The 4th IOAA Problems and Solutions

- Theoretical Competition
- Practical Competition: Data Analysis
- Observational Competition
- Team Competition
- Samples of Problems in Different Languages
- Samples of Solutions

The 4^{th} IOAA

Theoretical Competition

Please read these instructions carefully:

1. Each student will receive problem sheets in English and/or in his/her native language.
2. The time available for answering theoretical problems is 5 hours. You will have 15 short problems (Theoretical Part 1, Problem 1 to 15), and 2 long problems (Theoretical Part 2, Problem 16 and 17).
3. Use only the pen that has been provided on your desk.
4. Begin answering each problem on a new page of the notebook. Write down the number of the problem at the beginning.
5. Write down your "country name" and your "student code" on the cover of the notebook.
6. The final answer in each question or part of it must be accompanied by units and the correct number of significant digits (use SI or appropriate units). At most 20% of the marks assigned for that part will be deducted for a correct answer without units and/or with incorrect significant digits.
7. At the end of the exam put all papers and the notebook inside the envelope and leave everything on your desk.
8. Please write down logically step by step with intermediate equations/calculations to get the final solution.

Short Problem

Note: 10 points for each problem

1) In a binary system, the apparent magnitude of the primary star is 1.0 and that of the secondary star is 2.0. Find the maximum combined magnitude of this system.

Solution:

Let F_1, F_2, and F_0 be the flux of the first, the second and the binary system, respectively.

$$\Delta m = -2.5\lg(F_1/F_2)$$
$$(1-2) = -2.5\lg(F_1/F_2)$$ 5

So, $F_1/F_2 = 10^{1/2.5} = 10^{0.4}$

$$F_0 = F_1 + F_2 = F_1(1+10^{-0.4})$$ 3

The magnitude of the binary m is:

$$m-1 = -2.5\lg(F_0/F_1) = -2.5\lg(F_1(1+0.398)/F_1) = -0.36^m$$ 2

So, $m = 0.64^m$

2) If the escape velocity from a solar mass object's surface exceeds the speed of light, what would be its radius ?

Solution:

$$\sqrt{\frac{2GM_{object}}{R_{object}}} > c$$ 4

$$R_{object} < \frac{2GM_{object}}{c^2}$$ 2

$$R_{object} < \frac{2\times 6.6726\times 10^{-11}\times 1.9891\times 10^{30}}{(2.9979\times 10^{8})^2}$$

$$R < 2953.6m$$ 4

3) The observed redshift of a QSO is $z = 0.20$, estimate its distance. The Hubble constant is 72 km s^{-1} Mpc^{-1}.

Solution:

Recession velocity of the QSO is

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1} = 0.18$$ 4

According to the Hubble's law,

$$v = H_0 D$$ 2

The distance of the QSO is

$$D = v / H_0 = 0.18c / 72 = 750Mpc,$$ 4

Remarks： if the student calculate the distance using cosmological formula and arrive at the answer $D = 735\,Mpc$,assuming $\Omega_0 = 1.0$ will get the full mark.

4) A binary system is 10 pc away, the largest angular separation between the components is 7.0", the smallest is 1.0". Assume that the orbital period is 100 years, and that the orbital plane is perpendicular to the line of sight. If the semi-major axis of the orbit of one component corresponds to 3.0", that is a_1=3.0", estimate the mass of each component of the binary system, in terms of solar mass.

Solution:

The semi-major axis is

$a = 1/2 \times (7+1) \times 10 = 40\,AU$ 2

From Kepler's 3rd law,

$$M_1 + M_2 = \frac{a^3}{p^2} = \frac{(40)^3}{(100)^2} = 6.4 M_{sun}$$ 4

since $a_1 = 3'', a_2 = 1''$,then

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$ 2

$$m_1 = 1.6 M_{sun}, m_2 = 4.8 M_{sun}$$ 2

5) If 0.8% of the initial total solar mass could be transformed into energy during the whole life of the

Sun, estimate the maximum possible life time for the Sun. Assume that the solar luminosity remains constant.

Solution:

The total mass of the Sun is

$$m \approx 1.99 \times 10^{30} kg$$

0.8% mass transform into energy:

$$E = mc^2 \approx 0.008 \times 2 \times 10^{30} \times (3 \times 10^8)^2 = 1.4 \times 10^{45} J$$ 5

Luminosity of the Sun is

$$L_{sun} = 3.96 \times 10^{26} W$$

Sun's life would at most be:

$$t = E / L_{sun} = 3.6 \times 10^{18} s \approx 10^{11} years$$ 5

6) A spacecraft landed on the surface of a spherical asteroid with negligible rotation, whose diameter is 2.2 km, and its average density is 2.2g/cm^3. Can the astronaut complete a circle along the equator of the asteroid on foot within 2.2 hours? Write your answer "YES" or "NO" on the answer sheet and explain why with formulae and numbers.

Solution:

The mass of the asteroid is

$$m_1 = \frac{4}{3}\pi r^3 \rho = 1.23 \times 10^{13} kg$$ 2

Since $m_2 << m_1$, m_2 can be omitted,

Then $v = \sqrt{\dfrac{Gm_1}{r}} = 0.864 m/s$ 3

It is the first cosmological velocity of the asteroid.
If the velocity of the astronaut is greater then v, he will escape from the asteroid.

The astronaut must be at v_2 if he wants to complete a circle along the equator of the asteroid on foot within 2.2 hours, and

$$v_2 = \frac{2\pi \times (2200/2)m}{2.2 \times 3600s} = 0.873 m/s$$ 3

Obviously $v_2 > v$

So the answer should be "NO". 2

7) We are interested in finding habitable exoplanets. One way to achieve this is through the dimming of the star, when the exoplanet transits across the stellar disk and blocks a fraction of the light. Estimate the maximum luminosity ratio change for an Earth-like planet orbiting a star similar to the Sun.

Solution：

The flux change is proportional to the ratio of their surface areas, i.e.,

$$F_e / F_{sun} = (R_e / R_{sun})^2$$ 5

$$(R_e / R_{sun})^2 = 8.4\times10^{-5} \approx 10^{-4} \qquad 5$$

Obviously this difference is extremely small.

8) The Galactic Center is believed to contain a super-massive black hole with a mass $M=4\times10^6\ M_\odot$. The astronomy community is trying to resolve its event horizon, which is a challenging task. For a non-rotating black hole, this is the Schwarzschild radius, $R_s = 3(M/M_\odot)$ km. Assume that we have an Earth-sized telescope (using Very Long Baseline Interferometry). What wavelengths should we adopt in order to resolve the event horizon of the black hole? The Sun is located at 8.5 kpc from the Galactic Center.

Solution:

Observationally, the diameter of the Galactic black hole at the distance of $L = 8.5 kpc$ has the angular size,

$$\theta_{BH} = 2R_s / L \qquad 2$$

On the other hand, an Earth-sized telescope ($D = 2R_e$) has the resolution,

$$\theta_{tel} = 1.22\lambda/(2R_e) \qquad 2$$

In order to resolve the black hole at Galactic center, we need to have $\theta_{BH} \geq \theta_{tel}$,which marginally we consider $\theta_{BH} = \theta_{tel}$

This leads to,

$$\lambda = 4R_e R_s /(1.22L)$$ 4

Taking the values, we have

$$\lambda \approx 0.9mm$$ 2

This means that we need to observe at least at near sub-mm frequencies, which is in radio or far-infrared band.

9) A star has a measured I-band magnitude of 22.0. How many photons per second are detected from this star by the Gemini Telescope(8m diameter)? Assume that the overall quantum efficiency is 40% and the filter passband is flat.

Filter	$\lambda_0(nm)$	$\Delta\lambda(nm)$	$F_{VEGA}(Wm^{-2}nm^{-1})$
I	8.00×10^2	24.0	8.30×10^{-12}

Solution:

The definition of the magnitude is:

$$m_I = -2.5\lg F_I + const$$

Where F_I is the flux received from the source. Using the data above, we can obtain the constant:

$$0.0 = -2.5\lg(0.83\times10^{11}) + const$$

Thus,

$$const = -27.7$$

$$m_I = -2.5 \lg F_I - 27.7$$

$$F_I = 10^{\frac{m_I + 27.7}{-2.5}} = 1.3 \times 10^{-20} Wm^{-2} nm^{-1}$$ 4

For our star, at an effective wavelength $\lambda_0 = 800 nm$

using this flux, the number of photons detected per unit wavelength per unit area is the flux divided by the energy of a photon with the effective wavelength:

$$N_I = \frac{1.3 \times 10^{-20}}{hc / \lambda_0} = 5.3 \times 10^{-2}\ photons s^{-1} m^{-2} nm^{-1}$$ 3

Thus the total number of photons detected from the star per second by the 8m Gemini telescope over the I band is

$$N_I(total) = (tel.collectingarea) \times QE \times Bandwidth \times N_I$$

$$= (\pi \times 4^2) \times 0.4 \times 24 \times N_I$$ 3

$$= 26\, photons / s \approx 30\, photons / s$$

10) Assuming that the G-type main-sequence stars (such as the Sun) in the disc of the Milky Way obey a vertical exponential density profile with a scale height of 300pc, by what factor does the density of these stars change at 0.5 and 1.5kpc from the mid-plane relative to the density in the mid-plane?
Solution:

Since $h_z = 300 pc$, we can substitute this into the vertical(exponential)disc equation:

$$n(0.5 kpc) = n_0 \exp(-|500\ pc| / 300\ pc) \approx 0.189\, n_0$$ 5

In other words, the density of G-type MS stars at 0.5kpc above the plane is just under 19% of its mid-plane value.

For $z = 1.5 kpc$,this works out as 0.007 . 5

11) Mars arrived at its great opposition at UT $17^h 56^m$ Aug.28, 2003. The next great opposition of Mars will be in 2018, estimate the date of that opposition. The semi-major axis of the orbit of Mars is 1.524 AU.

Solution:

$$T_M = \sqrt{\frac{R_M^3}{R_E^3}} T_E = 1.881 years$$ 2

$$\frac{1}{T_s} = \frac{1}{T_E} - \frac{1}{T_M}$$

$$T_s = \frac{T_E \times T_M}{(T_M - T_E)} = \frac{1.881}{0.881} \times 365.25 = 779.8 days$$ 3

That means there is an opposite of the Mars about every 780 days.

If the next great opposite will be in 2018, then

$15 \times 365 + 4 = 5479\ days$

$5479 / 779.8 = 7.026$

It means that there will have been 7 opposites before Aug.28, 2018, 3

So the date for the great opposite should be

$5479 - 7 \times 779.8 = 20.4 days$, i.e.

20.4days before Aug.28,2018, 2

It is on Aug .7, 2018.

12) The difference in brightness between two main sequence stars in an open cluster is 2 magnitudes. Their effective temperatures are 6000K and 5000K respectively. Estimate the ratio of their radii.

Solution:

$$L_1 = 4\pi R_1^2 \sigma T_{\max}^4$$ 3

$$L_2 = 4\pi R_2^2 \sigma T_{\min}^4$$

$$\Delta m = -2.5\lg(L_{\min} / L_{\max}) = -5\lg(R_{\min} / R_{\max}) - 10\lg(T_{\min} / T_{\max})$$ 3

$$\lg(R_{\min} / R_{\max}) = -0.2\Delta m - 2\lg(T_{\min} / T_{\max}) = -0.24$$ 2

So,

$$R_{\min} / R_{\max} = 0.57$$ 2

13) Estimate the effective temperature of the photosphere of the Sun using the naked eye colour of the Sun.

Solution:

The Wien law is

$$\lambda_{\max} = \frac{0.29}{T}(cm)$$ 5

So the temperature is

$$T = \frac{0.29}{550 \times 10^{-9}} = 5272 \approx 5300K$$ 5

Or

$$T = \frac{0.29}{500 \times 10^{-9}} = 5800K$$

Note:5200~6000K all full mark

14) An observer observed a transit of Venus near the North Pole of the Earth. The transit path of Venus is shown in the picture below. A, B, C, D are all on the path of transit and marking the center of the Venus disk. At A and B, the center of Venus is superposed on the limb of the Sun disk; C corresponds to the first contact while D to the fourth contact, $\angle AOB = 90^\circ$, MN is parallel to AB. The first contact occured at 9:00 UT. Calculate the time of the fourth contact.

$$T_{venus} = 224.70 days, T_{earth} = 365.25 days, a_{venus} = 0.723AU, r_{venus} = 0.949 r_{\oplus}$$

Solution:

Since the observer is at the pole, the affect of the earth's rotation on the transit could be neglected.

then the Sun's angle at the earth extends as $\theta_0 = \arcsin(\frac{2r_{sun}}{1AU}) \approx 32.0'$;

the angular velocity of the Venus around the Sun, respected to the earth is ω_1,

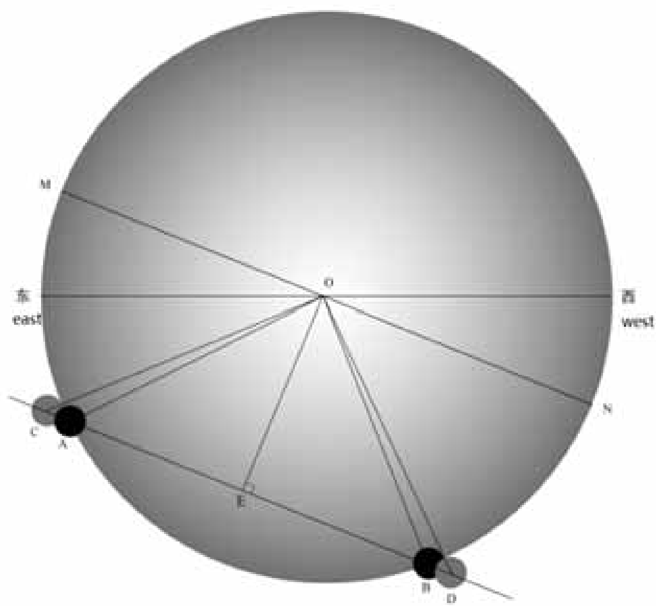
$$\omega_1 = \omega_{venus} - \omega_{earth} = \frac{2\pi}{T_{venus}} - \frac{2\pi}{T_{earth}} \approx 4.29\times10^{-4}('/s)$$ 2

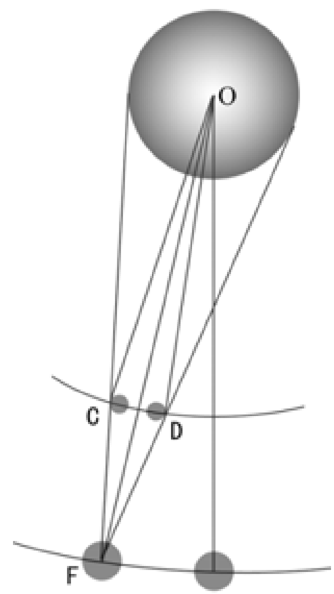
For the observer on earth, Venus moved θ during the whole transit ，

Let OE be perpendicular to AB,

OA=16 ' ∠AOB=90°, MN // AB，

So $OE = 11.3'$， $OC = \frac{d'_{venus}}{2} + \frac{r'_{sun}}{2}$， d'_{venus} is the angular size of Venus seen from Earth.





3

$$d'_{venus} = \frac{2\times 0.949\times 6378}{(1-0.723)\times 1AU} \approx 1',$$

$$OC \approx 16.5', \quad CD \approx 24.0',$$

$$CE = \sqrt{OC^2 - OE^2} \approx 12.0'$$

$$CD = 2CE = 24.0'$$

$$\text{So, } \theta = \angle CFD = 24.0',$$ 3

As shown on the picture,

$\theta' = \angle COD$ is the additional angle that Venus covered during the transit,

$$\frac{tg\frac{\theta}{2}}{tg\frac{\theta'}{2}} = \frac{0.723}{(1-0.723)}, \quad tg\frac{\theta}{2} = tg12', \theta' = 9.195';$$ 3

$$t_{transit} = \frac{\theta'}{\omega_1} = \frac{9.195'}{4.29\times 10^{-4\,\prime}/s} \times \cos\varepsilon, \text{ that is } 5^h 56^m 36^s,$$

So the transit will finish at about $14^h 57^m$. 2

15) On average, the visual diameter of the Moon is slightly less than that of the Sun, so the frequency of annular solar eclipses is slightly higher than total solar eclipses. For an observer on the Earth, the

longest total solar eclipse duration is about 7.5 minutes, and the longest annular eclipse duration is about 12.5 minutes. Here, the longest duration is the time interval from the second contact to the third contact. Suppose we count the occurrences of both types of solar eclipses for a very long time, estimate the ratio of the occurrences of annular solar eclipses and total solar eclipses. Assume the orbit of the Earth to be circular and the eccentricity of the Moon's orbit is 0.0549. Count all hybrid eclipses as annular eclipses.

Solution

the semi-major axis of Moon's orbit is a; its eccentricity is e; T is the revolution period; apparent radius of the Moon is r; the distance between Earth and Moon is d; the angular radius of the Sun is R_o

When the Moon is at perigee, the total eclipse will be longest.

$$\omega_1=v_1/d_1,\ t_1=2\ \ (r_1-R)/\omega_1$$

Here, ωis the angular velocity of the moon, and v is its linear velocity; t2 is the during time of total solar eclipse; r1 is the angular radius of the Moon when it's at perigee.

When the Moon is at apogee, the annular eclipse will be longest.

$$\omega_2=v_2/d_2,\ t_2=2(R-r_2)/\omega_2$$

Since $v_2/v_1=d_1/d_2=(1-e)/(1+e)$,we get:

$$\frac{t_2}{t_1}=\frac{R-r_2}{r_1-R}\times\left(\frac{1+e}{1-e}\right)^2 \qquad (1)$$

3

Moon orbits the Earth in a ellipse. Its apparent size r varies with time. When r>R, if there occurred an center eclipse, it must be total solar eclipse. Otherwise when r<=R, the center eclipse must be annular.

We need to know that, in a whole moon period, what's the time fraction of r>R and r<=R. $r \propto 1/d$.

But it's not possible to get d by solving the Kepler's equation. Since e is a small value, it would be reasonable to assume that d changes linearly with t. So, r also changes linearly with t. Let the moment when the Moon is at perigee be the starting time (t=0), in half a period, we get:

$$r = r_2 + kt = r_2 + \frac{2(r_1 - r_2)}{T} \cdot t, \qquad 0 \le t < T/2$$

Here, $k=2(r_1-r_2)/T$=constant.

When r=R, we get a critical t :

$$t_R = \frac{R - r_2}{k} = \frac{(R - r_2)}{2(r_1 - r_2)} \cdot T \qquad (2)$$ 2

During a Moon period, if $t \in (t_R, T - t_R)$, then r>R, and the central eclipses occurred are total solar eclipses. The time interval from t_R to T -t_R is Δt_T=T-2t_R. If $t \in [0, t_R]$ & $t \in [T - t_R, T]$, then r≤R, and the central eclipses occurred are annular eclipses. The time interval is $\Delta t_A=2t_R$.

4

The probability of occurring central eclipse at any t is the same. Thus the counts ratio of annular eclipse and total eclipse is:

$$\frac{f_A}{f_T} = \frac{\Delta t_A}{\Delta t_T} = \frac{2t_R}{T - 2t_R} = \frac{R - r_2}{r_1 - R} = \frac{t_2}{t_1} \Big/ \left(\frac{1+e}{1-e}\right)^2 \approx \frac{4}{3}$$ 1

Long Problem

Note: 30 points for each problem

16) A spacecraft is launched from the Earth and it is quickly accelerated to its maximum velocity in the direction of the heliocentric orbit of the Earth, such that its orbit is a parabola with the Sun at its focus point, and grazes the Earth orbit. Take the orbit of the Earth and Mars as circles on the same plane, with radius of r_E=1AU and r_M=1.5AU, respectively. Make the following approximation: during most of the flight only the gravity from the Sun needs to be considered.

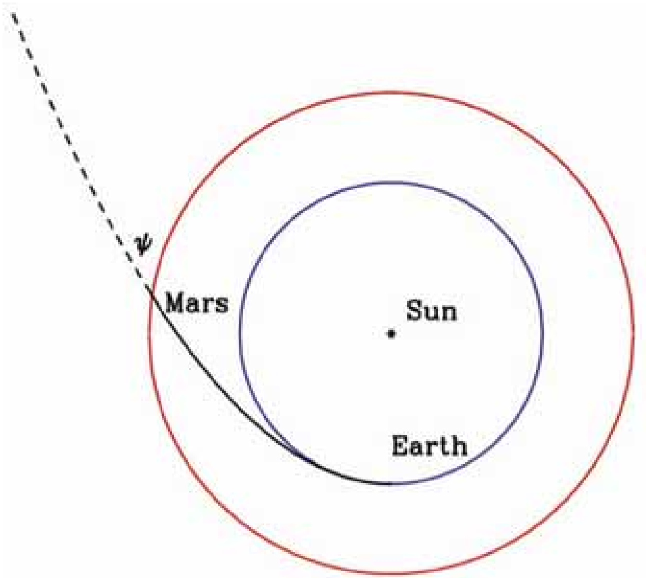


Figure 1:

The trajectory of the spacecraft (not in scale). The inner circle is the orbit of the Earth, the outer circle is the orbit of Mars.

Questions:

(a) What is the angle ψ between the path of the spacecraft and the orbit of the Mars (see Fig. 1) as it crosses the orbit of the Mars, without considering the gravity effect of the Mars?

(b) Suppose the Mars happens to be very close to the crossing point at the time of the crossing, from the point of view of an observer on Mars, what is the approaching velocity and direction of approach (with respect to the Sun) of the spacecraft before it is significantly affected by the gravity of the Mars?

Solution: (1) 10 points; (2) 20 points

(1) The orbit of the spacecraft is a parabola, this suggests that the (specific) energy with respect to the Sun is initially

$$\varepsilon = 1/2v_{\max}^2 + U(r_E) = 0$$ 2

and

$$v_{\max} = \sqrt{2U} = \sqrt{2k_{sun}/r_E}$$

The angular momentum is

$$l = r_E v_{\max} = \sqrt{2k_{sun} r_E}$$ 2

When the spacecraft cross the orbit of the Mars at 1.5 AU, its total velocity is

$$v = \sqrt{2U} = \sqrt{2k_{sun} r_M} = \sqrt{\frac{2}{3}} v_{\max}$$

This velocity can be decomposed into v_r and v_θ, using angular momentum decomposition,

$$r_M v_\theta = l = r_E v_{\max}$$ 2

So,

$$v_\theta = \frac{r_E}{r_M} v_{\max} = \frac{2}{3} v_{\max}$$ 2

Thus the angle is given by

$$\cos\psi = \frac{v_\theta}{v} = \sqrt{\frac{r_E}{r_M}} = \sqrt{\frac{2}{3}}$$

or

$$\psi = 35.26^\circ$$ 2

Note: students can arrived at the final answer with conservation of angular momentum and energy, full mark.

(2) The Mars would be moving on the circular orbit with a velocity

$$v_M \equiv \sqrt{\frac{k_{sun}}{r_M}} = \sqrt{\frac{2}{3}}v_E = 24.32km/s$$ 3

from the point of view of an observer on Mars, the approaching spacecraft has a velocity of

$$\overrightarrow{v_{rel}} = \vec{v} - \vec{v}_M$$ 2

Now

$$\vec{v} = v\sin\psi\,\hat{r} + v_\theta\,\hat{\theta}$$ 2

with

$$\sin\psi = \sqrt{1-\cos^2\psi} = \frac{1}{\sqrt{3}}$$

So

$$\overrightarrow{v_{rel}} = v\sin\psi\,\hat{r} + (v_\theta - v_M)\,\hat{\theta}$$
$$= \frac{1}{\sqrt{3}}\sqrt{\frac{2k_{sun}}{r_M}}\,\hat{r} + \left(\frac{2}{3}\sqrt{\frac{2k_{sun}}{r_E}} - \sqrt{\frac{k_{sun}}{r_M}}\right)\hat{\theta}$$
$$= \sqrt{\frac{2k_{sun}}{3r_M}}\,\hat{r} + \left(\frac{2}{\sqrt{3}} - 1\right)\sqrt{\frac{k_{sun}}{r_M}}\,\hat{\theta}$$ 8
$$= \sqrt{\frac{k_{sun}}{r_M}}(0.8165\,\hat{r} + 0.1547\,\hat{\theta})$$

The angle between the approaching spacecraft and Sun seen from Mars is:

$$\tan\theta = \frac{0.1547}{0.8165} = 0.1894$$ 3
$$\theta = 10.72^\circ$$

The approaching velocity is thus

$$v_{rel} = \sqrt{\frac{2}{3} + \left(\frac{2}{\sqrt{3}} - 1\right)^2}\sqrt{\frac{k_{sun}}{r_M}} = 20.21 km/s$$ 2

17) The planet Taris is the home of the Korribian civilization. The Korribian species is a highly intelligent alien life form. They speak Korribianese language. The Korribianese-English dictionary is shown in Table 1; read it carefully! Korriban astronomers have been studying the heavens for thousands of years. Their knowledge can be summarized as follows:

★ Taris orbits its host star Sola in a circular orbit, at a distance of 1 Tarislength.

★ Taris orbits Sola in 1 Tarisyear.
★ The inclination of Taris's equator to its orbital plane is 3°.
★ There are exactly 10 Tarisdays in 1 Tarisyear.
★ Taris has two moons, named Endor and Extor. Both have circular orbits.
★ The sidereal orbital period of Endor (around Taris) is exactly 0.2 Tarisdays.
★ The sidereal orbital period of Extor (around Taris) is exactly 1.6 Tarisdays.
★ The distance between Taris and Endor is 1 Endorlength.
★ Corulus, another planet, also orbits Sola in a circular orbit. Corulus has one moon.
★ The distance between Sola and Corulus is 9 Tarislengths.
★ The tarisyear begins when Solaptic longitude of the Sola is zero.

Korribianese	**English Translation**
Corulus	A planet orbiting Sola
Endor	(i) Goddess of the night; (ii) a moon of Taris
Endorlength	The distance between Taris and Endor
Extor	(i) God of peace; (ii) a moon of Taris
Sola	(i) God of life; (ii) the star which Taris and Corulus orbit
Solaptic	Apparent path of Sola and Corulus as viewed from Taris
Taris	A planet orbiting the star Sola, home of the Korribians
Tarisday	The time between successive midnights on the planet Taris
Tarislength	The distance between Sola and Taris
Tarisyear	Time taken by Taris to make one revolution around Sola

Table 1: Korribianese-English dictionary

Questions:

(a) Draw the Sola-system, and indicate all planets and moons.

(b) How often does Taris rotate around its axis during one Tarisyear?

(c) What is the distance between Taris and Extor, in Endorlengths?

(d) What is the orbital period of Corulus, in Tarisyears?

(e) What is the distance between Taris and Corulus when Corulus is in opposition?

(f) If at the beginning of a particular tarisyear, Corulus and taris were in opposition, what would be Solaptic longitude (as observed from Taris) of Corulus n tarisdays from the start of that year?

(g) What would be the area of the triangle formed by Sola, Taris and Corulus exactly one tarisday after the opposition?

(a) 5 points

(b) 5 points

(c) 3 points

(d) 2 points

(e) 5 points

(f) 5 points

(g) 5 points

Solution: (a) Drawing scaled diagram is impossible. Rough sketch is accepted.

(b) There are 10 days and nights per taris year. The obliquity is 3^o, which means that the planet's rotation is in the same direction as its orbit. Thus, total number of rotations per year is $10 + 1 = 11$.

Note: The obliquity is positive (similar to the Earth / Mars / Jupiter). This means, we have ADD one rotation. Subtracting one rotation by assuming opposite rotation (like the Venus) is incorrect.

(c) By Kepler's third law, $\frac{T^2}{R^3} = \text{Constant}$

$$\frac{T_{en}^2}{R_{en}^3} = \frac{T_{ex}^2}{R_{ex}^3} \tag{1}$$

$$R_{ex}^3 = \frac{1.6^2 R_{en}^3}{0.2^2} \tag{2}$$

$$R_{ex} = \sqrt[3]{64} \quad \text{endorlengths} \tag{3}$$

$$= 4 \quad \text{endorlengths} \tag{4}$$

(d) Using same logic as above

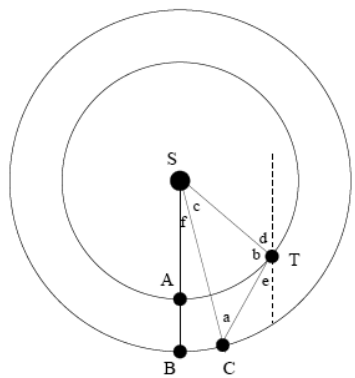
$$\frac{T_C^2}{R_C^3} = \frac{T_T^2}{R_T^3} \tag{5}$$

$$T_C^2 = \frac{9^3 R_T^3 T_T^2}{R_T^3} \tag{6}$$

$$T_C = \sqrt{729} \quad \text{tarisyears} \tag{7}$$
$$= 27 \quad \text{tarisyears} \tag{8}$$

(e) As Corulus is in Opposition, Sola - Taris - Corulus form straight line (in that order).
Distance = 9 - 1 = 8 tarislengths.

