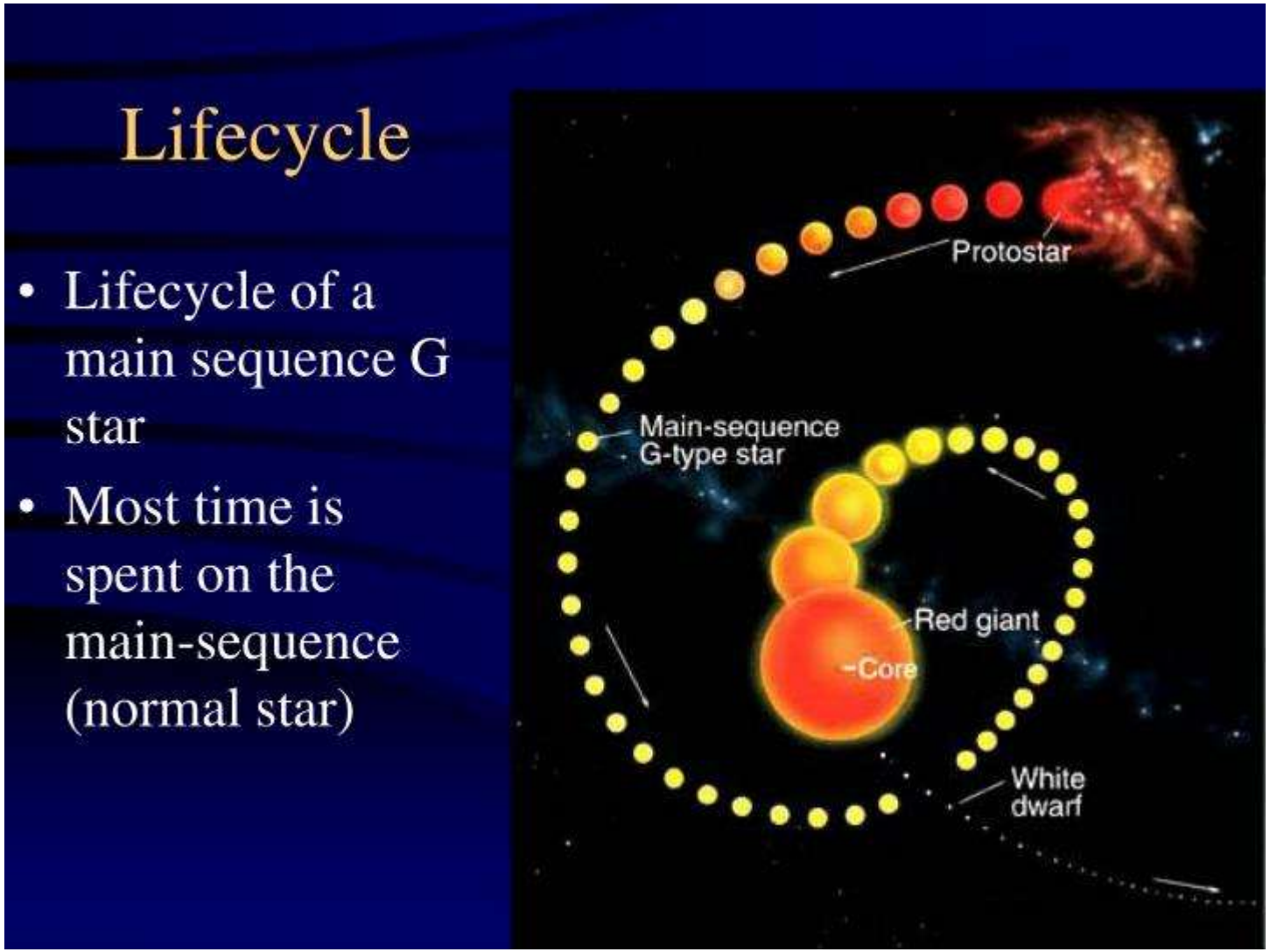
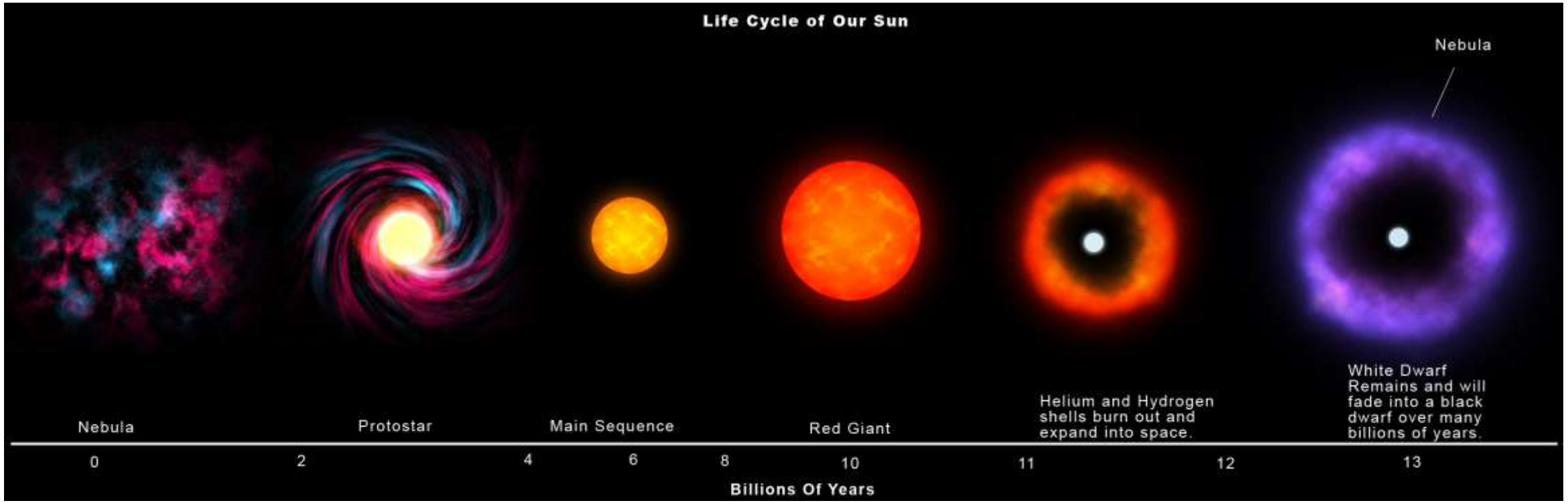
Fate of the Sun
Fate of the Universe

Jim Rauf

Lifecycle of The Sun -a Main Sequence G Star

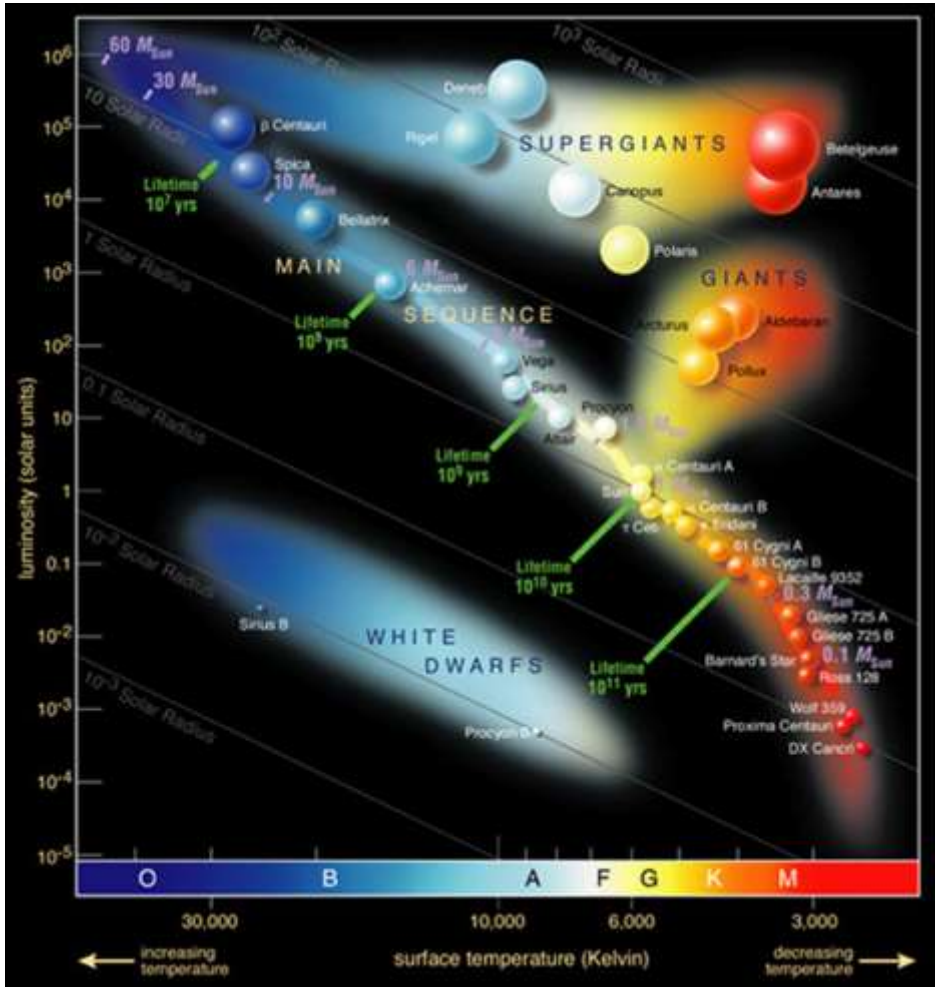


Fate of the Sun- Nebula to Nebula

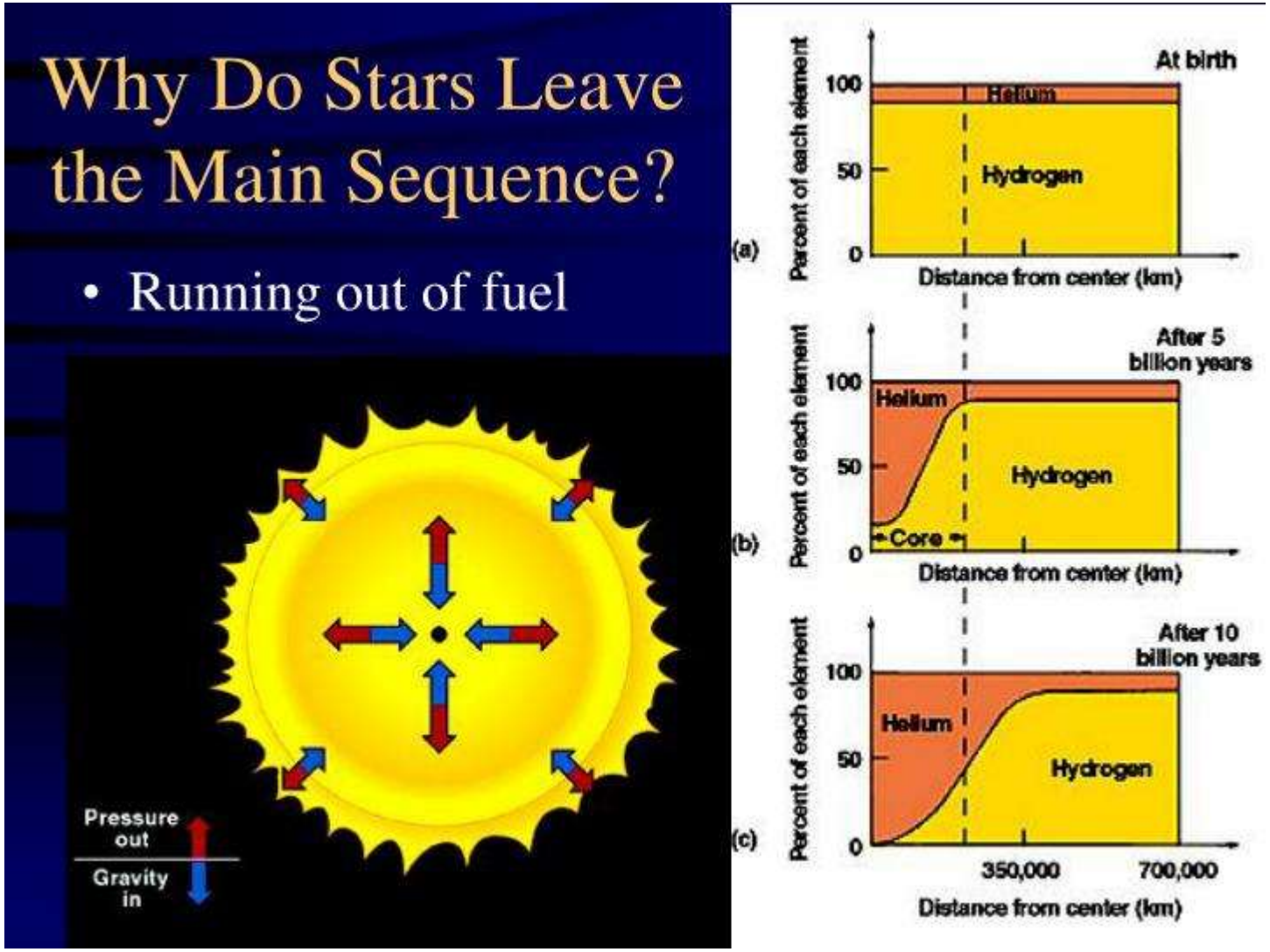


Fate of the Sun

- The Main Sequence:
- The Sun, like most stars in the Universe, is on the **main sequence stage** of its life, during which nuclear fusion reactions in its core fuse hydrogen into helium
- Every second, 600 million tons of matter are converted into neutrinos, solar radiation, and roughly 4 x 10^{27} Watts of energy
- For the Sun, this process began 4.57 billion years ago, and it has been generating energy this way every since
- So far, the Sun has converted an estimated 100 times the mass of the Earth into **helium** and **solar energy**



