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# HF(R) for MACS

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# Summary

- MACS (1 slide)
- Models for the MACS
  - HF: Hauser-Feshbach (1 slide)
  - HFR: High Fidelity Resonances (2 slides)

- HF, HFR: ingredients (1 slide)

- Model selection (3 slides)

- Examples for model 23n (2 slides)

- To the drip line (3 slides)

- Consequence and Future: model 54n ? (1 slide)

*<u>Note:</u> This presentation is intended people with strong background in nuclear reaction physics and nuclear data for astrophysics. Not all details are provided here.*

# MACS

- MACS: Maxwellian Averaged Cross Section
- MACS: helps to obtain reliable stellar nucleosynthesis predictions

$$\sigma_{Maxw} = \left(\frac{8}{\pi\mu(kT)^3}\right)^{1/2} \int_0^\infty dE\ \sigma_\gamma(E) E e^{-E/kT},$$

- $\sigma_\gamma$: capture cross section, obtained from measurements or calculations,
- kT: from 5 to 120 keV, with 30 keV commonly used as a reference,
- kT=30 keV: see the Kadonis database with experimental data.

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# Calculated capture cross section: HF

- The capture cross section for MACS is usually calculated with the Hauser-Feshbach approximation (HF)
  - Statistical model
  - Continuous capture cross sections
- Valid if
  - The compound framework is applicable (compound nucleus fully equilibrated before breaking)
  - The level density must be sufficiently large for individual resonances to overlap

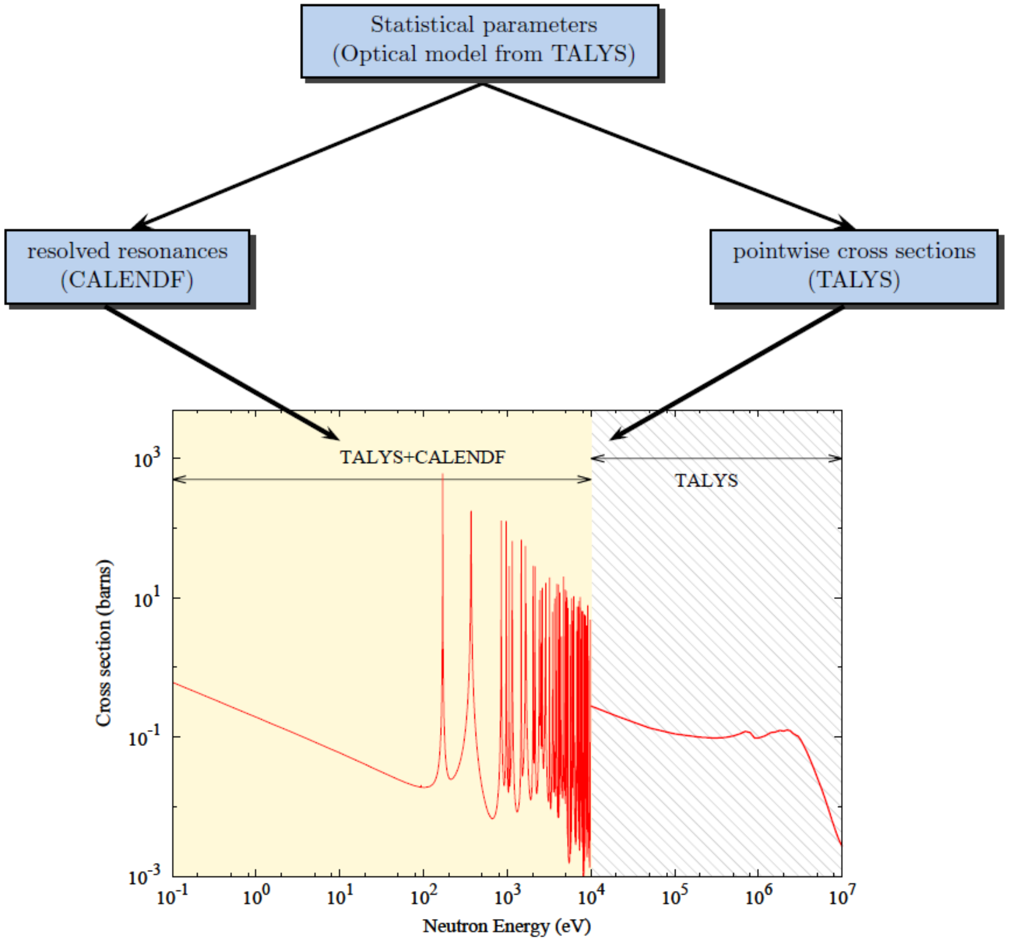
- For experimentaly unknown cross sections, HF is depending on
  - Level density model (ld)
  - Optical model (omp)
  - And gamma-strength function (γ-str)

- The HF is not applicable for the light isotopes and far from the stability line, but still used…

