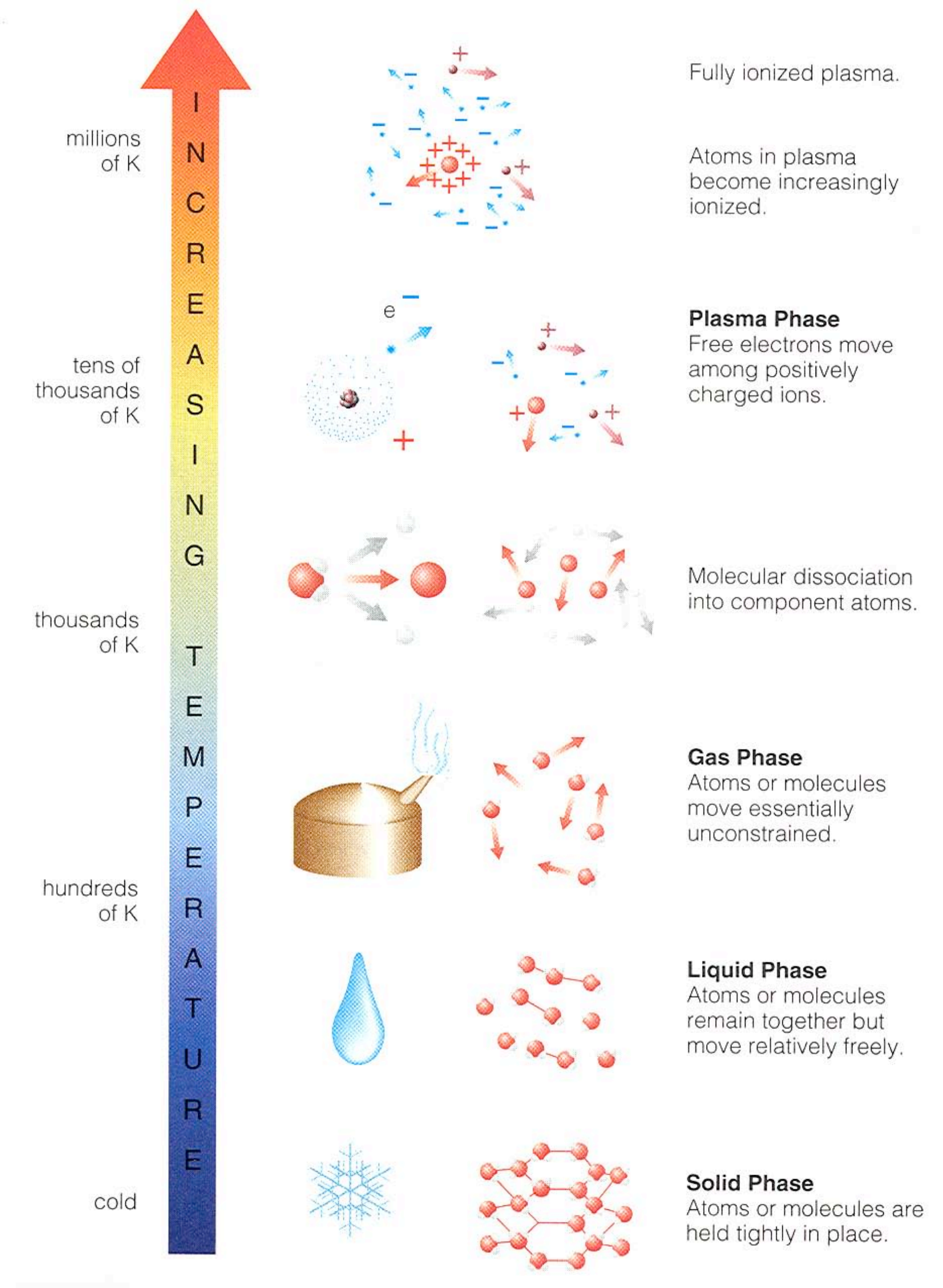
Habitable Planets



The general progression of phase changes.

Every substance can exist in different "phases," which depend on the temperature. As it cools, the •substance will undergo a transition from the gas, to liquid, to solid phase at certain critical temperatures. Each substance has its own critical temperatures.

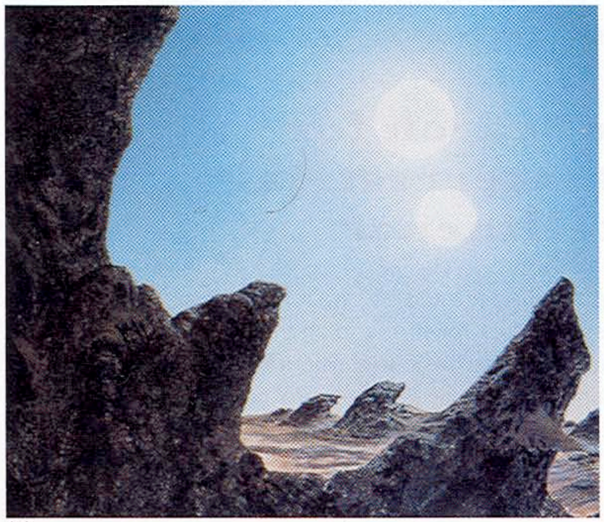
For life, we need the temperature to be low enough for complex molecules to form, so this requires temperatures below ~ 500 K. But it is difficult to imagine life without a *liquid* to serve a large number of functions. And there are very strong arguments that *water* is an amazingly unique liquid for this purpose.

Several substances remain liquid over a fairly large temperature range and are abundant enough so that they might form oceans. (This is why Titan, a moon of Saturn, is of such great interest.) But water is the hands-down winner in several other respects…

Liquid	Melting temp.	Boiling temp.	Range for liquid
Water (H_2O)	0 °C	100 °C	100 °C
Ammonia (NH_3)	−78 °C	−33 °C	45 °C
Methane (CH_4)	−182 °C	−164 °C	18 °C
Ethane (C_2H_6)	−183 °C	−89 °C	94 °C

The temperature of a planet's surface is mostly controlled by it's distance to it's parent star, because that determines how much energy it receives. The illustration below shows the Sun as it would appear from Pluto: Way too cold for *liquid* water → Pluto is far outside the "habitable zone."

Inside, outside, and within the liquid water habitable zone



(a)

(b)

(c)

Too hot, too cold, and just right. Scenes on imaginary planets emphasize that many extrasolar planets may not have conditions suitable for life. **(a)** The surface of this planet, close to a pair of hot, massive stars, is a sun-blasted desert. **(b)** On this world, far from a red and white pair of stars, all water is frozen. **(c)** Some worlds may exist in which liquid water persists and life forms have evolved.

(SOURCE: Paintings by Don Dixon, Ron Miller, and WKH, respectively.)

We can see the main effects related to the habitable zone here in our Solar System: Look what happened to Venus! (Fig. 9.3 in text) Consider how reversed has occurred on Mars

