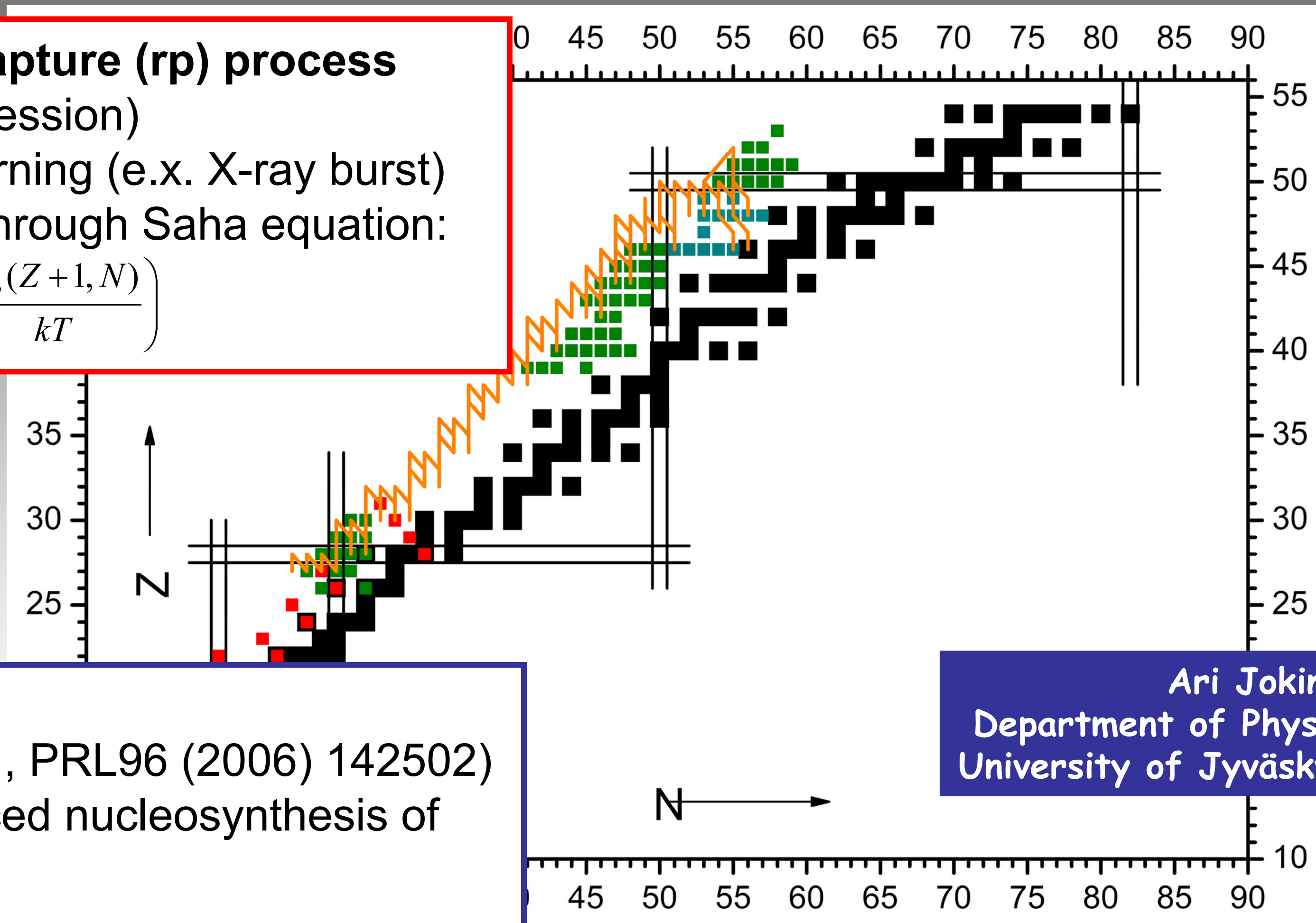
Mass measurements on the rp-process path

Rapid proton capture (rp) process
(H.Schatz, this session)
- Explosive H burning (e.x. X-ray burst)
- Masses enter through Saha equation:

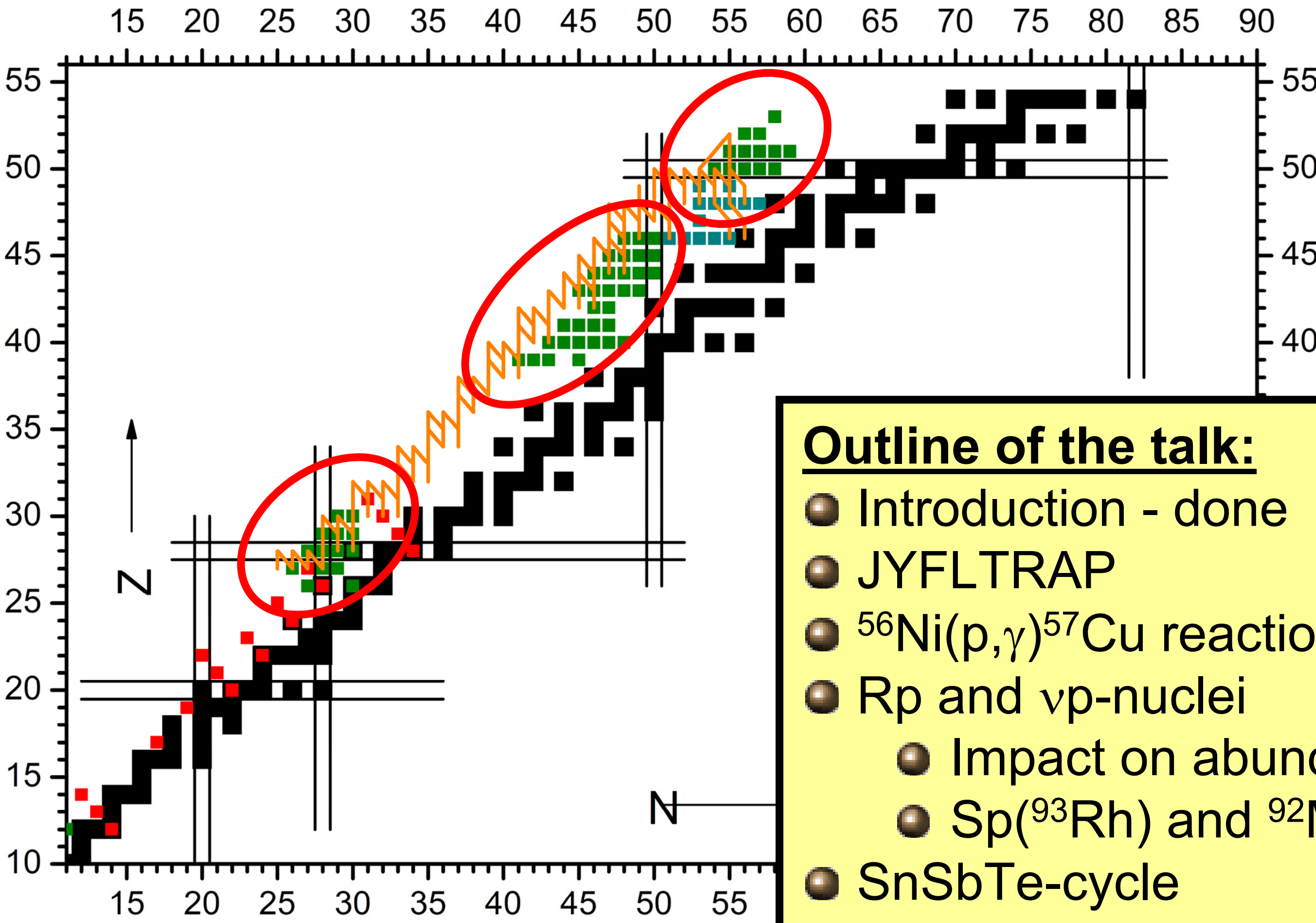
$$\frac{Y(Z+1,N)}{Y(Z,N)} \propto \exp\left(\frac{S_p(Z+1,N)}{kT}\right)$$



νp process
(C.Fröhlich et al., PRL96 (2006) 142502)
- Neutrino-induced nucleosynthesis of A>64
- Supernovae
- Candidate to explain solar abundances of light p nuclei ^{92,94}Mo and ^{96,98}Ru

Ari Jokinen
Department of Physics
University of Jyväskylä

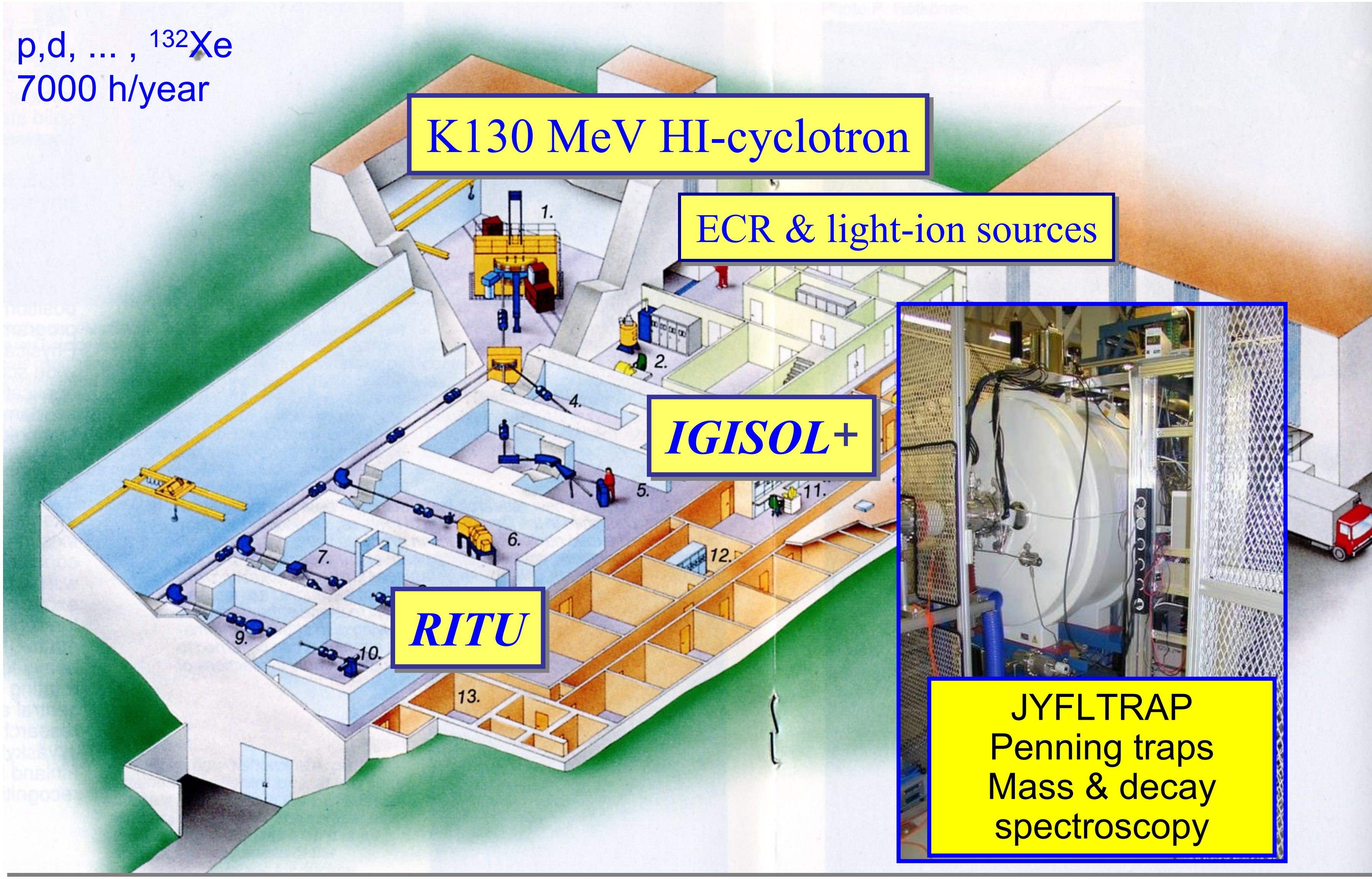
Outline



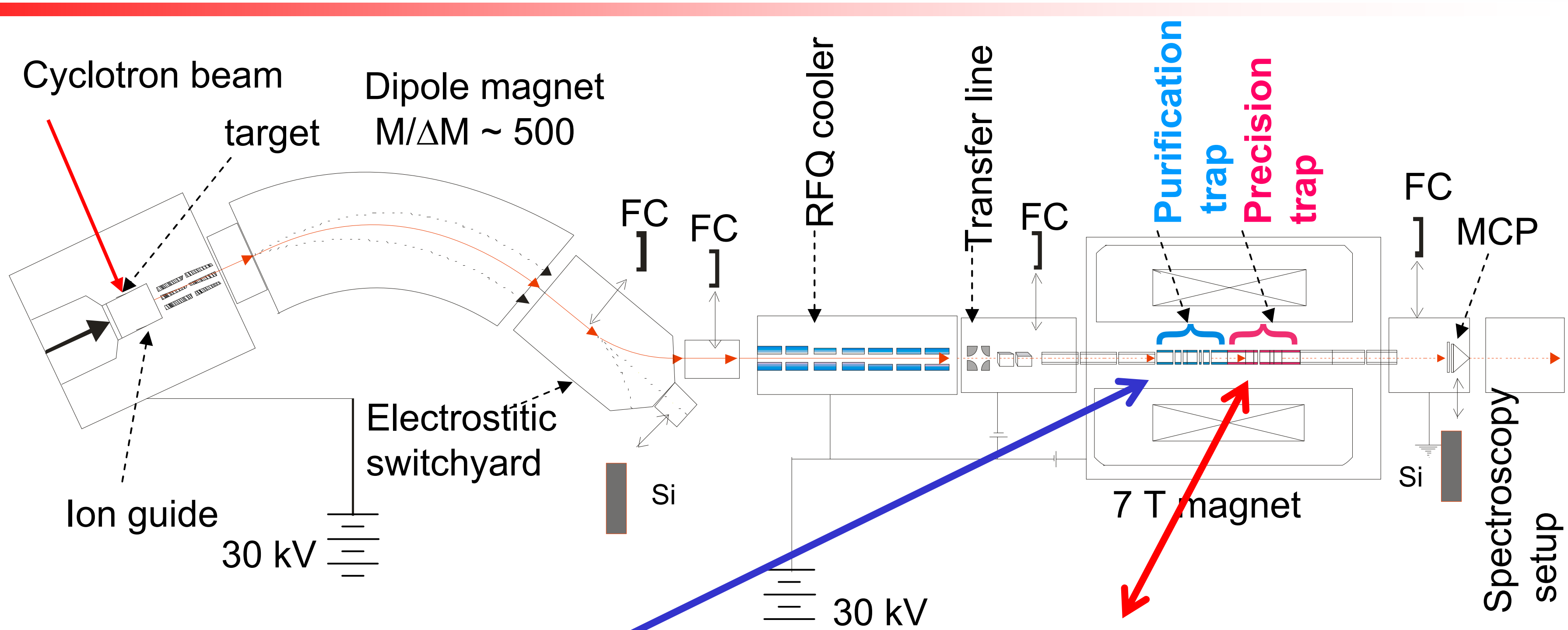
Outline of the talk:

- Introduction - done
- JYFLTRAP
- $^{56}Ni(p,\gamma)^{57}Cu$ reaction rate
- Rp and νp-nuclei
  - Impact on abundances
  - Sp(^{93}Rh) and ^{92}Mo/^{94}Mo ratio
- SnSbTe-cycle
- Outlook