# Calculated capture cross section: HFR

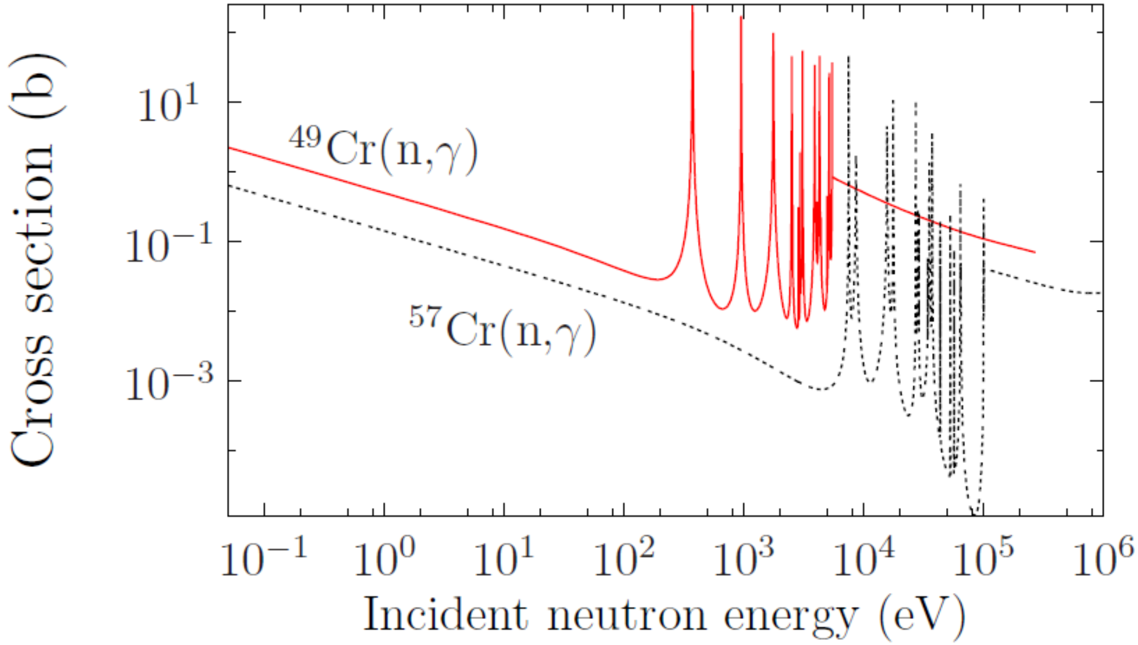
- Alternative approach to the HF calculations: the High Fidelity Resonance calculations (HFR)

- Presented in ANE 50 (2013) 60
  - Combine the 3 previous models (ld, omp and γ-str) to produce statistical resonances
- Uses the following scheme:
  - TALYS (input: ld + omp + γ-str)
  - CALENDF (input: TALYS output)
  - Output: statistical resonances



# Calculated capture cross section: HFR

- HFR calculations:
  1. TALYS + specific ld + specific omp + specific γ-str
  2. TALYS output: average $D_0$, $\Gamma_\gamma$, $\Gamma_n$, $\Gamma_f$… as a function of $E_n$
  3. CALENDF + TALYS output in the form of an ENDF-6 file
     - generate random ladders of resonances using the statistical properties
     - Just like in the unresolved resonance range,
     - But this time from 0 to a few 10 or 100 keV.



# Ingredients and models selection

- Different possibilities exist for the 3 models in TALYS
  - Level density models: 6 (from 1 to 6)
  - Gamma-strength function: 8 (from 1 to 8)
  - Optical model: 2 (Koning-Delaroche or Semi-microscopic optical model (JLM): y or n)

- To perform a validation, a comparison to Kadonis is performed with the $f_{rms}$ factor for 215 measured isotopes

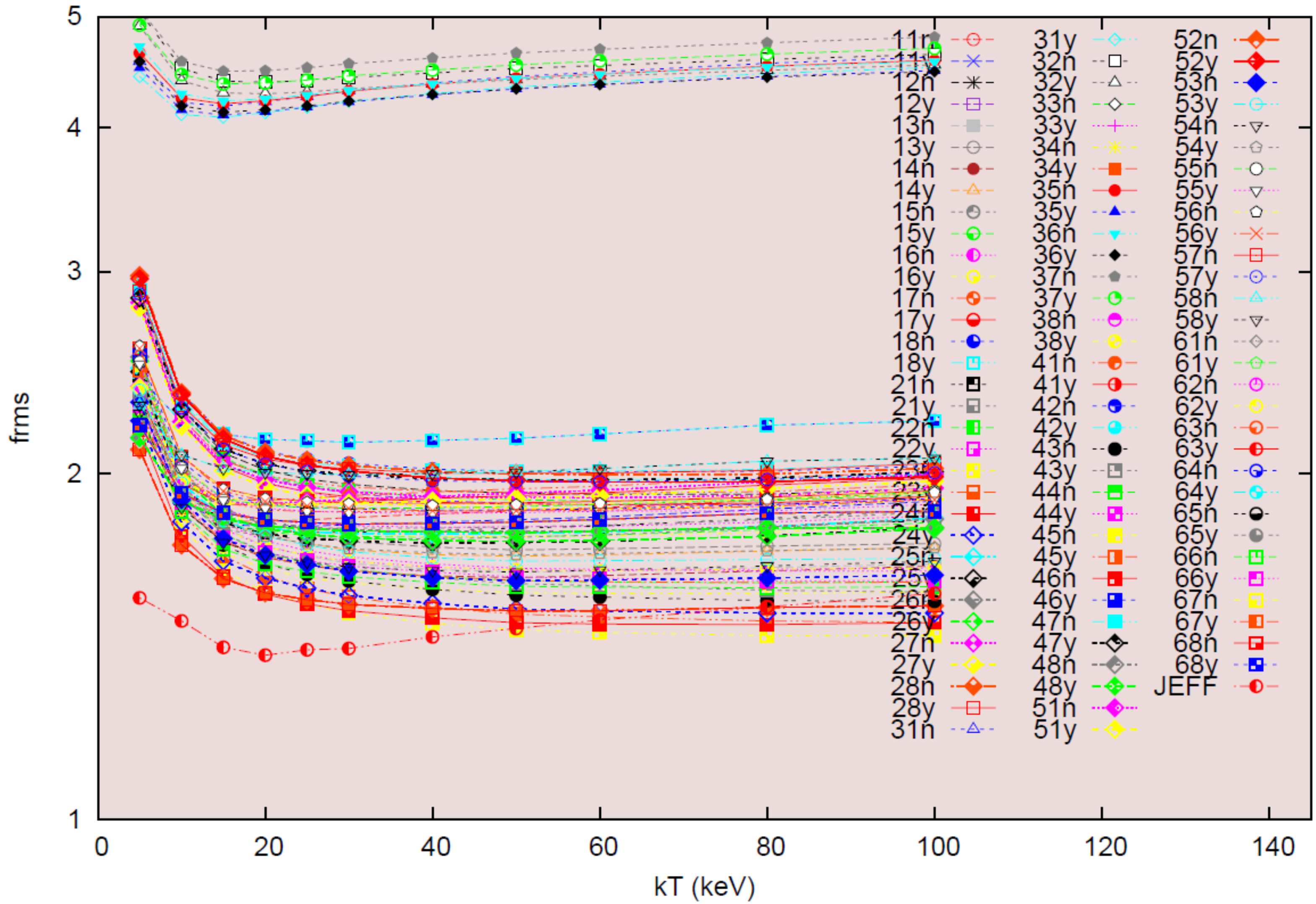
$$f_{rms} = \exp\left[\frac{1}{N_{tot}}\sum_{Z,A}\ln^2\frac{\langle\sigma_{th}\rangle}{\langle\sigma_{exp}\rangle}\right]^{1/2}$$

- In total 96 possibilities: 6x8x2 (96 for HF and 96 for HFR)

- In the following, cases will noted as “ijn” (11n, 23n…)
  - i=level density models,
  - j=gamma-strength function models and
  - n= JLM model (y for yes, n for no)

