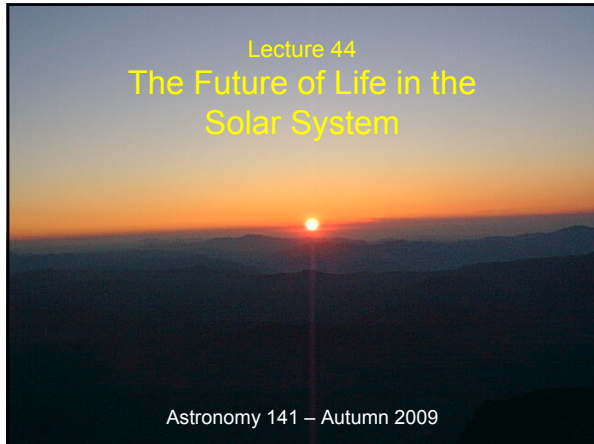


# Lecture 44: The Future of Life in the Solar System



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This lecture is about the future of life in the Solar System.

The Sun today is a steadily shining, middle-aged Main Sequence star.

The Sun was cooler and fainter in the past, and gets steadily brighter and hotter as it ages.

The Habitable Zone moves out as the Sun gets brighter, causing a runaway greenhouse effect on Earth.

Subsequent evolution of the Sun through the Red Giant phase renders the Earth airless and lifeless.

End state is a cold Earth orbiting a fading white dwarf star.

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On reaching the Main Sequence, the young Sun was a little fainter, smaller, and cooler than today

Took ~ 50 Myr to reach the Main Sequence

$L = 0.70 L_{\text{sun}}$   
 $R = 0.897 R_{\text{sun}}$   
 $T = 5586 \text{ K}$

As it fuses H into He in its core, it slowly gets **hotter & brighter** as it ages.

Jupiter

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# Lecture 44: The Future of Life in the Solar System



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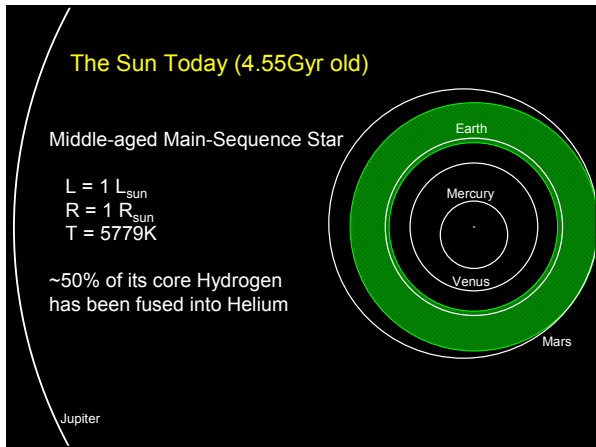
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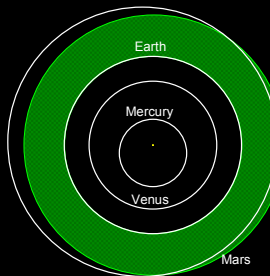
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# Lecture 44: The Future of Life in the Solar System

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

Extra solar energy triggers a **Moist Greenhouse Effect**

Atmosphere dries out as water vapor is lost to space.



The end of large surface life, but life might survive in deep in the oceans or underground

Jupiter

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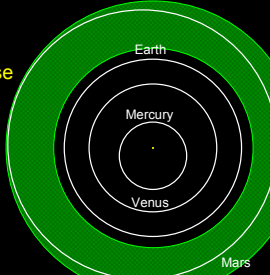
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When the Sun is ~9 Gyr old (3.5 Gyr from today) it will be 40% brighter...

Triggers a **Runaway Greenhouse Effect**

Oceans evaporate  
CO<sub>2</sub> locked in the crust is released into the atmosphere

Earth fully out of the Habitable Zone



Earth becomes like Venus is today, ending all life on the planet.

Jupiter

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# Lecture 44: The Future of Life in the Solar System

When the Sun is ~11Gyr old it will run out of Hydrogen in its core.

Inert He core starts to contract & heat up  
H fusion moves into a shell

$L = 2.21 L_{\text{sun}}$   
 $R = 1.575 R_{\text{sun}}$   
 $T = 5517 \text{ K}$

Sun leaves the Main-Sequence

Jupiter

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During the 1.3 Gyr after leaving the Main Sequence the Sun grows steadily into a Red Giant star

First 0.7 Gyr:  
Near-constant Luminosity of  $\sim 2.2 L_{\text{sun}}$   
Grows from  $1.6 R_{\text{sun}}$  to  $2.3 R_{\text{sun}}$   
Cools from 5517 K to 4902 K

Next  $\sim 0.6$  Gyr it climbs the Red Giant Branch.  
Luminosity climbs to  $2350 L_{\text{sun}}$   
Swells up from  $2.3 R_{\text{sun}}$  to  $166 R_{\text{sun}}$

Loses 28% of its mass in a strong wind that causes the planets to move outwards:

Venus to  $\sim 1 \text{ AU}$ , Earth to  $\sim 1.4 \text{ AU}$

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When it is 12.23 Gyr old, the Sun reaches the top of the Red Giant Branch, and swallows Mercury

$L = 2350 L_{\text{sun}}$   
 $R = 166 R_{\text{sun}} (0.775 \text{ AU})$   
 $T = 3107 \text{ K} (M0 \text{ III Star})$

Habitable Zone has moved out past Neptune and Pluto into the outer Kuiper Belt.

Helium fusion into Carbon and Oxygen ignites in the core...

Venus  
Earth  
Mars

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# Lecture 44: The Future of Life in the Solar System



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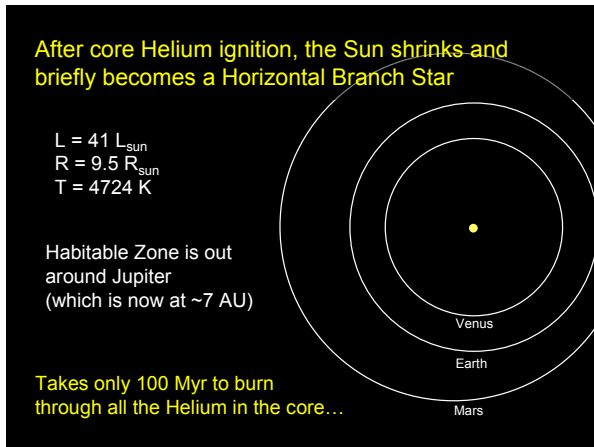
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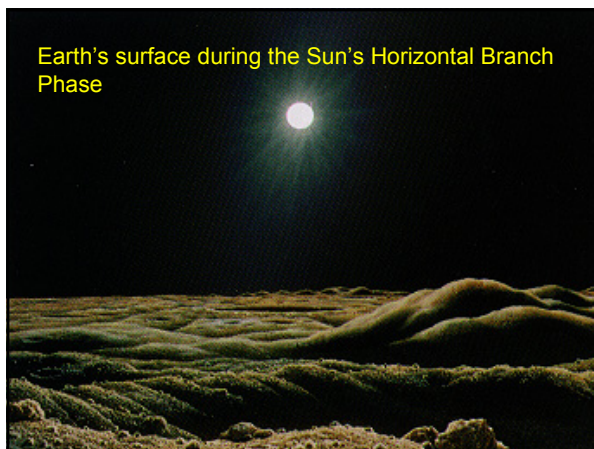
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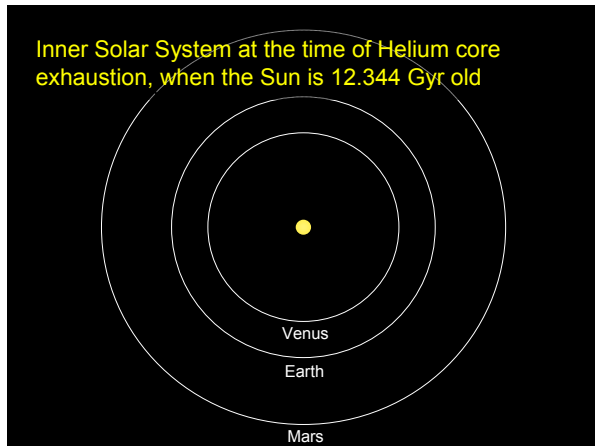
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# Lecture 44: The Future of Life in the Solar System



