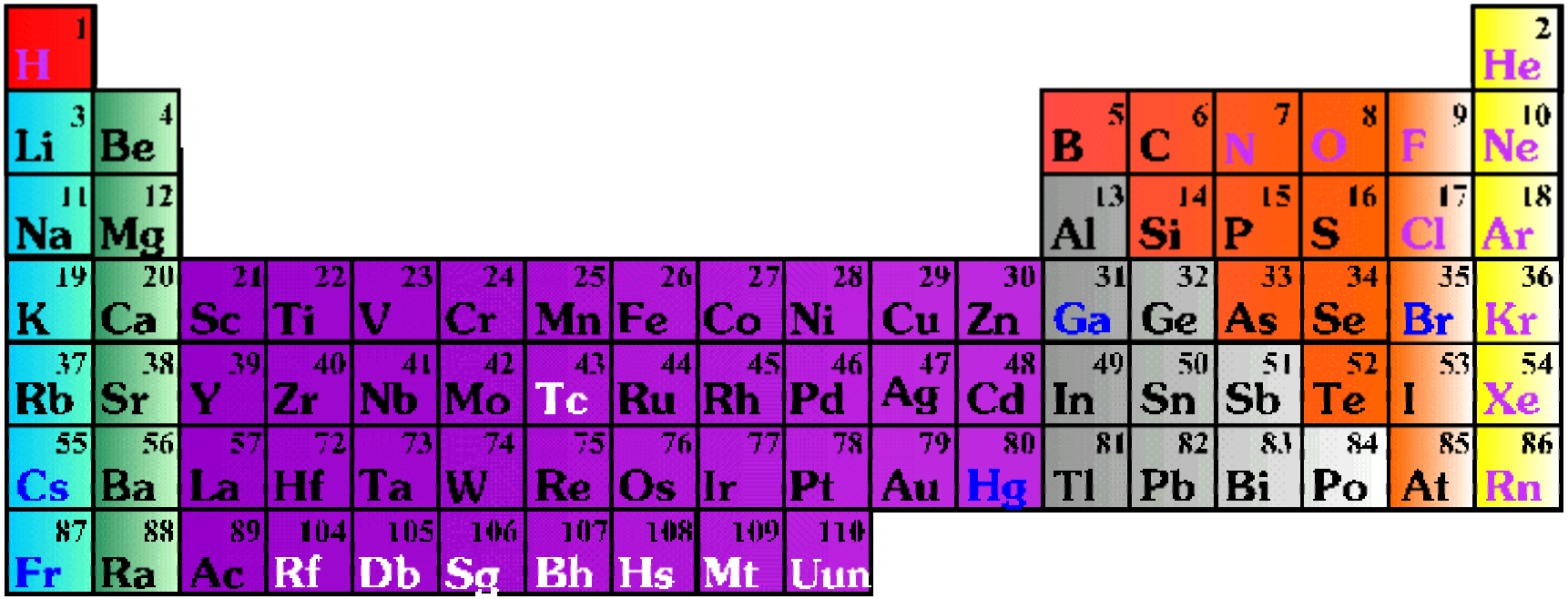
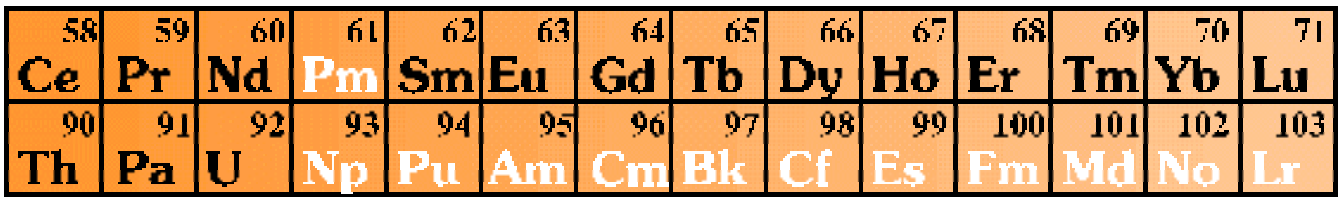
How to make gold