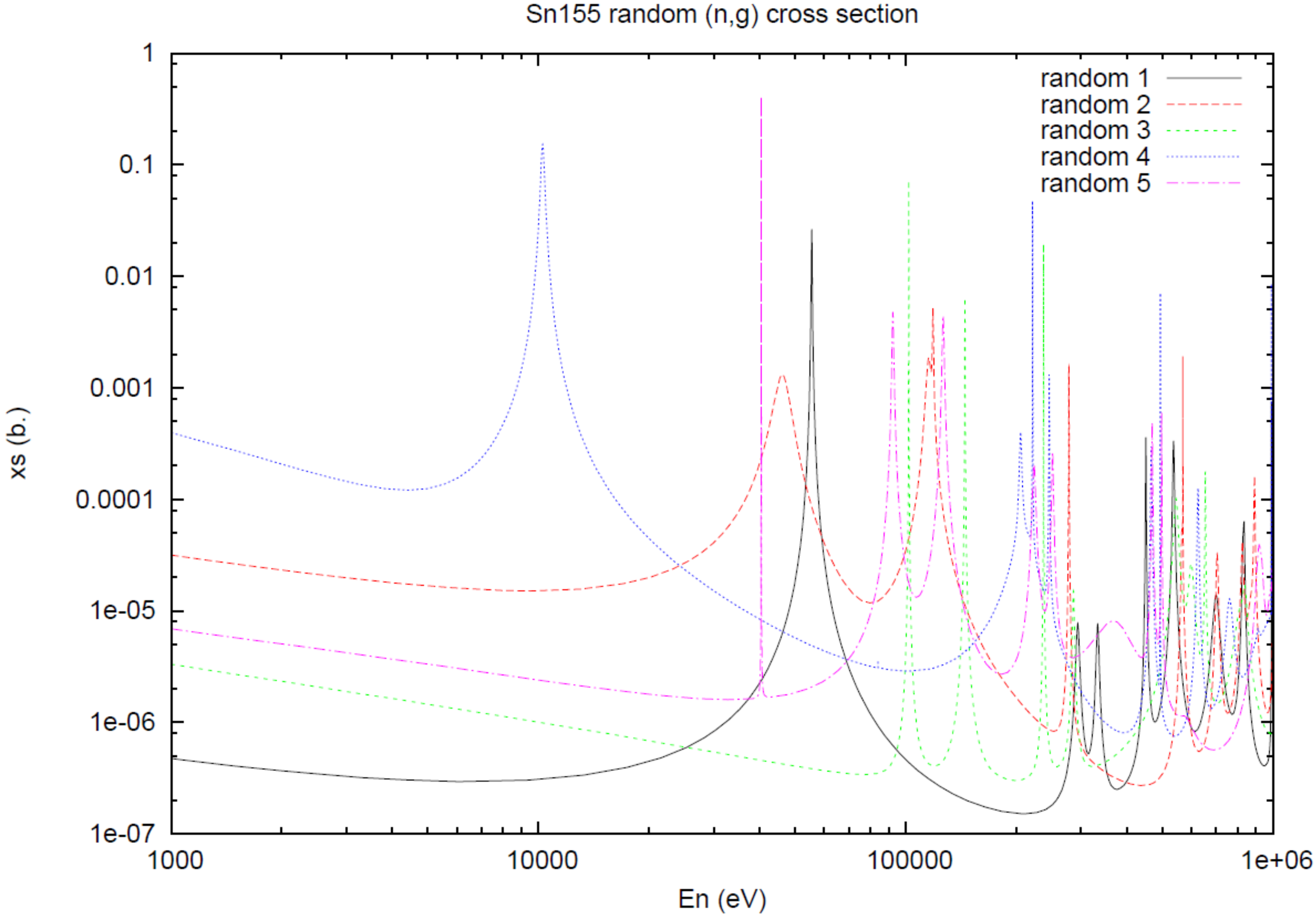
# Models selection for HF

- Model 23n is the most appropriate for HF approach



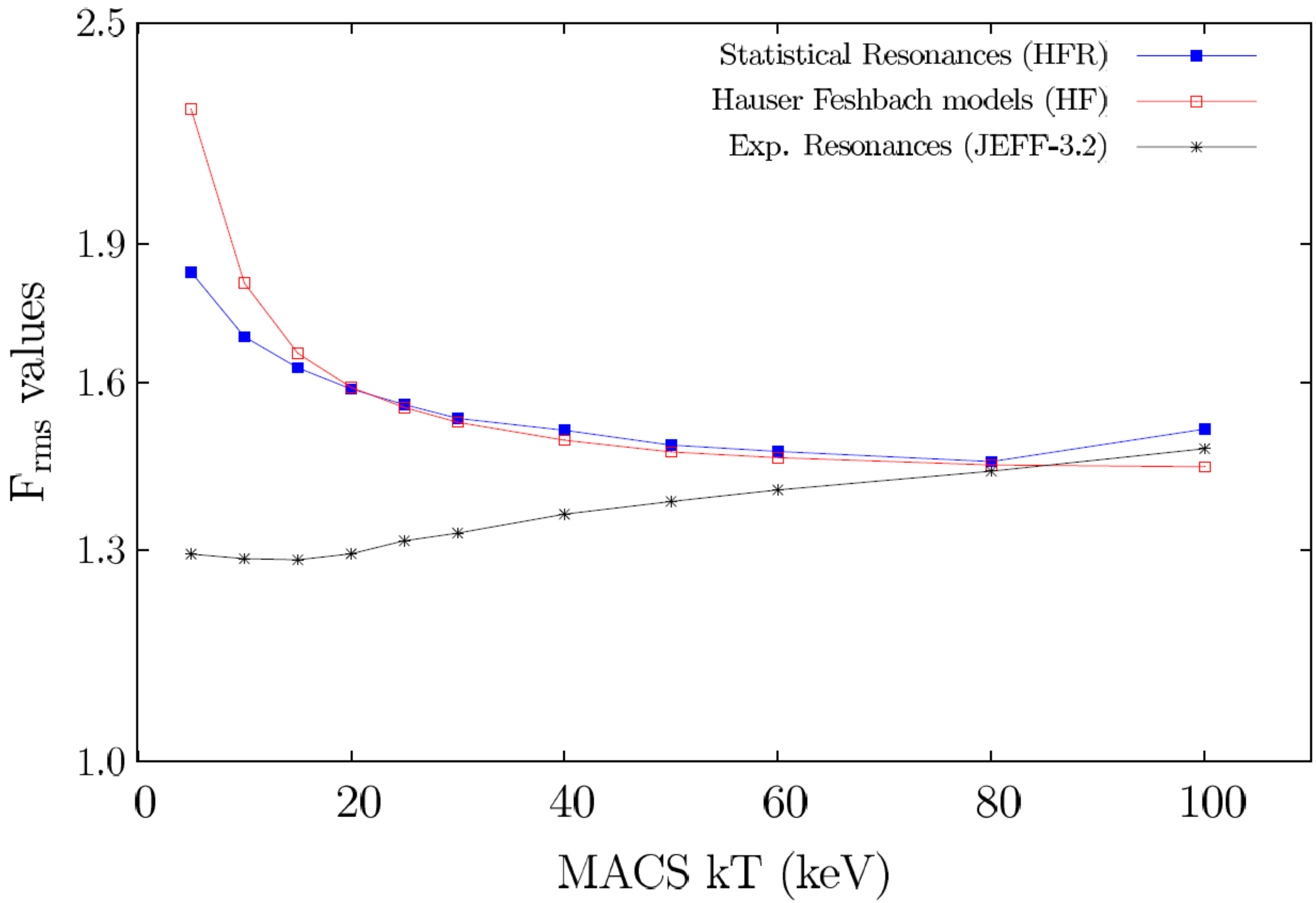
# Models selection: 23n for HFR

- HFR: for each isotope, 200 random cross sections are created and averaged together



