DEPARTMENT OF PHYSICS AND ASTRONOMY

Spring Semester 2006-2007

STRUCTURE AND EVOLUTION OF GALAXIES **2 HOURS**

Question 1 is compulsory, and counts for 50% of the final score.
Answer two of the remaining four questions (2, 3, 4, and 5), each counting for 25% of the final score.

A supplementary sheet containing the figures needed to answer questions 1a and 5c is attached.

A formula sheet and table of physical constants is attached to this paper.

The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

TURN OVER

1 COMPULSORY

(a) How does the appearance of spiral galaxies change from early types to late types? Discuss their bulge-to-disk ratios and the tightness of their spiral arms. Do the terms "early type" and "late type" in reality refer to an evolutionary sequence? [2]

Following the nomenclature introduced by Hubble's Tuning Fork, and the extension beyond Sc introduced by de Vaucouleurs, classify the three galaxies shown in the attachment. Justify your answer. [1.5]

Compare and contrast, in general terms, the formation scenarios for elliptical and spiral galaxies. Refer to the Eggen, Lynden-Bell & Sandage (ELS) and Searle & Zinn (SZ) scenarios where appropriate. [3]

How do cD galaxies differ from "normal" elliptical galaxies? Make a sketch to back up your answer. [1]

(b) Discuss the observations that led Walter Baade to define the properties of Population I and II stars in the Milky Way and the Local Group of galaxies. What are these properties? [2]

In recent years, there has been a surge of interest related to the hypothetical Population III stars. What would the properties of Population III stars be in terms of formation epoch and masses? What is the fundamental reason that there are presently no Population III stars left for us to observe? [1]

Why are star clusters with ages greater than about 10 Myr well represented by theoretical "simple stellar populations" (SSPs)? [1.5]

(c) Discuss the basic physical principles that make the Baade-Wesselink method for distance determination work. [2]

Compare and contrast two of the following methods for distance determination:

- the Globular Cluster Luminosity Function (GCLF);
- the Planetary Nebula Luminosity Function (PNLF);
- the Tully-Fisher relation (TFR), or the equivalent Faber-Jackson relation;
- surface brightness fluctuations. [2]

CONTINUED

QUESTION ONE CONTINUED

(d) For an object in dynamical equilibrium, the virial theorem states that

$$2T_{\mathrm{k}} + \Omega = 0,$$

where T_{k} is the total kinetic energy and Ω the potential energy.
Based on the (simplest!) proportionalities of the kinetic and potential energy to mass, velocity dispersion and radius, derive a rough approximation to describe the Fundamental Plane for elliptical galaxies,

$$r \propto \sigma^2 \Sigma^{-1}\left(\frac{M}{L}\right)^{-1}.$$

[Hints: the potential energy is proportional to M^2/r ; express the mass in terms of M/L, and use the definition of surface brightness, $\Sigma \propto Lr^2$.] [4]

TURN OVER

Answer two out of the following four questions:

2 (a) Describe and discuss our current view of the stellar populations in the Milky Way. In particular, discuss their key properties: age, flattening, and velocity dispersion. How has this changed from the original idea of Baade's Populations I and II? [3]

In the 1930's, Trumpler attempted to map the structure of the Milky Way using open clusters as tracers, based on the "faintness equals farness" and "smallness equals farness" approaches. What were the basic assumptions of these two approaches?
Both approaches led to discrepant results, however. Discuss the main reason for this, considering what we know now about the overall structure of the Milky Way and its components. [3]

Why did Shapley's work not suffer from the same effect when he carried out a similar exercise, but used globular clusters instead? [1]

(b) In view of your answer to the previous question (2a), is it likely that our census of the Milky Way's globular cluster population is complete, or are we still missing a significant number of globular clusters?
Where would we be most likely to find any "missing" globular clusters? [1.5]

(c) Discuss, as a function of distance from the centre of a spiral galaxy, where the luminous, baryonic and dark matter are expected to dominate. Justify your arguments based on "typical" galactic rotation curves. [1.5]

CONTINUED

3 (a) One of the key ingredients needed for models predicting the evolution of stellar populations and galaxies as a whole is the stellar initial mass function (IMF). Give the general parameterisation and slope for the often used Salpeter IMF. [1]

It is well known that the Salpeter IMF does not hold all the way down to the lowest stellar masses. Calculate the factor by which we would over or underestimate the mass of a star cluster if we used the Salpeter IMF instead of the more realistic IMF, with IMF exponents

$$\alpha = \begin{cases} -1.3 \quad ; & m \leq 0.5\, M_{\odot} \\ -2.3 \quad ; & m > 0.5\, M_{\odot}\,. \end{cases}$$

Assume that, for the purpose of this question, the stellar masses in a typical star cluster range from 0.1 $M_{\odot}$ to 100 $M_{\odot}$. [5]

(b) Discuss how one generally obtains the slope of the initial mass function for low-mass and high-mass stars, respectively. Once these slopes have been obtained, at which mass does calibration and normalisation of the resulting mass function normally happen? [2]

(c) Describe what happens to the distribution of the low-mass and the high-mass stars in a cluster due to dynamical interactions (mass segregation) over time. Relate your answer to arguments involving the conservation of energy. [2]

TURN OVER

4 (a) Briefly describe the "unified model" for active galaxies. Include in your description the various physical components believed to be found in active galaxies as a function of increasing radius. [2]

