Measurement of 40 new beta-decay half-lives on the r-process path

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30 Sept 2014

EURICA collaboration

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OUTLINE

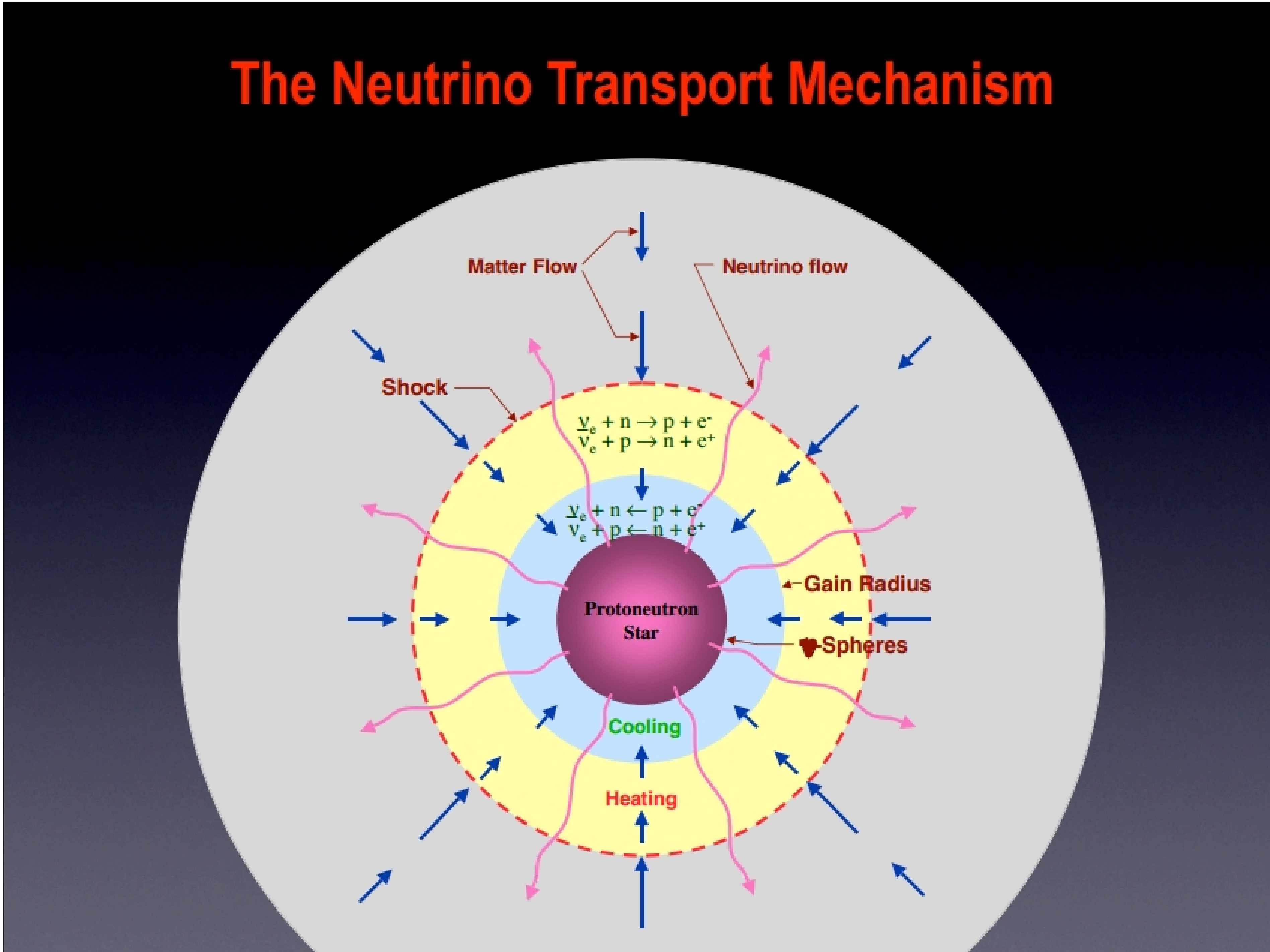
1. The r-process site
   - Core-collapse supernovae
   - Rotating magnetized proton-neutron star
   - Neutron star mergers

2. r-process mechanism

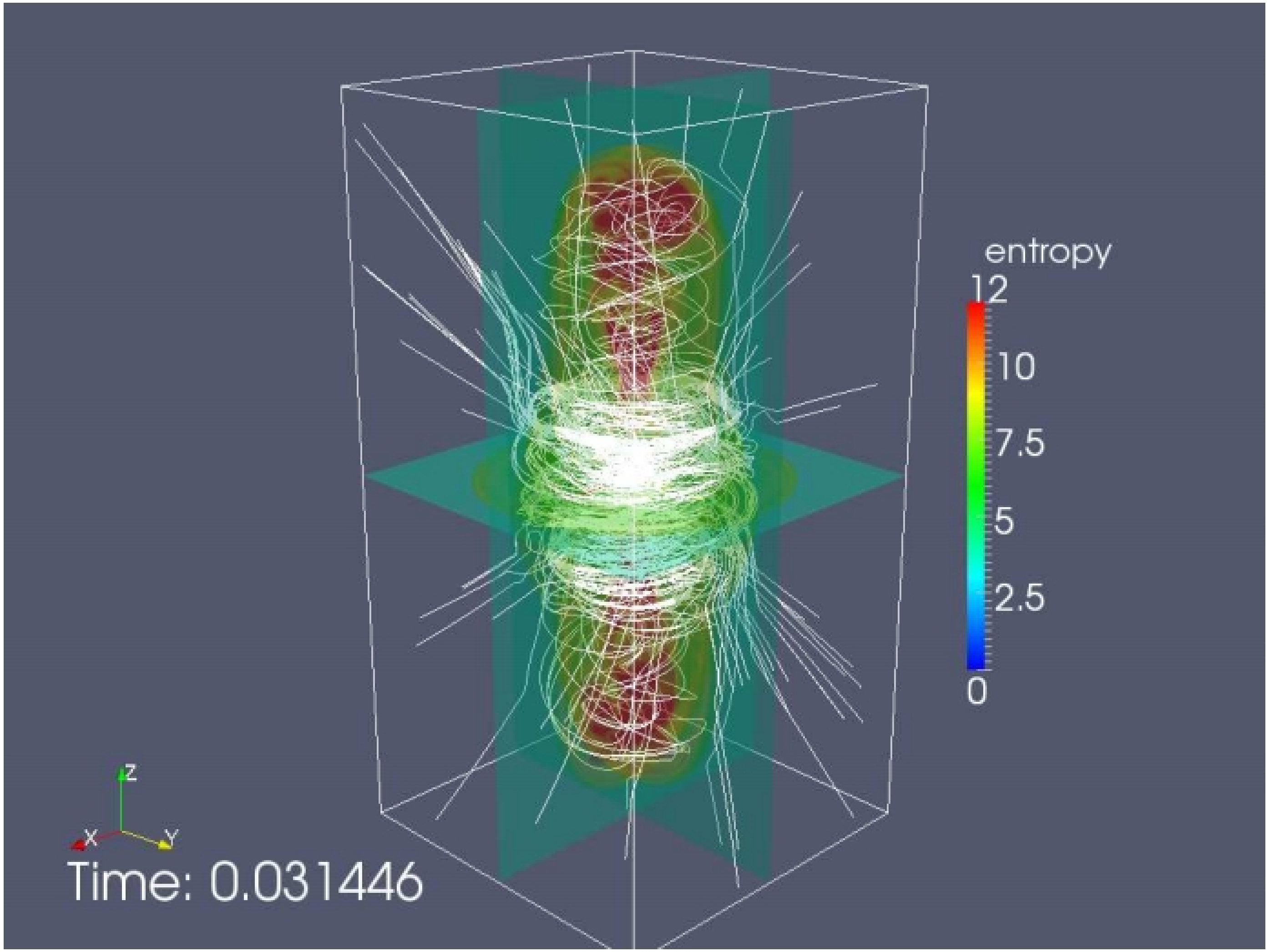
3. Metal poor stars

4. Experiment
   - Analysis
   - Results

5. Reaction network calculations
   - Are the new half-lives important?
   - Can we learn something about the r-process?

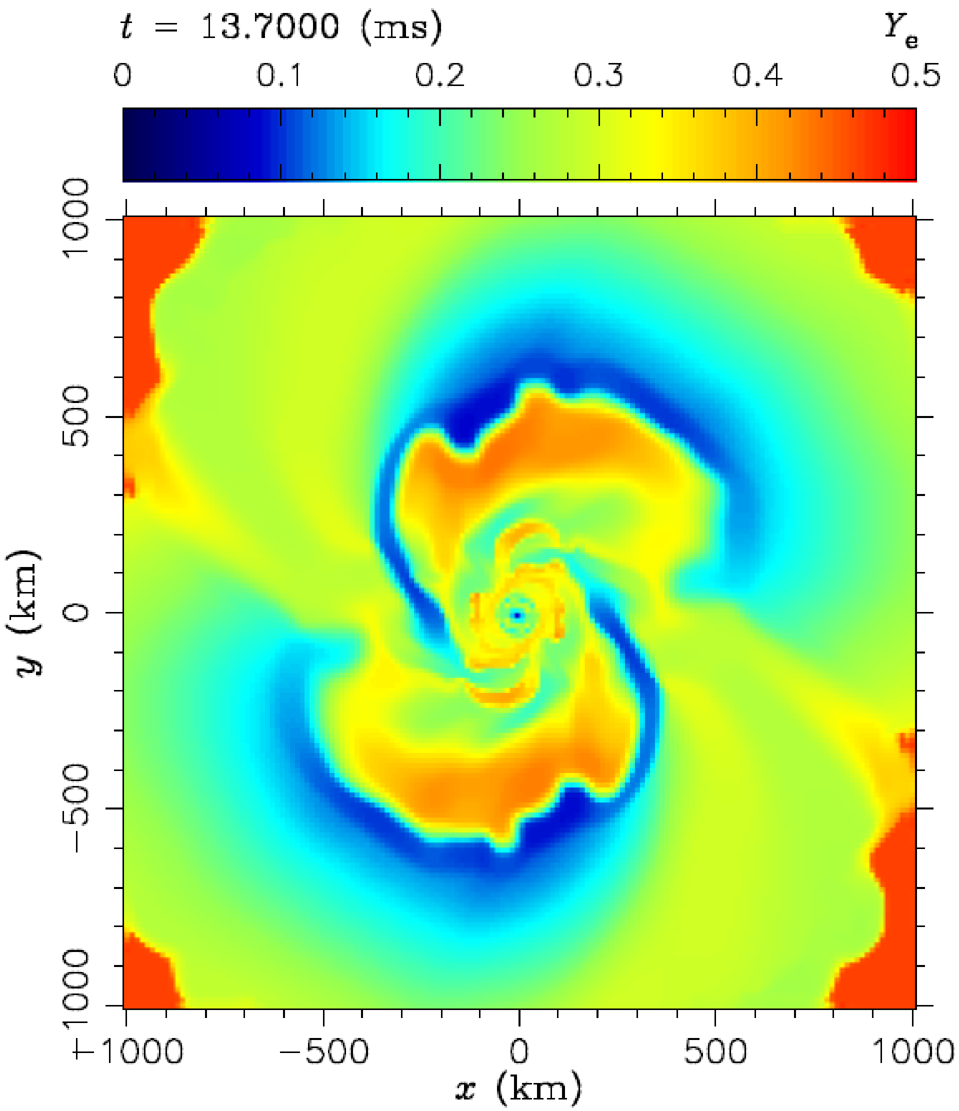

The Neutrino Transport Mechanism
Matter Flow
Neutrino flow
Shock
$\nu_e + n \rightarrow p + e^-$
$\bar{\nu}_e + p \rightarrow n + e^+$
$\nu_e + n \leftarrow p + e^-$
$\bar{\nu}_e + p \leftarrow n + e^+$
Gain Radius
Protoneutron Star
ν-Spheres
Cooling
Heating

Magnetorotationally driven supernovae



Magnetic field $10^{14} - 10^{15}$ G and rapid rotation (spin period P ~ few ms)