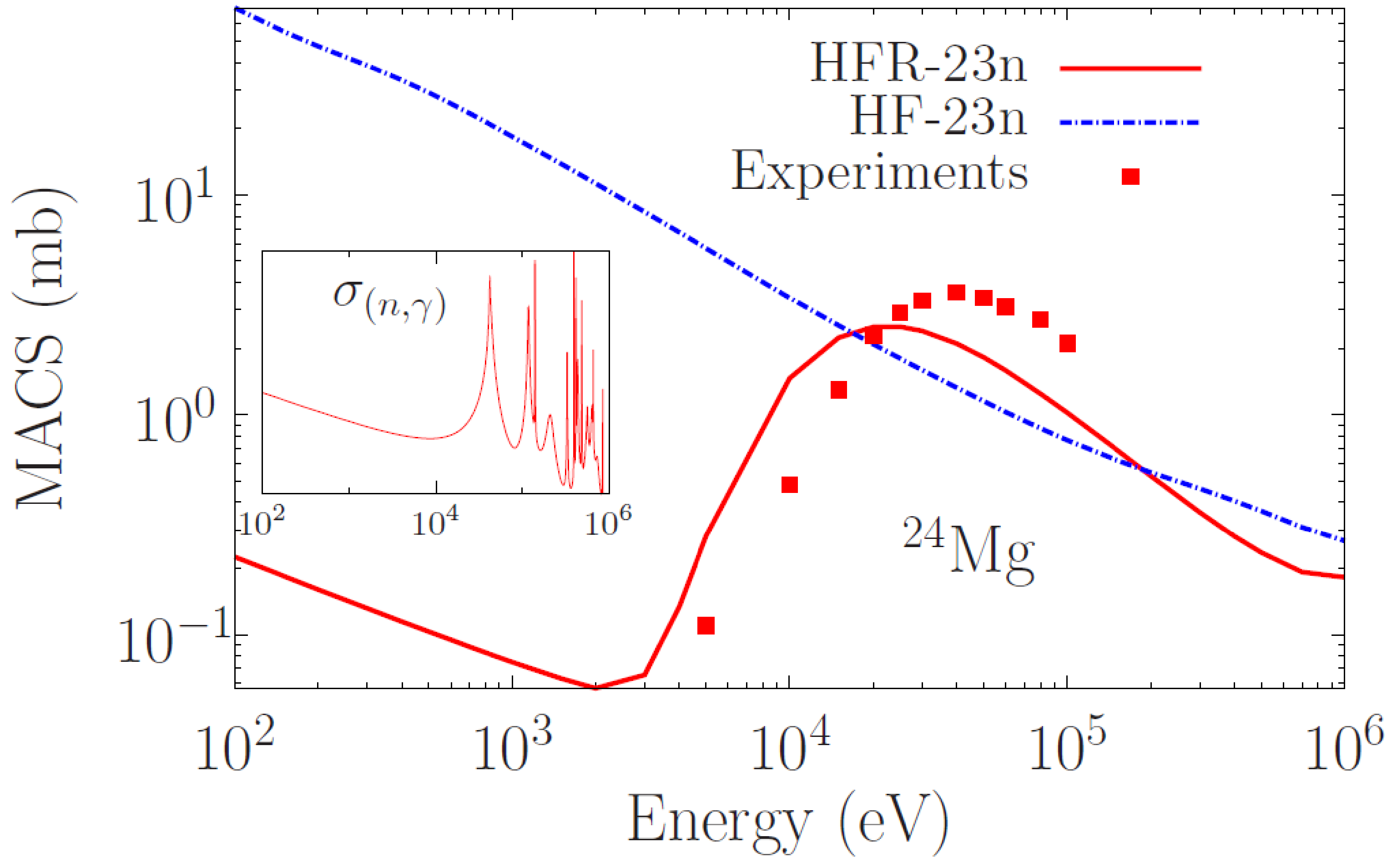
# Models selection

- Comparison with model 23n for HF and HFR for 215 isotopes



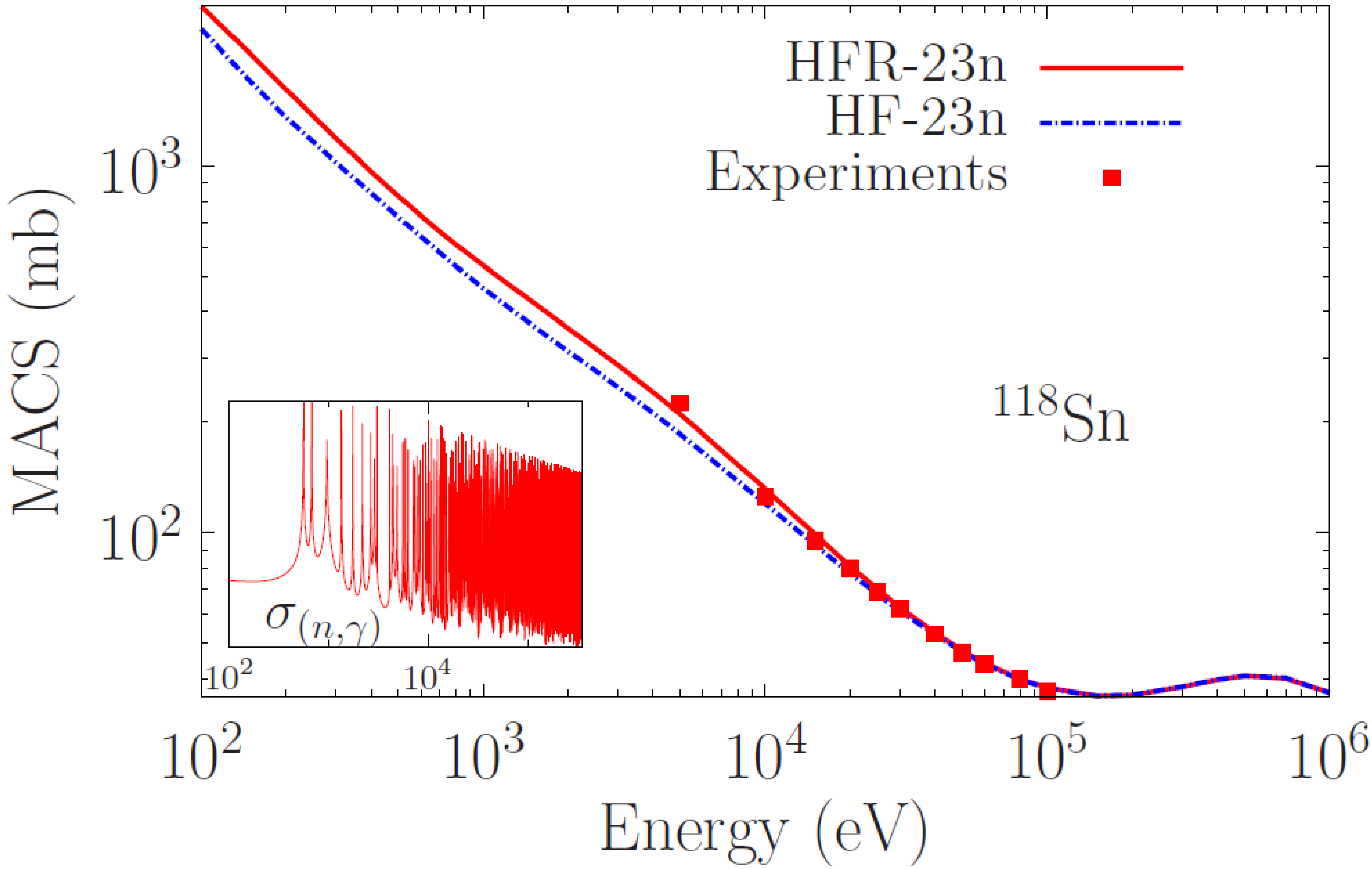
# Model selection: 23n example 1

- Light isotopes: Mg-24



