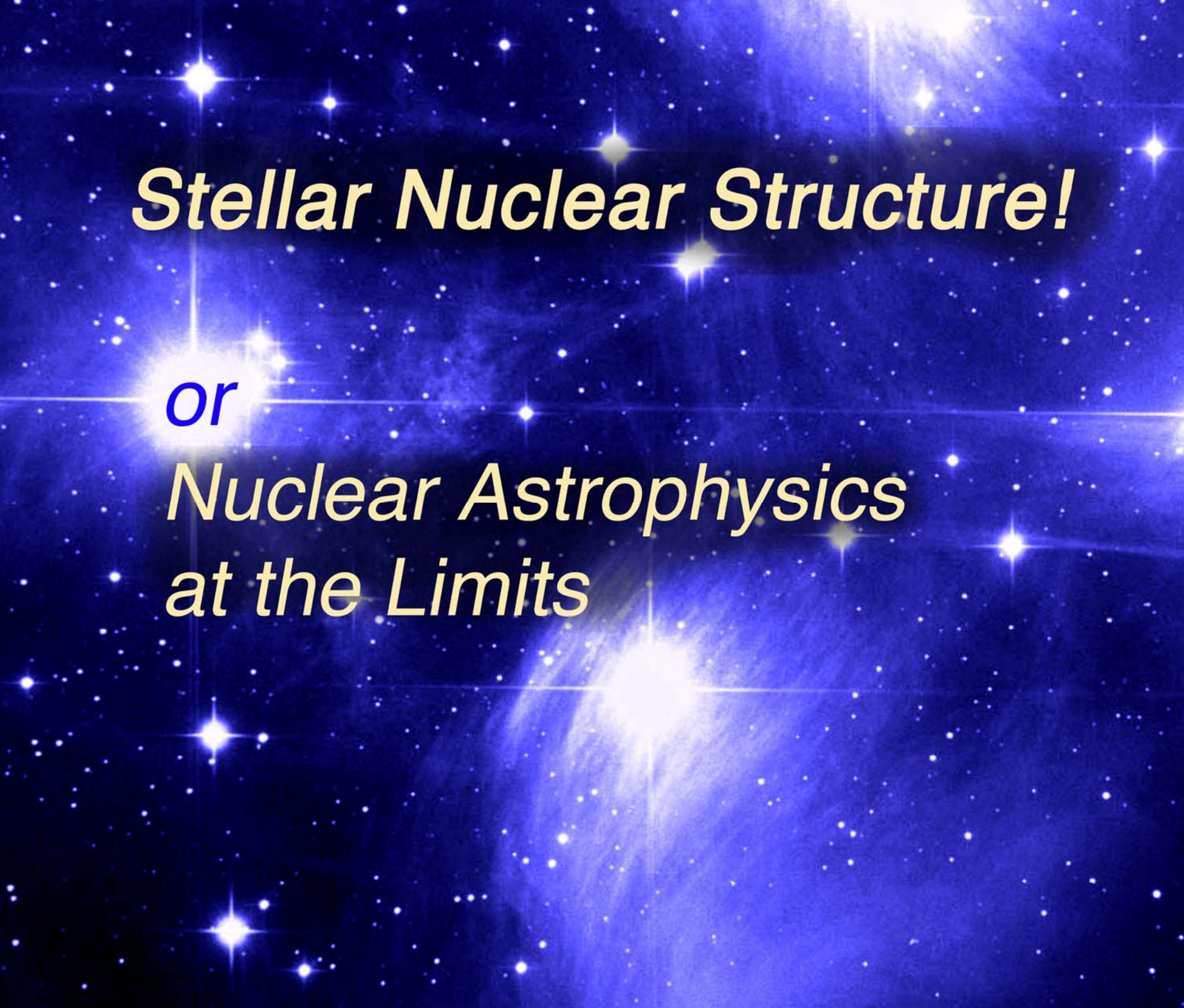
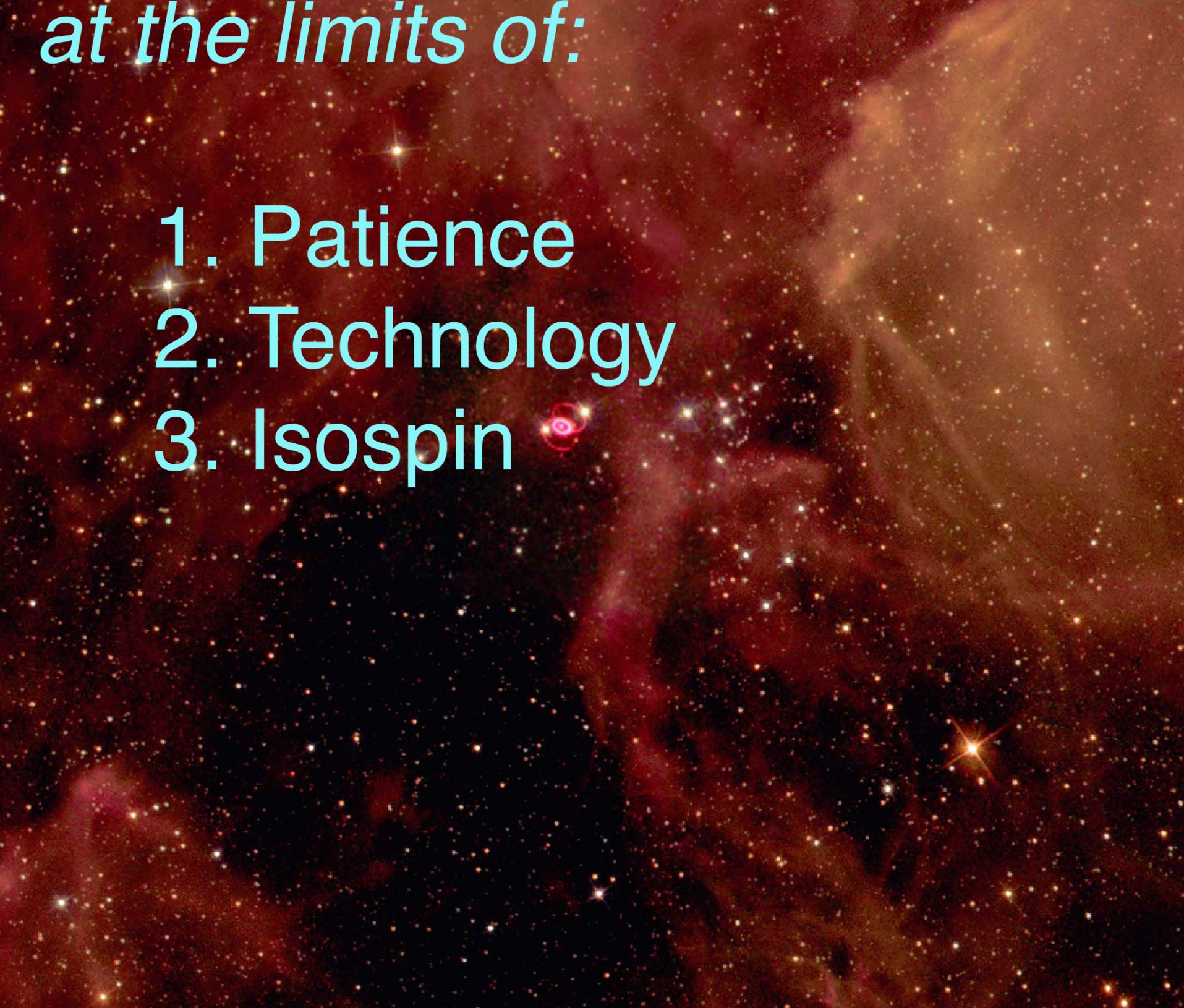

Stellar Nuclear Structure!

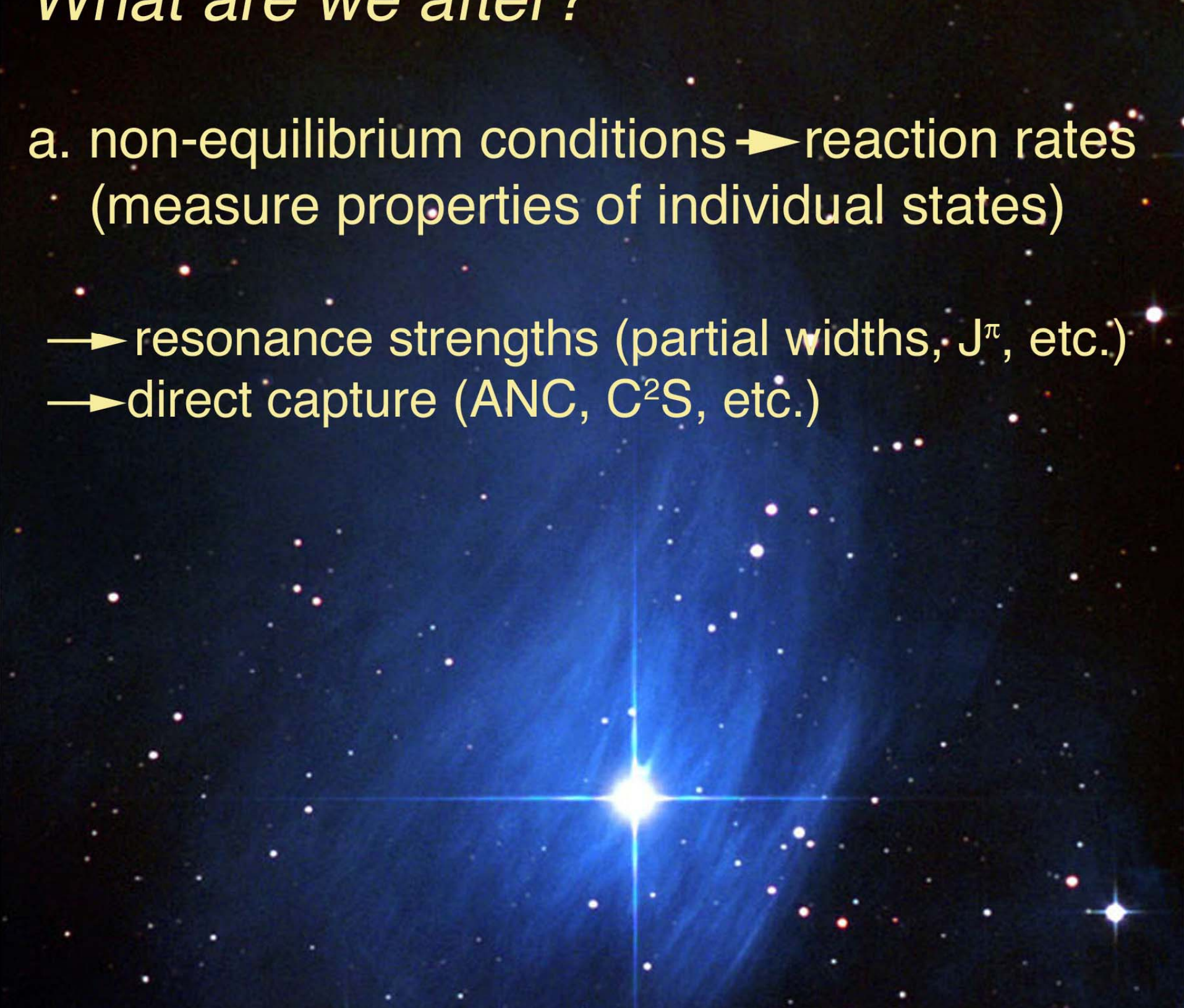

Stellar Nuclear Structure!
or
Nuclear Astrophysics
at the Limits


at the limits of:
1. Patience
2. Technology
3. Isospin

What are we after?

a. non-equilibrium conditions → reaction rates
(measure properties of individual states)

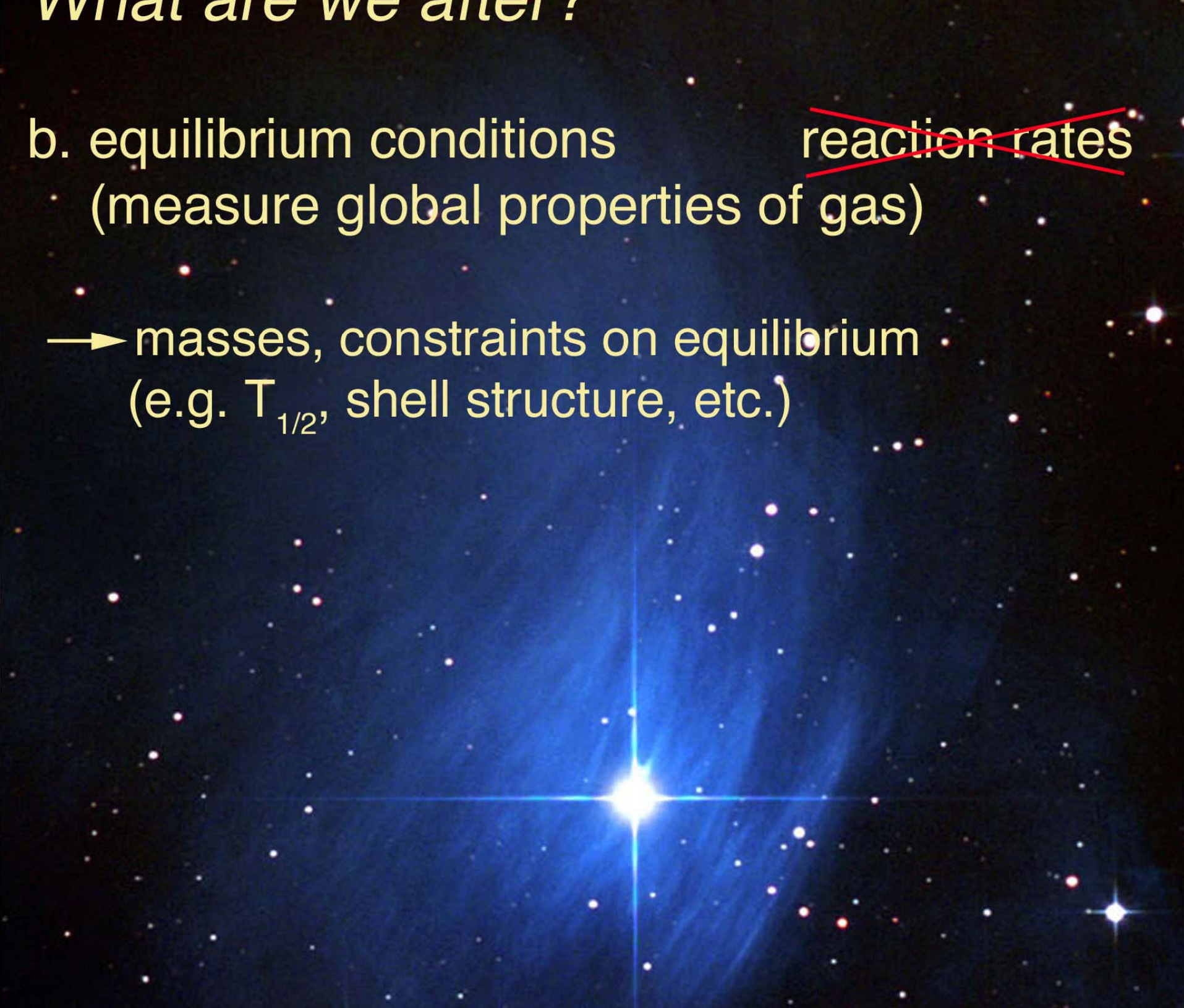
→ resonance strengths (partial widths, J^{π}, etc.)
→ direct capture (ANC, C^2S, etc.)



