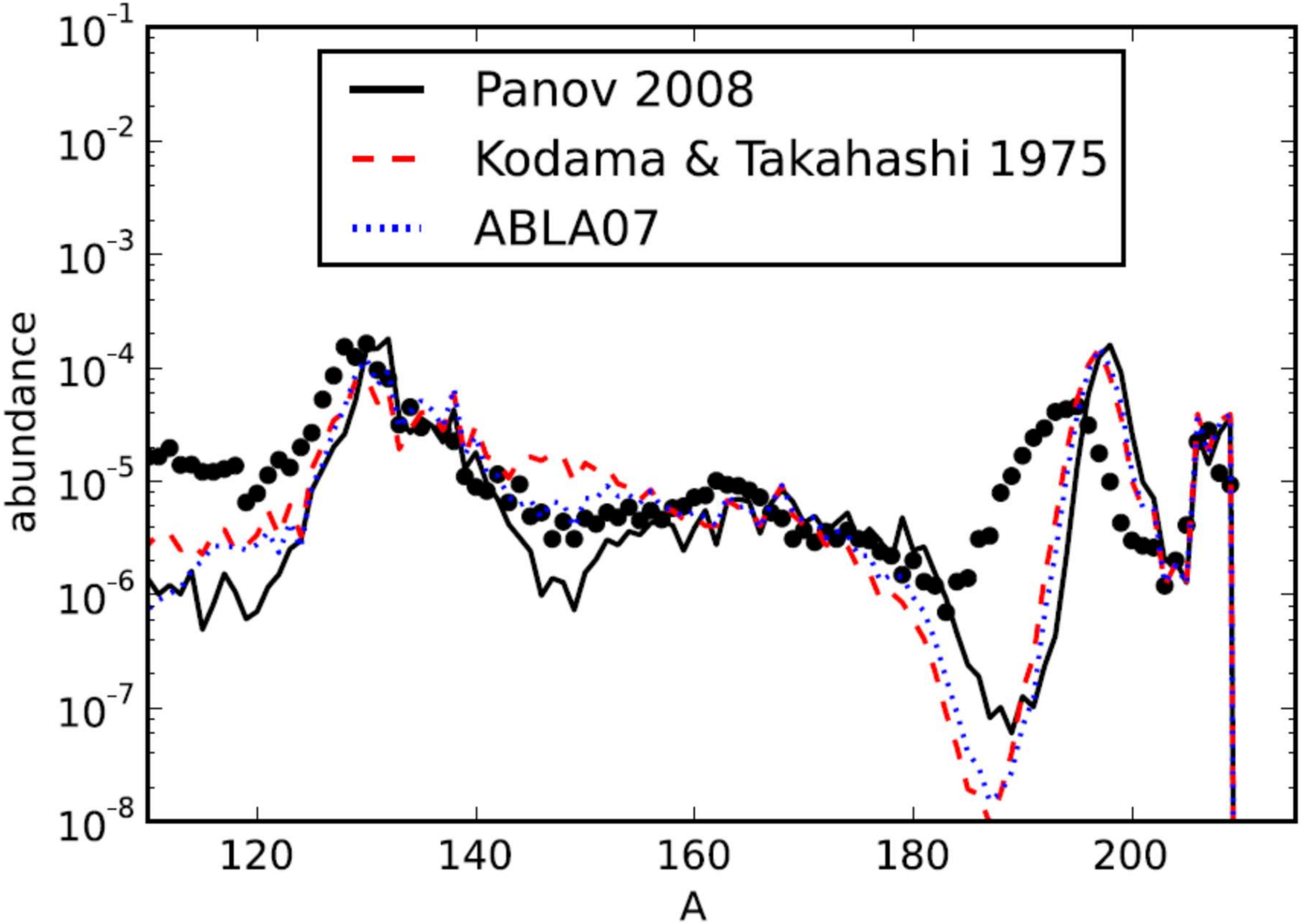
6 NRC "Kurchatov Institute" - ITEP, Russia;

