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Excellence Cluster
Universe

p-process simulations with an updated reaction library

I. Dillmann (TUM), F. Käppeler (FZK), T. Rauscher (Basel),
F.-K. Thielemann (Basel)

The KADoNiS p-process database

I. Dillmann (TUM), R. Plag (GSI), T. Szucs (ATOMKI), Zs. Fülöp (ATOMKI)

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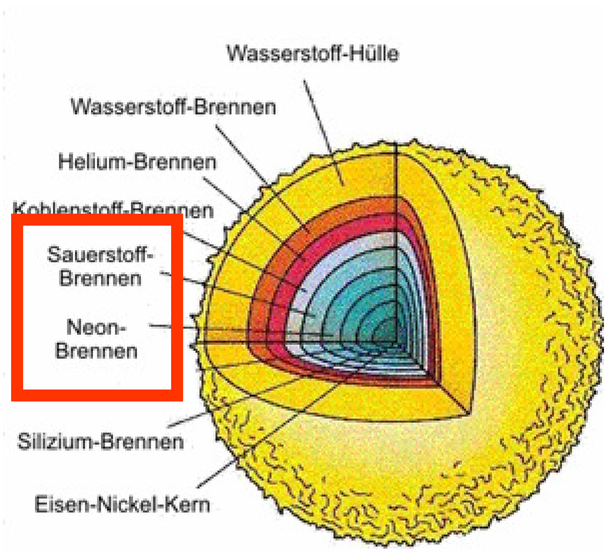
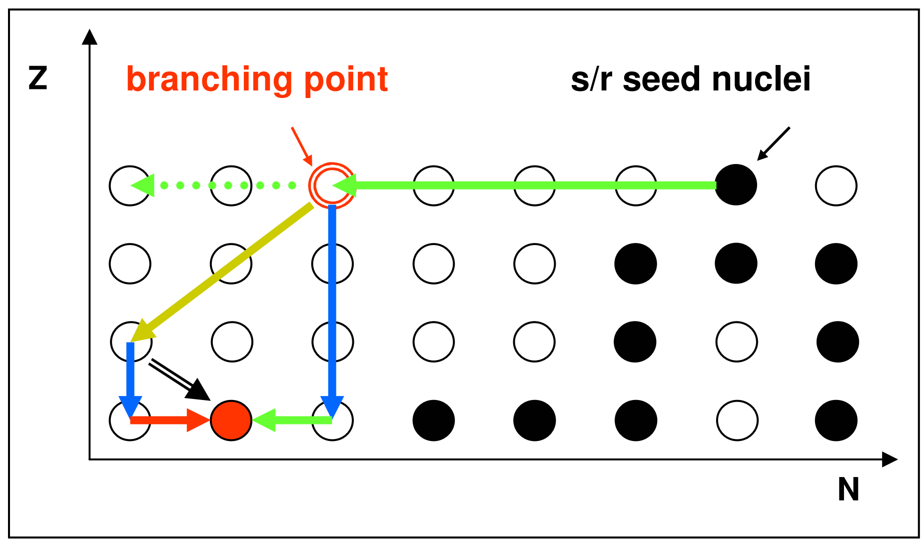
Mechanism of the γ process

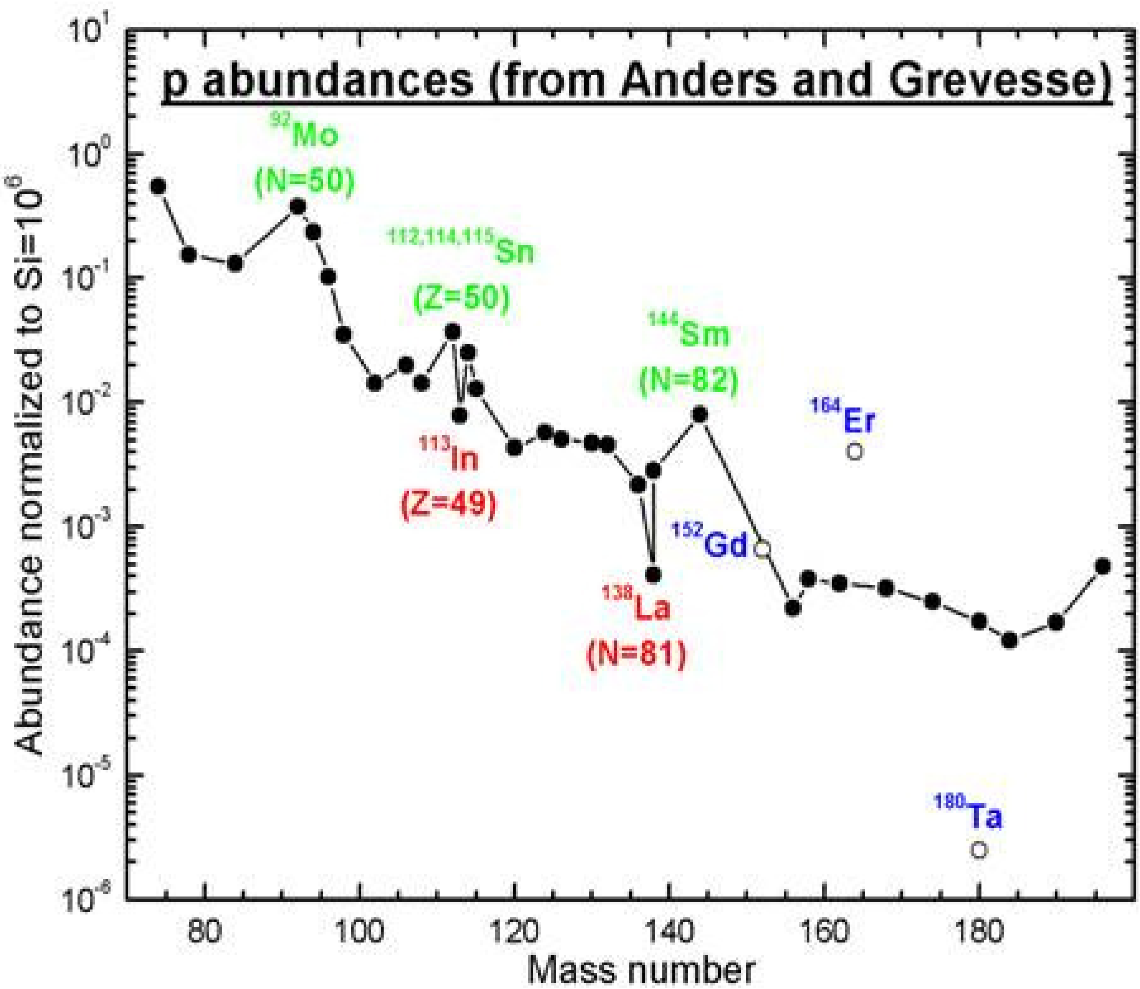
- Most favoured: **explosive O/Ne burning** during **SN II** in massive stars
- Outwards directed shock front heats shells up to 2-3 GK ⇨ Explosive burning in the O/Ne shell ignited for 1-10 s

- Photodisintegration by high-energy photons can produce p-rich nuclei from pre-existing heavy (s or r) seed nuclei („γ process“)





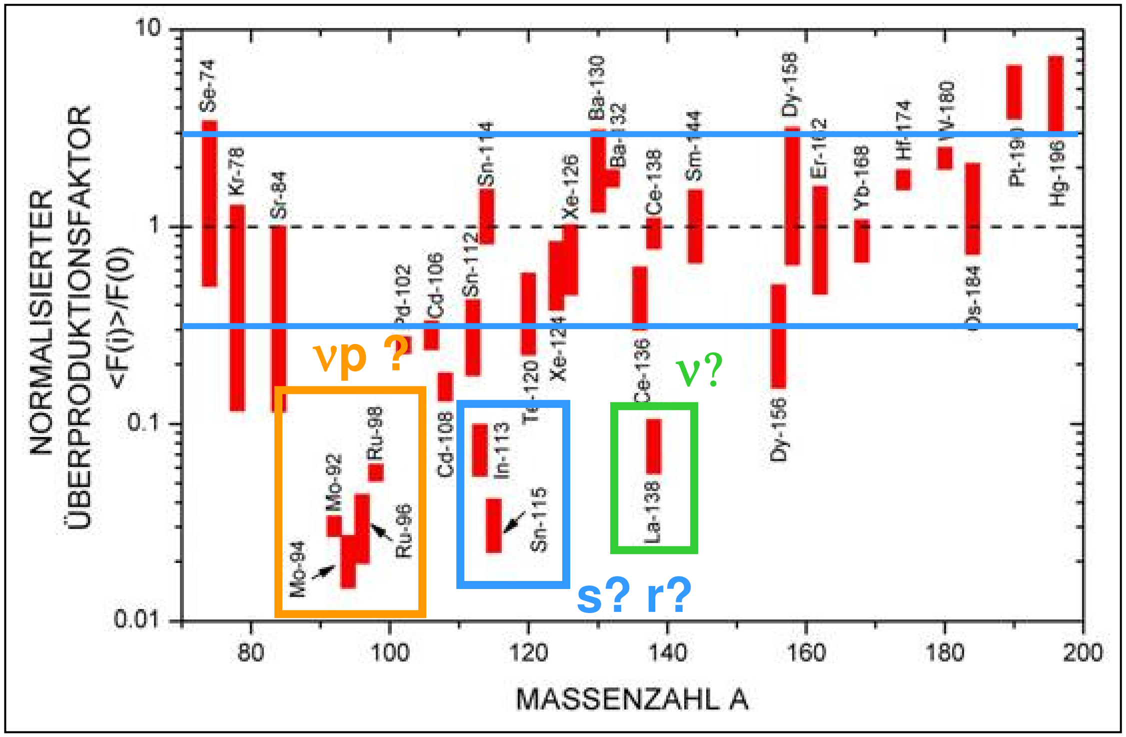
Solar p-process abundances



$$N_p = N_\odot - N_s - N_r$$

p-process problems

„Normalized overproduction factor“



if $\langle F \rangle / F_0 = 1$: solar

Norm. overproduction factors
in different SN II models
(13, 15, 20, 25 $M_\odot$)

