Direct Capture and the r-process

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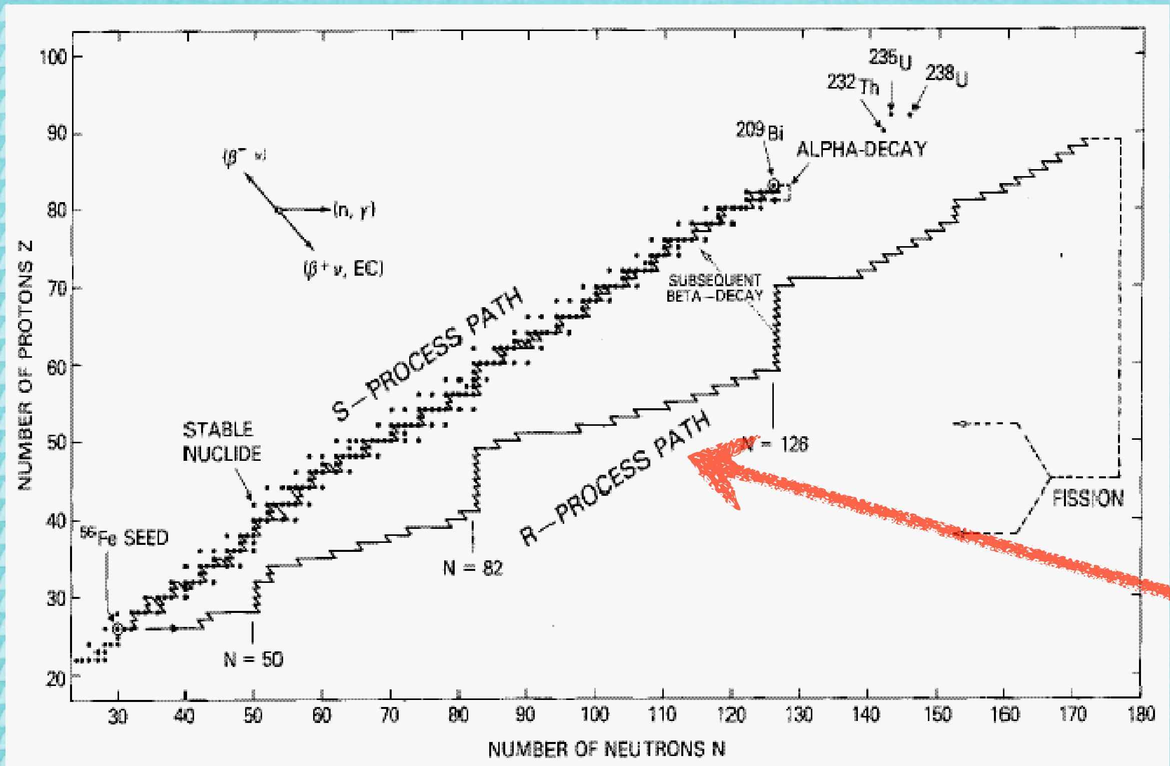
r-process nucleosynthesis



Astrophysical site(s) for the r-process is still unknown.

r-process path is not always in (n,γ)-(γ,n) equilibrium.

beta-decay,(n,γ)rates are also important!

Direct capture

Neutron-capture process
--->compound process + direct capture process

Mathews et al. (1983)
•Importance of direct capture on r-process
(HF method is invalid for nuclei on r-process path)
•Compare the reaction rates of Compound process and direct capture of Cd

Goriely (1997)
•Calculate direct capture reactions for all nuclei
•discuss the role of direct capture with canonical model.

