The 1st International Olympiad on Astronomy and Astrophysics

Chiang Mai, Thailand

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Chiang Mai, Thailand

Theoretical Competition

Wednesday, 5 December, 2007

QUESTION 1. (30 points for 15 short questions, 2 points for each short question)
Show, in a few steps in the writing sheets, your method of solution. Write your final answers in the answer sheets provided. Partial credits will be given for answers without showing method of solution.

1.1 For an observer at latitude 42.5^o N and longitude 71^o W, estimate the time of sun rise on 21 December if the observer's civil time is -5 hours from GMT. Ignore refraction of the atmosphere and the size of the solar disc.

1.2 The largest angular separation between Venus and the Sun, when viewed from the Earth, is 46^o. Calculate the radius of Venus's circular orbit in A.U.

1.3 The time interval between noon on 1 July and noon on 31 December is 183 solar days. What is this interval in sidereal days?

1.4 One night during a full Moon, the Moon subtends an angle of 0.46 degree to an observer. What is the observer's distance to the Moon on that night?

1.5 An observer was able to measure the difference in the directions, due to the Earth's motion around the Sun, to a star as distant as 100 parsecs away. What was the minimum angular difference in arc seconds this observer could measure?

1.6 A Sun-orbiting periodic comet is the farthest at 31.5 A.U. and the closest at 0.5 A.U.. What is the orbital period of this comet?

1.7 For the comet in question 1.6, what is the area (in square A.U. per year) swept by the line joining the comet and the Sun?

1.8 At what wavelength does a star with the surface temperature of 4000 K emit most intensely?

1.9 Calculate the total luminosity of a star whose surface temperature is 7500 K, and whose radius is 2.5 times that of our Sun. Give your answer in units of the solar luminosity, assuming the surface temperature of the Sun to be 5800 K.

1.10 A K star on the Main Sequence has a luminosity of $0.4 L_{\odot}$. This star is observed to have a flux of 6.23×10^{-14} W.m^{-2}. What is the distance to this star? You may neglect the atmospheric effect.

1.11 A supernova shines with a luminosity 10^{10} times that of the Sun. If such a supernova appears in our sky as bright as the Sun, how far away from us must it be located?

1.12 The (spin-flip) transition of atomic hydrogen at rest generates the electromagnetic wave of the frequency $n_0 = 1420.406$ MHz. Such an emission from a gas cloud near the galactic center is observed to have a frequency $n = 1421.65$ MHz. Calculate the velocity of the gas cloud. Is it moving towards or away from the Earth?

1.13 A crater on the surface of the Moon has a diameter of 80 km. Is it possible to resolve this crater with naked eyes, assuming the eye pupil aperture is 5 mm ?

1.14 If the Sun were to collapse gravitationally to form a non-rotating black hole, what would be its event horizon (its Schwarzschild radius)?

1.15 The magnitude of the faintest star you can see with naked eyes is $m = 6$, whereas that of the brightest star in the sky is $m = -1.5$. What is the energy-flux ratio of the faintest to that of the brightest?

QUESTION 2 **A PLANET & ITS SURFACE TEMPERATURE (10 points)**

A fast rotating planet of radius R with surface albedo a is orbiting a star of luminosity L. The orbital radius is D. It is assumed here that, at equilibrium, all of the energy absorbed by the planet is re-emitted as a blackbody radiation.

a.) What is the radiation flux from the star at the planet's surface? (1.5 points)

b.) What is the total rate of energy absorbed by the planet? (1.5 points)

c.) What is the reflected luminosity of the planet? (2 points)

d.) What is the average blackbody temperature of the planet's surface? (2 points)

e.) If we were to assume that one side of the planet is always facing the star, what would be the average surface temperature of that side? (2 points)

f.) For the planet in problem d:

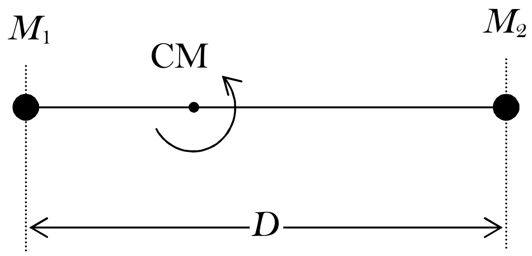
$a = 0.25$,

$D = 1.523$ A.U.,

calculate its surface temperature in kelvins for the value of $L = 3.826 \times 10^{26}$ W.

(1 point)

QUESTION 3 BINARY SYSTEM (10 points)



A binary star system consists of M_1 and M_2 separated by a distance D. M_1 and M_2 are revolving with an angular velocity w in circular orbits about their common centre of mass. Mass is continuously being transferred from one star to the other. This transfer of mass causes their orbital period and their separation to change slowly with time.

In order to simplify the analysis, we will assume that the stars are like point particles and that the effects of the rotation about their own axes are negligible.

a) What is the total angular momentum and kinetic energy of the system? (2 points)

b) Find the relation between the angular velocity w and the distance D between the stars. (2 points)

c) In a time duration $\mathrm{D}t$, a mass transfer between the two stars results in a change of mass $\mathrm{D}M_1$ in star M_1, find the quantity $\mathrm{D}w$ in terms of w, M_1, M_2 and $\mathrm{D}M_1$. (3 points)

d) In a certain binary system, $M_1 = 2.9\ \mathrm{M}_\odot$, $M_2 = 1.4\ \mathrm{M}_\odot$ and the orbital period, $T = 2.49$ days. After 100 years, the period T has increased by 20 s. Find the value of $\frac{\mathrm{D}M_1}{M_1 \mathrm{D}t}$ (in the unit "per year"). (1.5 points)

e) In which direction is mass flowing, from M_1 to M_2, or M_2 to M_1? (0.5 point)

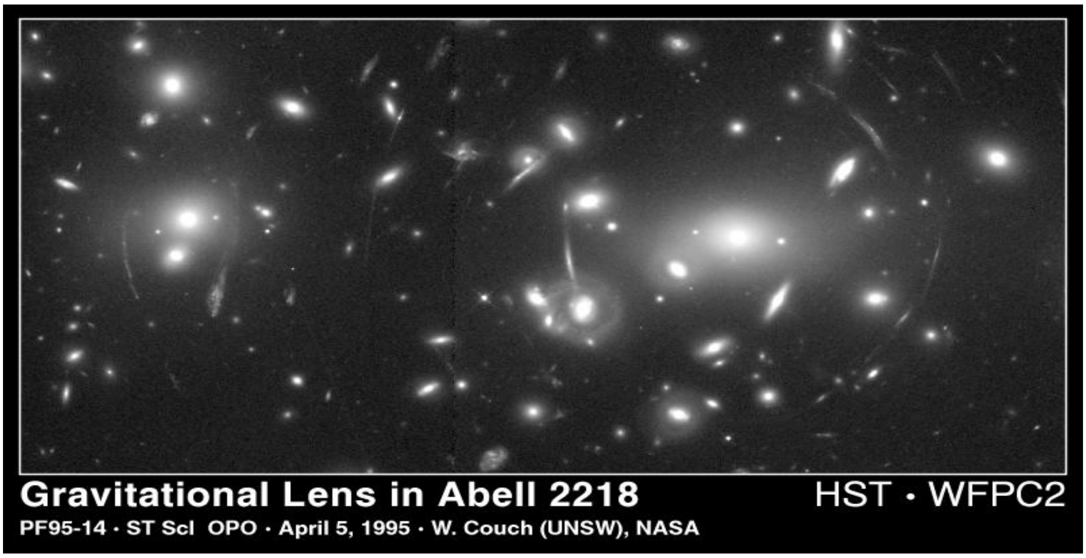
f) Find also the value of $\frac{\mathrm{D}D}{D\mathrm{D}t}$ (in the unit "per year"). (1 point)

You may use these approximations:

$(1+x)^n : 1+nx$, when $x = 1$;

$(1+x)(1+y) : 1+x+y$, when $x = 1, y = 1$.

<u>QUESTION 4</u> **GRAVITATIONAL LENSING (10 points)**



The deflection of light by a gravitational field was first predicted by Einstein in 1912 a few years before the publication of the General Relativity in 1916.
A massive object that causes a light deflection behaves like a classical lens.
This prediction was confirmed by Sir Arthur Stanley Eddington in 1919.

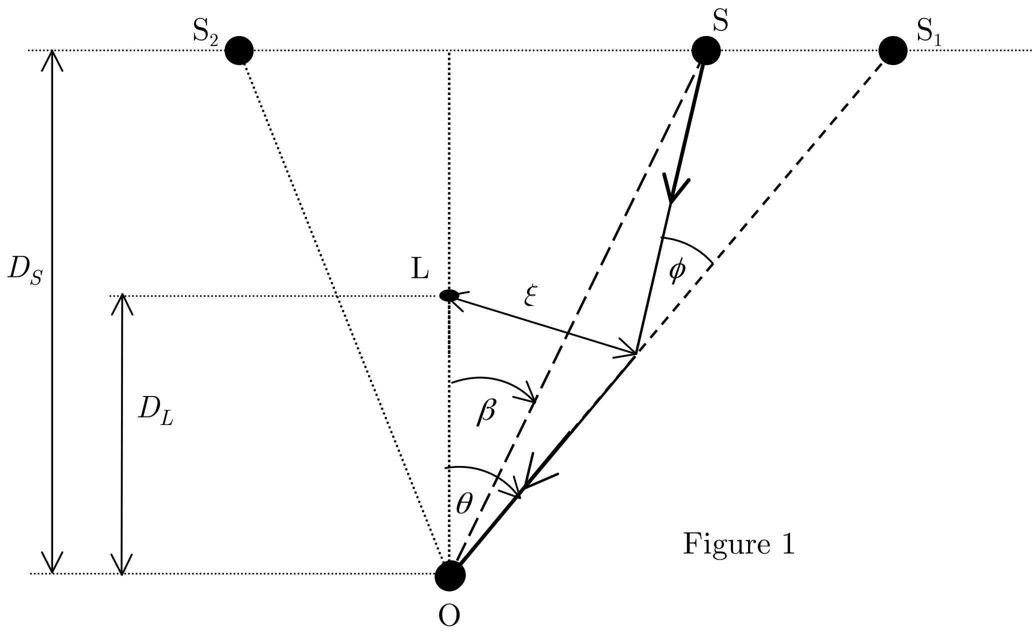


Figure 1

Consider a spherically symmetric lens, with a mass M with an impact parameter ξ from the centre. The deflection equation in this case is given by:

$$\phi = \frac{4GM}{\xi c^2} \quad \text{, a very small angle}$$

In figure 1, the massive object which behaves like a lens is at L. Light rays emitted from the source S being deflected by the lens are observed by observer O as images S_1 and S_2. Here, ϕ, β, and θ are very very small angles.

a) For a special case in which the source is perfectly aligned with the lens such that $\beta = 0$, show that a ring-like image will occur with the angular radius, called Einstein radius θ_E , given by:

$$\theta_E = \sqrt{\left(\frac{4GM}{c^2}\right)\left(\frac{D_S - D_L}{D_L D_S}\right)} \qquad \text{(2 points)}$$

b) The distance (from Earth) to a source star is about 50 kpc. A solar-mass lens is about 10 kpc from the star. Calculate the angular radius of the Einstein ring formed by this solar-mass lens with the perfect alignment. (1 point)

c). What is the resolution of the Hubble space telescope with 2.4 m diameter mirror? Could the Hubble telescope resolve the Einstein ring in b)? (2 points)

d). In figure 1, for an isolated point source S, there will be two images $(S_1 \text{ and } S_2)$ formed by the gravitational lens. Find the positions (θ_1 and θ_2)of the two images. Answer in terms of β and θ_E. (2 points) e). Find the ratio $\frac{\theta_{1,2}}{\beta}$ ($\frac{\theta_1}{\beta}$ or $\frac{\theta_2}{\beta}$) in terms of η. Here $\theta_{1,2}$ represents each of the image positions in d.) and η stands for the ratio $\frac{\beta}{\theta_E}$. (2 points)

f). Find also the values of magnifications $\frac{\Delta\theta}{\Delta\beta}$ in terms of η for $\theta = \theta_{1,2}$ ($\theta = \theta_1$ or $\theta = \theta_2$), when $\Delta\beta \ll \beta$, and $\Delta\theta \ll \theta$. (1 point)

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Experimental Competition (Observation)

Sunday, 2 December, 2007

Please read this first:

1. There are 2 parts to the questions. You have to use the provided equipment to point, observe and answer where appropriate.
2. The time available is **40 minutes** in total for the experimental competition (Observation), **20 minutes for each part**.
3. In Part I, use only the provided celestial object pointer to point at the target specified in the questions. **No other pointer is allowed**. The marker (examiner) at each observation station will then mark the answers directly in the question sheet. You must not write anything in the sheet apart from your country code and student code.
4. In Part II, use the provided binoculars to observe the objects and then answer the questions by writing or drawing directly in the question sheets.
5. At the end of both parts, leave the question sheets with the marker (examiner) at each observation station. You are not allowed to take any sheets of paper out of the observation station.
6. Use only the provided pen or pencil.
7. Students given questions in English and national language can answer in any one sheet but must return both to the marker (examiner).
8. Fill the boxes at the top of each sheet of paper with your country code, your student code.

Country Code	Student Code

PART I: Use the provided celestial object pointer (total 10 points)

1.1 Move the pointer along the celestial equator. **(1 point)**

✓ ✗

1.2 Aim the pointer at the vernal equinox. **(1 point)**

✓ ✗

1.3 In the constellation of Pegasus and its vicinity there is an obvious square of bright stars (*Great Square of Pegasus*), aim the pointer at the brightest star of the square. **(2 points)**

✓ ✗

1.4 Aim the pointer at the star named alpha-Arietis (α-Ari). **(2 points)**

✓ ✗

1.5 Start from the star named Aldebaran (α-Tauri) in the constellation Taurus, turn the pointer 35 degrees northward followed by 6 degrees westward (in equatorial coordinate). Then, aim the pointer at the brightest star in the field of view. **(4 points)**

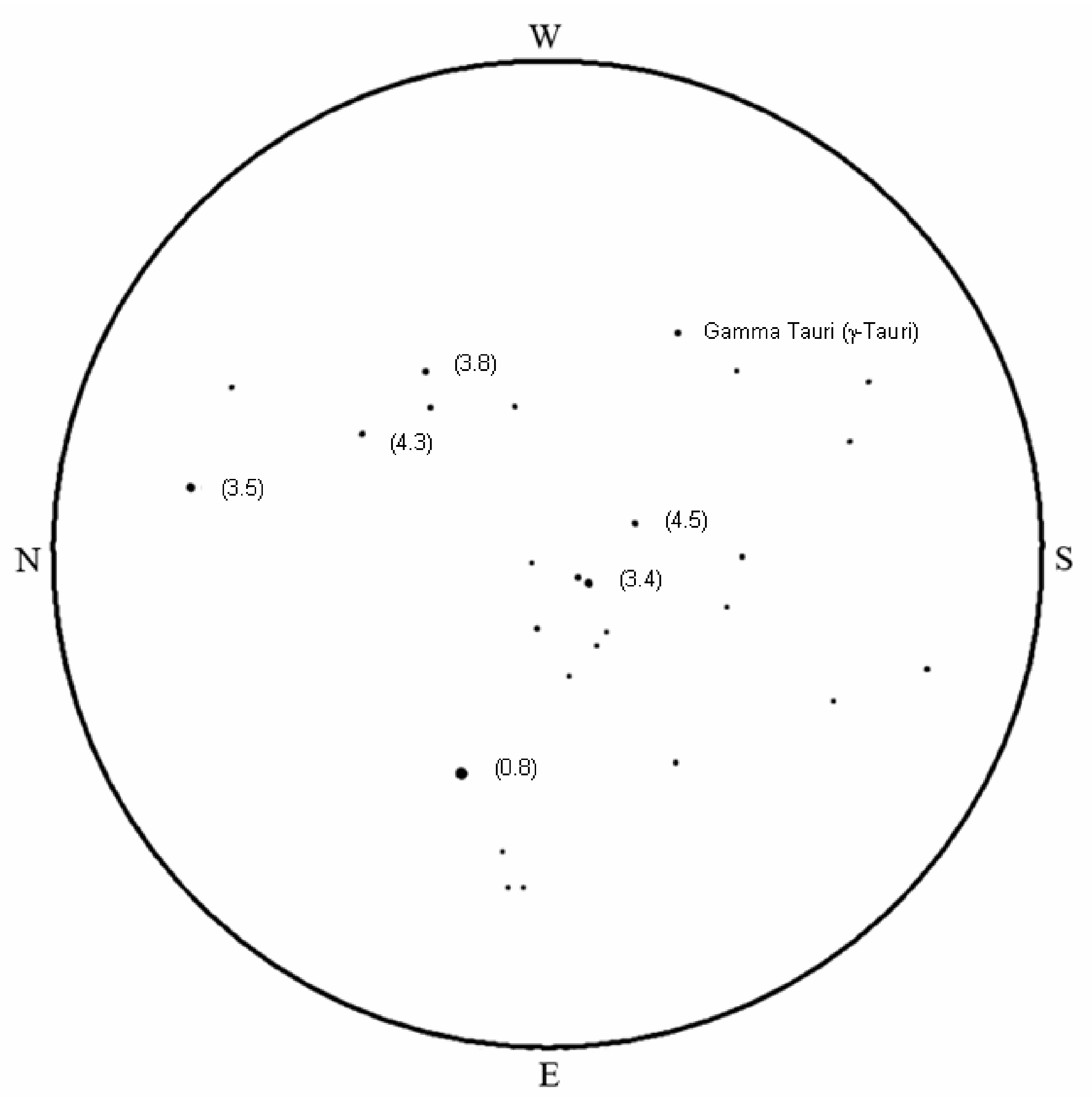
✓ ✗

Signature of Marker______________________________

Country Code	Student Code

PART II: Use the provided binoculars (total 10 points)

2.1 The open star cluster "Hyades" in constellation Taurus is one of the nearest clusters to us, being only 151 light years away. From the provided chart with brightness of some stars indicated by the apparent magnitude in parentheses, please estimate the apparent magnitude of the star Gamma-Tauri (γ-Tauri) to the nearest first decimal digit. **(5 points)**



7 X 50 Binocular FOV

Answer: The apparent magnitude of γ-Tauri = ____________

Marker (examiner) comments on sky condition: ___________________________________

Country Code	Student Code

2.2 Observe the Andromeda Galaxy (M31) then draw the approximate **<u>shape and size</u>** of the galaxy that you see through the binoculars in the frame below with correct orientation (in equatorial coordinates). The field of view of the binoculars is 6.8 degrees. **(5 points)**

W

N **S**

E

$\underbrace{\hspace{10cm}}_{\textbf{3 degrees}}$

Marker (examiner) comments on sky condition: ____

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Experimental Competition (Data Analysis)

Monday, 3 December, 2007

Please read this first:

1. The time available is 3 hours for the experimental competition (Data analysis). There are three questions (and a set of data table).
2. Use only the pen provided.
3. Use only the front side of ***writing sheets***. Write only inside the boxed area.
4. Begin each question on a separate sheet.
5. For each question, in addition to the ***blank writing sheets***, there are the ***Answer Sheets*** where you *must* summarize the results you have obtained. Numerical results should be written with as many digits as are appropriate.
6. Write on the blank ***writing sheets*** whatever you consider is required for the solution of the question. Please use *as little text as possible*; express yourself primarily in equations, numbers, figures, and plots.
7. Fill the boxes at the top of each sheet of paper with your country code, your student code, the question number, for each question the consecutive number of each sheet (Page Number), and the total number of ***writing sheets*** used. If you use some blank ***writing sheets*** for notes that you do not wish to be marked, put a large X across the entire sheet and do not include it in your numbering.
8. Students given questions, writing sheet and answer sheets in English and national language can answer in any one sheet but must return both to the marker (examiner).

9. At the end of the exam, arrange all sheets for each problem *in the following order:*
   - *Answer Sheet(s)*
   - used *writing sheets* in order
   - the sheets you do not wish to be marked
   - unused sheets and the printed question

   Place the papers inside the envelope and leave everything on your desk. You are not allowed to take *any* sheets of paper out of the room.

Some useful information for calculation

Astronomical unit (A.U.)	149,597,870 km
Mean distance, Earth to Moon	384,399 km
Obliquity of the ecliptic	23° 26'
Earth's mean radius	6,371.0 km
Earth's mean velocity in orbit	29.783 km/s
Sidereal year	365.2564 days
Tropical year	365.2422 days
Sidereal month	27.3217 days
Synodic month	29.5306 days
Mean sidereal day	23h56m4s.091 of mean solar time
Mean solar day	24h3m56s.555 of sidereal time

Question 1 **Galilean moons (4 points)**

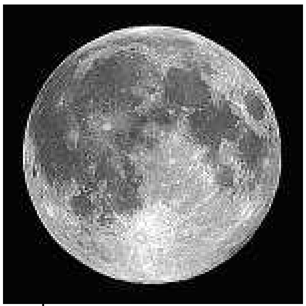
Computer simulation of the planet Jupiter and its 4 Galilean moons is shown on the screen similar to the view you may see through a small telescope. After observing the movement of the moons, please identify the names of the moons that appear at the end of the simulation. (Simulation will be played on screen during the first fifteen minutes and the last fifteen minutes of the exam)

Question 2 **The Moon's age (8 points)**

The 60th anniversary celebrations of King Bhumibol Adulyadej's accession to the throne of Thailand (GMT +07) were held on the 8th to the 13th June, 2006. Photographs of the Moon taken at the same hour each night are shown below:


8th June, 2006


9th June, 2006


10th June, 2006


11th June, 2006


12th June, 2006


13th June, 2006

Assuming that Albert Einstein's birth was at noon on 14th March, 1879, use the data provided above to find the Moon's age (number of days after the new moon) on his birth date in Germany (GMT +01). Please show the method used for the calculation in detail. Estimate the errors in your calculation.

<u>Question 3</u> **Solar System objects (8 points)**

A set of data containing the apparent positions of 4 Solar System objects over a period of 1 calendar year is given in Table 1. Show your method of data analysis carefully and answer the following questions.

Location of observer	Latitude :	N 18° 47’ 00.0”
	Longitude :	E 98° 59’ 00.0”

3.1 Put the letters A, B, C and D beside the appropriate objects on the answer sheet. **(2 points)**

3.2 During the period of observation, which object could be observed for the longest duration at night time? **(1 point)**

3.3 What was the date corresponding to the situation in 3.2? **(1 point)**

3.4 Assuming the orbits are coplanar (lie on the same plane) and circular, indicate the positions of the four objects and the Earth on the date in 3.3, in the orbit diagram provided in your answer sheet. The answer (sheet) must show one of the objects as the Sun at the centre of the Solar System. Other objects including the Earth must be specified together with the correct values of elongation on that date. **(4 points)**

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