Good reproduction for bulk of p isotopes within factor of 3

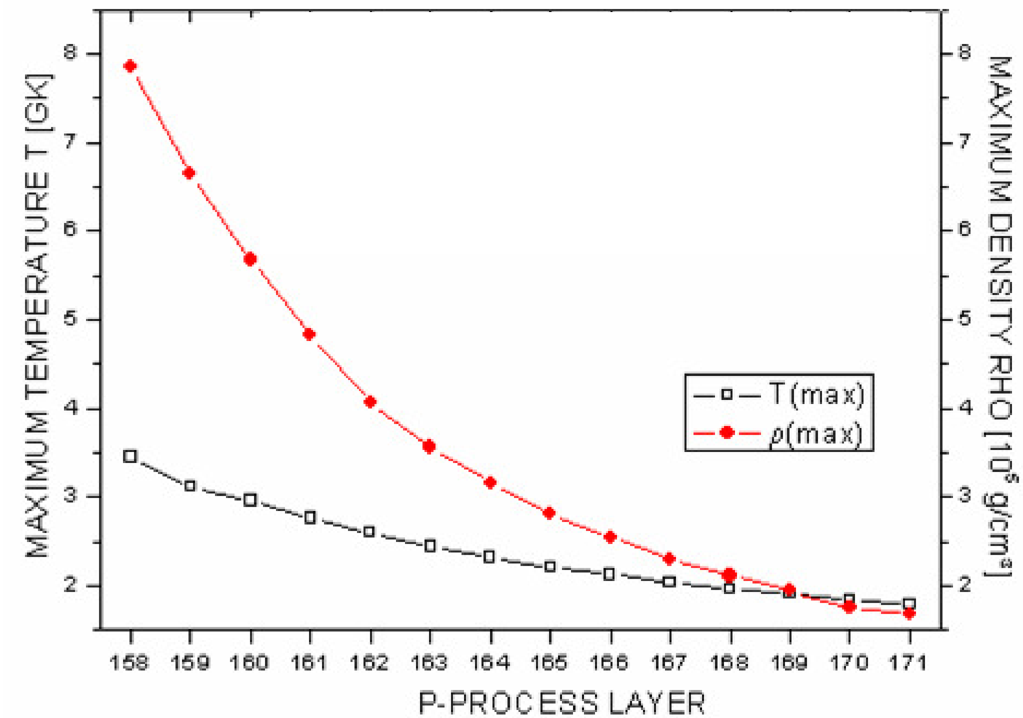
Problems with ^{92,94}Mo, ^{96,98}Ru, ^{113}In, ^{115}Sn, ^{138}La

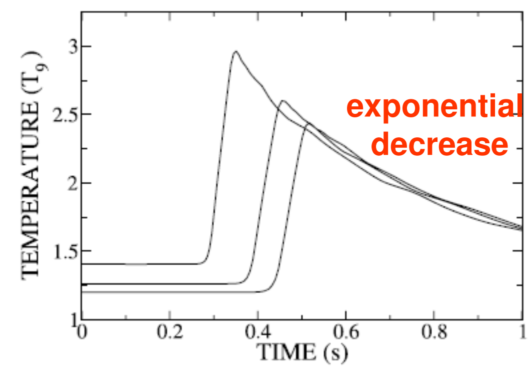
- p process abundances are **superposition of several processes** (γ, rp, ν, and νp)

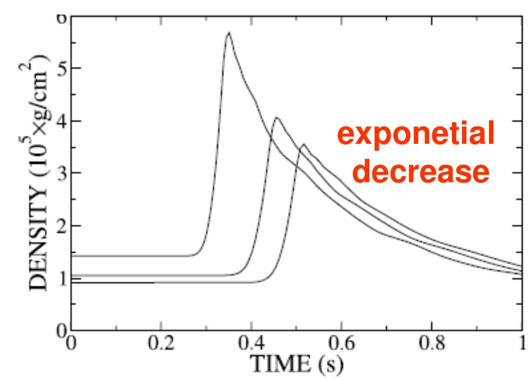
M. Rayet et al., Astron. Astroph. 227, (1990) 271
M. Rayet et al., Astron. Astroph. 208, (1995) 517

p-process network calculations

- parameterized SN II shock front model
- p-process zone of the **O/Ne burning** zone in a **25 M$_\odot$** star **(γ process)** subdivided into 14 single layers („158...171“)
- different layers have different peak temperatures and densities: Tρ profiles from T. Yoshida & M. Hashimoto







W. Rapp et al., Ap.J. 653, (2006) 474

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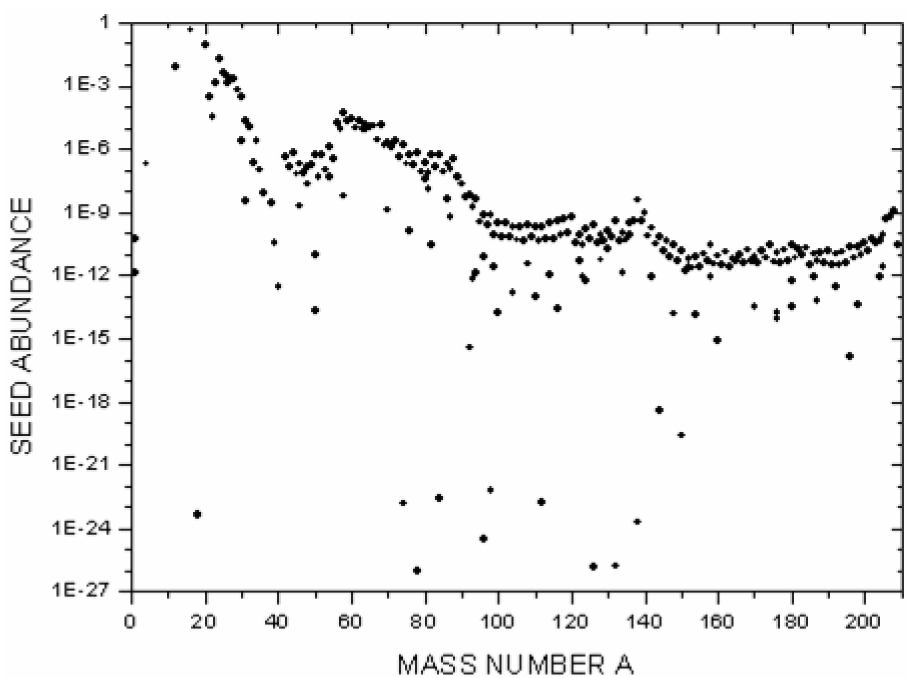
p-process network calculations

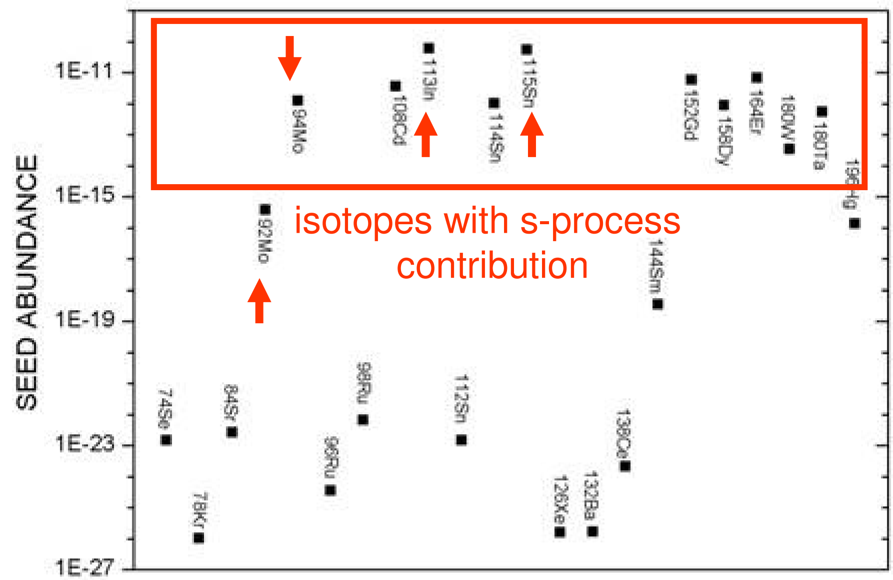
- (Complete) network: ~20000 reactions of 1814 isotopes

Final p abundance depends on initial seed abundances and Tρ profiles:

⇨ seed abundance NOT calculated self-consistently: pre-SN model of a 25 $M_{\odot}$ star



Initial abundances of p isotopes:



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The Updated Basel Reaction Library

Updated 2006 with (n,γ) cross sections from KADoNis v0.2
(Ph.D. thesis I. Dillmann, Uni Basel)

KADoNis v0.2 (Jan. 24th 2007)

KADoNis v0.3 (Aug. 28th 2009)

www.kadonis.org

New update needs to be included!

Updated Basel library:

⇨ *http://download.nucastro.org/astro/reaclib/*

Updated JINA library:

⇨ *http://groups.nscl.msu.edu/jina/reaclib/db/*

Outcome of update (25 $M_\odot$ star)

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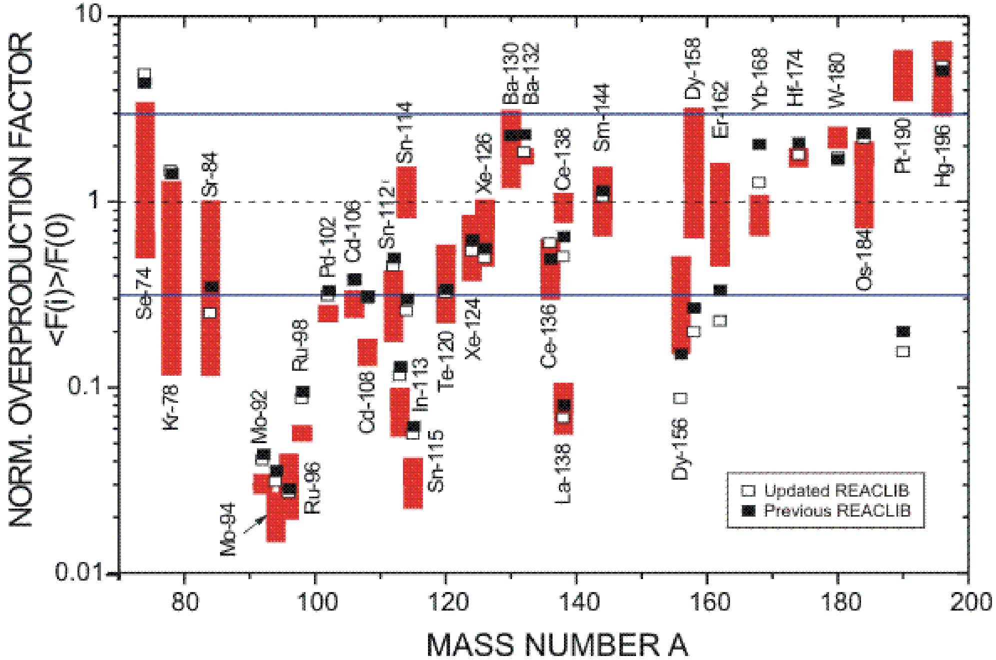
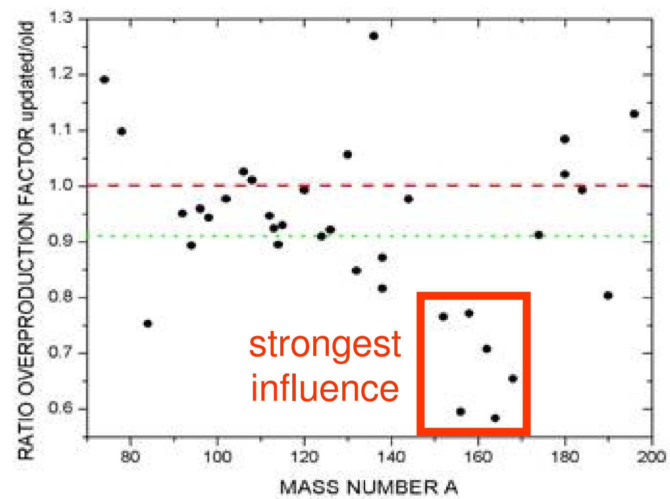


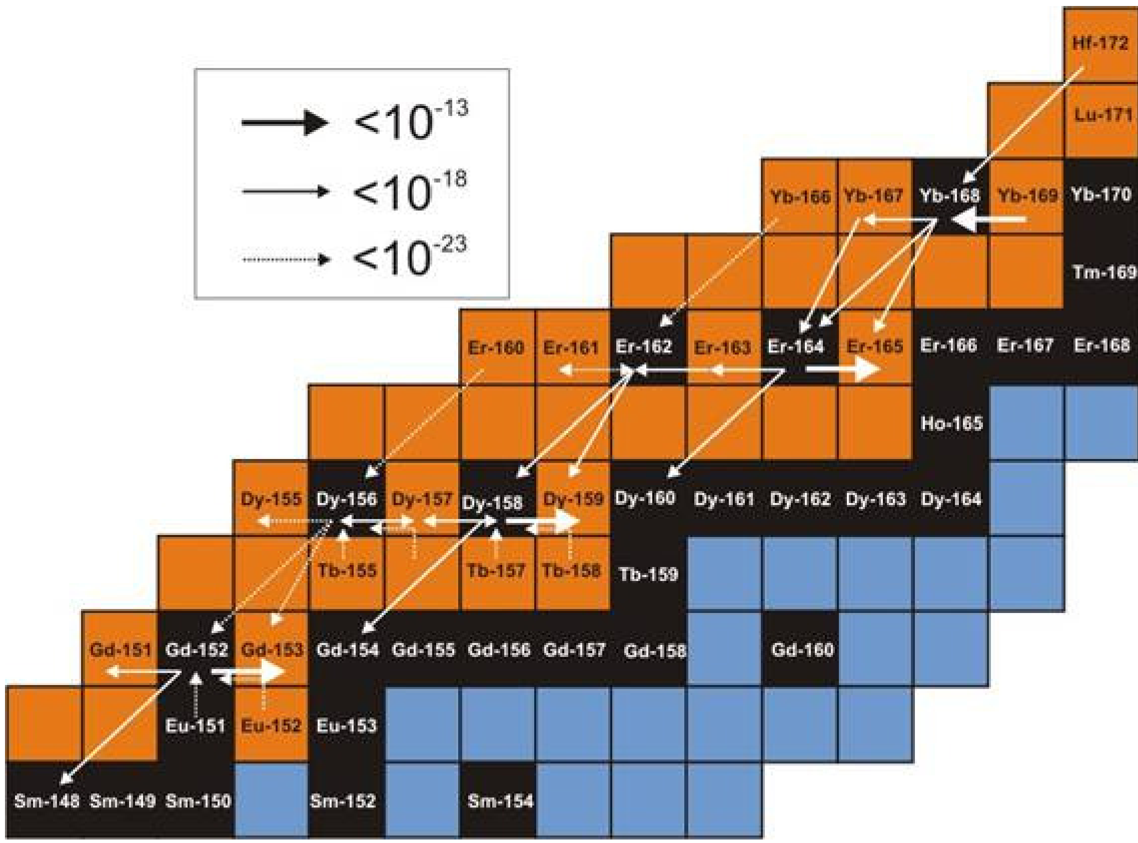
- 8% !



Why lower global production ?

Which updated (n,γ) reaction has such global influence?

Reaction flow A=150-170

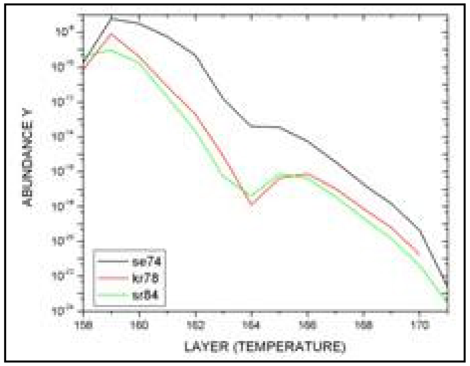


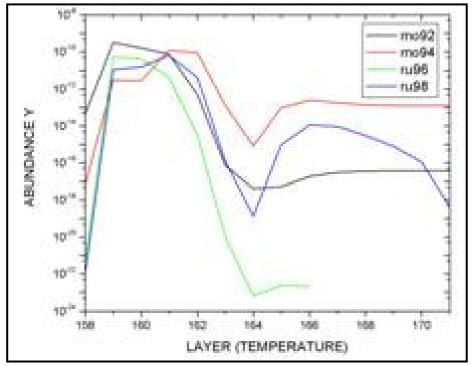
- Main flow: **(γ,n)** and **(γ,α)**
- Also **(n,γ)** and **(n,α)**

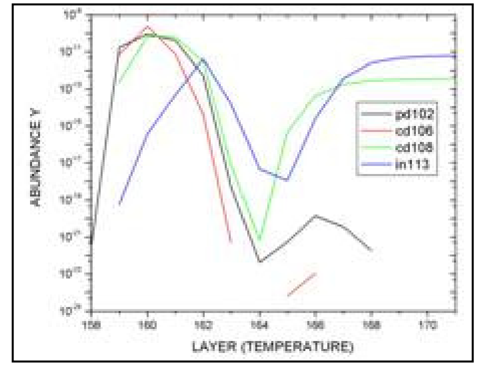
Flow with updated REACLIB up to **factor 60 lower**

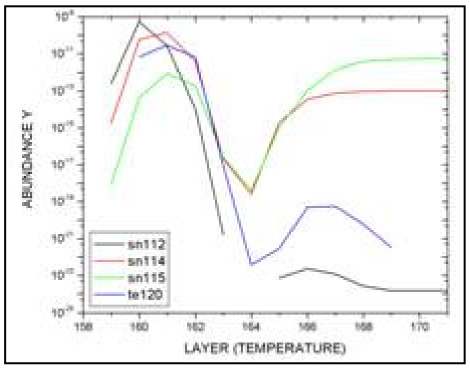
Where does this global influence come from?

