Instructions

1. The entire Olympiad lasts for 3 ½ hours and is worth a total of 200 marks.

2. The mark distribution amongst the components are given as follows. You are strongly advised to plan your time accordingly.

Component	Part	Marks	Weightage (%)
Theory	A	12	6
	B	54	27
	C	34	17
Data Response	D	40	20
Practical	P(A)	10	5
	P(B)	28	14
	P(C)	22	11

3. For parts B – D, you are allowed to use both sides of an SAO answer sheet. Start each new question on an empty side of an SAO answer sheet.

4. Fill in these details on the cover page and each side of an SAO answer sheet:
   - Year of competition
   - Your participant code
   - The part of the paper, and the question number
   - The page number – which should be continuous from 1 to *N*

5. Answer sheets with a participant's personal information (e.g. name, NRIC) or missing the above details will be voided.

6. You are allowed to use pen (with black or blue ink) or pencil to answer the paper.

7. Cross out all workings or answers you do not wish to be evaluated.

8. A constants sheet is provided separately for your use.

9. You are allowed to leave the venue early upon submission of your answer script (see clause 17), but only after one hour after the start of the paper and not within 30 minutes to completion of the paper.

10. Please raise your hand to seek assistance from the invigilators (e.g. to visit the restroom, request for more answer sheets, enquire about an ambiguity, etc.)

Competition Rules and Regulations

11. Only the use of scientific calculators is permitted. No graphing or programmable calculators are allowed.

12. Participants are to use their own stationary.

13. Participants are prohibited from possessing unauthorised electronic devices and reference materials.

14. Cheating, collusion to cheat or any integrity-related offences are grounds for immediate disqualification.

15. Participants are not allowed to leave their seat without permission or communicate with other participants.

At the End of the Competition

16. Stop writing immediately when instructed by the Organising Team. Do not fill in missing details on your answer sheets or the cover page after the command is given.

17. Staple your answer script in the following order.
    - Cover page (detach this from the question paper)
    - SAO Part A answer sheet
    - SAO answer sheets for Parts B – D, in continuous order from page 1 to *N*
    - Graph papers used in Part D
    - Practical component (fill in the participant code).

18. You may opt to retain the question paper and constants sheet for personal use. Return all unused answer sheets to the Organising Team.

19. Remain in your seat until all answer scripts are accounted for and the instruction for dismissal is given by the Organising Team.

Obligatory

20. "Shoot for the moon. Even if you miss, you'll land among the stars."
    \- *Les Brown*

Cover Page

1. Fill in all required details below, before time is up.

2. Ensure that all materials (answer sheets, graphing paper, practical question paper) you intend to submit for grading have been attached. Amendments to an answer script after it has been collected will not be entertained.

Participant Code	
Total Number of Pages of SAO Answer Sheets, *N*	

References used for the Specimen Paper

Q11
Diagrams extracted from: Vanderburg, A. (n.d.). Transit Light Curve Tutorial. Retrieved April 6, 2018, from https://www.cfa.harvard.edu/~avanderb/tutorial/tutorial2.html

Q13
Diagrams extracted from: Becker, R. H., Fan, X., White, R. L., Strauss, M. A., Narayanan, V., Lupton, R. H., … York, D. G. (2001). Evidence for Reionization at z ~ 6: Detection of a Gunn-Peterson Trough in a z = 6.28 Quasar. *The Astronomical Journal*, **122**(6), 2850-2857. doi:10.1086/324231, arXiv: astro-ph/0108097v3

Q15
Data extracted from: Eker, Z., Soydugan, F., Soydugan, E., Bilir, S., Gökçe, E. Y., Steer, I., … Demircan, O. (2015). Main-Sequence Effective Temperatures From A Revised Mass–Luminosity Relation Based On Accurate Properties. *The Astronomical Journal*, **149**(4), 131. doi:10.1088/0004-6256/149/4/131, arXiv: 1501.06585

P7
Image from: Meade. (n.d.). Meade LX70 Reflector, 6" [Digital image]. Retrieved April 6, 2018, from https://www.meade.com/meade-lx70-reflector-6.html

P8
Image from: NASA. (2013, May 23). Hubble reveals the Ring Nebula's true shape [Digital image]. Retrieved April 6, 2018, from
https://www.nasa.gov/mission_pages/hubble/science/ring-nebula.html

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Part A

Answer **ALL** questions in this part, on the SAO Part A answer sheet.

