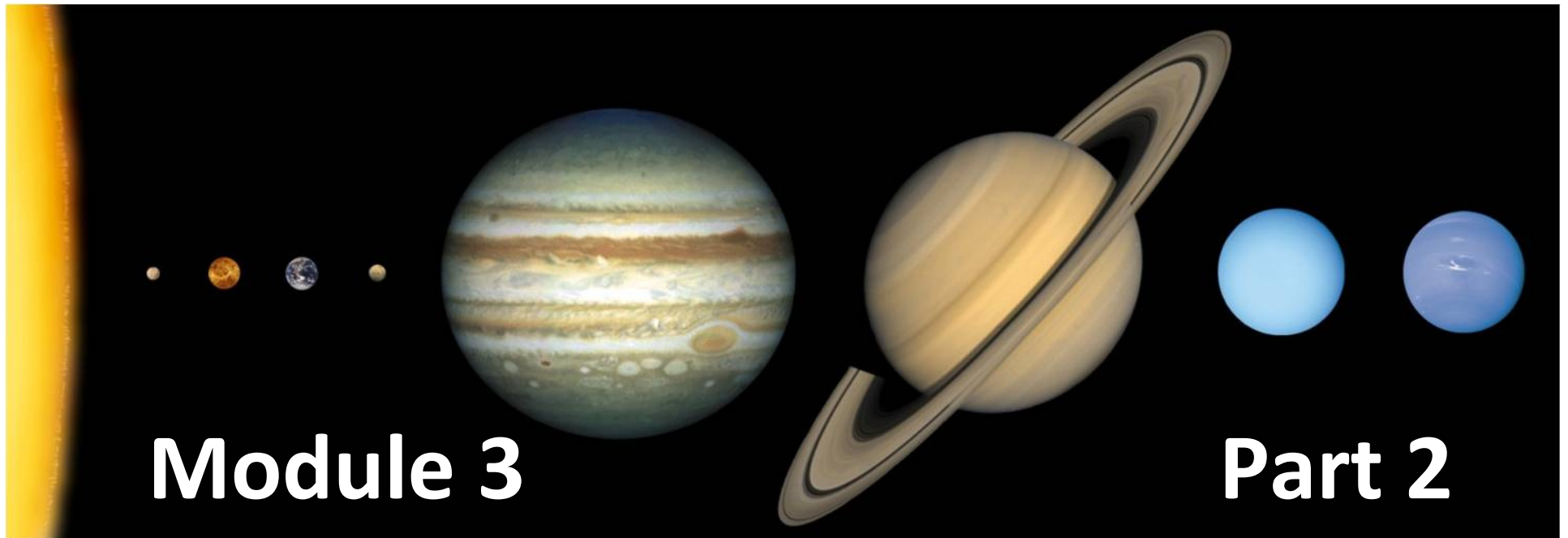


Earth Sciences 2150 – Fall 2022

Solar System and Planetary Science



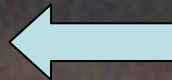
**The Wider Context of the Solar System
in the Galaxy and the Universe**

EASC 2150: The Solar System The Plan for Today (Part 2)

Where we fit into the Universe.

- The wider context of the Solar System as part of the Wider Universe.
- Ideas about the origin and development of the Universe.
- The concept of the expanding Universe.
- Understanding the distances to the stars, their sizes and temperatures, and the variation among them.
- Good stars and bad stars (from a planetary perspective)
- A review of essential components of the Solar System.

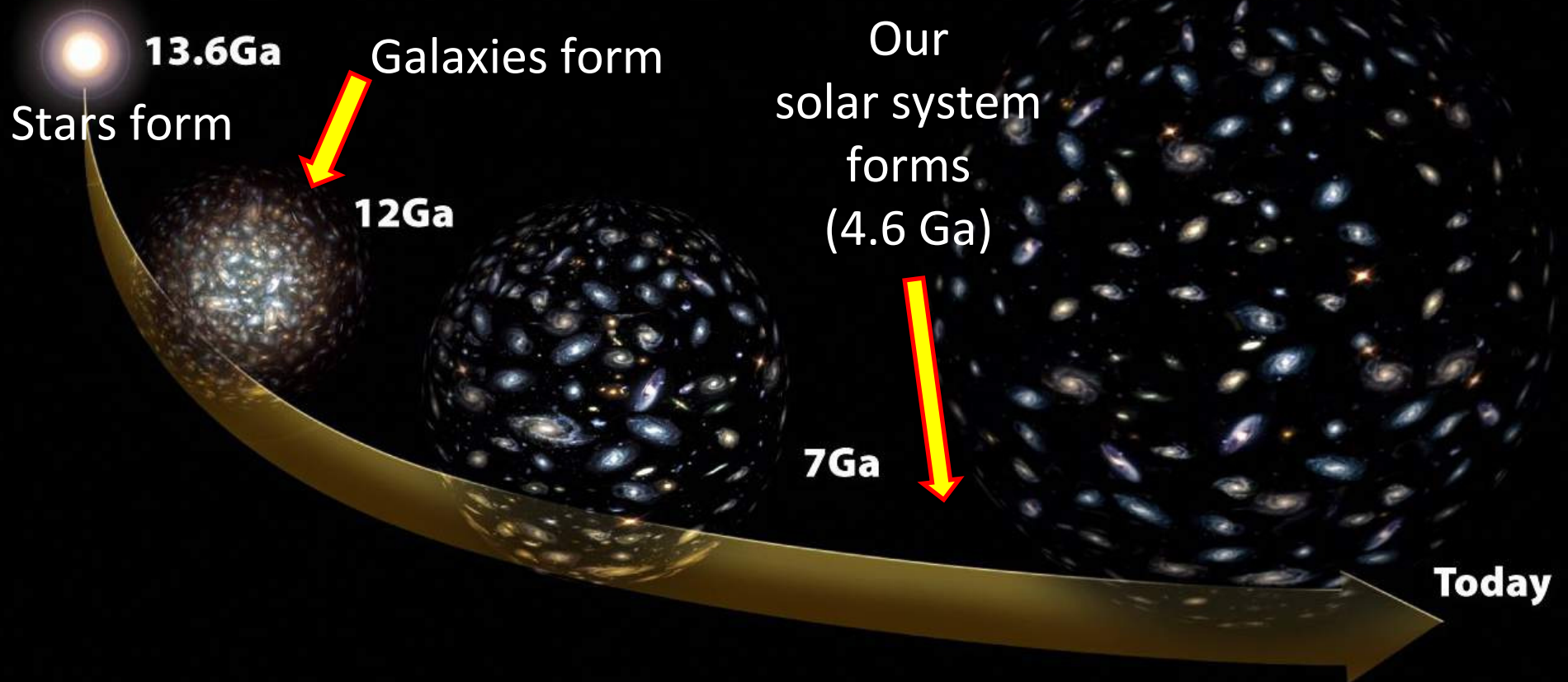
Earth is the tiny bluish dot in the light band across the lower part of the photo (the light band is dispersed dust catching sunlight). It is very hard to find us. We are not significant on the scale of the Solar System or the Universe.



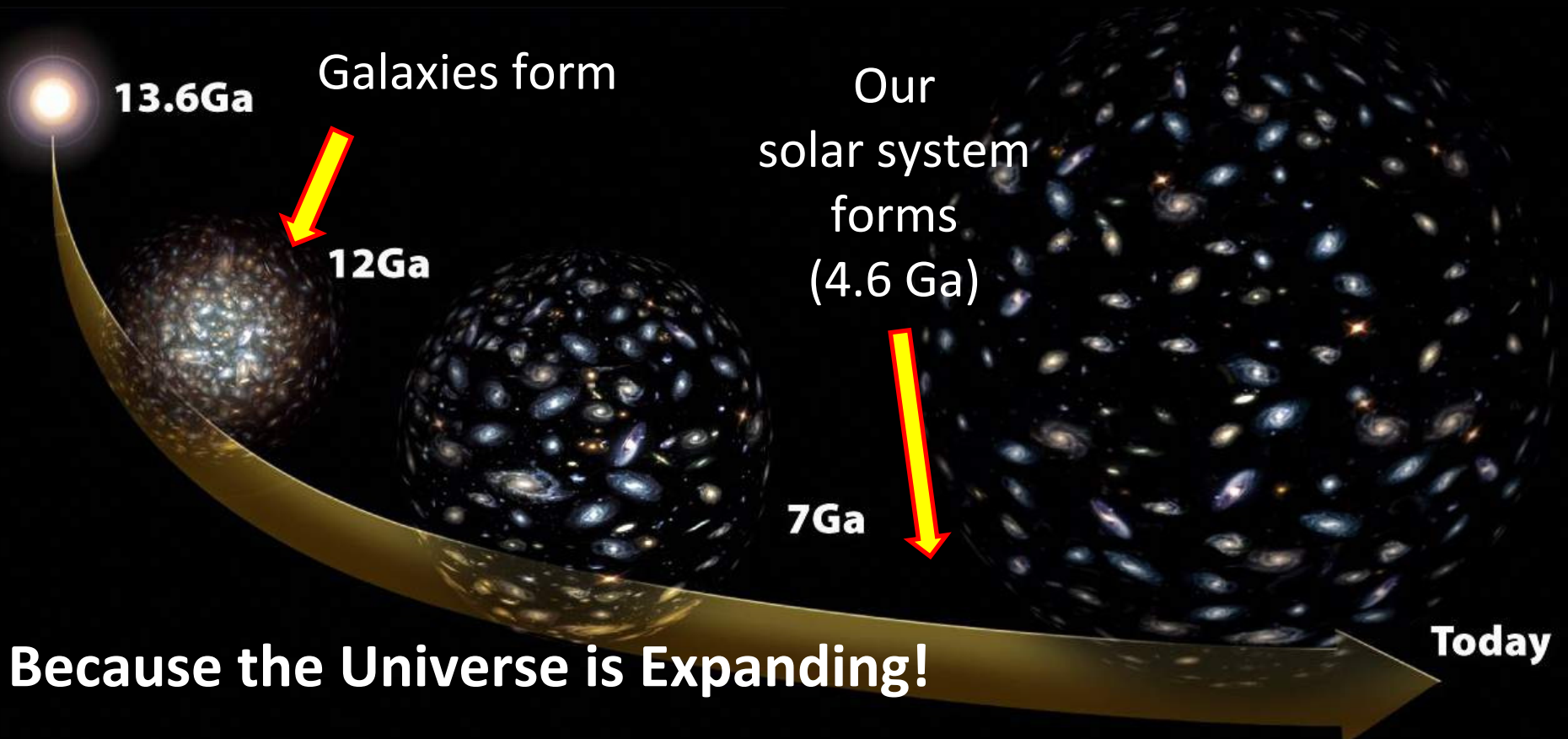
In the beginning, there was.....

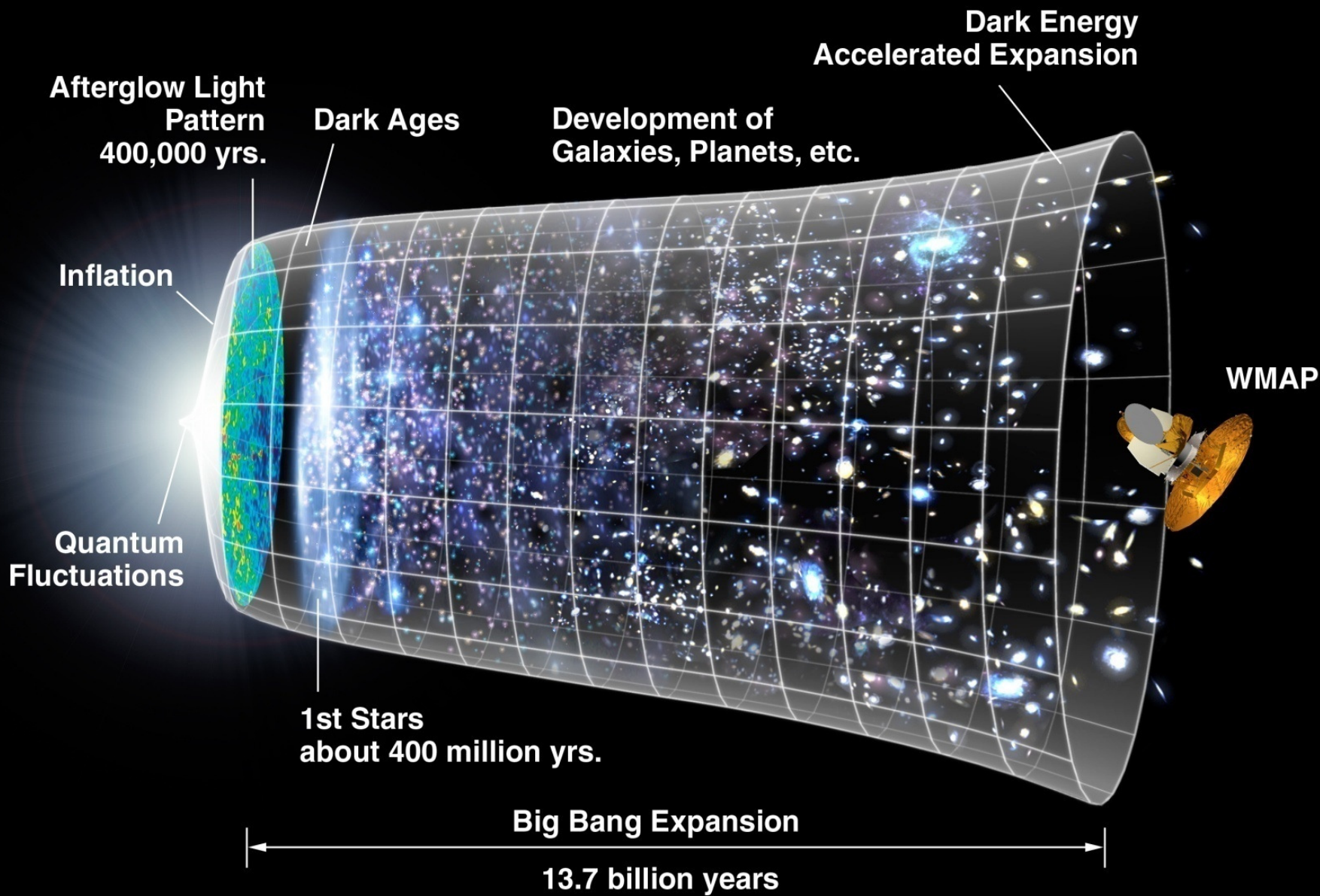
- The earliest moments of the Universe, and the sequence of events that led to what we now see, are things that are very difficult for most of us to visualize. They come from the work of theoretical physicists and 'cosmologists' and this stuff is about as esoteric and complex as science can be. We are not going to dwell for long in this time, and I recognize that some of it stretches our comprehension.
- **The Universe is estimated to have formed ~ 13.7 Ga**
- **Prior to "Time Zero" all mass and energy was contained within a single infinitely small point.....**
- **The "Big Bang" is the initial, incredibly fast expansion of the Universe, and this expansion continues today.**
- **The future of the Universe is more debatable, but many physicists believe that it will re-collapse ("the Big Crunch")**

- All of the mass and energy in the Universe was packed into a single small point.
- It exploded 13.7 Ga (13.7 billion years ago) and has been expanding ever since.
- Though the Universe is unimaginably big, it is not unimaginably old.....it definitely had a beginning.



- The early times of the Universe would have been completely alien to us, but within the first billion years or so, stars and galaxies would have formed.
- So, for most of its history, what we see now is what we had, in general terms. Aside from its SIZE.....





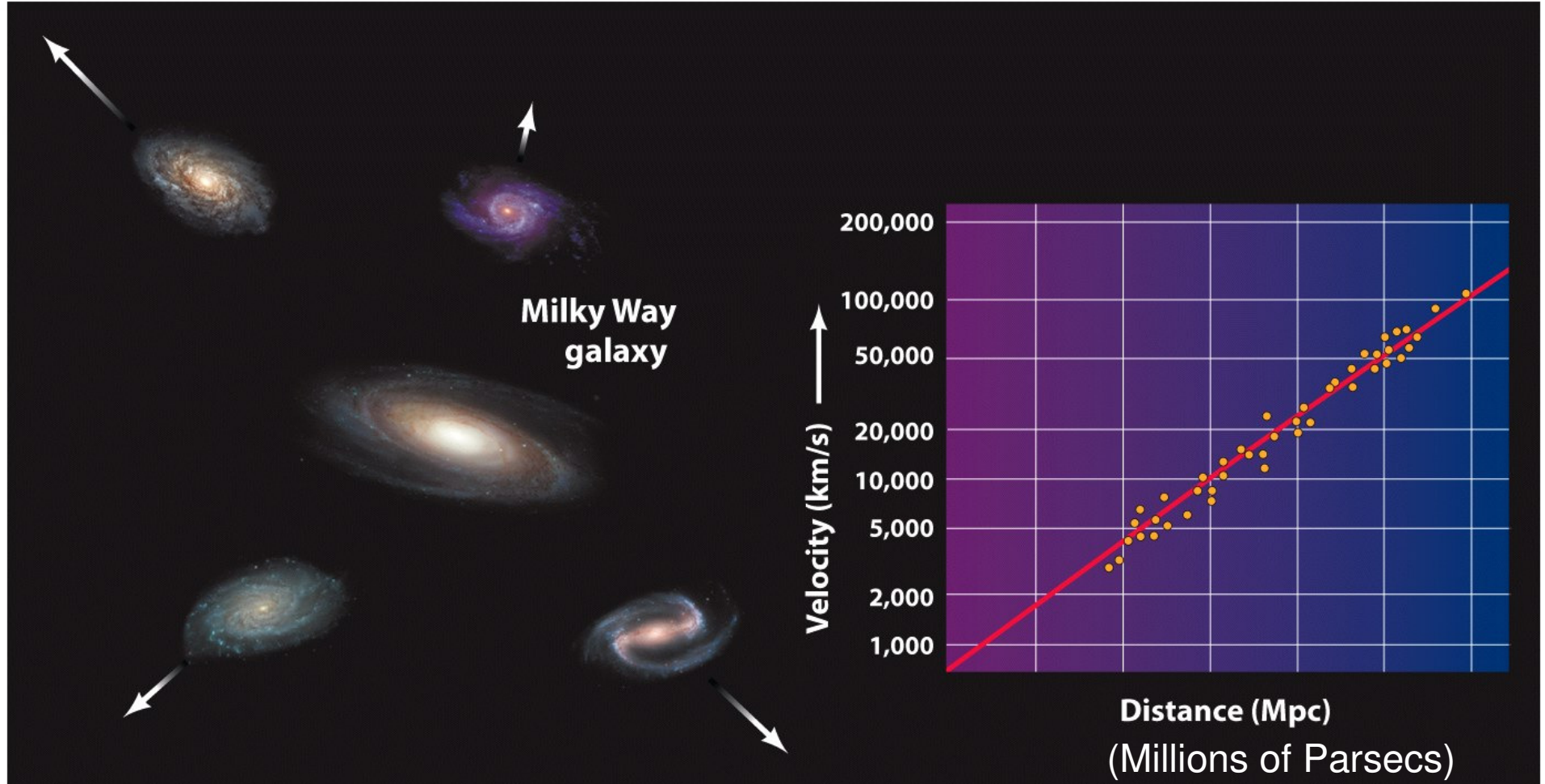
Edwin Hubble (1889-1953)



The ‘Hubble Constant’ is a measure of how fast the universe expands, and you’ve all heard of the Hubble Telescope.

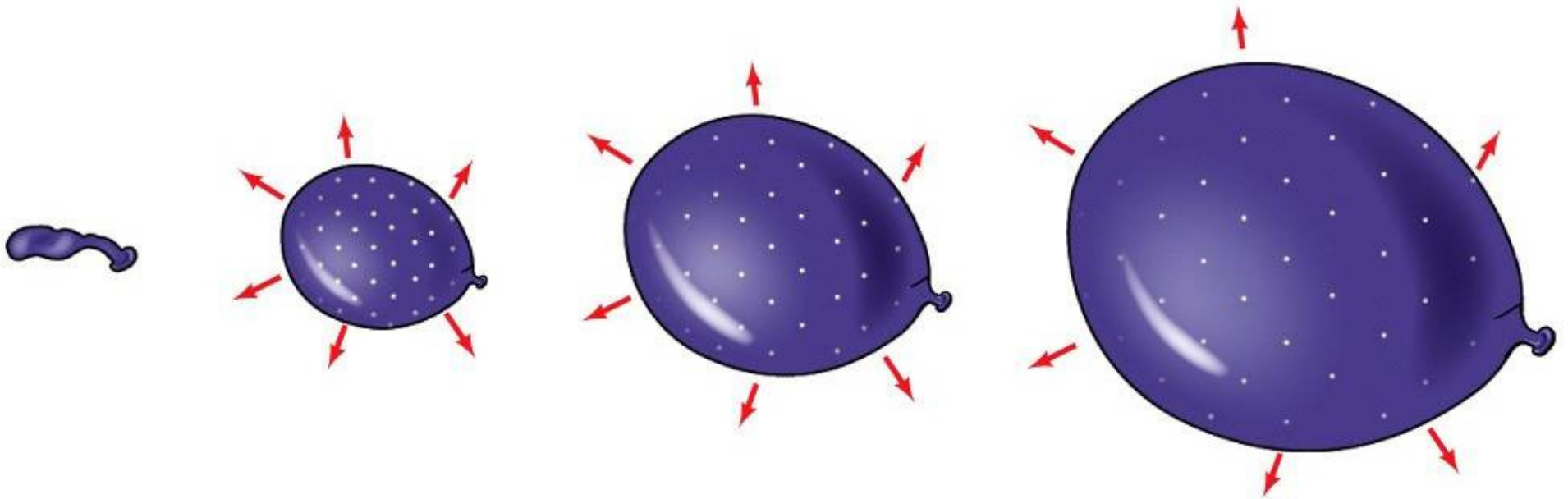
- Edwin Hubble is often called the ‘father of cosmology’. He discovered galaxies beyond our own, and established the vastness of the Universe.
- However, he is best known for having truly established the reality of an expanding universe. He did this by using the so-called ‘**Doppler Effect**’ – a shift in the wavelengths of emitted radiation from a moving object (to be discussed more later in the course)
- Hubble showed that other galaxies were moving away from ours, and that the further they were from us, the faster they were receding.

The Expanding Universe and Hubble's Law



- Light from distant galaxies is affected as a consequence of velocity – rather like how the sound of a vehicle changes pitch when it passes you. This gives us velocity. We estimate distance using another method, and find a linear relationship.

Expanding Universe: Balloon Analogy

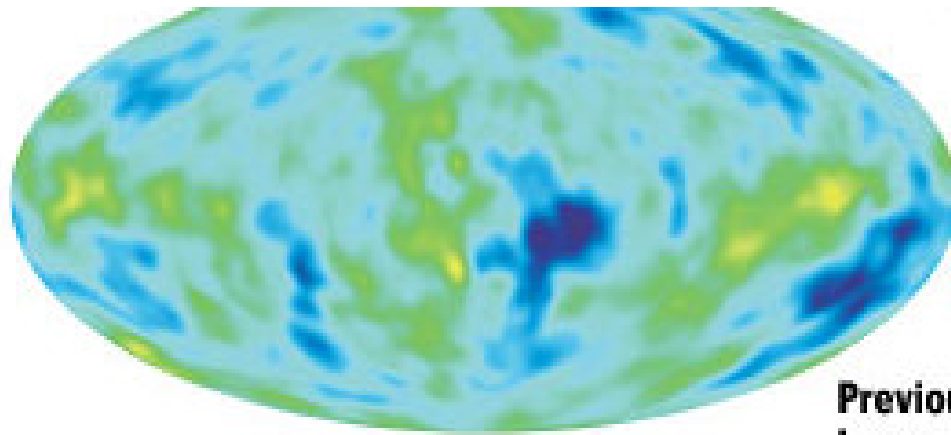


- The 'Balloon Analogy' is commonly used. Imagine how a balloon expands; with time individual points on the surface of the balloon (or within it) will continue to move apart.

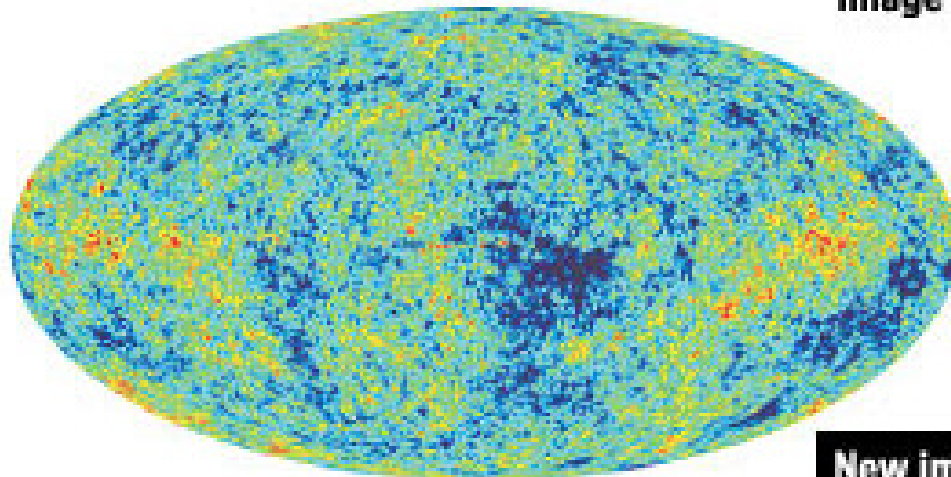
Can We Prove Any of This Stuff?

- The expanding universe is consistent with the concept of the big bang, but it doesn't actually prove it. However, there is other evidence and inference.
- In order to initially form the lighter elements (e.g., Hydrogen, Helium, Lithium – H, He, Li) a process of **nuclear fusion** is required, demanding extreme conditions. Heavier elements are formed within stars. The abundances of light elements in the Universe are consistent with early formation in the Big Bang Model.
- We also detect 'Cosmic Microwave Background Radiation', which is predicted by the model as a sort of universe-wide 'hangover' from the Big Bang.
- Other predictions of the model also fit observations.

Cosmic Microwave Background Variation



Previous image



New image

NASA's WMAP mission captured images of the oldest light in the universe that are 35 times more detailed than images from the agency's 1992 COBE mission.

