Syllabus content

	Recommended teaching hours
Core	**110 hours**
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Topic 1: The stars 32 hours

Essential idea: In considering the properties of stars and the basic processes happening within them, it is obvious that we should be using the Sun (*our* star) as the starting point to our understanding. It is relatively close to us, easily accessible to observation and we are able to situate orbiters to give us a constant stream of information.

1.1 The Sun

Nature of science:

Curiosity: Humans have had a long term fascination with the objects visible in the sky and have developed many ideas to help explain the observations they were able to make. (1.5)

Understandings:	International-mindedness:
• Historical development of the layout of the solar system • Eclipses • Newton's Law of gravitation • Kepler's Laws • Mass-distribution curve for the solar system • Luminosity • Black-body radiation and Wien's Law • Limb darkening • Sunspots • Granulation of Sun's surface • Chromosphere and corona • The interior of the Sun	• The historical development of ideas about the Sun has involved scientists from many different countries, using a common language for the structure of the Sun and the different planets in orbit **Theory of knowledge:** • Knowledge about the Sun has come from remote observations. How can we be certain of the processes taking place inside the Sun without direct measurements **Utilization:** • Physics (gravitation, astrophysics option, nuclear physics) **Aims:** • **Aim 2:** this topic allows for student to develop skills in data processing and analysis • **Aim 7:** modelling using a spreadsheet can be used to explore the motion of objects around a star

1.1 The Sun	
• Nuclear fusion • Proton-proton chain • Gamma radiation travels from the stellar core to the Earth **Applications and skills:** • Solving problems involving planetary orbits including Newton's law of gravitation, gravitational field strength, gravitational potential energy and kinetic energy and speed • Describing the relationship between gravitational force and centripetal force • Applying Newton's law of gravitation to the motion of an object in circular orbit around a point mass • Solving problems involving gravitational force, gravitational field strength, orbital speed and orbital period • Determining the resultant gravitational field strength due to two bodies • Deriving Kepler's 3rd law • Solving problems involving black body radiation • Applying nuclear reactions to the processes taking place in stars • Describing the composition, temperature and energy transport mechanisms of the interior of the Sun • Explaining that for fusion to occur high temperatures are required to overcome the electrostatic repulsion between like charges **Guidance:** • Students should know about planets, asteroids comets, the Kuiper belt and Oort cloud, and that gravity holds it together with the Sun at the centre (due to its huge mass), providing the centripetal force.	

1.1 The Sun	
• Understand that the Sun's output covers a wide range of the electromagnetic spectrum • The Sun's output approximates to a black body output • Sunspots indicate an 11/22 year cycle and that they come in pairs • Know that sunspot activity indicates the differential rotation of the photosphere • The chromosphere and corona may be defined by the temperature profile of the Sun's atmosphere and can be observed using an eclipse method e.g. using a coronagraph • Understand that the atmosphere can be viewed using restricted wavelength images (e.g., $H_{\propto}$ views) • Knowledge of solar features will include plages, filaments, and prominences • Appreciate the role of fusion in supporting the star, defining the size of the stellar core and changing the overall composition of the star • Understand the random walk through the Sun (requiring local thermodynamic equilibrium), the production of 'black-body' output and the relatively fast travel to the Earth through space • Know about the evidence for the solar interior based on neutrino detection and solar oscillations	

Essential idea: Science and in particular physics, has shown that one of the best ways of describing the universe around us is to use mathematics as a language. In order to extend our knowledge of stars beyond the qualitative and into the quantitative, it is crucial that we are able to make actual measurements of the properties of stars. Without such information, our understanding of the birth, life and death of stars and in fact, of the universe itself, would be severely restricted.

1.2 Measuring stars

Nature of science:

Reality: The systematic measurement of distances and brightness of stars and galaxies has led to an understanding of the universe on a scale that is difficult to imagine and comprehend. (1.1)

Understandings:

- Constellations
- Light pollution
- Movement of stars
- Astronomical distances
- Methods of measuring, size, surface temperature, composition and luminosity of stars
- The electromagnetic spectrum
- Stellar spectra
- Stellar parallax and its limitations
- Luminosity and apparent brightness
- Harvard Spectral Classification
- Stefan's law
- Hertzsprung-Russell (HR) diagram

Applications and skills:

- Using the astronomical unit (AU), light year (ly) and parsec (pc)

Theory of knowledge:

- The information revealed through spectra needs to be interpreted by a trained mind. What is the role of interpretation in gaining knowledge in the natural sciences? How does this differ from the role of interpretation in other areas of knowledge?
- Observing the universe using detectors capable of "seeing" gamma rays or radio waves has vastly increased our understanding of the universe. In which ways do advancements in technology allow our understanding to continue to grow?

Utilization:

- Similar parallax techniques can be used to accurately measure distances here on Earth

Aims:

- **Aim 1:** creativity is required to analyse objects that are such vast distances from us
- **Aim 4:** analysis of star spectra provides many opportunities for evaluation and synthesis
- **Aim 6:** local amateur or professional astronomical organizations can be useful for arranging viewing evenings
- **Aim 6:** software-based analysis is available for students to participate in astrophysics research

• Describing the method to determine distance to stars through stellar parallax • Solving problems involving luminosity, apparent brightness and distance • Explaining how surface temperature may be obtained from a star's spectrum • Relate the colour of light to the frequency of the radiation emitted • Describe the different regions of the electromagnetic spectrum • Describing emission and absorption spectra to explain how the chemical composition of a star may be determined from the star's spectrum • Sketching and interpreting HR diagrams • Identifying the main regions of the HR diagram and describing the main properties of stars in these regions **Guidance:** • Students should be able to use a Planisphere (not examinable) • Stars move with a transverse and radial velocity • Understand how to measure the luminosity of a star based on a measurement of flux density • HR diagrams will be used as a way of organising stars and to show their evolution • HR graphs labelling will be limited to luminosity vs temperature or luminosity vs spectral class • Students are expected to have an awareness of the vast changes in distance scale from planetary systems through to super clusters of galaxies and the universe as a whole • Regions of the HR diagram are restricted to the main sequence, white dwarfs, red giants, super giants and the instability strip (variable stars) • The mass-luminosity relation is not required	• **Aim 8:** be aware that light pollution seriously compromises observational astronomy and may often represent a significant waste of energy • **Aim 9:** as we are able to observe further into the universe, we reach the limits of our current technology's capacity to make accurate measurements

Essential idea: One of the primary concerns in astrophysics is how the universe started, how it is developing and how it will end. It is clear that the development of the universe will have a primary influence on how it will end and the way to understand this, and explain where the elements we see around us have come from, we need to study the birth, life and death of stars – this is the key into understanding many of the processes we see occurring in the wider universe.

1.3 The birth, life and death of stars

Nature of science:

Evidence: Our understanding of the processes taking place in stars has come about through the observation of many stars using telescopes and deducing the nature of stars based on this. (1.8)

Understandings:

- Star formation from a nebula
- Jeans criteria
- Star clusters
- Protostars
- T-Tauri phase
- The nature of stars
- Proton-proton chain reactions and the CNO cycle
- Brown dwarfs
- Death of a star
- Electron and neutron degeneracy pressure
- Triple alpha process ($3\propto$) to produce beryllium
- Secondary fusion to produce elements up to iron
- r-process to produce elements heavier than iron
- Stellar evolution on HR diagrams
- Black holes and escape velocity

International-mindedness:

- Due to the increasing costs involved in observing stars and galaxies, using telescopes placed into orbit around the Earth, funding is the result of the collaboration from a number of countries.

Theory of knowledge:

- How certain can we be about our understanding of the life cycle of the Sun, based around observations of distant stars?

Utilization:

- An understanding of how similar stars to our Sun have aged and evolved assists in our predictions of our fate on Earth

Aims:

- **Aim 10:** analysis of nucleosynthesis involves the work of chemists

Applications and skills: • Applying the Jeans criterion to star formation • Sketching and interpreting evolutionary paths of stars on an HR diagram • Describing the evolution of stars off the main sequence • Describing the formation of elements in stars that are heavier than iron including the required increases in temperature • Understanding the instability strip for a protostar and be able to describe how this affects the luminosity • Describing the s and r processes for neutron capture qualitatively **Guidance:** • Limited to main sequence stars • Understand the physics behind the collapse of a gas cloud into a star: - gravitation initiates the collapse - gravitational potential energy reducing - conservation of total energy leading to an increase in kinetic energy - rising kinetic energy relating to a rise in temperature - rising nebula density producing reduced radiation loss from the nebula - greater temperature finally producing a plasma - greater kinetic energy resulting in fusion (against the electrostatic repulsion) • Know how the condensing nebula produces a protostar and how this is seen on the Hertzsprung-Russell diagram (Hayashi tracks) • Understand that main sequence stars are defined by the fusion occurring in the core	

• Appreciate that the rate of fusion in the core strongly depends on the temperature of the core (equations are not needed) • Know that the main sequence lifetime is reduced for larger stars • Understand why there is a lower limit and upper limit for star size: - Lower limit due to a requirement to trigger fusion - Upper limit due to increased stellar wind • Be aware that the larger a star, the shorter the lifetime and the smaller their abundance • The death of stars will be limited to the formation of a white dwarf, neutron star or black hole • Students should know about hydrogen burning and the changes taking place when hydrogen burning stops • Be aware that secondary fusion reactions occur with greater temperatures up to the creation of iron • For this course, objects in the universe include planets, comets, stars (single only), planetary systems, constellations, star clusters, nebulae, galaxies, clusters of galaxies, white dwarf, neutron star, black hole, supernova remnant, red giant, supergiant, pulsar • Appreciate the importance of the solar abundances and the implication that the Sun is not a first generation star. Also appreciate the fact that the elements of life on Earth must also have been created in a previous supernova explosion • Only an elementary application of the Jeans criterion is required, i.e. collapse of an interstellar cloud may begin if $M>M_j$	

Topic 2: The planets 32 hours

Essential idea: If we are to understand our place in the universe, we need to be able to explain where the Earth came from and whether its location is preordained or due to random chance, and how this impacts on the wider question of the possibility of other life existing in the universe.

2.1 The origin of the planets

Nature of science:

Scientific ideas: Many theories have been developed to try to explain where the Earth came from but those which are based more on scientific understanding have a greater credibility. (2.6)

Understandings:

- Theories of the origin of the planets including reference to inferior and superior planets
- Solar nebula model
- Condensation and coagulation
- Significance of the Sun's T-Tauri phase for the composition of the planets
- Origin of the asteroids based on the gravitational influence of Jupiter
- Oort Cloud
- Origin of the Moon
- Planetary differentiation
- Forms of heating within a planet
- Creation of the Earth's magnetic field
- Terrestrial planets (ignoring Mercury) and gas giants
- Details of magnetic field configuration – type and possible origin

Theory of knowledge:

A number of theories exist to explain the origin of the Moon. What causes one theory to become more accepted than others in the scientific community? Is this the same in other areas of knowledge?

Aims:

Aim 4: evaluation of the different theories of the origin of the planets allows for students to understand the scientific method

Aim 9: although the current models help to explain the origin of the planets scientists continue to collect data to improve their understanding

2.1 The origin of the planets	
Applications and skills: • Identifying the main phases of planetary formation • Explaining the different models for the origin of the planets • Describing homogeneous and heterogeneous accretion and their dependence on the planet's growth rate compared with the nebulas cooling rate **Guidance:** • Models for the origin of the planets will be limited to - Nebular theories - Accretion theories - Tidal theories - Turbulence theories • Know that an original theory needs to explain the following: - planetary orbits are close to the plane of the Earth's orbit - planetary orbits are largely circular - all planets rotate in the same sense around the Sun - Only 2% of the solar system's angular momentum is contained in the Sun (Jupiter $\approx$ 65%) • Appreciate how planetary growth was affected by the distance from the Sun • Appreciate the significance of the gravitational and electrical forces in creating the planets • To aid planetary differentiation be aware of the following forms of heating - accretional heating - radiogenic heating - core formation heating - tidal heating	

2.1 The origin of the planets	
• Differentiation requires enough heat and material mobility • In the study of planets students should be aware of - internal structure - differentiated or not - details of satellites - volcanic activity – active or not, and why • Be aware of the evidence that the Earth is a differentiated planet (including magnetism and average density)	

Essential idea: The creation of a habitable planet within which our kind of life can flourish is a prime requirement if the universe is to sustain and allow for the development of carbon-based life. Understanding how this habitable space was created is vital if mankind is to have a future in the long term, a future that may require us to explore and colonise other planets. This knowledge will also be important in allowing us to survive and evolve on the Earth without degrading the biosphere to a point where life is not viable.

2.2 Life on Earth

Nature of science:

Public understanding: There is a great deal of conflicting information on climate change available and the public doesn't always understand the science involved and scientists had a key role in ensuring this information is shared in a way which can be easily accessible. (5.1)

Understandings:

- Original atmosphere of terrestrial planets
- Development of atmospheres of Venus, Earth and Mars
- Solar radiation and planetary weather
- Greenhouse effect and CFCs
- Upper and lower temperatures for life
- Effect of asteroids and asteroid impact on the production of life on Earth
- Evidence of impactors

Applications and skills:

- Knowing that the T-Tauri phase removed the original planet's atmosphere
- Understanding how the effects of global warming could compromise life on Earth
- Analysing data related to the greenhouse effect

Guidance:

- Appreciate the differences that have produced Earth's life-supporting atmosphere

International-mindedness:

- International organisations such as the IPCC have a great deal of responsibility in shaping governmental policies on an international scale to limit and reduce the effects of global warming

Theory of knowledge:

- Scientific understanding suggests that life on Earth began around 3.8 billion years ago. How does this fit with other ways of thinking?

Utilization:

- Biology, Chemistry, Environmental systems and societies

Aims:

- **Aim 4:** there exists a great deal of information on the greenhouse gases and their effect on life on Earth with can be critically evaluated
- **Aim 7:** databases should be accessed in order to analyse data on climate change
- **Aim 8:** there is scope for studying the environmental implications of scientific advancement

• Know the importance of the 'escape velocity' for a planet in discussing which gases can be held in the atmosphere and which cannot • Be aware of the general effect of solar radiation on a planet's weather including generation of Hadley cells within the atmospheric structure, comparing Venus, Earth and Jupiter • Students should be aware that lower temperatures do not provide enough energy for biochemical reactions, and that higher temperatures result in the denaturing of proteins • Students should be aware of the evidence for impactors on the Earth (Meteor Crater, Tunguska, various parts of Africa) and on the surface of the Moon • Be aware that it is thought that life on Earth has been compromised a number of times in the past (e.g. Permian mass extinction, Cretaceous-Tertiary mass extinction)	

Essential idea: It is an important question to ask *Are we alone in the universe?* The answer to this question touches upon so many different aspects of life, from the scientific probability for the creation of life in the universe to non-scientific questions about the *point* of life and the concept of a *god*. The implications for society of the answer to this question cannot be understated.

<table>
<tr><td colspan="2">2.3 The search for extra-terrestrial life</td></tr>
<tr><td colspan="2">Nature of science:
Economic: Is there a justification for spending vast amounts of money on looking for extra-terrestrial life when funds could be used instead to develop projects that are likely to have a more immediate, positive, impact on life on Earth? (4.7)</td></tr>
<tr><td>Understandings:
• Fermi paradox
• The search for extra-terrestrial life
• The Drake equation for the probability of life
Applications and skills:
• Calculations involving the Drake equation
Guidance:
• Be aware of at least two initiatives carried out since the late 1950s to further the search for extra-terrestrial life. Examples include ‘Suitcase SETI’, ‘Project Sentinel’, ‘Project META’, ‘The internet SETI project’, ‘Project Phoenix’
• Be aware of the significance of radio astronomy in the search for life and in particular, radio frequencies between 18 and 21 cm
• Be aware of how the discovery of the Pulsar was thought to have been a possible signal from extra-terrestrials
• Know the details of at least one probe within the solar system which was designed to look for life (e.g. Pathfinder mission, Mars explorer, Spirit and Odyssey)</td><td>International-mindedness:
• As in many areas of science, international funding is required in the search for extra-terrestrial life
Theory of knowledge:
• Our knowledge of living things is based entirely on what can be observed on Earth. Is it possible to imagine other forms of life which may exist outside of our planet?
Aims:
• Aim 8: students should be able to discuss economic implications resulting from the search for extra-terrestrial life</td></tr>
</table>

• Know and understand that the major candidates for life within the solar system outside Earth are presently thought to be Mars and Europa • $N = R_* . f_p . n_e . f_l . f_i . f_c . L$	

Topic 3: Galaxies 26 hours

Essential idea: Galaxies are the units that form the large scale structure of the visible universe and as such, are important areas of study. The Milky Way is *our* galaxy and as we are part of it, provides an ideal example from which to identify the structure and discuss the properties of such structures.

3.1 The Milky Way

Nature of science:

Forming a hypothesis: Although dark matter cannot be directly observed it can be inferred due to gravitational effects on the Milky Way. (2.5)

Understandings:

- Structure and constituents of the Milky Way
- Electromagnetic radiation
- Neutrinos
- Rotation curve for the Milky Way and the evidence for dark matter
- Mass distribution curve
- Dark matter
- Spiral arms
- Winding dilemma

Applications and skills:

- Describing rotation curves as evidence for dark matter
- Interpreting rotation and mass distribution curves

Guidance:

- Know where the Sun lies in the Milky Way

Theory of knowledge:

- Observations of the rotation of the Milky Way lead to the inference of dark matter. How valid a way of knowing is this?

Utilization:

- Physics: waves (physics sub-topic 7.2) nuclear physics (Topic 7)

3.1 The Milky Way	
• The Sun's oscillations may produce a disturbance of the Oort cloud which may then produce comet motion through the solar system • Know that it is thought that there is a supermassive black hole at the centre of each galaxy that is surrounded by a ring of molecular clouds • Students should know about the basic size and structure of the Milky Way including the disc, halo and nuclear bulge. In addition, the constituents are: - stars (population I and II stars, metallicity, age, and orbits) - gas (75% hydrogen and 25% helium, the form depends on temperature, around $10^{10}\mathrm{M}_{\odot}$) - dust ($0.1 - 1\mu\mathrm{m}$ particles, around $10^{8}\ \mathrm{M}_{\odot}$, restricts our ability to make optical measurements in the disc) - cosmic rays (85% protons, 12% helium, 2% electrons and 1% heavy nuclei) - magnetic field mainly aligned with the disc - electromagnetic radiation - neutrinos • Mass distribution and rotation curves beyond those for the Milky Way, will only be used for galaxies with a central mass and a uniform density • The spiral arms are centres of light output not stellar density	

Essential idea: It is crucial to be able to measure the properties of the different types of galaxy so that we are able to thereby discuss the properties of the universe itself, including its evolution through time. Such studies have also concluded that the vast majority of the universe is hidden to us and not visible as normal matter but rather, has a form referred to as *dark*.

<table>
<tr><td colspan="2">3.2 Measuring galaxies</td></tr>
<tr><td colspan="2">Nature of science:
Classification: Using the vast amount of data collected through observing galaxies, scientists have been classifying types of galaxies based on observed features. (3.1)</td></tr>
<tr><td>Understandings:
• The Hubble classification for naming galaxies
• Features of elliptical, lenticular and spiral galaxies
• Irregular galaxies
• Formation of galaxies as a result of density fluctuations in expanding gas produced by the Big Bang
• Cosmic distance ladder
-Trigonometric parallax
-Cepheid variables: period-luminosity relationship
-Type Ia Supernovae: maximum luminosity is a constant

Applications and skills:
• Describing the reason for the variation in the luminosity of Cepheid variables
• Determining the distance of galaxies using data on Cepheid variables
Guidance:
• Ellipticals
- Elliptical outline
- Featureless appearance
- Flattening factor</td><td>Theory of knowledge:
• Large parts of scientific understanding have been based around understanding the properties of matter. How did the postulate of the presence of dark matter in the 1960s change our understanding of matter?
Aims:
• Aim 3: classification is a highly effective scientific technique in the analysis of vast amounts of data</td></tr>
</table>

3.2 Measuring galaxies	
• Lenticulars - Lens shaped - Disc and bulge but no spiral arms - May be barred • Spirals - Disc, bulge and spiral arms - May be barred • Flattening factor, *f*, (with the degree of ellipticity of the galaxies given by $10 \times f$)	

Essential idea: Active galaxies provide evidence for the ongoing development and evolution of a galaxy and in turn, allow us to investigate the way the mechanisms which occur within a galaxy affect its properties.

<table>
<tr><td colspan="2">3.3 Active galaxies</td></tr>
<tr><td colspan="2">Nature of science:
Observing: Technology has allowed for the collection of large amounts of data on galaxies which has enabled scientists to classify them according to specific properties (1.8)</td></tr>
<tr><td>Understandings:
• Spectral peculiarity
• Active Galactic Nucleus (AGN)
• Starburst galaxies
• Quasars
• Radio galaxies
Applications and skills:
• Explaining the power sources for different types of active galaxies
• Describing the methods used to observe different types of galaxies
Guidance:
• AGN has at least four times the luminosity of the rest of the galaxy
• Be aware of the typical schematic of an AGN with a surrounding dust cloud, producing two radio lobes</td><td>Theory of knowledge:
How do you know that what we observe is real? Will we ever be able to travel so far?
Aims:
Aim 6: Databases and web-based images can be used to analysis information on different types of active galaxies</td></tr>
</table>

Topic 4: Cosmology 20 hours

Essential idea: The modern field of cosmology uses advanced experimental and observational techniques to collect data with an unprecedented degree of precision and as a result very surprising and detailed conclusions about the structure of the universe have been reached.

4.1 The birth, life and death of the universe

Nature of science:

Occam's Razor: The Big Bang model was purely speculative until it was confirmed by the discovery of the cosmic microwave background radiation. The model, while correctly describing many aspects of the universe as we observe it today, still cannot explain what happened at time zero. (2.7)

Understandings:

- The Big Bang model
- Cosmic microwave background (CMB) radiation
- Cosmological redshift
- Hubble's law
- Hubble's constant and the age of the universe
- The cosmological principle
- Olbers' paradox

Applications and skills:

- Describing both space and time as originating with the Big Bang
- Explaining how redshift data indicates the universe is expanding and how this leads to the idea of the Big Bang
- Describing the characteristics of the CMB radiation
- Explaining how the CMB radiation is evidence for a Hot Big Bang

International-mindedness:

There have been a variety of ideas and models for the origin of the universe and still many questions unanswered. It is clearly a question that cosmologists are vitally interested in across the globe and touches on non-scientific questions such as the existence of a god. The comments and research are hugely international since the thirst for answers touches virtually every human being.

Theory of knowledge:

Experimental data seems to show that the expansion of the universe is accelerating yet no one understands why. Will the experiments carried out on Earth (e.g. at CERN) ever completely explain all the questions?

Utilization:

- Physics, mathematics

Aims:

- **Aim 2:** unlike how it was just a few decades ago, the field of cosmology has now developed so much that cosmology has become a very exact science on the same level as the rest of physics

4.1 The birth, life and death of the universe	
• Solving problems involving Hubble’s law • Estimating the age of the universe by assuming a constant expansion rate **Guidance:** • Be aware of the elements considered to have been created in the Big Bang (H to Li) • Be aware of how the elemental abundance is changing over time through the birth, life and death of stars and the importance of these heavier elements to the creation of life	• **Aim 10:** it is quite extraordinary that to settle the issue of the fate of the universe, cosmology, the physics of the very large, required the help of particle physics, the physics of the very small

Essential idea: Galaxies are formed within the universe and seem to be randomly generated, forming large scale structures which are observable.

<table>
<tr><td colspan="2">4.2 Large scale structures in the universe</td></tr>
<tr><td colspan="2">Nature of science:
Observation: As the amount of data increases as a result of more detailed observations our understanding of the universe also increases. (1.8)</td></tr>
<tr><td>Understandings:
• Galactic distribution
• Galactic clusters
• Local groups
• Superclusters
• Walls of galaxies, including the Great Wall
• The galactic arrangement in the universe

Applications and skills:
Explaining the distribution of galaxies within the universe to include rich and poor clusters
Guidance:</td><td>International-mindedness:
As the discussion about the structure of the universe moves to larger and larger scales, the experiments that are needed in order to obtain more and more information become more expensive. As such, beyond the research teams themselves being international, there is a need for more countries to invest in the research to cover the cost–hence the large financial support from across the globe.
Theory of knowledge:
It is important to always question the basis upon which our ideas are founded. The large scale distances within the universe are based upon the galactic ladder of measurements and any flaw in any of them, would disrupt the stability of the knowledge base – as such, it is vitally important to always question our understanding and never try to obscure the problems that exists.</td></tr>
</table>

Essential idea: The density of the universe determines the geometry of spacetime which in turn, determines the eventual fate of the universe.

4.3 The shape of spacetime

Nature of science:

Paradigm shift**:** Over time there have been a number of different theories of gravitation and some of these have led to a major change in our understanding of the world around us. (2.3)

Understandings:

- The ancient Greeks
- Galileo Galilei and falling objects
- Isaac Newton and the universal law of gravitation
- Albert Einstein and General Relativity
- The effect of gravity is equivalent to the acceleration of an object
- Relativistic ideas about time and space can be reconciled by describing these things together as four-dimensional *spacetime*
- Geometries for spacetime
- Know that the Big Bang theory of cosmology raises questions
- Inflation

Applications and skills:

- Understanding the development of ideas of gravitational forces
- Understanding the consequences of the possible geometries of spacetime

Guidance:

- Students should be aware of the properties of different possible geometries for spacetime

International-mindedness:

Over time our understanding of the universe around us has changed, moving from the varying ideas of a relatively small number of societies (e.g., the ancient Greeks, the ancient Egyptians, etc) to the development of a more *invested* set of ideas, fundamentally based on the fact that the transfer of knowledge around the world became easier. This has led to the global nature of this area of human endeavour.

Theory of knowledge:

This area of astrophysics has wonderful examples where our understanding has been somewhat limited because of preconceived ideas whch have been forced upon the scientific community by other vested interested (largely based around religion). The movement from a geocentric model of the solar system to a heliocentric one was a huge move forward and a great example for TOK. Further, the empirical understanding that Kepler had was put on a more-theoretical basis by Newton's theory of Gravitation.

4.3 The shape of spacetime	
- Flat (flat plane) o Straight lines extend to infinity o Parallel straight lines do not intersect o Internal angles of a triangle add up to 180° o Circumference of a circle = $2\pi r$ - Spherical (sphere) o Straight lines come back to the same point. o Parallel straight lines do intersect (e.g. at the poles) o Internal angles of a triangle > 180° o Circumference of a circle < $2\pi r$ - Hyperbolic (saddle shaped) o Straight lines continue to infinity o Parallel lines diverge o Internal angles of a triangle < 180° o Circumference of a circle > $2\pi r$	