NUCLEAR PHYSICS DATA FOR ASTROPHYSICS

TUNL

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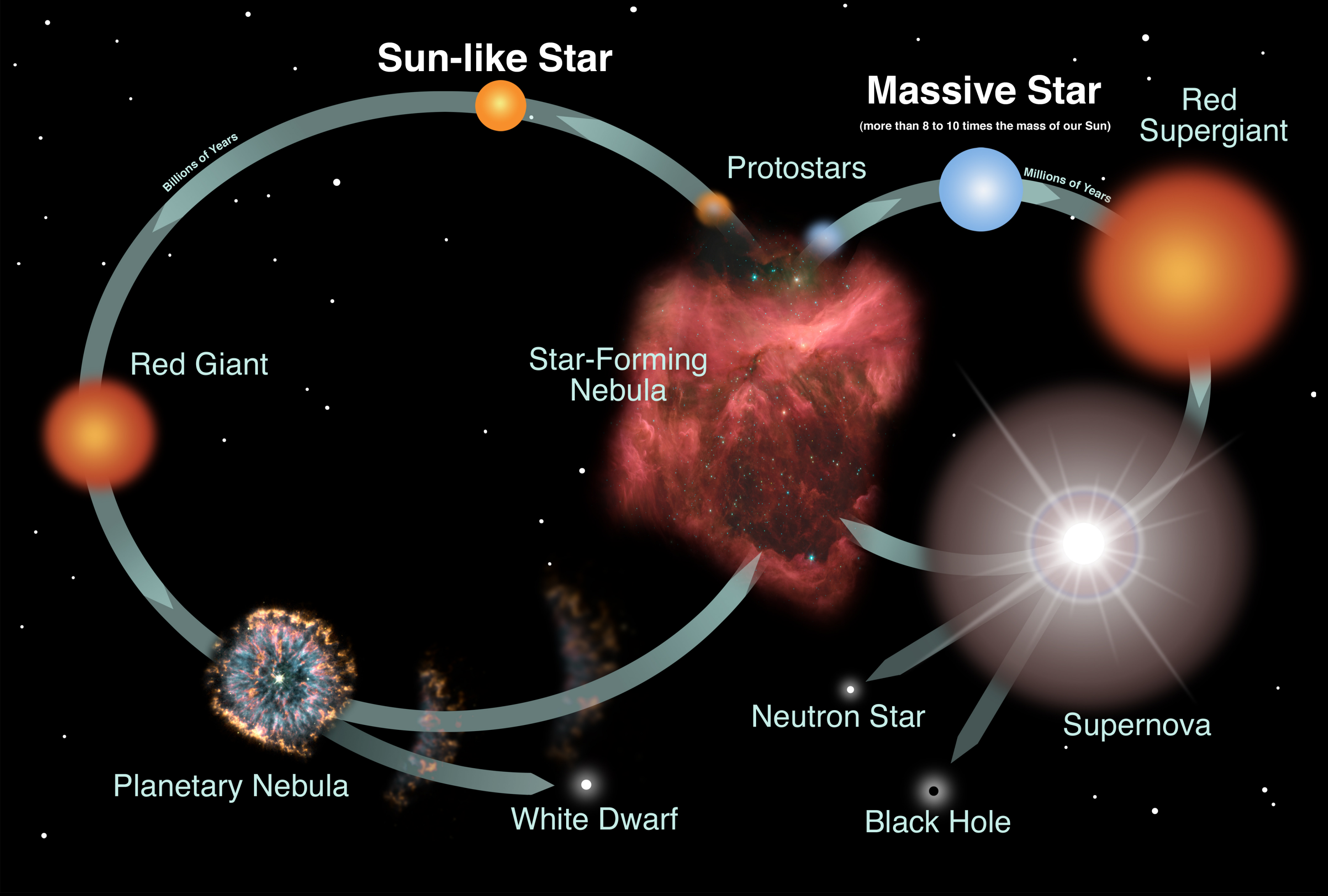
A SYMPHONY OF PROCESSES: r, p, rp, s, i, x, α, αp, ...