Fate of the Sun-Leaving the Main Sequence

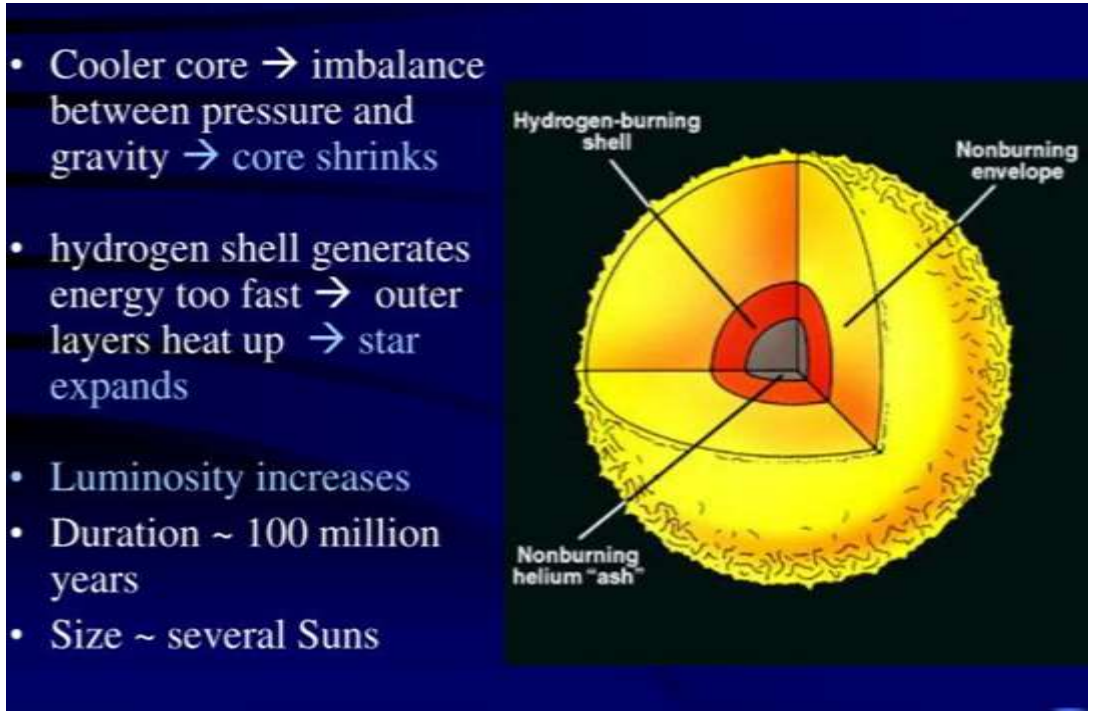


Fate of the Sun-Hydrogen Shell Burning

- As the supply of hydrogen in the core begins to decreases (having been fused into **helium**), the fusion rate goes down, and the amount of energy generated drops
- The temperature will then begin to drop and then the pressure will also decrease in the fusion core

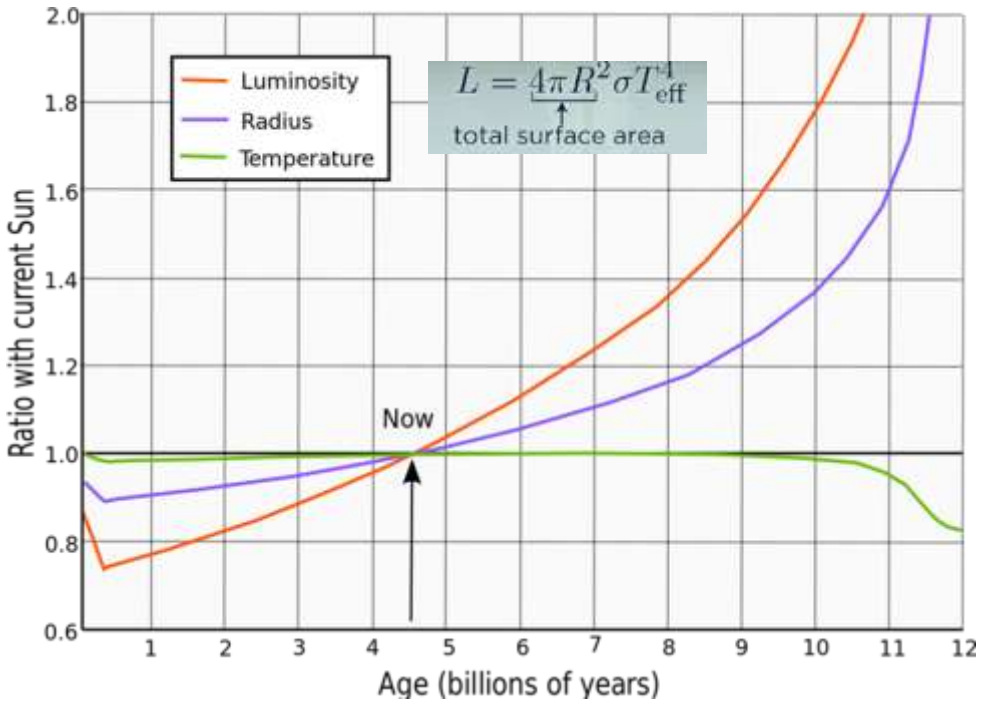
$$PV = nRT$$

- A drop in pressure means that the core region of the star will contract slightly
- This will cause the temperature to go up again, and the fusion rate for the remaining hydrogen in the core increases
- The sharp rise in temperature also starts a **hydrogen burning shell** around the core, a region that before was too cool (less than 15 million K) to sustain fusion before