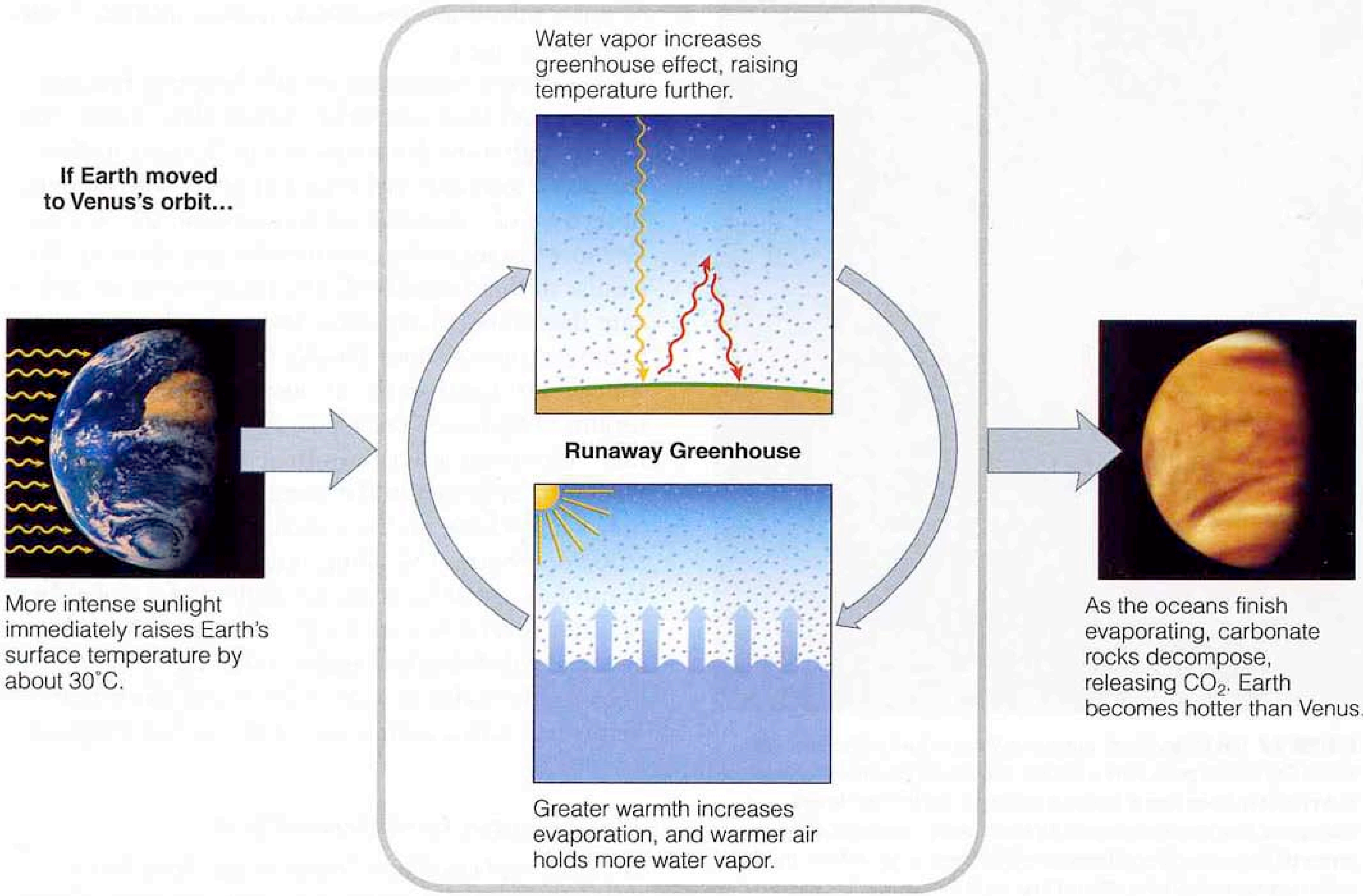
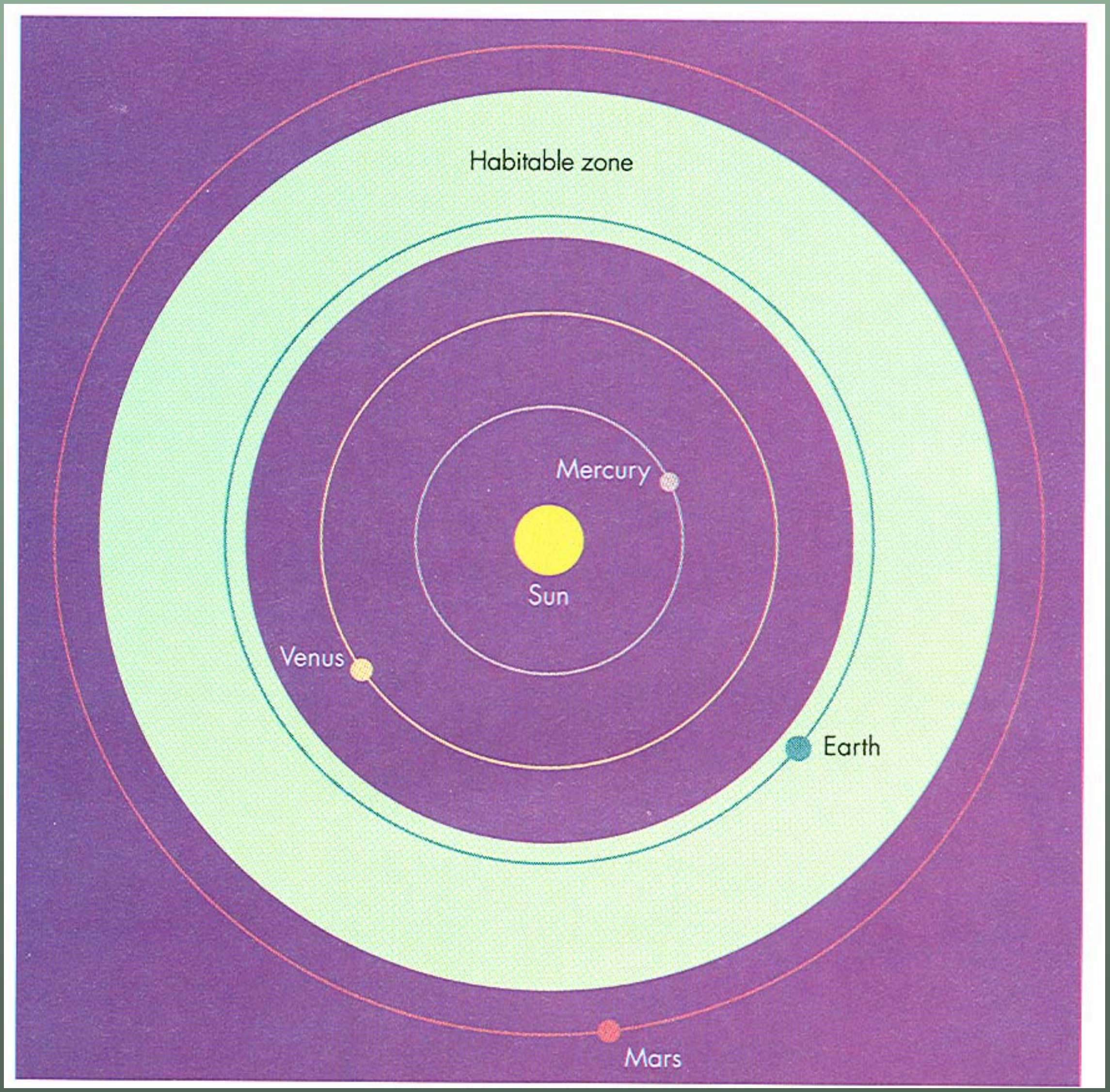


FIGURE 9.3 This diagram shows how, if the Earth were placed at Venus's distance from the Sun, the runaway greenhouse effect would cause the oceans to evaporate completely.

A calculation of the continuously habitable zone for the Sun. Notice that the Earth barely is inside!



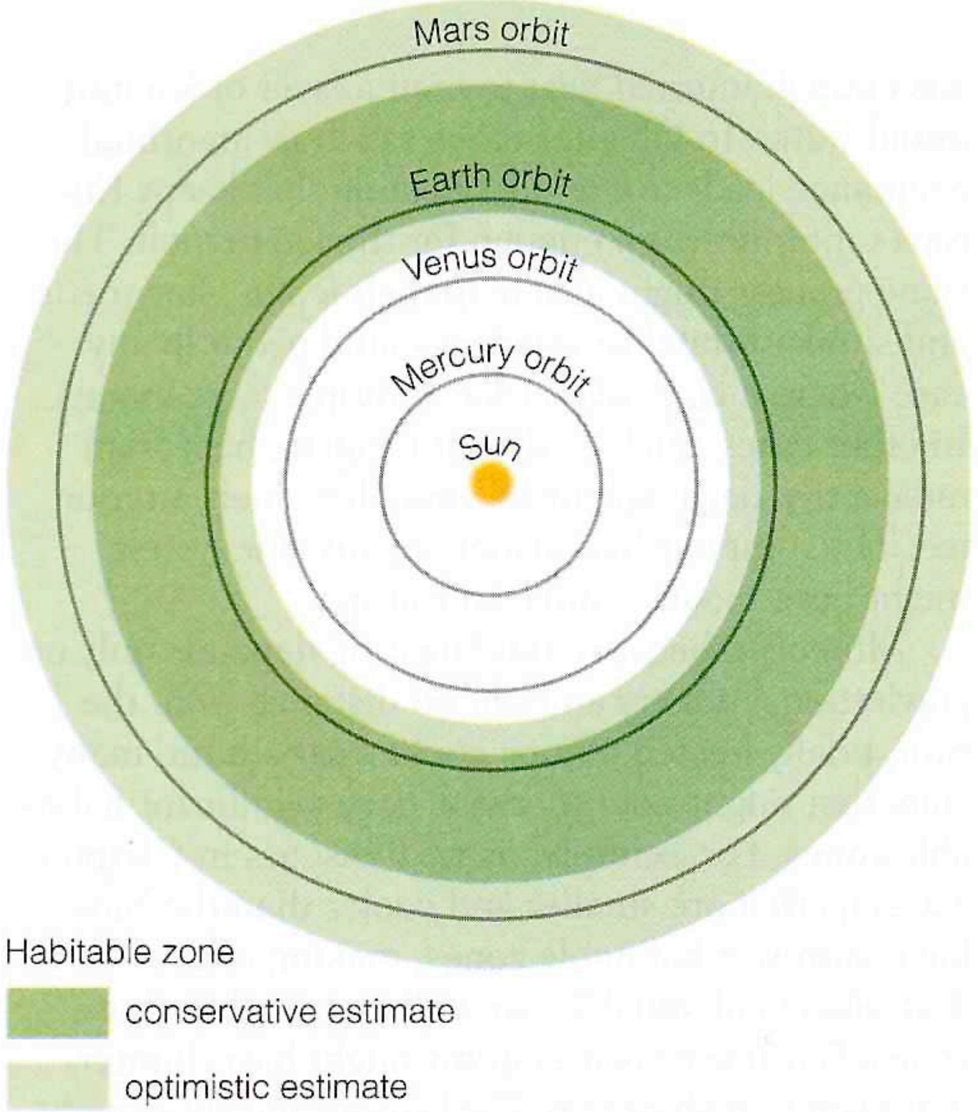
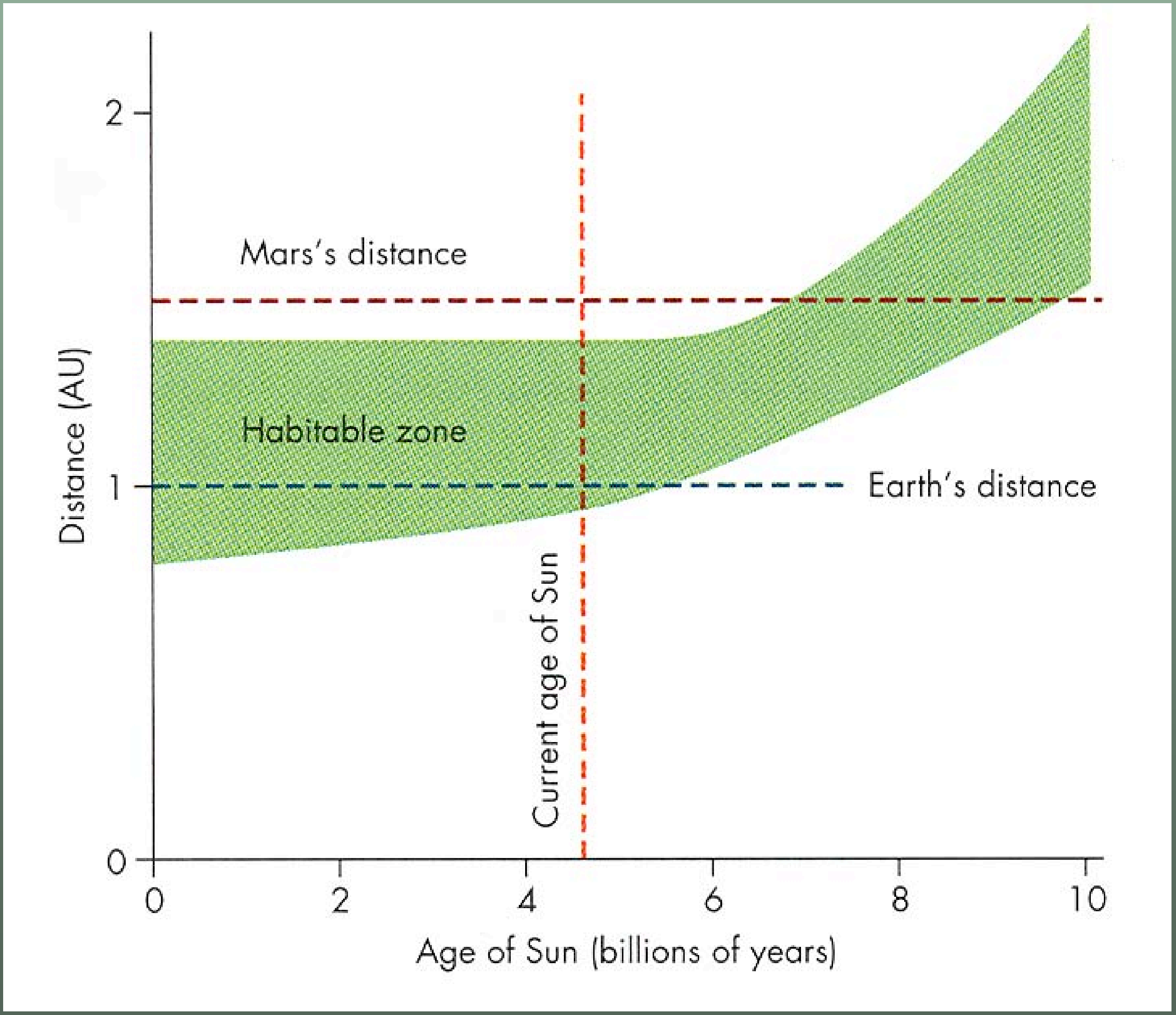


