

# How were Elements synthesized? (Nucleosynthesis)

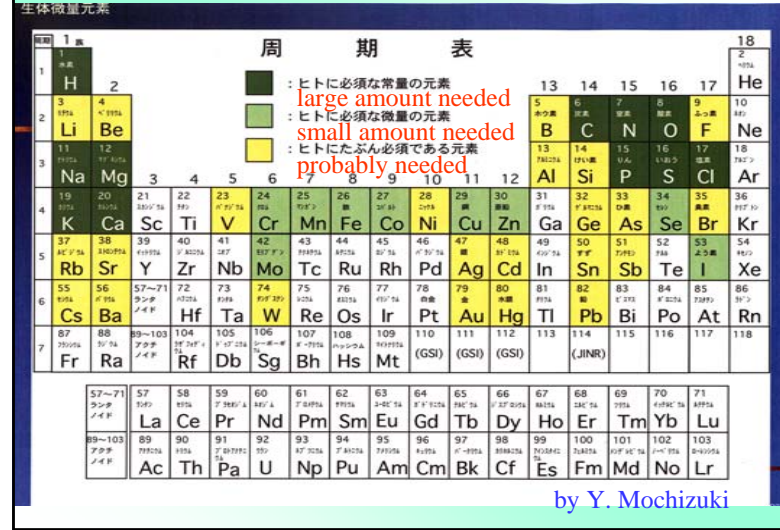


-the 6th lecture-

SS Jyvaskyla  
August 06-12, 2014

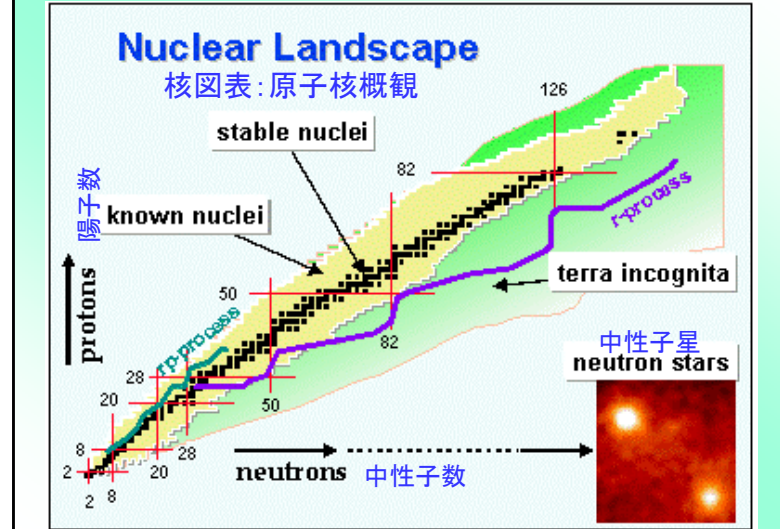
Yoshitaka Fujita  
Osaka University

# Elements Necessary for Life



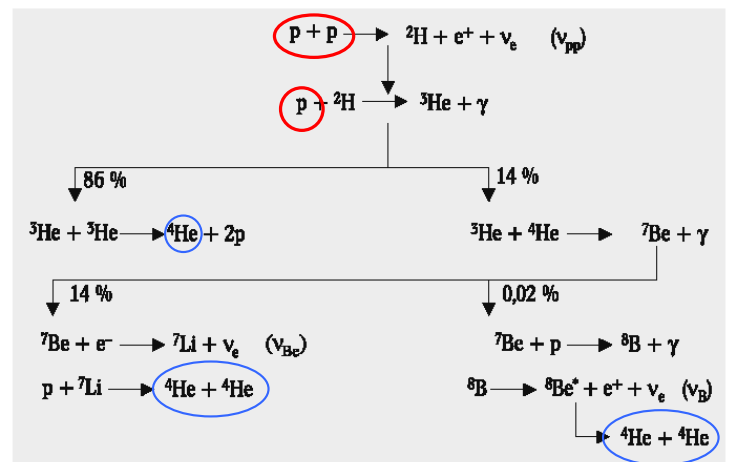
# \*\*\*Elements and Nuclei?

# Nuclear Chart

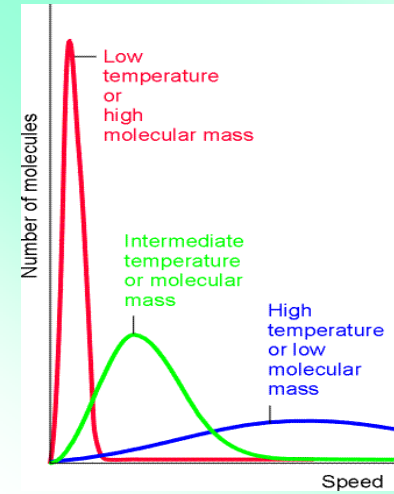




## Nuclear Fusion in the Sun



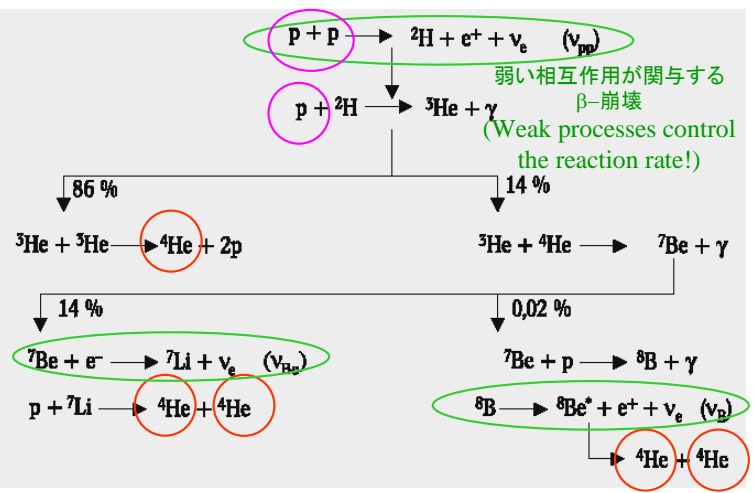
## Maxwell distribution



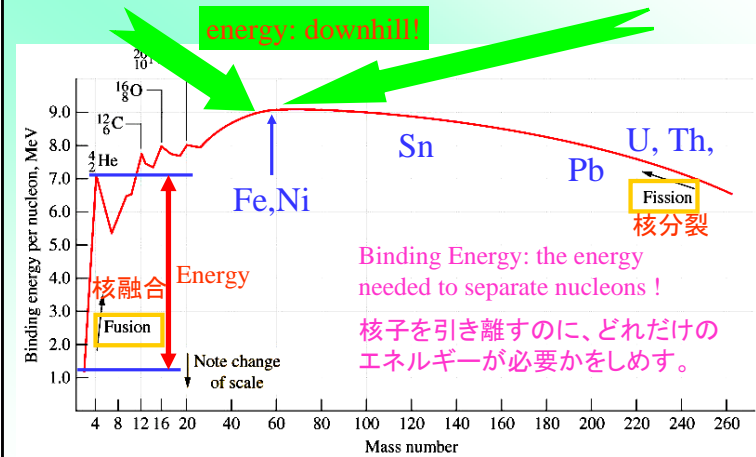
velocity  
 $\langle v^2 \rangle = 3kT/m$   
 kinetic energy  
 $\langle K \rangle = 3kT/2$

$10^4\text{K} \sim 1\text{ eV}$   
 $10^7\text{K} \sim 1\text{ keV}$   
 $10^9\text{K} \sim 100\text{ keV}$

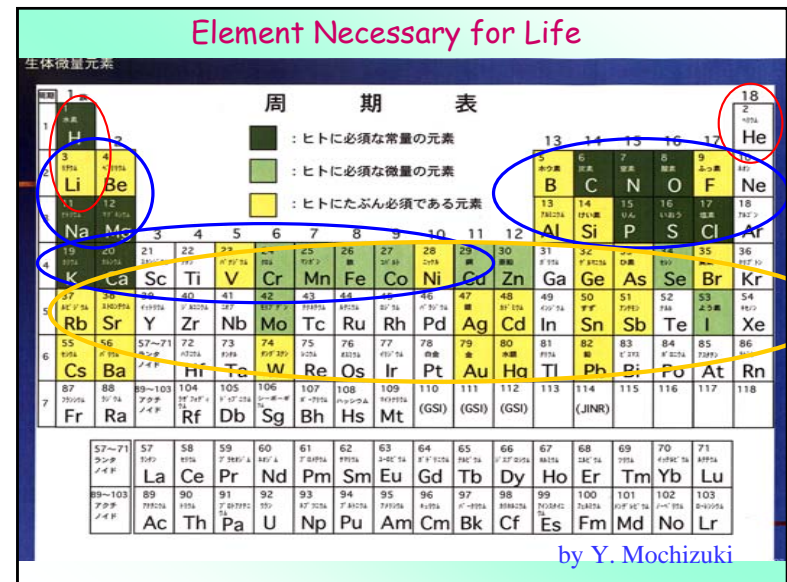
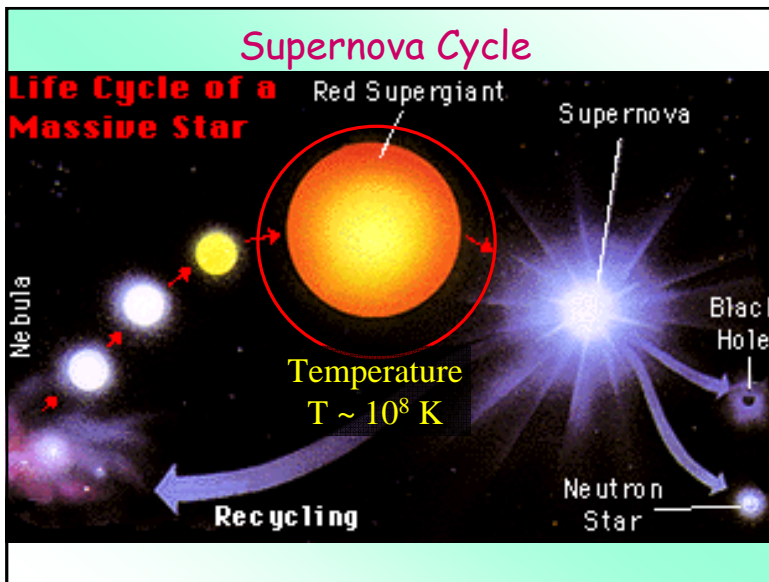
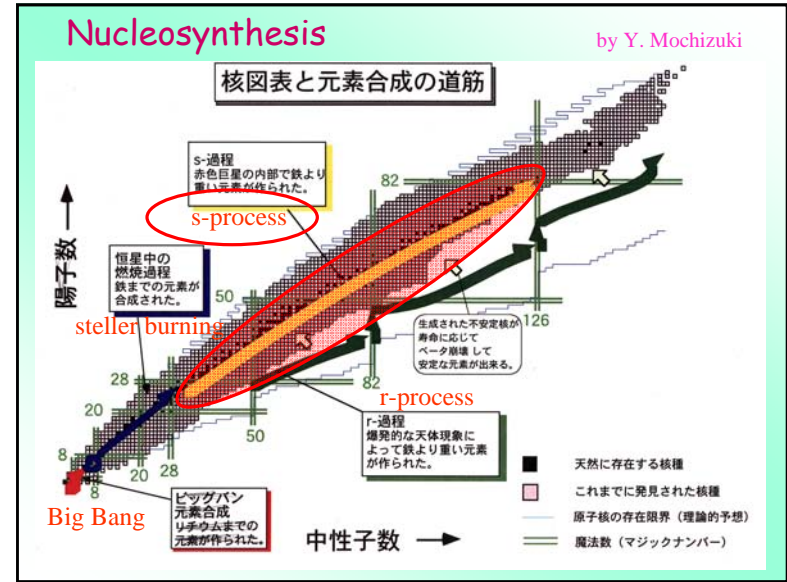
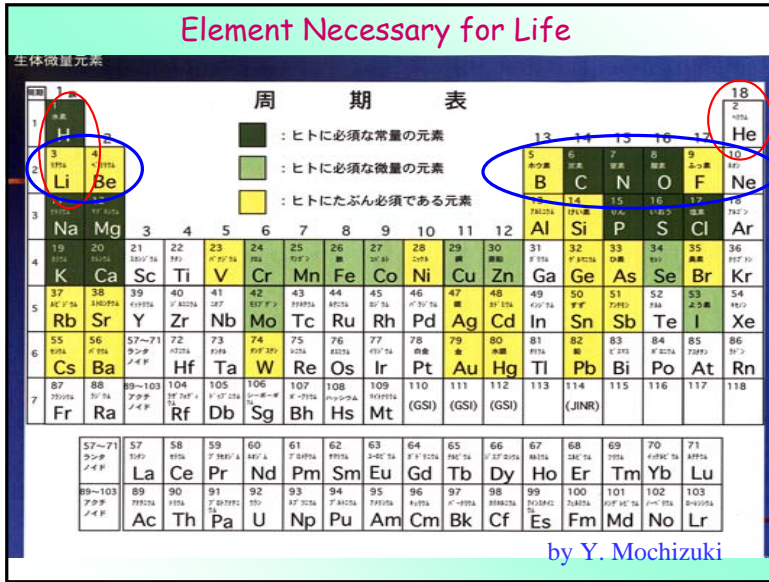
## ${}^1\text{H} \rightarrow {}^4\text{He}$ : Nuclear Reaction in a Star

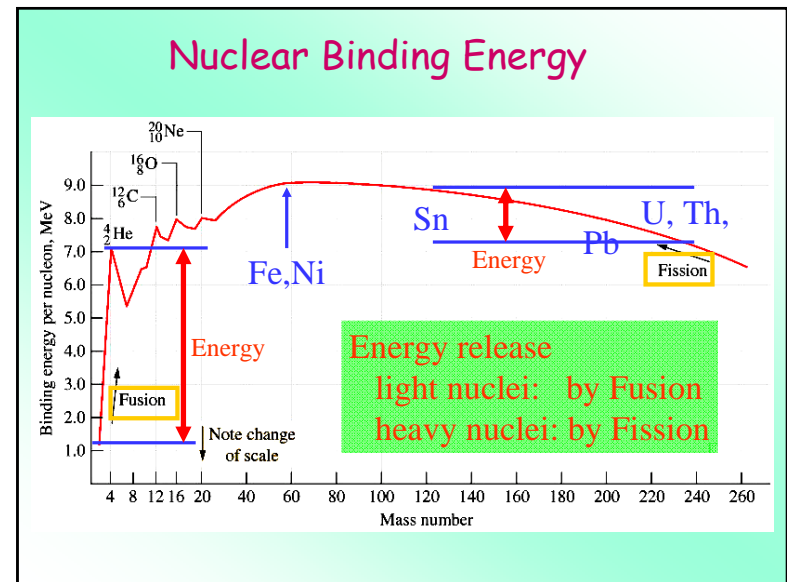
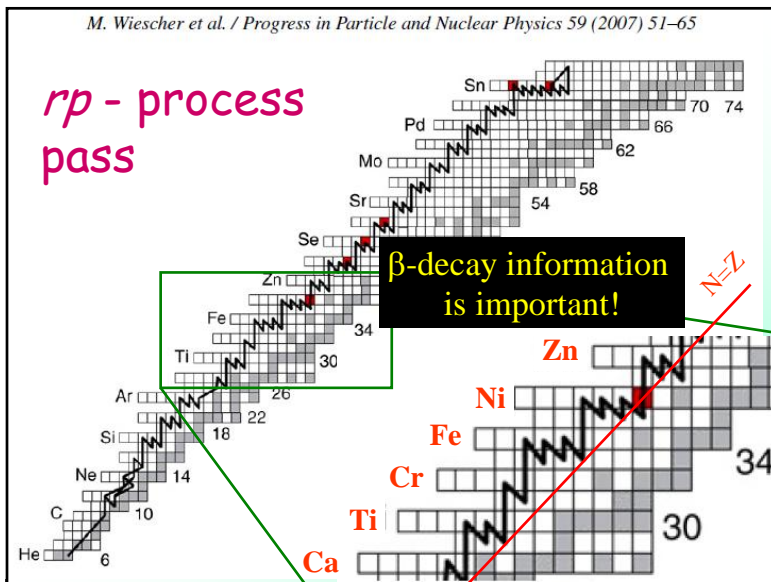
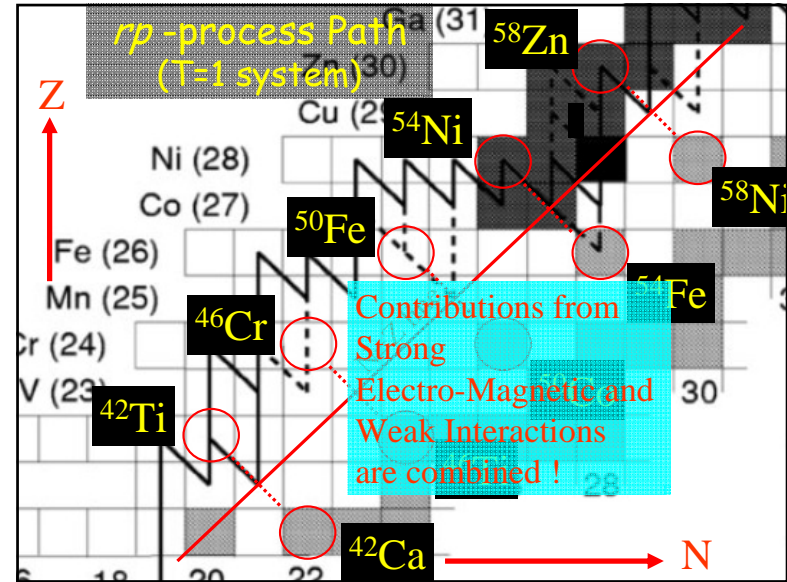
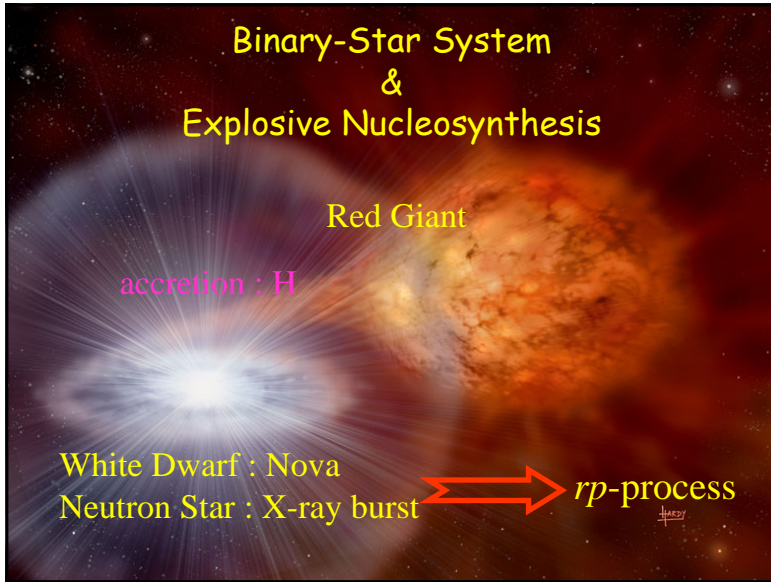


## Nuclear Binding Energy

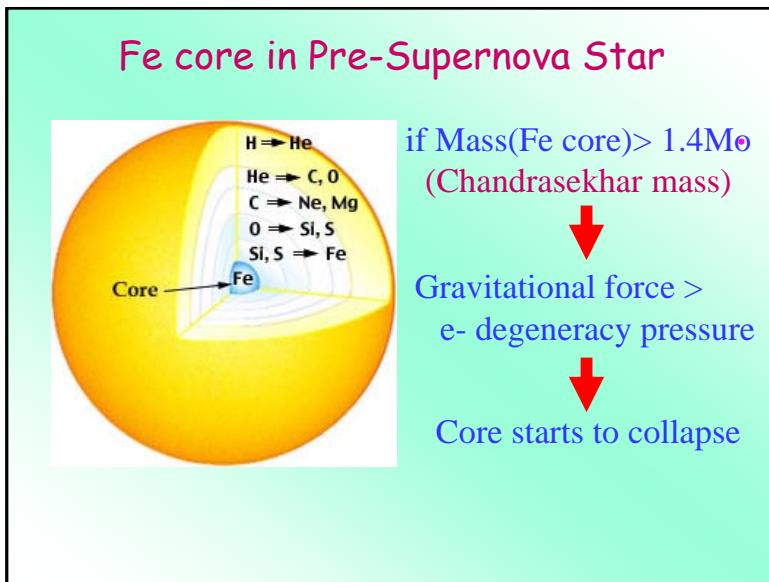
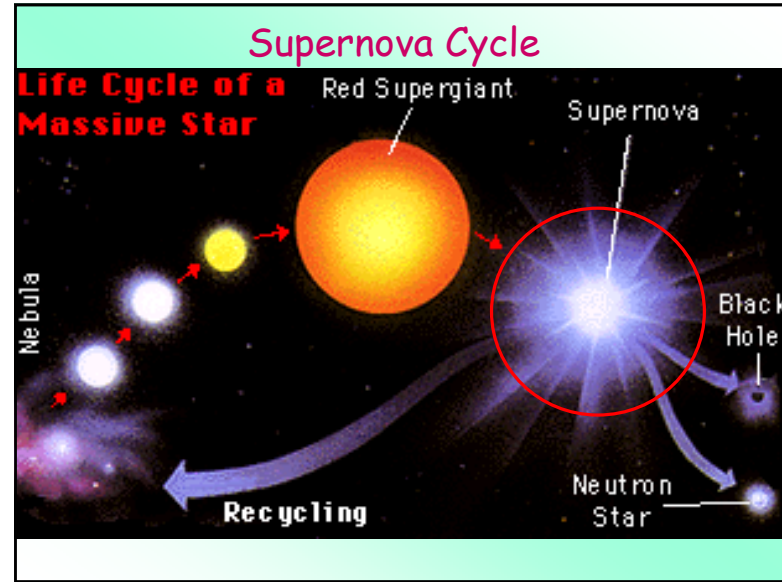
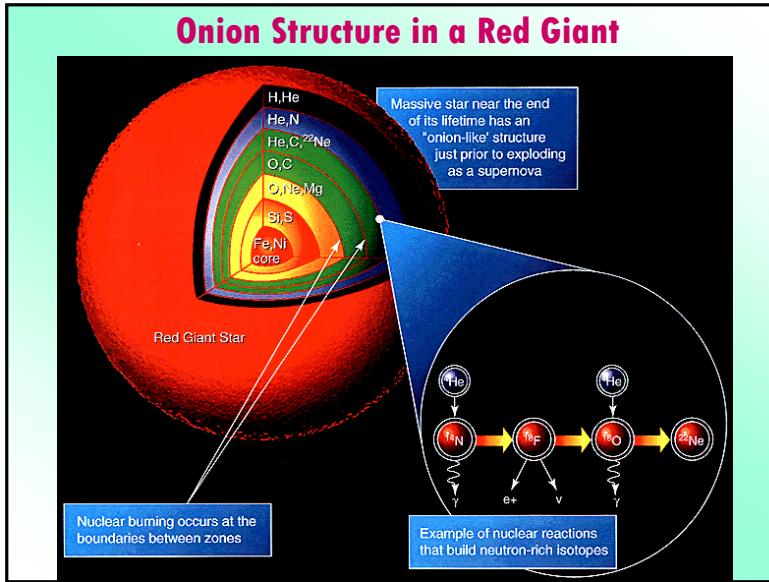








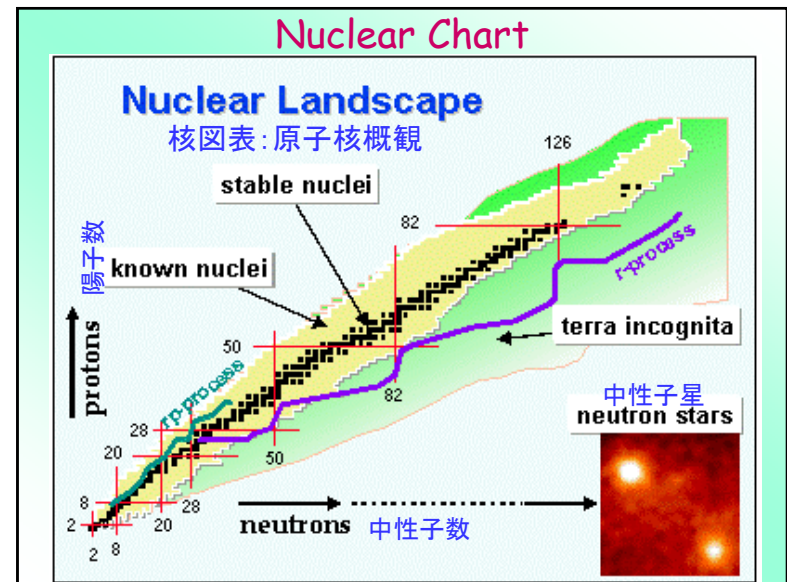
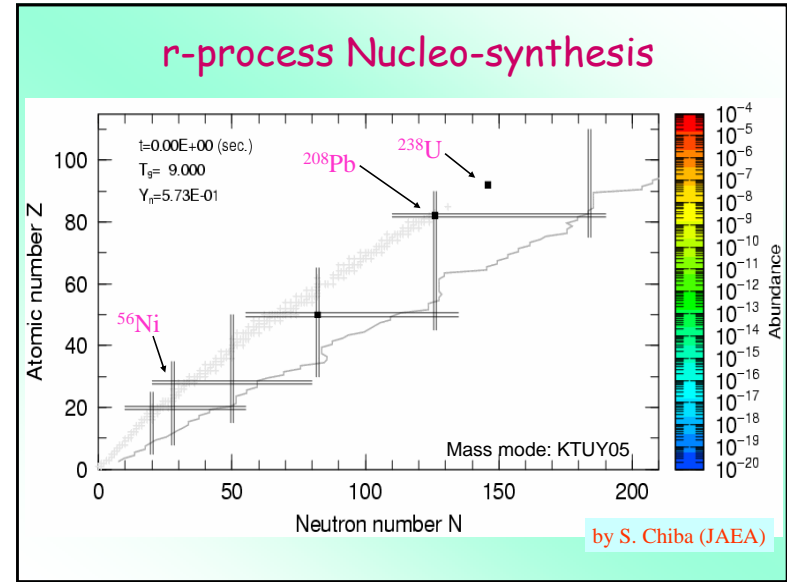
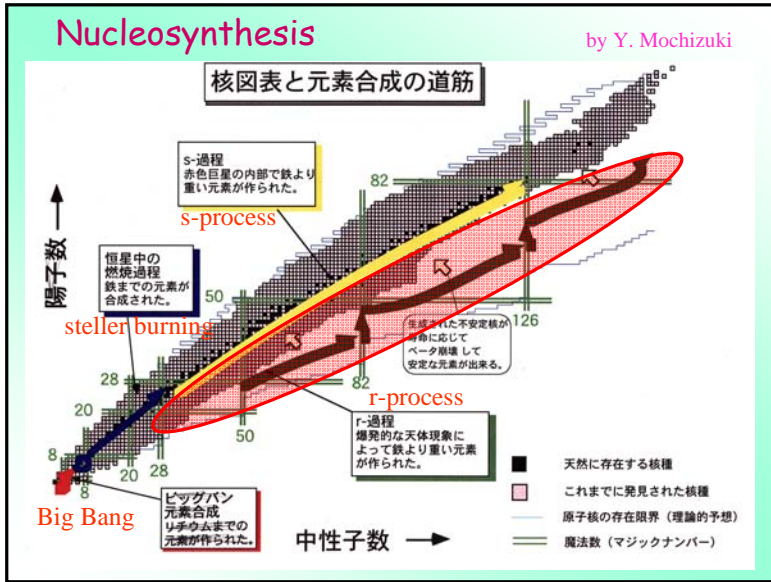




### Time Scale toward SN

Evolutionary Stages for 25 Solar Mass Star

Stage	Temperature (K)	Density ( $\text{g/cm}^3$ )	Duration
Hydrogen Burning	$4 \times 10^7$	5	$7 \times 10^6$ yrs
Helium Burning	$2 \times 10^8$	700	$5 \times 10^5$ yrs
Carbon Burning	$6 \times 10^8$	$2 \times 10^5$	600 yrs
Neon Burning	$1.2 \times 10^9$	$4 \times 10^6$	1 yr
Oxygen Burning	$1.5 \times 10^9$	$10^7$	6 months
Silicon Burning	$2.7 \times 10^9$	$3 \times 10^7$	1 day
Core Collapse	$5.4 \times 10^9$	$3 \times 10^9$	1/4 sec
Core Bounce	$2.3 \times 10^{10}$	$4 \times 10^{14}$	milliseconds

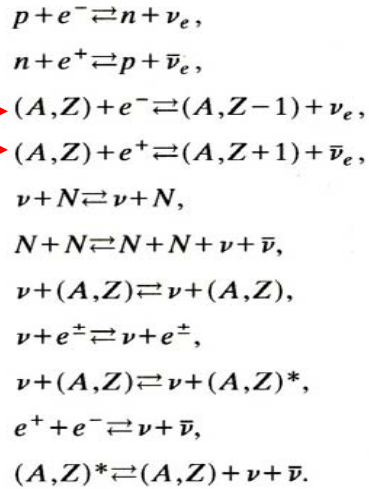


Crucial Weak Processes during the Collapse

mainly by  $\tau$  &  $\sigma\tau$

$(A,Z)$ =nuclei in the Cr, Mn, Fe, Co, Ni region *pf*-shell Nuclei !

K.L. & G.M-P  
Rev.Mod.Phys.75('04)819



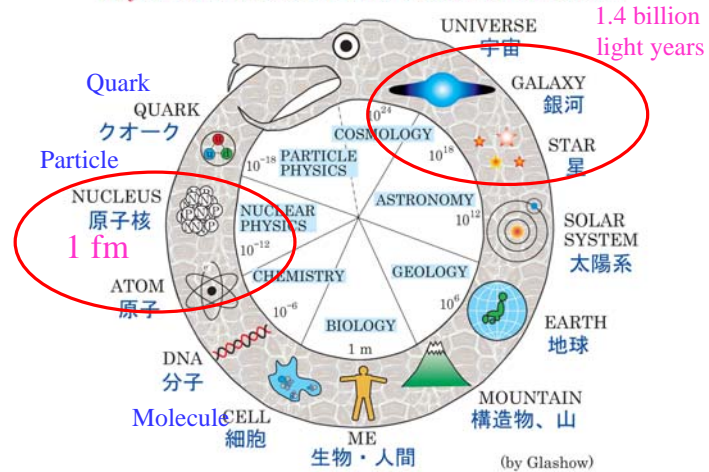
Eruption of Kilauea, Hawaii (1970's)



地熱: ウラン等、放射性元素の核分裂の熱  
Terrestrial heat: originates from Radio Activity like  $^{235}\text{U}$

自然の階層性 (ウロボロスの蛇)

Layer Structure of Nature (Snake of Uroboros)



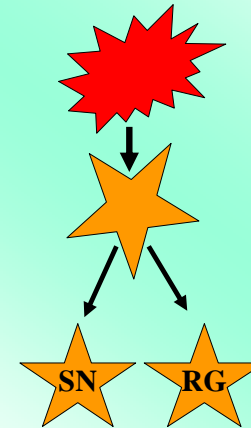
Cycling of Elements

Big Bang

H, He, Li

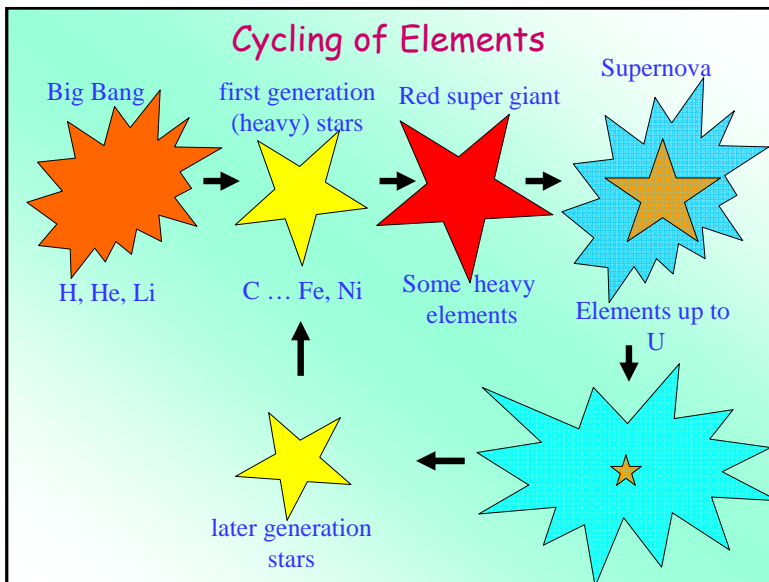
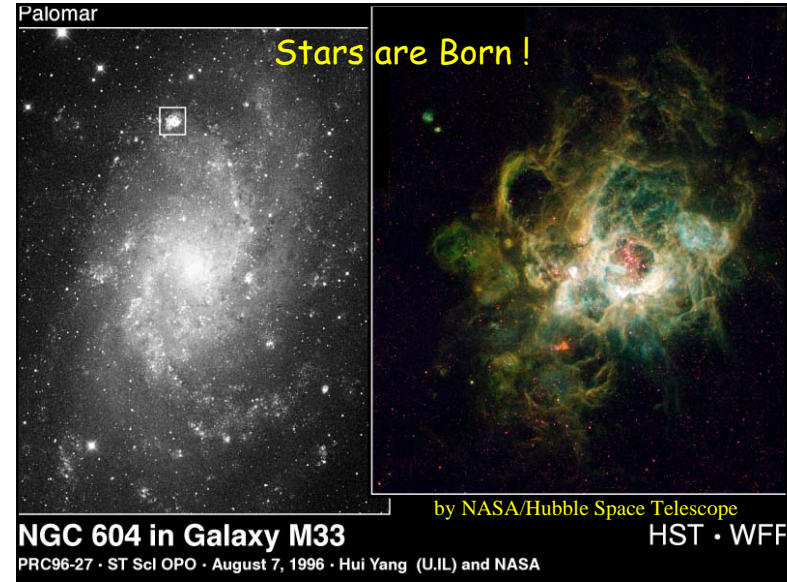
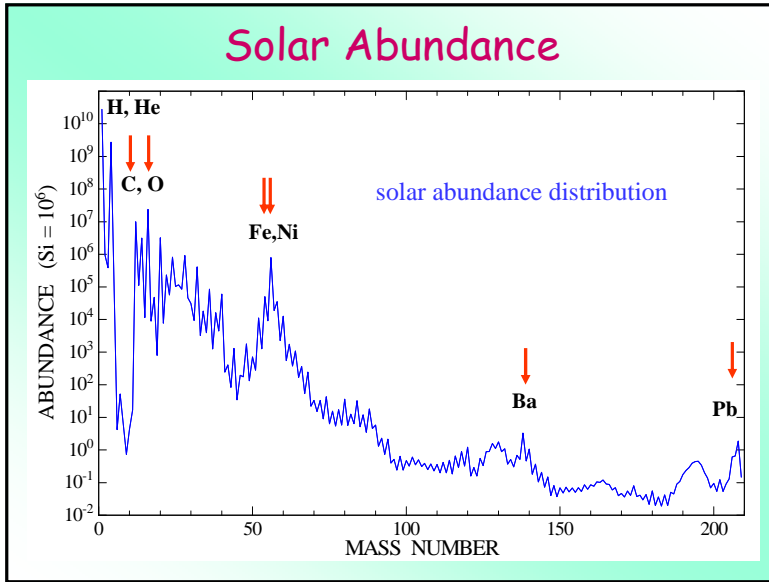
first generation of (heavy) stars

C ... Fe and some heavy elements



Elements up to U





### Elements Necessary for Life

生体微量元素

周期表

- : ヒトに必要な常量の元素 (large amount needed)
- : ヒトに必要な微量の元素 (small amount needed)
- : ヒトにたぶん必須である元素 (probably needed)

1	2											13	14	15	16	17	18										
1	H											5	B	C	N	O	F	10	He								
2	3	4											7	Li	Be											9	Ne
3	11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18									
	Na	Mg	Al	Si	P	S	Cl	Ar											36								
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36									
	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									
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe									
6	55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86									
	Cs	Ba	ラランチド	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn									
7	87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118									
	Fr	Ra	アクチノイド	Rf	Db	Sg	Bh	Hs	Mt	(GSI)	(GSI)	(GSI)	(JINR)														
8	89-103	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103											
	ラランチド	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu											
	アクチノイド	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr											

by Y. Mochizuki

## Who am I ?

Light elements are synthesized in STARS.  
Heavier elements : in Red Giants, and  
in Supernovae.

They spread at the time of Supernova Explosion.  
From the Star Dusts, our Earth was born.

Life was born eventually !”

Therefore, YOU are the CHILDEN of STARS !