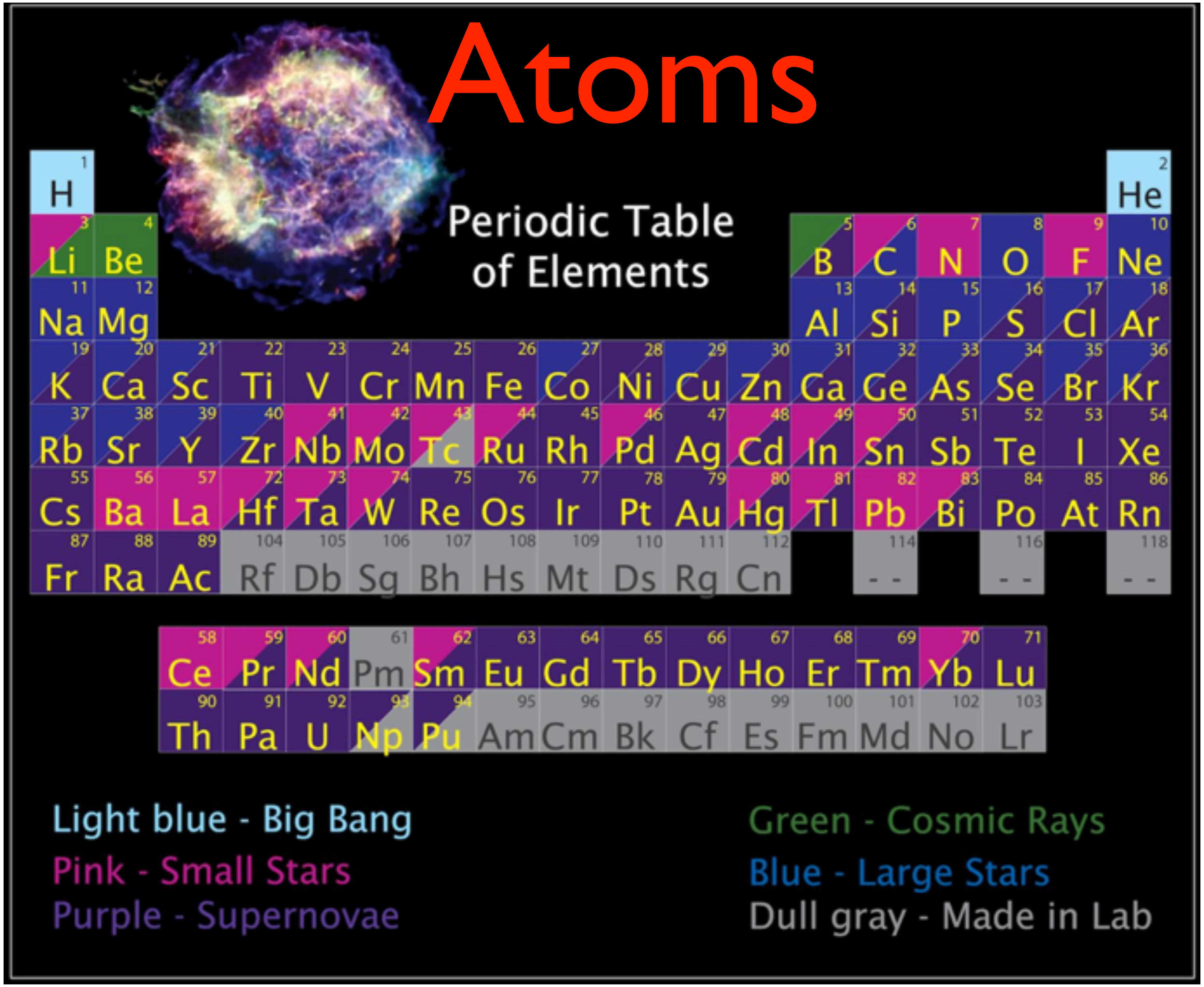
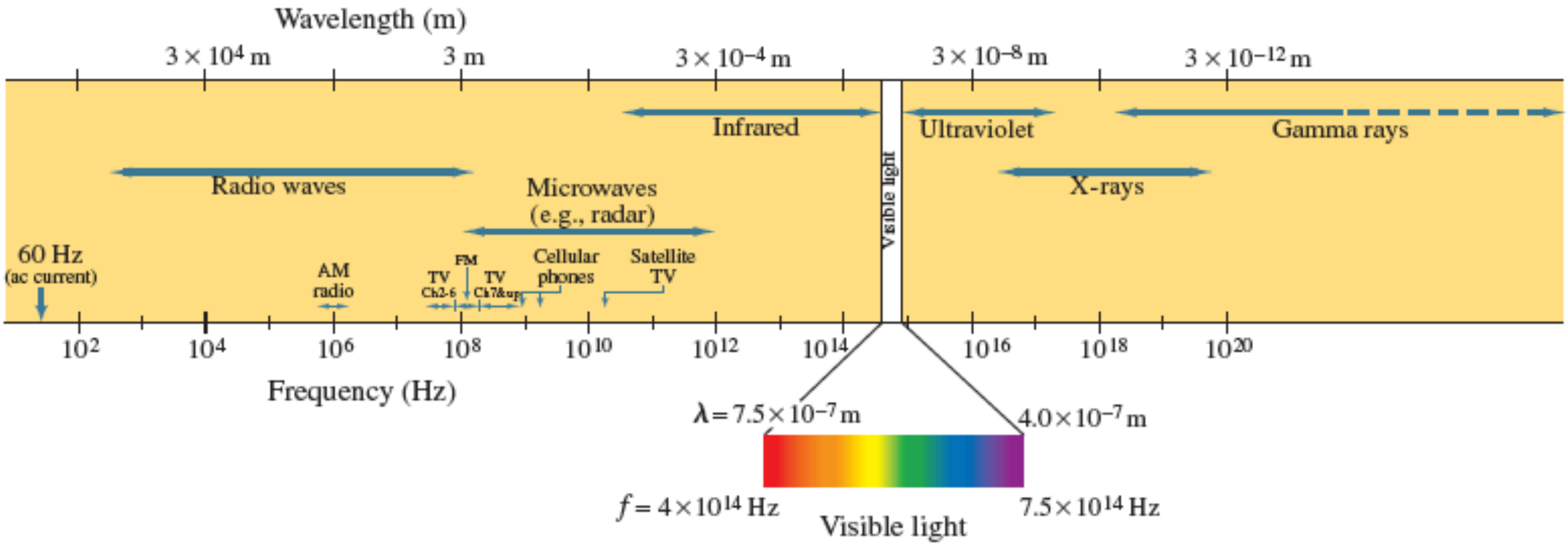
Physics 5K Lecture 5 - Friday May 4, 2012