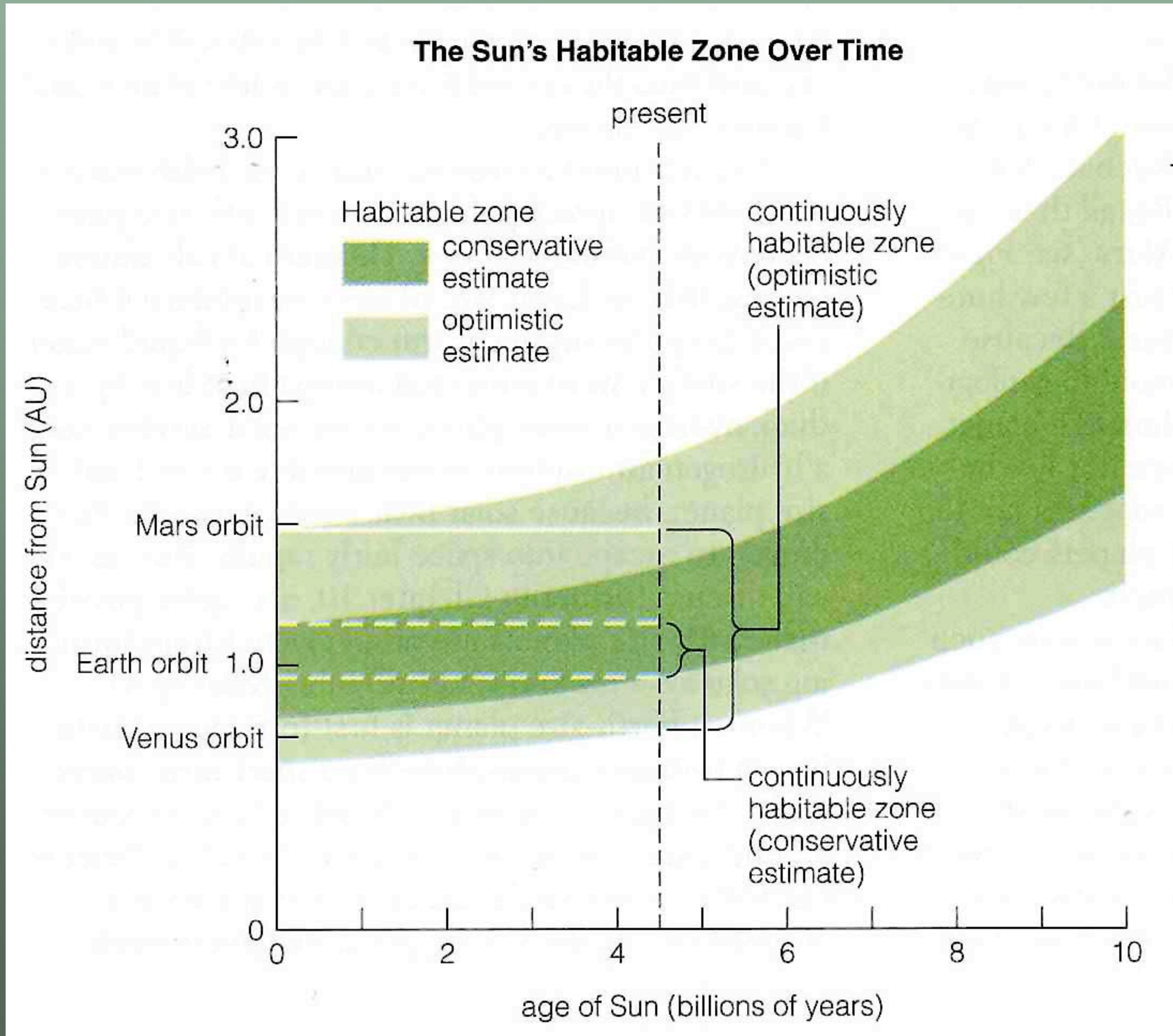
FIGURE 9.4 Boundaries of the Sun's habitable zone today. The narrower set of boundaries represents a model based on the more conservative assumptions, while the wider set represents the most optimistic scenarios.

Actually the answer is not so clear--depends a lot on the climate model and the assumptions. This illustration shows the results for two choices of assumptions (Fig. 9.4 in textbook).

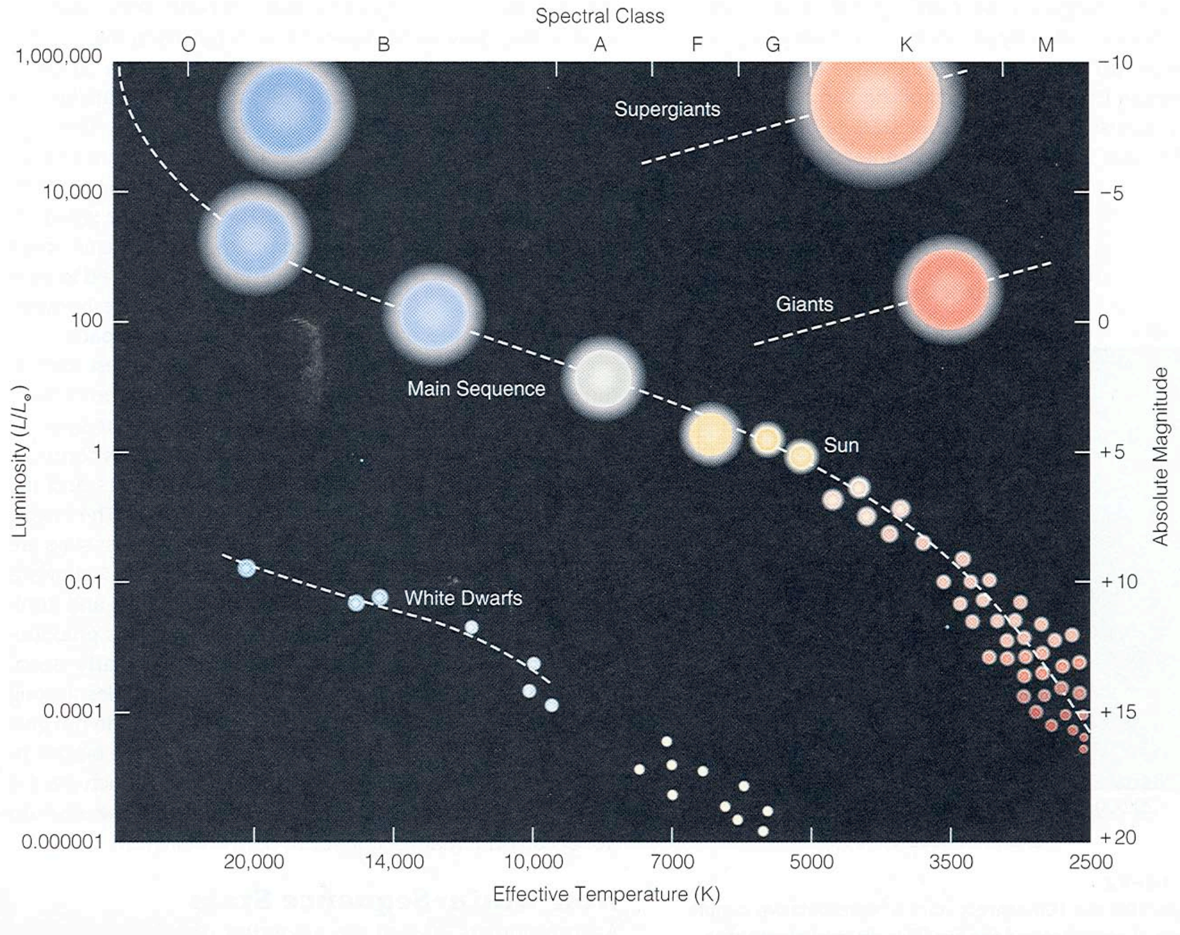
Time evolution of the Sun's habitable zone--moves further from Sun as the Sun ages and brightens, soon leaving the Earth behind.



