Honour School of Mathematical and Theoretical Physics Part C
Master of Science in Mathematical and Theoretical Physics

HIGH ENERGY ASTROPHYSICS
TAKE-HOME EXAM

TRINITY TERM 2016

MONDAY, 20 JUNE 2016, 12noon to WEDNESDAY, 22 JUNE 2016, 12noon

You should submit answers to ***all*** *questions. Answer booklets are provided for you to use but you may type your answers if you wish. Typed answers should be printed single-sided and the pages securely fastened together.*

You may refer to books and other sources when completing the exam but should not discuss the exam with anyone else.

The numbers in the margin indicate the weight that the Examiners expect to assign to each part of the question.

Section A

1. Describe how the cross-section for inverse-Compton scattering changes as the collision, seen in the electron's rest frame, changes from a Thomson scattering process to a Compton scattering process. For an electron with Lorentz factor $\gamma = 10^4$, what is the photon energy at which the transition occurs? [10]

2. The disc of the Milky way can be modelled as a cylinder of radius 10 kpc and height 0.5 kpc, with a uniform magnetic field of 10^{-10} Tesla. What is the minimum energy for which the radius of curvature of a cosmic ray proton will equal the disc height?

   By integrating the energy spectrum of cosmic rays observed on Earth, we deduce that the energy density in cosmic rays in the Milky Way disc is about $1 \times 10^{-13}\,\mathrm{J\,m^{-3}}$. Suppose that all these cosmic rays originate in supernova explosions, and that in a typical supernova explosion 10% of the energy released is deposited in cosmic rays. What must be the rate at which supernovae occur in the disc in order to maintain the population of cosmic rays? You may take the typical cosmic ray lifetime to be 10^7 years. [10]

3. Calculate the threshold energy above which a high-energy gamma ray may scatter against a photon of the extragalactic background light to produce an electron-positron pair (take the wavelength of the background photons to be one micron). Estimate the energy density in the extragalactic background light, stating your assumptions clearly, and hence estimate the mean free path in intergalactic space for gamma rays above the threshold energy. [10]

4. A gamma-ray of energy 1 TeV enters the Earth's atmosphere and creates an electron-positron particle cascade. Estimate the duration of the burst of Cherenkov light that results. Calculate the intensity of the Cherenkov light produced, and compare this to the intensity of the brightest stars. You may assume that the majority of the initial photon energy is ultimately radiated as Cherenkov light, and that the particle cascade starts at an altitude of 20 km and terminates at an altitude of 10 km. [10]

[TURN OVER]

Section B

5. Choose *two* of the following topics and write an essay, of about 2000 words, on each.

   - The formation of the highest-energy cosmic rays.
   - Comptonization of the Cosmic Microwave Background by galaxy clusters and by the intergalactic medium.
   - Observations of very-high-energy gamma rays from astrophysical sources.

[30 marks for each essay]

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