(Q1) Model white dwarf **[2 marks]**

White dwarves are stellar core remnants that resist gravitational collapse primarily through electron degeneracy pressure. A non-relativistic calculation gives rise to a polytrope solution, that describes the relation between the pressure and density of a model white dwarf,

$$P = K_1 \rho^{\frac{5}{3}}$$

Express the units of the proportionality constant K_1 in SI units.

(Q2) Horsepower **[2 marks]**

The metric horsepower (units: PS) was briefly used as a power-measuring unit in the 1960s and retains specific use today to describe the power output of automobile engines. 1 PS was defined as the power required to raise a mass of 75 kilograms against the Earth's gravitational force over a distance of one metre in one second.

Express the luminosity of the Sun, in metric horsepower.

(Q3) Hot and hotter **[2 marks]**

Sirius is a binary star system that is the brightest star in the Earth's night sky. Estimate the ratio of the surface temperatures of Sirius A to that of Sirius B.

(Q4) M1 **[2 marks]**

M1, the *Crab Nebula*, is the supernova remnant associated with the bright supernova observed by ancient astronomers in year 1054. Estimate the largest angular dimension of M1, in arcseconds.

(Q5) The dieting Sun **[2 marks]**

Kallenrode (2004) estimated that the rate of particles being carried away from the Sun by the solar wind is $n = 1.3 \times 10^{36}/s$. The Sun's mass also concurrently decreases due to nuclear fusion of hydrogen in its core. Estimate the ratio of the mass loss rates from the solar wind to that of nuclear fusion.

(Q6) And what about the Earth? **[2 marks]**

Indicate if the following statement is True or False.

≫ Assuming the mass of the rest of the Solar System remains unchanged, the radius of the orbit of Earth increases as the Sun evolves towards a red giant.

Part B

Answer **only 6 of the following 7 questions** on the blank SAO answer sheets.

(Q7) The ear of grain **[9 marks]**

The star α *Virginis*, with common name *Spica*, is a binary star system, with a combined apparent V-band magnitude of $m_V = 0.97$. Interferometry of the binary components by Herbison-Evans et al. (1971) gives the absolute V-band magnitudes of the two components as $M_{V,1} = -3.50$ and $M_{V,2} = -1.50$. Calculate the distance to *Spica*.

(Q8) The solar eclipse of 9 Mar 2016 **[9 marks]**

A total solar eclipse occurred on 9 Mar 2016, although only a partial eclipse was visible from Singapore. From data provided by NASA (Espenak, 2014), the local time and local sidereal time at the point of local greatest eclipse was 08^h24^m and 18^h28^m respectively, at which the geocentric coordinates of the Sun were $(\delta, \alpha) = (-04°24', 23^h19^m)$. Singapore has geographical coordinates of $(\phi, \lambda) = (1°17', 103°51')$ and is in the timezone UTC+08:00. Calculate the horizontal coordinates of the Sun at the point of greatest eclipse, (a, A) as seen from Singapore.

(Q9) Model globular cluster **[9 marks]**

Consider a model globular cluster composed of N stars each of mass M, distributed uniformly within a circle of angular radius θ_c. Express the minimum aperture D required to resolve individual stars in this cluster when observing at a wavelength λ, in terms of the above quantities.

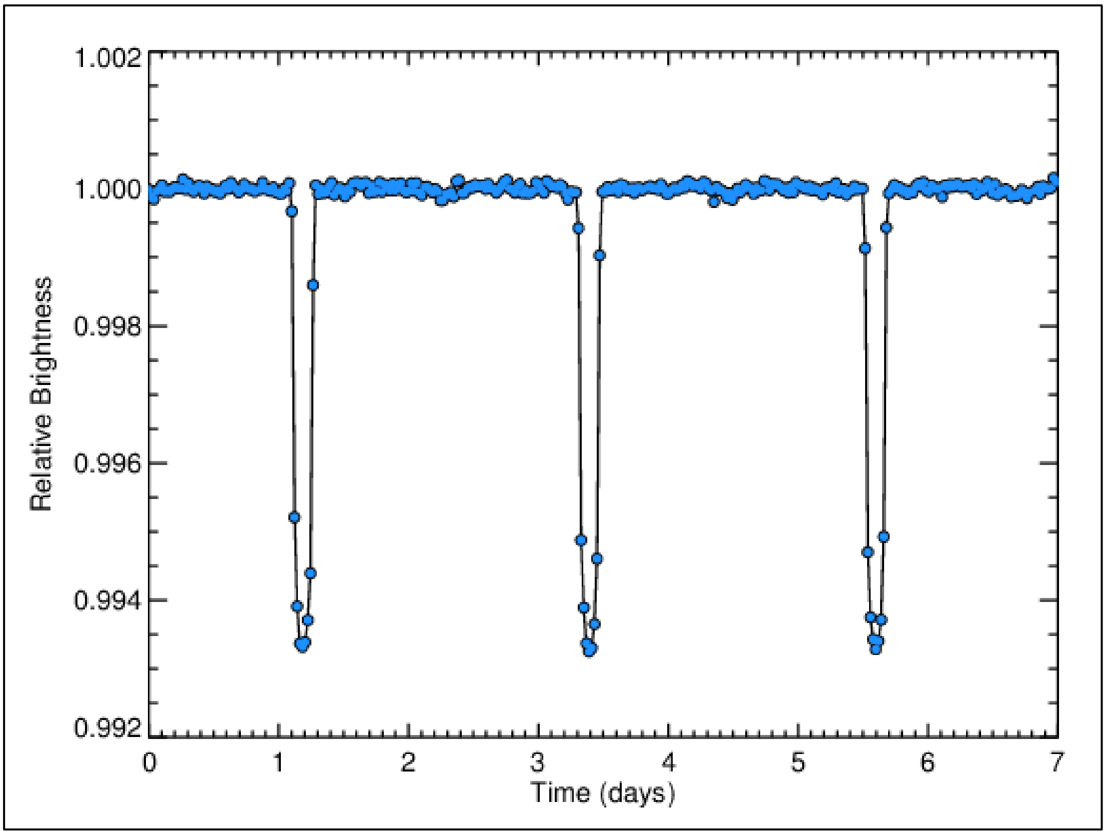
(Q10) Thin disk of the Milky Way **[9 marks]**

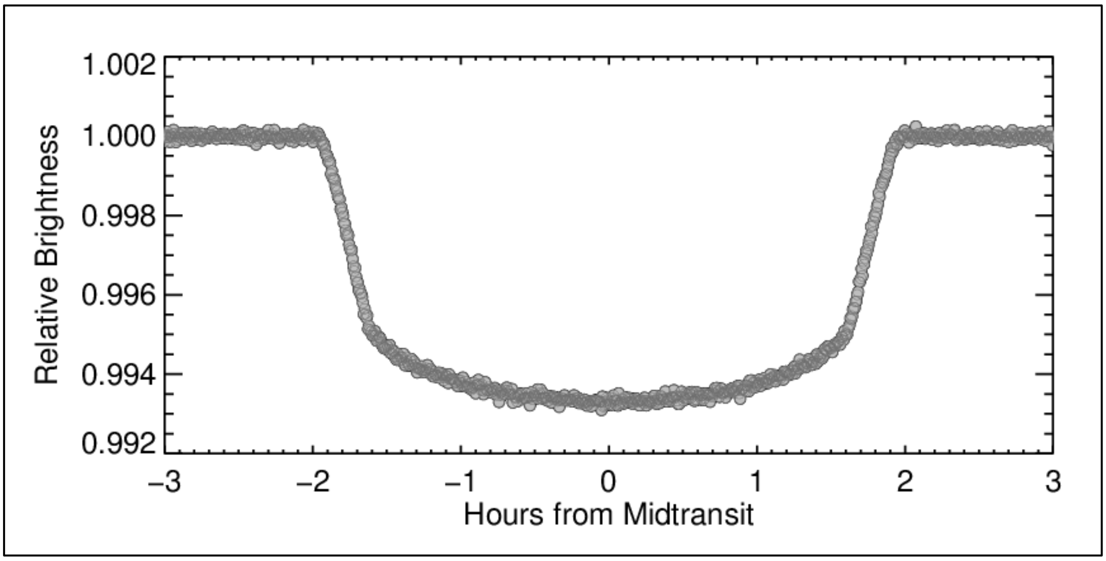
The thin disk is a key structural component found in both spiral and lenticular galaxies. Analysis and modelling of data from the Two Micron All-Sky Survey (2MASS) by Ojha (2000) provides estimates of the scale height[1] and scale length[2] of the Milky Way's thin disk at $h_z = 250\,pc$ and $h_r = 2800\,pc$ respectively. A paper by Karim et al. (2016) calculates that the Sun is at a distance above the Galactic mid-plane of $z_{Sun} = 17\,pc$. Using these estimates and the constants sheet, determine the Galactocentric distance r' along the mid-plane, at which the density of the disk has decreased to half the value from the density measured surrounding the Sun.

[1] The scale height is the distance from the Galactic mid-plane at which the density of the disk has declined by a factor of e from the mid-plane density.
[2] The scale length is the Galactocentric distance at which the density of the disk has declined by a factor of e from the central density.