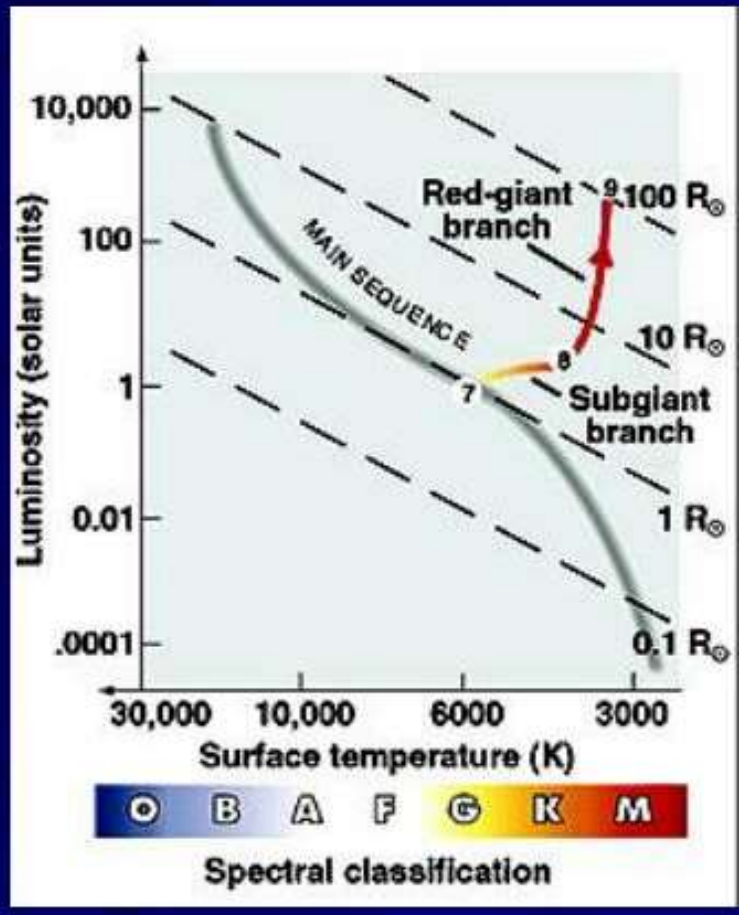
Fate of the Sun

- At present, this is leading to ~ 1% increase in luminosity every 100 million years
- And ~ 30% increase over the course of the last 4.5 billion years
- In 1.1 billion years from now, the Sun will be ~ 10% brighter than it is today, and this increase in luminosity will affect the planets in the **solar system**
- All the planets will receive more solar energy due to the luminosity increase
- In 3.5 billion years from now, the Sun will be 40% brighter than it is right now
- The Sun's increased luminosity (power output) will move the solar system's "habitable zone" outward



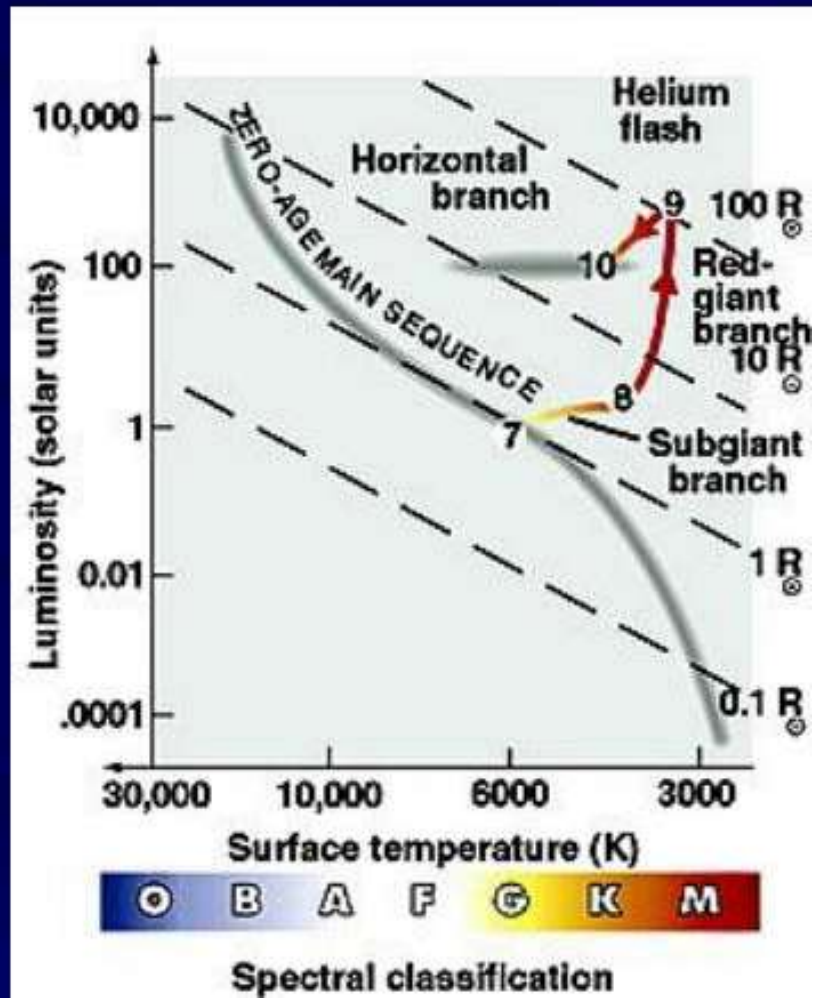
Fate of the Sun-Red Giant Phase

- Luminosity huge (~ 100 Suns)
- Surface Temperature lower
- Core Temperature higher
- Size ~ 70 Suns (orbit of Mercury)



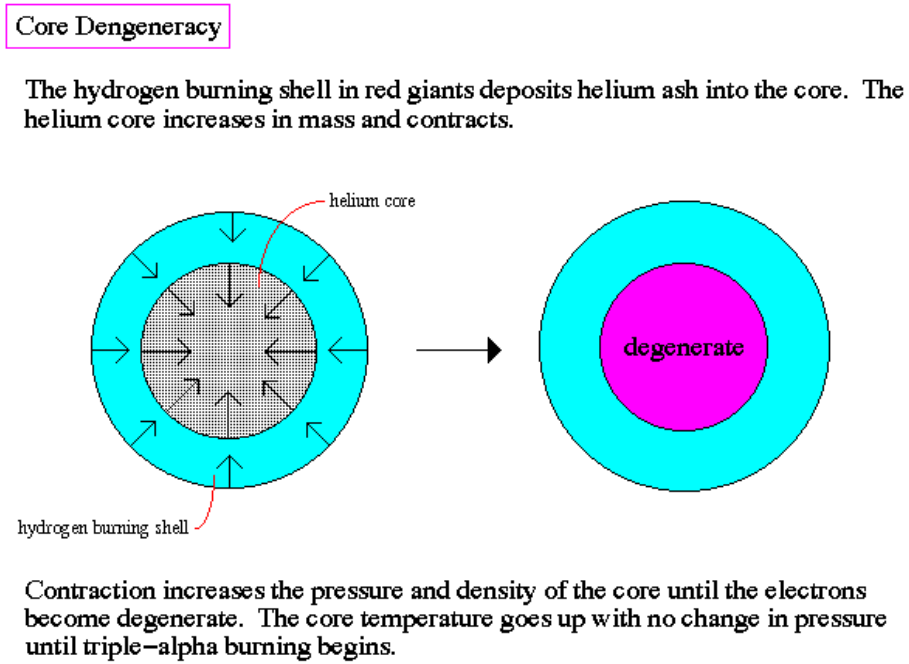
Fate of the Sun-Horizontal Branch-Helium Flash

