

# Nucleosynthesis:

Focusing on heavy elements (up to 2003)

**Periodic Table of Elements**

1																	2		
1	IIA																	0	
1	H																	He	
2	3	4																	10
2	Li	Be																	Ne
3	11	12	IIIB	IVB	VB	VIB	VII	VIII	IX	X	XI	XII	IIIA	IVA	VA	VIA	VIIA	18	
3	Na	Mg											Al	Si	P	S	Cl	Ar	
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
6	55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
6	Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
7	87	88	89	104	105	106	107	108	109	110									
7	Fr	Ra	+Ac	Rf	Ha	106	107	108	109	110									

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

Legend - click to find out more...

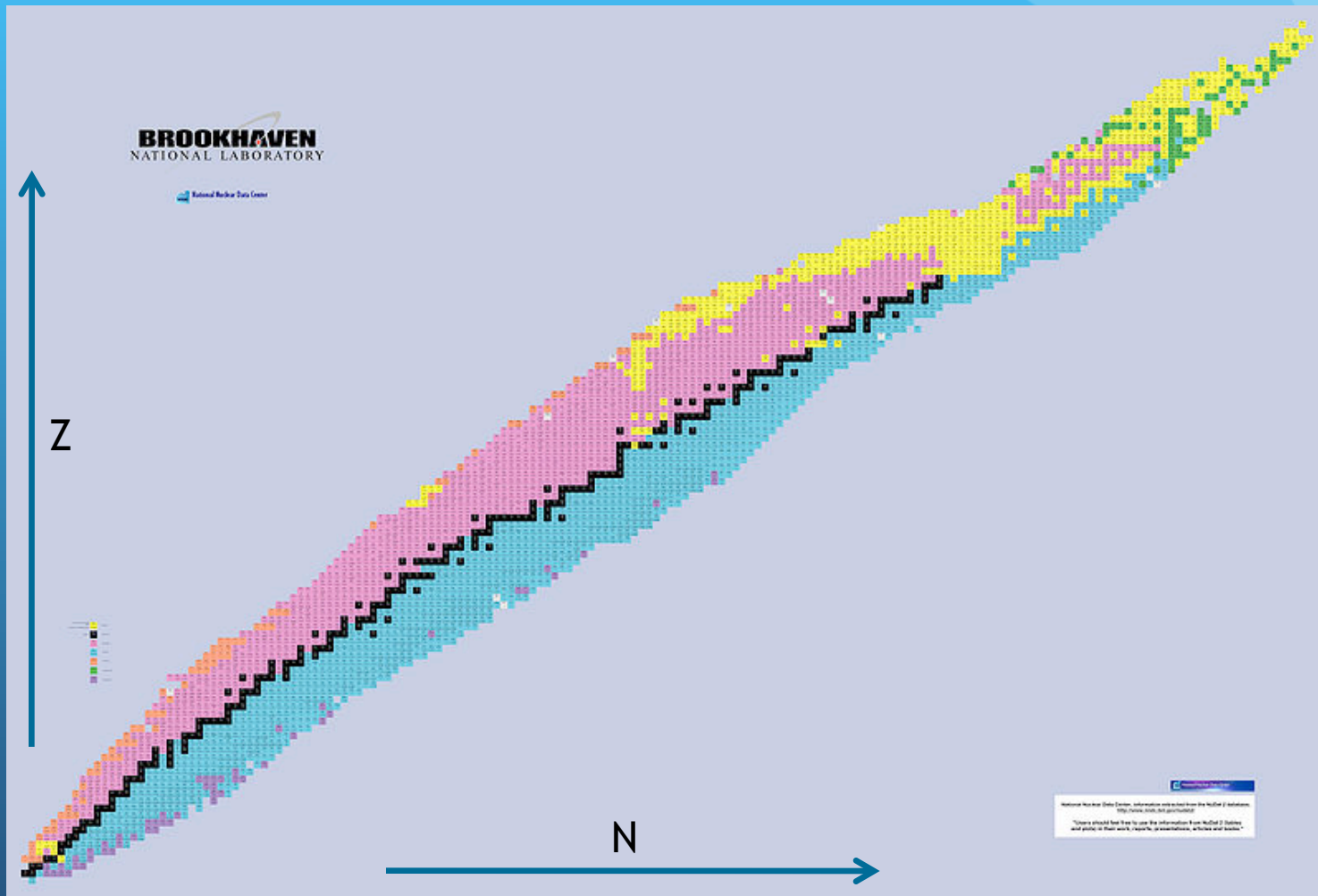
<span style="color: blue;">H - gas</span>	<span style="color: red;">Li - solid</span>	<span style="color: green;">Br - liquid</span>	<span style="color: purple;">Tc - synthetic</span>
<span style="background-color: lightgreen;">■</span> Non-Metals	<span style="background-color: lightblue;">■</span> Transition Metals	<span style="background-color: lightyellow;">■</span> Rare Earth Metals	<span style="background-color: lightorange;">■</span> Halogens
<span style="background-color: yellow;">■</span> Alkali Metals	<span style="background-color: cyan;">■</span> Alkali Earth Metals	<span style="background-color: magenta;">■</span> Other Metals	<span style="background-color: orange;">■</span> Inert Elements

