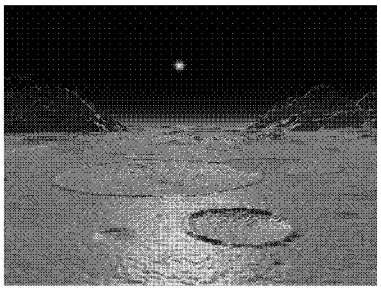
Thursday, December 2
The Future of the Solar System



Final exam: Tuesday, Dec. 7, 1:30 pm.

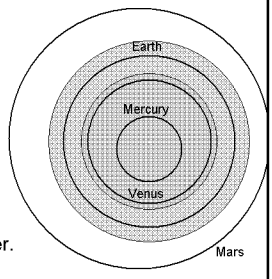
The Future of the Solar System
Key Concepts

1) The steady increase in the Sun's luminosity will make things uncomfortably hot on Earth.

2) When the Sun evolves into a red giant, Mercury will be toast & Earth will lose its air.

3) The end state of the Earth will be a cold airless planet orbiting a white dwarf.

The newborn Sun was a little fainter, smaller, and cooler than now.



$L = 0.70\ L_{sun}$
$R = 0.90\ R_{sun}$
$T = 5590\ K$

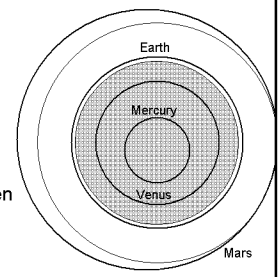
The Sun, as it converts H into He, slowly gets hotter & brighter.

Jupiter

The Sun today (4.55 Gyr old)

$L = 1\ L_{sun}$
$R = 1\ R_{sun}$
$T = 5780K$

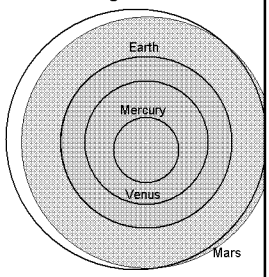
About 50% of its core hydrogen has been fused into helium.



When the Sun is 5.6 Gyr old (1.1 Gyr from now), it will be 10% brighter.

Extra solar energy will trigger a Moist Greenhouse Effect.

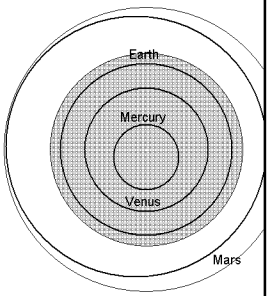
The atmosphere will dry out as water vapor is lost to space.



When the Sun is 9 Gyr old (3.5 Gyr from now), it will be 40% brighter.

Extra solar energy will trigger a Runaway Greenhouse Effect.

Oceans will evaporate; CO_2 will be unlocked from the crust.



The Earth will become like Venus is today, ending life on the planet.

When the Sun is ~11 Gyr old (~5.5 Gyr from now), it will run out of hydrogen in its core.

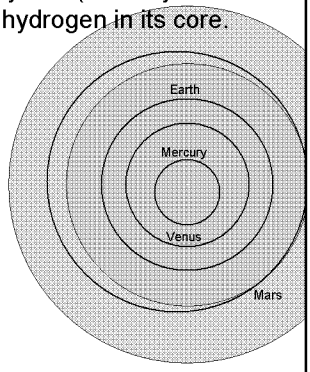
The inert He core will contract & heat up.

Fusion moves into a shell.

$L = 2.2\ L_{sun}$

$R = 1.58\ R_{sun}$

$T = 5520$ K

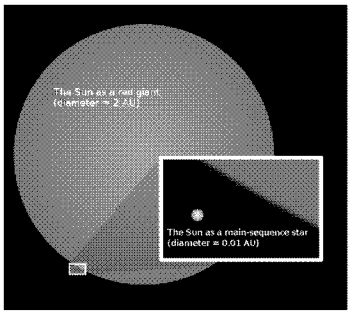


As the Sun gradually swells into a red giant, it develops a strong solar wind.

More than ¼ of the Sun's mass is lost.

Planetary orbits move outward.

Earth moves to ~1.4 AU from Sun.



When it is 12.23 Gyr old, the Sun will be a swollen red giant, engulfing Mercury.