- The core becomes hot and dense enough to overcome the barrier to fusing helium into carbon
- Initial explosion followed by steady (but rapid) fusion of helium into carbon
- Lasts: 50 million years
- Temperature: 200 million K (core) to 5000 K (surface)
- Size ~ 10 × the Sun



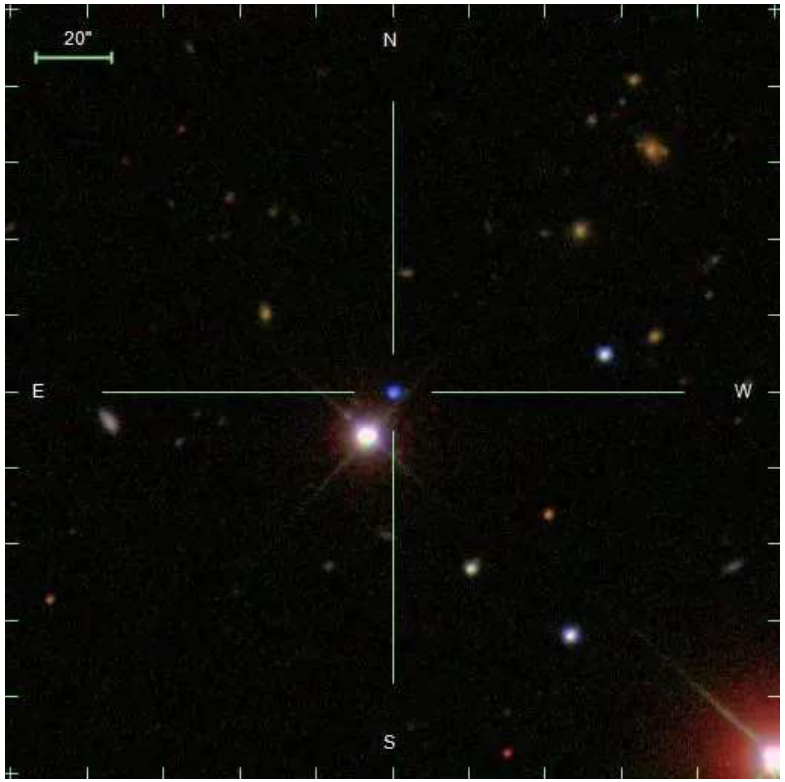
Fate of the Sun-After the Red Giant Phase

- A sun's evolution after the **red giant** phase depends on its mass
- The hydrogen burning shell eats its way outward leaving behind more **helium ash**
- The core becomes more massive and contracts
- Contraction heats the core, it becomes more dense
- The density of the core increases to where the electrons and helium nuclei become **degenerate**
- Electron and Neutron degeneracy are stellar applications of the **Pauli Exclusion Principle**
  - No two nucleons can occupy identical quantum states
- The core begins to act more like a liquid than a gas, it becomes incompressible
- Further contraction stops



Fate of the Sun-After the Red Giant Phase

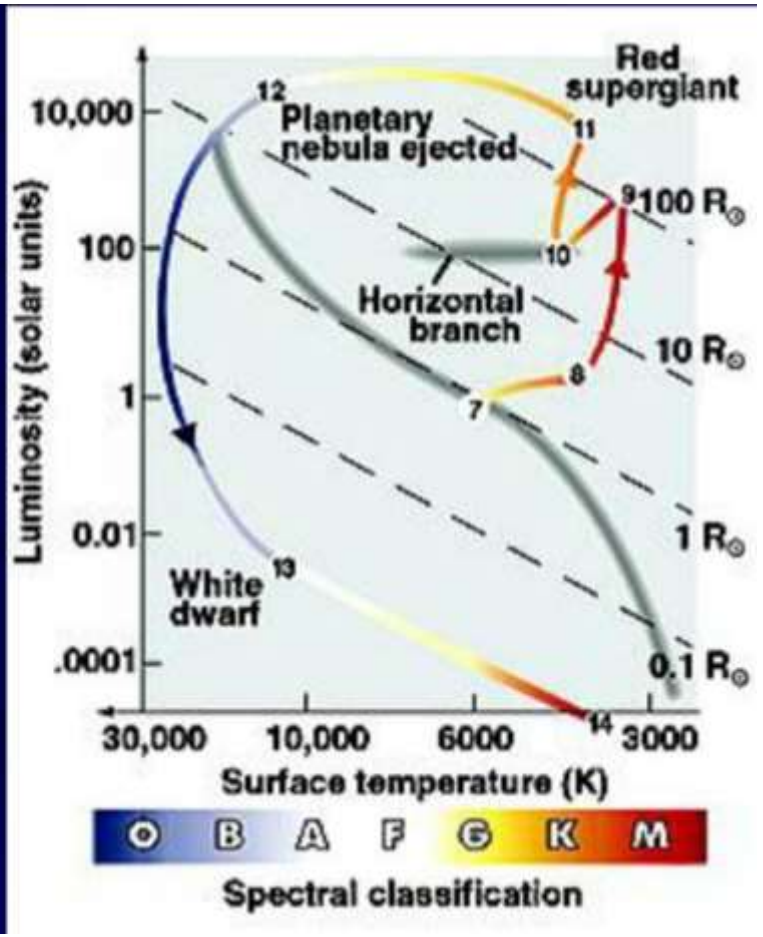
- The energy from the gravitational collapse is not sufficient to produce the neutrons (protons +electrons) of a neutron star
- Once the sun is degenerate, gravity cannot compress it any more
- Quantum mechanics dictates that there is no more available space to be taken upThe collapse is halted by electron degeneracy to form a **white dwarf**