7 Centre for Astrophysics Research, University of Hertfordshire, UK;

8 Institut Energie am Bau, Fachhochschule, Switzerland;

9 Aarhus University, Aarhus C, Denmark

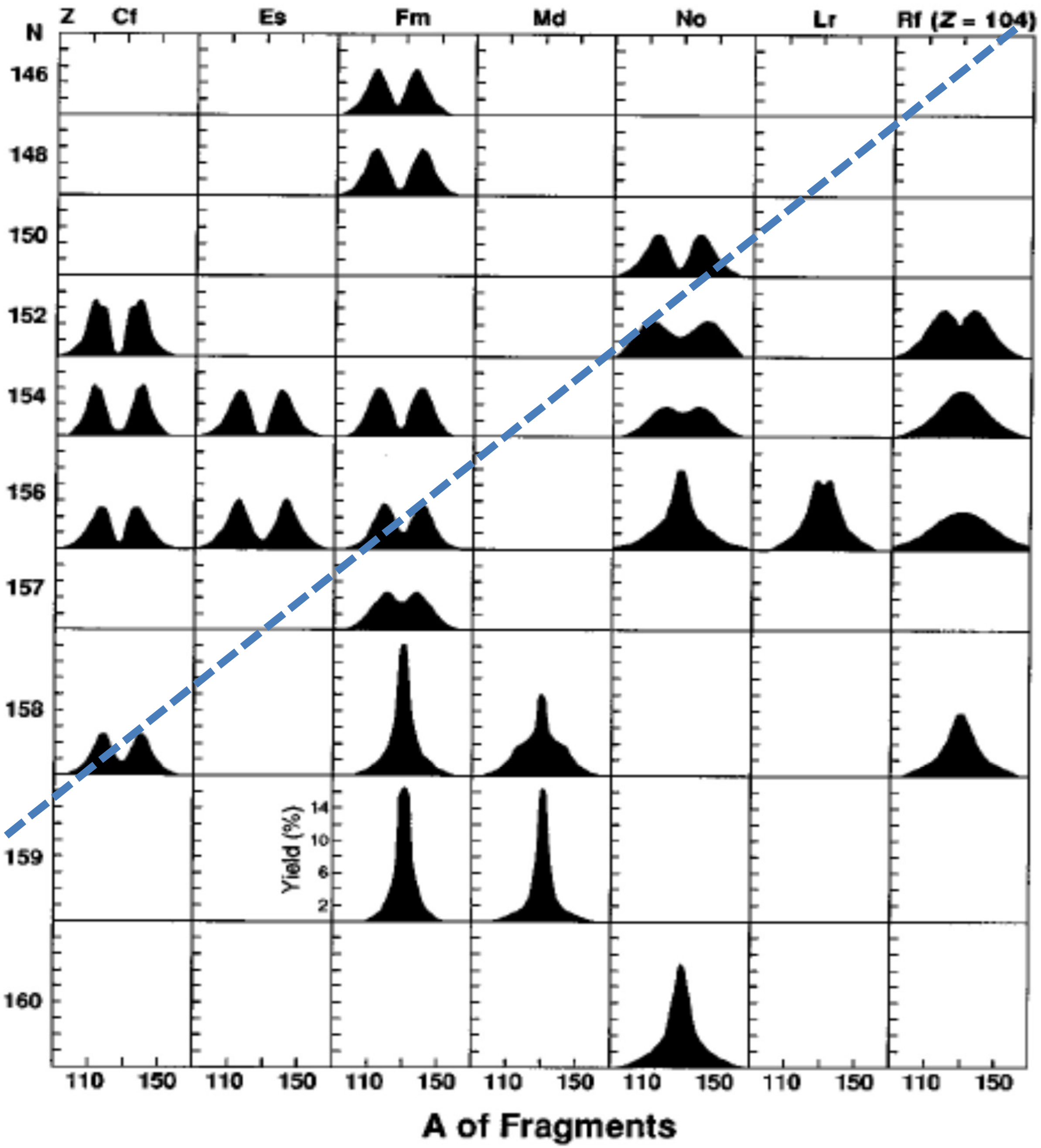
fission fragment distributions are tested for the mass model ETFSI-Q



Among majority of FFD models we will consider only global models

-B. D. Wilkins, Phys. Rev. C 14 (1976), In the model it is assumed that different splits in mass are basically determined by the number of available transition states above the potential energy surface behind the outer saddle point. Relative probabilities of formation of fission fragments are determined from potential energies of a system of two nearly touching coaxial spheroids with deformations.

- Based on Wilkins' approach: ABLA (K.-H. Schmidt, A. Kelic, 2008.
- GEF: General Description of Fission Observables; Goriely – 2015 SPY - CEA Centre de Saclay, 2012, Wilkins model + HF)
- **ABLA-** (abrasion-ablation model) The dynamics of the fission process responsible for the fragment formation is considered in an approximate way, but including the evaporation of fission neutrons.
- **FFDn** (Panov, 2001; Panov&Korneev, 2006, 2008) – based on nuclear systematics
- Schematic model by **Kodama&Takahashi** 1975