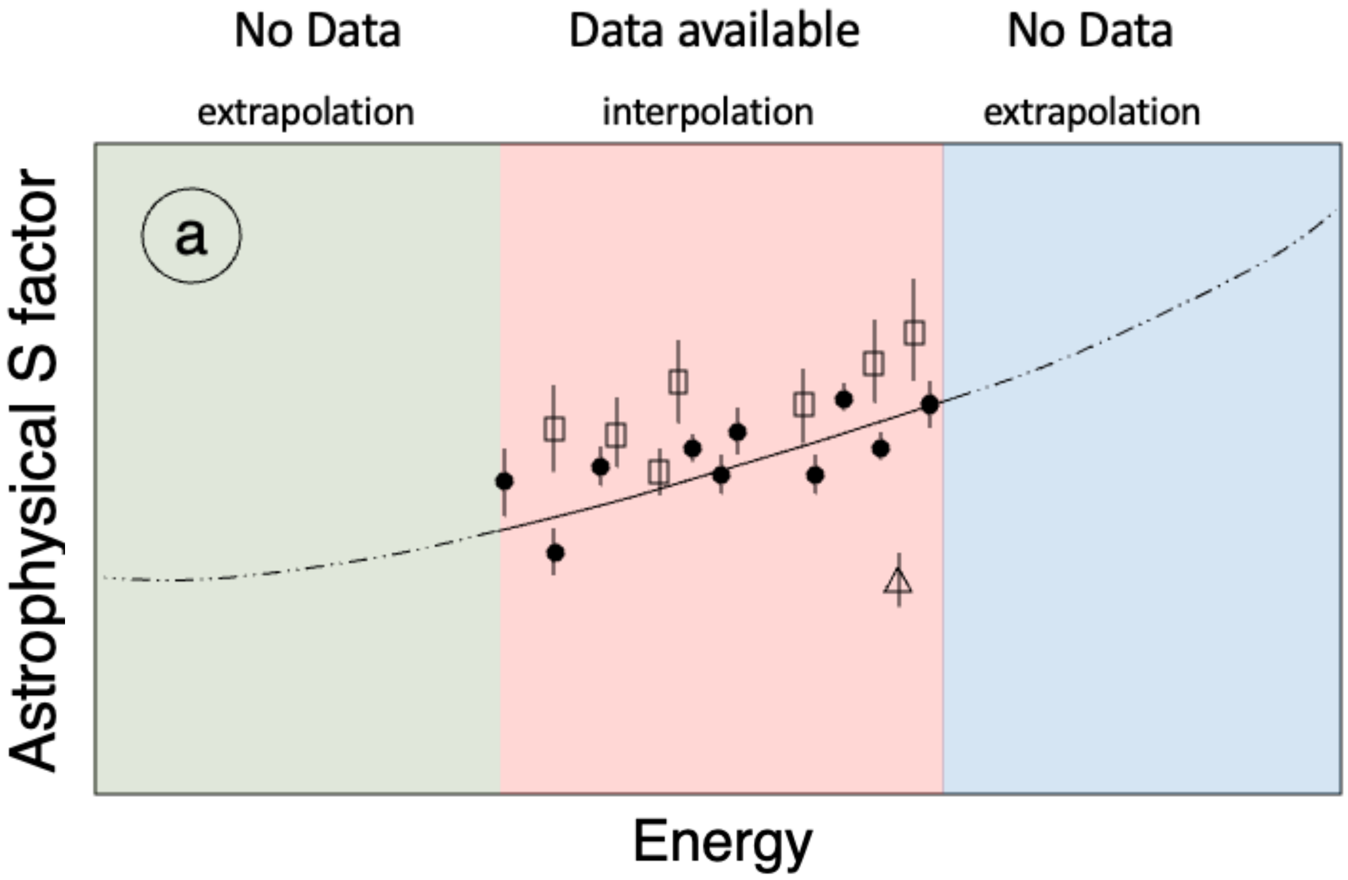
- all nuclear data are important for nuclear astrophysics

- in future: much more emphasis on uncertainties of nuclear data and derived quantities

- astrophysical S factor: $\sigma(E) = E^{-1}\, e^{-2\pi\eta}\, S(E)$

- reaction rate: $\langle\sigma v\rangle \sim T^{-3/2} \int E\, \sigma(E)\, e^{-E/kT}\, dE$

CASE I



needed:

- measured cross section
- nuclear theory
- statistical [e.g., Bayesian[1,2]] model for fitting

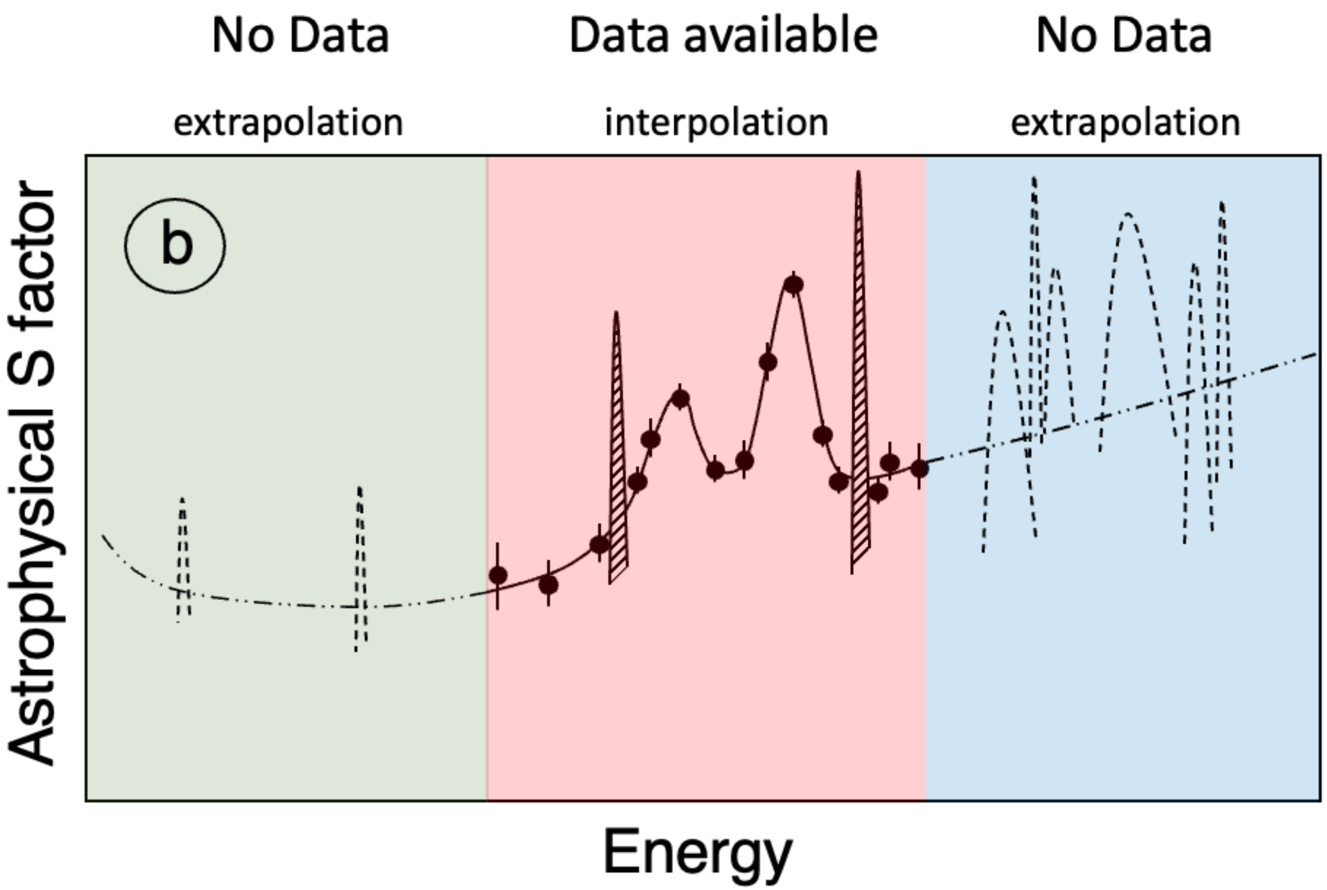
data bases:

- EXFOR
- original literature

examples: D(p,γ)^{3}He, D(d,n)^{3}He, D(d,p)^{3}H, ^{16}O(p,γ)^{17}F,...

[1] Zhang et al., PLB 751, 535 (2015) [2] Iliadis et al., ApJ 831, 107 (2016)

CASE II



examples: $^{14}N(p,\gamma)^{15}O$, $^{12}C(\alpha,\gamma)^{16}O$, $^{17}O(p,\gamma)^{18}F$, $^{23}Na(p,\gamma)^{24}Mg$...

needed:

- measured E_r , E_x , Q [masses]
- measured $\omega\gamma$
- measured cross sections
- measured J, C^2S or ANCs, τ
- nuclear theory [R matrix][1,2]
- reaction rate uncertainty[3]
- Hauser-Feshbach model
- level densities/OMP
- strength functions

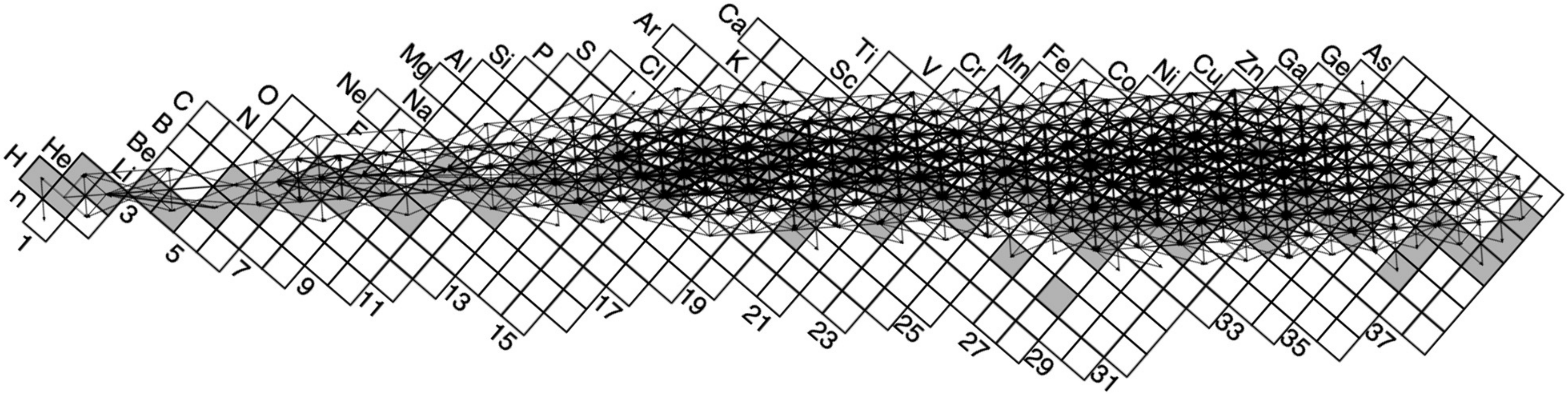
data bases/codes:

- AME/NUBASE
- ENSDF
- Endt 1990[4]
- original literature
- TALYS

[1] de Souza et al., PRC 99, 014619 (2019) [2] Odell et al., PRC 105, 014625 (2022)
[3] Longland et al., NPA 841, 1 (2010) [4] Endt, NPA 521, 1 (1990)

CASE III

examples: NSE or QSE in Type Ia Supernovae
[NSE: Nuclear Statistical Equilibrium; QSE: Quasi-Statistical Equilibrium]



- [reaction rates NOT needed for equilibrium]
- reaction rates needed for freezeout

needed:

- measured masses [binding energies]
- measured spins, excitation energies
- β-decay rates