(Q11) HAT-P-7 **[9 marks]**

HAT-P-7 is a F-type main sequence star that was discovered to host an exoplanet in 2008 by the Kepler Mission spacecraft. From SIMBAD and Welsh et al. (2010), the star has an apparent magnitude of $m_V = 10.46$, mass of $M = 1.53\, M_{sun}$, radius of $R = 1.98\, R_{sun}$, and a trigonometric parallax of $p = 0.00299''$. Shown below is the light curve of the system and an aggregated light curve of the *primary* transit, from Vanderburg. Calculate the radius and orbital radius of the exoplanet, and hence classify the exoplanet.





(Q12) Keeping time **[9 marks]**

The Global Positioning System (GPS) is a navigation system that provides geolocation and time information to a receiver on Earth, when there is unobstructed line of sight to four or more GPS satellites, that are in Medium Earth orbit at an orbital radius of 26,600 km. However, the combined effects of special and general relativity cause the clocks onboard the satellites to run 38 μs faster per day than clocks on Earth, which was corrected for in the design of the GPS. Calculate the change in orbital radius of the satellite network required, Δr, to minimise the corrections needed due to these relativistic effects. The gravitational time dilation at a radius r from a large and slowly rotating body can be approximated by

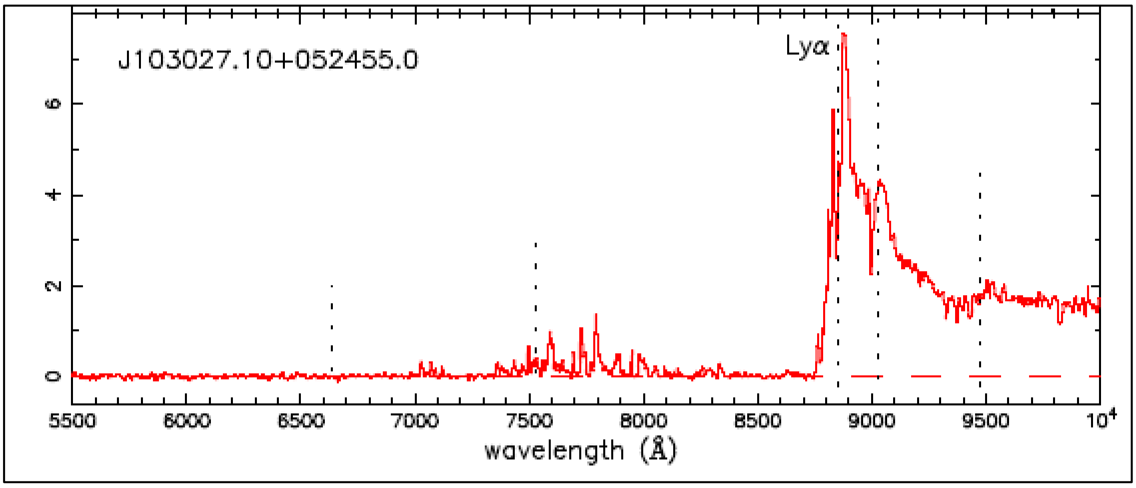
$$t = t_\infty \sqrt{1 - \frac{2GM}{rc^2}}$$

where t is the time elapsed and t_∞ is the time elapsed at a large distance from the body. As these relativistic effects are small, you may use the binomial approximation

$$(1 \pm x)^\alpha = 1 \pm ax$$

(Q13) The Gunn-Peterson trough **[9 marks]**

The Gunn-Peterson trough is a feature observed in the spectra of distant quasars due to the presence of relatively opaque neutral hydrogen in the Intergalactic Medium (IGM). The trough was first identified by Becker et al. (2001) from the suppression of electromagnetic radiation with wavelengths shorter than that of the Lyman-alpha line, at the redshift where the light was emitted. Shown below is the spectrum of the quasar in which the Gunn-Peterson trough was first identified in. Given that the rest wavelength of the Lyman-alpha line $\lambda_{Ly-\alpha} = 121.6\,nm$, calculate the scale factor a at the time the light was emitted. You may assume a matter-dominated Universe, for which the scale factor $a \propto t^{2/3}$.