Lane et al. 1996,PR C, Spontaneous fission properties

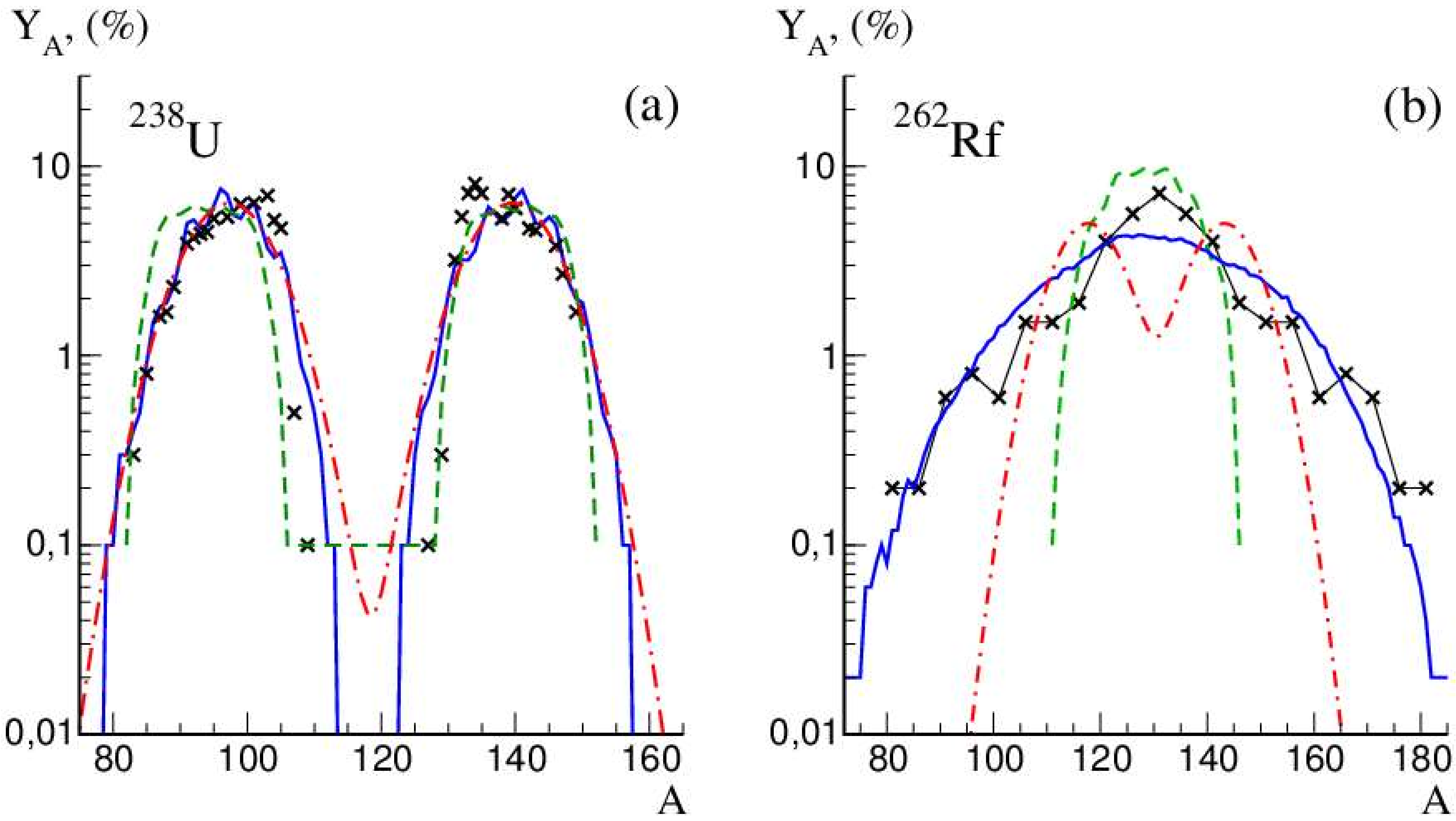
KT Kodama,Takahhashi, NP A, 1975

A_L=0.85*Afis-104.98 A_H=0.15*Afis+103.87

Z_A=Zfis*(Ai+0.6)/Afis

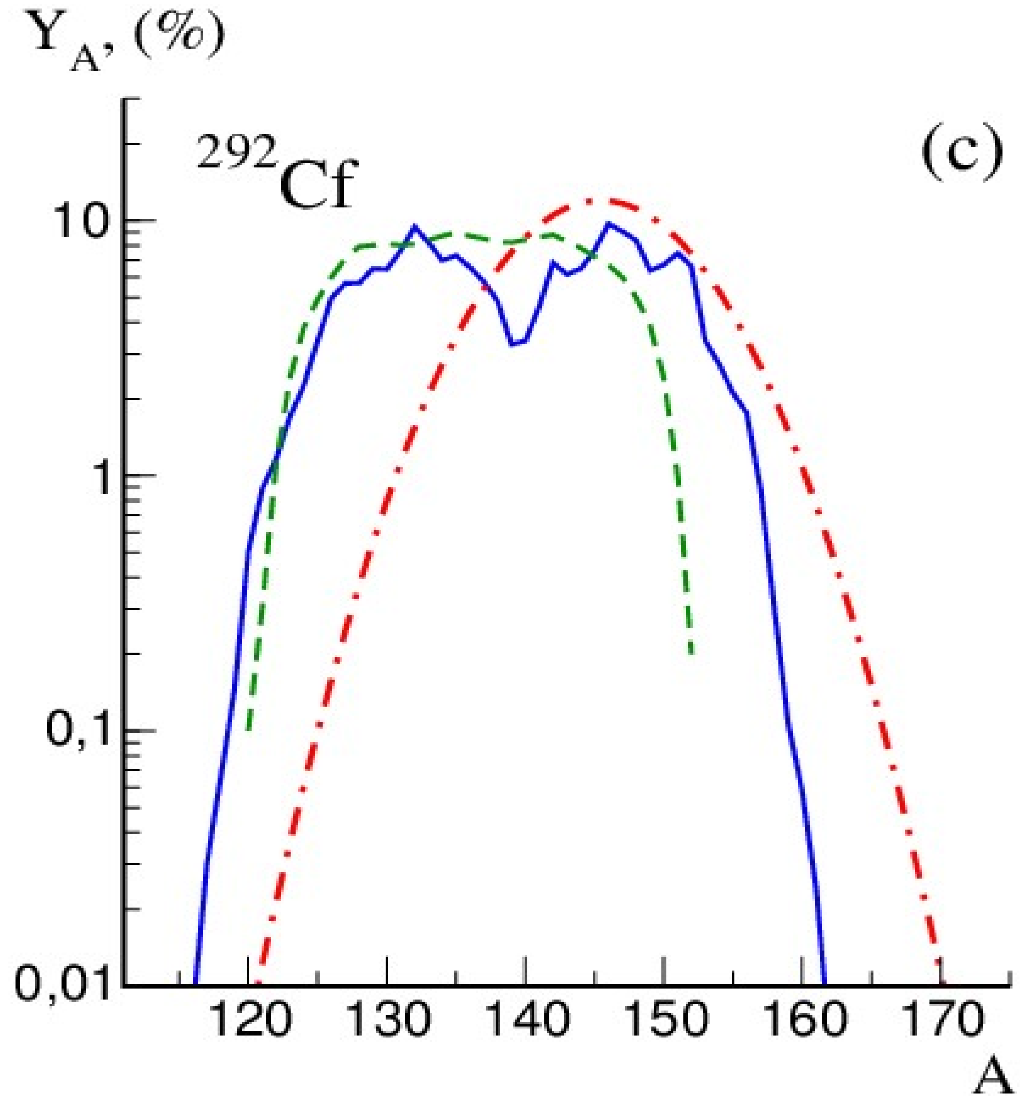
Y_{ff}(Zi,Ai)=exp(-(Zi-Z_A)**2/0.8)*
(exp(-(Ai-A_L)**2/78)+exp(-(Ai-A_H)**2/78))/
(3.14*sqrt(0.8*78))