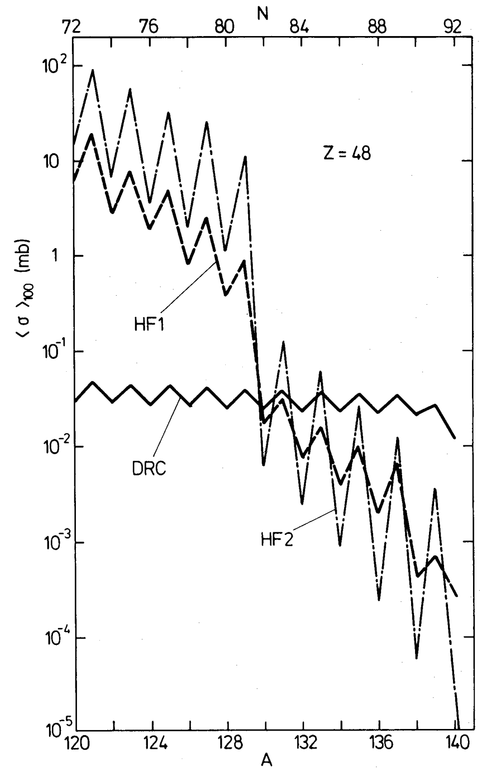


FIG. 1.—A comparison of Maxwellian averaged neutron capture cross sections at $kT = 100$ keV for Cd isotopes through the *r*-process path at $A = 130$. DRC indicates the direct radiative capture component. HF1 is the statistical model calculation of Thielemann (1980). HF2 is the analytical statistical model calculation of Woosley *et al.* (1975). Here it can be seen that, beyond the neutron closed shell at $N = 82$, the direct ratidative capture component dominates the neutron capture rate.

→ how direct capture works in dynamical calculations?

r-process calculation

Dynamical full network code

based on Meyer et al. 1994,
Modified by Terasawa & Orito(2001), Otsuki(2003)

$$\dot{Y}_p = \sum_{r,s} \frac{c_p}{c_r! c_s!} Y_r^{c_r} Y_s^{c_s} R_{rs} - \sum_q \frac{c_p}{c_p! c_q!} Y_p^{c_p} Y_q^{c_q} R_{pq}$$

~7000 nuclide, ~10000reactions for each time step

MASS…FRDM+AME03 (Möller et al. 1995)
(n,γ)…based on FRDM (Rauscher et al. 2000, Panov et al. 2009)
β-decay…based on FRDM (Möller et al. 2002)
charged current reaction…NACRE+Reaclib

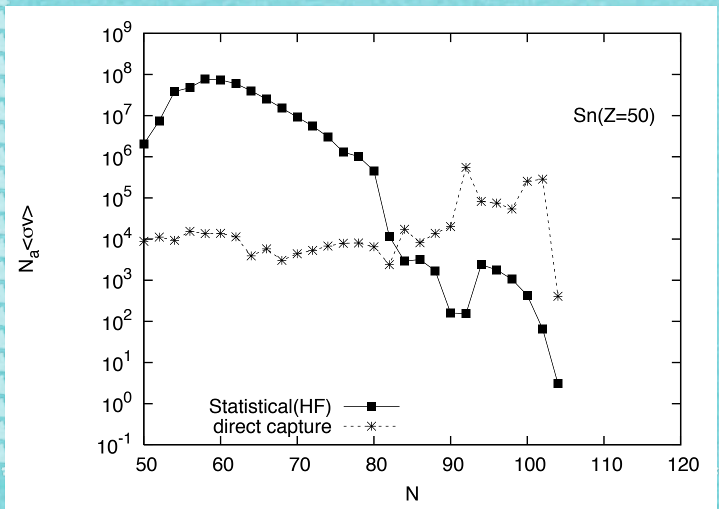
Physical condition
Spherical steady state flow