More complicated version from your textbook (Fig. 9.5). Notice that in the “optimistic” choice, Earth will remain in the habitable zone for 3-4 more billion years.



Stars come in many varieties--how should the habitable zone look for each of these classes of stars? How long do these different classes or phases last? Which type of star is the most or least numerous?



An H-R diagram for a selection of different types of stars. Stars are plotted schematically to show colors and relative sizes, but they are not to true scale. (This would require much larger red giants and much smaller white dwarfs.) Main-sequence stars, which release energy by fusing hydrogen into helium, run diagonally across the diagram.

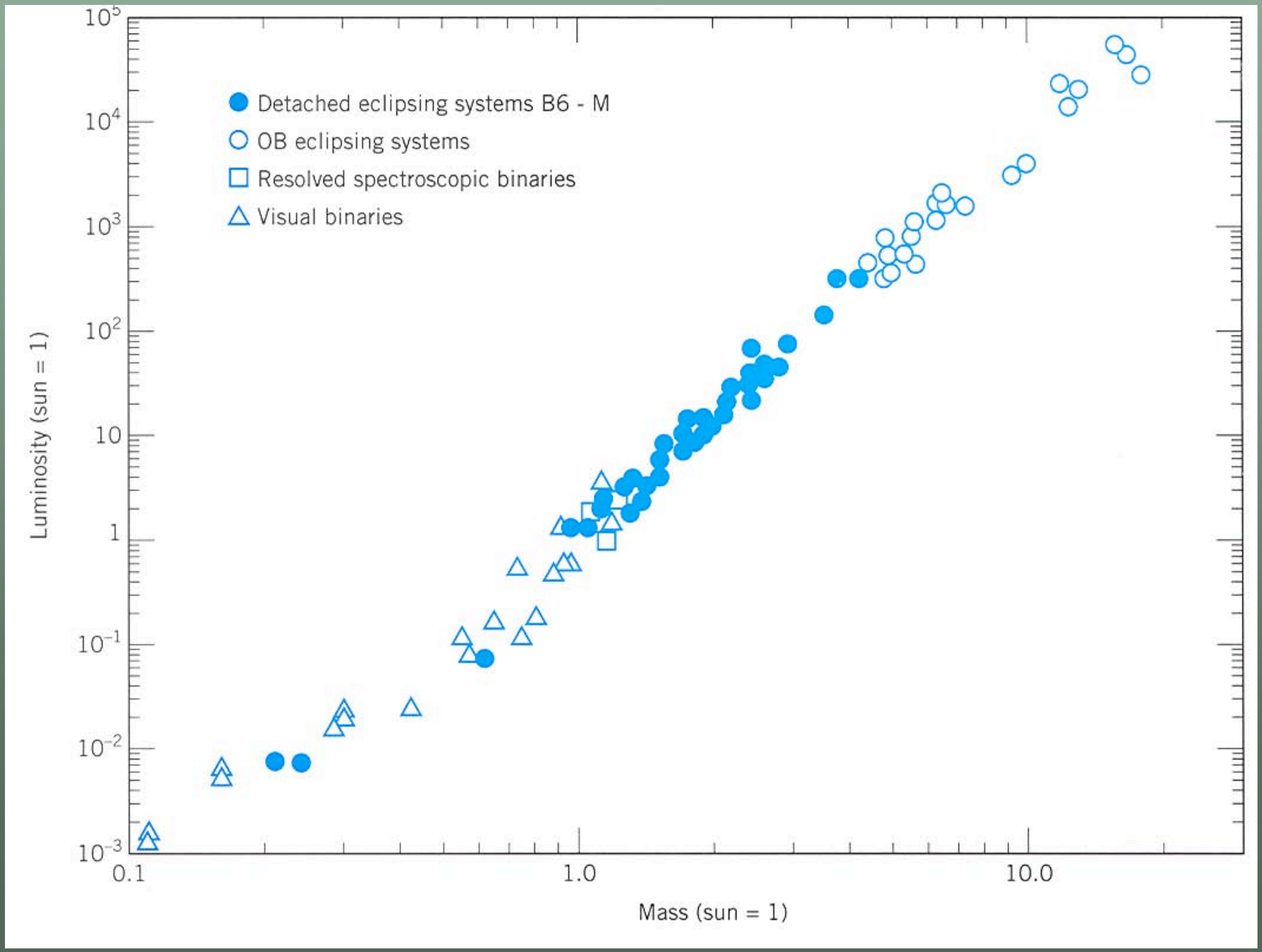
Some properties of main sequence stars of different spectral types (masses). Notice the huge variation in luminosity and lifetime. These quantities control our decisions about which stars we should inspect for terrestrial-mass planets and biomarkers.

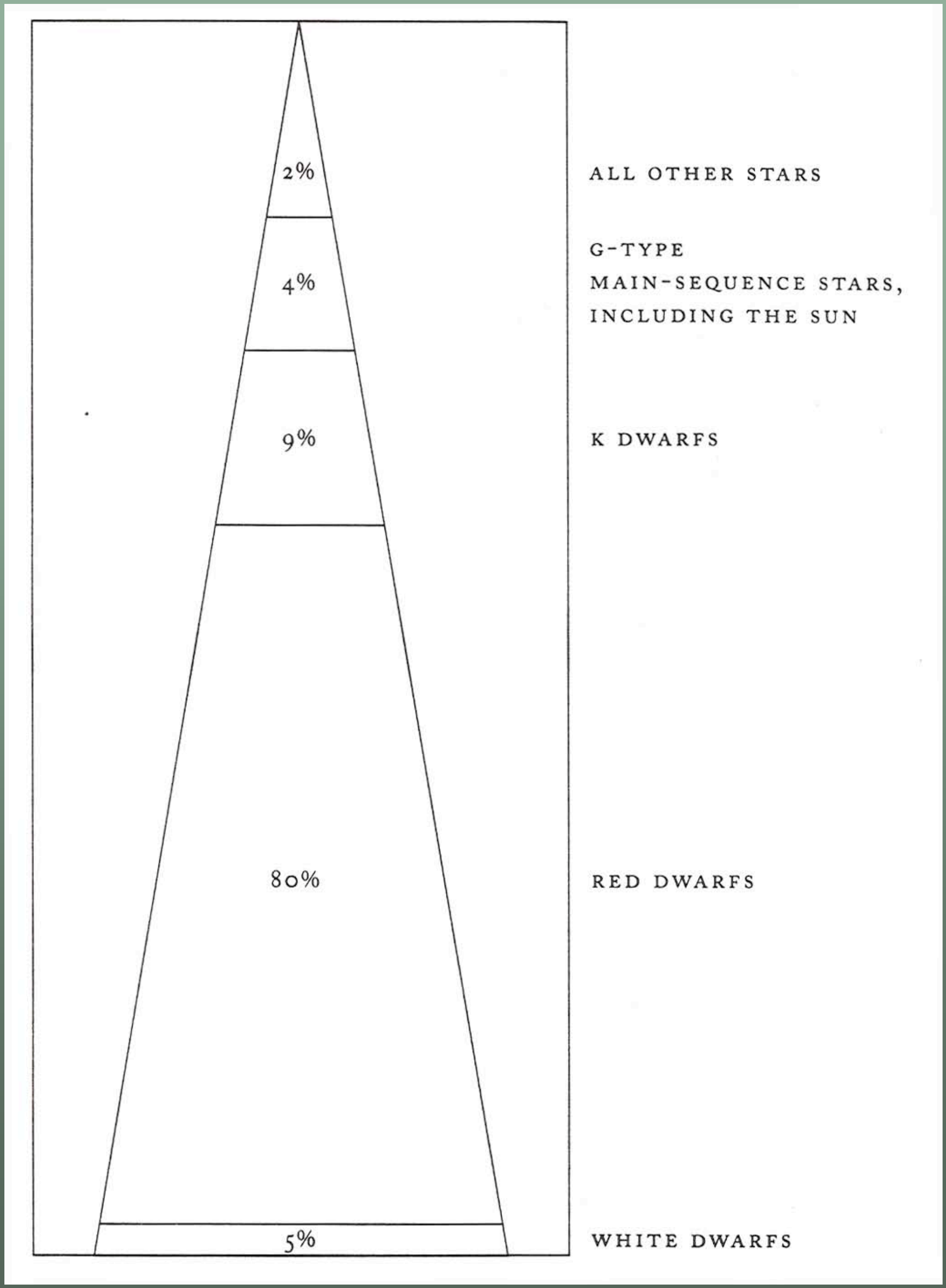
Table 10.1 Typical Properties for Hydrogen-Burning Stars of the Seven Major Spectral Types

Numbers given in "solar units" are values in comparison to the Sun; for example, a mass of 60 solar units means 60 times the mass of the Sun. Note that the Sun is a G star. (More specifically, the Sun's spectral type is G2.)

Spectral Type	Approximate Percentage of Stars in This Class	Surface Temperature (°C)	Luminosity (solar units)	Mass (solar units)	Lifetime (years)
O	0.001%	50,000	1,000,000	60	500 thousand
B	0.1%	15,000	1,000	6	50 million
A	1%	8,000	20	2	1 billion
F	2%	6,500	7	1.5	2 billion
G	7%	5,500	1	1	10 billion
K	15%	4,000	0.3	0.7	20 billion
M	75%	3,000	0.003	0.2	600 billion

The stellar luminosity-mass relation.

