Phys 132 – Introductory Astronomy
Notes-Cosmology, Neutrino Astronomy, Processes in the Sun

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Topic Covered

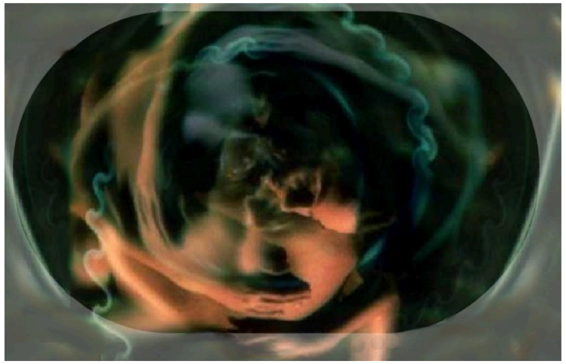
Cosmology: Includes the development of the scientific model of the universe, the geometry of space time and matter distribution in the universe.
Multimessenger Astronomy: Includes introduction to particle physics and Neutrino Astrophysics.
Sun: Introduction on energy transport in the Sun.

Techniques: Doppler Shift, Spectroscopy

Equations Introduced: Some equations on Doppler and redshift were introduced and photon energy $E=h\nu$ and $E=mc^2$.

References: As discussed in class, I use the Horizons text book. The different versions have different chapters. The chapters were, the Cosmology Chapter, parts of some of the other chapters covered spectra and Doppler shifts. I gave these references in class.

Cosmology



Cosmology is the study of the origin and development of the universe. Cultures have endeavored to answer the most fundamental questions for thousands of years.

- How did the universe form?
- How did it develop?
- What is the ultimate fate of the Universe

All cultures theorised the creation of the universe, here in Aotearoa-New Zealand the universe was created from the nothingness called Te Kore, followed by Te Po the night, and involves a complex number of phases which explains the creations of the stars and the planets by various gods such as Rangi, Papa, Wainui and Tangotango.

Other cultures such as the First Nation Canadians Ojibway and Anishnabe people tell of their creation stories describing a void aswell or possibility. From this then came Kitch Mautou who created the Sun, Stars, and earth.

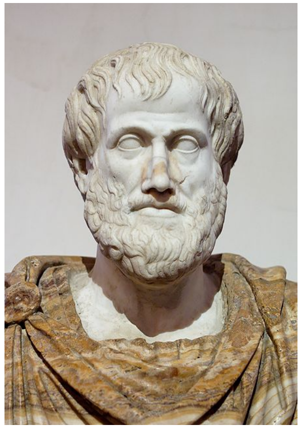
In Chinese creation stories it was Pan'ku or Pangu whom seperated heaven and earth which was mixed together. Before this there was great plainness, darkness and a void.

Other examples are the creation narrative are familiar to us such as Christian, Hindu, Judaism, Islam etc.

What we are interested in here is the more recent developments of scientific theory of the cosmological origins of the universe.

Development of the Cosmological Model

Much of the credit to modern models of the universe is attributed to the likes of Aristotle, Ptolemy and other Greek philosophers. Keeping in mind that their was significant influence on scientific theory from places such as the Middle East and India in ancient times.



Aristotle
384 B.C- 332 B.C

Aristole

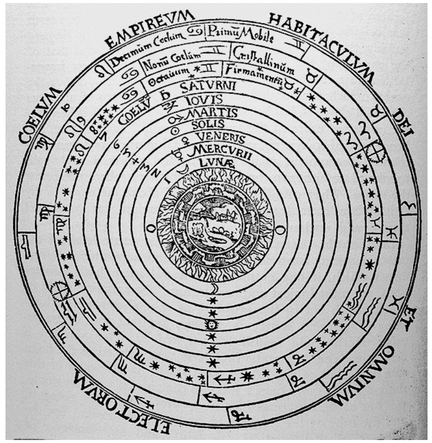
Aristotle known as the philosopher was alive from around 384 B.C- 332 B.C, whilst Ptolemy was alive around 100-170 AD. Later other notable people such as Newton, Copernicus and Galileo were fundamental to the development aswell. These early models of the Universe were Geocentric and models were in alignment with current doctrine of the time.

