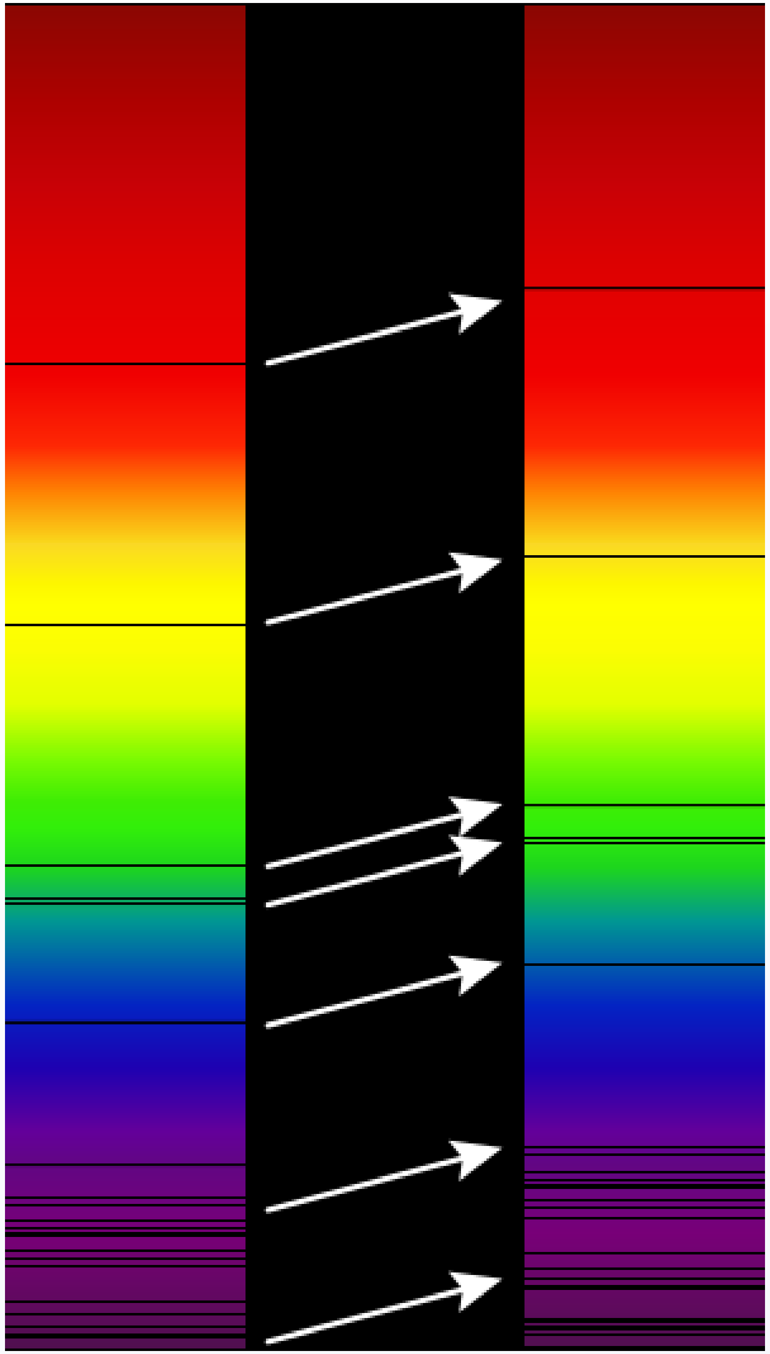
Week 1 – How Can We Determine the Universe's Size?