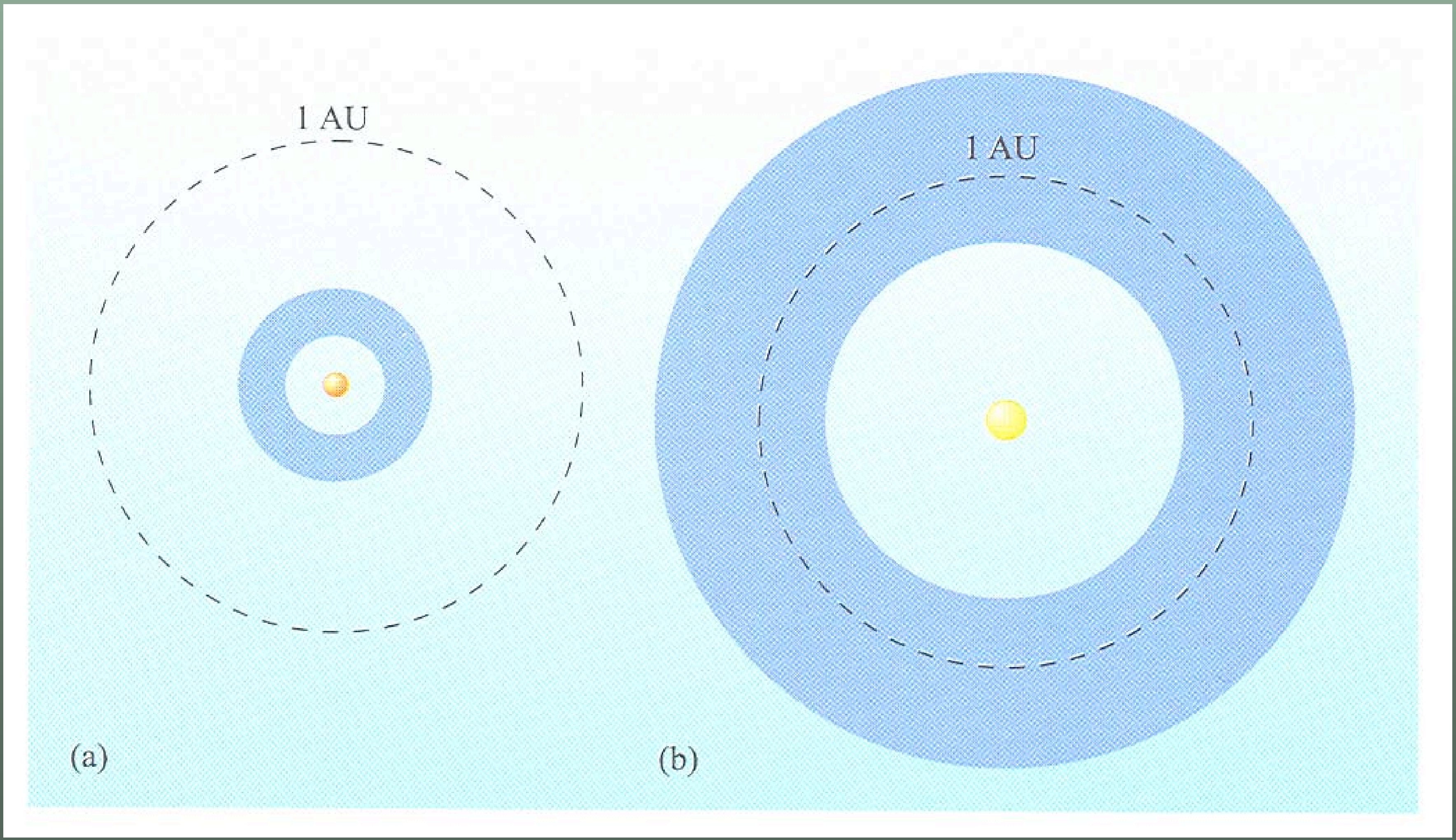


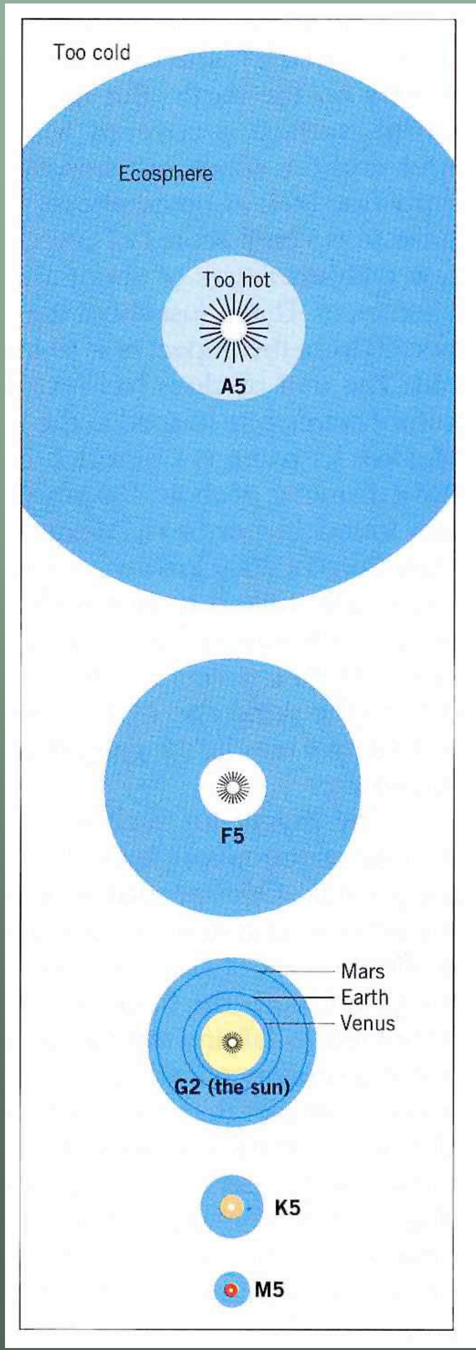


Relative fraction of different types of stars.

Choice seems obvious, but there are some problems with searches for Earth-like planets around red dwarfs (spectral class M main sequence stars).

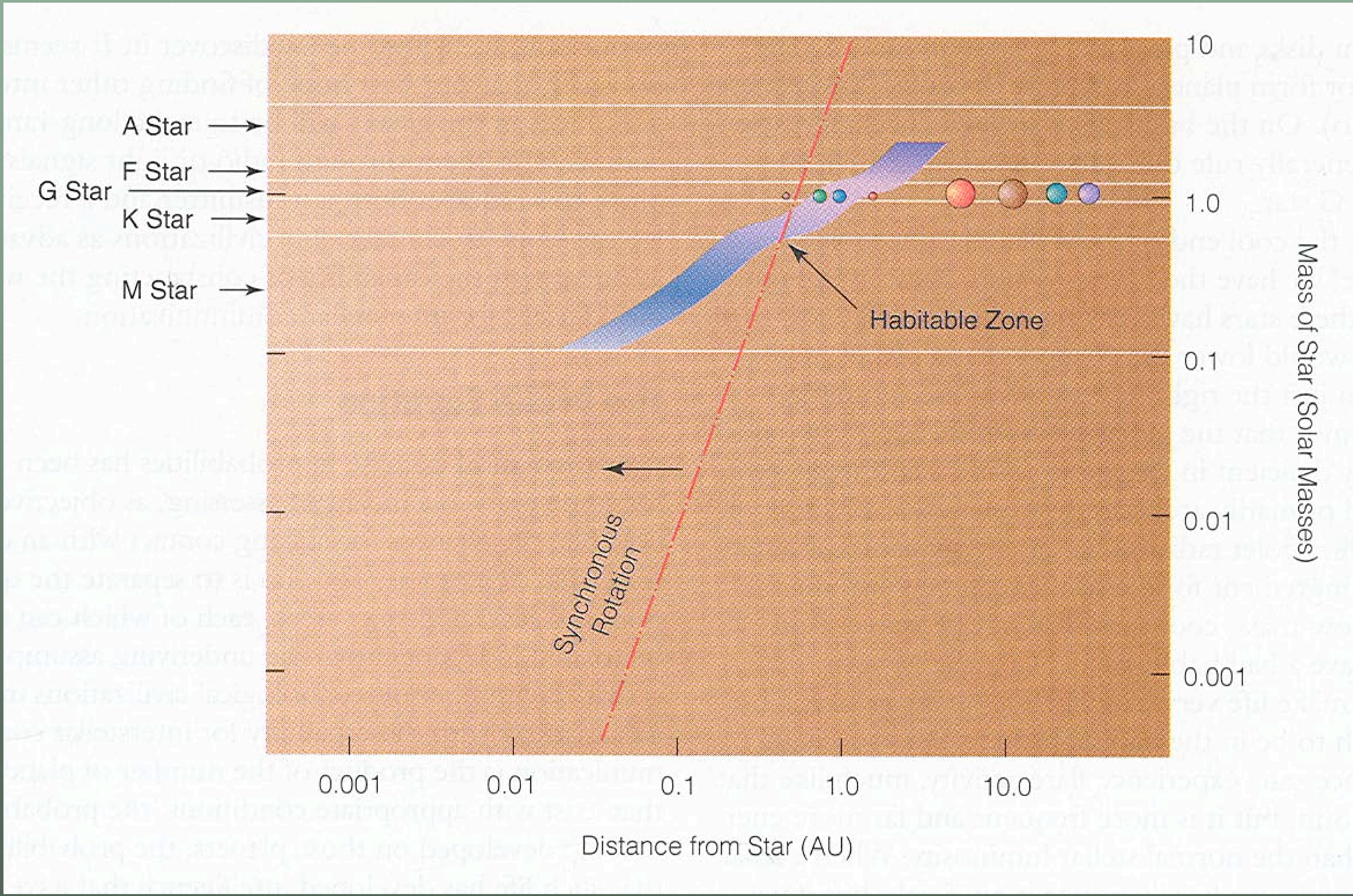
M dwarf habitable zone compared to that of a G-type (solar-like) star