What are the four main components found in the spectra of quasars, and how do they link in with the spatial components you discussed in the previous question? [2]

(b) Which forces are in equilibrium at the Eddington limit of an accreting black hole in the nucleus of an active galaxy? [1]

The outward radiation pressure force F_P on a hydrogen atom at a distance r from an isotropically radiating source of luminosity L is given by

$$F_P = \frac{L}{4\pi r^2 c}\sigma_T ,$$

where σ_T is the Thomson cross-section for light scattering from a free electron. Use this information to obtain an expression for the Eddington luminosity, L_{Edd}, of such a black hole. [2.5]

(c) Numerically, $L_{Edd} = 1.3 \times 10^{31} M_{BH}$ (in units of W), where M_{BH} is the mass of the black hole in units of $M_{\odot}$.
The accretion rate needed to maintain this luminosity is given by

$$L_{acc} = 6 \times 10^{39} \frac{dM}{dt} \text{(in units of W)} .$$

If we observe a quasar of luminosity $L_{QSO} = 0.8 \times 10^{41}$ W, and assume that the QSO is radiating at the Eddington rate,

– estimate the mass of the central black hole;

– calculate how much material (in $M_{\odot}$ yr^{-1}) the quasar must accrete to maintain this luminosity. [2.5]

CONTINUED

5 (a) Suppose that you have obtained deep observations of an old globular cluster in the Large Magellanic Cloud (LMC), characterised by a metallicity $Z = 0.2\ Z_{\odot}$ (20% of solar metallicity). Your colour-magnitude diagram reveals the existence of RR Lyrae variables with apparent magnitude $m_V = 19.5$ mag. From independent observations, we know that the absolute magnitude is given by

$$M_V = 0.13[\mathrm{Fe/H}] + 0.76.$$

Explain what is meant by the notation [Fe/H]. [1]

If we assume that there is a one-to-one correspondence between the cluster's metallicity and its iron abundance (and keep in mind your answer to the previous question), what is the distance to the cluster in kpc, and therefore to the LMC? You can neglect the effects of foreground extinction. [2.5]

(b) A powerful method to determine the ages of clusters that are resolved (in other words, in which we can see the individual stars) is by analysing the clusters' colour-magnitude diagrams (CMDs). Which feature is the principal diagnostic for age determinations? [1]

Back up your answer with a sketch of the CMD, and discuss how absolute magnitudes are affected by distance uncertainties. [1.5]

(c) The ring around supernova (SN) 1987A in the LMC, shown in the figure in the attachment, appears as an ellipse measuring about 1.21×1.66 arcsec on the sky. If its true shape is circular, show that the ring is inclined at $i \approx 43°$ to face-on.

If the ring radius is R, use the figure to explain why light travelling first via path B and then to us is delayed by a time $t_- = R(1 - \sin i)/c$ (where c is the speed of light) relative to light coming straight to us from the SN.

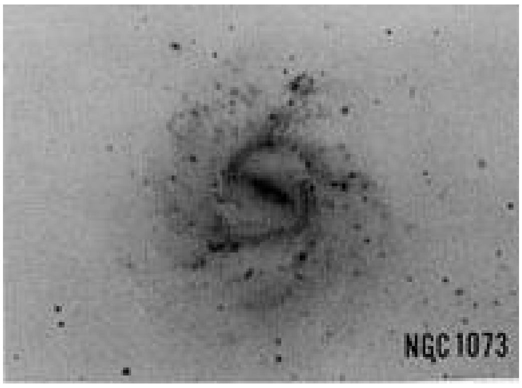
The measured value is $t_- = 86 \pm 6$ days. Find the radius R in light-days and hence the distance d to the SN in kpc. [4]

END OF QUESTION PAPER

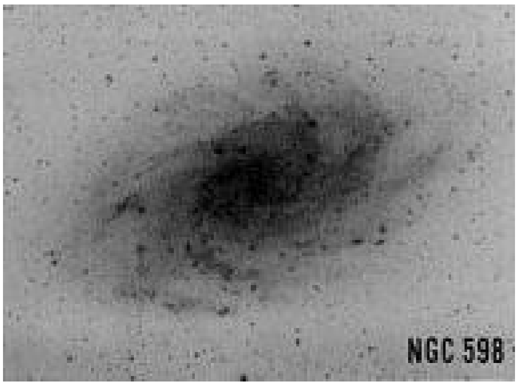
PHY216 EXAM
JUNE 2007
SUPPLEMENTARY FIGURES

QUESTION 1a:

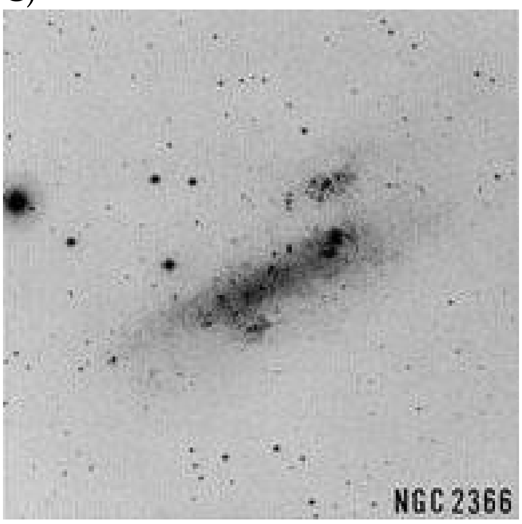
A)



B)



C)



QUESTION 5c: