Instructions

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

2. 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.

3. 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*

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

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

6. 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

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

8. Disruptive behaviour, cheating, collusion to cheat or any integrity-related offences are grounds for immediate disqualification.

At the End of the Competition

9. 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*
   - Tables from Part D
   - Graph papers used in Part D
   - Practical component (fill in the participant code).

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

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

Q12
Diagram extracted from: Buil, C. (2009, November 3). Spectrographic observation series: P Cygni (34 Cyg). Retrieved May 9, 2018, from http://astrosurf.com/buil//star/pcyg/pcyg.htm

Q13
Image from: Fuiji, A. (2005, December 13). Ground-based image of Orion, Canis Minor and Canis Major [Digital image]. Retrieved May 9, 2018, from https://www.spacetelescope.org/images/heic0516d/

Q14
Image of M87's jet from: NASA & The Hubble Heritage Team. (2000, July 6). Black Hole-Powered Jet of Electrons and Sub-Atomic Particles Streams From Center of Galaxy M87. Retrieved May 9, 2018, from http://hubblesite.org/image/968/news_release/2000-20

Annotated close-up Hubble image of M87's jet from: Biretta, J., STScI (1999, January 6). Superluminal Motion in the M87 Jet. Retrieved May 9, 2018, from http://www.stsci.edu/ftp/science/m87/m87.html

Q15
Diagrams and data extracted from: Tully, R., & Fisher, J. (1977). A new method of determining distances to galaxies. *Astronomy and Astrophysics*, **54**(3), 661-673. Retrieved May 9, 2018, from http://adsabs.harvard.edu/abs/1977A&A....54..661T

P3
Image from: Photon Instrument Ltd. (n.d.). Photon ED127 Triplet W/Accessories [Digital image]. Retrieved May 9, 2018, from http://www.photoninstrument.com/.sc/ms/cat/PHOTON INSTRUMENT REFRACTORS

Part A

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

(Q1) Welcome to the new SAO! **[2 marks]**

Because this question setter thinks that SI units are outdated, he has decided to use the SAO paper's characteristics to redefine our SI unit standards: a SAOTime is 3.5 hours, a SAOLength is 29.7 centimetres, and a SAOMass is 22.5 grams.

Express the universal gravitational constant G in SAOUnits, to 2 decimal places.

N.B: This unit system is only used in this question. SI units are definitely not outdated, and the committee has reprimanded this particular question setter.

(Q2) The hot Crab **[2 marks]**

The Crab is a photometric unit used in astronomy to measure the intensity of astrophysical X-ray sources. One Crab is defined as the intensity of the Crab Nebula within the corresponding X-ray photon energy range.

In the photon energy range from 2 to 10 keV, 1 Crab is equal to $I = 2.20 \times 10^{-8}\ erg\ cm^{-2}\ s^{-1}$. $1\ erg$ is equal to $10^{-7}\ J$. Express the intensity of $one\ Crab$ within this photon energy range in SI units.

(Q3) The small one **[2 marks]**

Estimate the mass of the dwarf planet *Pluto*, to one significant figure.

(Q4) Glowing spheres **[2 marks]**

Strömgren spheres are shells of ionised hydrogen (H II) detected around young massive stars of O or B spectral types, due to the large amount of ultraviolet and shorter wavelength radiation they emit. The radius of a classical Strömgren sphere R_S around a star is given by

$$R_S = \left(\frac{3N_*}{4\pi\alpha n_H^2}\right)^{\frac{1}{3}}$$

where N_* is the rate of emission of ionising photons and n_H the surrounding number density of atomic hydrogen. Express the units of the quantum-mechanical recombination coefficient α in SI units.

(Q5) Round and round **[2 marks]**

Three of the four Galilean moons, Io, Europa and Ganymede, are famed for their 1:2:4 Laplace resonance. Given that Io's orbital semi-major axis is $4.22 \times 10^8\ m$, calculate the ratio of Ganymede's orbital semi-major axis to that of Io's.

(Q6) Repeats **[2 marks]**

Indicate if the following statement is True or False.

≫ The synodic period of the superior planets from Earth is always greater than their sidereal periods.

Part B

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

(Q7) Habitable habitats **[9 marks]**

The habitable zone of a star is the range of orbital radii such that a planet orbiting within the range would have a temperature supporting liquid water on its surface, given sufficient atmospheric pressure.

Proxima Centauri B is an exoplanet orbiting the star Proxima Centauri. Suppose it exhibits the greenhouse effect, which intercepts and re-radiates a fraction $\epsilon = 0.4$ of the exoplanet's outgoing radiation back to the surface. Given the following information, calculate the equilibrium surface temperature of Proxima Centauri B. Then, suggest two reasons, with proper justification, why Proxima Centauri may be inhospitable to life.