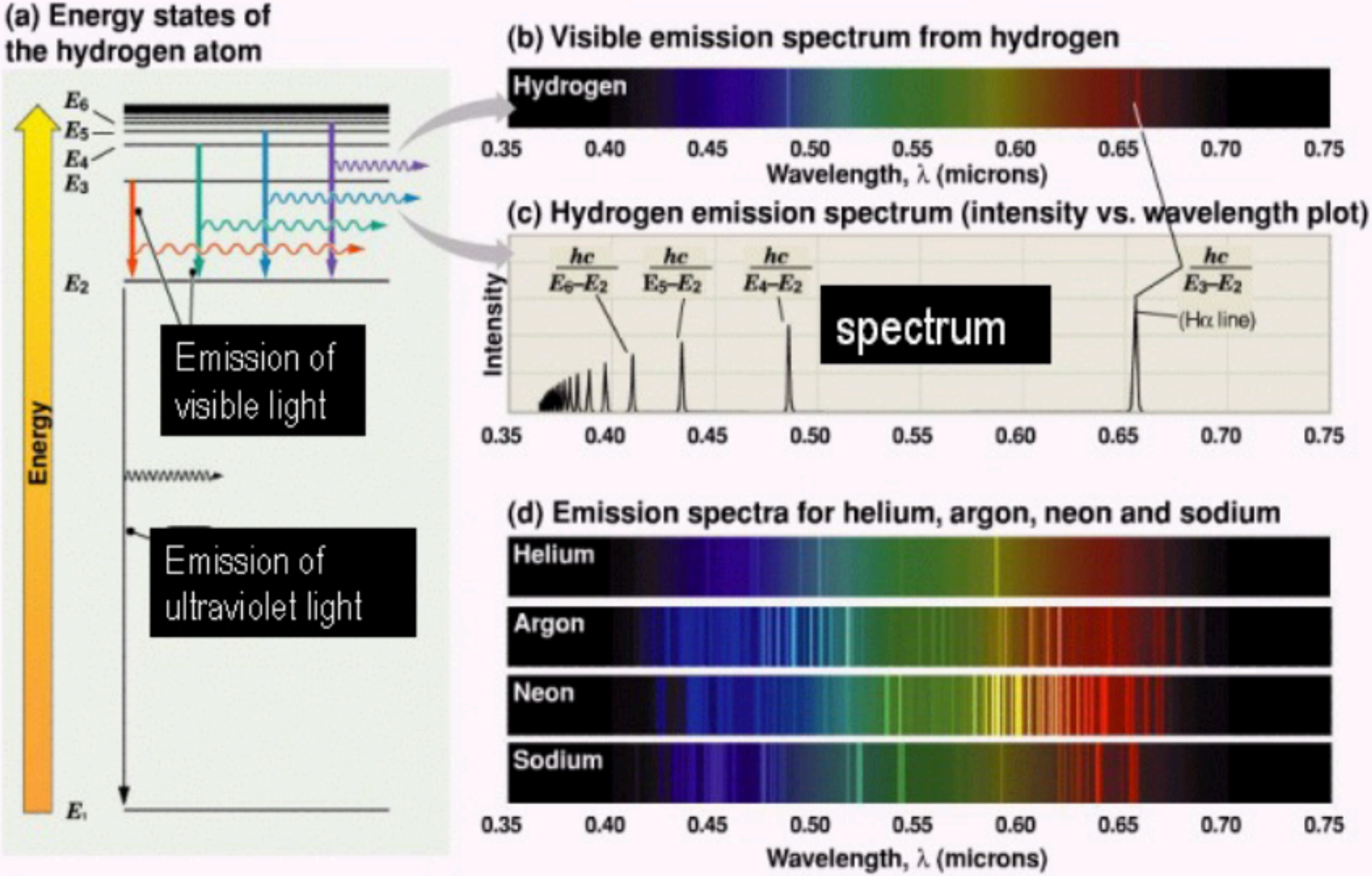


Joel Primack
Physics Department
UCSC

Giancoli **FIGURE 31–12**

The Electromagnetic Spectrum





Emission of visible light

Emission of ultraviolet light

spectrum

Each element has a characteristic spectrum

Brief History of Atomic Theory

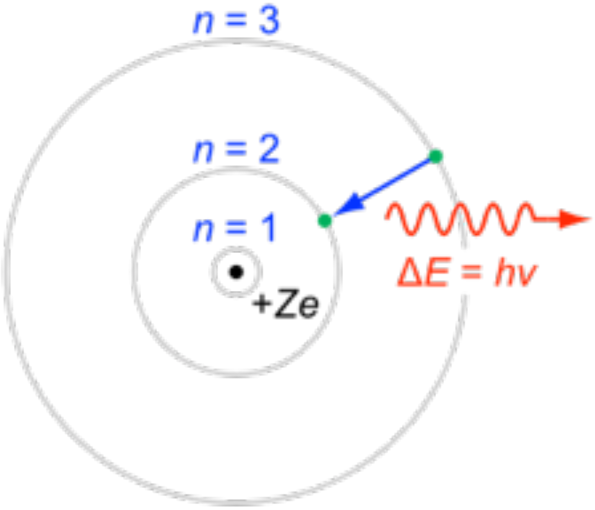
1904 Joseph J. Thomson’s "Plum Pudding" model of the atom:

a. Atoms consist of a large sphere of uniform positive charge embedded with smaller negatively charged particles (electrons).

b. The total positive charge of the sphere equals the total negative charge of the electrons.

1911 Ernest Rutherford: nuclear model of the atom

a. very small positively charged nucleus containing most of the mass of the atom
b. a very large volume around the nucleus in which electrons move
c. a nucleus containing positively charged protons
d. a number of protons equal to the number of electrons



1913 Niels Bohr’s “planetary” model for the hydrogen atom:

a. Electrons move around the nucleus in fixed orbits.
b. Electrons can only exist in certain discrete energy levels.
c. An electron in a particular orbit has constant energy.
d. An electron can absorb energy and move to a higher energy orbit of larger radius.
e. An excited electron can fall back to its original orbit by emitting energy as radiation.

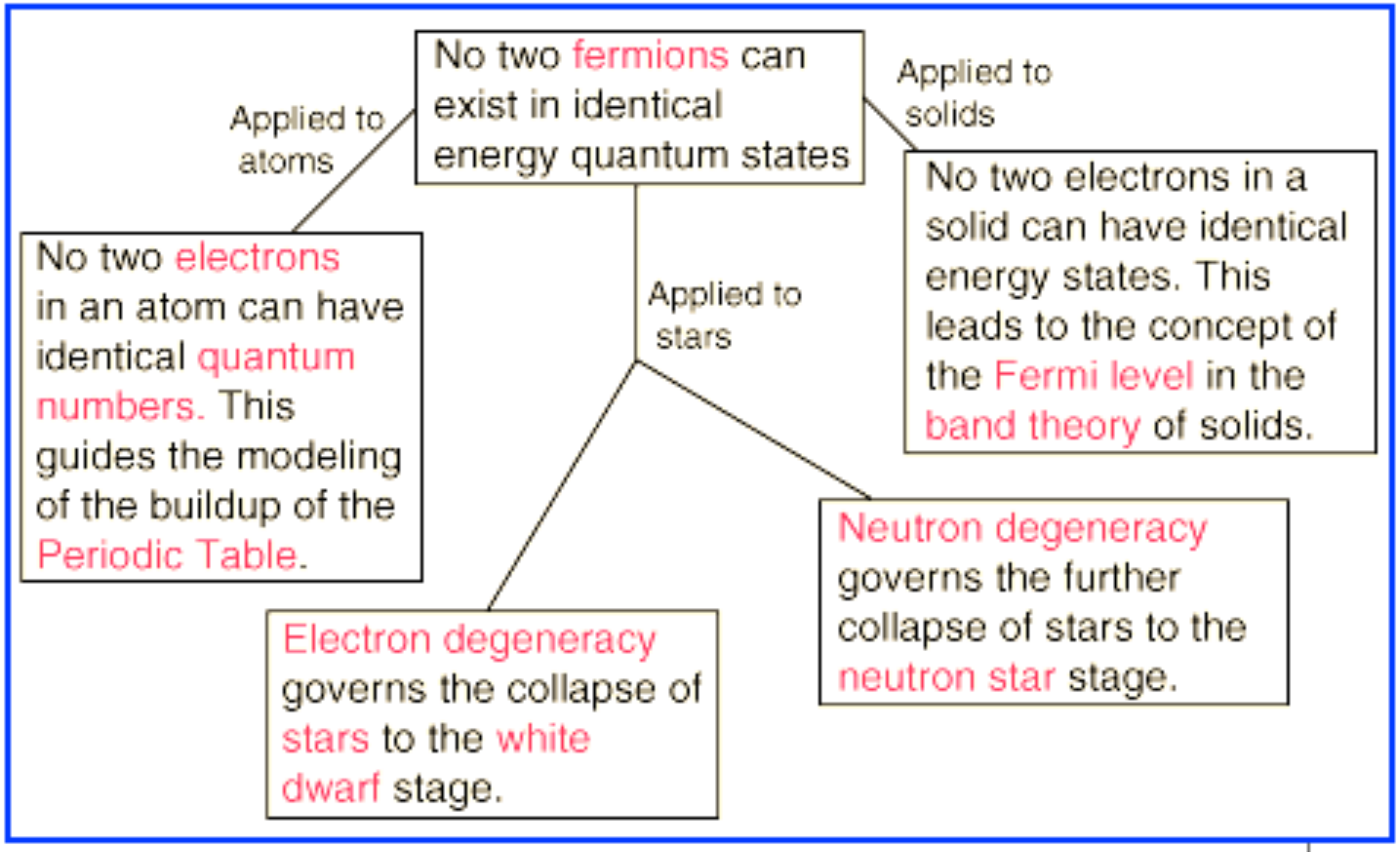
1926- Quantum Mechanical Model of the Atom

a. Electrons occupy orbitals, volumes of space around the nucleus with a high probability of finding the electron.
b. Energy levels are made up of energy sublevels.
c. Each sublevel contains a set of orbitals.
d. No orbital can contain more than 2 electrons (Pauli Exclusion Principle).

Fermions

Fermions are particles that have half-integer spin (spin 1/2, 3/2, ...) and therefore are constrained by the Pauli exclusion principle. Fermions incude electrons, protons, neutrons. Particles with integer spin are called bosons, and they behave very differently.

Pauli Exclusion Principle Applications



No two fermions can exist in identical energy quantum states

Applied to atoms

No two electrons in an atom can have identical quantum numbers. This guides the modeling of the buildup of the Periodic Table.

Applied to stars

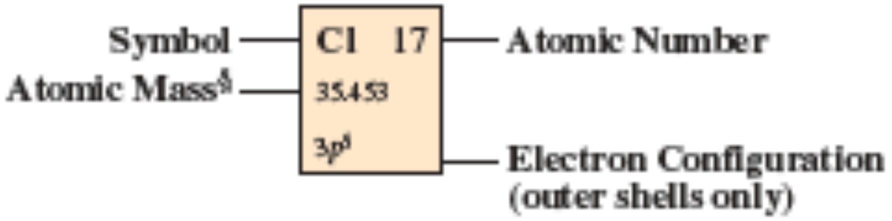
Electron degeneracy governs the collapse of stars to the white dwarf stage.

Neutron degeneracy governs the further collapse of stars to the neutron star stage.

