Q1.

The Earth is in the galaxy known as the Milky Way. The Andromeda Galaxy is one of the closest galaxies to the Milky Way.

(a) The Andromeda Galaxy approaches the Milky Way at a speed of 110 km s^{-1}.
The distance between the galaxies is 770 kpc.

Discuss whether these data can be used to estimate an age for the Universe.

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(2)

(b) There is a supermassive black hole at the centre of the Andromeda Galaxy. The mass of this black hole is 1.60 × 10⁸ solar masses.

Calculate the radius of the event horizon of this black hole.
State an appropriate unit for your answer.

radius = _____

unit = _____

(3)

(c)   Scientists predict that a quasar will be produced as the Milky Way and the Andromeda Galaxy merge.

Explain what is meant by a quasar.
Go on to suggest why a quasar may be produced as galaxies merge.

In your answer you should:

- describe the typical properties of a quasar
- explain how observations of quasars provide evidence for these properties
- suggest the process of quasar formation that is likely when two galaxies merge.

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(6)
(Total 11 marks)

Q2.

(a) State the defining property of a black hole.

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(1)

(b) In 2019, astronomers linked several radio telescopes to produce a single telescope called the EHT. The resolution of the EHT is the same as the resolution that a telescope with an aperture equal to the diameter of the Earth could achieve.

The table below shows data about the EHT and the Hubble telescope.

	Aperture	Operating wavelength
EHT	1.3×10^7 m	1.3 mm
Hubble	2.4 m	410 nm

Galaxy M87 is 5.3×10^7 light years from Earth. The supermassive black hole at the centre of M87 has a mass 6.5×10^9 times the mass of the Sun.

The radius of the event horizon is R.

The astronomers propose to use either the EHT or the Hubble telescope to observe stars whose distance from the centre of the black hole is less than $1000R$.

Discuss, with calculations, which telescope is more suitable for this observation.

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(4)

(c) A star is orbiting the black hole in M87. The star is observed in the plane of its orbit. The wavelength of a spectral line observed in the light emitted from the star varies between a maximum and a minimum value.

maximum value observed = 374.96 nm
minimum value observed = 373.53 nm

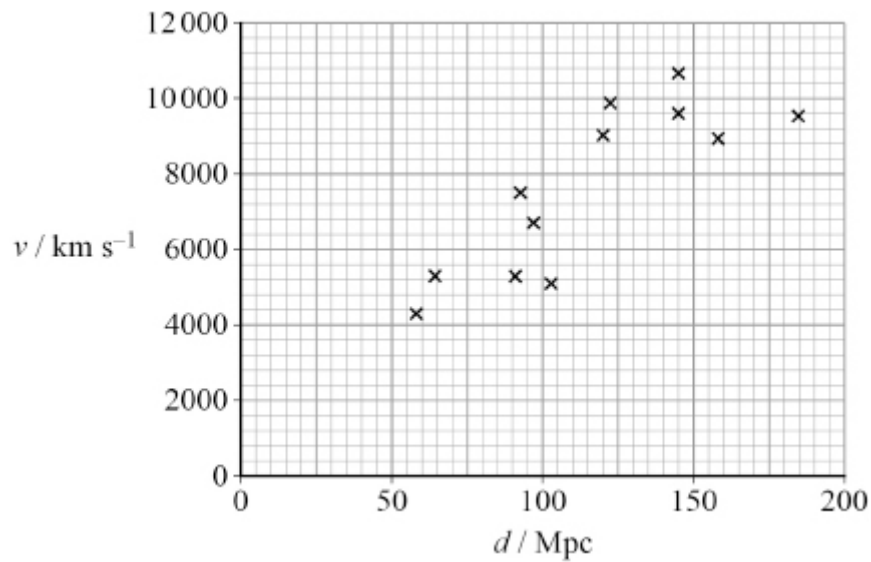Calculate the orbital speed of the star.

orbital speed = _____ m s^{-1}

(3)
(Total 8 marks)

Q3.

The graph below shows, for some galaxies, how their recession speed v varies with distance d from the Earth.

(a)   Estimate, using the graph above, the age in seconds of the Universe.

age of Universe = _____ s

(3)

(b)   The estimate in part (a) assumes that the Universe has expanded at a
       constant rate. Measurements involving type 1a supernovae that are at
       large distances from Earth caused astronomers to make a modification to
       this assumption.

       State:

       •   the modification
       •   the explanation that was proposed to account for this modification.

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Q4.

3C 273 was the first quasar to be discovered.

IC 1101 is one of the largest galaxies known.

The table below shows some information about these objects.

	Absolute magnitude	Apparent magnitude	Distance / Mpc
quasar 3C 273	**X**	12.8	760
galaxy IC 1101	−22.8	14.7	320

(a)   State the property of the quasar that led to its discovery.

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(1)

(b)   Show that the absolute magnitude **X** of quasar 3C 273 is about −27

(2)

(c)   Assume that the quasar and the galaxy are both viewed from the same distance.

Explain which would be the brighter object.

Go on to calculate the ratio $\dfrac{\text{brightness of brighter object}}{\text{brightness of dimmer object}}$.

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ratio = _____

(3)

(d)   The black hole at the centre of IC 1101 has a mass of $7.1 \times 10^{11}\, M_{\text{s}}$
       where M_{s} is the mass of the Sun.

   Calculate the average density within the event horizon of the black hole.

average density = _____ kg m^{-3}

(3)
(Total 9 marks)

Q5.

In the middle of the 20th century, there were two competing theories of the Universe.
In 1964, electromagnetic radiation was observed coming from all directions in space.
The diagram below shows the distribution of this radiation as observed from Earth.
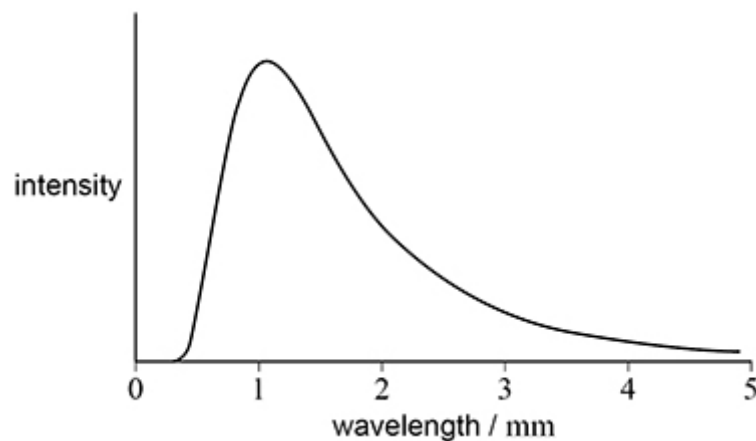
The graph provides evidence for one of these theories of the Universe.

Discuss the main features of this theory of the Universe.

In your answer, you should include:
• the main predictions and evidence for the theory, and
• a suitable calculation.

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(Total 6 marks)