Michael Spillane

# Some relevant terms

- $\beta$ -decay
- N-capture
- Mass number (A)
- Atomic (Proton) number (Z)
- Magic Numbers (for both 2,8,20,28,50,82 and for neutrons 126)

# Map of stable nuclei

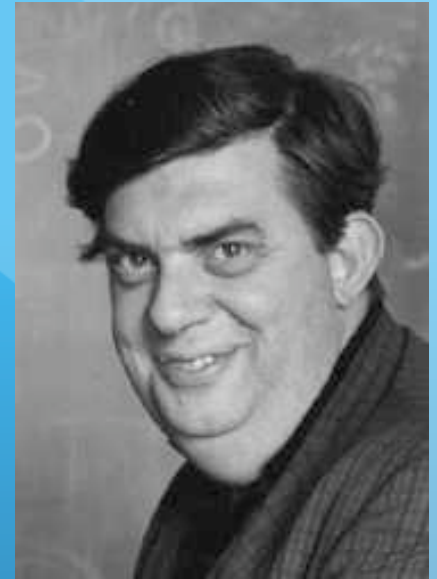


# History

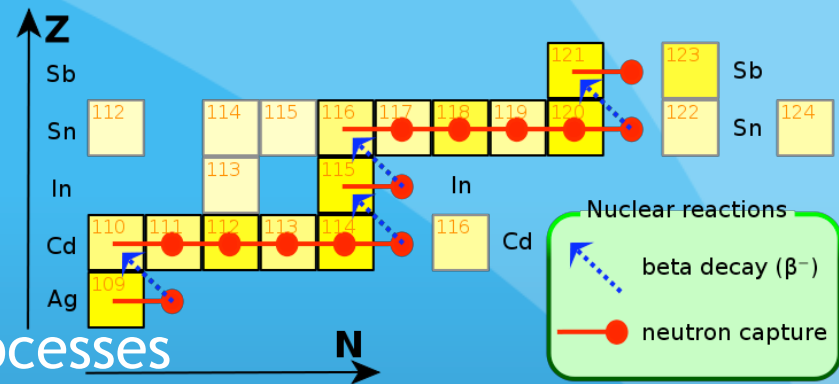
- In the 1920's Arthur Eddington suggested that the sun runs on fusion
- Just before WWII Hans Bethe determines a mechanism for the creation of  $^4\text{He}$
- The Big Bang as the source of all nuclei
- In 1956 a new and much improved experimental data was published on abundances of nuclei (Suess, Urey)

# B<sup>2</sup>FH

- This paper marked the start of stellar nucleosynthesis
- Rejected Big Bang as source of nuclei
- Divide all of the elements into two major subgroups (s-process and r-process)



