Core topics 15 hours

Essential idea: One of the most difficult problems in astronomy is coming to terms with the vast distances between stars and galaxies and devising accurate methods for measuring them.

D.1 – Stellar quantities

Nature of science:

Reality: The systematic measurement of distance 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:

- Objects in the universe
- The nature of stars
- Astronomical distances
- Stellar parallax and its limitations
- Luminosity and apparent brightness

Applications and skills:

- Identifying objects in the universe
- Qualitatively describing the equilibrium between pressure and gravitation in stars
- Using the astronomical unit (AU), light year (ly) and parsec (pc)
- Describing the method to determine distance to stars through stellar parallax
- Solving problems involving luminosity, apparent brightness and distance

Theory of knowledge:

- The vast distances between stars and galaxies are difficult to comprehend or imagine. Are other ways of knowing more useful than imagination for gaining knowledge in astronomy?

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 6:** local amateur or professional astronomical organizations can be useful for arranging viewing evenings
- **Aim 9:** as we are able to observe further into the universe, we reach the limits of our current technology to make accurate measurements

D.1 – Stellar quantities	
Guidance: • For this course, objects in the universe include planets, comets, stars (single and binary), planetary systems, constellations, stellar clusters (open and globular), nebulae, galaxies, clusters of galaxies and super clusters of galaxies • 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 **Data booklet reference:** • $d\,(\text{parsec}) = \dfrac{1}{p\,(\text{arc–second})}$ • $L = \sigma A T^4$ • $b = \dfrac{L}{4\pi d^2}$	

Essential idea: A simple diagram that plots the luminosity versus the surface temperature of stars reveals unusually detailed patterns that help understand the inner workings of stars. Stars follow well-defined patterns from the moment they are created out of collapsing interstellar gas, to their lives on the main sequence and to their eventual death.

D.2 – Stellar characteristics and stellar evolution

Nature of science:

Evidence: The simple light spectra of a gas on Earth can be compared to the light spectra of distant stars. This has allowed us to determine the velocity, composition and structure of stars and confirmed hypotheses about the expansion of the universe. (1.11)

Understandings:

- Stellar spectra
- Hertzsprung–Russell (HR) diagram
- Mass–luminosity relation for main sequence stars
- Cepheid variables
- Stellar evolution on HR diagrams
- Red giants, white dwarfs, neutron stars and black holes
- Chandrasekhar and Oppenheimer–Volkoff limits

Applications and skills:

- Explaining how surface temperature may be obtained from a star's spectrum
- Explaining 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
- Applying the mass–luminosity relation
- Describing the reason for the variation of Cepheid variables
- Determining distance using data on Cepheid variables
- Sketching and interpreting evolutionary paths of stars on an HR diagram
- Describing the evolution of stars off the main sequence
- Describing the role of mass in stellar evolution

Theory of knowledge:

- The information revealed through spectra needs a trained mind to be interpreted. 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?

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 4:** analysis of star spectra provides many opportunities for evaluation and synthesis
- **Aim 6:** software-based analysis is available for students to participate in astrophysics research

D.2 – Stellar characteristics and stellar evolution	
Guidance: • Regions of the HR diagram are restricted to the main sequence, white dwarfs, red giants, super giants and the instability strip (variable stars), as well as lines of constant radius • HR diagrams will be labelled with luminosity on the vertical axis and temperature on the horizontal axis • Only one specific exponent (3.5) will be used in the mass–luminosity relation • References to electron and neutron degeneracy pressures need to be made **Data booklet reference:** • $\lambda_{max}T = 2.9 \times 10^{-3}$ m K • $L \propto M^{3.5}$	

Essential idea: The Hot Big Bang model is a theory that describes the origin and expansion of the universe and is supported by extensive experimental evidence.

D.3 – Cosmology

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
- Hubble's law
- The accelerating universe and redshift (*z*)
- The cosmic scale factor (*R*)

Applications and skills:

- Describing both space and time as originating with the Big Bang
- Describing the characteristics of the CMB radiation
- Explaining how the CMB radiation is evidence for a Hot Big Bang
- Solving problems involving *z*, *R* and Hubble's law
- Estimating the age of the universe by assuming a constant expansion rate

International-mindedness:

- Contributions from scientists from many nations made the analysis of the cosmic microwave background radiation possible

Utilization:

- Doppler effect (see *Physics* sub-topic *9.5*)

Aims:

- **Aim 1:** scientific explanation of black holes requires a heightened level of creativity
- **Aim 9:** our limit of understanding is guided by our ability to observe within our universe

D.3 – Cosmology	
Guidance: • CMB radiation will be considered to be isotropic with $T \approx 2.76\text{K}$ • For CMB radiation a simple explanation in terms of the universe cooling down or distances (and hence wavelengths) being stretched out is all that is required • A qualitative description of the role of type Ia supernovae as providing evidence for an accelerating universe is required **Data booklet reference:** • $z = \frac{\Delta\lambda}{\lambda_0} \approx \frac{v}{c}$ • $z = \frac{R}{R_0} - 1$ • $v = H_0 d$ • $T \approx \frac{1}{H_0}$	

Additional higher level option topics

10 hours

Essential idea: The laws of nuclear physics applied to nuclear fusion processes inside stars determine the production of all elements up to iron.

D.4 – Stellar processes	
Nature of science: Observation and deduction: Observations of stellar spectra showed the existence of different elements in stars. Deductions from nuclear fusion theory were able to explain this. (1.8)	
Understandings: • The Jeans criterion • Nuclear fusion • Nucleosynthesis off the main sequence • Type Ia and II supernovae **Applications and skills:** • Applying the Jeans criterion to star formation • Describing the different types of nuclear fusion reactions taking place off the main sequence • Applying the mass–luminosity relation to compare lifetimes on the main sequence relative to that of our Sun • Describing the formation of elements in stars that are heavier than iron including the required increases in temperature • Qualitatively describe the s and r processes for neutron capture • Distinguishing between type Ia and II supernovae	**Aims:** • **Aim 10:** analysis of nucleosynthesis involves the work of chemists

D.4 – Stellar processes	
Guidance: • Only an elementary application of the Jeans criterion is required, ie collapse of an interstellar cloud may begin if $M > M_j$ • Students should be aware of the use of type Ia supernovae as standard candles	

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.

D.5 – Further cosmology

Nature of science:

Cognitive bias: According to everybody's expectations the rate of expansion of the universe should be slowing down because of gravity. The detailed results from the 1998 (and subsequent) observations on distant supernovae showed that the opposite was in fact true. The accelerated expansion of the universe, whereas experimentally verified, is still an unexplained phenomenon. (3.5)

Understandings:

- The cosmological principle
- Rotation curves and the mass of galaxies
- Dark matter
- Fluctuations in the CMB
- The cosmological origin of redshift
- Critical density
- Dark energy

Applications and skills:

- Describing the cosmological principle and its role in models of the universe
- Describing rotation curves as evidence for dark matter
- Deriving rotational velocity from Newtonian gravitation
- Describing and interpreting the observed anisotropies in the CMB
- Deriving critical density from Newtonian gravitation
- Sketching and interpreting graphs showing the variation of the cosmic scale factor with time
- Describing qualitatively the cosmic scale factor in models with and without dark energy

International-mindedness:

- This is a highly collaborative field of research involving scientists from all over the world

Theory of knowledge:

- Experimental facts show that the expansion of the universe is accelerating yet no one understands why. Is this an example of something that we will never know?

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
- **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

D.5 – Further cosmology	
Guidance: • Students are expected to be able to refer to rotation curves as evidence for dark matter and must be aware of types of candidates for dark matter • Students must be familiar with the main results of COBE, WMAP and the Planck space observatory • Students are expected to demonstrate that the temperature of the universe varies with the cosmic scale factor as $T \propto \frac{1}{R}$ **Data booklet reference:** • $v = \sqrt{\frac{4\pi G\rho}{3}}r$ • $\rho_c = \frac{3H^2}{8\pi G}$	