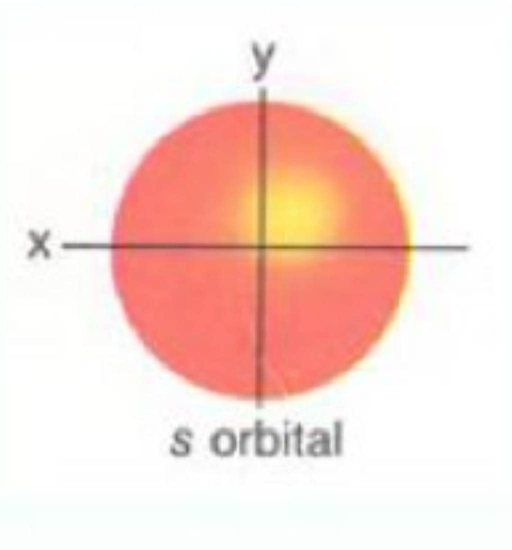
Applied to solids

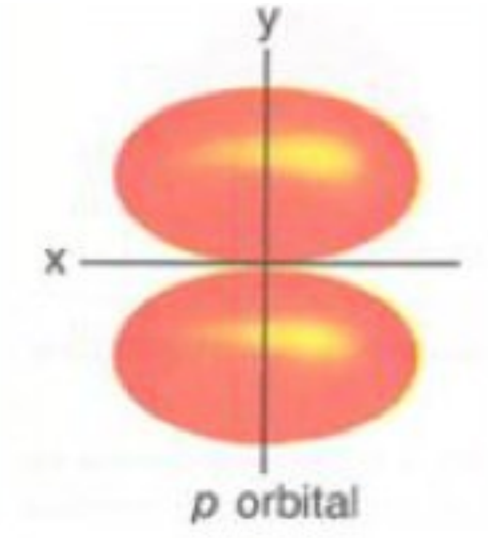
No two electrons in a solid can have identical energy states. This leads to the concept of the Fermi level in the band theory of solids.