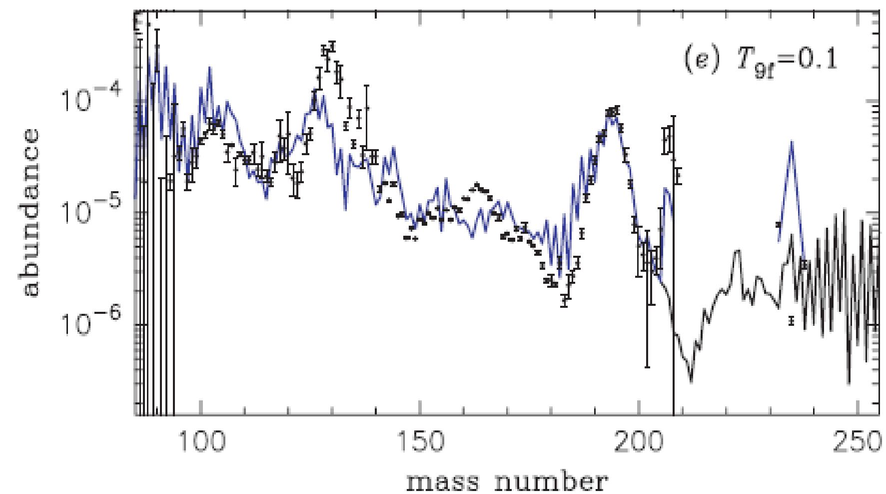
Neutron star mergers



S. Wanajo et al., APJL 789:L39, 2014

r-process mechanism / nuclear physics needed

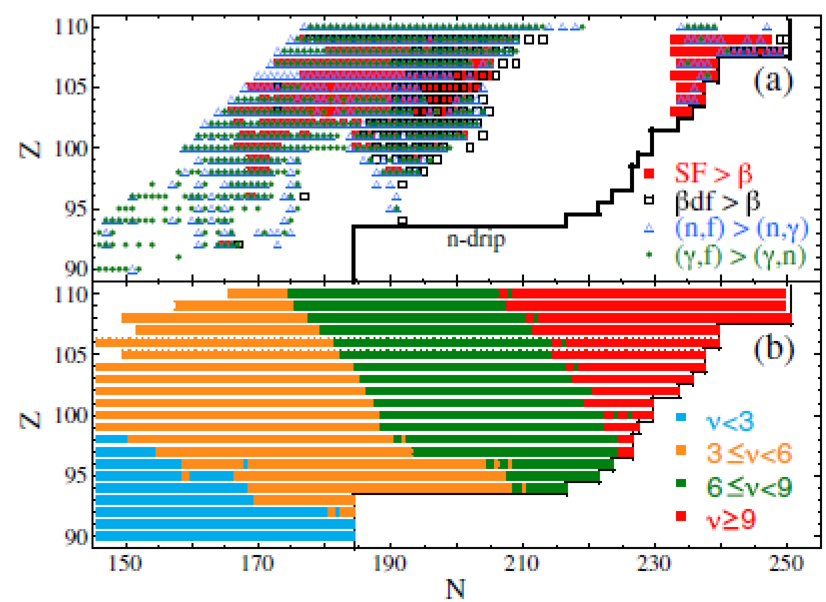
S. Wanajo, APJ, 666: L77 – L80 (2007)



– Freezout from (n,g) ↔ (g,n) equilibrium
    Hot r-process
        * *Half-lives*
        * *Masses*

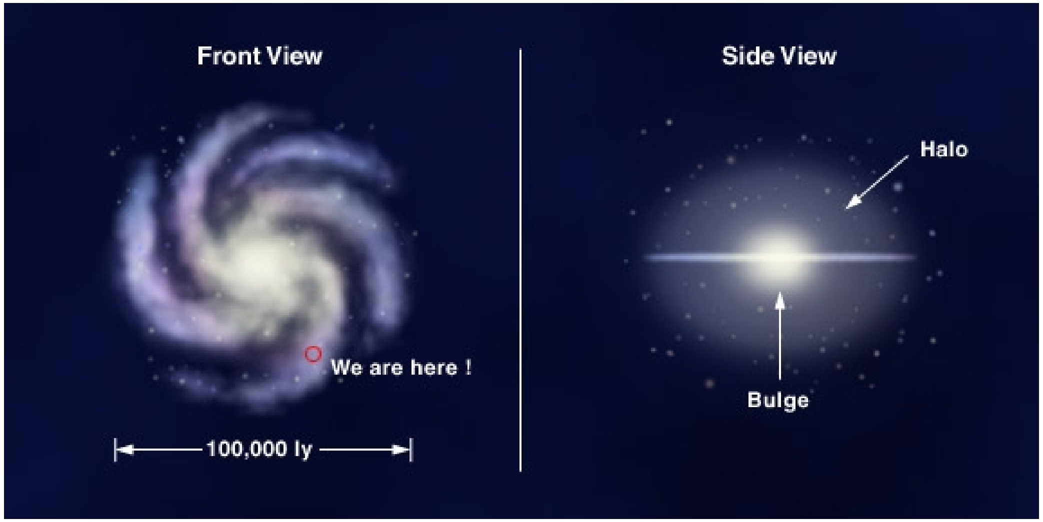
– Freazout from (n,g) / β-decay competition
    Cold r-process
        * *Half-lives*
        * *Masses*
        * *(n,g) cross sections*

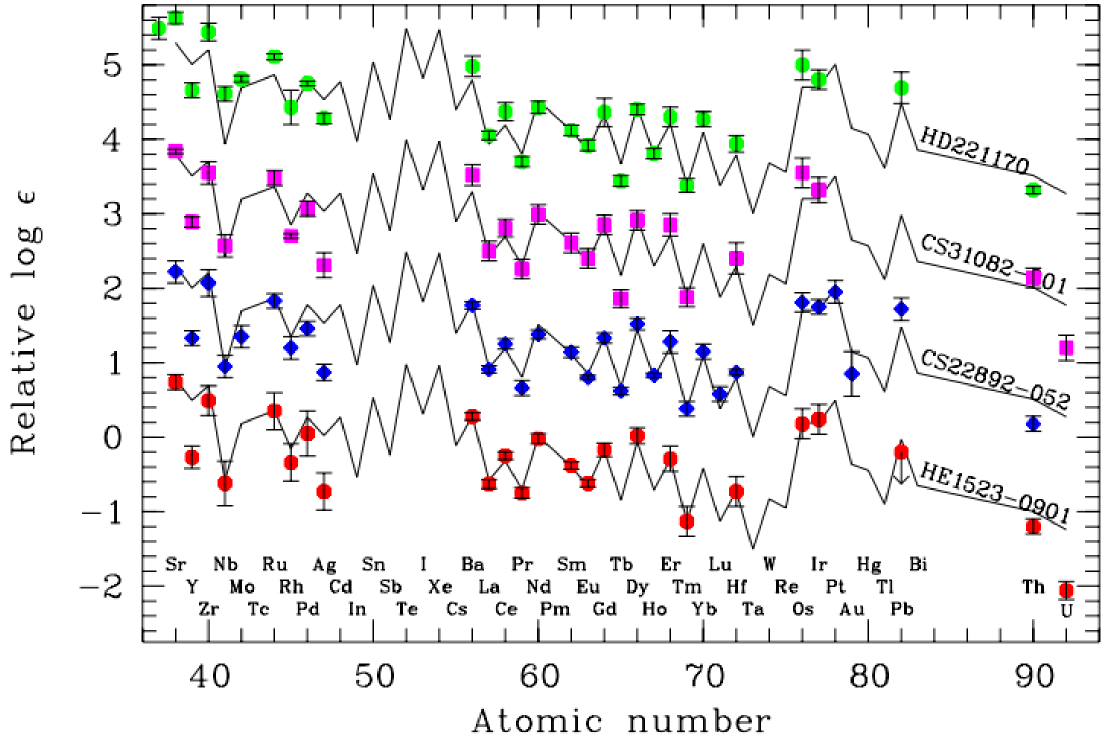
– Fission recycling
        * *Half-lives*
        * *Masses*
        * *(n,g) cross sections*
        * *fission fragment distribution*
        * *beta vs. beta-delayed F*
        * *number neutron/fission*
        * *neutron energy spectra*
        * *(n,f) > (n,g)*
        * *(g,f) > (g,n)*



S. Goriely, PRL 111, 242502, 2013

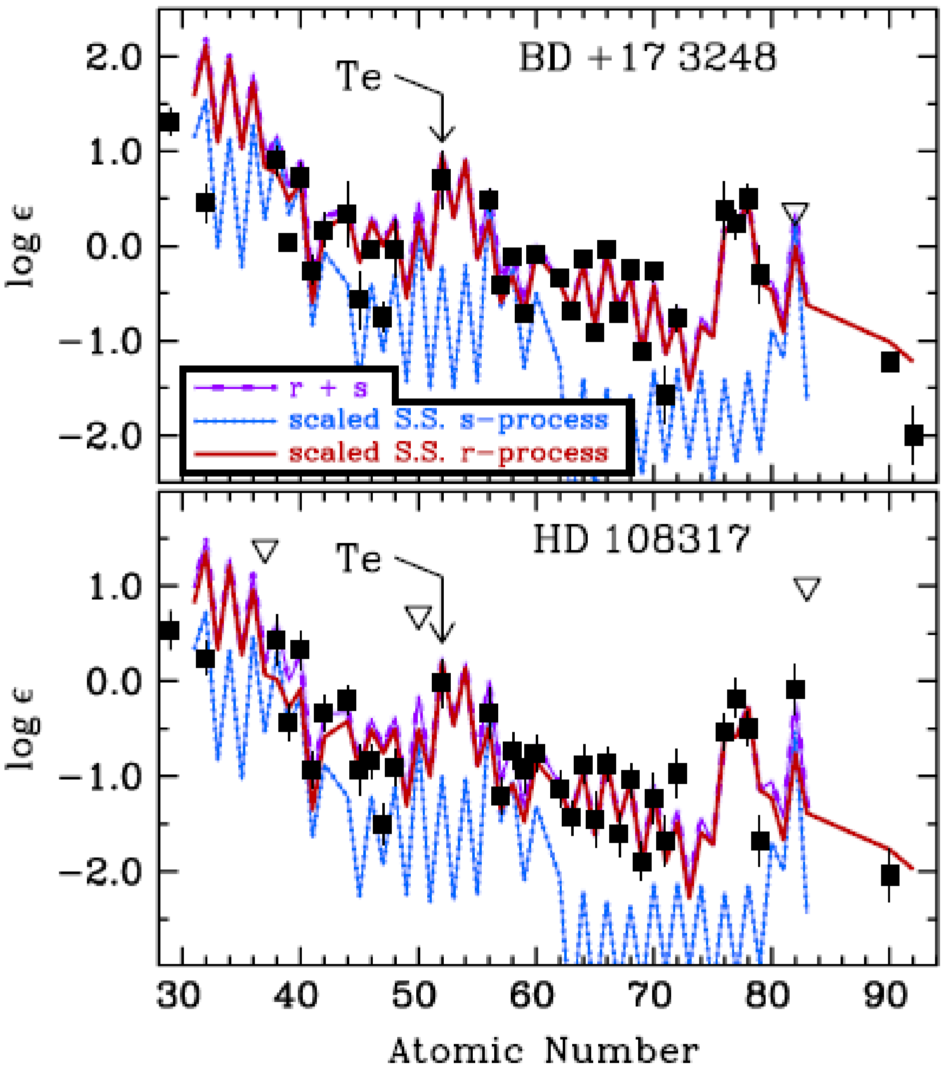
r-process universality



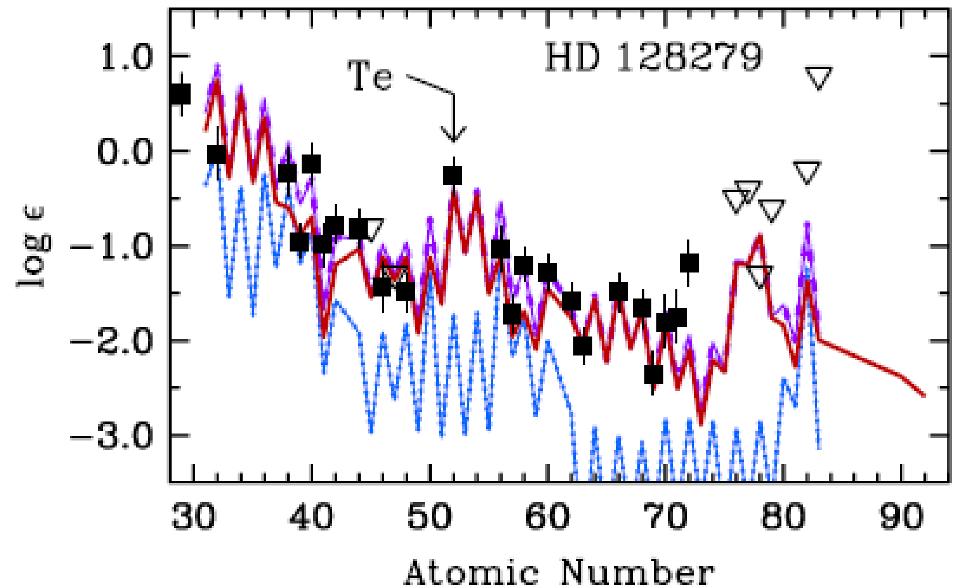


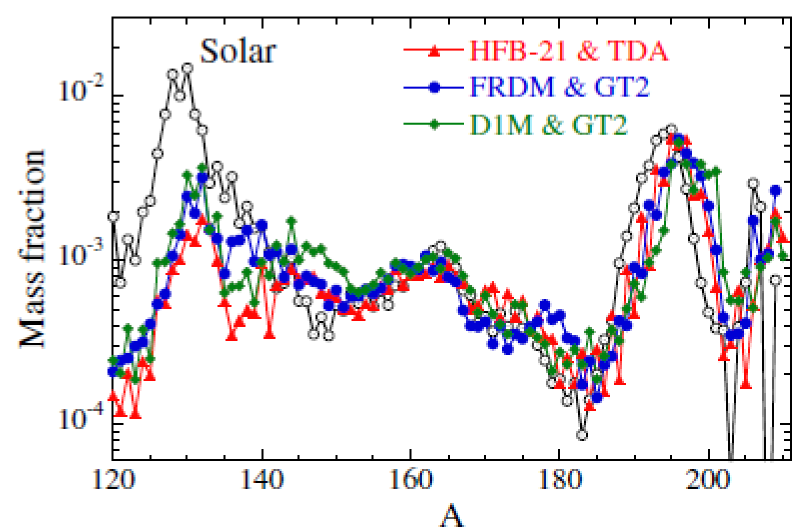
Elemental abundance in r-process enhanced metal poor stars compared to solar

