Queen Mary & Westfield College

UNIVERSITY OF LONDON

MSci EXAMINATION

PHY-915 (MSci 4608) Advanced Topics in Astrophysics

Friday, 26 May, 2000 10.00 –12.30

Time allowed 2 hours and 30 minutes.

Answer 3 questions:
At least ONE **from Section A and**
At least ONE **from Section B and**
Any other ONE **from any of Sections A,B,C.**

Each question carries 30 marks.
The mark ***provisionally allocated*** **to each section is indicated in the right margin.**

You may wish to use the following formulae in any question.

The Planck function

$$B_\nu = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT} - 1}.$$

SECTION A. ANSWER AT LEAST ONE QUESTION FROM THIS SECTION

1. (a) A pulsar needs to accrete ~ 0.1 M$_\odot$ in order to spin up to millisecond periods. Why do we think millisecond pulsars are spun-up in a low mass X-ray binary (LMXB) rather than a high mass X-ray binary (HMXB). [8]

   (b) In a LMXB, stable mass-transfer may be dependent upon angular momentum being removed from the system. For a main sequence companion in a close binary orbit, the loss of angular momentum can be due to magnetic braking. Describe the magnetic braking process. [8]

   (c) A neutron star is in a circular orbit with a low mass companion star. The mass-transfer is stable and the total mass is conserved. The change in angular momentum J_B is given by

$$\frac{\dot{J}_B}{J_B} = \frac{\dot{a}}{2a} + \left(1 - \frac{M_2}{M_1}\right)\frac{\dot{M}_2}{M_2},$$

   where a is the orbital separation, M_2 is the mass of the donor star, M_1 is the mass of the neutron star and a dot denotes differentiation with respect to time. The radius R_{L2} of the Roche lobe is

$$R_{L2} = 0.46a\left(\frac{M_2}{M_1 + M_2}\right)^{\frac{1}{3}}$$

   and the generic mass-radius relation $R \propto M^n$ applies.
   Show that

$$\frac{\dot{R}_{L2}}{R_{L2}} = n\frac{\dot{M}_2}{M_2}$$

   Use this result to eliminate a from the equation for $\frac{\dot{J}_B}{J_B}$ to show that loss of angular momentum can drive stable mass-transfer at a rate $\dot{M}_2$ given by

$$\frac{\dot{M}_2}{M_2} \sim \frac{\dot{J}_B}{J_B},$$

   provided that

$$M_2 \sim \left(\frac{n}{2} - \frac{1}{6}\right)M_1.$$

   [8]

   (d) Briefly describe two scenarios the can produce an isolated millisecond pulsar with planets in a globular cluster. [6]

2. (a) Describe the structure of a neutron star. Include a description of a soft and a stiff equation of state and discuss how they effect the physical properties of the neutron star. [14]

   (b) Young pulsars such as the Crab and Vela regularly experience discrete changes in their pulse periods resulting in a shorter pulse period. Describe the vortex-pinning glitch model and the starquake glitch model [14]
   Which is the preferred model for explaining glitches in the Vela pulsar and why? [2]

SECTION B. ANSWER AT LEAST ONE QUESTION FROM THIS SECTION

3. Define the absorption efficiency Q_{abs} of a dust grain, and state how it is related to the emission efficiency Q_{em}. [2]

   Dust grains of radius a may be assumed to have an absorption efficiency Q_{abs} which varies with frequency ν as $Q_{abs}/a = k_0\nu^n$ over the frequency range where the emission from the grains is significant, where k_0 and n are constants. It can be shown that the equilibrium temperature T of such grains in an optically thin spherical circumstellar dust shell varies with relative radius $r = R/R_0$ as $T = T_0 r^{-p}$ (where $p = 2/(4+n)$, R is radius and R_0 is some reference radius at which $T = T_0$). Consider an optically thin shell of material within which the grain number-density n_g varies as $n_{g0}r^{-q}$ between relative radii r_{min} and r_{max}, where n_{g0} is the number density of grains at R_0, and q is a constant. Show that, over a certain frequency range, the emitted flux density from such a shell will vary with frequency as

   $$S_\nu = z\,\nu^\alpha, \text{ where } \alpha = 3 + n + \frac{q-3}{p}$$

   and where an expression for z should be found. (You are not expected to evaluate any dimensionless integrals in your expression for z). [15]

   Sketch $\log S_\nu$ versus $\log\nu$. Indicate which features depend on the values of T at r_{min} and r_{max} and explain the reasons for the various features of the spectrum. [5]

   For typical values of $n = 1$ and $q = 3/2$, find whether the power-law exponent α of such a spectrum is more sensitive to small uncertainties in the value of n or to those in q. [4]

   Without deriving any further equations, explain why the observation of a power-law spectrum from dust around a star is not necessarily evidence that the emission is from an optically thin shell of material. Consider particularly the example of T Tauri stars. [4]

4. (a) Outline the general approach by which the scattering of electromagnetic radiation by particles is treated, defining the amplitude scattering matrix S and explaining how its form simplifies for spherical particles. Under what conditions is the assumption of Rayleigh scattering appropriate? [9]

   (b) Outline the method by which Mie treated scattering, indicating the types of particles for which such an approach is in practice tractable. Sketch the dependence of the efficiency factor Q_{ext} on $x = 2\pi a/\lambda$, where a is grain radius and λ is wavelength of electromagnetic radiation, for a typical material and explain the numerical value of the limit of Q_{ext} as $x \to \infty$. [7]

   (c) Outline the Discrete Dipole Approximation (DDA) method of calculating scattering by dust grains, indicating in which situations it is more appropriate than Mie theory. What practical limitations are there to application of the DDA method? [7]

   (d) Why are submillimetre-to-millimetre observations particularly well suited to determining the mass of dust around a star? Derive an expression relating the dust mass M_d, to the measured flux density S_ν, the distance D to the star, and relevant physical properties of the individual dust grains. [7]

SECTION C. THIS SECTION IS NOT COMPULSORY

5. (a) 'Z' sources trace out a letter z in the X-ray colour-colour diagram. While on the horizontal branch, they often exhibit quasi-periodic oscillations (QPOs) known as HBOs. Briefly describe the origin of this rapid variability. [5]

   (b) How are observations of the HI 21 cm line used to estimate the distance to a pulsar? [5]

   (c) What are the characteristic and kinematic ages of a pulsar. Are the two estimates in good agreement for old pulsars? [5]

   (d) Outline qualitatively under what conditions dust of various compositions may form near stars, stating what observations support these ideas. [5]

   (e) What evidence indicates the existence of dust disks around some young stellar objects? What further evidence suggests that some of these may be protoplanetary disks? [5]

   (f) What processes may modify the size and radial distribution of grains in circumstellar disks? [5]

END OF PAPER

JP Emerson (Course Organiser), SJ Unger (Deputy Course Organiser)