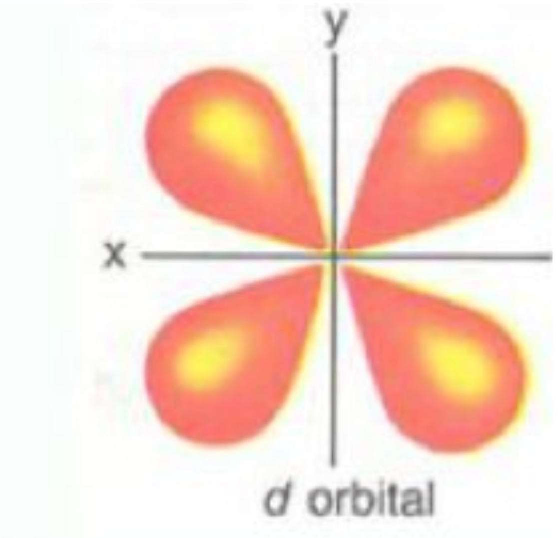
Periodic Table of the Elements§

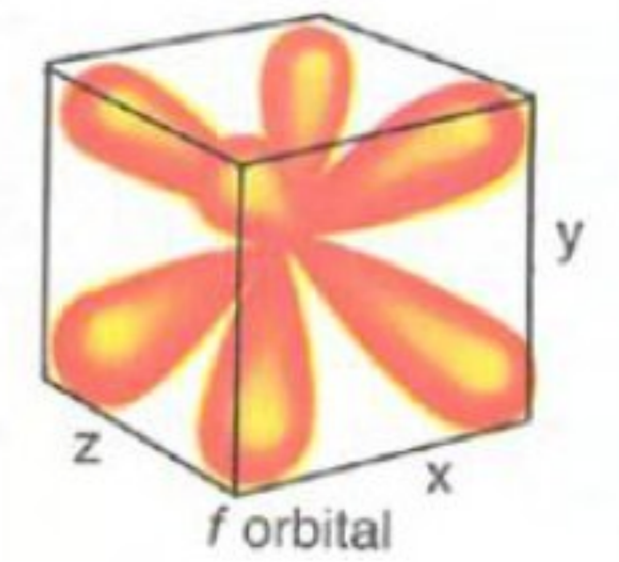


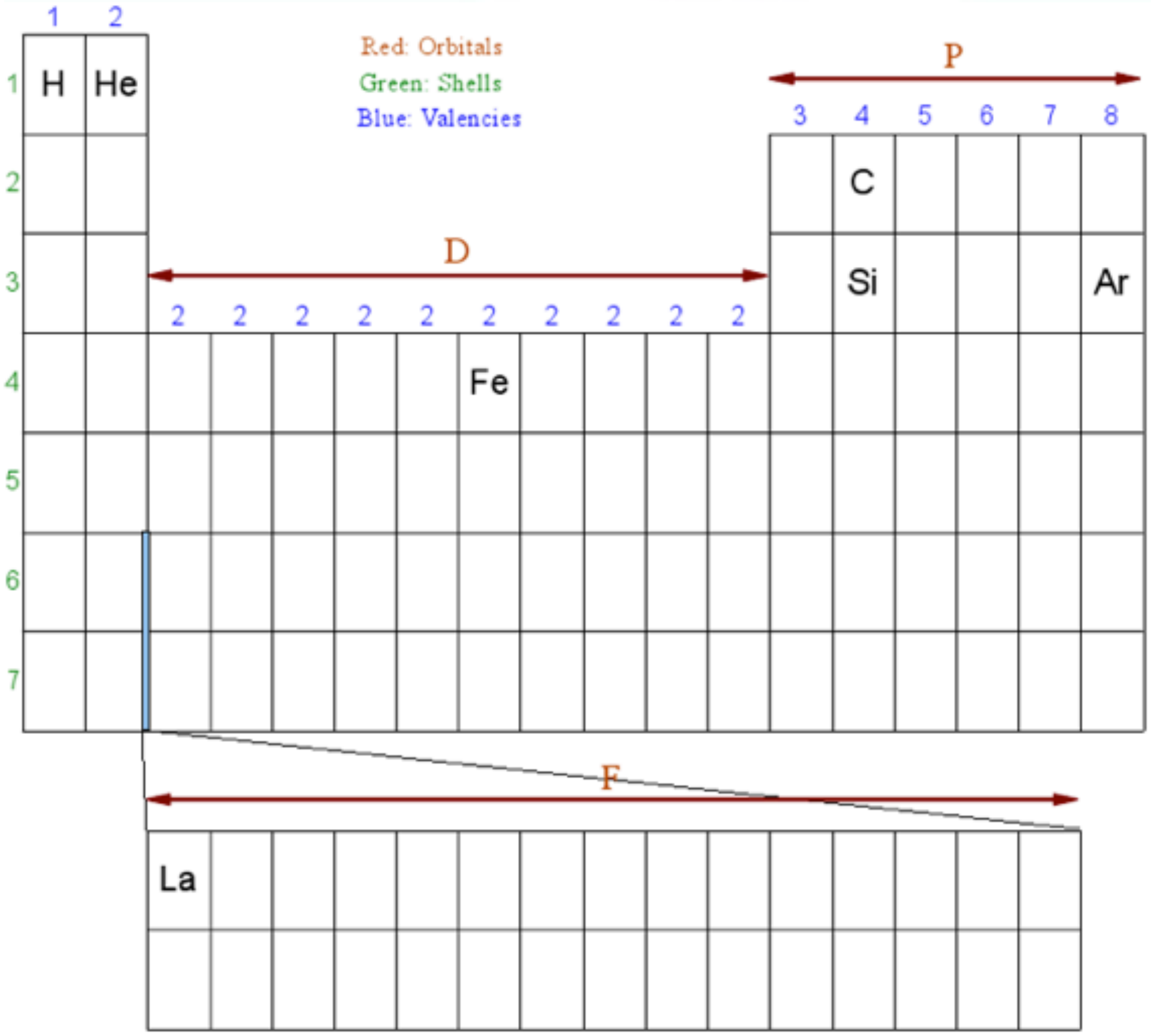
Group I	Group II	Transition Elements										Group III	Group IV	Group V	Group VI	Group VII	Group VIII
H 1 1.00794 $1s^{1}$																	**He** 2 4.002602 $1s^{2}$
Li 3 6.941 $2s^{1}$	**Be** 4 9.012182 $2s^{2}$											**B** 5 10.811 $2p^{1}$	**C** 6 12.0107 $2p^{2}$	**N** 7 14.0067 $2p^{3}$	**O** 8 15.9994 $2p^{4}$	**F** 9 18.9984032 $2p^{5}$	**Ne** 10 20.1797 $2p^{6}$
Na 11 22.98976928 $3s^{1}$	**Mg** 12 24.3050 $3s^{2}$											**Al** 13 26.9815386 $3p^{1}$	**Si** 14 28.0855 $3p^{2}$	**P** 15 30.973762 $3p^{3}$	**S** 16 32.065 $3p^{4}$	**Cl** 17 35.453 $3p^{5}$	**Ar** 18 39.948 $3p^{6}$
K 19 39.0983 $4s^{1}$	**Ca** 20 40.078 $4s^{2}$	**Sc** 21 44.955912 $3d^{1}4s^{2}$	**Ti** 22 47.867 $3d^{2}4s^{2}$	**V** 23 50.9415 $3d^{3}4s^{2}$	**Cr** 24 51.9961 $3d^{5}4s^{1}$	**Mn** 25 54.938045 $3d^{5}4s^{2}$	**Fe** 26 55.845 $3d^{6}4s^{2}$	**Co** 27 58.933195 $3d^{7}4s^{2}$	**Ni** 28 58.6934 $3d^{8}4s^{2}$	**Cu** 29 63.546 $3d^{10}4s^{1}$	**Zn** 30 65.409 $3d^{10}4s^{2}$	**Ga** 31 69.723 $4p^{1}$	**Ge** 32 72.64 $4p^{2}$	**As** 33 74.92160 $4p^{3}$	**Se** 34 78.96 $4p^{4}$	**Br** 35 79.904 $4p^{5}$	**Kr** 36 83.798 $4p^{6}$
Rb 37 85.4678 $5s^{1}$	**Sr** 38 87.62 $5s^{2}$	**Y** 39 88.90585 $4d^{1}5s^{2}$	**Zr** 40 91.224 $4d^{2}5s^{2}$	**Nb** 41 92.90638 $4d^{4}5s^{1}$	**Mo** 42 95.94 $4d^{5}5s^{1}$	**Tc** 43 (98) $4d^{5}5s^{2}$	**Ru** 44 101.07 $4d^{7}5s^{1}$	**Rh** 45 102.90550 $4d^{8}5s^{1}$	**Pd** 46 106.42 $4d^{10}5s^{0}$	**Ag** 47 107.8682 $4d^{10}5s^{1}$	**Cd** 48 112.411 $4d^{10}5s^{2}$	**In** 49 114.818 $5p^{1}$	**Sn** 50 118.710 $5p^{2}$	**Sb** 51 121.760 $5p^{3}$	**Te** 52 127.60 $5p^{4}$	**I** 53 126.90447 $5p^{5}$	**Xe** 54 131.293 $5p^{6}$
Cs 55 132.9054519 $6s^{1}$	**Ba** 56 137.327 $6s^{2}$	57–71†	**Hf** 72 178.49 $5d^{2}6s^{2}$	**Ta** 73 180.94788 $5d^{3}6s^{2}$	**W** 74 183.84 $5d^{4}6s^{2}$	**Re** 75 186.207 $5d^{5}6s^{2}$	**Os** 76 190.23 $5d^{6}6s^{2}$	**Ir** 77 192.217 $5d^{7}6s^{2}$	**Pt** 78 195.084 $5d^{9}6s^{1}$	**Au** 79 196.966569 $5d^{10}6s^{1}$	**Hg** 80 200.59 $5d^{10}6s^{2}$	**Tl** 81 204.3833 $6p^{1}$	**Pb** 82 207.2 $6p^{2}$	**Bi** 83 208.98040 $6p^{3}$	**Po** 84 (209) $6p^{4}$	**At** 85 (210) $6p^{5}$	**Rn** 86 (222) $6p^{6}$
Fr 87 (223) $7s^{1}$	**Ra** 88 (226) $7s^{2}$	89–103‡	**Rf** 104 (267) $6d^{2}7s^{2}$	**Db** 105 (268) $6d^{3}7s^{2}$	**Sg** 106 (271) $6d^{4}7s^{2}$	**Bh** 107 (272) $6d^{5}7s^{2}$	**Hs** 108 (277) $6d^{6}7s^{2}$	**Mt** 109 (276) $6d^{7}7s^{2}$	**Ds** 110 (281) $6d^{9}7s^{1}$	**Rg** 111 (280) $6d^{10}7s^{1}$	112 (285) $6d^{10}7s^{2}$						
†Lanthanide Series			**La** 57 138.90547 $5d^{1}6s^{2}$	**Ce** 58 140.116 $4f^{1}5d^{1}6s^{2}$	**Pr** 59 140.90765 $4f^{3}5d^{0}6s^{2}$	**Nd** 60 144.242 $4f^{4}5d^{0}6s^{2}$	**Pm** 61 (145) $4f^{5}5d^{0}6s^{2}$	**Sm** 62 150.36 $4f^{6}5d^{0}6s^{2}$	**Eu** 63 151.964 $4f^{7}5d^{0}6s^{2}$	**Gd** 64 157.25 $4f^{7}5d^{1}6s^{2}$	**Tb** 65 158.92535 $4f^{9}5d^{0}6s^{2}$	**Dy** 66 162.500 $4f^{10}5d^{0}6s^{2}$	**Ho** 67 164.93032 $4f^{11}5d^{0}6s^{2}$	**Er** 68 167.259 $4f^{12}5d^{0}6s^{2}$	**Tm** 69 168.93421 $4f^{13}5d^{0}6s^{2}$	**Yb** 70 173.04 $4f^{14}5d^{0}6s^{2}$	**Lu** 71 174.967 $4f^{14}5d^{1}6s^{2}$
‡Actinide Series			**Ac** 89 (227) $6d^{1}7s^{2}$	**Th** 90 232.03806 $6d^{2}7s^{2}$	**Pa** 91 231.03588 $5f^{2}6d^{1}7s^{2}$	**U** 92 238.0289 $5f^{3}6d^{1}7s^{2}$	**Np** 93 (237) $5f^{4}6d^{1}7s^{2}$	**Pu** 94 (244) $5f^{6}6d^{0}7s^{2}$	**Am** 95 (243) $5f^{7}6d^{0}7s^{2}$	**Cm** 96 (247) $5f^{7}6d^{1}7s^{2}$	**Bk** 97 (247) $5f^{9}6d^{0}7s^{2}$	**Cf** 98 (251) $5f^{10}6d^{0}7s^{2}$	**Es** 99 (252) $5f^{11}6d^{0}7s^{2}$	**Fm** 100 (257) $5f^{12}6d^{0}7s^{2}$	**Md** 101 (258) $5f^{13}6d^{0}7s^{2}$	**No** 102 (259) $5f^{14}6d^{0}7s^{2}$	**Lr** 103 (262) $5f^{14}6d^{1}7s^{2}$











Hydrogen's shell configuration is $1S^1$, meaning its lone electron resides in the 1st energy level and forms a probability cloud in the shape of an S-orbital (which is a sphere). The last '1' just means it has 1 electron.

Helium (He) has a configuration of $1S^2$.

Carbon (C), which has 6 electrons, is $1S^2$ - $2S^2$ - $2P^2$. Add up the number of electrons to confirm that C has 6 electrons: 2 + 2 + 2 = 6.

Silicon, which has 14 electrons, $1S^2$ - $2S^2$ - $2P^6$ - $3S^2$ - $3P^2$. Add up the number of electrons to confirm that Si has 14 electrons: 2 + 2 + 6 + 2 + 2 = 14

Iron (Fe) has 26 electrons:

$1S^2$ - $2S^2$ - $2P^6$ - $3S^2$ - $3P^6$ - $3D^6$ - $4S^2$

Lanthanum (La) has 57 electrons:

$1S^2$ - $2S^2$ - $2P^6$ - $3S^2$ - $3P^6$ - $3D^{10}$ - $4S^2$ - $4P^6$ - $4D^{10}$ - $4F^1$ - $5S^2$ - $5P^6$ - $6S^2$

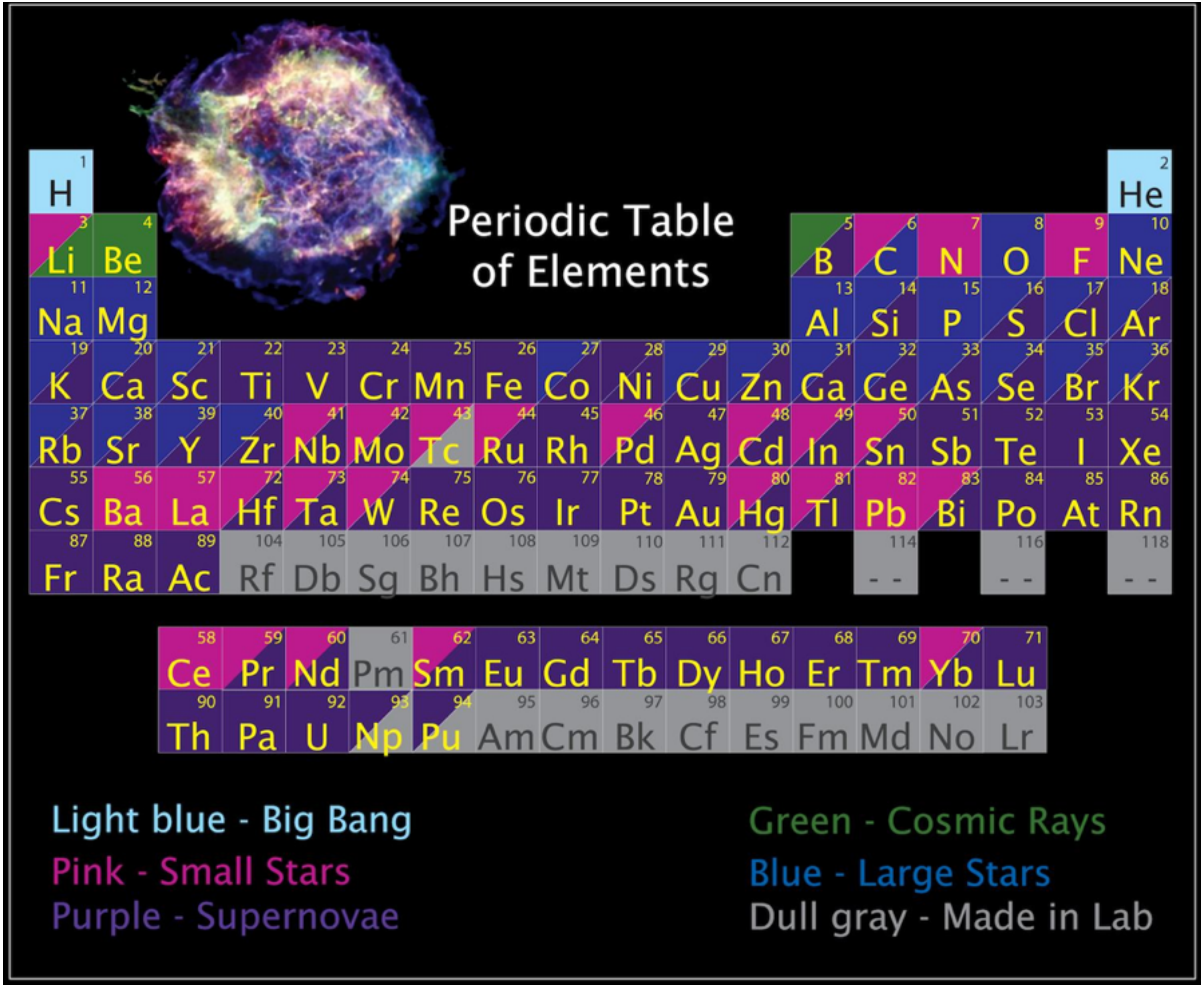
Atoms

The various kinds of atoms have different origins. Hydrogen and helium, the two lightest kinds, were made in the first few minutes of the universe after the Big Bang. A little more helium was made in stars by fusion, as we discussed in connection with barrier penetration.

After stars fuse the hydrogen in their cores, they start to fuse helium in their cores and they become red giant stars. Stars like the sun makes elements like carbon and nitrogen in this phase, but then they run out of fuel, eject their outer material, and become white dwarf stars surrounded briefly by their ejected outer material. These often beautiful objects are called planetary nebulae.

Big stars that start out with at least 8 times the mass of the sun have much more violent ends. They fuse much of the carbon and nitrogen into still heavier elements, like oxygen, sodium, magnesium, aluminum, and silicon. But pretty soon they can't make any more energy by fusion, their cores collapse into either neutron stars or black holes, and much of their material is ejected in spectacular supernovae. During the supernova process, the really heavy elements are made, all the way up to thorium and uranium. Such core collapse supernovas are called Type II supernovas.

Sometimes the white dwarf stars just fade slowly into black dwarfs. But roughly half of all stars are in binary systems, and if a white dwarf star has a close companion star that becomes a red giant, the white dwarf can accrete material from its companion by gravity until it becomes so massive that the entire star explodes as a thermonuclear bomb, turning much of its mass into elements like cobalt, nickel, and iron. This is called a Type 1a supernova.



Periodic Table of Elements

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 Ds	111 Rg	112 Cn		114 - -		116 - -		118 - -
		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		

Light blue - Big Bang

Pink - Small Stars

Purple - Supernovae

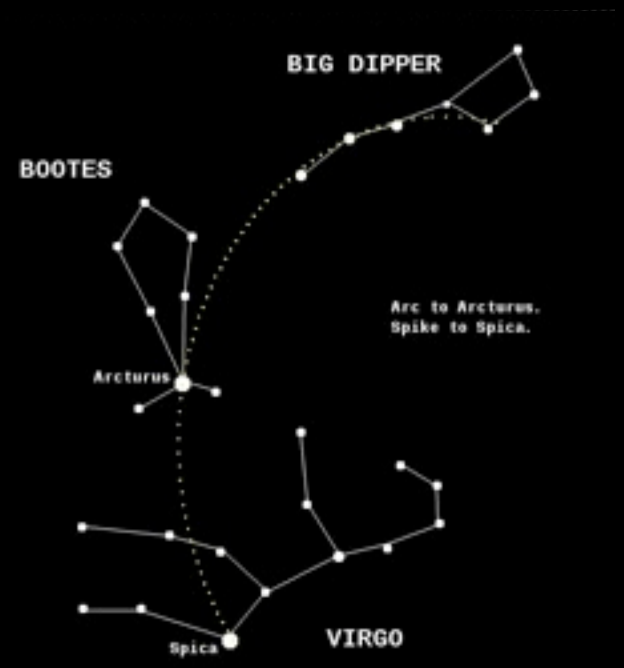
Green - Cosmic Rays

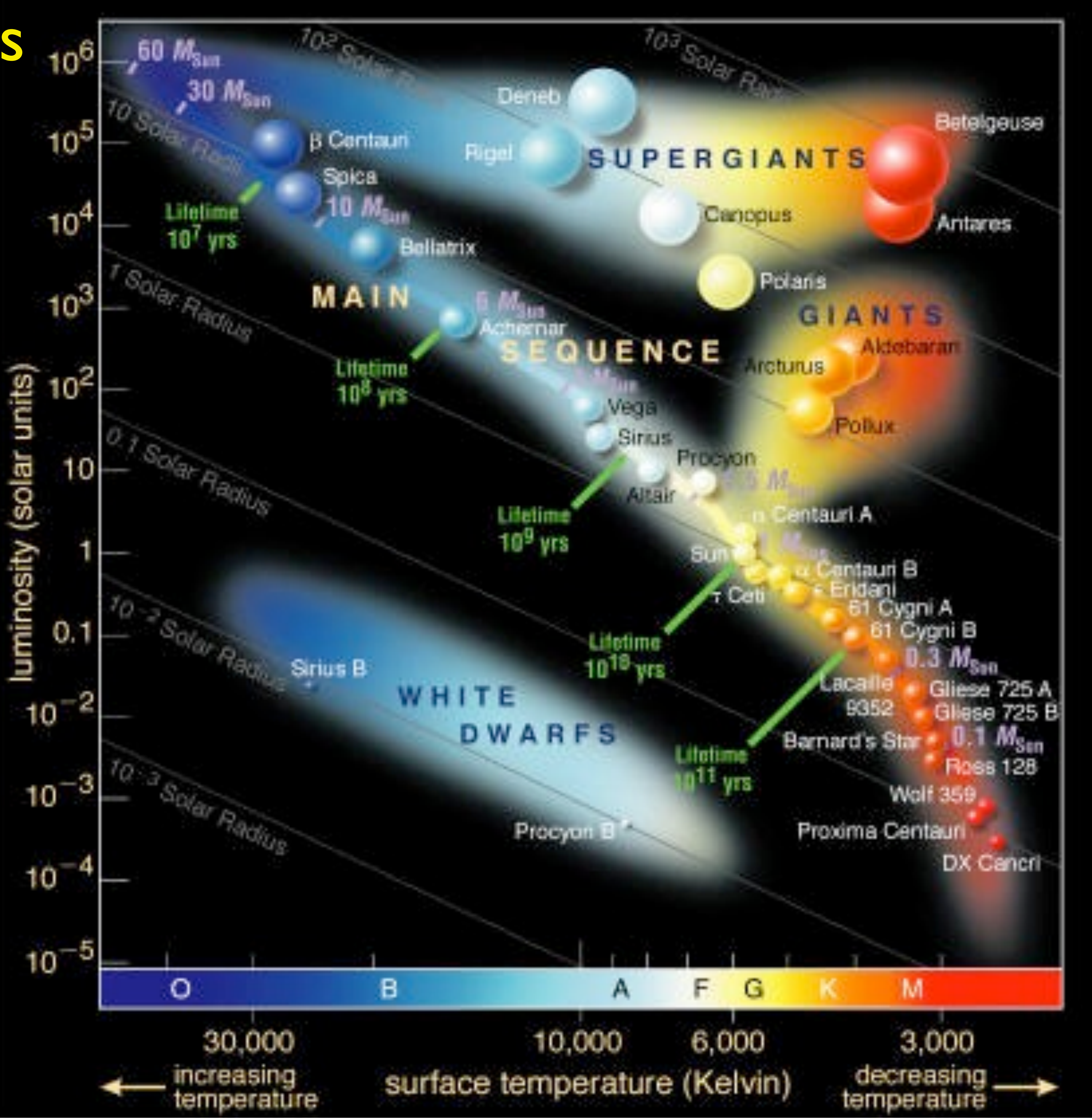
Blue - Large Stars

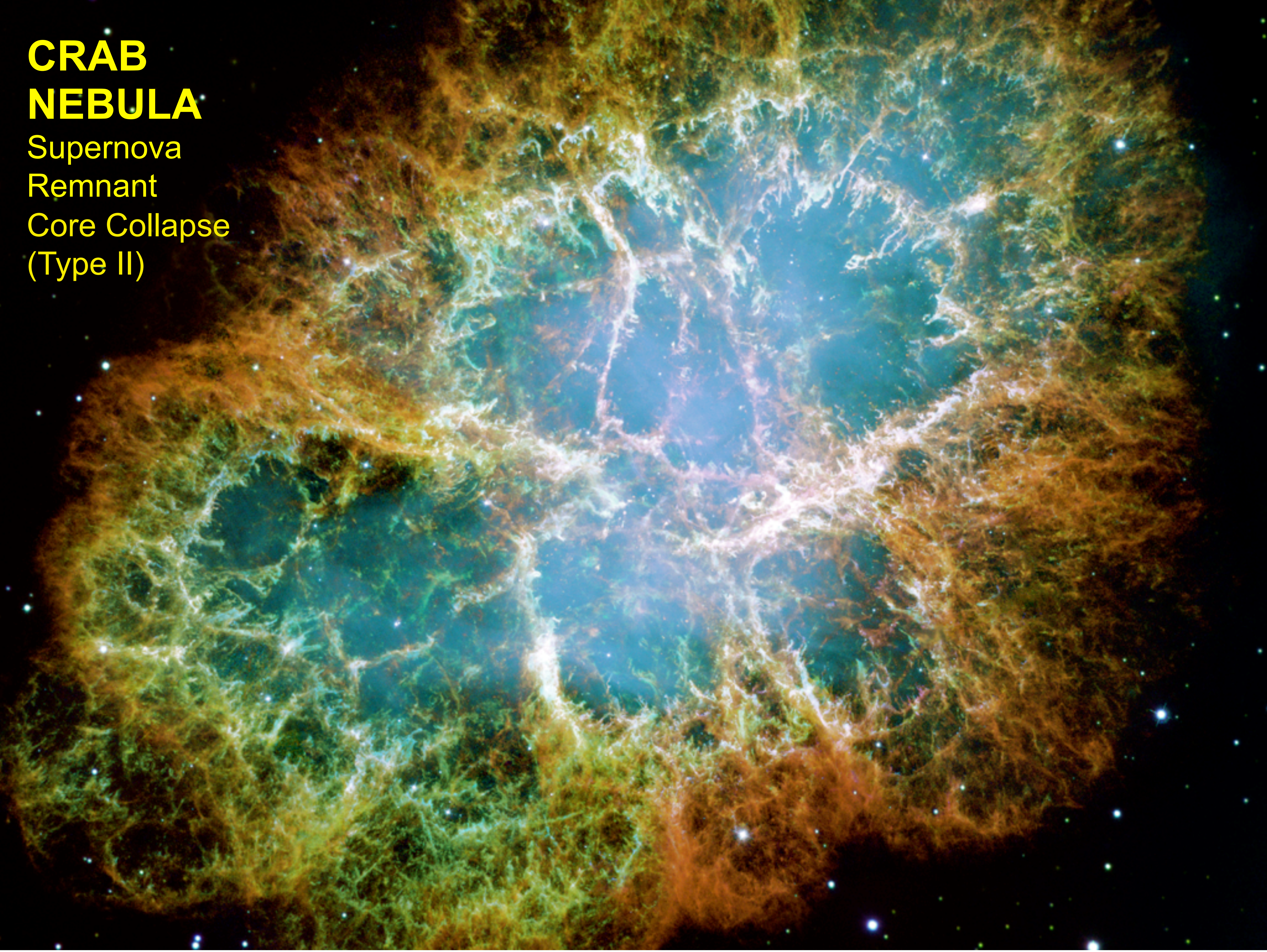
Dull gray - Made in Lab

Types of Stars

(Hertzsprung-Russell Diagram)



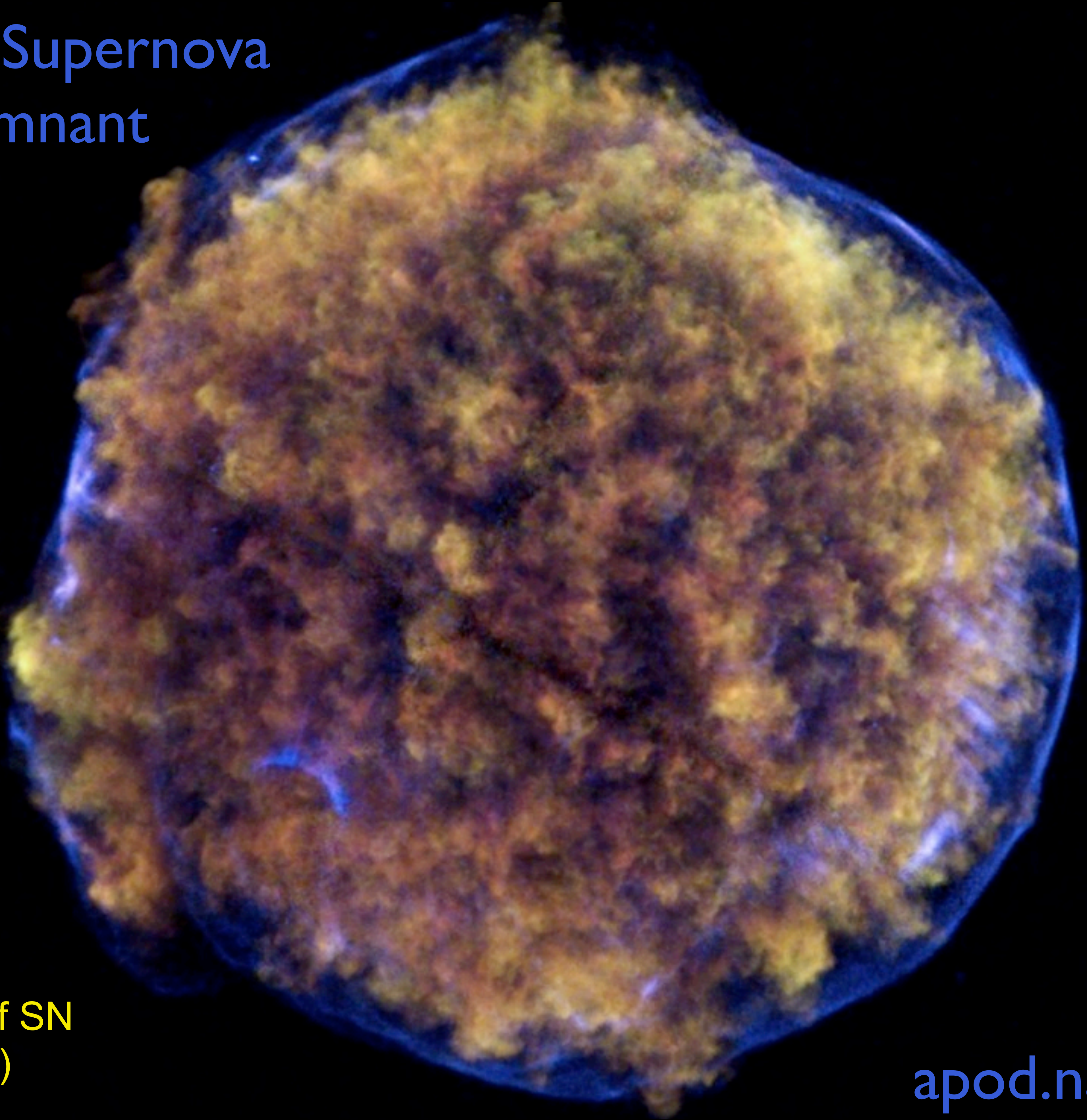




CRAB NEBULA

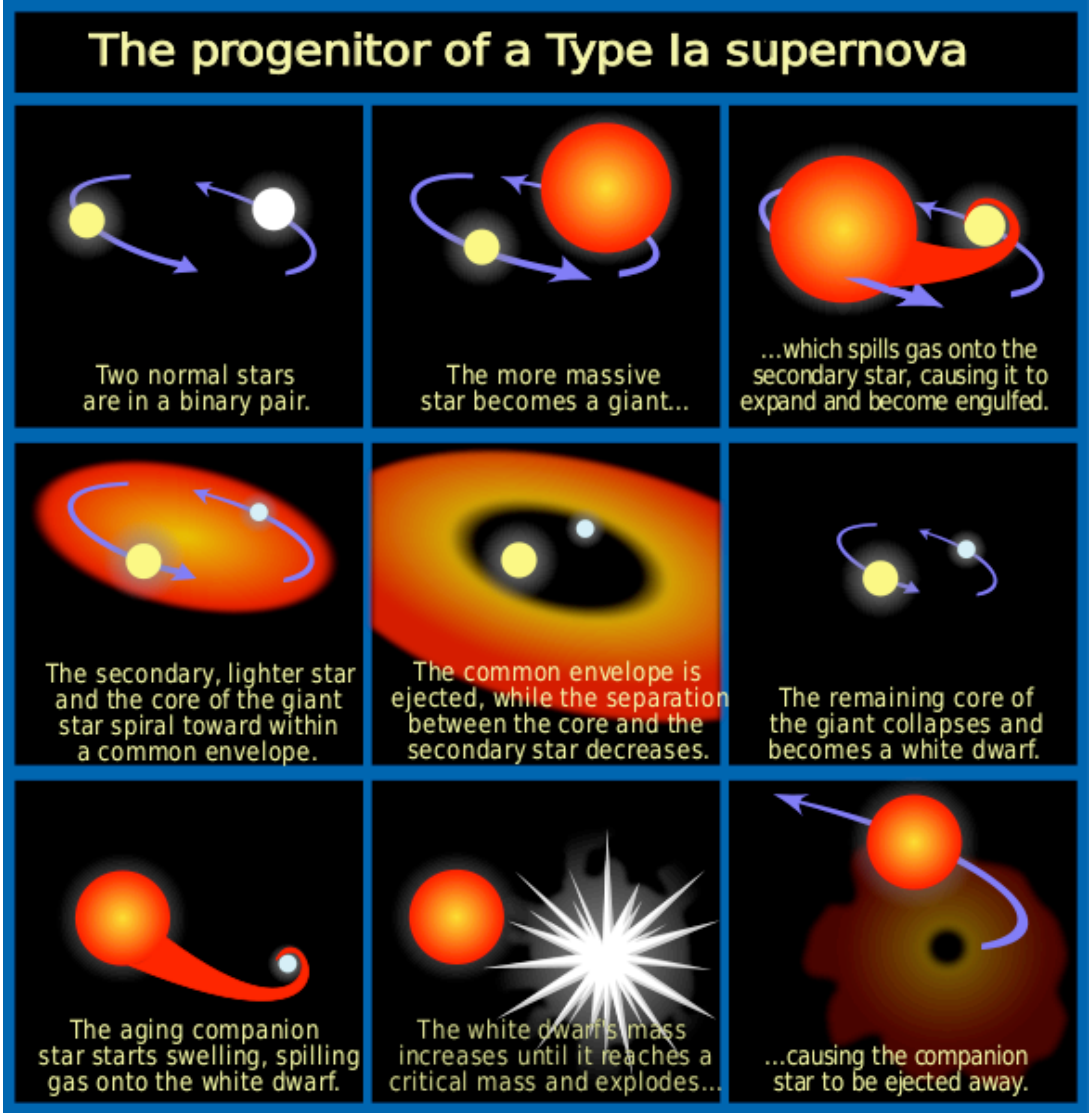
Supernova
Remnant
Core Collapse
(Type II)

Tycho's Supernova Remnant



White Dwarf SN
(Type Ia)

apod.nasa.gov



The progenitor of a Type Ia supernova

Two normal stars are in a binary pair.

The more massive star becomes a giant...

...which spills gas onto the secondary star, causing it to expand and become engulfed.

The secondary, lighter star and the core of the giant star spiral toward within a common envelope.

The common envelope is ejected, while the separation between the core and the secondary star decreases.

The remaining core of the giant collapses and becomes a white dwarf.

The aging companion star starts swelling, spilling gas onto the white dwarf.

The white dwarf's mass increases until it reaches a critical mass and explodes...

...causing the companion star to be ejected away.

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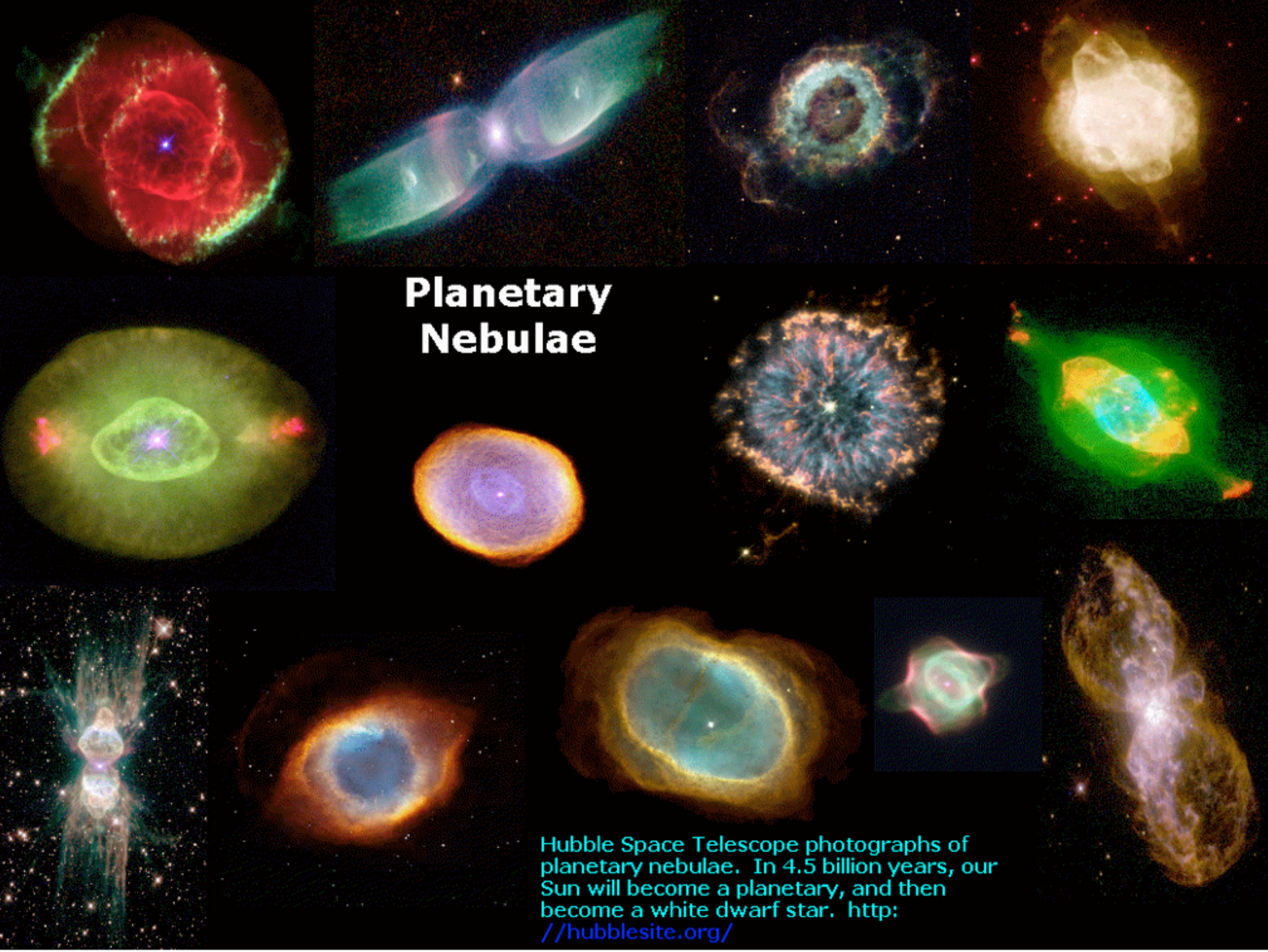
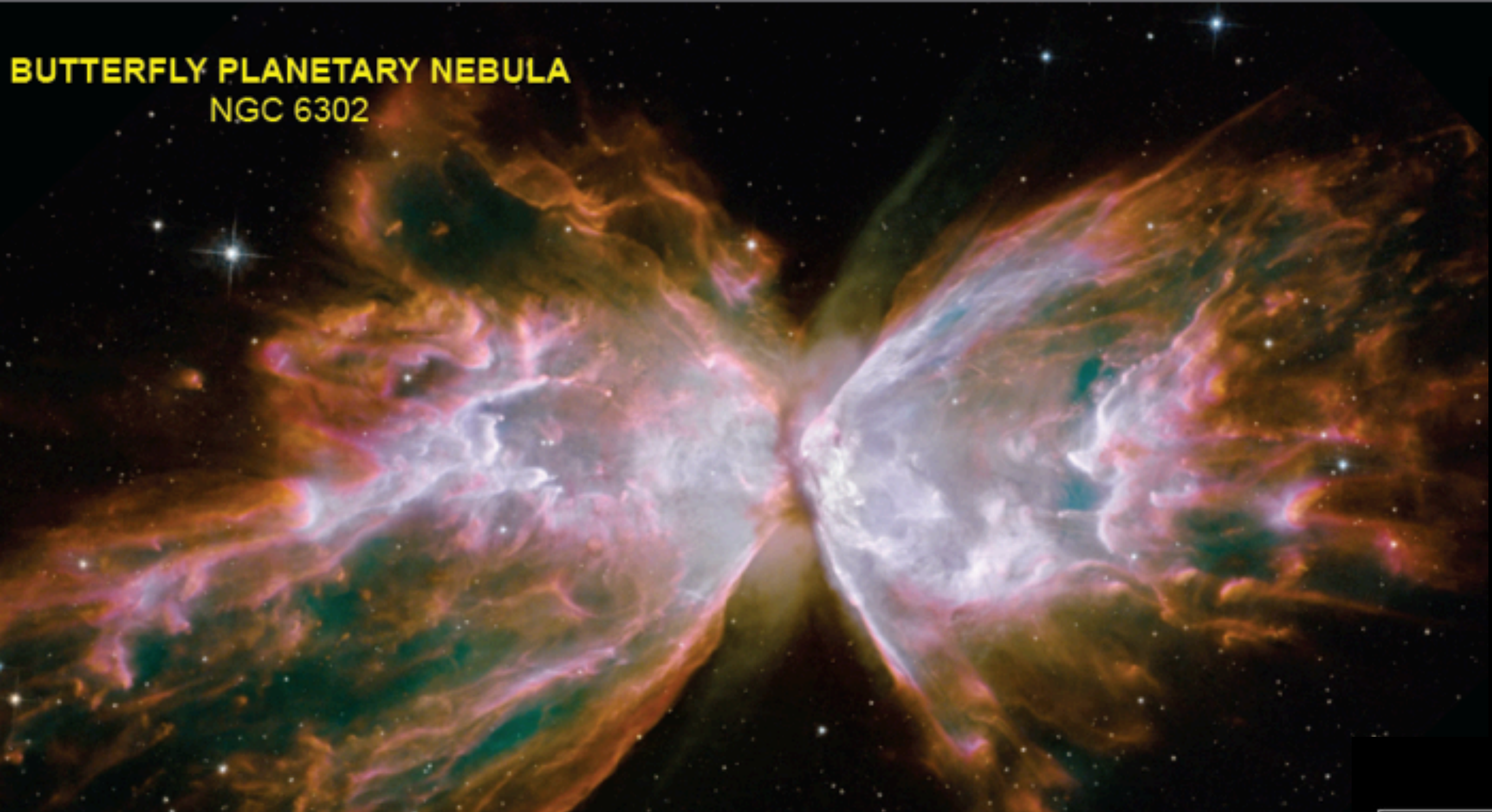
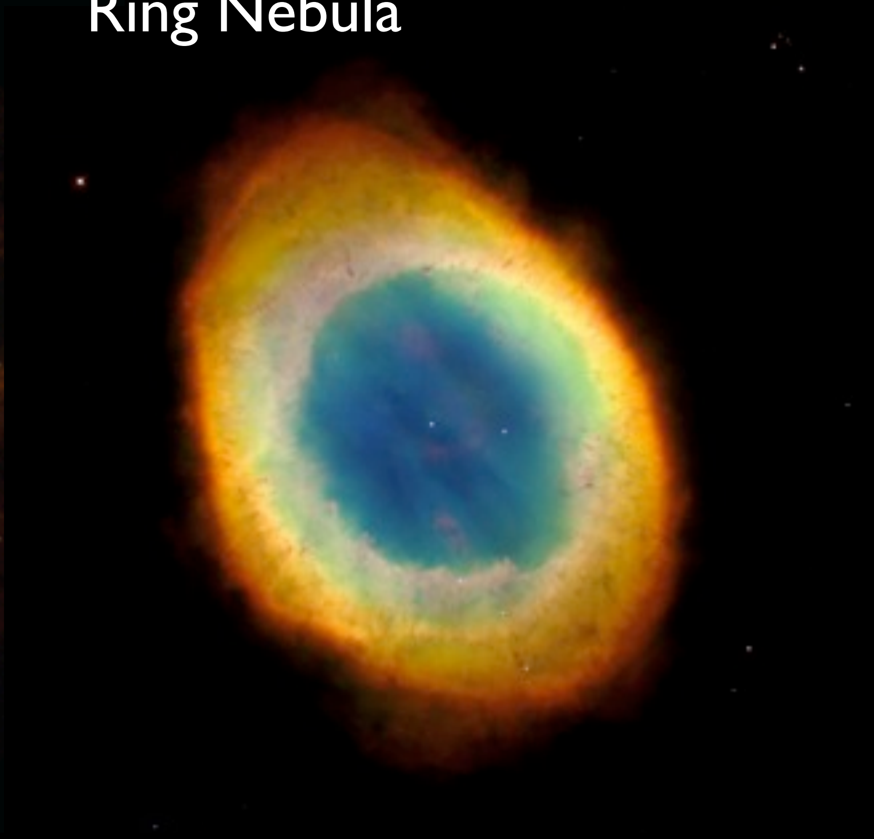
Planetary Nebulae

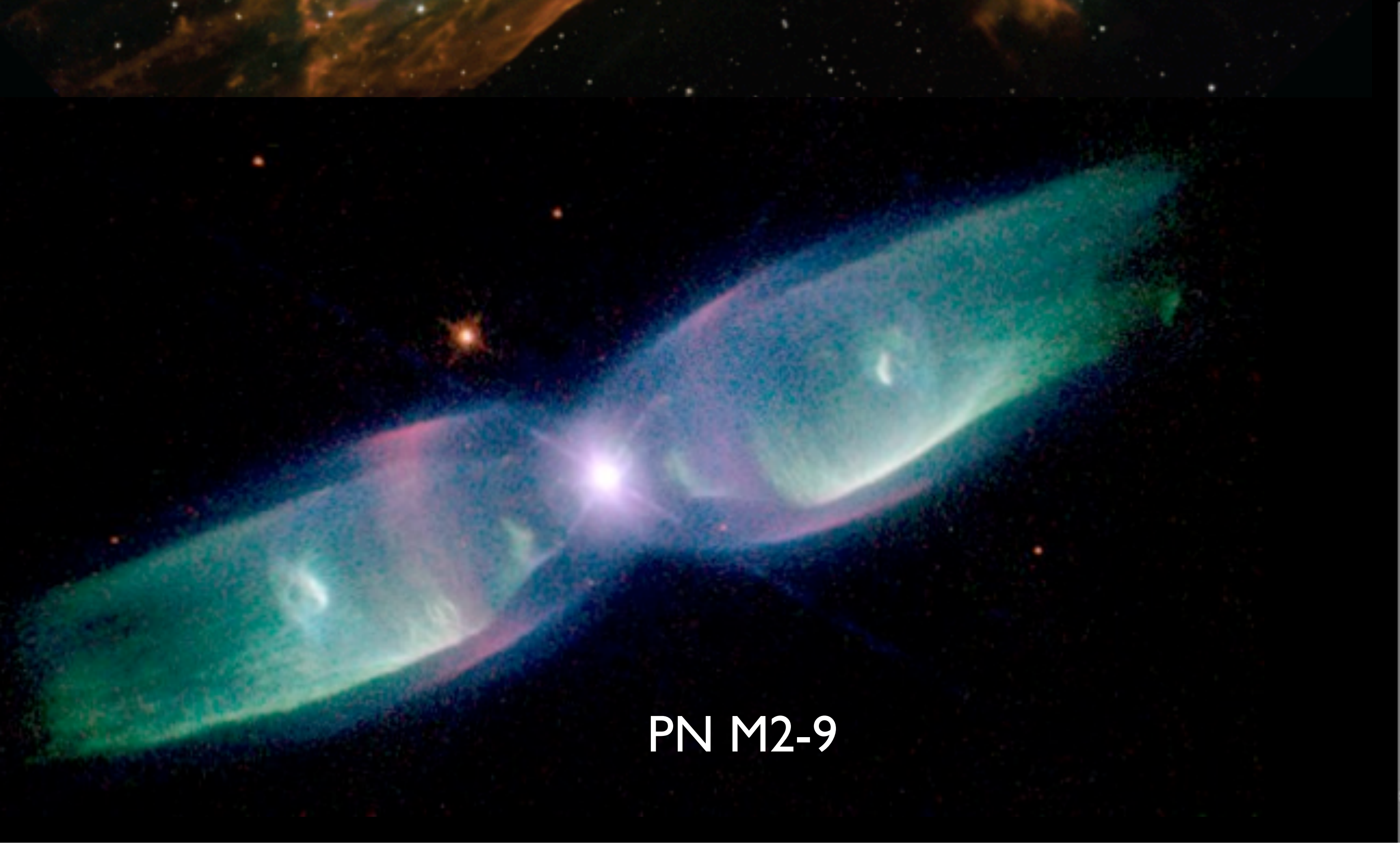


Hubble Space Telescope photographs of planetary nebulae. In 4.5 billion years, our Sun will become a planetary, and then become a white dwarf star. http://hubblesite.org/





Ring Nebula



PN M2-9

NGC 2392 • “Eskimo” Nebula

Helix Nebula NGC 7293 - Infrared Image

Distant worlds may be wildly different from Earth, but there are things that must be true of them all, simply because of the nature of stardust. For example, on any planet in the Galaxy, wherever you find watery seas and land, there will be sandy beaches. This is because oxygen and silicon are two of the most abundant heavy atoms produced before a star explodes in a supernova. Free-floating in space, they combine with each other and the hydrogen that is everywhere, making H_2O and SiO_2—water and sand—that travel together and become incorporated into new worlds.