

How to make gold

by Hendrik Schatz



(stable) Elements in nature

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

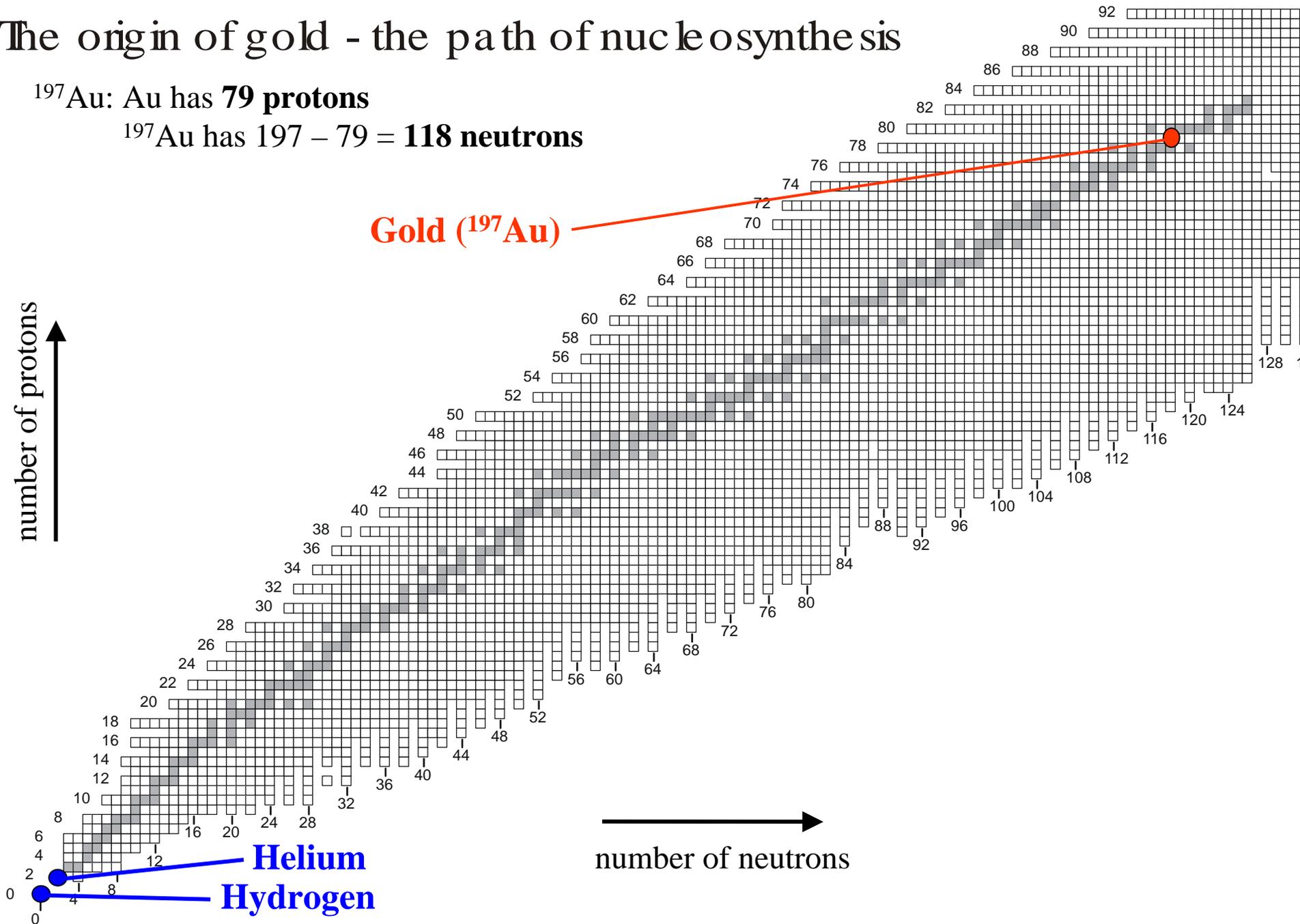
The origin of gold - the path of nucleosynthesis

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

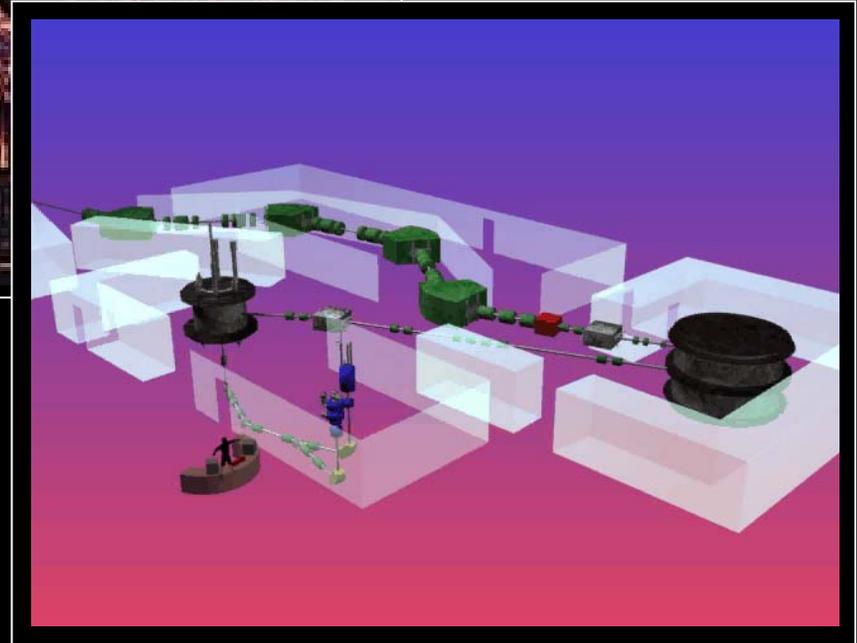
^{197}Au has $197 - 79 = \mathbf{118}$ neutrons

Gold (^{197}Au)

number of protons



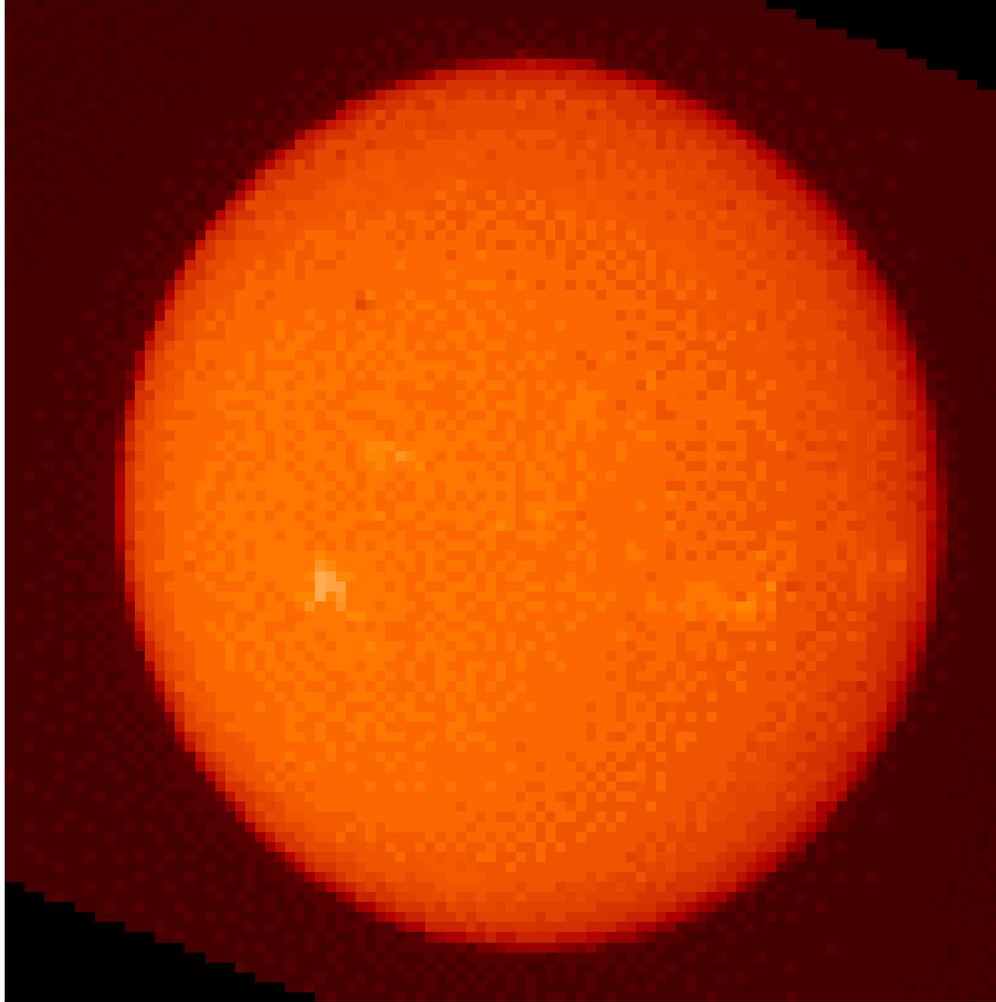
Nucleus
Factories





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

The sun shines 3.85×10^{33} erg/s = 3.85×10^{26} Watts for at least ~4.5 bio years



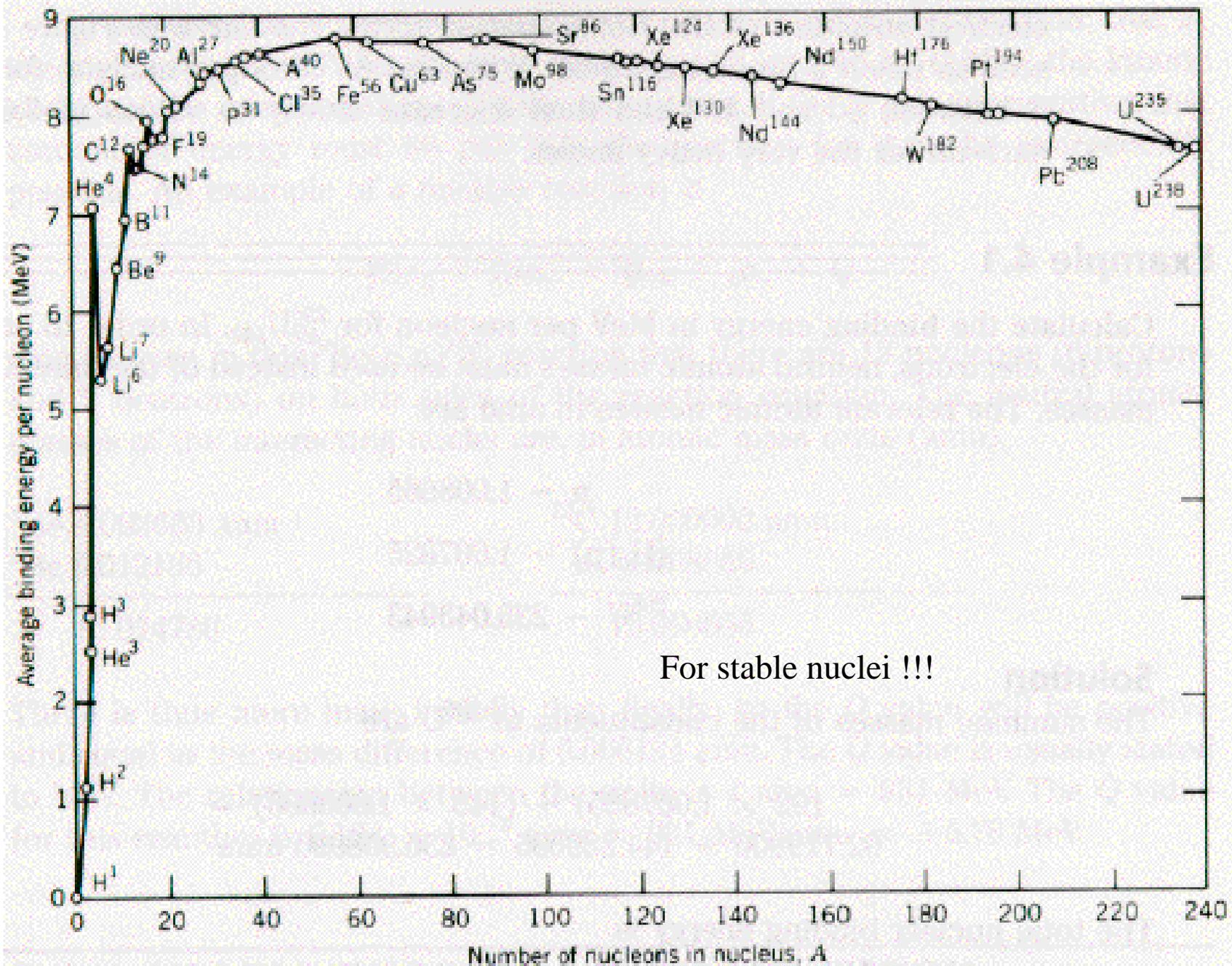
The entire sun made of coal would last ~ 4000 years

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

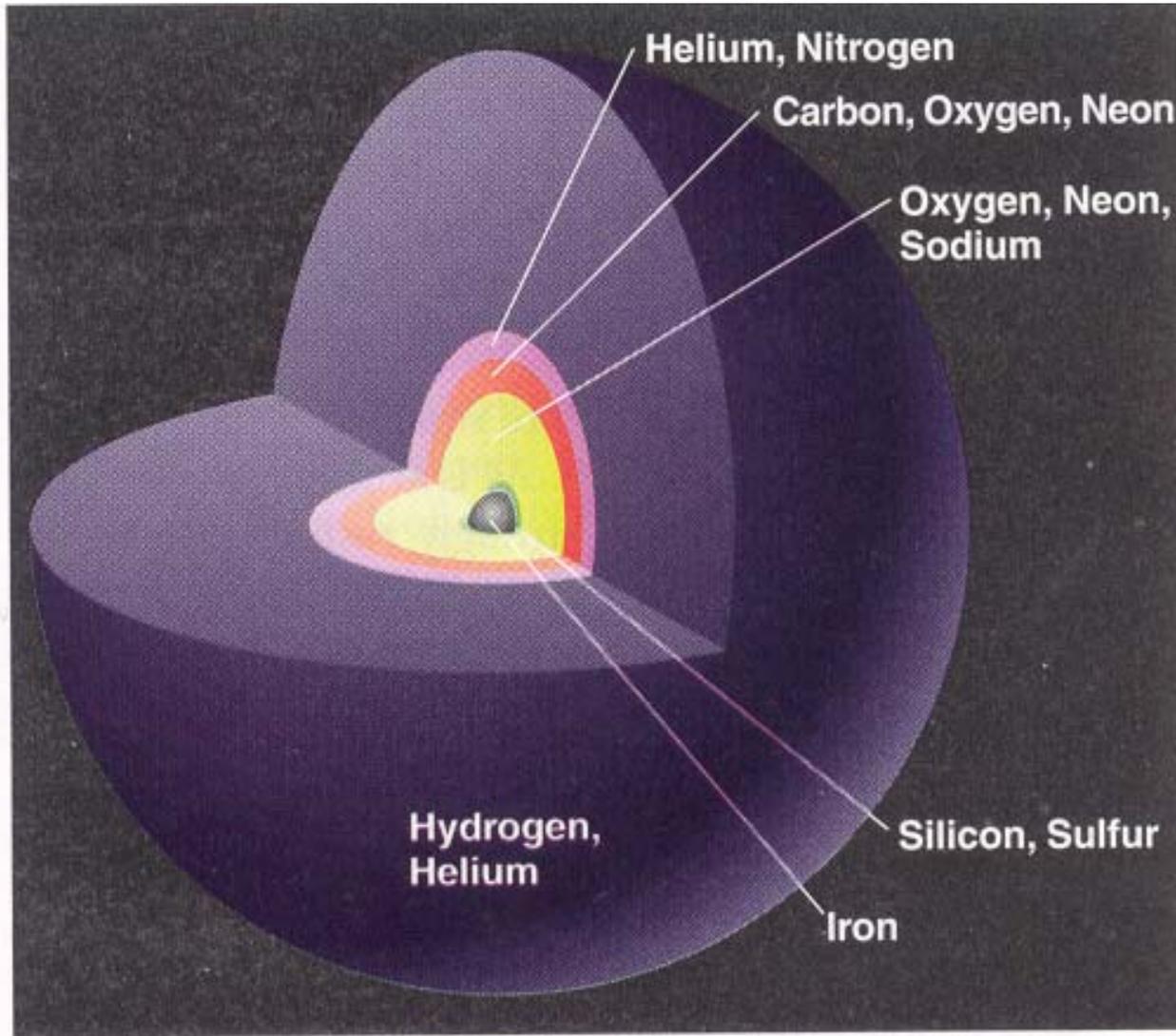
initially present: mostly hydrogen (~70% - from big bang)

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



Precollapse structure of massive star



Iron core collapses and triggers supernova explosion



The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

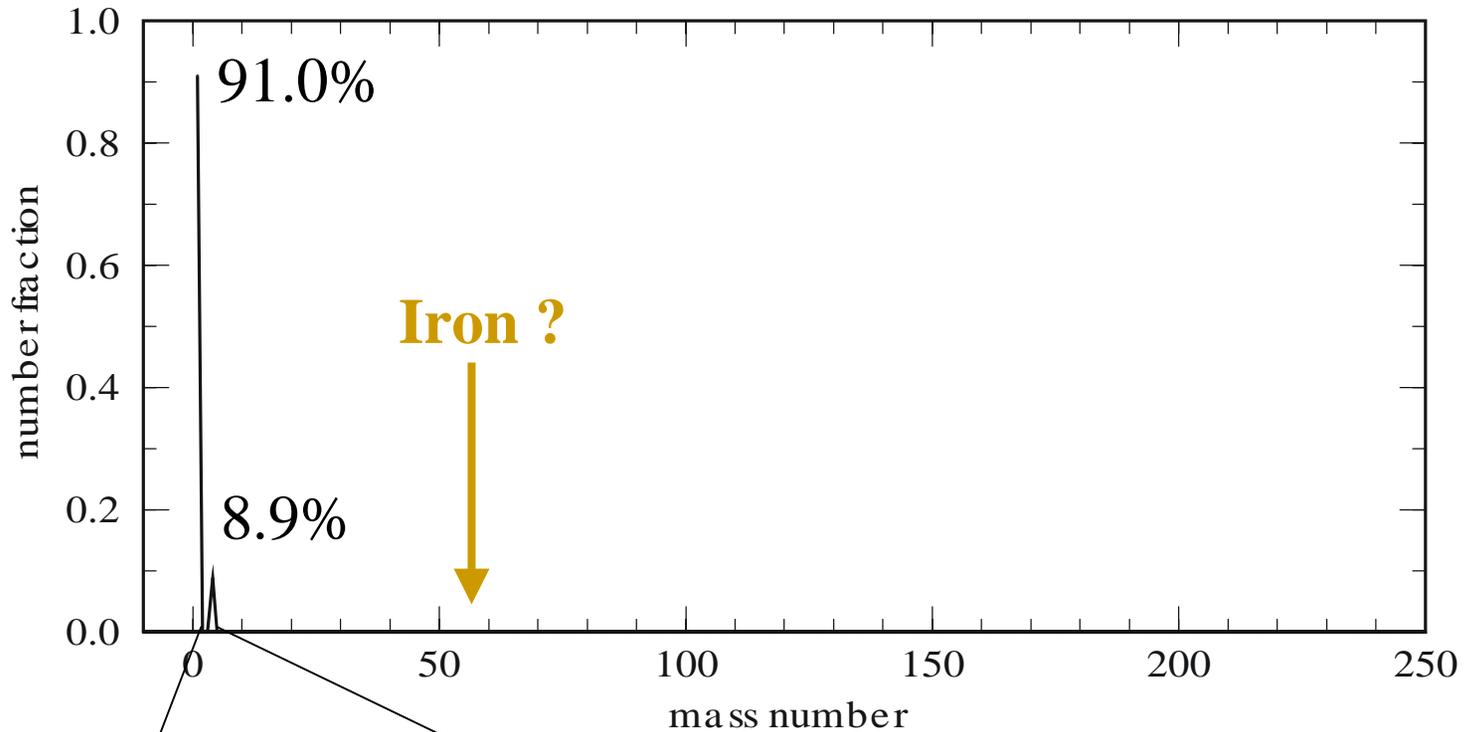
ESO PR Photo 40f/99 (17 November 1999)

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Is the universe made of iron ?

Nuclei in the Universe:

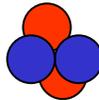


Hydrogen:



Mass number = 1

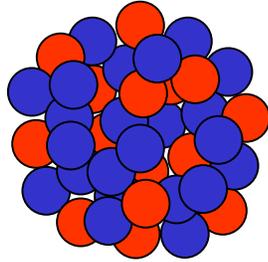
Helium:



Mass number = 4

... not yet

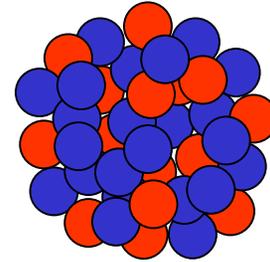
Iron:



26 protons + 30 neutrons

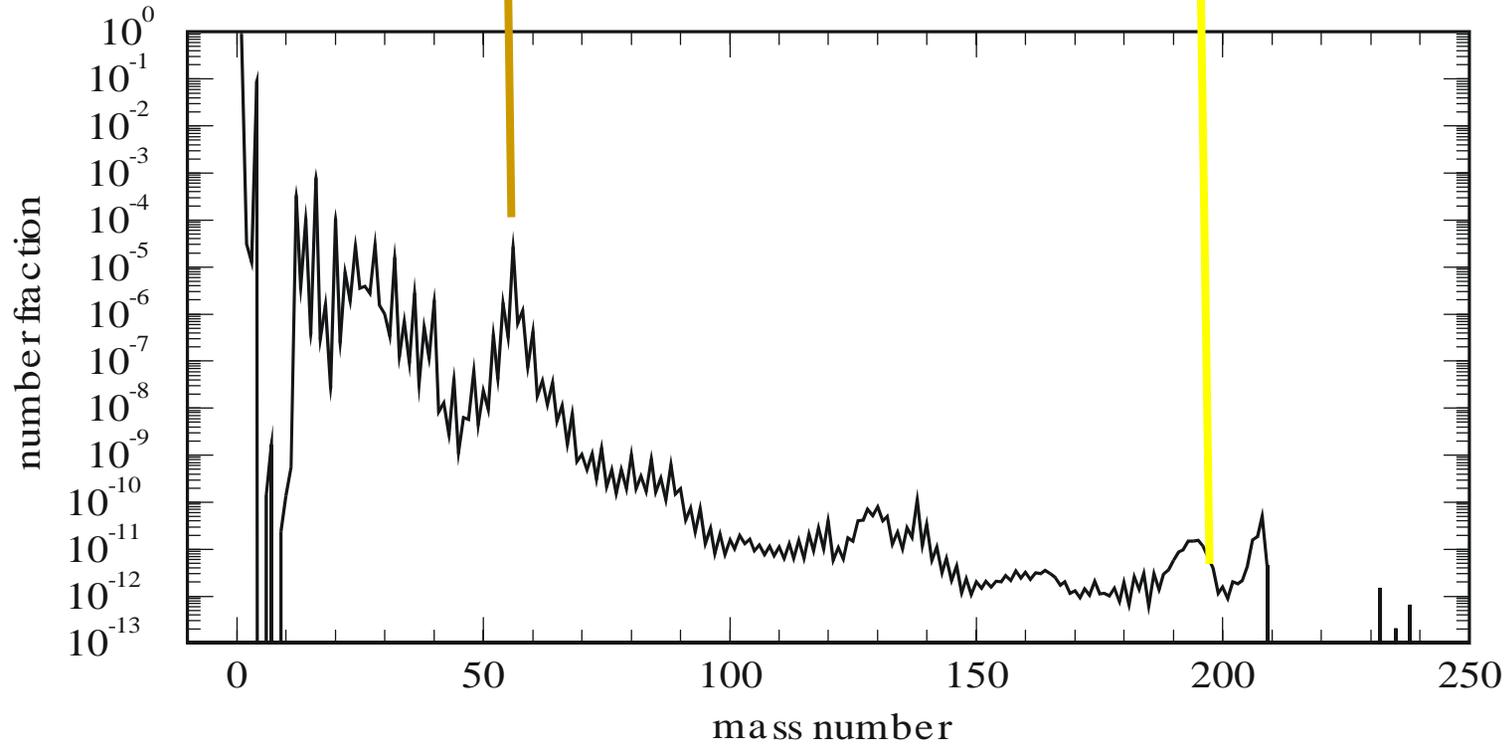
Mass number = 56

Gold:



79 protons + 118 neutrons

Mass number = 197

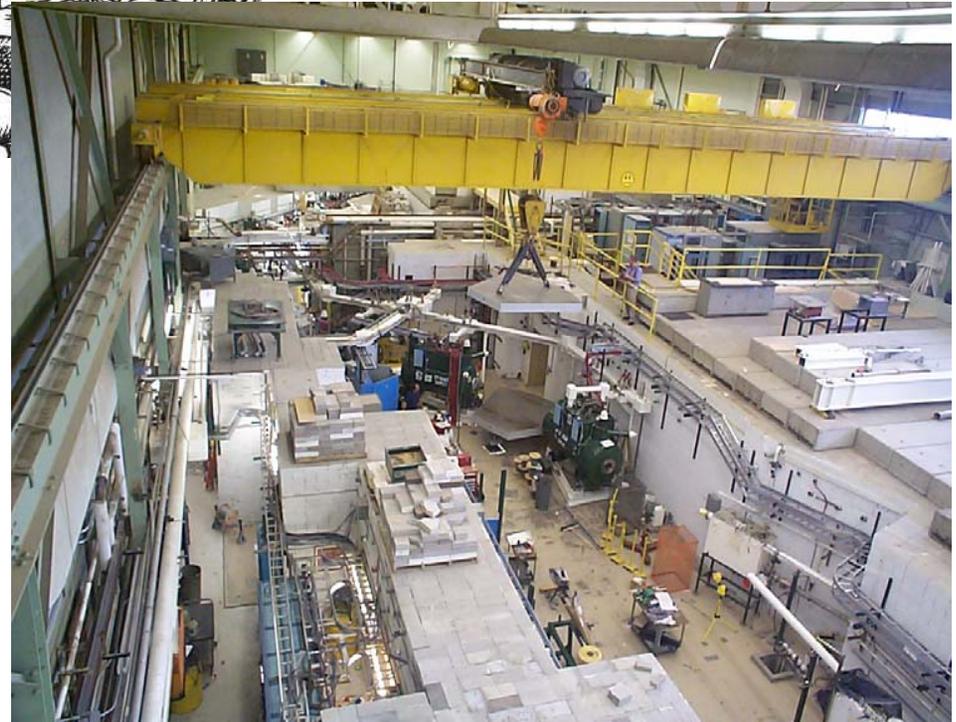


So how is gold made ?

Some earlier failed attempts (1590)

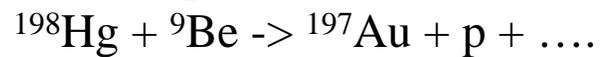


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... by a nuclear reaction

for example:



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

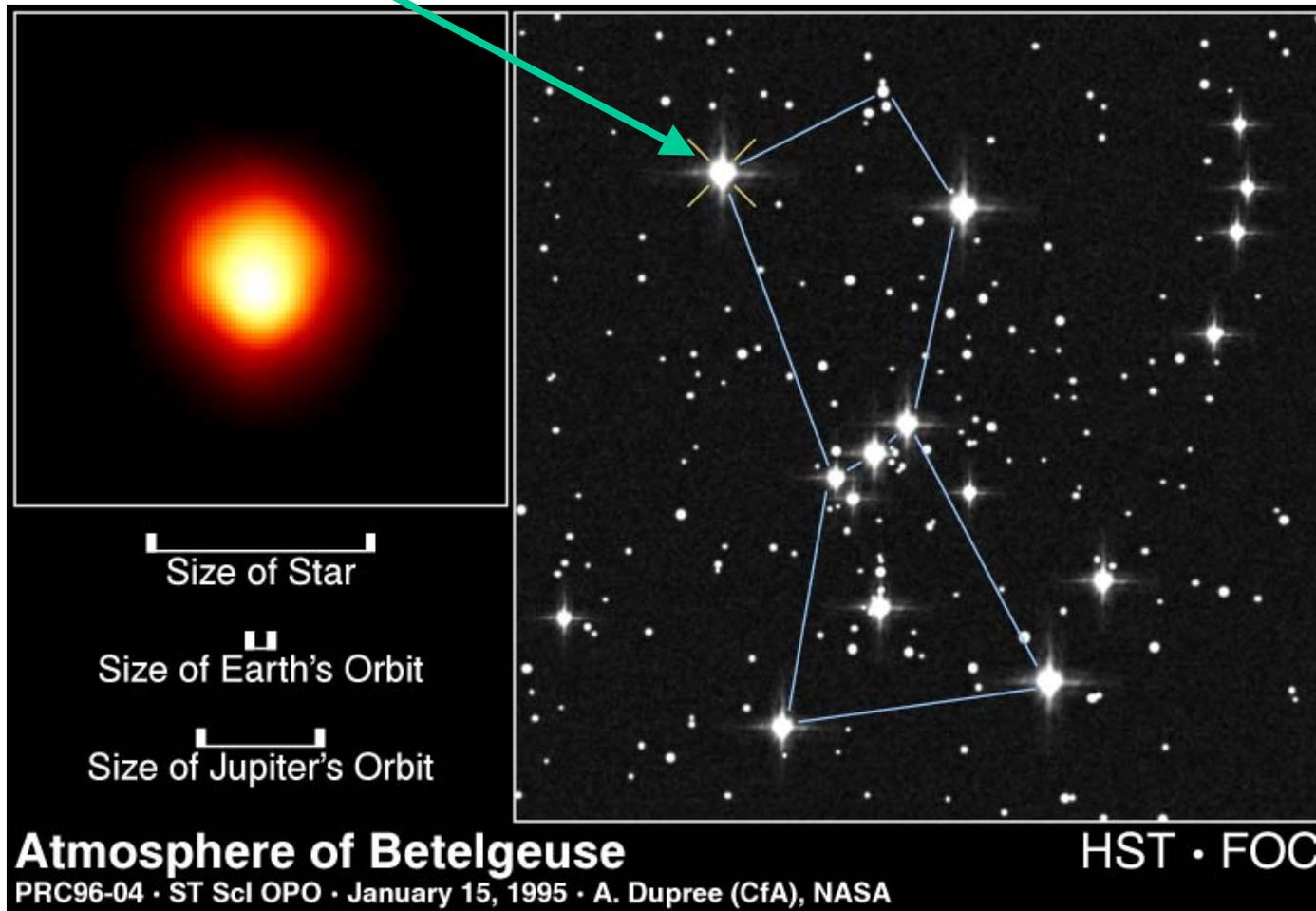
There are 2:

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

Do neutron capture process exercise

Where does the s-process happen ?

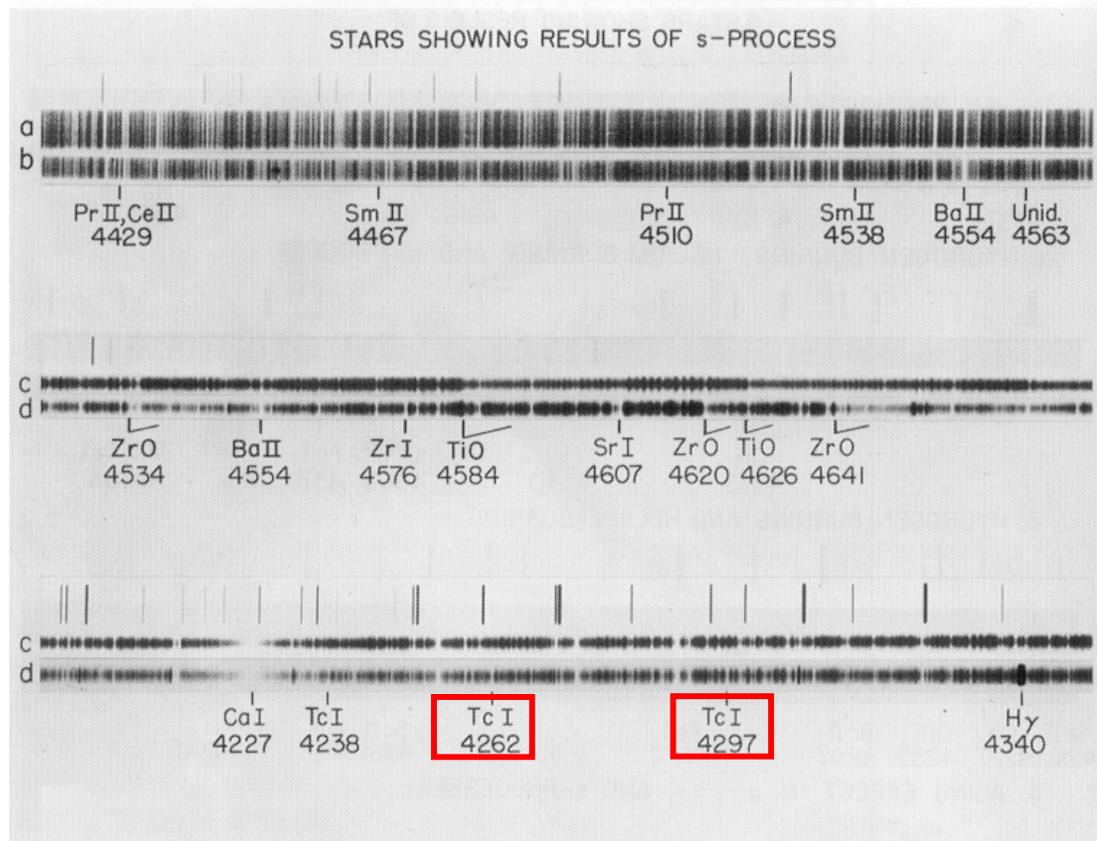
there !



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)

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

Question 3

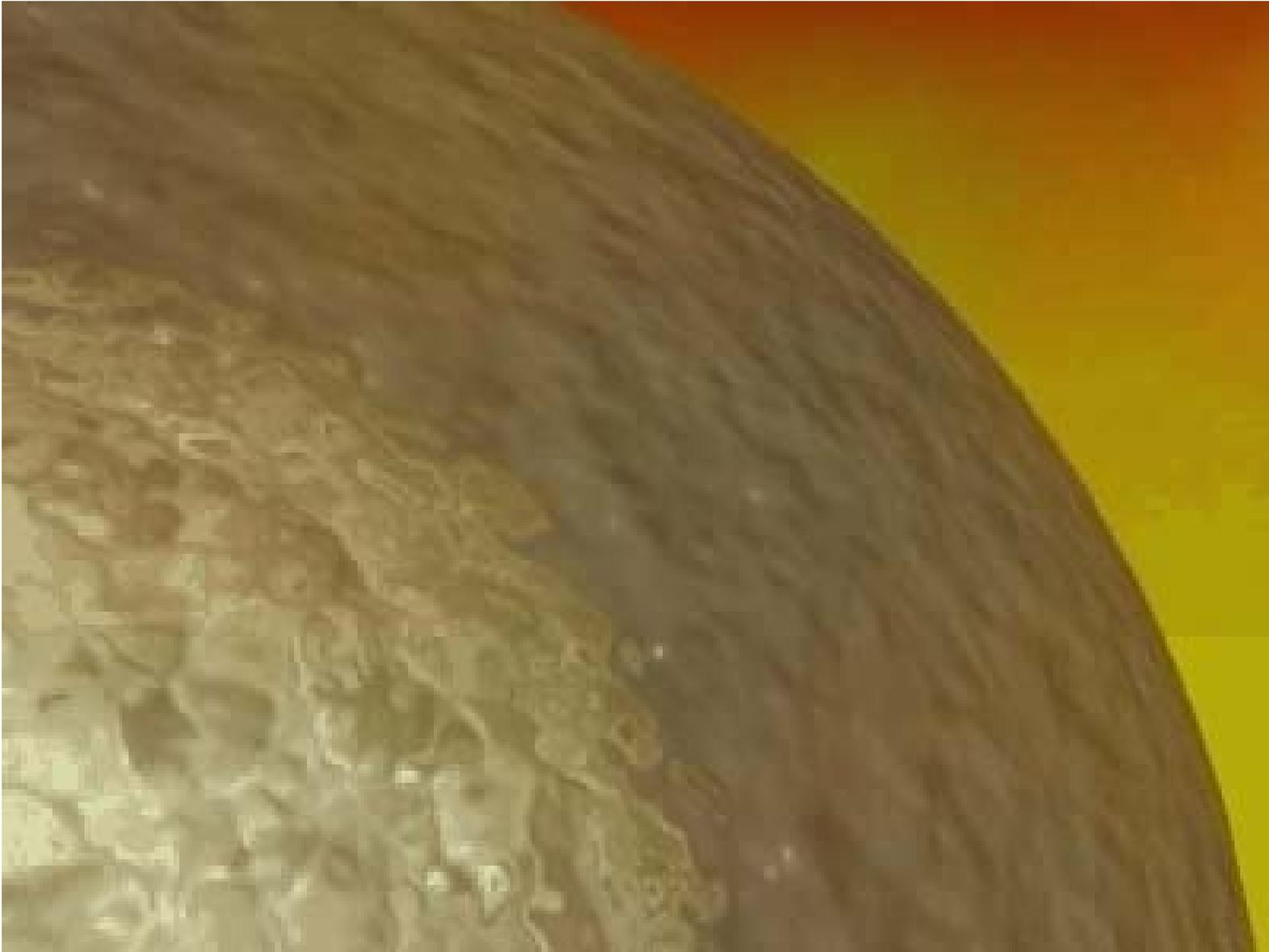
How were the elements from
iron to uranium made ?



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

JINA

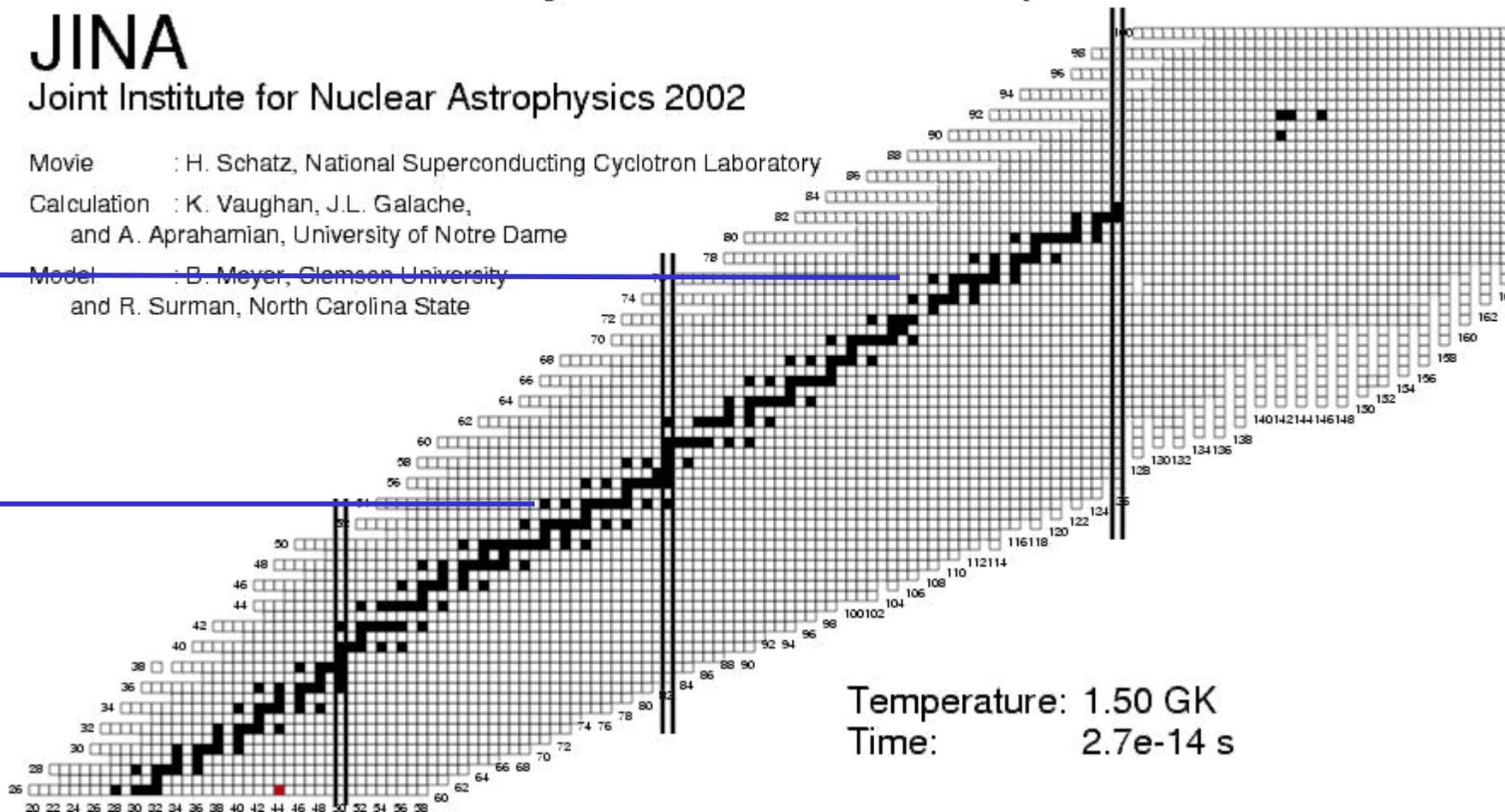
Joint Institute for Nuclear Astrophysics 2002

Movie : H. Schatz, National Superconducting Cyclotron Laboratory

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

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

Xe —

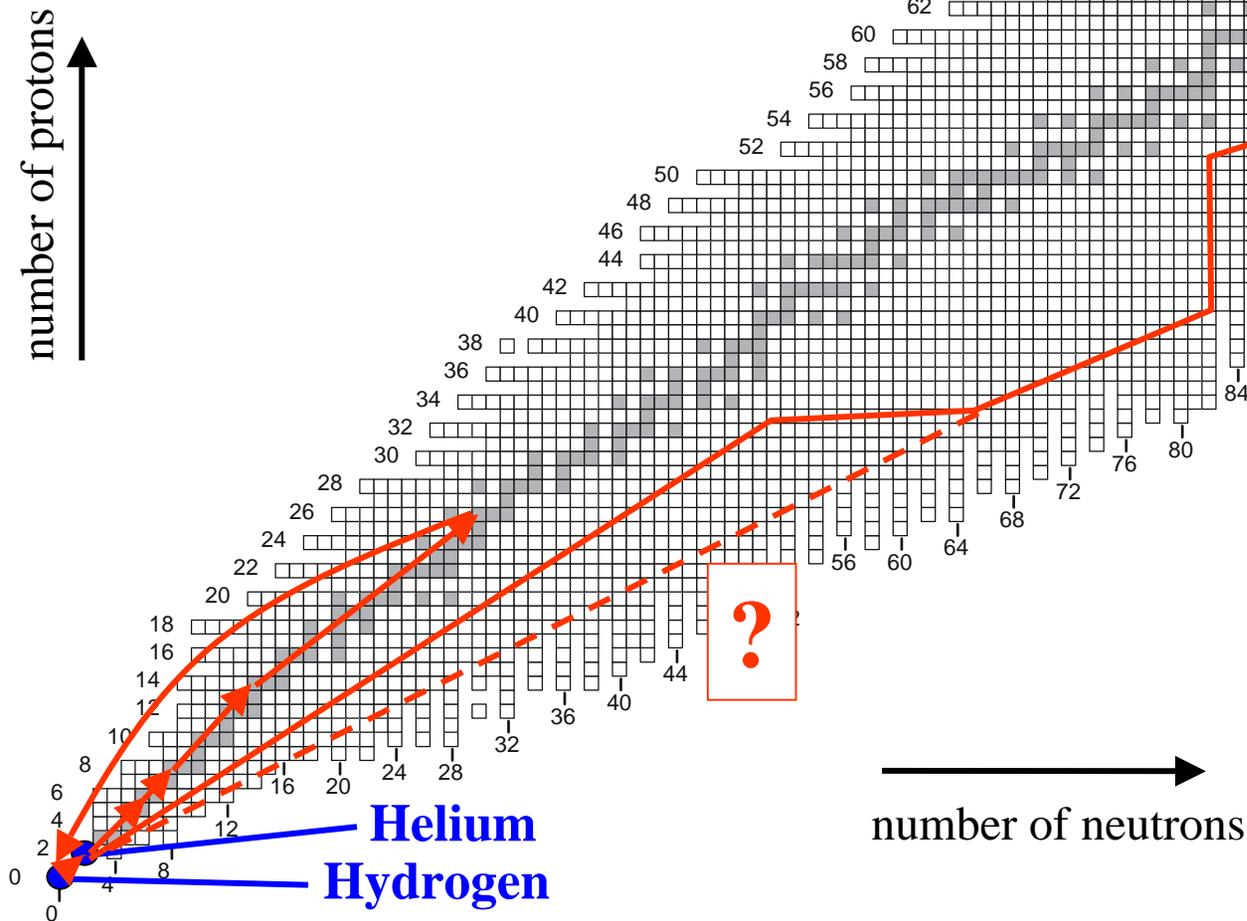


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Gold (^{197}Au)



NSCL and future facilities reach