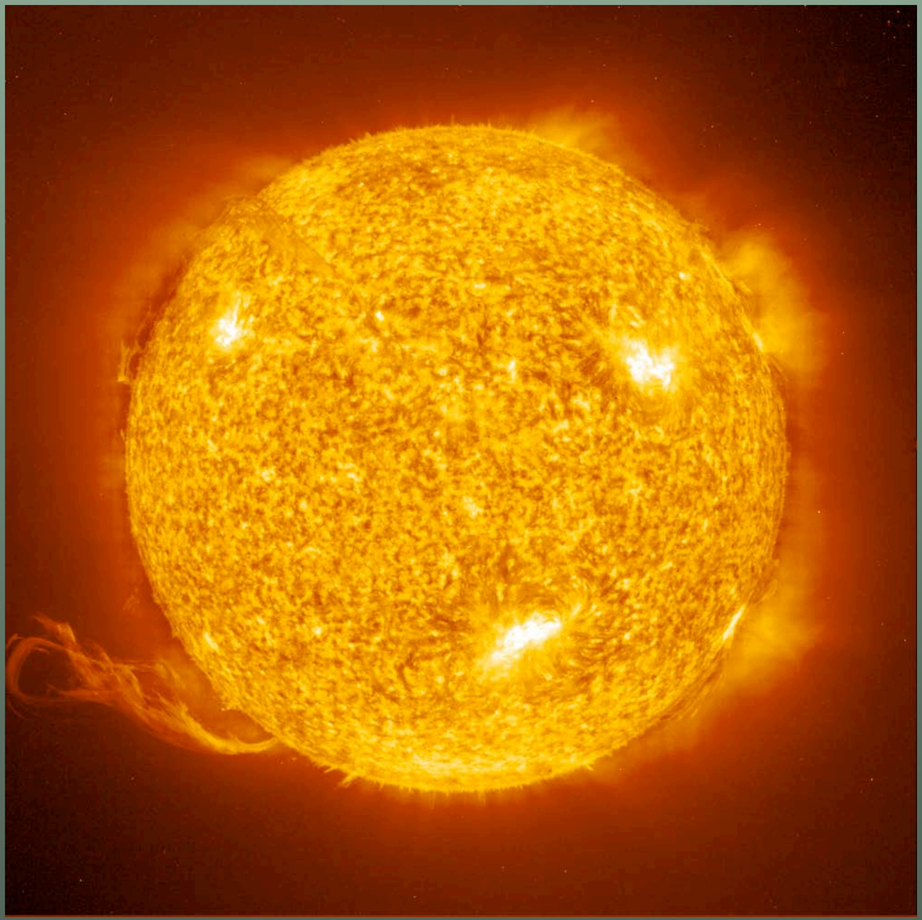
Liquid water habitable zone for stars of different masses (spectral types, *luminosities*)

Habitable Zone (blue band) for different stellar masses (vertical axis).
Note line for "synchronous rotation" (tidal locking)

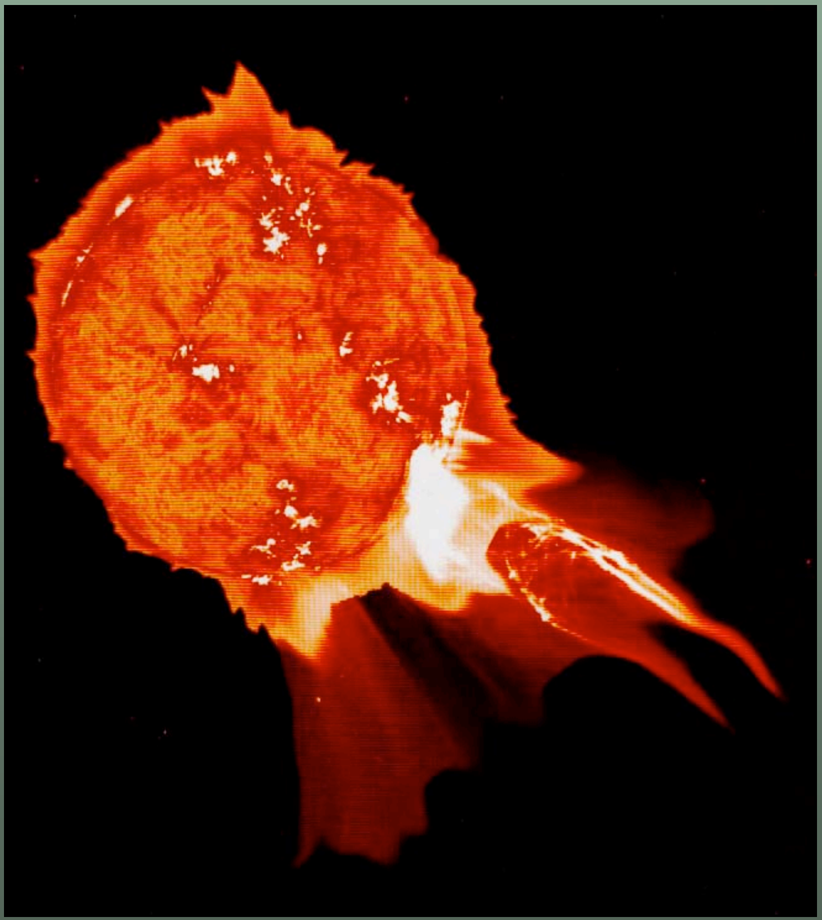


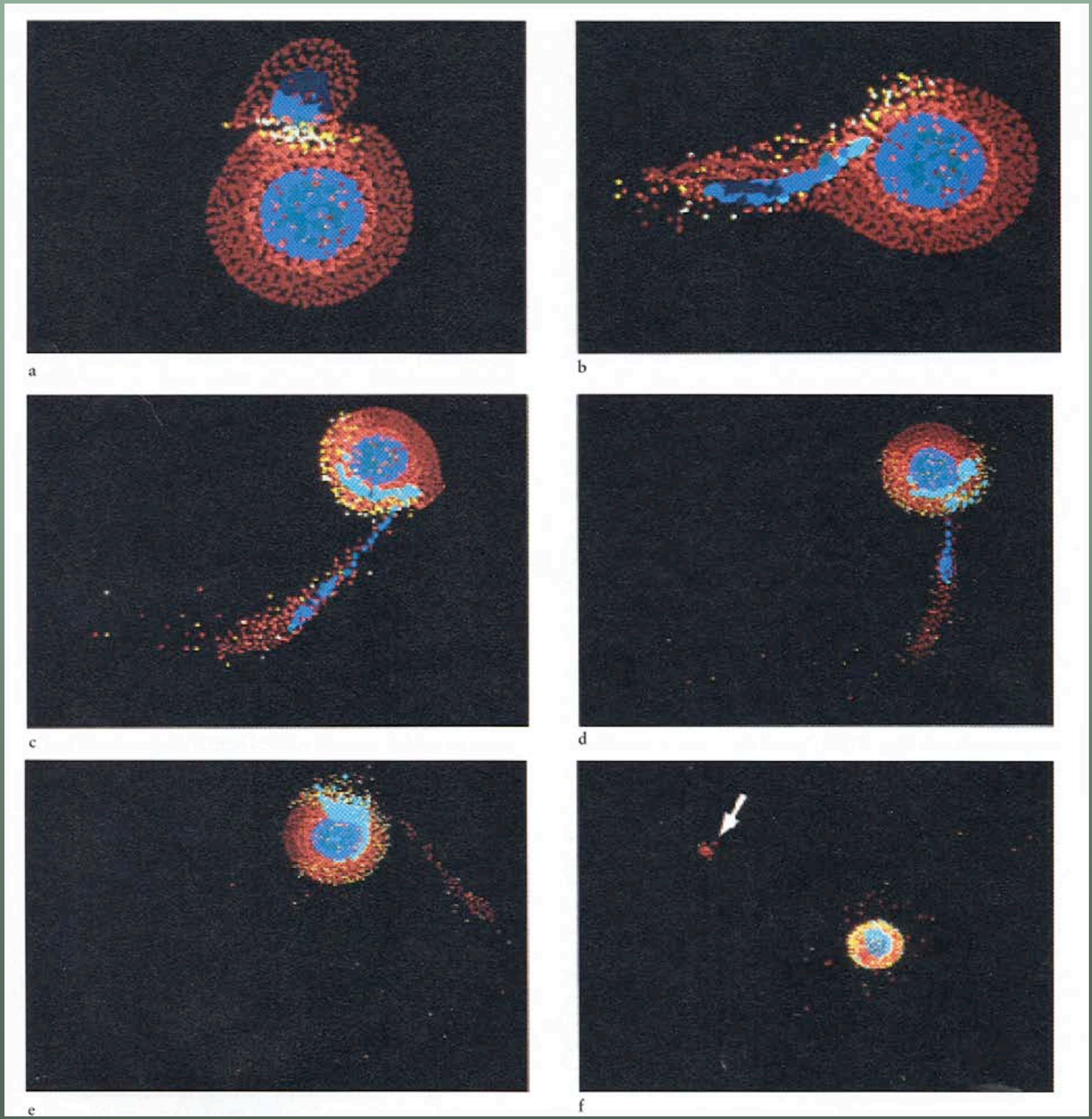
M star planets: No longer worried about synchronous rotation/tidal locking/atmospheric freezout, but many M stars are thousands or even millions of times more active (in flares, etc.) than the Sun

Active Sun in X-rays

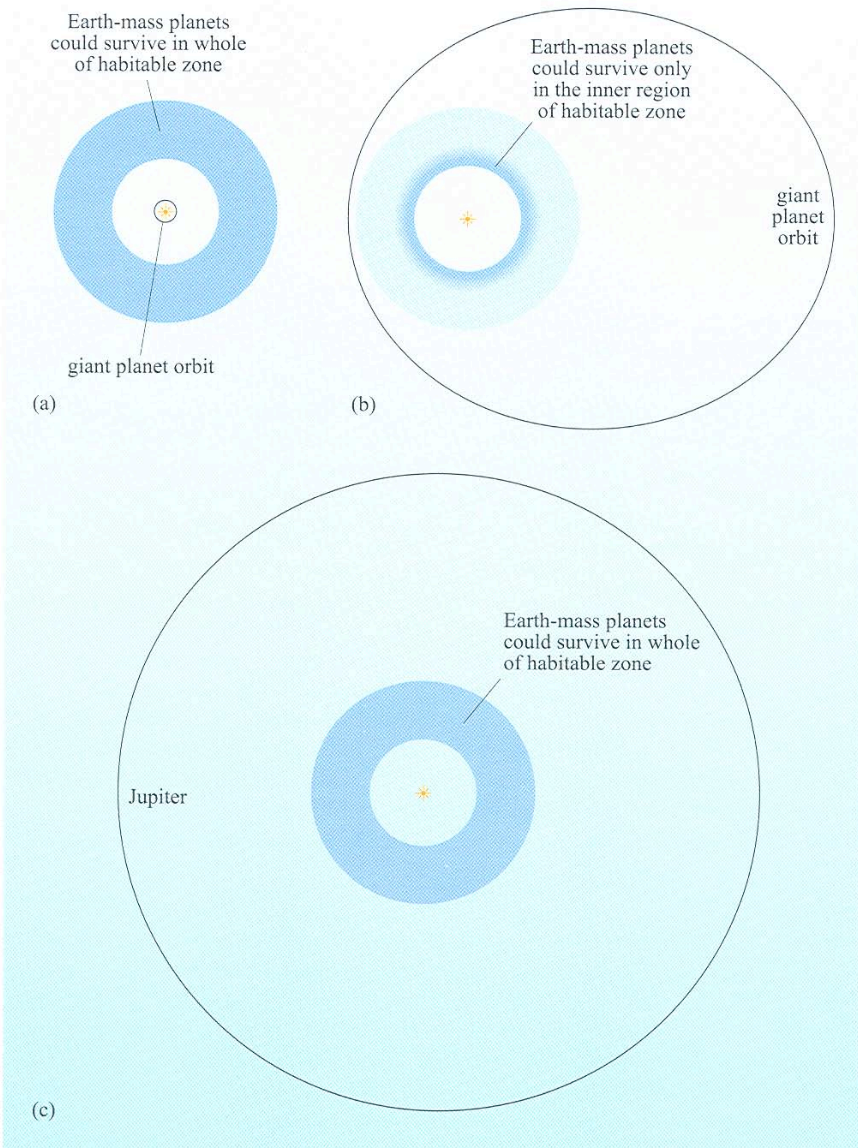


M star flares?





Don't forget the potential influence of our large moon on habitability (be able to name a couple of its most important effects). But if formed by impact, probably a very freakish event, so this would greatly reduce the chances for life-bearing planets.

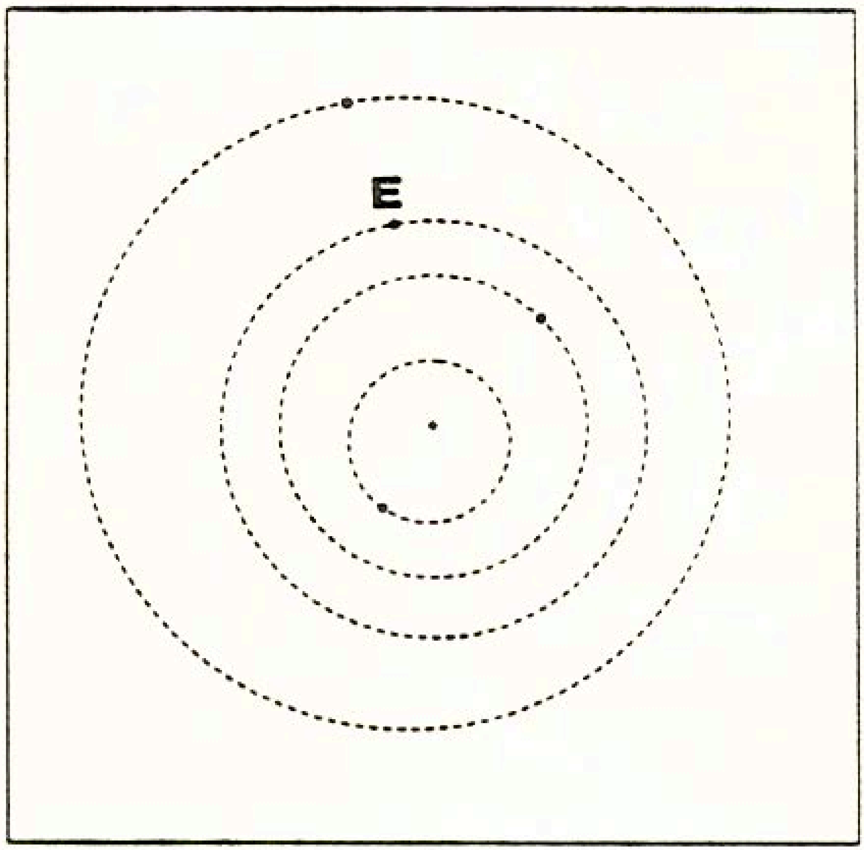


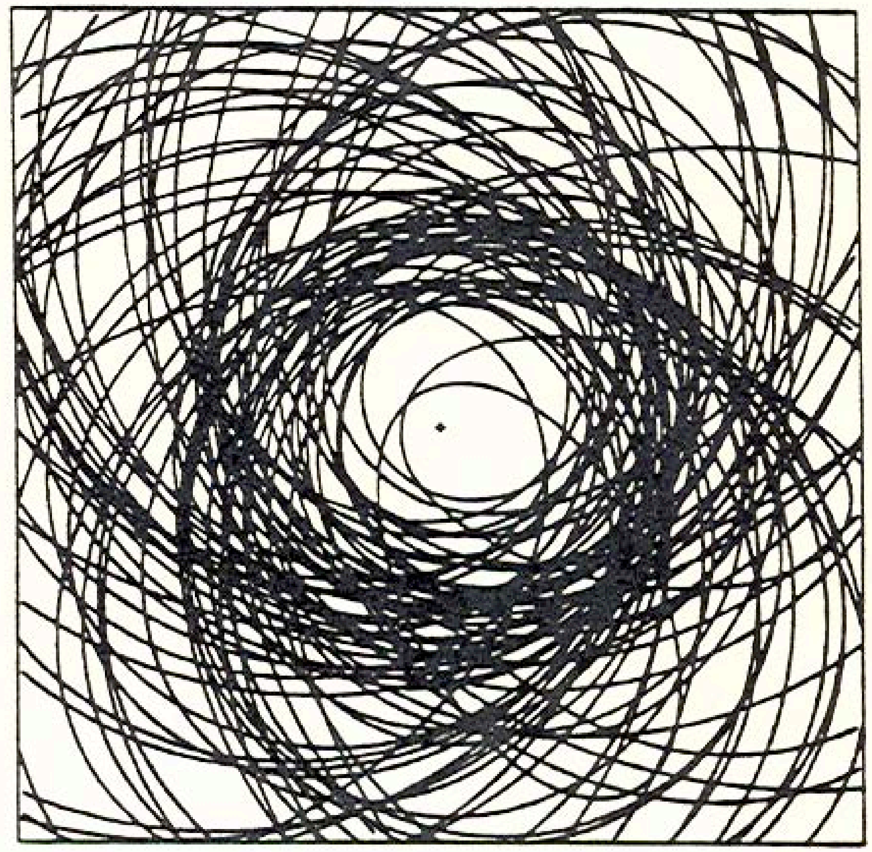
Survivable orbits for Earth-mass planets in the habitable zone where (a) the giant is very much interior to the habitable zone, (b) the giant is not far outside the habitable zone, (c) the giant is well outside the habitable zone as is the case with Jupiter in the Solar System.

The presence of a giant planet affects the stability of the orbit of a terrestrial-like planet in the habitable zone, *if* the giant planet orbit is sufficiently eccentric.

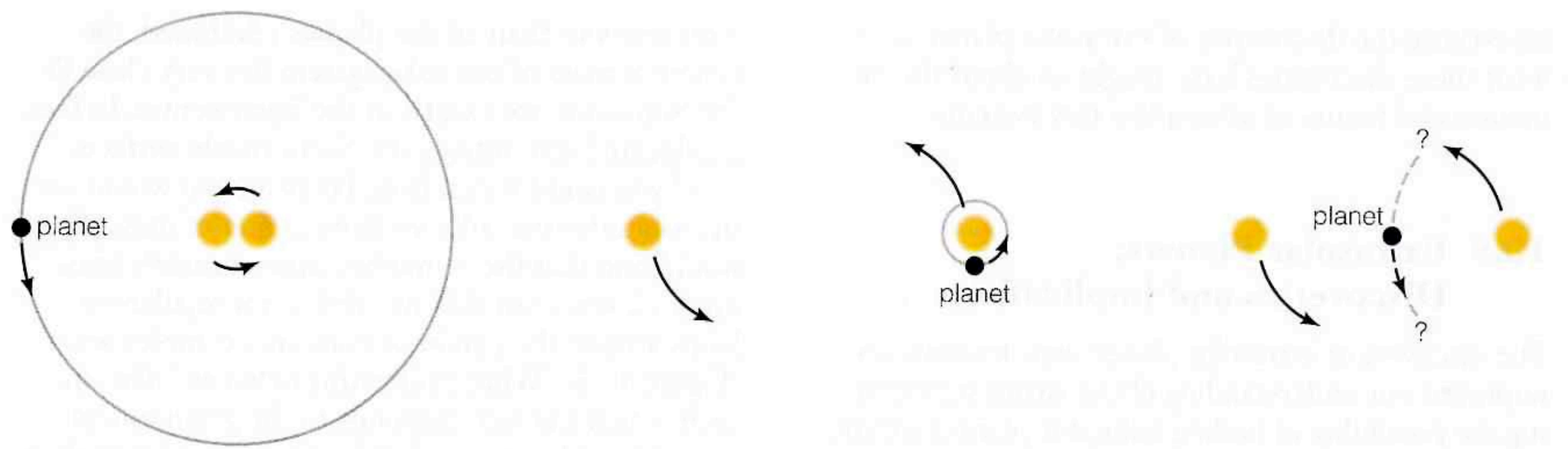
(But recall that an outer giant planet can also protect inner terrestrial-like planets by keeping most of the comets away, reducing the number of sterilizing impacts.)