- Astronomers discovered the CMB radiation by accident, and it emanates from the outer parts of the Universe – This is the record of the initial energy released in the big bang. The pattern is not uniform, so there was original heterogeneity.

– So, back to our neighborhood in the Milky Way. Enough of cosmology, for now. The Universe contains different types of stars, and their lifespans vary. Luckily for us, ours is long-lived.



You are **HERE!**

– We know that the Sun formed about 4.6 Ga, and it's about half-way thru its life. The Solar System and the Sun formed at the same time, and both have evolved over time. Details are for later.

Note that in this image we clearly see the varied colours of stars. Also, we see variations in brightness – and also apparent size.



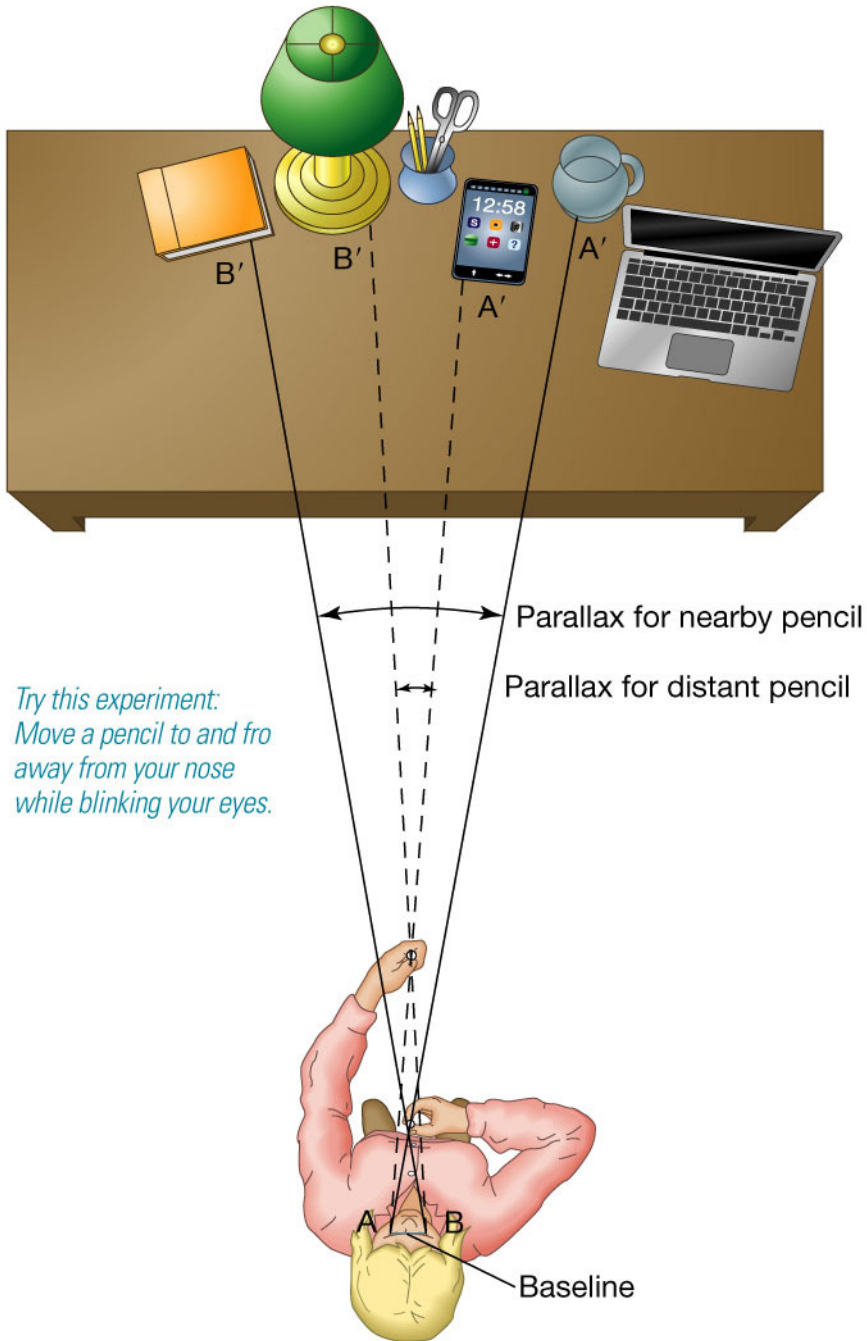
Globular Star Cluster M15 – About 33,000 Light Years from Earth and containing at least 1 million stars of various types – Hubble Image

Stars – The Really Big Picture

- We're concerned mostly with the planets of the solar system, but most of the matter in the universe is contained within stars - >> 99.9%.
- We don't know how many exist; we can't see them all.
- As we might expect, stars are not all alike. There are different types. Our Sun is just one type, which is fairly common. We're going to take a quick look at what we know about stars, because the history – and future – of any planetary system depends on stellar evolution.
- What we know comes from observations of the EM spectra of stars and other methods we can use to estimate distance, size and so on. We also have numerical models of the processes involved in stars.

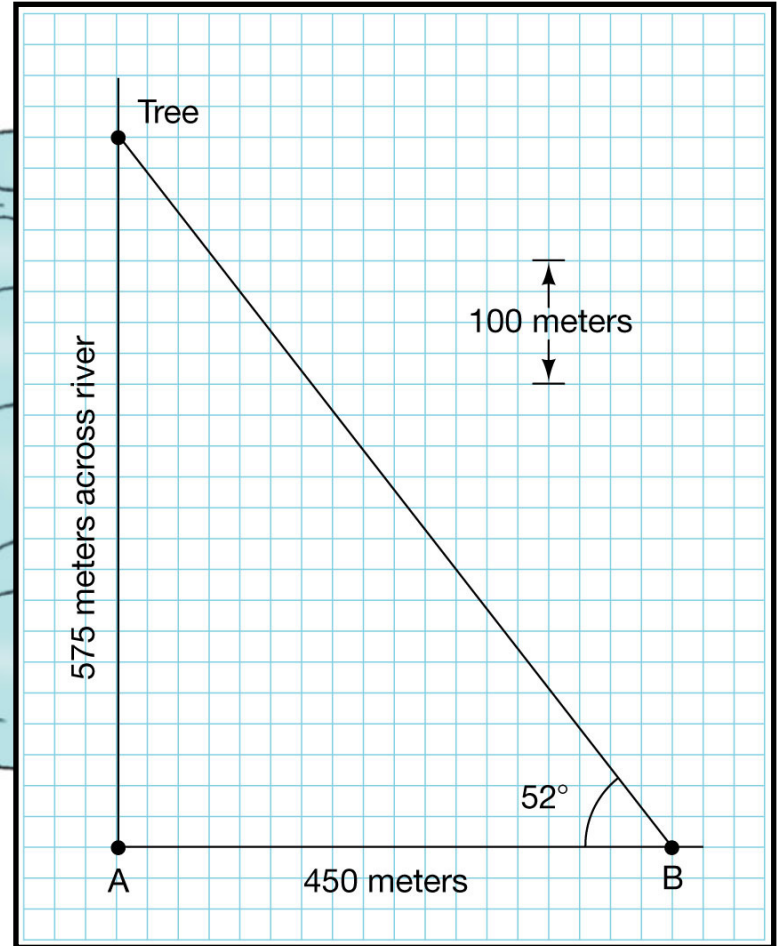
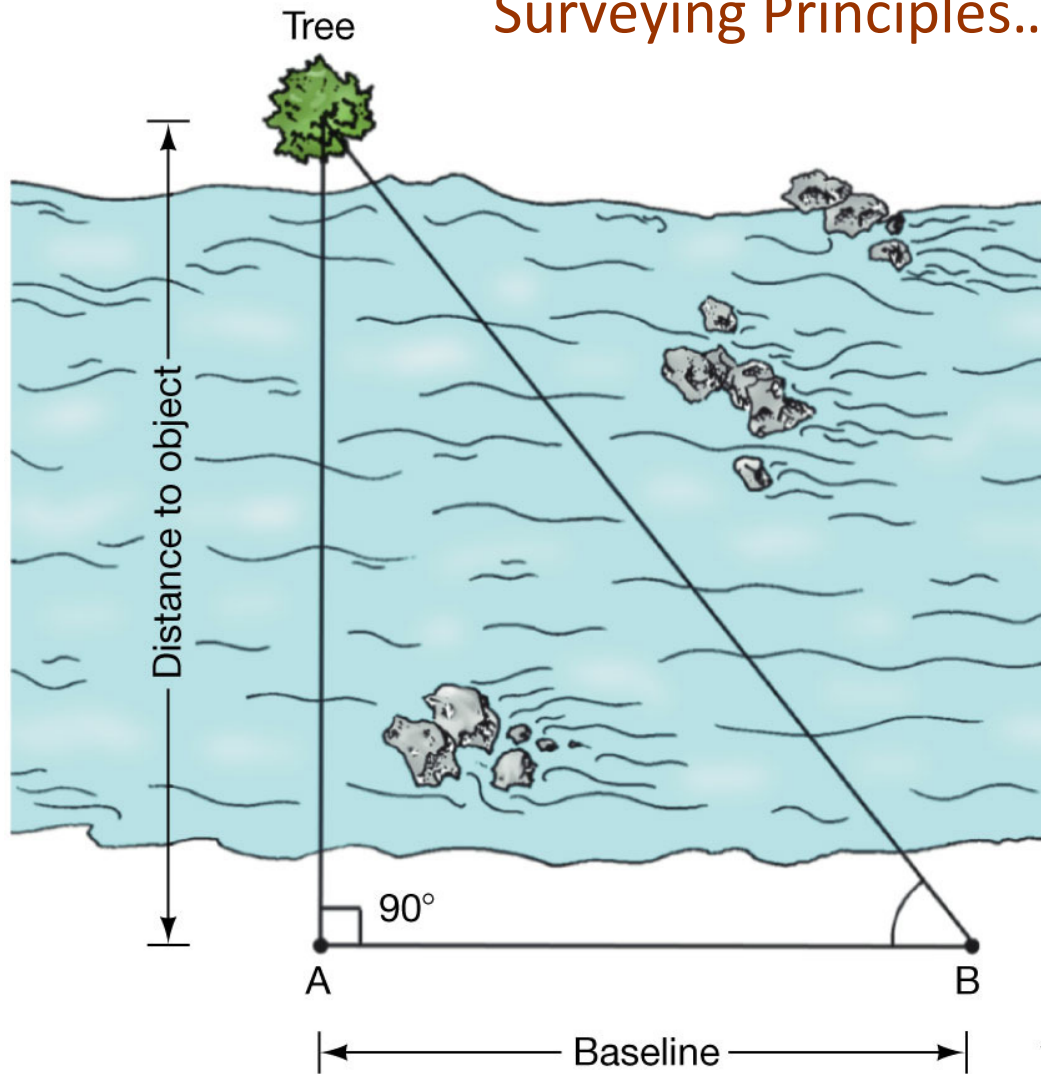
How Far Away are the Stars ?

- You already know that we measure distances to stars in light years or in Parsecs. And they are a very long way away from Earth. But how do we measure this?
- Also, how do we measure distances to the planets or the Sun? How do we know it's 150 million km away?
- The methods used involve simple principles of geometry, and are not so different to those that we use on Earth for surveying. In the end, we come back to the great old principles of trigonometry.
- Let us demonstrate by having you all raise a finger and position it in front of some object across the room. Close your right or left eye. Then change the eye.
- **What happens and why does it happen?**



- We have demonstrated the concept of **PARALLAX**.
- Try this again with your finger closer to your face rather than at arms length. What happens then?
- The shift in the position of an object against a ‘fixed’ background decreases with its distance from the two points of observation. If we can measure the position from two different locations, we can figure out the distance.

