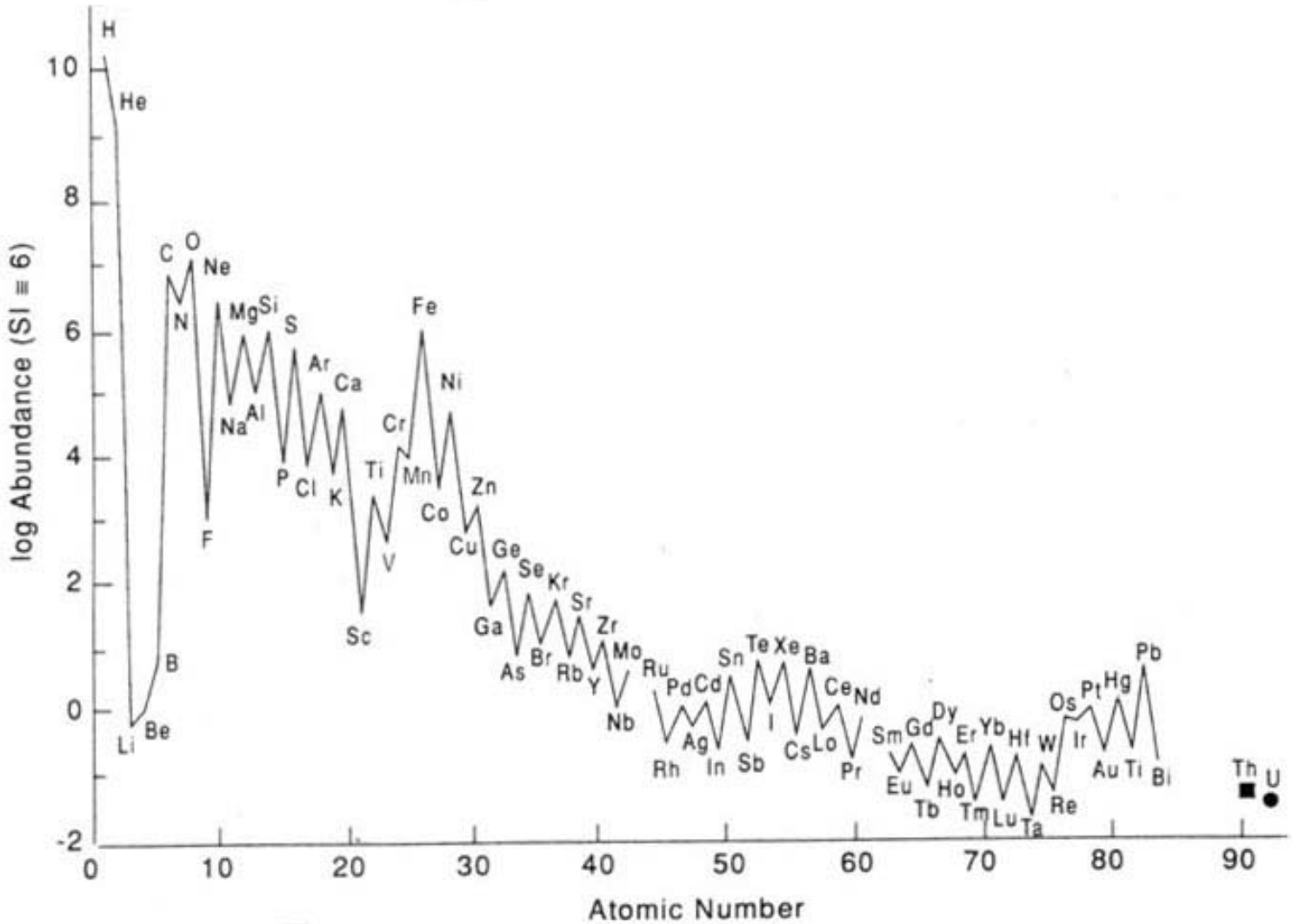
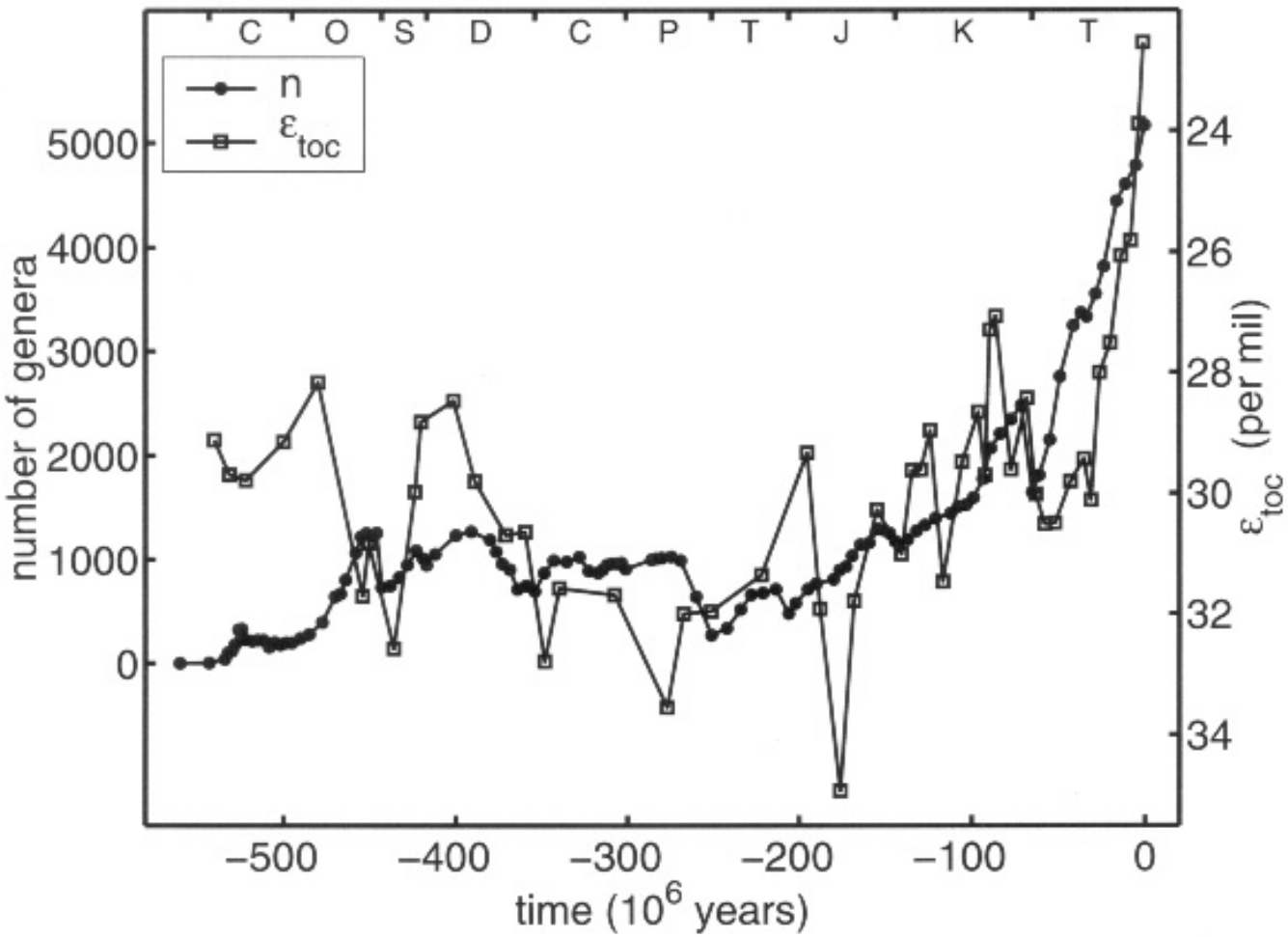
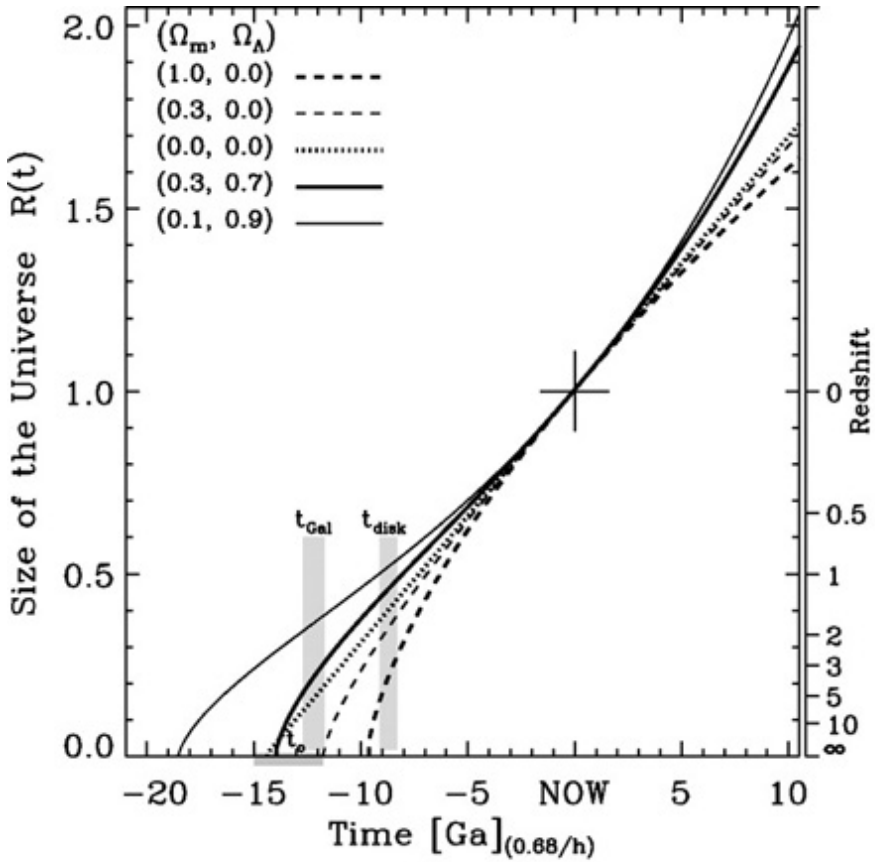