Abundance vs. Temperature



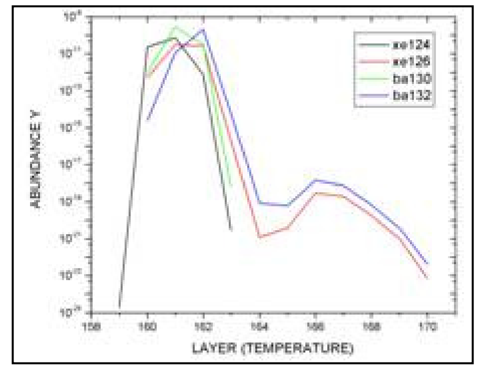


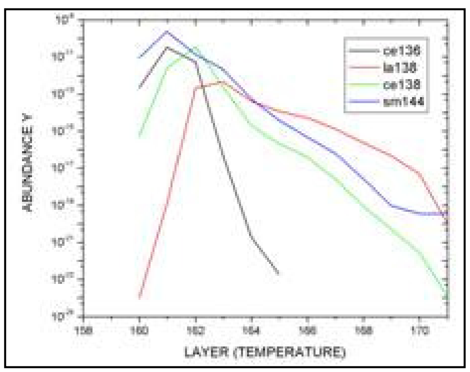


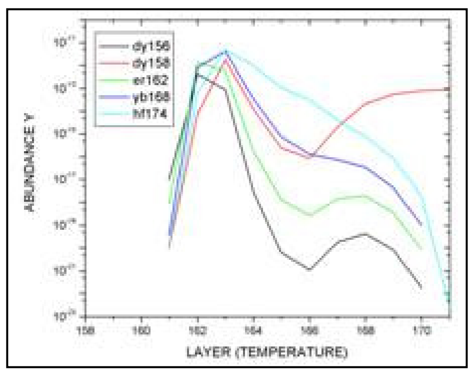


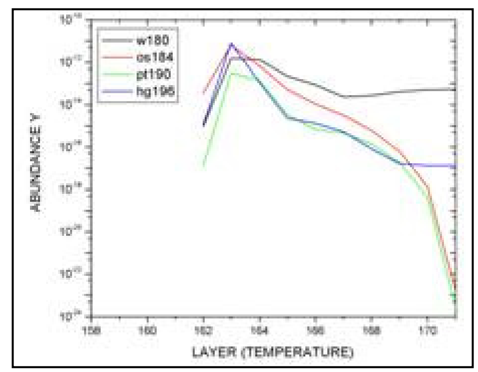
Why abundance „dip“ for light elements at layer 164 (T~ 2.4 GK)?

Production of heavy p-nuclei at lower T









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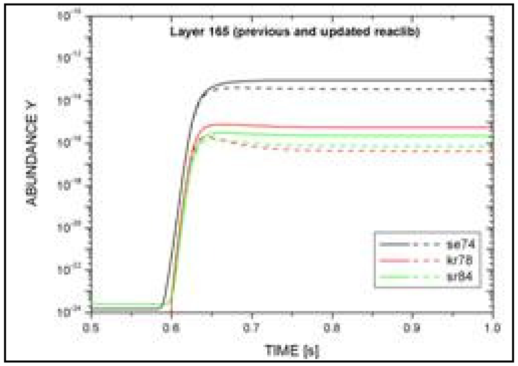
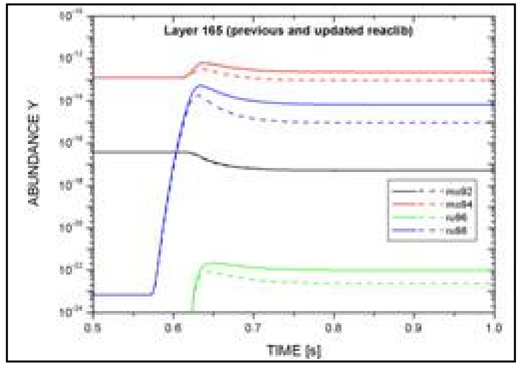
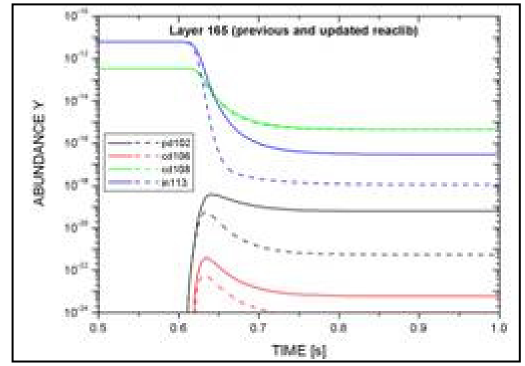
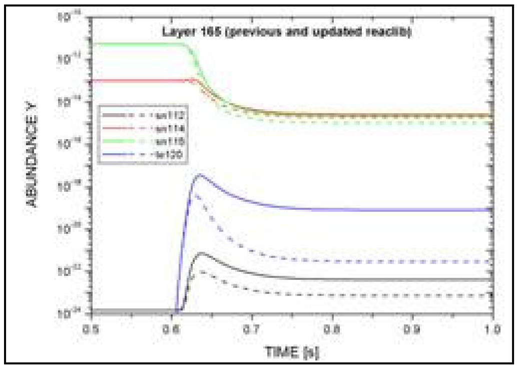
Abundances vs. Time (Ex. layer 165)

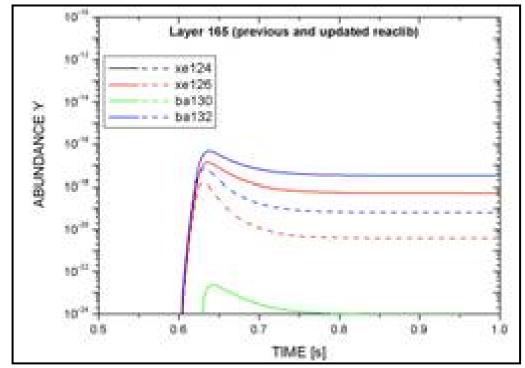


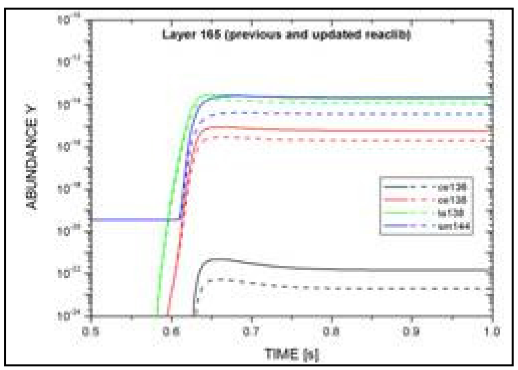


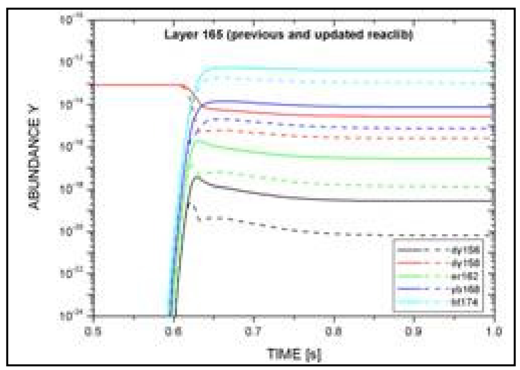


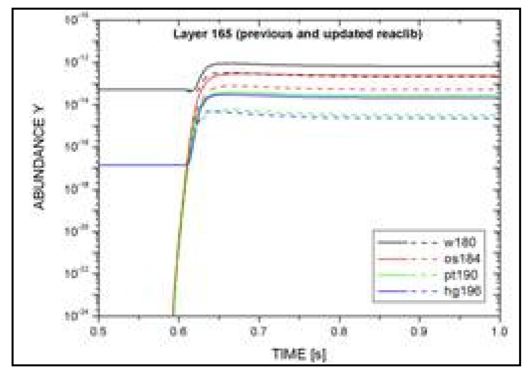


Lower abundances for all p isotopes with updated library!









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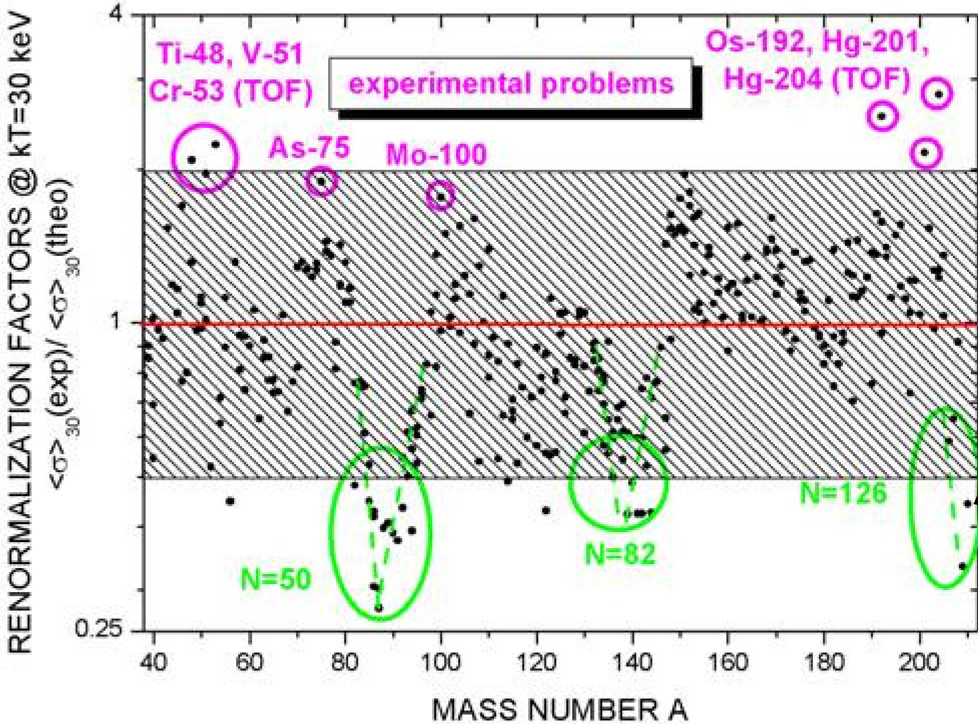
Why is the reaction flux lower?

- **Strongest reaction: $^{208}Pb(\gamma,n)^{207}Pb$**
- **Y(Pb-206, Pb-207, Pb-208, Bi-209):** ~ **75%** of total abundance for isotopes beyond Sm-144 !
- Hauser-Feshbach model has overpredicted these neutron capture cross sections



- Level density too low
- Microscopic corrections (FRDM) too strong at shell closures
- **weaker** experimental neutron cross sections compared to NON-SMOKER predictions:

Pb-206: f= 0.588

Pb-207: f= 0.650

Pb-208: f= 0.918

Bi-209: f= 0.334

⇨ much weaker flow to lighter nuclei **for all star masses !**

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The need of experimental data

• Influence of experimental (n,γ) data on overproduction factors shows necessity of **experimentally updated reaction libraries**

⇨ include new KADoNiS v0.3 cross sections
http://www.kadonis.org

⇨ include NACRE rates: use of JINA REACLIB
http://groups.nscl.msu.edu/jina/reaclib/db/

⇨ include experimental energy dependencies

Influence of $^{12}C(\alpha,\gamma)$, $^{13}C(\alpha,n)$, $^{22}Ne(\alpha,n)$...?

⇨ include heavy charged-particle data (KADoNiS p-process database)

Will there be a similar influence ?

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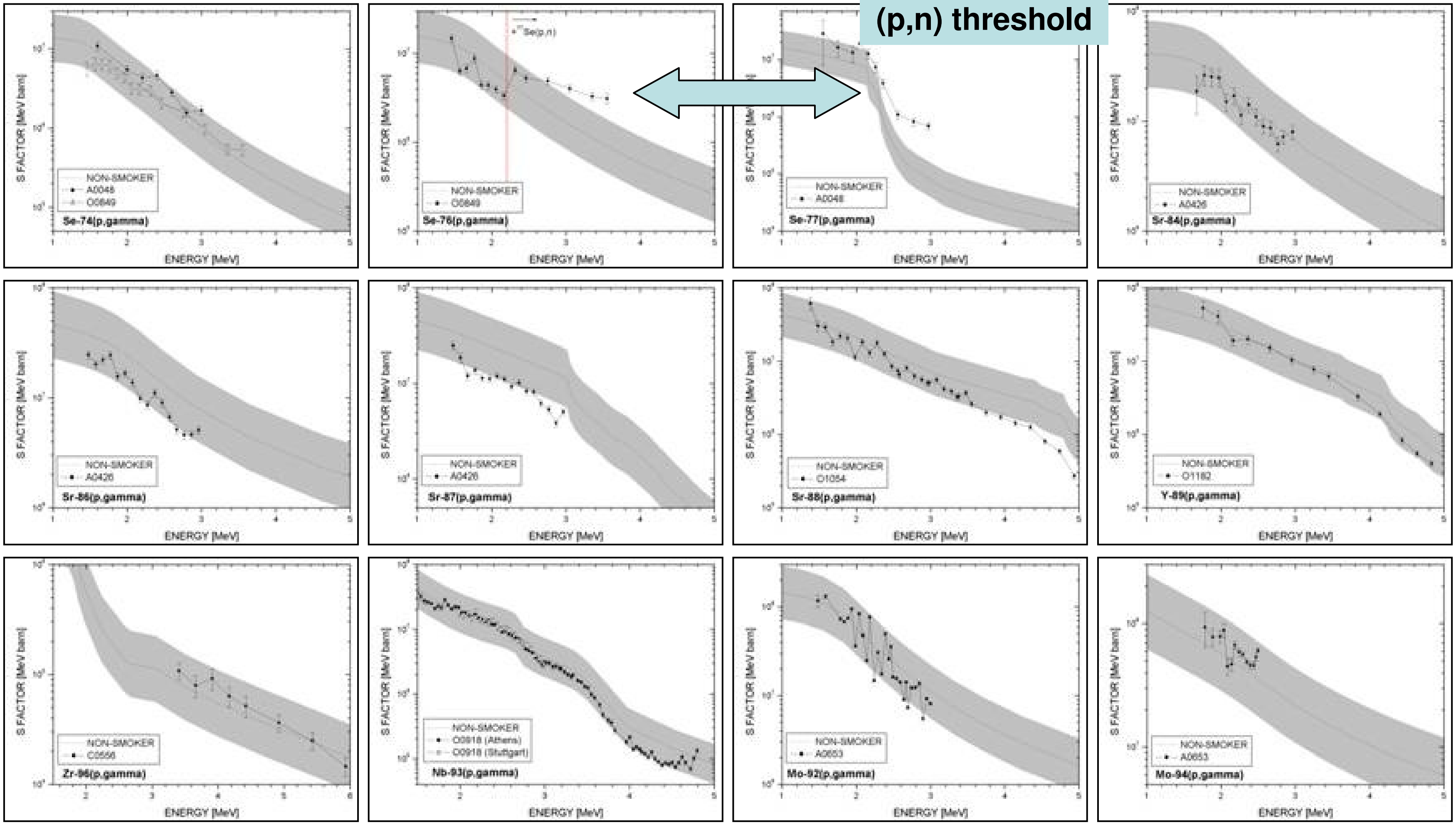
Status (p,γ) reactions

NON-SMOKER range *2 to /2

dips from (p,n) threshold



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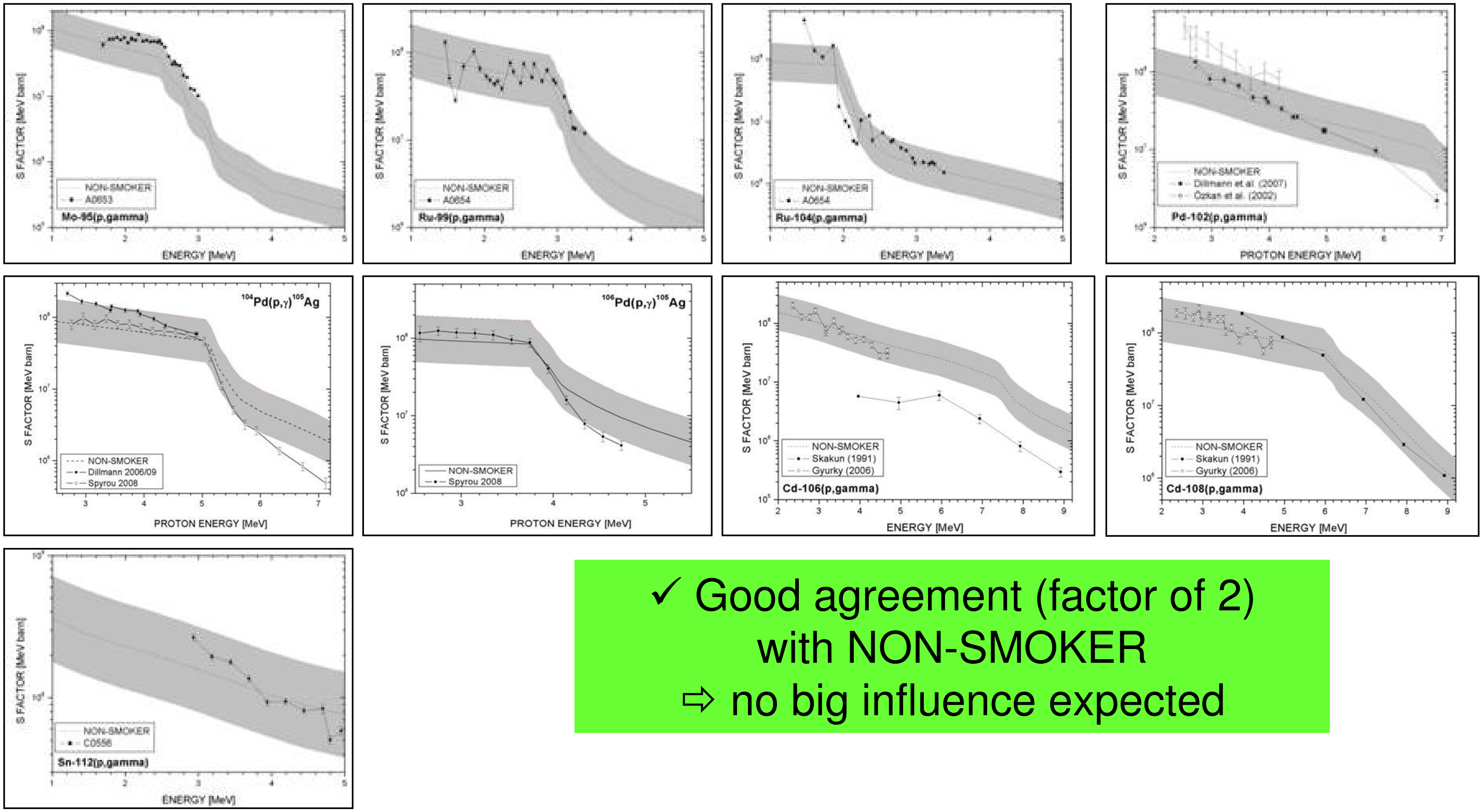
Status (p,γ) reactions

NON-SMOKER range *2 to /2



✓ Good agreement (factor of 2) with NON-SMOKER

⇨ no big influence expected

Status (p,γ) reactions

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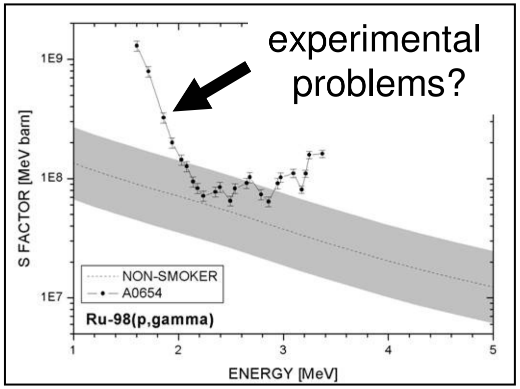
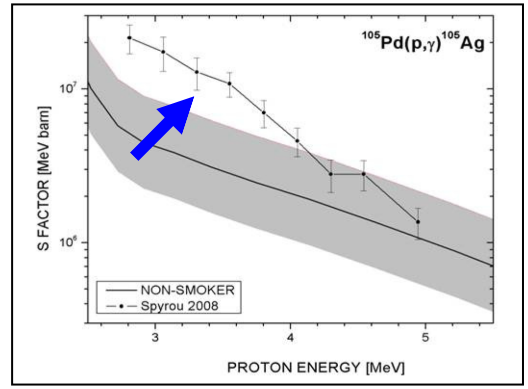
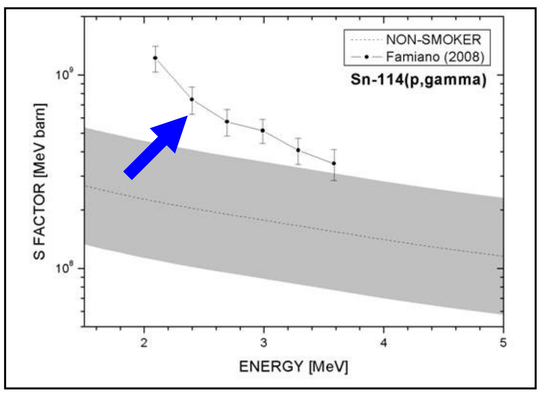
…but some not so good agreements:

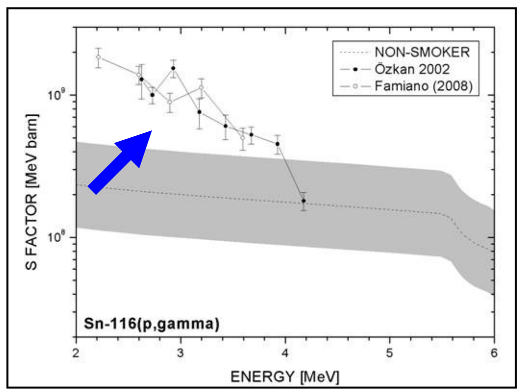


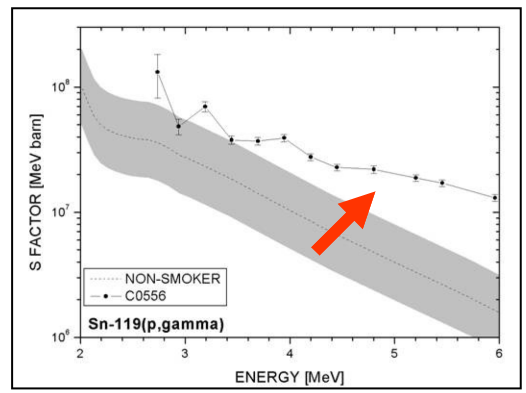
Ru-98
Pd-105
Sn-114
Sn-116
Sn-119

?





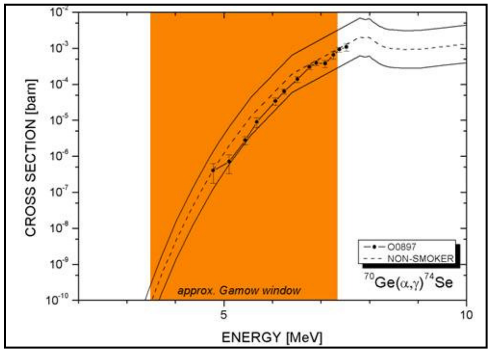


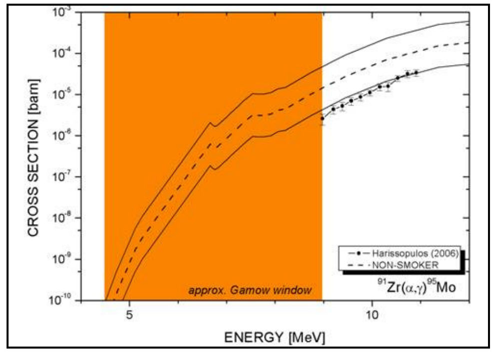


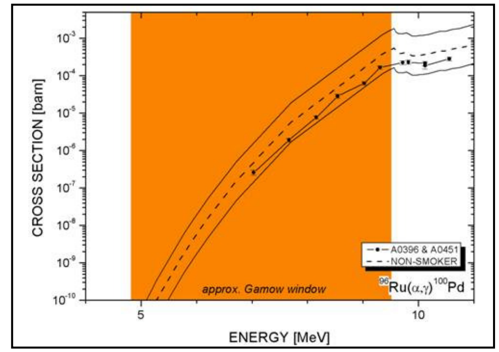
⇨ 21 good, 5 fail (Sn isotopes (Z=50) ⇨ model?)

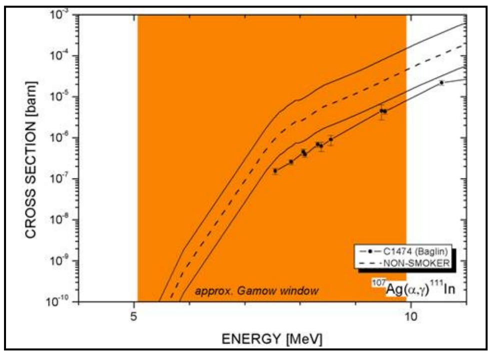
Status (α,γ) reactions

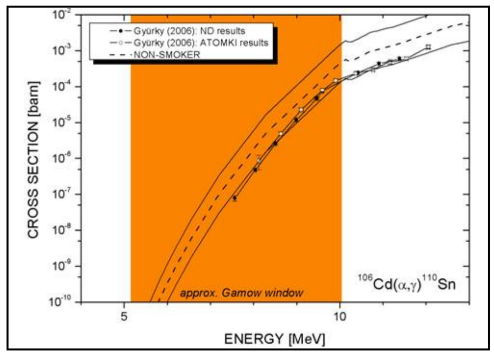
NON-SMOKER range *3.33 to /3.33

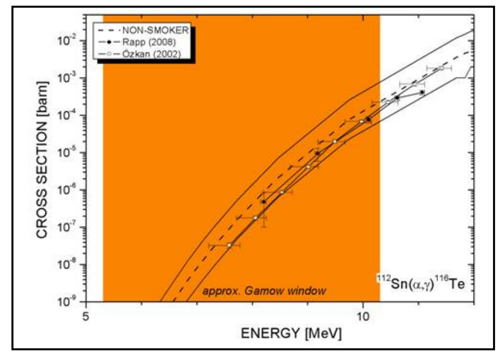


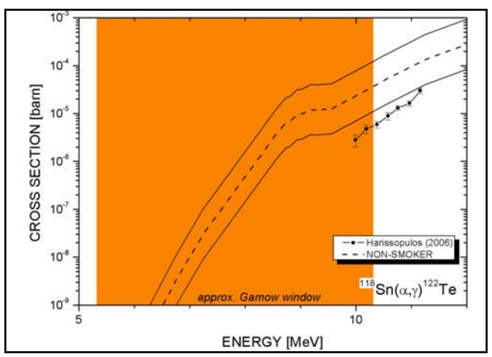


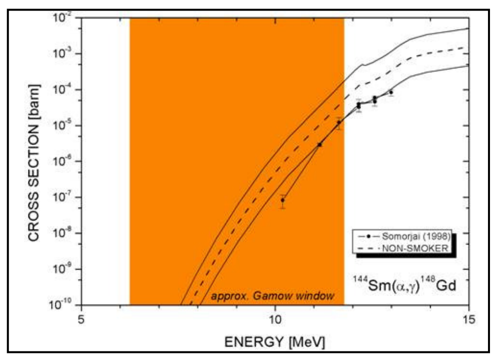








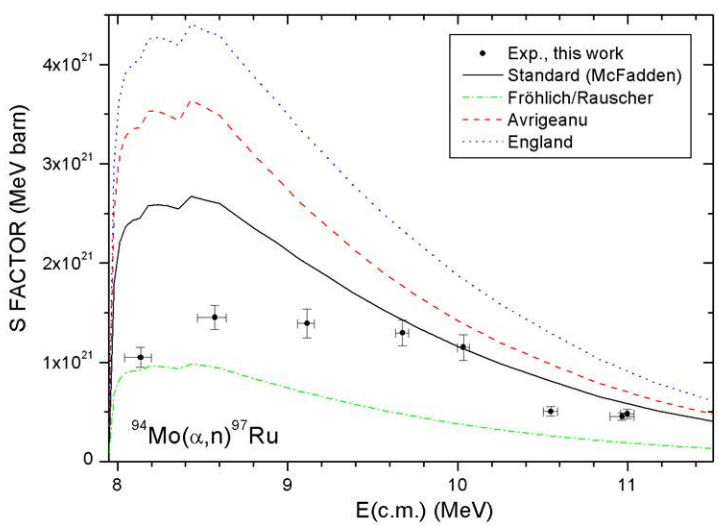


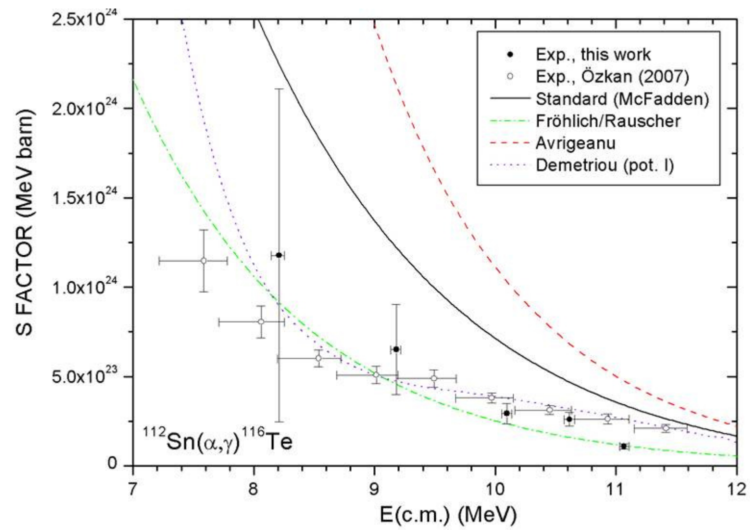


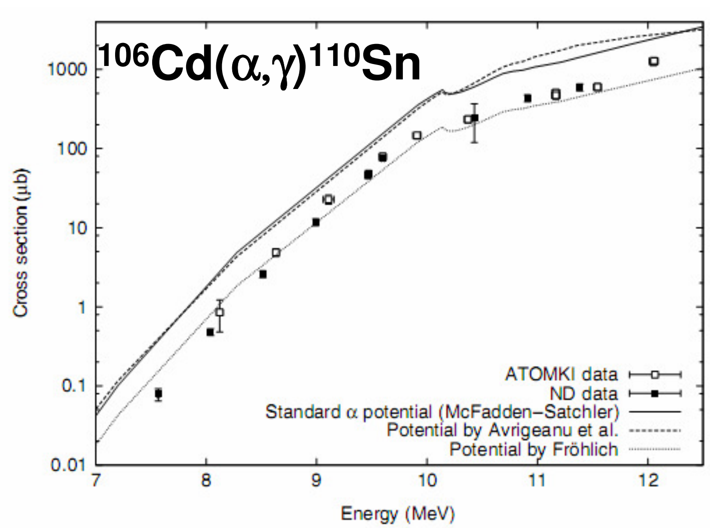
All results systematically LOWER than NON-SMOKER (McFadden-Satchler)

⇨ Better with other potentials (e.g. Fröhlich-Rauscher, Avrigeanu…) ?

Compare with different α-OMP







Which one reproduces data best?
Data lies between
Fröhlich-Rauscher and McFadden-Satchler

could not reproduce scattering data

overestimates data by factor 2

Avrigeanu: opt. potential from scattering may have to be modified before using for reactions

Sensitivity of γ- and α- widths

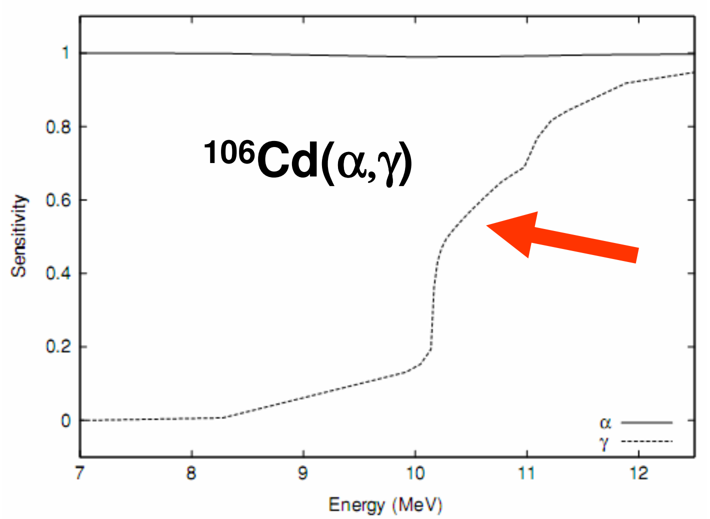


FIG. 7. Sensitivity of the (α, γ) cross section to a variation in the α and γ widths, respectively. The sensitivity is given as function of α center-of-mass energy. It ranges from 0 (no change) to 1 (the cross section is changed by the same factor as the width).

G. Gyürky et al., PRC 74, 025805 (2006)

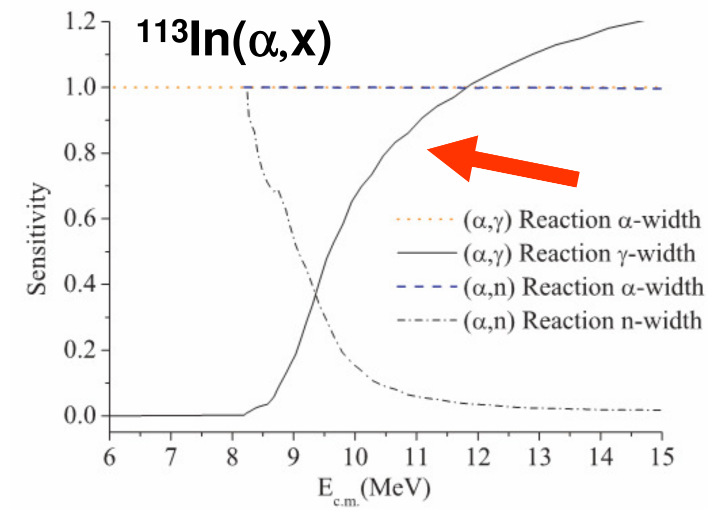


FIG. 5. (Color online) Sensitivity of the astrophysical S factor for the (α, γ) and (α, n) reactions on ^{113}In to a variation in the α, γ, and neutron widths, as a function of center-of-mass energy.

C. Yalcin et al., PRC 79, 065801 (2009)

- γ-width (normally) determines xs in capture reactions
  ⇨ here only the case for higher energies
- (α,n): sensitive to α-width (except close to threshold)
- (α,p): both equally sensitive

α-width is always important

Influence of (p,x) and (α,x) data

- Proton-induced data:
  - ⇨ good reproduction by NON-SMOKER
  - ⇨ **no drastic influence expected**
- Alpha-induced data:

  Standard α-OMP used in NON-SMOKER: McFadden-Satchler
  - ⇨ overestimates data
  - ⇨ „real“ rates lower
  - ⇨ **lower production rates!!!**
- Photodissociation data:

  Up to now neglected...

  How can data be used in reaction libraries?

Other influences/ improvements

- Seed nuclei:

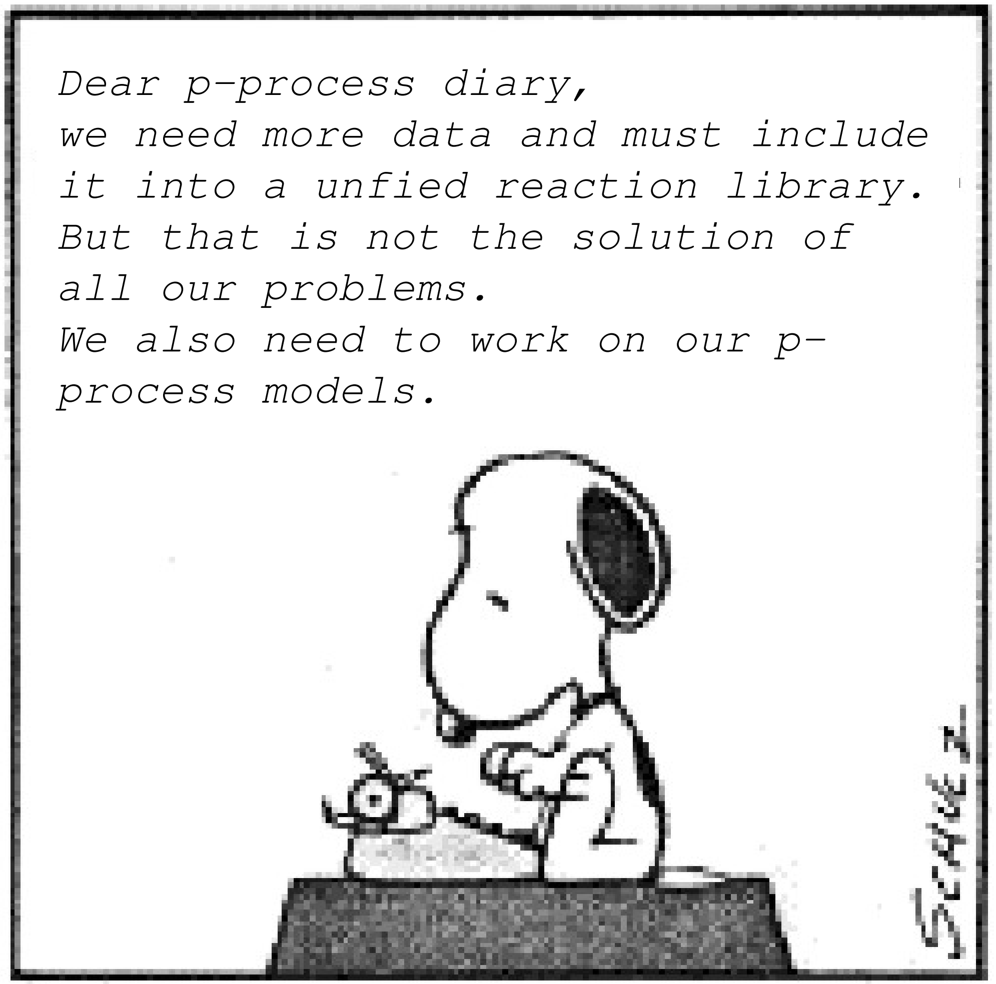
  ⇨ need to be calculated with updated reaction library **(strong influence from s process) !**

- simulation with other star masses ($8M_{\odot} < M < 25\ M_{\odot}$):

  ⇨ maybe different influences

- Combine with rp-/νp-simulations using **unified reaction library**

  ⇨ **JINA REACLIB**
  http://groups.nscl.msu.edu/jina/reaclib/db/


Dear p-process diary,
we need more data and must include it into a unfied reaction library.
But that is not the solution of all our problems.
We also need to work on our p-process models.

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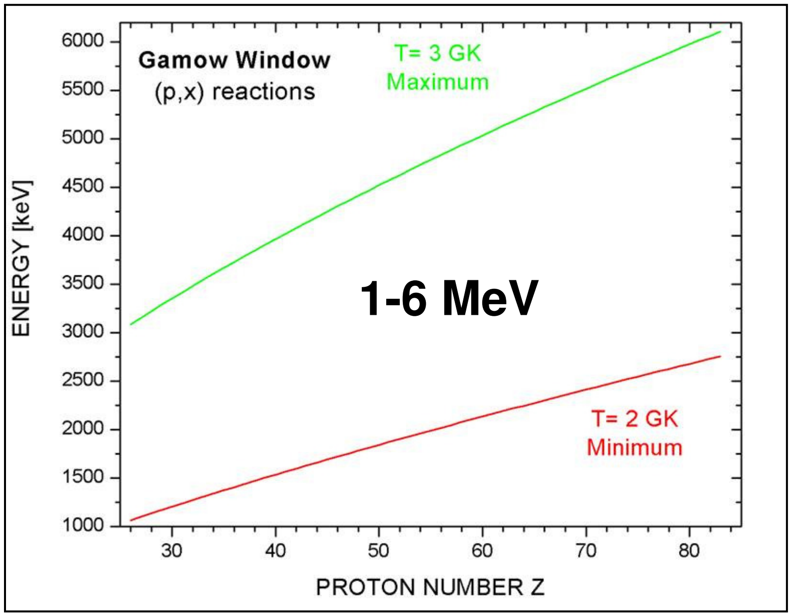
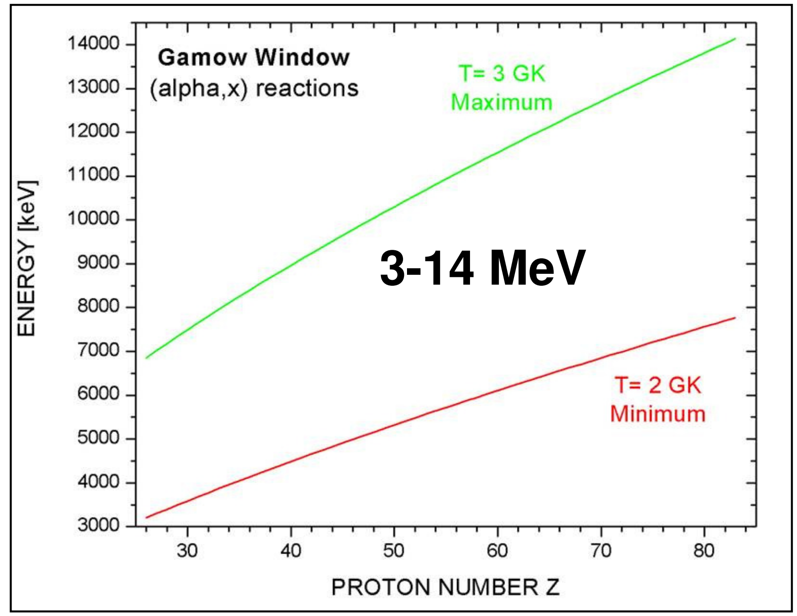
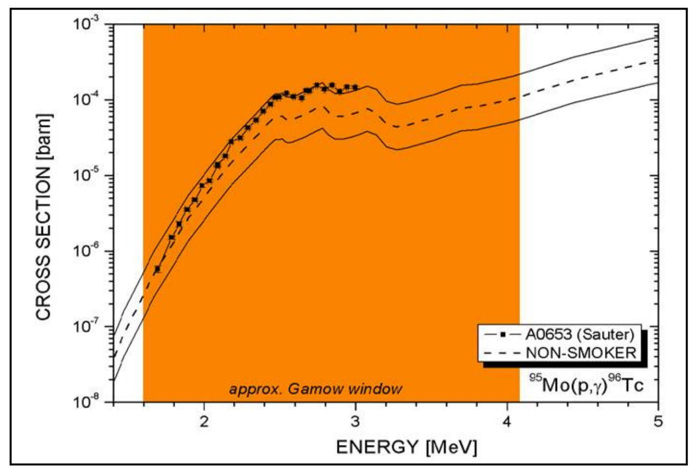
Gamow windows





- APPROXIMATION! For exact window use Fortran program „exp2rate.f“ from T. Rauscher
- only data within or close to Gamow windows useful
- KADoNiS: markers for location of Gamow windows



Which p-isotopes are produced?

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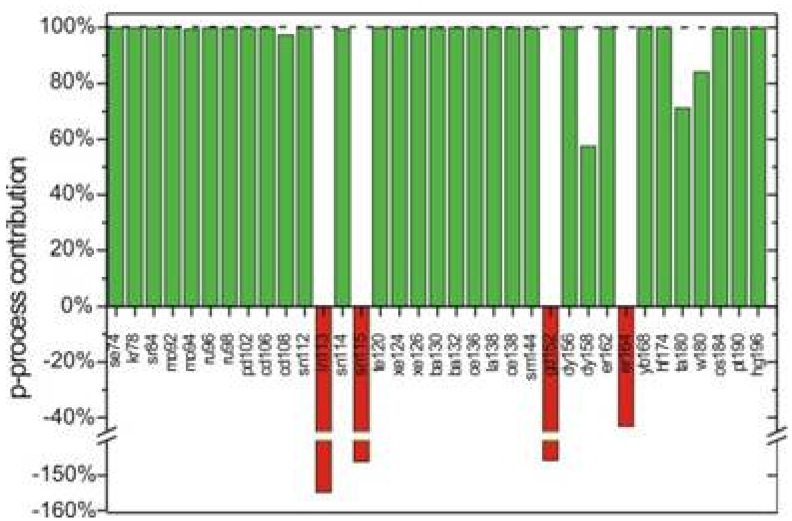

Small production of ^{158}Dy, ^{180}Ta, ^{180}W

No production of ^{113}In, ^{115}Sn, ^{152}Gd, ^{164}Er

Isotopes with strong s-process contributions

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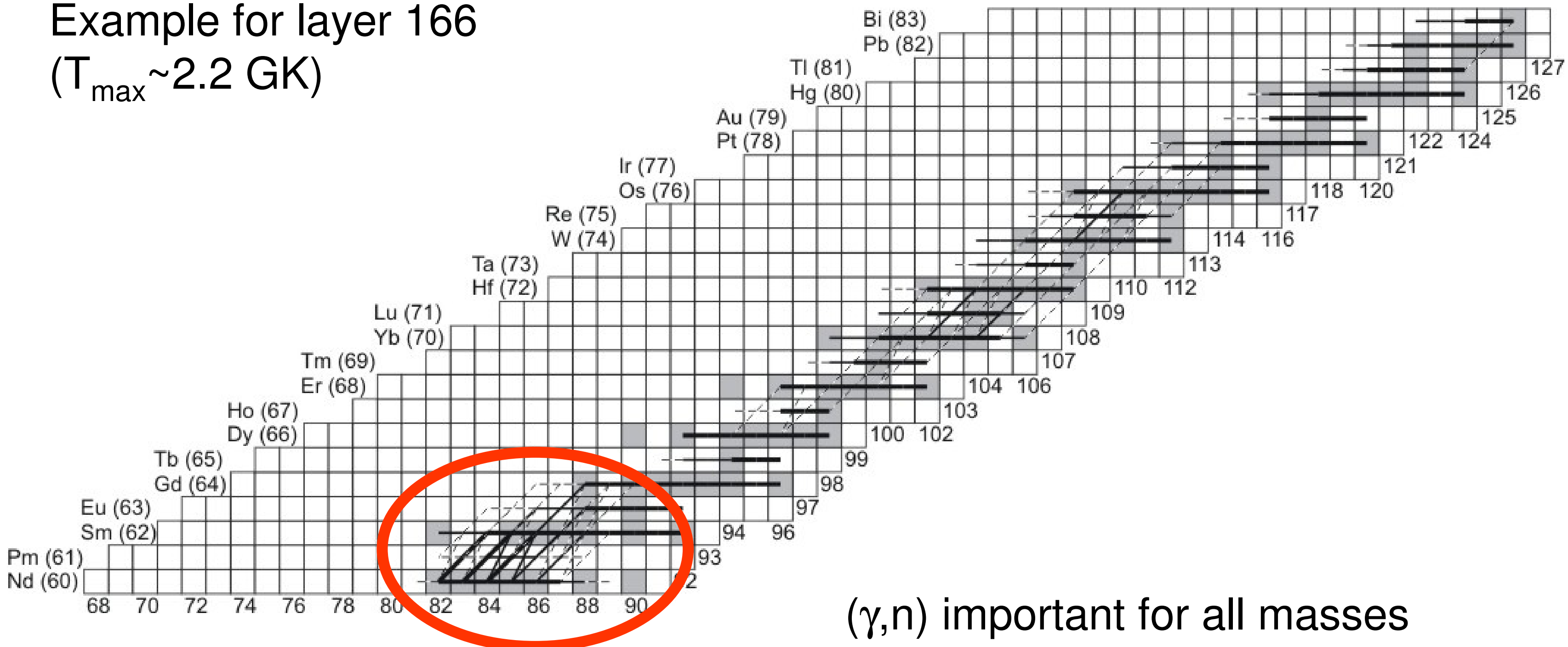
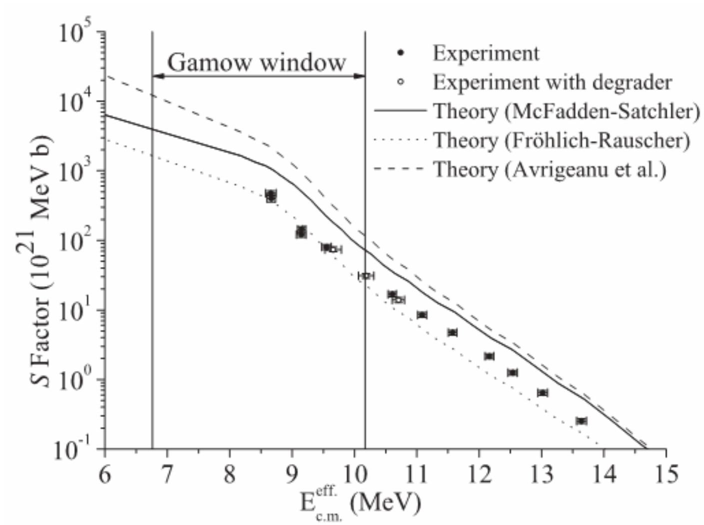
Reaction flow

Example for layer 166
(T_{max}~2.2 GK)



(γ,n) important for all masses
strong (γ,α) flows from Sm to Nd

$^{113}In(\alpha,\gamma)^{117}Sb$



$^{113}In(\alpha,n)^{116}Sb$