Part C

Answer **the whole question** on the blank SAO answer sheets**.**

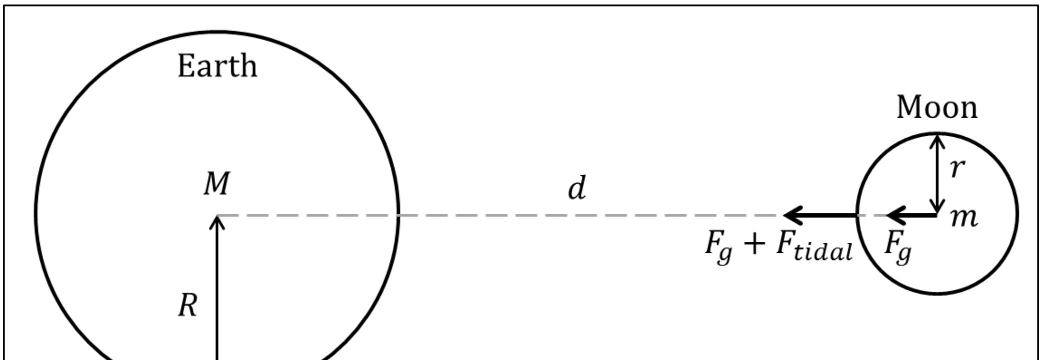
(Q14) The Earth and the Moon **[34 marks]**

Tidal forces are apparent forces that occur due to a gradient in the gravitational field across an orbiting body. The Earth-Moon system is the best studied case of tidal forces between two bodies; the Moon has sufficient mass and orbits sufficiently close to raise appreciable lunar tides on Earth. In this question, you may use the binomial approximation $(1 \pm x)^a \approx 1 \pm ax$ for small *x*.

(a) Consider the Earth, of mass *M* and radius *R*, and the Moon, of mass *m* and radius *r*, separated by a distance *d*. Show that the magnitude of the tidal force $|F_{tidal}|$ on the Earth from the Moon along the Earth-Moon axis can be approximated to

$$|F_{tidal}| \approx \frac{kMmr}{d^3}$$

where *k* is a constant to be expressed in other constants. [4]



(Schematic diagram not drawn to scale)

However, as Earth's rotation is much faster than the orbital motion of the Moon, the tidal bulge is dragged ahead of the position directly under the Moon. This creates a torque between the Earth and the Moon, which increases the orbital semi-major axis of the Moon at the expense of the rotation of the Earth, a phenomenon known as *tidal acceleration*.

(b) Munk et al. (1998) estimates that the total tidal dissipation of energy by tidal friction averages about $|P_{tidal}| \approx 3.75\, TW$. Calculate the present rate of increase of the Earth's rotational period Δt_{Earth} **per year**, given that from Lambeck (1980), the moment of inertia of Earth along its polar axis, $I_{Earth} = 8.01 \times 10^{37}\ kg\ m^2$. [6]

Lunar laser ranging experiments with mirrors left on the Moon during the Apollo missions have confirmed the recession of the Moon in its orbit. From 1970 to 2002, Williams et. al (2002) gives the average rate of recession of the semi-major axis of the Moon **per year** as $\Delta a_{Moon} = 38.0\ mm/yr$.

(c) However, only a small fraction *f* of the total tidal power dissipated by the Earth is transferred to the orbit of the Moon; the bulk is dissipated as heat by tidal friction in the oceans and their interactions with the Earth's crust. Calculate this fraction *f*. [6]

As the Moon recedes in its orbit, it is expected that its angular diameter would eventually be too small to totally occlude the Sun as viewed from Earth during eclipses, even after considering the eccentricity of the Earth's and Moon's orbits.

(d) Calculate the **maximal time** from now T_{max}, in years, to when total solar eclipses will no longer be visible from Earth, for the <u>trivial case</u> where

(1) the rate of recession Δa_{Moon},
(2) the eccentricity of the Earth's and the Moon's orbits, and
(3) the diameter of the Sun

does not change appreciably over the timescale T_{max}. [8]

The magnitude of the tidal power $|P_{lunar}|$ dissipated from lunar tides can be modelled by a power law of the form

$$|P_{lunar}| = kd^{\alpha}$$

where α is some real number.

(e) Suggest a reasonable value for α, and explain qualitatively your reasons for your suggested value. Hence, comment on assumption (1). [3]

(f) Calculate the ratio of the tidal force on the Moon from the Earth at perigee to that at apogee. Hence, comment on assumption (2). [4]

(g) From your knowledge of stellar evolution, comment qualitatively on assumption (3). [1]

(h) From your answers in parts (e), (f) and (g), comment on how your calculated estimate for the trivial case in part (d) will differ from that produced by a more thorough calculation and simulation. [2]

Part D

Answer **the whole question** on the blank SAO answer sheets and graphing paper.