r-process universality



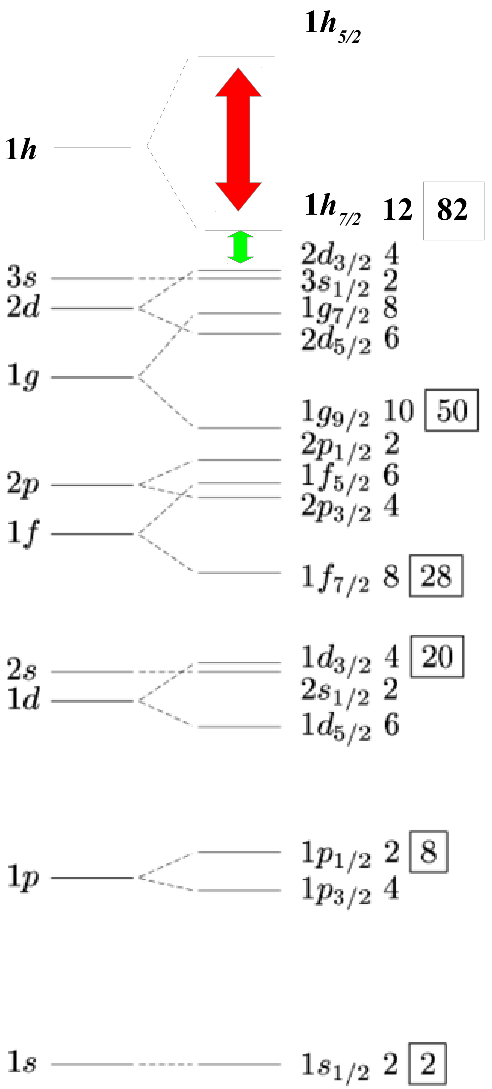
J. Roederer et al., APJ 747:L8 (2012)

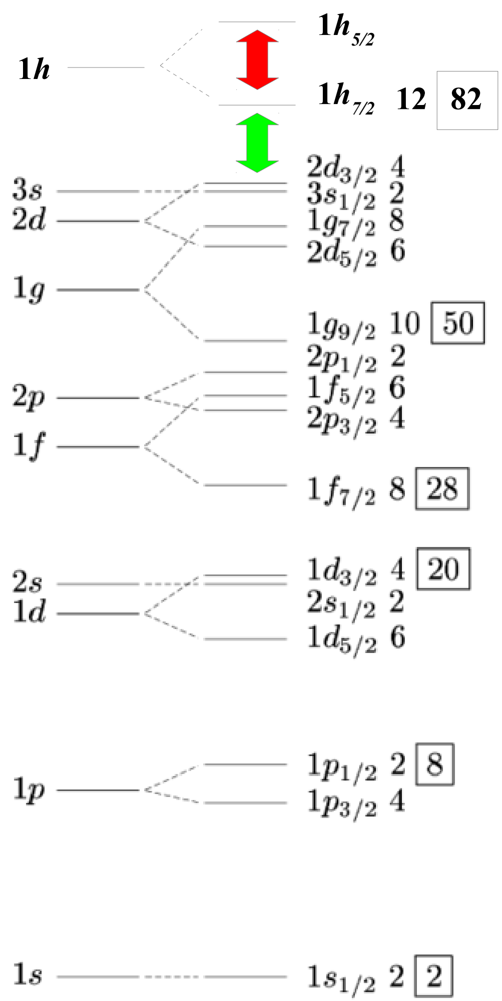




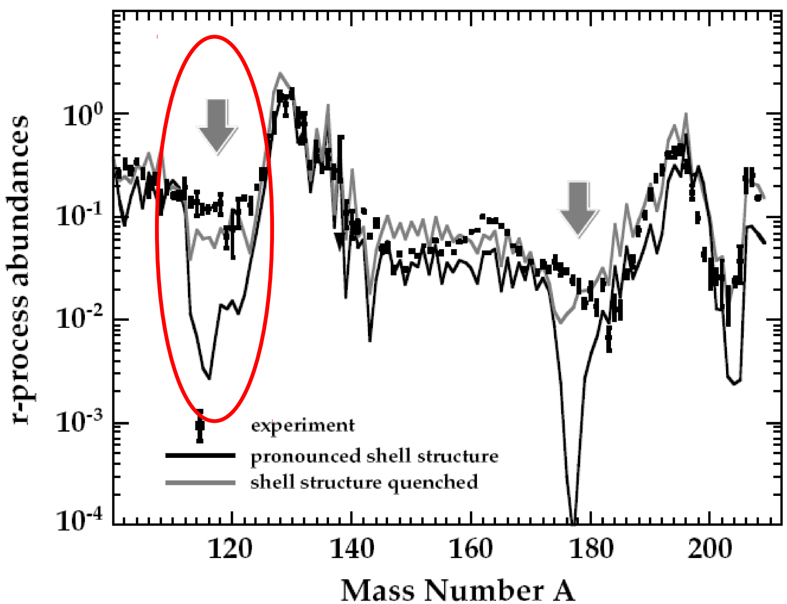
S. Goriely, PRL 111, 242502, 2013

Shell structure evolution





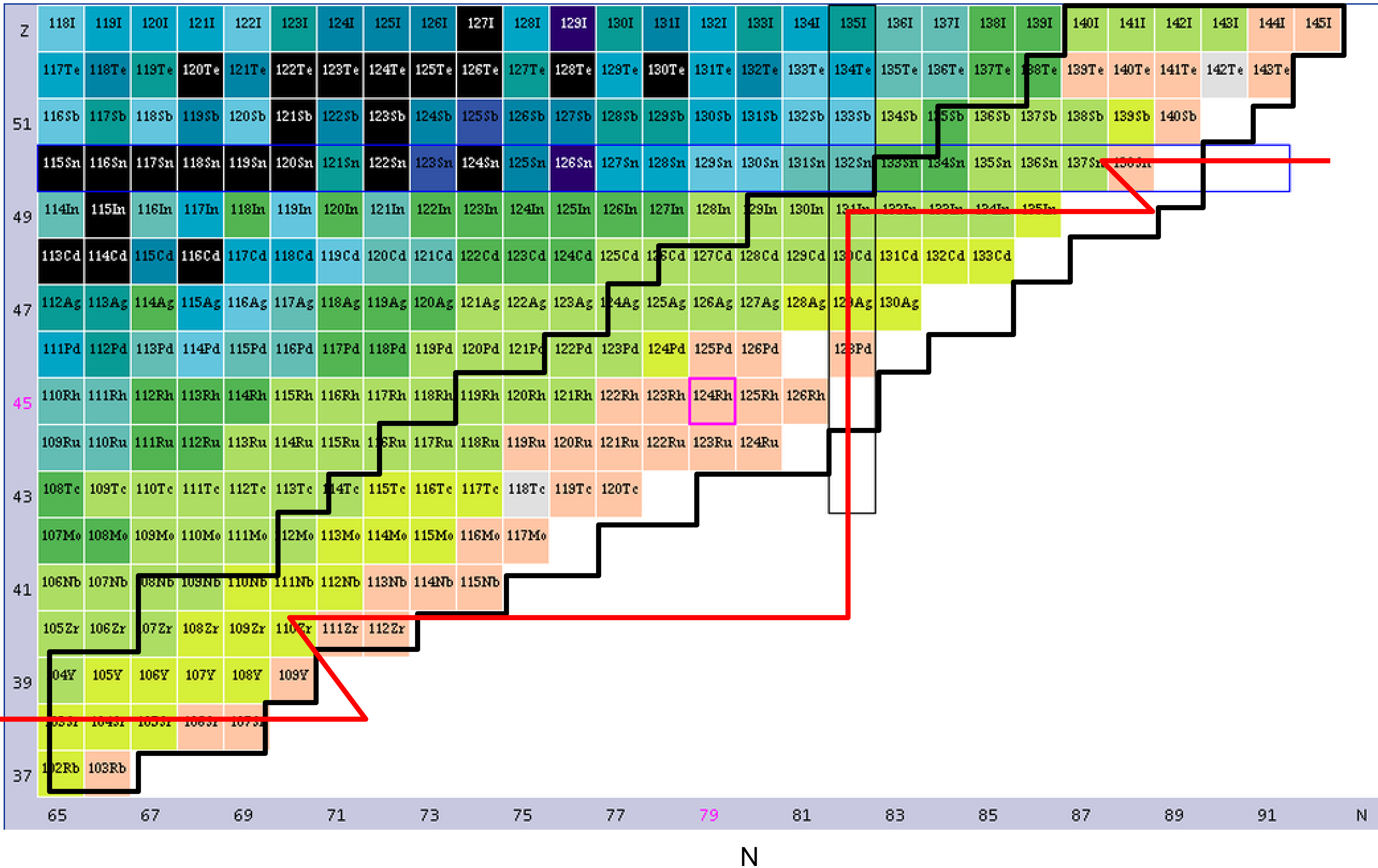
C. Freiburghaus et al., APJ 516:381–398 (1999)



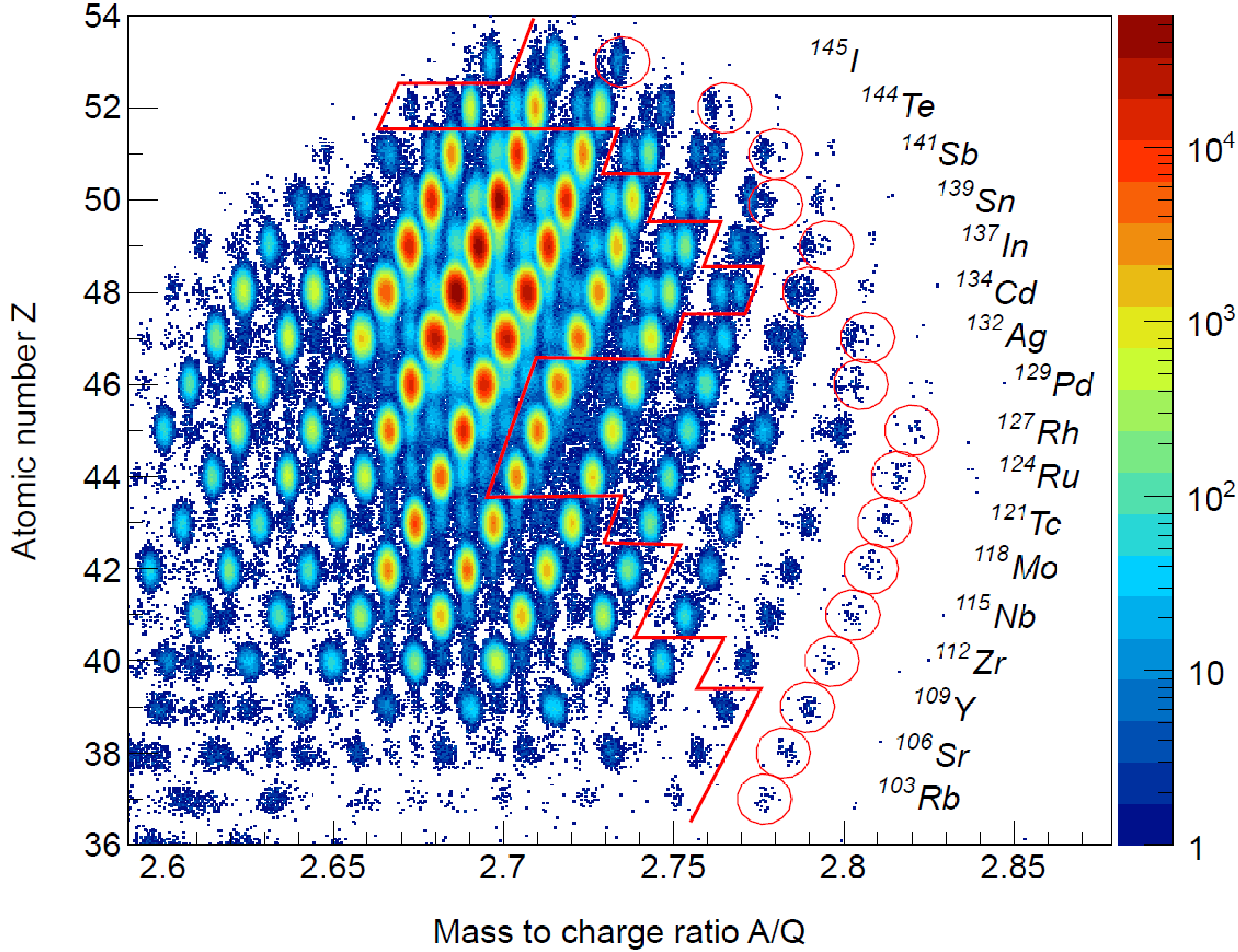
Profound astrophysical impact of:

- Quenching of the N=82 shell gap (need to study region around $^{128}Pd_{82}$)
- appearance of the a N=70 sub-shell closure (need to study region around $^{110}Zr_{70}$)
- J. Toppragge et al., PRL 112,13250,1 2014
- H. Watanabe et al., PRL, 113, 042502 (2014), PRL 111, 152501 (2013).

The half-lives we measured (3 BigRips settings)

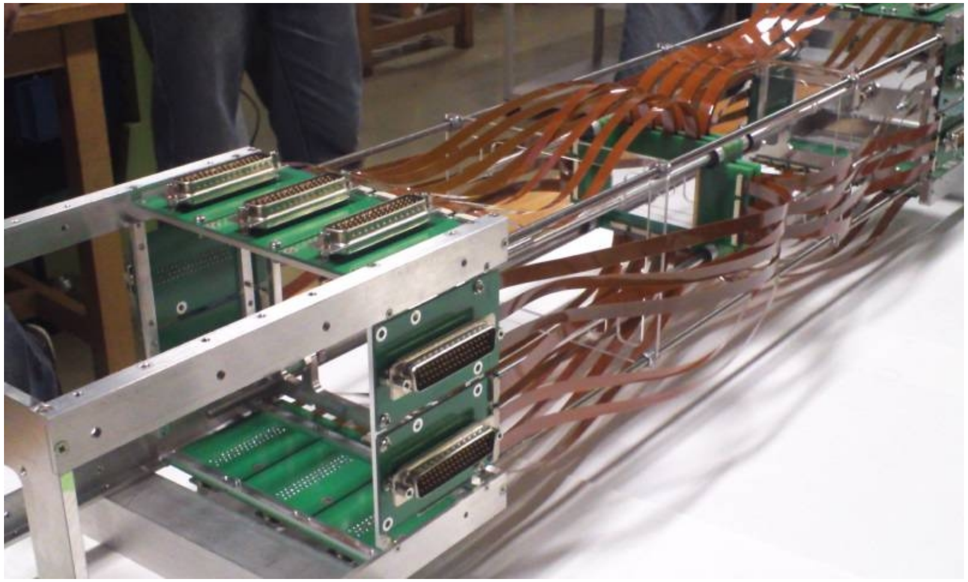


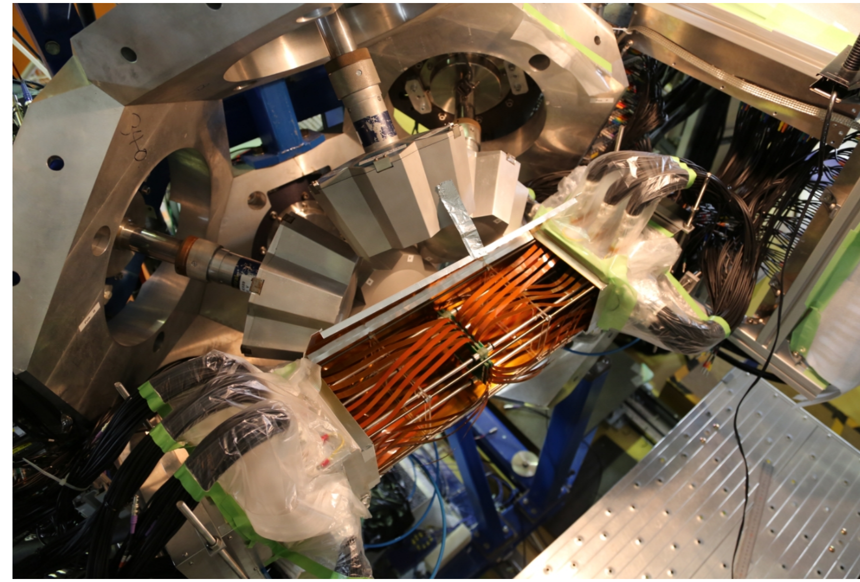
PID

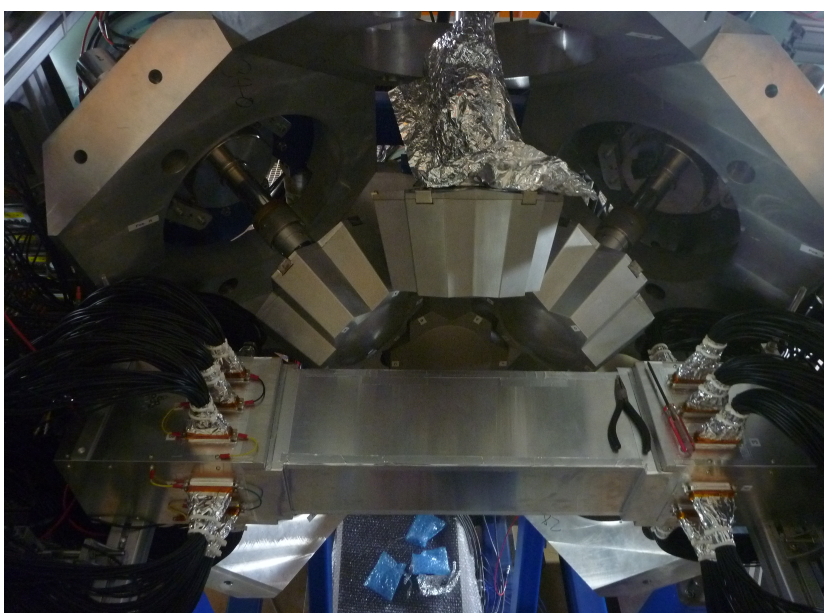


Y. Shimizu et al., in preparation

Wide-range **A**ctive **S**ilicon **S**tripped **S**topper **A**rray for **B**eta and **i**ons (WAS3ABi)



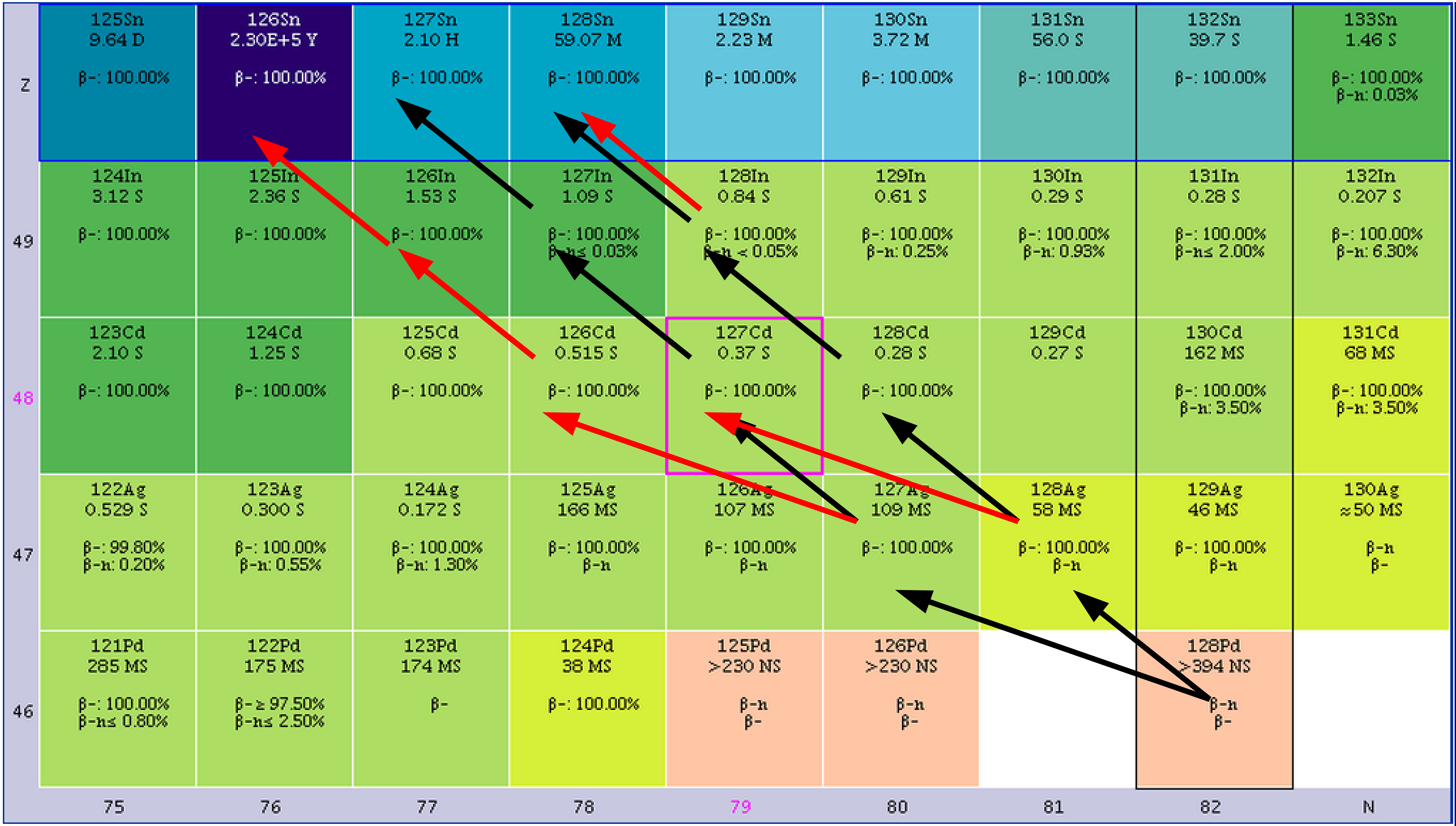




Collaboration RIKEN / TUM / IBS

- 8 DSSD 1-mm thick
- 20 keV threshods
- 20 keV energy resolution
- 100—200 pps Maximum rate
- cooled at 10 ^{0}C
- Q value capability?