Direct capture reaction rates

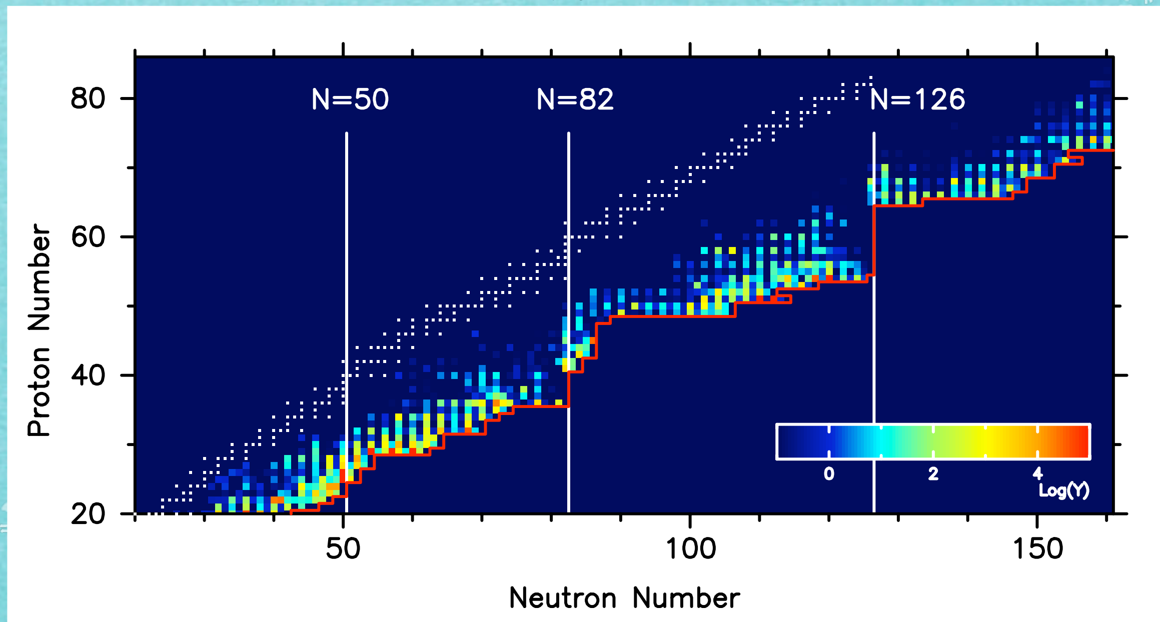
semi-analytic model (Typel et al. 2005)
-define a pattern of single-particle level using experimental data and scale it for each nuclei.
-considering deformation
-deformation and Sn from FRDM

Comparison between reaction rates of compound process(HF method, Rauscher et al. 2000) and direct capture rates(this work)

Sn(Z=50)