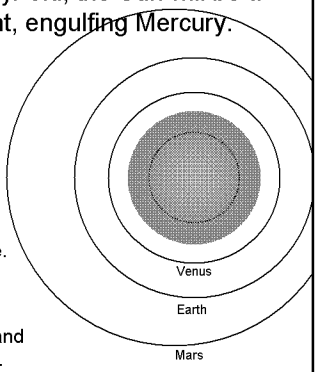
$L = 2350\ L_{sun}$

$R = 170\ R_{sun}$ (0.78 AU)

$T = 3110$ K (M Giant Star)

The Habitable Zone, at this point, will be beyond Neptune.

Helium fusion into carbon and oxygen ignites in the core...

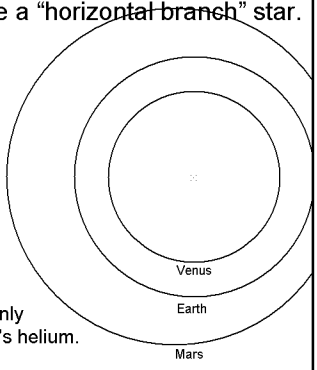


After fusion of helium begins in its core, the Sun will shrink and become a "horizontal branch" star.

$L = 41\ L_{sun}$
$R = 9.5\ R_{sun}$
$T = 4720\ K$

The Habitable Zone will be beyond Jupiter.

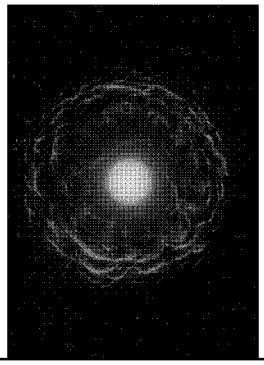
At this luminosity, it will take only 100 Myr to use up all the core's helium.



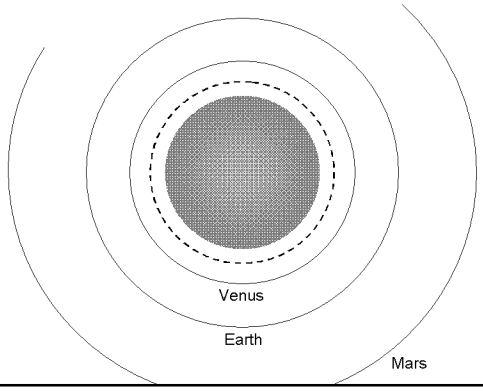
When helium runs out in the core, the Sun will swell into an "asymptotic red giant" star.

The Sun will contain an inert C/O core, surrounded by shells fusing He and H.

Pulsations in these shells will drive off more of the Sun's atmosphere.

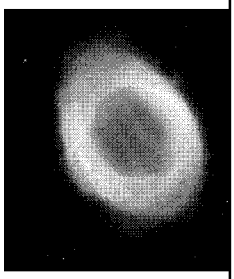


Pulsating asymptotic giant branch phase



The last pulsation unveils the hot carbon/oxygen core of the Sun.

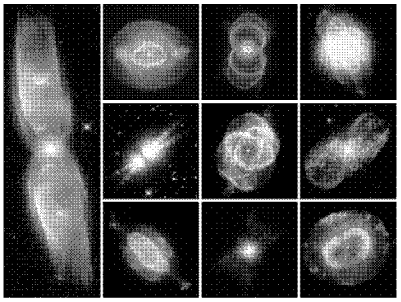
Ultraviolet light from the core will ionize the ejected gas, forming a **planetary nebula**.



The core evolves into a **white dwarf** with a mass half that of the Sun, and a radius equal to that of the Earth.

The Earth will end up 1.8 AU from the white dwarf.

Planetary nebulae are a striking, but short-lived, phase in a star's career.



They fade to invisibility in 30,000 years or so.

The Sun's normal evolution will render the Earth uncomfortably hot ~1 Gyr from now.

If humans are still around, we'll have to move further from the Sun.

However, 1 Gyr is long compared to an interstellar colonization timescale; it's also long compared to the typical lifetime of a species.

Final Lecture:

The Future of the Universe

Final Exam:

Tuesday, Dec. 7, 1:30 pm