What are we after?

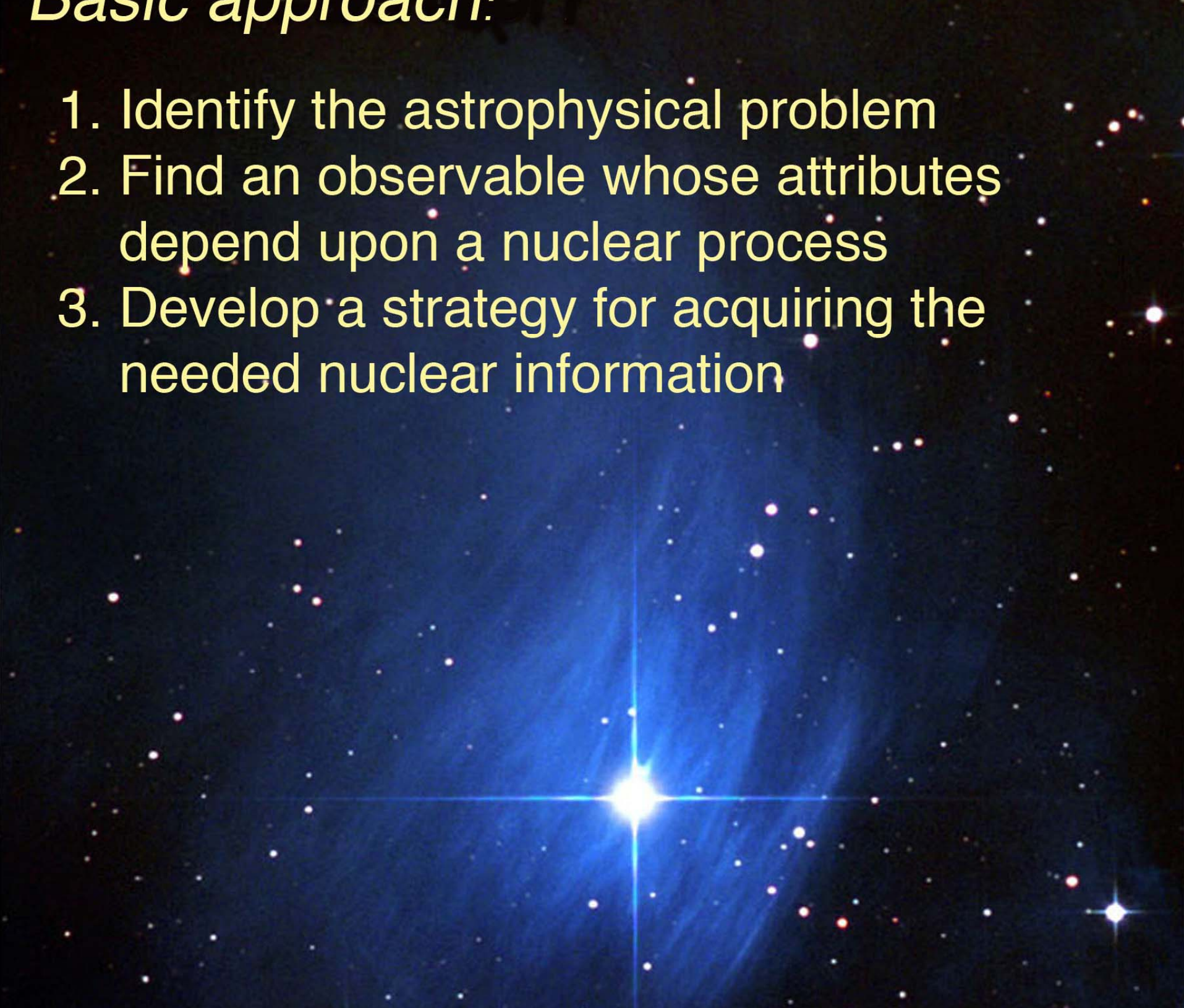
b. equilibrium conditions ~~reaction rates~~
(measure global properties of gas)

→ masses, constraints on equilibrium
(e.g. $T_{1/2}$, shell structure, etc.)

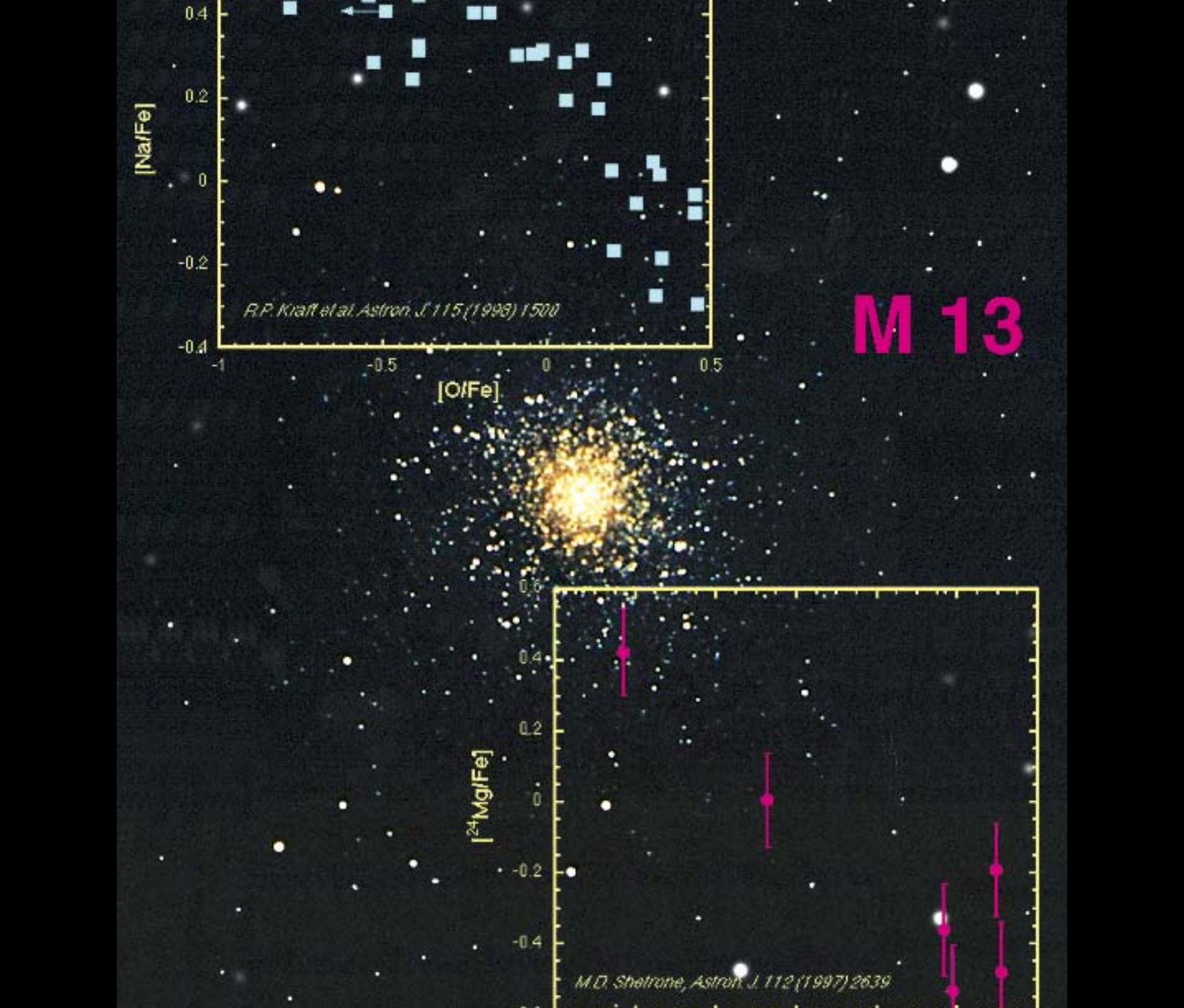


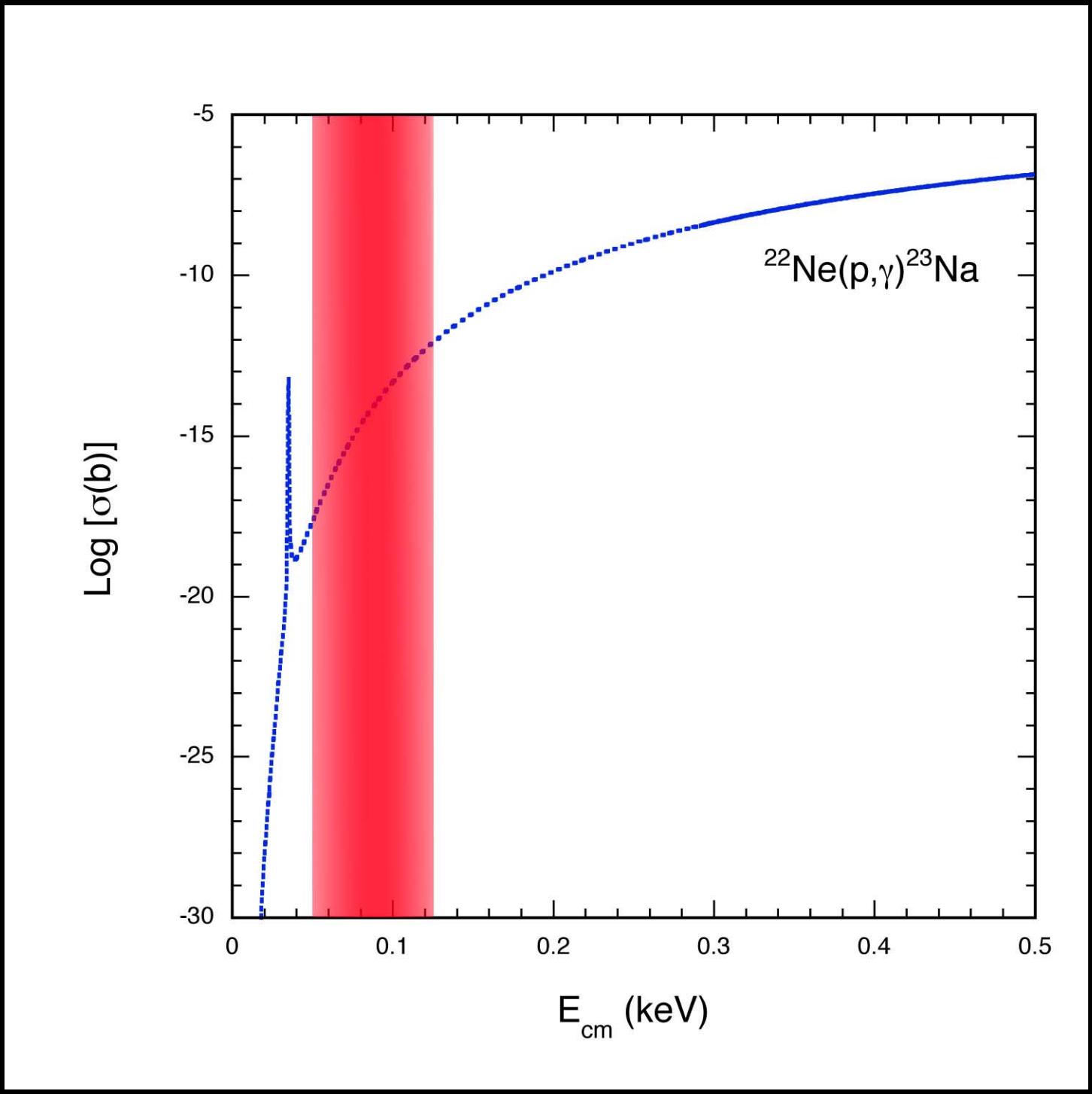
Basic approach:

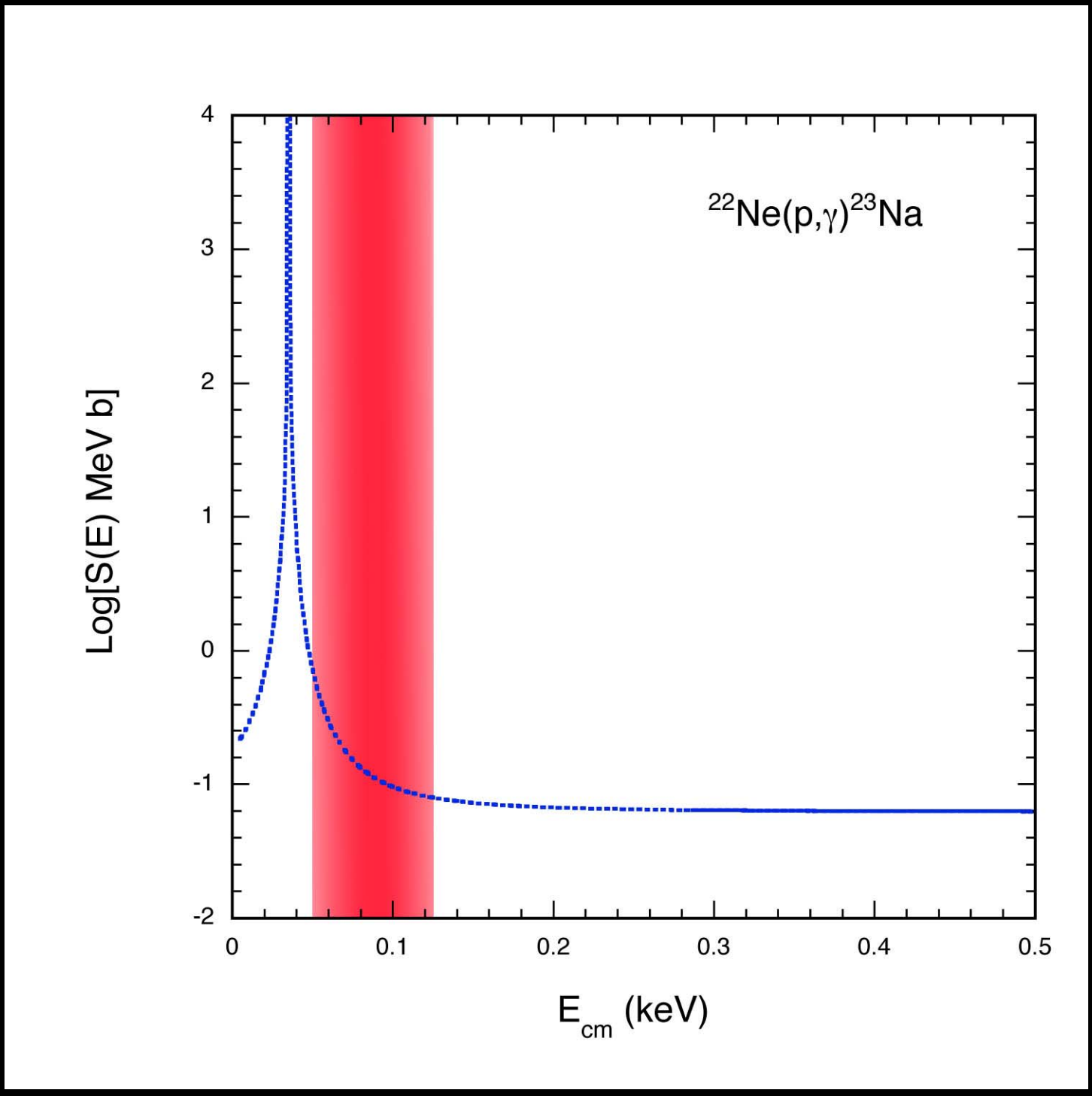
1. Identify the astrophysical problem
2. Find an observable whose attributes depend upon a nuclear process
3. Develop a strategy for acquiring the needed nuclear information

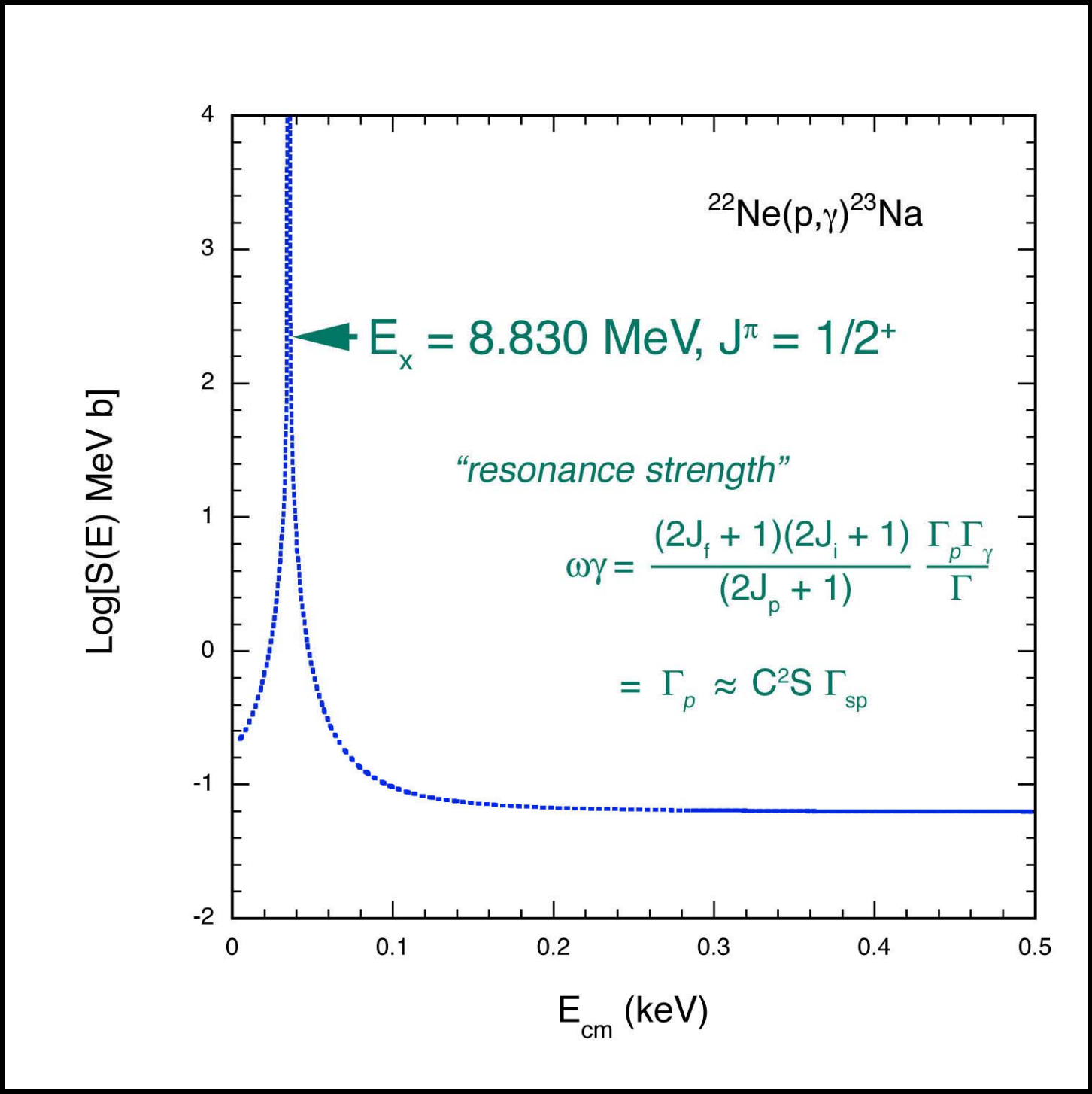


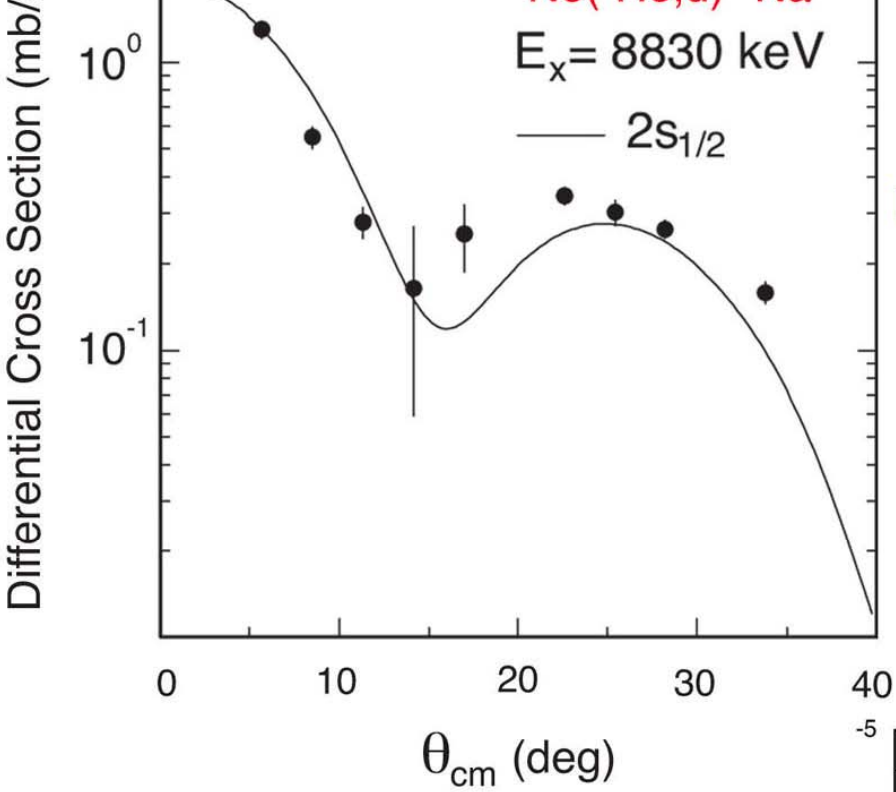
1. The limits of patience


M 13
[Na/Fe]
[O/Fe]
R.P. Kraft et al. Astron. J. 115 (1998) 1500
[24Mg/Fe]
M.D. Shetrone, Astron. J. 112 (1997) 2639


-5
-10
-15
-20
-25
-30
0
0.1
0.2
0.3
0.4
0.5
Log [σ(b)]
E_cm (keV)
22Ne(p,γ)23Na


^{22}Ne(p,γ)^{23}Na
Log[S(E) MeV b]
E$_{cm}$ (keV)
4
3
2
1
0
-1
-2
0
0.1
0.2
0.3
0.4
0.5

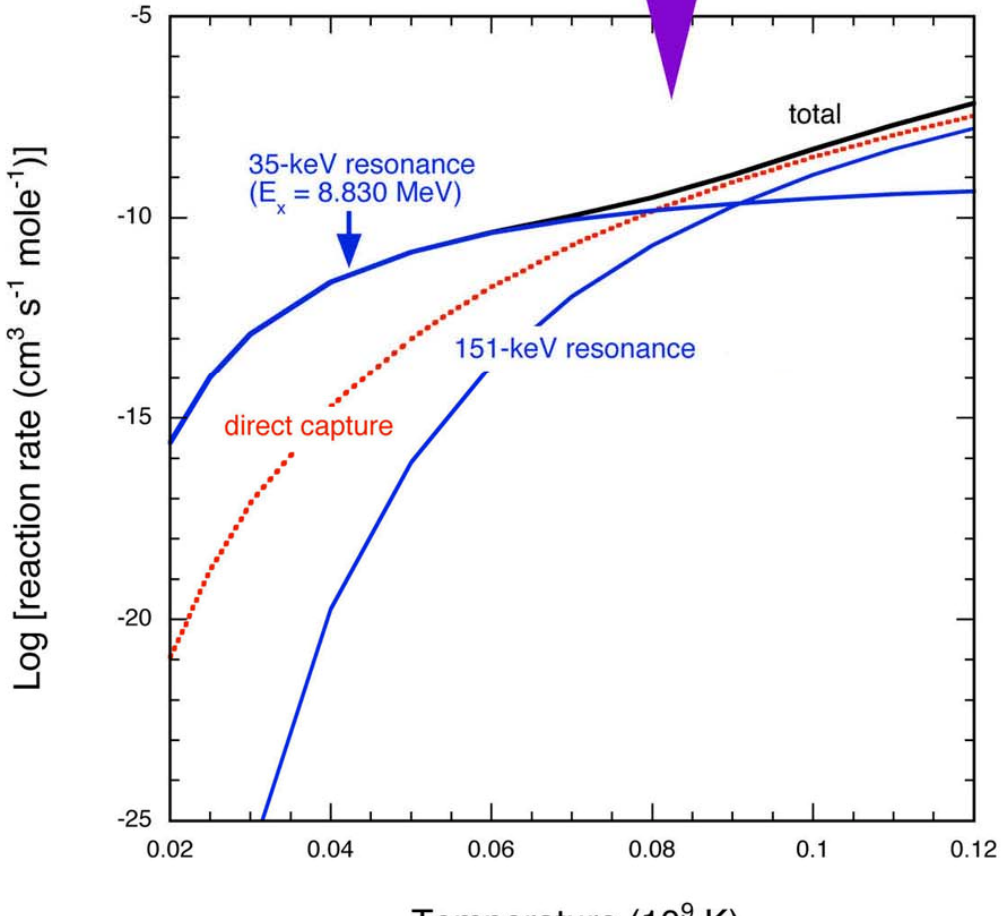

^{22}Ne(p,γ)^{23}Na
E_x = 8.830 MeV, $J^\pi = 1/2^+$
"resonance strength"
$\omega\gamma = \frac{(2J_f + 1)(2J_i + 1)}{(2J_p + 1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma}$
$= \Gamma_p \approx C^2S\, \Gamma_{sp}$
Log[S(E) MeV b]
E_{cm} (keV)
4
3
2
1
0
-1
-2
0
0.1
0.2
0.3
0.4
0.5



$C^2S = 0.02$

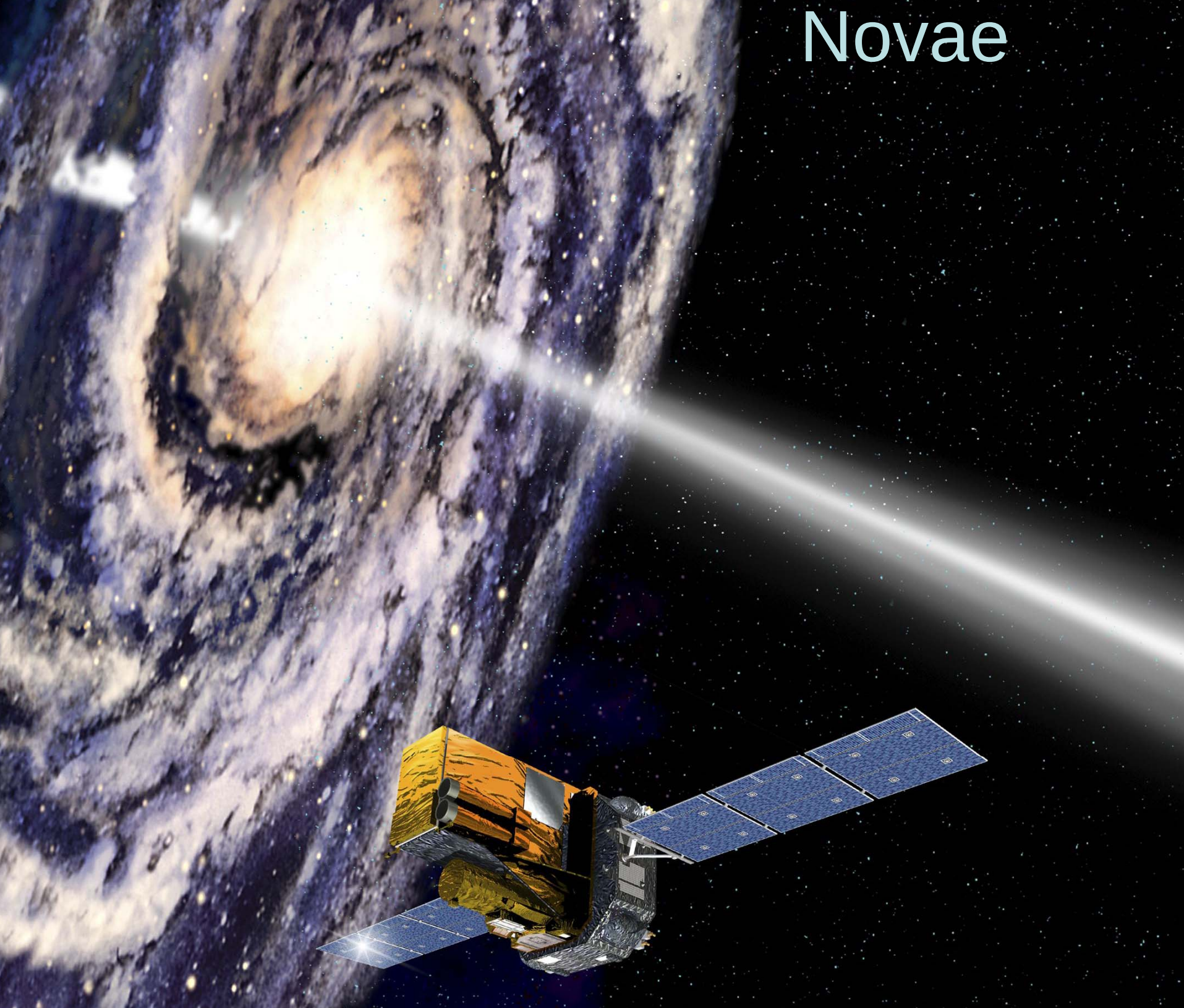
$\Gamma_p = 3.6 \times 10^{-15}$ eV

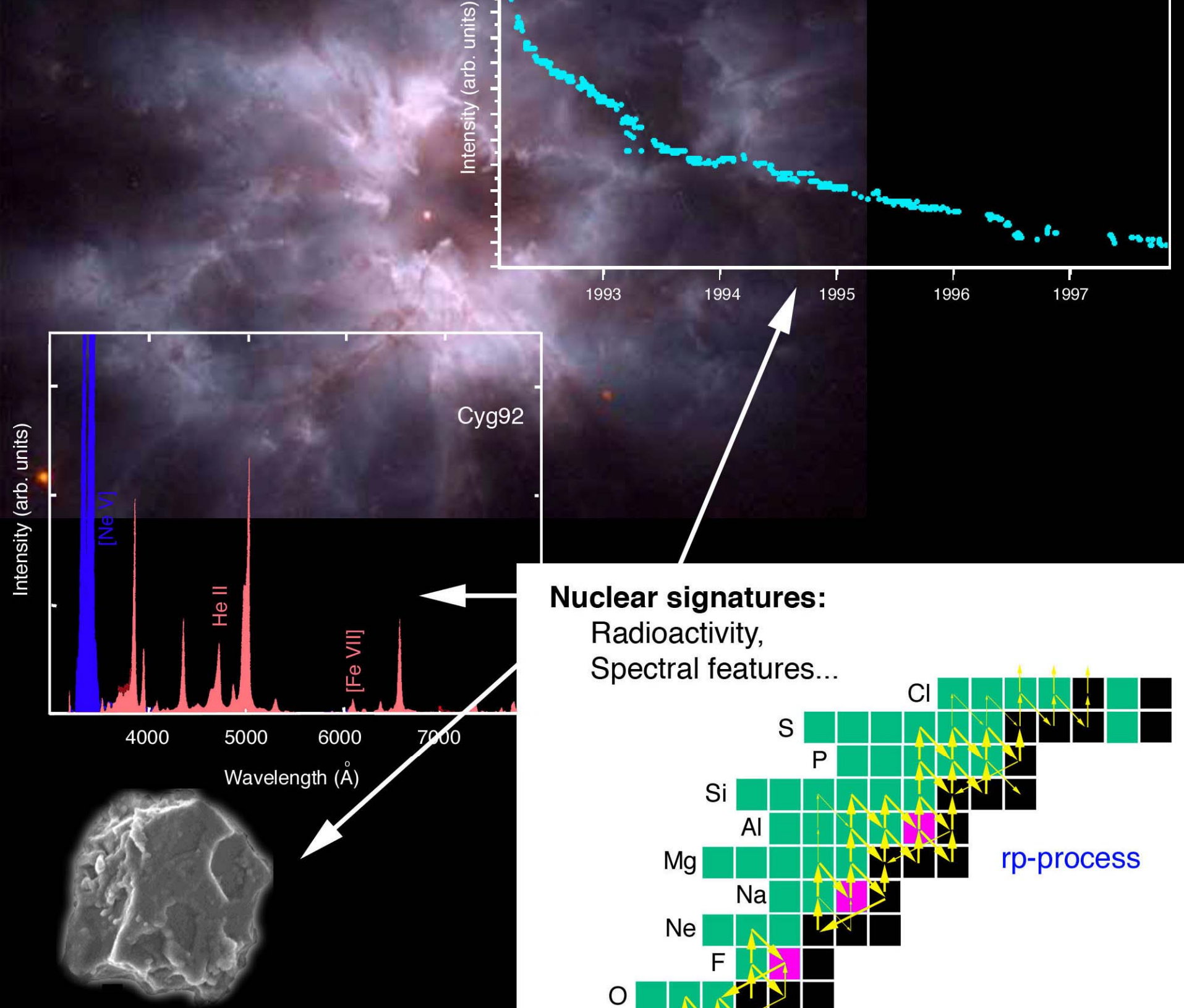
$\langle \sigma v \rangle = (2\pi/\mu kT)^{3/2} \hbar^2 \omega\gamma \, e^{-E_r/kT}$



2. The limits of technology

Novae




Intensity (arb. units)
1993
1994
1995
1996
1997
Cyg92
[Ne V]
He II
[Fe VII]
Intensity (arb. units)
4000
5000
6000
7000
Wavelength (Å)
Nuclear signatures:
Radioactivity,
Spectral features...
Cl
S
P
Si
Al
Mg
Na
Ne
F
O
rp-process

resonance reaction rate:

$$N_A\langle\sigma v\rangle \alpha \frac{(2J_f+1)(2J_i+1)}{(2J_t+1)} \frac{\Gamma_p\Gamma_\gamma}{\Gamma} e^{-E_r/kT}$$

resonance reaction rate:

$$N_A\langle\sigma v\rangle \alpha \frac{(2J_f+1)(2J_i+1)}{(2J_t+1)} \frac{\Gamma_p \Gamma_\gamma}{\Gamma} e^{-E_r/kT}$$

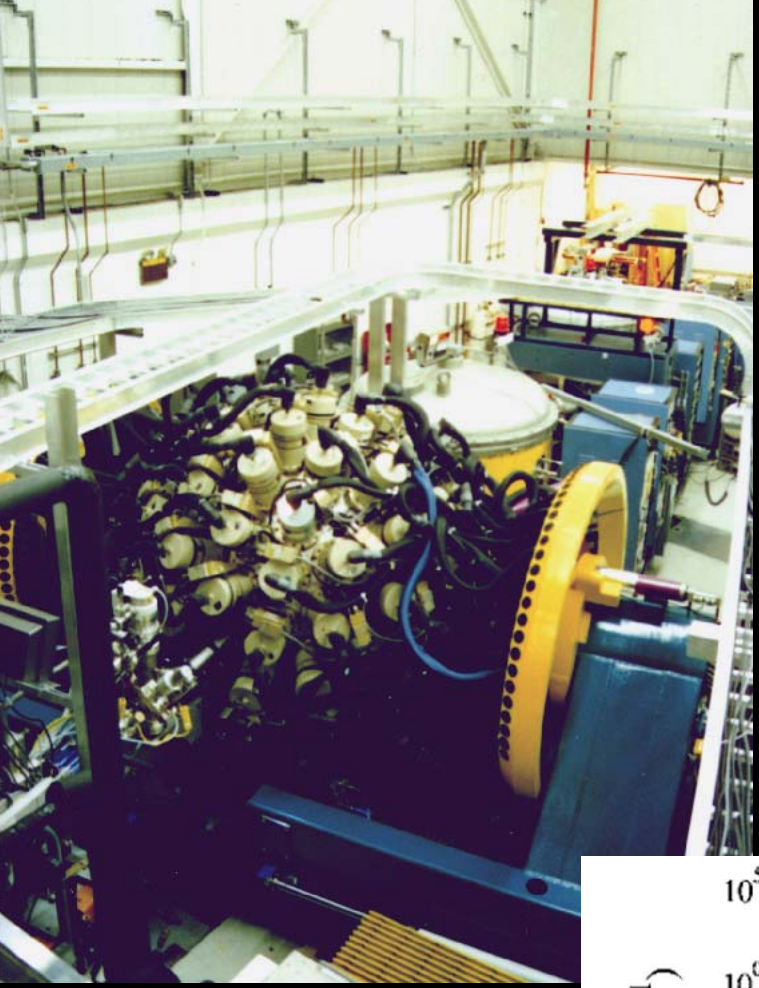
γ-decay

C^2S, analog-state assignment

γ-decay

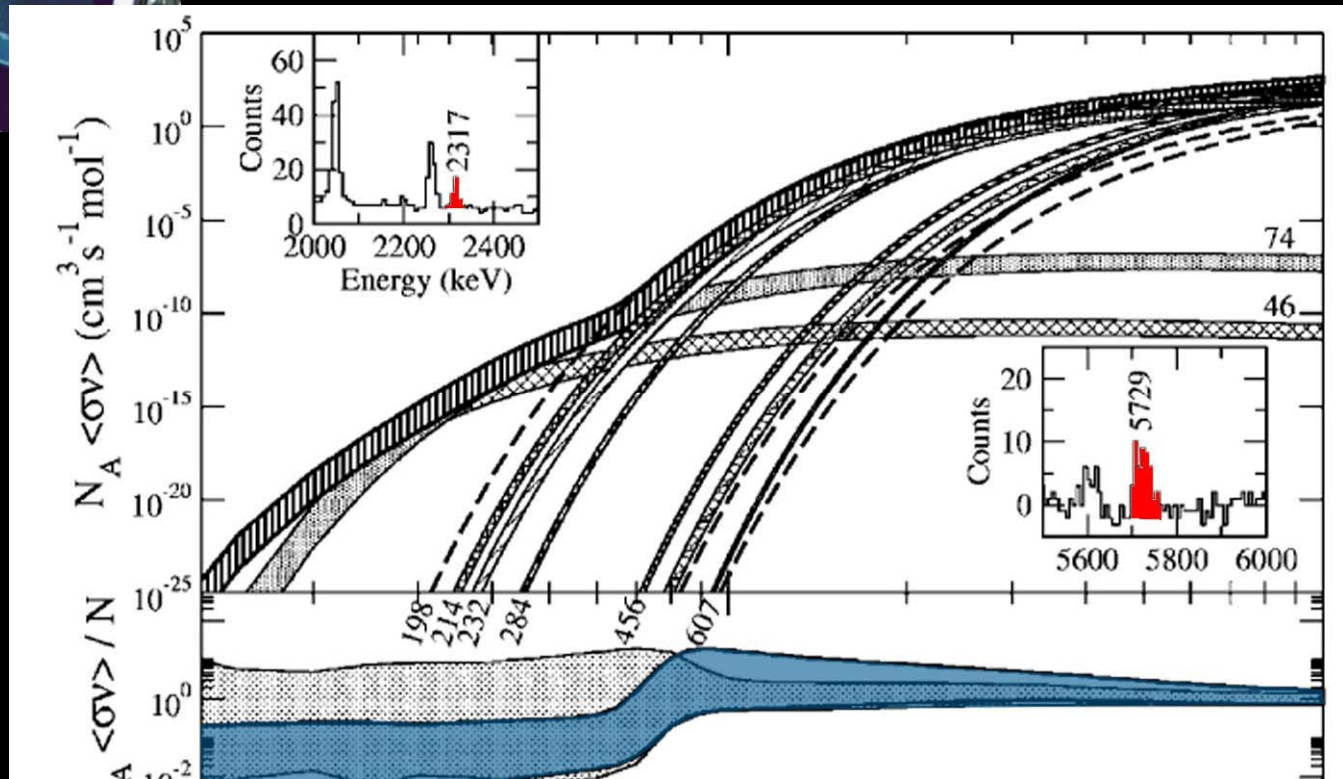
lifetime

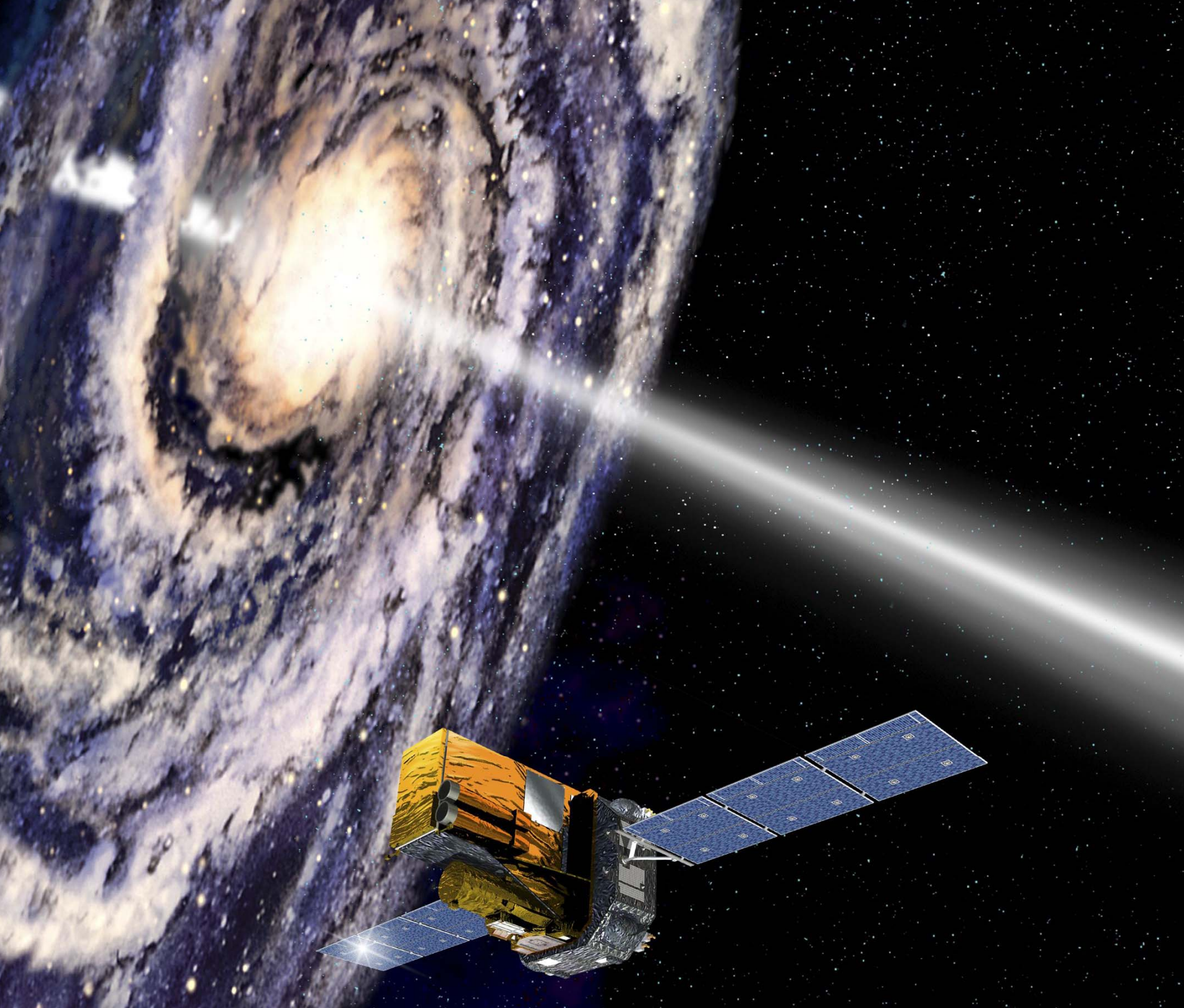
E_x



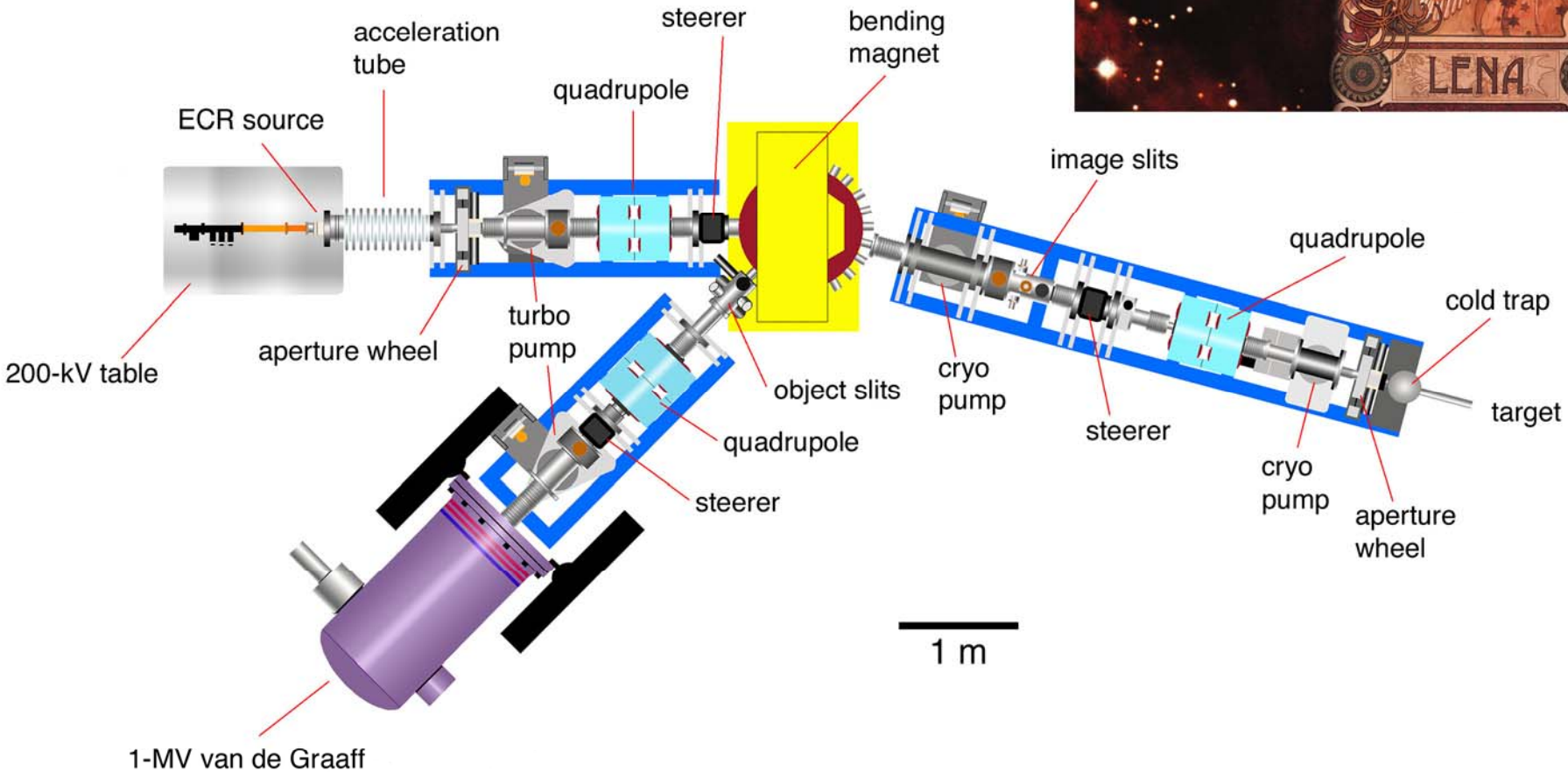
$^{22}Na(p,\gamma)^{23}Mg$ via $^{12}C(^{12}C,n)^{23}Mg$

*[D.G. Jenkins et al. PRL **92**, 031101 (2004)]*



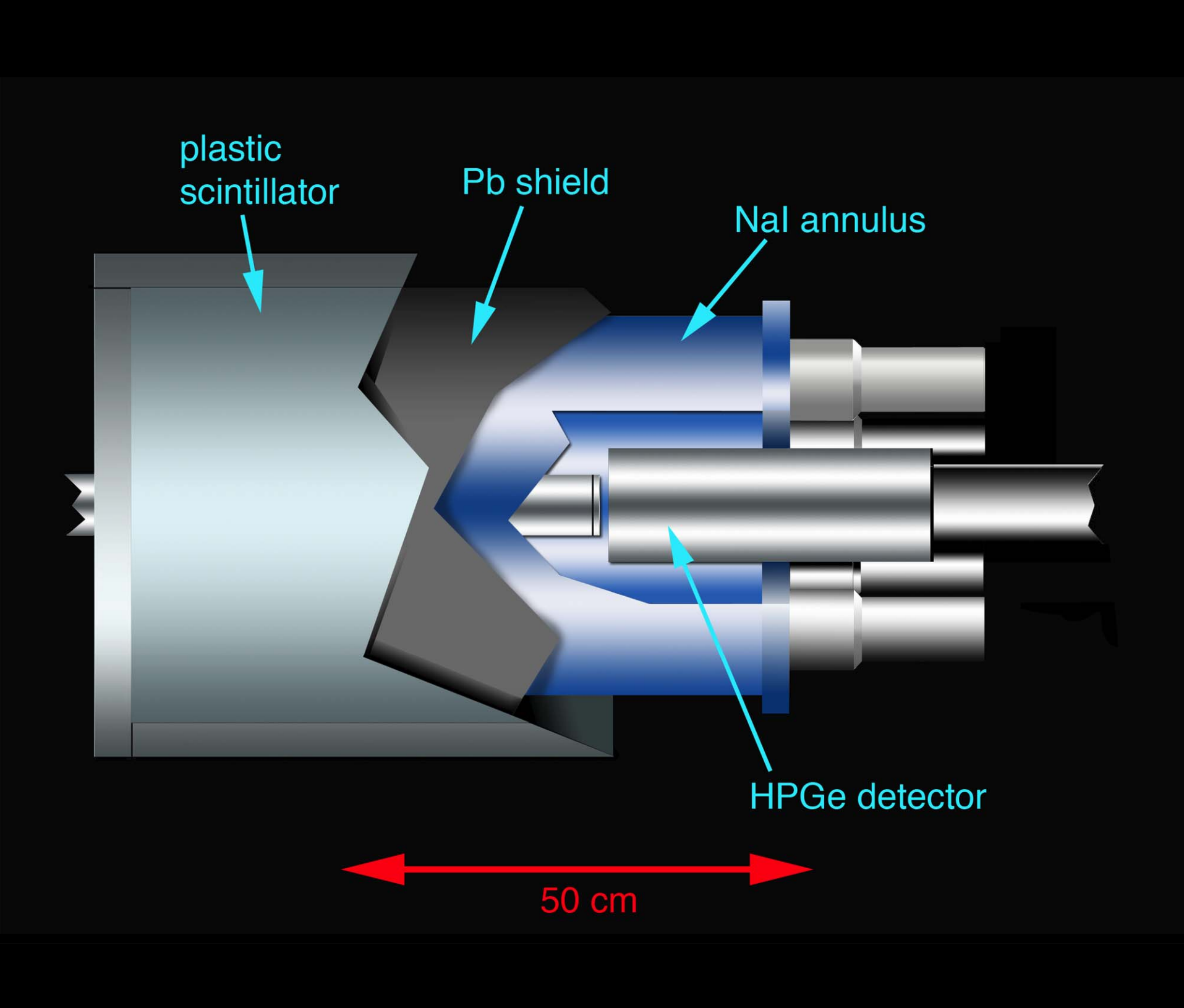


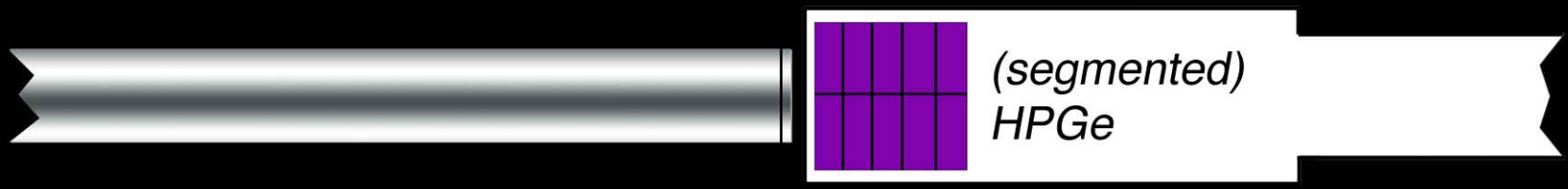
LENA



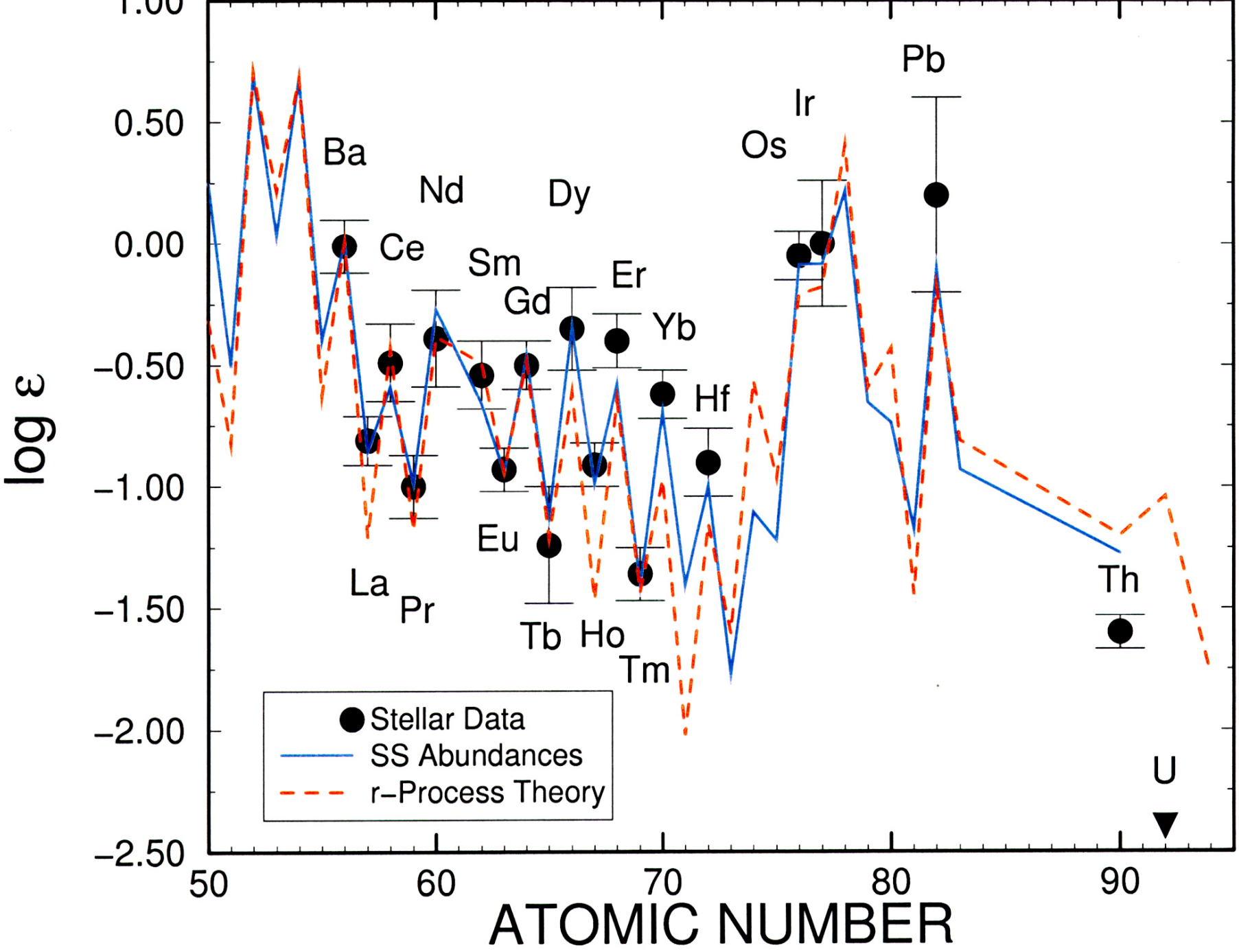
the Laboratory for Experimental Nuclear Astrophysics


beam
target
HPGe

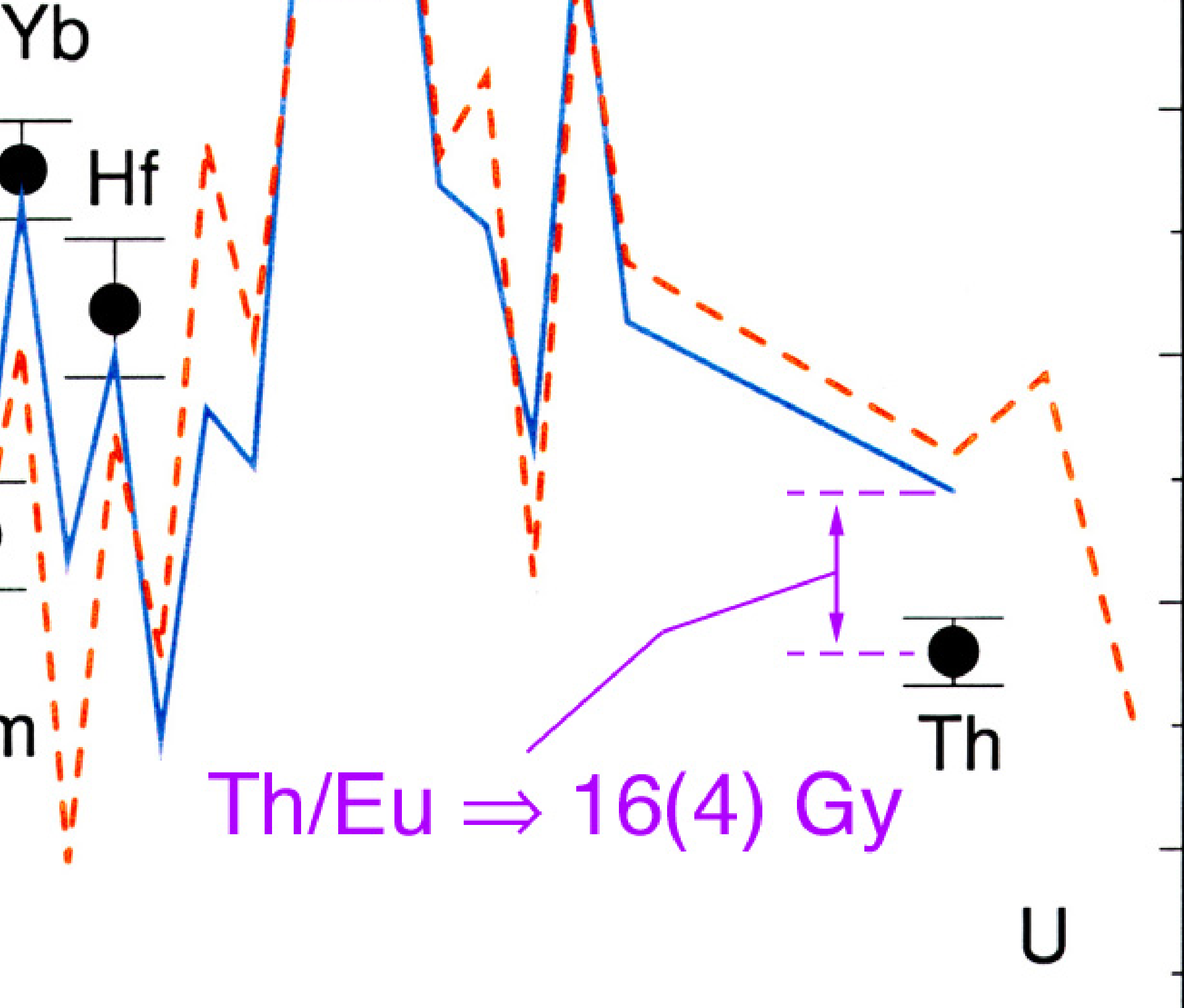

plastic
scintillator
Pb shield
NaI annulus
HPGe detector
50 cm

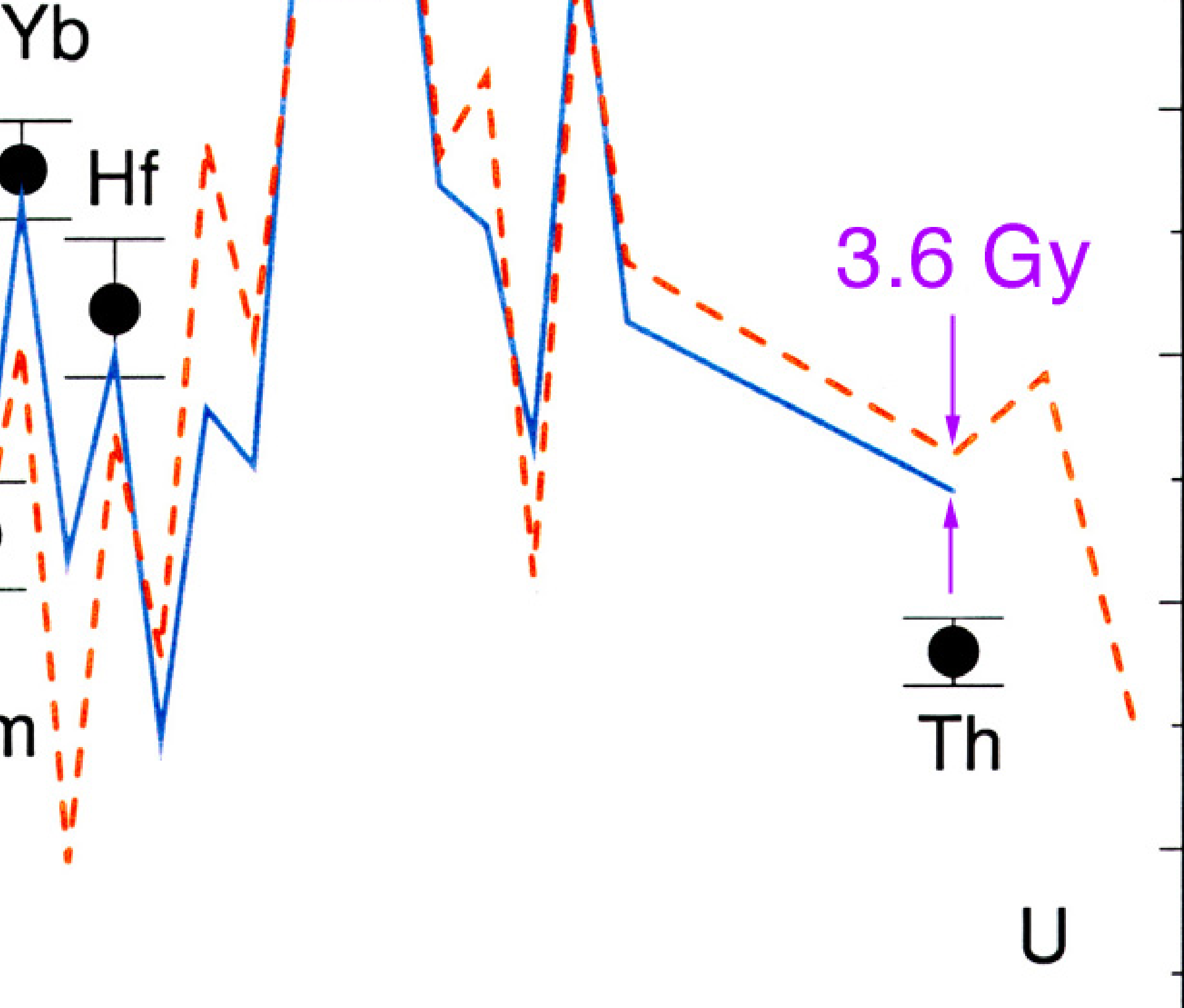

(segmented)
HPGe

3. The limits of isospin



C. Sneden et al., Ap. J. 533, L139 (2000)


Yb
Hf
Th
Th/Eu ⇒ 16(4) Gy
U


Yb
Hf
3.6 Gy
Th
U

Nucleosynthesis in the r-process

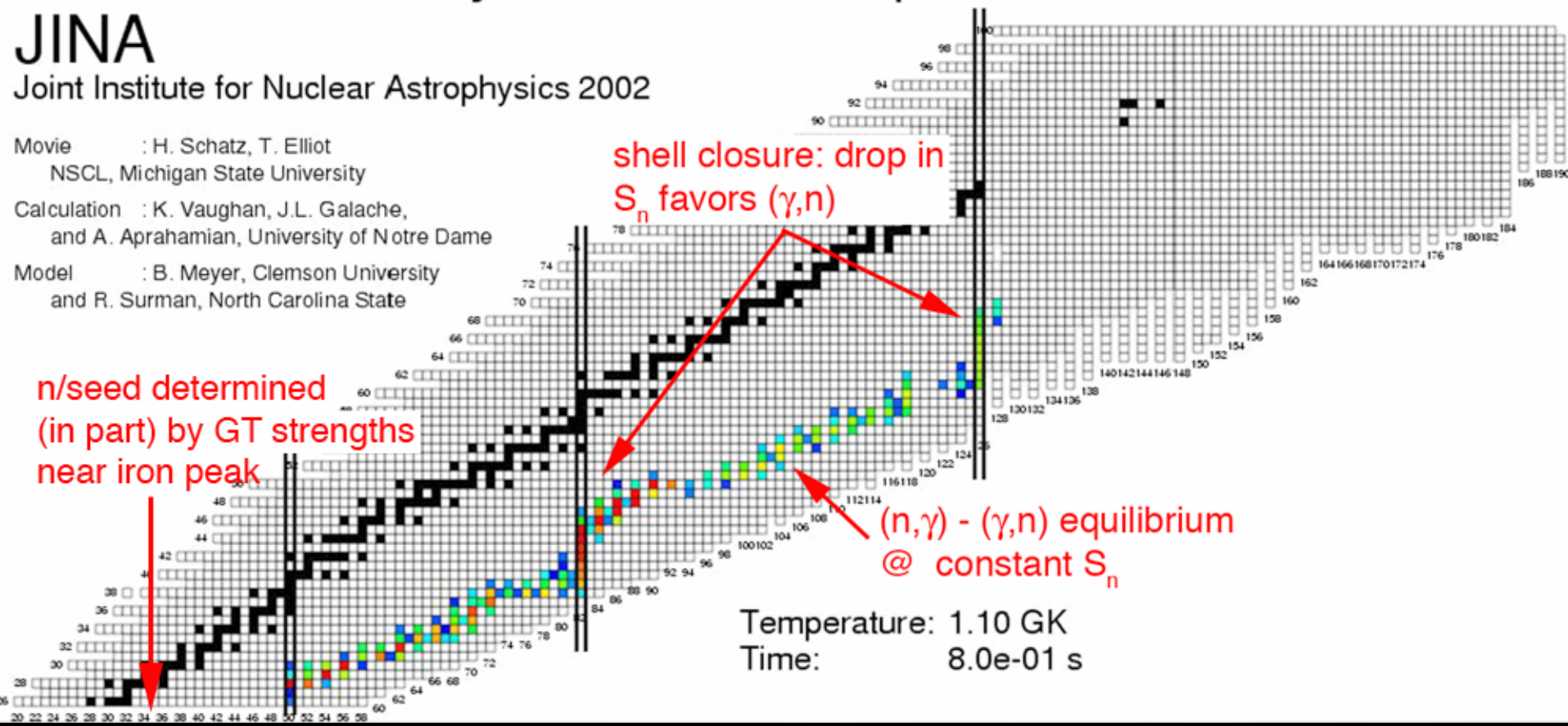
JINA

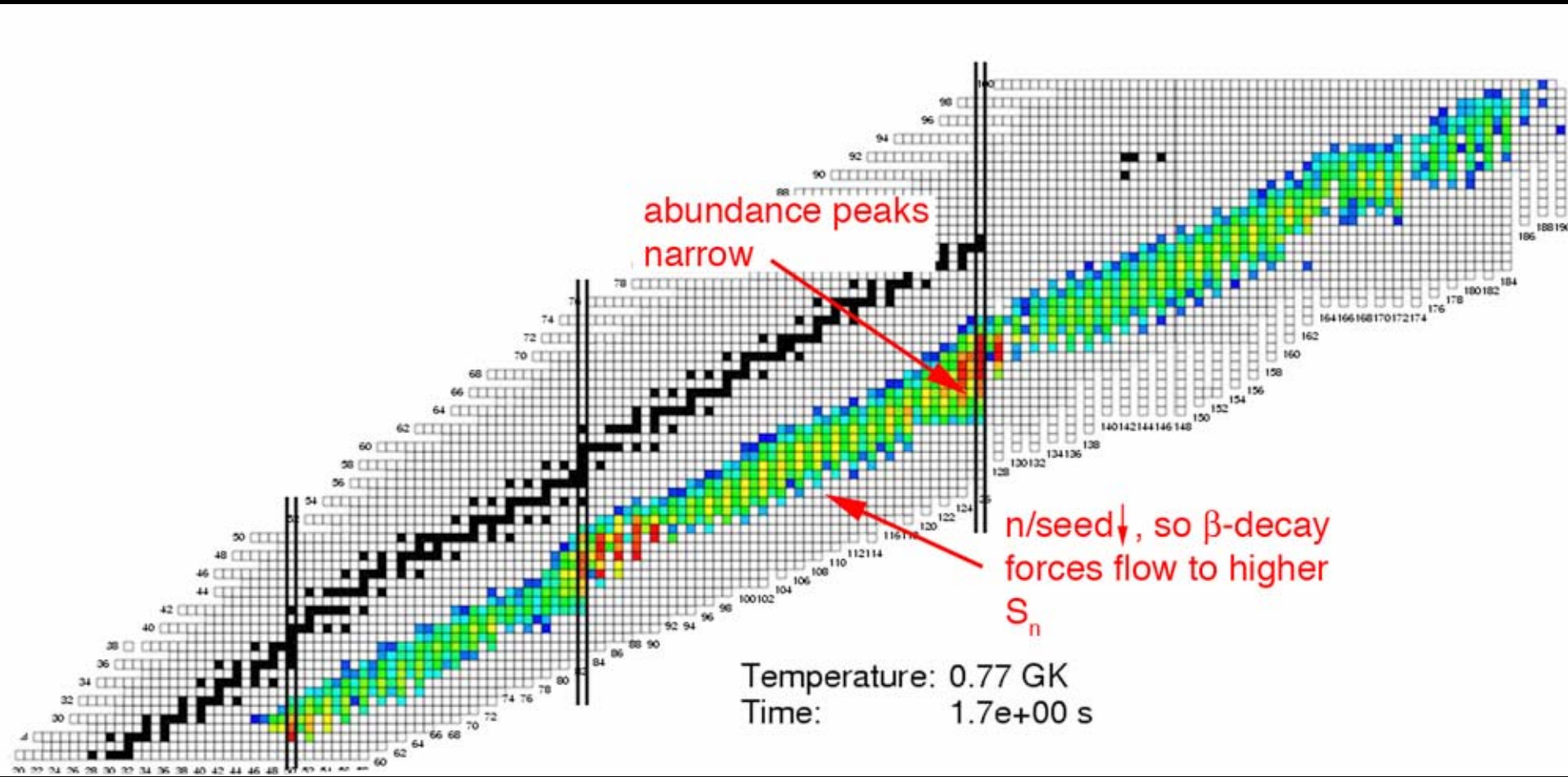
Joint Institute for Nuclear Astrophysics 2002

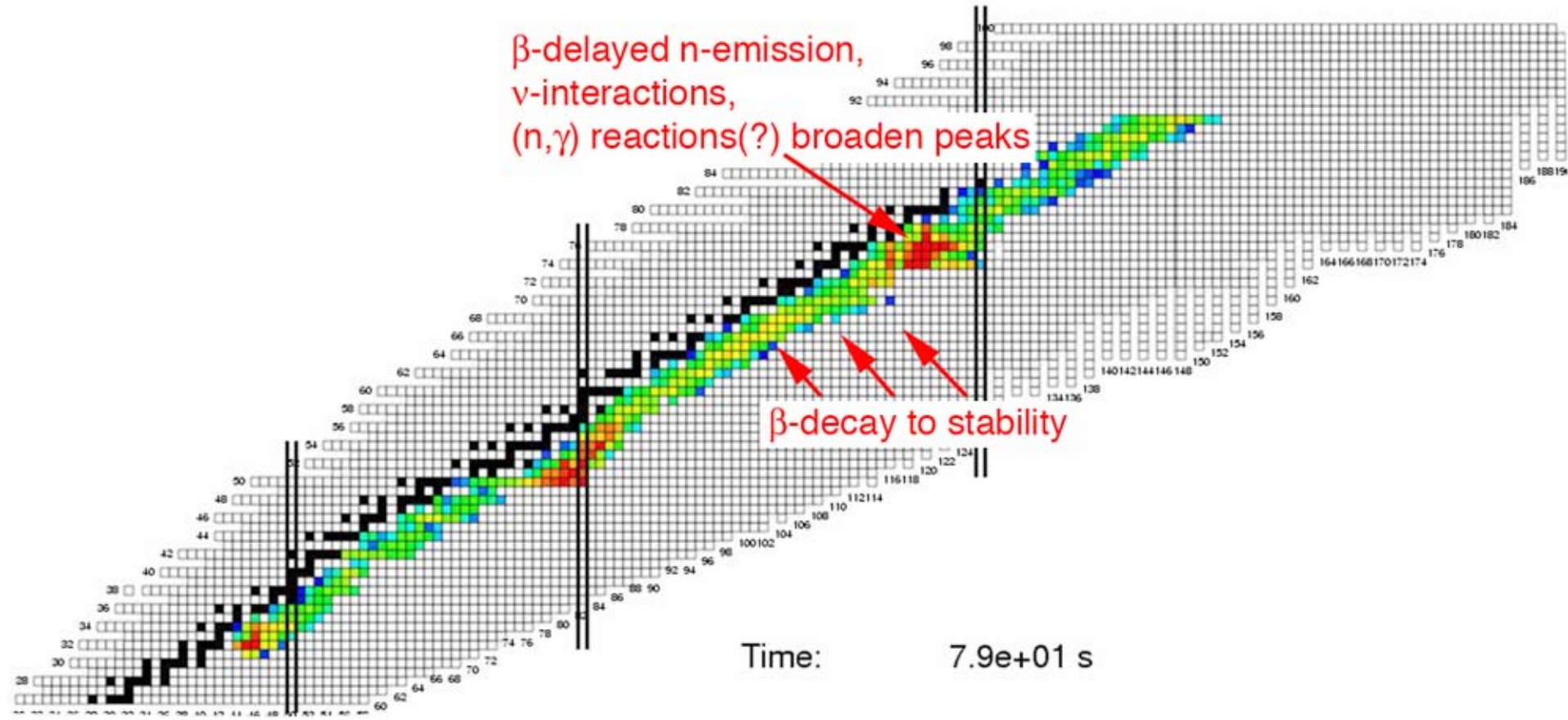
Movie : H. Schatz, T. Elliot
NSCL, Michigan State University

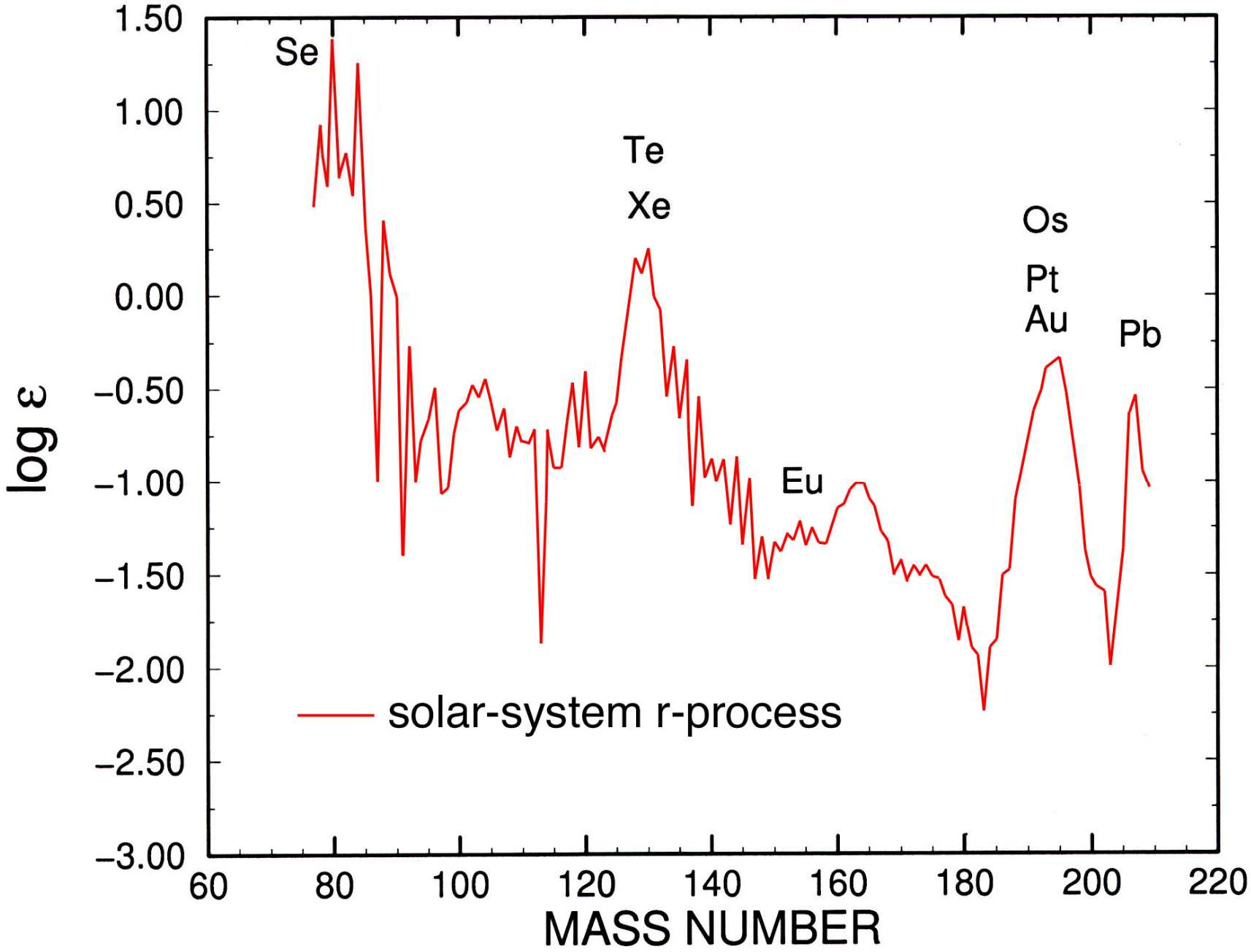
Calculation : K. Vaughan, J.L. Galache,
and A. Aprahamian, University of Notre Dame

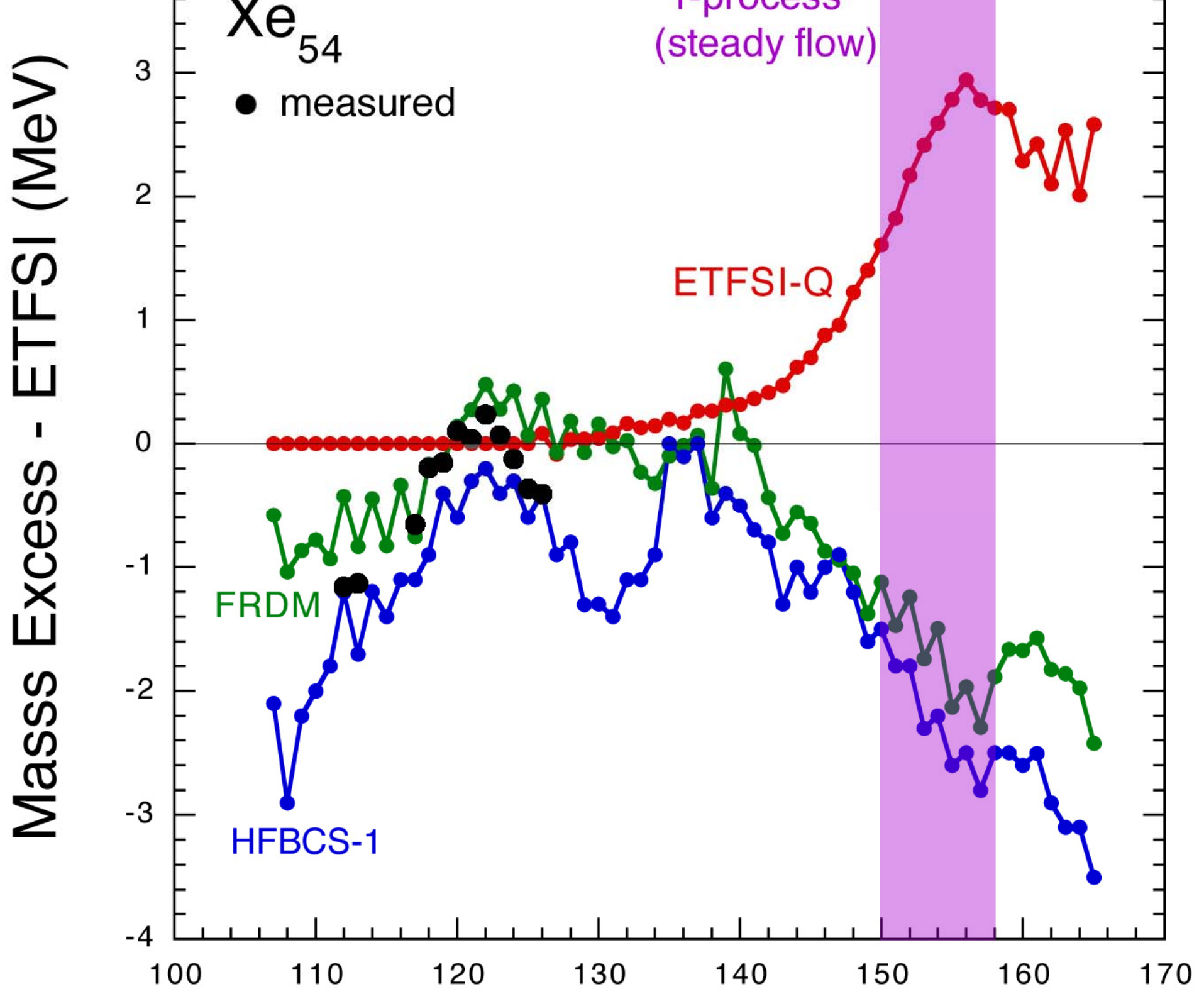
Model : B. Meyer, Clemson University
and R. Surman, North Carolina State

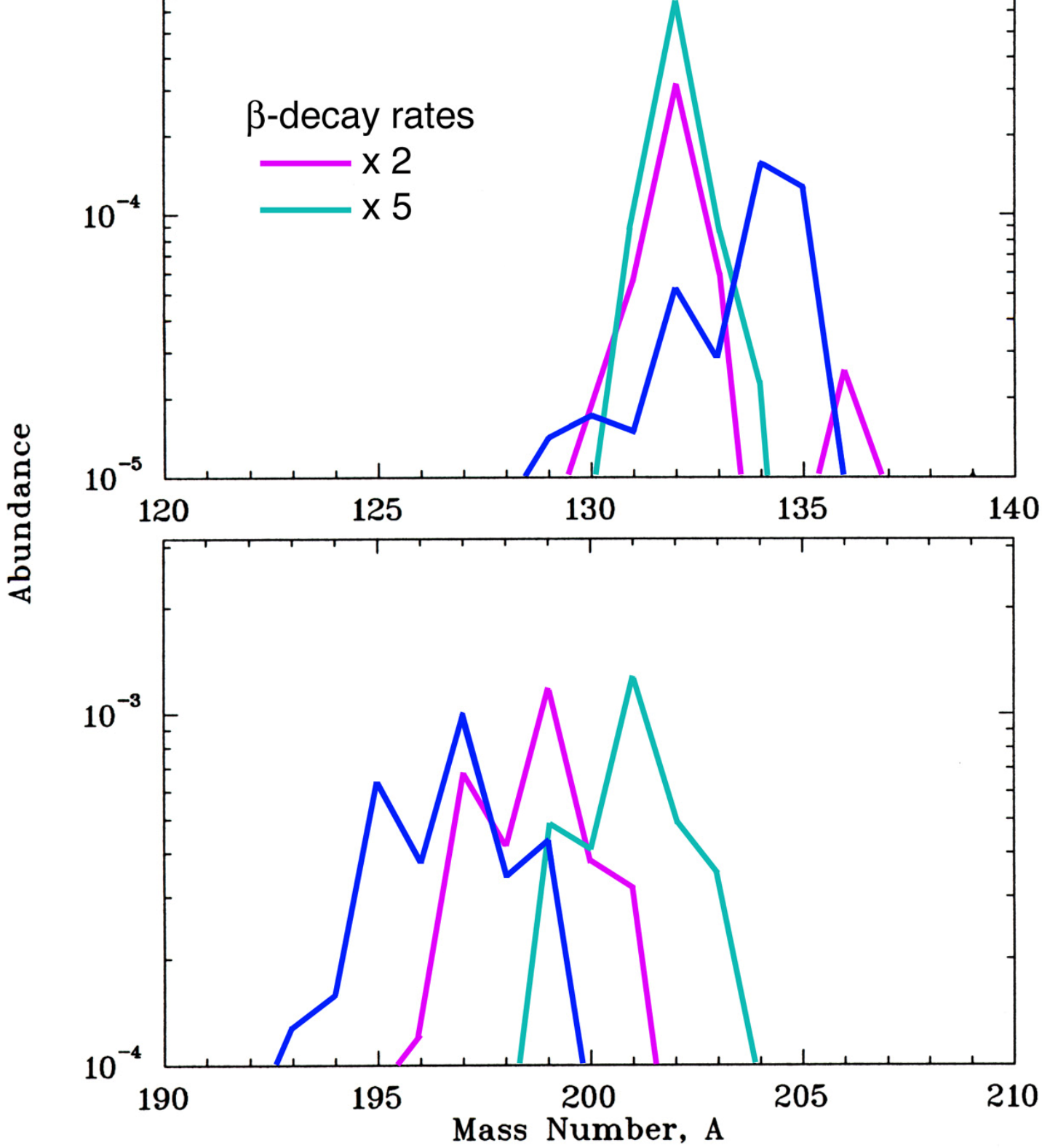


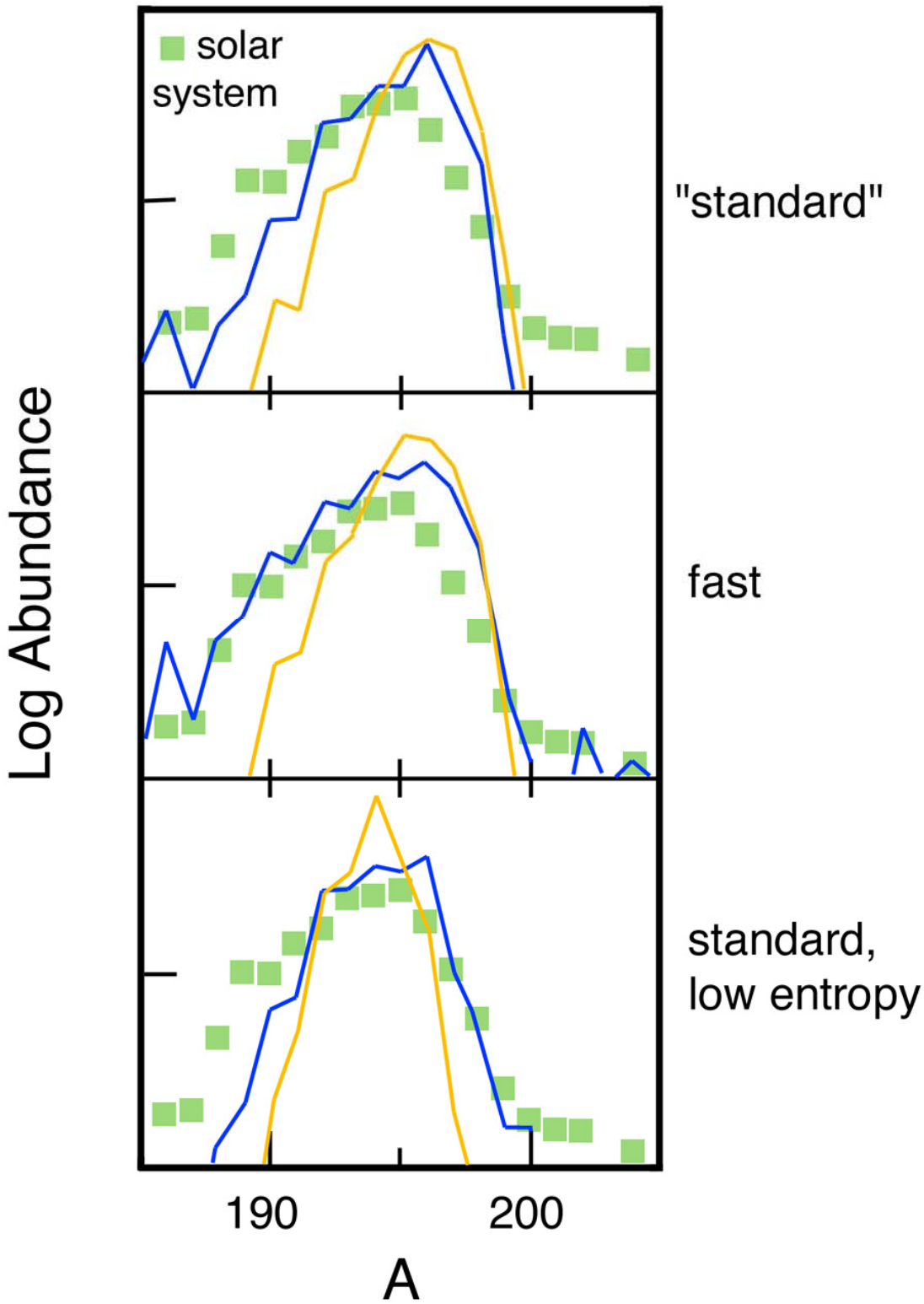

abundance peaks
narrow
n/seed↓, so β-decay
forces flow to higher
S_n
Temperature: 0.77 GK
Time: 1.7e+00 s

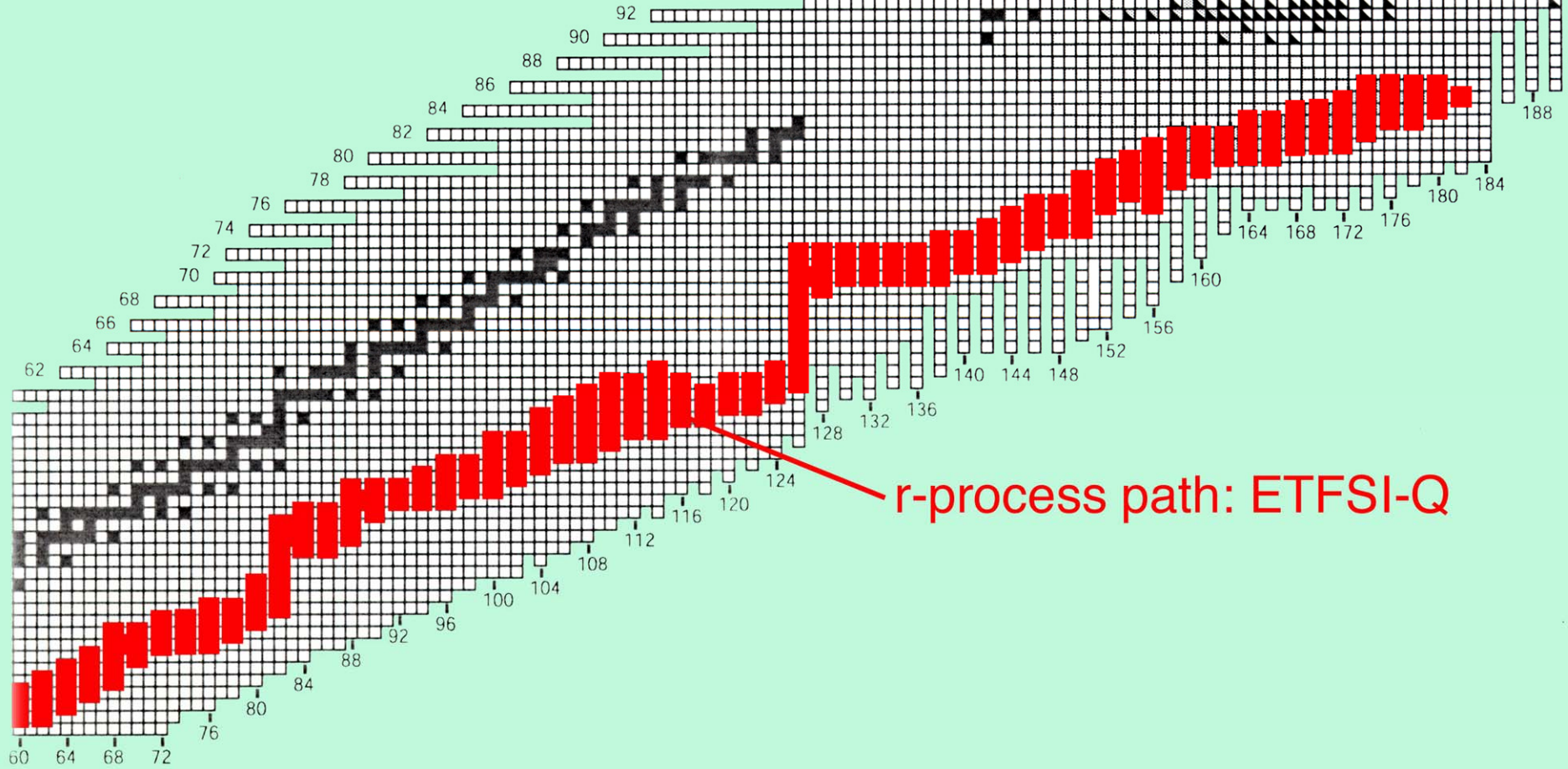

β-delayed n-emission,
ν-interactions,
(n,γ) reactions(?) broaden peaks
β-decay to stability
Time: 7.9e+01 s


1.50
1.00
0.50
0.00
−0.50
−1.00
−1.50
−2.00
−2.50
−3.00
log ε
60
80
100
120
140
160
180
200
220
MASS NUMBER
Se
Te
Xe
Eu
Os
Pt
Au
Pb
solar-system r-process


Xe54
measured
r-process
(steady flow)
ETFSI-Q
FRDM
HFBCS-1
Mass Excess - ETFSI (MeV)
3
2
1
0
-1
-2
-3
-4
100
110
120
130
140
150
160
170


β-decay rates
x 2
x 5
Abundance
10^{-4}
10^{-5}
120
125
130
135
140
10^{-3}
10^{-4}
190
195
200
205
210
Mass Number, A


solar system
"standard"
fast
standard, low entropy
Log Abundance
190
200
A



Need: masses
half-lives
weak rates
some (n,γ) rates
shell structure…

(all of which involve more fundamental issues in

Stars evolve because of changes in their chemical composition

i.e.

Stars evolve because of nuclear processes

Stars evolve because of changes in their chemical composition

i.e.

Stars evolve because of nuclear processes

These processes are governed by nuclear properties (and some stellar stuff too...)

Nuclear structure is an integral part of nuclear astrophysics