An outer giant planet can also affect the rate at which asteroids or comets invade the inner parts of the planetary system. This is a picture of asteroid oribts in our Solar System--if not for Jupiter's strong influence, their eccentricities would be much smaller. But Jupiter also keeps *comets* OUT of the inner solar system, protecting us from too many mass extinctions! So the presence of a giant planet, and its properties, may play a large role in determining habitability.





Should we search for life, or signals, from **binary star** systems? There is a potential for unstable planetary orbits, and intolerable climate variation. (Figure is from your textbook.)



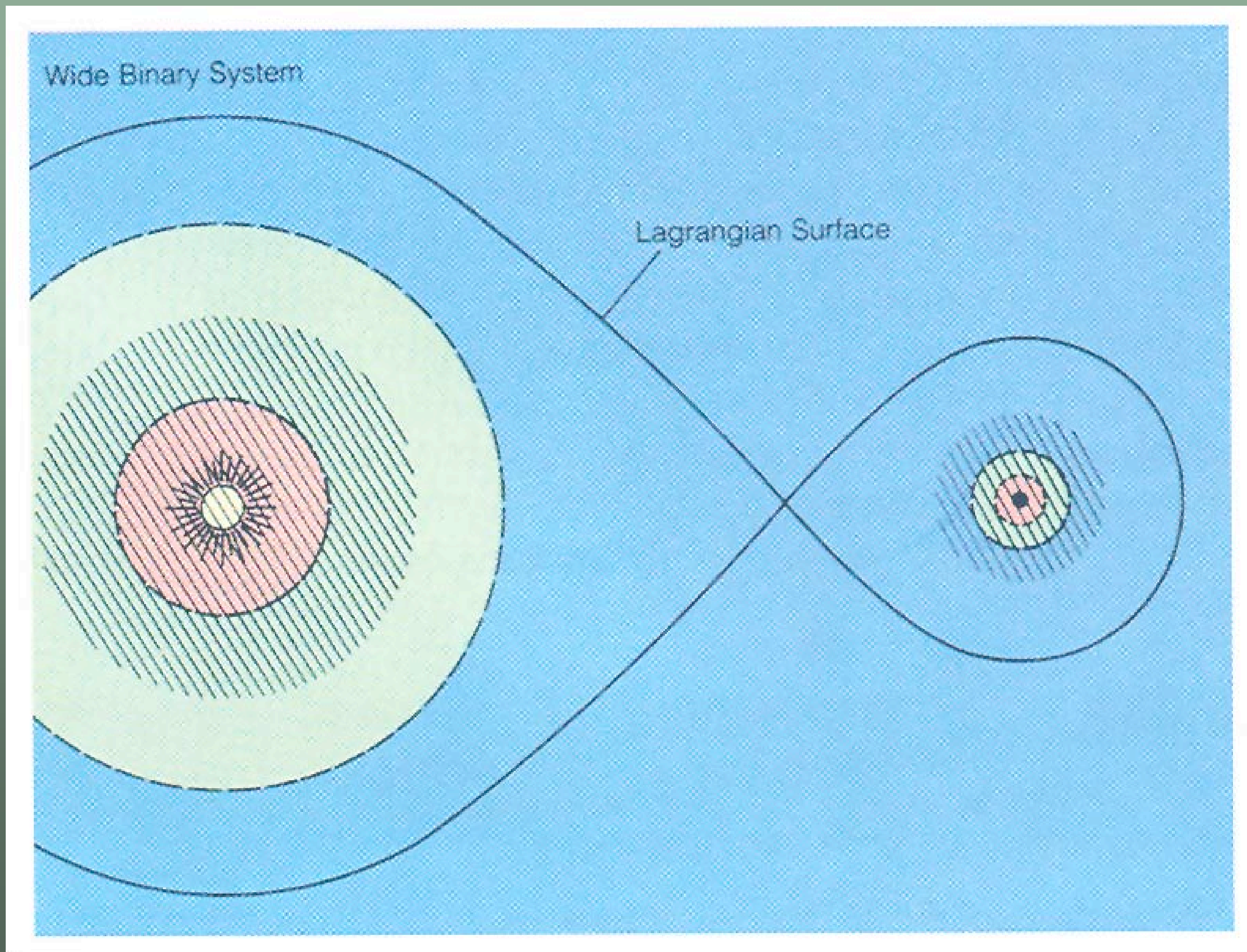
a *Potentially stable:* The planet orbits both stars; the radius of the planet's orbit is much larger than the separation between the stars.

b *Potentially stable:* The planet orbits one star; the radius of the planet's orbit is much smaller than the separation between the stars.

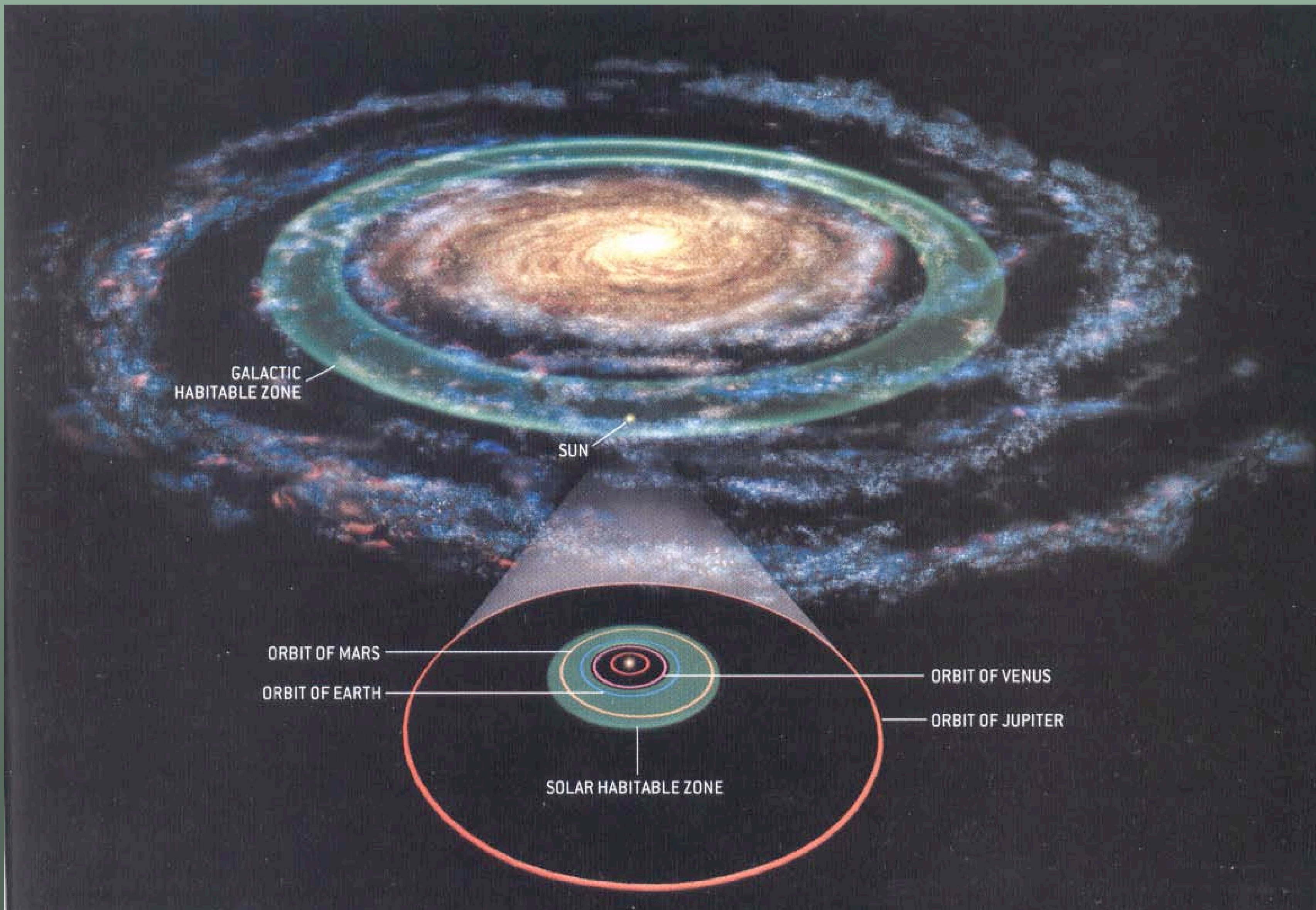
c *Not stable:* The orbit of the planet is neither much larger nor much smaller than the separation between the stars.

FIGURE 10.4 Three orbital possibilities in a binary star system.

Binary parent stars again: The “five-to-one rule”--orbits outside the hatched regions will be greatly perturbed by the companion, leading to irregular, eccentric orbits, or even ejection



A “galactic habitable zone?”--maybe some parts of our Galaxy are more favorable to planet formation or life than others. (Very speculative).



Some ways in which certain locations in our Galaxy *might* have low probabilities of planet formation or *might* be hazardous for life.