Present basical model- FFDn, referred as panov2008 (I. Panov et al., NP A, **688**, 587 (2001)) was based on Smirenkin & Itkis parametrization for heavier fragment (Nucl. Phys. 1989) Z_H=52-(Zf-80)*2/20, A_H=130 and extended for neutron-rich nuclei with Z_{fis}>92 и A_{fis}>260;

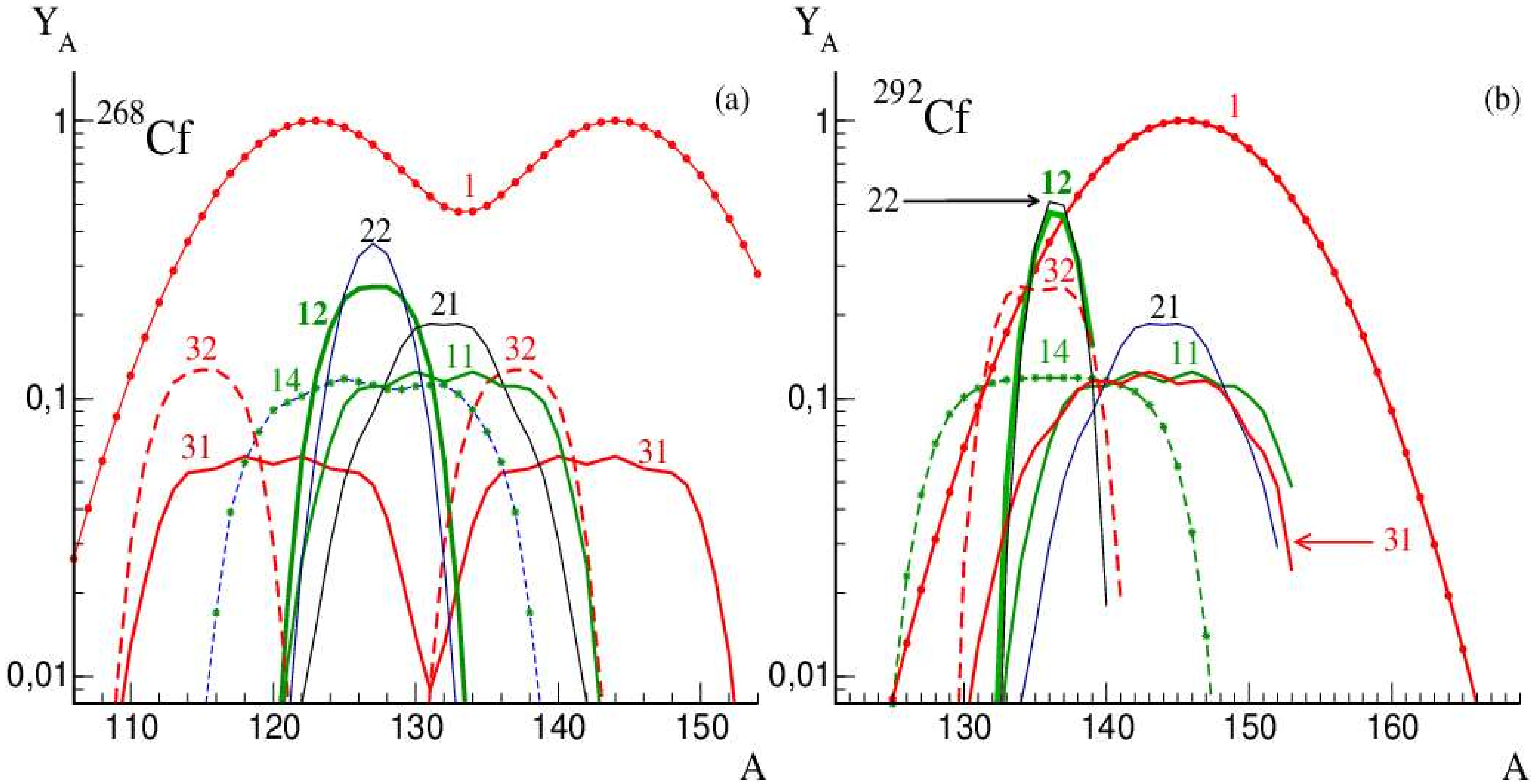


FFDn , KT-M, ABLA

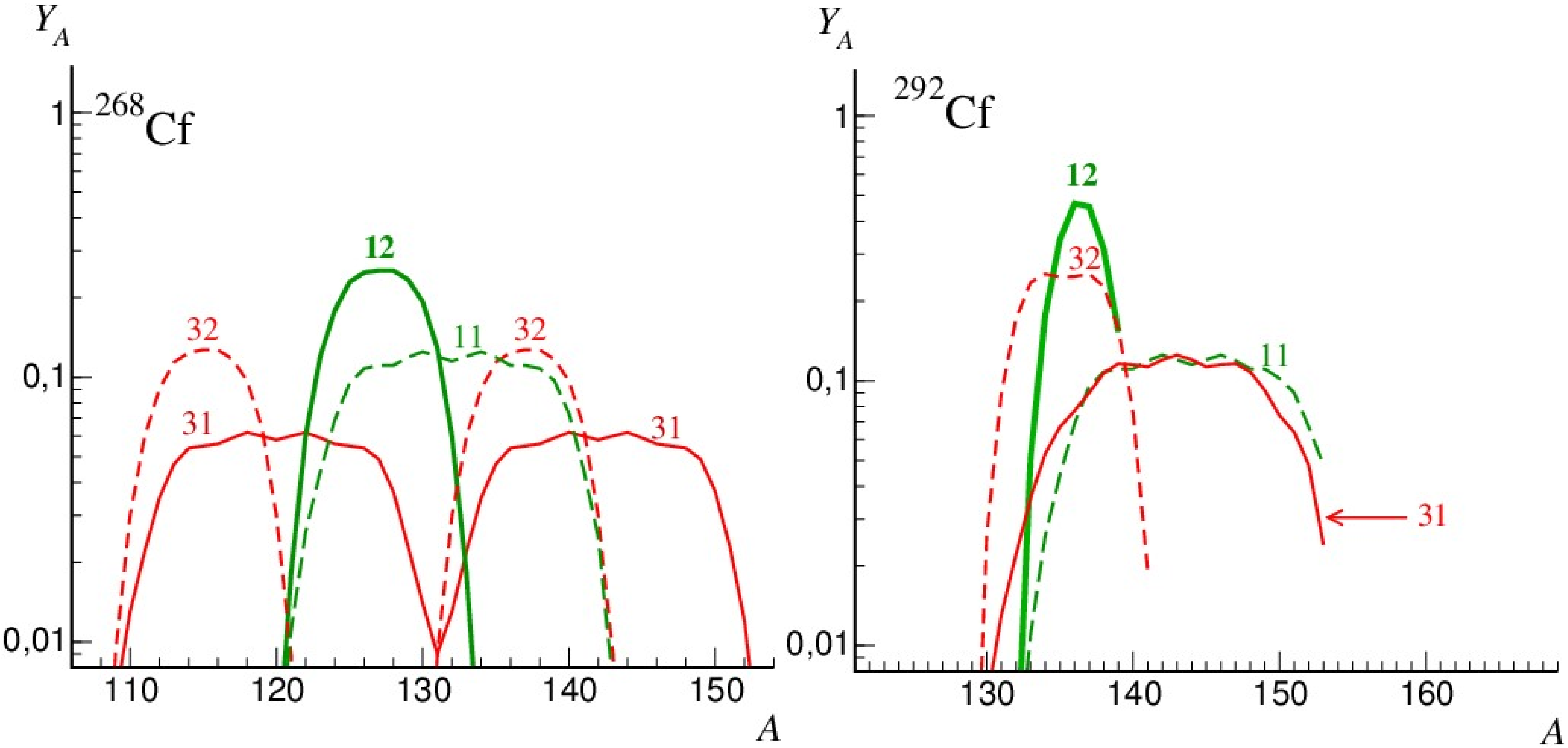
262Rf(Z=104) , Phys. Rev. C, 53, 2893 (1996).



