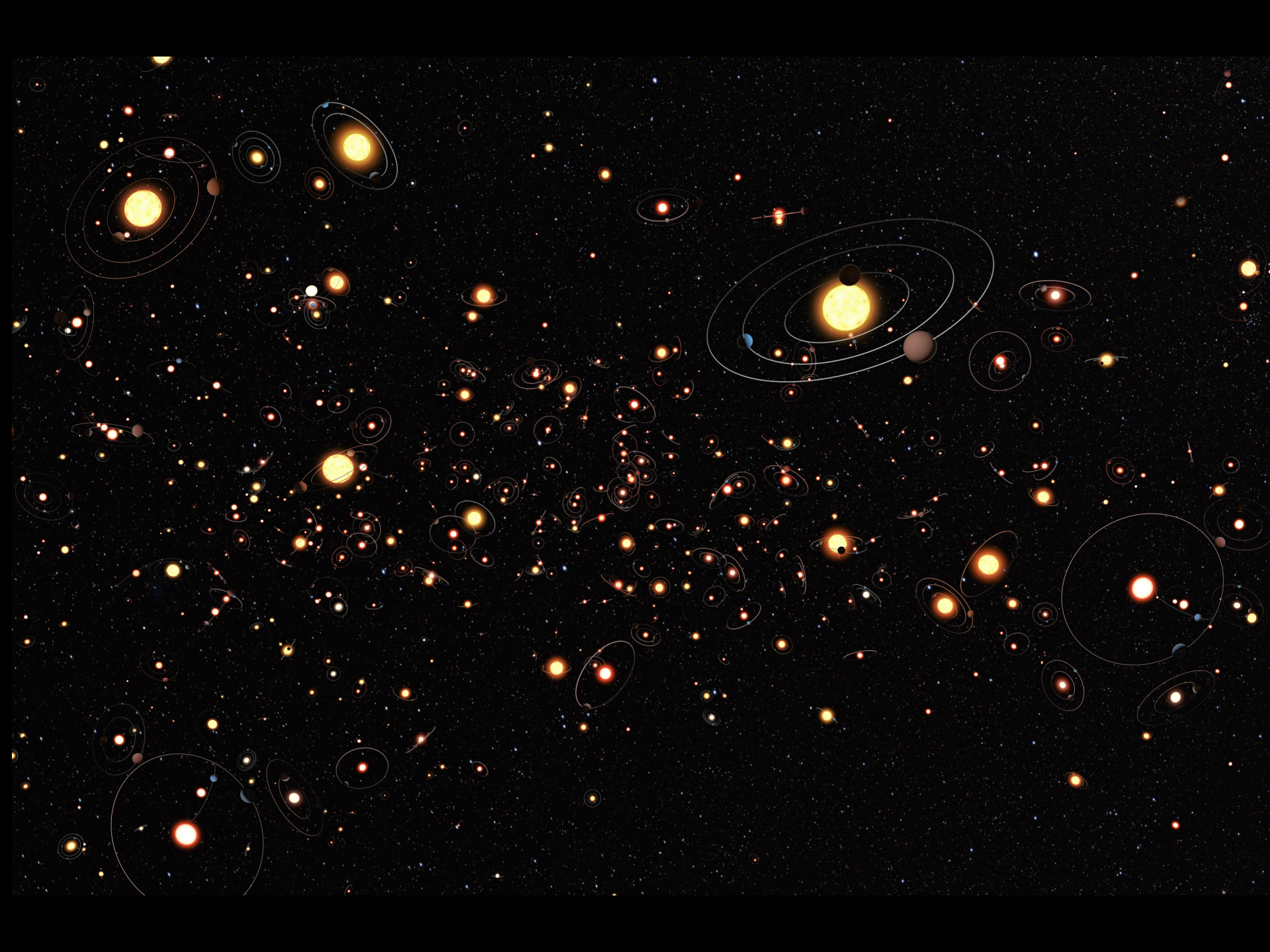
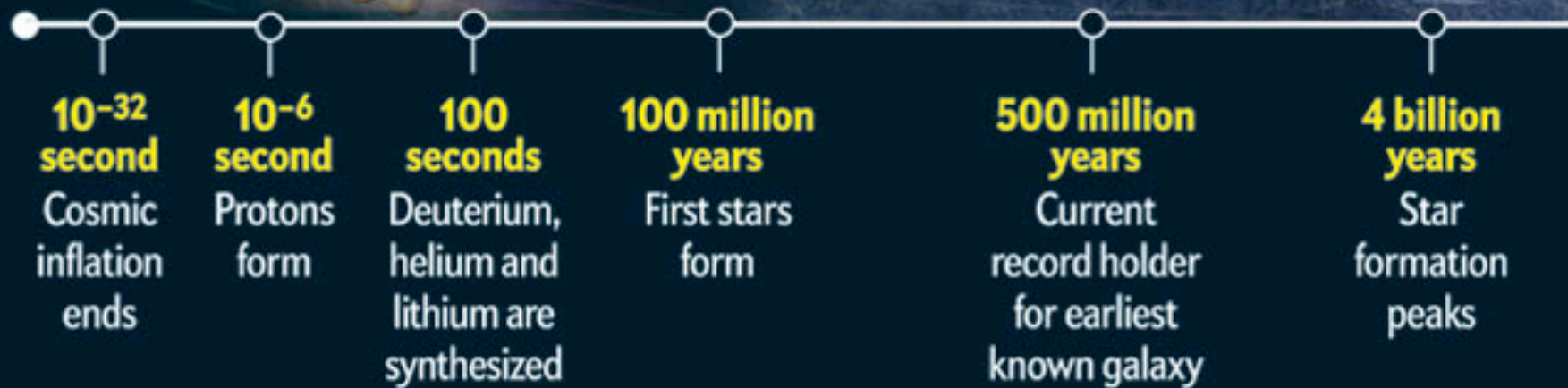
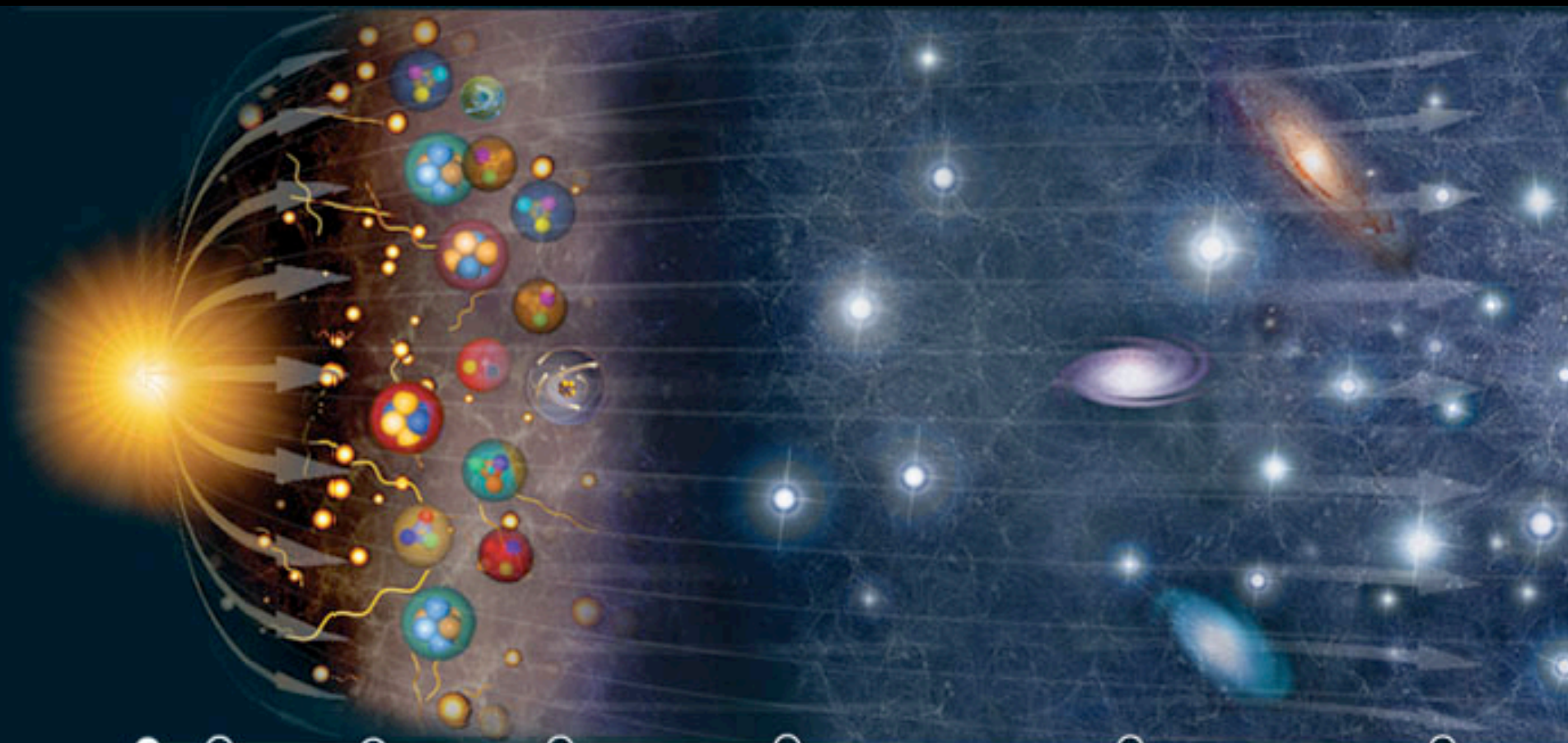


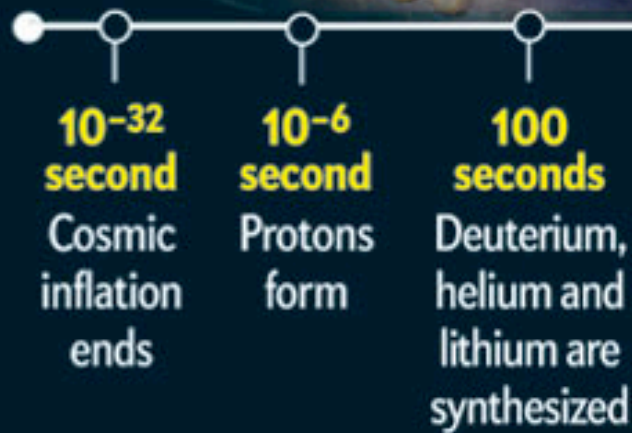
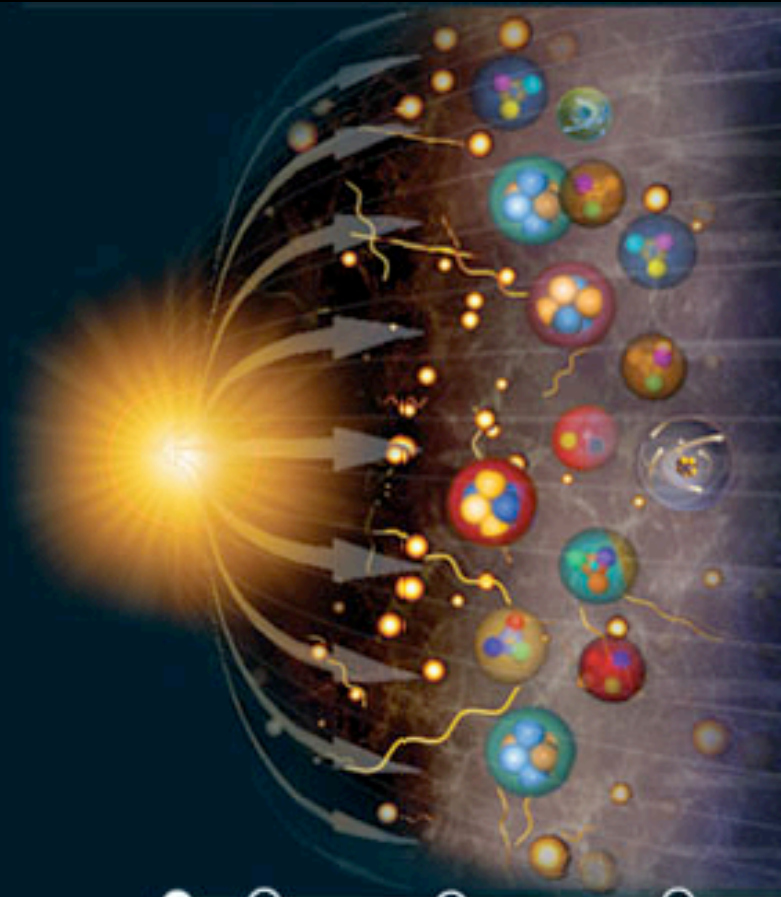


The Origin of the Elements

Lecture 1

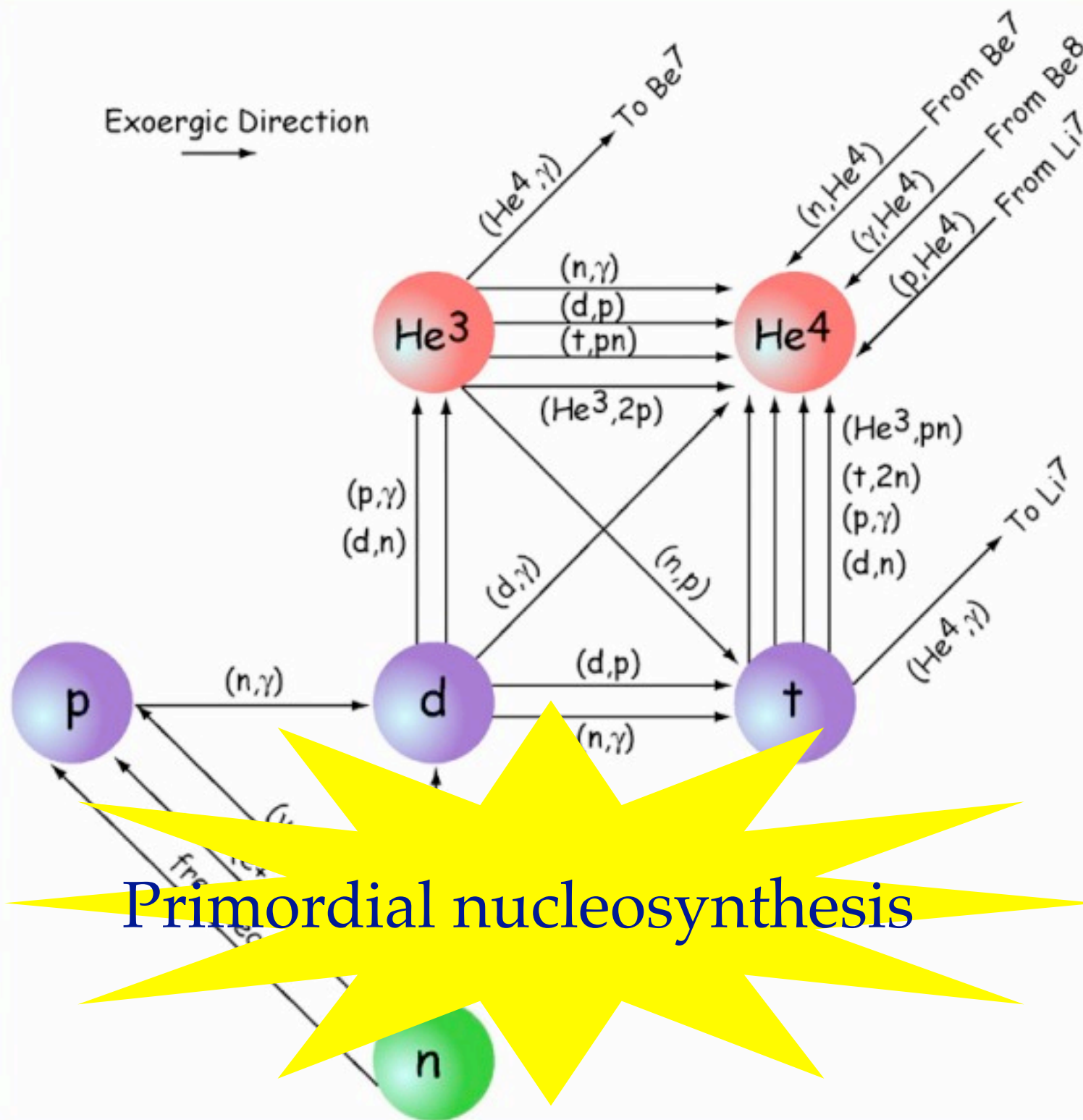




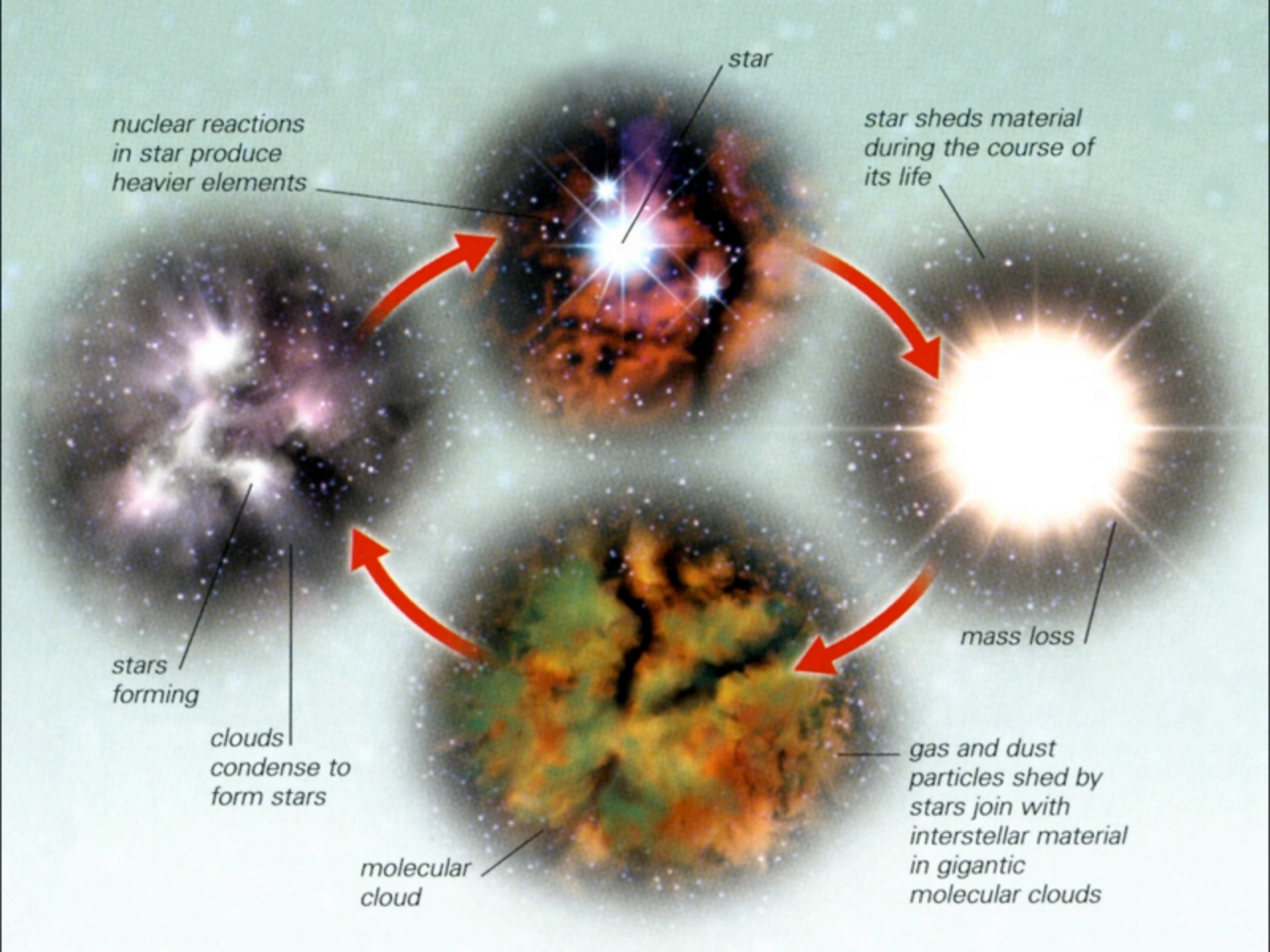


Robert Herman George Gamow Ralph Alpher





Primordial nucleosynthesis



A large, bold, black letter 'H' is centered on a white background. The letter is composed of two vertical bars and a horizontal crossbar, all in a thick, solid black font. The 'H' is perfectly symmetrical and occupies most of the frame.



He

Li Be B C N O F Ne

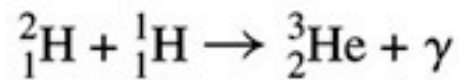
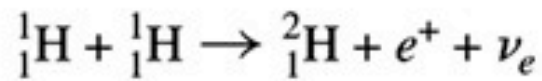
Na Mg Al Si P S Cl Ar

K Ca Sc Ti V Cr Mn Fe

Co Ni Cu Zn

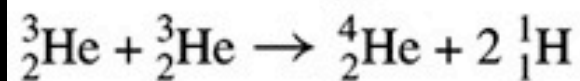
Area $\propto$
Cosmic Abundance



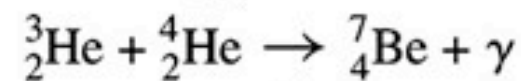


69%

31%

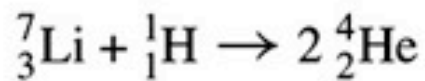
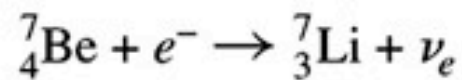


(PP I)

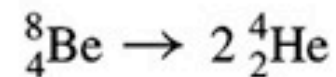
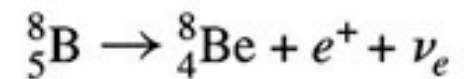
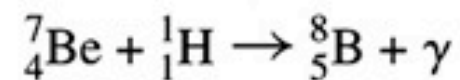


99.7%

0.3%

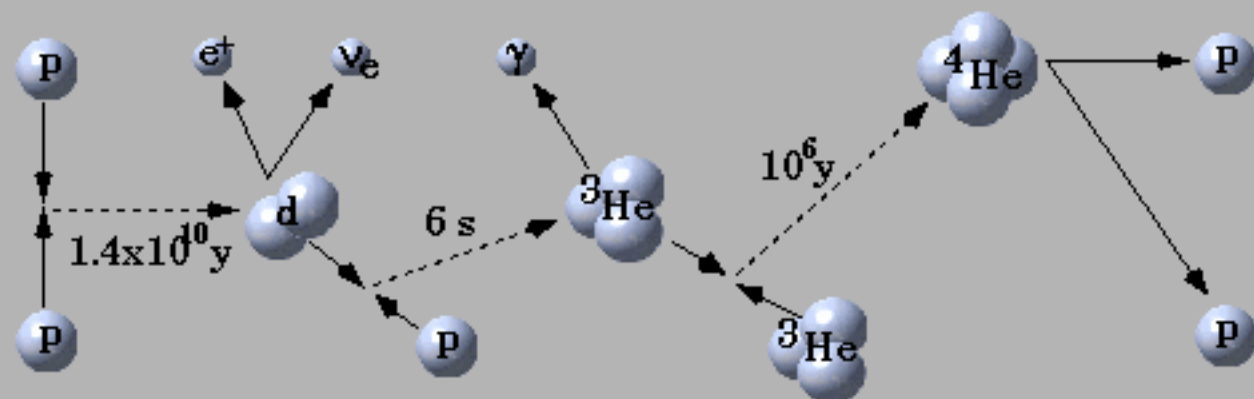


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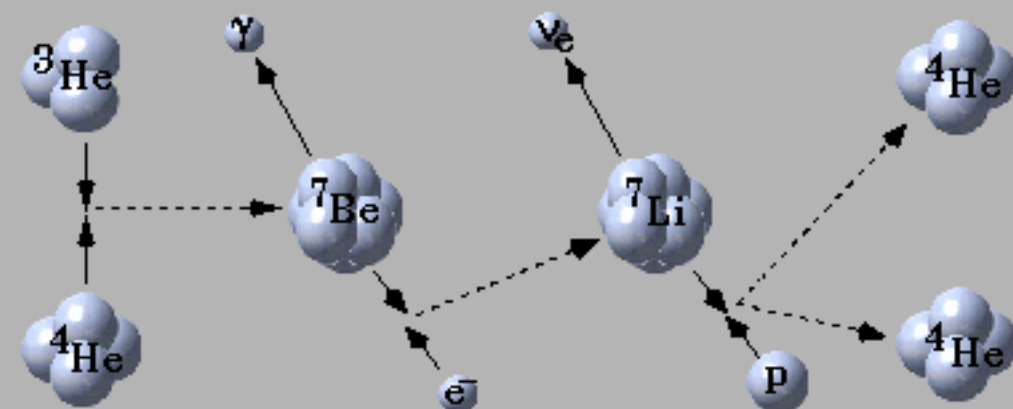


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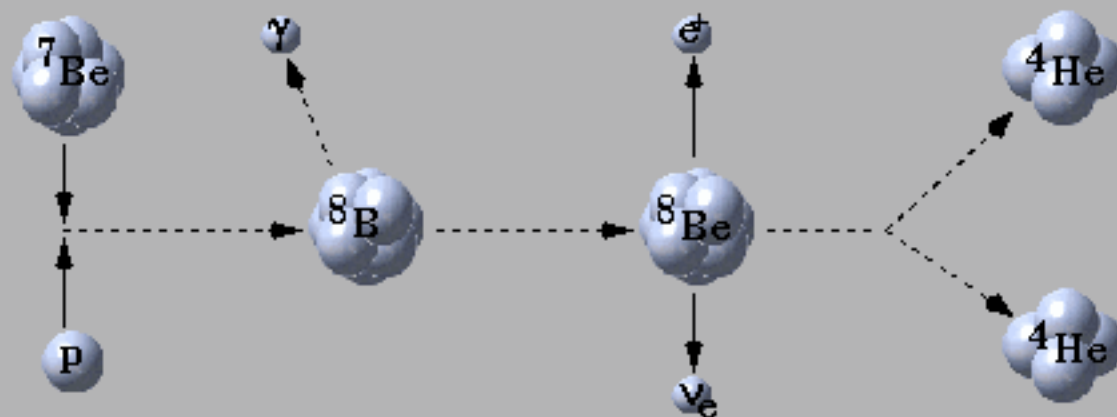
PPI

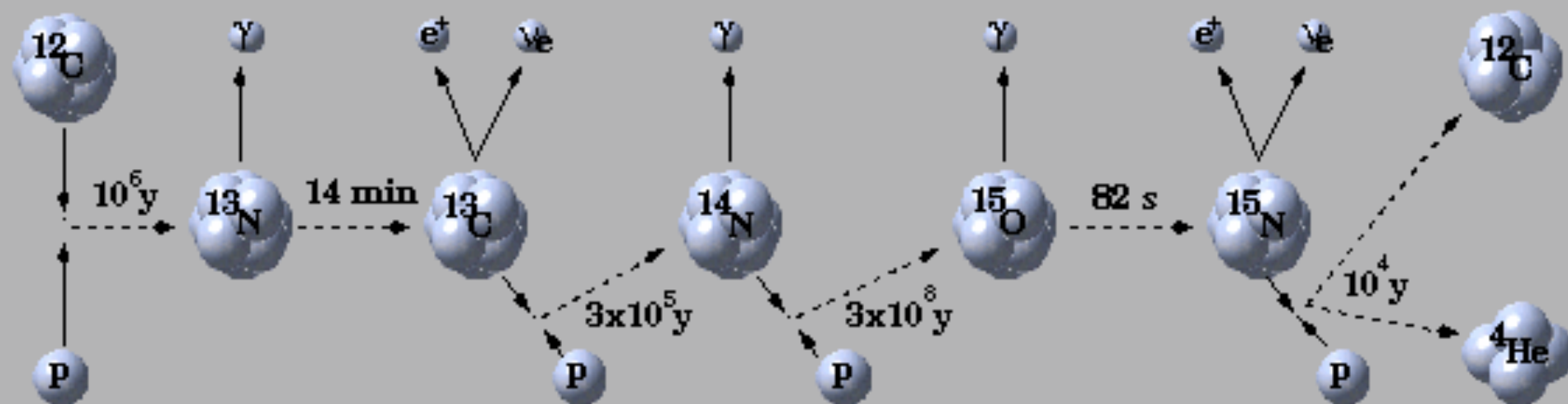


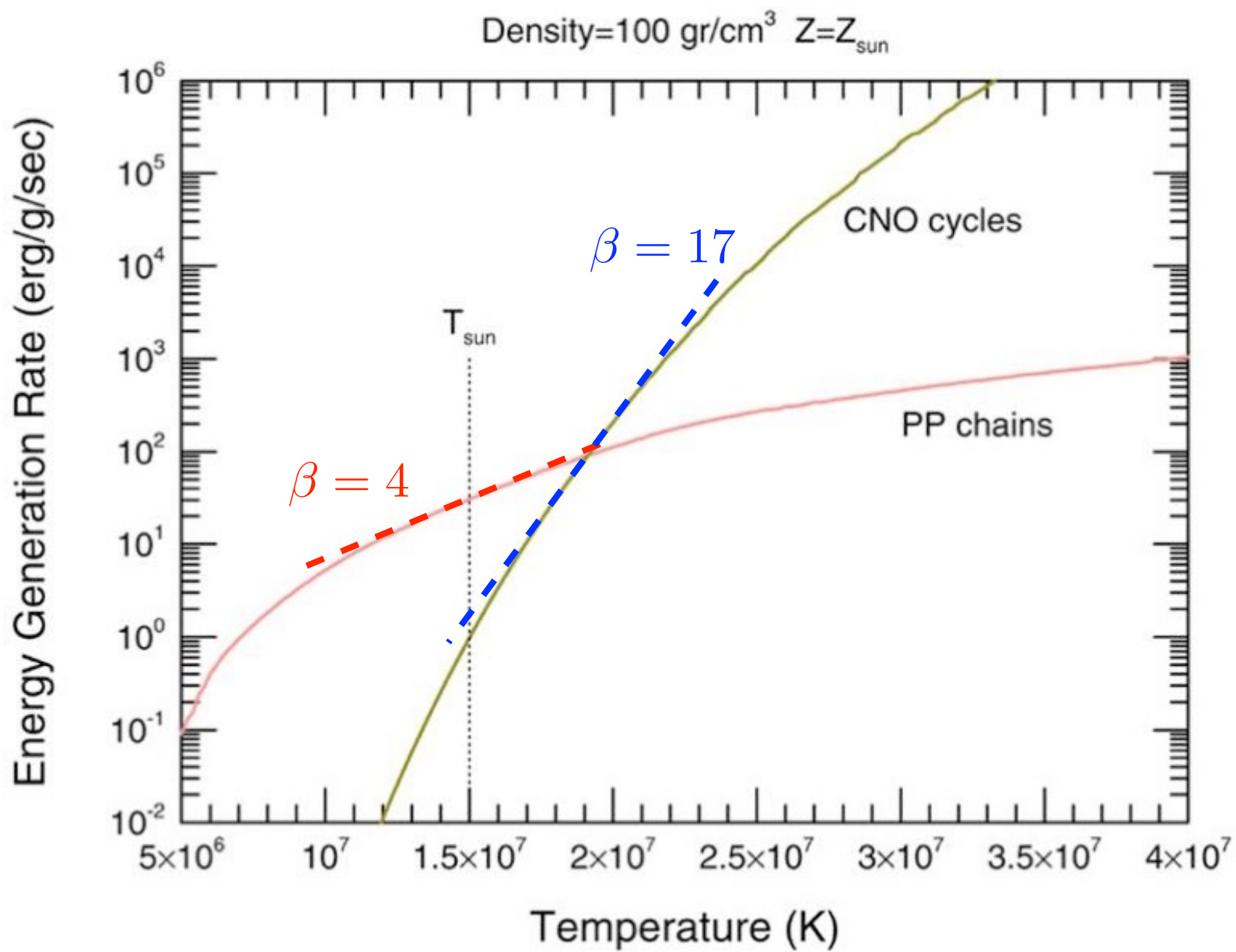
PPII



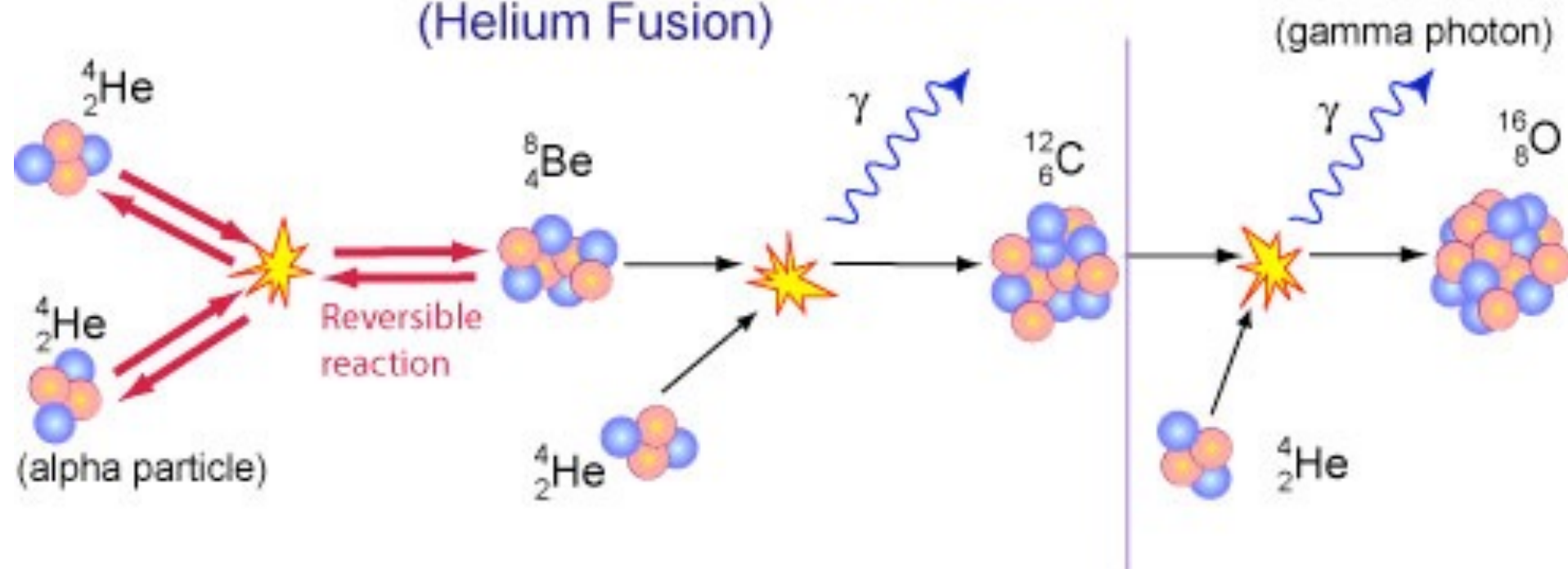
PPIII



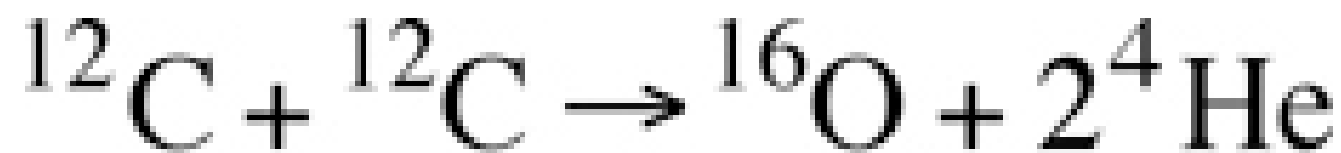


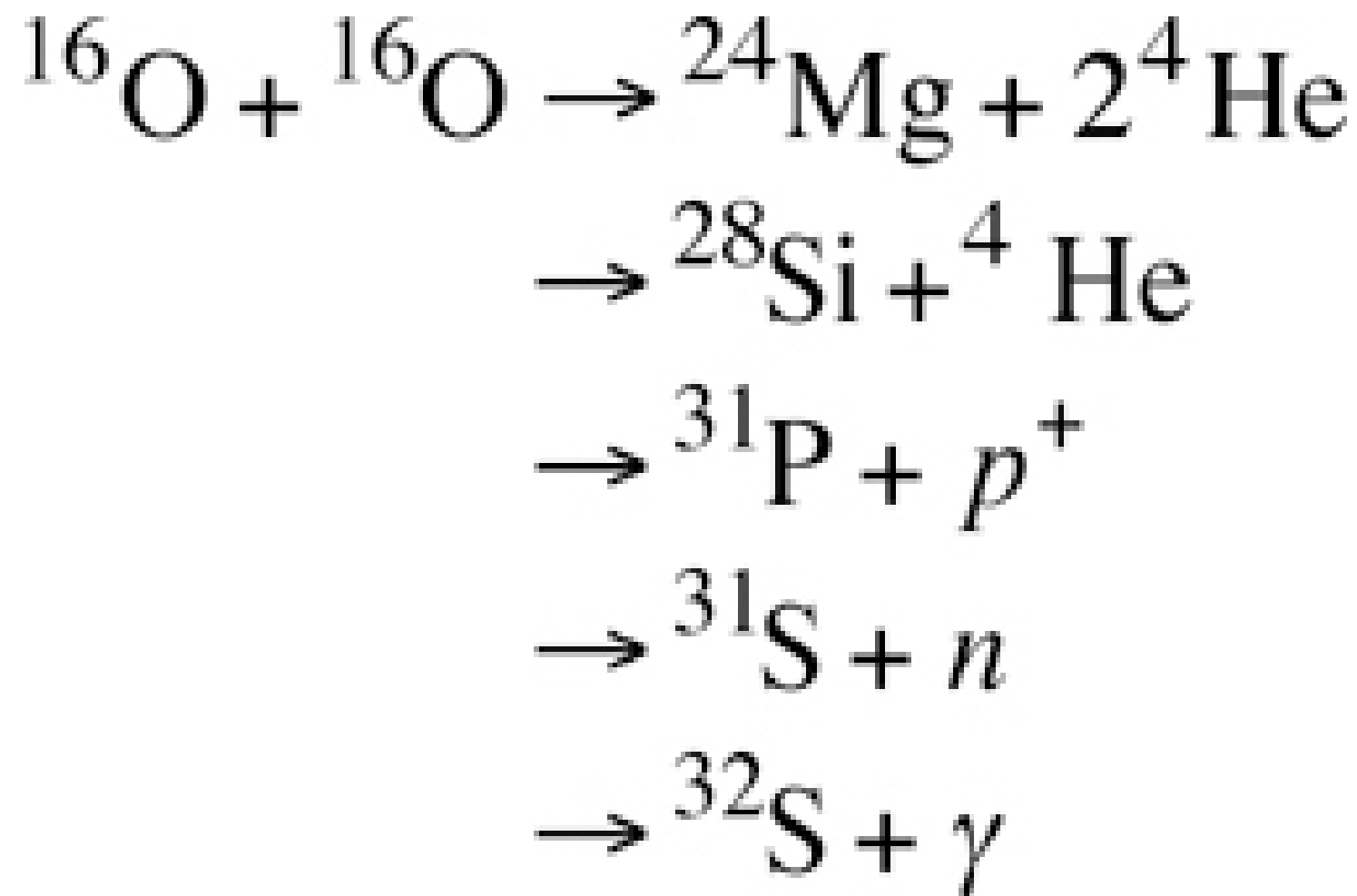


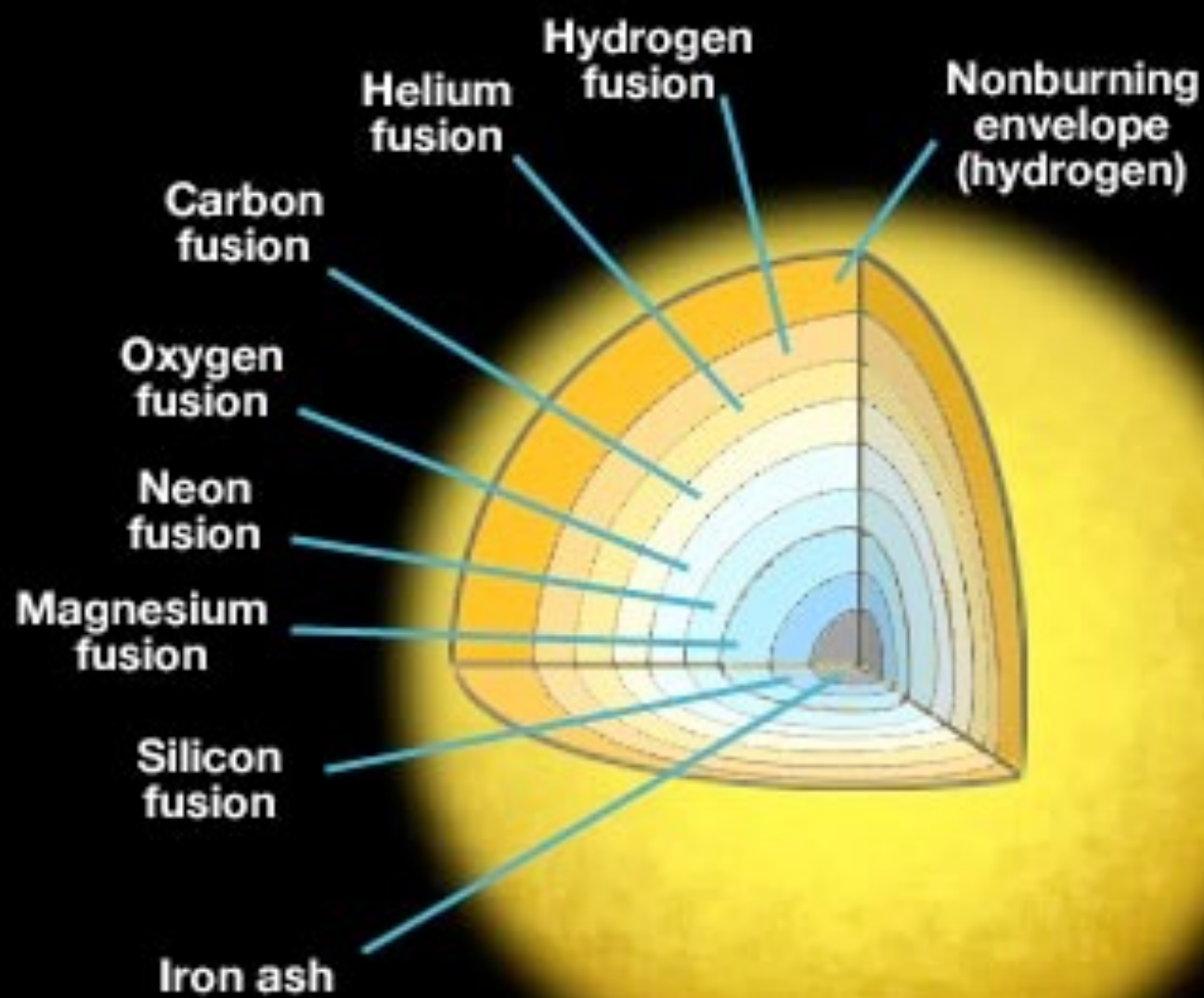
The Triple Alpha Process (Helium Fusion)

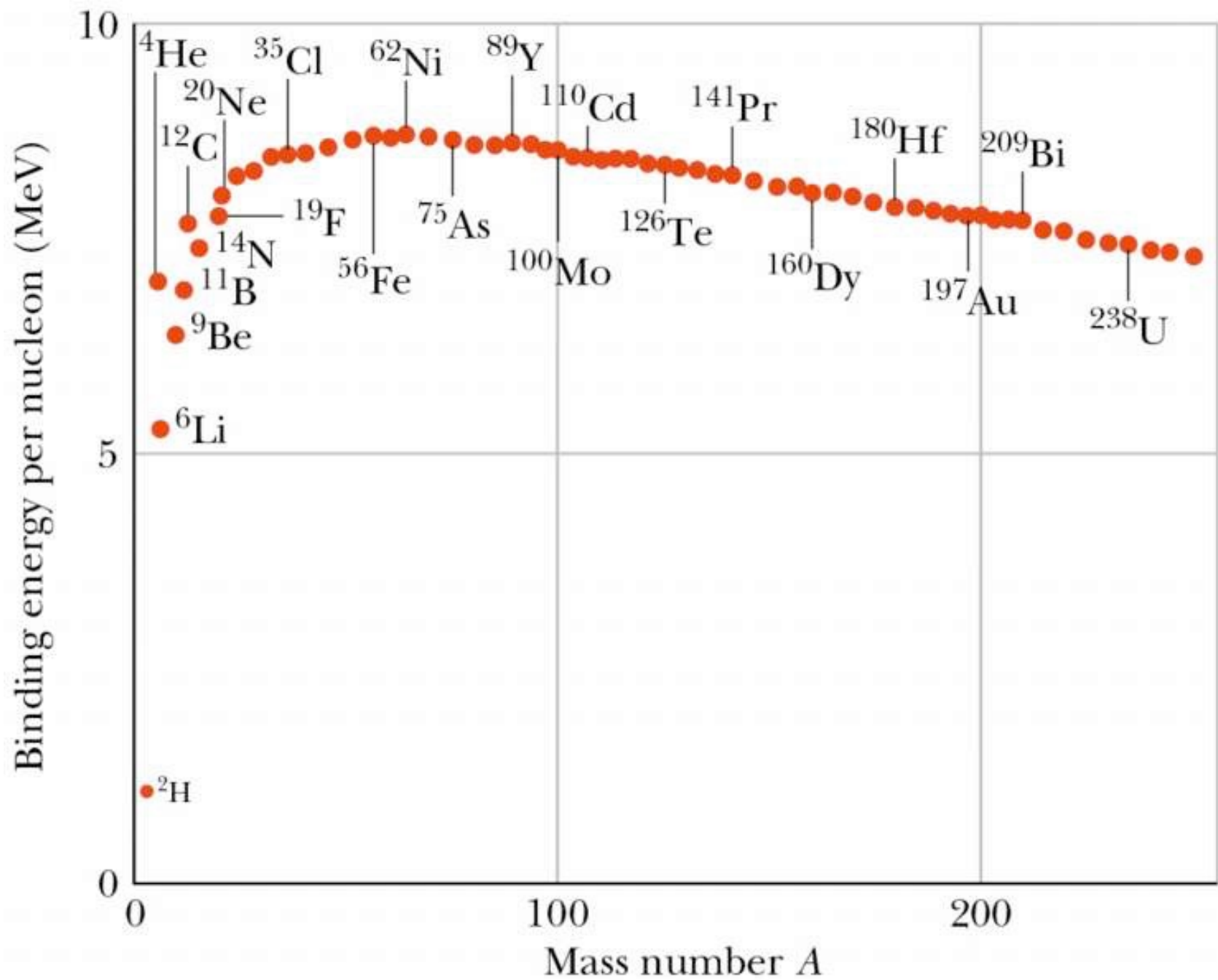




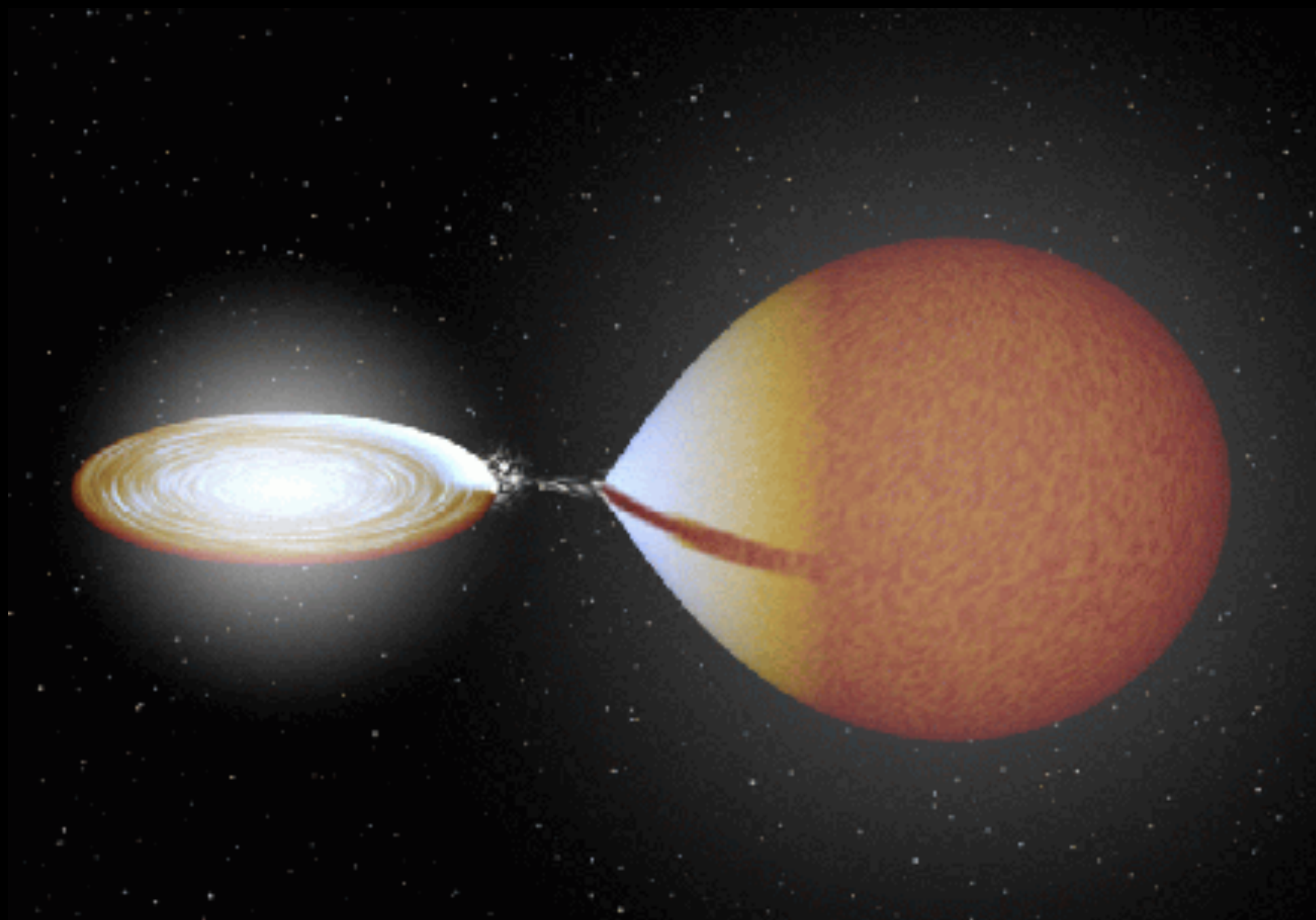






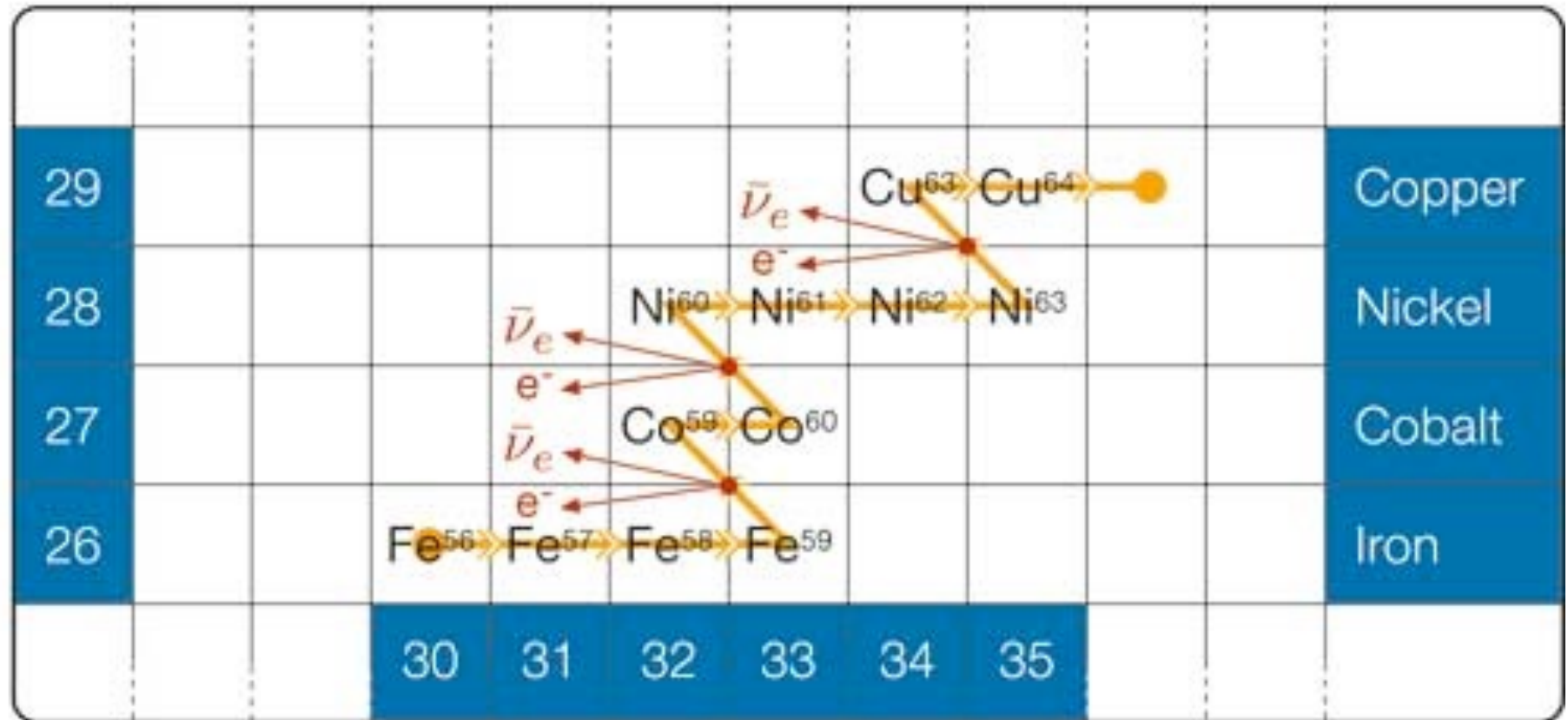






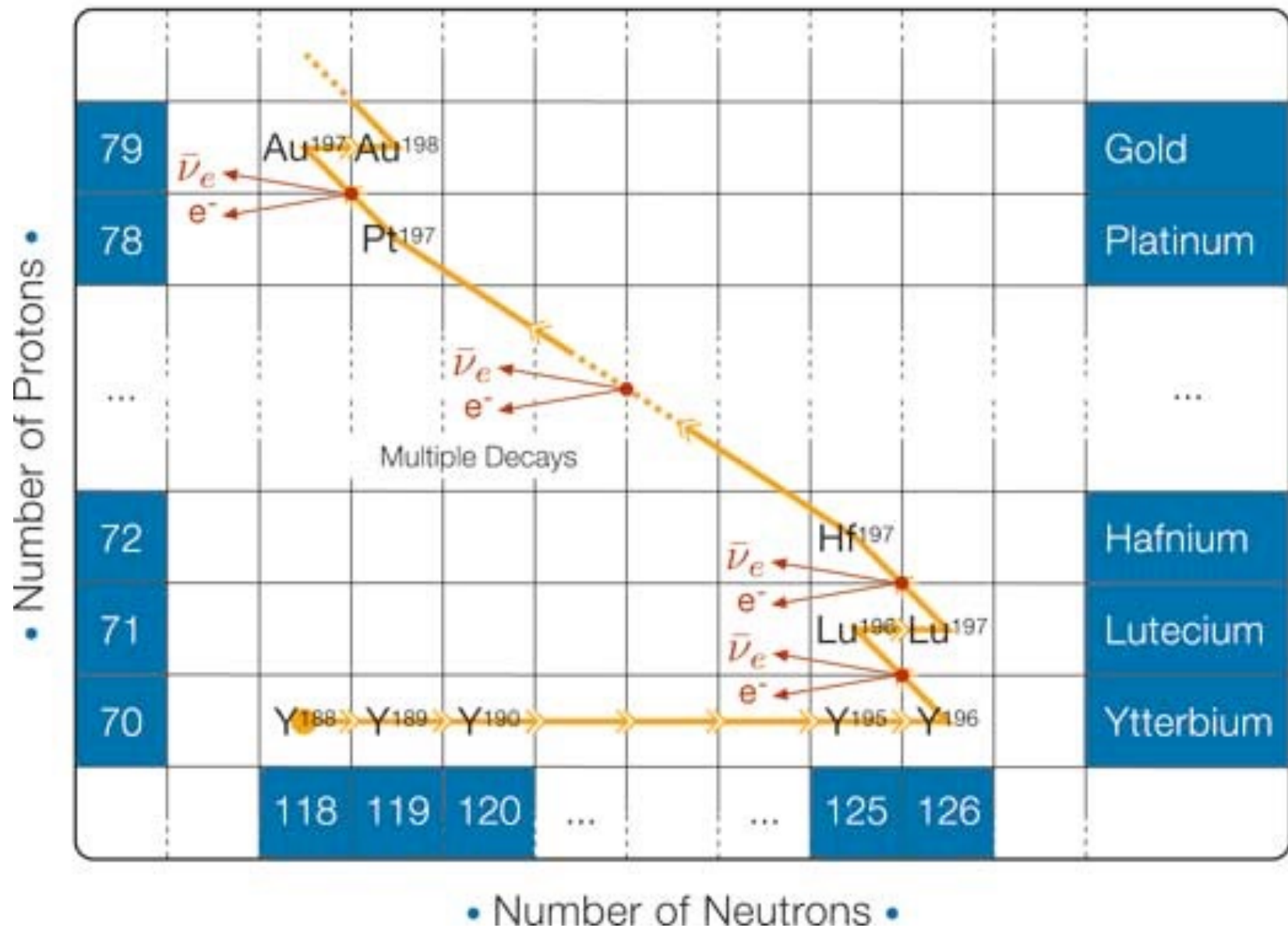
• s- Process •

• Number of Protons •



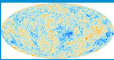
• Number of Neutrons •

• r- Process •

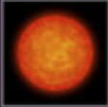
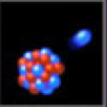




The Origin of the Solar System Elements

1 H	big bang fusion 						cosmic ray fission 						2 He						
3 Li	4 Be	merging neutron stars? 						exploding massive stars 						5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	dying low mass stars 						exploding white dwarfs 						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		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																		
		57 La	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			
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	Very radioactive isotopes; nothing left from stars											

ORIGINS OF THE ELEMENTS

H¹ Hydrogen	 The big bang  Dying low-mass stars  White dwarf supernovae  Radioactive decay																He² Helium															
Li³ Lithium	Be⁴ Beryllium	 Cosmic ray collisions  Dying high-mass stars  Merging neutron stars  Human-made																B⁵ Boron	C⁶ Carbon	N⁷ Nitrogen	O⁸ Oxygen	F⁹ Fluorine	Ne¹⁰ Neon									
Na¹¹ Sodium	Mg¹² Magnesium																	Al¹³ Aluminum	Si¹⁴ Silicon	P¹⁵ Phosphorus	S¹⁶ Sulfur	Cl¹⁷ Chlorine	Ar¹⁸ Argon									
K¹⁹ Potassium	Ca²⁰ Calcium	Sc²¹ Scandium	Ti²² Titanium	V²³ Vanadium	Cr²⁴ Chromium	Mn²⁵ Manganese	Fe²⁶ Iron	Co²⁷ Cobalt	Ni²⁸ Nickel	Cu²⁹ Copper	Zn³⁰ Zinc	Ga³¹ Gallium	Ge³² Germanium	As³³ Arsenic	Se³⁴ Selenium	Br³⁵ Bromine	Kr³⁶ Krypton															
Rb³⁷ Rubidium	Sr³⁸ Strontium	Y³⁹ Yttrium	Zr⁴⁰ Zirconium	Nb⁴¹ Niobium	Mo⁴² Molybdenum	Tc⁴³ Technetium	Ru⁴⁴ Ruthenium	Rh⁴⁵ Rhodium	Pd⁴⁶ Palladium	Ag⁴⁷ Silver	Cd⁴⁸ Cadmium	In⁴⁹ Indium	Sn⁵⁰ Tin	Sb⁵¹ Antimony	Te⁵² Tellurium	I⁵³ Iodine	Xe⁵⁴ Xenon															
Cs⁵⁵ Cesium	Ba⁵⁶ Barium																	Hf⁷² Hafnium	Ta⁷³ Tantalum	W⁷⁴ Tungsten	Re⁷⁵ Rhenium	Os⁷⁶ Osmium	Ir⁷⁷ Iridium	Pt⁷⁸ Platinum	Au⁷⁹ Gold	Hg⁸⁰ Mercury	Tl⁸¹ Thallium	Pb⁸² Lead	Bi⁸³ Bismuth	Po⁸⁴ Polonium	At⁸⁵ Astatine	Rn⁸⁶ Radon
Fr⁸⁷ Francium	Ra⁸⁸ Radium																	Rf¹⁰⁴ Rutherfordium	Db¹⁰⁵ Dubnium	Sg¹⁰⁶ Seaborgium	Bh¹⁰⁷ Bohrium	Hs¹⁰⁸ Hassium	Mt¹⁰⁹ Meitnerium	Ds¹¹⁰ Darmstadtium	Rg¹¹¹ Roentgenium	Cn¹¹² Copernicium	Nh¹¹³ Nihonium	Fl¹¹⁴ Flerovium	Mc¹¹⁵ Moscovium	Lv¹¹⁶ Livermorium	Ts¹¹⁷ Tennessine	Og¹¹⁸ Oganesson
		La⁵⁷ Lanthanum	Ce⁵⁸ Cerium	Pr⁵⁹ Praseodymium	Nd⁶⁰ Neodymium	Pm⁶¹ Promethium	Sm⁶² Samarium	Eu⁶³ Europium	Gd⁶⁴ Gadolinium	Tb⁶⁵ Terbium	Dy⁶⁶ Dysprosium	Ho⁶⁷ Holmium	Er⁶⁸ Erbium	Tm⁶⁹ Thulium	Yb⁷⁰ Ytterbium	Lu⁷¹ Lutetium																
		Ac⁸⁹ Actinium	Th⁹⁰ Thorium	Pa⁹¹ Protactinium	U⁹² Uranium	Np⁹³ Neptunium	Pu⁹⁴ Plutonium	Am⁹⁵ Americium	Cm⁹⁶ Curium	Bk⁹⁷ Berkelium	Cf⁹⁸ Californium	Es⁹⁹ Einsteinium	Fm¹⁰⁰ Fermium	Md¹⁰¹ Mendelevium	No¹⁰² Nobelium	Lr¹⁰³ Lawrencium																

This periodic table depicts the primary source on Earth for each element. In cases where two sources contribute fairly equally, both appear.