(Q15) The stellar mass-luminosity relation **[40 marks]**

The mass-luminosity relation for main sequence stars was first proposed in a paper by astronomer Jakob Karl Ernst Halm in 1911. This empirical relation has the functional form

$$L \propto M^{\alpha} \Rightarrow \frac{L}{L_{Sun}} = k\left(\frac{M}{M_{Sun}}\right)^{\alpha}$$

where L is the luminosity of the star, M is the mass of the star, L_{Sun} is the solar luminosity, M_{Sun} is the solar mass, k is a proportionality constant that depends on the mass of the star, and $\beta \leq \alpha < 6$ is the exponent of the power law.

(a) Suggest a value for β, and briefly justify your value with reference to stellar structure and processes in main-sequence stars. [2]

(b) An approximate value of α can be derived from basic physics and simplifying assumptions. Consider an ideal spherical star of mass M and radius R, with average density $\bar{\rho}$ and average particle mass $\bar{m}$. For hydrostatic equilibrium, the average pressure $\bar{P}$ is

$$\bar{P} = -\frac{E_g}{3V}$$

where $E_g = -\frac{3GM^2}{5R}$ is the gravitational potential energy of a spherical mass distribution of volume V. Using the Stefan-Boltzmann law and ideal gas law in the form

$$PV = Nk_BT$$

where N is the number of gas particles and k_B the Boltzmann constant, show that $\alpha = 10/3$. [5]

In reality, surveys of nearby stars and binaries on the main sequence show that the approximate mass-luminosity relation of $L \propto M^{10/3}$ deviates significantly from observed values for low- and high-mass stars.

Eker et al. (2015) proposes that a piecewise mass-luminosity relation provides a better fit for stars from different mass ranges – due to differences in internal structure and energy production rates per stellar mass M/L. Data of 55 stars within the mass range $0.38M_{Sun} \leq M < 23M_{Sun}$ are provided on Page 13.

(c) Plot $\lg\left(\frac{M}{L}\right)$ against M for $M < 7M_{Sun}$ to obtain **Graph 1A**. You should obtain a graph with two distinct breakpoints M_1, M_2 where $M_1 < M_2$, that divide the data into three linear distributions. Mark out M_1, M_2 on **Graph 1A** and indicate the corresponding mass boundaries. [6]

(d) Plot $\lg\left(\frac{M}{L}\right)$ against M for masses $M > 3M_{Sun}$ to obtain **Graph 1B**. You should obtain a graph with an additional distinct breakpoint M_3 that divides the remaining data into two linear distributions, for a total of four different linear distributions. [3]

The piecewise mass-luminosity relation for these four mass distributions of stars (very low-, low-, intermediate-, high-) can be expressed as

$$\frac{L}{L_{Sun}} = \begin{cases} 1.062\left(\dfrac{M}{M_{Sun}}\right)^{4.841}, & 0.38M_{Sun} \le M \le M_1 \\ k_2\left(\dfrac{M}{M_{Sun}}\right)^{q}, & M_1 < M \le M_2 \\ k_3\left(\dfrac{M}{M_{Sun}}\right)^{r}, & M_2 < M \le M_3 \\ k_4\left(\dfrac{M}{M_{Sun}}\right)^{s}, & M_3 < M < 23M_{Sun} \end{cases}$$

where k_2, k_3, k_4 are proportionality constants to be found, and M_1, M_2, M_3 are the mass boundaries that divide the data into four mass ranges.

(d) Plot three linear graphs to obtain the values of k_2, k_3, k_4 and q, r, s. Label your graphs **Graph 2**, **Graph 3**, **Graph 4** in the order of the increasing mass ranges. [14]

(e) State the trend in the exponents of the mass-luminosity relation with increasing mass. [1]

(f) Using the appropriate relation, calculate the expected absolute V-band magnitude M_V of the star *Fomalhaut*, given its mass $M = 1.92M_{Sun}$ as measured by Mamajek (2012) through astrometry. The bolometric correction for *Fomalhaut*, of spectral type A3V, is $BC = -0.07\ mag$. [6]

The trend identified in part (f) however, does not hold for stars with very low masses of $M \le 0.38M_{Sun}$. The mass-luminosity relation for such stars is approximately

$$\frac{L}{L_{Sun}} \approx 0.23 \left(\frac{\mathrm{M}}{\mathrm{M_{Sun}}}\right)^{2.3}$$

(g) With reference to the stellar structure and processes in very low-mass stars, suggest a reason for the small exponent in its mass-luminosity relation. [3]