by Hendrik Schatz

(stable) Elements in nature

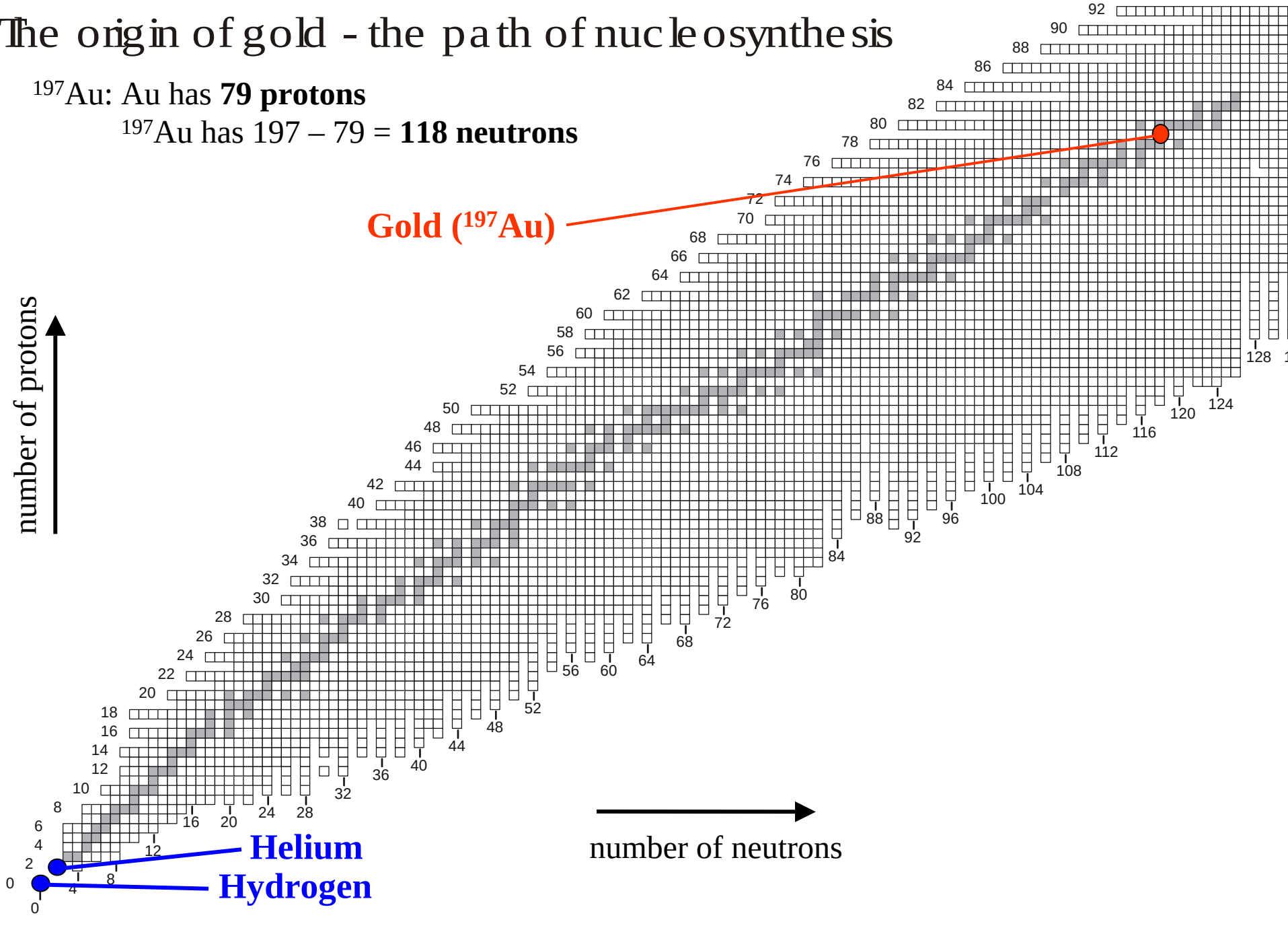


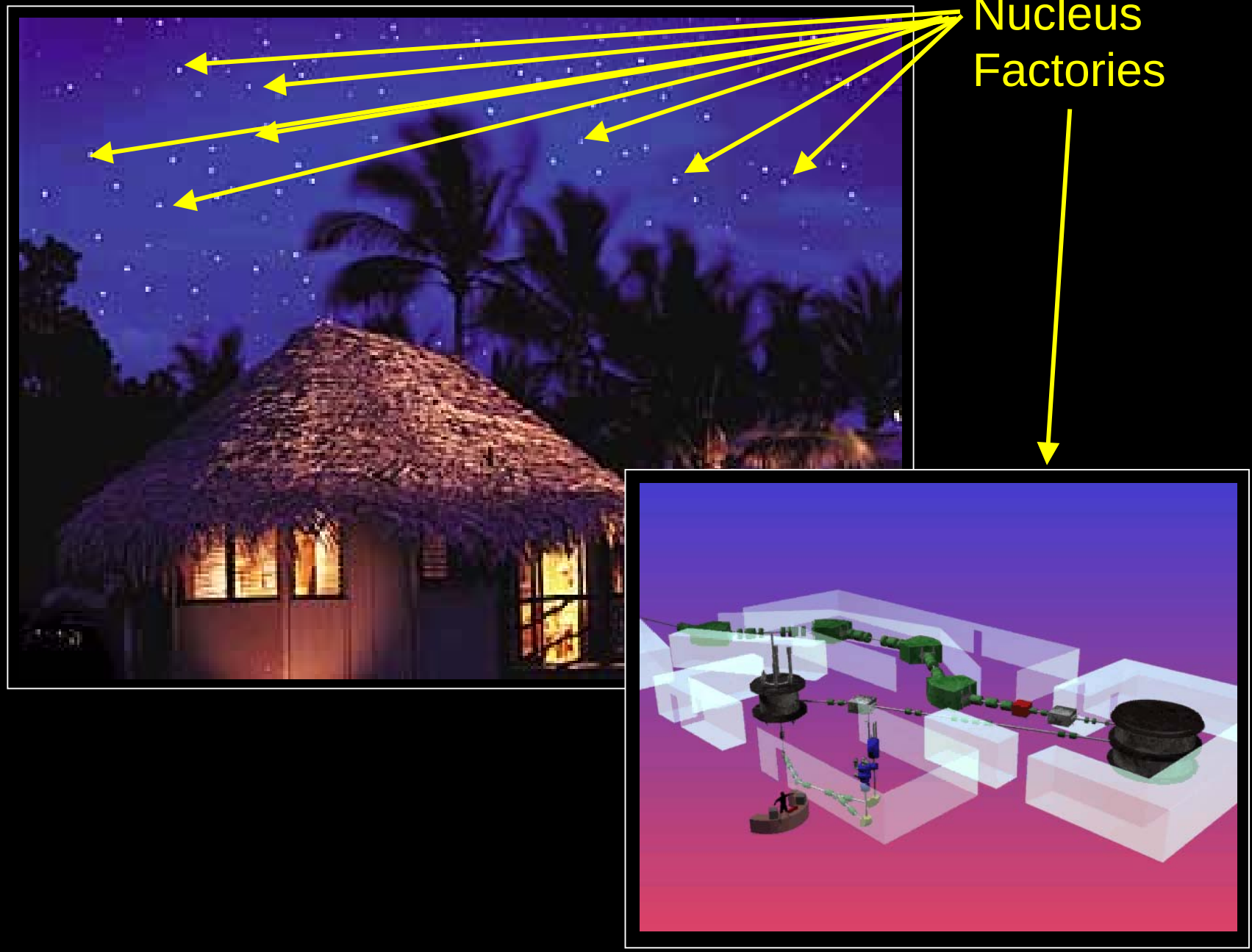


The origin of gold - the path of nucleosynthesis

^{197}Au: Au has **79 protons**

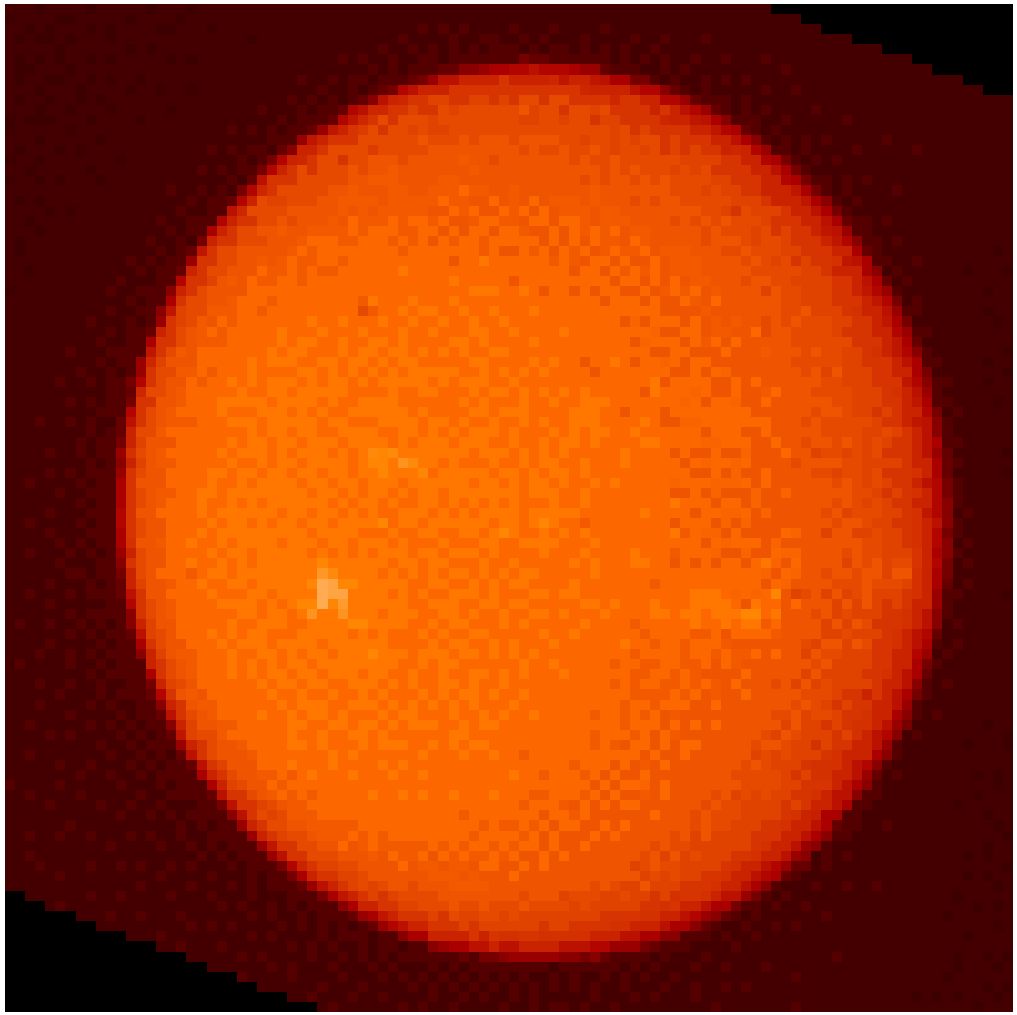
^{197}Au has 197 – 79 = **118 neutrons**




Nucleus
Factories

Creation of new elements is energy source of stars (and the sun)