Big Bang Unit - Waterford Astronomy

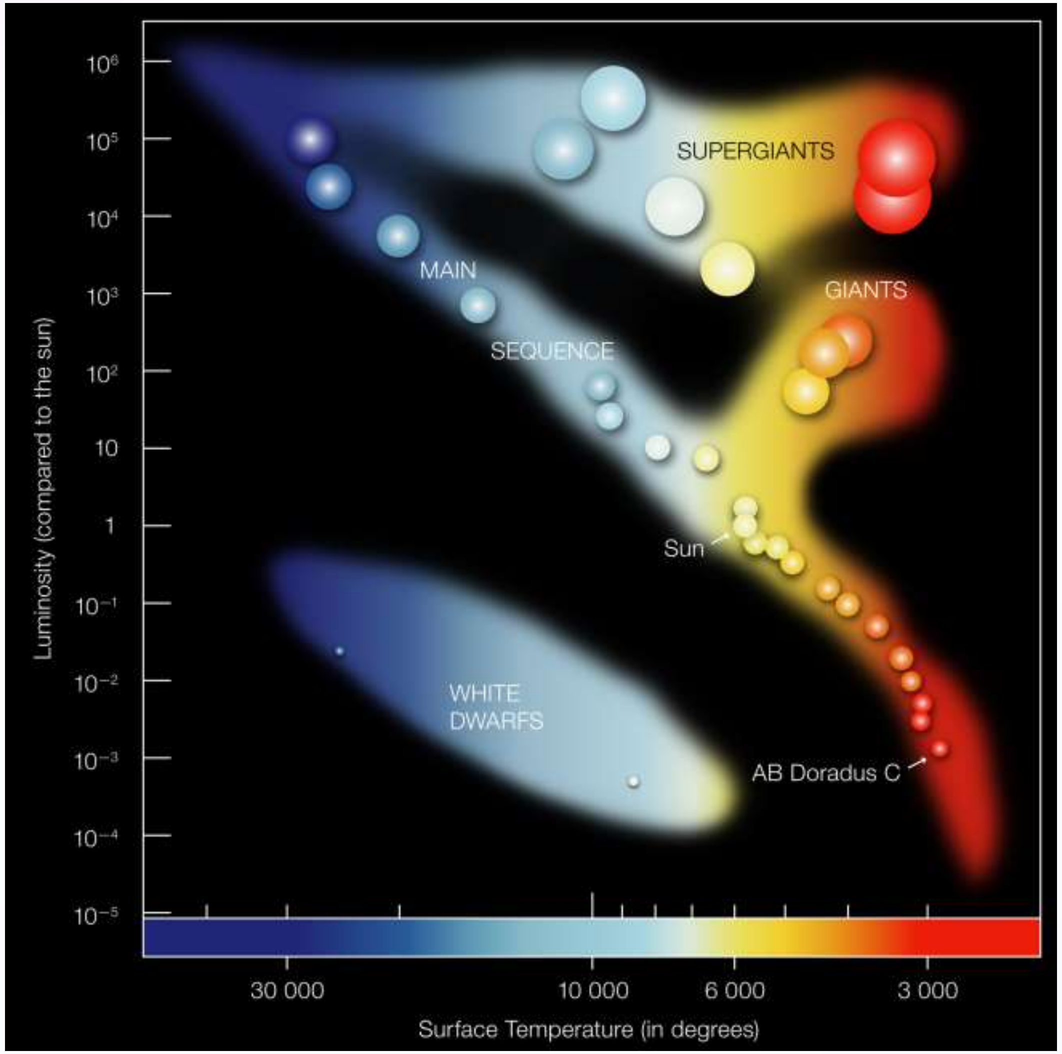
WATERFORD ASTRONOMY

Driving Questions

- **How Can We Determine the Universe's Size?**
  - How can we make conclusions about the size and age of the universe based on how light changes over large distances?
  - How is the size of the universe changing over time?
  - What do these changes indicate about the origins of the universe?



Source: [Wikimedia]