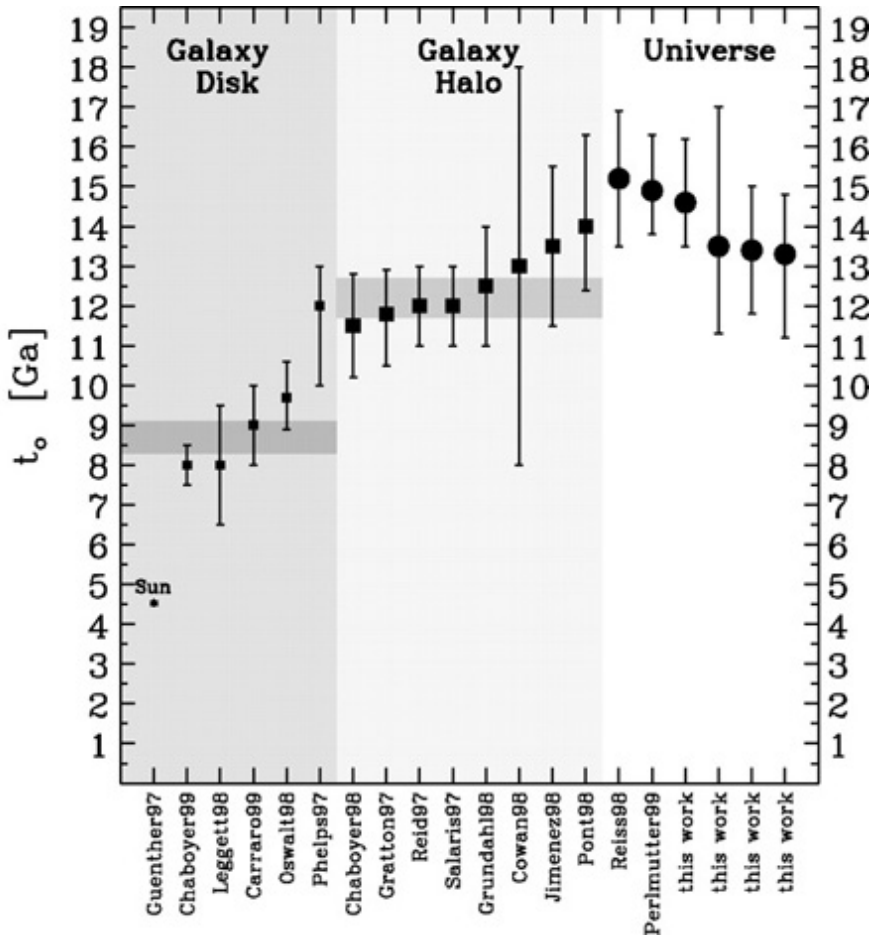
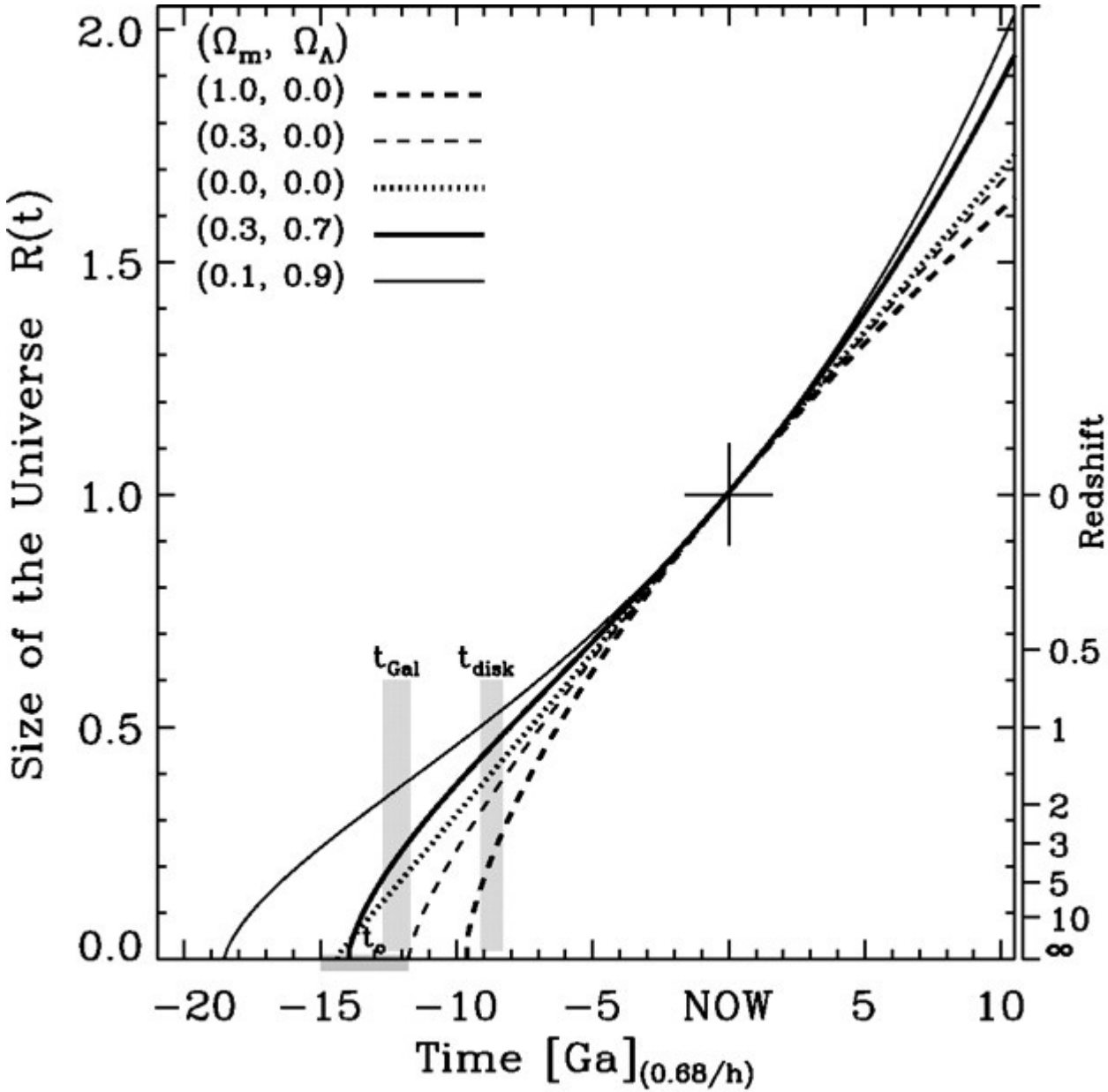