The sun shines 3.85e33 erg/s = 3.85e26 Watts for at least ~4.5 bio years



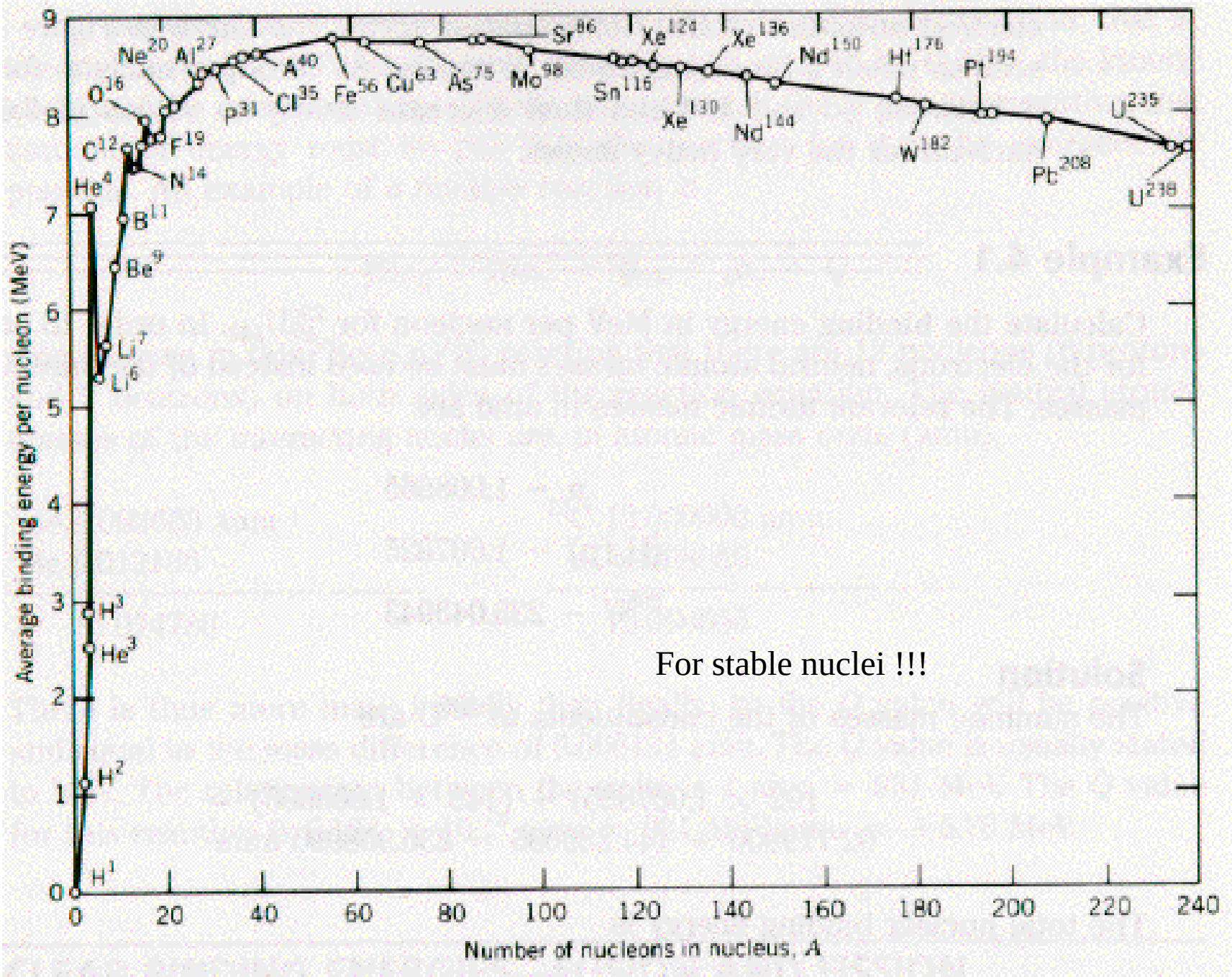
The entire sun made of coal would last ~ 4000 years

On the way to making gold: Burning stages of a 25 solar mass star

initially present: mostly hydrogen (~70% - from big bang)

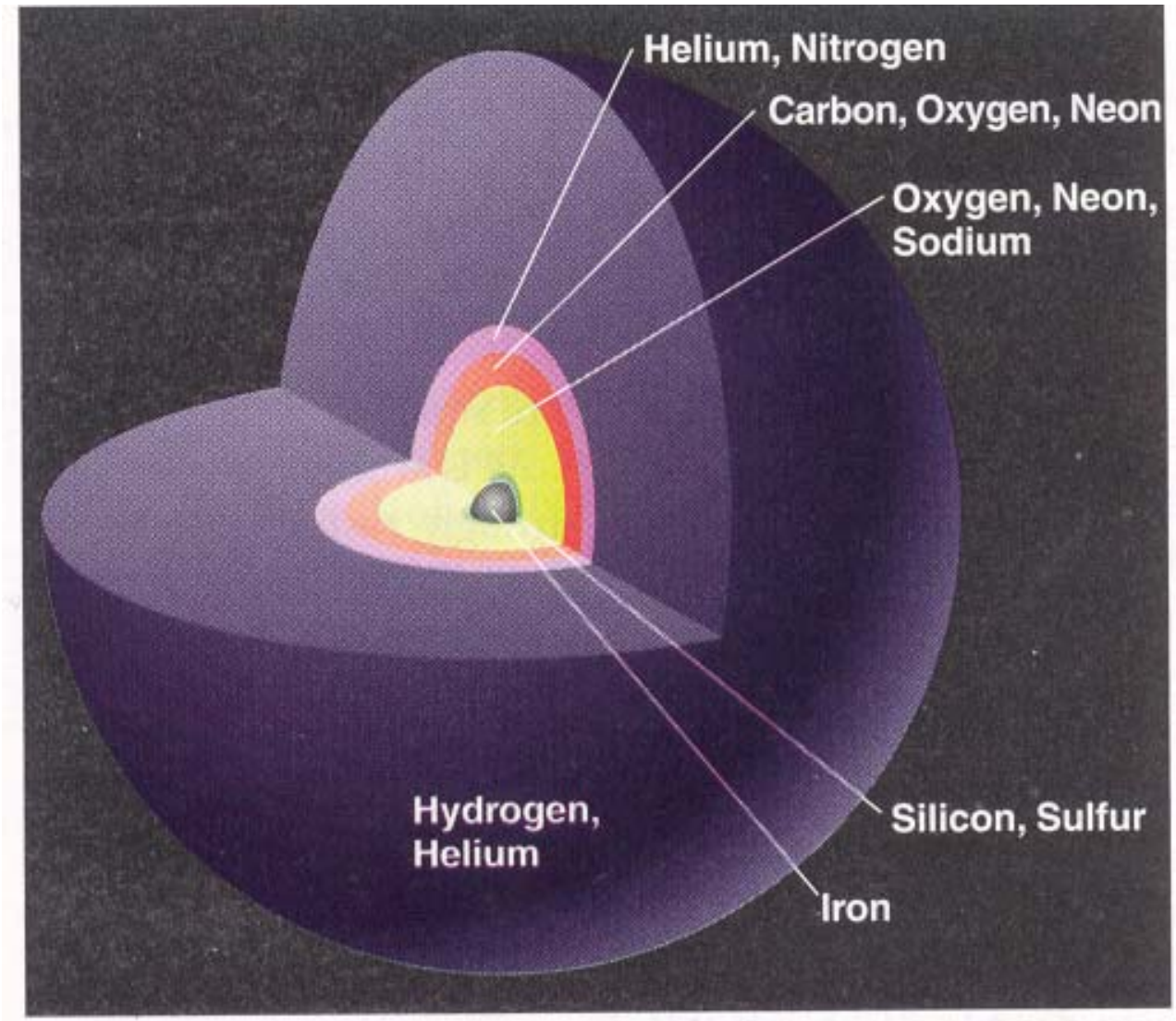
Hydrogen burning	7Mio yrs	Hydrogen (1p,0n)	Helium (2p, 2n)
Helium burning	700,000 yrs	Helium (2p,2n)	Carbon (6p, 6n), Oxygen (8p,8n)
Carbon(+Ne) burning	400 yrs	Carbon (6p,6n)	Oxygen (8p,8n)
Oxygen burning	8 months	Oxygen (8p,8n)	Silicon (14p,14n)
Silicon burning	1 day	Silicon (14p,14n)	Iron (26p,30n)

DEMO: Energy generation by nuclear reactions



For stable nuclei !!!