Y_A, (%)
292Cf
(c)
10
1
0,1
0,01
120
130
140
150
160
170
A

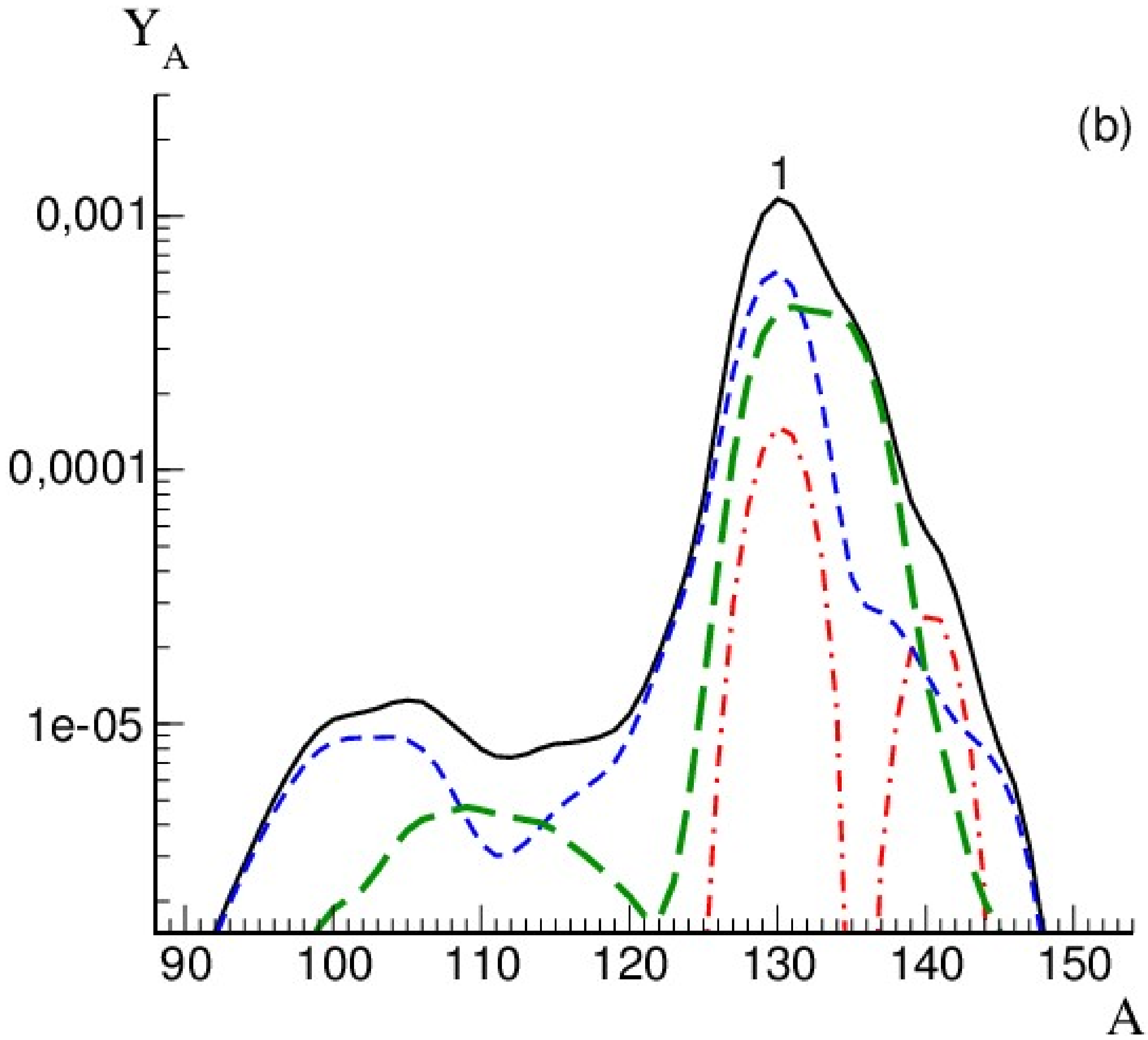


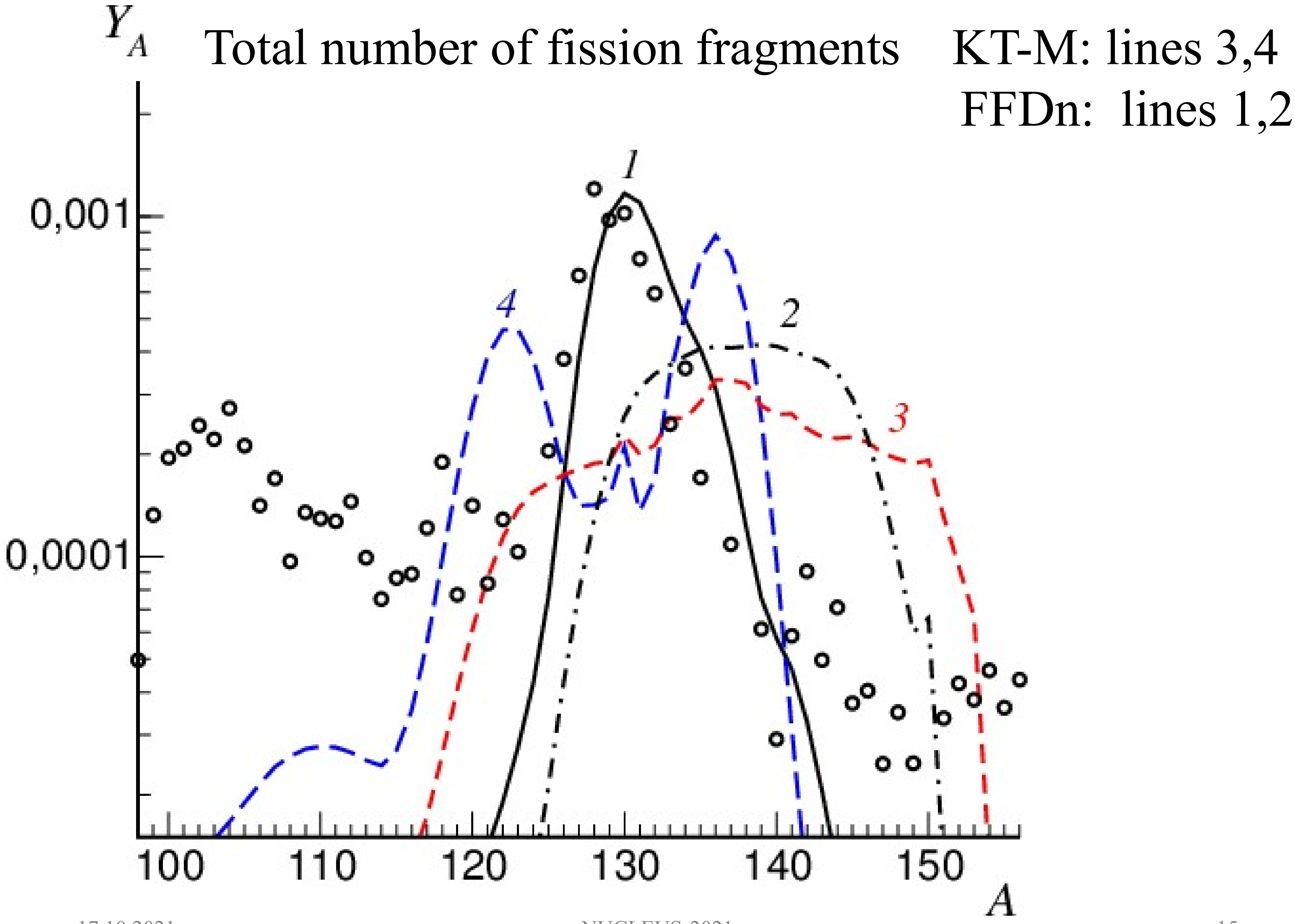
Fission fragment distributions for 268Cf , 292Cf , according to models:
FFDn with fission neutrons ν_n (line 12) and artificially reduced ν_n (line 11);
KT-M with fission neutrons taking into account (line 32) and with artificially reduced fission neutrons nn (line 31); FFDn, but with other parametrization [29] (line 14);
FFDn, based on normal distribution with ν_n (line22) and without ν_n (line21);



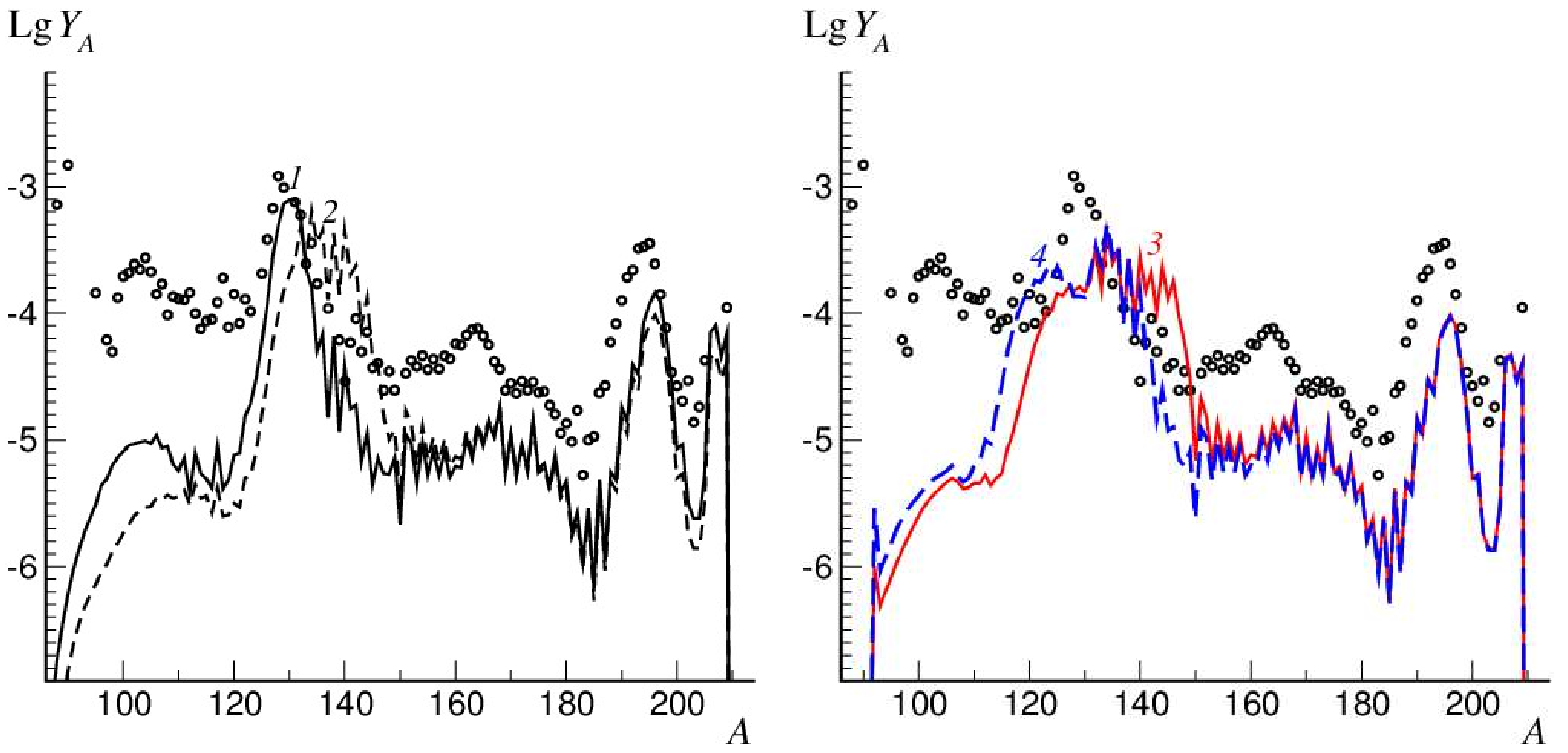
Fission fragment distributions for 268Cf , 292Cf , according to models: **FFDn** with fission neutrons ν_n (line 12) and artificially reduced ν_n (line 11);
КТ-М with fission neutrons taking into account (line 32) and with artificially reduced fission neutrons ν_n (line 31);

Total number of fission fragments (black line) when FFDn was applied and fission processes contribution (in color)





Y_A
Total number of fission fragments
KT-M: lines 3,4
FFDn: lines 1,2
1
2
3
4
0,001
0,0001
100
110
120
130
140
150
A