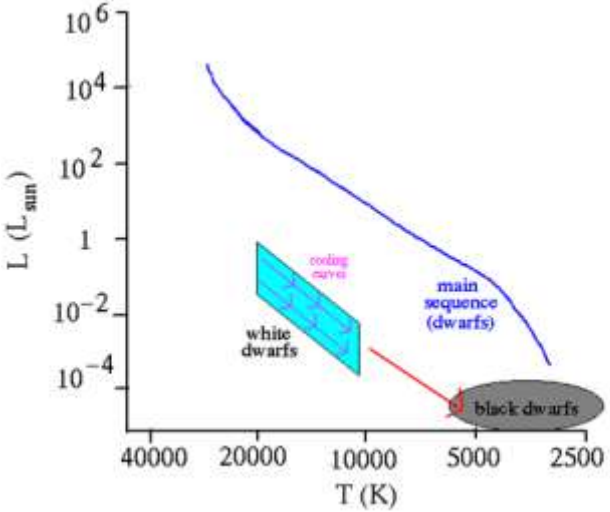


White dwarf SDSS J124043.01+671034.68

Fate of the Sun -After the Red Giant Phase-White Dwarf

- Core radiates only by stored heat, not by nuclear reactions
- core continues to cool and contract
- Size ~ Earth
- Density: a million times that of Earth – 1 cubic cm has 1000 kg of mass!





- The cooling process is very slow for white dwarfs
- After a billion years the white dwarf will be down to 0.001 the luminosity of the Sun
- The white dwarf will eventually give up all its energy and become a solid, crystal **black dwarf**

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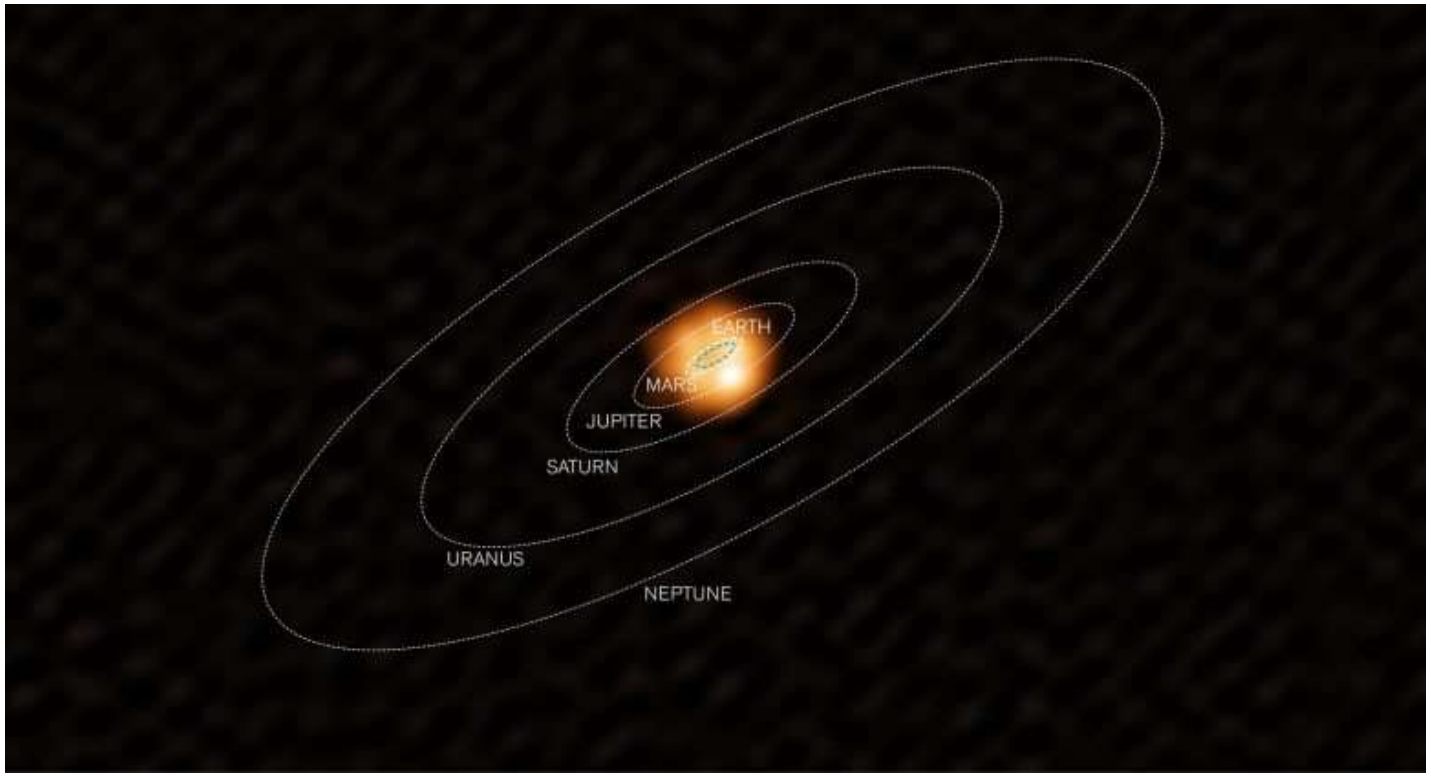
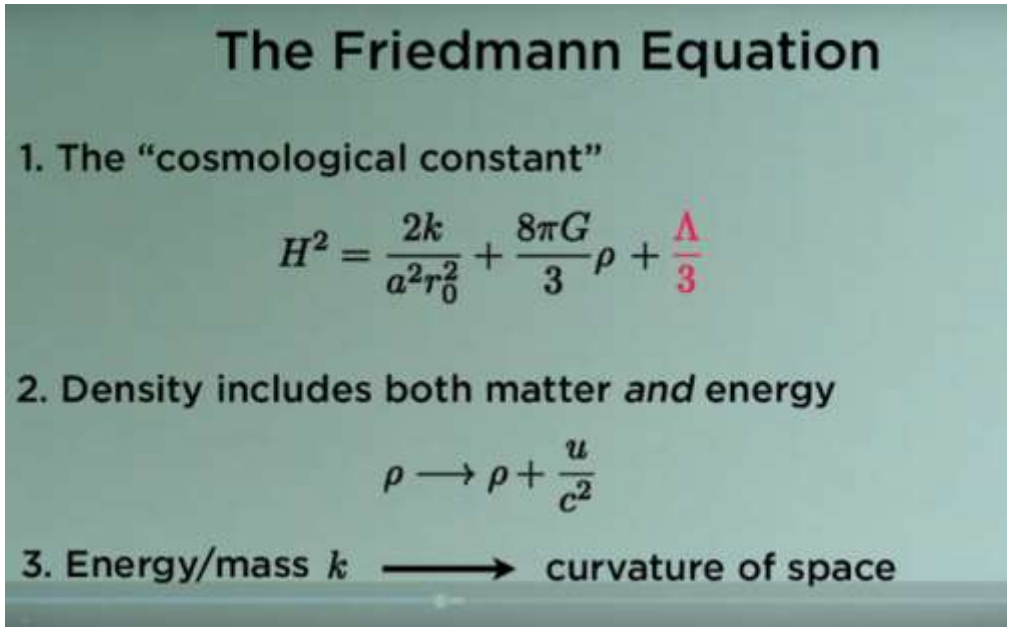