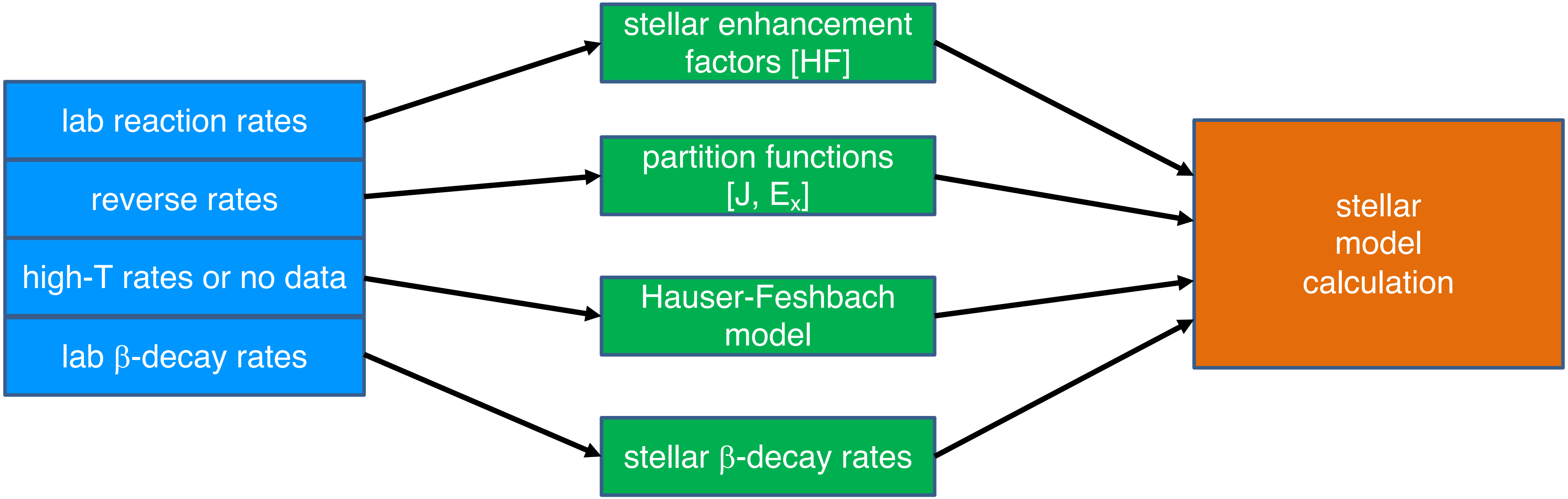
data bases:

- AME
- NUBASE
- ENSDF
- ...

