Practical completion

Problem 1: CCD Image Processing (60 points)

As an exercise of image processing, this problem involves use of a simple calculator and tabular data. Table 1.1 contains the pixel values of an image during the given exposure time. (table 1.1 is given in the accompanying CD). This image, which is a part of a larger CCD image, was taken by a small CCD camera, installed on an amateur telescope and using a *V* band filter. Figure 1.1 shows this 50×50 pixels image that contains 5 stars.

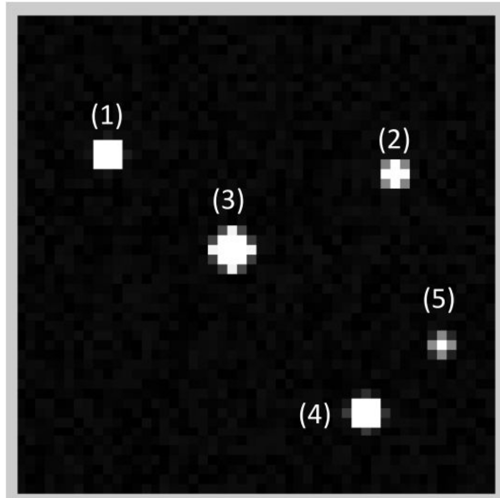


Figure (1.1)

In table 1.1 the first row and column indicates the pixels' x and y coordinates. Table 1.2 gives the telescope and the image specifications.

Table 1.2

Telescope focal length	$1.20\ m$
CCD pixel size	$25 \times 25\ \mu m$
Exposure time	$450\ s$
Telescope zenith angle	25°
Average extinction coefficient in V band	0.3 mag/airmass

The observer identified stars 1, 3 and 4 by comparing this image with standard star catalogues. Table 1.3 shows stars true magnitudes (m_t) as given in the catalogue.

Table 1.3

Star	m_t
1	9.03
3	6.22
4	8.02

a. Using the available data, determine the instrumental magnitudes of the stars in the image. Assume the dark current is negligible and the image is flat fielded. For simplicity you can use a square aperture.
Hint: The instrumental magnitude is calculated using the difference between the measured flux from the star in the aperture and the flux from an equivalent area of dark sky.

b. The instrumental magnitude of a star in a CCD image is related to true magnitude as

$$m_I = m_t + KX - Zmag$$

where K is extinction, X is airmass, m_I and m_t are respectively instrumental and true magnitude of star and $Zmag$ is zero point constant. Calculate the zero point constant ($Zmag$) for identified stars. Calculate average zero point constant $(Zmag)$. **Hint**: Zero point constant is the constant reducing extinction-free magnitudes to the true magnitude.

c. Calculate true magnitudes of stars 2 and 5.
d. Calculate CCD pixel scale for the CCD camera in units of arcsec.
e. Calculate average brightness of dark sky in magnitude per square arcsec (m_{sky}).
f. Use a suitable plot to estimate astronomical seeing in arcsec.

Problem 2: Venus(60 point)

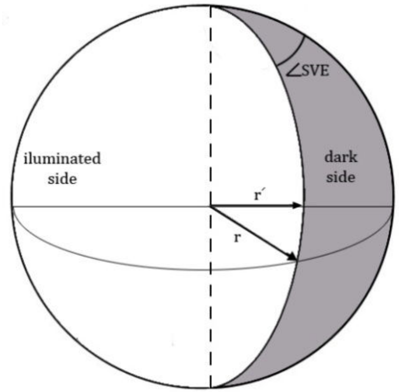
An observer in Deh-Namak (you will be taking the observational part of the exam in this region tonight) has observed Venus for seven months, started from September 2008 and continued until March 2009. During the observation, a research CCD camera and an image processing software were used to take high resolution images and to extract high precision data. Table 2.1 shows the collected data during the observation.

Table 2.1 description:

Column 1	Date of observation.
Column 2	Earth-Sun distance in astronomical unit (AU) for observation date and time. This value is taken from high precision tables.
Column 3	Phase of Venus, Percent of Venus disk illuminated by the Sun as observed from the Earth.
Column 4	Elongation of Venus, the angular distance between center of the Sun and center of Venus in degrees as observed from the Earth.

a) Using given data in table 2.1, calculate the Sun-Venus-Earth angle($\angle SVE$) . This is angular separation between the Sun and the Earth as seen from Venus. Write $\angle SVE$ angle in column 2 of Table 2.2 in your answer sheet for the all observing dates.

Hint: Remember that the line between light and shadow, in the phases, is an ellipse arc.



b) Calculate Sun – Venus distance in AU and write it down in column 3 of table 2.2 for all observation dates.

c) Plot Sun – Venus distance versus observing date.

d) Find perihelion $(r_{v,min})$ and aphelion $(r_{v,max})$ distances of Venus from the Sun.

e) Calculate semi-major axis (a) of the Venus orbit.

f) Calculate eccentricity (e) of Venus orbit.

Table 2.1

Column 1	Column 2	Column 3	Column 4
Date	Earth - Sun Distance (AU)	Phase (%)	Elongation (SEV; degree)
20/9/2008	1.0043	88.4	27.56
10/10/2008	0.9986	84.0	32.29
20/10/2008	0.9957	81.6	34.53
30/10/2008	0.9931	79.0	36.69
9/11/2008	0.9905	76.3	38.71
19/11/2008	0.9883	73.4	40.62
29/11/2008	0.9864	70.2	42.38
19/12/2008	0.9839	63.1	45.29
29/12/2008	0.9834	59.0	46.32
18/1/2009	0.9838	49.5	47.09
7/2/2009	0.9863	37.2	44.79
17/2/2009	0.9881	29.6	41.59
27/2/2009	0.9904	20.9	36.16
19/3/2009	0.9956	3.8	16.08

Solutions

Solution 1: CCD Image Processing

a) To measure instrumental magnitude we should choose an aperture. Careful investigation of the image, shows that a 5×5 pixel aperture is enough to measure m_I for all stars. m_I can be calculated using:

$$m_I = -2.5\log\left(\frac{\sum_{i=1}^{N} \mathrm{I}_{\mathrm{i(star)}} - \mathrm{N}\bar{\mathrm{I}}_{\mathrm{Sky}}}{\mathrm{Exp}}\right)$$

where $\mathrm{I}_{\mathrm{i(star)}}$ is the pixel value for each pixel inside the aperture, N is number of pixels inside the aperture, $\bar{\mathrm{I}}_{\mathrm{Sky}}$ is the average of sky value per pixel taken from dark part of image and Exp is the exposure time. Table (1.4) lists values for m_I and $Zmag$ calculated for all three identified stars.

$$\bar{\mathrm{I}}_{\mathrm{Sky}} = 4.42$$

$$N = 25$$

$$Exp = 450$$

Table (1.4)

Star	m_I	m_t	$Zmag$
1	-3.02	9.03	12.38
3	-5.85	6.22	12.40
4	-4.04	8.02	12.39

b) Average $Zmag$ = 12.4

c) Following part (a) for stars 2 and 5, we can calculate true magnitudes (m_t) for these stars

Table (1.5)

Star	m_I	m_t
2	-2.13	9.93
5	-0.66	11.4

d) Pixel scale for this CCD is calculated as

$$p = \frac{pixel\ size}{focal\ length} \times \frac{180 \times 3600}{\pi}$$

$$= 4.30''$$

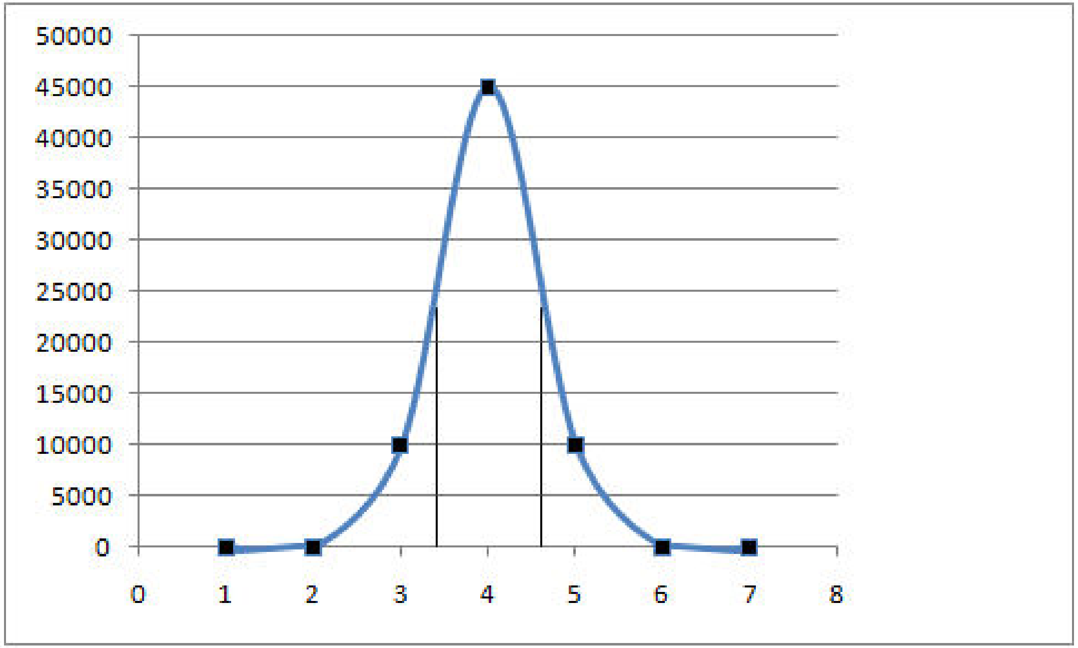
e) Average sky brightness:

$$m_{sky} = -2.5 \log \frac{\bar{\mathrm{I}}_{\mathrm{Sky}}}{(Exp)(p)^2} + Zmag$$

$$= 20.6$$

f) To estimate astronomical seeing, first we plot pixel values in x or y direction for one of the bright stars in the image. As plot (1) shows, the FWHM of pixel values which is plotted for star 3, is 1 pixel , hence astronomical seeing is equal to

$$seeing \cong 4''$$



Plot (1)

CCD Image Problem Marking Scheme

Part	Tot. Pts.	Details	Max.	Explanation
a	10	Relation	2	Each value :+2 $\bar{I}_{sky}$ (within calculation) : +2 m_I relation (in calculation) +2
		m_I	6	
		$\bar{I}_{sky}$	2	
b	10	Z_{mag}	10	$3Z_{mag}$ and average , for each less: - 2
c	10	m_t	10	For each one:+ 5, for each numerical mistake: -2
d	10	P (pixel Scale)	10	
e	10	Relation of m_{sky}	5	
		Value of m_{sky}	5	
f	10	Seeing	10	Seeing: +4, Gaussian profile: +3, FWHM: +3

Solution 2: Venus

a) The $\angle SVE$ angle should be calculated from the phase of Venus. Figure 2.1 shows that projected area of Venus disk which is illuminated by the Sun is

$$\frac{\pi r^2}{2} + \frac{\pi r r'}{2}$$

where

$$r' = r cos(\angle SVE)$$

Then,

$$Phase = (\frac{\frac{\pi r^2}{2} + \frac{\pi r^2 \cos(\angle SVE)}{2}}{\pi r^2}) \times 100 = \frac{100}{2}(1 + \cos(\angle SVE)) = 100 cos^2(\frac{\angle SVE}{2})$$

The angle $\angle SVE$ is calculated and written in table 2.2, column 2.

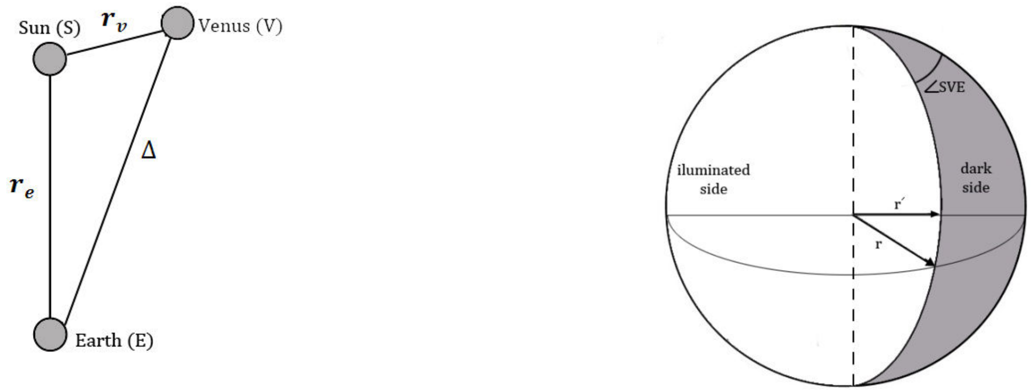


Figure 2.1

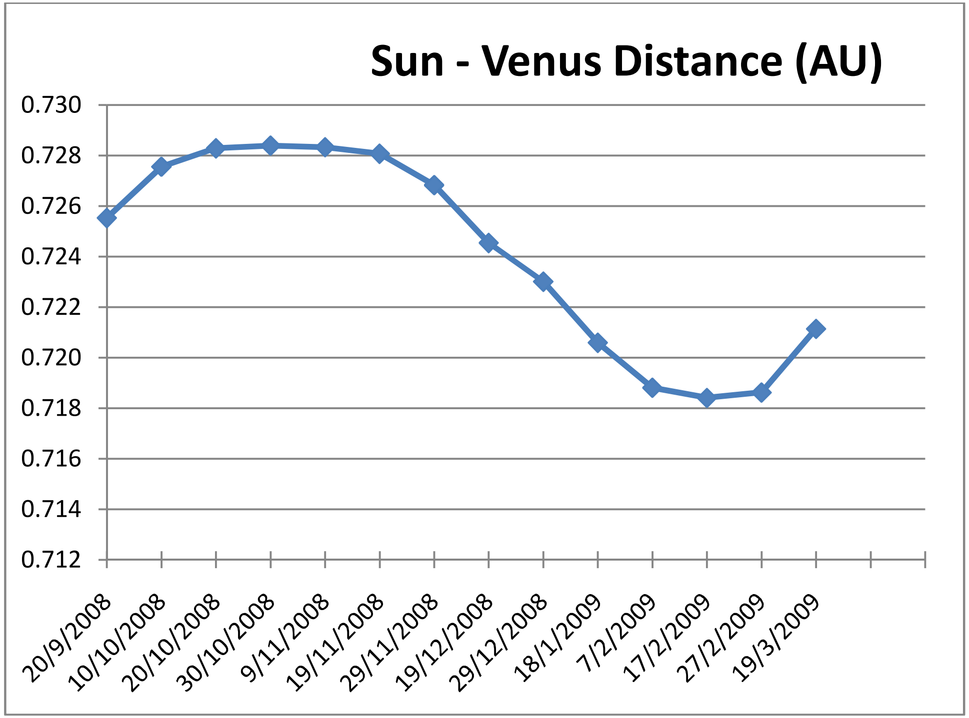
b) As in figure 2.1, in SEV triangle we have,

$$\frac{r_e}{\sin(\angle SVE)} = \frac{r_v}{\sin(\angle SEV)}$$

$$r_v = r_e \frac{\sin(\angle SEV)}{\sin(\angle SVE)}$$

where r_e and $\angle SEV$ (elongation) is given in table 2.1 then, r_v for all observing dates is calculated and written in table 2.2 column 3.

c)


Sun - Venus Distance (AU)
0.730
0.728
0.726
0.724
0.722
0.720
0.718
0.716
0.714
0.712
20/9/2008
10/10/2008
20/10/2008
30/10/2008
9/11/2008
19/11/2008
29/11/2008
19/12/2008
29/12/2008
18/1/2009
7/2/2009
17/2/2009
27/2/2009
19/3/2009

d) According to the obtained values written in table 2.2 column 3,

$$r_v^{max} = 0.728\ AU$$
$$r_v^{min} = 0.718\ AU$$

e) Semi-major axis is

$$a = \frac{(r_v^{max} + r_v^{min})}{2} = 0.723\ AU$$

f) Eccentricity could be calculated from both of aphelion and perihelion distances as

$$e = \frac{r_v^{max} - r_v^{min}}{2a} = 6.92 \times 10^{-3}$$

Table 2.2

Column 1	Column 2	Column 3
Date	SVE (°)	Sun - Venus Distance (AU)
2008-Sep-20	39.83	0.726
2008-Oct-10	47.16	0.728
2008-Oct-20	50.80	0.728
2008-Oct-30	54.55	0.728
2008-Nov-09	58.26	0.728
2008-Nov-19	62.10	0.728
2008-Nov-29	66.17	0.727
2008-Dec-19	74.81	0.725
2008-Dec-29	79.63	0.723
2009-Jan-18	90.57	0.721
2009-Feb-07	104.83	0.719
2009-Feb-17	114.08	0.718
2009-Feb-27	125.59	0.719
2009-Mar-19	157.52	0.721

Venus Problem Marking Scheme

part	Tot. Pts	Details	Max
a	16	Angle derivation	6
		Calculation of $\angle SVE$	10
b	14	Relation	4
		Sun-Venus distance	10
c	6	Plotting Sun-Venus distance	6
d	8	Perihelion	4
		Aphelion	4
e	8	a (relation)	4
		a (value)	4
f	8	e (relation)	4
		e (value)	4

Note: reported numbers in table 2 are not acceptable if they are out of 0.75 and 1.25 times of designer answer.