- New images show details on the surface of the red giant **W Hydrae**, 320 light years distant in the constellation of Hydra
- The star is a few billion years further on than the Sun in its life
- The dotted rings show the size of the orbits of the Earth (in blue) and other planets around the Sun for comparison

Fate of the Universe-Friedmann Equation –General Relativity



- K=0 Space is Flat
- K≠0 Space is Curved

- K $\lessdot$ 0 Space is Curved Like a Sphere
- K $\gtrdot$ 0 Space is Curved Like a Saddle

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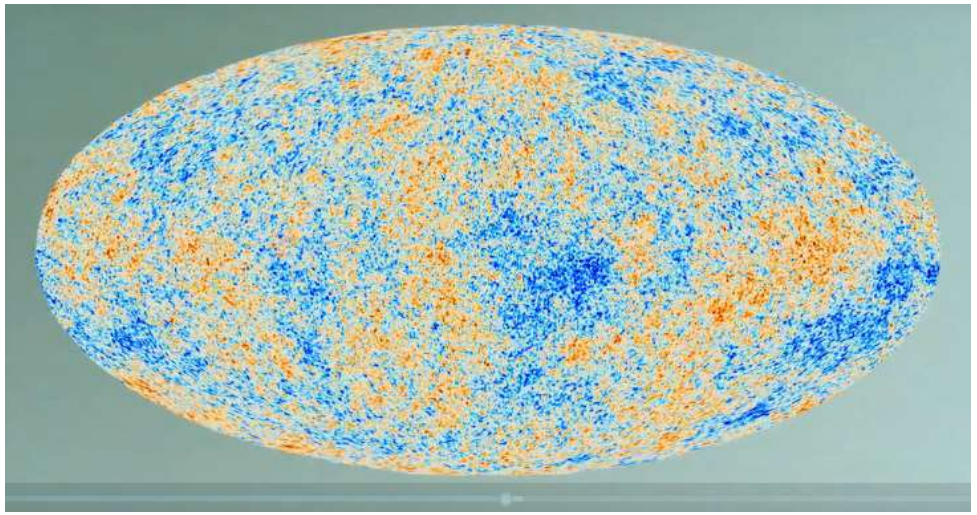
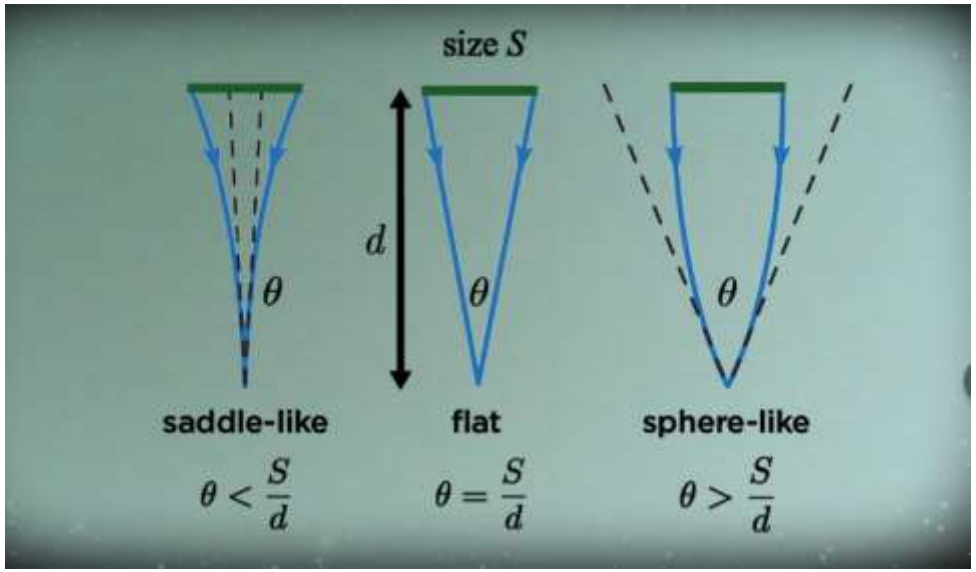


Cosmic Microwave Background Radiation



Measure dimensions of “hot spots” in CMB

Theta =S/d---K=0 and Universe is flat

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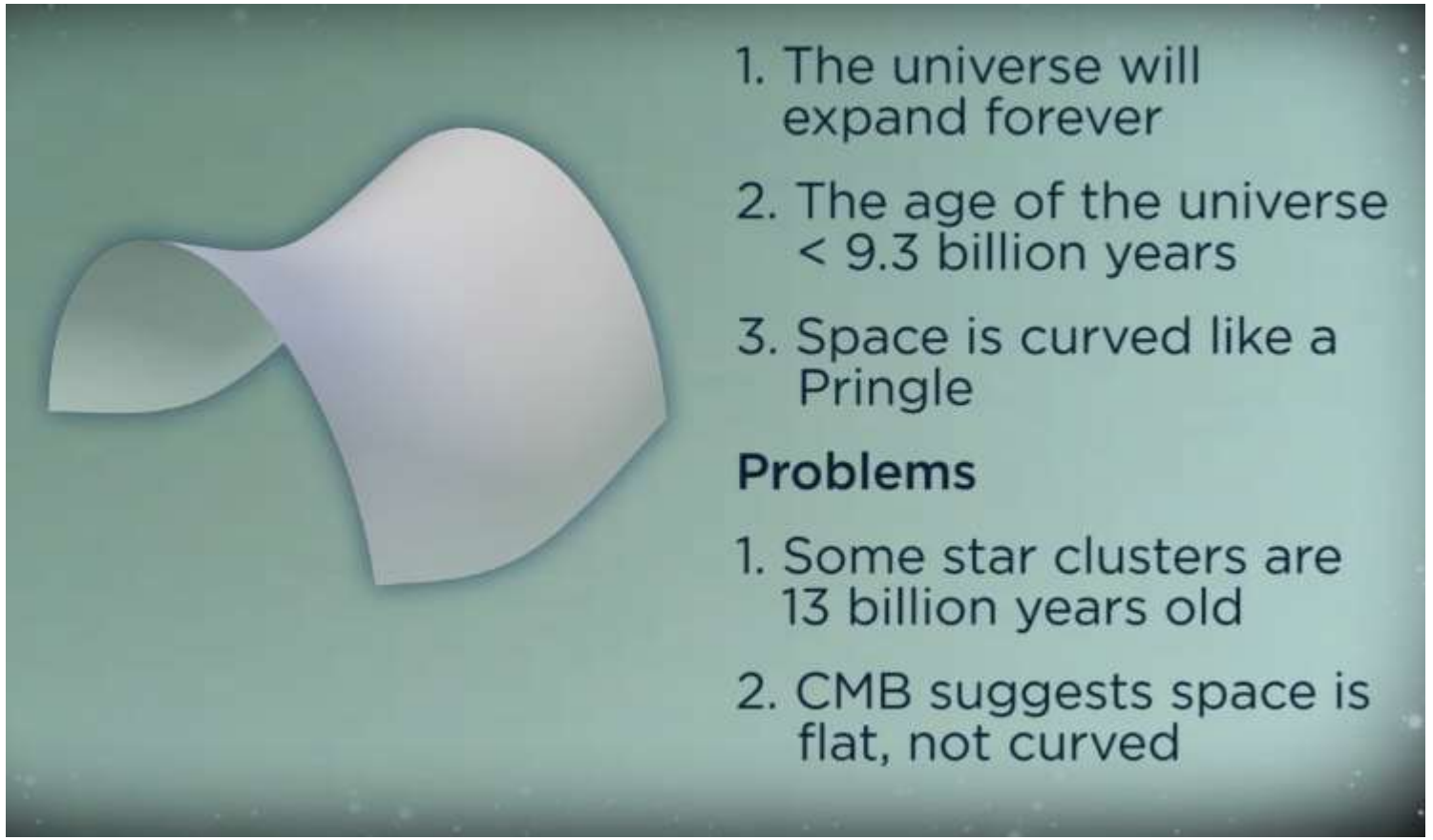

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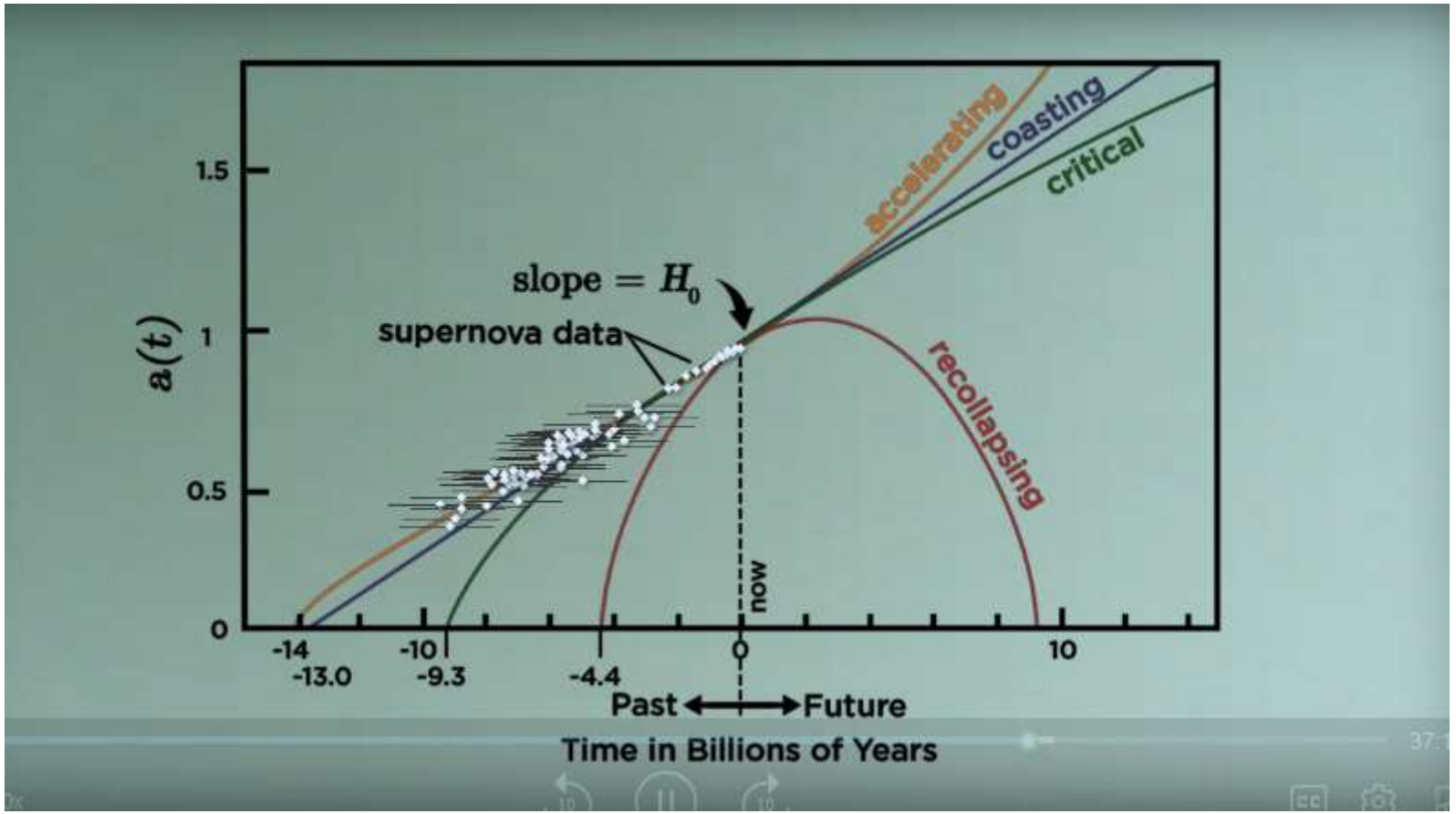

The universe is expanding at an accelerating rate

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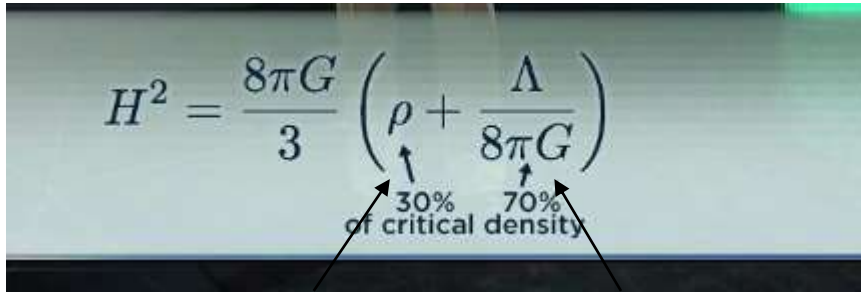

Density Dark Energy

The universe will continue to expand at an accelerating rate