Precollapse structure of massive star

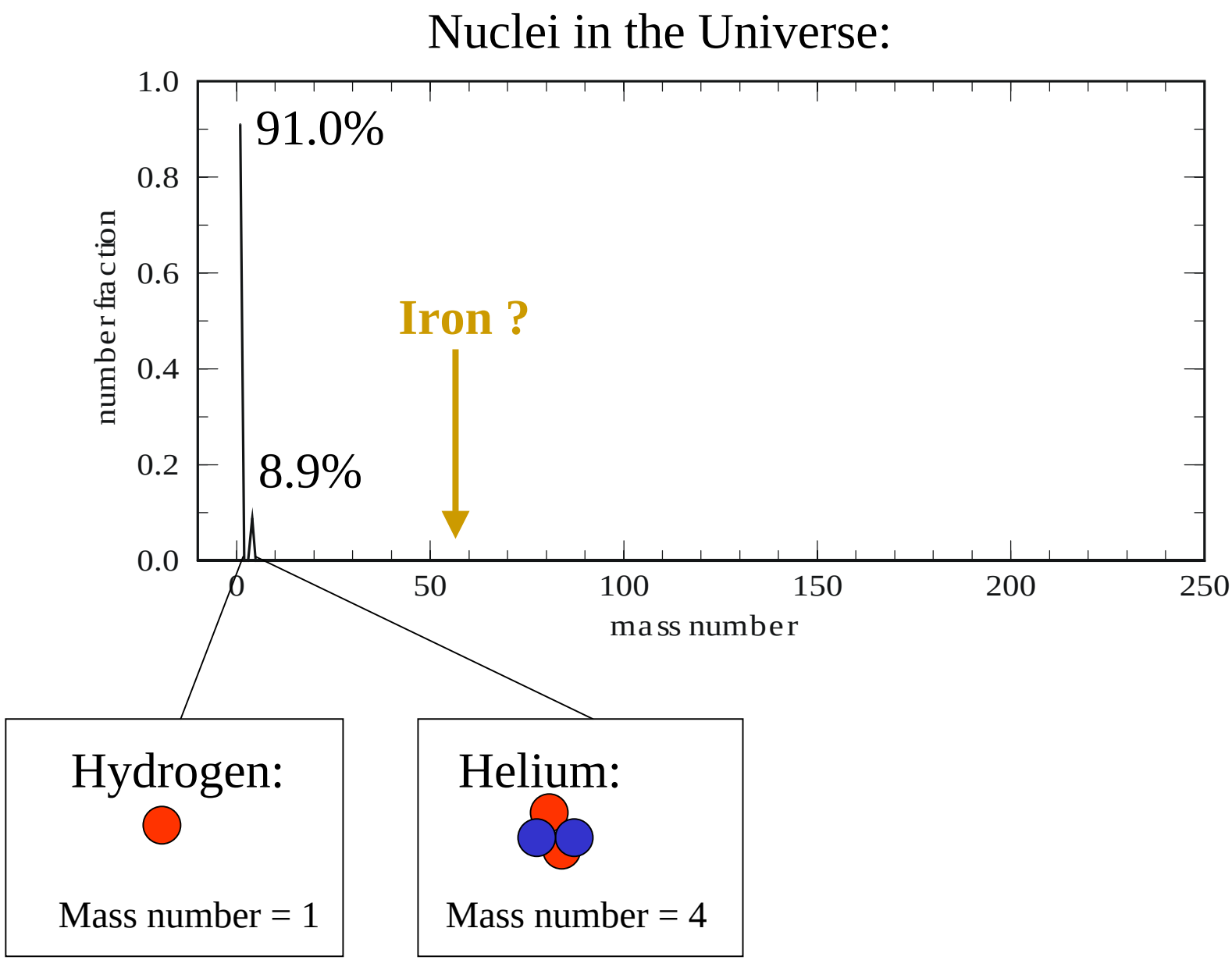


Iron core collapses and triggers supernova explosion

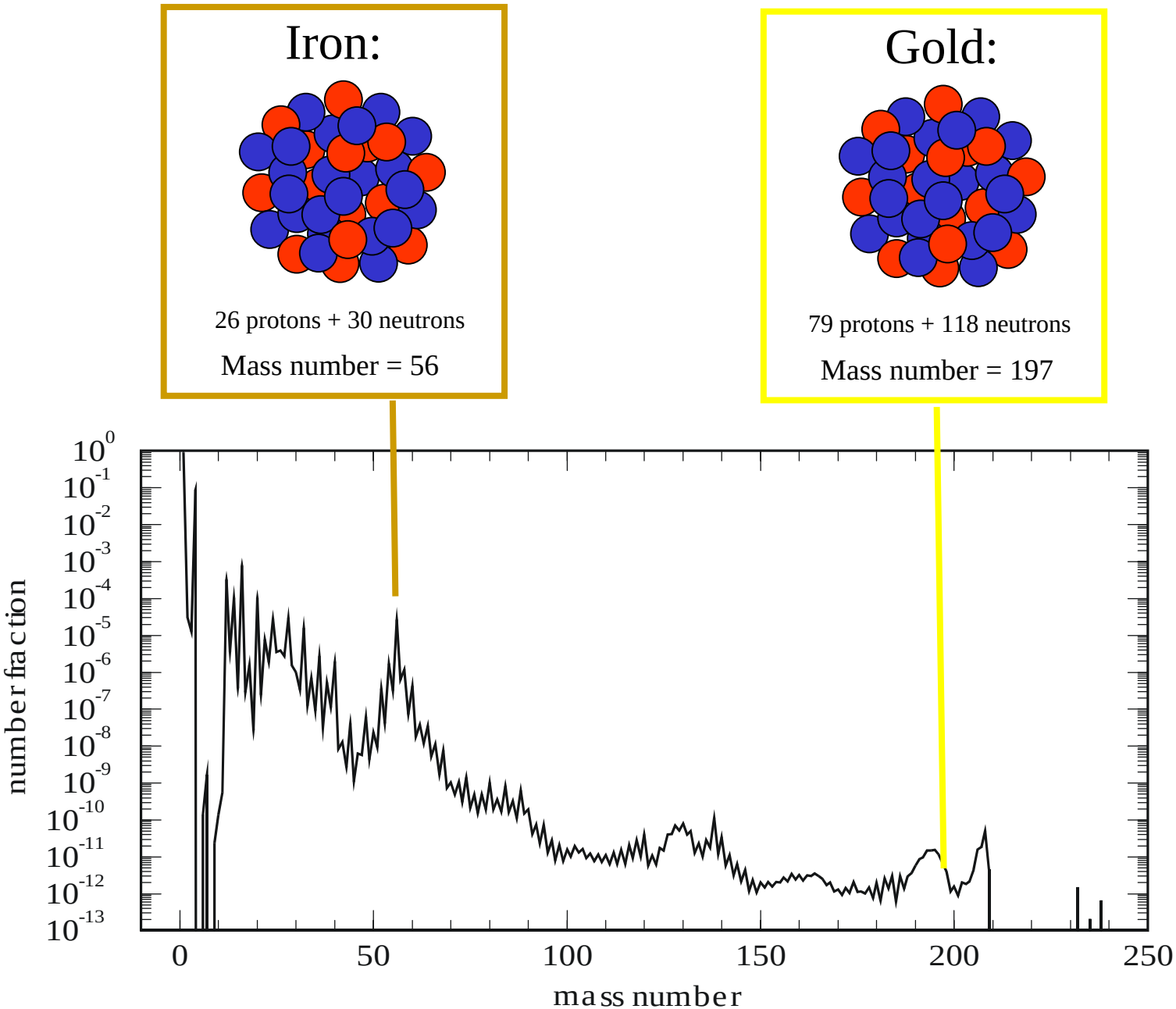
The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

ESO PR Photo 40f/99 (17 November 1999)

Is the universe made of iron ?

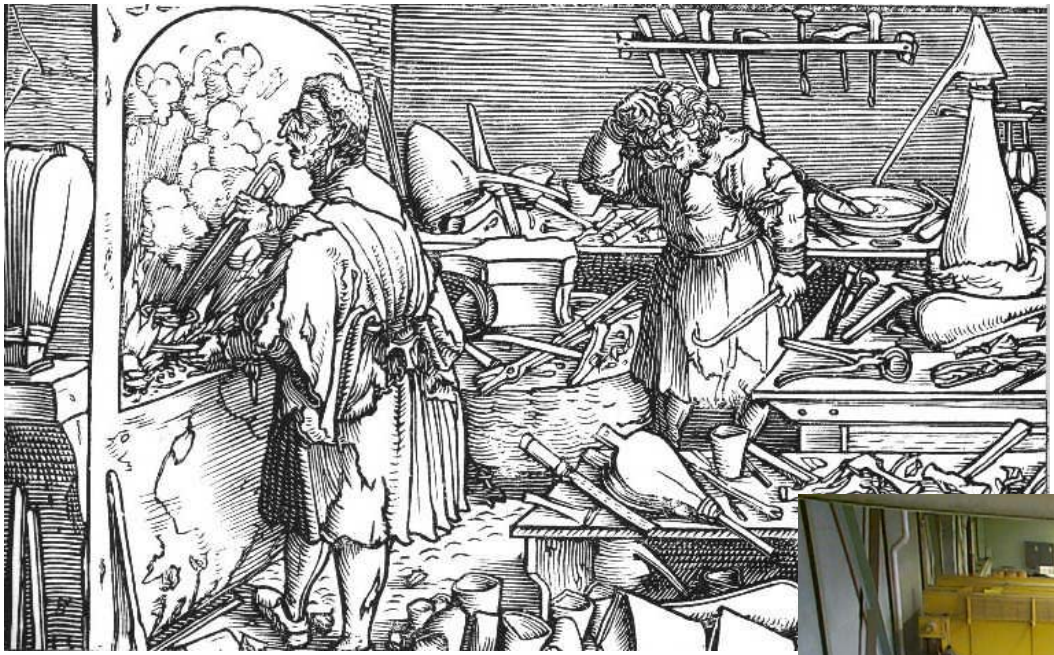


… not yet

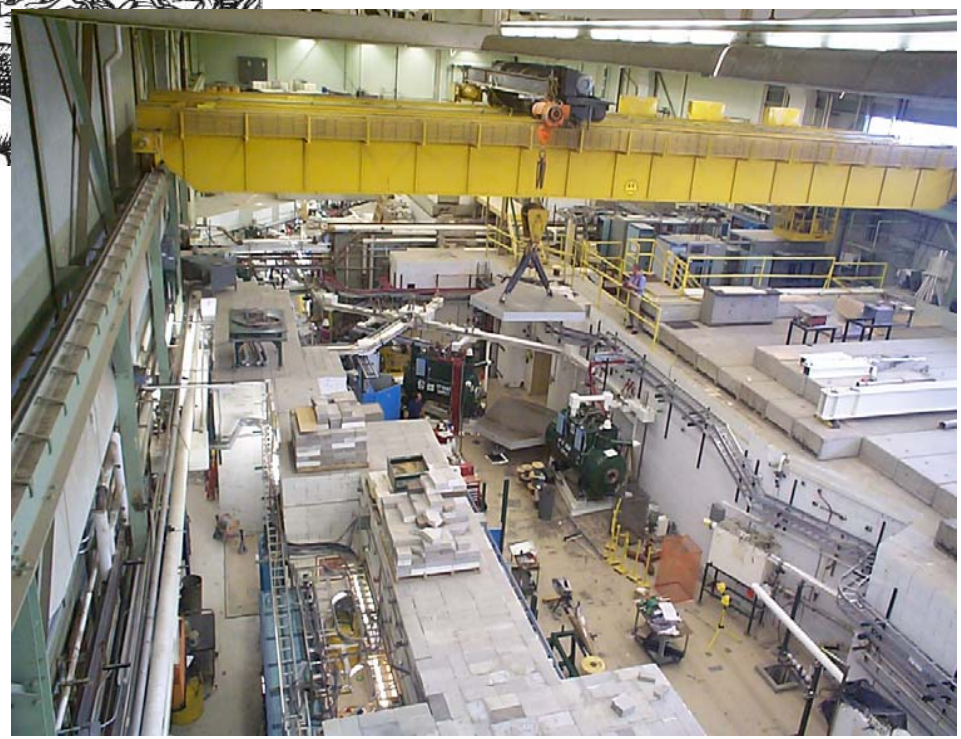

Iron:
26 protons + 30 neutrons
Mass number = 56
Gold:
79 protons + 118 neutrons
Mass number = 197
number fraction
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
0
50
100
150
200
250
mass number

So how is gold made ?

Some earlier failed attempts (1590)



NSCL



… by a nuclear reaction

for example:

$^{198}Hg + {}^{9}Be \rightarrow {}^{197}Au + p + \ldots.$

Makes gold from mercury

Iron from a previous generation of stars is exposed to a flux of neutrons

How does this create heavy elements ?

→ Neutron Capture Processes

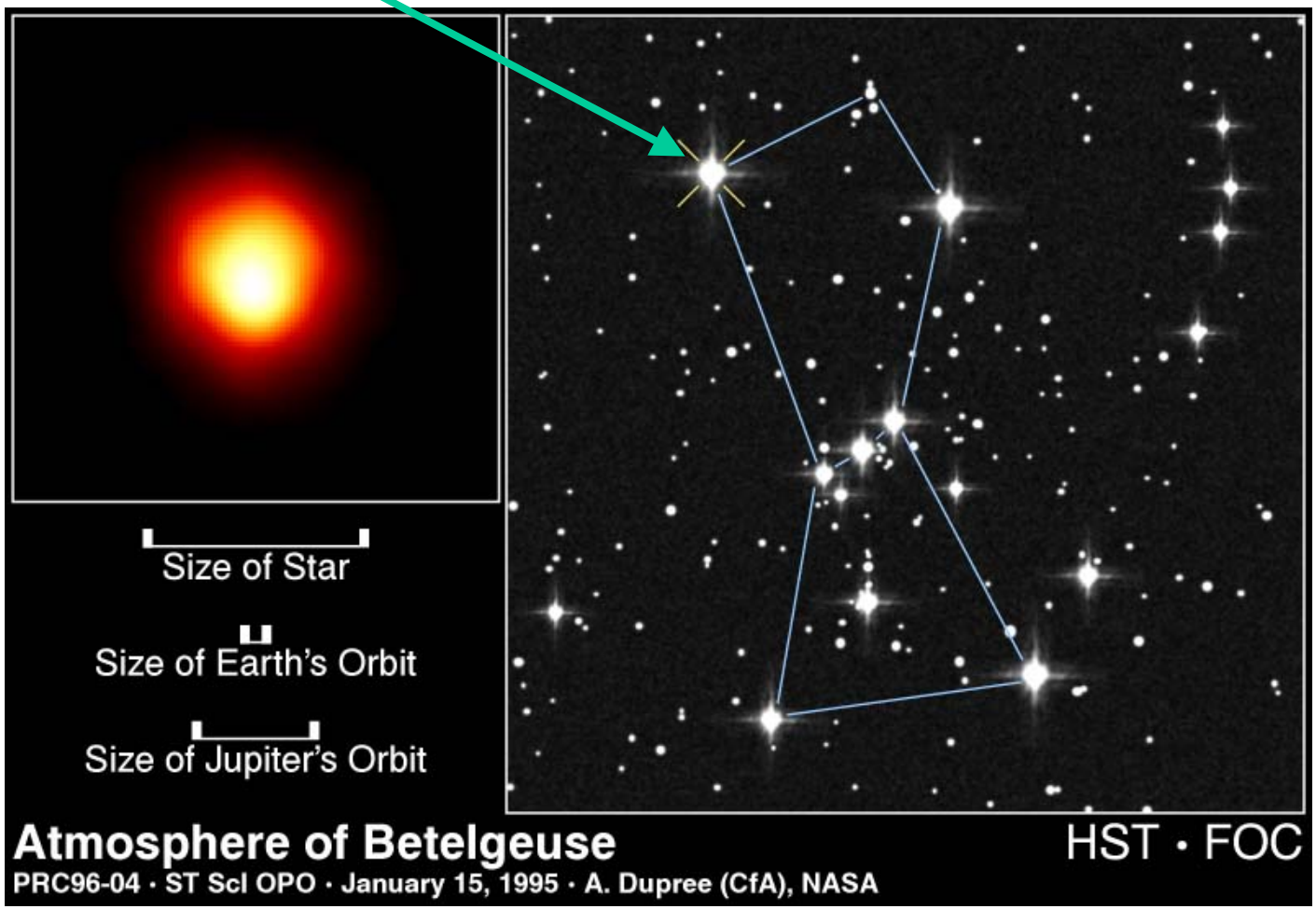
There are 2:

- s-process (slow neutron capture)
- r-process (rapid neutron capture)

Do neutron capture process exercise

Where does the s-process happen ?

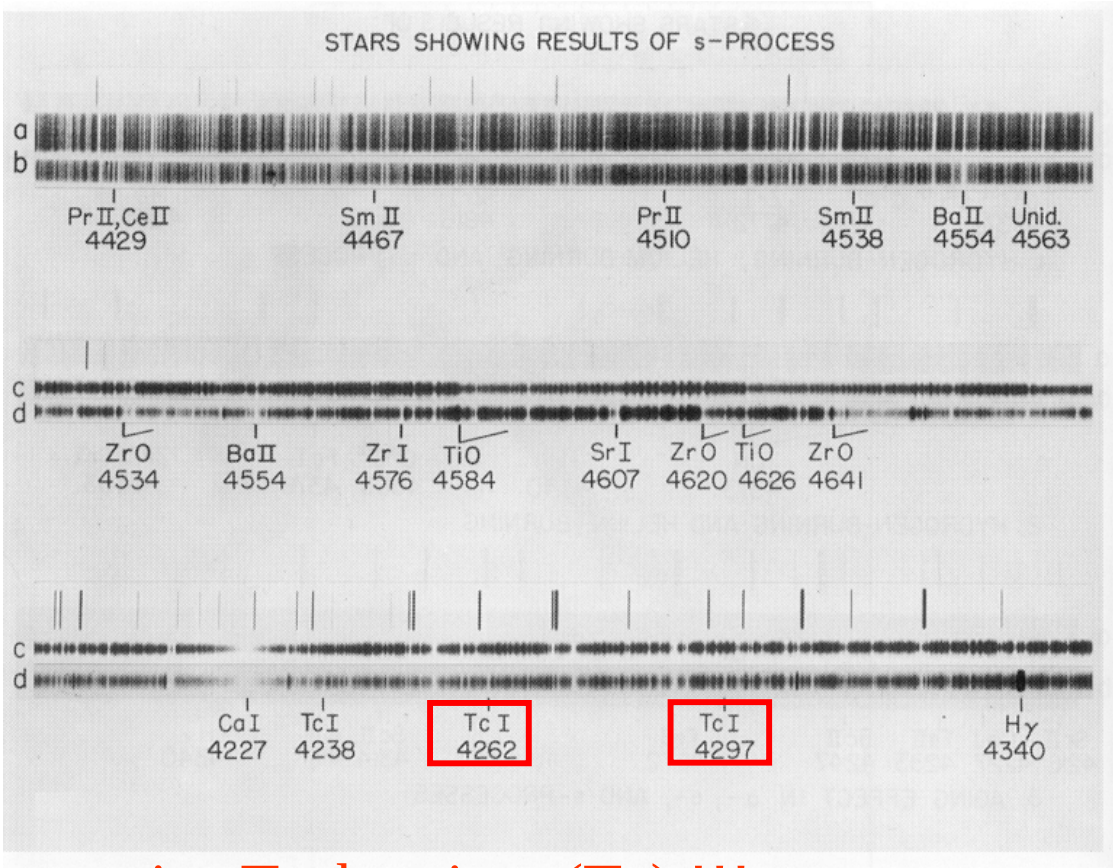
there !



in red giants – and it takes several million years !
(or, more correctly, low mass TP-AGB stars)

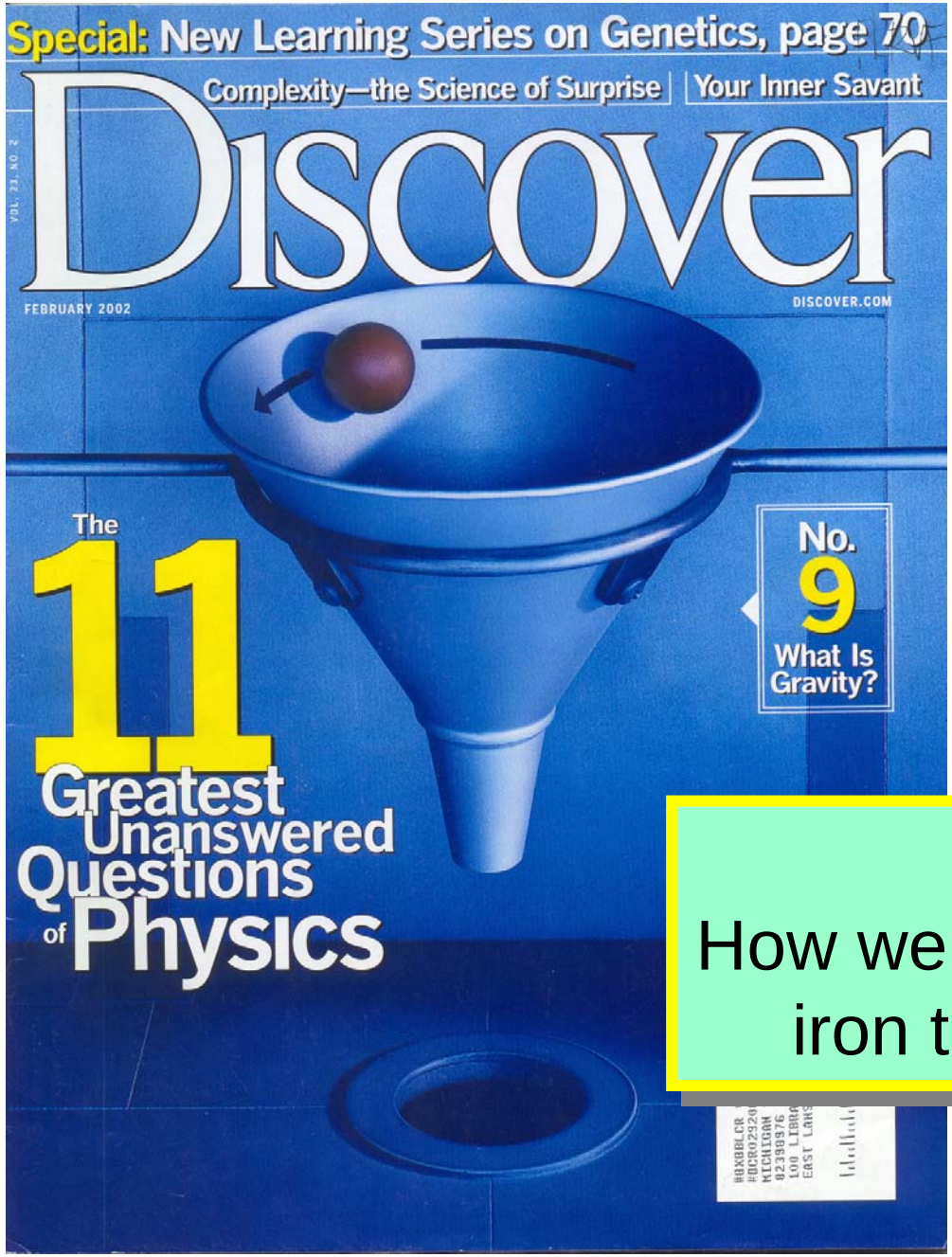
How can we tell ?

Analyze light from a red giant:



Star contains Technetium (Tc) !!!

(heavy element Z=43, $T_{1/2}$ 4 Mio years, Merrill 1952)



What about the r-process (and gold) ???

Question 3

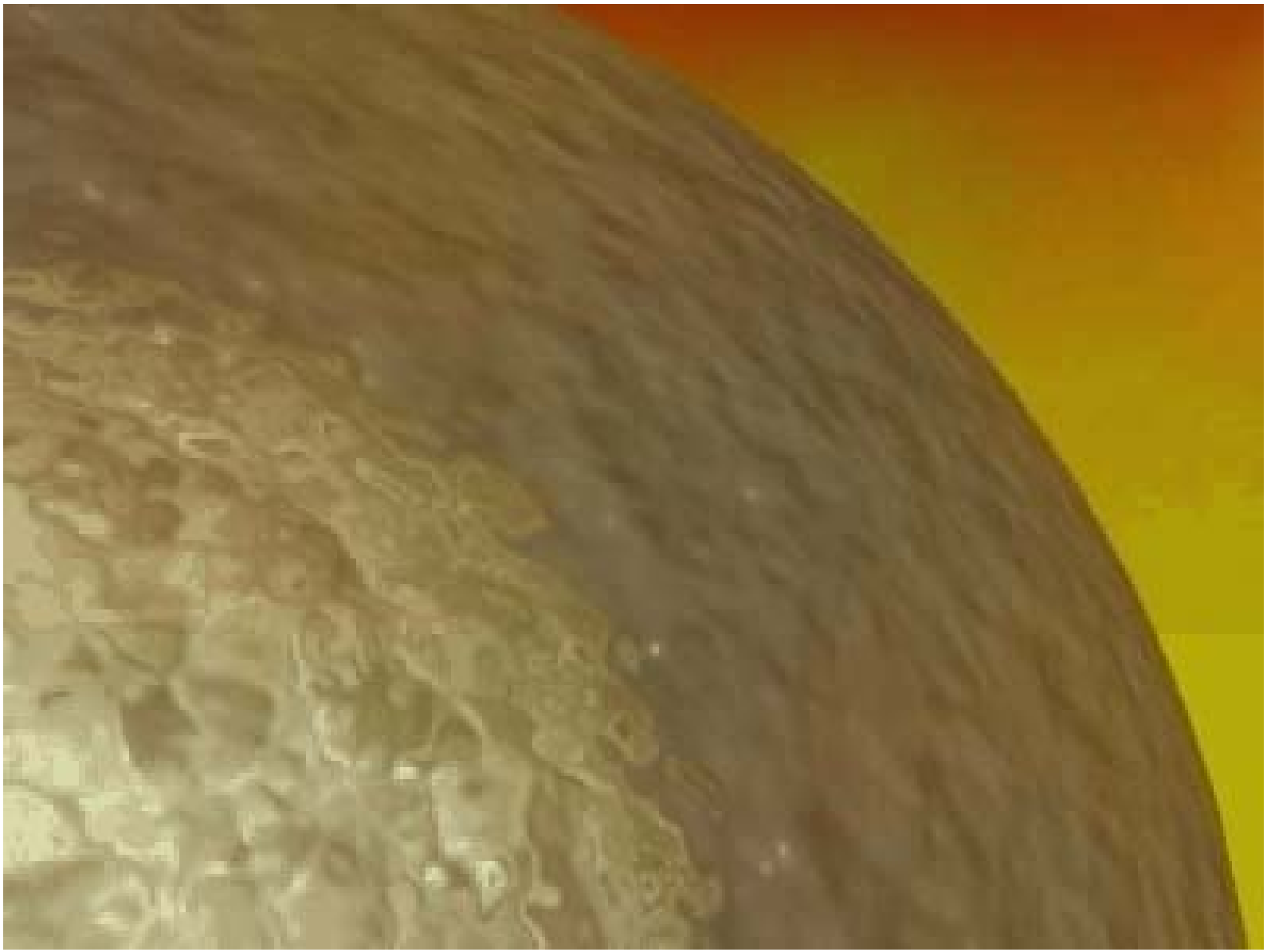
How were the elements from iron to uranium made ?

Neutron
star forms
(size ~ 10 km radius)

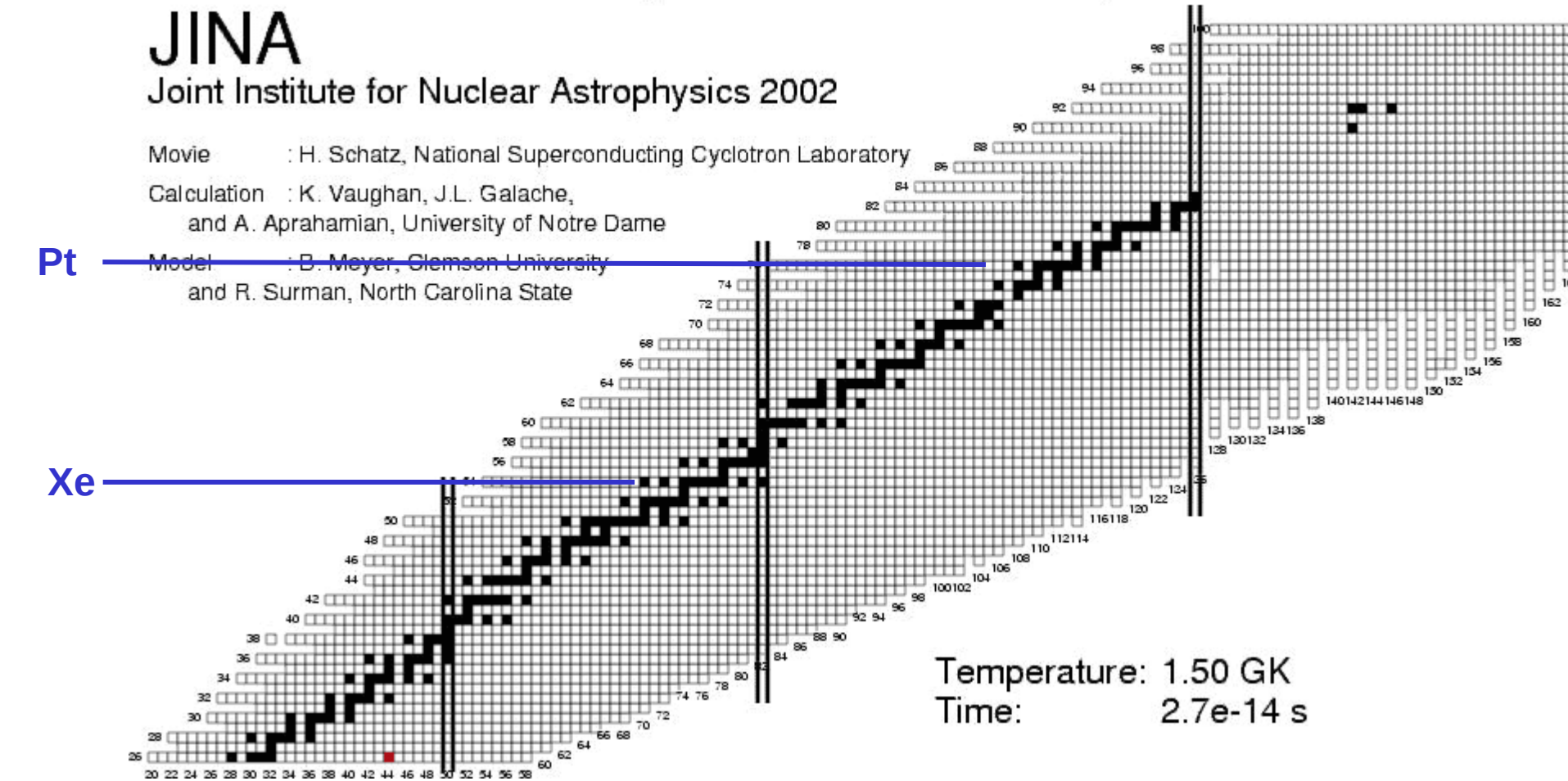
Matter evaporated off the hot neutron star

r-process site ?

How does the r-process work ? Neutron capture !



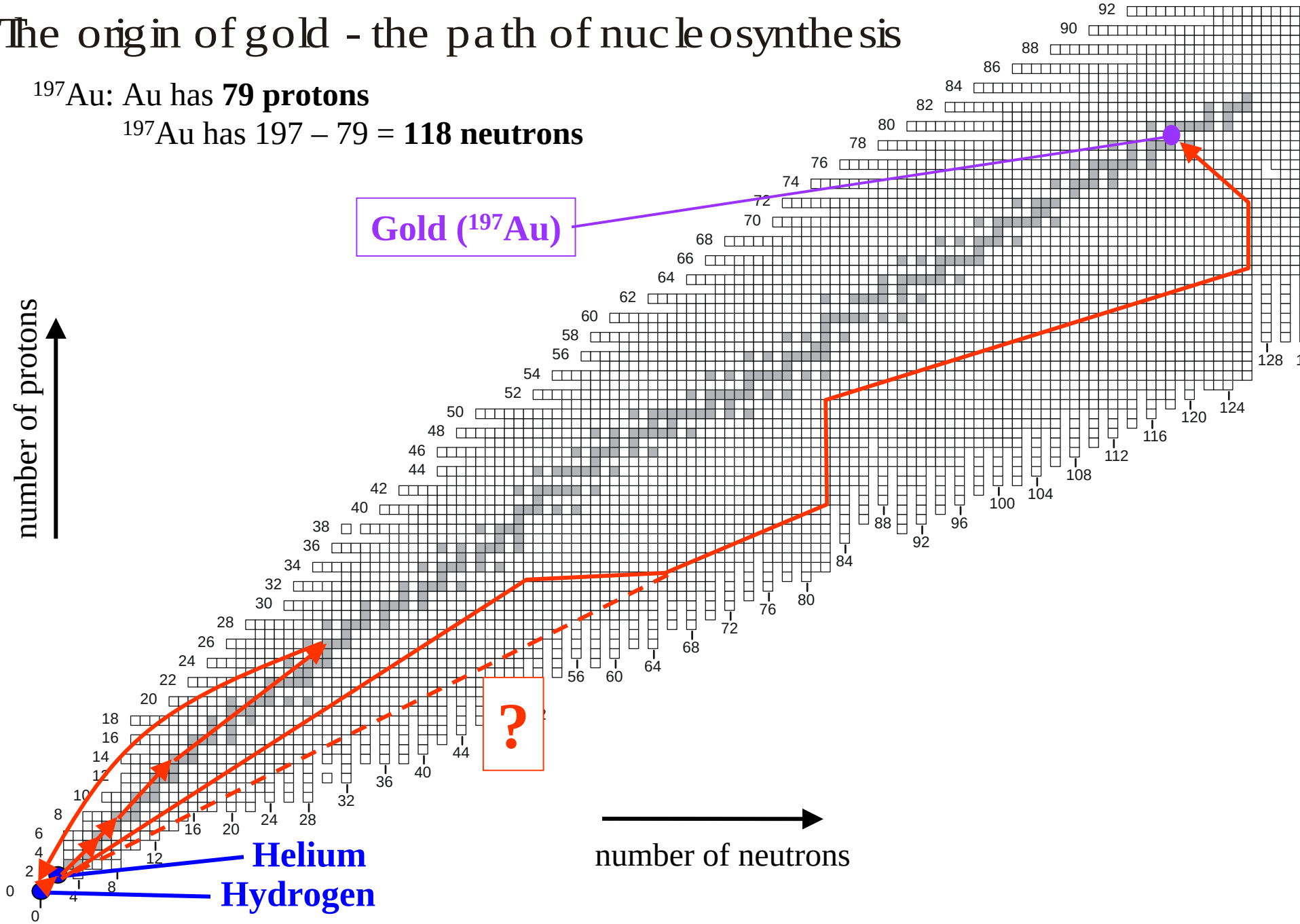
Nucleosynthesis in the r-process



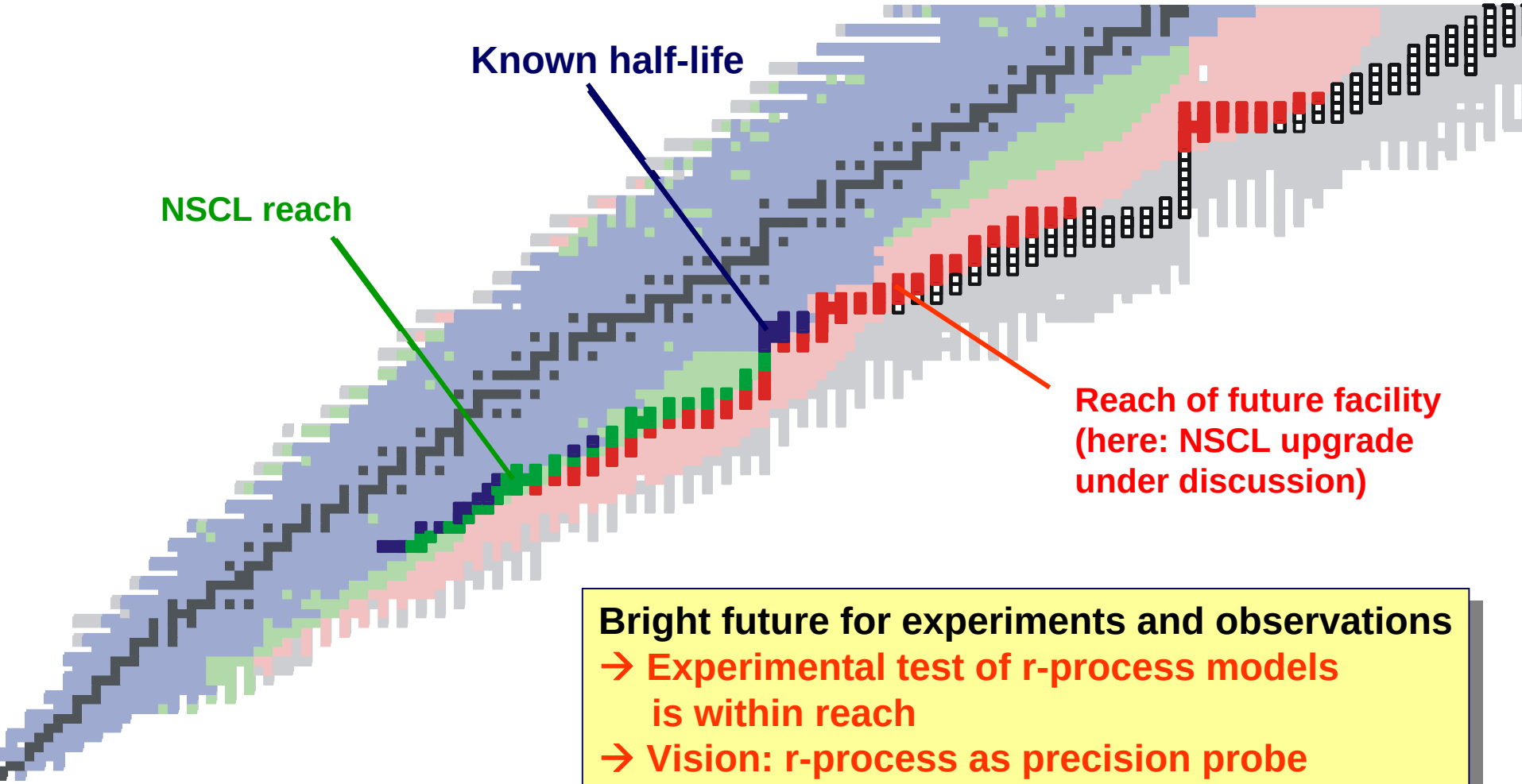
The origin of gold - the path of nucleosynthesis

^{197}Au: Au has **79 protons**

^{197}Au has 197 – 79 = **118 neutrons**



NSCL and future facilities reach



Bright future for experiments and observations

→ Experimental test of r-process models is within reach

→ Vision: r-process as precision probe