$M_{star} = 0.123 M_{Sun}$
$R_{star} = 0.141 R_{Sun}$
$T_{star} = 3042\ K$
$a_{planet} = 0.0485\ AU$

(Q8) Cassini's last dance **[9 marks]**

In 2017, the Cassini space probe in orbit around Saturn ran out of rocket propellant and was deliberately crashed into Saturn's dense atmosphere by NASA after a Grand Finale series of orbits. This was done to prevent biological contamination of Saturn's moons, designated as key future exploration targets.

Cassini completed its last full orbit of Saturn prior to the crash with an altitude of $h = 1680\ km$ above Saturn's surface[1], where its elliptical orbit carried it so low it briefly passed through Saturn's atmosphere. From the Cassini End of Mission Press Kit and Orbit Guide (NASA, 2017), in spacecraft time, Cassini reached periapsis at 6:47 pm UTC on 5 Sep 2017 and apoapsis at 12:18 am UTC on 9 Sep 2017. Calculate the apoapsis distance r_a of Cassini's last full orbit.

[1] As Saturn is a gas giant and does not have a solid surface, Saturn's radius is instead defined as the radius at which the atmospheric pressure is equal to 1 bar (100000 Pa), slightly less than the average atmospheric pressure on Earth at sea level.

(Q9) Viewing the Cosmic Microwave Background **[9 marks]**

The Cosmic Microwave Background (CMB) has been conclusively measured to possess a thermal blackbody spectrum with temperature $T = 2.73\,K$. Determine the density parameter of radiation Ω_r, when the peak wavelength of the CMB corresponded to the peak spectral sensitivity of the eye at night, at the wavelength of $\lambda_{peak} = 507\,nm$. The current value of the density parameter of radiation is $\Omega_{\mathrm{r},0} = 5.38 \times 10^{-5}$.

(Q10) Atmospheric refraction **[9 marks]**

Atmospheric refraction can produce some weird effects in Positional Astronomy. Suppose Thanos (aka the mad titan) is a mad Astronomer, and he decides to thicken the Earth's atmosphere to a point where the atmospheric refraction causes a deviation of $\psi = 5°$ near the horizon. The mad titan laughs at the amount of chaos he has brought upon the celestial sphere.

At certain latitudes, some stars that previously never rose above the horizon would suddenly become circumpolar (i.e. never setting) due to this change by Thanos.

Find these particular ranges of latitude where such a phenomenon can be observed. Neglect any small atmospheric refraction that existed before Thanos came along. **Hint: Read the question carefully, there is more than just one case to consider**.

(Q11) Reflection **[9 marks]**

When a photon bounces off a mirror, it will transfer some of its energy to the mirror and cause it to move. However, the photon that bounces away still has energy! What if we let the photon bounce continuously between two solar sails? Consider a solar sail where all the energy of the photon can be harvested, but only with the help of another mirror moving in the opposite direction.

A photon of initial energy E is bouncing between two perfectly-reflecting solar sails of mass $M_0 \gg E/c^2$, each moving with an initial velocity v. The direction of travel of the sails are anti-parallel to each other; the direction of travel of the photon is perpendicular to both sails. After a long time, the photon's energy will be entirely transferred to both sails. Given that the first solar sail absorbs more of the photon's energy than the second solar sail, express the ratio of the amount of energy absorbed by the first to second sail in terms of v. Please consider the case where v is relativistic.