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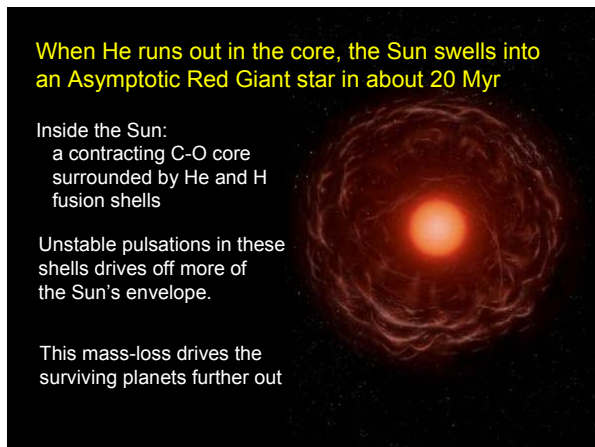
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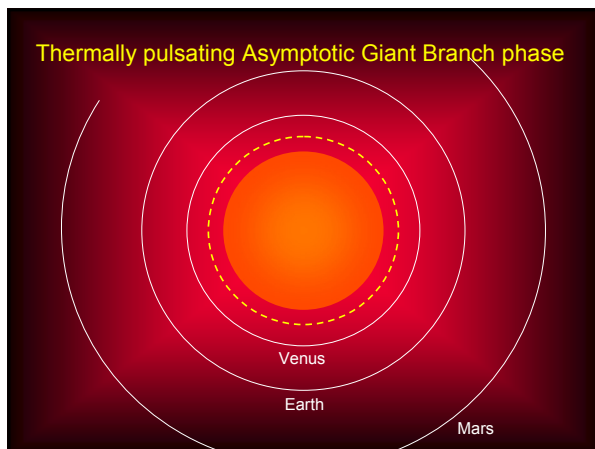
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# Lecture 44: The Future of Life in the Solar System

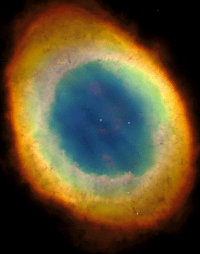
The last thermal pulse blows off the rest of the Sun's envelope over a few thousand years.

Hot C-O Core is unveiled

UV photons from the core ionize the ejected envelope gas, forming a *Planetary Nebula*

0.54  $M_{\text{sun}}$  C-O Core evolves into a *White Dwarf* with  $R \sim R_{\text{Earth}}$

The Earth ends up orbiting 1.85 AU away



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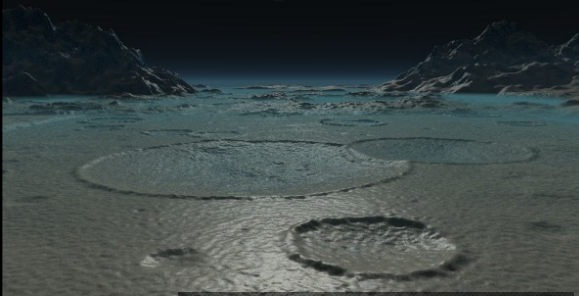
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The final state of the Earth is a cold, airless, lifeless world circling a fading White Dwarf star.



The view from Earth 8 Gyr from today

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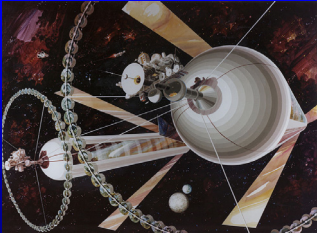
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The normal course of the Sun's evolution will render the Earth uninhabitable  $\sim 1$  Gyr from now.

If humans are still around, we would have to move further out into the Solar System

However, 1 Gyr is long compared to a modest interstellar colonization timescale...

It is also very long compared to the typical lifetime of a species (few Myr).



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