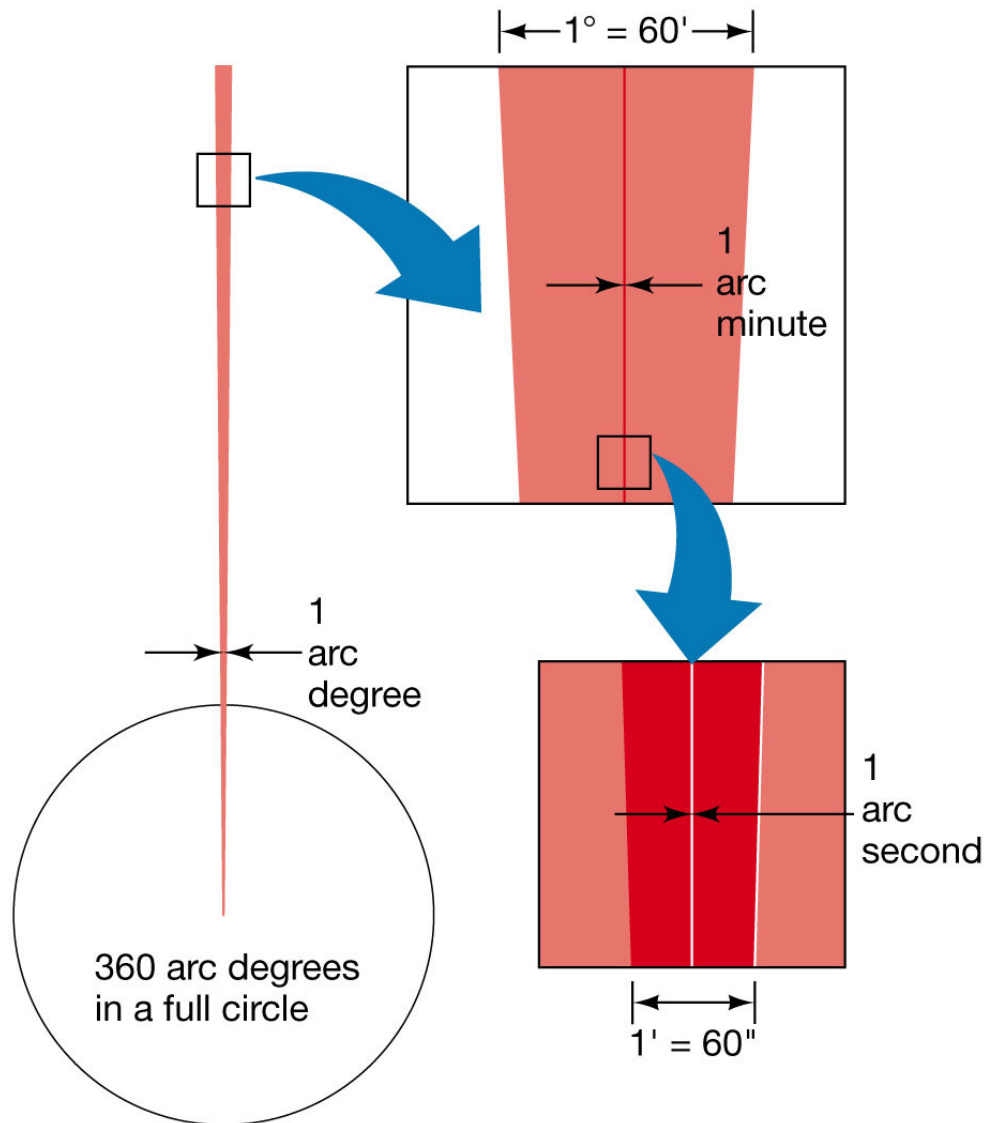
Surveying Principles....much the same



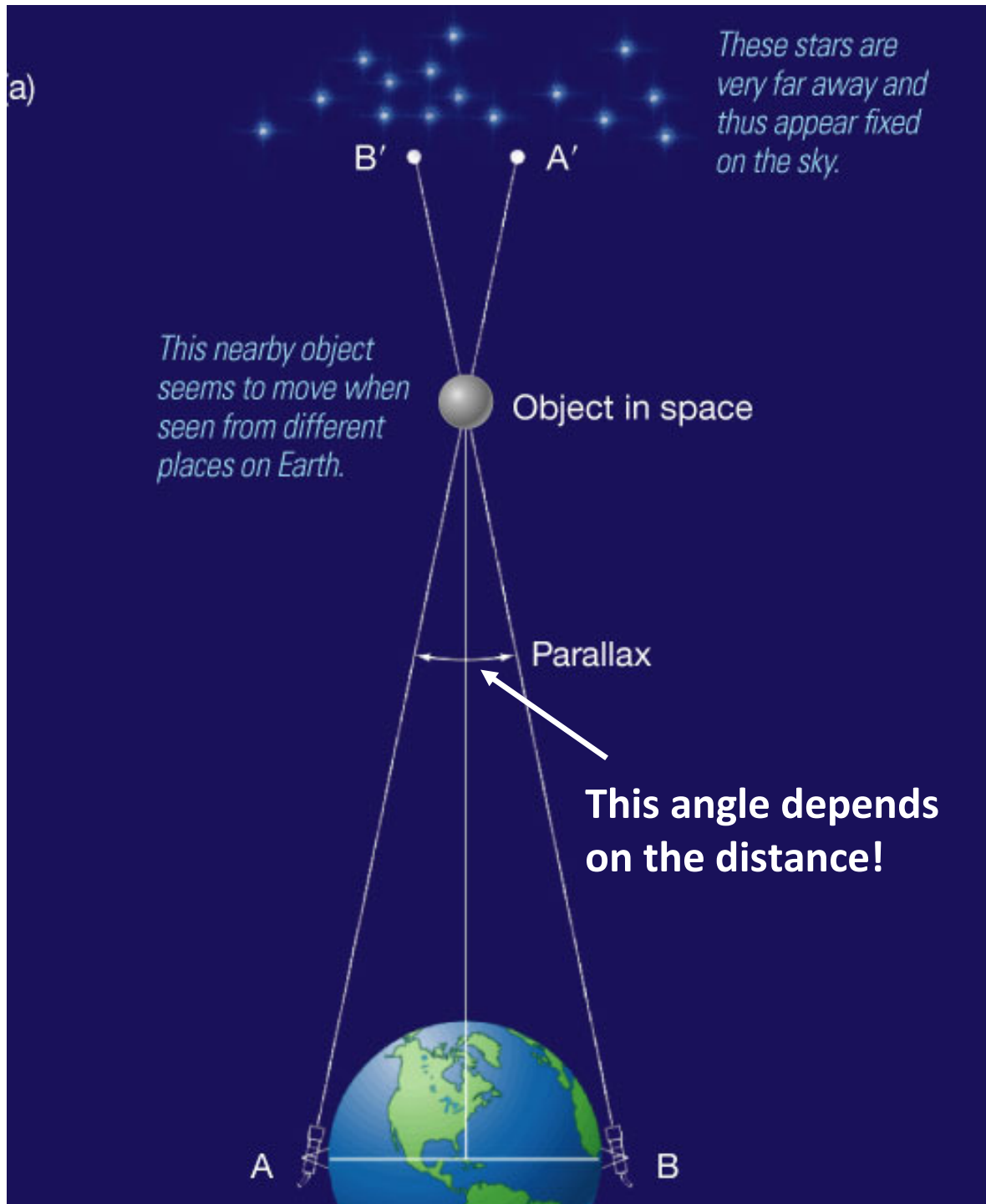
By measuring angles and knowing one dimension for a right angle triangle, we can calculate the lengths of all the sides. You should remember this!

Where are Things in the Sky?

We use ANGLES to locate them.



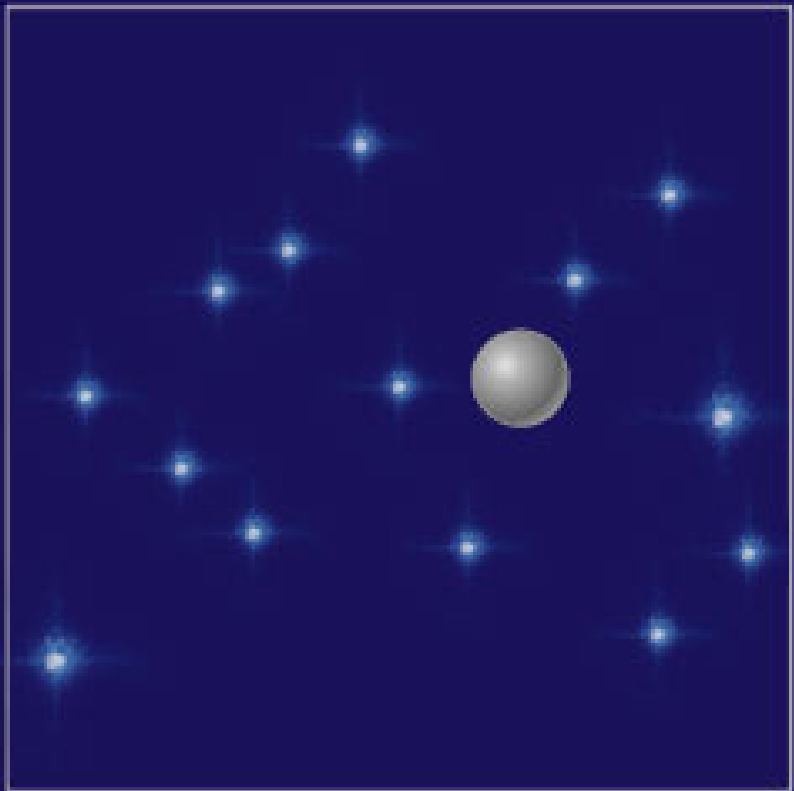
- We measure the positions of objects in the sky using angular coordinates from a given point of observation.
- The basic unit is the arc degree – there are 360 in a perfect circle. Each degree is divided into 60 arc minutes, and each arc minute is divided into 60 arc seconds.
- This is essentially the same as latitude and longitude measures in geography.



- If we observe some object from two locations – on either side of the Earth – at the same time - its angular position is different.
- From this, we make an imaginary triangle, and if we know the distance between the points, we can make two right-angle triangles.
- The rest is easy.....



(b)



As seen from A



As seen from B

Parallax Angles and Distance

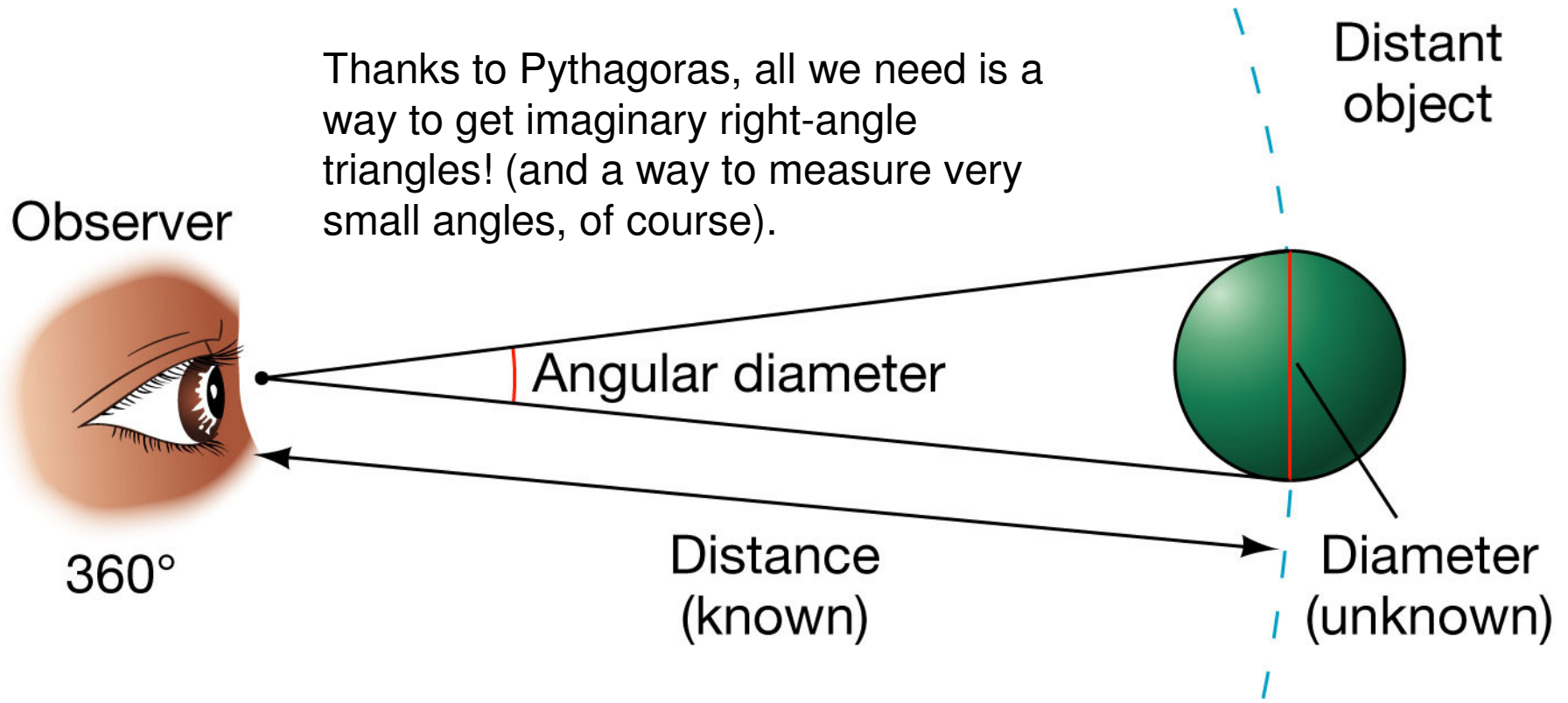
- Parallax measurements give us a method for estimating distances to objects, if we know the distances between the locations of measurements.
- For solar system objects, we can use measurements from different points on the Earth's surface – the longest baseline is then the diameter of the Earth.
- For stellar measurements, we need a much longer baseline, so we use measurements taken about 6 months apart – so the baseline is 3×10^6 km (2 AU).
- A star 3.2 LY away has a Parallax Angle of 1 second – which is where the term Parsec comes from.
- For **very** distant objects like some galaxies, angles are too small. But there are other spectroscopic methods.

But how big are celestial objects??

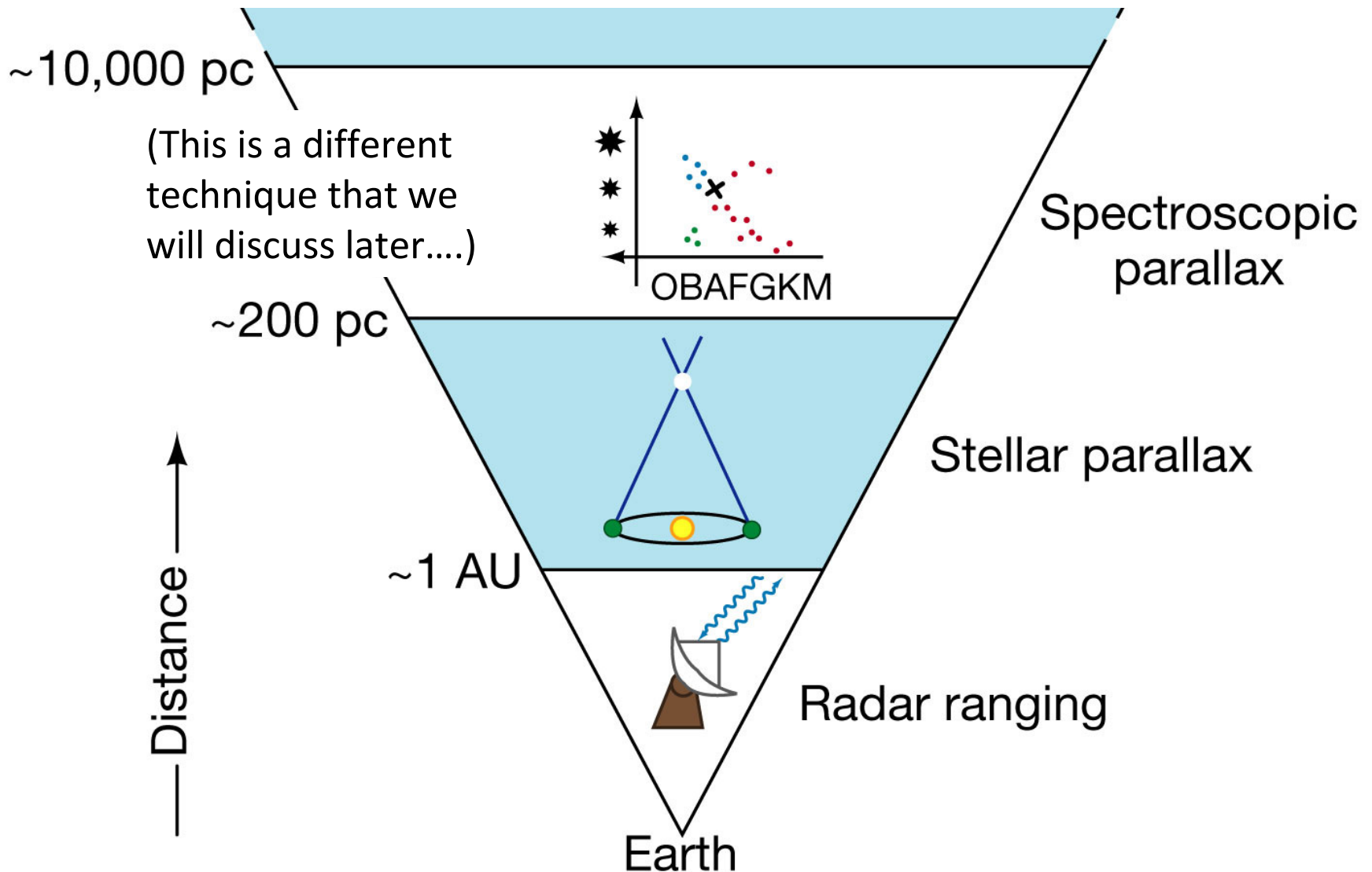


- The full Moon and the Sun both appear the same size in the sky, about *half an arc degree*.
- BUT - The Sun is ~ 400 times farther away from Earth than is the Moon, and so is actually ~ 400 times larger than the Moon.
- Once we know how far away something is, we can work out its REAL size from its apparent size – again, simple geometry.

Distance and the 'Small Angle Formula'

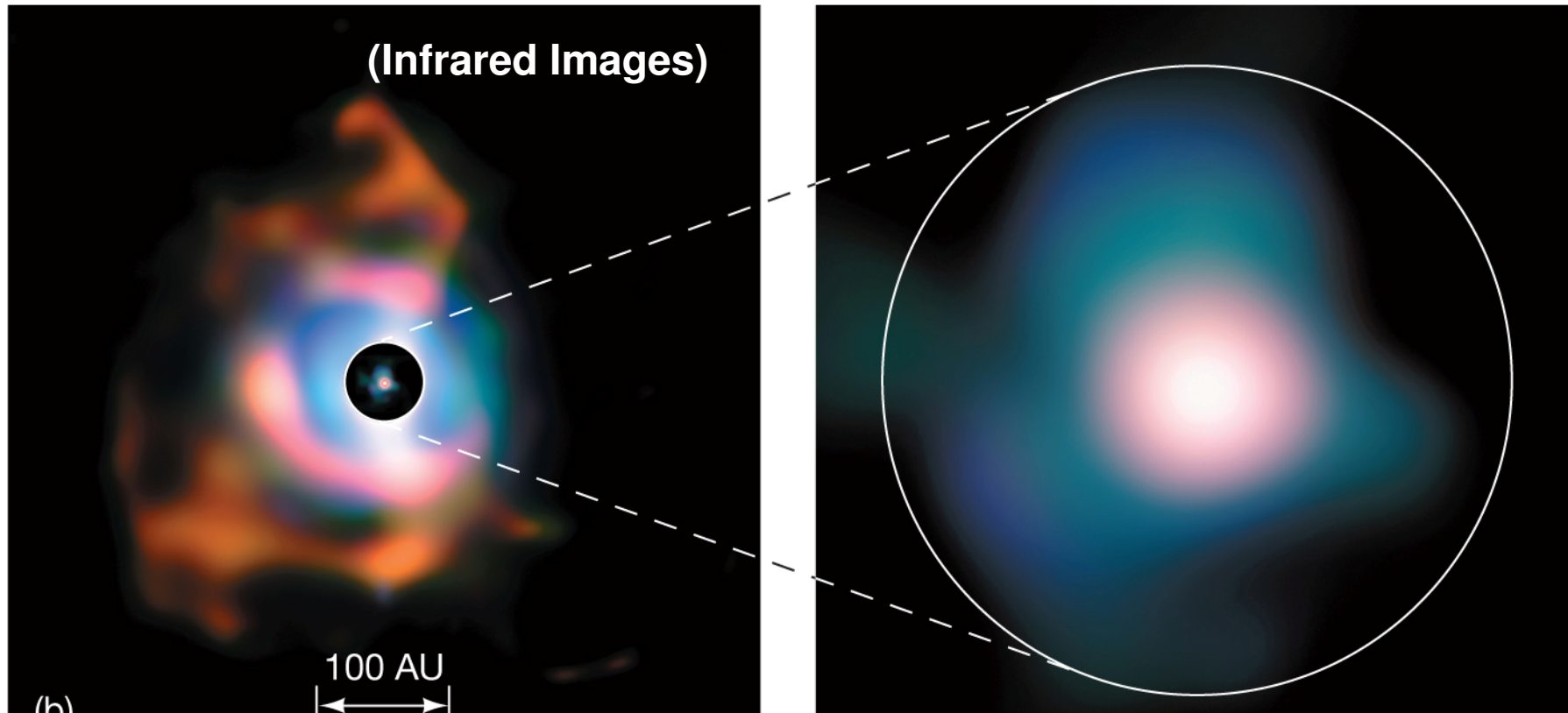


- The 'angular diameter' of an object is a function of its real size and its distance. If we know how big an object is, we can obtain the distance without parallax. If we know the distance, we can calculate the size. As the angles are always small, the formula is simple.



- We now have other high-tech methods such as radar ranging for objects in the Solar System, but parallax methods work well for around 600 LY. The space telescopes can make more precise measurements of parallax angles and stellar sizes.

Star Betelgeuse – The Ultimate Supergiant



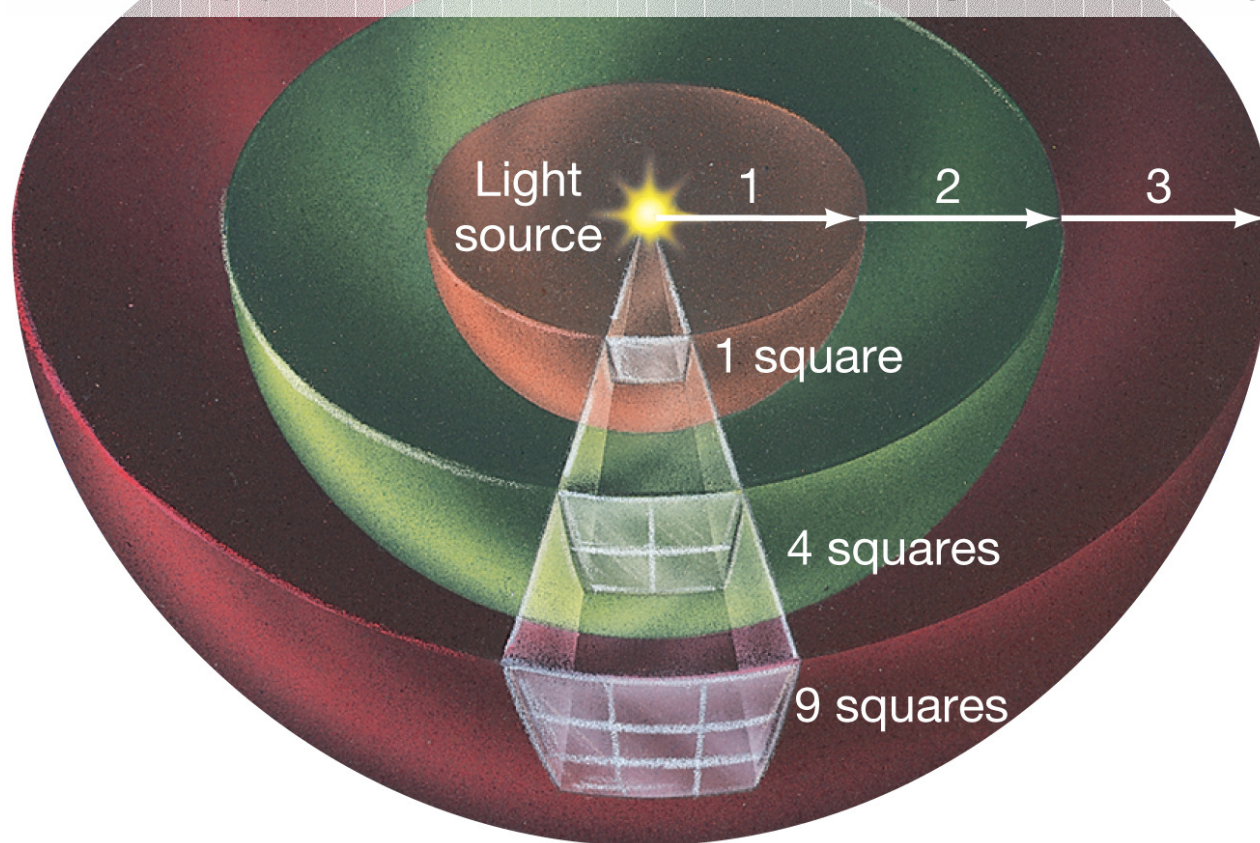
- **Very large stars can be ‘sized’ directly using their apparent size and distance – especially using space telescopes. Betelgeuse, in Orion, is 600 times larger than the Sun, so its outer limit is much larger than Earth’s orbit. Smaller stars are harder to measure....**

Information from Starlight – Vital!

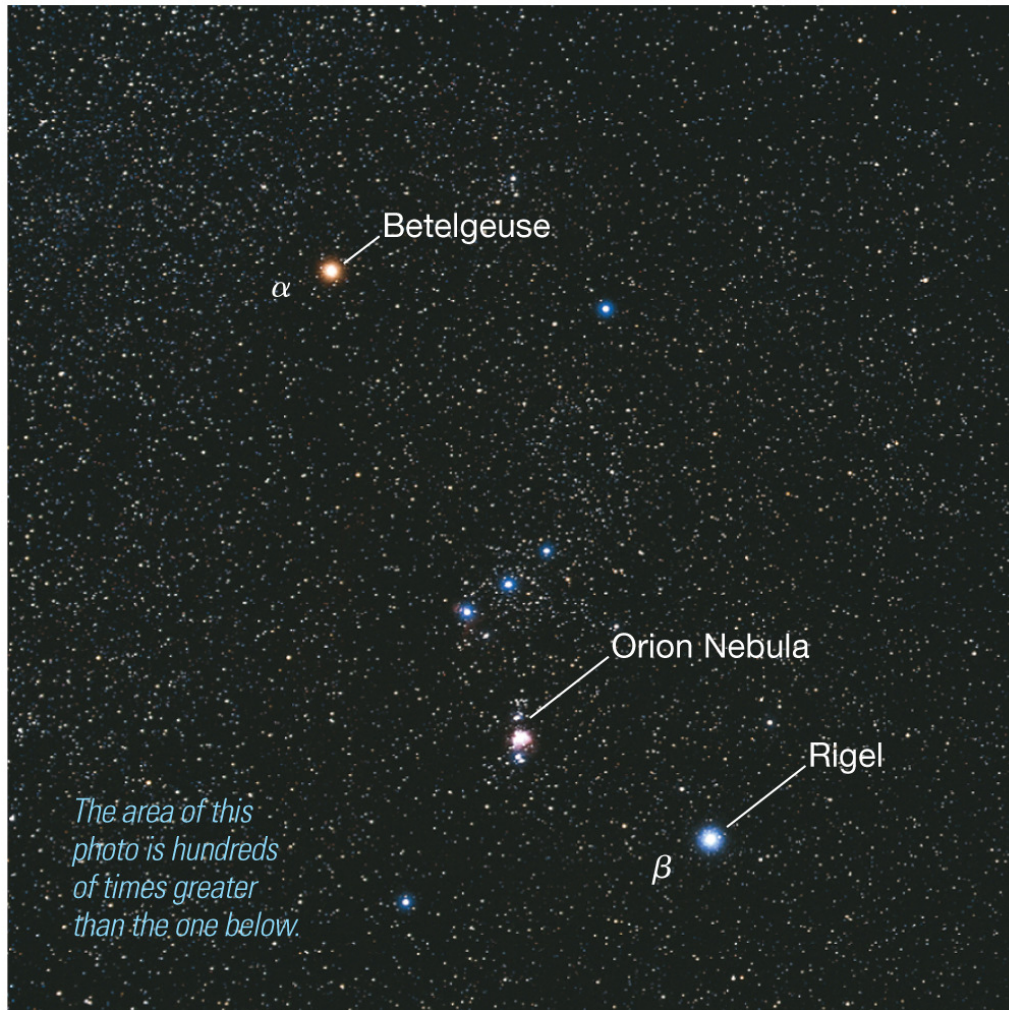
- The light from stars is energy from vast distances and it also looks back in time. All stars – like the Sun – produce vast amounts of electromagnetic energy.
- The intensity of such radiation diminishes with distance; we know this intuitively. But there are rules!
- If we know how far away a star is and how bright it is, we can estimate luminosity (energy it yields). This also has a relationship to size – more star, more energy.
- The wavelength ‘spectrum’ for any object that emits EM energy is linked to its temperature (we’ll discuss this later on). We also can gain compositional info from these spectral measurements.
- Guess what – we see some systematic patterns!

Figure 17.5

The Inverse Square Law – A Universal Truth (this appears time and time again in physics)



- The energy output from a star – or any object that emits EM follows the inverse square rule; if you double the distance, it diminishes by a factor of 4 (2^2)| if you triple the distance, it diminishes by a factor of 9 (3^2). And so on and so on and so on.



(a) ***We will discuss the nature of these relationships in a later class – for now, just note that spectra of objects are related to temperature.***

Colour and Temperature

- The colours of stars vary – a good example is the constellation Orion (the Hunter). Look at the difference between Betelgeuse (Red) and Rigel (Blue). Our sun has a yellowish colour.
- These colour variations are a measure of the temperature of a star's surface. Blue stars are much hotter than red stars. **Very much so!**

Temperatures of Stars versus Colours

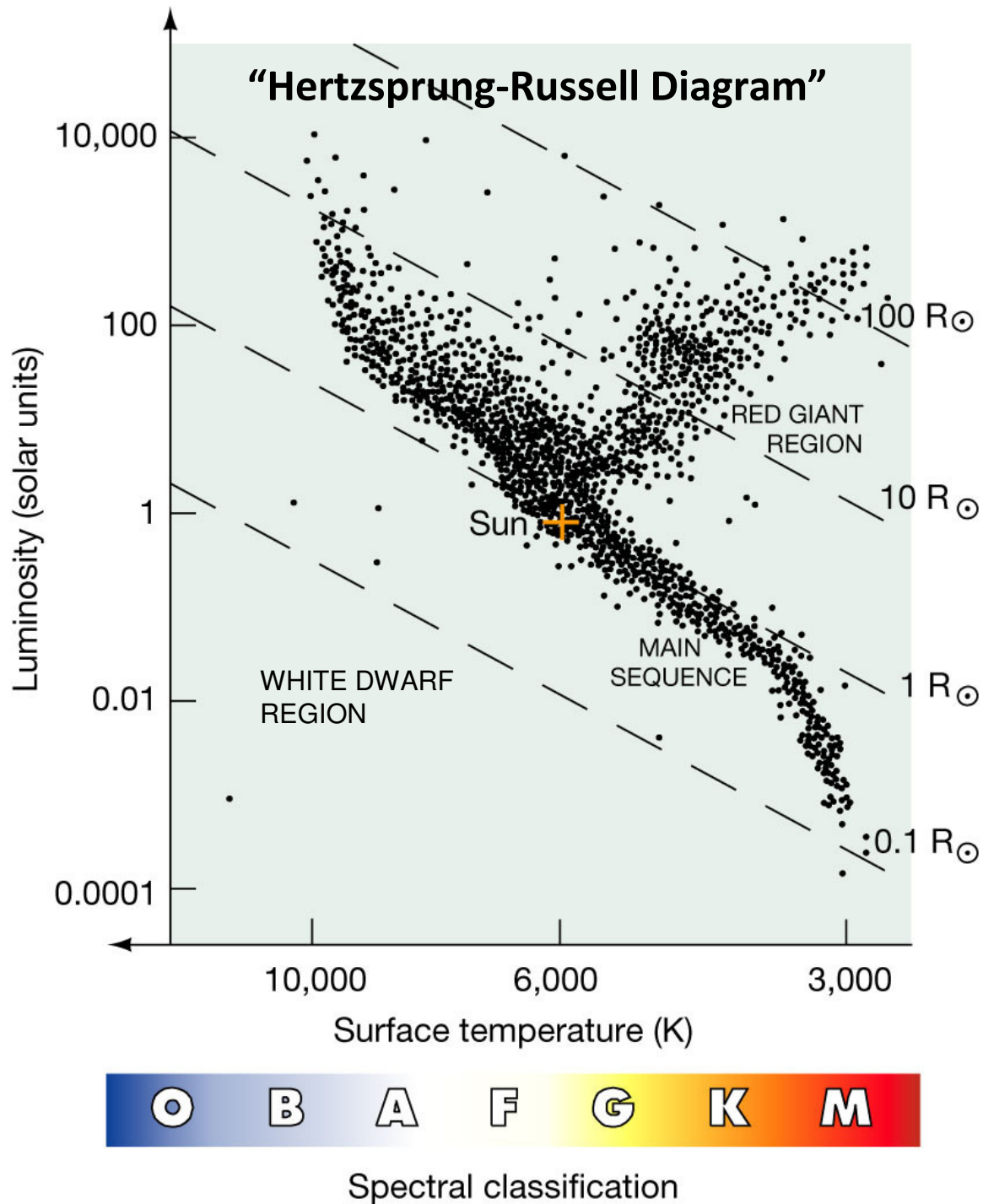
Surface Temperature (K)	Color	Familiar Examples
30,000	Blue-violet	Mintaka (δ Orionis)
20,000	Blue	Rigel
10,000	White	Vega, Sirius
7000	Yellow-white	Canopus
6000	Yellow	Sun, Alpha Centauri
4000	Orange	Arcturus, Aldebaran
3000	Red	Betelgeuse, Barnard's star

- There is of course also a link to total energy output – hot objects emit more energy than cooler objects – so white and blue stars are extremely energetic. They get the energy by fusing elements – so they use up fuel much more quickly.

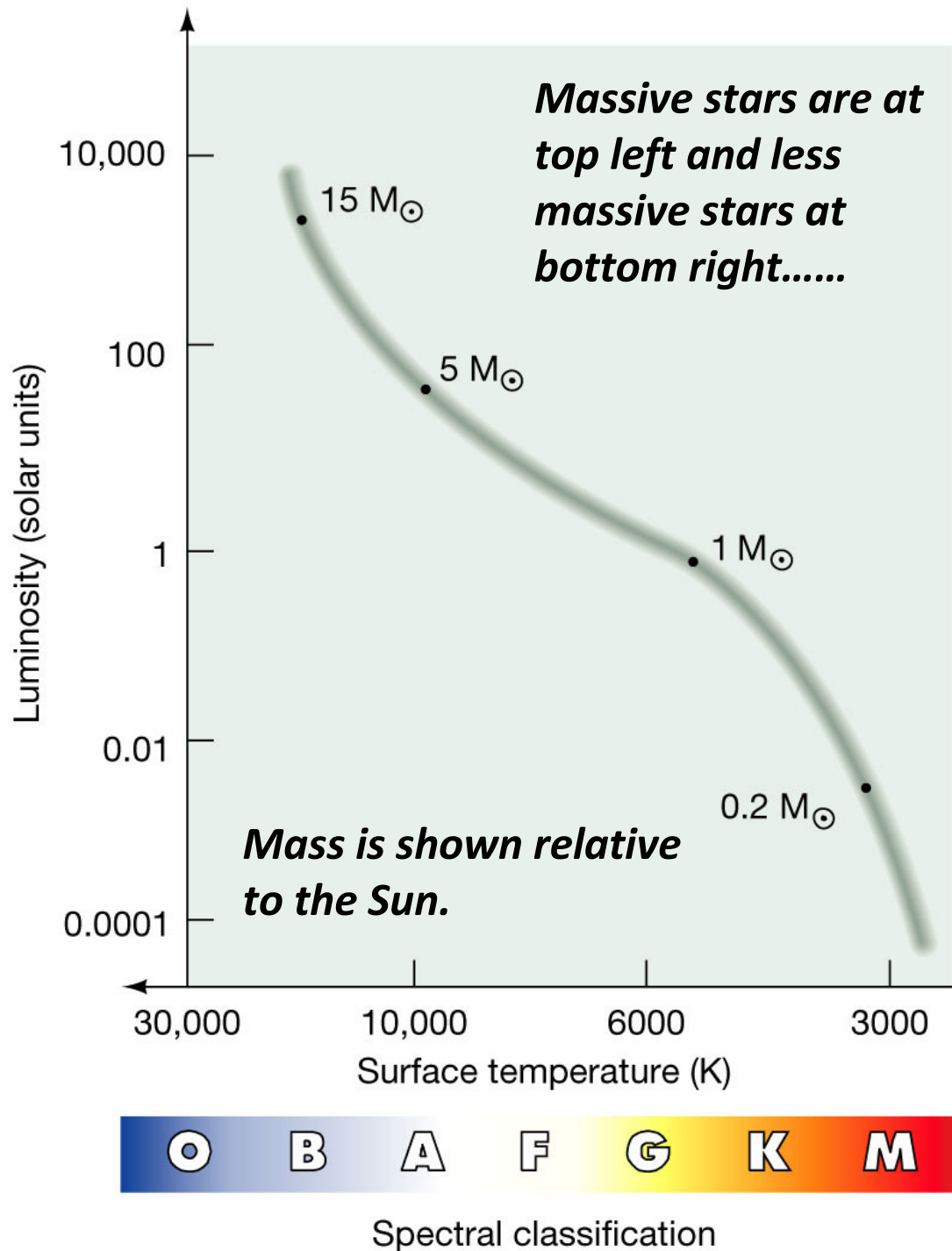
How Big are Stars? – They Vary a Great Deal



- We have ways of estimating the size/mass of stars (no details on exact methods).
- Stars vary greatly in size. Here are some examples, compared to the Sun.
- Many stars are much larger, but some are very small – not as large as Jupiter.
- From these various parameters, we can classify the populations of stars, and understand how they evolve.



- As you have likely guessed, we find some systematic relationships. On this plot of temp versus luminosity we find that **most stars** define a trend (Main Sequence).
- The **Red Giants** are an exception to this (we'll discuss later).
- We sit in the middle of 'Main Sequence' stars. Good for us!

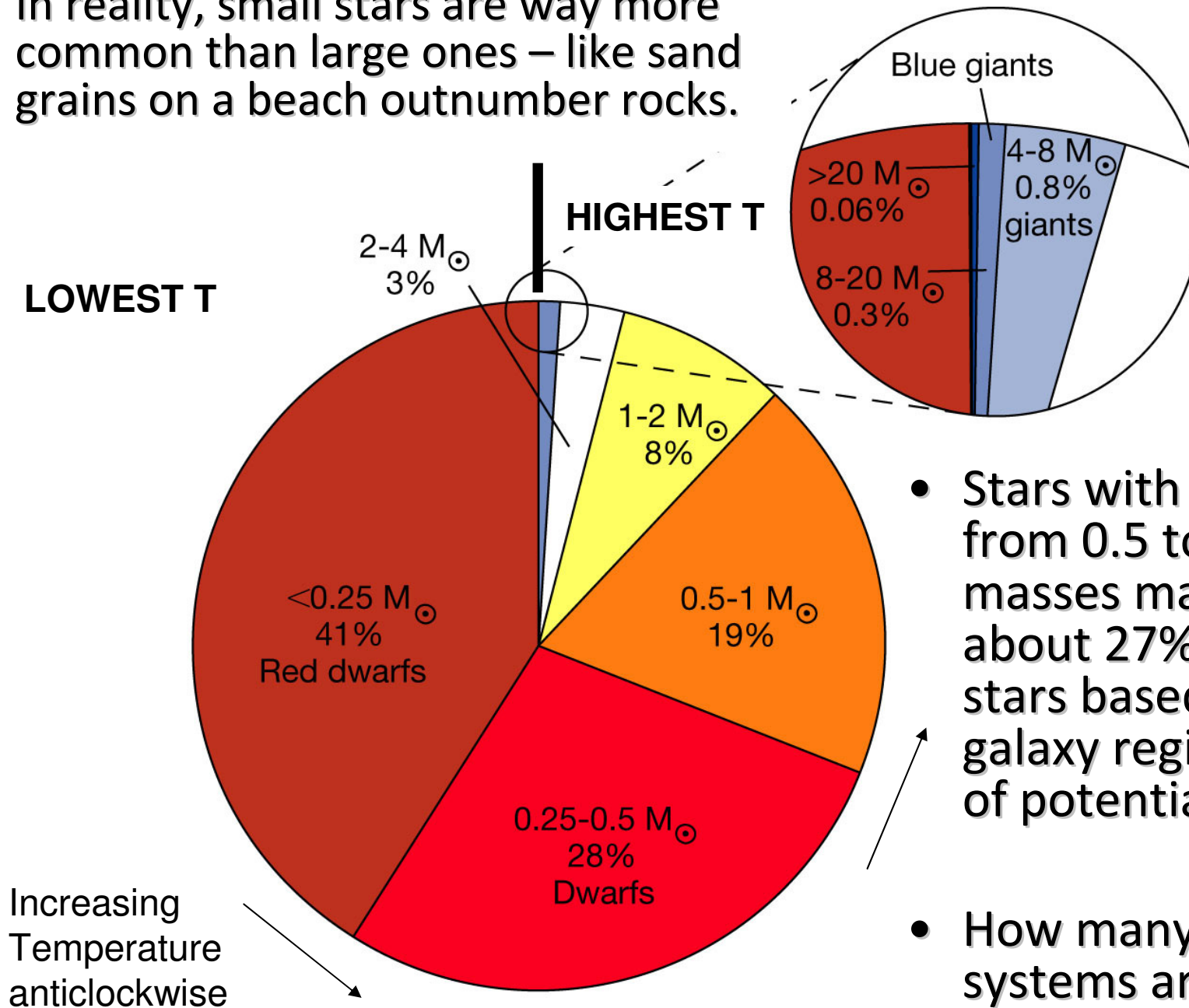


- We can also figure out the sizes (mass) of stars and their other properties.
- It turns out that the **Main Sequence** is defined almost entirely by the Mass of stars.
- The hot, luminous stars are all bigger than the Sun. But what does this mean?

Good Stars and Bad Stars.....

- In general, the massive hot stars are unsuitable candidates for habitable planets, as they emit lots of nasty radiation. More importantly, they have short life spans (< 100 m.y.). Not much time for evolution!!
- They run out of hydrogen fuel, shift to more energetic fusion reactions, and then they explode as “Novas”.
- Dwarf stars are extremely long-lived, but because they are small, they will only have a narrow ‘habitable zone’ in which life might be able to exist.
- Many stars are binary systems – again, these are likely not the best for stable planetary orbits.
- But the good news is that stars like the Sun are **very common** on the scale of the Universe.....

- In reality, small stars are way more common than large ones – like sand grains on a beach outnumber rocks.



- Stars with masses from 0.5 to 2 solar masses make up about 27% of all stars based on our galaxy region. Lots of potential.....
- How many solar systems are there?

Do other planetary systems exist? There is now plenty of evidence for this.

- We have observed areas where planetary systems appear to be forming, and there are now several methods that can detect individual planets in them and make inferences about them.

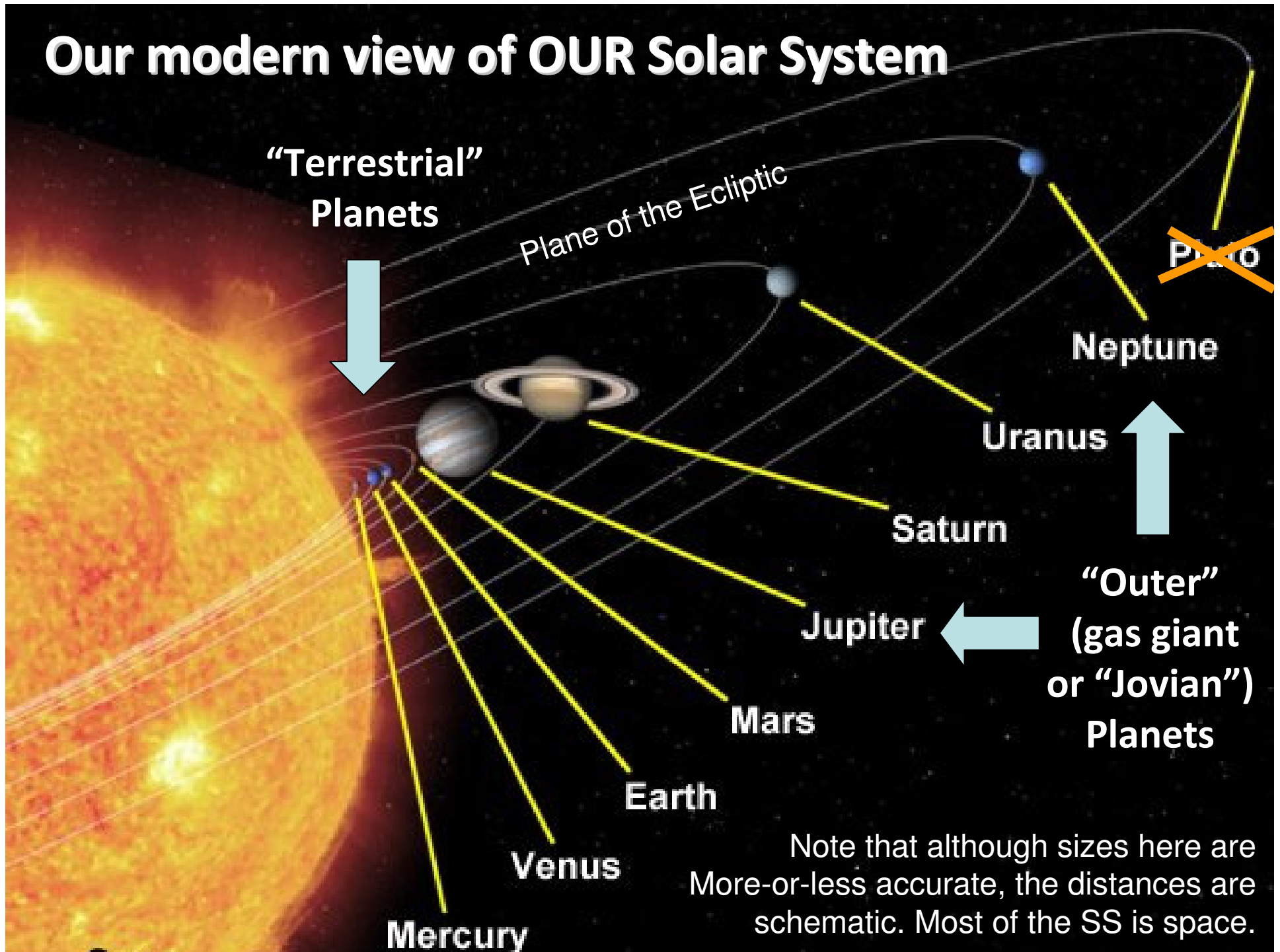


- Artist's impression (fanciful) of three exoplanets near a star about 33 LY from Earth. L 98-59b is the smallest exoplanet confirmed – between Earth and Mars in size.

Other Planetary Systems

- We will talk more about “Exoplanets” and how we detect them in another session, but some things are worth noting now.
- The data on exoplanets presently suggest that most are not at all like the Earth. They tend to be much bigger and in many cases orbit close to their stars – not in what we would consider ‘habitable’ zones.
- However, this view may not be accurate – the methods we use are not that sensitive, so it is likely that we are just seeing the things that are easy to see.
- The question of whether other planetary systems might truly resemble ours is important but not fully answered. It is one of the most critical things to know.

Our modern view of OUR Solar System





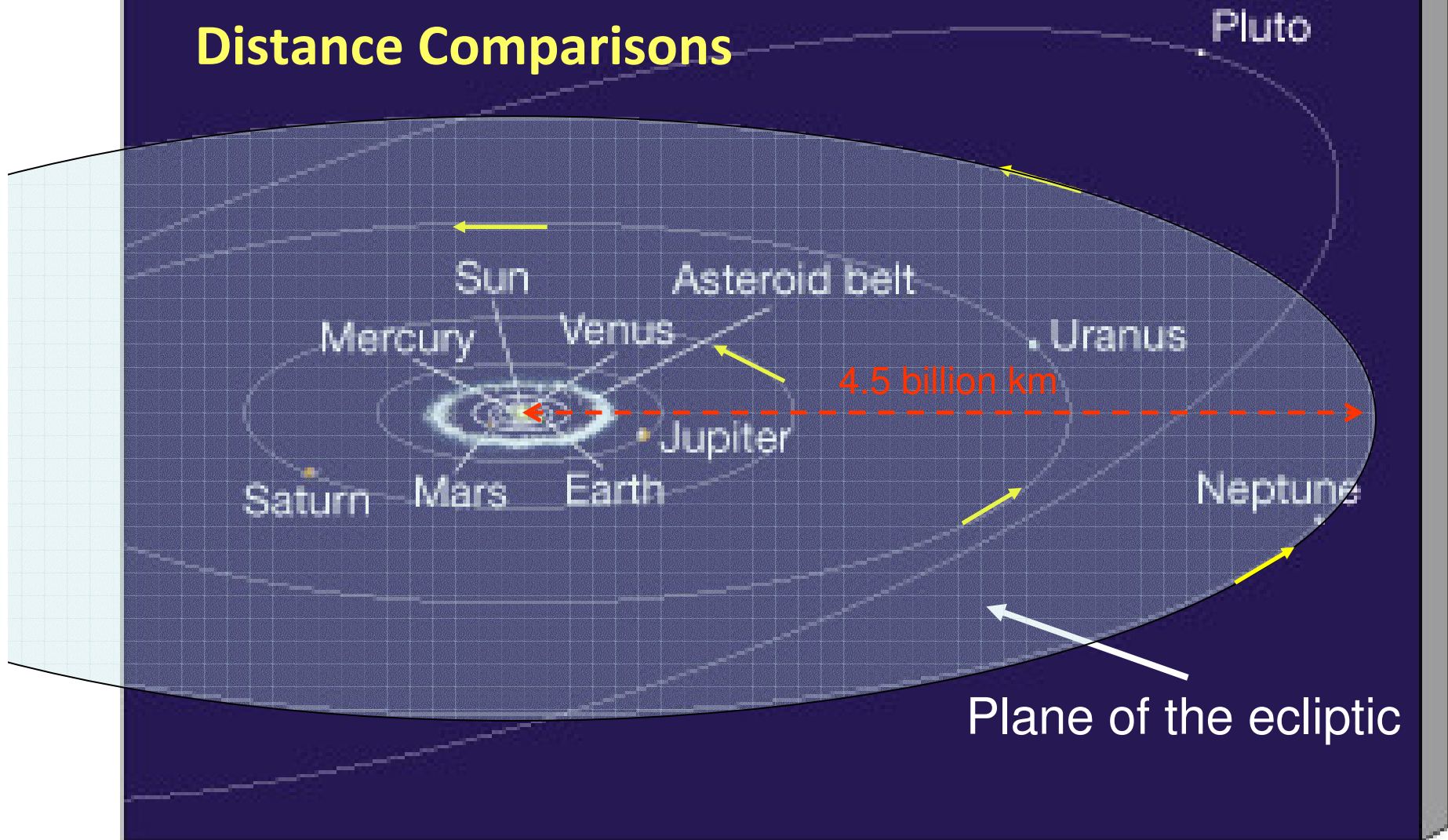
2016 – New Horizons

An interesting place!