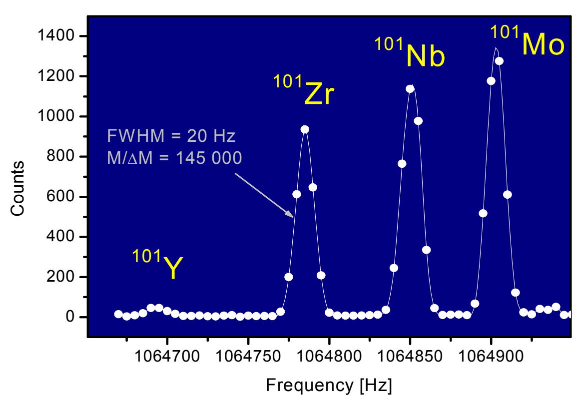
JYFL – Accelerator Laboratory



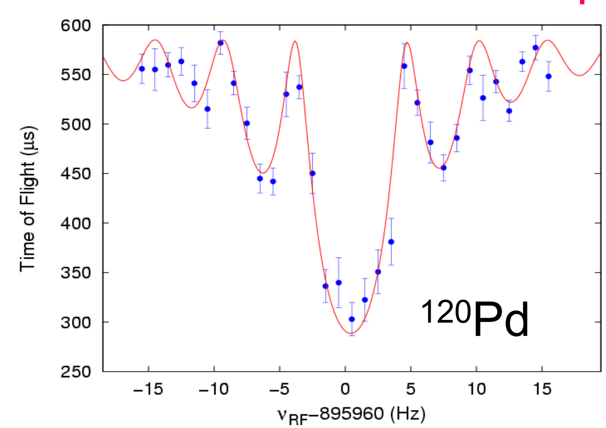
JYFLTRAP setup @ IGISOL



Purification scan



TOF-resonance in Precision trap



Basic equations for mass determination

$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

$$\frac{f_{c,\mathrm{ref}}}{f_c} = \frac{m - m_e}{m_{\mathrm{ref}} - m_e}$$

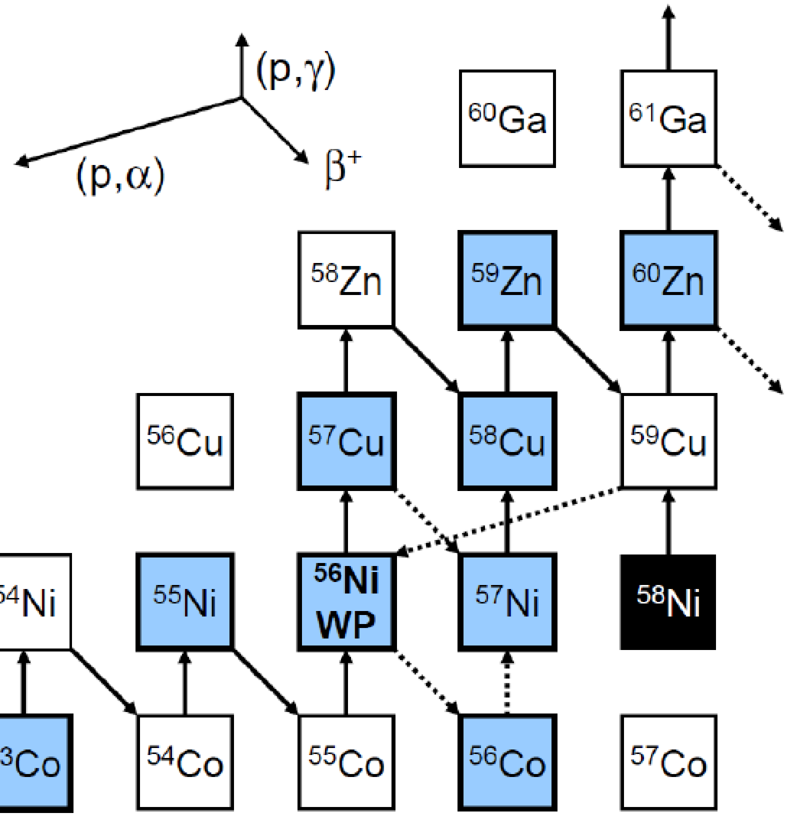
Waiting-point nucleus ^{56}Ni

$T_{1/2}(^{56}\mathrm{Ni}) = 6.075$ d

Historically endpoint of rp-process

Rp-process has to proceed vai proton capture on ^{56}Ni

→Rate of $^{56}\mathrm{Ni}(p,\gamma)^{57}\mathrm{Cu}$ becomes crucial !



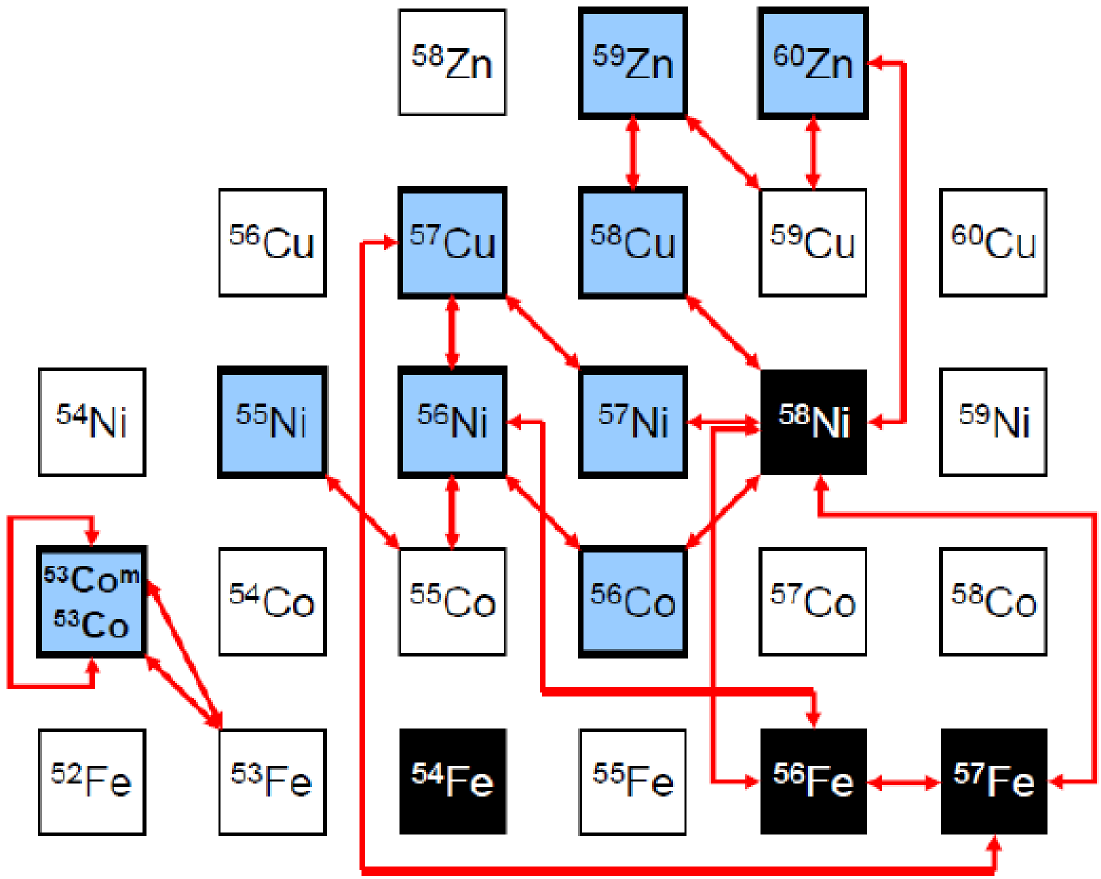
A.Kankainen et al., arXiv:1007.0978v1 6 Jul 2010 and poster NIC_XI_178

Network of mass measurements

Production:
^{3}He/p on ^{54}Fe/^{58}Ni
^{20}Ne on Ca

Analysis network:
13 nuclides
17 links

Results:
S_p of ^{57}Cu directly !
JYFLTRAP: 689.7(5) keV
AME03: 695(19) keV



A.Kankainen et al., arXiv:1007.0978v1 6 Jul 2010
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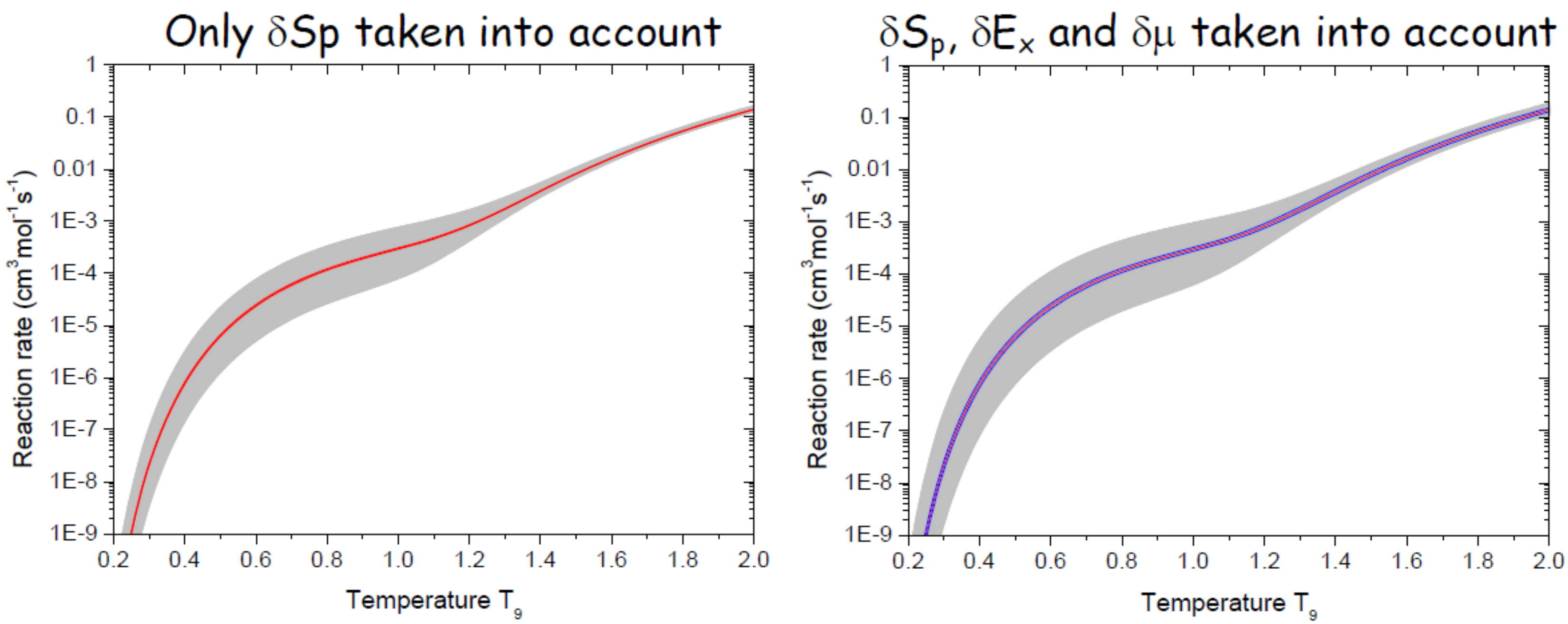
Reaction rate of $^{56}Ni(p,\gamma)^{57}Cu$



- Rate slightly higher than previously
- Uncertainties below 1 GK removed
- Rp-process proceeds beyond ^{56}Ni

A.Kankainen et al., arXiv:1007.0978v1 6 Jul 2010
and poster NIC_XI_178

Rp- and νp-process studies

stable nucleus

JYFLTRAP 2007 (^{58}Ni + ^{58}Ni)
V.-V. Elomaa et al., PRL 102 (2009) 252501

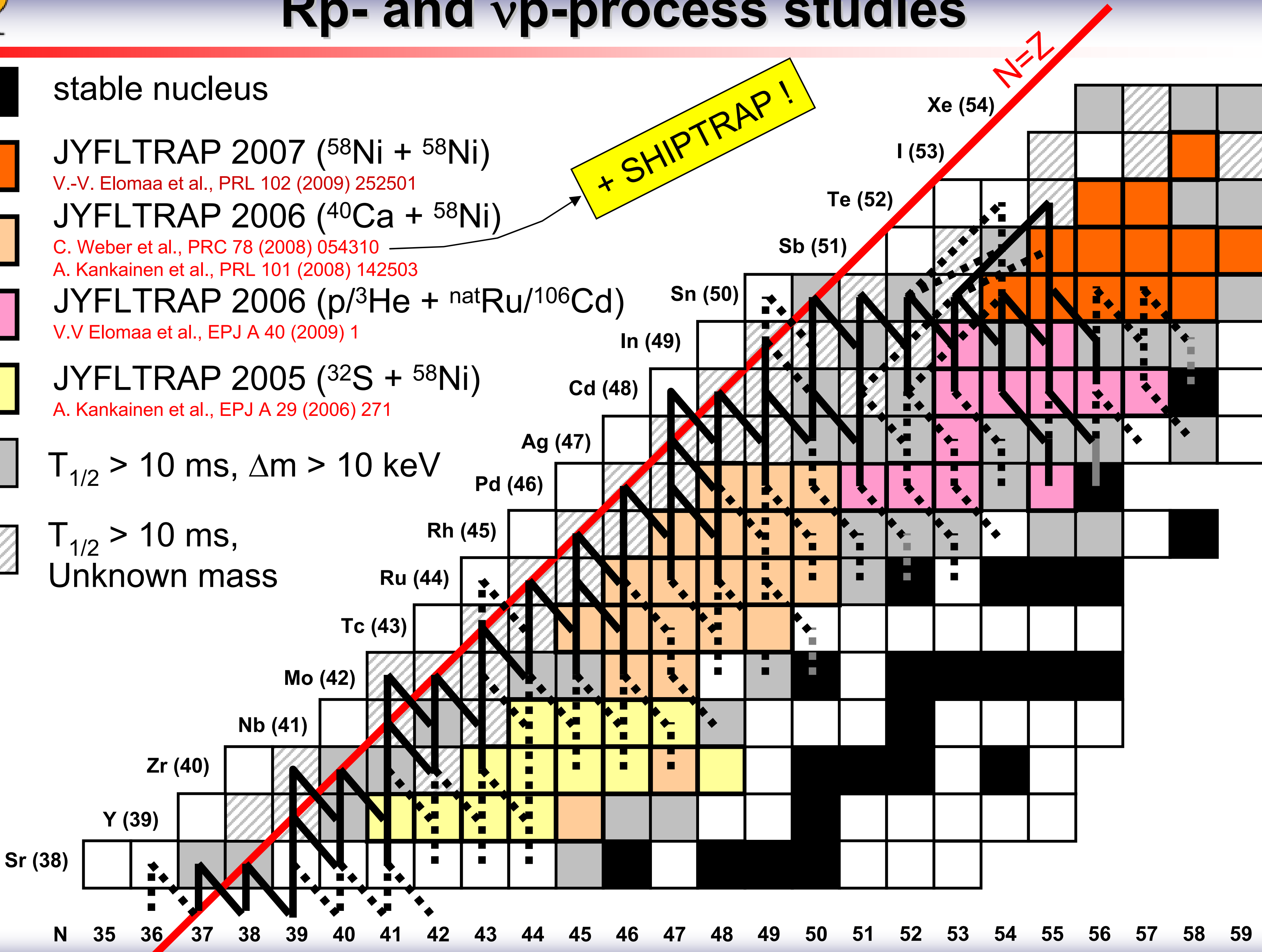
JYFLTRAP 2006 (^{40}Ca + ^{58}Ni)
C. Weber et al., PRC 78 (2008) 054310
A. Kankainen et al., PRL 101 (2008) 142503

JYFLTRAP 2006 (p/^{3}He + ^{nat}Ru/^{106}Cd)
V.V Elomaa et al., EPJ A 40 (2009) 1

JYFLTRAP 2005 (^{32}S + ^{58}Ni)
A. Kankainen et al., EPJ A 29 (2006) 271

$T_{1/2}$ > 10 ms, Δm > 10 keV

$T_{1/2}$ > 10 ms,
Unknown mass



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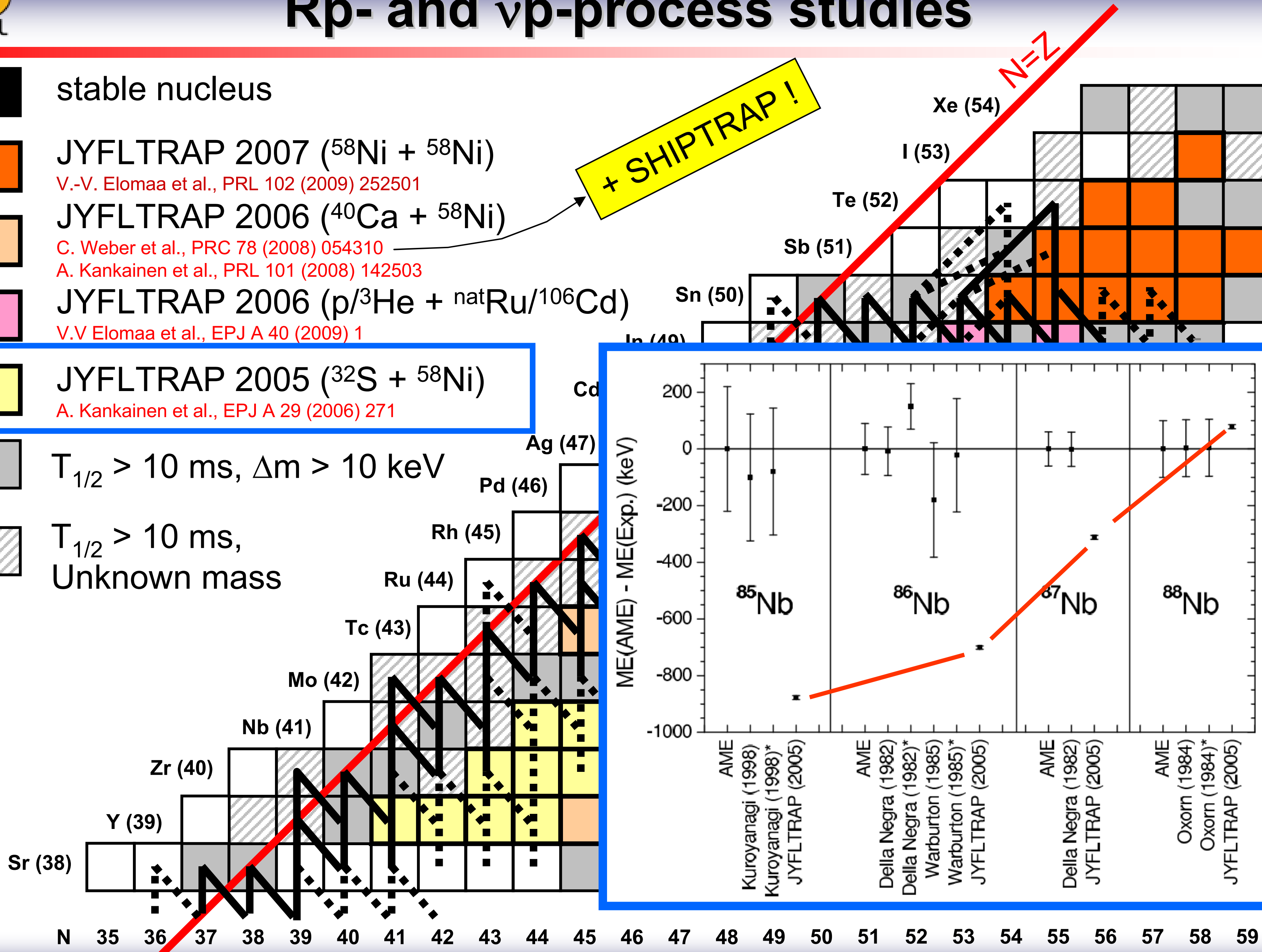
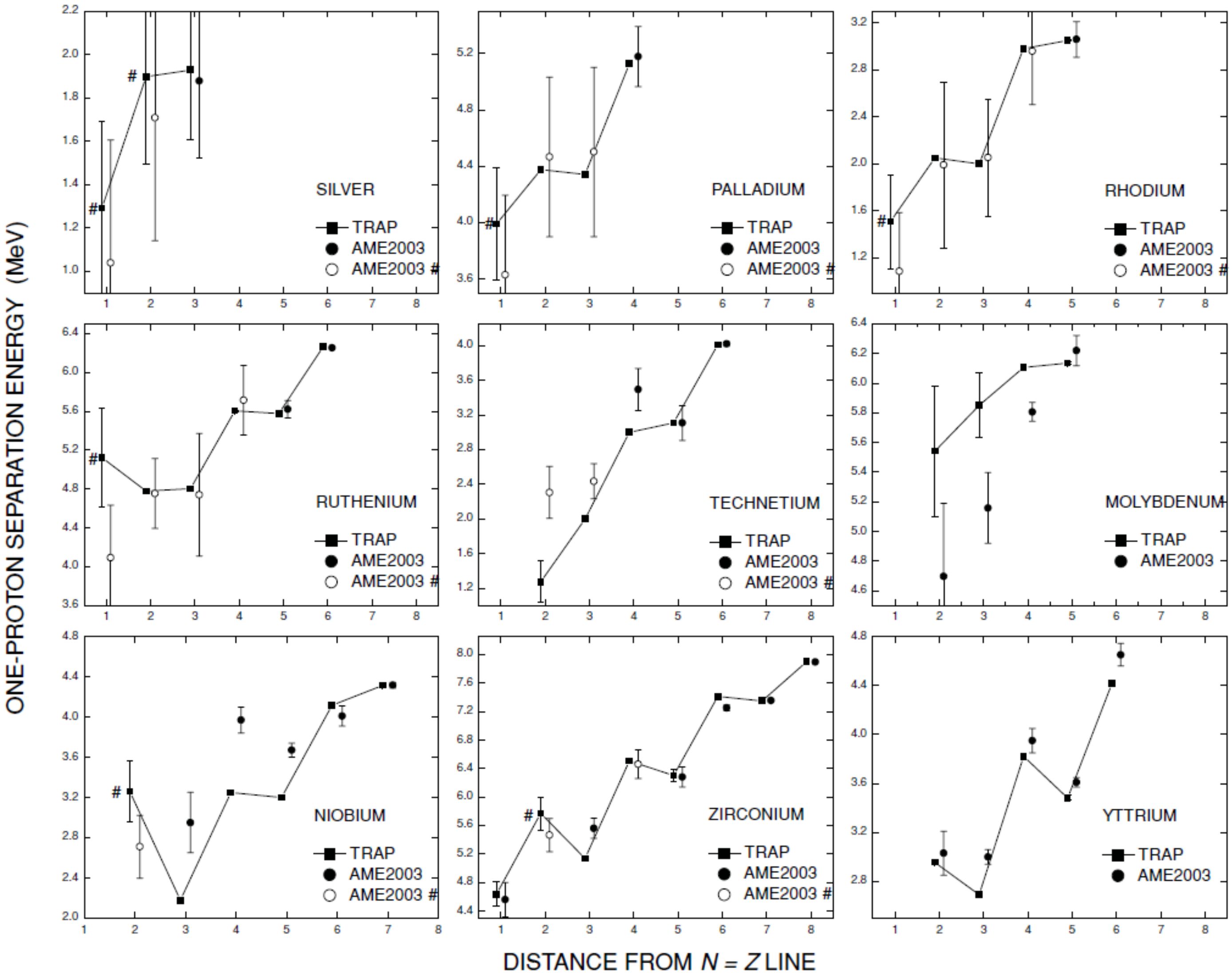


Proton separation energies

$$\frac{Y(Z+1,N)}{Y(Z,N)} \propto \exp\left(\frac{S_p(Z+1,N)}{kT}\right)$$



C. Weber et al., PRC 78 (2008) 054310

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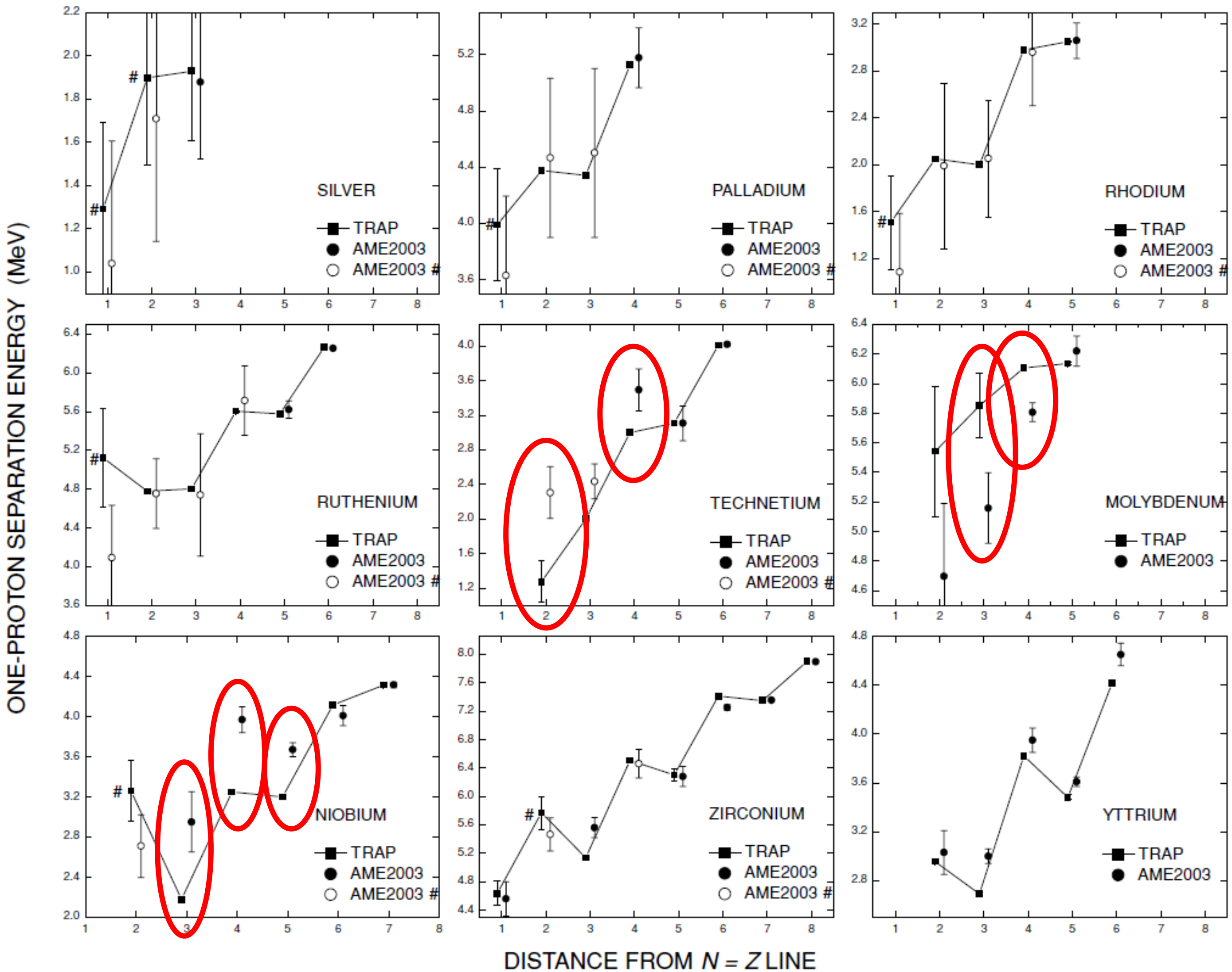

C. Weber et al., PRC 78 (2008) 054310

Impact on abundances (νp-process)

^{88}Tc mass deviation;
$\Delta me_{AME-TRAP}$= -1031keV

^{87}Mo(n,p)^{87}Nb instead of ^{87}Mo(p,γ)^{88}Tc, increase of ^{87}Nb

→ Higher ^{87}Sr abundance !

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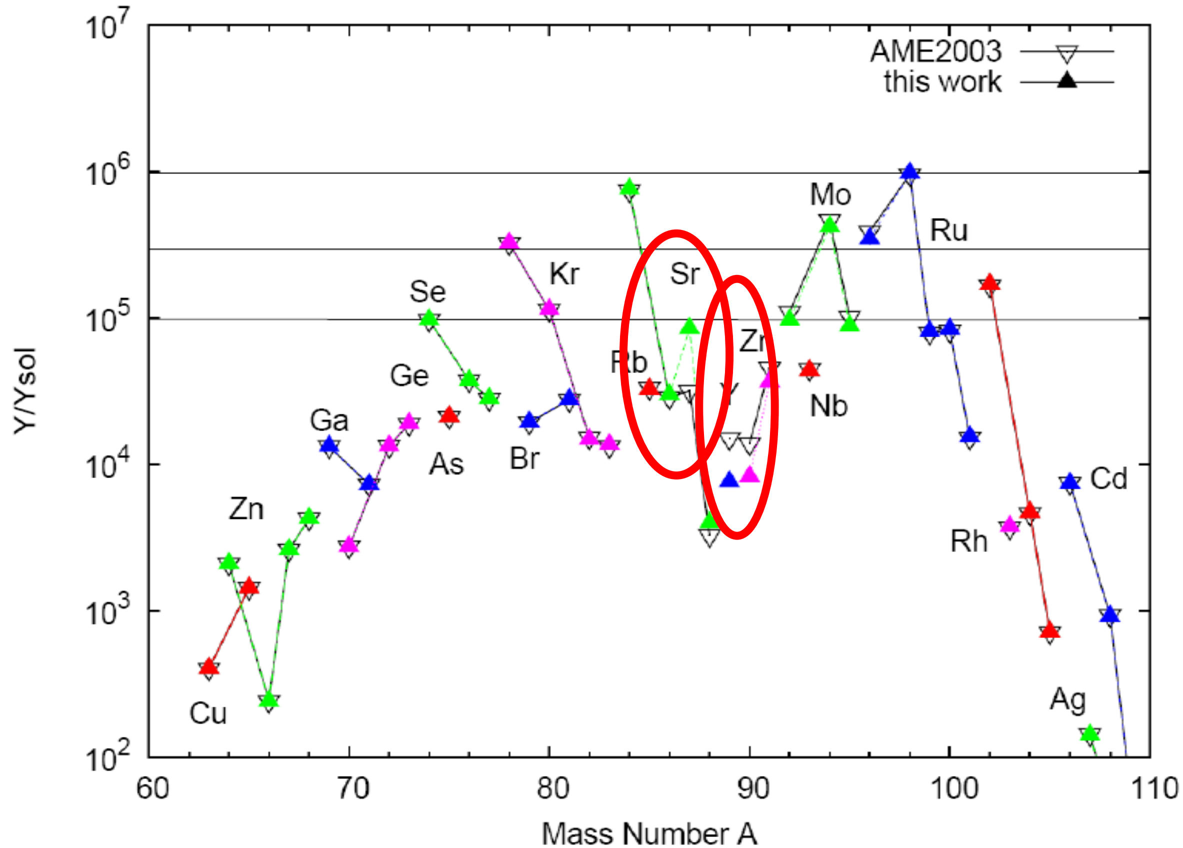
^{90}Tc mass deviation;
$\Delta me_{AME-TRAP}$= -486(240) keV

Increases the rate for ^{90}Tc(γ,p)^{89}Mo

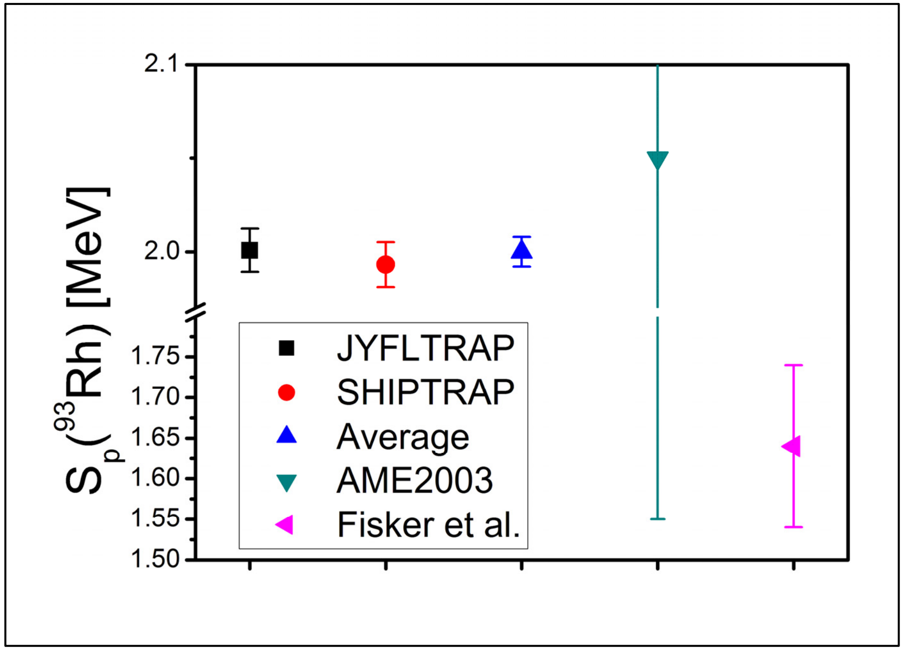
→ Reduces A=90 abundance !

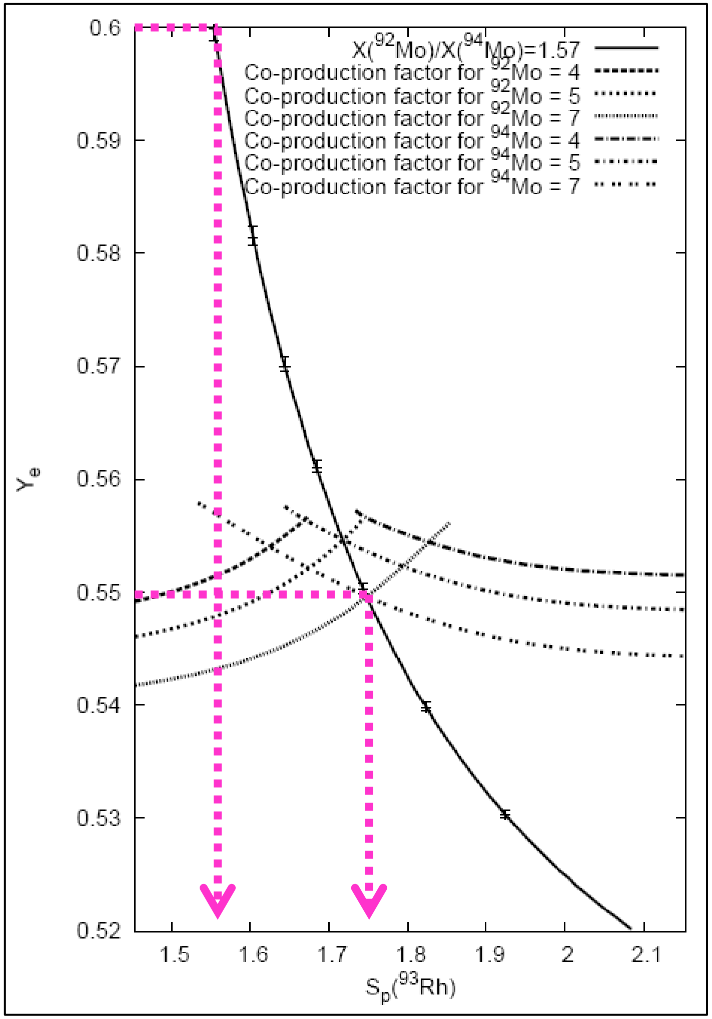


C. Weber et al., PRC 78 (2008) 054310

$S_p(^{93}Rh)$ and $^{92}Mo/^{94}Mo$ ratio

Predicting the proton separation energy of ^{93}Rh from supernova nucleosynthesis.
J. L. Fisker, R. D. Hoffman, J. Pruet, arXiv:0711.1502v1 [astro-ph] 9 Nov 2007





Present model with its parameters is not sufficient to reproduce solar abundance ratio of $^{92}Mo/^{94}Mo$

Canadian Penning Trap-results:
J. Fallis et al., PRC 78 (2008) 022801(R)
In agreement with JYFLTRAP and SHIPTRAP !
S_p = 2007(9) keV vs. S_p = 2001(5) keV

C. Weber et al., PRC 78 (2008) 054310

SnSbTe-cycle: End of the rp-process ?

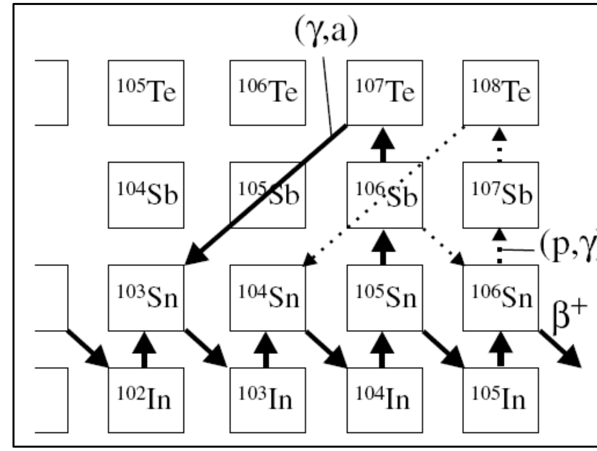
PRL 98, 212501 (2007) PHYSICAL REVIEW LETTERS week ending 25 MAY 2007

α Decay of ^{109}I and Its Implications for the Proton Decay of ^{105}Sb and the Astrophysical Rapid Proton-Capture Process

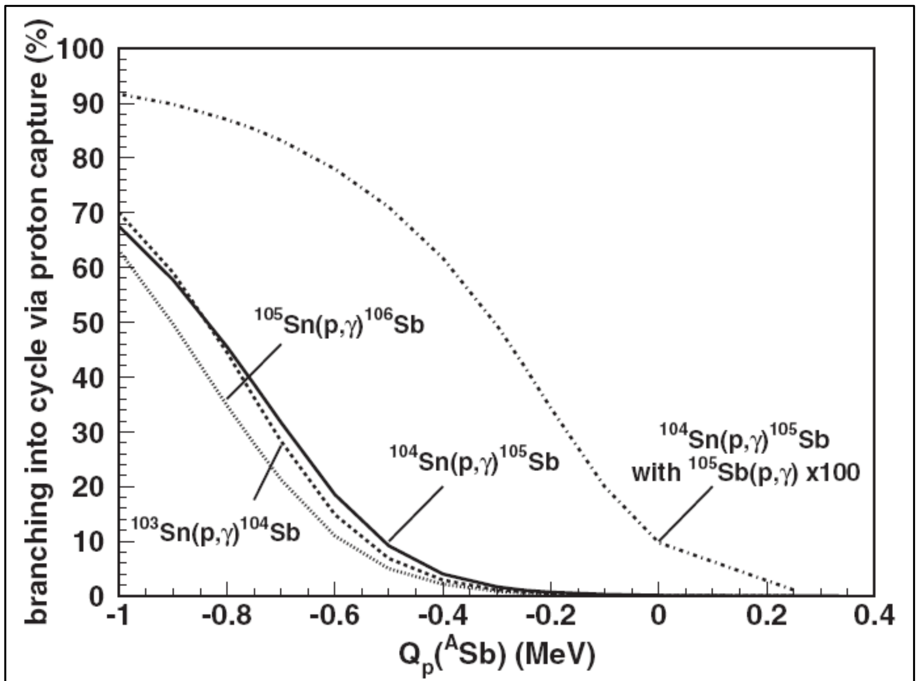
C. Mazzocchi,[1,2] R. Grzywacz,[1,3] S. N. Liddick,[4] K. P. Rykaczewski,[3] H. Schatz,[5] J. C. Batchelder,[4] C. R. Bingham,[1,3] C. J. Gross,[3] J. H. Hamilton,[6] J. K. Hwang,[6] S. Ilyushkin,[7] A. Korgul,[1,6,8,9] W. Królas,[9,10] K. Li,[6] R. D. Page,[11] D. Simpson,[1,12] and J. A. Winger[4,7,9]

Q_p(^{105}Sb) increased by 130 keV

No chance for SnSbTe cycle in ^{104}Sn (nor ^{103}Sn)



H. Schatz et al, PRL86 (2001) 3471



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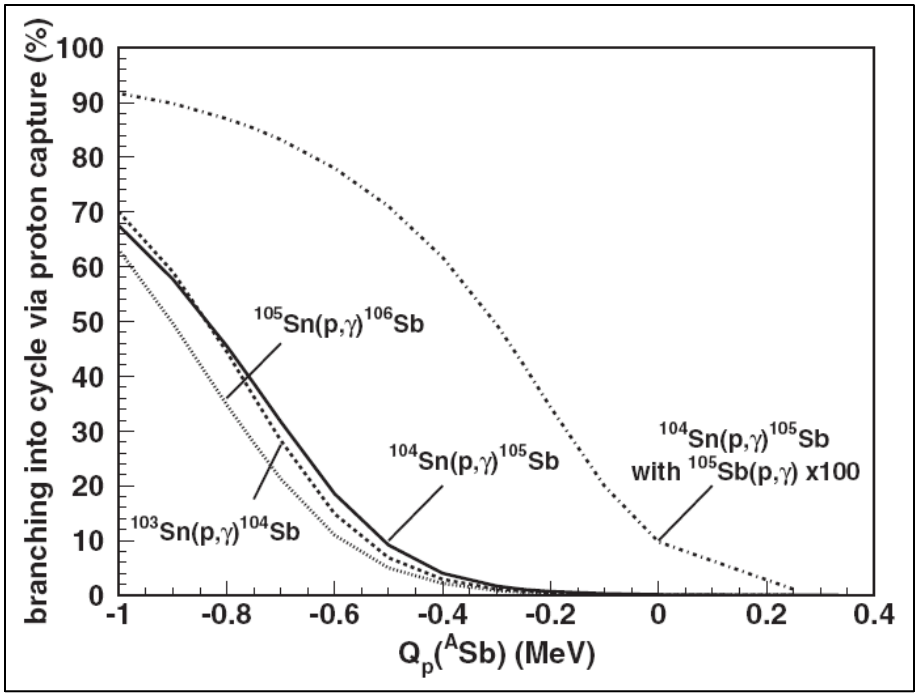


Could cycle develop in ^{105}Sn ?