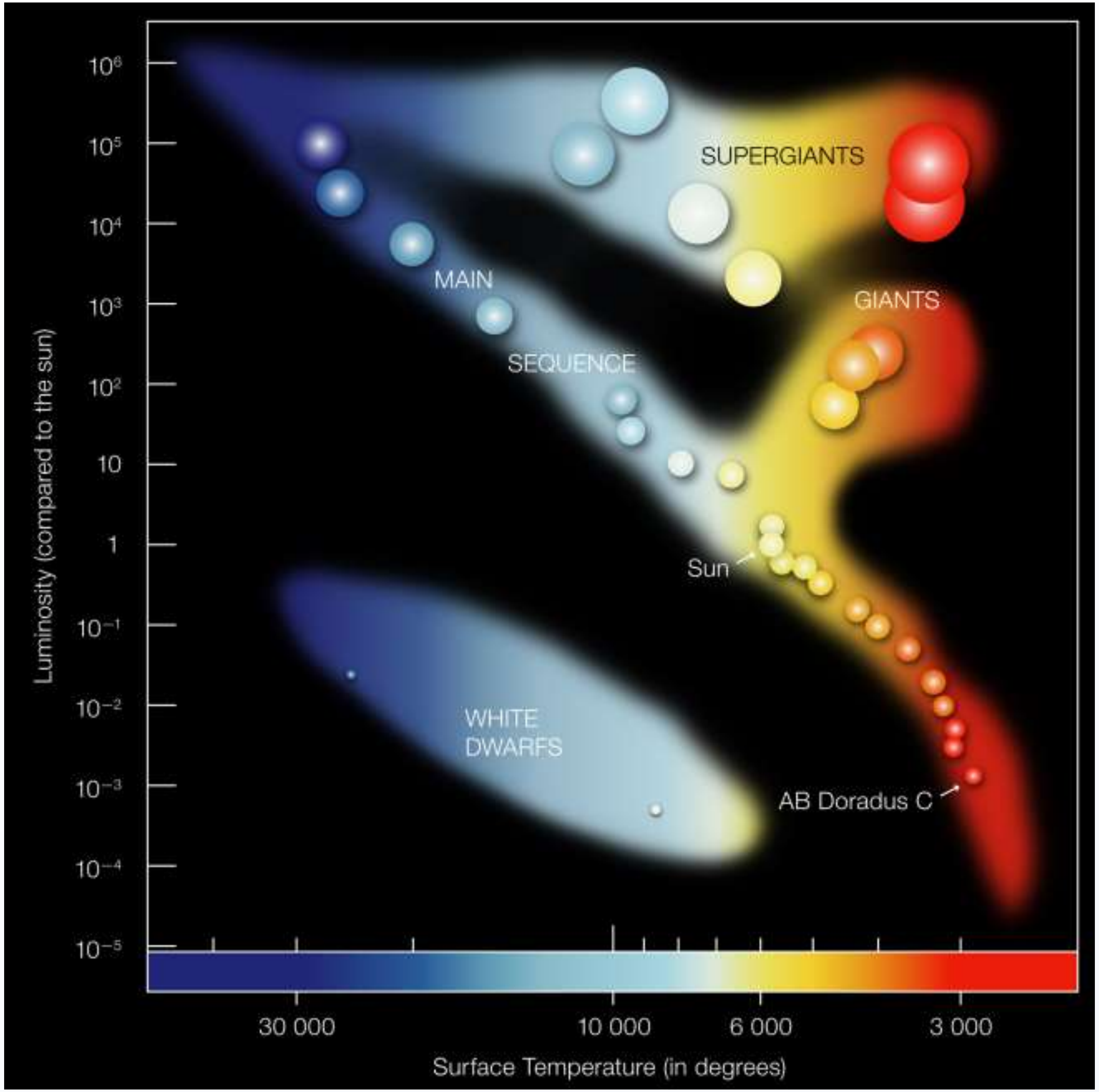


Life of Stars Unit Recap

Unit 2, Weeks 1-3

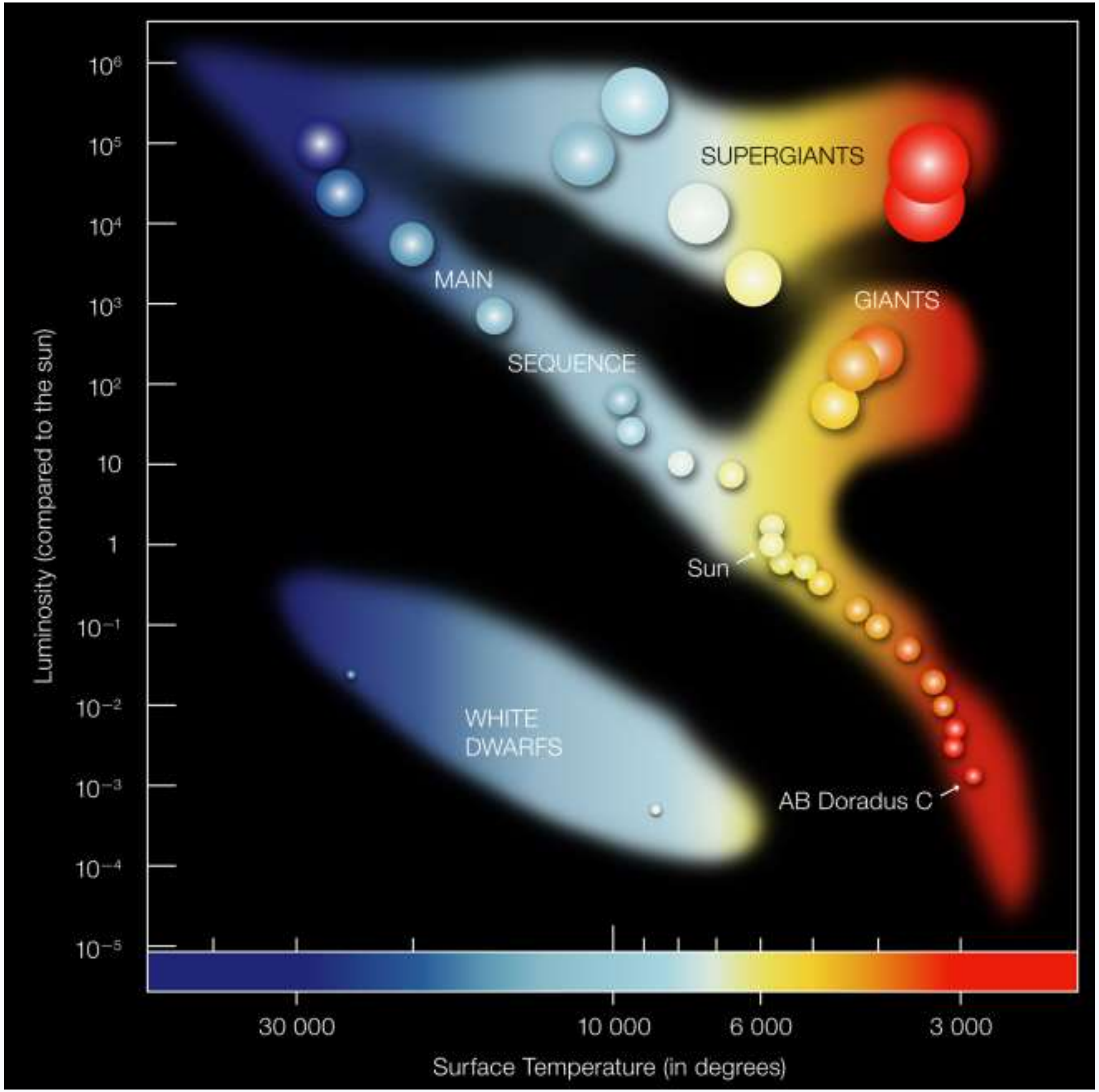
Life of Stars Recap

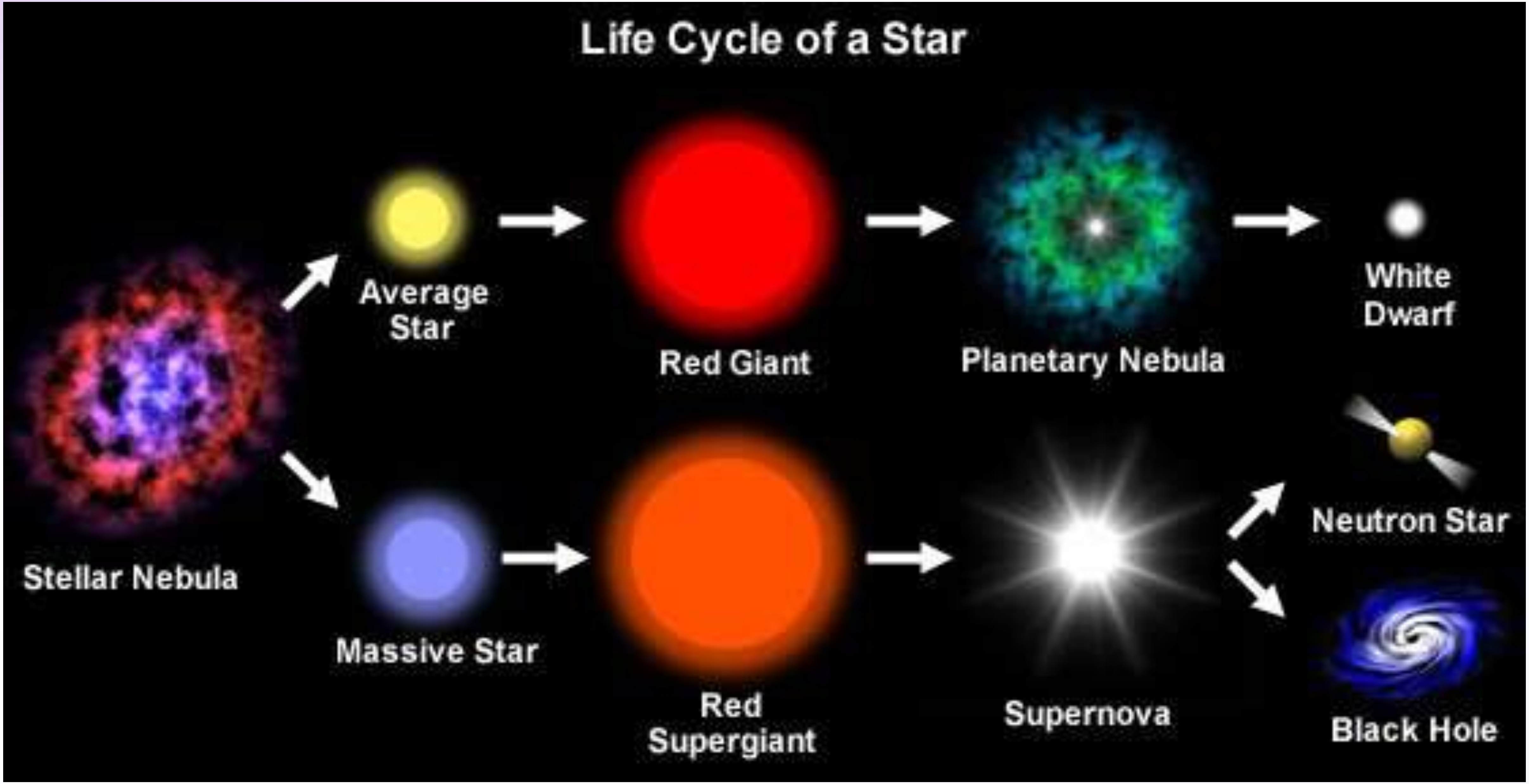
- **All stars go through a predictable series of changes.**
  - Initially, stars fuse hydrogen into helium in their cores (main sequence).
- **As stars deplete the hydrogen in their cores, they begin to change.**
  - The next steps depend on the mass of the star.
- **Low-mass stars (like our sun) begin to fuse hydrogen into helium in the outer layers, forming red giants.**
  - Eventually, fusion ends, forming planetary nebula and white dwarfs.



Life of Stars Recap

- **In high-mass stars, elements can continue to fuse up to iron as main sequence stars become super giants.**
  - As iron accumulates in the core, fusion slows and is unable to counteract the forces of gravity. This pressure combines protons and electrons into neutrons.
- **Compression of neutrons eventually results in a supernova explosion.**
  - The force of this explosion enables the fusion of elements above iron.
  - The remaining core either forms a neutron star or a black hole.




Life Cycle of a Star
Average Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Nebula
Neutron Star
Massive Star
Red Supergiant
Supernova
Black Hole

Life of Stars Recap

- **Mass defect is associated with the demise of high-mass stars.**
  - <u>Mass defect</u> – when fusion occurs, some mass is converted to energy; the mass of an atom is always less than the sum of the masses of its particles.
- **High mass stars have enough heat and pressure to continue nuclear fusion well beyond carbon, but only up to iron.**
  - Iron is the stopping point because of properties of atoms as described by the mass defect curve.
  - The fusion of elements that are lighter than iron releases energy, but the fusion of elements heavier than iron would require an input of energy.
  - As iron accumulates in the core high-mass stars, fusion slows and eventually stops.

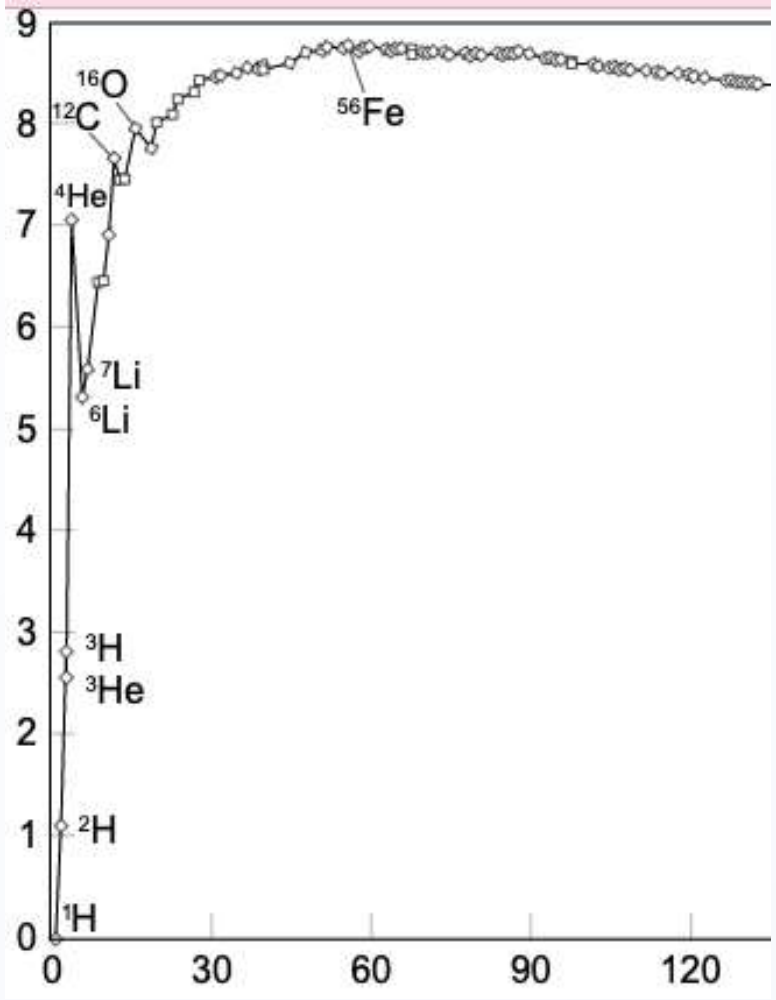


Image Source: Flickr

Measuring the Universe

Discovering the Universe

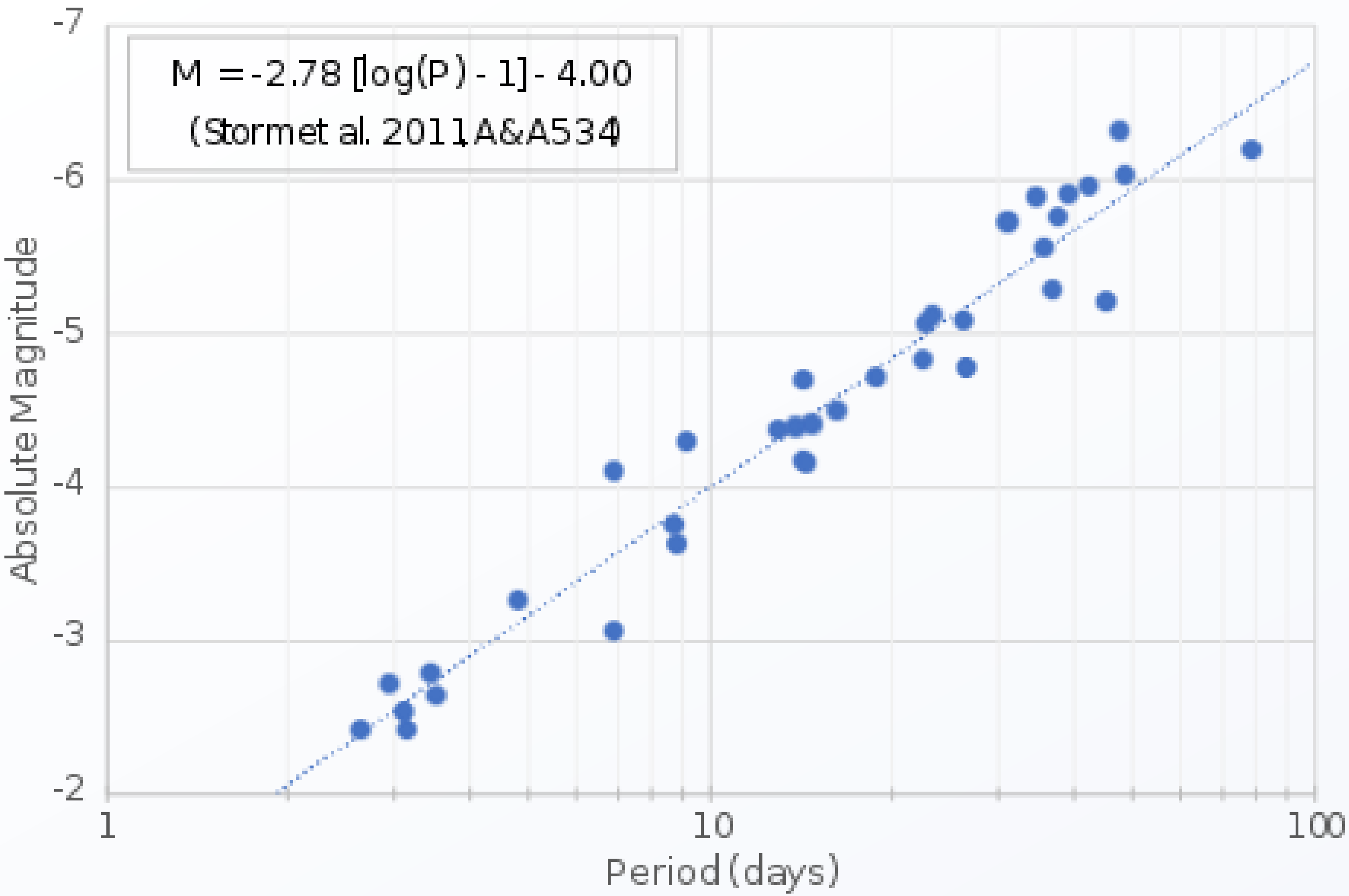
- **Prior to the 1920s, no one was aware there was a universe containing multiple galaxies.**
  - Prior to this, most was assumed that the Milky Way *was* the universe.
  - While it was known that individual stars could come and go, most assumed that the universe was eternal and unchanging.
- **During the 1920s, Harlow Shapely used Cepheid variables to determine distances in the Milky Way.**
  - Cepheid variables are stars that have predictably pulsating *luminosity* (brightness).
    - *Luminosity (or absolute magnitude) is the total amount of energy at all wavelengths (including light) a star emits each second.*
  - The slower a Cepheid variable star pulsates energy, the greater its luminosity.

RS Puppis is one of the brightest known Cepheid variable stars in our galaxy.

Cepheid Variables

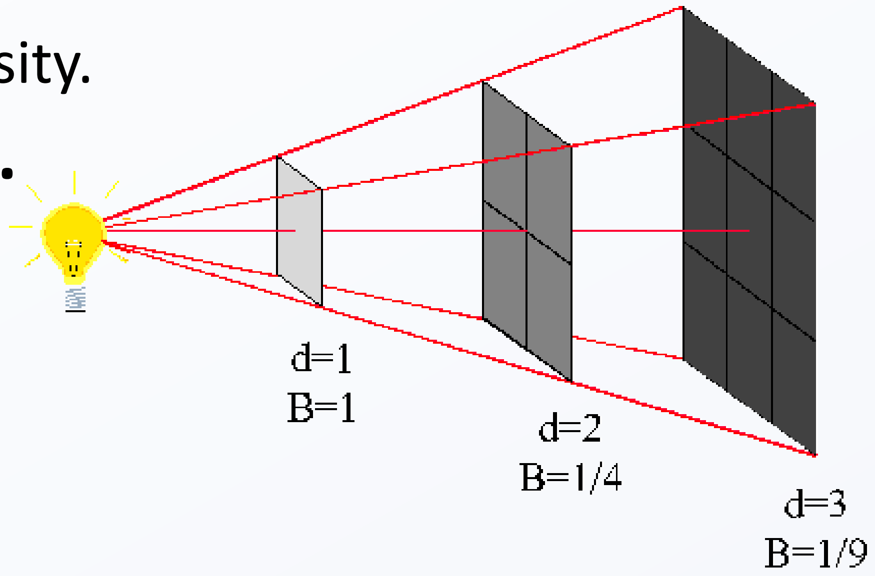
- **Cepheid variables are stars that pulsate light (like a blinking light).**
  - The slower they pulsate, the greater the intensity of light they emit.

- **Cepheid variables enable researchers to determine distance.**
  - To do so, astronomers compare the perceived brightness vs. their actual brightness.



Blinks, brightness, and distance.

- **Shapely calculated various Cepheid variable star's distance by comparing its luminosity to its apparent magnitude.**
  - Apparent magnitude is how much energy is received from a star on earth (i.e., how bright we perceive it to be).
  - Two stars with the same luminosity (actual brightness) will have different apparent magnitude (perceived brightness) if one is closer than the other.
- **The rate at which a Cepheid variable blinks determines its luminosity.**
  - The faster these stars "blink", the lower its luminosity.
- **Differences in magnitude determine distance.**
  - Apparent magnitude = luminosity / distance^2
  - Distance^2 = luminosity / apparent magnitude
  - Distance = (luminosity / apparent magnitude)$^{0.5}$



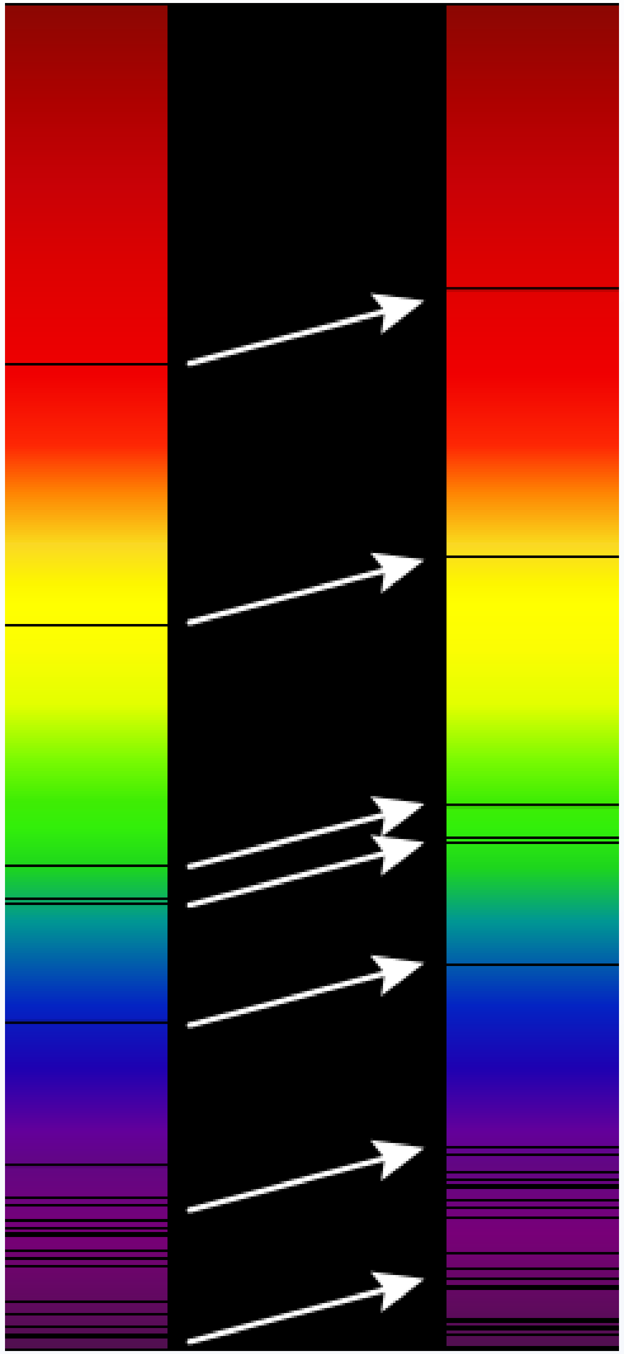
Shapely's Errors

- **Harlow Shapely's findings demonstrated that our sun was on the edges of the Milky Way.**
  - However, Shapely did not account for the amount which dust dims the perceived brightness of stars.
  - As a result, he overestimated the size of the Milky Way.
  - Shapely assumed that other galaxies were just nebulae (clouds of gas) within our own galaxy.
- **Edwin Hubble's work disproved Shapley's erroneous conclusions.**
  - Hubble's telescope was powerful enough to measure Cepheid stars in other galaxies.

Hubble's Findings

- **In two years of work, Hubble acquired only fifty usable photographs of Cepheid variable stars.**
  - However, this was enough data to confirm that distant Cepheid variable stars were too far away to exist within our own galaxy.
- **Hubble's work confirmed that the Milky Way was just one galaxy among many in the universe.**
  - This disproved the original idea that the Milky Way was the entire universe.
- **Hubble's research also indicated that the universe was changing and evolving.**

Image Source: Wikimedia



Redshift

- **Hubble recognized that light from distant galaxies exhibited a "<u>redshift</u>".**
  - As objects move away, the light they emit has longer wavelengths, shifting bands in the spectral signature (because red light has longer wavelengths than blue).

- **Hubble was able to compare data from Cepheid variables and redshifts to determine that the redshift in light from a galaxy is proportional to its distance.**
  - Objects further away had greater amounts of redshift.

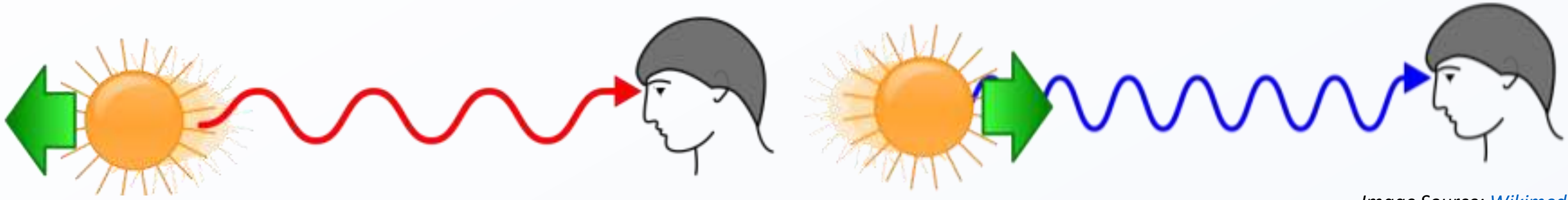
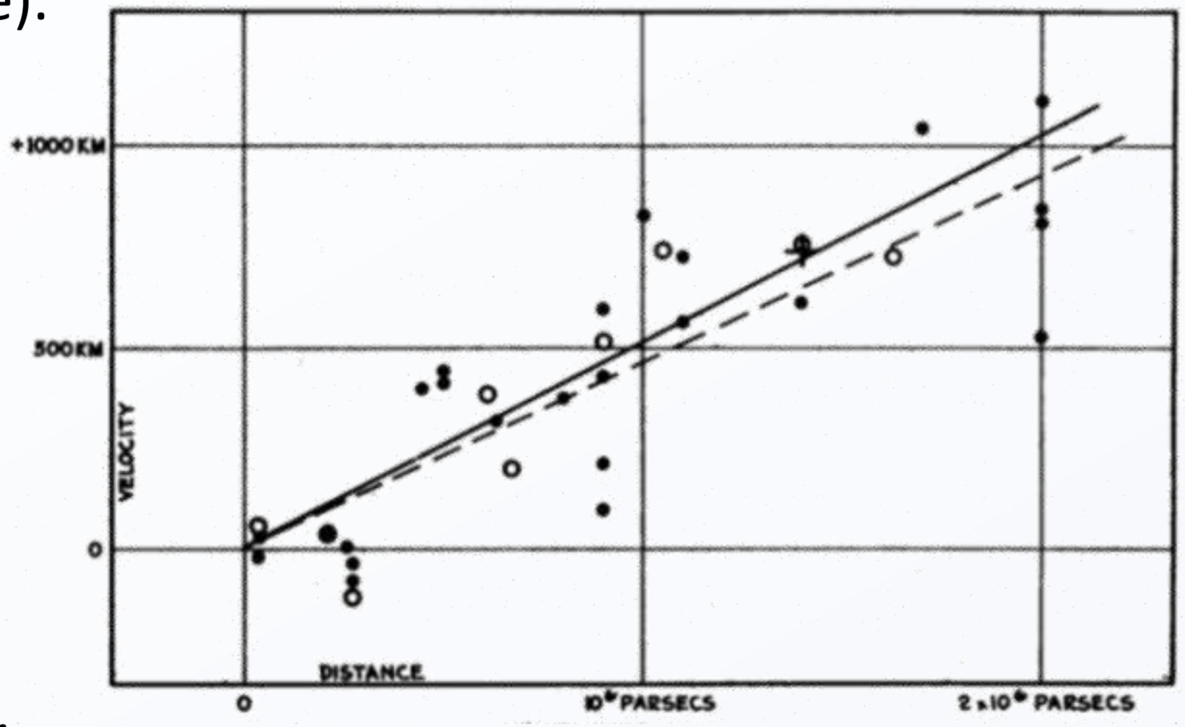


Image Source: Wikimedia

Hubble's Law

- **Hubble's law enables astronomers to calculate how fast galaxies are moving apart, enabling estimates for the age of the Universe.**
  - Hubble's Law - the rate at which a galaxy is moving away from a point is proportional to its distance from that point; *i.e.*, the further away the galaxy, the greater its *velocity* (distance / time).
- **The Hubble Constant indicates the relationship between the velocity and distance of a galaxy.**
  - The value of the Hubble Constant is reflected by the slope of this line →
  - If you know the Hubble Constant and the velocity of a galaxy (via redshift), you can determine its distance.
  - The Hubble Constant also reflects how quickly the universe is expanding.

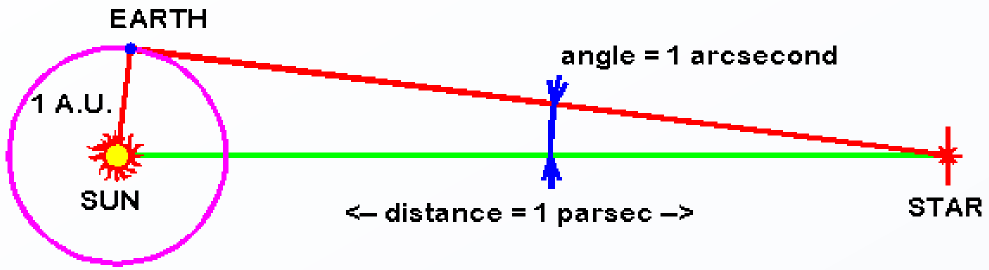


Source: PSU.edu

This graph shows the correlation between the velocity & distance of a galaxy. The line's slope = Hubble's Constant.