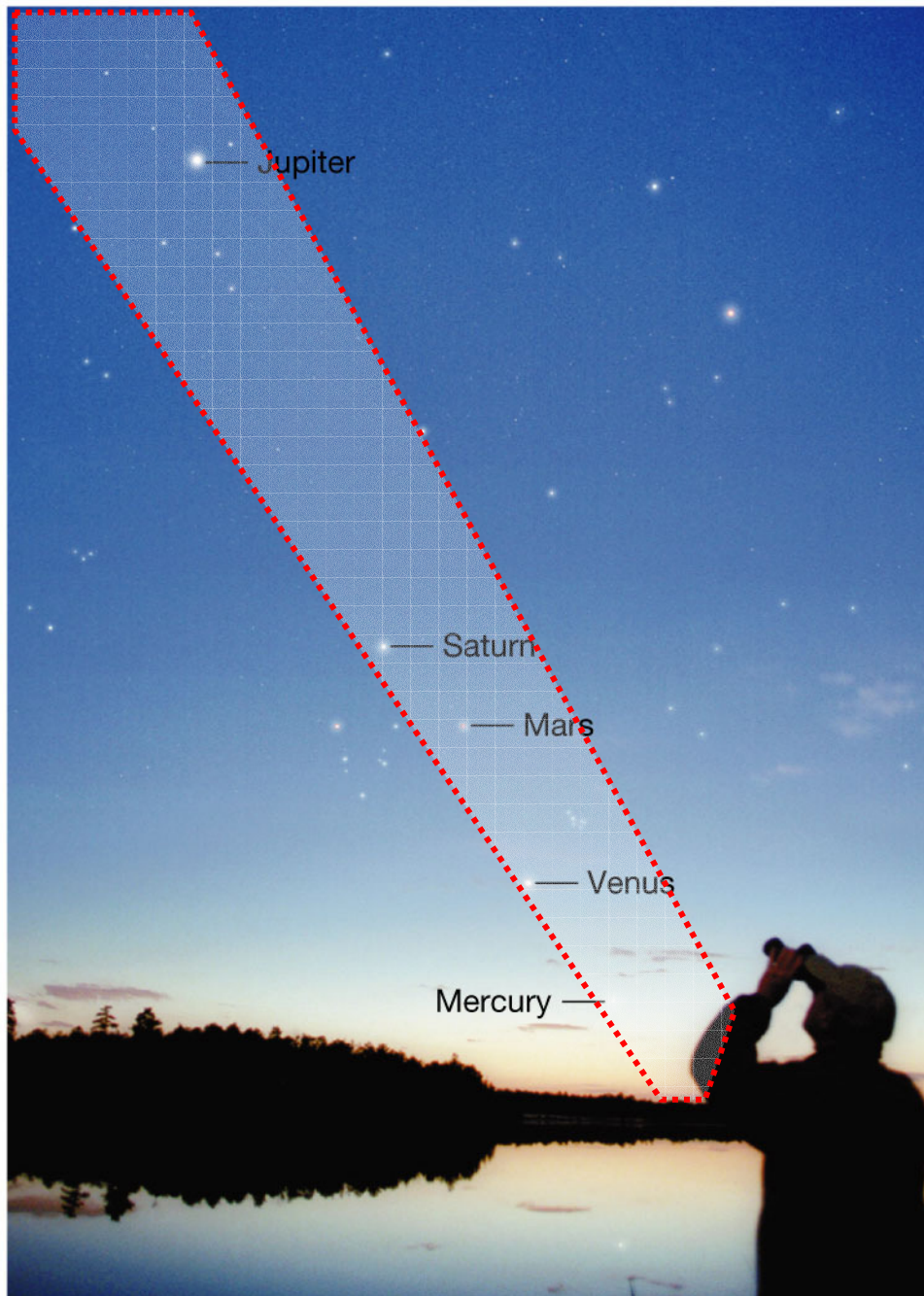
Eight or Nine Planets?

- When I learned about the Solar System it had 9 planets, and the most distant was Pluto. A name defining isolation...
- Pluto was thrown out of the Planetary club in 2006, and is now reclassified as a “dwarf planet” – A decision that still leads to controversy.
- Reasons? These are to do with its small size (other objects we now know of in distant regions are actually larger), and the fact that many other objects share its orbit, which is very strange.

Distance Comparisons



This diagram gives an idea of how spread out the system really is. On the scale of Neptune's orbit, the Sun is tiny and the planets would be invisibly small. Note how Pluto is well outside the Ecliptic.

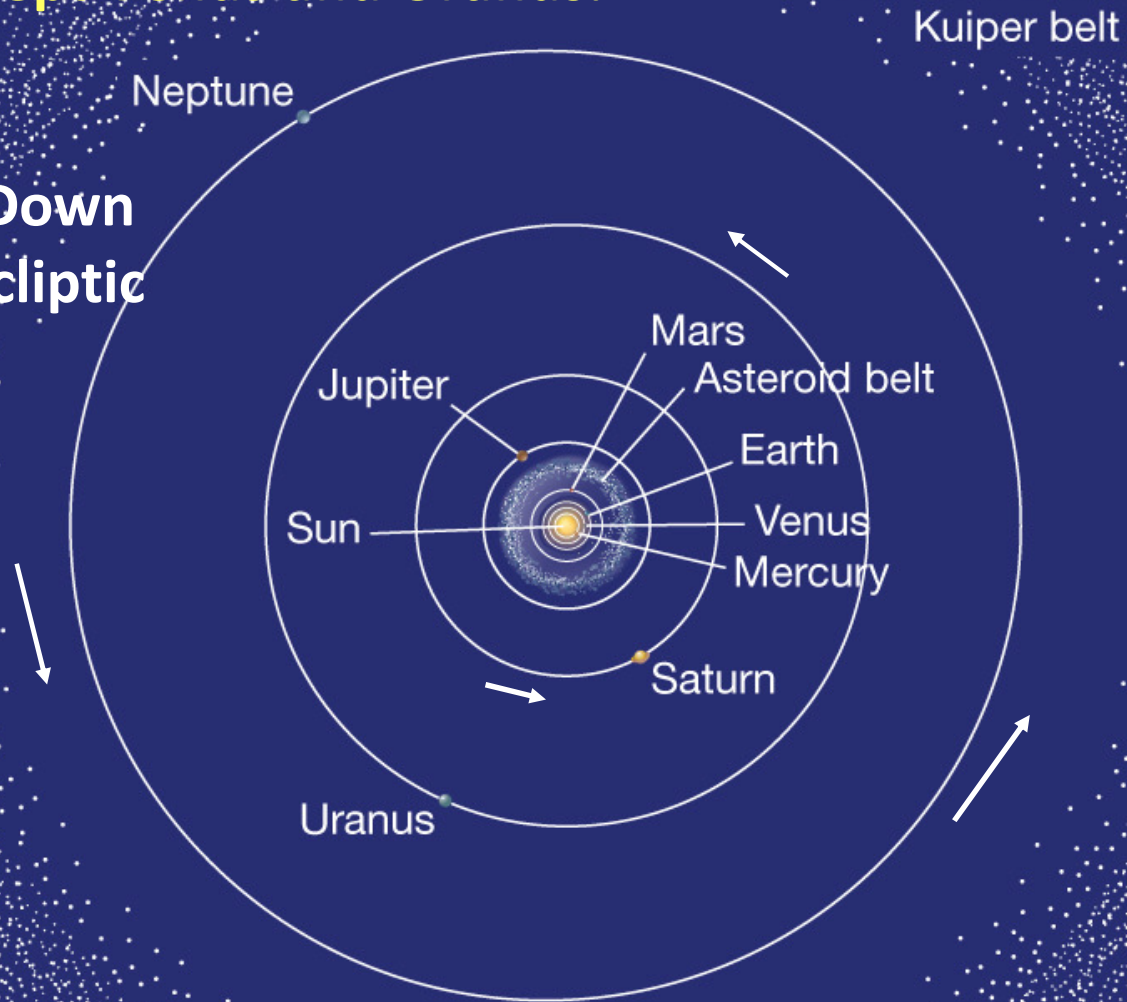


What's the Ecliptic??

- Technically, the plane that includes the Earth's orbit. It is also the general plane within which the planets move – it would be like an arch in the sky, but not directly overhead.
- This photo shows a rare planetary alignment in 2002, when five of the planets were all visible in one area.
- This means that they were all more-or-less along a line connecting the Earth to Saturn.

Note: All planetary objects that have a rotation axis also rotate in an anticlockwise manner – except Venus and Uranus.

**Looking Down
On the Ecliptic**



Note: Near-circular orbits (low eccentricity) and anticlockwise movement of all planets.

Summary Slides – Some Key Points from The Class (Module 3 – Part 2)

- These slides provide a summary of the really important ‘take-home’ points from this class. However, don’t assume that this is the limit on what we expect you to learn from the class, because some of the details in individual topics should also be absorbed. It’s a guide to key concepts only.
- You can find information on some (but not) all of the topics discussed in the Seeds and Backman text, specifically in Chapter 9 (Origins of stars, etc.) although this is more detailed than the context provided in this course. Stars and stellar evolution are not the main focus of our course, but this is very interesting stuff. If you want to learn more, enroll in Physics 2131.

About the Course

- This is an Earth Science course, but only one session is specifically about the Earth. It is a course about the bigger picture; the solar system, other planets as well as Earth, and some of the ideas of the science of 'planetology', which has a long way to go; it's just beginning. Some of this stuff is on the frontier of natural science.
- The Earth is unique in many respects – we know this – and it is likely that many of its features result from the impact of life on the planet. Life does not just live on Earth; it is a living planet. Life (especially us) continues to affect it – global warming from CO₂ emissions is an obvious example.
- The course breaks into two parts. The first has background and discusses ideas about the solar system as a whole, and also some of the methods that we use in trying to understand it. The second focuses on individual planets and some moons, and closes with discussion of possibilities for life.
- We are use to thinking of ourselves as the centre of the universe, but nothing could be further from the truth. We are located by an average star in the suburbs of the Milky Way, within a vast universe that contains billions of galaxies and has existed for over 13 billion years. The scale of the universe defies comprehension.

Cosmology and the Origins of the Universe

- Ideas about the origin of the universe are hard to get your head around – this is the field of cosmology, and it seems to depart from logic at times.
- The universe is vast, but it is not infinitely old. We estimate that it has existed for over 13 billion years, and it is expanding still. We know this from measuring the velocities of other galaxies, which are all moving away from us. A common analogy is that the universe resembles an inflating balloon.
- Cosmologists contend that it began as an incredibly rapid expansion from a single, infinitely small point (a singularity) – we call this the “Big Bang”. Some (but not all) contend that eventually it will recontract in a “Big Crunch”. The events surrounding the origin of the universe are understood through mathematical equations, but these make predictions that are consistent with many observations that we make. One of these is the presence of ‘cosmic microwave background’ radiation that comes from the outer fringes of the known universe. Interesting as it is, too much cosmology can give geologists a headache – the ideas are hard to visualize.
- Within a period of around 1 billion years, the first stars and galaxies are thought to have formed, so a familiar universe has long existed. Our Sun and solar system formed at about 4.6 Ga, so the universe has existed for about three times as long as us.

What is the Nature of the Universe?

- The Universe contains some pretty strange things like black holes and theoretical 'dark matter', but we are going to stick with the things that are a bit more tangible and real in the context of the Solar System.
- In this view, the universe is almost entirely dominated by stars, distributed in clumps called galaxies – planets are a trivial component of the whole deal. We are not focused on stars as such, other than the Sun, but we need to understand a bit about this wider background.
- We have ways of calculating the vast distances to stars (e.g., parallax) and ways of understanding how large they are, how hot they are, and how much energy they release. We also have models of the nuclear fusion processes that produce this energy – to be discussed more later on.
- Stars are not all the same – they vary in colour, in size, in temperature, in composition and in other parameters. They form a population, just like human beings. Studies of stellar populations reveal consistent patterns. There is generally a positive correlation between luminosity (related to size) and temperature, although some stars (notably 'red giants') defy this rule. In general, hot energetic stars (white or blue in colour) tend to be large stars, and cooler (reddish) stars are smaller. Hot stars produce vast amounts of energy, which means they consume larger amounts of 'fuel' over time.

Good Stars, Bad Stars and Average Stars

- The types of stars that make up the “Main Sequence” in which luminosity, size and temperature are linked have implications for planetary systems.
- Hot, Large, high-energy stars emit a lot of potentially nasty radiation in addition to visible light. They are probably not good candidates for habitable planets. Worse than this, they have short life-spans and eventually explode as Supernovas when their fusion reactions shift to a more energetic form. This would not give more than a few hundred million years for life to evolve.
- Cooler, generally small, low-temperature stars don't have this problem, and they have long life spans, but they emit smaller amounts of energy, which means that the size of any 'habitable zone' for any planets is very restricted. A planet would have to be in exactly the right location to be viable.
- There is more complexity to this, as stars evolve – and some will eventually become 'red giants' (more on this later) – but stars in the middle of the range have long stable life spans and reasonably large habitable zones should be present around them. These are mostly yellowish in colour.
- The majority of stars are smaller than the sun, but stars ranging from half to two times the solar mass make up about 27% of studied stellar populations – so we anticipate that large numbers of 'suitable' stars are available.

What do we know about other planetary systems?

- We are discovering more and more planetary systems around other stars as we continue to make observations, especially from orbital telescopes.
- The information we presently have indicates that many are very different from our own system – planets that we detect are in many cases much larger than Earth (like Jupiter or bigger) and orbit very close to stars.
- However, this may not be the real picture. Our methods are not that sensitive and long sequences of measurement would be needed to find planets more distant from stars. We may just be seeing the ones that are easiest to see!
- There are some examples of smaller planets that are thought to lie within what we think of as ‘habitable zones’ based on size and luminosity of their stars.
- So the question of what other planetary systems look like remains open.

Size and Geometry of the Solar System

- Pretty much every diagram you see of the solar system will misrepresent either the sizes of objects or the distances between them. The scale of the solar system is immense.
- The orbit of Neptune is about 4.5 billion km from the Sun, whereas we are just 150 million Km from Sun. So Neptune is 30 times further away (roughly). The terrestrial planets sit in a very small area close to the Sun, and most of the Solar System is empty space.
- The arrangement of objects is important. Most planets and other objects sit generally within the ecliptic plane (plane containing Earth's orbit and the Sun). All important Solar System objects orbit in an anticlockwise direction, when viewed from above the ecliptic. With very few exceptions, objects in the Solar system that rotate do so in an anticlockwise direction.
- These attributes are important – they must tell us something about the formation and evolution of the Solar System.