



**NTNU – Trondheim**  
Norwegian University of  
Science and Technology

Department of Physics

## **Examination paper for FY2450 Astrophysics**

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**Examination date: 31-05-2014**

**Examination time: 09:00 – 13:00**

**Permitted examination support material: Calculator, translation dictionary, printed or hand-written notes covering a maximum of one side of A5 paper.**

**Other information: The exam is in three parts and part 1 is multiple choice. Answer all questions in all three parts. The percentage of marks awarded for each question is shown. An Appendix of useful information is provided at the end of the question sheet.**

**Language: English**

**Number of pages: 7 (including cover)**

**Number of pages enclosed: 0**

**Checked by:**

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Date

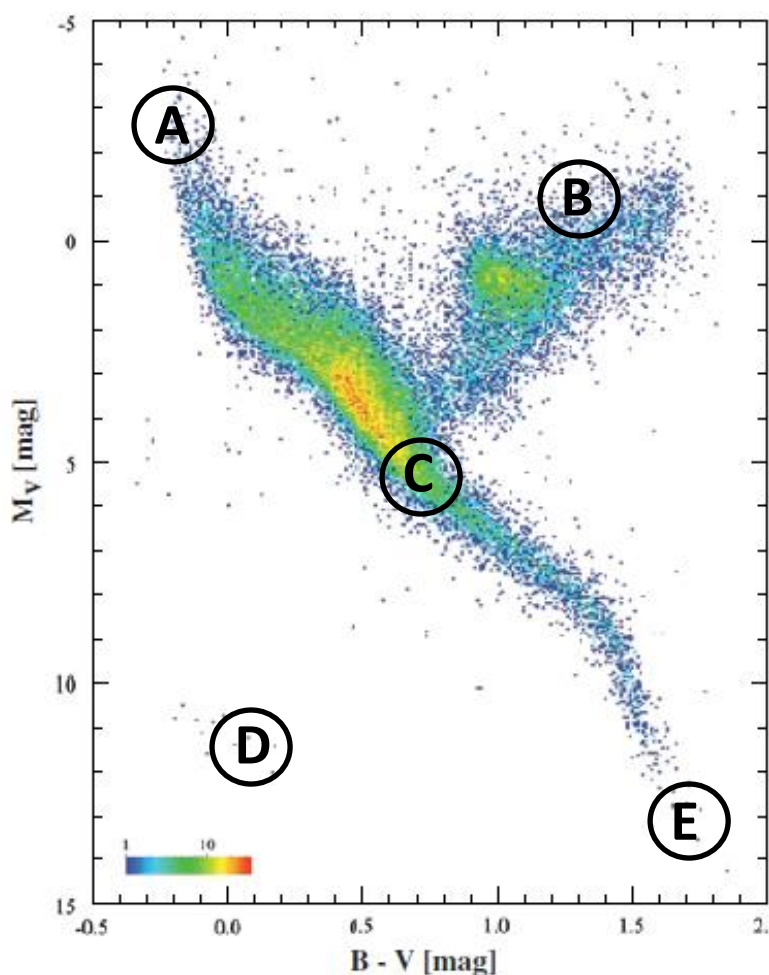
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**Part 1. (total 30%)**

Part 1 is multiple choice. 3 marks will be awarded for each correct answer. No marks will be awarded for an incorrect or missing answer. On your answer sheet draw a table that looks something like,

Question	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10
Answer										

and insert your answer in the boxes. Only the answers will be marked.



The diagram above shows a colour (B-V) versus absolute visual magnitude ( $M_V$ ) plot for solar neighbourhood stars compiled from observations from the Hipparcos satellite. Five regions labelled A, B, C, D and E are highlighted. Which region on the HR diagram contains:

(1.1) the stars with the smallest diameter (3%)

(1.2) the stars that emit the greatest energy per second per unit surface area (3%)

- (1.3) the stars with the largest diameter **(3%)**
- (1.4) the stars with the lowest mass **(3%)**
- (1.5) the main sequence stars with the smallest mass to luminosity ratio **(3%)**

Star	Spectral type	observations				
		apparent magnitude $m_V$ (mag)	observed colour $(B-V)_{\text{obs}}$ (mag)	distance $d$ (pc)	parallax half angle $p$ (arcsecs)	visual extinction $A_V$ (mag)
A	B0V		+0.50	300		
B	A0V	+7.6	+0.32			
C	F0V	+10.8				0.0
D	G0V		+1.27		0.0250	
E	K0V			50		0.3

The table above lists some observed properties of five different main sequence stars labelled A, B, C, D and E. The spectral type of each star is given. In the next five columns some observed properties of these five stars (as observed from Earth) are listed. Use the data provided and information in Appendix 1 to complete the table, and use the completed table to answer the following questions. (You may assume that the ratio of total to selective extinction ( $R$ ) is 3.1 towards each of the five stars).

- (1.6) Which star appears brightest when observed from Earth (in the V band)? **(3%)**
- (1.7) Which star is the closest to Earth? **(3%)**
- (1.8) Which star is the furthest away from Earth? **(3%)**
- (1.9) Which star appears reddest when observed from Earth? **(3%)**
- (1.10) Which star is observed through the highest optical depth of interstellar extinction (in the V band)? **(3%)**

**Part 2. (total 40%)**

(2.1) Using the data in Appendix 1, explain why you would expect a G0V-type star to live longer on the main sequence than a B0V-type star. State any assumptions you make. **(10%)**

(2.2) A brown dwarf has a mass somewhere between 13 and 75 times the mass of Jupiter. It is neither a main sequence star nor a gas giant planet. Summarise the difference between a main sequence star, a brown dwarf star and a gas giant planet in terms of the nuclear reactions. **(10%)**

(2.3) Teide 1 was the first brown dwarf to be observationally verified. It has an effective surface temperature of approximately 2600 K (compared to the Sun at 5800 K) and a radius approximately 10 % of the Sun's. Calculate the luminosity of Teide 1. Also estimate the wavelength of light where the spectrum of Teide 1 is most intense. At a wavelength of 500 nm what is the ratio of the energy emitted per unit surface area of the Sun to that emitted per unit surface area of Teide 1. **(10%)**

(2.4) The gravitational potential energy of a uniform spherical cloud of interstellar material is given by:

$$U = -(3GM^2) / (5R)$$

where M is the mass of the spherical cloud and R is its radius. The kinetic (thermal) energy of the material in the cloud is:

$$K = 3MkT / 2m$$

where m is the mean mass per particle in the cloud at a temperature of T. Use this to show that the minimum mass (sometimes called the Jeans mass) of a gravitationally-bound spherical cloud of a given temperature, composition and density ( $\rho$ ) is *approximately*,

$$M_J \approx 4[(kT) / (Gm)]^{3/2} \rho^{-1/2}$$

and calculate the smallest mass of a gravitationally-bound spherical cloud at a temperature of 60 K in a dense core in the interstellar medium composed of  $10^5$  hydrogen molecules per cubic cm. **(10%)**

**Part 3. (total 30%)**

A good way to envisage the problems associated with detecting extra-solar planets is to consider how observations of the Sun-Jupiter system would appear from a distance of 10 pc viewed from within the plane of Jupiter's orbit around the Sun. Using data from the Appendix and assuming Jupiter is in a circular orbit around the Sun at a Sun-Jupiter distance of 5.2 AU and a period of 11.9 years calculate the following:

(3.1) By how many magnitudes would the Sun's apparent brightness change as Jupiter transits across the Sun's face? How long will this transit last? **(6%)**

(3.2) By how much would the *angular* position of the Sun appear to move with respect to a fixed background of stars over the course of one Jupiter orbit? **(6%)**

(3.3) By how much would the Ba- $\alpha$  (rest  $\lambda = 656.281$  nm) spectral line in the Sun's photosphere appear to shift due to the change in radial velocity of the Sun over the course of one Jupiter orbit. **(6%)**

(3.4) Repeat questions 3a, 3b and 3c, but this time assume Jupiter is only 0.52 AU from the Sun (remember the orbital period will also change). Use your answers to demonstrate why extrasolar planet detections using combined photometric and spectroscopic methods have an observational bias towards so-called "hot Jupiters". **(12%)**

## Appendix 1. Properties of main sequence stars

Spectral type	$M_V^{(1)}$	$B-V$	$T_{eff}(K)^{(2)}$	$M/M_{Sun}$	$R/R_{Sun}$	$L/L_{Sun}$
O5	-6	-0.45	35000	39.8	17.8	$3.2 \times 10^5$
B0	-3.7	-0.31	21000	17.0	7.6	$1.3 \times 10^4$
B5	-0.9	-0.17	13500	7.1	4.0	$6.3 \times 10^2$
A0	+0.7	+0.0	9700	3.6	2.6	$7.9 \times 10^1$
A5	+2.0	+0.16	8100	2.2	1.8	$2.0 \times 10^1$
F0	+2.8	+0.30	7200	1.8	1.4	6.3
F5	+3.8	+0.45	6500	1.4	1.2	2.5
G0	+4.6	+0.57	6000	1.1	1.05	1.3
G5	+5.2	+0.70	5400	0.9	0.93	$7.9 \times 10^{-1}$
K0	+6.0	+0.81	4700	0.8	0.85	$4.0 \times 10^{-1}$
K5	+7.4	+1.11	4000	0.7	0.74	$1.6 \times 10^{-1}$
M0	+8.9	+1.39	3300	0.5	0.63	$6.3 \times 10^{-2}$
M5	+12.0	+1.61	2600	0.2	0.32	$7.9 \times 10^{-3}$

<sup>(1)</sup> Absolute V-band magnitude

<sup>(2)</sup> Effective surface temperature

## Appendix 2. Physical constants

speed of light	$c$	$2.998 \times 10^{10} \text{ cm s}^{-1}$	$2.998 \times 10^8 \text{ m s}^{-1}$
gravitational constant	$G$	$6.673 \times 10^{-8} \text{ dyne cm}^2 \text{ g}^{-2}$	$6.673 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$
Boltzmann constant	$k$	$1.381 \times 10^{-16} \text{ erg K}^{-1}$	$1.381 \times 10^{-23} \text{ J K}^{-1}$
Planck's constant	$h$	$6.626 \times 10^{-27} \text{ erg s}$	$6.626 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	$\sigma$	$5.670 \times 10^{-5} \text{ erg cm}^{-2} \text{ K}^{-4} \text{ s}^{-1}$	$5.670 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Wien displacement constant	$\lambda_{max} T$	$2.898 \times 10^{-1} \text{ cm K}$	$2.898 \times 10^{-3} \text{ m K}$
Rydberg constant	$R$	$1.097 \times 10^5 \text{ cm}^{-1}$	$1.097 \times 10^7 \text{ m}^{-1}$
mass of proton	$m_p$	$1.6726 \times 10^{-24} \text{ g}$	$1.6726 \times 10^{-27} \text{ kg}$
mass of neutron	$m_n$	$1.6749 \times 10^{-24} \text{ g}$	$1.6749 \times 10^{-27} \text{ kg}$
mass of electron	$m_e$	$9.1096 \times 10^{-28} \text{ g}$	$9.1096 \times 10^{-31} \text{ kg}$
mass of hydrogen atom	$m_H$	$1.6735 \times 10^{-24} \text{ g}$	$1.6735 \times 10^{-27} \text{ kg}$

## Appendix 3. Astronomical constants

astronomical unit	$AU$	$1.496 \times 10^{13} \text{ cm}$	$1.496 \times 10^{11} \text{ m}$
parsec	$pc$	$3.086 \times 10^{18} \text{ cm}$	$3.086 \times 10^{16} \text{ m}$
solar mass	$M_{Sun}$	$1.989 \times 10^{33} \text{ g}$	$1.989 \times 10^{30} \text{ kg}$
solar radius (mean)	$R_{Sun}$	$6.960 \times 10^{10} \text{ cm}$	$6.960 \times 10^8 \text{ m}$
solar luminosity	$L_{Sun}$	$3.839 \times 10^{33} \text{ erg s}^{-1}$	$3.839 \times 10^{26} \text{ J s}^{-1}$
Earth mass	$M_E$	$5.977 \times 10^{27} \text{ g}$	$5.977 \times 10^{24} \text{ kg}$
Earth radius (mean)	$R_E$	$6.371 \times 10^8 \text{ cm}$	$6.371 \times 10^6 \text{ m}$
Jupiter mass	$M_J$	$1.899 \times 10^{30} \text{ g}$	$1.899 \times 10^{27} \text{ kg}$
Jupiter radius (mean)	$R_J$	$6.991 \times 10^9 \text{ cm}$	$6.991 \times 10^7 \text{ m}$

**Appendix 4. The equations of stellar colour**

Planck's empirical law: Energy per second per frequency interval per unit area

$$I(\nu, T) = [2h\nu^3/c^2] / [\exp(h\nu/kT) - 1]$$

Planck's empirical law: Energy per second per wavelength interval per unit area

$$I(\lambda, T) = [2hc^2/\lambda^5] / [\exp(hc/\lambda kT) - 1]$$

Wien's displacement law: wavelength of maximum intensity

$$\lambda_{\max} T = 2.898 \times 10^6 \text{ nm K}$$

Stefan-Boltzmann law: Integrated energy per second per unit surface area

$$E = \sigma T^4$$

Integrated energy per second from a sphere: e.g. the total (bolometric) luminosity of a star

$$L = 4\pi R^2 \sigma T^4$$