(Q12) P Cygni **[9 marks]**

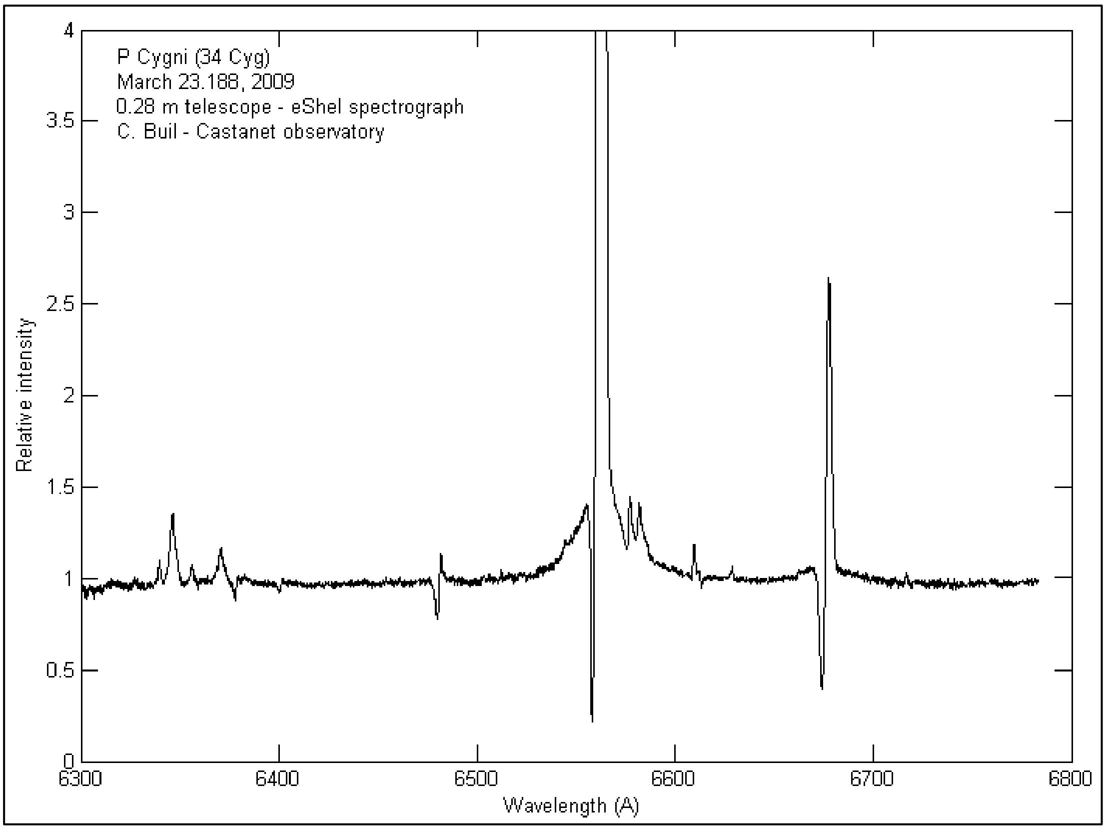
P Cygni is a hypergiant luminous variable (LBV) star of spectral type B1Ia$^+$ in the constellation of Cygnus. It is well-studied as its spectrum exhibits a distinctive spectroscopic feature known as a *P Cygni profile*, where both absorption and emission is present in the profile of the same spectral line. This indicates the presence of a gaseous shell rapidly expanding away from the star, and is suggestive of rapid mass loss from a dense stellar wind.

From Lamers et al. (1983) and Najarro et al. (1997), P Cygni has a mass of $M = 30M_{Sun}$, radius of $R = 76R_{Sun}$ and an estimated luminosity of $L = 6.10 \times 10^5 L_{Sun}$.

Shown below is a spectrum of P Cygni taken in 2009 by C. Buil, centred on the Hα line at rest wavelength $\lambda_{H\alpha} = 6563$Å.

Calculate the ratio of the root-mean-square velocity of hydrogen nuclei to the escape velocity on the surface of P Cygni. You should apply the kinetic theory of gases and may assume its surface temperature is equal to its effective blackbody temperature.

Hence, comment on the mechanism leading to the formation of the *P Cygni profile*.



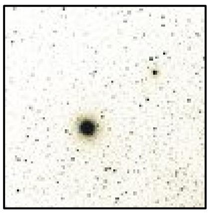
(Q13) Just a line **[9 marks]**

Canis Minor is a bright constellation seen in winter skies. Shown below is an image of its two brightest stars (with colour inverted for printing), along with their positional data. Calculate the angular distance between the two stars. **Do not assume planar geometry**.

The spherical cosine and sine rules are

$$\cos a = \cos b \cos c + \sin b \sin c \cos A$$
$$\frac{\sin a}{\sin A} = \frac{\sin b}{\sin B} = \frac{\sin c}{\sin C}$$

Name	Right Asc.	Declination	Apparent visual mag.
α CMi (Procyon)	07^h39^m	$+05°14'$	0.34
β Cmi (Gomeisa)	07^h27^m	$+08°17'$	2.89

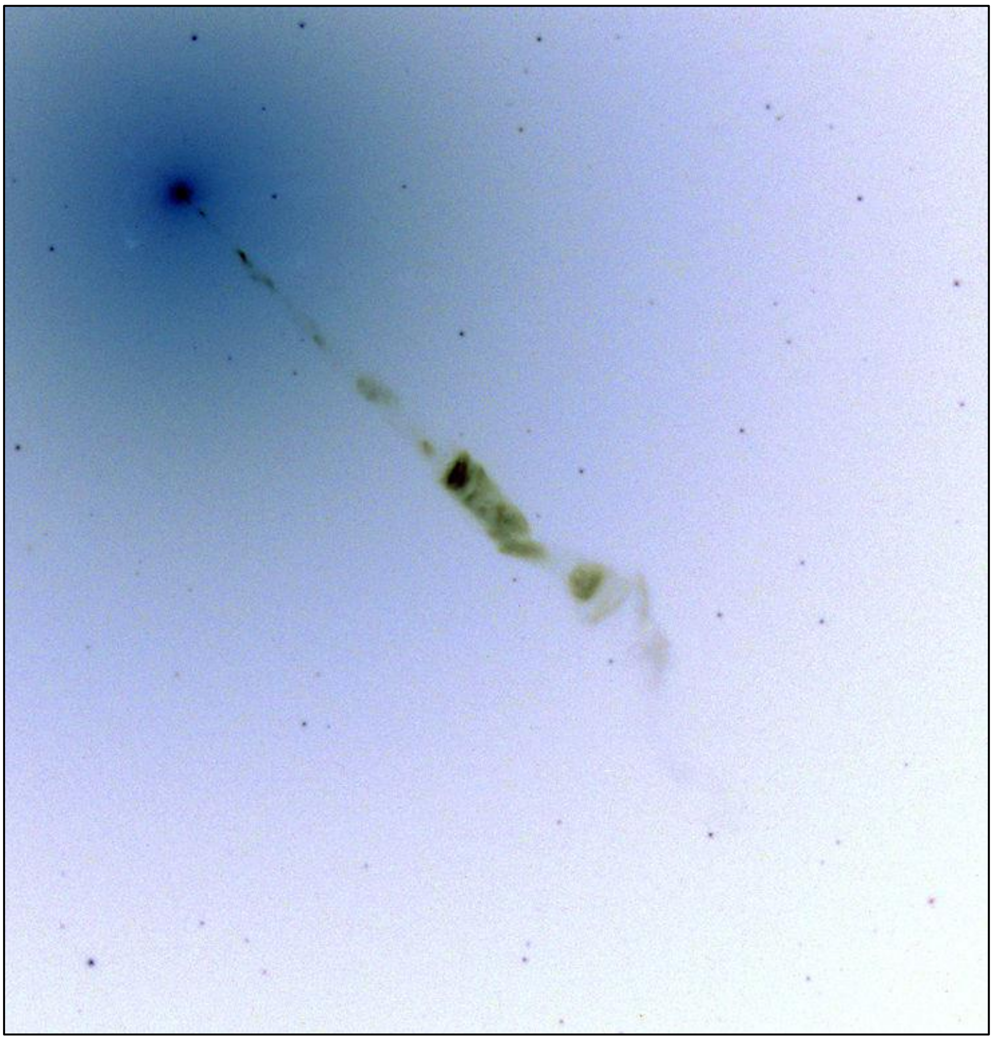


Part C

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

(Q14) Relativistic jet of the type-cD galaxy Messier 87 **[34 marks]**

The supergiant elliptical galaxy *Messier 87* (M87), located at a distance of $d_{M87} = 16.40\ Mpc$ as established by Bird et al. (2004), is the second most luminous galaxy in the Virgo galaxy cluster, and is physically located at its centre. It is notable for its large population of globular clusters and the highly collimated relativistic jet emitted from its active galactic nucleus (AGN).

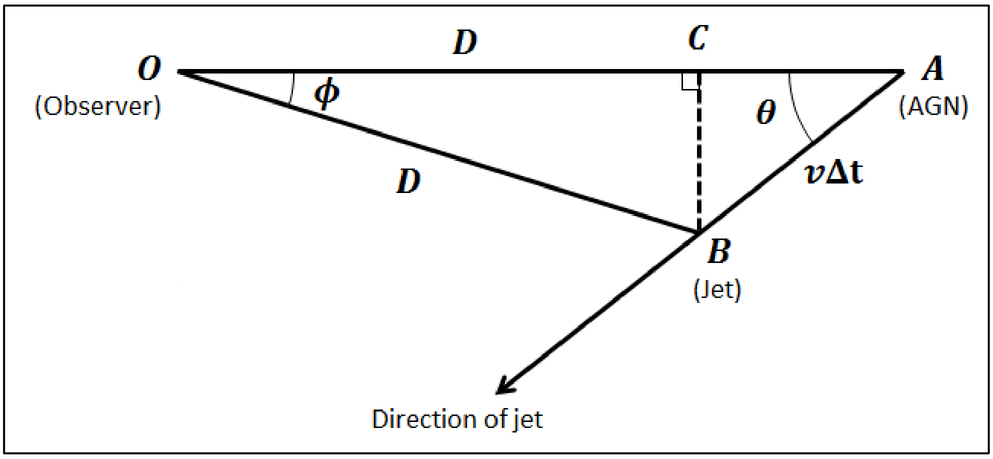


In 1998, scientists recorded exposures of M87's AGN and its jet through ultraviolet, blue, green and infrared filters. The data was collected by the planetary CCD 1 of the Wide Field Planetary Camera 2 (WFPC2) onboard the Hubble Space Telescope (HST), and combined to create the above colour image. Note that the colours in the image have been inverted for printing.

(a) The image on the previous page has dimensions, in pixels, of $(h, w) = (708, 678)$. Using the specifications for the HST and planetary CCD 1 of the WFPC2 given below, calculate the apparent transverse length of the jet in optical wavelengths D_{jet} in parsecs. [7]

Dimensions (in pixels)	Usable FoV	Pixel Size	Aperture of HST	Focal ratio (f-number)
800×800	$35'' \times 35''$	$15 \times 15\ \mu$m	2.40 m	28.3

Follow-up high resolution imaging of the AGN region of M87 by scientists from the Space Telescope Science Institute (STScI) in 1999 shows knots of matter and plasma in the relativistic jet. These knots were measured to have apparent transverse velocities exceeding the speed of light. Shown below is a schematic diagram of this phenomenon, known as *apparent superluminal motion*.



Consider a relativistic jet emitted from an AGN at point $\boldsymbol{A}$, moving along $\boldsymbol{AB}$ with velocity $\boldsymbol{v} = \boldsymbol{\beta c}$ at an angle $\boldsymbol{\theta}$ from the line of sight $\boldsymbol{OA}$. In a short time $\boldsymbol{\Delta t}$, such that the angle $\boldsymbol{\phi}$ is sufficiently small for $\boldsymbol{OC} \approx \boldsymbol{OB} = \boldsymbol{D}$, matter in the jet has travelled a distance $\boldsymbol{v\Delta t}$ from point $\boldsymbol{A}$ to point $\boldsymbol{B}$.

The relativistic jet emits a light ray at point $\boldsymbol{A}$ towards the observer $\boldsymbol{O}$, and after $\boldsymbol{\Delta t}$, emits another light ray from point $\boldsymbol{B}$ towards the observer $\boldsymbol{O}$. The light rays arrive at the observer $\boldsymbol{O}$ with a time delay $\boldsymbol{\Delta t'}$.

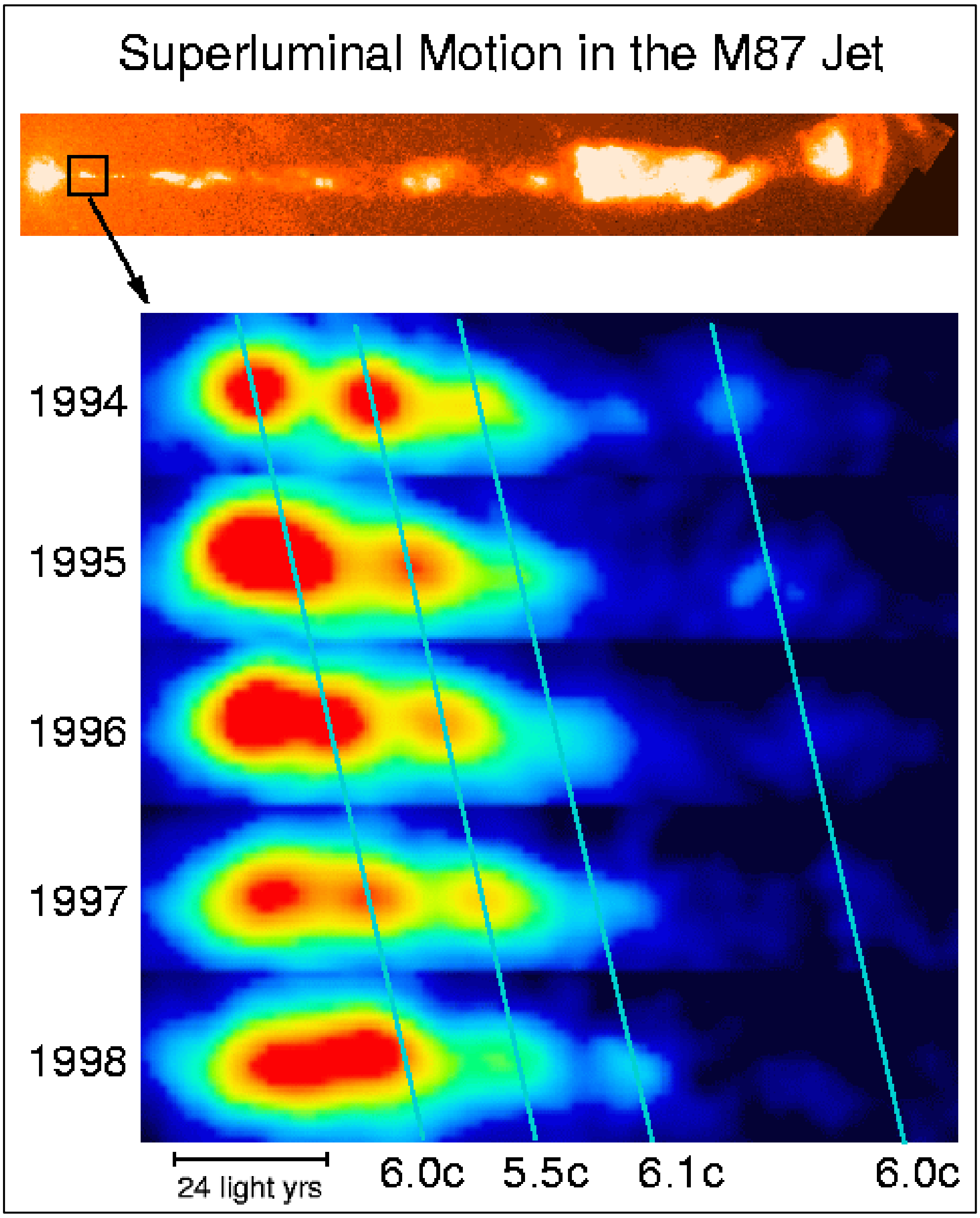
(b) With reference to the diagram above, prove that the time delay $\boldsymbol{\Delta t}$ can be expressed as

$$\Delta t = \frac{\Delta t'}{1 - \beta \cos \theta}$$

in terms of $\boldsymbol{\Delta t'}$, $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$. [7]

(c) With reference to the diagram above, use the small angle approximation to derive an expression for the apparent transverse distance $\boldsymbol{BC}$ travelled by the jet. Then, continuing from part (b), derive an expression for $\boldsymbol{\beta_t}$, the ratio of the apparent transverse velocity of the jet $\boldsymbol{v_t}$ measured along $\boldsymbol{BC}$ to the speed of light, in terms of $\boldsymbol{\beta}$ and $\boldsymbol{\theta}$. [5]

STSI published the following sequence of images recorded with the Faint Object Camera on the HST, which shows apparent motion of knots of matter at least five times the speed of light in the inner part of the relativistic jet of M87. The scale bar is provided for reference.



(d) Calculate the mean apparent transverse velocity of the inner part of the jet relative to the speed of light $\langle\boldsymbol{\beta_t}\rangle$, from the image above. [2]

(e) Let the physical velocity of the matter in the inner part of the relativistic jet of M87 be $\boldsymbol{v} = \boldsymbol{kc}$, where $0 < \boldsymbol{k} < 1$. Then, substitute $\langle \boldsymbol{\beta_t} \rangle$ from part (d) into the expression obtained in part (c), and using the trigonometric identity

$$R\cos(\theta \pm \alpha) = R\cos\alpha\cos\theta \mp R\sin\alpha\sin\theta$$

where R and α are positive constants to be found, find an expression for the emission angle of the relativistic jet $\boldsymbol{\theta}$, where $0° < \boldsymbol{\theta} < 90°$. [9]

(f) Continuing from parts (d) and (e), calculate the minimum velocity $\boldsymbol{v_{min}}$ of the matter in the inner part of the relativistic jet of M87. No calculus is required here, but you are expected to show your reasoning clearly. [4]

Part D

Answer **the whole question** on the blank SAO answer sheets and graphing paper.
Detach Table 1 and attach it to your answer script.

(Q15) The Tully-Fisher relation **[40 marks]**

The *Tully-Fisher relation* (TFR) is an empirical relationship between the intrinsic luminosity of a spiral galaxy and its angular velocity or emission line width. Here, we use the form

$$\Delta V(o) = Ae^{\alpha M}$$

where M is the absolute magnitude of the galaxy, e is the natural constant, α is an exponent, A is some constant to be found and $\Delta V(o)$ is the velocity width of the galaxy, explained below.

Table 1 provides actual data from Tully and Fisher's 1975 paper, as well as intermediate papers – here's your chance to make a groundbreaking discovery! The data comprises 10 galaxies, taken from 3 major clusters (The Local Group, M81 group and the M101 group).

Part 1: HI Profiles

Neutral hydrogen (HI) is ubiquitous in galaxies, and is detected from the radiation of wavelength of 21 cm it emits. Hence, this emission line is also commonly referred to as the *21-cm line*. For the interested student, this is a direct result of hyperfine splitting of the levels of the Hydrogen atom!

Figure 1 shows three graphs of the HI line profiles of the galaxies NGC 2366, 4236 and 5204 respectively. Due to the Doppler effect, the emission line is broadened, and so we observe it at a range of frequencies.

Each graph is a plot of the strength of the HI emission line against the velocity difference that caused the corresponding Doppler shift in the emission. In the original paper, the TFR uses the velocity width at 20% of the maximum intensity. This maximum intensity is computed across the whole broadened width of the HI line.

(a) Column 7 of Table 1 is incomplete. Use the three plots in Figure 1 to complete Column 7, documenting your estimations in your answer sheet. Note that all three graphs are linear in their vertical axes (i.e. no distortions in the vertical scale). [9]

Part 2: Absolute Magnitude

In this part, you are to determine the absolute magnitude of all the galaxies shown in Table 1 using Columns 1-4.

Column 1 contains the calibrated luminosity distances to each galaxy d_c.
Column 2 contains each galaxy's apparent magnitude m.
Column 3 contains extinction values for that galaxy due to galactic extinction, A_{ex}.
Column 4 contains additional extinction values for certain galaxies due to galactic absorption, A_{abs}. A dash here indicates that the extinction is assumed to be zero in calculations.

(b) Calculate the absolute magnitudes of each galaxy and fill in Column 5. Remember to correct for the extinction sources in Columns 3 and 4 to obtain the correct absolute magnitudes. [5]

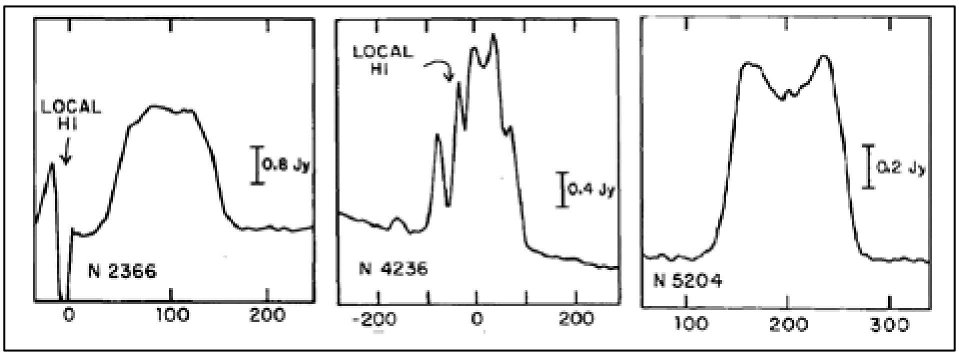
Part 3: The Tully-Fisher relation
Column 6 contains the relative inclination angle of the rotational plane of each galaxy, ξ.
Column 7 is the observed velocity width determined previously above, ΔV.
Column 8 is the true velocity width $\Delta V(o)$, which can be computed from

$$\Delta V(o) = \frac{\Delta V}{\sin \xi}$$

(c) Calculate and fill in Column 8. [5]

(d) Linearise the TFR, then plot a graph using relevant information in Table 1 to determine the exponent α, giving your answer with correct units. Remember to use the correct values in your graph! **Poor graphing etiquette will be penalised**. [21]

Figure 1: HI line profiles for missing data in Table 1



Jy stands for *Jansky*, a unit of spectral flux radiance equal to $10^{-26}\ W\ m^{-2}\ Hz^{-1}$. The horizontal axis of the graphs is in $km\ s^{-1}$.

Table 1 is detailed on the next page.

Table 1: Selected data from *Tully & Fisher* (1975)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Galaxy	d_c/Mpc	m	A_{ex}	A_{abs}	M	$\xi/°$	ΔV	$\Delta V(o)$
Local Group								
M31	0.710	4.33	0.44	0.60		78	535	
M33	0.817	6.19	0.12	0.17		55	198	
M81 Group								
M81	3.25	7.85	0.07	0.23		58	450	
NGC 2403	3.25	8.80	0.24	0.17		60	265	
NGC 4236	3.25	10.05	0.02	-		75		
IC 2574	3.25	10.91	0.04	-		68	117	
NGC 2366	3.25	11.41	0.19	-		63		
M101 Group								
NGC 5585	7.24	11.25	0	-		51	214	
NGC 5204	7.24	11.62	0	-		57		
Ho IV	7.24	12.95	0	-		70	103	

Participant Code	

Part P(A)

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

(P1) A for alpha **[2 marks]**

From your practical experience, which of the following stars (with their apparent magnitudes listed) is not visible to the naked-eye in Singapore?

A Alphard, $\alpha\ Hya$ (mag 2.00)
B Achernar, $\alpha\ Eri$ (mag 0.46)
C Alnair, $\alpha\ Gru$ (mag 1.74)
D None of the above

Answer

(P2) Seems bright? **[2 marks]**

Deep sky objects (DSOs) with bright (less positive) magnitudes are not necessarily always easy to observe. From your practical experience, which of the following bright DSOs is the easiest to observe in a small telescope in Singapore?

A *C92/NGC3372*, the *Eta Carinae Nebula* (mag 3.0)
B *M31*, the *Andromeda Galaxy* (mag 3.4)
C *M42*, the *Orion Nebula* (mag 4.0)
D *C20/NGC7000*, the *North American Nebula* (mag 4.0)

Answer

(P3) On the OTA **[2 marks]**

Shown below is an image of a telescope accessory (circled) attached to the optical tube assembly (OTA) of a refractor. Indicate in the box the option that describes the **main** purpose of using such an accessory.

A Balance the weight of the finder scope and accessories on the opposite end of the optical tube
B Reduce the rate of condensation of atmospheric water vapour on exposed mirror or lens surfaces
C Reduce lateral stray light entering the optical tube to enhance contrast during viewing and astrophotography
D This is not a telescope accessory; it is part of the optical tube

Answer

(P4) Noise **[2 marks]**

An astrophotographer wants to image Messier 42, the *Orion Nebula*, and has set up his DSLR attached to a well-calibrated guided telescope setup. Tick in the adjacent box, all options that describe measures that would improve the final signal-to-noise (SNR) ratio of the post-processed image.

	Increase the number of exposures but maintain total exposure time
	Increase the length of each exposure without oversaturating the image
	Increase the ISO setting on the DSLR
	Capture the exposures on a night with lower ambient temperature

(P5) All over **[2 marks]**

The following are four astronomical objects or phenomena that are visible from Earth. Tick in the adjacent box, all options whose spatial distribution is approximately isotropic and random in the night sky.