The Aristotlean model shown in the slides were the earth at the centre and the:

•Moon
•Venus

•Sun
•Mars
•Jupiter
•Saturn
•Fixed stars
then the
•Prime mover

all extending out from the earth.

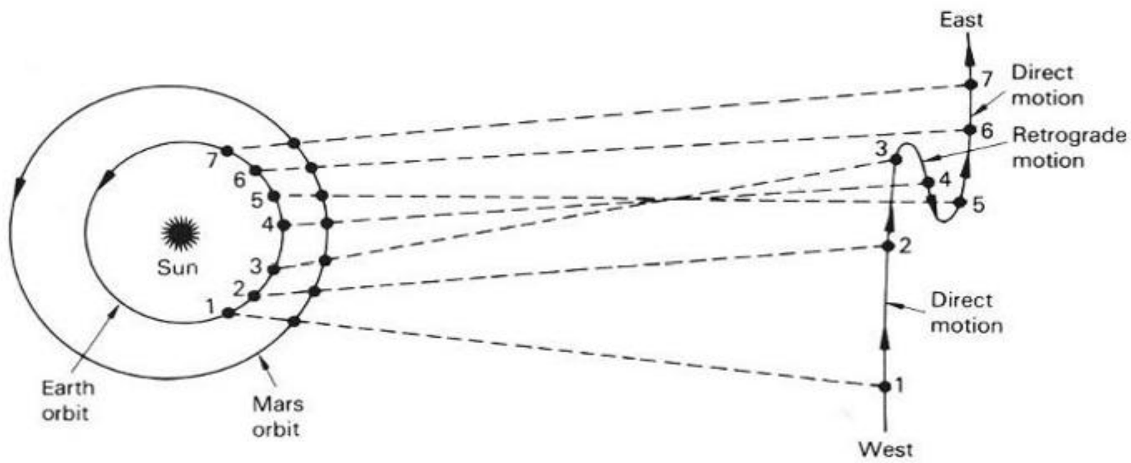


Retrograde Motion

As you can imagine this model was not able to account for certain observations. One in particular is the retrograde motion of the planet Mars. We know that we orbit around the sun along with other planets however since planets orbit at different speeds, when we lap a planet it's apparent motion in the sky appears to loop back, slow and continue moving to the west for a while then goes to the east.

In the video we saw the orbital motion of Mars and Earth around the Sun. Mars orbit is around twice that of Earth. The Sun , Moon and stars have their east west movement but as we observe night after night the planets will back track to the east. This is called retrograde motion. This can be explained (video) simply as we observe the earth orbiting around the sun as we come close to mars into opposition we can see that relative to the background stars simple overtaking makes it seem like the planet is changing course. In the video we saw the night by night example of mars path across the sky aswell.

The link for the video is: http://www.youtube.com/watch?v=72FrZz_zJFU

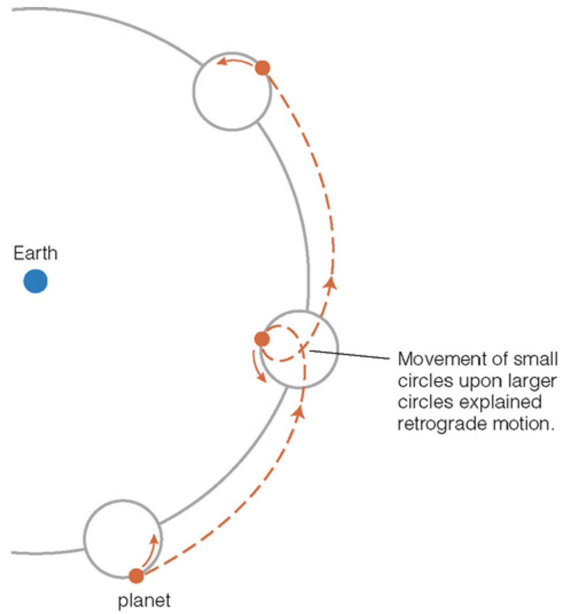


Ptolemy

In order for geocentric models to work Ptolemy introduced his epicycle model.

This explains that each planet orbits around another centre-epicentre aswell as orbiting around the earth. This still keeps it in line with geocentric models but explains the retrograde motion.

This model amazingly survived 1400years. As observations were more accurately measured, it became apparent that these models are incorrect.



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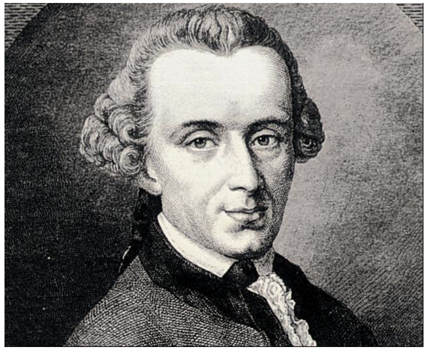
Nicolaus Copernicus

It took till the 1500's for their to be a shift from earth centered to sun centered universe, with Nicolaus Copernicus. But infact this took a long time to be accepted. With more observations came more technical and detailed models.

These models will be further discussed by Dr Ed Budding.

Toward Modern Models of the Universe

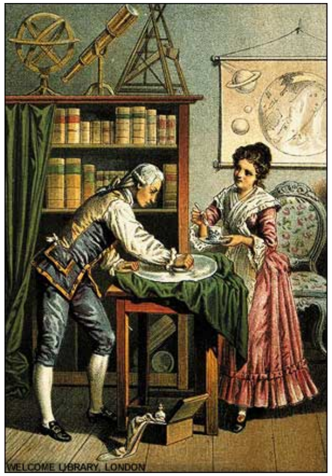
Up until the 1500's geocentric models dominated. In 1500's heliocentric models were introduced. Then incrementally shifts toward a universe that was not heliocentric occurred towards 1700's and 1800's



Kant (1724-1804)

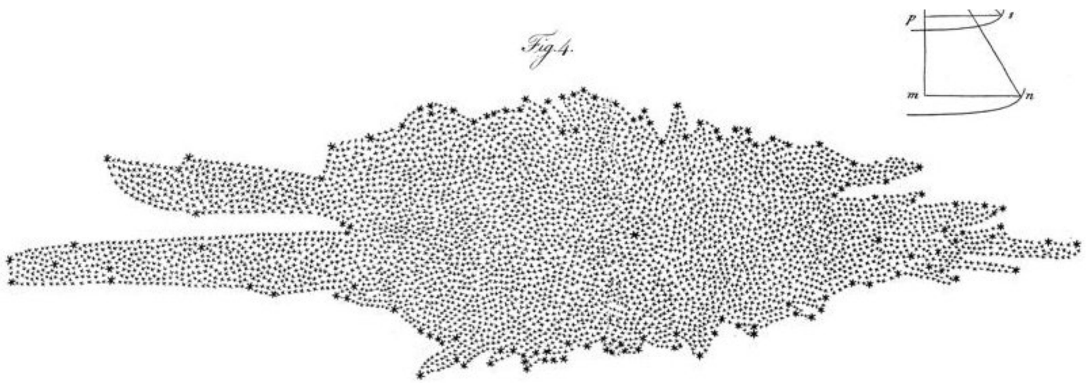
Kant

During the 18th century the use of the term solar system was normal place. And the likes of Kant (1724-1804) started bringing about the concept of the universe as a whole not just the solar system, describing a universe which was originally a chaotic mixture of elements of different densities spread through out an infinite space with forces positive and negative acting on the elements to produce star systems or galaxies as we call them today. He called them island universes, he had no observational information although he had heard about nebula and then postulated that they are separate worlds similar to our Milkyway galaxy.



Herschel's

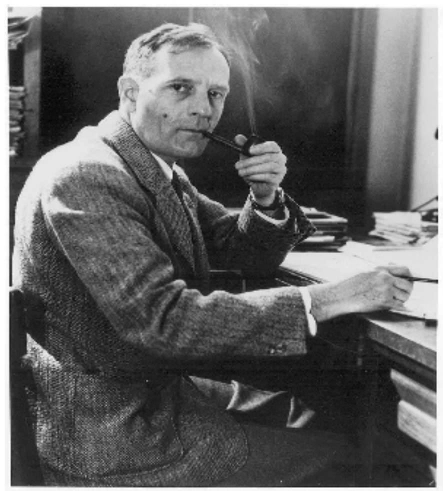
Astronomers in the 18th century were only just beginning to understand that galaxies existed beyond the Milkyway. At the end of the 18th century William and Caroline Hershel used the largest telescope of that time to study the shape of the Milkyway galaxy.



Map of the Milkyway done by William and Carolin Herschel.

Edwin Hubble

In the 20th century the idea of the island universe gained observational support when Edwin Hubble(1889-1953) discovered that the distances to some of these nebulae were greater than the size of the galaxy. He coined the term 'extra-galactic nebulae' for them. The distance to Andromeda galaxy was 20 times the distance of our galaxy. This thus confirmed that we were not the centre of the universe and infact the Universe was a collection of galaxies like our own Milkyway and we were just one of them.



This was announced in 1924 and was a true turning point of gave us a new scientific view of the universe.

Galaxy Redshifts

What Hubble observed was a shift in the wavelength of observes spectra from the galaxies towards the red end of the electromagnetic spectrum. These red shifts were first thought to be doppler shifts, that is that because the galaxies were moving away then the wavelengths of the light was stretched. We shall see later that this reasoning is considered incorrect.

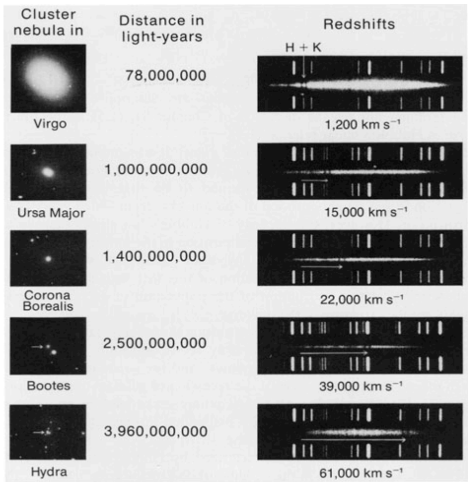
From these observations Hubble discovered a velocity distance relationship between galaxies using 46 spectra. He observed that the further the galaxy is, the faster they are receding away. His relationship as given as the following law called Hubble law:

$H=v/d$ where v is the recession velocity(kms^{-1}) and
d is the distance to the galaxy(MPc this is MegaParsec)

H is the Hubbles constant, which is not really a constant as it changed with time. Our best value for hubbles constant now is $H_0=69.32kms^{-1}Mpc^{-1}$.

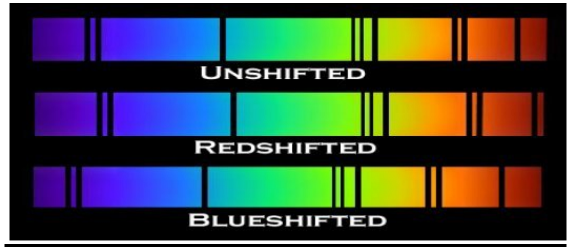
Here we see a galaxy at a distance in light years on the left and their speed, and spectra on the right. Shown are the Hand K lines of calcium are and where the lines were shifted to longer wavelength, this is more easily seen in the powerpoint version.

The H=v/d plot is shown aswell on the graph below.

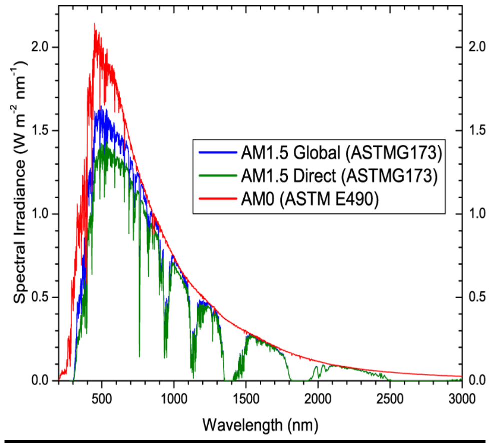


Spectra

Photons of different wavelength or energy are emitted from atoms and molecules when they are excited. These photons can be produced from different processes in objects such as fusion, or accelerated charged particles. They can also be formed by an atom absorbing a photon at one energy and then re-emitting it at another. If certain atoms present absorb a photon of a certain energy then is will produce an absorption line in the spectra. If there are lots of photons emitted at a certain energy or wavelength then this will produce an emission line.

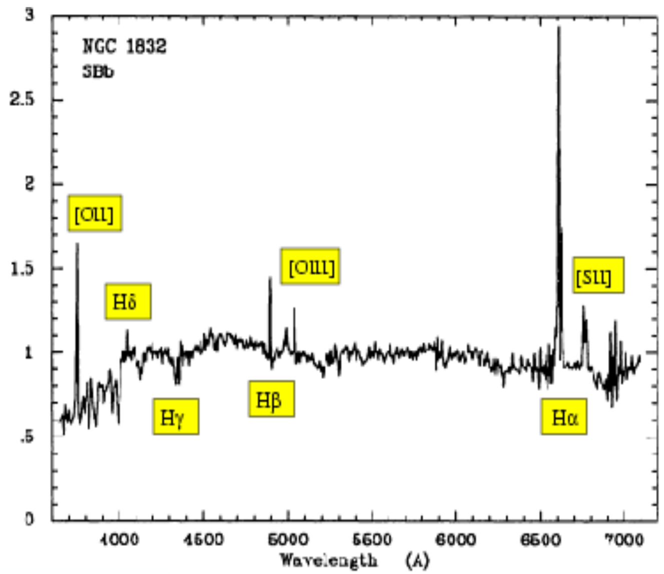


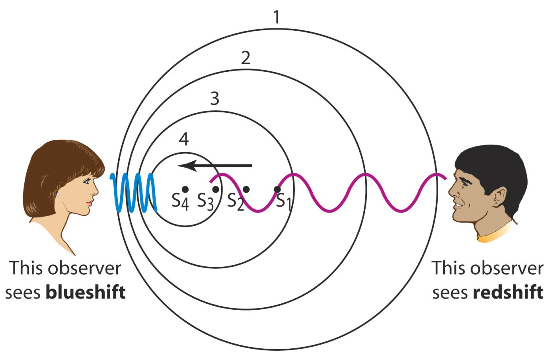
If we know these characteristic lines of emission and absorption then when there is a shift in them to a higher or lower energy or wavelength. Then we know something has happened to it either in the object or as it is travelling.



Doppler Shift

If we have a wave being emitted from a moving object then the wave will be stretched if the object is receding away from us and compressed if it is coming towards us. This can be heard as a train whistle changes pitch as it approaches and then goes away from us. This is a change in pitch or frequency and also a change in wavelength of the sound wave. This similarly occurs with light.





Hubbles discovery had radical implications on the cosmological model. Now instead of a static universe, now their was a universe that was expanding.

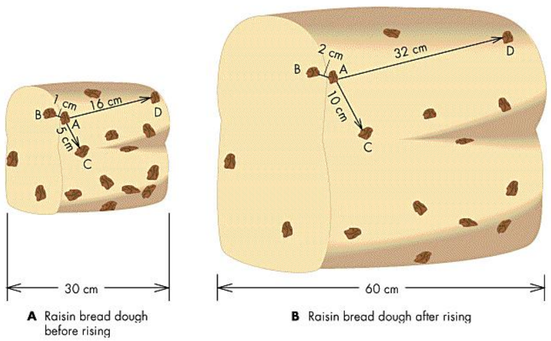
Prior to this in 1917 Einstein provided a model of a static Universe; at this earlier stage island Universe's or galaxies were still a controversial theory. This then changed with the Hubble's discovery of receding galaxies.

The initial reason as to why the spectral lines shifted to the red was initially thought to be due to the Doppler shift just described.

We saw in class that if you assume the Doppler effect then the recession velocities climb beyond the speed of light using classical physics, and if you account for relativistic effects then the speeds are still very close to the speed of light.

A new theory emerged which describes why the wavelengths were shifted. This theory describes how the waves are stretched as they travel through space, and as they travel it is actually the space which is expanding between us and the source.

This can be understood if we took at a loaf of fruit loaf with raisins distributed throughout, as the bread is cooked it rises and inflates increasing the distance between all raisins. The raisins are the galaxies and the dough is the space. The recession of the galaxies were elegantly explained by Einstein's general relativity in which he explains the expansion of space/time itself. Photons when leaving the galaxy for a long time will be stretched on the way.



Thus the expansion of the Universe is an expansion of the geometry and not just a simple recession. Just like the raisin in the bread are not moving away from each other, but the space between has increased.

So as space expands, what is it expanding into? Does it have an edge? If it is expanding now what does it expand from? These were the questions we are asking.

Our Current Model of the Universe

In the solar system we know the 8 planets, 1 star, moons, asteroid belt, Kuiper belt, Oort Cloud. In the milky way, our galaxy where we reside in the arm, is about 100,000 light years across with a possible halo of dark matter around it and a centre a core of massive black holes. On large scales we are part of the local group of galaxies which are gravitationally bound together. We observe million and millions of galaxies. Then on larger scales we see the galaxy chains with large voids between them and clusters of galaxies group into super clusters with filaments.

When we want to model the Universe and understand it, our models have to end up producing all these objects in the Universe. With huge advances in technology and improved models we now have been able to see back 13.37 Gyears into the past. And have made significant leaps in our understanding of the universe its beginning and it's eventual fate. Lets look at the beginning.

The Big Bang

The current best theory of what did the Universe expand from is based on us running the expansion back in time. If it contracts back down it will lead to a big crunch, we don't have the capability or the physics to imagine a time like this.

Our understanding can start just after the beginning where we can imagine a universe that was a hot dense soup of elementary particles and matters

This time < 10^{-4}s

temp >10^{12}Kelvin

At this time photons have enough energy to combine and pair produce protons and antiprotons. When protons and anti-protons collide they annihilate each other and create pure energy of photons.

Two photons must have in order to produce a particle must have an energy large enough to produce enough mass. This is where Einstein famous E=mc2 equation comes into play. E is the energy and m the mass and c the speed of light. A photon has an energy E=hv E the energy, h is the plancks constant and v is the frequency of the photon. Using these two equations we can obtain the Energy required to produce the particles. We went over this in class.

At time = 10^{-4}s
temp =10^{12}Kelvin

•Photon energy drops, they cannot pair produce protons and antiprotons now.
•However protons and antiprotons will still annihilate
•Due to quantum mechanical effects some matter survived.
•So now our Universe is mostly matter with a small amount of antimatter.

At around time 2mins
temp 10^{9} Kelvin
As the gas cools protons and neutrons start to combine to form deuterium 3He, 4He. This occurs by

Then Lithium and berelium
This is called nucleosynthesis
Thus elements with mass 5 and 8 are unstable.

The cosmic abundance is around Hydrogen 75^%, Helium 24-25% and Li and Be small %
All other elements were created in stars.

Straight after nucleosynthesis the Universe was a hot ionized gas of H, He, Li and Be and free electrons and the electrons had not bound to the atoms yet. In a gas of electrons photons interact with the electrons and can't get through the gas. Thus the gas was opaque to photons.

When the Universe was time = 300,000years old
temp =3000Kelvin

the electrons were bound to the atoms and the photons were able to travel freely.

The Universe became transparent. This is called the remnant radiation from the beginning of the Universe.

Over the 13Gyears that the Universe is thought to have existed the photons over that time would

have stretched and would now be observable in the microwave or mm wavelength range.
In 1965 Penzias and Wilson discovered this radiation as noise in their radio telescope.

As technology improved they could observe slight differences in the temperature of the radiation.

These fluctuations are thought to be the seeds of the earliest galaxies.
Where small overdensities regions in the hot plasma would develop when the Universe was 300,000 years old.
These region would attract matter gravitationally

From Time 300000 years-> Now
Temp->3k

Gravity has attracted matter to gas, stars, galaxies,clusters, a super cluster.

Fate of the Universe
As our universe continues to expand. Two major questions arise:
-will it continue to expand?
-will it ever stop and reverse?

There are four different possibilities

i.e which fate is determined by the universe itself, that is how dense it is.

Remember when I have mentioned how mass curves spacetime.

From Time 300000 years-> Now
Temp->3k

Gravity has attracted matter to gas…, stars, galaxies,clusters, a super cluster.

As our universe continues to expand.
There are four different possibilities

-Recollapsing Universe
-Expanding slowly to a halt
-Coasting expansion

-Accelerated expansion

Which fate is determined by the universe itself, that is how dense the Universe is. This is called the:

critical density, ρ_c = $4X10^{-30}$grams cm^{-3} .

This is the tipping point whether the Universe is closed, flat or open, if the critcal density is above, equal or below this value. So what does flat, closed and open Universe mean?

Our Expanding Universe and Space-time

In order to understand how our Universe is expanding we need to understand space-time and what is looks like and how it behaves. In class we looked at examples of how space is shaped, how it curves in the presence of the Earth, the Sun and Blackhole. The presence of a small mass curves space-slightly whilst the presence of a large mass or very dense object bends space-time significantly.

When we think of this we can extrapolate it to large scales and think about the Universe as a whole and how the entire mass of the Universe might be able to curve the entire space-time of the Universe. This curvature can be difficult to visualize in 3 dimensions, so we start with a 2 dimensional example and show how 2 ants might view a universe with different types of curvature.

In order to understand this we must look at the 2d example curvature analogy to the 3D Universe.

If we have an ant on an orange and the ant was a 2 D creature so that he ant could move across the surface and not up or down. So no 3d vertical component.

He/She could wander over the entire surface yet there would be no edge.

If he/she left tracks behind then eventually the ant would figured that it has tramped the entire universe and their was no edge and no center. That is the ant concluded that their Universe was finite and unbounded.

If it lived on a sheet of paper then it would find an edge and would be finite and bounded.

In a 3D case we could have a Universe that is finite in volume but curved in such a way that it is unbounded.

So how can we tell what sort of Universe do we have. There are 3 main choices.

1.Flat called zero curvature
2.Spherical called positive curvature
3.Saddle shaped called negative curvature.

How do we detect this?

In the case of the ant it can determine the curvature by drawing a circle or triangle and measuring the area or angles. The area of the circle or triangle total angle differs depending on the curvature of the space. For example in flat space time the angles of a triangle add up to 180 degrees, for a positive space time they are greater than 180 degrees and less than 270 degrees. For a saddle or hyperbolic space the angle are less than 180 degrees. If the ant could measure this then it could determine the curvature of its Universe.

Hyperbolic curvature is call –ve curvature and extends infinitely
Spherical curvature is called +ve curvature and is finite but with no boundary.
Flat curvature is called zero curvature and is infinite.

If the Universe is closed and positive curvature, then there is enough matter in the Universe to make it closed in on itself, and create a Universe that will expand then halt and recollapse and maybe repeat.

In an open Universe there is less density than the critical density and the Universe is a negative curvature and will keep on expanding .

For a flat Universe the critical density equals the density of the Universe and it will expand and slow nearly to a halt.