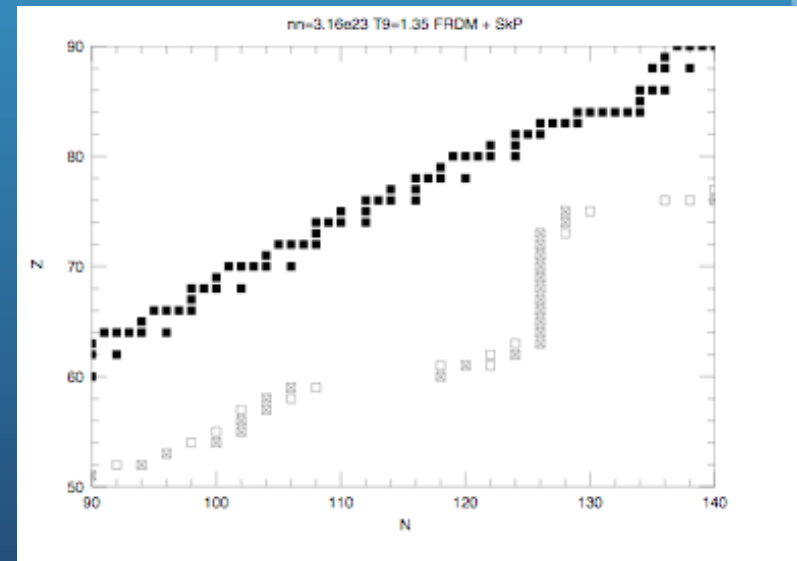
# S-process



- Best understood of the processes
- Slow is defined as  $\tau_b < \tau_n$
- A neutron is captured by a nucleus it then  $\beta$ -decays into a stable nuclei
- Because of this the s-process creates those nuclei that are near stability
- The only suspected location is in Asymptotic Giant Branch stars (AGB)

# R-process

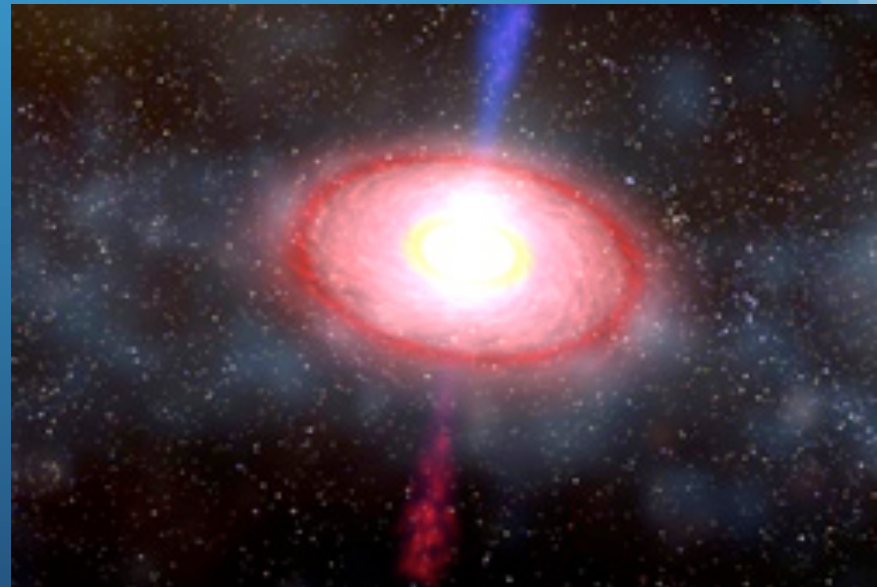
- By definition  $\tau_n \ll \tau_b$
- The best current model is called the waiting point approximation
- Typical temperatures  $\sim 10^9$  K and neutron densities  $>10^{20} \text{ cm}^{-3}$