log Abundance (Si ≡ 6)
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90
Atomic Number
H
He
Li
Be
B
C
N
O
Ne
F
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr
Y
Zr
Nb
Mo
Ru
Rh
Pd
Ag
Cd
In
Sn
Sb
Te
I
Xe
Cs
Ba
Lo
Ce
Pr
Nd
Sm
Eu
Gd
Tb
Dy
Ho
Er
Tm
Yb
Lu
Hf
Ta
W
Re
Os
Ir
Pt
Au
Hg
Ti
Pb
Bi
Th
U


C
O
S
D
C
P
T
J
K
T
n
ε_{toc}
5000
4000
3000
2000
1000
0
number of genera
24
26
28
30
32
34
ε_{toc} (per mil)
−500
−400
−300
−200
−100
0
time (10^6 years)


$(\Omega_m, \Omega_\Lambda)$
(1.0, 0.0)
(0.3, 0.0)
(0.0, 0.0)
(0.3, 0.7)
(0.1, 0.9)
Size of the Universe R(t)
Redshift
t_{Gal}
t_{disk}
t_o
Time [Ga]$_{(0.68/h)}$
NOW


Galaxy Disk
Galaxy Halo
Universe
t_o [Ga]
Sun
Guenther97
Chaboyer99
Leggett98
Carraro99
Oswalt98
Phelps97
Chaboyer98
Gratton97
Reid97
Salaris97
Grundahl98
Cowan98
Jimenez98
Pont98
Reiss98
Perlmutter99
this work
this work
this work
this work


$(\Omega_m, \Omega_\Lambda)$
(1.0, 0.0)
(0.3, 0.0)
(0.0, 0.0)
(0.3, 0.7)
(0.1, 0.9)
Size of the Universe R(t)
2.0
1.5
1.0
0.5
0.0
t_{Gal}
t_{disk}
t_e
−20
−15
−10
−5
NOW
5
10
Time [Ga]$_{(0.68/h)}$
Redshift
0
0.5
1
2
3
5
10
∞

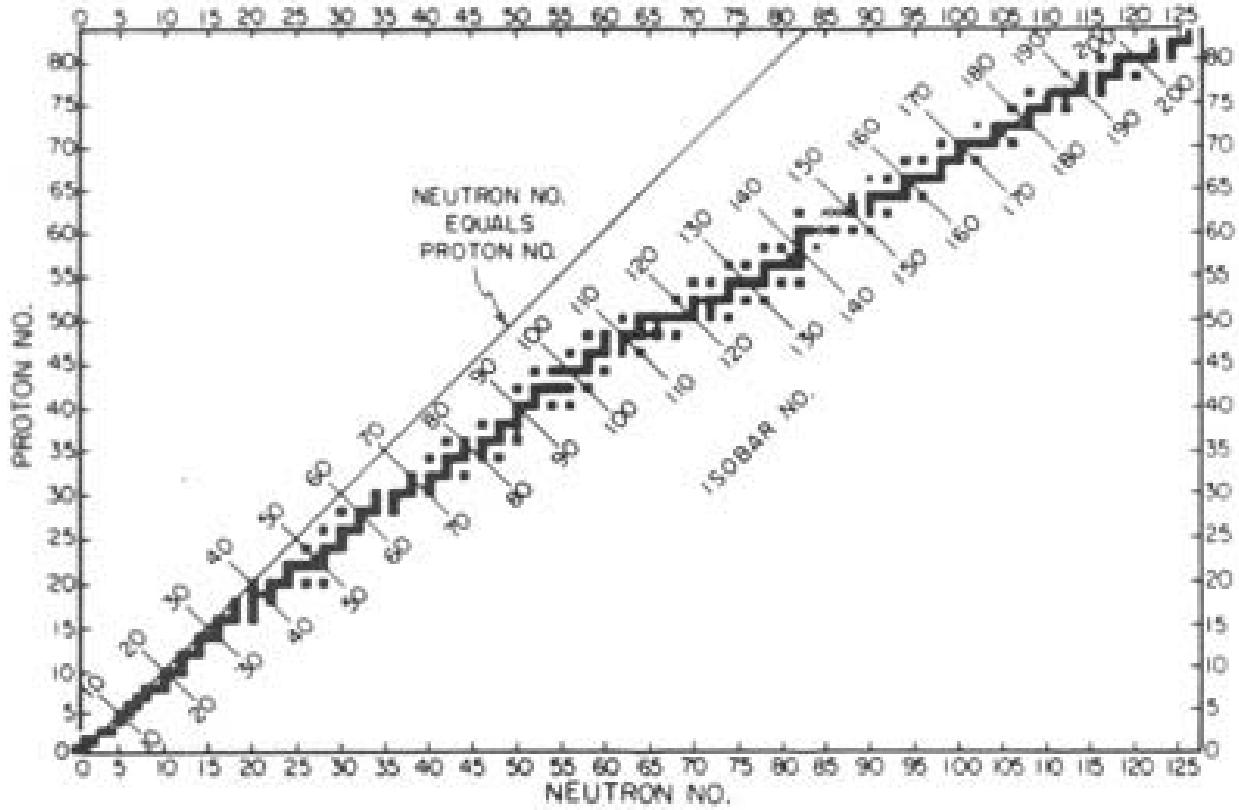


Figure 2-2. Stable nuclide configurations: The squares represent stable combinations of neutrons and protons. The x's represent radioactive nuclides whose half-lives are so long that they survive billions of years after their formation in stars. All the remaining combinations are radioactive with half-lives sufficiently short that they are no longer present in the solar system. Nuclides lying along the same horizontal line (i.e., those with the same proton number) are referred to as isotopes. Those falling along the same vertical line (i.e., those with the same number of neutrons) are referred to as isotones. Those falling along the same diagonal line (i.e., those with the same number of nuclear particles) are called isobars. The diagram terminates with the heaviest stable nuclide (^{209}Bi).

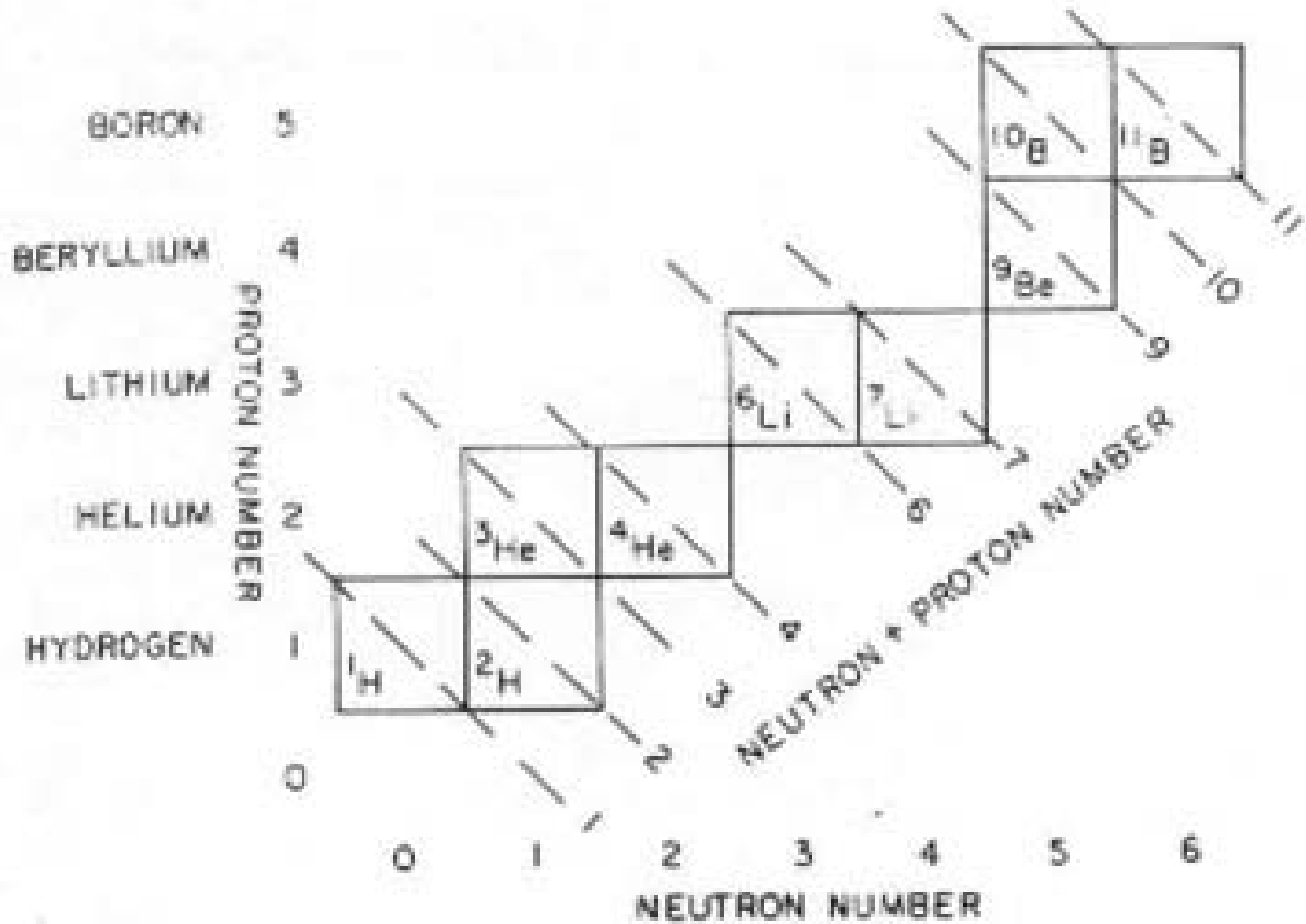
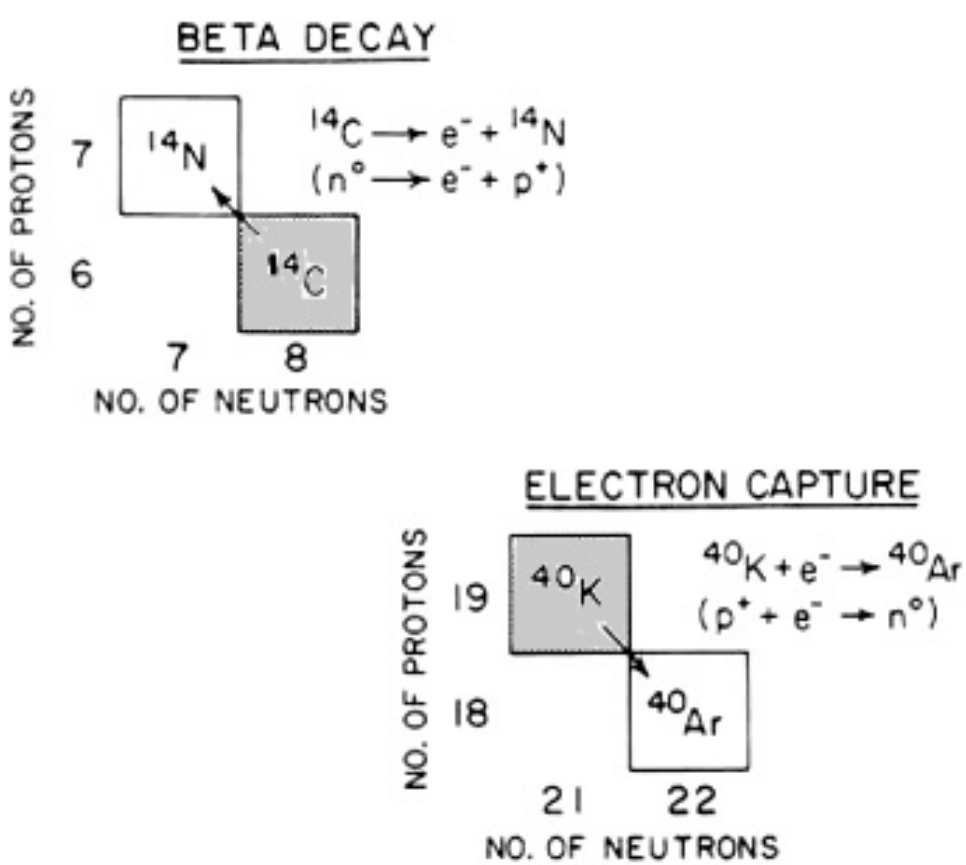


Figure 2-4. Stable nuclides with a particle number in the 1-to-11 range: Note that no stable nuclide exists with neutron-plus-proton number totaling 5 or 8. It is these two gaps in the chain that prevented element formation during the big bang from continuing beyond helium.


BETA DECAY
NO. OF PROTONS
7
6
^{14}N
^{14}C
$^{14}C \rightarrow e^- + {}^{14}N$
$(n^\circ \rightarrow e^- + p^+)$
7
8
NO. OF NEUTRONS
ELECTRON CAPTURE
NO. OF PROTONS
19
18
^{40}K
^{40}Ar
$^{40}K + e^- \rightarrow {}^{40}Ar$
$(p^+ + e^- \rightarrow n^\circ)$
21
22
NO. OF NEUTRONS
ALPHA DECAY
NO. OF PROTONS
92
91
90
^{238}U
^{234}Th
$^{238}U \rightarrow {}^{234}Th + {}^{4}He$
144
145
146
NO. OF NEUTRONS

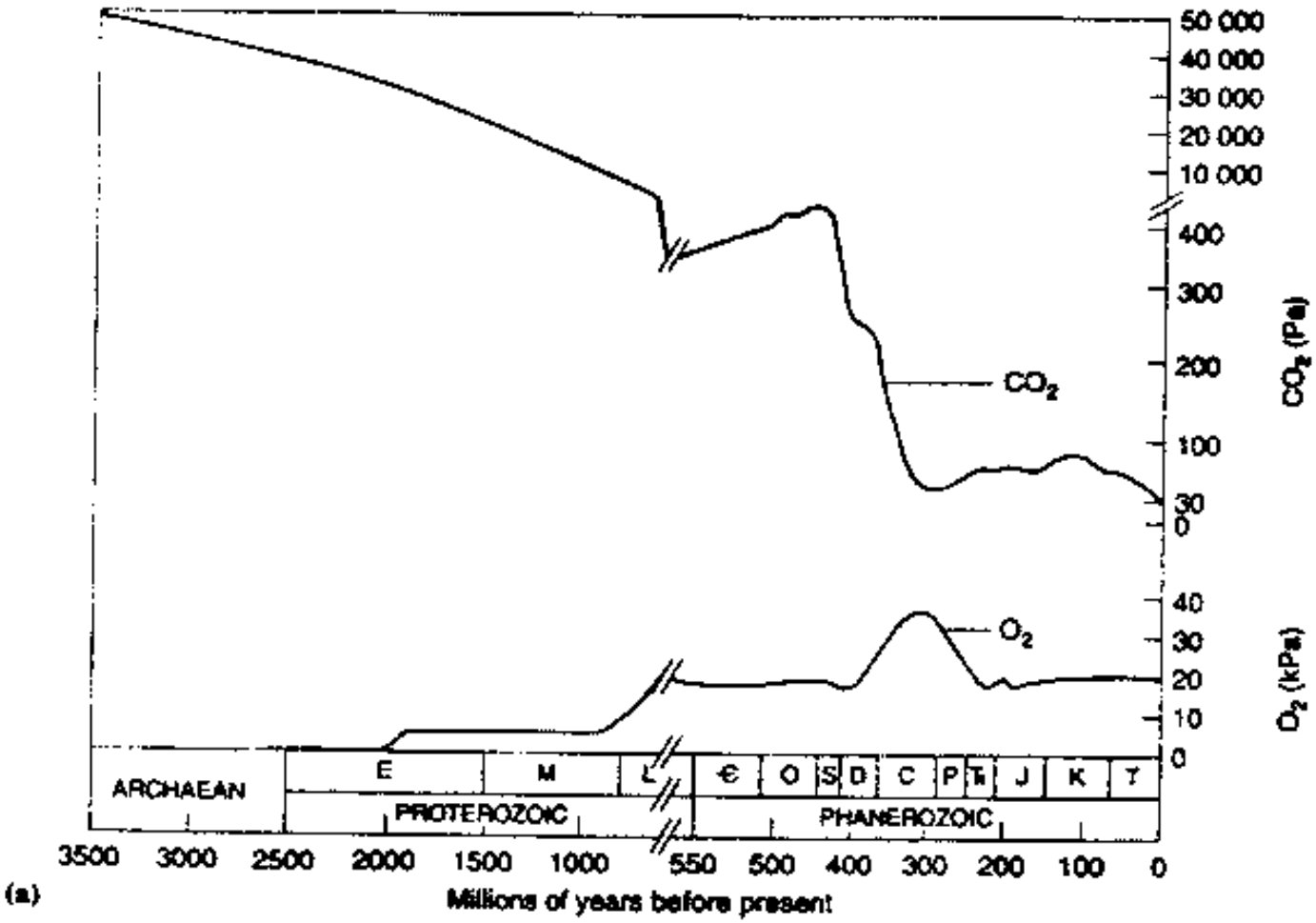


Figure L4 (a) A reconstruction of variations in the partial pressures of CO_2 and O_2 in the atmosphere through geological time using data from Berner (1990, 1993) and Berner and Canfield (1989) for the post-Cambrian epochs (i.e., the Phanerozoic). The absolute values and timing for the evolution of oxygen are not constrained in the Proterozoic epoch. (b) Major geological and biological epochs and their characteristics regarding the evolution of photoautotrophs in aquatic environments.

The Drake Equation

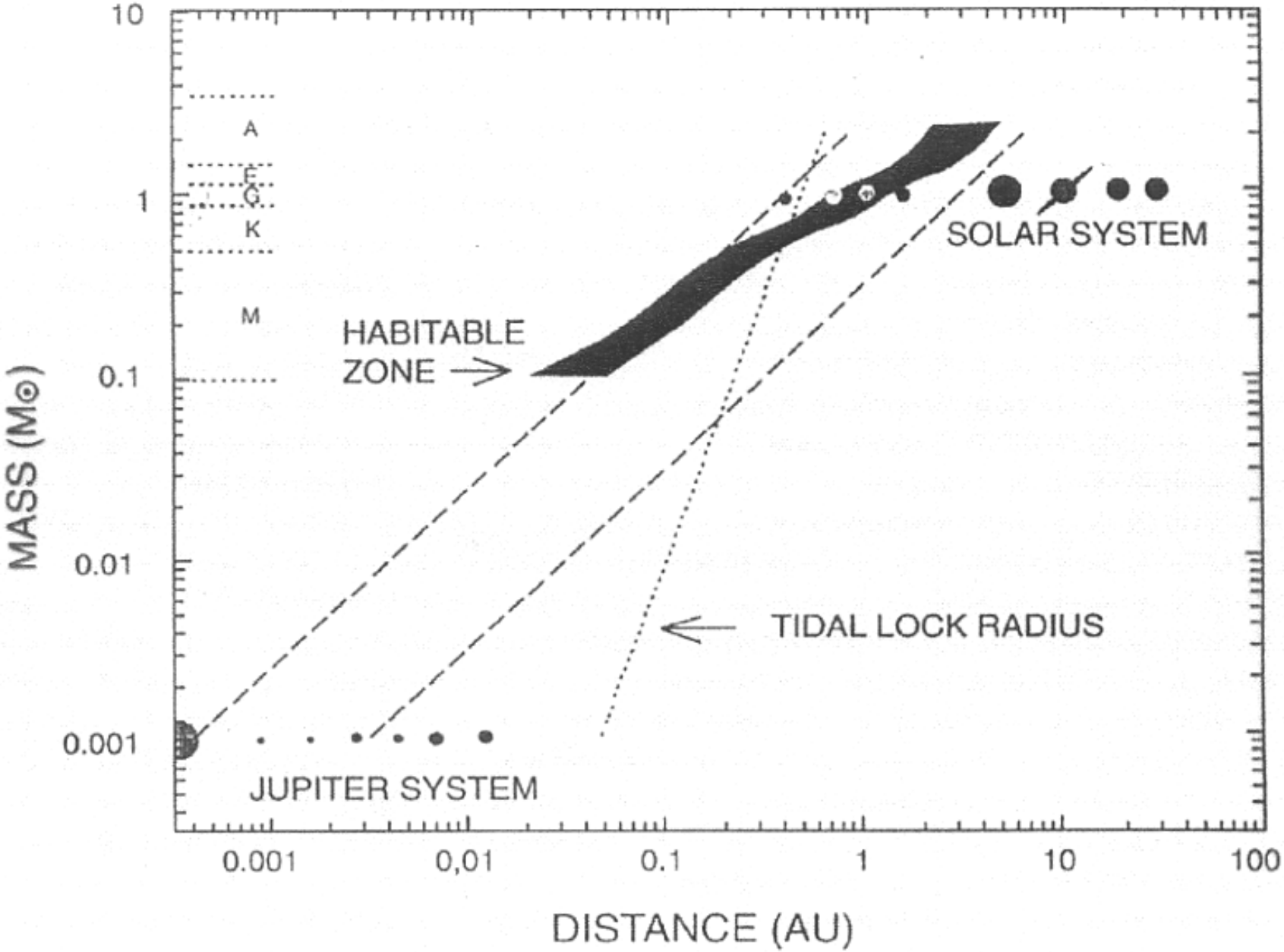
$$N^* \times fs \times fp \times ne \times fi \times fc \times fl = N$$

where:

N^* = stars in the Milky Way galaxy
fs = fraction of sun-like stars
fp = fraction of stars with planets
ne = *planets in a star's habitable zone*
fi = fraction of habitable planets where life does rise
fc = fraction of planets inhabited by intelligent beings
fl = percentage of a lifetime of a planet that is marked by the presence of a communicative civilization

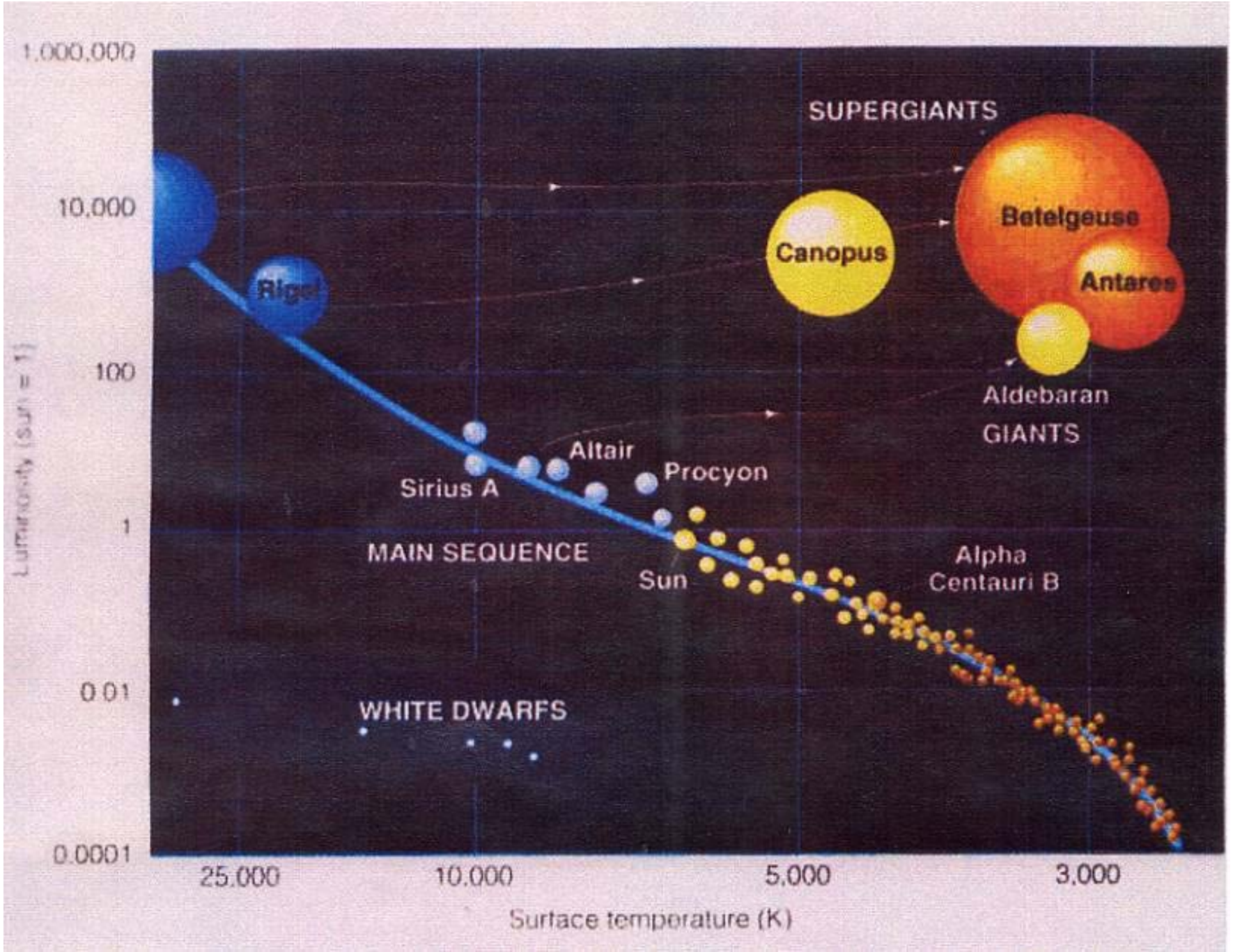
Let's do the numbers

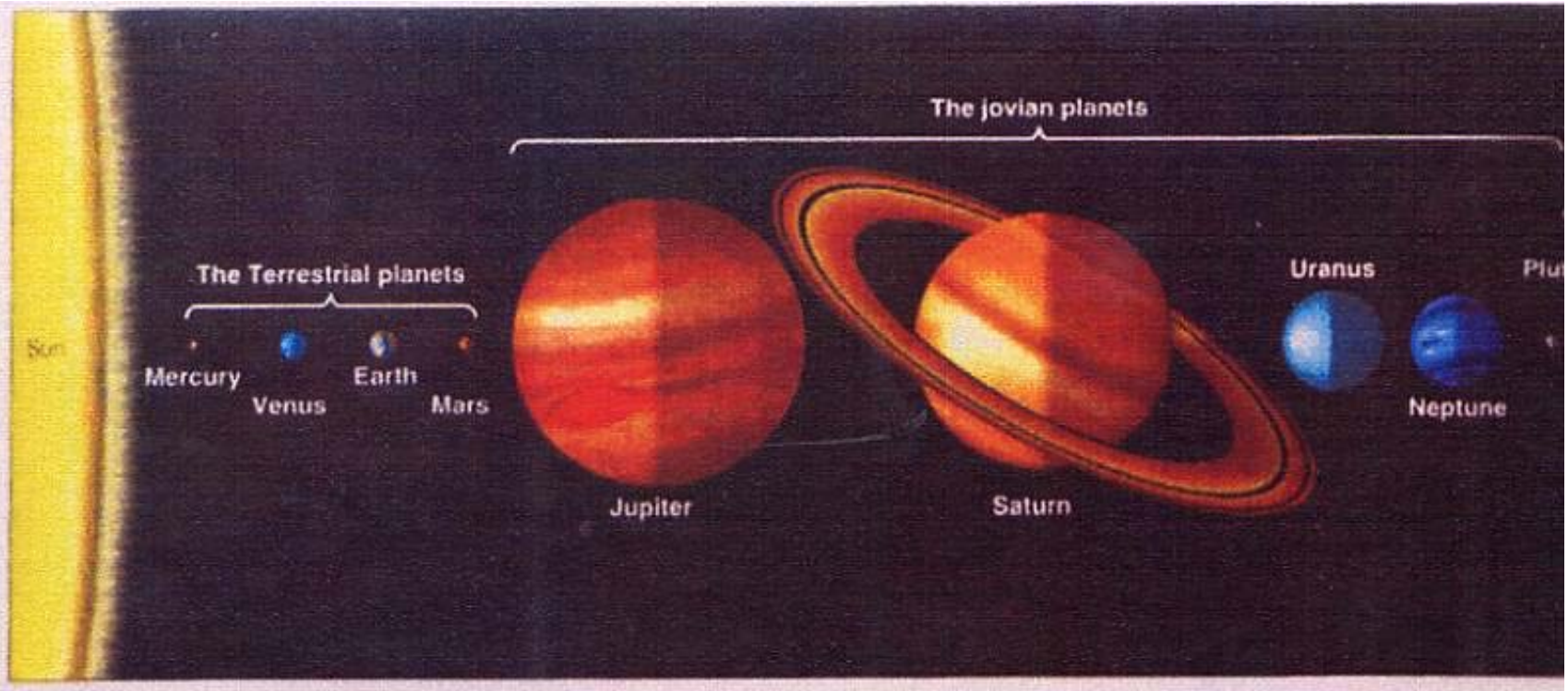
1. There are 10^{11} stars in the Milky Way
2. Given the rate of planet discovery, we can estimate that 1 to 10% of these stars have one or more orbiting planets.
3. Assuming that 1% of the orbiting planets is a terrestrial planet (so far none of the planets discovered fall into this category), within a zone of habitability...


10
1
0.1
0.01
0.001
MASS (M⊙)
A
F
G
K
M
HABITABLE
ZONE
SOLAR SYSTEM
TIDAL LOCK RADIUS
JUPITER SYSTEM
0.001
0,01
0.1
1
10
100
DISTANCE (AU)

We can conservatively estimate that there are between 10^6 and 10^7 planets capable of maintaining a film of liquid water on their surfaces.

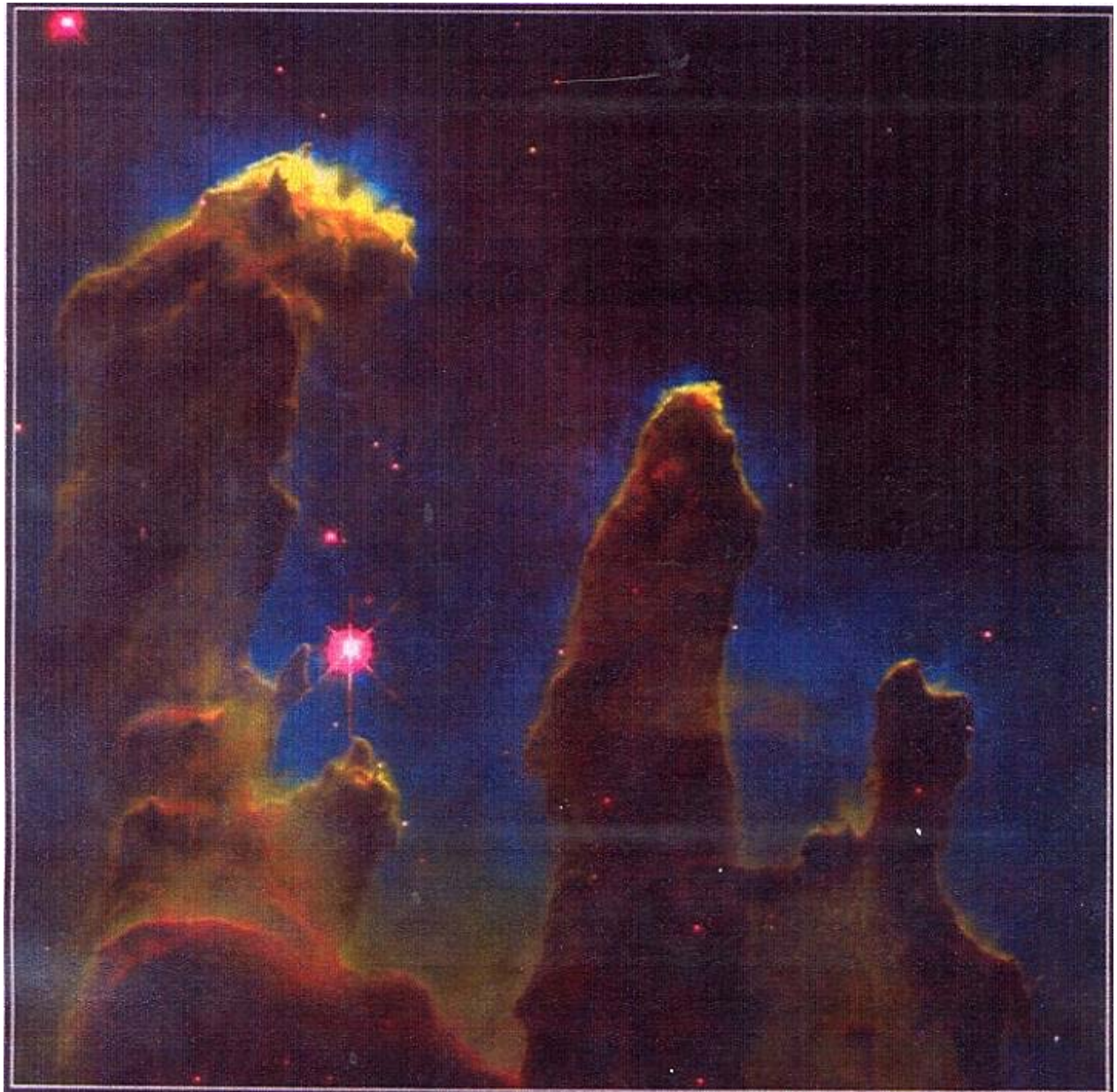
That is a lot of potential life-supporting planets!


1,000,000
10,000
100
1
0.01
0.0001
Luminosity (Sun = 1)
SUPERGIANTS
Betelgeuse
Canopus
Antares
Rigel
Aldebaran
GIANTS
Altair
Procyon
Sirius A
MAIN SEQUENCE
Sun
Alpha
Centauri B
WHITE DWARFS
25,000
10,000
5,000
3,000
Surface temperature (K)



8

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Diameter (km)	4880	12 104	12 756	6787	142 800	120,000	51 800	49,500	6000
Mass (Earth=1)	0 055	0 815	1	0 108	317 8	95 2	14 4	17 2	0 003
Density, g/cm^3 (water=1)	5 44	5 2	5 52	3 93	1 3	0 69	1 28	1 64	2 06
Number of moons	0	0	1	2	16	18	15	8	1
Length of day (in Earth hours)	1416	5832	24	24 6	9 8	10 2	17 2	16 1	154
Period of one revolution around Sun (in Earth years)	0 24	0 62	1 00	1 88	11 86	29 5	84 0	164 9	247 7
Average distance from Sun (millions of kilometers)	58	108	150	228	778	1427	58	4497	5900
Average distance from sun (astronomical units)	0 39	0 72	1 00	1 52	5 20	9 54	0 39	30 06	39 44



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J. Hester and P. Scowen (AZ State Univ.), NASA