Image Source: Earthsky.org

Putting It All Together



- **The Hubble Constant (rate of expansion of the universe) is roughly 70 km/s/Mpc (kilometers per second per megaparsec).**
  - A parsec is a measure of large astronomical distances. It is equivalent to 3.26 light years (*the distance an object moving at the speed of light travels in one year*).
  - A megaparsec equals one million parsecs, or 3.26 *million* light years.
  - The Hubble Constant indicates how fast the universe is expanding at a particular distance from earth as measured in megaparsecs.
- **Hubble's Law and the Hubble Constant both indicate that the universe is expanding.**
  - Hubble's Law: the further the galaxy, the faster it's moving.
  - Hubble Constant: an estimate of how fast the universe is expanding.
  - These values also indicate that the universe was once smaller.

The greater the distance of an object (in parsecs) from earth, the greater its velocity.

Distance (Mpc)	Velocity (km/s)
20	1440
50	3600
100	7200
200	14,440
300	21,600

Image Source: Wikimedia

Cosmic Microwave Background Radiation

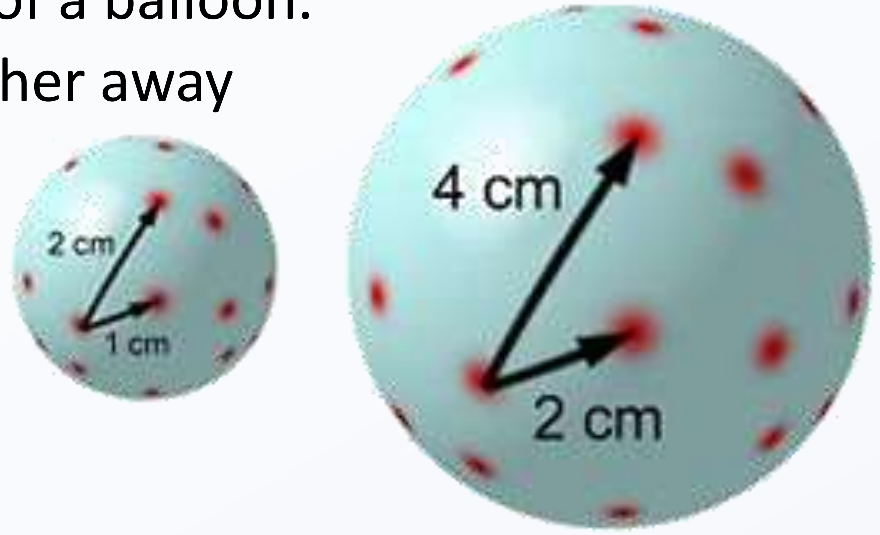
- **The idea of an expanding universe is also supported by cosmic microwave background radiation (CMBR).**
  - CMBR - a faint source of electromagnetic radiation that fills the universe, falling on Earth from every direction with nearly uniform intensity.
- **In 1964 two physicists (Penzias & Wilson) discovered CMBR by accident.**
  - They detected microwaves coming from all directions in the sky.
  - This indicated that the Universe was still about 2.73 degrees above absolute zero; this represents leftover heat radiation from the initial formation of the universe.
  - A static non-expanding universe would lack CMBR.
- **This suggests that the Universe was once very hot and dense.**
  - As it expanded, it cooled (similar to how a refrigerator expands a liquid into a gas to cool the inside).

The Holmdel Horn Antenna used by Penzias & Wilson.

Image Source: Physics World

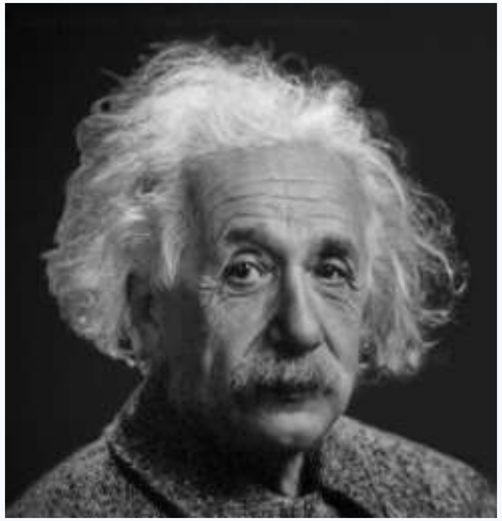
But…how?

- **The greater the distance of an object from earth, the faster at which it is moving away from earth.**
  - This makes it seem like the earth is the center of the universe (*but it's not*).
  - Rather, the greater the distance between *any two objects*, the greater the rate that they are moving away *from each other*.
- **The expanding universe is similar to an inflating balloon.**
  - Image drawing dots with a marker on the surface of a balloon.
  - As you inflate the balloon, each dot will move further away from each other.
  - The greater the distance between two dots, the greater the rate at which they move away.



Final Supporting Evidence

- **Einstein's Theories of Relativity (which explains the relationships between gravity, space, and time) also provides evidence for the Big Bang theory.**
  - The Theories of Relativity describe relationships between matter & energy and argue that space and time can change based on the influence of each other and from matter.
  - For example, as you approach the speed of light, time slows (a phenomenon known as time dilation). Furthermore, matter and energy are interchangeable ($E = mc^2$).
- **The math underlying Einstein's theories of relativity predicted a changing universe could not remain static & fixed.**
  - Einstein proposed these ideas long before Hubble's findings when most thought the Milky Way was the entire universe.
  - Initially, Einstein also thought the universe was static; he erroneously added a value (the cosmological constant) to "fix" his equations.
  - Without the cosmological constant, Einstein's calculations perfectly predicted the expansion of the universe a decade before Hubble.



Source: Pixabay