(f) In the figure, S is Sola, A and B are start of the year positions of Taris and Corulus, T and C are their positions after 'n' days. Angles are named from a to f. The dashed line is parallel to line SB. Triangle(SCT) is used for sine rule as well as answer in the next part. Figure is not to the scale.



$$
\begin{aligned}
a+b+c &= \pi && (9)\\
b+d+e &= \pi && (10)\\
d &= f+c && (11)\\
f+c &= \frac{2\pi n}{10} && (12)\\
f &= \frac{2\pi n}{270} && (13)\\
\sin b &= 9\sin a \text{ (By Sine Rule)} && (14)
\end{aligned}
$$

$$
\begin{aligned}
e &= \pi - b - d && (15)\\
&= \pi - b - c - f && (16)\\
&= a - f && (17)
\end{aligned}
$$

$$
\begin{aligned}
b &= \pi - (a+c) && (18)\\
&= \pi - \left(a + \frac{2\pi n}{10} - \frac{2\pi n}{270}\right) && (19)\\
&= \pi - \left(a + \frac{52\pi n}{270}\right) && (20)
\end{aligned}
$$

$$9\sin a = \sin\left(\pi - \left(a + \frac{52\pi n}{270}\right)\right) \quad (21)$$
$$= \sin\left(a + \frac{52\pi n}{270}\right) \quad (22)$$
$$= \left[\sin a \cos\left(\frac{52\pi n}{270}\right) + \cos a \sin\left(\frac{52\pi n}{270}\right)\right] \quad (23)$$
$$9 = \cos\left(\frac{52\pi n}{270}\right) + \cot a \sin\left(\frac{52\pi n}{270}\right) \quad (24)$$
$$\cot a = \frac{9 - \cos\left(\frac{52\pi n}{270}\right)}{\sin\left(\frac{52\pi n}{270}\right)} \quad (25)$$
$$a = \tan^{-1}\left[\frac{\sin\left(\frac{52\pi n}{270}\right)}{9 - \cos\left(\frac{52\pi n}{270}\right)}\right] \quad (26)$$

$$\lambda = \pi - e \quad (27)$$
$$= \pi + f - a \quad (28)$$
$$\lambda = \pi + \frac{2\pi n}{270} - \tan^{-1}\left[\frac{\sin\left(\frac{52\pi n}{270}\right)}{9 - \cos\left(\frac{52\pi n}{270}\right)}\right] \quad (29)$$

(g)
$$\text{Area} = \frac{1}{2} \times l(ST) \times l(SC) \times \sin \boldsymbol{c}$$
$$= \frac{1}{2} \times 1 \times 9 \times 0.568$$
$$= 2.56$$

The area is about 3(tarislength)^2

The 4th IOAA
Practical Competition
Data Analysis

Please read these instructions carefully:

1. You should use the ruler and calculator provided by LOC.
2. The time available for answering data analysis problems is 4 hours. You will have 2 problems.
3. Use only the pen that has been provided on your desk.
4. Begin answering each problem on a new page of the notebook. Write down the number of the problem at the beginning.
5. Write down your "country name" and your "student code" on the cover of the notebook.
6. At the end of the exam put all paper and the notebook inside the envelope and leave everything on your desk.
7. Write down logically step by step with intermediate equations/calculations to get the final solution.

Problem I CCD image (35 points)

Information:

Picture 1 presents a negative image of sky taken by a CCD camera attached to a telescope whose parameters are presented in the accompanying table (which is part of the FITS datafile header).
Picture 2 consists of two images: one is an enlarged view of part of Picture 1 and the second is an enlarged image of the same part of the sky taken some time earlier.
Picture 3 presents a sky map which includes the region shown in the CCD images.

The stars in the images are far away and should ideally be seen as point sources. However, diffraction on the telescope aperture and the effects of atmospheric turbulence (known as 'seeing') blur the light from the stars. The brighter the star, the more of the spread-out light is visible above the level of the background sky.

Questions:

1. Identify any 5 bright stars (mark them by Roman numerals) from the image and mark them on both the image and map.
2. Mark the field of view of the camera on the map.
3. Use this information to obtain the physical dimensions of the CCD chip in mm.
4. Estimate the size of the blurring effect in arcseconds by examining the image of the star in Picture 2. (Note that due to changes in contrast necessary for printing, the diameter of the image appears to be about 3.5 times the full width at half maximum (FWHM) of the profile of the star.)
5. Compare the result with theoretical size of the diffraction disc of the telescope.

6. Seeing of 1 arcsecond is often considered to indicate good conditions. Calculate the size of the star image in pixels if the atmospheric seeing was 1 arcsecond and compare it with the result from question 4.
7. Two objects observed moving relative to the background stars have been marked on Picture 1. The motion of one ("Object 1") was fast enough that it left a clear trail on the image. The motion of the other ("Object 2") is more easily seen on the enlarged image (Picture 2A) and another image taken some time later (Picture 2B).

Using the results of the first section, determine the angular velocity on the sky of both objects. Choose which of the statements in the list below are correct, assuming that the objects are moving on circular orbits. (Points will be given for each correct answer marked and deducted for each incorrect answer marked.)The probable causes of the different angular velocities are:

a) different masses of the objects,

b) different distances of the objects from Earth,

c) different orbital velocities of the objects,

d) different projections of the objects' velocities,

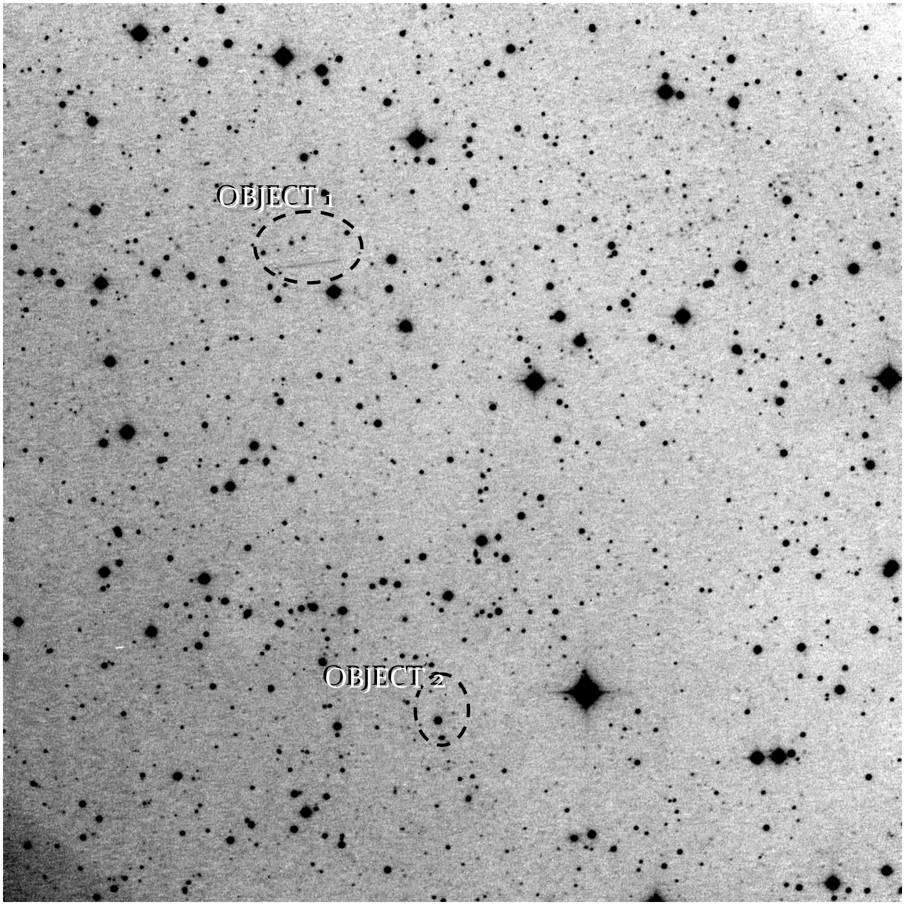
e) Object 1 orbits the Earth while Object 2 orbits the Sun.

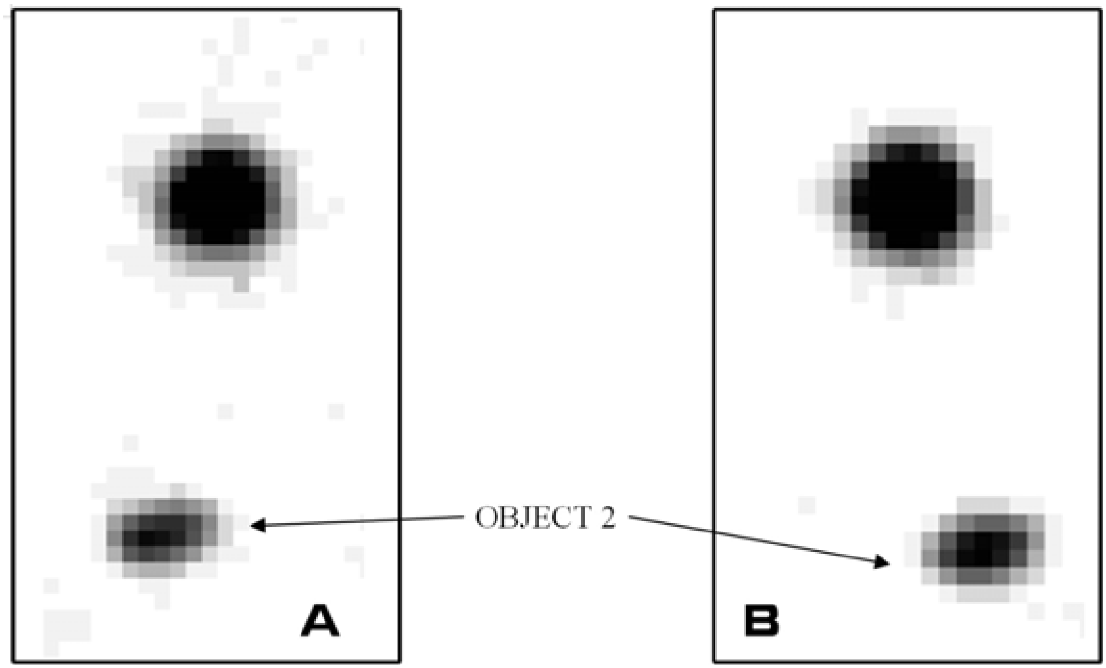
Data:

For Picture 1, the data are,

BITPIX =	16	/ Number of bits per pixel
NAXIS =	2	/ Number of axes
NAXIS1 =	1024	/ Width of image (in pixels)
NAXIS2 =	1024	/ Height of image (in pixels)
DATE-OBS= '2010-09-07 05:00:40.4'		/ Middle of exposure
TIMESYS = 'UT'		/ Time Scale
EXPTIME =	300.00	/ Exposure time (seconds)
OBJCTRA = '22 29 20.031'		/ RA of center of the image
OBJCTDEC= '+07 20 00.793'		/ DEC of center of the image
FOCALLEN= '3.180m'		/ Focal length of the telescope
TELESCOP= '0.61m '		/ Telescope aperture

Picture 1 for Problem I





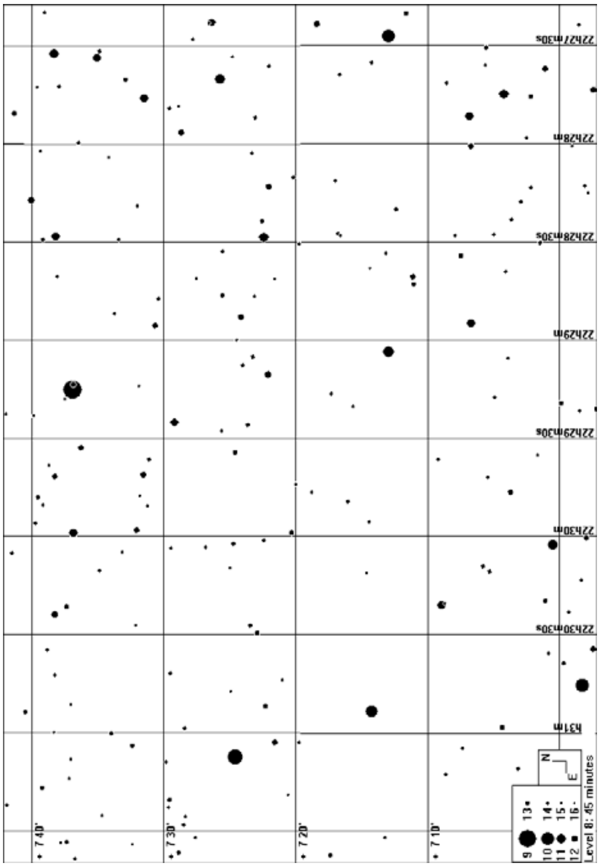
Picture 2 for Problem I:

A: The same area observed some time earlier. For this image the data are :

DATE-OBS= '2010-09-07 04:42:33.3' / Middle of exposure

B: Enlargement of Picture 1 around Object 2,

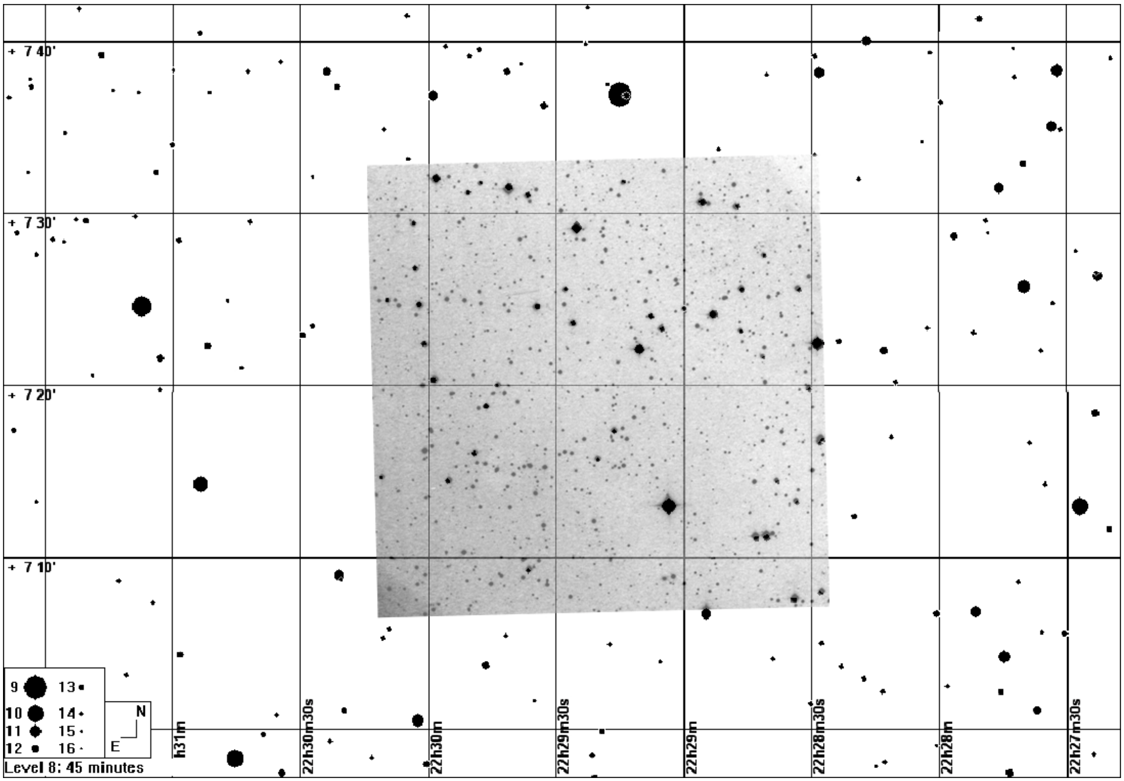
Picture 3 for Problem I:



Solution:

1) 0.5 point for one star, totally 2 points

2)



(2 p)

3) According to the pic of A2, it's easy to find the field of view of the telescope. It's about 26’, and the

declination of the center of the CCD image is 7.3°. Thus the side length of the field of view is :

$$26' \times \cos 7.3° = 1550''$$

Image scale is $d = f\theta$, so, $s = f/206.265$ mm/arcsec = 0.0154 mm/arcsec.

The chip size is 1550 × 0.0154 = 24mm. (4p)

4) The star is 10 pixels across, so the FWHM is 10/3.5 = 2.9 pixels. (4p)

Seeing is S = 2.9 pixels × 1.5"/pixel (from Q3 and 1024 pixels) = 4.4".

5) Theoretical (Airy) diffraction disc is 2.44λ/D radians in diameter:

$A = 2.44 \times 550 \times 10^{-9} / 0.61$ rad= 0.45" ~ 0.3 pixels

A << S (seeing).*(Accept all reasonable wavelengths: 450-650nm)* (4p)

6) Seeing = FWHM × 1.5"/pixel (from Q3) =1" . So, FWHM=1/1.5 pixel=1pixel

Printed image of star would then be s2=3.5×FWHM =3.5 pixels. (3p)

Note: if use : s2=1"*10 pix/4.4"=2.3 pix, 2 points.

7) For object 1, the trail of the object is about 107" (measured from pic 1, 300s exposure). It's angular velocity is:

$$\omega_1 = 107''/300s = 0.36\ ''/s$$

Note: accept to v±10% . (3p)

For object 2, it's moves about 8 pixels between pic 2A and 2B. 8 pixels ~ 12", and the time between exposures is 17m27s. It's angular velocity is: (3p)

$$\omega_2 = 12''/1047s = 0.012\ ''/s \text{ (accept } \pm 10\%) .$$

a) **wrong**: different masses of the objects, (+2/-1p)

b) **right**: different distances of the objects from Earth, (+3/-1p)

c) **right**: different orbital velocities of the objects, (+3/-1p)
d) **wrong**: different projections of the objects' velocities, (+2/-1p)
e) **rejected**: Object 1 orbits the Earth while Object 2 orbits the Sun. (0p)

Problem II: Light curves of stars (35 points)

A pulsating variable star KZ Hydrae was observed with a telescope equipped with a CCD camera. Figure 1 shows a CCD image of KZ Hya marked together with the comparison star and the check star. Table 1 lists the observation time in Heliocentric Julian dates, the magnitude differences of KZ Hya and the check star relative to the comparison star in V and R band.

The questions are:

1) Draw the light curves of KZ Hya relative to the comparison star in V and R band, respectively.

2) What are the average magnitude differences of KZ Hya relative to the comparison star in V and R, respectively?

3) What are the photometry precisions in V and R, respectively?

4) Estimate the pulsation periods of KZ Hya in V and R.

5) Give the estimation of the pulsation amplitudes of KZ Hya in V and R

6) What is the phase delay between the V and R bands, in term of the pulsation period?

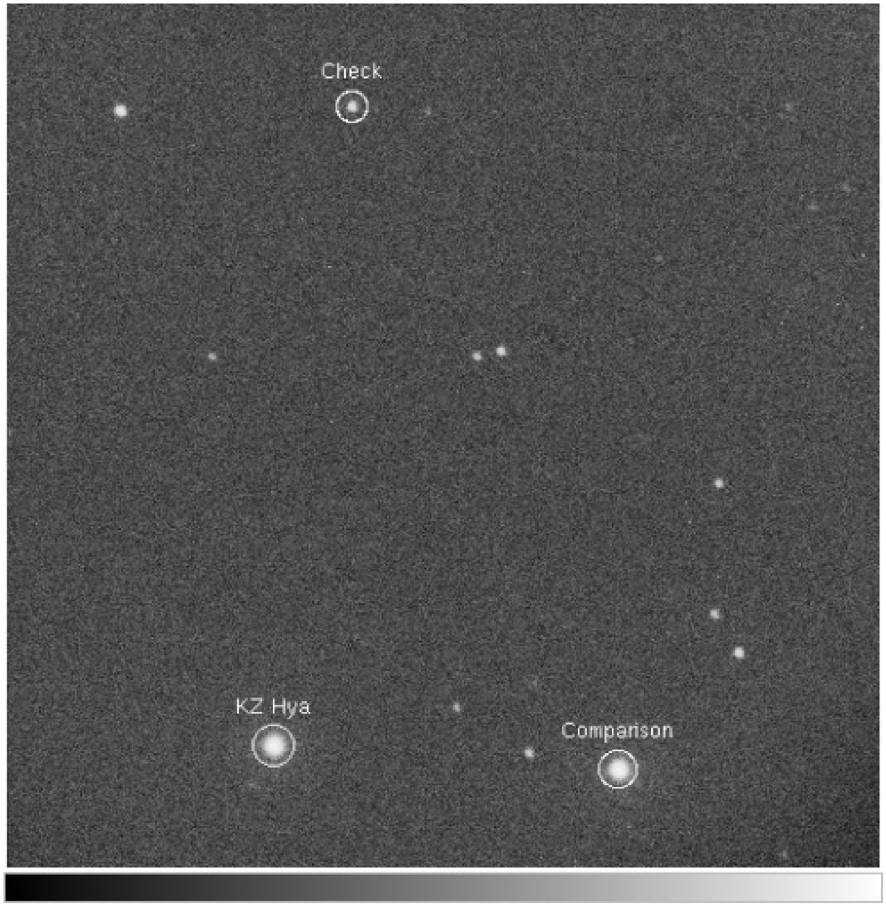


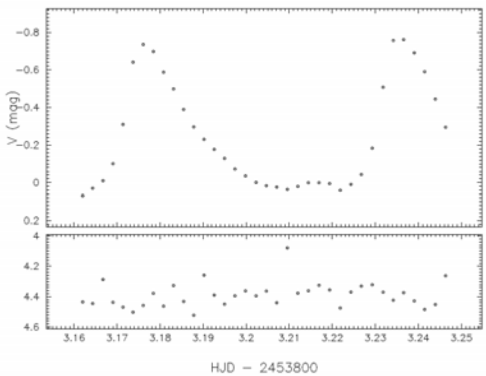
Fig. 1 for Problem II: A CCD image of KZ Hya.

Table 1 for Problem II: Data for the light curves of KZ Hya in V and R. ΔV and ΔR are KZ Hya relative to the comparison in V and R. ΔV_{chk} and ΔR_{chk} are the check star relative to the comparison in V and R.

HJD-2453800(t)	ΔV(mag)	ΔV_{chk}	HJD-2453800(t)	ΔR(mag)	ΔR_{chk}
3.162	0.068	4.434	3.1679	0.260	2.789
3.1643	0.029	4.445	3.1702	0.185	2.802
3.1667	-0.011	4.287	3.1725	-0.010	2.789
3.1691	-0.100	4.437	3.1749	-0.147	2.809
3.1714	-0.310	4.468	3.1772	-0.152	2.809
3.1737	-0.641	4.501	3.1796	-0.110	2.789
3.1761	-0.736	4.457	3.1820	-0.044	2.803
3.1784	-0.698	4.378	3.1866	0.075	2.805
3.1808	-0.588	4.462	3.1890	0.122	2.793
3.1831	-0.499	4.326	3.1914	0.151	2.793
3.1855	-0.390	4.431	3.1938	0.177	2.782
3.1878	-0.297	4.522	3.1962	0.211	2.795
3.1902	-0.230	4.258	3.1986	0.235	2.796
3.1926	-0.177	4.389	3.2011	0.253	2.788
3.195	-0.129	4.449	3.2035	0.277	2.796
3.1974	-0.072	4.394	3.2059	0.288	2.783
3.1998	-0.036	4.362	3.2083	0.296	2.796
3.2023	-0.001	4.394	3.2108	0.302	2.791

3.2047	0.016	4.363	3.2132	0.292	2.806
3.2071	0.024	4.439	3.2157	0.285	2.779
3.2096	0.036	4.078	3.2181	0.298	2.779
3.2120	0.020	4.377	3.2206	0.312	2.787
3.2145	0.001	4.360	3.2231	0.313	2.804
3.2169	0.001	4.325	3.2255	0.281	2.796
3.2194	0.005	4.355	3.2280	0.239	2.795
3.2219	0.041	4.474	3.2306	0.115	2.792
3.2243	0.009	4.369	3.2330	-0.111	2.788
3.2267	-0.043	4.330	3.2354	-0.165	2.793
3.2293	-0.183	4.321	3.2378	-0.152	2.781
3.2318	-0.508	4.370	3.2403	-0.088	2.787
3.2342	-0.757	4.423	3.2428	-0.014	2.780
3.2366	-0.762	4.373	3.2452	0.044	2.766
3.2390	-0.691	4.427	3.2476	0.100	2.806
3.2415	-0.591	4.483	3.2500	0.119	2.791
3.2440	-0.445	4.452	3.2524	0.140	2.797
3.2463	-0.295	4.262	3.2548	0.190	2.825

Solution:

1) 

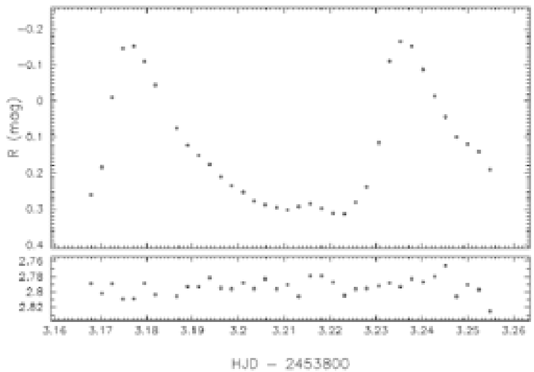


Fig.1. Light curves of KZ Hya in V.

Fig. 2. Light curves of KZ Hya in R.

6p

2) $\langle \Delta V \rangle = \frac{1}{n}\sum_{i=1}^{n} \Delta V_i = -0.248 mag$ 4p

$\langle \Delta R \rangle = \frac{1}{n}\sum_{i=1}^{n} \Delta R_i = 0.127 mag$ 4p

3) $\sigma_{\Delta V} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (\Delta V_i - \langle \Delta V \rangle)^2} = 0.083 mag$ 4p

$$\sigma_{\Delta R} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\Delta R_i - \langle \Delta R \rangle)^2} = 0.011 mag$$ 4p

4) measured from the differences of times at the maximum values of the fits of the two peaks in V and R, respectively: 0.06 days, 0.06 days.

4p

5) measured from the differences of magnitudes at the maximum values of the fits of the two peaks in V and R, respectively: 0.79 mag, 0.49 mag.

4p

6) measured from the differences of times at the maximum values of the fits of the first peaks in V and R: 0(±0.025) P.

5p

The 4th IOAA Observational Competition

I. Telescope Tests

1. Find M15, M27 or one specified star.
2. Estimate the magnitude of a specified star.
3. Evaluate the angle distance of two stars.

II. Tests in the Planetarium

1. The showing is the night sky in Beijing on 21 o'clock tonight. You have two minutes to observe it.
The examiner will point 5 constellations using the laser pen one by one. Each constellation will be pointed about 1 minute. Write down the name of the five constellations. 25 points in total and 5 points per constellation.
Answer:
Cygnus (Cyg), south fish place (Psa), Delphinus (Del), corona borealis (Crb), proxima centauri (Sgr)

2. Write down any five constellations that lie on current celestial equator. 10 minutes, 25 points. More than five constellations, no additional points.
marking criterion:
Virgo (Vir), Serpens (Ser), Ophiuchus (Oph), Aquila (Aql), Aquarius (Aqr), Pisces (Psc), Cetus (Cet).

-- One constellation (included in the above 7 constellations), 5 points.

Libra (Lib), Hercules (Her), Scutum (Sct), Delphinus (Del), Equuleus (Equ), Pegasus

(Peg).

-- One constellation (included in the above 6 constellations), 2 points

3. The showing is the night sky in Beijing on a specified night. Determine the month that the night belongs to. What's the age of the moon for this night? Be accurate to one unit. 10 minutes, 20 points.

marking criterion:

The time is 19h30m, February 15, 2008.

The month: February ~ 10 points
January or March ~ 5 points
Other ~ 0 points

Moon's age: about 9. ~ 10 points
8 or 10 ~ 7 points
7 or 11 ~ 3 points
Other ~ 0 pints

The 4^{th} IOAA

Team Competition

Assembling Telescope (indoor)

The Problem

Every team is given 10 minutes to assemble a telescope with an equatorial mount, so that it is ready for tonight's observation.

Once the competition starts, the assembling procedure will be monitored and judged by a jury, for any mistake in the process. And the assembling process will be timed. When the assembling is finished, the students of the group should raise their hands to indicate the assembling is completed. The jury should record the time taken for the assembling, after which the students should not be allowed to touch the telescope again. After the jury has checked the assembled telescope for the assembling quality, the participating group should take apart the telescope assembly and restore the various parts to the condition as they were before the assembling process.

The coordinates of Beijing is (116°48', 40°32')

Procedure:

The competition is divided into 4 rounds, with each round having 6 teams participating. The team with highest overall score wins.

Marking scheme

1. Time taken for the assembly: 50%
2. Team participation and collaborating skills: 20%
3. Major mistakes: 30%:
   a) The balance of the telescope, in both axes.
   b) Is the parts corrected put together: finder scope, fine adjustment knobs in both axes, and eyepieces, etc.
   c) Are all the screws and knobs securely fastened?
   d) Is the polar axis roughly adjusted? (The participants will be given the rough condition of the North.)