# Model selection: 23n example 2

- Heavy isotopes: Sn-118



# HFR, 23n, to the neutron drip line

- About 3300 isotopes from Li to Bi
- Ground states only

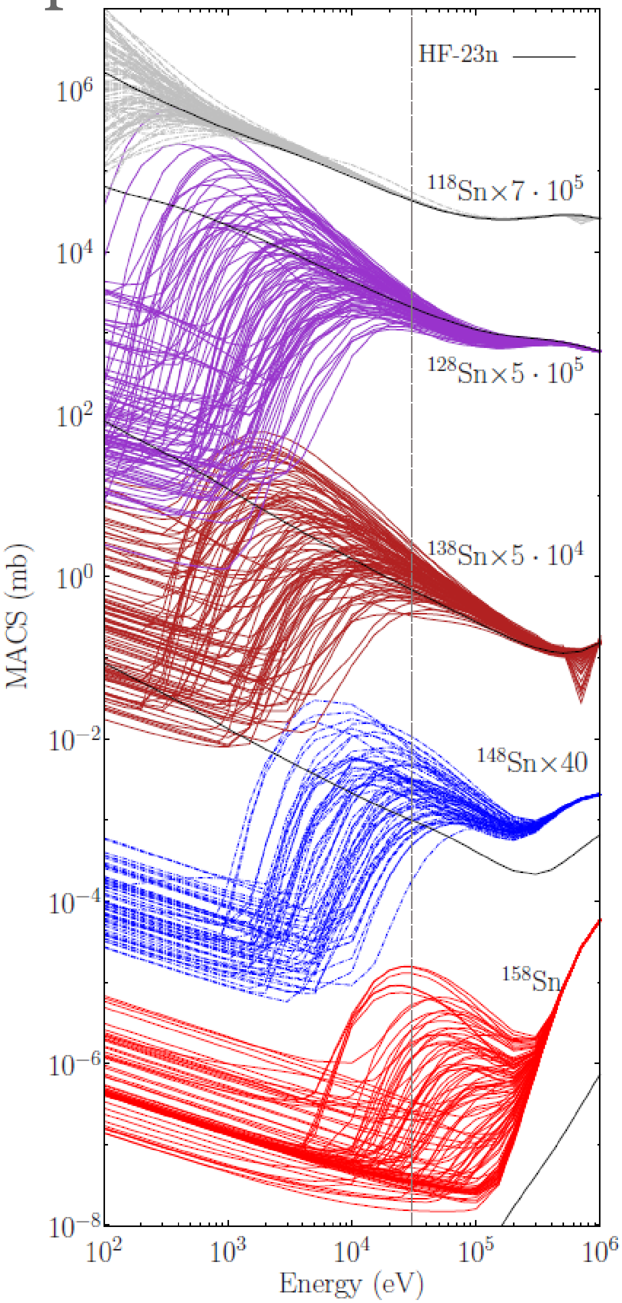
- For each isotope, 200 calculations for the HFR
- 1 calculation = cross section + MACS
- These 200 calculations/isotope are averaged into 1 MACS value at 30 keV/isotope

  ⟶ 3300 MACS (HFR)

- For each isotope, 1 calculation for the HF
- 1 calculation = cross section + MACS

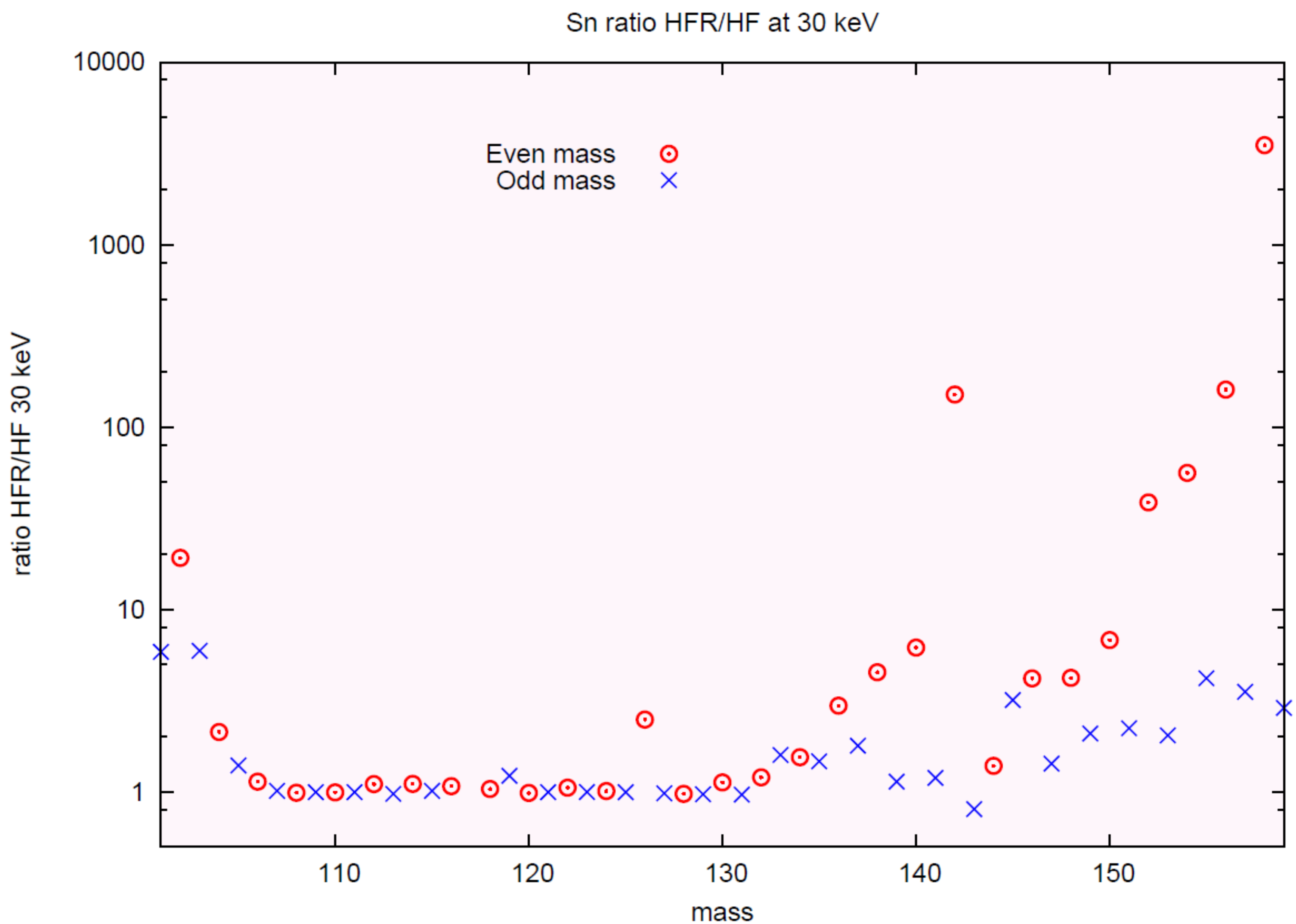
  ⟶ 3300 MACS (HF)