- depends on the $Q_p(^{106}Sb)$
- Q_p = -930(210) keV

  [A. Plochocki et al, Phys. Lett. 106B (1981) 385]
- Q_p = -360(320) keV

  [AME2003, G. Audi et al., NPA 729 (2003) 337]

JYFLTRAP:

S_p= 424(8) keV

V.-V. Elomaa et al., PRL 102 (2009) 252501

Conclusions:

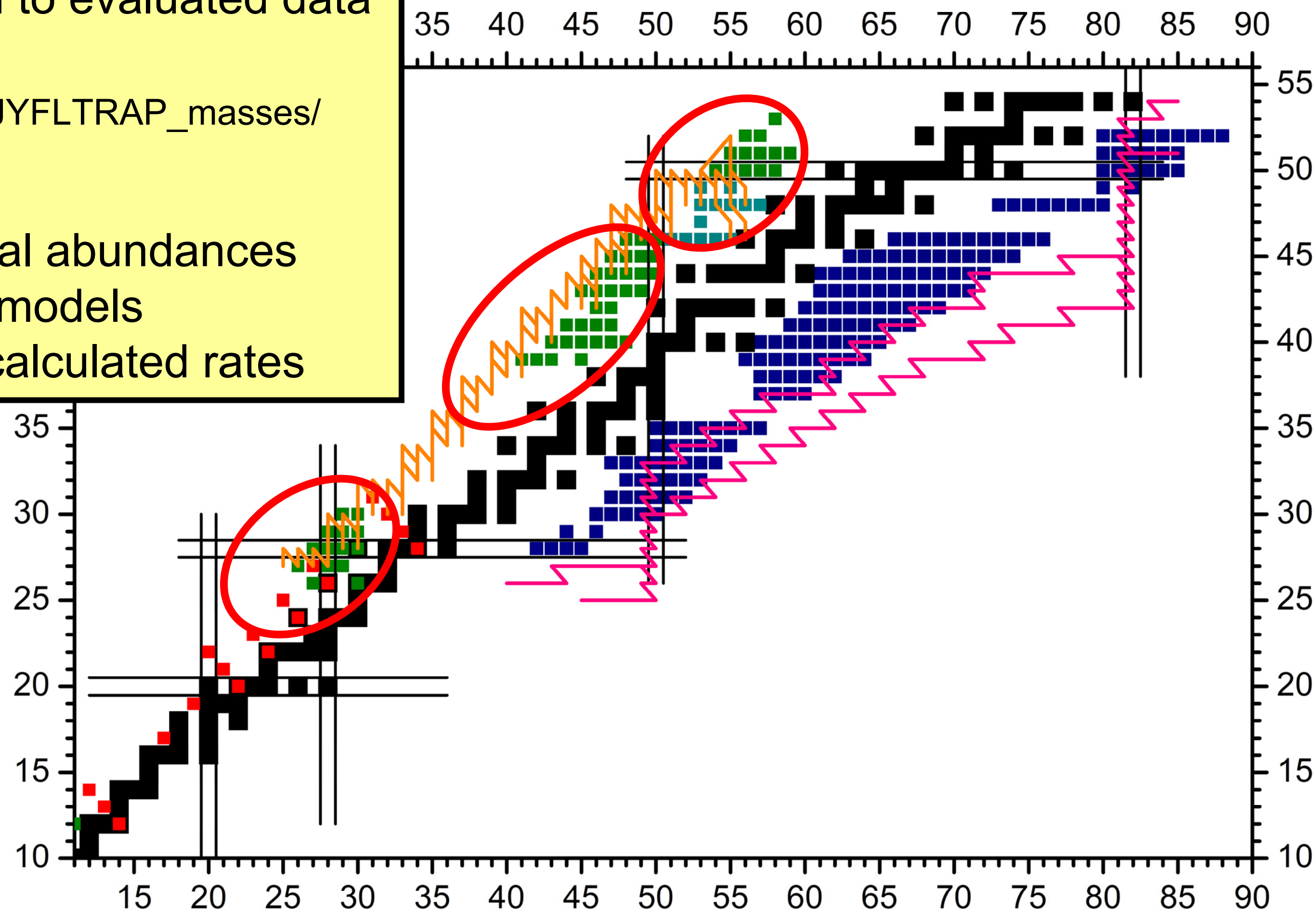
- Branching to the SnSbTe cycle reduced from 50 % to 3 %
- Reduces late-time He production
- Slightly longer, less luminous burst tail
- In a final composition, broader distributions of ^{68}Zn, ^{72}Ge, ^{104,105}Pd and residual He

Summary and outlook

- ~90 neutron-deficient nuclides measured at JYFLTRAP
- Deviations compared to evaluated data

http://research.jyu.fi/igisol/JYFLTRAP_masses/
and ISOLTRAP database

- Modest impact on final abundances
- Test of astrophysics models
- Strong influence on calculated rates



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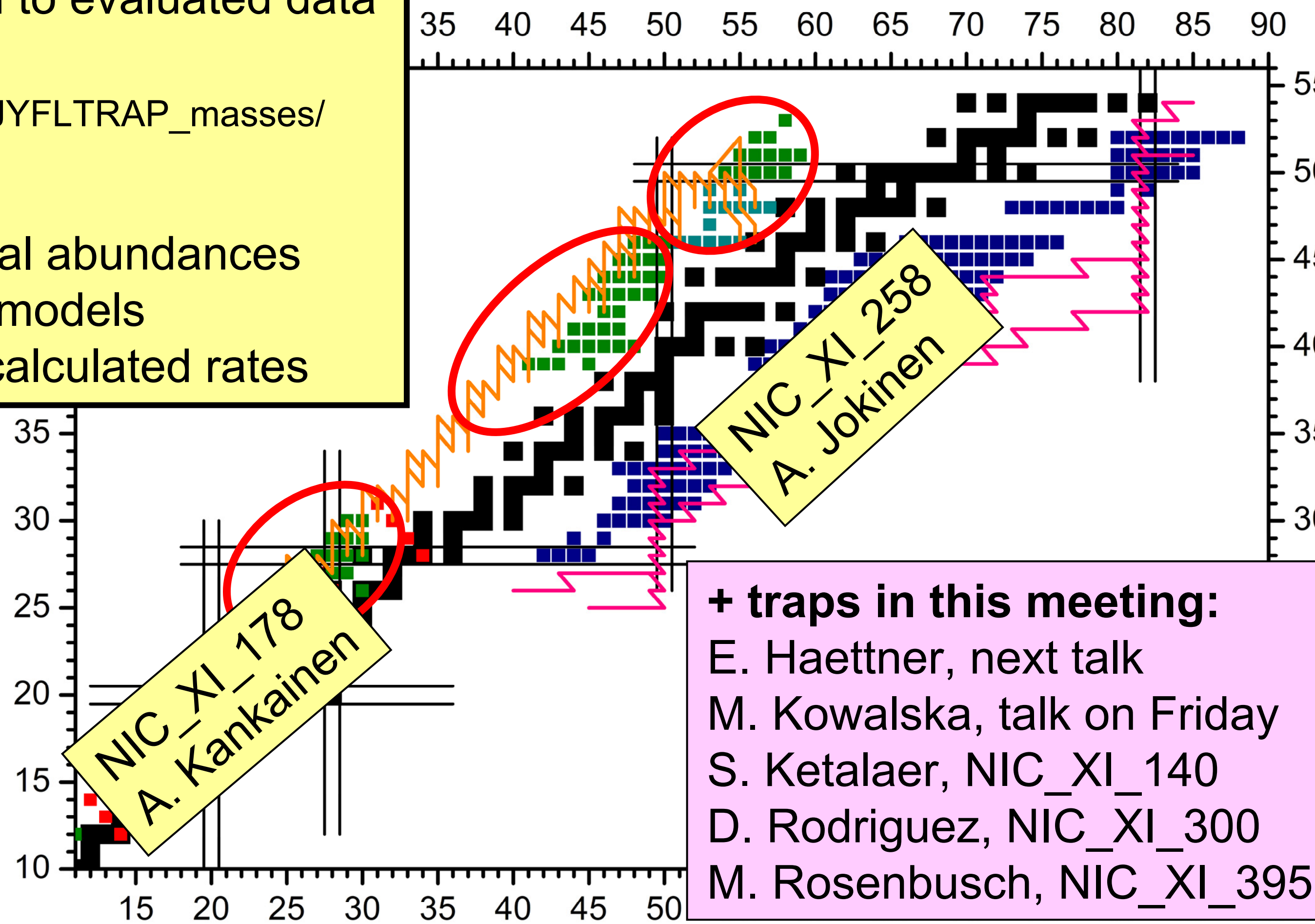

+ traps in this meeting:
E. Haettner, next talk
M. Kowalska, talk on Friday
S. Ketalaer, NIC_XI_140
D. Rodriguez, NIC_XI_300
M. Rosenbusch, NIC_XI_395

V.-V. Elomaa, T. Eronen,
U. Hager, J. Hakala, A. Jokinen,
A. Kankainen, V. Kolhinen,
I. Moore, H. Penttilä,
S. Rahaman, S. Rinta-Antila,
J. Rissanen, A. Saastamoinen,
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