	Nearby stars (with proper motion exceeding one arcsecond per year)
	Globular clusters
	Supernovae remnants
	Gamma-ray bursts

Part P(B)

(P6) Starry Night Over the Rhône **[28 marks]**

The star chart below shows the night sky at 9pm local time on 11 Nov 2018 (49 days after the Autumnal Equinox), from the Rhône (UTC +01:00), at an unknown latitude and longitude.

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) Trace out the local prime vertical with a solid arc, and label it V. [1]

(b) Trace out the constellation named after a vain queen in Greek mythology who boasted of her daughter's beauty, with solid lines connecting its stars. [2]

The Great Square of Pegasus

(c) Trace out the asterism *the Great Square of Pegasus* with solid lines connecting its stars. [2]

(d) One of the four stars that make up the vertices of the *Great Square of Pegasus* is in fact within another constellation's boundaries. Mark out this star with an arrow → and write either its common name or IAU designation in the box below. The tip of the arrow should point unambiguously at the star. [3]

Answer	Common name/Bayer designation of star:

Observation Targets

(e) The planet *Mars* is visible with an apparent magnitude of $m = -0.41$. Amongst the stars in the night sky, only *Sirius* and *Canopus* appear brighter. Mark out *Mars* with a double-headed arrow ↠. The tip of the arrow should point unambiguously at the planet. [2]

(f) The following three deep sky objects (DSOs) are visible in the star chart. Mark out all 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. [6]

(i) M31, the *Andromeda Galaxy*
(ii) M1, the *Crab Nebula*
(iii) M13, the *Great Globular Cluster in Hercules*

Missing Tails

(g) Three stars have been removed from the star chart. Mark out the locations of each of these three stars with a cross ×, and write their name adjacent to it. The centre of the cross will be taken as the position of that star. [6]

(i) Deneb, $\alpha\ Cyg$
(ii) Deneb Algedi, $\delta\ Cap$
(iii) Deneb Kaitos (Diphda), $\beta\ Cet$

[Question continues on the next page]

The Rhône

(h) Due to the nature of the stereographic projection, the zenith angle z of a point on the star chart is given by

$$z = 2\arctan\left(\frac{R}{R_0}\right)$$

where R is the radial distance from the origin (centre) of the star chart and R_0 is the radius of the star chart. Estimate the latitude of the Rhône to the nearest tenth of a degree, and indicate if it is North (N) or South (S) of the Equator. [2]

Answer	Latitude =

(i) In the star chart, the star $\gamma\ Cep$, with common name *Errai*, is marked out. *Errai* has a right ascension of $23^h 40^m$. Estimate the longitude of the Rhône to the nearest tenth of a degree, and indicate if it is West (W) or East (E) of the Prime Meridian. [4]

Answer	Longitude =

Part P(C)

(P7) The sidewalk **[22 marks]**

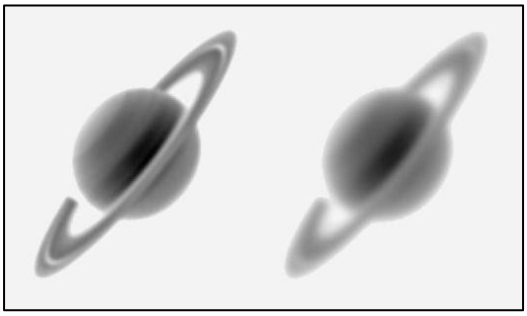
As a local astronomy enthusiast, you decide to organise your own sidewalk astronomy stargazing event in the evening of August 2018 with a group of friends. Answer the following questions in the blanks provided.

(a) For the best stargazing experience, outline three considerations for the location of your sidewalk astronomy event. **You do not need to propose an actual location**. [6]

(b) For the sidewalk event, you have brought along your Newtonian reflector and equatorial mount. Describe the sequence of steps you would take to set up your telescope to be ready for viewing, specifying accessories or tools where necessary. [5]

(c) Your telescope is currently pointed at *Messier 6*, the *Butterfly Cluster*. You intend to show the crowd *Messier 7*, the *Ptolemy Cluster*, next. In what direction(s) and how much do you adjust your telescope (on your **equatorial mount**) to point to *M7* from *M6*? [4]

(d) Mid-way through the event, someone accidentally knocked over your telescope. You right your telescope back up and attempt to point at *Saturn* in *Sagittarius*. However, unlike earlier (left image below), you are unable to focus *Saturn* in the eyepiece to achieve a sharp and crisp view of the planet, only obtaining a blurred and fuzzy view (right image below).



Describe what has happened to your telescope and how you would fix your telescope, with aid of accessories or tools if necessary, to restore the view of *Saturn* to that of the left image above. Labelled diagrams are accepted as part of your answer. [7]