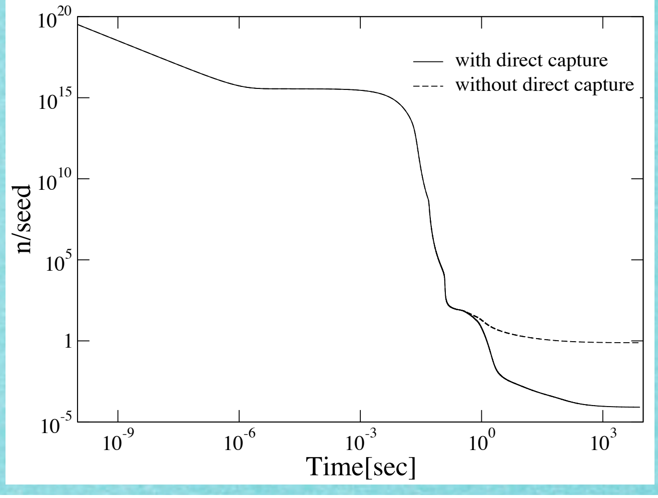


$N_A\langle\sigma v\rangle_{DC}/N_A\langle\sigma v\rangle_{HF}$

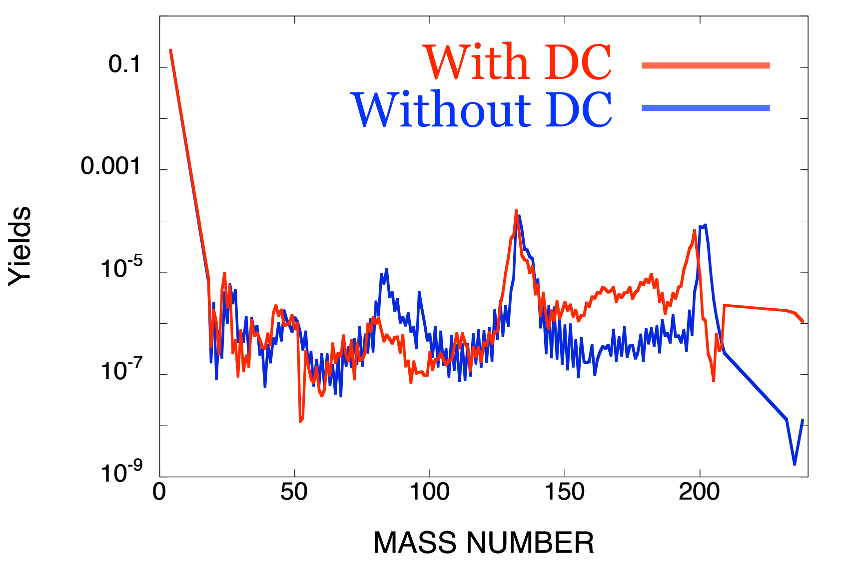


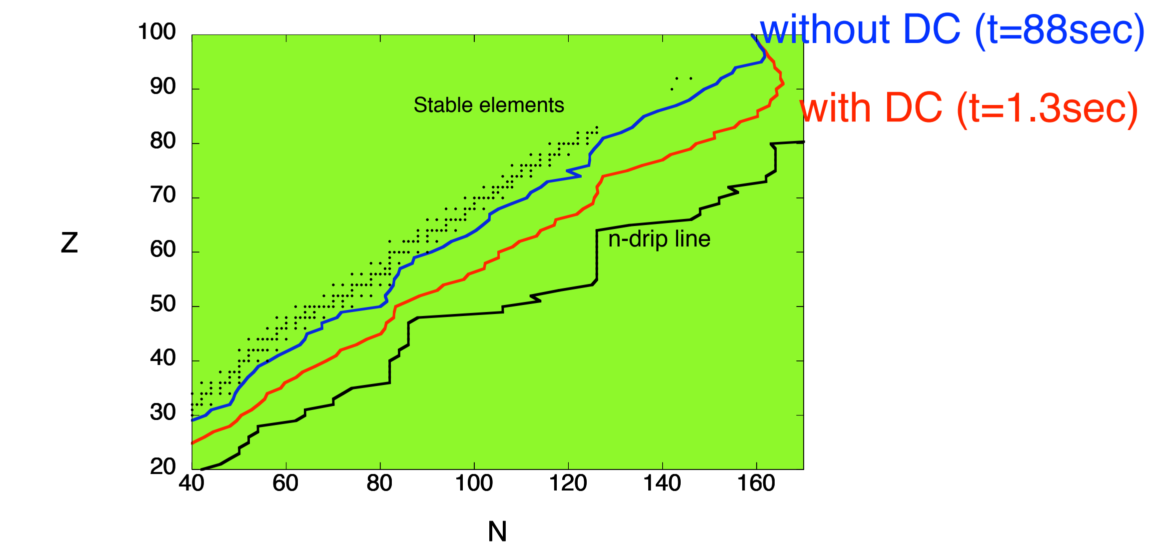
Effect of direct capture reaction

the direct capture furthers r-process and make freeze out earlier.
---> Change final abundance



Wind solution with S=250



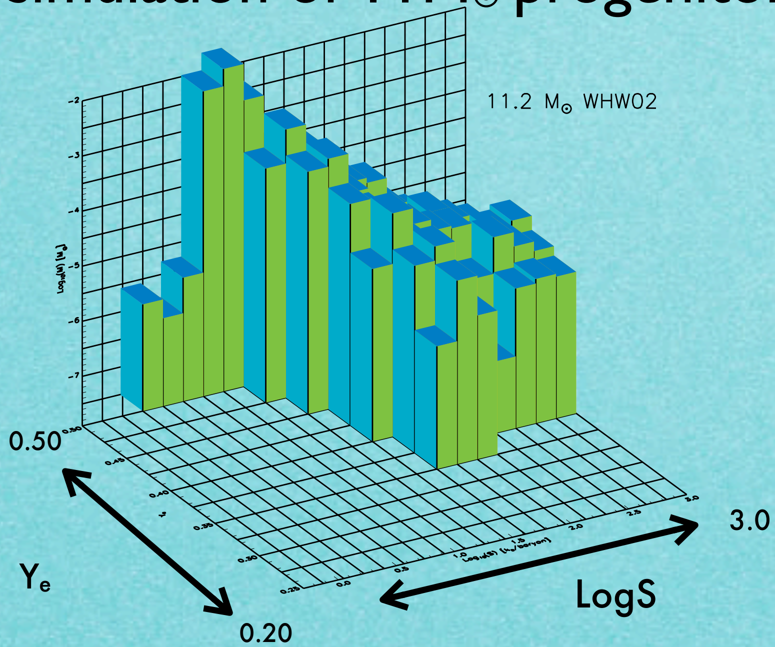


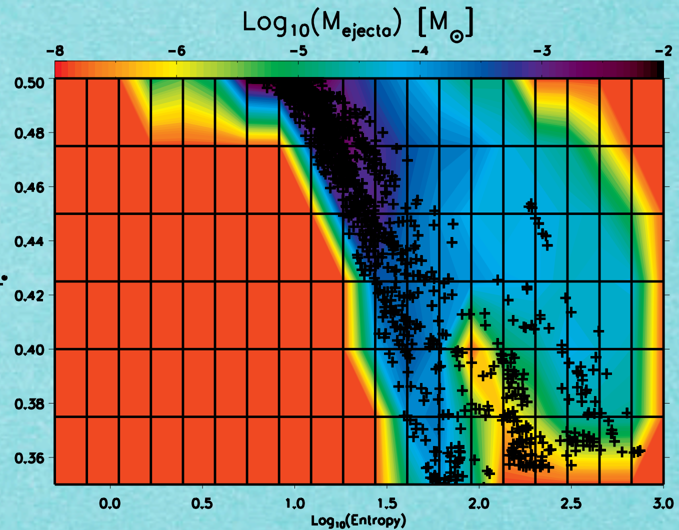
Direct capture and r-process in supernova

accretion cause core oscillation

Burrows et al. (2006)

simulation of $11M_\odot$ progenitor





	NDW	Burrows
S	<500	$9\sim10^5$
Y_e	~0.45	0.33~0.49

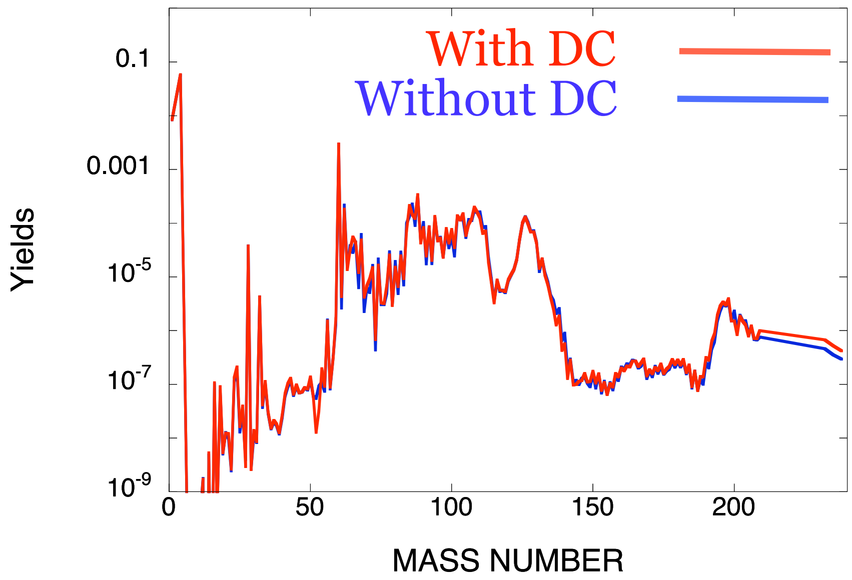
S, V_{rad}, Y_e of 9086points at r=1000km

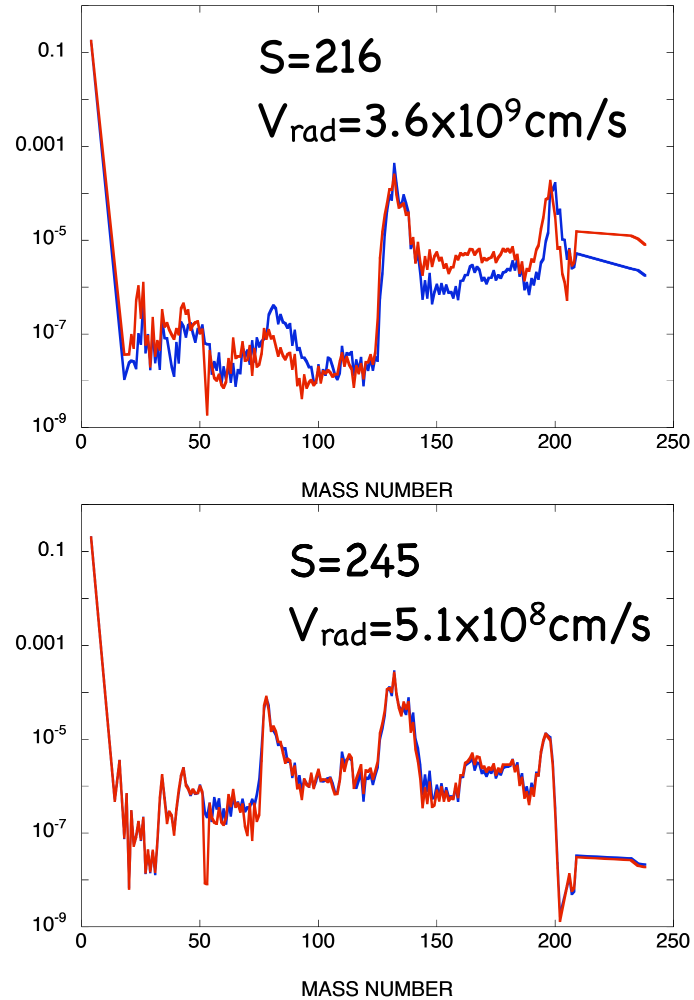
assume constant V_{rad} & $S, Y_{e(1000km)}=Y_{ei}$

r-process calculation of 366 representative

Direct capture and r-process in supernova

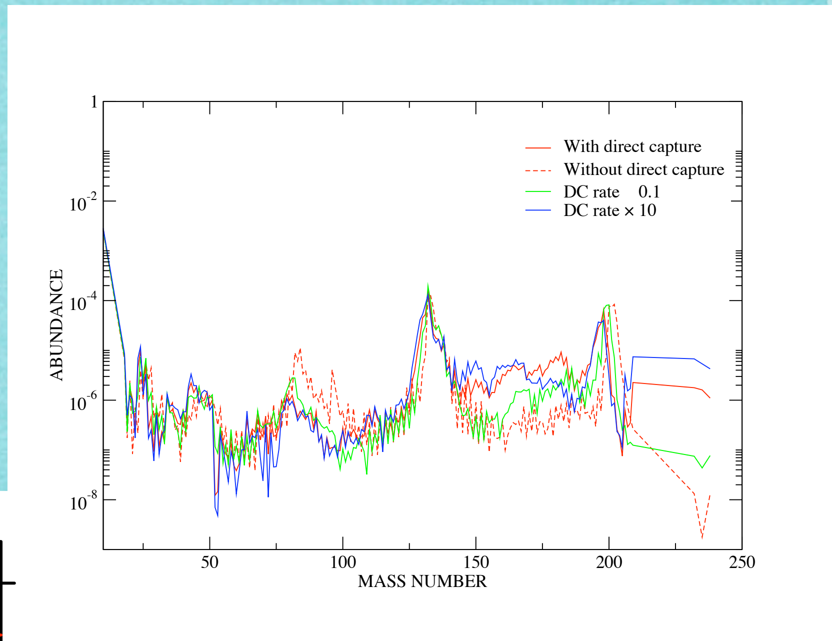
Total yield with and without direct capture



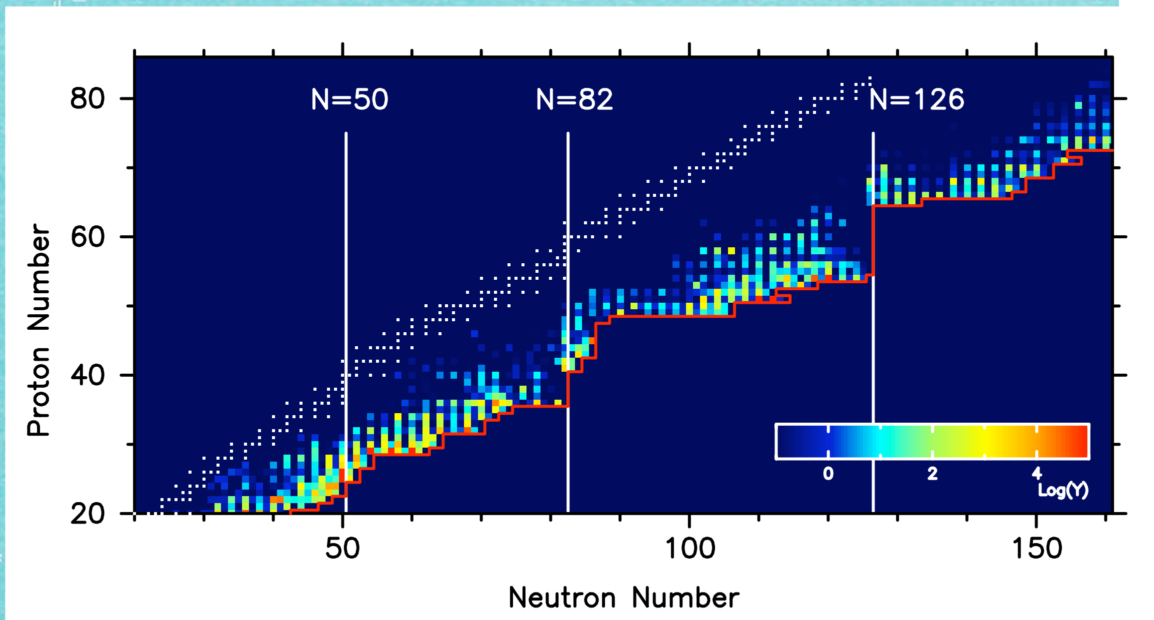


Direct capture increases actinide slightly, but did not change the position of the 3rd peak

Direct capture reaction rates



In our model, direct capture of N~50 nuclide are significant

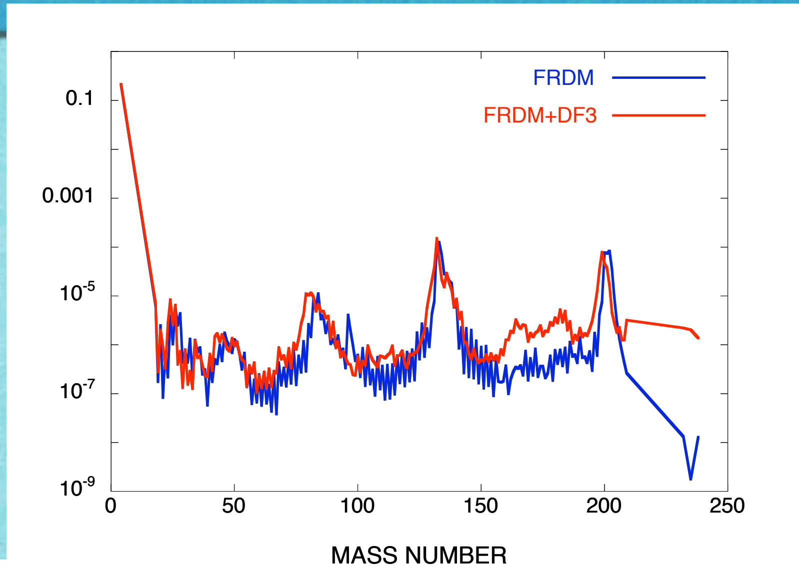


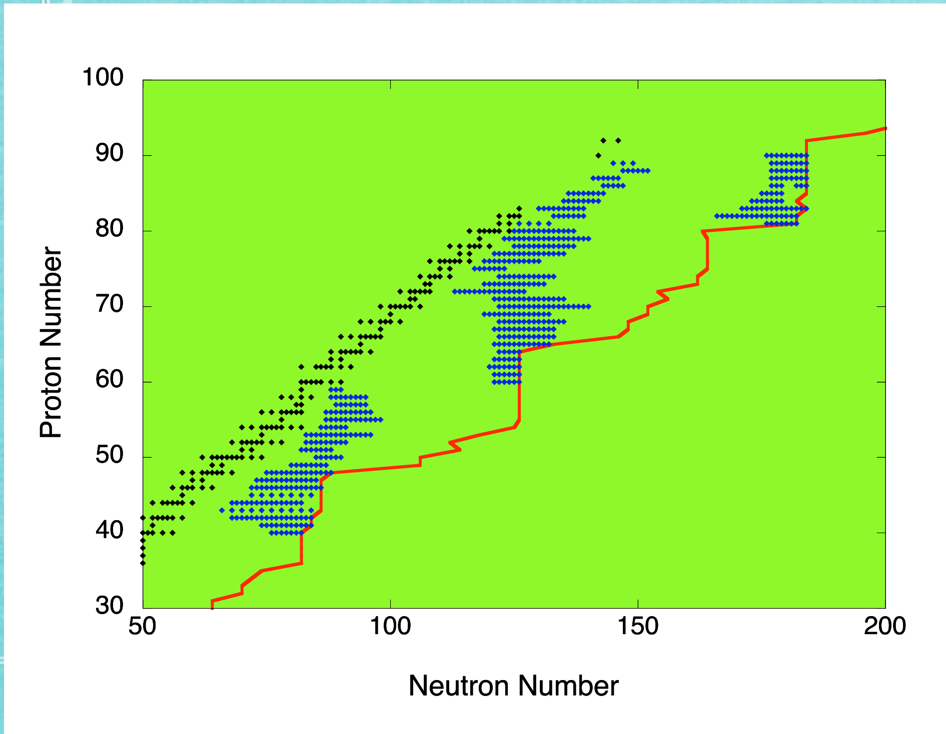
An order of magnitude difference changes final yield significantly.

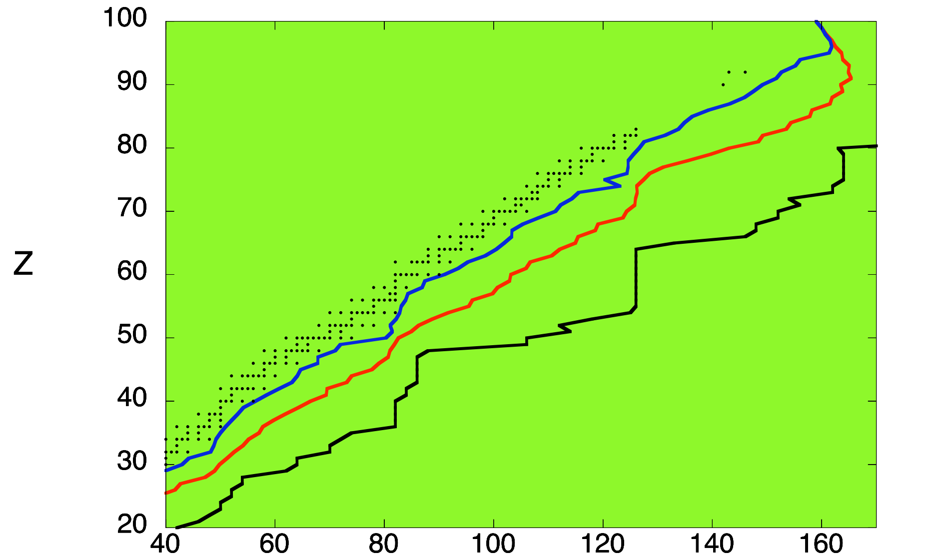
Effect of βdecay

Beta-decay rates By I.Borzov
DF theory + CQRPA
$\beta_{1/2}$~1/2 compare to FRDM

Short β half-lives also make freeze-out earlier.







Summary

- We have studied the role of direct neutron capture reaction in r-process nucleosynthesis
  - The direct capture furthers r-process and make freeze-out earlier. It changes the final yield drastically.
  - Short β half lives also make freeze-out earlier.
  - neutron-capture reaction rates and beta-decay are important for the r-process.
  - Experimental measurement of neutron-capture reaction rates around N=50 nuclei are strongly desired.