Mass and luminosity data for 53 selected stars in binary systems

S/N	Star Name	$\frac{M}{M_{Sun}}$	$\log\left(\frac{M}{M_{Sun}}\right)$	$\log\left(\frac{L}{L_{Sun}}\right)$	$\log\left(\frac{M}{L}\right)$
290	2MASS J23143816+0339493 B	0.383	-0.417	-1.824	-1.407
114	CU Cnc A	0.427	-0.370	-1.770	-1.400
289	2MASS J23143816+0339493 A	0.469	-0.329	-1.602	-1.273
135	2MASS J103055210334265 A	0.499	-0.302	-1.444	-1.142
98	2MASS J07431157+0316220 B	0.544	-0.264	-1.398	-1.134
41	2MASS J 04480963+0317480 A	0.567	-0.246	-1.187	-0.941
108	TYC 5998-1918-1 B	0.687	-0.163	-0.910	-0.747
107	TYC 5998-1918-1 A	0.703	-0.153	-0.810	-0.657
225	V568 B	0.827	-0.082	-0.516	-0.434
159	V636 B	0.854	-0.069	-0.408	-0.339
234	KIC 6131659 A	0.922	-0.035	-0.146	-0.111
134	ZZ UMa B	0.960	-0.018	-0.090	-0.072
222	V565 A	0.995	-0.002	0.029	0.031
224	V568 A	1.075	0.031	0.258	0.227
7	NGC188 KR V12 A	1.102	0.042	0.344	0.302
116	VZ Hya A	1.271	0.104	0.481	0.377
291	IT Cas A	1.330	0.124	0.607	0.483
156	DM Vir A	1.454	0.163	0.698	0.535
174	TV Nor B	1.661	0.220	0.907	0.687
20	XY Cet A	1.773	0.249	1.084	0.835
172	V335 B	1.844	0.266	1.157	0.891
101	V392 Car A	1.900	0.279	1.162	0.883
103	AI Hya A	1.974	0.295	1.241	0.946
173	TV Nor A	2.048	0.311	1.328	1.017
88	SW CMa B	2.105	0.323	1.382	1.059
72	FT Ori A	2.168	0.336	1.426	1.090
87	SW CMa A	2.240	0.350	1.567	1.217
195	V624 A	2.277	0.357	1.560	1.203
287	V396 Cas A	2.397	0.380	1.640	1.260
10	Zet Phe B	2.545	0.406	1.793	1.387
207	V451 A	2.769	0.442	1.932	1.490

S/N	Star Name	$\frac{M}{M_{Sun}}$	$\log\left(\frac{M}{M_{Sun}}\right)$	$\log\left(\frac{L}{L_{Sun}}\right)$	$\log\left(\frac{M}{L}\right)$
160	Psi Cen A	3.114	0.493	2.150	1.657
199	V906 B	3.246	0.511	2.163	1.652
9	Zet Phe A	3.922	0.594	2.515	1.921
164	GG Lup A	4.106	0.613	2.381	1.768
182	V760 B	4.610	0.664	2.650	1.986
149	EP Cru B	4.830	0.684	2.790	2.106
181	V760 A	4.969	0.696	2.827	2.131
245	V399 Vul B	5.440	0.736	3.088	2.352
123	CV Vel B	5.977	0.776	3.138	2.362
122	CV Vel A	6.076	0.784	3.206	2.422
252	V379 Cep B	6.233	0.795	3.149	2.354
70	V1388 Ori A	7.421	0.870	3.697	2.827
244	V399 Vul A	7.550	0.878	3.694	2.816
86	HI Mon B	9.864	0.994	4.137	3.143
251	V379 Cep A	10.873	1.036	4.130	3.094
85	HI Mon A	11.426	1.058	4.220	3.162
281	CW Cep A	11.797	1.072	4.245	3.173
276	AH Cep B	13.714	1.137	4.315	3.178
238	V453 Cyg A	14.377	1.158	4.518	3.360
275	AH Cep A	15.565	1.192	4.466	3.274
144	EM Car B	21.376	1.330	4.922	3.592
143	EM Car A	22.833	1.359	5.021	3.662

Participant Code	

Part P(A)

For the entire practical component, answer **ALL** questions on the question paper itself.

(P1) The Andromeda-Milky Way merger **[2 marks]**

From measurements of the Andromeda Galaxy's blueshift and transverse velocity, scientists predict that the Milky Way and Andromeda Galaxy (M31) will gravitationally interact and merge in about 4 billion years. Given that M31 and the Milky Way are the largest and second-largest galaxies in the Local Group respectively, indicate in the box the option that describes the most likely classification of the resultant galaxy after the merger is complete.