# R-process sites



- Core collapse supernova
- Neutron star mergers



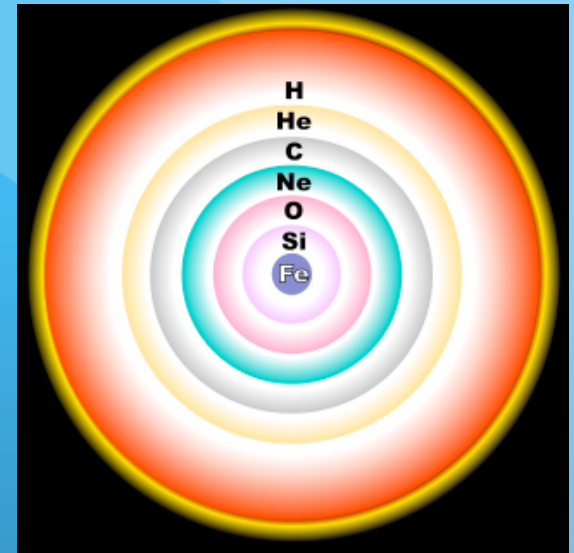


# P-process

- There are 35 neutron deficient nuclei for  $A > 70$  some of these can be made through the s-process
- This method also relies on photodisintegration of s-process seeds (s-nuclei)
- Certain elements are under produced using this method for the p-process
- Adding neutrinos will fix some problems but not all
- Increasing the number of s-nuclei present also could help

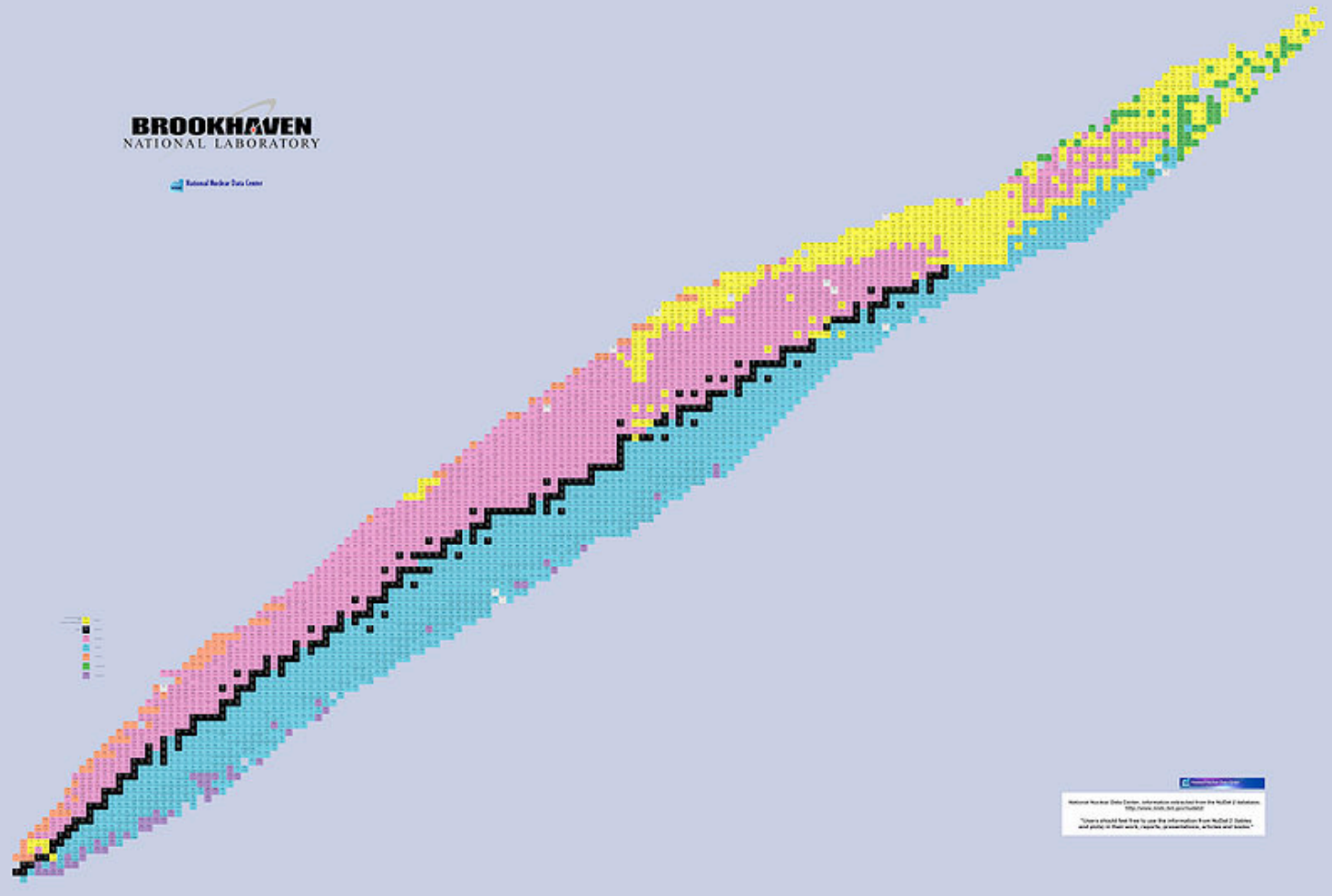
# P-process sites

- O/Ne layer in highly evolved massive stars
- X-ray novae
- Neutrino driven winds originating from supernova
- Super critical accretion disks (SSAD's) around a star following supernova



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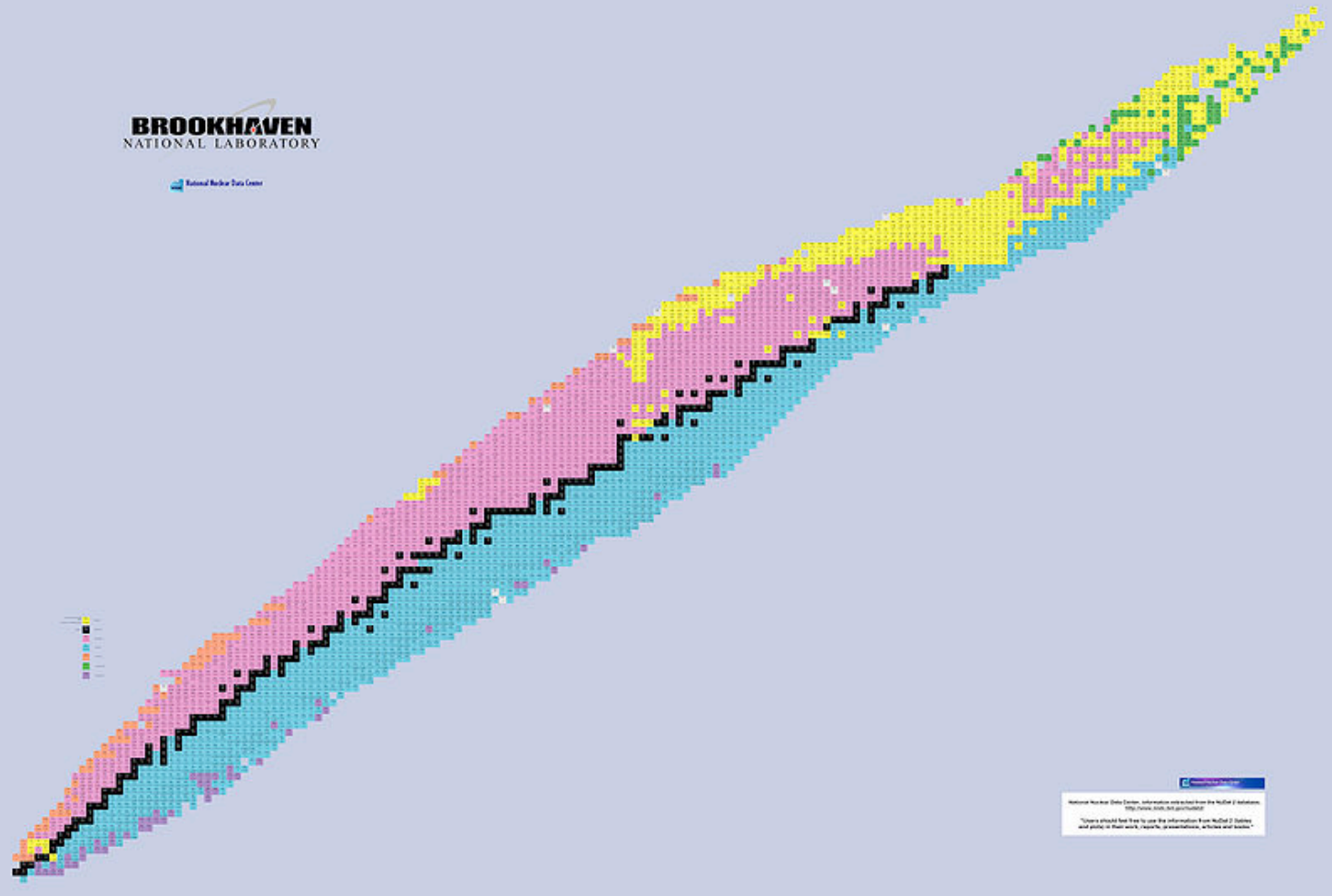


  
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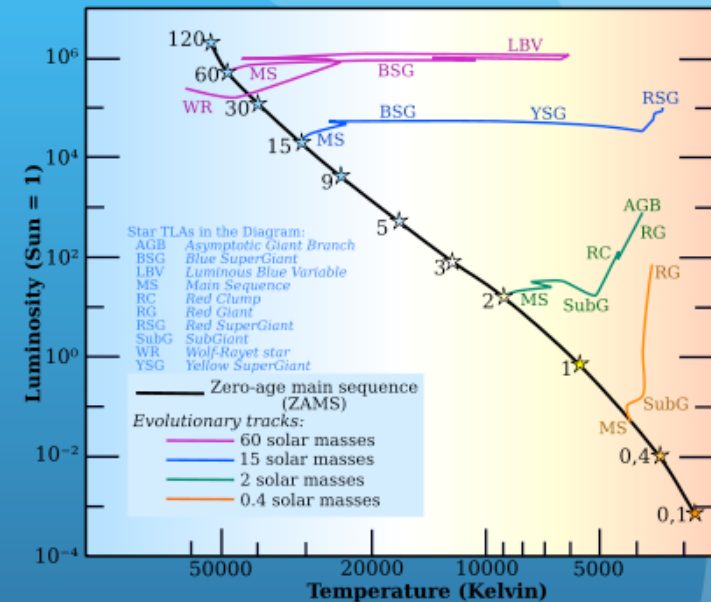
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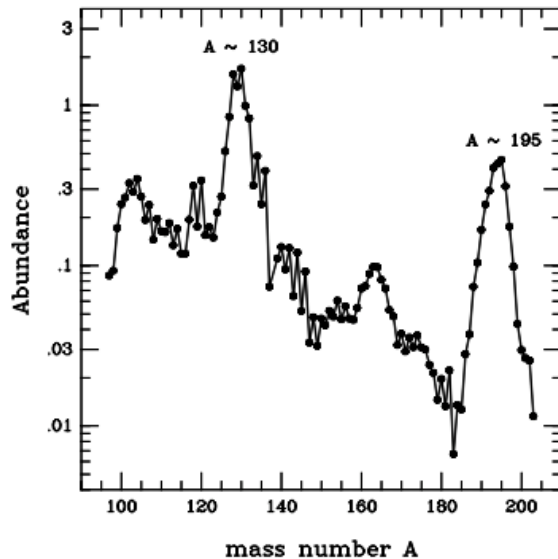
  
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# Creation of nuclei $56 < A < 130$

- S-process creates those near stability (AGB stars)
- R-process creates another 50% relevant magic number is  $N = 82$



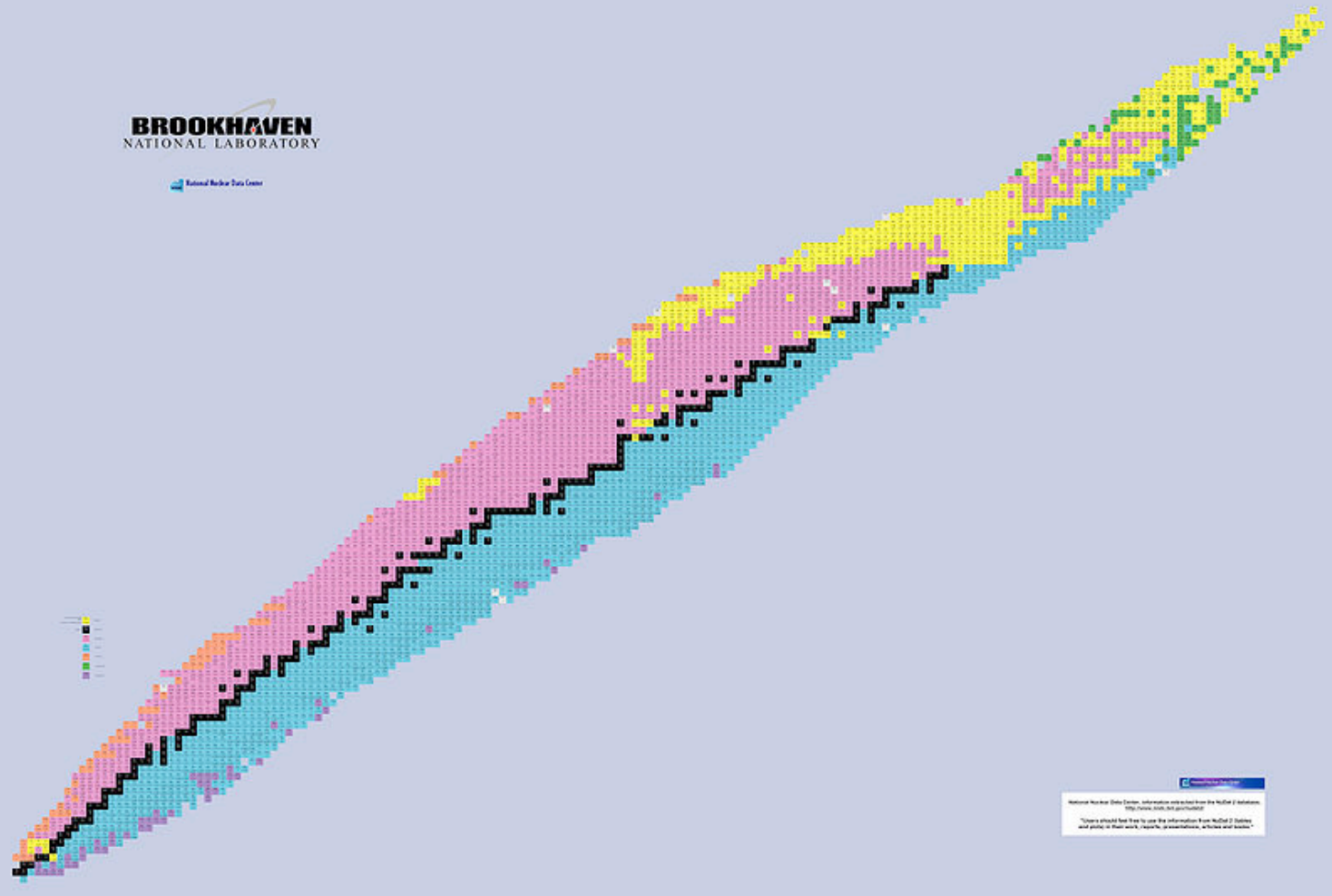
Kappeler et al. 1989



- P-process creates most of the neutron deficient isotopes

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# Creation of nuclei $A > 130$

- S-process continues to make elements near stability with mass numbers up to  $A = 204$
- R-process creates those far from stability, but there are problems with creation sites (relevant magic number  $N = 126$ )
- Humans have manufactured some elements not found in nature with  $Z$  up to 103





# Conclusions

- Models which have existed since the 1950's provide excellent qualitative explanations of abundance data
- The models however fail on describing the finer points of the abundance data
- More information is needed about masses, cross sections, and b-decay rates for nuclei far from stability
- Also better models are needed for supernova and their production of neutrinos