CP 4-607

Queen Mary and Westfield College

UNIVERSITY OF LONDON

MSci EXAMINATION

ADVANCED TOPICS IN
EXTRAGALACTIC ASTRONOMY PHY-911

SUMMER 1998

Time allowed: TWO HOURS

Answer **TWO** questions only. No credit will be given for attempting a further question.

Each question carries 20 marks. The mark *provisionally allocated* to each section is indicated in the margin.

TURN OVER WHEN INSTRUCTED

Physical and Astronomical Constants

Gravitational constant	G	6.670	10^{-11} N m^{2} kg^{-2}
Speed of light	c	2.998	10^{8} m s^{-1}
Mass of proton	m_p	1.673	10^{-27} kg
Thomson cross-section	σ_T	6.652	10^{-29} m^{2}
Boltzmann constant	k	1.381	10^{-27} J K^{-1}
Stefan-Boltzmann constant	σ	5.670	10^{-8} W m^{-2} K^{-4}
Mass of Sun	$M_\odot$	1.989	10^{30} kg
Radius of Sun	$R_\odot$	6.960	10^{8} m
Parsec	1 pc	3.086	10^{16} m
Year	1 y	3.150	10^{7} s
Astronomical Unit	1 AU	1.496	10^{11} m
Electron Volt	1 eV	1.602	10^{-19} J

Also, where necessary, use the following value for the Hubble constant:

Hubble constant	H_o	50 km s^{-1} Mpc^{-1}

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1. Outline **briefly** why many astronomers believe that the ultimate power source in active galactic nuclei (AGN) is the accretion of matter through a disk around a supermassive black hole. [2]

For the case of a thin, steady state accretion disc, the variation with radius r of the disk temperature $T(r)$ (disk assumed *optically* thick) is

$$T(r) = T_L\left\{\left(\frac{r_L}{r}\right)^3\left[1-\left(\frac{r_L}{r}\right)^{\frac{1}{2}}\right]\right\}^{\frac{1}{4}}$$

where,

$$T_L = \left[\frac{3}{8\pi}\frac{GM\dot{m}}{r_L^{\,3}\sigma}\right]^{\frac{1}{4}},$$

r_L is the radius of the last stable orbit, M is the mass of the central black hole, $\dot{m}$ the rate at which material flows toward the black hole, and σ is the Stefan-Boltzmann constant.

Show that the maximum temperature occurs at about $1.4r_L$ and is about half T_L. The disc extends in as close as three Schwarzschild radii to the central black hole; show that the maximum expected temperature T_{max} is given by

$$T_{\max} = 1.1\times10^5 M_8^{-\frac{1}{2}}\dot{m}_1^{\frac{1}{4}}$$

where M_8 is the mass of the black hole in units of 10^8 $M_\odot$ and $\dot{m}_1$ is the infall rate in units of solar masses per year. [8]

If $M_8 = 1$ and $\dot{m}_1 = 1$, what is the typical wavelength of photons emitted by material at this temperature. Comment on your result. [2]

Show that for an observer at distance D whose line of sight makes and angle θ to the normal to the plane of the disk the observed flux density S_ν is given by

$$S_\nu = \frac{4\pi h\nu^3\cos\theta}{c^2D^2}\int_{r_L}^{r_{max}}\frac{rdr}{\left(e^{\frac{h\nu}{kT(r)}} - \theta 1\right)}$$

where r_{max} is the effective radius of the disc. By making suitable approximations use the above expression for S_ν to deduce the shape of the predicted continuum emission spectrum of the accretion disc in the low frequency *($\nu << kT(r_{max})/h$)* and high frequency *($\nu >> kT(r_L)/h$)* limits. **State without proof** the predicted form of the spectrum between these limits and sketch the overall spectrum. How does this compare to measured AGN continuum spectra? [8]

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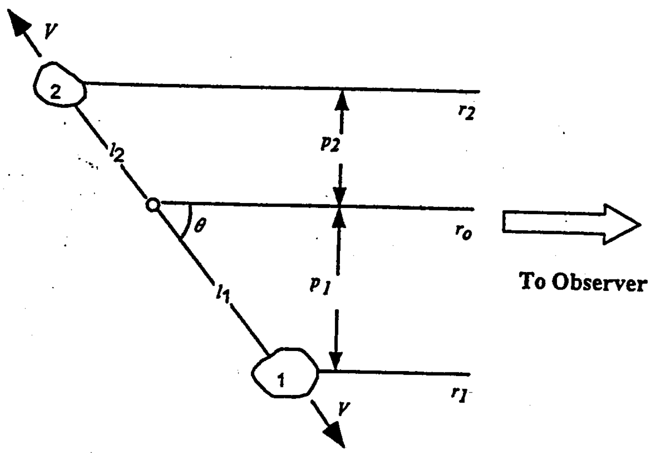
2. Describe **briefly** the main observational features of a classical double radio source. [2]



The figure shows lobes 1 and 2 of a radio source separating from the central galaxy at velocity V. The line joining the centres of the lobes makes an angle θ to the line of sight to Earth. Simultaneous observations are made of the radiation received from the central galaxy and the two lobes. Show that the times t_e, t_1 and t_2 of emission of this radiation from the central galaxy and the two lobes are related by

$$t_i = t_e \pm \frac{l_i \cos\theta}{c},$$

where the subscript $i = 1$ and 2 for lobes 1 and 2 respectively, the l_i are the distances the lobes have travelled from the galaxy at the time of emission of the radiation, and the upper sign refers to lobe 1 and the lower to lobe 2. c is the speed of light. [5]

Use this result to show that the projected distances p_1 and p_2 of the two lobes on the sky at the time of observation are related by

$$\frac{p_1}{p_2} = \frac{1+\frac{V}{c}\cos\theta}{1-\frac{V}{c}\cos\theta}.$$

How can this result be used to get a statistical upper limit to the velocity V? [6]

Various observations have determined that V is likely to about $0.1c$. Show that if the lobes were unconfined, their diameters would be greater that their mutual separation, in contradiction to observation which shows that the diameters of the lobes are less than about a third of their separation. [3]

Discuss **qualitatively** possible mechanisms for confining the lobes. [4]

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3. The lobes of a particular radio galaxy have a volume V and are threaded by a magnetic field B. Suppose that the number of relativistic electrons per unit volume having energies between E and $E+dE$ is given by

$$N(E)dE = N_o \times \left(\frac{E}{E_o}\right)^{-p} dE.$$

By considering the radiation from all electrons in the energy range E_1 to E_2 write down expressions for the total energy content E_e of the electrons and their synchrotron luminosity L_S. **[Hint:** An energetic electron with energy E in the presence of a magnetic field B radiates a power $P = bB^2E^2$ at a characteristic frequency $\nu = aBE^2$ where a and b are constants] [5]

The radio flux density spectrum of the lobes is observed to be a power law i.e. $S(\nu) = S_0\left(\frac{\nu}{\nu_0}\right)^{\alpha}$ where $\alpha = (1-p)/2$ and S_0 is the flux density at ν_0. Assuming that the energy of the protons present in the lobes is K times the energy in the electrons show that the *total* energy in the lobes (i.e. in the magnetic field and the particles) is given by;

$$E_{total} = (1+K)\left(\frac{a^{1/2}}{b}\right)\left(\frac{2+2\alpha}{1+2\alpha}\right)L_S B^{-3/2}\frac{\left[\nu_2^{\frac{(1+2\alpha)}{2}} - \nu_1^{\frac{(1+2\alpha)}{2}}\right]}{\left[\nu_2^{1+\alpha} - \nu_1^{1+\alpha}\right]} + V\frac{B^2}{2\mu_o}$$

where ν_1 and ν_2 are the frequencies corresponding to electron energies E_1 and E_2 respectively and μ_0 is the permeability of free space. [6]

By assuming equipartition of energy between the particles and the magnetic field obtain an expression for B. [2]

A nearby radio galaxy is at redshift z=0.023, has a measured flux density of 12 Jy at 178 MHz (1Jy = 10^{-26} W m^{-2} Hz^{-1}), and shows a power-law spectrum with spectral index $\alpha = -0.75$ that is known to extend from 178 MHz to an upper cut-off at 90 GHz. The radio emission comes from two lobes either side of the galaxy, each of which looks roughly circular on the sky, and is 12 arcminutes across. Assuming that the protons in the lobes carry about 100 times more energy than the electrons estimate the source synchrotron luminosity, the magnetic field in the lobes and the total energy stored in the source. [7]

[In SI units $a = 2.9\times10^{36}$, $b = 1.6\times10^{12}$ and $\mu_0 = 4\pi\times10^{-7}$ H m^{-1}.]

End of Examination: Dr. A. G. Murray, Prof. P. E. Clegg.