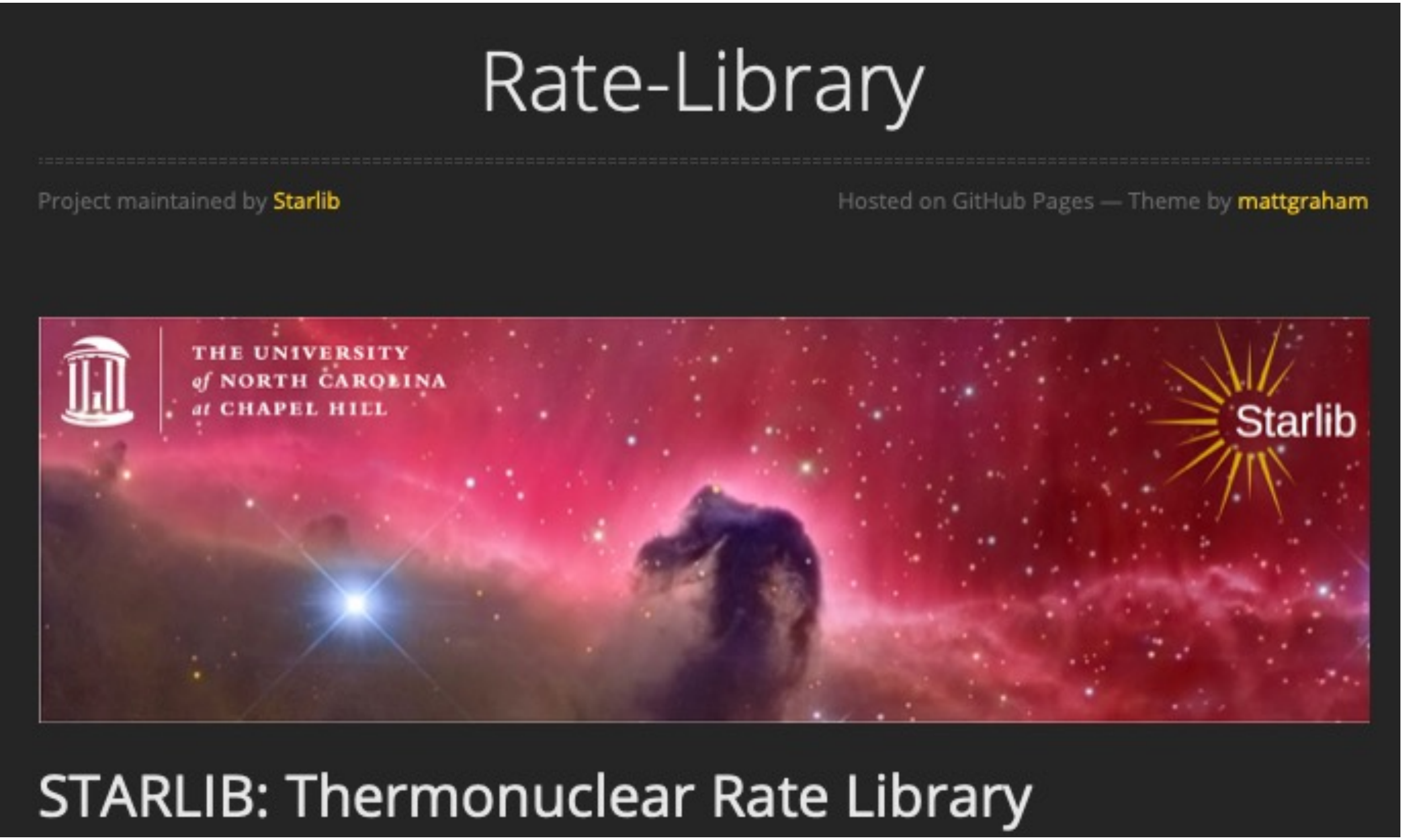
CASE IV: RAPID NEUTRON CAPTURE PROCESS

figure courtesy of Matt Mumpower

FROM NUCLEAR DATA TO STELLAR MODEL INPUT



- nuclear data needed: excitation energies, spins, level densities, branching ratios, Gamow-Teller strengths, ...
- **what are the uncertainties in the "corrected" quantities [from model predictions]?**



https://starlib.github.io/Rate-Library/

Sallaska, Iliadis, Champagne, et al., ApJS 207, 18 (2013)

other rate libraries:

- REACLIB [Thielemann <2000]
- REACLIB [Rauscher/Thielemann]
- JINA REACLIB
- BRUSLIB [2012]
- KADoNiS [2014]
- several others...

Starlib

STARLIB contains:

- reaction rates
- rate uncertainties
- rate probability densities
- used in MC sensitivity studies

NEW REACTION RATE / S FACTOR EVALUATIONS

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updates of:

REVIEW OF MODERN PHYSICS, VOLUME 83, JANUARY–MARCH 2011

Solar fusion cross sections. II. The *pp* chain and CNO cycles

E. G. Adelberger, A. García, R. G. Hamish Robertson, and K. A. Snover

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\+ 44 additional co-authors

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Nuclear Physics A 841 (2010) 1–30

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

Charged-particle thermonuclear reaction rates: I. Monte Carlo method and statistical distributions

R. Longland [a,b], C. Iliadis [a,b,*], A.E. Champagne [a,b], J.R. Newton [a,b], C. Ugalde [a,b], A. Coc [c,d], R. Fitzgerald [e]

Berkeley SF III workshop [July 2022; organizers: Serenelli, Guglielmetti, Bemmerer, Haxton]

- ≈ 60 participants [co-authors]
- focus on S factors
- goal to publish by July 2023

- mainly: Richard Longland & CI
- focus on reaction rates
- goal to publish by early 2024
- concurrent major new STARLIB release

RECOMMENDATIONS FOR NUCLEAR DATA PROGRAM

1. **Ensure that evaluated nuclear data are up-to-date:**
   - measured ground-state masses, spin-parities, half-lives [AME, NUBASE]
   - cross sections, S factors [EXFOR,...]
   - energies, spin-parities, lifetimes of excited levels [ENSDF]
   - resonance parameters [strengths, partial widths,...]

2. **Support evaluation of derived nuclear quantities:**
   - laboratory reaction rates [MC method to derive uncertainties]
   - Hauser-Feshbach predictions: level densities, optical potentials, strength functions [uncertainties?]
   - stellar weak interaction rates [uncertainties?]

3. **Provide modern tools for statistical analysis of nuclear data and derived nuclear quantities:**
   - Bayesian models, machine learning, genetic algorithms,...

“Ultimately, the future of nuclear physics in this endeavor is a coherent combination of data and theory, which advances our understanding of astrophysics”

[quote by Matt Mumpower]

QUESTIONS?