- Ratios of HFR/HF for MACS values

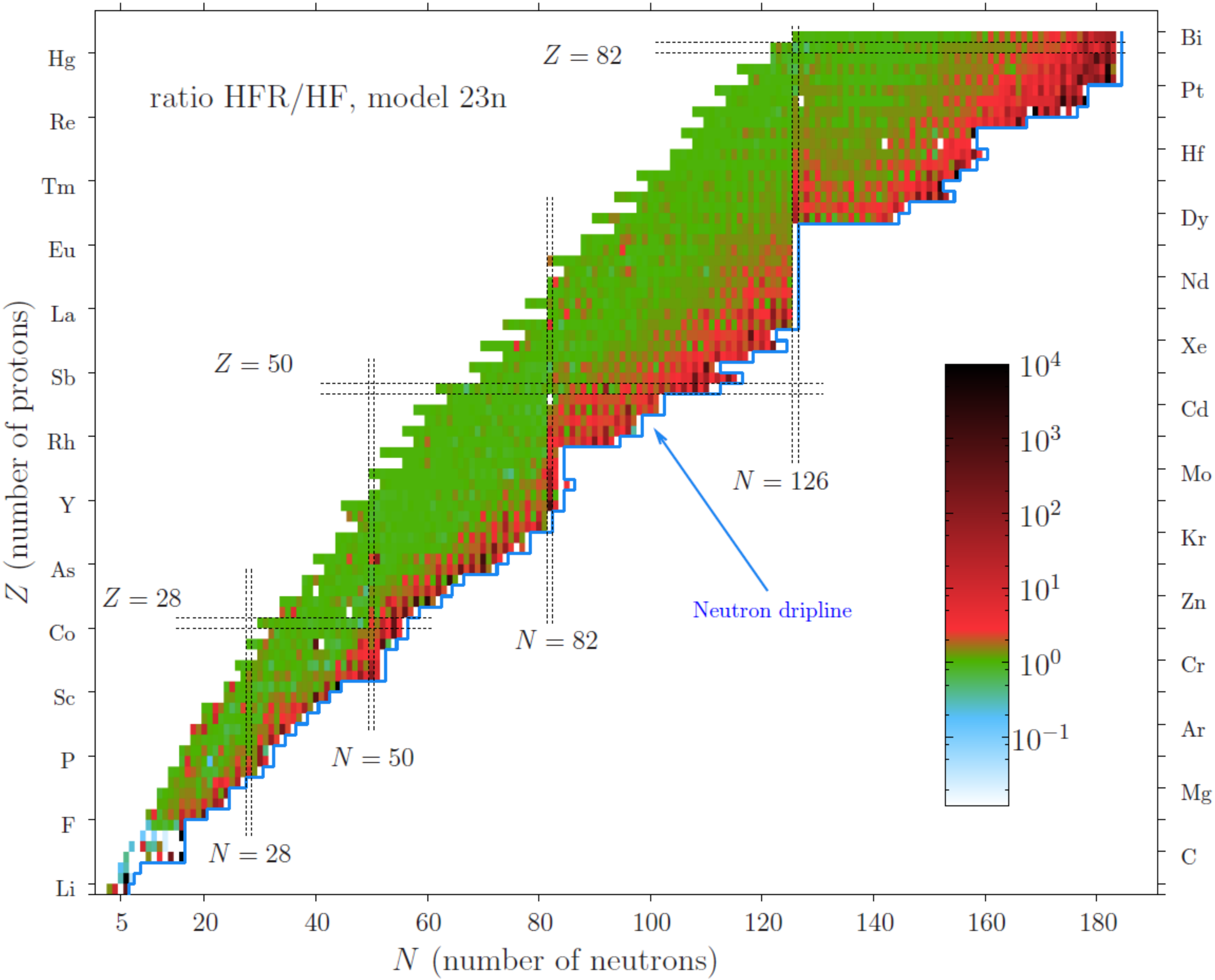


# HFR, 23n, to the drip line

- Example for the Sn isotopes as a function of their mass



# HFR, 23n, to the drip line



# Conclusion

- Ratios of MACS for HFR/HF can be larger than 1000,
- Does it matter for astrophysics, or for the lifetime of the universe ?

- Future applications:
  - Not only for ground state isotopes,
  - Semi-microscopic model (54n),
  - Can we use this to assess the uncertainties due to the models ?
  - Limit of CALENDF above inelastic channel, how to solve this ?
  - We can also apply for PhD fundings…

# Wir schaffen Wissen – heute für morgen