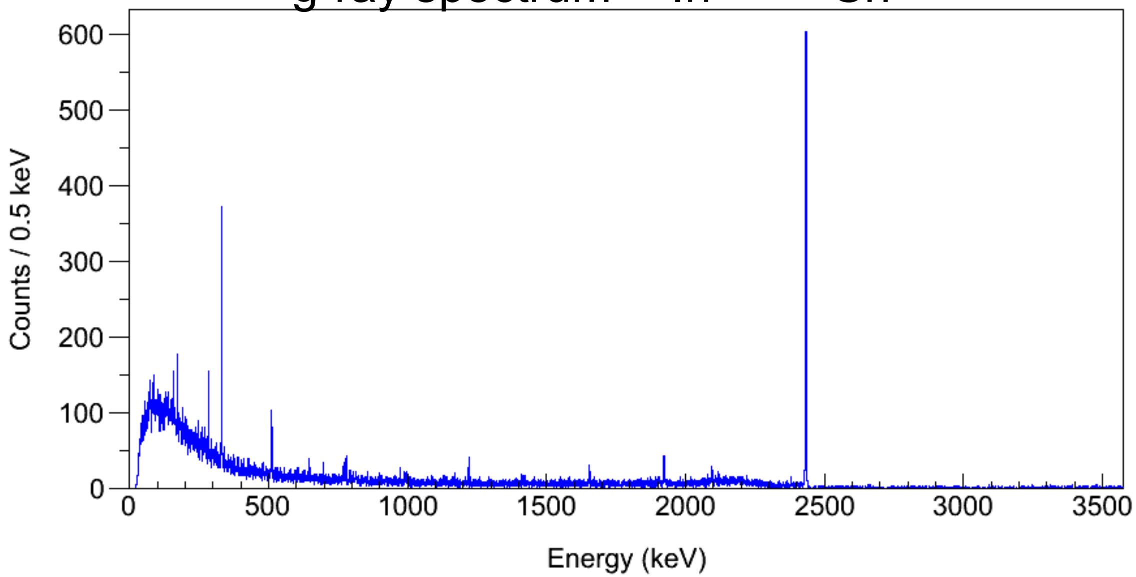
^{128}Pd beta-decay



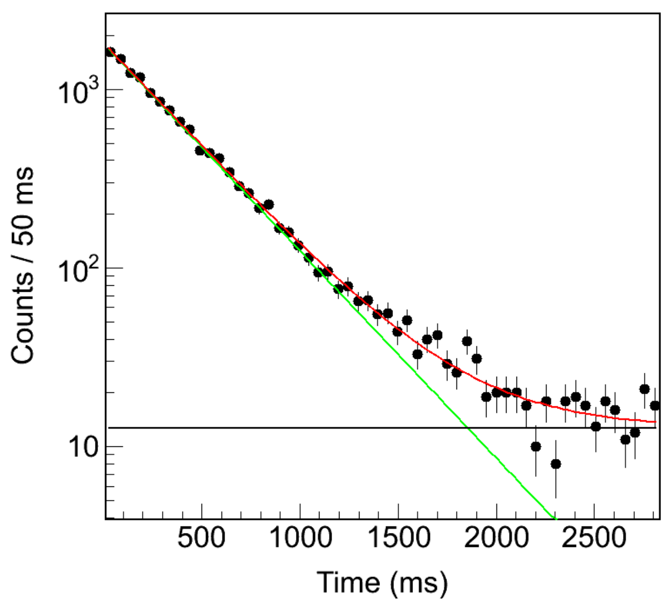
^{134}Cd beta-decay half-life

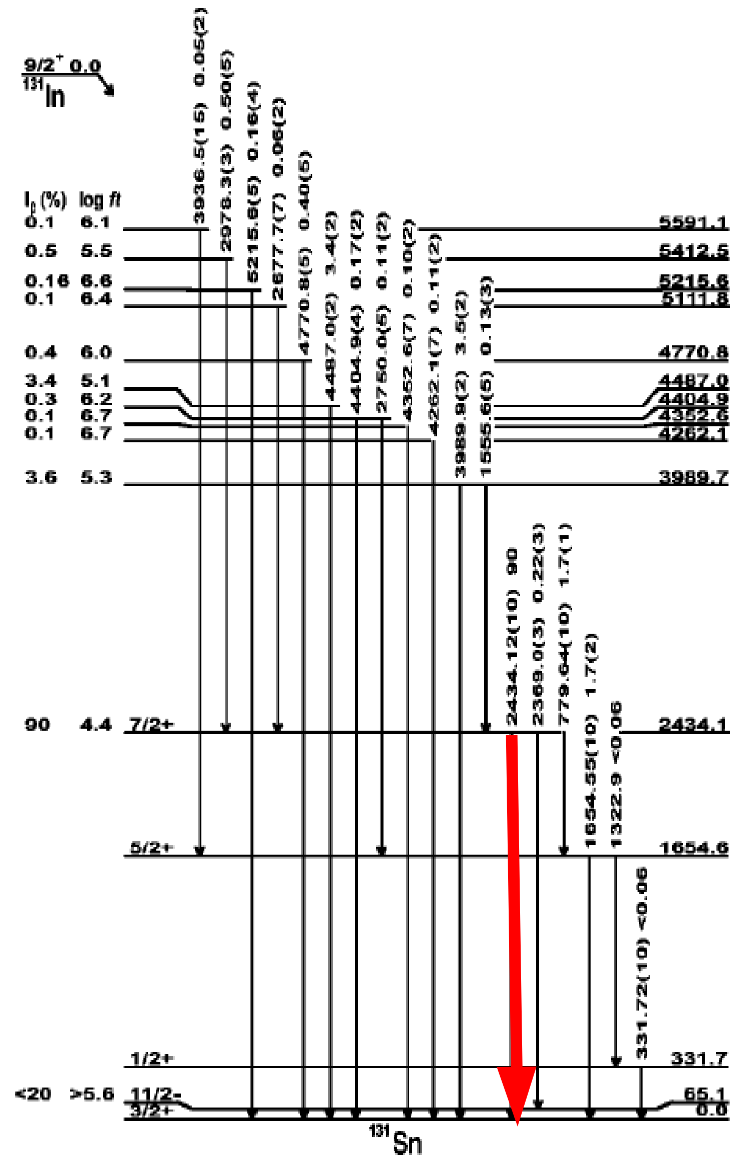
^{131}In decay

g-ray spectrum ^{131}In → ^{131}Sn



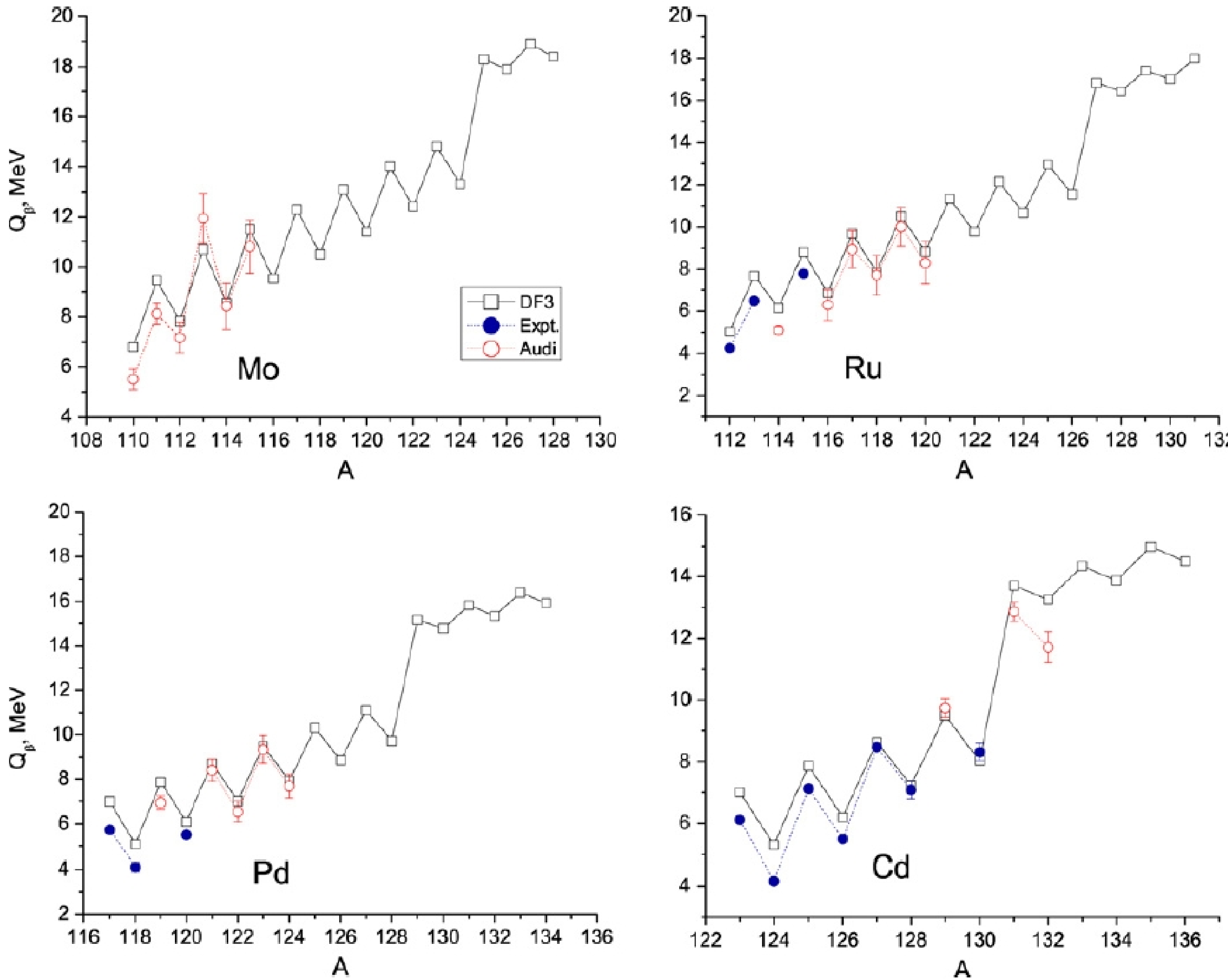
b-decay curve gated on 2434 kev





FOGELBERG et al. PHYSICAL REVIEW C 70, 034312 (2004)

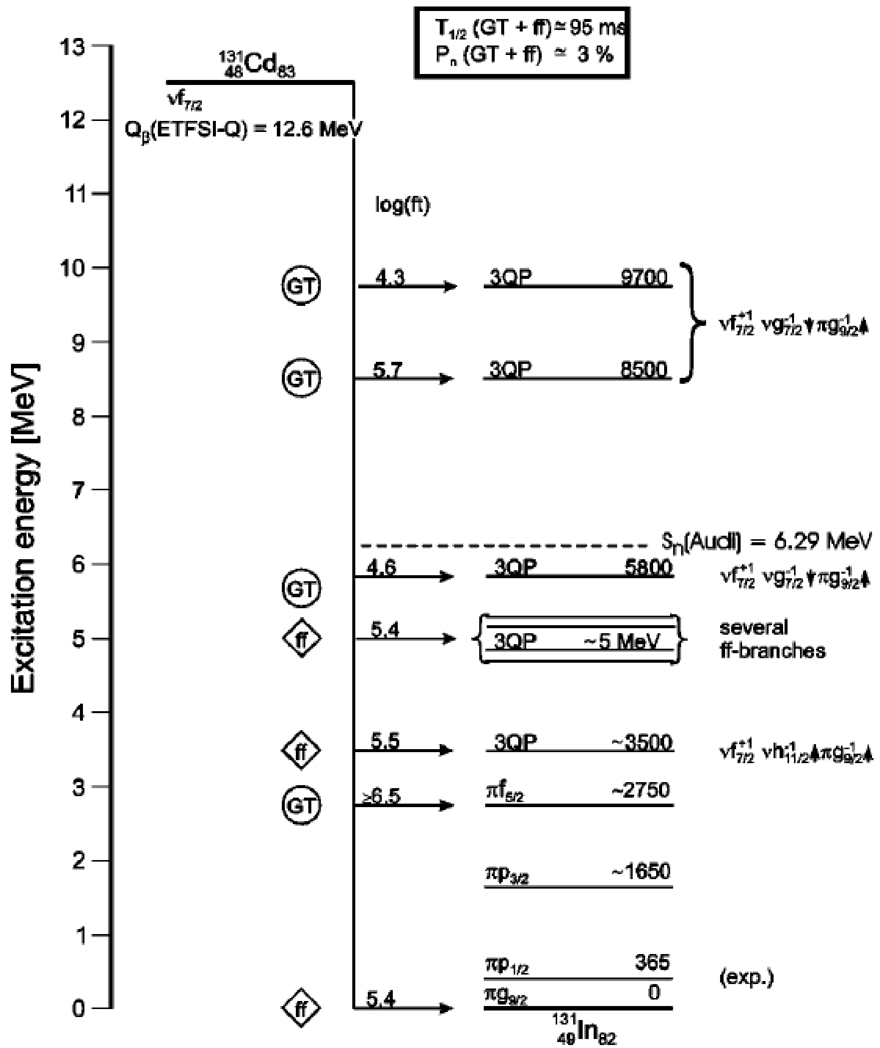
B-decay Q-values



Borzov et al., Nuclear Physics A 814 (2008) 159–173

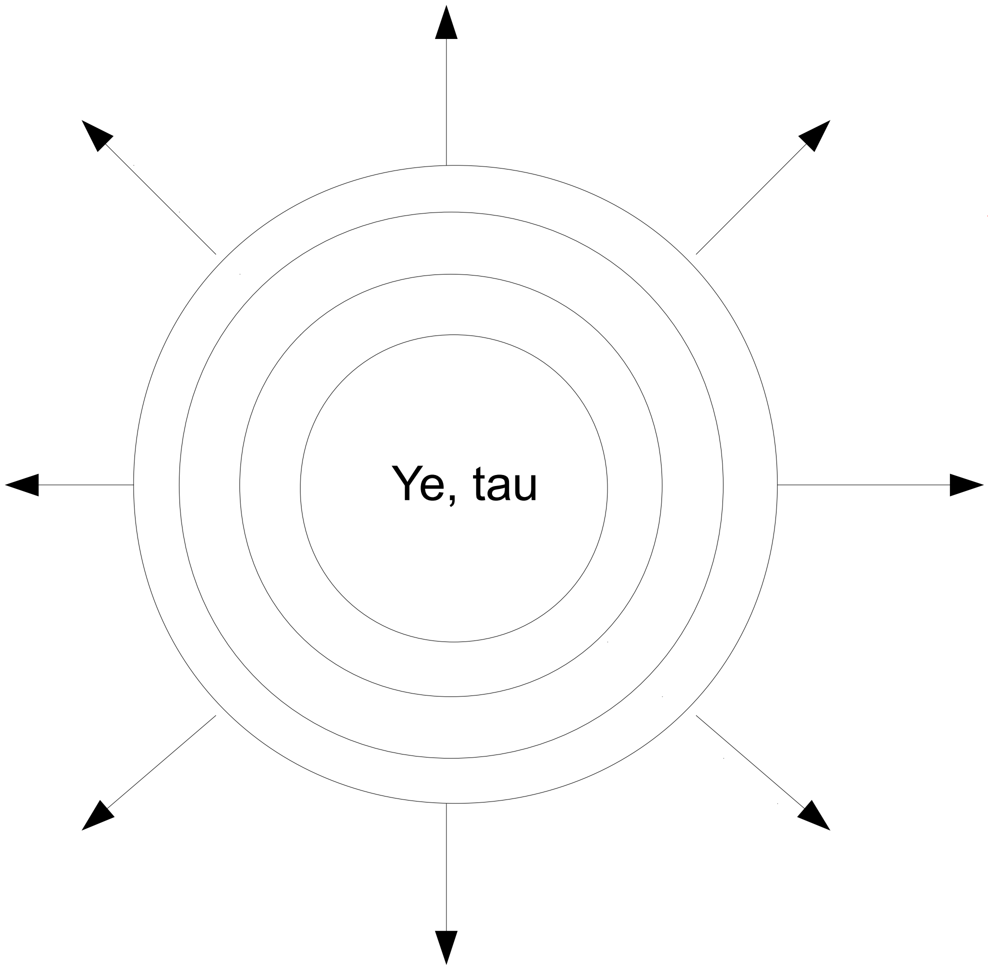
^{131}Cd calculated decay (QRPA)

^{131}Cd → ^{131}In decay



Hannanwald et al., PRC 62, 054301 (2000)

r-process reaction network calculations



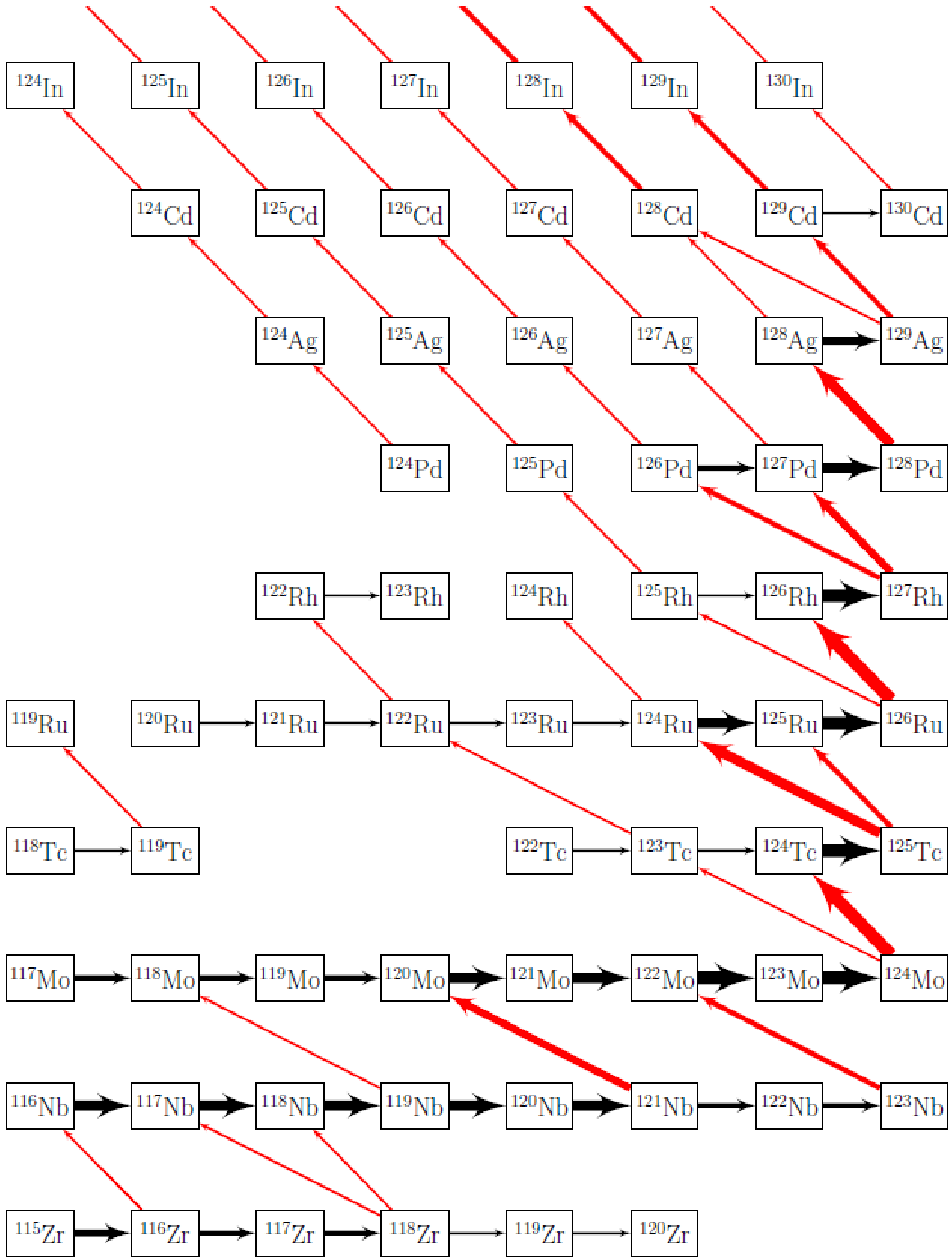
What is the r-process path?

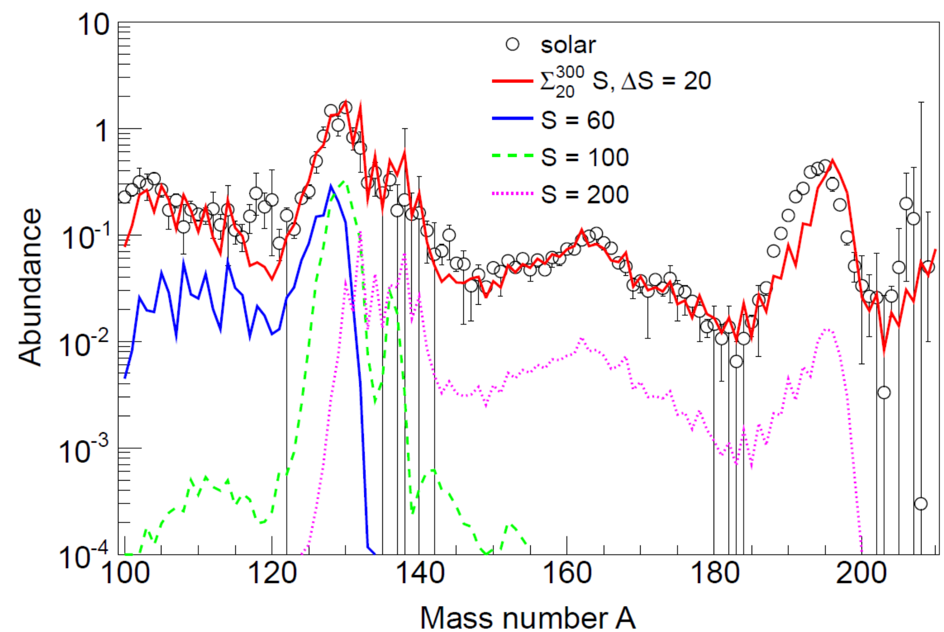
Supernovae case

Ye, tau

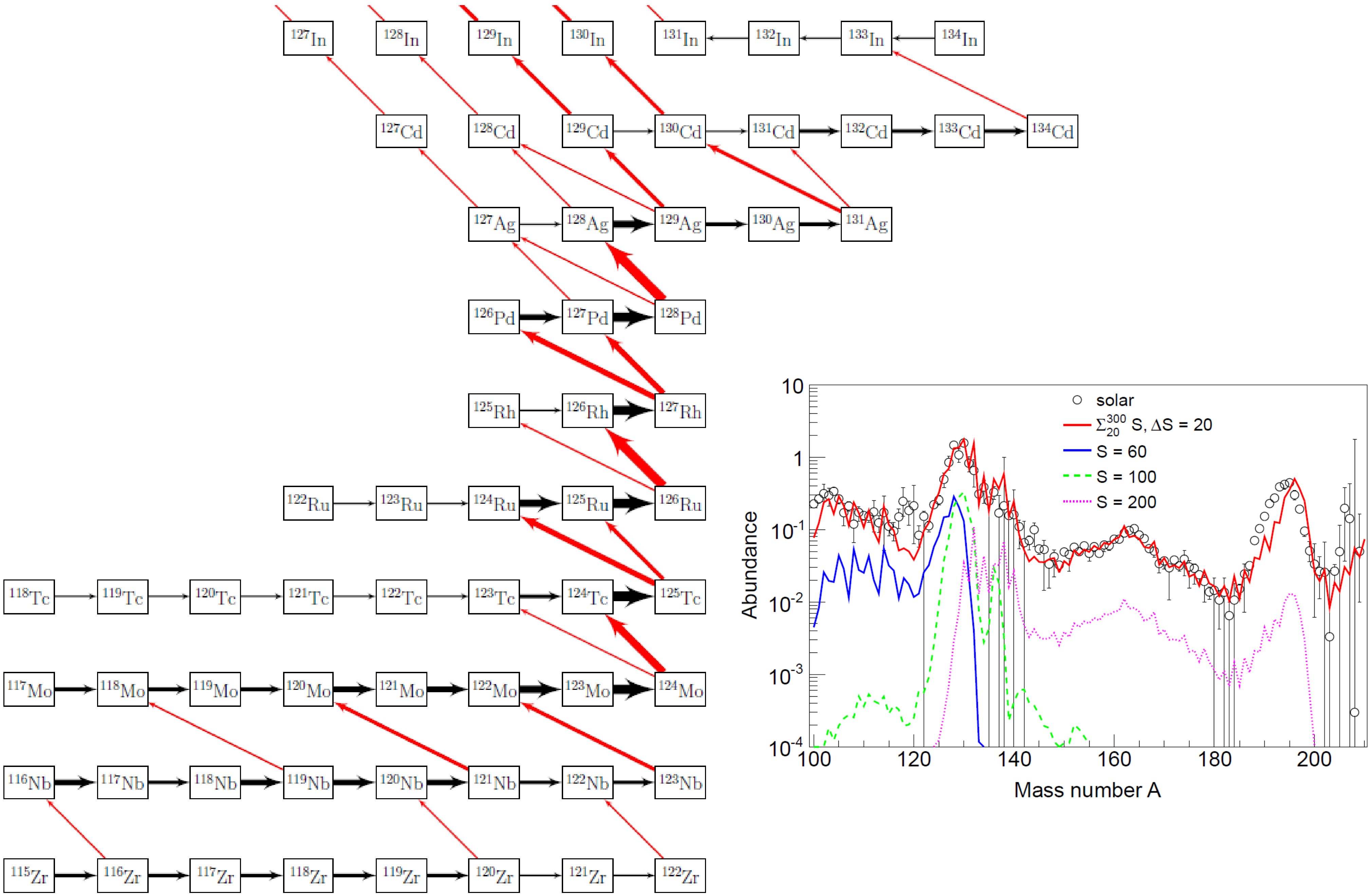
$S_i = S_i(T, rho)$ for one layer

S=60 component

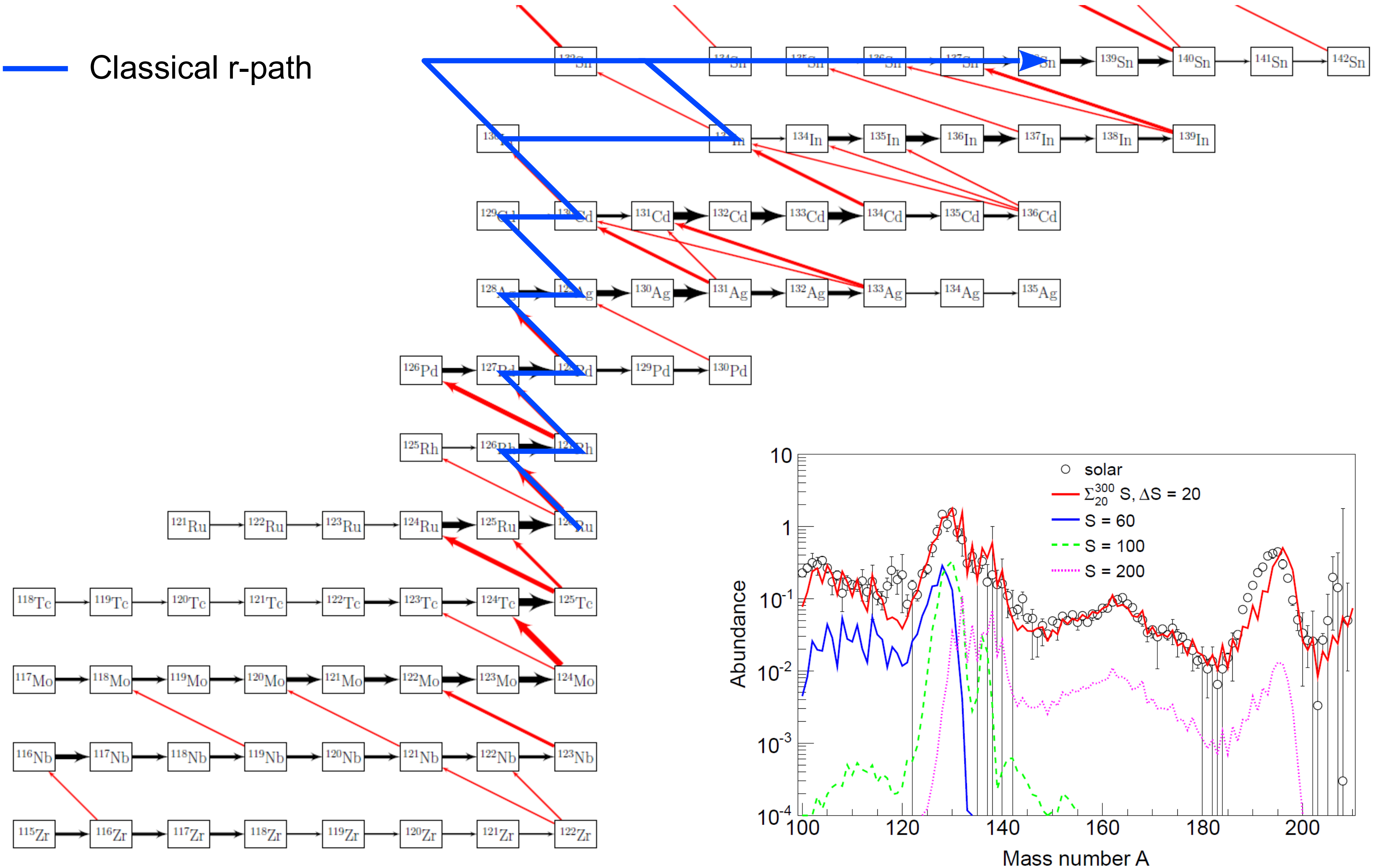




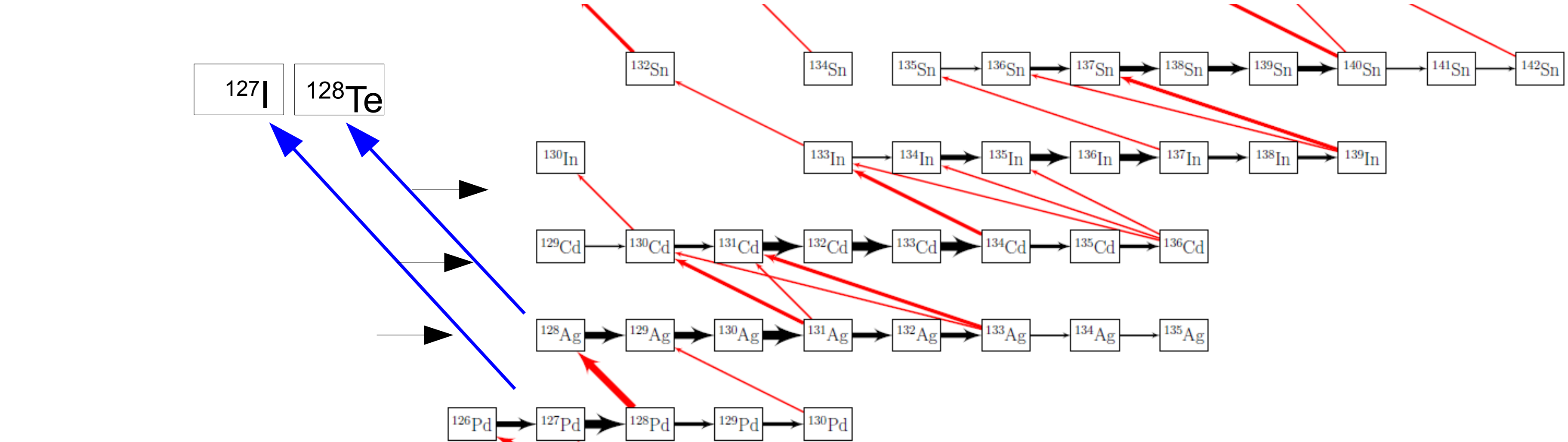
How half-lives constraints the r-path



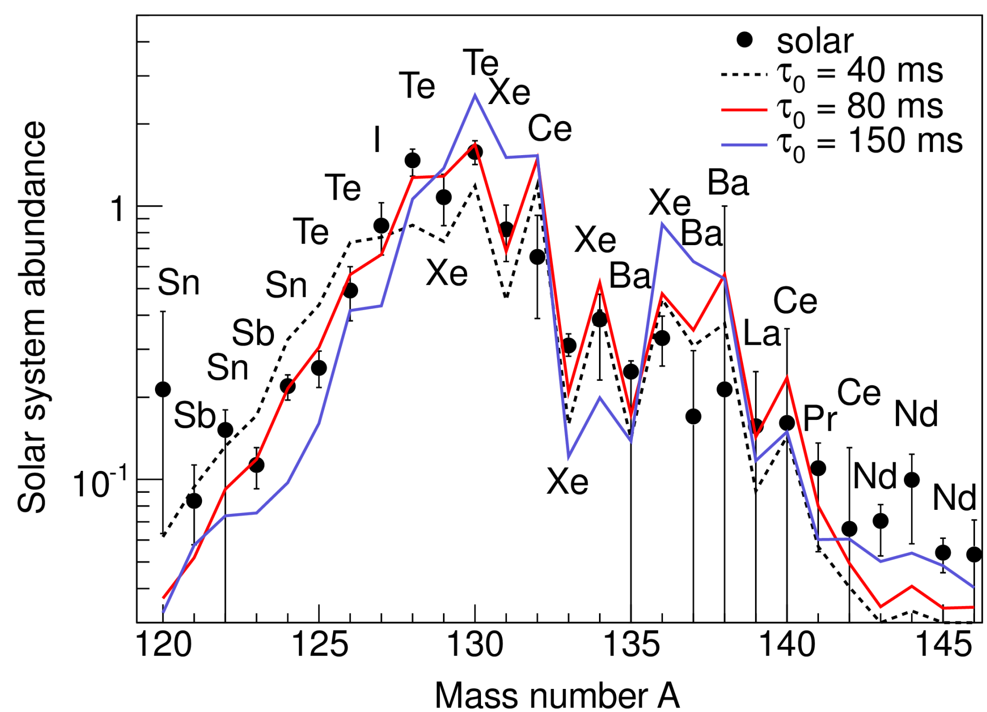
How half-lives constraints the r-path



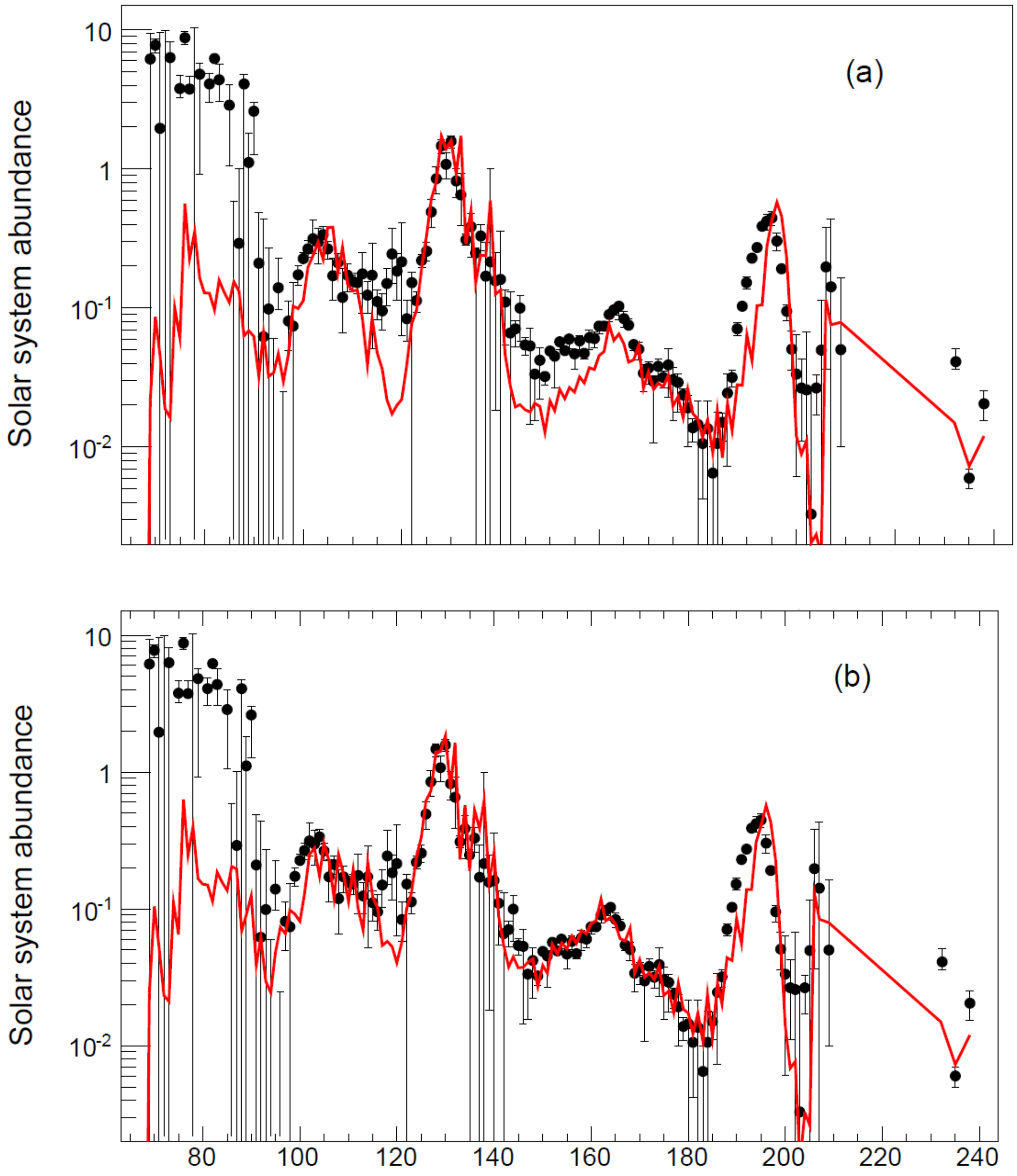
The role of ^{128}Pd half-life and the importance of ^{128}Te



A=130 peak for different tau



R-process with new half-lives



Ye = 0.30(5)

tau = 80(20) ms

S = 20 – 500

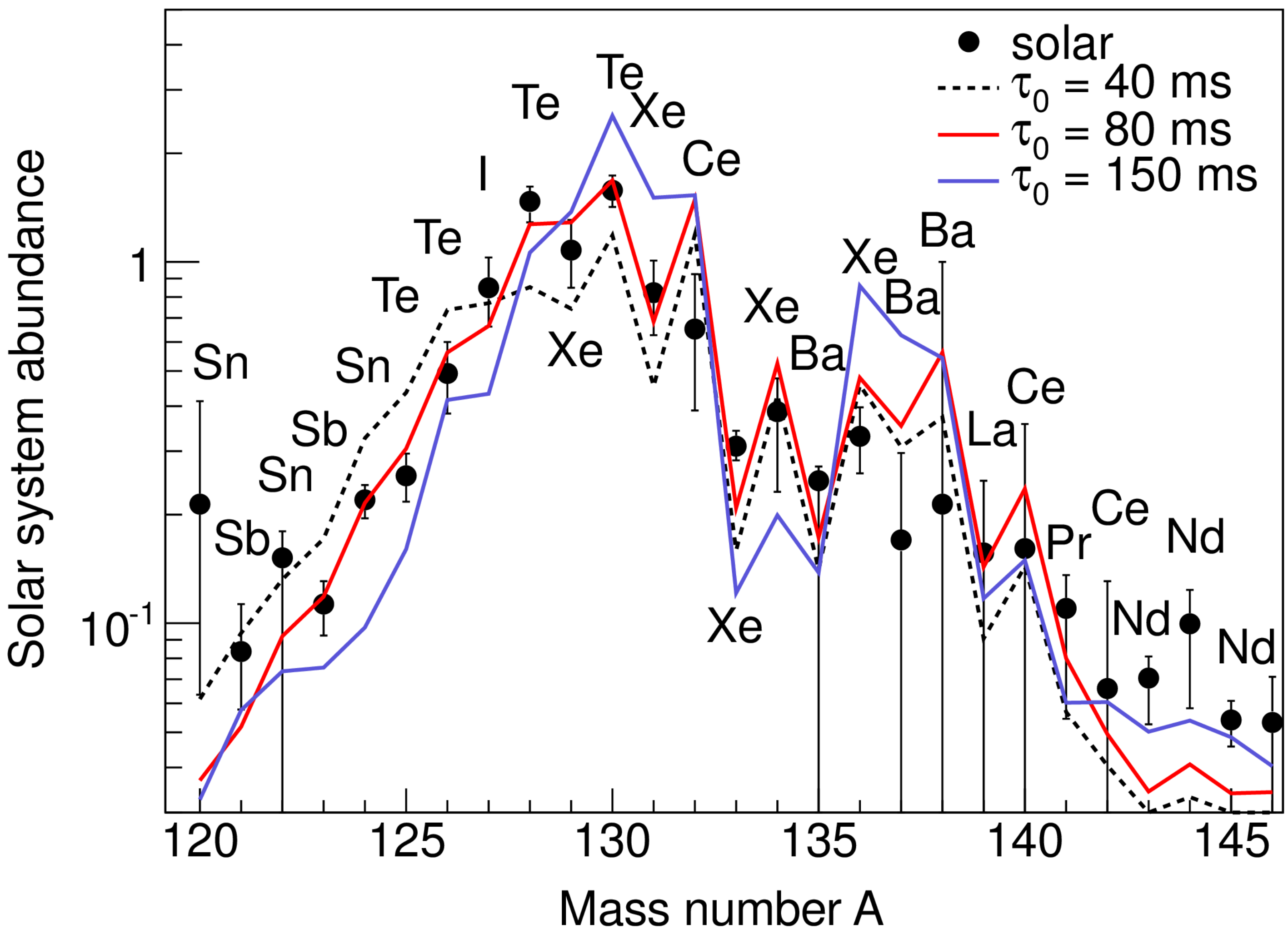
Mass model

– half-lives are important for r-process calculations

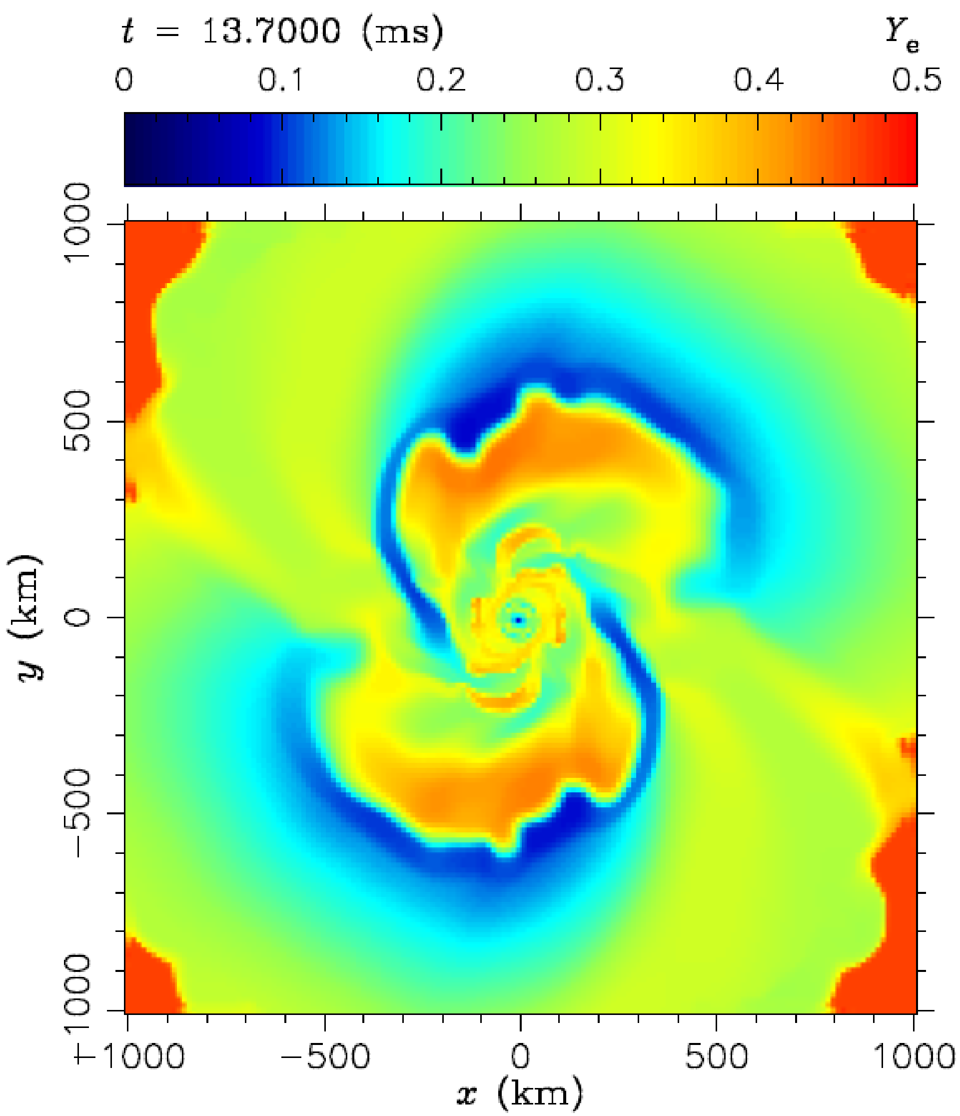
– Hot scenario works

What about universality?

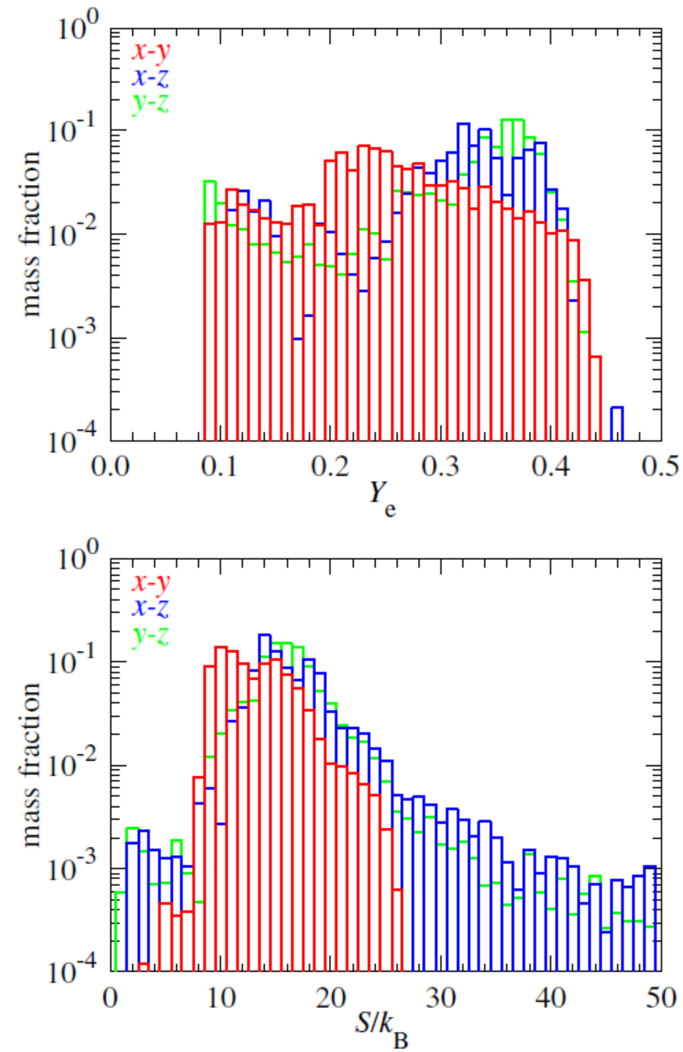
A=130 peak for different tau



Neutron stars merger

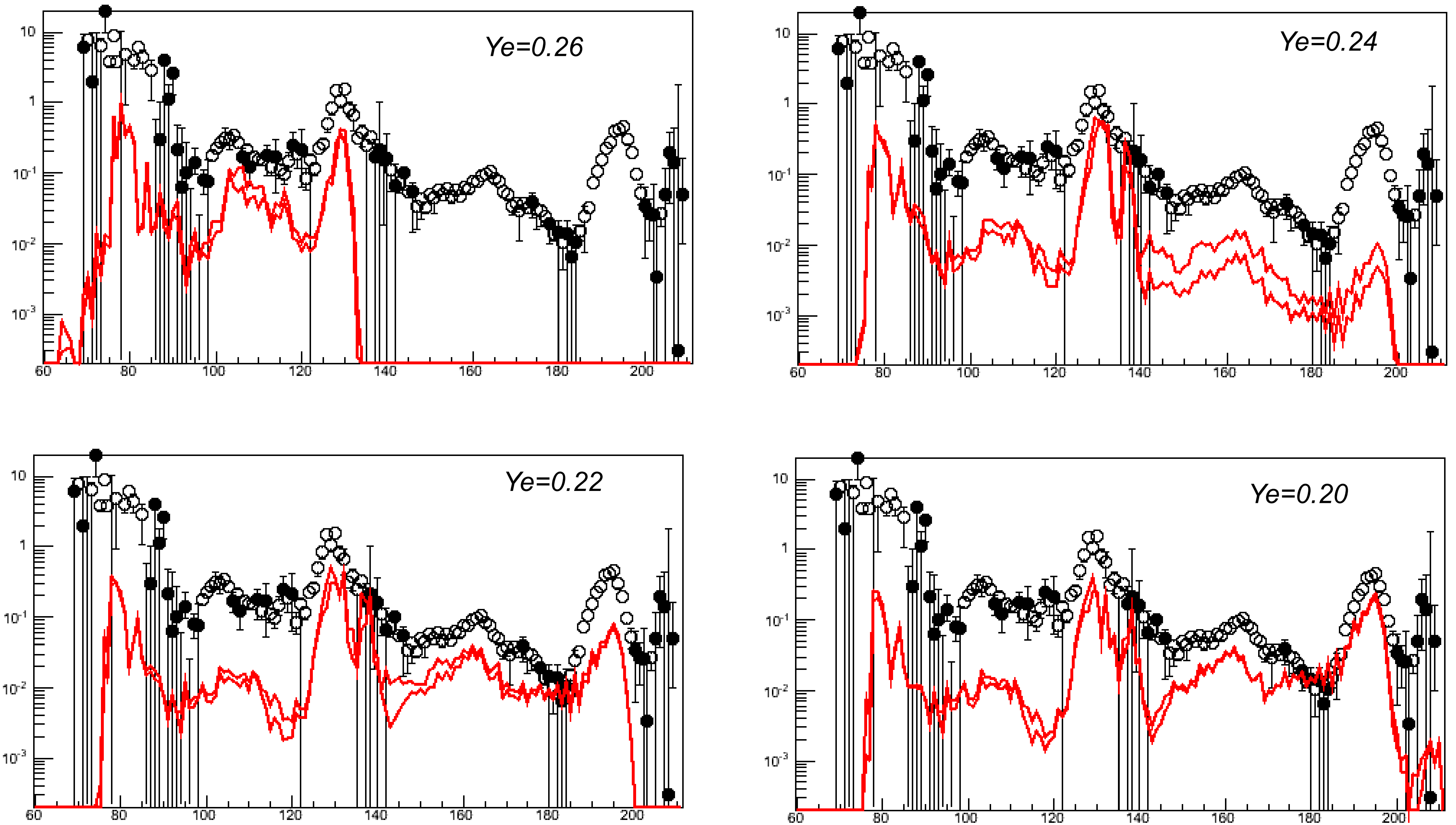


Ye, S distribution in x-y plane of a neutron star



S. Wanajo et al., APJL 789:L39, 2014

Neutron star Y_e components

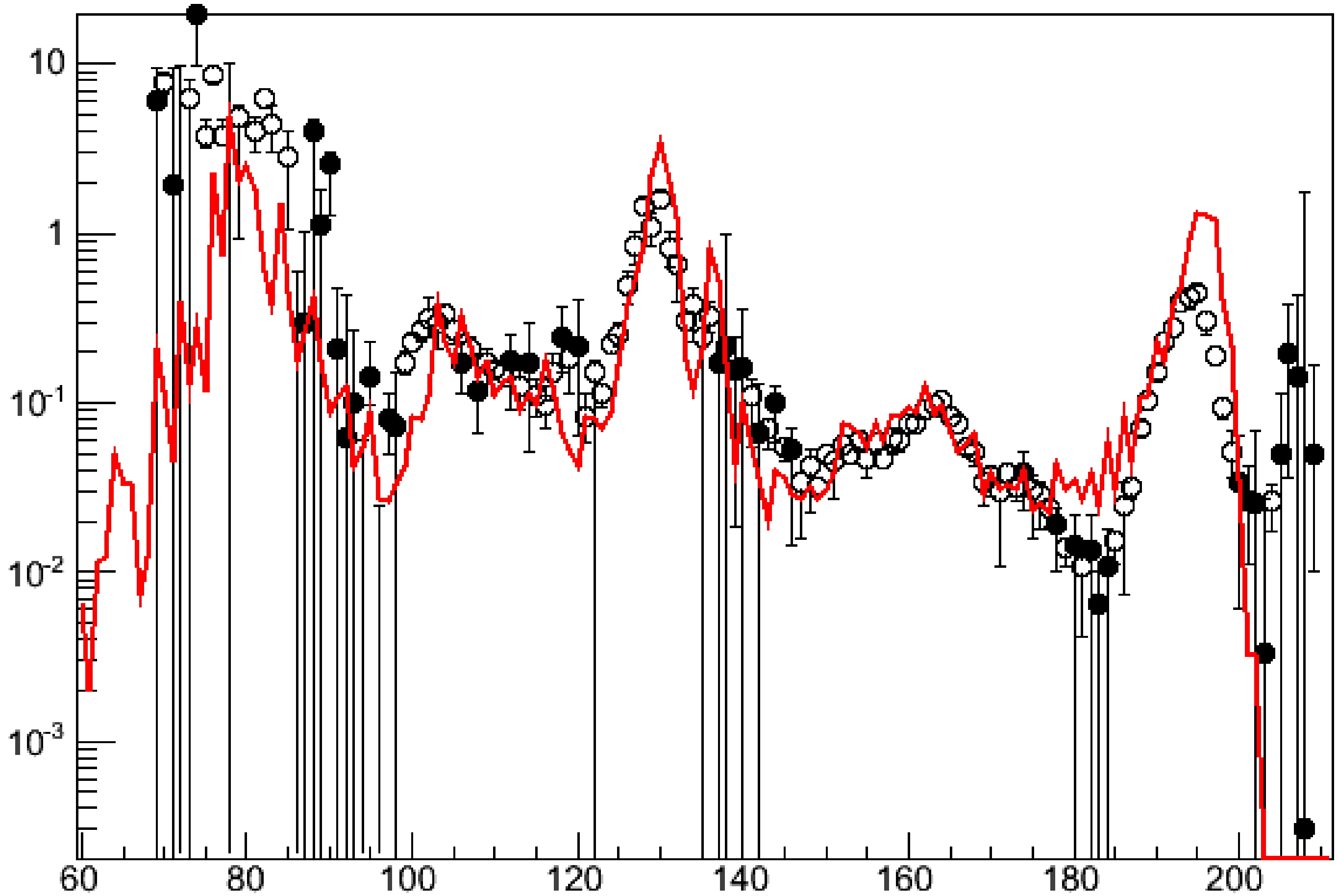


Comparison between old and new half-lives

Neutron-stars merger

Superposition of Ye = 0.1 – 0.4

Neglecting beta-decay heat



Conclusions

- No evidence of nuclear structure changes capable of modifying gross properties
- The nuclei we have studied are on the r-process path, some do have waiting point character
  - reliability of calculations
  - details of the final abundance
  - **measured numbers that have shaped the composition of our Galaxy**
- New half-lives support r-process as freezout from (n,g) – (g,n) equilibrium
- Detection of Sn, Sb in metal poor stars could inform on the conditions of a single r-process event