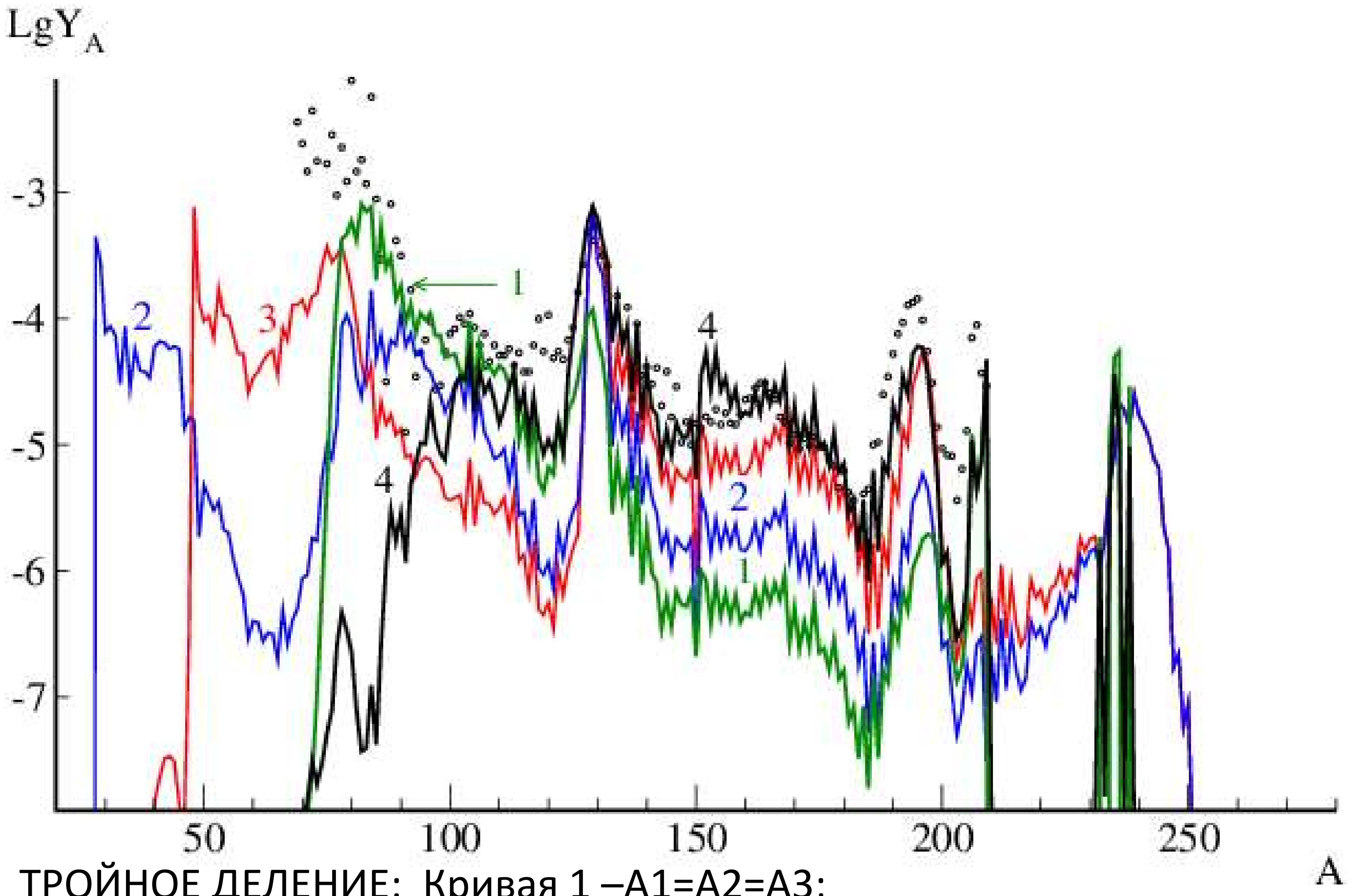


line 1 — basic parametric set for fission fragment distribution model

Dashed line 2 – model FFDn, but fission neutrons ν_n switch off ;

line 3 – basic model KT-M - no fission neutrons ν_n ;

Line 4 – model KT-M, but with fission neutrons ν_n included;



ТРОЙНОЕ ДЕЛЕНИЕ: Кривая 1 –A1=A2=A3;

Кривая 2 – A1=A2; A3=48; Кривая 3 –A1=A2; A3=28;

CONCLUSIONS

Application of fission fragment distribution models –FFDn and KT-M to the r-process model, on the results of nucleosynthesis in NSM scenario have shown:

1. The abundance near A~130 peak strongly depend on multiplicity of fission neutrons. The evaporation of neutrons reduce strongly the fragment masses.
2. For better agreement with observation mass distribution should be rather symmetric (one-hump) than asymmetric (two-hump) one.
3. The other parameters of the models are of minor importance.

And we can conclude that the models taking into account fission neutrons and symmetric fission for majority of actinides can describe well the second peak especially when fission cycling occurs.

Thank you for attention!

And project RSF № 21-12-00061 for support.

o - Solar abundance of the r-elements (small circles) and model calculations Y_A in the model of Neutron star merger (in red). Blue line – after alpha-decay when β-decay rates for Z>80 were increased in 3 times. ИМ **(Panov et al. Astronomy Letters, 2008;)**