A Elliptical galaxy (type *E*)
B Spiral galaxy (type *S*)
C Lenticular galaxy (type *S0*)
D Irregular galaxy (type *Im*)

Answer

(P2) Sunrise in Singapore **[2 marks]**

The time of sunrise in Singapore remains relatively unchanged across the course of a year. Indicate in the box the option that is closest to the median time of sunrise in Singapore, in local time (hours and minutes).

A 0500
B 0600
C 0700
D 0800

Answer

(P3) Seeking alignment **[2 marks]**

Indicate in the box the option that describes the most accurate method of polar alignment for an astrophotography setup.

A Three-star alignment
B North alignment using a compass
C Alignment of the polar axis to Polaris
D Drift alignment

Answer

(P4) The Trifid Nebula **[2 marks]**

Messier 20, the *Trifid Nebula*, is popular amongst amateur astronomers as it contains an unusual combination of multiple types of nebulae. Tick in the adjacent box, all options describing a component nebulae found in M20.

	H II region (emission nebulae)
	Planetary nebulae
	Supernova remnant
	Reflection nebulae
	Dark nebulae

(P5) The opposition **[2 marks]**

Tick in the adjacent box, all options that describes a pair of Solar System bodies that can never be in opposition to each other to an observer on Earth.

	The Sun and Saturn
	Mars and Jupiter
	The Moon and Mercury
	Venus and Ceres
	The Sun and the Moon

Part P(B)

(P6) The night of Vernal Equinox **[28 marks]**

The star chart below shows the night sky at 0000h on the night following the Vernal Equinox (on 21 March 2018), from Singapore (UTC +08:00), at latitude $1° \, 17' N$ and longitude $103° \, 51' E$.

Complete the questions on the following page. Note that the size of stars and objects are scaled by their brightness in the night sky, with brighter objects appearing larger.

(a) Along the horizon (circumference of the star chart), mark out the approximate location of cardinal West, with a cross ×. [2]

(b) Trace out the local meridian with a solid arc, and label it M. [2]

(c) Trace out the constellation of *Leo* with solid lines connecting its stars. Label its alpha star α on the star chart. [4]

(d) The pole star *Polaris*, *α Ursae Minoris*, is visible. Mark out the star with an arrow →. The tip of the arrow should point unambiguously at the star. [2]

(d) The following four deep sky objects (DSOs) are visible in the star chart. Mark out any three of these DSOs, each with a hollow circle O, and write that DSO's catalogue designation adjacent to it. The centre of the hollow circle will be taken as the position of that DSO. [9]

(i) M41, an open cluster
(ii) C80, the *ω Centauri Cluster*
(iii) C92, the *Eta Carinae Nebula*
(iv) M51, the *Whirlpool Galaxy*

(e) Calculate the local hour angle of the first point of Libra. [5]

Answer	LHA =

(f) From your answer in (g), mark out the first point of Libra with a cross ×, and label it Ω. State the constellation whose boundaries the first point of Libra currently resides within. [4]

Answer	Constellation:

Part P(C)

(P7) Orthogonal **[10 marks]**

Shown below is the manufacturer's image of the *6" f/5 Meade LX70 R6 Newtonian optical tube assembly* on the *Meade LX70 Equatorial Mount*.

(a) On the image, indicate the polar and declination axes of the telescope by drawing a straight line through each and labelling them P and D respectively. [4]

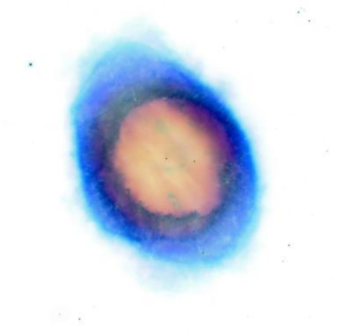
(b) On the image, indicate the directions of motion in RA and declination by drawing a circular arrow ↺ around the appropriate axes and labelling them RA and Dec respectively. [2]

(c) On the image, indicate the declination clutch locking knob by circling it and labelling it K. [2]

(d) On the image, indicate the latitude adjustment knob by circling it and labelling it L. [2]

(P8) **Colours** **[12 marks]**

Shown below is a colour-inverted image of M57, the *Ring Nebula* in constellation *Lyra*, as imaged by the Hubble Space Telescope. At an astronomy retreat at a dark sky site, another astronomer asks you to help him image *M57*. In the space below, plan out a step-by-step procedure for imaging *M57*, including details of your setup, equipment used and processing to the final image, providing specification where necessary.



Proposed setup and procedure for imaging M57: